The radial velocities of the uncommon SrCrEu magnetic star 49 Camelopardalis

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1 The scientific goals

In 1994-1995 we carried out the test radial velocity observations of SrCrEu stars with the Moscow State University CORAVEL-type radial-velocity spectrophotometer (RVS, Tokovinin (1987)). The main goals of the observations were testing the fitness of accurate radial velocity (RV) measurements with CORAVEL-type spectrophotometers with cross-correlation templates for the asteroseismology of Ap stars (Mkrtichian, 1994), determination of typical accuracy for stars with different rotational velocities, search for pulsational RV variability. The excess of metallic and rare-earth element spectral lines in spectra of Ap stars holds out hope to achieve a suitable accuracy of V_r measurements even for the early A and F Ap stars.

The typical FOp SrCrEu stars γ Equ ($v \sin i < 5$ km s^{-1}) and 49 Cam ($v \sin \% = 22$ km s^{-1} (Bonsack et al., 1974)), as the two stars with the low and relatively high rotational velocities were included in our program.

The complete results with the analysis of rapid V_r variability of these two stars will be published in a separate article; we note here only that the typical internal errors of a single one-minute integration for γ Equ on the 1.0 m telescope of the Simeiz Station of the Sternberg Institute were in the range of 120-300 m s^{-1}, the accuracy of 8-minute integration time for 49 Cam at the 0.7 m telescope of the Sternberg Institute gaves a typical internal error per single measurement of 450 - 870 m s^{-1}.

2 The 1994-1995 RVs of 49 Cam

The 1994 observations of 49 Cam were carried out on the 0.7 m Zeiss telescope of the Sternberg Astronomical Institute (Moscow, Russia) during 4 nights in spring. We used the cross-correlation mask of Alpha Bootis (Tokovinin, 1987) not optimized for Ap stars.

Our first estimates of V_r in 1994 immediately show significant differences (approximately +13 km s^{-1}) between our estimates of the mean RV and the value 1.4 ± 1.5 km s^{-1} from Wilson's General Catalog of Radial velocities (Wilson, 1953; Young, 1945).

A comparison of our 1994 data and the available V_r for the 49 Cam RVs given in the papers of van den Heuvel (1971), Bonsack et al. (1974) shows a monotonic increase of the mean V_r from 1.4 km s^{-1} to about 15 km s^{-1} over the last 50 years.

We continued our RV measurements of 49 Cam during three nights in the spring-summer of 1995 and detected an unpredictable rapid decline in the RVs during 1994-1995 from +16 km s^{-1} to -0.9 km s^{-1}.

The compiled mean V_r data of all the authors are presented in Table 1.

The first and second columns give the year and the mean Julian Dates of observations, respectively, the third and fourth — the estimates of the mean V_r and the standard error of the mean, the

Table 1: Mean radial velocities of 49 Cam.

Year	$\overline{JD}$ 2440000.+	$\overline{VR}$ km s^{-1}	σ km s^{-1}	N	Ψ_{rot}	Reference
$\leq$1945	-	1.4	1.5	4	-	Young,1945
1969	384.3	5.3	0.3	6	-	Heuvel,1971
1971-72	1422	7.2	0.12	17	-	Bonsack et al.,1974
1994	9419.418	16.22	0.95	1	0.851	This paper
1994	9449.350	13.82	0.62	11	0.835	-
1994	9455.363	14.55	0.9	12	0.237	-
1994	9469.333	9.98	0.87	11	0.496	-
1995	9789.349	6.63	0.62	1	0.151	-
1995	9791.424	4.37	1.17	2	0.635	-
1995	9865.323	-0.89	2.42	2	0.875	-

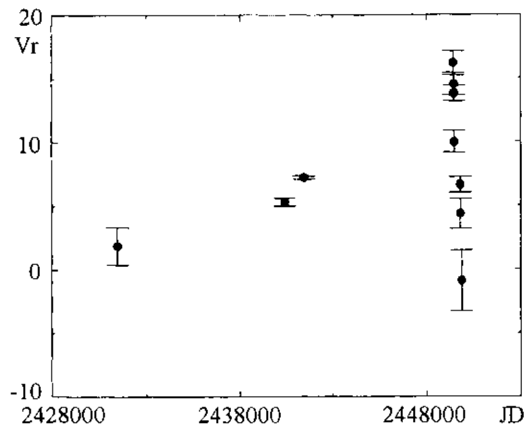

Figure 1:

fifth and sixth — the number of averaged estimates and the rotational phase, and the last column gives the references.

