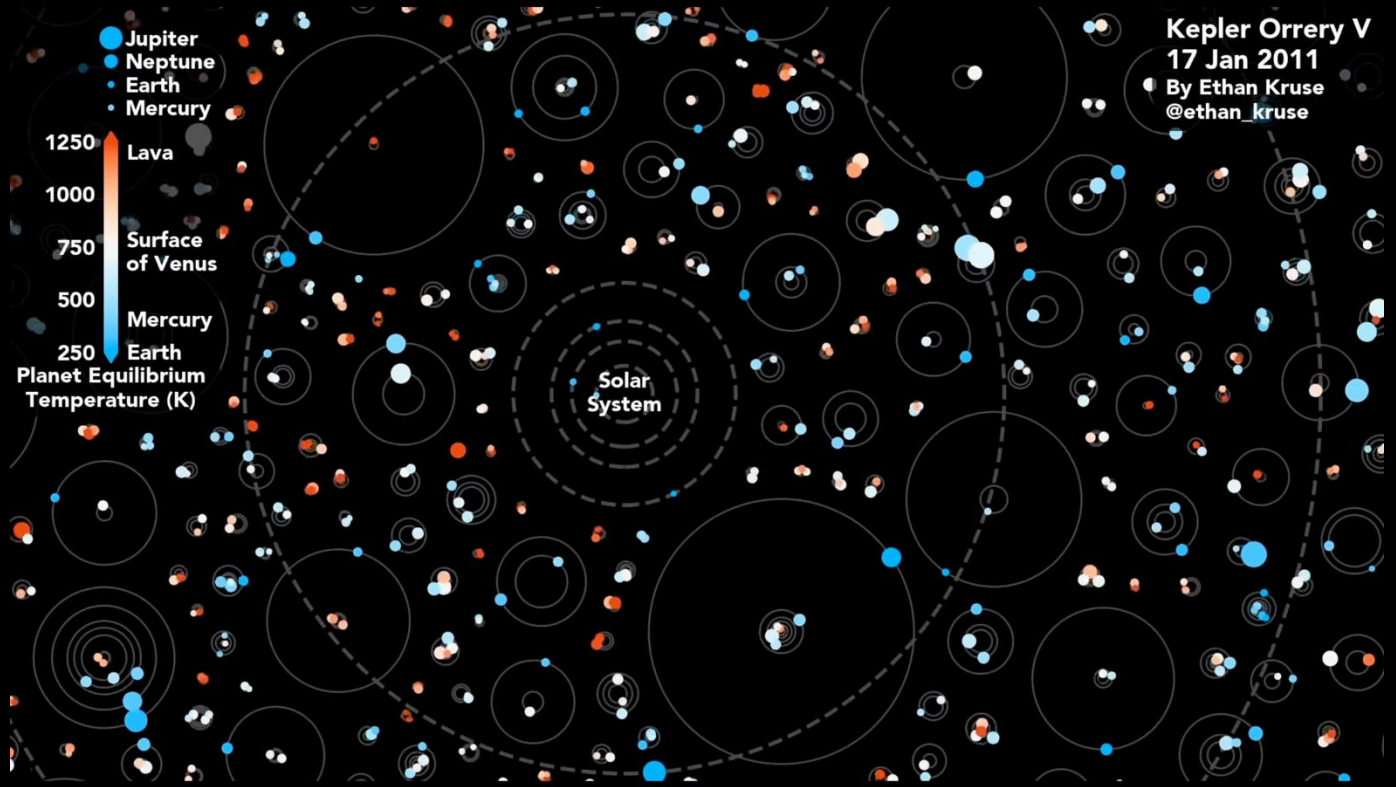
Is the solar system common?



Carina Persson
Chalmers University of Technology, Onsala space observatory

The architecture of planetary systems

We don’t want just a lot of planets, we want as many planets as possible in the same system.

The architecture of a system includes parameters like e.g. the distribution of

- planet radii, masses and hence types over orbital separation,
- the co-planarity and orbital parameters e.g., orbital eccentricities and inclinations,

as a function of stellar spectral types.

