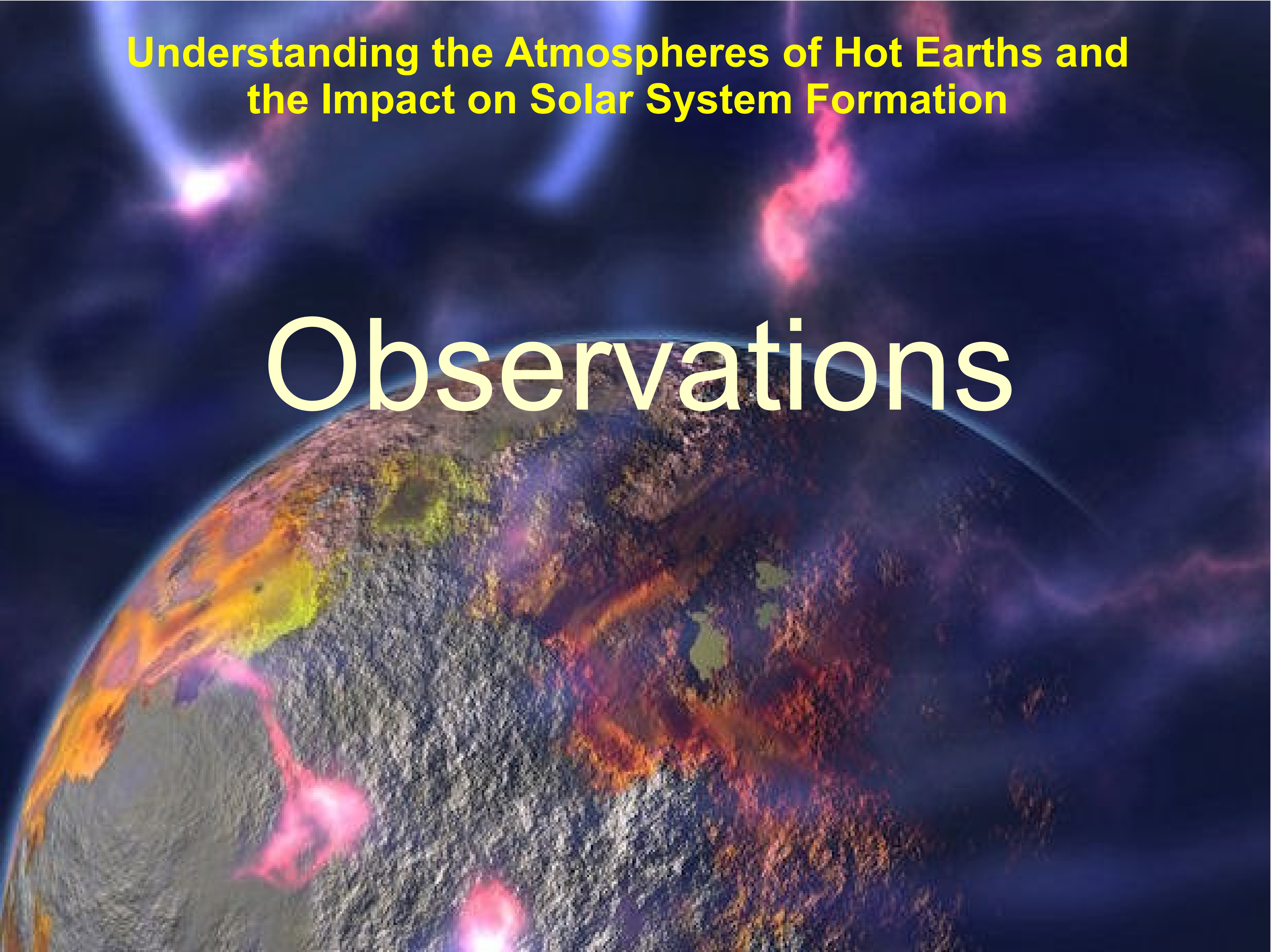
# Understanding the Atmospheres of Hot Earths and the Impact on Solar System Formation



## Observations

# Welcome

Thanks to Nate for organizing this!

Thanks to NASA-Glenn for hosting us, again.

# Exoplanet Overview

## And Progress Report of our Observational Efforts

# Outline:

1) What has been found-
    - i) Planets
    - ii) Characterization Techniques
    - iii) Properties of planets.

