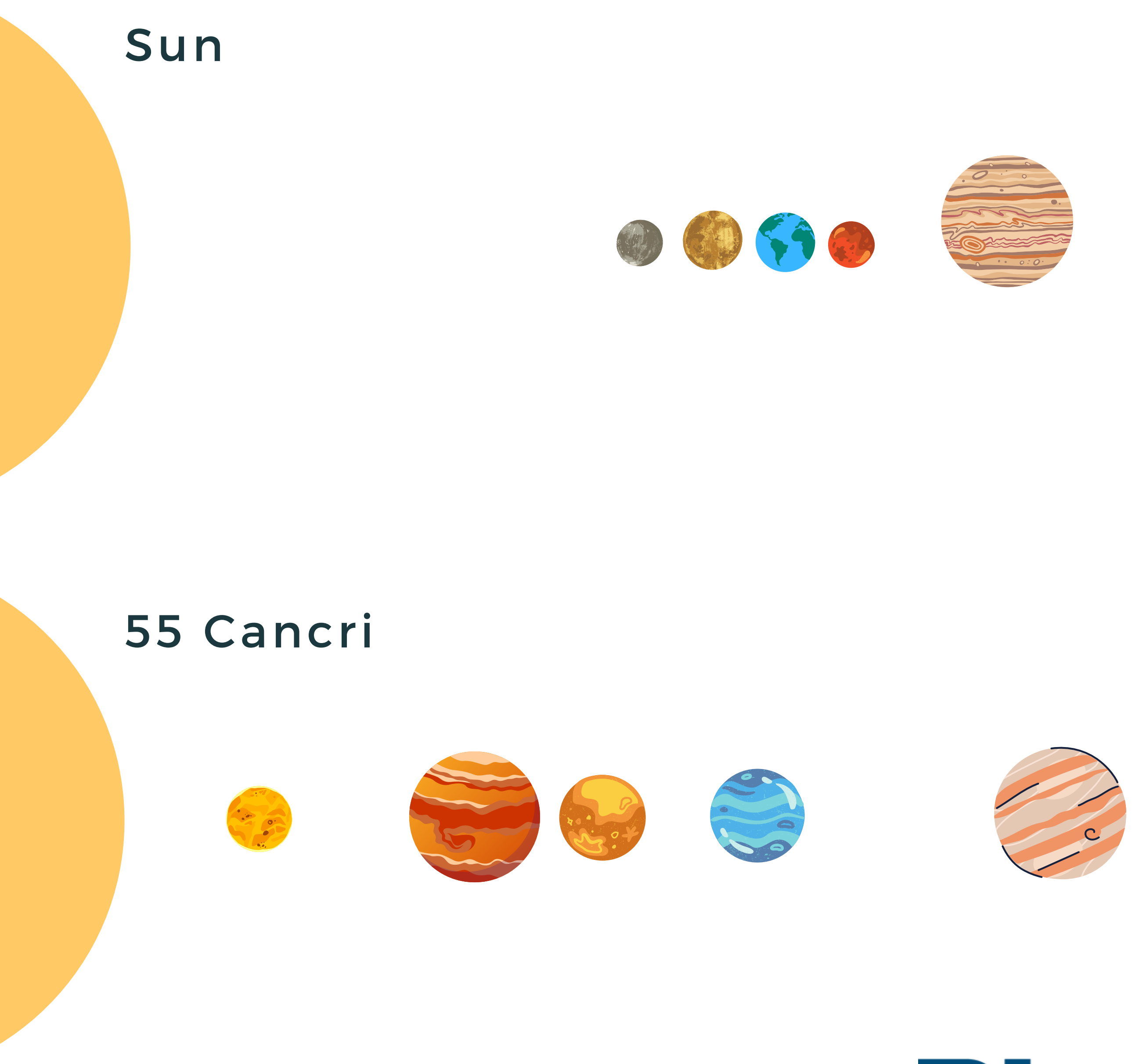
Temperate giant planets: golden targets for linking detection and modeling

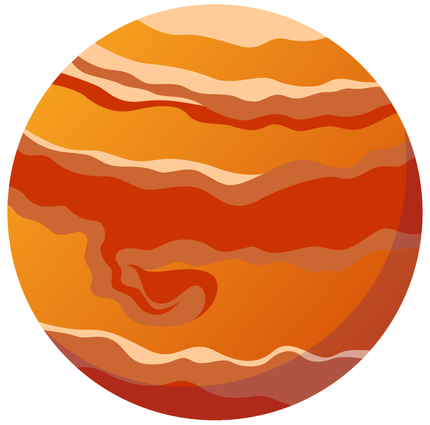


Solène Ulmer-Moll

Collaborators:
Monika Lendl, Christoph Mordasini
Hugh Osborn, Sam Gill, CHEOPS & NGTS teams

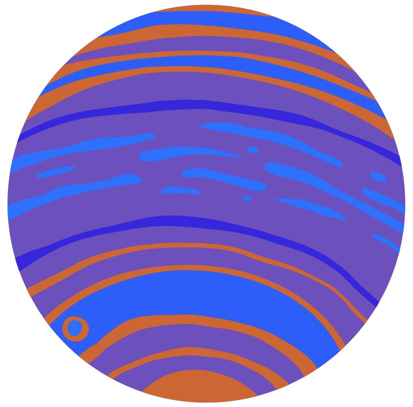
PlanetS National Centre of Competence in Research
Swiss National Science Foundation
UNIVERSITÄT BERN
UNIVERSITÉ DE GENÈVE

Temperate Jupiters are a link between HJs and the Solar System giants



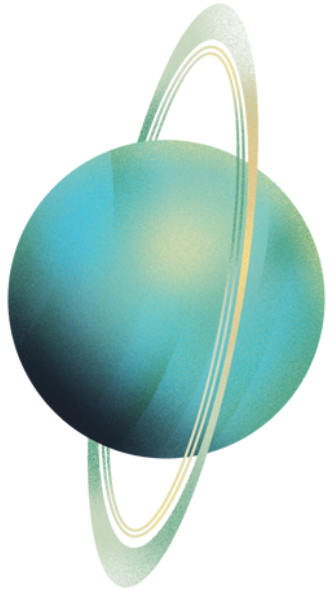
Hot Jupiters (HJs)

Highly irradiated and strong tidal interactions
Equilibrium temperature: 1000 - 3000 K
Orbital period < 10 days
Overall low eccentricity distribution



Warm and temperate Jupiters

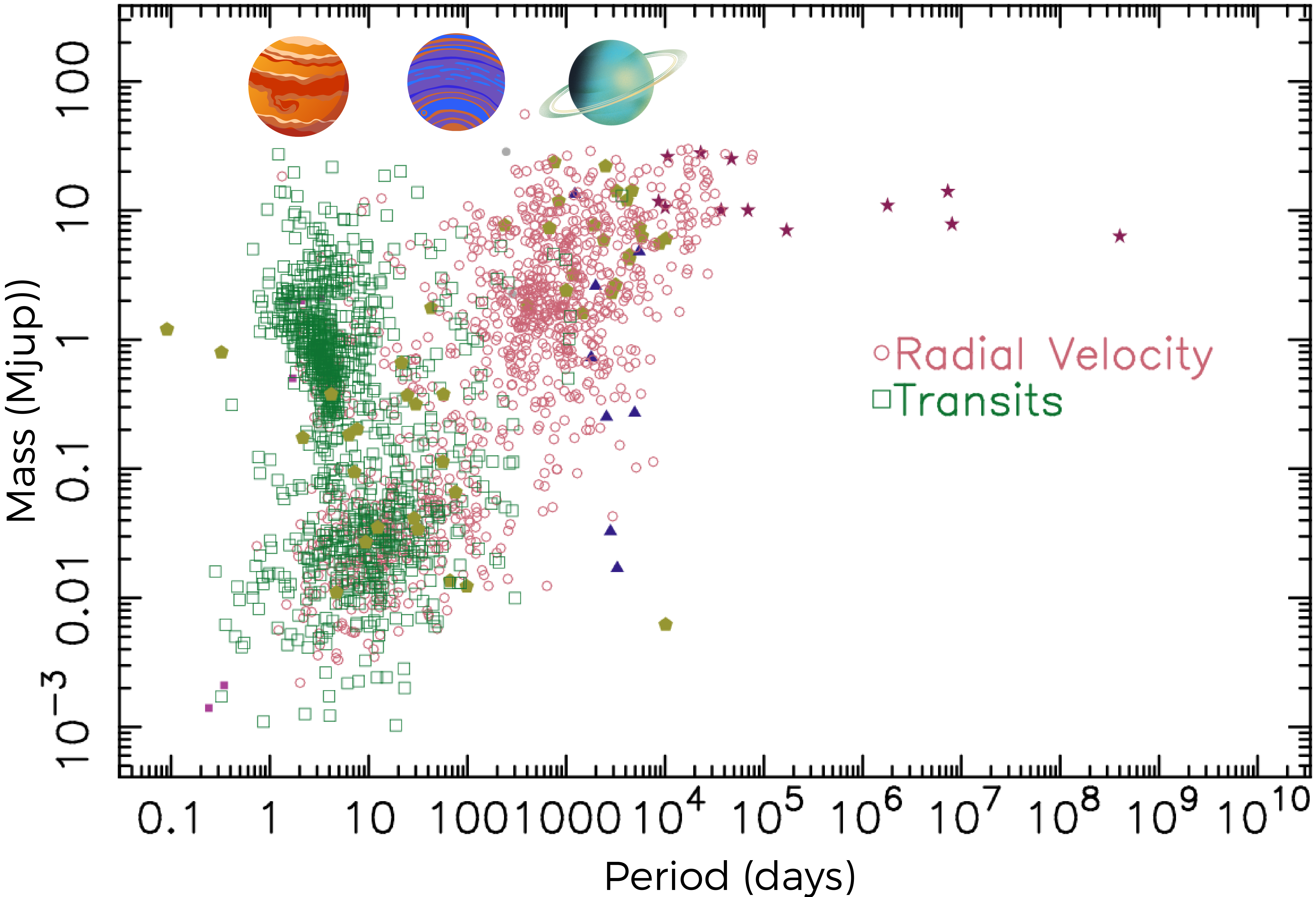
Less irradiated, atmospheres are usually not inflated
Equilibrium temperature: ~300 - 900 K
Orbital period: 10/20 - ~ 300 days
Wide range of eccentricity distribution



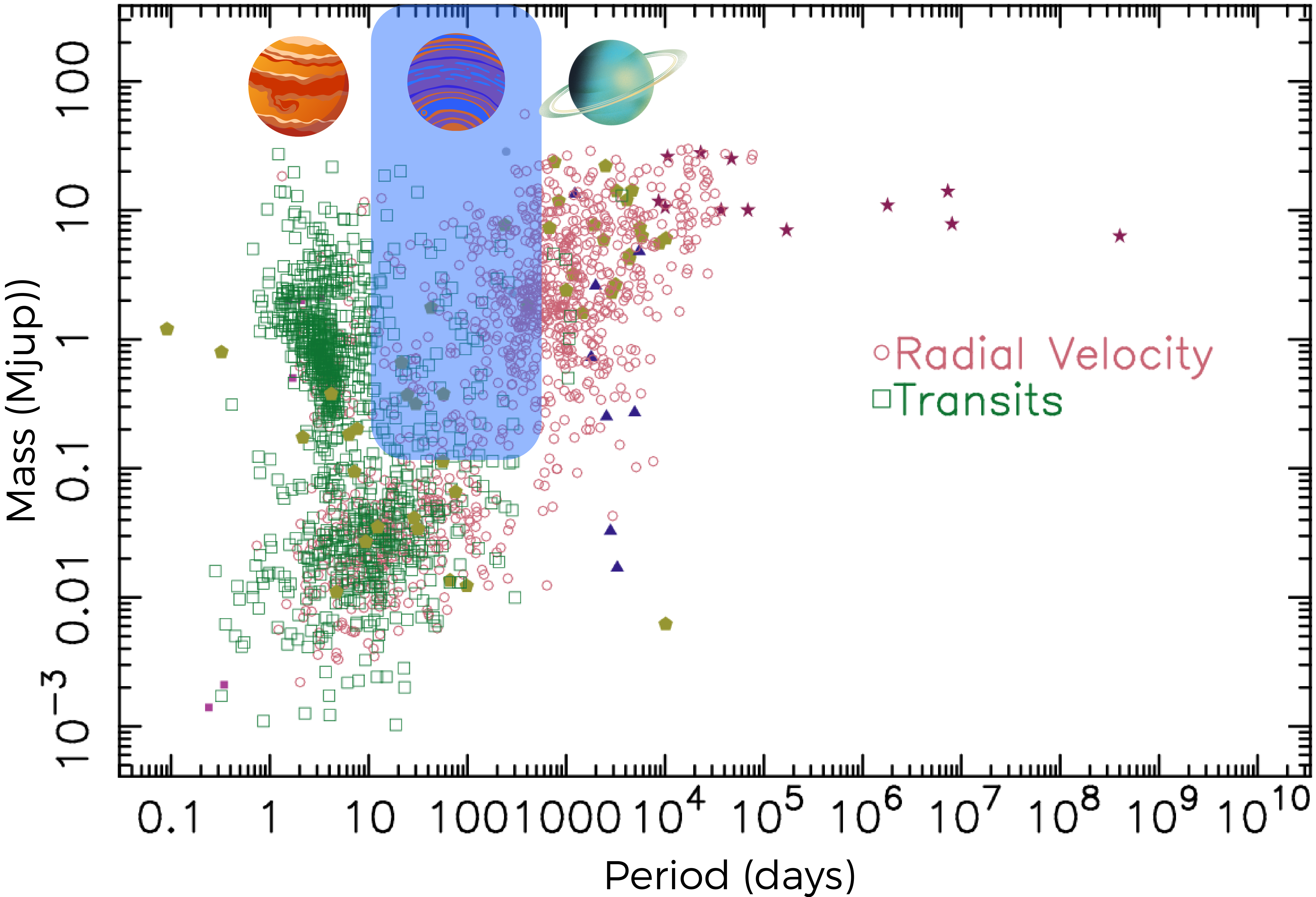
Solar System giants

Equilibrium temperature 70 - 160K
Orbital period > 4000 days
Low eccentricities
Known to host moons and rings

Joining RV and transits to detect temperate Jupiters

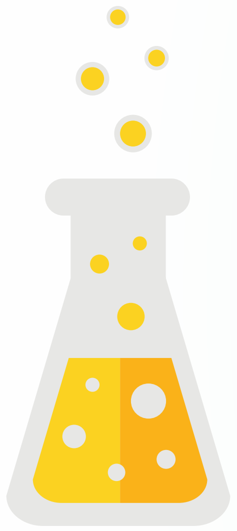


Joining RV and transits to detect temperate Jupiters



Characterize new temperate planets with photometry and spectroscopy

What are the orbital periods, masses, and radii of these warm planets?



