First results from the Warm Object Rossiter McLaughlin Survey (WORMS)

Alexis M. S. Smith, Szilárd Csizmadia, Jan-Vincent Harre

DLR Institute of Space Research (formerly Institute of Planetary Research), Berlin

Image: Danielle Futselaar & Franck Marchi, SETI Institute

Motivation

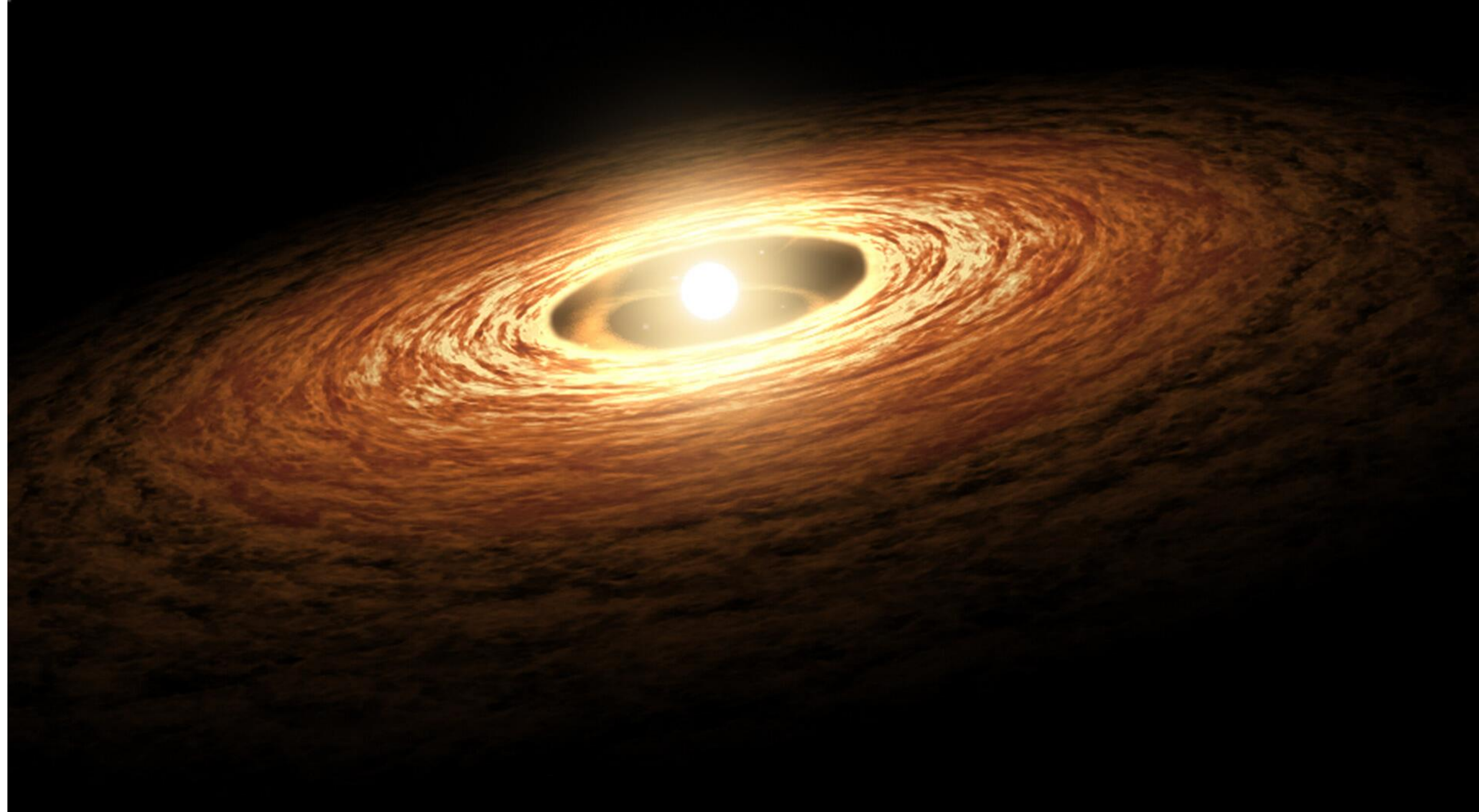


Image: NASA/JPL-Caltech

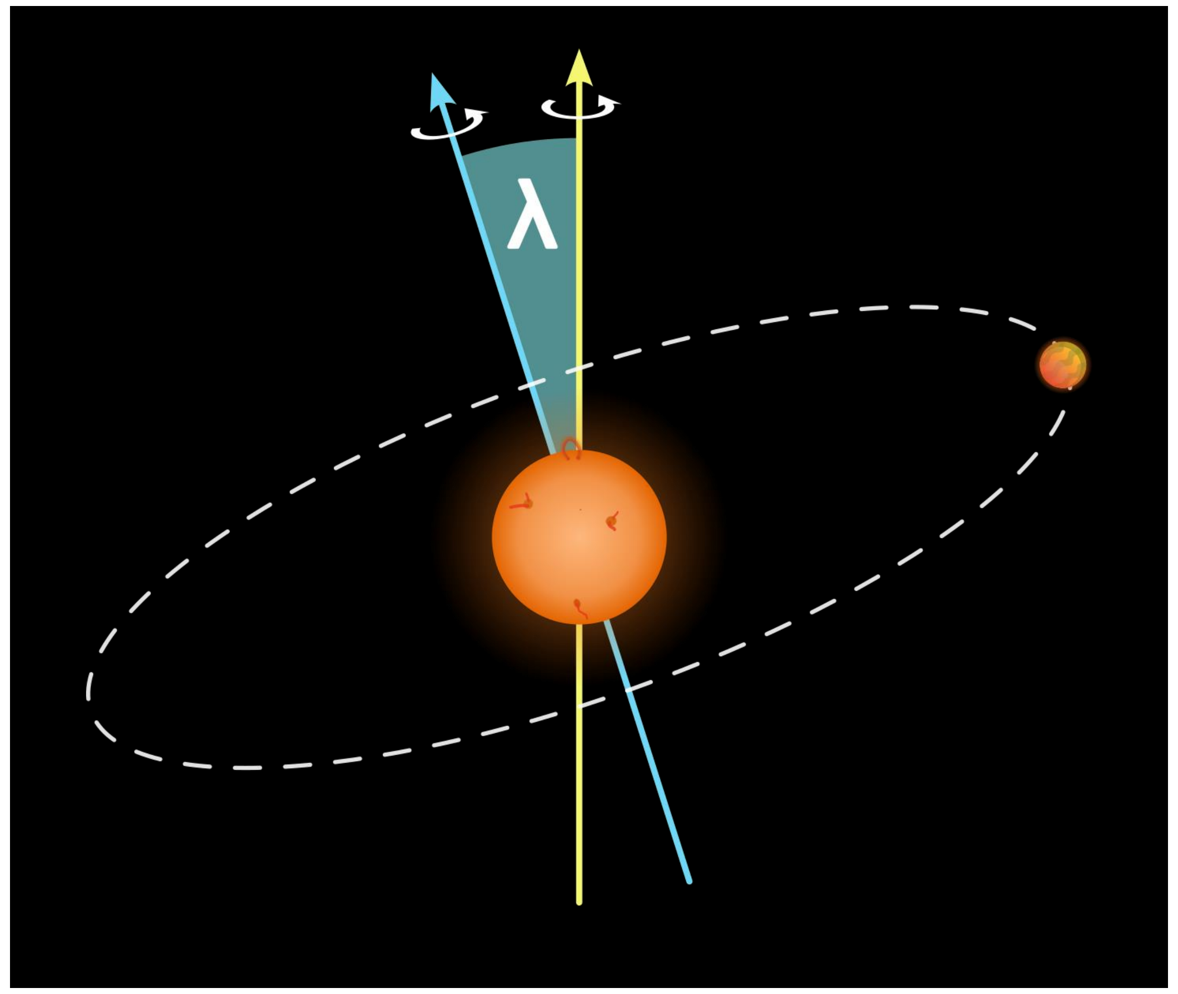
- Warm & hot giants probably formed as cool giants and migrated:
  - disc-driven migration → low-eccentricity, low-obliquity orbits
  - dynamic, high-eccentricity migration → high obliquity
- Important to understand inner architectures to couple to outer architectures that will be revealed by e.g. Gaia DR4
  - How does warm giant planet occurrence / obliquity / eccentricity / mass correlate with presence and properties of outer giant planets?
- Some evidence that warm Jupiters (WJ, $P \gtrsim 8$ d) might be a distinct population from the hot Jupiters (HJ, $P \lesssim 8$ d)
  - WJ more likely to have companion planets
  - orbital properties (obliquities, eccentricities)