2) What our strategy is-
    - i) Observing
    - ii) Image processing
    - Iii) Current results

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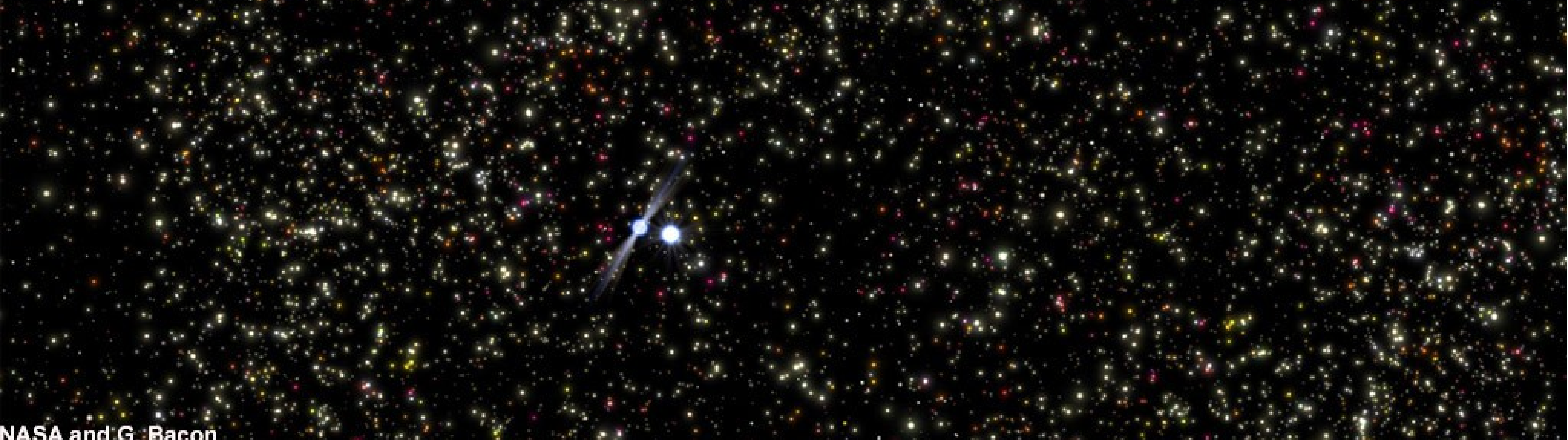
# A little history

The first extrasolar planet detected was published in 1992: Wolszczan & Frail detected two planets of 2.8 and 3.4 Earth masses (the first superEarths!) orbiting a pulsar.

This system now has 3 planets (4 possibly) with the smallest having $0.02M_{Earth}$

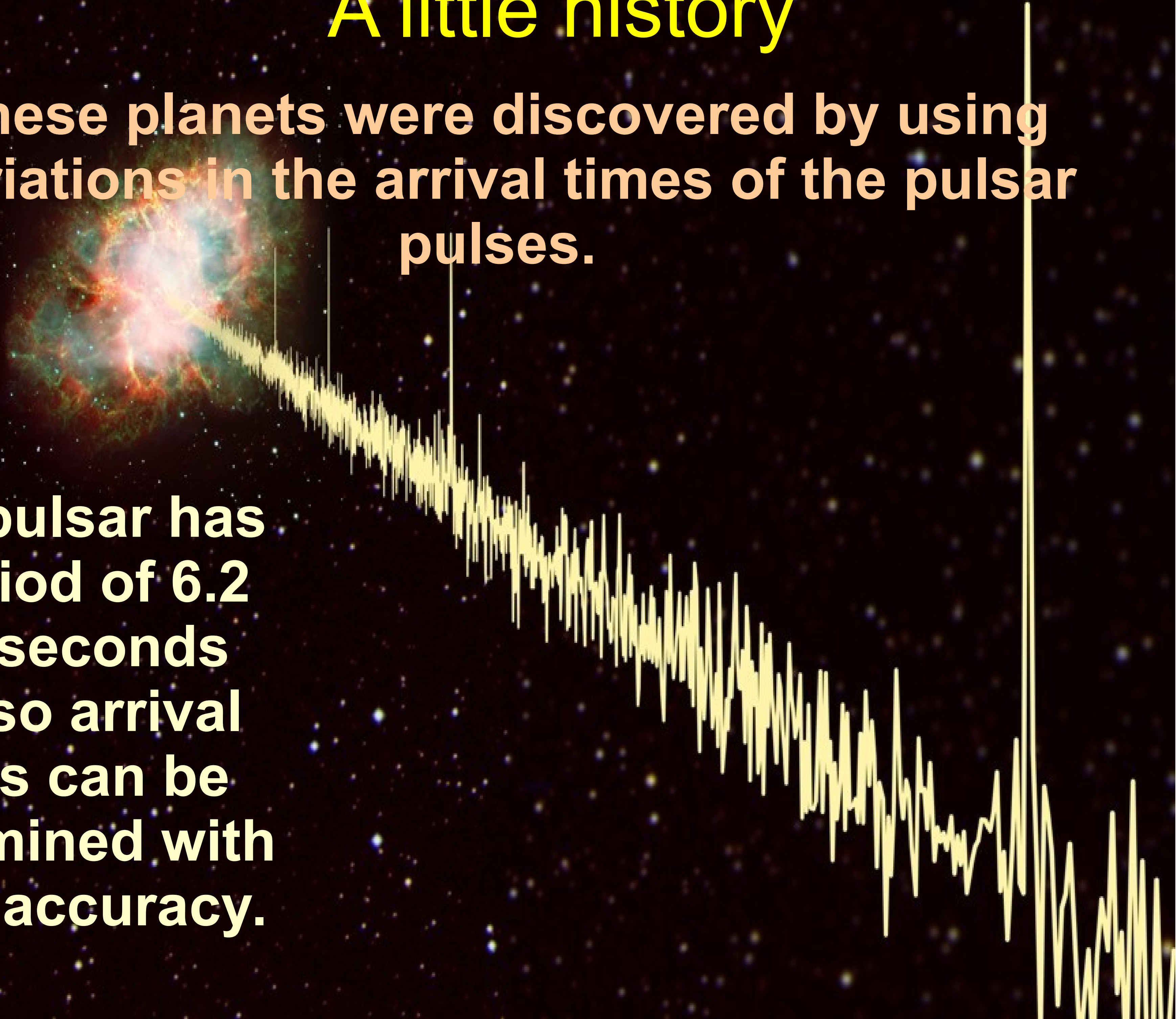
That's 1.8 Lunar masses!



