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The BVRI Light Curves and Period Analysis of the Beta Lyrae System XX Leonis

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Abstract. The contact eclipsing binary system XX Leonis (p = 0.97 days, Sp A9) has been analysed using the PHOEBE programme, based on the Wilson-Devinney code. The BVRI light curves were obtained during spring 2006 using the 20-cm telescope and ST-7 CCD detector. The effective temperature of the primary component determined from the photometric analysis is $T = (7342 \pm 14)\,K$, the inclination of the orbit is $i = (84.83 \pm 0.29)^\circ$ and the photometric mass ratio $q = (0.40 \pm 0.01)$. Also the third body hypothesis was suggested, based on the period analysis using 57 minimum times and resulting the period of the third body $p_3 = (59.66 \pm 0.05)\,yr$, amplitude $A = (0.036 \pm 0.028)\,day$ and zero eccentricity which gives the minimum mass $M_{3,min} = (0.91 \pm 0.01)\,M_\odot$.

Keywords. stars: binaries, binaries: close, binaries: eclipsing, stars: fundamental parameters, stars: individual (XX Leo)

1. Introduction

The binary system XX Leonis (SV* P 3370, AN 355.1934, BD+14 2177) was discovered to be a variable by Tsesevich (1954). It is an eclipsing binary star of 11^{th} magnitude, the period is close to one day and the depth of primary minimum is about 0.5 mag. The spectral type of the primary is A9V and of secondary K0. It was included in a catalogue of apsidal motion binaries by Hegedüs (1988), but this hypothesis was rejected.

2. Light curve analysis

The preliminary solution of the light curve (using Washington filter system) computed by Shaw (1998) classified XX Leo as a near-contact binary, but the period analysis indicates constant period. The second analysis with satisfactory data was performed by Stark et al. in 2000 but with only R and V light curves and also without a satisfactory light curve solution. So the masses of the components are still not very convincing. We assume here $M_1 + M_2 = 2.41\,M_\odot$, according to the derived spectral types from the previous analysis.

The new light elements derived from our period analysis using 57 minimum times (see Figure 2) for XX Leo are:

$$\begin{array}{l} \mathrm{Min\,I = HJD}\ \ 24\,50540.6831 + 0\overset{\mathrm{d}}{.}971135899 \cdot \mathrm{E}. \\ \qquad\qquad\qquad\qquad \pm 0.0076 \pm 0\overset{\mathrm{d}}{.}000000473 \end{array} \tag{2.1}$$

We have measured the light curves using standard Bessell B,V,R,and I filter system with the 20-cm telescope and ST-7 CCD detector. These measurements were done in private observatory in Brno, Czech Republic, during 20 nights in spring 2006. In the

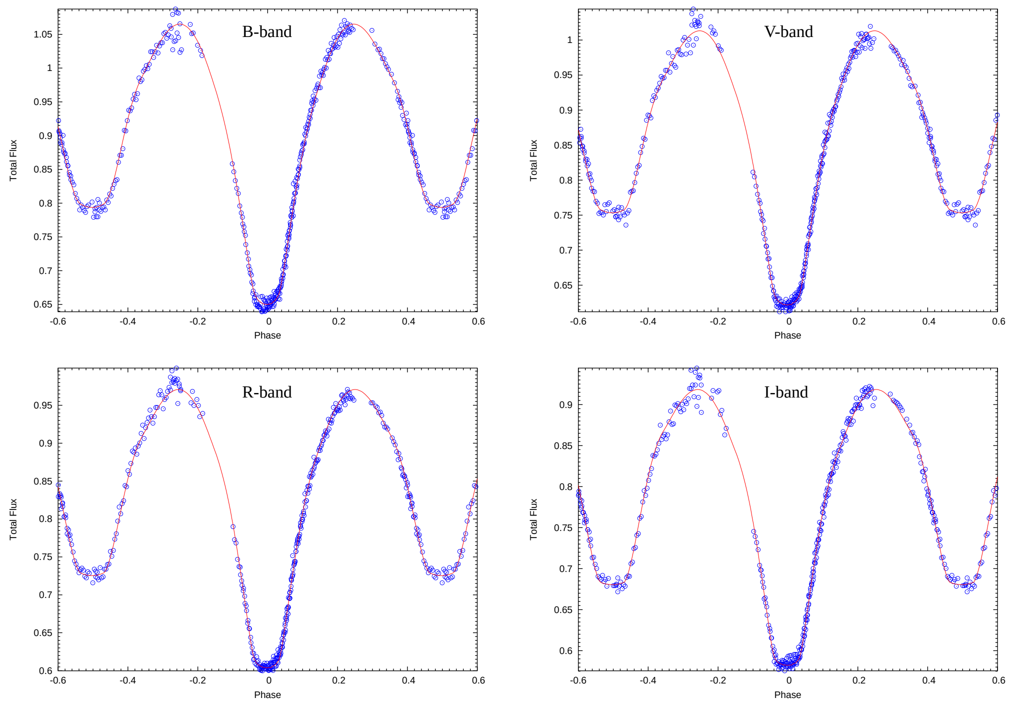

Figure 1. Light curves of XX Leo measured through Bessell filters B,V,R and I during spring 2006. Altogether 1495 data points (with no weightening scheme) and also the theoretical curves are plotted. On the x-axis is the phase according to the ephemeris above and on the y-axis is the relative total flux from the system.

