THE MAGNETIC FIELD STRUCTURE OF THE SINGLE LATE-TYPE GIANT β CETI IN THE PERIOD JUNE 2010 – JANUARY 2012

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1 Introduction

β Ceti (K0 III) is one of the Zeeman detected single late-type giants (Aurière et al., 2009). Other detected single G-K giants with weak magnetic fields have been studied in Konstantinova-Antova et al., 2008; 2009; Aurière et al., 2009. Up to now, from that sample there are two giants for which the magnetic field topology have been studied – the Ap star descendant EK Eri (Aurière et al., 2011) and the fast rotating effectively single giant V390 Aur (Konstantinova-Antova et al., 2012). Here we present the behavior of magnetic activity indicators CaII K, Hα, CaII IR (854.2 nm), radial velocity and the surface-averaged longitudinal magnetic field B_l of β Ceti. Applying the Zeeman Doppler Imaging (ZDI) technique, two magnetic maps were obtained for the star for the periods of observation June 2010 – December 2010 and June 2011 – January 2012.

The mass of β Ceti is M = 2.8 – 3.2 Msol and the radius is R = 15 – 17 Rsol (according to the literature). Using models of Charbonnel & Lagarde (2010), we inferred a mass of M = 3.5 Msol and a radius of R = 16.9 Rsun. Its value of V-R = 0.72 places it to the left of the coronal dividing line in the HRD where stars are supposed to have a chromosphere, a transition region and a corona. The strong magnetic activity of β Ceti has been discovered since it is the highest X-ray luminosity source (log Lx = 30.2 erg/s) in the solar neighbourhood (d ≤ 30) (Maggio et al., 1998), in which coronal loops exist (Eriksson et al., 1983) and which presents flares (Ayres et al., 2001).

From the Li abundance log ε (Li) < 0.01 and the ratio C^{12}/C^{13} = 19, it could be suggested that the star has already undergone the first dredge-up stage (Sägesser & Jordan, 2005).

2 Observations and data reduction

The data

- 38 spectra have been collected for the star β Ceti
- June 2010 – January 2012 is the observational period

The instruments

- **NARVAL & ESPaDOnS** – twin fibre-fed echelle spectropolarimeters. NARVAL (Aurière, 2003) operates at the 2m Téléscope Bernard Lyot at Pic du Midi Observatory, France. ESPaDOnS (Donati et al., 2006a) oparates at the 3.6m CFHT.
- In a polarimetric mode, both of the spectropolarimeters have a spectral resolution of about 65 000 and a spectrum coverage 370 – 1050 nm.

Data reduction

- **LibreEsprit** (Donati et al., 1997) – spectra were automatically extracted with this software
- **the Least-Squares Deconvolution technique** (LSD; Donati et al., 1997) - enables averaging of several thousand absorption lines taken from one spectrum which increases the signal-to-noise ratio (S/N). In the case of β Ceti, the method enabled us to average about 12 700 lines with a S/N greater than 1000. Mean photospheric Stokes I and Stokes V profiles were computed for each spectrum. Then, the longitudinal magnetic field B_l in Gauss was computed using the first-order moment method (Donati et al., 1997; Rees & Semel, 1979; Wade et al., 2000).
- **Zeeman Doppler Imaging (ZDI)** - a tomographic technique for measuring and mapping magnetic fields at the stars surface from sets of rotationally modulated circularly polarised profiles of spectral lines (Donati et al., 2006b). Synthetic Stokes V profiles were computed and iteratively compared to the real profiles. A very good fit was obtained (χ^2 = 2.2 – 2.4) between the model and the observations.

