Magnetic Stars, 2011, pp. 171 – 174

Magnetic Fields of Hot Pulsating Stars

Hubrig S.[1], Ilyin I.[1], Schöller M.[2], Morel T.[3], Briquet M.[4], de Cat P.[5]

[1] Astrophysikalisches Institut Potsdam, Potsdam, Germany
[2] European Southern Observatory, Garching, Germany
[3] Institute for Astrophysics and Geophysics, Liége University, Liége, Belgium
[4] Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Leuven, Belgium
[5] Koninklijke Sterrenwacht van België, Brussel, Belgium

Abstract. In spite of recent detections of magnetic fields in a number of β Cephei and slowly pulsating B (SPB) stars, their impact on stellar rotation, pulsations, and element diffusion is not sufficiently studied yet. One reason for this is the lack of knowledge of rotation periods, magnetic field strength distribution and temporal variability, and field geometry. New longitudinal field measurements of four β Cephei and candidate β Cephei stars, and two SPB stars were acquired with the FORS2 at the VLT. These measurements allowed us to carry out a search for rotation periods and to constrain magnetic field geometry for a few stars in our sample.

Key words: stars: early-type – stars: magnetic field – stars: oscillations – stars: variables: general – stars: fundamental parameters – stars: individual (ξ^1 CMa, 15 CMa)

1 Introduction

Over several years we have undertaken a magnetic field survey for main–sequence pulsating B–type stars, namely the slowly pulsating B (SPB) stars and β Cephei stars with the FORS1/2 in the spectropolarimetric mode at the VLT. This allowed us to detect for the first time the longitudinal magnetic fields of the order of a few hundred Gauss in four β Cephei stars and 16 SPB stars. For a few such stars we obtained multi-epoch magnetic field measurements to determine their magnetic field properties (strength, magnetic field geometry, and time variability) to study the impact of magnetic fields on the rotation, pulsation, and diffusion. Here we report our results of monitoring a few targets.

2 Observations and Magnetic Field Measurements

Multi–epoch time series of polarimetric spectra of the pulsating stars were obtained with the FORS2 on Antu (UT1) from 2009 September to 2010 March in service mode. Using a slit width of $0\farcs4$, the achieved the spectral resolving power of the FORS2 obtained with the GRISM 600B of about 2000. The β Cephei stars ξ^1 CMa and 15 CMa were observed 11 and 13 times, respectively. A detailed description of the assessment of the longitudinal magnetic field measurements using the FORS 2 is presented in our previous papers (e. g., Hubrig et al., 2004a, 2004b, and references therein).

The mean longitudinal magnetic field $\langle B_z \rangle$ was derived using

$$\frac{V}{I} = -\frac{g_{\mathrm{eff}} e \lambda^2}{4\pi m_e c^2} \; \frac{1}{I} \; \frac{\mathrm{d}I}{\mathrm{d}\lambda} \langle B_{\mathrm{z}} \rangle \, , \tag{1}$$

where V is the Stokes parameter which measures circular polarisation, I is the intensity in the unpolarised spectrum, g_{eff} is the effective Landé factor, e is the electron charge, λ is wavelength, m_e is electron mass, c is the speed of light, $\mathrm{d}I/\mathrm{d}\lambda$ is the derivative of the Stokes I, and $\langle B_{\mathrm{z}} \rangle$ is the mean longitudinal magnetic field. The measurements of the longitudinal magnetic field were carried out in two ways, using the whole spectrum ($\langle B_{\mathrm{z}} \rangle_{\mathrm{all}}$), and using only the hydrogen lines ($\langle B_{\mathrm{z}} \rangle_{\mathrm{hyd}}$). Two additional polarimetric spectra of ξ^1 CMa were obtained with the SOFIN spectrograph, installed at the 2.56 m Nordic Optical Telescope in La Palma, one on September 13, 2008, and another one on January 01, 2010. The SOFIN (Tuominen et al., 1999) is a high–resolution echelle spectrograph mounted at the Cassegrain focus of the NOT and equipped with three optical cameras providing different resolving powers of 30 000, 80 000, and 160 000. The star was observed with alow–resolution camera with $R = \lambda/\Delta\lambda \approx 30\,000$. We used the 2K Loral CCD detector to register 40 echelle orders partially covering the range from 3500 to 10 000 Å with the length of spectral orders of about 140 Å at 5500 Å. The polarimeter is located in front of the entrance slit of the spectrograph and consists of a fixed calcite beam splitter, aligned along the slit, and a rotating super–achromatic quarter–wave plate. Two spectra, circularly polarized in opposite sense are recorded simultaneously for each echelle order, providing sufficient separation by the cross–dispersion prism below 7000 Å. Two such exposures with quarter–wave plate angles, separated by 90° are necessary to derive circularly polarised spectra. The spectra were reduced with the 4A software package (Ilyin, 2000).

