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The observations of deeply eclipsing polars FL Ceti and CSS 081231: 071126+440405

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Abstract. We present the results of our observations of two deeply eclipsing polars FL Ceti (SDSS J015543.40+002807.2) and CSS 081231: 071126+440405. FL Cet has very deep eclipses of about 6 mag. During last years polar was observed at all three stages of brightness – a "low", an "intermediate" and a "high" state. The profile of the light curve strongly depends on the level of brightness, i.e. on an amount of transferred matter. In a "high" state, there is not any faint phase of brightness and some humps are observed. In a "low" state a faint phase, lasted of about 1/3 of the orbital period, is present. The second object – CSS 081231: 071126+440405 is a new (possible) polar, discovered by the Catalina Sky Survey in December 2008. It exhibits a very deep eclipse and an unusually deep dip at the phase $\varphi \sim 0.85$.

Key words. Stars: cataclysmic variables – polar – photometrical observations – white dwarf

1. Introduction

Cataclysmic variables (CVs) are binary stars of very short orbital periods, in which a low-mass red K-M dwarf secondary overfills its equipotential Roche lobe and transfers matter to a white dwarf primary. Because the transferred material carries substantial angular momentum, it does not immediately fall down on a white dwarf but forms an accretion disc around it.

Polars (or AM Her-stars) are peculiar subtype of cataclysmic variables. The white dwarfs in polars have the strong magnetic fields (usually, $B > 20$ MG). A main characteristic of polars is the absence of an accretion disc. The matter from the red dwarf is channeled and flows onto magnetic pole (poles) of the white dwarf. The main sources of emission are the accretion columns above poles. Most of the polars are synchronized. The linear and circular polarization is one of the polar hallmarks.

We present the photometric observations of FL Ceti and the new (possible) polar CSS 081231: 071126+440405.

2. FL Ceti

At first the object was announced as a possible eclipsing CV with an orbital period 87 minutes in the Sloan Digital Sky Service (SDSS J015543.40+002807.2) by Szkody et al. (2002) and named FL Cet by Kazarovets et al. (2005). The first light curve obtained by

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Dubkova et al. (2003) at the 2.56-m Nordic Optical Telescope exhibits a very deep eclipse of about 6 mag. Thereafter, the object was observed by Woudt et al. (2004), Wiehahn et al. (2004) during a few days at a "low state". Polarimetry showed that SDSS J0155 is a polar.

Monitoring of FL Cet by XMM-Newton-telescope and optical photometry, spectroscopy and polarimetry Schmidt et al. (2005) in a "high state" confirmed a magnetic nature of the object. O'Donoghue et al. (2006) carried out the fast photometry (100–300 ms) of FL Cet at SALT telescope equipped with SALTICAM instrument and investigated the eclipse with the high time resolution. They described stepped shape of the eclipse, similar to a two-step eclipse of UZ For Perryman et al. (2001), explained by a two spots on the white dwarf surface, situated on one meridian and giving most bulk of radiation of the system. Because of the high accuracy of the observations by O'Donoghue et al. (2006), we used their ephemeris: HJD = 2452969.322083(5) + 0.0605163312(7)E for calculation of the times of eclipses.

Our observations of FL Cet were obtained from September 2003 till November 2010. The most of them were taken at the Crimean laboratory of the SAI (60cm, 125cm telescopes) and at the Stará Lesná Observatory of the AISAS (50cm telescope). Our observations in 2003–2004 were shortly described in New-Katysheva & Shugarov (2005). The light curves of FL Cet, taken in 2003-2005 and presented in New-Katysheva et al. (2007), show the humps corresponding to two or more spots on the white dwarf surface.

In the years 2003, 2004 and 2006, the polar was in a "low state", but from August to December 2005 it was in a "high state" of brightness. In August 2007 it was in a "low state" again. In November 2007 we detected the brightness increase up to 3 magnitude, when polar entered to an "intermediate state". In Fig. 1 the R-light curve taken in 2005–2010, is presented. Except the year 2006 and part of the year 2007, the polar was bright. It reached the maximum of brightness in 2010.

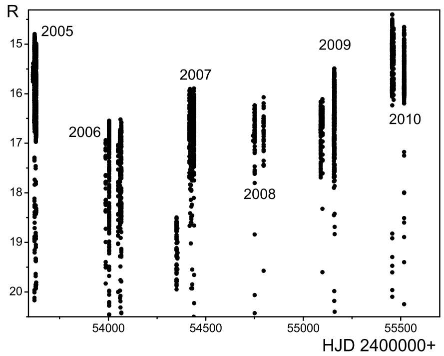

Fig. 1. The R–light curve of FL Cet from 2005 till 2010.

In a "low state" the light curve from the phase φ = 0.3 to 0.65–0.68 exhibited a flat base - a faint phase, when a side of the white dwarf opposite the secondary was visible (see also New-Katysheva & Shugarov 2005; New-Katysheva et al. 2007).

