Precise Stellar Parameters are Crucial for Constraining Transiting Exoplanet Interiors

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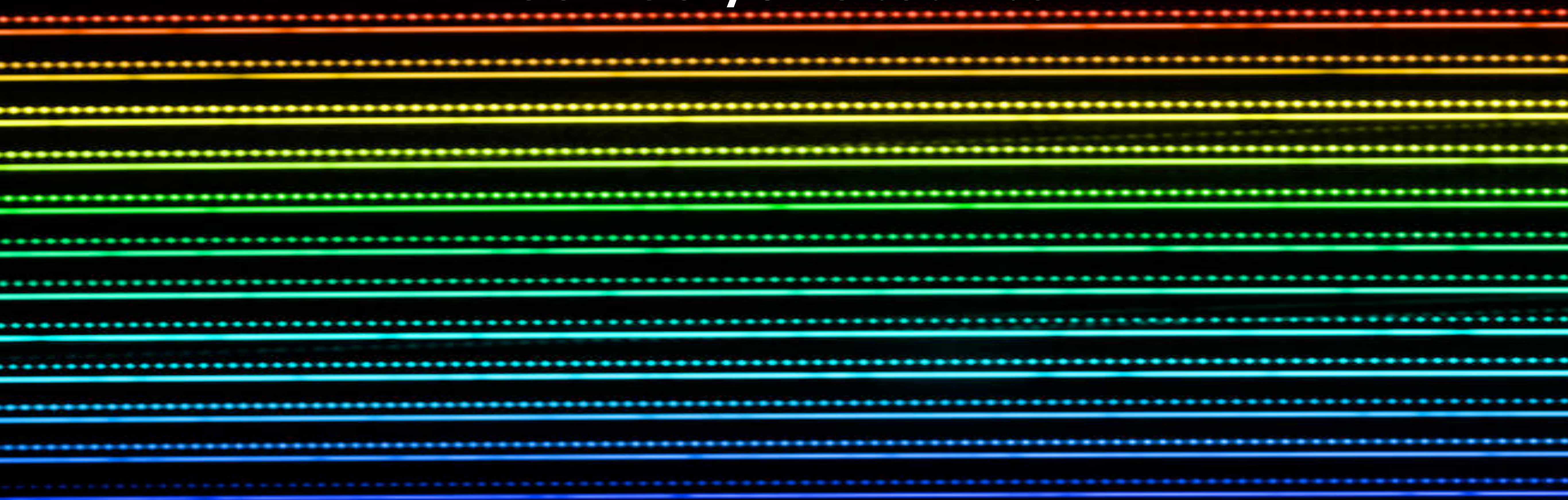


Juliette C. Becker, Lars A. Buchhave, Annelies Mortier, Eric Lopez, Luca Malavolta, Raphaëlle D. Haywood, David W. Latham, David Charbonneau, Mercedes Lopez-Morales, Christophe Lovis, Alessandro Sozzetti, Francesco Pepe, Andrew Collier Cameron, Xavier Dumusque, Emilio Molinari, Stephane Udry, Fred C. Adams, Aldo Bonomo, Rosario Cosentino, Luca Di Fabrizio, Aldo Fiorenzano, Avet Harutyunyan, Vania Lorenzi, Marco Pedani, Francois Bouchy, John Asher Johnson, Michel Mayor, Giusi Micela, Giampaolo Piotto, David Phillips, Ken Rice, Dimitar Sasselov, Damien Segransan, Chris Watson