First analyses of Kepler and comparisons with planet synthesis models suggest

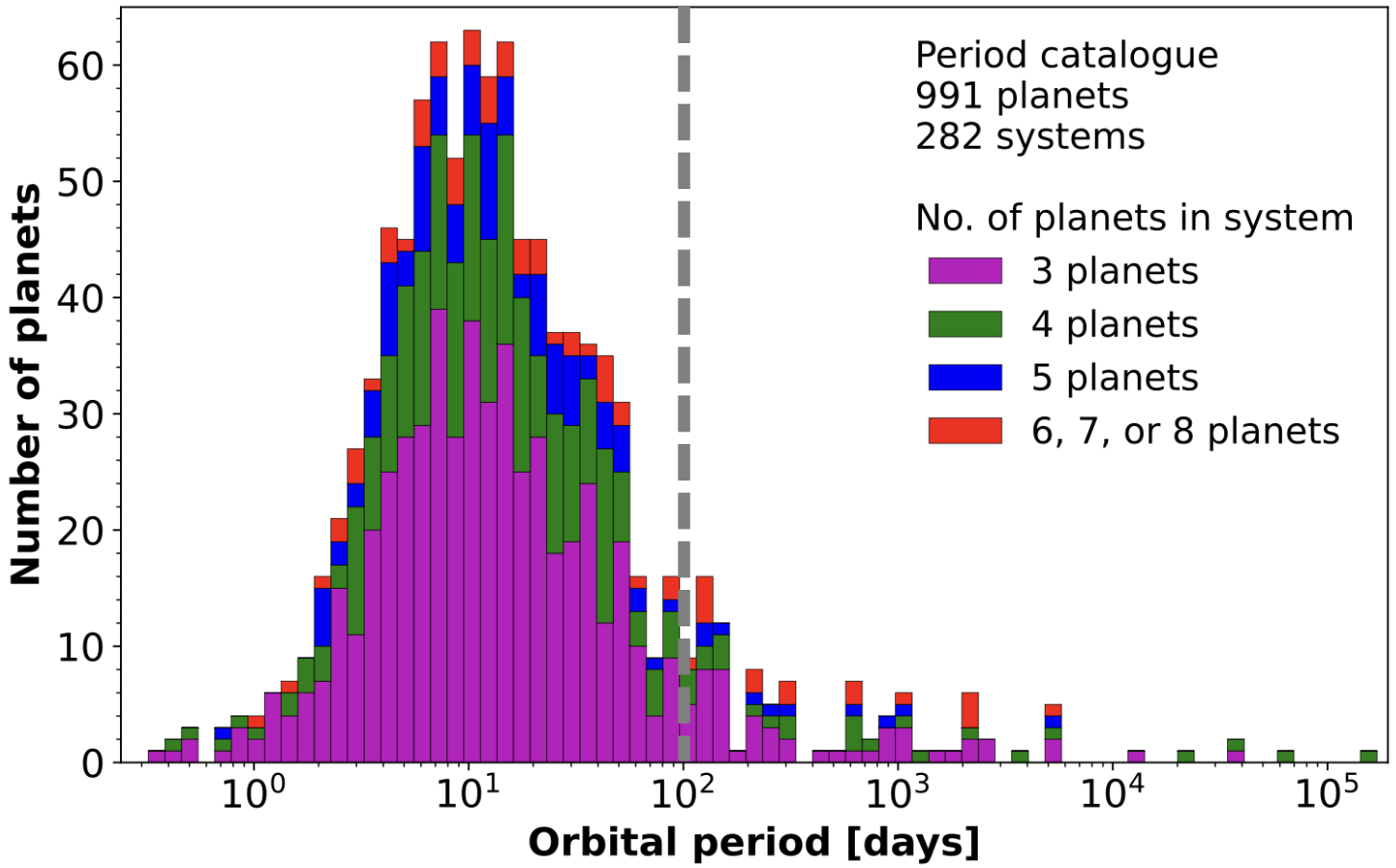
- adjacent planets having similar sizes with a trend (for most) towards increasing sizes for outer planets,
- (small) planets in the same system that are similar in radii could, however, be rather different in mass and vice versa,
- so far it seems that typically the planetary radii of a given planetary system are more similar than the masses.

What fraction of planetary systems have a structure similar to the Solar System?

How many have multiple/no gas giants?

How many systems include Earth-like habitable planets?

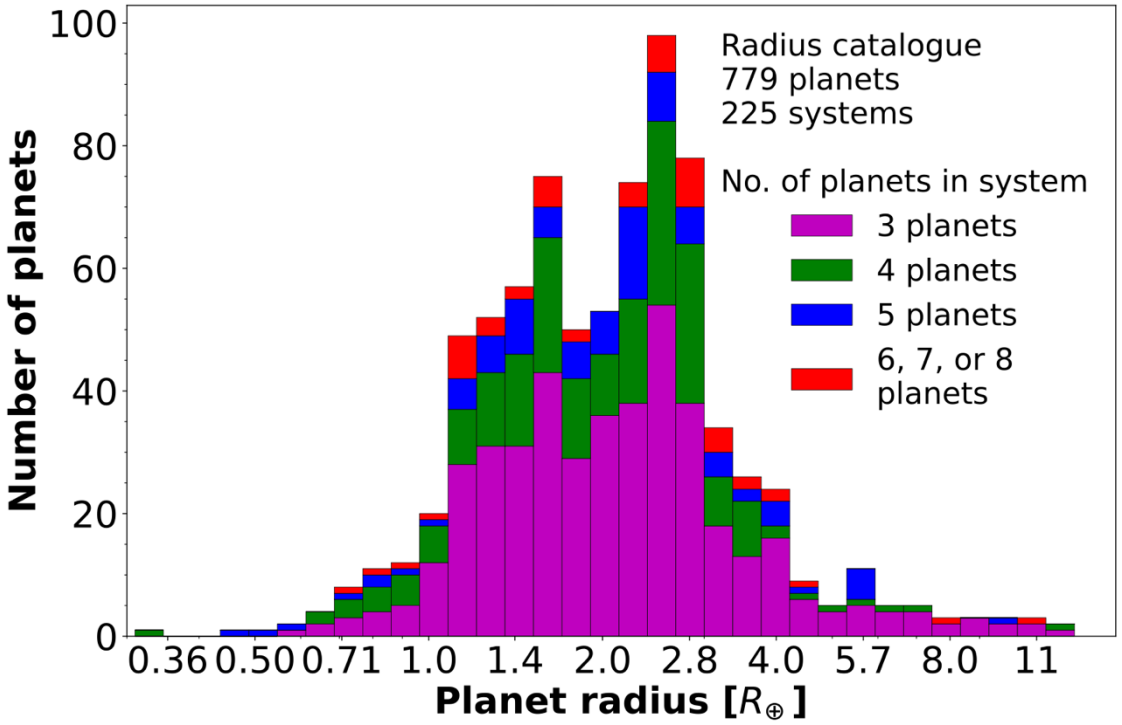
Few detected planets in systems with ≥ 3 planets

