

Water ice lines around super-Jovian planets and Implications for giant moons

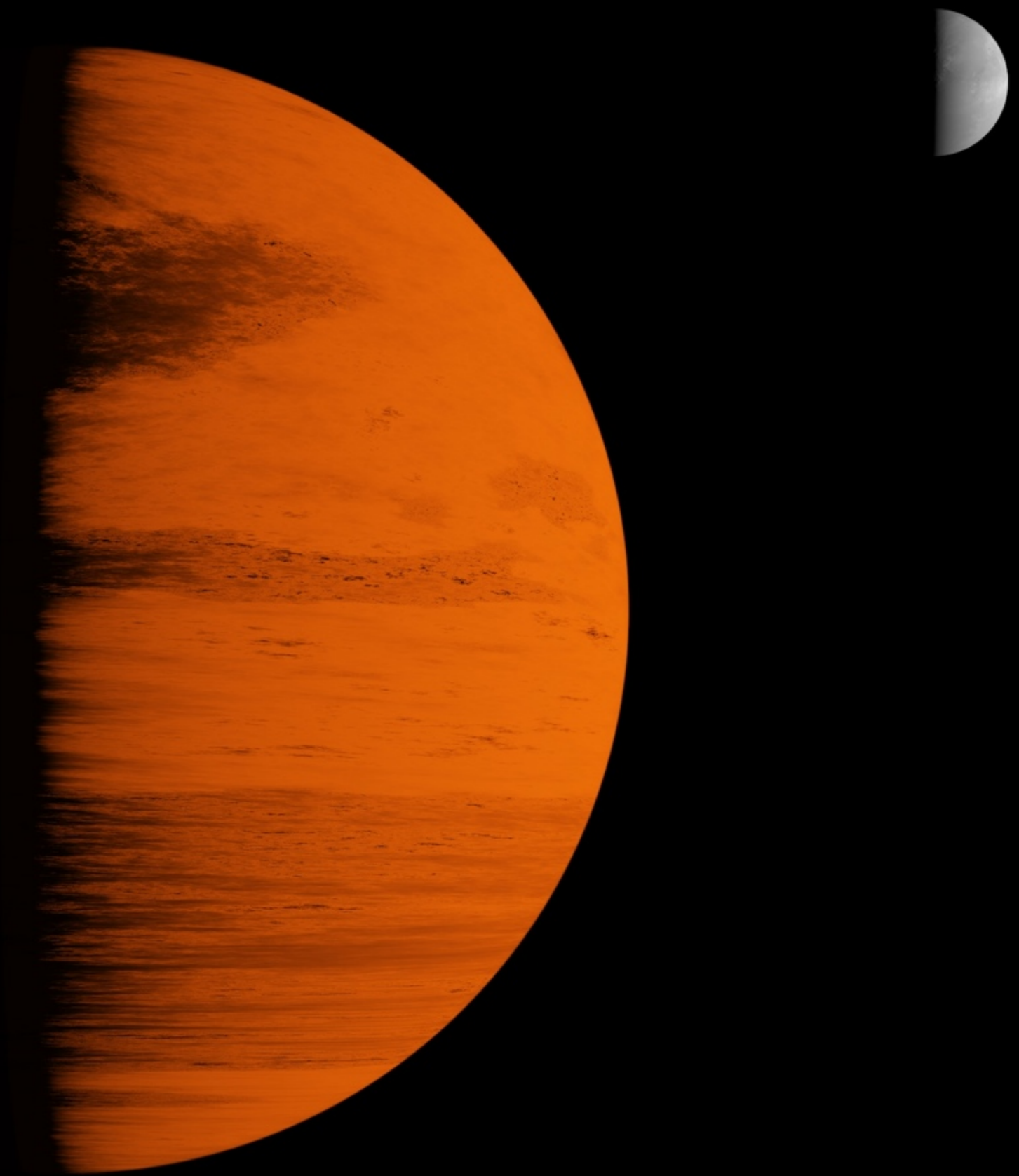
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In collaboration with

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**THE CONTENT OF THIS TALK HAS BEEN MODIFIED
TO COMPLY WITH PUBLICATION EMBARGOS**

Why bother about moons?

They tell us about the fine structure of planet formation.