Know Thy Star Conference, October 9, 2017

Gravitationally differentiated bodies have layers of different materials

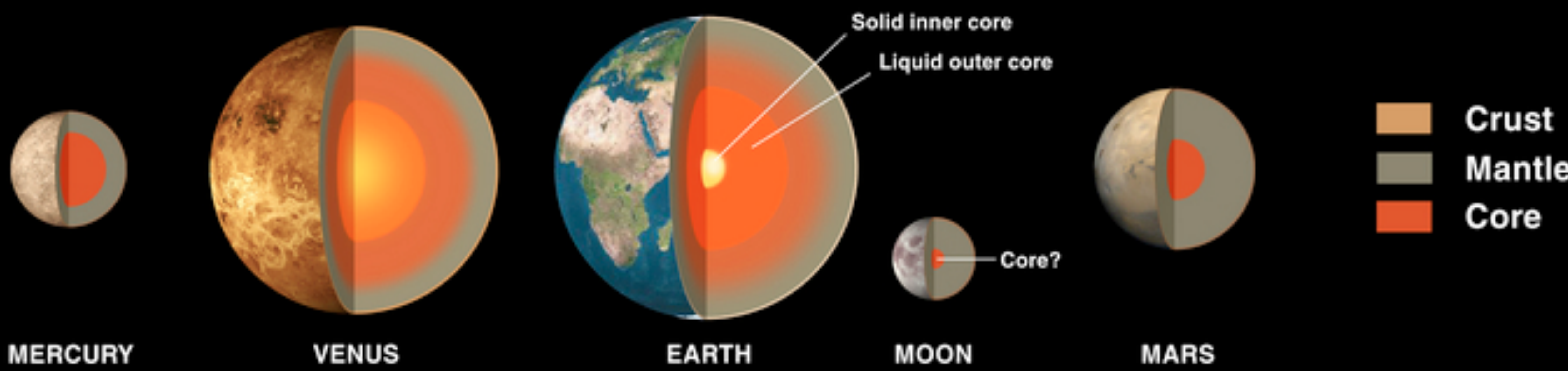


Image: NASA

Gravitationally differentiated bodies have layers of different materials

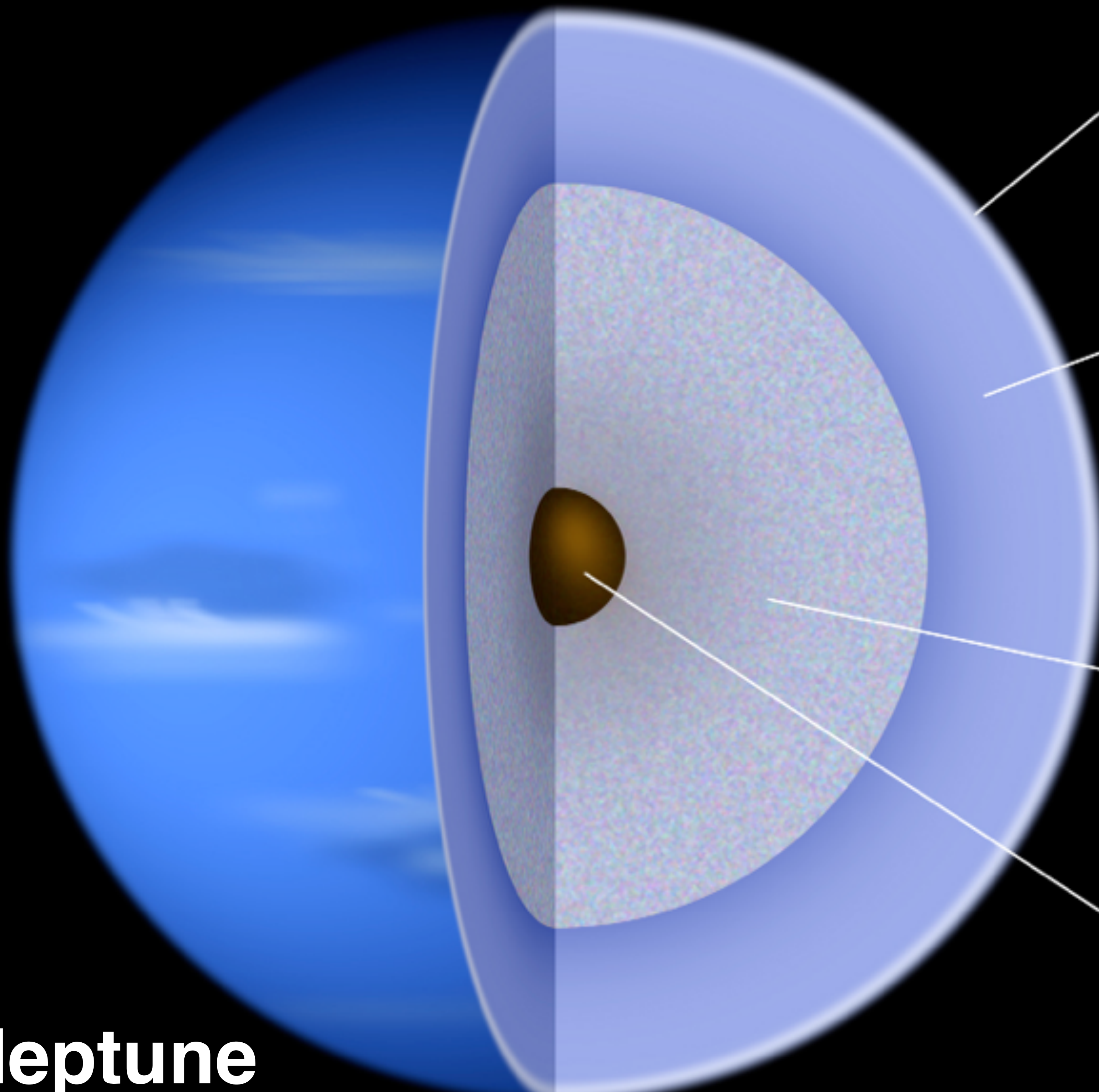
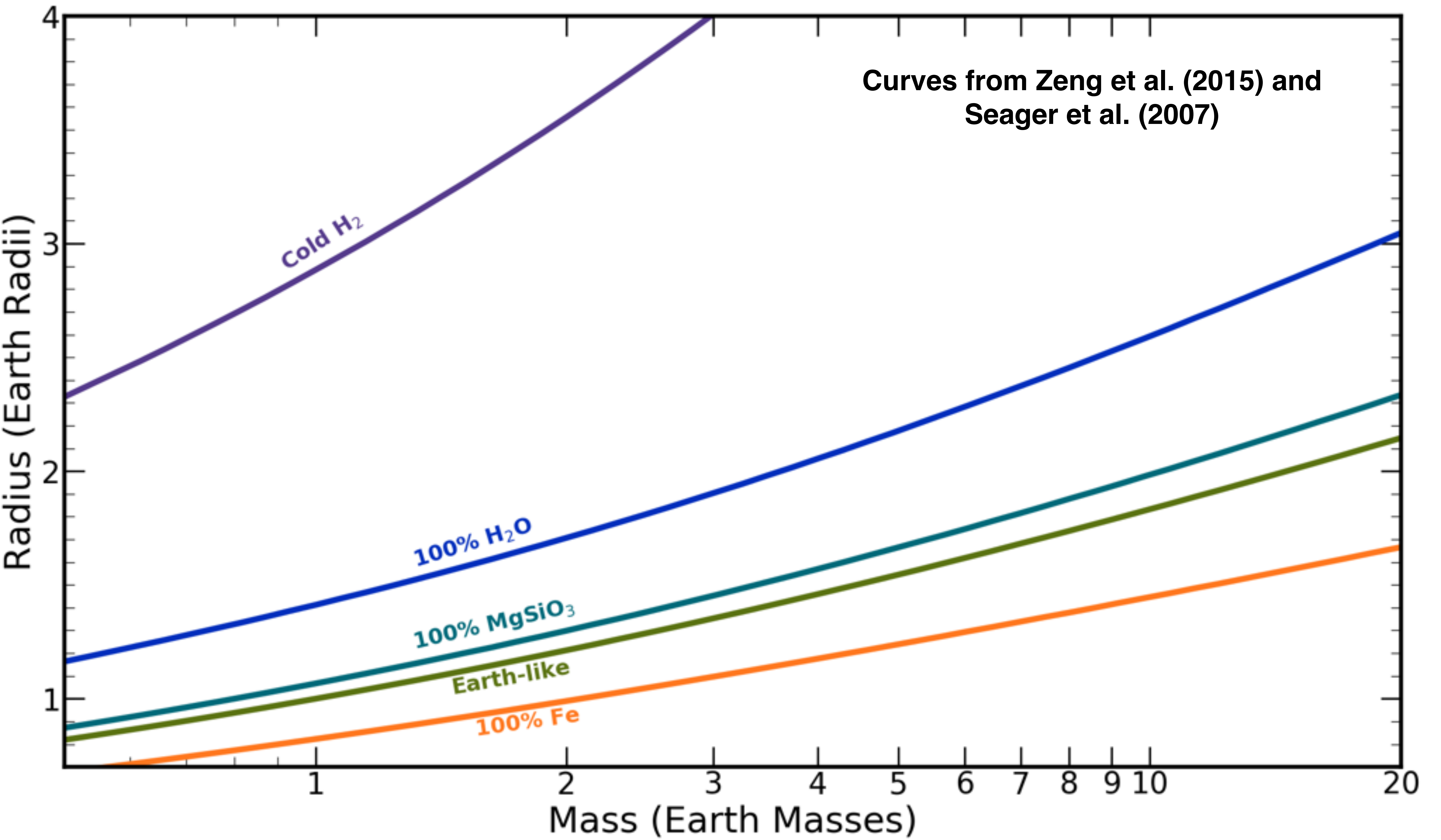
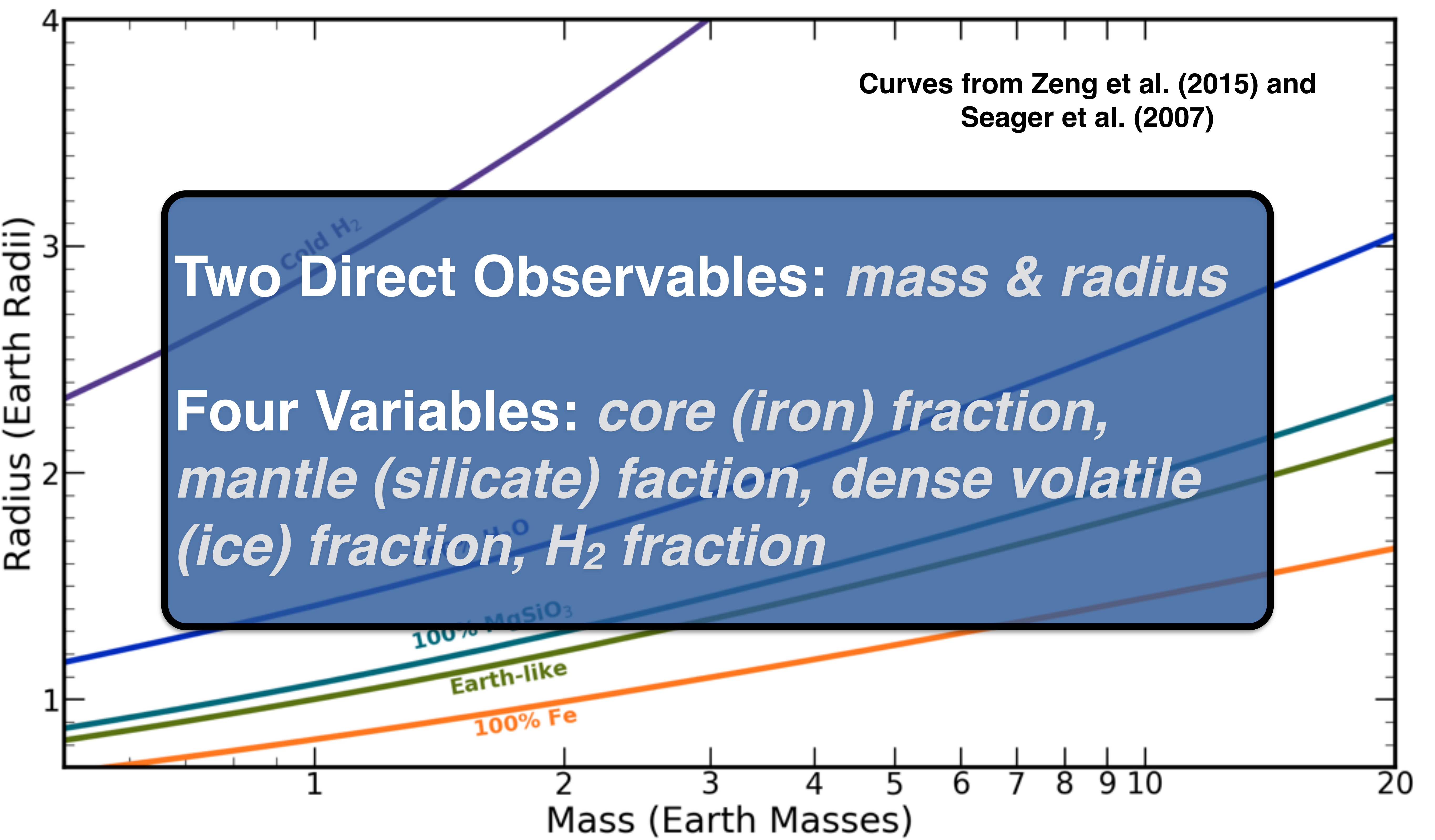


