Planetary Occurrence Rates Around Early-M Dwarfs with HADES

Matteo Pinamonti[1], **HADES Collaboration**

[1]INAF – OATO, Torino, Italy

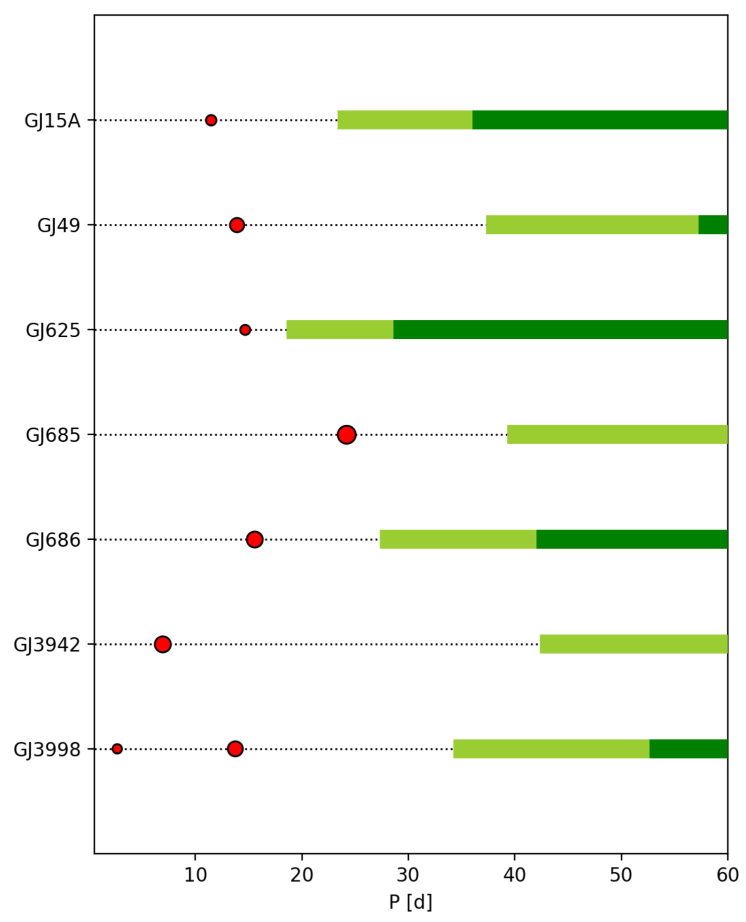
Abstract

We present the complete Bayesian statistical analysis of the **HArps-n red Dwarf Exoplanet Survey** (HADES), which RV monitored a large sample M dwarfs with HARPS-N at TNG, over the last 8 years.

The targets were selected in a narrow range of spectral types from M0 to M3, in order to study the planetary population around a well-defined class of host stars. We take advantage of **Bayesian statistics** to derive an accurate estimate of the detectability function of the survey [1]. Our analysis also includes the application of **Gaussian Process** (GP) approach to take into account stellar activity induced RV variations around the most observed targets. The MCMC+GP technique has proven very effective in the study of M dwarf planetary systems, helping the detection of most of the HADES planets [e.g. 2,3]. From the detectability function we can calculate the occurrence rate of small mass planets around early-M dwarfs: taking into account only the already published HADES planets, the planets occurrence rate results to be only f_{occ}=7.0%, for $m_p \sin i<10\ M_\oplus$ and P<10 d. This lower value than the usual estimates for M dwarfs, could be a hint of a lower occurrence of exoplanets around earlier-type M dwarfs. We also present a new lower estimate of the occurrence rates of temperate planets inside the Habitable Zone of early-M dwarfs η<16.1% for planets with $m_p \sin i<10\ M_\oplus$.

1) The HADES Sample

The initial HADES sample was constructed by selecting northern targets with spectral type between **dM0** and **dM3**, visual magnitude **V < 12**, discarding close binaries, fast rotators, high-activity stars and/or targets with incorrect spectral type after a **consistent** re-derivation of **stellar parameters** [4]. For this study we also selected only targets for which at least 10 spectra were collected, resulting in a sample of **56 targets**.



The observations were carried out from August 2012 to December 2018, with an average timespan $\langle T_s \rangle$=1760 d. The RV were derived with the **Template-Enhanced Radial velocity Re-analysis Application** [TERRA, 5], with an average number of RVs per target of 77, and a maximum of 194 RVs for GJ3998 [2].

