The HADES RV Programme with HARPS-N@TNG

HADES: THE HArps-n red Dwarf Exoplanet Survey

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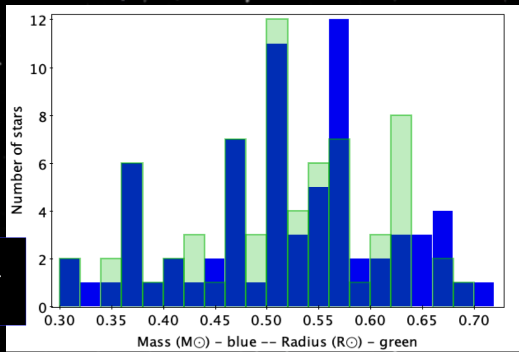
Many efforts to detect Earth-like planets around low-mass stars are currently devoted to almost every extra-solar planet search. **M dwarfs** stand as ideal targets for Doppler radial velocity searches as their low masses and luminosities make low-mass planets orbiting within their habitable zones more easily detectable than those around higher-mass stars. Nonetheless, the statistics of the frequency of this kind of planet hosted by low-mass stars remains poorly constrained.

Our M-dwarf radial velocity monitoring with HARPS-N within the HARPS-N Red Dwarf Exoplanet Survey Radial Velocity (**HADES**) project started in 2012 and is contributing to the widening of the current statistics through the in-depth analysis of accurate radial velocity observations in a narrow range of spectral sub-types from M0 to M3, to investigate the planetary population around a well-defined class of host stars.

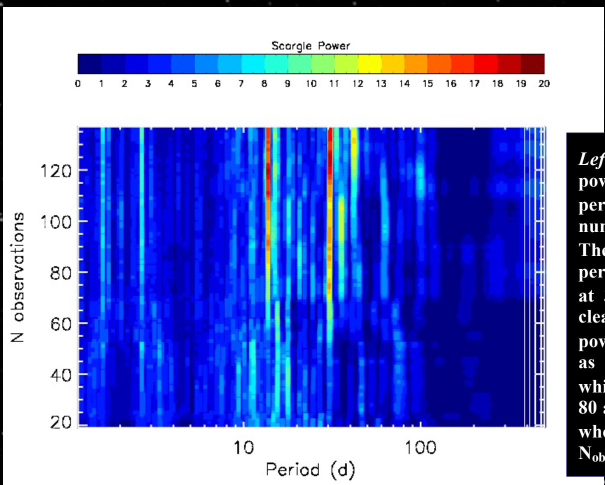
The HADES project is the result of a collaborative effort between the Italian Global Architecture of Planetary Systems (GAPS) Consortium, the Institut de Ciències de l'Espai de Catalunya (ICE), and the Instituto de Astrofísica de Canarias (IAC).

THE HADES SAMPLE

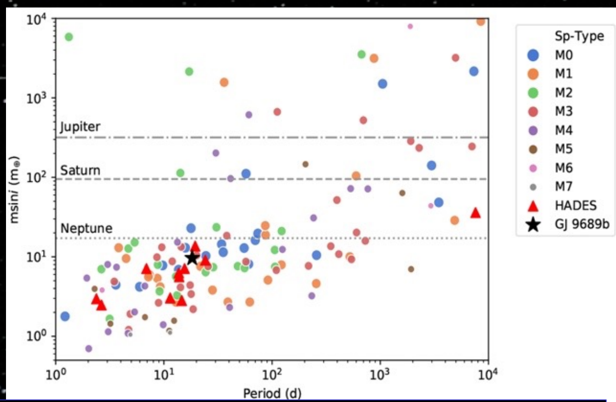
The complete original sample is composed of 106 stars, ranging from M0 to M3 spectral type, and 0.3 to 0.7 in solar masses, selected from the Lépine & Gaidos and Palomar/Michigan State University catalogs, with the additional criterion to be part of the APACHE catalog, with a visible magnitude lower than 12 and with a high number of Gaia mission scans. The selection criteria used to build the M stars catalog are meant to reach a good characterization of the systems. From the complete sample, 27 stars were rejected during the first semester of observations (binary systems, fast rotators, peculiar stars, high activity, earlier type stars, and/or wrong spectral type).



