The BRITE spectropolarimetric program

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A high-resolution spectropolarimetric survey of all (573) stars brighter than magnitude $V = 4$ has been undertaken with Narval at TBL, ESPaDOnS at CFHT, and HarpsPol at ESO, as a ground-based support to the BRITE constellation of nano-satellites in the framework of the Ground-Based Observing Team (GBOT). The goal is to detect magnetic fields in BRITE targets, as well as to provide one very high-quality, high-resolution spectrum for each star. The survey is nearly completed and already led to the discovery of 42 new magnetic stars and the confirmation of several other magnetic detections, including field discoveries in, e.g., an Am star, two δ Scuti stars, hot evolved stars, and stars in clusters. Follow-up spectropolarimetric observations of approximately a dozen of these magnetic stars have already been performed to characterise their magnetic field configuration and strength in detail.

1 Introduction

Magnetic fields have a significant impact on internal stellar structure through their role in rotation, the transport of angular momentum, mixing, and mass loss. They also impact the circumstellar environment, e.g. through confinement of the wind particles into a magnetosphere. As a consequence, knowing the magnetic properties of the BRITE targets is crucial to interpret the BRITE data correctly.

In particular, a magnetic field produces a splitting of pulsation modes. The observed magnetically split multiplets depend on the field strength and on the obliquity of the field compared to the rotation axis (see, e.g., Shibahashi & Aerts, 2000). Therefore, knowledge of the magnetic properties is fundamental for proper pulsation mode identification for seismic modelling. Not knowing that the star is magnetic could lead to misinterpreting pulsation multiplets as high-order modes instead of low-order magnetically-split modes and, thus, to an incorrect derivation of the internal stellar structure.

In addition, the presence of a magnetic field inhibits mixing inside the star. This was observed, for example, in the β Cep star V2052 Oph. In this star seismic models were found to require no overshooting in spite of the relatively high rotational velocity (Briquet et al., 2012). This could be explained by the presence of a ~400 G dipolar field (Neiner et al., 2012), since this field strength is well above the critical field limit at which theory predicts a magnetic inhibition of mixing in this star (Zahn, 2011). This example shows how knowing magnetic properties can yield improved constraints for seismic modelling.

Magnetic fields can also be present in other types of pulsators. For example, the recent discovery of magnetic δ Scuti Ap stars (Neiner & Lampens, 2015; Escorza et al., 2016), or the class of rapidly oscillating Ap (roAp) stars, require the consideration of magnetic effects in the study of the pulsations in these types of stars.

As a consequence, we endeavoured to perform a complete spectropolarimetric survey of all the 573 brightest ($V \leq 4$ mag) targets in the sky and characterise those for which a magnetic field is detected. This survey will also provided a complete magnitude-limited sample for the statistical analysis of the occurence of magnetic fields in stars.

2 The BRITE spectropolarimetric survey

The BRITE survey has been performed with the three high-resolution stellar spectropolarimeters available in the world: Narval at TBL (Télescope Bernard Lyot) in France, ESPaDOnS at CFHT (Canada-France-Hawaii Telescope) in Hawaii, and HarpsPol at La Silla in Chile. Narval was used for all stars with a declination above $-20°$, ESPaDOnS for those between $-45°$ and $-20°$, and HarpsPol for the targets below $-45°$. High-quality spectropolarimetric data were already available in archives for 87 stars among the 573 targets. Therefore, we needed to observe only the remaining 486 stars.

About 50% of the targets in the sample are hot stars, while the other 50% are mostly evolved cool stars (see Fig. 1). Hot stars host fossil magnetic fields, which are usually simple (mostly dipolar) in structure, stable, and rather strong (above 300 G at the poles), but appear in only about $\sim$10% of hot stars (Grunhut & Neiner, 2015; Neiner et al., 2015c). On the contrary, cool stars host dynamo fields similar to our Sun, which are produced contemporaneously by the star itself, are variable on short timescales, very weak on average (but can be stronger in spots), and observable in most cool stars. Therefore, we separated the sample in two groups: hot stars between spectral types O and F5, for which we aimed at detecting longitudinal field strengths with error bars of the order of 5 G (i.e. dipolar field strength above 50 G), and cool stars with spectral types between F5 and M, for which the desired precision was 10 times better.

