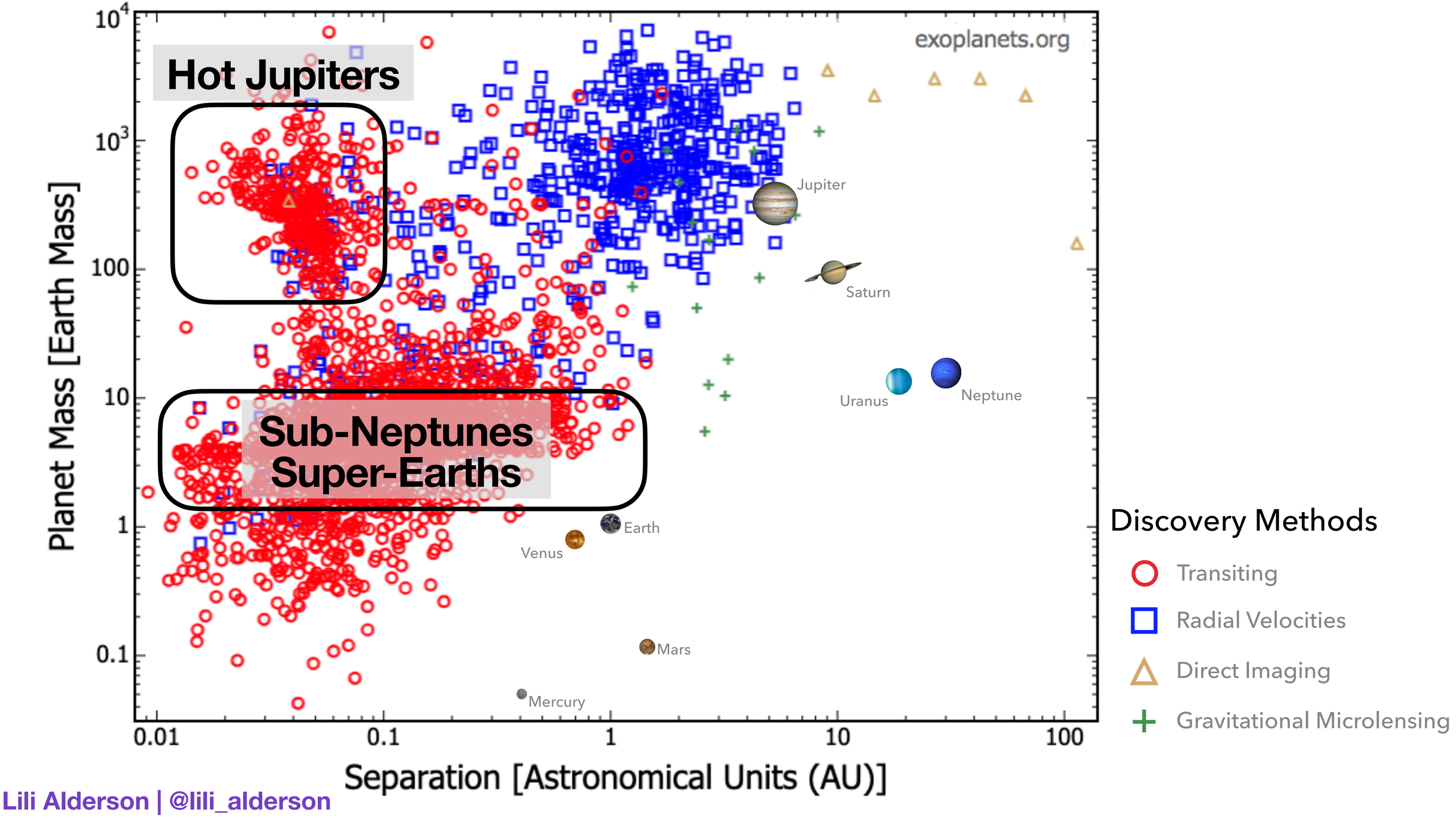
Atmospheres Across the Radius Valley

Lili Alderson

ExoExplorers
March 8th 2024



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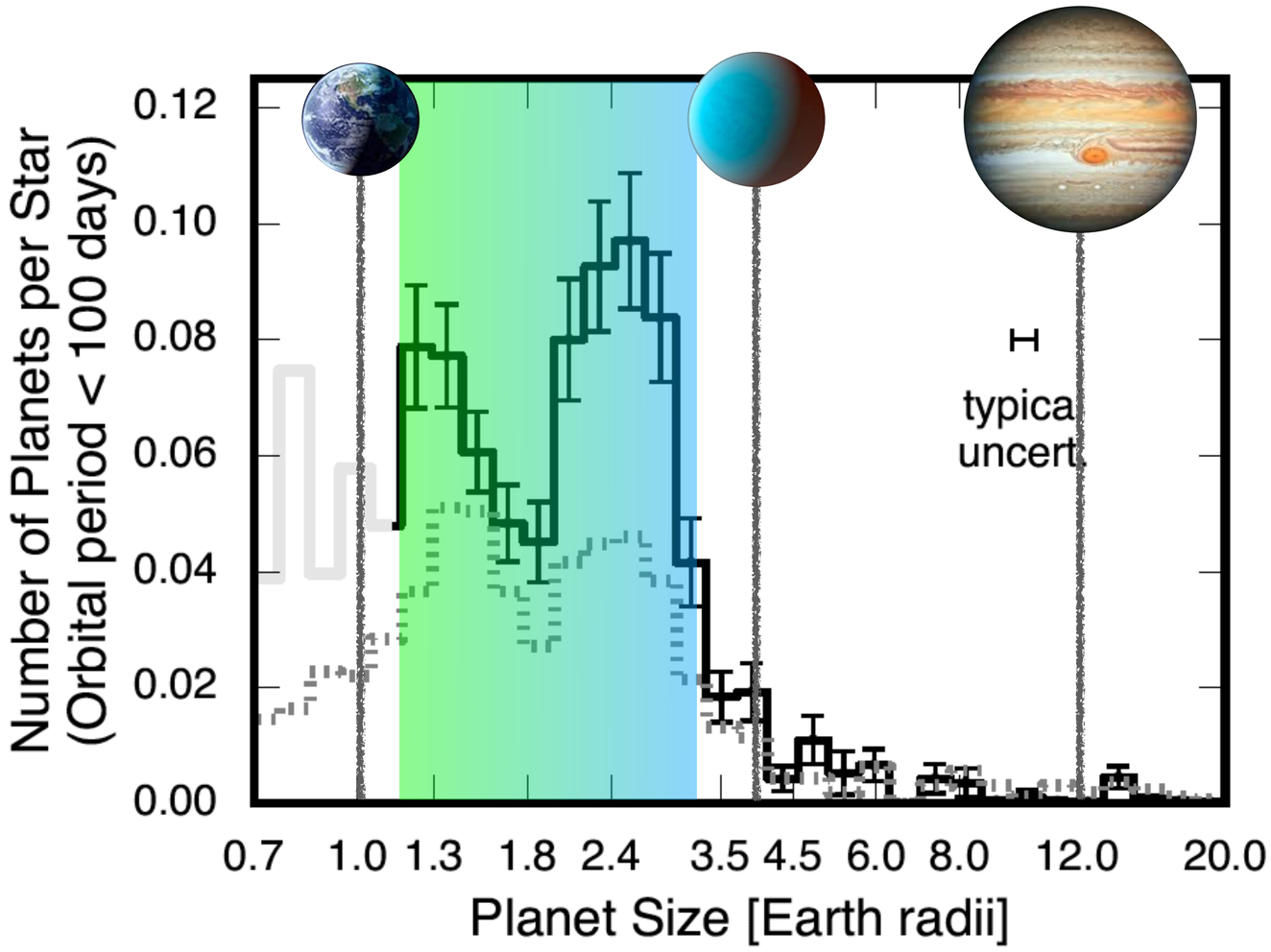
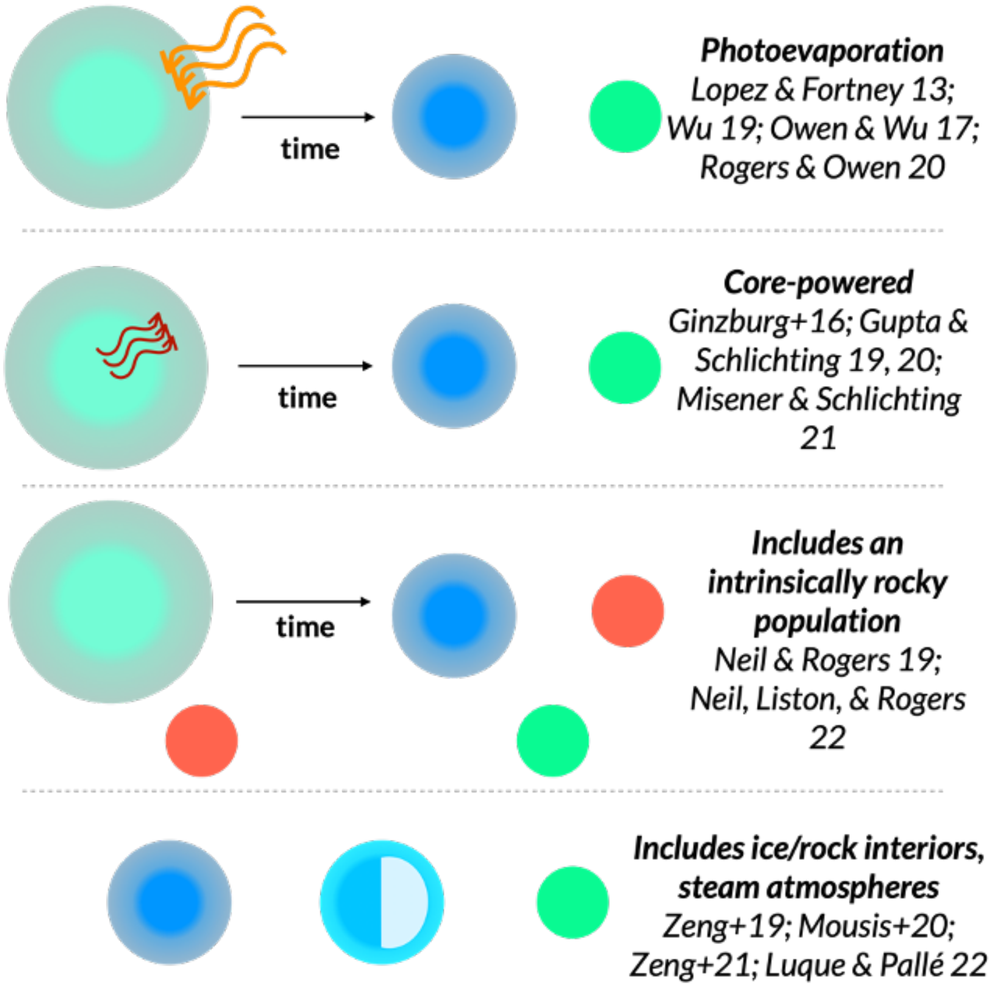
Radius Valley

- How did it get here??! Atmospheres can provide clues





Compositions of Mini-Planets for Atmospheric Statistical Study (COMPASS)

- designed to build a critical link between atmospheric characterization and planetary demographics
- observing 11 exoplanets in transmission with NIRSpec/G395H (3–5μm), including four pairs of planets in the same system
- aim to measure the prevalence of major molecular species expected to provide key insights into the formation and evolution pathways of exoplanets

Importance of Sample Selection in Exoplanet Atmosphere Population Studies
N. E. Batalha et al 2023

