Stellar activity of the M dwarf GL205 as seen by SPIRou, SOPHIE and TESS

Pia Cortes-Zuleta, Isabelle Boisse, the SPIRou team, the SOPHIE team
Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France

Interactive poster: piacortes.github.io/TSC2_poster

M dwarfs and stellar activity

M-dwarfs are the most abundant stars in our galaxy and interesting targets for exoplanet surveys. Dedicated radial velocity (RV) surveys of M dwarfs are being performed by the spectrographs SOPHIE and SPIRou, in the optical and near-infrared regimes, respectively. Both aim to search and characterize small planets around nearby M dwarfs.

One of the main limitations to detect Earth-like planets around M dwarfs is the presence of stellar activity. Features in the stellar surface, such as spots and plages, break the flux balance and thus, distort spectral lines [1,2]. As the RV is measured from the stellar spectra, this will include the effect introduced by the activity. Stellar activity indices can be derived by measuring the chromospheric emission in specific spectral lines such as Ca II H&K and Hα, among others. However, these lines are located in the optical domain.

GL205

GL205 is an early M dwarf (M1.5), with an effective temperature of Teff=3490 K. It has been monitored by HARPS, HARPS-Pol, and NARVAL. Using the Hα and Ca II H&K indices, the rotational period was found to be around 33 days [3]. In more recent studies the period was measured at 35 days using the S-index [4]. Photometry data in the V band showed a periodicity of 33 days and a possible long-trend magnetic cycle [4,5]. Moreover, Zeeman Doppler Imaging revealed hints of differential rotation in the surface of GL205[6], which could explain the inconsistency in the periods found from different activity indices.

The aim of this work is to characterize the stellar activity in the optical and near-infrared domains of the moderately active M dwarf GL205, using photometry from TESS and spectroscopy from SOPHIE and SPIRou. After the characterization and removal of the stellar activity jitter, we expect to look for planetary signals as no planet has been confirmed orbiting this star.

TESS photometry

GL205 was observed in sectors 6 and 32 from November 12th to January 7th of Year 1 and from November 19th to December 16th of Year 2. As it is typical for M dwarfs due to their high levels of activity, we spotted two flares events in sector 6 at JD = 2459471.01 and JD = 2459484.15 (see Fig. 1)

The expected rotational period of GL205 is around 33 days, so one data sector will not cover a complete rotational cycle. However, we applied a Lomb-Scargle periodogram in both sectors, combined and independently. Sector 6 shows a peak of periodicity at 14.4 days, which could be interpreted as the Prot/2 harmonic of the true rotational period Prot [7]. Sector 32, however, shows a peak at 7.7 days. The periodogram of both sectors together is inconclusive, as a consequence of the gap of almost two between them.

The mean flux levels of both sectors are different as shown in Fig. 1 and Fig. 2. The flux obtained during sector 32 shows higher variability and less mean flux than sector 6, indicating that the star was more active during this epoch. For M dwarfs, higher levels of activity may increase the presence of spots on the stellar surface. These dark regions will reduce the amount of total flux emitted by the star.

