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A three-year photometric study of the oscillating Algol-type binary CT Her

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Abstract

We present the first results of a multi-site photometric campaign carried out in 2004-2006 on the Algol-type eclipsing binary system CT Her, the primary component of which is a δ Scuti-type pulsator. Our observations include (almost complete) binary light curves in the filters B and V which have been analysed following the principles of the Wilson-Devinney method. After removal of the best-matching light curve solution, the residual B and V light curves have been investigated for their pulsational content.

Individual Object: CT Her

Science case

CT Her (= BD $+18^o$ 3160, GSC 01509-01142) is an Algol-type eclipsing binary of photographic magnitude 10.6(max)-11.7(min) and spectral type A3V+[G3IV] with an orbital period of 1.7863748 days (Kholopov et al. 1998). Kim et al. (2004) have recently shown that the primary component is a δ Scuti variable star with a main

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pulsation period of 0.46 hr (27 min) and a (total) amplitude of at most 0.03 mag. CT Her is thus an oscillating Algol-type binary (also called 'oEA star'). The oEA stars are the former secondaries of evolved, semi-detached eclipsing binaries that are (still) undergoing mass transfer and form a new class of pulsators close to the main-sequence (Mkrtichian et al. 2002, 2004). Their unique feature consists of mass accretion onto the atmosphere of the pulsating star (via the inner Lagrangian point L1 of the binary). Mass accretion affects the mass, radius, density as well as the evolution of the oEA star (depending on the accretion rate). Their characteristics were discussed by Mkrtichian et al. (2005). Although the oEA stars exhibit the pulsational properties of classical δ Scuti stars, their evolutionary history is entirely different. This is why such stars represent a new challenge for theoretical models.

Presently, 21 such systems have been detected and detailed studies of some of these binary systems have only just begun (except for the long-term and well-documented case of RZ Cas, cf. Rodríguez et al. 2004; Lehmann & Mkrtichian 2004; Mkrtichian et al. 2007). Such studies are of prime importance for a correct understanding of the pulsation properties in the presence of tidal effects and/or mass accretion episodes in close binary systems. Among the known oEA stars, we chose to monitor the eclipsing binary CT Her photometrically for several reasons:

(a) The previous light curves showed modulation, implying a multiperiodic pulsator in a fast eclipsing binary system (it has one of the shortest orbital periods of the class).

(b) It also has the highest ratio P_{orb}/P_{puls} (~95) of the class.

(c) Its (O-C) diagram shows significant orbital evolution (Kreiner et al. 2001).

Observations and light curves

CT Her was observed during three successive years, starting with its discovery as an oEA star in the spring of 2004. We collected more than 1100 photometric measurements in the (Johnson) V filter and over 4900 in the (Johnson) B filter using various small telescopes at observatories located on three different continents (in 2004-2005). Most of the observations were collected during the dedicated multi-site campaigns in 2005-2006. The number of useful nights is 36 (with the filter B) and 15 (with the filter V).

CT Her is an eclipsing system with a period of 1.7863748 days (Kholopov et al. 1998) which fades ~1 mag and ~0.1 mag during the primary and the secondary minimum respectively. The light curve in the V-band (single data set) is shown in Figure 1. The peak-to-peak amplitude in V-light, including the ellipticity and reflection effects in the close binary (without eclipses) is ~0.01-0.02 mag. Likewise, the light curve in the B-band (combined data set) is shown in Figure 2.

