Stellar Activity or a Planet?

Revisiting **Dubious** planetary signals in M-dwarf systems

D.P. González[1], N.Astudillo-Defru[2] & R.E. Mennickent[1]

[1] Departamento de Astronomía, Facultad Ciencias Físicas y Matemáticas, Universidad de Concepción, Av. Esteban Iturra s/n Barrio Universitario, Concepción, Chile
[2] Departamento de Matemática y Física Aplicadas, Universidad Católica de la Santísima Concepción, Alonso de Rivera 2850, Concepción, Chile

Motivation

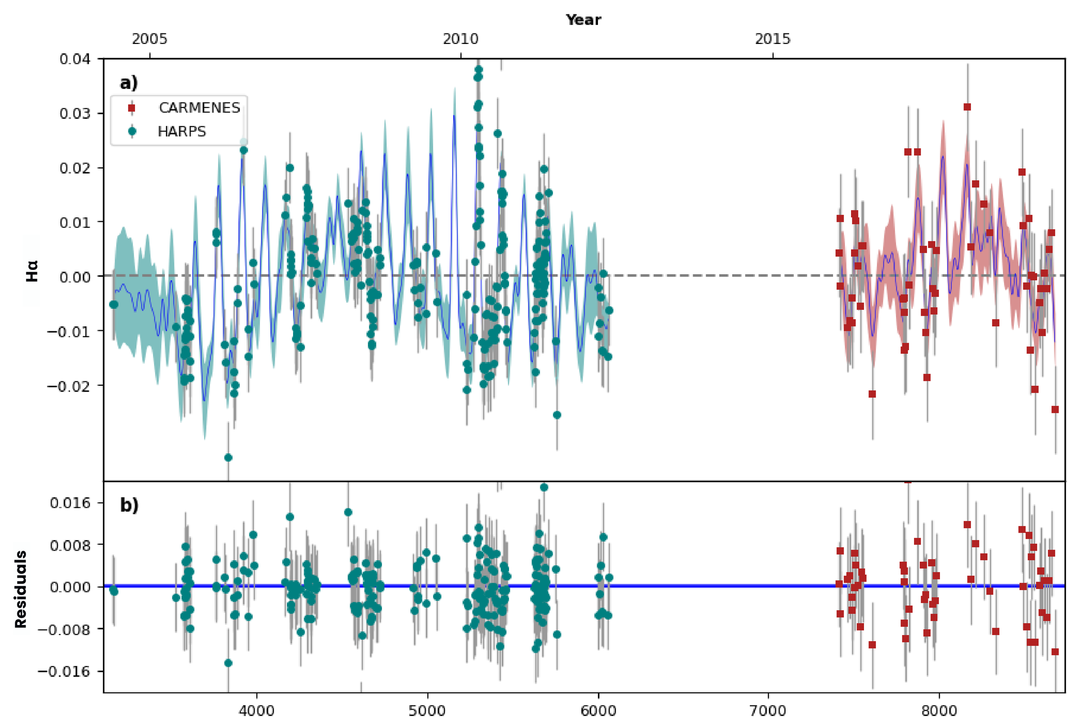
M-dwarfs are known to be magnetically active. Stellar Activity can impact the shape of stellar spectral lines and thus inducing apparent Radial Velocity (RV) variations. When these induced signals are periodic they can be misinterpreted as planetary signals. In this context, **GJ581** is M3 dwarf that host a multiplanetary system: **b(5.37d), c(12.9d), d(66.6d), e(3.15d), f(433d)**, and **g(36.6d)**; and it has a reported stellar rotation period of about 132.5 $\pm$ 6.3 days (Suárez Mascareño et al., 2015), which is **twice** and **four** times the orbital periods of **d** and **g** planetary signals, respectively. The similarity between the rotation period and the orbital period raises questions about whether the signals are planets or an artifact of stellar activity since these activity signals tend to appear at the stellar rotation period and its harmonics (Boisse et al., 2011). The aim of this work is to **confirm or dismiss the planetary nature of the RV signature attributed to M-dwarfs** by analyzing the spectroscopic stellar activity indicators and RVs from HARPS, HIRES & CARMENES to search for periodic and stable signals.

1. Data

For this analysis, we used publicly available ESO HARPS spectra and calculated RVs with NAIRA algorithm (Astudillo-Defru et al., 2015). We also included public RV data from HIRES & CARMENES.
In order to account for stellar activity we calculated spectroscopic activity indicators such as: Hα, Hβ, Hγ, Na I D, and S-index using the method described by Gomes da Silva et al. (2011).