- (1)** Earth and Moon formed after a giant **collision** ([Hartmann & Davis 1975](#)).
- (2)** The Galilean moons constrain the late stages in Jupiter's **accretion** disk ([Canup & Ward 2006](#)).
- (3)** The tilt of Uranian moon system suggests multiple giant **impacts** on the young Uranus ([Morbidelli+ 2012](#)).
- (4)** Neptune **captured** Triton from a minor body binary ([Agnor & Hamilton 2006](#)).

Moons could outnumber planets in the stellar HZs ([Heller & Barnes 2014](#)).

Why bother about exomoons?

They could be detectable with Kepler and Plato 2.0.

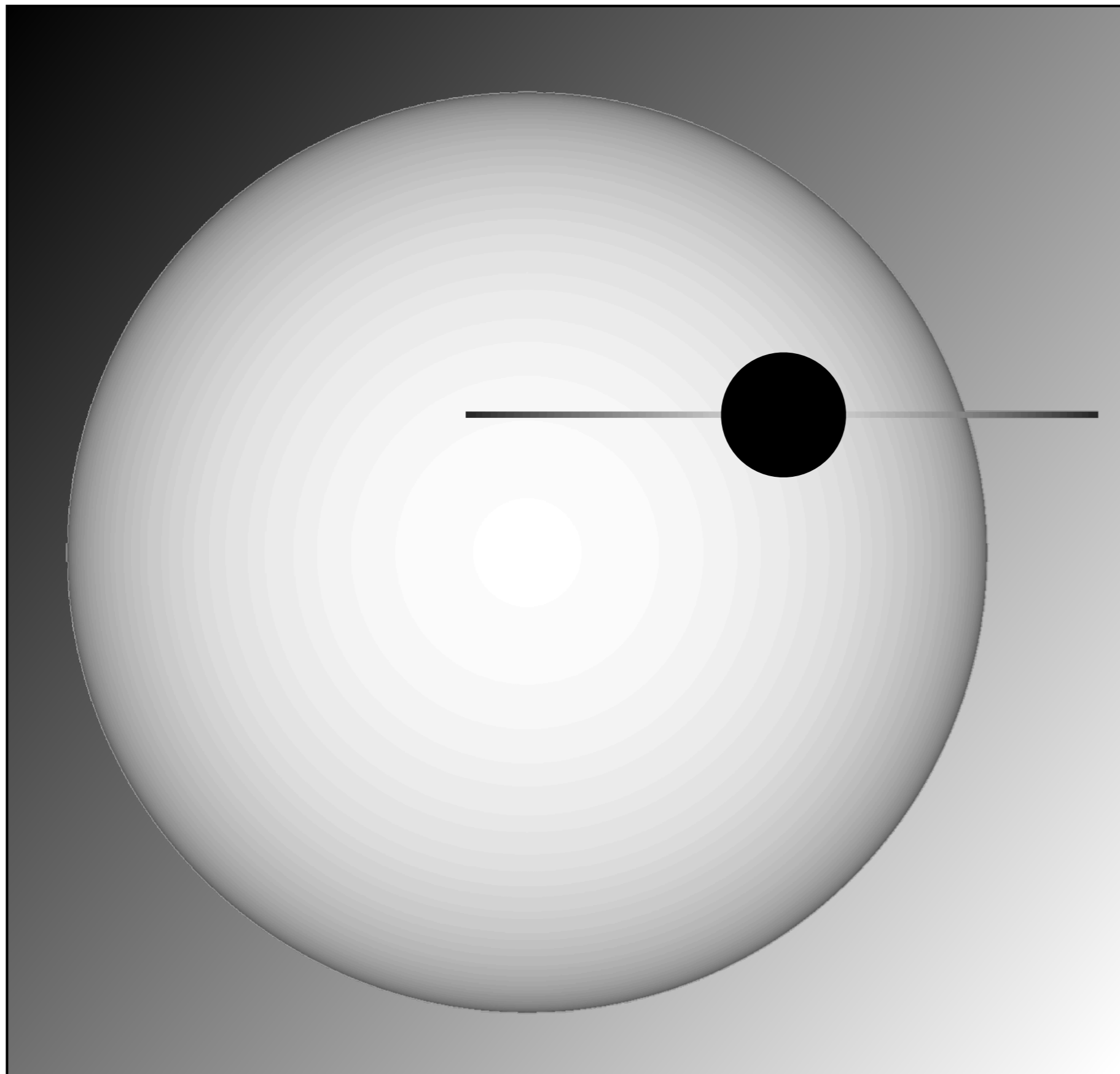
- The “[Hunt for Exomoons with Kepler](#)” ([Kipping et al. 2012](#)) searches TTV and TDV of transiting planets.

