

Lessons learned from RV follow-up of long-period small-size transiting planets

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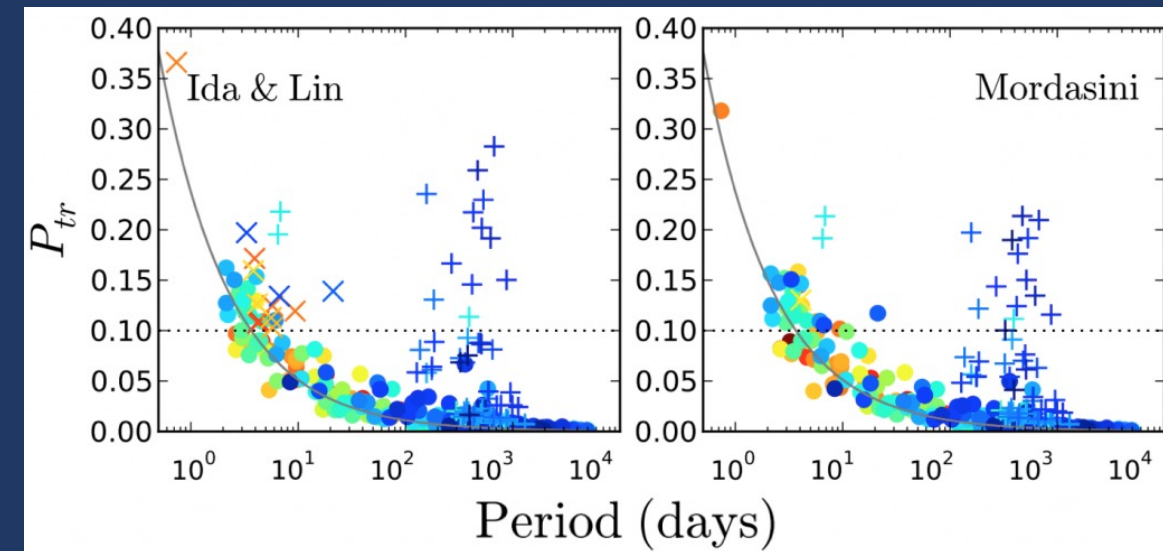
Postdoc @ Geneva with François Bouchy

RV Follow-up of long-period transiting planets

- Long period (>10, 20, 50, 100 days...)
 - Or **warm** (insolation <121, 48, 14, 6 S_{\oplus} for Sun)
(insolation <3.8, 1.5, 0.44, 0.17 S_{\oplus} for M3)

Natural challenges

- Less targets (transit probability)
-> often fainter targets
- $RV\ K \propto P^{-1/3}$

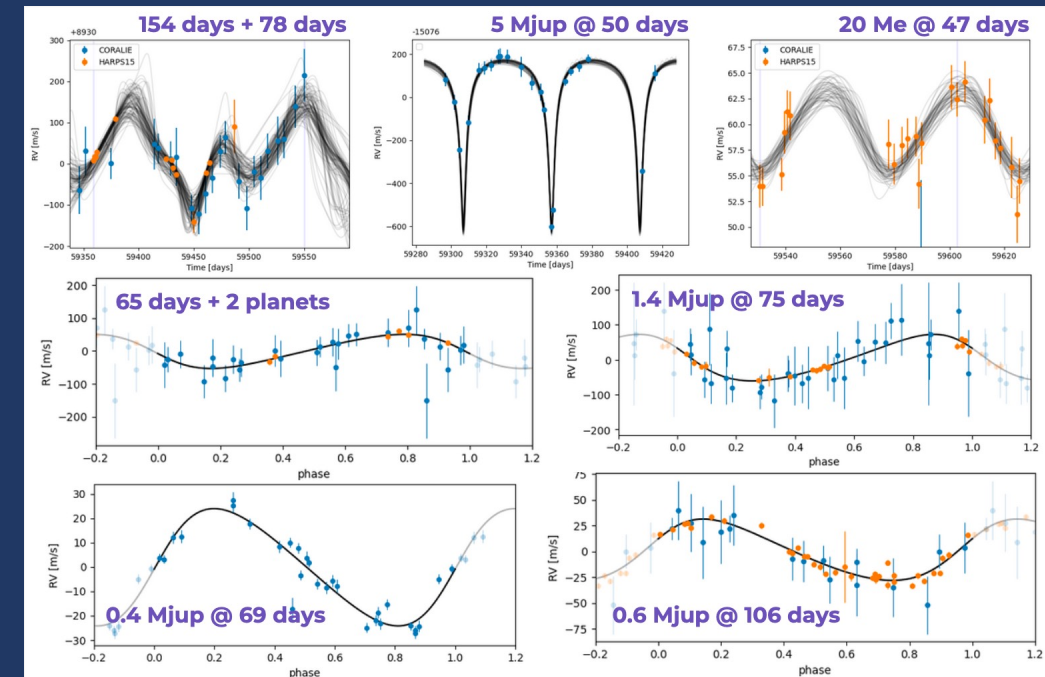


Stevens & Gaudi (2013)

RV follow-up of long-period Giant planets

Summary by Solène Ulmer-Moll
in collaboration with
François Bouchy, Monika Lendl...
+NGTS +TSTPC

- CORALIE: 1 year TESS warm giant follow-up
 - P107/P108 CORALIE time ~ 1.0 night / week
 - Period >20 d, Radius $>6 R_e$, $V_{\text{mag}} < 12.5$
- 50 candidates spectroscopically vetted
 - Detection: 9 targets (18%):
 - 7 Planets, 2 Brown dwarfs
 - Promising: 13 targets (26%):
 - Stopped: 3 targets (6%):
 - Unclear: 5 targets (10%):
 - False positive: 20 targets (40%):
- Upper limit on false positive rate: 50%