NASA and G. Bacon

# A little history

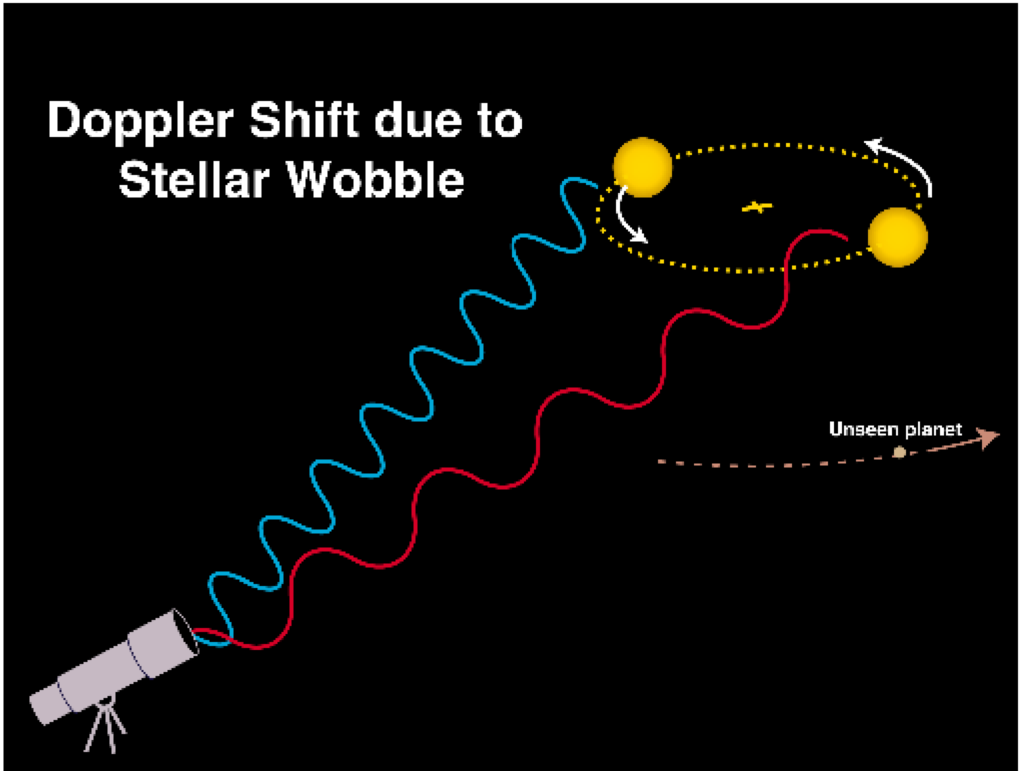
These planets were discovered by using variations in the arrival times of the pulsar pulses.

