Measuring the small-scale magnetic fields of M dwarfs with *ZeeTurbo*

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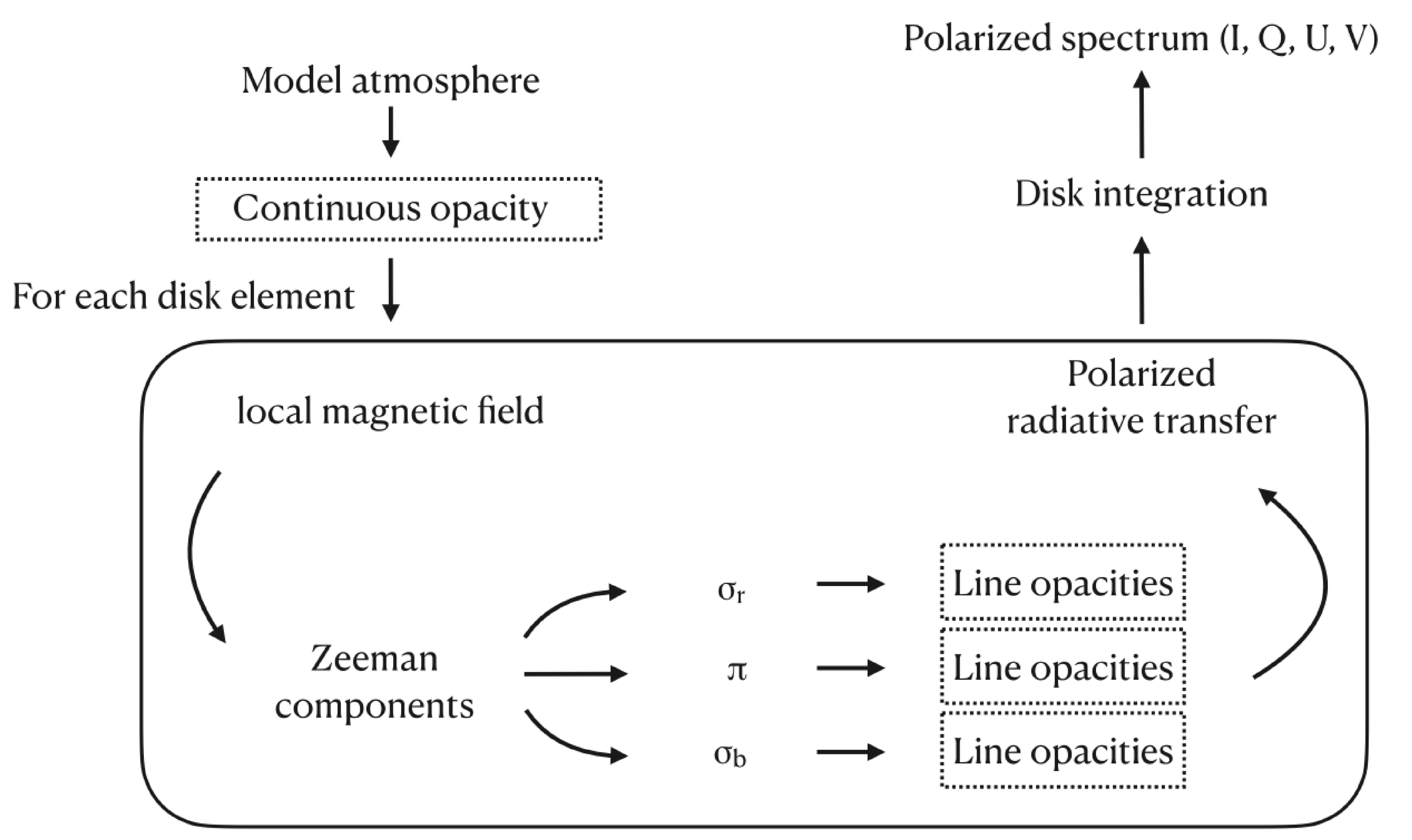
ABSTRACT