Image: NASA

We infer the interior structures of exoplanets from mass and radius



We infer the interior structures of exoplanets from mass and radius

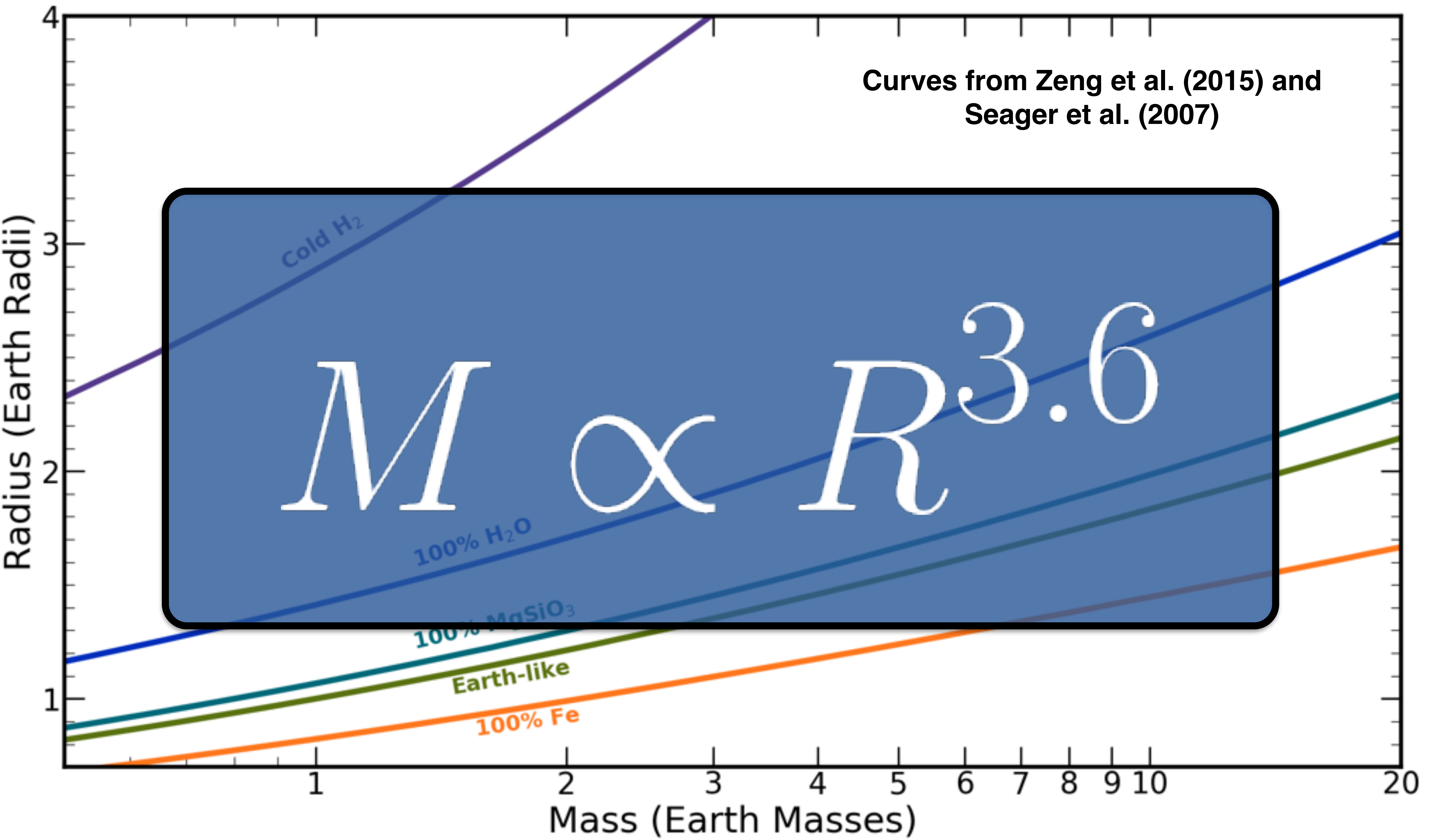


Curves from Zeng et al. (2015) and Seager et al. (2007)

Two Direct Observables: ***mass & radius***

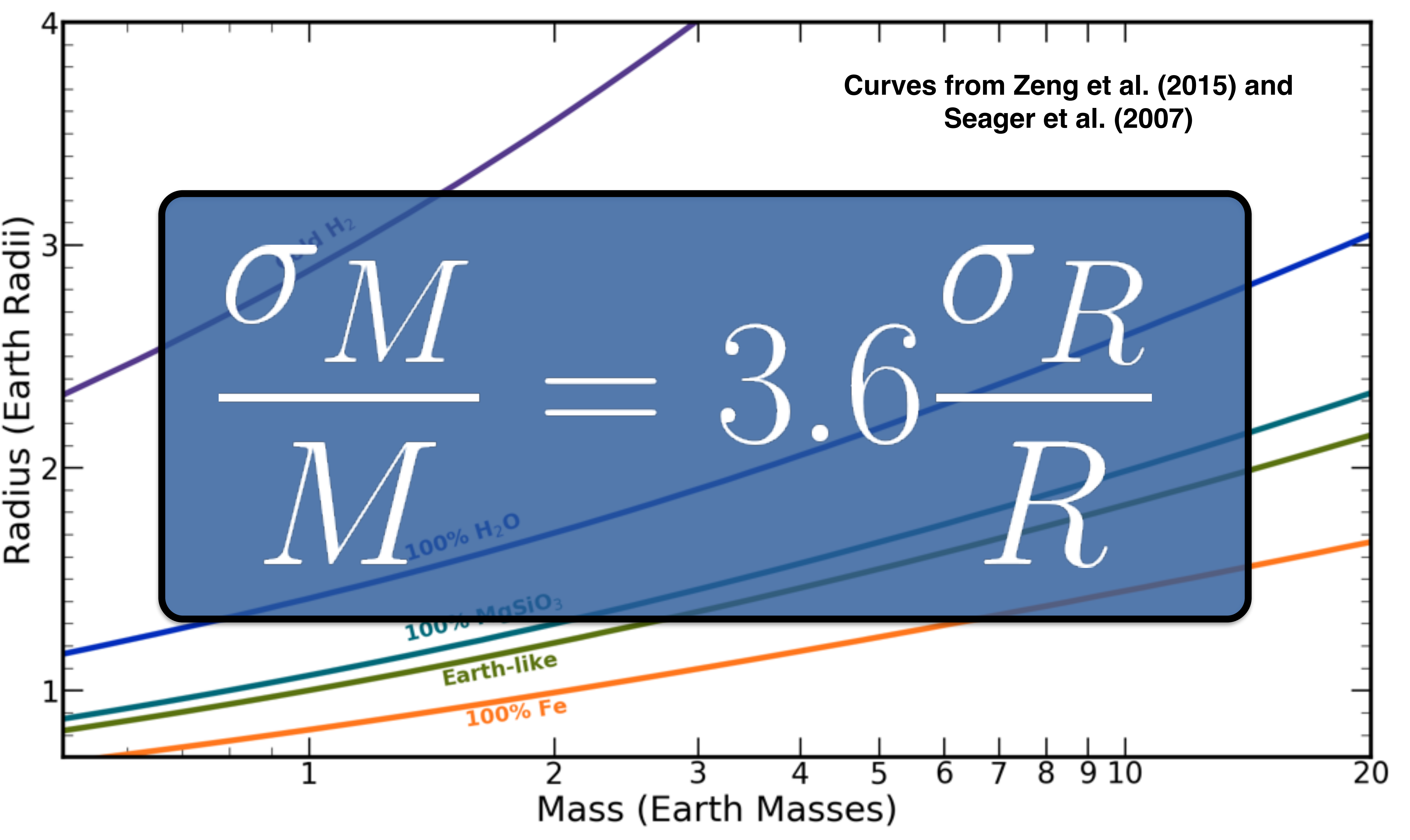
Four Variables: ***core (iron) fraction, mantle (silicate) faction, dense volatile (ice) fraction, H_2 fraction***