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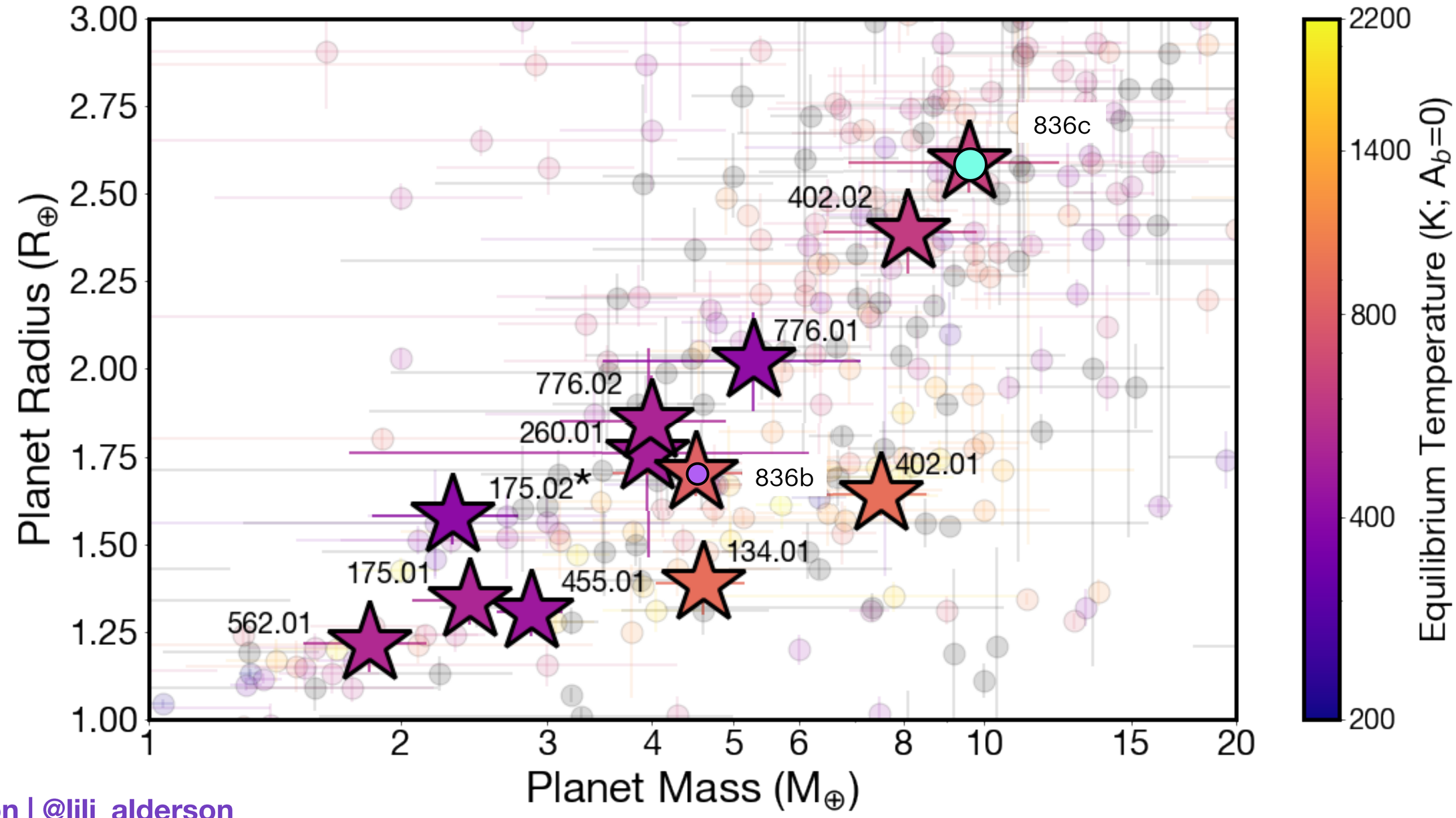
COMPASS Sample



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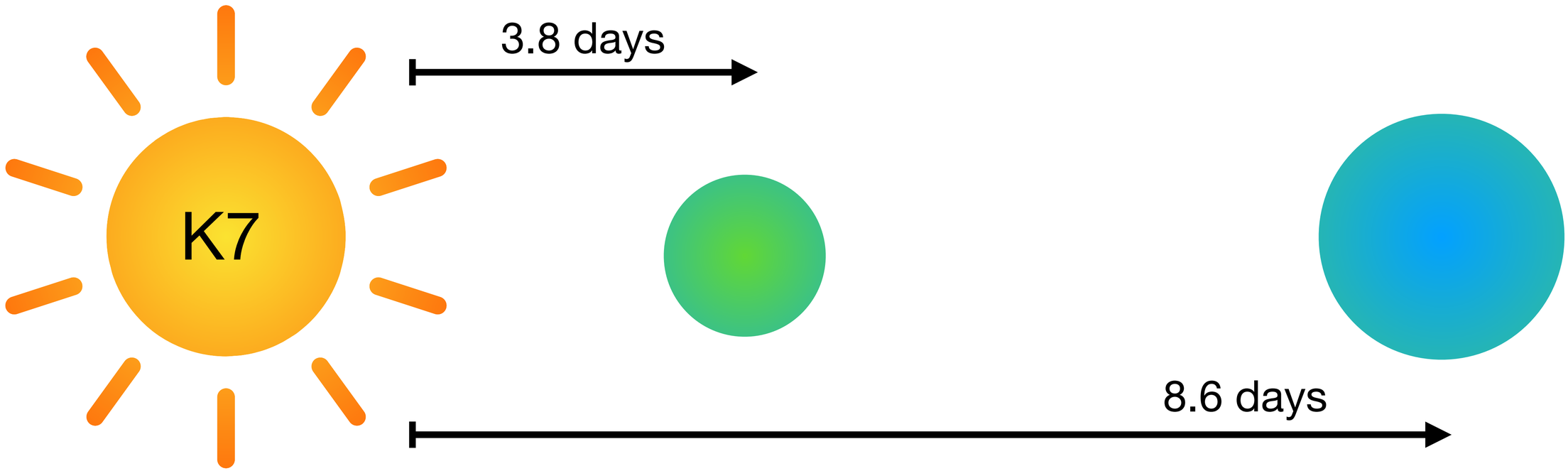
TOI-836 System



- Super-Earth TOI-836b
  - 1.704 R_E
  - 4.53 M_E
  - T_{eq} ~870K
- Sub-Neptune TOI-836c
  - 2.58 R_E
  - 9.6 M_E
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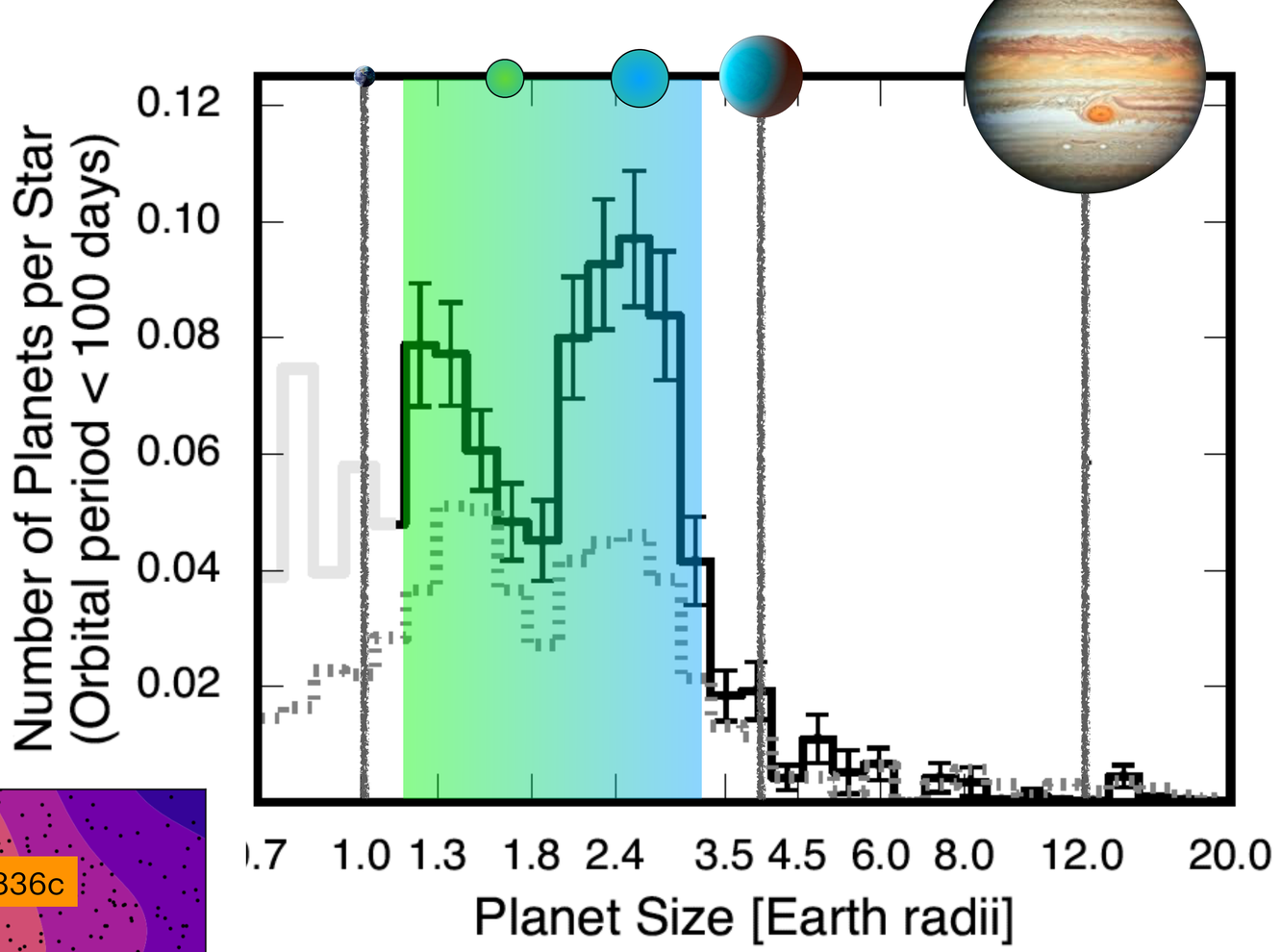
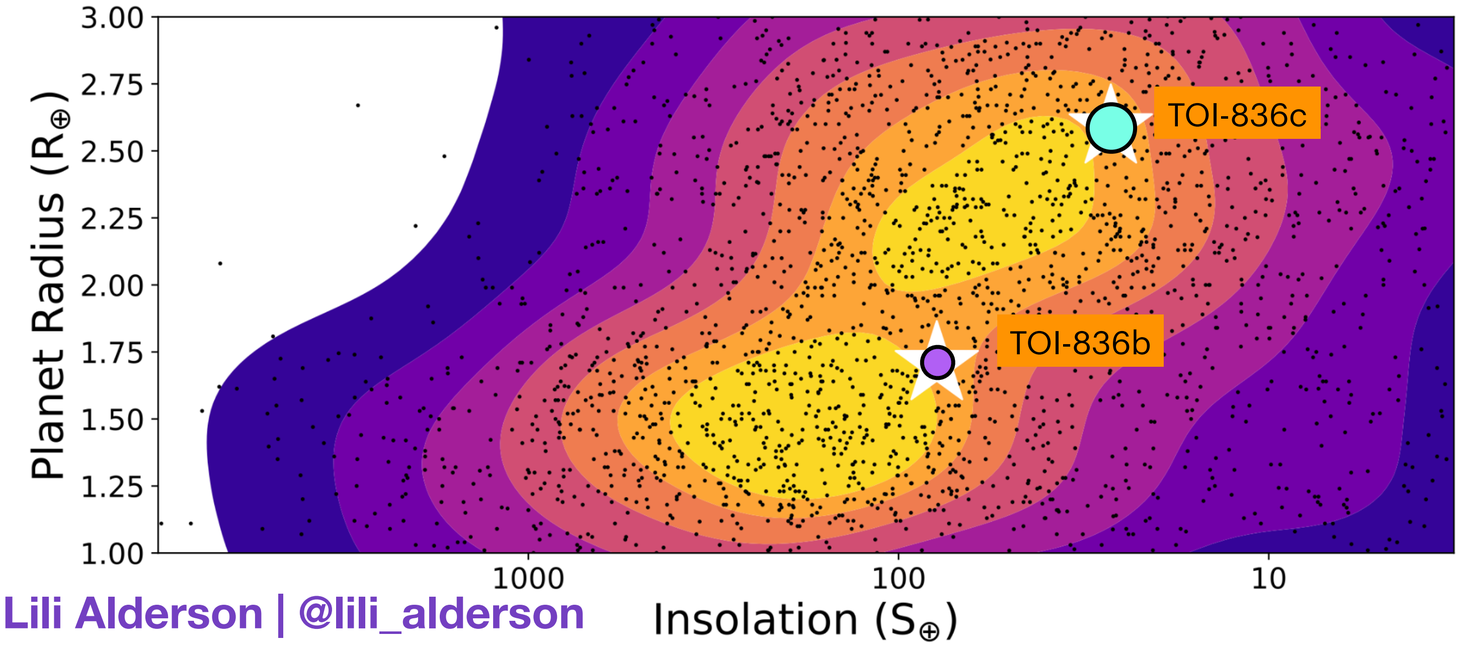
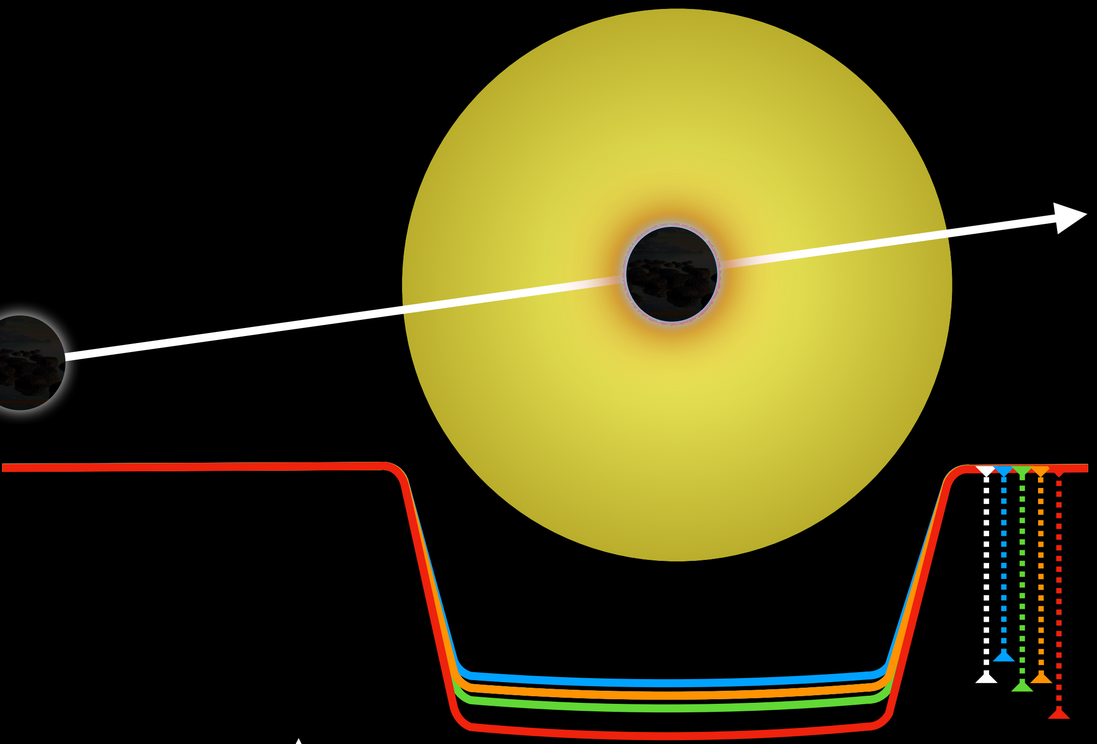
TOI-836 System

