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Preliminary report

# PROGRESS REPORT ON THE MONITORING ACTIVE LATE-TYPE STARS IN 2005/2006 AND THE ANALYSIS OF V523 CAS

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**SUMMARY: We present the light curve analysis of late-type binary V523 Cas for the season 2005. The spot has been revealed on the secondary. According to theoretical considerations, the spot appeared to be hotter than the surrounding photosphere and located at middle latitudes (the radius 40° and latitude 48°). The light curves for other stars in the observational list (many of them again with O'Connell effect), for the same season, have been made electronically available. These objects are SV Cam, IV Dra, BI Vul, DD Com, 12 Cam and II Peg.**

**Key words. Stars: late type – Stars: activity – starspots – Stars: individual: V523 Cas**

## 1. INTRODUCTION

Magnetically induced solar activity includes such diverse phenomena as non-radiative heating of a global mean chromosphere and corona, as well as time-dependent effects such as flares, sunspots and prominences. These phenomena have stellar counterparts, often on a dramatically enhanced scale.

Starspots are analogues of sunspots wherein strong coherent magnetic fields radically alter subphotospheric convection, reducing the efficiency of energy transport and simultaneously removing subphotospheric energy in the form of waves to accelerate winds. Thus, the starspots properties are worth studying because useful information on stellar dynamo can be revealed. Variable (including spotted) stars observations have long history record, and since Hall's (1994) pioneering paper on spot signatures on RS CVn system, more systematic observations (let us say monitoring) of spotted stars emerged, and this type of scientific programme was subsequently adopted on many observatories. Naturally, monitoring progressed later to fully robotic observations (see e.g. Strassmeier et al. 1997, Weber 2002, Rodonó et al. 2004, for overview).

To make a contribution to the databases, we have been monitoring several selected active late-type stars (often with really poor bibliography) and we have tried to determine the basic spot properties such as the temperature, area and location, on a sample of active late-type stars using photometric methods. These techniques are powerful in the case of eclipsing binaries and are occasionally used for single stars. A spot signature can be revealed, and physical properties such as overall magnetic cycle, differential rotation, 'flip-flop' phenomenon etc, can be estimated from the light curves on longer time bases.

## 2. OBSERVATIONS

New observations in BVR filters were obtained on 7 nights in total, with 0.6m and 0.5m telescopes at Stará Lesná (SL) observatories in the season 2005/2006. Photoelectric photometer was attached to 0.6m telescope while ST10 CCD camera was used in the case of 0.5m telescope. The differential photometry was performed with basic sequence 3xS-3xV-3xCH and with sky background; S stands for standard star, V for variable star and CH for comparison (check) star respectively. Data reduction details and main characteristic of instruments can be found, for example, in Zboril and Djurašević (2004). The targets were included in the list because of very poor bibliography or long term monitoring. Table 1 lists the log of observations. Binaries observed in more than single night were actually observed in nights with total gap less than 3 weeks. Data sets are available on-line at URL address `http://www.ta3.sk`.

## 3. V523 CAS ANALYSIS

To analyze the asymmetric light curve of eclipsing binary we used Djurašević's code (Djuravsević et al. 1998) which is based on the Roche model geometry and allows the inverse problem solution. The minimization is done in an iterative cycle of corrections of the model parameters. The inverse solution gives the estimates of system parameters and their standard errors. The procedure is based on Marquardt's (1963) algorithm and the optimum model parameters are obtained through the minimization of $\sum(O-C)^2$, where (O-C) are the residuals between the observed and synthetic light curves for a given orbital phase. Thus, the standard errors are derived from the covariance matrix. The demonstration of the code for close binary systems is given e.g. in Djurašević (1992), and later in Zboril & Djurašević (2004). The asymmetries in light curves are assumed to be caused by spots on the system components. The spotted regions are considered as circular and characterized by four parameters: the temperature contrast of the spot in comparison with surrounding photosphere, and the angular radius, longitude and latitude. To achieve more reliable estimates of the model parameters in the light curve analysis we applied appropriate coordinate grid (72x144 = 10 368 individual elementary cells per star). The intensity and angular distribution of the radiation of individual cells are determined by the stellar effective temperature, limb darkening, gravity darkening and by the effect of reflection in the system. The adopted algorithm is robust and numerical tests with artificial light curves have shown the stability of solution for spots located in the equatorial zone as an initial iterate in test runs. Besides, the code allows the treatment of disc structure in the system and determination of its geometry.

