GSC 2314–0530: the shortest-period eclipsing system with dMe components

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ABSTRACT

CCD photometric observations in VRI colours and spectroscopic observations of the newly discovered eclipsing binary GSC 2314–0530 (NSVS 6550671) with dMe components and a very short period of \( P = 0.192 \, 636 \, \text{d} \) are presented. The simultaneous light-curve solution and radial velocity solution allow us to determine the global parameters of GSC 2314–0530: \( T_1 = 3735 \, \text{K}; T_2 = 3106 \, \text{K}; M_1 = 0.51 \, \text{M}_\odot; M_2 = 0.26 \, \text{M}_\odot; R_1 = 0.55 \, \text{R}_\odot; R_2 = 0.29 \, \text{R}_\odot; L_1 = 0.053 \, \text{L}_\odot; L_2 = 0.007 \, \text{L}_\odot; i = 72.5^\circ; a = 1.28 \, \text{R}_\odot; d = 59 \, \text{pc} \). The chromospheric activity of its components is revealed by strong emission in the H\(\alpha \) line (with mean \( EW = 5 \, \text{Å} \)) and several observed flares. Empirical relations for mass–\( M_\text{bol} \), mass–radius and mass–temperature are temperature are derived on the basis of the parameters of known binaries with low-mass dM components.

Key words: stars: activity – binaries: eclipsing – binaries: spectroscopic – stars: fundamental parameters – stars: late-type – stars: low-mass.

1 INTRODUCTION

Although M dwarfs are the most numerous stars in our Galaxy, their masses, metallicities and the age dependences of their stellar luminosities and radii are poorly calibrated. The reason for this is the selection effect, which plays against the detection of fainter and smaller stars.

Fewer than 20 binaries with low-mass dM components have empirically determined masses, radii, luminosities and temperatures (see Section 5 later). As a result the mass–luminosity relation is determined by only a few low-mass stars. This deficiency has hindered the development of models for the cool dense atmospheres of M dwarfs. It is established that all available models underestimate the radii (by around 10–15 per cent) and overestimate the temperatures (by 200–300 K) of short-period binaries with dM components (Ribas 2003; Maceroni & Montalban 2004).

The Northern Sky Variability Survey (NSVS) contains a great number of photometric data (Wozniak et al. 2004) and allows searching of variable stars and determination of their periods and types of variability. A multiparametric method for searching for variable objects in large data sets was tested on the NSVS (Dimitrov 2009) and as a result many eclipsing stars were discovered. One of them was GSC 2314–0530 \( \equiv \) NSVS 6550671 (\( \alpha = 02^h 20^m 50.9^s, \delta = +33^\circ 20' 46.6' \)).

On the basis of the NSVS photometry obtained in 1999–2000 we derived the ephemeris

\[
HJD(\text{Min I}) = 245 \, 1352.062 + 0.192 \, 637 \times E \tag{1}
\]

and built its light curve (Fig. 1).

We found that this star has also been assigned as SWASP J022050.85+332047.6 according to the SuperWASP photometric survey (Pollacco et al. 2006). Norton et al. (2007) reported its coincidence with the ROSAT X-ray source 1RXS J022050.7+332049.

Initially GSC 2314–0530 attracted our interest because of its short orbital period, as there were only a few systems with non-degenerate components and periods below the short-period limit of 0.22 d (Rucinski 2007); GSC 1387–0475 with \( P = 0.217811 \, \text{d} \) (Rucinski 2007; Rucinski & Pribulla 2008), ASAS J071829–0336.7 with \( P = 0.211249 \, \text{d} \) (Pribulla, Vanko & Hambalek 2009), star V34 in the globular cluster 47 Tuc with \( P = 0.2155 \, \text{d} \) (Weldrake et al. 2004) and BW3 V38 with orbital period \( P = 0.1984 \, \text{d} \) (Maceroni & Rucinski 1997; Maceroni & Montalban 2004).

When we established that the components of GSC 2314–0530 were dM stars, our interest increased and we undertook intensive photometric and spectral observations in order to determine its global parameters and to obtain new information regarding dM stars as well as short-period binaries.
2 OBSERVATIONS AND DATA REDUCTION

2.1 New photometry

The CCD photometry of GSC 2314–0530 in the VRI bands was carried out at Rozhen National Astronomical Observatory with the 2-m RCC telescope equipped with a VersArray\(^1\) CCD camera (1300 × 1340 pixels, 20-μm pixel, field of 5.25 × 5.35 arcmin) as well as with the 60-cm Cassegrain telescope using the FLI\(^2\) PL90000 CCD camera (3056 × 3056 pixels, 12-μm pixel, field of 17.1 × 17.1 arcmin). The average photometric precision per data point was 0.005–0.008 mag for the 60-cm telescope and 0.002–0.003 mag for the 2-m telescope. Table 1 presents the journal of our photometric observations.

It should be noted that the observations on 2009 December 30 are synchronous in VRI colours.

Standard stars of Landolt (1992) and standard fields of Stetson (2000) were used for the reduction of the photometric data. The standard stars were chosen on the basis of the method of Everett & Howell (2001); Table 2 presents their colours. The values of \(J – K\) are from the catalogue NOMAD (Zacharias et al. 2005) while the values of other parameters are our estimations. The field of the variable and standard stars is shown in Fig. 2.

