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# GSC 4560–02157: a new long-period eclipsing cataclysmic variable star

Anton V. Khruslov[1], Anatoly V. Kusakin[2], Elena A. Barsukova[3], Vitaly P. Goranskij[4], Azamat F. Valeev[3] and Nikolay N. Samus[1,4]

[1] Institute of Astronomy, Russian Academy of Sciences, 48 Pyatnitskaya Str., Moscow 119017, Russia; *khruslov@bk.ru*
[2] Fesenkov Astrophysical Institute, Almaty 050020, Kazakhstan
[3] Special Astrophysical Observatory, Russian Academy of Sciences, Nizhny Arkhyz, Karachai-Cherkessian Republic 369167, Russia
[4] Sternberg Astronomical Institute, Lomonosov Moscow State University, 13 University Ave., Moscow 119092, Russia

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**Abstract** We study the newly discovered variable star GSC 4560–02157. CCD photometry was performed in 2013–2014 at the Tien Shan Astronomical Observatory, and a spectrum was obtained with the 6-m telescope of the Special Astrophysical Observatory in June, 2014. GSC 4560–02157 is demonstrated to be an eclipsing variable star ($P = 0.265359^{\rm d}$). All its flat-bottom primary minima are approximately at the same brightness level, but the star's out-of-eclipse brightness and brightness at secondary minima vary considerably (by up to $0.6^{\rm m}$) from cycle to cycle. Moreover, there are short-term (time scale of 0.03–0.04 days) small-amplitude brightness variations out of eclipse. This behavior suggests a cataclysmic nature for the star, which is confirmed with a spectrum taken on 2014 June 5. The spectrum shows numerous emissions of the hydrogen Balmer series, HeI and HeII.

**Key words:** stars: dwarf novae — binaries: eclipsing — stars: individual: GSC 4560–02157

## 1 INTRODUCTION

Among short-period spectroscopic and eclipsing binaries, cataclysmic stars are of special interest. These systems contain a white dwarf and an ordinary dwarf, yellow or red, which donates matter to the Roche lobe of the white dwarf. Matter flows, accretion disks and hot spots (or hot lines) at the interaction between the flow and the disk all cause complicated light variability, e.g., changing brightness levels at different activity states, outbursts, quasi-periodic variations, humps on the light curve, etc. For a general review of cataclysmic variable stars, see Warner (1995).

In this paper, we present the discovery and study of the new variable star GSC 4560–02157. It is shown to be a short-period eclipsing variable star exhibiting, outside its primary minima, strong variations of the brightness level, with superimposed short-term brightness variations. The cataclysmic nature of the new variable could be confirmed with its spectrum, which was taken with the 6-meter telescope of the Special Astrophysical Observatory.

## 2 DISCOVERY AND PHOTOMETRIC OBSERVATIONS

Variability of GSC 4560–02157 was suspected by one of the authors (A.V. Khruslov) in 2005 from the publicly available data of the Northern Sky Variability Survey (NSVS; *http://skydot.lanl.gov/nsvs/nsvs.php*, Woźniak et al. 2004). The star is $14''$ from GSC 4560–02269, and NSVS data refer to a blend of two stars. In March, 2013 (JD 2456364), we started CCD photometry of the two stars in order to establish which of them varies.

The actual variable star is GSC 4560–02157 ($15^{\rm h}43^{\rm m}36.65^{\rm s}$, $+75^\circ15'41.1''$, J2000.0 in the 2MASS Point Source Catalog, Skrutskie et al. 2006).

Our CCD observations in the Johnson $R$ and $V$ bands were performed at the Tien Shan Astronomical Observatory of the V.G. Fesenkov Astrophysical Institute, at an altitude of 2750 m above sea level. The observatory has two Zeiss 1000-mm telescopes. Most of our observations were performed with the eastern Zeiss 1000-mm reflector (the focal length of the system was 6650 mm with the detector being an Apogee U9000 D9 CCD camera). During the last three nights (JD 2456772–2456784), we used the newly introduced western Zeiss 1000-mm reflector (the focal length of the system was 13 250 mm with the detector being an Apogee F16M CCD camera). In the $R$ band, we obtained 2455 brightness measurements (JD 2456364–2456784), and in the $V$ band, 828 measurements (JD 2456739–2456784). We performed reductions using the MaxIm DL aperture photometry package.