Measure the interior composition of temperate planets.

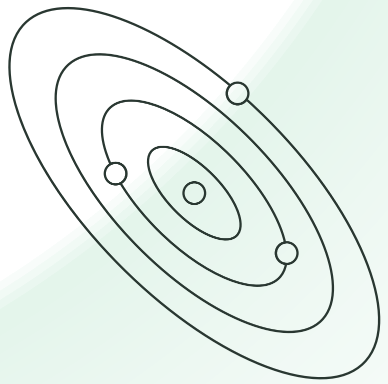
What is their fraction of heavy elements?

Determine the atmospheric composition of gas giants.

What is their atmospheric metallicities?

Study the dynamics of eccentric temperate Jupiters.

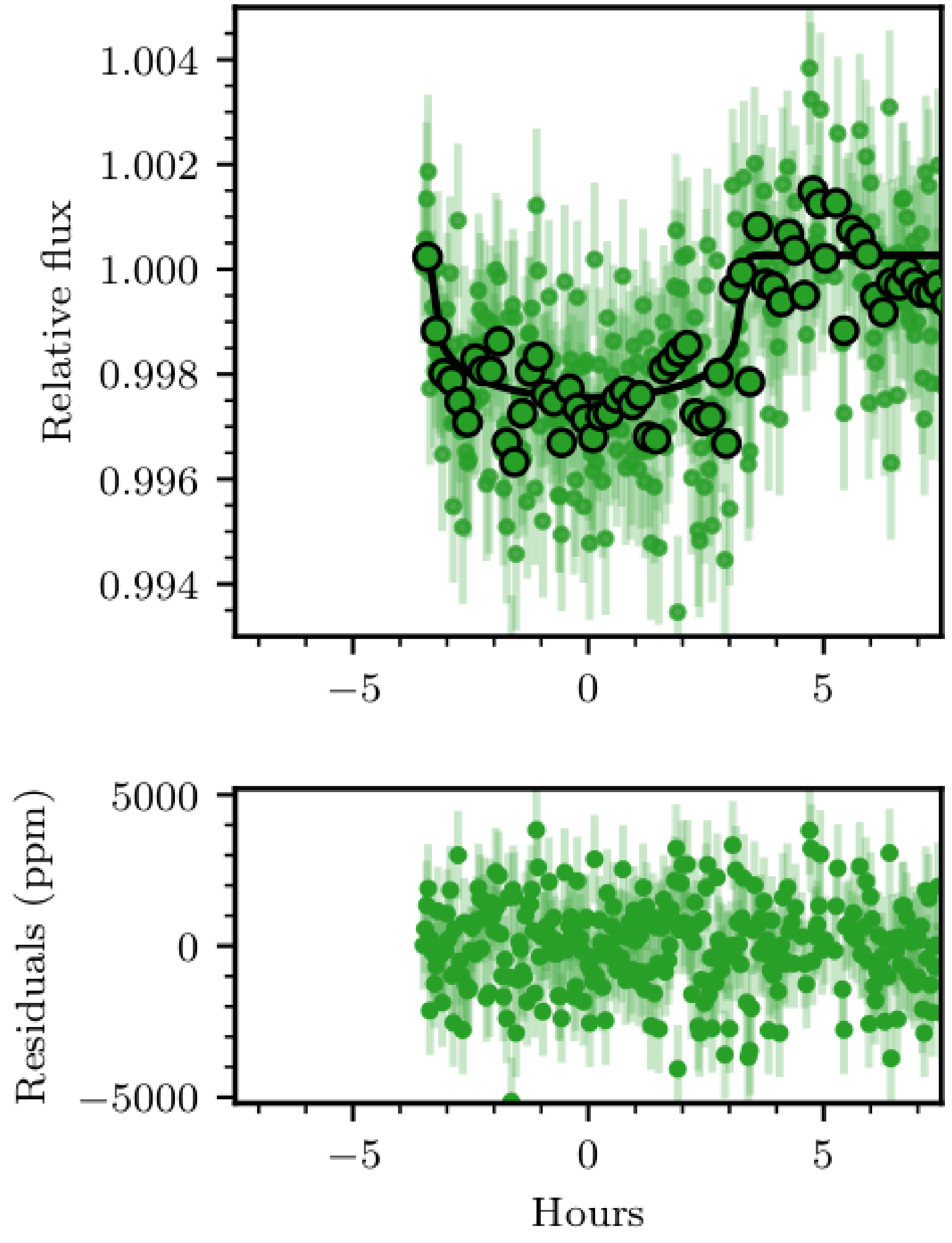
Are they misaligned with their host star?



