

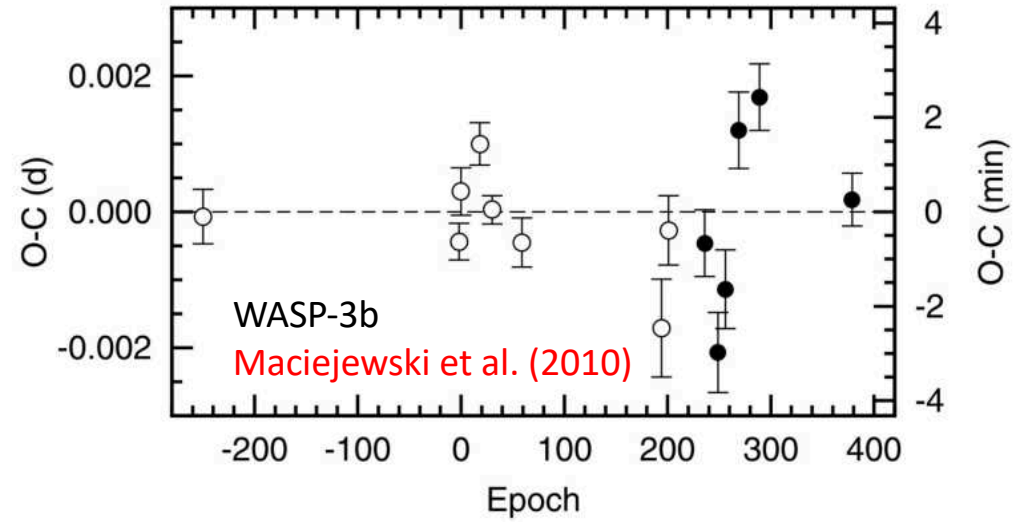
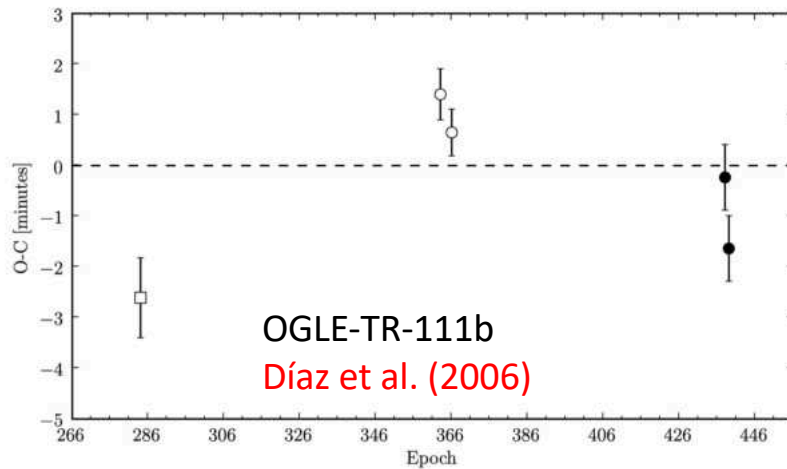
The strongly interacting planetary system WASP-148.

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CNRS
Institut d'astrophysique de Paris
Observatoire de Haute-Provence

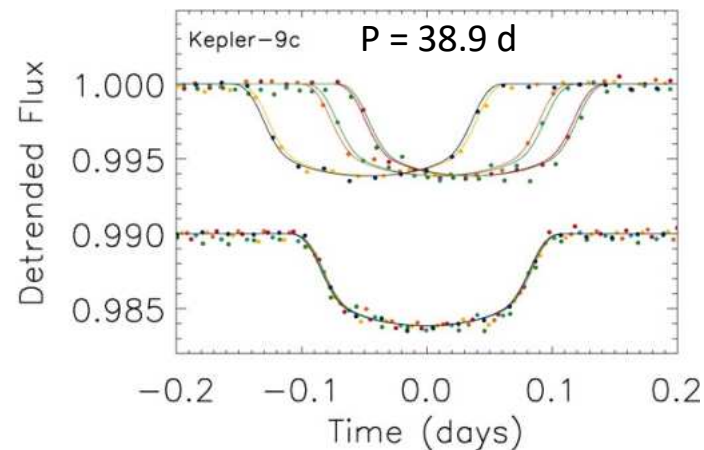
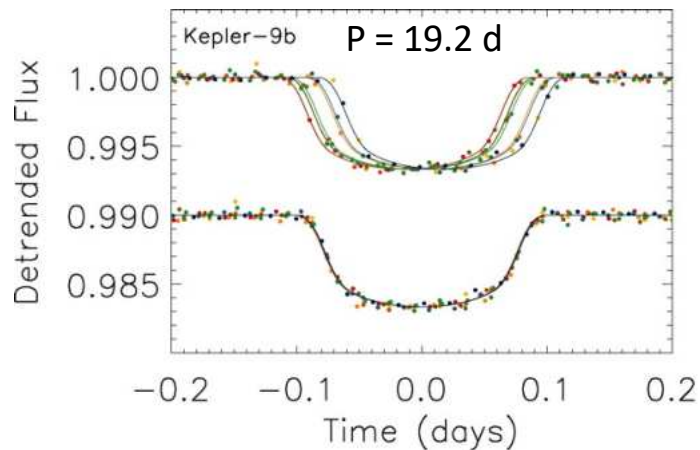
Including contributions from R.F. Díaz, J.-M. Almenara,
A.C.M. Correia, J. Laskar, N. Heidari, A. Lecavelier,
SOPHIE/SuperWASP/TESS teams...

*Coimbra, Portugal, July 7, 2025
Detection and Dynamics of exoplanets (DDE)
Interplay between theory and observation*

Past tentative TTV detections from the ground



Detections from space



Kepler-9
Holman et al. (2010)

Detection of a candidate for a possible transiting giant exoplanet with SuperWASP photometry

G5V

$V = 12.2$

$T_{\text{eff}} = 5555 \pm 90$

$\log g = 4.49 \pm 0.03$

$[\text{Fe}/\text{H}] = +0.01 \pm 0.08$

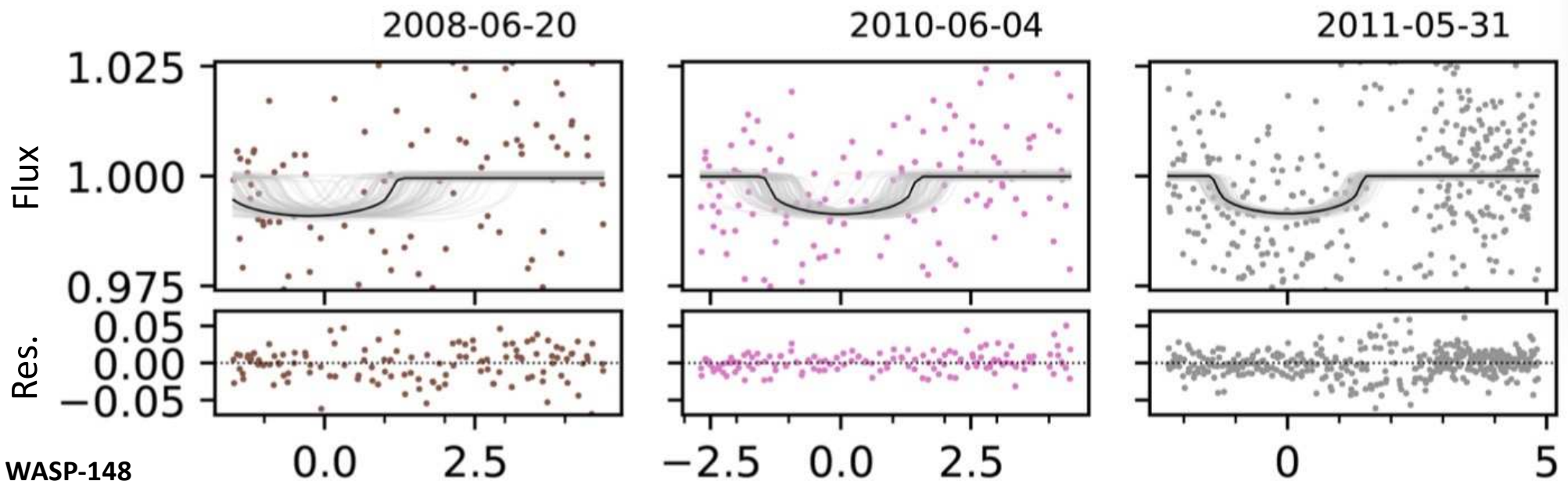
$M_* = 0.96 \pm 0.05 M_{\text{Sun}}$

$R_* = 0.92 \pm 0.02 R_{\text{Sun}}$

Transit depth: $\sim 1\%$

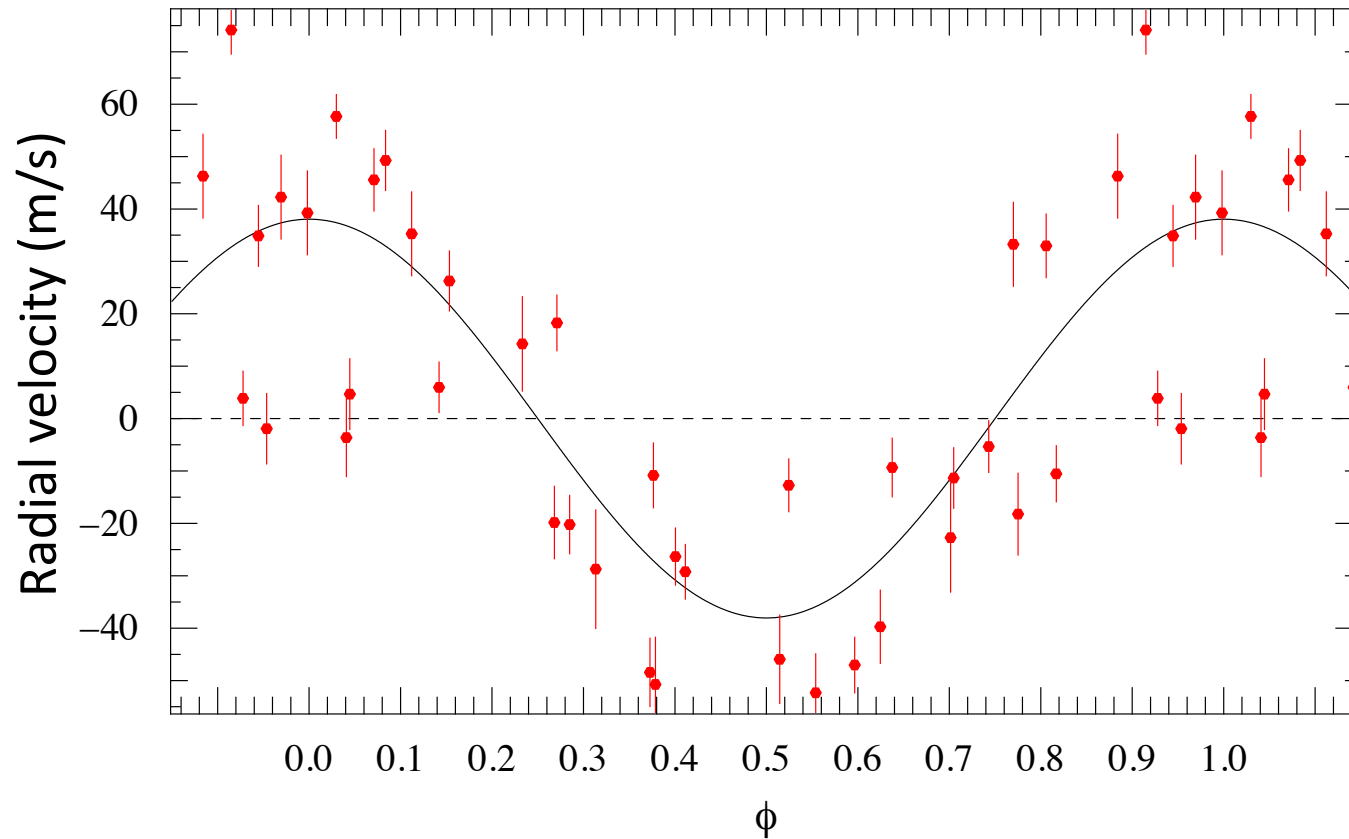
Orbital period: 8.8 days

Transit duration: ~ 3 hours



WASP-148

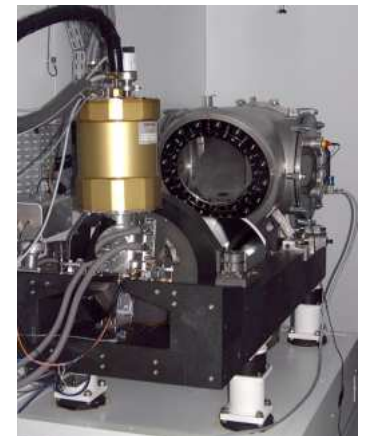
Characterization of the SuperWASP candidate with SOPHIE RVs