We infer the interior structures of exoplanets from mass and radius



$$M \propto R^{3.6}$$

We infer the interior structures of exoplanets from mass and radius

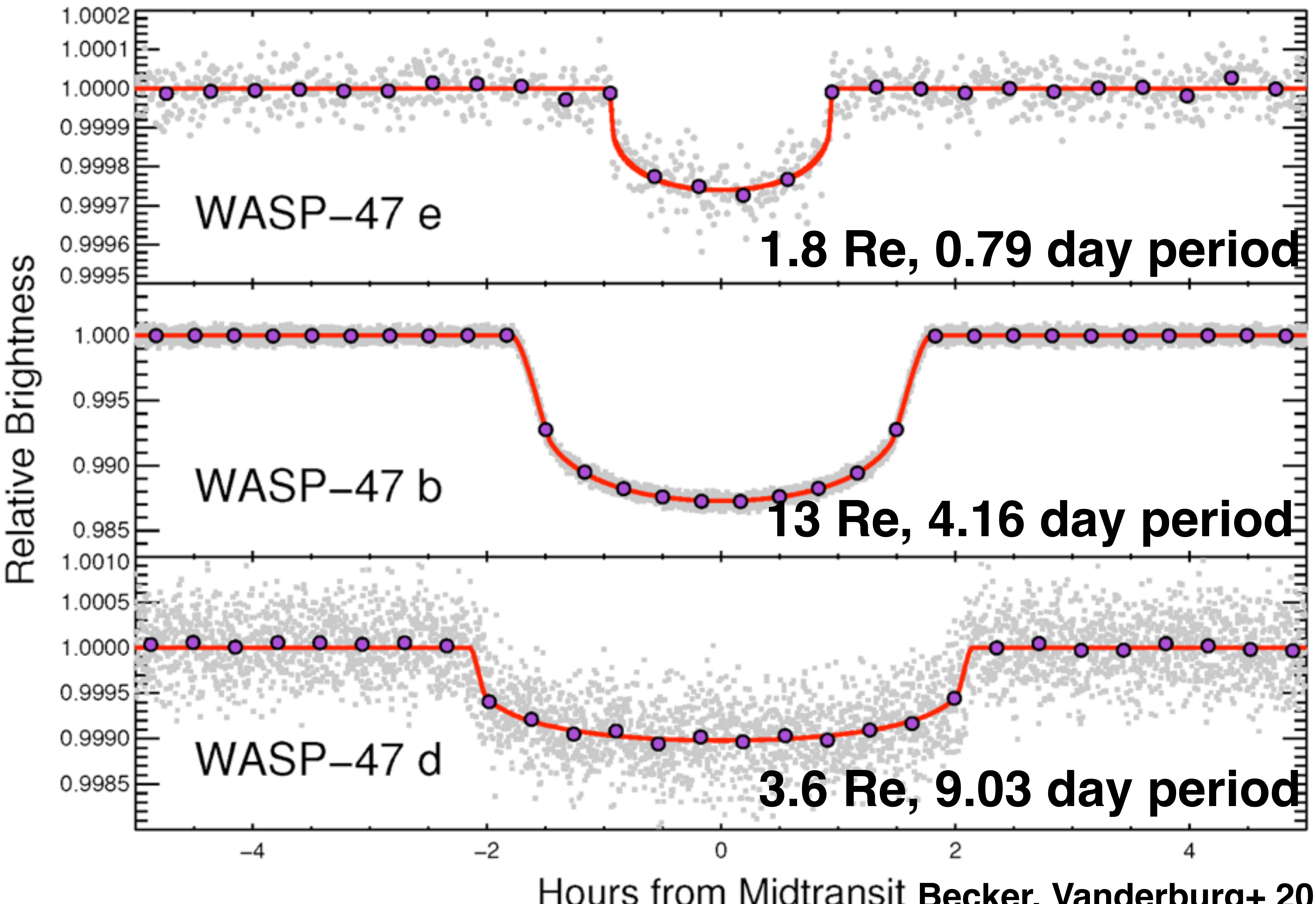


$$\frac{\sigma_M}{M} = 3.6\frac{\sigma_R}{R}$$

For strong interior structure constraints, we need:

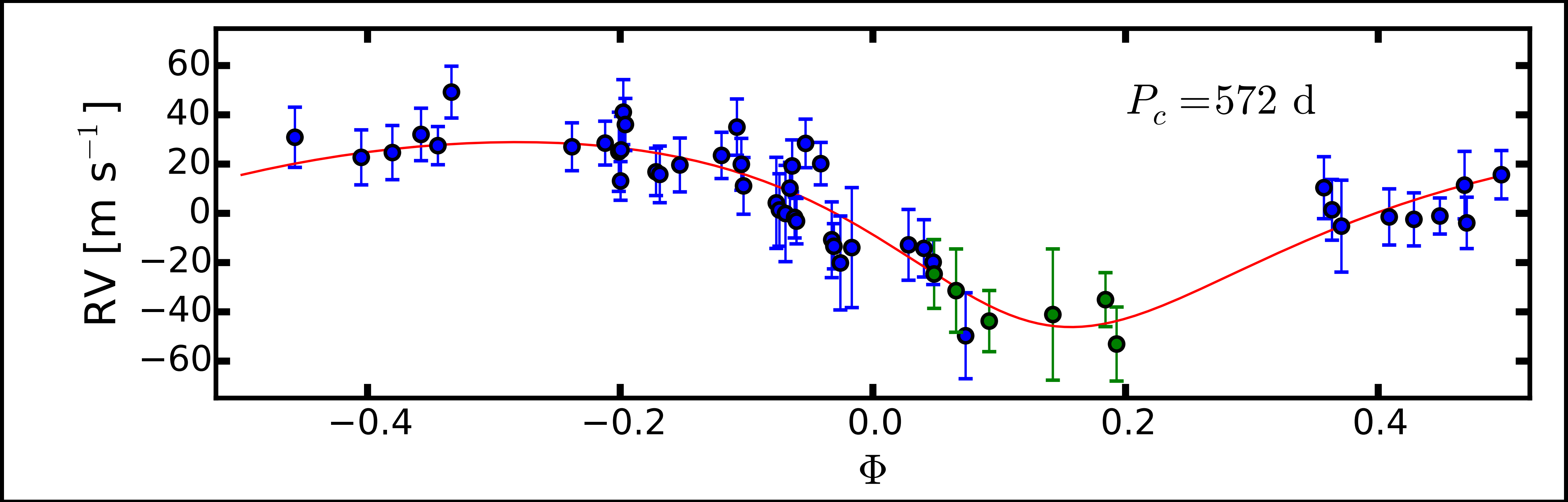
- Precise $R_p/R_\star$
- Precise RV semiamplitude:
- Precise stellar parameters, especially $R_\star$:

Case Study: WASP-47

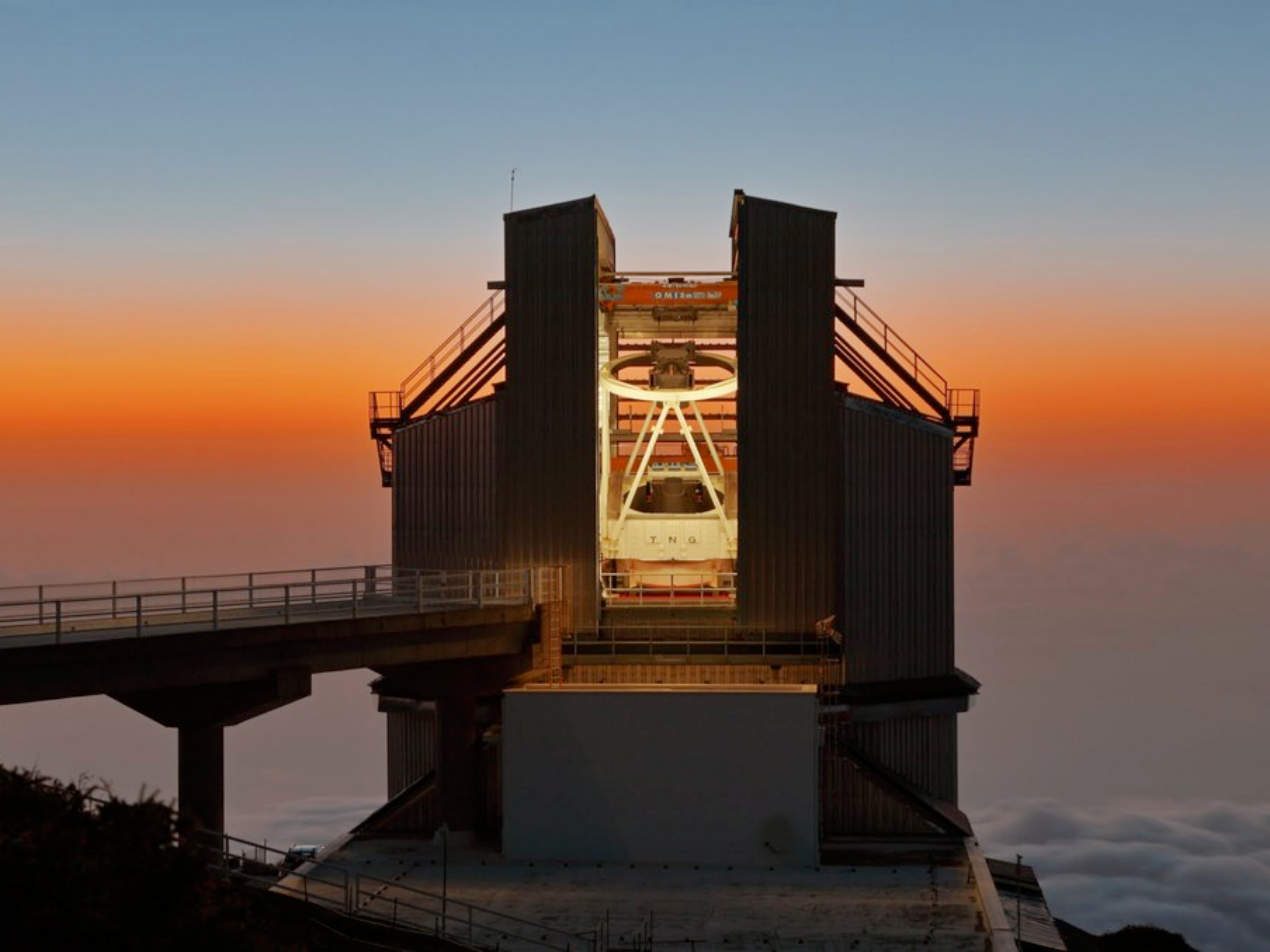


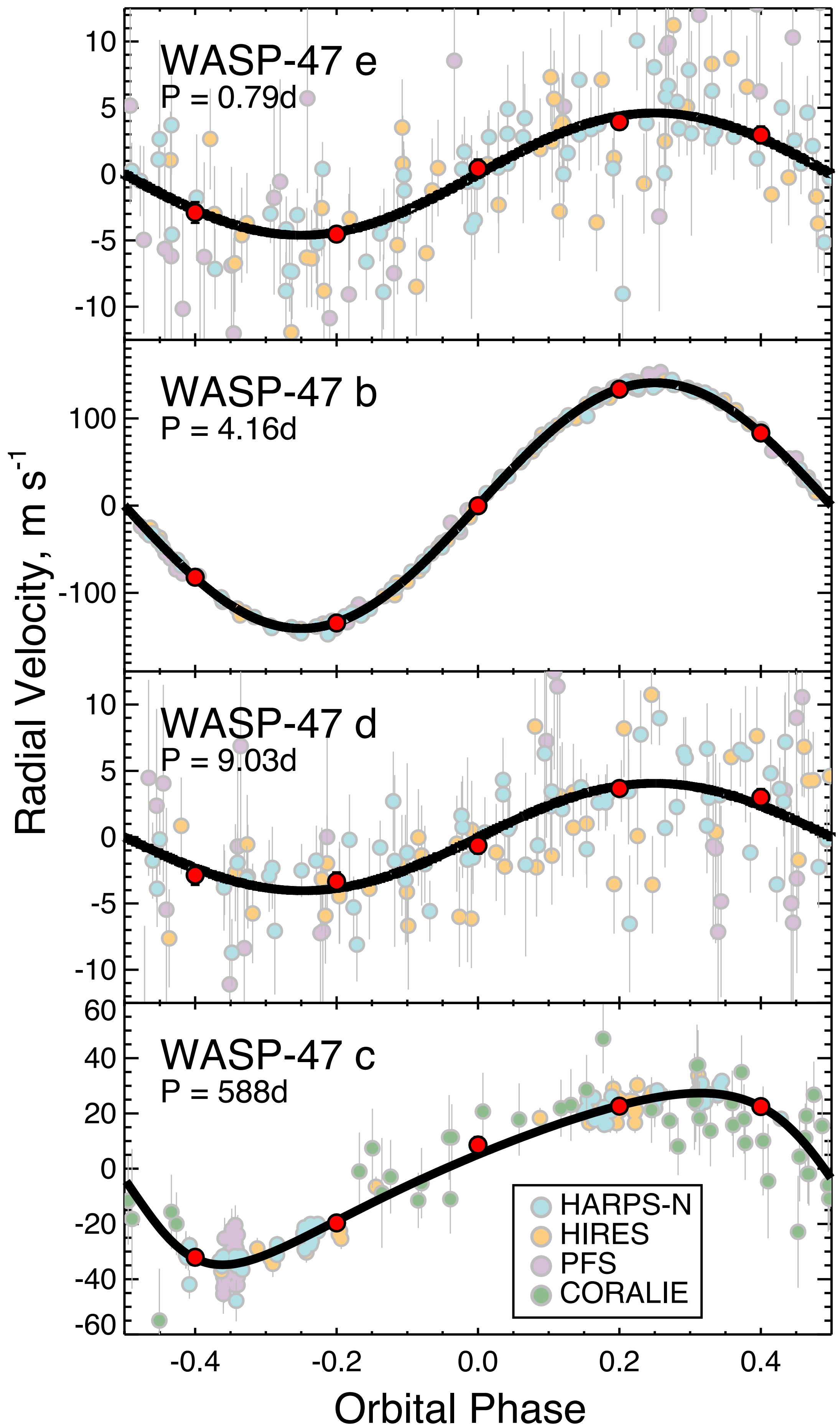
Becker, Vanderburg+ 2015

WASP-47 c



Neveu-VanMalle+ 2015


T N G



Vanderburg+2017

Including archival data from Neveu-VanMalle 2015, Dai+2015, Sinukoff+2016

WASP-47 is a good system for interior structure constraints

- **Precise $R_p/R_\star$:** limb darkening, impact parameter, transit depth, short cadence data.
- **Precise RV semiamplitude:** Lots of precise RVs, good sampling/phase coverage,understanding of stellar activity
- **Precise stellar parameters, especially $R_\star$:** Asteroseismology, measured stellar density, eclipsing binary/circumbinary planets, solar twin, etc.