Identifying planet candidates

Oct 2018

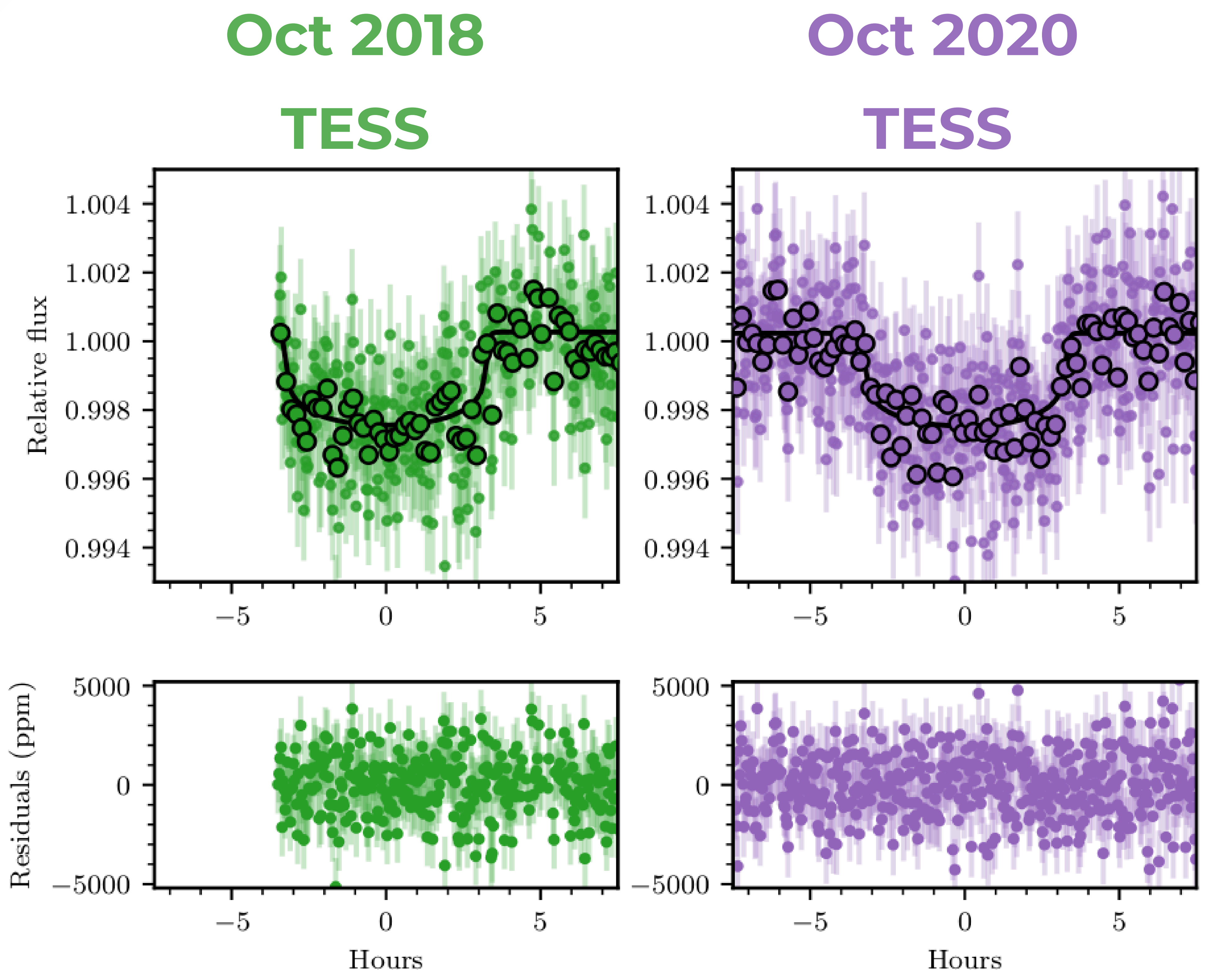
TESS



TESS observes a patch of the sky for 27 days in a row

Planets with an orbital period longer than this will appear as a single transit

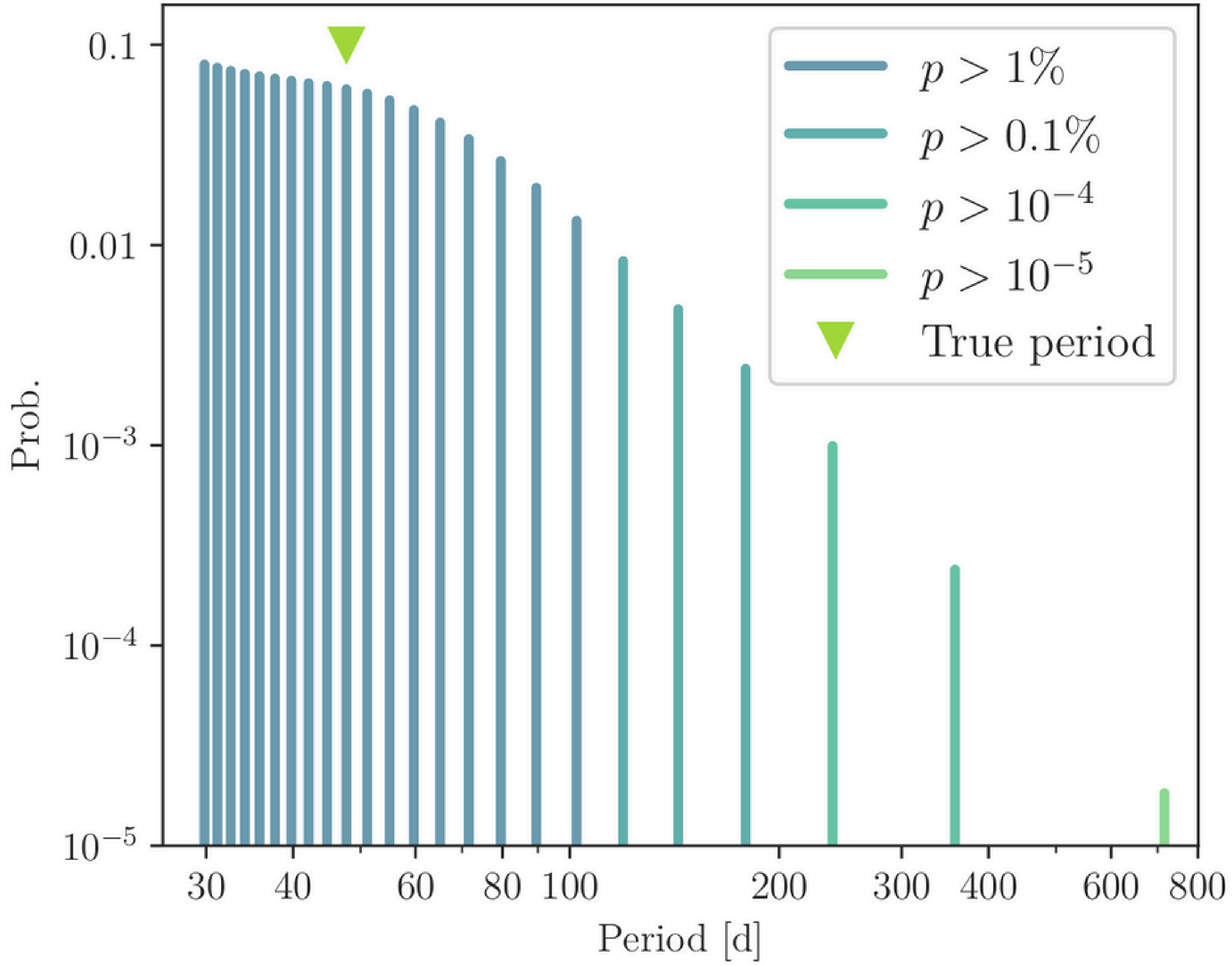
Identifying planet candidates



Two years later, TESS observes a second transit of the same planet

We now have a set of possible period aliases

Planning the follow-up of period aliases

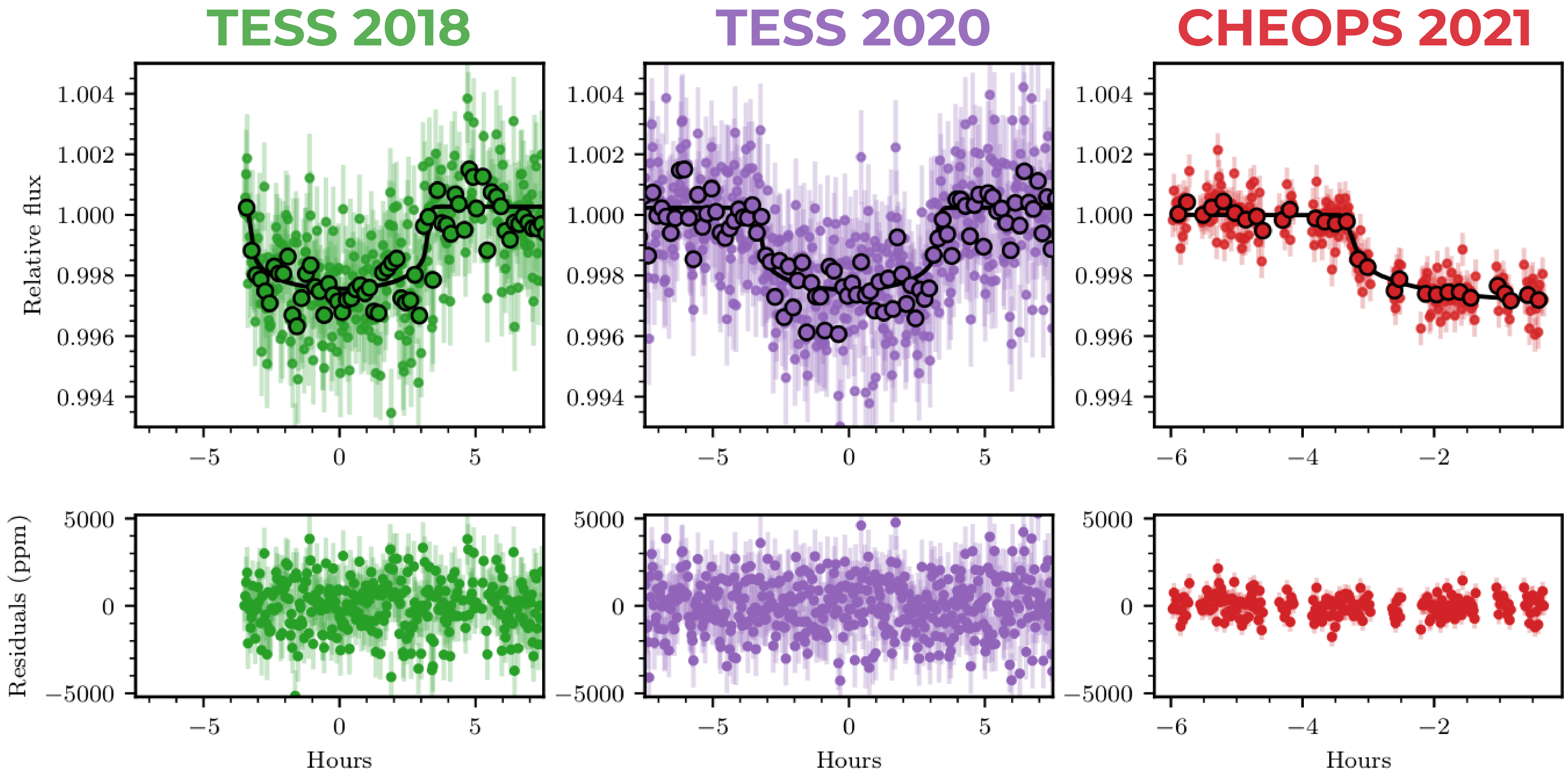


We have more than 20 possible periods. We attribute a probability to each period alias to prioritize the follow up.

We target the best period aliases with CHEOPS.

MonoTools (Osborn+2022)

Recovering warm planets with CHEOPS

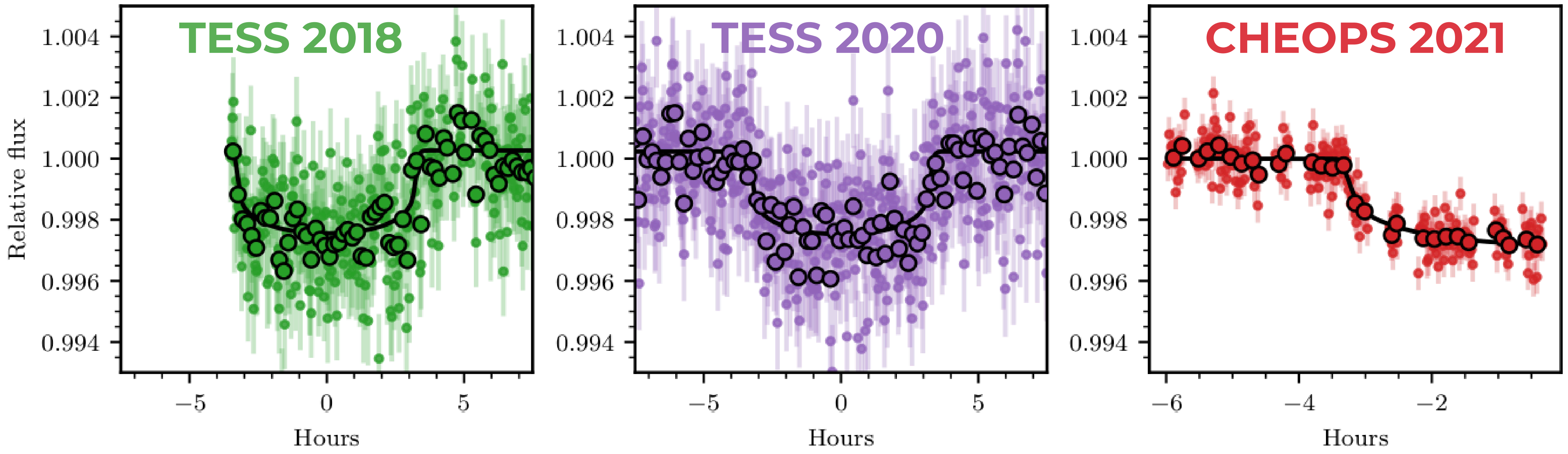


We solved the period after only 5 observations
and detected a 48-day Neptune mass planet

Ulmer-Moll+ (2023)

Recovering warm planets with CHEOPS

CHEOPS Duos GTO program: follow shallow duo-transit candidates



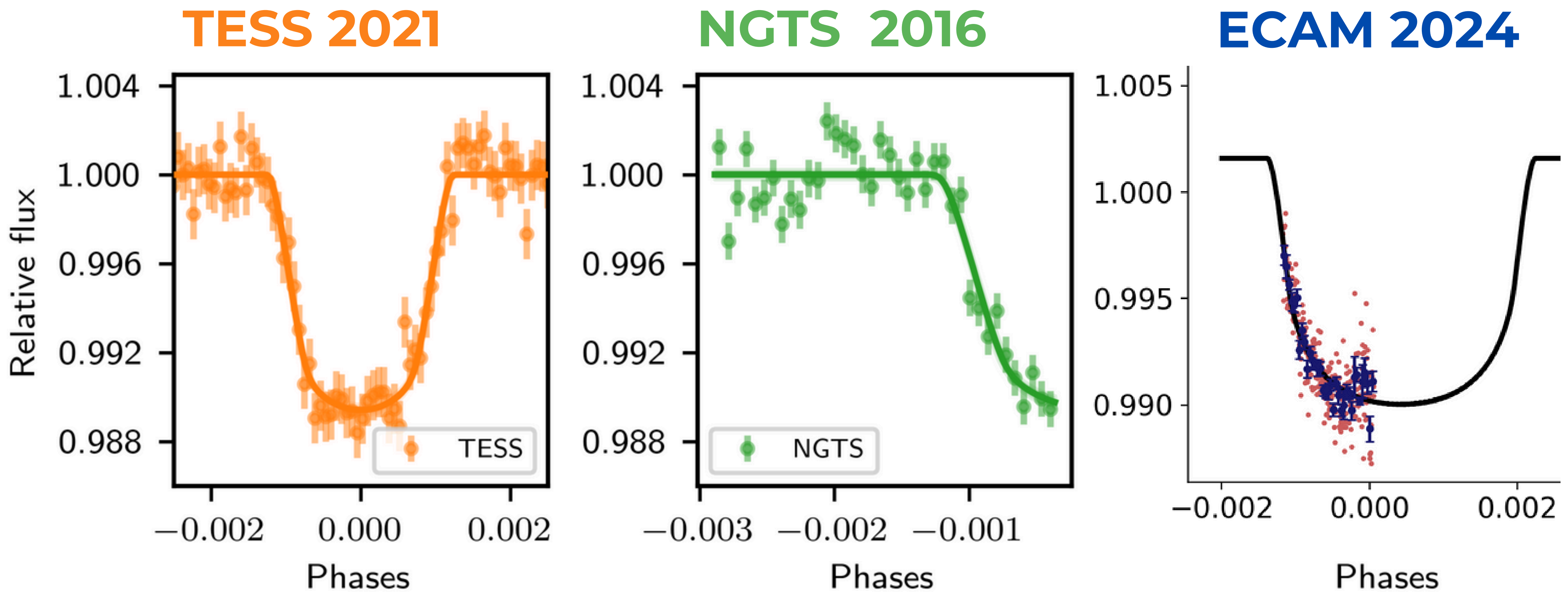
TOI-5678 - Ulmer-Moll + (2023)

& ground-based facilities

Photometric precision to detect 0.1% in transit depth
250 nights / year dedicated to mono and duo transit follow-up

NGTS
NEXT-GENERATION TRANSIT SURVEY

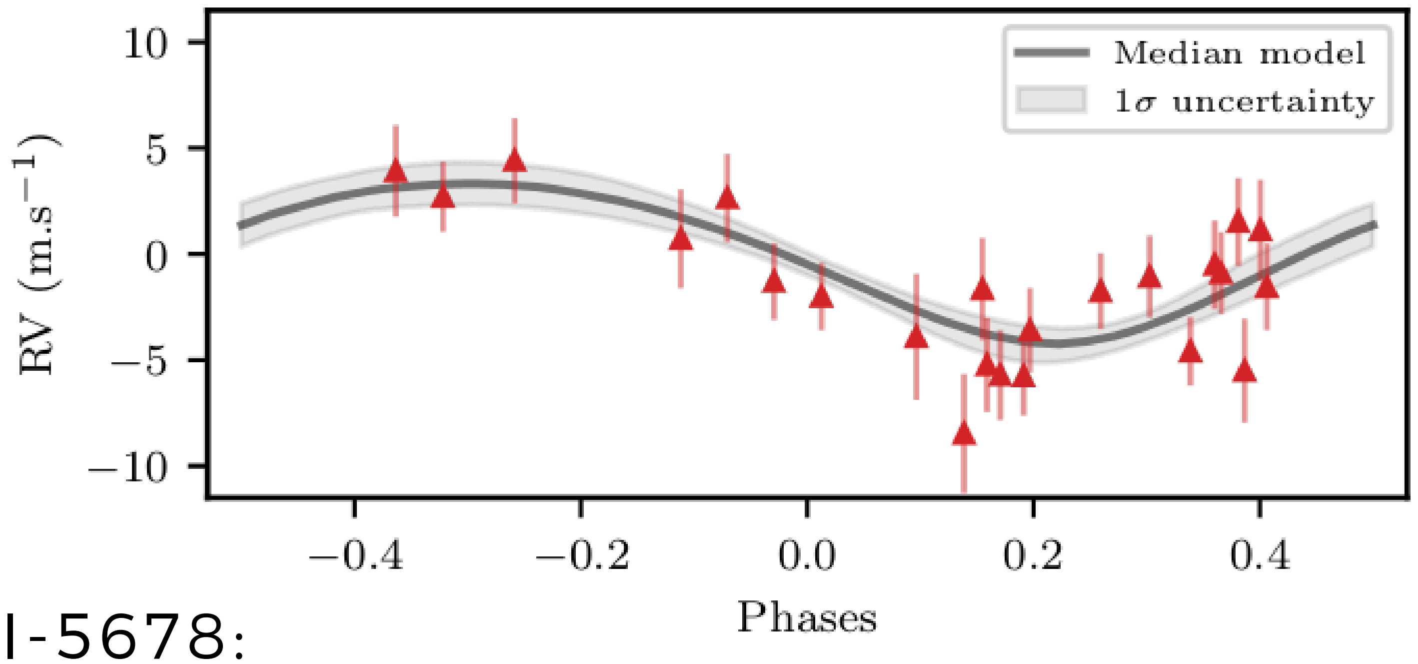
- EulerCam



TOI-4862 - Battley, Collins, Ulmer-Moll + in press (2024)

