Characterising companions to *TESS* planet-hosts with *Gaia* and VLT/SPHERE

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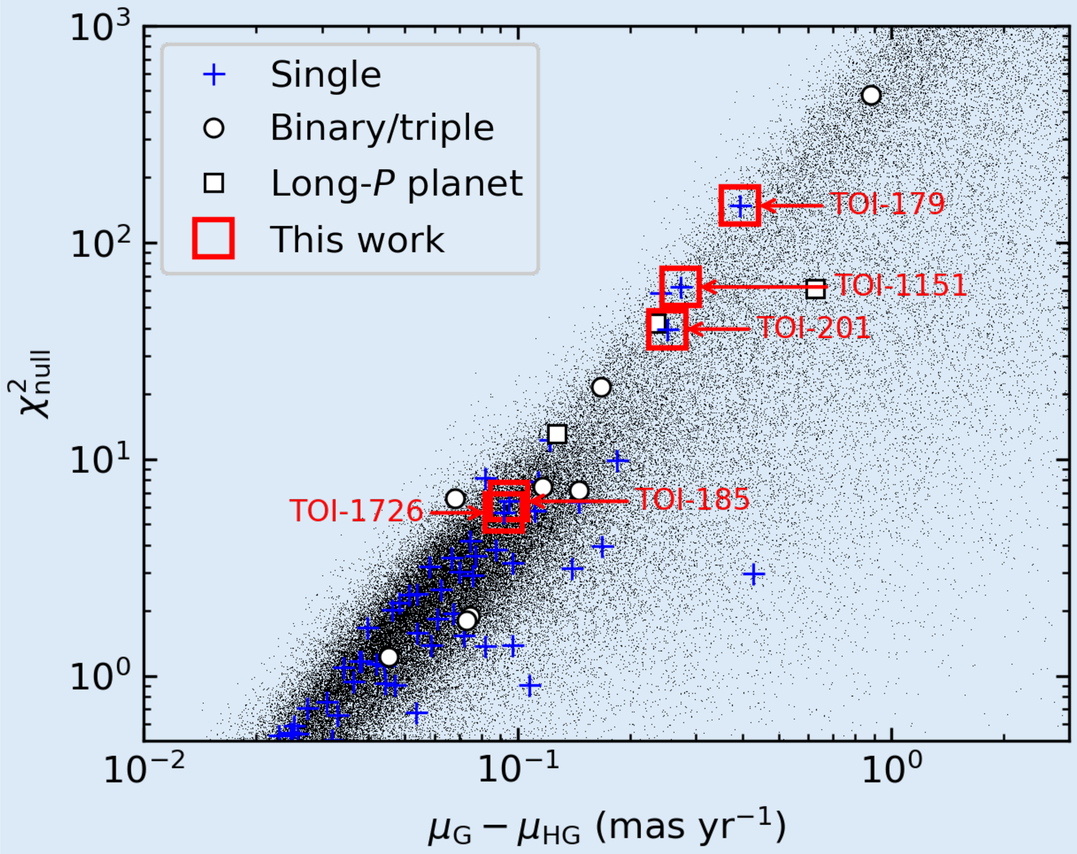
Background This is a status update on an ongoing project to detect and measure the orbits of long-period stellar and substellar companions to *TESS* planet-hosts using a combination of astrometry, RVs, and high-contrast imaging. These can play a significant role in the formation and dynamical evolution of planetary systems:

- The truncation of the protoplanetary disk can significantly shorten the lifespan of a disk[1], as well as limiting the amount of material available to form planets[2].
- The gravitational interaction with the disk can increase the eccentricities of planetesimals, raising their relative velocities and decreasing the efficiency of collisions[3].
- After planet formation, a distant companion can alter the architecture of the inner system. Large mutual inclinations can induce Kozai-Lidov oscillations leading to high-eccentricity migration[4], a mechanism that has been invoked to explain the population of Hot Jupiters for which *in situ* formation is challenging to explain.

