TOI-1135: Sub-Saturns are Universally Misaligned

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Introduction

The Solar System exhibits several planets well aligned with their host star, however studies of hot and warm Jupiters (HJs and WJs) have shown that exoplanets can sometimes be misaligned. From analyses HJs and WJs, it has been shown that HJs are more likely to be misaligned than WJs.[1]

Studying the obliquities of sub–Saturns will provide further insights as to which properties, such as stellar temperature, planet-to-star mass ratio, and stellar age affect the alignment of stellar systems.

TOI-1135 is a hot sub-Saturn orbiting a hot, young star and is an excellent candidate for probing the question of how planetary mass affects a planet's likelihood of being misaligned.

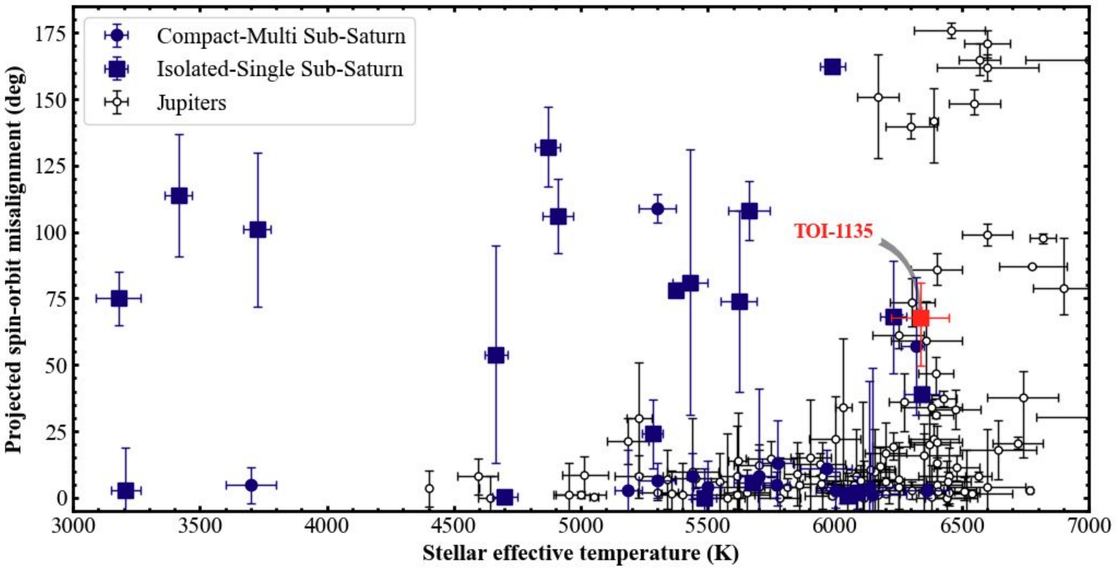
Observations

Photometric observations of TOI-1135 were conducted using the Transiting Exoplanet Survey Satellite (TESS) in sectors 14, 19, 20, 26, 40, 47,53, 59, and 74.[2] 17 total spectroscopic measurements of TOI-1135 were collected using the High-Resolution mode (R ~ 110, 000) of the NEID spectrograph. on the WIYN 3.5m telescope at Kitt Peak National Observatory.[3]

Analysis

To derive the sky-projected spin-orbit angle, we used `allesfitter`[4] to perform a simultaneous global fit to the Rossiter-McLaughlin (RM) measurements from the NEID spectrograph, radial velocity (RV) measurements from the CARMENES spectrograph at the Calar Alto Observatory[5], and the light curves obtained from TESS. From this analysis we determine the sky-projected spin-orbit angle for TOI-1135 is $\lambda = 67.9^{+18.1}_{-13.2}$ °.

We performed a periodogram analysis on the TESS light curves for this system with transit data masked out to derive the stellar spin velocity and constrain the spin-orbit angle along the line-of-sight.[6] This analysis obtained a stellar rotation rate of 5.13±0.5 days, which resulted in an obliquity of $\Psi = 70.01^{+12.67}_{-16.5}$°.