Why bother about exomoons?

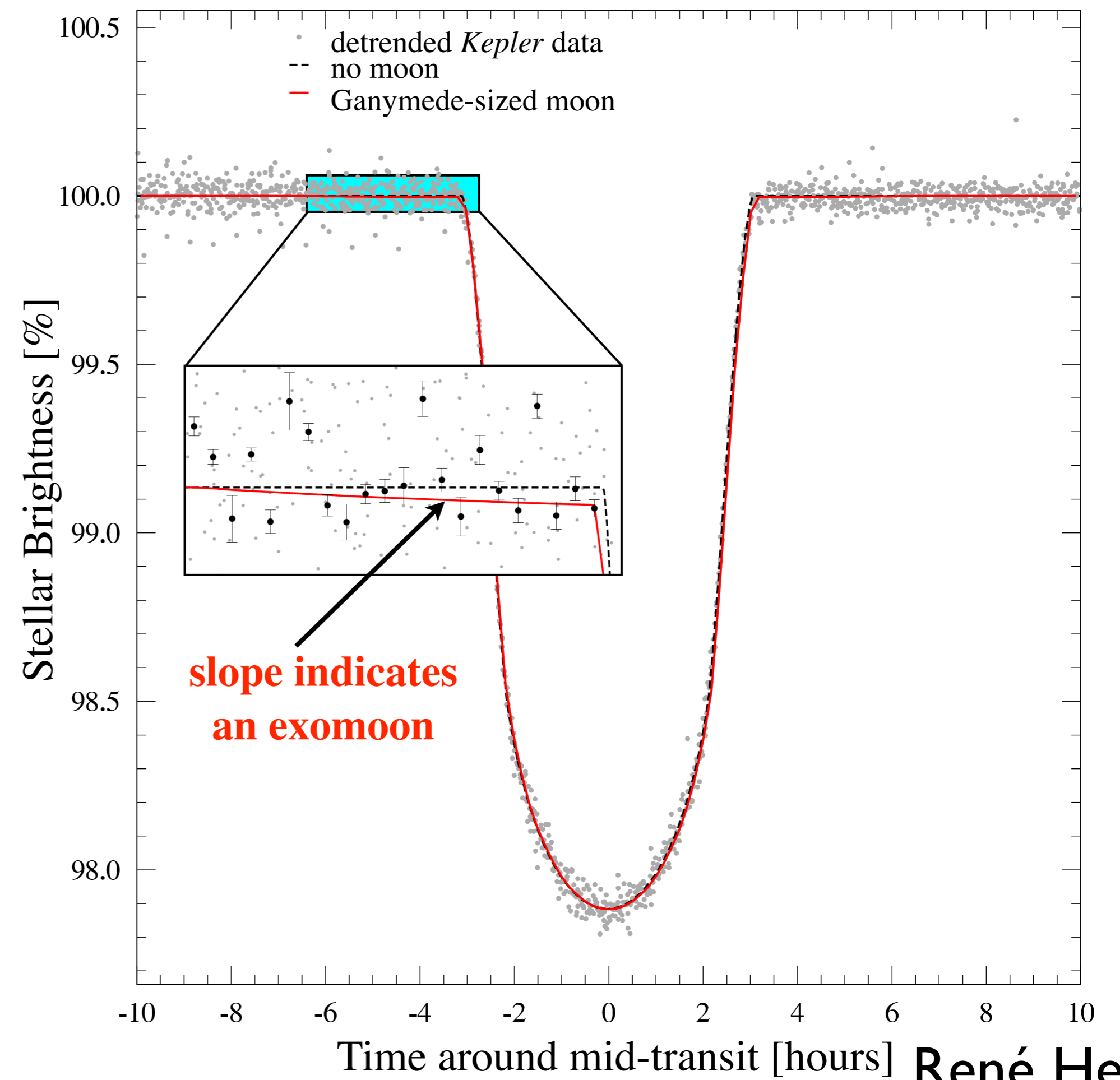
They could be detectable with Kepler and Plato 2.0.

- Ganymede-sized moons can be detected by Kepler and Plato 2.0 ([Heller 2014](#)).