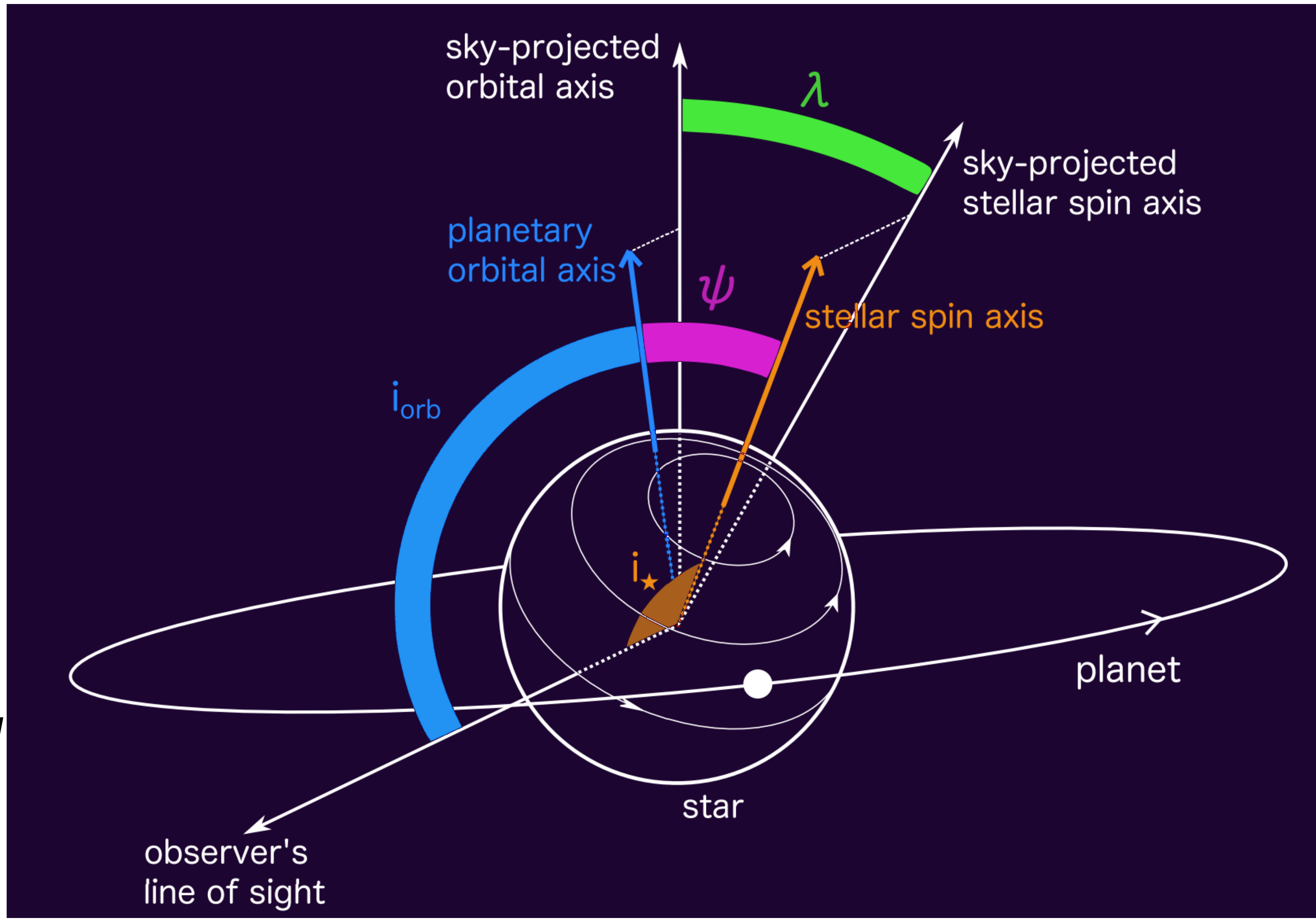
Stellar obliquity

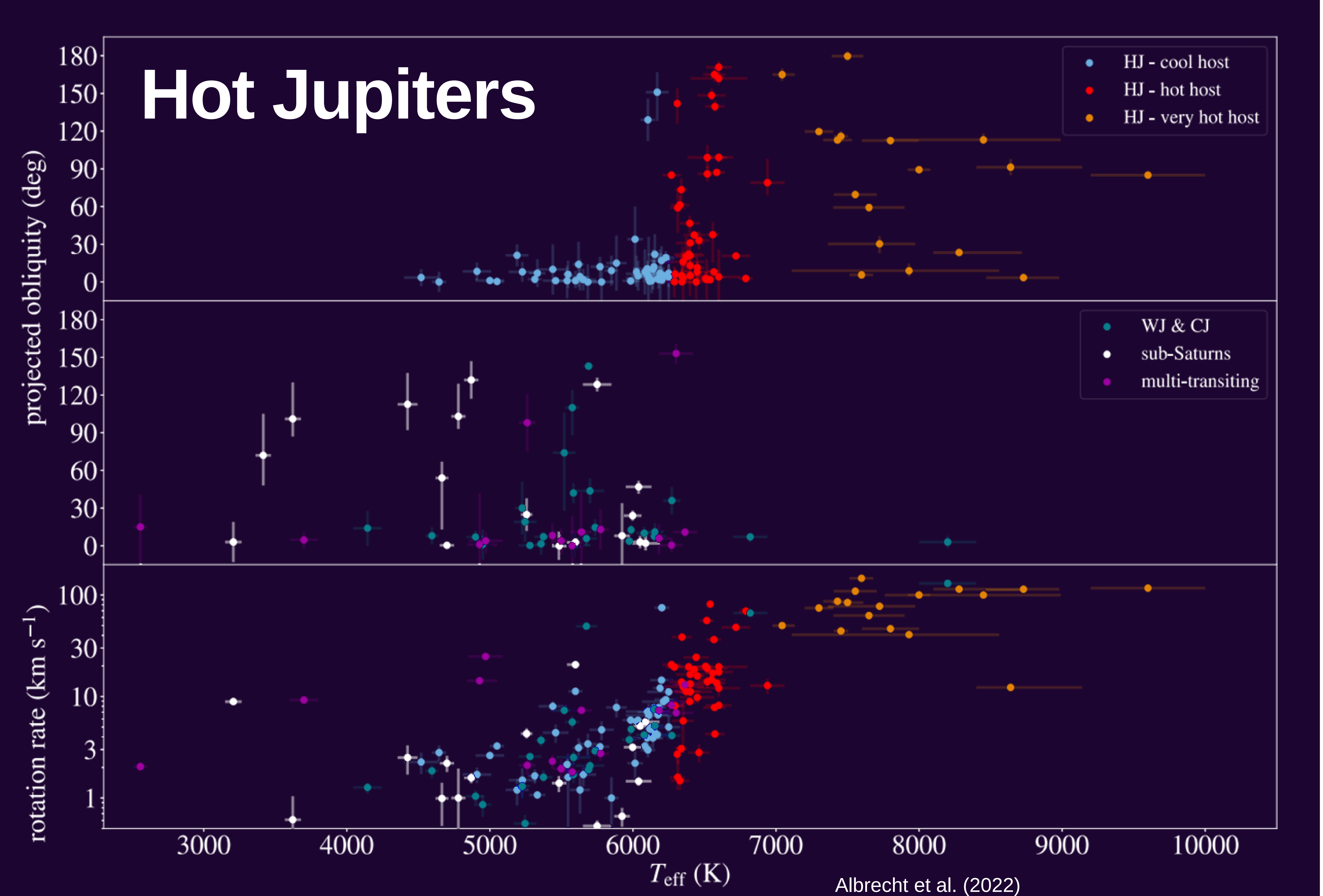
- The stellar obliquity, or spin-orbit angle, is a key tracer of migration history:
  - disc-driven migration should result in low obliquities
  - dynamical migration should result in high obliquities and eccentricities
- Tidal interactions between the planet and the star's convective zone may act to erase this primordial obliquity, if the planet is close enough to the star (e.g. HJs)
  - strong dependence on star — planet separation (e.g. Jackson et al. 2008)

$$\frac{1}{e}\frac{de}{dt} \propto a^{-13/2}$$

- (Holt)-Rossiter-McLaughlin effect (Holt 1893, Rossiter 1924, McLaughlin 1924) allows the measurement of the *sky-projected* obliquity, λ.







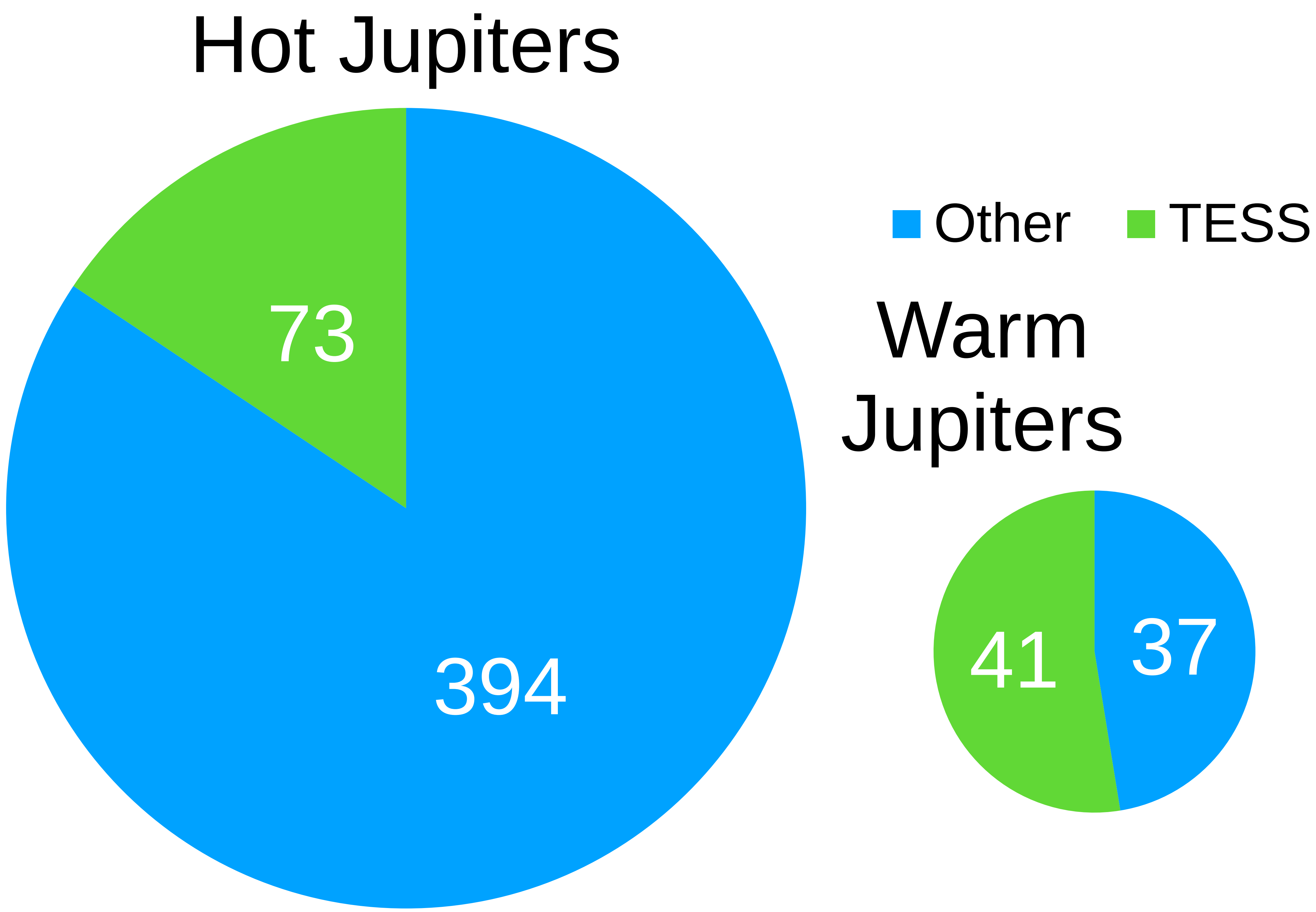
Albrecht et al. (2022)