M dwarfs are obvious targets for the search of exoplanets in the habitable zone of their host stars. They also host magnetic fields, that can impact spectral characterization and radial velocity measurements. Constraining the atmospheric and magnetic properties of M dwarfs is crucial to understand the processes at the origin of magnetic field generation, stellar formation and evolution. We present the results of studies aimed at putting accurate constraints on the effective temperature ($T_{\rm eff}$), surface gravity ($\log(g)$), metallicity ([M/H]), α–enhancement ([α/H]) and average magnetic fields of M dwarfs, relying on high-resolution spectra. We developed a new tool, ZeeTurbo, by implementing the Zeeman effect and polarized radiative transfer in Turbospectrum. High-resolution nIR spectra recorded with SPIRou at the Canada-France-Hawaii Telescope (CFHT) are compared to grid of models computed with ZeeTurbo for various magnetic field strengths. We rely on a Markov chain Monte Carlo (MCMC) to estimate the atmospheric parameters and magnetic field strength of M dwarfs from posterior distributions. We applied out tools to 49 targets, retrieving atmospheric parameters and magnetic fields measurements in good agreement with previous studies. We identify a number of targets whose spectra are well reproduced by non-magnetic models, and identify a few stars (e.g. GJ 1289 and GJ 1286) with larger small-scale magnetic fields in spite of their long rotation periods.