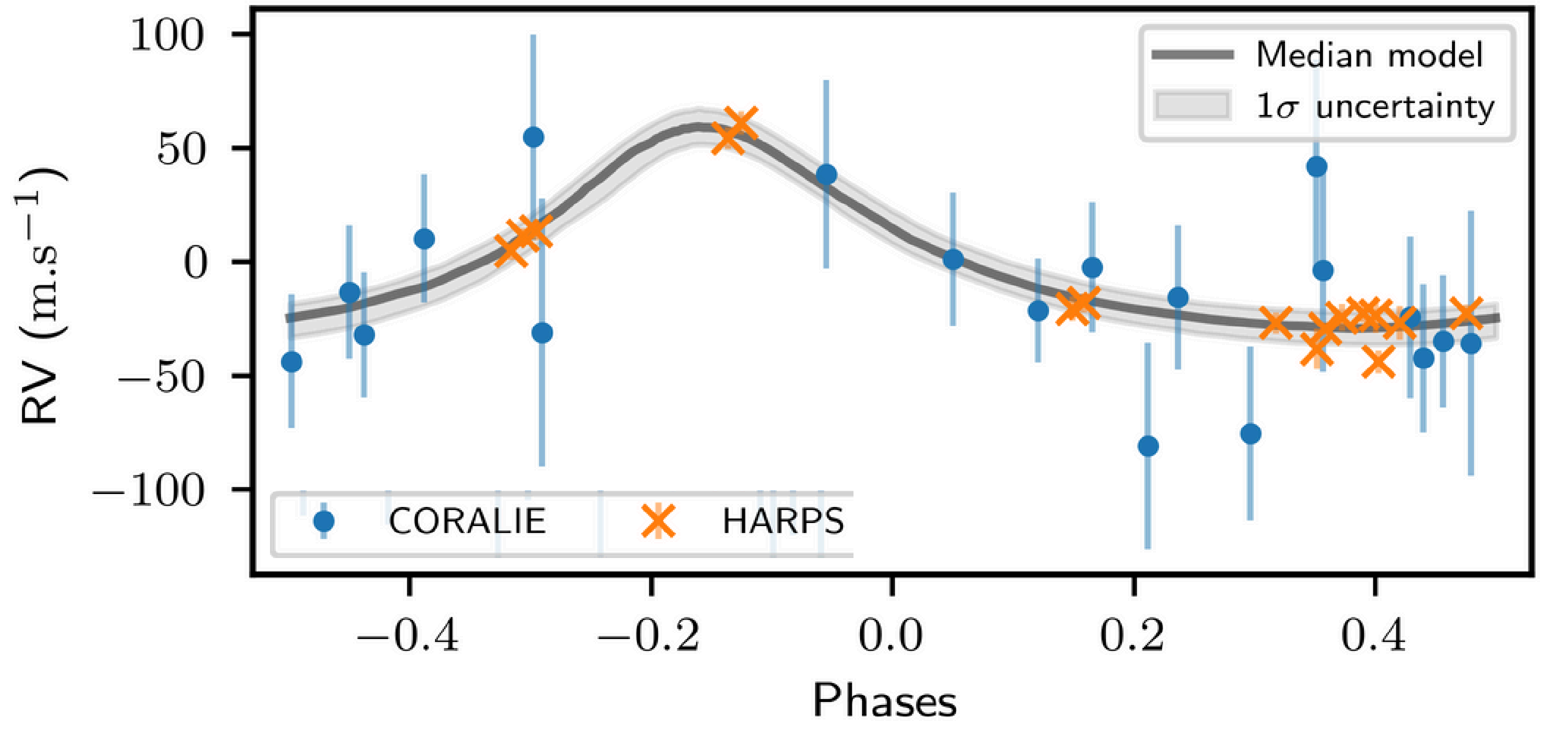
Measuring masses of warm planets

CORALIE program
@ Euler telescope
15 nights / year
to vet candidate and
characterize massive planets



TOI-5678:
a Neptune mass planet on a 48 day orbit

HARPS warm giant program
to measure masses and
eccentricities of warm and
low-mass transiting planets.



TOI-4862:
a Jupiter mass planet on a 98 day orbit

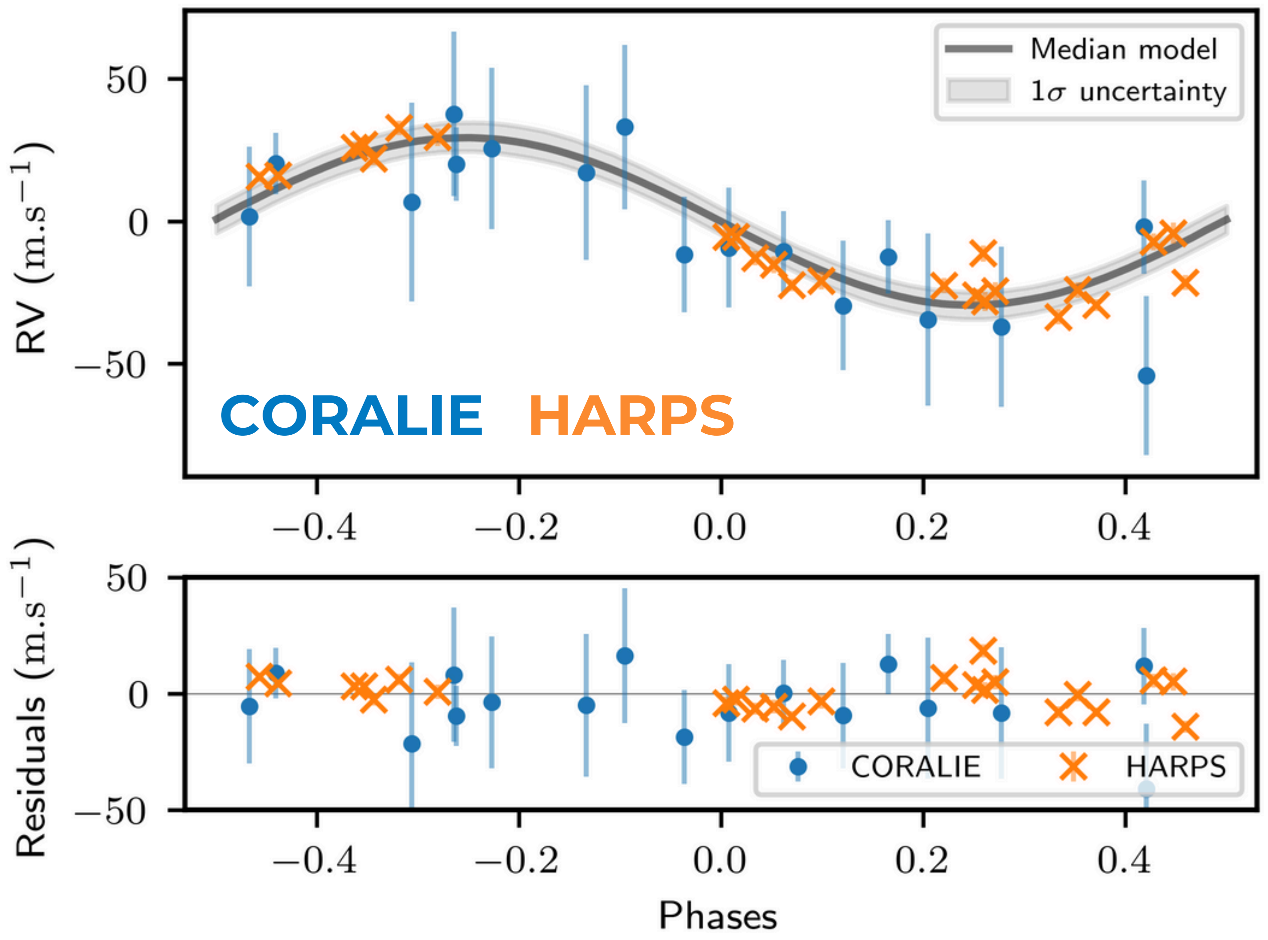
4 successful proposals
30 nights: 2021-2023

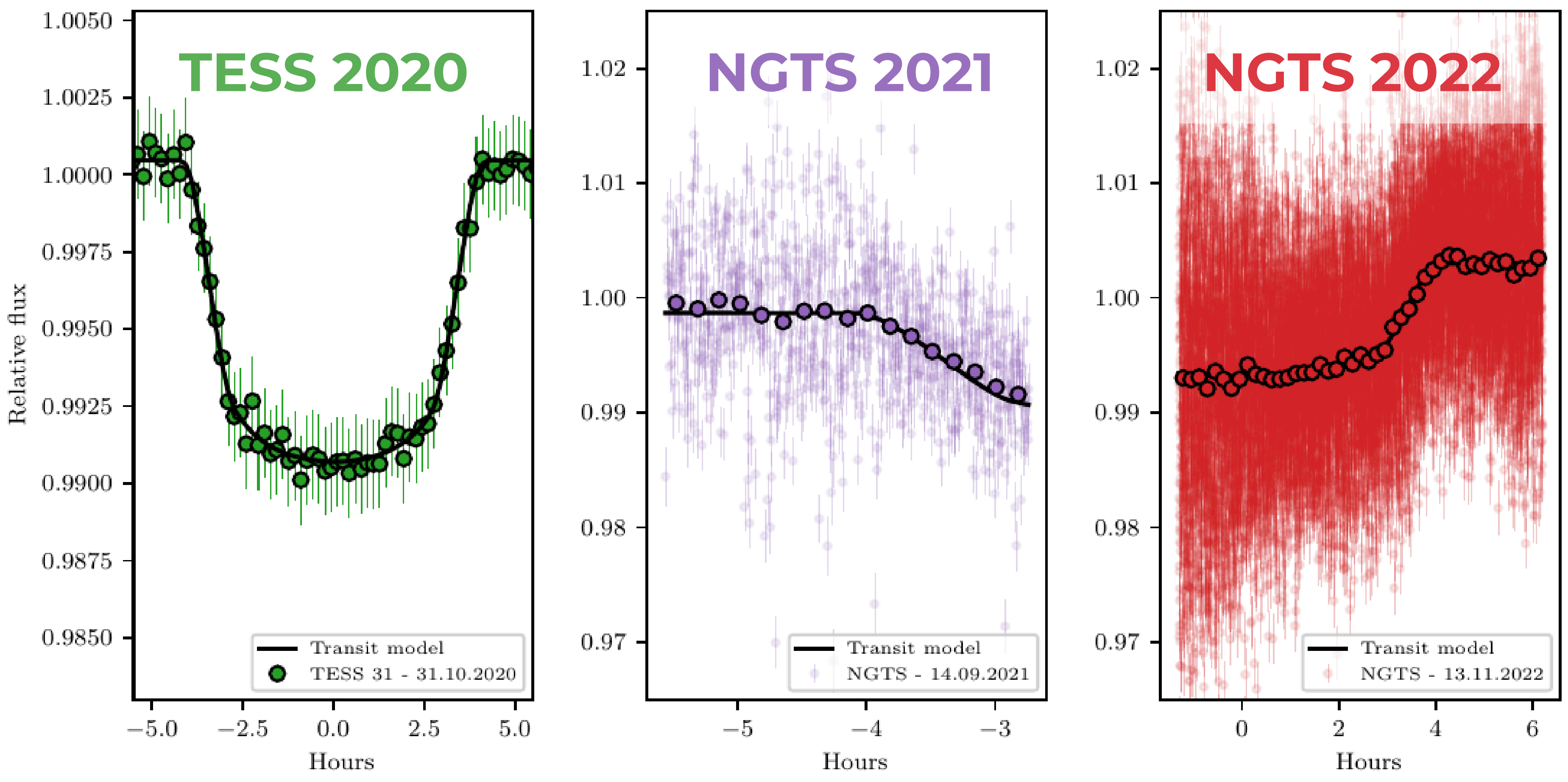
New HARPS large program: 2023 - 2025
PI: Ulmer-Moll

Towards temperate Jupiters P > 100 d

TOI-2449 b:

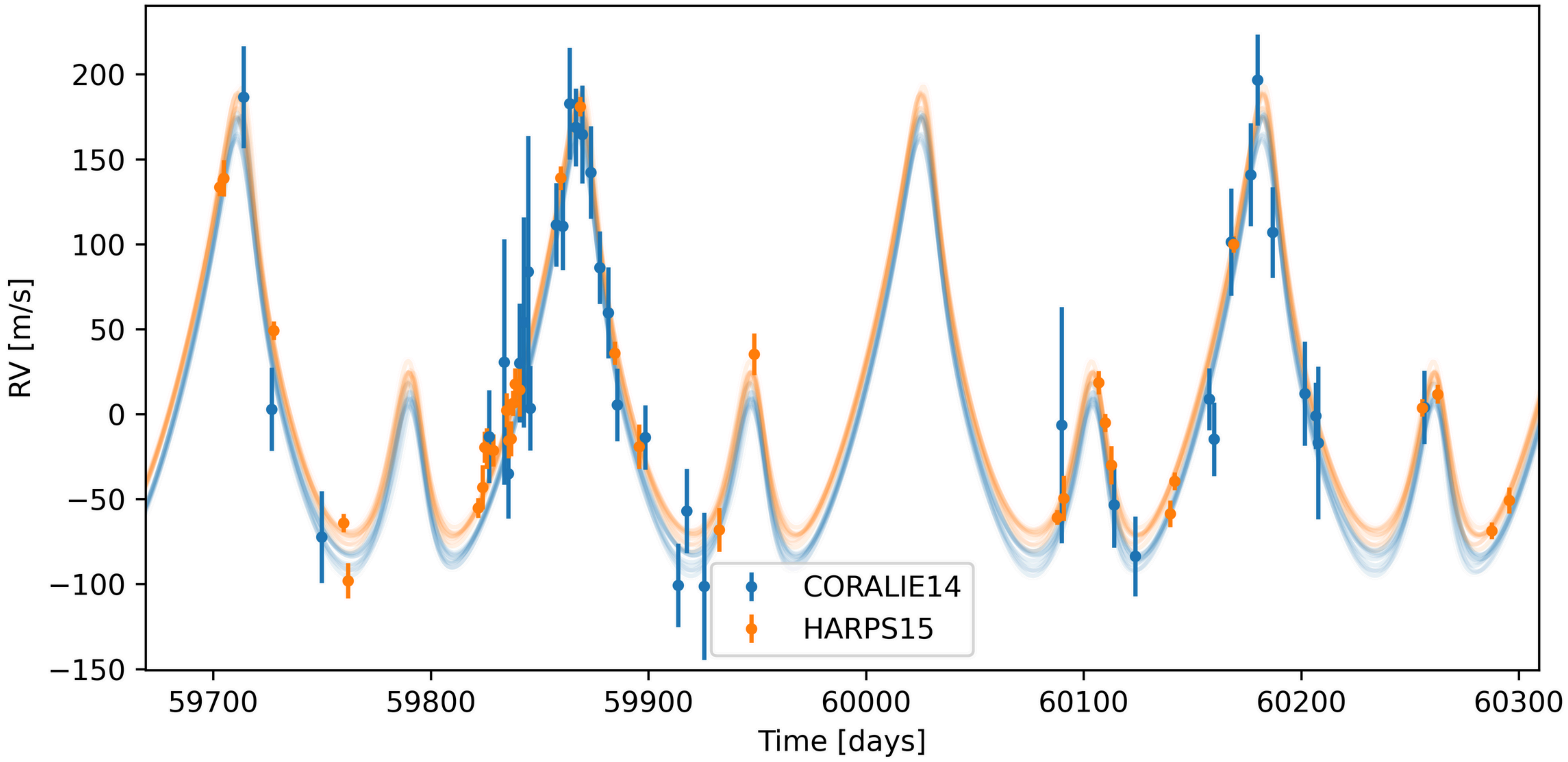
0.64 Mj with an orbital period of 106 days
Equilibrium temperature of 400 K





