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TOI-561 b: A 2500 K Earth-Size Planet with Non-Primordial Envelope in the Galactic Thick Disk

TOI-561 is a galactic thick disk star hosting an ultra-short period planet of 1.45 R⊕: one of the oldest known Earth-sized exoplanets (~10 Gyr), and among the first discovered beyond the thin disk of our galaxy[1,2]. As a thick disk star, TOI-561 is one of the most iron depleted (-0.41 dex) and alpha-enriched (0.23 dex) exoplanet hosts. To determine the composition of this planet, we collected high-precision Radial Velocity measurements and used equation-of-state modeling for iron and silicate rock. We have determined that the low density of TOI-561 b requires this planet to have a volatile envelope, despite its size and proximity to its host star.

References

[1] Lauren M. Weiss et al 2021 AJ 161 56
[2] G Lacedelli et al 2020 MNRAS 501 3
[3]Seifahrt, A., St¨urmer, J., Bean, J. L., & Schwab, C. 2018, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 10702, Ground-based and Airborne Instrumentation for Astronomy VII, ed. C. J. Evans, L. Simard, & H. Takami, 107026D
[4] Cottaar, S., Heister, T., Myhill, R., Rose, I., & Unterborn, C. 2016, BurnMan: Lower mantle mineral physics toolkit, ascl:1610.010

High-Precision Mass Measurement with Maroon-X

To measure the mass and composition of this planet, we present the first simultaneous radial velocity program combining Maroon-X[3], a new fiber-fed RV spectrometer on Gemini-N, and HIRES, a well-characterized spectrometer on Keck I. Using these new RVs, along with archival data from HIRES and HARPS-N, we find a mass of 2.3 ± 0.17 M⊕ for TOI-561b--**the most precise mass measurement yet for a rocky exoplanet**. New and archival RVs are shown phase-folded with our best-fit model in Figure 1.

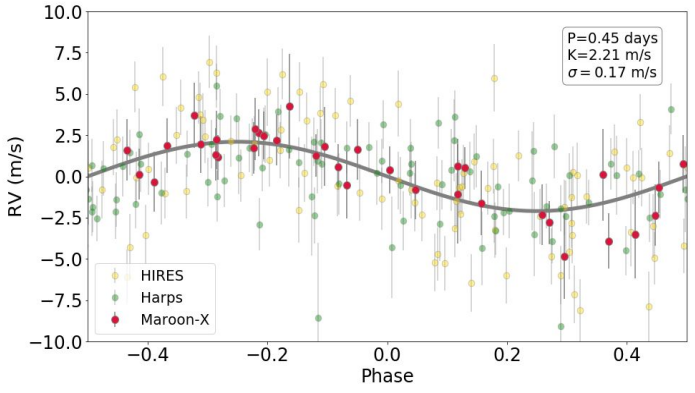
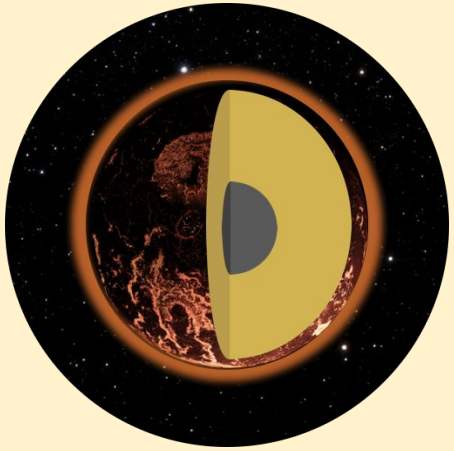


Fig 1.

A Low Density Super-Earth

With this mass we find a density of 4.3 ± 0.3 g/cm^3 for TOI-561 b--**the lowest measured density to date for super-Earths with 1<R<1.5 R⊕**. This density is shown in context with the full population of sub-Neptune size exoplanets with RV masses in Figure 2.

Fig 2.



It has a gaseous envelope, even though it's a "rocky" planet!

Planet Composition

We modeled the planet interior with geologically motivated equations-of-state for iron and magnesium silicate[4]. We found that compositions including only iron and rock were unable to reproduce the measured mass and radius to within 3σ. **Instead, TOI-561 b needs an atmosphere to comprise at least 7% of its radius.**

With an equilibrium temperature of 2500 K and a radius typical of rocky planets, TOI-561 b is unlikely to harbor a primordial H/He envelope, but this atmosphere could be volatile outgassing from magma, or from the evaporation of heavier species from the mantle itself.

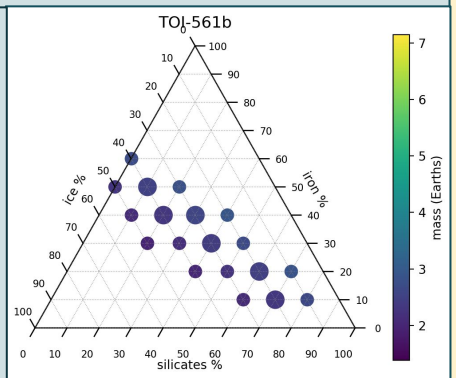


Fig 3.