3 Results

Our study is concentrated on the behavior of the magnetic field B_l in comparison with the variations of the activity indicators and on mapping the surface magnetic field geometry of the star. Our results are:

- β Ceti shows significant variations in B_l in the interval 0.1 – 8.2 G. It remains of positive polarity for the whole observational period (Fig. 1). The dataset could be separated in two parts – June 2010 – December 2010 and June 2011 – January 2012. In the first part B_l has a larger amplitude than the second one.
- B_l shows almost sinusoidal variations with time (Fig. 1). Such a sinusoidal variation of B_l is consistent with a global dipole field configuration (Landstreet & Mathys, 2000).
- We calculated the rotational period of the star using the whole dataset following the approach of Petit et al. (2002). Fitting the data with the ZDI model at fixed information content and minimizing χ^2, we found a possible period of 217 days.
- The ZDI model indicates a dominant poloidal component which contains about 98 % of the reconstructed magnetic energy and shows that the large scale magnetic field is mainly axisymmetric.
- Two ZDI maps were computed for the two parts of the dataset, presented at Fig.2 and Fig.3 with χ^2 = 2.2 and χ^2 = 2.4 respectively for the first and for the second map, and for *i* = 60 deg. Both ZDI maps are dominated by a dipole almost aligned on the spin axis. The dipole strength is weaker in the second observational period. No other significant magnetic structures could be recognized in other two magnetic field components – azimuthal and meridional.
- The behavior of the activity indicators and the radial velocity (RV) correlates very well with the B_l variations (Fig.1). This correlation is in good agreement with the dipole topology which we reconstructed for β Ceti from the ZDI inversion method.