Table 2 presents a sample of our photometric data (the full table is available in the online version of the article, see Supporting Information).

Some of our photometric runs covering the orbital cycle well are presented in Fig. 3.

The Fourier analysis of all our photometric data performed by the software PERIOD04 (Lenz & Breger 2005) leads to the ephemeris

\[
HJD(\text{Min I}) = 245 1352.061633 + 0.192 6359 \times E. \tag{2}
\]

The newly obtained period value is almost the same as that of ephemeris (1) of the NSVS data, which means that the orbital period of GSC 2314–0530 is stable.

The colour indices of our target (Table 2) lead to an M spectral type for the binary. Taking into account the almost equal eclipse depths of the light curve, i.e. the close temperatures of the components as well as the short orbital period of the system, we may conclude that the two components of GSC 2314–0530 are dM stars.

The value of the period obtained is below the short-period limit and reveals that our target is the shortest-period binary with dM components.

Fig. 4 shows the folded light curves from all our photometric data phased according to ephemeris (2).

2.2 Spectroscopy

We obtained 26 spectra of GSC 2314–0530 with resolution 0.19 Å pixel\(^{-1}\) during 2009 November–December covering a spectral range of 200 Å around the H\(\alpha\) line. We used a CCD Photometrics\(^3\) AT200 camera with the SITE SI003AB 1024 × 1024 pixel chip mounted on the Coude spectrograph (grating B&L632/14:7) on the 2-m RCC telescope at Rozhen.

The exposure time was 15 min during 2009 November 26 and 20 min during 2009 December 31 and 2010 January 01. All stellar integrations were alternated with Th–Ar comparison-source exposures for wavelength calibration. The bias frames and flat-field integrations were obtained at the beginning and end of the night. The mean signal-to-noise ratio (S/N) for our observations was around 24, i.e. acceptable for radial velocity determination. Table 4 presents the journal of our spectral observations.

Reduction of the spectra was performed using IRAF packages and involved bias subtraction, flat-fielding, cosmic-ray removal, one-dimensional spectrum extraction and wavelength calibration. Fig. 5 illustrates the orbital variability of the stellar spectra while Fig. 6 presents one-dimensional H\(\alpha\) profiles at some orbital phases.

3 ANALYSIS OF THE SPECTRAL DATA

The spectra of GSC 2314–0530 obtained show wide-emission H\(\alpha\) lines, implying high rotational velocities as well as absorption TiO bands at 6569 and 6651 Å (Fig. 5). These spectral features suggest a dMe classification for GSC 2314–0530.

The spectral contribution of the secondary component is visible only in the H\(\alpha\) line (Fig. 5). This is why we determined the radial velocities of the two stellar components by fitting the H\(\alpha\) lines at each phase with Gaussians (Fig. 7).

Table 4 and Fig. 8 present the radial velocities of the stellar components of GSC 2314–0530. Their fit corresponds to values \(K_1 = V_1 \sin i = 109.7 ± 3.2\) km s\(^{-1}\), \(K_2 = V_2 \sin i = 211.3 ± 5.8\) km s\(^{-1}\) and \(V_0 \sin i = -1.2 ± 5.7\) km s\(^{-1}\). They lead to mass ratio \(q = 0.519 ± 0.029\) and binary separation \(a \sin i = 1.22 ± 0.04\) R\(\odot\).

4 ANALYSIS OF THE PHOTOMETRIC DATA

The qualitative analysis of the new photometric data (Fig. 4) leads to several conclusions.

1. Min I is deeper than Min II. This means that the temperature of the secondary is lower than the temperature of the primary.

2. The light maxima are not equal. This O’Connell effect implies the presence of surface-temperature spot(s).

3. Max I appears at the expected phase of 0.25 while the phase of Max II is around 0.78. As a result the second half of the light

\(^1\)Princeton Instruments, Trenton, NJ.

\(^2\)Finger Lakes Instrumentation, Lima, NY.

\(^3\)Photometrics, Tucson, AZ.
Table 1. Journal of the photometric observations.

| Date        | HJD (start) | Phases  | Filter | Exp. [s] | N  | Telescope |
|-------------|-------------|---------|--------|----------|----|-----------|
| 2009 July 25| 245 5038.482 | 0.725–1.298 | R      | 120      | 126 | 60-cm     |
| 2009 July 26| 245 5039.484 | 0.927–0.491  | R      | 120      | 54  | 60-cm     |
| 2009 July 27| 245 5040.468 | 0.032–0.693  | R      | 120      | 83  | 60-cm     |
| 2009 July 28| 245 5041.501 | 0.395–0.881  | R      | 120      | 62  | 60-cm     |
| 2009 Oct 21 | 245 5126.412 | 0.210–1.294  | V      | 15       | 737 | 2-m       |
| 2009 Nov 13 | 245 5149.178 | 0.393–1.389  | I      | 10       | 850 | 2-m       |
| 2009 Nov 13 | 245 5149.375 | 0.419–1.391  | R      | 10       | 835 | 2-m       |
| 2009 Nov 20 | 245 5156.324 | 0.489–0.521  | B      | 120      | 3   | 60-cm     |
| 2009 Nov 20 | 245 5156.325 | 0.495–1.862  | V      | 60       | 183 | 60-cm     |
| 2009 Nov 20 | 245 5156.326 | 0.498–0.529  | R      | 30       | 3   | 60-cm     |
| 2009 Nov 20 | 245 5156.326 | 0.500–0.531  | I      | 30       | 3   | 60-cm     |
| 2009 Dec 30 | 245 5196.225 | 0.610–1.785  | V      | 120      | 65  | 60-cm     |
| 2009 Dec 30 | 245 5196.226 | 0.616–1.791  | R      | 60       | 65  | 60-cm     |
| 2009 Dec 30 | 245 5196.227 | 0.619–1.810  | I      | 60       | 65  | 60-cm     |