- HJs - generally aligned around cool stars, often misaligned around hot stars
  - interpreted as tidal realignment of HJs orbiting cool stars (Winn et al. 2010)

The existing sample

WJs with measured obliquity

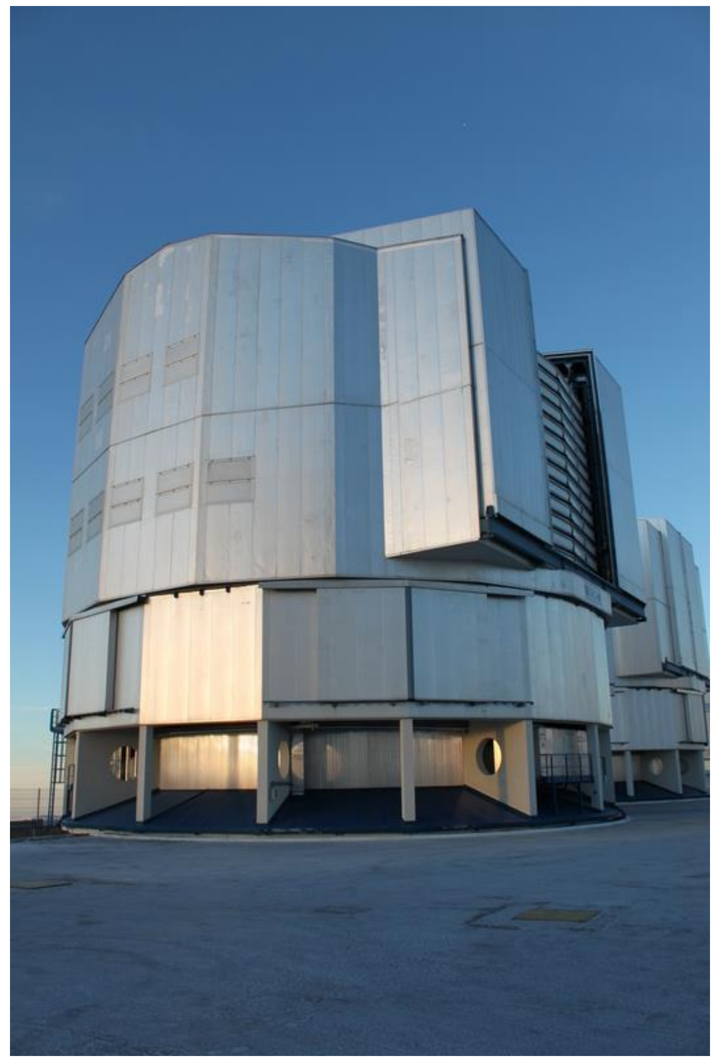
- Sample of WJs with obliquity measurement is small
  - fewer WJs known (harder to detect than HJs, particularly from ground)
  - difficult to schedule RM observations (typically ~1 chance per year per observatory)
  - From 1st WJ RM (Cochran et al. 2008) to 2023: 14 systems measured
  - Most WJs appear to be aligned (low obliquity)
  - more measurements needed!

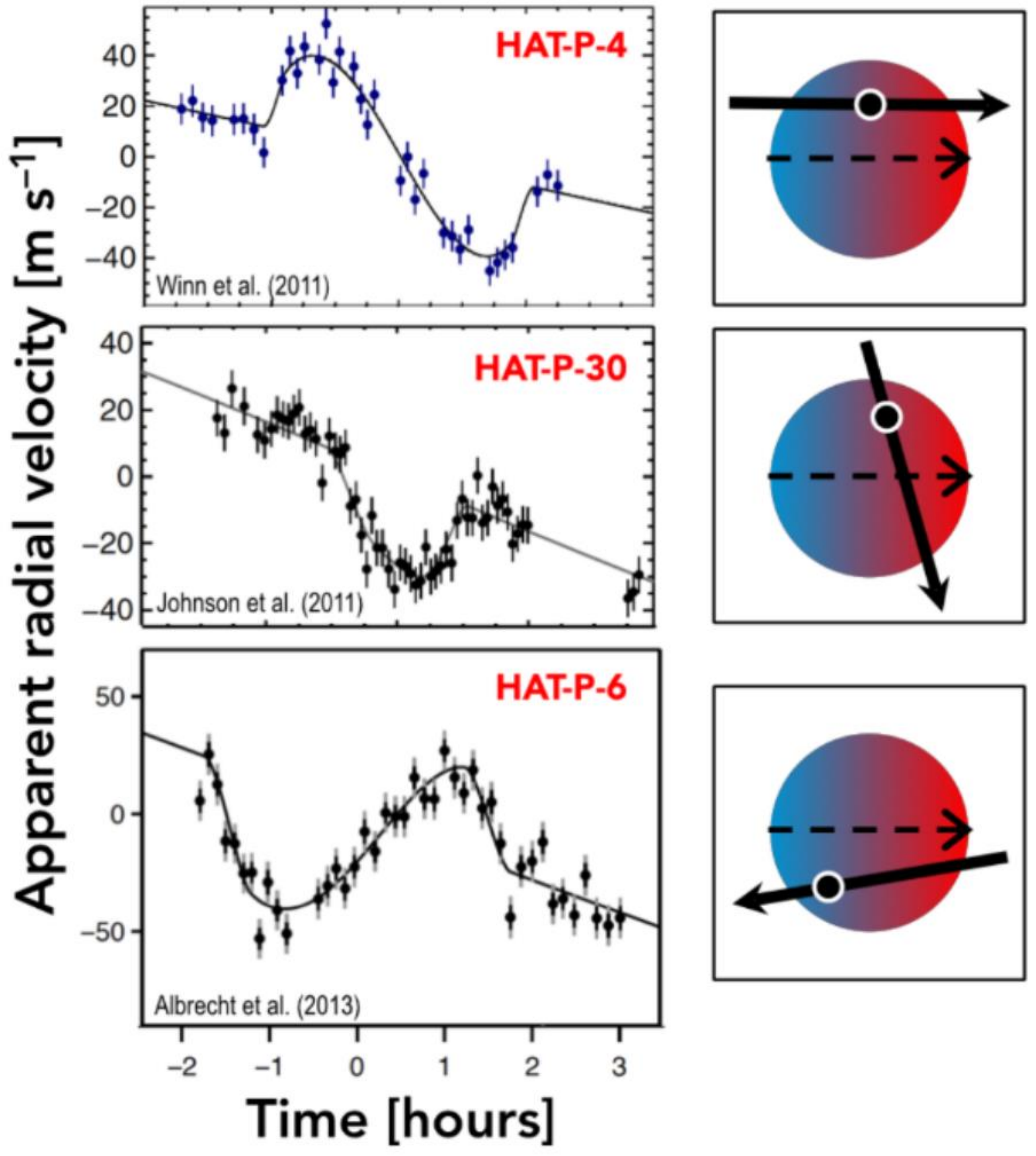


- Source: NASA Exoplanet Archive (2024 May)
- Transiting planets with:
  - $0.3 < M_p/M_{Jup} < 13$
  - $R_p/R_{Jup} > 0.5$
  - $P/d < 8$ (HJs)
  - $8 < P/d < 100$ (WJs)

Increasing the sample size

- To increase the sample of warm Jupiters with obliquity measurements, we initiated a monitoring programme with the VLT/ESPRESSO (112.2617, PI: Smith) – submitted 2023 March
- unbiased sample of warm Jupiters:
  - ESPRESSO capable of measuring at low *v*sin*i*
  - no requirement for short transits that fit into a single night: 2x partial RMs
  - no preference for single or multi-planet systems
- 11 targets over 4 semesters (8 in a single night, 3 spread over 2 nights) without previous* RM measurement
- Simultaneous photometry (for ephemeris refinement, stellar activity monitoring) from **NGTS**, TRAPPIST-South (Mathilde Timmermans), LCOGT (David Anderson)
- 8 targets successfully observed (2024 March – 2025 Sept). Two targets lost to bad weather, 1 target to be observed (Jan. 2026).
- Two targets will be observed with HARPS-N in November / December 2025



