2004

Legitimating Astronomy

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LEGITIMATING ASTRONOMY

A thesis in fulfilment of the requirements for the award of the degree of

Doctor of Philosophy

from

University of Wollongong

by

Graham Howard, B.A., Ms.Soc.

Science, Technology and Society
2004

CERTIFICATION

I, Graham Howard, declare that this thesis, submitted in fulfillment of the requirements for the award of Doctor of Philosophy, in Science, Technology and Society, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

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ABSTRACT

Science is usually justified in terms of its utilitarian attributes. Modern professional astronomy has no obvious utilitarian rationale, yet it receives considerable resources to carry on its work. Concepts from the sociology of science and political sociology can be used to help explain this apparent puzzle. The means by which astronomy succeeds in procuring resources can be seen in terms of a process of legitimation. Professional astronomy justifies and explains itself to specific audiences, ensuring that funding agencies will see astronomy as worthy of support. Several activities are suggested as legitimation practices. The mechanics of funding are discussed, followed by a description of modern professional astronomy as a 'big science'. Boundary work and popularisation are examined as important legitimation practices. Boundary work constructs a path for astronomy that legitimises it by allying the field to successful sciences such as physics, and distancing it from other activities such as ufology and astrology. Astronomy is popular with the public, and this popularity gives rise to a groundswell of support, and is used to promote astronomy as educating a public that will support science in general. The professional structures of astronomy serve to mark out astronomers as an elite scientific group, with an esoteric knowledge that includes high levels of mathematics. Astronomers" specialist technical skills can be of use in a variety of situations, but the scientific and mathematical knowledge itself also contributes to successful legitimation. It is concluded that the primary rationale for the funding of astronomy is humanistic rather than utilitarian.

ACKNOWLEDGEMENTS

I thank my supervisor, Dr. Brian Martin, for his support, and especially for his flexibility and tolerance; Madeline O'Connor, for giving me the time to work on the thesis; and Linda Giovinazzo, for proofreading the manuscript. I dedicate this thesis to Dr. Andrew Collier, Department of Philosophy, University of Southampton, England.

EXPLANATORY NOTE ON STYLE

The style used throughout the thesis is MLA (Modern Language Association). Dates of cited works in the text are not included unless there is more than one work cited by the same author. Double quotes are used for direct quotes of persons. Other quotes, for example to express scepticism, irony, or obliqueness, are single quotes.

INTRODUCTION

According to a recent U.S. Government commissioned report, “The fundamental goal of astronomy and astrophysics is to understand how the universe and its constituent galaxies, stars, and planets formed, how they evolved, and what their destiny will be” (National Research Council 2001: 3). Working towards this goal requires enormous resources. Therefore modern professional astronomy is an expensive science. Conventional assumptions about science stress its practical utility and instrumental links with development (Drori et al. 2). But astronomy is a science that has no obvious utilitarian rationale. As Drori et al. ask “What practical applications follow from evidence of ice on Jupiter?” (Drori et al. 12). And “Much scientific activity has always seemed to have few instrumental benefits for the modern system or for particular elites in it, as with the current and expensive exploration of various distant and receding galaxies” (Drori et al. 27). Drori et al. give numerous historical examples of investments in science that have no instrumental component (Drori et al 224), and most of their examples are from astronomy: “scientists are given resources to study the origins of the universe, the moons of Jupiter, the possibility of life on Mars, the search for extraterrestrial intelligence, the origins and evolution of mankind, and so on. Such understandings count as ‘progress’ of a sort. However, it is difficult to imagine that such investments produce enhanced immediate economic returns, especially relative to other possible investments” (Drori et al. 225).

So how do astronomers garner resources from society? In particular, what arguments, tactics and strategies do they use? In other words, astronomers, their lobbyists and supporters must resort to various legitimation practices to ensure that their discipline garners resources to continue their work and develop the discipline. A distinction should be made between the actual reasons for the copious public patronage of astronomy, and the legitimation practices that enable the continuance of effective support. The real reasons for resource allocation may be related to the legitimation practices in complex and interesting ways, but that is not my concern here. In short, my concern is to answer the following question: how does the modern profession and discipline of astronomy legitimate itself?

The Legitimation of Science

There are two ways of looking at the legitimation of a science. Social Studies of Science, even before the advent of SSK (Sociology of Scientific Knowledge), has tended to limit its analysis to internalist notions of legitimation. That is to say, a scientific specialty is examined in terms of how it becomes legitimate scientific knowledge. Such a perspective limits its frame of reference to legitimations within science. A clear example of this approach is that of Mulkay (1972). In his study, Mulkay examines the social processes by which scientific information is generated, accepted as valid by the scientific community, and passed on to the wider society. What he does not do is examine how it comes to be accepted as legitimate by the wider society, that is to say, explained and justified to the extent that the wider society is willing to give the profession resources to carry on more work. In Mulkay's type of explanation, legitimacy is conferred from within science, because it is the knowledge itself that is being legitimised in terms of its scientific worth. Mulkay, unlike subsequent ethnographers such as Latour, acknowledges at the end of his account that it is one sided: "The argument developed here is incomplete, in so far as it ignores the impact on basic research of influences originating outside the research community" (Mulkay 1972: 57). Since then, how a particular scientific specialism legitimates itself to the wider society has been largely ignored. In this thesis, I propose to examine how a particular scientific discipline legitimates itself to the wider society. In other words I shall take an externalist approach. The internal-external distinction has limitations and has been questioned, but it is convenient for my purposes to help explain my approach. But as we shall see, it is sometimes impossible to separate internalist and externalist explanations of legitimation.

The scientific legitimacy of a field of inquiry as a science is primarily about debates between scientists. Ravetz noted the "tendency of established scientific disciplines to create a world of their own and then live totally within it" (Ravetz: 114). This implies that there are two types of scientific legitimacy: internal legitimacy (legitimacy within the scientific community), and external legitimacy (legitimacy in relation to those not directly involved in the scientific activity being legitimated, and legitimacy with the non-scientific world). SSK analysts have tended to focus on internal legitimacy and have given internalist explanations. I am interested in astronomy's relationship with the external, non-astronomical, both scientific and non-scientific world. I attempt an externalist explanation. An influence on astronomy can be internal or external. A study of astronomy can be internalist or externalist. The respective terms are conceptually distinct, but closely related. An internalist study will examine internal influences, and an externalist study will examine a science's relation with the world external to it. It is with this latter type of legitimacy that I am concerned. I focus particularly on legitimacy with the non-scientific world, as ultimately it is from the non-scientific world that astronomy obtains resources.

Logically, just because an activity has successfully legitimised itself as a science, it does not automatically follow that the field of inquiry is able to obtain resources to pursue its work. In order to obtain funding a scientific activity must not only be legitimised internally, but also externally legitimised. To obtain external legitimacy, astronomers must engage with powerful individuals and groups to gain access to resources; their activities then thus become overtly political. Astronomers must compete with other groups outside of science, within science and sometimes even within their own discipline. What determines the outcome of these struggles? By focusing on astronomy, which is an old, established science, we may be able to gain some insight into the processes and mechanisms at work at the interface between science and the political system.

Another way of looking at this is to contrast what Collins and Pinch call the 'constitutive forum' and the 'contingent forum'. The constitutive forum consists of the formal methods of communication between scientists based on supposedly universal premises: theorising, experimentation, publication in journals, conferences. The contingent forum comprises those actions by scientists which are not (according to orthodox views of science) supposed to affect the constitution of objective knowledge, and which are therefore supposed to be incidental to the constitution of knowledge: popular periodicals, fund raising, publicity seeking, the setting up of professional journals, and any other form of communication that is not in the constitutive forum (Collins and Pinch 239-240). Collins and Pinch show that the success or otherwise of parapsychology is not resolvable within the limits of the constitutive forum. Thus even for a field to legitimise itself to other scientists negotiations must take place outside of the internal formal communication structures within science. The constitutive and contingent forums more or less correspond with the notions of internalist and externalist explanations, but clearly, the legitimation of astronomy as a whole takes place in the contingent arena. And it is with this arena that I am primarily concerned.

The answer to the problem of legitimation does not lie in a Latourian study of the laboratory, or in the case of astronomers, in the observatory. Rather, we must look for the answer 'downstream' (Gieryn 1999: 1), that is to say, at the boundaries between the inside and outside of astronomy: at that point where astronomy intersects other social systems, such as other sciences, 'pseudosciences', and the state. Downstream here refers to astronomy's relationships with its neighbours. Just as scientists such as John Tyndall in the nineteenth century had to battle on behalf of science in general over and against the competing cultural authorities of religion and mechanics, so today specific disciplines have to engage in an agonistic field sometimes with, sometimes against, other disciplines, and with 'pseudosciences', various private economic interests, and the state itself. In focussing on legitimation, I also address the reasons why modern western societies continue to fund an expensive, pure science such as astronomy. I analyse the various strategies that astronomers, their supporters, apologists and lobbyists use to legitimate their discipline.

The boundaries of astronomy are not given, but are achieved through negotiation: astronomers and their lobbyists must attempt to convince, persuade and influence power to dispense resources. I examine and classify the various ways in which the boundaries between astronomy and non-astronomy are negotiated.

Sociologists of science, especially since the advent of SSK (Sociology of Scientific Knowledge), have been primarily concerned with the internal workings of science by examining the production of knowledge at the micro level. However, as Mulkay noted back in 1979 the possibility of a sociology of scientific knowledge means that the content of scientific knowledge cannot be understood without recourse to the world external to science: there are direct external influences on the content of what scientists consider to be genuine knowledge. There have been attempts to account for the content of science by reference to the influence of the external society. One such study is Forman's claim that quantum mechanics was a scientific response to a social environment characterised by uncertainty. But Forman did not concentrate on the actual legitimation practices of physicists; to Forman the link between society and scientific content was unmediated.

As well as external factors influencing the content of scientific knowledge, scientists themselves influence the external society: the communication is two-way. And one of the ways in which scientists communicate with the 'wider society', indeed, must do, is to negotiate with the wider society to obtain resources for their work. To do this they must legitimate their science: they must explain and justify their science such that society will give them resources.

Astronomy was one of the positivist philosopher Comtes' six basic sciences (Habermas 1971: 73). But, according to Comte, astronomy, "despite the important part it plays, contributes only through its indispensable foresight and cannot bring about any direct modification of the surrounding milieu … " (quoted in Habermas 1971: 72). We shall see there is more to it than this.

I look at actual strategies by astronomers, their representatives and their allies to legitimate their science. Indeed, one of the reasons for the emergence of science and technology studies is that previously philosophers of science had uncritically accepted scientists'' own versions of what they do as the starting point for metascience. For the purposes of this study, however, astronomers'' own self-understanding of their legitimation activities is a crucial part of the phenomenon in question. Any study that does not take into account astronomers'' own understanding of what they are doing would be incomplete. Astronomers''self-understanding may or may not be a reflection of what 'actually' happens, but it is useful to know in itself as part of the dynamics of astronomy, and it may give insights into how legitimation occurs. Moreover, an important part of astronomy''s legitimation is how legitimacy is achieved in the eyes of astronomers themselves.

The Relevance of Legitimacy to Astronomy

Legitimation is a key concept in political sociology, but its relevance to modern astronomy may not be immediately apparent. I use the term broadly in the Weberian sense, as elucidated by Berger and Luckmann (79, 111). To Weber legitimacy and authority are closely linked, in fact on occasions he uses the terms as if they are synonymous (Weber 1948: 78-79).

Legitimate domination is domination that is seen as *justified* by those on whom it is wielded (Weber 1948: 78). Berger and Luckmann (79, 111) elucidate the concept and apply it to medicine. Medicine as a discipline and profession had to be explained and justified to get people freely to use doctors, and for society to give resources to doctors. Similarly, astronomy as a profession and discipline must explain and justify itself to get resources. This explanation and justification I call *legitimation*. Applied to the topic of this thesis, legitimacy involves the successful explanation and justification of astronomy, to the extent that agencies are willing to disseminate resources to astronomy. Authority is legitimate domination (Weber 1968: 216). In the specific case of astronomers, legitimation involves the power to influence others based on recognised knowledge and expertise, and especially the power to influence those responsible for decision making with regard to dissemination of resources to astronomy. The result of successful legitimation is that astronomers are given command (domination) over resources ceded to them by society.

I mean by institution a social configuration with shared values that persists over time because it is accepted as legitimate (convincingly explained and justified) and valuable (Drori et al. 3). As Shapin notes, "Social institutions require sources and grounds of legitimacy" (Shapin 1995: 28). Indeed, we can, with Mary Douglas, use the concept of 'institution' to mean any legitimised social group, irrespective of size or level of organization. This institution can be a political party or a group of scientists (Shapin 1995: 28fn.). The concept of legitimacy has often been used in connection with the state, and in particular with government. But there is certainly no need to so restrict its use. As Barker has noted: "there remains a very wide usage which extends far beyond the specifically political application" (Barker 20). It is even possible to argue that political legitimation is subordinate to other forms of legitimation. Marxists, for example, would argue that the state legitimises class rule. Barker denotes four accounts of legitimacy: "non-governmental institutions which are in some sense legitimate in their own terms; of non-governmental institutions which are legitimised by the state; of states as externally legitimised; and of states as autonomously legitimised" (Barker 43n). A study of the legitimation of astronomy is an example of the first type of account of legitimacy.

I hope to show that the above demarcations are not rigid lines, but can flow into each other. For example, the state can sometimes help to legitimise astronomy. Moreover, although astronomy is not an institution that is part of the state apparatus, its legitimation is political in the sense used by Barker. That is to say, it "derives either from the character of the institution or persons claiming or enjoying it, or from the procedures which they follow in taking or exercising power, rather than from the substance of what they say they wish to do" (Barker 23). I also hope to show that the legitimacy of astronomy is also political in that it does, like political legitimacy, involve a moral imperative. That is to say, in order for actors to be convinced that astronomy has successfully explained and justified, they must believe that astronomy is in some sense a good thing. It is important to note that this study of legitimacy does not imply a belief or otherwise in the legitimacy of astronomy. The study is objective in the sense that it attempts to give an account of how astronomy legitimises itself in society. It is an account of what is in fact largely regarded as legitimate, not what should be legitimate. This study is a non-normative, descriptive and ultimately a taxonomic account of the legitimation of professional astronomy. However, I have no doubt that much of the material here will be of use to those engaged in normative debate about the legitimation of astronomy. Moreover, I have obviously made normative choices in my selection of topic and the methods by which I approach that topic. Finally, by elucidating the various ways in which astronomers and their lobbyists justify and explain their activities, I will inevitably give ammunition to those both for and against expenditure of societal resources on astronomy. As Barker notes, "No-one, it seems, wishes not to appear legitimate" (Barker 14).

My initial contention is that astronomy has become an institution in a way that it was not in the past. Astronomy is now much more than just a body of knowledge shared by a loose network of amateur observers. Instead it is a scientific discipline: a profession and a community with its own language, with a plethora of supportive arrangements, including technology and equipment in the form of observatories, university courses, international agreements and public relations. Moreover, as Lenoir notes, "disciplines are political institutions that demarcate areas of academic territory, allocate privileges and responsibilities of expertise, and structure claims on resources" (Lenoir 58). Disciplines set boundaries and demarcate hierarchies of experts and amateurs. As such disciplines are also discourses of power as well as instruments of knowledge production. Astronomy as a discipline is thus inherently political.

The Institutionalisation of Science

I mean by institutionalisation the process by which astronomy came to be a social configuration with shared values that persists over time because it is accepted as legitimate and valuable. An historical account of how Western science was institutionalised has been given by Shapin, who argues that history can tell us much about the origins of scientific institutions. In particular, Shapin argues that the legitimacy (explanation and justification) of modern science was formulated in the gentlemanly conduct of seventeenth century England. Shapin argues that both seventeenth century English science and modern science are, like other human institutions, based heavily on testimony, authority (legitimate domination of knowledge), and above all, trust (Shapin 1995: xxxv). Indeed, Shapin goes further and asserts that truth itself is a social conception and a collective accomplishment (Shapin 1995: 5). Furthermore, we can, with Foucault, connect the notion of truth with that of power, for those in power to a great extent get to decide what counts as truth. Therefore, any study that addresses truth also addresses power. As power is a political concept truth becomes political. The concept of legitimacy is an overtly political concept. As Crick notes: “What is meant by legitimacy or legitimate authority? That is the master question of politics” (Crick 1959: 150). Crick is using the term ‘authority’ here in its Weberian sense of legitimate domination.

Whoever addresses power also addresses morality, for the practices by which we accomplish truth are synonymous with our moral order. To put it more crudely, if those in power decide what counts as truth, they also decide what counts as morality. Thus, a comprehensive study of scientific legitimacy must encompass the sociology of science, political sociology, political science, political theory, philosophy of science, political philosophy and ethics.

The Institutionalisation of Astronomy

How did astronomy come to be an accepted profession and discipline? Astronomy did not start out as an institution, but at some point in history the unity of history and individual biography were broken down and people doing astronomy had to be taught; at this point the institutionalisation of astronomy began. At the same time, there arose the need for legitimation: the passing on of knowledge had to be explained and justified. Thus, the process of legitimation is closely related to the process of institutionalisation: the two processes grow together. In astronomy, this change was obviously a gradual process, culminating in the complex arrangements that exist today. As an institution, astronomy exists independently of any single astronomer: an individual astronomer may die, but astronomy, as an institution, will go on. It can be said then that astronomy as an institution exists as a social fact in the Durkheimian sense, and can be studied as such.

A typical motive for legitimators is the integration of the institution into the main fabric of society, such that it will be more difficult to dislodge the institution from its place in society. Legitimation not only tells an individual he or she should perform an action or support an institution; it also tells him or her why he or she should do so. In the words of Berger and Luckmann, "'knowledge' precedes 'values' in the legitimation of institutions" (Berger and Luckmann 111). Nevertheless, in practice, as Shapin notes, the cognitive order and the moral order cannot be separated (Shapin 35). The ufologist (person who studies UFOs) who challenges the scepticism of an astronomer is not only making an intellectual challenge, he or she is also distrusting the astronomer and committing an act of hostility. For he or she is challenging the astronomer''s status as legitimate knowledge producer and provider. By denying the astronomer''s right to colonize his or her mind, the ufologist is denying the ability of the astronomer "to contribute to a world-known-in-common" (Shapin 38). Of course, astronomers have also been known to be hostile to ufologists!

In a democratic society the allocation of funds mean that priorities have to be set and choices made among competing interests. Such decisions are inherently political and depend more on judgements of relative value than on scientific knowledge or technical feasibility. As as a *Science* editorial notes: "to launch a satellite requires some knowledge of the laws of physics, but the decision to use that knowledge is not itself a matter of physics. The decision rests on a complex system of values which, although difficult to express, culminates in the judgement that available funds should be spent to further the IGY program rather than, say, to reduce the national debt." (Turner 1055). Governments spend millions of dollars in building and maintaining expensive observatories while (to make one possible comparison) millions starve in the third world and poor citizens of first world countries experience cuts in welfare. This tells us something about the priorities of modern societies. And yet "the dominant image of science is instrumentalist. Science is seen as a tool for economic development. Science can produce improvements in human health and life, as with medical knowledge" (Drori et al. 223). The issue becomes more interesting because astronomy, unlike, say medical science, has no obvious immediate instrumentalist justification. Therefore, justifications based on practical benefits cannot account for the importance that astronomy plays in the scientific life of many nations, especially in terms of expenditure. However, even an applied interdisciplinary area such as medicine has to legitimise itself. As Berger and Luckmann argue:

> It is not enough to set up an esoteric sub-universe of medicine. The lay public must be convinced that it is right and beneficial, and the medical fraternity must be held to the standards of the sub-universe. Thus the general population is intimidated by images of the physical doom that follow ignoring the doctor's advice; it is persuaded not to do so by the pragmatic benefits of compliance, and by its own horror of illness and death. To underline its authority the medical profession shrouds itself in the age-old symbols of power and mystery, from outlandish costume to incomprehensible language, all of which are legitimated to the public and to itself in pragmatic terms. Meanwhile, the fully accredited inhabitants of the medical world are kept from 'quackery' (that is, from stepping outside the medical sub-universe in thought or action) not only by the powerful external controls available to the profession, but by a whole body of professional knowledge that offers them 'scientific proof' of the folly and even wickedness of such deviance. In other words, and entire legitimating machinery is at

> work so that laypersons will remain laypersons, and doctors doctors, and (if at all possible) that both will do so happily (Berger and Luckmann 105).

Medicine, unlike astronomy, obviously addresses vital and universal needs. Moreover, even when official medicine was no more successful in curing disease than its rivals, or when there is cynicism about the profession, it has a certain amount of credibility and authority (legitimate domination of the relevant field of knowledge), because doctors are professionals to whom one goes with private problems. Thus psychological and emotional factors can hold sway in medicine in a way that is not the case with astronomy. Medicine also has a clear market of non-organized clients; astronomy has no obvious client group at all. Medicine is particularly well served by the nature of the service it provides, whereas this is not obviously true of astronomy. Modern medicine not only legitimates the discipline of biology, on which it is founded, but also physics (X-rays etc) and chemistry (drugs etc). Moreover, biology has other public policy connections: public health, the food supply, agriculture, and even social policy. Even a social science like psychology has obvious practical implications in terms of improving relationships and behaviour. Psychology derives this imperative by analysing mental achievements related to a purpose. In contrast astronomy analyses celestial phenomena that have no apparent ultimate purpose (Polanyi 1958: 369).

A further comparison may be made with chemistry. Chemistry has been institutionalised in a number of spaces: federal, state and local governments, as well as academe. But more important than any of these has been industry. For chemists, industry was and is the major employer, and the history of chemistry has been tied to the development of industry, culminating in the use of chemistry in World War One, which has been called the chemists' war (World War Two being the physicists' war). The link with industry insured that chemistry would have a strong applied component, providing a legitimising rationale; industry has become the legitimising apparatus of chemistry. Astronomy, or at least the modern astronomy of astrophysics, can make no such claims as an applied science.

If such easily legitimised fields such as medicine and chemistry need a legitimising apparatus, how much more so must astronomy? Astronomers and their supporters must therefore have recourse to a range of arguments, tactics, and rhetoric to persuade citizens and governments to part with large sums of money to enable the astronomical profession to carry on its work. What arguments do astronomers and their lobbyists use to justify their existence and activities? What is the process by which governments (and in some cases private sponsors) come to accept the need for the allocation of resources to the science of astronomy?

An understanding of the above process necessitates the examining of the complex interplay between modern science and the political and economic system. This hopefully will help with the more general goal of understanding the relationship between them. More specifically, a study of the successful explanation and justification of astronomy may go a long way to answering the question of astronomers that Mukerji addresses in her study of oceanographers. Mukerji asserts: “The puzzle is why the U.S. government also supports in universities and private laboratories basic research done with no immediate or even obvious long term benefit to the state” (Mukerji 4-5). In a recent empirical study of several countries, Drori et al. actually found that investment in scientific research has a negative economic impact (Drori et al. 228-246).

Such an analysis needs the perspective not only of the sociology of science but also of political sociology. A prerequisite for the explanation and justification of astronomy to the extent of being deserving of a nation’s resources is its legitimation first as a science. Despite the social movements of the mid to late twentieth century, science is still the ‘backbone’ of Western societies, and with ‘the New World Order’ is fast becoming the basis of the whole world economy. Moreover, again with the qualification of the cynicism of sections of the population, science is still regarded as the basis of authoritative knowledge. Modern societies are based more and more on what Latour calls “technoscience” (Latour 1987: 174-175). Indeed, he goes further and calls modern societies “techno-scientific”. As science has such a hegemonic position in modern society, any activity accorded the status of ‘science’ is automatically accorded higher esteem. Thus one way that astronomy legitimises itself is by its very existence as an old, established science: science becomes its own explanation and justification. In other words, part of the legitimation of science is the ideology of science for its own sake. Astronomy is especially suited for this type of justification because it is, or at least appears to be, the archetypal ‘pure science’. Despite the connection between astronomy, space science and the military, astronomy and astronomers are still seen as heroes exploring the universe, a view attested by the popularity of astronomical items in the popular media. But as Lenoir has pointed out, just because what a discipline does is not carried on for any instrumental or utilitarian outcome, it does not follow that the scientists are ‘disinterested’ in the Mertonian sense (Lenoir 6-7). As I shall show, astronomy is a profession and as such the community of astronomers has its own social, economic and ideological interests.

The purely scientific justification for astronomy then can be seen as part of a broader ideology of science which pervades our techno-scientific society. The notion of ideology is often linked to the notion of legitimation in the political arena (see Marcuse 1964, Habermas 1975). Blume takes up the connection:

> To respond in terms of the prestige of writing is to say that people attach special credence to the authority of science, even when science cannot demonstrate their truth or falsehood. This is to claim for science a wide legitimation. One might say that science is a set of beliefs to which people are happy to resort to on occasions of doubt. This is precisely the meaning of the term ideology (Blume 61).

Thus astronomy as the oldest and most established science is already part of a persuasive set of beliefs to which social actors appeal in situations of a certain kind. Science has authority: legitimate domination of knowledge, even when it does not demonstrate how it comes to obtain that knowledge. Astronomy ‘piggybacks’ onto the whole institution of science, thus giving astronomers and their lobbyists a head start or at least an advantageous starting off point when bargaining for resources. Moreover, the secure scientific status of astronomy is such that that it has been used to legitimise other, newer sciences. Freud for example countered the reproach that psychoanalysis did not admit of experimental verification by arguing that astronomy does not experiment with heavenly bodies but is limited to their observation. But Habermas counters that in astronomy controlled observation is possible, whereas in psychoanalysis this control is replaced by “The Intersubjectivity of mutual understanding about the meaning of incomprehensible symbols” (Habermas 1971: 253).

Of course ideology alone cannot explain why astronomy is so successful at explaining and justifiying itself. Blume unfortunately does not take us any further in understanding the interplay of science and the political system. His political sociology of science is based on a broadly Mertonian institutional perspective and focuses primarily on the role conflicts produced by the interaction of the social system of science and the political system, and especially on the part eminent scientists have played in broadly political issues. He ignores the deeper issues of power in society that determine how resources are allocated to different scientific enterprises. His book, published in 1974, was written before publication of the landmark works in the sociology of scientific knowledge (Barnes, Bloor) and ethnographic studies of scientific knowledge negotiation (for example Latour and Woolgar). Blume does not address the suggestion that the very content of science can be affected by social and political factors: his account of science and the political process is formulated in accordance with what Mulkay calls, “the customary assumptions about the character of scientific knowledge and the nature of the scientific ethos” (Mulkay 1979: 110).

Informed by the perspective that the content of science and mathematics is an appropriate topic of study by the sociologist, we can see that the content of astronomical knowledge may itself be part of a complex ideological system (this does not necessarily imply anything about the epistemological status of astronomical knowledge: its truth or falsity). The task set by Popper (1989, 2002), and others before him, was to find some sort of demarcation criterion between science and pseudo-science or non-science. For example: falsifiability, testability, deduction, induction and empirical verification seem to have been shown to be inadequate criteria by the sociology of scientific knowledge (Barnes 1974; Mulkay 1979). The most influential demarcation criterion has been Popper’s criterion of falsifiability. This was theoretically challenged as early as 1958 by Polanyi, who claimed that classification systems such as those in crystallography are of value in understanding experience, but are not rendered unscientific by falisfiability. Facts that are not described by the theory are regarded as irrelevant (Polanyi 1958: 47). Polanyi claimed that science is personal knowledge, which transcends the distinction between subjectivity and objectivity: “In so far as the personal submits to requirements acknowledged as independent of itself, it is not subjective; but in so far as it is an action guided by individual passions, it is not objective either” (Polanyi 1958: 300). Personal knowledge “Commits us, passionately and far beyond comprehension, to a vision of reality. Of this responsibility we cannot divest ourselves by setting up objective criteria of verifiability—or falsifiability, or testability, or what you will” (Polanyi 1958: 64). Polanyi’s alternative is that an affirmation will be acceptable as part of science in terms of its scientific value the more it possesses: certainty (accuracy), systematic relevance (profundity) and intrinsic interest (Polanyi 1958: 135-136). Of these criteria, intrinsic interest is highly personal. Yet the notion of intrinsic interest seems to imply a natural link between subject and object. Polanyi sees this as being an essential part of the scientific enterprise. Moreover, this scientific enterprise involves not only by reason, rationality and logic, but also belief. To Polanyi belief is not dogmatic or unscientific. Rather, “To believe something is a mental act: you can neither nor disbelieve a passive experience. It follows that you can only believe something that might be false” (Polanyi 1958: 313).

It has been asserted that ‘scientific method’ can be seen as an ‘evaluative resource’, that is, a tool to justify conclusions already arrived at by other means (Woolgar 1988: 13). To bring in a very different theoretical discourse, this is rather like seeing astronomy as part of the ‘ideological superstructure’ of society (Althusser 123-173). Astronomy becomes not so much an innocent study of the universe as part of a social superstructure, which helps to maintain a particular social structure. Again, this does not imply that astronomical knowledge is ‘false’ in scientific terms. For example, astronomy could be seen as part of a nationalist ideology, as when observatories are justified by national prestige. More broadly, astronomy could be seen as part of a scientific ideology upon which a society is based. Both of these issues are addressed later.

The successful legitimation of astronomy is signalled — and reinforced — by its prominent role in popular culture: the mass media regularly proclaim new discoveries and feature interviews with prominent astronomers. The popularisation of astronomy is very much a double-edged sword. On the one hand, it helps in the legitimation process and on the other, it poses certain problems: hangers on, cranks, the confusing of astronomy with astrology, the association of astronomy with deviant sciences such as ufology. Astronomy must therefore create boundaries around itself: it must demarcate itself from the deviant sciences that surround it; this is especially important for certain areas within astronomy such as the search for extraterrestrial intelligence (SETI).

Astronomy may be regarded as a good test case by which to negotiate the above problems, for, as previously stated, unlike other sciences, astronomy has no obvious utilitarian goals or benefits. Justifications are therefore of great interest: they are oblique, esoteric and often refer to the nature of societies, the nature of humans; they are sometimes philosophical and can even border on the spiritual and quasi-religious. This lack of obvious practical use/benefit means that the rhetoric and tactics must include appeals to ‘what binds us’ (Latour 1991: 3), and therefore provide a means by which our society may be illuminated. At first glance, the oldest science is not such a good fit with the new sociology of scientific knowledge. Astronomy was the epitome of the old philosophy and sociology of science: it appears to be a good fit with the received philosophy and sociology of science: namely objective and neutral, its results arrived at independently of external societal influences. As an advocate of the postmodern view of science Rouse asserts:

> One might say that the traditional philosophical modal of the local site of research is the Observatory. Scientists look out at the world or bring parts of it inside to observe them. Whatever manipulative activities they perform either are directed at their instruments or are attempts to reproduce phenomena in a location or setting where they will be observable. The new empiricism leads us instead to take seriously the laboratory. Scientists produce phenomena: many of the things they study are not ‘natural events’ but are very much the result of artifice. The classical sciences were astronomy, mathematics and mechanics and descriptive biology, anatomy and geology, whose objects were readily available whose objects were readily available for description and reflection. More characteristic of science as it is practiced today are high-energy

> physics, electromagnetism, thermodynamics, chemistry and experimental biology in its many subfields (Rouse 23).

Rouse correctly points out that the disciplines characteristic of science as it is practised are constructed by the scientists themselves. However, for the new sociology of science to work it must apply to all sciences, not just ‘those more characteristic of science as it is practiced today’.

Woolgar has shown that the constructivist approach can be applied as much to astronomy as any other science. In analysing the discovery of pulsars, Woolgar shows that what is now called ‘a new kind of radio source’ is best seen as a ‘current consensus’ or ‘temporary stable construction’, which has been constructed out of a series of previous ‘incarnations’ such as ‘possible interference’, ‘temporary flare up’ or ‘unusual interference’ and ‘communication from extra-terrestrials’. Further negotiations may result in a different ‘temporary stable construction’. Thus, the new sociology of science can be applied as much to astronomy as high-energy physics.

However, in analysing astronomy as an institution, rather than limit myself to SSK, I also pursue a different type of social analysis of astronomy; I analyse its overtly political dimensions. My concern is not primarily with the content of astronomical knowledge. Neither am I concerned with the legitimation of that knowledge as scientific or ‘real’ knowledge. Rather, I am concerned with the successful explanation and justification of astronomy as an activity worthy of attaining resources from society. Thus, in the sense that my interest is astronomy as an institution, rather than its content, my approach is Mertonian. Merton saw the sociology of science as being concerned with science as a social system rather than with the content of science. Thus, I examine astronomy as part of the social system of science. However, as will be shown, internalist and externalist explanations cannot be completely separated. In examining modes of legitimation I examine strategies such as boundary work and popularisation, which bring me closer to SSK. I have also found the concepts of Jurgen Habermas to be particularly useful as explanatory tools.

In the last analysis, the foundation of any form of legitimation is ethics. That is to say, legitimation must be based on some ultimate notion of the good. As Shapin points out, “What counts for any community as true knowledge is a collective good and a collective accomplishment” (Shapin 5). Truth is therefore a social institution (Shapin 6). But legitimation is foremost a political concept. Thus in order to understand the legitimation of astronomy we must make use not only of the concepts and perspectives of the sociology of science but also those of political sociology. Political sociology has to do with the social basis of power. An account of the legitimation of astronomy should thus also locate astronomers in the power structure relations of society, in terms of class, status and power.

Max Weber writes: “Power is the probability that one actor within a social relationship will be in a position to carry out his own will despite resistance, regardless of the basis on which this probability rests” (Weber 1947: 152). Power is not a thing or a possession. Rather, power is a network of relationships which enable an individual or group to successfully mobilise resources to achieve clearly defined goals (Clegg 2, 207). Thus, we are not just talking about state power, but social power. Analysts such as Miliband (1969) and Habermas (1973) have made strong arguments that state legitimation cannot be separated from economic and social legitimation, even in western type societies in which the state does not control the economy and society. It is indeed highly likely that Barker’s assertion that for most people, “The state has not been established but had been absorbed as a part of a received social environment” (Barker 162).

If legitimation of government and the state and that of the rest of society cannot be separated, there is no reason why scientific institutions should not be included in this political rubric. However, sociologists of science have usually limited themselves to talking about the legitimation of particular sciences in relation to science as an institution. They have not seen legitimation as an overtly political concept. Studies of deviant science (for example Collins and Pinch 1982, and Rosenberg 1991) have sought to show how activities normally regarded as being on the fringes of science attempt to legitimise themselves as ‘proper’ or ‘true’ sciences, and left it at that. The political implications of this legitimacy, and the extent to which scientific legitimacy leads to political legitimacy, have not been examined. I attempt to go beyond legitimation within science and attempt to describe how astronomy legitimates itself to the non-astronomical community, as it is this wider legitimacy that is crucial for funding.

Structure of the Thesis

My objective is to give an account of the ways in which professional astronomy legitimates itself, such that it obtains resources from society to carry on and develop its activities. In attempting to attain this goal I use methods from the sociological perspective. I use both traditional sociological methods such as: systemic/institutional analysis, interviews, pluralist political sociology, discourse analysis, analysis of case studies, and concepts from the sociology of scientific knowledge (SSK). In terms of data, although my thesis is concerned with professional astronomy in general, a disproportionate amount of data is from the United States. This is because a disproportionate amount of astronomy is done in the U.S., and there is a disproportionate amount of data is from the U.S. In addition, I was lucky enough to live in New York and Boston for a period of time while researching my thesis, and while in Boston worked at the Massachusetts Institute of Technology (MIT). I was therefore able to interview professional astronomers and astrophysicists at such institutions as Columbia University, Stony Brook University and at MIT.

I undertook interviews with twenty astronomers and astrophysicists in order to provide some insight into ways that astronomers themselves see the field as being legitimated: successfully explained and justified. The interviews were done with a relatively small number of astronomers, but since their responses were virtually unanimous in some areas, the views expressed are quite likely to hold through the profession as a whole. I was seeking qualitative information on the sorts of arguments, beliefs and passions that astronomers have, in relation to the legitimation of their discipline and profession. My purpose was to develop a sociological model of how astronomy legitimates itself, so my goal in interviewing was empathic and imaginative understanding rather than to obtain and analyse quantitative data.

In chapter one, I introduce relevant concepts from political sociology, and show how they can be used to understand the process of legitimating astronomy. I outline the three most influential perspectives on power in political sociology — the elitist, Marxist and pluralist perspectives — and explain why the pluralist perspective is the most useful in helping to understand the process of legitimation in astronomy. I characterise astronomers as both an interest group and a pressure group in the political system. I begin my analysis of astronomers' attempts to gain funding with an analysis of the public policy section on the web site of the American Astronomical Society. I deepen my study with detailed discourse analysis of the relevant budgetary congressional hearings, which determine funding for American Astronomy. I then explore in empirical detail the relationship between legitimation and funding using four case studies: Jodrell Bank, the first large radio telescope in Britain; the Gemini Project, an international project involving the participation of several countries; the Hubble Space Telescope, which was the first large extra-terrestrial telescope; and the International Space Station, which is a manned space program in which astronomers are participating. I complete the chapter with some general conclusions informed by my analysis and the case studies.

In chapter two, I describe and examine astronomy as a big science, that is to say, a science that has large amounts of resources and technology. I attempt to show that astronomy's status as a big science is an important factor in its explaining and justifying astronomy. I begin the chapter by discussing the notion of big science. I then briefly describe the evolution of astronomy from little science to big science. I follow this with a description of present day astronomy. Next I describe how astronomy as a big science explains and justifies itself, and explicate the synergistic relationship between astronomy as big science and the legitimation process. Finally I offer some general propositions about astronomy as big science and legitimation.

In chapter three, I use the notion of boundary work to highlight certain important features of the legitimation process in astronomy. I argue that astronomers use boundary work as a way of legitimising (explaining and justifying) the discipline. Astronomers and their advocates engaged in boundary work for a variety of subjective reasons, but one objective effect of boundary work is the legitimation of astronomy. I argue that boundary work is itself a legitimation practice. I begin the chapter by discussing the notion of boundary work and I explain the relevance of the concept for legitimation. I then give examples of astronomical boundary work: the Velikovsky affair, astrology, ufology, SETI, amateur astronomy, social differentiation, astronomy as pure science, physical boundaries, demarcation disputes, and disciplinary boundary work such as physics. Finally I state some conclusions about boundary work and legitimation arising from my discussion.

In chapter four, I examine the role of popularisation in the legitimation process. I argue that popular support is important for astronomy. Given this importance, popularisation becomes legitimation practice. I introduce the concept of popular culture and explain its relevance to the legitimation of astronomy. I also locate the popularisation of astronomy in terms of the popularisation of science as a whole. I examine the relationship between astronomers as popularisers and the 'popularisees': those who are the objects of popularisation. I examine the role of trust in the relationship between astronomers as 'knowers' and the 'knowees' upon whom they impart knowledge. I examine examples of famous and successful popularisers: Carl Sagan, Paul Davies, Stephen Hawking and Patrick Moore. An example is then given of an attempt at popularisation that was a relative failure: the early popularisation of the Hubble Space Telescope. Finally, I suggest some general conclusions about how popularisation explains and justifies astronomy.

In chapter five, I give an account the way in which astronomy's status as a profession enhances the legitimacy of the discipline. In what sense is astronomy a profession? In so far as it is a profession, how does this professionalism successfully explain and justify the discipline? The chapter consists of eight sections. In the section 'Astronomy as an Occupation and Career', I make some general comments about astronomy from the point of view of work. In the section 'Professional and Amateur Astronomy', I contrast the two activities and suggest that the differences have implications for legitimising professional astronomy. In the section 'The Scientific Professions and the Enlightenment', I characterise professional astronomy as part of the Enlightenment project, and suggest that historically being part of said project has assisted in legitimation. In 'Astronomers as Intellectuals', I show the link between intellectualism and legitimacy. In the section 'The Role of Mathematics', I make a connection between the esoteric nature of mathematics and legitimacy.

In the conclusion, I summarise and synthesise the previous chapters and suggest some general theoretical conclusions deriving from the analysis presented in those chapters, together with an analysis of my interviews with twenty astronomers. Finally, informed by my analysis, I return to my original question: given that astronomy, unlike other scientific disciplines such as physics or biology, has no obvious utilitarian rationale, what arguments, strategies, tactics and rhetoric do astronomy advocates use to persuade funding agencies to part with large sums of money to allow professional astronomy to carry on its work?

CHAPTER ONE

ASTRONOMERS IN THE POLITICAL PROCESS

Introduction

Traditionally in political sociology there have been three ways to look at power: pluralist, elitist, and Marxist. The pluralist view sees society as being composed of many competing groups struggling for power, with no one group dominating. The majority of analysts writing in the field of political sociology have held this view: Aron, Dahl, Dahrendorf, Easton, Galbraith, Lipset, Parsons and Sampson to name but a few. The elitist view holds that one group has power, and that this situation is both legitimate and inevitable. This view was held by the Italian sociologists Mosca and Pareto, and the French sociologist Michels. The Marxist view is that one group, a ruling class, holds power, but that power is neither legitimate nor inevitable. Marx, Engels, Lenin and Trotsky of course held this view. More recently the ruling class theory has been elucidated by Ralph Miliband.

The most influential of these perspectives in Western political sociology has been the pluralist one, which sees society as being composed of many different interest groups struggling to glean resources from the state and other societal agencies to get outputs in terms of favourable public policy. The pluralist view is also the perspective that is most useful in understanding the relationship between astronomers and the political system. Clearly, astronomers are neither part of a ruling class nor part of a ruling elite, and to dismiss astronomers as part of either one small fraction of either a middle class or a working class is uninteresting from the standpoint of this thesis. But from the standpoint of pluralism, astronomers can be seen as one of many interest groups negotiating with other interest groups and putting pressure on the state to improve their situation — to maximise and stabilise the resources given to them. I do not intend here to refute the elitist and Marxist perspectives or to reject them wholesale. Indeed, I am of the strong belief that they both extremely useful in other contexts. But for the purposes of my thesis, the pluralist approach appears to be more useful. In particular, elite and Marxist perspectives do not appear to give much insight into astronomy's specific struggles for funds. I have also found that virtually all writing about astronomy in the political context assumes a pluralist model. This is because the very notion of characterising astronomers as a distinct unit of analysis negates the more general notions of class and elite, which are more useful in examining societies at a macro level.

We can thus use the pluralist perspective to analyse the ways in which they use what power they have to attain favourable outcomes from the political system. Astronomers can be seen as both an interest group and a pressure group; they are a group of people sharing the same interests, who become a pressure group when they put pressure on the state to further those interests.

The link between legitimation and interest is clear. In order to accomplish their goals as an interest group, astronomers must legitimate what they do. The measure of the success of astronomers as an interest group is also the measure of the success of their legitimation practices. In contemporary society astronomers, or more specifically *some* astronomers, engage with the political system to get their point of view across, with a view to achieving the outcome of favourable public policies. Favourable here means resulting in funding for their salaries, technology and supporting infrastructures. We can see then that there is a synergistic relationship between legitimation and funding. Successful explanation and justification helps in gaining funding, and obtaining funding adds to legitimacy. Hence, looking at struggles for and over funding can give insight into legitimation processes and outcomes.

The chapter is divided into four sections. The first section is concerned with astronomers and public policy. In this section I introduce the reader to the fact that organized astronomers are seeing the importance of public policy to their being able to carry on their science. Second, using the specific example of the federal legislative process in the United States, I describe how astronomers and their representatives actually engage with the legislature to obtain resources. Third, I examine four case studies. The first is Jodrell Bank, the first large radio telescope in Britain. The second is the Gemini Project, an international project involving the participation of several countries. The third is the Hubble Space Telescope, which was the first large extra-terrestrial telescope. The fourth case study is the Space Station, which is a manned space program in which astronomers are participating. I complete the chapter with some general conclusions informed by my analysis and the case studies.

Astronomers and Public Policy

Almost unanimously, my interviewees (see appendix) said that at least some astronomers should engage in political lobbying. The importance of political lobbying to contemporary professional astronomy is evident on the web site of the American Astronomical Society. The site has a section devoted exclusively to public policy (http://www.aas.org/public_policy). In this section there is a document entitled 'An Astronomer's guide to public policy'. The document contains information for astronomers about why they need to get involved in science policy, how to get involved, who to contact and where to contact them. The page also includes links to home pages of relevant members of Congress, key congressional committees, and other astronomy and science policy home pages. The decision to include such information symbolises the transition from astronomers as an apolitical uncoordinated mass to a pressure group. Although as one of my interviewees, David Helfrand said, "We are never going to be able to compete with the NRA [National Rifle Association]", such political organization would be unheard of years ago. The fact that such a web site exists indicates that astronomers could now be in the process of becoming an interest group organized in such a way that they can put pressure on the political system to further their own interests in terms of public policy. Using a functionalist perspective, we can say that these pressures constitute inputs to the political system, which processes them and then eventually produce various outputs. The measure of the success of the inputs is the desired output of funding.

Specifically, the American Astronomical Society urges astronomers to get politically involved and to lobby various federal legislators. The document quotes Peter Boyce, Executive Officer of the AAS, who offers the following advice:

> Talk about the importance of science in broad issues. Do not make a special pleading for your project or just your science — except as part of the nation's overall science program. Do not make negative statements about other programs. This is extremely counterproductive. Keep your science explanations VERY simple. Congressmen do not

> have the time or background to understand the scientific nuances which may be important to you (American Astronomical Society 2000).

Boyce's advice is that astronomers should legitimise their research projects and fields in terms of the benefits of science as a whole. Boyce thus advocates that astronomy piggybacks on other sciences, or rather, science in general, in order to engage successfully in the agonistic field of the scientific-political system. Astronomers would not like to think of their field as being parasitic, but this is precisely what it is in terms of the type of argument used to obtain resources from society. The discipline and profession of astronomy cannot 'stand on its own two feet' to legitimise itself; it must portray itself as part of a larger noble human endeavour. Astronomy here is only legitimised in terms of science as a whole being a good thing for society to pursue. Boyce's arguments imply that astronomy benefits most when it allies itself with the rest of science. Indeed, more and more, the interests of astronomers cannot be distinguished from those of other scientists. This is of course particularly true of space science. Clearly, astronomers can benefit in terms of information and public support from North American Space Agency (NASA) projects such as the Pathfinder Mars explorer, even though astronomers involved in the project are in a minority; other project members may be engineers, geologists, meteorologists etc. Boyce's point about keeping explanations simple highlights the necessity for astronomers to present their research work in layperson's terms.

Engaging with the Legislature

As the United States is by far the biggest funder of astronomy, it is useful to examine the process whereby US astronomy resources are procured. The majority of funding for Astronomy in the United States comes directly from the astronomy budgets of the National Science Foundation (NSF) and the Office of Space Science (OOSS) at NASA (National Academy of Sciences 26). But these agencies in turn have to obtain funding from the United States government. In the United States, the key House of Representatives and Senate committees responsible for making decisions about astronomy funding are the House Appropriations Committee, the House VA-HUD (Veteran's Affairs — Housing and Urban

Development) Appropriations Subcommittee, the Senate Appropriations Committee, the Senate VA-HUD Appropriations Committee, the House Budget Committee, the Senate Budget Committee, the House Committee on Science, the House Basic Research Subcommittee, the House Space and Aeronautics Subcommittee, the Senate Committee on Commerce, Science and Transportation, and the Senate Science, Technology and Space Subcommittee. These committees decide how much to give agencies like the National Science Foundation and NASA, which in turn fund specific programs. Whether astronomers can continue their work thus depends to a large extent on the decisions made by these bodies.

The National Science Foundation (NSF) is the lead Federal agency for the support of ground-based astronomy in the United States, providing about two thirds of the federal support, including almost all federal support for radio astronomy. During the last few years a steadily increasing proportion of funding has come from NASA, at the expense of the NSF. Indeed, my MIT astronomer interviewees had experienced this shift in funding from NSF to NASA. A recent report by the US Space Science Board pointed to the problems caused by this situation, and observed that the NSF had been unable to give adequate support to the programs it funded. The document argues against the transfer of all astronomy and astrophysics funding from NSF to NASA, and concludes that astronomy and astrophysics should be jointly funded by NSF, NASA and DOE (Department of Defense), as well as other participants (National Academy of Sciences 34). Funding is provided through grants, contracts, and cooperative agreements awarded in response to unsolicited, investigator initiated proposals. Thus when the political system, in the US in the form of Congress, processes astronomers' demands for resources, astronomers are represented to a great extent by the NSF, whose agents present astronomers' claims to congressional subcommittees.

Discourse analysis of subcommittee hearings can shed some light on the arguments used by astronomers' representatives, as well as the mechanisms and processes involved in the determination of resources allocated to astronomy, and hence its legitimacy. In the Hearings before the Subcommittee of the Committee of Appropriations in the House of Representatives of the One Hundred and Fourth Congress, for the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations for 1997, a physicist, Dr Neal Lane, Director of the National Science Foundation, represented astronomers' interests. Dr Lane was responsible for persuading Congress to part with large sums of money for various basic sciences, including astronomy. Lane asserts:

> If an ordinary citizen were asked to name a field of research that is unlikely to generate much in the way of discoveries that would quickly find their way to the marketplace, it would not be surprising if astronomy were mentioned. But the determination of precise positions for satellites can only be accomplished by very long baseline interferometry (VLBI) radio telescopes fixing on distant cosmic radio sources. The Global Positioning System that uses satellites to precisely pinpoint our location at any spot on the globe would be impossible without such precision. GPS has important applications for the military, recreation, transportation, and even for reducing the time and cost of commercial airline flights. GPS is a multibillion dollar industry that would have been impossible without astronomical research (U.S. Congress. Senate Appropriations Committee 1997).

Here Lane makes one of the few clear utilitarian arguments I found in the course of my research.

In the United States, financial appropriations for the National Science Foundation astronomy budget are part of the Mathematical and Physical Sciences Activity Budget, along with mathematical sciences, physics, chemistry, materials research, and some multi-disciplinary activities. The National Science Foundation's 2002 budget request includes the following:

> The Mathematical and Physical Sciences Activity (MPS) supports a strong and diverse portfolio of research and education in astronomical sciences, chemistry, materials research, mathematical sciences and physics. The purpose of this work is threefold: to deepen our understanding of the physical universe; to use this understanding in service to society; and to prepare the next generation of scientists who are essential for continued progress. The mathematical and physical sciences underpin many other

> scientific endeavours and serve as the training ground for at least half of all doctoral scientists now employed in U.S. industry. The MPS Activity supports areas of inquiry that are critical for long-term U.S. economic strength and security, providing a substantial portion of federal funding for fundamental research at academic institutions in these areas, and in some subfields, provides for most of the federal investment (National Science Foundation 2002).

Lane similarly links astronomy with other basic sciences and long term utilitarian benefits:

> NSF has learned through experience that the way it can have the biggest impact on things like the technologies that will make happen what Dick Zare has just said is to choose the best people with the best ideas who are trying to push scientific frontiers and give them the tools necessary to achieve those ends. And when we do that, what we find is not only do they advance science, chemistry, physics, biology, whatever it may be, astronomy, but they also push the technologies. They generate, in ways that could not be predicted, new challenges and new ideas that will lead, in fact, to the kinds of applications that we really all dream about and that we know are possible. So what we really will be supporting is scientists, researchers, scientists and engineers, educators, who need these technologies and need to take risks at the frontier. Push them as hard as anybody can (United States Congress. Senate Appropriations Committee 1997).

NASA Director Daniel Goldin, after listing some of NASA's astronomical facilities' scientific discoveries together with those of other NASA scientific facilities, concludes by making the following case:

> NASA has been a terrific investment for the country. We do very real things to make life better for all Americans. Whether the concern is the environment, health care, the economy, or our children's education, NASA is making a unique contribution. One way we do that is by preserving U.S. leadership in cutting-edge science and technology. Our past work has led to

> tremendous breakthroughs in such diverse areas as mobile communications, air transportation, biomedical research, information systems, and new industrial tools. These types of new technologies mean a stronger America, but not without the workforce of the future to support the new technologies. NASA nurtures America's students to give them better opportunities for the future; our education programs reach more than 3 million people each year, from elementary students to post-graduates (US Congress. Senate Appropriations Committee 1997).

Spending on astronomy is here justified by linking it with “cutting edge science and technology” and in turn linking this with more general benefits, including economic ones. The testimonies by Lane and Goldin constitute unusually utilitarian justifications for astronomy.

In making the case for SETI funding, astronomer Christopher Chyba uses spin-off arguments:

> SETI research has had concrete spin-offs both for biomedical technology (as I mentioned in my testimony, for the detection of breast cancer) and for more conventional astronomy. It has also provided what I would call "educational spin-offs." The idea behind the technology spin-offs is that signal-detection techniques developed to perform the data-intensive SETI searches provide sophisticated but general methods for detecting extremely weak signals in the midst of background noise. This means that the SETI detection algorithms could potentially be applied to a wide variety of non-SETI applications that require a similar “search for a needle in a haystack”.
>
> Perhaps the most concrete example concerns a very important biomedical problem, the detection of breast cancer in its early stages. Thirty-two million screening mammograms are performed in the United States annually. But since 95% of mammograms are normal, if mammogram screening could be automated with a very high degree of reliability, the cost of breast cancer screening could be significantly reduced and, just as importantly, doctors would have more time for examining the small fraction of mammograms that show something suspicious. Computer-aided diagnosis

could become routine as digital technologies come into use for mammogram images. Mathematically, the detection of weak signals coming from distant stars is very similar to the detection of the micro-calcifications that signal the possibility of cancer, but which can be lost or hidden in all the background structure in the mammogram X-rays.

In addition to medical technology applications, SETI research has had significant spin-offs in areas of astronomy. One example lies in the detection of planets around other stars. The “matched filter” detection algorithms developed for SETI are used in the *Kepler* mission, a spacecraft mission under consideration by NASA to detect extra-Solar planets by searching for a slight dimming in the light from the star as a planet moves across its face. Once again, the SETI techniques are helping to pull a faint needle of a signal out of a haystack. A second example of a spin-off lies with the impact that the design and construction of the Allen Telescope Array (ATA) will have on future radio telescopes. As I described in my written testimony, until now it was only practical to construct the collecting area for a major radio telescope as a single enormous dish (as at Arecibo, Puerto Rico), or as several large dishes (the Very Large Array in New Mexico has 27 dishes) whose output is combined. But the ATA will be constructed using over three hundred fifty mass-produced dishes—at about 20% of the price of a conventional radio telescope of the same collecting area. SETI telescope technology research has resulted in a cutting-edge design that will alter the way that future radio telescope facilities are built. The Square Kilometre Array (SKA) is an international ground-based radio telescope that will have a million square meters of collecting area, making it one hundred times more sensitive than the most sensitive existing radio telescopes. The National Academy of Science's last decadal review endorsed a technology development program for the SKA, for the “unprecedented images” and “great discovery potential” that it will allow. The SKA is a major part of the future of radio astronomy, and the ATA is pioneering techniques that could be used to build the SKA. In effect, the ATA is the leading prototype for the SKA — so that the SKA design might well prove to be another SETI spin-off.

> One final, but very important, spin-off from our SETI work is what I would call the "educational spin-off". The Institute has substantial education and public outreach components, both in the form of hundreds of talks given by Institute scientists to audiences of all ages, and more formally in terms of curriculum development … Speaking from my personal experience as a teacher and as a public lecturer, a powerful way to inspire young people, and to attract and hold the interest of adults, is to teach science in the context of exciting questions such as the scientific search for life elsewhere in the universe. Addressing this problem scientifically requires elements of all the sciences, and the "hook" of searching for life helps make teaching basic or advanced concepts in these areas more appealing to students of all ages (US Congress. House of Representatives 2001).

Chyba makes an indirect utilitarian argument by linking SETI with medicine. This has been also been done with other astronomical activities: imaging techniques used in astronomy, it is claimed, can also be used for medical imaging. Then there is an internalist justification: activities in one field of astronomy benefit other fields of astronomy. Education is also seen by Chyba as a spin-off. SETI, as an activity that excites the public and especially youth, gets students interested in science in general. As we shall see, the education argument is a common one used by astronomy advocates.

In contrast, at the same hearing, astronomer Neil de Grasse Tyson uses non-utilitarian justifications. After giving numerous examples of media and public fascination with exobiology, Tyson concludes:

> The discovery of extraterrestrial intelligence, if and when it happens, will impart a change in human self-perception that may be impossible to anticipate. If we don't soon find life elsewhere, what will matter most is that we had not stopped looking. Our species demands that we keep looking. Deep in our soul of curiosity we are intellectual nomads—in search of other places, in search of other life forms because we derive

> almost as much fulfilment from the search as we do from the discovery (United States Congress. House of Representatives 2001).

Tyson’s remarks are humanistic. SETI is to be funded simply because we want to do it; it is in our nature to do it.

Another of my interviewees, Charles (‘Chuck’) Hailey, asserted: “spin-offs in astronomy are low, and NASA overestimates the spin-offs”. Hailey also said that spin-off arguments are “dangerous”, and that the “purist justification is the only safe one”. He concluded, “the utilitarian argument is bullshit”.

The above quotes are of course selective, but my search of the US government’s website has confirmed that they are representative of the type of arguments used when astronomers argue their case before the legislature. In fact few general externalist justifications of astronomy can be found. In most cases the arguments take the form of internalist justifications, that is, justifications made on the basis of astronomical discoveries themselves. It can be seen that in the political setting astronomers use a variety of legitimation (explanatory and justificatory) arguments, ranging from technological and educational spin-offs to representing astronomy as a manifestation of human nature.

On occasions, the executive arm of the state can support astronomers against their own funding agencies. Senate staff member and powerful clerk of the VA-HUD-Independent Agencies Appropriations Subcommittee, Dick Malow, forced a commitment from the National Science Foundation to construct two eight-meter telescopes, one in Chile, the other in Hawaii. The previous year, appropriators had provided $4 million to purchase initial glass for both projects, with an understanding that British Commonwealth nations pay half the total $176 million cost. Malow wanted to ensure at least one telescope would be built, and wrote a series of questions for VA-HUD sub-committee chairman Traxler that compelled NSF officials to accept the commitment publicly. In this way congressional hearings in the US can both provide information on astronomy policy for all stakeholders, including astronomers, and at the same time ensure funding for specific projects.

Apart from the NSF, the main source of funding for professional astronomy in the United States is NASA. Much of NASA's funding is not for astronomy, but NASA does manage some telescopes, and some of the space science managed by NASA is astronomical. From the standpoint of NASA funding, astronomy is subsumed under the general funding category 'Space Science' which also includes physics and space exploration. The non-astronomical activities of NASA put astronomers in a difficult position. On the one hand astronomers depend on NASA for certain projects, and can benefit in terms of spin off from NASA's space science activities; on the other hand astronomers oppose some of NASA's activities that appear to impinge upon, or in some cases take away resources from, their own activities. Thus the relationship between astronomers and NASA is partially contradictory. NASA enables some astronomers to do astronomy that they would otherwise not be able to do, but at the same time has its own priorities that are not necessarily those of astronomers. As will be shown, NASA also is an institution characterised by specific power structures and dynamics that can bring it into conflict with the priorities and values of astronomers.

Using the example of AXAF (Advanced X-Ray Astrophysics Facility) Tucker and Tucker describe the process by which an idea for a project becomes a fully-fledged NASA mission. At the beginning of the process, even the name of the program appeared to be instrumental in getting the project off the ground:

> Any mission the size of AXAF must travel a long and treacherous road before it arrives at a NASA launching pad. Before the satellite carrying the dreams of its creators lifts off the pad, the dream must have been shared by tens, then hundreds, then thousands of people—scientists, NASA officials, industry management, engineers, technicians, congressional staffers, members of Congress and the executive branch, and ultimately the voters, who may be called on to express their support of NASA in general and a specific mission in particular. The first part of the trail must be blazed by the individual or group that conceives the mission. They—it must become 'they', not just one person, who are proposing the mission or it will be stillborn—formulate a concept, such as a large X-ray telescope, and begin to sell it to their scientific peers. This is done by

> making personal appearances—preferably as invited speakers, a cachet that lends important credibility—at meetings of the American Astronomical Society or the International Astronomical Union, and at meetings of the scientific advisory committees of NASA and the National Academy of Sciences (Tucker and Tucker 60).