As of mid-August 2016, we have obtained 129 hours of Narval queue service time, 56 hours of ESPaDOnS queue service time, and 23.2 nights (equivalent to 210 hours) in visitor mode of HarpsPol time. In addition, a large amount of observations were executed using C-time with Narval and ESPaDOnS, as the BRITE targets are excellent queue fillers at telescopes. In total we observed 464 stars, which corresponds to a $\sim$95% completion of the survey (as of mid-August).

Data were collected in circular polarisation (Stokes V) mode and the signal-to-noise ratio in the intensity spectrum is above 1000 for all targets, and often above 2000. We obtained one measurement per star and applied the Least Square Deconvolution (LSD) technique (Donati et al., 1997) with template masks extracted from VALD (Piskunov et al., 1995; Kupka et al., 1999) to search for magnetic signatures. If a Stokes V signature was detected, we usually obtained a second measurement to confirm the magnetic detection.

Fifty-two stars were found to be magnetic, which corresponds to a 11% detection

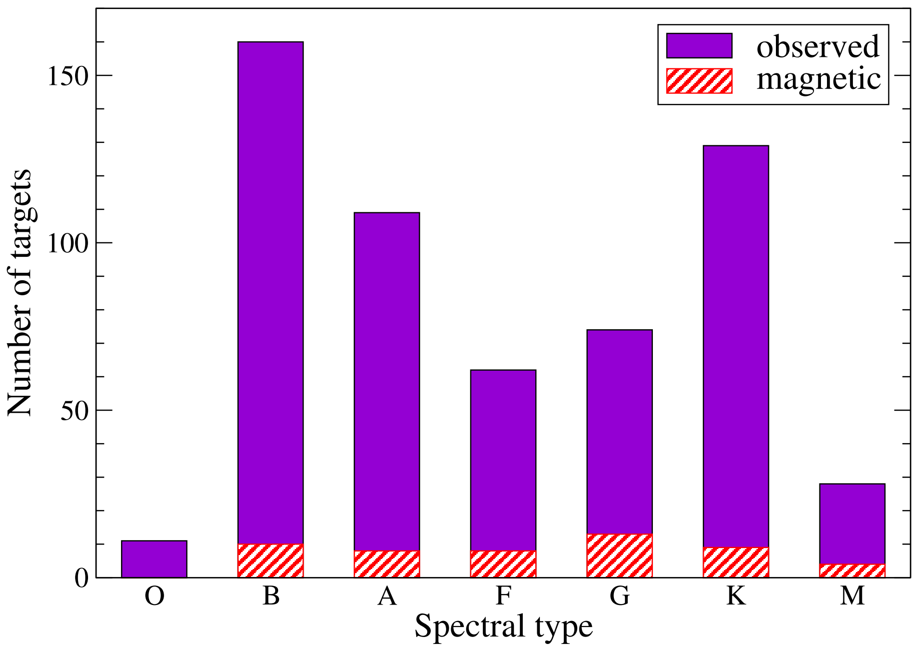

Fig. 1: Number of stars in the sample (full bars) and number of detected magnetic stars (hatched bars) per stellar type.

rate, including 42 stars that were not known to host a magnetic field before this survey (see Fig. 1). This includes four B and A supergiant stars, 14 other B and A stars, seven F, G, and K dwarfs or subwarfs, 23 F, G, and K giants or supergiants, and four M giants. While the detection rate of 9% in hot stars corresponds to the known ∼10% occurence rate of magnetism in these objects (Grunhut & Neiner, 2015), the rate of detections in cool stars (11%) is lower than expected for these stars (see Petit et al., 2014). This rate increases to 19% when considering only class V stars of F, G, and K types. Therefore, the low detection rate is probably partly due to the fact that most cool stars in the sample are evolved and thus their field is weaker than on the main sequence, and partly due to the fact that fields are variable and can be below our detection threshold at the time of observation.

The most interesting magnetic targets were then transferred to the follow-up part of the program for a full magnetic characterisation.

3 Spectropolarimetric follow-up of magnetic BRITE targets

When a star is found to be magnetic in the survey, multiple spectropolarimetric observations are acquired at various phases of the rotation cycle. In this way, it is possible to observe the magnetic field under various angles and, using the rotational modulation of the Stokes V profile and longitudinal field value, it is possible to reconstruct the magnetic field configuration on the stellar surface (such as the obliquity angle between the rotation axis and magnetic axis), its strength, and obtain additional stellar parameters (e.g., the rotation period and the inclination angle of the star's rotation axis with respect to the observer).

