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The shortest period field contact binary★

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ABSTRACT

Photometric and spectroscopic results for the contact binary GSC 01387–00475 (ASAS 083128+1953.1) are presented. The existence of this binary with the orbital period of $P = 0.2178$ d strengthens the argument that the cut-off of the period distribution for contact binaries – until now defined by CC Comae – is very sharp. The only case of a still shorter period is known in a globular cluster where more compact contact configurations are in fact expected. While the spectroscopic orbit of GSC 01387–00475 is well defined, the low orbital inclination of the binary and the presence of a spectroscopic companion contributing about 1/3 of the total light conspire to reduce the photometric variability to ≃0.09 mag. The photometric data are currently inadequate to identify the source of the small amplitude (0.02–0.03 mag) intrinsic variability of the system.

Key words: binaries: close – binaries: eclipsing – binaries: spectroscopic – stars: evolution.

1 INTRODUCTION

The period distribution of contact binaries is known to have a sharp cut-off at short periods (Rucinski 1992a, 2007). Currently, the shortest period, well researched, field system is CC Comae with $P = 0.2207$ d; for the most recent spectroscopic data and references on CC Com, see Pribulla et al. (2007). The period distribution cut-off does not have a fully satisfactory explanation. A recent suggestion (Stepien 2006) sees it as a result of a very strong decrease in the efficiency of the angular-momentum (H) loss with the decreasing mass (M) along the Main Sequence (MS) for the 'saturated' magnetic-activity case. Specifically, $-\mathrm{d}H/\mathrm{d}t \propto \omega\, R^2 M \propto M^3$, since for the lower MS the radius scales with the mass, $R \propto M$. The cut-off would be then a result of the finite age of the binary population forming contact systems.

The All Sky Automated Survey (ASAS) (Pojmański 1997, 2004; Pojmański & Maciejewski 2005; Paczyński et al. 2006) has been contributing greatly to the discovery of many contact binaries in the still not fully explored magnitude range 8–13 mag, particularly in the Southern hemisphere where hundreds of contact binaries remain to be discovered. Out of seven variable stars discovered by the ASAS and originally classified as contact binaries with periods shorter than the CC Com period (Rucinski 2006), six have been subsequently shown (Rucinski 2007) not to be binaries at all. In this paper, we describe the only system which remained ASAS 083128+1953.1. With the orbital period of 0.217811 d, which is by 1.3 per cent shorter than that of CC Com ($P = 0.220686$ d), this is the shortest period sky-field contact binary currently known (an even tighter system exists in a globular cluster, see Section 6).

Instead of the ASAS designation, we use the Guide Star Catalogue (also Tycho) name of the star, GSC 01387–00475. In addition to our spectroscopic observations obtained at the David Dunlap Observatory (DDO), we present an analysis of photometric V and I data from the ASAS survey, supplemented by white-light (un-filtered) photometric observations from DDO.

Contact binary stars have been a subject of several recent spectroscopic studies at the DDO, leading to over one hundred radial-velocity orbits (see the last published paper DDO-12, Pribulla et al. 2007). In the DDO series, we normally group binaries into batches of 10; this is done because of the similarity of many targets as well as of our desire not to further inflate the close-binary star literature. This paper is an exception as it describes only one object. However, we feel that the star deserves a speedy and separate publication because of its special position at the very end of the orbital period sequence.

2 LITERATURE INFORMATION

GSC 01387–00475 is located at J(2000) 08:31:27.88, +19:53:03.5. Its Tycho-2 (Høg et al. 2000) mean magnitudes are: $B_T = 11.922$ and $V_T = 10.712$ resulting in $B - V = 1.03$ and the spectral type on the Main Sequence of K4V. This is inconsistent with $V - I = 1.25$ from the ASAS project (Section 3) which suggests $B - V = 1.12$ and thus K5V. Our own direct spectral classification from the blue classification spectra (a window of about 650 Å wide centred on 4200 Å) is a well-defined K3V while the Two-Micron All-Sky Survey (2MASS) magnitudes result in $J - K = 0.72$ corresponding to the spectral type K5V. The spread in the estimated spectral types

★Based on the data obtained at the David Dunlap Observatory, University of Toronto and the All Sky Automated Survey.

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Table 1. Sample of ASAS *V* and *I* photometry of GSC 01387–00475. The full table is available as Supplementaryh Material.