Clearly astronomers working for NASA need a range of political and communication skills to successfully initiate new programs. In the case of AXAF, two groups of astronomers combined to get the program through the various bureaucratic obstacles that needed to be overcome to become a fully funded project. These obstacles take the form of five of what NASA calls 'phases': two detailed definition studies, design, development, and operations (Tucker and Tucker 61). At any stage a program risks being stalled and possibly stopped completely, and political skills are needed to garner support and move the process along. The AXAF itself got bogged down at the design and development phases. When this happened two of the proposers, Harvey Tannernbaum and George Clark, got together and wrote letters to 240 of their closest friends in the astronomical community. The letter urged the astronomers to write to the Associate Administrator for Space Science, Burt Edelson, emphasising the importance of proceeding with the AXAF. The letter campaign succeeded in getting the AXAF moving again (Tucker and Tucker 72). At this point, other groups of specialist astronomers, the infra-red and ultra-violet groups, saw the success the AXAF people were having in moving their project along. This caused them to speak out on behalf of their own pet projects. It seemed for a while that the three specialties would be in direct competition with each other, but the political savvy of the AXAF group had already ensured the priority of their project (Tucker and Tucker 73-74).

Even once accepted by NASA a project had to go through the Office of Management and Budget (OMB) and of course Congress. In the case of the AXAF, the project was initially rejected by the OMB, but the political savvy of the astronomers paid off here too. AXAF advocate Tananbaum asserted: "It's not unusual for the OMB to oppose new starts. It is a closed process there; they don't talk outside of the government. Only to NASA. We were committed. We had support all the way, from Pellerin to Fisk to Fletcher. It is like a game of chicken. People at OMB know how important the program is for you. If you take the challenge, they back off" (Tucker and Tucker 102-103). At this time, Charles Pellerin was the Director of the Astrophysics division at NASA Headquarters. Pellerin was a strong supporter of AXAF. He took it upon himself to reframe the AXAF proposal such that it would appeal firstly to the scientific community, then to NASA, and ultimately to Congress. He and the AXAF astronomers created a concept they called great observatories vision, consisting of Hubble, GRO (Gamma Ray Observatory) AXAF and SIRTF (Shuttle Infrared Telescope Facility). Pellerin and his colleagues produced a cartoon booklet entitled *The Great Observatories for Space Astrophysics*, which they distributed widely among the opinion makers on Capitol Hill, within NASA, in the scientific community, and to schools (Tucker and Tucker 78-79). According to Pellerin, "they were brawlers, scrappers and hell raisers" (Tucker and Tucker 83-84).

When the AXAF project again became stalled, Pellerin once again stepped in and kept it moving. MIT astronomer and fellow AXAF advocate Claude Canzinares called Pellerin "the consummate infighter" and "so clever, so articulate, so brilliant, that he managed to keep it uncertain. With that uncertainty, I could proceed and do the bureaucratic part better" (Tucker and Tucker 88). AXAF advocate James Fletcher appealed to the President's budget review board, who rejected the appeal. Fletcher then went to President Reagan. Fletcher sent Reagan several memos, emphasising that the US had no X-ray mission but the Soviets had. The memos concluded with the message question, 'To whom will the future of space belong?' AXAF then became part of Reagan's budget recommendation to Congress of 1988. AXAF advocates found out who the influential person was on the appropriate committee (VA-HUD). It was chief of staff Richard Marlow. Marlow was impressed by the dedication, honesty and enthusiasm of the AXAF astronomers, in particular their letter writing campaign to members of Congress. According to NASA administrator Leonard Fisk, who by now was supporting AXAF, the letters were very effective. Despite Marlow's positive impression, he was wary of recommending financing AXAF because of Hubble cost overruns. He therefore agreed to fund AXAF if they could build a mirror in three years (Tucker and Tucker 106-108). AXAF accepted the deal, completed the mirror in the allotted time, and AXAF was funded.

Planetary Versus Galactic and Extragalactic Astronomy

The involvement of NASA in astronomy originated more from its interest in planetary astronomy than in galactic or extragalactic astronomy. With the development of rocketry during and after the Second World War, the exploration of the Moon and the planets became a real possibility. After the war the United States procured Werner Von Braun and other rocket specialists. Von Braun et al. chose the United States partly because it was the most able to provide resources for interplanetary travel (Tatarewicz 14). The Von Braun team then embarked on rocket development that eventually led to the Apollo program. During this period the various armed forces vied for control of the project. When NASA was created in 1958 they joined the fray, and got control of the lunar project in 1959 when Eisenhower transferred the Von Braun team to them (Tatarewicz 14).

But in October 1957 the Soviet Union beat the United States into space with the successful launch of Sputnik I. The effect of Sputnik I on the United States and the West in general cannot be overestimated. Sputnik I spurred on the development of astronomy. Observatories were needed to track satellites, as with Jodrell Bank in Britain. But the successful launch of Sputnik I also gave a boost to rocketry in the United States, which was terrified of Soviet superiority in space. There was a desire to even the score with the Soviets, and to demonstrate America’s prowess in space (Mudgway 1-2). Rocketry in turn affected the development of astronomy, but in specific ways. Exploration of the planets required much background information that could most economically be done using ground based astronomical facilities.

Ironically, planetary astronomy was the very field that had been neglected by professional astronomers for half a century. The development of spectroscopy, improvements in optics making possible large mirrors and the subsequent discovery of external galaxies caused most professional astronomers to turn their attention to galactic and extra-galactic astronomy, to the detriment of planetary astronomy.

The neglect of planetary studies was compounded by American astronomer Percival Lowell's mistaken interpretation of Italian astronomer Giovanni Schiaparelli's observation of Martian *canali* (Italian for 'channels') as *canals*. Informed by his mistranslation of the Italian, Lowell interpreted his own observations as artificial canals on the red planet. The subsequent debunking of Lowell's interpretation of his observations helped turn the mere neglect of planetary astronomy into actual disrepute (Tatarewicz 2-3). Moreover, although Lowell had done some respectable planetary astronomy, his observations of artificial canals encouraged a certain kind of public interest, already kindled by stories such as H.G. Wells' *The War of the Worlds*. Such interest "tended to encourage cranks to enter this field, which is difficult enough without them" (Tatarewicz 2), and graduate astronomy students were warned off planetary studies: "The senior student astronomers told their students that the planetary system does no longer offer a subject for astronomical research which would lead to significant new findings" (Tatarewicz 2). In the early part of this century, right up to at least the mid 1950s, professional planetary astronomy had become discredited and almost entirely abandoned, and stellar and galactic astronomy held centre stage. Planetary astronomy was almost entirely the province of amateur astronomers (Tatarewicz 1).

Thus the involvement of astronomers with the space program in general, and NASA in particular, actually caused the direction of astronomy to change; planetary astronomy, having been neglected for so long, was brought back on to centre stage. As the case studies below show, the relative autonomy of astronomers, their relations with sympathetic and hostile agencies, and agencies with other agendas, all affect the degree to which astronomers can legitimate (explain and justify) their work.

Four case studies

Four case studies of large astronomical endeavours will serve to highlight the strategies involved in legitimating specific projects in modern astronomy. A key measurement of legitimation is practical success. That is to say, astronomy is legitimised in so far as society is prepared to expend resources to maintain and extend its activities.

Jodrell Bank

The case of Jodrell Bank is significant to the analysis of astronomy legitimation because it shows how one individual can successfully legitimise a major project to the extent that society parted with enough resources for its successful completion.

Because astronomers lack political organization, one option is to lobby individually. Indeed, a large portion of the American Astronomical Society home page public policy section is devoted to explaining to astronomers precisely how to do this. In recent history, major projects have in fact been lobbied for individually.

Jodrell Bank, the first large radio telescope ever built, and still the largest steerable radio telescope in existence, was successfully lobbied for by its creator, Sir Bernard Lovell (Lovell 1968). By 1951, Lovell had already carved himself a reputation as a physicist, and was well respected at his place of employment, Manchester University. Lovell had attended the University of Bristol, from which he received his Ph.D in 1936. After obtaining a position as Assistant Lecturer at Manchester University he became a member of its cosmic ray research team until 1939, when he published his first book, *Science and Civilisation*. During World War II Lovell did important research in the use of radar for detection and navigation purposes for which he was awarded the Order of the British Empire in 1946. In 1947 Manchester University finally appointed him Senior Lecturer.

In the early forties, the fledgling discipline of radio astronomy was rapidly growing. Martin Ryle and his colleagues at Cambridge University, and J.L. Pawsey and his colleagues at Sydney University, were studying radio waves from the sun. Thus Lovell's suggestion of using a radio telescope to study celestial phenomena was an idea whose time had come. Research groups were springing up in other scientific sites, and this body of work was grounded in other work in the 1930s, by Jansky and Reber in the 1930s and Hey in the Second World War. The early fifties were a time of generally uncritical support of science, nation building, and a post-war acceptance of a government role in funding left over from the Second World War. Lovell found himself in a position of being in the right place at the right time. His reputation within the university earned him the support, firstly of his head of department and then the vice chancellor, and it appears that these and other personal contacts were crucial in getting the project off the ground (see for example Lovell 1968: 1-3 and 32-36), and in maintaining the momentum of the project in very difficult financial times (Lovell 1968: 85). Eventually the project was to cost over 400,000 pounds, but it is clear from Lovell's account that there would have been no hope of the telescope being built had the final cost been known. Rather, the process began with an initial grant of 1000 pounds in 1947 from the DSIR (Department of Scientific and Industrial Research) for a transit telescope to do radio work on meteor echoes. Soon after, Lovell found that the radio telescope could be used to study other celestial phenomena, and thereafter Lovell put in ever-larger requests, all of which were granted, and the cost grew exponentially over a period of years until completion in 1957.

Of crucial importance in the success of Jodrell Bank was the unquestioning support of Manchester University (Lovell 1968: forward by Rainford x; Lovell 35, 116, 120-121). Crucial also was support from influential individuals at the very top of the University echelon (Lovell 1968: 35), including Lord Simon, Chairman of the University Council and his wife, Lady Simon, who was a member of that body. Lord Simon "adored big projects" and socialised with the Lovells in their home. Even when berating Lovell for his administrative incompetence, Simon was "determined that it would not fail" (Lovell 1968: 100). There was also the "fanatical enthusiasm, drive and energy of Bernard Lovell" (Rainford, in Lovell x), and personal contacts both within and without the university (Lovell 1968: 84). For example, Lovell was personally acquainted with Sir Ben Lockspeiser, Secretary of the Department of Scientific and Industrial) Research (DSIR), the major scientific funding agency in the UK at the time (Lovell 1968: 28, 96).

In short, Lovell was part of a social class of influential individuals whose ideology was sympathetic to the project. This social networking was crucial in maintaining the project, which also had the support of the Royal Astronomical Association, the major organization for British professional astronomers, and in particular support from its chairman, Sir Edward Appleton (Lovell 1968: 33). Moreover, although Lovell had problems with some contractors, he was able to build close relationships with others, and certain prominent and influential individuals associated with some of the private contractors involved in the building of Jodrell Bank were sympathetic to the ideology and vision of the telescope and readily gave of their time at no profit to themselves (Lovell 1968: 60-61). Reading between the lines of Lovell's account, it appears that another factor, power to ride roughshod over the wishes of local farmers, was also important, at least in determining the successful acquisition of Lovell's preferred site for the telescope (Lovell 1968: 37-40).

Once the enormous financial and technical difficulties associated with the building of the first big radio telescope were overcome, and once the telescope achieved a worldwide reputation, Lovell found it relatively easy to add to the Jodrell Bank complex, building smaller, specialist radio telescopes (Lovell 1968: xv).

It also seems that despite sporadic lack of support and even hostility to Lovell's persistent requests for more money by top Ministry administrators, key officials within the DSIR continued to support Lovell. This left Lovell with a Mertonian/Vannevar Bush philosophy of government interference with astronomy:

> I was disillusioned and aghast at this blindness to the needs of the future. In the autumn of 1957 Britain had the only instrument in the world capable of giving non-visual information about the device which the Russians launched Sputnik I. The fact that it had this ability owed little to those whose job it really was to look after these matters. However, it must not be thought that I bore any grudge. On the contrary, at the end of the affair, I was gratified that we had been left as free agents, to use the telescope on these matters as we thought fit, and not shackled with a financial commitment which might well have ended with a grievous diversion of the telescope from its astronomical researches (Lovell 1968: 86).

The above quote is instructive, for it illuminates the political paradigm in which astronomers worked in the nineteen fifties. Lovell was dealing with a transatlantic political/scientific system dominated by Vannevar Bush's philosophy of the autonomy of science, buttressed by the ideology of Mertonian norms of universalism, disinterestedness, and organized scepticism, in which scientists, including astronomers, expected, and got, a certain amount of money each year, and told to 'get on with it'. In other words, government support without control.

In the case of the seven-year saga of the building of Jodrell Bank, one factor that appears to be a consistent influence on the progress of the project was the degree of independence of the DSIR from central government and parliamentary scrutiny. As previously mentioned, the DSIR was partly composed of scientists who were sympathetic from the beginning to Lovell's vision. However, even in the nineteen fifties, as time went on, and the project went more and more over budget, at certain points the Treasury intervened in such a way as to stall the project. The Treasury in turn was being pressured by the Accounts Committee, which at that time was overseeing DSIR expenditure. It appears that Lovell dreaded any interference from the Treasury, who were "afraid of the Public Accounts Committee" (Lovell 1968: 148). Lovell's relationship with the DSIR was ambivalent, but it did appear to provide a buffer between him and the project and central government. The Jodrell Bank case thus highlights the importance of relatively independent agencies that can fight for the interests of astronomers and their projects, and that can act as a buffer between them and hostile agencies.

What makes the story of Jodrell Bank so extraordinary from the point of view of legitimation is that despite the fact that, as Lovell himself admits, he was administratively incompetent, and despite the fact that the project went way over budget and suffered one disaster after another, the telescope was completed to eventual acclaim. Part of the reason seems to be that once started, the project developed a life of its own, independently of any of the actors involved. The big financial problems did not become apparent until the project was well under way. By this time large amounts of money had already been invested (though even by 1950s standards, the project deficit of 260,000 pounds was dwarfed by other government budgetary deficits in military projects, see Lovell 1968: 151), and the telescope was physically extremely conspicuous on the Cheshire skyline. It would have been unthinkable to bring the project to a halt not only because of the money already spent, but also because of the loss of face it would entail to all involved.

In the midst of the worst troubles, when Lovell had caused Manchester University to be a quarter of a million pounds in debt, Lovell wrote in his diary "the proceedings had left me utterly miserable. I used to seek comfort by gazing at the great mass of the telescope. The hugeness of it, even at that time, somehow made it seem inevitable that it would have to be finished" (Lovell 1968: 120), and "The unfolding of the financial chaos in 1955 occurred against the backcloth of the growing telescope steel work. Indeed, it seemed as impervious to the financial troubles as is was to the winter winds. I often wished that our meetings could be under its shadow. The growth of our deficit seemed less important when measured against the actuality of what had already been achieved" (Lovell 1968: 123). And again, "By the time the crisis came the completion of the project was inevitable" (Lovell 1968: 151). Indeed, had the full cost of the project been known to the money givers at the beginning, it is likely that the project "would have died a quick death" (Lovell 1968: 32). Once the project got under way it would have been more difficult to stop it than to continue it. Clearly, the project needed legitimising most at the beginning.

In fact the telescope's financial troubles continued from 1955 right up until and beyond the beginning of its operations in 1957 in which Lovell himself was "only an anguished spectator" (Lovell 1968: 148). As the cost of the telescope soared way beyond its budget, the Treasury took a more pro-active role and the DSIR became less of a buffer, even though the DSIR itself took "a poor view of this Treasury intervention in handling money which has already been granted to them" (Lovell 1968: 149). Commenting on the intervention of the Treasury Lovell asserts:

> I felt at the time and still feel today that these conditions were made by men whose first concern was the preservation of their own skins, who had no conception of the likely consequences of their action, and whose horizon was limited by the walls of their offices...the consequences of the Treasury's conditions were disastrous in the extreme, and only by the narrowest of margins did the project continue to move forward to success (Lovell 1968: 150).

Lovell's cry here is one of the scientist pleading for independence against 'interference' in the form of public accountability; Lovell himself admits that the reason for the Treasury's intervention was fear of the Public Accounts Committee (Lovell 1968: 150). The DSIR was a buffer between Lovell and the government partly because it was a separate, independent body, but more importantly because it was composed of individuals who were both bureaucrats and scientists.

Having prominent scientists with whom to liaise in the bureaucracy was clearly an important factor in Lovell's final victory. Even when the DSIR's Scientific Grants Committee were critical of Lovell, they still thought that the project should proceed and supported it (Lovell 1968: 52, 106). At one point the project's enormous budget overrun strained Lovell's relationship even with the DSIR, but Lovell was again saved by the appointment of a sympathetic Chairman of the DSIR Advisory Council (Lovell 1968: 98). Even when the government instructed the DSIR to appoint an independent committee of inquiry into the finances of the telescope, the eventual composition of the committee ensured that the DSIR would continue to support the project. This is not to say that this was a foregone conclusion or that the committee was just rubber stamping the project, for it appears that Lovell was given a genuine grilling. Rather, the committee was composed mainly of scientists (Lovell 1968: 132-133) who were sympathetic to the idea of the telescope, and were likely to find means to support it in one way or another. Moreover, by this time, as Lovell himself notes, "the sheer momentum and massiveness of the project saved it from stoppage and disruption" Lovell 1968: 137).

International events transformed the project's social status into a world famous scientific success. In this context the boosts given to Jodrell Bank by both the Russian Sputnik and the American Lunar Pioneer probes cannot be overestimated. It was the successful tracking by the telescope of signals from these two probes and the subsequent gratitude of those involved with the probe that proved the telescope's worth to the media and the public.

In the case of Sputnik I, media perceptions raced ahead of the project, and created a situation in which the telescope was forced into a public demonstration of its utility. Even though Lovell had given no indication that the telescope would be used to track the now orbiting Soviet satellite, press and broadcasting personnel appeared around Lovell's home and the telescope. Lovell at first resisted the temptation to track the satellite just for a "beep beep" (Lowell 1968: 192) but changed his mind when he found out that, incredibly, no other British facility was tracking it. Simultaneously, the telescope's engineer Husband informed the press that the telescope was now operational and expressed his desire that the telescope be used to demonstrate his engineering achievement. Lovell agreed as long as Husband completed his engineering work on the telescope's computer controls, and work that had previously been thought would take months was completed in two days. By the time of the demonstration the BBC had more engineers on site than were on Lovell's staff. The response from project astronomers was mixed; some saw it as an opportunity, others saw it as interference with their work. After the successful tracking demonstration Lovell went from local villain to national hero. The Prime Minister made an announcement in the House of Commons, referring to Jodrell Bank as "Our great radio telescope". Lovell defended the 'publicity stunt' by answering his critics that "important scientific results were obtained" which were published in *Nature* (Lovell 1968: 192).

From the time of the tracking of the Sputnik, Lunik and Pioneer probes, press comments were "almost violently pro-telescope" (Lovell 1968: 219). Moreover, in the wake of the Pioneer tracking, Americans took an increasing interest in supporting the telescope. Americans regarded it as "almost a joke" that Britain should have produced an instrument like this and its use was being restricted on financial grounds (Lovell 1968: 220). Visiting American Congressmen thought that the telescope's financial plight was "absurd" (Lovell 1968: 220-221), and during this period American politicians showed more interest in the telescope than did the British government (Lovell 1968: 221).

Eventually it was agreed that NASA pay Jodrell Bank a sum per hour when the telescope was engaged in cooperative projects: "The Jodrell Bank telescope then became an integral part of the U.S. deep space instrumentation facility", and it was this that brought the telescope's financial worries to an end (Lovell 1968: 222). This came in the wake of a continuing failure of the British government to come to the telescope's rescue (Lovell 1968: 228). Soon after this arrangement was made, transmitting equipment was attached to the telescope. In 1960 signals were transmitted to Pioneer V, which contributed to the success of that mission. By May 1960 the telescope's debt was cleared, courtesy of NASA and a personal gift from Lord Nuffield of 25,000 pounds. Throughout this period, the British government refused to donate any funds, even though the telescope had proved itself to the extent of becoming a national public icon.

We can see that Lovell succeeded partly because of his reputation and persistence. But Lovell also succeeded because early on he managed to define his project firmly in the camp of big science, firstly in terms of its conception and then once funding started rolling in, by sheer momentum, so that both existing and potential funding agencies had a vested interest in the success of the project. Once so defined, it became difficult to bring the project to a halt. Finally, when the telescope had been built and the British government refused to pay its debt, Jodrell Bank was in a position to justify itself to NASA by successfully tracking Pioneer V.

The Gemini Project

Completed in 2002, the Gemini facility is an international project involving the building and use of two (hence ‘Gemini’) eight metre optical and infra-red telescopes, one in the Northern hemisphere in Hawaii and the other in the Southern hemisphere in Chile. The participating countries are United States, Canada, Britain, Australia, Chile, Argentina and Brazil. Costing $200m, the project is 50% funded by the United States, whose astronomers are allocated 50% use time (McCray 2004: 2, 172, 210). In the United States, the Gemini proposal had to compete with another all American proposal, which for a while appeared the favoured alternative when Canada temporarily pulled out of the project. But then Canada rejoined, albeit with a reduced commitment. Chile and Australia were persuaded to join the project and thus the financial gap left by reduced Canadian participation was plugged (McCray 2004: 242). With the financial gap plugged Gemini was chosen because of the economies of scale the twin telescopes had as compared with the national proposal (McCray 210-211). Gemini has been described as a ‘hyper-telescope’ (McCray 2004: 8, 248-257): a large, organic entity (in this case two telescopes thousands of miles apart), consisting of a network of complex equipment monitored by astronomers. With modern computerised telescopes like Gemini, astronomers no longer fit the heroic image of the observer sitting alone in the telescope. Rather, they work in front of a computer monitor analysing data. Thus the typical modern professional astronomer works in much the same way as millions of other professionals. Of course with space telescopes such as Hubble direct observing is impossible anyway. And the importance of data analysis is highlighted by the fact that NASA finding for research using the Hubble Telescope includes not only observing time but also separate funding for data analysis (McCray 2004: 268). It is no longer even necessary for the astronomer to be physically at the telescope: technicians point the telescope and astronomers analyse the data remotely (McCray 2004: 271). Modern observatories have been described as 'data factories' and guest researchers as 'customers' (McCray 2004: 274).

In the 1980s, not only the United States, but also Canada and Britain were considering building new, large astronomical facilities. In Britain and Canada professional astronomy is almost wholly government funded. In both cases, the 1980s were characterised by cuts in government spending, including cuts in science budgets. Hence these countries began to consider international collaboration. Since 1987, Britain and then Canada had discussions with the National Optical Astronomy Observatories (NOAO), which consisted of the then three federally funded American optical observatories, with a view to collaborating on a major jointly funded project. NOAO, in turn, was managed by a parent agency, the Association of Universities for Research in Astronomy (AURA). In 1989 and 1990 astronomical representatives from Britain and Canada met with AURA and it was decided to embark on a major project involving the three nations.

In 1990 Congress passed House Resolution 5158, which gave the American astronomical community $88m with which they could either share two telescopes with international colleagues, or have one telescope for their sole use. The notion of international collaboration was also supported by the then National Science Foundation (NSF) Director, Erich Bloch, who wanted to limit spending on basic research, and who saw international collaboration as a way of keeping part of his basic research budget under control (McCray 2000: 687). So the decision went ahead to go for an international project, over the head of many American astronomers, who had originally hoped for a new national observatory in Hawaii, to which they would have exclusive use (McCray 2000: 703). This transfer of control over research decisions away from astronomers to NSF officials has been a notable feature of recent American astronomy (McCray 2004: 44).

In 1990 the British Science and Engineering Research Council formally voted to join the United States and Canada in a collaborative project. For their part, British and Canadian astronomers were pleased that the project was going ahead; their respective domestic political and economic environments were not conducive to more government spending on astronomy; they thus were relieved to get any major new facility. The US would provide 50% of the funding, and Britain and Canada 25% each. More meetings followed and by 1993 the political framework for Gemini was in place.

The Gemini Project was sold to dissenting American astronomers as a 'niche' project. Gemini was not unique: its telescopes would be 'ordinary'. But, the novelty sold to gain community support was that a) Gemini would offer astronomers the opportunity for observing in both Northern and Southern hemispheres and b) the opportunity to observe both optically and in infrared.

The fact that Gemini had to be 'sold' to some astronomers shows astronomers do not constitute a disciplined unified political group. In the US, as McCray (2000) notes, astronomers wanted different types of facility depending on their own situation, and in particular, depending on whether they were one of the 'haves' who were able to use private facilities, or one of the 'have nots' who are restricted to national facilities. In Britain and Canada however, because facilities are government run, there does not seem to be the same conflict of interest: British and Canadian astronomers gave it their unqualified support. In the United States, Gemini became the most politicised and contentious project in the history of ground based astronomy (McCray 2004: 215). Even the choice of mirror grinder, Corning Company instead of Angel Company, whose technology some American astronomers thought to be superior, exposed the divisions in the astronomical community. British and Canadian astronomers favoured the Corning technology, and international cooperation between astronomers was for a while at risk (McCray 2004: 226). Some astronomers were happy to cede such decision making to project managers and systems engineers; others pointed to the Hubble mirror fiasco as evidence that astronomers should retain their influence and authority (legitimate domination in their field of knowledge) in such matters (McCray 2004: 222), and the project was for a while under threat of cancellation.

This threat was enough to bring recalcitrant astronomers brought around and eventually a unified front was presented to Congress. In the last analysis, Gemini got off the ground because astronomers presented a more or less unified international front.

The Hubble Space Telescope

An international, but mainly American, project, The Hubble Space Telescope is the most ambitious and expensive astronomical project to date (apart from the still incomplete and only partly astronomical Space Station, which it predates — see below). Its conception and building involved hundreds of administrators, engineers and other workers, and astronomers were the final 'end users'. The early history of the project illuminates the power dynamics between astronomers and government in a dramatic way. Even prior to launch, one astronomer 'took heat' from NASA bureaucrats by suggesting that if the Telescope were to dip below its normal altitude, a shuttle should be sent up to give it a boost (Chaisson 39). Later, NASA would indeed have to send up subsequent shuttles to fix the telescope, albeit for different reasons. I use Chaisson's book *The Hubble Wars* extensively as a source in this section and in the chapters on astronomy as big science and boundary work. Chaisson is a valuable source for information about the astropolitical dimensions of the Hubble Space Telescope. He was one of the astronomers employed by NASA to work on Hubble and was the spokesman and director of educational programs for the Space Telescope Science Institute, a NASA-supported group of university astronomers with responsibility for planning and directing the telescope's observational problem (The New York Times Book Review 5). *The Hubble Wars* won the American Institute of Physics Science Writing Award.

NASA was such a strong and autonomous power centre that when government wanted independent information about the progress of the telescope they would contact one of the astronomers to get a true, unbiased, picture, rather than contact NASA (Chaisson 62, 94). NASA appears to have had a militaristic attitude of secrecy toward the project, not wanting to expose the telescope to public scrutiny. When quizzed by the press, NASA would descend into obscurism (Chaisson 69). By allowing themselves to become involved with NASA, astronomers effectively relinquished at least some control over their work. An early manifestation of this was the suggestion by certain astronomers that students should be allowed to use the Space Telescope for public relations and educational reasons. NASA vehemently opposed the proposal, fearing loss of control. Eventually the idea was abandoned (Chaisson 85).

A similar situation arose when Hubble astronomers wanted to release ‘first light’ pictures to the public via the media. NASA fought the proposal doggedly, and only agreed to the idea after a long struggle (Chaisson 97-99). NASA also rejected a request by astronomers to share ‘first light’ (the first Hubble observations) with the public (Chaisson 106). NASA went even further when astronomers organised a presentation on the Space Telescope for educators and journalists. NASA allowed the presentation to go ahead, adding its own speakers to the four presenting astronomers. According to Chaisson, the NASA speakers “spoke technically as though addressing their colleagues”, so that the audience understood little of what was said. The astronomers (claims Chaisson) presented the project in layman’s language, and included statements that corrected exaggerations that NASA had given at the beginning of the project to gain public support. NASA officials censored the astronomers’ presentations out of the televised program on NASA’s cable channel, leaving only the technical presentations. According to Chaisson, during the early stages of the project, any sharing of Hubble science to educators and their students was achieved by astronomers *despite* NASA (Chaisson 107). When Chaisson resorted to arranging programs with Maryland Public Television, NASA told the Scientific Institute (the official organization of Hubble astronomers) to stop the programming.

Thus in the early stages of the Hubble project it is clear that astronomers were in a conflict relation with NASA, which was exacerbated by personal animosity between the Director of the Science Institute, Riccardo Giacconi, and the astronomy head at NASA headquarters, Charles Pellerin. Tucker and Tucker confirm Chaisson’s critique. Comparing Hubble to the AXAF (Advanced X-ray Astrophysics Facility) project they note the fact that Giacconi and the other AXAF collaborators were old friends and worked as a team: “The key was teamwork. We set up a good coordinating team with NASA, scientists and industry. We kept each other informed. We had one story. We shared contacts and information. And we had lots of facts to support our case” (Tucker and Tucker 102). Tucker and Tucker also note the greater autonomy of the astronomers on the AXAF who were able to oversee the project from beginning to end. Two teams of scientists working together from beginning to end ran the AXAF project. The Hubble Space Telescope on the other hand was run by one project scientist and a deputy, and was characterised by a total lack of involvement between the astronomers and engineers (Tucker and Tucker 62-65).

More importantly, astronomers were incensed that NASA had been disseminating false information to the public about the capability of the telescope, the most outrageous of which was NASA's claim that the Space Telescope would be able to see seven times farther than any other telescope (Chaisson 111). One NASA official claimed that the Space Telescope would be the 'salvation of the world'. When an astronomer's exposure of these claims was printed in *The Washington Post*, the astronomer's boss was summoned to NASA headquarters and reprimanded (Chaisson 112). In desperation, a group of astronomers met to decide whether to accept NASA's exclusive approach or to include the educators and the public in Hubble science. According to Chaisson, three eminent astronomers were contacted for their opinion, and all three advised the Hubble astronomers to accept NASA's approach (Chaisson 113). Because NASA held the purse strings, astronomers henceforth kept quiet about the exaggerated claims disseminated about the project. Astronomers, however, received unexpected help when a Senator repeatedly demanded to know what education programs NASA was putting into place around the project (Chaisson 113-114).

Astronomers' involvement with NASA began before the advent of Hubble. In the 1960s NASA began building radio telescopes that formed a Deep Space Network (DSN) to track satellites and space probes. NASA has had a policy of allowing scientists to use its facilities, which meant that radio astronomers, for example, could use the DSN for radio astronomy. In 1997 a NASA official claimed that the DSN is a world-class instrument for radio astronomy, which allows astronomers to take advantage of the latest technology. The official said there was a symbiotic relationship between DSN technology and DSN science, which benefits both (Mudgway 11). Radio astronomy became a permanent element of the DSN. Apart from the synergistic relationship between the technology required for deep space communications and that for deep space science, astronomers also brought prestige to NASA.

According to Mudgway (13), what was good for radio astronomy was also good for the DSN, and vice versa.

However, astronomers' involvement with NASA has subtle and profound astropolitical implications. Before NASA, astronomers could claim to be reasonably independent, whether based in academic institutions or working for one of the governmental scientific agencies. With NASA, however, astronomers linked themselves to an organization charged with specific objectives by the US government. Moreover, NASA is a large, powerful and very political organization, highly conscious of its role of flagship of the US space program. In short, NASA is an organization with its own agenda, which sometimes happens to coincide with the needs of astronomers, but often does not, and sometimes the agenda is diametrically opposed to the needs of astronomers. The Hubble mirror fiasco engendered a lot of soul searching by astronomers. Astronomer Jim Gunn uses extreme language to describe his perception of astronomers' situation in the wake of the Hubble mirror disaster:

> We have lost control of our destiny, having handed it to a bureaucratic agency which means well enough but is unable to handle large projects of its own (c/f. The Shuttle) and certainly not ours. We were not 'screwed over' — we have been exquisitely vulnerable to precisely this sort of thing happening for years; it is part of our sorry heritage which began with gentleman astronomers in their coats and ties at Mount Wilson, continued with the sorrier example of the national observatories, and has culminated with the first of the Great Observatories, probably the most expensive scientific failure in history. We are a discipline of technical incompetents, happy to let our or NASA's engineers build our tools to their desires, not ours … the smaller NASA missions which have worked and worked well have had strong and close ties to the scientists, but even that has not prevented cost and schedule from climbing through the roof because of the ever-present aerospace industry, whose last gift to us we may not survive swallowing … it was an ASTRONOMICAL failure; it was an ASTRONOMICAL satellite, and it does not matter a whit that it was some fool at PE that caused it and some entirely expected failure of NASA's criminally infantile QA

> program that failed to catch it … if I were a congressman I would think twice about giving another nickel without some evidence that the discipline was at least aware of what had happened and had some notion of what do the next time … NASA's style is killing/may have already killed us (Chaisson 201-202).

Such self-castigation denotes that the Hubble astronomers felt a certain self-hatred at having been involved in such a fiasco, even though the mirror disaster was not their fault. Astronomers did not design, manufacture or grind the mirror, neither were they involved in NASA's quality control operations, which should have picked up the Perkin-Elmer mistake. However, Jim Gunn's tirade implies that the astronomers could have taken more responsibility for the mirror design and construction. Further evidence for this exists in the form of the contrasting experience of astronomers involved with the Einstein X-Ray telescope project.

In contrast to the Hubble astronomers, the Einstein X-Ray astronomy team appointed one of their own, Leon Van Speybroeck, to be responsible for mirror design and construction. Speybroeck kept in constant contact with Peter Young, the scientist in charge of the project at Elmer Perkin. Speybroeck, according to one of his colleagues, "hovered over those mirrors like a mother hen, and according to another, "never let them out of his sight during the crucial periods" (Tucker and Tucker 48). Tucker and Tucker write: "With Young's cooperation, Van Speybroeck pushed for ever more precise polishing of the mirrors and better testing procedures at every stage of the process, pressing the limits of existing technology and trying NASA's patience." (Tucker and Tucker 48). The result of the Einstein X-Ray team's approach was a perfect set of mirrors.

The Congressional Board of Inquiry Report into the Hubble mirror aberration found that the blame should be shared by Perkin-Elmer and NASA: specifically, engineers at Perkin-Elmer, and management at NASA. It was Perkin-Elmer engineers who ignored several warnings about a possible problem, and NASA managers who accepted their fabrications without ordering checks (Chaisson 227). Yet Gunn feels that astronomers should take responsibility. Moreover, a small proportion of the total number of astronomers even in the US were directly involved with the Hubble telescope project in its early stages, yet Gunn's tirade suggests that the fortunes of this group would somehow profoundly influenced the fortunes of the whole astronomical community. If astronomers 'sell their souls to the devil' and hook up with an all-powerful organization such as NASA, there is a danger that their fortunes will rise and fall with the fortunes of that organization. In the wake of the Hubble mirror fiasco, some NASA managers were fired, other project leaders quit and leadership of the project was transferred from Marshal Headquarters in Huntsville, Alabama, to the Goddard Fight Centre in Maryland. It appeared to the astronomers that the project was both leaderless and rudderless, with no one in charge (Chaisson 209). Chaisson himself at one point wondered why he "had become associated with such a technically thin and managerially clumsy organization" (Chaisson 211). Chaisson extends his critique, referring to astronauts, he asks, "Why would those brave men and women want to place their lives in the slippery hands and misguided judgments of such a reactionary system of management?" (Chaisson 252).

As the point was reached where Hubble astronomers were plunged into the depths of despair, the Science Institute, the group representing Hubble astronomers, had a retreat in which a possible vote of no confidence in NASA was discussed, or at least some sort of break in diplomatic relations. But, as Chaisson asks: "How can you break relations with your sole source of funding? Some of us felt like hostages, others' deep seated frustrations emerged as in a group therapy session, all of us were confused about what posture to assume toward NASA" (Chaisson 294-295). Self-doubt was manifest:

> "Are we wasting our lives continuing to hitch our wagon to NASA?" "Look," said another, "there has been no evil intent or skulduggery." In the end, we reached a weak consensus that the degree of programmatic inertia at the agency was so overwhelming that nothing we could publicly say or do would likely make a difference, and we decided not to speak out as a group. In hindsight, our reluctance to adopt a strong public stand might have been a mistake (Chaisson 295).

Astronomers' involvement with NASA is a double-edged sword. Despite their high status, most astronomers are employees. As long as astronomers are employed by an educational institution they have a certain amount of autonomy, but in the case of a high profile, high powered, highly politicised organization such as NASA, which engages astronomers for specific projects which can enhance its own prestige, astronomers' autonomy is diminished, and the responsibility of legitimating astronomy is handed over to others, who may have other agendas. On the other hand, astronomers benefit from their relationship with NASA not only from the professional opportunities it affords them, but also from the prestige of NASA as a representative of America's technological prowess.

The International Space Station

Typically, astronomers are sceptical about manned space exploration, arguing that better astronomical work can be done using unmanned probes. Similarly, astronomers have not supported NASA's 'Freedom' space station project (Munson 138), although they have not found the intestinal fortitude to join other scientists in a coalition of fourteen leading scientific and engineering organizations, including the American Physical Society and the American Mathematical Society, in outright opposition to it (Munson 151). In 1991 NASA, supported by President Bush, gave top priority to the space station project, even though many scientists and members of Congress spoke out against its cost and questionable scientific worth. NASA's leaders were so fanatical about the project that they even agreed to fund it by taking monies from elsewhere within its own budget, rather than from other programs (Munson 105). Astronomers would have been the losers here, since NASA was agreeing to cut space science funding for the sake of the space station. Astronomers did not support NASA's stand, but their reluctance to join other scientists in the 'Science Coalition' actively opposing it highlights both their political weakness and their symbiotic relationship with NASA. Astronomers went as far as sending faxes opposing the space station to the chairman of the VA-HUD sub-committee, but backed down after the administration offered to give more money to the NSF's astronomy program in the form of funding for the rehabilitation of observatories (Munson 91). According to one space physicist, the scientists were told that if they valued their grants they would keep quiet (Munson 91). NASA, with its strong bias toward large, expensive projects, claimed that the station would, amongst other things, be a permanent observatory for astronomers, even though most astronomers opposed it. Early on, the American Astronomical Society weighed in against the project, but was easily outmanoeuvred by more powerful project supporters (Munson 58). Overall, the activities of astronomers showed their political weakness.

A key factor in congressional support of the space station was the fact that it would offer contracts to businesses and provide jobs in a number of congressional districts (Munson 137). Astronomers here are at a distinct disadvantage; even large astronomical facilities do not create a large number of jobs.

The post Second World War culture of autonomous scientists being given funding to choose their own topics of research independent of government has been replaced by funding determined by a close relationship between government and science. Today's policy culture of science is a function of this relationship. This change in culture is the result not only of the growing influence of government on science but also the fact that science is no longer an individual enterprise but an organizational one (Ruscio). Most astronomers now work for organizations, typically educational institutions, or sometimes for a government agency such as NASA. In the political arena, the organization's interest is not always that of individual astronomers.

One manifestation of this new government-science policy culture is so-called 'pork barreling': the illegitimate dissemination by government of resources without due process, such as peer review, and for the benefit of special interests rather than the general good or the scientific merits of the research. In science policy, pork barreling usually takes the form of earmarking: funds directly awarded by a funding body such as Congress, for specific projects not included in the agency's request. Earmarking is done at the appropriations level. For example, the United States Congress has taken advantage of the appropriations process to make grants available to designated universities. Earmarking funds for universities bypasses the usual procedure established by early science legislation and partly by tacit agreement between the science community and government. In the past, Congress appropriated funds for general functions and left decisions about specific proposals to scientists. As no peer review is involved such allocations are vulnerable to the charge of being examples of'pork barreling'. Examples can be found of pork barreling within astronomy. NASA in particular has been criticized for receiving funds as a result of earmarking. According to Spaceref.com in 2001

NASA received funding for many projects through earmarking (Spaceref.com 2001). Examples of NASA funds received as a result of
earmarking are: Pluto-Kuiper Belt Mission ($105 million in FY 2003), Europa Orbiter mission ($40 million in FY 2003), Large Millimeter Telescope (FCAD/UMass) ($25 million since 1994) (http://earth.ast.smith.edu/courses/ast220/earmarks04.html).

When a powerful congressman such as appropriations chairman Robert Byrd sees benefits to his local constituency, astronomers can win out. Soon after Byrd was made appropriations chairman, he pork barrelled a number of projects into his state of West Virginia, and one of these was a telescope at the National Radio Astronomy Observatory, costing $75 million (Munson 152). By 1991, scientific support for the space station had evaporated (Tucker and Tucker 133). Despite the lack of scientific justification, NASA diverted funds from other astronomical projects such as AXAF to fund the space station (Tucker and Tucker 135).

As a result of its stand on the space station, NASA lost money in 1992, and all new NASA projects, including astronomical projects such as the infrared space telescope, were put on hold (Tucker and Tucker 187). A whole range of interests, including astronomers, lost out because of the single-minded purposefulness of a minority of appropriators supported by aerospace corporations (Tucker and Tucker 55, 70, 73). At the time of writing (April 2002) NASA continues to pour money into the space station to the detriment of other projects.

Conclusion

I have used several case studies to illustrate some of the ways in which astronomers' representatives negotiate in the political process to achieve favourable outcomes in the form of funding. Astronomers can be seen as an interest group in the political sense because they share a common interest in terms of being the recipients of specific state resources. Astronomers are becoming more organized as astronomy is having to explain and justify itself both with the public and the state. Part of this process is that organizations such as the American Astronomical Society are taking on the role of political advisers to their constituents. It is still the case however, that astronomers are generally represented indirectly when negotiating with the state, by agencies such as the NSF. If one group of astronomers achieves success, this enhances the interests of other astronomers in so far as the other astronomers can use the equipment built with the resources. Astronomers, as a distinct and separate group, are politically weak, and their fortunes are very much intertwined with those of scientists in related disciplines such as physics.

The case of Jodrell Bank shows that a charismatic astronomer with political skills and political connections can achieve much in procuring significant resources for a specific project and gaining much positive publicity and therefore legitimacy (explanation and justification) for the profession.

The case of Gemini shows that internationalism is now a factor in the process of legitimation; one of the reasons the project was eventually accepted was the fact that it was international and therefore the costs could be shared. However, internationalism as a factor in legitimation in astronomy is nothing new. In the 1890s, when George Ellery Hale created the *Astrophysical Journal,* he was "especially careful to create an editorial board that was international in scope. This insured the legitimacy of the venture" (Lankford 229). Just as nationalism can be a source of legitimation, so can internationalism. If a venture is national, such as Jodrell Bank, nationalist justifications are used. If it is international, such as Gemini, internationalist justifications can be used. But the two types of legitimation practices do not necessarily have to be mutually exclusive. International projects can also enhance the prestige of the individual nations involved with them, both in terms of direct scientific contributions and because of the prestige involved in international cooperation. However, as astronomy becomes globalized, it is likely that internationalist legitimation practices will become more prevalent.

The Hubble Telescope and the space station both show the relative political weakness of astronomers when they are subsumed in an organization whose primary goal is not astronomy. Astronomy therefore, in order to legitimise and advance itself, was compelled to 'change direction' and accommodate the priorities of the funding institution. Legitimation is not a process that takes place in a vacuum. Its very accomplishment can mean sacrifices, which will advance certain sections of the profession, and be detrimental to others. The process of legitimation itself changes the science. My analysis and the case studies indicate that in general, astronomers are politically weak. But as I hope to show, they do have certain advantages: being big science in an age where big science is seen as prestigious, being a hard science in a scientific culture, and having a subject matter that appears to be intrinsically interesting to large sections of the public.

It can be seen that each of the case studies — Jodrell Bank, Gemini, Hubble and the International Space Station — shows a synergistic relationship between legitimation and funding. That is to say, there is a two-way interaction between legitimation and funding: legitimation leads to funding, which leads to more legitimation, which leads to further funding, which leads to further legitimation, and so on. This synergistic relationship is revisited in the conclusion.

CHAPTER TWO
ASTRONOMY AS BIG SCIENCE
Introduction

Modern astronomy is 'big science'. It is an expensive science, and demands considerable resources from funders. In this chapter an account is given of the process whereby astronomy's entry into the 'big science' league in every sense is part and parcel of its legitimation. On the one hand the fact that astronomy has become 'big science' is evidence of successful legitimation practices; on the other once it became a big science, this very status enabled it to receive more resources and attain status as even bigger science. First I introduce the notion of 'big science', and then I give an account of the evolution of astronomy from little science to big science. Next I touch on the evolution of astronomy. I then explicate how astronomy as big science legitimates itself. Finally I reach some tentative conclusions about the relationship between big science and the process of legitimation. The extent to which astronomy has become big science can be seen as a measure of the success of the various legitimation strategies adopted by astronomers and their supporters. Indeed, as Capshew and Rader note, "By the early sixties, with the advent of NASA and the national space program, the term 'Big Science' was firmly affixed as a label for projects that required large-scale organization, massive commitments of funds, and complex technological systems" (Capshew and Rader 4).

The Concept of 'Big Science' as Applied to Astronomy

The term 'big science' was coined by Alvin Weinberg in 1961 in a commentary written for the journal *Science* on the "Impact of large-scale science on the United States." In his article Weinberg uses "Big Science" as a synonym for "large-scale science". Drawing comparisons with the pyramids of Egypt and the cathedral of Notre Dame, Weinberg suggested that "the monuments of Big Science such as particle accelerators, rockets and space vehicles play an analogous role in expressing the highest values and deepest aspirations of modern culture (Weinberg 1961: 161). Weinberg himself contributed to the debate about the rationale for science funding, posing it as a question of whether governments should support science as a form of high culture or have a utilitarian rationale, and favoured the latter (Weinberg 1964 3-14).

Weinberg's notion of "Big Science" was first used extensively and influentially as a conceptual tool in the sociology of science by de Solla Price (63). De Solla Price was struck by the exponential growth of science in the mid-twentieth century and by the large-scale character of modern science. Behind the term is the assumption that science is measurable and quantifiable. Price used variables such as expenditure on science, number of scientists employed, publications and citation numbers as indicators of the dramatic growth of science in the twentieth century. In the words of Price: "Why should we not turn the tools of science on science itself … in an attempt to develop a calculus of scientific manpower, literature, talent and expenditure on a national and on an international scale?" (Price xv, xvi). The research speciality known as scientometrics was given impetus by his work, as was the quantitative analysis of science more generally.

Price saw the exponential growth of science as a natural law (de Solla Price 5). Writing in the early sixties, when expenditure on science was still rising at a rapid rate, he foresaw that science could not continue growing at the same rate, otherwise there would come a time when "there would be two scientists for every man, woman, child and dog" (de Solla Price 19). As Price foresaw, science has ceased to grow exponentially, but it has not changed in the way that he predicted. Price thought that there would be a levelling off. He predicted that there would be a saturation point, that is, science funding would stop growing and level off. Far from being a council of despair for science, Price characterised his prediction as a council of hope: "We have the prospect of exciting new tactics for science, operating with quite new ground rules" (de Solla Price 32). The levelling off period Price saw as a period of "stable saturation" (de Solla Price 32).

While Price himself noted that the observatories of Ulugh Beg in Samarkland in the fifteenth century and of Tycho Brahe in the sixteenth century, and Jai Singh in India in the seventeenth century each absorbed large fractions of their nation's resources (Price 8n). In the nineteenth century astronomy "underwent a large scale social process of rationalization" (Smith 17). During this period leading astronomers such as Pickering and Airy embraced the factory system as their organisation model, characterised by a hierarchical division of labour and large scale projects such as *Carte du Ciel*. It was also during this period that large telescopes, such as that constructed in Armagh by the Earl of Ross, made their appearance. Thus the move toward big science in astronomy began well before the twentieth century. But the process was by no means even and linear. Instead it was uneven, patchy, discontinuous and contingent.

De Solla Price's methodology has been applied to recent astronomy by Jaschek (1991). Jaschek, taking a historical approach, notes that the size of the astronomical community, like the rest of science, has grown exponentially. But as he acknowledges (Jaschek 265), there are problems in quantifying the number of astronomers, not the least of which is the problem of definition: who qualifies to be included in the label 'astronomer'? A dictionary definition would give us all those who study and practise astronomy, which would include amateur astronomers, including dabblers such as myself.

This thesis is concerned with only with professional astronomers: individuals who are paid to do astronomy. As Jascheks notes, however, what constitutes 'astronomer' has meant different things at different times (Jaschek 265). For the most part, Jaschek is content to follow Price's approach by measuring science by the number of publications. This is useful but not entirely adequate. There is the obvious criticism of such quantitative analysis that it does not take into account the quality of papers, which can be seen as an alternative measure of contribution to the field: not all scientific papers are equal. Moreover, from the standpoint of estimating the number of professional astronomers, it is quite possible that some individuals are gainfully employed as full time or part time or temporary professional astronomers but publish no or hardly any papers. Jaschek himself admits that "The relation between the number of authors and the number of astronomers must change, in the sense that fewer astronomers are required to produce the papers found in the literature" (Jaschek 279).

Membership of the International Astronomical Union is another measure considered by Jaschek, but this would underestimate the figure, as some astronomers are not members of the IAU. In addition to the exponential growth of the number of astronomers, the number of countries represented in the IAU has also grown. Europe's participation fell from predominance, whereas the US and Canada together now contribute approximately one third of all astronomers, and countries outside North American and Europe doubled their share (Jaschek 272). Jaschek suggests that we have still not reached the ceiling for the total number of astronomers, because of the large number of countries that can still participate in the global increase (Jaschek 273). The same type of growth can be seen if we measure astronomy by the number of observatories (Jaschek 269). There is no perfect measure, but whichever measure is used, it is clear that astronomy has been growing (Jaschek 271). According to a recent U.S. report, “the astronomical community is still growing significantly faster than the U.S. population as a whole” (National Research Council 6). Moreover, the astronomical literature does not seem to have reached saturation point yet, and continues to grow exponentially (National Research Council 20). However, as a NASA document points out when discussing planetary astronomy, little science and big science can coexist (Butrica 1998). The relationship of little science to big science is more complex than a simple chronological evolution from little science to big science.

What is clear is that the size of the astronomical community has grown since the Second World War. According to McCray (2004: 16) just before the war the American Astronomical Society had only about 700 members. This was due to greater resources provided by the NSF and NASA, which also gave employment to astronomers not associated with the private universities, and to the entry of physicists and electrical engineers into the field (McCray 2004: 16-17). Federal dollars have funded large telescopes such as the National Center for Optical Astronomy at Kitt Peak, in Arizona. Kitt Peak was the first major observatory to be built using Federal funds. Before this, America astronomy had to rely on private philanthropists and state funds.

The Evolution of Astronomy into Big Science

The oldest known astronomy is aboriginal astronomy, which probably dates back at least 40,000 years (Haynes et al. 7). From then on, until at least the middle of the nineteenth century, astronomy was ‘little science’ in the sense that it was practised by individuals looking up at the night sky using the naked eye. When astronomy was little science there was little to legitimate. Until the mid-nineteenth century, astronomical research institutions were small-scale establishments. From 1859, with the invention of spectroscopy and the consequent advent of astronomy, there took place a process of institutional isomorphism. That is to say, as new technologies transformed production, successful institutions incorporated elements of rationality into increasingly complex structures. This institutional transformation happened in astronomy. Small single instrument observatories were replaced by large, complex observatories led by powerful directors. Both the directors and the observatories were in competition with each other (Lankford 185-200). These observatories were structurally similar to other institutions; they were in line with patterns and practices in the wider society, and this increased their legitimacy. During this period of transformation American astronomy became extremely aggressive in terms of its entrepreneurial approach to funding. In 1902 there were more requests to the Carnegie Institute of Washington from astronomy than from any other discipline (Lankford 194). Moreover, in a data driven science like astronomy, professionals must have access to sophisticated instruments that can provide data with which to solve astronomical problems. This instrumentation is expensive and available in a limited number of observatories. Access became a critical factor (Lankford 271). By 1940, astronomy could be described as ‘big science’. This description does not refer to the size of the astronomical community. Indeed, chemistry and biology had and have more personnel. Rather, the term ‘big science’ here refers to the structure and organisation of the profession, and its capitalisation, and in particular big technology. Today, no professional astronomer, qua professional, would dream of using the naked eye, or even consider doing astronomical research, without the plethora of large, sophisticated and expensive equipment that characterises modern professional astronomy. It is this plethora of equipment more than anything that demarcates modern ‘big science’ from pre-modern ‘little science’.

Astronomy has, in terms of expenditure, become very big science indeed since the 1960s (Smith 15). War time technological developments and the accompanying development of expertise made big astronomy possible, especially radio astronomy, which was big science almost from its inception (Edge and Mulkay 251). But it was the fear caused by the Soviet success of Sputnik 1 that caused the US government to consider ploughing more money into space science; astronomy benefited from this renewed commitment to space. In this sense astronomy cannot be separated from space science; a line can be traced back from the Apollo program to astronomical observations of the Moon. Apollo would not have been possible without accurate observations for possible landing areas and physical environment analysis. As astronomy got “bigger” top astronomers found themselves chairing committees that “ask for things that in the end cost several billion dollars” (Edge and Mulkay 16). These astronomers themselves can feel uncomfortable at having to ask for such large sums, but rationalise their situation by “knowing that vastly greater amounts are thrown away on things of absolutely no redeeming value whatever” (Edge and Mulkay 16).

Since World War Two, astronomy has not only become big science, it has also fragmented. Traditional land based optical astronomers now collaborate (and in some cases compete) with radio astronomers, x-ray astronomers, infra red astronomers, gamma ray astronomers, and astronomers using rocket borne and space based instruments. Astronomers also collaborate with scientists from other disciplines, especially physicists.

The transformation of astronomy into big science went hand in hand with its increasingly close relationship with physics, so that most modern astronomers are now astrophysicists. This merger of astronomy with astrophysics is well documented by Lankford (1997). According to Lankford, the ‘old’ astronomy was dominated by celestial mechanics, the study of the motions of celestial bodies, and astrometry, the measurement of the position of celestial bodies and the creation of celestial catalogues. With the invention of spectroscopy in 1859 the new discipline of astrophysics emerged, which quickly caught the imagination of newly qualified young researchers. Conflict ensued between the ‘old’ and ‘new’ astronomy and eventually a paradigm shift occurred, that transformed astronomy from a discipline in which the main focus of attention was on the position and motion of celestial bodies to one in which the main focus was on their composition. Part of this fusion of physics and astronomy was the emergence of radio astronomy. Most of those involved with the emergence of radio astronomy were not astronomers but physicists with technical skills in radar and radio (Edge and Mulkay 17-20). Physicists were drafted into radar research during the Second World War as part of the mobilization of scientific expertise. When the war ended, these physicists became unemployed and, keen to return to academia, founded the profession and discipline of radio astronomy

(Agar 266). The skills they learned in wartime, for example, with radar, were eminently adaptable to radio astronomy, which, by definition, is dependent on sophisticated equipment. Expenditure on science grew rapidly in Britain after 1945, as the teaching of science in higher education (Agar 266). Nowadays, a growing fraction of astronomical knowledge comes not from visible light but from radio waves, infrared waves and X-rays, the study of which can only be accomplished with sophisticated and expensive equipment.

While post-war America turned its atom bomb knowledge into high-energy physics, Australia and Britain turned their wartime radar expertise into developing the early field of radio astronomy. Astronomy as big science thus partially developed out of the combination of the development of scientists' wartime skills and the equipment that the war developed. Moreover, the very emergence of new sub-disciplines in astronomy such as radio astronomy, that utilise new technologies, create even more big science; very large arrays in radio astronomy, such as the British MERLIN project and the American VLA, in which several radio telescopes are used together to mimic a radio telescope equivalent to their collective size, lead to even bigger science. The radio telescope's collection dish must be thousands of times larger than the mirror of an optical telescope to achieve the same resolution. But the relationship is symbiotic: "Further development of undergraduate astronomy education may hold the key to restoring the Physics community to the standing it once held" (Edge and Mulkay xxiii), and as Van Der Kruit notes, "not unjustifiably, most astronomers consider the *Astrophysical Journal* as the primary general journal in the field of astronomy" (Van Der Kruit 163). The other major journal in the discipline is *Monthly Notices of the Royal Astronomical Society*, a large proportion of which consists of articles on astrophysics.

The problem of funding

When astronomy was little science, and required limited funding, securing grants was simple and, at least in the case of American astronomy, easy (Lankford 206-207). But with modern big astronomy budget cutbacks have taken astronomers into an extremely unstable situation. But budget cutbacks did not mean the abandonment of large-scale projects. Rather, those projects which were left were large scale, but fewer. Astronomy can therefore be characterised as big science not only because of the amount of money needed for its continuance as a whole, or because of the number of astronomers employed, but also by the large scale nature of its individual projects. Astronomy may suffer budget cuts, and fewer astronomers may be employed, but it can still usefully be characterised as big science because of the large-scale nature of projects that require expensive, sophisticated and physically large configurations of equipment. These fewer projects will involve radio, cosmic, infrared, ultra violet, x-ray, gamma ray, as well as optical equipment.

The simple fact is that thinking big in terms of projects is more likely to result in a successful outcome in terms of funding, partly because a big project is more likely to get the attention of someone high up in the funding organization, and partly because of economies of scale: “A small, innovative project such as the X-Ray Explorer stood little chance of getting through the NASA bureaucracy. But a large program—there is a profound relationship between in size and importance in the minds of NASA officials—might make enough clout to make it happen” (Tucker and Tucker 26), and “With NASA you have to think big to get anyone’s attention” (Tucker and Tucker 28). In contrast to the Explorer proposal, a much bigger X-Ray telescope proposal, the Einstein Observatory, put forward by a consortium consisting of A,S&E (American Science and Engineering — a private company formed by two MIT alumni), Columbia University, the Goddard Space Flight Centre (of NASA), and MIT, was successful (Tucker and Tucker 46-47). This success enabled X-ray astronomy to become part of the mainstream of astronomy. Moreover, by reserving a significant amount of observing time for guest observers, and by making their data public, the Einstein program attracted specialists on other wavelengths to X-ray astronomy (Tucker and Tucker 52).

As the case of the X-Ray telescope shows, big science can be “characterised as a political instrumentality deployed for the purposes of its patrons. In space research, for example, much effort has been expended on modifying laboratory instruments so they will work in the environment of space, launching them into place, and providing reliable communication systems. But such feats of engineering and science take place within the context of NASA” (Capshew and Rader 9). NASA, as Toulmin has pointed out, is “a political agency making political decisions … a state within a state” (Toulmin 355).

The Scale of Astronomy Funding

The table below shows population and funding data for astronomy in OECD countries taken from Van Der Kruit (1994).

Table 1 — The Scale of Astronomy Funding

Country	Population in millions	Number of International Astronomical Union members	No. of Researchers	GNP ($b)	Budget ($m)
Australia	16.9	173	180	211	40
Belgium	9.9	81	131	152	20
Canada	26.7	206	213	474	21
Denmark	5.1	50	71	93	9
Finland	5.0	29	87	99	28
France	60.3	561	953	940	214
Germany	77.5	429	488	1416	300
Italy	57.8	373	772	826	177
Japan	124.5	50	370	2830	207
Netherlands	14.9	162	196	232	39
Spain	39.8	161	194	336	54
Sweden	8.4	84	92	170	11
Switzerland	6.7	55	100	188	30
UK	57.3	481	1200	646	179
USA	252.5	2069	4200	4961	812

USA is of course ‘top dog’ in terms of absolute amount spent on astronomy. In every OECD country nearly all of this funding comes from central government. The exception is US ground-based optical astronomy, most of which is funded either privately or by states (National Academy of Sciences 2001: 27).