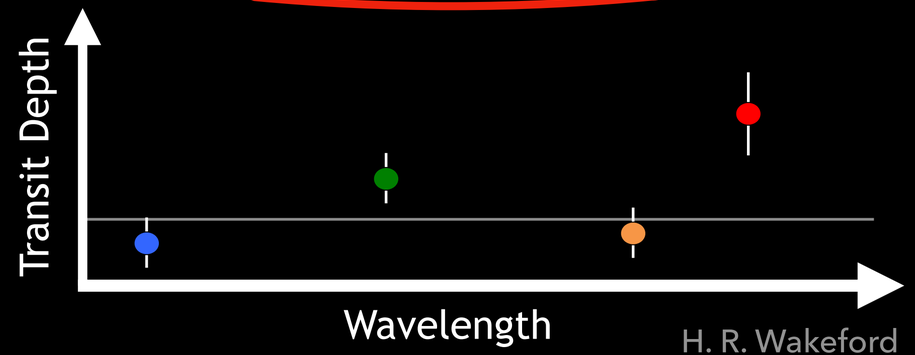
- System straddles the radius valley
  - Expected to be driven by photoevaporation or core powered mass loss

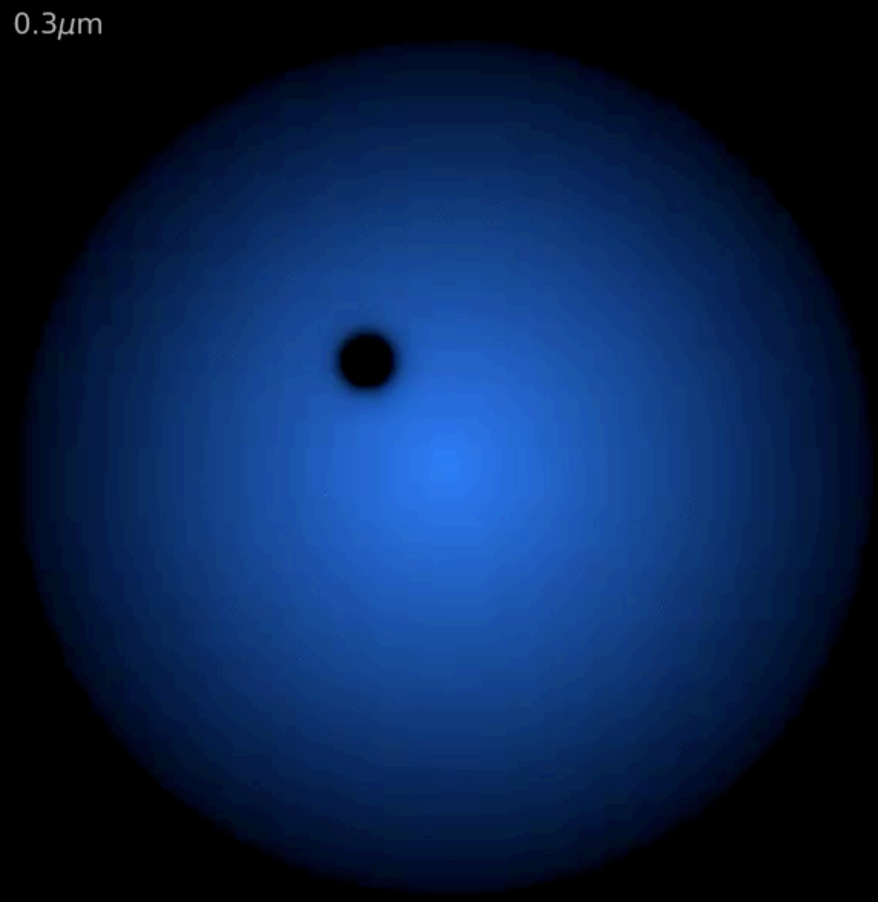


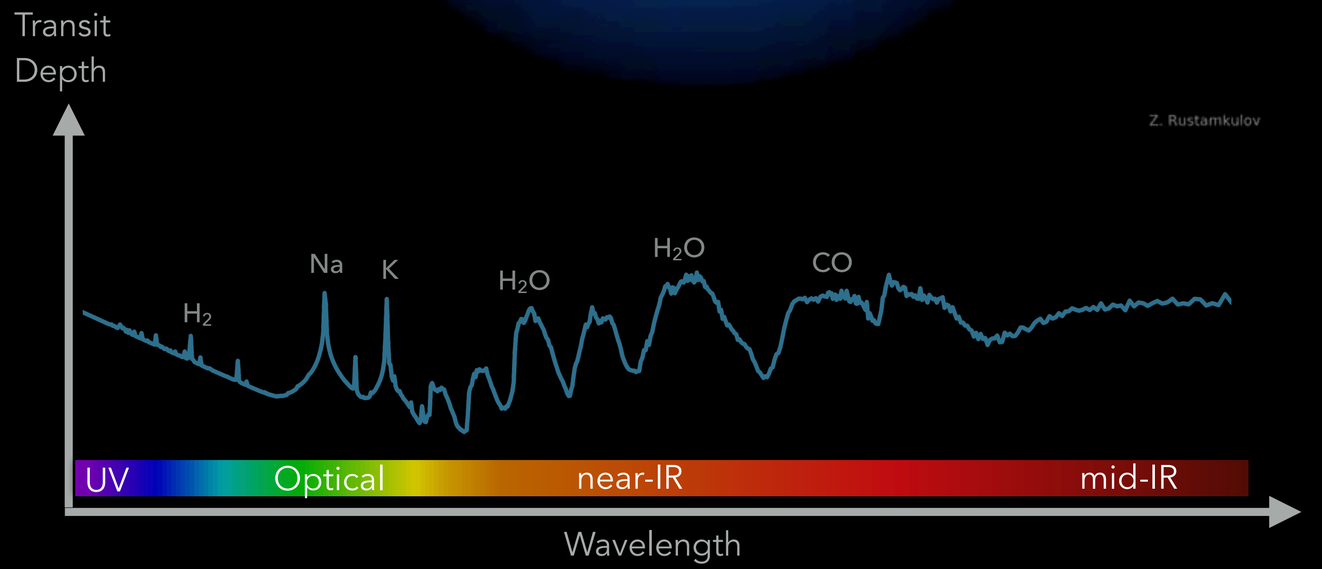


Transmission Spectroscopy









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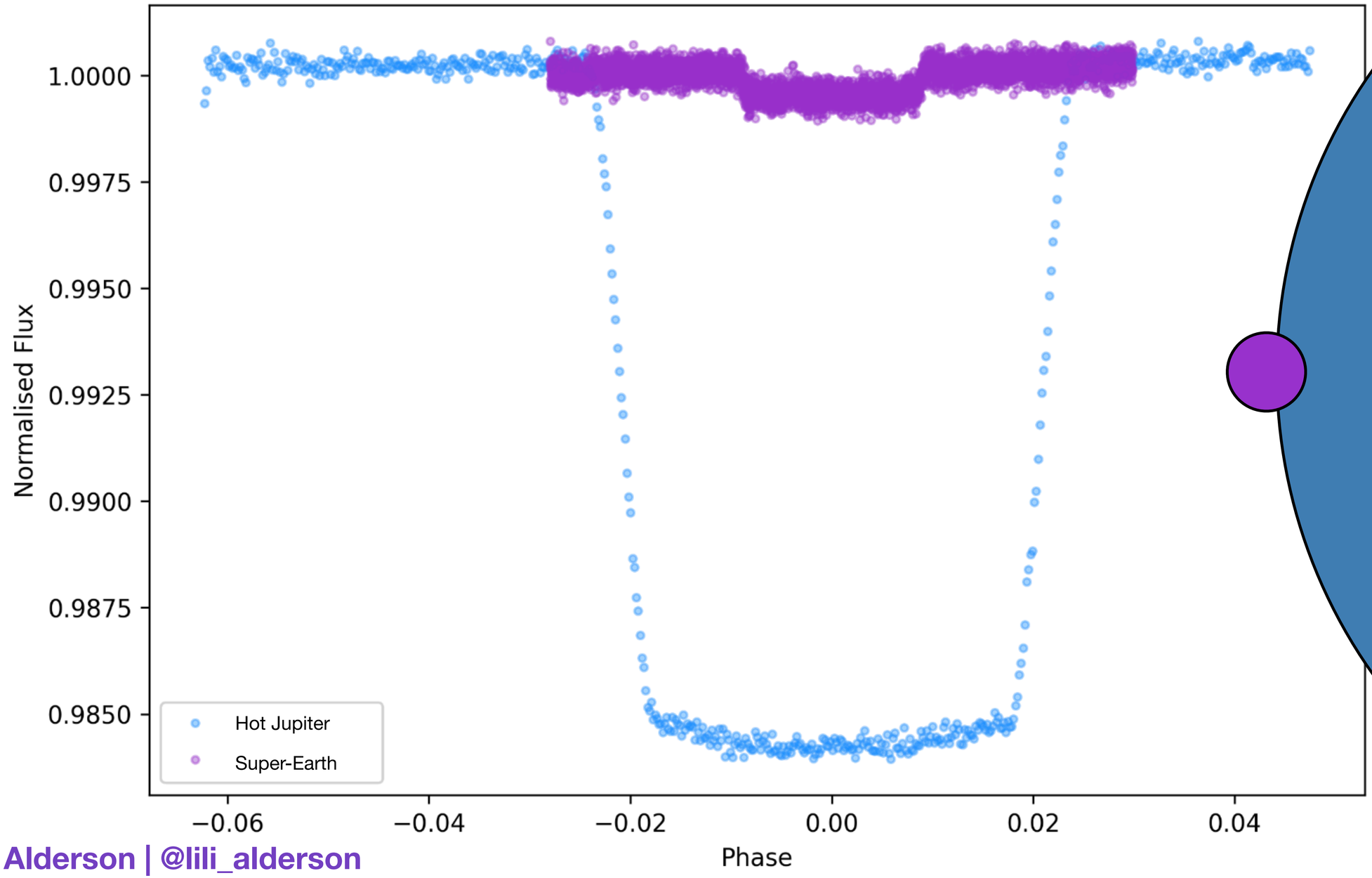
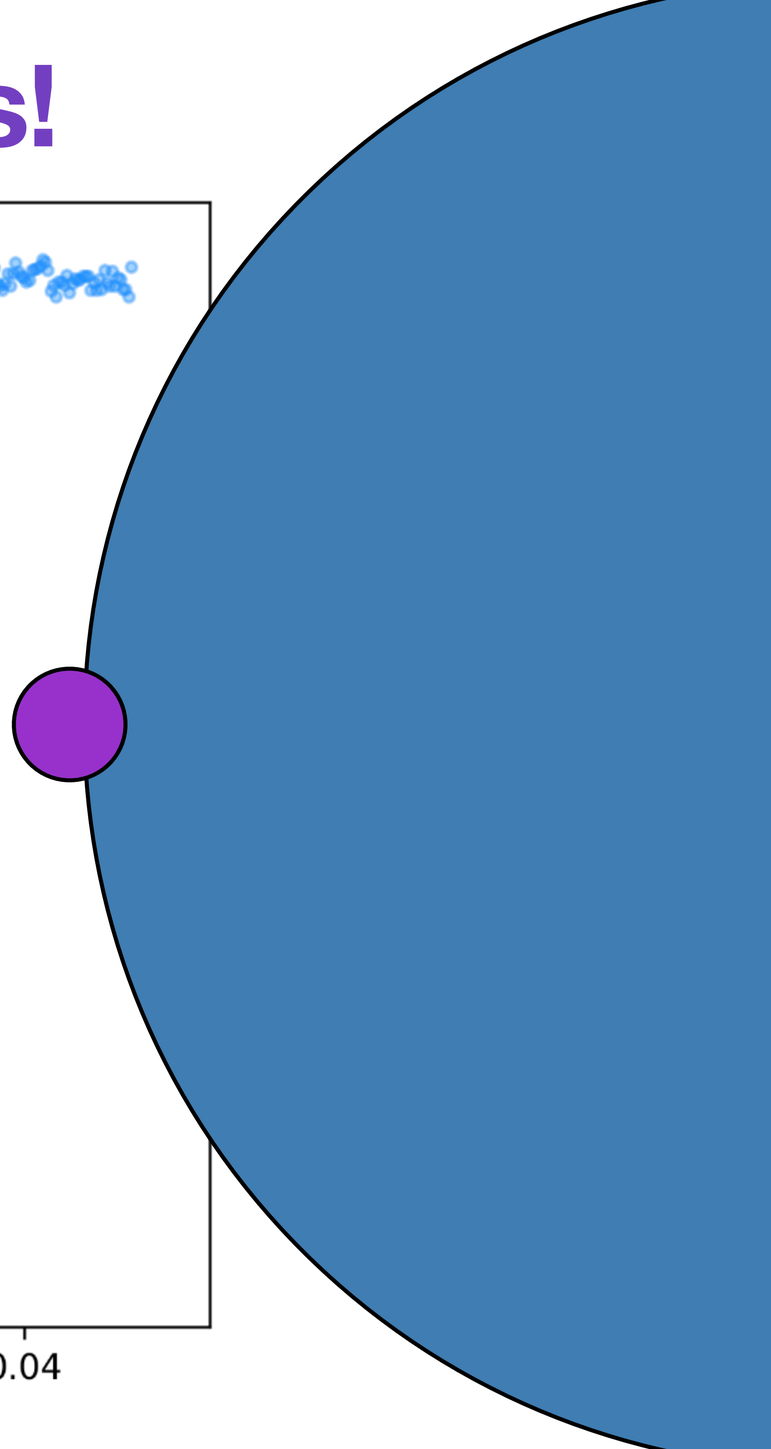
Small Planets are not Hot Jupiters!