***Right panel*: the distribution of stellar masses and radii of the HADES sample**

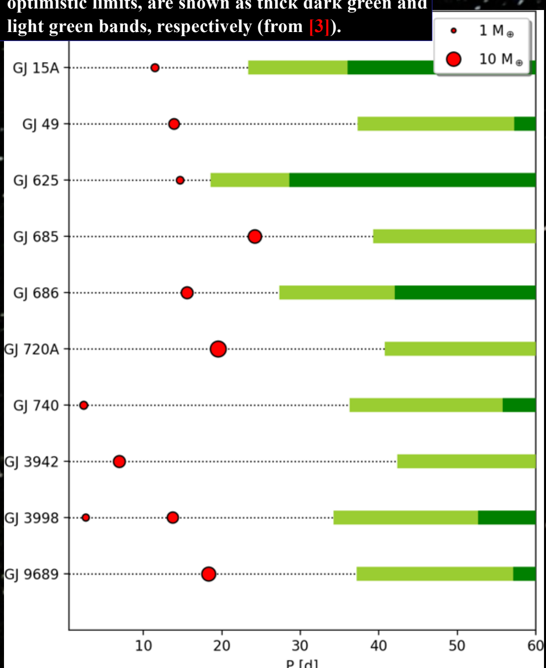


***Left Panel:* Periodogram power of the inspected periods as a function of the number of observations. The most significant periods (the reddest ones) at 30.7 d and 13.7 d are clearly visible with a high power for $N_{obs} > 60$, as well as the period at 2.65 d, which increases for $N_{obs} > 80$ and the period at 42.5 d whose power increases for $N_{obs} > 110$ (from [9]).**



***Upper Panel:* Known radial velocity planets (planetary mass vs. orbital period diagram) around M dwarfs (as listed at http://exoplanet.eu/ in December 2020). Planets discovered by the HADES survey are shown as red triangles (from [18], the planet GJ 9689 is shown as a black star).**

***Bottom Panel:* Overview of the HADES detected planetary systems. The sample's published planets are shown as red circles: the symbol size is proportional to the minimum planetary mass. Each system's Habitable Zone conservative and optimistic limits, are shown as thick dark green and light green bands, respectively (from [3]).**



The analysis is more or less articulated, depending on the target and the activity level. Each step in the analysis is meant to try to distinguish the stellar signals from the keplerian signals. Two photometric programs regularly and almost simultaneously follow up the sample of M stars to characterize the stellar activity, to highlight periods that are due to chromospheric inhomogeneities modulated by stellar rotation and differential rotation, and thus to distinguish from the periodic signals those due to activity and to the presence of planetary companions. The RVs seasonal analysis is very useful to verify the stability of the periodic signal. Once we are confident that the periodicity is due to a planetary companion, we fit the time series of the radial velocities with a keplerian model combined with a Gaussian process quasi-periodic model, to take in account the activity signal, to derive the minimum planetary mass and the planetary parameters. **We have discovered 11 planets in 10 planetary systems (9 super-Earths, 1 sub-Neptune and 1 super-Neptune), and 5 more candidate planets have recently been found.**

The complete analysis of the HADES survey includes the results obtained concerning the statistical ([1], [2], [3]), activity ([4], [5], [6]), and characterization ([7], [8]) part, as well as the planet revealing part ([9] to [18]), around M dwarfs.

References: [1] M. Perger et al. (2017) *A&A*, Volume 598, id.A26. [2] E. González-Álvarez et al. (2019) *A&A*, Volume 624, id.A27. [3] M. Pinamonti. et al. (2022) *A&A*, Volume 664, id.A65. [4] J. Maldonado et al. (2017) *A&A*, Volume 598, id.A27. [5] G. Scandariato et al. (2017 *A&A*, Volume 598, id.A28. [6] A. Suárez Mascareño et al. (2018) *A&A*, Volume 612, id.A89. [7] J. Maldonado et al. (2015) A&A, Volume 577, id.A132. [8] J. Maldonado et al. (2020) *A&A*, Volume 644, id.A68. [9] L. Affer et al. (2016) *A&A*, Volume 593, id.A117. [10] A. Suárez Mascareño et al. (2017) *A&A*, Volume 605, id.A92. [11] M. Perger et al. (2017) *A&A*, Volume 608, id.A63. [12] M. Pinamonti et al. (2018) *A&A*, Volume 617, id.A104 [13] L. Affer et al. (2019) *A&A*, Volume 622, id.A193. [14] M. Perger et al. (2019) *A&A*, Volume 624, id.A123. [15] M. Pinamonti et al. (2019) *A&A*, Volume 625, id.A126. [16] B. Toledo-Padrón et al. (2021) *A&A*, Volume 648, id.A20. [17] E. González-Álvarez et al. (2019) *A&A*, Volume 649, id.A157. [18] J. Maldonado et al. (2021) *A&A*, Volume 651, id.A93.

L. A. ACKNOWLEDGES SUPPORT FROM THE ARIEL ASI-INAF AGREEMENT N. 2021-5-HH.0