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Constant Magnetic Field of ξ^1 CMa: Geometry or Slow Rotation?

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Abstract. We report recent observations of the sharp–lined magnetic β Cep pulsator ξ^1 CMa (= HD 46328). The longitudinal magnetic field of this star is detected consistently, but it is not observed to vary significantly, during nearly 5 years of observations. In this paper we evaluate whether the constant longitudinal field is due to intrinsically slow rotation, or rather if the stellar or magnetic geometry is responsible.

1 Introduction, Observations and Stellar Parameter Determination

ξ^1 CMa is known to be a B0.5 pulsator with sharp lines. The longitudinal magnetic field of this star, first detected by Hubrig et al. (2006) with FORS1, is detected consistently during over than 5 years of observations, but has remained approximately constant at $B_z \sim 375$ G. Within the rigid rotator paradigm, two explanations can explain this behaviour: either the star rotates very slowly, or the stellar or magnetic geometry is responsible for the constant value of the longitudinal magnetic field. We acquired 18 Stokes V ESPaDOnS spectra ($370 \leq \lambda \leq 1000$ nm, $R = 65,000$, $S/N \sim 1000$ per 1.8 km/s pixel) with the aim of a thorough study of the magnetic field, investigating its rotational period and geometry.

Table 1: Stellar parameters of ξ^1 CMa.

T_{eff}	27500 ± 2000 K
$\log g$	3.50 ± 0.20
$L/L_\odot$	38370
$R/R_\odot$	8.6
$M/M_\odot$	~ 9.0
$\dot{M}$	$7.5 \cdot 10^{-10}$
v_{inf}	~ 1400 km.s^{-1}
$v \sin i$	$\leqslant 15$ km.s^{-1}

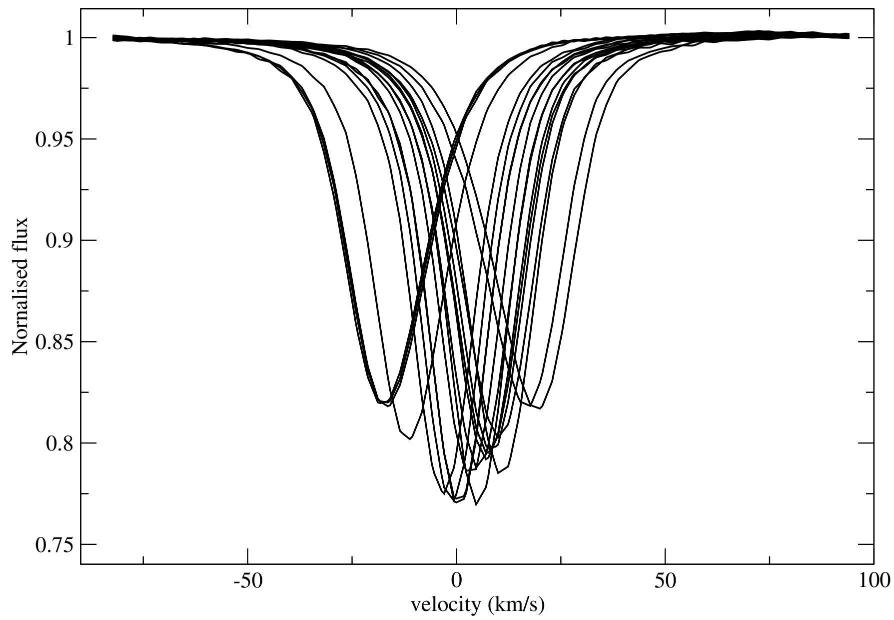

Figure 1: LSD Stokes I profiles showing a strong pulsational variability

We employed CMFGEN to determine physical and wind parameters of ξ^1 CMa. The results are resumed in Table 1. The luminosity was computed using the parallax of van Leeuwen (2007; 2.36 mas), which provides a good fit to the IUE (SWP+LWR) low resolution and large aperture data. An $E(B-V)$ of 0.04 was also used (consistent with Savage et al. (1985), for example). The projected rotational velocity is constrained to be $v \sin i \leq 15$ km/s.

2 Magnetic Field and Rotational Period

Longitudinal magnetic field measurements were inferred using the Least–Squares Deconvolution (LSD) with a line mask carefully customized to the spectrum of ξ^1 CMa. All spectra yield definite detections of the Stokes V profiles and flat diagnostic N profiles with longitudinal field uncertainties of ~ 7 G. A straight–line fit to the longitudinal field measurements extracted from the Stokes V gives a reduced χ^2 of 4.8, while analogous measurements extracted from diagnostic N give reduced χ^2 of just 1.1. This points to a weak variability of the Stokes V that is not present in N.

