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MOBSTER: MAGNETO-ASTEROSEISMOLOGY OF HOT STARS WITH TESS

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Abstract. Magnetism has a strong impact on hot stars, including their internal structure. Therefore, performing magneto-asteroseismology provides valuable insight into hot stars and allows us to better constrain seismic models. However, only few magnetic pulsating hot stars have been identified and studied so far. Thanks to the TESS space mission, it is possible to find many magnetic hot stars including pulsating ones. The MOBSTER collaboration aims to identify magnetic candidates from TESS data, confirm and characterize their field with high-resolution spectropolarimetry, and ultimately perform magneto-asteroseismology on the most suitable targets.

Keywords: asteroseismology, stars: magnetic field, stars: chemically peculiar, stars: early-type, stars: oscillations, MOBSTER, TESS

1 Magnetic hot stars

About 10% of hot (OBA) stars are magnetic. Their fields are stable over decades, have typical polar field strengths of $\sim$3 kG at the stellar surface and usually a simple oblique dipolar configuration (Shultz et al. 2019). The fields are thought to be of fossil origin, i.e. a remnant from stellar formation (see Neiner et al. 2015, and references therein). In addition, a few A stars have been found to host ultra-weak magnetic fields (e.g. Blazère et al. 2016). These ultra-weak fields could be ubiquitous in OBA stars but are very difficult to detect with current instrumentation.

The presence of a magnetic field in a hot star has multiple consequences: in massive stars, wind particles escaping from the star are forced to follow magnetic field lines and can get trapped in a circumstellar magnetosphere (Petit et al. 2013). Moreover, in intermediate-mass stars, if the field is strong enough, it can create chemical enhancements at the stellar surface due to radiative diffusion along the field lines (Alecian & Stift 2010). In addition, if the star pulsates, the oblique magnetic field breaks the symmetry of the system and produces a splitting of the pulsation frequencies. The size of the frequency splitting is directly linked to the strength of the magnetic field, but the relative amplitude of the components of the split multiplet depends on the obliquity of the field with respect to the pulsation axis (Shibahashi & Aerts 2000). Knowing that a star is magnetic is thus crucial for pulsation mode identification. The field also modifies the period spacings of gravity-mode pulsations, which can then be used as a diagnostic of the strength of the internal magnetic field (Prat et al. 2020). Finally, above a fairly low strength the field inhibits mixing inside the star and there is thus no overshoot in magnetic stars (Zahn 2011).

As a consequence, magnetic hot stars are very interesting targets for asteroseismic studies. Magneto-asteroseismology indeed allows us to put additional constraints on seismic models and to extract more information about the internal structure of hot stars.

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2 Magnetic candidates from TESS

The inclination of the magnetic axis with respect to the rotation axis of the star produces rotational modulation of many observables, such as Hα, IR, and X-ray emission from the magnetosphere, UV resonance lines sensitive to the wind, polarization (Stokes) profiles, and light intensity. In the hotter stars the modulation of the light curve is due to varying column density of material in the magnetosphere along the line of sight as the star rotates, while in tepid stars it is due to the chemical elements accumulating in spots appearing on and disappearing from the visible half of the stellar surface. In both cases, rotational modulation of the light curve of a hot star is thus a good diagnostic of the presence of a magnetic field.

Using this property, three magnetic pulsating hot stars have been identified with Kepler2 (Buysschaert et al. 2018b). In addition, one hot magnetic pulsating star (HD 43317) was observed with CoRoT (Pápics et al. 2012; Briquet et al. 2013), and a few roAp stars with Kepler (e.g. Kurtz et al. 2011; Balona 2013). The BRITE constellation and associated BritePol spectropolarimetric program (Neiner & Lèbre 2014) observed some pulsating magnetic hot stars but those were already known from ground-based observations. Moreover, advanced seismic modelling has only been done for one such star so far (HD 43317, Buysschaert et al. 2018a) because of the small number of pulsation modes present in the other targets. It is therefore necessary to identify more magnetic pulsating hot stars.

The TESS mission observes most of the sky, with each target beeing observed for at least 28 days and up to 1 year depending on its coordinates (Ricker et al. 2015). The TESS data thus provide an excellent database to search for magnetic candidates through rotational modulation of their light curves. We cross-correlated our list of bright (V<10) magnetic candidates identified from TESS data with the list of chemically peculiar stars identified by Hümmerich et al. (2020) thanks to the characteristic 5200 Å flux depresssion observed in spectra from the LAMOST survey. We obtained 119 highly probable magnetic candidates. We plan to observe 48 of the 119 selected targets with high-resolution spectropolarimetry using ESPaDOnS at CFHT (Canada France Hawaii Telescope), with the aim to detect any magnetic field with a strength above 300 G. We consider that the remaining 71 stars are either less interesting from the seismic point of view or require too much observing time at CFHT. However, those 71 discarded targets are very likely magnetic stars as well. In addition, from the TESS data of the 48 selected magnetic candidates we identified 25 stars that show pulsational signals. These candidate magnetic pulsators are perfect targets for magneto-asteroseismology. Figure 1 shows an example of such a pulsating magnetic star, TYC 4766-330-1, which was indeed confirmed to be magnetic with ESPaDOnS at CFHT.

