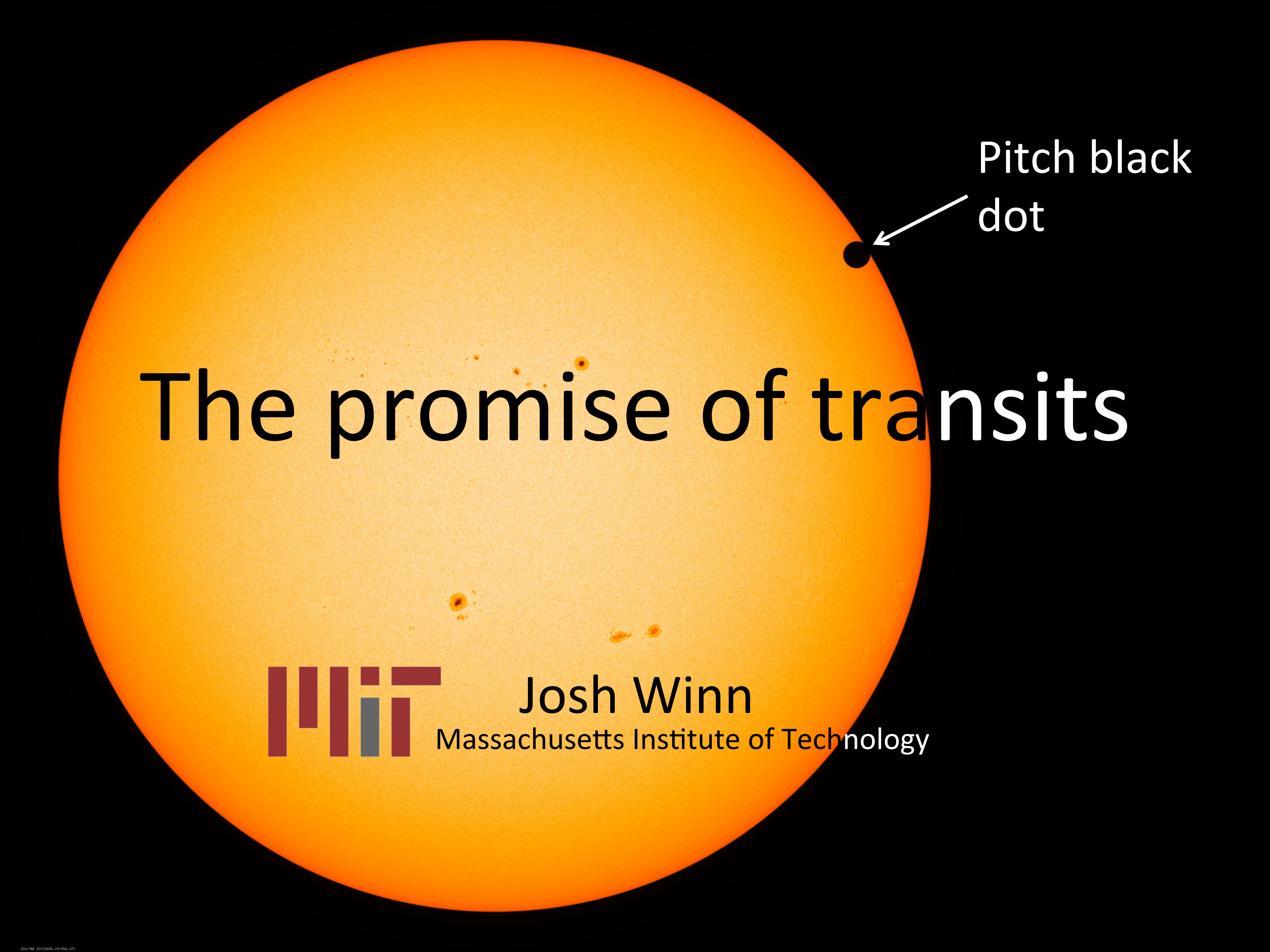
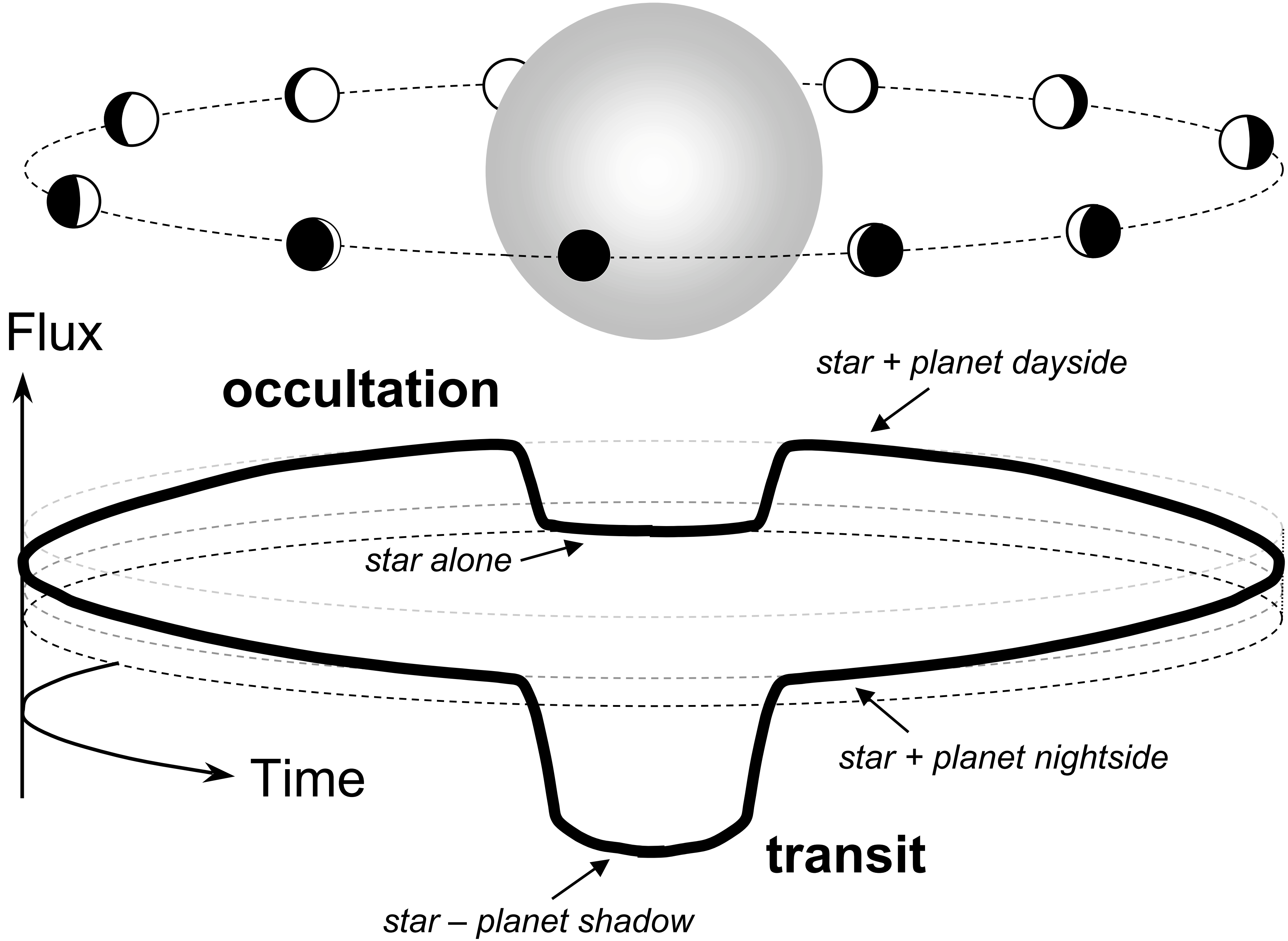
Pale blue dot

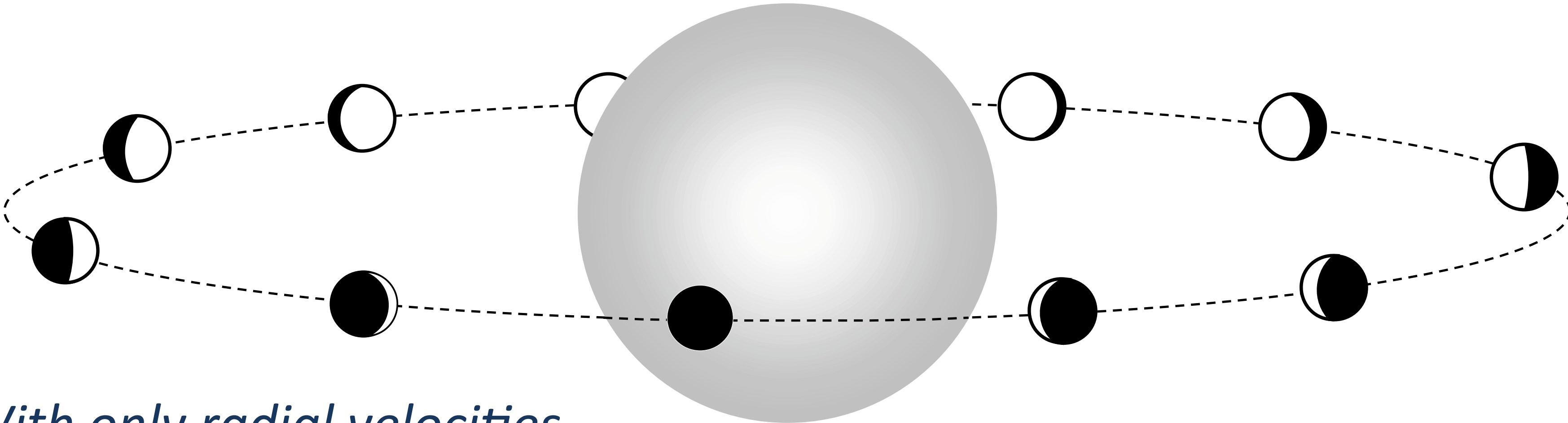
The promise of transits

Josh Winn
Massachusetts Institute of Technology


Pitch black dot
The promise of transits
Josh Winn
Massachusetts Institute of Technology


Flux
occultation
star + planet dayside
star alone
Time
star + planet nightside
transit
star – planet shadow

Winn (2010)



