Observational Constraints on Rocky Planet Interior and Atmospheric Compositions from XUV Irradiation and Stellar Abundances

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February 5, 2025

Know Thy Star Know Thy Planet 2

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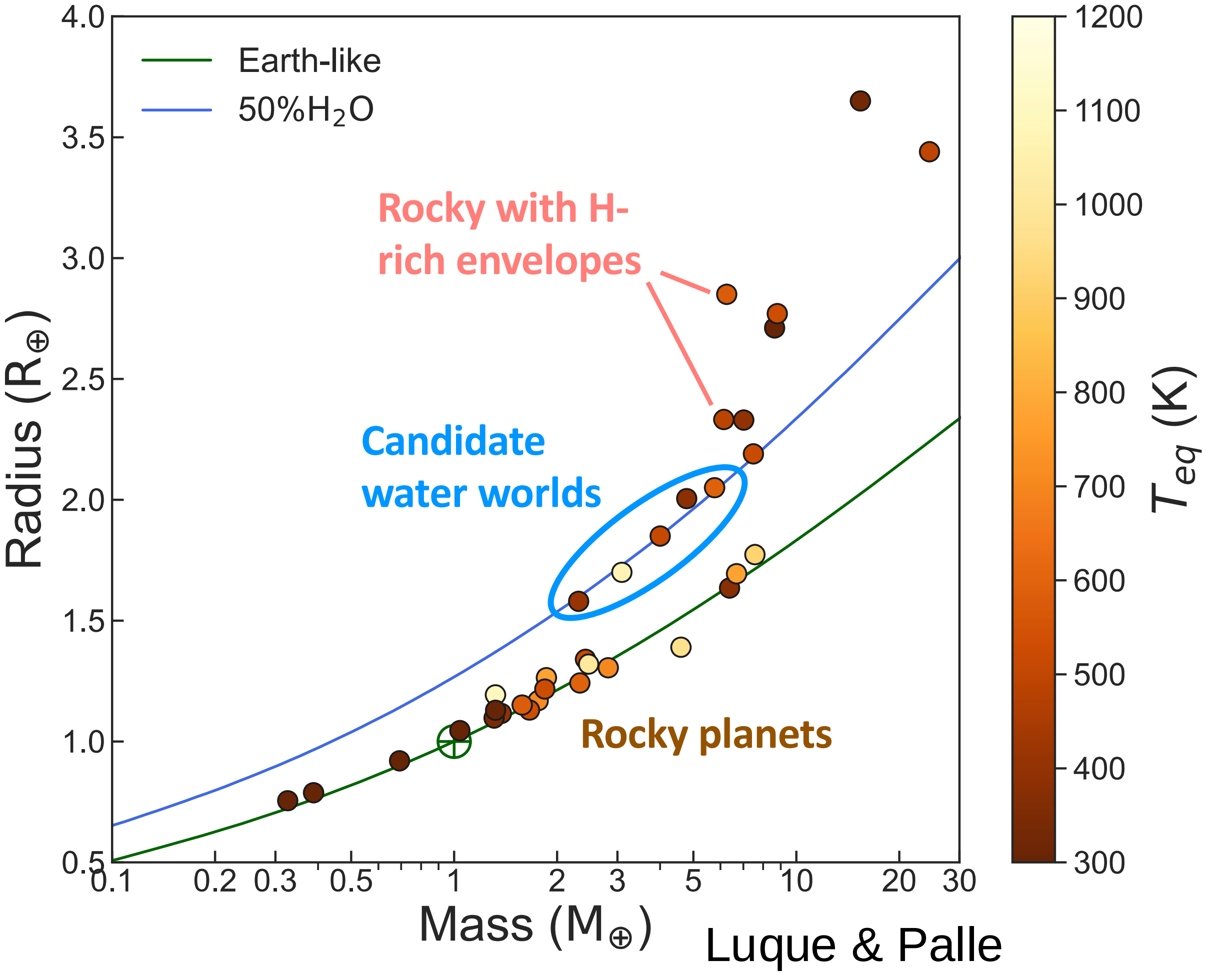
Image: NASA/JPL-Caltech/MSSS

