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TOI-1431b/MASCARA-5b: An Ultra-hot Jupiter Orbiting One of the Hottest & Brightest Known Exoplanet Host Stars

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Introduction

TOI-1431b/MASCARA-5b is an **ultra-hot Jupiter** on a **~2.65d orbit** [1]. Ultra-hot Jupiters are the **hottest** and most **irradiated** planets known with dayside temperatures **> 2200K** [2]. This planet was detected by the Multi-site All-Sky CAmERA (MASCARA, [3]) between 2015 - 2018 and later by *TESS* [4] between Aug. & Oct. 2019 in Sectors 15 & 16.

- Radial velocities: SONG, SOPHIE, FIES, NRES, and EXPRES. $K = 294.1 \pm 1.1$ m/s, **precise RV orbit!**
- Planet parameters from photometry + RVs in Allessitter [5]:
 - Mass: $M_p = 3.14 \pm 0.19 M_J$
 - Radius: $R_p = 1.51 \pm 0.06 R_J$ ($16.9 \pm 0.7 R_\oplus$)
 - Bulk density: $\rho_p = 1.2 \pm 0.2$ cgs
- Stellar parameters from Simbad & SED fit in EXOFASTv2 [6]:
 - $V_{\text{mag}} \sim 8.1$, **bright!**
 - Age: $0.29^{+0.32}_{-0.19}$ Gyr, **young!**
 - $T_{\text{eff}} = 7690^{+400}_{-250}$ K, one of the **hottest** host stars (Fig. 1)!
 - $M_* = 1.90^{+0.10}_{-0.08} M_\odot$ and $R_* = 1.92 \pm 0.07 R_\odot$
 - Spectral type: Am (kA5mF2 [7]), usually in tight binaries.
 - $v_{\text{sin}i} \sim 6$ km/s, **very slow rotator!**

TESS photometry reveals the **planet's thermal emissions** from the **full phase curve** and **secondary eclipse** (Fig. 2), providing its dayside and nightside temperature as $T_{\text{day}} = 2983 \pm 68$ K and $T_{\text{night}} = 2556 \pm 65$ K, respectively. The nightside temperature is the **second hottest** ever measured (Fig. 3a)! The low day/night temperature contrast (~ 400 K) suggests **very efficient heat transport** between the dayside and nightside hemispheres (Fig. 3b).

Analysis & Results

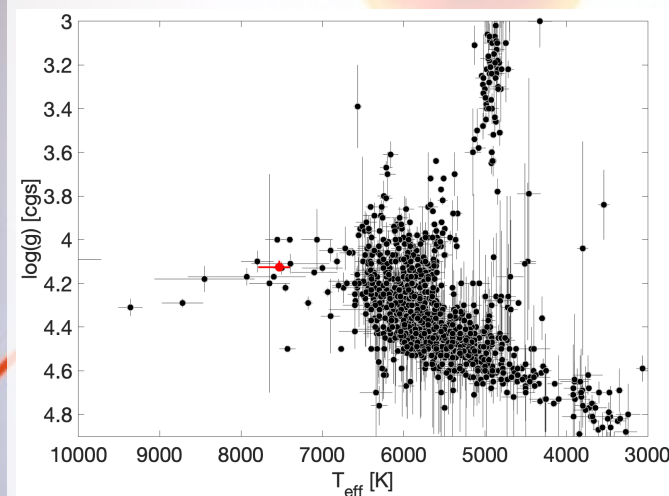


Fig. 1: Plot of stellar effective temperature versus surface gravity for planet hosting stars. TOI-1431 is plotted as the red point and shows that it is one of the hottest (top 1%) known planet hosting stars.

