DETECTION OF LOW-MASS EXOPLANETS WITH SPIROU

Retrieving stars rotation period with the Zeeman broadening of atomic lines

Merwan Ould-Elhkim

Supervisors: Claire Moutou, Jean-François Donati

SPIRou, irap, école normale supérieure paris-saclay, Université Toulouse III Paul Sabatier

Summary

In order to study the significance of the Zeeman broadening to retrieve stellar signals, the width of various **atomic lines** of interest has been computed over time for a set of stars which rotation period is known. This allowed to make a statistical study and highlight which atomic lines were more likely to be suited as future stellar indicators for **SPIRou**.

Introduction

SPIRou is a spectrograph operating in the **infrared** (0,98-2,5μm) which aims at detecting exoplanetary signals around nearby M dwarves with the **radial velocity method**[1]. The instrument is at a level of precision that makes it sensible to noise coming from the star itself namely stellar spots, granulation, magnetic activity and so on. This may induce RV signals of a few meter-per-second which can impend the detection of low-mass exoplanets or introduce spurious RV signals in the data.

In the search of habitable exoplanets it is necessary to address this issue and to come up with strong stellar indicators which help to disentangle between stellar and planetary signals. The **Zeeman broadening** could provide such a feat by giving a measure of the magnetic field strengths at small scale [2]. Since this effect scales with the wavelength, it is stronger within **SPIRou** wavelength domain than with optical spectrographs.

Methodology (Data Extraction)

First, **atomic lines** of interest were taken from the VALD database[3] for effective temperatures of 2500, 3000 and 3500K and a log *g* of 5,0.

Example with Gliese 699

- Atomic lines are first selected according to the star temperature.

- Lines that are within known **telluric zones** are removed.

- The spectra are blaze normalized and only the lines with a **median depth below 0.6** over time are kept. This whole process usually leaves 30 to 100 atomic lines to study. Below is the potassium line at 1243.5675nm for illustrative purpose.