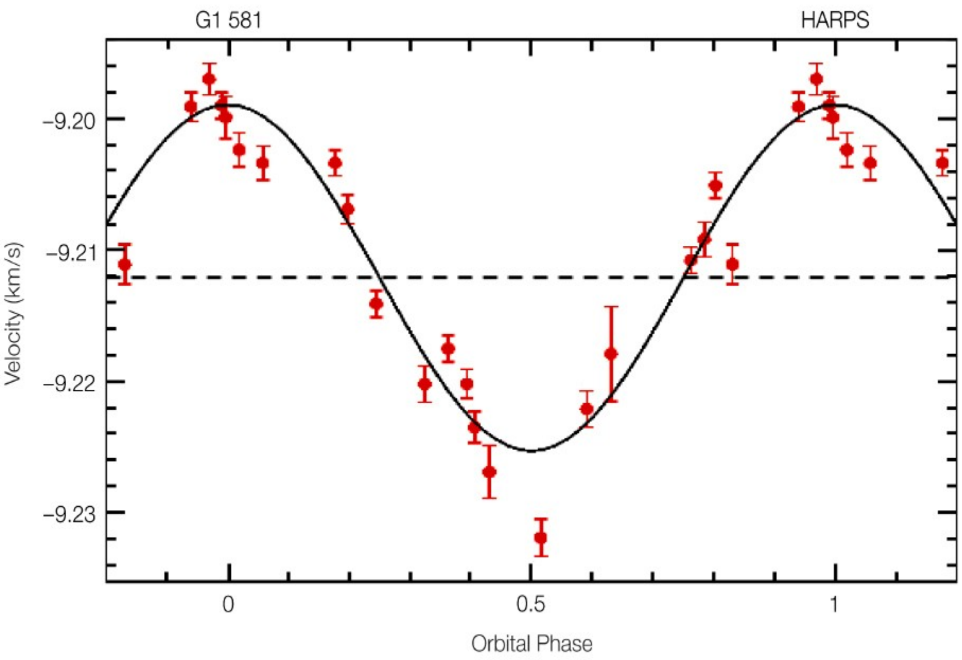


This pulsar has a period of 6.2 milliseconds and so arrival times can be determined with great accuracy.

The first extrasolar planet around a 'normal' (main-sequence) star was discovered in 1995 by Swiss astronomers.

The planet has $M=0.5M_{Jupiter}$ and orbits in 4.2 days. It was discovered via Doppler shifts in the host star's spectrum- the RV method





# The RV method used a new technique of observing through an iodine cell.

BUT... this method only works for bright stars and is biased towards massive planets in short orbits at low inclinations, which produce the highest velocities.

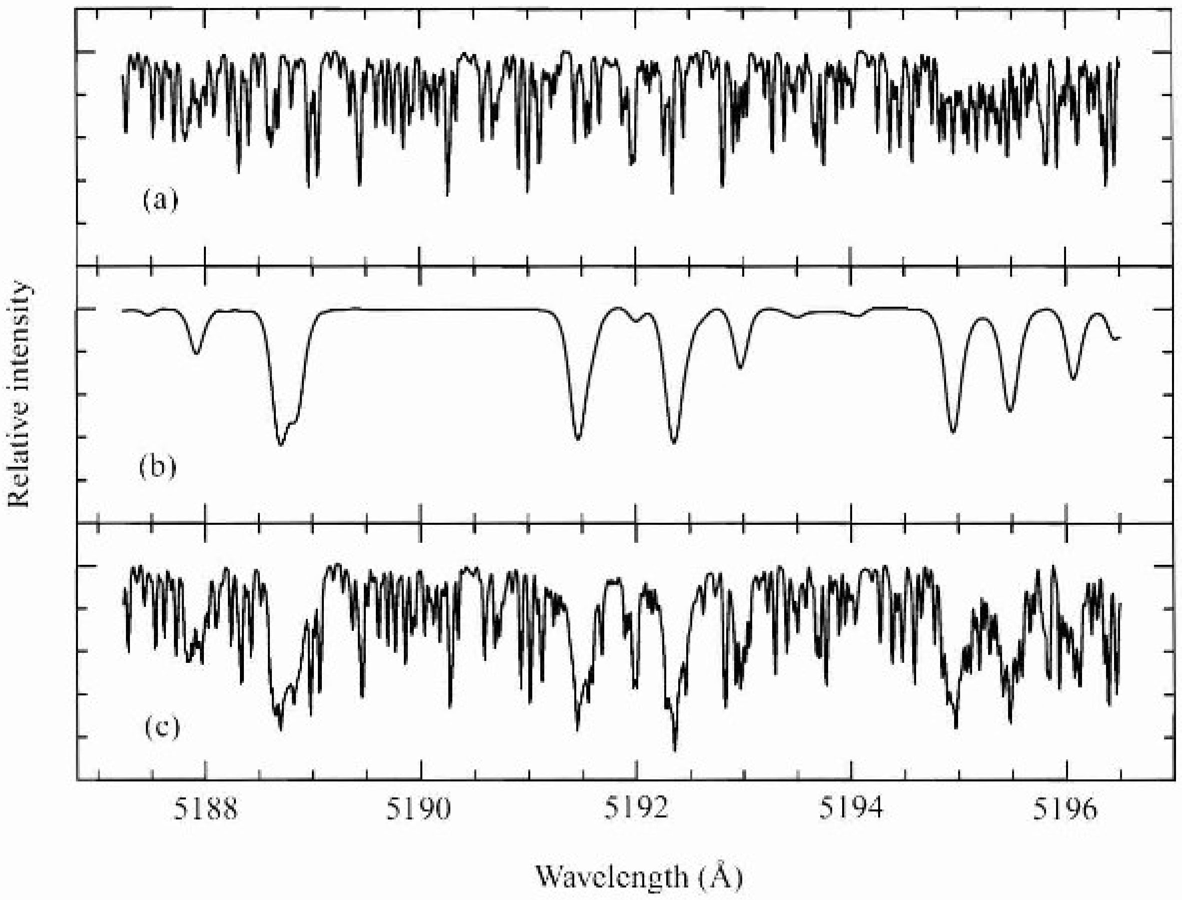


**Figure 13.3.** Illustration of high-precision Doppler measurements with an iodine cell. (a) Iodine cell absorption spectrum. (b) Spectrum of Procyon. (c) Spectrum of Procyon with the iodine cell in front of the spectrograph slit. The relative Doppler shift between the iodine and star spectra is determined by fitting the spectra from (a) and (b) to the combined spectrum. Figure courtesy William D. Cochran.

