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Abstract

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Keywords

Ret, Hyi, Hipparcos, Photometry, Analysis

Disciplines

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UX Ret And CN Hyi: Hipparcos Photometry Analysis

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Keywords: Binary stars: subcategory, contact binary stars: UX Ret, CN Hyi

Abstract

Objectives: *We present an analysis of the Hipparcos photometry of the contact binary systems UX Ret and CN Hyi. The Wilson-Devinney code is employed to model the V band light curve for several fixed values of the mass ratio. From the quality-of-fit of the different solutions a final solution is derived for each system. Absolute values of the system are derived using the parallax data from the Hipparcos catalog. Analysis of the V band photometry of two stars (EL Aqr and FN Cam) with spectroscopically known mass ratios is also provided as a validation for the methods adopted for this study.*

1. INTRODUCTION

Contact binary stars are important test beds for theories of stellar evolution. Although numerous light curves have been published very few have been analyzed using modern techniques. We have previously reported (Wadhwa and Zealey, in press) an analysis of the Hipparcos photometry for EL Aqr adopting the spectroscopic mass ratio. In this paper we report the feasibility of using the grid method with single V band photometry to obtain accurate mass ratios and then apply the methods to the Hipparcos photometry of two contact binary stars: UX Ret (α_{2000} 03 57 34–54 21 26.6) and CN Hyi (α_{2000} 02 45 37–71 14 09.4).

The Wilson-Devinney (WD) code as supplied with the WD-Win 3.6 package (Nelson, 2002) is employed to analyse the Hipparcos photometry of the two newly classified contact binary systems. Since no spectroscopic mass ratio is available for either system a search for a solution is made for several fixed values of “ q ” in a range from 0.1 to 2.5. This method is commonly referred to as the “grid method” described by Maceroni et al. (1983). The potential, temperature of the secondary, luminosity of star 1 and inclination are adjusted for each value of “ q ” to obtain a reasonable visual fit using the LC part of the WD code. These preliminary parameters were then used as the starting parameters for the DC component of the WD code. The following parameters were adjusted during iterations: the inclination (i), temperature of the secondary (T_2), the non-dimensional potential ($_31 = _32$), and the monochromatic luminosity of star 1 (L_1). Iterations were carried out until the suggested corrections were less than the estimated error for each parameter. The quality of the solution for each value of the mass ratio is provided by the sum of the squares of the errors between the observed and calculated light curve. This value is often referred to as the residual. The value of “ q ” with the smallest residual was then chosen for a more detailed analysis in which “ q ” also acts as a free adjustable parameter. This is described in detail.

2. PHOTOMETRIC MASS RATIO FROM HIPPARCOS

As a measure of the feasibility of using the above method for accurate light curve analysis where the photometric coverage is limited, we compared our results for the mass ratio for two other Hipparcos contact binary stars, which had recently been studied spectroscopically. The Hipparcos photometry data for both stars was reduced as described later and other parameters were set as described later or from standard calibrations. EL Aqr (α_{2000} 23 47 18.35–08 05 12.1) was discovered as a variable star by Hoffmeister (1933) and then rediscovered by Stepien (1968), who correctly identified it as a contact binary star. Rucinski et al. (2001) observed the system spectroscopically and determined the system to be an A type contact binary and estimated a small mass ratio of $q = 0.203 \pm 0.008$.

Unfortunately the Hipparcos satellite obtained photometry for only about 60 epochs for this star with poor coverage at minima and photometric analysis in such a case is impossible. The All Sky Automated Survey (ASAS) plans to observe more than 10^7 stars brighter than 14th magnitude with the view to detecting interesting variables. Four instruments of differing aperture carry out the survey simultaneously and most data reduction has been automated. Initial V band photometry results have recently been released and confirm the accuracy reported in the pilot programmes (Pojmanski, 2002). EL Aqr was included in the initial survey and combining the ASAS and Hipparcos data yields a 153-point dataset with good phase coverage and reasonable good coverage of the minima. As most other Hipparcos datasets contain well over 100 data points we felt it reasonable to test our method for searching the mass ratio on the combined Hipparcos and ASAS data.

As described, the “grid” method was applied to several fixed values of “ q ” in the range 0.1–0.6. The following parameters were adjusted during iterations: the inclination (i), temperature of the secondary (T_2), the non-dimensional potential ($z_1 = z_2$), and the monochromatic luminosity of star 1 (L_1). Iterations were carried out until the suggested corrections were less than the estimated error for each parameter. The results indicated a minimum around 0.2 however the residual against mass ratio curve was relatively flat between 0.15 and 0.5. To ensure that we had detected the deepest minimum a more refined search for the mass ratio was made for values between 0.2 and 0.45. The results of the “ q ” search are illustrated in Figure 1 and it is clear that the photometric mass ratio lies between 0.2 and 0.22.