The total range of the star's brightness variations is between $14.40^{\rm m}$ and $15.53^{\rm m}$ in $R$, and $14.75^{\rm m}$ and $16.10^{\rm m}$ in $V$.

Table 1, available in its complete form in the electronic supplement to this paper, contains our photometric observations. Here we present the first lines of the table (photometry in each of the colors) for guidance concerning its format.

**Table 1** Observations

| JD hel (1) | RA (J2000.0) (2) | Dec (J2000.0) (3) | Mag (4) | Sigma (5) | Band (6) |
|---|---|---|---|---|---|
| 2456740.1422 | 15 43 36.65 | +75 15 14.1 | 15.726 | 0.017 | $V$ |
| 2456740.1436 | 15 43 36.65 | +75 15 14.1 | 15.785 | 0.017 | $V$ |
| 2456740.1450 | 15 43 36.65 | +75 15 14.1 | 15.860 | 0.017 | $V$ |
| 2456740.1464 | 15 43 36.65 | +75 15 14.1 | 15.848 | 0.017 | $V$ |
| 2456740.1478 | 15 43 36.65 | +75 15 14.1 | 15.791 | 0.020 | $V$ |
| ... | | | | | |
| 2456364.4342 | 15 43 36.65 | +75 15 14.1 | 14.974 | 0.005 | $R$ |
| 2456364.4353 | 15 43 36.65 | +75 15 14.1 | 14.971 | 0.005 | $R$ |
| 2456364.4365 | 15 43 36.65 | +75 15 14.1 | 15.006 | 0.005 | $R$ |
| 2456364.4376 | 15 43 36.65 | +75 15 14.1 | 14.996 | 0.006 | $R$ |
| 2456364.4387 | 15 43 36.65 | +75 15 14.1 | 15.002 | 0.011 | $R$ |
| ... | | | | | |

Notes: The complete form of this table is available in *http://www.raa-journal.org/docs/Supp/ms1970table1.dat*. Here we present the first few entries (photometry in each of the colors) for guidance concerning its format.

The finding chart (Fig. 1) identifies the variable star, comparison star, and check star. The comparison star was GSC 4560–01221 ($15^{\rm h}43^{\rm m}36.53^{\rm s}$, $+75^\circ18'04.2''$, J2000.0), and the check star was GSC 4560–01352 ($15^{\rm h}43^{\rm m}03.53^{\rm s}$, $+75^\circ17'55.1''$, J2000.0). The magnitudes of the comparison star in the GSC2.3 catalog (Lasker et al. 2008) are $R = 14.11$ and $V = 14.33$.

## 3 RESULTS

We analyzed the time series using the Lafler–Kinman method (Lafler & Kinman 1965) implemented in the WinEfk code developed by one of the authors (V.P.G.). GSC 4560–02157 is found to be an