3 Spectropolarimetry

So far, the MOBSTER collaboration (David-Uraz et al. 2019) observed 21 of the 48 magnetic candidates with ESPaDOnS at CFHT. The data were analyzed with a Least-Squares Deconvolution technique (LSD, Donati et al. 1997) to extract magnetic signatures with a high signal-to-noise ratio. We obtained 20 clear magnetic detections, i.e. a 95% success rate in the confirmation of the presence of a magnetic field in these stars. The only non-magnetic star, TYC 2838-1789-1, is a spectroscopic binary (SB2) and had been flagged as dubious in Hümmerich et al. (2020). These very encouraging results show that our target selection process is very efficient, thanks to the combination of data from TESS and the LAMOST survey, and the vast majority of our magnetic candidates should indeed turn out to be newly discovered magnetic stars.

For the most interesting targets, i.e. those that are confirmed to be magnetic and show pulsational signal in the TESS data, we will acquire follow-up spectropolarimetric observations with the aim to obtain ~20 spectropolarimetric measurements per star spread over their stellar rotation period, to fully characterize the magnetic configuration and strength. A first target, HD 86170, is scheduled for follow-up observations in the fall 2021 with NeoNarval at TBL (Télescope Bernard Lyot, Pic du Midi, France). Figure 2 shows the first spectropolarimetric observation of HD 86170 obtained with ESPaDOnS at CFHT in February 2021, indicating a clear magnetic signature.

Finally, the high-quality spectropolarimetric data will also be used to determine the stellar parameters (e.g. $T_{\rm eff}$, $\log g$, $v \sin i$, abundances) of the targets at the precision needed for seismic modelling.

4 Conclusions

The MOBSTER collaboration has set up a program to search for magnetic pulsating hot stars in the TESS data, with the goal to perform magneto-asteroseismology. The magnetic candidate selection process is very efficient,