A subset of CORALIE & HARPS detected planets



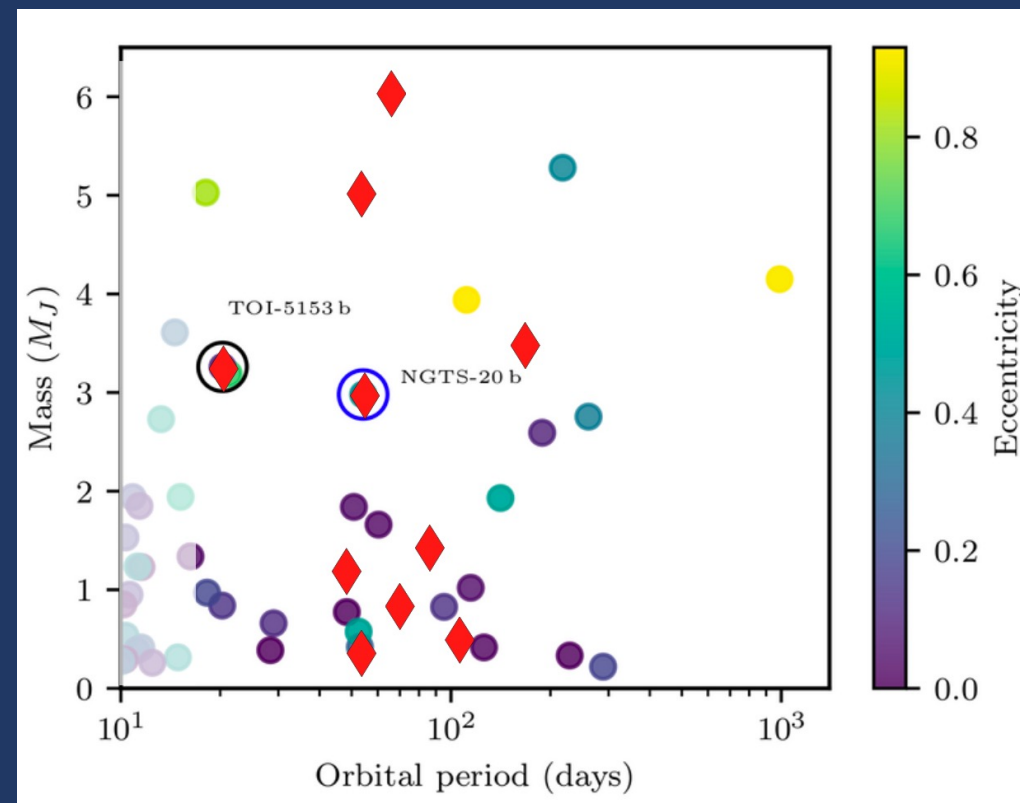
RV follow-up of long-period Giant planets

- HARPS: 1 year warm giant follow-up
 - P107: 7.2 nights (Bouchy) P108: 7.9 nights (Ulmer-Moll)
 - Period >20 d, Radius >6 Re, Vmag < 12.5
- 25 candidates observed
 - Detection: 10 targets (40%)
 - Promising: 9 targets (36%)
 - Unclear: 5 targets (20%)
 - False positive: 1 target (4%)
- Upper limit on false positive rate: 24% but only 13% of observing time

Summary by Solène Ulmer-Moll

in collaboration with

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New discoveries in red

Lessons from RV FU of long-period Giant transiting planet candidates

- Much easier with 2 compared to 1 transit
 - Aliases easier to constrain (phase fold to match RVs)
- Multiple dedicated facilities allows chasing aliases and orbits
 - e.g., CORALIE+NGTS
- Several targets unclear even with nice transit
 - difficult to decide when to stop
 - Stellar activity likely not the problem
- Multi-planet systems not found often