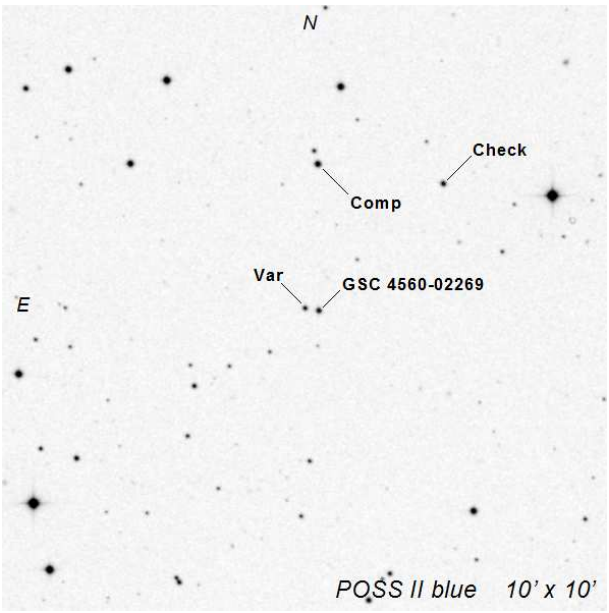


**Fig. 1** The finding chart, with the variable, its close neighbor, comparison star, and check star marked.

Algol-type eclipsing binary with a short period (about 0.265 days); it exhibits considerable brightness variations outside the primary eclipse. During the primary eclipse, the brightness remains at approximately the same magnitude for all the observed cycles. However, the star's brightness, outside the primary eclipse, slowly changes its level between different orbital cycles by as much as $0.5^{\rm m}-0.6^{\rm m}$; small short-term brightness variations are superimposed. In any individual cycle, the star is redder in the primary minimum than outside it. The ephemeris for the primary eclipses is:

$$\mathrm{HJD(min)} = 2456719.314 + 0.265359^{\rm d} \times E.$$

The light curves folded with the orbital period are displayed in Figure 2. The duration of the primary minimum is $D = 0.18P = 0.05^{\rm d}$, and the eclipse is apparently a total one ($d = 0.05P = 0.012^{\rm d}$). The level of the secondary minimum varies with general changes in the brightness level outside the primary eclipse.

For comparison, Figure 3 shows the light curve of the known dwarf nova GY Cnc, folded with its orbital period, $0.1754424988^{\rm d}$ (Feline et al. 2005). The observations we use are those available from the Catalina Surveys (Drake et al. 2009). The scattered bright data points correspond to dwarf-nova outbursts. The period of the binary GY Cnc is somewhat shorter than that of GSC 4560–02157, and no outbursts of GSC 4560–02157 have been detected so far, but the general character of the eclipsing light curves is very similar for the two stars. The spectrum of GY Cnc reproduced in Szkody et al. (2009) resembles that of GSC 4560–02157 very strongly.

Individual cycles outside the primary eclipse reveal small-amplitude short-period brightness variations (Fig. 4). To study them, we analyzed the more complete 2014 $R$-band data. Observations during primary eclipses were excluded, and the remaining data were reduced to the same brightness level, thus eliminating comparatively slow outside-eclipse brightness level variations. A total of 1637 brightness estimates obtained in this way (JD 2456716–2456784) were subject to frequency analysis using Deeming's method (Deeming 1975). A part of the power spectrum is shown in Figure 5.

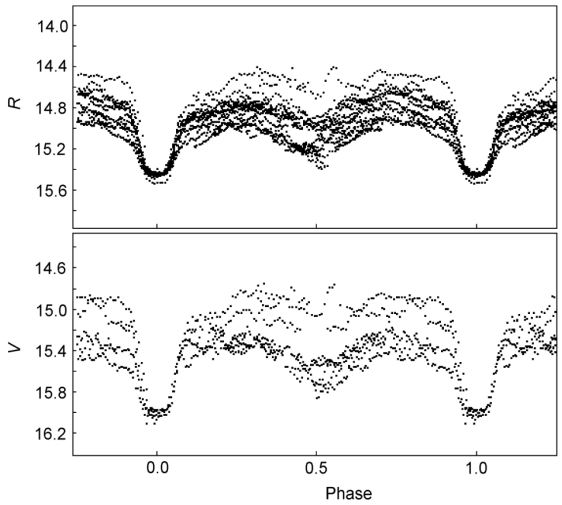


**Fig. 2** The light curves of GSC 4560–02157 (HJD (min) 2456719.314 + 0.265359$\times E$) in the $R$ and $V$ bands, folded with the orbital period.

