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PERIOD CHANGE AND SURFACE ACTIVITY OF THE ECLIPSING BINARY UV LEONIS

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UV Leonis is a $V = 8\overset{\mathrm{m}}{.}9$ eclipsing binary that consists of two solar-type G0 and G2 stars ($M_1 = 1.13M_\odot$, $M_2 = 1.09M_\odot$, $R_1 = 1.081R_\odot$, $R_2 = 1.186R_\odot$, $T_1 = 5916K$, $T_2 = 5861K$; Frederik & Etzel, 1996) for which period change and surface activity have already been reported by Wunder (1995), Frederik & Etzel (1996), Popper (1997) and Snyder (1998). We present the results based on a thorough photometric study conducted at the Črni Vrh Observatory, Slovenia, that accompany the published $O - C$ catalog by Kreiner et al. (2000).

We obtained Johnson B and V photometric measurements of UV Leonis from Feb 27, 2000 to Apr 04, 2001 with a 19-cm, f/4 flat field $S{-}C$ telescope and HiSys-44 CCD imaging detector: in total 1564 measurements in B and 1579 in V filter. Measurements have been reduced by the `DAOPHOT` package (Stetson 1987) based on 6 standard stars: `HIP 51949`, `HIP 52070`, `TYC 845 73 1`, `TYC 845 71 1`, `HIP 51902` and `HIP 52099`. Standard deviation of the data was measured from the comparison star `TYC 845 73 1` of a constant magnitude that is comparable to that of UV Leonis. The minima extraction has been done with the algorithm proposed by Kwee & Van Woerden (1956); we present the results in Table 1.

In recent years a significant effort has been made to estimate the $O - C$ behaviour as a function of time: a sudden change in period was suggested by Wunder (1995), a sine function fitted to the quadratic change of $O - C$ by Snyder (1998). By inspecting the $O - C$ catalogue by Kreiner et al. (2000) with added data from Bíró & Borkovits (2000), Borkovits et al. (2001, 2002) and from this paper, we find that the sudden (discrete) change in period is a preferable assumption, as demonstrated by Fig. 1. The data of minima from the catalog prior to 1949 have not been used in calculations because of their poor accuracy. Fig. 1 shows that a sudden change in period appeared at HJD $\sim$ 2444362 (May 1980) with the following ephemeris deduced before and after the change:

$$\mathrm{HJD_{min}} = 2437616.2091(4) + 0.6000849(21)\mathrm{E} \qquad \text{for HJD} < 2444362, \qquad (1)$$

$$\mathrm{HJD_{min}} = 2448617.5761(3) + 0.6000864(12)\mathrm{E} \qquad \text{for HJD} > 2444362. \qquad (2)$$

Error estimates are based on the accuracy of the minima determination for HJD and $O - C$ dispersion for period. They are given in parentheses to show the accuracy of the last decimal place. Ephemeris are generally consistent with the results of Wunder (1995), though observations obtained in the last 6 years contribute to a more reliable linear solution since the period change (Eq. 2).

HJD_{min} (error)	Type	Pts.	Filter	HJD_{min} (error)	Type	Pts.	Filter
2451602.4045 (3)	Primary	5	*B*	2452001.4634 (2)	Primary	31	*B*
2451602.4068 (7)	Primary	5	*V*	2452001.4641 (2)	Primary	31	*V*
2451606.6073 (2)	Primary	58	*B*	2451625.5089 (3)	Secondary	120	*B*
2451606.6073 (1)	Primary	58	*V*	2451625.5091 (2)	Secondary	119	*V*
2451626.4097 (2)	Primary	120	*B*	2451952.5575 (6)	Secondary	31	*B*
2451626.4098 (2)	Primary	119	*V*	2451952.5574 (4)	Secondary	32	*V*
2451956.4576 (4)	Primary	22	*B*	2451955.5581 (6)	Secondary	32	*B*
2451956.4579 (4)	Primary	22	*V*	2451955.5581 (7)	Secondary	32	*V*
2451957.6582 (2)	Primary	16	*B*	2451961.5544 (6)	Secondary	28	*B*
2451957.6579 (2)	Primary	16	*V*	2451961.5536 (6)	Secondary	28	*V*
2451959.4584 (5)	Primary	31	*B*	2451963.3589 (5)	Secondary	13	*B*
2451959.4584 (3)	Primary	31	*V*	2451963.3588 (5)	Secondary	13	*V*
2451962.4586 (4)	Primary	32	*B*	2451991.5611 (9)	Secondary	12	*B*
2451962.4587 (3)	Primary	32	*V*	2451991.5603 (9)	Secondary	12	*V*