ξ^1 CMa is a well–known β Cep pulsator that displays monoperiodic radial mode photometric and line profile variability with a period of 0.209 days (e. g. Heynderickx et al., 1994). Our spectra sample a full pulsational cycle and reveal a peak–to–peak radial velocity variation of 38 km/s. The Stokes I and V profiles are also strongly modulated by the pulsation as it can be seen in Figure 1. Saesen et al. (2006) conclude that this represents the radial mode.

We performed a period search of the Stokes V longitudinal field measurements using a Lomb–Scargle algorithm, detecting a significant power at 4.2680 days. When the longitudinal field measurements are phased with this period they describe a sinusoidal variation, as it can be seen in Figure 2, with amplitude ~ 30 G and reduced χ^2 of 1.2.

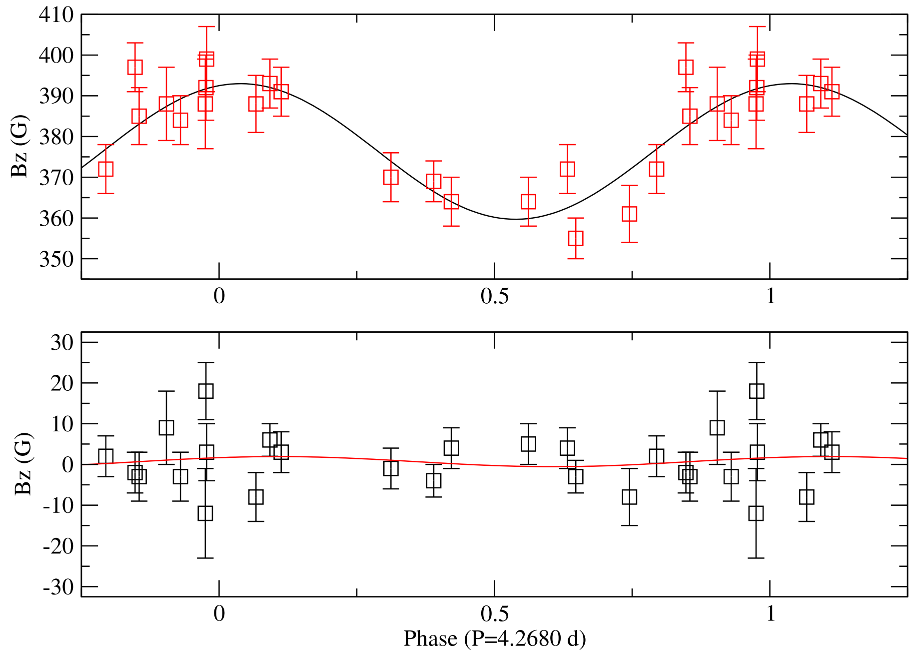

Figure 2: Phased longitudinal magnetic field measurements with the 4.2680 day period. The upper frame shows measurements obtained using the V profiles, while the lower frame shows measurements, obtained using the diagnostic null N profiles.

3 Hα Emission and UV Wind Line Morphology

We observe emission in the Hα line profile. We extracted the emission profile shown in Figure 3 from each spectrum using the ATLAS9 Balmer line profiles, computed according to the parameters of ξ^1 CMa as a photospheric template. For each spectrum the photospheric profile was shifted by the measured radial velocity, then subtracted from the observations. We first tested the method using the Hβ, which shows no evidence of emission. The residuals, shown in Fig. 2, show essentially no structure. When applied to Hα, on the other hand, strong residuals are revealed associated with the emission. The derived emission profile is approximately constant and is characterized by a FWHM of $\sim$120 km/s.

The UV C IV and Si IV wind lines of ξ^1 CMa show no variability in the IUE spectra acquired in 1978 and 1979, as it can be seen in Figure 4. They are remarkably similar to those of the magnetic star β Cep at the phases of maximum emission (i. e. when the star is viewed closest to the magnetic pole). This could imply that we currently view ξ^1 CMa near its magnetic pole as well. Such a configuration is potentially consistent with either a long rotation period or a pole–on geometry. Nevertheless, a lack of variability observed in the UV and optical wind lines leads us to prefer the pole–on geometry model.