As of mid-August, such a spectropolarimetric follow-up had already been per-

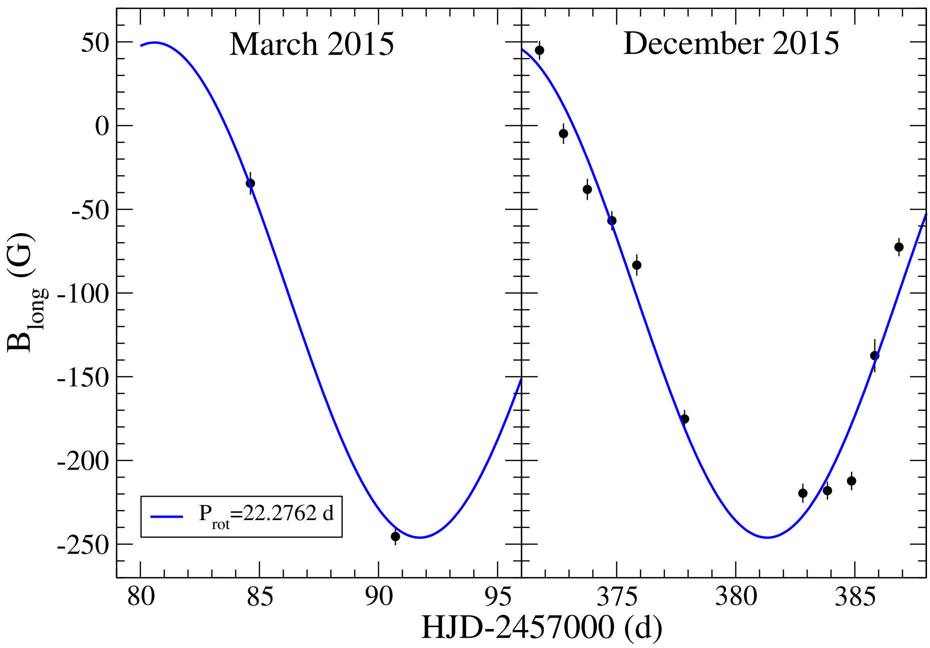

Fig. 2: Longitudinal field measurements (dots) of the B3 V star i Car obtained with HarpsPol, with a dipole fit (curve).

formed for 11 magnetic BRITE targets, and was ongoing for seven others. Among these 18 targets, 13 are B and A stars, and five are F and G stars. Four of the 18 targets are binary systems. Follow-up observations will continue in 2016 and 2017.

3.1 The B3 V star i Car

Figure 2 shows an example of a hot star, the B3 V star i Car, detected to be magnetic in the BRITE spectropolarimetric survey with two measurements gathered in March 2015 (Neiner et al., 2015b). In December 2015 we acquired 11 additional measurements and could determine its dipole field strength (~1 kG) and rotation period (P_{rot} ~22.28 d). The rotation period can be precisely determined thanks to the two datapoints obtained in March 2015.

A dipole fit is shown in Fig. 2. Deviation between this fit and the data could indicate that the field includes a quadrupole component, or that the shape of the longitudinal field curve is modified by surface abundance patches.

3.2 The Am star Alhena ≡ γ Gem

Another interesting example of a hot star detected to be magnetic in the BRITE spectropolarimetric survey is the Am star Alhena (Blazère et al., 2016a). While it was recently discovered that all Am stars studied with sufficient precision host ultra-weak magnetic fields with a peculiar magnetic signature shape (Blazère et al., 2016b), Alhena is the first example of a magnetic Am star showing a standard Zeeman signature.