HJD	*V* or *I*	Filter
245 2622.7490	10.335	*V*
245 2624.7771	10.411	*V*
245 2635.7268	10.374	*V*
245 2635.7268	10.322	*V*
245 2637.7681	10.375	*V*

may result from the presence of the newly detected spectroscopic companion (Section 5).

The trigonometric parallax of GSC 01387–00475 is unknown. The extrapolated to short periods M_V calibrations (Rucinski 2000) give substantially different values of $M_V = +6.17$ and $+7.16$, for the assumed $B - V = 1.03$ and $V - I = 1.25$, respectively; this is based on the assumed $V_{\max} = 10.33$ and the binary contribution of 2/3 to the total brightness of the system. The extrapolated M_V calibrations are very approximate and this very system may eventually help in establishing them for the shortest periods. Because of the uncertain colour indices and the calibrations, the implied distance estimates span a range between 53 and 84 pc.

The proper motion of GSC 01387–00475 is -11.1 ± 1.6 mas yr^{-1} and $+5.5 \pm 1.6$ mas yr^{-1} in the two tangential sky directions (Høg et al. 2000). Assuming the convention of Johnson & Soderblom (1987), the solar motion $UVW_{\odot} = +9, +12, +7$, and the radial velocity of the binary $V_0 = +22.21$ km s^{-1} (Section 4), the space velocity components are $UVW = -10.3, +5.6, +16.5$ km s^{-1} for the distance of 53 pc and $UVW = -11.4, +6.5, +15.4$ km s^{-1} for the distance of 84 pc. Therefore, the star has a rather moderate space velocity.

A marginally significant X-ray source 1RXS J083127.8+195301 (*ROSAT* flux: 0.102 ± 0.020 cts s^{-1}, Voges et al. 1999) is located within 6 arcsec of the optical location indicating a positional coincidence. GSC 01387–00475 has not been recognized before as a visual binary, there are no obvious visual companions close to it and none was noticed in the slit view during the spectroscopic observations.

3 PHOTOMETRY

The ASAS data (Pojmański 2004; Pojmański & Maciejewski 2005; Paczyński et al. 2006),[1] for GSC 01387–00475 have been collected during six consecutive seasons (2003–2008) in the *V* band and during three seasons (2003, 2005 and 2006) in the *I* band. Only the best, grade 'A', observations were used. The data are listed in the on-line Table 1 and consist of 290 observations in the *V* filter and 102 observations in the *I* filter.

When plotted with the spectroscopic time elements ($T_0 =$ 245 2623.1423, $P = 0.217811$ d; Section 4), the phased observations (Fig. 1) show a light curve of a small amplitude of about 0.09 mag, but with a relatively large scatter, particularly in *V*, of about 0.02–0.03 mag. The scatter is larger than expected for the ASAS data at the same magnitude level (Pojmański 2004) where it should be typically below 0.015–0.02 mag. The scatter is not due to any period changes as the eclipse times do not show any systematic shifts during the six-year span of the ASAS observations.

[1] For details, see: http://www.astrouw.edu.pl/∼gp/asas/asas.html and http://archive.princeton.edu/∼asas/

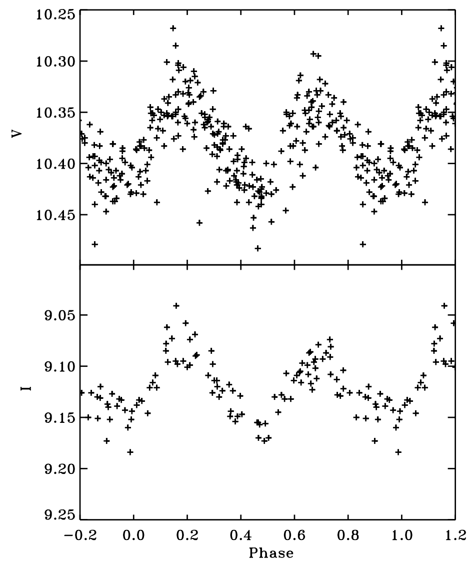

Figure 1. The *V* and *I* photometric band ASAS data for GSC 01387–00475 versus the orbital phase calculated using our spectroscopic conjunction (eclipse) prediction as in Section 4.

Table 2. Sample of the DDO differential, unfiltered photometry of GSC 01387–00475 relative to GSC 01387–00510. The full table is available as Supplementary Material.