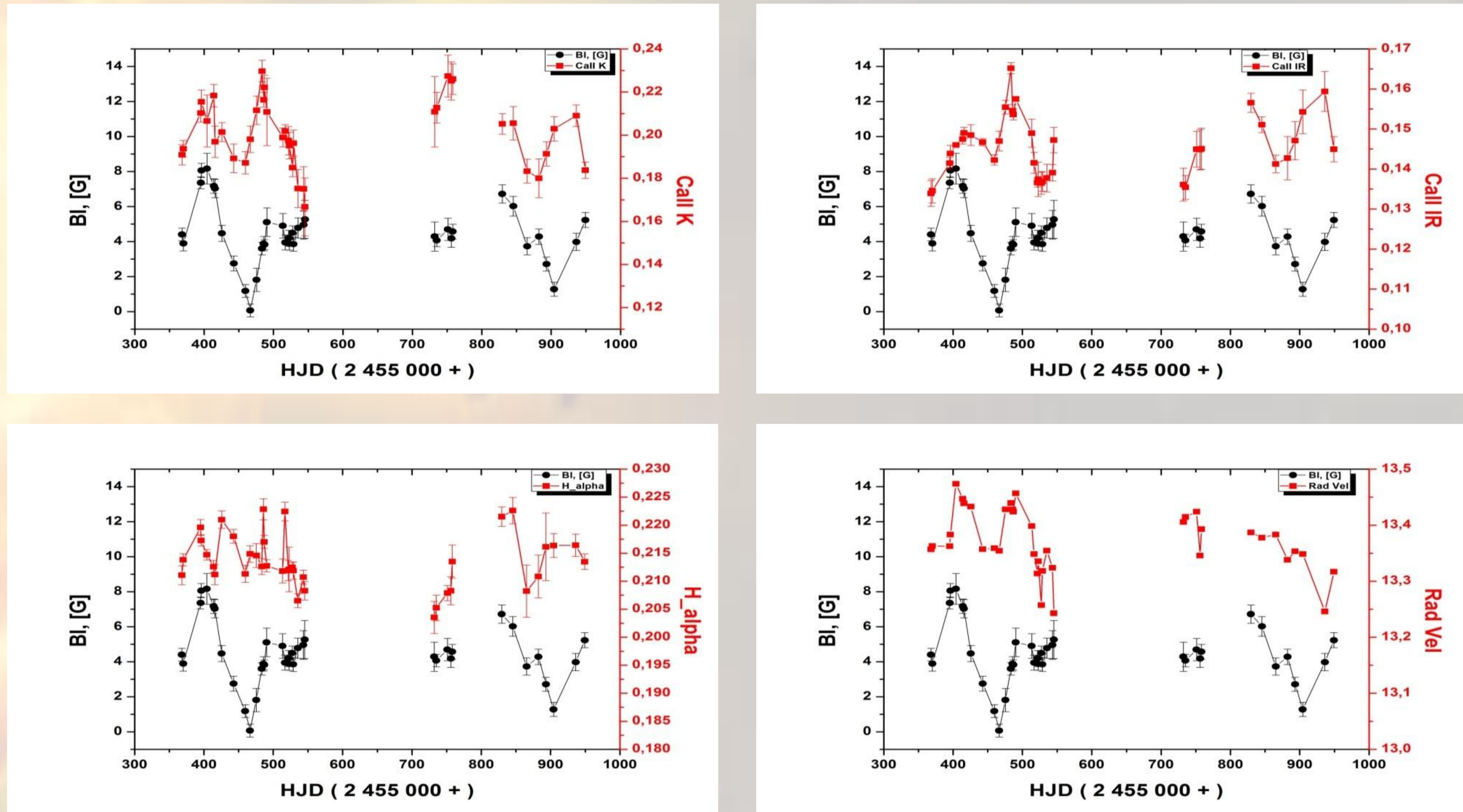

Fig.1 Simultaneous time variations of B_l with activity indicators CaII K, CaII IR, Hα and radial velocity in the period June 2010 – January 2012. Each panel has two Y-axis – left one is for B_l (black dots) and right one is for the labeled activity indicator and the radial velocity (red squares). The RV stability of NARVAL and ESPaDOnS is of the order of 30 m/s (Moutou et al., 2007).

