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WHAT CAN STELLAR MAGNETIC FIELDS TELL US ABOUT STAR-PLANET INTERACTIONS?

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Abstract. Interactions between hot-Jupiters and their host stars are expected to occur in close-in planetary systems. These interactions influence the planet (via tidal heating, evaporation of the atmosphere, orbital evolution, etc.), but can also influence the star. Magnetospheric interactions can enhance stellar chromospheric activity. On the other hand, tidal interactions influence the stellar magnetic field. Thus, studying this magnetic field can give us insights into the interactions occurring in these systems.

I will present the results of the first spectropolarimetric survey of hot-Jupiter hosting stars. The stellar magnetic properties will be presented and compared with those of cool stars without hot-Jupiter companions. From this survey, we observed the first large-scale magnetic cycle for a star other than our Sun, which shows a flip in polarity occurring on yearly timescales. I will discuss the possible role of star-planet interactions on short cycles such as this.

In addition to this observational aspect, I will discuss the effect the stellar magnetic field on the planet, planetary environment and planetary radio emission.

Keywords: Techniques: polarimetric, Stars: magnetic field, Stars: solar-type

1 Introduction

The discovery of the first exoplanet around a solar-like star in 1995 (Mayor & Queloz 1995) opened the door to a new era in planetary science. In two decades, thousands of exoplanets have been detected. The characteristics of these exoplanets and their orbits are diverse. An non-negligeable fraction of the first detections consisted of hot-Jupiters. A hot-Jupiter is a Jupiter-mass planet orbiting very close to its parent star, usually within 0.1 au. Those systems challenged our understanding of planet formation and migration. Interactions between the planet and the star are expected to occur, because of the proximity and the masses of the two bodies. These interactions will affect the planet, but they are also thought to affect the star.

Tidal interactions were invoked to try to explain the inflated radius of some exoplanets, the orbital obliquities, and the excess rotation of some stellar hosts (see, e.g. Ibgui et al. 2010; Winn et al. 2010; Pont 2009; Brown et al. 2011). It was recently suggested that elliptical (or tidal) instabilities, generated by interactions between tidal waves, can induce magnetic field in stars (Cébron & Hollerbach 2014).

On the other hand, magnetospheric interactions affect the two bodies in different ways. They can induce planetary radio emission (see Zarka 2007, for a review). Different emission scenarios and predictions were discussed in the literature (Grießmeier et al. 2007; Jardine & Collier Cameron 2008; Nichols 2012; Vidotto et al. 2012), but so far detections of exoplanetary radio emission have not been confirmed, only non-detection (and thus upper limits) and hints of detections are reported (Smith et al. 2009; Lecavelier des Etangs et al. 2013; Sirothia et al. 2014). Stellar activity can be enhanced by magnetospheric interactions (Cuntz et al. 2000), an enhancement modulated by the planetary orbital period. This was observed for some systems, but the same systems don't show such enhancement at different observing epochs (Shkolnik et al. 2003, 2005, 2008). The change in the configuration of the large-scale magnetic field from one epoch to the other might be responsible for that, given that these interactions depend primarily on the magnetic field (see, McIvor et al. 2006; Lanza

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2009). Enhancement in stellar X-ray activity was reported in Kashyap et al. (2008), a conclusion contradicted by Poppenhaeger et al. (2010).

Those different studies, although contradictory sometimes, show that the knowledge of the large-scale magnetic field of the star is necessary to model the interactions, interpret observations and make realistic predictions for induced emission. Comparing the magnetic properties of a sample of hot-Jupiter hosts to those of stars without known hot-Jupiter is important to study if the tidal and magnetospheric interactions influence the characteristics of the magnetic fields. We remind the reader here that for these cool stars, the magnetic field is produced by dynamo mechanism operating in the outer convective envelope of the star.

2 Stellar sample and study of magnetic field

In order to study if tidal and magnetospheric interactions affect the magnetic field of planet hosting stars, we have chosen a small sample of 10 hot-Jupiter hosts. The sample consists of F, G and K dwarfs, with a rotation period between 2 and 40 days. The hot Jupiter around these stars has a mass between 0.2 and 20 Jupiter mass. We were able to detect the field for 7 stars (τ Boo, HD189733, HD179949, HD73256, HD102195, HD46375, HD130322). Three of those stars have multi-epoch observations, allowing the study of the evolution of the field. We were unable to detect the field of Corot-7, HAT-P-2, XO-3.