Ulmer-Moll et al. (in prep)

Two long-period Jupiters in 2:1 resonance



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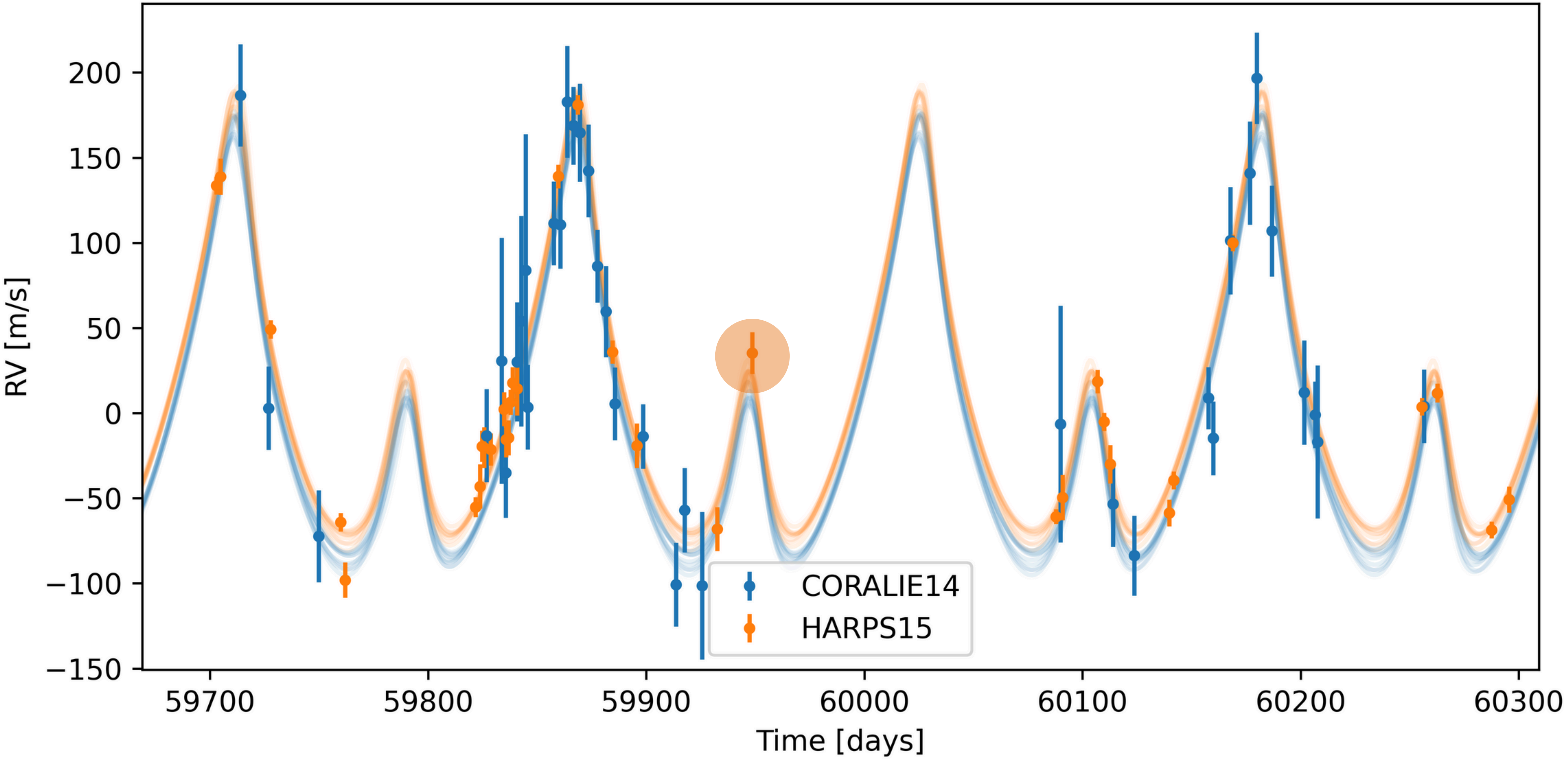

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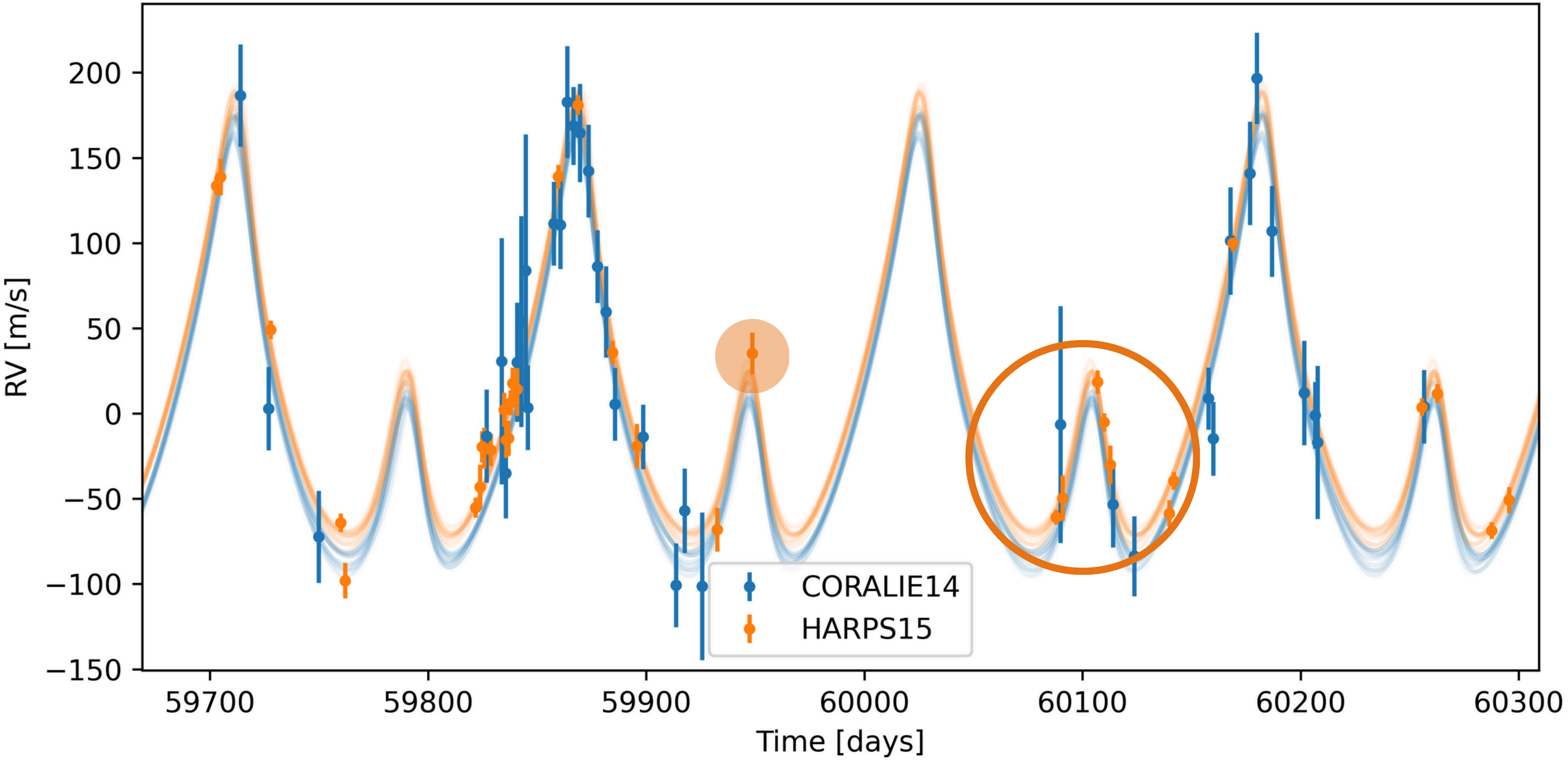

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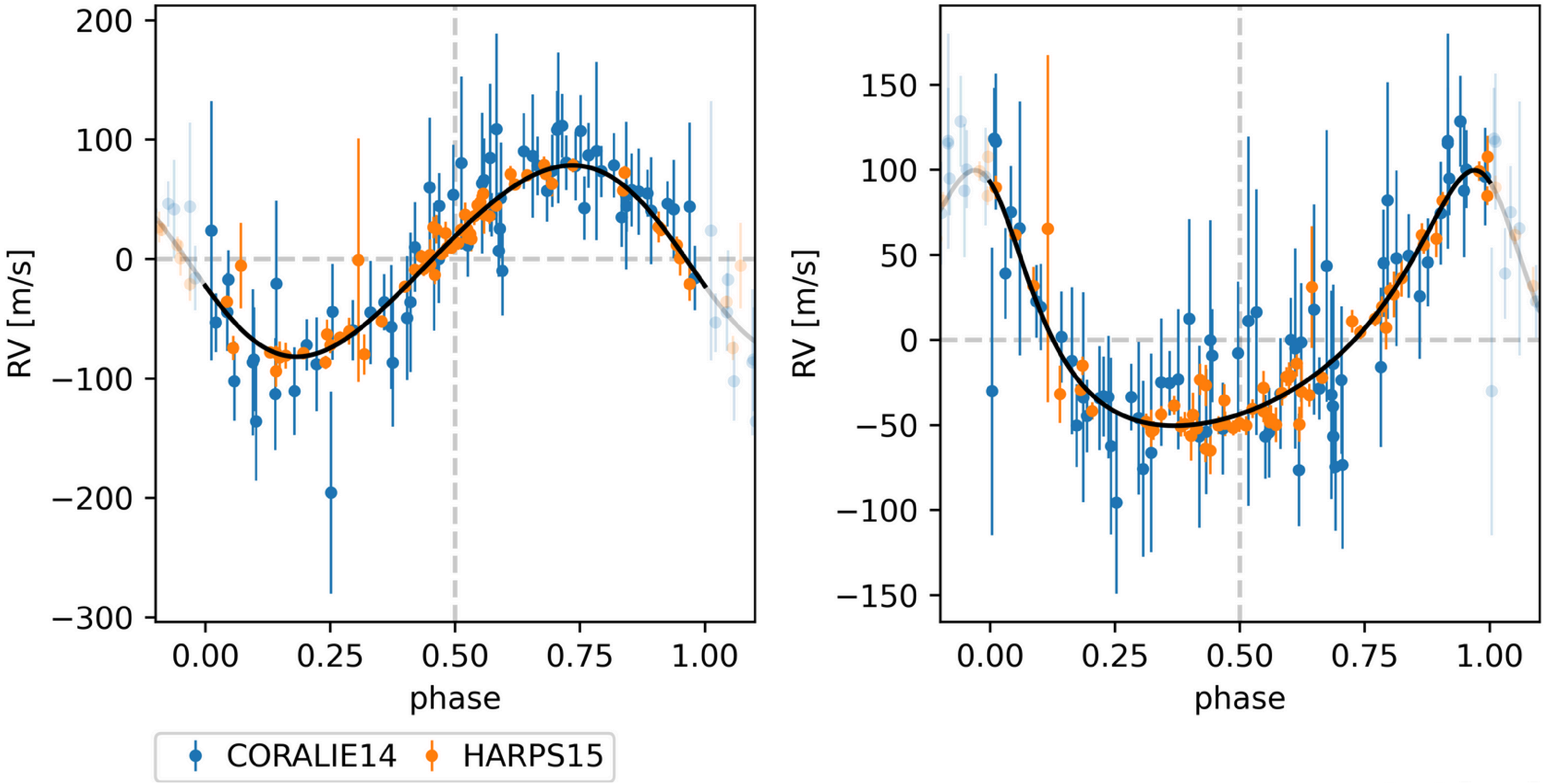