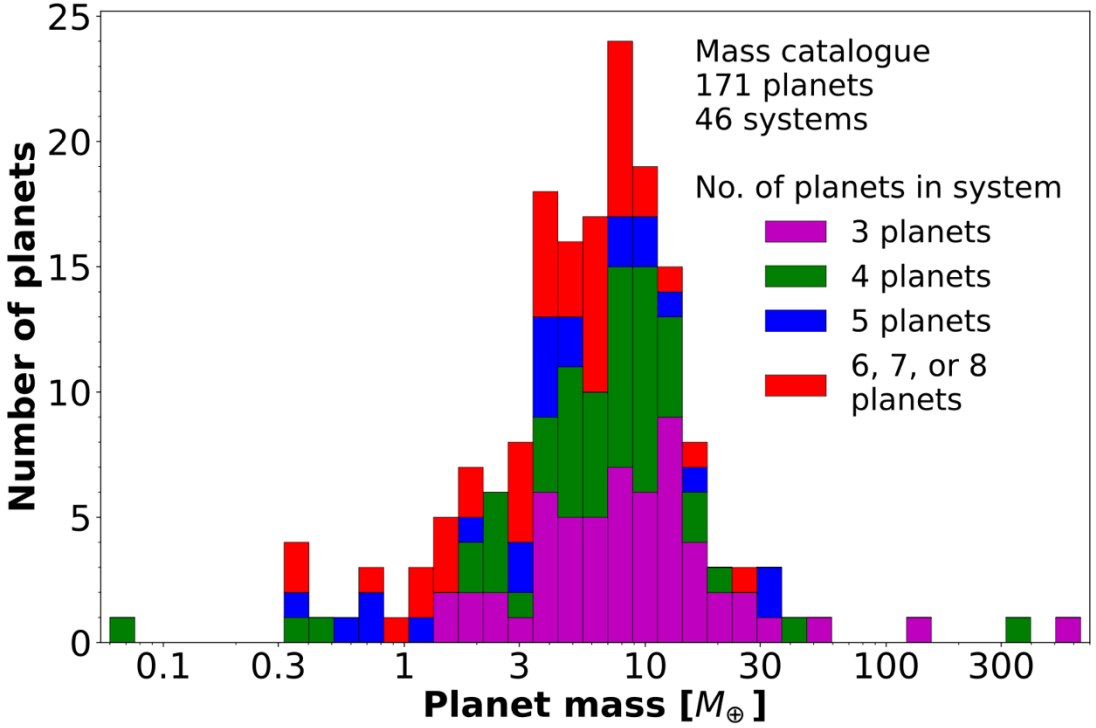


Data from NASA's exoplanet archive as of 28 June 2024. No limits on uncertainties.

Alexandra Muresan, Carina M. Persson, Malcolm Fridlund, A&A, 2024, 692, 122

Detected radii/masses of planets in systems with ≥ 3 planets





True masses from RVs (with inclination derived from transits) or TTV masses.

Data from NASA's exoplanet archive as of 28 June 2024. No limits on uncertainties.