Studying the large-scale field of stars can be done using spectropolarimetry and indirect imaging techniques such as Zeeman-Doppler Imaging (ZDI) (Donati et al. 1997, 2006). Spectropolarimetry consists of studying the polarisation inside the spectral lines. When the spectral lines are formed, if there is a magnetic field, it would induce Zeeman splitting, and the spectral lines will be polarised. In order to infer the magnetic field, one can study the polarisation signatures induced by this field, and, by mean of tomographic imaging, reconstruct the large-scale field. High resolution spectra can be collected using spectropolarimeters such as ESPaDOnS at CFHT and NARVAL at TBL. It is important to note here that the polarisation in spectral lines of cool stars induced by their magnetic field is extremely small, usually within the error bars. In order to be able to detect the signal, we use a multi-line technique, called Least-Square Deconvolution (LSD, Donati et al. 1997). LSD combines the information from many spectral lines and produces a mean profile with a higher S/N ratio than for single lines. Zeeman-Doppler Imaging is a tomographic imaging technique. It allows the reconstruction of the large-scale magnetic field map of a star, using the polarimetric information in spectra collected over one or more stellar rotation. Actually, different field orientation (e.g. radial, azimuthal) produces different polarisation signatures. When the star rotates, the signatures of a particular magnetic region will be shifted due to the Doppler effect. The signature in the profile will also depend of the position of the feature on the stellar surface. Collecting spectra over a stellar rotation allows, using ZDI (and maximum-entropy regularisation), to produce the simplest magnetic map that would produce the polarisation signatures in the collected spectra (Vogt et al. 1987; Semel 1989). The magnetic field orientation, the location and the strength of the features can thus be determined using ZDI.

As already mentioned, one needs a high S/N time-series of spectra to be able to perform ZDI. Depending on the spectral type, magnitude and characteristics of the star, a single map reconstruction can require up to three observing nights.

3 Field topologies and evolution

3.1 Field characteristics

We reconstructed the magnetic maps of the seven stars for which we have detected a magnetic field. Each map is a description of the field in a spherical coordinate system, with the radial, azimuthal and meridional components reconstructed. Using ZDI, we can calculate all the field characteristics, i.e. field strength, the energy in the poloidal and toroidal components, the degree of axisymmetry. Our analysis (Fares et al. 2009, 2010, 2012, 2013) shows that the general characteristics of the field of planet hosts of our sample is not different from those not harbouring a hot-Jupiter. Tidal and magnetospheric interactions, although present in these systems, don't seem to influence the global field characteristics. For cool stars more massive than about 0.8 solar mass, there seems to be a trend in the field characteristics: stars with a Rossby number greater than one have weak fields, with a dominant axisymmetric poloidal component. Stars with a Rossby number less than one have stronger fields, dominated by the toroidal component, with a non-axisymmetric poloidal component. Stars hosting a hot-Jupiter show similar characteristics, see Fig 1.

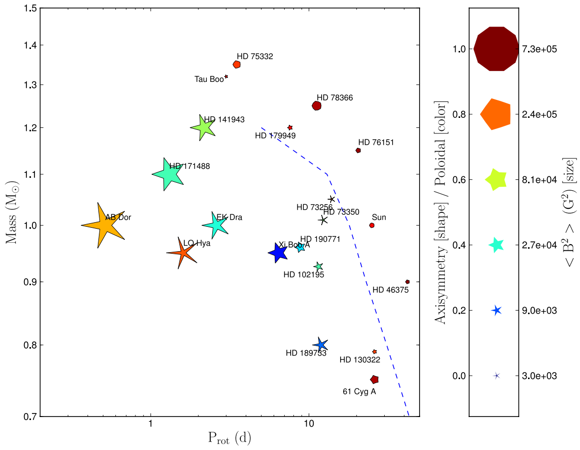


Fig. 1. Mass-rotation diagram of 18 reconstructed stellar magnetic fields. Planet host stars have their names indicated in red, while other stars without detected hot Jupiters have their names indicated in black. The dashed line represent Rossby number = 1.0. The size of the symbol represents the field strength, its colour the contribution of the poloidal component to the field, and its shape how axisymmetric the poloidal component is. Fig. from Fares et al. (2013)

3.2 Field evolution

τ Boo was observed over many observing epochs, covering 5 years. This system is particular because the star is an F star, with a shallow convective envelope, orbited by a massive planet of about 6 Jupiter mass. The planet and the star are synchronised, i.e. the star has the same rotational period as the planetary orbital period, both of 3.3 days. We observed, for the first time for a star other than the Sun, a flip in the polarity of the large-scale magnetic field. This flip happens every year, indicating a cycle of 2 years (or less). Such a cycle is a fast cycle when compared to the solar 22 year cycle. The origin of such a short cycle is not yet understood, it might be due to the shallow convective envelope, or to the synchronisation of the outer envelope with the planet, possibly by tidal interactions. More observations of F stars are needed, as well as observations of planet hosts in order to conclude on the effect of tidal interactions on short cycles.