HJD	Δm
245 4422.8607	−0.584
245 4422.8610	−0.589
245 4422.8614	−0.587
245 4422.8617	−0.590
245 4422.8621	−0.596

Because of the northern sky location observed from the southern observatory of Las Campanas, the ASAS data points were acquired relatively infrequently, with typical spacing of 2–3 d, with some gaps lasting as long as several days. The large scatter can therefore come from some other source of variability, either due to the binary itself or to its spectroscopic companion (Sections 4–5).

While conducting the spectroscopic observations at the DDO, simultaneous unfiltered photometry of GSC 01387–00475 was obtained on six nights (2007 Nov. 18 to 2008 March 25) using the 15 cm finder of the main 1.88 m telescope. The photometric sampling was more rapid, when compared with that of the ASAS data, with the typical spacing between observations of one minute. The observations (the on-line Table 2) clearly show a well defined, low amplitude ($\Delta m = 0.09$) binary light curve on individual nights. The small differences between the nights of typically 0.01–0.02 mag (Fig. 2) do not have an explanation and may correspond to relatively slow brightness variations although their time-scale cannot be established from our very infrequent nightly observations.[2] Unfortunately, we cannot exclude a possibility of some instrumental causes because the 15 cm finder camera was never meant to serve

[2] The long duration of the DDO observations was not planned and was entirely due to the poor weather during the 2007/2008 winter. At DDO, we normally try to obtain a reasonable spectroscopic phase coverage in as short a time span as possible.

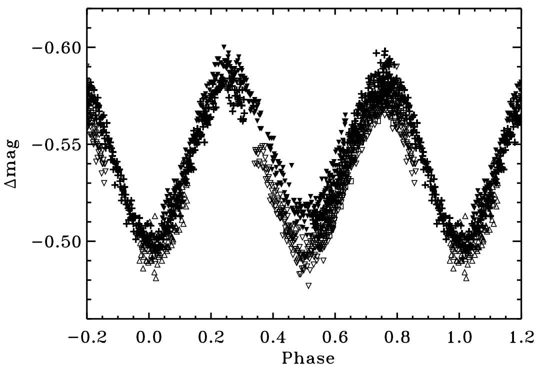

Figure 2. The unfiltered DDO photometry of GSC 01387–00475 versus the orbital phase calculated using the time of the spectroscopic conjunction (Section 4). Different symbols are used for different nights.

as a precise photometric instrument and its long-term stability is entirely unknown. Therefore, we are not sure if the photometric scatter in the ASAS data can be explained by the night-to-night shifts observed during the DDO observations.

The DDO observations shown in Fig. 2 are expressed as magnitude differences relative to the comparison star GSC 01387–00510. Three eclipses were observed sufficiently to establish times of minima at HJD 245 4422.9169(5), 245 4525.6136(3), and 245 4550.6627(3); the standard errors are expressed in units of the last decimal place and are given in parentheses. Based on these, the value of the photometric epoch is by 0.0018 d later than based on the spectroscopic results (Table 4).

While the small amplitude of the binary variations is partly due to the presence of the third star in the system which 'dilutes' the binary star signal (Section 5), most of the amplitude reduction must come from the low orbital inclination. Assuming the contact model with the spectroscopic mass ratio of $q = 0.47$ (Section 4) and the 2/3 light contribution of the binary to the total brightness (Section 5), we estimate the orbital inclination at $i = 42 \pm 3$ degrees; the uncertainty includes an unknown (and presumed small) degree-of-contact of the binary.

4 SPECTROSCOPY

Spectroscopic observations of GSC 01387–00475 were obtained using the slit spectrograph in the Cassegrain focus of 1.88 m telescope of the DDO. The spectra were taken in the window of 240 Å around the Mg I triplet (5167, 5173 and 5184 Å) with an effective resolving power of about 12 000 provided by a diffraction grating with 2160 lines mm^{-1} and 240 μm slit at the scale of 0.117 Å pixel^{-1}. The efficient program of Pych (2004) was used for removal of cosmic rays from the two-dimensional spectral images. One-dimensional spectra were extracted by the usual procedures within the IRAF environment[3] after the bias subtraction and the flat field division. The exposure times were always 500 s long, which corresponds to 2.6 per cent of the orbital period.