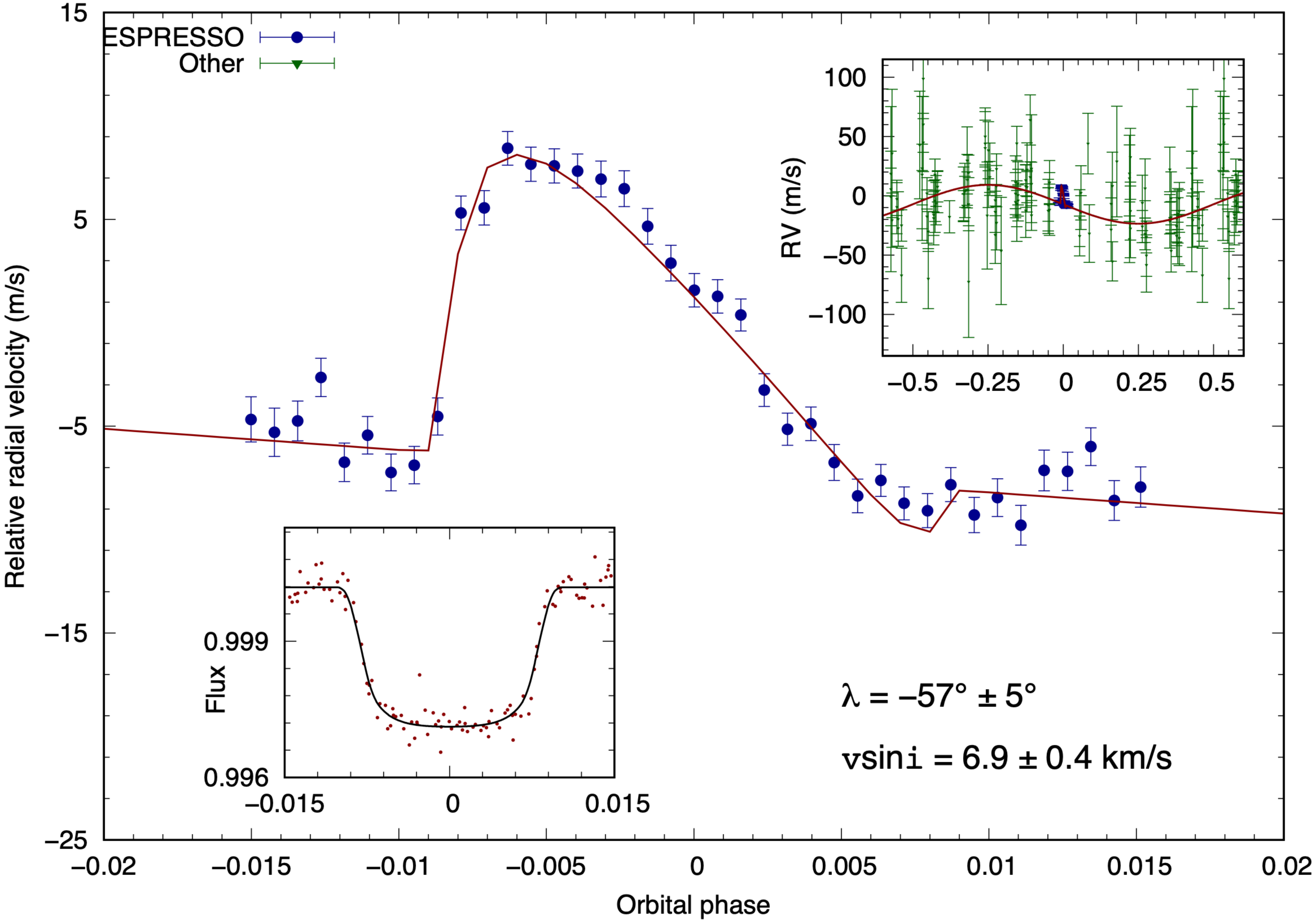


Colomer et al. (2019)

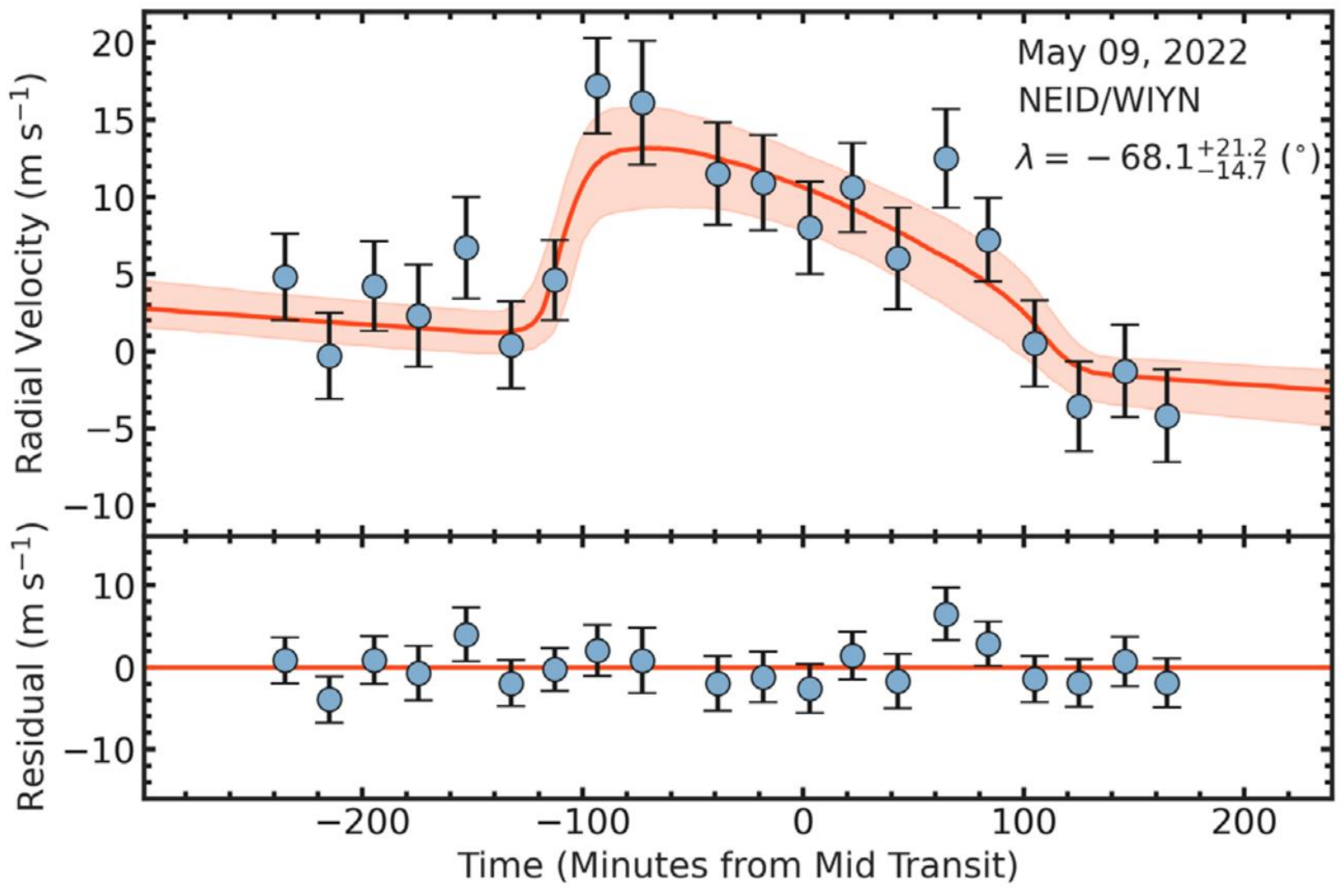
TOI-1842 b

PRELIMINARY

P = 9.57 d (Wittenmyer et al. 2022)



- Significant misalignment
- Our result (λ = -57° ± 5°) is consistent with Hixenbaugh et al. (2023): λ = -68.1° +21.2° -14.7°
- [ESPRESSSO error bars 3-4x smaller, 2x as many points]

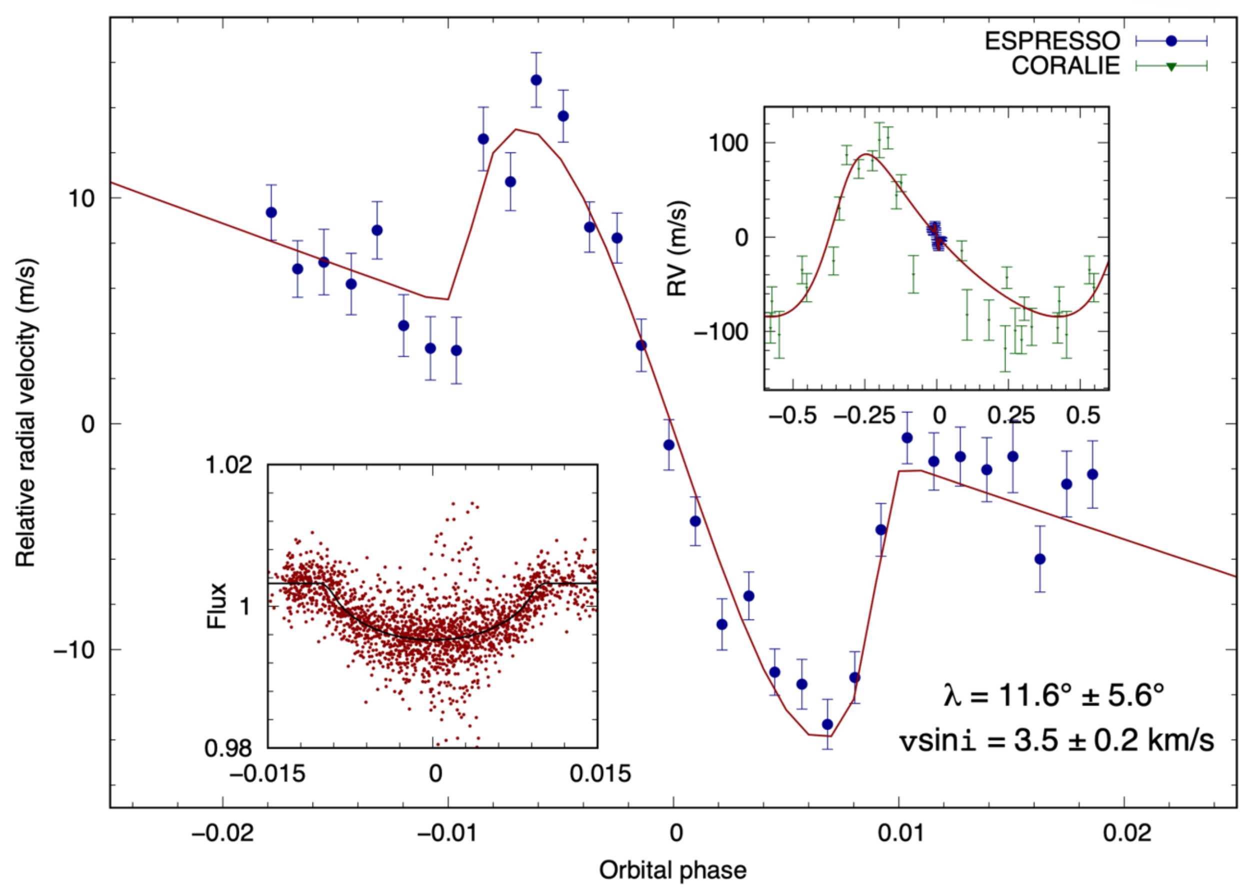


Hixenbaugh et al. (2023)