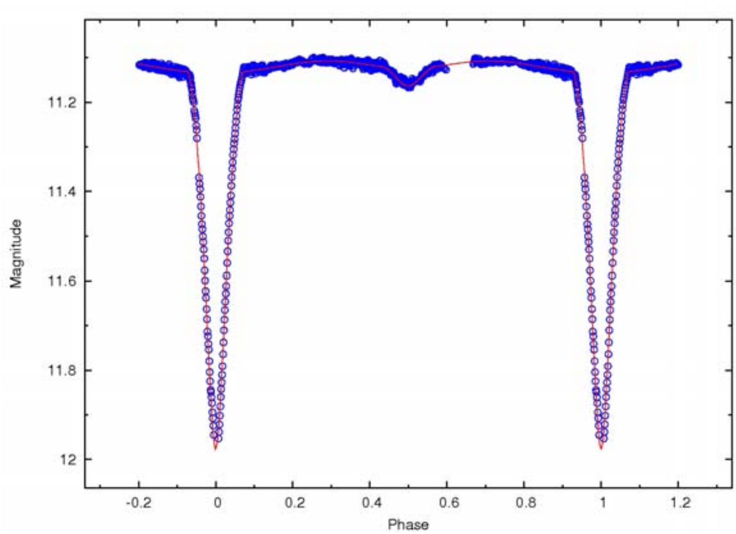

Figure 1: Binary light curve and solution in the filter V

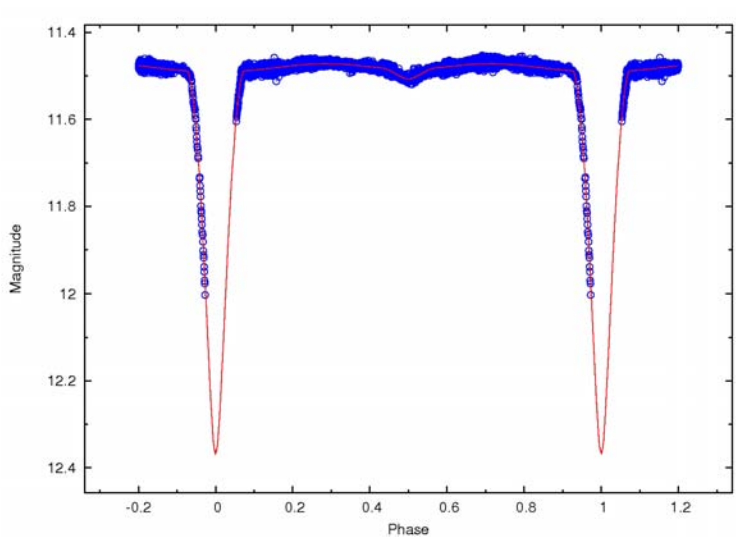

Figure 2: Binary light curve and solution in the filter B

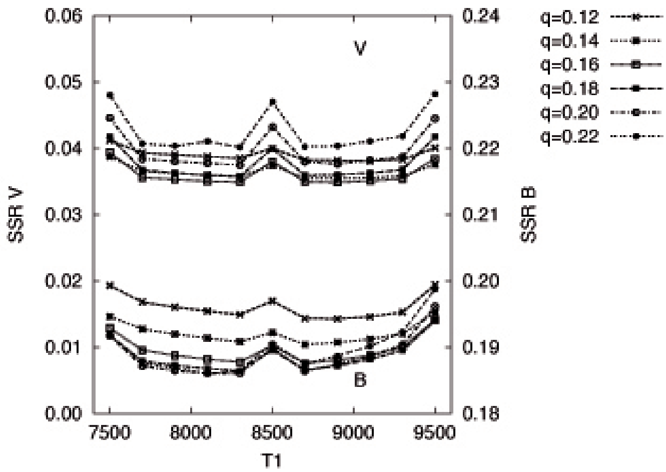

Figure 3: Evolution of the parameter q as a function of T_1 in the modelling process

Binary light curve modelling

Using the user-friendly programme PHOEBE (version 0.29c, Prsa & Zwitter 2005), we performed a simultaneous modelling of both light curves. PHOEBE (which stands for 'PHysics Of Eclipsing BinariEs') is based on the 2003 version of the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1990) for solving binary light curves and/or radial velocity data all together. We modelled using MODE 5, which corresponds to a semi-detached binary configuration in which the secondary component fills its limiting lobe (as required for the class to which CT Her belongs). Exploration of the parameter space as a function of T_1 showed that there is a range of possible solutions. As an example, Figure 3 illustrates the evolution of the parameter q as a function of T_1. The surface temperature of the primary component was subsequently fixed to T_1=8700 K (for an A3V star) but also to T_1=8200 K (for an A5V star, and corresponding to the $(B\text{-}V)_{Tycho}$ colour index of 0.154 assuming zero reddening, cf. Budding et al. 2004).

The gravity darkening coefficients, g_1 and g_2, and the bolometric albedos, A_1 and A_2, were assigned theoretical values corresponding to a radiative atmosphere in the case of the primary component (with spectral type A3V) and to a convective atmosphere in the case of the secondary component (with spectral type G3IV). The limb darkening coefficients were taken from Van Hamme (1993). Only approximately determined absolute geometric elements of CT Her are currently known. From Svechnikov & Kuznetsova (1990) we used a=8.52 solar radii for the semi-major axis, while the mass ratio, q=0.27, was adopted as a starting value. The secondary star's surface temperature, T_2, the inclination, i, the mass ratio, q, the dimensionless potential, Ω_1, the fractional luminosities of the primary component, L_1, in B-, and V-light were set as adjustable parameters during the minimization procedure. As a result of the ad-