Starting with the preliminary solution ($q = 0.2$) from the “grid” search a more detailed analysis was made using the DC part of the WD code with “ q ” treated as an additional free parameter. The addition of mass ratio as a free parameter can lead to strong correlation between the parameters however the problem can be solved using multiple subsets in sequence (Wilson and Biermann, 1976). The free parameters were divided into two subsets as follows: $\{q, L_1\}$ and $\{i, T_2, z\}$ and iterations were again carried out until the error of a parameter was greater than the estimated correction. The final photometric mass ratio was determined to be 0.209 which compares very favorably with the spectroscopic value of 0.203.

Figure 1: Mass ratio (q) search grid for EL Aqr. Although the residuals are similar for values of q from 0.15 to 0.45 there is a definite minimum at $q = 0.2$.

FN Cam was discovered by the Hipparcos mission as a contact binary with a period of 0.677128 day and an approximate range of 0.5 magnitudes. Good quality Hipparchos photometry for about 125 epochs is available for analysis. As this star had also been studied recently with both photometric and spectroscopic solutions available (Pribulla et al., 2002) it was chosen as the second test star for the methodology adopted for this study.

TABLE I: Comparison of results for FN Cam using the methods described in this report with those from spectroscopic and photometric data

	Current analysis	Pribulla et al.
Mass ratio (q)	0.250	0.222
Inclination (degrees)	69.9	71.2
Potential (β)	2.22	2.16
Luminosity ($L_1/(L_1 + L_2)$)	0.73	0.75

Even though a spectroscopic mass ratio was available a “ q ” search was made using the grid method described. Residuals were calculated using the DC part of the WD code for a range of “ q ” values from 0.1 to 0.6. From Figure 2, which illustrates the “ q ” search grid, it is clear that the smallest residual is around $q = 0.25$. Detailed analysis with mass ratio starting at 0.25 and acting as an additional free parameter and using multiple subsets is summarized in Table I, which also includes a comparison with recent photometric and spectroscopic results.

The current methods provide accurate estimation of the mass ratio using Hipparcos photometry.

Figure 2: Mass ratio (q) search grid for FN Cam. Analysis of the Hipparcos photometry shows a definite minimum at $q = 0.25$.

It is clear from the above analyses of the single band photometry with around 100–150 data points and good phase coverage that it is possible to obtain reliable photometric mass ratios and hence other parameters. We have applied the above techniques to analyse the Hipparcos photometry of two contact binary stars.

3. UX RET AND CN HYI

The variability of UX Ret was first described by Strohmeier et al. (1965). The Hipparcos mission classified it as a periodic variable with a period of 0.490104 day and an approximate range of 0.7 magnitudes. At maximum the apparent magnitude is approximately 8.2 with a B-V of 0.453 and F5V spectral type. The Hipparcos parallax for the system (8.21 mas) has a small 8.6% error therefore the absolute magnitude is well determined.

CN Hyi is a new Hipparcos discovery classified as a contact binary with a period of 0.4561070 day and an approximate range of 0.3 magnitudes. At maximum the apparent magnitude is approximately 6.6 with a B-V of 0.449 and F6V spectral type. As for UX Ret, the parallax of CN Hyi (17.33) has a small error of less than 4%.

Neither star has been studied spectroscopically and no previous analysis of the Hipparcos light curve has been published. In this paper we reduce the Hipparcos photometric data to yield light curves in the V band we then analyze these with a recent version of the Wilson-Devinney code (WD code) to yield basic parameters for both systems. As the distance of the systems is fairly well established, this is used to estimate the absolute system parameters.

4. DATA REDUCTION

Accurate broadband photometry of UX Ret and CN Hyi was acquired for more than 100 epochs by the Hipparcos satellite. The Hipparcos magnitudes (Hp) differ slightly from standard V magnitudes and a transformation to V magnitudes is required prior to using data in light curve analysis. In a recent paper Rucinski and Duerbeck (1997) presented a simplified process of transforming Hipparcos magnitudes to visual magnitudes by considering differences in Hp and V directly as a function of the color index (B–V). They established one and two parameter relationships, $H_p - V = 0.17(B - V) + 0.03$ and $H_p - V = 0.22(B - V)$. They recommended the use of the latter, noting that the intercept should be zero by definition. The values for the color index for each star noted above were used to correct all Hp magnitudes to V magnitudes using the single parameter transformation.

Only those results regarded as being of good photometric quality by Hipparcos were included to yield a final dataset of 120 observations for UX Ret and 113 for CN Hyi.

As the $V_{\max}$ for both stars is poorly recorded it was estimated from the fifth centile value from the Hipparcos observations and corrected as described. $V_{\max}$ of 8.2 (UX Ret) and 6.56 (CN Hyi) were adopted and all magnitudes converted to flux to yield the observed light curves.