The rotational phases were calculated according to ephemerides of Leroy et al. (1994)

JD(negative crossover)= 2441254.08 + 4.2866E days.

The mean RVs versus the Heliocentric Julian Date are presented in Fig. 1. Unfortunately, for the mean value of 1.4 km s^{-1} given in Wilson's catalog and in the original reference (Young, 1945) the date of observations is not given, we mark this point in Fig. 1 with an arrow as related to some moment before the date of publication in 1945.

Fig. 2 displays our 1994-1995 observations with their error bars as well as the adjusted linear fit (dashed line) of the data. The rapid decline of V_r with 0.029 km s^{-1} day^{-1} is well seen from our data.

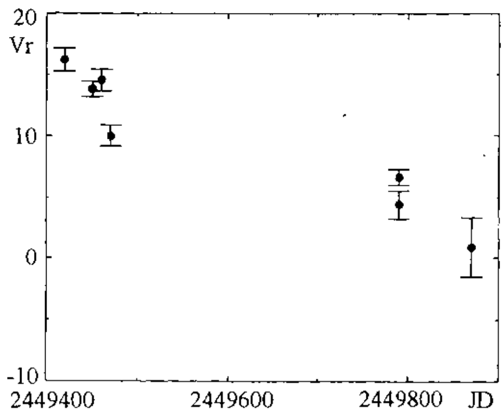

Figure 2:

3 Discussion

One can suppose that the probable reason for the detected V_r variations is the binary motion of 49 Cam. From our 1994-1995 data the orbital period must be about several years. However, in contrast to our results the 1971-1972 observations of Bonsack et al. (1973) spanning 328 days did not show the peak to peak V_r changes higher than ± 2 km s^{-1} and any tendency to monotonic changes.

The nature of such significant differences, in principle, can be produced by the well-known effect of inhomogeneous surface distribution of elements and star rotation. The range of such expected rotational differences is limited by $\pm$ $v \sin i$ value and can be approximately ± 22 km s^{-1} for 49 Cam. The temporal trends can be estimated as

$$\frac{\Delta V_r}{\Delta t} \leq \frac{4v \sin i}{P_{rot}} (\text{km s}^{-1}\text{h}^{-1}), \tag{1}$$

and if we take P_{rot} = 4.2866 days and $v \sin i$ = 22 km s^{-1}, this trend can have the upper limit of values 0.8 km s^{-1}hour^{-1} and, in principle, can be measurable with the RVS during one night of observations.

However, in our case, as the made Alpha Bootis cross-correlation masks are not optimized for SrCrEu stars (see Mkrtichian (1994) concerning the problem of optimization of masks for introducing the periodic spatial filters and gaining the detection sensitivity to nonradial modes) and rejected all the visible spectral lines, the possible influence of V_r variations caused by surface inhomogeneities and stars rotation was minimized both for the data of Young (1945), Heuvel (1972) and Bonsack et al. (1974) where the spectral lines of different elements were involved in the calculation of mean velocity per single plate, and different rotational phases were involved in the calculation of the mean velocity of stars.

Nevertheless, possible small variations in our mean RVs versus the rotational phase can be seen from Fig. 3, where we present the residuals of our estimates relative to the linear fit.

According to Stift (1985), the RV determinations with CORAVEL-type spectrophotometers would give the spurious phase-dependent RV variations due to line asymmetry produced by Zeeman splitting. For an 8 kG magnetic field and rotational velocities between 5 and 10 km s^{-1} he gives the RV amplitude of 10-20 km s^{-1}.

