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Spectroscopic orbit of the ex-eclipsing binary SS Lac in the young open cluster NGC 7209

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Abstract. The not-more-eclipsing system SS Lac in the young open cluster NGC 7209 has been recently and oddly enough announced to show a constant radial velocity. Puzzled by this finding, we have monitored the system during 1997 obtaining 24 Echelle+CCD spectra over 8 orbital revolutions. Our spectra reveal a nice orbital motion with periodic splitting and merging of spectral lines from both components.

An accurate orbit has been derived, together with individual masses of the stars. SS Lac presents a moderately eccentric orbit and a full synchronization between stellar rotation and orbital revolution.

Key words: Binaries: eclipsing – Binaries: spectroscopic – Stars: individual (SS Lac) – Open Clusters: individual (NGC 7209)

1. Introduction

According to recent photometry (cf. Vansevicius et al. 1997) SS Lac belongs to the young open cluster NGC 7209 . Hoffmeister (1921), Dugan & Wright (1935), Wachmann (1936), Nekrasova (1938) and Kordylewski et al. (1961) described SS Lac as an eclipsing binary of 14.4 days period, with significant eccentricity because the equal depth secondary eclipse occurred at phase 0.57. However, more recent observations by Zakirov & Azimov (1990), Lacy (1992), Mossakovskaya (1993) and Schiller et al. (1996) show that the eclipses no longer occur. The end of the eclipsing phase is set around 1940 by Mossakovskaya (1993) and around 1960 by Lehmann (1991). The latter ascribes the rotation of the plane of the orbit to the presence of an unseen third body in the system, orbiting at a great distance the closer central pair.

Quite puzzling has been the report by Schiller et al. (1991) and Schiller & Milone (1996) that 1983-84 spectra of SS Lac did not reveal the expected double–lined nature of the spectra nor any variation of the radial velocity tracing the orbital motion. Using available predictions for the rate of change of the SS Lac orbital inclination, Schiller & Milone (1996) expected a semi-amplitude of the radial velocity curve of 150 km sec^{-1}, far in excess of their instrumental resolution. They suggested that SS Lac could be a triple system suddenly become chaotic or that a close encounter with another NGC 7209 member could have ionized the binary (cf. Schiller 1996).

Stimulated by the Schiller et al. (1991) report, Etzel et al. (1996), Stefanik et al. (1996) and Etzel & Volgenau (1996) announced in IAU Circulars that, according to their preliminar spectroscopic observations, SS Lac is a double–lined system, with indications of variability in the radial velocities. So far no investigation of the orbital motion of SS Lac has appeared in literature.

As an ex-eclipsing binary in a well populated young open cluster, SS Lac clearly deserved further investigations to clarify the whole issue. In this note we report about our spectroscopic monitoring of SS Lac performed to the aim of confirming the binary nature and to derive the spectroscopic orbit.

2. Observations

Twenty-four Echelle+CCD spectra of SS Lac have been obtained with the Asiago 1.82 m telescope during 1997. They cover the range from 4300 to 6600 Å with a resolution of $\lambda/\triangle\lambda \sim$22,500 at H$\beta$ (from the FWHM of comparison spectrum Thorium lines). The spectra have been reduced in a standard way with the IRAF software package. A sample of Hα profiles recorded on our spectra is shown in Figure 1, where the periodic splitting and merging of the individual components is evident.

On our spectra we measured only the radial velocities of the Hα, Hβ and Hγ lines (the latter over two distinct Echelle orders). A few other metallic lines were indeed visible, but too weak for meaningful measurements. The radial velocities reported in Table 1 come from the hydrogen lines, weighted

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according to the S/N of the stellar continuum around the line (typically 6:4:3 for Hα:Hβ:Hγ).