Table 1. Our primary and secondary minima of UV Leonis. HJD is given with an error estimate in parentheses for the last two decimal places. We also present the number of data points (Pts.) that have been used for minima determination. B and V stand for Johnson B and V filters.

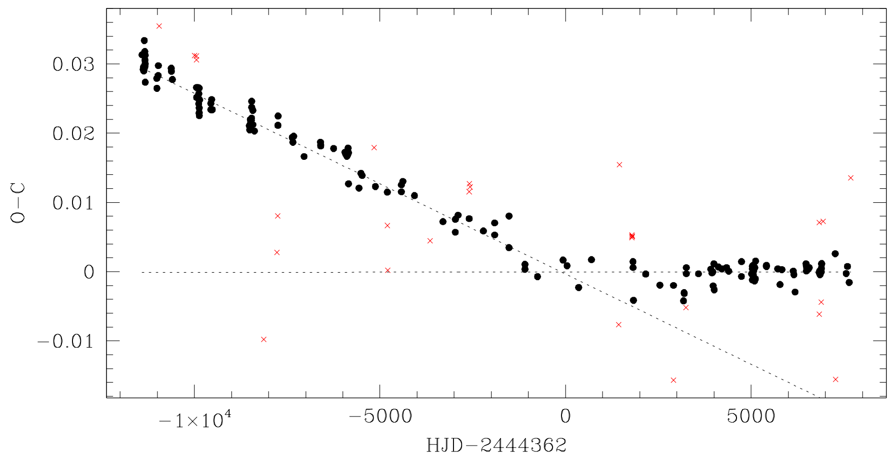

Figure 1. $O-C$ diagram for UV Leonis. Dashed lines represent the ephemeris before (Eq. 1) and after (Eq. 2) the sudden period change at HJD $\sim$ 2444362 (May 1980). Data taken from Kreiner et al. (2000), Bíró et al. (2000), Borkovits et al. (2001, 2002) and this paper (see text for details). The points marked with a cross were considered as outlayers and were not used in ephemeris calculation.

To try to understand the underlying physics that could govern such a sudden period change, we made a crude estimate of the mass loss that could cause such a change. From the equation of total orbital angular momentum (L) and the Kepler's law we obtain the following relationship:

$$\frac{\mathrm{d}L}{L} = \left[\frac{2}{3} + \frac{q}{3(1+q)}\right]\frac{\mathrm{d}m_1}{m_1} + \left[1 - \frac{q}{3(1+q)}\right]\frac{\mathrm{d}m_2}{m_2} + \frac{1}{3}\frac{\mathrm{d}P}{P}, \qquad (3)$$

where $q = m_2/m_1$ and P is the period of UV Leonis. The angular momentum change dL can only be 0 or negative and the mass ratio is close to 1 so both square brackets have the value of 5/6. In order to cause the period change of $\mathrm{d}P/P = 2.5 \times 10^{-6}$ the total mass lost from the system had to be no less than 1.9×10^{24} kg or a third of the mass of the Earth. Since our binary consists of two main sequence stars that appeared undisturbed around HJD 2444362, we see no plausible physical background to justify such a significant mass loss effect. The period change might, on the other hand, be assigned to the near-periastron passage of an unobserved third body of low mass. We plan to investigate this assumption furtherly.

Based on purely photometric data, Frederik & Etzel (1996) proposed the presence of the two near-polar dark spots on the outer hemisphere of the cooler star, which accounted for their model result that the hotter, more massive star is the smaller and less luminous one. This result has been argued by Popper (1997), who based his work on purely spectroscopic data to conclude that the hotter star is the more luminous one.