It is significant that the OECD chose astronomy for its first megascience forum in

1992. The forum brought together ‘expert astronomers’ from seventeen OECD countries at La Palma, Canary Islands, in 1992 “to examine the situation of megascience in astronomy and to discuss the role that international cooperation plays today, and even more importantly, is certain to play in the future development of astronomy projects”. According to the OECD forum on megascience, modern professional astronomy is big science “because of the large facilities which are an essential component of the tool-kit of the modern astronomer” (OECD 65). Astronomy, along with particle physics, is the most expensive discipline in terms of expenditure on equipment, and these two disciplines together use the greatest number of large installations (OECD 65). A more recent U.S. report affirms the importance of international collaboration for U.S. astronomy (National Research Council 8).

Latour (1987) claims that the demarcation between science and the humanities is to be found merely in the amount of resources obtained by the ‘hard’ or natural sciences. If Latour’s thesis is correct, it follows that the more resources are ploughed into a discipline, the more it becomes ‘scientific’. Thus the quest by astronomers for more resources is also a quest for scientific legitimation; the more resources are ploughed into astronomy the greater is its status as a science, and the more distance it creates between itself and other ‘non-scientific’ activities. Latour’s thesis, however, is not widely accepted, and of course is only one of many possible ways of demarcating ‘hard’ and ‘soft’ sciences.

Modern astronomy is one of the most expensive scientific endeavours; huge telescopes are needed to examine inter-stellar phenomena such as pulsars and quasars, black holes and distant galaxies. The most expensive civilian scientific project in the history of humankind is the Hubble Space Telescope, the design and manufacture of which alone cost $1.54 billion (Chaisson 114), and since then has gone beyond $2 billion, and is expected to go beyond $6 billion by the time its fifteen-year mission is over. The Hubble Telescope’s cost overruns were such that other NASA projects in which astronomers were involved were affected: “When Hubble coughed, other astrophysics and space science programs at NASA got pneumonia as money flowed out of their budgets into Hubble’s” (Tucker and Tucker 81).

The building of such telescopes constitutes a considerable project for which only governments are willing to pay. Thus astronomers are heavily reliant on the support of governments for their livelihoods. Throughout the 1980s astronomers, like other groups reliant on government funding, experienced considerable professional hardship due to government budgetary cutbacks. Astronomy is particularly vulnerable to such cutbacks as it cannot offer an immediate return in terms of profit or spectacular social or medical breakthrough. Even when a spectacular astronomical discovery is made, such as the claimed finding of organic molecules on a meteorite from Mars, some members of the public may ask why money is spent on astronomy when there are social problems at home. What is of interest here is not that the question is asked, but why it is that astronomy is picked on in this way when other costly activities are not, such as cosmetics research or Hollywood filmmaking. Part of the answer could be that astronomy is mainly government funded, and tax-funded expenditure is easily compared with social expenditure in a way that corporate expenditure is not. But astronomy is also vulnerable to such attacks because it is not part of the daily lives of the majority of the populace. Hollywood movies and cosmetics are a part of the daily psyche of modern society; we are constantly bombarded with images encouraging us to relate to them. In contrast, astronomy is only an important regular activity for a small percentage of the population; occasional spectacular discoveries are not enough to ensure the support of a populace whose daily concerns are light years away.

Thus the fact that astronomy is big science, both physically and financially, is a double-edged sword. On the one hand the big science image enhances its status and helps to legitimise it amongst other scientists, on the other its largely government funded cost and its lack of obvious utilitarian benefits makes it vulnerable to attack from those with other priorities.

In Australia, the largest sources of funding are the Department of Education, Science and Training (DEST), and the Commonwealth Scientific and Industrial Research Organization (CSIRO). In Britain, funding for astronomy is initiated by various Select Committees: House of Commons Select Committee on Science and Technology, House of

Commons Public Accounts Committee, House of Lords Select Committee on Science and Technology, and the House of Lords Select Committee on European Communities, the Parliamentary and Scientific Committee. In order that the various committees may obtain relevant and accurate information, the Parliamentary Office of Science and Technology provides ‘independent and objective’ analysis of science and technology based issues for both houses of parliament. Its program of work is decided by a board comprising members of both Houses and all parties, together with representatives of the scientific community. These bodies make recommendations to Cabinet, which then disseminates funding through the Office of Science and Technology, which is now part of the Department of Trade and Industry. The OST is given a budget by parliament, and decides what proportion to give to astronomy. This funding is then given to the Particle Physics and Astronomy Research Council (PPARC) which is the principal direct funder (about 80%) of professional research in astronomy, astrophysics and planetary science in the United Kingdom. In 1996 the biggest portion of this went to extragalactic astronomy and cosmology, next came stellar astronomy with 15%, then instrumentation, techniques and spacecraft with 12% (Particle Physics and Astronomy Research Council 2000).

According to the National Committee for Astronomy of the Space Academy “The preservation and further development of a healthy program of Australian observational astronomy requires a solid basis in theoretical physics” and recommended “That current funding for theoretical astrophysics should be maintained at least at the current proportion of support for astronomy as a whole” (National Committee for Astronomy of the Australian Academy of Science xviii). The reliance of astronomy on large-scale expensive equipment thus spilled over into physics. Many modern professional astronomers do not have degrees in astronomy but in physics, or even engineering. A recent Australian report notes the intimate relationship between modern astronomy and physics, and recommends a unified policy strategy (National Committee for Astronomy of the Australian Academy of Science 60). Corporations also use generic and transferable techniques in making both astronomical and industrial and defence equipment, as outlined in the section on the Hubble Space Telescope mirror. These relationships connect astronomy with commerce and industry.

The recent extension of the boundaries of astronomical technology into space itself accentuates even more the move towards bigger and bigger science. According to the OECD megascience forum approximately 50% of modern astronomical expenditure is now associated with space astronomy, and access to space missions is an important strategic element in modern astronomy (OECD 9).

Professional astronomers typically work in large institutions. 50% of American astronomers are employed by universities, 18% in government laboratories and federally funded research centres and 17% in non-profit institutions (Osterbrock 71). To a great extent they are dependent on Federal funds; in the US, the two agencies that administer these funds are the National Science Foundation (NSF) for ground-based research, and NASA for space missions and space projects such as the Hubble Space Telescope (National Research Council 2). NASA is a larger organization than NSF and its charter focuses on space science; NASA launches space missions and conducts related research (National Research Council 29). NSF and NASA have different cultures and characteristics that derive from their different missions (National Research Council 18). NSF is primarily a science agency, and NASA is primarily a mission agency (National Research Council 33).

Over the last two decades, there has been a trend towards more NASA funding for astronomy, so that today NASA gives more grants to astronomy than the NSF (National Research Council 2). In fact NSF's share of support fell from 60% at the beginning of the 1980s to 30% at the end of the 1990s (National Academy of Sciences 2000: 1, 56). The reversal is due to the enormous amount of NASA funding going to space astronomy projects (National Academy of Sciences 2000: 8). Of space projects, by far the most expensive so far has been the Hubble Space Telescope, which accounts for more than one third of all NASA astronomy support, exceeds the total NSF grants program and also exceeds the total NASA astronomy Research and Development program! (National Academy of Sciences 2000: 41). This has resulted in decreasing funds for those subfields that have relied solely on NSF funding, such as broad based theory, computational astrophysics and radio astronomy (National Academy of Sciences 2000: 1, 56). The lack of NSF funding has also meant that, although the number of ground-based facilities have grown, instrumentation, theory and observer grants have not kept pace (National Research Council 2). An increasing fraction of U.S. papers cite support by NASA and non-U.S. agencies, whereas the fraction citing NSF support has declined (National Academy of Sciences 2000: 21).

Most of my interviewees (see appendix) said they were funded either by NSF or NASA, or both, and several commented on the increasing importance of NASA funding in relation to NSF funding. Two astronomers asserted that this trend toward NASA rather than NSF funding was a ‘double edged sword’. On the one hand it assures astronomers funding, and funding for big, expensive projects, but on the other, NASA is project oriented, and oriented toward certain areas of interest, such as planetary astronomy and the origin of the Solar System. During the twentieth century the trend within astronomy has actually been away from these areas of study, toward research into far distant objects and processes: galaxies, black holes, quasars, pulsars etc. The shift in funding source is changing the direction of astronomy; in fact reverting it, to an extent, back toward areas of study that were popular toward the end of the 1800s and the beginning of the 1900s. This shift, however, is only a matter of degree; NASA does indeed fund far distance astronomy. Moreover, a recent report investigated the possibility of transferring NSF’s astronomy responsibilities to NASA, but rejected the idea (National Research Council ix, 1, 4). The committee writing the report, the Committee on the Organization and Management of Research in Astronomy and Astrophysics, concluded that such a transfer would “have a net disruptive effect on scientific work. Because of its combined commitment to investigator-initiated research, interdisciplinary research, and educating the scientists of the future, the NSF is the right institution to sponsor ground-based astronomy and astrophysics. And further, such a move would not necessarily address integration of … ground based optical/infrared private and state observatories. NSF’s close working relationship with the college and university community makes it the natural focus for integration of this third component” (National Research Council 3). In fact, the committee recommended that NSF astronomy component be strengthened to provide more effective support for ground based astronomy (National Research Council 3), and stated that NSF should retain its leadership role in ground-based astronomy and astrophysics (National Research Council 33).

In the United States, the demarcation between the NSF and NASA is almost complete; the NSF funds only ground based astronomy and NASA funds little ground based astronomy (National Research Council 7). The NSF is responsible for the U.S. contribution to big international projects such as Gemini, as well as a network of astronomical observatories. There are almost no alternative funds. Between 1984 and 1990, funding for U.S. astronomy was flat, barely keeping pace with inflation (National Research Council 14). During this period, some projects, such as the Very Large Array (VLA), which originally cost $150 million in 1980, faltered because of lack of investment in infrastructure (Waldrop 268). Even here, when funding was static, the trend towards larger projects continued; a large part of the NSF's funding that would have gone to the VLA went to the newer and even bigger project, the Very Long Baseline Large Array (VLBLA). At this time US astronomy funding found itself in direct competition with NSF science education funding (Waldrop 268) and this in a 'zero sum' battle against housing and veterans' affairs, as well as NASA's $30 billion space station. US astronomy did not benefit from Reagan's emphasis on defence spending, but on the other hand, funding for astronomy did not collapse; astronomy did not suffer the fate of some federally funded social programs during this period, though percentage increases were held below physics which could more obviously defend itself by establishing its usefulness to defence.

Apart from general science funding levels and competition between sciences, astronomy funding can be affected by the bureaucracies, structures and procedures of funding. In 1991 Jodrell Bank, the pioneering and iconic British radio telescope owned and run by Manchester University, suffered funding cuts because of a new formula that the Universities Funding Council (UFC) used to calculate the money that each university was given for research. Jodrell Bank's Director Rod Davies legitimised increased funding for the facility by arguing that it serves the whole British radio astronomy community, whilst at the same time arguing that although the extra funding should come from the Science and Engineering Research Council (SERC) Jodrell Bank should retain its independence from that body because “Jodrell Bank can be more efficiently run from a university” (Aldhous 733). Observatories that depended solely on SERC had also suffered a decrease in funding of one third from 1965-1985. Britain’s refusal to join the European Southern Observatory made the situation worse, and some British astronomers migrated to the United States (McCray 2004: 173).

Other funding problems at Jodrell Bank highlight the necessity for professional astronomy to become big science if it is to survive. Although the Jodrell Bank facility is an excellent post war example of British big science (Butrica 1996: 112), planetary radar astronomy there met its demise because lack of personnel and computer facilities made it impossible for Lovell to compete against the more fully resourced American radar astronomers. According to Butrica, “the small scale of planetary radar astronomy at Jodrell Bank did it in” (Butrica 1996: 114), this “was a lesson in the dangers of little science, not big science” (Butrica 1996: 112).

Astronomy’s Ambivalent Position

Astronomy appears to occupy an anomalous position between the big hard sciences such as physics and the popular culture. It is ‘big’ and ‘hard’ in the sense that it uses large, expensive equipment, and yet ‘soft’ in that because of its tenuous utilitarian and defence links it must legitimate (explain and justify) itself in populist and non-pragmatic terms, much in the way that the humanities and arts legitimate themselves. Thus Osterbrock, in arguing to other scientists for more funding for astronomy, is forced to fall back on astronomy as a science popular with the general public:

> The role of astronomy is not only to probe the universe, but also to challenge people to think about deeper questions and to learn more about science. Astronomy is by far the most interesting of the sciences to general population, as newspaper and television coverage, popular books and thousands of amateur astronomy societies, clubs and groups demonstrate (Osterbrock 73).

Overtly utilitarian justifications for astronomy are now difficult to find. One of the few that I have been able to find is given by Astrosoc, the Astronomy Society of the University of Leicester, in England:

> Astronomy helps us to find out about the universe and our place within it. We also train people in modern technology; many who don't eventually become astronomers go out into the "real world" and contribute to mainstream industry and the economy. Astronomical research also has important implications for other branches of science. For instance, we use stars as "remote laboratories" in which we can study matter under conditions we just couldn't achieve on Earth. This helps us refine our knowledge of fields such as atomic physics, which is vital in many fields with practical applications in everyday life. In our own group, we have developed sensitive X-ray detectors for astronomical research, and these detectors are currently being adapted for use in medical applications (University of Leicester. Department of Astronomy).

The use of astronomy here is thus threefold: 1) Astronomical training can prepare an individual for employment in other, more practical fields; 2) Astronomical knowledge can be of use in other, more practical fields; 3) Tools designed for use in astronomy can be adapted for use in other, more practical fields. Note that even here the uses are indirect — no practical use is claimed for astronomy itself.

A more typical justification is that given by Hubble Space Telescope astronomer Eric Chaisson. He says his usual justification is along the lines that, "It is not just any civilisation, but the great civilisations, that leave legacies." And one occasion, when asked by a senator "Why are you astronomers so excited about the Space Telescope?" he responded that the pay-off was likely to be intellectual, educational, and cultural. He also stressed to the senator direct technological spin-offs were unlikely, or at least intangible (Chaisson 30). In discussing supposed economic benefits of the Space Telescope, Chaisson says:

> Although NASA repeatedly pitches the economic benefit angle — "for every dollar invested in the space program, seven dollars are returned to society" — I judge this to be a specious argument for which there is no evidence. *Hubble*'s vaunted technology will not likely produce a new can opener or better washing machine. Nor should it. The giant eye in the sky was built neither to improve our economy nor to challenge our Cold War enemies. Rather the Hubble Space Telescope is an expression of technological poetry, pure and simple. The magnificent orbiting observatory seeks knowledge for the sake of knowing, discovery for the sake of discovering, to understand cosmic beauty for its own sake. All things considered, the Hubble project is a measure of the extent to which humane beings — human with an 'e' — are willing to devote some time, money and resources to allow our species the opportunity to rise above the mundane activities on planet Earth (Chaisson 32).

Chaisson goes on to exhort the supposed educational benefits of the Hubble Space Telescope:

> Educationally, the Hubble Space Telescope project can help enormously to enthuse children to consider careers in science and technology, as well as to inspire non-technical persons of all walks of life — the intelligent taxpayer — to appreciate better the technical society we all share. Clearly, we live in a time when the majority of the public does not understand what science is about or what scientists do. The general public is, by and large, scientifically illiterate, and pre-college teachers are both confused about our fast moving subject and lack the confidence to teach it. All manner of alarms have been sounded in recent studies, including for example, those (in a government sponsored survey) showing that nearly 30 percent of adult U.S. citizens think that the Sun revolves around the Earth, while an additional 28 percent do not know that it takes one year for our planet to orbit the

> Sun. Unfortunately, 'gee-whiz' statistics like these do not help to ameliorate the fact that the youth of America are failing to learn adequate science and math skills. The shortfall undermines our economy, which depends on advanced technology and industrial motivation. The result, in my view, is an erosion of our technological work force, which might in turn become a threat to our democratic way of life (Chaisson 31).

Chaisson's justifications echo the responses given by my interviewees, but Chaisson goes further than most by linking up the humanistic justification with education, scientific literacy, the economy and ultimately democracy and civilisation. Although there are unlikely to be any short term practical spinoffs from Hubble Space Telescope, Chaisson argues that *in the long term* astronomy can benefit the economy by helping to improve scientific literacy, and by encouraging more people to go into science. Astronomy then, according to this most sweeping of justifications, which brings in everything, can ultimately save 'our democratic way of life'. Once again, the justification for astronomy relies on linking it up with science in general. Astronomy is not a 'stand alone' science, but astronomers argue that it is uniquely placed to improve scientific literacy because it is already popular with the general public.

But for much of astronomy's history, and especially during the transition from astronomy as little science to astronomy as big science, the justification of astronomy was mainly utilitarian. Observatories were built to facilitate timekeeping, navigation, trigonometric surveys, meteorology, magnetic surveys and time recording. Such activities helped to develop the discipline in the eighteenth and nineteenth centuries, but were at the same time its bane; real astronomical work was subordinated to these activities, to the extent that amateur astronomers could do more publishable work than their professional colleagues. In nineteenth century Australia for example, notable amateur astronomers such as Brisbane and Franklin instilled in the public a respect for astronomy, and published more papers than their professional counterparts. (Haynes et al. 2). Indeed Haynes et al. claim that in nineteenth century Australian astronomy it was amateurs, not professionals, who did most of the ‘consciousness raising’ that fostered an interest which was crucial to funding (Haynes et al 150). In contrast, after 1859, the year that marked the beginning of spectroscopy, astronomical and astrophysical research in the United States became increasingly divorced from practical applications. Astrometry and celestial mechanics achieved levels of precision far in excess of the demands of practical navigation. Astrophysical research in solar and stellar spectroscopy offered no practical returns. Yet private patronage grew rapidly without concern for the material value of the research (Lankford 15). By 1887 spectroscopy had brought about a change in the direction of professional astronomy, such that astronomy historian Agnes Clerke was able to observe: “the science of the heavenly bodies has … become a branch of terrestrial physics, or rather a higher kind of integration of their results” (Clerk 463). Astrometry and celestial mechanics, which had practical uses for timekeeping and navigation, were gradually superseded by astrophysics, which had no practical benefits (Lankford 34). Astrometry and celestial mechanics had come close to reaching their limits in terms of their timekeeping and navigation applications, and professional astronomers now turned their attention away from the position and movements of celestial phenomena to their composition and structure. Astronomy could thus no longer be justified solely by its connections with improved timekeeping and navigation. A continuation of the tradition of legitimation by practical application was attempted in 1879 by Langley, who suggested that solar physics, through its study of solar radiation and sun spots, might lead to a better understanding of changing weather patterns on earth, and thus might lead to long range weather forecasting (Lankford 56, 368-369), but this led nowhere because the new astronomy contributed little to the astrophysics of the solar system (Lankford 58). By 1940 astrophysics had supplanted the old astronomy as the major focus of the profession. Astrometry and celestial mechanics were divided into an applied component that produced data for navigation and time keeping, and a smaller group working on research. But there was a general feeling that in the old astronomy there were few challenging problems left to solve. Collection and analysis of data had become routine; mechanical computing devices took the place of human computers, and astrometric data were collected by photography, and time keeping had been simplified by photographic instrumentation and the international short wave radio network (Lankford 368). Today celestial mechanics is of course subsumed in general relativity, and time keeping precisioned by computers.

The difficulty which astronomers face when confronted with governments who are prepared to fund only utilitarian science was highlighted when Britain vetoed a five percent increase in the European Space Agency's budget in 1988, effectively freezing the funds available to the agency. Kenneth Clarke, the British space minister, justified the veto on the grounds that, "we cannot see sufficient scientific, industrial or commercial benefits to justify such a huge increase" (Astronomy 1998: 14). At the same time other governments were supporting the space agency for scientific reasons, so it can be inferred that it was the commercial/industrial benefits that weighed most with the minister.

The Economic Vulnerability of Astronomy

Its apparent status as a 'pure' or 'basic' science, and expense as a big science, makes modern astronomy as an institution therefore particularly vulnerable to changes in government policy, economic fluctuations, and sudden transformations in the social order. In Britain Margaret Thatcher's cutbacks in pure science research made things particularly hard for astronomers, and in the former Soviet Union the socio-economic upheavals have proved a disaster for them. In addition to the problems afflicting all former Soviet scientists — low and unreliable salaries, lack of funds, more scientists than the economy can support — ex-Soviet astronomers have unique problems. Since the break-up of the Soviet Union, many smaller observatories are now in independent republics that have nationalised them and cut them off from institutes in Moscow that were once a main source of funding and collaboration. Some of these observatories are close to war zones.

Fighting between Armenia and Azerbaijan meant that the Armenian Byurakan Observatory virtually closed down, and according to Hall (1994) most of the astronomers there have left or are struggling to survive. One astrophysicist carves wooden pipes which he sells to buy food (Hall 1274), and nothing had been heard of the fate of the Samakh Observatory for over a year (Hall 1274). In Soviet republics, and especially in Russia itself, where the 'free market' is seen as the main hope of national salvation, "astronomy has even less to offer in terms of wealth creation than other basic sciences" (Hall 1274). Hall quotes Bochkarev, co-chair of the Euro-Asian Astronomical Society in Moscow: "All the observatories and institutes in Russia are just about continuing to work" (Hall 1274). In this situation, modern astronomy's internationalism becomes a handicap, with much meaningful work frustrated because of blocked off borders. Not surprisingly, this situation has caused many former Soviet astronomers to migrate to the west, but even here, it seems that many ex-Soviet astronomers would prefer to set up long term collaborations that would enable them to continue working in their home institution (Hall 1274). Those who do succeed in migrating sometimes have difficulty in finding jobs as it has become increasingly harder for even western astronomers to find jobs in their own countries (Hall 1274).

Astronomers' Skills as Legitimators

Hall admits, "Astronomy is never going to be a great money maker" (Hall 1275). Thus astronomers continue to be confronted with their problem of being a non-utilitarian basic science in a world that increasingly evaluates science in terms of market based cost-benefit philosophy. The closest that astronomy can come to justifying itself on utilitarian grounds is couched in terms not so much of the discoveries made by astronomers as in the skill they acquire in their profession:

> It has also become well recognised that local astronomically-trained postgraduate students are highly respected and sought after in such disparate industries as robotics and financial analysis...the broad education which these students have received during their postgraduate training includes an integrated grasp of physics, engineering and computer software, and project development and management, which is a potent and enriching combination for the current needs of Australian industry. They have also been given an unusually strong grounding in the management of technically complex systems and in problem solving, which are essential criteria for many positions. For Australia to share fully in the high technology revolution sweeping the globe, it is necessary to train the personnel who

> will be able to exploit the new technology to the full (National Committee for Astronomy of the Australian Academy of Science xiii).

Thus astronomers become useful for their skills rather than for any information they provide qua astronomers. This would seem to support Mukerji's claim (Mukerji 5) that scientists are an elite reserve labour force that the government can call upon at any time for their scientific expertise. Mukerji describes the relation between scientists and government as "less a text based system for conveying facts, and more a form of oral discourse for conveying opinions" (Mukerji 5). Moreover, as Rossides (278) notes, elites like to pretend that their rule is based on science and professionally produced knowledge — the association between state power and science has a history at least to the absolute monarchies of Europe. The rule of elites benefits from the legitimacy of science and their misrule can be blamed on ignorance. The non use or use of scientific research across the board can provide a handy excuse for policy failure.

As no direct practical benefit can be propounded, such links must be created: "We cannot emphasise strongly enough that the spearhead of economic growth is research, and that fundamental research and the culture of investigation and discovery is the root of successful applied research and development" (National Committee for Astronomy of the Australian Academy of Science xxiii). Thus, calling for more research is itself also a way of justifying more funding. References to supposed spin-offs from astronomy to industry are mainly generic: "economic growth is now primarily driven by advances in high technology, precisely the conditions which are provided by the VLT project and membership in the ESO" (National Committee for Astronomy of the Australian Academy of Science 63). Here the link is made between astronomy as big science and the wider societal good. Radio astronomy for example, "has a good track record for stretching the limits of technology and transferring the benefits to industry. Recent examples include the development of Telstra Satellite ground-station systems, as a direct spin-off from the construction of the antennas for the Australia Telescope. These have earned Australia more than $15 million in exports to Asia, and more than $40 in export replacement" (National

Committee for Astronomy of the Australian Academy of Science 63). The document then quotes a cost-benefit analysis by Anderssen and Hampton (Analysis of CSIRO Industrial Research-Earth Station Antennas, Research Paper No.6. Canberra: AGPS, 1991), which concluded that "the direct benefit/cost ratio for earth station antennas is 2.0 (and is 3.6 for exported antennas), and the most 'intangible' benefit is the demonstration of Australian capability" (National Committee for Astronomy of the Australian Academy of Science 65). Australian radio astronomers also developed an internationally adopted aircraft landing system, INTERSCAN (National Committee for Astronomy of the Australian Academy of Science 64). These examples show that a justification for astronomy can be made in terms of the view that modern societies develop through the application of scientific advances to new forms of technology (Collins 1979). Generally however, astronomy can only be justified in utilitarian terms by reference to the skills of astronomers, rather than the astronomical discoveries they make or the information they provide qua astronomers.

Astronomy can be seen as one means by which governments can promote nationalism. Indeed, nationalism can be seen as a cultural value that scientists can use in their legitimating rhetoric (Abbott 185). Astronomy can use its status as big science to muscle its way into government funding. This was the case in nineteenth century Victoria, where funding for a large state observatory was approved as a statement of its independence (Haynes et al. 3), its wealth from gold, and its cultural tradition. Similarly the Australian National Telescope, a big centennial project, looked back to Australia's European origins and looked forward to the role that Australia could play in international science (Haynes et al. 3). In nineteenth century Russia and Germany, astronomical facilities were built with the deliberate intent to impress the outside world, communicating the message of national leadership in science (Golinski 87).

Thus astronomy as big science helps to foster positive myths that can be a substitute for convict origins. Astronomy here becomes the personification of a national culture. To use Gellner's phrase, astronomy becomes 'co-cultural'; it conveys the condition of satisfying nationalism, without employing its own language and implicit assumptions. (Gellner 33). Astronomy represents the whole nation, or at least the best of the nation.

Talking of the AXAF (Advanced X-ray Astrophysics Facility) Leonard Fisk, Associate Administrator for Space Science at NASA, said, "Here was something the US could do uniquely" (Tucker and Tucker 101). This nationalistic legitimation for astronomy has found expression in the successful Australian feature film *The Dish,* which gives a humorously heroic account of the role of the Parkes Radio Telescope in tracking and relaying pictures from Apollo 11. The aesthetic appeal of modern telescopes also helps to give astronomy an iconographic status.

It can still be said that countries build observatories for national prestige. The memoranda written to support and promote Jodrell Bank are littered with "rhetoric of national prestige" (Agar 267). Chaisson too, is not shy of using nationalistic arguments to justify spending on astronomy, in the form of evoking the frontier spirit:

> Today, our terrestrial frontiers are gone. But the heavens look overhead, providing for our imaginations what the Western horizon once was. As such, America's leadership in astronomy and space science reflects the continuing significance of exploration and discovery for our democratic institutions and for our citizens personally. America needs an astronomical frontier — not to make our country vibrant but to make us great into the indefinite future. In short, we need something akin to a "Strategic Education Initiative" to secure for individual citizens the cultural, educational — indeed perhaps spiritual — benefits of our having an astronomical frontier. A decidedly nationalistic argument to be sure, for its intended recipient was a U.S. senator, yet one easily rationalised for all peoples of the globe (Chaisson 32).

The Case of Chile

The case of Chile is illuminating, as it highlights the unusual and complex influences that shape modern international astronomy as an institution, and the ways in which national events and relationships between nations can affect the legitimacy of astronomy.

The fact that Chile contains high, clear and dry regions makes it a particularly attractive place to build a modern observatory. This is especially the case in northern Chile, which has low humidity and minimal atmospheric turbulence (McCray 2004: 238). Three observatories have been built: two by the US, the Cerro Tololo and Cerro Las Campanas, and one by the European Southern Observatory at La Silla. It is conceivable that in a small way such a situation can redress the balance between the rich north and the poor south. Within the astronomical community this has in fact happened. The few professional Chilean astronomers have an advantage over their foreign counterparts because they get preferred access to foreign built observatories on their soil (Appenzeller 1995). Indeed, this advantage seems to have paid off in terms of quality measured by citations; even though there are only about two-dozen astronomers in Chile (Appenzeller 819), they have 0.78% of astronomical journal publications and their citation rate, at 7.46 per article, is the highest in the world. (Van Der Kruit 165).

Americans used economic arguments to entice Chile to join the Gemini project (McCray 2004: 241). When the US bodies built their Chilean observatories in the 1960s they immediately set aside 10% of their telescope time for Chilean astronomers, but Chilean plans to exploit this opportunity were put on hold soon afterward, for in 1973 General Augusto Pinochet overthrew the elected Marxist government of Salvador Allende in a brutal military coup. Pinochet was generally hostile to universities and academics and during the seventeen years of military dictatorship universities shrank and many intellectuals and academics fled abroad. Pinochet's retirement in 1990 made the way for a democratic government.

With the end of the Pinochet dictatorship and the establishment of democracy Chilean astronomy emerged as a small but vibrant profession. It is interesting that the emergence of Chilean astronomy coincided with the ending of dictatorship and the expansion of democracy. Drori et al. see expansion of the cultural authority of science as connected with the spread of notions of universal human rights. The universalist rationalism of science sees human agents as rational actors in a predictable world. Like

Merton, they see a connection between science and democracy, and globalisation is extending both systems, as well as the spread of human rights (Drori et al. 24-25).

In 1993 Chile joined the Gemini project, but under circumstances that later caused problems for the astronomical community. Chile's entry into Gemini was overseen by a group of politicians who did not formally consult with the astronomical community. To make matters worse, an election in 1994 brought in a new government that was less interested in Gemini. The new government threatened to pull out of the project. AURA's original negotiations with Chile were only with the Universad de Chile and other astronomers were left out. There were thus disagreements among astronomers and disagreements between astronomers and their government. When representatives from the participating Gemini countries made a joint appeal, the government agreed to keep its full participating status (McCray 2004: 246-247).

Chilean astronomers are taking advantage of their abundance of allotted observatory time and are undertaking long-term, time intensive searches for supernova, quasars and other astronomical objects that astronomers elsewhere, facing stiffer competition for telescope time, might not be able to do (Appenzeller 819).

Chilean astronomers are in the lucky position of having an abundance of viewing time because of the number of telescopes in located in the country because of its high terrain and dry climate. The very advantage that Chilean astronomers have, and the potentialities that advantage gives for growth in Chilean astronomy, has actually caused a rift within the ranks of the national profession. The Gemini project had caused conflict because of the way it was imposed on Chilean astronomers, and because its expense meant that there were few resources left for other projects. Chile spent $1 million on astronomical research, and $700,000 of that went to fund Gemini (McCray 2004: 248). Some Chilean astronomers reacted against government involvement. While some Chilean astronomers, like Anguita and Masa, favour a national government funded astronomy program, others, like Quintana, disagree: "The problem with state institutions is that they tend to become bureaucratic, rigid; there's a lack of competition once you are there". Such a view could be connected with the fact that Quintana thinks that a government-funding agency would be a threat to university programs like his own at the Catholic University. Quintana advocates a government supported council for astronomy that would channel funds to regional universities wanting to set up programs and provide salary supplements (Appenzeller 820). Here two alternative philosophical approaches to funding appear to be at stake; on the one hand, direct and centralised government funding which would seem to offer a guaranteed and secure funding, but at the same time possibly encroach on the autonomy of astronomers, and on the other a more hands off form of funding, which would be more difficult to secure, because of the unwillingness of politicians and bureaucrats to give money without any strings attached, but would allow astronomers more autonomy. There is of course also a hint in this dispute of wider philosophical differences about the two basic alternative prescriptions for organizing the affairs of a society, namely public versus private ownership and control. Maza, for example, laments the fact that government spending of any kind is out of vogue in the free market Chile of today: “To tell you the honest truth, I don’t know how we’re going to convince our politicians. It’s a shame, the people outside are waiting” (Appenzeller 820).

The fact that Chile, with its limited financial resources, remained a full participant in Gemini shows how international big science can distort small national science.

The Internationalisation of Astronomy

Cooperation between nations in astronomy is nothing new. In 1761 and 1769 astronomers from England, France and several other countries collaborated in putting together expeditions to observe the transit of Venus. These endeavours required major investments in equipment and logistical support, and according to Capshew and Rader (21), they contributed to the evolution of an international community of scientists.

The more astronomy is internationalised, the more it becomes part of an established social system. De-funding of international projects has implications for a nation’s relationships with other nations. Therefore, internationalisation itself can aid the legitimation process. Modern astronomy, and this is a characteristic typical of big science, is truly international. According to the OECD, international cooperation in astronomy:

> is long standing and is a natural part of the landscape of astronomical research. The nature of astronomical research has long made international cooperation necessary, and its manifestly peaceful and non-profit character has made such collaboration politically uncontroversial...the authorship of published articles shows that international cooperation is very real. When choosing locations for ground based observatories, objective scientific criteria...are of such overriding concern that national chauvinism is generally an unimportant factor (OECD 64).

Similarly, a recent U.S. government commissioned report asserts: "To attempt to address some of the most challenging scientific questions facing them, astronomers will increasingly need 'world facilities,' which are so large that they require the participation of many nations to succeed." (National Academy of Sciences 2001: 31).

All of the new large astronomical projects, such as the European Southern Observatory's Very Large Telescope and the Very Large Interferometer, and planned astronomical facilities in Antarctica, are being built by international consortia (National Committee for Astronomy of the Australian Academy of Science 44-45). It seems therefore that astronomy continues to move from a national phase to an international phase.

The growing international character of modern astronomy is particularly evident in Australia, where 55% of all published articles are being undertaken in collaboration with an international partner or partners (National Committee for Astronomy of the Australian Academy of Science 1995 14). A 1995 government report states: "the development of new world class astronomical facilities is now almost exclusively the province of international consortia, with site selection being a prime consideration" (National Committee for Astronomy of the Australian Academy of Science xii) and continues, "Driven by the revolution in global information technology, and constrained by the cost of front-line facilities, astronomers have become even more international in their outlook" (xxi), and "Australian astronomy has relied principally on local research facilities. However, as we move towards the end of the century, there are whole classes of important problems for which innovative forefront research in astronomy will rely more and more upon access to facilities that are international in nature" (National Committee for Astronomy of the Australian Academy of Science 64). Such international collaboration is not limited to personnel or individual telescopes. Single pieces of equipment are now international, such as the Global Oscillation Network Group Solar oscillation telescope (GONG), the VLBI, which involves complex operational procedures to use telescopes simultaneously. Thus networks of telescopes are used as a single piece of equipment. Projects such as the ESO and VLT are beyond the resources of any one nation, and as astronomers see the need for probing deeper into the universe, there is every reason to suppose that this trend will continue.

Further evidence of the internationalisation of modern astronomy is found in the very response of the international astronomical community to the problems in the former Soviet Union. The American Astronomical Society raised $50,000 from its members to help maintain Russian observatories. Although a relatively small amount, the money apparently made the difference between people leaving the field and staying; the International Science Foundation contributed $1 million, and the European Southern Observatory provided a similar sum (Hall, 1275). International oriented entrepreneurialism is also evident. A team led by Viktor Afanasiev, a former director of the Soviet Astronomical Society (SAO), secured a scientific trip for his team to the Kitt Peak telescope in exchange for building a new spectrograph for the instrument, and other researchers at the SAO are trying to raise money by establishing a visiting astronomers program, whereby foreign astronomers pay $100 a night to observe there (Hall 1275).

In their study of the emergence of radio astronomy in Britain, Mulkay and Edge found that there was more cooperation than competition among radio astronomers (Edge and Mulkay 253-256). This seems to be the case with modern astronomy in general. Modern astronomy seems to be a cooperative science, with astronomers sharing views on research priorities within their discipline. What is important to astronomers is their autonomy to make their own decisions about prioritising research (Bahcall 1991). Top astronomers typically travel to other countries to use special equipment, and astronomers from many different countries use the biggest observatories. Professional astronomy is truly an international community, as a glance at the publications in any major scholarly astronomical journal will show. Modern professional astronomy thus plays the dual role of promoting nationalism and internationalism. Astronomy is international in another way. Large national astronomical agencies, like the National Optical Astronomy Observatory (NOAO), fund observatories in countries other than those in which they are based. For example the NOAO has set up observatories in Chile, while the National Science Foundation is also setting up observatories in Chile (Kaiser 641).

One conspicuous and spectacular example of the growing internationalism of astronomy is the aforementioned Gemini Project (McCray (2000, 2004). Gemini was a truly international collaboration between seven countries scattered all over the world (see chapter 1: 51-54). McCray examines the Gemini project in terms of the ‘moral economy’ of astronomy. His conclusion is that Gemini was a victory for the ‘have not’ American astronomers, who rely on nationally funded observatories, over the ‘haves’ who already have access to large, independently funded telescopes, and wanted resources diverted to state run facilities. The sacrifice the ‘have nots’ had to make was to have to share Gemini with international colleagues. British and Canadian astronomers, lacking equivalent facilities in their own countries, strongly supported Gemini. While some American astronomers liked the idea of an international facility, others were opposed to Gemini, because they would have preferred a national facility. But when they saw their choice was between a shared, internationally facility and nothing, they chose sharing (McCray 702-706). However, although the project is international, like Hubble it is not equally international, 47.6% of the project being funded by the U.S. and U.S. astronomers being allocated 51.6% of telescope time on Gemini North, and 41.6% of telescope time on Gemini South (National Academy of Sciences 2000: 71).

Such an international project can threaten entrenched national astronomical institutions. For example, the British government is considering diverting funding to the Gemini project from the Royal Observatory, thus putting the future of this established institution in question. Even this institution now owns an observatory in Los Palmos, and the suggestion to merge the two Royal Observatories, at present split between Edinburgh and Cambridge, would signify a move toward even bigger science. Similarly, the Kitt Peak Observatory in the US, one of the country's biggest, is also under threat of closure, partly because of diverted funding to the Gemini Project (McCray 641). Big science, in this way, becomes even bigger, not only in terms of size of project, but also in terms of the funds astronomers must have to travel to use such facilities; not all astronomers can afford to bring students to Chile. Consequently, even some astronomers are questioning the move to bigger and bigger astronomy. But the growing internationalism means that traditional disparities, such as the gap between North and South, can be challenged. Remote areas such as those in Chile, which have the advantage of being of a high altitude and having a dry climate, can benefit considerably from the influx of capital that an observatory can provide. Neither is the internationalism of astronomy solely caused by the move toward bigger science. Due to science spending cuts by the Thatcher government, British astronomers turned to colleagues abroad even for help in research projects that didn't require expensive new equipment (Whitney 11).

Modern astronomy thus behaves like a trans-national corporation; funding agencies may be based in a particular country, and financed by the government of that country, but they increasingly build observatories in any country where the geographic and economic conditions are most suitable. Thus it could be that we are witnessing the beginning of a decline in national astronomy and the rise of international astronomy. As projects become bigger, so any particular nation, even the United States, begins to question the wisdom of 'going it alone'. Astronomy's growing trans-national nature can sometimes work to its advantage in unexpected ways. The 1995-96 British government's science budget allocation gave the Particle Physics and Astronomy Research Council, the main astronomy funding body in Britain, a 9% increase over the previous year, the largest increase of any agency, but this was not deliberate government policy. On the contrary, the government wanted to prioritise wealth-creating areas, and PPARC, according to *Science* is, "the one with perhaps the least potential for wealth creation" (O'Brien 782). The enormous increase was due to European currency fluctuations, which caused large net increases in subscriptions to international consortiums like CERN and the European Space Agency (O'Brien 782).

Aside from the ongoing problem of limited funding and budget cuts, the different perspectives and expectations of politicians and astronomers as social groups are an important factor in the determination of astronomical outcomes. Astronomers are used to thinking analytically and in the long term; modern astronomical projects are typically long term, requiring many days or nights of patient observation followed by lengthy and in depth analysis of data, and timelines for project completion are unpredictable; it cannot be known in advance where the analysis of data will lead in terms of resulting meaningful information and knowledge that will lead to a practical understanding of celestial phenomena. In contrast, politicians and bureaucrats who are responsible for decision making with regard to funding often work according to deadlines, and sometimes relatively short time period deadlines, with a view to producing visible results in time for the next election, and the resulting decisions, from the astronomer's point of view, may not be in the best interests of astronomy.

In contrast, a typical large-scale astronomical project can take ten years from inception to completion (OECD 74). When astronomers asked Congress to appropriate funds for the Advanced X-Ray Astrophysics Facility (AXAF), Congress stipulated that it would appropriate funds only if the mirrors were completed to working standards by a specified date. Astrophysicist Harvey Tananbaum commented, "I don't know that we had a choice. Technically, we weren't asked if this was acceptable of not; it was decided at a closed meeting...and the word came back this is what we were to do". (Marshall 508). As it happened, the mirrors passed the test, but Congress cut AXAF's budget by $60 million because, while holding NASA's overall budget steady, it decided to spend more money on bigger, publicly prestigious and glamorous projects: the space station and the Earth Observing System. This further highlights the trend toward bigger and fewer projects; AXAF's $1.6 billion cost was dwarfed by that of the space station ($30 billion), and the EOS ($11 billion) (Marshall 510). The frustration of astronomers at this way of making astronomy policy is evident in the responses of two involved astronomers. Mushotsky said, "Science doesn't work to rigid requirements" and added that the whole notion of legislating milestones for research is wrong-headed (Marshall 510). Another astronomer, Tananbaum, responded, "Since we formally started this program, 3 years have gone by and launch has receded between 2.5 and 3 years. That's disturbing" (Marshall 510). But according to House appropriation subcommittee chief Malow, the AXAF test, "worked out pretty darn well...if my career had to come to an end suddenly, I would like to go out with that one" (Marshall 510).

Astronomy as big science has certain positive aspects with regard to astronomers' political interests. Big science means that astronomers collaborate and establish strategic plans giving policy makers a consensus on priorities. International cooperation means that astronomers are less divided along national lines, and can adopt a unified front against attacks. And internationalism means that research projects become complementary rather than duplicative, again minimising competition and maximising cooperation and unity. Astronomy as big science thus means that astronomers more and more become an international unified socio-political group. This tendency is also encouraged by the growing specialisation within astronomy. As astronomers more and more specialise in their own specific newly emerging areas such as gravitational wave astronomy, neutrino astronomy, infrared and optical aperture synthesis, dark matter detection and ultra-high energy gamma-ray astrophysics, they are less likely to encroach onto other astronomers' areas. Again cooperation rather than competition is the prevailing tendency. In the words of the OECD, "The nature of astronomical research has made international cooperation necessary, and its manifestly peaceful and non-profit character has made such collaboration politically uncontroversial" (OECD 64).

Of course this international cooperation can mean risking conflicts between contributing nations, or groups of nations. For example, although NASA funded the bulk of the Hubble Space Telescope, there was some contribution from other countries, notably Canada and thirteen European countries, though the European Space Agency (ESA). NASA consistently underplayed the role of the ESA, and did not consult them when making changes to the telescope. In one press conference, the ESA came on last, and just when they were about to speak a NASA official announced buffet lunch and the press gallery emptied. NASA also offended the ESA by displaying only NASA's logo on the first light images and not that of the ESA (Chaisson 138-139). NASA was able to get away with this behaviour because the project, though international, was not equally international — it was largely paid for, run, and controlled by NASA, an organization owing allegiance to neither astronomers nor foreign agencies.

Competition was also apparent between Europeans, in the form of European Space Telescope astronomers competing with land based European astronomers. The leader of the European astronomers on the telescope, Duccio Macchetto, raced to get sharp images of faint objects before the astronomers at the newly built European Southern Observatory at La Silla, Chile. The La Silla telescope cost only $13 million, about one hundredth the price of the Hubble telescope, so if the La Silla telescope could get better than or even as good as images of distant objects, it would have been highly embarrassing for the Hubble group (Chaisson 141-142). When looking for a comparison image taken from a European observatory, instead of obtaining one from their "competitor" at ESO, they used a photograph from the Nordic Optical Telescope that displayed relatively poor resolution. The comparison was between a poor ground based photograph and a doctored Space Telescope image. When challenged on this issue NASA's only comment was to complain that its logo on the press release of the image was too small (Chaisson 144). On this occasion the ESA logo was indeed bigger than the NASA logo (Chaisson 145). According to Chaisson, NASA raised concern about their logo to the point of obsession (Chaisson 251). Logos apart, my research suggests that professional astronomers develop trans-national and trans-cultural networks. This is despite intense competition between nations in certain areas (National Research Council 2000 73-74).

When Big Science Goes Wrong

Launched in 1990, the Hubble Space Telescope is the biggest and most expensive astronomy program to date. For a while it was also NASA's showcase scientific program, at its inception bringing the agency more favourable press than at any time since the era of *Apollo*. It was launched by the space shuttle Discovery on 24th April 1990. According to one historian, on this day the Discovery carried not just a twelve ton space telescope but the expectations of scientists, politicians, and a public audience stimulated by a relentless media campaign (McCray 2004: 204).

Hubble is the largest, most powerful observatory ever employed in space. NASA built the Space Telescope with the help of the European Space Agency (ESA) and numerous industrial contractors. Named after the famous astronomer Edmund Hubble, the Hubble Space Telescope is an unmanned, orbiting vehicle designed to undertake a long-term international program of scientific exploration of the cosmos. HST enables astronomers to probe the visible universe with several times finer resolution and many times greater sensitivity than any other machine built by humans. The heart of the telescope is the 94.5" (2.4 meter) primary mirror designed and manufactured by Hughes Danbury Optical Systems, formerly part of the Perkin-Elmer Corporation. Its sensitivity and high resolution enables Hubble to see deep into the past, and address profound questions such as the time and nature of the origin of the universe.

A month after Hubble entered orbit, astronomers at the Space Telescope Institute received long awaited "first light" images from the telescope. Instead of clear images, they saw merely a blur. The company that had ground the mirror, Perkin-Elmer, had made a huge error when grinding the mirror, which caused a spherical aberration, which was not discovered by NASA quality control. Hubble's mirror had been inspected neither by Perkin-Elmer nor NASA. The result was that the problem was not discovered until the Hubble Space Telescope was in orbit. The way that NASA handled the fallout from this event illuminates how particular modes of promotion can be dysfunctional to an astronomical project and to astronomers. For the Hubble mirror fiasco also damaged the reputation of the astronomical community. In advocating Hubble, astronomers adapted to the institutional culture of NASA and its industrial contractors. Astronomers accepted that Hubble would be operated as a large-scale facility. Individual astronomers took passive and ineffectual roles in the planning of the project (McCray 2004: 205-206). However, astronomers, while sidelined in the design, planning, and implementation of the project, were still associated with it in the public mind.

The spherical aberration problem of the main Hubble telescope mirror highlights the potential fragility of big science. As Chaisson points out: “Such is modern science, big science. A microscopic imperfection only a few percent of a width of a human hair can nearly cripple a $2-billion piece of scientific apparatus” (Chaisson 176). Indeed, when a project as big as the Hubble telescope goes wrong, it can have a profound effect on public perception and national policy. The problems with Hubble’s mirror, and the ensuing bad publicity, exacerbated by NASA’s poor handling of the affair, broke perceived links between the space program and technological perfection. Instead, such links were demonstrated by military technology in the Gulf War. The disaster of the Hubble mirror aberration also highlights the *risk* involved in doing big science — the bigger the science the bigger the risk. The Hubble telescope was an attempt to make a technological leap forward, but such a leap inevitably involved many novel technical complexities, each of which had an element of risk. The fact that there was no back up space telescope (indeed there could not be, for this would have doubled the already astronomical cost) meant that the risk was all the greater. Perhaps NASA’s mistake was to make space seem prematurely routine, when, as the Challenger disaster had already shown, it is fraught with risk. As Diane Vaughan has shown, the Challenger launch decision can be seen as an example of a paradigm, in this case the low risk assumptions of NASA officials, persisting in the face of contradicting anomalies (Vaughan 400-402).

As Smith points out, the telescope and the program to construct it were “the products of a great range of forces: scientific, technical, social, institutional, economic and political” (Smith 25-26). NASA, like any large organization, has divisions in which decision making takes place within a specified area of concern. However, in the case of the Space Telescope, an observation plan was outlined before launch, but no back up plan was initiated in case circumstances necessitated a change in imaging strategy. Moreover, no one was put in charge of making such decisions should such circumstances arise. The resulting confusion added to NASA’s disastrous handling of the mirror aberration, which meant that imaging strategy would have to be altered. The bureaucratic inertia causing an inability to be flexible according to changing circumstances was highlighted when astronomers tried to find alternatives to the existing plan.

Given the mirror problem, astronomers devised a plan to take advantage of the position of Saturn and get images of ‘the great white spot’ that they were confident would be superior to anything taken from the ground. But “None of the NASA managers wanted to take responsibility for ordering the observations; the media might find out about it, and if it failed the helmsmen might be plastered against the wall by screaming NASA administrators further up the chain” (Chaisson 300). Astronomers simply by-passed the NASA bureaucracy and went ahead and took images of Saturn (Chaisson 300). Astronomers, though mere employees and end users, were on this occasion able to use their expertise to subvert the formal decision making procedures of their employing organization in order to do astronomy. This was possible because on this occasion there were no procedures put in place for such an eventuality. This tactic was repeated later to get images of Mars and put them in the public domain (Chaisson 328-329). In sociological terms the informal organization took over from the formal organization.

Conclusion

The effect of becoming big science on the legitimacy of astronomy is two fold: on the one hand there is more to legitimate, in the sense that big science requires more resources than little science; on the other the status of big science itself aids in legitimation. To return to the comparison with aboriginal ‘little science’: in modern astronomy, sophisticated equipment and techniques separate astronomers from their fellow citizens and from nature; they must use equipment as a mediator between themselves and the object of study. Thus the technology can be seen as a manifestation of the alienation of astronomers from nature and from non-professional astronomers. The central role of mathematics can also be seen as a manifestation of such alienation (Porter 18). Aboriginal astronomy was part and parcel of the aboriginal way of life; it was pragmatic; it helped with predicting food availability and supply, weather conditions, seasons, and helped to provide moral guidance. Modern astronomy can do none of those things, although, as we shall see, it now has pretences to invade the area of morality through its supposed philosophical connections.

One way of looking at the history of astronomy is to see it as gradually transforming first through the use of equipment such as the telescope, then the building of observatories by individuals such as Hooke and Herschel, through to observatories built by institutions such as universities, through to national observatories, and finally to the present stage of international consortia. We thus move from the little science of ancients using their naked eyes, through to the medium science of the first Galilean telescopes and the observatories built by individuals, then the big science of institutional observatories, through to the big science of national observatories, to the megascience of international observatories. But paradoxically, with large databases and cheaper computers, and with some astronomers working under volunteer conditions, the demarcation between big science and little science is becoming blurred (Keel 4). In fact, it is conceivable that technology, which at first created big science, will now cause its decline. The majority of astronomers I interviewed spent most of their time not at large telescopes, but in their small offices working on data downloaded from a variety of sources: telescopes, data bases, and other pcs. As one astronomer put it: “today astronomers keep the same hours, work in the same environment, and go through the same motions as everyone else: they come to their office in the morning, sit down at a workstation, and surf the net” (Hapgood 49).

Big science came about largely in the West; eastern science for the most part remained little science. Modern astronomy, seen as part of Western big science, is a continuation of a tradition that can be traced back to the Ancient Greece, of seeing nature as in some way being rational and susceptible to the control of humans. Modern astronomy, through its use of technology, extends this notion of rationality into the whole Universe. Astronomy as big science has also helped provide the practices and ideologies that have helped legitimate the shift from a small property economy to a concentrated political economy: big observatories require big capital. Moreover, as Habermas notes, governments can improve conditions for the realisation of capital by replacing the market mechanism through what he calls “unproductive government consumption” such as armaments and space exploration (Habermas 1975: 35). Expenditure on non-utilitarian astronomy can be seen as part of this unproductive government consumption. Moreover, as there is more and more overlap between astronomical technology and military technology, astronomy can actually be seen to enhance military integrity.

As unproductive government consumption expenditure on astronomy can also, in certain economic circumstances, be useful in a Keynesian way in that it provides employment and governmental demand, whilst at the same time enhancing national integrity. In other economic circumstances however, the cost of such unproductive government consumption can become a burden — an overloading of the public budget. In such times expenditure on astronomy will be questioned.

Astronomy as big science underlines C. P. Snow's thesis of the two cultures. In 1959 Snow outlined the influential thesis that there exist in modern societies two cultures: a scientific culture and an intellectual culture: the humanities. Snow thought that this dichotomy, traced back to the debate between Hobbes and Boyle in the 1660s by Shapin and Schaefer in *Leviathan and the Air pump*, was detrimental to society and is characterised by hostile polarisation. Modern big science makes this gap bigger by widening the gap between the resources available to scientists and those in the humanities, highlighting Latour's point about the crucial difference between science and non-science being not one of epistemological demarcation but one of resources. In astronomy this gap is particularly evident as astronomers use enormous pieces of technology requiring sophisticated skills to operate. Their ability to utilise such equipment marks them out as a specialist elite, if not in monetary reward, certainly in intellectual status. Moreover, the continuing success of astronomy in terms not only of its discoveries but also its continuing ability to procure resources is evidence that science does not have to be experimental to succeed. Thus Hobbes's critique, as outlined by Shapin and Schaefer, of Robert Boyle's view that all science should be experimental is at least partially vindicated. At a more general level, the nature of the relationship between astronomy and state funding supports Lyotard's view that the state spends:

Large amounts of money to enable science to pass itself off as an epic: the state's own credibility is based on that epic, which it uses to obtain the public consent its decision makers need. It is not inconceivable that the recourse to narrative is inevitable, at least, to the extent that the language game of science desires its statements to be true but does not have the resources to legitimise their truth on its own. Scientific knowledge cannot know and make known that it is the true knowledge without resorting to the other, narrative kind of knowledge, which from its point of view is no knowledge at all (Lyotard 27-29).

CHAPTER THREE

ASTRONOMY AS POPULAR CULTURE: THE ROLE OF POPULARISERS IN THE LEGITIMATION PROCESS

Introduction

Popularisation is crucial in the legitimation process because astronomy is largely publicly financed, and in the era of economic rationalism no funding can be taken for granted. The more public support astronomy has, the more likely it is able to attract resources from government. This point was confirmed in my interviews; almost unanimously, my astronomer interviewees said that public support was crucial to their work. Another expression of the importance of popularisation of astronomy to the profession is the conclusion of a major US government commissioned report on American astronomy, which recommends giving a coordinated public information program top priority (National Research Council 5). Popularisation is particularly crucial in contemporary astronomy in an era of economic rationalism and populist market oriented economics. Astronomy is vulnerable to government cuts and, like other sciences, is expected to show its relevance to the public in an era in which society is more and more dominated by popular culture. At the epistemological level, popularisation is crucial because, "as facts are translated from the language in which they are represented among specialists to language appropriate for a lay audience, they become consolidated as knowledge. As experts describe their findings to nonexperts, facts are simplified and rendered more dramatic, and the sureness with which they are held is strengthened, even among the experts themselves" (Golinski 34).

It is important to note that there is a large body of literature on the public understanding of science that is deliberately not addressed here. I do not intend to survey the vast amount of literature on the popularisation of science. Instead, my goal is both limited and specific. My arguments and case studies are merely intended to elucidate the relevance of popularisation to the legitimation process in astronomy.

The chapter is divided into seven sections. First, I introduce the concept of popular culture and explain its relevance to the successful explanation and justification of astronomy. I then locate the popularisation of astronomy as a subset of the popularisation of science; namely, the popularisation of pure science, which has its own problems and legitimation practices. Third, I examine the role of trust in the popularisation of astronomy, and its implications for the relationship between astronomer as populariser and the layperson in the role of 'popularisee'. The explication of the role of trust then leads me into a discussion of popularisation and inequality, in which I make the case that, contrary to intuition and received wisdom, popularisation can actually highlight the inequality between 'knower' and 'knowees'. At this point I examine examples of famous and successful popularisers: Carl Sagan, Paul Davies, Stephen Hawking and Patrick Moore. An example is then given of an attempt at popularisation that was a relative failure: the early popularisation of the Hubble Space Telescope. Next, informed by the popularisation case studies, I broaden the discussion and examine some socio-cultural aspects of astronomy popularisation. Finally, I draw together my arguments in order to come to some general conclusions about how popularisation relates to the legitimation of astronomy.

Popular Culture and the Popularisation of Science

The study of popular culture has blossomed in Anglo American sociology in the last twenty years, especially in Britain. Popular culture studies are not usually associated with science studies, but it is the contention here that when scientists popularise their discipline they are making science part of popular culture. There is some disagreement about the meaning of popular culture but recurring themes can be found in most writing that claims to be addressing popular culture. Rossides (186) identifies two overlapping meanings. First, popular culture can refer to the symbols and emotions of ordinary people as opposed to the culture of elites. The second commonly used meaning is that popular culture refers to the symbols and sentiments that are accessible during leisure time. This meaning encompasses the former meaning; it includes the symbols and emotions of ordinary people and the culture of elites, or what is sometimes called 'high culture'. When science popularises itself it becomes popular culture in the latter sense: it is not restricted to the lower classes — 'ordinary people' — but appeals to all strata in society, perhaps the educated more than the uneducated. Thus when science popularises itself it becomes both popular culture and elite or high culture. In fact, with the exception of popularisation in schools, astronomy popularisation is specifically not aimed at the social category of *ignorant person* or the uneducated (Rossides 221). The astronomer as populariser carries standards of a way of life — science — to the population at large.

The notion of the popularisation of science has traditionally meant the transmission of scientific knowledge from scientists to the lay public. But Whitley (1985) has challenged this view. Whitley expands the notion of popularisation to include such activities as communicating with scientists in other specialisms, explaining scientific concepts to other stake holding professionals (such as representatives of government, legislative and funding agencies), writing educational textbooks for science students, as well as books, radio and television programs for the educated public. Similarly, Hilgartner (1990) argues that the precise location of the boundary between genuine scientific knowledge and popularised representations is difficult to pin down, because scientific knowledge is communicated in many contexts: laboratory shop talk, technical seminars, scientific papers in journals, literature reviews, grant proposals, textbooks, policy documents and mass media accounts (Hilgartner 1990: 524). Hilgartner argues that all of these contexts could be said to consist in some form of popularisation, and that popularisation is most usefully seen as a spectrum. Popularisation, to Hilgartner, is a matter of degree. The boundary between real science and popularised science can be drawn at various points depending on what criteria one adopts.

The trouble with defining popularisation so broadly is that it comes close to referring to *all* communication performed by scientists, thus making the term vacuous. While it is useful to see popularisation as a continuum, for the purposes of this chapter I concentrate on the latter end of the continuum. Popularising to the lay public and key powerful professionals, unlike communicating to other scientists and explaining concepts to students, has an overtly legitimative and political dimension. Astronomers' dealings with those in state agencies are dealt with in the next two chapters. Here I want to address the role of popularisation of astronomy to the lay public through the mass media, and its role in the legitimation of astronomy. But Whitley is surely correct when he asserts that what differentiates popularisation from other forms of scientific communication is, "The transmission of intellectual products from the context of their production to other contexts" (Whitley 12). Using a functionalist perspective, if we see astronomy as a social system, education and popularisation are both inputs, and the outputs are spectacular discoveries, which generate more popularisation and education etc, through what Larson calls a "demonstration effect" (Larson 31). That is, popularisation is the means by which impressive achievements that serve to facilitate scientific support are disseminated amongst the public.

Historical aspects of astronomy popularisation

Popularisation of science to the lay public is not new. In Dante's time (1265-1351) astronomy was popular both because of its connection with astrology (Orr 211), and because it was thought of as a noble and elevating study itself (Orr 217). Robert Boyle, in seventeenth century England, was aware that "the circulation of knowledge in public space was deemed vital for securing its veracity and legitimacy." (Shapin 1995: 338). In late seventeenth century England, the Royal Society frequently enacted dramatic, theatrical experiments to entertain Charles II and his court. And in the eighteenth century, much science moved into what Habermas has called the emerging public sphere.