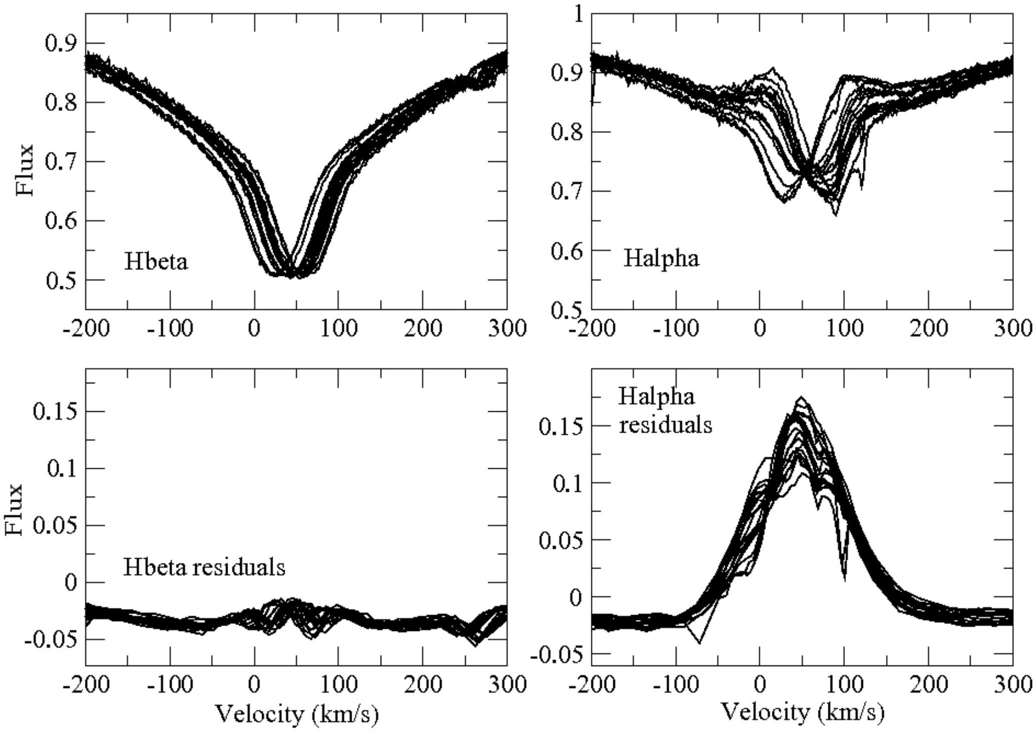

Figure 3: Hα and Hβ line profiles and residuals after shifting and subtraction of an appropriate ALTLAS9 model Balmer profile from the 18 spectra. Results for Hβ are presented on the left and results for Hα on the right.

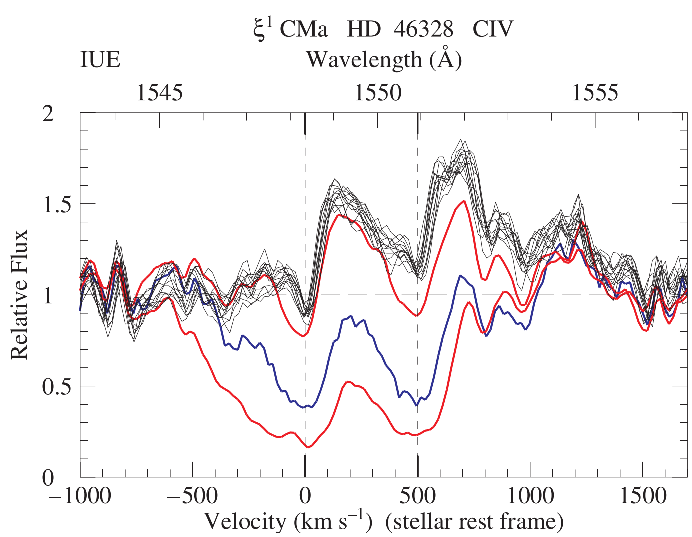

Figure 4: The C IV and Si IV UV wind profiles of ξ^1 CMa (black) of the magnetic star β Cep in red, and of a non–magnetic star 1 Cas (blue), obtained in 1978 and 1979.

4 Conclusions: Magnetic Field, Stellar Geometry and Rotation

The lack of any secular change in the field during the period of observations, in combination with a very high precision of the magnetic measurements suggests either that the rotational period of the star is remarkably long, or that the stellar geometry is such that the disc–integrated line–of–sight component of the field remains approximately constant.

The latter model is more consistent with the observed stability of the Hα and UV line emission, the UV line morphology, and the period detected in the longitudinal field measurements.

If β Cep has $i = 60°$ and $\beta = 85°$, the magnetic pole comes within 35° of the line of sight. If we accept the arguments above, the magnetic pole of ξ^1 CMa must come as close to the line of sight, and furthermore it must remain there. This would all be self–consistent if the 4.26 day period is in fact the stellar rotation period.

For the star to be rotating in 4.26 days, the rotation axis must be quite close to the line–of–sight (inclination of 5 to 10°) to be consistent with the low $v \sin i$, and in that case a weak modulation of the longitudinal field can be matched by a 1450 G dipole with obliquity $\beta = 25°$. This would imply, in fact, that the magnetic pole is never more than 30° from the line of sight.

An accurate determination of the $v \sin i$ of this star is critical to confirming this view, as effectively any non–zero value of $v \sin i$ would imply that the rotational period is shorter than the total span of the observations.

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