Determining the stellar rotation period is key in order to asses the origin of the signals

The stellar rotation period can be derived by modeling spectroscopic activity indicators using a **Gaussian Process (GP)** regression with a quasi-periodic kernel. Therefore, we employed Radvel (Fulton et al. 2018) to determine the periodic component attributable to the stellar rotation period of this kernel by modeling **Hα**.



We obtained a stellar rotation period value of:

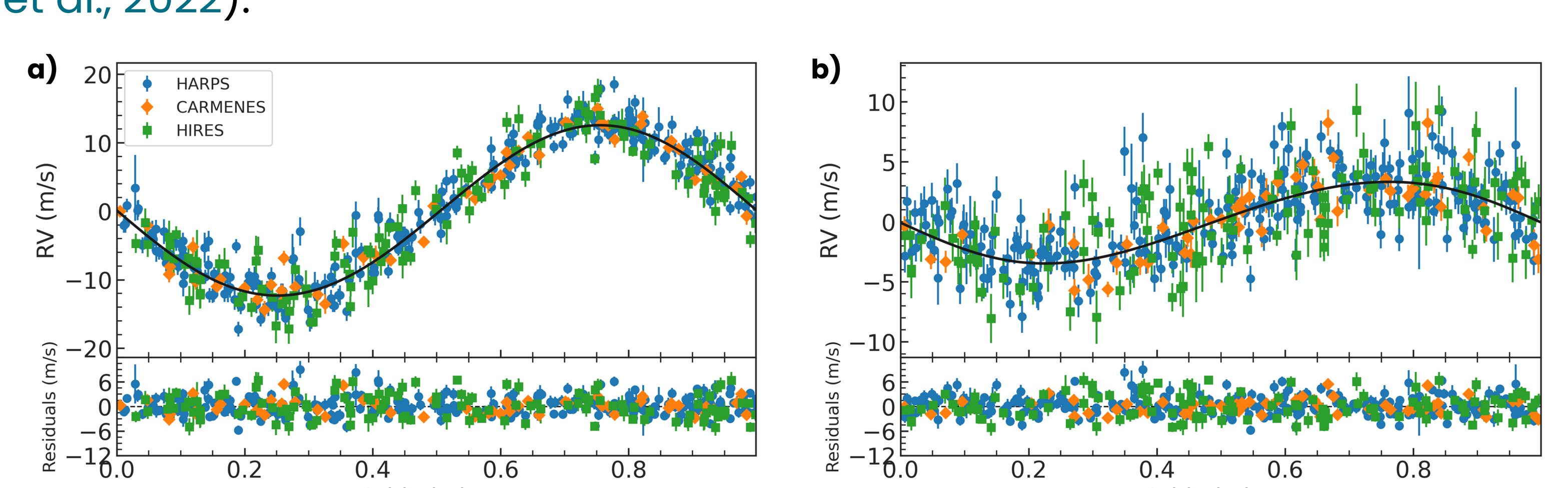
$$P_{rot} = 132.24^{+1.82}_{-1.71}\,[d]$$

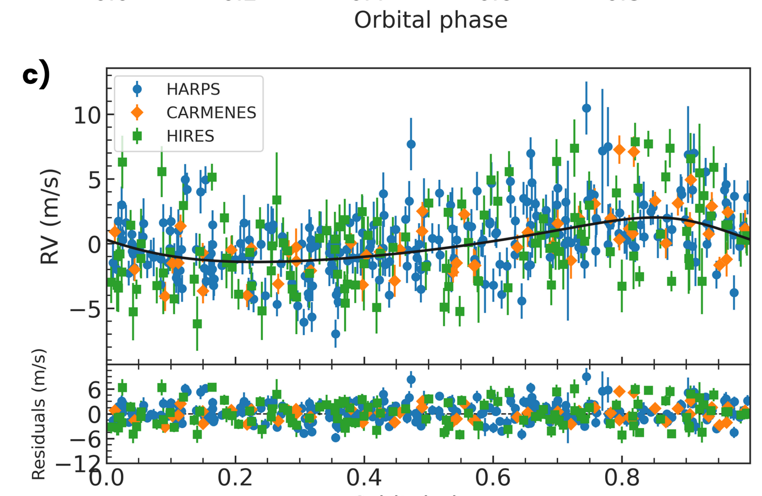
improving the measurement reported in Suárez Mascareño et al. (2015)

Fig. 1: Hα time series modelled with a GP using a quasi-periodic kernel. a) Model showing the GP resulting from the median of the hyper-parameters' posteriors (blue curve). The coloured zone depicts the model 1-σ confidence. b) Residual of the fit.

3. Keplerian Fit

GJ581 RVs were adjusted with a 3-Keplerian model using Pyaneti (Barragán et al., 2022).