WASP-185 b

PRELIMINARY

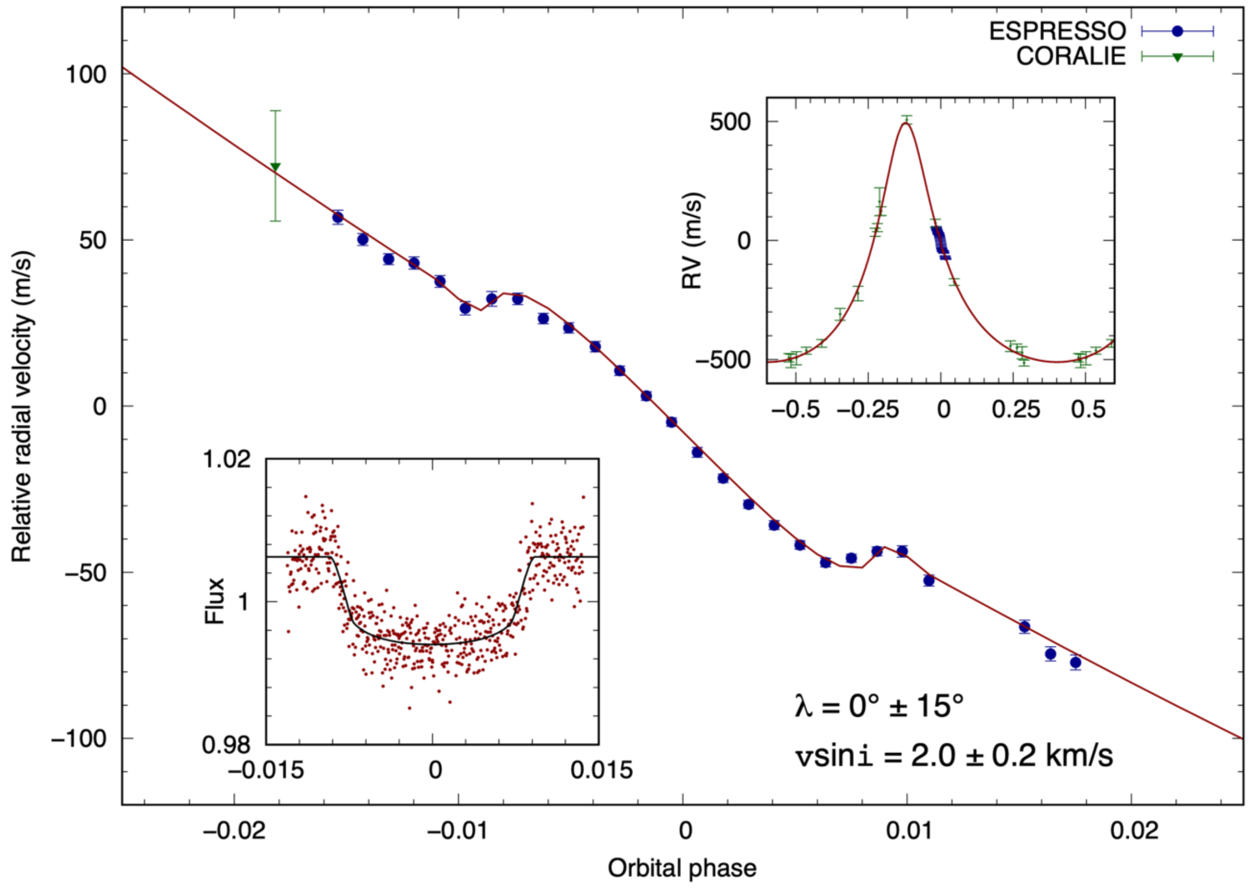
P = 9.39 d (Hellier et al. 2019b)



WASP-162 b

PRELIMINARY

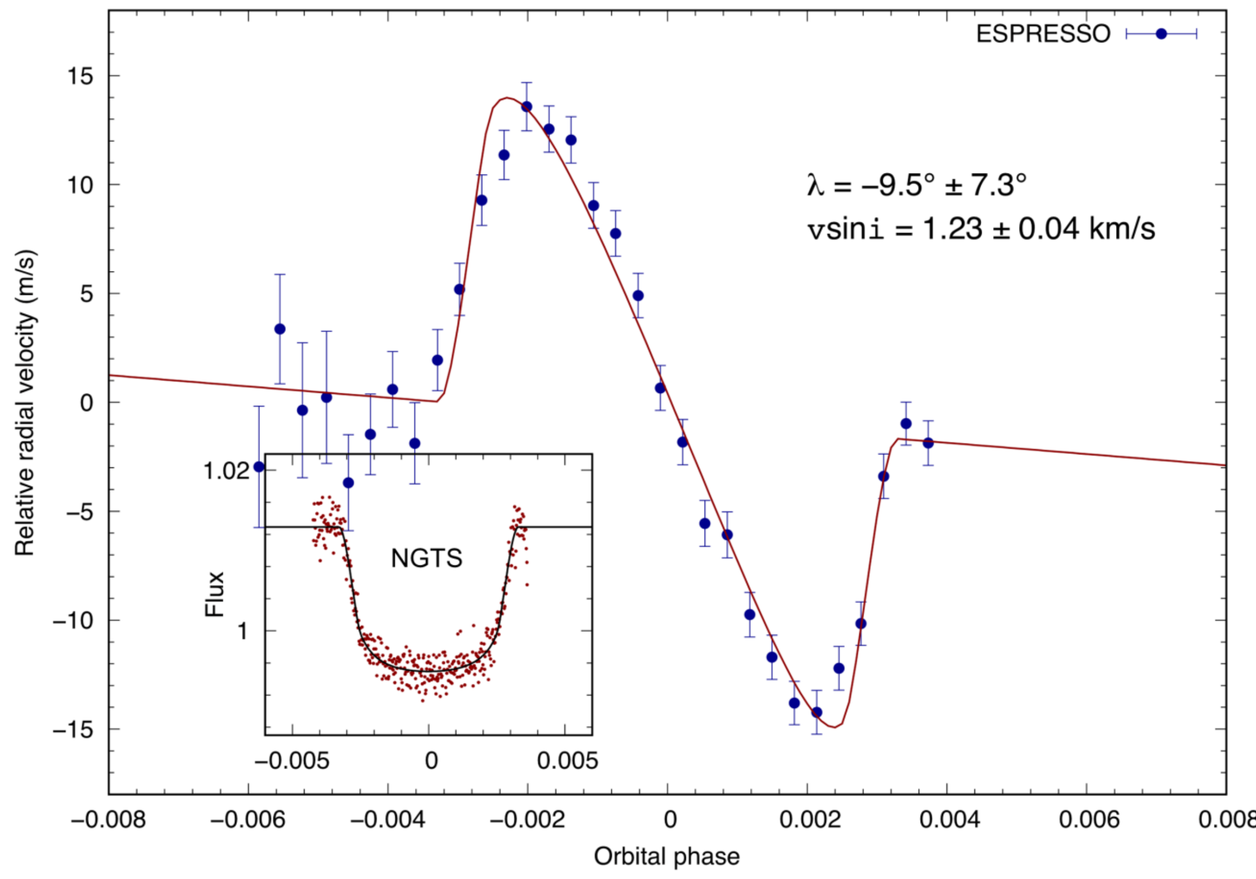
P = 9.62 d (Hellier et al. 2019a)



TOI-216 c

PRELIMINARY

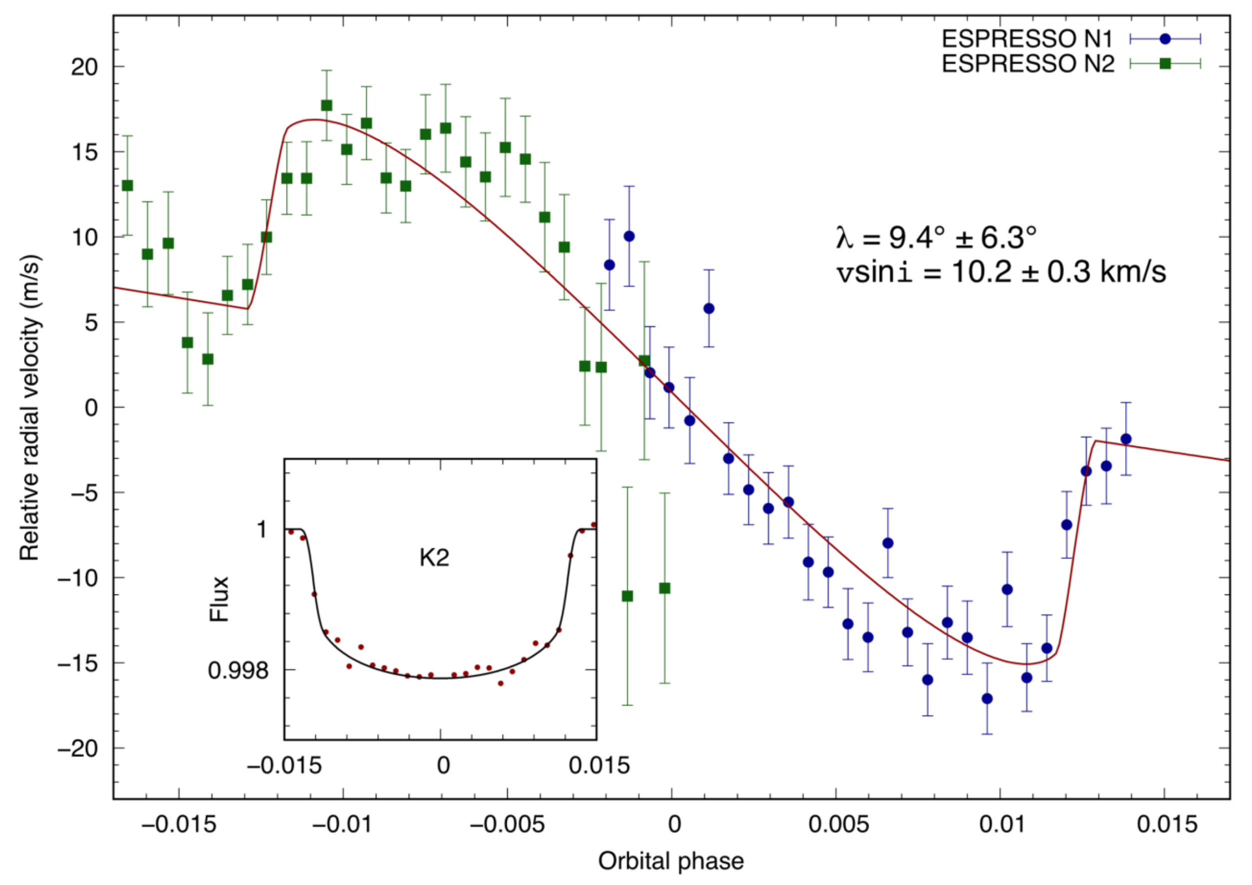
P = 34.55 d (Kipping et al. 2019)