Table 2. Colours and proper motion of the variable star and standard stars.

| ID          | V     | B – V      | V – R      | V – I     | J – K      | pmRA    | pmDE    |
|-------------|-------|------------|------------|-----------|------------|---------|---------|
| GSC/USNO-B1 | mag   | [mag]      | [mag]      | [mag]     | [mas yr\(^{-1}\)] | [mas yr\(^{-1}\)] |
| Var         | 2314–0530 | 13.36      | 1.18       | 0.88      | 2.38       | 0.87     | 144.0   | −112.0  |
| St1         | 2314–1784 | 12.12      | 0.30       | 0.25      | 0.57       | 0.29     | −000.8  | −008.3  |
| St2         | 2314–1378 | 12.24      | 0.29       | 0.24      | 0.58       | 0.34     | −000.1  | −001.6  |
| St3         | 2314–1655 | 12.40      | 0.22       | 0.20      | 0.46       | 0.27     | 005.5   | −004.0  |
| Twin        | 1233–004625 | 16.91     | 1.41       | 1.03      | 3.02       | 0.87     | 140.0   | −112.0  |

Table 3. BVRI photometry of GSC 2314–0530. This is a sample of the full table, which is available with the online version of the article (see Supporting Information).

| HJD Magnitude Filter |
|----------------------|
| 245 5156.329 669     | 14.8530 | B       |
| 245 5156.332 679     | 14.8490 | B       |
| 245 5156.335 689     | 14.8300 | B       |
| 245 5156.417 320     | 13.3610 | V       |
| 245 5156.418 512     | 13.3618 | V       |
| 245 5156.419 890     | 13.3619 | V       |
| 245 5156.420 167     | 13.3624 | V       |
| 245 5156.420 700     | 13.3547 | V       |
| 245 5156.420 978     | 13.3583 | V       |
| 245 5156.421 128     | 13.3609 | V       |

Figure 2. Observed field around GSC 2314–0530.

The light curve is quite distorted. A similar asymmetry is also visible in the NSVS light curve (Fig. 1) of the star almost 10 yr earlier, i.e., this distortion is possibly permanent. We note that the shape of the light curve of GSC 2314–0530 in the phase range 0.5–0.8 resembles to some degree that of cataclysmic stars with their peculiar standstills, causing a delay in the light increase after the minimum.

(4) The \( V – I \) light curve of GSC 2314–0530 (Fig. 9) clearly reveals that the system becomes redder after the two eclipses and bluer after the two quadratures. The phases of the extrema of the \( V – I \) light curve have around 0.05 phase delays with respect to those of the light curves, except for the second maximum of \( V – I \) for which the delay is more than 0.10.

(5) We observed several flares of GSC 2314–0530 (Fig. 3), which resemble those of UV Ceti stars (see more in Section 6).

In order to determine the global parameters of GSC 2314–0530 we modelled our VRI folded curves simultaneously by the following procedure using the software PHOEBE (Prša & Zwitter 2005).

(i) We fixed the mass ratio \( q = 0.519 \) from our radial velocity solution.

(ii) The obtained components of the heliocentric space velocity \( U = −23 \text{ km s}^{-1}, V = −44 \text{ km s}^{-1} \) and \( W = −12 \text{ km s}^{-1} \) allow us to assume solar metallicity for the emission of GSC 2314–0530 (Leggett 2000).
According to table 2 of VandenBerg & Clem (2003), this out-of-eclipse colour index corresponds to a mean temperature of the binary $T_m = 3560$ K.

It should be noted that the index $B - V = 1.18$ mag of GSC 2314--0530 corresponds to a mean temperature of around 4400 K, i.e. 840 K higher than that obtained by the $V - I$ index. This is a new confirmation of the conclusion that the majority of dMe stars have $B - V$ colours too blue for their $V - I$ colours (Stauffer & Hartmann 1986). Our result also shows that the temperature difference obtained from the two colour indices ($V - I$ and $B - V$) is higher than 200–300 K (Ribas 2003; Maceroni & Montalban 2004) and can reach 800 K.