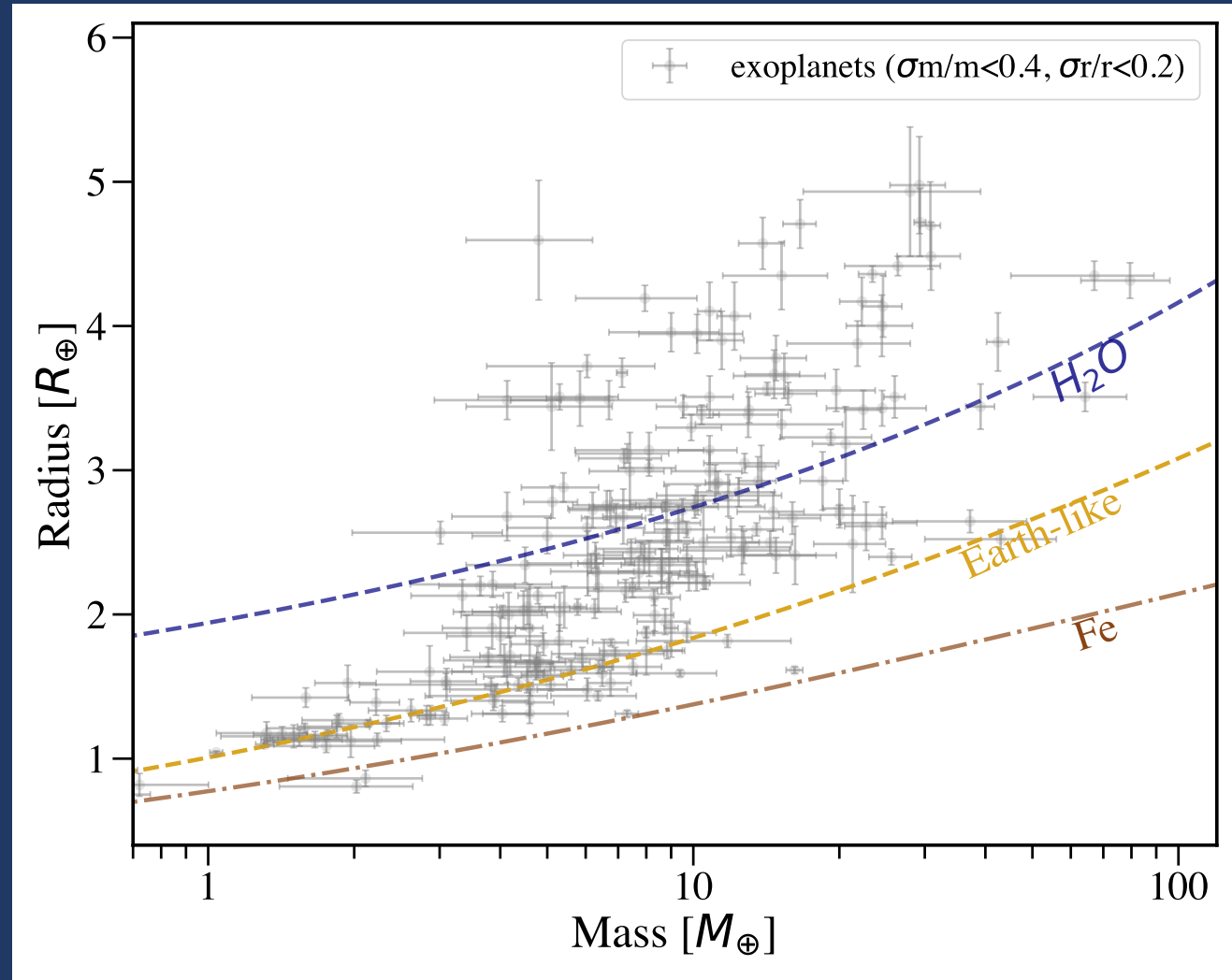


RV follow-up of long-period small-size planets

We want density

→ Mass precision <0.4 , Radius precision <0.2

224 planets in exoarchive with $R_p < 5 R_\oplus$

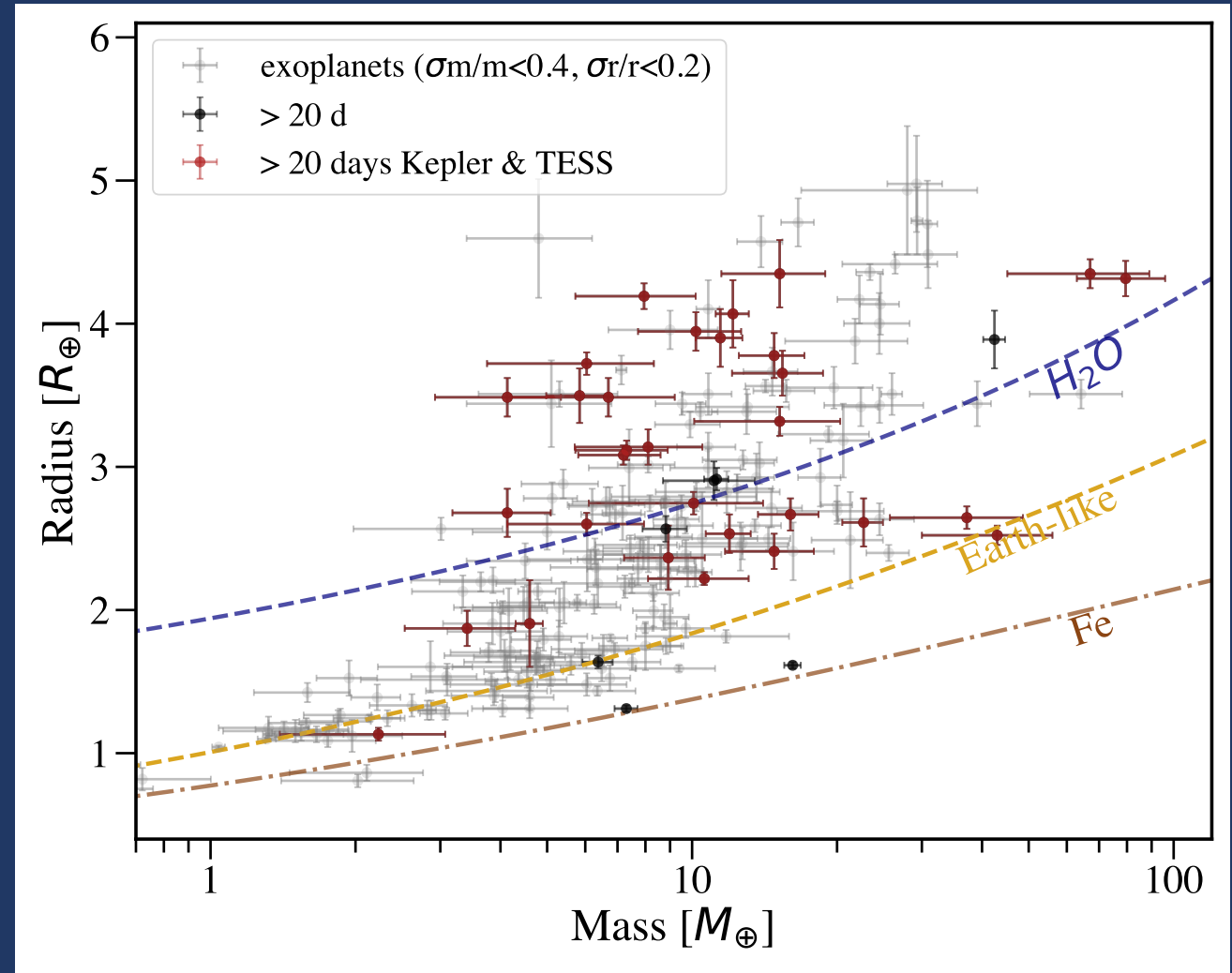


RV follow-up of long-period small-size planets

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224 planets in exoarchive with $R_p < 5 R_\oplus$
38 planets $p > 20$ d (31 Kepler+TESS)



RV follow-up of long-period small-size planets

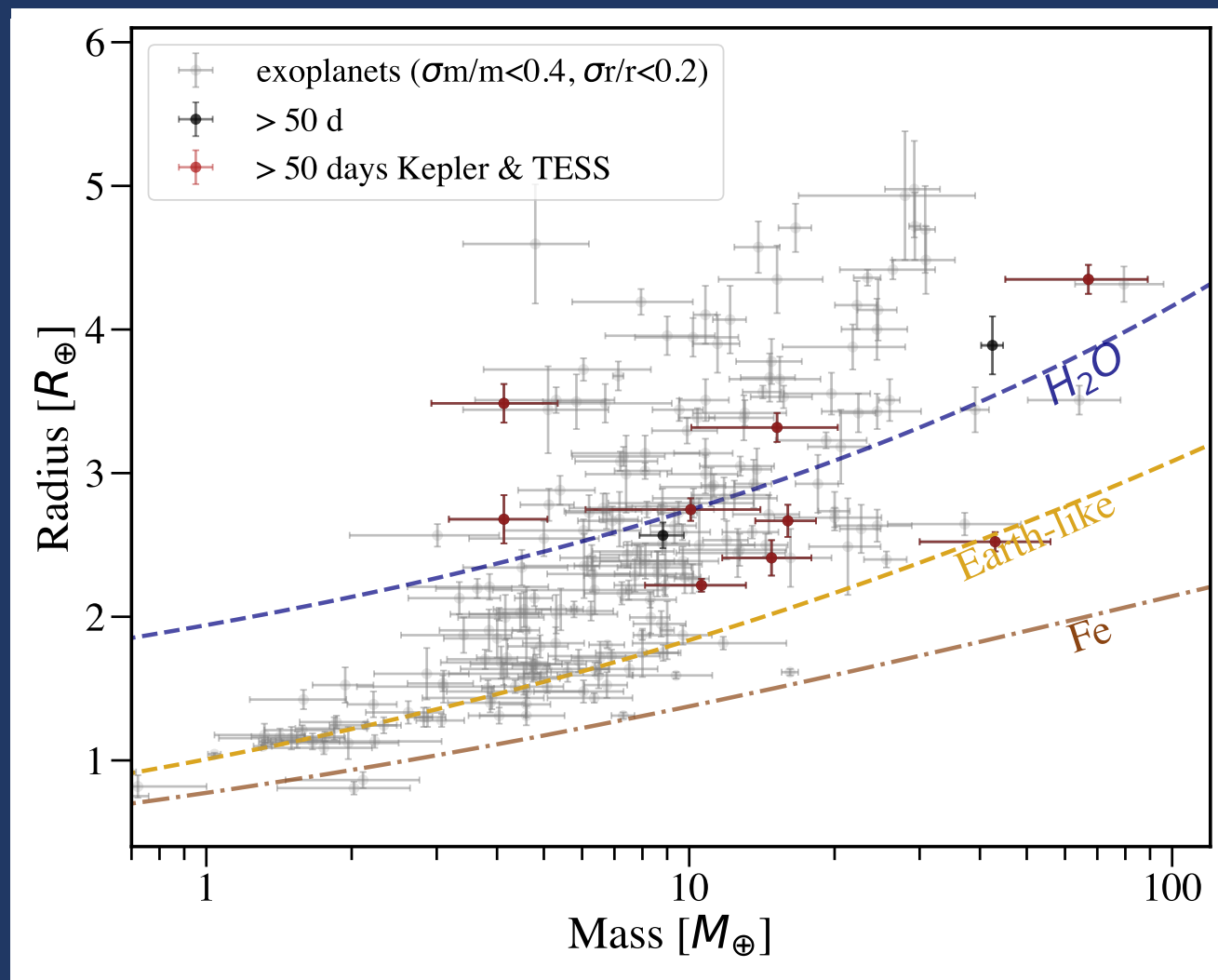
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38 planets $p > 20$ d (31 Kepler+TESS)