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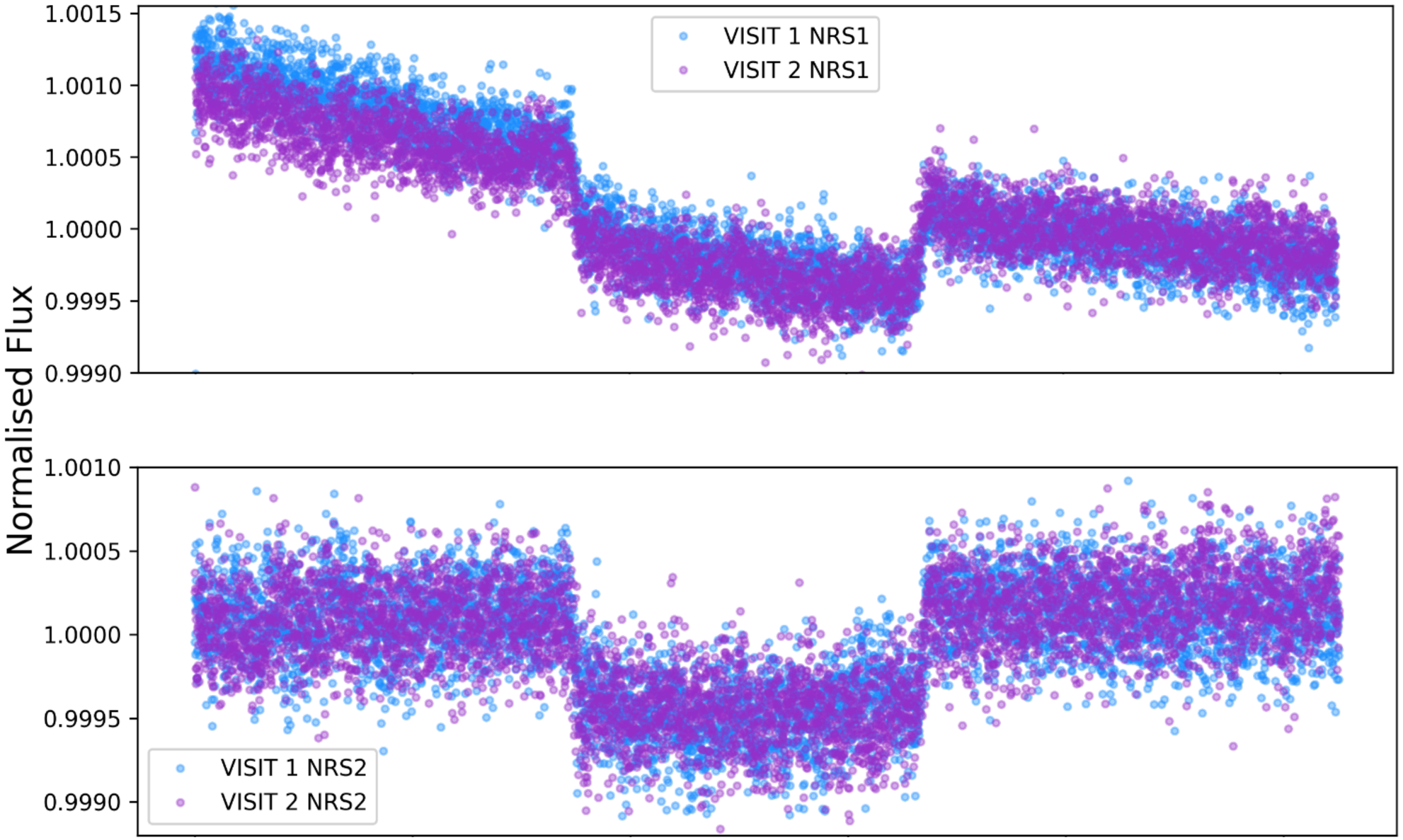
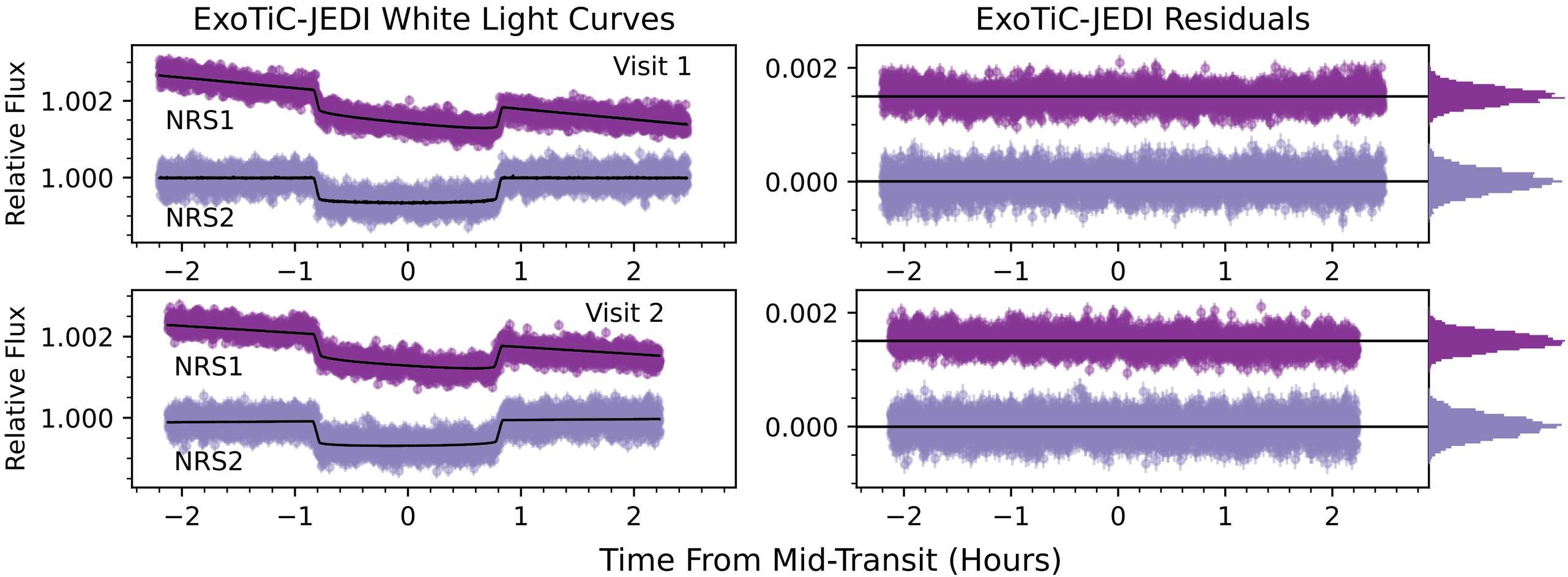
Instrument Systematics

- Linear(ish) trends in brighter targets
- Two NIRSpec detectors each behave differently
  - NRS2 is exposed less frequently than NRS1
  - NRS2 not totally “free” from systematics



TOI-836b

- Observed 2 transits in March 2023
- Reduce data with 2 independent pipelines - ExoTiC JEDI and Eureka!