(v) At the first stage, we fixed $T_1 = 3700$ K (taking into account that the temperature of the primary component $T_1$ is higher than $T_m$) and varied the secondary temperature $T_2$, the orbital inclination $i$ and the potentials $\Omega_1$, $\Omega_2$. In order to reproduce the O’Connell effect and light-curve distortions we had to add two cool spots on the primary’s surface and to vary their parameters: longitude $\lambda$, latitude $\beta$, angular size $\alpha$ and temperature $T_{sp}$.

Moreover, in order to obtain a good simultaneous fit for the three colours $VRI$ from the same stellar and spot parameters we added a third light $L_3$ which contributes differently to the different colours. We consider the last supposition as an artificial step to compensate for the peculiar energy distribution of dM stars, which appear especially faint in the $V$ band, probably owing to high TiO absorption as well as the large contribution of the spots.

(vi) After obtaining a good fit of our $VRI$ photometric data, we began to vary the temperature of the primary also. As a result we obtained the best light-curve solution, the parameters of which are given in Table 5. The respective synthetic $VRI$ light curves are shown in Fig. 4 as grey lines. They coincide very well with the observational data at all phases except for flares.

The potentials obtained correspond to relative mean stellar radii $r_1 = 0.431$ and $r_2 = 0.228$, revealing that the primary component almost fills its Roche lobe (Fig. 10).
Table 4. Journal of the spectral observations and parameters of the Hα lines.

| No | HJD    | S/N | phase | \( RV_1 \) [km s\(^{-1}\)] | \( RV_2 \) [km s\(^{-1}\)] | \( EW_{\text{total}} \) [Å] |
|----|--------|-----|-------|-----------------------------|-----------------------------|-----------------------------|
| 01 | 245 5162.375 293 | 23 | 0.88 | 89.2 ± 3.3 | -157.5 ± 6.2 | 4.97 |
| 02 | 245 5162.385 975 | 19 | 0.93 | 42.8 ± 3.7 | 4.56 |
| 03 | 245 5162.396 657 | 22 | 0.99 | -9.3 ± 6.6 | 3.61 |
| 04 | 245 5162.407 335 | 21 | 0.04 | -57.9 ± 4.5 | 63.0 ± 4.0 | 6.64 |
| 05 | 245 5162.418 012 | 27 | 0.10 | -68.0 ± 4.5 | 99.1 ± 10.8 | 4.34 |
| 06 | 245 5162.428 689 | 28 | 0.15 | -92.8 ± 3.2 | 210.3 ± 9.3 | 4.04 |
| 07 | 245 5162.439 367 | 28 | 0.21 | -116.6 ± 4.4 | 165.8 ± 6.9 | 3.53 |
| 08 | 245 5162.450 048 | 29 | 0.27 | -120.7 ± 4.6 | 174.0 ± 7.9 | 3.62 |
| 09 | 245 5162.460 726 | 28 | 0.32 | -86.7 ± 2.6 | 187.1 ± 3.2 | 4.60 |
| 10 | 245 5162.471 405 | 30 | 0.38 | -81.6 ± 4.3 | 176.4 ± 4.9 | 4.49 |
| 11 | 245 5162.482 903 | 25 | 0.44 | -48.4 ± 2.2 | 5.47 |
| 12 | 245 5162.493 582 | 26 | 0.49 | -0.6 ± 3.8 | 5.55 |
| 13 | 245 5162.514 939 | 25 | 0.60 | 73.4 ± 5.6 | -106.5 ± 12.9 | 5.34 |
| 14 | 245 5162.526 143 | 24 | 0.66 | 93.8 ± 4.1 | -170.6 ± 5.9 | 4.94 |
| 15 | 245 5162.537 036 | 26 | 0.72 | 96.2 ± 3.4 | -222.2 ± 8.6 | 6.18 |
| 16 | 245 5197.222 839 | 18 | 0.78 | 120.7 ± 7.4 | 5.92 |
| 17 | 245 5197.236 667 | 29 | 0.85 | 93.9 ± 3.0 | -160.6 ± 9.1 | 5.07 |
| 18 | 245 5197.250 817 | 27 | 0.92 | 48.6 ± 4.4 | -123.3 ± 4.5 | 5.34 |
| 19 | 245 5197.264 965 | 28 | 0.99 | -37.1 ± 4.9 | 5.59 |
| 20 | 245 5197.279 111 | 27 | 0.07 | -60.1 ± 3.0 | 5.67 |
| 21 | 245 5197.293 257 | 29 | 0.14 | -91.7 ± 4.8 | 198.2 ± 10.0 | 4.16 |
| 22 | 245 5197.308 131 | 29 | 0.22 | -119.1 ± 4.3 | 212.2 ± 7.8 | 4.44 |
| 23 | 245 5197.322 278 | 30 | 0.29 | -101.8 ± 2.9 | 191.2 ± 6.1 | 3.76 |
| 24 | 245 5197.336 431 | 28 | 0.37 | -75.4 ± 4.0 | 168.5 ± 6.1 | 3.65 |
| 25 | 245 5198.274 197 | 25 | 0.23 | -91.5 ± 3.4 | 205.3 ± 4.3 | 6.04 |
| 26 | 245 5198.288 351 | 25 | 0.31 | -72.2 ± 4.0 | 199.8 ± 4.0 | 6.29 |

Figure 5. The orbital variability of the spectra of GSC 2314–0530 from 2009 November 26.

