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ON THE ACCRETION STATE SWITCHING IN EX Dra

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Introduction. EX Dra is a long-period (5.04 h) dwarf nova with deep eclipses ($1\overset{\mathrm{m}}{.}5$) and about 2^{m} - 3^{m} amplitude outbursts. It was classified as an eclipsing dwarf nova by Barwig et al. (1993). Baptista, Catalan and Costa (2000), using photometric observations, found that this system has a mass ratio $q = 0.72$ and an inclination angle $i = 85°$. They estimated the white dwarf mass to be $M_1 = 0.75$ M$_\odot$ and the red dwarf mass to be $M_2 = 0.54$ M$_\odot$. Knigge (2006) determined the spectral class of the mass donor to be M1.5±0.5. Assuming that the flux densities at mid-eclipse are indicative of the secondary star, Baptista, Catalan and Costa (2000) estimated 290 pc as the lower limit for the distance. Following Knigge (2006), another estimate of the lower limit distance using 2MASS JHK photometry and the K-band magnitude of the red dwarf gives 216 pc. However, this value contradicts our eclipse mapping data, because during quiescent states the accretion disc becomes too cold to provide outbursts. A detailed discussion can be found in Halevin et al. (2008).

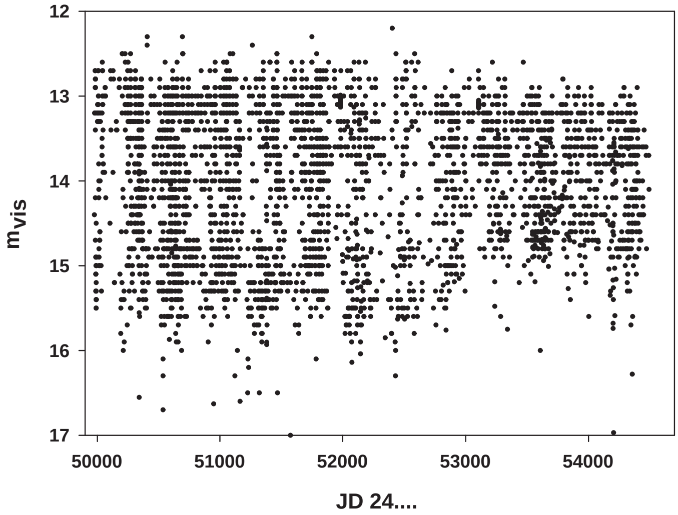

Figure 1. Long-term light curve of EX Dra for AAVSO visual and CCD observations.

Studies of eclipse timings show that the ephemeris is not described by a simple linear relationship. Baptista, Catalan and Costa (2000) found that the ephemeris must be modified by adding a sinusoidal term with a 1479^{d} period. Another estimate by Shafter and Holland (2003) gives a sinusoidal period of 1823^{d}. According to the previous investigators, EX Dra showed outbursts with a cycle of about 20 days and a duration of about 10 days.

Observations and data analysis. In our work we used 3500 visual and V band CCD observations of EX Dra, obtained by members of American Association of Variable Star Observers (AAVSO) during the time interval from 1995 to 2008.

One can see the long-term variability of EX Dra in the AAVSO light curve (Fig. 1). Visual inspection shows two different states of activity in the system: before and after JD 2452650. Significant change of the system behavior is clearly visible: before JD 2452650, EX Dra has a quiescent magnitude of about $15\overset{\mathrm{m}}{.}5$, and after this date, the quiescent magnitude is approximately 15^{m}. At the same time, the maximum brightness becomes lower, with outburst amplitudes reduced from 3^{m} to 2^{m}.

We used Fourier techniques on our data, divided into two sets, to analyze the outburst cycle length: before the state switching and after it. Power spectra for the two segments of the EX Dra light curve can be seen in Fig. 2.

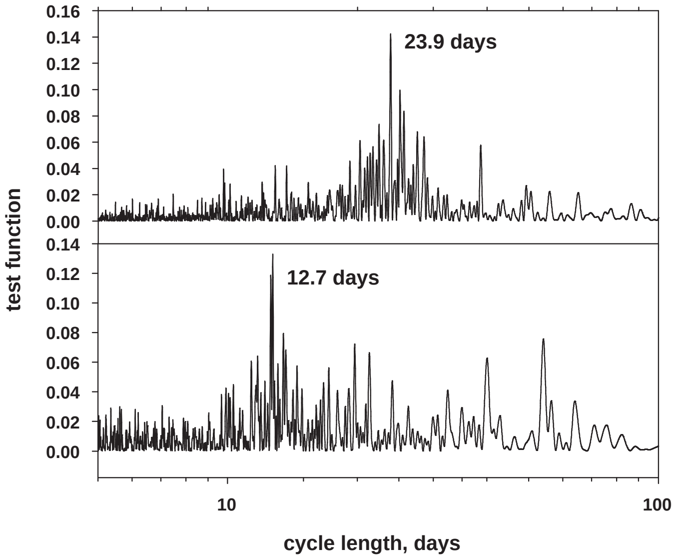

Figure 2. Power spectra for EX Dra observations before JD 2452650 (top) and after (bottom) this date.