And this was largely the state of things for the next 15 years.

About 300 planets were discovered.

Improvements in the RV method detected planets down to about 8 Earth masses in very short orbits of a day or so.

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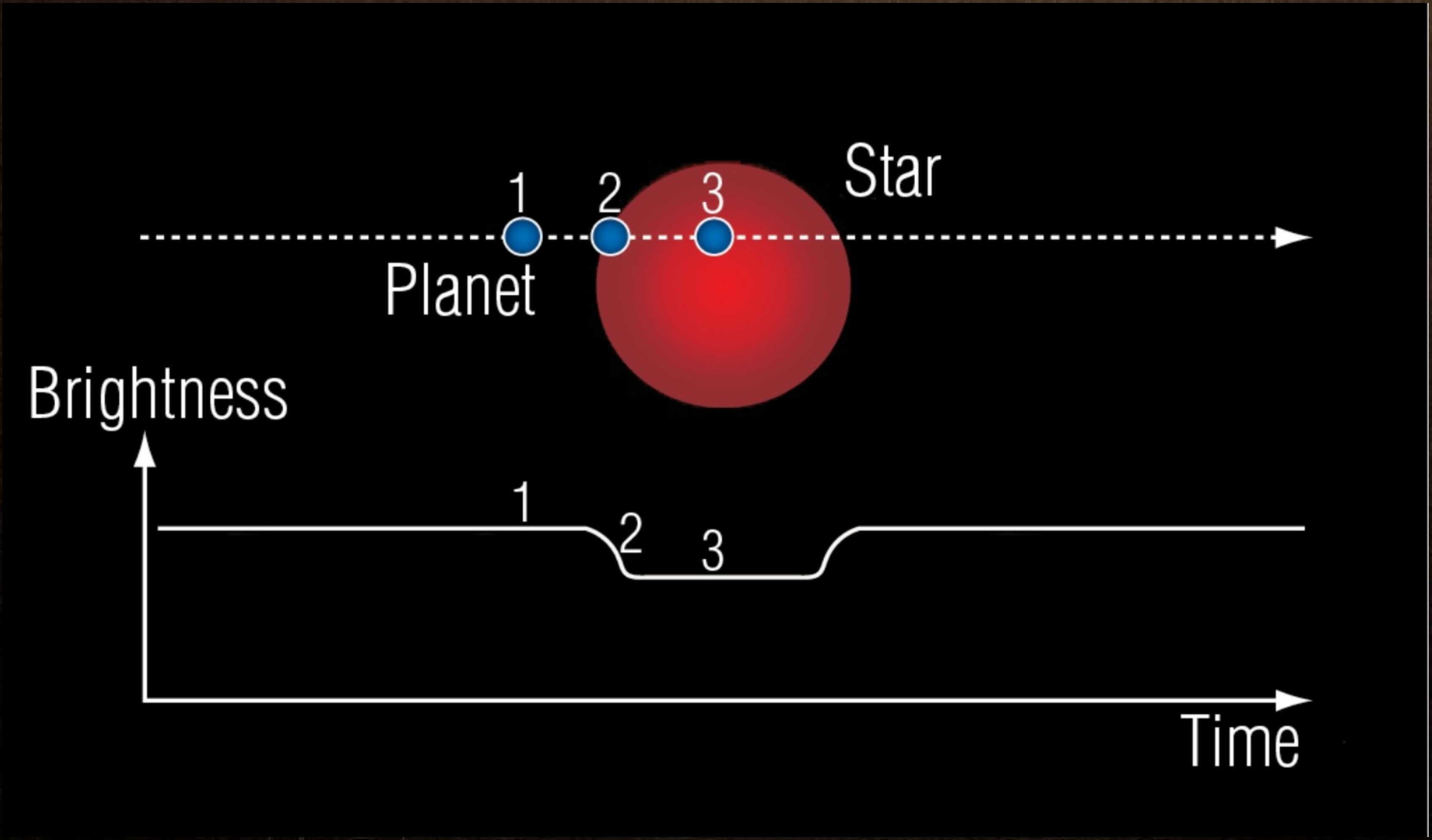
About 300 planets were discovered.

Improvements in the RV method detected planets down to about 8 Earth masses in very short orbits of a day or so.