Figure 1: Sector 6 photometry

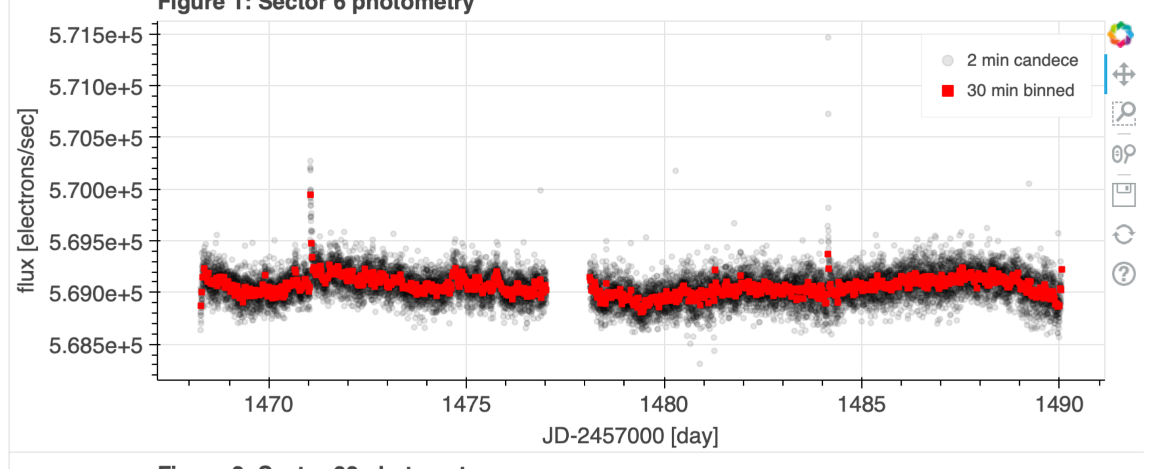
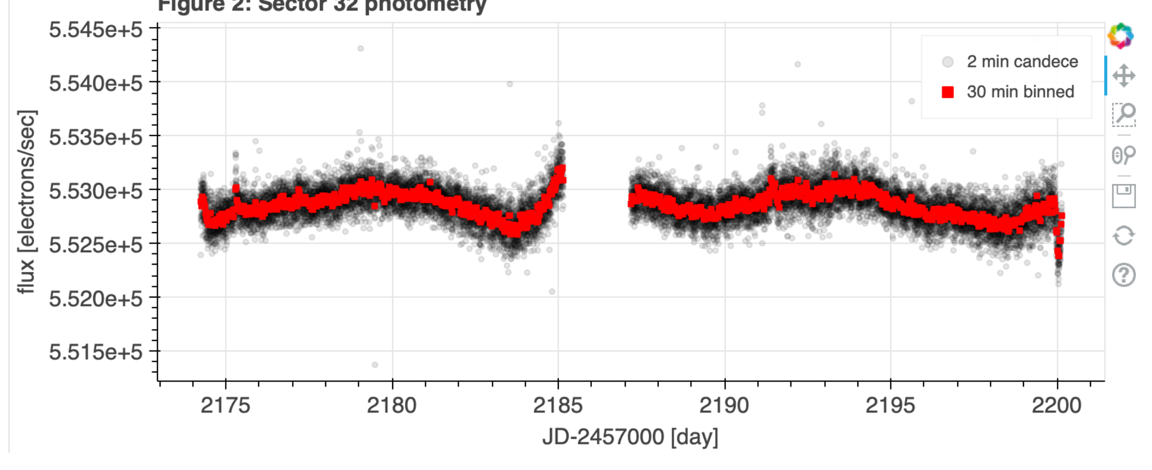


Figure 2: Sector 32 photometry



SOPHIE+SPIRou spectroscopy

SOPHIE [8,9] is a spectrograph in the optical regime, located at the Observatoire de Haute-Provence in France. It monitored GL205 from 2019 to 2021 as a part of the Recherche de Planetes Extrasolaires (RPE) sub-program dedicated to searching for Neptunes and super Earth-like planets around M dwarfs. We applied the NAIRA code, which is based on the template matching algorithm [10], to obtain high-precision radial velocities. A total of 44 measurements were obtained, with an RV root-mean-squared (RMS) of 4.5 m/s.

SPIRou [11,12], on the other hand, is a near-infrared spectropolarimeter and high-precision velocimeter mounted at the Canadian-France-Hawaii Telescope (CFHT) in Hawaii. Its observations of GL205 were more or less contemporary to SOPHIE, i.e between 2019 and 2021. A total of 372 spectra were obtained but each epoch corresponds to a sequence of four different light polarizations. As we considered the mean of each polarization sequence, the total number of SPIRou measurements is 93. The RV measurements from SPIRou were computed using the LBL method [13], and they have an RV RMS of 4.4 m/s. Figure 3 shows the RV time series of SOPHIE and SPIRou data.

The Lomb-Scargle periodogram of the complete time series of radial velocities shows a peak at 33.9 days (see Fig. 4), which corresponds to the stellar rotational period. Moreover, there are no signs of the harmonics Prot/2 and Prot/3.

