

Simultaneous MOST photometry and high-resolution spectroscopy of Spica, a binary system with a massive β Cephei star component.

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Abstract

We present the data from a unique observational study of Spica, a binary system with a primary component of β Cephei type. We exploit simultaneous high-resolution spectroscopic observations and high-precision photometry obtained by the MOST satellite. By disentangling the spectra of this binary, we get an accurate determination of the orbit. Future work includes a full seismic analysis of the system.

Individual Objects: Spica (α Virginis)

Introduction

The bright star Spica (α Virginis, $m_v = 1.04$) has long been known to be a spectroscopic binary (Vogel 1890) with an orbital period of almost exactly 4 days and a relatively high eccentricity of $e = 0.18$ (Batten, et al. 1989). The eccentricity causes the line of apsides to rotate with a period of 139 days (Aufdenberg et al. 2007). Shobbrook et al. (1969, photometry) found the primary component to be a β Cephei variable with a pulsation frequency of 5.75 d^{-1} . Several studies of the β Cephei variation were conducted from 1967 until 1974. Lomb (1978, photometry and radial velocities) found that the pulsation amplitude had been decreasing and, by 1972, had become undetectable. Balona (1985, photometry and radial velocities) suggested that the amplitude decrease is a geometric effect and that the amplitude varies over the precession cycle of the system (~ 200 years). Smith (1985a,b, spectroscopy) observed Spica spectroscopically and suggested a number of short-period modes among which toroidal modes. These are not visible in photometry due to their high degree. Recently, Dukes et al. (2005) obtained a number of photometric observations from 1996 until

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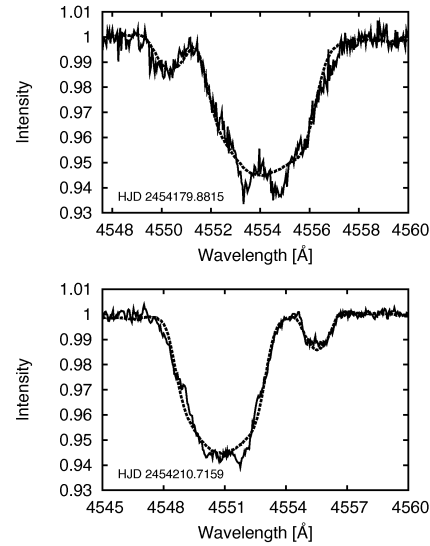


Figure 1: Spectra (full lines) taken with the Euler (top) and DAO (bottom) telescope. In both cases the phase of the system is such that the two stellar spectra are well separated. The dashed line shows the combined KOREL fit of both components for that particular phase.

2004 and concluded that there is no sign of the original 5.75 d^{-1} term even though Balona's model (Balona 1985) predicts that the amplitude during that time of observations should be detectable. In order to get an accurate determination of the orbit and to give conclusive arguments concerning the variability of the system, we have set up a unique ground-based spectroscopic and space-based photometric campaign.

Data

Ground-based data

The ground-based data originate from a high-resolution spectroscopic bisite campaign. We used both the CORALIE spectrograph with a resolution of 50000 attached to the 1.2-m Euler telescope at La Silla (Chile) and the coude spectrograph of the DAO 1.2-m telescope at Victoria (Canada) with a resolution of 45000. In total 1856 observations were gathered using 2 different telescopes. The average S/N ratio near 4500 Å ranged between 300 and 800. Table 1 summarizes the logbook of our spectroscopic data. All data were subjected to the normal reduction process, which consists of de-biasing, background subtraction, flat-fielding and wavelength calibration. Finally, the heliocentric corrections were computed. The common technique of normalizing the spectra to the continuum by fitting a cubic spline function gave considerable scatter in the equivalent width of the lines. Therefore we used a different strategy (see e.g. Telting & Schrijvers 1998). We normalized the spectra night per night. We used the mean spectrum as a template and divided each individual spectrum by this nightly average. We normalized these quotient spectra by fitting low-degree polynomials, which turned out

Table 1: Log of our spectroscopic bisite campaign. The Julian Dates are given in days (-2454000), ΔT denotes the number of nights, N is the number of spectra and S/N denotes the average signal-to-noise ratio for each observatory measured at the continuum between 4500 and 4551 Å.