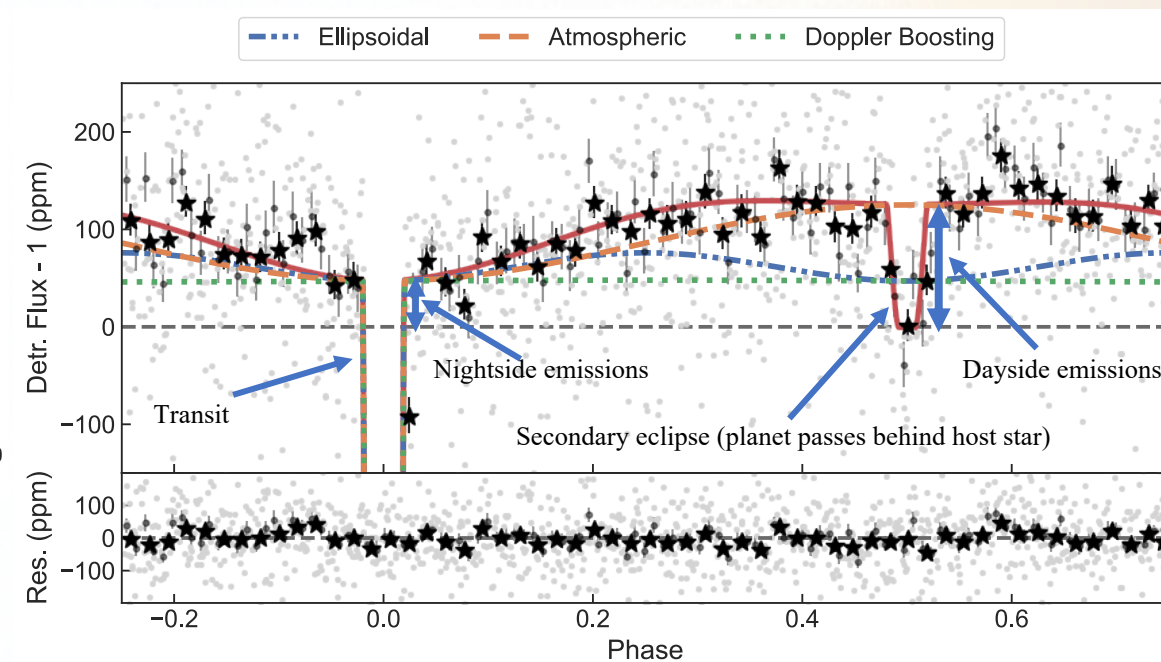


Fig. 2: The phase-folded *TESS* light curve, zoomed in to show the phase curve and secondary eclipse. The dark grey points are the binned photometry at a cadence of ~ 13 minutes and the black stars are the binned photometry at a cadence ~ 26 minutes. The grey dashed line represents no emission from TOI-1431b.

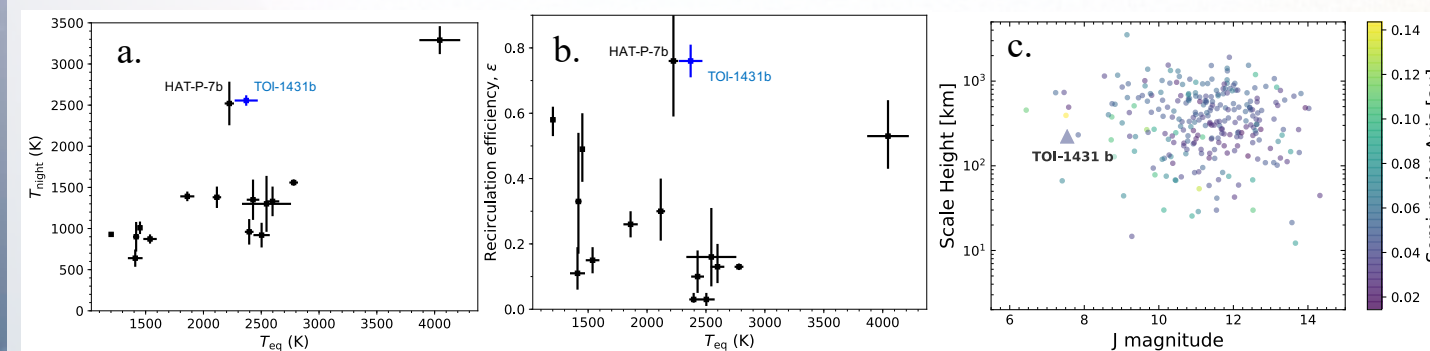
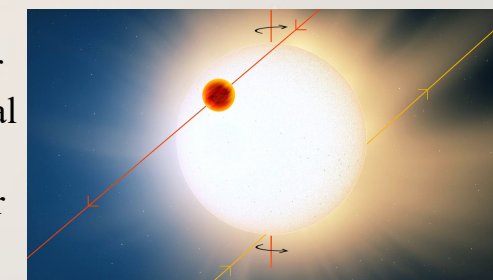


Fig. 3: **a)** Planet equilibrium vs nightside temperatures, comparing TOI-1431b to other hot and ultra-hot Jupiters. **b)** Planet equilibrium temperatures vs atmospheric recirculation efficiencies for the same sample of planets in a). **c)** Host star brightness in J_{mag} vs atmospheric scale heights of hot Jupiters, showing TOI-1431b orbits one of the brightest hosts.

Conclusions

- Planet's atmospheric scale height is $H_p = 220 \pm 30$ km (Fig. 3c), suitable for atmospheric characterization from space missions such as JWST.
- The planet's **nightside temperature** of ~ 2600 K is the **second hottest** ever measured!
- The Rossiter-McLaughlin effect reveals that the planet is on a **retrograde orbit**, projected obliquity of $\lambda = -155^{+20}_{-10}$ [8].
- The retrograde orbit for TOI-1431b suggests that it experienced **high eccentricity migration** shortly after formation, perhaps due to interactions with another planet or distant stellar companion.
- Linger questions:
 - Is the planet responsible for star spin-down (via tidal braking) and transforming A star into an Am star?
 - If yes, for Am stars that don't have a close-in stellar companion host a hot/ultra-hot Jupiter instead?



Artist impression of TOI-1431b and its retrograde orbit. Video simulation can be found here (<https://youtu.be/CO6r7676qR4>).



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