K2-99 b

PRELIMINARY

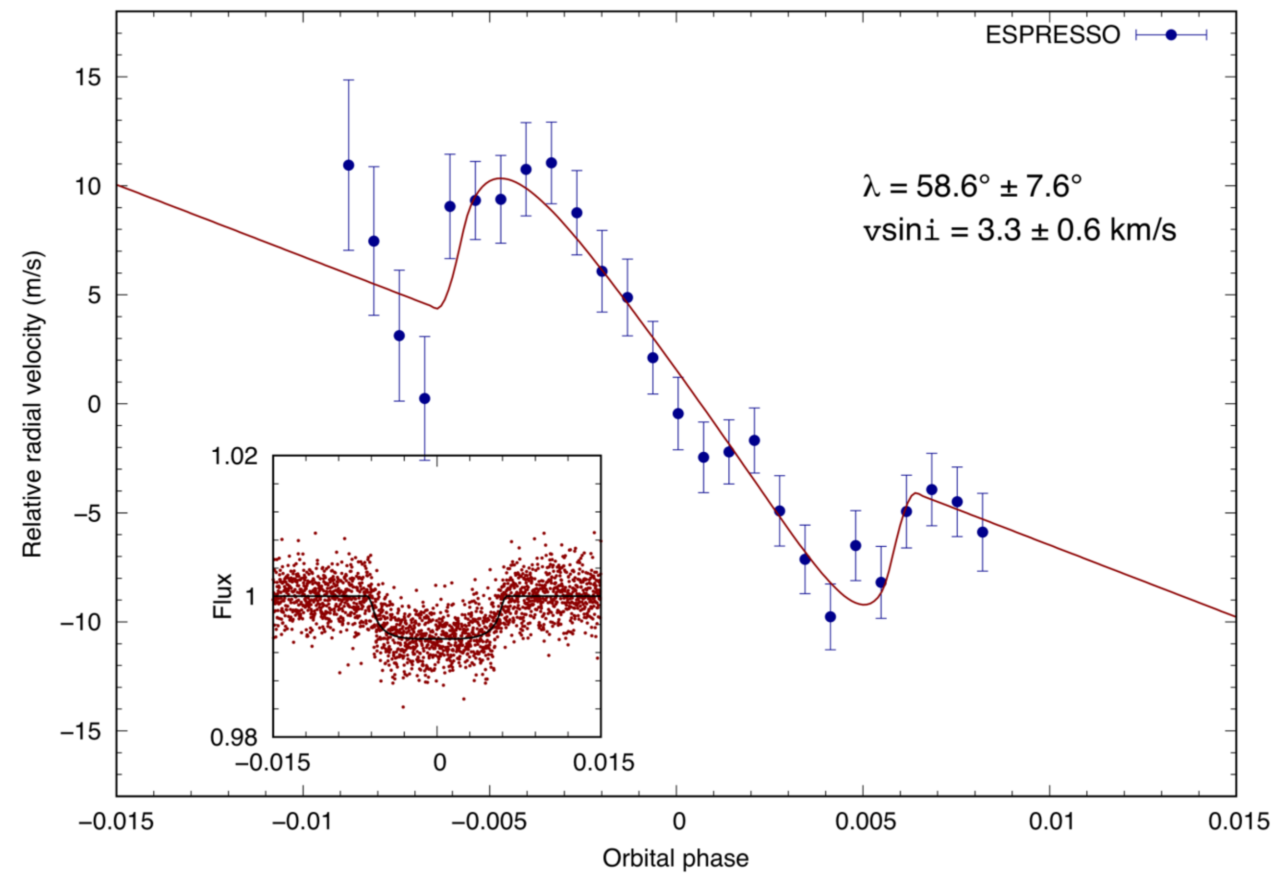
P = 18.25 d (Smith et al. 2017, 2022)



HATS-17 b

PRELIMINARY

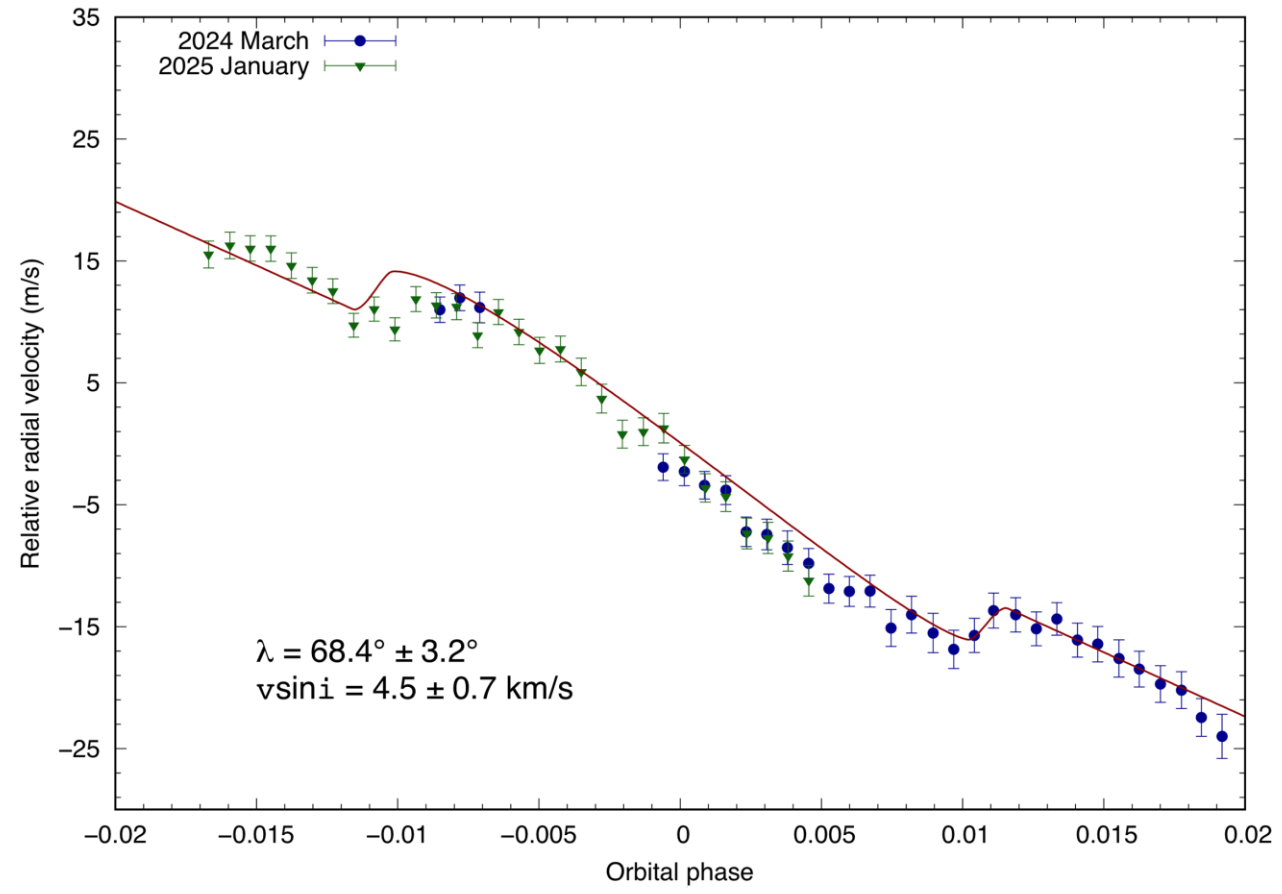
P = 16.25 d (Brahm et al. 2016)