By studying additional companions, we can investigate the dynamical history of individual systems and complete the multiplicity census for transiting systems.

Astrometric trends with *Hipparcos* and *Gaia*

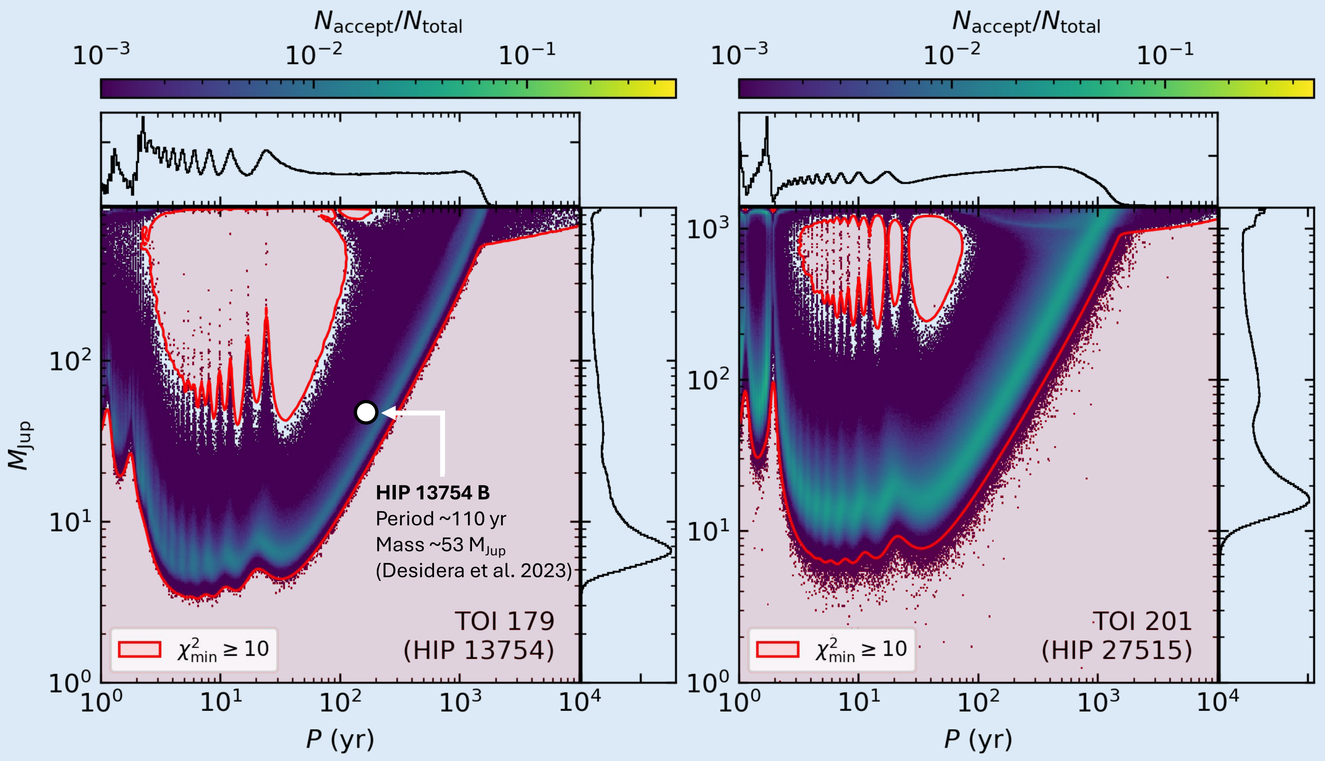
The astrometric reflex motion induced by a long-period companion can be measured by comparing the position and proper motions in both the *Hipparcos* and *Gaia astrometric* catalogues[5].



Goodness of fit to a single-star model plotted against proper motion anomaly for TOIs without known companions (crosses), with a stellar companion (circles) and with a long-period planet (squares).

Predicted companion properties

There's a complex mapping between the proper motion anomaly and the mass and orbital period of the companion. With some simplifying assumptions, we can perform rejection sampling to exclude regions of this parameter space.