With only radial velocities…

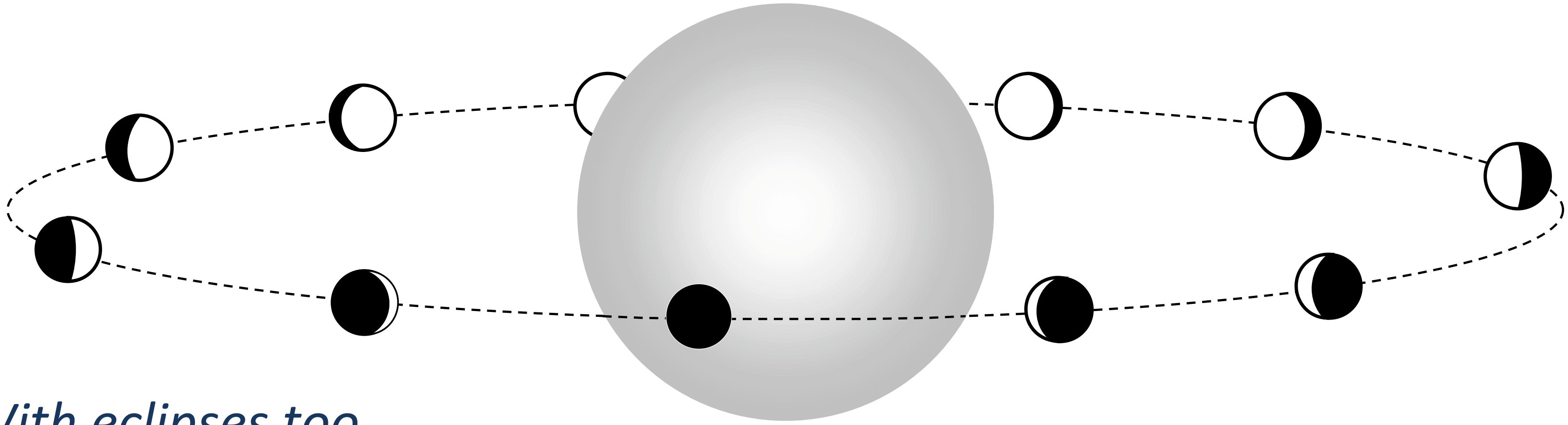
Orbital properties

Period

Eccentricity

Planet bulk properties

Minimum mass



With eclipses too…

Orbital properties

Period

Eccentricity

Planet bulk properties

Mass

Radius

Planet atmospheric properties

Emission spectrum

Transmission spectrum

Reflectance spectrum

Phase function

Stellar properties

Limb darkening function

Gravity darkening function

Spots and plages

Obliquity

Multiple-planet systems

Dynamical masses

Mutual inclinations

Resonances and chaos

Multiple-star systems

Circumbinary planets

For the future

Moons and Trojans

Oblateness and rings

Apsidal motion constant

Relativistic precession

Orbital decay

Applegate effect

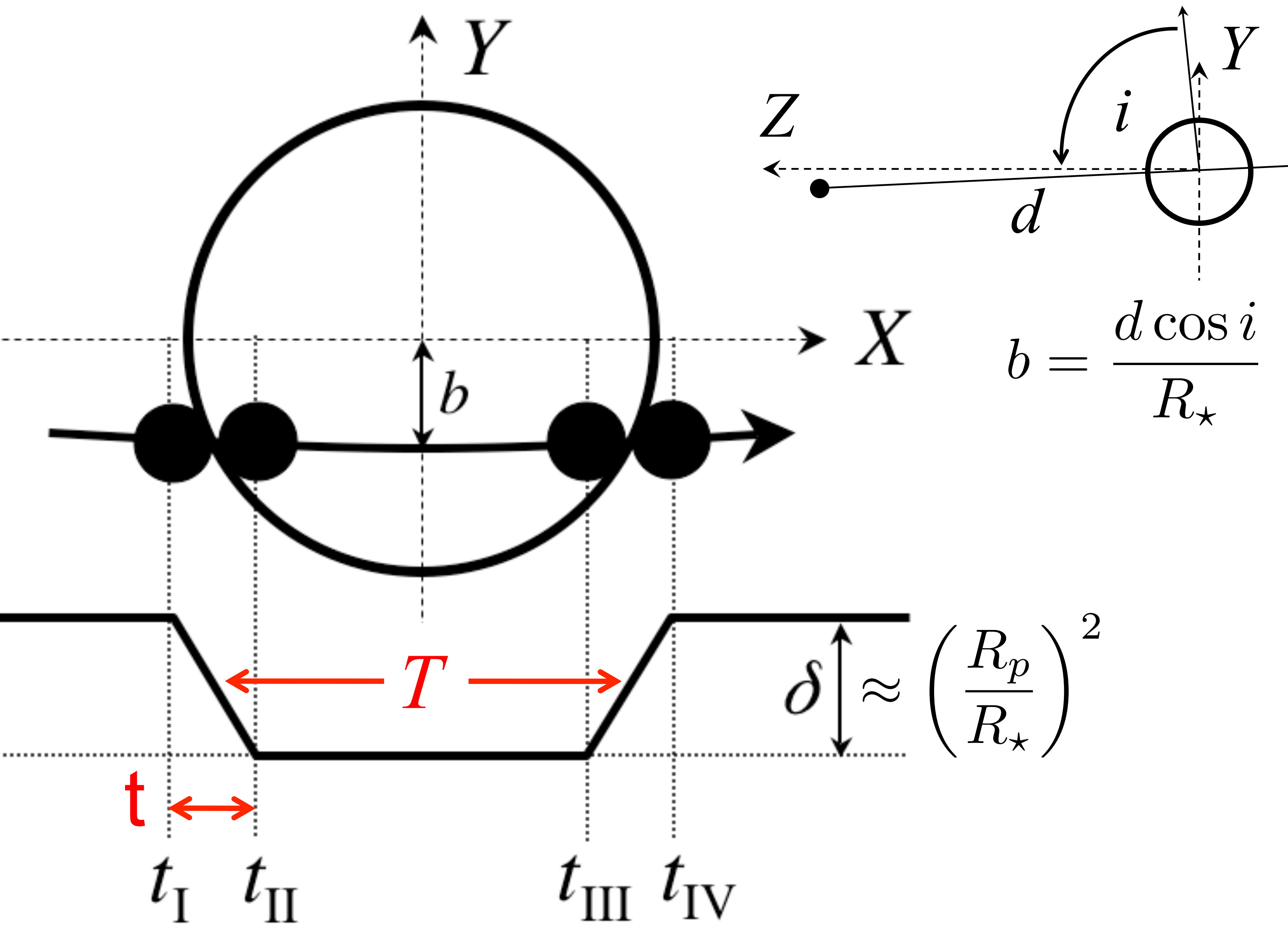
Planetary wind speed

Yarkovsky effect

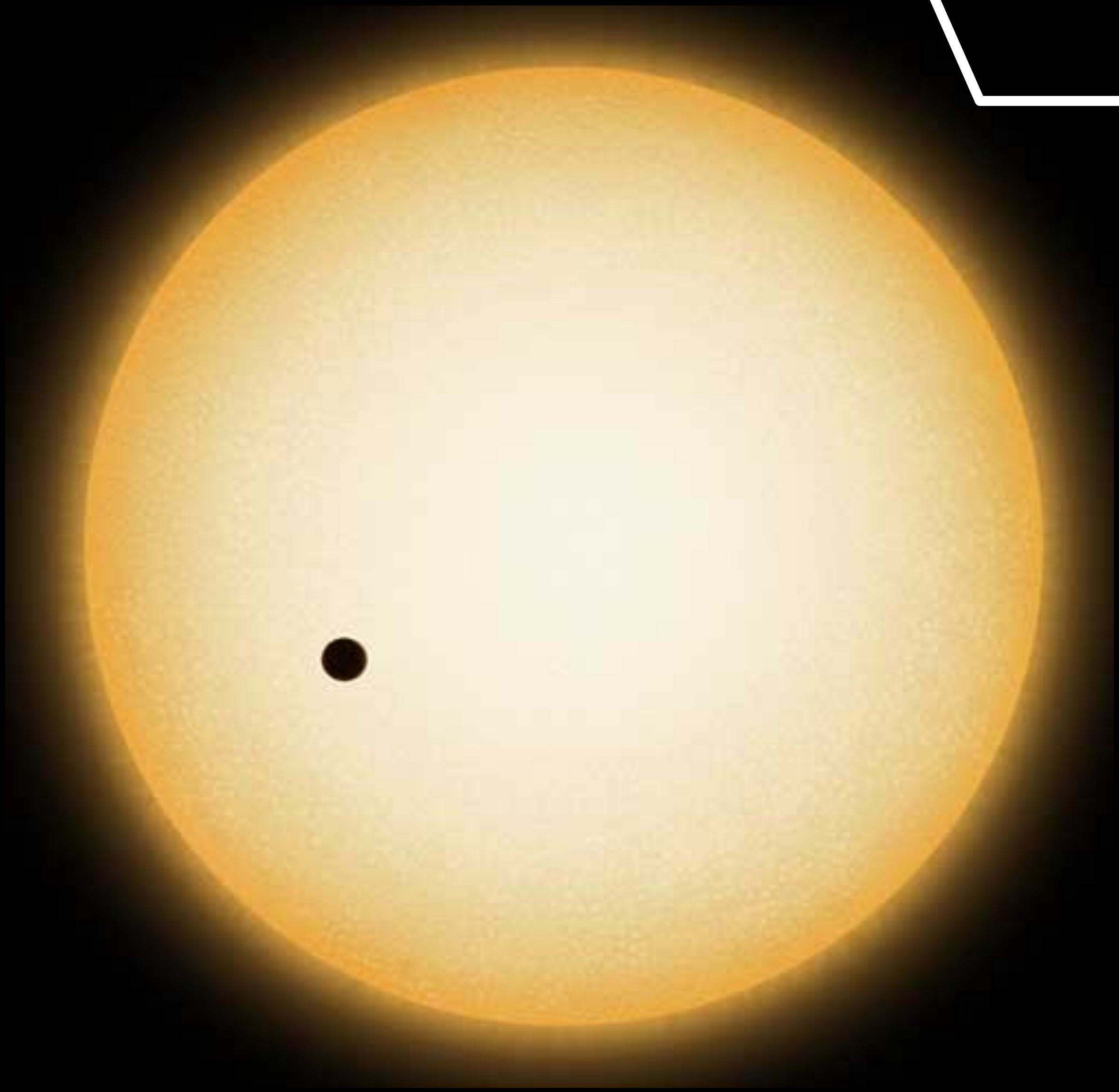
Planetary magnetic field

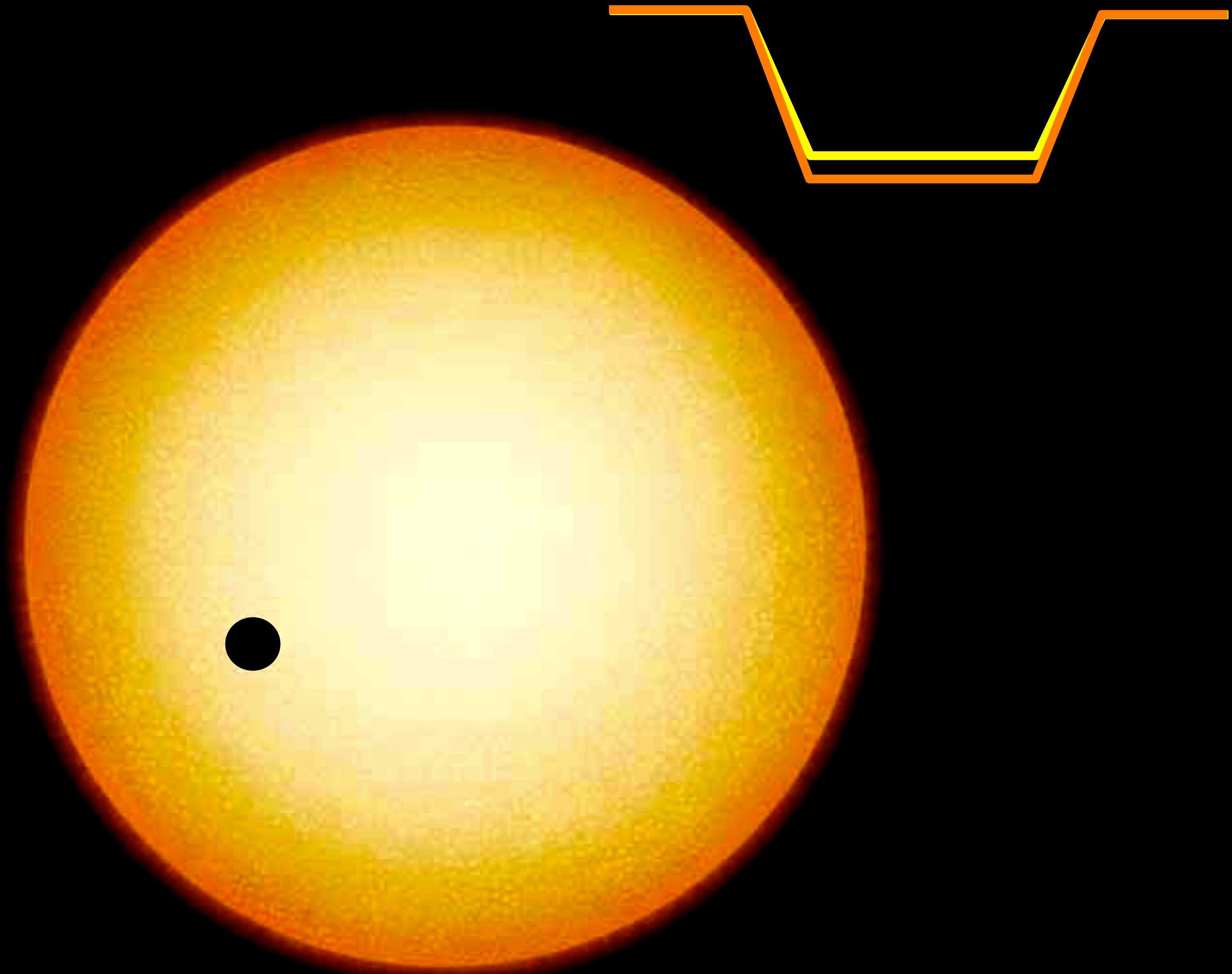
Planetary aurorae

Artificial planet-sized objects

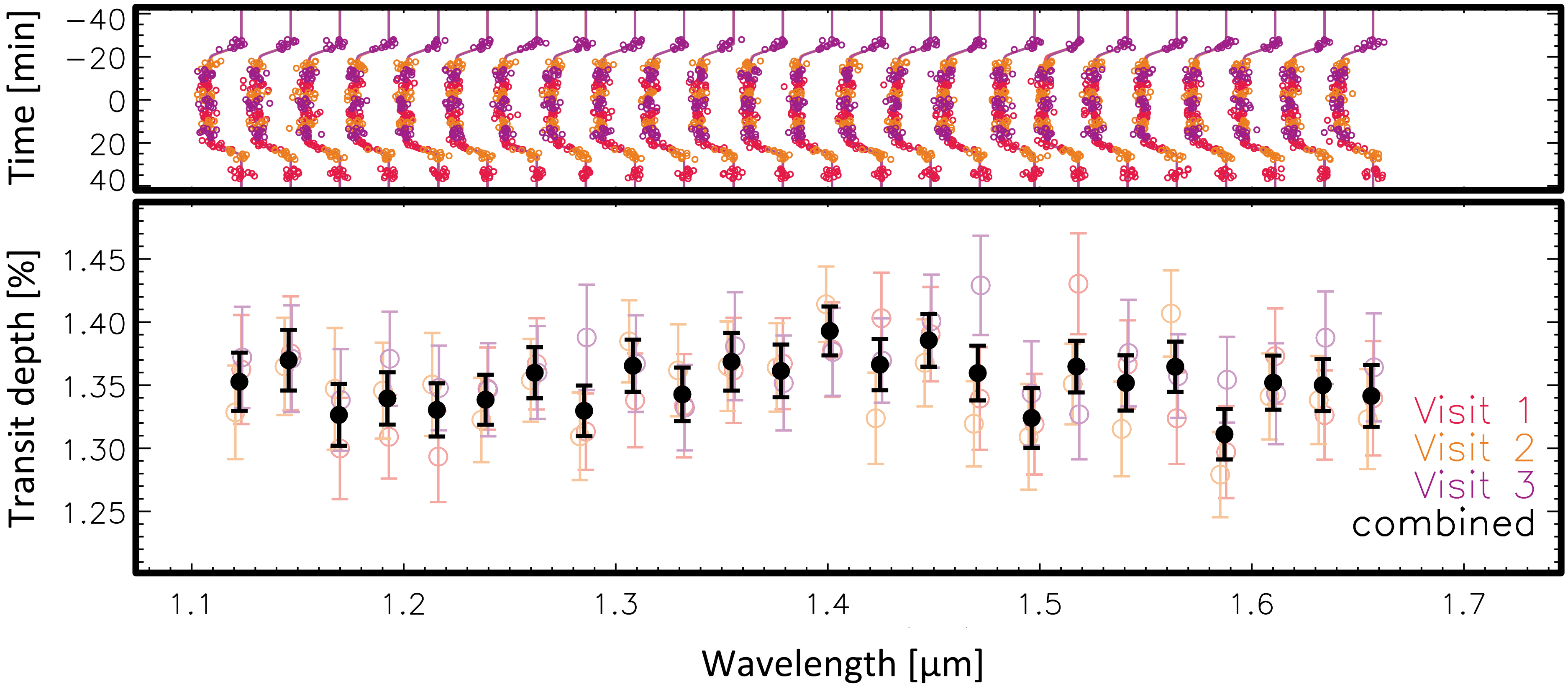


Y
Z
i
Y
d
X
b
b = d cos i / R⋆
T
δ ≈ (Rp / R⋆)^2
t
tI
tII
tIII
tIV

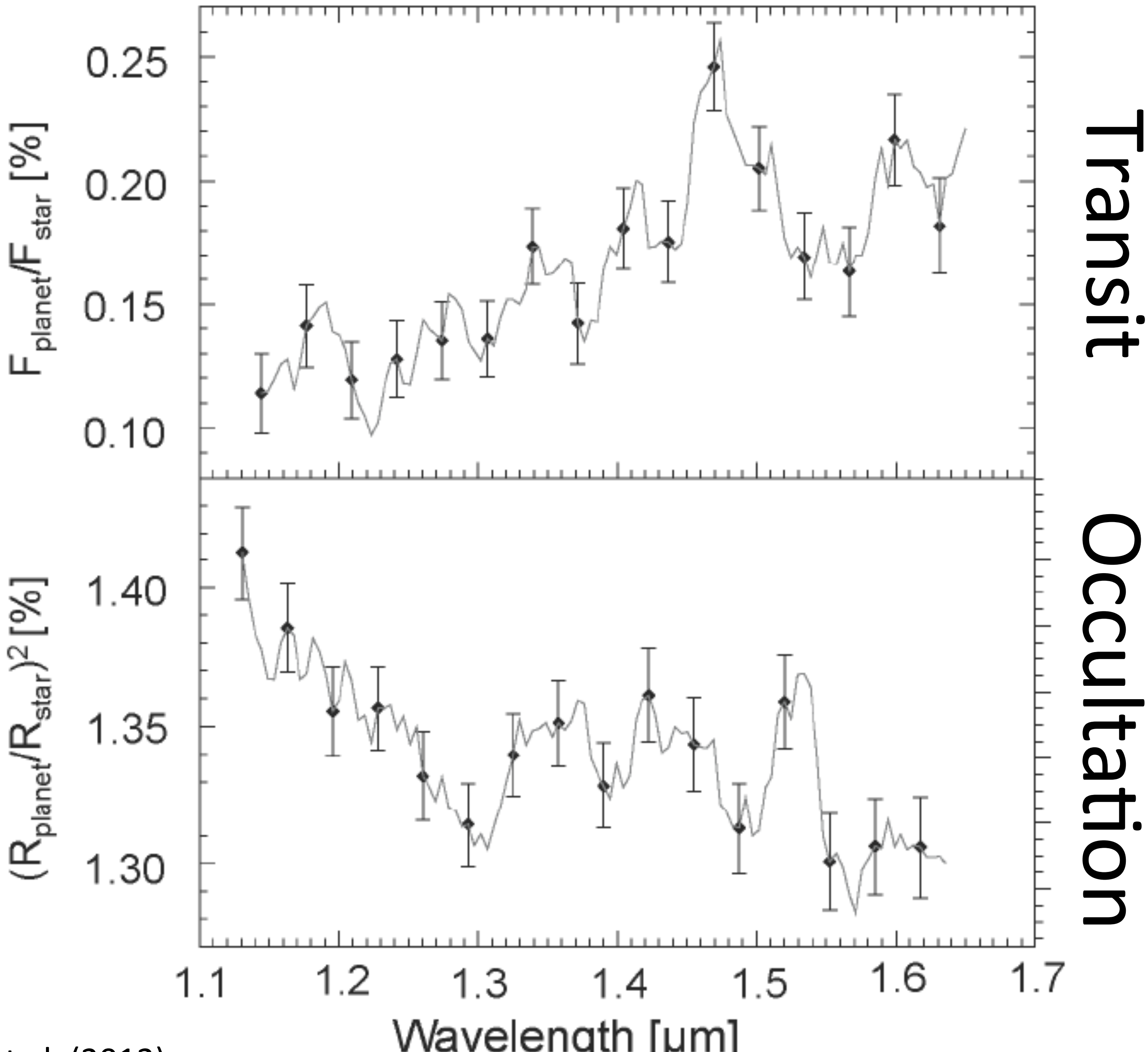


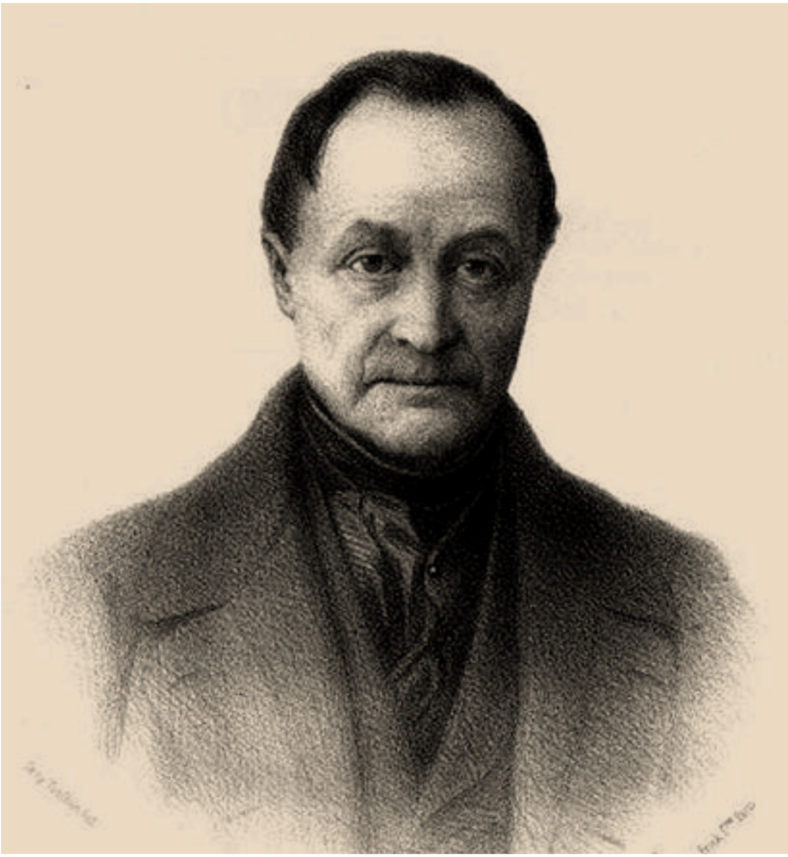
Transmission spectroscopy



Berta et al. (2012)



Swain et al. (2012)



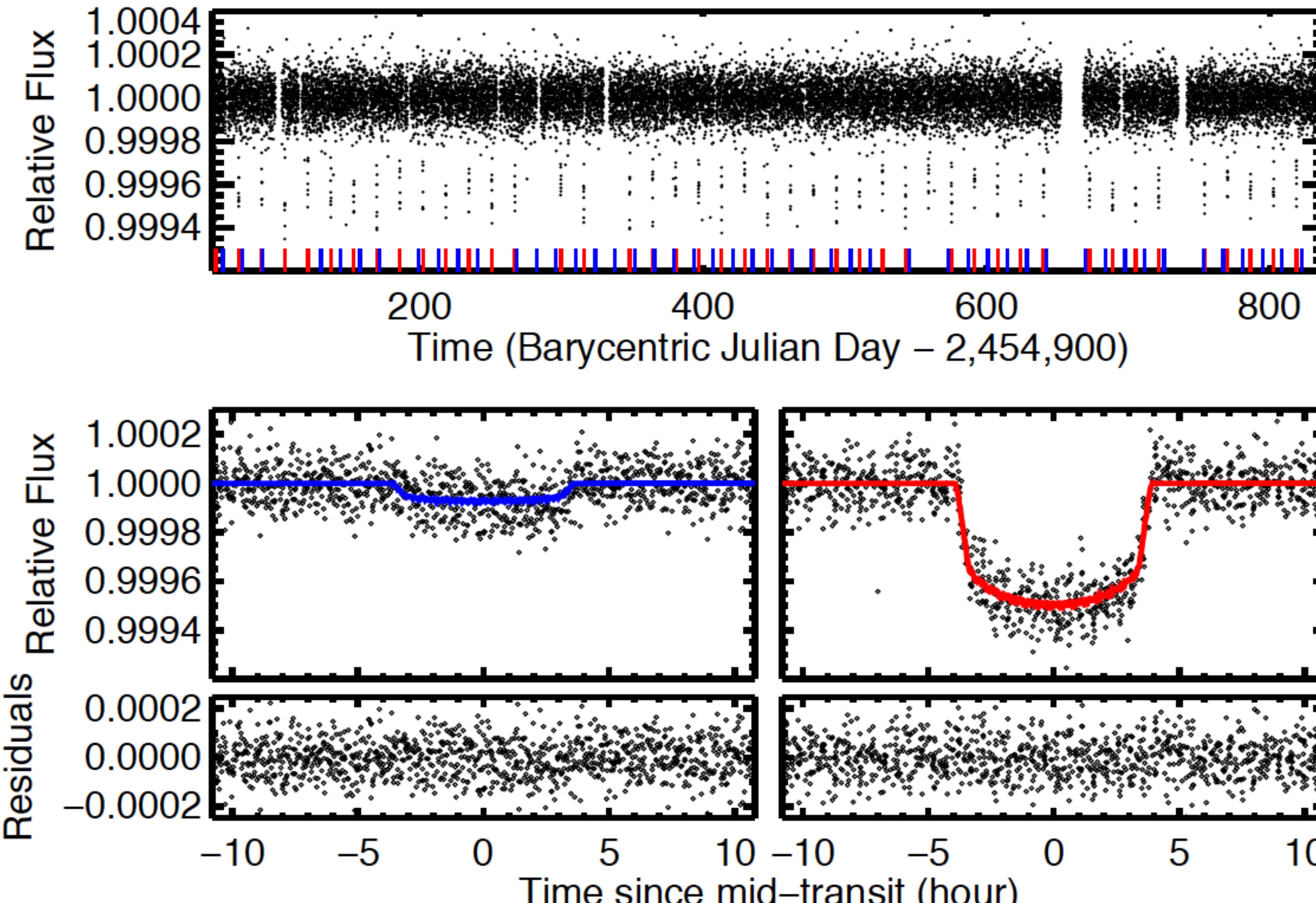
Auguste Comte,
Positive Philosophy (1853)

We see how we may determine their forms, their distances, their bulk, and their motions, but we can never know anything of their chemical or mineralogical structure; and, much less, that of organized beings living on their surface. ... All physical, chemical, physiological, and social researches are out of the question in regard to the planets.