5 GLOBAL PARAMETERS OF GSC 2314–0530

Using the photometric value of the orbital inclination \( i = 72.5 \), we consecutively determined the following global parameters of GSC 2314–0530:

(i) orbital velocities of the two components \( V_1 = 115.1 \pm 3.4 \text{ km s}^{-1} \) and \( V_2 = 221.6 \pm 6.1 \text{ km s}^{-1} \);

(ii) orbital separation \( a = 1.28 \pm 0.04 \text{ R}_\odot \);

(iii) masses of the components \( M_1 = 0.51 \pm 0.02 \text{ M}_\odot \) and \( M_2 = 0.26 \pm 0.02 \text{ M}_\odot \);

(iv) absolute (mean) radii of the components \( R_1 = 0.55 \pm 0.01 \text{ R}_\odot \) and \( R_2 = 0.29 \pm 0.01 \text{ R}_\odot \);

(v) surface gravity \( \log g_1 = 4.68 \) and \( \log g_2 = 4.95 \);

(vi) stellar luminosities \( L_1 = 0.053 \pm 0.002 \text{ L}_\odot \) and \( L_2 = 0.0070 \pm 0.0006 \text{ L}_\odot \);

(vii) bolometric absolute magnitudes of the components (using \( M_{\text{bol}} = 4.72 \) \text{ M}_\odot \) \( M_{\text{bol}} = 7.91 \pm 0.04 \text{ mag} \) and \( M_{\text{bol}} = 10.11 \pm 0.09 \text{ mag} \), as well as the bolometric absolute magnitude of the binary \( M_{\text{bol}} = 7.77 \pm 0.05 \text{ mag} \);

(viii) absolute V magnitude of the binary \( V = 9.5 \pm 0.05 \text{ mag} \) (using \( B-V = -1.73 \) corresponding to \( T_{\text{bol}} \) from table 2 of VandenBerg & Clem 2003);

(ix) distance to the binary \( d = 59 \pm 2 \text{ pc} \).

Figure 6. The Hα profiles at some phases.
Figure 7. The two Gaussians (grey lines) reproducing the Hα line (dots) of the two stellar components, and their sum (black line) fitting the total Hα profile of GSC 2314−0530.

Figure 8. Radial velocities of the two components of GSC 2314−0530 (the sizes of the error bars correspond to 3σ) and their fits by the code PHOEBE (Prsa & Zwitter 2005).

Figure 9. V−I light curve of GSC 2314−0530 from synchronous VRI observations with a 60-cm telescope.

Table 5. Best light-curve solution from PHOEBE.

| Parameter     | Value     |
|---------------|-----------|
| i             | 72.5 ± 0.1 |
| T1            | 3735 ± 10 |
| T2            | 3106 ± 10 |
| Ω1            | 2.944 ± 0.002 |
| Ω2            | 3.545 ± 0.009 |
| λSp1          | 147 ± 5 |
| βSp1          | 70 ± 10 |
| αSp1          | 20 ± 1 |
| TSp1          | 3175 ± 50 |
| λSp2          | 195 ± 5 |
| βSp2          | 75 ± 10 |
| αSp2          | 8 ± 1 |
| TSp2          | 3175 ± 50 |
| L3(V)         | 0.171 ± 0.003 |
| L3(R)         | 0.222 ± 0.002 |
| L3(I)         | 0.298 ± 0.002 |

Figure 10. Three-dimensional model of GSC 2314−0530 at phase 0.75.

It should be noted that while the masses and radii of the components were directly determined, their temperatures and absolute magnitudes required external calibrations, which are poorly known for late stars.

We calculated the equatorial velocities of the components by measuring the rotation broadening of their Hα lines (using i = 72.5°). The obtained values \( V_{rot1} = 145 ± 15 \text{ km s}^{-1} \) and \( V_{rot2} = 69 ± 15 \text{ km s}^{-1} \) reveal that the components of GSC 2314−0530 are quite fast rotators. Thus our target confirms the conclusion of Stauffer & Hartmann (1986) that stars with larger velocities have centrally peaked Hα emission while slower rotators have centrally reversed profiles, as well as the conclusion of Worden, Schneeberg & Giampapa (1981) that stars with centrally peaked Hα emission profiles belong to the class of short-period binaries.

Some of the global parameters of GSC 2314−0530 determined, together with those of other known binaries with low-mass dM components, are given in Table 6. The columns correspond to star name, period \( P \) in days, temperatures \( T \) of the components, masses \( M \), radii \( R \) and luminosities \( L \) of the components in solar units, orbital inclination \( i \) in degrees, mass ratio \( q \); colour index \( V−I \) of the binary, bolometric absolute magnitudes \( M_{bol} \) of the components, orbital separation \( a \) in solar radii, distance \( d \) in pc, type of binary configuration (D = detached, SD = semidetached) and references.