Saturn-sized exoplanet with moon transiting a $0.57 R_{\odot}$ star

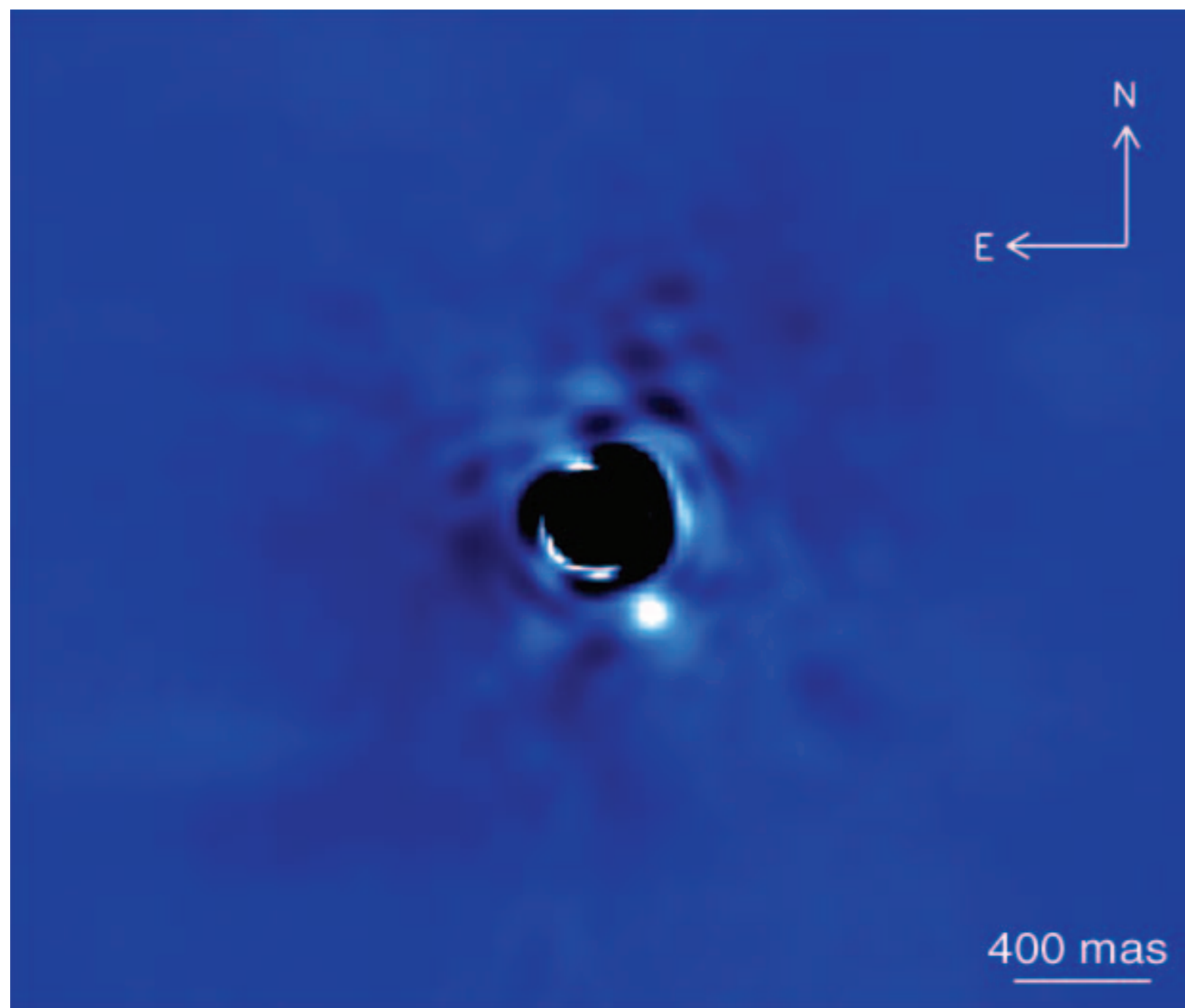


Kepler light curve compared to models



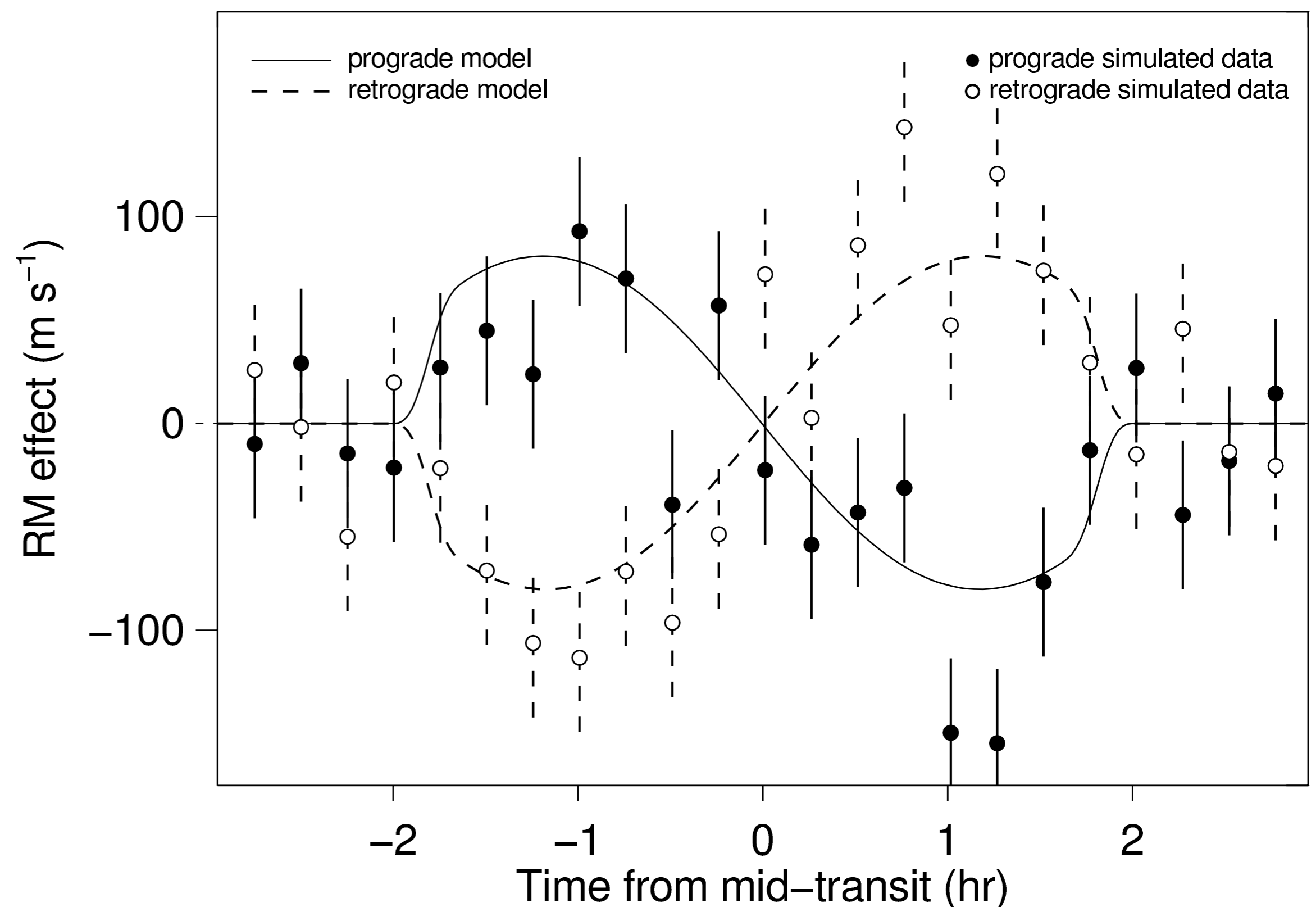
Why bother about exomoons?

A CRIRES-like spectrograph at E-ELT can determine a moon's sense of orbital motion via the Rossiter-McLaughlin effect.



beta Pic b

(Lagrange et al. 2010, NaCo @ VLT)



(Heller & Albrecht 2014, submitted)

Can giant planets form giant moons?