Josh Winn,
Exoplanets (2010)

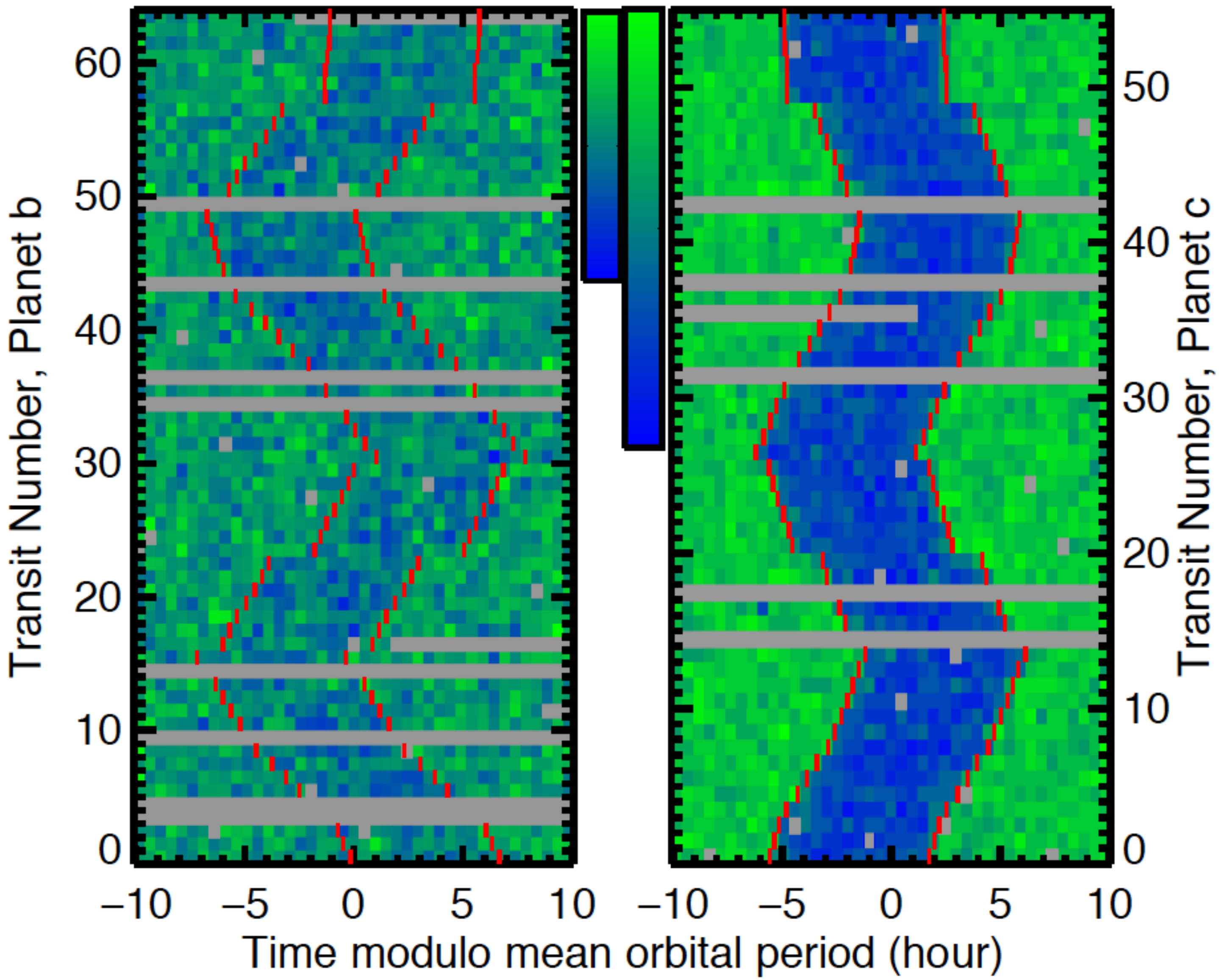
Ideally one would like to know the mass in kilograms, and the radius in kilometers, to allow for physical modeling and comparisons with solar system planets. With only a transit light curve, this is impossible. The light curve by itself reveals the planet-to-star radius ratio but not the planetary radius, and says nothing about the planetary mass.

Photodynamics



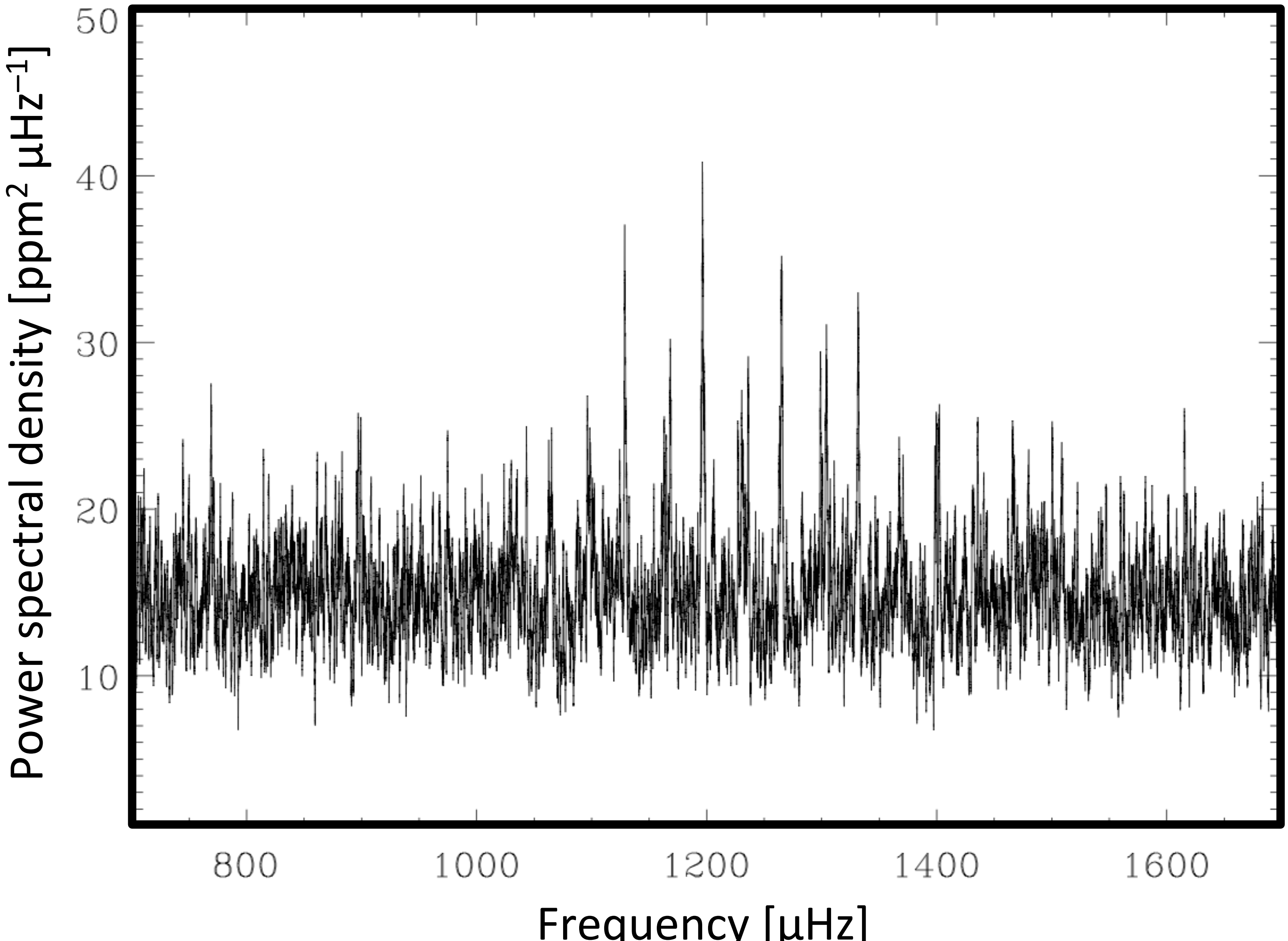
Carter, Agol, Chaplin, et al. (2012)

Photodynamics



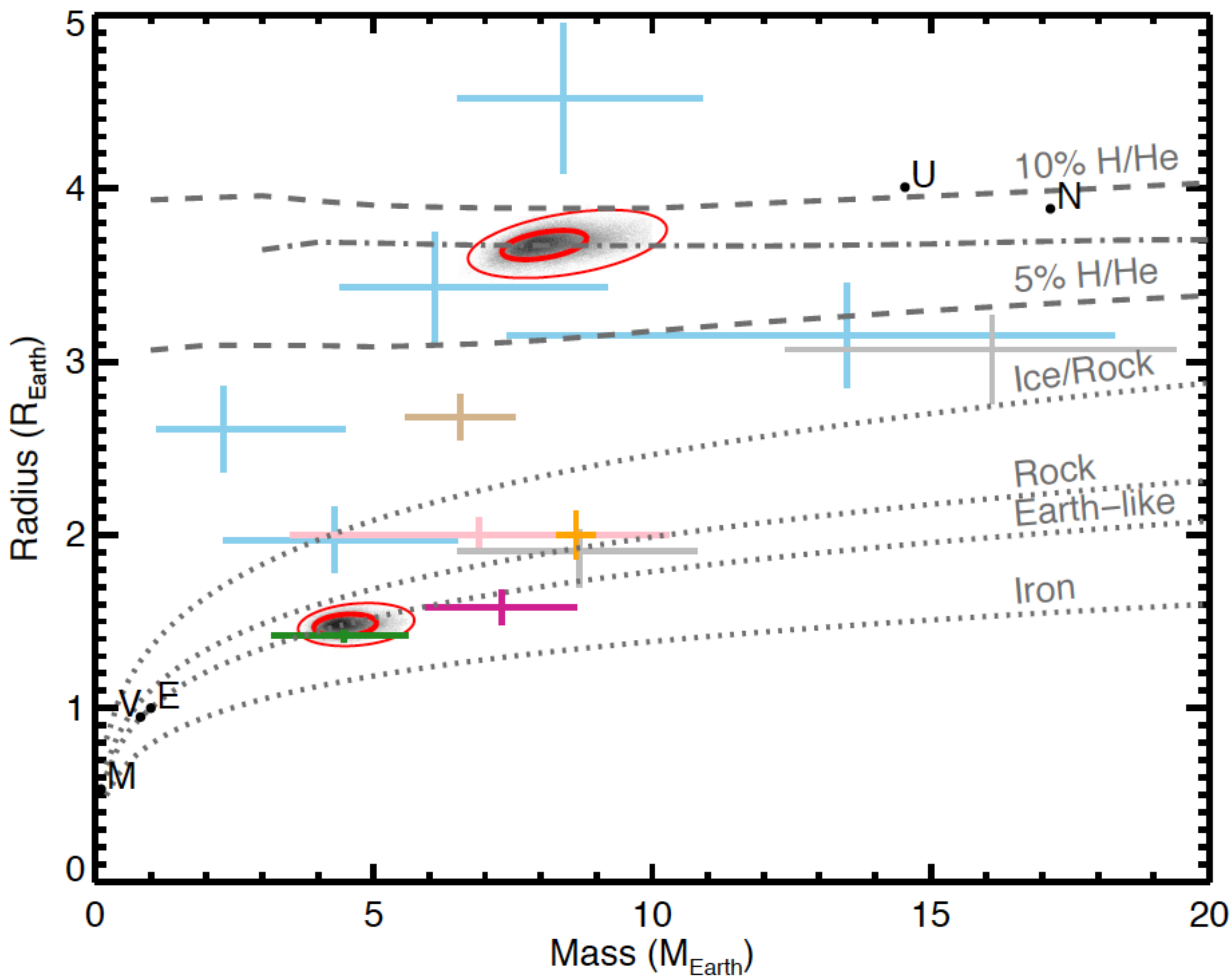
Carter, Agol, Chaplin, et al. (2012)

Asteroseismology



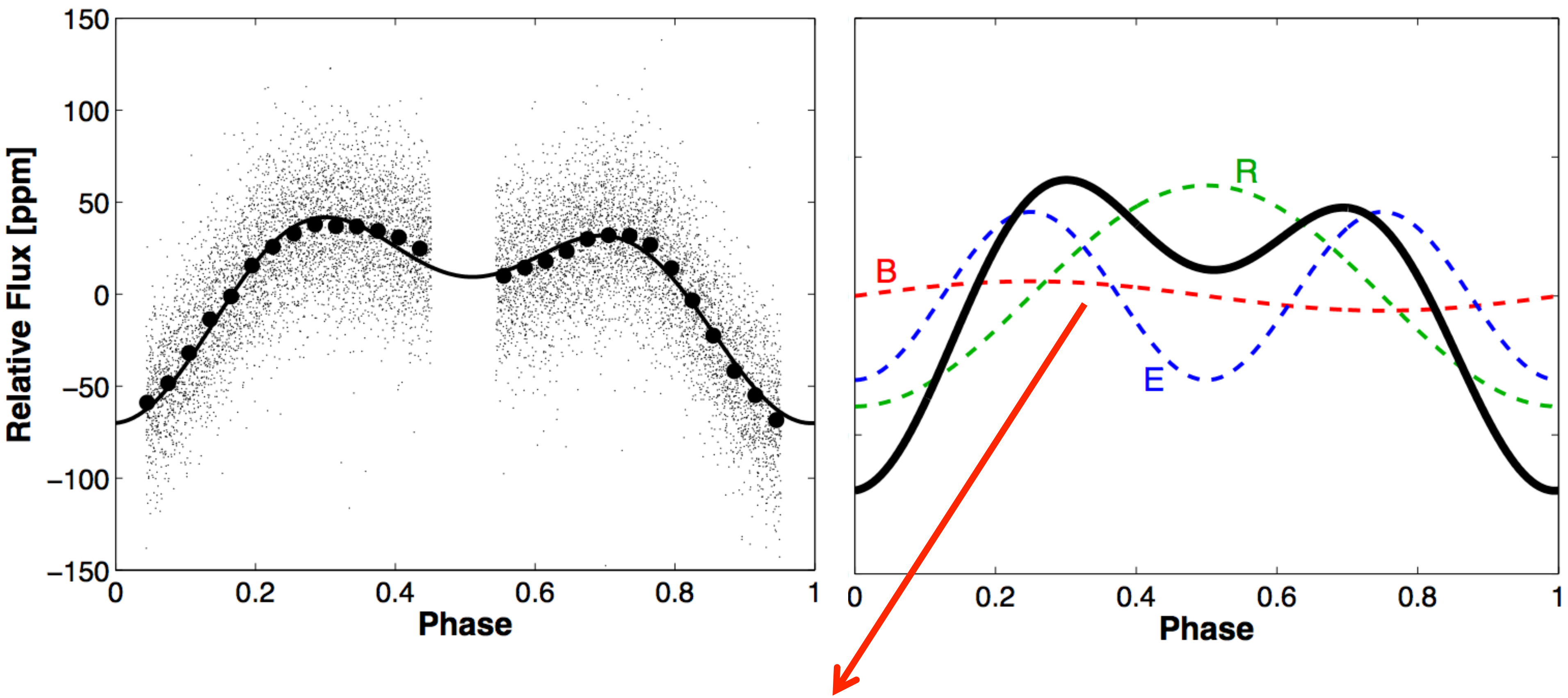
Carter, Agol, Chaplin, et al. (2012)