The known hot Jupiter, planet e's short period, old quiet sun-like host star, and bright V-band magnitude contribute to:

- **Precise $R_p/R_\star$: limb darkening**, **impact parameter**, **transit depth**, **short cadence data**.
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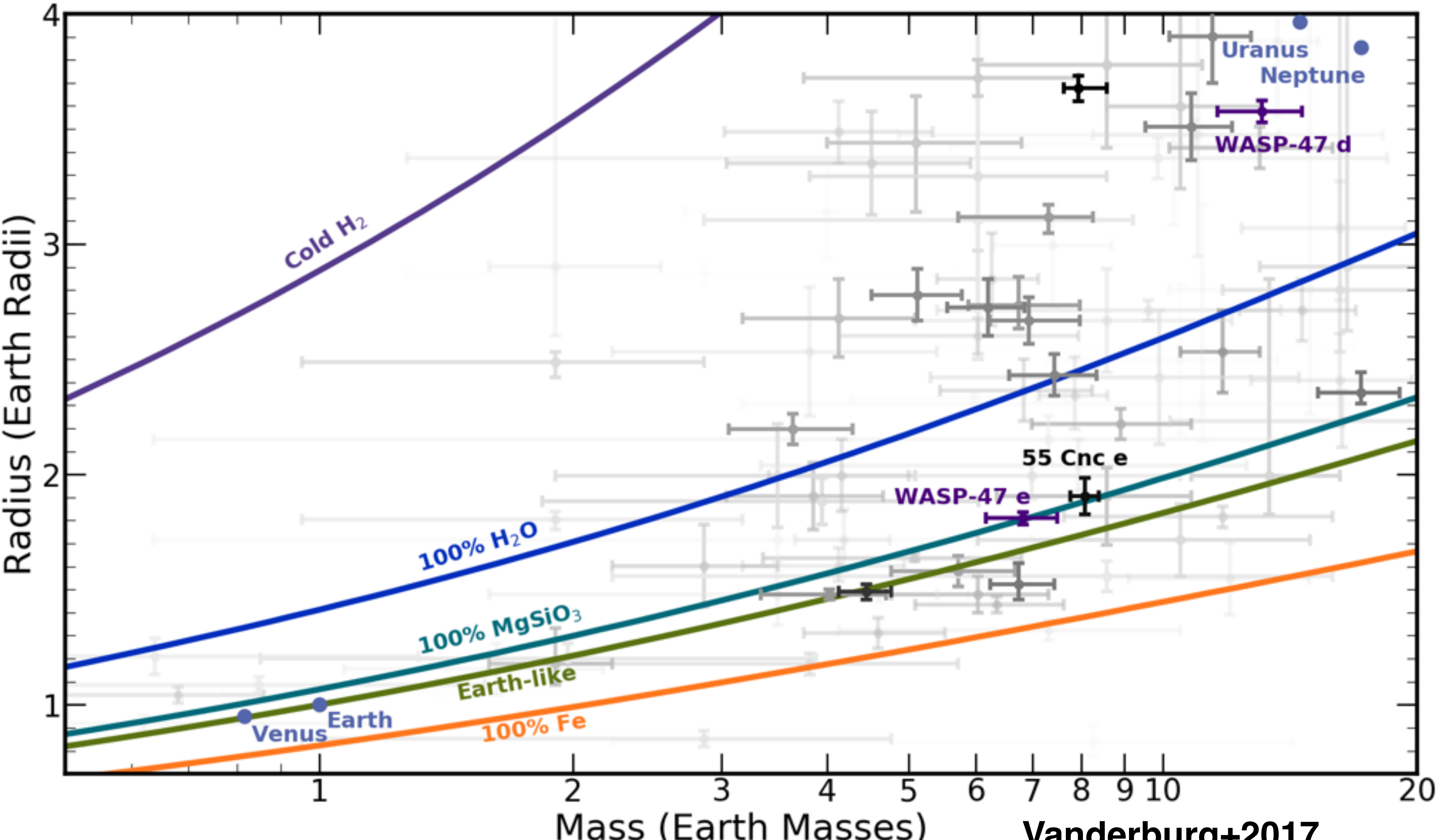
0.5% and 0.8% $R_p/R_\star$ for planets d and e

10.9% and 9.5% K for planets d and e

3% and 1% for $M_\star$ and $R_\star$

WASP-47 e does not have an Earth-like core



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In the TESS era:

- **Precise $R_p/R_\star$:** limb darkening, impact parameter, transit depth, short cadence data.

- **Precise RV semiamplitude:** Lots of precise RVs, good sampling/phase coverage, understanding of stellar activity

- **Precise stellar parameters, especially $R_\star$:** Asteroseismology, measured stellar density, eclipsing binary/circumbinary planets, solar twin, etc.

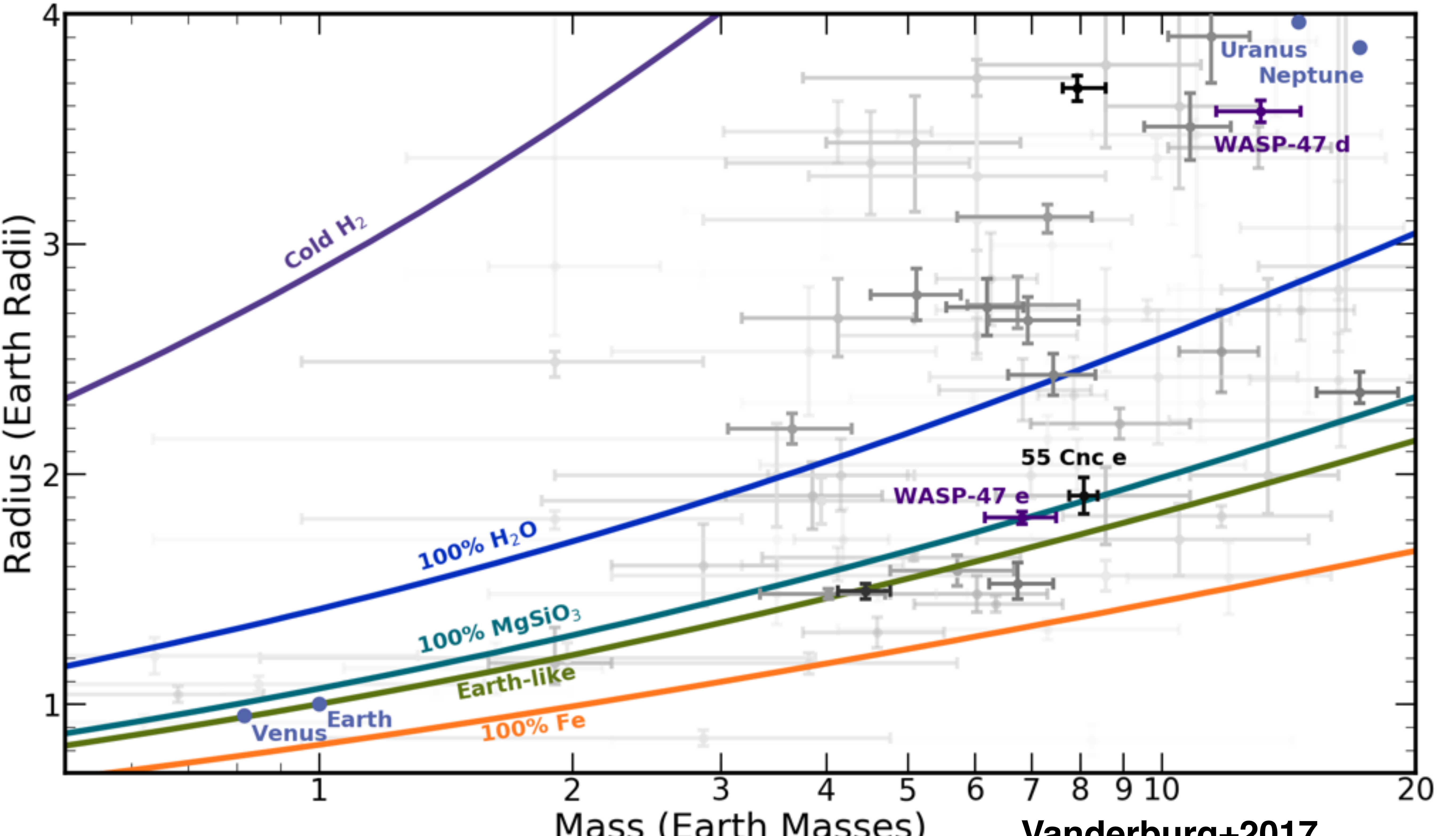
Advantages of TESS over Kepler:

- **Precise $R_p/R_\star$:** limb darkening, impact parameter, transit depth, **short cadence data**.
- **Precise RV semiamplitude: Lots of precise RVs, good sampling/phase coverage, understanding of stellar activity**
- **Precise stellar parameters, especially $R_\star$:** Asteroseismology, measured stellar density, eclipsing binary/circumbinary planets, solar twin, etc.