The compositions of small M Dwarf planets are poorly understood



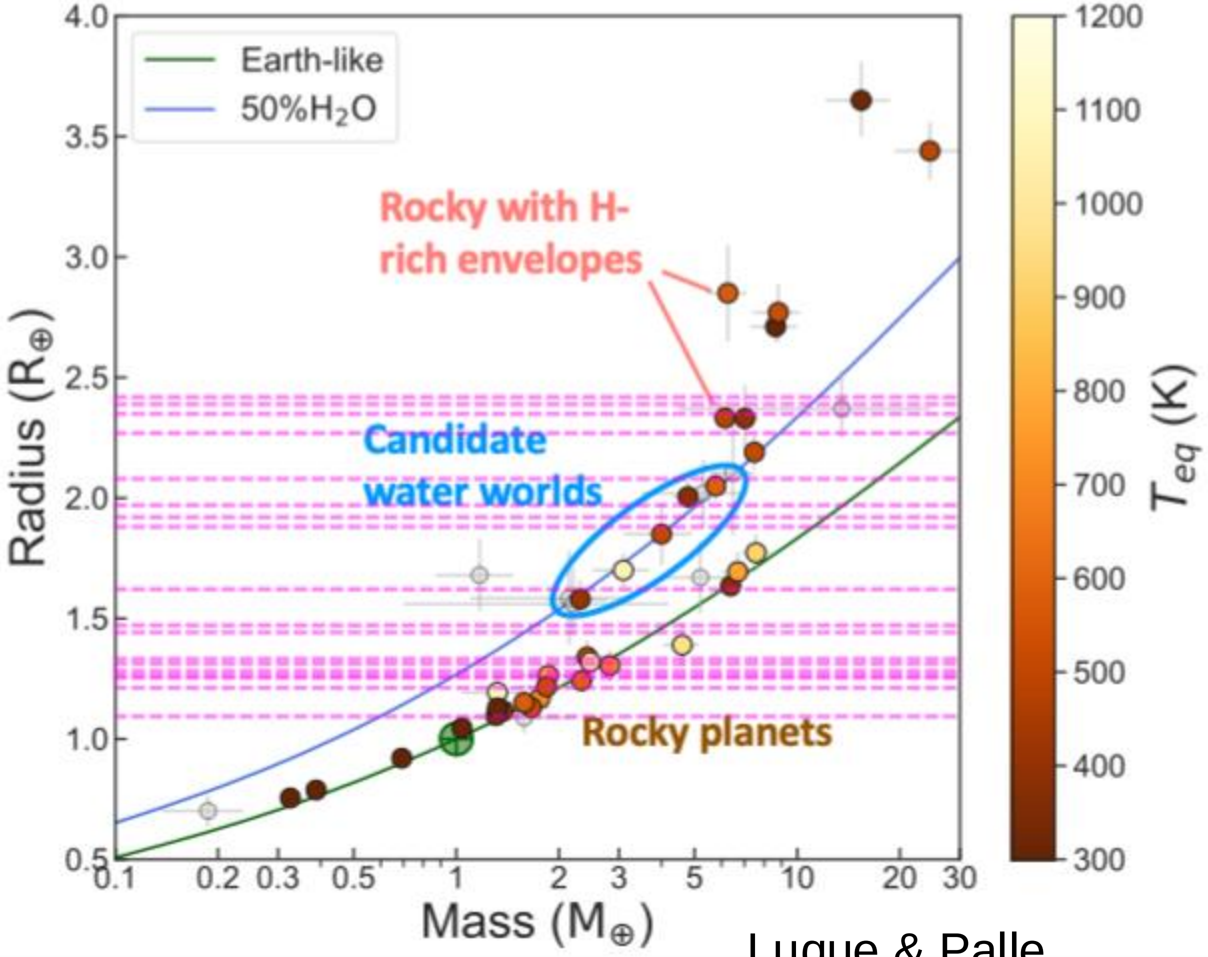
Luque & Palle 2022

Mass and radius measurements are a first step

The compositions of small M Dwarf planets are poorly understood

Image: Palomar Observatory/Caltech

Over 80 transit observations of 19 planets across 8 multi-planet systems to date!



Luque & Palle 2022

Mass and radius measurements are a first step

Understanding ambiguous planet compositions ~without~ JWST

Image: Palomar Observatory/Caltech

Measure planet masses and radii with transit timing variations (Palomar)

K2-3 (Diamond-Lowe et al. 2020), LTT 1445A and GJ 486 (Diamond-Lowe et al. 2024), TOI-431 and ν^2 Lupi (King et al. 2024)

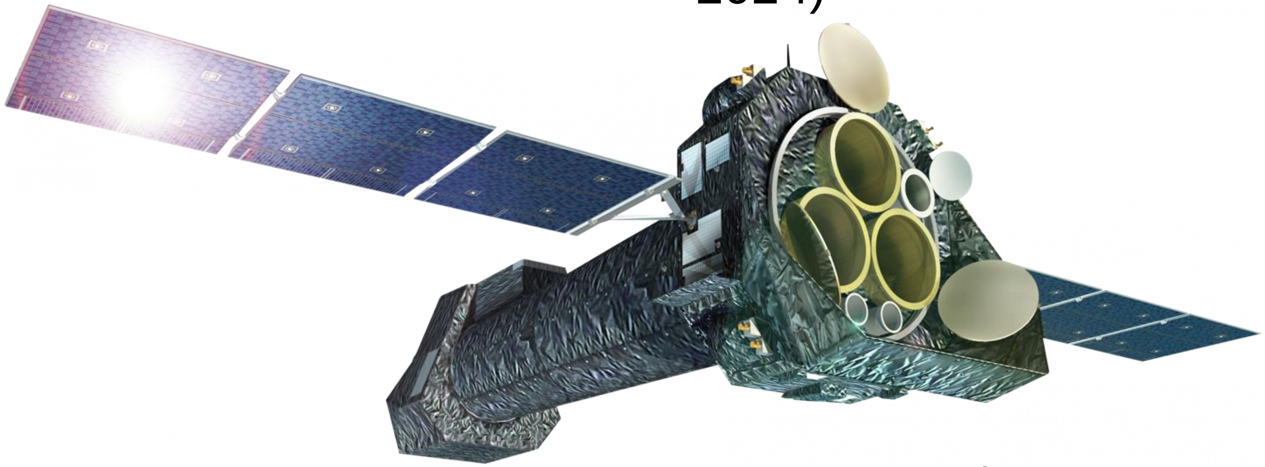
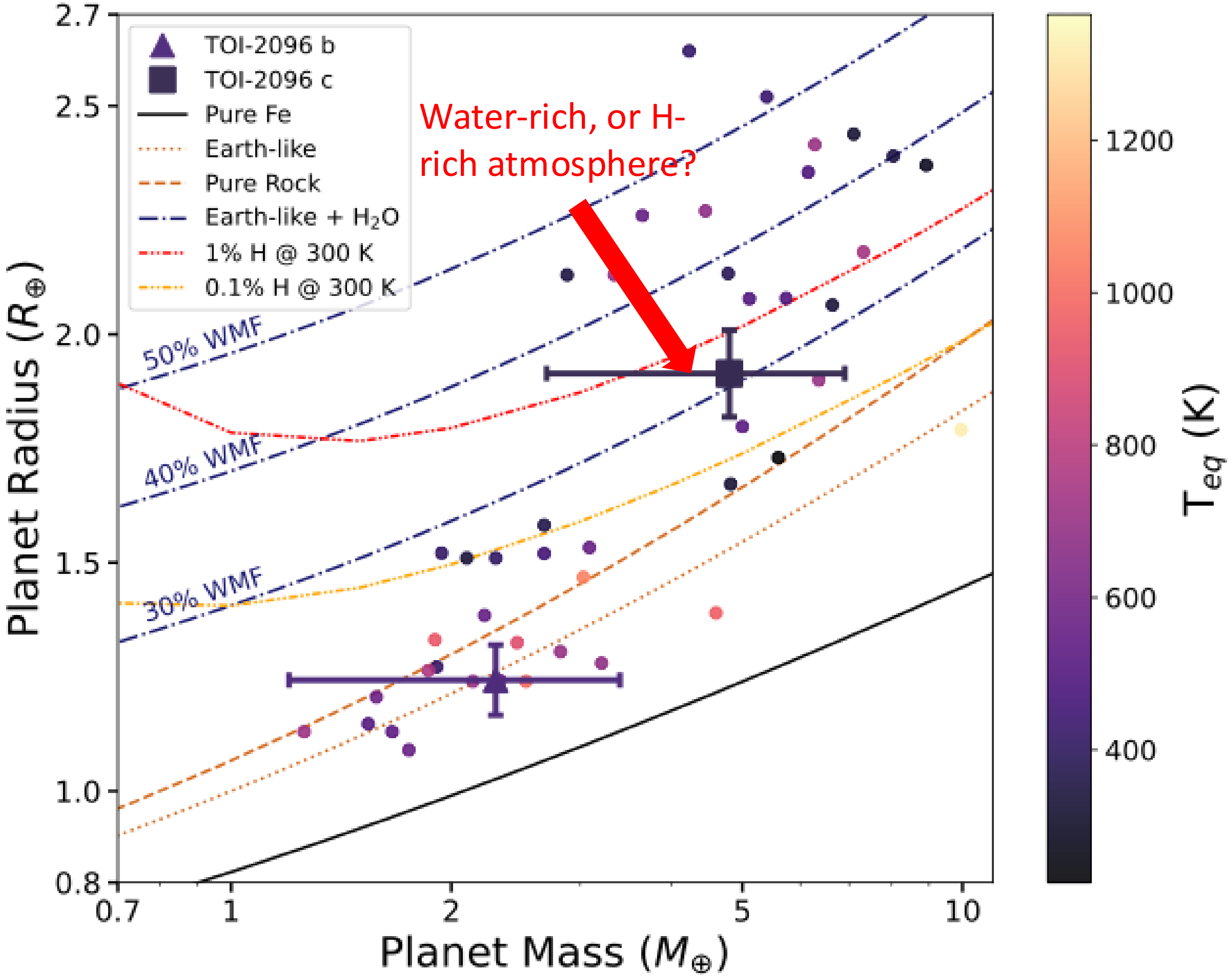