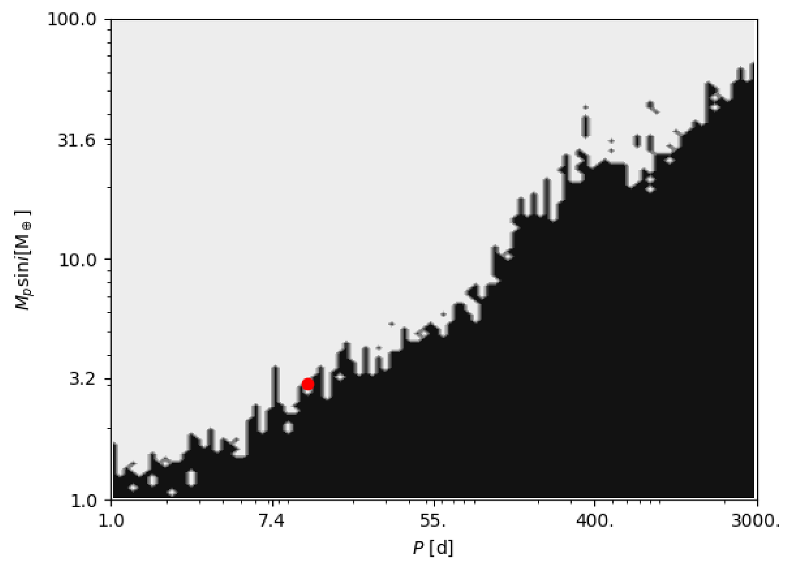
To date **8 shot-period planets** have been detected in the HADES sample [6 and references therein], plus **1 long period companion** [4]. The 8 short period planets are shown in the Figure (**red circles**, with size scaling with the minimum mass), compared to the conservative (**dark green**) and optimistic (**light green**) Habitable Zone (HZ).

2) Technique: Emcee Bayesian analysis

We use **Bayesian statistics** to estimate the **occurrence rate** and **detectability function** of extrasolar planets in our sample of M dwarfs, following the approach by Tuomi et al. 2014 [1]. For each time series of their sample, the observed number of planet in a given period-mass interval $\Delta_{P,M}$ can be expressed as:

$$f_{\mathrm{obs},i}(\Delta_{P,M}) = f_{\mathrm{occ},i}(\Delta_{P,M}) \cdot p_i(\Delta_{P,M}),$$

where f_{obs}= number of observed planets per star, f_{occ}= occurrence rate of planets per star, p_i= detectability function for target i.



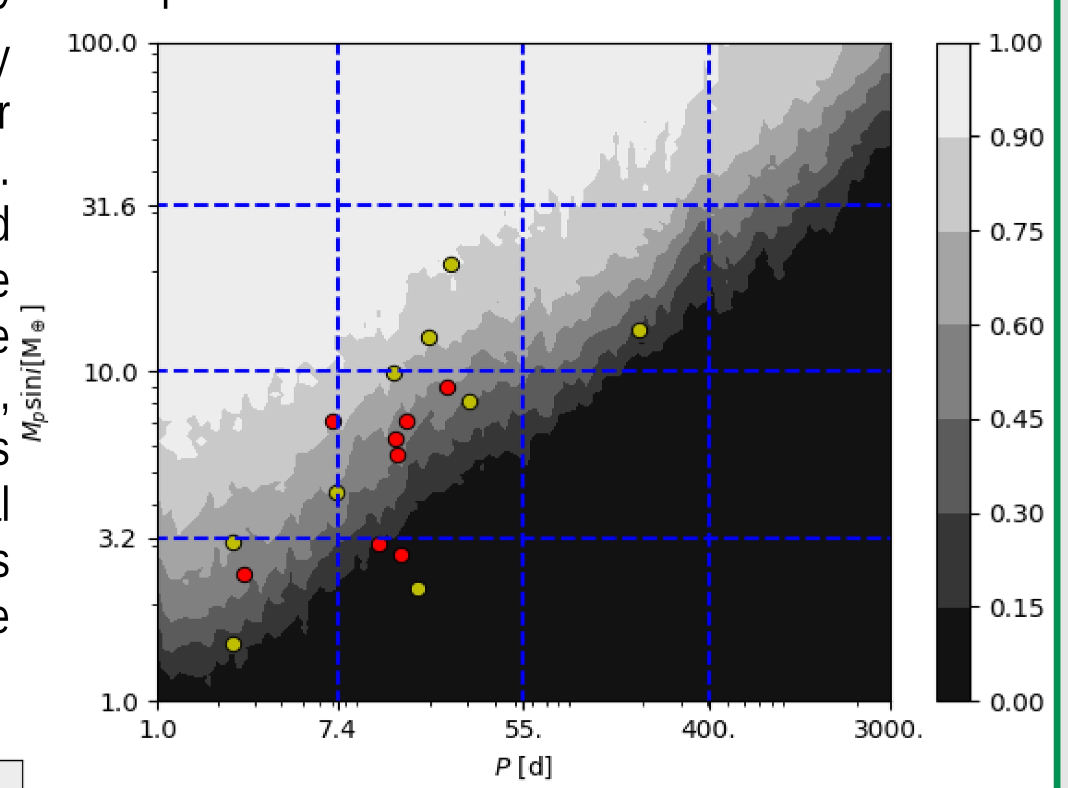
Assuming that k_i Keplerian signals were detected in the i-th time series, the detectability function p_i can be computed by applying with a sampling algorithm a k_i+1-signals model: k_i+1th parameter chains sample (P,M) regions were signals detection is impossible, i.e. the likelihood is so poorly constrained that are not forbidden to nonexistent planetary models. (see [1] for details).