Fig. 11 shows empirical diagrams of mass–\( M_{bol} \), mass–radius and mass–temperature for the low-mass stars from Table 6 (total

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Table 6. Parameters of binaries with low-mass dM components.

| Name          | $P$  | $T$  | $M$  | $R$  | $L$  | $i$ | $q$ | $V-I$ | $M_{bol}$ | $a$  | $d$  | Type | Ref. |
|---------------|------|------|------|------|------|-----|-----|-------|-----------|------|------|------|------|
| CU Cnc=GJ 2069A | 2.77 | 3160 | 0.43 | 0.43 | 0.016 | 86  | 0.92| 2.80  | 9.19       | 0.92 | 12.8 | D    | (1)  |
| 2MASS J01542930+0053266 | 2.64 | 3700 | 0.66 | 0.64 | 0.069 | 86  | 0.95|       | 7.62       | 8.70 | 623  | D    | (2)  |
| NSVS 06507557  | 0.51 | 3960 | 0.65 | 0.60 | 0.079 | 83  | 0.42| 2.13  | 7.48       | 2.65 | 111  | D    | (3)  |
| NSVS 07394765  | 2.26 | 3170 | 0.56 | 0.58 | 0.030 | 84  | 1.16|       | 8.52       | 2.60 | D    | D    | (4)  |
| NSVS 07453183  | 0.37 | 3340 | 0.68 | 0.72 | 0.060 | 89  | 1.07| 1.40  | 7.77       | 7.75 | 169  | D    | (4)  |
| UNSW-TR-2      | 2.11 | 3870 | 0.53 | 0.64 | 0.082 | 743 | 0.95| 7.43  | 7.05       | 1.28 | 59   | D    | (5)  |
| CM Dra         | 1.27 | 3150 | 0.23 | 0.25 | 0.005 | 90  | 0.93|       | 10.47      | 3.75 | D    | D    | (6)  |
| TrES HerO-07621| 1.12 | 3500 | 0.49 | 0.45 | 0.027 | 83  | 0.93|       | 8.64       | 2.25 | 118  | D    | (7)  |
| YY Gem         | 0.81 | 3820 | 0.60 | 0.62 | 0.070 | 86  | 1.00| 1.92  | 7.57       | 3.87 | D    | D    | (8)  |
| GJ 3226        | 0.77 | 3313 | 0.38 | 0.37 | 0.016 | 83  | 0.75| 2.73  | 9.20       | 3.08 | 42   | D    | (9)  |
| 2MASS 04463285+1901432 | 0.62 | 3220 | 0.47 | 0.56 | 0.034 | 81  | 0.41| 2.59  | 8.39       | 2.66 | 540  | D    | (10) |
| V405 And       | 0.465| 4050 | 0.49 | 0.78 | 0.147 | 66  | 0.42|       | 10.71      | 11.03| D    | D    | (11) |
| GU Boo         | 0.49 | 3920 | 0.61 | 0.62 | 0.082 | 88  | 0.98| 1.90  | 7.43       | 2.79 | 100  | D    | (12) |
| SDSS MEB-1     | 0.41 | 3320 | 0.27 | 0.27 | 0.008 | 85  | 0.88|       | 9.96       | 1.85 | D    | D    | (13) |
| NSVS 01031772  | 0.37 | 3615 | 0.54 | 0.53 | 0.043 | 86  | 0.92|       | 8.08       | 2.20 | 40   | D    | (14) |
| OGLE BW3 V38   | 0.198| 3500 | 0.44 | 0.51 | 0.035 | 86  | 0.95| 2.45  | 8.39       | 1.35 | 400  | SD   | (15) |
| GSC 2314-0530  | 0.192| 3735 | 0.51 | 0.55 | 0.053 | 72  | 0.52| 2.34  | 7.91       | 1.28 | 59   | SD   | (16) |

References: (1) Ribas (2003), Delfosse et al. (1999); (2) Becker et al. (2008); (3) Cakirly & Ibanoglu (2010); (4) Coughlin & Shaw (2007); (5) Young et al. (2006); (6) Metcalfe et al. (1996); (7) Creevey et al. (2005); (8) Bopp (1974), Torres & Ribas (2002); (9) Irwin et al. (2009); (10) Hebb et al. (2006); (11) Vida et al. (2009); (12) Lopez-Morales & Ribas (2005); (13) Blake et al. (2008); (14) Lopez-Morales et al. (2006); (15) Maceroni et al. (1994); (16) this paper.

number 34). These stars occupy relatively narrow bands of the diagrams. This means that the luminosities, radii and temperatures of these stars depend on their masses. These statistical relations can be described by the following formulae:

$$M_{bol} = 13.0 - 13.4 \times M + 7.7 \times M^2,$$

$$R = 0.019 + 1.002 \times M,$$

$$T = 2983 + 396 \times M + 1333 \times M^2.$$  

We assume that the greater scatter of the mass–temperature diagram is due mainly to the weakly established calibration $T/(V-I)$ for late low-mass stars. Moreover, some star temperatures probably have been determined without taking the reddening into account.

6 ACTIVITY OF GSC 2314−0530

The manifestations of stellar activity as $H\alpha$ emission, spots, flares, etc., are a consequence of magnetic fields. It is assumed that fully convective late stars have a strong, long-lasting, magnetic field. According to Mullan & MacDonald (2001), the larger radii and lower temperatures of dM stars can be explained by the presence of strong magnetic fields, and their activity is at the saturation limit.