Binary V523 Cas (GSC03257-00167, K4, $m_V$=10.88) of W UMa type demonstrates interesting aspects of stellar dynamo. Probably first claims of cool spots on components appeared in Zhukov (1985), radial velocity study was presented by Milone et al. (1985), the light curve solution by Maceroni (1986). Complex study of the physical nature and orbital behavior was performed by Samec et al. (2004), who presented non-linear ephemeris confirming period increase/decrease in this contact binary. The system could undergo thermal relaxation oscillations and probably goes down to shallow contact mode (see also Qian 2003). What is important, Samec et al. (2004) solved the light curves for the season September 1998, and with the help of radial velocity curves study, surprisingly found the bright spot on (less massive) secondary. The following ephemeris after Samec have been used (though time-span of observations does not currently justify the inclusion of sine term)

$$\begin{aligned} \mathrm{MinI} = & \ \mathrm{HJD}\ 2446708.8030 + 0^d.233691049 \times E + \\ & + 1.02.10^{-11} \times E^2 + \\ & + 0.0364 \times \sin(3.87.10^{-5} \times E - 1.042). \end{aligned} \tag{1}$$

**Table 1.** The log of observations.

| *Star* | *Date* | *Filter* | *Nights* |
|---|---|---|---|
| SV Cam | IX,X 2005 | VR | 25.IX, 19.X |
| V523 Cas | IX 2005 | VR | 1.IX |
| BI Vul | IX 2005 | VR | 21.IX |
| IV Dra | V,VI 2005 | VR | 27.V, 28.V, 24.VI |
| 12 Cam | X,2005-III,2006 | BV | 12 nights |
| II Peg | XI,2005-II 2006 | V | 9 nights |
| DD Com | IV 2006 | VR | 22.IV |