Our measurements have been obtained in two consecutive seasons, the first one in 2000 (1973 measurements) and the second one in 2001 (1176 measurements). The unmistakable vertical shift in light curves between the two seasons (Figs. 2, 3) shows the signs of UV Leonis' surface activity. The magnitudes of standard stars remained constant at all times, so instrumental errors are ruled out; the vertical shift is real.

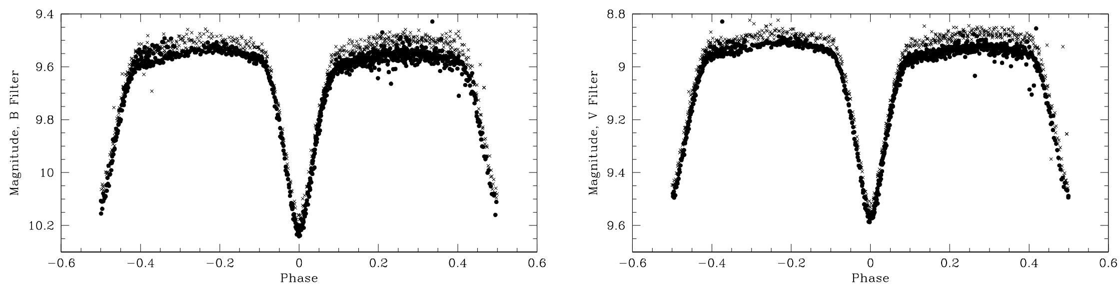

Figure 2. The B (left) and V (right) filter light curves of the seasons 2000 (filled circles) and 2001 (crosses).

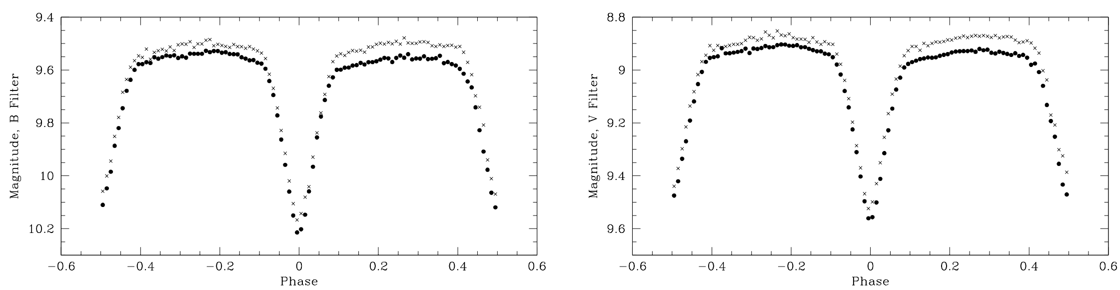

Figure 3. The B (left) and V (right) filter binned light curves of the seasons 2000 (filled circles) and 2001 (crosses). The data has been binned to 100 points in phase to demonstrate that the difference between both seasons is only a vertical offset.

The magnitude offset shown in Fig. 3 is $\sim 0.03 - 0.05$, the second season measurements being *brighter* than the first season. This yields a flux difference of $\sim 3\%$ to 5% or a total surface temperature difference of $\mathrm{d}T/T \sim 0.01$. If we adopt the average temperature factor of dark spots from Frederik & Etzel (1996) ≈ 0.85 ($\mathrm{d}T/T \sim 0.15$), then such spots should cover $\sim 1/15 \approx 7\%$ of stellar surfaces. The distribution of these dark spots on stellar surfaces is a non-trivial problem because of modeling degeneracies. However, to obtain a strict vertical shift observed in Figs. 2 and 3, two plausible distributions make sense: 1) large near-polar spots which don't get eclipsed at any time and 2) a fair amount of small, uniformly distributed spots over the visible surface.

This paper is a preliminary study of UV Leonis based exclusively on photometric data. A complete spectrophotometric study including 74 echelle spectra obtained at the 1.8m Ekar telescope (Asiago, Italy) is being analysed and will be presented later.

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Erratum

Anton Paschke reports a probable typing error in IBVS 1325. The time of the minimum of XX Cep observed by R. Diethelm in 1975 (as printed in IBVS 1325: 42439.383 Diethelm 1975) should be 42439.370 according to the BBSAG Bulletin No. 20.

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The Editors