Since the early nineteenth century, scientists have been required, to varying degrees, to justify their activities to audiences that ultimately fund their work but do not share their expertise. Prominent scientists popularised science in the nineteenth century (Eidelman, Bayertz, Gieryn 1999), and as early as 1846, spectacular pictures of astronomical discoveries made the pages of *The Pictorial Times* (Secord 468). Indeed, it was claimed that astronomy in particular was "a sure fire way to attract the opposite sex" and that "women were especially open to the romance of astronomy", and it was even suggested that astronomy had "direct physiological effects on the female body" (Secord 163). The connection between gender and astronomy as a romantic endeavour is further highlighted by the justification for the study of astronomy given by the first female professional astronomers in the nineteenth century. Astronomy in the American women's colleges was "seen through the lenses of Victorian romanticism" (Lankford 312-131). A romantic philosophy of nature provided a bond that united all who studied at observatories. This romantic philosophy is epitomised by astronomer Antonia Maury in her poem "Dome Verses": "Whether for use of knowledge, all things in common hold … no human meets and measure serve, but nature's higher law … nature blends with spirit, in love's dissolving day" (Lankford 313). However, despite the entry of women into the profession, during this period astronomy, like botany, geology and chemistry, was alien to most readers and publishers (Secord 214).

However, until the mid nineteenth century, astronomy, in the form of astrometry and celestial mechanics, was able to justify itself through its practical applications in improvements in time keeping and navigation. By the mid nineteenth century astrometry and celestial mechanics had not yet reached their limits in terms of these practical applications, but had reached their limits in terms of major discoveries. At the same time the invention of spectroscopy in 1859 made astrophysics, which had no equivalent practical applications, a viable scientific alternative to the old astronomy. But the new astronomy had no markets. The first consumers of astrophysical knowledge were other scientists: not only other astrophysicists, but also physicists, and especially high-energy physicists. At this point, popularisation became more important, and popularisers such as Samuel Langley and Charles Young were brought in to legitimate the new science. They also brought its results to the attention of wealthy donors (Lankford 38-39).

Just before the great change in astronomy, there was a major attempt to legitimate astronomy to the public. In a widely read article in *Harper's* Elias Loomis, a scientist at New York University, justified astronomy on both economic and cultural levels. Observatories were providers of the foundations of accurate timekeeping instruments. And the astronomers who provided the information for the *Nautical Almanac* provided an essential aid to navigators and thus an essential aid to sea transport. But Loomis went further. His cultural justification foresaw the need for non-utilitarian justifications for astronomy. Loomis argued that astronomy has a positive cultural influence on society. "An astronomical observatory … is a centre of genial influence, which directly or indirectly imparts life and efficiency to all subordinate institutions of education". Astronomy also offered a form of recreation that could “inspire the mind with noble sentiments” (Loomis 56).

Unlike the old astronomy of astrometry and celestial mechanics, which could be justified on the grounds of their contribution to navigation and time keeping, the new astronomy of astrophysics had to rely on popularisation from the beginning. As early as 1897 astronomer J.E. Keeler, writing of the importance of astrophysics, asserted that the new astronomy had already discovered unexpected wonders in the universe, and this provided good copy for the mass circulation urban press and monthly magazines (Lankford 58). Examination of nineteenth century American newspapers suggests that the building of observatories received wide coverage and competition between observatories was a favourite subject of reporters as far back as the 1890s (Lankford 376). In the early twentieth century, the powerful and entrepreneurial directors of the great new observatories in America regarded good public relations of the utmost importance, and one of them, Campbell of the Lick Observatory, became a master of promoting his observatory to the media (Lankford 197). Another, Lowell of the Flagstaff Observatory, used mass circulation magazines rather than scientific journals to publicise his observatory’s discoveries (Lankford 202).

Moreover, the growing influence of mass media on culture, combined with the abandonment of the post World War Two consensus that government should provide scientists with funds and then leave them alone to do science, has given popularisation a new importance. The need for establishing common interest between professional astronomers and sections of non-astronomers through the popularisation of astronomy is now essential. To put it another way, scientists are now more accountable and, as Porter puts it: “Public responsibility breaks down the boundaries around the research community and makes it necessary to satisfy a larger audience” (Porter 229). It is important to note however that astronomers do not popularise to an undifferentiated mass, but for segmental publics. That is to say, they do not have to appeal to everyone, or to the public as a whole, only to sections of the population. As Whitley would argue, the public here can include other scientists and even other astronomers. As a science, astronomy is peer oriented rather than client oriented, but in recent years economics has encouraged the profession to reach out and communicate to others both their discoveries and the excitement of making those discoveries. In this endeavour, astronomy is well placed as compared with most other sciences, for large sections of the public do seem to have a fascination with the cosmos into which astronomy populariser can tap.

The Popularisation of Pure Science

In a climate of economic rationalism, Daniels' observation about the relationship between nineteenth century science and democratic societies is particularly relevant to professional astronomers today:

> The frankly avowed pursuit of pure knowledge is a luxury that a democratic society will allow only the well-established profession. This implies that in the early stages it will be hazardous to attempt to justify scientific training and research in terms of scientific values alone. Until such time that the power of science over the environment becomes perfectly obvious, the scientist must seek some other means of contact with the relevant public. That is to say, the emergent profession has no choice but to justify its work in terms of its social purposes, and in doing so, it must appeal to general cultural values (Daniels 152).

Daniels is correct, for, however legitimate they think their science is, when promoting their science, scientists must deal with power and with ideology. And, as Habermas notes, "The structure of symbolic interaction and the role of cultural tradition … are the only basis on which power and ideology can be comprehended" (Habermas 1971: 42). In other words, astronomers have to work within systems of meaning already established outside of their field; they must adopt a language other than their own to popularise their science. In another article, Daniels attempts to date the appearance of the notion of science for science's sake, at least for America:

> Previously, science had been 'sold' to the public in terms of its importance to American values — utilitarian, equalitarian, religious — or even as a means of social control, depending upon the speaker's best estimate of his audience. But in the 1870s for the first time, great numbers of scientific spokesmen began to vocally resent this dependence upon values extraneous to science. The decade, in a word, witnessed the development, as a general shared ideology, of the notion of science for science's sake (Daniels 1699).

The notion of science for science's sake is particularly important for astronomy, as it has no utilitarian benefits to argue for in its repertoire of rhetoric. Astronomy, however, can benefit from society's general commitment to science. The argument goes that science must be kept healthy because it is the only source of valid knowledge. Since science is the only true valid knowledge, it necessarily leads to public benefit, and any interference with or withdrawal of support from science inevitably leads to economic and military decline. Thus, it is suggested that *in the long run* pure science promotes the general welfare. Astronomy cannot but benefit from this standard professional ideology of science. Moreover, the situation is by no means clear in relation to applied research. This point is highlighted by Ben-David, who asserts:

> Most scientific work is supported because of the expectation of social benefits, such as improved health, higher productivity, etc. Research related to health, agriculture, and manufacturing industry is much more heavily supported than research which has no apparent relationship to social welfare, economic progress, or military effectiveness. The rationale for this type of research is not unambiguously established because thus far it has been impossible to measure whether the results to an investor from applied research have been as great as some alternative use of his capital. Nevertheless, the support continues, because the plausibility of the belief that on a global scale and in the long run mankind has

derived material and not only cognitive or cultural benefits from research (Ben-David: 205).

Frankel's assertion about scientists in general is particularly true of the astronomical profession: "Scientists have taken to heart the notion that flattering public attention may advance grantmanship and careers" (Frankel 1105). Contrast this with the situation in 1957, when astronomer Bernard Lovell wrote that on 3 October 1957, the date of the launch of Sputnik I, "We had the attitudes and characteristics of the traditional scientific establishment, resentful of publicity and waging a war with the Press whose unwelcome attention we had attracted" (Lovell 160). Similarly, Patrick Moore wrote in 1959: "A British University professor of astronomy wrote a review in which all popular books came under heavy censure. His grounds were that they were scientific journalism; that they could not hope to present a full picture, and were thus bound to be misleading; and that they gave a wrong idea of what astronomy was about". (Moore 1960: 1). When Jodrell Bank opened in 1957 the general public were regarded as 'gawpers' who should be controlled and kept at a distance. It was left to the Department of Science, Industry and Research (DSIR) to put pressure on Lovell and his colleagues to open the telescope up to the public (Agar: 272-273). At that time, the prevailing practice in science policy was based on views espoused by Vannevar Bush in the 1940s, and summarised here by Michael Polanyi:

> The pursuit of science can be organized...in no other manner than by granting complete independence to all mature scientists. They will then distribute themselves over the whole field of possible discoveries, each applying his own special ability to the task that appears most profitable to him. The function of public authorities is not to plan research, but only to provide opportunities for its pursuit. All they have to do is to provide facilities for every good scientist to follow his interest in science. (Polanyi 1951: 89).

In astronomy, the above situation creates the conditions that will facilitate outcomes such as spectacular discoveries, which would facilitate public support. Harvard astronomer Harlow Shapley was at the forefront of the post World War Two efforts by Vannevar Bush and others to put this philosophy into practice and make US science as free as possible from immediate political interference (Gieryn 1999: 78). Astronomy fares well when new knowledge is seen as intrinsically good, and it is thought that scientists should be well funded and left alone to do their work.

The theoretical justification for the autonomy of science can be found in CUDOS: the norms of Communalism, Universalism, Democracy and Organized Scepticism, propounded by Merton. Universalism means that claims to truth be assessed independently of the attributes of their proponents; communism (or communalism) is the disavowal of secrecy in knowledge discovery; disinterestedness is an adherence to objectivity as opposed to personal self interest; and organized scepticism refers to attitude personified by peer review: no theory is accepted on the basis of the authority of the proponent, and all theories are tested. According to Merton, these norms themselves ensure a neutral and detached search for knowledge. Therefore, scientists should be left alone to get on with the job. Pure science was justified on the assumption that any practical benefits were unpredictable: you can never tell which basic science will have a trade off in practical benefits. Thus, the only safe and sensible policy was to fund science and let the scientists decide on the direction of research. Only in such an ideological environment could an astronomer afford the luxury of denigrating the popularisation of his discipline. Mertonian norms are now seen as object of historical inquiry rather than an unproblematic resource (Golinski 54). For example, scientific claims *are* generally accepted on the basis of authority (legitimate domination of knowledge).

Driven by economics, scientific elitism has given way to popularism. Of course by becoming populist, astronomers are seeking to maintain themselves as an elite. Moreover, astronomy must now be taken out of the world of science itself, and into the public arena. As NASA publicist Edward Weiler said: “People have a right to see what their investment is returning. If all the telescope does is fill in the *Astrophysical Journal* and *Astronomical Journal*, that's a failure." (Weiler 1416).

The general public now has the chance to form a wealth of fragmented opinions about science and technology, from a large variety of mediated views put forward by various social actors, such as the mass media, industry, and regulatory bodies in the public arena (Christisdou, Dimopoulos, and Koulaidis 347). Using these media, astronomy legitimators must work within definite parameters; premature announcements, exaggerated and repetitive claims and overstating the significance of results can be self-defeating and incur the disapproval of other astronomers (Weiler 1416-1418). Thus, popularisation of scientific research may jeopardise its legitimacy within the scientific community. Scientists in the nineteenth century chastised popularisers such as John Tyndall for weakening their claim to scientific authority (legitimate domination of knowledge). (Gieryn 1999: 42). But paradigm shifts caused by external factors can change what is acceptable and what is not acceptable to the scientific community in terms of both the form and content of what is popularised. Nevertheless, the populariser treads a fine line between 'legitimately' legitimising her discipline and delegitimizing herself in terms of her colleagues, for example by distorting the science in order to popularise it (Hilgartner 2000: 103-104). As one science policy expert, Harvey Brooks, complained in 1971, "the psychological and intellectual involvement of the public tends to occur only in relation to costly 'spectaculars' such as the Apollo program … and this public interest in turn tends to distort the values and goals of science itself" (Capshew and Rader 12). The picture is further complicated by the fact that science itself is partly legitimated by its use of particular denoted jargons (Verhaegen 323-351). But a populariser has to limit or even eliminate jargon in order to successfully popularise.

Limiting jargon is only one facet of the modifications scientists make when they popularise science to the non-scientific public. Indeed, when scientists popularise they are engaging in *performance*. The term here is used in the sense used by Goffman. That is to say, it is a metaphor that can be used to analyse how individuals present themselves in every day action and how audiences receive them. The performance metaphor highlights the fact that social actors are aware that their actions and discourse create impressions and, like actors on stage, use a range of dramatic devices to create desired responses from audiences. A convincing performance can display confidence and enhance credibility (Hilgartner 7-15). As we shall see, some astronomy popularisers are superlative performers

The Popularity of Astronomy

Evidence of the popularity of astronomy is given by a recent major U.S. report: planetariums and observatories are popular visitor destinations, with 28 million visits per year; observatory visitor centres are similarly popular; astronomical discoveries are well covered by the media; magazines devoted to astronomy enjoy wide circulation; astronomy television and radio shows are popular; and astronomical web sites are among the most popular destinations on the web (National Research Council 142). The growth of astrobiology has the potential to make astronomy even more popular (National Research Council 158). One reason for the popularity of the discipline is that astronomy in general, and astrophysics in particular, addresses fundamental questions to which religion and philosophy also address themselves. As we shall see, this connection has been used to full effect by some astronomy popularisers.

In contrast, although chemistry has been taught in secondary schools since the nineteenth century, and today, along with physics and biology, constitutes a major part of high school science curricula, chemistry does not capture the public imagination in the same way as astronomy: there is no popularising infrastructure such as that described above. There are few amateur chemistry clubs or popular journals devoted to chemistry, and no amateur chemistry organizations whose members have made contributions to the science. In short, astronomy has deeper cultural roots than chemistry.

The special role of astronomy in promoting public interest in science has thus been emphasised in certain contexts. A recent U.S. government commissioned report on astronomy states:

> Astronomers have a vital role to play in contributing to the development of science education in the United States. Among scientists, astronomers make a

> disproportionately large contribution to the improvement of public science literacy relative to the comparatively small size of the astronomical community because of the broad appeal of astronomical concepts and ideas … each year 28 millions visits are made to planetariums in the United States. More than 200,000 college students take an astronomy course each year. Thus roughly 10% of all college students will take an astronomy course before they graduate, and for many of these astronomy will be the only science course they ever take. Astronomy is heavily covered by the media, has attracted millions of people on the web, and enjoys the support of hundreds of thousands of amateur astronomers (National Research Council 47-48).

Because children are interested in astronomy it can be a gateway into science, and society needs more scientists. Another recent US report on astronomy devotes a whole section on the role of astronomy in public science education. The report says that "Astronomy's most significant contribution to society lies in the area of science education, broadly conceived to include (1) raising public awareness of science, (2) conveying scientific concepts to students at all levels and to their teachers, and (3) contributing to educating a technically capable and aware citizenry. Astronomy is relevant to each of these goals, and it can act as a pathfinder in stimulating people's interest in all of science" (National Academy of Sciences 2001: 138-139).

Leaps in technology can give astronomers a boost in promoting their science, for example the printing press gave astronomers a new means to disseminate astronomical information, as did replacement of books by articles in journals as the main vehicle for dissemination of knowledge (Jaschek 268). The advent of mass circulation newspapers was a major boost for the promotion of astronomy to the mass public; even today the science sections of major newspapers such as the *Sydney Morning Herald* and *New York Times* frequently have articles about the latest astronomical discoveries. Improved astronomical technology (bigger, more powerful and sophisticated equipment), such as radio telescopes, gave astronomers new opportunities to promote their profession and discipline to the public. The Department of Science, Industry and Research (DSIR) presented Jodrell Bank

Radio Telescope as “the great public spectacle” of British science (Agar 268). Interestingly, this potential spectacle was not apparent in other key scientific projects in the 1950s, such as nuclear physics facilities at Harwell or CERN (Agar 268). More efficient means of communication, for example television and now the Internet, give astronomers more ammunition at their disposal to promote their discipline and profession.

Successful Popularisers

Some astronomers are able through their position and communication skills to popularise astronomy to the extent that they can reach a mass audience. I have picked three of the most successful in order to highlight the notion that astronomy can legitimise itself to the lay public through the mass media. It is important to note that here I examine selected leading lights in the profession; there are many others that contribute to the process. I hope that by examining the most prominent popularisers, some salient features of astronomy popularisation can be revealed. Through these salient features I attempt to show how these popularisers contribute to the legitimation of astronomy.

Carl Sagan

Without doubt, the best-known astronomy populariser is the late Carl Sagan (1934-1996). Before becoming a populariser, Sagan distinguished himself as a research scientist. He was involved in the successful Mariner, Pioneer, Voyager and Viking planetary missions, promoted the field of exo-biology, and was a passionate advocate of SETI (Search for Extraterrestrial Intelligence). In addition to his astronomical work, Sagan wrote influentially on the nuclear winter, the greenhouse effect and became a staunch defender of science and reason against creationism and ‘‘pseudoscience’’. He wrote a Pulitzer prize winning book, *The Dragons of Eden,* and a science fiction novel, *Contact*, which was made into a successful science fiction film. Sagan was also an anti nuclear weapons campaigner and environmentalist activist. Through his television series *Cosmos* Sagan attained the status of world superstar (Davidson 1999, Poundstone 1999).

Sagan’s story is relevant because he has succeeded on a scale far beyond anyone else in taking astronomy into the popular arena, and indeed making astronomy part of popular culture. According to one of my interviewees, Dr Van Gorton, “Carl Sagan did more for astronomy than anyone else [to legitimise astronomy]". *Cosmos* was the most successful science television science program ever and was watched by millions of people in many countries. In *Cosmos* Sagan uses astronomy as a flagship for science. His explicit aim is to use astronomy as a vehicle to promote science in general, to encourage young people to go into science as a profession, and even to advocate science as a mode of life. To Sagan, science is not just a body of knowledge or a method: it is a way of life.

Sagan's method of advocacy is to appeal to our sense of wonder: the same sense that makes science fiction popular. The link with science fiction is manifest in many recurrent scenes in the series, for example when Sagan is seen behind the controls of an imaginary interstellar spacecraft. Sagan invites us to share his sense of wonder and excitement as we follow his exploration of the universe: "Our feeblest contemplations of the Cosmos stir us — there is a tingling in the spine, a catch in the voice, a faint sensation" (Sagan 4).

The series' breadth was another plus, linking astronomy with other fields, not only within science but also with religion and philosophy. Social and political theory are also alluded to at the beginning of the series, when Sagan blames the fall of Ancient Greek civilisation on the fact that it was a slave society, and in the final episode when he asks "Who speaks for Earth?" he places astronomy on the side of the environment against those who would, because of their short-sightedness, destroy the Earth by a nuclear catastrophe. Such linkages capture audiences that a narrower approach would miss. Sagan showed where his viewers are located on the map of the Universe, and made it clear that astronomy was the means by which he was able to show them their location. The great achievement of *Cosmos* was that it located astronomy on the public's mental map of culture.

Sagan, in talking of *Cosmos*, asserts, "I was positive from my own experience that an enormous global interest exists in the exploration of the planets and in many kindred scientific topics — the origin of life, the Earth, and the Cosmos, the search for extraterrestrial intelligence, our connection with the Universe. And I was certain that this interest could be excited through that most powerful communications medium, television."

(Sagan 1980: xii). Sagan's biographer is well aware of the political role that the "superstar scientist" attaches to the popularisation of astronomy:

> He believes passionately that a broad public understanding of science is not merely useful, but absolutely necessary in the modern world so dominated by science and technology. Modern scientific research is notoriously expensive and much of it could not be carried out without public support. The public must be willing to pay, with tax dollars, for space probes of other planets or radio-telescope explorations of distant planets (Cohen 8).

In *Cosmos* Sagan turned astronomy's apparent lack of utility into an asset. Astronomy's image as pure science enabled Sagan to hold astronomy up as the exemplar of his noble vision of science as a moral good in itself. The message Sagan was propounding is the Popperian one that not only is science the only correct way to uncover knowledge about the world; it is also the most moral way. Indeed, Sagan asserts that it is a moral imperative that the populace know about and support science; such support is the only hope for humankind, for only science can save humankind from its reptilian evil side. Sagan gives potted examples from history to support his claim, such as his interpretation of Dutch exploration. According to Sagan, the Dutch economy and society benefited because the Dutch were more interested in knowledge than commerce when they went exploring, not for personal reward. In other words, science pursued for its own sake, that is, out of sheer curiosity and sense of wonder, will benefit humankind, and *only* this will benefit humankind. For Sagan, all other roads will lead to disaster. Sagan thought that teaching people *about* science and its place in the culture of modern society was as important as teaching the content of science. This philosophy came across strongly in Sagan's last work, *Demon Haunted World*, in which he defended science against creationists, ufologists, psychics, postmodernists, and other irrationalists. Luckily for Sagan and other astronomers, a large portion of the general public shares their curiosity about the universe. The popularisation process itself of course enhances this curiosity. However, as the philosopher Peirce notes:

> It is quite true that the Gnostic Instinct is the cause of all purely theoretical inquiry, and that every discovery of science is a gratification of curiosity. But it is not true that pure science is or can be successfully pursued for the sake of gratifying this instinct … Curiosity is their motive; but the gratification of curiosity is not their aim … man is not so happy as to be provided with a full stock of instincts to meet all occasions, and so is forced upon the adventurous business of reasoning … where … the few find, not old fashioned happiness, but success (Peirce, quoted in Habermas 1971: 133-134).

Whereas the satisfaction of curiosity may be enough for the public, the astronomer wants to satisfy his curiosity and achieve success, broadly defined, for example in terms of credibility with her or his peers.

Cosmos did not attempt to be objective or neutral with the issues it addressed. Its appeal was not primarily to the intellect, but like Stanley Kubrick's film *2001: A Space Odyssey, Cosmos* appealed to the psyche. The imparting of knowledge was subordinated to emotional music and images designed to impart a sense of wonder. The persuasive role of images in science has been studied in various contexts (Golinksi 146, 149, 157). In astronomy, images can be particularly spectacular, and in some cases uniquely stunning. Such images capture the imagination of large sections of the public, filling them with a sense of wonder. The persuasive use of images in astronomy has been documented in the nineteenth century (Golinski 157-161) and as far back as 1647 (Golinski 149).

According to one writer, the presentation of science in *Cosmos*, "Creates a mythic understanding of science which serves for television audiences the same needs that religious discourse has traditionally satisfied for church goers" (Lessl 175). By championing science through astronomy on *Cosmos* Sagan invited his audience to see astronomy as representative of all that is good in science. By presenting astronomy as the flagship of science and the scientific ethos, Sagan's *Cosmos* was both an advertisement for astronomy as a field, and for science in general. He presented the programs with a missionary zeal usually associated with religious evangelists. Like Spinoza, Sagan saw human kind as part of nature, and that there is no God apart from nature. This becomes clear in the second episode: "We are star stuff. We are a way for the Cosmos to know itself". This comes close to a religious metaphor. Astronomy as the archetypal 'pure science' gains legitimacy from this rhetoric, as it speaks to spiritual needs. Perhaps the ultimate irony of Sagan's popularisation is that he claimed to represent a rational form of legitimation, but in doing so relied heavily on charisma.

By the time *Cosmos* was broadcast, the paradigm shift away from scientific scepticism about popularisation had become so complete that no respectable scientist would publicly criticise Sagan for popularising astronomy (although some criticised the *science* in *Cosmos*). "Sagan says that none of his colleagues has ever come and directly told him that his popularisation of science was wrong" (Cohen 118). Sagan gives two reasons for this: "One, scientists don't do science for conventional rewards — salaries are not high. Scientists get a psychic and emotional satisfaction from doing it. The more people understand the emotional attraction of science, the happier scientists are. One scientist, after seeing an episode of 'Cosmos', said to me, 'Thank you. You've made me a hero to my kids'. That's the personal reason that scientists favour popularisation if it's done well" (Cohen 118). Popularisation thus perpetuates the notion of scientist as hero, even though, as Sagan admits, *Cosmos* was anything but a one man production — the *Cosmos* staff was about 150 people (Cohen 106). Sagan adds:

> The other reason is that science subsists on public funds, and if the public doesn't know what's happening it is not likely to continue to support it. Fundamental research is funded almost exclusively by the government. Yet the amount of money spent on science is a trivial fraction of our wealth. A lot of scientific research is the seed corn of the future; you can eat the corn and get through one more winter, but

> then you're dead the following year. I'm hoping Cosmos will make people realise the natural resonance they have with the scientific endeavour (Cohen 118).

Here Sagan makes explicit what most popularisers leave implicit, that astronomy cannot expect to justify itself only, or even mainly, on perceived utilitarian benefits. The popular imagination must be captured; there must be a linking of minds with at least sections of the populace.

Also implied throughout Sagan's popularisations, in particular *Cosmos*, is that science in general, and astronomy in particular, can contribute to the individual's self-actualisation, which in an individualist society is a cultural value that can help legitimise science (Abbott 186).

In Carl Sagan's *Cosmos* the gap between imagination and reason is reduced. The romantic idea of a science of the imagination assumes an empirical aspect. This scientific character of imagination is also recognised in mathematics and other aspects of scientific activity, but it performs a special function in the popularisation of astronomy: that of appealing to the sense of wonder in non-scientists. Sagan was also a passionate, active, and vocal supporter of SETI. SETI plays a role in popularisation because it allows astronomers to delve into ground that is popular with the public: aliens. Astronomy is uniquely placed to tap into these needs through SETI programs. But over and above promoting SETI, possibly Sagan's great contribution to the explanation and justification of astronomy through popularisation is conveying science in general and astronomy in particular as a search of meaning, rather than a means of attaining power over nature.

Paul Davies

Paul Davies was born in London in 1946 and obtained a doctorate from University College London in 1970. He is currently Professor of Natural Philosophy in the Australian Centre for Astrobiology at Macquarie University, Sydney. He has held academic appointments at Cambridge and London Universities, the University of Newcastle upon Tyne, the University of Adelaide and the University of Queensland, although he remains based in South Australia, where he runs a science, media and publishing consultancy called

Orion Productions. In addition to his research, Professor Davies is well known as an author, broadcaster and public lecturer. He has written over twenty-five books, both popular and specialist works. In 1995 Davies was awarded the Templeton Prize for progress in religion, the world's largest prize for intellectual endeavour.

Davies is one of the most prolific science popularisers in recent years. He is an appropriate writer to analyse in this context because, although he is first and foremost a physicist, much of his popularising work is about cosmology, and he has published one book about SETI. Through his discussions of the origin of the universe he uses and touches on the findings of modern astronomy, and thus helps to explain and justify the discipline to a wider audience. Through a host of popularisations such as *God and the New Physics, The Mind of God, Are We Alone?,* etc., Davies makes cosmology and modern physics capture the public imagination. As one of my interviewees, Charles ('Chuck') Hailey, said, "the pubic don't relate to quarks, but do to cosmology." Through cosmology, astronomy now appears to provide front-line troops for the popularisation of science. In so far as modern cosmology has an observational side, it is astronomy.

Some of Davies's later popularisations touch on religion. Cosmology, because its subject matter is the universe as a whole, is well placed as either a substitute for, or complement to, religion. Durkheim sums up the relationship very well. Writing of science in general Durkheim says:

> The essential ideas of scientific logic are of religious i.e. social origin … having left religion, science tends to substitute itself for this latter in all that which concerns the cognitive and intellectual functions (Durkheim 429).

These religious/spiritual connections are crucial in popularisations as they touch on the needs of lay people, who may not be interested in scientific details, but look to science to provide some meaning to their lives. Thus:

> The structure of space and time lies at the very foundation of both physical science and our perceptual experience of the world...so much of the subject matter discussed overlaps with domains of intellectual activity normally associated with metaphysics, than hard science. Yet today, science is on the brink of suggesting answers to many of the questions so long puzzling to theologians and philosophers alike. No account of these developments is complete therefore, without an examination of the place of humankind and human society in the new universe. The impact on society of changing ideas about space, time, and the nature of the cosmos has always been profound. The revolution now in progress could alter forever, not only humankind's perspective of the universe, but also of his or her own place in that universe (Davies 1977: vi).

Davies then makes a direct link between pure science and the need for meaning in the lives of non-scientists. This linkage is one way in the sense that its existence and agenda is derived from the point of view of the scientist, and is thus a manifestation of a power relationship But that is not to say that there is not real learning on the part of the lay audience. As Stuart Hall notes: "Culture is a broad site of learning, and perhaps we learn best and are most open to ideas when the barriers between the discipline and the academy and the experiences of everyday life are broken down" (quoted in McRobbie 66). The relationship is at once one of power and of learning. It is a classic example of what Foucault would call power/knowledge.

Davies's legitimations are not confined to making such links. In *Superforce* Davies touches on:

- Nationalism: "Doubtless there is a strong nationalistic flavour involved in all big science. As in the arts or sport, it's nice to win the prizes, and world acclaim" (98).
- Practical spin-offs: "valuable experience is gained in new technologies which can have important spin-off in other scientific enterprises" (98).

• Military science: "most branches of science are eventually exploited at some stage by military technology" (99).

Scientists should not feel compelled to defend basic research by appeal to spin-off (most especially of the military variety), historical analogy, or vague promises about miracle gadgets: "Physicists conduct their research primarily for its own sake, from a deep sense of curiosity about how the world is put together, and for a desire to know and understand nature in ever greater detail" (Davis 1984: 99). Thus society is invited to share the scientists' curiosity and to be willing to expend the required funds without any other justification. Modern theoretical physics, like a newborn baby, requires no outside legitimation: it is the Kantian ethic of moral laws devoid of utility applied to science, which is seen as an end, not only as a means; science is an end in itself.

In *God and the New Physics* Davies takes the connection to the non-scientist's needs a stage further, into the realm of meaning. Astronomy, especially via its sub-discipline of cosmology, is uniquely placed to fill the gap in meaning created by secularisation and disaffection with established religions. Davies is quick to see the opportunity and in *God and the New Physics* becomes an avid promoter of science as a meaning provider. He begins by assuring the reader that, "Science offers a surer path to God than religion" (Davies 1983: ix) and concludes, "Only by understanding the World in all its many aspects...will we come to understand ourselves and the meaning behind the universe, our home" (Davies 1983: 229). The selling point, not only for Davies but also for Cosmology and its associated disciplines, is to say to the public words to this effect: "Let us do basic science and we will find God (or at least help you find God), and give meaning to your life". Davies is thus appealing over the heads of government bureaucracies and funding agencies directly to the lay public, and there is a sense in which any agency that wants to cut funding will have to take on not only Davies, cosmologists and astronomers, but also the constituency that he has created, that is, his readers.

Like Sagan, Davies is aware of the importance of SETI in popularisation: "The interest in SETI among the general public stems in part … from the need to find a wider context for our lives other than this earthly existence provides. With the exception of the United States, which has seen a revival of religion, modern western societies have become more secular, and for many, conventional religion has lost its credibility. The belief in super-advanced aliens out the somewhere in the universe can provide some measure of comfort and inspiration for people whose lives may otherwise appear boring and futile" (Davies 1995: 136).

By linking science, philosophy and religion, Davies has tapped in to the truism in the adage 'Man does not live by bread alone'. Here the legitimation of science is the same as that commonly heard for the humanities: an appeal to a higher instinct in society, adding weight to Latour's view that the only essential difference between the natural sciences and social sciences and humanities is not one of method but one of resources (Latour and Woolgar 256-257, Latour 1983). In Bourdieu's terms, Davies has turned Cosmology into a form of symbolic capital, offering in effect this proposition**:** "Invest in Cosmology and we Cosmologists will help you find meaning". There is also a hint that Cosmology can lead to a liberating metaphysics, which can take humankind "Beyond the limits of the social" (Habermas 1975: 126). Cosmology can also offer the possibility of overcoming alienation through understanding the universe.

Writers such as Paul Davies become very much like TV evangelists, in the sense that they are giving the public what they want: appealing to the public's real need for hope of God and an afterlife, by saying in effect Cosmology has shown us that the Universe is too clever for it to have originated by chance. Here God can be an abstract, rather than a biblical God: "A communicative structure that forces men, on pain of a loss of their humanity, to go beyond their accidental, empirical nature to encounter one another *indirectly*, that is, across an objective something that they themselves are not" (Habermas 1975: 121). The fact that Stephen Hawking's interpretation of his own work and others leads him to dispense with the notion of God is irrelevant. As Deepak Chopra has shown, a wide range of meanings can be drawn from Hawking's text. There is no need for the cosmologist to always conclude that there is a God, though if there is at least one important and promoted figure (Paul Davies) who does say this, it certainly doesn't do the cause any harm. It is enough that cosmology can appeal to the public's desire for the answers to big questions, and to feel a part of something bigger, and to appeal to their sense of mystery. Black Holes, Quasars, and other bizarre phenomena also appeal to this sense of mystery.

To Hawking and Davies the Universe is rational, and they are at the apex of the evolutionary journey that leads them to ask the question: 'What is the meaning of the universe?' Their view of evolution is Hegelian, with themselves being the culmination of human reason able to unravel the mysteries of the universe. The Hegelian notion of 'Absolute Mind' is also useful here. In *The Phenomenology of Spirit* Hegel sees religion, art and scientific knowledge as three forms of absolute mind. Astronomy popularisation brings together science, art (via images) and spirituality (via cosmology).

Sir Patrick Moore

Popularisation is also enhanced by characterisation. As the case of Sagan has shown, charismatic authority can help legitimate astronomy. In Britain, years before Sagan became famous, astronomy had a populariser who, while having a broad knowledge of astronomy, went beyond mere science and became a cultural icon.

For over forty years, Patrick Moore has been the most well known populariser of astronomy in Britain. *The Sky at Night*, Moore's regular monthly astronomy program on the British Broadcasting Corporation television station (BBC), began in April 1957 and is still being shown, making it the longest running television series in British television history. Moore was born in 1923, and at time of writing (August 2003) he is still presenting the program! Privately educated because of his poor health, Moore became interested in astronomy as a hobby. In the early 1950s his talent for communication inspired him to become a freelance author. Despite his 'amateur' status, from 1965 to 1968 he was Director of the Armagh Planetarium in Northern Ireland. Moore was awarded the OBE in 1968 and the Royal Astronomical Society's Jackson-Gwilt Medal in 1977. He is a prolific writer and his books now total over 60. Moore has also been active in cricket, chess and music, playing the xylophone and composing operas (Abbott 114). He has also been active in conservative politics, was a member of the now defunct United Country Party, and is now a member of the right wing Freedom Association, as well as the anti European Union United Kingdom Independence Party.

As the BBC *Sky at Night* website notes: “Partly thanks to his larger-than-life personality, bachelor Patrick’s own fame extends far beyond astronomical circles” (British Broadcasting Corporation 2003). In Britain Patrick Moore is as famous for his eccentricity as he is for his knowledge of astronomy, and over the years has appeared as a celebrity on many TV and radio shows which have nothing to do with astronomy or science. He has appeared on television and radio programs ranging from topical discussion programs to game shows. Moore’s position is unusual, for he is self-taught and in the amateur tradition, both in terms of his background and in terms of his own amateur work; apart from a period in which he was director of the planetarium of the observatory in Armagh in Northern Ireland, he has never been employed in a full time capacity by any particular observatory. His specialty is the Moon, and he has been involved in activities associated with amateur astronomy such as comet hunting. He has not been involved in activities normally associated with professional astronomy, such as using large telescopes to do extra-galactic work.

What makes Moore unique amongst astronomy popularisers is that he has managed to retain the image and approach of the enthusiastic amateur. Apart from the stint as Director of Armagh Observatory, Moore has never been employed as a professional astronomer, but is admired and respected within the professional astronomical community. As a celebrity and popular communicator, he has positive contact with professional astronomers; he thus sits astride professional and amateur astronomy. Moore plays on his eccentric image, characterised by untidy hair and fast, high-pitched speech, and has over the years become something of a British institution. Moore helps to legitimate the profession by providing a supportive and moral link between it and the amateur community, and by taking the discipline into the popular and mass media, and making it part of British popular television culture.

In conclusion, popularisers now play a key role in the legitimation of astronomy. Using communication skills, use of the media, and charisma, they are able to sustain and enhance the public profile of astronomy. Popularisers create links that locate astronomy in a web of institutions that are the part of what a Marxist would call the ‘ideological superstructure’ of society. Sagan makes connections between astronomy and science in general, Davies with philosophy and religion, Moore with amateur astronomy and British popular culture. These linkages locate astronomy with other institutions already legitimised. Astronomy is therefore seen as a natural part of society.

A Study in Failure: The Early Promotion of the Hubble Space Telescope

It is relevant to include an example of the failure of popular legitimation because legitimation practices are exposed when they fail. The example of the early failure of the popularisation of the Hubble Space Telescope highlights the lengths to which astronomers and their lobbyists will go to promote their discipline. The weaknesses of the discipline are also highlighted. It is at such a time when the contract between astronomy and society might become broken, or at least strained. It is only in such times that the funding of astronomy (or some aspect of it) is called into question. Under normal circumstances it is unquestioned by the media or the public. When a reason for non-acceptance is made apparent, then the justification for acceptance is by implication stated also. An identification of the circumstances that strain the support of the media and the public will suggest in what other circumstances that acceptance and support can be maintained and even strengthened. For it is in such times that astronomers are forced to justify what they do. Acceptance of astronomy funding may for most people be a matter of habit, but the character of the habit will be most easily viewed when broken. Given that large amounts of funding take place, successful explanation and justification is the norm. Legitimacy is thus more often sustained than created. Once damaged, however, legitimacy must be created again. Cases such as those of the Hubble Space Telescope are rare in astronomy, because astronomers usually make the news only when they have made a discovery, not when they have failed. In the case of large, high profile projects in astronomy, big science and popularisation come together. Big, expensive projects have to be justified to the public.

From the time of its launch, NASA’s propaganda machine went overboard, using the telescope to promote itself as an organization. NASA used a shuttle to launch the telescope, when such a launch could just as well have accomplished by an unmanned vehicle (Chaisson 13). Second, NASA's overconfidence didn't allow room for possible escape routes when the device had problems (Chaisson 13). NASA also failed to give the mission a historical perspective and in press announcements ignored the contribution on non-NASA individuals (Chaisson 15). Moreover, from the beginning, NASA exaggerated the possible capabilities of Space Telescope to the point of fostering myths. For example they claimed that space telescope would be able to see appreciably further into the universe than existing ground telescopes. But actually the Hubble telescope could not see appreciably farther. Rather it enables astronomers to see *more* because of its resolution and sensitivity**.** That is to say, it has more clarity of seeing, sharpness of vision, and can therefore perceive finer details on celestial objects than can ground based telescopes. This is not because of its size but because of its location; ground based telescopes must observe the universe through Earth's murky atmosphere. Hubble's ability to distinguish between two adjacent sources of light, is, according to one astronomer, the single most important scientific justification for the Space Telescope (Chaisson 30).

NASA administrators insisted on distancing the organization from both the public and astronomers who were the telescope's end users. NASA press conferences were characterised by technical jargon incomprehensible to the layman. The editor of *Sky and Telescope* commented: "NASA's image suffers because it sends before the public scientists and engineers who are not skilled at communication. These people often appear either as arrogant, boring parodies of Dr. Strangelove or as talking potatoes" (Chaisson 199). Its exaggerated claims for the telescope around the time of launch caused it severe public relations problems when several technical problems, notably but not only, the aberration on the main mirror, caused the telescope to function below expectations. By the time these problems became apparent, NASA had already alienated a large section of its end users, and became more concerned with controlling what they said to the public rather than sharing the problems with the public.

The early hype of the telescope left NASA no room to manoeuvre when things went wrong. The result was that the organisation lost credibility with the scientific community and the public, who were reading critical comments about the telescope by an increasingly cynical media (Chaisson 127, 130). According to Chaisson, the astronomers themselves were torn between being honest about the telescope's inadequacies and their loyalty to, or in some cases fear of, NASA. Their typical compromise was summarised by Chaisson as "When pressed, resort to technical truth" (Chaisson 132). In contrast, a high NASA official, when instructing astronomers on how to deal with the media concerning 'first light' images, told them to, "Give the media as little as possible" (Chaisson 132). When the 'first light' images were finally processed, NASA insisted on sending the press poor quality images processed by their own personnel at Goddard, rather than waiting for higher quality ones produced by the astronomers' own Science Institute. The result was that Canadian and European newspapers got better images than the American newspapers, as the Science Institute felt free to send them (Chaisson 134). The *Baltimore Sun* commented on the images: "They looked as though they had been taken by a chimp and developed at Fotomat" (Chaisson 145). NASA's insistence on taking sole credit for Hubble achievements backfired when things went wrong; it was then assigned responsibility for failure.

NASA's problems were not only caused by bad handling of promotion and public relations. The original mirror problem was partly the fault of the Perkin-Elmer (now Hughes-Danbury) Company, which ground the mirror, but also partly the fault of NASA quality control, which did not thoroughly check the grinding (Chaisson 155). Moreover, NASA had no backup plan for when things went wrong, with the result that its first attempts to analyse the problem were incompetent and fruitless (Chaisson 163). Its first instinct was to publicly deny there was a problem: "At this time the telescope's systems are healthy, in proper working order, with only occasional, minor anomalies to report" (Chaisson 164). This was consistent with its response to the astronomer who first communicated to NASA that there was a serious problem with the mirror (Chaisson 168).

No amount of spin could avoid the eventual admission to the media and the public that the main mirror of Hubble was suffering from a major optical flaw, and once it had run out of spin, it fell silent, making no public announcements.

NASA also gagged its employees and astronomers from talking to the media, and ordered at least one astronomer not to mention Hubble's problems to an educational outreach program for teachers, this after an irrefutable case had been made that the main mirror was suffering from spherical aberration (Chaisson 170-171). The result was that the press went wild, attacking NASA and exaggerating the mirror's deficiencies (Chaisson 169). Ironically, NASA's earlier obsession with control of the project ultimately caused it to completely lose control of events. NASA was hoist on its own petard. NASA's incompetent handling of the media had a knock on effect. Astronomers involved in the Hubble project were tainted to the extent that a Hubble astronomer due to speak not about Hubble but about education to a Governors' conference was disinvited (Chaisson 193). The Hubble mirror fiasco also affected other projects such as AXAF (Advanced X-ray Astrophysics Facility), funding for which was held up by its perceived similarity to Hubble (Tucker and Tucker 93). In order to justify their project, the AXAF astronomers had to distance it from and differentiate it from Hubble (Tucker and Tucker 101).

The failure of NASA's early promotion of the Hubble Space Telescope also highlights the connection between popularisation and education. In my interviews, when I asked about popularisation, several interviewees substituted the word 'education', and one explicitly repudiated the word 'popularisation' for 'education'. For example interviewee David Helfrand asserted, "We educate, not promote". When astronomers observed how NASA handled communication to the public via the media about the Hubble mirror problem, the disjunction between popularisation and education brought about by NASA's approach became apparent:

> I am not a detractor of NASA science and am firmly behind their unmanned program. Their weakness lies in public relations, unconsciously structured to titillate and to perpetuate scientific illiteracy. Every new space venture is labelled in terms of superlatives; either it is the first, the greatest, the most important, the longest, or the most significant. There must always be a gimmick. There is seldom a word about complexity or subtlety. In pampering the media with sound bites we are

> all done a disservice. NASA happens to do expensive science and not every mission has to be the first or the greatest. Above all, the goals are usually far more complex than can be effectively communicated in thirty seconds or in a few paragraphs. Most of the research can only be understood in a broader context, one that involves an overview of the work of thousands of ground-based planetary scientists, astronomers, atmospheric physicists, geophysicists, and biologists around the world. Let us raise the level of scientific literacy in our nation so that we will no longer have to resort to shoddy sales techniques in order to find support for that exciting adventure of the collective human spirit, the scientific search for knowledge (Gerrit Verschuur, quoted in Chaissson 203).

To Verschuur, like my interviewees, popularisation is a form of education. By such a conflation astronomers can legitimate (explain and justify) the popularisation of their science by aligning it with the generic justifications for scientific education and indeed education in general. Thus if one opposes allocating resources to astronomy one is opposing allocating resources to education. Astronomy is thus aligned with the fundamental value of an educated public.

But the link between popularisation and education can be used to distort what actually happens. NASA's 'fact sheet' — a supposedly educational document, produced by their Public Affairs Office when the mirror problem broke — highlights the complex relationship between popularisation and education:

> The activation and fine tuning of the telescope's onboard instruments, called 'orbital verification', proceeded well, with only a few minor problems arising … What was supposed to be a simple engineering test turned out to be a pleasant surprise for scientists … a 'pure' spherical aberration, a problem relatively easy to correct much like the way an eye doctor corrects poor vision with spectacles (Chaisson 209).

The above Orwellian doublespeak is an attempt to use language to turn a disaster into a 'pleasant surprise.' It attempts to save NASA's popularity by 'educating' the public. Education and popularisation can thus be used negatively to distort situations and feed the public with disinformation. Compounding the deception of the press and public, Chief NASA scientist Leonard Fisk called the aberration 'a minor inconvenience'. In contrast, Roger Angel, an astronomer and optical expert, called the aberration, "the largest single mistake that's been made in optics" (Chaisson 227). According to Chaisson, "NASA management had clearly not learned the lesson taught by the great physicist Richard Feynman who, as a member of the Challenger Investigative Board, has aptly put it: 'Reality must take precedence over public relations. Nature cannot be fooled'" (Chaisson 253).

Chaisson links popularisation, education, and organisational support. In a memo written for the NASA hierarchy at the height of the Hubble mirror problem, Chaisson urged NASA to put images into the public domain as soon as possible. This would cause "children to consider careers in science and engineering, as well as to share with our colleague astronomers the results of the Hubble science mission and thus win back the support of the university scientific community" (Chaisson 214). Clearly, to Chaisson, popularisation, education and peer support are not only not in conflict but complement each other. But he says the boundaries between actually doing science and the popularisation of science must be maintained. Chaisson talks of "the need to harness those zealously in search of media-feeding discoveries" and proposes an editorial review board "to guarantee the validity of new science results emanating from *Hubble*, lest we fall potential prey to a cold-fusion scenario and begin doing science at press conferences rather than among peers" (Chaisson 252-253).

Hubble astronomers disagreed amongst themselves as to when to make images public to the extent that conflicting accounts of scientific progress and image quality were given to the press. Chaisson and others wanted to get images out as soon as possible, arguing that this would take the heat off of the project in the sense of convincing the public that the mirror problem had not negated the possibility of doing quality astronomical work. Others thought it better to wait until the mirror problem was fixed before allowing images into the public domain. The irreconcilable differences between these two groups caused yet another public relations disaster. As Chaisson's group arranged to have images made available to the public another Hubble astronomer contacted the *San Jose Mercury*, and gave an interview to a hostile journalist ridiculing the decision to make images available immediately, saying it was a public relations stunt, and implied that the images were of poor quality. The result was that the new images were greeted with scepticism by the media. The images were published in few newspapers, although the international astronomical community showed growing excitement about them (Chaisson 268-269). Thus division as to what constituted appropriate science for the media meant that the media got two conflicting stories from astronomers about Hubble. Lacking expertise to decide for themselves, the media erred on the side of caution and took a sceptical approach.

While the astronomers were fighting amongst themselves, NASA, adopting a crisis management approach, had switched the management of the telescope from a team at Huntsville, Alabama, to a team at the Goddard Space Centre in Maryland. But the new team proved just as conservative and paranoid as the old team. When Chaisson asked them for permission to let journalists see the first spectrograph recordings from Hubble, the response was: "No, no, the press has no business there. Keep them out. Your OSS area remains off limits to the media" (Chaisson 304-305). The new management's conservatism was further highlighted when one of the world's most eminent astronomers, Margaret Burbridge, visited the Hubble Science Institute and praised the inaugural observation. NASA could have exploited this vote of confidence, but instead 'the bastion of male conservatism' sent out a botched press release, without consulting the Science Institute (Chaisson 315). Journalists were confused and the telescope was again ridiculed. Like the previous management team, the Goddard group released an 'educational' document wrongly claiming that Hubble could see many times farther into the Universe than any other telescope (Chaisson 344). When the leader of the Science Institute, Riccardo Giacconi, challenged this document, the Goddard group filed a grievance against him and said that the Institute was part of Hubble's problem, because it issued media and educational announcements that were full of 'elitist science' (Chaisson 344).

The case of the early popularisation of the Hubble Space Telescope illuminates two aspects of popularisation, one negative, one positive. The first and most obvious is that popularisation, when badly done, can backfire, delegitimising astronomy, even when, as in this case, astronomers themselves are not to blame. NASA's hype and dishonesty negatively affected astronomers both in terms of morale and in terms of public perception. But even in this failure, we see that the efforts of some of the Hubble astronomers to conflate popularisation with education point to a powerful strategy by which popularisation can contribute to legitimation. My interviewees also used this conflation of popularisation with education. Finally, the recent US national report on astronomy affirms the centrality of astronomy's unique role in "education and public outreach" (National Research Council 15).

The Role of Trust in the Popularisation of Astronomy

As the case of the early popularisation of the Hubble Space Telescope shows, legitimacy broke down when the media ceased to believe NASA's propaganda about the telescope. Conversely, when Sagan, Davies, Hawking and Moore pontificate on matters astronomical, they have authority based on trust; the public, not having the expertise to challenge what they say, must trust that what they say is the truth. This highlights the importance of trust in popularisation. In fact trust is crucial if popularisation is to legitimate astronomy. As Polany notes, the transmission of social lore and intellectual artefacts can only take place when popular audiences place an exceptional degree of confidence in distinguished features or famous writers (Polanyi 1958: 207).

At a general level, it appears that the popularisation of science in the mass media does work, if success is measured by the support the public gives to science. A Canadian study found that scientific literacy was positively correlated with attitudes of trust and feelings of efficacy towards science, and the results were explained in terms of potential positive exposure to science in general not only in formal science training in the education system but also to informal information sources such as the media (Einsiedel 1994). Every time there is an article in a newspaper or magazine, every time there is a television documentary about some aspect of astronomy, this can said to be an advertisement for the profession, and therefore, a form of legitimation. In each case the audience are passive recipients of information, and simply trust the authority (legitimate domination) of the imparter of information; the popularisee must suspend scepticism and put trust in the authority of the populariser. Such public hawking of their wares, far from weakening the monopoly over knowledge of scientists and professionals, can actually increase it. When discoveries are broadcast in the popular media little is said about science in the making; the focus is usually on the discovery itself. Moreover, because of the central role of higher mathematics in astronomy, astronomers are particularly immune from losing their monopoly over knowledge production and dissemination.

There is a sense in which astronomers are their own market, but the need for popularisation means that astronomers, in addition to their peers, have a market for their product outside of the astronomical community. Like the consulting professions, astronomers have a lay open market. More precisely, while many astronomers are content to do research and have their peers as their market, other astronomers do outreach work and communicate their findings to the lay public. My respondents generally thought that it is only necessary for *some* astronomers to do what they termed 'education'. They are right. For popularisation to work, it is only necessary for some astronomers to engage in it, not the whole profession. Popularisation activities can take many forms, the most novel of which is the emergence of an astrotourism movement, with astronomers opening up Bed & Breakfast observatories (Ferris 59).

The importance of trust in science has nowhere been more forcefully made than by Shapin in his study of the emergence of English science in the late seventeenth century. Traditionally, legitimate knowledge has been defined by the *lack* of trust. If we say that we know something on the basis of trust, this is understood as meaning that we have no legitimate knowledge. Trust and personal authority stand against traditional notions of legitimate authoritative knowledge (science). Even today, many still accept John Locke's assertion that "In the sciences, every one has so much as he really knows and comprehends. What he believes only, and takes upon trust, are but shreds." (Locke 115). Shapin proceeds to make a powerful logical argument as to why in almost every case, perhaps all cases, knowledge is based on trust; "Distrust is something which takes place on the *margins* of trusted systems" (Shapin 17). Polanyi had earlier made a similar point when he asserted: "A system of scientific facts and standards can be said to exist only to the extent to which each scientist trusts all the others" (Polanyi 1958: 375). Thus trust is necessary within the scientific community as well as between the scientific and non-scientific community. According to Polanyi, only when there is such trust can science "Survive as a coherent system of superior knowledge, upheld by people mutually recognizing each other as scientists, and acknowledged by modern society as its guide" (Polanyi 1958: 375). Golinski makes a similar point: "Scientists do not always challenge other experimenters' claims because, most of the time, they repose trust in the competence of their colleagues. The social links that bind scientific subcultures together are essential conditions for the production of consensually accepted knowledge (just as, in Kuhn's analysis, relations of authority are basic to normal science). Most scientists, most of the time, live their lives within a supporting matrix of trust" (Golinski 29).

When the layperson (non-professional astronomer) reads about the discovery of planets around nearby stars and passes on this information, he or she is deemed to have real knowledge of the discovery on the basis of source and authority (legitimate domination of the field of knowledge), even though the layperson was not privy to the discovery. This point of course is also applicable not only to non-astronomer scientists but even to other astronomers who have not personally detected the new planet. No astronomer knows all of astronomical knowledge as an individual; most astronomical knowledge they have comes second hand. In fact it even applies to the astronomers who make the discovery, for they trust that the equipment they use is made so as to perform its appointed tasks effectively. Theoretically they trust (assume correct) the authority (legitimacy) of a host of previous theories. If we see a new discovery as a roof, then this roof is on a house, already standing, built of previous discoveries, theories and assumptions about equipment. Alternatively, we could use Shapin's analogy of a tree: "A piece of suggestive, if disputable, etymology links the English words *trust* and *truth* through a Germanic word for 'tree' — as firm and straight as a tree. Trust/truth is therefore, like a tree, something to be relied upon, something that is durable, which resists and will support you. Without that durable thing to lean on, you could not do anything." (Shapin 19-20).

In the case of popularisation, the point has even more force, for in most cases lack of access to equipment and lack of expertise will prevent most laypersons from personally directly accessing newly discovered phenomena. The average layperson interested in astronomy is several social steps away from directly witnessing new celestial phenomena; they are several steps removed from the event of the discovery. Moreover, the popularisee does not deliberately weigh testimony. He or she merely believes the populariser. Popularisation is based on trust. Trust itself implies cooperation, which in turn implies a moral bond. As Shapin notes, "The epistemological paradox [of trust and scientific knowledge] can be repaired only by removing solitary knowers from the centre of knowledge making scenes and replacing them with a moral economy" (Shapin 27).

Laypersons assume that professional astronomers have relevant skills, or what Shapin calls "perceptual competence" (Shapin 75)**,** not possessed by the layperson. It is this perceptual competence that authorises astronomers to categorise ufologists as prone to undisciplined or inaccurate perceptions, or even of being delusional. Shapin, in tracing the origins of our modern notion of *scientist* to the English gentlemen of the seventeenth century, notes that the testimony of common people was often thought of as being unreliable as compared to that of the English gentleman (Shapin 78). Testimony is reliable or unreliable, depending on the knowledgeability of those who provide it (Shapin 262). Similarly, the reliable scepticism of the modern astronomer is to be believed against the unreliable testimony of laypersons who witness UFOs. The relationship between astronomy popularisers and their public is the continuation of a tradition dating back to at least the seventeenth century, when scientists were aristocratic gentlemen. Secord, in his study of Victorian popularisation, writes of "the observational triumphs of *aristocratic* astronomy" (Secord 467). Shapin's remark that scientists do not reject but manage trust (Shapin 195) applies just as much to modern astronomers as to seventeenth century English gentlemen scientists. Thus astronomical legitimation has its roots in pre-capitalist legitimations of inequality, which are reflected in the ideal of gentlemanly disinterestedness. This is related to the notion of *noblesse noblige*, which embodied the nobility's ideological aversion to commercial pursuits and its belief, anchored in a religious view of the world, that high rank imposes duties as well as conferring rights.

Popularisation and Inequality

Popularisation is based upon an unequal relationship between the knower and the ignorant. In logical terms, popularisation is generally formal (linear) rather than interactive (two-way). But this is not enough. The ignorant must have a desire to know, a desire to be 'enlightened'. In Bensaude's words, popularisation "invents a public defined in relation to science rather than in relation to itself" and can be traced to the beginning of the Enlightenment in France. When these factors are present, popularisation can perform the function of legitimating the existence, status and profession of the knowers, who take the form of an elite, in Pareto's sense of the term, that is, a superior social group (Pareto 1423-1424). Indeed, it could be argued that the one-way popularisation of astronomy is a continuation of the scientisation of the public sphere, and that this scientisation is part of a general tendency that empowers experts and excludes citizens, thus bringing a decline of civic discourse. The actual practice of professional astronomy negates the modernist notion that science in principle is universally available to everyone. Paradoxically, the scientific cultural elite depend more and more on the material support given by the mass of non-creative citizens (Polanyi 1958: 220).

Pareto was concerned to highlight the inevitability of inequality in all human societies, but we do not have to agree with Pareto's rationale in using the concept in order to see its usefulness in understanding the relationship which popularisation both depends upon and sustains. Popularisation depends upon astronomers being an elite in relation to the masses; they must be seen to be superior in knowledge. Popularisation is thus dependent upon and sustains *inequality* between scientists and the masses. This view contradicts the received view that popularisation closes the gap between scientists and lay people; on the contrary, it can maintain and increase that gap. For what the public is usually getting in popularisation is not actual science, not 'science in the making' as Latour would put it, but the results of science in an idealised form, or 'science ready made'.

For popularisation to succeed in its task of explaining and justifying science, it is not even necessary for non-scientists to actually learn anything. As Huxley told John Tyndal: "What they want, and what you have, are clear powers of exposition — so clear that people may think they understand even if they don't. That is the secret of Faraday's success, for not a tythe of the people who go to hear him really understand him" (quoted in Gieryn 1999: 41). I have acquaintances who have bought and read *A Brief History of Time* and who have admitted to me that they do not understand it. Many others have bought but not read the book. They remain, however, in awe of Stephen Hawking.

The notion that astronomers who have access to genuine astronomical knowledge simplify that knowledge in order that laypersons can understand it is a useful political tool. Popularisation implies that genuine astronomical knowledge belongs to a realm that cannot be accessed by the general public, but is the excusive reserve of astronomers. Hilgartner makes a similar point: "the dominant view sets aside genuine scientific knowledge as belonging to a realm that cannot be accessed by the public, but is the exclusive preserve of scientists. It thus buttresses the epistemic authority of scientists against challengers by outsiders" (Hilgartner 1990: 530). Hilgartner continues: "most fundamentally, the dominant view shores up the epistemic hierarchy which ranks scientists above such actors as policy makers, journalists, technical practitioners historians and sociologists of science, and the public" (Hilgartner 1990: 533-534).

When astronomy becomes popular culture the discourse is very much one-way. The knower, the astronomer, imparts knowledge to passive recipient *knowees*. The *knowee* cannot respond directly to the *knower's* impartation of knowledge, but has to accept the *knower's* word on faith. The *knowee* is not an active participating equal but a passive consumption unit. On the other hand, to be sure, the *knowee* is participating in a culture, merely by reading an article or watching a television program about astronomy. This participation however, is strictly limited. The situation is accurately described by political sociologists Almond and Verba:

> If elites are to be powerful and make authoritative decisions, then the involvement, activity and influence of the ordinary man must be limited. The ordinary citizen must turn power over to elites and let them rule. The need for elite power requires that the ordinary citizen be relatively passive, uninvolved, and deferential to elites. Thus the democratic citizen is called on to pursue contradictory goals; he must be active, yet passive, involved, yet not too involved, influential, yet deferential (Almond and Verba 478-479).

In contrast to amateur astronomy, the promotion of professional astronomy takes place without the input of laypersons. In this context astronomers are seen as the ultimate embodiment of rationality. The reason for the *knowee's* dependence on, and therefore inequality with, the knower is that the knower is considered to have access to objective reality and therefore to have objective knowledge. The relationship between the knower and *knowee* is one of authority and deference. The *knowee* is therefore a slave to the objective order of things. The *knower* has legitimate domination of the field of knowledge to which the *knowee* aspires.

