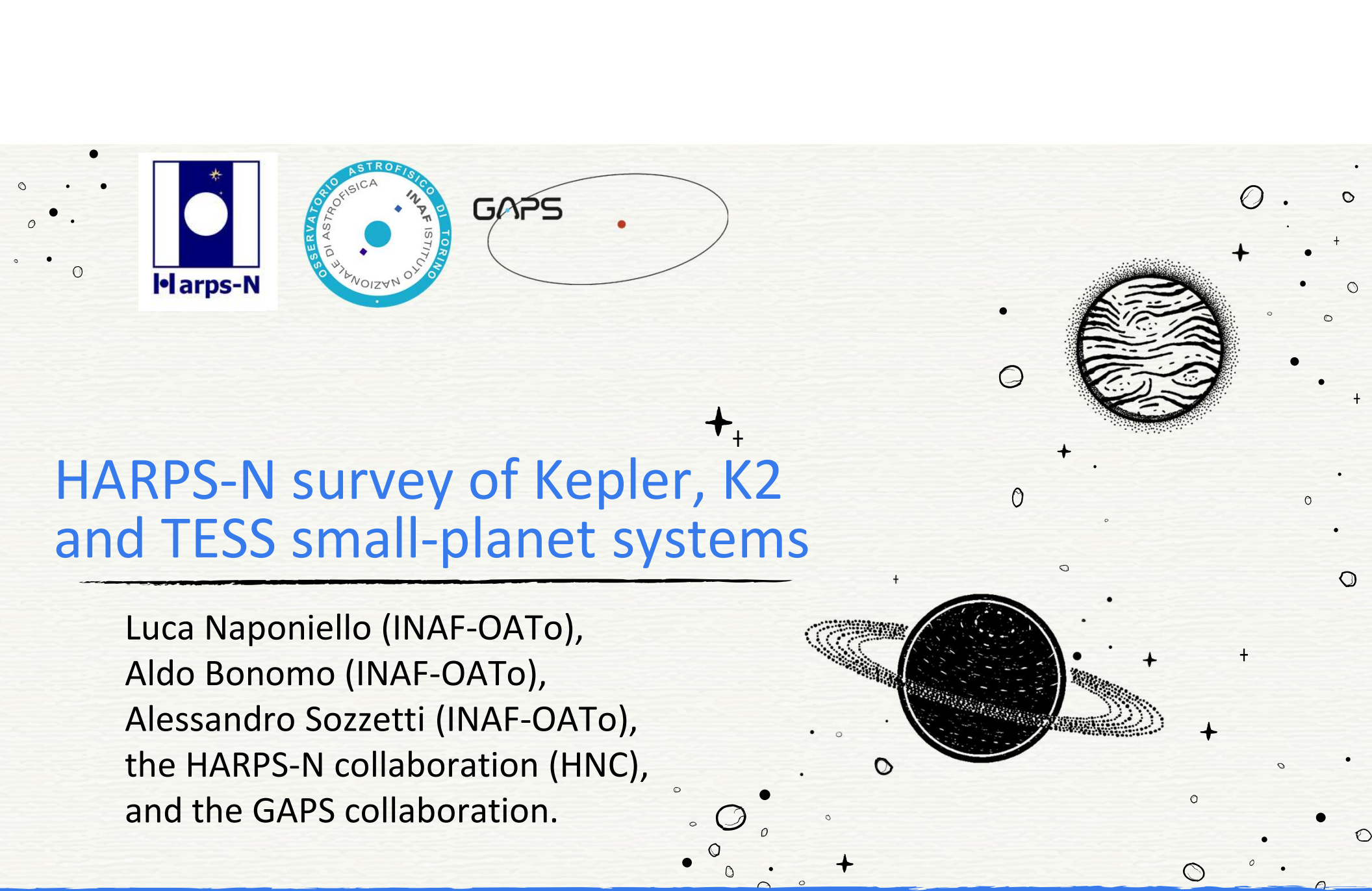


HARPS-N survey of Kepler, K2 and TESS small-planet systems

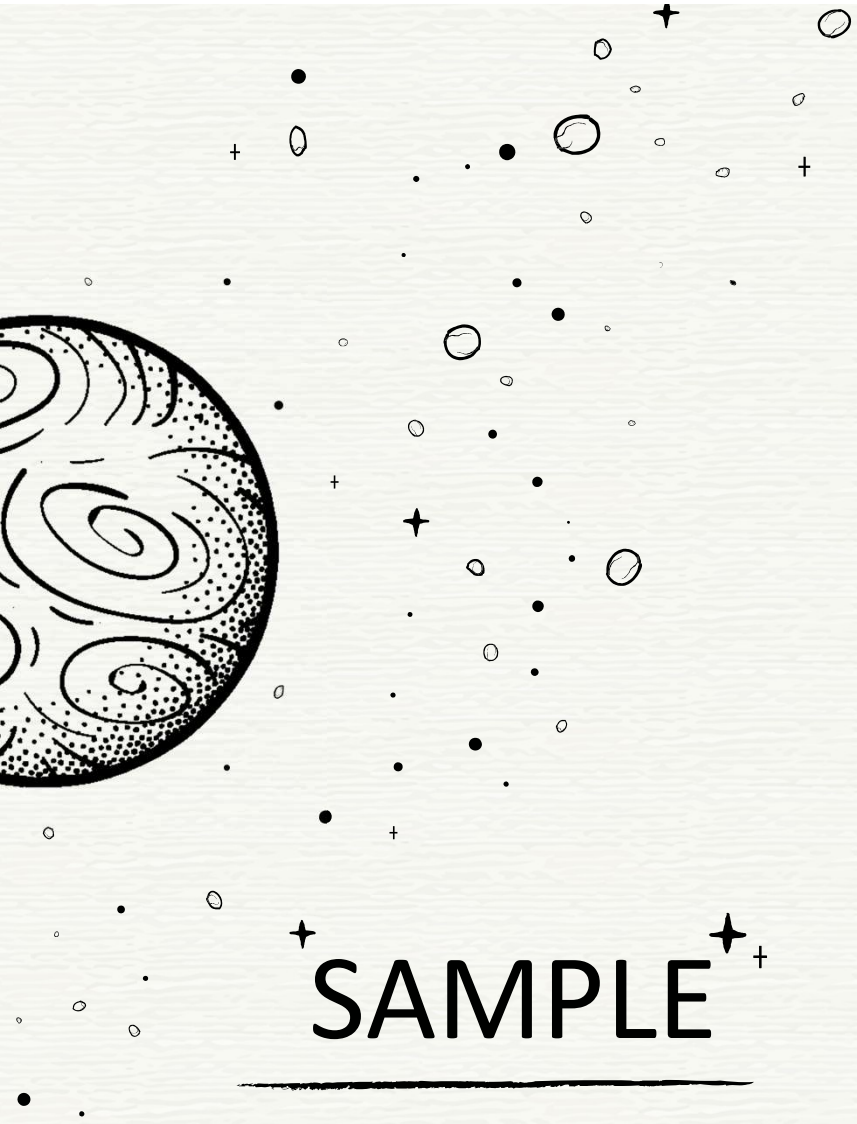
Luca Naponiello (INAF-OATo),
Aldo Bonomo (INAF-OATo),
Alessandro Sozzetti (INAF-OATo),
the HARPS-N collaboration (HNC),
and the GAPS collaboration.