Figure 3: SOPHIE+SPIRou radial velocities time series

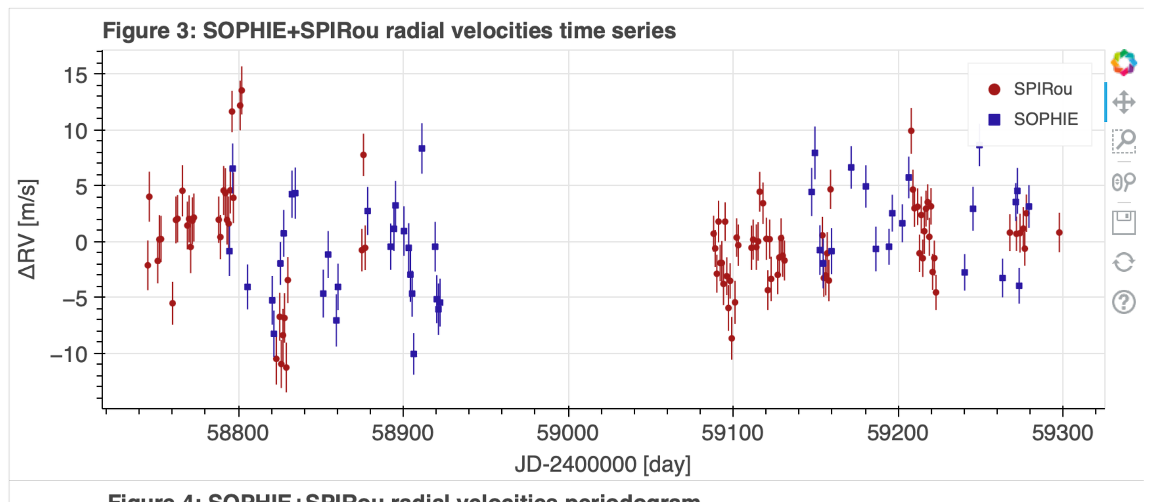
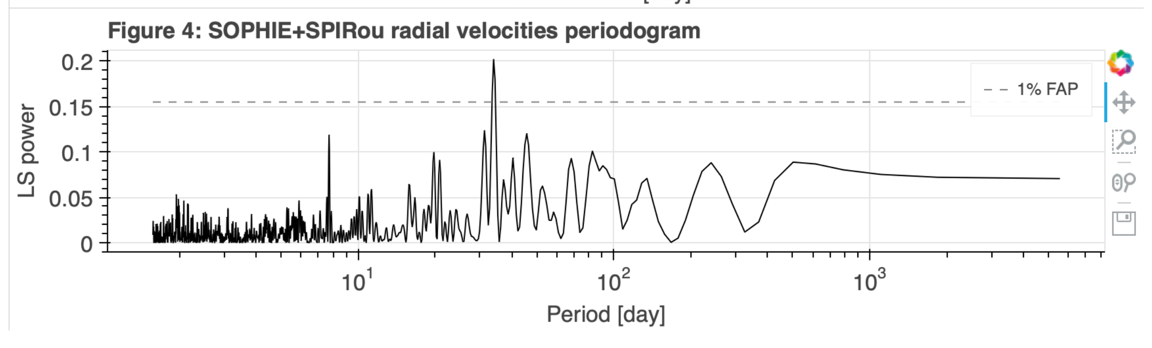


Figure 4: SOPHIE+SPIRou radial velocities periodogram



Stellar activity indicators

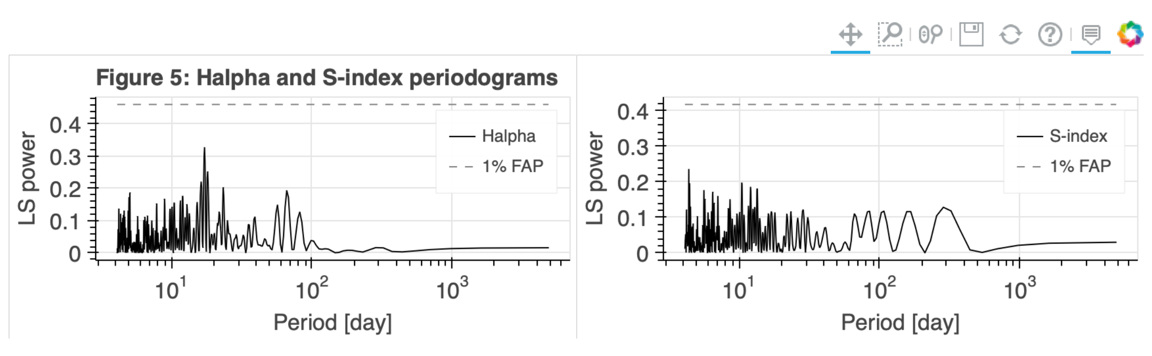
The biggest advantage of having almost simultaneous data in the optical and near-infrared regimes is that we can compare the levels of activity as seen in different wavelength domains. However, the standard stellar activity indicators, such as Halpha, Ca II H&K, and S-index, use spectral lines located in the optical. In the near-infrared, at least within the SPIRou domain, there is a lack of activity indicators. The Ca II IRT line at λ8500Å has been used as an activity indicator for M dwarfs however, it is outside the SPIRou domain. From a study in an M dwarfs sample from the CARMENES [13] project, it has been found that Ca II IRT is correlated with Hα [15]