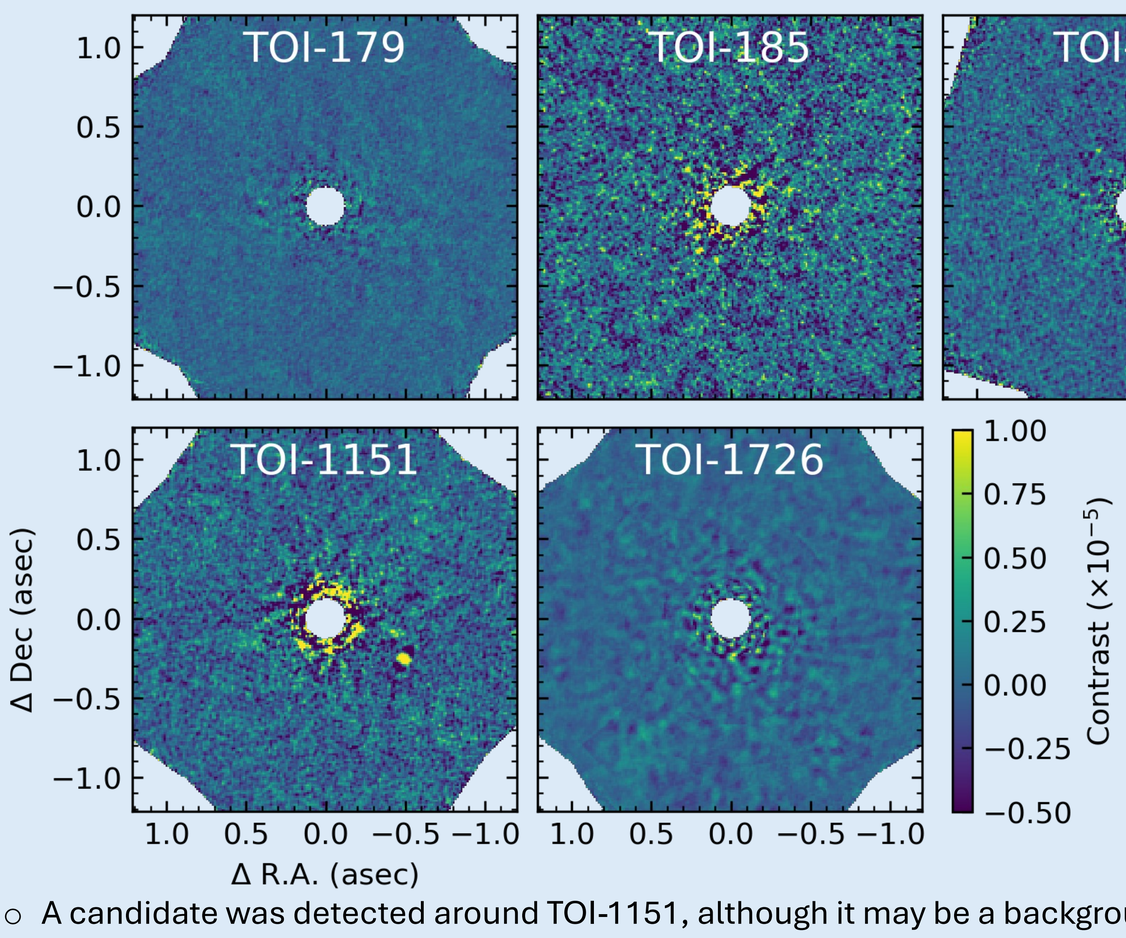


(left) TOI-179, a ~400 Myr star host to a Neptune-mass planet on a 4d orbit has a long-period substellar companion that was recently discovered[6].

(right) TOI-201, a ~900 Myr star host to a Saturn-mass planet on an eccentric 53d orbit[7].