Image: ESA/XMM-Newton

Measure stellar XUV irradiation to quantify atmospheric mass loss (XMM-Newton)

Case Study 1: TOI-2096

- M4 host star, 3300K
  - Pozeulos et al. 2023
  - 4.4-day rotation
  - Large flares
- TOI-2096 b: T_{eq} = 445 K
- TOI-2096 c: T_{eq} = 349 K



Can TOI-2096 c Retain a Primordial H-rich Atmosphere?

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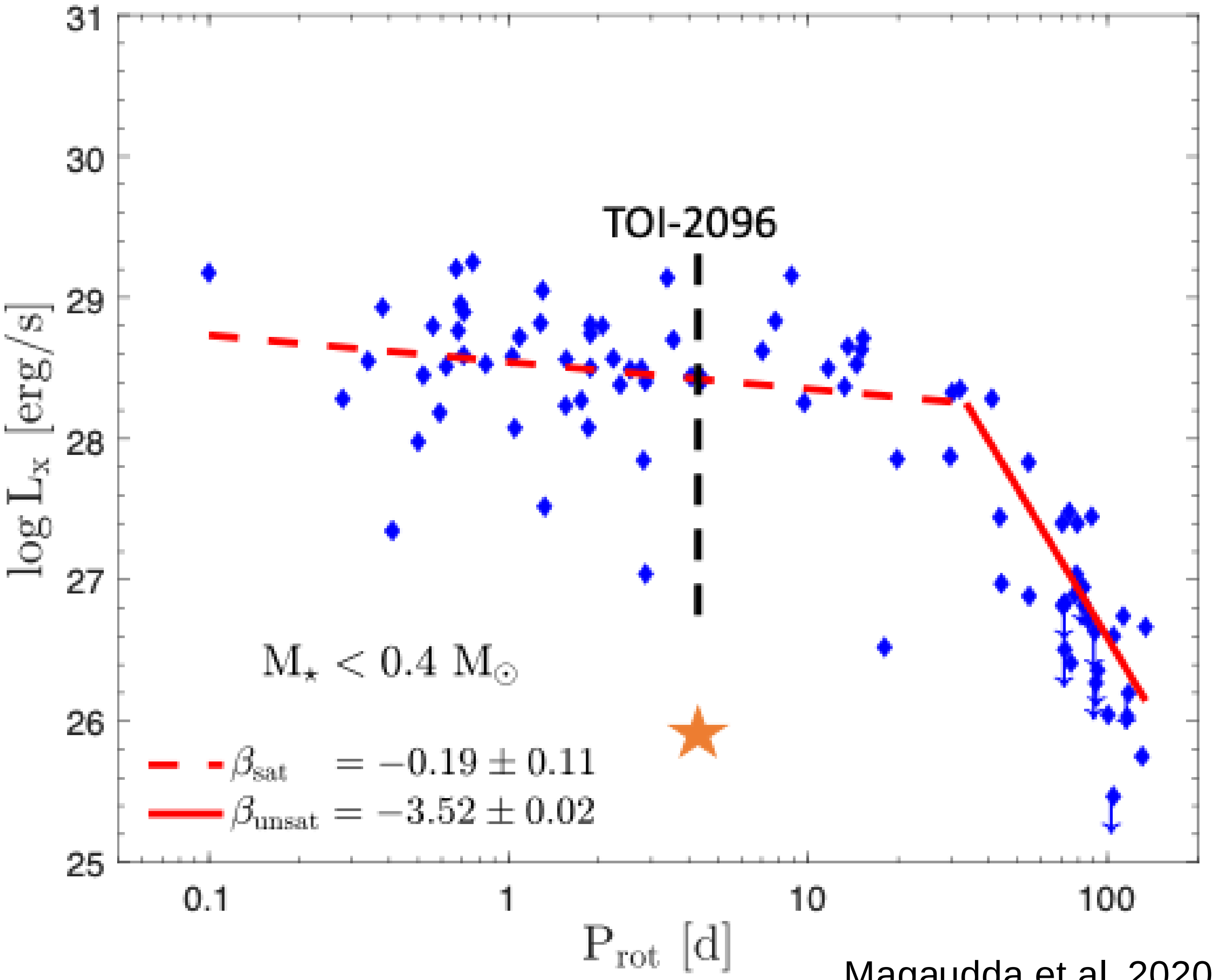
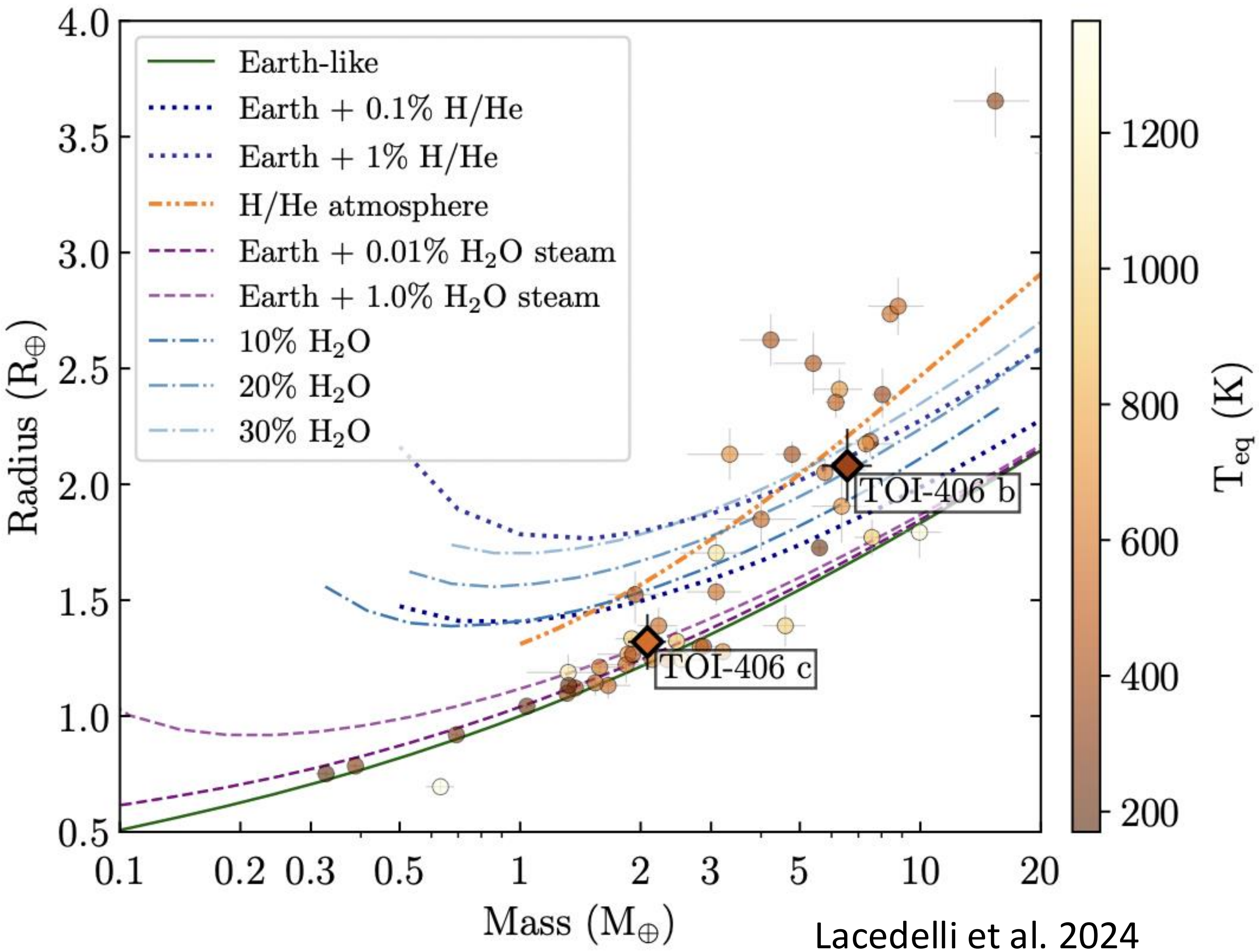