11 planets $p > 50$ d (9 Kepler+TESS)



RV follow-up of long-period small-size planets

11 planets with mass precision <0.4 , Radius precision <0.2 and $P > 50$ days

7/11 multi-planet systems

7/11 masses from RVs

Effort

HD136352d: Mp=8.8 Rp=2.57 Period=107.2 Teff=5664.0	La Silla Obs	649 HARPS over 11 years, Rp CHEOPS+2022
HD95338b: Mp=42.5 Rp=3.89 Period=55.1 Teff=5212.0	Las Campanas Obs	83 PFS (discover) 11 HARPS, Rp TESS+2020 (single)
K2-263b: Mp=14.8 Rp=2.41 Period=50.8 Teff=5368.0	K2	63 HARPS-N RVs (single)
Kepler-129c: Mp=43.0 Rp=2.52 Period=82.2 Teff=5770.0	Kepler	6 years of Keck/HIRES RVs
Kepler-20d: Mp=10.1 Rp=2.75 Period=77.6 Teff=5495.0	Kepler	104 HARPS-N, 30 Keck/HIRES (5 planets)
Kepler-289d: Mp=4.1 Rp=2.68 Period=66.1 Teff=5990.0	Kepler	Kepler TTVs
Kepler-411d: Mp=15.2 Rp=3.32 Period=58.0 Teff=nan	Kepler	Kepler TTVs
Kepler-413b: Mp=67.1 Rp=4.35 Period=66.3 Teff=4700.0	Kepler	CBP, mass - eclipse time variations (single+KOI)
Kepler-538b: Mp=10.6 Rp=2.22 Period=81.7 Teff=5547.0	Kepler	23 HIRES 86 HARPS-N +GP (single+KOI)
Kepler-79e: Mp=4.1 Rp=3.49 Period=81.1 Teff=6174.0	Kepler	Kepler TTVs
TOI-561e: Mp=16.0 Rp=2.67 Period=77.2 Teff=5455.0	TESS	82 HARPS-N (4 planets, low activity no GP)



RV follow-up of long-period small-size planets

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224 planets in exoarchive with $R_p < 5 R_\oplus$

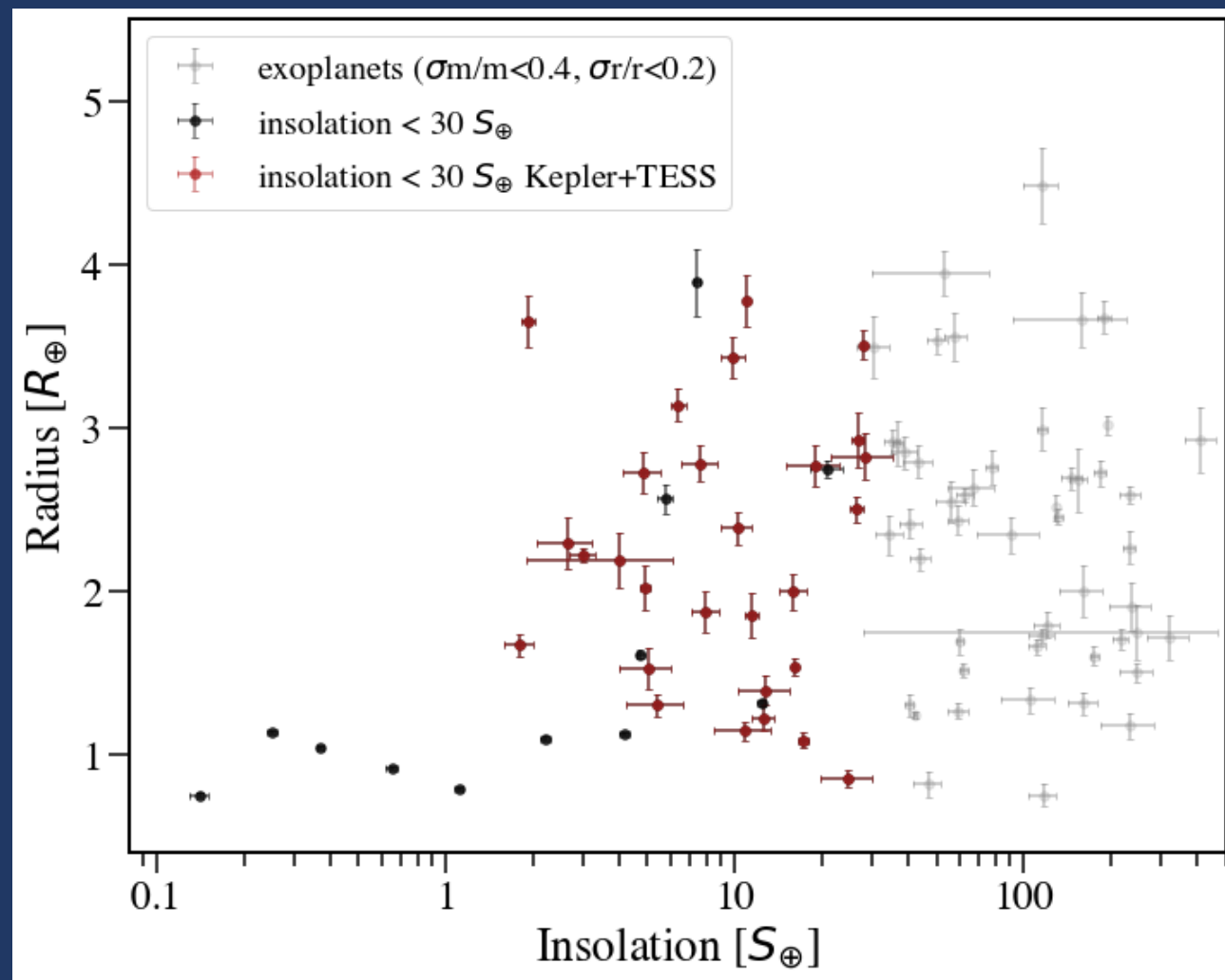
38 planets $p > 20$ d (31 Kepler+TESS)