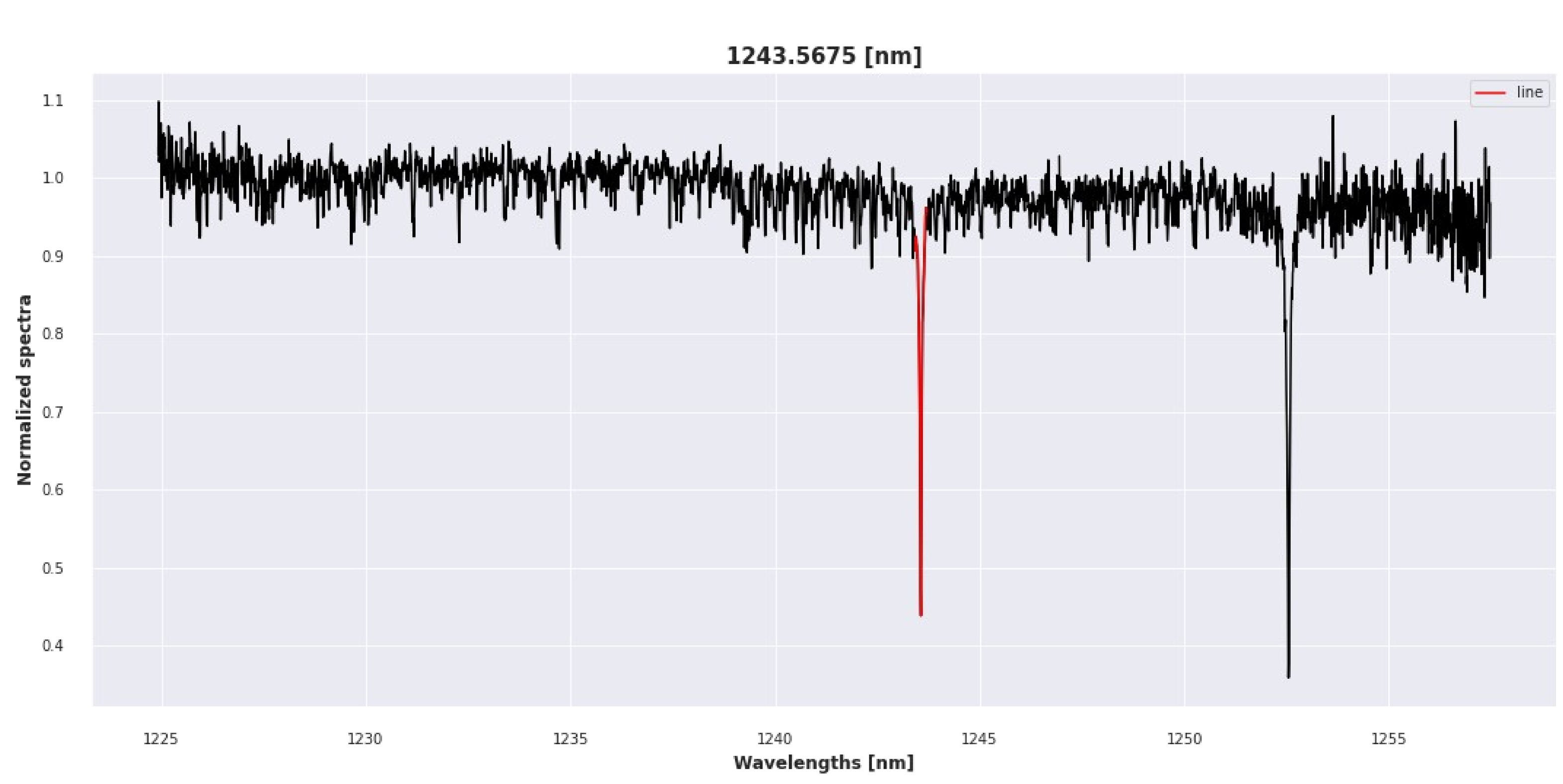

Fig. 1: *Spectrum of Gl699 around the 12436.5657nm K line (red).*

Extracting data from the 1243.5675nm K line

- A Gaussian process (GP) is fitted in an interval of **25km/s** around the line so as to to remove the noise in all spectra[4]. The **mean** of all *GPs* over time is then fitted as well as its **first** and **second** derivatives.

