The KOBE experiment: filling the habitable zone desert in late K-dwarfs

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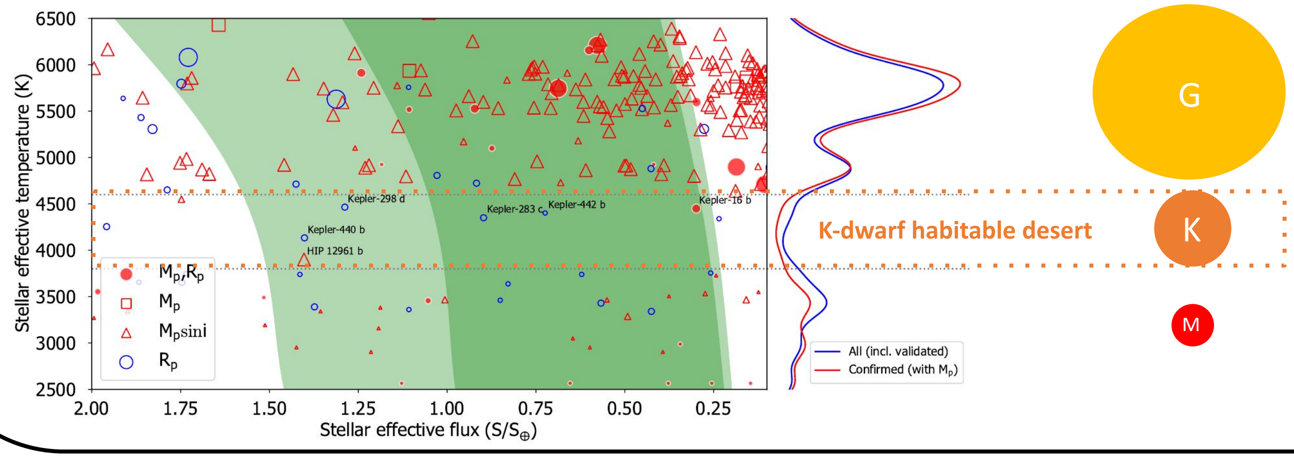
Context. The KOBE experiment

The KOBE experiment (K-dwarfs Orbited by Habitable Exoplanets; **Lillo-Box et al. 2022**, submitted) is aimed at searching for new worlds within the habitable zone (HZ) of K-dwarf stars through the radial velocity method using the CARMENES spectrograph. The survey is currently monitoring 50 pre-selected late K-dwarf stars, where we expect to find a significant number of planets according to planet occurrence rates in this stellar regime.

K-dwarf stars are the ideal hosts to search for planets in the HZ. Contrary to G-dwarfs, the HZ is closer, thus making planet detection easier. And contrary to M-dwarfs, the stellar activity is much smaller, hence having a lower impact in the detectability and in the true habitability of the planet. Despite this, there is a desert of habitable worlds around K-dwarfs due to the lack of surveys devoted to this parameter space.



The need for coetaneous photometry

K-dwarfs are among the most quiet stars in terms of activity. However, the low-amplitude RV signals from HZ planets can be disturbed by the presence of active regions. A key technique to achieve very precise RV measurements consists of simultaneously characterizing this stellar activity by measuring the so-called activity indicators. These indicators can be obtained from the spectra from which the RV is acquired or from additional observations (e.g. photometry has been proved to be a good indicator; **Aigrain et al. 2012**). The vast majority of works that take into account activity indicators, make use of those extracted from the RV spectra alone, due to its observational simplicity. However, the KOBE long-cadence of 9 days is not enough to properly sample the activity of K dwarfs. With typical rotation periods of 40 days (and a range between 10-50 days, **McQuillan et al. 2014**), the RV cadence would only sample up to 5 data points per stellar rotation.

Methodology

We fit the spectroscopic and photometric data through a Bayesian approach combined with a Markov chain Monte Carlo (MCMC) sampling. The signals caused by stellar activity can be seen as correlated quasi-periodic noise. To deal with it, Gaussian Processes (GP) are an increasingly common tool. Thus, we model the RV through a Keplerian and a GP, and jointly we model the full width of half maximum (FWHM) of the cross correlation function (CCF) and the photometric time series through GPs with shared hyperparameters. In particular, we use a quasi-periodic kernel of the form