A frequency analysis was performed on the longitudinal magnetic field measurements $\langle B_{\mathrm{z}} \rangle_{\mathrm{all}}$ (which generally show smaller sigmas) available from our previous work (Hubrig et al., 2006, 2009), and the current studies using a non–linear least–squares fit of the multiple harmonics utilizing the Levenberg–Marquardt method (Press et al., 1992) with an optional possibility of pre–whitening the trial harmonics. To detect the most probable period, we calculated the frequency spectrum for the same harmonic with a number of trial frequencies by solving the linear least–squares problem. At each trial frequency we performed a statistical test of the null hypothesis for the absence of periodicity (Seber, 1977), i. e. testing that all harmonic amplitudes are at zero. The resulting F–statistics can be thought of as the total sum including covariances of the ratio of harmonic amplitudes to their standard deviations, i. e. as a signal–to–noise ratio (Ilyin, 2010). The F–statistics allows to derive the false alarm probability of the trial period based on the F–test (Press et al., 1992). For four out of the studied six stars the resulting amplitude spectra displayed dominant peaks. The equivalent periods were 2.18 d for the β Cephei star ξ^1 CMa and 12.64 d for the β Cephei star 15 CMa. Phase diagrams of the data folded with the determined periods are presented in Fig. 1. The quality of our fits is described by the reduced χ^2–values, which is 0.41 for ξ^1 CMa, 0.47 for 15 CMa.

The most simple modelling of the magnetic field geometry is based on the assumption that the studied stars are oblique dipole rotators, i. e. their magnetic field can be approximated by a dipole with the magnetic axis inclined to the rotation axis.

Using stellar fundamental parameters and assuming that the studied stars are oblique dipole rotators, we obtain an obliquity angle $\beta = 79.1 \pm 2.8°$ for ξ^1 CMa and $\beta = 67.1 \pm 28.2°$ for 15 CMa.

3 Summary

An insufficient knowledge of the strength, geometry, and time variability of magnetic fields in hot pulsating stars has until now prevented important theoretical studies on the impact of magnetic fields on the stellar rotation, pulsations, and element diffusion. Although it is expected that the magnetic field can distort frequency patterns (e. g. Hasan et al., 2005), such perturbation is not yet detected in hot pulsating stars. The splitting of non–radial pulsation modes was observed for