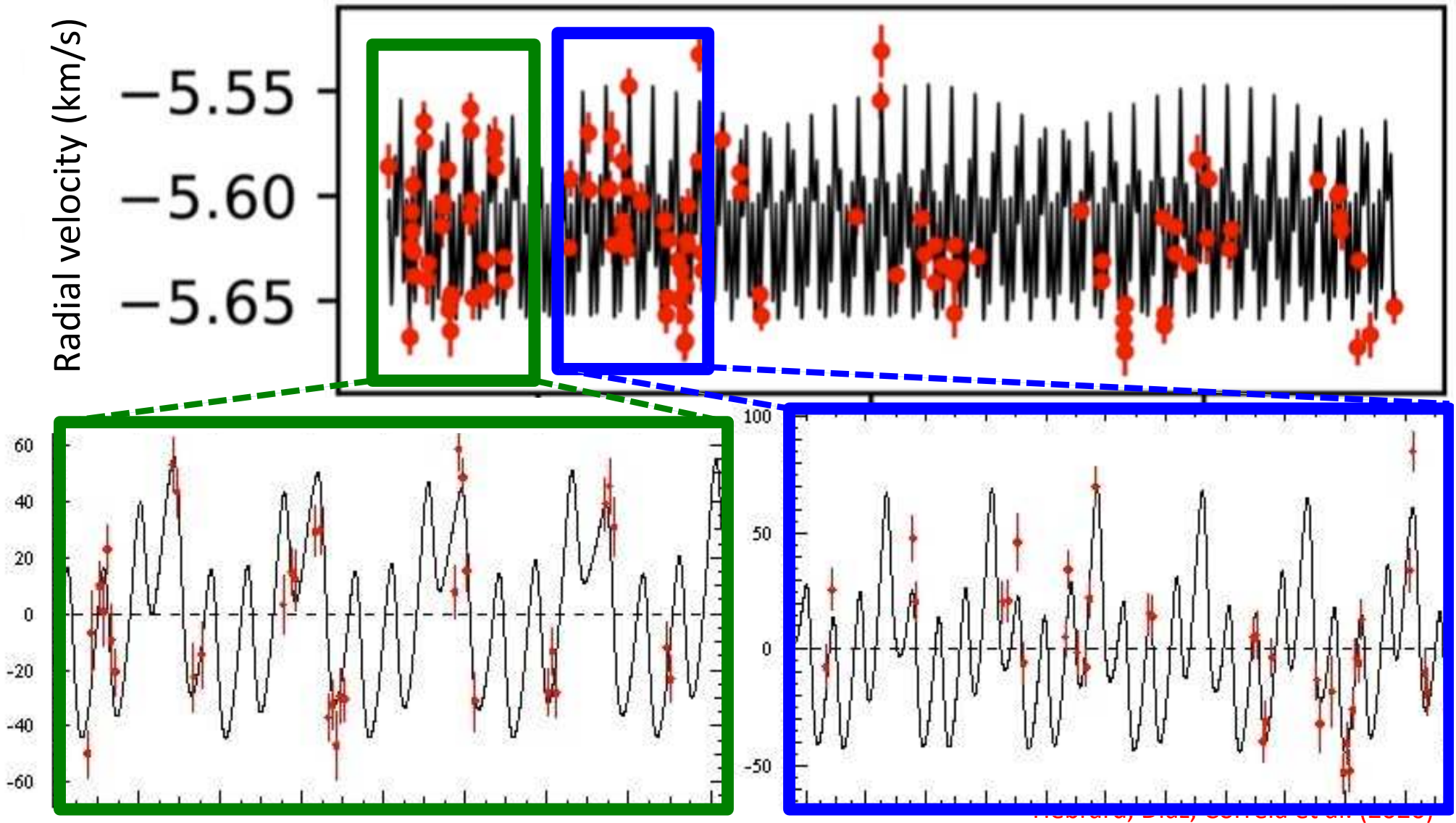
Period: 8.8 days

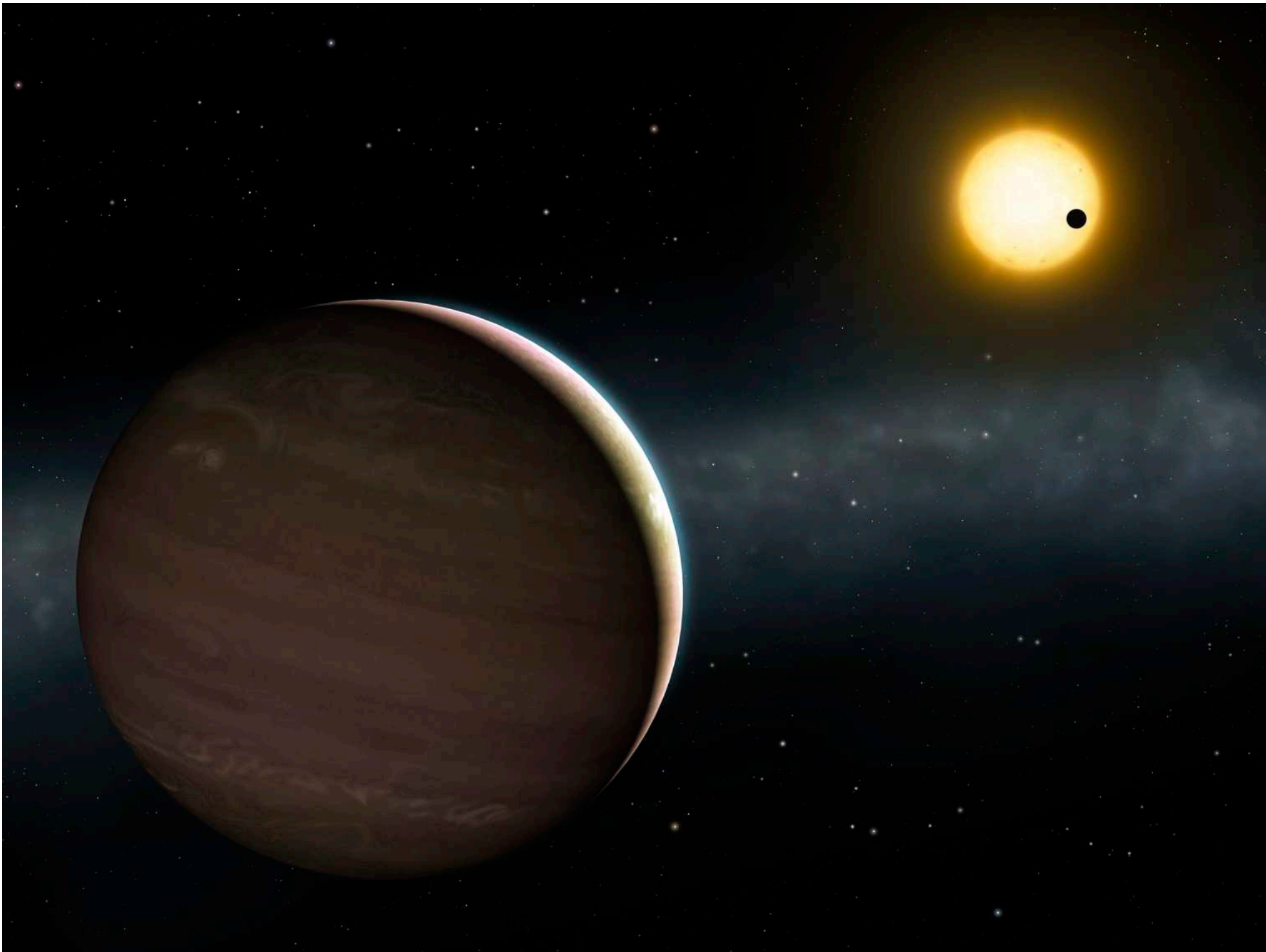
Mass: $\sim 0.4 M_{\text{Jupiter}}$

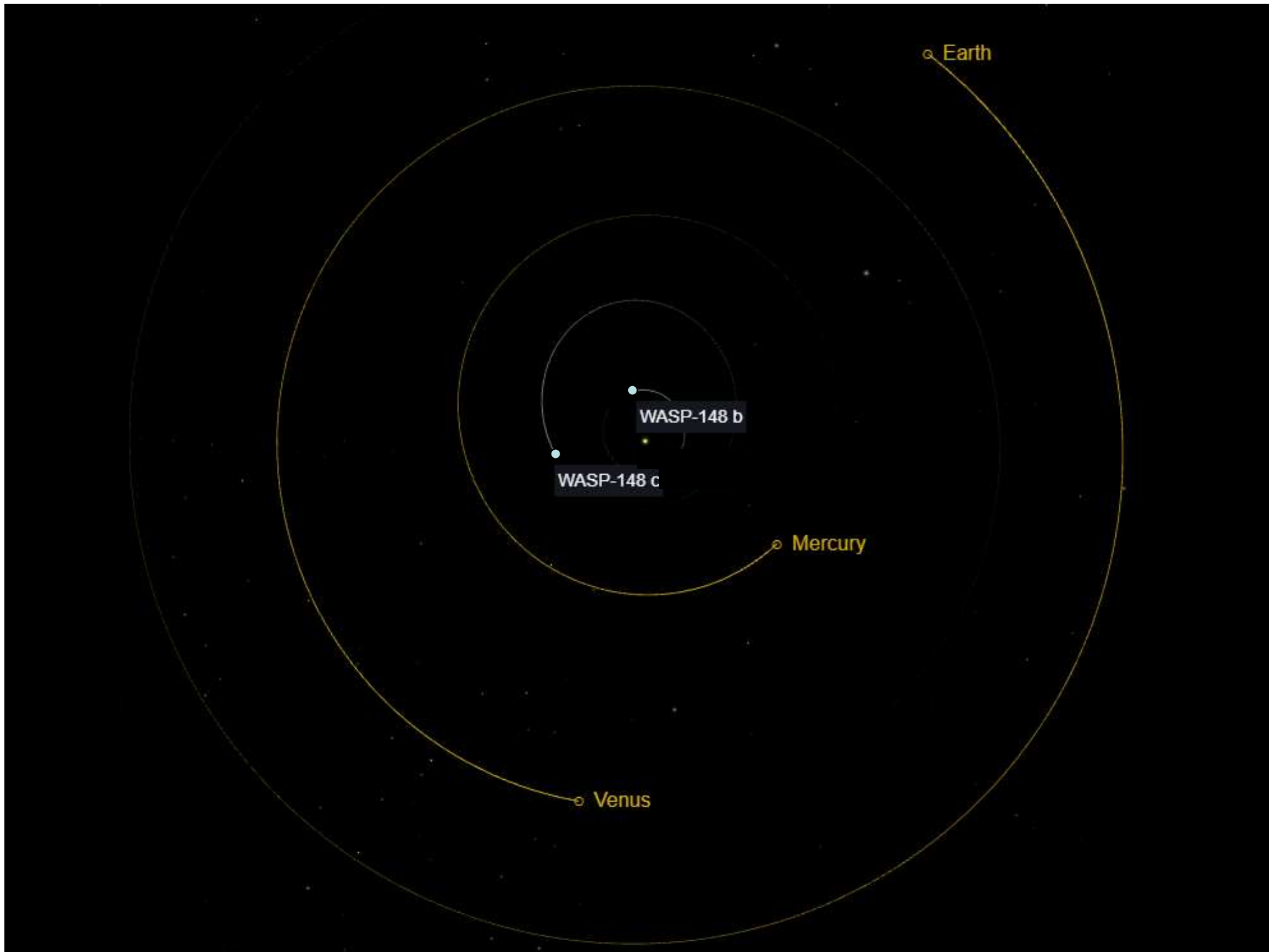
WASP-148b



Characterization of the multiplanetary system with SOPHIE







Near Mean-Motion Resonance

~1:4

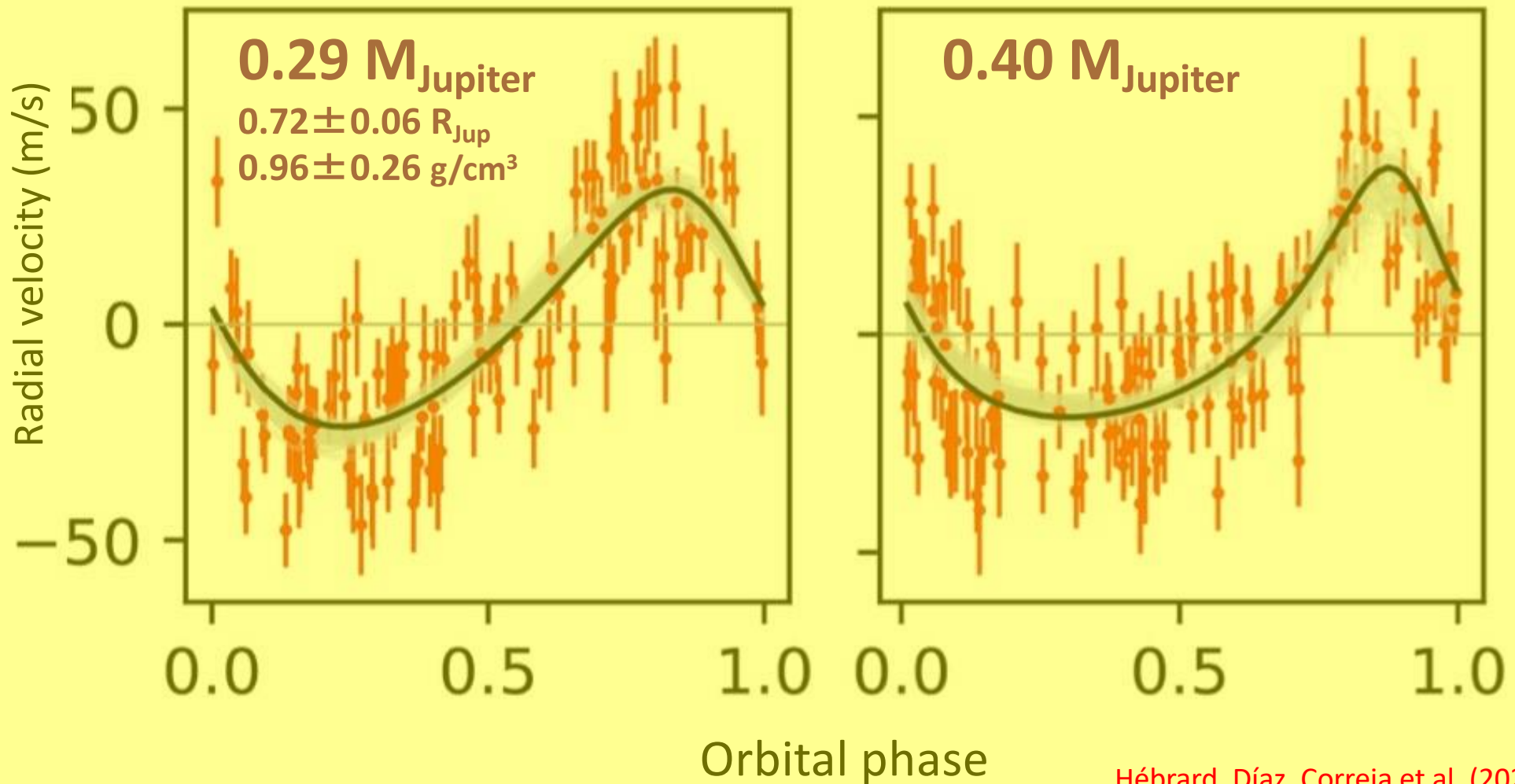


$P = 8.80\text{d}$

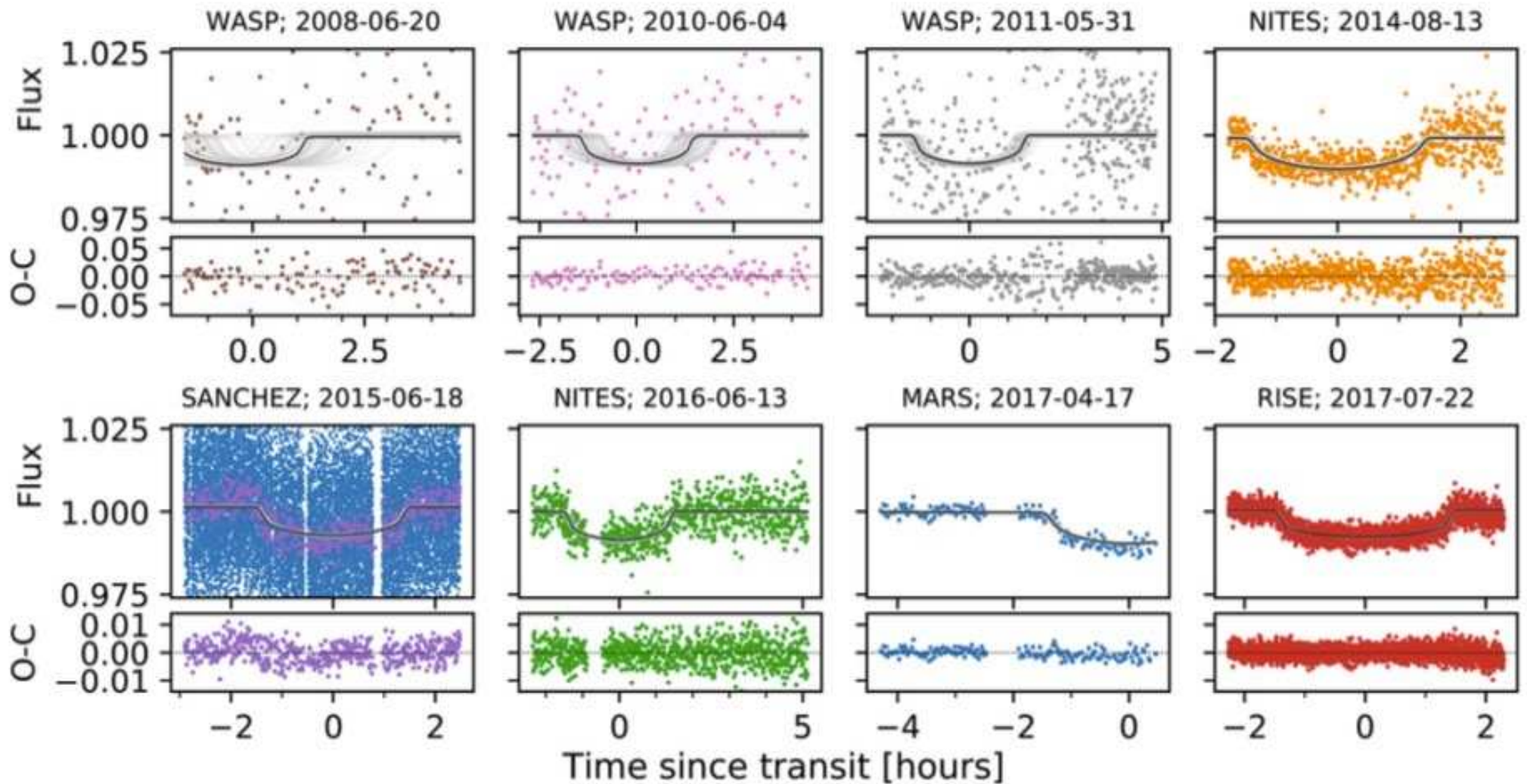