Photodynamics + Asteroseismology



Carter, Agol, Chaplin, et al. (2012)

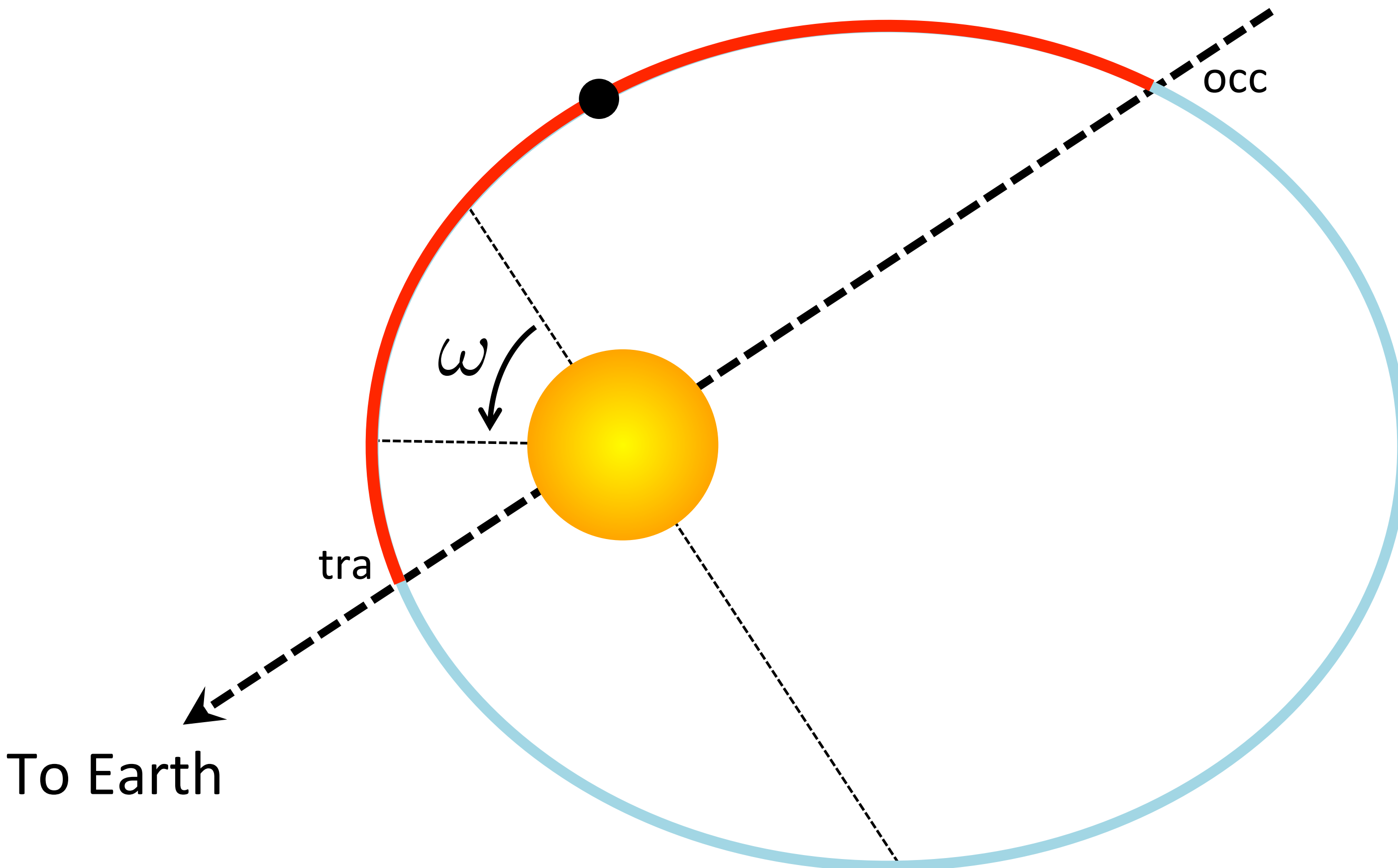
Doppler boosting



$$A_{\mathrm{boost}} \propto \frac{K_{\mathrm{RV}}}{c}$$

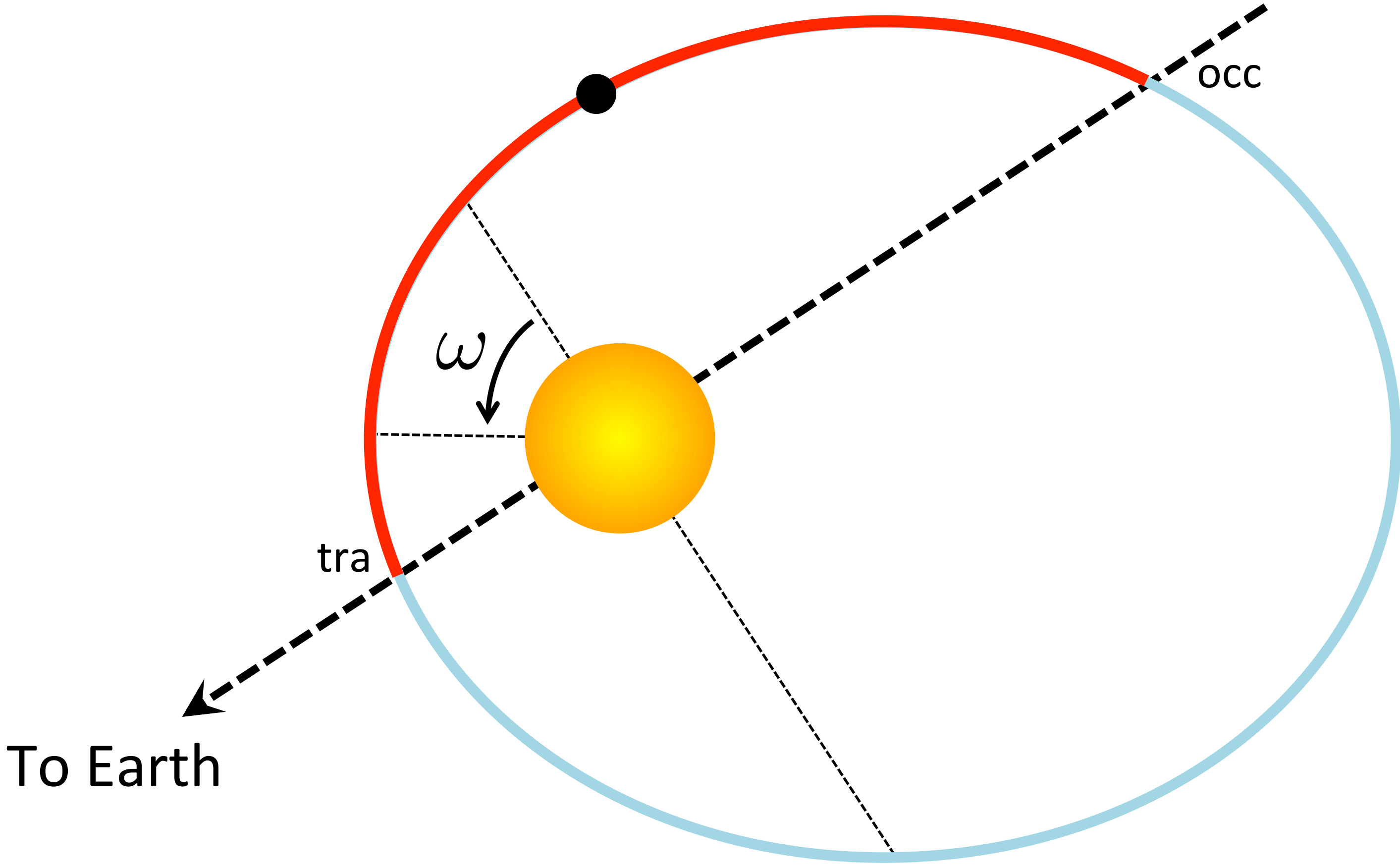
Shporer et al. (2012)

Eccentricity



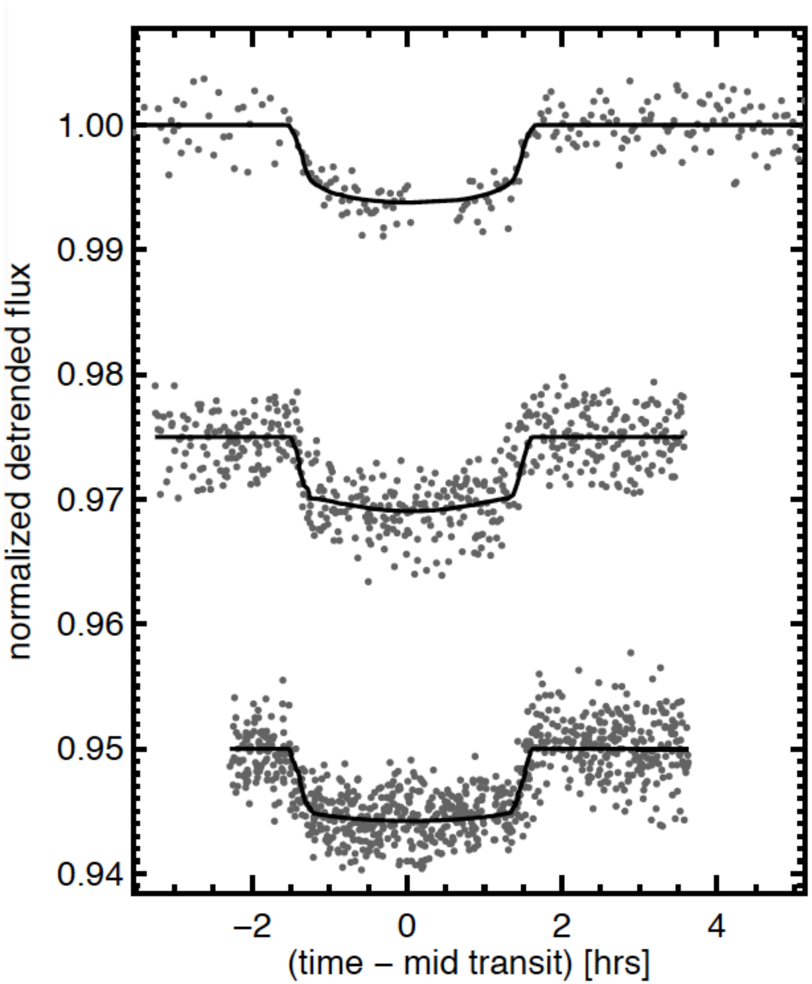
$$\Delta t_c \approx \frac{P}{2}\left[1 + \frac{4}{\pi} e \cos\omega\right] \qquad \frac{T_{\rm occ}}{T_{\rm tra}} \approx \frac{1 + e\sin\omega}{1 - e\sin\omega}$$

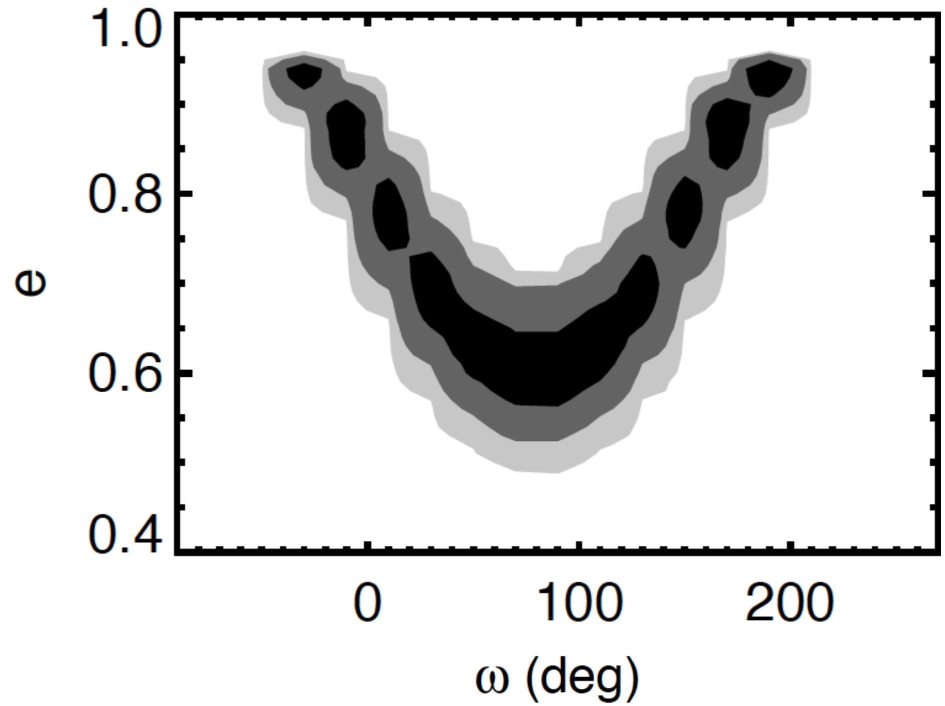
Eccentricity



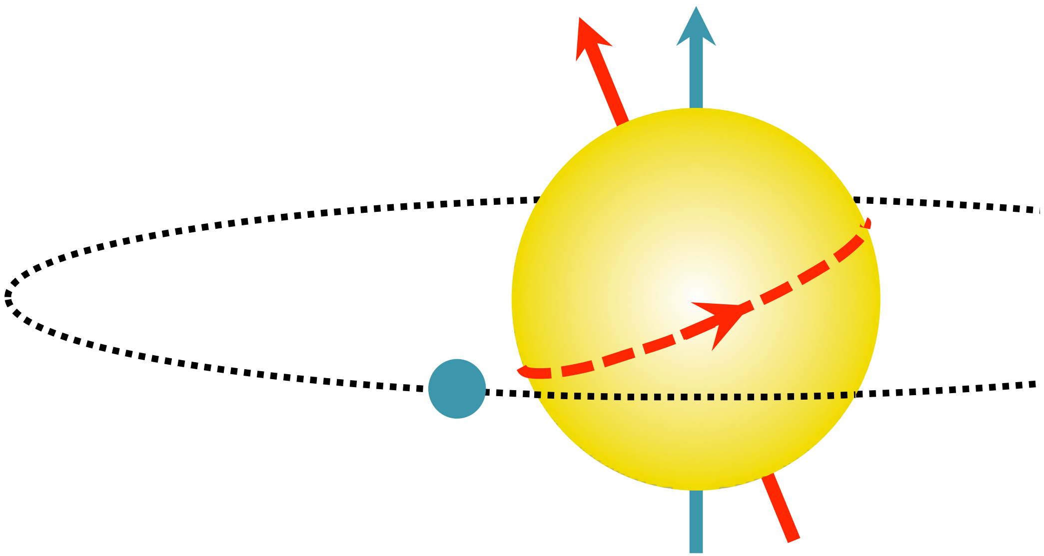
$$T_{\rm tra} \propto \rho_\star^{-1/3} \; \frac{\sqrt{1-e^2}}{1+e\sin\omega}$$

The photoeccentric effect





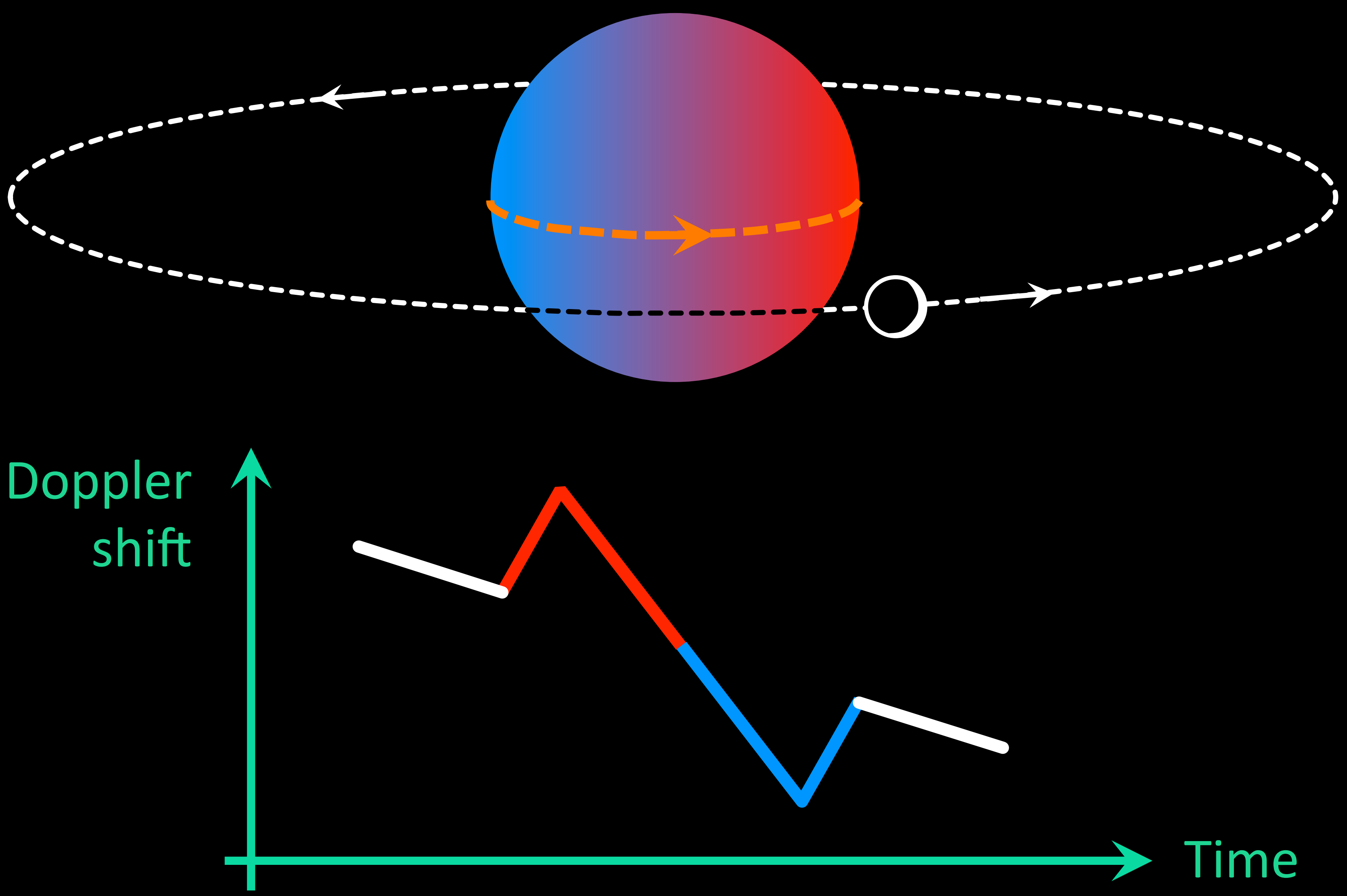
Dawson et al. (2012)