Disadvantages of TESS over Kepler:

- **Precise $R_p/R_\star$: limb darkening, impact parameter, transit depth,** short cadence data.
- **Precise RV semiamplitude:** Lots of precise RVs, good sampling/phase coverage, understanding of stellar activity
- **Precise stellar parameters, especially $R_\star$: Asteroseismology, measured stellar density, eclipsing binary/circumbinary planets, solar twins, etc.**

With stellar density prior



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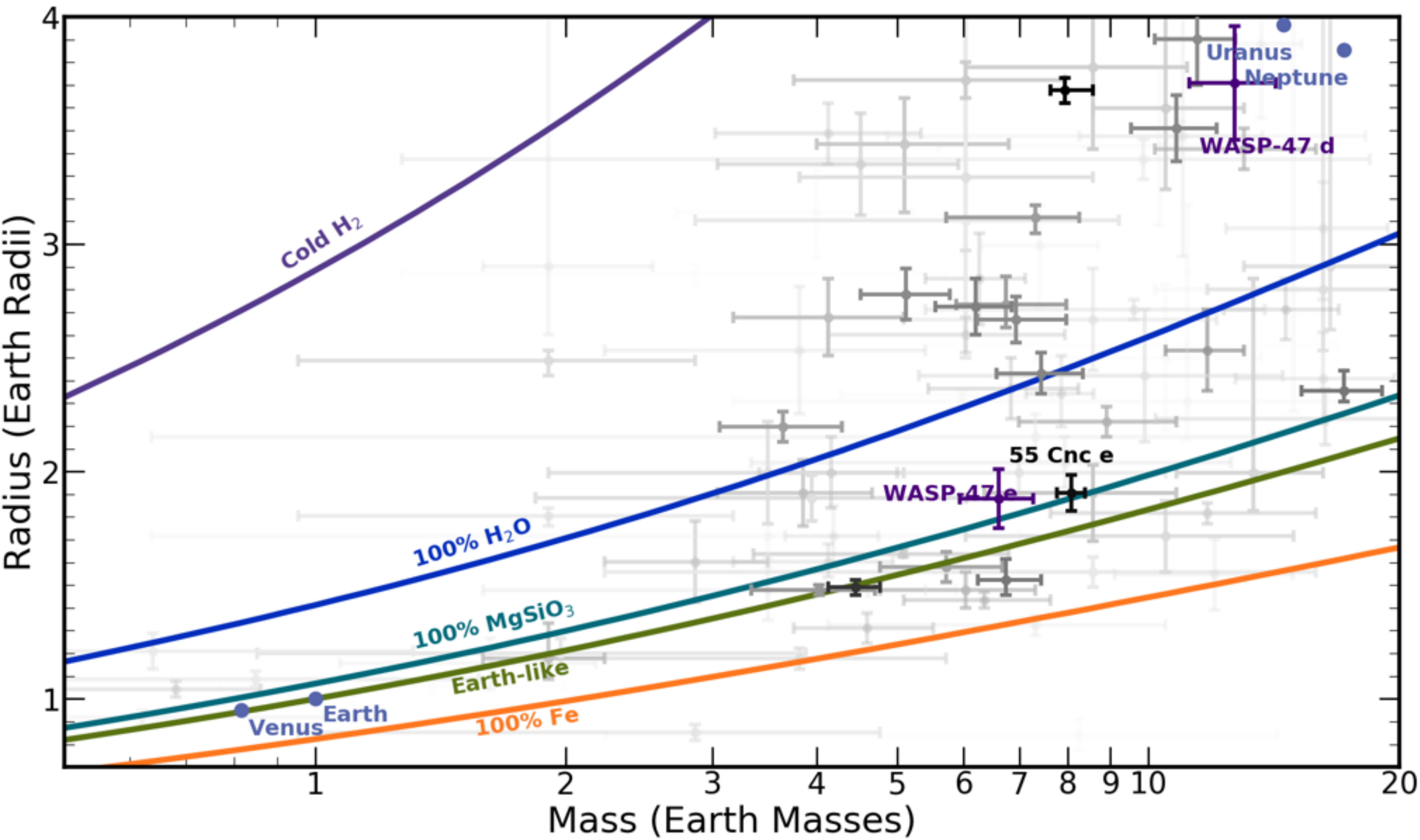
Without stellar density prior



Asteroseismology will be relatively rare for planet hosts - Campante+ 2016

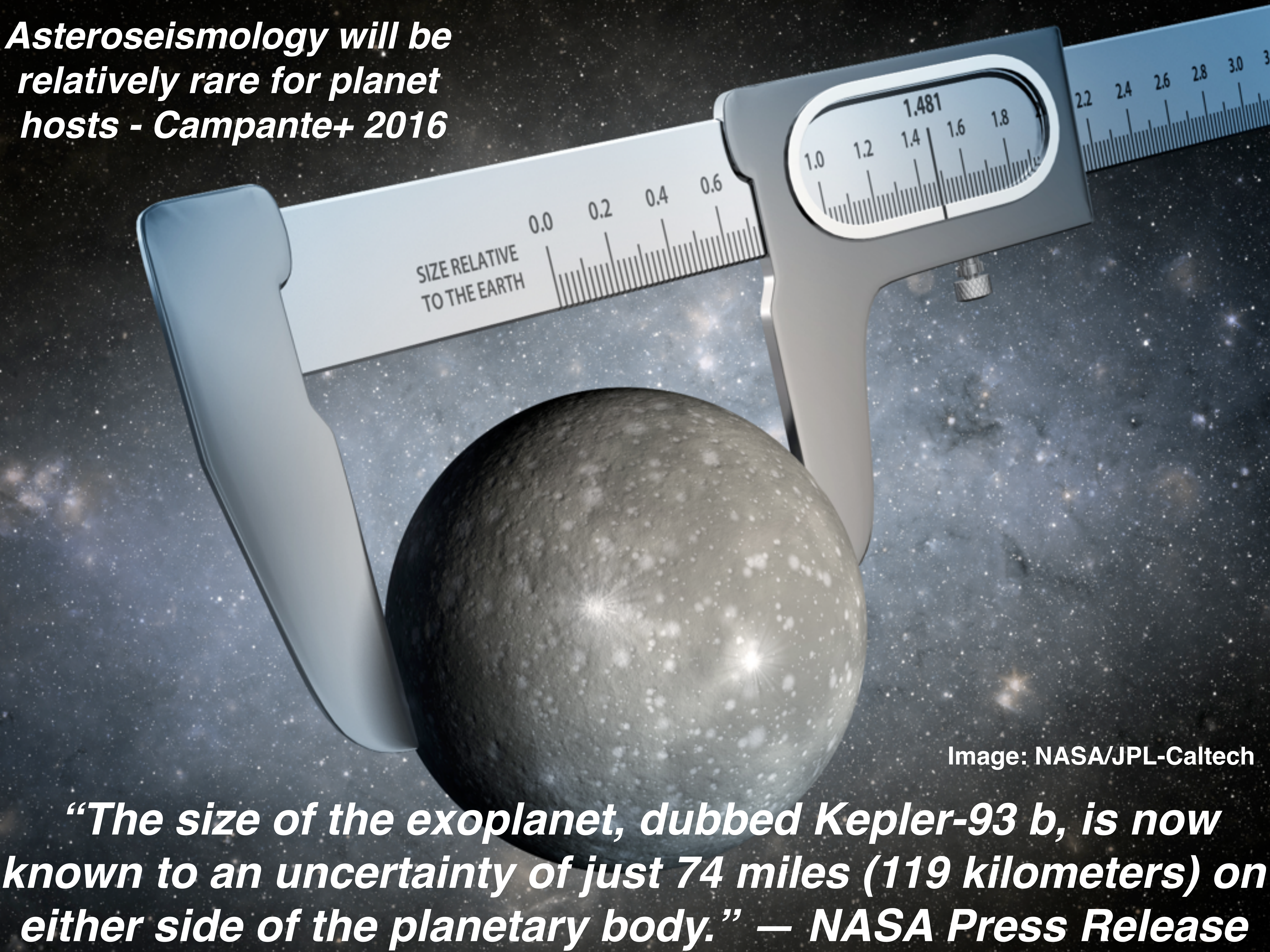


Image: NASA/JPL-Caltech

"The size of the exoplanet, dubbed Kepler-93 b, is now known to an uncertainty of just 74 miles (119 kilometers) on either side of the planetary body." — NASA Press Release