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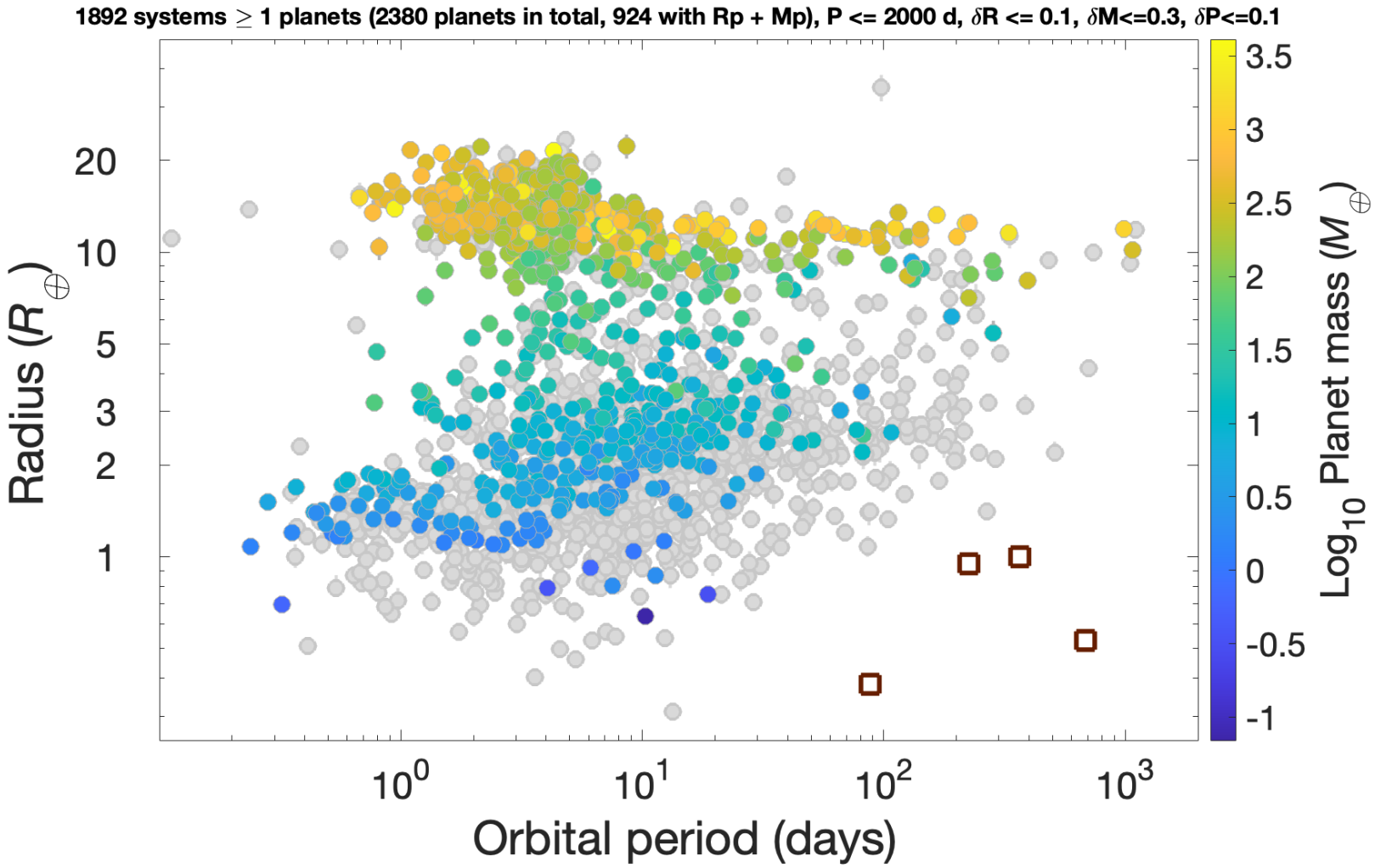
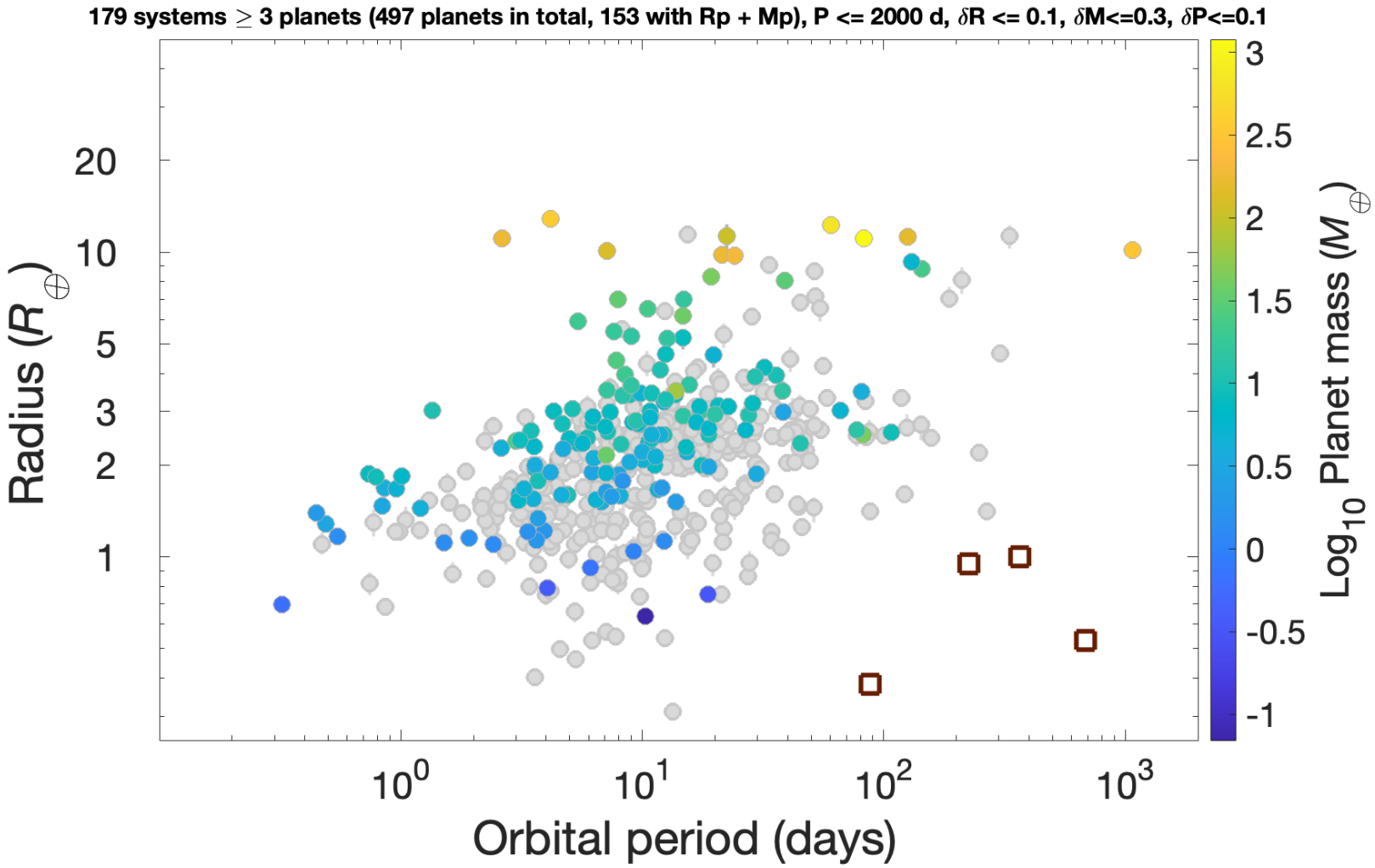
Radii and masses vs. period in all systems (multi + single)



Data from NASA's exoplanet archive as of 12 April 2025.

Radii and masses vs. period in systems with ≥ 3 planets



Data from NASA's exoplanet archive as of 12 April 2025.

Number of planets in systems ≥ 3 planets with measured masses and radii

224 planets in total in 95 systems with (of which 70 have their masses only from TTVs; 51 planets in total have orbital periods > 80 days including single planet systems).

152 planets in total in 76 systems (of which 44 have their masses only from TTVs) with **uncertainties ≤ 30 % and ≤ 10 %** in mass and radius, respectively. **Only 5 planets have orbital periods > 83 days.**

For $R < 4\ R_{\oplus}$ and uncertainties ≤ 30 % and ≤ 10 % in mass and radius, respectively, there are

- **124 planets in 66 systems**.

For $R < 2\ R_{\oplus}$ and uncertainties ≤ 30 % and ≤ 10 % in mass and radius, respectively, there are

- **47 planets in 32 systems**.