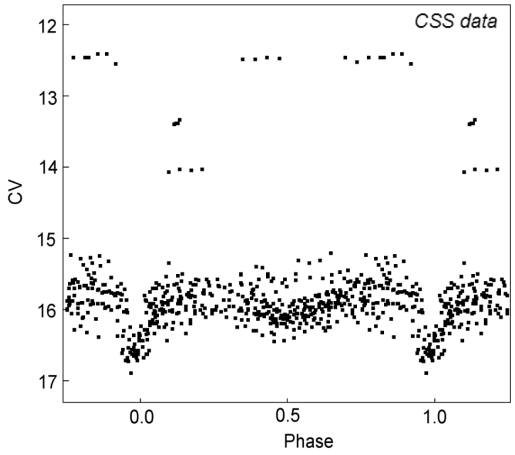


**Fig. 3** The light curve of the known dwarf nova GY Cnc, based on data from the Catalina Surveys, folded with the orbital period ($P = 0.1754424988$). The data points above the eclipsing light curve correspond to outbursts.

Table 2 lists the six most prominent frequencies. These variations had the largest amplitude (up to $0.3^{\mathrm{m}}$) on the last night, JD 2456784.

The complex behavior of GSC 4560–02157 resembles that of cataclysmic variables. To check the cataclysmic nature of the star, we performed spectroscopic observations.

The 6-m telescope of the Special Astrophysical Observatory (North Caucasus, Russia) was used to take a single spectrum of the star on 2014 June 5 UT 22:43:07 (JD hel 2456814.4466). The SCORPIO camera with a VPHG 550 g grism was used to take a spectrum of GSC 4560–02157 with a resolution of 13 Å. The exposure time was 600 s. The computed heliocentric correction was

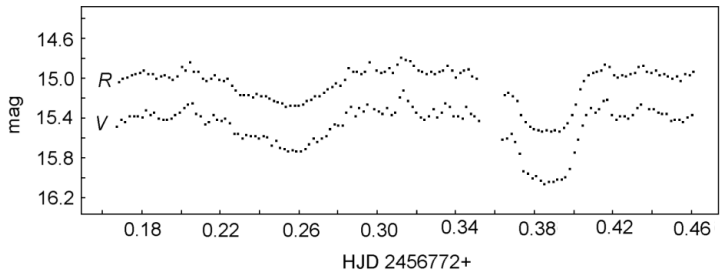


**Fig. 4** The light curves of GSC 4560–02157 in the $R$ and $V$ bands from a single orbital cycle, showing short-period brightness variations.

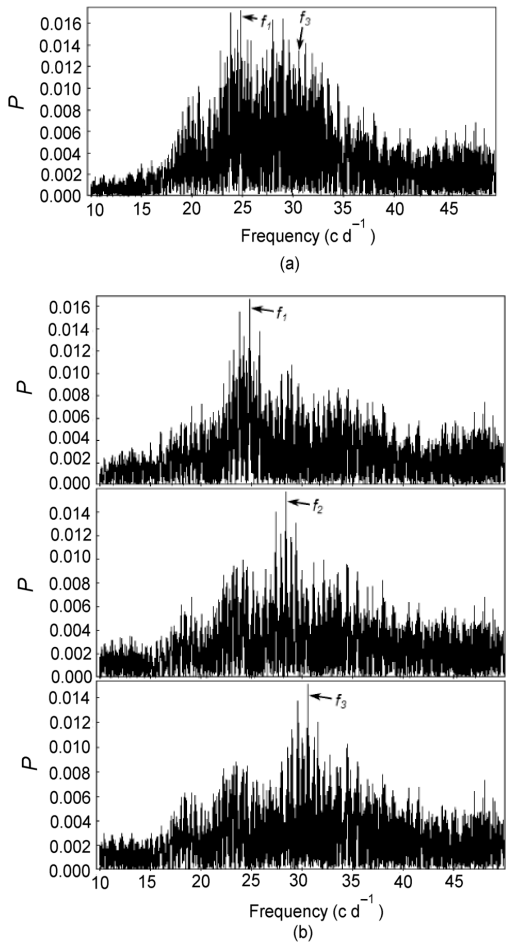


**Fig. 5** (a) The power spectrum of GSC 4560–02157. (b) The power spectra for the first three frequencies, after all other frequencies were pre-whitened.