HARPS-N sample of inner SP systems

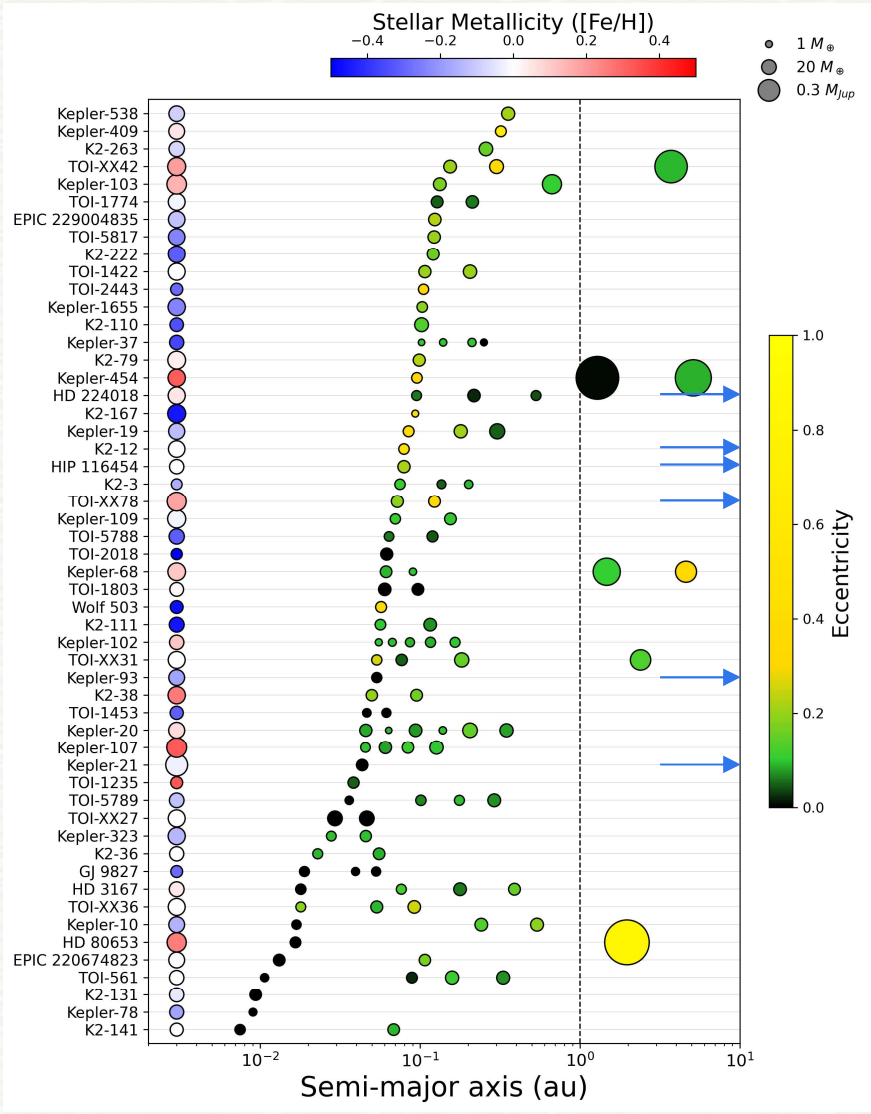
- 17 Kepler systems (Bonomo et al. 2023)
- 20 K2 systems (Bonomo et al. 2023, **+ HD 224018 / K2-420**)
- **16 TESS systems (TOI-561, TOI-1235, TOI-1422, TOI-1453, TOI-1774, TOI-1803, TOI-2018, TOI-2443, TOI-5788, TOI-5789, TOI-5817, TOI-XX36, TOI-XX27, TOI-XX42, TOI-XX78, TOI-XX31)**

Conditions:

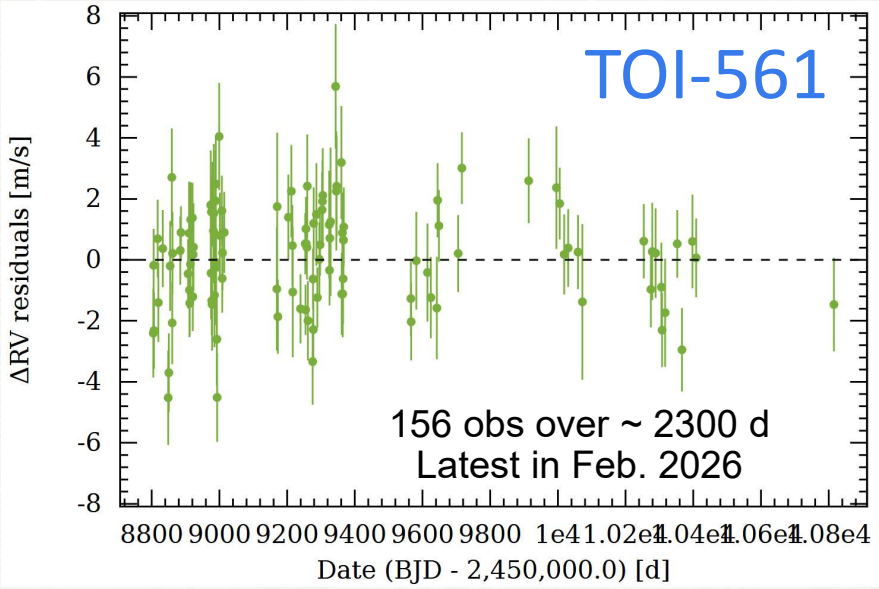
- At least one inner ($P_{orb} < 100$ days) SP ($1 \leq M_p \leq 20 M_\oplus$ within 1σ)
- At least 20 HARPS-N measurements with a baseline longer than 1 year
- No inner hot/warm giants ($P_{orb} < 100$ days, $M_p \geq 0.3 M_{Jup}$ within 1σ)