We see here that before JD 2452650 the periodogram shows one prominent peak corresponding to the cycle length of 23.9 days. For the later state of EX Dra, the power spectrum shows two peaks near 12.6 and 12.7 days. The last one is higher and we consider it as representing the new cycle length time-scale.

The information about photometric and time-scale changes of the system behavior is summarized in the Table 1.

Detailed light curve inspection shows that the last system state is described with a very unstable outburst behavior and in principle we cannot use the 12.7 day cycle length as the only outburst variability parameter.

Table 1: Photometric parameters of the two states of EX Dra.

Parameter	$JD_{obs} < 2452650$	$JD_{obs} > 2452650$
Visual magnitude in maximum	$(12.90 \pm 0.17)^m$	$(13.08 \pm 0.13)^m$
Visual magnitude in minimum	$(15.41 \pm 0.23)^m$	$(14.78 \pm 0.18)^m$
Outburst cycle, days	23.9	12.7

To perform more detailed data analysis, we used wavelet analysis to search for possible evolution of outburst cycles. A detailed description of wavelet analysis principles can be found in Foster (1996). Here we used the code written by Foster to calculate the weighted wavelet Z-transform (WWZ) map (Fig. 3).

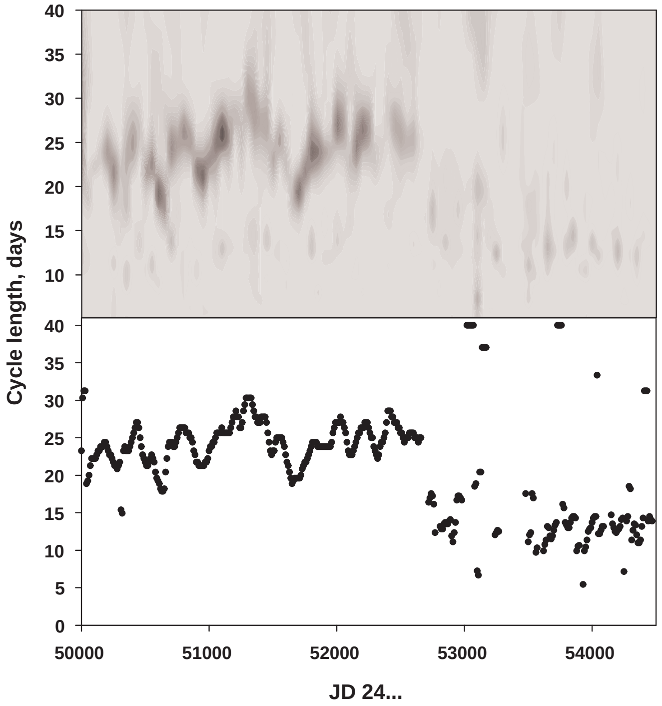

Figure 3. Weighted wavelet Z-transform map and the dominant cycle length evolution for Fig. 1 observations.

Fig. 3 shows the wavelet map for AAVSO data (top), and the curve (bottom) which represents evolution of the most prominent time-scales of the wavelet map. The wavelet map shows a dramatic switching of the outburst time-scale from the nearly regular 20-25 days cycle length before JD 2452650 to one with less prominent outbursts that have a time-scale of about 10-15 days.

The wavelet analysis also gives JD 2452665 as a more precise determination of the moment of state switching. Before this date we see smooth cycle length changes in the range from 18 to 30 days. These changes have two different timescales: a short one of about 225 days and a long one with 1280 days. The last time scale is close to the period of system ephemeris changes determined by Baptista, Catalan and Costa (2000). After the state switching the system behavior becomes more complicated. With the current shorter outburst cycle, we now need more frequent observations of this star to achieve good time resolution in order to resolve variability details of the system.

Discussion. To explain the state switching of the system we analyzed the dependence of the outburst cycle length from the other system parameters. From the standard α-disc solutions we have the formula for the viscous time-scale (Frank, King and Raine, 2002):

$$t_{visc} \sim 3 \times 10^5 \alpha^{-4/5} \dot{M}_{16}^{-3/10} M_1^{1/4} R_{10}^{5/4} s \qquad (1)$$

where $\dot{M}_{16}$ is mass transfer rate in 10^{16} g s^{-1} units, M_1 is white dwarf mass in solar masses and R_{10} is accretion disc radius in 10^{10} cm units.

One can see that simply increasing the mass transfer rate by the minimum system brightness increase factor ($\sim$ 1.7) in our case cannot explain the observed decrease of the outburst cycle by more than 1.8 times. To provide an additional decrease of the viscous time-scale, we would need to decrease the accretion disc size by a factor of 1.4. The other possible explanation is to increase the α parameter value in the disc.

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