CONTENTS

PRELIMINARY RESULTS OF DOPPLER IMAGING ANALYSIS OF roAp STAR α Cir

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ABSTRACT. Based on high-resolution spectra, we investigate the abundance distribution of chromium and silicon on the surface of α Cir using Doppler Imaging technique. Results of our analysis show the presence of chromium and silicon spots on the surface of α Cir as well as large gradients of the abundances of these elements.

Key words: Stars: Alpha Circini; methods:Doppler imaging mapping

1. Introduction

α Cir(HD 128898; HR 5463) is one of the brightest rapidly oscillating Ap (roAp) stars. Despite of the fact that this is one of the best studied roAp stars showing vertical stratification of several chemical elements (see Kochukhov et al. 2009), Doppler Imaging (DI) analysis of this star was not carried out so far. In this paper we fill in this gap in the study of α Cip and represent preliminary results of DI mapping based on chromium and silicon lines. In Sect.2, we shortly describe the observational material that we have at our disposal as well as the data reduction procedure. Sect.3 is devoted to the description of DI technique while the results are presented in Sect.4. Finally, Sect.5 gives the summary of our study.

2. Observations and data reduction

We have obtained 5 high-resolution spectra with the UCLES coude echelle spectrograph installed at the 3.9-m Anglo-Australian Telescope (AAT) and 6 high-resolution spectra with the UVES echelle spectrograph installed at the 8.2-m Very Large Telescope (VLT). The spectra cover wavelength range from 6115 Å to 6155 Å. Although the UVES spectra have been reduced with the standard pipeline installed at the telescope, we had to reduce the spectra from UCLES. For this aim, an automatic data reduction procedure have been developed.

Table 1: Journal of observations. HJD is the heliocentric Julian Date, ϕ is the corresponding rotational phase.

Seq.	Source	HJD	ϕ
1	UCLES	2453510.844	0.812
2	UCLES	2453511.851	0.037
3	UCLES	2453512.891	0.269
4	UCLES	2453513.902	0.495
5	UCLES	2453514.892	0.716
6	UVES	2451945.894	0.430
7	UVES	2451946.895	0.654
8	UVES	2451947.889	0.876
9	UVES	2451953.895	0.217
10	UVES	2451954.893	0.440
11	UVES	2451955.900	0.665

Table 1 gives the journal of observations. Rotational phases have been computed in accordance to the Julian Dates calculated for all spectra as follows:

$$HJD = 2453937.2086 + 4.4790 * E. \quad (1)$$

3. Doppler Imaging technique

Stellar surface inhomogeneities, such as a nonuniform distribution of temperature or chemical composition, lead to characteristic distortions in the profiles of Doppler broadened stellar spectral lines. In the course of stellar rotation these distortions will move across the line profiles due to the changes in visibility and Doppler shifts of individual structures at the stellar surface.

The Doppler imaging (DI) technique utilizes the information contained in the rotational modulation of the absorption line profiles and reconstructs features at the surfaces of stars by inverting a time series of high-resolution spectra into a map of the stellar surface.

4. Results

We started with the selection of the spectral line profiles showing variability with rotational phase. For

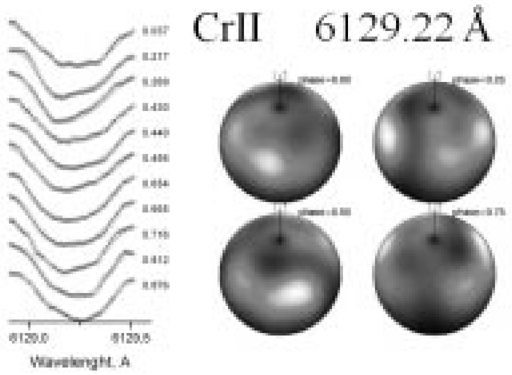

Figure 1: Stellar surface abundance map for Cr in spherical projection obtained based on Cr II 6129.22 Å line. Comparison between observed (crosses) and computed (solid lines) spectra are given to the left. Scale is in dex.