MODELING SPECTRA OF MAGNETIC STARS

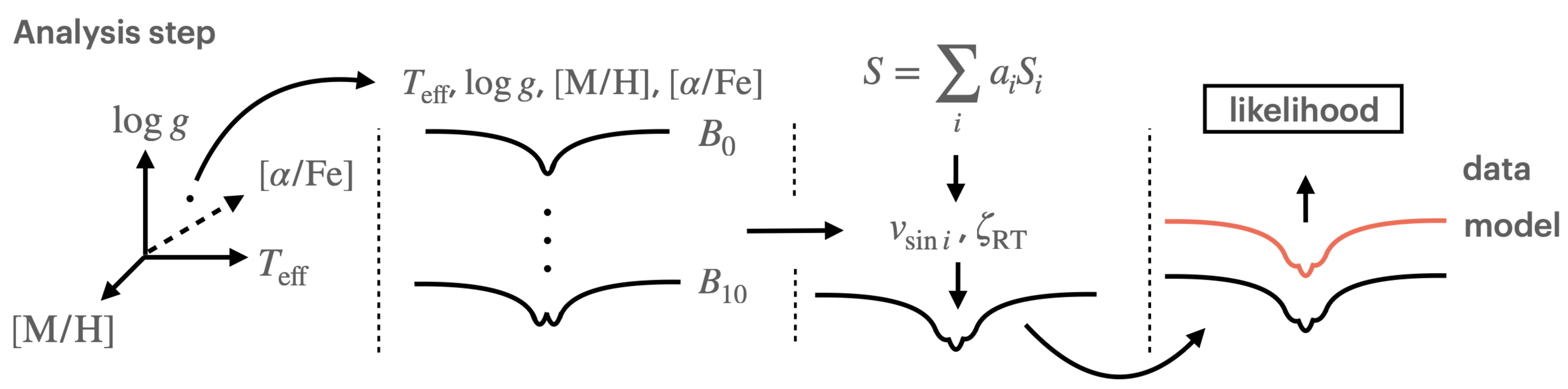
ZeeTurbo: Zeeman + Turbospectrum



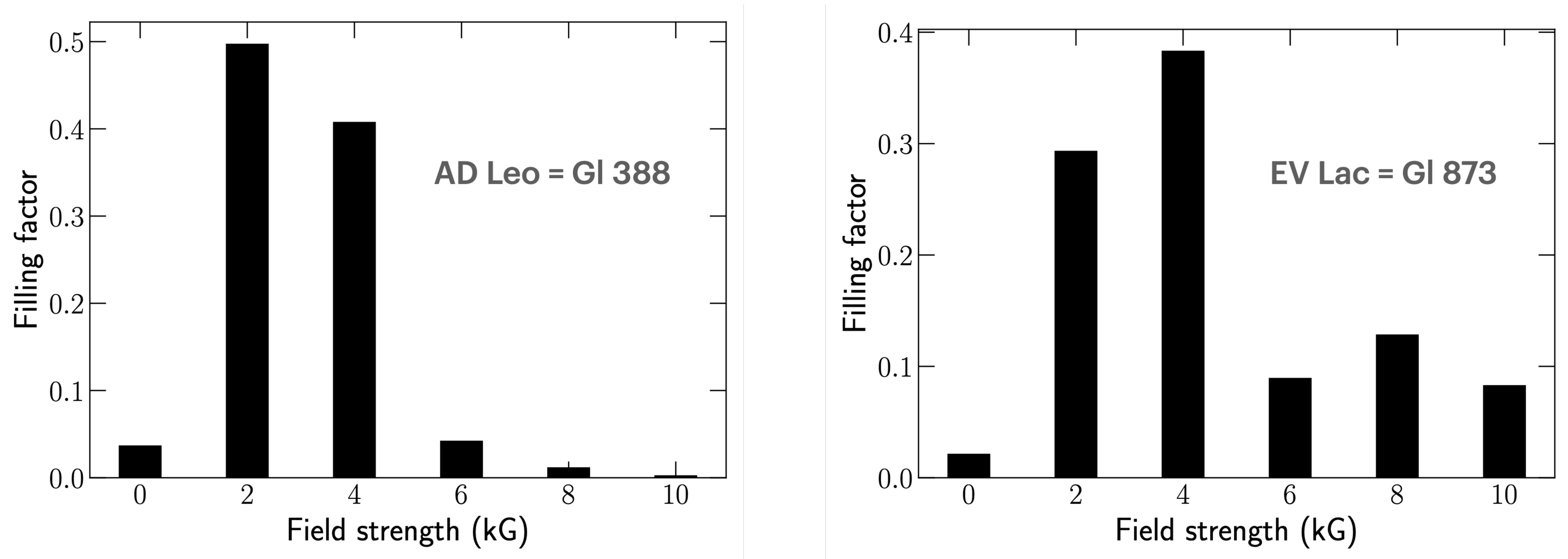
ZeeTurbo takes opacity computation from *Turbospectrum*[1] and solves the polarized radiative transfer equation[2] with routines adapted from the *Zeeman*[3] code.

Fitting models to spectra of magnetic targets

We built a grid of synthetic spectra computed for various combinations of atmospheric parameters and magnetic field.