Another way of putting this is to use Habermas's notions of communicative and instrumental reason (Habermas 1984). Communicative reason derives from the notion of practical reason, as used by Aristotle and Kant. Practical or communicative reason is concerned with the ends of human action and is worked out in rational discourse (logos) between free citizens in the public or political sphere (polis). In contrast, modern instrumental reason does not communicate through dialogue with others and debate about the ends of life — it simply tells you what to do, or uses manipulation and/or force. Popularisation is instrumental rather than communicative reason. It is largely one way, and the popularisee is largely passive. He or she rarely gets the chance to communicate with the populariser, and when he or she does, it is not as an equal but under terms and agendas set by the populariser. Thus popularisation, far from promoting equality by spreading knowledge, can be seen as promoting inequality by ideologically legitimating inequality.

Socio-Cultural Aspects of Astronomy Popularisation

In popularising, the astronomer tries to communicate directly and authentically the thrill of discovery, but attempts to translate the mathematics into ordinary language. If the astronomer is successful, the result is a mutual intersubjective understanding that binds populariser and popularisee in a kind of community, if not of thought, then at least of language. The astronomy populariser is like an anthropologist attempting to make a foreign culture understood by her own culture.

The astronomy populariser, like a job applicant trying to convince a potential employer of her employability, attempts to make links between the field's special attributes and the needs (both real and encouraged) of the general public. The individual's need for meaning, previously more often than not sought in religious experience, is now, some writers argue, to be found in cosmology. Thus astronomy, via cosmology, is indeed uniquely placed to succeed in promoting itself over the heads of government directly to the needs of the public. Astronomy becomes 'big science' in the philosophical sense, as well as in the economic sense. The philosophical and economic conditions feed off each other. Astronomy, perhaps more than any other science, involves mystery: it is clear to the interested public that they are exploring the unknown. My interviewees shared this view; the locus of their legitimation was aesthetic and humanistic, rather than mechanistic and utilitarian. Some viewed their work as a mythic narration of society and cosmos, quite contrary to the old-fashioned positivist defenders of science who would have argued that it is not the job of the scientist to deal with the nature of truth or the meaning of the universe. To them, science is not limited to 'facts'. If science is not so limited there is no need for citizens to look elsewhere (for example poetry, philosophy, religion) to the answers to these larger questions. Astronomy has thus legitimised itself by encroaching into other areas.

Astronomy, especially cosmology, is at the forefront in attempting to answer utterly fundamental questions about our place in the universe. Brown puts such popularisations at the very centre of legitimation of contemporary science: "Think of the enthusiasm engendered by myths of the beginning and end of the universe arising from popular cosmology, and publicised in best-selling books and popular media productions" (Brown 541). Myth here is obviously not used in a derogatory sense, but in the sense of providing social narratives that have meaning. These myths, according to Brown, "Serve to communicate with popular culture, by informing the laity about science" (Brown 541).

A common legitimation tactic used by astronomy popularisers to seduce the lay public is to establish astronomy as part of a *high culture.* Thus, Fred Hoyle begins, "Man's claim to have progressed far beyond his fellow animals must be supported not by his search for food, warmth and shelter (however ingeniously conducted) but by his penetration into the very fabric of the Universe. It is in the world of ideas and in the relation of his brain to the Universe itself that the superiority of man lies. The rise of man may justly be described as an adventure of ideas" (Hoyle 1). Hoyle, like John Tyndall in the nineteenth century, promotes science as a "means of culture" (Gieryn 1999: 53). Like philosophy, art and literature, astronomy should be supported precisely because is it above instrumental action. However, as the case of Patrick Moore shows, astronomy can also be popularised by making it part of *popular culture*.

The need to build alliances with laypersons is not only analogous to a political alliance; it *is* a form of political alliance. Like politicians, popularisers flatter their potential constituents. Talking of *Cosmos*, Sagan writes: "It is dedicated to the proposition that the public is far more intelligent than it has been given credit for." (Sagan 1980: xiii). Popularisers intend the public to move from passive to active acceptance of astronomy funding, or to use David Held's phrase, "ideal normative agreement". That is to say with all possible information, it is what ought to be done (Held 301-2).

Latour's notion of the alliance between objects of study and scientists is useful here. (Latour 1987: 86-91). In popularising astronomy, the astronomer presents celestial phenomena to the lay public and says 'for your edification'. The astronomer becomes a salesperson for the celestial phenomena. The popularisation process is thus not totally social; it could not take place without the astronomer having something to promote to her audience. When a reporter asked Sir James Jeans how he would describe himself, he said, "I am a publicity man for the planets." (Moore 1984: 64). In popularisation then, astronomers work with their allies, celestial phenomena, to forge an alliance with as much of humanity as possible, certainly with enough sections of it to help them to promote and maintain the hegemony of the notion of pure science as high culture. In this case, high culture is not in conflict with popular culture; on the contrary, they are synonymous. Even NASA is not beneath using titles from popular science fiction television shows as chapter headings for one of its publications (Butrica 2003).

Conclusion

When popularising astronomy, astronomers are promoting their arena of study as a science, and are emphasising the contrast between its scientificity and adjacent 'pseudosciences' such as astrology and ufology. In popular culture, ufology sides with the believers that UFOs are alien spacecraft. In contrast professional astronomy regards its scientific scepticism as a higher form of culture that gives it a greater understanding of reality. Several of my astronomer interviewees expressed concern about the lack of public understanding of science, but left it unclear as to what exactly they meant by 'understanding' in this context. At the same time prominent astronomy popularisers see their expertise in astronomy and knowledge of cosmology as giving them the right to make authoritative comments on non-astronomical matters. This leap from being specific intellectuals — 'mere' astronomers — to being universal intellectuals seems to be a significant factor in the popularisation and legitimacy of modern astronomy. It is a drastic example of what Mulkay calls "intellectual mobility" (Mulkay 1972: 53). The astronomer as populariser cannot be seen merely as a competent technician. The typical astronomy populariser is a writer, a personality, a Renaissance man. Indeed, some of the most successful popularisers cut across disciplinary lines, writing not only in other scientific areas but also science fiction. Examples par excellence of this are Arthur C. Clarke and Isaac Asimov. Carl Sagan wrote one science fiction novel. Patrick Moore has written several science fiction novels for young people, and Fred Hoyle wrote some science fiction novels, such as *The Black Cloud*, and two television serials *A For Andromeda*, and a sequel, *The Andromeda Breakthrough*, both of which were then turned into novels. But some popularisers go beyond even this. Sagan, Davies and Hawking have attempted to take on the role of philosopher to whom the layman can to turn for profound utterances on the basic questions of life. Astronomy and its related disciplines are ideally placed to make full use of the political advantages of promoting certain of their more prominent individuals as universal intellectuals. Voltaire is the prototype of such intellectuals: a man of ethics and wisdom to whom the people could turn to for advice on important and fundamental questions: a man of justice, of law, who fights despotism and abuses of power.

Intellectual heroes can be a powerful tool in enhancing the prestige of astronomy. The University of Adelaide turned Paul Davies into a public Renaissance man when they created for him the Chair of Natural Philosophy. Davies then began to appear on Australian television pronouncing on philosophical and even sociological matters, such as being part of a panel of 'prominent citizens' on an ABC (Australian Broadcasting Corporation) discussion about the future of Australia. The fact that is so all encompassing and borders on philosophy has implications for the authority (legitimate domination of knowledge) of science in general. The popularisation of cosmological findings supports Habermas's claim that: "The authority of science can thus encompass both the broadly effective critique of arbitrary structures of prejudice and the new esoterics of specialised knowledge and judgement" (Habermas 1975: 84). Astronomers like Sagan and Moore and cosmologists such as Davies are able to use the their authority (legitimate domination of knowledge) to gain access to mass media and pronounce on matters other than science. These skilled popularisers use a combination of all three modes of legitimation: inspiration, rational argument and even empathy (a shared sense of wonder with the universe).

Popularisation thus plays a major role in legitimising astronomy. The use of mass media, the importance of charismatic figures and use of rhetorical strategies, such as relating astronomy to human spiritual needs, all help to maintain solid support from the public. Here the role of language cannot be overestimated. To use Gieryn's metaphor (Gieryn 1991: x), as astronomical discoveries make their way "downstream" to the public arena, they are mediated and represented in ways that inculcate awe and respect. We all like to know where we are, and astronomers construct a map that locates us in relation to the Universe.

The public consumption of astronomy, while perhaps not the main reason for continued funding, cannot but aid astronomy in its negotiations with the state. In fact a recent major report on American astronomy accredits astronomy's popularity with the general public as generating large amount of private funding for observatories (National Research Council 11). Given this popularity, astronomers are able to point to astronomy as playing a crucial role in educating the public in science. In short, popularisation ensures that the public understands just enough about astronomy to be awed into passive admiration and continued funding. Indeed, contrary to what some of my astronomer interviewees asserted, it is questionable whether a better-informed public serves the institutional and budgetary interests of astronomy.

The unequal relationship between the populariser and the popularisee is also dependent on, and reinforces, the professional status of the astronomy. With the odd exception of Patrick Moore**,** the major astronomy popularisers are professional scientists. When astronomers popularise astronomy they are also popularising themselves as professionals, and promoting astronomy as a profession. The notion of popularisation is thus intricately bound up with the notion of professionalism. Popularisation and professionalism feed into each other: the discipline and the profession are promoted together. Astronomers' elite status is enhanced by the notion that they are 'special' people, set apart from the masses. Thus Sagan comes across as an attractive Renaissance man. To use Gramsci's term, popularising astronomy maintains the *hegemony* of astronomers as a professional elite. In popularisation the astronomer is a depoliticised hero and achiever, and in the case of Sagan, a super-hero, and space becomes the final frontier of exploration. Although astronomers criticise various aspects of the manned space program, in terms of popularisation the two endeavours feed off each other: popular interest in one creates interest in the other.

It can be seen that modern professional astronomy is part of both popular and high culture. As part of modern culture astronomy is well placed to attract resources from fund givers. Moreover, the fact that astronomy has succeeded in becoming embedded in popular culture by the efforts of Patrick Moore and other popularisers means that it is a 'natural' part of society, part of what Habermas (1984) calls the “life world” — the taken for granted part of society. Once so embedded, astronomy’s legitimation is all but assured. But in order to be popular in the right ways — ways that ensure maximum legitimation — astronomy must walk a tight rope between being too popular, then therefore less scientific, and too highbrow and elitist. At least one astronomy populariser, Carl Sagan, straddled that tightrope. Some of his professional colleagues thought him a “Reckless speculator”, while ufologists and other ‘pseudoscientists’ thought of him as “The Dark Prince of Scepticism, the party pooper who coldly shot down their ideas about UFOs, psychic phenomena, and other fringe ideas” (Davidson 224). Walking the tightrope of popularisation is one example of boundary work. Indeed, the culturally dominant notion that in popularisation genuine scientific knowledge is simplified, distorted, degraded or polluted, is itself a form of boundary work, because ‘genuine’ scientific knowledge is sharply demarcated with ‘popular’ science (Hilgartner 1990: 520). Thus, the discussion of popularisation naturally leads on to a discussion of boundary work, the subject of the next chapter.

CHAPTER FOUR
BOUNDARY WORK IN ASTRONOMY

In this chapter I look at the notion of boundary work and its relevance to legitimation in astronomy. The chapter begins with an explanation and discussion of the concept of boundary work and the theory behind it. I then examine examples of boundary work in astronomy: ‘pseudosciences’ (the Velikovsky affair, astrology, and especially ufology), SETI, amateur astronomy, social differentiation, astronomy as pure science, physical boundaries, demarcation disputes, and disciplinary boundary work such as physics. Finally I attempt to explain why astronomers engage in boundary work. I also extend Gieryn’s concept to encompass physical boundaries and boundary work *within* astronomy. The danger here is of course that the concept becomes so generalised as to lack content. However, in the limited context of the particular examples of physical boundaries and internal demarcation disputes, the explanatory power of the concept overrides the risk.

The Concept of Demarcation

The concept of boundary work has been developed by Gieryn (1983, 1995, 1996, 1999) as an alternative to the ‘objective’ demarcation criteria established by philosophers of science such as Karl Popper. Philosophers of science have claimed that science is demarcated from non-science by its method. As far back as 1837 William Whewell, who coined the term ‘scientist’ in 1833 (Golinski 67) claimed that science was demarcated from non-science by its use of induction (Golinski 4). By mid twentieth century, logical positivists such as A. J. Ayer claimed that science and non-science are separated by empirical verification: scientific theories are capable of being empirically verified. Indeed, Ayer went further and claimed that any statements that could not be verified were meaningless (Ayer 7, 65, 200). But the most influential demarcation claim was made by philosopher Karl Popper.

Popper (1989, 2002) thought that science was demarcated from ‘pseudoscience’ (or non-science) by its use of the method of falsification. It is not clear whether Popper intended his demarcation principle to be descriptive or prescriptive. If descriptive, ethnographic studies of science have shown it to be false (for example Latour and

Woolgar) and have supported the common sense view that the notion of a scientist actively looking for evidence against her hypothesis is slightly ridiculous. If prescriptive, its scope does not come within the study of the sociology of science.

As I have shown elsewhere the term ‘pseudoscience’ is itself problematic. There are some theories that are on the borderline between science and ‘pseudoscience’, and the borderline is fuzzy. In fact Laudan (1983) has suggested that we drop the term ‘pseudoscience’ because there are so many cases of science on the borderline (Howard). However, the term does serve as a descriptive term to distinguish those activities such as ufology and astrology that are not regarded by astronomers as being legitimate sciences. I put the term in quotes to emphasise my own neutrality the scientific status of the ‘pseudociences’ I discuss. Suffice it to say that the scientific community’s feeling about activities they call ‘pseudosciences’ is that they are “the study of the non-existent by the incompetent” (Westrum 1982: 89)

Gieryn’s proposition is that demarcation is itself a form of boundary work. Rather than there being a natural boundary between science and non-science, demarcation criteria such as falsification are constructions by scientists, philosophers of science and others that serve to create boundaries between some activities and others for reasons of political and/or economic self-interest.

Gieryn suggests that essentialist characterisations of science such as demarcation are a reflection of the way that scientists themselves demarcate their profession and activities from other activities. In other words they are methods of legitimation. Gieryn’s thesis is supported in a study done by Mulkay and Gilbert, who found that many scientists who are aware of Popper’s thesis like and support it, and see it as an accurate reflection of what they do. Popper, like philosophers of science before him, saw demarcation criteria as being ‘natural,’ and based on ‘objective criteria’. But rather than being ‘objective’ or ‘natural’ such characterisations are used by scientists as a political resource. In contrast to demarcation, the concept of boundary work is a sociological one that points directly to social processes by which demarcations, or boundaries, are constructed. The concept of boundary work then is in the tradition of the perspective on science known as constructivism: "that which regards scientific knowledge primarily as a human product, made with locally situated cultural and material resources, rather than as simply the revelation of a pre-given order of nature" (Golinski ix). Constructivism, as a methodological orientation, draws attention to the notion that scientific knowledge is a human creation made with available cultural and material resources, "rather than the revelation of a natural order, which is pre-given and independent of human action" (Golinski 6). Constructivism follows the symmetry principle of the 'strong programme'. That is, it remains neutral on what constitutes good or bad science, real science or pseudoscience. Constructivism is thus the appropriate methodological tool with which to analyse boundary work; it can be descriptive without taking sides.

For the purpose of this thesis, boundary work theory has the advantage of highlighting the historical and sociological activities of astronomers, and explains how demarcations (boundaries) can change over time. More importantly, the concept of boundary work can help us understand how astronomers can use supposedly objective and natural demarcations to explain and justify their discipline and profession. The concept of boundary work can be a useful tool in analysing the legitimation of astronomy. It is a useful tool for analysing astronomers' relationships between themselves and their neighbours, whether welcome neighbours, such as physicists, geologists and amateur astronomers, or unwelcome, such as astrologers and ufologists.

Boundary work then, is a means by which scientists demarcate their activities from non-scientists, and between themselves and other scientists. It is important in legitimising astronomy because astronomers have to walk a tightrope between aligning themselves with those social systems, disciplines and activities which will enhance their legitimacy and those which will hinder it. Boundary work is the means by which astronomers construct the location of that tightrope. It is important to note that boundary work can apply both to the cognitive/technical norms (the content of what is studied), and to the methodologies used to study that content (Zuckerman). Boundary work is also therefore an ontological activity; it negotiates what constitutes reality but defining what comes within the remit of certified knowledge and defines the means by which that knowledge is characterised.

Boundary work is an explicitly political activity, as it is concerned with power relationships. Indeed, scientists' involvement with policy can itself be seen as a form of boundary work; scientists must convince audiences that they have not overstepped their sphere of authority (area of legitimate domination). (Hilgartner 2000: 10). In 1897, comparing science to politics, astrophysicist J.E. Keeler noted the relative lack of clarity between domains in science (Keeler 271-288). As we shall see, this is particularly true of astronomy and physics.

Astronomers are in a position, especially when popularising, to locate themselves in relation not only with other adjacent disciplines, but also in relation to various 'psuedosciences' from which they wish to disassociate themselves. For our purposes, 'pseudoscience' may be seen as synonymous with deviant science. As Dolby notes, deviant science "is that which is rejected by the orthodox scientific experts, and which they may label 'pseudo science'" (Dolby 10, 11).

Boundary work is a social process, undertaken by actors defending and sometimes extending their strategic position in relation to other groups. Unlike philosophical demarcation criteria, boundary work does not depend on unchanging, supra-historical epistemological breaks. Boundary work emphasises the social, historical, and context dependency of scientific disciplines. It also highlights the political nature of demarcation disputes.

Moreover, at different points in time, astronomers will ally or distance themselves from the same activity, as with astrology in the time of Kepler versus astrology today. As Polanyi points out, ancient Babylonian astronomy was part of astrology, but eventually outgrew astrology and proved astrology wrong (Polanyi 1958: 354). SETI is an opposite example: astronomers once distanced themselves from it; now, many of them embrace it.

What specific boundary forming activities take place within the profession of astronomy? I now use the examples of Panspermia,Velikovsky, astrology, ufology, SETI, amateur astronomy, the characterisation of astronomy as 'pure' science, and boundary disputes, to elucidate the concept of boundary work as applied to astronomy.

Fred Hoyle and Panspermia

Sometimes a deviant astronomical theory emerges from within the profession, as when Sir Fred Hoyle proposed the theory of panspermia, the idea that life on earth originated from interstellar space. Panspermia was never accepted by the astronomical community. But because Hoyle was a respected, established and well known astronomer, his reputation remained intact, at least for a while. However, while promoting this theory, Hoyle was marginalized by the astronomical establishment, so that in 1993, a Royal Society publication could describe the theory as “a travesty of science,” and accuse Hoyle of hubris and incompetence. The boundary work that effected this marginalization was conducted to a considerable extent via communications: publications, conference papers, funding applications, and friendship networks that can all be used to separate the acceptable from the unacceptable, and place unorthodox science beyond the pale. Boundary work establishes not just intellectual but also social and physical distance between the orthodox and the unorthodox. This distance makes the relationship between them interesting as a communication phenomenon: as communities diverge, communication must necessarily become more like popularisation as each new community becomes increasingly expert about its own social and intellectual resources and increasingly lay about those of others. An excluded scientist’s only means of reaching other scientists is through popularisation. Thus popularisation a key tool in boundary work—it acknowledges and defines its audience as some separate “other”—and communication that functions across such a separation serves, irrespective of genre, as popularisation (Gregory 26).

After several attempts to promote their theory to the scientific community, Hoyle and Wickramasinghe felt they were running up against passive opposition. Writing in 1984 about this period, they said that funding was harder to find, and the “refereed journals, to which a wise scientist touches his or her forelock,” had stopped considering their work. Attitudes had changed when they started working on polysaccharides, “because of their biological association apparently.” They described the funding agency, the Science and Engineering Research Council, as “one of the outstanding Gilbert-and-Sullivan operettas of the twentieth century," and the scientific community as "an orchestra that exhausts itself with every crescendo." A few months later, Hoyle testified in court on behalf of Creationists in Little Rock, Arkansas, who wanted their share of curriculum space. Hoyle argued that Darwinian evolution was just a theory and should not be privileged over any other theory (Gregory 29).

In 1986, Hoyle and Wickramasinghe published a popular book entitled *Archaeopteryx, the Primordial Bird: a Case of Fossil Forgery?* They claimed that the celebrated "missing link" fossil was a fake. In a review for *Nature*, zoologist and curator Tom Kemp wrote: "At best this book is mischievous; at worst it might well be described as evil, because it betrays that morality of objectivity that science cherishes. Perhaps Archaeopteryx is a fake. Certainly the possibility should be investigated. But it should be done by people who actually understand fossils … not by a couple of people who exhibit nothing other than a Gargantuan conceit that they are clever enough to solve other people's problems for them, when they do not even begin to recognise the nature and complexity of those problems" (Gregory 31).

Another nonfiction account of life-from-space theory, *Cosmic Life-Force*, was published in 1988. Less detailed than its predecessors, it concluded with a chapter on "The concept of a Creator." One reviewer hoped that the book would be the last on the subject. Yet *Our Place in the Cosmos* retold the story in 1993. It contained little that Hoyle and Wickramasinghe had not said before, but it was resoundingly condemned. *Nature*'s reviewer wrote, "This book cannot be taken seriously as a work of science," but thought it an interesting document of a great scientist's decline. In *Science and Public Affairs*, the house journal of the Royal Society, chemist Peter Atkins wrote: " … this book is not worth the paper it is written on … it is a travesty of science … a personal diatribe against established science … one can only hope that it will … expose the author's [sic] hubris and incompetence to the point that publishers will cease pestering us with their nonsense" (Gregory 32). According to its assistant editor, *Science and Public Affairs* chose to publish such a strident review, rather than ignore the book, because Hoyle was supposed to be "one of us"—he was a Fellow of the Royal Society—and could not be allowed to bring the scientific community into disrepute in this way. The book's publisher, Dent, should also be warned that they risked losing the cooperation of the scientific community (Gregory 32).

Hoyle published more than 500 academic papers in distinguished journals on various topics in astrophysics during a 60-year career, and some of these contribute to the cosmological lineage of life-from-space theory: they provide physical conditions and a sufficiently long period of time for his cosmic chemistry to have the desired synthetic effect. However, the papers do not discuss the organic content of dust grains—which is the first stage of the theory proper, the point at which cosmology met biology, and the first step away from orthodoxy—until the early 1970s. Hoyle's theory is interdisciplinary and presents a radical challenge to the paradigm. The ideal home for such science is *Nature*, which is where Hoyle's papers were appearing until 1977. *Nature* has a very broad international and interdisciplinary readership, and its prestige is high: it is in the first rank of journals for astronomers. It could have afforded legitimisation for Hoyle's ideas from the two communities—biological and astronomical— whose ideas it challenged. But Hoyle soon found himself unwelcome at *Nature*, and had to go elsewhere. The papers seem to confirm Hoyle's contention that it was his more explicit excursions into biology that lost him *Nature*'s support: his last few publications there, written in 1977, concern "prebiotic" and "organic" molecules in the interstellar medium; the very last is about polysaccharides in space. Hoyle's colleagues have suggested that *Nature*'s editor, John Maddox, made decisions personally about whether or not to publish Hoyle, outside of the peer-review system. Maddox has responded that the problem with publishing Hoyle's work became not so much that referees' reports were negative, but that potential referees would refuse the task. Nevertheless, at a time when, according to Hoyle, peer-reviewed journals were refusing his work—between 1977 and 1984, when he made this claim—his papers were appearing frequently in a peer-reviewed journal, *Astrophysics and Space Science*, a small, specialized astronomical journal of lower prestige than *Nature* (both Hoyle and Wickramasinghe have served on its editorial board). Thus the theory, while remaining in a single medium, moved from a relatively high-prestige interdisciplinary community with a large membership into a relatively low-prestige specialist community with a small membership; and this process was achieved by Hoyle's exclusion from the prestigious community. Hoyle and Wickramasinghe continued to publish in *Astrophysics and Space Science*, where they advanced the idea that interstellar grains are bacteria. The broader implications were subsequently discussed in popular books (Gregory 35-36). The reviews did boundary work in so far as they served to separate Hoyle from the collegiality of the scientific community. Yet they also served to confirm Hoyle's membership in that same community: the books prompted not the implicit rejection that could have been achieved had they been ignored, but the explicit rejection of attention-grabbing (if uncomplimentary) accounts in prestigious journals. Thus in book reviews, Hoyle found his ideas "published" in *Nature* and elsewhere, despite the disapproval of his scientific peers; and was thus engaging in mutual communication with the scientific community—his continuing membership was confirmed. The remark from the Royal Society's editorial office, that Hoyle, as "one of us," ought to know better, endorses this. However, since there is no forum or genre in which an author can reply to a book review, any mutual communication must cease once the review is published: the entire exchange can consist only of the book (or lecture or broadcast) that is reviewed, and the review itself. Once those communications have been completed, the boundary defined by non-communication is drawn once more.

Thus critical book reviews do two different types of boundary work: first, they bring an author into a community in order that he might be criticized on that community's terms; second, the author is excommunicated by his own enforced silence. Hoyle's pamphlets from University College Cardiff Press in the early 1980s attracted much less attention than the books. Since it is unlikely that these publications were not circulated for review, the implication is that they were ignored. Perhaps, unlike the popular books with their potential readerships of impressionable lay people, the pamphlets were not considered a threat to the authority of orthodox science. But at this time, Hoyle was embracing a cosmic deity and Arkansas creationists; and both Darwinism and orthodox epidemiology were targets for his criticisms. Perhaps at this stage, then, the scientific community declined to acknowledge Hoyle, not even granting him the chilly embrace of a hostile review. The result was that Hoyle, though left untroubled by any adverse comments, was implicitly rejected by the scientific community (Gregory 37).

In the case of *Archaeopteryx*, however, Hoyle was a scientist making scientific claims—even if he was a cosmologist making claims about paleontology and evolutionary theory. The Natural History Museum's response to *Archaeopteryx* was an explicit rejection of his claims, and it generated more press coverage than had the book itself. With one foot already in the public domain, a scientific institution such as this museum could give space to *Archaeopteryx* within its own walls without conferring scientific legitimisation. The scientific community, embodied by the museum, could respond to Hoyle in the public space provided by the museum, without actually embracing Hoyle within a purely scientific space. Thus the exhibition provided an opportunity for scientists to reject Hoyle in what for them was a legitimate forum, without actually bringing Hoyle within the boundaries of science (Gregory 37-38). The balance between explicit and implicit rejection changes through Hoyle's career: unorthodox ideas in popular media that scientists could ignore in the 1970s—when popularisation by scientists in the UK was neither common nor welcomed by peers — generated explicit condemnation in the 1990s, when popularisation was encouraged but policed. Hoyle himself never mentioned the benign cosmic intelligence except in forums classically regarded as popular and contingent, such as newspaper articles and popular books, and even he, as an experienced and fundamentally well-socialized scientist, stepped back from that position during the explicit rejection of his work in the early 1990s. Within academic media, the thesis moved down a prestige scale and from an interdisciplinary to a specialist journal; and within popular media it moved from more specialist to more popular presentations—in both regards, the constitutive character declined and the contingent grew as marginalization progressed. However, this analysis challenges the notion that popularisation is a necessarily a by-product of or afterthought in academic practice. It shows a scientific theory that began life and developed in the public domain, for example, in newspapers and novels, and was then returned to its embryonic state so that it should develop again, to the apparent surprise of its authors, in academic media. The constitutive author (and his peers) is apparently often blind to his own contingent self—or is born again, like his theory, when he enters the constitutive forum. When Hoyle's theory had developed to the point at which it became unacceptable in academic media, it was returned to the public domain, where it recapitulated and continued its career (Gregory 39).

Similarly the even more outlandish theory of Nobel Prize winning biologist Francis Crick. In a co-authored 1973 article in the journal *Icarus*, and again in 1983 in a book entitled *Life Itself,* Crick extended Hoyle's theory, suggesting that intelligent beings brought life to earth. Crick called his theory 'directed panspermia'. Unlike Hoyle, Crick never pursued his theory over time, so although the theory was never accepted by the scientific community Crick's reputation remained intact.

The story of Hoyle's various deviant theories show the complex relationship between internal and external legitimation within astronomy. Internal deligitimation can lead an astronomer to attempt legitimation in alternative external arenas, such as various popular venues. The perpetrator of deviant theories from within the astronomical community can be tolerated for a while, but persistent production of deviant theories can after a while affect the reputation of even a highly respected astrononmer such as Hoyle. Moreover, initial high status within the astronomical community is no guarantee that deviant theories will be accepted.

Velikovsky

In contrast, when someone from outside the scientific community proposes a controversial astronomical theory, the response constructs a rigid boundary between astronomy and non-astronomy. Astronomers, like other scientists, are territorial when it comes to what counts as a source of astronomical knowledge, and will go to great lengths to defend their right to be the sole source of such knowledge. Sometimes a theory comes 'out of left field' from an outsider, who, because he or she is not part of the astronomical community, and does not use accepted methods or resources, is kept outside of the boundaries of the science of astronomy. The response of astronomers constitutes a defence and reaffirmation of the boundaries of astronomy.

A striking example of such a defence can be found in the way that astronomers treated someone who was not one of them, who claimed to advance a novel astronomical theory, namely, psychoanalyst Immanuel Velikovsky. In 1950 Velikovsky published a book entitled *Worlds in Colllision*. The book was the result of ten years of research (Plait 2002). In it Velikovsky claims that various catastrophes recorded in ancient texts were real events. The book sold so well that Velikovsky produced a sequel, *Earth in Upheaval*, in which similar claims are made. In 1950, the Hayden Planetarium's attempt to mount an exhibition about the unorthodox cosmology of Immanuel Velikovsky cost its curator his job. But Velikovsky, unlike Fred Hoyle, was not a cosmologist, and his scientific credentials were slender: he had no claim on any scientific space.

Although his popularity has waned, Velikovsky still has many followers. There is a large body of literature on the Velikovsky Affair, including classic treatments by Bauer and De Grazia.

Velikovsky questioned many of the principles of physics and astronomy, advancing a radical theory about the history of the Solar System, particularly the planet Venus. Velikovsky used legends and the Bible to support his hypothesis that the planet Jupiter emitted a large comet, which became the planet Venus a mere few thousand years ago. Venus was ejected by Jupiter, and then careened around the Solar System, passing both Mars and Earth, and affecting them in various ways, causing catastrophes described in ancient texts, and finally settled into its present orbit. Velikovsky's research was built around historical and archaeological evidence, rather than astronomical observations. Astronomer Philip Plait cites Velikovsky's thesis as a classic example of 'pseudoscience' on the same epistemological level as astrology and creationism (Plait 176).

Velikovsky's thesis proved popular with sections of the public because it appeared to make the Old Testament compatible with science. It was, needless to say, greeted with hostility and even venom by the professional astronomical community. According to Ginenthal (1995) astronomers had not read the book before criticising it, and displayed an emotional reaction bordering on hatred. When Velikovsky first presented his ideas to Harvard astronomer Harlow Shapley in 1946, Shapley responded angrily by writing letters to his colleagues stating that “if Dr Velikovsky is right, the rest of us are crazy” (Mcaulay 317). Shapley later wrote vitriolic letters to the editor at the publisher, Macmillan, when they were preparing the manuscript for publication. The Harvard astronomer asserted that Macmillan’s reputation as a scientific publisher would be damaged by publishing such a book. According to Plait, there were even intimations that Shapley would use his influence to pressure scientists to boycott Macmillan’s books, and as a result Macmillan transferred the publishing rights to Doubleday (Plait 184). The book, no doubt aided by the controversy, became a runaway best seller. In the sixties it became popular with counter culture students; it was a symbol of rebellion against establishment science.

In 1952, the American Philosophical Society gave Velikovksy’s opponents a chance to attack him but did not allow him a forum to refute them (Ben Yehuda 116). In response to the continued popularity of Velikovsky’s book**,** the American Association for the Advancement of Science in 1974 sponsored a semi-public debate between Velikovsky and his scientist detractors in an attempt to discredit the book once and for all. One of the leading scientists in the debate was Carl Sagan. Plait said of the debate that both sides lost. Velikovsky made rambling speeches that neither supported nor detracted from his cause. On the side of established science, there was posturing and posing. Sagan “did a terrible job of debunking Velikovsky’s ideas” (Plait 185), making straw man arguments, and only attacking small parts of Velikovsky’s thesis.

Scientists Confront Velikovsky transcribes the talks given by scientists at the debate — Velikovsky’s talk is not in the book. Sagan is given an extra 50% more space to refute Velikovsky’s claims using arguments not in Sagan’s original paper, but Velikovsky was not given any room to rebut Sagan’s rebuttals. Because of this word length dispute, Velikovsky withdrew his paper from the book. According to astronomer Philip Plait, Sagan’s arguments “Are not all that great” (Plait 185). Fellow scientist and science fiction writer Jerry Pournelle called Sagan’s performance shameful: “Sagan wisecracked through the whole ‘debate’, never once confronting anything Velikovsky said, and mostly using his verbal skills to ridicule the old man. It was as shameful a thing as I ever saw Carl do” (“The Velikovsky Affair and Other Musings”).

Although astronomers still reject Velikosky's specific thesis, many scientists now accept the general thesis that evolution is affected by catastrophes.

The venomous reaction to Velikovsky cannot be explained by reference to falsification or any other supposed scientific method. In opposing Velikovsky astronomers were asserting their right to be the sole arbiters in what counts as an astronomical theory; they were drawing a boundary between themselves as a profession and outsiders like Velikovsky who dared challenge some of their epistemological assumptions. The correctness or otherwise of Velikovsky's theory is irrelevant; many cosmological theories, such as the steady state theory, have been discredited but were held on to by their proponents well after evidence had been found that supported the big bang hypothesis. In the aforementioned cosmological controversy, the discourse did not reach the emotional heights of the response to Velikovsky's claims. Therefore the hostility toward Velikovsky and his theory cannot lie solely with the theory itself, but can be explained in part by bringing in socio-political factors, such as the security and status of the profession. In short, Velikovsky was a threat to astronomy's professional monopoly over decisions about astronomical knowledge and so he had to be debunked in no uncertain terms. Here the boundary work by astronomers involved excluding an 'imposter' scientist by focusing attention on the poser's failure to conform to expected methodological standards mapped out as genuine scientific practice such as proper instrumentation, credentials, peer review, objectivity and scepticism. The Velikovsky affair highlights the fact that boundary work can become highly personalised, establishing criteria of inclusion and exclusion within the profession, and also marks the process of *internal* unification of the profession of astronomy.

In recent years astronomy has been more concerned with distancing itself from two 'deviant sciences': astrology and ufology.

Astrology

Astrology, or the 'science' of the relationship between celestial phenomena and terrestrial events, is as old as astronomy itself, and historically in many cultures was synonymous with astronomy. Indeed, the European astronomers Kepler, Brahe and Copernicus were also astrologers. But modern astronomy both as a discipline and a profession goes to great lengths to distance itself from astrology.

The usual stance taken by astronomers is that astronomy is a science and astrology is not. Astrology and astronomy cover much the same subject matter: celestial phenomena. But unlike astronomy, astrology is 'unscientific' and therefore astronomy must go out of its way to distinguish itself from astrology 'to avoid any misunderstandings'. The reality, however, is more complicated than this, and an analysis can uncover power relations at work, which serve to enhance the legitimacy of astronomy independently of any supposed epistemological superiority of the discipline.

As Wright has shown, the 'success' of medicine and the 'failure' of astrology cannot be explained by the proposition that medicine was more successful as a form of healing than astrology (Wright 85-101). In the seventeenth century in England people turned to astrology just as much as medicine as a form of healing, and there is no evidence that *at the time* medicine had a better success rate at healing than did astrology. The eventual victory of modern medicine over astrology as the accepted and preferred form of healing can be attributed as much to power relations as to the ability of medicine to heal the sick. These power relations included the fact that doctors were able to form themselves into what we would today call a profession with certain attributes: a language, journals, geographical space, social networks and an ideology of 'ethics'. Medicine was able to distinguish itself from astrology by "establishing its elite as the possessors of a special professional domain bearing a distinctive ideological relationship to the developing capitalist mode of production" (Wright 92). One such domain is the Baconian notion of the domination of nature. The point is that *at the time* the intellectual superiority of medicine over astrology was by no means proved; this came later, and was itself part of the political struggle.

An analogy can be made here with modern professional astronomy, which, unlike astrology, confronts the universe in a challenging way with its enormous telescopes and extraterrestrial probes. Modern astronomy is big science and technological, and its resources dwarf those of astrologers. This physical boundary forming is just as important as and is related to the ideological boundary forming done by astronomers themselves in relation to astrology, ufology and amateur astronomy. Irrespective of the epistemic status of astrology, the boundary created by the unequal resources of the two activities reinforces the ideological boundary. Moreover, the relationship between astronomy and astrology changes with time and place. Kepler, an astronomer and astrologer, used astrology as "A public relations statement adapted to the mass-medium needs of the seventeenth century" (Feuer 142). The case of astrology demonstrates that in addition to epistemic differences, boundary work can be both the result of, as well as the cause of, unequal resources. Most importantly, it emphasises the need for astronomy to be seen as a hard science untainted by mysticism.

Ufology

Although there have been recorded sightings of unidentified flying object through history, it is generally agreed that the modern era of ufology began on June 24, 1947. A thirty-two year old pilot, Kenneth Arnold, was flying his single-engine plane over the Cascade Mountains in the United States, when he saw a bluish flash of light. On closer examination, he discerned nine discs apparently flying in formation at incredible speeds (estimated to be over 1600 miles per hour). Upon Arnold's landing, reporters assaulted him with questions about his experience to which he said "[the discs] flew like a saucer would if you skipped it across the water." The papers quickly coined the phrase 'flying saucers'. Within days of this report, dozens of people began to report similar experiences. Soon after, the term 'flying saucer' was used by a newspaper to describe the objects, and in 1949 an investigation by the US Air Force used the term 'Unidentified Flying Object' (Denzler 4). According to UFO debunker Donald Menzel, the term 'UFO' is a misnomer because it implies that all sightings of UFOs are of "material reality", a view to which he does not adhere (Menzel 124-134). Objection can also be made to the word 'flying' because not all phenomena labelled 'UFOs' are air born — some are on the ground. The term 'flying' also assumes propulsion (Westrum 1977: 273). The term 'unidentified object', though vague, would perhaps be more appropriate.

Interestingly, in the years following 1947 there was some genuine interest and little hostility toward the UFO phenomenon from astronomers and space scientists. In 1949 a US Air Force report concluded that flying saucer reports did give evidence of extraterrestrial intelligence (Hynek 173). In the 1950s even the Jet Propulsion Laboratory in Pasadena, California, had a UFO club (Denzler 186 n. 99) although they would not admit their interest openly (Denzler 72). In 1953 a poll of forty-five well-known astronomers, carried out by another astronomer, found that six of them had seen UFOs (Westrum 1977: 280). There were several articles about UFOs in scientific journals up until 1971, after which there were very few. The conventional wisdom was and is that astronomers never had UFO sightings, but surveys suggest this wisdom is wrong (Denzler 74). A small number of prominent astronomers have even come forward publicly to report that they had sighted a UFO. The most famous of these is the discoverer of Pluto, Cyde Tombaugh. UFO sightings were also reported by Walter Webb, a lecturer in astronomy at the Hayden Planetarium in Boston; Seymour Hess, the Chair of the Meteorology Department at Florida State University; Percy Wilkins, Bart Bok of the Mt. Stromlo Observatory in Canberra; Robert Johnson, Chief of the Adler Planetarium in Chicago; and by the Majorca Observatory in Spain. Frank Halstead, the curator of the Darling Observatory in Duluth, North Dakota, stated that he thought we should assume we have space visitors. The father of German rocket development, Hermann Oberth, stated that he thought UFOs were interplanetary vehicles (Denzler 73-75). The above examples are however, exceptions, and are all from the 1940s, 1950s and 1960s, the latest being from 1966 (Denzler 73-75).

As late as 1968 an astronomy textbook used in US Air Force Academy classes included a non-critical chapter about UFOs (Denzler 37). But in the same year a scientist wrote that UFO experiences were rare amongst scientists, and that he thought UFOs were not real in the same way as ball lightening (Westrum 1977: 280). On the other hand, a survey by Surrock published in 1977 found that 53% of all astronomers felt that UFOs deserved scientific study. However, very few astronomers admit to seeing UFOs, and this low rate of reportage by astronomers affects the processing of UFO reports, which will proceed one way if astronomers are thought to see UFOs, another way if they are thought not to (Westrum 1977: 280). The 1977 study seems to be itself an anomaly, and the general response to UFOs among not only astronomers but scientists in general seems to be to debunk them, to the extent that those scientists who do have UFO experiences feel obliged not to tell their fellow scientists (Westrum 1977: 284). As Hynek found, the more typical reaction of astronomers to UFOs has generally ranged from embarrassment through to ridicule (Hynek 7-10). Hynek did however find one MIT astronomer who had refused to report his sighting due to fear of ridicule (Hynek 47). Hynek blames the situation on the Air Force, which took control of the UFO phenomenon and shrouded it in a veil of "military science fiction" (Hynek 174).

Had there been a continuing scientific commission or institute, the subject would have become more dignified and opened the way for its inclusion into mainstream science (Hynek 174). Instead, the longest running investigation into UFOs, Project Bluebook, for which Hynek was scientific consultant, showed little scientific interest in the UFO problem and was completely divorced from the scientific community (Hynek 186-187). The conclusion of the resulting Condon Report was that UFOs were not worthy of scientific study. According to the dissenting Hynek, the report was characterized by bias, prejudice and ridicule rather than any attempt at scientific methodology (Hynek 205). Moreover, the journal *Science* refused to publish a powerful critique of the Condon Report by a systems engineer (Hynek 207-210, 269).

The only serious attempt by the professional astronomical community to openly debate UFOs in a systematic and organized way was the Symposium at the Annual Meeting of the American Association for the Advancement of Science in 1960. The Symposium was published as *UFOs —A Scientific Debate*. Indications of boundary work abound in this publication. At the outset it was expressed that, "public understanding is at stake and that the borders between scientific and non-scientific need explicit delineation"

(Sagan 1972: xix). The book also notes "the possible harm done to science education by pseudoscientific UFO reports, magazines, and books" (Sagan 1972: 3). The majority of contemporary leading ufologists, people such as Arthur Shuttlewood and Jenny Randles, were not professional scientists, and were not allowed to attend. With the exceptions of the papers by James MacDonald, Robert Hall and J. Allen Hynek, the book and the symposium were largely debunking exercises. On the anti UFO side, astronomer Donald Menzel, an extremist UFO debunker, became suspicious of Sagan for even stooping to debate with the ufologists (Davidson 226-228). Menzel was concerned that Sagan was swaying too far from complete dismissal of ufologists. Sagan's intellectual speculations about life in the universe apparently contributed to his failure to achieve tenure at Harvard University (Davidson 200-205). There was more resentment in the wake of the success of *Cosmos,* although it is difficult to say how much of this resentment was of Sagan's scientific speculations and how much was due simply to the immense popular success of the project (Davidson 263-264). This suspicion of Sagan by many of his peers indicates that an astronomer who sways too close to the boundary risks the ire of his colleagues.

The late J. Allen Hynek was an astronomer and the scientific consultant for the US Air Force investigation programs into UFOs: Project Sign, Project Grudge, and Project Blue Book. Hynek was originally a sceptic, but in the course of his investigations into the phenomenon became a champion of ufology, at least to the extent of advocating that some sightings should be taken seriously and even investigated by scientists. Hynek was denied a voice in most of his profession's publications and was reduced to publishing articles about UFOs in the popular press such as *Playboy* (Denzler 68-69). Hynek was on the one hand denied a voice in most professional publications, yet at the same time ridiculed for presenting his work outside of them. Indeed, in addition to Hynek, other ufologists who were also scientists, such as Jacques Vallee and James MacDonald, were denied the opportunity to publish in refereed journals because their subject matter was considered to lie outside the realm of science. As a study by the University of Colorado shows, as far back as 1968 scientific journals were reluctant to publish articles about UFOs, even when they were written by astronomers (University of Colorado 264-270, note 22).

The effect was to exclude the minority of pro-ufology scientists from the network of citation and referencing that constitutes the production of knowledge. They were also denied access to sources of funding of science such as the National Science Foundation. Westrum concludes that the news media and Air Force help to set the sceptical agenda (Westrum 1977: 285). The US Air Force in particular has appeared to go out of its way to debunk UFOs (Westrum 1977: 287-288). Indeed, according to Westrum it was the Air Force and mass media who convinced most of the scientific community that UFOs are not extra-terrestrial (Westrum 1977: 292). A similar point is made by Blake, whose study indicates that scientists were aided in their attempts to belittle and ridicule ufology by journalists and the US Air Force. Once so ridiculed and belittled, ufologists find it impossible to get published in respectable scientific publications. The intellectual expulsion of ufology from science meant that ufology was conceptually downgraded from 'knowledge' status to that of 'belief' or 'ideology'. Thus boundary work can become a hermeneutic circle, which the outsider cannot penetrate.

It seems that roughly from the early 1970s onwards, astronomers and other scientists closed ranks and constructed an impenetrable boundary between their disciplines and ufology. This roughly coincides with the era in which scientific budgets began to be squeezed, and astronomers and their lobbyists were beginning to have to engage in more intensive legitimation practices than had previously been the case. It also roughly coincides with the emergence of SETI as a semi-legitimate branch of radio astronomy. It could be that in order to legitimise their embryonic field SETI astronomers felt they had to distinguish themselves from ufologists. The closer the apparent connection between two areas, the greater the need for boundary work to distinguish them. According to Denzler, the few learned treatments of ufology concentrated on the more extreme abductee and contactee stories, rather than the more mundane but believable cases of mere sightings: "If one were to read only the scholarly literature on the subject (which would be a very brief project!) one might well conclude that those who believe in ufos are socially marginal characters … one would have to believe that virtually all UFO believers — or at least all serious students of the phenomenon — are contactees or their disciples" (Denzler xiv).

At the beginning of the UFO era, 1947 and the years following, the Cold War was just beginning, and ignorance of Soviet technology fuelled speculation that UFOs were real Soviet craft. Thus from 1947 well into the 1950s, the UFO phenomenon was a political as well as a scientific issue. However, once Soviet origin of UFOs had been discounted, most scientists had become convinced that UFOs posed no threat and no promise for scientific or technological knowledge. From the early 1950s onwards media sensationalism seemed to indicate that the UFO phenomenon was primarily religious in nature, that is to say, based on belief (Denzler 10), despite the fact that most serious students of the phenomenon took pains to distance themselves from the fantastic and the religious (Denzler xv). In the popularisation *Are We Alone?* for example Paul Davies lumps all UFO reports together and says, "No clear distinction can be drawn between them and descriptions of the religious variety of, say, the Fatima variety" (Davies 1995: 33).

Astronomers and other scientists have regularly deplored the fact that large numbers of the populace 'believe in UFOs'. This association of UFOs with popular belief has moved the topic out of the realm of the physical sciences and into the realm of the social sciences and humanities, where it has been studied as an artefact of personal psychology, or sometimes of society and culture. In short, UFOs are seen as a modern myth, rather than scientific phenomenon. UFO reports then become creative interpretations rather than rational statements of actual experience. The classification of UFOs as a modern myth, combined with the psychological and spiritual experiences reported by people encountering UFOs, helped to push ufology away from science and toward religion (Denzler 106). However, the lingua franca of the UFO community remains scientific (Denzler 157).

Once ufology had become detached from science and associated with religion, the door was now open for a scientific debunking of ufology, which can be seen as a form of boundary work by astronomers and other scientists. Ufology came to offer an opportunity for astronomers to legitimate their epistemological superiority, and ally themselves to other sciences and distance themselves from 'pseudoscience'. Ufologists are not usually trained scientists, they operate in a different space to astronomers, and constitute a possible threat to the hegemony of the profession; if ufology became legitimate in the eyes of the public astronomers would lose some credibility, because a confirmation of their thesis that the Earth was or is possibly being visited by extraterrestrial intelligence would pose a problem for astronomers. Such a confirmation would be an embarrassment for astronomers, because celestial phenomena UFOs come within the province of astronomy, and such a discovery would mean that they have been unobservant. Moreover, their embarrassment would be compounded by the fact that their consistent and near unanimous debunking of the activity had been mistaken. Their very debunking of ufology has given them an investment in its continued marginalisation. Shapin relates that English gentlemen scientists refrained from relating implausible matters — even if these matters were believed to be true and even if they had been witnessed by the potential testifier (Shapin 213). The majority of modern astronomers too play it safe and maximise their credibility by debunking UFOs.

Thus at a certain point ufology came to be seen by most astronomers and other scientists as a ‘pseudoscience’. It is worth spending time examining this notion. The implication of the term ‘pseudoscience’ is that ufology claims to advance or to exemplify the methods and principles of science, but in fact does not.

Scientists themselves engage in boundary work in the very way they characterise ‘pseudoscience’. Friedlander (ix-xii, 164), for example, characterises ‘pseudoscience’ as observations and theories, usually made by non-scientists, which resemble science. He distinguishes ‘pseudoscience’ from pathological science (careless method, faulty interpretation) and fraudulent science (deliberate manipulation). Friedlander says that ‘pseudoscience’ is produced by simple assertions of fact rather than the ‘internalist consensus’ of the scientific community. ‘Pseudoscience’ is supported by belief rather than rational argument or demonstration, and is presented in other than professional venues. ‘Pseudoscience’ also tends not to have a significant mathematical foundation. However, the ethnographic studies cited elsewhere have noted the frequent lack of consensus in the scientific community, which itself changes over time, and the role of belief as well as ‘rational’ argument. Moreover, the role and importance of mathematics varies greatly between disciplines.

Thus Friedlander, like Popper, characterises ‘pseudoscience’ in opposition to ‘real, genuine science’, placing ‘real, genuine science’ in a hegemonic epistemological position. In response ufologists argue that Friedlander’s characterisation constitutes a hermeneutic circle: they are accused of being unscientific because they do not use traditional scientific avenues such as peer reviewed journals, whilst being denied access by their accusers to those scientific resources. In fact, ufologists started their own refereed journal, the *Journal of UFO Studies*, but it has never been accepted by mainstream professional scientists (Denzler 95). As for professional scientists who took various aspects of ufology seriously, such as astronomers Hynek and MacDonald, and psychiatrist John Mack, who came to believe in alien abductions, their public support for ufology did not help their scientific careers, and they were seen by the majority of their peers as being on the precarious boundary of scientific legitimacy (Denzler 69). Most serious UFO investigators are amateur enthusiasts, and this in itself keeps them apart from the professional scientific community.

A key theme which astronomers use in demarcating their science from ufology involves the position of the observer. Various studies have noted that the facticity of a ‘scientific fact’ is demonstrated by the scientist positioning herself so that she is seen as a passive observer witnessing an objective event which is totally outside of herself; as a discovery moves toward facticity so the scientist/agent/observer becomes separate from it, so that the fact appears completely independent and objective (see for example Latour and Woolgar; Woolgar). When astronomers make comments about ufology they contrast their own ‘objective science’, in which astronomical phenomena exist independently of the observer, with ufology, in which the observer (witnesses) are posited in the centre of the phenomena, thus sidelining the phenomena to the realms of psychology and sociology. For example, Goldsmith and Owen assert that when examining evidence concerning UFOs, “We must deal with eyewitness testimony, with all its contradictions and personal biases … to attempt to evaluate all possible natural explanations … represents an immense task, often one that may reveal the dark side of human nature … hence it is not surprising that few scientists have devoted much effort to a study that they see mainly as the realm of sociologists and psychologists. Indeed, most scientists are poorly trained to deal with problems in which the observer plays a key role in the phenomenon" (Goldsmith and Owen 484-485). Later, they say, "Eyewitness accounts can never by themselves prove whether a given event did or did not occur. The problem of mental interpretation grows especially acute with strange objects in the sky" (Goldman and Owen 493). Goldman and Owen do not say how astronomy differs; the difference is assumed. The facticity of UFO reports and thereby the credibility of ufology as a legitimate field of study is thus undermined by centralising the observer and sidelining the phenomena. Positioning of the observer is then a key tactic in boundary forming between astronomy and ufology. Thus Hynek's assertion that at least some UFO reports "describe a new fact" (Hynek 214) was not supported by other astronomers.

Moreover, as Westrum has found, the type and flow of evidence about anomalies such as UFOs constitutes a form of 'social intelligence' that affects the likelihood of acceptance by scientists. The flow of intelligence in the case of UFOs (typically non-repeatable sightings by non-scientists) is not 'logical' and therefore is not likely to be acceptable. Westrum's explanation for the general debunking of UFOs by scientists is explained by the interests of the scientific community and the logic of scientific belief (Westrum 1977: 271). Westrum sees parallels between UFOs and sea serpent reports and meteorite reports in the pre-scientific state (Westrum 1977: 272). The difference is that sea serpent reports received considerable support from the scientific community (Westrum 1977: 272). In the case of meteorites, the possibility of stones falling from the sky was rejected out of hand by eighteenth century scientist John Pringle, but we now know Pringle was wrong (Westrum 1977: 295-296).

Astronomers often assert that the reason they reject ufology is because the evidence is not convincing. Goldman and Owen note**, "**Without clear cut evidence, the proponents of the extraterrestrial hypothesis for UFOs face a difficult task when they seek to prove that we are being visited by other civilisations" (Goldman and Owen 495). What counts as evidence has been shown to be socially determined, in so far as it is based on prior assumptions. One such assumption amongst astronomers is that the so-called 'evidence' is only eyewitness reports; no 'physical' evidence is forthcoming. At least this is the view of sceptics such as Menzel. However, Hynek claims there is evidence (Hynek 28). In fact, one of Hynek's three categories of UFO sightings, Close Encounters of the Second Kind, is characterised by the physical effects left (Hynek 29, Ch. 9, 229). Hynek concludes, "the data that now lie scattered about, if properly processed, could establish the substantive nature of the UFO phenomenon beyond reasonable doubt" (Hynek 218). Of course sceptics such as Menzel offer alternative explanations for such physical effects.

The problem with the criticism of 'eyewitness' reports is that they are seen as legitimate not only in a court of law but also in science. Many UFO cases are based on several or in some cases many eyewitness reports. That is, the reports are 'intersubjectively tested'. See, for example, the Lakenheath case (Sagan 1972: xxv-xxvi), the Socorro case (Hynek 144-145) and the Father Gill case in New Guinea, in which thirty-seven independent witnesses described the same phenomenon (Denzler 38, Hynek 145-150, Sagan 1972: 146-153). Individual cases cannot be replicated and experiments cannot be done. But reports of sightings over a long period of time seem to suggest a coherent set of observations (Ben-Yehuda 158). It could therefore be argued that such reports should under Popperian scientific methodology invoke further inquiry. The lack of such inquiry and the ignoring of such reports by astronomers can be seen as resulting not solely from scientific reasoning. Hynek overheard a conversation in which a scientist told a ufology researcher that if only one tenth of that amount of data had been obtained from research in his own field, he would not have hesitated to accept it as legitimate evidence (Denzler 109). Clearly it is not testimony itself which is at issue here, but *whose* testimony. Testimony is sorted into reliable and unreliable depending on the "knowledgeability and skill of those providing it" (Shapin 262). The relationship between the professional astronomer and the ufologist is a continuation of a tradition that dates back at least from the seventeenth century, when, as Shapin notes, "A distinction was thus introduced between the realities which made themselves available for competent experience and the experience actually had by different sorts of persons. Having an experience here is to be accounted an entitlement" (Shapin 262).

Of course ufologists engage in their own boundary work. In their search for scientific legitimacy, the more scientifically minded fight the attempts of debunkers to conflate abductees, contactees and their cults with the study of aerial anomalies focusing on systematic investigation and data gathering; claiming that while the former is religious, the latter is an observational science comparable to astronomy (Denzler 65). They also fight attempts by both debunkers and other ufologists to associate ufology with religion and 'new age theology', and attempt to ally themselves with astronomy (Denzler 140-141). As late as 1996, MUFON had volunteer members who had degrees in astronomy (Denzler 18). But the fact that the vast majority of ufologists are amateurs is reason enough to ensure that the field remains fully outside acceptable science. One disadvantage that ufologists have in their boundary work is that there is no single legitimating structure or organization that has had the resources to be able to draw the boundaries. Despite the existence of serious organizations such as MUFON ufology has been characterised by a proliferation of UFO magazines, television shows and Internet sites on the paranormal, which include UFOs as part of their subject matter. These media devoted to the paranormal help to sabotage any attempt by more scientifically minded ufologists to gain scientific respectability for their activities. One response to the non-acceptance of ufology by science is to revel in it: to assert that normal science is incapable of resolving the UFO enigma. This view was enhanced by the abductee phenomenon, and encouraged by the popularisation of the 'New Physics' (Denzler 115). Hynek argues that given the data, it is the sceptics and debunkers that are being unscientific (Hynek 170).

Arthur C. Clarke, Carl Sagan, and other popularisers have argued that no one has found a piece of a UFO, so there is no tangible evidence. However, as we have seen, what counts as evidence is problematic. Hynek claimed there was evidence, but Clarke and Sagan would argue that physical markings are not evidence; only a fragment of a UFO proven to be alien would count as evidence. The bar for what counts as evidence is considerably higher amongst the UFO sceptics, because, as Sagan has insisted, 'Extraordinary claims require extraordinary evidence'. However, there is no direct, tangible evidence for the existence of extra-terrestrials, and yet SETI has now become a respectable field of activity. The astronomical community (or at least parts of it) can envisage spending large sums of money to detect extra-terrestrial intelligence using radio telescopes; they do not have a similar enthusiasm for UFO research. According to Westrum, exobiologists and astronomers interested in interstellar communication are seldom interested in UFOs (Westrum 1977: 293). Evidential arguments seem inadequate as the sole explanation of the different relations of ufology and SETI to astronomy. Ufologists argue that if scientists wait until they could personally see a UFO or its remains before they begin to take a serious interest in them, ufology would remain at a standstill (Denzler 35).

We can see that astronomy is not definable merely by the group of true statements it makes about its subject matter. It is also composed of acceptable errors (Denzler 68). For example, most astronomers would agree that the Steady State theory is in error. But none would say that its creators, Hoyle, Bondi and Gold are not scientists because they made this error. In contrast, ufology stands outside these errors; it is outside the accepted paradigm, outside respectable parameters. To most astronomers, ufology consists of wild, undisciplined statements that do not come within the rubric of astronomy or even science. Indeed, one response of astronomers is that the existence and popularity of ufology is a manifestation of the failure of scientific educators to produce a scientifically informed public; a failure of science to popularise itself among the masses so as to make its own ideas and approaches to natural phenomena a part of the intellectual currency of everyday life. Thus the relationship of ufology to science is to deepen the problems inherent in producing a scientifically informed populace. Ufology, on rare occasions, has broken through the boundary constructed by astronomers, as in the aforementioned American Association for the Advancement of Science meeting in 1960, only to be immediately repulsed. The upshot of this situation was that the scientists' most common formal contact with ufology was through debunkers such as Donald Menzel, a Harvard astronomer, and Philip Klass, editor of *Aviation Week and Space Technology*.

Ufology thus became a 'pseudoscience' to be either ignored or attacked, but mostly ignored. Both reactions constitute a rejection of ufology. Collins and Pinch contrast these two types of rejection. If a theory is ignored it is implicitly rejected; if attacked it is explicitly rejected. Many physical theories are implicitly rejected. Even published theories can be rejected by the absence of response to the published article (Collins and Pinch 239). But ufology doesn't even get this far. Indeed, even astronomers who spend time attacking ufology would be at pains to distance themselves from Denzler's inclusion of them as part of the UFO community (Denzler 4).