TOI-481 b

PRELIMINARY

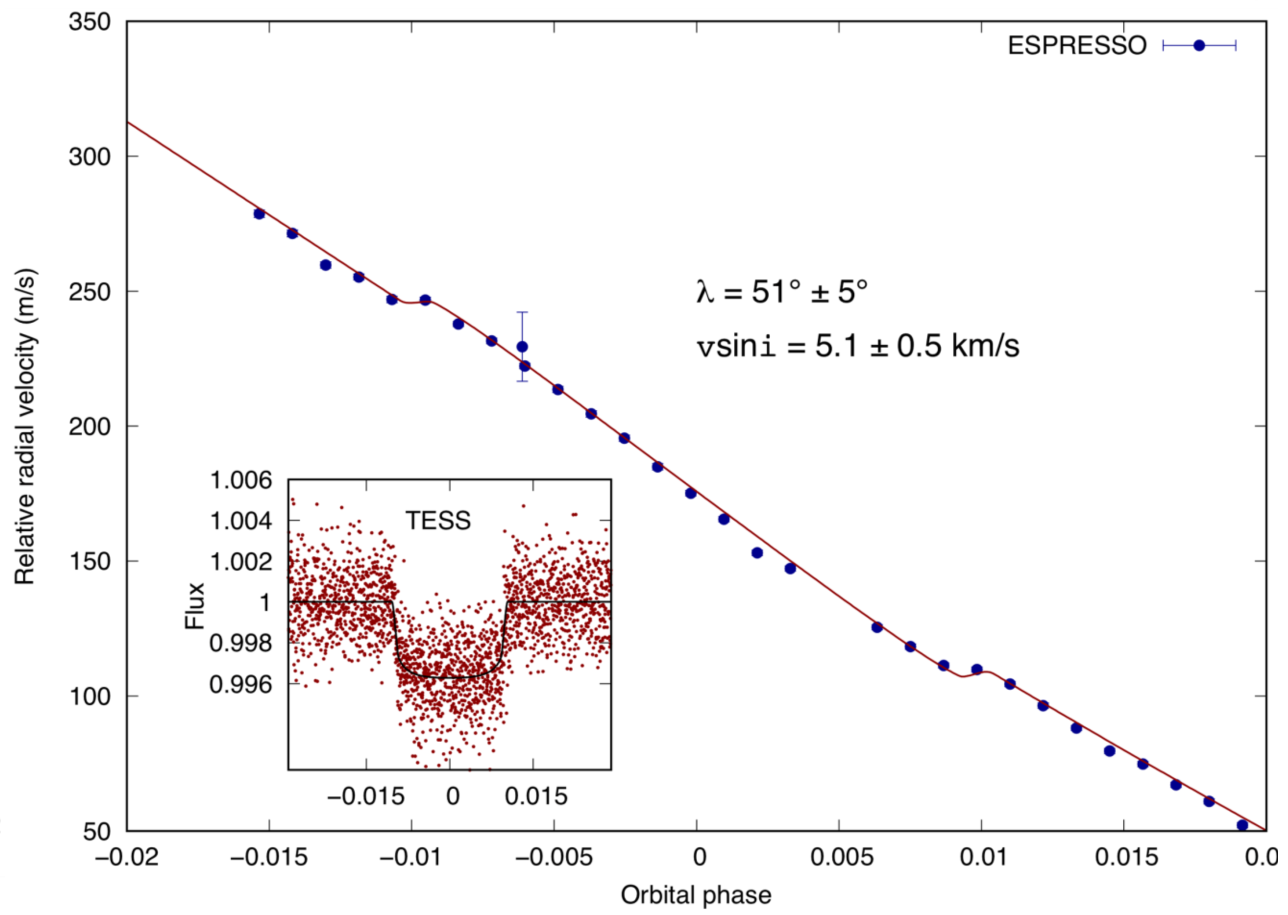
P = 10.33 d (Brahm et al. 2020)



TOI-172 b

PRELIMINARY

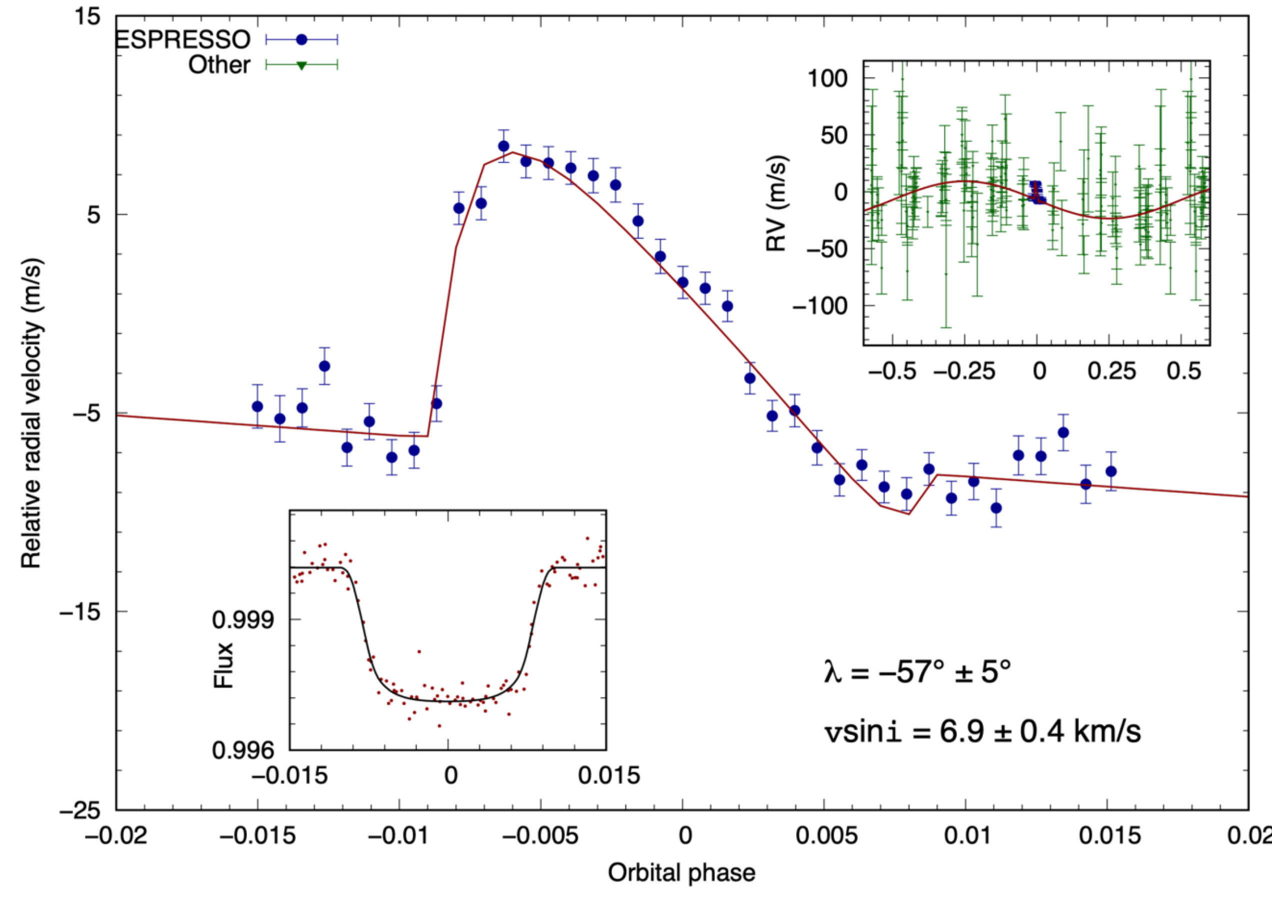
P = 9.48 d (Rodriguez et al. 2019)



TOI-1842 b

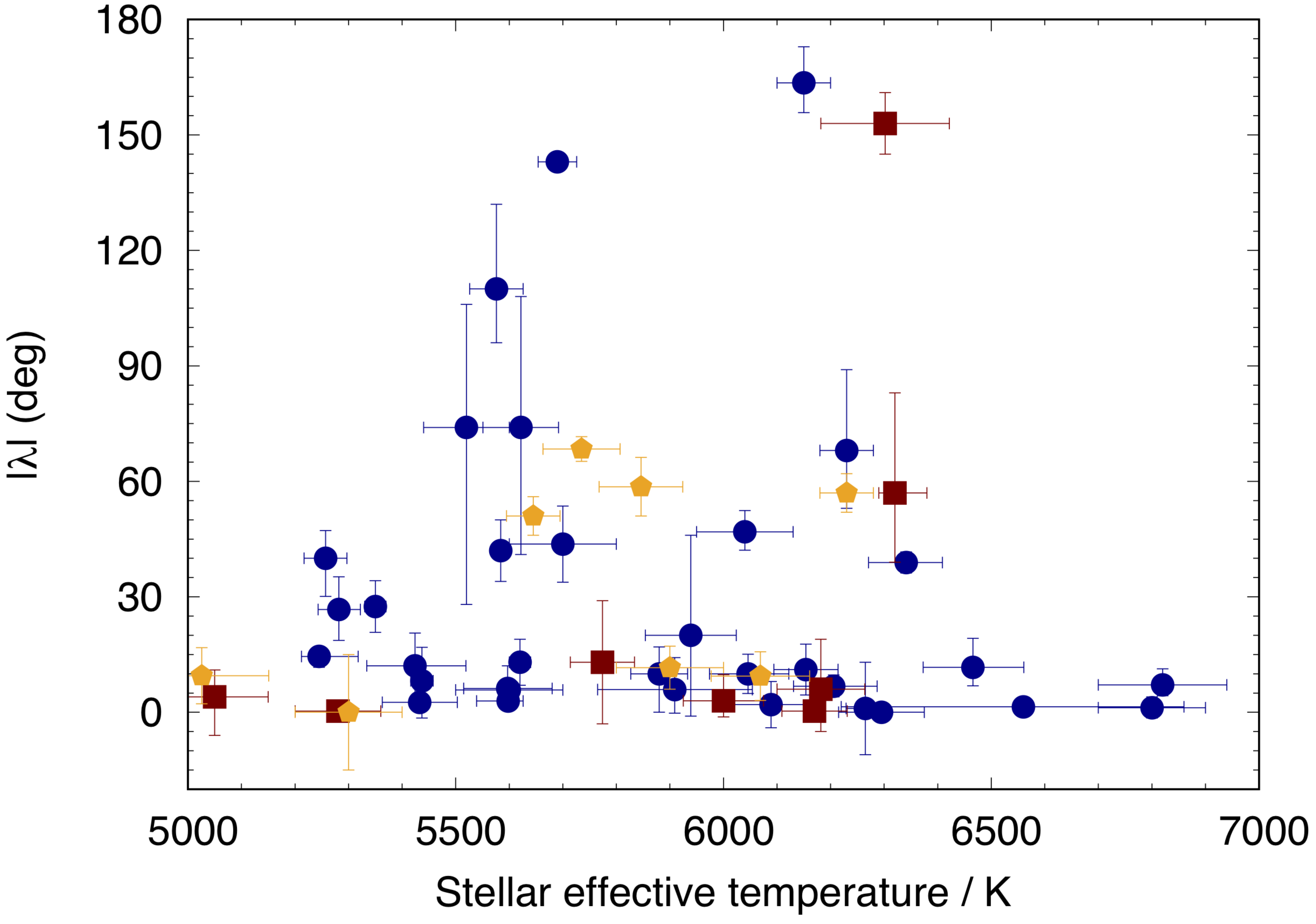
PRELIMINARY

P = 9.57 d (Wittenmyer et al. 2022)



What does the sample look like now?