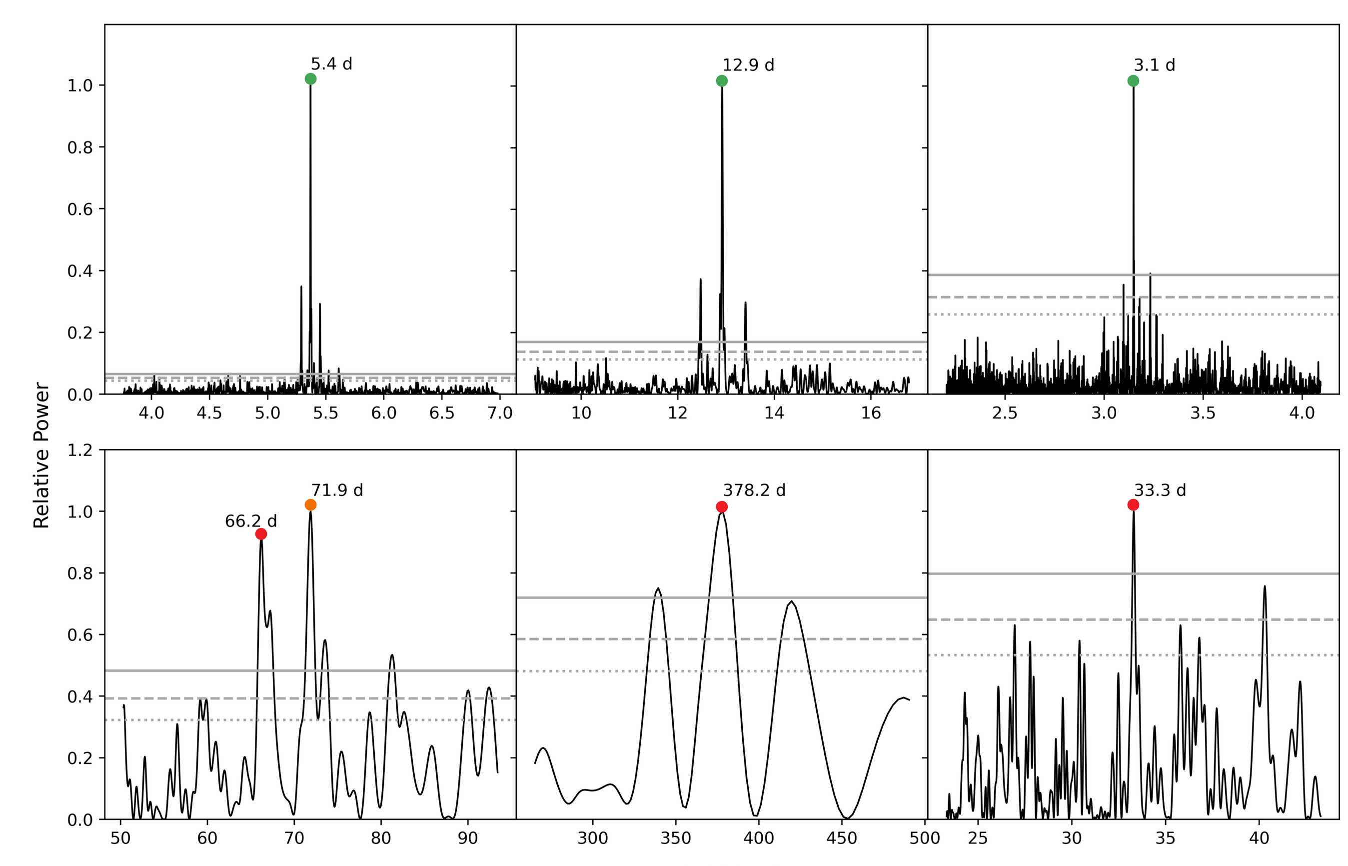
d)

Parameter	GJ581 b	GJ581 c	GJ581 e
P (days)	5.368	12.91	3.148
K (m/s)	12.41	3.39	1.74
$M(M_\oplus)$	15.60 ± 0.69	5.69 ± 0.28	1.78 ± 0.11

Fig 4: Phase folded RV curves. *a)* for GJ581 b signal. *b)* for GJ581c signal. *c)* for GJ581e signal. The black curve represents the best-fit keplerian orbit. *d)* Shows some of the **best fit parameters** for the GJ581 system based on the combined RVs.

2. Radial Velocity

For the Radial Velocity analysis, we computed the Generalized Lomb-Scargle **(GLS)** periodogram (Zechmeister & Kürster, 2009) of the RVs and the residuals. We have been able to detect and confirm periodic signals corresponding to planets **b**, **c** and **e**, with orbital periods of 5.37, 12.9 and 3.1 days, respectively.