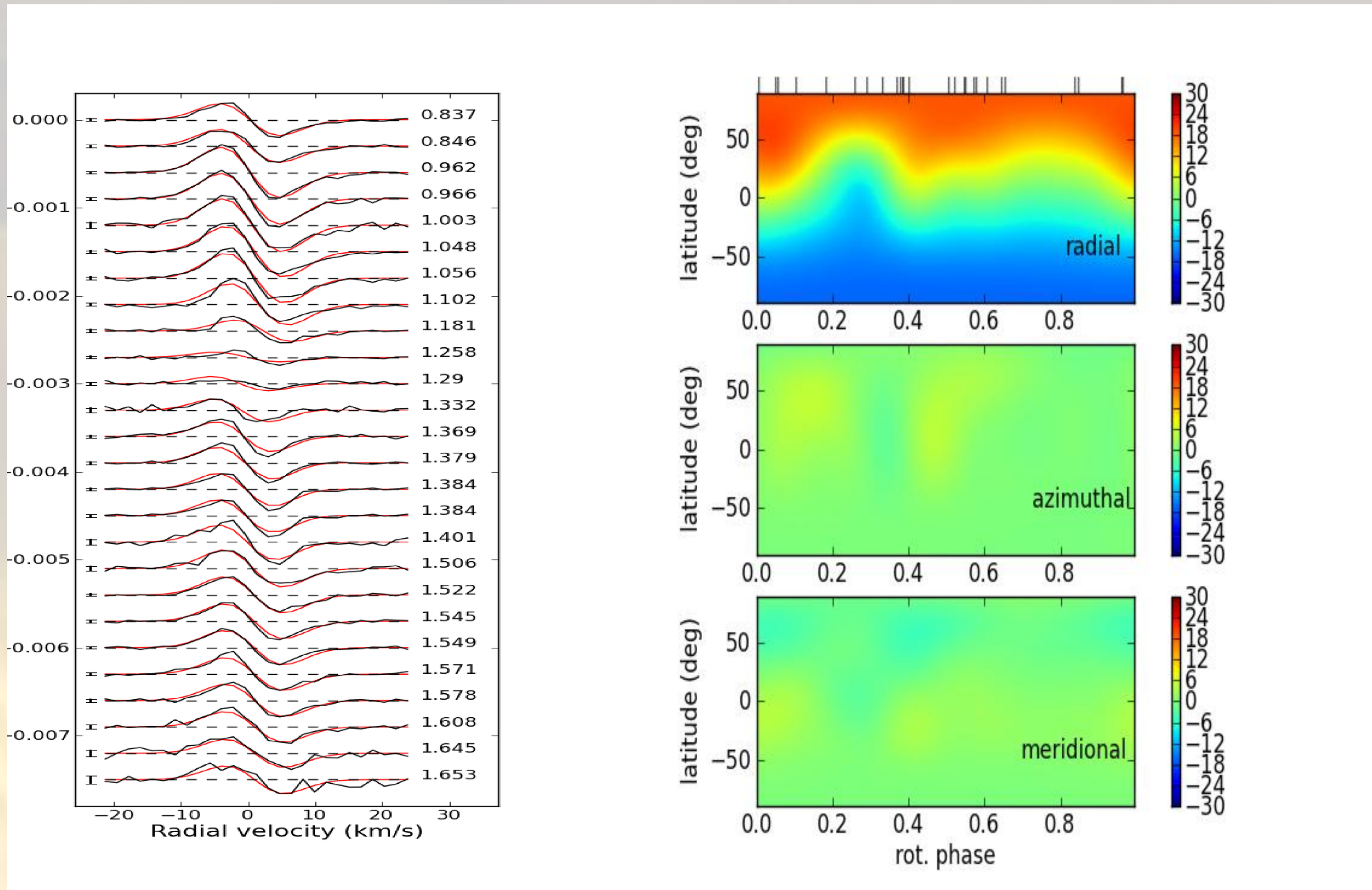

Fig.2 β Ceti in the period June 2010 – December 2010.
Left panel: Normalized Stokes V profiles – observed profiles (black); synthetic fit (red); zero level (dash lines). All profiles are shifted vertically for display purposes. The rotational phases of observations are indicated in the right part of the plot and the error bars are on the left of each profile.
Right panel: The magnetic map of β Ceti for *i* = 60°. The three panels are the three field components in spherical coordinates. The magnetic field strength is in Gauss. The vertical ticks on top of the radial map show the phases when there are observations.