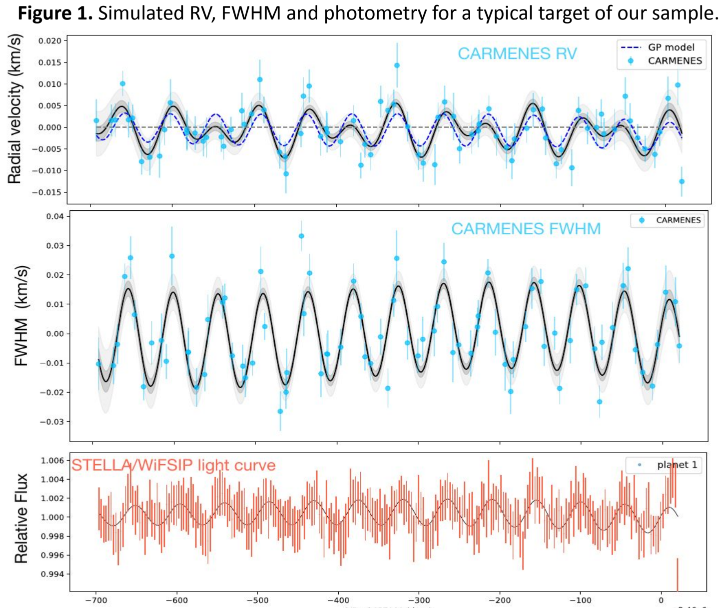
$$\eta_1^2 \exp\left[-\frac{(t_i - t_j)^2}{2\eta_2^2} - \frac{2\sin^2\left(\frac{\pi(t_i - t_j)}{\eta_3}\right)}{\eta_4^2}\right]$$

where η_1 is the amplitude of the correlations, η_2 is the timescale of the correlation decay, η_3 defines the periodic component and η_4 controls the relative importance of the periodic and decaying components.

Results

Simulated data

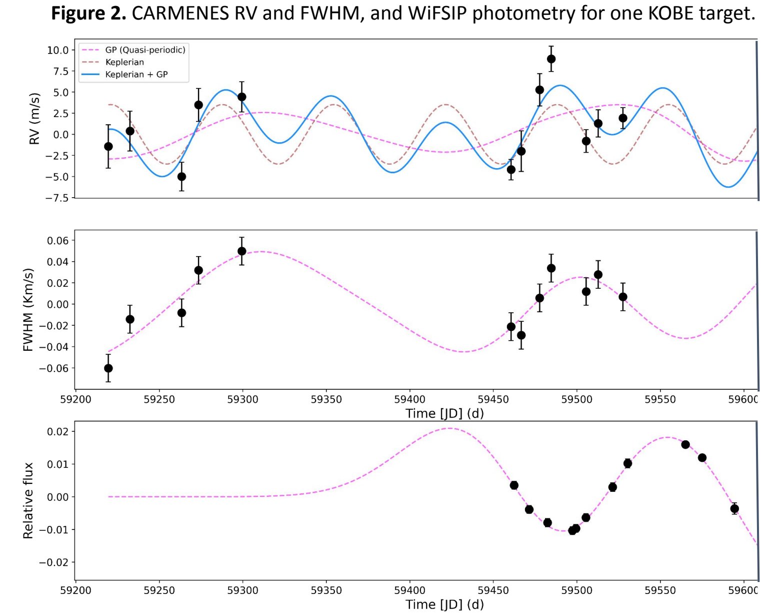
Figure 1. Simulated RV, FWHM and photometry for a typical target of our sample.



In Fig. 1 we show 2 years of 3-day cadence simulated WiFSIP photometry and 9-day cadence CARMENES data for a typical target of our sample. We used the SOAP2 package (**Dumusque et al. 2014**) to simulate the photometric and spectroscopic effects of two spots covering 0.38% of the stellar surface, and two plages covering 1.68%. We then injected a simulated Keplerian signal of 4 m/s in an orbital period of 86.5 days. We analysed the simulated dataset by both using and not using the photometric time series. Our results show that in this simulation the planet is detected in both cases but the planet properties are a 30% more precise when using the photometric time series. For lower-mass planet simulations we find that only when using the WiFSIP photometry we can significantly detect the signal.

Observed data

Figure 2. CARMENES RV and FWHM, and WiFSIP photometry for one KOBE target.



We have a large program granted (2021B-2023A). Due to long-term technical problems, WiFSIP has been inoperative during practically the whole semester 2021B and great part of 2022A. In 2021B, we have an average of 6 profitable images per target, and in 2022A the amount of images increases up to 12. These numbers are much less than the expected for these dates (~45), so our current photometric data do not improve the results obtained from the CARMENES data alone. However, in some cases (e.g. the target of Fig. 2) we start to see a correlation between the spectra-derived activity indicators and WiFSIP extracted photometry. Currently, the technical problems seem to be solved, so semester 2022B will be of crucial importance in order to assess the success of the program.

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the KOBE experiment

Laboratorio de MUNDOS LEJANOS Remote Worlds Lab

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