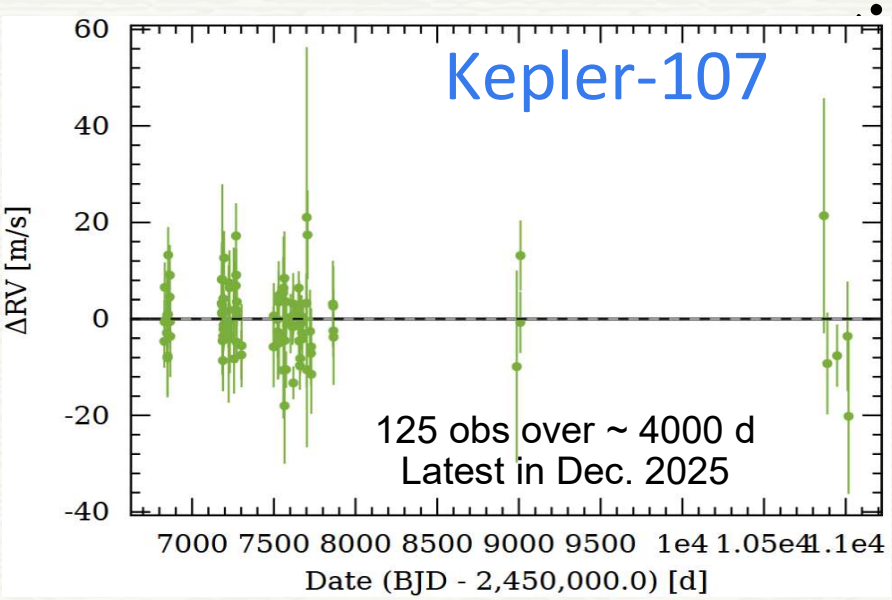


SAMPLE

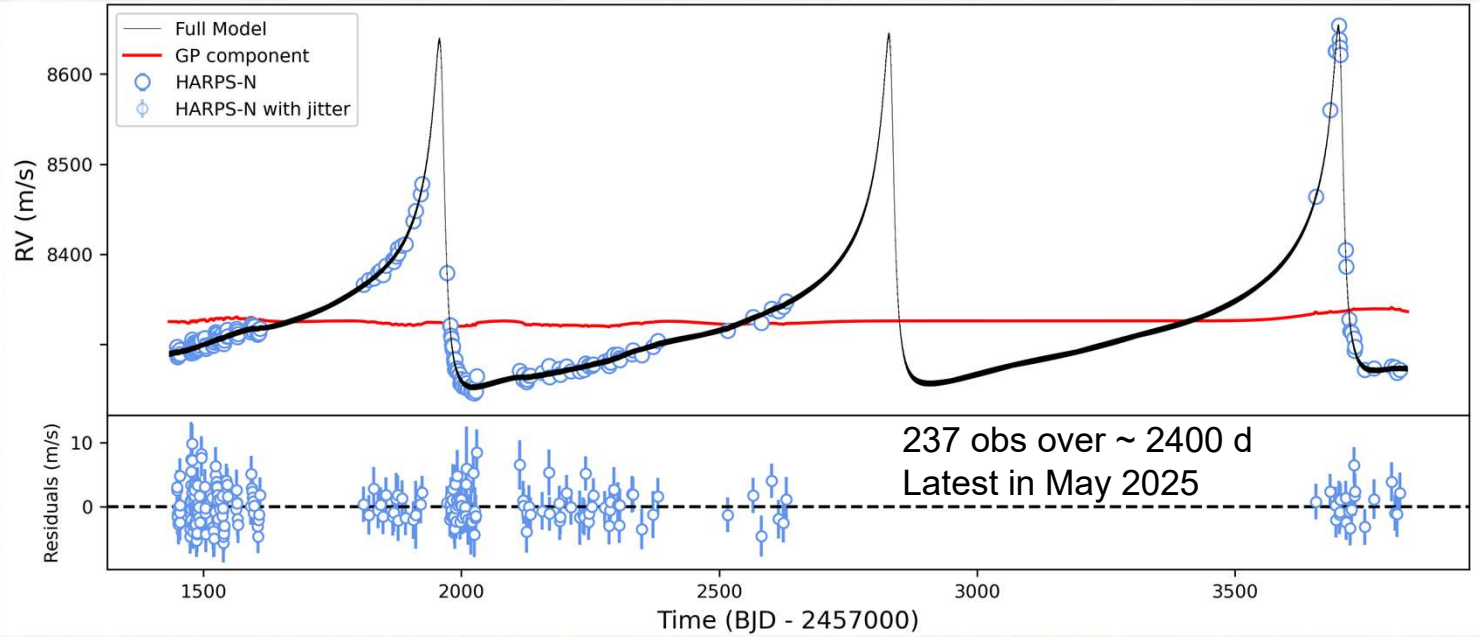

Stellar Metallicity ([Fe/H])
−0.4
−0.2
0.0
0.2
0.4
1 $M_\oplus$
20 $M_\oplus$
0.3 M_{Jup}
Kepler-538
Kepler-409
K2-263
TOI-XX42
Kepler-103
TOI-1774
EPIC 229004835
TOI-5817
K2-222
TOI-1422
TOI-2443
Kepler-1655
K2-110
Kepler-37
K2-79
Kepler-454
HD 224018
K2-167
Kepler-19
K2-12
HIP 116454
K2-3
TOI-XX78
Kepler-109
TOI-5788
TOI-2018
Kepler-68
TOI-1803
Wolf 503
K2-111
Kepler-102
TOI-XX31
Kepler-93
K2-38
TOI-1453
Kepler-20
Kepler-107
Kepler-21
TOI-1235
TOI-5789
TOI-XX27
Kepler-323
K2-36
GJ 9827
HD 3167
TOI-XX36
Kepler-10
HD 80653
EPIC 220674823
TOI-561
K2-131
Kepler-78
K2-141
10^{-2}
10^{-1}
10^{0}
10^{1}
Semi-major axis (au)
Eccentricity
1.0
0.8
0.6
0.4
0.2
0.0