Using the optical and near-infrared RV measurements of GL205, we compared the standard activity indicators in the optical: Hα and S-index with K λ12435Å, Al λ13154Å, Ti λ10499Å, and Fe λ11693Å lines in the near-infrared. All of these elements have shown hints of being good activity tracers in the optical or for Sun-like stars [16,17,18,19,20].

We analyzed the temporal evolution of the equivalent width (EW) of K, Al, Ti and Fe lines. The EW was measured using an MCMC fitting routine of a Voigt profile. Then, we applied a Lomb-Scargle periodogram in the EW time series of the spectral lines, in order to see if there are correlations with the rotational period of the star.

Figure 5 shows the periodogram of Hα and the S-index, measured from the SOPHIE data. No significant periodicity is detected above 1% of the false alarm probability (FAP). The highest peak in the Hα peridogram is at 17.2 days, which correspond to the Prot/2 harmonic. There is also a peak around 66 days, close to two times the rotational period. In the case of the S-index periodogram, no periodical signals are detected.

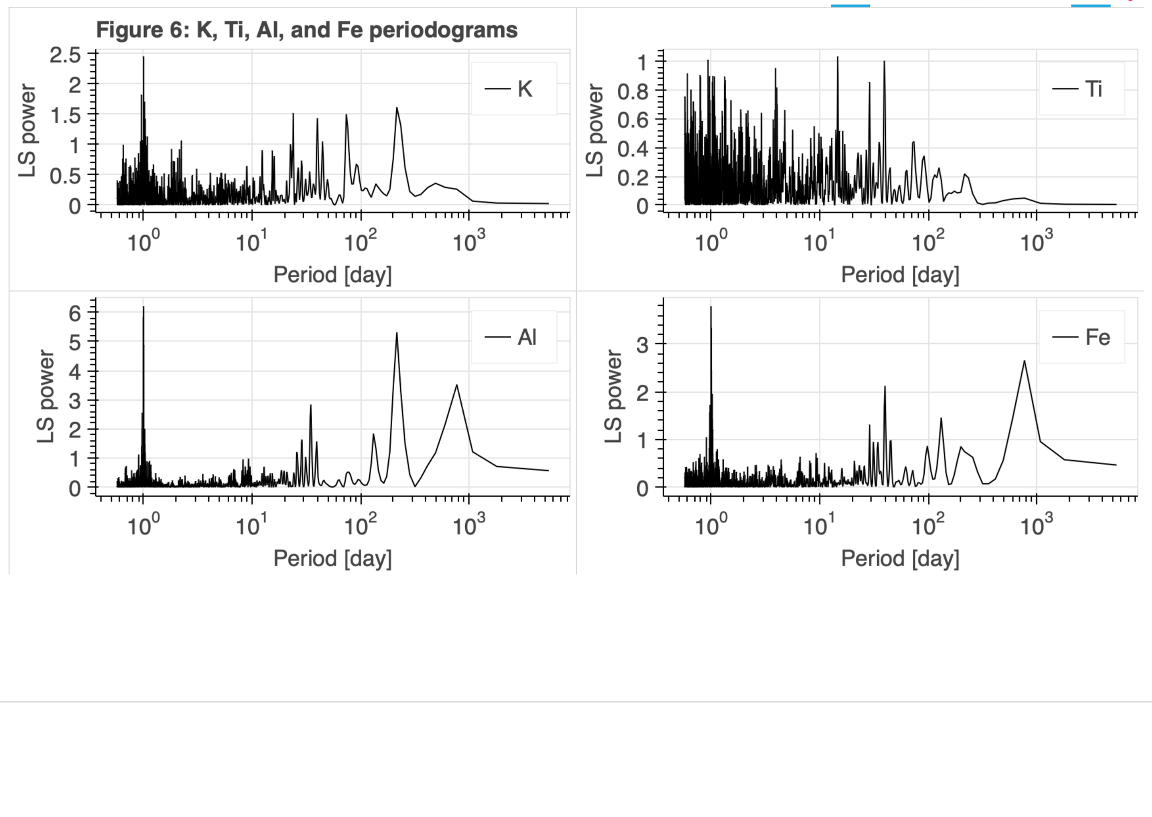
Figure 5: Halpha and S-index periodograms