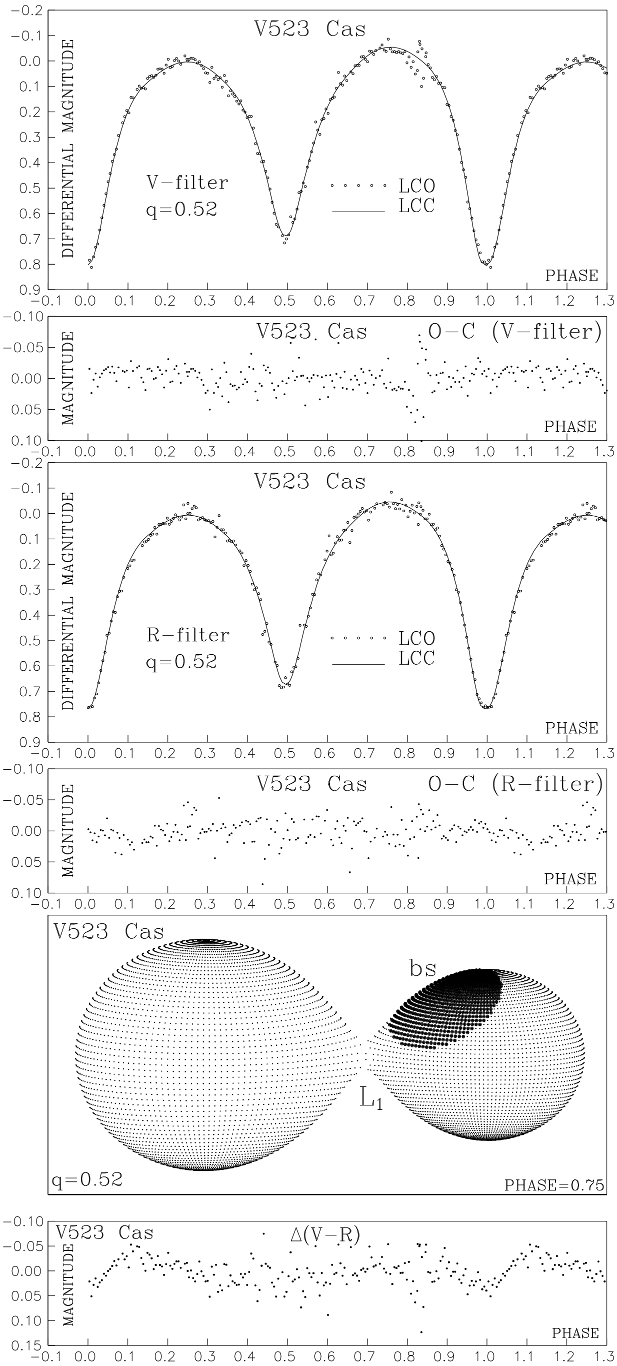


**Fig. 1.** *Observed (LCO) and synthetic (LCC) light curves of the V523 Cas with final O-C residuals obtained by simultaneous analysis of the V and R observations, the view of the system at the orbital phase 0.75 with parameters from the inverse problem solution, and differential* $\Delta(V-R)$ *colour curve.*

## 4. RESULTS

**V523 Cas** has proven to be a challenging system. As already mentioned, the system is also a subject of oscillations investigations. Detailed study on stellar parameters and spots given by Samec et al. (2004) revealed *bright spot* on (less massive) secondary using consistent data, i.e. photometric and spectroscopic (the radial velocities) curves, simultaneously. The analysis of our data set confirms the bright spot on secondary star. The system shows a marginal overcontact with the degree $f_{\rm over} \sim 5\%$, with less massive smaller component being somewhat hotter than primary. On the level of hypothesis, if smaller component suffers contraction, a part of gravitational energy can be translated to heat and therefore smaller component may turn to be a hotter one.

In the present light curve analysis, the value for the mass-ratio of the components ($q = m_{\rm h}/m_{\rm c} = 0.52$) and for the temperature of the cooler primary star ($T_c = 4762$ K) were taken from Samec et al. (2004) and fixed in the inverse problem solving. For gravity-darkening exponents and stellar albedos we used standard values for convective atmospheres ($\beta_{c,h} = 0.08$, $A_{c,h} = 0.5$).

Considering albedo as the free parameter we show that the secondary star albedo is much higher than the theoretically expected value, i.e. there is probably a hot-spot region on the stellar hemisphere facing the neighboring component. Thus, by fixing the albedo to its theoretically expected value ($A$=0.5), the light curves were solved assuming the existence of a bright spot on the smaller, hotter, less massive component. The solution with a bright spot area located on the less massive star, near the connecting neck region of the common envelope, gives a satisfactory fit to the analysed light curves (see Table 2 and Fig. 1.

The estimated errors of the parameters arise from the non-linear least-squares method, on which the inverse-problem method is based. The real uncertainties of these parameters may be larger than the estimated ones (approximately 10 times). This is due to the influence of errors of the model input parameters, which are taken as fixed in the inverse-problem solution, and the presence of non-linearity in parameter space.

The scenario with the dark spot on either of components was examined but the obtained solutions are of much poorer quality, and less probable. Though not noted explicitly, the spot inclusion was necessary in our modelling, since the solution without spots was not satisfactory, with sum of squares easily differing by as much as 100 %.