WJs with measured obliquity

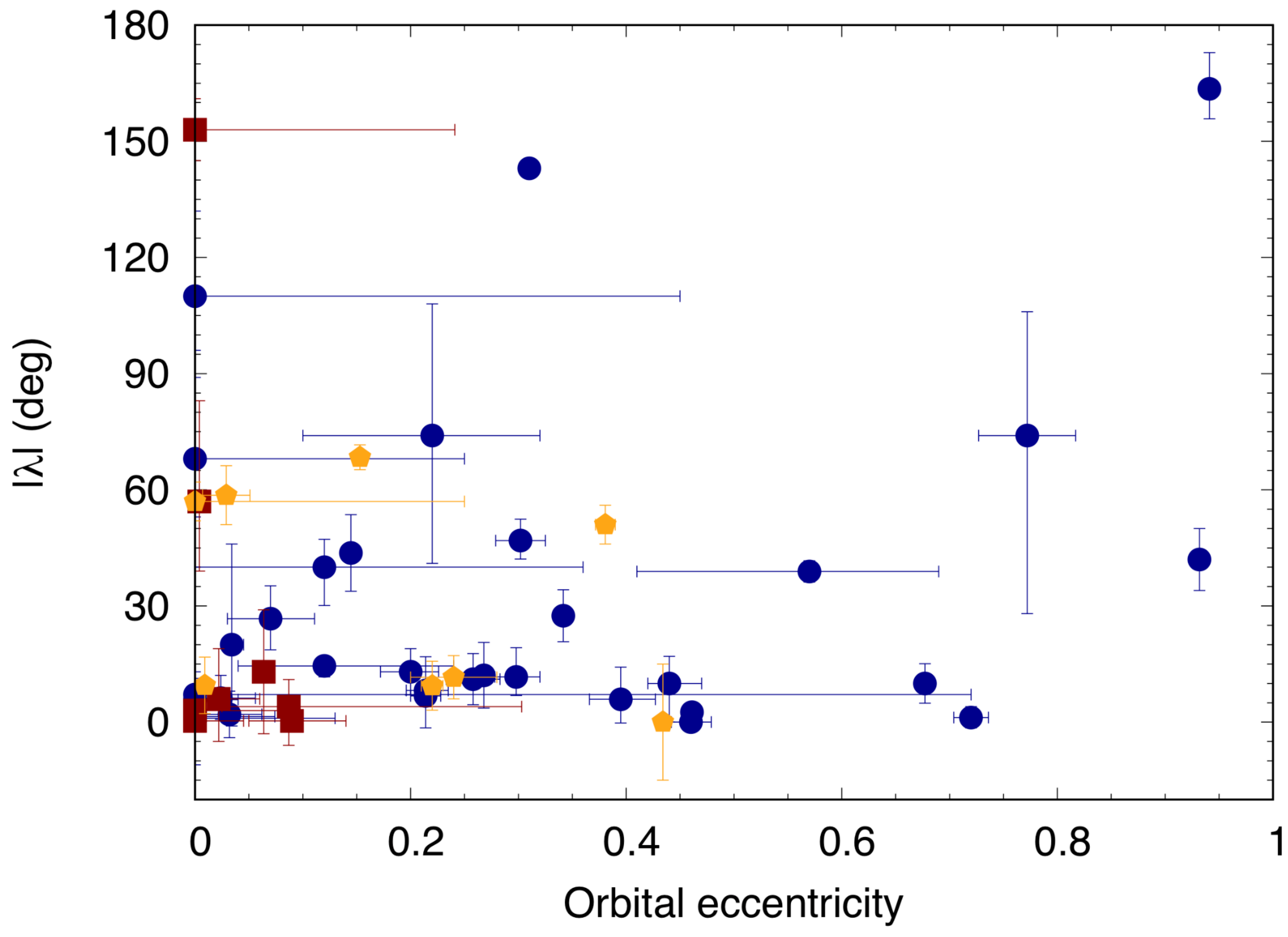


- Blue: single-planet systems
- Red: multi-planet systems
- Orange: our targets

- Two years ago, there were only 15 measurements, our proposal aimed to 'almost double' the sample size to 26
- We were not the only people to have the same idea!
- See recent papers from e.g. Espinoza-Retamal et al. 2024, Wang et al. 2024
- There are now ~40 measurements (using broad definition: $P > 8$ d, $R_p > 0.5\ R_{jup}$)
- No trend evident with stellar temperature

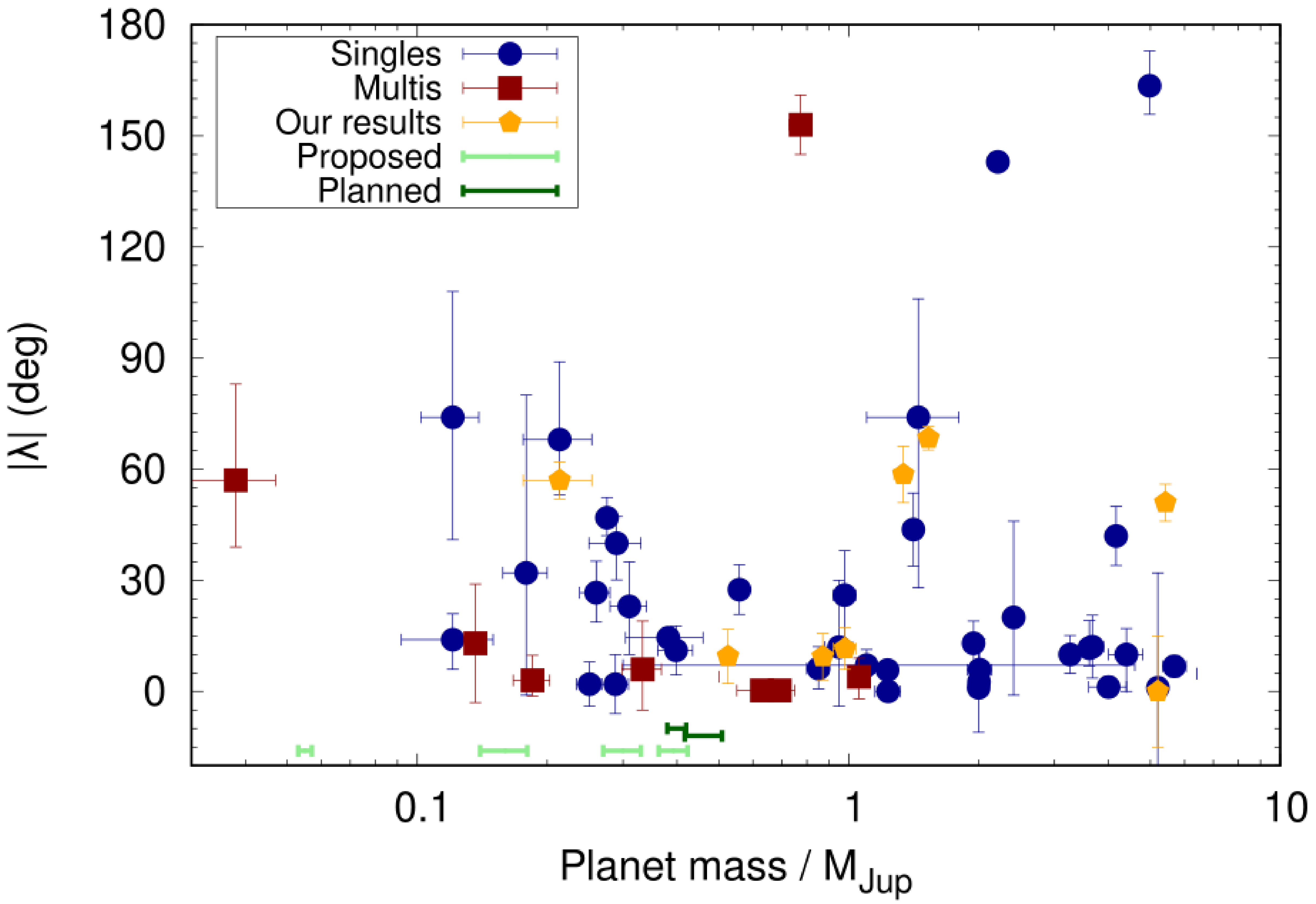
What does the sample look like now?

WJs with measured obliquity



- Blue: single-planet systems
- Red: multi-planet systems
- Orange: our targets

- Possible correlation with orbital eccentricity – but in the opposite direction to expectations!
- **Are warm Saturns preferentially misaligned compared to warm Jupiters?**



Conclusions

- The first results from our programme show four aligned WJs, and four (potentially) misaligned - not all WJs are in dynamically relaxed systems!
- Hints of correlations:
  - planet mass: are warm Saturns more misaligned than warm Jupiters?
  - eccentricity: are eccentricity and obliquity anti-correlated?
- Alternative / addition to tidal realignment paradigm:
  - More massive stars may form more giant planets → planet – planet scattering → misaligned orbits (e.g. Hixenbaugh et al. 2023)
  - There may be multiple Saturns in a system → planet – planet scattering → misaligned orbits
- Correlations with stellar/planetary multiplicity, outer architecture, etc largely unexplored
- A paper reporting our results is in prep – look out for it soon!

Huge thanks to the VLT night astronomers: Martina Baratella, Jesus Corral-Santana, Elisa Garro, Julia Seidel, Jonathan Smoker, Elyar Sedhagati, Jose Maria Rain Sepulveda, Abel de Burgos Sierra, and everyone else at ESO who made these data possible!