VLT/SPHERE imaging

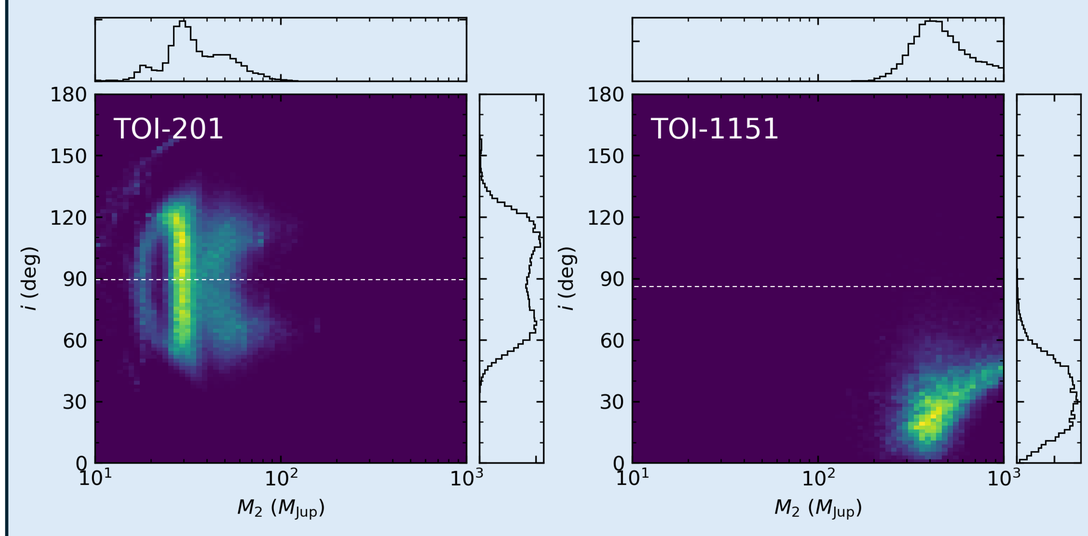
We observed five TOIs exhibiting a significant proper motion anomaly with VLT/SPHERE.



- A candidate was detected around TOI-1151, although it may be a background star (b=4°).
- We do not recover the companion around TOI-179 despite the predicted favourable contrast and separation at this epoch (Δm=6 mag, ρ=180 mas).

Preliminary results

With either an astrometric orbit or long-term trend, and the well-constrained inclination of the inner system, the relative alignment of the orbital planes of the system can be measured.



- **TOI-201 –** A fit to the RV and astrometry suggests a co-planar orbit for the eccentric outer companion. Further RV monitoring needed!
- **TOI-1151 –** Assuming the candidate is bound, it would have to be a low-mass white dwarf that is strongly misaligned relative to the inner system. Unlikely, but cannot yet exclude.
- **TOI-179 –** Joint fit to the published astrometry and proper motion anomaly suggests nearly edge-on orbit (i~100°), however strong tension between mass and luminosity.

Conclusions and Future work

- The null detections with SPHERE allow us to exclude stellar and high-mass brown dwarf companions with periods >100yr.
  - It is likely that these three systems host a high-mass planet/low-mass brown dwarf with a period between a few years and a few decades.
  - We will synthesise these limits with the astrometric/RV trends to further constrain the mass and orbit of the distant companions.
- Although not resolved with VLT/SPHERE, we were able to place constraints on the inclination of the companion to TOI-201 from the astrometric and RV trends.
- We will further investigate the candidate around TOI-1151 to exclude the more exotic white dwarf scenario.

References: (1) Müller, T. W. A. & Kley, W. 2012, A&A, 539, A18; (2) Artymowicz, P. & Lubow, S. H. 1994, ApJ, 421, 651; (3) Thébault, P. et al. 2006, Icar, 183, 193; (4) Fabrycky, D. & Tremaine, S. 2007, ApJ, 669, 129; (5) Brandt, T. 2021 ApJS, 254, 42; (6) Desidera, S. et al. 2023, A&A, 675, 158; (7) Hobson, M. J. et al. 2021, AJ, 161, 235.