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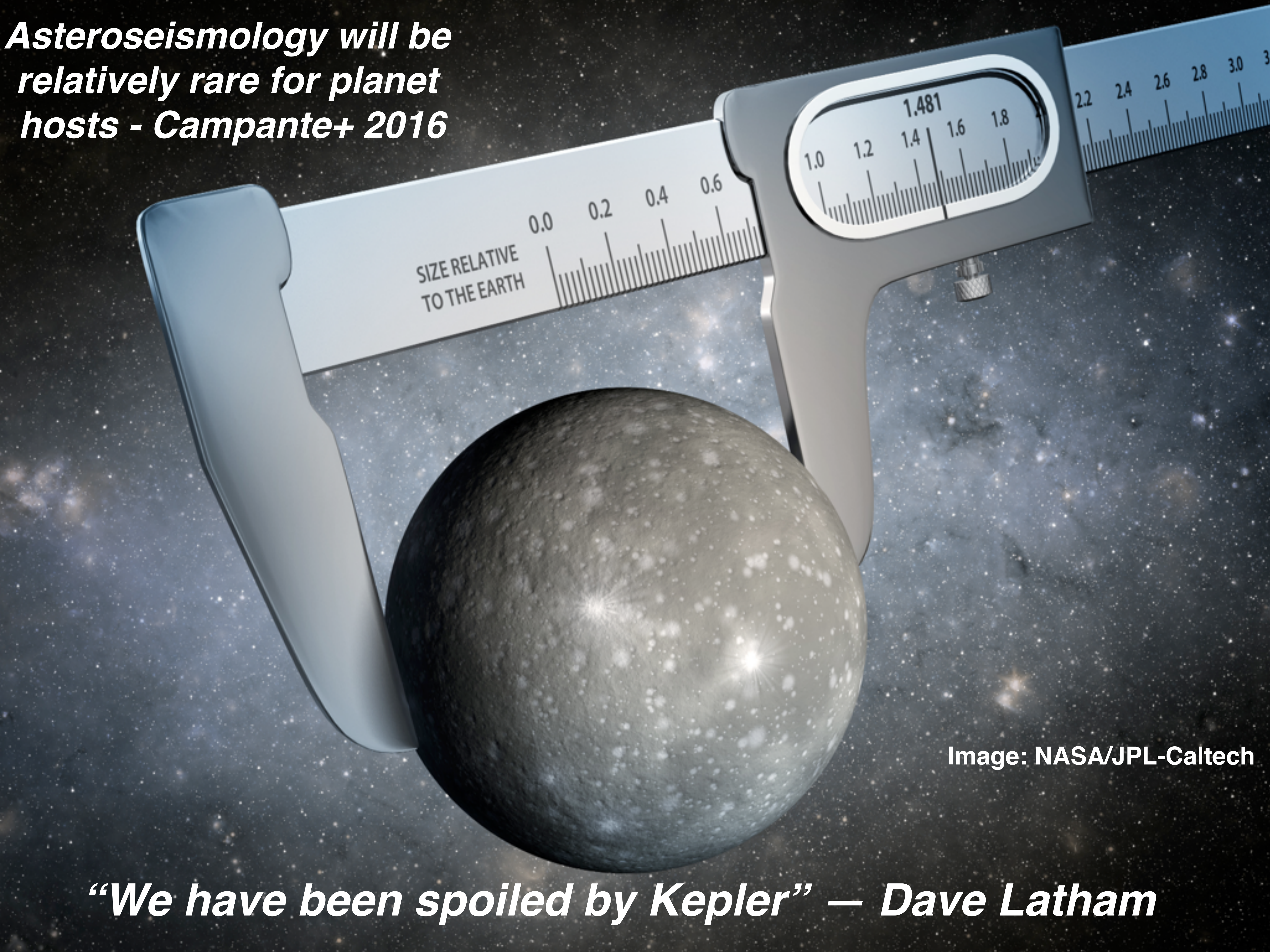
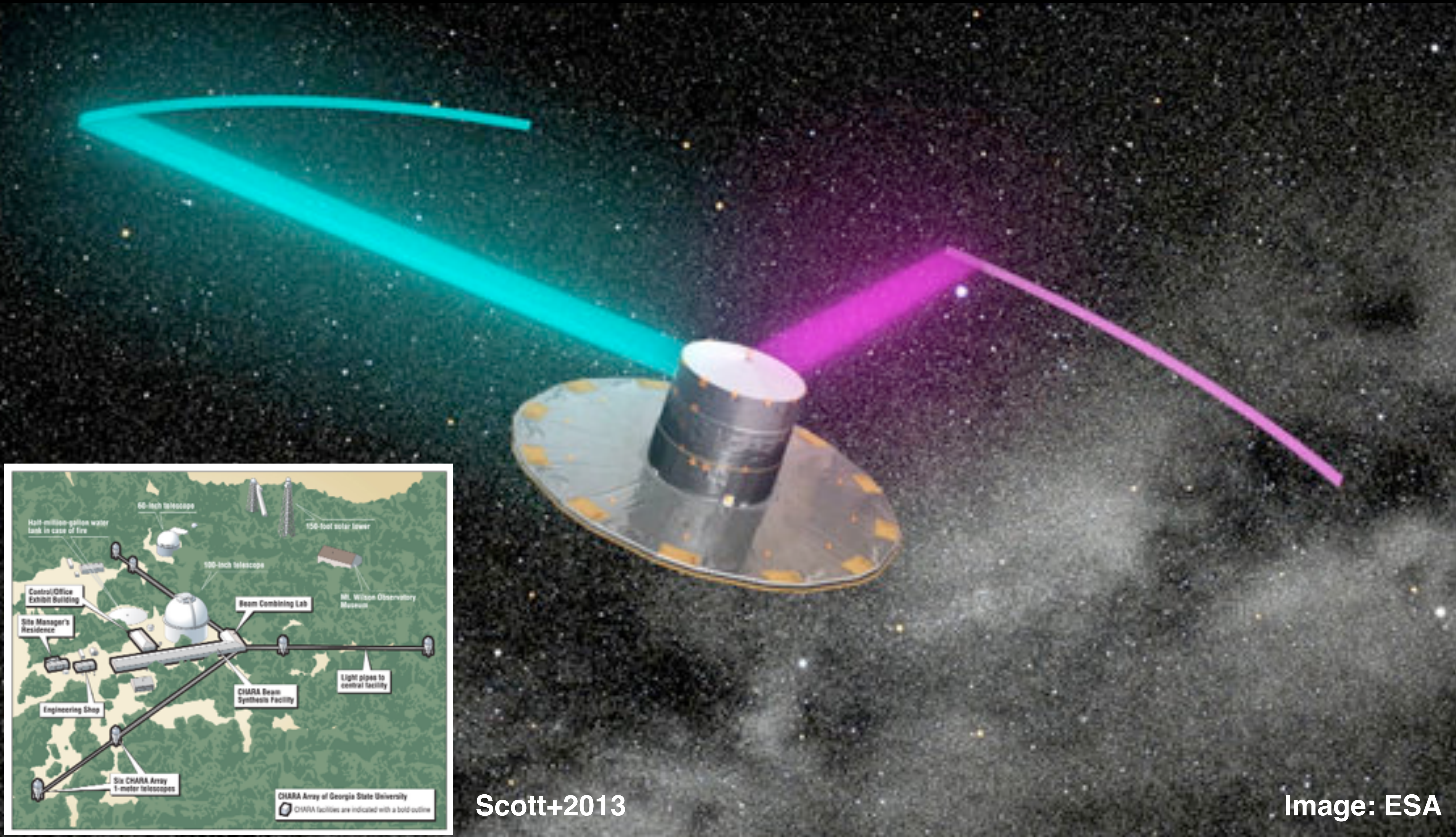


Image: NASA/JPL-Caltech

"We have been spoiled by Kepler" — Dave Latham

Other constraints on stellar parameters?



Scott+2013

Image: ESA

Summary

- Constraining the interior structure of a rocky exoplanet requires very precise stellar parameters, especially for the stellar radius.
- WASP-47 e is less dense than an Earth-like core/mantle composition, and therefore likely has an envelope of heavy volatile elements like water.
- For the TESS era, we should be strategic how we choose planets to follow up with RVs. Prioritize targets where precise $R_p/R_\star$s and stellar radii are possible, and stop observing when the planet mass uncertainty is about 3.6 times larger than the radius uncertainty.

Exoplanet Interior Structures in the Kepler Era