Magaudda et al. 2020

Case Study 2: TOI-406

- M3 Host star, 3400 K
  - 30-day rotation
  - Quiet
- TOI-406 c: 584 K
- TOI-406 b: 368 K



Lacedelli et al. 2024

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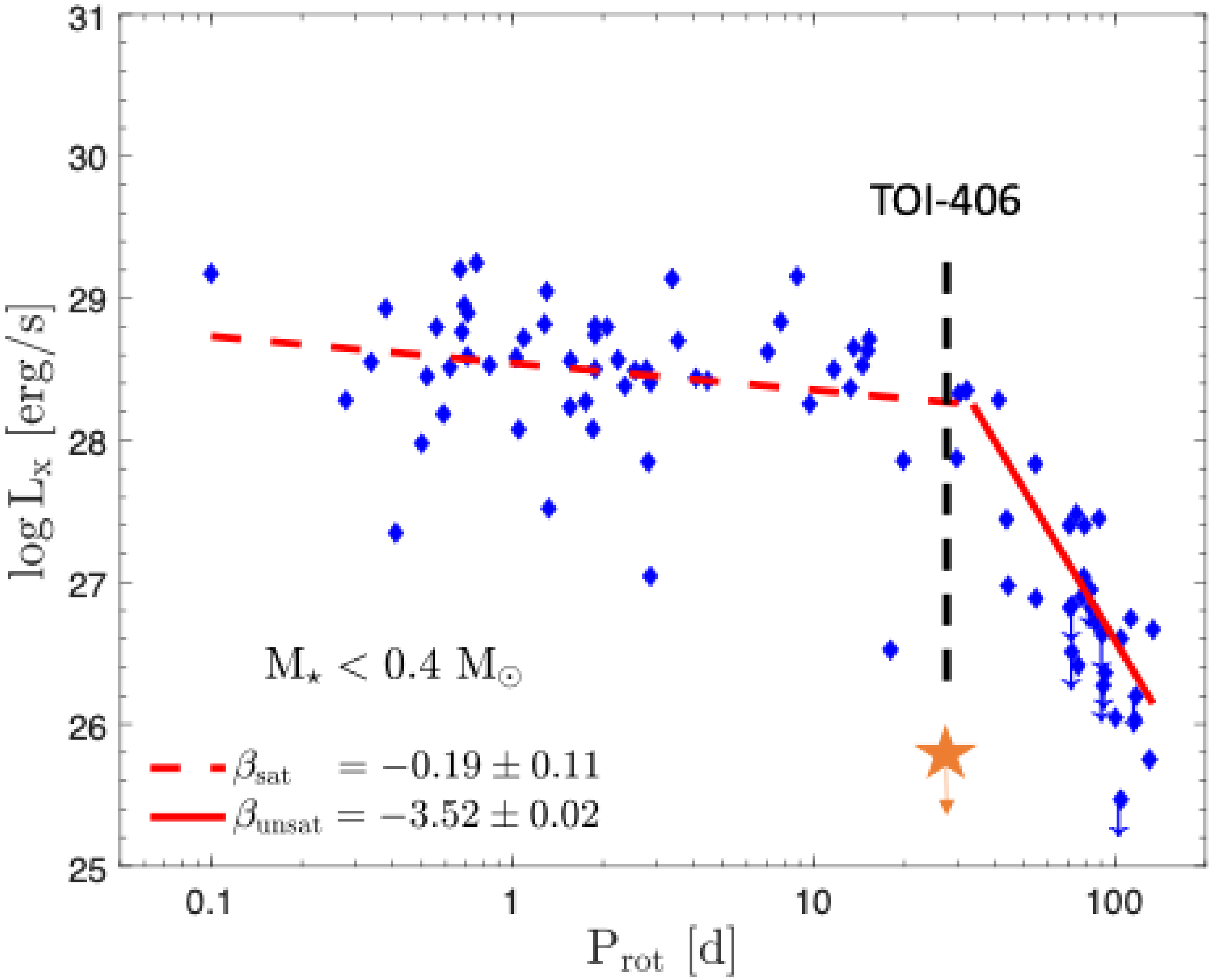
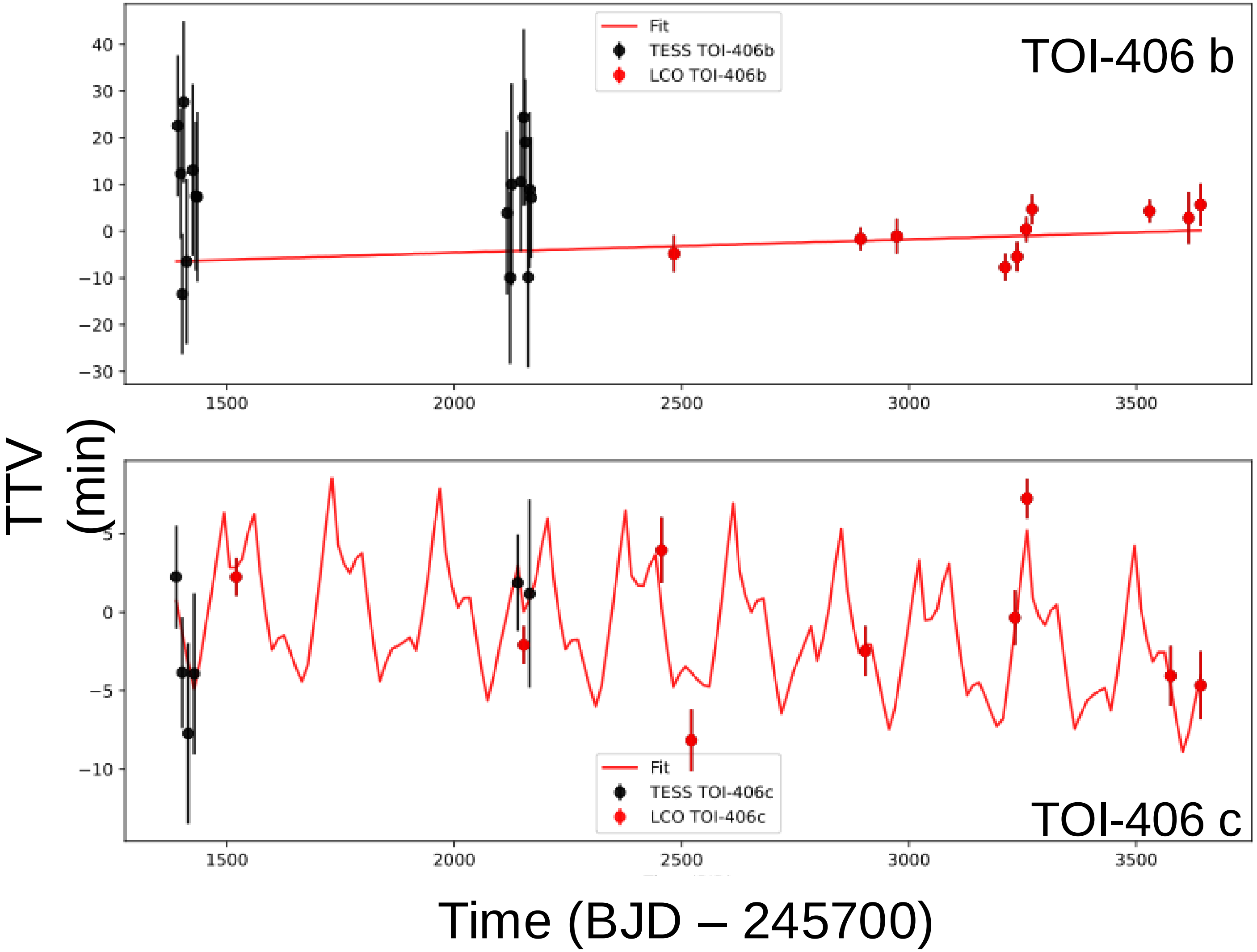


