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HOW MUCH DO MAGNETIC FIELDS IMPACT STELLAR CHARACTERIZATION?

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Abstract. With our new tool, `ZeeTurbo`, used to model spectra of magnetic stars, we devised a process to simultaneously constrain the atmospheric parameters and average magnetic fields ($<B>$) of M dwarfs. Our process was applied to 6 targets observed with the near-infrared spectropolarimeter SPIRou, installed at the Canada-France-Hawaii Telescope, in the context of the SPIRou Legacy Survey. We derived atmospheric parameters and $<B>$ in agreement with previous studies and reported rotation periods. We further assessed the influence of magnetic fields on the characterization of M dwarfs, and show that neglecting them can lead to significant offsets in the estimated effective temperature, surface gravity and metallicity of the stars.

Keywords: spectroscopy, low-mass stars, magnetic fields, infrared

1 Introduction

The study of magnetic fields hosted by M dwarfs is essential to better constrain the properties of planets orbiting them, and to better understand their formation and evolution. In the recent years, several studies relied on high-resolution near-infrared (nIR) spectroscopy to estimate the atmospheric properties (such as the effective temperature $T_{\rm eff}$, log surface gravity $\log g$ and metallicity [M/H]) of M dwarfs (e.g., Passegger et al. 2019; Marfil et al. 2021; Cristofari et al. 2022a,b). At the same time, several studies relied to high-resolution spectroscopy to measure the Zeeman broadening of the line profiles (see, e.g., Kochukhov 2021), allowing one to probe magnetic fields on smaller scales than with Zeeman-Doppler-Imaging techniques (Donati & Brown 1997; Donati et al. 2006).

Studies aimed at characterizing the magnetic properties of stars typically assume a set of atmospheric parameters. Conversely, studies attempting to constrain atmospheric parameters tend to avoid active targets, to neglect the effect of magnetic fields, or to focus on lines with near to zero Landé factors. With the improvement of spectroscopic observations and models, it now becomes possible to assess the impact of magnetic fields on the estimation of stellar properties, by relying on spectral lines with different Landé factors in order to constrain both magnetic fields and atmospheric parameters at once.

We rely on our new tool, `ZeeTurbo` (Cristofari et al. 2023), built from the `Turbospectrum` (Plez 2012) and `Zeeman` (Landstreet 1988) codes, to compute high-resolution nIR spectra of M dwarfs from MARCS model atmospheres (Gustafsson et al. 2008). We fit our models to spectra recorded with SPIRou (Donati et al. 2020) in the context of the SPIRou Legacy Survey (SLS) to estimate both the average magnetic field ($<B>$) and atmospheric parameters of 6 magnetic M dwarfs: AU Mic, Gl 388, Gl 410, EV Lac, Gl 406 and PM J18482+0741 (PM J18 in the rest of this manuscript).

2 Characterizing magnetic M dwarfs

Our magnetic fields estimates place our targets in the unsaturated dynamo regime of the Rossby (Ro) – $<B>$ diagram (see Fig. 1, Left). Furthermore, we found that our estimates are consistent with those of previous studies (Reiners et al. 2022), with differences that can be attributed to the choice of selected lines, models, assumed atmospheric parameters or even with the evolution of magnetic fields with time.

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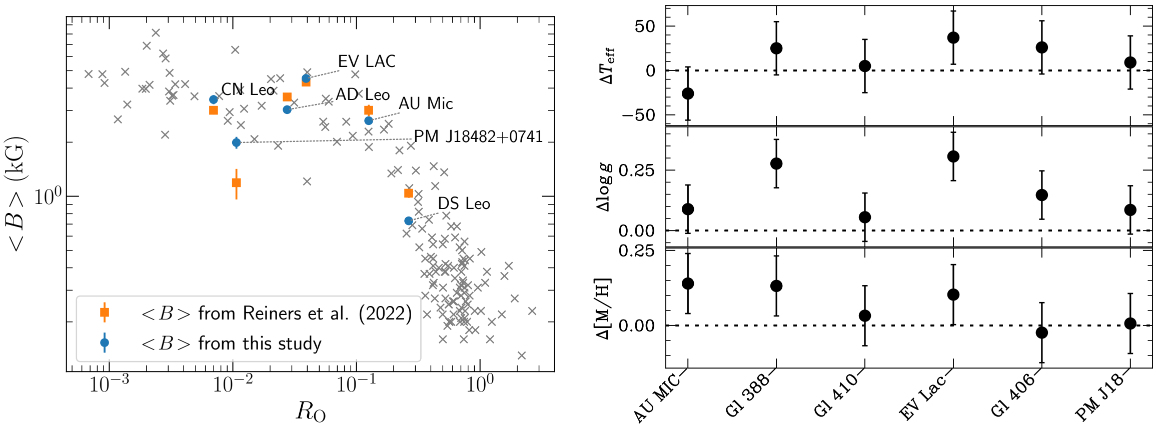

Fig. 1. Left: Rossby–$< B >$ diagram for 6 magnetic M dwarfs observed with SPIRou. The gray crosses mark the position of stars studied in (Reiners et al. 2022). **Right:** Residuals between values derived with magnetic and non-magnetic models.

We compared the derived atmospheric parameters recovered with magnetic models to those obtained with non-mangnetic models in Fig. 1 (Right). Our analysis relied on about 30 atomic lines with Landé factors ranging 0 to 2, and about 40 magnetically insensitive molecular lines mainly from one CO band. We obtained significant differences in the results, with an overall tendency to find larger estimates of $T_{\rm eff}$, $\log g$ and [M/H] with non-magnetic models, with the exception of AU Mic whose temperature is found smaller with non-magnetic models. The difference between the two sets of parameters reach values comparable to our error bars on $T_{\rm eff}$ and [M/H] ($\sim$ 30 K and $\sim$ 0.10 dex, respectively), and up to two times our error bars on $\log g$, estimated to $\sim$ 0.05 dex. The significant impact on $\log g$, in particular, can result from the broadening of the spectral lines caused both by this parameters and magnetic fields. We note that $\log g$ is among the most difficult parameters to accurately constrain, even for weakly-active M dwarfs (Cristofari et al. 2022b). The inclusion of magnetic fields in the modeling of moderately active stars is, therefore, likely to influence the atmospheric parameters estimates, and can be used to provide better constraints on the stellar properties overall.

Our method can be applied to a larger sample of M dwarfs with slower rotations (see Donati et al. 2023b) in order to detect and quantify the strength of their small-scale magnetic fields (Cristofari et al., submitted). By analyzing spectra on a nightly basis, we will also study the temporal evolution of the detected fields, and search for rotational modulation in the obtained time series, such as what was done in Donati et al. (2023a).

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