Long.	Lat.	Telescope	Julian Date Begin	End	ΔT	N	Amount and quality S/N
Dominion Astrophysical Observatory (DAO)							
$-123^{\circ}25'$	$+48^{\circ}31'$	1.2-m	191	210	7	105	800
Euler telescope in La Silla (Chile)							
$-70^{\circ}44'$	$-29^{\circ}15'$	1.2-m	178	191	11	788	300
			208	220	12	801	
			304	312	8	162	
Total					31	1856	

to be much easier than fitting the raw spectra. Subsequently, we constructed a final set of normalized spectra using the fits to the quotient spectra and a normal continuum fit of the template spectrum. For our study, we considered the Si III triplet around 4567 Å because these spectral lines are sufficiently strong and are dominated by temperature broadening, such that the intrinsic profile can simply be modelled with a gaussian. Moreover, they are not too sensitive to temperature variations (see De Ridder et al. 2002; Aerts & De Cat 2003), so that neglecting these variations remains justified. Fig. 1 shows 2 spectra of Spica taken in 2 opposite orbital phases of the system.

Space-based photometry

The space-based data originate from the MOST satellite (Walker et al. 2003) which has a 15 cm Rumak-Maksutov optical telescope feeding a CCD photometer. Because of its brightness, Spica was an excellent target for the MOST satellite and was observed in the principal mode of MOST, which is Fabry imaging (see Walker et al. 2003). The light curve of Spica was sampled using ~ 30 sec. exposures over a baseline of ~ 22.92 days resulting in a duty cycle of $\sim 44\%$. The MOST data reveal the orbital frequency and many of its harmonics, as well as the 5.75 d^{-1} frequency, already reported in the literature. This frequency has a very low amplitude (0.6 mmag), which explains why it was missed in some earlier studies. Moreover, clear line-profile variability is detected in our spectroscopic data (see Fig. 1), pointing out the multiperiodicity of the star, in agreement with the findings by Smith (1985a,b). The reported amplitude change of the photometric mode is therefore likely a result of unresolved beating with very low amplitude modes only visible in spectroscopy. A full analysis of the MOST light curve will be published elsewhere.

Orbital determination

In order to derive the orbital parameters of Spica and to analyse the possible variability of both components, we used the technique of spectral disentangling. This technique determines the contributions of both components to the composite spectra and the orbital parameters in a self-consistent way. We used the code KOREL (*version 2.12.04*), made publicly available by Hadrava (1995, and references therein). KOREL cross-correlates the input spectra with the disentangled component spectra to provide relative radial velocities. It is important to mention that the technique of spectral disentangling is found to be robust and successful also in the presence of complex variations of line shapes due to non-radial oscillations (Frémat et al. 2005, Harmanec et al. 2004, Uytterhoeven et al. 2004, De Cat et al. 2004). The

Table 2: Final solution of the orbital parameters of Spica from KOREL. P is the orbital period, T_0 is the time of nodal passage, e is the eccentricity, ω is the longitude of periastron, $K_{1,2}$ are the amplitudes in radial velocity of both components (1 denotes the primary, 2 the secondary component), q is the mass ratio and $d\omega/dt$ is the advance of periastron (U is the corresponding apsidal period).

Parameter	KOREL
P	4.0145 days
T_0	HJD 2440690.05
e	0.13
ω	128.9 deg
K_1	115.9 km s ⁻¹
K_2	182.5 km s ⁻¹
$q(m_2/m_1)$	0.63
$d\omega/dt$	0.0071 deg/day ($U=139$ years)

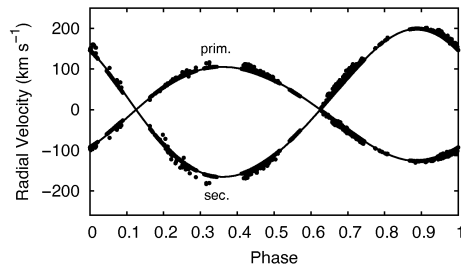


Figure 2: Radial velocities of the spectra for both components after disentangling (black dots) as a function of orbital phase together with the theoretical model (black lines) with orbital parameters listed in Table 2.

orbital parameters were derived applying KOREL to all 1856 spectra in the Si III triplet spectral region. During the fitting procedure, eight free parameters were allowed to describe the orbit of the close binary system. Table 2 lists the final solution for these unknowns. Fig. 1 shows the combined KOREL fit together with the observations for 2 different phases of Spica and Fig. 2 shows the radial velocities of both components after disentangling, together with the theoretical model with orbital parameters of Table 2.

Future work

We are presently trying to improve the orbital parameters of Spica by fitting the radial velocities of the disentangled spectra simultaneously with the complete light curve from MOST through a Wilson-Devinney algorithm. The results from two independent public codes, FOTEL (Hadrava 2004) and PHOEBE (Prša & Zwitter 2005), will be compared with each other. Afterwards we will investigate the variability of the system in two ways. First of all, we will subtract the binary model from the light curve and look for variability in the residuals. Secondly, we will investigate the disentangled spectra which can give us information on the variability of both components separately. Subsequently, this will allow us to apply spectroscopic mode identification techniques on the found modes with state-of-the-art codes, such as FAMIAS (Zima 2008).

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