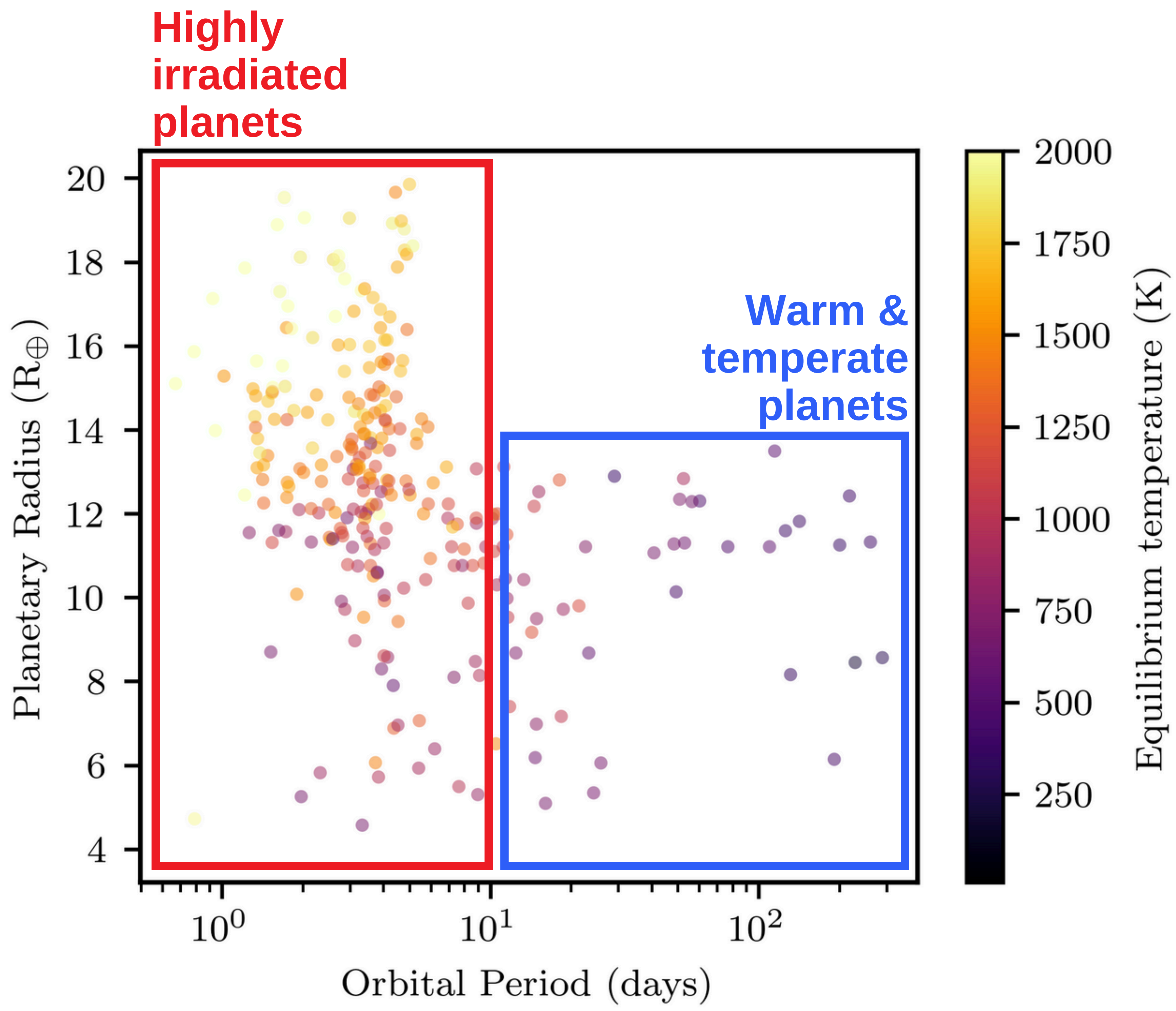
Planet b
Non-transiting
1.25 Mjup @ 78.5 days
moderate eccentricity: 0.3

Planet c
Duo transiting planet (TESS+NGTS)
2.15 Mjup @ 157 days
smaller eccentricity: 0.1

Doubled the number of warm transisting planets

In 3 ans, this photometric and spectroscopic follow-up work, we detected and characterized **30 new transiting exoplanets.**

This projet doubled the known population of warm and temperate transiting planets.



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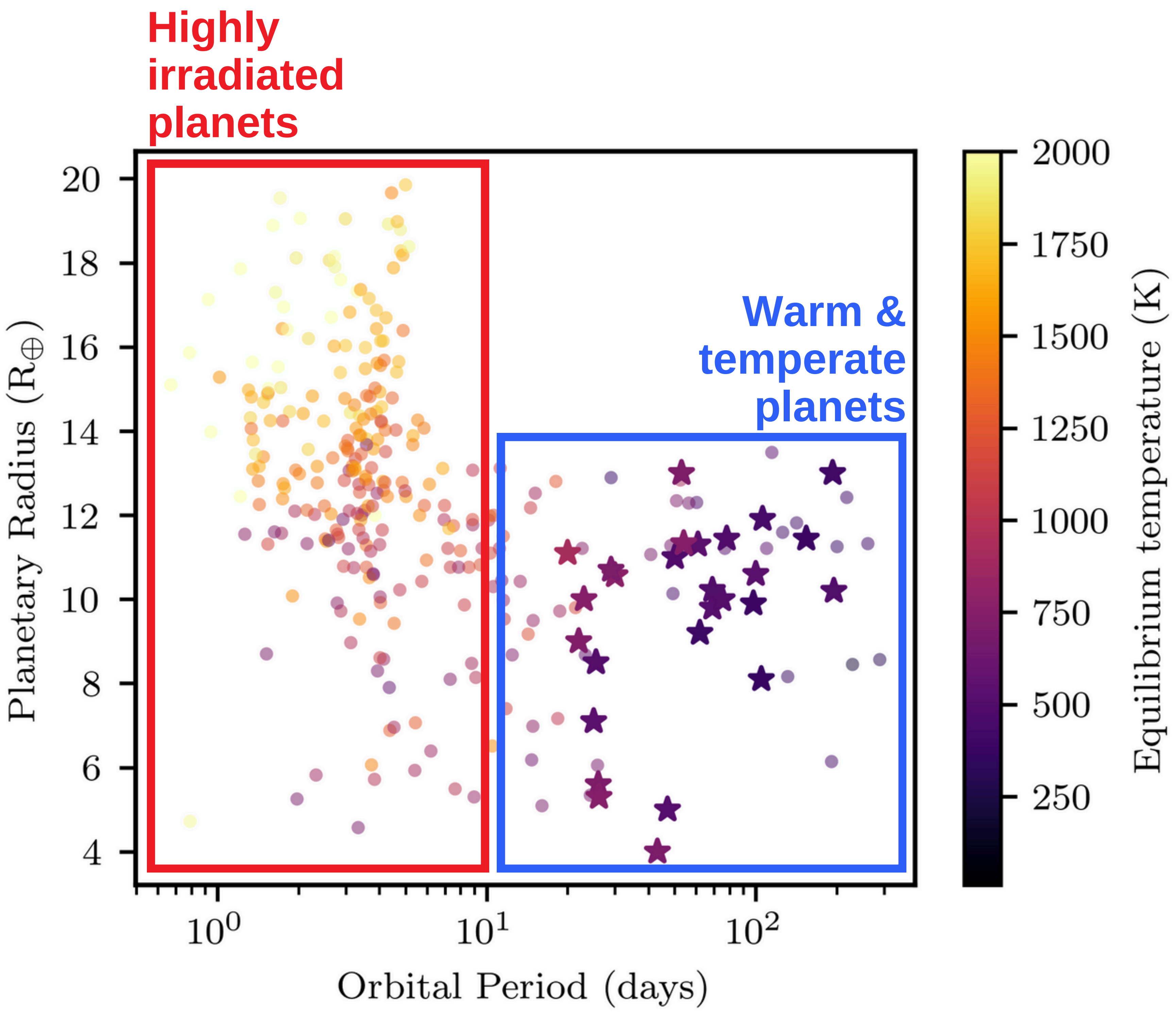
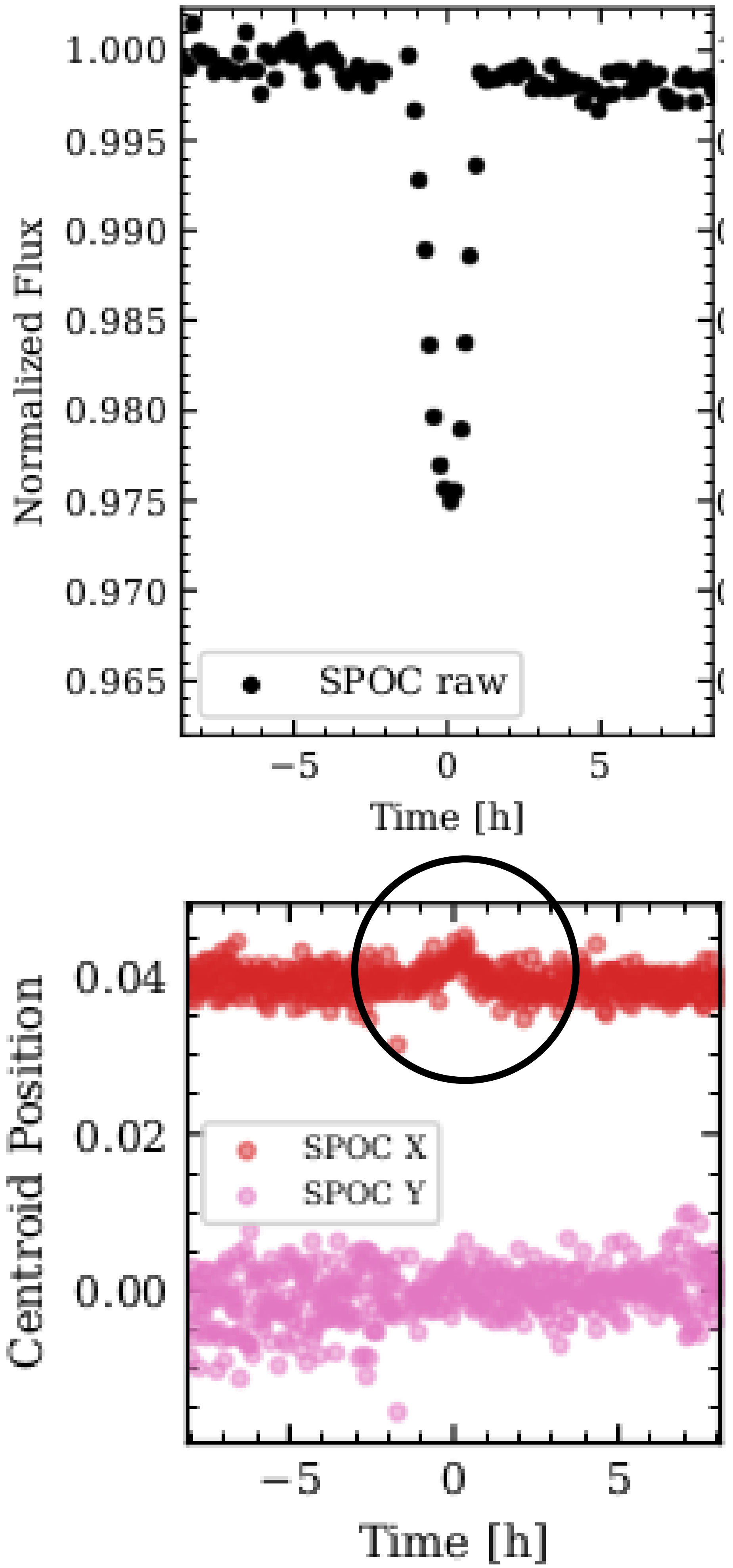


Lessons learned

Identification of single transiting events

- Different pipelines usually find different transit events (mostly due to detrending methods), except for obvious cases
- Centroid information is essential to rule out FP



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Prioritarisation for RV follow-up is not trivial

- Clearly good candidates
- Ranking needed : a lot of candidates have different pros & cons (active star but clear transit event, crowded field)
- Observational contraints (observability ...)