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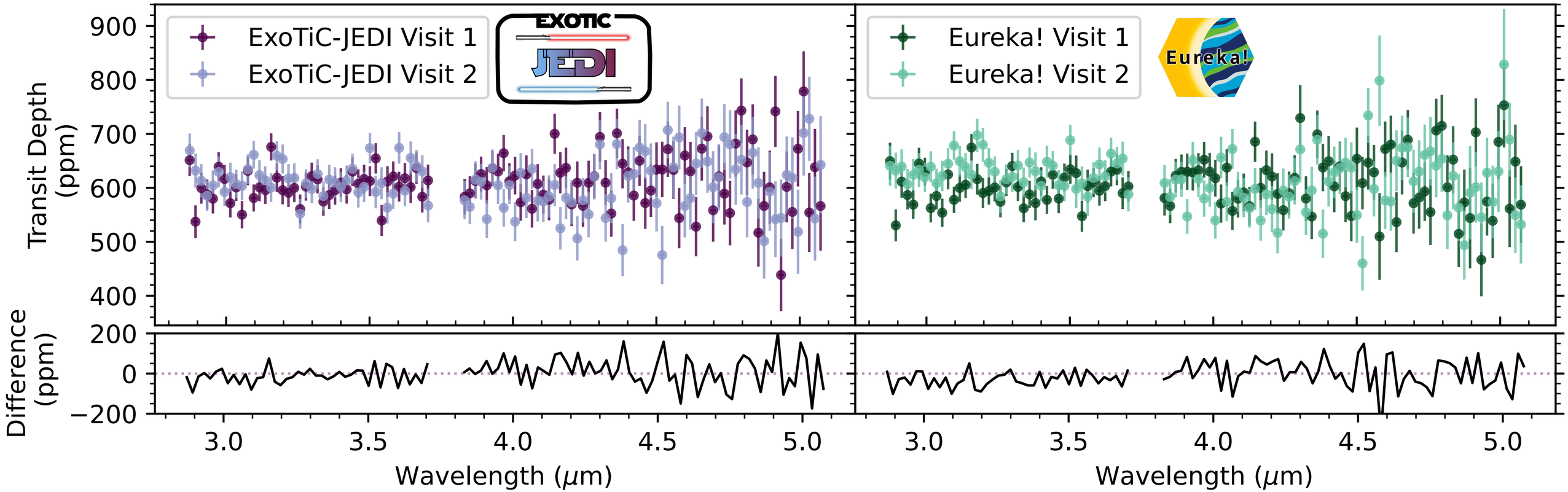
Transmission Spectra

- Spectra from both visits agree well
  - median difference 39 ppm and 48ppm compared to single visit transit depth uncertainty of ~35ppm



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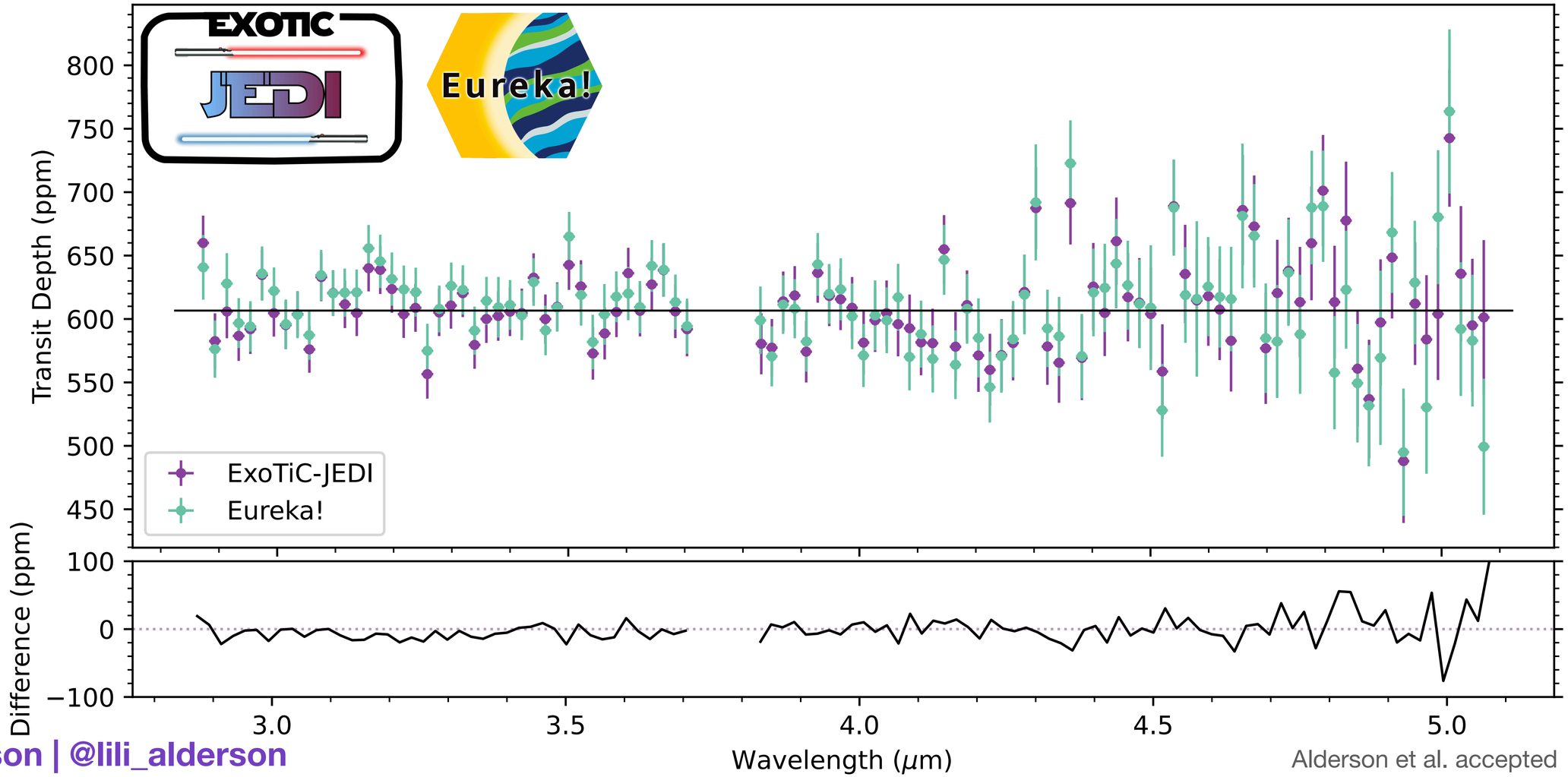
Transmission Spectrum

- Combined spectra agree between pipelines with no obvious spectral features
  - median difference 10ppm compared to uncertainty of 25ppm