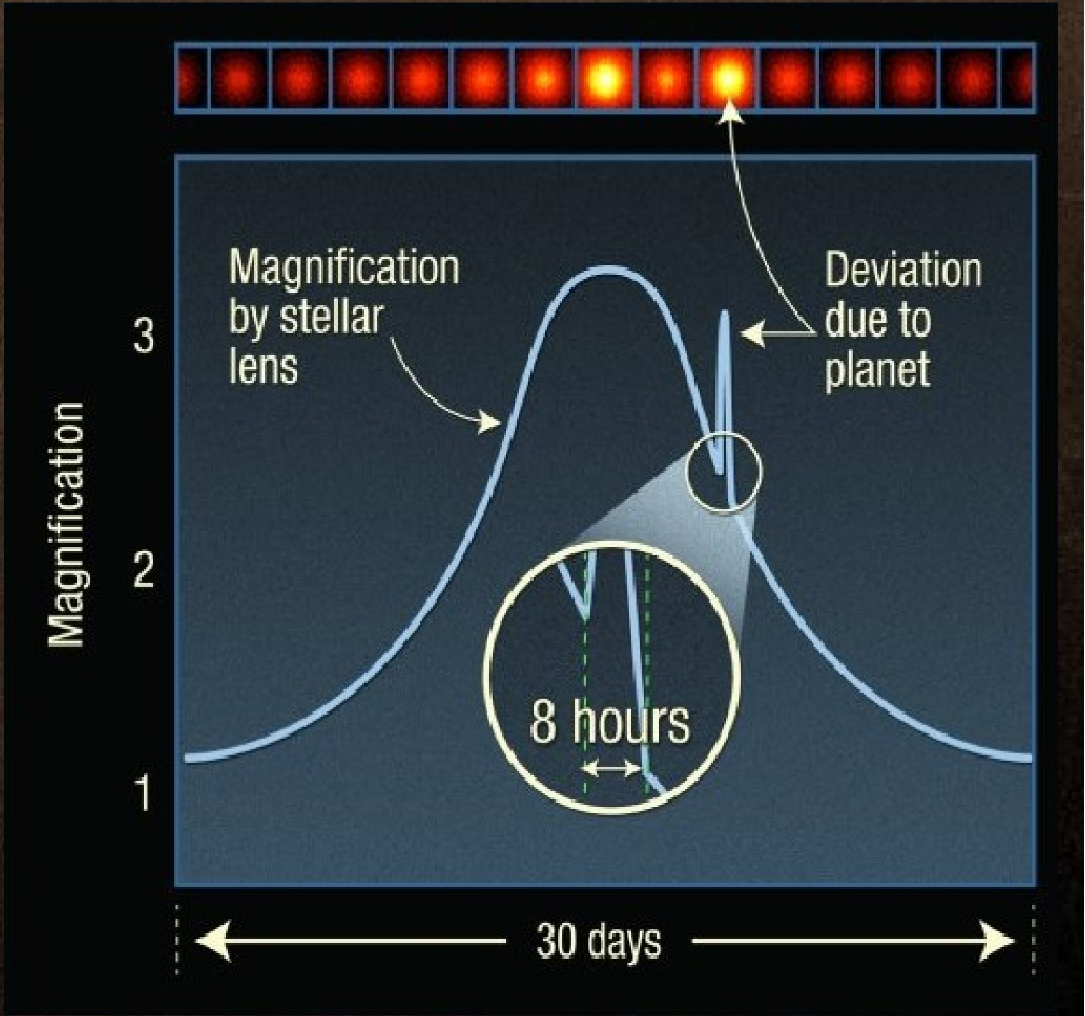
**This method still cannot detect our solar system analogs.**