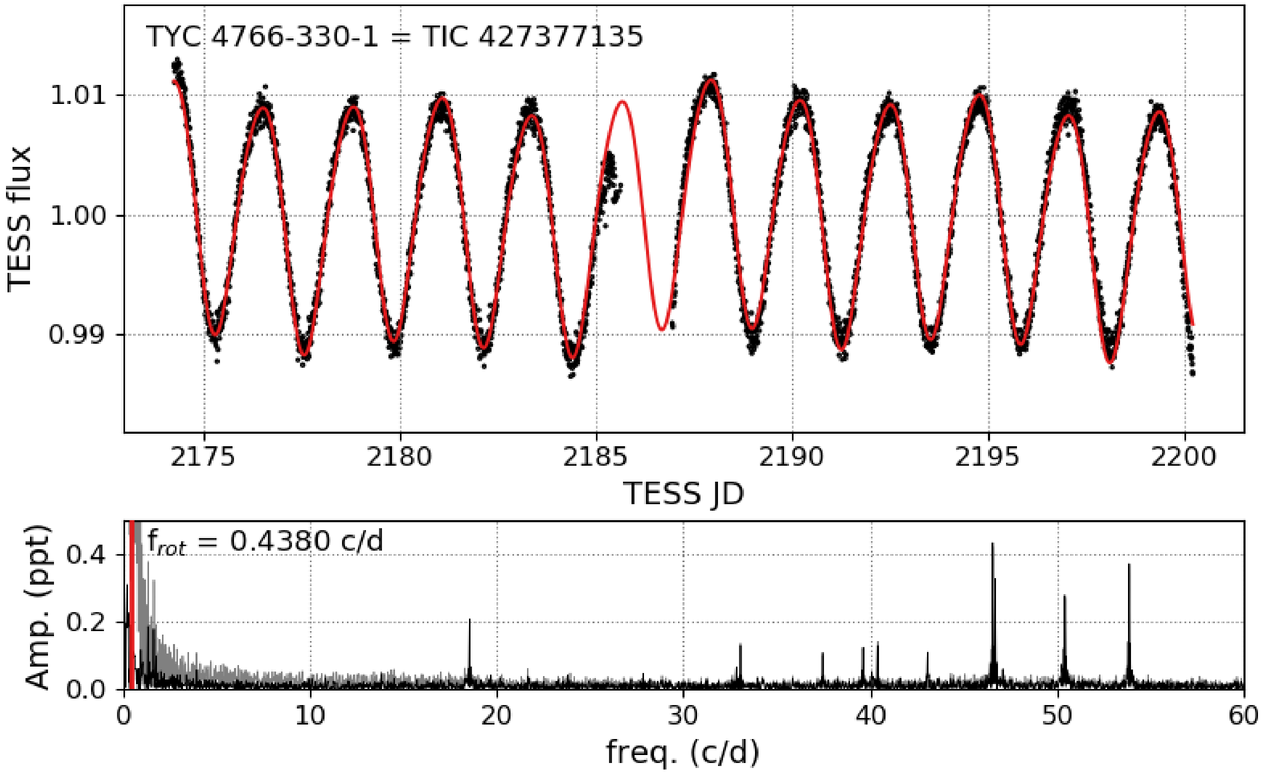

Fig. 1. Top panel: Light curve of TYC 4766-330-1 obtained by TESS in its sector 32 taken with a 10-min cadence, showing obvious rotational modulation. Bottom panel: Fourier transform (FT) of this light curve showing the original FT in grey and the FT after prewhitening for the rotation frequency (in red) and its first harmonic in black. Clear pulsational signal is present in the FT in addition to rotational modulation.

thanks to the combination of TESS and spectroscopic data, with 95% of the candidates confirmed to be magnetic so far using high-resolution spectropolarimetry at CFHT. Several very interesting magnetic pulsating targets have already been identified and will be the subject of follow-up spectropolarimetric observations at CFHT and TBL in the coming semesters to fully characterize their magnetic field. These results will be the starting point for magneto-asteroseismic modelling of hot stars by the MOBSTER collaboration.

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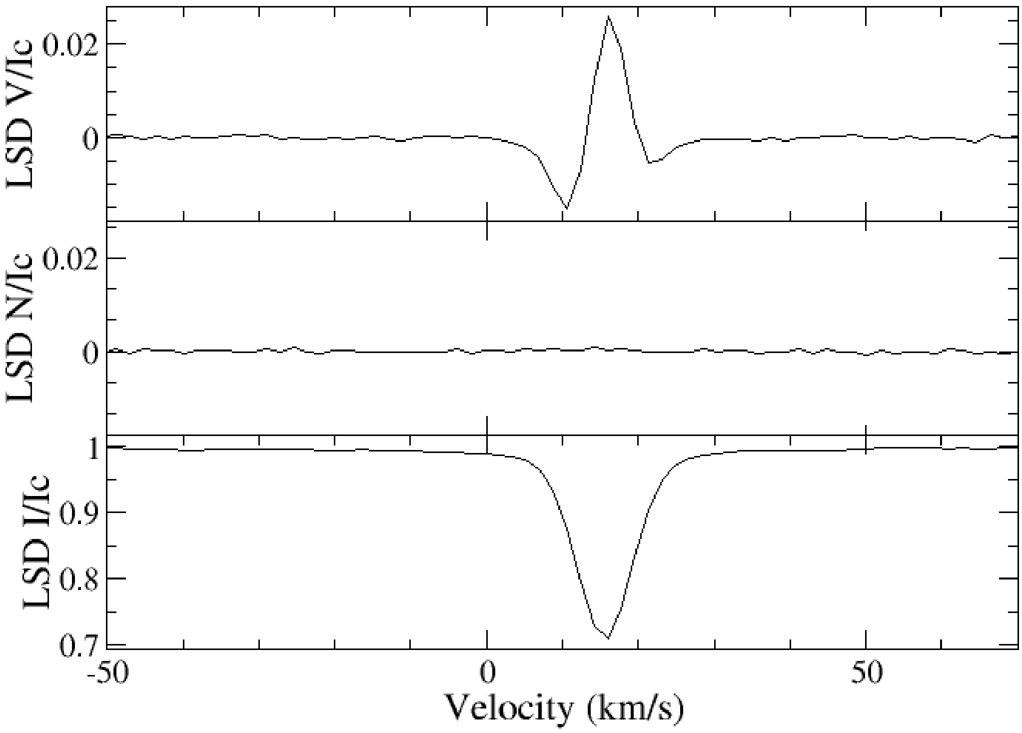

Fig. 2. ESPaDOnS observation of HD 86170 showing a clear magnetic detection in the LSD Stokes V profile (top), no detection in the null polarization used to check for spurious polarization signals (middle), and the LSD intensity line profile (bottom).

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