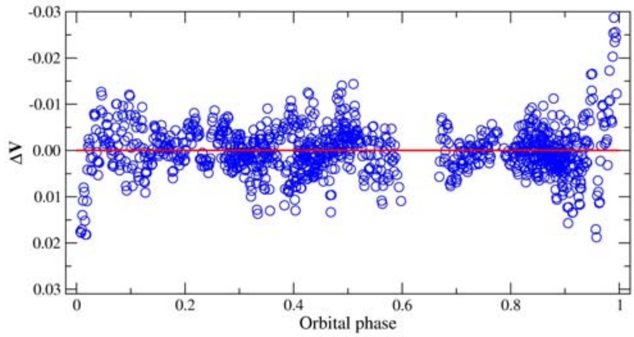

Figure 4: Residual light curve in the filter V

justment, we found a couple of solutions fitting the light curves very well. The binary configuration is thus not (yet) uniquely determined: equivalent solutions were found adopting either T_1=8700 K or T_1=8200 K (with corresponding values of q and also T_2) as the primary's surface temperature. In all cases, the mass ratio is smaller than was previously assumed (i.e., $q < 0.20$). In both cases, the adjustment is excellent for the B-data (but the primary minimum is lacking) and good for the V-data (the predicted curve at primary minimum is not entirely satisfactory due to a lack of just a few data points at the crucial time).

After subtraction of the light curve solution adopting T_1=8700 K, the residual light curves were closely examined in both filters. These light curves are illustrated by Figures 4a and 4b. Because the phase of primary minimum is not completely covered by our observations, we can detect some small systematic deviations in the orbital phase bin 0.95-0.05. The residual standard deviation is 4.5 mmag in the V-band and 5.9 mmag in the B-band (after the removal of some data points at or near the phase of primary minimum, easily detectable in both figures). We performed the same exercise with T_1=8200 K. The result that is presented next is independent of the adopted choice for the binary model (partly because of the difference in the time scales involved).

Period analysis of the residual data

After subtraction of a consistent and suitable model for both light curves of CT Her, we detected the presence of multiperiodic, small-amplitude oscillations with a (maximal) peak-to-peak amplitude of 0.02 mag in both residual data sets. We performed the Fourier analysis with Period04 (Lenz & Breger 2005) and computed successive periodograms after prewhitening of the strongest signal from each previous run. In this way, seven significant frequencies were identified in the largest data set at our disposal (consisting of 4299 B-band residuals).

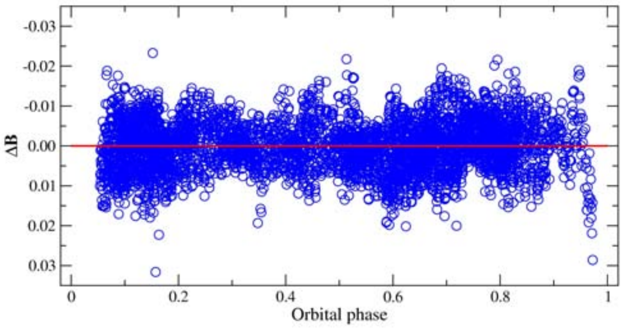

Figure 5: Residual light curve in the filter B

The frequencies, amplitudes, signal-to-noise ratios and the fractional variance reduction, R, resulting from a multi-parameter fit of the B-band residual data set to a solution with seven frequencies, five of which are concentrated in the range 45-53 d^{-1}, can be found in Table 1. Also note that two of these frequencies lie in the lowest range ($< 1.1\ d^{-1}$): these are possibly due to a non-intrinsic phenomenon such as remaining small effects linked to the orbital variation. Two high-quality residual light curves are shown in Figures 5 and 6 (whose time axis in days shows a modified Julian date). Obviously, the residual data and the proposed solution agree well. Of the five high-range frequencies listed, two are probably affected by the (1 day)$^{-1}$ aliasing phenomenon (they are flagged with asterisks in Table 1). After prewhitening, the remaining standard deviations in the V- and the B-band are respectively 3.5 and 3.8 mmag.

Similar though less significant results were found from the Fourier analysis of the V-band data set (consisting of 1083 V-band residuals): apart from two frequencies in the lower frequency range ($< 3.3\ d^{-1}$), the frequencies f2, f3, f6, and the (1 day)$^{-1}$ alias frequency (f4 - 1) were recovered, thereby confirming four of the five pulsation frequencies detected in the B-band.