11 planets $p > 50$ d (9 Kepler+TESS)

100 planets with $R_p < 5 R_\oplus$ and insolation

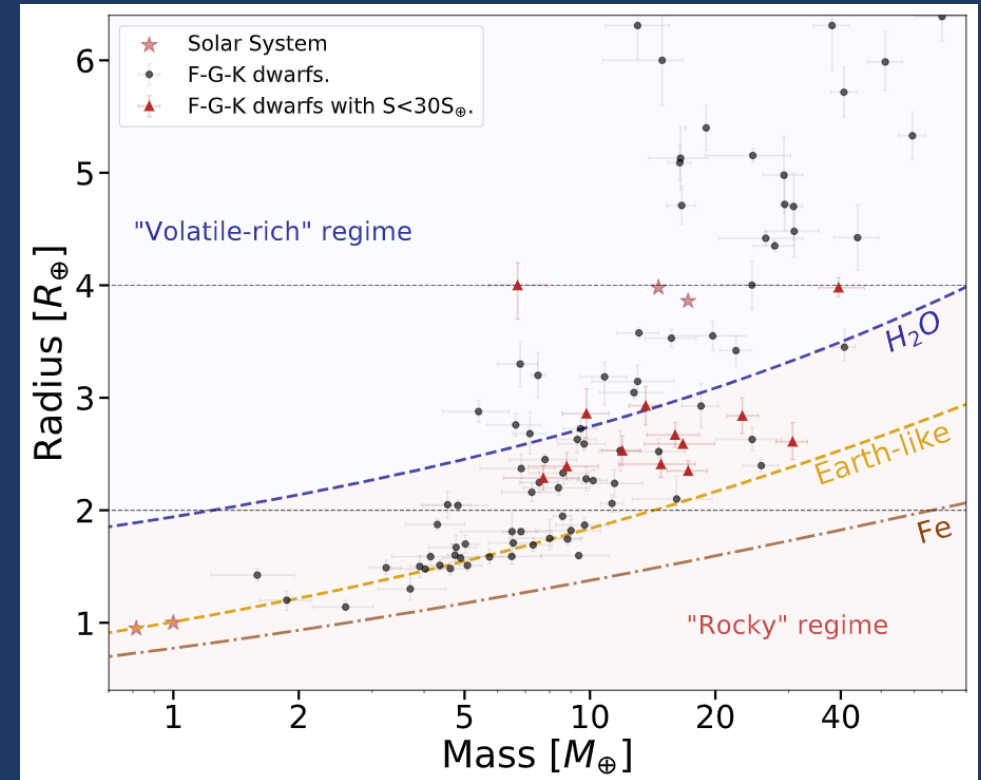
51 planets $S < 50 S_\oplus$ (36 Kepler+TESS)

40 planets $S < 30 S_\oplus$ (28 Kepler+TESS)



RV FU of TESS warm sub-Neptunes with ESPRESSO

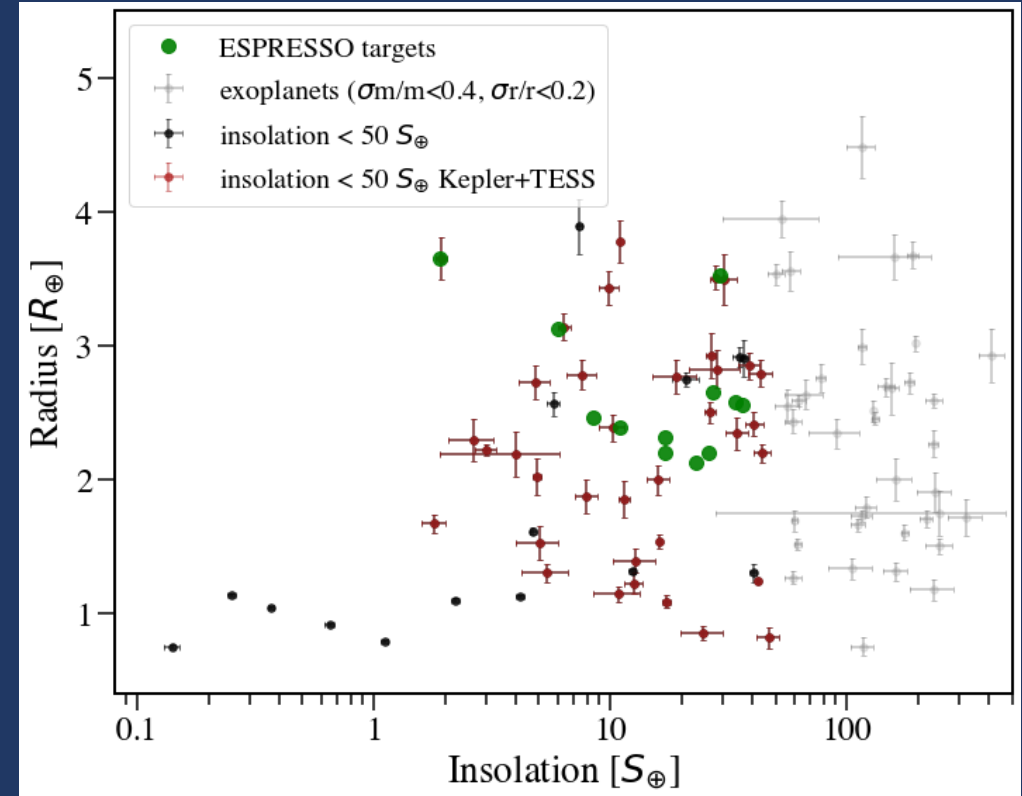
- P107 (PI Bouchy): 166 RVs / 68 hrs allocated
P109 (PI Bouchy): 173 RVs / 69 hrs allocated
- 12 Targets
- 2-4 R_{\oplus} , $P > 20$ days or $S < 30/50 S_{\oplus}$
- Similar motivation as warm Giants
+2-4 R_{\oplus} mainly rocky or have low-density envelopes?
+how envelope affected by stellar irradiation?