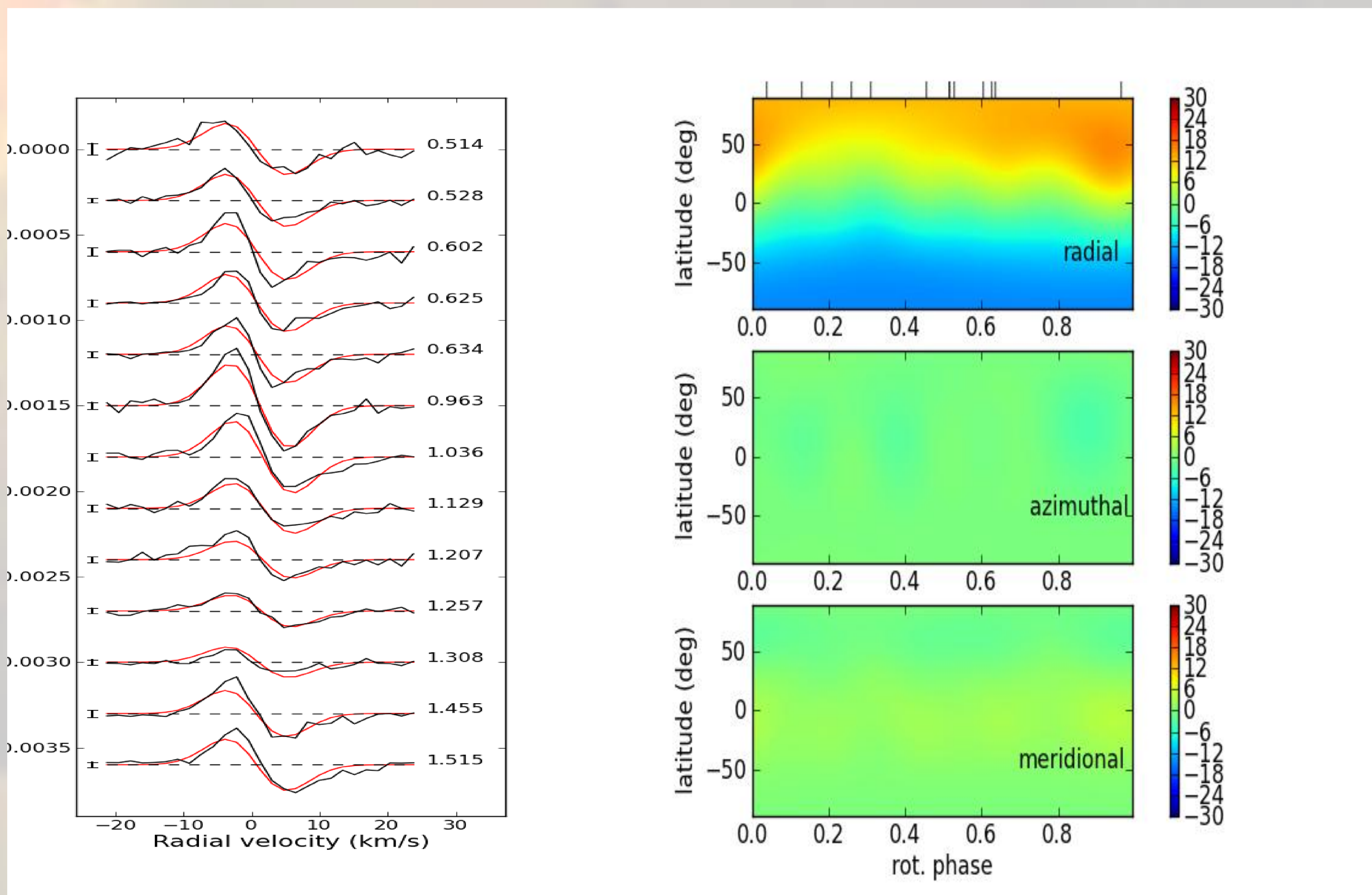

Fig.3 β Ceti in the period June 2011 – January 2012.
Explanations are the same as for Fig.2.

Conclusions

Using the model of Charbonnel & Lagarde (2010), we obtained 116 days for the convective turnover time at Hp/2 above the base of the convective envelope and the corresponding Rossby number is Ro = 1.9 for β Ceti (Aurière et al., in preparation). This value of Ro is not consistent with the high activity level that we observe in this star. Taking also into account the dipolar surface magnetic field topology that we obtained in our study, we suggest that β Ceti could be an Ap star descendant as EK Eri (Aurière et al., 2011).

References:
Aurière, M., 2003, EAS Publ. Series 9, 105
Aurière, M. et al., 2009, IAUS, 259, 431
Aurière, M. et al., 2011, A&A, 534, 139
Ayres, T.R. et al., 2001, ApJ, 562, 83
Charbonnel, C.; Lagarde, N., 2010, A&A, 522, 10
Donati, J.-F. et al., 1997, MNRAS, 291, 658
Donati, J.-F. et al., 2006a, ASPC Ser., 358, 362
Donati J.-F. et al., 2006b, MNRAS, 370, 629
Eriksson, K. et al., 1983, ApJ, 272, 665
Konstantinova-Antova, R. et al., 2008, AIPC, 1043, 405
Konstantinova-Antova, R. et al., 2009, IAUS, 259, 433
Konstantinova-Antova, R. et al., 2012, A&A, 541, 44
Landstreet, J.D. & Mathys, G., 2000, A&A, 359, 213
Maggio, A. et al., 1998, A&A, 330, 139
Moutou , C. et al., 2007, A&A, 473, 651
Petit, P. et al., 2002, MNRAS, 334, 374
Rees, D. E.; Semel, M. D., 1979, A&A, 74, 1
Sägesser, S. N.; Jordan, C., 2005, ESASP, 560, 931
Wade, G. et al., 2000, MNRAS, 313, 823

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