4 Stellar corona and beyond

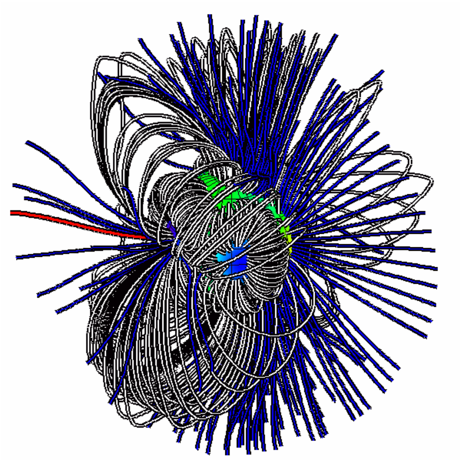
Using the reconstructed magnetic maps, we can extrapolate the magnetic field to the stellar corona. The theoretical modelling of the stellar corona can be done using a potential field source surface model (e.g. McIvor et al. 2006), a force free model (e.g. **?**) or a stellar wind model (e.g. Vidotto et al. 2012). In all cases, when the map is reconstructed, it can be used as a boundary condition for the field extrapolation, making the modelling of the corona more realistic. Fig 2 shows an example of such extrapolation, for HD189733, using a potential field source surface model.

From this extrapolation, one can study the environment around the planet and on the planetary orbit. We calculate the stellar magnetic energy at the position of the planet. Since the stellar magnetic field is not a simple axisymmetric field, this energy is variable on the orbit. This implies that the environment surrounding around the planet on its orbit is variable, see fig 2.

From the study the magnetic energy around the planet, we can predict the planetary radio emission from interactions, using, for example, the magnetic energy model of Zarka (2007); Grießmeier et al. (2007). We find that the radio emission is variable on the orbit, and is modulated by the beat period between the rotation of the star and the orbital period of the planet. This variability reflects the variability in the planetary environment.

5 Conclusions

Star-Planet interactions in close-in planetary systems affect both the planet and the star. The stellar large-scale magnetic field influence these interactions and can be influenced by them. We studied the magnetic field of a sample of hot-Jupiter hosting stars. We found that the magnetic field characteristics are not different from



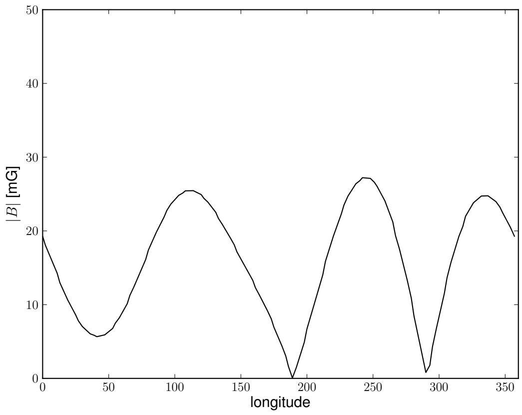


Fig. 2. Left: The extrapolated magnetic field of HD 189733 for June 2007. White lines corresponds to the closed magnetic lines, blue ones to the open field lines, and the red line corresponds to the field line joining the planet to the star at a given (arbitrarily selected) orbital and rotation phase. **Right:** The magnetic field at the distance of the planet as a function of stellar longitude for June 2007, adapted from Fares et al. (2010)

those of stars without a hot-Jupiter. However, the magnetic field of τ Boo varies over a cycle of 2 years, a fast cycle compared to the solar one. The shallow convective envelope, high differential rotation, but also the synchronisation with the planet, and thus tidal interactions might be responsible for such a short cycle. Our studies show that in order to understand the environment around the planet, one must study the stellar field. This is also the case for predicting realistically the planetary emission due to star-planet interactions. Finally, multi-wavelength campaigns allow characterising the system from the stellar surface till the planetary orbit. In case of positive detection (bow shock, radio emission), the magnetic field of the planet can be inferred.

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