Prized results from HARPS

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Low-mass/habitable/transiting planets orbiting M dwarfs

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Abstract. Searching for planets around stars with different masses probes the outcome of planetary formation for different initial conditions. The low-mass M dwarfs are also the most frequent stars in our Galaxy and potentially therefore, the most frequent planet hosts. This has motivated our search for planets around M dwarfs with HARPS. That observing program has now run for almost a decade and detected most of the known low-mass planets orbiting M dwarfs (m sin i $< 20\,M_\oplus$), including the least massive (GJ581e, $m \sin i = 1.9\,M_\oplus$) and the first potentially habitable planets (GJ581c&d GJ667Cc, GJ163c). This proceeding shortly reviews the detections made with HARPS, reports on the occurrence of planets around M dwarfs and how they mesh up with planet formation theory. It also highlights our sensitivity to low-mass habitable planets, the first direct measure of $\eta_\oplus$, and the recent detection of a transiting planet the size of Uranus.

1. FROM INDIVIDUAL DETECTIONS ...

Our search for planets around M dwarfs was initiated on HARPS Guaranteed Time of Observations (GTO) and was extended by a Large Program with a focus on habitable super-Earths and transiting planets. Our programs have been successful with the detection of 16 planets (with even more being in the publication process) and including very interesting cases. They have minimum masses ranging from 1.9 $M_\oplus$ to 4 M_{Jup} and orbital periods from a few days up to 10 years. As illustrated by the top panel of Fig. 1, the detections of our program (filled red circles) sample a unique parameter space of temperate low-mass planets. So far, 4 of them could be super-Earths in the habitable zone : GJ581c&d [12, 16], and more recently GJ667Cc [6] and GJ163c [4]. And altogether, these detections represent a majority of planets known around M dwarfs, and a much larger fraction of the smallest ones.

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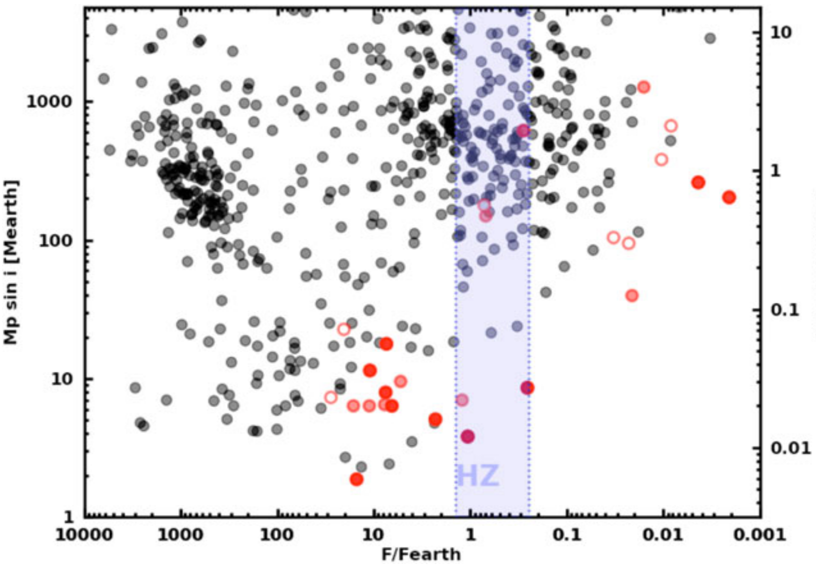

Figure 1. Diagram of confirmed planets as a function of their (minimum) mass and the flux they receive from their parent star. The flux is normalized by the flux our own Earth receives from the Sun and serves as a temperature proxy. Detections marked in red correspond to planets orbiting M dwarfs and filled circles are those included in our sample. The habitable zone is marked in blue according to Venus and early-Mars criteria [15]. GJ581d, GJ667Cc and GJ163c appear inside the habitable zone whereas GJ581c is outside and close from its hotter edge.

2. ... TO A STATISTICAL PICTURE ...

Altogether, these detections also hold some clues to the planet formation processes. In particular, their occurrence rate as a function of planetary mass, period and eccentricity and also as a function of stellar mass and metallicity can be compared to model predictions.

To infer the frequency of occurrence of M-dwarf planets as a function of their minimum mass and orbital period we computed detection limits for all individual time series. We then combined them altogether in a single diagram (Fig. 2) to obtain the number of stars that were observed with enough sensitivity to detect planets, depending on their minimum mass and period. Eventually, we found that the super-Earths ($1 < m \sin i < 10\,M_\oplus$) with orbital periods $1 < P < 10$ days have a frequency of $36^{+25}_{-10}\%$ and that those with periods $10 < P < 100$ days have a frequency of $52^{+50}_{-16}\%$; meaning that super-Earths with periods $10 < P < 100$ days have a frequency of $88^{+56}_{-19}\%$. Almost one planet per star... Combining the detection limits with the number of planets detected in the habitable zone, we also derived $\eta_\oplus = 0.41^{0.51}_{-0.13}$, the frequency of $1 < m \sin i < 10\,M_\oplus$ planets in the habitable zone of M dwarfs. For the first time, $\eta_\oplus$ is directly measured, rather than extrapolated from the statistic of more massive and/or shorter-period planets.