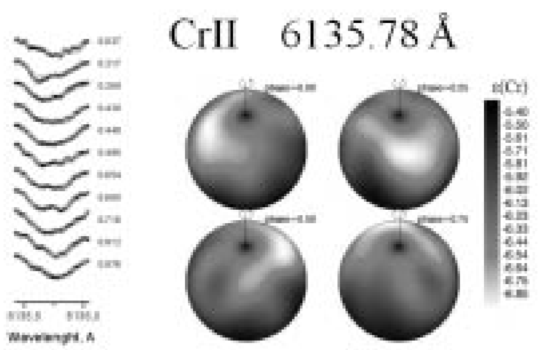

Figure 2: Same as Fig. 1 but for Cr II 6135.78 Å line.

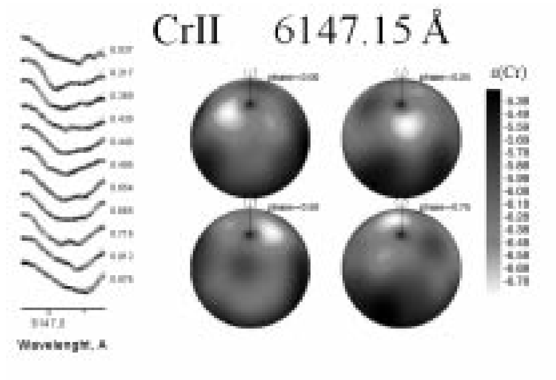

Figure 3: Same as Fig. 1 but for Cr II 6147.15 Å line.

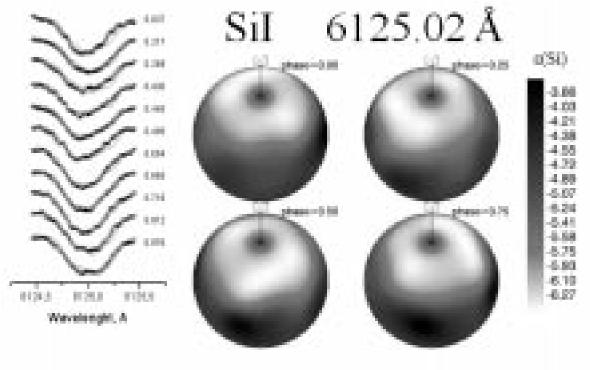

Figure 4: Same as Fig. 1 but for Si I 6125.02 Å line.

our analysis, we have selected three Cr II lines (Cr II 6129.22 Å, Cr II 6135.78 Å, Cr II 6147.15 Å) and one Si I line (Si I 6125.02 Å).

For the DI analysis, we used the INVERS8 program (Piskunov & Rice 1993) which uses Tikhonov regularization delivering results in the sense of the smoothest map in terms of stellar surface abundances that is possible to fit the observations at a certain level. The program uses pre-calculated tables of intrinsic line profiles which have been computed with the SynthV code (Tsymbal 1996) using the LLmodels atmosphere models (Shulyak et al. 2004). Atomic line lists were taken from the VALD database (Kupka et al. 2000).

Figs. 1–3 show the abundance distribution for Cr in spherical projection. Comparison between observed (crosses) and computed (solid lines) line profiles are shown to the left. The bright spots of lower chromium abundance are clearly seen on the surface of the star and the observed line profiles are well fitted. The rotational velocity of 12.5 km s^{-1} and the inclination angle of the rotation axis to the line of sight of 35° were adopted in the model.

As shown in Fig.4, the abundance distribution of Si on the surface of α Cir is characterized by a large spot of lower abundance located at the rotational pole of the star. Both, Cr and Si show large gradients of the abundances of about 2.4 dex.

5. Discussion

Based on high-resolution spectra obtained with two different instruments, we have carried out Doppler Imaging analysis of roAp star α Cir. Despite of the small number of spectra that we had at our disposal, we could show that both Cr and Si are inhomogeneously distributed on the star's surface showing large gradients of about 2.4 dex.

In future, we plan to carry out a more detailed study of α Cir based on extended spectroscopic observations.