$P = 34.5\text{d}$

WASP-148 b;

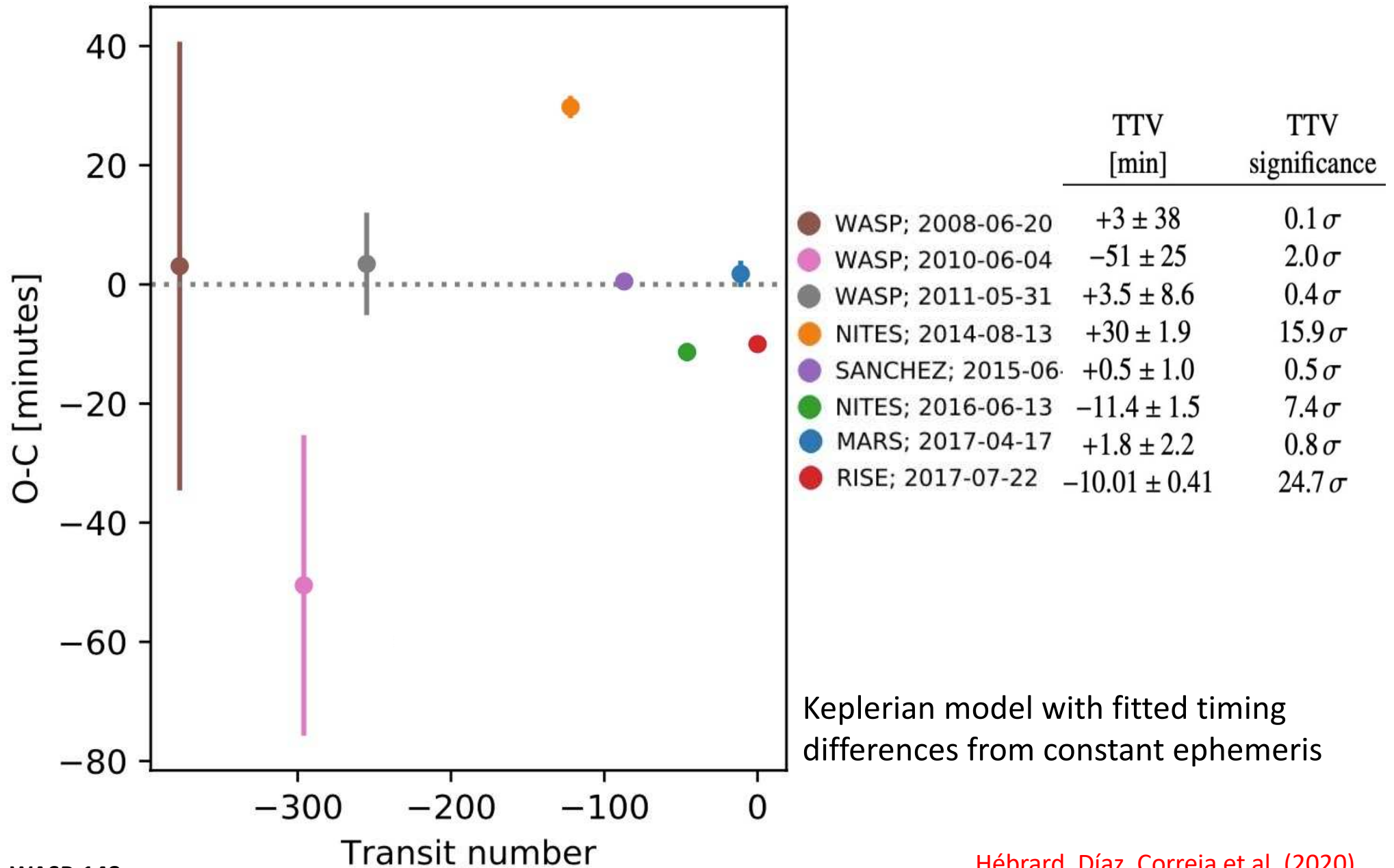
WASP-148 c;



Observation of photometric transits



Detection of transit-timing variations (TTVs)

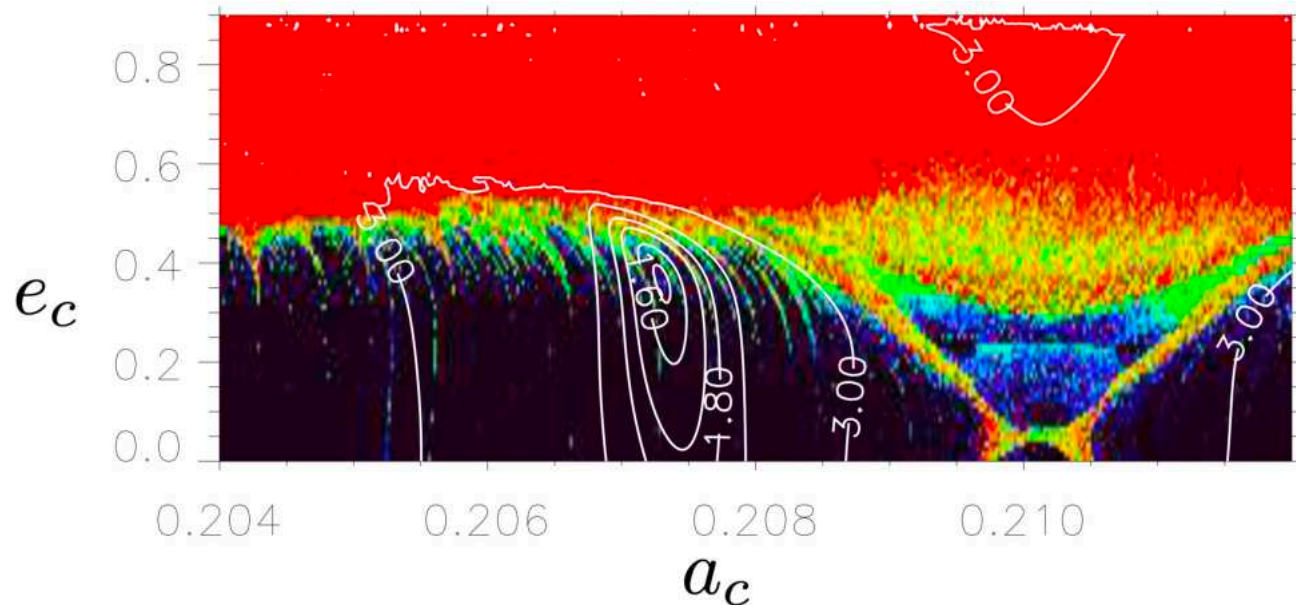


First dynamical analyses

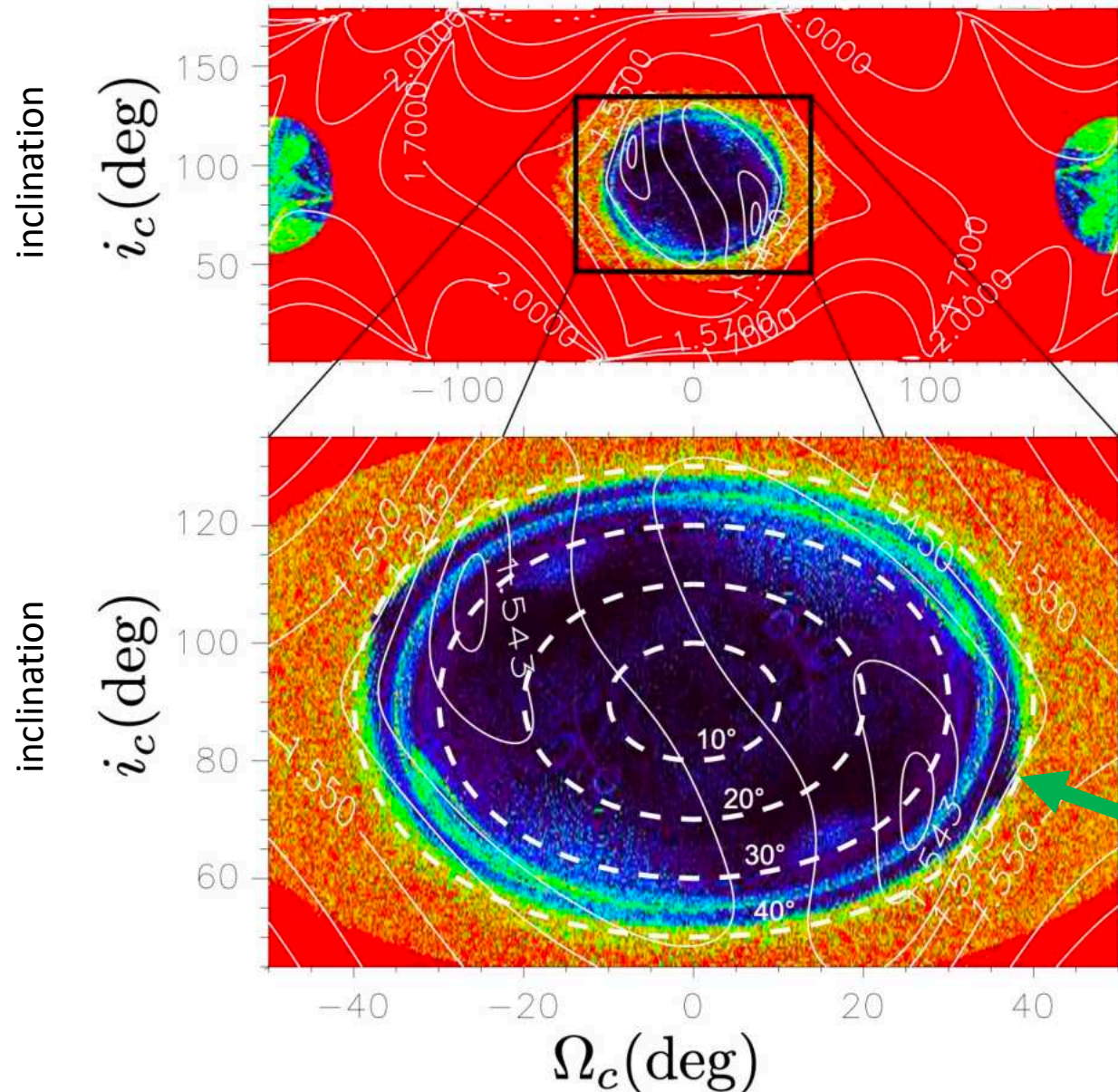
- N-body fit (following Correia et al. 2010) provides similar results as Keplerian fit