FGK Exoplanets with density

RV FU of TESS warm sub-Neptunes with ESPRESSO

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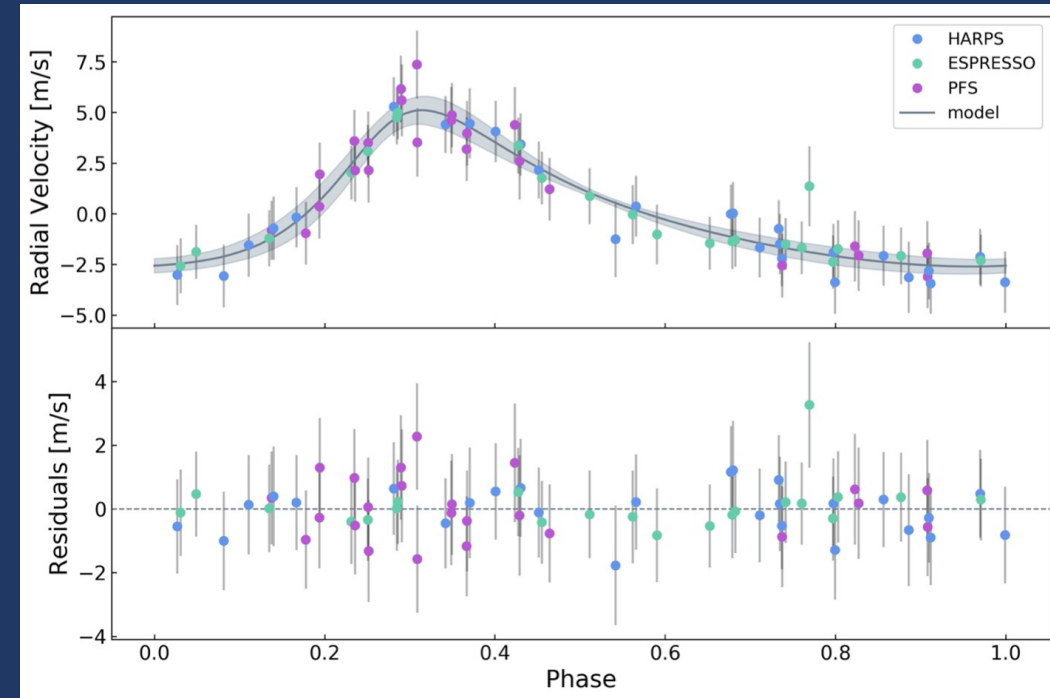


Exoplanets with density and ESPRESSO targets

Clear detections with with additional facilities

TOI-757

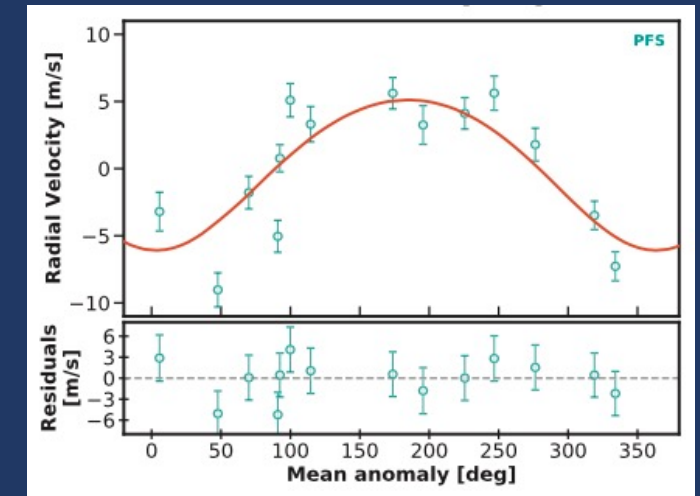
- $2.12 R_{\oplus}$, 17.5 days, $23 S_{\oplus}$
- 22 ESPRESSO, 27 HARPS, 24 PFS
- Alham Al Qasim in prep.
- 0.16 mass precision: $13.7 \pm 2.2 M_{\oplus}$



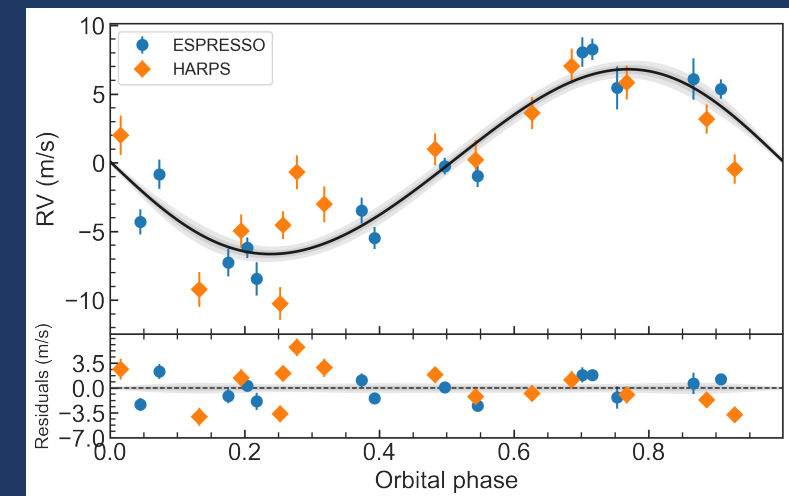
Clear detections with with additional facilities

TOI-1231

- $3.65 R_{\oplus}$, 24.2 days, $1.9 S_{\oplus}$
- 14 PFS (Burt et al. 2021), 14 ESPRESSO
- 0.21 \rightarrow 0.05 mass precision
 $15.4 \pm 3.3 M_{\oplus}$ (Burt et al. 2021)
 $18.73 \pm 0.97 M_{\oplus}$ +ESPRESSO