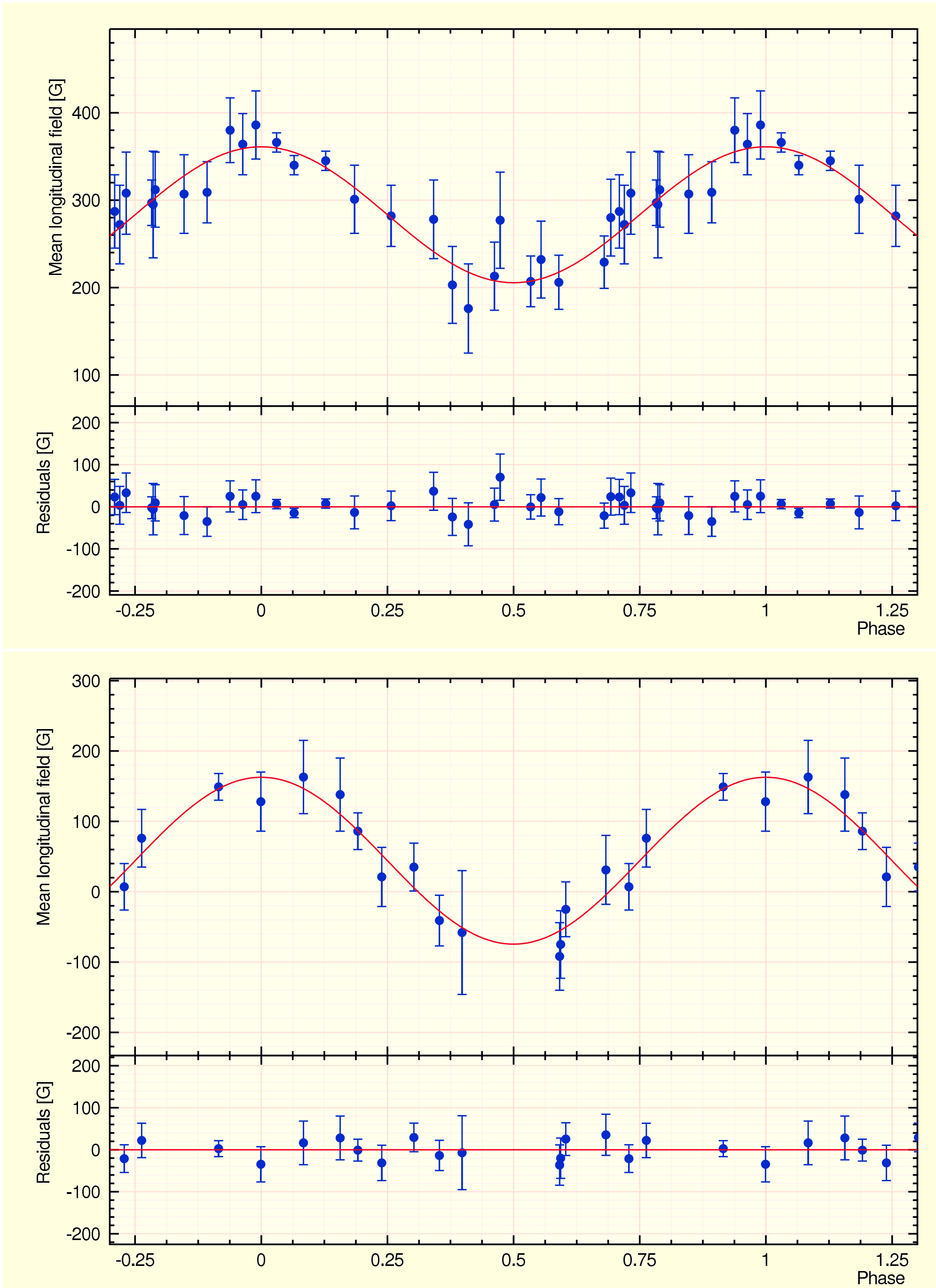

Figure 1: Phase diagrams with the best sinusoidal fit for longitudinal magnetic field measurements. The residuals (Observed – Calculated) are shown in the lower panels. The deviations are mostly of the same order as the error bars, and no systematic trends are obvious, which justifies a single sinusoid as a fit function. The fits correspond to ξ^1 CMa (upper) and 15 CMa (lower).

15 CMa by Shobbrook et al. (2006), but an identification of these modes is still pending. The magnetic β Cephei star sample indicates that they all share common properties: they are the N–rich targets (e. g., Morel et al., 2008) and, as discussed by Hubrig et al. (2009), their pulsations are dominated by a non–linear dominant radial mode (see also Saesen et al. (2006) for ξ^1 CMa). The presence of a magnetic field might consequently play an important role in explaining such a distinct

behaviour of magnetic β Cephei stars. More precisely, chemical abundance anomalies are commonly believed to be due to the radiatively–driven microscopic diffusion in stars rotating sufficiently slow to allow such a process to be effective. However, we need an additional clue to account for the fact that both normal and nitrogen–enriched slowly rotating stars are observed. Interestingly, Silvester et al. (2009) used the LSD technique to measure magnetic fields in a small number of hot pulsating stars, but failed to detect magnetic fields in most of them. However, the majority of stars in their sample were observed only once or twice during the same night, usually with poor signal–to–noise ratio. Obviously, such results are rather misleading and consequently give a biased picture of the actual status of the presence of magnetic fields in massive stars.

References

Hasan S. S., Zahn J.–P., Christensen–Dalsgaard J., 2005, A&A, 444, L29

Hubrig S., Kurtz D. W., Bagnulo S., Szeifert T., Schöller M., Mathys G., Dziembowski W. A., 2004a, A&A, 415, 661

Hubrig S., Szeifert T., Schöller M., Mathys G., Kurtz D. W., 2004b, A&A, 415, 685

Hubrig S., Briquet M., Schöller M., De Cat P., Mathys G., Aerts C., 2006, MNRAS, 369, L61

Hubrig S., Briquet M., De Cat P., Schöller M., Morel T., Ilyin I., 2009, Astron. Nachr., 330, 317

Ilyin I. V., 2000, "Numerical methods for the data analysis", Manuscript

Ilyin I. V., 2010, private communication

Morel T., Hubrig S., Briquet M., 2008, A&A, 481, 453

Press W. H., Teukolsky S. A., Vetterling W. T., Flannery B. P., 1992, "Numerical Recipes", 2nd ed., Cambridge University Press

Saesen S., Briquet M., Aerts C., 2006, Comm. in Asteroseismology, 147, 109

Seber G. A. F., 1977, "Linear Regression Analysis", New York, Wiley

Shobbrook R. R., Handler G., Lorenz D., Mogorosi D., 2006, MNRAS, 369, 171

Silvester J., Neiner C., Henrichs H. F., Wade G. A., Petit V., Alecian E., Huat A.–L., Martayan C., Power J., Thizy O., 2009, MNRAS, 398, 1505

Tuominen I., Ilyin I., Petrov P., 1999, in: Karttunen H., Piirola V. (eds), "Astrophysics with the NOT", University of Turku, Tuorla Observatory, 47