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"INTER-LONGITUDE ASTRONOMY" (ILA) PROJECT: CURRENT HIGHLIGHTS AND PERSPECTIVES. I. MAGNETIC VS. NON-MAGNETIC INTERACTING BINARY STARS

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ABSTRACT. We present a review of highlights of our photometric and photo-polarimetric monitoring and mathematical modeling of interacting binary stars of different types classical, asynchronous, intermediate polars with 25 timescales corresponding to different physical mechanisms and their combinations (part "Polar"); negative and positive superhumpers in nova-like and dwarf novae stars ("Superhumper"); symbiotic ("Symbiosis"); eclipsing variables with and without evidence for a current mass transfer ("Eclipser") with a special emphasis on systems with a direct impact of the stream into the gainor star's atmosphere, which we propose to call "Impactors", or V361 Lyr-type stars. Other parts of the ILA project are "Stellar Bell" (pulsating variables of different types and periods - M, SR, RV Tau, RR Lyr, Delta Sct) and "New Variable".

Key words: Variable stars: cataclysmic, pulsating, eclipsing, interacting binary

The monitoring of the first star of our sample AM Her was initiated by Prof. V.P.Tsessevich (1907-1983). More than 300 papers were published, with a total number of studied variable stars exceeding 1400. The previous review of the "Inter-Longitude Astronomy" ("ILA") campaign was published by Andronov et al. (2003). For the CCD observations, we mainly use the BVRI calibration of A.Henden.

The "top of the top" of the recent highlighs are:

- **TT Ari** (nova-like superhumper): discoveries of a back switch between the states of positive and negative superhumps (Andronov et al., 1999, 2005a); of a "loop" at the "Period of Quasi-Periodic Oscillations (QPO) brightness", contrary to a previous suggestion on dependence of characteristics of superhumps and QPOs on brightness (Kim et al., 2009); of drastic brightness variations up to 2 mag during a prolonged exotic "low luminosity state" started in October, 2009 and continued for one year, finished just before final version of this paper, passing through stages (with increasing luminosity) of positive superhumps, double wave of positive superhumps; negative superhumps.

- **DO Dra** (an "outbursting intermediate polar" or a "magnetic dwarf nova"): discoveries of the new type of variability "Transient Periodic Oscillations" (TPO), which are interpreted by model of plasma blobs spiralling down to the magnetic white dwarf; correlation of the decay rate and outburst brightness; out-of-outburst luminosity variations (Andronov et al., 2008);

- **V1432 Aql** (asynchronous polar): discovery of a third type of eclipses in the system, self-consistent model for the arc-shaped accretion structure (Andronov and Baklanov, 2007); determination of the most accurate value of the synchronization time of 96.5 ± 1.5 years (Andronov and Baklanov, 2006) in an excellent agreement with former theoretical prediction for another system AM Her with similar physical parameters (Andronov, 1987ab);

- **AM Her** (synchronous polar): Discovery of two-component nature of the "shot noise" with characteristic time-scales of 9.8 and 170 sec based on the 24117 seconds of CHANDRA observations, which justifies the "Z-pinch"-type magnetohydrodynamic instability in falling plasma blobs "spaghetti" (Andronov et al., 2003, 2005b). More detailed self-review was published by Andronov (2008);

- **BY Cam** (asynchronous polar): detailed study of previously discovered switching of accretion from pole to pole with a phase of spin-orbital beat; correlation between the color index and brightness, which is an agreement with a cyclotron emission of the accretion column (Andronov et al., 2008); detection of drastic changes of the amplitude of variations of polarization which may be explained by variations of the accretion structure dependent on periodically changing angle between the line of centers and the magnetic axis (Breus et al., 2007);

- **Intermediate polars** (BG CMi, MU Cam =1RXS J062518.2+733433, FO Aqr, AO Psc, 1RXS J063631.9 +353537, 1RXS J070407.9 +262501, 1RXS J180340.0 +401214, 1RXS J192626.8 +132153, 1RXS J213344.1 +510725, PQ Gem, V405 Aqr): study of the rotational evolution of magnetic white dwarfs in these systems based on long-term monitoring; some systems exhibit acceleration (Andronov, Ostrova and Burwitz, 2005) or deceleration (Kim et al., 2005) of rotational acceleration (i.e. negative or positive $\mathrm{d}^2P/\mathrm{d}t^2$), for interpretation of which a model of precession was proposed (Andronov, 2005); the statistical dependence of phases of spin pulses on orbital phase was detected in MU Cam, indicating modulation of the accretion structure with a periodically changing angle between the magnetic axis and the line of centers (Kim et al., 2005);