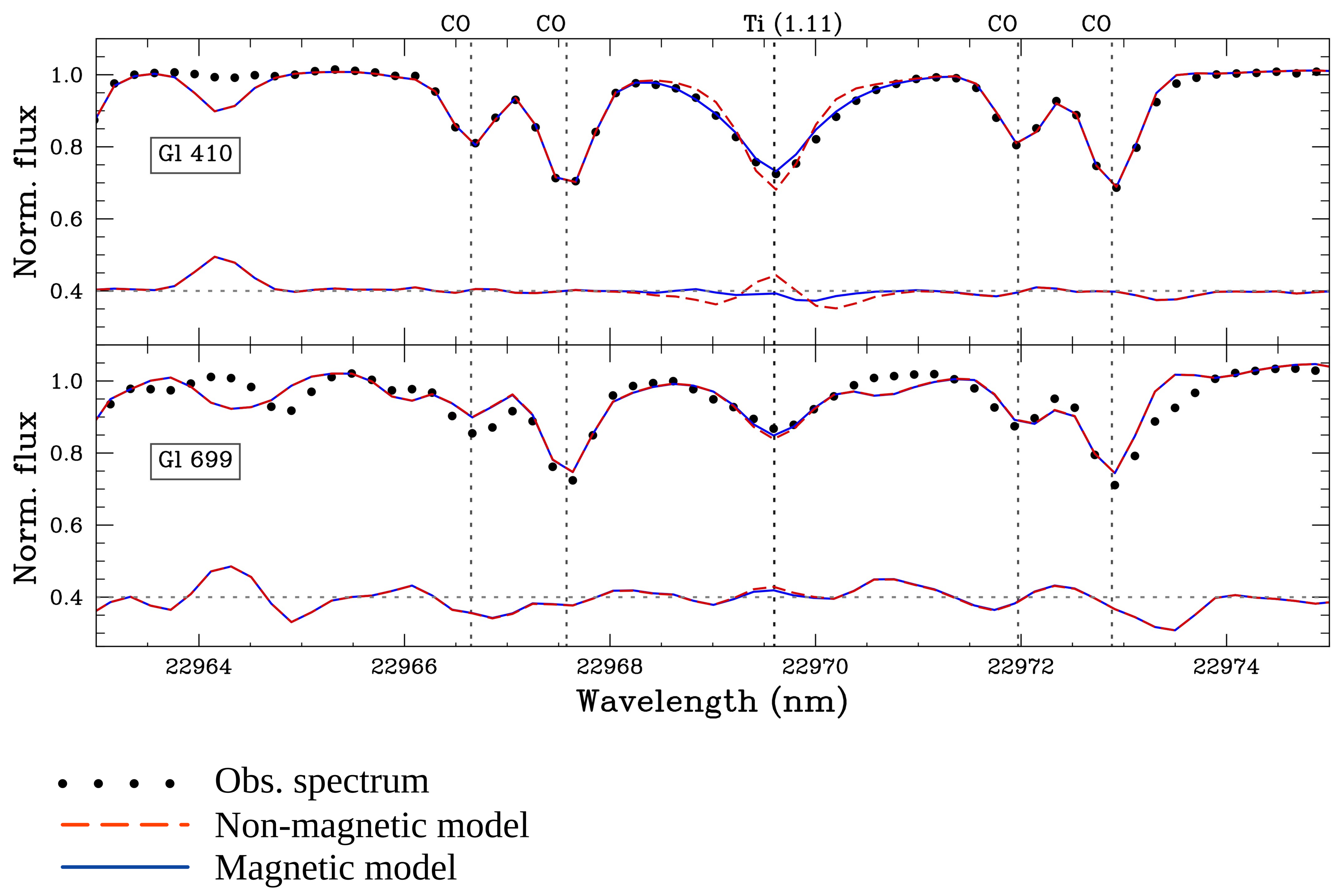
We fit our data with linear combinations of synthetic spectra computed for various magnetic field strengths and estimate atmospheric parameters and filling factors (ai) from posterior distributions[4] computed with an MCMC.