Caveat: TOI-406 Transit Timing Variations

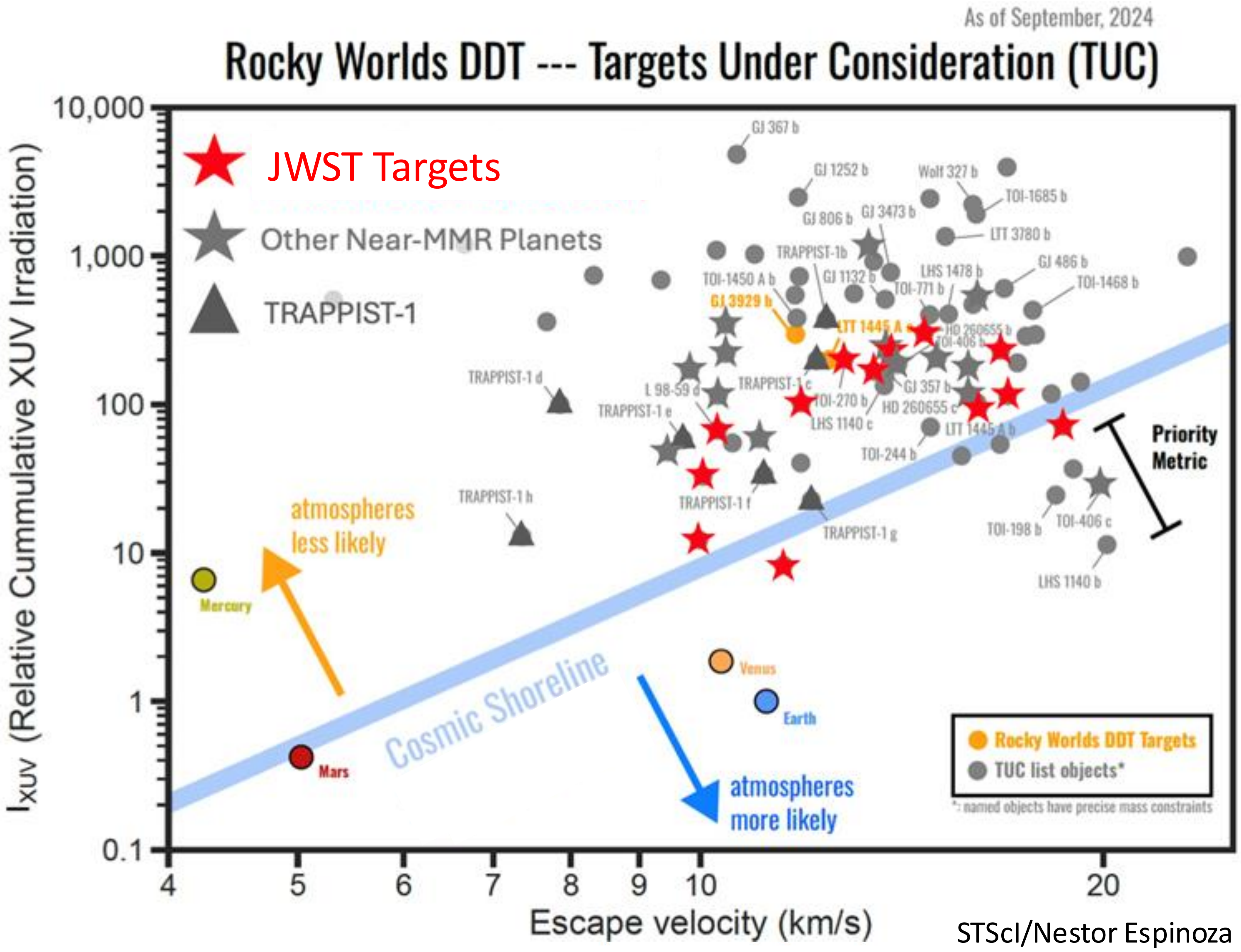
- Larger TTVs than expected from 4:1 resonance
- Two potential explanations:
  - Eccentric orbits (unlikely due to tidal damping)
  - Undetected, low-mass third planet



Work by Yale PhD Student Kendra Nguyen

Eccentricity-driven tidal heating?

