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Detecting magnetic fields in Ap/Bp stars observed with the K2 space mission

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Abstract. To study the effect large-scale magnetic fields have on the interior of hot stars, we compiled a list of chemically peculiar Ap/Bp stars that were observed with K2 with the future goal of investigating their seismic properties employing space-based photometry. A sub-sample was observed with high-resolution spectropolarimetry to detect the anticipated large-scale magnetic field usually hosted by Ap/Bp stars. We confirm the presence of such a field for 75 % of the stars in the sample. Thus, not all stars in the sample host the expected large-scale magnetic field.

Key words: stars: magnetic field – stars: rotation – stars: early-type – stars: oscillations

1. Introduction

About 10 % of hot OBA-type stars host a large-scale magnetic field. These magnetic fields typically have a simple geometry (a dominantly dipolar structure), with strengths ranging from several 100 G up to a few 10 kG, and stability over long time scales. There seems to be no correlation between the magnetic field properties and other stellar parameters. Therefore, they are believed to be of a fossil origin, produced during earlier evolutionary phases (Neiner et al., 2015).

These large-scale magnetic fields influence the chemical composition of several elements, such as Si, Eu, Cr, Fe, or He, while also creating brighter surface abundance inhomogeneities. The latter produces typical rotational modulation signatures in photometry. Both rotational modulation and peculiar abundances are employed as indirect diagnostics for the presence of a large-scale magnetic

field in hot stars. As these magnetic fields extend to the stellar interior, they may have an impact on these regions. Theory and simulations suggest an enforced uniform rotation rate in the radiative envelope (e.g., Ferraro, 1937; Moss, 1992), leading to a smaller convective core overshooting region (e.g., Press, 1981; Browning et al., 2004). Yet, observations to confirm this scenario remain scarce.

Only asteroseismology, the study of non-radial oscillations inside stars, is able to probe the internal properties (Aerts et al., 2010). At present, these have only been successfully utilized for two magnetic hot stars, namely β Cep (Shibahashi & Aerts, 2000) and V2052 Oph (Neiner et al., 2012; Handler et al., 2012; Briquet et al., 2012). Briquet et al. (2012) confirmed the theoretical predictions for a smaller convective core overshooting layer for magnetic stars, but this remains the only such study to date. We intend to increase the number of known magnetic pulsating hot stars to have a larger sample to perform magneto-asteroseismology, the coherent and combined study of magnetometry and asteroseismology, to measure the effect of the large-scale magnetic field on the stellar interior.

We constructed our sample by cross-matching the Renson & Manfroid (2009) catalogue, containing known chemically peculiar stars, with the observing campaigns of the K2 space mission (Howell et al., 2014). More than 60 Ap/Bp stars or He weak/strong stars were observed with K2, resulting in $\sim$90 days of high-quality, high-cadence, space-based, white-light photometry for each star. We constructed a sub-sample out of these stars, by selecting the brightest and slowest rotating stars. This sub-sample was observed with high-resolution spectropolarimetry to confirm the presence of the anticipated large-scale magnetic field. We discuss these results here.

2. Magnetometry

2.1. Data

All stars were observed at least once with the high-resolution spectropolarimeter ESPaDOnS (Donati et al., 2006), mounted on CFHT at Mauna Kea in Hawaii in circular polarization mode. Standard settings were employed and each spectropolarimetric sequence consisted of four consecutive sub-exposures. The observations were reduced with the LIBRE-ESPRIT (Donati et al., 1997) and UPENA softwares available at CFHT, and span from 370 nm to 1050 nm. We normalized the spectropolarimetry by interactive spline fitting per spectral order (Martin et al., 2017, submitted).

2.2. Zeeman signature

For each star, we estimated stellar parameters by fitting synthetic spectra to the Balmer lines (Kurucz, 1993; Martin et al., 2017). From these estimates, we selected the closest VALD3 line mask (Ryabchikova et al., 2015) available in

Table 1. Details of the magnetometric analysis of the sample. Spectral types from the Renson & Manfroid (2009) catalogue are provided and known binary systems are indicated. For each observation, we provide the exposure time, $t_{\rm exp}$, the magnetic detection status, and the determined longitudinal magnetic field B_l.