Menzel established a five-part model for testing UFO information. Reports should be: first hand, untarnished by interpretations made concurrently with the observation, come from a qualified observer, backed up by independent, reliable observers, and finally, written down and signed by the observers(s) (Menzel 150-151). The notion of a qualified observer is, however, problematic. Moreover, when sightings appeared to confirm to Menzel's criteria, such as the New Zealand sighting by Father Gill, and a multiple sighting in Tennesee, the debunkers put different interpretations on the phenomena (Denzler 81). This 'shifting the goalposts' indicates that Menzel's standards, far from being objective criteria, are a form of boundary work. To ufologists, the debunkers themselves were not being scientific, and were armchair critics who had not done any fieldwork in the subject. Ufologist Jacques Vallee retorted that the scientific method had never been used to study UFOs, and that rather than being an embarrassment to science, a scientific study of UFOs would be an excellent way to educate the public about how science works (Denzler 87). The UFO community complained that scientists did not specify what they meant when they demanded 'one good case'. What is 'a good case'? When ufologists came up with what they considered a good case, scientists, they claimed, would raise the evidentary bar (Denzler 87-88). In reply, Carl Sagan would assert 'Extraordinary claims require extraordinary evidence'. One sceptic went so far as to admit 'no witness is credible who bears a sufficiently strange story'.

At present, however, ufology is unable to break out of its status as a 'pseudoscience', partly because of the boundary work by astronomers. This boundary work is partly based on a reasonable and "justified fear of being ridiculed and losing prestige and credibility" (Ben-Yehuda 167).The boundary work of astronomers and other scientists in relation to ufology can be seen as an ideological effort and is characterised by a debunking and dismissive rhetorical style designed to belittle those on the margins of the discipline who might constitute a threat to the hegemony of the profession. The 'scientific method' used by astronomers to distinguish themselves from ufologists and astrologers can be seen as an ideology used for political purposes. As Gieryn notes "Just as readers come to know Holmes better through contrasts to his foil Watson, so does the public better learn about 'science' through contrasts to non-science" (Gieryn 1999: 791). But as the case of astronomy, astrology, and ufology shows, despite the attempts of ufologists to interpret UFOs in a way that maintains a respectable public image (Denzler 29), the 'knowing' attained by the public is of a form that legitimises the knowledge claims of astronomy at the expense of astrology and ufology.

On the one hand, astronomers must distance themselves from 'UFO nuts'; on the other, they must maintain the public's interest. The position of the tightrope they walk changes with culture and technology. When astronomers distance themselves from ufology they contrast their high culture (elite scientific scepticism) with popular culture, which sides with the believers (Van Riper 284-286).

The purely 'scientific' then cannot explain astronomers' hostility towards ufology. This hostility can be seen as an example of boundary forming on the part of astronomers. It is one strategy by which astronomers can secure and maintain academic respectability. In this context Bourdieu's comment about American official sociology can be applied to astronomers. Bourdieu writes that American official sociologists "Impose a demarcation of the scientific and the non-scientific which is designed to forbid any inquiry liable to question the basis of their respectability" (Bourdieu 22). Bourdieu continues: "Different representations of science correspond to different positions in the scientific field … these representations are *ideological strategies* and *epistemological positions* whereby agents … aim to justify their own position and the strategies they use to maintain or improve it, while at the same time discrediting the holders of the opposing position and strategies" (Bourdieu 40). Ufology is characterised as 'non-scientific' and so not worthy of the astronomers' time. The boundary forming done by astronomers in relation to ufology can be seen as a form of social differentiation. A small minority of high profile professional astronomers, such as Sagan, have been willing to debate the issue in public, but on the whole, despite the public's interest in the topic, confirmed by the many UFO stories in the mass media, astronomers continue to be dismissive. Thus the activities of modern astronomy cannot solely reflect the level of public interest. Astronomers as a profession are given a certain amount of autonomy to decide what to investigate. On occasions they choose what is popular, but not always.

The Search for Extra-terrestrial Intelligence (SETI)

Both SETI and ufology study the same problem: extraterrestrial intelligence. Both activities lack evidence that would convince sceptics that aliens exist. But SETI has become a legitimate science, whereas ufology has not. Why is this?

Dolby (1979) specified three ways for deviant science ('pseudoscience') to become normalized: first, ideas similar to those of the deviant science can be developed by scientists; second, scientists take ideas from the deviant science; third, the deviant science can become orthodox. SETI is an example of the third way. SETI does share the assumption of ufology that extra-terrestrials exist, and so has an element of the second way.

SETI is not the only case of boundary crossing in astronomy. In the eighteenth century scientists ridiculed people who claimed to have seen "stones falling from the sky" (meteorites). Pioneer radio astronomers Janksy and Reber at first suffered the experience of having their science rejected as 'unbelievable' by observational astronomers (Ben-Yehuda 126-127). But the case of SETI makes an interesting counterpoint to ufology. In twenty years, SETI has gone from being a lunatic fringe activity, a virtual subset of ufology, to being an established and at least semi-respectable sub-field of radio astronomy; it has crossed the boundary from 'pseudoscience' to science proper. SETI has travelled from the world of speculation, folklore, fiction and 'pseudoscience' into the world of scientific legitimacy. It still shares with the UFO phenomenon the lack of direct evidence; no one has discovered an alien civilisation or any artefact that would count as evidence, yet SETI using radio telescopes has become, at least for some professional astronomers, scientifically respectable. Astronomers would possibly say that the nature of the evidence is different, but this shows that what counts as evidence is not itself self-evident! The language game of professional astronomy has to do with big science; large radio telescopes can be used to do SETI, but if the astronomer were to investigate UFOs she would not know where to begin in terms of equipment. To the ufologist, the evidence is persuasive enough to warrant further investigation. To some professional astronomers at least, SETI, but not ufology, is worth pursuing. For SETI, the process of legitimation began in 1959, when Cocconi and Morrison published their paper in *Nature* suggesting the feasibility of using radio telescopes to search for communications from extraterrestrial intelligence.

The idea that extra-terrestrial intelligence exists is by no means new. In fact philosophers, theologians and scientists have discussed it for centuries. By the beginning of the twentieth century the general scientific opinion was that although extra-terrestrial intelligence might exist in other parts of the universe, the possibility of contact was discounted. Thus during the first half of the twentieth century discussion of the topic became the preserve of science fiction writers rather than of scientists. This remained the case until 1959, with the landmark paper by Cocconi and Morrison.

The journey of SETI from the world of ‘pseudoscience’ into the world of science involved many landmarks, some of which were overtly ‘scientific’ and some that were purely political in the narrow sense. The first landmark was Cocconi and Morrison’s paper. This was a breakthrough because it was the first paper written by respectable astronomers in a reputable scientific journal suggesting that SETI was an appropriate activity for radio astronomers. The second major landmark was when a professional astronomer, Frank Drake, who has since become a major SETI lobbyist, used a large radio telescope at Green Bank, West Virginia, to do a search. The title of the enterprise, ‘Project Ozma’ reflected the still uncertain status that SETI had within the astronomical community, Ozma referring to *The Wizard of Oz*. A third landmark was the overtly political struggle to extract money from Congress for the activity. Another purely scientific landmark was the discovery of planets in other Solar Systems (such discoveries are still being made and each one brings fresh discussions about the possibility of life on other worlds).

Another landmark took place in 1971: the SETI convention held in Byurakan in Armenia. The convention attracted some respectable and well known astronomers. The convention put SETI on the astronomical map and mapped out strategies for research. According to Ben-Yehuda (1985) the convention was the most significant event in the history of SETI, and since then, SETI research has gradually developed as an accepted scientific activity.

Though they range from the purely 'scientific' to the purely 'political', legitimation landmarks form a continuum and their significance for the legitimation of SETI cannot be understood separately. Each one was a step forward in terms of SETI becoming a legitimate scientific enterprise. Here the merging of the 'scientific' with the overtly 'political' in the traditional sense becomes clear. In order to become accepted as a legitimate activity, SETI had to win the approval of Congress, and overcome Senator Proxmire's giving it his 'Golden Fleece' award for the year's silliest waste of taxpayer's money. Proxmire was able to point to the fact that SETI had failed to pick up any alien transmission, and the fact that at that time, the SETI community remained small, with a tendency to inbreed, the same names appearing on committees, panels, papers, and searches (Edelson 125-126). It took a 'big name' like Carl Sagan to convince Proxmire that SETI was indeed a reasonable enterprise. Neither was opposition to SETI limited to those sceptical of its success. In 1976, one of Britain's leading astronomers, Sir Matin Ryle, in a letter to the New York Times, urged radio astronomers not to make known our existence to extra-terrestrials lest the earth be invaded by hostile beings.

The case of SETI highlights the fact that what constitutes 'astronomy' is not static. Astronomy has now broadened to include SETI as a legitimate field of study. It does not require a leap of faith to speculate that, if SETI succeeds, and signals from a technological civilisation are detected, this would cause the boundaries of astronomy to broaden yet again, to include some phenomena that now come under the rubric of the 'pseudoscience' of ufology.

It can be seen that in order to legitimate itself SETI has had to succeed in both the constitutive (formal communication within science) forum and the contingent (informal communication including outside the scientific field) forums (Collins and Pinch 239-241). Articles have to be published in authoritative journals, such as the article by Cocconi and

Morrison in *Nature* (constitutive), professional organizations are formed, such as the SETI Institute (contingent), as well as negotiating in the political arena and in the mass media (contingent). According to Edelson, in the early fifties, Cocconi wrote to Sir Bernard Lovell, Director of the newly built Jodrell Bank Radio Telescope, suggesting a search for electromagnetic beams of radiation modulated in a rational way, such as trains corresponding to prime numbers. The tone of Cocconi's letter was "half apologetic for proposing a project that at first looks like science fiction" (Edelson 126). Lovell was apparently very polite in his rejection, saying that Jodrell Bank was too busy with other projects. Ben-Yehuda may be exaggerating but is not completely wrong when he says that today such a request would not be automatically rejected, even politely (Ben-Yehuda 216).

Following suggestions by Markus (1987) one can trace hermeneutically the changing meanings associated with the changing boundaries of a scientific discipline. Astronomers constructed a language that was appropriate for SETI discourse; a language that would be scientifically legitimate. For example, language associated with science fiction, such as the word 'alien', is rarely seen in peer reviewed SETI articles.

In the end SETI gained the support of enough high-status scholars to win legitimation. Though still controversial with many astronomers in terms of whether it warrants significant resources, SETI is now a respectable area of study within astronomy. The link with ufology no longer debars SETI from scientific legitimacy, to the extent that physicist Paul Davies is able to suggest that interest in both SETI and UFOs is part of a wider religious quest (Davis 1995: 135-136). SETI legitimation is not complete; that is to say, it is still controversial. For a while Congress funded a SETI program, but then abandoned it. Project Phoenix, the biggest SETI program in existence, is now privately funded. SETI is an example of cognitive, rather than methodological boundary movement. That is to say, there was a change in the notion of what it is reasonable to study, rather than a change in methodology. Finally, the case of SETI supports Ben-Yehuda's proposition that "the labelling of ideas as deviant or pseudoscientific have much to do with the cultural matrix (paradigm) or scientific belief system that prevail in a specific scientific discipline at any given time" (Ben-Yehuda 122).

Amateur Astronomy

Given the boundaries previously mentioned between professional and amateur astronomy, the question arises: to what extent is amateur astronomy a science? Clearly, amateur astronomy in *not* a science if to be a ‘science’ requires an infrastructure like that of professional astronomy. I refer here of course to modern astronomy. Boundaries change over time. The discoveries that established astronomy as a field of scientific inquiry were made by amateurs. In the 19th and 20th centuries those discoveries were formalised and measured by a new breed of publicly funded professional astronomers, working with telescopes well beyond the reach of the amateurs.

Modern science, unlike say the science of 18th century England, is characterised by professionalism and an infrastructure that includes equipment, laboratories (or in the case of astronomy, observatories) and peripheral personnel: technicians, lab assistants etc. Amateur astronomy has none of these; its status as a ‘hobby’ means that it is a completely different political entity to professional astronomy, even when there is some overlap in activity. Amateur astronomy has no need of the kinds of legitimation activities that professional astronomy needs, because it does not aspire to the political status of professional astronomy, neither does it require expensive resources. Whilst relations between professionals and amateurs are generally positive, professionals engage in demarcationary boundary work when amateurs attempt to encroach on prestigious professional activities, as with the Hubble Telescope, where some astronomers complained bitterly about the possibility of amateurs being given observational time (Chaisson 83).

The word *amateur* entered the English language around 1784, and the word *scientist* was coined by William Whewell in 1840. For most of its history astronomy has been an amateur pursuit; there were no professional astronomers or other scientists, so there was no need for the words.

Their decision to concentrate on interstellar and extragalactic phenomena further differentiates professional astronomers from ufologists, amateur astronomers and astrologers. In contrast, this same decision constitutes a boundary blurring between astronomy and theoretical physics, especially via cosmology. The crucial turning point here was in 1859, when the invention of spectroscopy led to astrophysics being a viable alternative to astrometry and celestial mechanics. These old astronomies were more susceptible to useful amateur input, but the new astrophysics required expensive spectroscopic equipment. Thus from the mid nineteenth century until mid twentieth century, professional astronomers distanced themselves from amateurs and moved closer to their physicist neighbours.

Coinciding with the advent of astrophysics, astronomy emerged as a distinct profession. This process was a part of the general emergence of professionalism in the nineteenth century (see chapter five). In the latter part of the nineteenth century and the early twentieth century there was a dramatic rise in the building of observatories and a consequent growth in professional astronomy. Amateurs found that they could not command the resources available to professionals. Thus a strict demarcation emerged between professional and amateur astronomy. Confrontations between amateurs and professionals were superseded by cooperation on terms dictated by professionals (Lankford 376), with a reasonably strict division of labour between amateurs and professionals: amateurs limited themselves to comet and meteor hunting, variable star searching, and providing data which professionals interpreted. Professionals concentrated on galactic and extra-galactic phenomena.

One notable exception to the strict demarcation between professional and amateur astronomy was the early days of radio astronomy. Experiments by Karly Jansky, a radio engineer for Bell Telephone Company, confirmed the existence of extra-terrestrial radio waves. Jansky published his findings in 1932, in the *Proceedings of the Institute of Radio Engineers.* Jansky's claim that radio waves came from celestial bodies was met with incredulity by optical astronomers. In 1938, Grote Reber, another radio engineer took up where Jansky had left off. Reber attempted to submit a paper to the *Astrophysical Journal*. When the paper was sent for peer review the reviewing astronomers complained they couldn't understand the engineering terminology and questioned Reber's crudentials. His paper was rejected by the reviewers but the editor, Dr. Struve, was impressed by the paper and published it anyway. Reber's paper appeared in the *Astrophysical Journal* in 1940.

According to Edge and Mulkay: "It is, perhaps not surprising that the scientific community would not immediately notice the work of a largely self-taught amateur … the optical astronomers were, of course … rather doubtful about the reliability of the information presented by this unknown amateur" (Edge and Mulkay 263). When it was first presented, the work of Janksy and Reber had no recognition or support from optical astronomers. This was because that their work presented a new, unconventional scientific speciality. This speciality had no structure. It was understood by radio engineers, who did not see its significance, and not understood by astronomers, who, if they had understood it, would have seen its significance. The prevailing paradigm of optical astronomy did not include the methodology of analysing radio waves.

The strict demarcation between amateur and professional astronomy lasted until the 1960s. Since the 1960s there has been a transformation in the relationship between professional and amateur astronomy. From around the mid-nineteenth century to the mid-twentieth century amateurs typically had limited resources: small telescopes, with little or no peripheral technology, whilst professional astronomers had access to enormous resources, such as the 200 inch telescope on Mount Palomar. Professionals published in *Astrophysical Journal*, while amateurs, if they did publish, published in *Amateur Astronomy* or *Sky and Telescope*. Professionals studied interstellar and extra-galactic space, while astronomers studied the Solar System, meteors and comets. This is still the case to a great extent, but things are changing.

The advent of space based astronomy and the coupling up of American astronomy with NASA means that professionals too now study Solar planets. Moreover, the rapid development of computerised technology is moving the contour line between professional and amateur astronomy. In fact there is a revolution now happening in amateur astronomy. Parts of the Milky Way previously accessible only to professionals have been brought within the reach of amateurs. The transformation of amateur astronomy, which is affecting its relationship with professional astronomy, is the result of three technological innovations. Dobsonian telescopes, which are cheap reflecting telescopes, make reasonably powerful telescopes available to amateurs with limited means. CCDs (Charged Coupling

Devices) enable amateurs to take quality astronomical photographs of deep space phenomena; CCDs enable amateur astronomers to produce results rivalling those of planetary science professionals (Ferris 174). The Internet enables amateurs access to numerous databases and networks, and the ability to order up automated observing runs on telescopes they never need to visit. Thanks to digital cameras, computers, software and broadband communications a committed amateur has access to equipment of a sophistication that only a handful of observatories could afford 20 years ago. The Internet allows amateurs to co-ordinate their activities and multiply their power. And the open source movement has enabled amateurs with limited resources to gain access to powerful software. Moreover, the very fact that professional astronomy has become big science means that it cannot do certain things that amateurs can do. Typically, professionals only image one portion of the sky at a time, and big telescopes are usually only able to take a few images a night. Focussing on specific portions of the sky, usually in deep space, means that professionals overlook a lot of celestial phenomena. Whereas amateurs are free to do what they like, including making observations that have no scientific worth! (Ferris 110).

There is a growing sense that amateurs and professionals complement each other, and collaboration between the two groups is increasing (Ferris 50-51). To cite some examples, professionals lack the time to wait for unpredictable star fluctuations, so a group of amateurs from several countries have organized themselves into an international network to monitor them. Since then there have been hundreds of collaborations of variable star analysis between professionals and amateurs (Ferris 52-54). Amateurs have the numbers and time that professionals lack, and are often better equipped to engage in long term projects. In June 1988, there was a Martian dust storm, professional astronomers were unable to observe the storm because they couldn't get telescope time at short notice or had bad weather; amateurs then helped the professionals target the Hubble Space Telescope to catch Mars at the right times to catch the storms, and afterwards helped them to revise their data (Ferris 178). Amateurs from several countries were able to observe the dust storm and documented it on videotapes, photographs, and drawings. Professionals were grateful for this (Ferris 130).

A similar collaboration took place with regard to Jupiter, where amateurs made CCD images that were up to Hubble standards in terms of the information available in a single image, and comparable with images taken of Jupiter by the *Cassini* space probe (Ferris 188-189). Observations of Jupiter's moons by amateurs have similarly been on a par with those of professionals; amateurs have been given time to do serious astronomical work on the moons using the Hubble Telescope (Ferris 184), and their earthbound observations on Jupiter's moons have been comparable with those of both Hubble and Voyager (Ferris 186). Professional astronomer Reta Beebe comments on the advantages amateurs have over professionals in regard to observing Jupiter: "Amateurs typically own telescopes in the range of six to twelve inches, and they have a high probability of being able to see the planet through a turbulence bubble in Earth's atmosphere. Given the rapid response of the human eye, it's hard to beat what an amateur observer may see in an instant, and an instant is all that an observer may need to discern that there's something strange going on" (Ferris 193).

Professionals have requested the help of amateurs in asteroid hunting (Ferris 162). On occasions, professionals and amateurs make the same discoveries at the same time (Ferris 152), and the famous discovery of comet Shoemaker-Levy was a joint discovery by professionals Eugene and Carolyn Shoemaker and amateur David Levy. In fact it was Levy who instigated the making of exposures that led to the discovery (Ferris 168). The media and public response to the discovery led to an increase in the number of professional astronomers searching for comets and asteroids (Ferris 169). Finally, robotic astronomy has at the same time made professional astronomy more economically efficient and created yet another dimension of reciprocity between professional and amateur astronomers (Ferris 234).

Personal computers now affordable by many amateurs enable them to carry out operations once reserved for a university mainframe. Perhaps the most interesting and important collaboration between professionals and amateurs is the SETI@home Project (http://setiweb.ssl.berkeley.edu/). SETI@home is run from the University of California at Berkeley, but is sponsored by many private groups. It involves thousands of amateurs all over the world in an ongoing systematic search for extra terrestrial intelligence. Anyone with a computer and an Internet connection can participate. Participants download software as a screensaver. When the computer is not in use the screensaver receives and analyses chunks of data and sends them to the project. All the participant has to do is download the screensaver. We have here an unprecedented example of absolute minimal input from participants with the potential for contributing to one of the greatest scientific discoveries of all time. There is no reason why such distributed computer power could not be used in other astronomical projects, as well as projects in other fields.

The social ramifications of this are difficult to predict, but it is already apparent that amateur astronomers can and do carry out important work both complementing and supplementing the activities of professional astronomers. One possibility is that this new community of high tech amateurs will replace sections of the professional community. If use of distributed computing power by amateurs spreads, this could change the whole social structure within the discipline. It is possible that teams of professional astronomers based at observatories or university departments will be replaced by millions of home based astronomers with varying degrees of professionalism.

There are, however, at present, limits to what amateurs can achieve. A recent major report on US astronomy considers amateur astronomy a key part of the astronomical enterprise through amateurs participating in some aspects of professional research, but notes the obvious fact that there is no direct funding for amateur astronomers to do research (National Research Council 12). They cannot launch probes deep into space or theorise new discoveries. It is unlikely that amateurs will make significant discoveries in quantum physics, for example. Professionals will remain important. Yet Ferris has predicted that astronomy and other fields like it will increasingly become ‘pro-am’ activities, in which professionals and amateurs will sometimes compete and often complement one another’s work.

But there are other important differences between professional and amateur astronomy that are related to the process of legitimation. Modern professional astronomy cannot be understood merely as a discipline that addresses itself to the study of celestial phenomena. It is also a political entity, in the sense that it must engage in a power struggle to wrest resources from influential agencies in society. Amateur astronomy does none of these things, and so can be considered as a separate entity, not part of astronomy proper. Amateur astronomy can, however, be a useful ally to professional astronomy. An army of amateur astronomers can always be called upon to support the profession in various ways: attending meetings and conferences, supporting various outreach activities, disseminating positive arguments for astronomy, generally helping to maintain a high public profile for astronomy and maintaining its popularity. One astronomer recently enlisted amateur astronomers in his debunking of ufology (Plait 206). It remains to be seen in how the increasing potential of amateur astronomy as a result of computer technology will impact on the ability of professional astronomy to obtain resources. One possibility is that history will come full or partial circle, so that once again, amateurs will come to dominate the field.

Astronomy and Physics

Until the advent of spectroscopy in the mid nineteenth century, astronomy could be clearly delineated from physics because it was largely limited to astrometry and celestial mechanics: studying the position and movements of heavenly bodies. The discovery of the electromagnetic spectrum and the invention of the spectroscope meant that astronomers could now study the composition and structure of celestial phenomena. This brought them much closer to physicists. Agnes Mary Clerke, the historian of nineteenth century astronomy, noted that the disciplinary lines were blurring: “The astronomer has become … a physicist”. Clerke observed that there were no new groundbreaking discoveries left to make in celestial mechanics and astrometry, and that astrophysics was a new birth of knowledge (Clerk 142). Since astrophysics has come to dominate professional astronomy, the lines between astronomers and physicists have become increasingly blurred. This change did not occur without conflict. Astrophysics emerged outside of the astronomical community and was legitimated only when the generic community accepted astrophysics as an appropriate scientific activity. Crucial to the acceptance was the acceptance of the importance of “boundary objects” (Star and Griesemer 393), which were of interest both to those trained in physics and astronomy, such as the composition of stars. Boundary objects are produced when scientists from different disciplines collaborate to produce representations of nature that cut across already existing disciplines. The astronomers and physicists analysing the composition of stars shared the common goal of understanding the phenomenon. Such boundary objects act as bridges between disciplines.

As astrophysics emerged out of spectroscopy there were no clear lines of demarcation between the new science and the established field of physics. According to the Oxford English Dictionary the term ‘astrophysics’ was first used in 1869, but for many years was written “astro-physics”. Thus the *Astro-physical Journal* appeared in 1895 and The Astronomical and Astro-physical Society of America was launched in 1899 (Lankford 54). The formation of such societies and journals were crucial steps in the legitimation of astrophysics. Thus by the end of the nineteenth century the boundary between astronomy and physics was already becoming blurred.

In addition, a pivotal point was the creation of dedicated facilities for the express purpose of astrophysical research. In 1897 astronomer George Ellery Hale dedicated the Yerkes Observatory for this purpose, and in his dedication made a comprehensive statement about the goals of the new astronomy. Hale asserted that one of the primary missions of the Yerkes Observatory was to strengthen the good will and common interest that draw astronomers and physicists into closer touch (Lankford 70).

It is thus no surprise that, according to a recent U.S. report, “the largest set of interactions of astronomy with other fields currently involves theoretical physics” (National Research Council 154). The association with physics assists astronomers in their struggle for resources: physics is one of the best-resourced disciplines; particle accelerators for example cost billions of dollars. There are also rapidly growing interactions with computational sciences; there is also potential for interactions with biology via astrobiology, a budding sub-discipline of astronomy (National Research Council 157-158).

The relationship between modern astronomy and physics is complex. In the above example astronomy and physics are clearly delineated, but in the case of astrophysics, which constitutes much of modern astronomy, the boundaries break down completely. When Dr Lane of the NSF argues for funding for astronomy, he is doing boundary work by associating astronomy with physics and making the case for them together. The boundary between astronomy and physics disappears in the case of astrophysics, which constitutes much of modern professional astronomy; a boundary has been created *within* astrophysics: particles as tools for remote observation and the physics of particles themselves (National Research Council 22). Much of modern astronomy is about studying what celestial bodies are made of rather than their position and movements; modern professional astronomy can be chemistry as well as physics. For example, two projects specifically recommended by the recent report *Astronomy and Astrophysics in the New Millennium* will be dedicated to studying the chemistry of white dwarfs (National Research Council 72), and another to studying the chemical evolution of galaxies and related phenomena (National Research Council 108-109). In X-Ray astronomy, there is no distinction between physics and astronomy whatsoever: "The problem with cosmic ray physics is that it is cosmic ray astronomy … there are only two things cosmic ray physicists can do to increase their chances of success … " (Tucker and Tucker 8).

Here we have a group of scientists who prefer to be called physicists actually doing astronomy (studying celestial phenomena); boundary work between physics and astronomy works both ways. Moreover, the boundaries between astrophysics and cosmology and nuclear and particle physics are becoming blurred (National Research Council 2000: 72). Increasingly, important astronomical discoveries are being made at the interfaces between disciplines (National Research Council 2001: 7), where boundary work becomes boundary fusion. *Astronomy and Astrophysics in the New Millennium* asserts the importance of astrophysical infrastructures to support observational work: "The committee emphasises that telescopes alone do not lead to a greater understanding of the universe. So that maximum benefit can be obtained from the current and proposed new facilities, the committee recommends a vigorous and balanced program of astrophysical theory, data archiving and laboratory astrophysics" (National Research Council 2001: 96). The same report overtly uses astronomy's interdisciplinary nature, especially its technological and instrumentation aspects, to claim that astronomy contributes to a strong technical workforce (National Research Council 2001: 160, 170).

Astronomy as Pure Science

The image of astronomy as an innocent pure science also constitutes a boundary, which serves to legitimate the discipline and the profession. The creation of such an image ensures that on one hand astronomers do not have to show that astronomy must have positive utilitarian results or spin-offs, and on the other ensures that astronomers are not associated with negative consequences of related big sciences such as the arms industry. As Gieryn notes: “Public and political pleas for the regulation of science often result from dissatisfaction with its *practical* accomplishments: either scientists fail to provide the technological fix that the public desires, or they produce technological capabilities that the public fears or loathes” (Gieryn 1983: 781-795). Thus astronomy’s image as a pure science shields it from some of the perceived negative attributes of science.

The central role of mathematics in professional astronomy also constitutes a boundary between that practice and astrology, ufology and amateur astronomy. The emphasis on mathematics in university astronomy courses and in the professional journals maintains and extends the boundary, and ensures that professional astronomers are an elite, in Pareto’s sense of the term (superior social group).

As Gieryn points out, the choice is between the two models of science. In one, basic science is synonymous with applied science, or at least directly leads to it. The other is a more sequential view of science, with pure science indirectly leading to applied science via a complex and subtle process of serendipity, not depending on specific discoveries but on “putting the taxpayers’ dollars on a winning horse” (Gieryn 1999: 205). The situation with astronomy, is however, quite different from the Cold Fusion fiasco Gieryn discusses. With Cold Fusion, the sequential model went against Pons and Fleishmann. They tried to go over the heads of peer reviewers and appealed directly to politicians and general public via the media, attempting to convince them that cold fusion was a ‘winning horse’. Their attempt failed. In contrast, since astronomy has no clear, direct or obvious utilitarian benefits, astronomers resort to making a case for astronomy independent of any utilitarian claims.

With astronomy, 'winning horse' must be broadly defined as being more than just the successful practical application of science leading to technological and economic improvements. It is rather a horse that wins for its own sake. Finally, the very questions posed by modern astronomy cut across traditional disciplines and government agencies, calling for change in the social relationships both between scientists and between government agencies (National Research Council 18, 196).

Physical Boundaries

As well as epistemic boundaries, such as those between amateur and professional astronomy or, between astronomy and ufology or astrology, there are also physical boundaries. Astronomers must fight for physical (spatial) boundaries with other interests and technologies. Moreover, as Agar points out, boundaries that are cultural and social artefacts can become physically reified (Agar 273).

Recently, astronomers have begun to make common cause with environmentalists, as in the case of light pollution. But sometimes astronomical projects can be destructive to the environment. Environmentalists protested against the construction of the Mount Graham International Observatory (MGIO), financed by the University of Arizona and other US and international agencies. The environmentalists argued that the facility might cause the extinction of a rare form of Red Squirrel endemic to the Mount Graham area. The squirrel depends upon the health of the mixed conifer and fir trees on the mountain. The construction of the MGIO permanently removed or destroyed 8.6 acres of the 24-acre area designated for the telescopes. Native American and environmental groups sued, claiming that a power line to the summit would further harm red squirrel habitat. Proponents of the telescope claim that the power line will replace the frequent truck shipments of diesel fuel needed for generators and eliminate the possibility of an environmentally damaging oil spill from a motor vehicle accident. Studies have shown that contrary to the environmentalists' claims, squirrel population has increased since the building of the MGIO (Ryback 30).

According to Chaisson, every shuttle launch causes the death of thousands of fish, due to the surrounding water becoming extremely acidic. An official Air Force document states: “These affected animals should be considered dedicated in the interests of the mission” (Chaisson 16).

Astronomers working on the light pollution issue found allies among marine biologists concerned with nesting sea turtles. The turtles, it seems, prefer their beaches dark at night (Ferris 13). In Britain light pollution has now become a national issue, with amateur and professional astronomy groups making common cause with the Society for the Protection of Rural England in lobbying for a decrease in light pollution (Adam 2003). The two groups then supported the recommendations of a Commons select committee on science and technology report. The report:

> Warns that the majority of professional astronomy now takes place outside the UK — due to the poor and unpredictable weather conditions of the British Isles, their hemispherical position and to the continuing encroachment of light pollution on British skies. The MPs highlighted the importance of the UK's “thriving” amateur astronomy community, which provides important observational data to professional astronomers (Associated Press 2003).

Here astronomy becomes an overtly political entity: a pressure group allying with and fighting alongside other pressure groups against opposing interests, in this case the lighting industry. In fighting for darkness, astronomers define their struggle in terms of popular themes, for example by defining the artificial lighting of the night sky as “light pollution” and a form of “environmental degradation” (Burton and Gural 82).

Such problems are now regarded as so urgent that the American Astronomical Society now has a committee on light pollution and radio interference. In radio astronomy, certain wavelengths must be kept set aside for astronomical use. Similarly, measurements of faint radio signals from distant galaxies require an environment with low levels of artificial radio noise. Signals from a relatively low-power local radio station completely overwhelm cosmic radio waves. Therefore, radio astronomers must avoid the wavelengths at which radio and television stations broadcast. Earthbound radio astronomy could not exist if certain wavelengths were not off limits to radio and television stations. Since the inception of the discipline radio astronomers have had to negotiate frequency/wavelength boundaries with other interests. "Broadcasting for television and radio entertainment was merely a small part of the huge problem of accommodating everybody's interest in the restricted band of wavelengths: the armed services, the Home Office, commercial enterprises, civil aviation, and a host of other interests all laid claim to use of radio frequencies for communication purposes" (Lovell 1968: 174). About two-dozen bands have been allotted to radio astronomy by international convention, but conventions change and radio astronomers must continually battle against proposed encroachments into their part of the electromagnetic spectrum. The result of the negotiations for these set aside spaces constitutes a boundary that gives an indication of astronomy's place in society.

Lovell and his colleagues at Manchester University also became players in local politics. Geographical boundaries were constructed and defended. The Jodrell Bank telescope, of course, took up a physical space, and this physical space, extending beyond the actual physical extent of the telescope and its environs, came into conflict with other local interests. The city of Manchester, at this time, was having population over spill problems, and one of the options the city was considering was developing the area around Congleton, dangerously close to the telescope. Lovell wrote to the DSIR explaining to them the dangers posed by a development in Congleton. The DSIR in turn sent this memo to the Ministry of Housing. The local weekly *Congleton Chronicle* managed to get hold of a copy of the memo, and proceeded to mount a vitriolic campaign against the telescope and against Lovell personally. At this point the telescope came up against local business people who were in favour of the development. Matters came to a head at a town meeting which was "hostile in the extreme" towards Lovell (Lovell 1968: 166). The next issue of the *Congleton Chronicle* was almost entirely devoted to the telescope, and to personal attacks against Lovell.

Such was the hostility of the townspeople toward the now infamous Lovell that he ceased to go into Congleton. The town clerk of Congleton met with Lovell and a compromise was worked out, so that a limited amount of development could take place in Congleton, with a minimal effect on the telescope. But Congleton withdrew their support for the compromise. Questions were asked in the House of Commons, and the result was a meeting comprising a delegation of local Congleton representatives, Cheshire County Council, the DSIR and Lovell and Rainford from Manchester University. Crucial to the outcome of the meeting was that the Parliamentary Secretary was sympathetic towards the project. A compromise was finally settled on which differed little to that which Lovell had earlier made to Congleton Town clerk. By this time, so many resources had been ploughed into the project that the government was reluctant to see it abandoned. Relations between Congleton local authority and Jodrell Bank remained strained and Lovell bemoans the fact that individuals have challenged the development of the telescope merely “because they saw the chance of making a considerable sum of money for building sites, not because they wished to live there themselves” (Lovell 1968: 169).

Ironically, the advanced technology of the telescope came into conflict with public utility technology. In the early 1950s**,** when the project began, the surrounding area had no electricity; apart from a few private electricity supply plants, villages used oil lamps or candles. For the telescope, this was good. Overhead mains generate electrical noise and nearby electrical equipment radiates more energy into a radio telescope than an entire extragalactic nebula. Again, boundary construction comes into play. Lovell objected to proposals for electricity lines that came near to the telescope. Lovell came into conflict with electricity authority officials, who were entirely unsympathetic to his case. In his account Lovell accuses electricity officials of “self justification” by using “uninformed comments about the levels of interference to be experienced from other sources in the neighbourhood with which the writer tried to justify the additional source of trouble which would be caused by this line” (Lovell 1968: 171). Gone here is the rational, objective scientist. Lovell’s attitude is more clearly seen in terms of a political activist fighting for a cause in which he passionately believes.

As with the Congleton affair, central government resolved the dispute. The matter went to the Ministry of Fuel and Power, who organized a meeting chaired by the Minister's deputy for electrical affairs. At this meeting Lovell was "outnumbered fifteen to one" (Lovell 1968: 172), and he comments "the minister's deputy was not at all impressed by the largeness of the Authority's deputation and asked his secretary in my hearing if they had no other work to do" (Lovell 1968: 172). Lovell thought that, "The size of the confrontation had the psychological effect of placing me with the Minister's deputy as the party resisting the invasion of my office by these aggressive individuals" (Lovell 1968: 172). The Minister's Deputy instructed the electricity authority to re-route the line away from the telescope. Lovell was to experience more conflicts with the electricity authority, but with similar resolutions. Friendly negotiation rather than conflict resolved a possible similar conflict with the electrification of British Rail. One of the British Rail representatives was, as Lovell notes, "an enthusiastic and knowledgeable amateur astronomer" (Lovell 1968: 174). As Agar notes, both the preservation of frequencies for the telescope and the legal constraints on certain nearby activities constituted the observatory's definition and operation as a privileged scientific site (Agar 279).

Demarcation Dispute 1 — Astronomers Versus Physicists

A recent case of astronomical boundary work involved the possibility of the earth being struck by a large meteorite. The emergence of this theme as a public issue can divided into several phases. Phase one, the genesis of the theme, happened in 1978 when physicists Luis and Walter Alvarez discovered large amounts of iridium in an area in Italy from the K-2 boundary: between the Cretaceous and Tertiary periods. Iridium is rare in the Earth's crust but common in meteors and asteroids. This led to the second landmark in 1980, when after a period of detailed analysis of the area and the iridium the physicists proposed the bold conjecture that an asteroid, or large meteor, had impacted the Earth and destroyed two thirds of all life, including the dinosaurs. The third landmark came in 1990, when a 20-mile wide impact crater was discovered in the Gulf of Mexico. The size of the crater and its estimated age corresponded to the physicists' conjecture. This discovery was the catalyst that launched the theme of a celestial object damaging the Earth into the public arena. The door was thus opened for astronomers to enter the debate. They could use their skills and equipment to search near space for potential Earth smashers. Thus astronomers now had a chance to portray themselves as group having some practical use. A group of asteroid astronomers began a campaign to put comet/asteroid detection on the policy agenda. Their case was enhanced when Comet Shoemaker-Levi ploughed into Jupiter. In July 1994 more than a dozen fragments from the comet crashed into the giant planet, causing damage over an area 4-5 times bigger than the area of the Earth. The spectacular impact explosions were seen by millions of people on television. A spate of TV shows and Hollywood movies followed featuring the Earth being attacked by entities from space. The comet also had the effect of galvanising planetary astronomers around the cause of constructing a defence system for the earth against a possible giant meteor strike. The comet was a political godsend for astronomers; it put them in the public limelight, and for once, their discipline could be seen as the one that could have some practical benefit. After all, it was astronomers who discovered the Shoemaker-Levi comet, and it was astronomers who would be able to design appropriate searching technology, and it would be astronomers who would keep vigilance, searching the skies for possible earth slayers.

Enter NASA. The US National Air and Space Administration is an institution that forms a bridge between disciplines. It is a boundary breaking entity. Within its financial power are not only astronomers but also other space scientists from other disciplines and with other interests. NASA also creates boundaries between activities to suit its convenience. For example Space Science programs are divided into astronomy, which refers to everything outside the Solar system; planetary exploration; Solar-terrestrial science, which refers to studies of the sun and its interaction with Earth's magnetic field and upper atmosphere; and Earth sciences, which refers to the study of Earth from space. These activities are all of course space science, but in NASA only the last two are space science, as distinct from astronomy (Tucker and Tucker 81). Once created and put in a situation where they were competing for budgets, it was inevitable that they would come into conflict. For example the astronomers (as defined by NASA) competed with the space scientists to get their AXAF project off the ground (Tucker and Tucker 83).

In 1992 at the request of Congress, NASA was charged with developing a strategy for protecting the planet from a cosmic collision. Dozens of space scientists spent months advising NASA on asteroid detection and inception. NASA had planned to release its proposals in March of that year, neatly wrapped up in a scientific consensus, signed by both planetary astronomers and physicists involved in weapons research. However, it was not to be. As meetings were held, it became apparent that the scientists involved in the project were deeply split. In one camp, astronomers felt that astronomers with astronomical equipment modified to detect approaching near earth large asteroids would be enough, with ground based back-up projectiles as a back up. On the other, physicist Edward Teller and his weapons research colleagues backed a 'Star Wars' type technology; their philosophy was the best means of defence is attack. The laid-back attitude of astronomers contrasted harshly with the aggressive, macho stance of the physicists. The astronomers were so incensed by the physicists' recommendations that they angrily demanded that NASA revise them (Smith F8). What was at stake here was essentially a demarcation dispute between astronomers and physicists who were basically weapons scientists, and whose allegiance was to the military. More profoundly, it was also a philosophical debate over our attitude and approach to outer space. Do we want merely to understand and explain the universe, or do we want to conquer, dominate and control it? In the words of Louis Friedman, Executive Director of the Planetary Society, the military scientists wanted, "To introduce weapons in space. And they'll come up with any justification they can to do that" (Smith F8). Of relevance here is the fact that astronomy is mostly observational (although astronomers do sometimes extract signals from noise using instrumentation), whereas most other sciences involve much stronger 'interaction' with nature — smashing atoms, mixing chemicals, dissecting frogs, drilling bores etc. In short, the astronomers wanted the emphasis of any program to be detection; the weapons physicists wanted the emphasis to be on deflection.

The result of the dispute was that the astronomers won. Since Comet Shoemaker-Levi NASA has put into place two Near Earth Orbit (NEO) programs, both of which are detection oriented: NEAT (Near Earth Asteroid Tracking) run by their Jet Propulsion

Laboratory at Pasadena, and which detects smaller objects, and Spaceguard, which is a program to detect larger objects based on six 2.5-metre ground-based telescopes, whose task is to detect 95% of NEOs at a cost of $300 million. The other major NEO programs are Spacewatch, a detection program based at the University of Arizona, and LINEAR, run by the US Air Force. The fact that even the one NEO program run by the military is a detection program highlights the success of the astronomers' lobbying. It is not clear why NASA chose the astronomers' approach, but it is likely that it is a decision based on relative costs. It is also possible that NASA is of the view that there is no need to prepare deflection techniques now until an object is found headed toward Earth.

Thus what began as an attempt by asteroid astronomers to enrol the public's fascination with dinosaurs, planetary collisions, and the idea of Earth under attack, to promote interest in asteroid astronomy, ended up in an acrimonious dispute over whose idea of humans' relation to outer space should determine policy. Here a group of astronomers engaged in boundary work with a group of physicists in a dispute in which the territory was near Earth space. This was not, of course, a dispute between astronomers in general and physicists in general, but a dispute between a sub-group of a sub-group within astronomy — asteroid astronomers, who were a sub-group of planetary astronomers, and a group of physicists who were weapons specialists. The astronomical sub-sub-group also had a power relationship with other members of their discipline. One planetary astronomer noted, “Astronomers, your colleagues, people you'd see in the cafeterias, they thought anyone who was doing Solar System astronomy — looking at these rocks, basically — had to be of questionable mentality” (Smith F8). The Shoemaker-Levi event raised the status of planetary astronomy in relation to the rest of professional astronomy. The fact that NASA, which is playing an increasingly important role in US astronomy funding compared to the National Science Foundation (NSF), is interested in planetary astronomy should help to maintain and increase its status. Note that this was not merely a disagreement over policy, but a demarcation dispute; at issue was not only what to do but who should decide what to do.

Demarcation Dispute 2 — Astronomers Versus Engineers

With the increasing sophistication of astronomical equipment, boundary work now takes place between astronomers and engineers. On the Hubble Space Telescope, designed, built and maintained by engineers, astronomers have had to work closely with engineers. One Hubble astronomer likened the gap between them to C. P. Snow's gulf between technologists and humanists, saying "neither scientist or engineer truly appreciate each other or even speak the same language" (Chaisson 92). The astronomers, as end users, saw the telescope as a purely scientific instrument. The engineers saw it as a technological challenge. Indeed, the first images taken by Hubble, the so called "first light" images, were chosen not because of their astronomical interest or public relations value, but for engineering purposes (Chaisson 142-143). There was also conflict between astronomers and engineers during the commissioning period of the Space Telescope. Engineers were supposed to be in charge of orbital verification, but astronomers wanted to be involved in checking the instruments to maximise observing utility. This 'meddling' by astronomers was resented by the engineers, who saw the astronomers merely as 'end users'. The astronomers were told to keep out of the way until the telescope was ready for them to begin their observations (Chaisson 168-169). Boundary work took place between astronomers and engineers over the science verification period. During the SVP (science verification period) when the Hubble was being tested, engineers were officially in charge of its manoeuvres, and when NASA extended the SVP astronomers took steps to bypass the engineers' control and manoeuvred the craft to get images of Mars and put them in the public domain (Chaisson 328-329).

Further conflict between astronomers and engineers took place when it was discovered that the main mirror was suffering from spherical aberration. The engineers 1) denied there was any aberration, saying the mirror was merely out of focus, then 2) maintained that the data were inconclusive, and finally 3) admitted that something must be wrong with the mirror. Once stage 3) had been reached, engineers became despondent, some became physically or emotionally sick, and the chief engineer even expressed concern that there might be suicides (Chaisson 172-173). NASA administrator Leonard

Fisk asserted the failure (of the mirror) was the space-science equivalent of the *Challenger* disaster, and reportedly cried (Chaisson 174). Such over reaction may be at least partially explained by the previous tactics of NASA: hyping the telescope to the point of exaggeration, distortion and even telling outright falsities about the capabilities of the telescope, insisting on taking all of the credit for the telescope (and hence the blame when things went wrong) and not having a back-up plan in case things did go wrong. Astronomers also became emotionally distressed and sick (Chaisson 180,197), and one Hubble astronomer claims that he stopped admitting to anyone what he did for a living (Chaisson 203).

At this point boundary work became withdrawal. The lead scientist for the wide-field and planetary camera stated that he had no desire to pursue his science goals, because the planetary camera would no longer be an improvement on ground-based telescopes. Rather than do second rate non-competitive science he determined to do no science at all (Chaisson 181). NASA's program scientist for Space Telescope joined in the withdrawal: "No real science could be done with the telescope's main camera … *Hubble* is running above [worse than] ground-based capability" (Chaisson 185). Both points were untrue. Moreover, when NASA did finally publicly admit that the main mirror was suffering from spherical aberration, they did so in a dramatic press conference that "transformed a technical problem into a social crisis" (Chaisson 186). Had NASA consulted the astronomers about what could and could not have been done with the telescope they would have been able to give the public a more balanced, less negative picture, for although the mirror was damaged it was still possible to do groundbreaking work with it. Instead, NASA veered from one extreme to the other. At the beginning they made statements exaggerating the capabilities of the telescope, and then when problems arose they exaggerated the problems. The media took up NASA's implication that the telescope was now useless, which was not the case. It was only by being consistently honest about the problems with the telescope that astronomers were able to avoid the NASA bashing exercise that ensued in Congress (Chaisson 187-189).

Even in the midst of the mirror debacle, boundary work took place *between* astronomers on the Hubble project. Those astronomers who felt they could still do meaningful work in their area sought to exercise damage control in their own interest, and manoeuvred to bolster those parts of their observing program that could still be done, while protecting the rest of their intended observations from rival astronomers, "whom they regarded as poachers" (Chaisson 203). The guaranteed time observers (GTOs) were particularly active astropolitically (Chaisson 203), pressing NASA for additional telescope time, moving to prolong their allocated time, since the mirror aberration meant that observations would take more time to complete; this meant that non GTOs would have less time allocated and would have to wait longer for that time.

Demarcation Dispute 3 — Astronomers Versus Astronomers

One form of boundary work has recently come to the fore with the advent of the Space Telescope. This is a form of boundary work done by individual astronomers against other astronomers. It is analogous to the concept of copyright in authorship. Involved is the notion that phenomena of a celestial object can become the private property of its observer. In outlining its rules of telescope engagement for the Hubble Space Telescope, NASA in its policy #2, stipulated: "All observations obtained by the Space Telescope on the basis of a peer reviewed and selected proposal shall be proprietary for a normal, one year period" (Chaisson 101). Once the Hubble Space Telescope project was under way, NASA gave astronomers exclusive rights to their data for one year. Once this was given, no-one else knew the computer password needed to gain access to science data without permission from the principal investigator. After this proprietary period, the observational data entered the public domain. Thus data about celestial objects could and did become the legal property of an astronomer. The reason for this was that getting time on the Hubble telescope is a difficult and competitive process. Proposals must be written, and if accepted, another proposal must be submitted giving specific details of the proposed project. There follows another delay between the second proposal submission and actual observing time. The observations are then analysed. This whole process can take months or even years, and it was felt that fairness requires that some time should be given to the observing astronomers to analyse and possibly publish their results, thus preventing other astronomers from exploiting the data worked for by observers.

The down side of proprietary rights was that it encouraged a form of possessive individualism, which manifested itself in negative ways. One astronomer for example claimed proprietary rights to the Orion Nebula, though his claim was ignored when it came to observation (Chaisson 320). Although some astronomers wanted photographs of celestial objects to be part of the public domain, including some that would constitute discoveries, others wanted only scientifically insignificant pictures to be disseminated: “the early images should produce no new science” (Chaisson 97). This put the astronomers responsible for choosing the pictures in a difficult situation, for it was possible that any pictures chosen might serendipitously contain an exciting discovery. They thus had to produce images to the media and public that were at the same time both spectacular and astronomically uninteresting. This they did, but it wasn’t enough to satisfy at least one astronomer. According to Chaisson, the astronomer responsible for choosing the first light objects, the resulting confrontation was as follows:

> The same member … who had objected earlier now objected again. And this time he did so violently. In the most uncouth manner I’ve ever experienced in my career … he screamed that a couple of his favourite cosmic objects were on my list. It was as though the sight of ‘his’ celestial object among the candidate early targets had triggered a proximity fuse. While I was formally addressing the group, attempting to articulate carefully the rationale used in preparing the list, and while perfectly willing to entertain deletion of specific objects, he repeatedly and heatedly interrupted, eventually blurting out loudly and with great emotion, ‘If you look at those objects before I do, I’ll kill you’ (Chaisson 101). This same objector persisted in his vehement reluctance to let anyone else observe ‘his’ object even when the technical and public relations problems of Hubble were causing most of the rest of the Hubble astronomical community to pull together (Chaisson 205).

To Chaisson, it was evident that the objector was "steadfastly opposed to sharing *any* Space Telescope findings with the public. The fears behind such an attitude are well founded. During the Voyager encounter with Jupiter a technician serendipitously discovered a volcano on Io that astronomers had missed. Hubble astronomers did not want a repeat of this embarrassing incident" (Chaisson 102). An author in a trade magazine quoted one Hubble astronomer as saying: "If [we] immediately release that information, every Joe Blow can read the newspaper, get out his plastic ruler, and scoop you." To which the author of the article added, "In this case, of course, 'Joe' would have to have at least a graduate's knowledge of astronomy" (Chaisson 102). In order that no other persons would have the slightest chance of using the photos to make discoveries, astronomers had divided the universe up so that the first photos shown to the media and the public would yield no new science. The original objector and a senior NASA official, who controlled the astronomers' grant money, teamed up to attempt to undermine the whole ERO program: "The public is illiterate about science anyway. It's none of their business. Do you mean to say that informing the public is an important part of this project?" (Chaisson 211).

In my interviews most astronomers were sensitive to and supportive of the notion of sharing their science with the public, but NASA appears to have brought out the opposing tendency; its own secretive, possessive, and paranoid attitude towards the public spilled over into some of the science team. The emerging fetish for ownership was highlighted when Chaisson approached another astronomer about the ERO program. The astronomer's response was, "Who will own these data?" (Chaisson 211). When the BBC (British Broadcasting Corporation) visited the Science Institute to film a documentary about the Space Telescope some astronomers argued they should not be allowed to look at the data the telescope had so far collected: "These are proprietary data", and "No, no, no, you can't film the image on my computer screen". There ensued arguments between two groups of astronomers as to whose property were the data (Chaisson 217).

Finally, when Chaisson approached Ed Weiler, the *Hubble* program scientist at NASA Headquarters for some early images to be made public, his response, though sympathetic, was that it could not be done because "Proprietary data rights are killing us"

(Chaisson 210). As a result of the objections of some astronomers and the intervention of the NASA official, the ERO project was abandoned. Any such similar initiatives could not be gotten off the ground because NASA had put no-one in charge of making such decisions (Chaisson 211). Chaisson's call for Hubble astronomers "to rise above individual concerns about proprietary rights and to work together as a team for the good of the project" (Chaisson 214) fell on deaf ears. In fact, matters got worse. At a subsequent meeting, the same objector who had threatened to kill Chaisson got hysterical, causing a guest engineer attending the meeting to exclaim, "I'll be damned if some of you guys don't need a child psychologist". Pushing and shoving brought the meeting to a close (Chaisson 230). Later, when a team of astronomers took images that were of better quality than an earlier team's images, and the second team's images were presented to the media, the leader of the first team berated the leader of the Science Institute giving media accessibility to the second team. The Science Institute astronomer, "Walked out when [the first astronomy team leader] became so emotionally worked up as to begin involuntarily spitting on my food while giving me hell. I found it the most disgusting moment of my career at the Science Institute" (Chaisson 342). Boundary work within a discipline can, it appears, become personally vicious. Here we have individual astronomers attempting to set territorial boundaries between themselves and other astronomers; in other words, boundary work *within* astronomy.

Neither were all the heated discussions amongst astronomers solely about observing rights to celestial objects and phenomena. Hubble astronomers spent a good part of a day discussing what to call the pictures that the public were to be allowed to see. Chaisson's term 'pretties' was disliked by some astronomers, and it was finally decided to call them early-release observations or EROs (Chaisson 103).

While it is important to note that it was only some astronomers who objected to Chaisson's approach of sharing Hubble's discoveries, and that others were enthusiastic supporters (Chaisson 103), it is still significant that the objectors obviously felt strongly about the issue, and attempted to establish clear boundaries between their property and what the media and the public should be allowed to see. Indeed the objector who threatened to kill Chaisson refused to allow *any* of “his” celestial objects into the public domain (Chaisson 104). This boycott of the sharing policy had a domino effect. At least one other astronomer argued that if the first objector was not going to let his objects into the ERO public domain, neither would he let *his* objects into the ERO public domain, because he didn’t want the first objector to be able to see *his* objects if he couldn’t see those of the first objector (Chaisson 104). Astronomers thus construct boundaries between themselves, the media and the public, and even between themselves.

The idea of celestial objects being the property of individual astronomers enhanced internal boundary work amongst the Hubble astronomical community. The mirror problem meant that several GTOs would not, for the time being, be able to observe some of “their” objects, but they did not want any other astronomers to observe them either. The question arose should such objects be locked with everyone else being forbidden to observe them until the GTOs were in a position to observe them themselves? Thus the issue of proprietary data became politicised, in a way probably not originally intended. Some astronomers viewed their research and its funding as a right. The US federal grants system (of which Hubble was a part) had become a form of social welfare for some astronomers. It was the resulting grant money that caused, according to Chaisson (204), many astronomers from speaking their minds about NASA. As it happened, the GTOs got their way, and were secured 30% more observing time, and got their proprietary rights extended for up to two years after the time Hubble was fixed. The result was that numerous objects were prohibited from being observed for several years (Chaisson 204). Once again, NASA was hoist on its own petard.

Despite its growing international character, credit disputes can still break out in the astronomical community. Such disputes however are not necessarily caused by direct disputes over discoveries. Rather, a dispute can occur when one group of astronomers feels that their work is being ignored at the expense of others. In the case of the Space Telescope, this happened not because one group of astronomers deliberately undermined the work of others, but because the parent organization, NASA, was so concerned that it should get prime credit for the work of the telescope that other groups involved, such as the

European Space Agency (ESA), were ignored. NASA refused to acknowledge the role of the ESA, who were operating the faint object camera on Hubble. The ESA in turn, however, botched up their attack on NASA by descending into nationalist factions about the wording of their planned press release (Chaisson 269).

Disciplinary Boundary Work

Boundary work in astronomy can take the form of boundary forming between astronomy as 'science' and ufology and astrology as 'pseudoscience', but can also take the form of encroachments on other disciplines, as with cosmologists such as Hawking and Davies attempting to encroach on philosophy and theology. By encroaching on these disciplines they extend the boundaries of astronomy into knowledge territories formally occupied by others. It is important to note that both types of boundaries are fluid; as the example of SETI shows, there is no strict unchanging demarcation line between science and 'pseudoscience'. There is also no strict unchanging demarcation line between astronomy and other disciplines; the boundaries are constantly changing. Indeed, what we call astronomy is constantly changing. Whereas until the mid-nineteenth century astronomy was about the positions and motions of celestial phenomena, now it is primarily about what those phenomena are made of. In the case of modern professional astronomy, these boundaries are affected by technological developments, such as the emergence of radio astronomy (Edge and Mulkay), the ability to attain resources for projects, the success of popularisers, and the general climate of acceptance for such popularisers in the wider society. Davies and Hawking could not be the influential names they are without the general atmosphere of receptivity amongst the general populace.

In the case of technological and political developments, the invention of the radio telescope and the willingness of governments to fund large radio telescopes meant that astronomers were able to delve into the far reaches of space and time, thus encroaching on fields normally assigned for philosophy and religion. Indeed, in the case of Paul Davies, Adelaide University created a new position just for him: Chair of Natural Philosophy (Davies has since moved on to Macquarie University). Such a title was a symbolic tribute to his success at boundary extension. It also indicates a move back to a time before the boundaries between the natural sciences and the humanities were created and fixed by Hobbes and Boyle (Shapin and Schaffer 1985). Davies, as well as other popularisers such as Sagan, went from being disciplinary specialists to universal intellectuals. Such boundary extension not only enhances their own prestige but also that of their discipline. When popularising then, astronomers are in fact managing cultural boundaries.

Why do Astronomers Engage in Boundary Work?

Boundary work is an interesting theoretical concept, but it is important to remember *why* astronomers and other scientists engage in boundary work. It is because it is in their interest to do so. Occasionally, boundary work can 'rebound' and harm the interests of astronomers, as when they construct boundaries against each other. Generally, however, astronomers *gain* credibility of a certain kind among specific groups by distancing themselves from activities they define as 'pseudoscience', and by allying themselves with credible and established sciences such as physics. This is not to suggest that there are not good scientific reasons for such alliances. The suggestion is merely that, intermixed with these scientific reasons, boundary work also has a political dimension, in terms of furthering the interests of astronomers.

The very internationalism of modern astronomy (probably the most international of scientific disciplines, in the sense that astronomers from any country can and regularly do use observatories in any country) extends the spatial boundary of the discipline. Astronomers thus form an 'invisible college' which transgresses national boundaries. Individual regions can be transformed by astronomy; a formally barren and useless mountaintop in Chile can suddenly become an economic Mecca. There is a sense in which astronomers constitute a placeless community, challenging notions of nationality.

But astronomers construct boundaries in a much more profound way. They attempt to maintain, control and extend their own disciplinary space but also construct society's notion of space by constructing the language with which we speak about celestial phenomena. For example the notion of outer space did not exist before modern astronomy. As Redfield notes (Redfield 266) "By opening the possibility of outer space and reordering connections on the globe, a modern sky redefines human place". The astronomer substitutes natural space with the space manufactured by observatories. Moreover, by locating humans in the universe, astronomers have considerable power to manipulate philosophical notions about the place of humans in the universe. By affecting such notions, astronomers can explain and justify themselves as the source of our view of the world. Boundary construction thus has a profoundly political and philosophical dimension. By creating new celestial phenomena — for example black holes, quasars, and pulsars — modern astronomy creates new boundaries, extending what is known and setting new limits on our knowledge of the universe defined by astronomers.

Boundary forming also has a political function (a power dimension) in that it can be used to increase the subject areas covered by the profession. Modern astronomy, via cosmology and its close relation to physics, is in an ideal position to do this. Just as D'Alembert and Diderot sought to include matters of ethics and morals and questions about the spiritual under the compass of reason (their reason) (Gieryn 1995: 393-443), so Paul Davies, Carl Sagan, et al. use astronomy to encroach on philosophy, religion and social questions. Such encroachments (boundary expanding) help to legitimate astronomy as a moral and social force in society, and can no doubt influence lay resource providers who have no natural disposition towards the physical sciences.