These results mesh up well with other recent results from other surveys. The Kepler mission also indicates a high occurrence rate for super-Earths orbiting late-K to early-M dwarfs ($3600 < T_{\rm eff} < 4100$ K) with Howard et al. [9] and Gaidos et al. [10] reporting an occurrence rate of $30 \pm 8\%$ and $36 \pm 8\%$, respectively. The steep rise in the planetary mass function toward lower mass planets is given further credit by micro-lensing surveys which, for instance, find a $62^{+35}_{-37}\%$ occurrence rate for 5–10 $M_\oplus$ planets at large separation (0.5–10 AU) [5]. We only note that Dressing et al. [7] find a somewhat lower occurrence rate for habitable-zone planets around M dwarfs.

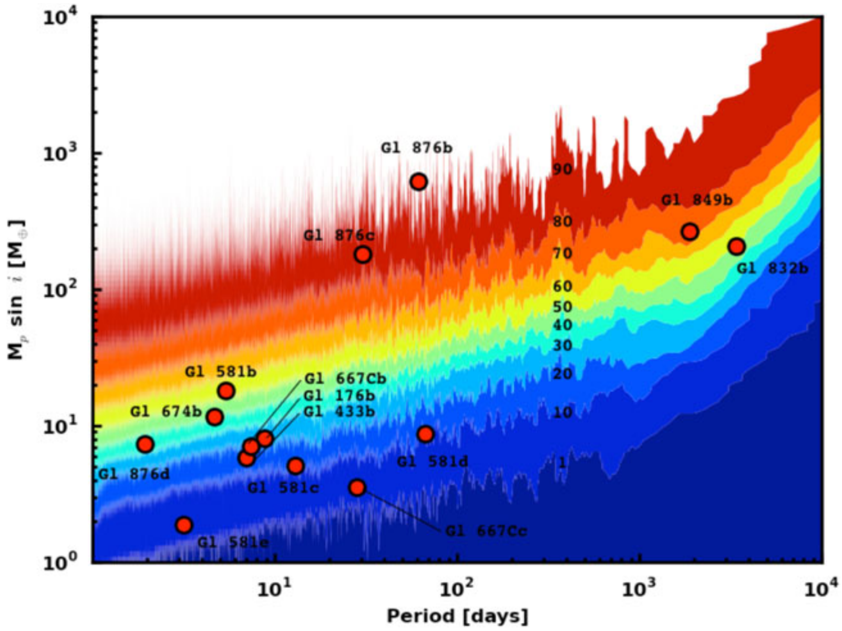

Figure 2. Survey sensitivity derived from the combined phase-averaged detection limits for individual stars (GTO sample only). Iso-contours are shown for 1, 10, 20, 30, 40, 50, 60, 70, 80, and 90 stars. Planets detected or confirmed by our survey are reported by red circles and labeled by their names (GTO data only).

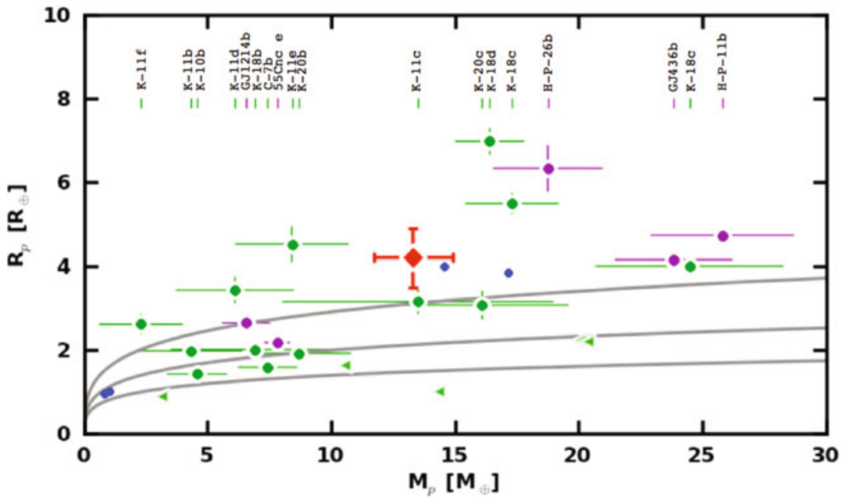

Figure 3. Mass-radius diagram with GJ3470b in red.

3. ... AND THE STRUCTURE AND COMPOSITION OF M-DWARF PLANETS

Last but not least, our survey recently detected GJ3470b, a transiting planet that has the size of Uranus. Its large transit depth and relative brightness makes GJ3470b one of the most favorable exoplanets for the spectroscopic characterization of its atmosphere [3]. Fig. 3 shows how GJ3470b fits in the mass-radius diagram.

4. NEXT

Whereas we could directly measure the occurrence rate of super-Earths, we however still have marginal sensitivity to truly Earth-mass planets. Fig.. 2 additionally shows for instance that we have sensitivity to GJ581d-like planets ($m \sin i = 7\,M_\oplus$) around eleven stars, but to GJ667Cc-like or GJ581e-like planets ($m \sin i = 4\,M_\oplus$) around only three. Our future efforts will thus concentrate on this mass regime.

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