Towards the mysterious origins of warm Jupiters

New stellar obliquities from VLT/ESPRESSO

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Motivation

Stellar obliquity as a tracer of migration history

- 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.

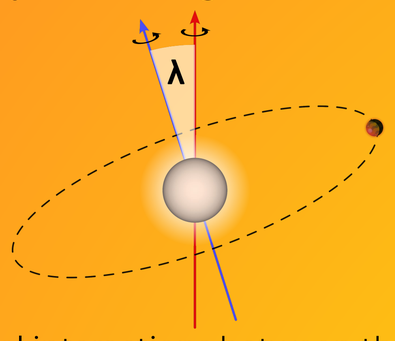


Fig. 1 - Schematic showing the (sky-projected) obliquity angle, λ - the angle between the stellar rotation axis and the orbital angular momentum vector

- Tidal interactions between the planet and the star's convective envelope act to erase this primordial obliquity, if the planet is close enough to the star: HJs aligned around cool stars (Winn et al. 2010).
- Tides have a very strong dependence on the star – planet separation (e.g. Jackson et al. 2008).
  - warm Jupiters too distant to be re-aligned by tides (unlike HJs).
- (Holt)-Rossiter-McLaughlin effect (Holt 1893, Rossiter 1924, McLaughlin 1924) allows the measurement of the sky-projected obliquity, λ (Fig. 1).

The existing sample

Few warm Jupiters with measured obliquity

- The existing sample of WJs with measured obliquity is small
  - fewer WJs are known (harder to detect than hot Jupiters [HJs], particularly from the ground) - see Fig. 2.
  - difficult to schedule RM observations (typically ≲ 1 chance per year per observatory).
  - from first WJ obliquity measurement (Cochran *et al.* 2008) to 2023: **14 systems measured.**
  - recently, TESS has discovered many new WJs, ripe for obliquity measurements!

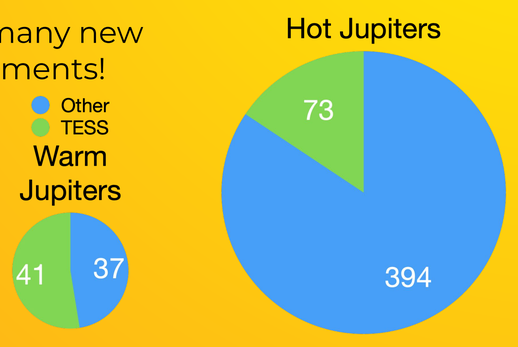


Fig. 2 - Comparison of the number of known HJs and WJs, discovered by TESS and by other means. Data are from the NASA Exoplanet Archive (2024 May)

Our survey

Increasing the number of WJs with measured obliquity

- Monitoring programme with the VLT/ESPRESSO (112.2617, PI: Smith) to measure RM effect for more WJs.
- Unbiased sample of WJs:
  - ESPRESSO capable of measuring at low *v*sin*i*
  - Not restricted to short transits that fit into a single night: 2x partial RMs possible
  - No preference for single or multi-planet systems
- 11 targets with no previous obliquity measurement.
- Simultaneous photometry for ephemeris refinement & stellar activity monitoring with NGTS, TRAPPIST-South (M. Timmermans), LCOGT (D.R. Anderson).
- Northern targets with TNG/HARPS-N (via OPTICON).

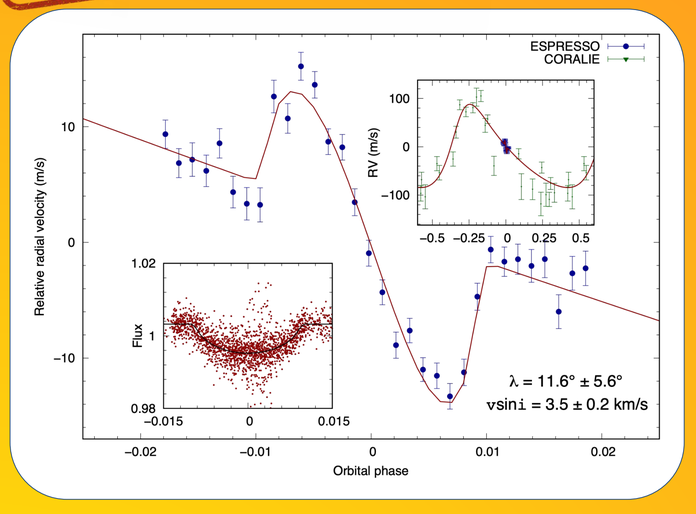
Name	P / d	T_{eff} / K	V-mag
TOI-2158 b	8.60	5673	10.9
WASP-185 b	9.39	5900	11.0
TOI-172 b	9.48	5640	11.4
TOI-1842 b	9.57	6230	**9.8**
WASP-162 b	9.62	5300	12.2
TOI-481 b	10.33	5735	10.0
HATS-17 b	16.25	5846	**12.4**
K2-99 b	18.25	6069	11.2
TOI-5153 b	20.33	6300	11.9
TOI-216 c	34.55	5026	12.4
NGTS-20 b	54.19	5980	11.2