How many rocky planets might be tidally heated?



STScI/Nestor Espinoza

How does tidal heating affect planetary composition?

Super-earths, e.g. L 98-59 b (Bello-Arufe et al. 2025)

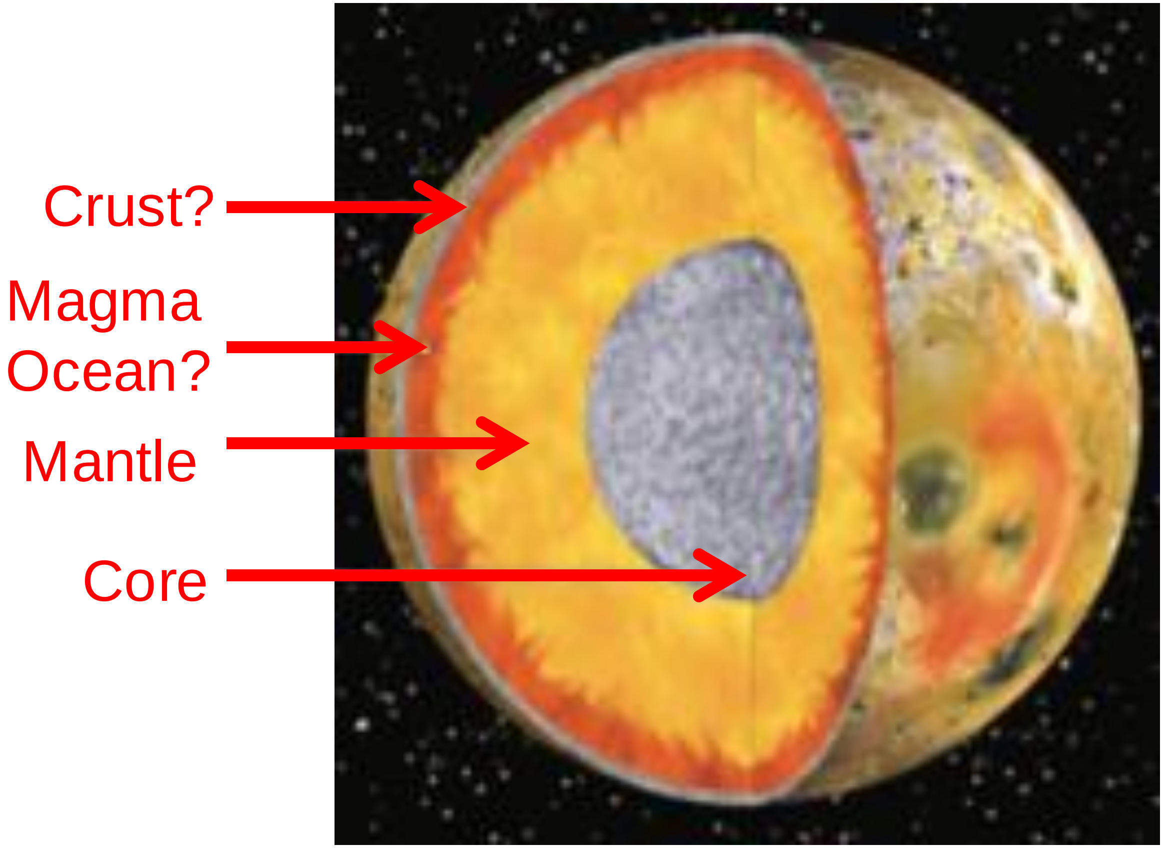


Image: Xianzhe Jia, University of Michigan

Sub-Neptunes, e.g. TOI-270 d (Benneke et al. 2024)

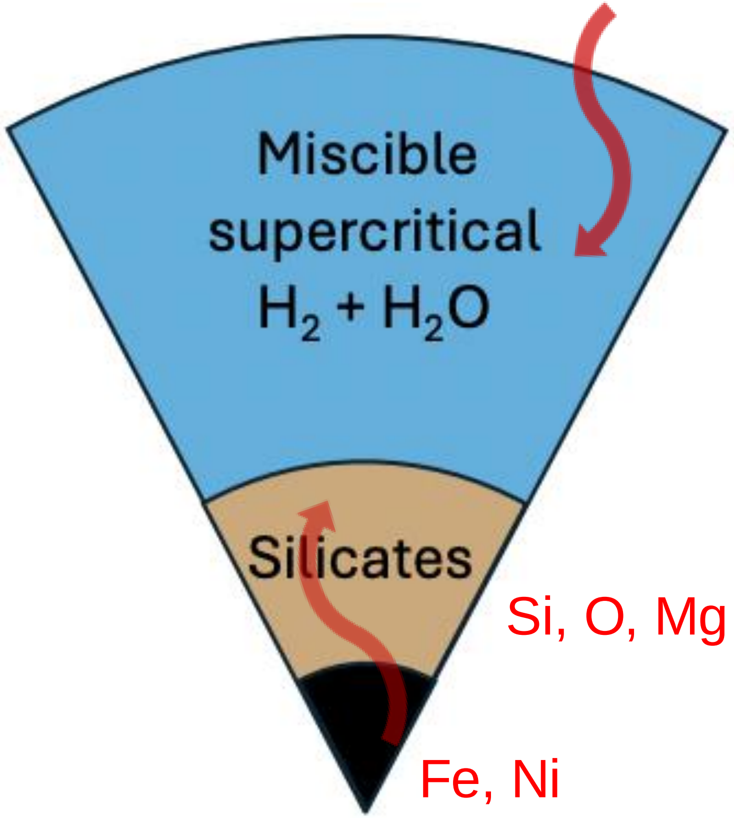
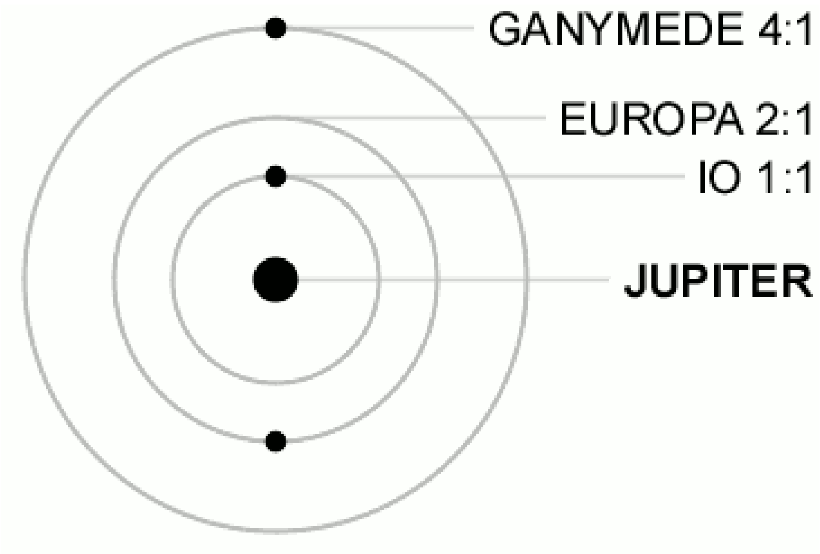