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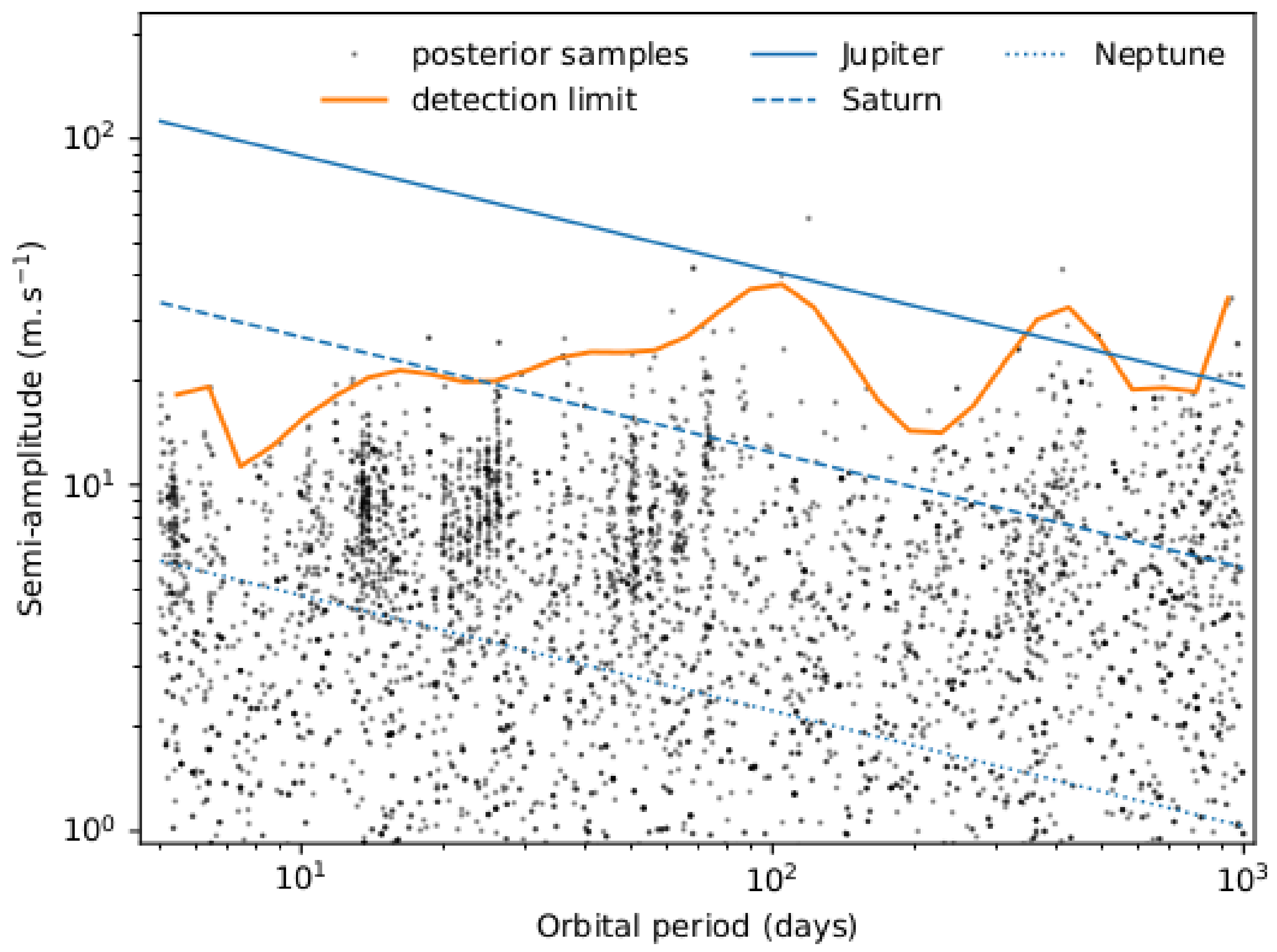
Not all cases will be solved with RVs

- Despite transit events vetted on target and RV follow-up, some candidates are not ruled out as FP nor confirmed
- additional observations needed : AO imaging

RV detection limit

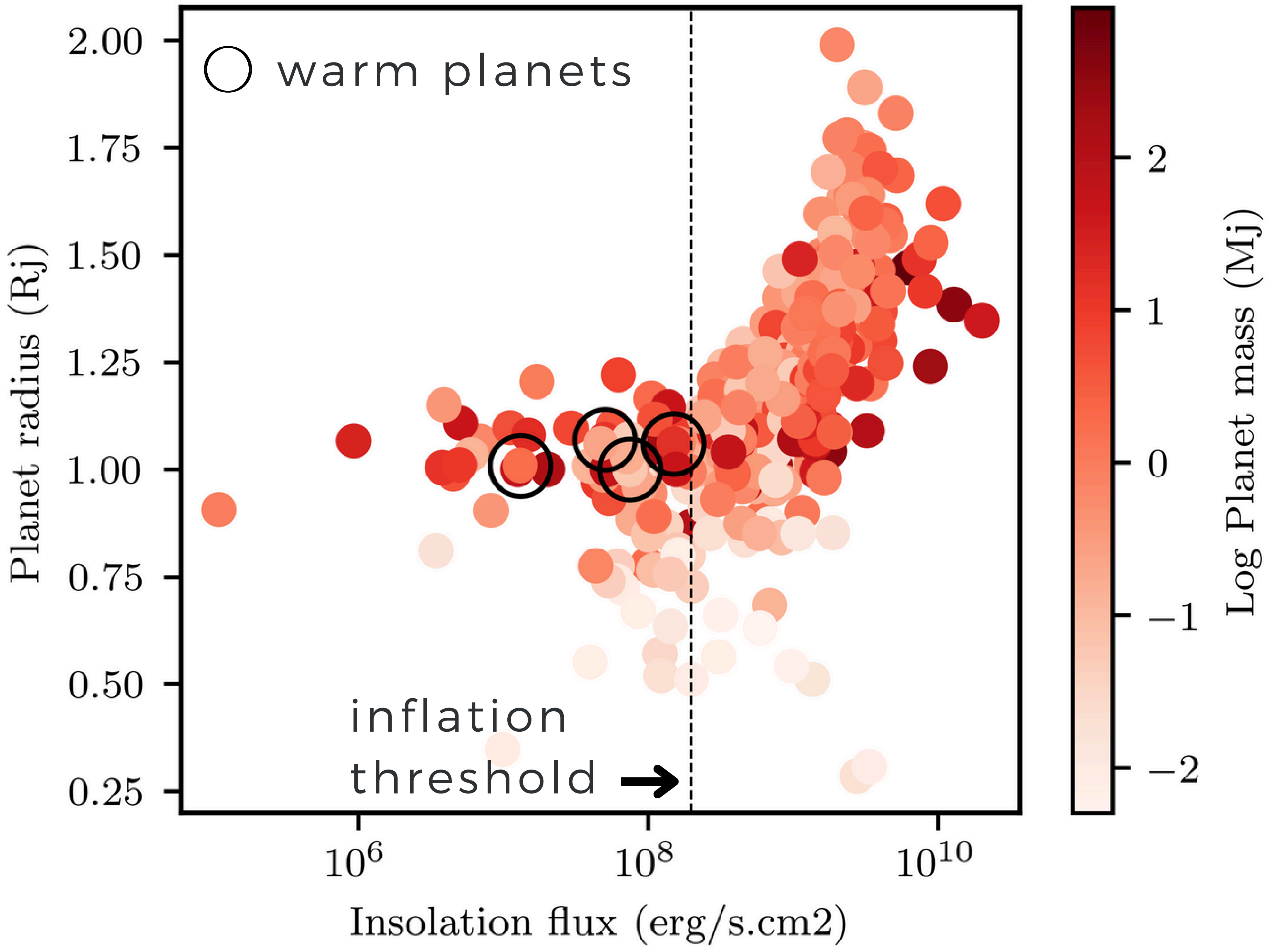


Cooler planets are ideal to explore their composition

We have precise mass and radius measurements for these warm giant planets.

They receive lower levels of stellar irradiation than HJs and usually do not have inflated atmospheres.

No degeneracy between radius inflation mechanisms and composition study.



How to estimate the planet's composition?

We combine **observations and modeling**
to measure the amount of heavy elements and metal enrichment.

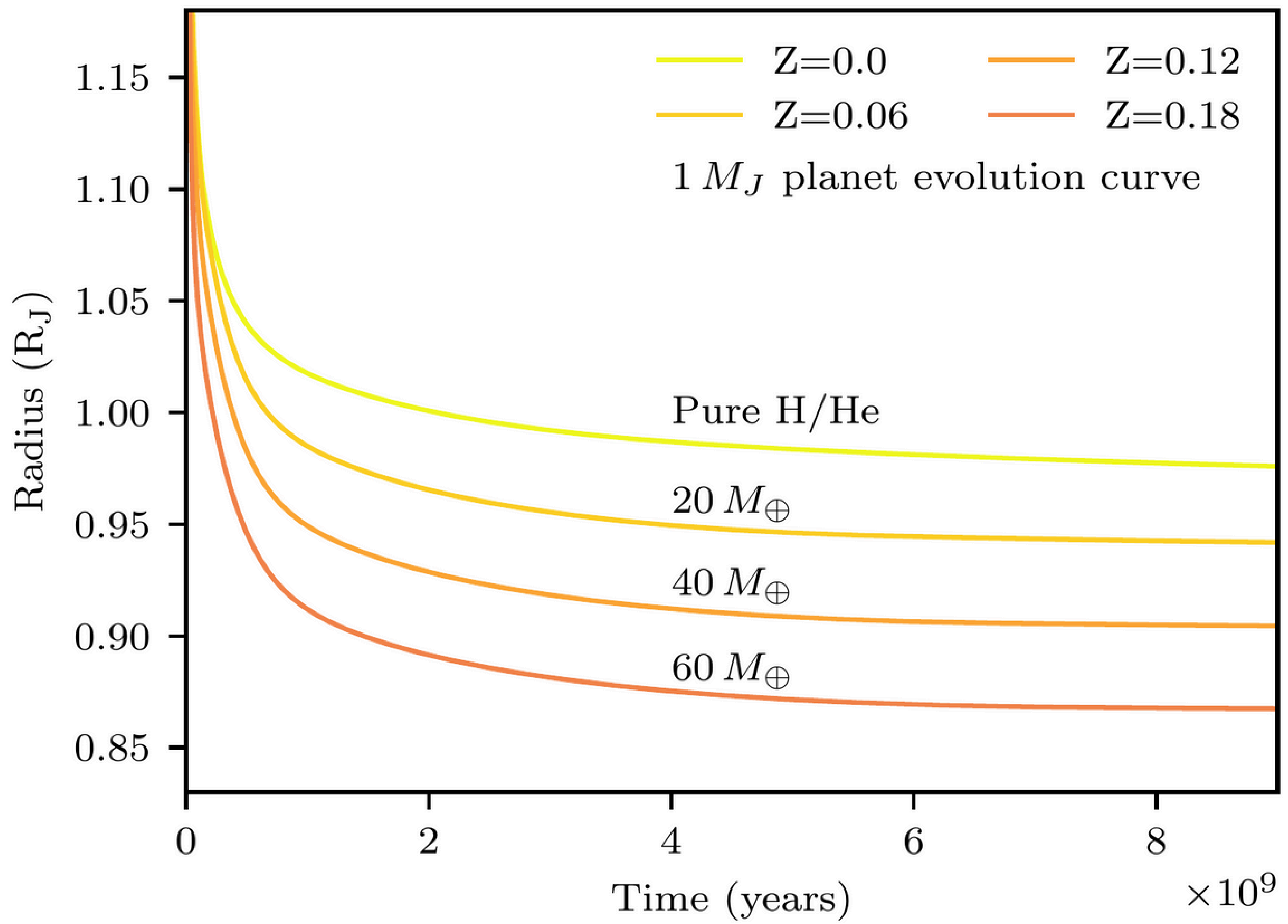
Observables: planetary mass, radius, orbital period, and stellar age

We model the evolution of the planet with time

Radius decreases with age and heavy element enrichment

We can explore the impact of varying the heavy elements (Z) in the envelope

Completo code
Mordasini et al. (2012)

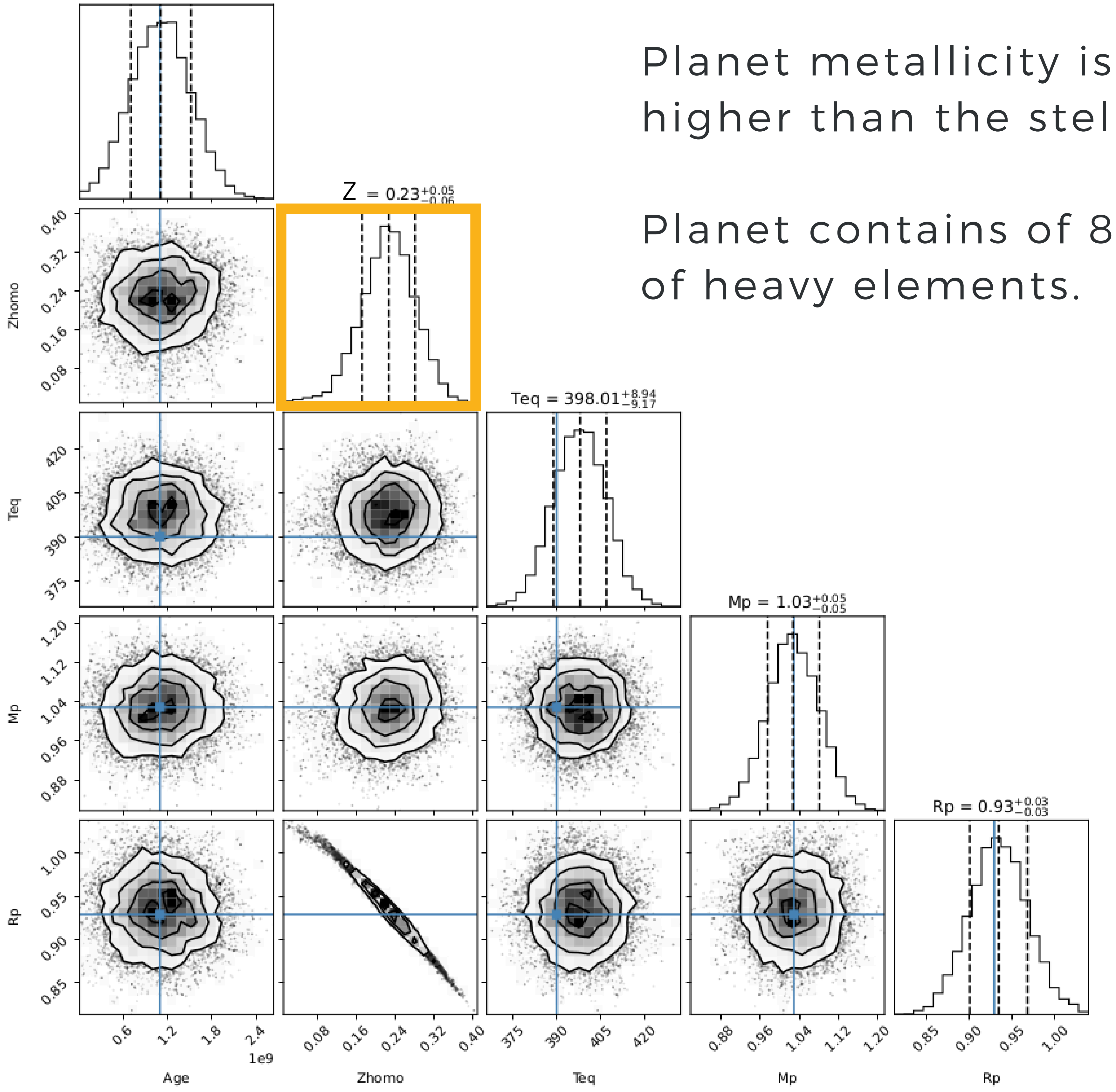


Warm Jupiters are metal-enriched

TOI-4862 b
1 Mjup @ 98 days
Teq: 400K
Age: 1.1 (+-0.4) Gyr

- late-stage accretion of planetesimals (Mousis+2009, Shibata+2020)

- multiple mergers during gas accretion phase (Ginzburg & Chiang 2020)



Planet metallicity is 20x higher than the stellar one

Planet contains of 85 Me of heavy elements.