Note here that astronomy does not have to be *one thing* for boundary work to be successful. In fact boundary work is most successful when astronomy is multi-dimensional. When distancing astronomy from astrology and ufology, astronomers emphasise astronomy's empirical nature, whereas when extending boundaries on the borderline of philosophy and religion, astronomy is theoretical. When Paul Davies and Stephen Hawking extend the boundaries of cosmology into religion and philosophy, they emphasise the abstract nature of theoretical astronomy to blur and sometimes even obliterate the boundaries between these activities. The method of boundary work by Davies and Hawking makes a case for public support of astronomy (via cosmology) that does not rest on technological applications.

Similarly, the astronomers in my interviews were doing boundary work when they quoted Homer's *Odyssey*, portrayed astronomy as part of high culture, and emphasised the role of astronomy in fulfilling the spiritual needs of society. They were forming boundaries between astronomy and religion, philosophy, literature, and the humanities in general. They did not emphasise the difference between astronomy and these other activities. Rather, they emphasised the similarity, thus extended the boundaries of astronomy such that astronomy is culturally adjacent to, not far distant from them.

In this chapter, I have shown how astronomers demarcate themselves from different types of potential challengers: pseudo-astronomers, amateur astronomers, deviant or fraudulent astronomers, and so on. Boundary work by astronomers plays an important role in legitimising astronomy as a science deserving of societal and government support. In addition, modern astronomy parasitically ‘hangs around’ its more powerful younger kin physics, hoping for, and sometimes getting, spin-off resources. More generally, by locating astronomy on a map of science along with physics, geology and other disciplines, and disassociating themselves from ‘pseudosciences’ such as astrology and ufology, astronomers distance themselves from the losers, the have-nots, and ally themselves with the winners, the haves. Astronomy competes for territory with its weaker, hostile neighbours astrology and ufology, and cooperates with its stronger neighbour physics. In the case of astrology and ufology, a rhetoric of difference is used; in the case of physics, a rhetoric of similarity. The reactions of the astronomical community to claims made by adjacent ‘pseudosciences’ help astronomy to redefine its own boundaries and assumptions and reinforce rigidity and stability (Ben-Yehuda 143).

It is important to emphasise that such statements make no comment about the truth or falsity of astronomy in relation to astrology and ufology. As Gieryn notes, “Epistemic authority itself exists only to the extent that it is claimed by some people (typically in the name of science) but denied to others (which is exactly what boundary work does)” (Gieryn 1999: 14).

Finally, the construction of a boundary between science and non-science must be in competent hands. It is therefore necessary “that some kind of social body be established for the competent assessment of scientific works, to define and maintain the boundary between valid scientific findings on the one side and error and nonscience on the other” (Ben-David:

190). According to Ben-David, these social bodies, the emerging salaried scientific professions, were instrumental in clarifying the boundaries between science and non-science because: “the mechanisms allocating payment in practice eliminated the ambiguity previously prevailing in the demarcation of scientific activity.” The boundary line between science and non-science was thus institutionally defined (Ben-David: 193). This implies that scientific professions play a role in the legitimation of science, and it is to this question, in relation to astronomy, that I now turn.

CHAPTER FIVE

ASTRONOMY AS A PROFESSION

Introduction — Professionalism and Legitimacy

In this chapter an account is given of the way in which astronomers' status as professionals enhances the legitimacy of their discipline. I ask the following questions: in what way can astronomy claim to be a profession, and how does the success or otherwise of this claim affect its legitimacy? How is it that astronomy's organization as a profession and public presentation as a profession helps it to explain and justify itself? The chapter consists of the following sections: 'Astronomy as an Occupation and Career', in which I make some general comments about astronomy from the point of view of work and legitimacy; 'Professional Astronomy and Amateur Astronomy', in which I contrast the two activities and suggest that the differences have implications for legitimising professional astronomy; 'The Scientific Professions and the Enlightenment', in which I locate professional astronomy in the Enlightenment project, and suggest that historically being part of the said project has assisted in legitimation; 'Astronomers as Intellectuals', which shows the link between intellectualism and legitimacy; finally, 'The Role of Mathematics', which makes a connection between the status and esoteric nature of mathematics and legitimacy. The conclusion asserts that astronomers themselves are the main beneficiaries of astronomy's status as a profession.

There is a large body of sociological literature on professions. Typically, sociologists have listed a set of traits that are supposed to demarcate those occupations labelled 'professional' from those that are 'merely' occupations (Johnson 21-38).

Sociologists have usually demarcated professions from other occupations by such criteria as being in possession of a body of esoteric knowledge, ethics, sense of service, and a clientele. According to the 'trait' approach, or 'taxonomic' approach, as Saks calls it, astronomers have most of the traits usually associated with this notion of a profession, except they have no clientele. A typical example of the 'trait' approach is that of sociologist William Goode, who describes a profession as an occupation with the following traits:

> (1) Its members are bound by a sense of identity. (2) Once in it, few leave. (3) Its members share values in common. (4) Its role definitions vis-à-vis other members and non-members are agreed upon and are the same for all members. (5) Within the areas of communal action there is a common language, which is understood only partially by outsiders. (6) The community has power over its members. (7) Its limits are reasonably clear, though they are not physical over its members. (8) Though it does not produce the next generation biologically, it does so socially, through its control over the selection of professional trainees, and through its training processes it sends these recruits through an adult socialisation process (Goode 194).

This approach, which came from the structural functionalist perspective, has been discredited as being merely a justification for the professions (Rossides 7) and some contemporary theorists now think that the concept is no longer useful.

But the concept of a profession is still regarded as meaningful at a societal level in that it is associated with certain occupational standards of conduct. Sociological research in the professions is founded on the work of Talcott Parsons and Everett Hughes. Parsons, being influenced by Weber, saw modern capitalism as being characterised by rational/legal authority: impersonal rules and regulations hold together what would otherwise be an anarchic society. In such a situation, professions are an anomaly, for their apparent altruism contradicts the rational utilitarian calculations characterised by what the theory said about individuals' choice of occupation. Parsons concluded that what characterised the professions was a shared orientation to success, whether material or non-material, as judged by prevailing normative standards. These standards overrode the utilitarian calculus of the Weberian 'rational economic man'. Parsons' functionalist view of the professions sees them as an integral part of the modernisation process in which sacred-agrarian ascriptive society gave way to a secular industrial achievement society based on the institutionalisation of knowledge.

Hughes worked in the symbolic interactionist tradition of social theory. Key to Hughes' sociology of work are the concepts of *license* and *mandate*. According to Hughes, all occupations have a license to carry out certain specific activities in exchange for money, goods and services. It is this formalised exchange relationship that distinguishes work from non-work spheres. If members of a particular occupation have a sense of community by virtue of their shared work experience, they can claim a mandate to define, for themselves and others, proper conduct in relation to their work, to influence its technical content, styles of delivery and even patterns of public demand and response.

This is especially true in relation to the professions, which Hughes regards as the prime illustration of the possible legal, intellectual and moral scope of a mandate. Professions tell the rest of their society what is good and right for it: they can also set the terms of thinking about problems which fall into their domain. They exemplify in an extreme form the role of trust in modern societies with an advanced division of labour. Hughes rightly regards these features as matters of degree rather than absolute: they are present in all occupations. In consequence, any occupation may aspire to be a profession if it can reconstruct its license and in acceptance of an enlarged mandate. Hughes concluded that the term 'profession' is a symbolic label for desired status (Elliot). Significantly, Hughes did not accept at face value the image that professions presented of themselves. According to Hughes, a profession is "Not so much a descriptive term as one of value and prestige" (Hughes 210). One of Hughes' characterisations of professionals is particularly appropriate to astronomy as a profession: "Those occupations in which caeat emptor cannot be allowed to prevail and which, while they are not pursued for gain, must bring to their practitioners such a level that they will be respected and such a manner of living that they may pursue the life of the mind" (Hughes 364).

The key point about both Parsons' Weberian perspective and Hughes' Durkheimian perspective is that both imply that being a member of a profession in some way demarcates the professional from other workers in terms of social stratification, in terms of class, power and especially in terms of status; to claim membership of a profession is to claim prestige. Therefore any occupation that is categorised as a profession will have enhanced prestige. The word 'professional' is still commonly used and therefore has meaning. As Derber, Schwartz, and Magrass note, the merits of professionalism are enshrined in our language, and professions are associated with unquestioned virtues (Derber, Schwartz and Magrass 3). Astronomers as scientific professionals are firmly situated in the middle levels of the stratification system. In Weberian terms, this middle level location is determined by the ability of astronomers to command rewards in the marketplace, as a function of their possession of knowledge and theoretical skills. In this sense their profession is legitimised on the achievement of socially recognised expertise, which is itself derived from a system of education and credentialing.

Are there, then, occupations which have certain traits that mark them off as 'professional'? Whether one takes an essentialist or nominalist position, one cannot avoid the problem of definition. In answer to this question, an important point is that the concept is very much an Anglo American one. Overwhelmingly, the sociological literature on the subject comes from Britain and the United States. That is to say, the concept of 'profession' is historically and geographically specific. It tells us something about those societies. Over the past two hundred years, certain occupations have been labelled professions, and the resulting labelling has had significant effects on those occupations. The first so labelled were medicine, law and the clergy. Since then, other occupations have striven to be included in such labelling. In practice, a whole number of occupations have, with varying degrees of success, negotiated and accomplished the label 'profession', including scientists. Indeed, as Abbott notes, "The major shift in legitimation in the professions has thus been a shift from a reliance on social origins and character values to a reliance on scientization or rationalization of technique and on efficiency of service" (Abbott 195)

While occupations called professional are constantly changing and the term is vague and fluid, it remains important because, once an occupation is labelled a profession, the members of that occupation hold a higher status than would otherwise be the case, and have more power than would otherwise be the case. Larson notes, "professions are occupations with special power and prestige. Society grants these rewards because professions have special competence in esoteric bodies of knowledge linked to central needs and values of the social system, and because professions are devoted to the service of the public, above and beyond material incentives" (Larson x).

Sociologist of science Joseph Ben-David claims that scientists do indeed have certain features in common with other occupations such as medicine, law and engineering, even though there are considerable differences between these occupations. The common features are: a high educational qualification as a prerequisite for entry into the occupation; the privilege of monopoly in the performance of certain functions; a measure of control of admission into the occupation; the authority (legitimate domination) of a professional body over the conduct of its members; a resistance against lay interference in the affairs of the profession; and regulation of competition among members of the profession (Ben-David: 187). Ben-David acknowledges that these features are not equally present in all the professional occupations, and that there are large differences in the exercise of these functions among various professions within the same country and within the same profession in different countries (Ben-David: 187-188). Astronomers certainly have these characteristics, except their professional bodies do not have particular control over their conduct.

Astronomers produce an intangible good; knowledge, and it is society's values, rather than its needs, with which their knowledge is linked. Larson also correctly points out that professionalism does not have clear boundaries. Is nursing a profession? In some ways yes, in some ways no, depending on time, place and context. If we use Weber's ideal type methodology, we will find that some professions, possibly medicine and law, correspond very closely to the ideal type. Others, like nursing and other occupations, will have some of the list of attributes and not others. Astronomy and other sciences come fall within the latter category. They do not have a specific client group. On the other hand they possess a body of esoteric knowledge gained though years of higher education consisting largely of theoretical training. They are also relatively autonomous. In particular, astronomers as scientists conform to Freidson's definition: "A profession is distinct from other occupations in that it has been given the right to control its own work … only the profession has the recognised right to declare … outside evaluation illegitimate and intolerable" (Freidson 1970: 71-72). Indeed, astronomers are allowed to define the very standards by which their competence is judged, through peer review, conferences etc. In this sense, like other scientists, they are a colleague oriented, rather than client oriented, profession.

According to Derber, Schwartz and Magrass, professional power has turned professionals into a new class of mandarins, and they accordingly label modern societies as "mandarin capitalism". Derber, Schwartz and Magrass may overstate their case, but the fact that astronomers are professionals does give them power as well as status, and is therefore significant from the standpoint of legitimacy. Astronomers not only have considerable autonomy over their work, but also benefit from the image of science in general and astronomy in particular as 'pure' science. As long as society in general values science, so astronomers are valued. It is, however the case that autonomy over conditions and the technical content of their work gives astronomers a qualitative distinction from more proletarian occupations.

While a strict definition is impossible, there does remain a cluster of attributes which some occupations have that give them increasing legitimacy: a code of ethics, an esoteric body of knowledge gleaned from advanced academic study, existing high status (which the label professional enhances) and a client group. The above-described link between the so-called professions and *positive* attributes has been described as the ideology of professionalism. That is to say, certain occupations are idealised in order to give them higher status, even though the idealised account of the profession may bear little or no correspondence with reality. Rossides has described three attributes and processes in professional ideology:

> 1. Long years of training required in the knowledge and skills of each profession gave assurance that all professionals were competent, or at least, the best possible.
> 2. Free and fair competition assured that those who had the natural talent or inclination for particular professions would go into them, and that, in any case, the

intrinsic connection between knowledge and virtue would ensure altruistic services to clients and the community.

3. The professions would also be harnessed to social functions by ethical codes and by professional associations (Rossides 217).

Occupations that have attained the label profession have at least some of these attributes. It can be seen that the above traits are positive, and such favourable traits would contribute to the legitimacy of the profession and the discipline. Social usefulness is not a criterion of professionalism, except in so far as being connected to broad social functions as in (3). In so far as astronomy has the above attributes, these can be said to of themselves contribute to the legitimacy of the profession. As (2) implies, professions are claimed to be self-regulating (Collins 132). This applies to scientists in general and astronomers in particular, as does Collins' notion that an ideal profession has a set of skills that occupy the mid-point of a continuum between complete predicability and complete unpredictability of results (Collins 133).

More recent radical/conflict sociopolitical perspectives define a profession more negatively as, "An occupation that has succeeded in keeping its numbers low in relation to need or has devised other ways to guarantee itself high material benefits regardless of performance" (Rossides 51). Similarly Parkin defines professionalisation as a particular type of exclusionary closure, based on credentialism and sees it as "a strategy designed, amongst other things, to limit and control the supply of entrants to an occupation in order to safeguard or enhance its market value". These groups, organised as professional associations, keep the price of labour artificially high by requiring unnecessary education for entry into the field. Johnson, too, emphasises the power relationship between professionals and their clients: "the producer defines the needs of the consumer and the manner in which these needs are catered for" (Johnson 45). The broadest definition of all is that given by Freidson, who defines a professional as someone who has higher education credentials (Freidson 1986: 1).

Marxist analysts of professions also offer structuralist definitions, but tend to be even more cynical about professions than their Weberian counterparts. Baran, one of the more generous Marxists, acknowledges that scientists and physicians from part of a diverse group with interests objectively opposed to the bourgeoisie, although he recognises that such strata are supported by the economic surplus in capitalist societies. He claims that the demand for their services would not only continue, but also be greatly enhanced in a socialist society. Ehrenreich and Ehrenreich are more typical of the Marxist view, characterising professions as salaried mental workers who do not own the means of production but exist in a mutually contradictory relationship with the working class by virtue of their role in reproducing capitalist culture and class relations.

The advantage of these structural definitions, both Weberian and Marxist, is that they enable the analyst to address the difference between what a group claims its members to be and do with what they actually are and do, and between what is generally believed about a group and what is actually the case. Generally, the structuralists appear to agree that professionalisation is a function of the bargaining skills of occupational groups seeking the status of the label ‘profession’. At a more general level, they agree that professions are occupational groups characterized by some configuration of concrete status privileges.

Whichever definition is used, it is clear that astronomy has at least some of the features of what is commonly known as a profession. However, rather than search for a rigid definition of ‘profession’ the purpose of this chapter is to ascertain which, if any, features about the occupation of astronomy helped towards legitimating it.

Until the 1970s, most sociologists of the professions accepted the self-idealised account of the professions at face value. However, sociologists such as Abbott, Freidson and Roth have given accounts of the professions which assert that in practice the altruistic and objective ideals are rarely met, and that in reality, deviation from those ideals is the norm. These analysts, however, concentrate on certain professions, and ignore those such as astronomers, whose profession is more difficult to critique because they are natural scientists with no obvious links to clients. For the same reason, astronomers have been ignored in the more radical critiques of professions by sociologists, such as Rossides and

Johnson. Lawyers have come under criticism for being interested in money rather than justice, and the medical profession has come under attack for having a too narrow view of health: ignoring environment, prevention, nutrition, being too reliant on drugs and surgery, and being hostile to natural therapies. Millions have to varying degrees abandoned Western scientific medicine in favour of various alternative medicines. Astronomers, having no specific client group and no equivalent of the Hippocratic oath, have avoided such criticisms.

Moreover, unlike their next of kin, the physicists, astronomers have not been subjected to the critique that their profession has subordinated itself to the military. Although links between the military and professional astronomy can be found, it would be wrong to say that professional astronomy is subordinated to the military in any direct way. The links are more indirect and institutional. For example, NASA, for whom a growing number of American astronomers work, was founded on Cold War tensions. Similarly, fear of Soviet technological prowess, such as Sputnik, spurred on astronomical projects such as Jodrell Bank; the cold war spurred on military technology, including space military technology, some of which has had astronomical uses. A good example is rocket technology, which, in addition to being useful for missiles, could also be modified for use in space vehicles with astronomical applications, such as the guidance system of NASA's Saturn rocket booster (MacKenzie 305). But the relationship is two-way. Astronomy can be of use to the military, as when evaluation of stellar-initial guidance systems was contracted out to the astronomy department at Massachusetts Institute of Technology (MacKenzie 249). In the case of the emergence of radio astronomy, there is an interesting historical parallel with the emergence of automated machine tools, as described by Noble (1984). In both cases, technically trained scientists and engineers emerged from the war looking for opportunities. The concepts and potential of radio astronomy had been laid down by Jansky and Reber in the 1930s. Scientists and engineers refined these techniques in the war, and afterwards were eager to find applications for radar and radio technology. However, unlike automated machine tools, astronomy remained in the civilian sphere.

Golinski, following Foucault, has suggested an alternative to the notion of professionalism. Golinski suggests that instead of studying the development of professions, sociologists, at least with respect to scientists, substitute the notion of disciplines, which he claims has more historical explanatory power. The notion of professionalism ignores the important differences between the traits of the various scientific disciplines, whereas an analysis of the development of disciplines highlights these differences (Golinski 68-69). Golinski acknowledges that disciplines are power structures that regulate behavior and codes of practice from within; the emphasis is on internal regulation. The concept says little about status and the interaction of the group with society. In contrast, whether real or not, the ideology of professionalism is helpful in understanding how astronomers legitimise themselves as a group to those outside the group.

Although recent sociological critiques of the professions have some merit, the fact that professionalism is still a powerful ideology means that it can still enhance the legitimacy of the profession. Moreover, the nature and subject matter of astronomy means that astronomers have been able to avoid criticisms that other professions have faced.

Astronomy as an Occupation and Career

Sociologist Andrew Abbott describes a career as “as strategy invented in the nineteenth century to permit a coherent individual life within a shifting market place.” (Abbott 324).

Using a systems approach, Abbott sees professions as groups vying over jurisdiction of defined areas. The results of such jurisdictional claims can be settled by a direct appeal to the public (Abbott 60), as when astronomers popularise their discipline. Abbott also characterizes different types of jurisdiction settlements: full jurisdiction, subordinate jurisdiction, intellectual jurisdiction, settlement by division of labour, and advisory jurisdiction (Abbott 69-79). In the age of factory observatories astronomers were usually able to attain full jurisdiction over the observation and analysis of celestial phenomena. Today however, they are more likely to have to share jurisdiction with physicists, engineers, geologists, meteorologists etc. This is especially the case with space based astronomy.

Abbott also found that there was migration between professions (Abbott 132). Astronomy in the nineteenth century was a permeable profession in which careers were flexible (Abbott 130-131). As a flexible career, astronomy was characterised by variation in the age of recruitment and educational requirements, as well as frequent on-the-job training. Astronomers were thus entrepreneurial and had some freedom to manage their careers. Astrometry and celestial mechanics emerged out of the independent amateur tradition. With the emergence of astrophysics, astronomy became less independent and more fused with other scientific professions.

Today, an astronomer will often be part of a physics department rather than a separate astronomy department. Most astronomers who work in academic institutions combine teaching and research. In the US, about 30% of professional astronomers are employed by the federal government or in a federally supported observatory or laboratory. A further 10% work in private industry and business (American Astronomical Society 2001). Today, few astronomers spend a high proportion of their time actually observing. Most spend most of their time analysing and interpreting data using computers. According to one astronomer: “Like most astronomers nowadays, I spend most of my work hours in front of a computer” and another: “It is very unusual in today’s day and age for an astronomer not to have a good to very good background in computers and programming” (NASA 2001).

The field is small and popular, and therefore competition for permanent staff positions is intense. Typically, about twelve years of study, apprenticeship and temporary posts are involved. The result is that the few lucky individuals who establish careers as professional astronomers are highly dedicated, and they are passionate about what they do, as was evident in my interviews.

The vast majority of astronomers are males, though this seems to be slowly changing. According to the Baltimore Charter for Women in Astronomy, 15% of all professional astronomers worldwide are now women, with the proportion varying from none in some countries to half in others. The entry of women in professional astronomy in the 1840s is an topic worthy of a separate thesis. Suffice to say here that it was a process that required its own legitimation (Lankford 304). The American Astronomical Society claims that astronomers as a group are striving to encourage a vigorous affirmative action approach to recruiting. The AAS also claims that one quarter of all young astronomers are women, and that this fraction is growing. They assert: “It is hoped that future years will see a healthy and more equitable balance of men and women of all races in astronomy” (American Astronomical Society 2001). In the classic Marxist sense astronomers do not own their means of production, but sell their labour in a market. They are therefore workers: professional workers, but workers all the same. Thus any social advantage they accrue as astronomers does not come from their class position, but rather from their status position as scientists. However, the market in which astronomers compete is not a free market. The long years of education limit the supply of astronomers, thus giving them a similar advantage to other professionals as compared with non-professional occupations.

Running parallel with the professional/non-professional dichotomy is the idea of primary and secondary markets (Miller 154-155). A primary labour market has high wages, good working conditions, chances of advancement and employment stability. Secondary markets are not as structured, have few promotion possibilities and a high turnover. Secondary markets often include high concentrations of ethic and racial minorities, and young people and women. Within the primary market Miller posits a further distinction between higher-tier jobs, characterised by job security, autonomy, high pay and status, as well as opportunities for promotion and mobility, and lower-tier jobs, providing security but little autonomy, lower pay and less chance of mobility. Although both primary and secondary markets exist in the astronomical community, clearly most professional astronomers constitute a primary market. Moreover, once a tenured professor or astronomer attached to an observatory, most astronomers could be considered to have higher tiered jobs within the primary market.

Professional Astronomy and Amateur Astronomy

I have elsewhere examined the relationship between professional and amateur astronomy in relation to boundary work. In this section I contrast professional with amateur astronomy in such a way as to highlight those features of professional astronomy that enhance its legitimacy.

As the various scientific professions emerged in the nineteenth century, resources and rewards were allocated to these professions rather than amateurs. Once scientists began to be paid for their work, amateurs had little chance to compete (Ben-David 193).

However, amateur astronomers are able to do useful work in astronomy, make genuine discoveries, and contribute to the development of the discipline. But they can do this only within certain parameters. A perusal of amateur astronomy magazines shows that the content covered is mainly non-mathematical: no lengthy training in mathematics and physics is required to be an amateur astronomer. In contrast, becoming a professional astronomer requires a long period of study and apprenticeship. By this means the university produces both astronomical knowledge and more astronomers. In addition to producing knowledge, universities are systems for the reproduction of the producers of knowledge. Such specialist training is one of the classic traits of a profession. The length of study involved itself gives the profession a certain status it would otherwise not have. Such barriers can be seen as a form of boundary work whereby professional astronomers demarcate themselves from amateur astronomers.

The relationship between professional and amateur astronomy is complex but has been generally positive, and one of mutual but distant respect (Stebbins). At the personal level, amateur astronomers serve to legitimise professional astronomy by giving it support in terms of their interest and participation. At the structural level, any possible competition is averted by the existence of a variety of practices and traditions that serve to demarcate professionals from amateurs. Most important is a long series of educational obstacles to overcome before attaining professional status, and the related skills associated with such educational achievements, especially mathematical skills, which are generally not needed for amateur astronomy. Because most amateurs do not use mathematics to do astronomy, they can use everyday or ‘ordinary’ knowledge. But this knowledge disqualifies them from practising in a professional capacity. According to Derber, Schwartz and Magrass, this disqualification of ordinary knowledge is not an inevitable outcome of the rapid growth in science, but results from the way in which professionals have sought to appropriate knowhow and use it to achieve their own ends. Professionals so not seek to totally discredit everyday knowledge, but to limit its claims and carefully regulate its boundaries (Derber, Schwartz and Magrass 63). Thus the demarcation between professional and amateur astronomy can be seen as a form of boundary work. Indeed, education can be seen as the means by which astronomers as a profession are produced. This is because astronomers produce an intangible good — knowledge. The education system through which professional astronomers journey also produces what Larson calls ‘cognitive exclusiveness’ (Larson 15), that is, a teaching monopoly over on their specific tools and techniques. This education system, together with peer review, helps astronomers to maintain a monopoly of credibility over their subject. Larson notices two professional similarities between medicine and astronomy. First, both use the authority (legitimate domination of knowledge) of science to explain and justify themselves as professionals. Second, both, through the education system both use the education system to give themselves a monopoly of authoritative knowledge (cognitive exclusiveness) in their field, and to reproduce themselves as professionals.

The fact that much ‘useful’ astronomy can be done by amateurs without sophisticated mathematical skills also means that the type of work amateurs do is both quantitatively and qualitatively different from that which professionals do, even though many professional astronomers are also keen amateur astronomers (Ringwald). For example professionals have access to sophisticated equipment, much of which requires mathematical, computing, and sometimes engineering skills to use effectively. Such specialist equipment is not only expensive but is also rare and in much demand, and often has long waiting lists. Astronomers must sometimes wait months before being able to use a particular piece of equipment or observatory; observatory time is at a high premium. Thus the logic of demand and supply dictates that generally only the elite will have access to the expensive equipment that is essential for making certain types of discoveries. This is still the case to a great extent, not withstanding the changes previously noted with regard to the Internet, CCDs and Dobsonian telescopes. Amateurs are still both ‘kept in their place’, a certain distance from professional astronomers, while at the same time giving professional astronomy legitimacy by their interest and support for and participation in the activity.

There is, of course, some overlap. The aforementioned Patrick Moore is very much in the amateur tradition, but as a well-known celebrity he has access to some of the biggest observatories in the world. This is not because of his expertise but because he is a highly successful spokesperson for the discipline and therefore for the profession. Moreover, professional astronomers will also read popular journals such as *Sky and Telescope* that are also read by amateurs and require no mathematical skills to understand. A cursory glance at issues of amateur journals such as *Sky and Telescope* and *Astronomy* reveals that those pages not covered in advertisements for telescopes and other astronomical equipment are mainly concerned celestial phenomena that are relatively close in astronomical terms: comets, meteors and planetary astronomy. The exception to this is articles about the constellations, which can be seen with the naked eye. Those few articles about interstellar astronomy are entirely general and non-mathematical. In contrast, professional journals have become highly mathematical, and reliant on specialised vocabulary and elaborate theoretical frameworks, often assumed to be familiar, while there is virtually no mathematics, and limited jargon in the amateur journals. This situation is not as clear as it used to be, because of aforementioned technological developments, but it is still generally the case.

Although professional astronomers keep a certain distance from amateur astronomers, there are generally good relations between the two groups, and amateurs who are members of societies are often characterised by their competence and the seriousness with which they take their hobby. The professional astronomers I interviewed spoke highly of amateur astronomers, and not one had anything negative to say about them. However, when professional astronomers get bad publicity at a national level this can affect relations between professionals and amateurs at a local level. For example, the Hubble mirror debacle one professional astronomer was accused by a *Sky and Telescope* journalist of having been corrupted by NASA, and another was booed off the stage at an amateur astronomers' convention in Vermont (Chaisson 198-199).

The study of celestial phenomena is divided into those areas suitable for professional astronomy, work that requires expensive technology, such as interstellar work, and those that require a minimum of equipment, such as comet hunting. On those few occasions when professional astronomers work on astronomically close phenomena, talented amateurs may be lucky enough to be involved in a spectacular discovery, as with the Shoemaker-Levy comet. Similarly, in the early days of Jodrell Bank, when Lovell was studying meteors, he elicited the help of a gifted amateur, Manning Prentice (Lovell 1968:10), but as soon as Lovell realised the potential of his project, there was no mention of amateurs.

In the relationship with amateur astronomy, boundary work and popularisation intersect. Astronomers keep a respectful distance from amateur astronomers as a whole, but will use certain of them when needed. Patrick Moore, the most well known 'amateur', is such a gifted communicator that he is often called upon to interpret new discoveries for the public. However, though self-educated in the amateur tradition, he is a full time paid communicator of astronomy.

In theory, there is no reason why professionals could not limit themselves to the work that amateurs do, and of course do a lot more of it. But if this were to happen the whole apparatus of professional astronomy would collapse; it would no longer be big science, using expensive equipment, and would therefore no longer be a profession, with a status, and could no longer lay claim to expensive resources provided by society. The choice to have astronomers concentrate on long distance big science is a political/historical/economic decision; such a decision cannot be explained by reference to the advantages of knowing about quasars and pulsars against knowing about celestial phenomena that do not require big science. There is no objective higher value in knowing about quasars than knowing about meteors. Why is this decision made in the first place? Why is big science valued more than small science? The answer lies in the wider society.

Much of modern professional astronomy has become a branch of physics, such that astronomical discoveries and events are covered in physics journals. For example, the Nov./Dec. 1995 issue of *Contemporary Physics* contains articles about new developments in telescope design and observations by the Hubble Space Telescope of distant galaxies. Such publication traits serve to reinforce the demarcation between professional and amateur astronomy; the demarcation in publications is a reflection of the epistemological demarcation and the political demarcation. This is not to say that there is no overlap; indeed, if there were none amateur astronomy could not function to legitimise professional astronomy. For amateur astronomy to perform such a function there must be some shared knowledge and shared infrastructure: this to attain the moral support of the amateur community. Such a shared experience is provided for by institutions such as the IAU (International Astronomical Union) Central Bureau for Astronomical Telegrams, in Cambridge, Massachusetts, which is the world's official clearing house for comet, nova and supernova discoveries. Amateurs "find about a third of all new comets...most novae brighter than 10th magnitude, a fair number of the supernova in relatively nearby galaxies, and variable stars" (MacRobert 48.) Thus, standardised forms for recording astronomical information serve as a boundary object linking professional astronomers to amateur astronomers, in the same way that "standardised forms for recording information about the ecological circumstances in which a zoological specimen was found served as a boundary object linking professional scientists to amateur naturalists, conservationists, and even trappers" (Gieryn 1999: 415).

Astronomical knowledge can be seen as being hierarchically stratified. The knowledge gleaned by amateurs rarely finds its way into professional journals, and rarely makes the pages or the TV screen of the mass media. In contrast, spectacular astronomical discoveries by professionals are sometimes deemed important enough to make even the front pages of major newspapers. Moreover, professional astronomy is deemed important enough to warrant the expenditure of vast sums. It is an example of what Fisher calls "a hierarchically stratified knowledge system" (Fisher 99). Not all astronomical knowledge is equal. This epistemological inequality contributes also to the political inequality implied by the elite position of astronomers as professional scientists. Amateur astronomers may do intricate work that professional astronomers will say is of value, but no matter the quality of work the amateur is still an amateur: his astronomy can never be any more than a serious hobby. He has no access to resources or infrastructure that the professional takes for granted, and so the resulting knowledge production is of a different order than that attained by the professional. In short, amateur astronomy is populist astronomy, whereas professional astronomy is elitist.

The Scientific Professions and the Enlightenment

The Enlightenment project is far from dead, and lives on in the very scientific basis of our society. The high status of science in general and astronomy in particular has a lot to do with its being part of that project. It is here argued that being part of the Enlightenment philosophy has historically been beneficial to the legitimising of astronomy as an activity for which society should pay.

We have already seen the connection between astronomy and nationalism. The notion of professionalism itself is also bound up with the growth of the nation state and the need to justify the power of the state. This is especially so of the scientific professions, which developed in academic institutions in the nineteenth century. In turn the development of the scientific professions was bound up with the enlightenment notion that there is a world external to us, and that genuine knowledge of that external world can be obtained by rational means. The resulting knowledge is therefore considered superior to other forms of knowledge, such as indigenous knowledge. Therefore, astronomy as a profession cannot be separated from astronomy as a discipline. Astronomy as a profession is legitimated by the perception that astronomers are objective generators and dispensers of objective knowledge.

There have been astronomers, in the sense of people observing the stars, since the dawn of humankind. But astronomy, as a profession, that is to say, a particular group of individuals who are paid to study celestial phenomena and who are given status by doing so, can be traced back to the feudal system (Rossides 11). The technology available in these agrarian societies created new occupations and new hierarchies: serfs, slaves, tenants, and a hereditary nobility. The new occupations had a hierarchy of importance and a hierarchy of status and power. The emergence of a central bureaucracy produced a social technology of professional civil servants that made it possible to coordinate and control a large and diverse population. The landlord class supplied sons for the army and civil service. Astronomers were part of this civil service, along with tax collectors, healers, magicians and upper clergy.

But the world-view that was conducive to the emergence of astronomy as a profession can also be traced back to Ancient Greece. The notion that the universe is rational and can therefore be studied rationally, as well as being explained without reference to supernatural forces, is a necessary precondition for there to be a group of individuals whose job it is to uncover that rationality. Moreover, the ancient Greek view that knowledge could be justified for its own sake, without utilitarian benefits, is of obvious benefit to the profession of astronomy. But modern professional astronomers are not merely philosophers using mathematics to calculate the mechanics of the universe like Ptolemy and Eratosthenes; they study the universe empirically. The French Enlightenment laid the foundations for this by abandoning the Greek distrust of experience, the senses, and the world of facts. The phenomenal world, declared the philosophes, is orderly in and of itself and thus accessible to human beings. This empirical outlook, which had been developing for centuries, received full institutionalisation in the nineteenth century. The stage was thus set for the justification for governments to provide paid astronomers with expensive equipment to reveal the mysteries of the universe. These astronomers derived their professional authority from their embodiment of rational procedures, that is to say, Weberian rational/legal authority.

For the scientific professions to exist, certain assumptions, usually associated with the Enlightenment, need to prevail in society. First, that knowledge about the Universe can be obtained independently of time and place through the exercise of human reason (objective knowledge). Second, that knowledge can improve our personal and social lives; this second assumption does not necessarily mean that the knowledge should improve either society or individuals economically. Third, that there are special methods and people to provide and apply knowledge; and fourth, that knowledge will be communicated from those who generate it to those who need to know, whether it be rulers or common citizens. During the eighteenth century these beliefs became embedded first in French and Scottish society and then throughout the western world. Westerners came to take it for granted that empirical laboratory science was a force for good: that it was the key to progress. One of the ways in which the new faith in empirical knowledge was institutionalised was professionalism. By the end of the nineteenth century, occupational groups emerged claiming jurisdiction over specific fields of knowledge. Disciplines and corresponding professions emerged, each with its own subject matter, credentials, research journals, and associations. What united and still unites the professions, especially the scientific professions, is the following claim succinctly summarised by Rossides:

> We are neutral, altruistic, objective searchers for and dispensers of knowledge; we can be judged only by our fellow professionals since we possess a high and difficult to obtain knowledge base; since knowledge is power and yields virtue, our activities will be service oriented; whatever our deficiencies, we are the best guarantee of both knowledge and an improved society (Rossides 24).

As the chapter on popularisation has shown, 'service' in the case of astronomers is understanding and spiritual development of the individual and the cultural development of society, as well as entertainment in the broadest sense.

In European countries that had strong states, professions were employed by the state and had a sense of public service. In contrast, professionals in the United States tended to be employed privately and to promote themselves, securing income from private clients. This was also true of astronomers: more European astronomers were employed by the state, whereas American astronomers were more likely to be employed privately or by privately run educational institutions. Moreover, each nation developed a philosophy that complemented the particular attributes of science in that nation, such as empiricism in

Britain and pragmatism in the United States. Both of these philosophies, in their own way, argued that truth is derived from experience, thus legitimating empirical laboratory science. Dorothy Ross has even been argued that American social science in general has been an attempt to link private property and science with the health and destiny of humanity. Behind these philosophies is the Enlightenment proposition that the individual can be liberated by knowledge. This proposition is particularly useful to professional astronomers when they popularise their science.

If we locate the emergence of professions with the establishment of professional associations, then it is clear that the professions in Western Europe and the United States emerged towards the end of the nineteenth century. In the United States for example, the first professional law association was established in 1878, dentistry in 1867, architecture and pharmacy in 1868, social work 1874, school teaching and veterinary medicine in 1879, accountancy and business in 1881, historians 1884, economists 1885, and political scientists 1889 (Rossides 37-38). Bledstein has attempted to show the how the rise of science and the professions both contributed to and helped legitimate unequal power relations. Each of these professions established an occupational monopoly over a specific area of knowledge. Unlike amateur societies, professional associations limited membership, thus creating elites who were able to control access to credit and facilities within given fields. In this higher education had and has a role. That is, it persuades the public that astronomers are competent and trustworthy. By standardising admissions, prescribing formal courses of study, giving examinations, and conferring higher degrees, higher education ensured the perception that those who finally became professional astronomers had achieved their positions by their own merit rather than on the basis of family inheritance, favouritism or subjectivity.

The essence of the new professionalism consisted of a belief that it was possible to master nature’s principles. Theoretical knowledge would give the professional the ability to control phenomena within their field. Theoretical knowledge also provided the metaphysical legitimacy for a power relationship between professionals and their clients. Armed with knowledge, the professional was a free, autonomous independent individual.

But this freedom of the professional had conservative consequences. Professional claims to competence, augmented by rituals, costumes, technology and ritual settings, resulted in the dependence of the professional's clients. This is also true of scientists, including astronomers. Since only highly qualified professional astronomers have access to the expensive and sophisticated equipment necessary for certain types of astronomical research (and have the skills to use that equipment), their clients (governments, other astronomers, interested members of the public) are reliant on them for knowledge about certain types of celestial phenomena. This is the case despite the existence of thriving amateur astronomy, for, as previously shown, there is a clear demarcation in the phenomena investigated by professional and amateur astronomers. As with popularisation, the net result of professionalism is to establish a system of inequality in which the lay public has to trust that expert professional astronomers are telling the truth. True, astronomical discoveries must be confirmed before they are accepted, but this confirmation takes place *within* the astronomical community. Those outside this community must simply accept that the community is telling the truth. Thus astronomers, like other professionals and other scientists, have a power relationship with their clients.

Astronomers as Intellectuals

In the case of astronomy, professional standards in general often include an intellectual element. In astronomy, it is this intellectual element that is all-important. Astronomy is first and foremost an *intellectual* profession. For example, while it would be crude to make a rough equation between educational attainment and intellectualism, it is at least the case that generally the status of intellectual implies a higher level of education. That is to say, while having a high level of education is not sufficient in order to attain the status of intellectual, it is, in most cases, a necessary condition. It is virtually impossible to become a professional astronomer without both a PhD and postdoctoral experience. This puts astronomers in an elite group right at the apex of the educational pyramid.

Mannheim accurately pointed to the one unifying factor common to all intellectuals, no matter what their specific subject expertise:

> Although they are too differentiated to be regarded as a single class, there is, however, one unifying sociological bond between all groups of intellectuals, namely, education, which binds them together in a striking way. Participation in a common educational heritage progressively tends to suppress differences of birth, status, profession, and wealth, and to unite the individual educated people on the basis of education they have received … One of the most impressive facts about modern life is that in it, unlike preceding cultures, intellectual activity is not carried on exclusively by a socially rigidly defined class, such as a priesthood, but rather by a social stratum which is to a large degree unattached to any social class and which is recruited from an increasingly inclusive area of social life (Mannheim 155-156).

The sociological notion of the intellectual is logically distinct from the notion of the professional. Intellectuals were prominent in ancient Greece. Indeed, in *The Republic* Plato argued that intellectuals — 'philosopher kings' — should rule society. The intellectual, in contrast to the professional, is a generalist. Intellectuals analyse and comment on the society in which they live, and their analyses and comments may be listened to by opinion leaders. Intellectuals also make predictions and prophesise. In ancient societies astronomer-priests forecast weather vital to crops in agrarian societies; they were, to an extent, generalists, or, as Rossides asserts, "Symbol creators who have society wide influence" (Rossides 53).

At first glance, it may seem that modern professional astronomers are not, strictly speaking, intellectuals. Although their profession requires years of study at a high level, they are specialists, and much of their work is highly technical. However, in recent years some astronomers, especially those concerned with popularisation in the mass media, have indeed taken on the role of public intellectual. Carl Sagan, in *Cosmos,* comments on a range of big issues from the role of science in society to the environment. As Ben-Yehuda notes: "There can be little doubt and Carl Sagan, through his 1981 series 'Cosmos', earned himself a worldwide reputation (not to mention income). The scientist is perceived as a wiseman who reveals the ultimate truth and unravels the secrets of our physical and social universe" (Ben-Yehuda 174). In short, Sagan became a public intellectual.

Similarly, popularisers such as Paul Davies use cosmology to promote a particular metaphysics. Not so recently, both Bernard Lovell and Fred Hoyle have used their status as prominent astronomers to comment on wider socio-political questions. Thus although most astronomers would not normally be considered intellectuals, and certainly not public intellectuals, a few prominent popularisers have taken on that role. By virtue of being prominent astronomers, Sagan, Lovell and Hoyle have been able to use their communication skills to turn themselves into generalists whose comments on wider social issues are thought by publishers and producers to be worthy of broad dissemination.

The role of the intellectual in society is not as prominent as it once was, but intellectualism still has a role to play, albeit a small one, in the legitimation of astronomy. When playing the role of intellectual, there is no need for astronomers to adopt any particular standpoint, or to be consistent with the position on non-astronomical issues adopted by other astronomers. Rossides' assertion that "Lawyers and Physicists, for example, can serve any cause, organizational structure or country" (Rossides 48) can also be applied to astronomers. Astronomers still have one advantage over other professional disciplines. Whereas most professional disciplines have developed into sub-disciplines and sub-specialities, astronomers still can be said to constitute a single community. Astronomy has indeed branches such as radio astronomy, and sub-specialities such as infrared astronomy, but it is not the case (yet) that these specialities lack communication with each other. As one of my interview respondents, Dr Van Gorton, asserted: "Astronomers still talk to each other". However, astronomy is vulnerable to one charge that is put against other disciplines: that they work on problems which are irrelevant to important issues and social problems that confront society; hence the need for non-utilitarian legitimation. In their role as intellectuals astronomers are greatly helped by the crucial role of mathematics in astronomy.

The Role of Mathematics

It is here argued that the central role of mathematics is beneficial to the profession of astronomy, both because it limits the supply of astronomers and because of the esoteric nature of that knowledge. Wilensky has observed that "if the technical base of an occupation consists of vocabulary that sounds familiar to everyone, or if the base is scientific, but so narrow that it can be learned as a set of rules by most people, then the occupation will have difficulty claiming a monopoly of skill or even a roughly exclusive jurisdiction" (Wilensky 148). Mathematics, as a form of rational discourse (Derber, Schwartz and Magrass 28), is part of an intellectual structure that supposedly helps to keep the personal values, biases and feelings of astronomers from influencing their professional work. The influence of mathematics rose with the rise of capitalism. Capitalism demands quantitative equivalence of one worker's output for another, one product's value for another. A money economy assigns a number to everything: "Quality no longer matters, quantity decides everything". (Marx 57). Max Weber agreed about the relationship between quantitative methods and capitalism: "everything should be capable of being expressed in numerical calculable terms, and is so expressed" (Weber 85). Moreover, mathematics as theory gives the appearance of impersonal, detached, objective knowledge. And as Derber et al note, "theory can add legitimacy, helping to define professionals as a distinct university based class" (Derber, Schwartz and Magrass, 55). It is in the university that astronomers are able to both produce and monopolise knowledge which completes their demarcation from amateurs.

As Kuhn has noted, astronomy is not only the oldest of the sciences, but along with optics and statics was one of a group of activities that developed vocabularies and techniques which even in the Hellenistic period in Greece were inaccessible to most citizens. Even at this time, these three activities were intimately associated with mathematics, as well as harmonics (Kuhn 1976: 5). Mathematics (which Kuhn says is older than astronomy) along with astronomy, optics and statics Kuhn calls "classical physical sciences" (Kuhn 1976: 6). There was a unity between mathematics and astronomy that continued until the nineteenth century when the two disciplines became professions with their own institutional forms (Kuhn 1976: 27). Shapin also notes: “In early modern culture the terms ‘mathematics’ and ‘the mathematical sciences’ were far more inclusive than present-day understandings of mathematics. The legacy of mathematical sciences inherited from antiquity included, in addition to the ‘pure mathematics’ (geometry and arithmetic), such forms of physical enquiry as astronomy, optics, statics, and musical theory” (Shapin 315). And Lankford notes that mathematics was important in the astrometry and celestial mechanics of the professional astronomy of the nineteenth century (Lankford 140).

The fact that higher mathematics is inaccessible to most lay people has been and is a powerful intellectual weapon. It is also a *secret* weapon. Even for those without maths phobia, the level of maths required for conducting contemporary professional astronomy is beyond the practical reach of most laypersons. The high level of mathematics necessary for professional astronomy means that astronomers can talk in a secret language that the layman does not understand. Kuhn notes that even in antiquity, mathematics was characterised “by vocabularies and techniques inaccessible to laymen and thus by bodies of literature directed exclusively to practitioners.” (Kuhn 1976: 36). The hard sciences are made esoteric, even mystical, by their use of higher mathematics. In the ‘science wars’ for example, mathematics was used by certain scientists in an attempt to debunk critics of science: “Certainly it is in higher mathematics that the scientist possesses a language that has not been mastered by most literary writers on science. Maths becomes [Alan] Sokal’s citadel or bunker, safe from most social critics of science” (Dusek 135). Dusek goes on to say that the fact that Alan Sokal’s hoax article was about quantum gravity made it harder to spot, and therefore the ideal topic (from Sokal’s point of view) for such a hoax. Quantum gravity is such an esoteric field that even many physicists have not studied it and it is not a typical scientific field (Dusek 135).

Collins and Restivo note that “Mathematics is the theoretical core of most empirical sciences that have reached any level of complexity … it may be a model for innovation in all sciences in so far as they are theory driven” (Collins and Restivo). This is certainly true of astronomy. Modern astronomy, along with physics, more than any other science has mathematics as a central tool. Moreover, some of the justifications I came across in my interviews were similar to the justification for mathematics given by prominent mathematicians Hilbert and Weil: “The glory of the human spirit” (Collins and Restivo 220). In a similar vein Fang and Takayama associate mathematics with poetry and high culture in general (Fang and Takayama 76). At Cambridge University in the nineteenth century, mathematics attempted to establish analogies between the natural laws in astronomy to contribute to natural theology. It avoided utilitarian approaches, and supported a conservative political ideology bolstered by an educational reform movement (Lenoir 69-70).

Using as their starting point Weber’s assertion that “The belief in the value of scientific truth is the product of certain cultures and is not the product of man’s original nature”, Fang and Takayama look for the origins of mathematics as a science and find it in Ancient Greece (Fang]and Takayama 109, 207). According to Fang and Takayama, mathematics became a science in ancient Greece, as an offshoot of philosophy and legitimised itself by being certain, universalistic, and demonstrative (Fang and Takayama 107). The science of mathematics was a necessary condition for the development of the other sciences: “The science, again, of astronomy or chemistry or physics could not completely divorce itself from the magic or religion or speculative philosophy of astrology, alchemy, and metaphysics, respectively, until mathematics had become a science in the proper sense” (Fang and Takayama 108). From the standpoint of professionalism there is, of course, a contradiction here. On the one hand there is mass access to the education system that in principle can give mathematical expertise to anyone who cares to be adequately trained and qualified. On the other hand, mathematical expertise is also used to claim superior rewards and to establish social distance from other occupational groups. The higher levels of the educational hierarchy claim meritocratic legitimations for their selection of entrants.

To Fang and Takayama the demonstrative nature of mathematics was particularly important for its legitimacy in ancient Greece: mathematical debates took place in public, and it was this public nature of the debate that legitimised it: “If one argues with his opponent in public … and can anticipate the feeling of shame when he will have lost the argument in front of other people, he is bound to try harder to beat his opponent at debate. To win, however, he must convince the latter and the people in front of them as well as himself. To convince them in public, he must be able to win them over to his side by demonstrating as objectively as possible how right he is" (Fang and Takayama 176)

We can also infer that the general notion of knowledge for its own sake, so necessary for the legitimacy of astronomy, can be traced to ancient Greece. Thus 'Greek Fire', in the form of the legacy of the notion of the value of knowledge for its own sake, helps to legitimise astronomy today. As Derber et al note, "Knowledge for itself has more legitimacy in the liberal arts curricula than in the professional schools, but it permeates the ideology of all university faculties. Many academics embrace it deeply" (Derber, Schwartz and Magrasss 35). In astronomy knowledge as technique and knowledge for itself come together.

Fang and Takayama conclude that modern science is inseparable from mathematics, which has as its quintessential characteristic universalistic demonstrability (Fang and Takayama 255-256). In Marxist terms, mathematics can be seen as part of the superstructure of society, or even a 'supersuperstructure' as it sometimes appears to develop completely independently of any economic base (Fang and Takayama 262).

Even Bloor, who champions the view that mathematics is amenable to sociological analysis, acknowledges that mathematics has an authority (legitimate domination of knowledge) beyond the empirical:

> It seems that mathematics embodies truths that which have quite a compelling nature … the truths of mathematics are not only compelling, they are unique and unchanging … the authority of a mathematical step as it presents itself to our consciousness is at least akin to absolute moral authority … the individual confronts mathematics as a body of truths that must be mastered … whilst there clearly exist cultural differences, for example in religion and social structure, all cultures develop the same mathematics (Bloor 75).

Thus mathematics is cognitive rationality in its pure form. John Stuart Mill’s empiricist account of mathematics is used by Bloor to debunk the logical account given by Frege and Russell. To Mill’s psychological explanation Bloor adds a social component, asserting that mathematical theories are social conventions (Bloor 77-85). Nevertheless, Bloor’s initial description of the way mathematics is received and perceived attests to its powerful social imagery.

Another aspect of the power of mathematics in legitimation is its association with objectivity. Such power is enhanced in a society that is characterised by what Porter calls “cultures of objectivity” (Porter 3). Porter regards numbers, graphs and formulas as “strategies of communication” (Porter viii). The language of mathematics is highly structured and rule bound, and is seen as being synonymous with rigour and universality. Mathematics minimises the need for intimate knowledge and personal trust, and is a form of communication that goes beyond locality, community and political and ethnic cultures. Because mathematics is seen in this way, disciplines, which are heavily mathematical, such as astronomy and physics, are given added epistemological legitimacy. Quantification is seen as being an essential part of ‘the scientific method’ and any discipline that extensively uses quantification will have an advantage over those disciplines, which use ‘mere’ qualification. In astronomy, this obsession with quantification and rigour was not something that was originally inherent in the discipline, but came about historically as instruments improved (Porter 200-201).

Mathematics is thought to involve rules so constraining that the desires and biases of individuals are cancelled out. This implies the subordination of personal interests and prejudices to public standards, even though most of the public is unable to comprehend scientific mathematical reasoning! This paradox is noted by Porter (74). Knowledge apparently becomes detached from the individuality of its makers. More generally a society that values quantification conforms very well to Max Weber’s notion that modern societies are characterised by: “Bureaucratic administration which means fundamentally domination through knowledge” (Weber 1949: 225-226). Mathematics was also thought to be character building and like Greek and Latin a sign of good breeding (Porter 202).

Haddens has detailed how the status of mathematics as a legitimator of knowledge was enhanced in the sixteenth century by its ability to help commerce. As science grew in the west, those disciplines which were most mathematical such as physics became the 'hardest' sciences, and the harder the science, the more legitimate the knowledge. Quantifiability and measurement became the benchmark for reliable scientific knowledge, and consequently mathematics added legitimacy to the knowledge claims of those disciplines.

Given that mathematics is so central to modern professional astronomy, and has enabled astronomy to make profound discoveries, it is difficult to make the claim that mathematics is merely an artificial device for monopolising access to the occupation (Collins 9). It is not necessary, however, to suggest that astronomers deliberately use mathematics to limit the number of astronomers, as, for example Mesopotamian priests used hieroglyphic writing to limit their number (Derber, Schwartz and Magrass 17). Mathematics in astronomy, as in other professions, does play a role in limiting the number of astronomers. Even Robert Boyle is seventeenth century England "remarked upon the relative inaccessibility of mathematics. To go on as mathematicians did was, in his view, to restrict the size of the practicing community" (Shapin 337). Hitherto, this has also included limiting specifically the number of women and ethnic minorities in the profession. This, however, could be changing, as more women and at least certain ethnic groups succeed in mathematics. In fact the percentage of women astronomers is growing, and they are becoming politically active ("Baltimore Charter for Women in Astronomy").

Astronomers, more perhaps than any other professions apart from professional mathematicians and physicists, must attain an exceptionally high standard of mathematics before being considered for a professional position. The high mathematical standards give the impression that astronomers are members of an intellectually superior group (an elite in Pareto's sense) who possess abilities and talents that the average person lacks. Mathematics also gives astronomers an esoteric body of knowledge apart from any empirical discoveries they might make. Some astrophysical theories, it is claimed, can only be explained mathematically. Thus the elite status of astronomers is enhanced. Mathematical rigour can also help to form and maintain communities of scientists, who cannot control the phenomena they study.

At a more philosophical level, pure mathematics has been seen as the ultimate expression of the culmination of human intelligence; the apex of human evolution (Polanyi 1958: 84). Mathematics as pure, abstract thought transcends experience (Polanyi 1958: 85). Moreover, the notion that mathematics is a reflection of the real world (nature expressing herself to humans), objectifies and deifies mathematics, and gives it a metaphysical, almost supernatural aura. The high status of mathematics contributes to the high status of astronomers. Mathematics also enhances the impression that astronomy is a 'hard' science and that its findings are objective, value free and neutral. As Rossides notes, mathematics not only represents "objectivity as metaphysics (or as the law and the will of God)" but also creates "the moral idea of objectivity as impartiality, fairness and jusice" and the result of this is "to depoliticise the exercise of power" (Rossides 115). In this sense, mathematics in astronomy can be seen as a form of boundary work. Moreover, astronomers, having access to objective truth, are in a high status position, which can enable them to make authoritative pronouncements on matters other than astronomy. It could be argued that the high level of mathematics required for entry into professional astronomy means that astronomers are overtrained. Such overtraining gives to the profession the character of possessing esoteric knowledge, which confers a form of power, or at least status, on the possessor of such knowledge. An interesting thought experiment would be to try to imagine professional astronomy without advanced mathematics. As indigenous and amateur astronomers have shown, astronomy without advanced mathematics is entirely possible. But such an astronomy would be a very different one to that which exists today.

Conclusion

According to the critique of professions, the idealised account of astronomy as a pure, innocent, non-partisan, harmless, neutral science is a social construction that benefits astronomers. In particular, the intricate systems required for professional astronomy, such as advanced mathematics and skills using sophisticated equipment, protect astronomers from evaluation by laypeople. The content of astronomy is subject to peer review by other professional astronomers, not by laypeople. Like other professions, they, or rather the educational systems and hierarchical structures which produce them, create dependency on the part of their clients, whether those clients be governments or laypeople interested in astronomy. Thus professional astronomers are an elite in the Paretoian sense because they possess superior knowledge of a particular subject matter. We should not forget the fact that prime beneficiaries of astronomers' talents and abilities are astronomers themselves. All of my interview respondents expressed a high level of work satisfaction. Astronomers become astronomers because they want to. Their work is satisfying and creative, their remuneration, while not superlative, is adequate, and their working conditions and environment generally favourable. In short, astronomers themselves are the chief beneficiaries of their professional status.

CONCLUSION

Here I summarise and synthesise the previous chapters and suggest some general theoretical conclusions deriving from my research. I try to answer the question I posed at the beginning of the thesis. Namely, given that astronomy, unlike other scientific disciplines such as medicine, has no obvious utilitarian benefits, what arguments, strategies, tactics and rhetoric do astronomy advocates use to persuade funding agencies to part with large sums of money to allow professional astronomy to carry on its work? My answer, based upon my analysis and interviews, points towards astronomy as a humanistic discipline; its legitimations are more like those of activities such as literature, philosophy, and history, rather than those of the hard, practical, applied sciences. The findings of my study also suggest that, in the case of astronomy, we must look to the wider society for explanations of why astronomers are able to do their research. Astronomy successfully explains and justifies itself and continues to successfully procure resources from society because: first, it has popular support; second, it has an educational role; third, because modern societies are 'scientific' in that they value science for its own sake, and acknowledge that science is the foundation of society. In other words astronomy benefits from what Drori et al. call "the general cultural authority of science" (Drori et al. 10). There follows a brief summary of the findings of each chapter, followed by some general theoretical conclusions.

The first two chapters approach the problem of funding in different ways. 'Astronomers in the Political Process' examined astronomers as political actors and assessed their power; it was found that astronomers are politically weak, and that astronomy's fortunes are intrinsically bound up with the state. The case studies in the political process chapter indicate that there is a synergistic relationship between legitimation and funding: the more funding a project gets, the more it is legitimated, and the more legitimated it is, the more funding it gets, and so on. 'Astronomy as Big Science' begins with the assertion that astronomy is the oldest science. It may the case that astronomy's position as the oldest science itself helps in funding. Brown has put the following paradox:

> Scientific knowledge is generated by a politics of truth that can only exist in an autonomous community of knowledge producers, one in which there is accountability to one's scientific peers. Such knowledge production depends on external sources for its institutionalisation as an autonomous practice, but if those external funders excessively direct the scientific enterprise they undermine its capacity to produce new knowledge, a capacity that motivated the original funding. This also explains the apparent paradox that the most "mature" disciplines, those with the most accumulated symbolic capital, also are the most autonomous and the best funded disciplines — for example, economics in the social sciences and physics in the natural sciences (Brown 543).

In the above described situation astronomy benefits both because it is an old, established science, and because of its close association with physics. This paradox also helps explain why sciences like astronomy, which have no obvious use to funders, are able to obtain resources. A description of astronomy as big science highlights the gap between the resources available to scientists and those in the humanities. The very resources that characterise modern professional astronomy both serve to and are a manifestation of the successful legitimation of astronomy.

'Astronomy as Popular Culture' highlights the unequal relationship between the populariser and the popularisee. Popularisation is also dependent on, and reinforces, the professional status of astronomy. With the odd exception of Patrick Moore, the major astronomy popularisers are professional astronomers or astrophysicists. When astronomers popularise astronomy they are also popularising themselves as professionals, and promoting astronomy as a profession. 'Astronomy as a Profession' suggests that astronomers can be an elite in the Paretoian sense because they possess superior knowledge of a particular subject matter. The chapter also suggests that the very status of astronomy as a science helps to the legitimate the profession. The big science of modern astronomy is cast in the mold of industrial capitalism and rests on broad based popular support.

Astronomy occupies a secure niche both in the scientific community and in the larger culture.

Taxonomy of Legitimations

Modern astronomers engage in a variety of types of legitimations. Even within a single scientific discipline like astronomy, diversities and differences of legitimacy must be recognised. Furthermore, they do not always work separately; sometimes two or more legitimation practices work together. As Barker notes: "there are many forms of legitimacy, and their diversity may provide a series of waterproof bulkheads preventing challenges in one area from seeping through into the next" (Barker 157). Legitimation practices vary in kind, combination and intensity over time and space.

More specifically, legitimations of modern astronomy may be classified as follows:

- **Defence and national prestige**: broadly defined: not just national defence in the narrow sense, but the desire for power, national prestige or autonomy.
- **Economic**: the supposed connection between modern astronomy and the need to ensure the development and therefore competitiveness of industry, or more generally the desire to accelerate economic development.
- **Social**: relating to the transmission of culture, education and the supposed needs and desires of non-astronomers.
- **Philosophical**: the notion that astronomy is uniquely placed to help answer fundamental questions about humanity's place in the universe, the existence of a Supreme Being, and the nature of the universe.
- **Humanistic/Scientific**: the notion that science, in itself, is a good thing, and requires no other justification. The conversation between astronomers and the universe, and that between astronomers and non-astronomers, must be seen as a good in itself for professional astronomy to continue.