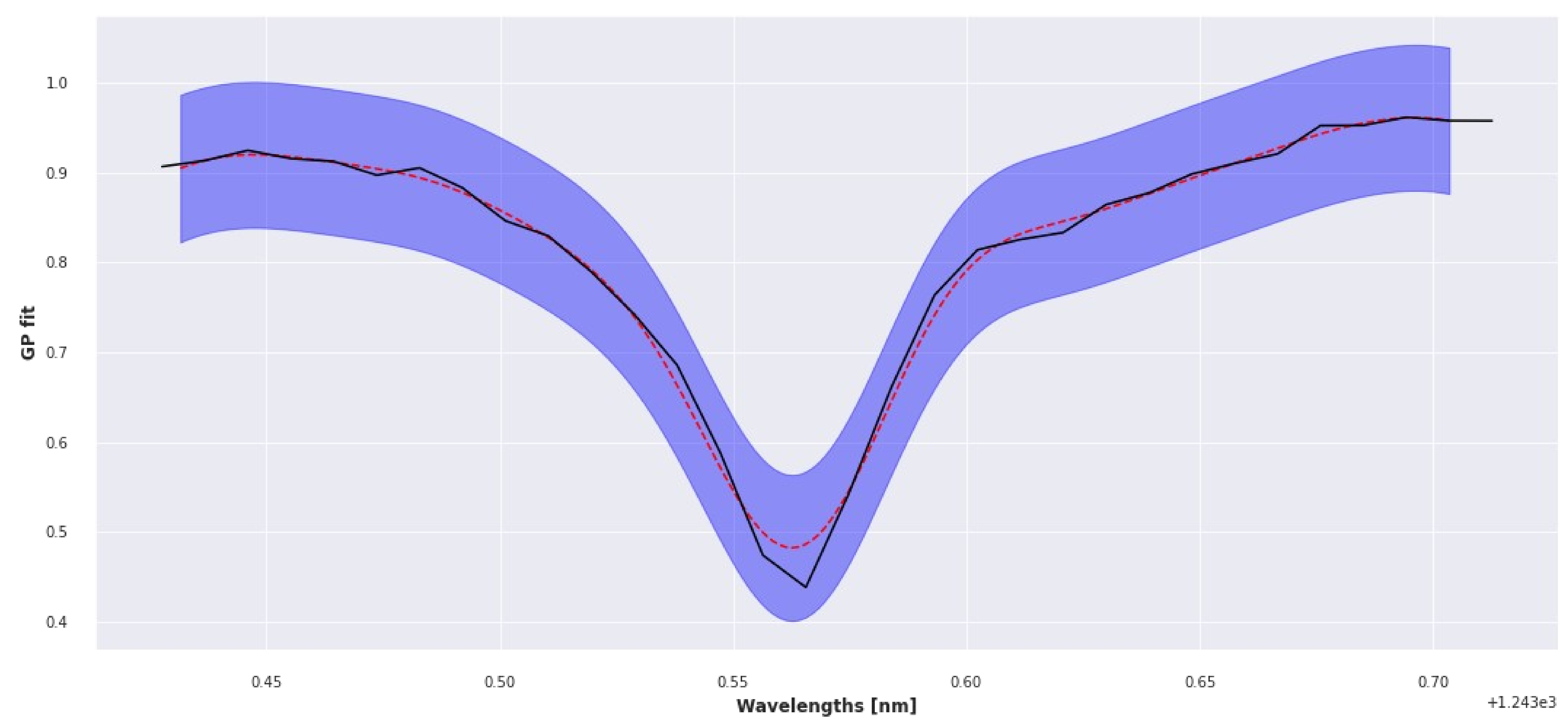

Fig. 2: The 1243.5657nm K line in a 25km/s interval (black). The fitted Gaussian process is the dashed red line and the blue area is the zone one standard deviation away from the mean.

Methodology (Timeseries Analysis)

For a given line, all the Gaussian processes are projected to the mean μ and its derivatives:

$$GP = \gamma + a\,\mu + RV\, d\mu/d(RV) + DDV\, d^2\mu/d(RV)^2$$

The projection of the line over the second derivative, **DDV**, is related to its **relative width**. This gives access to a timeserie which is analyzed using a **bayesian periodogram**.

It consists in computing on a frequency grid the logarithm of the **bayes factor** (*log BF*) at each frequency, ***log BF > 5*** corresponding to a signal statistically significant. This gives for our illustrative K line a period at 149.34 days, which is the current known rotation period for Gl699.

