A super-Earth in the habitable zone of GJ 3998

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Summary

M dwarfs are light and therefore attractive for exoplanet radial-velocity detections. However, they often exhibit stellar activity that may attenuate or mimic planetary signals. We present a velocimetric analysis on one such M dwarf, GJ 3998 ($d = 18.2\,\mathrm{pc}$), with two earlier published super-Earths: GJ 3998 b and GJ 3998 c. We use additional data from the HARPS-N spectrograph to look for more. We constrain the stellar rotational period to 30.2 ± 0.3 d, confirm GJ 3998 b and GJ 3998 c, and detect a third planet: GJ 3998 d. This new planet has an orbital period of 41.78 ± 0.05 d, a minimum mass of $6.07^{+1.00}_{-0.96}\,M_\oplus$, and a mean insolation flux of $1.2^{+0.3}_{-0.2}\,\Phi_\oplus$. This makes GJ 3998 d one of the few known planets with Earth-like insolation flux.

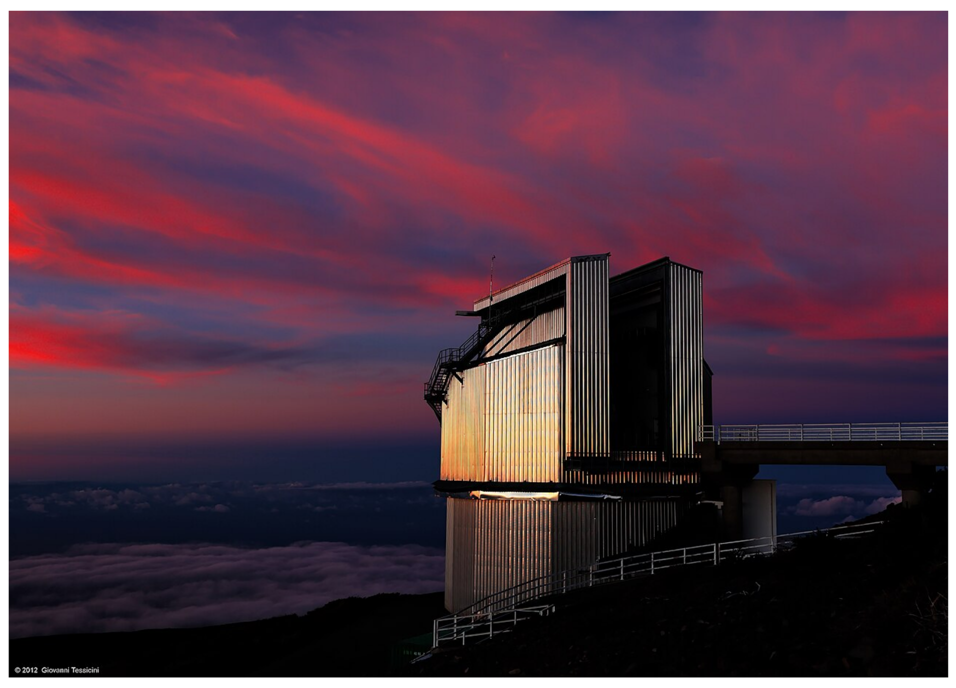
