HARPS spectropolarimetry of O and B-type stars

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Abstract Our knowledge of the presence and the strength of magnetic fields in massive O and B-type stars remains very poor. Recent observations indicate that the presence of magnetic fields is responsible for a wide range of phenomena observed in massive stars at different wavelengths, such as chemical peculiarity, excess of emission in UV-wind lines and periodic UV wind-line variability, unusual X-ray emission, and cyclic variability in Hα and He II λ4686. However, it is difficult to establish relationships to multiwavelength diagnostics, as the strength of the detected magnetic fields and their geometry differ from one star to the other. In this work, we present new magnetic field measurements in a number of O and B-type stars of different classification observed with HARPS in spectropolarimetric mode.

1. Introduction

Recent observational and theoretical results emphasised the potential significance of magnetic fields for stellar structure, evolution, and circumstellar environment of massive O- and B-type stars. Our previous searches for magnetic fields in massive stars were mostly based on FORS 1/2 low-resolution polarimetric spectra obtained at ESO/Paranal. On the other hand, a large number of spectropolarimetric HARPSpol observations became publicly available in the ESO archive in recent years, among them the spectra of pulsating β Cephei stars, Be stars, and massive O-type stars. In this work, we present new magnetic field measurements for the two β Cephei stars HD 55857 and HD 64503 with spectral types B0.5V and B2.5V, respectively; the Be star HD 92939 with spectral type B4V, the blue straggler θ Car, and two O-type stars, ζ Pup with spectral type O4f(n)p, and the Of?p star CPD −28 2561. Among this sample, results of magnetic field measurements were previously published only for θ Car and the Of?p star CPD −28 2561 (Hubrig et al. 2008 [1]; 2011a [2]; 2013 [3]).
2. Magnetic field measurements in B-type stars

For the measurements of the magnetic fields in the sample of stars observed with HARPSpol, we used the moment technique developed by Mathys (e.g. Mathys 1991 [4]). All four studied B-type stars have large $v \sin i$ values, from 113 km/s for $\theta$ Car up to 187 km/s for HD 64503 (Telting et al. 2006 [5]). In Fig. 1 from top to bottom, we present the spectra of HD 92238, HD 55857, HD 64503, and $\theta$ Car in regions around the O II $\lambda$4662 and Si III $\lambda$4552 lines. For the magnetic field measurements, we used all unblended metal lines, and He I lines. The He II $\lambda$4686 line was used only in the measurements of the two hottest stars, $\theta$ Car and HD 55857.

The spectra of the same stars in the spectral regions around the He I $\lambda$4713 and He II $\lambda$4686 lines are presented in Fig. 2. The most recent abundance analysis of $\theta$ Car showed nitrogen overabundance typical of the values found for other slowly-rotating (magnetic) B-type dwarfs and carbon depletion (Hubrig et al. 2008 [1]). For this star, we attribute the chemical peculiarities to a past episode of mass transfer between the two binary components. Among 26 magnetic field measurements using FORS 1 spectropolarimetric data, only a few measurements had a significance level of $3\sigma$. On the other hand, a periodicity of the order of 8.8 min was detected in the magnetic data. Such a periodicity is surprising, and if it is not spurious, its discovery would give rise to the important question whether the presence of pulsations could cause such a periodicity. No studies of short-time pulsations exist for $\theta$ Car so far. B0 main-sequence stars are expected to pulsate in low radial order p- and g-modes with periods of the order of hours (typically 3 to 8 h). For such massive stars, periods of the order of a few minutes would correspond to high radial order p-modes, but non-adiabatic codes do not predict their excitation. However, since current models do not take into account the presence of a magnetic field, one cannot exclude the possibility that magnetic fields would favour the excitation of these types of modes in analogy to roAp stars, which do possess a magnetic field and pulsate in high radial order modes of the order of a few minutes.

The results of our measurements are presented in Table 1. The first column lists the name of the target, followed by the MJD value, signal-to-noise ratio of the studied spectrum, and the measured longitudinal magnetic field. In spite of the very high S/N achieved in the HARPSpol observations, the accuracy of the measurements in the rather fast rotating
massive stars is relatively low. Formally significant detections above the $3\sigma$ level were achieved in the $\beta$ Cephei stars HD 58647 and HD 64503.
Table 1. Measurements of the mean longitudinal magnetic field using high-resolution HARPS spectra.

| Object | MJD   | S/N | \(\langle B_z \rangle\) |
|--------|-------|-----|---------------------|
| HD 58647 | 55913.183 | 560 | −212±64             |
| HD 64503 | 55912.279 | 660 | 127±38              |
| HD 92938 | 55707.959 | 560 | −117±48             |
| θ Car   | 55706.095 | 710 | 72±48               |
| ζ Pup   | 55910.226 | 600 | 145±93              |

The obtained values of longitudinal magnetic fields listed in Table 1 clearly confirm our previous conclusions that magnetic fields of kG order cannot be expected in \(\beta\) Cephei and Be stars (Hubrig et al. 2006 [6]; 2009a [7]; 2009b [8]).

3. Magnetic field measurements of the O4 star ζ Pup and the Of?p star CPD −28 2561

ζ Pup, which is one of the closest and brightest massive stars, is a fast rotating (\(v \sin i\) is about 200 km/s) runaway star, having had a possible encounter with the cluster Trumpler 10 (Hoogerwerf et al. 2001 [9]). No magnetic field is detected in this star, taking note that the measurement accuracy is the lowest among the sample stars.

A rather strong magnetic field in the Of?p star CPD −28 2561, of the order of a few hundred Gauss, was detected a few years ago by Hubrig et al. (2011a [2]; 2013 [3]) using FORS 2 observations. Walborn (1973 [10]) introduced the Of?p category for massive O stars displaying recurrent spectral variations in certain spectral lines, sharp emission or P Cygni profiles in He I and the Balmer lines, and strong C III emission lines around \(\lambda 4650\). Spectropolarimetric observations on three consecutive nights in 2011 revealed strong variations in both the longitudinal magnetic field strength and several hydrogen and helium line profiles (Hubrig et al. 2012 [11]). Unfortunately, the HARPSpol spectrum of this star has very low S/N, only about 100, preventing accurate magnetic field measurements. Our measurements indicate that the field has negative polarity and is at least 400–500 G strong.
4. Summary

Our previous magnetic field measurements using the VLT instruments FORS 1/2 in spectropolarimetric mode revealed the presence of weak magnetic fields in a few β Cephei stars, among them the record holder ξ^1 CMa with a magnetic field of the order of 300–400 G (Hubrig et al. 2006 [6]; 2009 [7]; 2011b [12]). Recent high-resolution spectropolarimetric observations of two stars of this type with HARPSpol support their weak magnetic nature with detections at a significance level of about 3σ. Future magnetic field measurements are urgently needed to determine the role of weak magnetic fields in modeling oscillations of B-type stars.

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