Figure 1 you can see the theoretical curves with the individual data points. These measurements were analysed using the PHOEBE programme (see Prša (2005)), based on the Wilson-Devinney code (see eg. Wilson (1971)). The final values for both components for the temperatures (T_i), mass ratio (q), inclination (i), relative luminosities (L_1, L_2, l_3), limb-darkening (x_i, interpolated from the Van-Hamme's tables), albedo (A_i) and gravity darkening (g_i) coefficients and synchronicity parameters (F_i), respectively, are in the Table 1. We have used the "double contact binary" mode during the computation, because of the best numerical result, the best agreement with the previous results (primary and secondary spectral type A9 and K0, respectively) and also the period analysis. Regrettably we have no RV curve, so we cannot estimate another parameters more precisely, for example the masses and dimensions of the system. The mass ratio computed only from the photometry is not very reliable. Spectroscopy of XX Leo would help us to estimate these parameters.

From the mass of the potential third body (about $0.9 M_{\odot}$, from the period analysis) we could conclude that this star on the main sequence should be G9 spectral type. Also from the light curve analysis we can see that this body has almost the same luminosity as the secondary component, so both approaches lead to the same result.

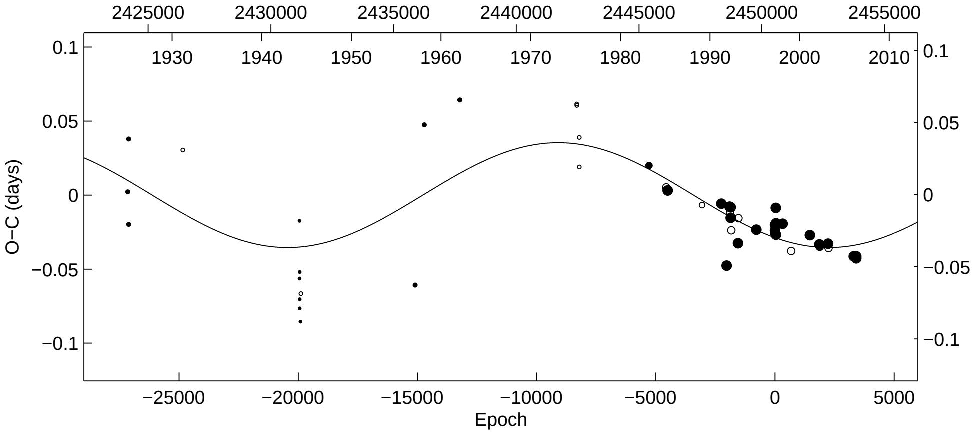

Figure 2. O-C diagram of XX Leo.

3. Period analysis

The previous period analysis of XX Leo was performed by Stark et al. (2000), but no significant variation was found because of small data set. Also in the paper by Srivastava (1994) was found that the period of the binary is constant. We have used 57 minimum times covering more than 80 years. In the Figure 2, there are individual minimum times marked as dots and circles for the primary and secondary minimum, respectively. We can see no evident displacement of secondary minima, so the apsidal motion could be ruled out. Bigger the symbol, bigger the weight. Also the light-time effect hypothesis curve is shown. The final results of the fit are in the Table 2. We have fixed the value of eccentricity to zero because of the best agreement with the photometric results.

From the third-body hypothesis also the mass function and minimum mass of the third body was calculated. The mass function is $f(m_3) = 0.068 M_\odot$, so the minimum mass of the third body is $0.91 \pm 0.02 M_\odot$. As we can see, this suggested body might be a bit more massive than the secondary component, what in a good agreement according to the luminosities of the individual components from the light curve analysis. Secondary

Table 1. Physical parameters of XX Leo.

Parameter	Value	Parameter	Value
$T_1[K]$	7342 ± 14	$x_{1,B}$	0.603 ± 0.009
$T_2[K]$	4991 ± 88	$x_{1,V}$	0.508 ± 0.009
M_2/M_1	0.401 ± 0.002	$x_{1,R}$	0.408 ± 0.008
$i[^\circ]$	84.835 ± 0.287	$x_{1,I}$	0.320 ± 0.010
$L_{1,B}$	0.891 ± 0.003	$x_{2,B}$	0.866 ± 0.115
$L_{1,V}$	0.841 ± 0.002	$x_{2,V}$	0.724 ± 0.095
$L_{1,R}$	0.809 ± 0.002	$x_{2,R}$	0.597 ± 0.079
$L_{1,I}$	0.783 ± 0.002	$x_{2,I}$	0.489 ± 0.080
$L_{2,B}$	0.070 ± 0.002	A_1	0.215 ± 0.019
$L_{2,V}$	0.079 ± 0.002	A_2	0.875 ± 0.094
$L_{2,R}$	0.089 ± 0.001	g_1	0.807 ± 0.034
$L_{2,I}$	0.106 ± 0.001	g_2	0.069 ± 0.087
$l_{3,B}$	0.040 ± 0.003	F_1	0 (fixed)
$l_{3,V}$	0.080 ± 0.002	F_2	2.249 ± 0.018
$l_{3,R}$	0.102 ± 0.002		
$l_{3,I}$	0.111 ± 0.002		

Table 2. Parameters of the third component.

Parameter	Value
$p_3[yr]$	59.66 ± 0.05
$A[d]$	0.036 ± 0.028
$\omega[^\circ]$	19.22 ± 12.98
e	0 (fixed)
$T_0[JD]$	2437200.62 ± 216.63

and tertiary component seems to be rather similar, what could be interesting example for spectral disentangling.

4. Conclusions

We have performed new analysis of the contact binary of the Beta-Lyrae type XX Leo. New light curves were measured and analysed. Also new period study has been done. The hypothesis of the third body was suggested, according to the third light in the LC solution and also from the light-time effect hypothesis. Both hypothesis are in very good agreement and leads to the third body comparable to the secondary.

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