Broadening functions (BFs), which can be considered as images of the binary system in the radial velocity domain (Fig. 3) were extracted by the method described in Rucinski (1992b) and Rucinski (2002) (see also other papers of the DDO series, e.g. Pribulla et al. 2007). As templates served stars HD 3765, K2V, $V_r = -62.3$ km s^{-1} and HD 65583, G8V, $V_r = +13.2$ km s^{-1}. The integrals of the BFs are substantially larger than unity, of 1.09 and 1.46, respectively, implying an increased combined strength of the lines, in agreement with the estimated spectral type of the binary of K3/5V.

[3] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the NSF.

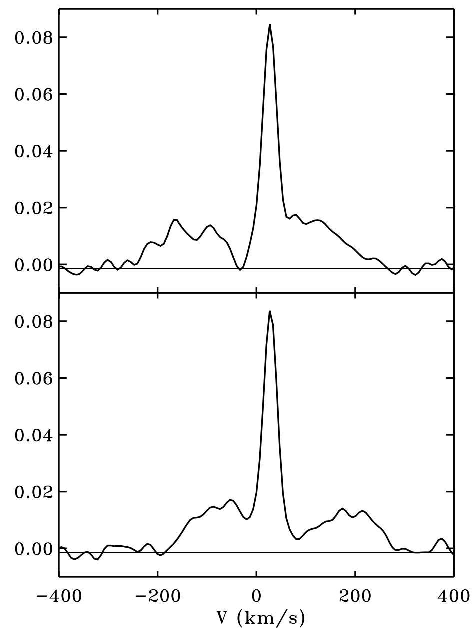

Figure 3. The BFs for two orbital phases of GSC 01387–00475: the upper panel for 0.754 and the lower panel for 0.257. The vertical scale is in basically arbitrary units of the BF intensity per 6.7 km s^{-1} pixel; for a perfect spectral match of the template, an integral over the BF in such units would give exactly unity.

Table 3. Sample of the radial velocities of all three components of GSC 01387–00475. Weights w_i refer to the quality of radial velocity determinations. The full table is available as Supplementary Material.

HJD	V_1	V_2	V_3	w_1	w_2
245 4422.8610	95.25	−139.00	26.68	1.0	1.0
245 4422.8670	96.72	−131.92	25.89	1.0	1.0
245 4422.8730	87.27	−125.25	25.30	1.0	1.0
245 4422.8803	79.16	−111.99	26.39	1.0	1.0
245 4422.8863	61.79	−91.06	27.60	0.5	0.5

The phase system that we used assumes the zero phase at the time of the eclipse of the more massive component. It is not clear if this component has a larger surface brightness; the light curves are not defined well enough to distinguish which of the eclipses is the deeper one. The photometric scatter appears to be larger during the secondary minima (Fig. 2), but this may be due to the unevenly dense photometric phase coverage.

The BFs are well defined with a prominent signature of a third, slowly rotating component. The radial velocities of all three components (the on-line Table 3) were measured using our standard approach developed in the DDO series (Pribulla et al. 2007): we fitted the BFs by three Gaussians, subtracted the Gaussian of the third component, and then fitted a double rotational profile to the residual binary peaks.

The radial-velocity orbit of GSC 01387–00475 is shown in Fig. 4. Given the short exposures and the relative faintness of the system, the orbit is surprisingly well defined. The spectroscopic parameters

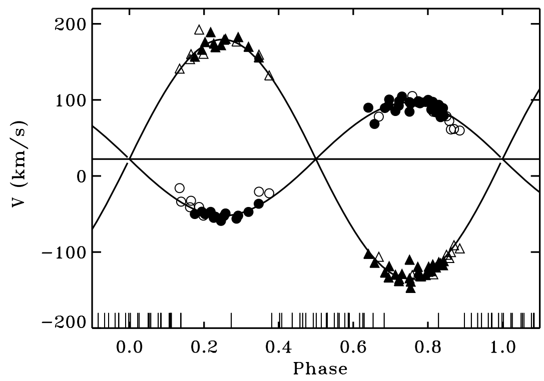

Figure 4. The radial velocity orbit for the binary star GSC 01387–00475. The phases are counted from the conjunction with the more massive component behind. Observations carrying a reduced weight of 1/2 are marked by open symbols. The orbital elements are given in Table 4. Phases of unused spectra with blended or poorly defined signatures of both components in the BFs are marked at the bottom margin of the figure.