Conclusions

Using approximate photometric and absolute elements as starting parameters to describe the system CT Her and its two components, we modelled of the combined V- and B-light curves and obtained an improved semi-detached binary model using the code PHOEBE (following the principles of the Wilson-Devinney method). After subtraction of a suitable light curve solution, the out-of-primary-eclipse V- and B-residual data sets were subsequently analysed using standard Fourier techniques. The frequency searches of the residuals revealed four, possibly five, significant pulsation

Table 1: Multi-parameter fit of the B-band residual data of CT Her

Ident.	Freq. (d^{-1})	Stand. error (d^{-1})	Amp. (mmag)	σ_{res} (mmag)	S/N	R (%)
f1	1.01109	fixed	3.3	5.2	9.0	–
f2	52.93410	0.00001	3.6	4.6	13.3	–
f3	49.20573	0.00002	2.4	4.4	7.5	–
f4	45.69108*	0.00003	1.6	4.2	5.0	–
f5	0.18807	fixed	1.5	4.1	4.2	–
f6	47.81079*	0.00003	1.5	3.9	4.7	–
f7	53.23493	0.00003	1.5	3.8	5.6	35

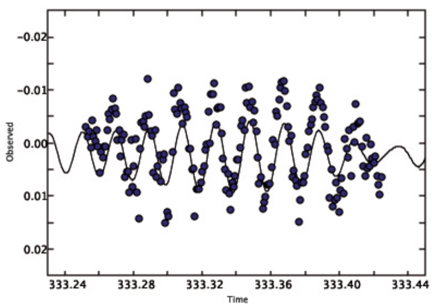

Figure 6: Residuals and multi-frequency solution on JD 2453905.5 (filter B)

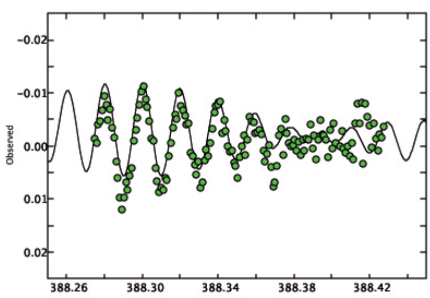

Figure 7: Residuals and multi-frequency solution on JD 2453960.5 (filter B)

frequencies lying in the range 45 to 53 c/d with semi-amplitudes of only 4 to 1 mmag, three of which are well-identified (f2, f3, and f7 do not appear to be affected by the aliasing phenomenon). These detections are independent of the adopted solution for the binary modelling. The remaining standard deviation of the V- and the B-residuals spread over 3 years is respectively 3.5 and 3.8 mmag, in some cases the residual light curves show clear systematic deviations still too large to be caused by white noise only.

The next step regarding the analysis of CT Her will consist in incorporating the new light curves collected in 2007 at the *Observatorio de Sierra Nevada* in the present analysis, with the aim of better determining the multiple pulsation frequencies. Since the binary parameters and configuration are currently not uniquely determined, we will try to also include some primary minima in the light curves. In addition, we have applied for telescope time to acquire radial velocity data in the hope of obtaining a consistent determination of the absolute parameters of this interesting Algol-type binary.

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References

Budding, E., Erdem, A., Cicek, C., et al. 2004, A&A 417, 263

Kim, S.-L., Koo, J.-R., Lee, J. A., et al. 2004, IBVS 5537, 1

Kreiner, J. M., Kim, C. H., & Nha, S., 2001, Atlas of O-C Diagrams of Eclipsing Binary Stars, Crakow, Poland [http://www.as.ap.krakow.pl/ephem/]

Lehmann, H., & Mkrtichian, D. E. 2004, A&A 413, 293

Lenz, P., & Breger, M. 2005, CoAst 146, 53

Mkrtichian, D. E., Kusakin, A. V., Gamarova, A. Yu., et al. 2002, ASPC 256, 259

Mkrtichian, D. E., Kusakin, A. V., Rodríguez, E., et al. 2004, A&A 419, 1015

Mkrtichian, D. E., Rodríguez, E., Olson, E. C., et al. 2005, ASPC 333, 197

Mkrtichian, D. E., Kim, S.-L., Rodríguez, E. 2007, ASPC 370, 194

Prša, A., & Zwitter, T. 2005, ApJ 628, 426

Rodríguez, E., García, J. M., Mkrtichian, D. E., et al. 2004, MNRAS 347, 1317

Kholopov, P. N., Samus, N. N., Frolov, M. S., et al. 1998, The Combined General Catalogue of Variable Stars, ed. 4.1, Sternberg Astronomical Institute and Institute of Astronomy, Moscow

Svechnikov, M. A. & Kuznetsova, Eh. F. 1990, Catalogue of approximate photometric and absolute elements of eclipsing variable stars, Ural university, Sverdlovsk

Van Hamme, W. 1993, AJ 106, 2096

Wilson, R. E., & Devinney, E. J. 1971, ApJ 166, 605

Wilson, R. E. 1990, ApJ 356, 613