Timeline

2012: HADES, a radial-velocity programme probing nearby M dwarfs, begins

2013: GJ 3998 receives its first HARPS-N measurement through HADES

2016: With 136 spectra, Affer et al. (2016) discover GJ 3998 b and GJ 3998 c

2024: With 204 spectra, we begin re-analysis



The 3.6 m TNG, La Palma

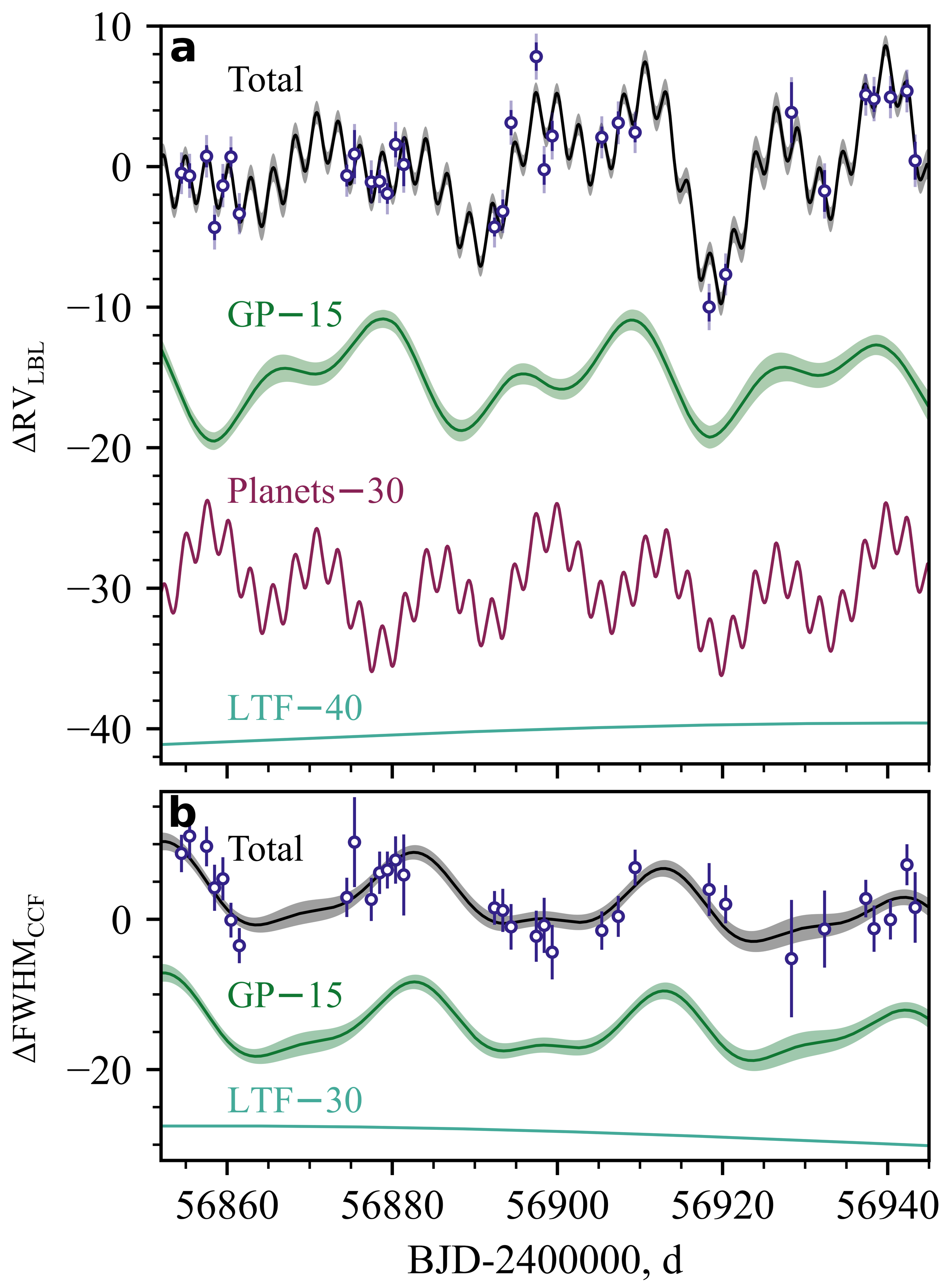
Methods

Stellar activity is stochastic in nature. We model it through Gaussian processes (GPs). We assume that the correlation between measurements is sensitive to a certain period, and that it exponentially diminishes at a certain timescale.

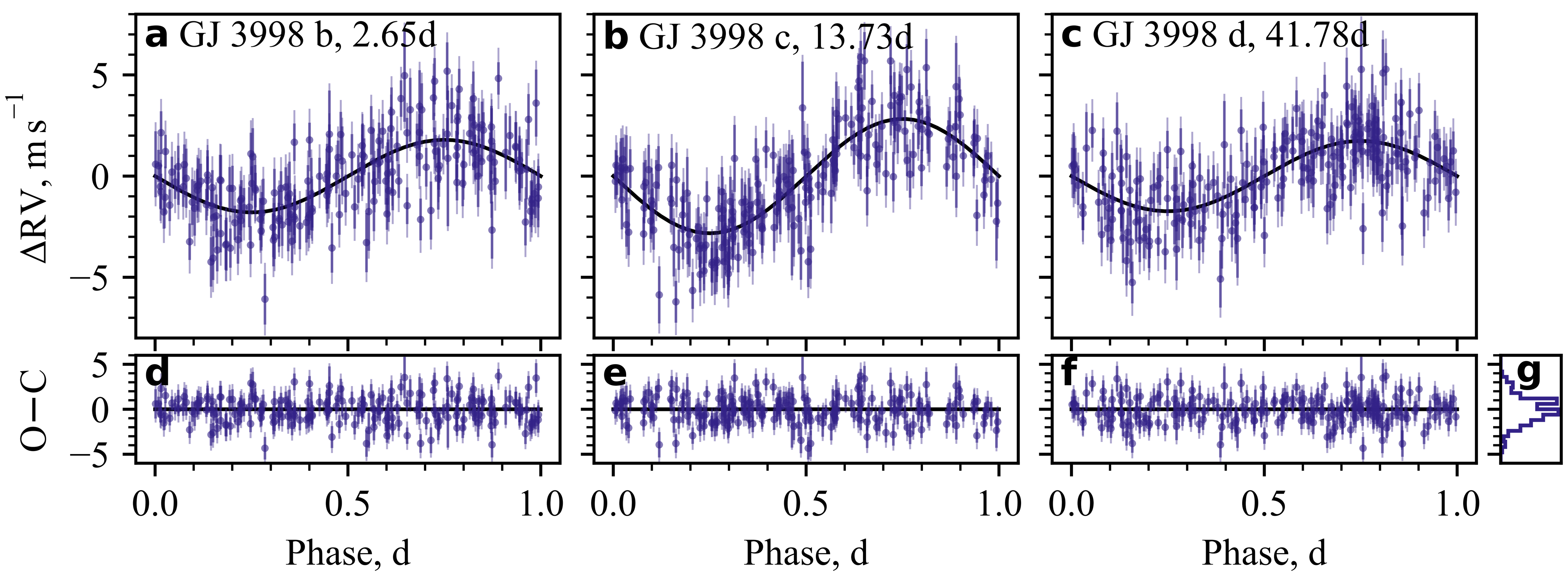
To combat overfitting, we assume the same correlation between RV and an ancillary physical quantity (an activity indicator; AI), and we try to model stellar activity on both quantities at the same time. Then, from first principles defined in Aigrain, Pont, and Zucker (2012) and Rajpaul et al. (2015), we solve