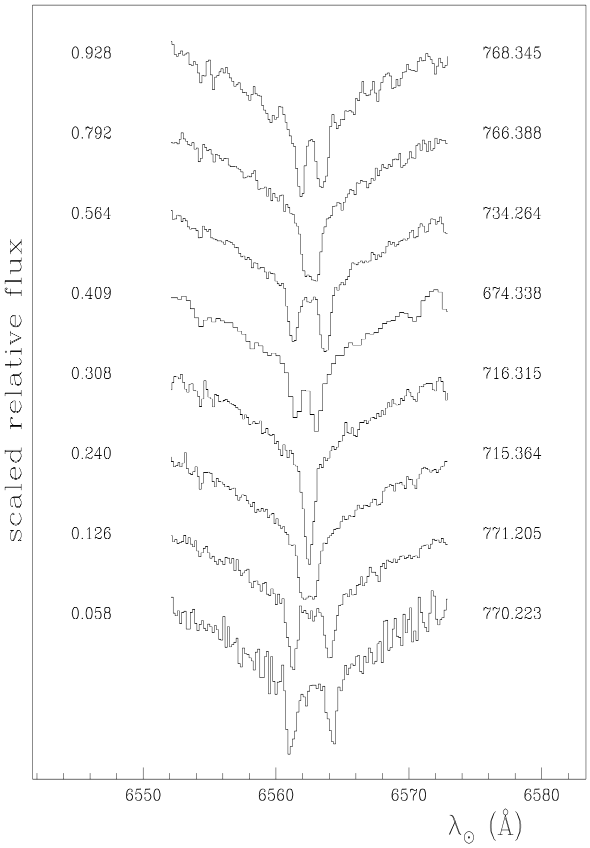

Fig. 1. A sample of Hα profiles of SS Lac reckoned according to the orbital phase. The merging and splitting of the spectral lines is evident. The orbital phase on the left is counted from periastron passage (cf. Table 2).

3. Spectroscopic orbit

Our observations were secured over a time span covering less than 8 orbits of SS Lac and therefore are not suited for a very accurate period determination. A Deeming-Fourier analysis of data in Table 1 suggests a period of 14.4±0.3 days, very close to the 14.416 days determined from eclipse timing by several Authors (e.g. Brancewicz & Dworak 1980). In the computation of the orbit, the period 14.41638 from Eq.(2) has been adopted (see below).

The orbital solution is given in Table 2. With the exception of Ω and eccentricity, the formal errors for the other elements are $\leq$1.5%, with a weighted deviation of the observations from the computed orbit of $\sim$0.8 km sec^{-1}. The solution is graphically presented in Figure 2.

It is worth to compare the photometric and spectroscopic orbital solutions (cf. Savedoff 1951) through the combination of the eccentricity (e) and longitude of the periastron (Ω) elements (cf. Struve 1948):

$$e\cos\Omega = \frac{2\pi}{P}\,\frac{(t_2 - t_1 - \frac{1}{2}\times P)}{(1+\mathrm{cosec}^2 i)} \qquad (1)$$

The photometric value is +0.110 (Dugan & Wright 1935), very close to the +0.117 value from the spectroscopic orbital solution in Table 2 (and orbital inclination from sect. 4.3). Thus the photometric and spectroscopic orbital solutions appear in excellent agreement.

Table 1. Heliocentric radial velocities of the SS Lac components. Solid line and filled circles in Figure 2 refer to star *a*. The quoted errors are probable errors. When the two components were too close in radial velocity for line splitting into individual components, a single value is given (central column). $MJD_\odot$ = $JD_\odot$ – 2450000.

$MJD_\odot$	$RV^a_\odot$	err.	$RV_\odot$	err.	$RV^b_\odot$	err.
659.537	14.06	0.21			–49.99	0.14
660.562	34.58	0.39			–68.13	1.07
673.414			–18.69	1.95		
674.337	22.40	1.61			–54.14	1.24
675.361	38.94	1.41			–72.88	2.09
701.448			–20.42	0.90		
714.336	–73.89	1.89			35.91	4.56
714.378	–71.98	1.55			33.63	1.27
715.329			–22.27	1.03		
715.363			–19.00	0.94		
716.315			–17.17	1.08		
716.561			–18.40	0.35		
717.530	20.53	0.28			–58.77	0.15
732.271	25.41	0.38			–65.65	0.74
732.317	25.87	0.09			–67.03	0.26
734.264	44.13	1.01			–83.81	1.57
748.391	41.49	1.04			–85.81	0.80
765.510	26.04	2.00			–70.85	1.19
766.209	0.75	2.10			–60.55	2.00
766.388	0.09	3.45			–47.79	2.38
767.326			–18.14	1.41		
768.345	–64.94	1.09			24.18	1.59
770.223	–102.93	0.50			64.26	0.50
771.205	–97.58	0.50			53.61	0.50