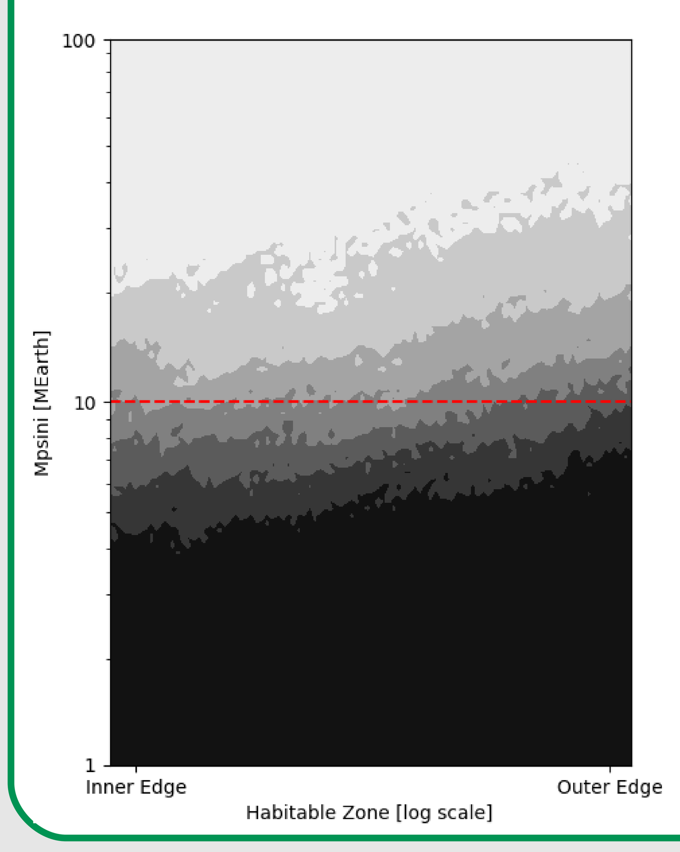
The figure show the **detection map** for **GJ15A**, with the inner planet [3] shown as a **red circle** : the black area correspond to $\boldsymbol{p_i}$**=0**, the white area correspond to $\boldsymbol{p_i}$**=1**.

3) Results: Survey Detection Map

The Figure shows the **Global Detection Map** of the Survey. The **red circles** show the published HADES planets (see Figure in panel 1), while the **yellow circles** show additional planetary candidates yet to be published.

As expected, the detectability function increases for larger masses and shorter periods. Most of the **planets** and **candidates** are found in the region of the parameter space with **intermediate detectability**, while a few are found in regions with very low Global Detectability (around the targets with the largest and most dense time series).





Even if no planet was discovered inside the Habitable Zone (see Figure in panel 1), we computed the Detectability Function as a function of the minim mass and of the position inside the HZ, which allowed us to compute the upper limits of the occurrence rate $f_{occ,HZ}$ of **habitable planets** (see Equation in panel 4):

$f_{occ,HZ}$<2.3% for $m_p \sin i$>10 $M_\oplus$, and $\boldsymbol{f_{occ,HZ}}$**<16.1%** for $m_p \sin i$<10 $M_\oplus$. The value for small-mass planets is compatible with previous estimates fo early M dwarfs [7].