$$\left|\begin{aligned} \mathrm{RV} &= A\,G(t) + B\left(\frac{\mathrm{d}G}{\mathrm{d}t}\right)_{t_\mathrm{meas}} \\ \mathrm{AI} &= C\,G(t), \end{aligned}\right.$$

where A, B, C are quantity-specific fit parameters, and $G(t)$ is the GP estimation of the stellar activity at given times of measurement t_meas.

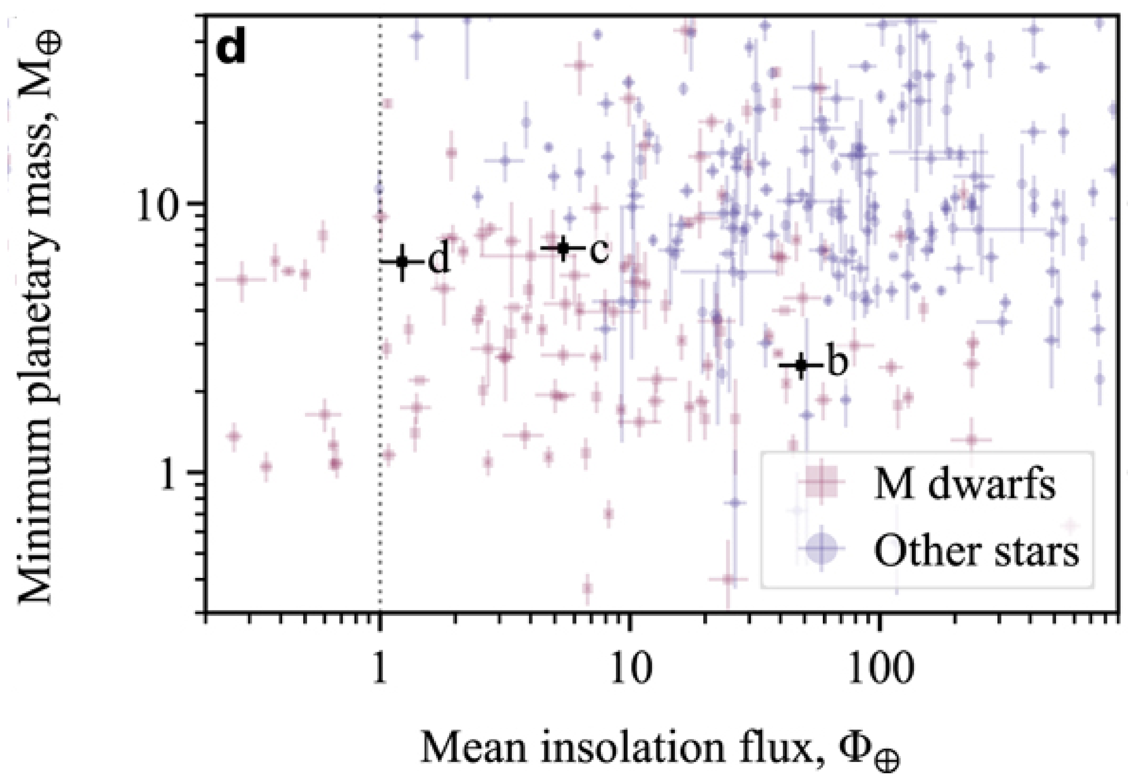


Raw time series against our model.



The isolated RV signals of the three planets against our data.

Results



GJ 3998 d is **one of the few** known planets with Earth-like flux ($\Phi = 1.2^{+0.3}_{-0.2}\,\Phi_\oplus$), and the second such planet around similar-mass stars after GJ 3293 b (Astudillo-Defru et al., 2015). It is a welcome addition in our neighbourhood, both to exoplanetary demographists and to the general community.

"la Caixa" Foundation

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References

Affer, L. et al. (Oct. 2016). In: *A&A* 593, A117.
Aigrain, S. et al. (Feb. 2012). In: *MNRAS* 419, pp. 3147–3158.
Astudillo-Defru, N. et al. (Mar. 2015). In: *A&A* 575, A119.
Rajpaul, V. et al. (Sept. 2015). In: *MNRAS* 452.3, pp. 2269–2291.
Stefanov, A. K. et al. (Mar. 2025). In: *A&A* 695, A62.