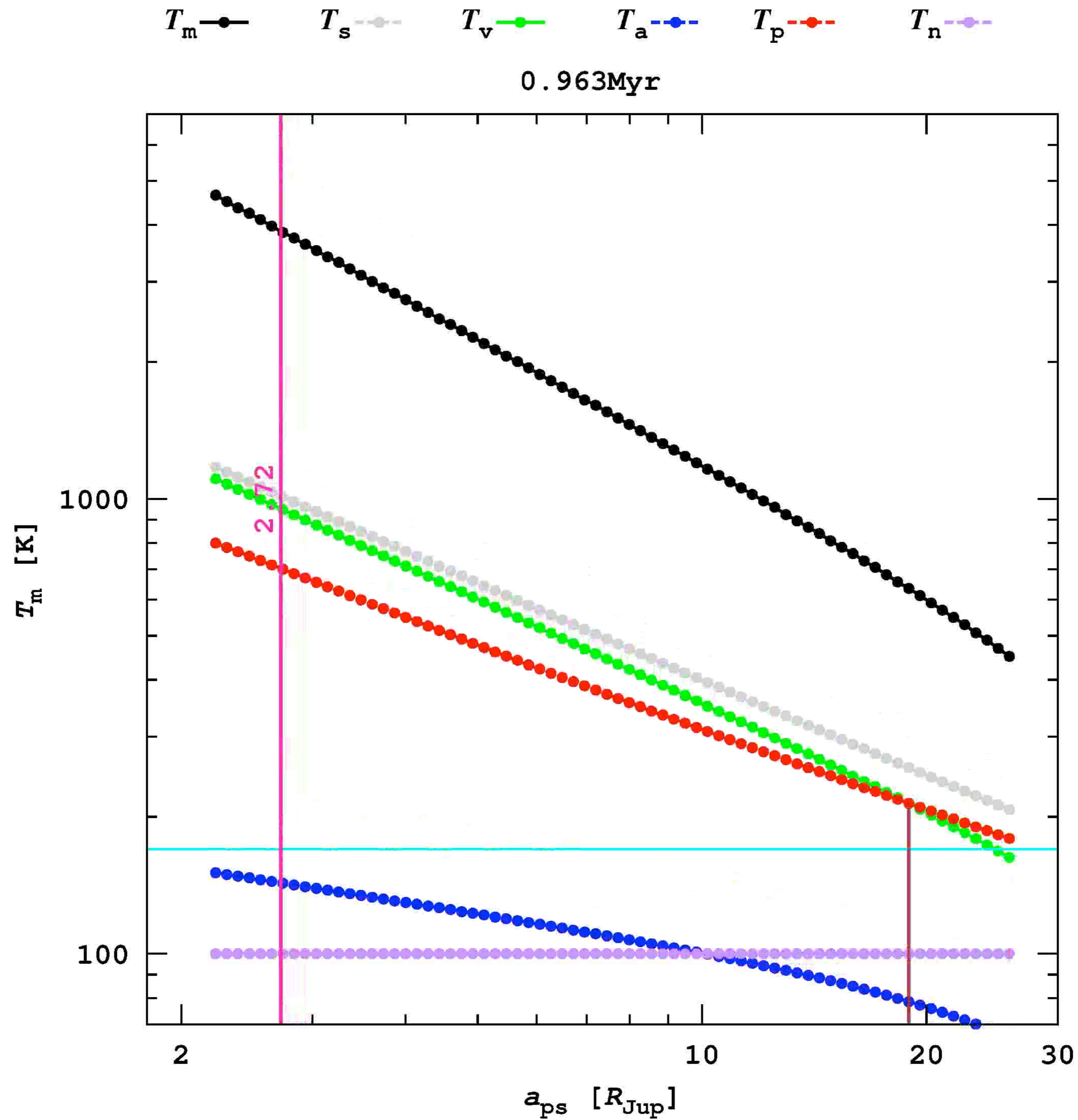
We trace H₂O ice lines in accretion disks around super-Jovian planets
([Heller & Pudritz 2014](#), submitted).

- 2D semi-analytical model
in vertical hydrostatic balance
(based on [Canup & Ward 2006](#);
[Makalkin & Dorofeeva 2014](#);
[Machida+ 2008](#); [Mordasini 2013](#))
- rotationally symmetric
circumplanetary disk with
 - (1) planetary irradiation
 - (2) viscous heating
 - (3) accretional heating
 - (4) heating from the ambient stellar nebula

**FIGURE UNDER
PUBLICATION EMBARGO**

H₂O ice lines around accreting super-Jovians

**FIGURE UNDER
PUBLICATION EMBARGO**



H₂O ice lines around accreting super-Jovians

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H₂O ice lines around accreting super-Jovians

We randomize disk opacities (κ_P) and shutdown accretion rates (\dot{M}_{shut}).