4. Discussion

4.1. Eclipse timing

The $MDJ_\odot$=716.315 spectrum in Figure 1 presents a perfect radial velocity superposition of the two spectra, thus it corresponds to eclipse conditions. The eclipse ephemeris given by Mossakovskaya (1993)

$$Min\ I \ = \ 2415900.76 + 14.41619(\pm 0.00013) \times E$$

predicts a +0.456 day shift for the $MJD_\odot$=716.315 spectrum, which is comparable with the propagation of the uncertainty on the period. Imposing phase coincidence between Mossakovskaya's principal minimum and $MJD_\odot$=716.315 spectrum, this leads to the improved ephemeris

$$Min\ I \ = \ 2450716.32(\pm 0.15) + 14.41638(\pm 0.00010) \times E \quad (2)$$

The slightly longer orbital period nearly coincides with those given by Brancewicz & Dworak (1980, P=14.4163 days) and by Dugan & Wright (1935, P=14.41629 days).

Table 2. Orbital elements for SS Lac. Where appropriate, the second value correspond to the component *b* represented by a dotted line and open circles in Figure 2. The quoted errors are the formal errors of the orbital solution. The entry "*deviation*" is the weighted deviation of the observed radial velocities from the computed orbital solution. $MJD_\odot$ = $JD_\odot$ – 2450000.

		star *a*	star *b*
period	(days)	14.41638	
baricentric velocity	(km sec^{-1})	–21.2±0.3	
semi-amplitude	(km sec^{-1})	74.7±1.1	77.6±1.4
eccentricity		0.122±0.019	
$a_i$sin$i$	(AU)	0.098±0.001	0.102±0.002
$T_\circ$	($MJD_\odot$)	741.4±0.2	
Ω	(deg)	332±9	
deviation	(km sec^{-1})	0.87	0.70
inclination	(deg)	78	
mass	($M_\odot$)	2.68	2.57

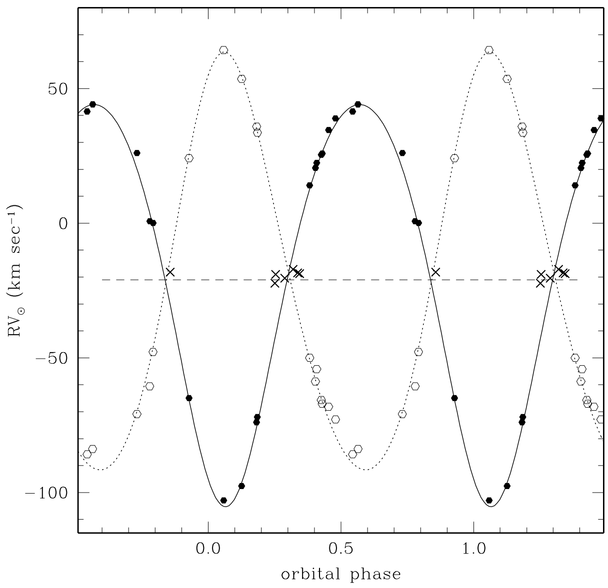

Fig. 2. Orbital solution for SS Lac. The curves give the orbital solution of Table 2. Solid curve and filled circles refer to component *a* in Tables 1 and 2. The crosses mark spectra for which the too small velocity separation caused merging of the two components into a single line. The dashed line is the baricentric velocity (–21.2 km sec^{-1}).

4.2. Spectral classification

The absence of He I absorptions, the paucity of metallic lines and the very strong Stark broadening of the wings of the Balmer lines suggest a spectral classification around A2 V, virtually identical for the two members (cf. Figure 1). A more refined classification however needs devoted observations at the head of the Balmer series. Component *b* appears slightly less luminous than component *a*, as suggested by the relative depths of the central Doppler cores and contribution to the overall Hα line wings in Figure 1. A lower brightness agrees with the slightly smaller mass of component *b* (cf. the semi-amplitudes and semi-major axes in Table 2) and the just slightly reduced amplitude of *b* eclipses compared to *a* eclipses (a few hundredth of a magnitude, cf. Dugan & Wright 1935, Mossakovskaya 1993).