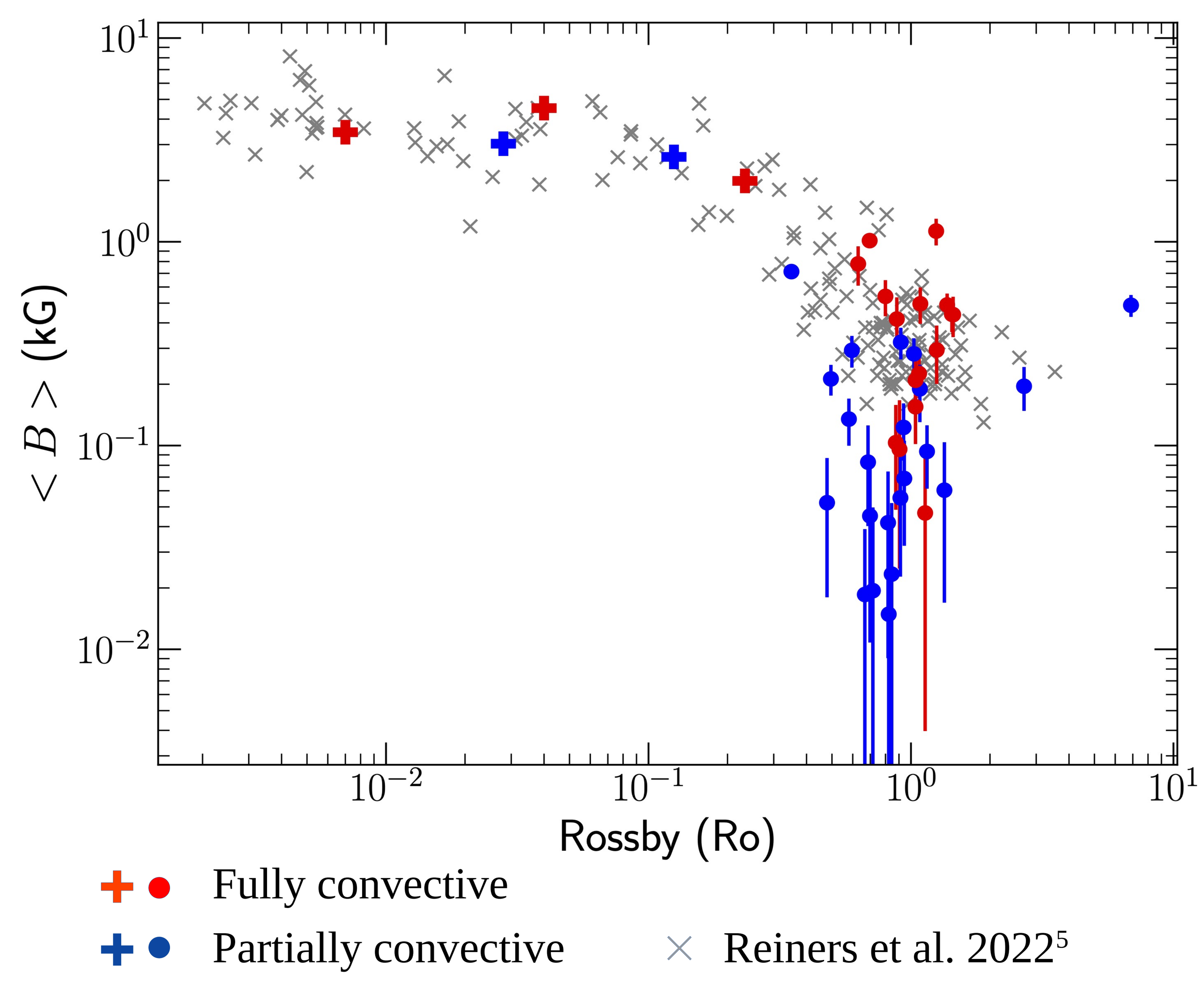
We observe differences in the distribution of filling factors for different stars, indicating that for some of them, stronger magnetic components play a larger role in the overall magnetic flux, which could result from surface inhomogeneities.

RESULTS

ZeeTurbo models allow us to obtain reliable constraints on the magnetic fields of M dwarfs by relying on magnetically sensitive and insensitive lines simultaneously.



Average magnetic fields



We obtained <B> estimates for 49 stars[4,6], most of which fall in the unsaturated dynamo regime. The magnetic field of a few stars is found to be rather large in spite of their long rotation periods, while the spectra of other targets with similar Rossby numbers is well reproduced by non magnetic models.

CONCLUSIONS

We developed a process relying on a MCMC to fit spectra computed with our new tool *ZeeTurbo* to high-resolution spectra. We applied our process to 5 strongly magnetic and 44 weakly to moderately active M dwarfs observed with SPIRou. We derived constraints on their magnetic field strengths and atmospheric parameters in agreement with the literature.

What are the next steps?

Short term: With our tools, we will search for rotational modulation of small-scale magnetic fields of M dwarfs, such as that observed for AU Mic[7], and expand our analysis to pre-main sequence (PMS) stars. We will apply our analysis to stars observed in the southern sky with WINERED, installed at the Magellan/Clay telescope.

Long term: We aim at providing the community with reliable tools to constrain magnetic fields and atmospheric parameters of low-mass stars, in order to better understand the origin of magnetic fields generation, stellar formation and evolution.

REFERENCES

(1) Alvarez R., Plez B., 1998, A&A, 330, 1109
(2) Martin B., Wickramasinghe D. T., 1979, MNRAS, 189, 883
(3) Landstreet J. D., 1988, ApJ, 326, L967
(4) Cristofari P. I., et al., 2023, MNRAS, 522, 1342
(5) Reiners A., et al., 2022, A&A, 662, A41
(6) Cristofari P. I., et al., 2023, MNRAS, 526, 5648
(7) Donati J.-F., et al., 2023, MNRAS, stad1193

Scan the QR code (or click it) to check out more !

Or visit https://paulcristofari.github.io/

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