Science in general and particular sciences use all the types of legitimation listed. Indeed, my research showed evidence of all of the above types, but used in different contexts. However, there is no reason to suppose that all sciences use all the different types of legitimation practices equally. While my analysis has uncovered all of the above forms of legitimation in astronomy, it has found that philosophical and humanistic/scientific legitimation types are the most prevalent. This proposition is subject to an important qualification. In the past, the humanistic legitimation was by no means the most important. As late as the nineteenth century astronomy was legitimated by its value to ocean-borne trade and commerce, and astronomers were charged with developing aids to navigation. But by mid-century astronomical research of a non-utilitarian nature was being supported, and astronomical research became increasingly divorced from practical applications. Astronomy and celestial mechanics achieved levels of precision far in excess of the demands of practical navigation. The new field of astrophysical research offered no practical returns. Philanthropists and the scientifically minded public funded astronomical research without demanding economic payoff (Lankford 15). Legitimation changes over time. The humanistic legitimation appears to be the most prevalent now, but was not so in the past, and may not be in the future.

The above taxonomy cuts across Weber's three ideal types of legitimacy. Astronomy's legitimations more closely correspond to a more substantive type of legitimacy mentioned by Weber. This fourth type of legitimacy is a variation of the 'rational-legal' type, but 'legal' is replaced with 'value'. Thus, this type of legitimacy arises from, "The belief in the absolute validity of the order as the expression of ultimate values of an ethical, aesthetic or of any other type" (1968: 33); and again, "A rational belief in the absolute validity of the order as an expression of ultimate values, whether they be moral, aesthetic or of any other type" (Weber 1947: 127).

Although I have found humanistic legitmations to be the most prevalent, it can be seen that astronomers use different justificatory discourses depending on the circumstances. For example, in the context of nation building, national prestige is used. This is especially the case with specific large, expensive projects. Jodrell Bank was built on such a legitimation, when Britain had emerged from World War Two and rationing, was losing its colonies, but was experiencing an economic boom, which made the pursuit of such a project a possibility. As the chapter on big science showed, when making the case for funding to government agencies, astronomers use not only national prestige but also supposed economic/practical spin-offs, even though during my interviews astronomers, with the partial exception on Neil de Grasse Tyson, played down economic benefits. It is possible that my interviewees were comfortable telling me what they really thought as I was not a funding agency. When advocating for astronomy funding in general, astronomers can use the public interest in astronomy to argue for its positive contribution to raising public awareness of science, conveying scientific concepts to students at all levels and to their teachers, and contributing to educating a technically capable and aware citizenry (see page 117).

Broadly, my research supports the findings of Drori et al. who assert the importance of the cultural authority (legitimate domination) of science over any instrumental value it may have: "the crucial element of the expansion of science is indeed its broad authority, rather than its instrumental functions, powers, and interests" (Drori et al. 23). My findings support those of Drori et al. and others that analysts have been mistaken attempting to find explanations of scientific growth in terms of functionalist, instrumentalist, and utilitarian connections (Drori et al. 16).

On a more philosophical level, astronomy is legitimated because, as a science, its discoveries have a relation to truth (Habermas 1975: 97). Legitimation in astronomy is a rational value oriented type of authority (Habermas 1975: 99). That is to say, astronomy is legitimised on the basis that scientific truth is valued in the societies in which astronomy is legitimated. As Polanyi notes, "No important discovery can be made in science by anyone who does not believe that science is important in itself, and likewise no society which has no sense for scientific values can cultivate science successfully" (Polanyi 1958: 220). For astronomy to be legitimated science must be the ideology of the system of authority (Habermas 1975: 101). Science here is a cognitive activity that is esoteric, yet formalised and standardised enough to be, in principle, accessible to all who would undergo prolonged training.

My research thus supports the hypothesis of Lenoir, who highlights the role of a materialistic ideology of power and realism in causing the German state to support experimental physiology as science for its own sake, independent of practical application (Lenoir 76-77). Lenoir emphasizes the symbolic aspects of scientific legitimation. The experimental physiologists never claimed that society would derive direct, practical results from the application of their science. Rather, they emphasised the importance of science for creating a style of thought and mental attitude that was essential to the future of Germany (Lenoir 94). However, it is now thought that German support for scientific and technical education, including for science for its own sake independent of practical eduction, was indeed one of the significant factors in the rise of German industry and power at the end of the nineteenth century (Lenoir 97).

Drori et al. too see science as more than just cultural authority (legitimate domination of knowledge). In addition to its cultural influence, Drori et al. see science as an having an ontological role: "much scientific activity cannot be seen as instrumental at all … one can better analyse the expansion of science by seeing science, in relation to actorhood, as having an ontological role … science provides elaborated, rationalized, and more complete conceptions of the nature of things, including the nature of the human and organizational actors themselves. Science thus establishes a cosmos in which responsible and authorititative human actorhood is enhanced: first, an eternal frame within which human actors exist, and second, a demonstration of the all knowing agentic competence of these actors" (Drori et al. 35). Thus science, and especially astronomy, sustains cosmologies, or abstract pictures of the universe, within which human social actors exist and maintain their universal status, or legitimacy, as agentic entities:

> There is a continuing concern with the location of the human actor in the wider lawful and rational universe. This involves, far beyond instrumental considerations, a concern with the fundamental nature of human social, psychological, and physical life, and of the contexts of existence. Such are the fascinations with the linguistic, evolutionary, and sociocultural prehistories, including prehistories of the Earth, the solar system, and indeed the universe. It becomes important to know about the big

> bang, the existence of life on Mars, or the potential location of other intelligent life forms in the universe (Drori et al. 36).

Within astronomy there is a general cognitive consensus as to what constitutes knowledge, which results from either continuous growth or revolutionary changes; either way, the change must be regarded as progress. This cognitive activity is what explains and justifies astronomy as a science. As Thomas Kuhn asserts: "We tend to see as science any field in which progress is marked … if we doubt, as many do, that non-scientific fields make progress, that cannot be because individual schools make none. Rather, it must be because there are always competing schools, each of which constantly questions the very foundations of the others" (Kuhn 1970: 162-163). Thus science and progress are closely related concepts. Indeed, in the nineteenth century astronomy in particular was singled out as *the* science associated with progress. The newly popularised nebula hypothesis was seen as being evidence of an evolving, and therefore progressive, universe. This notion of progress was not only epistemological but also moral. Astronomy was seen as morally progressive because it familiarised observers with God's handiwork, thereby making them closer to God (Secord 57-59, 163). Indeed, developmental cosmology was seen as underpinning a new kind of society (Secord 514). We see that non-utilitarian astronomy is nothing new. Even prior to Victorian times important astronomical debates of previous centuries were about issues such as the motions of the planets, not just about issues of practical importance such as navigation and timekeeping.

In a world where science is the cardinal system of cognitive validation and legitimation, any scientific profession has a head start in the process of legitimation. Any activity that is regarded as science is given the ultimate legitimation of an objective, independent, incontrovertibly more effective inquiry, which opens up the possibility of unlimited progress. The scientific cognitive base of astronomy links the profession to the dominant system of cognitive legitimation: the ideology of science as a method and world view rather than science as a body of knowledge. Put simply, astronomers, like engineers and social scientists, carry the prestige of science (Drori et al. 290).

Astronomy benefits from the fact that in modern society, in which rational/legal authority is dominant, science has a broad authority over nearly every domain of social activity. Moreover, science has epistemic authority, and as Gieryn notes (Gieryn 1999: 1) this resembles cultural authority. In Gramscian terms, astronomers are a group of intellectuals who have ‘organic ties’ to fractions of the ruling class. In the modern world, science is the hegemonic discourse. But persuasion and justification depend on ideological resources (in this case the ideology of pure science, detachment, scientific objectivity), the import and legitimacy of which are ultimately defined in terms of hegemonic power, as well as hegemonic legitimacy; special bodies of experts, such as astronomers, are entrusted with the task of defining a section of reality, but this trust is to be understood within the confines of the dominant ideology, of which science is one major pillar. The process of popularisation, in particular, involves a delegation of authority (legitimate domination of knowledge of the cosmos) to the astronomer, and involves an act of trust.

Popularisation

Given a society in which science and progress are seen as synonymous, as long as there are what are thought of as rational grounds for accepting the findings of astronomy, no other justification is necessary. Given the division of labour between professional and amateur astronomy, professional astronomers are the legitimate producers of important astronomical knowledge. The lay public has no other choice but to accept their definitions of what constitutes astronomical knowledge. We have also seen that the charisma of celebrity astronomers plays a role, albeit a minor one, in the legitimation process. Science is the ideological form of justification for astronomy. Over and above this citizens must be convinced that science is in the general interest. The notion of truth, is however, bound up with that of morality. Modern astronomy simply continues the connection between the notions of truth and morality.

Because of the changing nature of the economy, astronomers have had recourse to forms of legitimation that were hitherto unnecessary. Popularisation is now an intricate part of the astronomical process.

On the issue of popularising astronomy, most of the astronomers I interviewed verbally supported it, and none actively opposed it. Out of the twenty astronomers I interviewed, three — David Helfrand, Neil de Grasse Tyson, and Eric Chaisson — were popularisers of astronomy, having written popular books and appeared on television, while another, Jacqueline Van Gorkon, was actively engaged in dialogue with people in the humanities and social sciences. Another, Marc Kaminkowski, said that "astronomy, like literature, is entertaining". Interviewee Will Van Der Veen said, "many funded intellectual activities, such as the arts, have no practical benefit. Astronomy asks: where do we fit in? what are we? It has religious overtones".

However, it is evident that at least some astronomers on the Hubble project were opposed to sharing their discoveries with the media and the public. According to Hubble astronomer Chaisson:

> It is usually an elitist minority of scientists who are unalterably opposed to an interaction with the public, or with non-scientific students, and these are the ones who tend to be vocal, powerful and insistent. The academic scientist who stresses research to the virtual exclusion of teaching, who hoards results instead of sharing them, is often the one who percolates to the top of leading university departments. Scientists who were inclined to work with the public to help the citizenry better understand the subject matter and methodology of science, or even to teach well in universities, are looked upon as second class citizens in the science community (Chaisson 350).

Such attitudes on the part of scientists are contributing to a widening of the culture gap and even a "slide towards a scienceless society" (Chaisson 350). Chaisson obviously has a low opinion of the commitment of his colleagues to the public promotion of astronomy. As an insider, his view cannot be discounted, but the evidence is surely against his negative characterisation. The number of popular astronomy books published has risen exponentially over the past twenty years, and even though only a minority of astronomers may be engaged in popularisation, their impact is significant. Moreover, with the exception of Eric Chaisson, my interviewees flatly contradict his view. It could be that my interviewees were telling me what they thought I wanted to hear, but the interviews were done in confidence. It seems clear that the direction, if only for purely economic reasons, is for more astronomers to be involved in some form of popularisation and promotion. Indicative of this is the information on lobbying on the AAS web site. It seems, however, that there are contradictory pressures involving popularisation. Being a populariser does not necessarily benefit an individual in terms of seeking status within the astronomical community, but it is good for the community as a whole**.** Astronomy's popularity in general, however, means that it is the most effective of all the physical sciences in terms of attracting students to a career in science (National Research Council 172).

Boundary Work

Exact and sensitive boundary forming is necessary to allow astronomers the status of authoritative science and to demarcate them from others whom society may not see in such a high regard. As society's opinion of different groups changes, so boundaries change. Thus boundaries are not rigid entities; they shift with new scientific discoveries and with society's changing values. The discovery of organic molecules on a meteorite from Mars has implications for exobiology and therefore for SETI. Such a discovery can expand the boundaries of astronomy by rejuvenating SETI lobbyists and giving their goals more legitimacy. But the discovery of extra-terrestrials would not constitute a utilitarian rationale for astronomy. As Ferris notes: "Detection of an alien radio signal presumably would constitute the greatest discovery in the whole history of science, but nobody really knows what it would be good for" (Ferris 24).

The case of astronomical boundary work supports Gieryn's view of boundary work as being strategic, practical action (Gieryn 1999: 23). However, Gieryn says that when the stakes are autonomy, science gets purified: demarcated from all political and market concerns; but if the stakes are material resources for scientific instruments, research materials, or personnel, science gets unpurified, erasing the borders between truth and policy. In other words, science becomes applied and practical. This is not the case with astronomy. Even when astronomers argue for more resources, they do not argue by and large along utilitarian lines. With the partial exception of its role in education, the evidence seems to support the notion that its practitioners see astronomy, even when justifying resources allocation, as a non-utilitarian endeavour. The one clear exception is when the political context of appealing to the legislator, and here it is usually non-astronomers, such as David Lane and Daniel Goldin, who are doing the legitimising. Legislators are more likely to be persuaded by economic and nationalist rhetoric, so this is what is used. However, rational scientific authority does not have to be utilitarian to be legitimate. Justification for astronomy in terms of practical spin-offs in astronomy is only effective when coupled with other forms of justification. A recent U.S. government report on astronomy devotes only twelve pages out of 207 pages on the practical benefits of astronomy. These include: the development of antennas, mirrors, and telescopes, sensors, detectors, and amplifiers; spectrometers, imaging technology, precision timing and position measurement instrumentation; data analysis and numerical computation; and environmental studies (National Research Council 146-154).

Purity as Legitimation

The results of my study do show that astronomy is ‘pure’ in the sense that astronomy’s success in obtaining resources from modern capitalist societies cannot be explained by reference to practical spin-offs or narrow economic explanations. This is particularly born out in my interviews with astronomers. In one sense, tactics have changed little since the nineteenth century. Like Tyndall before them, my interviewees emphasised that science has cultural values beyond practical utility — virtues not likely to be appreciated and financially supported by profit-seeking venture capitalists. Astronomers, like Tyndall, present an alternative case for government funding of science not reliant on any practical spin-offs. To my interviewees, astronomy is akin to philosophy in that it is a source of intellectual discipline, but most of all, a search for truth. One interviewee specifically referred to peer review in the legitimation process, implying that legitimation to society was synonymous with legitimation within science. Other interviewees emphasised the philosophical/spiritual benefits of astronomy, as opposed to utilitarian, with the partial exception of Neil de Grasse Tyson, Director of the Hayden Planetarium; this could be because of his position, in which he is heavily involved in the popularisation of astronomy to the members of the public, and therefore has to use the whole gamut of rhetorical resources in order to legitimate his profession. Tyson emphasised the spiritual, educational and 'practical' role of astronomy, the latter being mainly in the form of spin-offs such as medical imaging. But even he emphasised that the spiritual role was the most important.

The most common justification for astronomy given by my interviewees was humanistic; it makes humans more noble, in the same ways as doing English, philosophy, and so on. People are interested in knowing their place in the universe. Where did we come from? Why are we here? Where are we going? Who are we and what is our place in the Universe?

In general, my research supports Hall's view that: "The pursuit of science for utilitarian ends is a very unhistorical projection backward from our own age" (Hall 15). We can see that professional astronomers have carved out for themselves a specialised niche: they have a unique product: knowledge of the universe obtained from sophisticated technology and higher mathematics. Their product/service is also useful to dominant groups in terms of national prestige. This remains the case in an age of international astronomical endeavours.

Professional astronomy now has an identifiable and standardised career structure and intellectual space. These institutional arrangements help to demarcate professional astronomy from 'pseudosciences' such as astrology and ufology on the one hand, and amateur astronomy on the other. Cognitive boundary work also creates social boundaries that distinguish astronomy from other disciplines. These boundaries are more fluid than those between astronomy and 'pseudosciences', enabling astronomy to latch on to, or even to overlap, with disciplines that can be of use in legitimation. For example, modern astronomy in the form of astrophysics, in addition to being epistemologically helpful, is also useful from the standpoint of legitimation, because astronomy here is fused with another discipline which is highly legitimised: physics. So astronomers establish their own distinct niche within the market of scientific discourse, marking out their particular topics and methods from those of other disciplines, and they make alliances with practitioners of other sciences. Distinctions help to define the enterprise as a unique and independent knowledge practice; alliances help to defend and validate this independent status. Astronomy loses nothing by allying itself with physics. Astronomers may have lost something however by allying themselves with NASA, which has an agenda of its own and, as one of my interviewees claimed, 'distorts the direction of astronomy'.

Danziger summarises this situation succinctly. On the subject of the institutionalisation of disciplines, Danziger writes that it is:

> A political process in which alliances have to be formed, competitors have to be defeated, programs have to be formulated, recruits have to be won, power bases have to be captured, organizations have to be formed, and so on. These political exigencies necessarily leave their mark on the discipline itself, and not least on its investigative practices. The political environment largely determines what types of knowledge product can be successfully marketed at a particular time and place. The goal of producing an appropriate type of product plays a crucial role in the selection of investigative practices within the discipline. Ultimately, the limitation of investigative practices results in corresponding limitations on the knowledge products that the discipline has to offer. So, in the end, those with sufficient social power to have an input into this process are likely to get the kinds of knowledge products that are compatible with their interests (Danziger 182).

On the other hand, by buying into NASA, astronomers can participate in the myths of heroic exploration, expansion and conquest (Tucker and Tucker 80). The notion of astronomy as heroic exploration is also emphasised by the National Academy of Sciences, in a recent report on astronomy in the United States. In it the authors assert that "Perhaps the most persuasive, but least quantifiable justification is the importance American society has always attached to exploring new frontiers, and in the deep human desire to understand how we came to be, the kind of universe we live in, whether we are alone, and what our ultimate fate will be. Exploring frontiers of unimaginable mystery and beauty, astronomy speaks compellingly to these fundamental questions" (National Academy of Sciences 2001: 138).

The notion of "extending the frontiers of human knowledge" has occurred in different contexts in the course of my research: in the address of Dr. Neal Lane to the Senate Appropriations Committee; in Chaisson's book on the Hubble wars; and here in the National Academy of Sciences report. Similarly, Christisdou, Dimopoulos and Koulaidis found that the most common types of metaphor about science found in popular media are those that describe science and technology as extending the frontiers of human knowledge. This was especially the case with space science and astronomy, which they found to be almost exclusively represented as a discipline opening new perspectives and extending human experience to new, unforeseen landscapes, by being described as activity of adventurous exploration, mystery resolution, or involving the receiving and decoding of messages from unknown worlds (Christisdou, Dimopoulous and Koulaidis 356).

A Humanistic Discipline

As several of my astronomer interviewees pointed out, because the public is so interested in astronomy, it is a good way of getting them interested in science in general. The educational role of astronomy was also emphasised by several interviewees.

Several astronomers I interviewed placed education high in the reasons for funding. The argument given by two interviewees was that in schools, the one subject sure to grab the attention of school children is astronomy. My interviewees should have said two subjects, the other being dinosaurs. But the point remains that astronomy does get children interested in science, and helps produce scientists for the nation. In this indirect manner, popularisation produces a sort of utilitarian rationale for doing astronomy. Interestingly, Drori et al., in an empirical study of several countries, found that although there was sometimes a negative relationship between expenditure on science research and economic growth, the relationship was positive between a scientific labor force and economic growth (Drori et al. 232-246). Thus there is some support for this economic link.

If the nation needs scientists, it should fund astronomy, for astronomy provides that first spark of interest in science. Herein also lies a ‘spin-off’ argument: interest in astronomy is said to spin-off into an interest in other sciences. Through popularisation, astronomy has the practical use of producing scientists. A related effect of the successful popularisation of astronomy is that it helps to sustain a scientific society, which in turn supports astronomy, and so on. In order for this cycle to continue, it is essential that astronomy be represented in a way that captures the imagination of the public, young and old. Popularisers of astronomy such as Carl Sagan, Patrick Moore, Stephen Hawking and Paul Davies create a cultural space for astronomy, sustaining and enhancing public support for the science.

Although the focus in the process of legitimation of astronomy is decidedly non-economic, a key goal, certainly, is economic, namely to secure for astronomy various professional resources such as more employment opportunities, increased attention to astronomy in schools and universities, and most important of all, a high level of direct funding for astronomy from government. ‘Resources’ here can also mean cultural resources as well as economic resources. Status, autonomy and power are also important and cannot be reduced to economics. For example the wages and investment behind some blue-collar occupations such as drilling rig crews may be higher than that of astronomers, but their status and autonomy are much lower. Astronomy is thus a cultural resource.

All of my interviewees said astronomers need the support of the public, in particular because the public pay their wages through taxes. One astronomer objected to the term ‘promote’ and preferred ‘explain’: if the public understands what astronomers do then they will automatically support it. One astronomer said a case couldn’t be made to justify astronomy based on economic spin-offs, although some astronomers try to do this because they think it will be effective.

The general feeling among the astronomers I interviewed was that astronomy has a natural support group in the general public. Interviewees universally thought that astronomy was popular with the public, more popular than other sciences. Two interviewees contrasted astronomy’s popularity with the lack of interest and even hostility of the public toward physics. Physics thus benefits from astronomy's popularity, not only through astrophysics and other links, but also because astronomy's popularity spills over into general support for science. Most interviewees saw support for astronomy and other sciences as being inseparable. One interviewee asserted that it is wrong to try to analyse astronomy in isolation from the other sciences, even though only a minority of interviewees worked directly with scientists from other disciplines. In short, my interviews supported the notion that astronomy's legitimation cannot be separated from the legitimation of science in general.

To sum up, the astronomers I interviewed were concerned to legitimise astronomy not by its marketplace value, but through its role in education, culture, and the spiritual life of the community. The main thrust of their response was that astronomy should be funded precisely because it was pure knowledge that had, for the most part, no direct use in the industrial marketplace. One of my interviewees even mirrored Tyndall by mentioning Homer's *Odyssey* in response to my first question. Another, Eric Chaisson, was most emphatic that NASA was making a big mistake in trying to promote astronomical activities by reference to any perceived practical or economic spinoffs. Chaisson is of the strong opinion that astronomy can only be and must be justified in terms of knowledge for knowledge's sake, and should be seen as part of a civilized culture; scientific curiosity is a sign of a healthy and civilized society. Most of my interviewees spoke along these lines, although Chaisson was the most emphatic and outspoken in his view that astronomy is a humanistic rather than a utilitarian discipline. Chaisson added the term 'exploration' to the notion of curiosity, the implication being that curiosity leads to exploration.

My interviewees saw popularisation as synonymous with education, and some decried the lack of scientific education amongst Americans, as well as the lack of financial support and career opportunities.

Moreover, unlike physicist Alan Sokal and his allies Gross and Levitt in the 'science wars', who would like us to equate science with nature, my astronomer interviewees were quite happy to see astronomy as part of culture: both high culture and popular culture. They saw no contradiction between their hard science and promoting astronomy as a humanistic discipline. Indeed, some of my interviewees recognised the very survival of professional astronomy was dependant on its successful marketing as a cultural product. But the overview of astronomy as a profession shows that in addition astronomy must possess sufficiently occult properties to bar unwanted persons. Most of all, astronomers claim that their activities contribute to a cumulating cultural progress.

Here, then, is at least one scientific discipline that does quite not fit into the narrowly strategic explanations favoured by sociologists of scientific knowledge. To give an example, Cozzens, in her summary of the 'actor-network' approach of Callon and Latour, uses the terms "translation" and "enrolment" explain how scientists bring patrons into their networks by persuading them that they can solve their problems through the scientists' research (Cozzens 168-169). Thus the structure of science is shaped by scientists' search for power through networks of enrolled elites. Finally Cozzens explicitly denies that scientific knowledge can be 'pure' because it only produces knowledge that is good *for some particular purpose* (Cozzens 181). She then asserts that "the sociology of scientific knowledge forces us to abandon the notion that our knowledge is by virtue of being scientific, a generic means to human ends and to consider exactly whose ends it serves". This has been part of the rationale behind my study. The link between the polity, the economy, public and private corporations, and scientific research is more complicated than Cozzens' interpretation would allow. Much scientific research is indeed directly influenced by the special interest of employing corporation, but this is generally not the case with astronomy. Astronomy highlights the complexities of the links between research and the wider society. For example, one astronomer I interviewed, Bruce Elmergreen, was employed by IBM, who allowed him to allot a portion of his work time doing astronomical research which was not related to IBM's research and development needs. This should not be taken as a 'defence' of IBM. It merely highlights the point that crude interest and enrolment theory cannot explain the work of all scientists. Moreover, we can see that the case of Jodrell Bank shows that local factors can sometimes be important in legitimising a particular project.

There is a range of political forces ranged against the professional astronomical community. It might appear that the media are generally friendly towards astronomy, which indeed they are. However, the media like ‘pretty pictures’, a sensational story, and are impatient, wanting a quick fix, in terms of the receiving and imparting of astronomical information. This sometimes annoys astronomers, as they see it as being in conflict with pure science and with scientific education, as was evident with the early period of the Hubble Space Telescope. In short, the relationship between the astronomical community and the mass popular media is profoundly ambivalent: on the one hand they need the media to promote their profession, on the other they want to pursue ‘pure’ science and educate the public.

A similar relationship exists between professional astronomy and the military. In the nineteenth century a good proportion of American astronomers entered the field from military related sciences, while others left astronomy for military science (Lankford 141-142, 148). On the one hand astronomy has used techniques designed by and for the military, and has even embarked on joint projects with the military, on the other the open ideology of astronomers conflicts with the tradition of secrecy within the military. This was a contradiction that caused conflict on the Hubble Space Telescope project. Astronomers were particularly resentful that the military intelligence community had experience with complex space missions but looked silently on while civilians struggled to accomplish technically what had already been achieved by the military.

One possibility for the employment for some astronomers supporting military technology is found in the recent doctrine of ‘Full Spectrum Dominance”. This notion was formulated by the US Forces Joint Command and expounded in a document entitled “Joint Vision 20/20”. The document advocates the attainment by the United States of “Full Spectrum Dominance”, which is: “The ability of U.S. Forces, operating unilaterally or in combination with multilateral and interagency partners, to defeat any adversary and control any situation across the full range of military operations” (United States Joint Chiefs of Staff: 6). The document asserts that “space forces play a critical role in awareness … space doctrine, organizations, training, material, leadership and personnel will evolve to fully realize the potential of space power". Thus full spectrum includes space. Some astronomers are experts at imaging. And full spectrum dominance required efficient systems to track satellites and transmit communications to them from mobile platforms. There is already such a system in existence in the US (Mann 2001: 36), and similar systems in Europe (Nitschke 42). However, whether full spectrum dominance will involve the astronomy profession on a significant scale remains to be seen, and any prediction about the effect of full spectrum dominance on the profession is pure speculation.

Contradiction and ambivalence also reign in relation to boundary work between astronomers and other adjacent professions such as engineers. Again, this is highlighted in the case of the Space Telescope. On the one hand astronomers needed the engineers to design and point the telescope, on the other, once the telescope was in space, and the astronomers, as end users, wanted to take over, they became resentful when NASA continued to give engineers responsibility for manoeuvring the craft.

Astronomers' experience with NASA, and particularly with the Hubble Space Telescope, highlights the political weakness of astronomers. Conflicts and frustrations grew as astronomers found themselves at the mercy of an employing organization that had both different priorities than theirs and, in their eyes, an inefficient and incompetent management. On the Hubble telescope, as with other NASA space probes, astronomers are merely end users, and they are just one group among several with stakeholding interests; others include NASA management and engineers, who have different priorities and interests to those of astronomers. One partially effective bulwark against these opposing groups was the Space Telescope Science Institute, a group of Hubble astronomers, which worked as a pressure group representing the interests of all astronomers involved with the Space Telescope. Unfortunately the group was created too late to influence the design of the telescope. Had such a group been involved in overseeing the design, the disastrous mirror problem might not have occurred.

Technoscientific Societies

I have argued that the profession of astronomy benefits from the high status of science. Indeed, it is not just that in modern society that science has a high status, but that science and technology cannot be separated either from each other or from the outer, 'non-scientific' society, so that what we have in Latour's words is a '*technosociety*' (Latour 1987: 174-175). In such a society, it is not only feasible but also quite easy for even a non-utilitarian 'pure' science such as astronomy to legitimate itself such that society pours resources into its maintenance and development. To use Habermas's phrase, science is a "principle of organization" of modern society (Habermas 1975). According to Habermas, organizational principles limit the capacity of a society to learn without losing its identity. At an abstract level, organizational principles determine the learning mechanism on which development of the productive forces depend**.** Organizational principles also determine the range of variation for the interpretive systems that secure identity. Finally, they fix the institutional boundaries for the possible expansion of what Habermas calls "steering" capacity: the ways in which society decides on changes in direction (Habermas 1975: 7-8). If we regard science in general as such an organizational principle, astronomy, as a hard science, is well placed to benefit. Polanyi makes the point that pure science depends on a theory of knowledge that is personal, which in turn implies an ontology of the mind and "a sociology in which the growth of thought is acknowledged as an independent force. And such a sociology is a declaration of loyalty to a society in which truth is respected and human thought is cultivated for its own sake" (Polanyi 1958: 264). Science is at once subversive and at the same time helps maintain social order. It is cognitively subversive because it challenges traditional beliefs, but because its discoveries eventually command more or less universal assent, science legitimates the society that gives it the autonomy to make such discoveries (Ben-David: 189).

Continuing our use of Habermas's abstract account of the process of legitimation in society, even though astronomy is not, strictly speaking, a utilitarian discipline, we can include it in the general range of productive forces that help humankind expand control over outer nature "through the medium *of utterances that admit of truth*" (Habermas 1975:

9). In this way, technically utilisable knowledge is coupled with reflexive learning processes (Habermas 1975: 22). As we saw in the chapter on popularisation, rather than merely being about facts, the findings made popular in *Cosmos* come close to philosophical notions of *truth*: that is, about humankind's place in the cosmos. If we use Habermas's way of looking at truth and control, we see that the two do not have to be completely separated. Moreover, "objective knowledge", like the legitimacy of valid norms in society, ensures a "*community of shared meaning*" (Habermas 1975: 10). Again using Habermasian terminology, we can characterise science in general as a "goal value" of modern society (Habermas 1975: 10). That is to say, science is seen as an end in itself, and requires no other justification. The discoveries of astronomy are a free collective commodity. Once again, astronomy benefits. Having superseded theology as the basis of knowledge, science, and in particular astronomy, via cosmology, has fallen heir to the existential questions addressed by theology: Are we alone? What is the meaning of life? (Denzler 158).

But science has not completely replaced religion, especially in the United States, which shows that science and religion can co-exist side by side. It has been said that science and religion are two dreams between which Western civilisation presently finds itself (Needleman 2-3).

Looked at in this way, science itself can be seen as a legitimating world-view or ideology. Such ideologies "remove the counterfactual validity claims of normative structures from the sphere of public thematization and testing" (Habermas 1975: 19). In other words, once an activity comes within the legitimating world-view of a society, it no longer needs legitimating, and does not generally have to submit itself to public scrutiny. In the United States the example par excellence of this is the military, expenditure on which is rarely questioned. In the case of astronomy, astronomers and modern western society share a repertoire of basic themes or presuppositions: a shared imaginative inheritance. As in Ancient Greece, 'pure' sciences such as astronomy are legitimised by virtue of shared values. Astronomy is thus the author of its own legitimacy, and the expressor of a principle of which it is not the source. Astronomy is part of a scientific social system that is a reflection of shared norms. In fact we can see that behind the legitimation of astronomy are expressed a set of values: there is the intrinsic value of studying astronomy, the scientific value, the economic value (a minor value according to my research) and a leisure value: the study of astronomy for entertainment. In the case of astronomy it seems that the intrinsic value and the scientific value are intertwined: the study of astronomy for its own sake *is* a scientific value. Behind the values is a more general morality that is part of the technoscientific society. In short, astronomy, embedded firmly within the rubric of science, will be respected in a society that respects science.

Habermas says that it is humankind's nature to learn, and therein lies 'rationality', and so learning does not need to be explained (Habermas 1975: 15). Clearly, the long history of astronomy supports this view. If Habermas is correct, then this by itself can explain why society continues to plough resources into astronomy, and the 'spin-offs' are indeed spin-offs, and are not essential for astronomy funding. The important thing is that the citizen can be discursively convinced of the truth of astronomical findings, as opposed to the need for astronomy at all; in a 'technosociety', such a need is assumed, as with other scientific disciplines. Mulkay makes a similar point when he says that the appearance of formal rationality "helps the scientific profession to maintain its credibility in the wider society and to obtain economic and social support" (Mulkay 1979: 82). Thus in a 'rational' society that values 'truth' the distinction between internal legitimation (of scientific knowledge; within science; to other scientists) and external legitimation (to non-scientists; 'the wider society') breaks down.

But is 'pure' astronomy really that pure, despite its lack of utilitarian rationale? Since Bacon, science has been about the conquest of nature. The first step towards such a conquest is the *comprehension* of nature. By helping us to understand the universe, astronomy opens up the future *possibility* of its conquest. The understanding of aspects of the universe is political in the sense that it circumscribes our entire culture: it gives us a different sense of our place in the universe and therefore a different sense of our selves. Part of astronomy's legitimation is the notion that science can suggest qualitatively new relations between people. This is an overtly political notion. As Marcuse notes: "The science of nature develops under the *technological a priori* which projects nature as potential instrumentality, stuff of control and organization. And the apprehension of nature as (hypothetical) instrumentality *precedes* the development of all particular technical organization." (Marcuse 153). In other words, "The transcendental framework of the process of inquiry establishes the necessary conditions for the possible extension of technically exploitable knowledge" (Habermas 1971: 133). The notion of transcendence is taken up by Lankford, in his explanation of astronomy's popularity in nineteenth century America:

> Public support for astronomy in the pre-Civil War era rested on its spiritual and culture value, not on any material contributions astronomers might make to American life. Apparently Americans valued astronomy as a way of achieving spiritual transcendence. Even in the pre-Civil War era of keen sectarian competition, Protestants of whatever denomination could agree that astronomy was a powerful teacher of spiritual values. As gilded age materialism threatened to erode evangelical religion, the glories of the heavens served to remind Americans that there were higher values than the 'Bitch goddess of success' (Lankford 376).

According to Lankford, the longing for transcendence also played a role in the development of amateur astronomy in America (Lankford 377). Similarly, modern astronomy appeals to the transcendent in humans. Modern research has shown that the overwhelming majority of scientists work on directly utilitarian projects in corporate and government settings. More often than not, it is impossible to separate basic from applied research. Astronomy is an exception to this rule. However, the very characterisation of astronomy as a pure science is itself part of the legitimation process. As the analysis of boundary work has shown, the demarcation of pure and applied science is a social construction, performed by society and scientists to serve particular ends. Applied research leads to patentable and profitable results. Basic research remains in the public domain of universities and is rewarded more by status than money. Each helps to legitimise the other.

Pure science extends an intellectual warrant to applied science and technology, whereas the latter proclaims that basic research often (though not always) leads to something of practical use. In this way astronomy helps to maintain the notion of the cognitive legitimacy and autonomy of science and the instrumental utility of science: the ‘pure’ sciences ‘back up’ the ‘applied’ sciences.

Astronomers derive much of their power from the fact that they are scientists. In a society where science is held in such high esteem there is no reason to suppose that astronomy will not continue to be able to obtain resources for its work. Thus, the fate of astronomy is inextricably linked to the fate of science as a whole. As Gieryn (1999: 1) asserts, "‘science’ often stands metonymically for credibility, for legitimate knowledge, for reliable and useful predictions, for a trustable reality: it commands assent in public debate. If ‘science’ says so, we are more often than not inclined to believe it or act on it — and to prefer it over claims lacking in this epistemic seal of approval" (Gieryn 1999: 1). In such a society, where science dominates in the way that religion once did, just as religion never had to consistently prove itself in utilitarian ways, neither does science.

Social sciences have attempted to emulate the hard sciences in their attempt to legitimise themselves as ‘scientific’; Pareto specifically singled out astronomy, along with physics, as a science that has produced results that he preferred; librarians in America have relabelled their field ‘library science’. The natural sciences, of which astronomy is one, epitomise the search for truth to which professionals in general claim to aspire. In short, one way that professional astronomy legitimises itself is by being part and parcel of this thing we call science.

We have seen that astronomy legitimises itself in the same way as the humanities. Thus the continued existence of professional astronomy is evidence that astronomy does satisfy a genuine human need. We all need reality: to use Habermas’s terms, intelligibility in an intersubjectively validated lifeworld. Using Maslow’s hierarchy of human needs, we can say that astronomy satisfies the human need of fulfilment.

Astronomy also has spin off industries in the form of magazines and other media. Thus astronomy has at one and the same time truth-value and exchange value. Astronomy is a pure science that gives us true knowledge, but it also sells and excites. Modern astronomy especially promotes the notion of technological rationality. Astronomers, like philosophers, are intellectually productive, rather than materially productive. They produce discoveries, ideas and theories, rather than new technologies, though of course there are exceptions to this. Unlike philosophers they use large material resources to produce their knowledge. Moreover, astronomy's legitimation on the basis of truth-value is constructive, rather than destructive. Because it is legitimised on the predicate of knowledge for its own sake, it promotes community, not conflict. Astronomy as high culture does not disturb the status quo. The philosophy of modern professional astronomy, if there is one, is that technology can be used to take us back to the values of the Enlightenment and classical Greece. Given that astronomy does not generally legitimise itself on a utilitarian basis, it is forced to use classical notions of the good: an intelligent life is better than a stupid one, and reason and freedom converge. Implicit in this type of justification is the notion that there should be a specific class of people who should be paid to produce knowledge that has no provable use. In this astronomers are 'purer' than many contemporary philosophers, who emphasise the practical use of philosophy. In short, the Enlightenment gave rise to modern science, including modern astronomy. As long as Enlightenment values dominate society, astronomy benefits.

Astronomy is a unifier: it can be appreciated by all, cutting across class, race and gender; it 'benefits' all social groups and interests. As a Chinese amateur astronomer recently said: "Astronomy is the most significant [way to] unify us. Although we have different skin colours and live in different countries, we should all be the family on this planet. No other cause is so noble in my eyes" (Ferris xvi). This, together with the aforementioned role astronomy plays in nation building, makes astronomy a binding force for nation states. Astronomy is, albeit in a small way, functional in that it is an *integrating* force in society. To put it another way, astronomy, or rather the accomplishments of astronomy, through impressive and 'successful' technology, *validate* the social system that finances it (Marcuse 17). This is closely connected with astronomy as a nation builder.

Politically, the spectacular discoveries of astronomy can in turn legitimate the state as funder and supporter of science.

Astronomy is a binding force in another way. Durkheim acknowledged the functional role of religion in binding societies. Similarly, astronomy's cosmological quasi-religious overtones emphasise humanity's commonality. Paul Davies acknowledges an explicit link between SETI and religion. Davies sees aliens as being a 'halfway house' to God and quotes astronomer Fred Hoyle's idea of alien superintelligence playing a role similar to Plato's Demiurge in relation to 'the good', or God. Davies sees SETI as being part of a long standing religious quest as well as a scientific project, that touches a deep chord in the human psyche (Davies 136-138).

Pure Science and the Human Condition

It is not the case that the resources astronomy procures are primarily determined by economics and defence needs. As Greenberg notes, "the basic researcher is not primarily, and perhaps not at all, concerned with utility. His objective is an understanding of fundamental phenomena, regardless of their utility." (Greenberg 9). It is thus to the advantage of astronomers to appeal to all aspects of the human condition. All sciences, not only astronomy, have relied not only on practical arguments but also on philosophical, metaphysical and spiritual ones to explain and justify (legitimise) their continued existence. All sciences have a 'pure' or basic side, which, although having a connection with practical applications, cannot be solely legitimated on the basis of those connections. This is particularly the case with modern astronomy, because of its tenuous connections with the practical world; most astronomy is regarded as 'pure' or 'basic' science, which cannot and is not justified alone on the basis of practical benefits. One of my interviewees, Neil de Grasse Tyson, first listed some spin-offs, but then said the "Real reason is that astronomy asks the deep question, and takes the man in the street beyond the 9-5 existence."

Any such non-utilitarian legitimations must make certain assumptions about the nature of humans. We are not merely economic, practical animals, but have a spiritual side to which it is important enough to devote resources. Astronomy as a science can aid in the development and possible fulfilment of our spiritual side. Moreover, the argument must be that astronomy*, as compared with other sciences*, is uniquely placed to fulfil this spiritual need; this since astronomy is competing with other sciences for funds. An extra legitimation is necessary: not all sections of society, including resource providers, will share the above assumptions. Therefore it is necessary to provide one more legitimation that will capture these people: astronomy must be seen as a good thing in itself. Thus the positivist view that implies that science 'is a good thing' and that 'good things come out of science' is also propounded. This view was summed up by astronomer Sir Bernard Lovell: "fundamental research in astronomy or any other subject is essential to the well being of modern civilisation" (Lovell 1963: 386). Lovell also sees astronomy as an alternative to militarism: "The fate of human civilization will depend on whether the rockets of the future carry the astronomer's telescope or a hydrogen bomb" (Lovell 1963: 386). Marcuse asserts that, "The quantification of nature, which led to its explication in terms of mathematical structures, separated reality from all inherent ends and, consequently, separated the true from the good, science from ethics." (Marcuse 146). But modern astronomy, especially in its popularisation, reunites science and ethics, in a way that, say, medicine does not. The task of the astronomer is not to cure individuals, but is, like the philosopher, to comprehend the universe. In its guise of 'pure' science, astronomy reunites the true and the good. As Marcuse notes: "True, the rationality of pure science is value-free and does not stipulate any practical ends, it is 'neutral' to any extraneous values that may be imposed upon it. But this neutrality is a *positive* character" (Marcuse 156).

The fact that astronomy is popularised as a pure science is itself political. In a political sense, the ultimate legitimation for astronomy is liberation. Astronomy is concerned with ends, not just means. The universe becomes something that can be comprehended by and potentially organised by Reason. In the short term, however, astronomy focuses on our very powerlessness in the face of the magnitude of the universe. The universe is glorified. This is particularly apparent in Carl Sagan's television series *Cosmos*. Here, astronomy projects existence and defines unrealised possibilities; in this it has more in common with art than applied sciences. Beautiful, mind-numbing images of galaxies reunite art and science. We have also seen that in the popularisation of astronomy there is a certain conception of an individual learning for his/her own sake, and the implication that such learning can contribute to the development of the individual. This is not a new idea. In the *Grundrisse*, Marx writes of the understanding of nature leading to the "development of the social individual" (quoted in Habermas 1971: 50). The notion of learning for its own sake sits well with the notion of science for its own sake. It is also important that individuals have the free time to pursue such activities: "The reduction of society's necessary labour to a minimum, which then has its counterpart in the artistic, scientific and other education of individuals through the time that has become free for all of them and through the means that have been created" (quoted in Habermas 1971: 51). Polanyi also notes the similarity between art and science when discussing the theory of ideal gases in crystallographic theory: "It is not merely a scientific idealization but the formalization of an aesthetic ideal, closely akin to that deeper and never rigid definable sensibility by which the domains of art and art-criticism are governed" (Polanyi 1958: 48), and again: "A scientific theory which calls attention to its own beauty, and partly relies on it for claiming to represent reality, is akin to a work of art which calls attention to its own beauty as a token of artistic reality" (Polanyi 1958: 133). Of course a scientific theory is not beautiful if it is false, but this is merely one of the standards of scientific value (Polanyi 1958: 195).

Polanyi uses the theory of relativity to elucidate his argument about the importance of beauty in science, and extends it into the realm of popularisation:

> A theory like that of relativity continues to attract the interest of ever new students and laymen by intimations of its beauty yet hidden to their understanding: a beauty which is rediscovered every time a new mind apprehends the theory. And it is still for the sake of this remote and inaccessible beauty, and not for its few useful formulae (which could be memorised in a minute), that relativity continues to be valued as an intellectual triumph and accepted as great truth. All true appreciation of science by the public continues to depend on the appreciation of such beauty—even though sensed only at second hand; it offers an indirect tribute to the

> values that the multitude have been taught to entrust to a group of men whose cultural guidance they have accepted. Though the torrent widening towards the ocean no longer breaks new paths, the intellectual passions which had urged on the discoverer still pulsate in the common valuation of science (Polanyi 1958: 172)

Thus not only science itself but also its popularisation depends on its aesthetic qualities. Indeed, Polanyi goes further and says that the whole notion of science being justified in terms of its contribution to material welfare implies that it will no longer be valued by the intellectual passions of scientists, but will be assessed according to its probable utility for strengthening public power and improving the standard of living. Scientific value will be discredited and its appreciation suppressed (Polanyi 1958: 142). Thus the existence of science depends on society giving resources to satisfy the intellectual passions of scientists rather than promoting material wealth directly. Moreover, these intellectual passions "delight in cherishing something external to us, for its own sake" (Polanyi 1958: 174). There is thus a persistent gap between pure science and technology: natural science, unlike technology, cannot be represented in terms of practical procedure (Polanyi 1958: 175). Polanyi notes that "this distinction is recognised by patent law, which draws a sharp distinction between a *discovery*, which makes a new addition to our knowledge of nature, and an *invention*, which establishes a new operational principle serving some acknowledged advantage" (Polanyi 1958: 177). Polanyi acknowledges links between science and technology. There are some technologies that are founded on the findings of pure science, and some sciences that can be technically justified. But the conceptual gap remains: "To the extent to which a technical process is an application of scientific knowledge it contributes nothing to science" (Polanyi 1958: 179). Polanyi sees a utilitarian challenge to pure science for its own sake in what was then the Soviet Union, and he condemns it as a "menace to science" (Polanyi 1958: 180). Social studies of science since Polanyi wrote this in 1958 challenge this distinction, but my research suggests that it does still apply to astronomy. In fact Polanyi gives an example from astronomy to make his point. Polanyi refers to Arago acclaiming Leverrier's discovery of Neptune in 1846 as "one of the noblest titles of his country to the gratitude and admiration of posterity" and remarks, "No contribution to knowledge could be more useless than was the discovery of this remote new planet" (Polanyi 1958: 182). Finally Polanyi broadens his argument to encompass humanity's mental existence: "We owe our mental existence predominantly to works of art, morality, religious worship, scientific theory and other articulate systems which we accept as our dwelling place and as the soil of our mental development" (Polanyi 1958: 286).

Popularisers such as Sagan and Davies, (though perhaps not Moore, who tends to limit himself to specifics and details) by encouraging the popularisee to think about the big questions, also encourage self-reflection, where "Knowledge for the sake of knowledge comes to coincide with the interest in autonomy and responsibility" (Habermas 1971: 197-198). Astronomy can thus claim to have an emancipatory cognitive role attained through rational reflection (Habermas 1971: 198). If we define reason broadly with Habermas as being the pleasure of connection with the existence of an object or action (Habermas 1971: 198), astronomy (as a pure science) is where reason, knowledge and interest intersect. Astronomy, like self-reflection, can be emancipatory, because "Knowledge and interest are one in the movement of self-reflection" (Habermas 1971: 289). To put it another way, astronomy can be emancipatory because knowledge (for its own sake) and interest (broadly defined) are inextricably connected. The legitimation of astronomy must go beyond the technical and instrumental. Truth must be valued in addition to utility. The legitimation of astronomy then comes close to the way Schelling legitimised philosophy:

> The fear of speculation, the ostensible rush from the theoretical to the practical, brings about the same shallowness in action that it does in knowledge. It is by studying a strictly theoretical philosophy that we become most immediately acquanted with Ideas, and only Ideas provide action with energy and ethical significance (Schelling quoted in Habermas 1971: 301).

Habermas then goes on to explicate the Greek notion of *theoria*, the root of our word 'theory'. In Ancient Greece *theoria,* philosophically, meant "contemplation of the cosmos" (Habermas 1971: 301). Furthermore, this contemplation was thought to affect the conduct of life. What was important was not merely the content of the theories but the formation of the theorists themselves of a thoughtful and enlightened mode of life. The Enlightenment took up this idea and aimed at a scientific culture based on the positivist notion that science is emancipatory. Modern astronomy has in common with Greek philosophy a commitment to theory and the supposed severance between knowledge and interest. Polanyi likens the structure of such scientific commitment to that of "any pioneer of art, thought, action or faith" (Polanyi 1958: 308). Astronomy and philosophy also have in common that they both claim to be committed to a theoretical attitude that frees their practitioners from dogmatism and both have the cosmological intention of describing the universe in its law-like order. My research supports the view of Drori et al., that, "science provides a cultural umbrella sustaining the ontological status of the rationalized human actor. It defines a lawful and universal nature (including human social nature) in which the rationalized human actor can make sense" (Drori et al. 41).

It is perhaps not surprising, therefore, that the legitimation of astronomy has similarities with the legitimation of philosophy. My research on astronomy as popular culture does appear to indicate that, at a societal level, the popularisation of astronomy does appear to be a part of a wider system of deference. Given that astronomy does not legitimate itself on a utilitarian basis, rather on the notion of knowledge for knowledge's sake, it must assume that there is a passion for such knowledge.

In a society that values science astronomy can, to a great extent, legitimise itself without reference to external entities. In other words the legitimation of astronomy depends on a notion of human nature. That is, in contrast to Nietzsche's notion of the will to power, for astronomy to legitimise itself there must be an innate desire to discover the truth: a will to truth. This conception of human nature is captured by the pragmatist philosopher Peirce: "Human opinion universally tends in the long run to a definite form, which is the truth … there is then to every question a true answer, a final conclusion, to which the opinion of every man is constantly gravitating." (Quoted in Habermas1971: 93). Polanyi makes a similar point when he asserts that a culture in which scientific passions thrive is a coefficient of a society that fosters love of truth (Polanyi 1958: 203). An evolutionary ethic is also implied**:** the more humans understand the universe the more they will "orient their purposive-rational action according to natural laws, embody increasingly ideas and propel the rationalisation of the universe." (Habermas 1971: 132). This philosophy is particularly apparent in the legitimising popularisations of Sagan and Sokal, in their crusades against 'irrationalism'. Astronomy is chained to the notion of progress, and the modernist notion of increased power and freedom of humanity through mastery of nature.

If the legitimation of astronomy depends on a conception of human nature, then the science/society relationship is more than just sociological, it is, as Drori et al. point out, ontological. According to Drori et al., instrumental lines of thought about science:

> Leave out the cosmological or ontological science/society relationship … pure theory does not disappear into application; it is reinforced by the demands of the empowered modern human actor for ontological status as an entity in the universe and as a rational knower of the universe. Thus, every step in the expansion of human actorhood produces both an expansion of instrumental science (the technical gadgetry of applications) and an expansion in cosmological, universal, and logical/mathematical theorization. The same human actors who now take an interest in scientifically managing the details of diet, administration, and poverty now also avidly support massive expenditures for the study of miles of Antarctic ice, of theories about the origin of both humankind and the universe, and so on. The instrumental scientific rationalization of the human actor and its environment is accompanied by the ontological quest for understanding of when the sun will burn out (Dori et al. 39).

Thus astronomy is part of a system (science) that is a general rationalizing force that offers an interpretive framework creating world order, and which enjoys great legitimacy to comment on social priorities. In other words, the legitimation of astronomy points to a social role for science that is, as Dori et al. say is cosmological and ontological rather than instrumental.

Any justification for astronomy ultimately rests on the Kantian notion of "the glorious ideal of a universal realm of ends in themselves" (Habermas 1971: 199). Knowledge must not only serve as an instrument but also transcend mere self-preservation (Habermas 1972: 313). Once legitimised, acceptance of astronomy funding as part of the national enterprise becomes a habit, and the need for legitimisation is diminished. As Barker notes, "habitual legitimacy may be the most important form of legitimacy, because it is an acceptance of unquestioned right." (Barker 33). Barker's habitual legitimacy bears a close resemblance to Weber's ideal type traditional legitimacy. Legitimation involves presenting astronomy as the embodiment of an ideal: as representative of something higher than the trivial and the mundane. But this ideal has many faces, depending on the context and specific purpose of the legitimation; in one context it might be nationalism, in another internationalism, yet another, humanism.

Any process of justification must stop somewhere, and it is my contention that beyond the Kantian ideal, we must rest with Wittgenstein's assertion that "The danger here, I believe, is one of giving a justification of our procedure when there is no such thing as a justification and we ought simply to have said: *that's how we do it*" (Wittgenstein 74).

APPENDIX — INTERVIEWS WITH ASTRONOMERS

The Interviews

My goals in conducting interviews with astronomers were strictly limited. The interviews are only one small part of my overall thesis. I did not have the time or the resources to conduct any large-scale statistical survey of the professional astronomical community. The interviews do not constitute a large sample, or even a representative sample, a general survey of opinion, still less a comprehensive examination of astronomers' perspectives, since I only focus on questions relating to legitimation. Rather, the interviews are a source of first-hand, vivid observations and quotes that illustrate my arguments. They were done to check that I had not missed anything obvious through my reading of the literature; a test to see if any astronomers articulate ideas about legitimation in a different style or angle face-to-face than what I picked up through the literature. However, within these limits, the interviews do help to paint a picture of astronomers' perspectives on legitimation.

Methodology

One of the important differences between elite and specialist interviewing, of the kind I do here, and standardised survey interviewing of 'the man in the street' is that it is not obvious who should be interviewed. Obviously astronomers, but how to choose which ones? Convenience of access and nearness were obviously one factor. Technology has come to my aid in the form of e-mail. I have been in sporadic e-mail contact with an astronomer at the Edinburgh Observatory, in Scotland, who has taken some interest in my research issues. This person was the first on my list of astronomers to interview. Being in New York City at the time of the interviews, I sought out the company of astronomers in this geographical area. Where possible, I interviewed astronomers who were also engaged in some form of lobbying or political activity in relation to their profession and discipline. I was especially interested in astronomers who had been around long enough to be aware of the political issues associated with astronomy. Responses to early interviews helped me to make contacts with other astronomers. Thus, there was a dynamic that took over and made the decisions for me. I wanted to avoid any sort of pressure, and so always gave potential interviewees a choice of dates, times and venues. In all cases I contacted the interviewees myself, rather than have anyone else do it. I was also flexible in terms of time, as interview time varied according to responses to questions. However, if asked by an astronomer, I would usually respond by saying the interview need not take more than ten or fifteen minutes. I was never more precise than I had to be when asked what exactly was I looking for. Of course, I always explained who I was and truthfully told why I wanted the information. When doing interviews in person I always presented appropriate identification.

I wanted to start off with quite vague and general questions, rather than start by asking questions directly about the interviewee or their research. I had no wish to intimidate interviewees, so felt that it was best to start off with general questions and move to the particular and personal. For similar reasons, I tried to make the interviews discussions or conversations rather than rat tat questions. I felt I would be able this way to 'get into the astronomers' minds' this way. All interviews were recorded using a cassette recorder. I wanted my interviewees to be 'informants' rather than statistics. Social anthropologists use the term 'informant' to refer to someone who supplies or collects information for the anthropologist on a continuing basis, who enters into a more or less personal relationship with the anthropologist "in order to bring about cognitive learning on the part of the latter" (Dexter 72).

It can be seen that the techniques involved in intensive interviewing of experts are different from those in a standardized survey of 'the man in the street'. In the sort of interviews done here, much more flexibility is allowed, or even encouraged. Another difference is that respondents are easily identifiable. The issue of confidentiality is important, and it was important for me to assure interviewees that any remarks they made would not be used against them. Methodologically, the justification for this kind of interview design is that a detailed analysis of a small number of cases might be more instructive for some purposes than an effort to study a number of cases. It is also the case that interview techniques can vary with the sort of person being interviewed. In statistical terms, my interviews were not random samples, but convenience samples. I had to seek out my subjects and prevail upon them to give me the information I wanted.

Much of this depended upon circumstance and luck, for example working at the Massachusetts Institute of Technology. At MIT I was able to interview luminaries such as Philip Morrison. And of course there is no control group for comparative purposes.

I decided to begin with a general question, as this was more likely to put respondents at ease, rather than a direct question about their own work. I wanted to maximise the probability of establishing a good rapport right at the beginning, and the questions that I felt were more likely to be problematic were left until the end of the interview. As far as possible I kept my questions to a minimum, and kept them short. It was important to me to let the astronomers do the talking; it was their show, so I let them run with the ball. A good interviewer is not only one who knows how to ask the right questions but also one who knows how to listen. My goals dictated that I let the astronomers volunteer what they thought was important, within the frame of reference of the questionnaire. Although I started off with the same questions to every respondent, I maintained the right to ask different follow up questions depending on each respondent's answer, in order to probe deeper into the astronomer's meanings. I would follow up for detail. In this way hypotheses could be tested as I went along.

The limitation of interviewing is of course that the informant's statement represents merely the perception of the informant, filtered and modified by his or her cognitive and emotional reactions and reported through his or her personal verbal usages. The interviewer gets only the informant's picture of the world as he or she sees it. More than that, the interviewer is getting this information only as the informant is willing to pass it on in this particular interview situation. This is why interviews constitute only part of the overall study, and why any conclusions deriving from interviews must be tentative. Dexter (120-121) divides informant's reports into the following subjective data: the informant's opinions, that is, the cognitive formulation of his or her ideas on a subject, and the informant's attitudes, that is, his or her emotional reactions to the subjects under discussion; the informant's values, that is, the organizing principles that underlie his or her opinions, attitudes and behaviour; the informant's hypothetical reactions, that is, his or her projection of what he or she would do, think of feel if certain circumstances prevailed, and the actual tendencies of the informant to behave or feel when confronted with certain stimulus situations. My goal was that after obtaining pictures of the above phenomena from each individual, I would be able to get some general picture by comparing informant's accounts of their views on the legitimation process. An immediate problem here is, at what point does presentation and interpretation of data become a reconstruction? My solution was to keep interpretation to a minimum, and in my own account to let the astronomers speak for themselves.

Questionnaire for a Selected Group of Astronomers

1. The first question is about justifying expenditure on astronomy. What, in your opinion, are the most important reasons for allocating resources to astronomy? For example, are philosophical and spiritual issues important, or do you think that expenditure on astronomy can be entirely justified by practical, for example economic, contributions to society? How would you justify expenditure on professional astronomy generally?

2. Do you think it is important for at least some astronomers to engage in non-astronomical activities such as political lobbying and the promotion of their work to the public, or do you think it is sufficient for you to just get on with your research and let others worry about such matters?

3. This question follows naturally from the previous one. Do you think that public support for astronomy is crucial to your work, or do you think that funding could continue without it?

4. What sort of contact do you have with other scientists in other disciplines, for example physics?

5. How is your work funded?

Supplementary questions:

i Who else do you think I should interview?

ii Would you like to see a draft of what I write about the interviews (it might be some time before you receive it)?

iii Is there anything that you would like to ask me?

Table 2 — Details of Interviews with Astronomers		
Name of astronomer	**Institutional affiliation**	**Date of interview**
Jacqueline Van Gorkon	Columbia University	25/03/99
Charles Hailey	Columbia University	26/03/99
Marc Kaminkowski	Columbia University	26/03/99
Arlin Crotts	Columbia University	27/03/99
Bruce Elmergreen	IBM Watson Research Centre, NY	28/04/99
Neil de Grasse Tyson	Hayden Planetarium, New York	26/05/99
David Helfrand	Columbia University	29/05/99
Steve Lawrence	Columbia University	10/06/99
Jules Halpern	Columbia University	10/06/99
Will Van der Veen	Columbia University	11/06/99
Deane Peterson	Stony Brook University, Long Island	02/07//99
Frederick Walters	Stony Brook University, Long Island	02/07/99
Michael Simon	Stony Brook University, Long Island	02/07/99
Jacqueline Hewitt	Massachusetts Institute of Technology	10/05/02
Ed Berschinger	Massachusetts Institute of Technology	15/05/02
James Elliot	Massachusetts Institute of Technology	01/05/02
Walter Lewin	Massachusetts Institute of Technology	10/06/02
Philip Morrison	Massachusetts Institute of Technology	15/06/02
Claude Canizares	Massachusetts Institute of Technology	21/05/03
Eric Chaisson	Tufts University	11/06/03

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