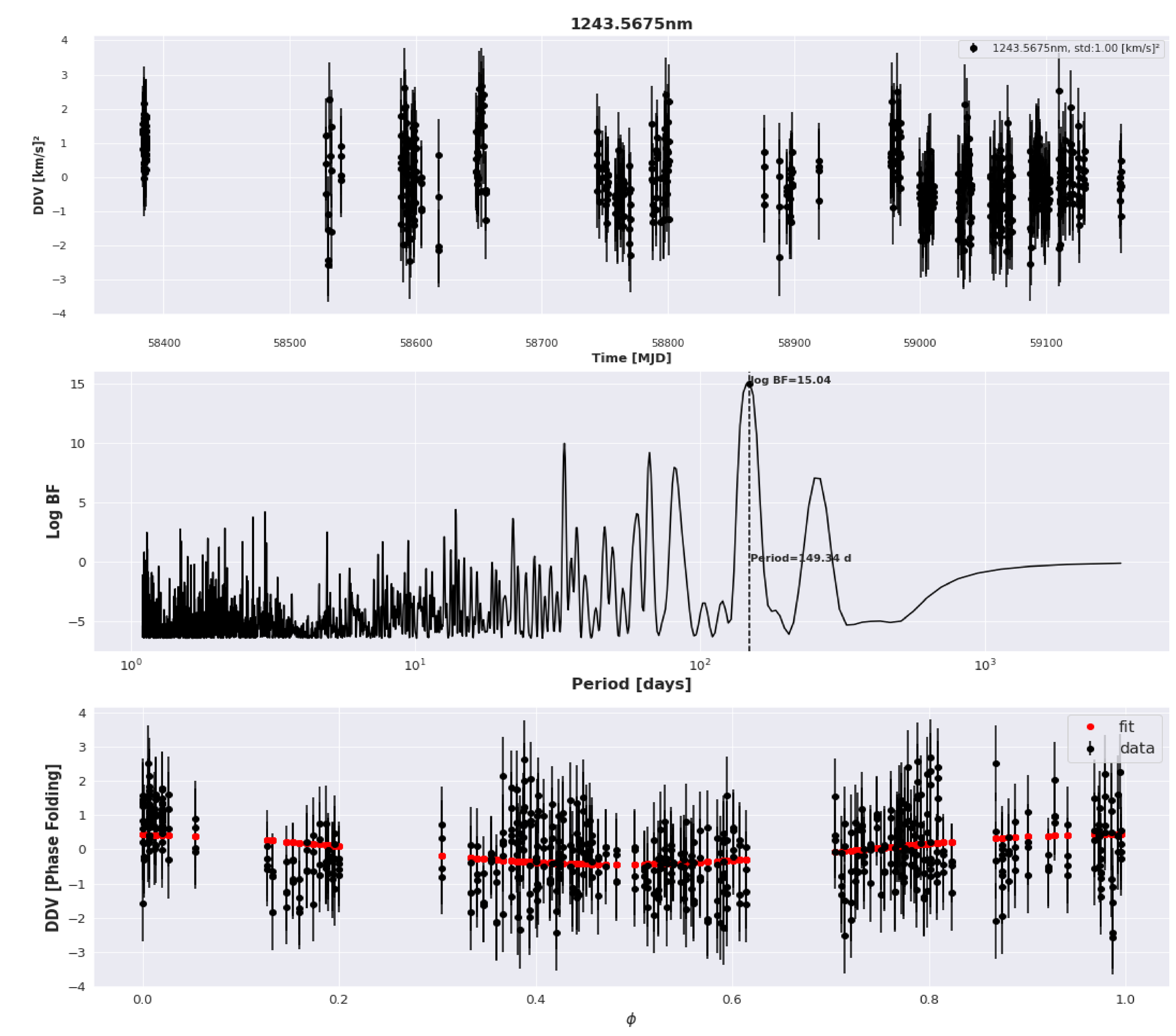

Fig. 3: (Top) DDV timeseries of the 1243.5657 K line. (Middle) Bayesian periodogram of this timeseries with a prominent peak at 146.34 days with a log BF of 15.04. (Bottom) Phase folding of the time series at the found period with the fitted signal in red.

Preliminary Results and Perspective

This whole process was done on various **atomic lines** and diverse stars the rotation period of which is known which allows to determine lines that could be good indicators. Nine stars with no strong magnetic activity were studied, a tendency seems to stand out for a **Ti** line at **1049.899nm** to correctly extract the rotation periods.