$$e_b = 0.22 \pm 0.06 \quad e_c = 0.36 \pm 0.09$$

- Stability analysis (following Laskar 1990, 1993) assuming co-planar orbits



First dynamical analyses



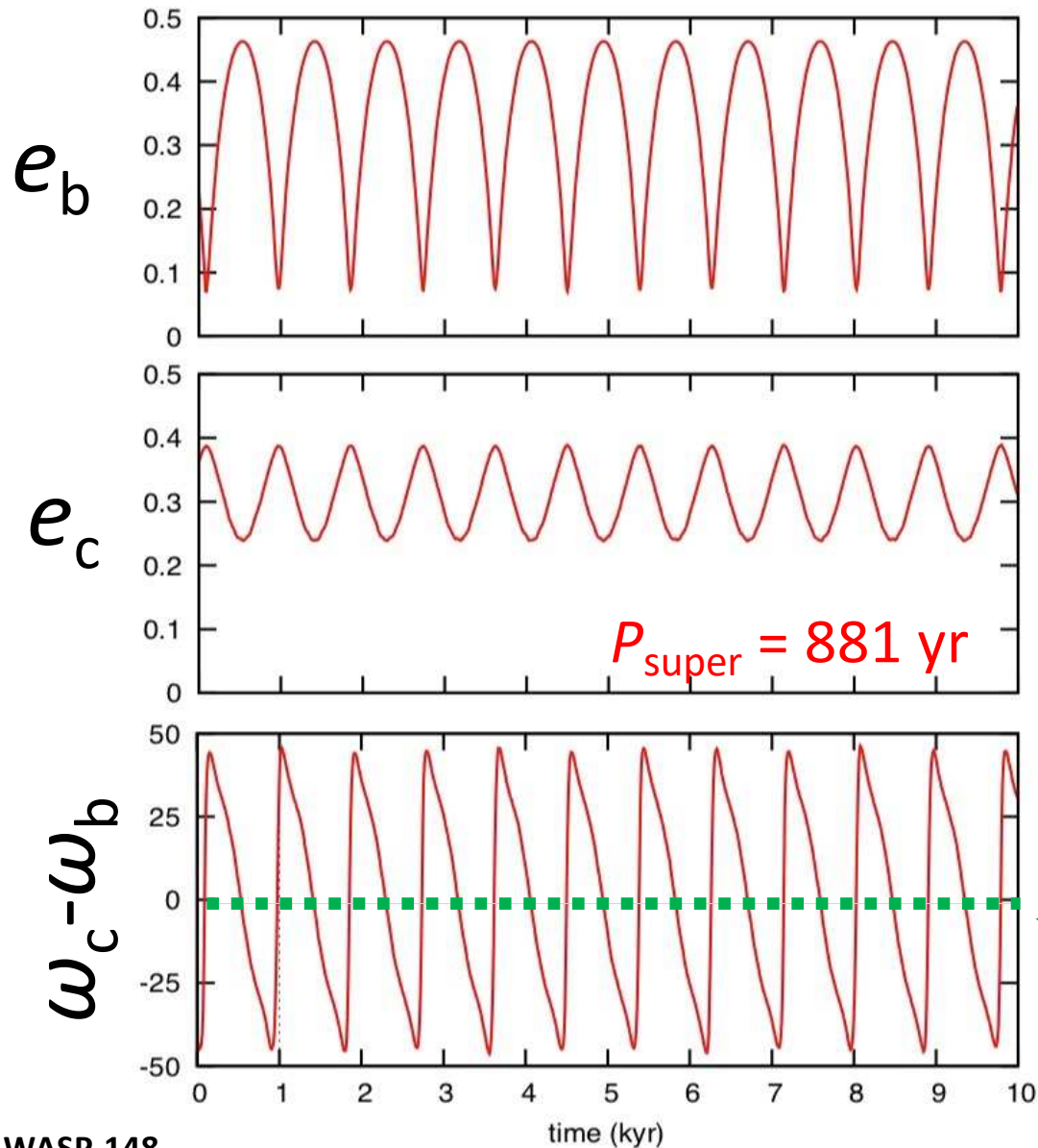
Stability analysis

Two poorly-constrained parameters in the system, both concerning the WASP-148c orbit:

- longitude of ascending node (Ω_c);
- inclination (i_c).

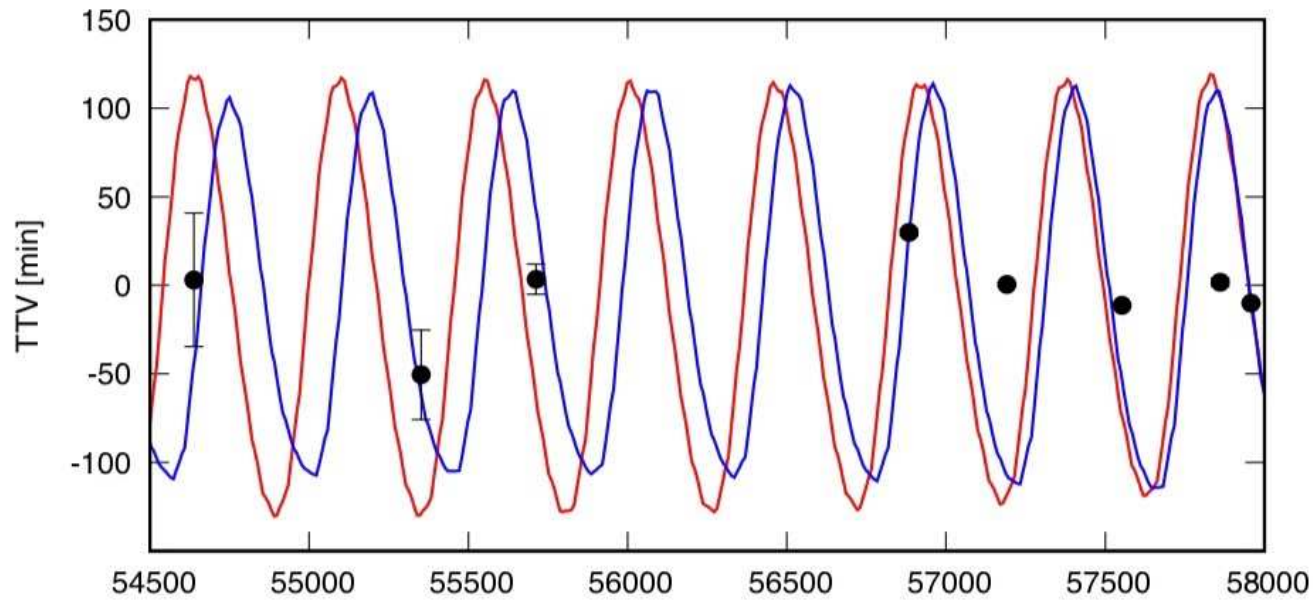
isolines of constant mutual inclination:
10, 20, 30, 40°

First dynamical analyses

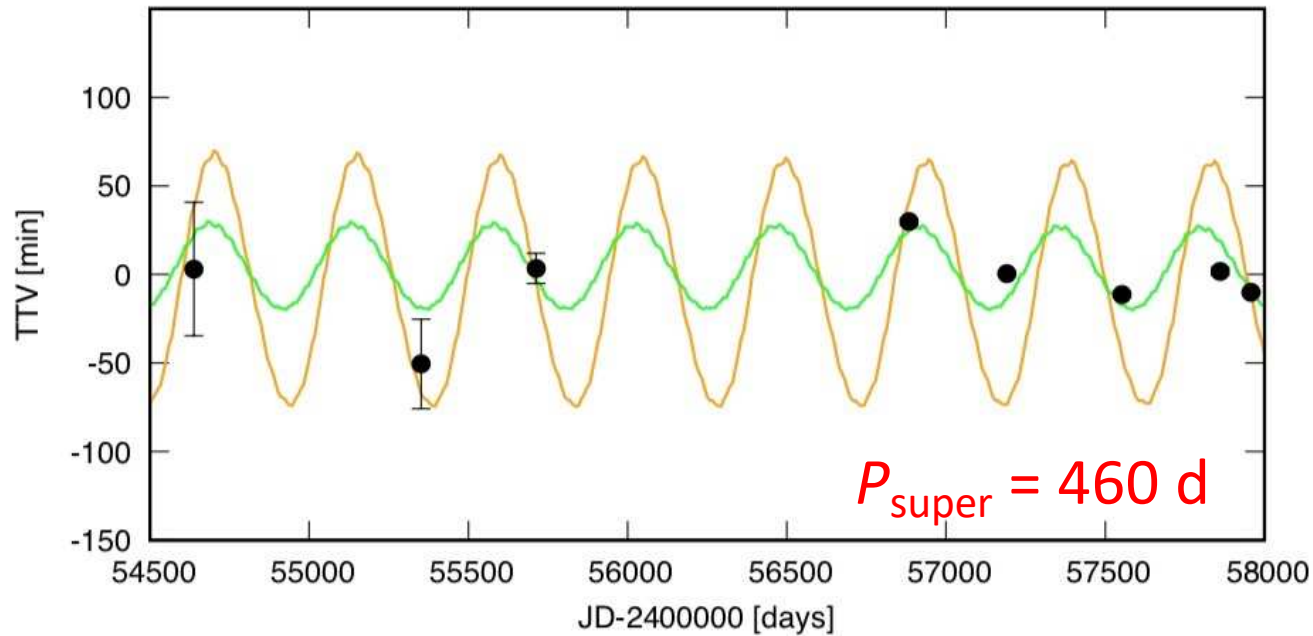


- strong coupling due to the proximity of the two orbits
- planets b and c both precess
- the two pericenters are locked, $\omega_c - \omega_b$ oscillates around 0°

First dynamical analyses



$$i_c = 90^\circ$$
$$i_c = 60^\circ$$



$$e_b = 0.18$$
$$e_c = 0.29$$

$$e_b = 0.11$$
$$e_c = 0.21$$

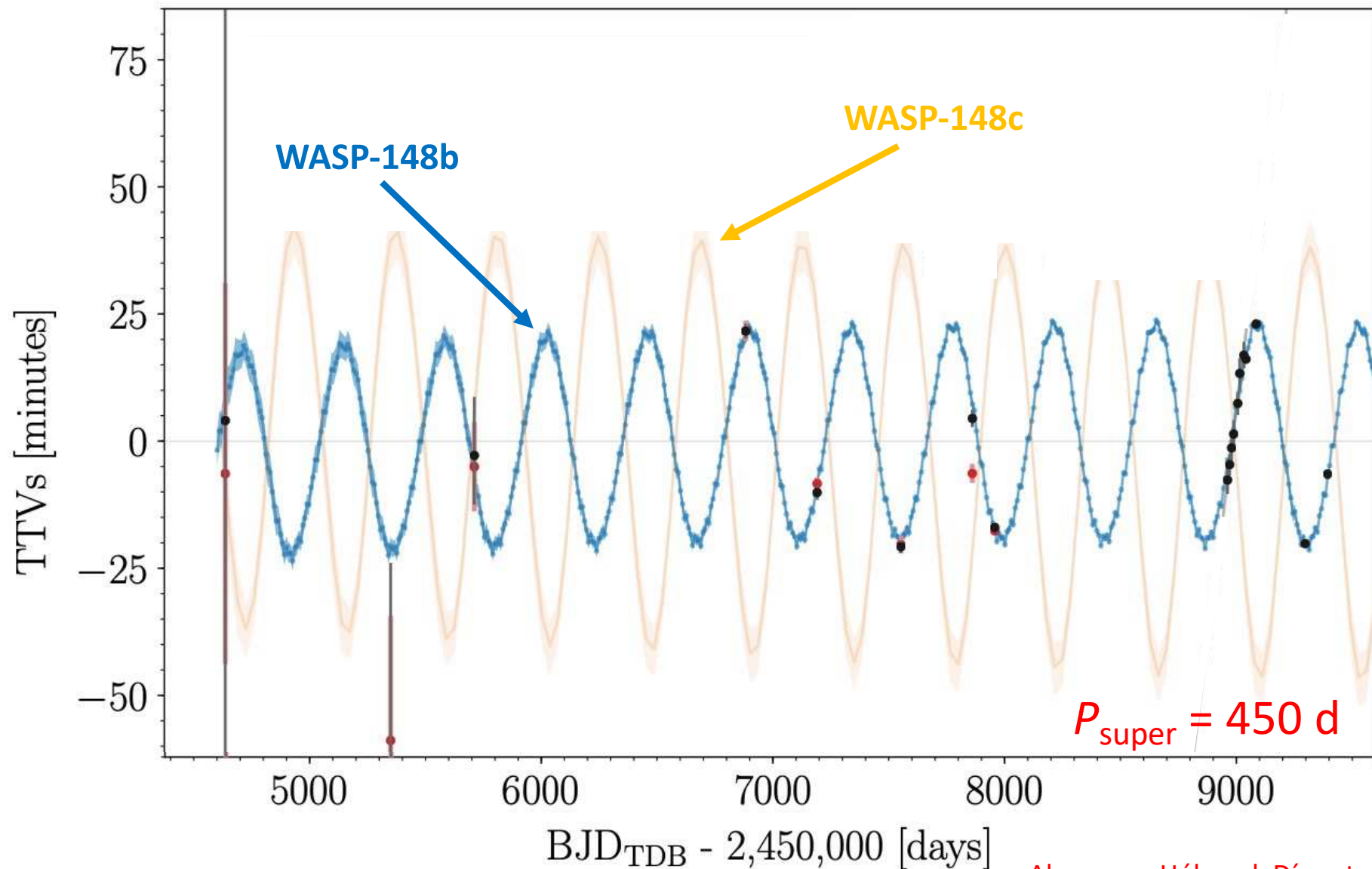
$$P_{\text{super}} = 460 \text{ d}$$

If $e=0$: TTVs < a few seconds

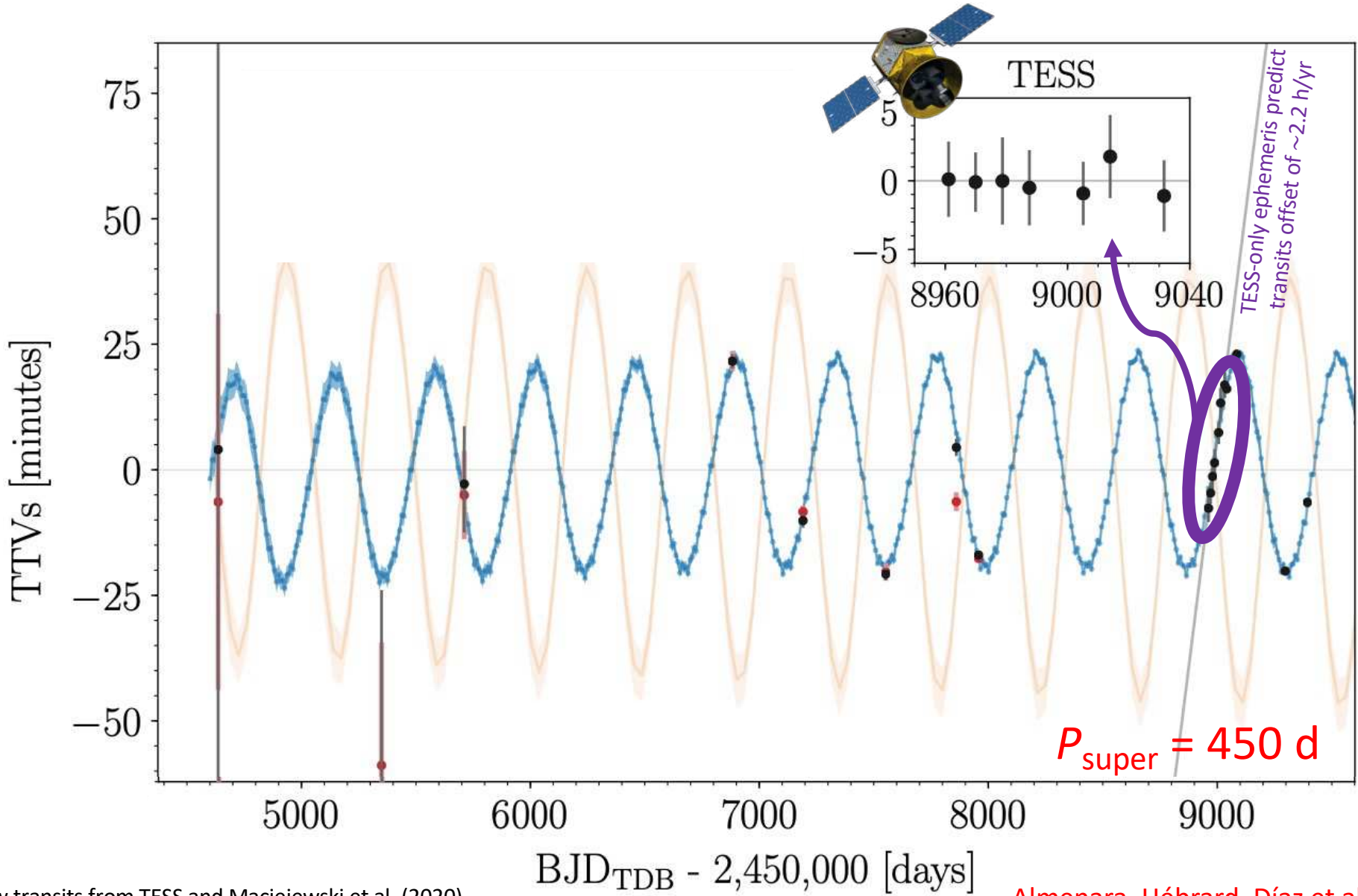
Hébrard, Díaz, Correia et al. (2020)