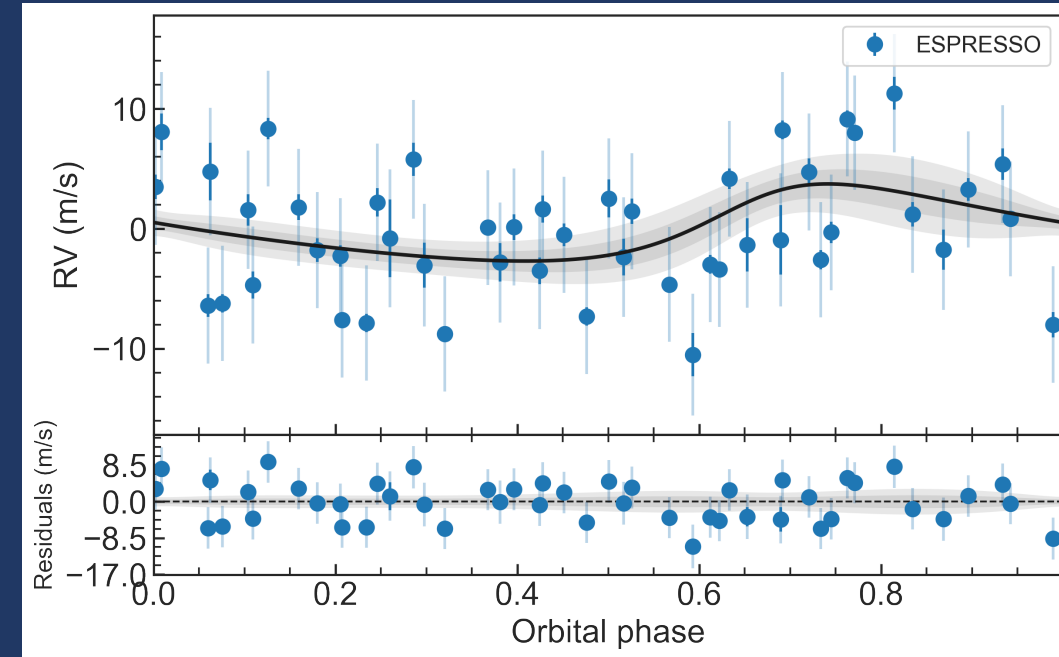
Burt et al. (2021)



ESPRESSO only mass detection

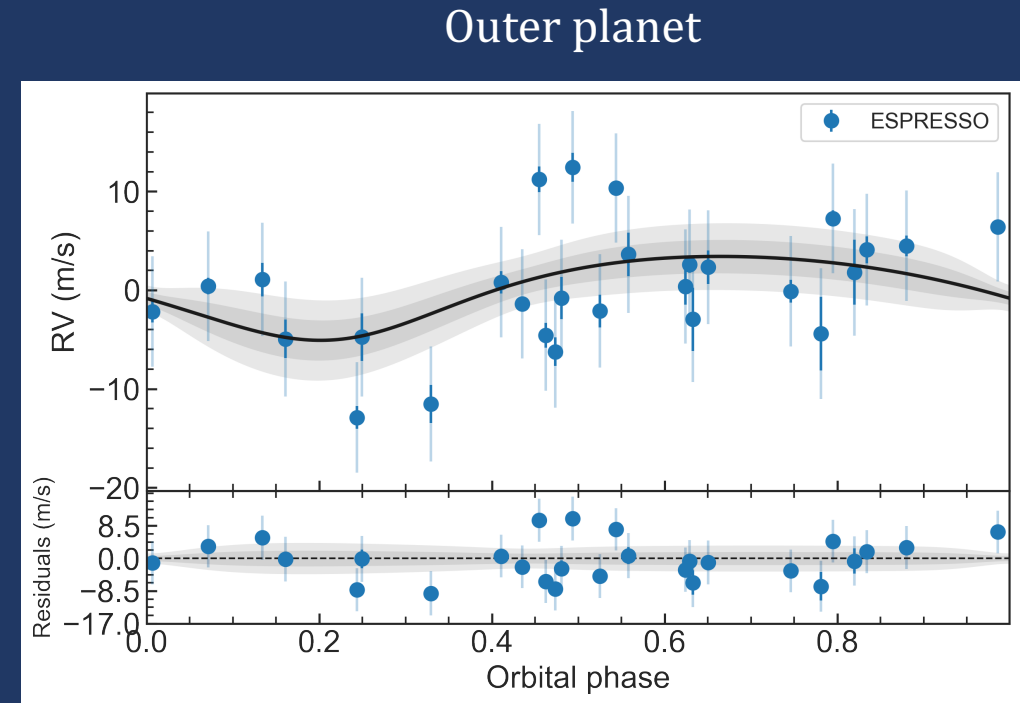
TOI-133

- $2.20 R_{\oplus}$, 8.19 days, $26 S_{\oplus}$
- 48 ESPRESSO
- 0.39 mass precision: $7.3 \pm 2.8 M_{\oplus}$
- May benefit from activity model



Multi-planets found

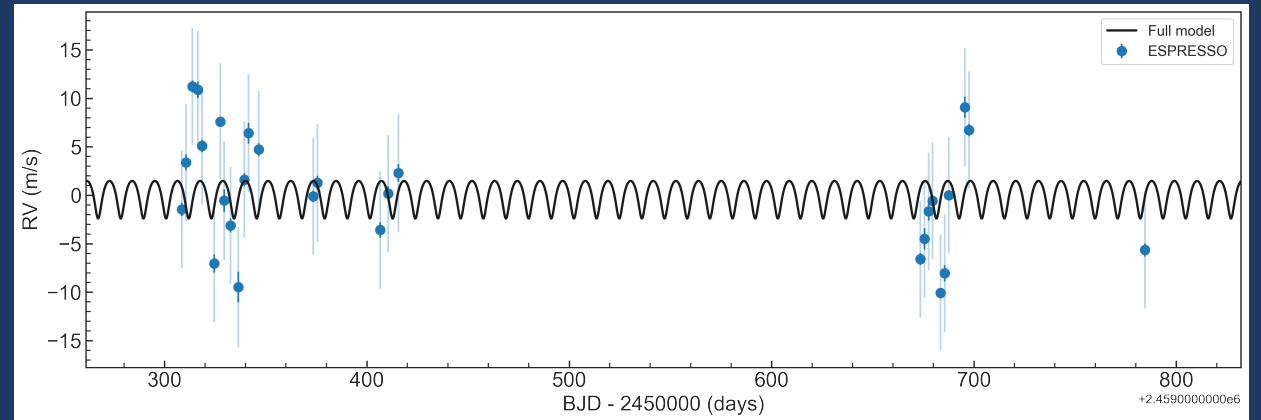
- **TOI-213**
 - $2.46 R_{\oplus}$, 23.5 days, $8.5 S_{\oplus}$
 - *inner planet: $1.22 R_{\oplus}$, 7.8 days, $37 S_{\oplus}$
- 28 ESPRESSO
- 0.44 mass precision: $14.7 \pm 6.6 M_{\oplus}$
+unconstrained inner planet
- Signals in activity indicators