Figure 3 shows 20 LSD profiles of Alhena taken with Narval between October

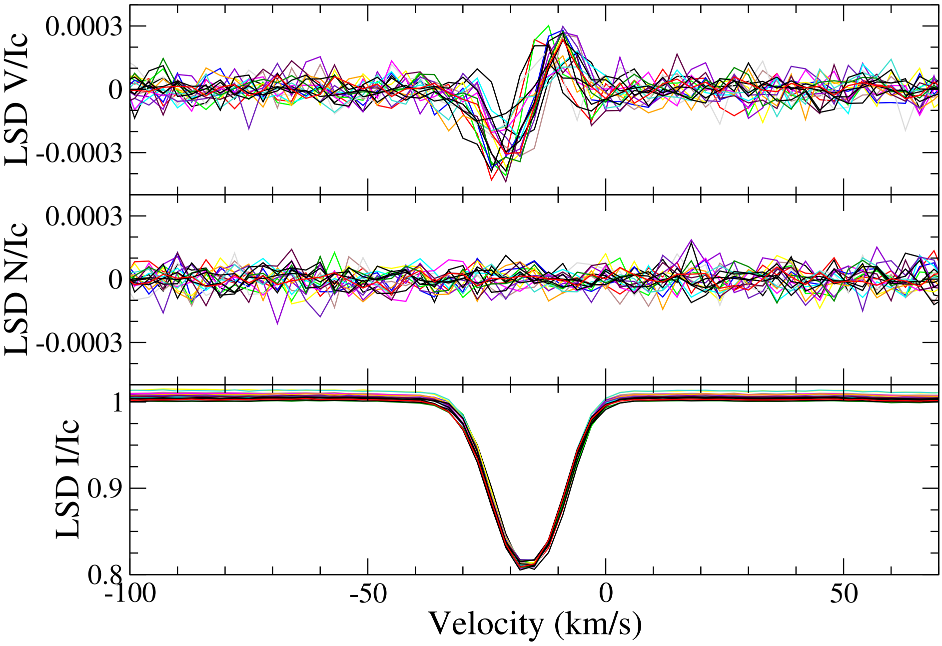

Fig. 3: LSD Stokes I (bottom), null polarization (middle), and Stokes V (top) profiles of the Am star Alhena, obtained with Narval. The Stokes V profiles show standard Zeeman signatures, contrary to other Am stars.

2014 and April 2016. The variation of the Stokes V profile is small over the 1.5 years of observations, suggesting that Alhena is seen under a specific geometrical configuration.

Moreover, its field, although weak (longitudinal field of a few gauss), is stronger than the field of the other magnetic Am stars (less than 1 G). The difference could be related to the lower level of microturbulence in Alhena (Blazère et al., 2016a). Indeed, the peculiar Stokes V shape observed in the other Am stars is thought to be due to supersonic convection flows in the shallow convective shell, which could be the source of sharp velocity and magnetic gradients (Blazère et al., 2016b).

3.3 The F7 V star χ Dra

Figure 4 shows an example of a cool star: the magnetic detection in the binary system χ Dra obtained during the survey in May and July 2014. In the first observation the spectral lines of the two stars are superimposed and thus the LSD profiles do not allow to distinguish the two components. Fortunately, the radial velocity of the two stars were different in the second observation and the LSD profiles clearly show that the F7 V star is magnetic, while its cooler companion is not (with our detection threshold). Longitudinal field values measured for χ Dra are of the order of a few gauss.

Preliminary modelling of series of follow-up data obtained in 2015 and 2016 indicates that the rotation period is of the order of 5 days and show that the field of χ Dra is relatively simple with a strong poloidal component. Such simple configurations are not common in cool stars. χ Dra might be located near the transition between fossil and dynamo fields.