# Transits of a few (already known) planets were detected from Earth.

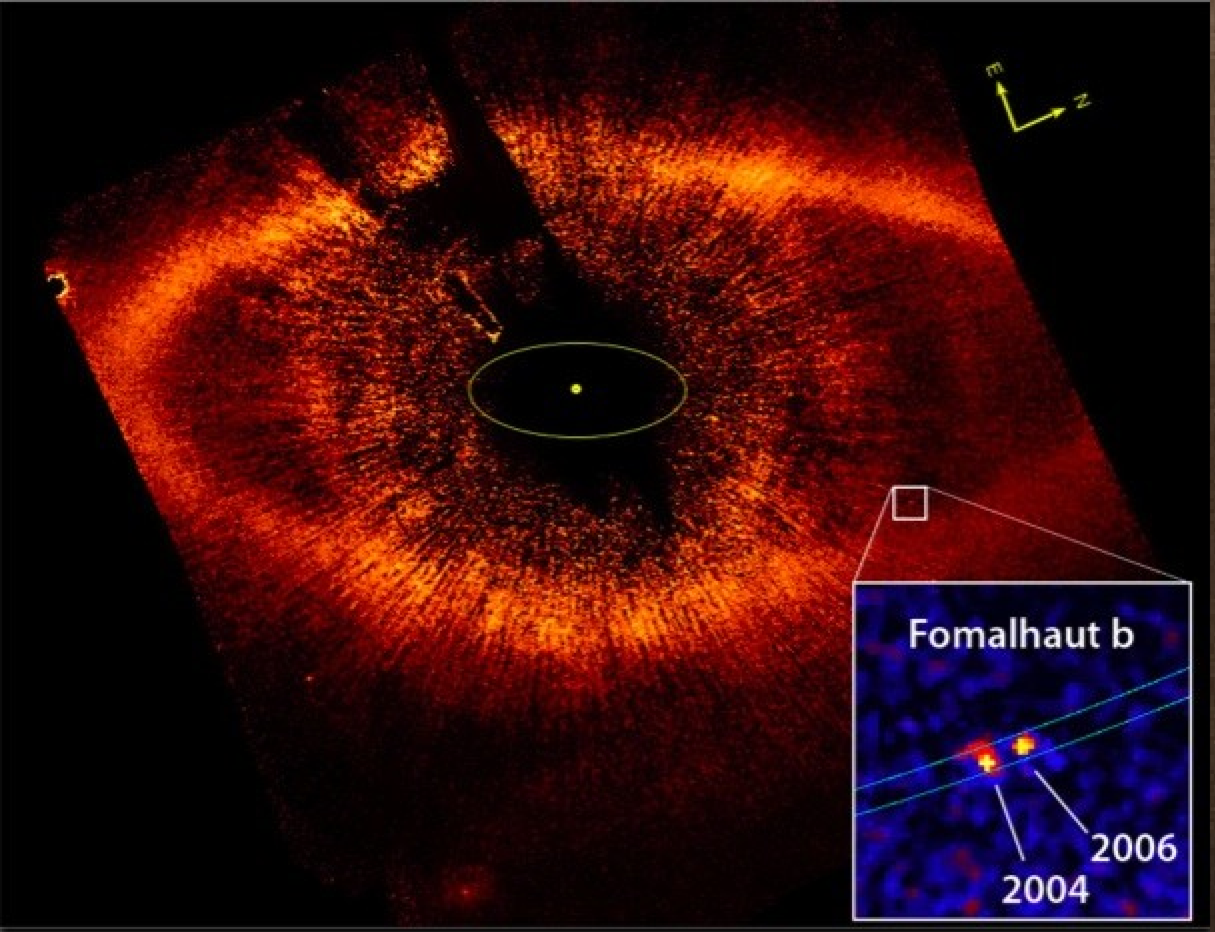


# A few planets were detected using microlensing.

These events do not repeat.

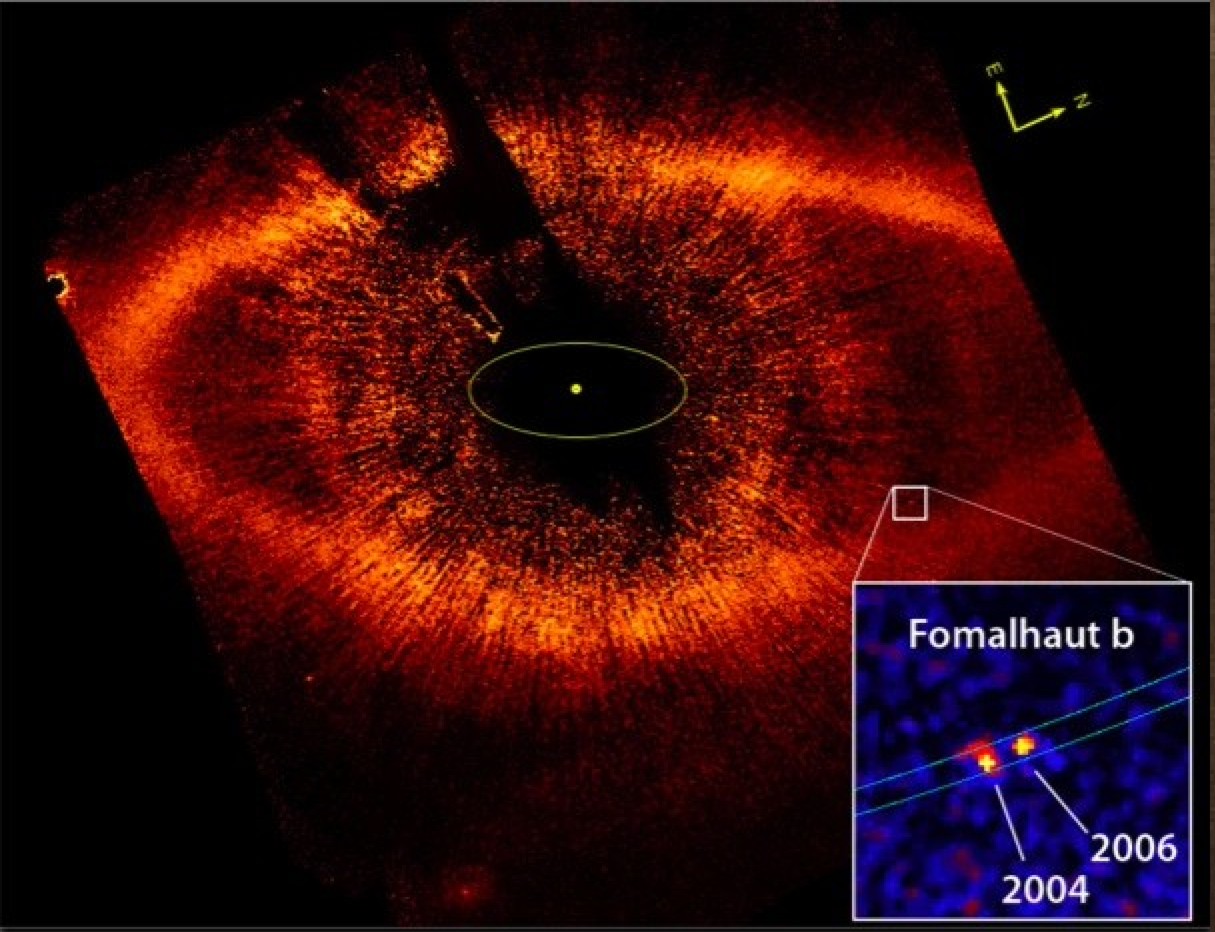


These are all indirect methods! The planet itself is not measured, only its effect on the host star.