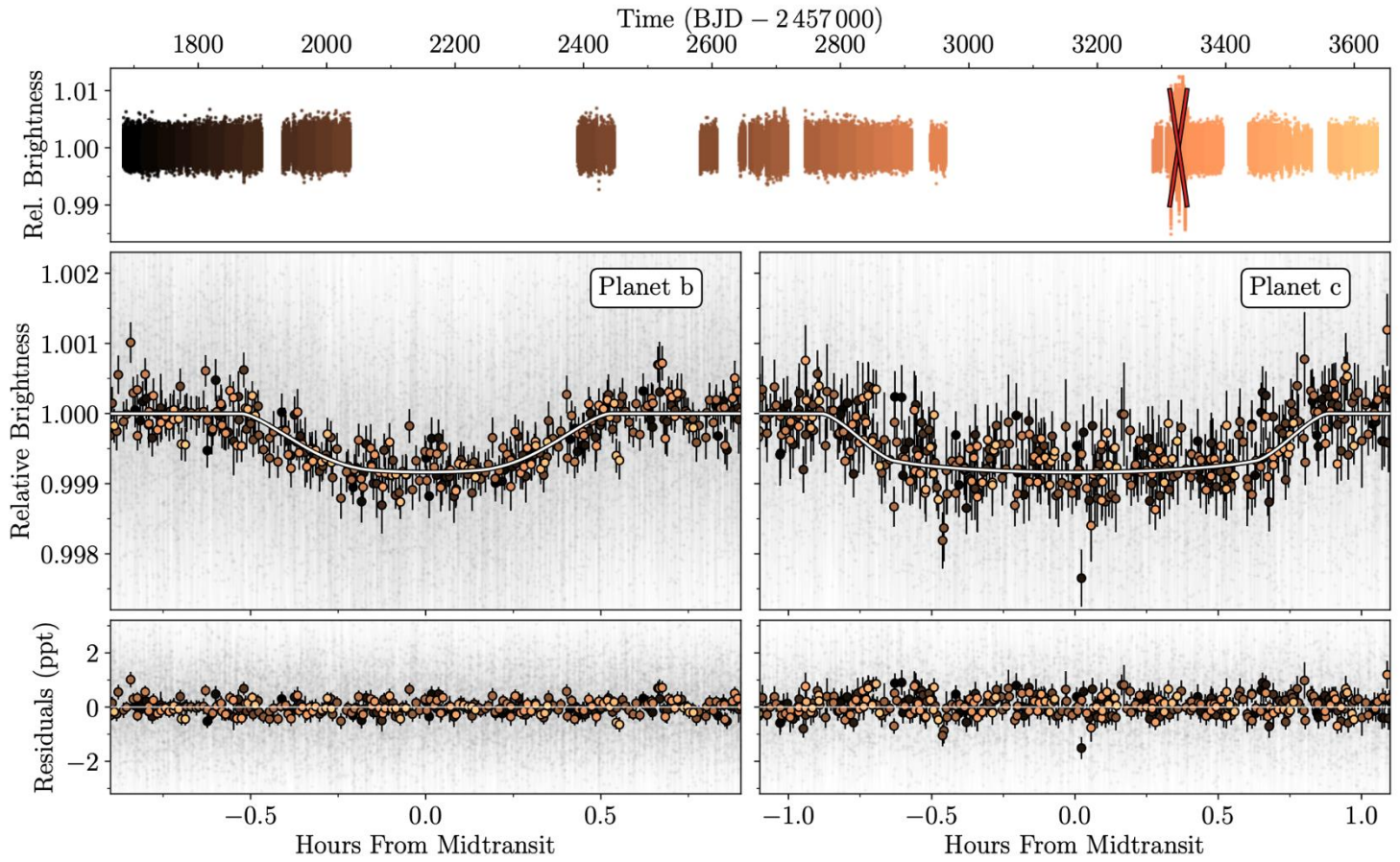
Using uncertainties 10 % and 3 % for mass and radius, respectively, (goal of PLATO) there are

- 27 planets in total of all sizes and masses in 15 systems (of which 7 are the Trappist-1 planets).

PLATO will significantly extend the number of well-characterised multi-planet systems, in particular for orbital periods longer than 80 days.

Example:

TOI-1438: A rare system with two short-period sub-Neptunes and a tentative long-period Jupiter-like planet orbiting a K0V star



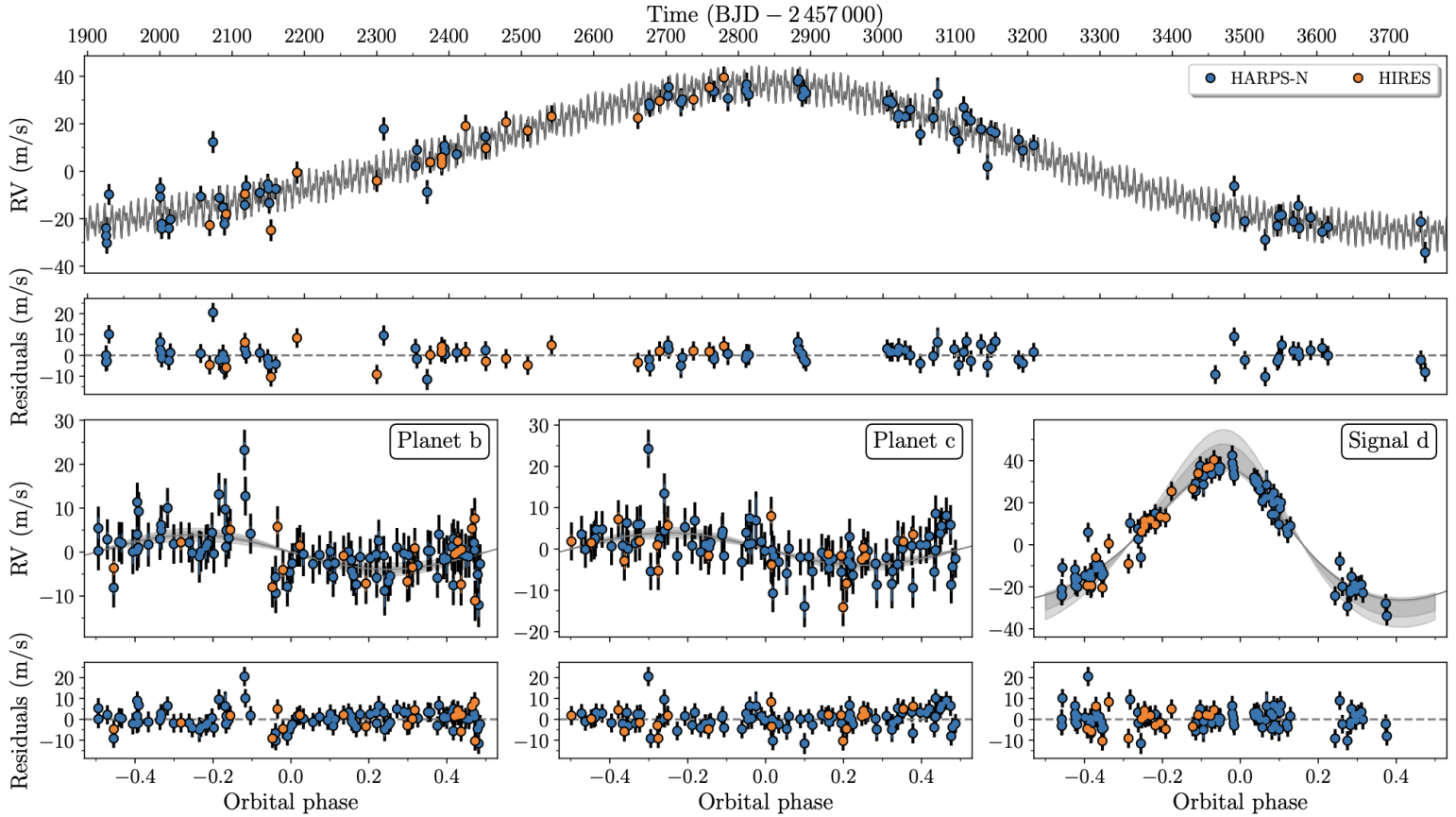
TESS data: 38 sectors between 2019 and 2024.