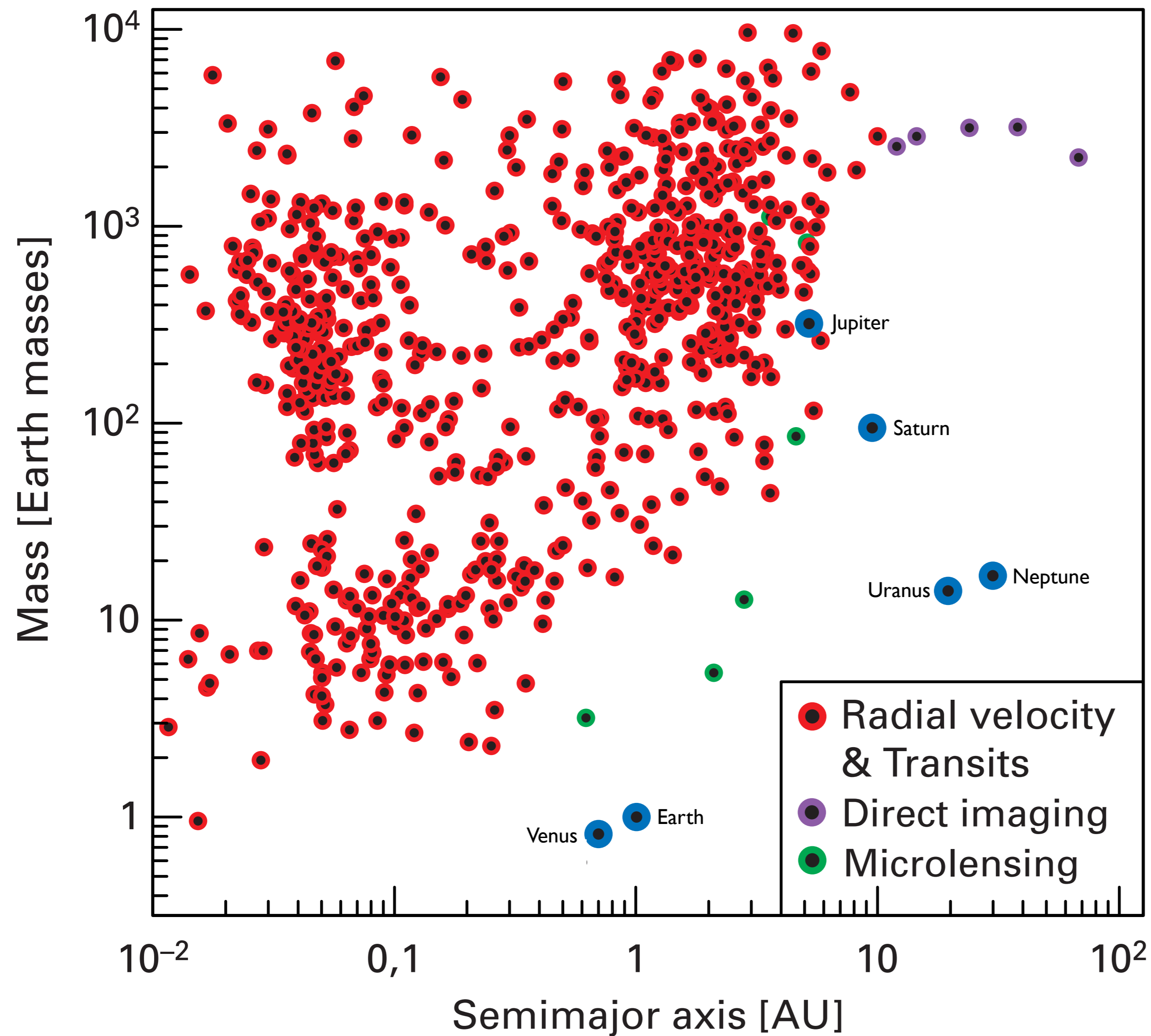
Dust-to-mass ratio is $X = 0.006$, all planets are at 5.2 AU from a Sun.