Examples with no evident trend





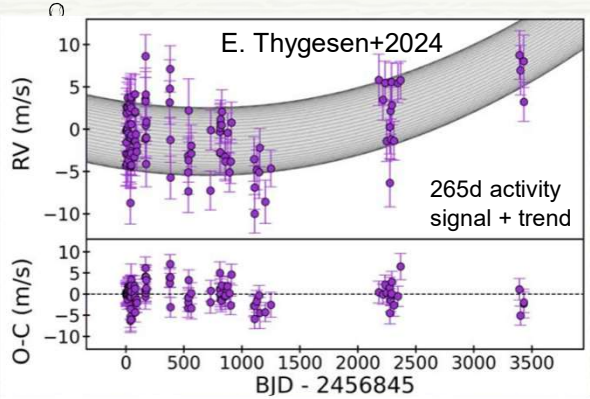
The case of HD80653 c / K2-312 c

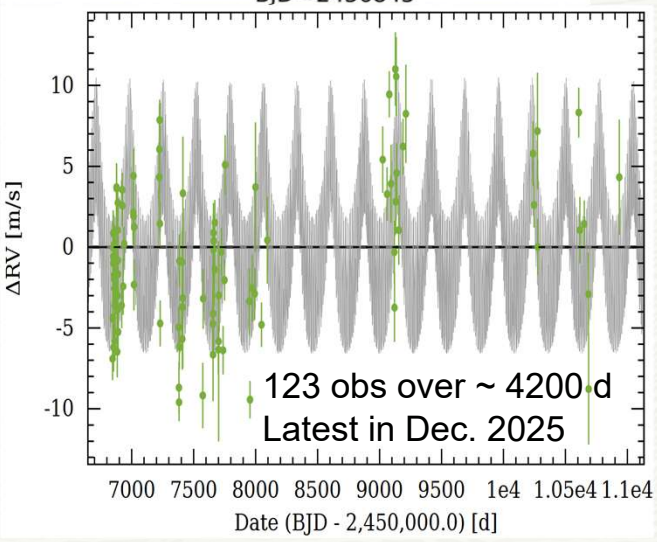


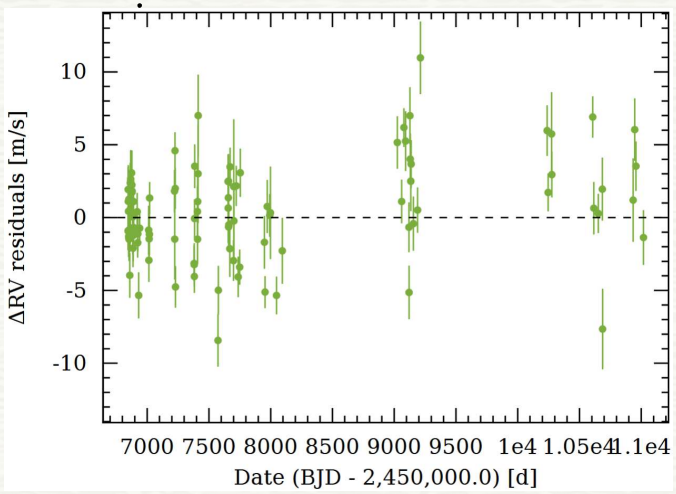
Naponiello et al.
in prep.

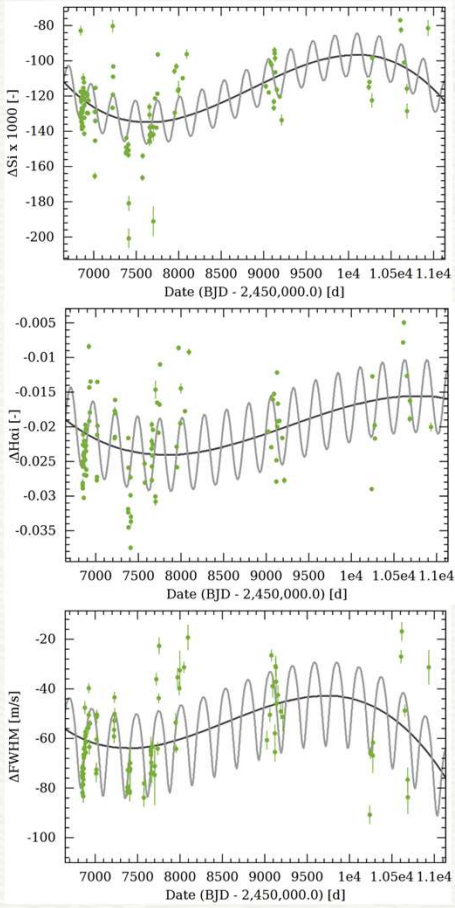
$P = 871.4^{+0.5}_{-0.2}$ d, e = 0.843 ± 0.002, a = 1.88 ± 0.08 au, Msin*i* = 5.47 ± 0.17 M_{Jup}