Photodynamical modelization

Carter et al. (2011), Almenara et al. (2018a,b)



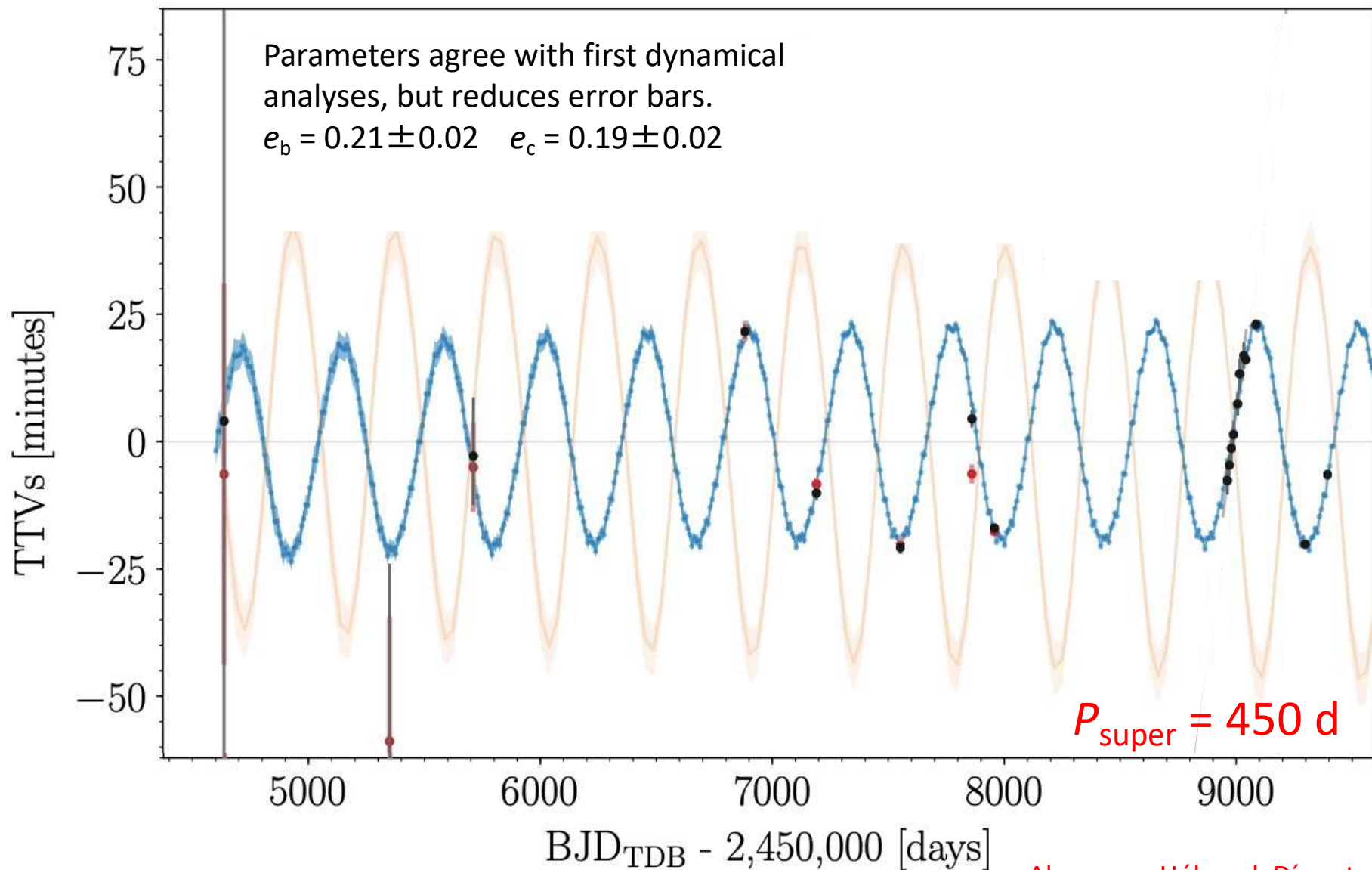
Photodynamical modelization



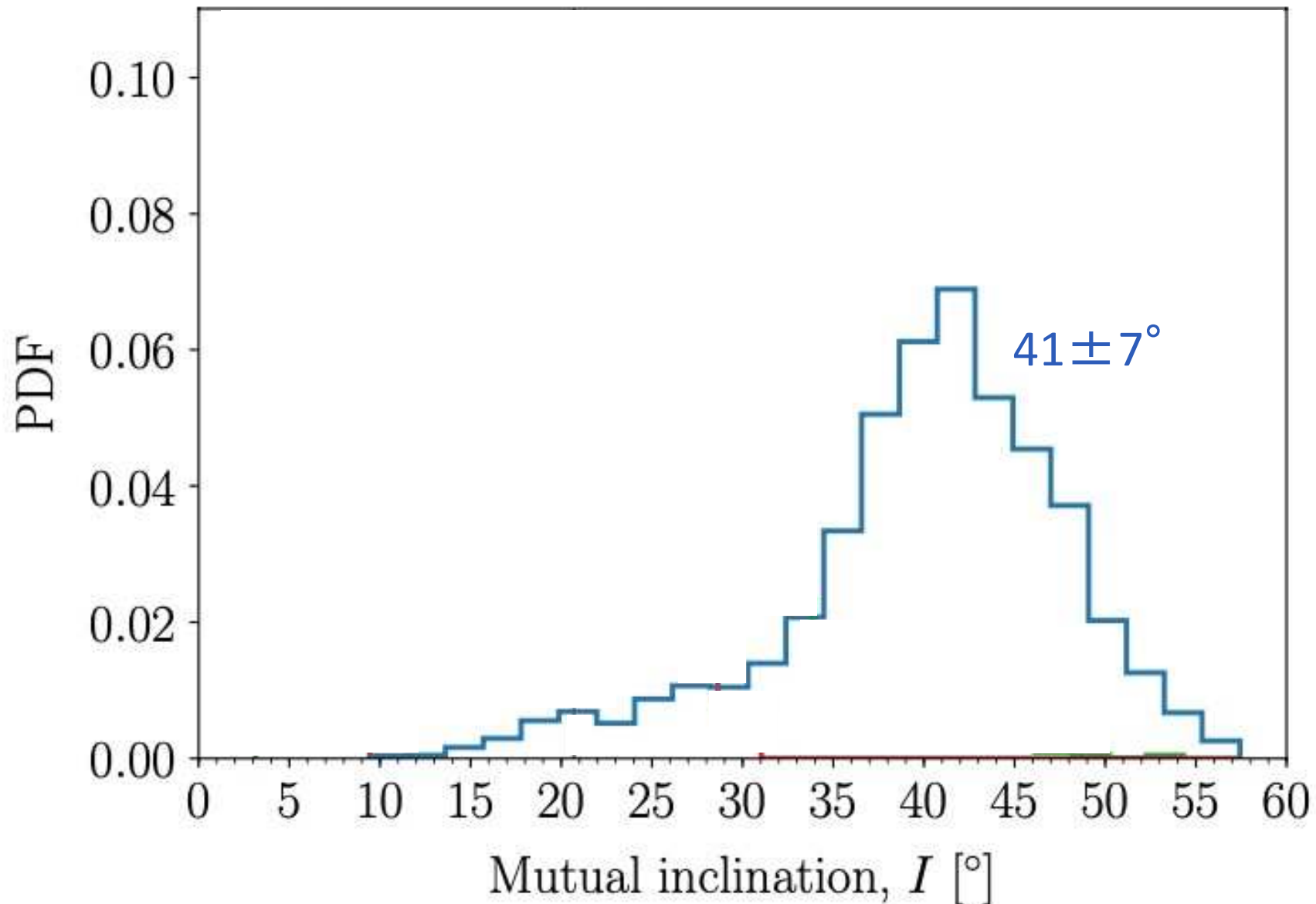
New transits from TESS and Maciejewski et al. (2020)

Almenara, Hébrard, Díaz et al. (2022)

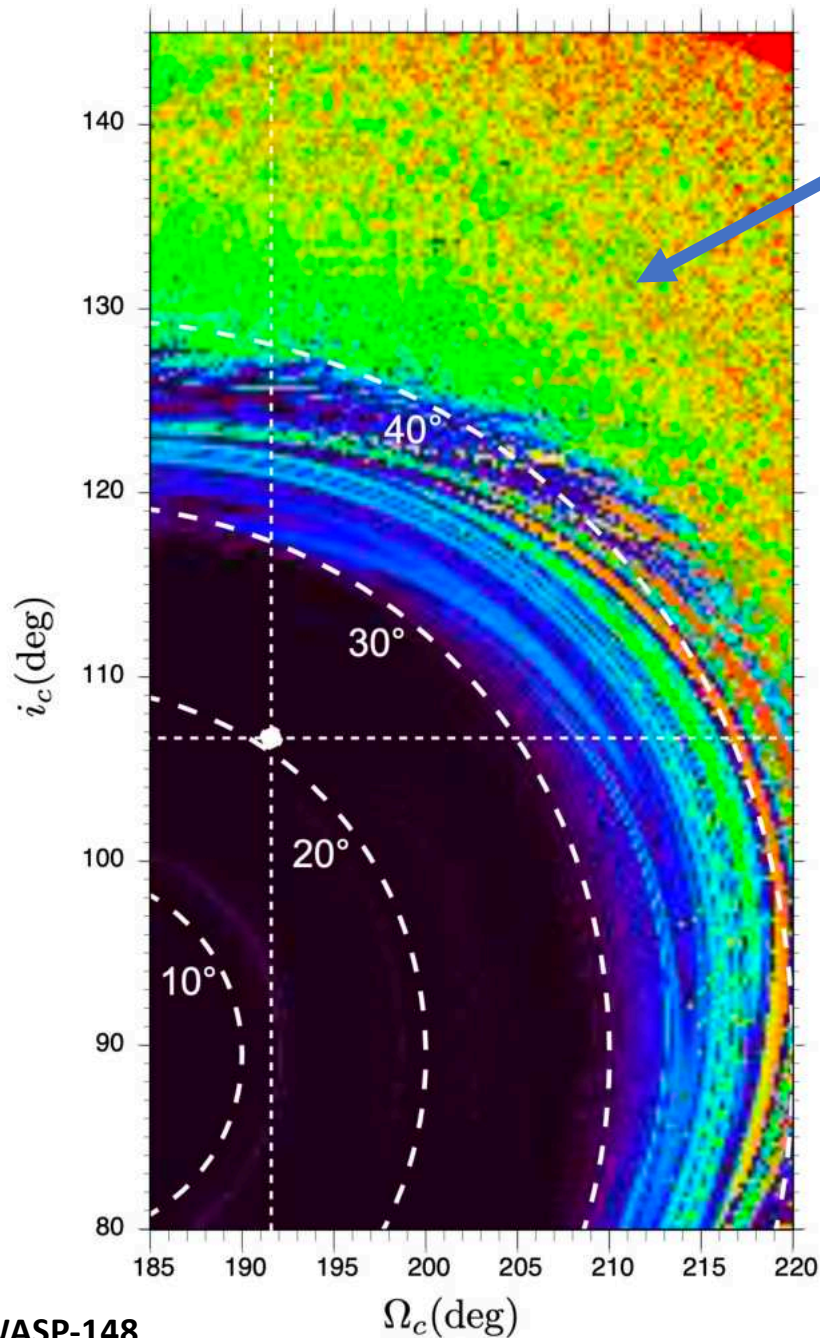
Photodynamical modelization



Mutual inclination of both planets?