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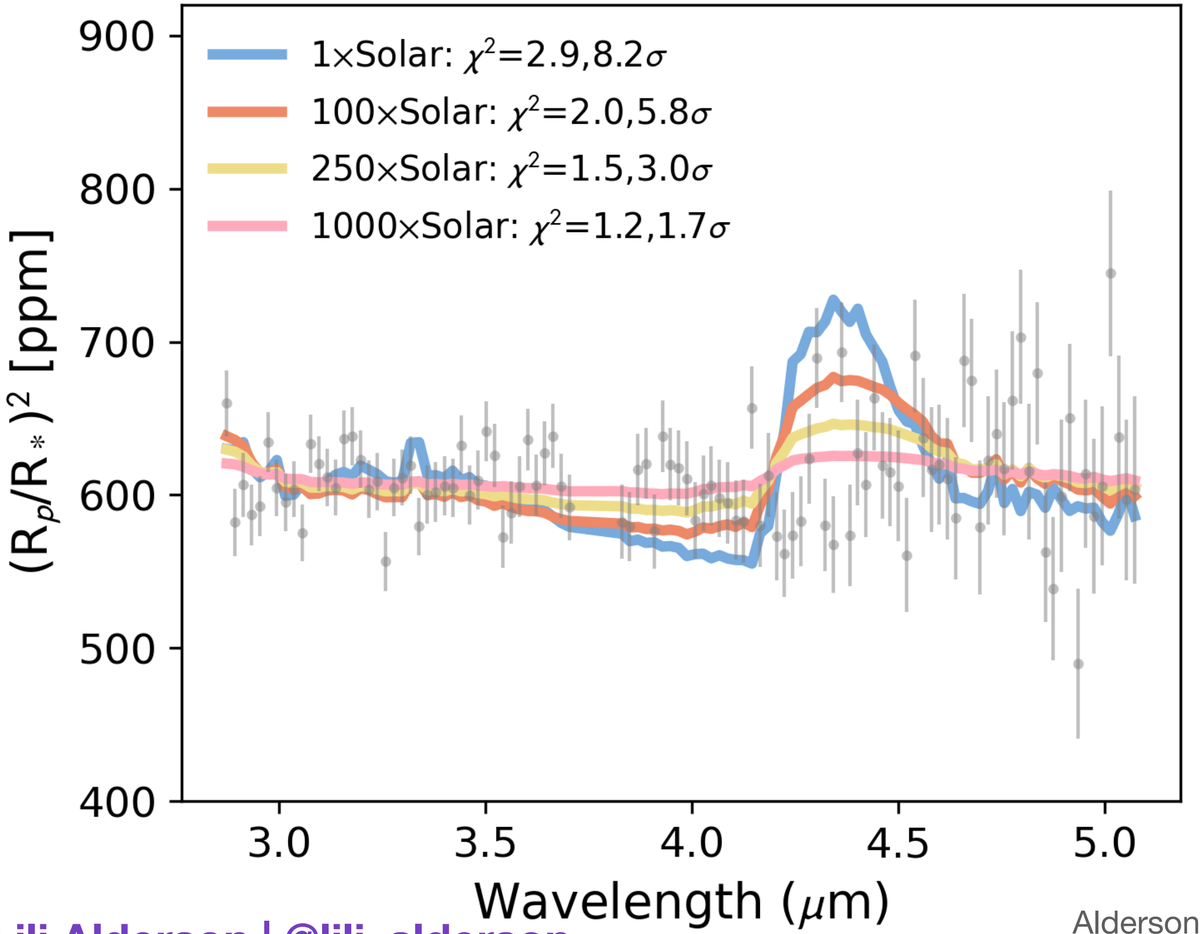
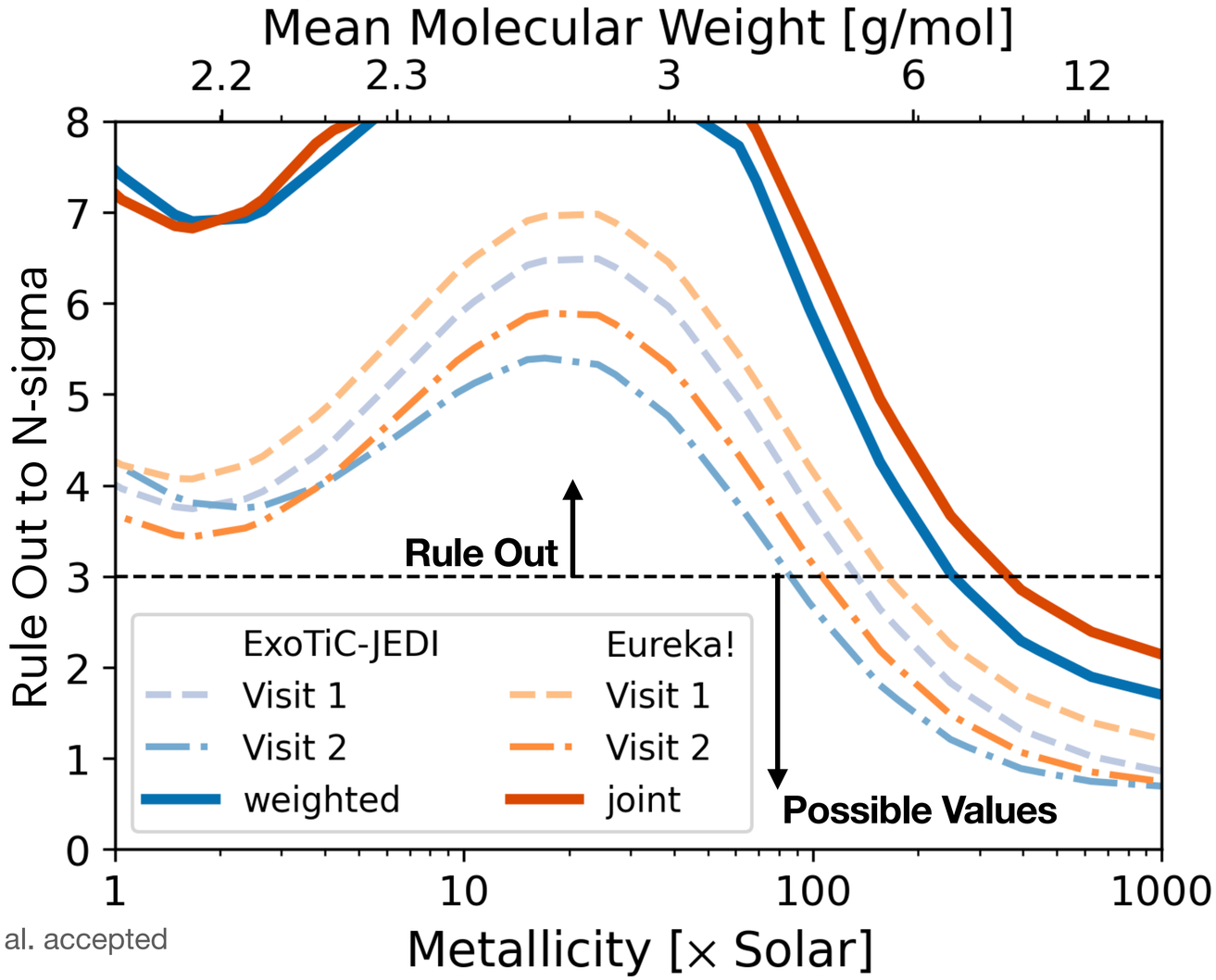
Atmospheric Inferences

- Clearly rule out low mean molecular weight (puffy H_2/He dominated) atmospheres
- Atmospheres >250x solar metallicity are statistically possible





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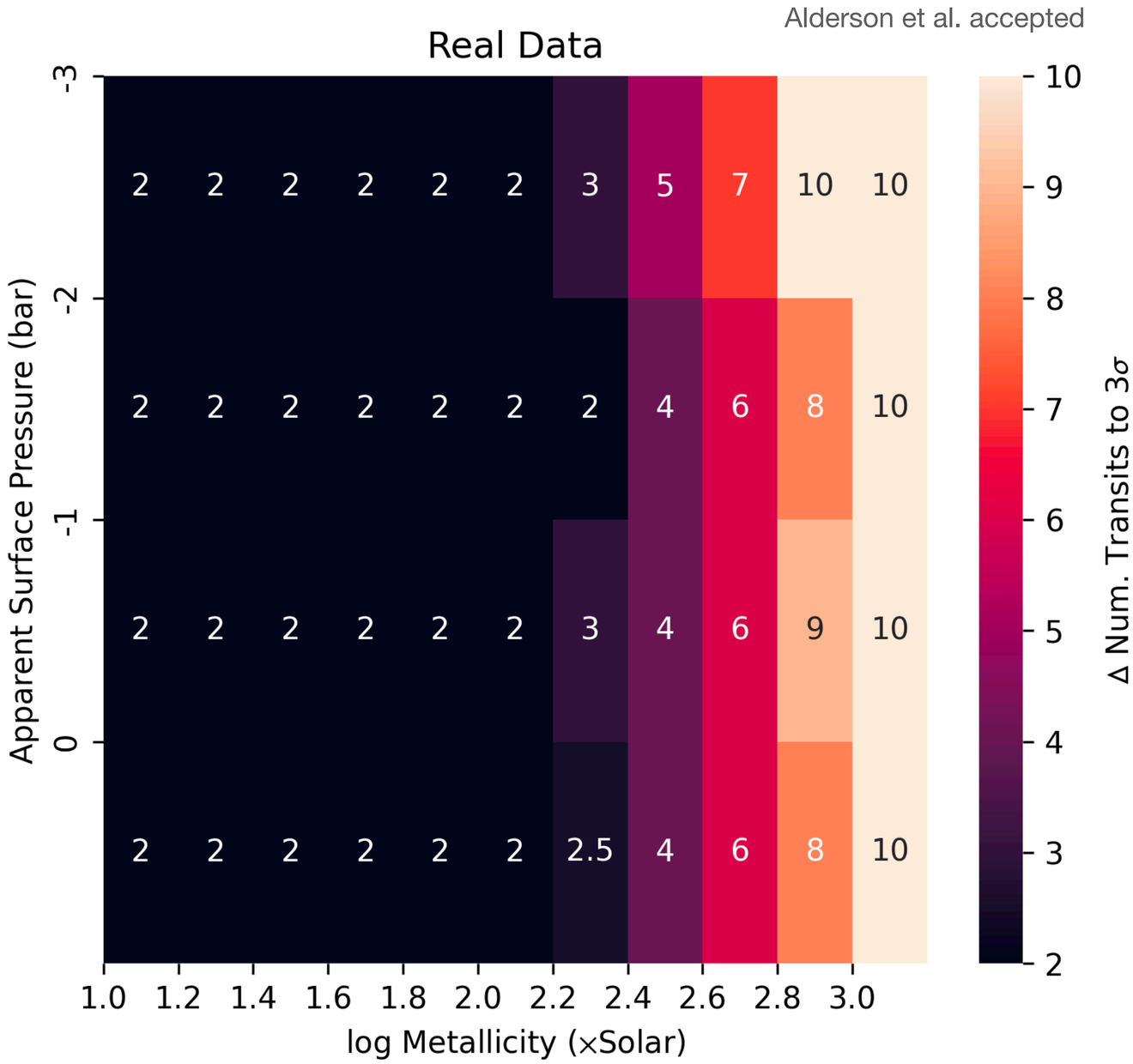
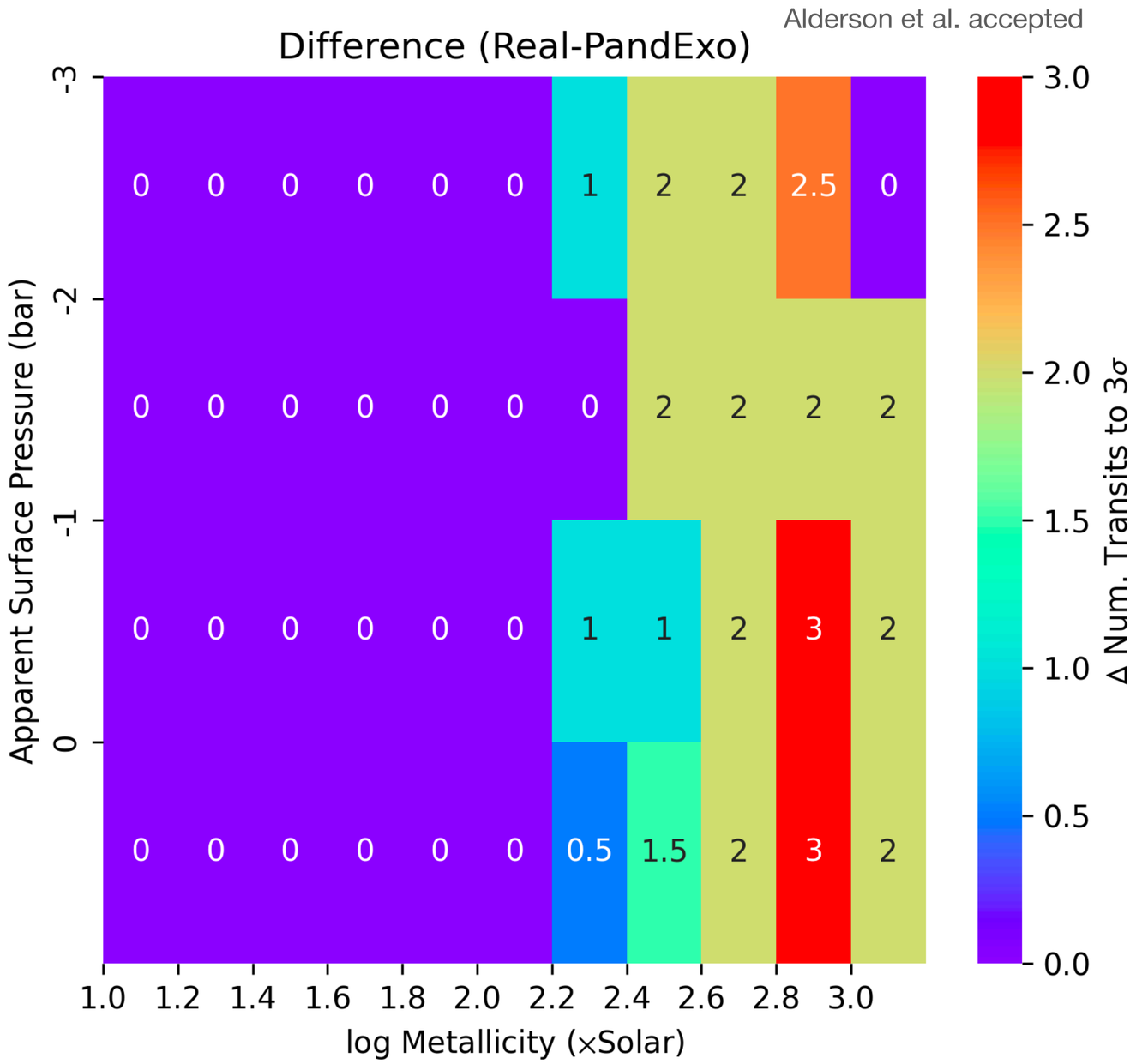
Implications for Future Observations