V = 10.957, $M_\star$ = 0.88 $M_\odot$, P_b = 5.1 days, P_c = 9.4 days, R_b = 3.0 $R_\oplus$, R_c = 2.8 $R_\oplus$.

Carina M. Persson, Emil Knudstrup,… Alexandra Muresan,… Alexander Mustill, … Malcolm Fridlund et al, submitted to A&A 2025.

Example:

TOI-1438: A rare system with two short-period sub-Neptunes and a tentative long-period Jupiter-like planet orbiting a K0V star



HARPS-N data: 85 RVs between 17 March 2020 and 15 March 2025.

P_b = 5.1 days, P_c = 9.4 days, $P_d \sim$ 7.6 years, M_b = 9.9 $M_\oplus$, M_c = 11.8 $M_\oplus$, M_d sin i= 2.1 M_{Jup}.

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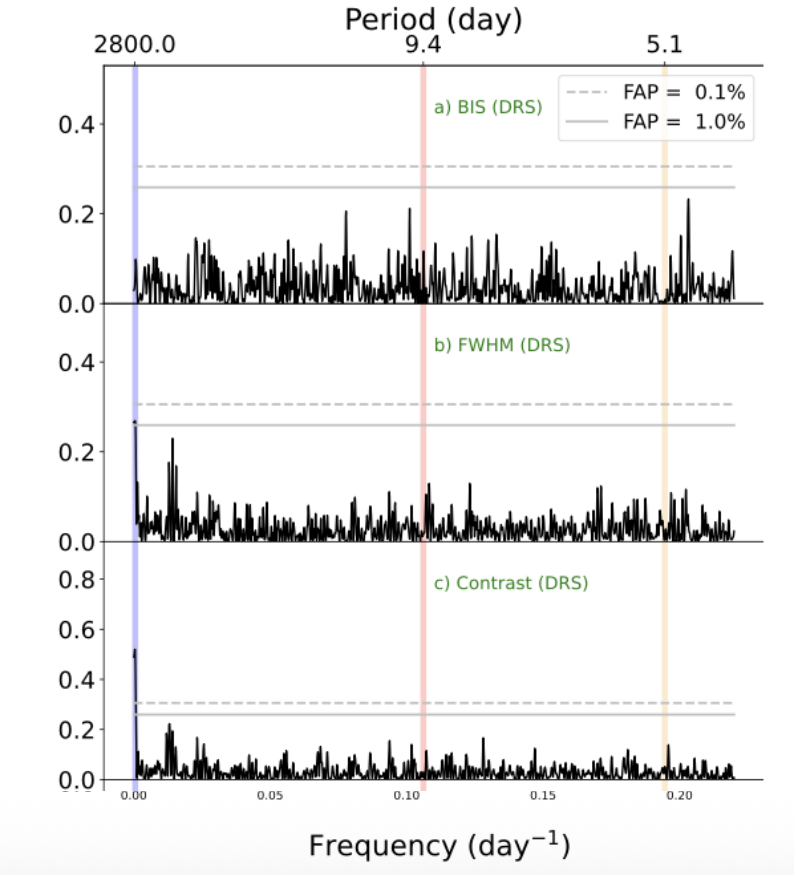