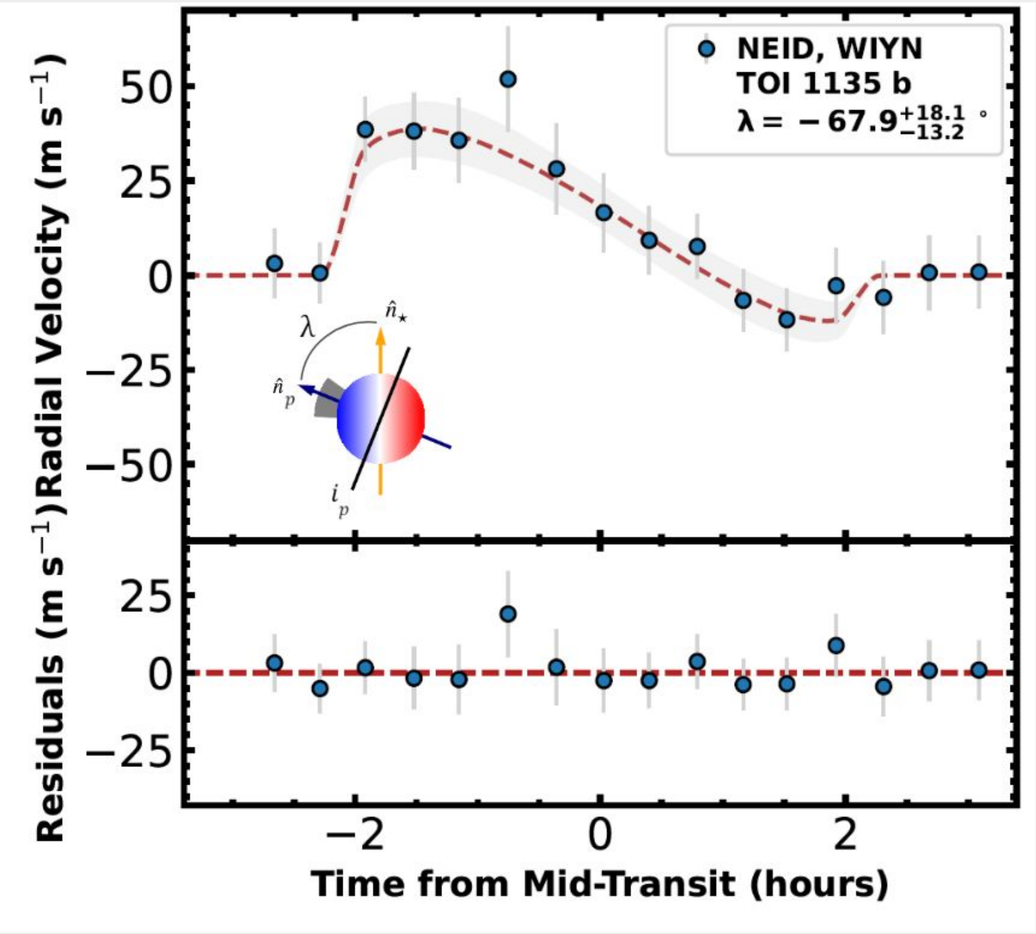


Discussion

TOI-1135 is a hot sub-Saturn which is misaligned relative to its stellar host. Since there are far fewer obliquity measurements for sub-Saturns than there are for HJs and WJs, every measurement of sub-Saturns provides valuable information regarding which factors encourage misalignment.

As shown in the lower left plot, sub-Saturns exhibit misalignment across a wide range of stellar effective temperatures. This correlation with stellar temperature provides a piece of the puzzle that is vital for evidence of tidal realignment.

From this obliquity measurement of TOI-1135, we find further evidence that isolated planets are more likely to be misaligned than compact multis, as well as less massive planets are more likely to be misaligned than more massive planets, regardless of stellar temperature.



Top Figure: RM measurements and model residuals. Best-fitted model is shown by red-dashed line, and uncertainty is represented by gray shadow.

Left Figure: Stellar effective temperature vs projected spin-orbit misalignment for both isolated sub-Saturns and sub-Saturns in compact multi-planet systems, as well as Jupiters.

References

[1]Albrecht et al. 2022
[2]Ricker et al. 2014
[3]Detailed information available at https://neid.ipac.caltech.edu/docs/NEID-DRP/
[4]Günther& Daylan 2019, 2021
[5]Mallorquín et al. 2024
[6]Masuda & Winn 2020

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