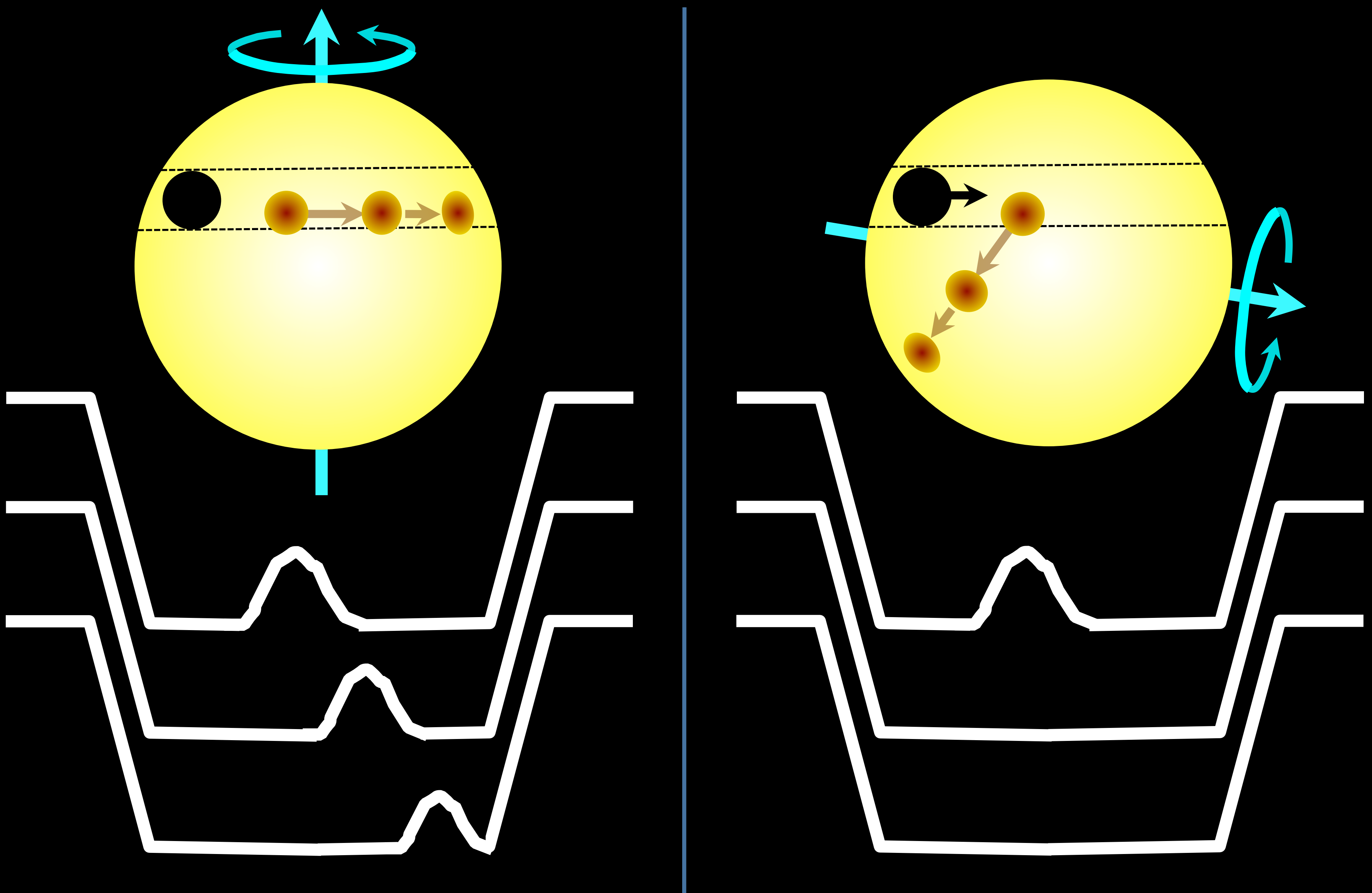
Stellar obliquity

- Sun’s obliquity is 7° — how typical is this?
- Whatever produces ***hot Jupiters*** may also perturb inclinations

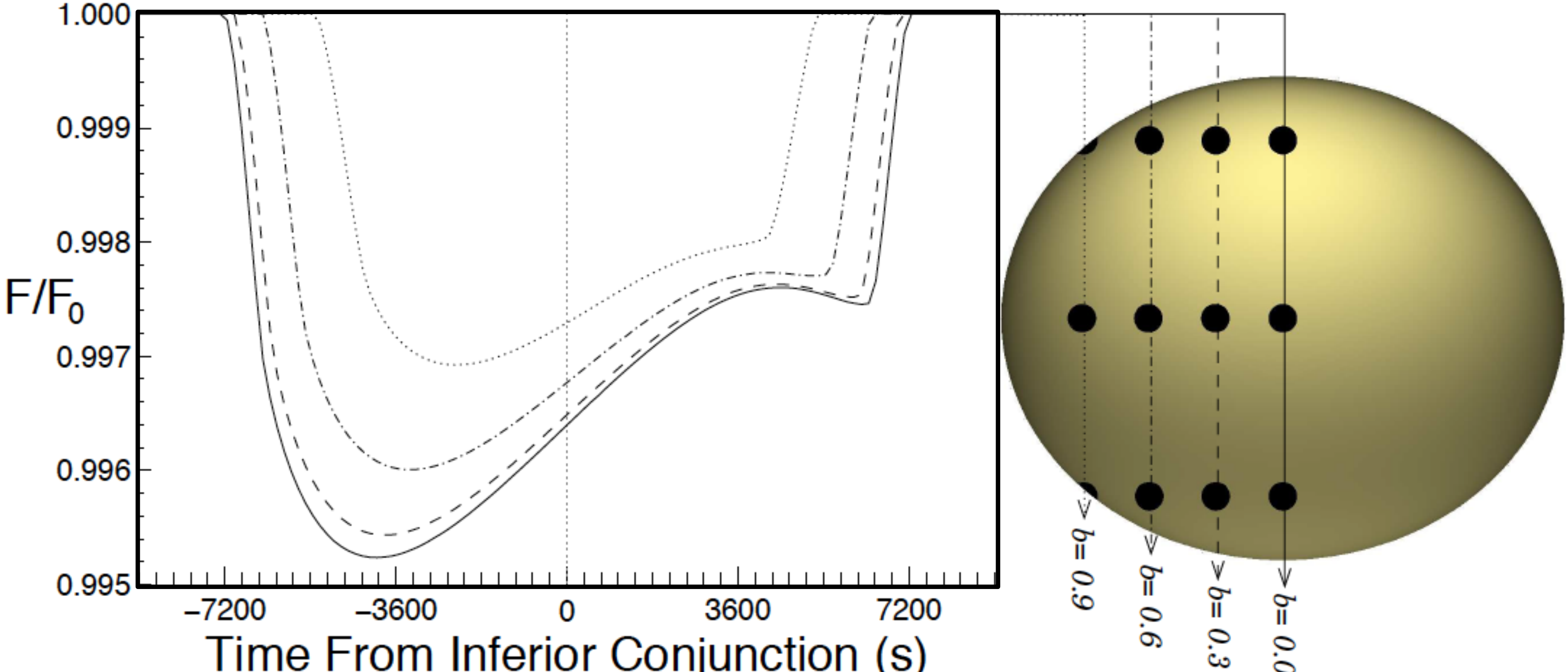
Rossiter-McLaughlin (RM) effect



Sanchis-Nutzman (SN) effect

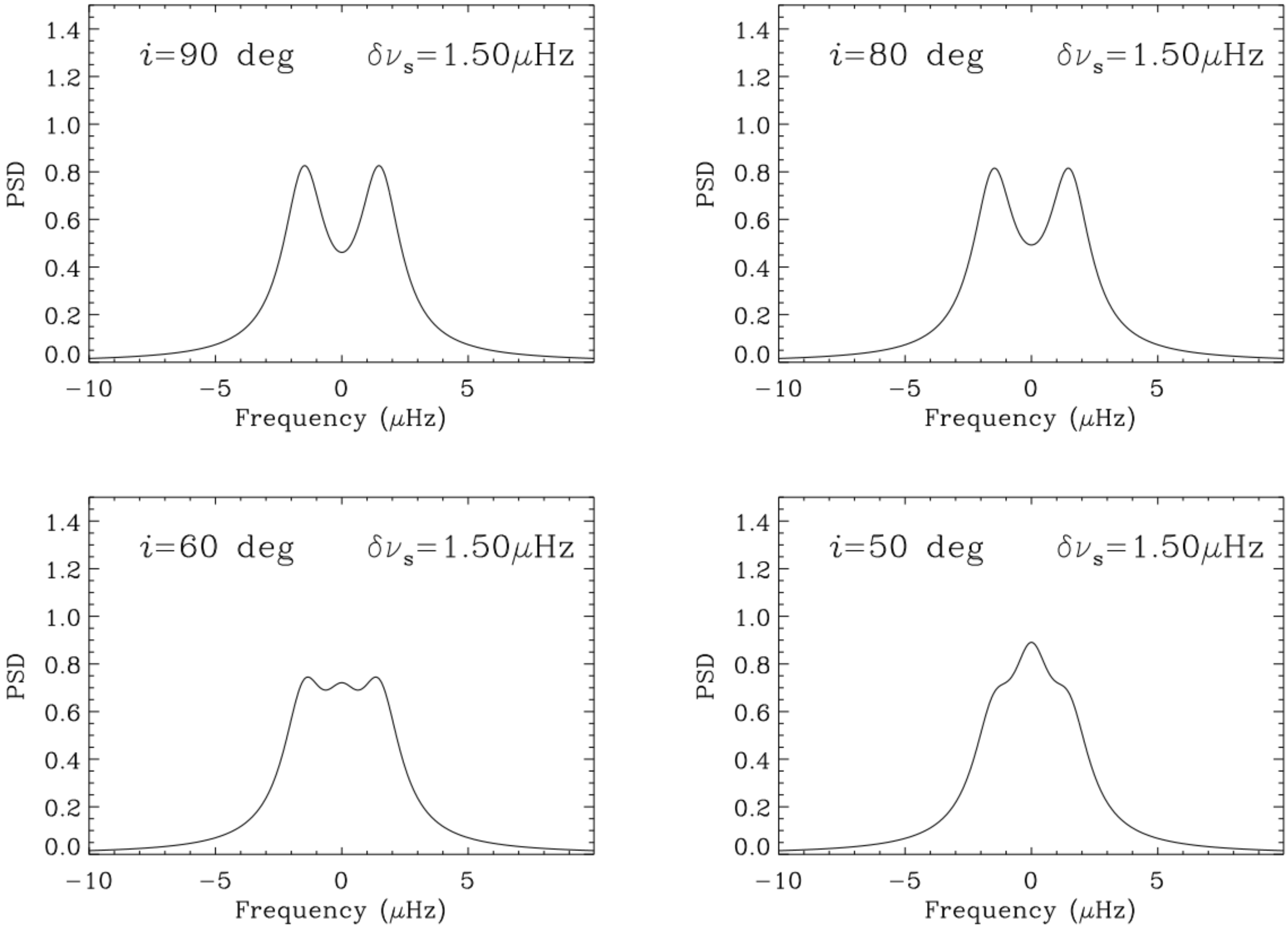


Barnes-Szábo (BSz) effect

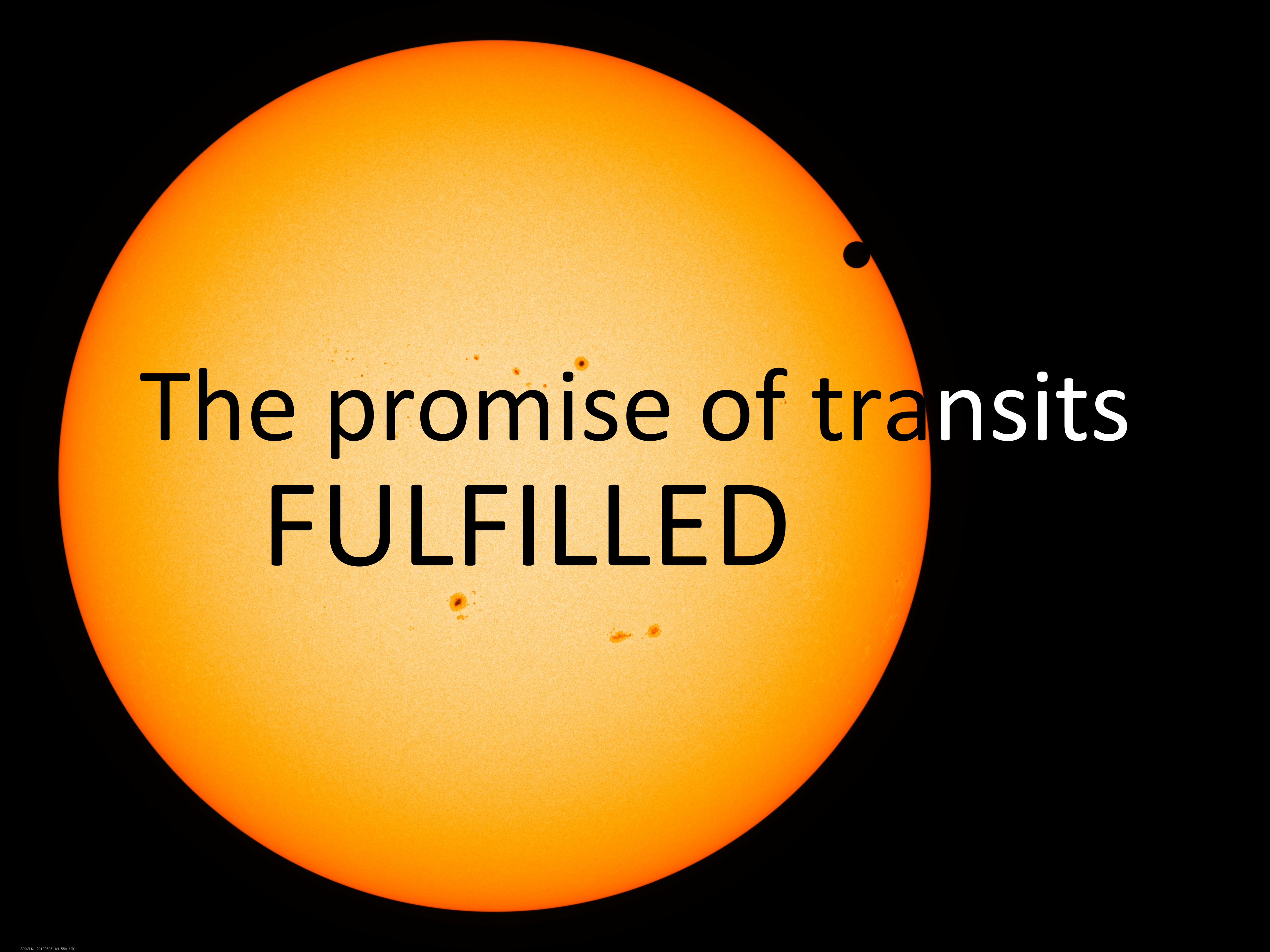


Barnes et al. (2011)