The case of K2-2

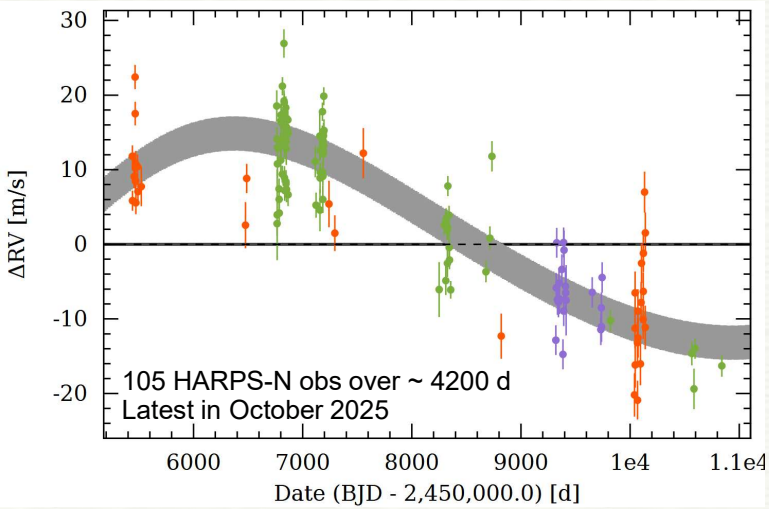




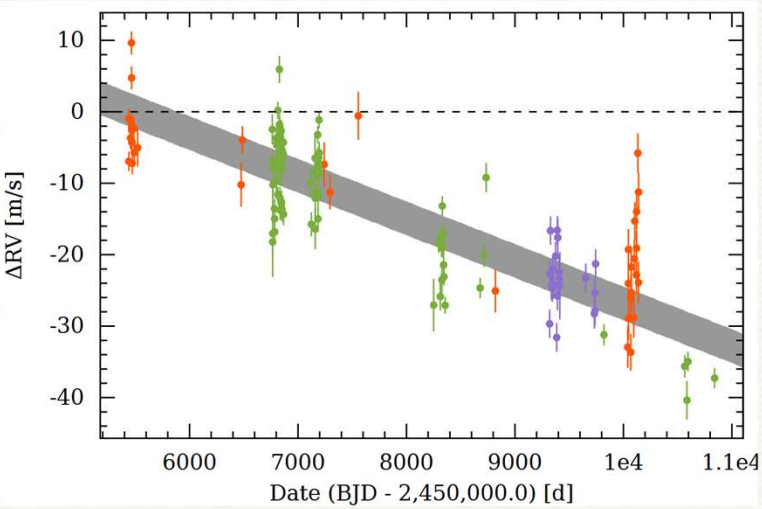




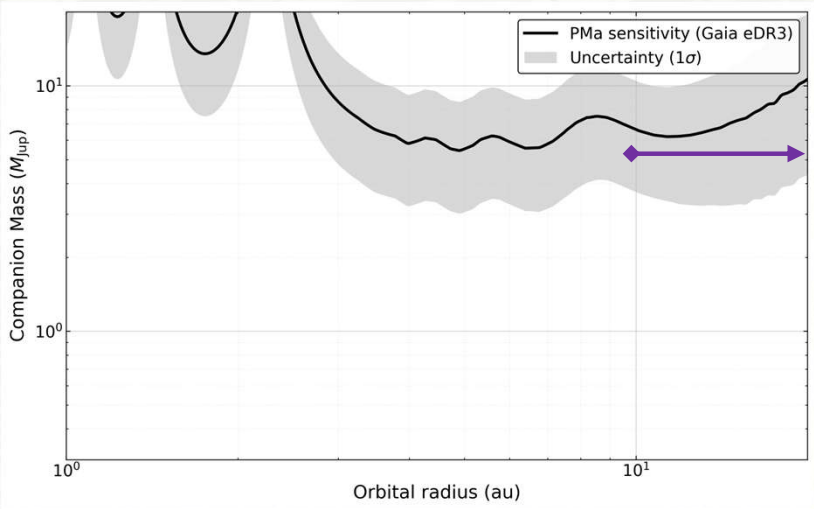
The case of Kepler-21

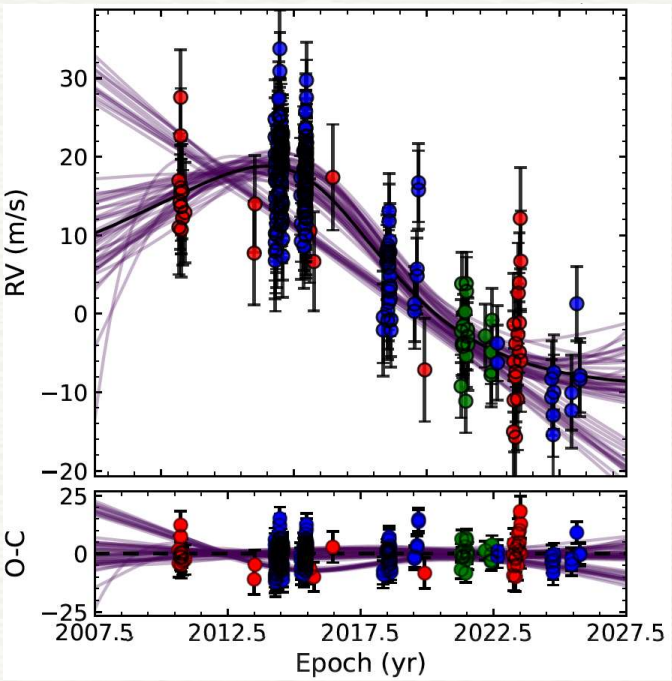