The periodograms of proposed indicators in the near-infrared are shown in Figure 6. Even though none of the tested spectral lines show a significant peak at the expected rotational period, all of them have less-significant peaks between 30 and 40 days. Moreover, peaks close to the harmonics at Prot/2 and Prot/3 can be found too. This may be a confirmation of the differential rotation of the stellar surface, as proposed by Hebrard et al. 2016. The lines K and Ti both have a significant peak at 215 days, that could be related to the magnetic cycle of the star.

The fact that none of proposed spectral lines show a clear peak at the expected rotational period is a clue to understand better the stellar activity of moderately active M dwarfs. For them, we may expect that the model that describes their activity cycle is complex and includes several factors, such as the differential rotation.

Figure 6: K, Ti, Al, and Fe periodograms



Conclusions

* In this work, we showed preliminary results of the stellar activity characterization of the M dwarf GL205, using TESS photometry and SPIRou and SOPHIE spectroscopy.

* TESS photometry of GL205 describes an evolution of its activity levels. It's clear that the star was more active during sector 32, where the mean flux level was lower given to a wider coverage of spots in the surface.

* SOPHIE and SPIRou monitored GL205 over two years, in the optical and near-infrared domains, respectively. A Lomb-Scargle periodogram shows a peak at 33 days, which corresponds to the rotational period of the star.

* We analyzed four new spectral lines in order to characterize the stellar activity in the near-infared: K, Ti, Al, and Fe lines, due to the lack of known spectral lines used as activity indicators in SPIRou domain. In the optical, we computed Hα and the S-index from SOPHIE spectra. None of the spectral lines studied show a significant peak at the expected rotational period. However, in some cases the harmonics at Prot/2 and Prot/3 appear in the periodograms.

* The proposed spectral lines in the near-infrared show different results: most of them have periodicities in a range between 30 to 40 days. Several peaks in the periodogram, close to the rotational period are an indicator of differential rotation in the surface of the star. Moreover, Ti an K show a long-term periodicity of around 215 days that could be related to the magnetic cycle of GL205.

* Finally, we have shown that it is fundamental combining photometry and spectroscopy data, when it is available, to perform a proper characterization of the stellar activity of M dwarfs. Specially in the case of moderately active M dwarfs, as GL205, whose activity cycle may be more complex than expected.

References

[1] Dumusque et al. 2011 [2] Boisse et al. 2012 [3] Bonfils et al. 2013 [4] Toumi et al. 2019 [5] Kiraga & Stepien 2007 [6] Hebrard et al. 2016 [7] Boisse et al. 2011 [8] Perruchot at al. 2008 [9] Bouchy et al. 2013 [10] Anglada-Escude and Butler, 2012 [11] Donati et al. 2018 [12] Donati et al. 2020 [13] Artigau et al. in prep [14] Quirrenbach et al. 2016 [15] Schöfer et al. 2018 [16] Barrado y Navacués et al. 2001 [17] Robertson et al. 2016 [18] Cretignier et al. 2019 [19] Spina et al. 2020 [20] Yana Galarza et al. 2019

Pia Cortes-Zuleta
PhD student
Laboratoire d'Astrophysique de Marseille
pia.cortes@lam.fr