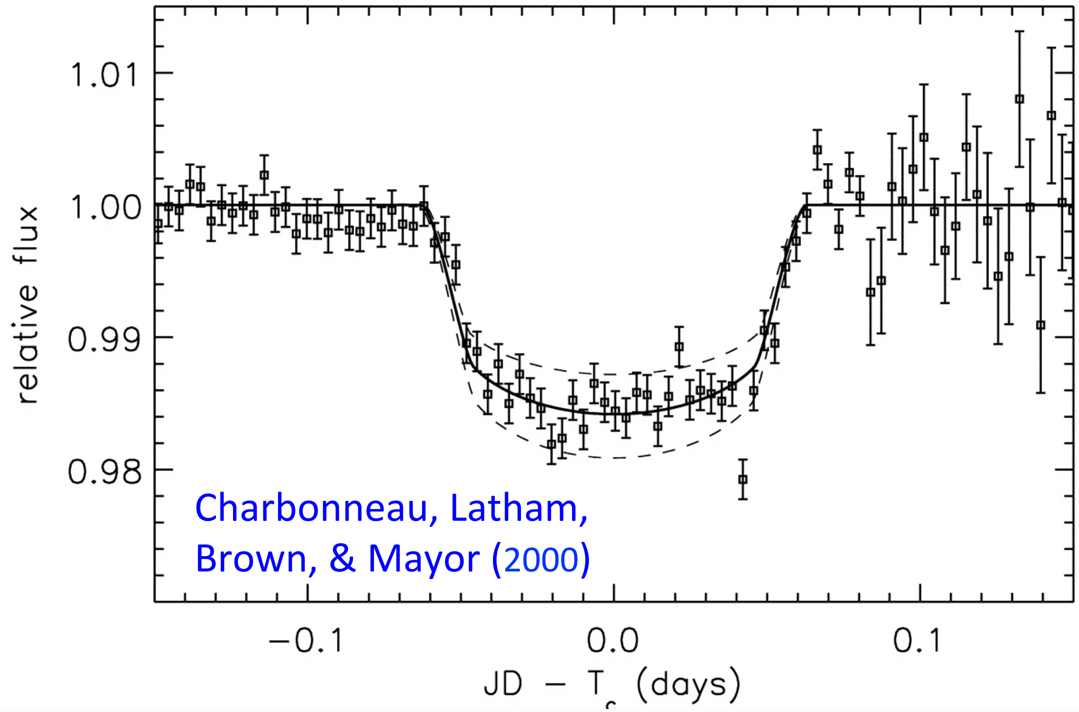
Gizon-Solanki (GS) effect

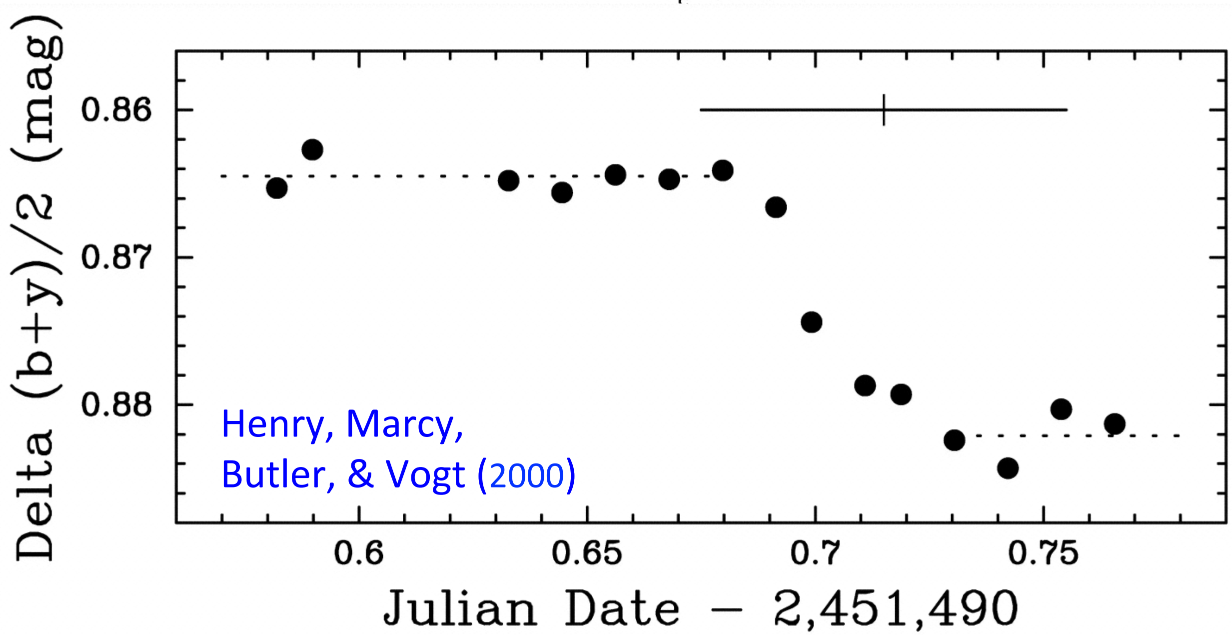


Chaplin et al. (in prep.); see also Gizon & Solanki (2003)


The promise of transits
FULFILLED

When was the first announcement of the detection of a planetary transit?


1.01
1.00
0.99
0.98
relative flux
−0.1
0.0
0.1
JD − T (days)
Charbonneau, Latham,
Brown, & Mayor (2000)

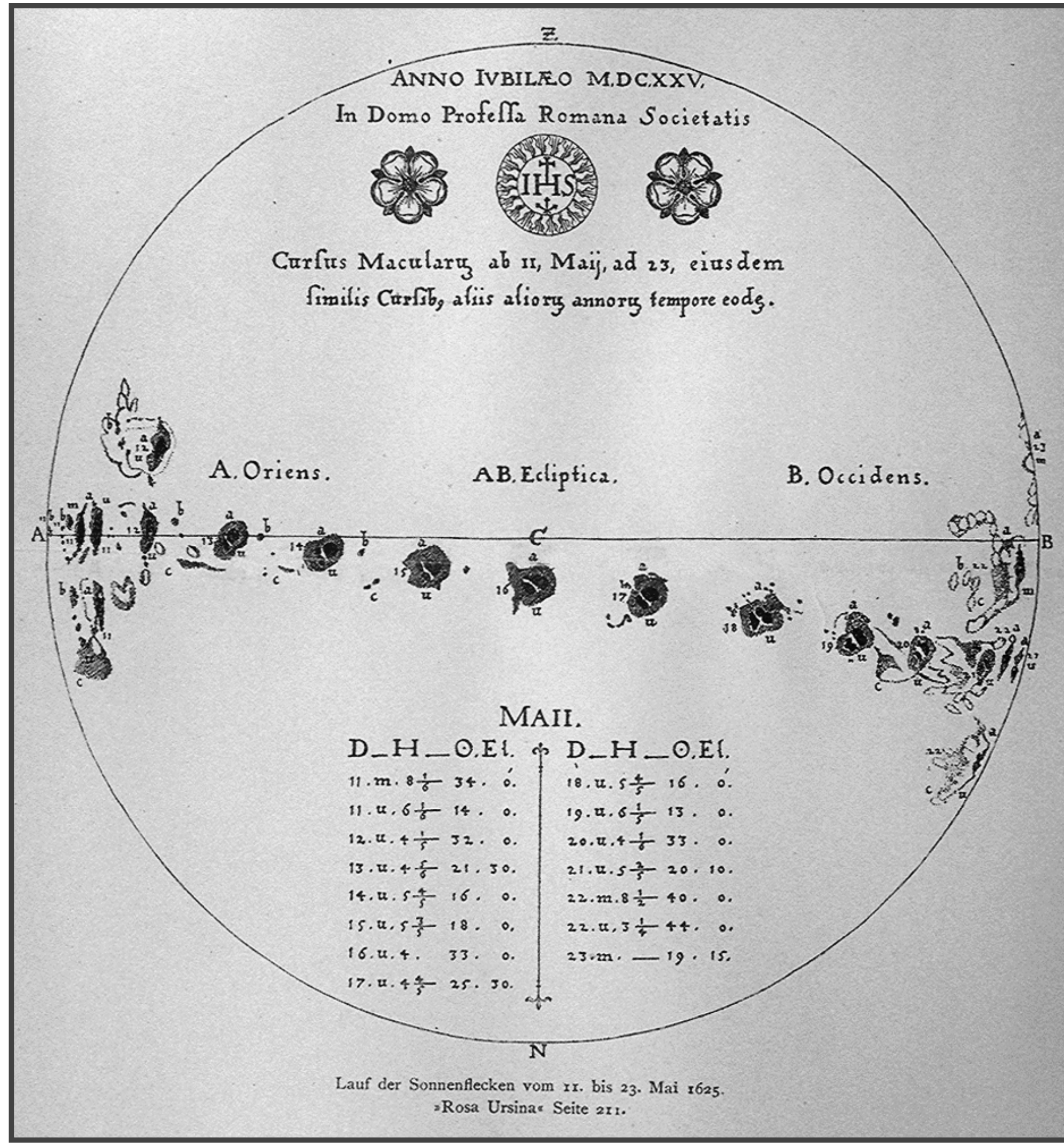

0.86
0.87
0.88
Delta (b+y)/2 (mag)
0.6
0.65
0.7
0.75
Julian Date − 2,451,490
Henry, Marcy,
Butler, & Vogt (2000)

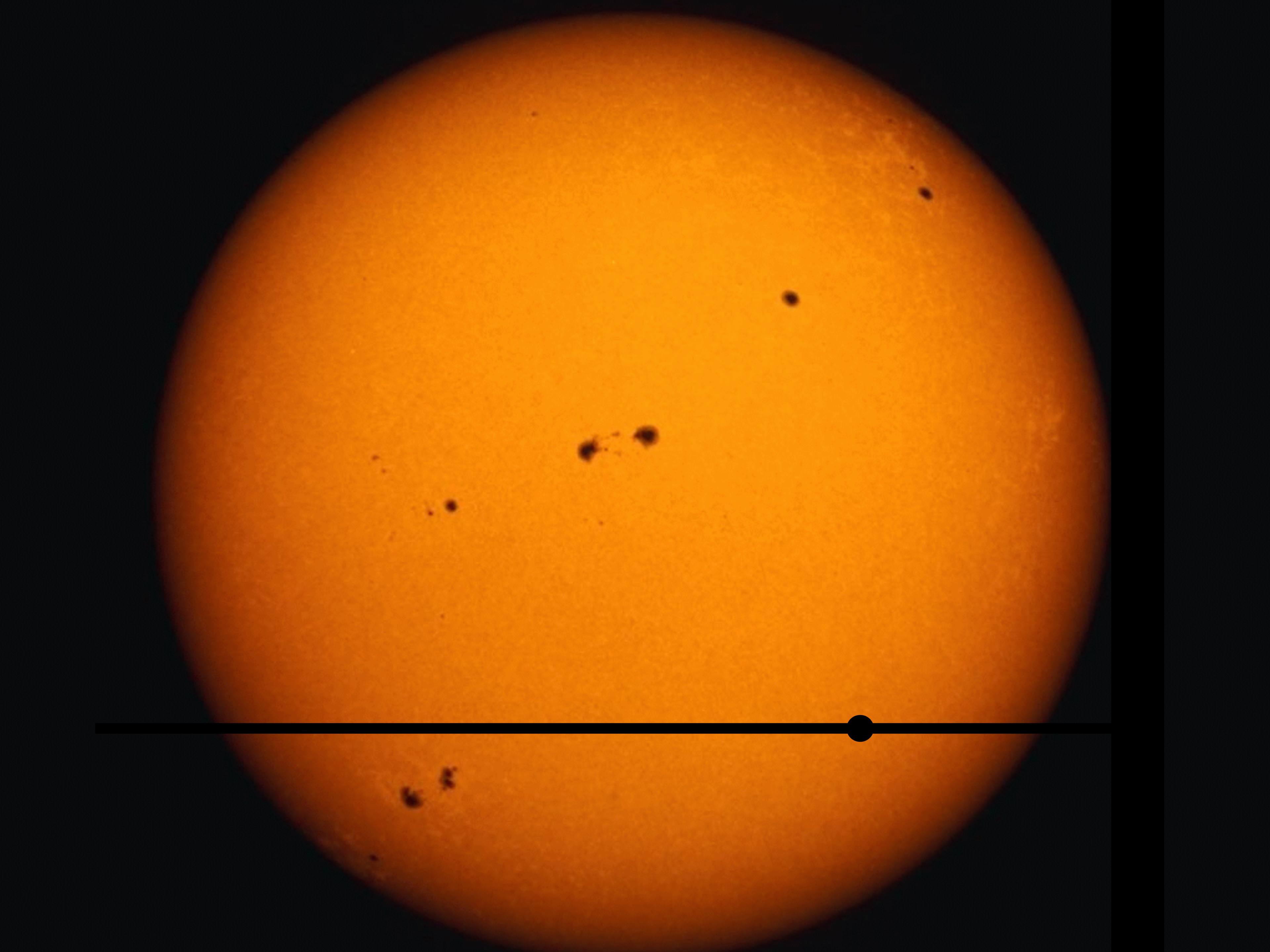
Jeremiah Horrocks (1639)

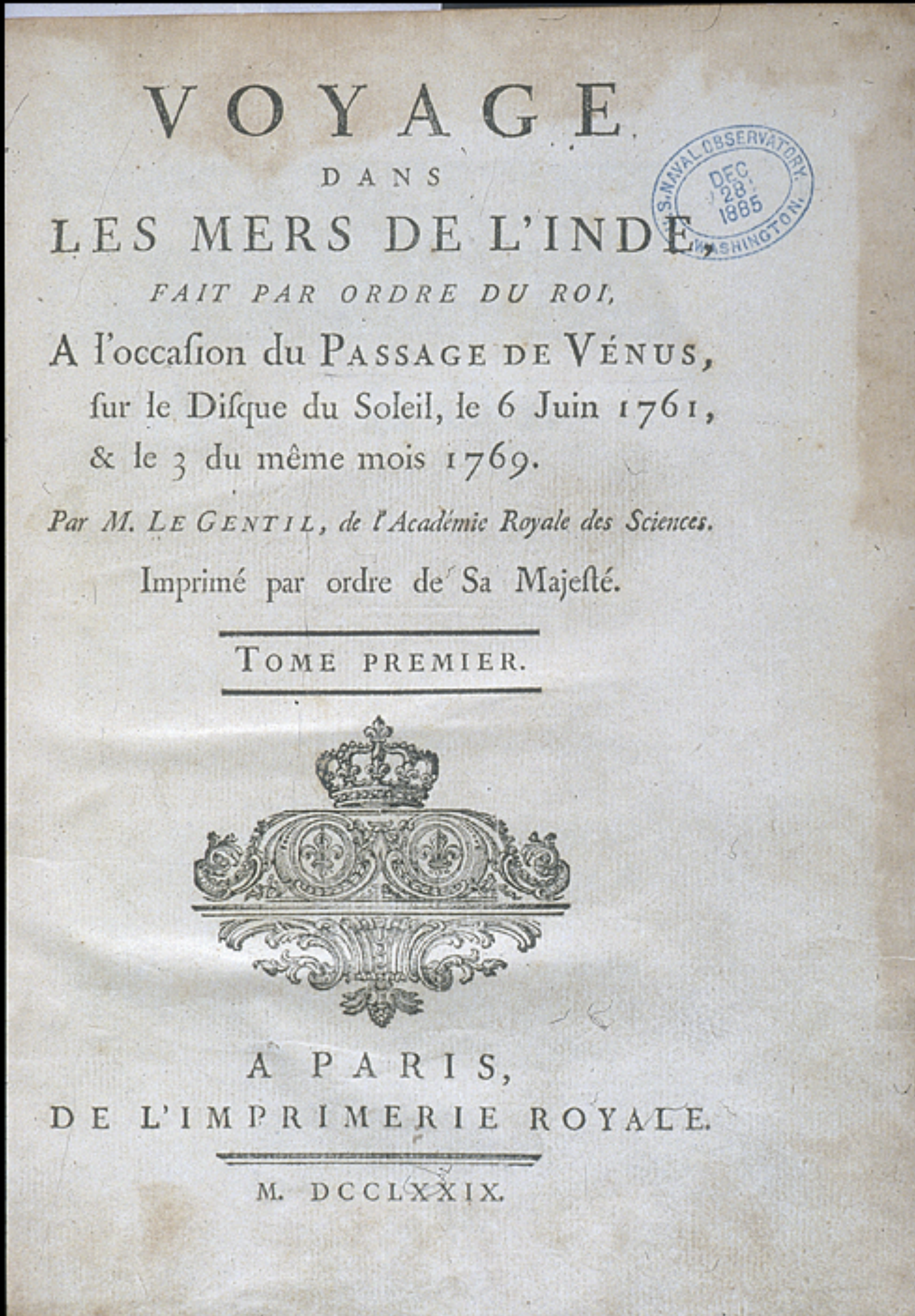
Christoph Scheiner (1611)

Christoph Scheiner (1611)

Rosa Ursina






VOYAGE
DANS
LES MERS DE L'INDE,
FAIT PAR ORDRE DU ROI,
A l'occaſion du PASSAGE DE VÉNUS,
ſur le Diſque du Soleil, le 6 Juin 1761,
& le 3 du même mois 1769.
Par M. LE GENTIL, de l'Académie Royale des Sciences.
Imprimé par ordre de Sa Majeſté.

TOME PREMIER.

A PARIS,
DE L'IMPRIMERIE ROYALE.

M. DCCLXXIX.

Guillaume Le Gentil

- Destination captured
- Waited 8 years
- Clouded out
- Contracted dysentery
- Shipwrecked
- Declared dead

John Goodricke

"A series of observations on, and a discovery of, the period of variation of the light of the Bright Star in the Head of Medusa, Called Algol," *Phil. Trans.*, 73, 474 (1783)

PROPOSAL FOR A PROJECT OF HIGH-PRECISION STELLAR RADIAL VELOCITY WORK

By Otto Struve

Berkeley Astronomical Department,
University of California.

The Observatory, 72, 199

1952 July 24.

There seems to be at present no way to discover objects of the mass and size of Jupiter; nor is there much hope that we could discover objects ten times as large in mass as Jupiter, if they are at distances of one or more astronomical units from their parent stars.