4.3. Orbital inclination

The spectral classification of the two components can be turned into a physical radius of R=2.25 $R_\odot$ from interpolation of tabular values given by Allen (1973). The orbital separation from Table 2 is $a \sin i$ = 0.200±0.002 AU = 42.5±0.5 $R_\odot$. Lehmann (1991) has shown that the system presented total eclipses (central eclipses given the nearly identical size of the components) in 1900-1915, and afterward the eclipses monotonically reduced in depth until they disappeared around 1960. From separation and size of the two components it may be computed that at the end of the eclipsing season the inclination was $i \sim 83°$. The corresponding linear change in orbital inclination is

$$\frac{d\mathrm{i}}{dt} = 0.13 \pm 0.01 \quad deg\ yr^{-1} \qquad (3)$$

which is significantly lower than the di/dt = 0.18 deg yr^{-1} obtained by Lehmann (1991) on the assumption of a B7 V classification for both components (clearly ruled out by our spectra that show no evidence for HeI absorption lines). From Eq.(3) and the occurrence of central eclipses at the beginning of this century, the current orbital inclination is

$$i_{(1998)} \sim 78° \qquad (4)$$

The above results indicate that the non-eclipsing season of SS Lac lasts for about 1275±90 years.

4.4. Rotational velocities

The rotational velocity of the components of SS Lac has been derived by comparison with standard stars from Sletteback (1975), which were observed under the same instrumental conditions. The velocity turned out to be the same for both components:

$$V_{rot} = 10 \pm 5 \quad km\ sec^{-1} \tag{5}$$

The dependence on inclination (see Eq[4]) has been removed under the assumption that the rotational and orbital axes are parallel. A $V_{rot} = 10 \pm 5$ km sec^{-1} means that rotational and orbital motion are synchronized, the orbital velocity amounting to $V_{orb} = 8$ km sec^{-1}.

It is worth to note that SS Lac shows synchronization when the orbital circularization is still far from being achieved. The two phenomena seems therefore to evolve over quite different time scales, in agreement with the theoretical expectations (cf. Zahn 1977).

The expected synchronization time for a binary with the SS Lac parameters may be estimated from the Tassoul's (1987) formalism to be:

$$\begin{aligned} t_{syn}(yrs) &\geq 2500 \times [P(days)]^{\frac{11}{4}} \\ &\geq 4 \ million\ years \end{aligned} \tag{6}$$

which is relatively short compared to the NGC 7209 cluster age (300 million yrs according to Lynga 1985). The synchronization status cannot therefore be used to decide if SS Lac is or not a primordial binary of NGC 7209.

4.5. Individual masses

A straightforward application of the Kepler's III law to Table 2 data gives 2.57 and 2.68 $M_\odot$ for the masses of the two SS Lac components. The tabular mass from Allen (1973) for the A2 V spectral type is 2.78 $M_\odot$. The agreement may be considered quite good in view of the uncertainties in the preliminary spectral classification and tabular interpolation.

4.6. Mass-Luminosity relation

Vansevicius et al. (1997) have estimated a 1.0 kpc distance and a A_V=0.54 mag extinction to NGC 7209. Using a bolometric correction *B.C.*= –0.29 mag for the spectral type A2 V (Allen 1973), the bolometric magnitude of the SS Lac components is

$$M_{bol} = +0.25 \quad mag \tag{7}$$

corresponding to a luminosity $L = 65\ L_\odot$. The mean mass for the two components is 2.63 $M_\odot$. At this mass the *Mass-Luminosity* relation has the numerical form (cf. Bowers & Deeming 1984):

$$log \frac{L}{L_\odot} = 0.479 + 2.91\ log \frac{M}{M_\odot} \tag{8}$$

which predicts $L \sim 50\ L_\odot$ for the SS Lac components. The agreement between the observed and predicted luminosity is satisfactory in view of the uncertainties in the distance, reddening and the approximate bolometric correction.

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