- Need 8 more transits to distinguish between 250x and 1000x solar metallicities

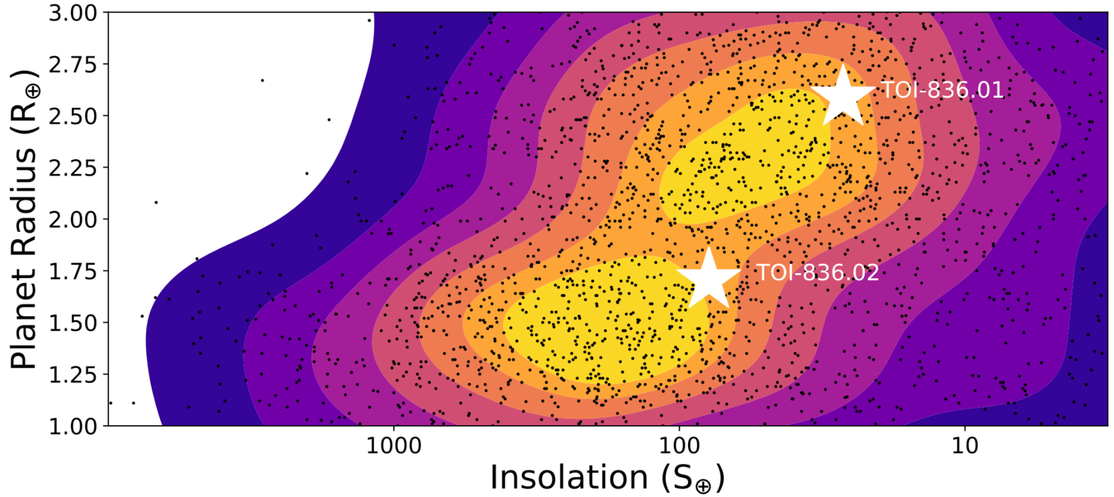


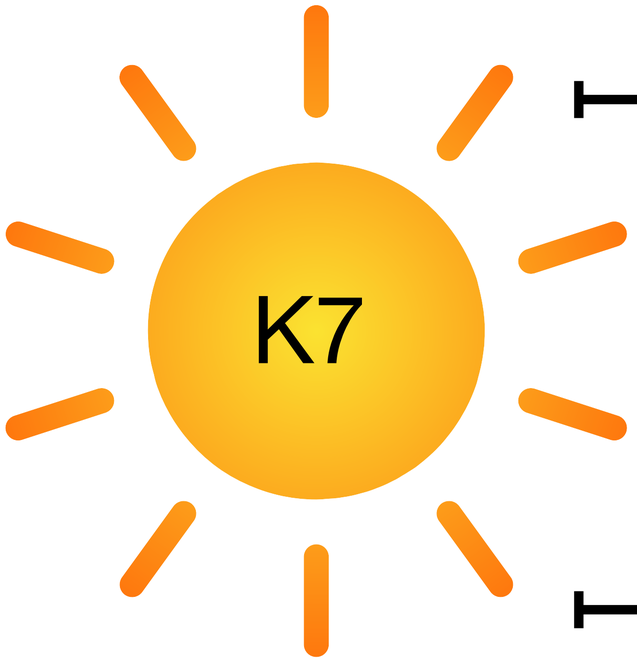
Implications for Future Observations

- Need 8 more transits to distinguish between 250x and 1000x solar metallicities
- PandExo appears to be slightly too optimistic in predicting the number of transits needed to robustly constrain very high metallicity atmospheres
- Future observation proposals in this parameter space should consider being more conservative in their technical justification

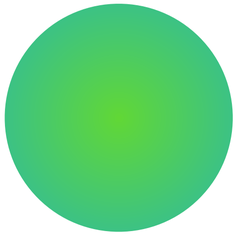


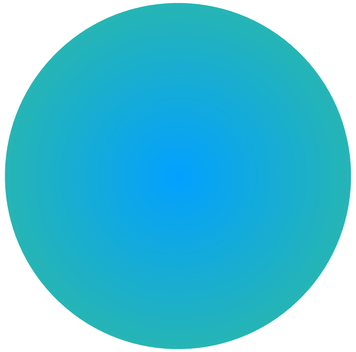
TOI-836 System





3.8 days





8.6 days

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  - 1.704 R_E
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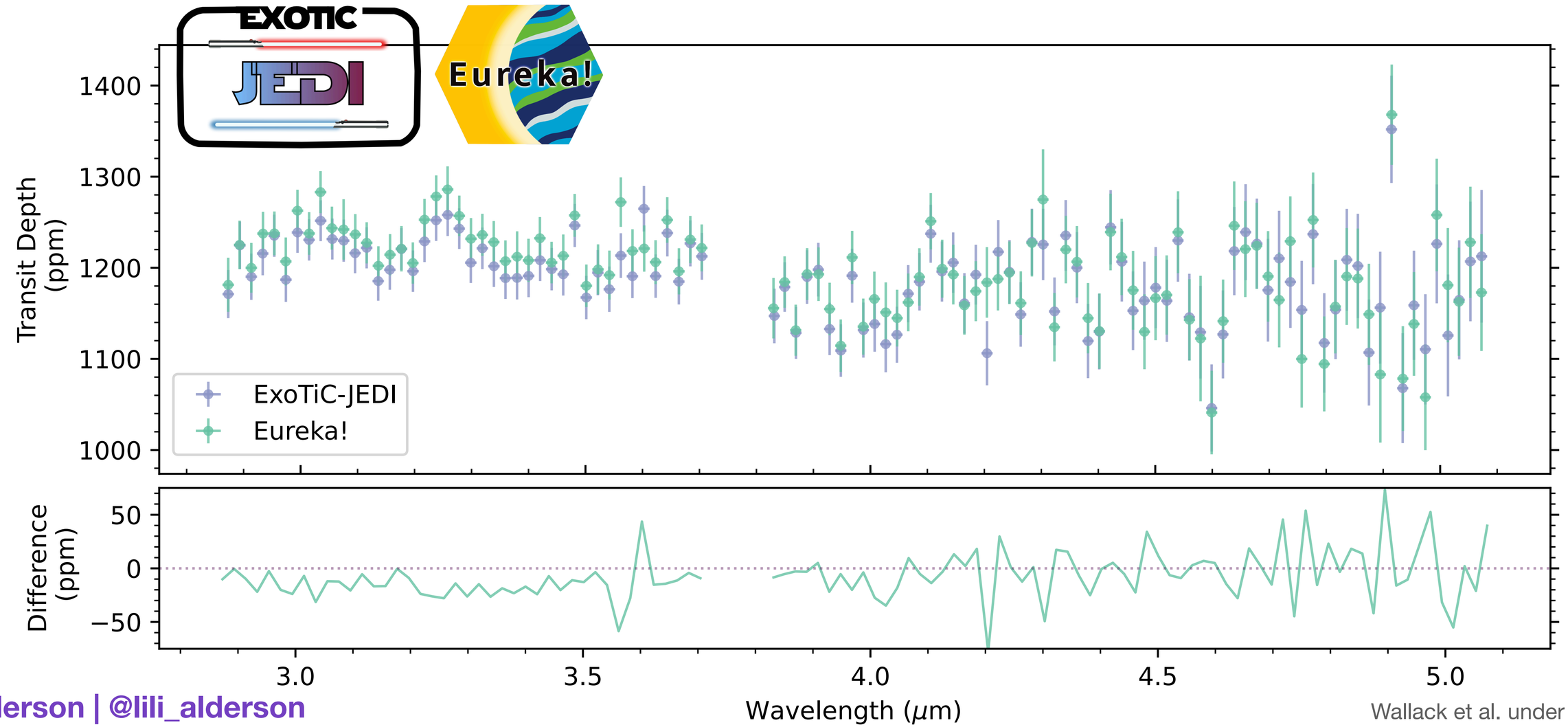
Transmission Spectrum - TOI-836c

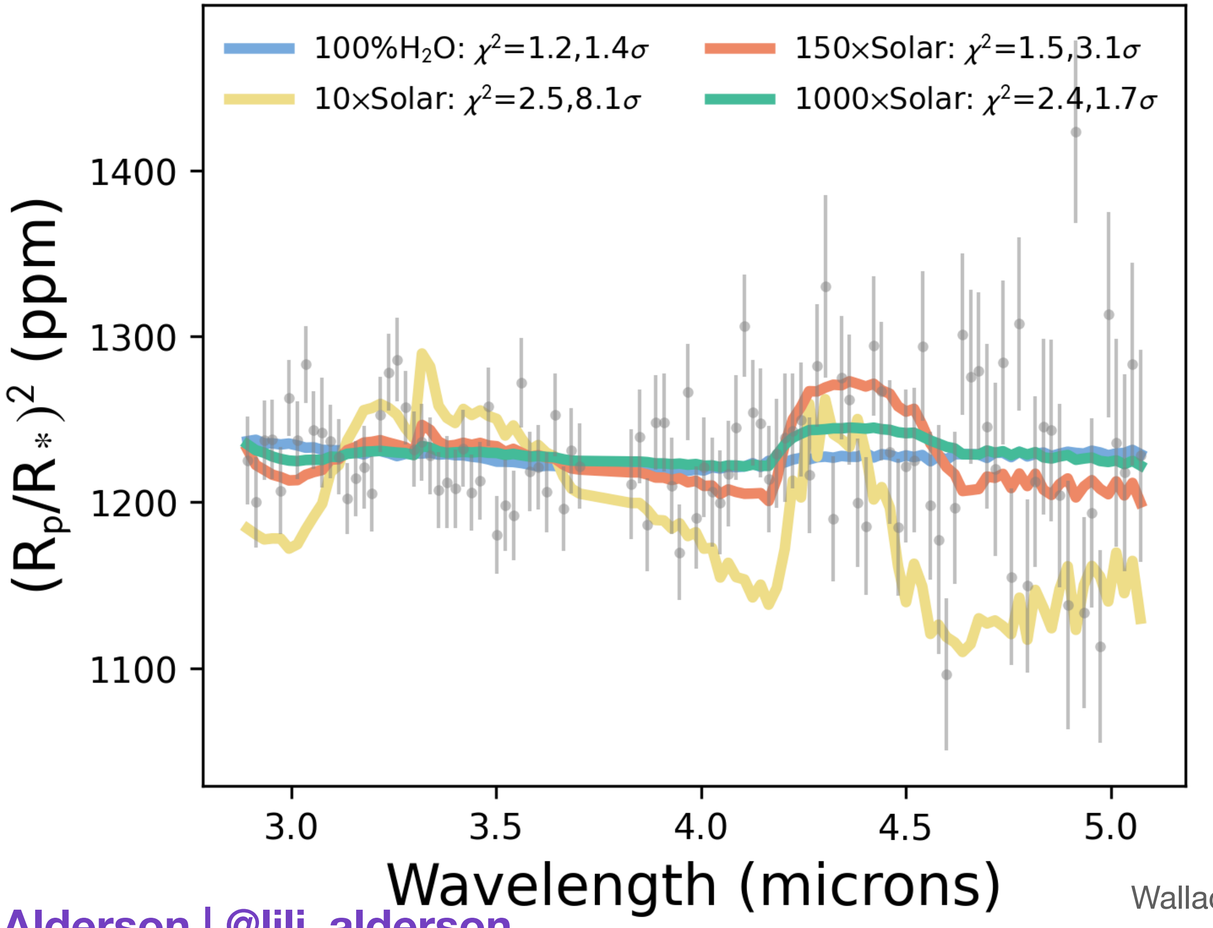
- median difference 16ppm compared to uncertainty of 35ppm, though appears to be an offset between detectors