Perhaps the significant spot coverage decreases the photospheric temperature, and the star compensates for this by increasing its radius to conserve the total radiative flux.

6.1 Surface spots

The photospheric activity of late stars is demonstrated mainly by the O’Connell effect and distorted light curves. These can be reproduced by surface-temperature inhomogeneities (spots). It is reasonable to assume the existence of cool spots by analogy with our Sun. Usually they are allocated to the primary star, although the same effect can be reached as a result of spots on the secondary; however, then the spots should be larger and/or cooler. There are also fits of the light curves of late binaries with bright spots (Torres & Ribas 2002; Maceroni et al. 1994). These are interpreted as a uniform distribution of dark spots covering most of the stellar surface except for a spot-free area, i.e. ‘bright spots’ represent the true photosphere.

The light curves of all binaries with low-mass dM components from Table 6 are distorted and they have been reproduced by large cool spots with angular radii reaching up to 80°.
The distorted light curves of GSC 2314−0530 were reproduced by two cool spots on the primary component (see their parameters in Table 5) covering 3.5 per cent of its surface. The fact that the shape of the light-curve distortions of GSC 2314−0530 remains the same for almost 10 yr means that the main (larger) spot visible at phase 0.6 represents a long-lived active region on the primary surface.

6.2 Hα emission

The EW of the Hα line is a useful indicator of chromospheric activity for M dwarfs because those stars are much brighter at 6500 Å than at 3900 Å. Stauffer & Hartmann (1986) divided dM into four subsets ordered by chromospheric activity. The least chromospherically active dM have weak Hα absorption line. As the chromosphere increases, the EW of the Hα absorption first increases then decreases and finally Hα goes into emission.

Table 4 presents the orbital variations of the EW of the total Hα emission of GSC 2314−0530. Although it seemed to change irregularly in the range 3.6–6.6 Å during the cycle, we noted a trend of the EW being smaller around the first quadrature than around the second. The exceptions from this trend are the large EW values of the only two spectra from 2010 January 01 at phases 0.23 and 0.31. These may be due to a flare event. Such a supposition is reasonable, because two of the observed flares are around first quadrature.

The foregoing trend of the Hα emission is opposite from that of the total light of GSC 2314−0530, which is larger at the first quadrature than at the second. Such an anticorrelation is typical for chromospherically active stars of types RS CVn and BY Dra.

Table 7 presents the EW of the Hα emission of some binaries with low-mass dM components from Table 6 in their normal state (out of flare). The comparison reveals the strong Hα emission of GSC 2314−0530. This result is not surprising taking into account the low temperature and fast rotation of its components.

The mean value $EW = 5\,\text{Å}$ of the Hα emission of GSC 2314−0530 is considerably smaller than that of accreting pre-main-sequence dMe stars for which Hα emission has $EW > 10\,\text{Å}$.

6.3 Flares

Flare activity is typical for late stars. The last column of Table 7 shows those stars from Table 6 in which some flares have been registered (denoted by ‘Y’).

During our observational runs we were witnesses of six flares of GSC 2314−0530, which revealed its high flare activity. The amplitudes $A$ and durations $\tau$ of the observed flares are given in Table 8.

It should be noted that three of the observed six flares occurred around the phase of maximum visibility 0.6 of the large, stable spot (Sp1). This implies a correlation between the two signs of stellar activity: spots and flares. Both of them are manifestations of a long-lived active area on the primary star.

In addition to the optical flares, there is information about X-flares of GSC 2314−0530 (Fuhrmeister & Schmitt 2003).

6.4 Angular momentum

Small orbital angular momentum is a characteristic feature of all short-period systems ranging from CVs to CB that seem to be old, being at later stages of angular-momentum-loss evolution as a result of period decrease.

We calculated the orbital angular momentum of the target using the expression (Popper & Ulrich 1977)

$$J_{\text{rel}} = M_1 M_2 \left( \frac{P}{M_1 + M_2} \right)^{1/3},$$

where $P$ is in days and $M_i$ are in solar units.

Table 8. Observed flares of GSC 2314−0530.

| Date      | HJD$_{max}$ | Phase | Filter | $A$ [mag] | $\tau$ [min] |
|-----------|-------------|-------|--------|-----------|--------------|
| 2009 Oct 26 | 2455000 +   | 0.61  | V      | 0.022     | 4            |
| 2009 Nov 13 | 2455000 +   | 0.64  | I      | 0.005     | 22           |
| 2009 Nov 13 | 2455000 +   | 0.84  | I      | 0.027     | 13           |
| 2009 Nov 13 | 2455000 +   | 0.61  | R      | 0.085     | 19           |
| 2009 Nov 13 | 2455000 +   | 0.31  | R      | 0.015     | 9            |
| 2009 Nov 20 | 2455000 +   | 0.31  | V      | 0.092     | 25           |
The obtained value \( \log J_{\text{bol}} = -1.01 \) of GSC 2314–0530 is considerably smaller than that of RS CVn binaries and detached systems, which have \( \log J_{\text{bol}} \geq +0.08 \). The orbital angular momentum of GSC 2314–0530 is smaller even than that of contact systems, which have \( \log J_{\text{bol}} \geq -0.5 \). It is larger only than that of short-period CVs of SU UMa type.