In Fig. 2 we present the phase R-light curves, folded with the orbital period. During these two seasons FL Cet was in its "high state" with a strong accretion. In contradiction to a "low state", the LCs in the "high state" are more dissected and practically have not any flat bottom. The increase of LC begins from the phase φ = 0.25–0.3, immediately after the minimum of brightness. The direction of eclipse is denoted by arrows ("ecl"), another arrows, with designation of the phase, show some maxima and minima of the LCs. In 2010, the deep dip near the phase 0.88 was clearly visible. The average LCs in Fig. 2 are distinguished by asterisks.

In 2007 and 2008, the polar was in an "intermediate state". The mean LCs R, V, folded with the orbital period, are plotted in Fig. 3. It is interesting to note the unusual form of the V light curve – it has two humps of practically equal magnitude. Such a form of the light curve was observed in FL Cet for the first time.

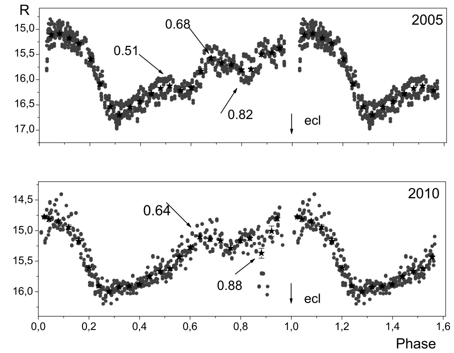

Fig. 2. The phase R-light curves of FL Cet, folded with the period 0.0605163312 days during a “high state” in 2005 (top) and 2010 (bottom). The eclipse is denoted by arrow.

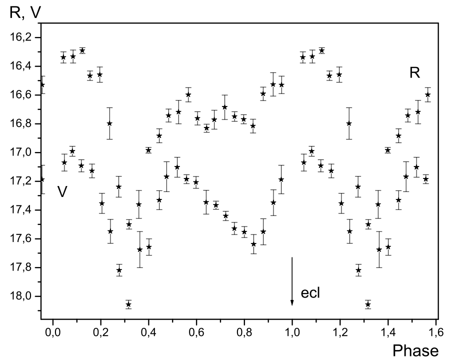

Fig. 3. The mean phase R, V – light curves during an “intermediate state” in 2008.

3. CSS 081231: 071126+440405

A new possible polar CSS 081231: 071126+440405 (further, J0711+44) was discovered by the Catalina Sky Survey on the 31st of December 2008 Drake et al. (2009). Boyd (2009) reported about three orbital cycles in a “high state” with a very deep eclipse and a deep dip at the phase 0.8. Thorne et al. (2010) obtained the B, V observations of the object in a “low state” in October 22–25, 2009. They determined the ephemeris $HJD = 2455126.8960(1) + 0.081376(3)E$ and

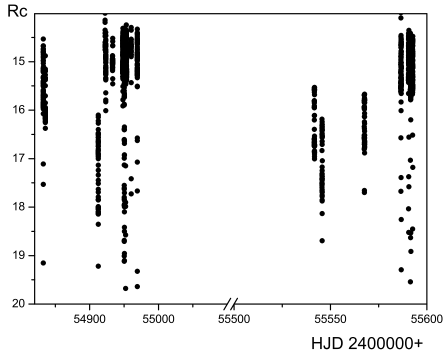

Fig. 4. The R_C–light curve of J0711+44 in 2009–2011.

noticed an interesting fact about the shift of a dip to the phase$\varphi \sim 0.1$. The dip is supposed to connect with the eclipse of the white dwarf by the region of matter accumulation - stagnation region.

Bailey (1993) found the changes of the longitudes of the accretion spots on the white dwarf in polars WW Hor and DP Leo with time. They explained it by the magnetic interaction between the strong field of the white dwarf and weak one of the secondary.

Our observations started in the New Year’s Eve 2009 and continued till May 2009. The next set was obtained in December 2010 and January 2011. All data were taken with the SBIG ST10-XME camera mounted in the Newton focus of the 50cm telescope and with the Finger Lake SITe TK1024-camera, mounted in the Cassegrain focus of the 60cm telescope at the Stará Lesná Observatory of the AISAS.

The R_C light curves of J0711+44 obtained during 2009 –2011 are presented in Fig. 4. The phase R_C and ΔV light curves in 2009 are plotted in Fig. 5 top and bottom, respectively. For a better resolution of orbital light variations, the observations in eclipses were removed.