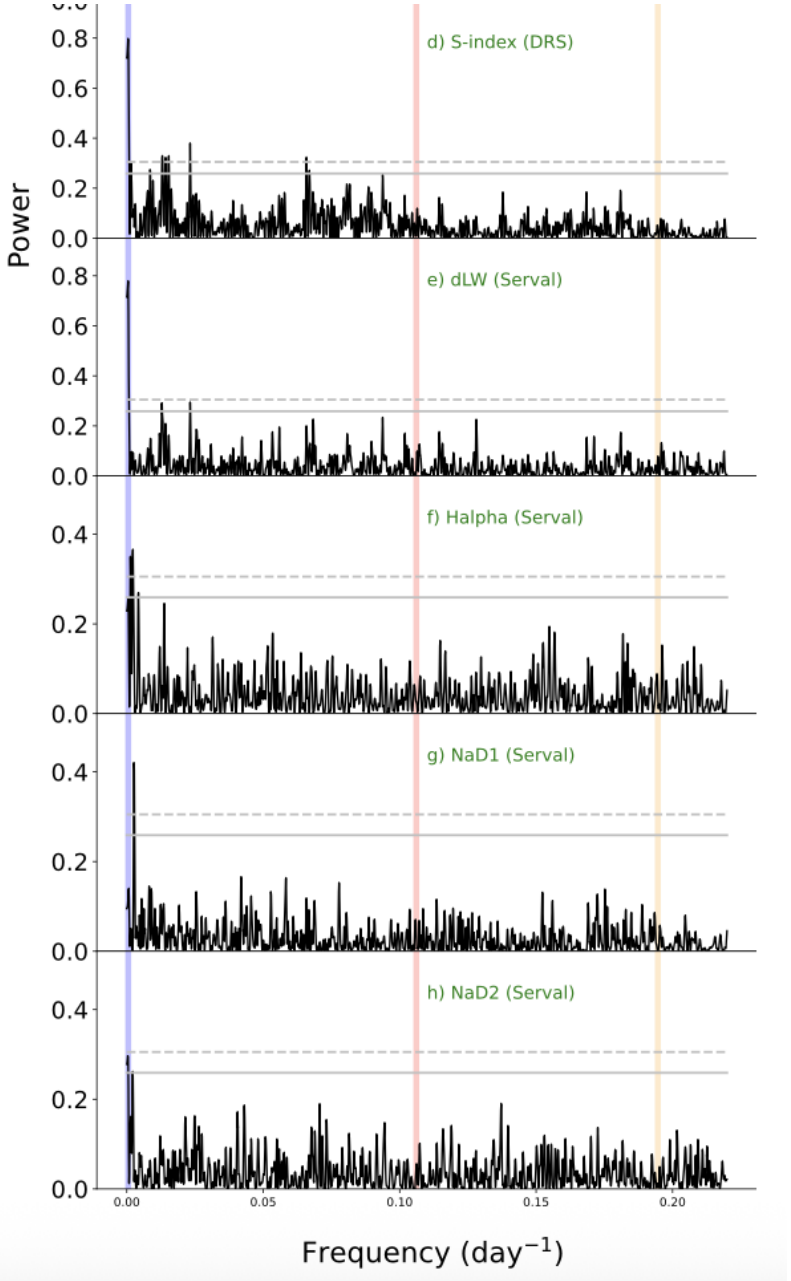

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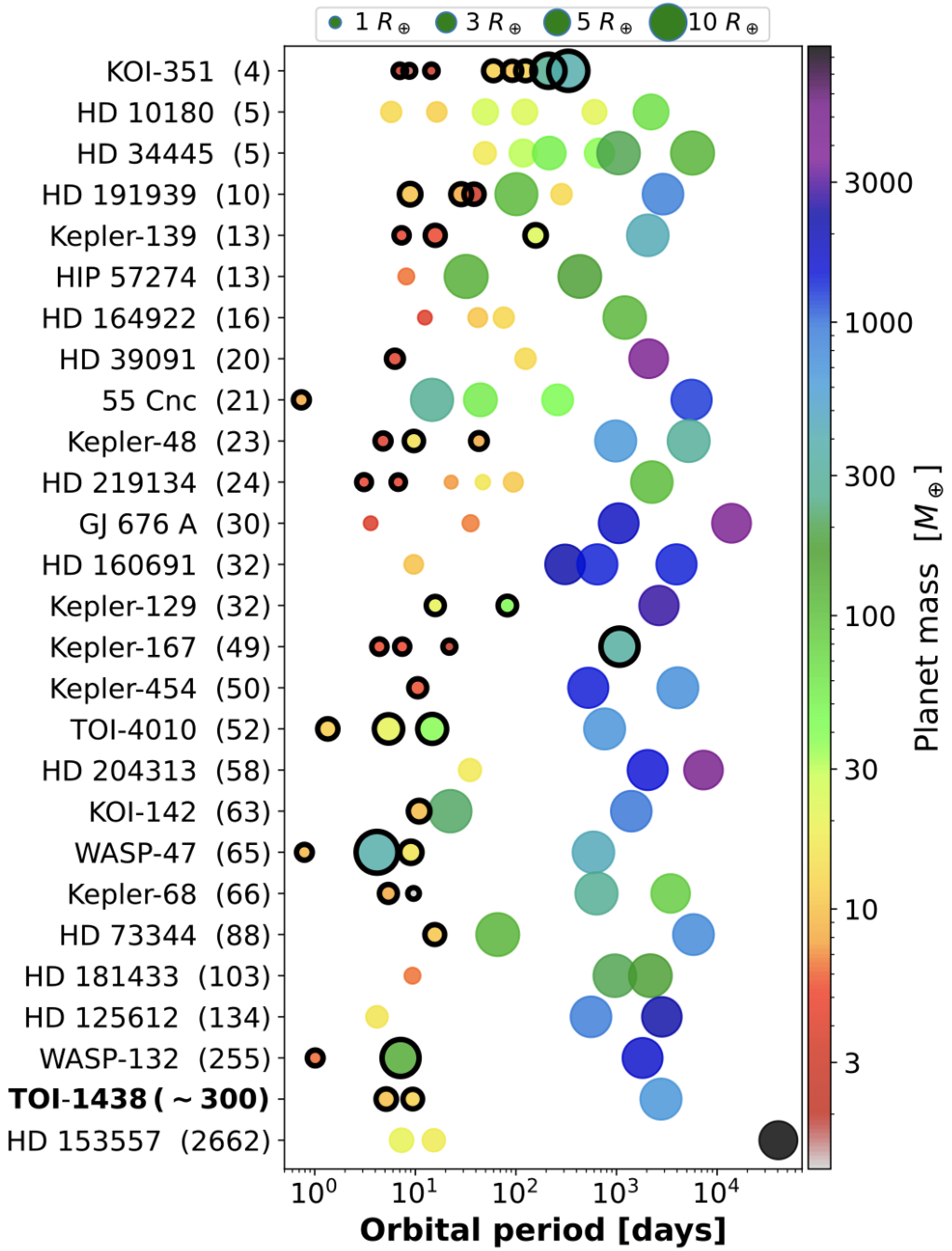
Alexandra Muresan,... Alexander Mustill, ...
Malcolm Fridlund et al, submitted to A&A 2025

Nice with a long-orbital period planet!