**FIGURE UNDER
PUBLICATION EMBARGO**

H₂O ice lines around accreting super-Jovians

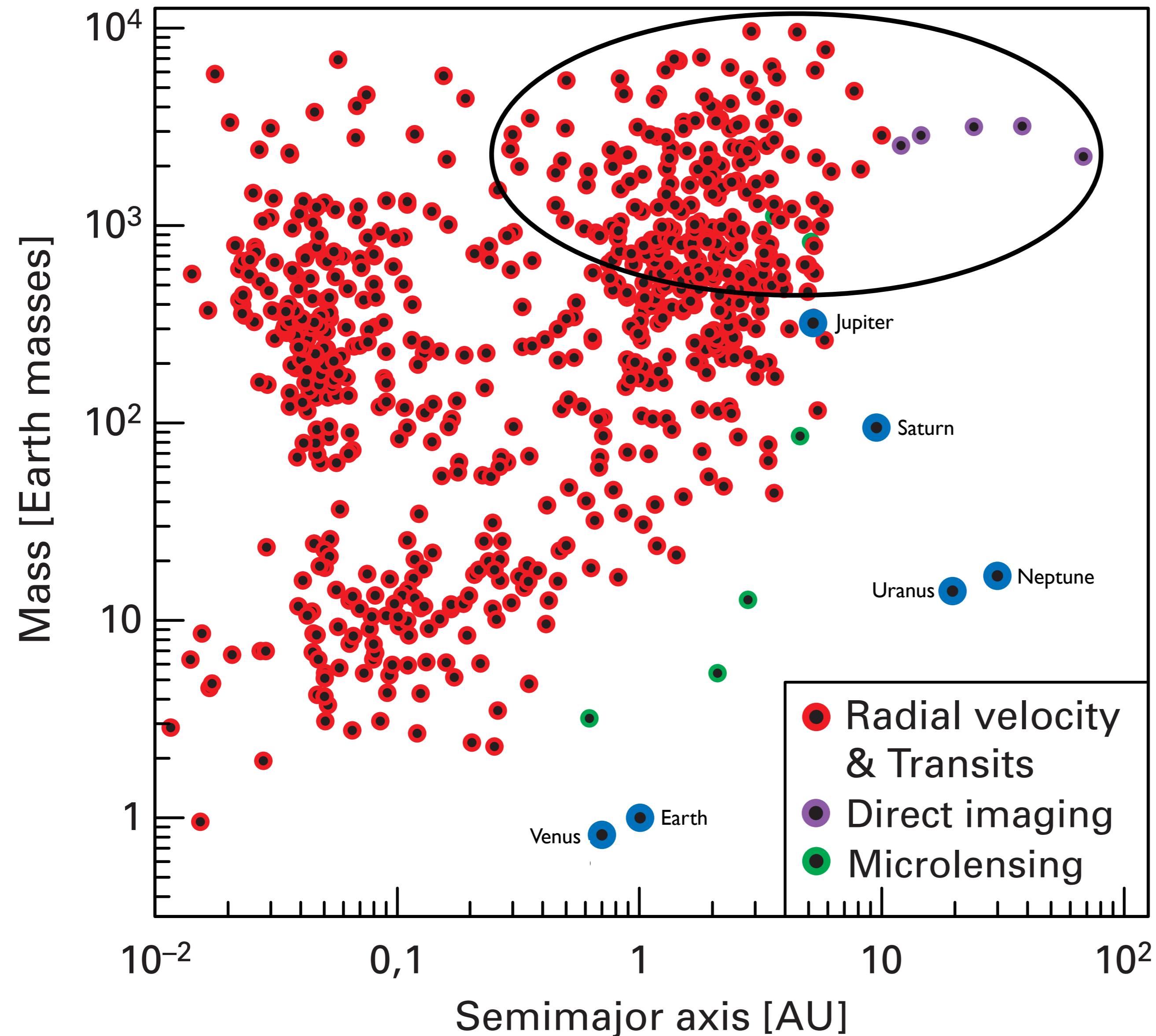
**FIGURE AND CONCLUSIONS
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PUBLICATION EMBARGO**

H₂O ice lines around accreting super-Jovians



(Mordasini+ 2014)

H₂O ice lines around accreting super-Jovians



These super-Jovians should be orbited by Mars-mass moons!

(Mordasini+ 2014)

Predictions

**FIGURE AND CONCLUSIONS
UNDER
PUBLICATION EMBARGO**

Related Literature

Heller, R., Williams, D., Kipping, D. et al. *AsBio* (2014) 1408.6164
Formation, Habitability, and Detection of Extrasolar Moons

Heller, R. *ApJ* (2014) 1403.5839
Detecting extrasolar moons akin to Solar System satellites with an orbital sampling effect

Heller, R., Armstrong, J. *AsBio* (2014) 1401.2392
Superhabitable Worlds

Heller, R., Barnes, R. *Int. J. of Astrobiology* (2014) 1311.0292
Runaway greenhouse effect on exomoons due to irradiation from hot, young giant planets.

Heller, R., Zuluaga, J. *ApJL* (2013) 1309.0811
Magnetic shielding of exomoons beyond the circumplanetary habitable edge