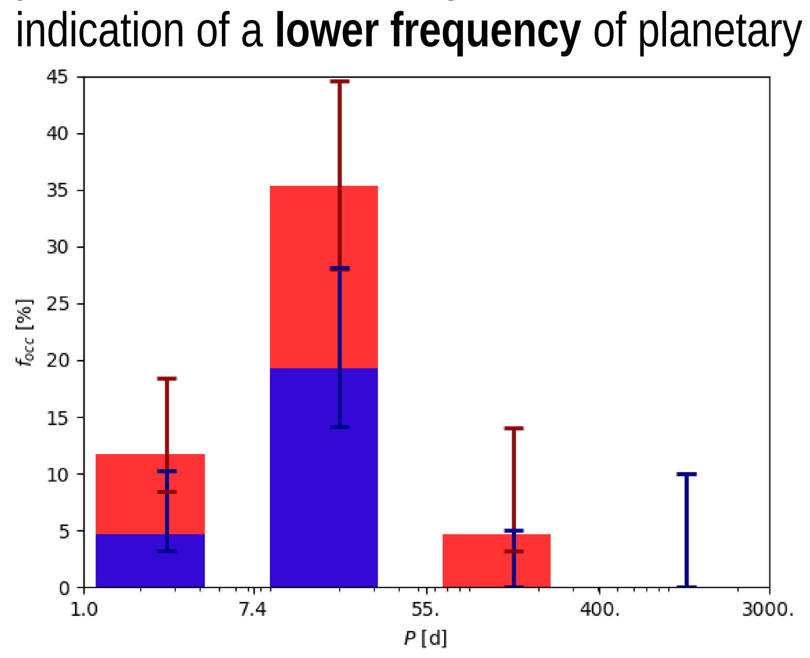
4) Results: Planetary Occurrence Rates

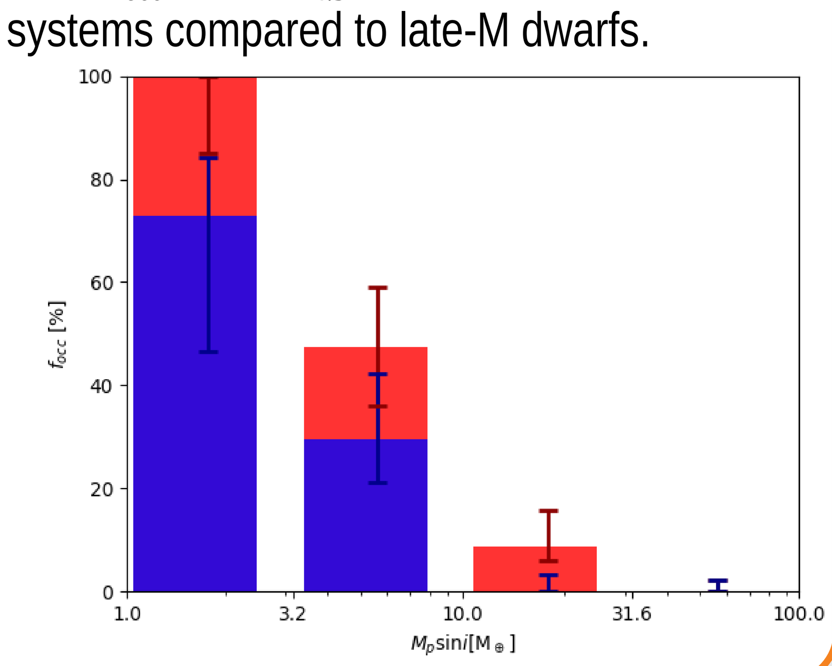
Given the Detectability Function the planetary occurrence rates can be computed from the **binomial distribution**:

$$\mathcal{P}(k \mid N, f_{\mathrm{occ}}) = \frac{N!}{k!(N-k)!} f_{\mathrm{occ}}^k (1 - f_{\mathrm{occ}})^{N-k}$$

where N is the number of targets sensitive to planets in $\Delta_{P,M}$, and k is the number of planets detected in $\Delta_{P,M}$.

The two Figures show Occurrence rates as a function of the period and minim mass, (the bins correspond to the **blue grid** in the Figure in panel 3): as previously observed [8] the occurrence rates greatly increases at smaller masses, while the **period distribution** seems to peak around P≈10 d, with a low number of very-short period planets. We also computed the occurrence rate in the 2D interval $m_p \sin i$<10 $M_\oplus$ and P<10 d, and obtained, taking into account only published HADES planets, $f_{occ}=7.0^{+8.0}_{-2.3}\%$ **lower than previous estimates** for M dwarfs [8]. Adding also the additional candidates shown in the Figure in panel 3, we obtain a higher occurrence rate of $f_{occ}=17.6^{+9.2}_{-4.9}\%$, which could still be a indication of a **lower frequency** of planetary systems compared to late-M dwarfs.





Contact details: m.pinamonti.astro@gmail.com

References

[1] Tuomi, M., Jones, H. R. A., Barnes, et al. 2014, MNRAS, 441, 1545;
[2] Affer, L., Micela, G., Damasso, M., et al. 2016, A&A, 593, A117;
[3] Pinamonti, M., Damasso, M., Marzari, F., et al. 2018, A&A, 617, A104;
[4] Maldonado, J., Scandariato, G., Stelzer, B., et al. 2017, A&A, 598, A27;
[5] Anglada-Escudé, G. & Butler, R. P. 2012, ApJS, 200, 15;
[6] Pinamonti, M., Sozzetti, A., Giacobbe, P., et al. 2019, A&A, 625, A126;
[7] Dressing,C. D., Charbonneau, D. 2015, ApJ, 807, 45;
[8] Bonfils, X., Delfosse, X., Udry, S., et al. 2013, A&A, 549, A109;