**Table 2.** V523 Cas V and R light curves simultaneous fit with formal errors.

| Quantity | |
|---|---|
| $n$ | 373 |
| $\Sigma(\mathrm{O}-\mathrm{C})^2$ | 0.1892 |
| $\sigma$ | 0.0225 |
| $q = m_\mathrm{h}/m_\mathrm{c}$ | 0.52 |
| $T_\mathrm{h}$ | $4991 \pm 12$ |
| $T_\mathrm{c}$ | 4762 |
| $A_\mathrm{c} = A_\mathrm{h}$ | 0.5 |
| $\beta_\mathrm{c} = \beta_\mathrm{h}$ | 0.08 |
| $f_\mathrm{c} = f_\mathrm{h}$ | 1.0 |
| $\mathrm{A_{bs} = T_{bs}/T_h}$ | $1.10 \pm 0.01$ |
| $\theta_\mathrm{bs}$ | $40.0 \pm 1.2$ |
| $\lambda_\mathrm{bs}$ | $137.6 \pm 3.8$ |
| $\varphi_\mathrm{bs}$ | $48.0 \pm 2.1$ |
| $F_\mathrm{c}$ | $1.006 \pm 0.001$ |
| $i$ [°] | $83.5 \pm 0.3$ |
| $a_1^\mathrm{c,h}(\mathrm{V;R})$ | $+0.6732, +0.6565;\ +0.7075, +0.7012$ |
| $a_2^\mathrm{c,h}(\mathrm{V;R})$ | $-0.8495, -0.7404;\ -0.7715, -0.7069$ |
| $a_3^\mathrm{c,h}(\mathrm{V;R})$ | $+1.7372, +1.6434;\ +1.5134, +1.4394$ |
| $a_4^\mathrm{c,h}(\mathrm{V;R})$ | $-0.6876, -0.6976;\ -0.6311, -0.6290$ |
| $\Omega_\mathrm{c,h}$ | 2.8992 |
| $\Omega_\mathrm{in}, \Omega_\mathrm{out}$ | 2.9141, 2.6048 |
| $f_\mathrm{over}[\%]$ | 4.82 |
| $R_\mathrm{c,h}[D=1]$ | 0.413, 0.305 |
| $\mathrm{L_c/(L_h + L_c)}$ | 0.569[V]; 0.577[R] |
| $\mathcal{M}_\mathrm{c}[\mathcal{M}_\odot]$ | $0.78 \pm 0.02$ |
| $\mathcal{M}_\mathrm{h}[\mathcal{M}_\odot]$ | $0.40 \pm 0.02$ |
| $R_\mathrm{c}[\mathrm{R}_\odot]$ | $0.74 \pm 0.02$ |
| $R_\mathrm{h}[\mathrm{R}_\odot]$ | $0.55 \pm 0.03$ |
| $\log g_\mathrm{c}$ | $4.58 \pm 0.02$ |
| $\log g_\mathrm{h}$ | $4.56 \pm 0.03$ |
| $M_\mathrm{bol}^\mathrm{c}$ | $6.26 \pm 0.05$ |
| $M_\mathrm{bol}^\mathrm{h}$ | $6.71 \pm 0.06$ |
| $a_\mathrm{orb}[\mathrm{R}_\odot]$ | $1.687 \pm 0.012$ |

**Note:** $n$ - total number of the V and R observations, $\Sigma(\mathrm{O}-\mathrm{C})^2$ - final sum of squares of residuals between observed (LCO) and synthetic (LCC) light-curves, $\sigma$ - standard deviation of the observations, $q = m_\mathrm{h}/m_\mathrm{c}$ - mass ratio of the components, $T_\mathrm{c,h}$ - temperature of the cooler and hotter component, $\beta_\mathrm{c,h}$, $A_\mathrm{c,h}$, $f_\mathrm{c,h}$ - gravity-darkening exponents, albedos and nonsynchronous rotation coefficients of the components respectively, $\mathrm{A_{bs}}$, $\theta_\mathrm{bs}$, $\lambda_\mathrm{bs}$ and $\varphi_\mathrm{bs}$ - bright spot temperature coefficient, angular dimension, longitude and latitude (in arc degrees), $F_\mathrm{c}$ - filling factor for the critical Roche lobe of the cooler component, $i$ [°] - orbit inclination (in arc degrees), $a_1^\mathrm{c,h}$, $a_2^\mathrm{c,h}$, $a_3^\mathrm{c,h}$, $a_4^\mathrm{c,h}$ - nonlinear (V;R) limb-darkening coefficients of the components (Claret's formula, Claret & Hauschildt 2003), $\Omega_\mathrm{c,h}$, $\Omega_\mathrm{in}$, $\Omega_\mathrm{out}$ - dimensionless surface potentials of the components and of the inner and outer contact surfaces respectively, $f_\mathrm{over}[\%]$ - degree of overcontact (Wilson and Devinney 1971), $R_\mathrm{c,h}$ - polar radii of the components in units of the distance between the component centres, $L_\mathrm{h}/(L_\mathrm{h} + L_\mathrm{c})$ - luminosity (V;R) of the more massive hotter star (including bright spot on the secondary), $\mathcal{M}_\mathrm{c,h}[\mathcal{M}_\odot]$, $R_\mathrm{c,h}[\mathrm{R}_\odot]$, - stellar masses and the effective radii of stars in solar units, log $g_\mathrm{h,c}$ - logarithm (base 10) of the system components effective gravity, $M_\mathrm{bol}^{c,h}$ - absolute bolometric magnitudes of V523 Cas components and $a_\mathrm{orb}[\mathrm{R}_\odot]$ - orbital semi-major axis in units of solar radius.

