Stars and their variability observed from space
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RESULTS OF LIGHT-CURVES ANALYSES FOR THE DWARF NOVA EX DRA

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Abstract. The results of a long-term photometric observations of the cataclysmic variable EX Dra acquired between 2014 and 2016 in Crimea (24 nights, more than 10500 measurements) are presented. The observations were performed using CCD photometers mounted on 50-cm and 60-cm telescopes in the visible and red, during both quiescent and active states. These observations were used to derive the orbital period of the system. A combined model that takes into account the radiation fluxes from the gaseous stream and a hot spot on the lateral surface of the accretion disk was used to determine the parameters of the system components (white dwarf, red dwarf, accretion disk and hot spot, and gaseous stream). Variations of the parameters when the system changes from one activity state to the other were considered. Six light-curves displaying an unsatisfactory disagreement between the observed and theoretical light-curves can be fitted successfully using a version of the combined model that includes hot spots on the secondary's surface. That model is able to reproduce qualitatively a secondary minimum in the light-curves that exhibits shifts of this minimum from phase 0.5. The parameters of dark spots on the red-dwarf surface were determined. The data obtained indicate that the outbursts in the EX Dra are related to instabilities in the matter outflowing from the secondary.

Keywords: photometry, cataclysmic variables, dwarf novæ, light-curves

The cataclysmic variable EX Dra (HS1804+6753, $\alpha = 18^h04^m14.11^s$ and $\delta = +67°54'12.2''$), which has an orbital period of about 5 h and deep eclipses $\sim 1.5^m$, was detected in the Hamburg Quasar Survey (Bade et al. 1989). It was shown to be an eclipsing dwarf nova by Barwig et al. (1993). Outbursts occurs every $\sim 10 - 30^d$ with durations up to $\sim 10^d$. The brightness at outburst is about 13.5^m, and 15^m at quiescence.

Observations of EX Dra were made with two telescopes of Sternberg Astronomical Institute in Crimea: the 60-cm with a CCD detector Apogee 47 in 2014–2015 (17 observational sets), and the 50-cm with a CCD detector Apogee Alta U8300 in 2015–2016 (7 observational sets). The accuracy of our data is $0.02 - 0.06^m$.

Parameters of EX Dra were derived from the light-curves using a "combined" model that takes into account the presence of a hot spot on the lateral surface of the geometrically thick disk and of a region of enhanced energy release near the disk edge, at the base of the gas flow (the so-called "hot line"). The shape of the few light-curves obtained in quiescence could not be described in sa tandard model, so we added the presence of dark spots on the secondary surface. The non-ellipsoidal contribution of secondary radiation enabled us to describe anomalous minima at phases ~ 0.2 and ~ 0.7 (Fig. 2, right).

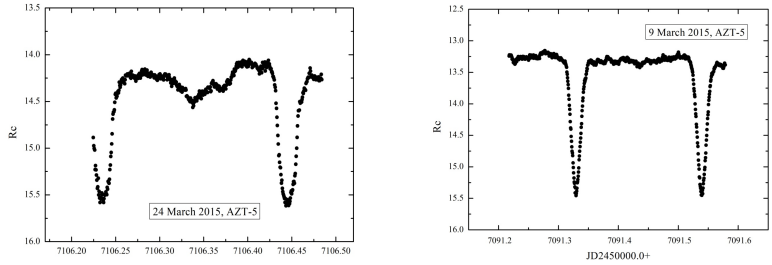

Fig. 1. Photometric observations of EX Dra obtained with the SIA 50-cm telescope: **Left:** Quiescence. **Right:** Outburst.

Our results:

The value of the orbital period of the EX Dra system was derived from our numerous new observations of this system in the quiet state. This value, $P_{orb} = 0^d.2099366(6)d$, coincides with the previous value obtained from spectroscopic observations of the star.

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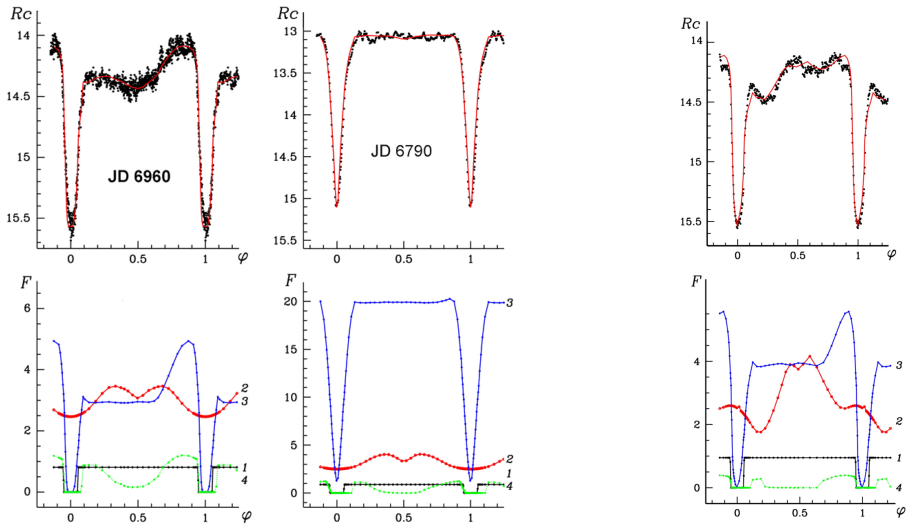

Fig. 2. Left: Typical light curves of EX Dra. Left: light-curves during quiescence; right: during outburst. Observations are shown as points, theoretical curves as the red line. The contribution of different components to the total luminosity is indicated by the white dwarf (1), red dwarf (2), disk with hot spot(3), hot line (4). **Right:** The same for one of the abnormal light-curves.

Table 1. Accretion disk and hot line parameters of EX Dra in the *Rc* band

Parameter	Inactive state	Active state
R_d, accretion disk radius in a_0	0.16−0.32	0.31−0.36
e, eccentricity	0.003−0.3	0.003−0.3
$0.5\beta_d$, thickness of the outer edge of accretion disk, °	0.5−1.7	0.6−1.6
T_{in}, temperature of inner regions of the disk, K	19 100−25 700	24 200−33 400
γ, parameter showing temperature changes along the radius of the disc	0.43−0.58	0.24−0.42
T_{ww}, temperature of windward side of gaseous stream, K	29 000−75 600	33 600−86 500
T_{lw}, temperature of leeward side of gaseous stream, K	31 800−66 500	30 600−78 900

A combined model that takes into account the presence of a hot spot on the lateral surface of the accretion disk and the contribution of light from a gaseous stream near the outer edge of the disk can be applied successfully to determine the main parameters of EX Dra in its different states of activity, at least for most of the light-curves studied (Khruzina 2011). A few of the light-curves observed could not be fitted satisfactorily with theoretical ones in the combined model. We therefore added to that model one or two dark spots on the surface of the secondary. Taking the existence of dark spots into account, we were able to reproduce qualitatively the shift of the secondary minimum from $\varphi \sim 0.5$.

The outbursts in the EX Dra system are related to the instability of the matter outflowing from the secondary (MTIM model), according to Baptista (2012).

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