or



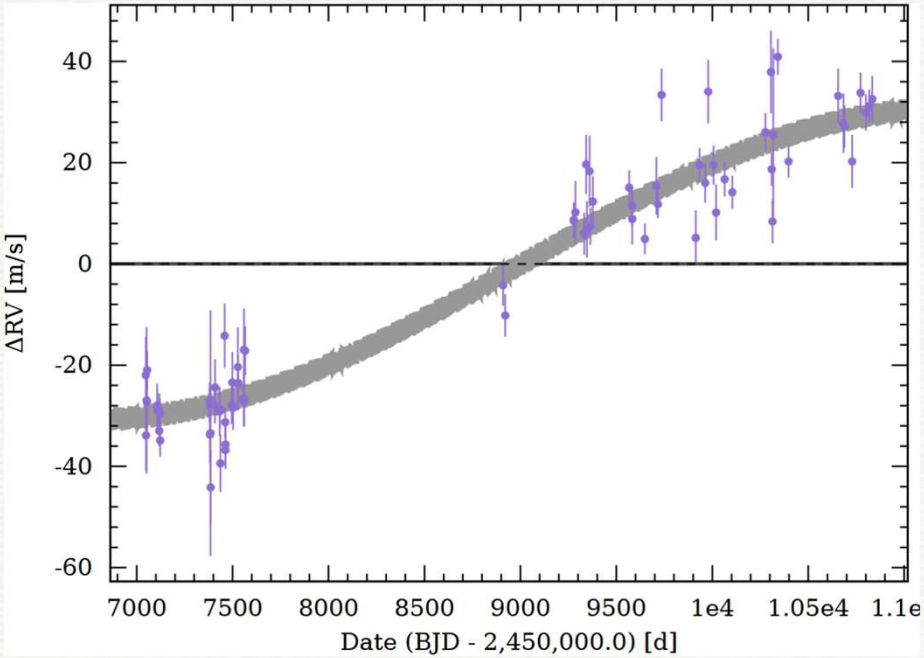
The case of Kepler-21

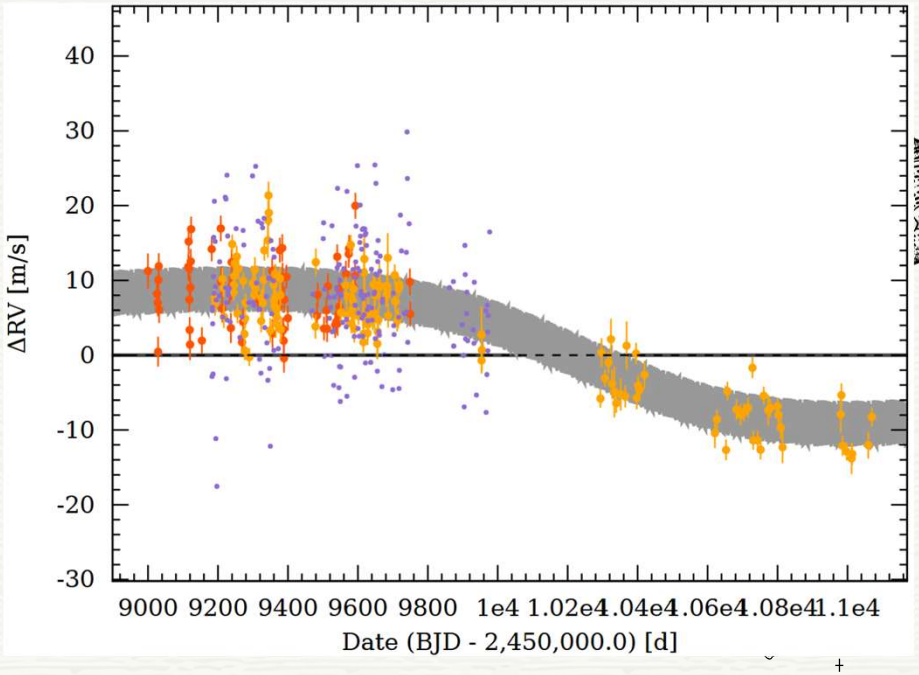


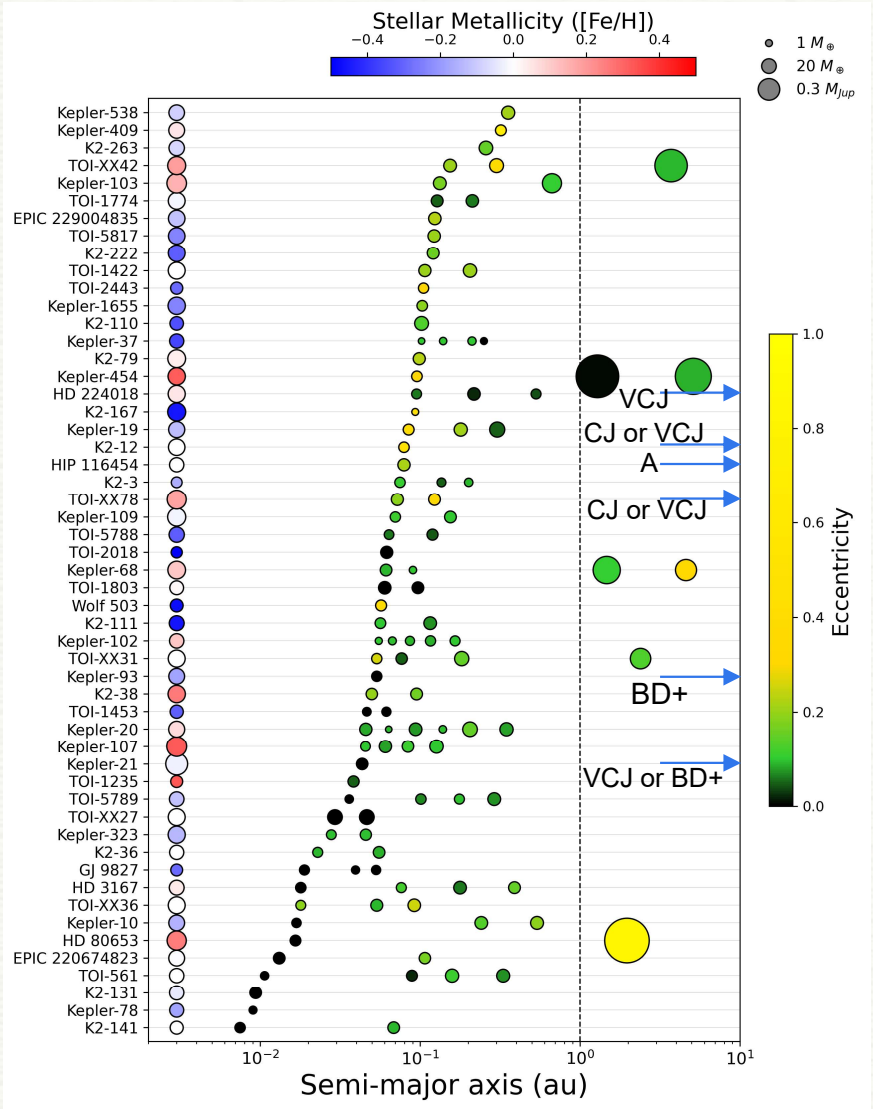


github.com/t-brandt/orvara
(T. D. Brandt et al. 2021)