The small orbital angular momentum of GSC 2314–0530 implies the existence of a past episode of angular-momentum loss during binary evolution. It also means that GSC 2314–0530 is not a pre-main-sequence object. This conclusion is supported by the values of \( \log g \) of its components.

### 6.5 X-ray emission

The X-ray emission of the stellar corona is directly related to the presence of magnetic fields and consequently gives information about the efficiency of the stellar dynamo.

Rucinski (1984) established that the X-ray luminosity decreased for later M stars, while the ratio \( L_X/L_{\text{bol}} \) did not change significantly from M0–M6. As a result he proposed the ratio \( L_X/L_{\text{bol}} \) as the most relevant measure of activity of M dwarfs. Vilhu & Walter (1987) found that the upper boundary of \( L_X/L_{\text{bol}} \) for late M stars is \( \sim 10^{-1} \).

In addition to all indicators of stellar activity in the optical (surface inhomogeneities, emission lines, flares), the star GSC 2314–0530 also shows X-ray emission (it is identified as ROSAT X-ray source 1RXSJ022050.7+332049) and X-ray flares.

On the basis of the measured X-ray flux \( F_X = 4.266 \times 10^{-13} \) erg cm\(^{-2}\) s\(^{-1}\) of GSC 2314–0530 at quiescence (Voges et al. 1999; Schmitt, Fleming & Giammappa 1995) and the derived distance 59 pc, we calculated its X-ray luminosity \( L_X = 1.68 \times 10^{34} \) erg s\(^{-1}\).

This value is at the upper boundary \( L_X \approx 29 \) for D M stars (Rosner et al. 1981; Caillault et al. 1986). The value \( f_X/L_{\text{bol}} = 0.7 \times 10^{-3} \) of GSC 2314–0530 is almost at the upper boundary of this ratio and considerably higher than that of M dwarfs studied by Rucinski (1984) and Caillault et al. (1986).

It is known that the activity and angular-momentum loss tend to be saturated at high rotation rates (Vilhu & Walter 1987). Owing to its short period and high activity, GSC 2314–0530 is perhaps an example of such saturation.

### 7 IS GSC 2314–0530 ALONE?

Our observed field (Fig. 2) contains the weak star USNO-B1 1233–0046425. We called it Twin, due to it having the same tangential shift as our target star GSC 2314–0530. Table 2 presents the proper motion and the colours of Twin according to the catalogue NOMAD. USNO-B1 1233–0046425 has \( V - I = 3.02 \), corresponding to a temperature of less than 3200 K.

We suspect that our ‘twins’ may form a visual binary. The angular distance between them of 61 arcsec corresponds to a linear separation of around 3500 au for a distance of 59 pc. Such a supposition is reasonable, because it is known that short-period close binaries are often triple systems (Pribulla & Rucinski 2006). In particular, the object TrES Her0–07621 from our Table 6 has a red stellar neighbour at a distance of 8 arcsec with close proper motion (Creevey et al. 2005).

To check the supposition that Twin is a physical companion of GSC 2314–0530, astrometric observations of the ‘twins’ are required.

### 8 CONCLUSIONS

The analysis of our photometric and spectral observations of the newly discovered eclipsing binary GSC 2314–0530 allows us to derive the following conclusions.

1. This star is the shortest period binary with dM components with a period below the short-period limit.
2. From simultaneous radial-velocity and light-curve solutions we determined the global parameters of GSC 2314–0530: inclination \( i = 72.5 \); orbital separation \( a = 1.28 \) R\( \odot \); masses \( M_1 = 0.51 \) M\( \odot \) and \( M_2 = 0.26 \) M\( \odot \); radii \( R_1 = 0.55 \) R\( \odot \) and \( R_2 = 0.29 \) R\( \odot \); temperatures \( T_1 = 3735 \) K and \( T_2 = 3106 \) K; luminosities \( L_1 = 0.053 \) L\( \odot \) and \( L_2 = 0.007 \) L\( \odot \); distance \( d = 59 \) pc.
3. We derived empirical relations for mass–M\( \text{bol} \), mass–radius and mass–temperature on the basis of the parameters of known binaries with low-mass dM components.
4. The distorted light curve of GSC 2314–0530 was reproduced by two cool spots on the primary component. The next sign of activity of GSC 2314–0530 is the strong H\( \alpha \) emission of its components. Moreover we registered six flares of GSC 2314–0530. Half of them occurred at the phases of maximum visibility of the larger stable cool spot on the primary.

The analysis of every appearance of magnetic activity revealed the existence of a long-lived active area on the primary of GSC 2314–0530. The high activity of the target is a natural consequence of the fast rotation and low temperatures of its components.

Our study of the newly discovered short-period eclipsing binary GSC 2314–0530 presents another small step toward understanding dMe stars and adds new information to the poor statistics of low-mass dM stars. Recently these have become especially interesting as appropriate targets for planet searches, due to the relatively large transit depths.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 3. BVRI photometry of GSC 2314−0530.

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