Weak/null RV signals

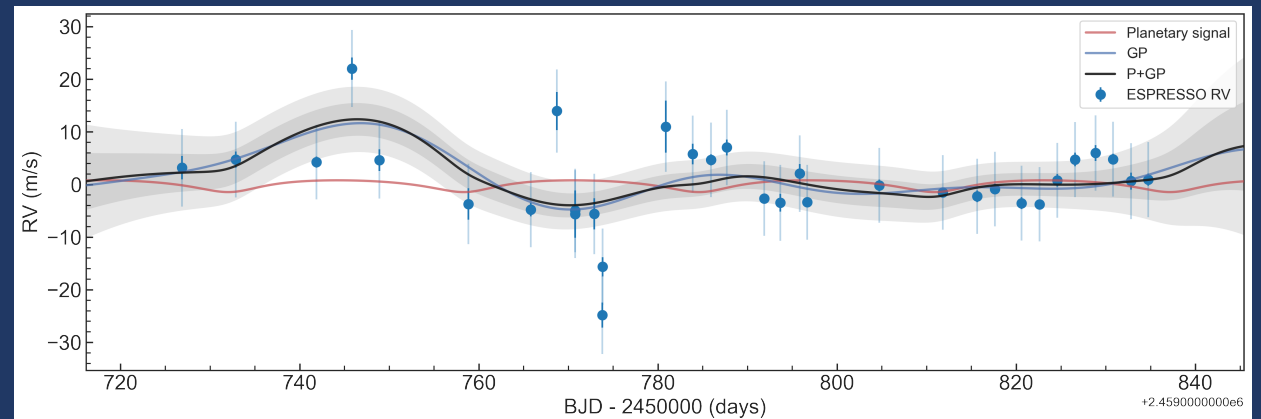
TOI-815

- $2.58 R_{\oplus}$, 11.2 days, $34 S_{\oplus}$
- 28 ESPRESSO
- upper limit $\sim 10.7 M_{\oplus}$



TOI-215

- $3.52 R_{\oplus}$, 26.3 days, $29 S_{\oplus}$
- 35 ESPRESSO
- upper limit $\sim 11.2 M_{\oplus}$



Need more RVs

TOI-461

- $2.31 R_{\oplus}$, 14.5 days, $17 S_{\oplus}$
- 6 ESPRESSO, 19 HARPS: $\sim 12 M_{\oplus}$

TOI-4320

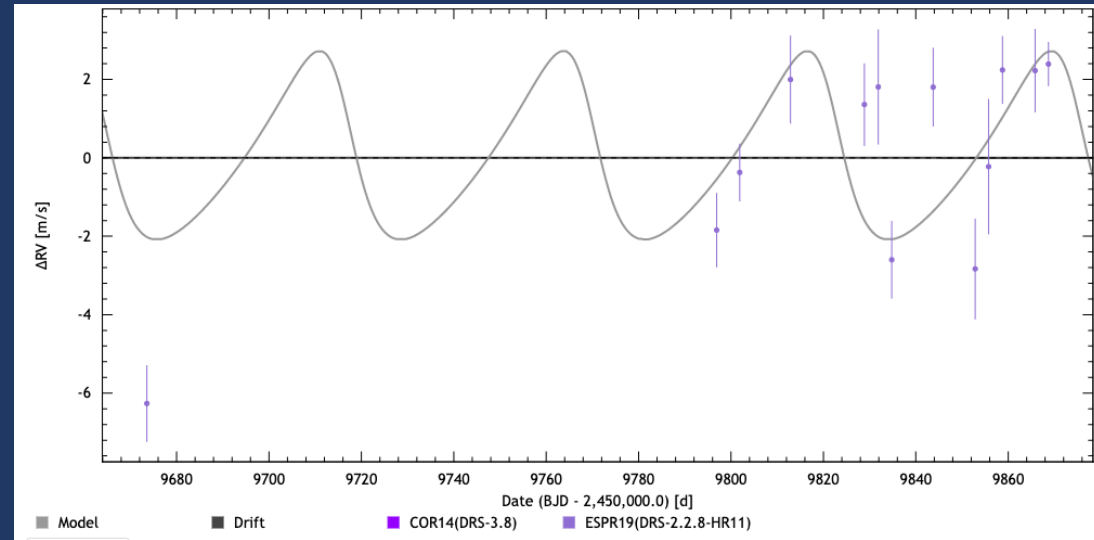
- $2.2 R_{\oplus}$, 25.1 days, $17 S_{\oplus}$
- 12 ESPRESSO $\sim 10 M_{\oplus}$

TOI-707

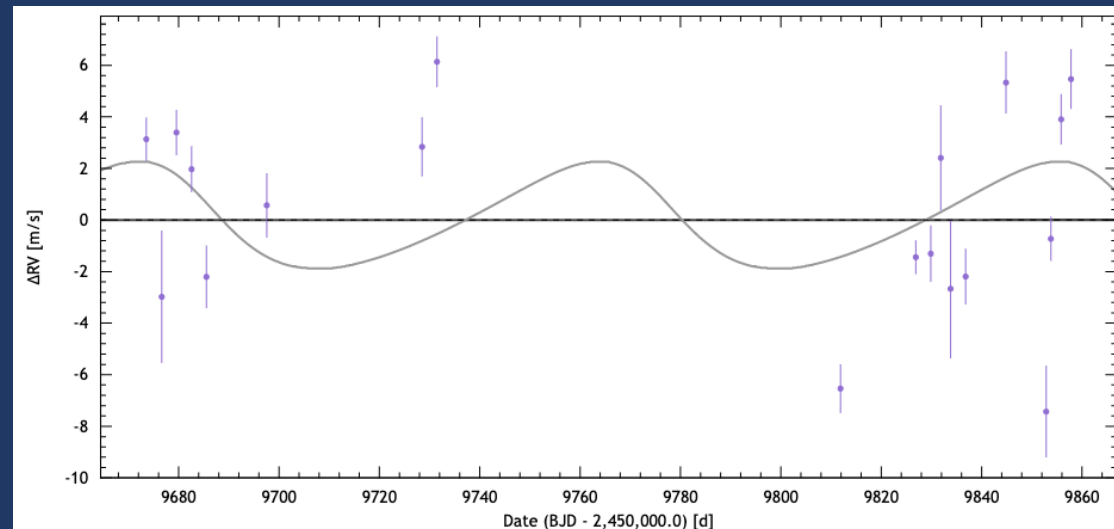
- $2.39 R_{\oplus}$, 52.8 days, $11 S_{\oplus}$
- 12 ESPRESSO $\sim 13 M_{\oplus}$

TOI-1221

- $3.12 R_{\oplus}$, 91.7 days, $6 S_{\oplus}$
- 19 ESPRESSO $\sim 14 M_{\oplus}$



TOI-707



TOI-1221