K2-12 and TOI-XX78





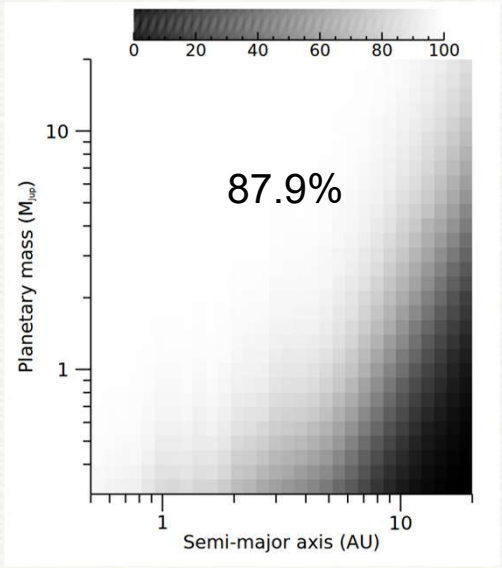


5/51 CJs in SP systems

4/8 CJs around high met. stars

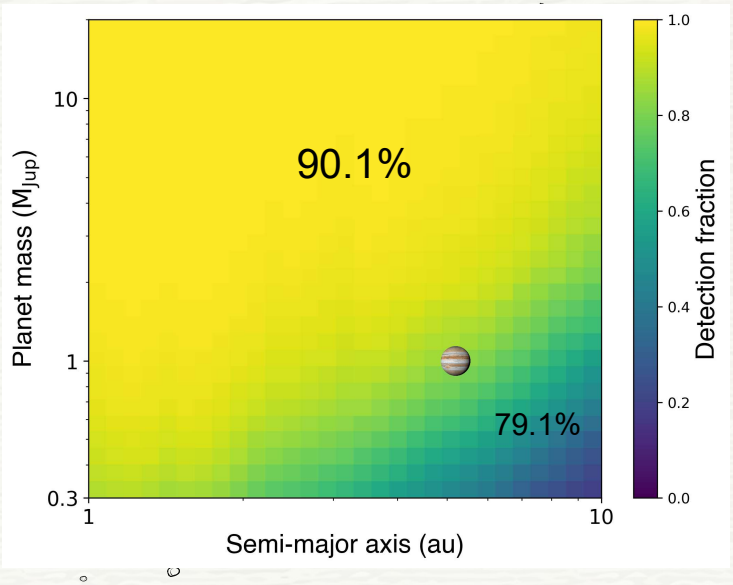
Completeness and occurrence rate

$f_{CJ|SP} = 9.2^{+7.7}_{-2.9}\%$



Bonomo et al. 2023

$f_{CJ|SP} = 10.9^{+6.4}_{-3.1}\%$



Naponiello et al. in prep

Current planning

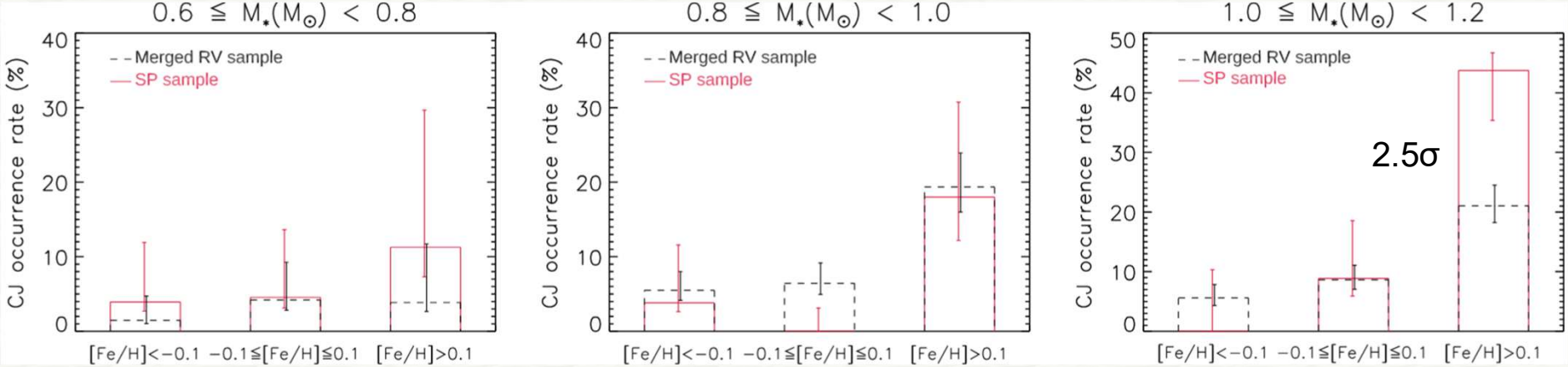
- We’re going to obtain few more HARPS-N RVs for some targets;
- Separate publications are being prepared by the HNC for the new systems;
- Finally, we’re going to homogeneously fit the systems following Bonomo et al. (2023).

Beyond HARPS-N…

- Carefully selected sample of 217 SP systems detected through transits and RVs, as available in the NASA Exoplanet Archive;
- Carefully selected comparison sample of 1167 solar-type stars from RV surveys, regardless of the presence of CJs;
- Homogeneously computed CJ completeness for all these systems;
- $f_{CJ|SP} = 13.4^{+2.8}_{-2.0}\%$ (vs. $f_{CJ} = 10.4^{+1.0}_{-0.8}\%$) at average stellar mass and metallicity (very well compatible with $f_{CJ|SP}$ estimated in the HARPS-N sample alone);
- …

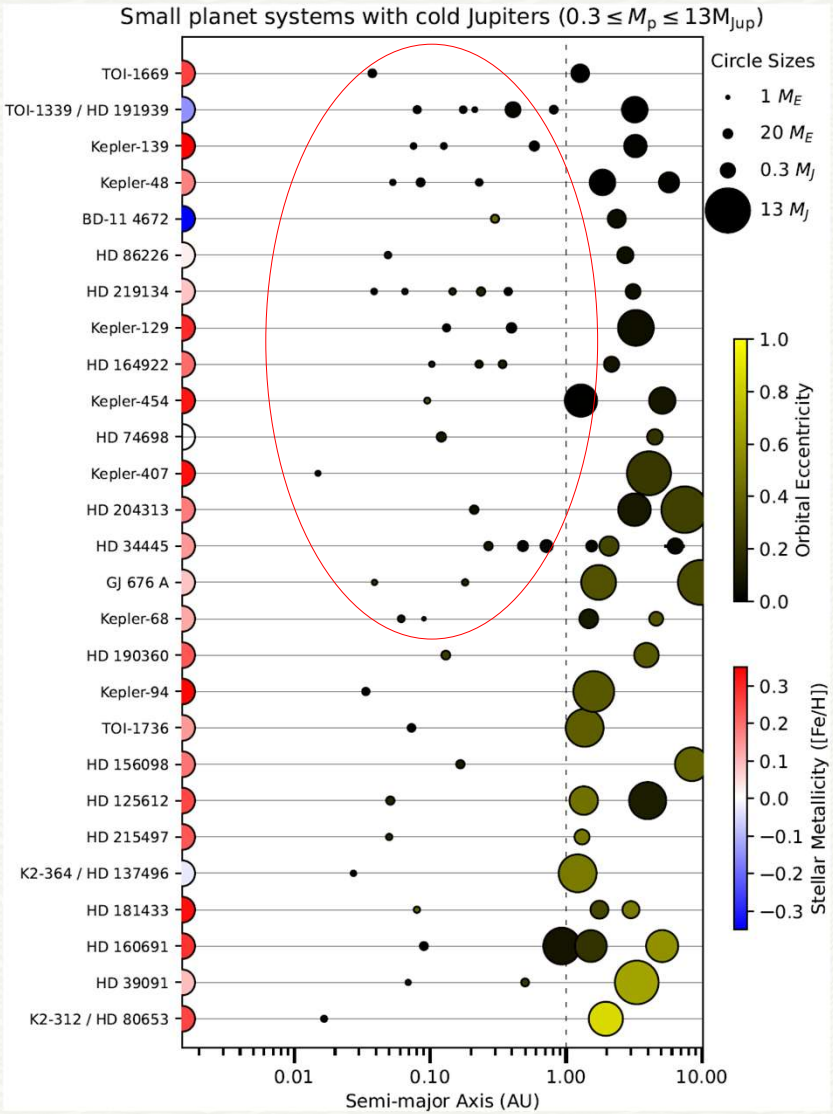
Bonomo, Naponiello, Pezzetta et al. (2025)

- Possible correlation at super-solar mass and metallicity;



Bonomo, Naponiello, Pezzetta et al. (2025)
See also Bryan & Lee (2025)

- Correlation between SP multiplicity and CJ eccentricity;



Bonomo, Naponiello, Pezzetta et al. (2025)

- No link between SP multiplicity and CJs:

$$f_{SP,n\geq 2 \mid \text{no CJ}} = 43^{+4}_{-3}\% \text{ (81 out of 190)}$$
$$f_{SP,n\geq 2 \mid \text{CJ}} = 37^{+10}_{-8}\% \text{ (10 out of 27)}$$

- No link between SP multiplicity and CJs:

  $f_{SP,n\geq 2 \mid \text{no CJ}} = 43^{+4}_{-3}\%$ (81 out of 190)

  $f_{SP,n\geq 2 \mid \text{CJ}} = 37^{+10}_{-8}\%$ (10 out of 27)

- No link between CJ multiplicity and single SP systems:

  $f_{n=1\ SP \mid n=1\ CJ} = 63^{+9}_{-12}\%$ (12 out of 19)

  $f_{n=1\ SP \mid n>1\ CJ} = 62^{+13}_{-18}\%$ (5 out of 8)

- No link between SP multiplicity and CJs:

$f_{SP,n\geq2 \mid no\ CJ} = 43^{+4}_{-3}\%$ (81 out of 190)

$f_{SP,n\geq2 \mid CJ} = 37^{+10}_{-8}\%$ (10 out of 27)