**Table 2** Frequencies Detected Outside Eclipses

| ID | $F(\mathrm{c/d})$ | $P(\mathrm{d})$ | Semi-amplitude (mag) |
|---|---|---|---|
| $f_1$ | 24.8432 | 0.0402525 | 0.0171 |
| $f_2$ | 28.4026 | 0.0352080 | 0.0165 |
| $f_3$ | 30.5982 | 0.0326817 | 0.0138 |
| $f_4$ | 31.9354 | 0.0313132 | 0.0120 |
| $f_5$ | 27.7483 | 0.0360383 | 0.0114 |
| $f_6$ | 20.7149 | 0.0482744 | 0.0100 |

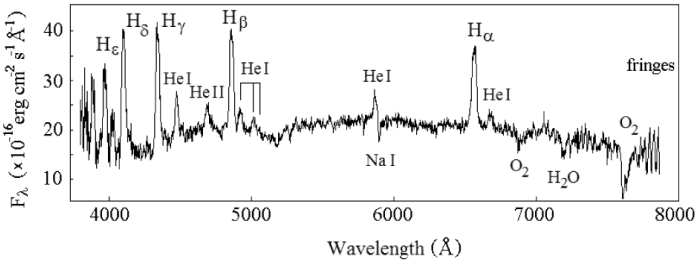


**Fig. 6** The spectrum of GSC 4560–02157.

$\Delta V_r = -5.6$ km s$^{-1}$. The radial velocity of the star was nearly zero. The spectrum (Fig. 6) reveals strong emission lines of the Balmer series. HeI and HeII emissions are also clearly seen. The right side of the spectrogram shows infrared interference fringes, typical of CCD spectroscopy. Also present are features of interstellar sodium and terrestrial water. The spectrogram definitely confirms that GSC 4560–02157 is a cataclysmic variable. Note that the spectrum was taken at the phase 0.505 of the above light elements for the eclipsing variations, and thus at approximately the secondary minimum. The $V$-band magnitudes of the star measured just before the spectrogram, on JD 2456814.4395 and JD 2456814.4402, are 15.676 and 15.627 respectively. Thus, the star was rather faint in the corresponding secondary minimum.

No X-ray source has so far been detected at the position of GSC 4560–2157, but this is not surprising for a faint and apparently distant star.

## 4 DISCUSSION

The data we have accumulated for GSC 4560–02157 clearly identify it as a cataclysmic eclipsing system. The Algol-type light curve exhibits a rapid start of the eclipse; the time from the beginning of the eclipse to the onset of the totality phase is about 15 minutes. Thus, the eclipsed element of the system is rather compact. The star's brightness is nearly constant during the primary minimum, indicating that it is the eclipsed compact element that is responsible for different brightnesses in different orbital cycles and for multiperiodic short-term variations. The latter could be pulsations of the white dwarf. The 0.04-day pulsation period is rather large for pulsating white dwarfs (ZZ Ceti variables), but variables with such a behavior are known, and some authors (e.g., Hermes et al. 2013) suggest a new type of extremely low-mass (ELM) white dwarfs. In our case, several oscillations are clearly present, but their stability is not beyond doubt; they can turn out to be quasi-periodic oscillations, for example, like those noted for MT Draconis (Zubareva et al. 2011). The changing brightness level outside eclipses is apparently related to the brightest, central parts of the accretion disk, which is also occulted during primary eclipses.

## 5 CONCLUSIONS

The results of our photometric and spectroscopic observations definitely show that GSC 4560–02157 is a new eclipsing cataclysmic variable. So far, no outbursts have been detected from the star, though it resembles known eclipsing dwarf novae both photometrically and spectroscopically. Further observations are needed to reveal possible additional manifestations of the star's cataclysmic activity, like outbursts, and high and low states.

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