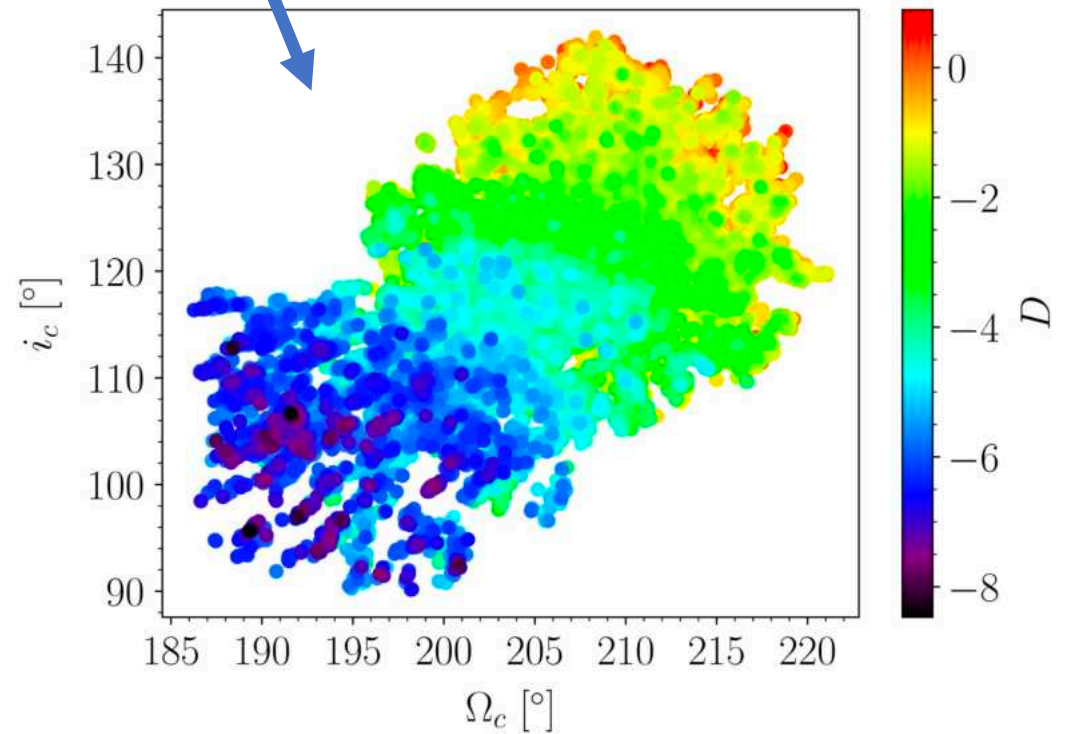


Stability of the system



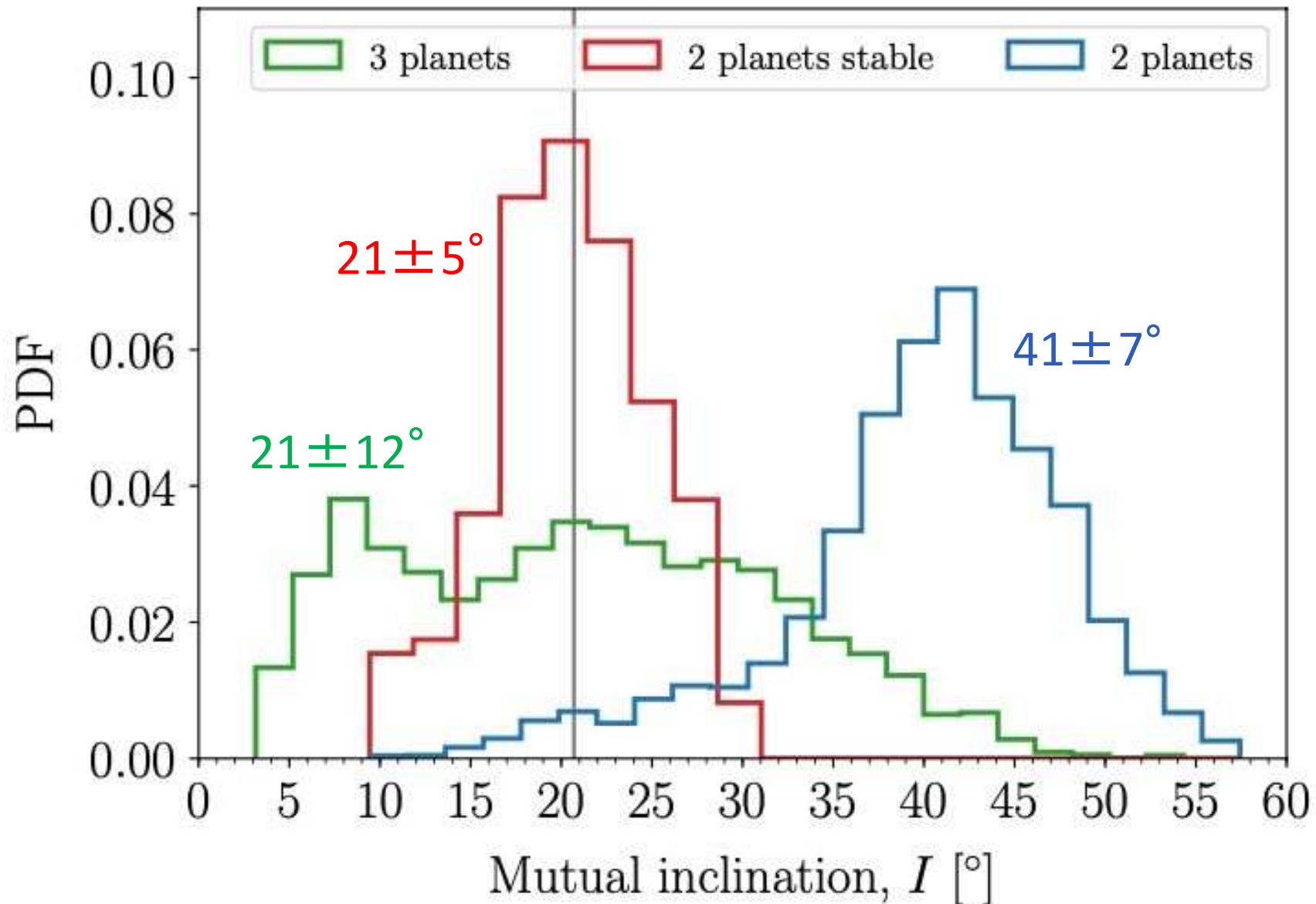
Two different ways to study stability:

- exploring the (Ω_c, i_c) space around the best solution;
- computing the stability at each step of the MCMC

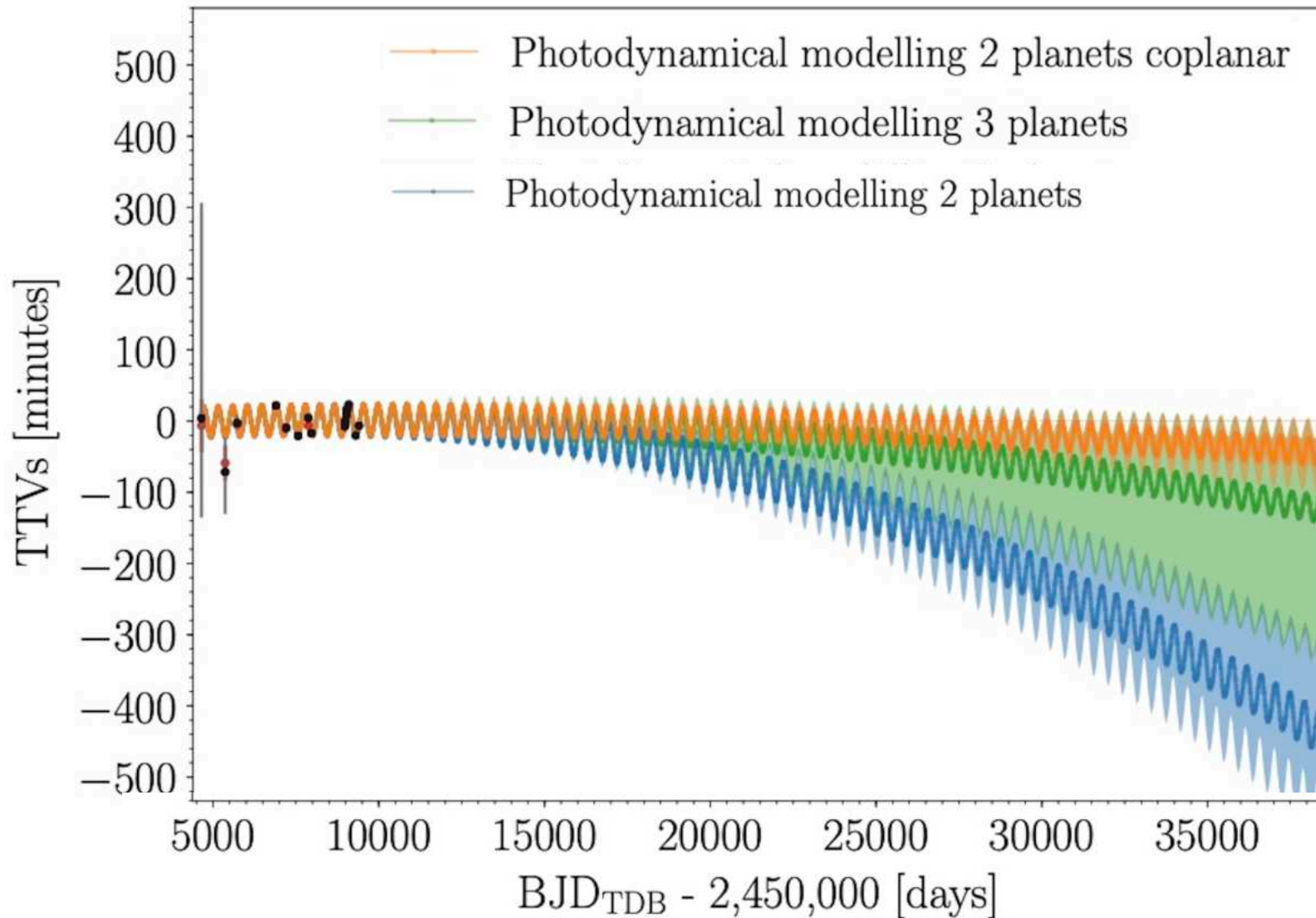


Both methods provide similar results

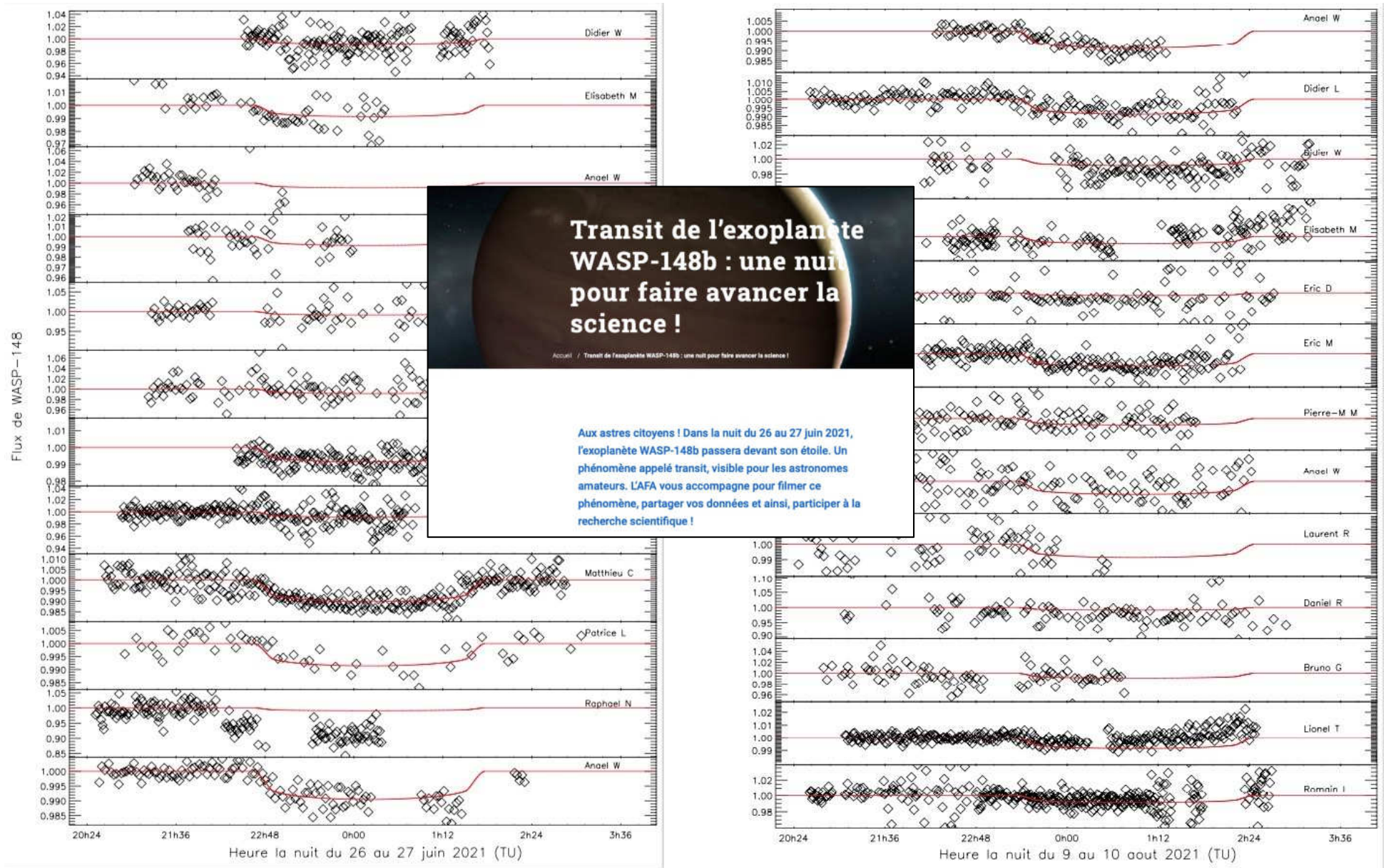
Mutual inclination of both planets?