Table 4. Parameters of the spectroscopic orbit of GSC 01387–00475.

Parameter	Unit	Value	Std. err.
P	d	0.217811	Fixed
T_0		245 2623.1423	0.0005
V_0	$\mathrm{km\,s^{-1}}$	22.21	0.68
K_1	$\mathrm{km\,s^{-1}}$	74.40	0.89
K_2	$\mathrm{km\,s^{-1}}$	157.00	1.25
$(M_1 + M_2)\sin^3 i$	$\mathrm{M_{\odot}}$	0.280	0.008
$q = M_2/M_1$		0.474	0.008

are listed in Table 4. With the orbital inclination of $i = 42 \pm 3$ degrees (Section 3), the total mass of the binary, $M_1 + M_2 = 0.94 \pm 0.16\,\mathrm{M_{\odot}}$, appears to be reasonable for a contact binary of the K3/5V spectral type; the light curves are currently too poor to lift the large inclination uncertainty in the sum of the masses. The estimated total mass appears to be very similar to that of CC Com, $M_1 + M_2 = 1.083 \pm 0.012\,\mathrm{M_{\odot}}$; the mass ratio, $q = 0.474 \pm 0.008$ is also similar, CC Com: $q = 0.527 \pm 0.006$ (Pribulla et al. 2007).

5 THE SPECTROSCOPIC COMPANION

The third component of GSC 01387–00475 was analyzed as a single star from the BFs, after removal of the close-binary signature. The radial velocities of the companion were measured only for the best quality BFs. The error per observation was larger than typically for single, sharp-line stars ($<1.0\,\mathrm{km\,s^{-1}}$) and equalled $1.27\,\mathrm{km\,s^{-1}}$ which may be partly explained by the variable 'cross-talk' from the underlying, rapidly changing contribution of the binary in the BFs (see Fig. 3). The average radial velocity, $V_3 = 27.42 \pm 0.18\,\mathrm{km\,s^{-1}}$ (the error evaluated assuming the constant value), is similar to, but significantly different from the centre of mass velocity of the binary of $V_0 = +22.21 \pm 0.68\,\mathrm{km\,s^{-1}}$. This measurable difference may suggest a moderately short orbital period of the third component relative to the common mass centre.

The value of the rotation broadening is indeterminable from the BFs. We can give only an upper limit of $V_3 \sin i < 15\,\mathrm{km\,s^{-1}}$.

The luminosity ratio of the third star relative to the binary, estimated from the integrated peaks in the BFs, such as in Fig. 3, is $L_3/L_{12} = 0.546 \pm 0.015$. This value is most likely an over-estimate because of the biased continuum normalization during rectification of the spectra: the normalization applies to the real continuum for the sharp-line companion and to the pseudo-continuum for the heavily blended spectra of the close binary. An estimate including this systematic effect is $L_3/L_{12} = 0.50 \pm 0.05$. Thus, the three components of GSC 01387–00475 appear similar in their luminosity so that the third component is also a mid-K type dwarf.

6 CONCLUSIONS

The existence of GSC 01387–00475 confirms that the short period cut-off of the contact binary period distribution at 0.22 d is sharp and well defined. CC Com is definitely not an exception. The existence of a still shorter period contact binary V34 identified by Weldrake et al. (2004) in the globular cluster 47 Tuc with the period of $P = 0.2155$ d is consistent with both current explanations: the expected smaller dimensions of contact binaries in globular clusters (Rucinski 2000) and with the more advanced age of such binaries compared with the Galactic field objects (Stepien 2006).

GSC 01387–00475 may be slightly less massive than CC Com and thus slightly more extreme in its properties. However, as an eclipsing and spectroscopic binary, GSC 01387–00475 is a less convenient object for detailed studies than CC Comae because it has a lower orbital inclination angle and hence does not show total eclipses as does CC Com. Additionally, its light curve may be subject to unexplained intrinsic variations, possibly with a long time-scale of weeks or months. The variability may be due to the binary itself or to its spectroscopic companion which contributes about 1/3 of the total light of the system. The existence of the companion one more time confirms the recent results that practically all contact binaries have companions on wide orbits (D'Angelo, van Kerkwijk & Rucinski 2006; Pribulla & Rucinski 2006; Rucinski, Pribulla & van Kerkwijk 2007).

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article.

Table 1. ASAS *V* and *I* photometry of GSC 01387–00475.

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