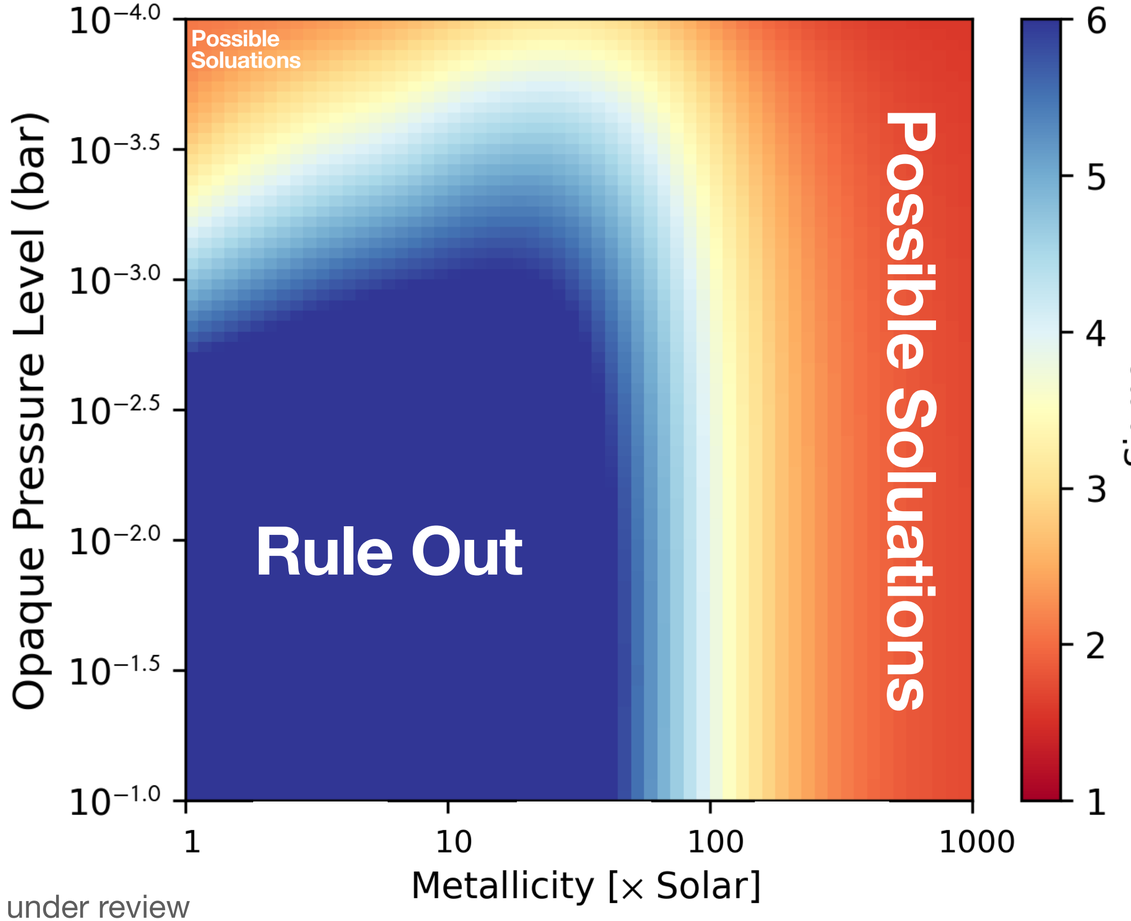


Wallack et al. under review

Atmospheric Inferences - TOI-836c

- In general, rule out metallicties <175x solar, though solar metallicities are possible in a highly lofted cloud scenario, fitting for offset between detectors
- Microphysical modelling shows aerosols at pressures greater the 0.1-1mbar are plausible

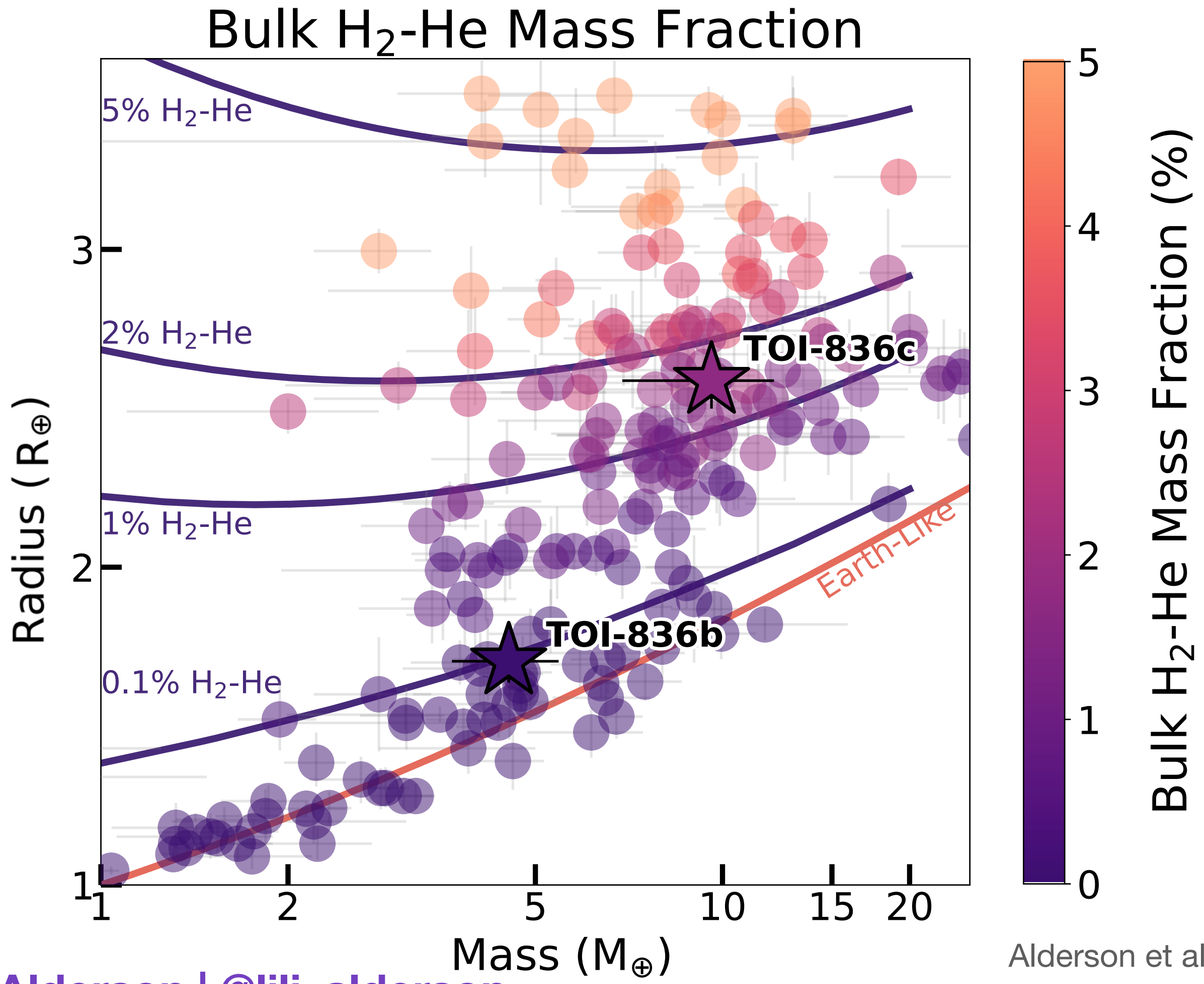


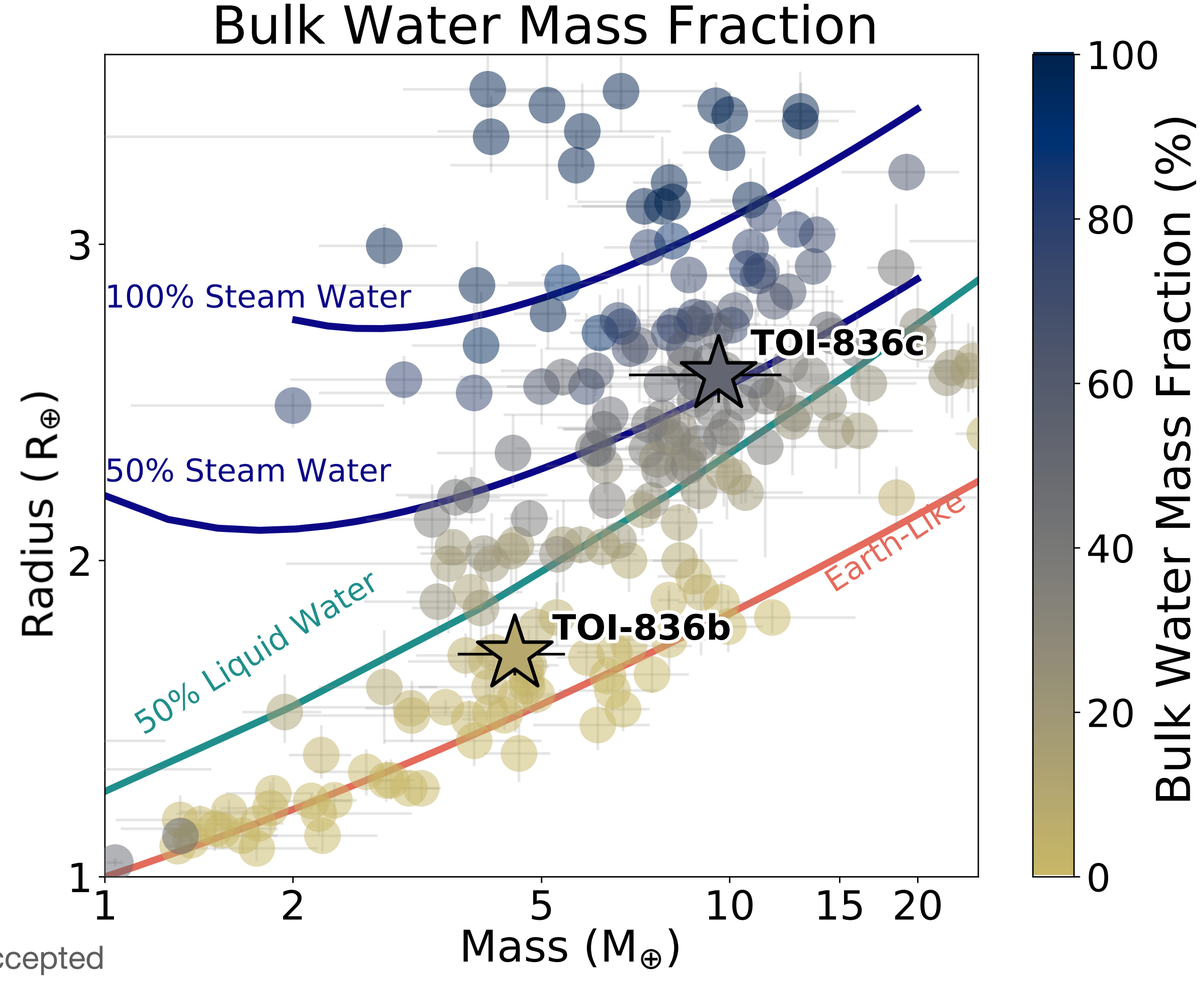


Wallack et al. under review

The TOI-836 System

- TOI-836b does not have a H_2/He-dominated envelope, but could have lost any primordial H_2/He envelope via photoevaporation within ~400 Myrs
- TOI-836c could still retain a primordial H_2/He envelope





Alderson et al. accepted

Key Takeaways

- Small planets with JWST are challenging
  - Bright hosts and small signals result in additional systematics
  - Planning for future observations may wish to be more conservative in their predictions or request 1-2 additional transits
- TOI-836b does not have a H/He dominated atmosphere, ruling out metallicities <250x solar
- TOI-836c could have a H/He dominated atmosphere in the presence of highly lofted clouds, though at more reasonable pressures rule out metallicities <175x solar

Alderson et al. accepted

Wallack et al. under review