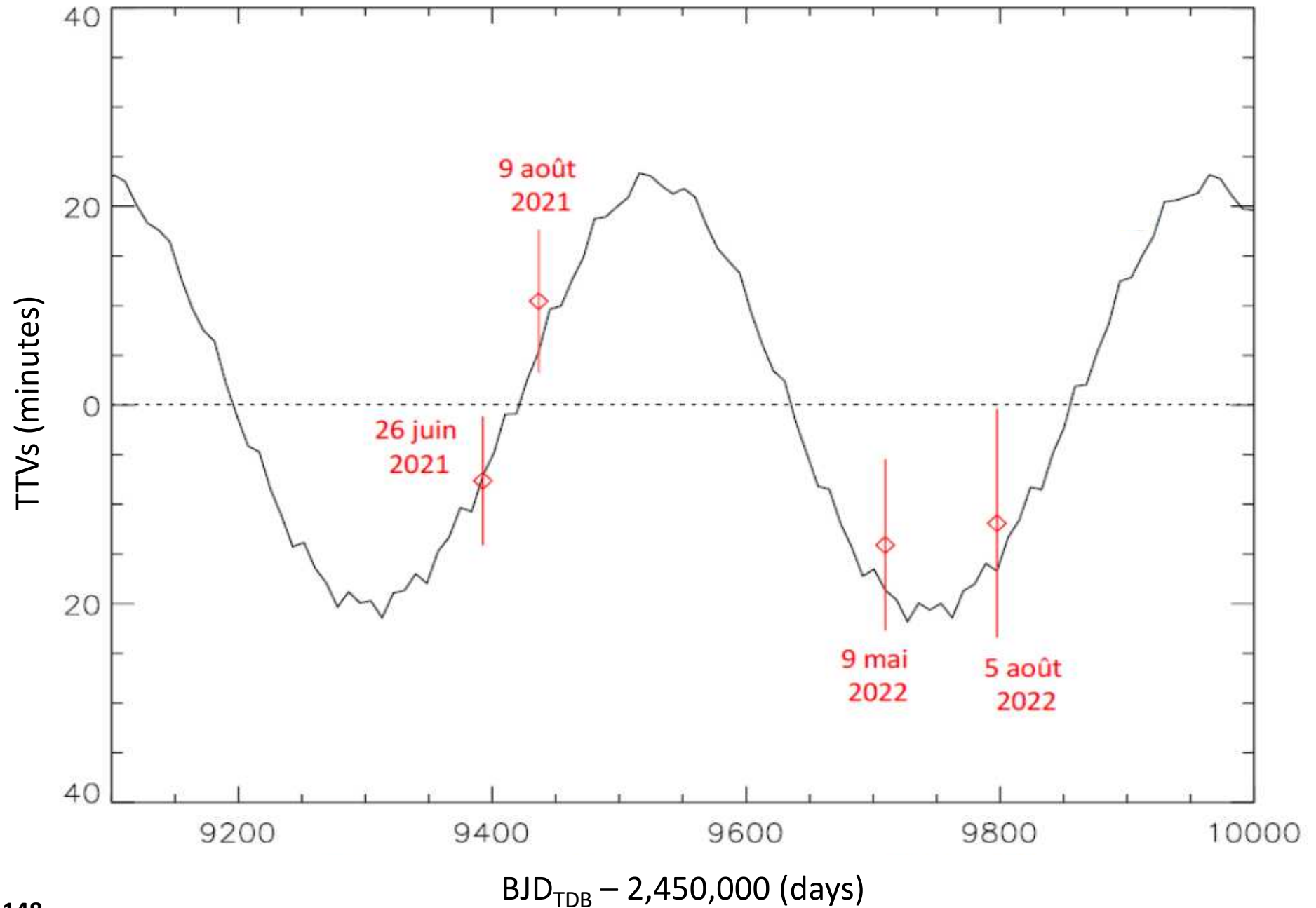
A third planet in the system?



TTV detection by volunteer astronomers

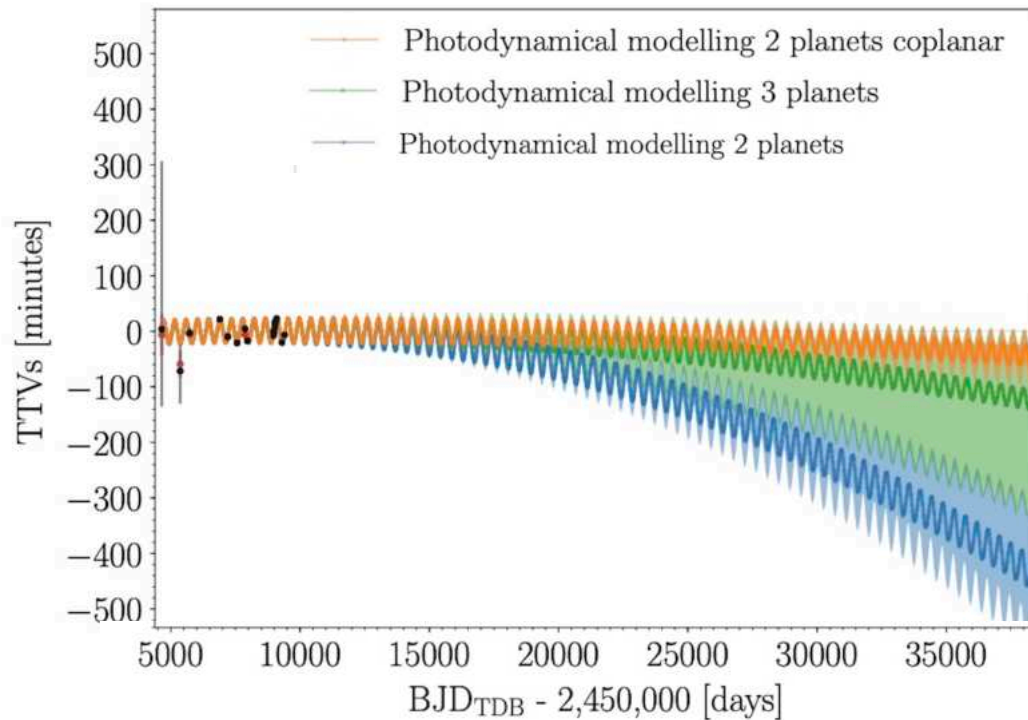


TTV detection by volunteer astronomers

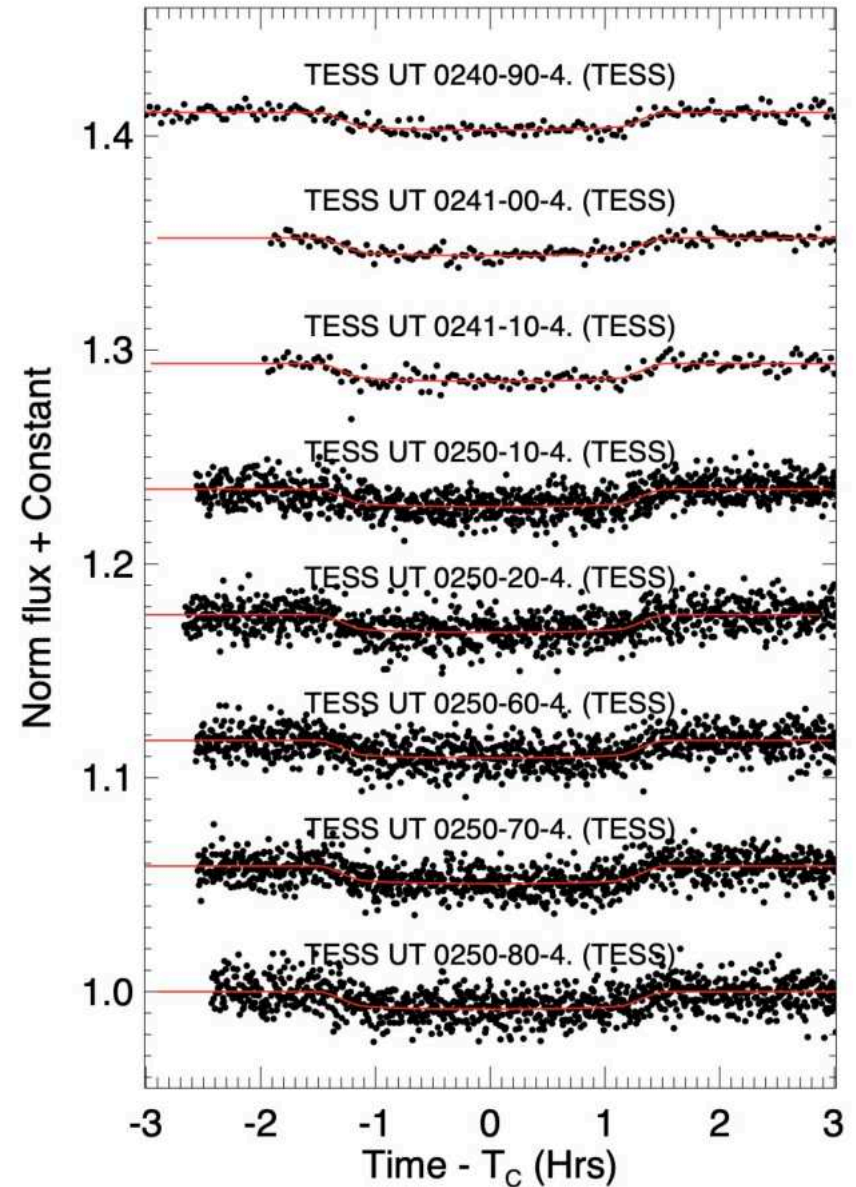


New TESS transits

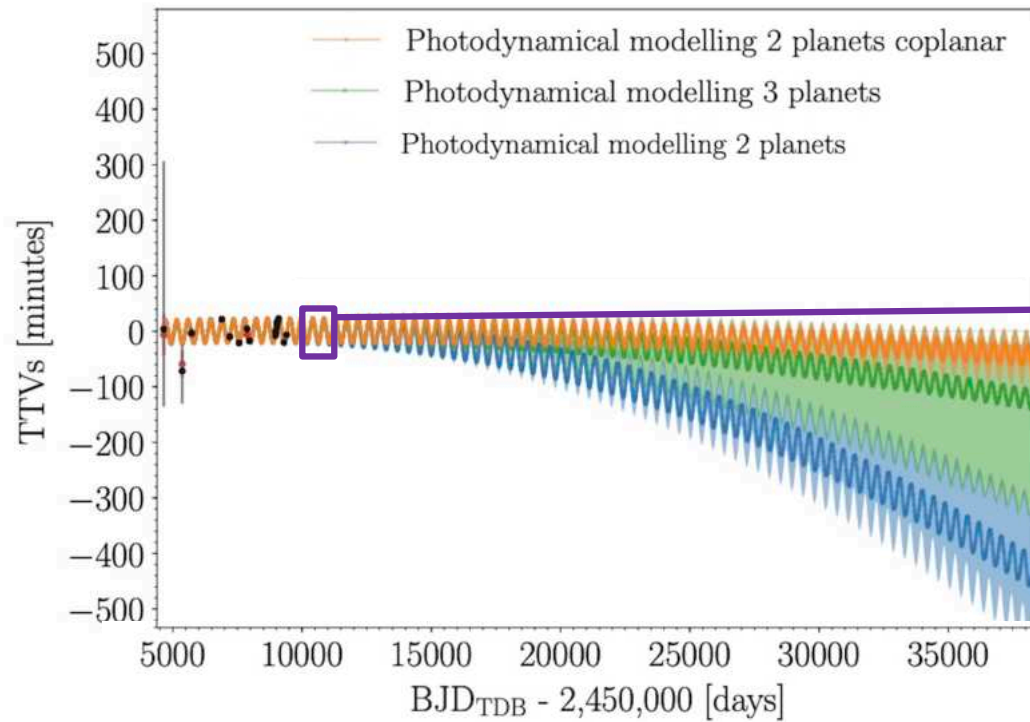
from Neda Heidari



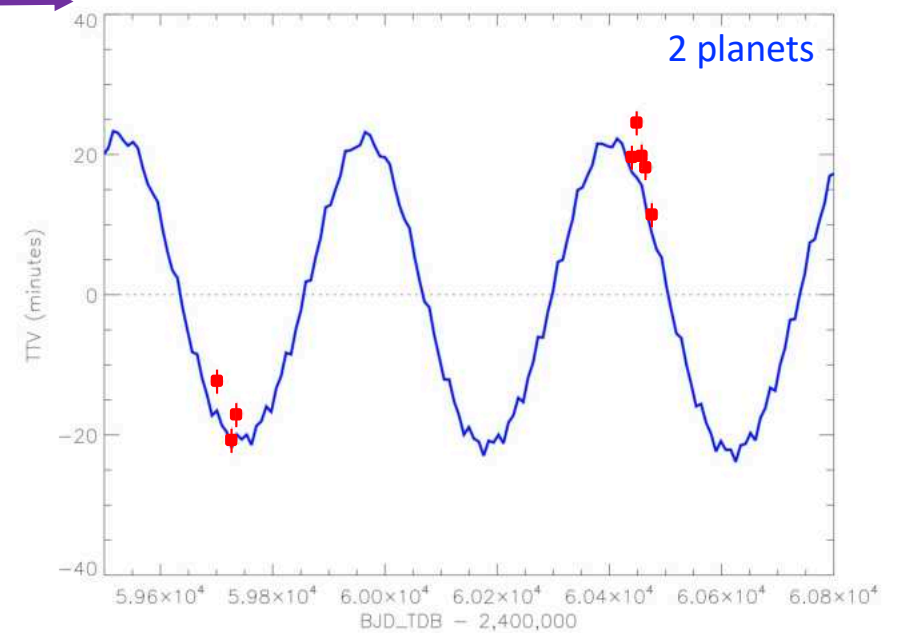
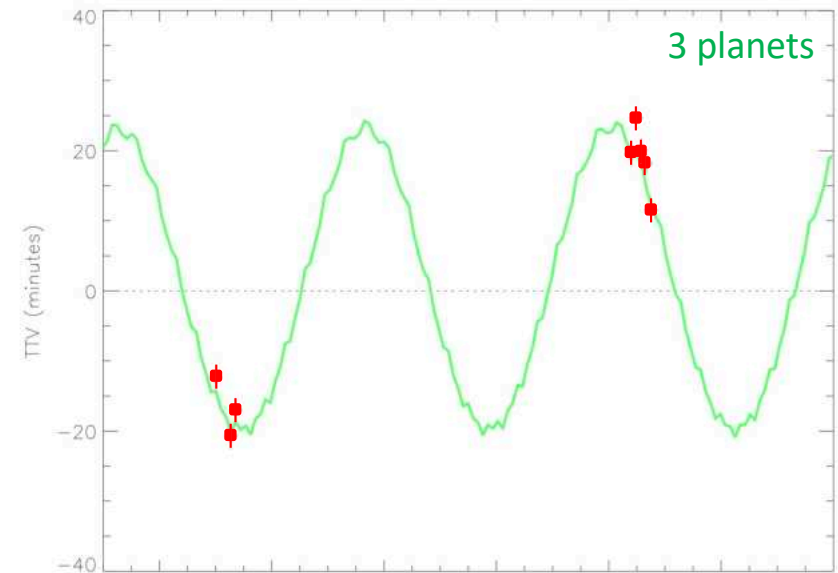
Almenara, Hébrard, Díaz et al. (2022)