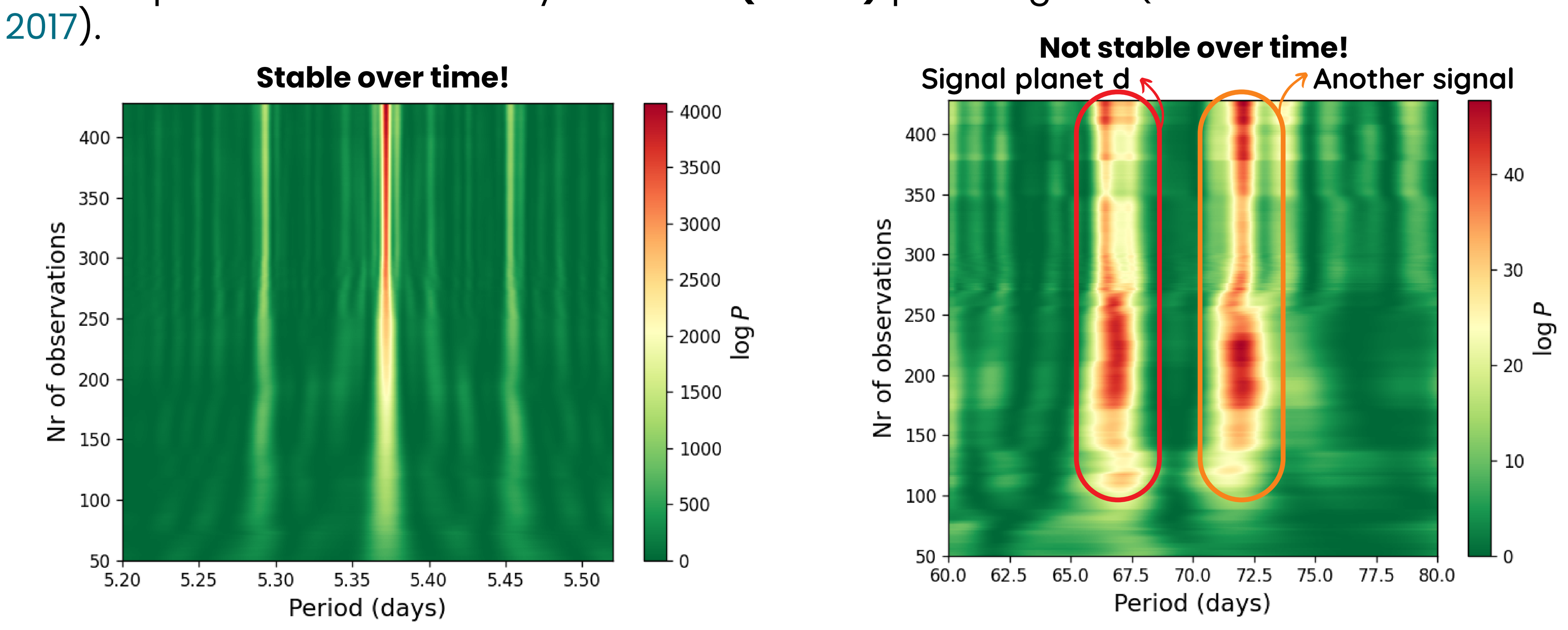


For the other signals, we observed an additional periodic signal of 71.9 days alongside the 66.6-day signal attributed to planet d. Notably, we also identified periodic signals with periods of 378 and 33 days.

Fig. 2: GLS periodograms of GJ581 from the RVs' time series. The solid, dashed and dotted horizontal lines represent the 0.3%, 4.6%, and 31.7% FAP levels corresponding to a 3σ, 2σ, and 1σ detection threshold, respectively

Temporal Stability Analysis based on the principle that stellar activity signals are variable and incoherent.

We computed the Stacked Bayesian GLS **(sBGLS)** periodogram (Mortier & Collier Cameron, 2017).



As expected, the level of confidence in the detection of a planetary signal increases as more data is added.

Incoherent signals

Fig 3: Stacked BGLS periodogram for the RVs data, zoomed around 5.4 days (left) and 68 days (right). Amount of observations is plotted against period, with the colour scale indicating the logarithm of the probability, where redder is more likely.

4. Future Work

While our observations suggest that the 'd' signal may not be of planetary origin, further statistical analysis is needed to confirm or refute the signal. The next step is to fit a multiplanet keplerian model including stellar activity simultaneously, to compare the models between the different numbers of Keplerians and determine which is more favorable. Once this analysis gets consistent with previous works, it will be applied to others M-dwarfs.

Want to ask/discuss something?
You can email me at **dagonzalez2018@udec.cl**

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