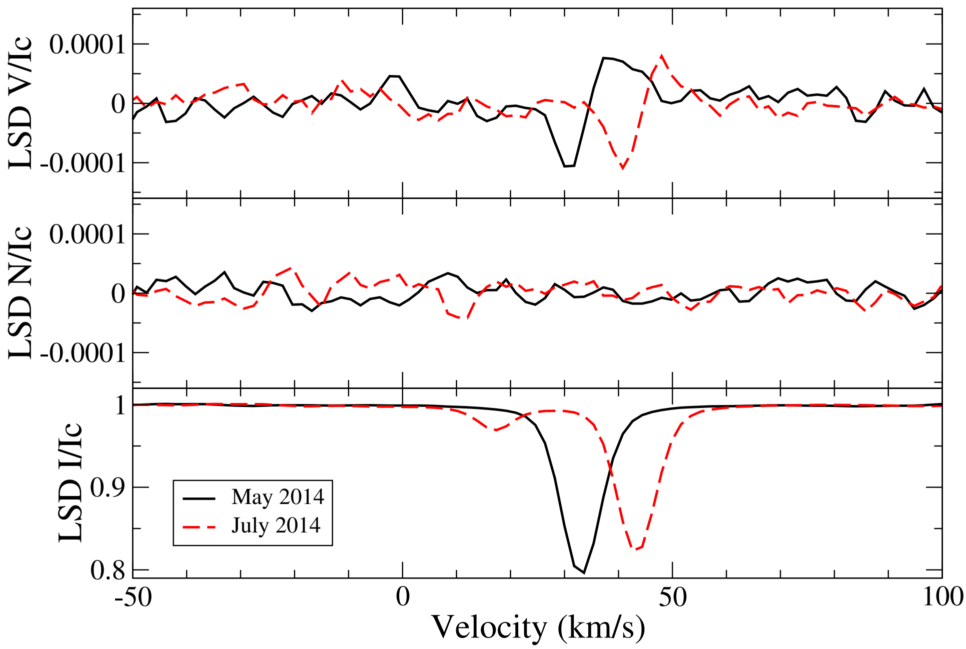

Fig. 4: LSD Stokes I (bottom), null polarization (middle), and Stokes V (top) profiles of the F7 V+K system χ Dra, obtained with Narval. In the observation collected in May (shown as solid lines) the lines of both stars are superimposed, while the observation gathered in July (shown as dashed lines) clearly shows that the F7 V star is the magnetic one.

3.4 The M giants

A magnetic detection was obtained in four M giants in our sample: δ Oph (M0.5 III), γ Cru (M3.5 III), σ Lib (M3/4 III), and β Gru (M5 III). β Gru and γ Cru were observed with HarpsPol, σ Lib with ESPaDOnS, and δ Oph with Narval. A magnetic signature is clearly visible in these four targets, as shown in Fig. 5.

4 Conclusion

We have almost completed the spectropolarimetric survey of all 573 stars brighter than $V = 4$ mag, using all three high-resolution stellar spectropolarimeters available in the world. We acquired one high-resolution, high signal-to-noise spectrum of each target, for which no adequate data was available in the archives yet. We detected 52 magnetic stars, including 42 new ones.

Follow-up observations of the most interesting magnetic stars allow us to characterise their magnetic field in detail. This will allow us to provide crucial information for the interpretation of the BRITE photometric data, as well as strong constraints for seismic modelling of the pulsating stars. This combined technique, called magneto-asteroseismology, is developing fast (Neiner et al., 2015a; Mathis & Neiner, 2015) and is particularly appropriate for bright stars which can be easily studied with spectropolarimetry even when they host weak magnetic fields.

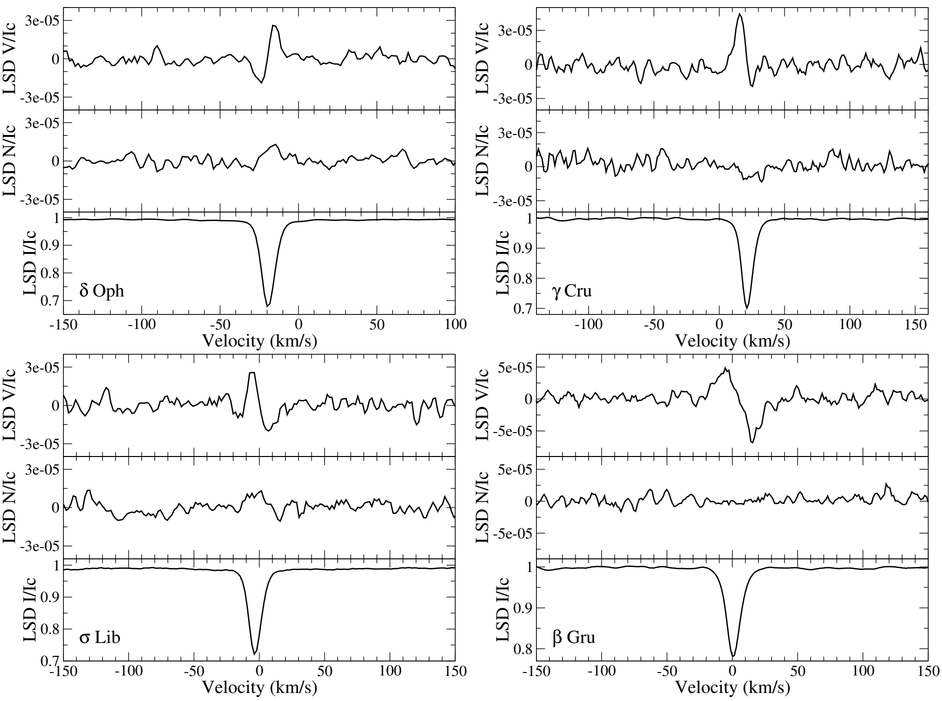

Fig. 5: LSD Stokes I (bottom), null polarization (middle), and Stokes V (top) profiles of the four M giants detected to be magnetic in the survey.

Finally, for all stars including those that are not magnetic, the exquisite spectra collected in this program can be used to determine stellar parameters and chemical abundances.

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