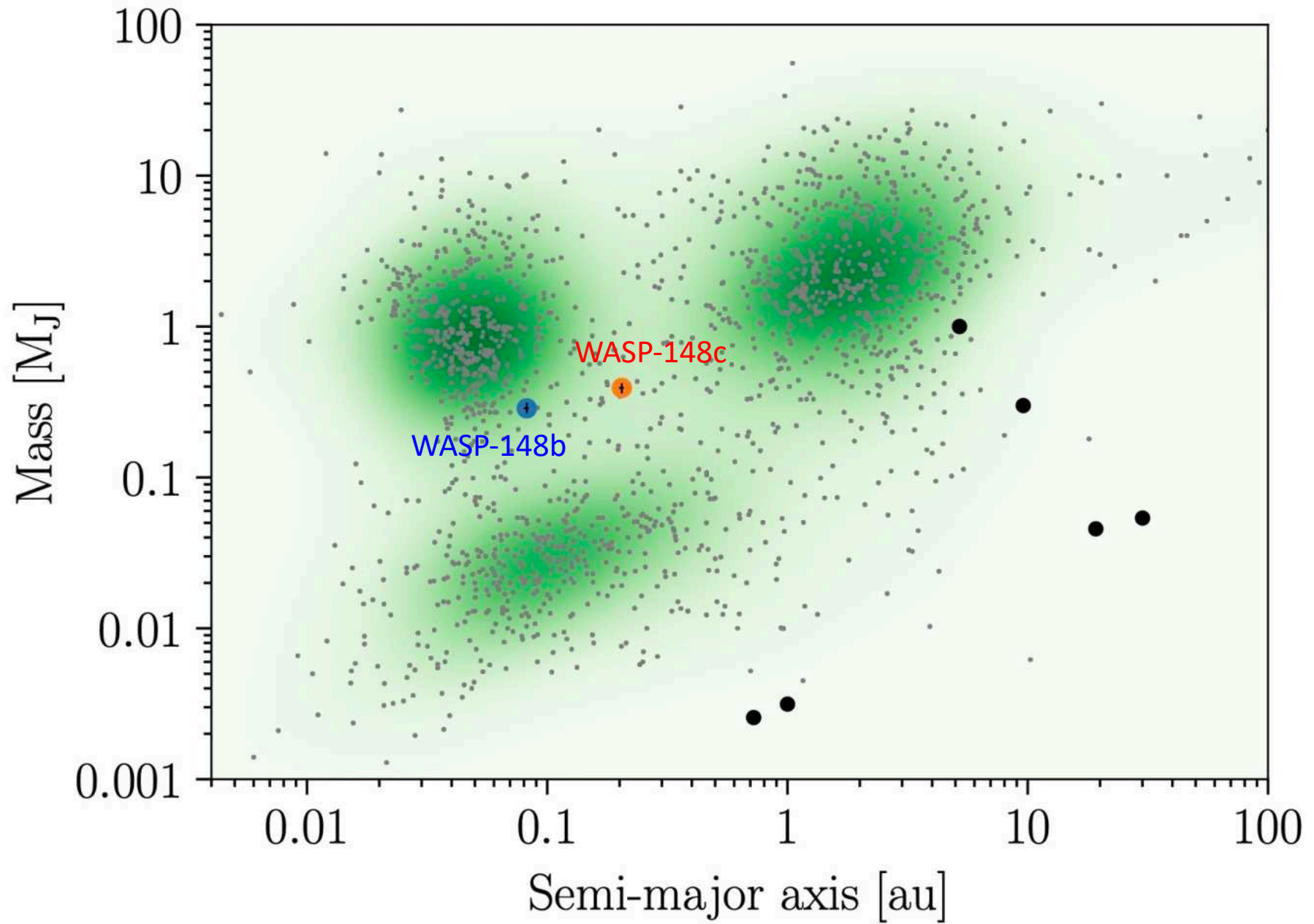


New TESS transits

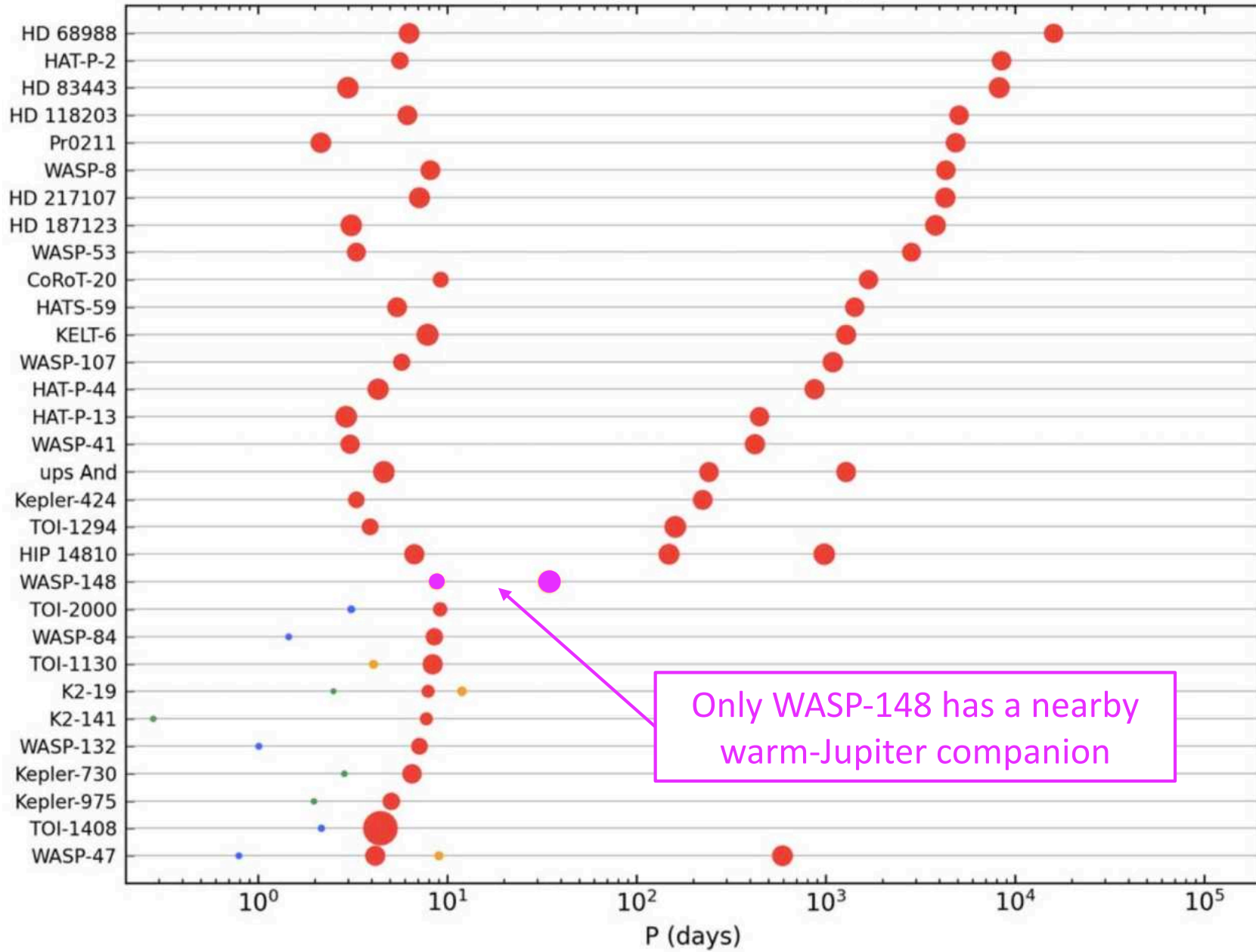


Almenara, Hébrard, Díaz et al. (2022)



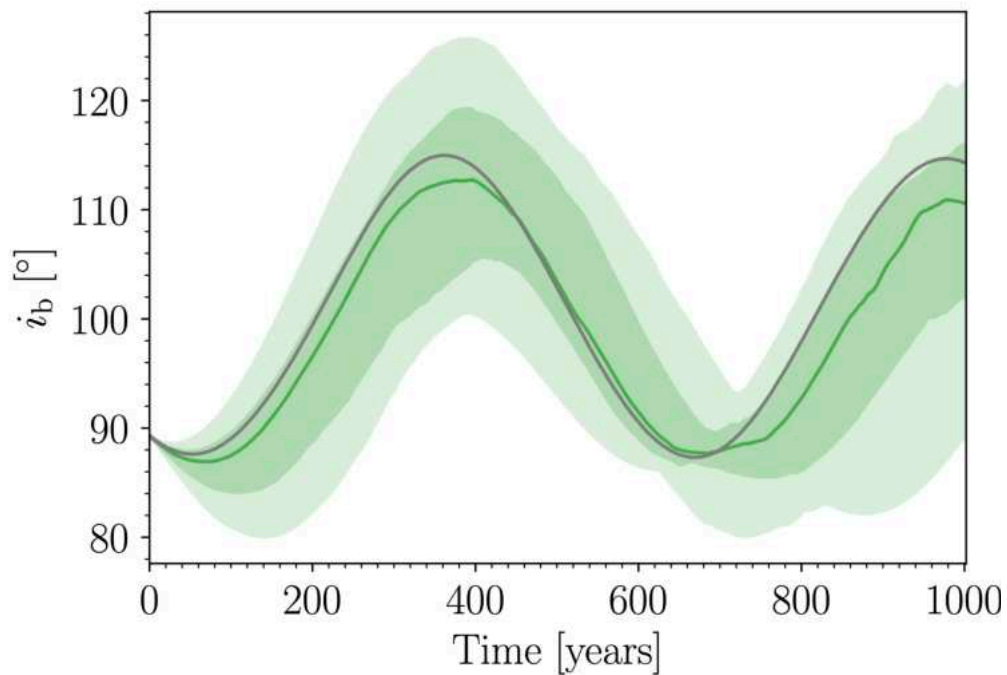


Multiplanet Systems with Hot Jupiters



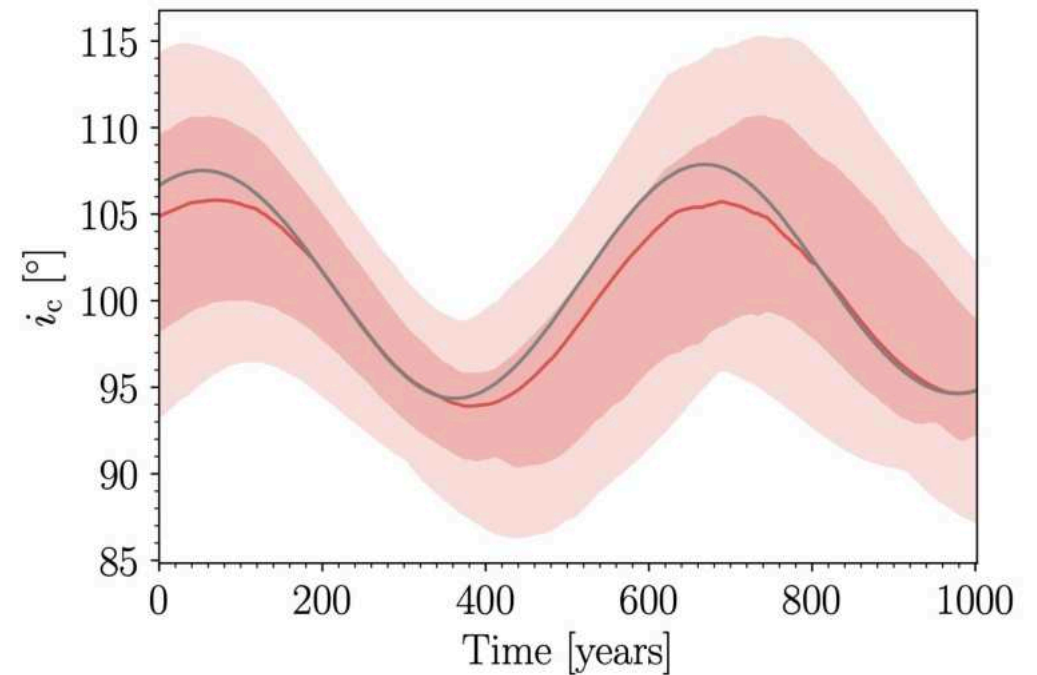
Orbits evolution?

WASP-148b won't transit anymore within 200 years...

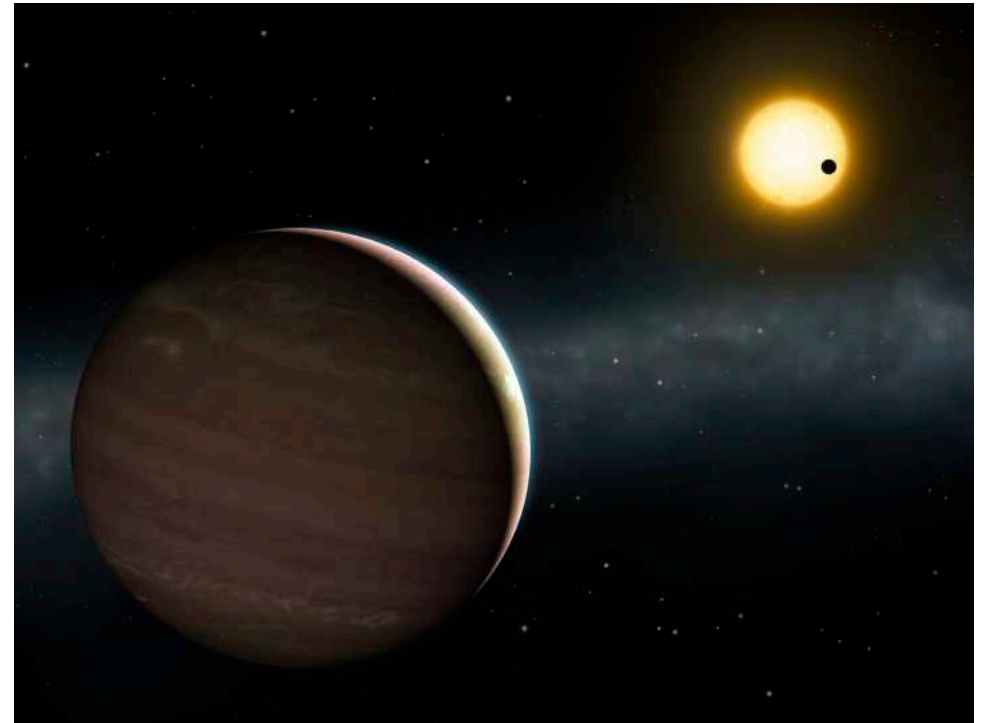


...then will transit again within 600 years !

WASP-148c never transits within 1000-year evolution



The exoplanetary system WASP-148



- Two giant planets
- Strong interactions
- Only known hot-Jupiter–warm-Jupiter pair
- A few-minute TTVs, observed from space and ground, including by volunteers astronomers
- Several dynamical approaches provide similar results
- Ongoing follow-up could characterize a third, outer planet
- To be continued for 200 years! (at least)