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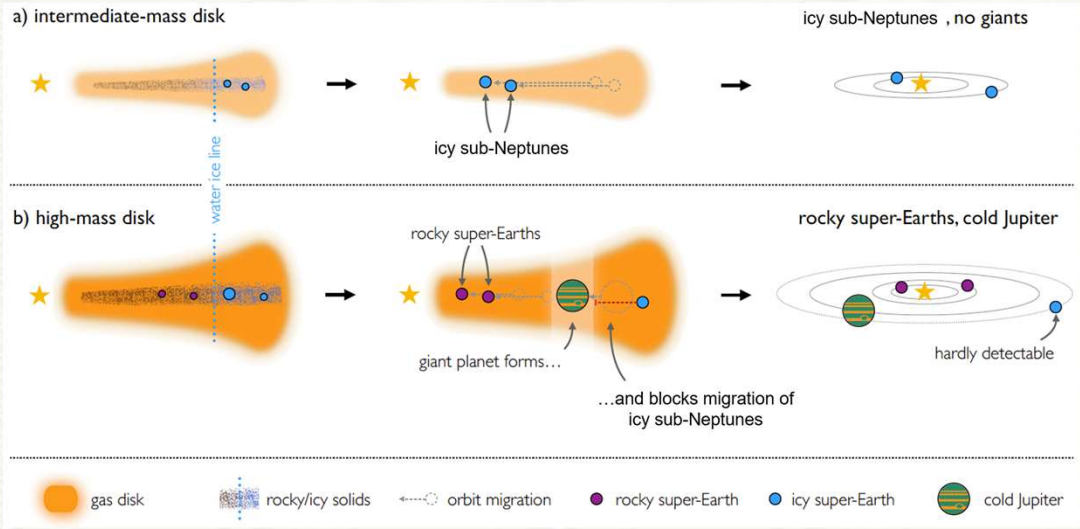
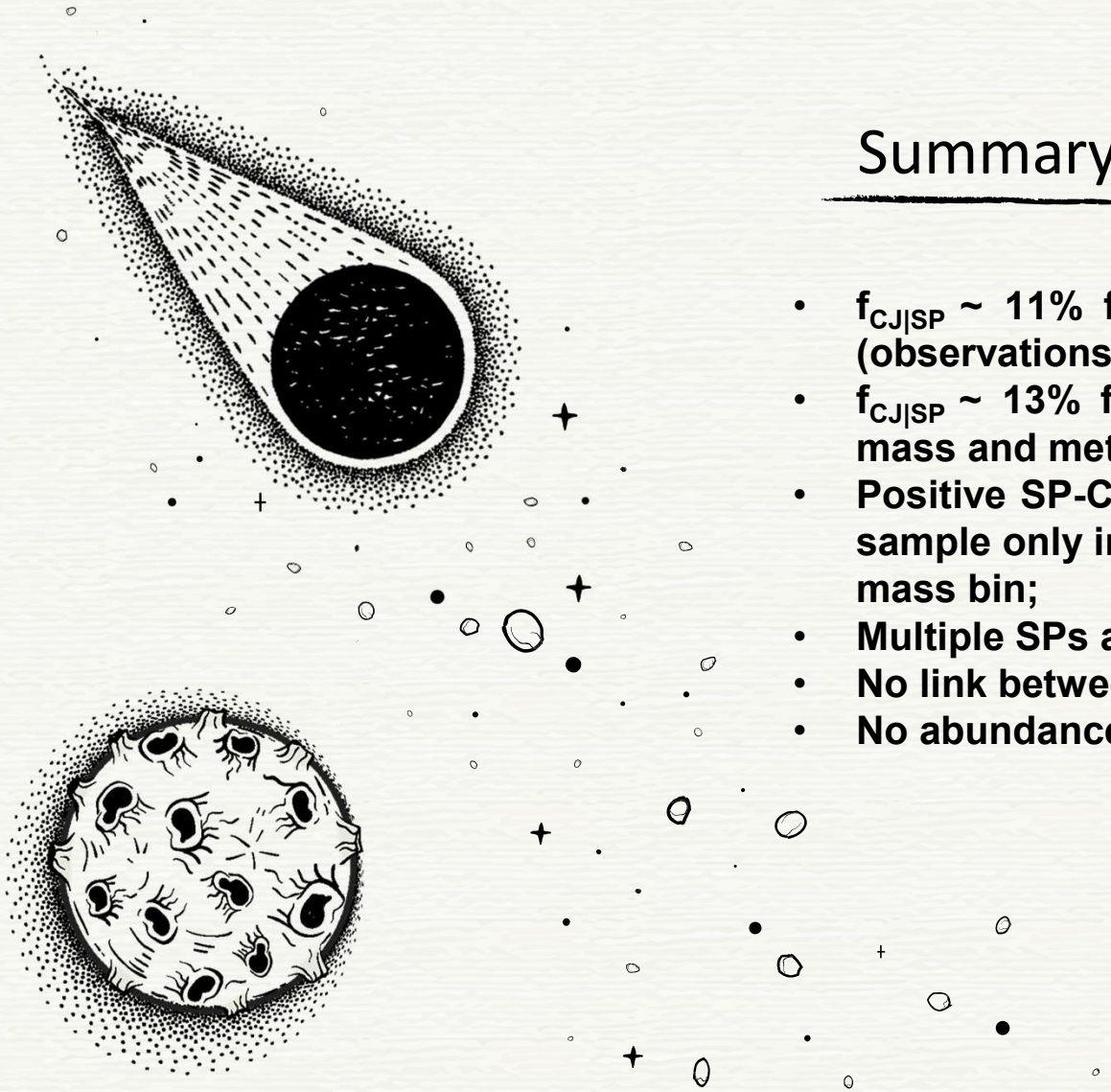
$f_{n=1\ SP \mid n\geq1\ CJ} = 62^{+13}_{-18}\%$ (5 out of 8)

- SP of rocky composition (i.e. located between the 100% iron and 100% silicate composition lines in the mass-radius diagram) do not represent the majority of the SP-CJ systems:

$f_{rocky\ SP \mid CJ} = 33^{+13}_{-9}\%$ (5 out of 15)



Schlecker et al. 2021



Summary

- **$f_{CJ|SP}$ ~ 11% from the HARPS-N survey of SP systems (observations still ongoing!);**
- **$f_{CJ|SP}$ ~ 13% from the global sample (at average stellar mass and metallicity);**
- **Positive SP-CJ correlation detected at 2.5σ, in the global sample only in the super-solar metallicity and super-solar mass bin;**
- **Multiple SPs are mostly found in systems with low-e CJs;**
- **No link between SP multiplicity and CJ, or viceversa;**
- **No abundance of rocky SPs in SP-CJ systems.**

Thanks!

luca.naponiello@inaf.it