- **OT J071126.0+440405** (synchronous polar with 3 types of eclipses): discovery of 3 distinctly separate luminosity states based on 100+ nights of mono and multi-color observations; determination with best accuracy of the parameters of the light curve; elaboration of self-consistent theoretical model for structure of the system, which is dependent on luminosity (i.e. the accretion rate);

- **Eclipsing nova-like variables** (DW UMa, BH Lyn, PX And, other SW Sex stars): besides superhumps and QPOs, they exhibit an ultra-violet excess (seen in the U-B color index) at the eclipse (e.g. Andronov et al., 2001), indicating an extended hot emission region (like an accretion disk corona) and thus a physical unreliability of thin disk models;

- **Positive vs. Negative Superhumps** in non-eclipsing Nova-Like variables: besides a large international campaign on TT Ari, we arrange occasional campaigns for V603 Aql. In 2004 the system was found to ehxibit either positive superhump with a period 0.14813(10), or the statistically significant waves with $3^{\mathrm{d}}9$, $1^{\mathrm{d}}4$, $0^{\mathrm{d}}135$, which may be interpreted as the negative superhump-orbital, the beat periods (negative superhump - positive superhump) and the negative superhump with low amplitude, respectively (Andronov et al., 2005c). Similarly to TT Ari, another star MV Lyr showed dependence of colors of variations with time scale - the most "blue" spectral energy distribution correspond to the quasi-periodic oscillations (QPO), the most "red" is time-averaged emission and the negative superhumps are intermediate in color temperature (Andronov and Antoniuk 2005). Using advanced methods for mathematic modeling of multi-component signals, from the observations obtained during 6 nights following "the king of superoutbursts" in WZ Sge, we succeeded to detect not only a orbital variablity with prominent eclipses of the accretion disk, but also "early superhumps", which have become dominating only two weeks later (Andronov et al., 2002).

- **Symbiotic stars:** photographic photometry and time series analysis was made for dozens stars during an international campaign initiated by Hric and Skopal (1989). For recent studies of these stars, we use different methods: periodogram, wavelet, scalegram analysis and global (polynomial + trigonometric polynomial fits) and local (running parabolae, running sine fits), see e.g. Andronov and Chinarova (2003).

- **New Eclipsing and Pulsating variables:** from the database of BV Hipparcos-Tycho observations, we have found 863 new variables (Andronov et al., 1999), the majority of which are eclipsing or pulsating variables. For such a study, we have used trigonometric polynomial fits of 1, 2, 3 orders and than specially developed algorithms of "EAC" ("EA catcher", which is effective for noisy observations not only of the EA-type systems, but also for the types EB and EW) and "RR Catcher" (Andronov, Cuypers and Piquard, 2010). More than fifty new variable stars were discovered, studied and classified by N.Virnina. From those, 27 discoveries were reported separately in this volume (Virnina, 2010b). It should be noted that, from this sample, 10 systems (i.e. $\sim 37\%$) exhibit statistically significant difference between the brightness at maxima arguing for a presence of spots.

- **VSX J052807.9+725606**: discovery of large asymmetry of the newly detected variable (Virnina, 2010a, Virnina and Andronov, 2010) with an amplitude increasing towards shorter wavelengths, which were interpreted in terms of the model proposed for V361 Lyr (Andronov and Richter, 1987), i.e. an extremely bright hot spot caused by a direct impact of an accretion stream from the donor to the accretor's atmosphere at a precontact stage; this allows to propose a new class of "Impactors".

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HIGH-ACCURACY MAGNETIC FIELD MEASUREMENTS ON COOL GIANT β GEMINORUM

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ABSTRACT. Pollux is a weakly-active yellow giant neighbor of the Sun with known regular surface magnetic field about 1 Gauss. We present new high-accuracy magnetic field measurements of β Gem which were obtained during 2010 at Crimean Astrophysical Observatory with 2.6-m telescope and Stokesmeter.