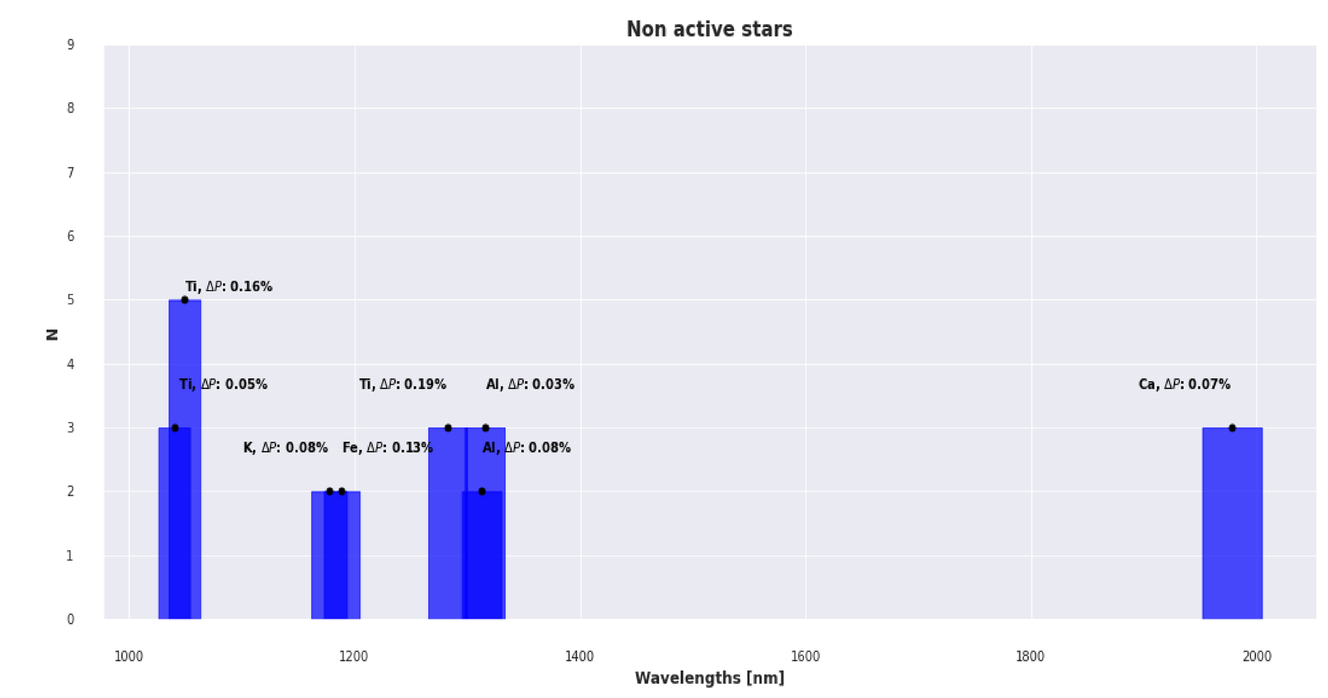

Fig. 4: All lines that were able to correctly identify more than two rotation periods are shown. At the top of the bar is written their relative variation to the known period.

Future work will consist in conducting this study on a larger set of stars. All atomic lines which were extracted from this work are potential **stellar indicators** which will help in disentangling between stellar and planetary signals in the search of low-mass exoplanets. The most promising one being the 1049.899nm Ti line which is able to retrieve the star rotation period with a success rate above 50%.

References

[1] Donati, J.-F., "*SPIRou: NIR velocimetry and spectropolarimetry at the CFHT*", **Monthly Notices of the Royal Astronomical Society**, vol. 498, no. 4, pp. 5684–5703, 2020.

[2] Reiners, A., "*Radial velocity signatures of Zeeman broadening*", **Astronomy and Astrophysics**, vol. 552, 2013. doi:10.1051/0004-6361/201220437.

[3] Kupka, F., Dubernet, M.-L., and VAMDC Collaboration, "*Vamdc as a Resource for Atomic and Molecular Data and the New Release of Vald*", **Baltic Astronomy**, vol. 20, pp. 503–510, 2011. doi:10.1515/astro-2017-0328.

[4] Rajpaul, V. M., Aigrain, S., and Buchhave, L. A., "*A robust, template-free approach to precise radial velocity extraction*", **Monthly Notices of the Royal Astronomical Society**, vol. 492, no. 3, pp. 3960–3983, 2020. doi:10.1093/mnras/stz3599.