Our ESPRESSO targets.
Green: observed in 2024 March & April (see Results)
Blue/red: hottest/coolest host

Results

PRELIMINARY

First ESPRESSO observations



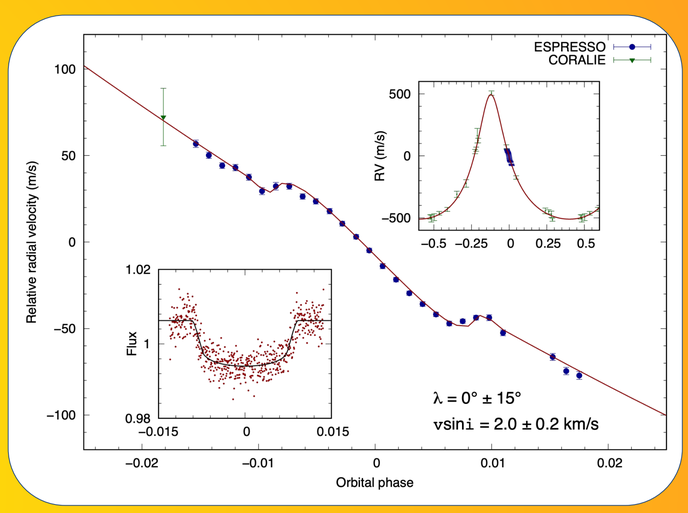
Fitting new data alongside archival RVs using TLCM (Csizmadia 2020).

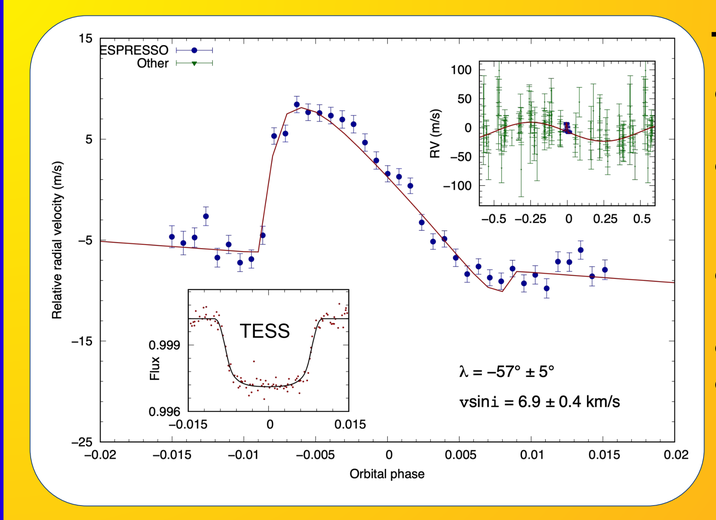
WASP-185 b

- P = 9.39 d (Hellier *et al.* 2019a).
- Simultaneous photometry from TRAPPIST-South.
- Seems to be aligned.
- λ = 12° ± 6°

WASP-162 b

- P = 9.62 d (Hellier *et al.* 2019b).
- Simultaneous photometry from TRAPPIST-South.
- Seems to be aligned.
- λ = 0° ± 15°



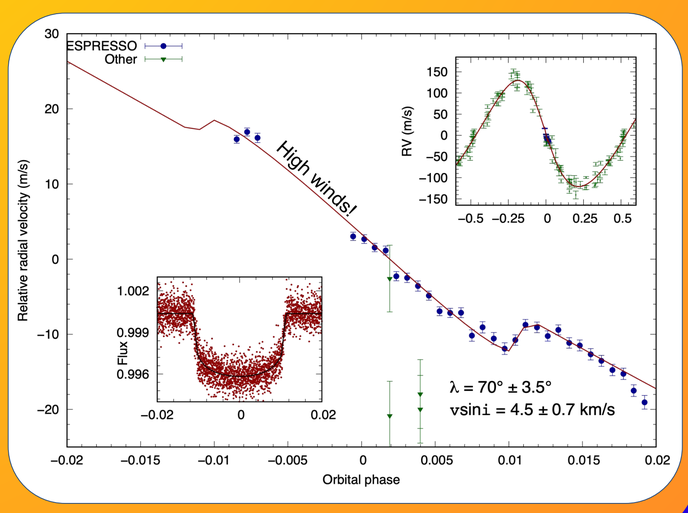


TOI-1842 b

- P = 9.57 d (Wittenmyer *et al.* 2022).
- Simultaneous photometry from LCOGT (not shown).
- Significant misalignment.
- λ = -57° ± 5°
- Consistent with Hixenbaugh *et al.* (2023): -68.1° +21.2° -14.7°

TOI-481 b

- P = 10.33 d (Brahm *et al.* 2020).
- No simultaneous photometry (technical problems).
- Possible significant misalignment, but inconclusive.
- 1st half of transit will be observed in late 2024.



Conclusions

Not all warm Jupiters are on aligned orbits!

- First results show two aligned WJs, and at least one (probably two) misaligned systems.
- Larger sample could reveal trends with stellar type, multiplicity, etc., and whether HJs and WJs migrated with different mechanisms.
- **More warm Jupiter obliquities coming soon!**

References

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