## 5. CONCLUSIONS

We performed the light curve modelling of close binary V523 Cas. The observational data were obtained in 2005. V523 Cas turned out to be interesting system (perhaps even more from evolutionary point of view). We obtained the following results by way of modelling: secondary is hotter than primary and one bright spot at middle latitudes has been found on star's surface (radius 40°, longitude 138°, latitude 48°; longitude is measured from opposite to neck i.e. $\lambda = 180°$ at the neck, and latitude is measured from equatorial plane i.e. $\varphi = \pm 90°$ at poles). This bright spot produces asymmetry of the light curves.

Samec et al. (2004) also found the bright spot on the secondary, which is located close to the neck zone. Their solutions show much larger degree of overcontact ($f_{\mathrm{over}} \sim 29\%$) and significant temperature difference between the components ($\Delta T = T_h - T_c \sim 340K$), which is inconsistent with what we know about typical short period shallow contact binaries.

Other targets (SV Cam, BI Vul, IV Dra, DD Com, 12 Cam and II Peg) also display the activity induced signatures (spots) during the season 2005/2006, but their modelling is beyond the scope of this paper.

Monitoring of spotted targets helps to match and understand magnetic cycle and stellar dynamo associated with it. Such studies are especially needed if the stellar atmosphere faces rather anomalous (extreme) conditions (which is the case in close binaries with distorted atmospheres). Many results already proved the power of monitoring: this is certainly the case with monitoring of starspots as tracers of differential surface rotation (Cameron 2002), starspots cycles from long-term photometry (Oláh and Strassmeier 2002), the brightness variability of late-type stars (Messina et al. 2004).

Since there is a difference in magnetic activity between the Sun and the active stars, there may be considerable differences in their magnetic field distributions. For example, a recent work on magnetic flux tubes suggests higher spot latitudes for rapidly rotating stars (Schuessler 2005). Monitoring the activity induced variability and specific spot modelling on stars (single or binaries) thus remains necessary to achieve better observational aspects of these phenomena.

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# ПРАЋЕЊЕ АКТИВНИХ ЗВЕЗДА ПОЗНИХ СПЕКТРАЛНИХ ТИПОВА ТОКОМ 2005/2006 И АНАЛИЗА V523 CAS

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*Претходно саопштење*

У раду је представљена анализа кривих сјаја двојног система позног спектралног типа V523 Cas за сезону 2005. Утврђено је постојање пеге на секундарној компоненти. Пега је веће температуре у односу на околну фотосферу, у складу са неким теоријским разматрањима, и налази се на средњим латитудама (радијус пеге 40° и латитуда центра 48°). Криве сјаја осталих звезда са посматрачке листе (од којих многе такође показују О'Конелов ефекат) електронски су доступне. Ову групу звезда чине SV Cam, IV Dra, BI Vul, DD Com, 12 Cam и II Peg.