Caveats on the inferred metallicities

The inferred planetary metallicities have large uncertainties due to

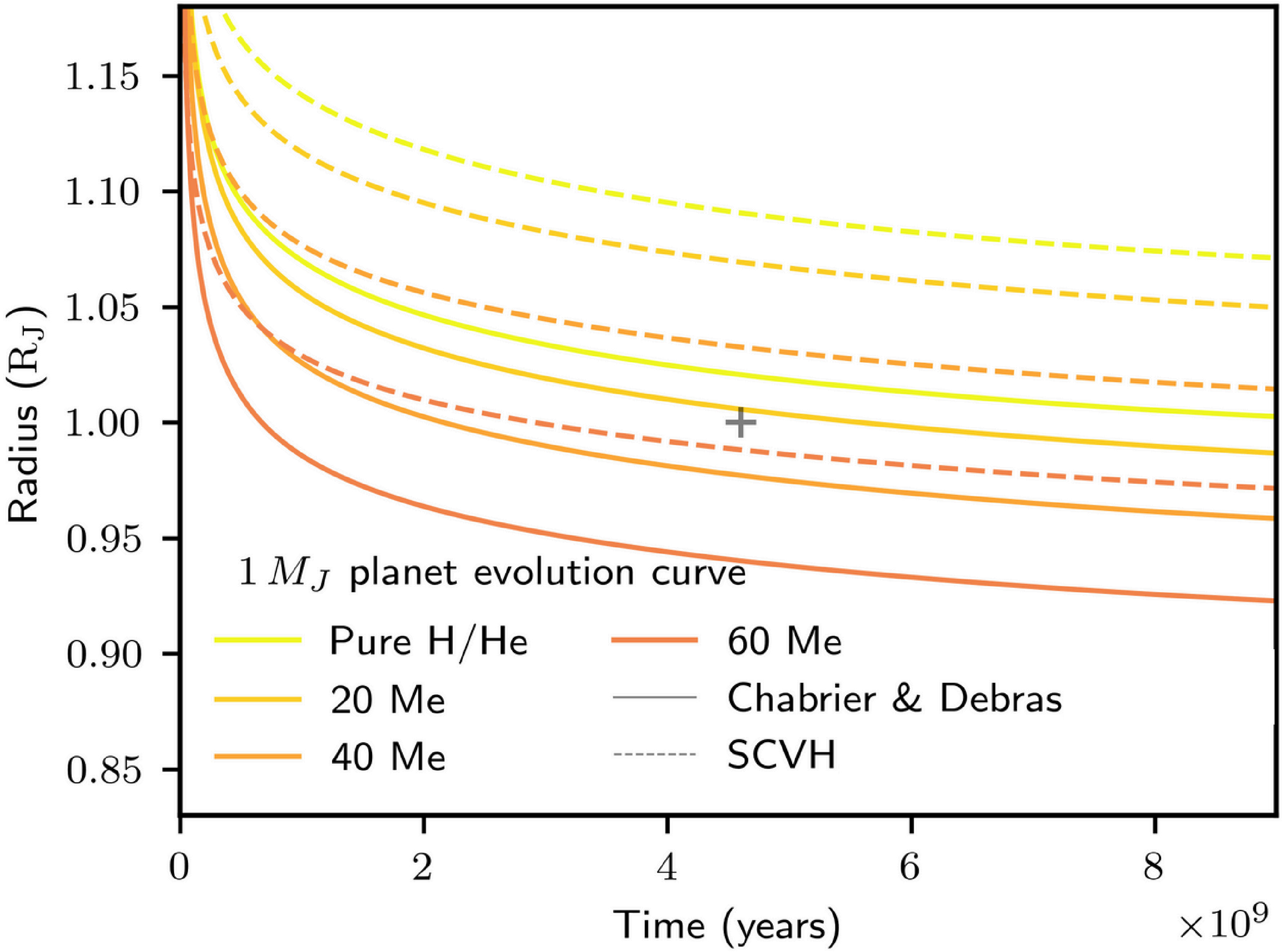
- uncertainties on planetary mass, radius, and stellar age ✓
- uncertainties on the model specifications ✗

Radius evolution track for a 1.0 Mjup planet at 0.1 au (~ 1500K)

New equation of state (CMS) for H and He leads to overall smaller planets

(hydrogen is denser under certain pressures and temperatures in CMS in comparison to SCvH)

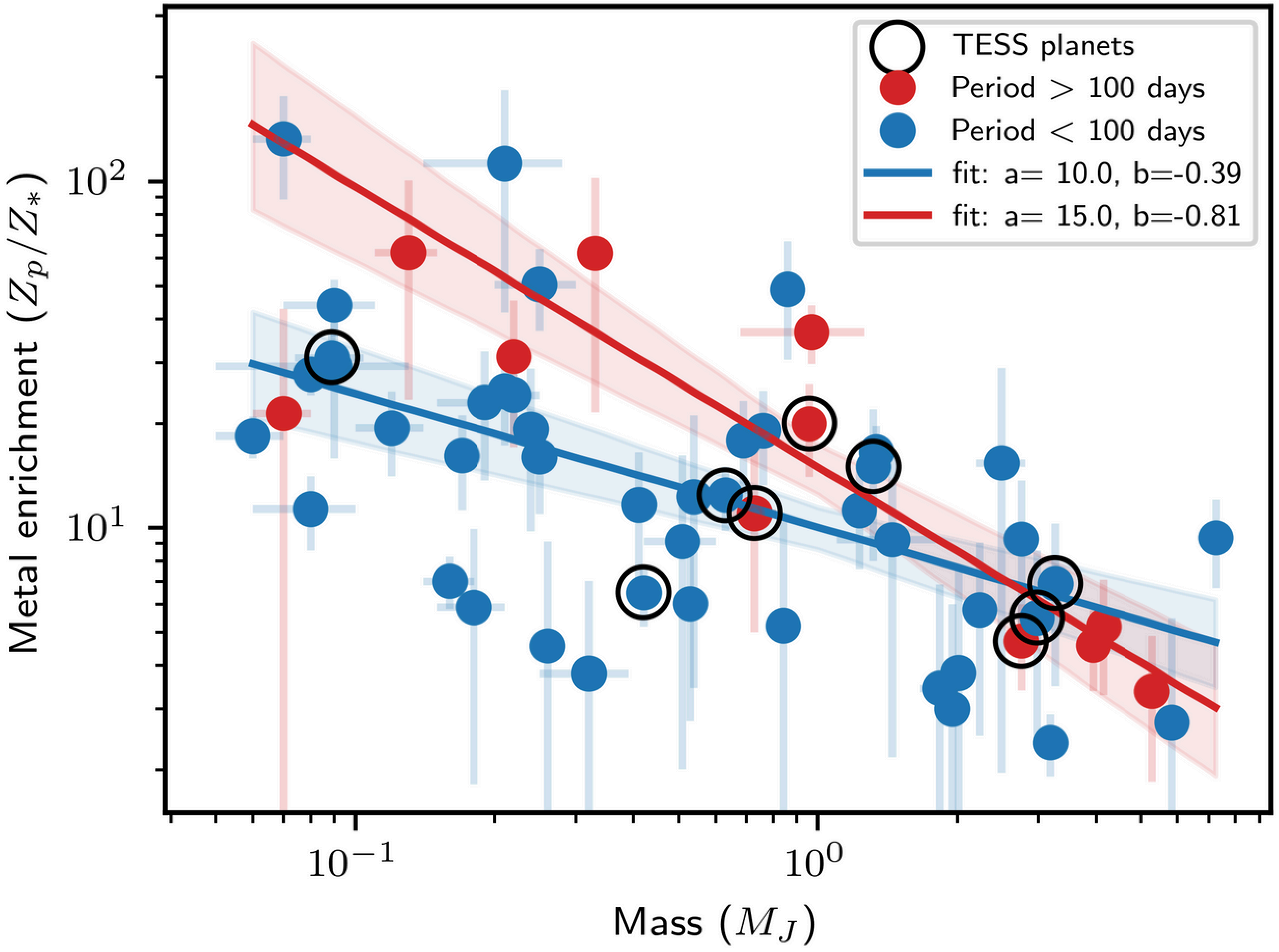
The inferred mass of heavy elements varies by several earth masses



Planet metal-enrichment correlates with planetary mass

An inverse correlation is expected from core-accretion formation models.

The newly detected planets match well with this correlation.



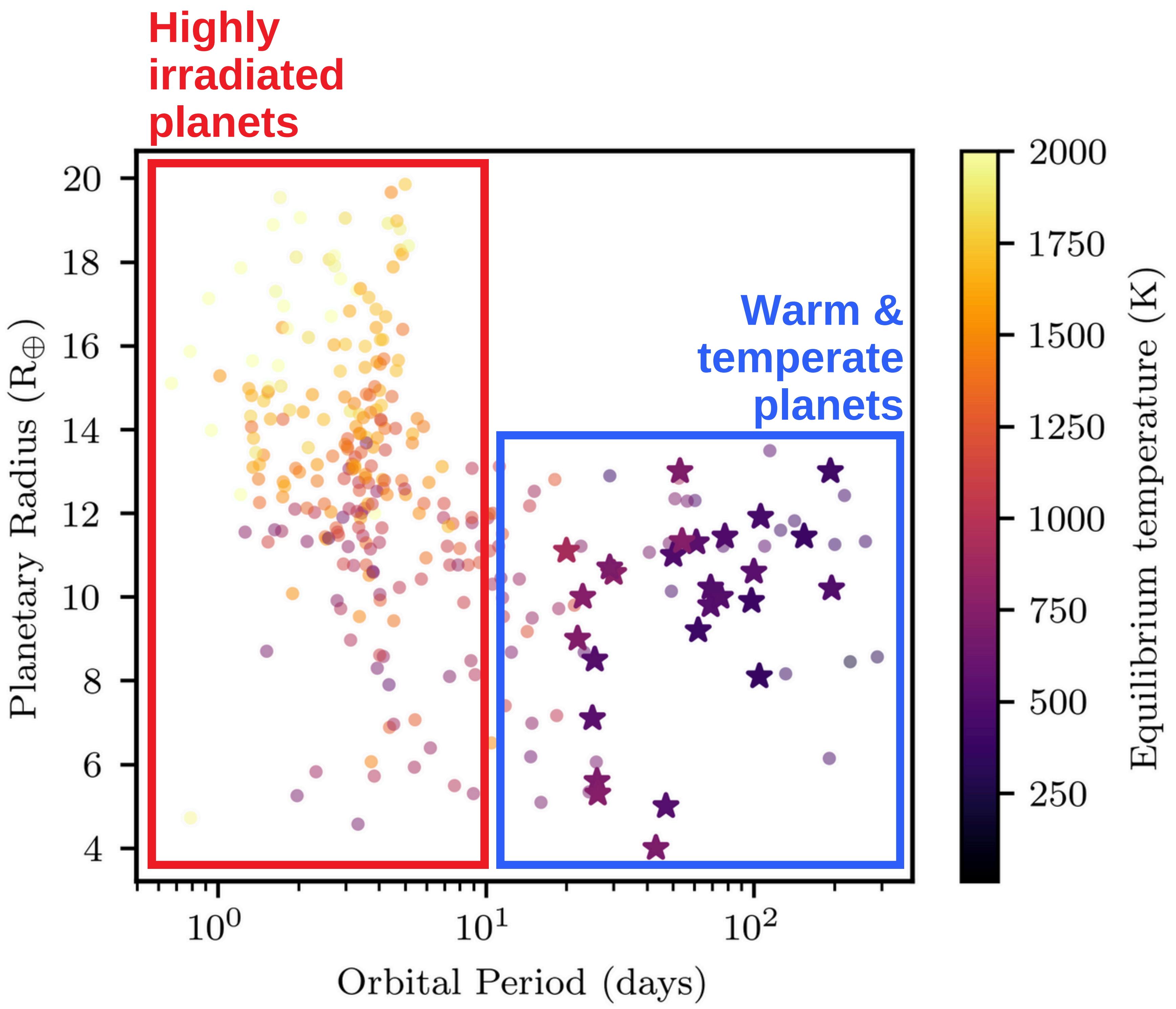
Updated from Dalba + 2022

In summary

Characterised 30 new transiting warm and temperate planets around bright stars

These new warm Jupiters will be very well characterized and allow to test planet formation models.

PLATO will make a crucial contribution by easily detecting these transiting giant planets on long-period orbits, extending beyond the habitable zone.



Extra slides