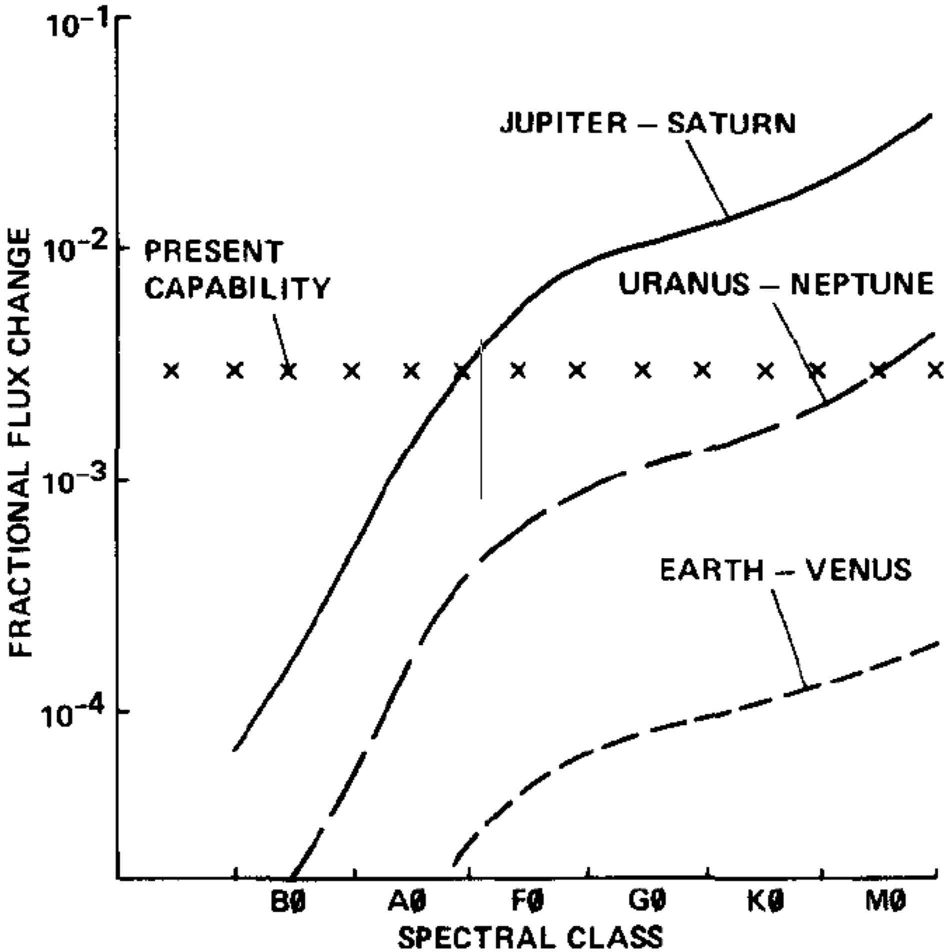
But there seems to be no compelling reason why the hypothetical stellar planets should not, in some instances, be much closer to their parent stars than is the case in the solar system.

...it should be possible, without much difficulty, to discover planets of 10 times the mass of Jupiter by the Doppler effect.

There would, of course, also be eclipses.

Modern history of transits

- Borucki & Summers (1984) – survey design



Modern history of transits

- Borucki & Summers (1984) – survey design
- Mayor & Queloz (1995) – hot Jupiters

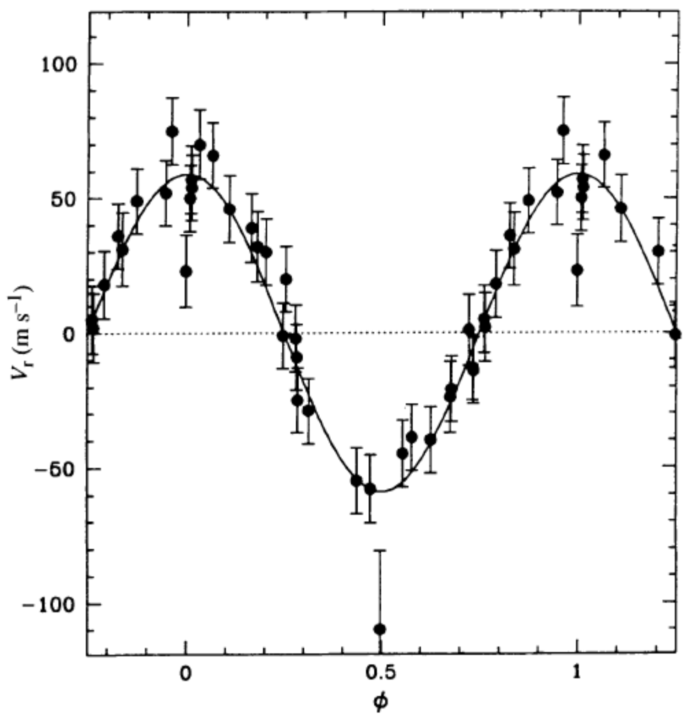
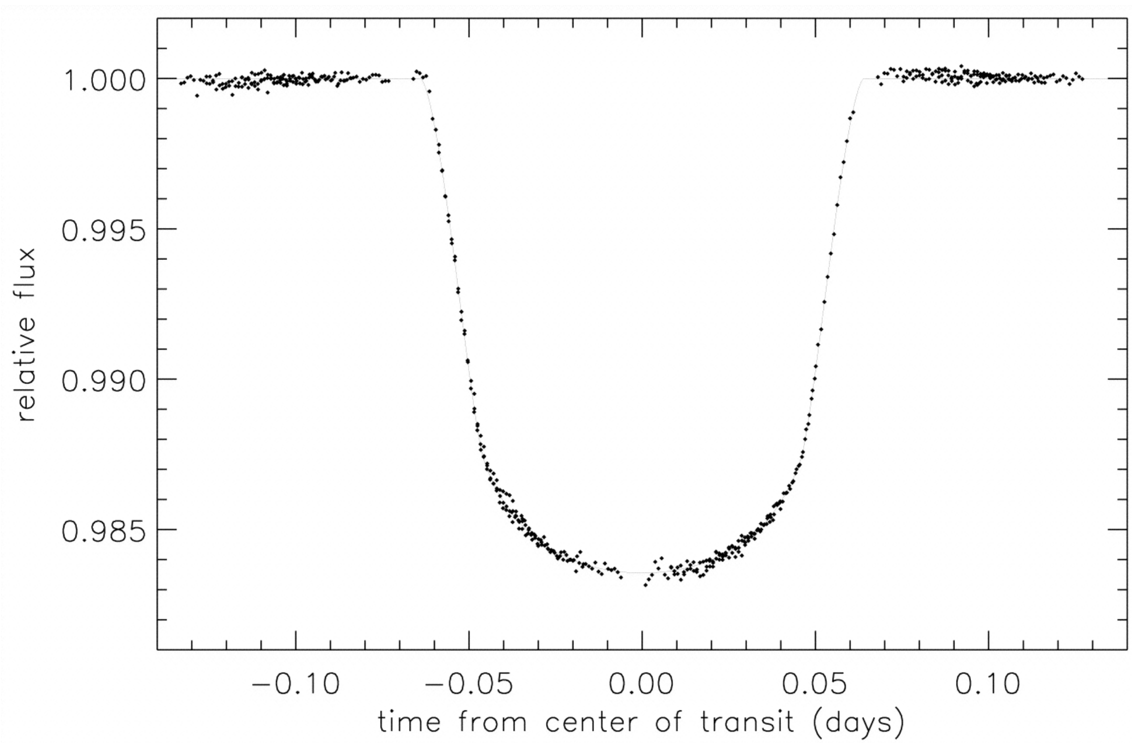


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.

Modern history of transits

- Borucki & Summers (1984) – survey design
- Mayor & Queloz (1995) – hot Jupiters
- Charbonneau+ (2000), Henry+ (2000), Brown+ (2001)



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- Konacki et al. (2003) – Discovery via transit
- Alonso et al. (2004) – Wide-field survey

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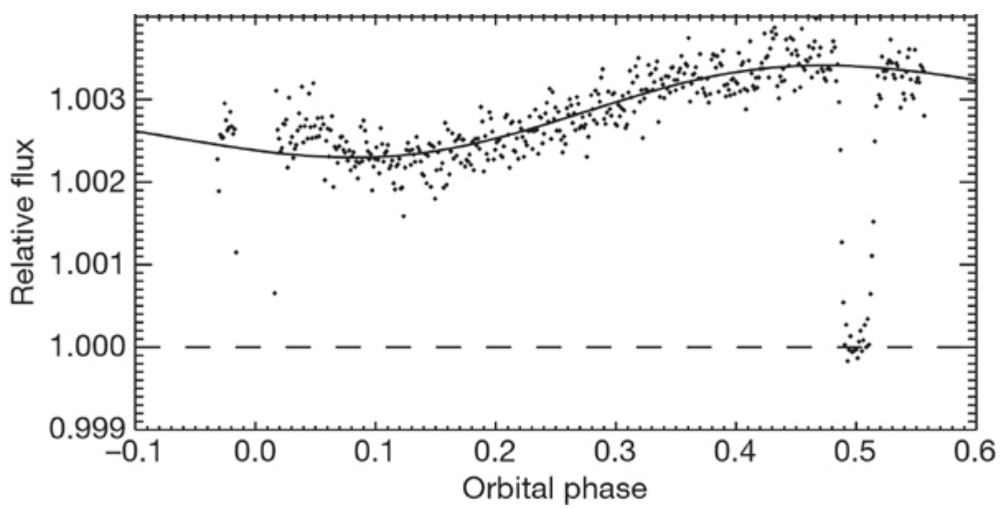
- Knutson et al. (2007) – Phase curve



Modern history of transits

- Borucki & Summers (1984) – survey design
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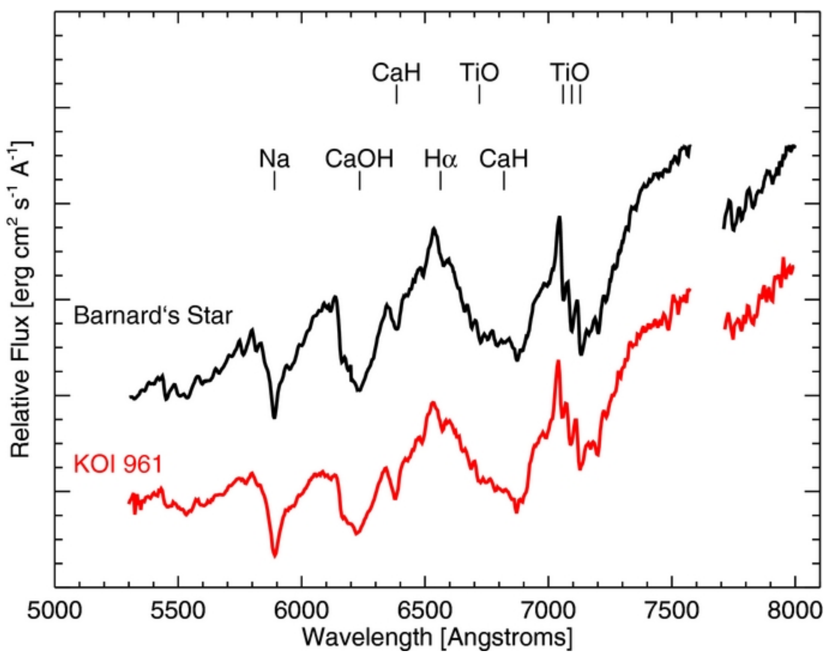
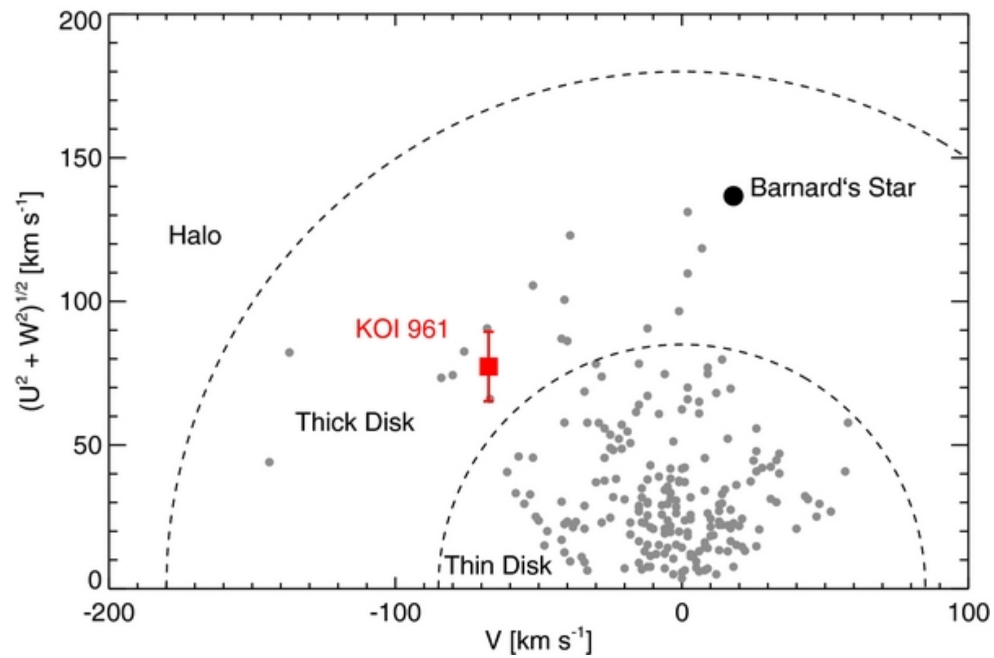
- Charbonneau+ (2000), Henry+ (2000), Brown+ (2001)
- Konacki et al. (2003) – Discovery via transit
- Alonso et al. (2004) – Wide-field survey
- Knutson et al. (2007) – Phase curve
- Barge et al. (2008) – first *Corot* results
- Léger et al., Charbonneau et al (2009) – super-Earths
- Borucki et al. (2010) – first *Kepler* results

Characterizing the cool KOIs.
III. KOI 961: A small star with large proper motion and three small planets

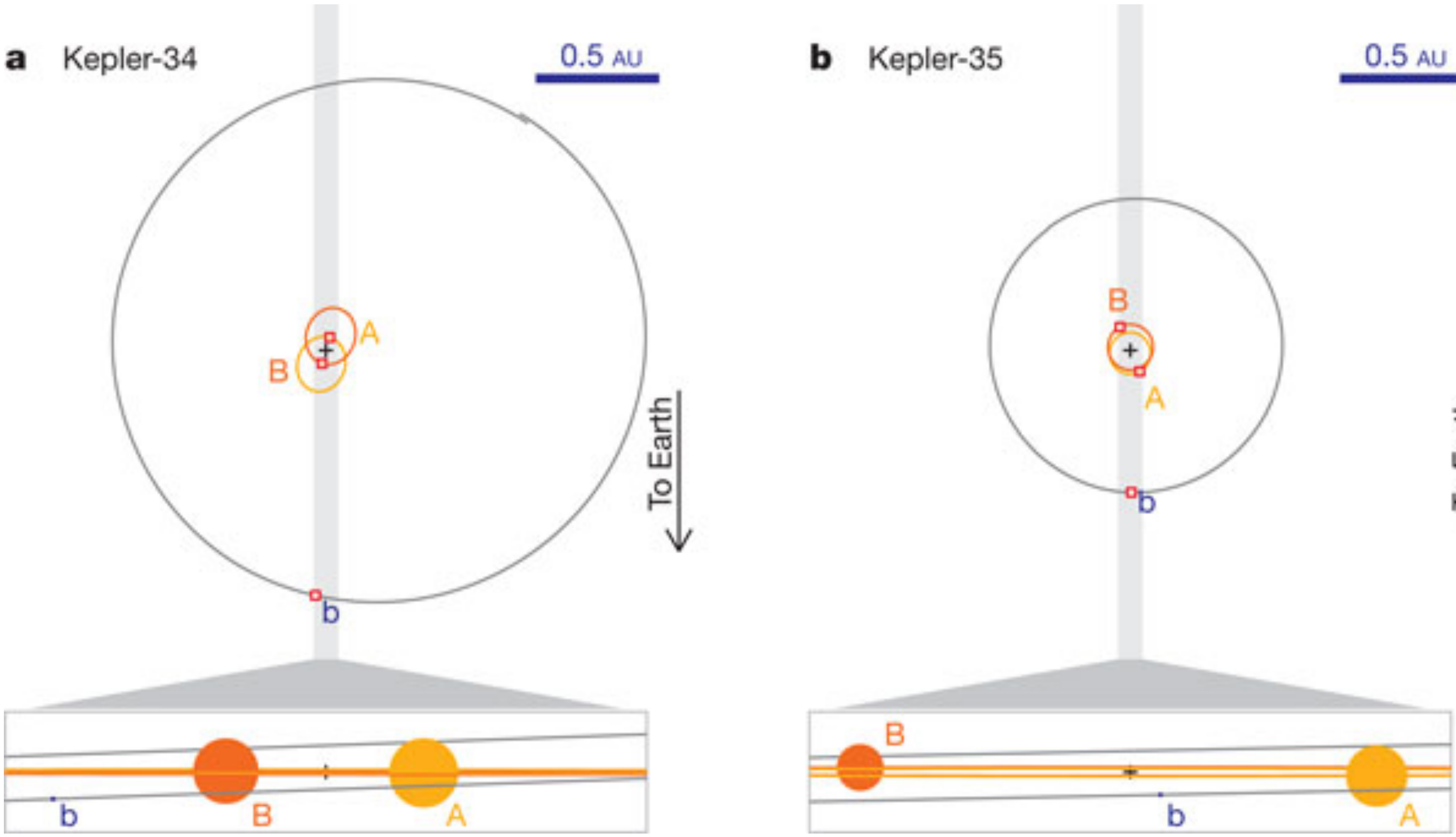




KOI	Period (days)	R_P ($R_\oplus$)
961.01	$1.2137672 \pm 4.6 \times 10^{-6}$	0.78 ± 0.22
961.02	$0.45328509 \pm 9.7 \times 10^{-7}$	0.73 ± 0.20
961.03	$1.865169 \pm 1.4 \times 10^{-5}$	0.57 ± 0.18