Key words: Stars: magnetic field; stars: individual: β Gem.

1. Introduction

Pollux (β *Geminorum*, HD 62509, HR 2990) is a single bright and well-studied star, classified as a K0 IIIb giant. The distance to Pollux was measured by Hipparcos and equals to 10.3 pc. Interferometric measurements have determined stellar diameter of $8.8 \pm 0.1\ R_\odot$ (Nordgren et al., 2001). Published parameters differ for different investigators. Values of effective temperature $T_{eff} = 4660 \div 4920$ K, a surface gravity $\log g = 2.52 \div 3.15$, metallicity $[Fe/H] = -0.07 \div 0.19$, and stellar mass $M_\star = 1.7 \div 2.3 M_\odot$. The radial velocity variations with a period of 554 days have been discovered for β Gem by Hatzes & Cochran (1993). The main hypothesis for these variations is that they due to a planetary companion with a mass of $2.9 M_{Jup}$. Subsequently Hatzes et al. (2006), Reffert at al. (2006) and Han et al. (2008) confirmed this explanation with a revised period in the range of 590–596 days. Aurière et al. (2009) reported the detection a weak magnetic field about 1 Gauss on the surface of Pollux changing with radial velocity's period of 589.64 days.

2. Observations

Spectropolarimetric observations of β Gem were carried out at the Crimean Astrophysical Observatory using coudé spectrograph of 2.6-meter Shajn telescope and Stokesmeter. Our data overlap interval of 9 nights from 25 February to 2 May 2010. 194 circular polarization spectra were collected with resolution ∼30000 and signal-to-noise ratio from 270 to 580.

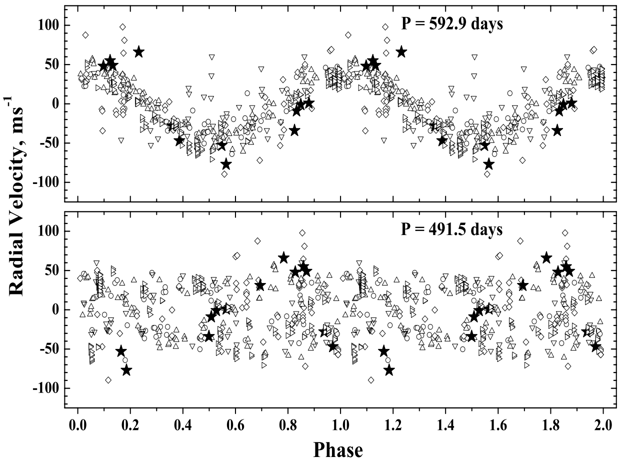

Figure 1: Radial velocities folded in phase with the orbital period of 592.9 days (upper panel) and the magnetic field's 491.5 days period (lower panel). The different symbols correspond to different source of radial velocity data. Diamonds are data from Larson et al. (1993), upside down triangles – from Hatzes and Cochran (1993), upward triangles – from Reffert et al. (2006), circles – from Hatzes et al. (2006), right triangles – from Han et al. (2008), and asterisks are from Aurière et al. (2009).

3. Results

We performed search for periodicity with the program Period04 (Lenz & Berger, 2004). Using all available radial velocity measurements from literature we re-determined the planetary companion rotation period, $P_{pl} = 592.9 \pm 0.6$ days. The upper frame in Fig. 1 shows the variations of radial velocity with orbital period of 592.9 days (phases were computed with ephemeris $P_{RVmax} = 2444158.8 + 592.9$ days). The lower frame in Fig. 1 shows the variation of radial velocity with magnetic field period. In the last case there is no periodic variations for all data, as it should have been, in spite of the radial velocities measurements from Aurière et al. (2009) which shown by asterisks.