But – there are signals from stellar activity at long periods…

There could be both a third planet and stellar activity, but we need more observations to resolve the signals.

Thus planet d is so far tentative.



Example of architectures of the so far only 27 detected systems with minimum three planets and at least one inner small/low-mass planet ($R < 4\ R_\oplus$ or $M < 20\ M_\oplus$) and one outer giant ($R > 8\ R_\oplus$ or $M > 90\ M_\oplus$) with $P_{orb} > 300$ days, including the TOI-1438 system assuming a planetary nature of signal d.

The largest orbital period ratio between two adjacent planets in each system increases from top to bottom and is written in parentheses after the name of the host star.

The sizes and colors of the circles indicate the radii and masses of the planets, respectively.

Planets with transit measurements are outlined in black.

All planets have RV measurements except for HD 73344 b, Kepler-167 b, c, and d, as well as the eight planets orbiting KOI-351.

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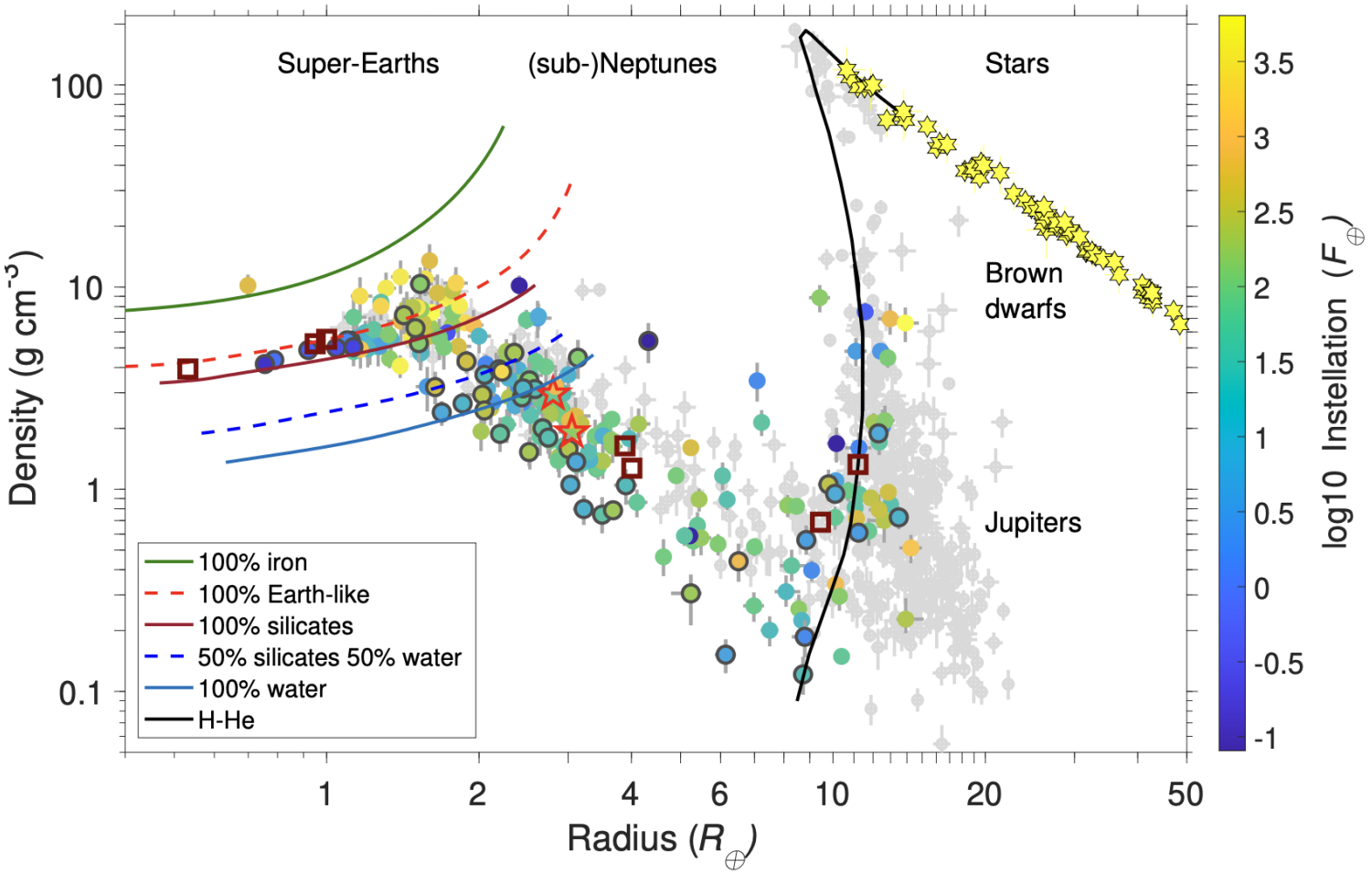
Alexandra Muresan,... Alexander Mustill, ...
Malcolm Fridlund et al, submitted to A&A 2025.

We need both radii and masses for as many planets in each system as possible in order to compare types of planets as a function of architecture



Density vs. radius diagram of the 230 planets in 159 systems with ≥ 2 planets from the NASA exoplanet archive with uncertainties better than 21 % and 7 % in mass and radius, respectively, color-coded with instellation.

The planets plotted in grey are single planet systems.

The masses are derived from radial velocity measurements (181 planets) or from transit timing variations (49 planets outlined in dark grey), and the radii are derived from transit photometry.

Interior models from Zeng (2019) and Baraffe (2003, 2008).

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