The WDWin (Nelson, 2002) package consists of the WD code, a windows interface for the WD code, which allows for easier writing of the input data files and a number of other utilities. Based on the light curve morphology the stars were treated as contact binary systems and as such mode 3 of the WD code was adopted. The temperature of the primary star was fixed at 6640K (UX Ret) and 6510K (CN Hyi) according to the standard calibrations. Nonlinear (square root law) limb darkening coefficients were interpolated from Van Hamme (1993) using a utility provided as part of the WDWin package. As the reported spectral classes of the stars would indicate convective envelopes, gravity brightening was set at 0.32 and bolometric albedos were set at 0.5 for each star. Black body approximation was used for the stars' emergent flux and simple reflection treatment was applied.

Since no spectroscopic mass ratio is available for either system a search for a solution was made for several fixed values of “ q ” in a range from 0.1 to 2.5. The potential, temperature of the secondary, luminosity of star 1 and inclination were adjusted for each value of “ q ” to obtain a reasonable visual fit using the LC part of the WD code. These preliminary parameters were then used as the starting parameters for the DC component of the WD code. The following parameters were adjusted during iterations: the inclination (i), temperature of the secondary (T_2), the non-dimensional potential ($\beta_1 = \beta_2$), and the monochromatic luminosity of star 1 (L_1). Iterations were carried out until the suggested corrections were less than the estimated error for each parameter.

Graphical representations of the residuals against mass ratio for UX Ret and CN Hyi are shown in Figures 3 and 4, respectively. Starting with the preliminary solution from the “grid” search for each star a more detailed analysis was made using the DC part of the WD code with “ q ” treated as an additional free parameter. Iterations were again carried out until the error of a parameter was greater than the estimated correction. The variable parameters were divided into two subsets as follows: $\{q, L_1\}$ and $\{T_2, i, \beta\}$. To determine the final error of the parameters the final iteration was carried out with all five parameters being free. The final solutions for UX Ret and CN Hyi are summarized in Table II with errors for each parameter being the standard deviation reported by the WD code. The calculated error of the potential for CN Hyi is relatively high at about 0.9% and at a mass ratio of 0.25 this results in a

relatively large 12% error in the fillout for the system. The observed and calculated light curves are illustrated in Figure 5 (UX Ret) and Figure 6 (CN Hyi).

Figure 3: Mass ratio search grid for UX Ret. Best fit occurs at $q = 0.5$.

TABLE II: Final solutions for UX Ret and CN Hyi

Parameter	UX Ret	CN Hyi
Mass ratio (q)	0.503 ± 0.01	0.25 ± 0.01
Inclination (i)	78.86 ± 0.79	60.09 ± 0.56
Potential ($s_1 = s_2$)	2.67 ± 0.01	2.30 ± 0.02
Temperature primary (T_1) ^a	6640 K	6510 K
Temperature secondary (T_2)	6503 ± 45 K	6310 ± 40 K
Luminosity primary (L_1)	7.64 ± 0.1	9.2 ± 0.1
Luminosity secondary (L_2) ^a	4.01	2.39
Fillout (%)	71 ± 3	34 ± 12
r_1/a (mean)	0.4942	0.5196
r_2/a (mean)	0.3820	0.2845

^aFixed or software calculated.

Figure 4: Mass ratio search grid for CN Hyi. Best fit occurs at $0.2 < q < 0.3$.

5. ABSOLUTE PARAMETERS AND CONCLUDING REMARKS

Based on Hipparcos parallax measurements the absolute magnitude of the UX Ret system is 2.87 and using the relative luminosities calculated from the light curve solution we obtain the absolute magnitude of star 1 as 3.33. Using the standard main sequence calibrations this corresponds to a M_1/M_0 ratio of 1.3 (spectral class F5), M_2/M_0 ratio of 0.65 (spectral class K4) and a total mass of $1.95M_0$. These values are well within the range of observed values for other contact binaries and agree with recorded spectral type. The fillout at 0.71 is rather high for a contact binary which may be an indicator that this is an evolved system. Three-dimensional representation of the system is illustrated in Figure 7.

Similarly, the absolute magnitude of the CN Hyi system is 2.74 and again using the relative luminosities calculated from the light curve solution we obtain the absolute magnitude of star 1 as 3.0. Using the standard main sequence calibrations this corresponds to a M_1/M_0 ratio of 1.41 (spectral class F3), M_2/M_0 ratio of 0.35 (spectral class M3) and a total mass of $1.76M_0$. Three-dimensional representation of the system is illustrated in Figure 8.

In this study we show that careful examination, reduction and analysis of the Hipparcos photometry can yield good estimates of the absolute parameters of newly discovered contact binaries. We hope to continue this work to increase the database of contact binary star parameters and to identify interesting systems for supplemental study.

Figure 5: The observed (open circles) and WD fitted (line) light curves for UX Ret.

Figure 6: The observed (open circles) and WD fitted (line) light curves for CN Hyi.

Figure 7: 3D representation of UX Ret at phase 0.25.

Figure 8: 3D representation of CN Hyi at phase 0.20.

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