From the analysis of power spectrum of magnetic

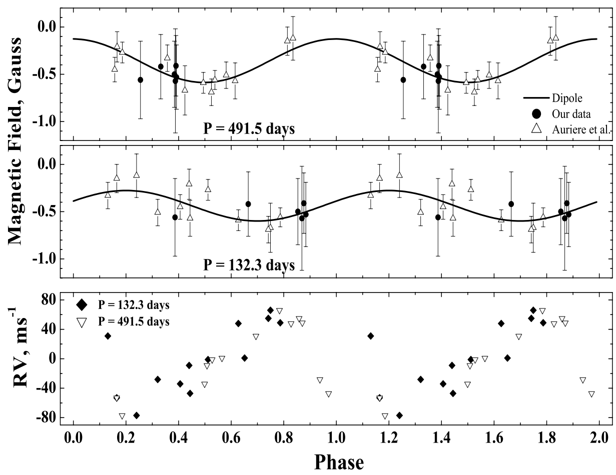

Figure 2: Longitudinal magnetic field folded in phase with the axial rotation period of 491.5 days (upper panel) and with period of 132.3 days (middle panel). Filled circles are our measurements of magnetic field; open triangles – data from Aurière et al.; dipole fit is shown by solid line. Bars are rms errors of measurement. Lower panel shows radial velocity's variations with the periods 132.3 days (filled diamonds) and 491.5 days (open triangles) using data from Aurière et al.

field measurements the axial rotation period of star, 491.5 days, was evaluated with 98% statistical significance (see Fig. 2, upper panel). For clear analysis we excluded lie out points. Using the Hipparcos photometry Hatzes et al. (2006) estimated a best fit period of 132.3 days the origin of which was not determined. The same period presents in power spectrum of the magnetic field measurements, but its statistical significance is only 77% (see Fig. 2, middle panel). In addition, because $2/(1/132^d.3 - 1/491^d.5) = 362.2$ days is very closed to year, we concluded that this period is artifact of frequency beating of star rotation period and year's season observations. The best fit to the magnetic field data in the case of the centered dipole gives the following results: the angle between spin axis and line of sight $i = 31^\circ \pm 1^\circ$ is in agreement with Hatzes' et al. (2006) $i = 28^\circ \pm 3^\circ$, and the angle between both the spin and dipole axes $\beta = 133^\circ$.

In the lower panel of Fig. 2 the radial velocity from paper by Aurière et al. (2009) are phase-folded with two periods, 491.5 and 132.3 days. One can see the discrepancy between other authors' data and measurements by Aurière et al. (2009). The methods of RV measurements of both arrays of data differ from each other. In contrast to the nonpolarimetric data of other authors, the RV obtained by Aurière et al. (2009) were calculated using spectropolarimetric observations. The last RV data demonstrate the presence of both periods while the magnetic period, 491.5 days, is absent in data of other authors. We do not know the nature of such discrepancy between RV data from Aurière et al. (2009) and others authors.

In Fig. 3 all points of the magnetic field measurements are presented. We suppose that four lie out points of the curve fitting are the result of the active regions emergence on the stellar surface as it was discovered for solar-like star 61 Cyg A (Plachinda, 2004). Additional data, which will require further observations, are needed in order to confirm this result.

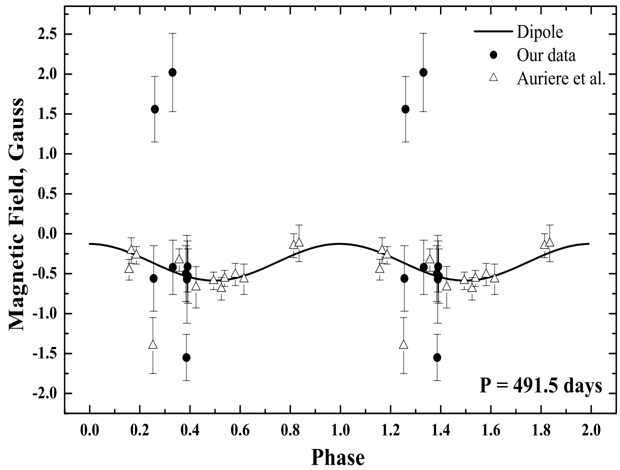

Figure 3: Magnetic field measurements folded in phase with the axial rotation period of 491.5 days. All points of the magnetic field measurements are presented. Filled circles are our measurements of magnetic field; open triangles – data from Aurière et al.; dipole fit is shown by solid line.

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