Image: Benneke et al. 2024

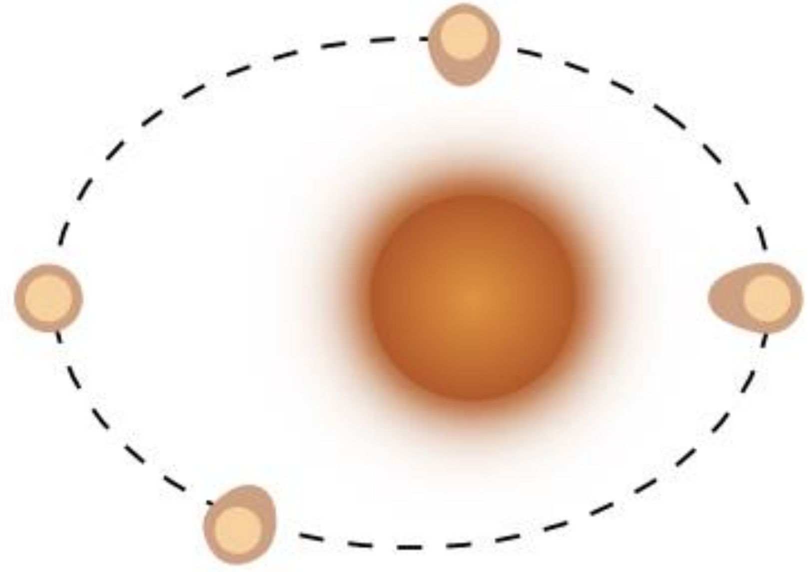
M Dwarf refractory abundances from The Cannon (Behmard et al. 2025)!

Stellar abundances provide context clues

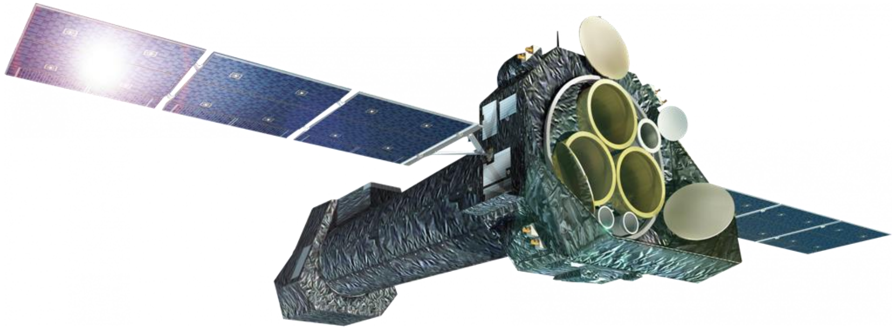
Summary



TTVs yield precise planet densities (and reveal hidden planets)

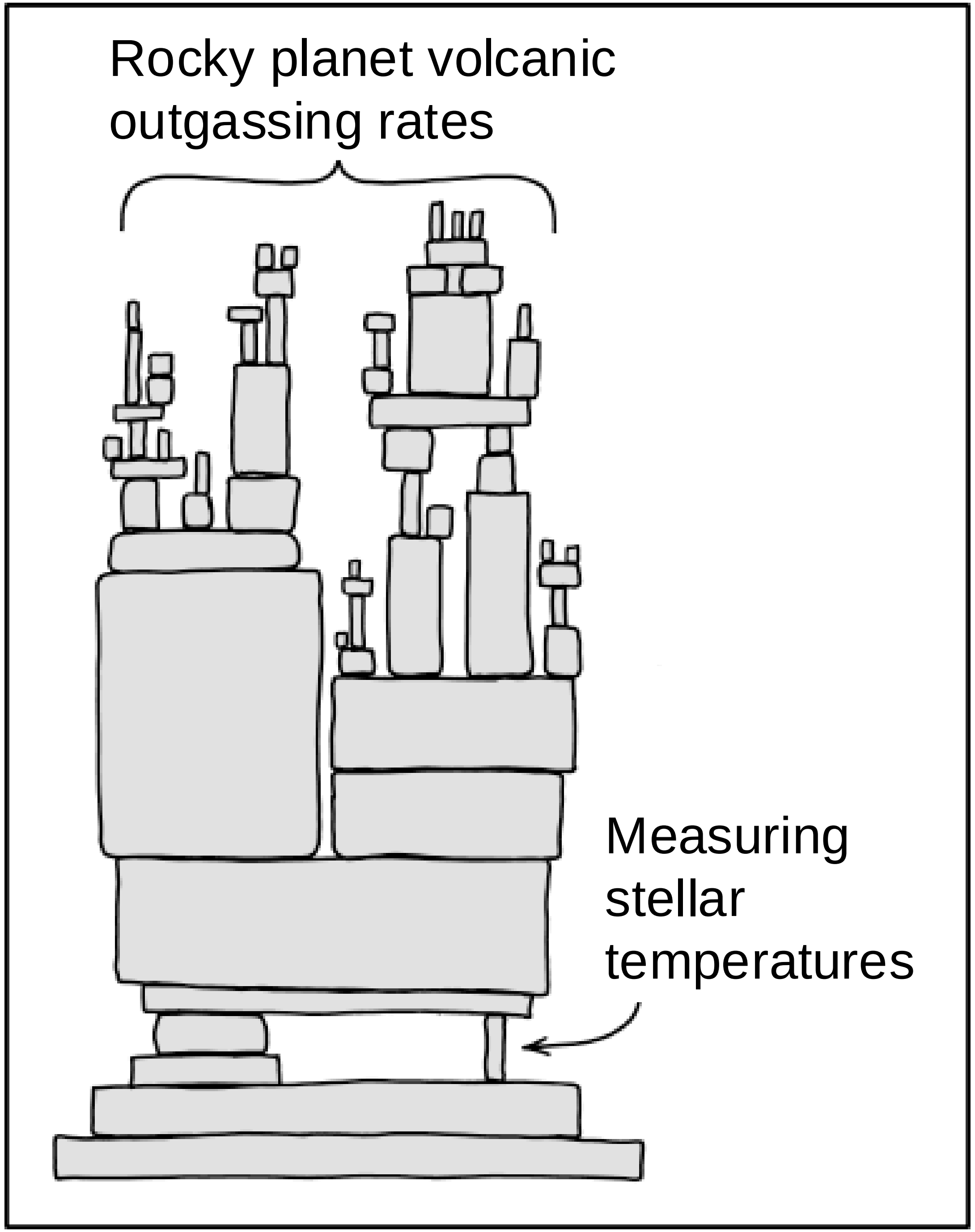


Tidal heating can reshape planet properties, stellar refractory abundances give added constraints