Star	Spectral type	$t_{\rm exp}$ [s]	Detection	B_l [G]
HD 97859	B9 Si	4×1272	DD	653 ± 127
HD 107000	A2 Sr	4×338	DD	240 ± 10
		4×338	DD	168 ± 11
HD 134759	Bp Si + ...	4×37	DD	304 ± 28
		4×37	DD	369 ± 29
HD 139160	B7 He wk. + ...	8×22	ND	37 ± 48
HD 152366	B8 Si	4×599	DD	-112 ± 15
HD 152834	A0 Si	4×267	DD	229 ± 18
HD 155127	B9 Eu Cr Sr	4×676	DD	-402 ± 6
HD 158596	B9 Si + ...	4×1060	DD	532 ± 36
HD 164224	B9 Eu Cr	4×1089	DD	464 ± 24
HD 165972	B9 Si	4×517	DD	-281 ± 46
HD 166804	B9 Si	4×443	DD	-486 ± 47
		4×443	DD	-510 ± 47
		4×443	DD	-422 ± 63
HD 173406	B9 Si	4×214	ND	-23 ± 39
HD 173657	B9 Si Cr	4×226	ND	-113 ± 81
HD 177013	A2 Eu Cr Sr	4×310	DD	128 ± 34
HD 177562	B8 Si	4×262	ND	16 ± 17
HD 177765	A5 Eu Cr Sr	4×120	DD	1189 ± 20

our pre-calculated library, to construct an average line profile with the LSD technique (Donati et al., 1997). Absorption lines that blend with any Balmer line, telluric features, or known diffuse interstellar bands were discarded, and the line depth of the lines in the mask were adjusted to match the observations. Most of the observations show distortions in their LSD Stokes I profiles, caused by possible pulsations or rotational modulation. We show two examples of these LSD Stokes profiles in Fig. 1.

For each observation, we determined the False Alarm Probability (FAP; Donati et al., 1997) that a Zeeman signature is present in the LSD Stokes V profile. Definite detections (DD) have a FAP$< 10^{-3}$ %, non-detections (NDs) correspond to a FAP$> 10^{-1}$ %, and marginal detections (MDs) fall in between these limits. We indicate the detection states for each observation in Table 1. In the studied sample, 12 stars have a DD, while 4 stars have a ND. No obvious correlation was noted between the detection status and the estimated stellar parameters or binarity.

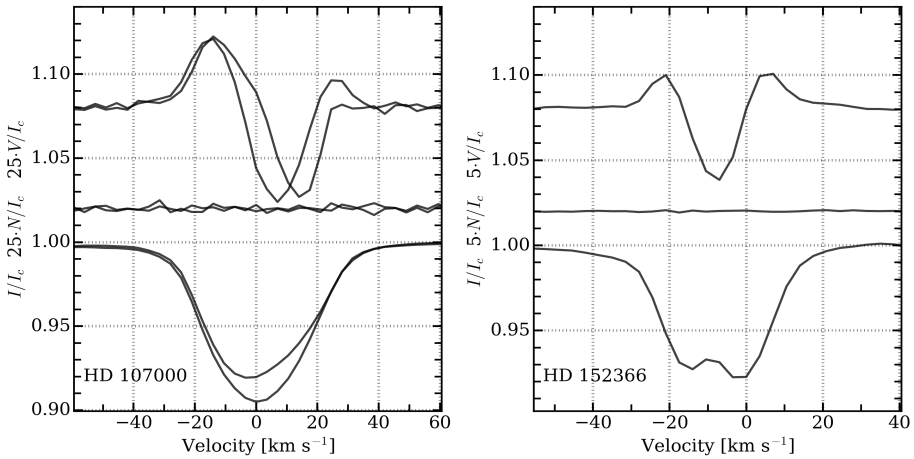

Figure 1. LSD Stokes profiles for two of the stars in the sub-sample. Each panel indicates the LSD StokesI profile (*bottom*), the diagnostic null profile (*middle*), and the LSD StokesV profile (*top*) with an arbitrary offset for increased visibility.

2.3. Longitudinal field measurements

In addition, we determined the longitudinal magnetic field (Rees & Semel, 1979) for each spectropolarimetric observation, and provide these values in Table1. The strength of the field of the confirmed magnetic stars is consistent with what is anticipated for hot magnetic stars, ranging from about 100 G to more than 1 kG.

3. Conclusions and summary

We have compiled a sample of 60 candidate magnetic magnetic Ap/Bp stars that have been observed with K2 space-photometry to detect stellar pulsations. A sub-sample was observed with high-resolution spectropolarimetry to evaluate the presence or absence of large-scale magnetic fields. ESPaDOnS data confirms the presence of such a magnetic field for 75 % of the sub-sample. The K2 photometry might aid to confirm the presence of a magnetic field for the remaining 4 stars through indirect diagnostics. We conclude that some of the stars in the complete sample do not host a large-scale magnetic field in spectropolarimetry but might reveal magnetic signatures in the K2 photometry.

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