The depth of a dip in the LC at the phase $\sim$ 0.85 can be used to calculate a direct value of an optical depth of the stagnation region (SR). If we denote by I_0 and I_1 intensities of the ra-

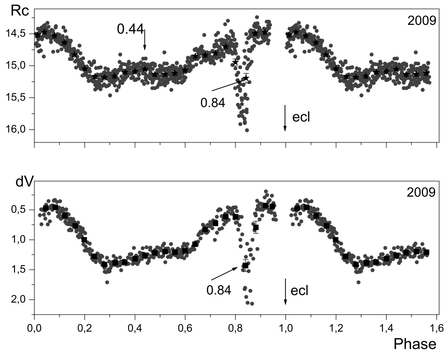

Fig. 5. The R_C and ΔV phase light curves of J0711+44 in 2009, folded with the ephemeris HJD = 2455126.8960 + 0.081376. The eclipse is denoted by arrow. The deep dip in the phase 0.84 is clearly seen.

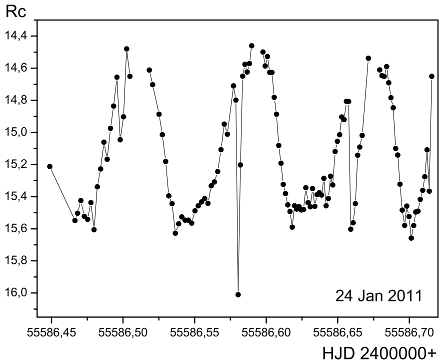

Fig. 6. The R_C–light curve of J0711+44 on January 24, 2011 at a "high state". The data from eclipses were removed.

diation outside and inside of the dip, m_0 and m_1 their magnitudes, then $I_1 = I_0 \cdot e^{-\tau}$, where a mean optical depth of the stagnation region $\tau = \Delta m/(2.5 \cdot \lg e) \sim 0.92\Delta m$. Here $\Delta m = m_1 - m_0$. If $\Delta m \sim 1$ the optical depth of SR could be large enough.

Because the states of polars depend on an amount of accreting matetial, the optical depth of the "low state" of stagnation region is small. And in the "high state" the optical depth of SR increases due to the growth of the transferred matter.

Fig. 6 show three subsequent orbital cycles of J0711+44 in R_C-band. The data from the eclipses were removed. The very deep dips on the light curves are clearly visible. Dramatic cycle to cycle changes of the depth of the dip are caused by a variable accretion from the red dwarf.

The mean R_C–light curves of J0711+44 at the different stages of brightness are plotted in Fig. 7. The difference between the average light curves are clearly seen. They have different depth of the cavity (between bright hump and a faint phase, except eclipses and dips). The difference between the maximum and minimum R_C is ~1.24 for an "intermediate state", ~1.8 for the "low state" and ~0.7 mag for the "high state".

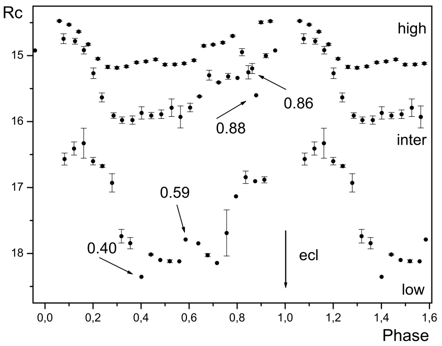

Fig. 7. The mean R_C phase light curves of J0711+44 folded with the ephemeris HJD = 2455126.8960 + 0.081376 at different stages of the brightness: a "high" (top), an "intermediate" (middle), and a "low" (bottom) state. The eclipse data were removed. The eclipse is denoted by arrow.

4. Conclusions

We present the results of our observations of two deeply eclipsing polars FL Ceti and CSS 081231: 071126+440405. The light curves of both systems are similar. They exhibit very deep eclipses: FL Cet of about 6 mag and J0711+44 – more than 4 mag. Both objects show very variable light curves and fast changes of their state.

During the last years, the polar FL Cet was at all three stages of brightness – a “low”, an “intermediate” and a “high” state. The profile of the light curves depends on the level of brightness, i.e. on the amount of transferred matter. In a “high” state there is not any faint phase of brightness and some humps are observed. In a “low” state only a faint phase lasted about of 1/3 of the orbital period is present. FL Cet have more than two meridional spots. They can be visible in the “high” and “intermediate” state.

CSS 081231: 071126+440405: has a deep dip at the phase ~ 0.85, which is very intensive (~ 1.2 mag) at a “high state”. It is necessary to carry out the polarimetric observations of the object to affirm the existence of a strong magnetic field.

Up to now, the reason of the switch between the “low” and “high” states for nova-like variables is unresolved problem.

5. Discussion

DAVID BUCKLEY: Last observations in a “low state” of FL Cet show that it changes from a 2-pole to a 1-pole accretor.

NATALY New-Katysheva: Yes, our observations FL Cet in a “low state” show that there are not any hot spots on the side of a white dwarf opposite the red dwarf. But in the “high state” one or two humps appear. FL Cet is very interesting polar, definitely.

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