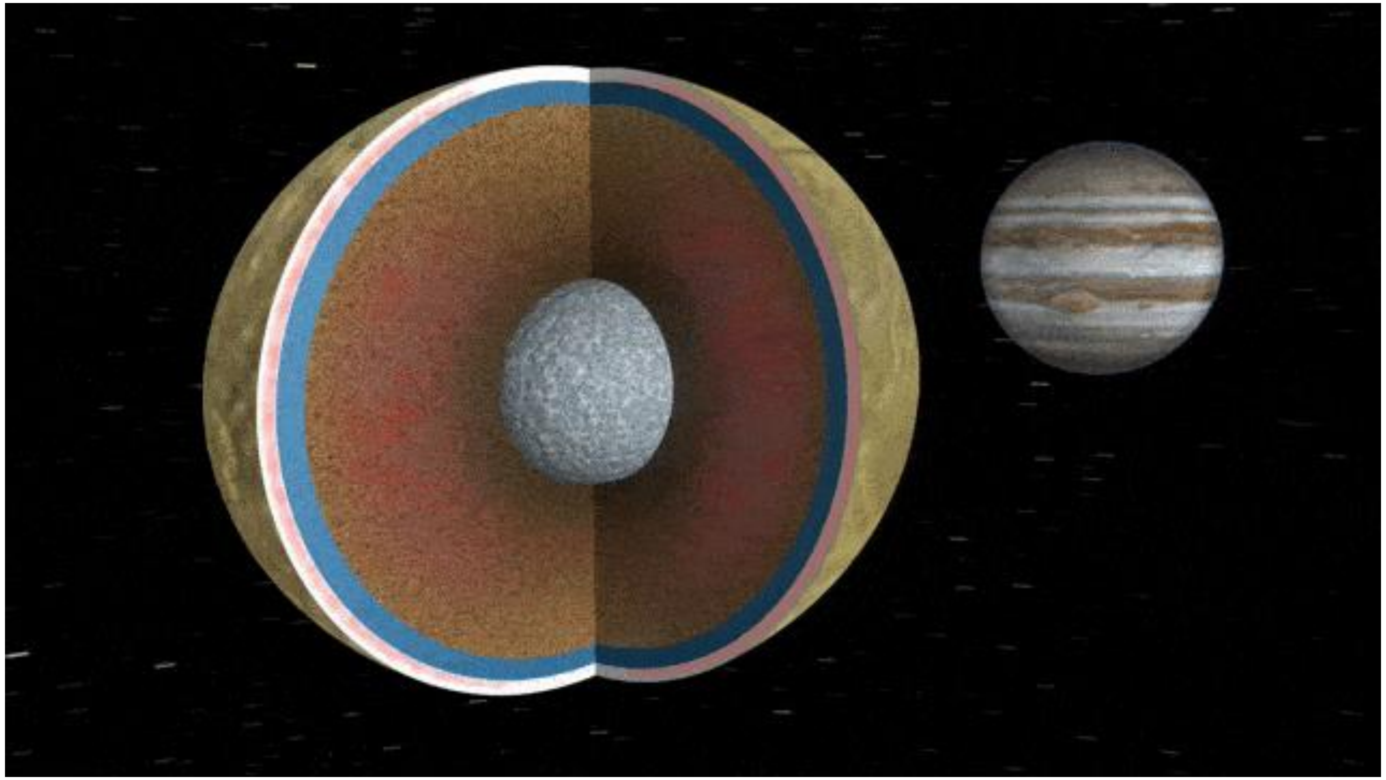
Stellar XUV fluxes give more context on planetary atmospheres

Images: Wikimedia Commons, ESA/XMM-Newton, Seligman et al. 2024

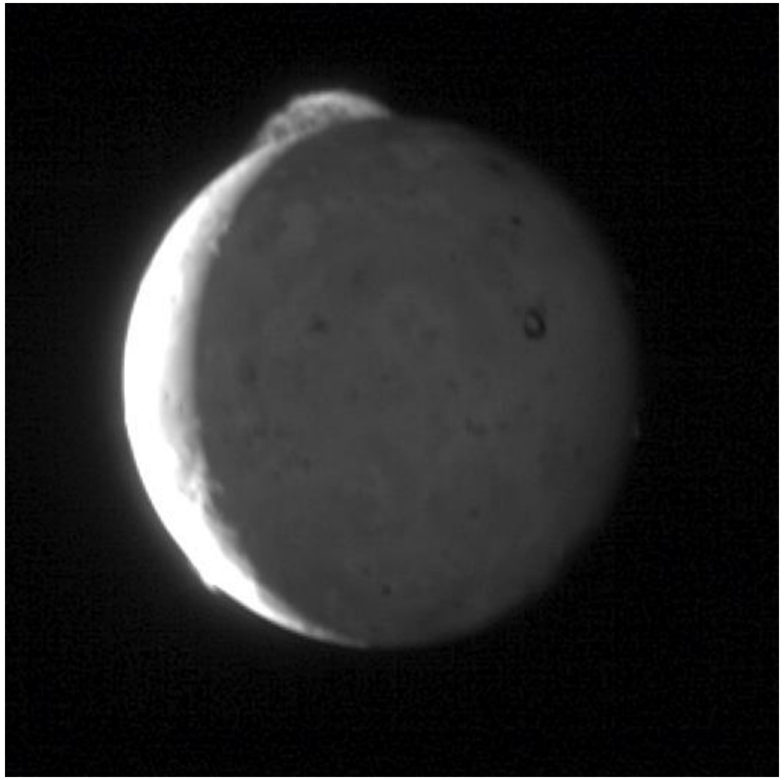

Rocky planet volcanic outgassing rates
Measuring stellar temperatures

xckd

Planetary atmospheres are governed by radiation from above AND below



NASA/JPL



NASA/JHU APL/SRI