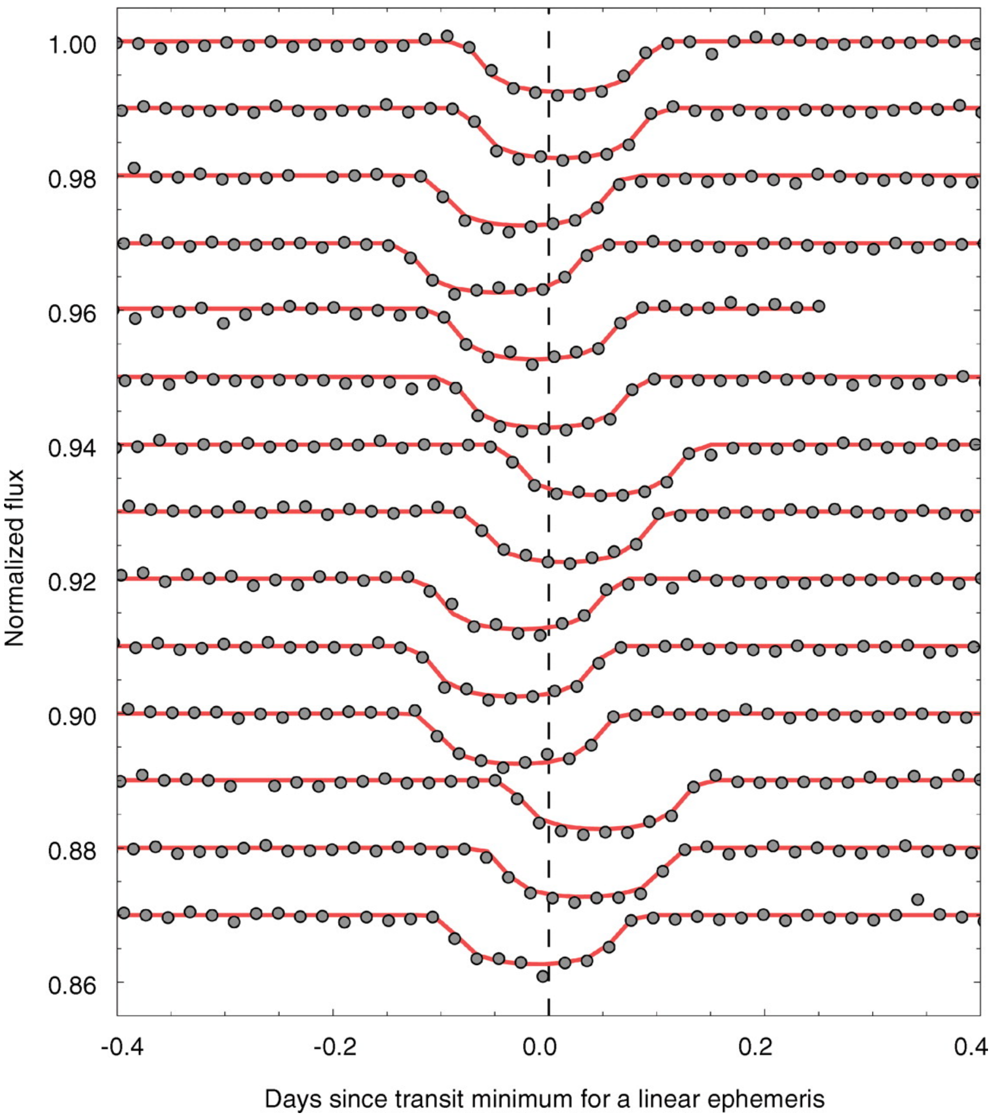
Muirhead et al. (2012)

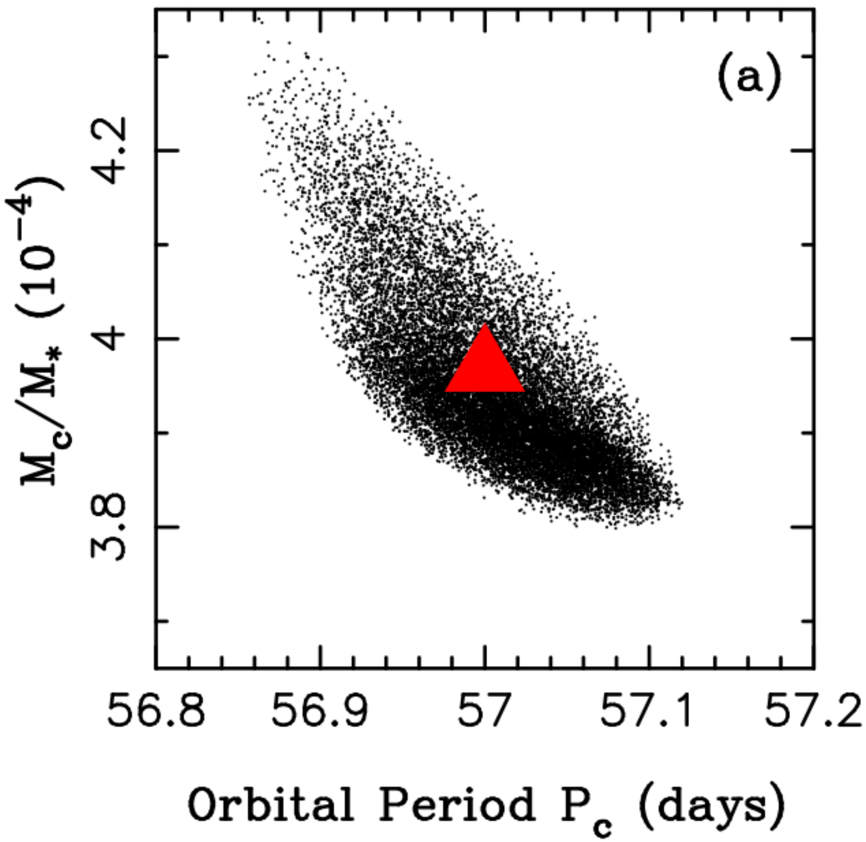
Transiting circumbinary planets Kepler-34 b and Kepler-35 b



Welsh et al. (2012)

The detection and characterization of a nontransiting planet by transit timing variations





Nesvorny et al. (2012)
see also Ballard et al. (2011)

An abundance of small exoplanets around stars with a wide range of metallicities

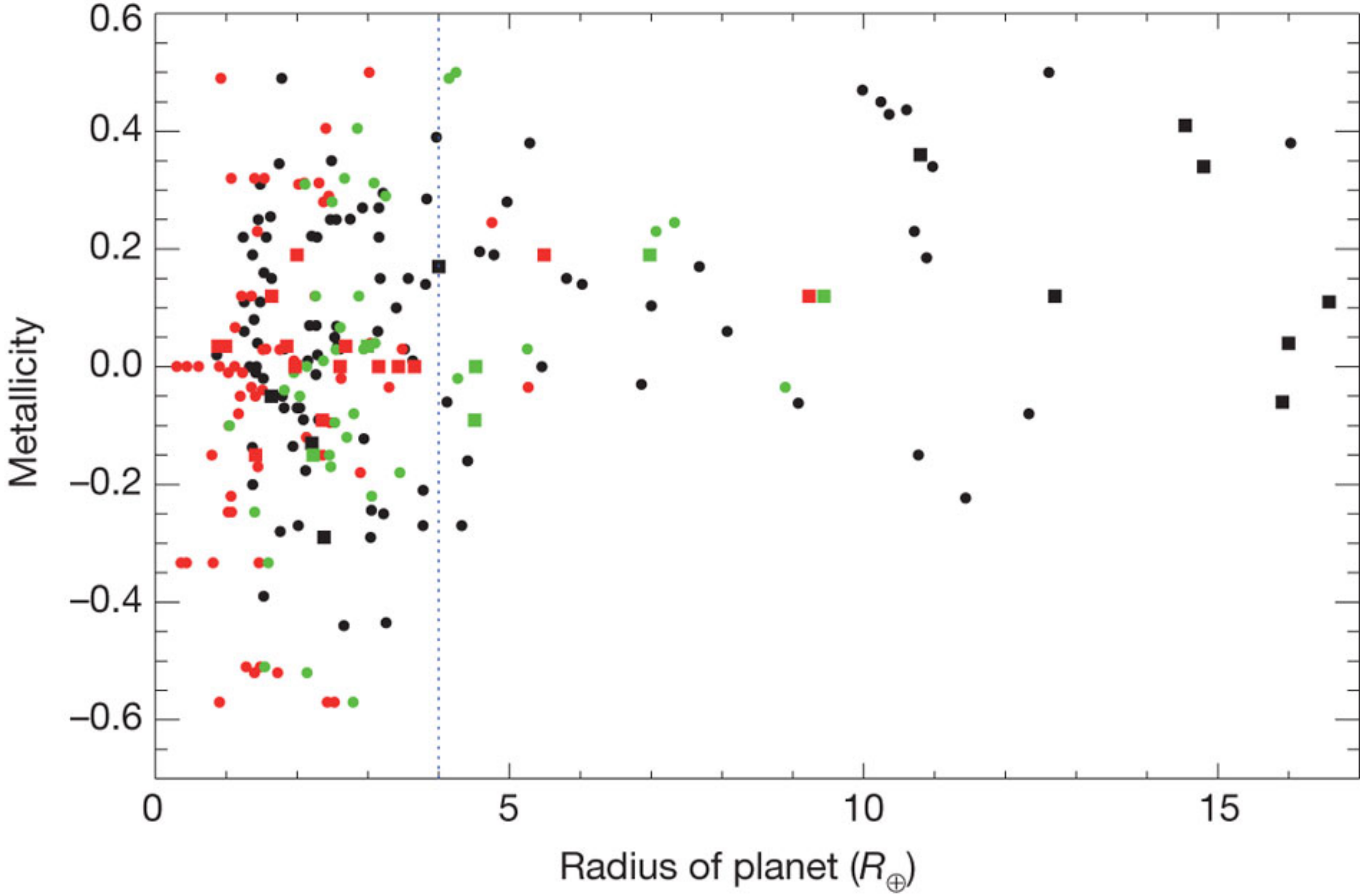


Figure 3 | Individual host-star metallicity as a function of planet radius. The black dots represent single-planet systems, whereas the green dots represent the largest planet and the red dots represent all the smaller planets in multiple-planet systems. The confirmed, published Kepler planets in our samples are plotted as squares with the same colour code as the dots.

Buchhave et al. (2012)

Rapid dynamical chaos in an exoplanetary system

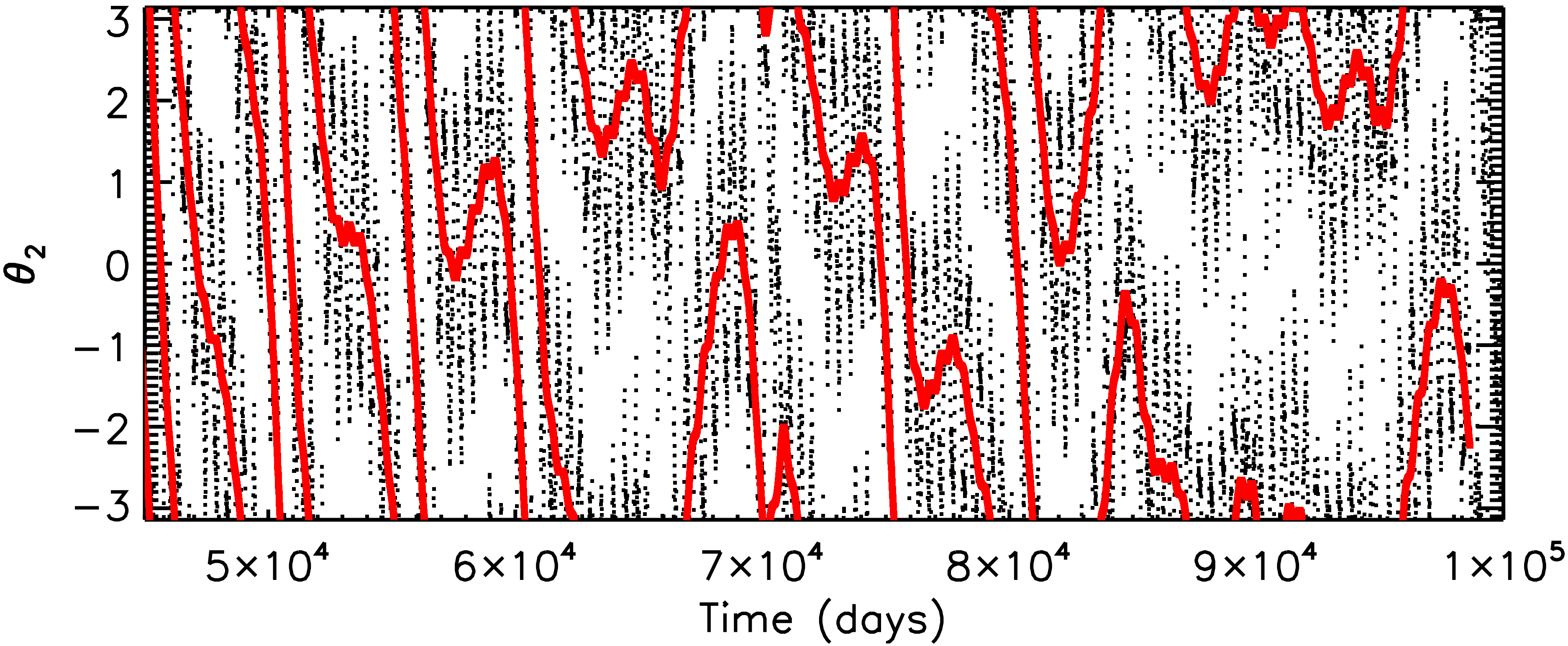
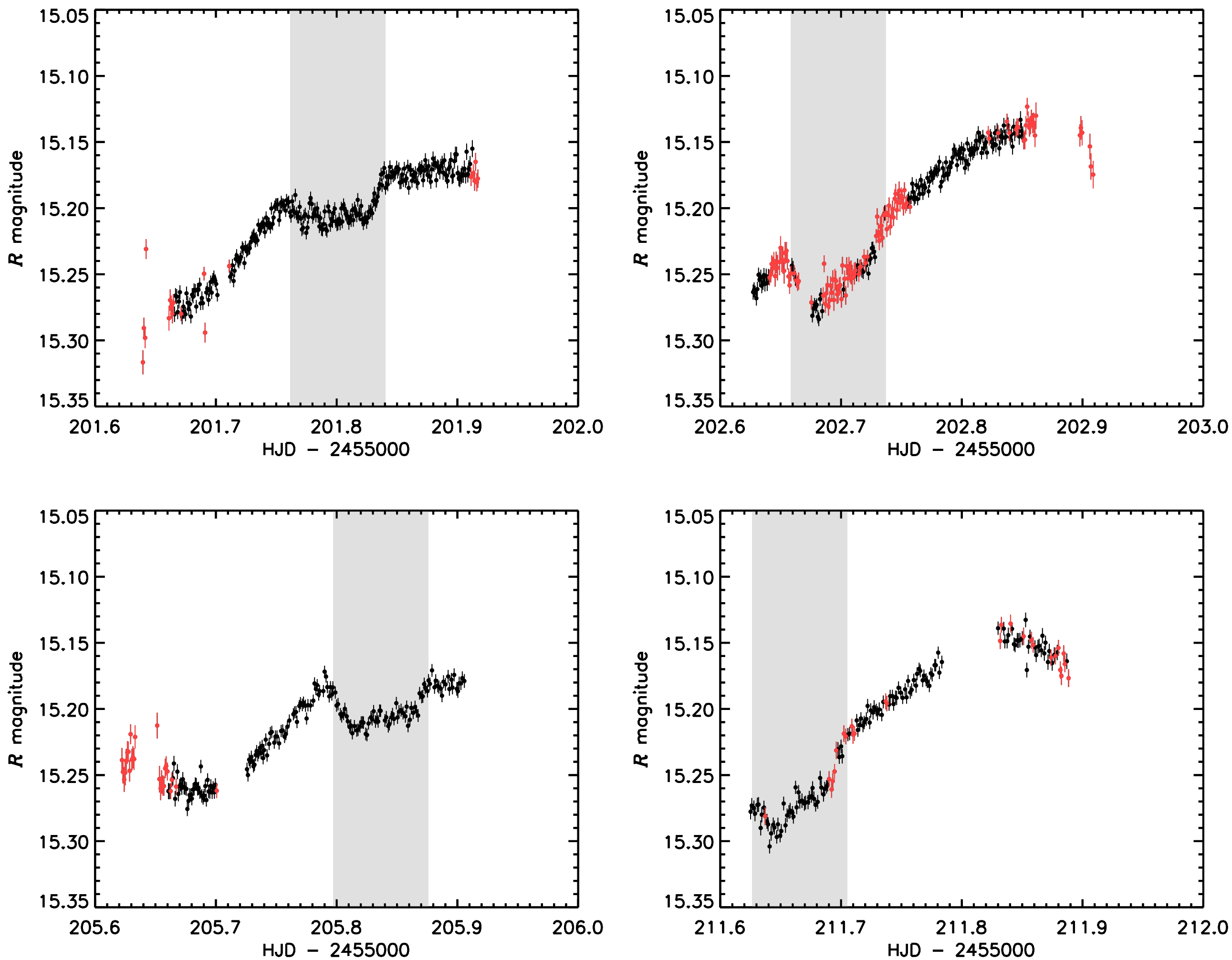


FIG. 2.— Chaotic evolution of the resonant angles $\theta_1 = 34\lambda_c - 29\lambda_b - 5\varpi_b$ and $\theta_2 = 34\lambda_c - 29\lambda_b - 5\varpi_c$ for a randomly chosen trajectory from the long lived region. The red overlaid points show a smoothed version of the black points to guide the eye.

Deck et al. (2012)

The PTF Orion Project:
A possible planet transiting a T-Tauri star



Van Eyken et al. (2012)

Gold mine

Gold mine – or gold rush?

"Every new field has its little run of luck, and the exoplanet game is going to be tougher at *<prestigious journal>* now that that's over."

— astronomy editor of *<prestigious journal>*

Reasons for optimism

- It always seems “too late”
- The peak is probably broad
- Both contenders for the next NASA Explorer mission are transit missions (TESS and FINESSE)
- *Spitzer*: hot Jupiters :: *JWST* : small planets

SDO/HMI 20120606_041559_UTC

Reasons for optimism

Our most fundamental and precise knowledge of *stars* comes from eclipsing systems, even after more than a century since eclipses were first observed. The same is likely to be true for exoplanets.

SDO/HMI 20120606_041559_UTC