However, these expected spurious phase-dependent magnetic RV variations overlapped those

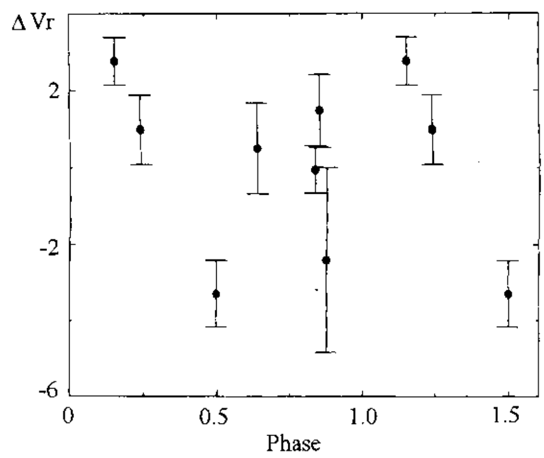

Figure 3:

produced by the surface chemical elements inhomogeneities are in disagreement with 1994-1995 drastic decline of RVs covering different rotational phases. It is possible that a weak contribution of this effect occurs in the phase curve of RV residuals in Fig. 3.

According to Leroy et al. (1994) 49 Cam has strong and variable linear polarization (upper limit about 0.26 *%)* and the magnetic field configuration departs from the simple dipole structure. Among 40 Ap stars they have observed 49 Cam as one of the most peculiar and almost unique object.

The magnetic nature of such RV variations can basically be explained if during 1994-1995 49 Cam changes the magnetic field configuration, as in the yet unexplained case for the magnetic star 52 Her, which twice showed the rapid reversal of magnetic polarity from about +2 to -2.8 kG in 1975-1978 and from -2.8 to +1.6 kG in 1978-1980 (Gerth, 1990). However, for the case of 52 Her this polarity reversal was not affected by any significant radial velocity variations.

Note, that evidence of low amplitude cyclic magnetic field variations in Ap stars (similar to the solar p-mode frequency changes with solar cycles) is coming from the asteroseismology of roAp stars. Every roAp star from the sample of the well-studied roAp stars shows cyclic frequency variations of nonradial modes (Kurtz et al., 1994).

Returning to 49 Cam, we want to note that the incomplete time coverage and the absence of simultaneous magnetic field measurements does not permit us at present to decide whether the detected V_r variability is caused by the binary motion of the star or it is driven by the effects of the magnetic field influence on asymmetry of spectral lines.

4 Conclusions

Based on the previous investigations and our 1994-1995 radial velocity observations we can summarize the results of our work as follows:

- We made 40 new radial velocity measurements of 49 Cam covering different rotational phases.

- A comparison between our data and all published estimates of 49 Cam RVs shows a slow increase in RV of 49 Cam from 1.4 km s^{-1} in the early forties up to 16.2 km s^{-1} in 1994.

- Our 1994-1995 RVs show a rapid decline from 16.2 km s^{-1} to -0.9 km s^{-1}. The linear trend approximation of such a decline is 0.029 km s^{-1} day^{-1}.

- We discussed the possible nature of the yet unexplained character of V_r variations in the star and mark the uncommon nature of such variations.

5 The present and future work

Due to the uncommon behaviour of **49** Cam the question of significance is to revise the behaviour of **49** Cam RVs in the past. In the SAO collection of spectrograms there are nine **9 A**/mm plates of **49** Cam taken with the Main Stellar Spectrograph, which cover **1982-1983-1984** interval and could be used for RV measurements.

In the spring of **1995,** one of the authors (MDE) carried out three-night spectral observations of **49** Cam within the interval of rapid RVs decrease with the SAO **6** m telescope echelle spectrometer "LYNX" (Panchuk et al., **1993)** at the Nasmyth-**2** focus covering different rotational phases . The reduction of the CCD spectra is now in progress and would support the CORAVEL results.

Futher multisite complex investigations of **49** Cam based on surface magnetic fields and abundance mapping, radial velocity and photometric observations are needed for defining the nature of this puzzling star.

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