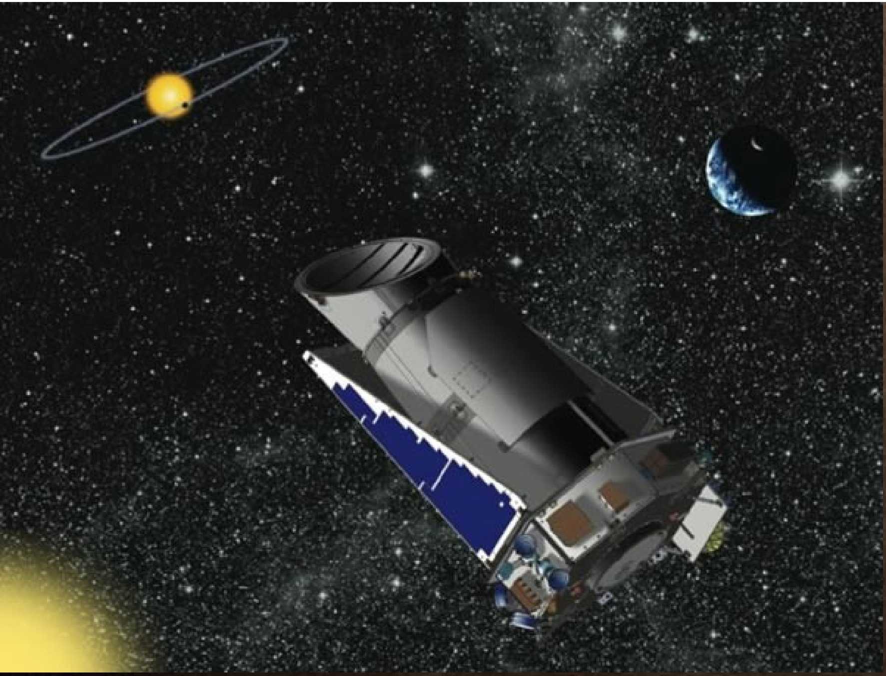
# Direct imaging:

Big planets far from their host stars. Fomalhaut b is $2M_J$, 115 AU from its host star.

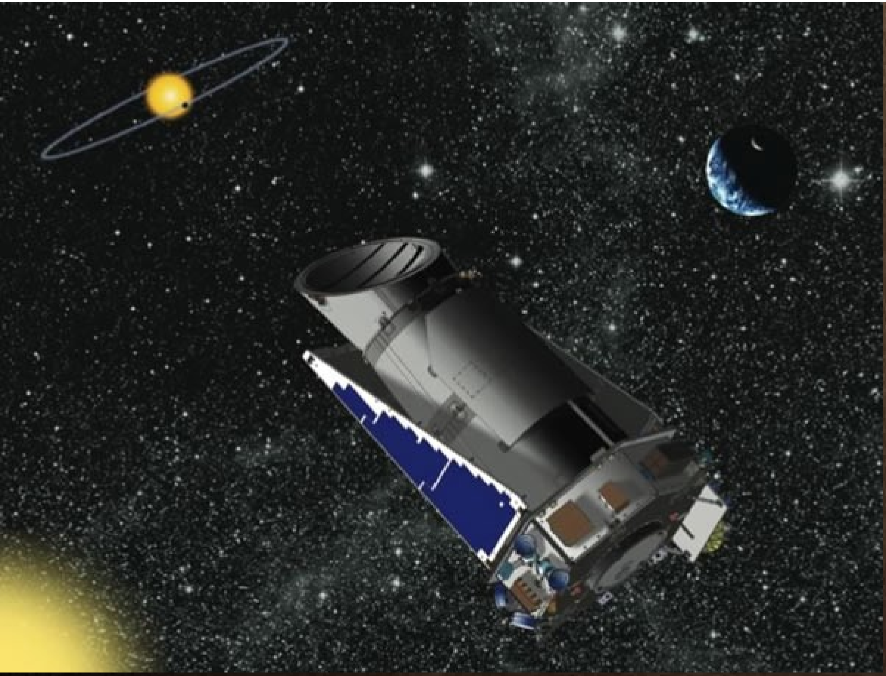


Direct imaging: currently works for big planets far from their host stars. Fomalhaut b is $2M_J$, 115 AU from its host star.

**So far this method cannot detect solar system analogs**

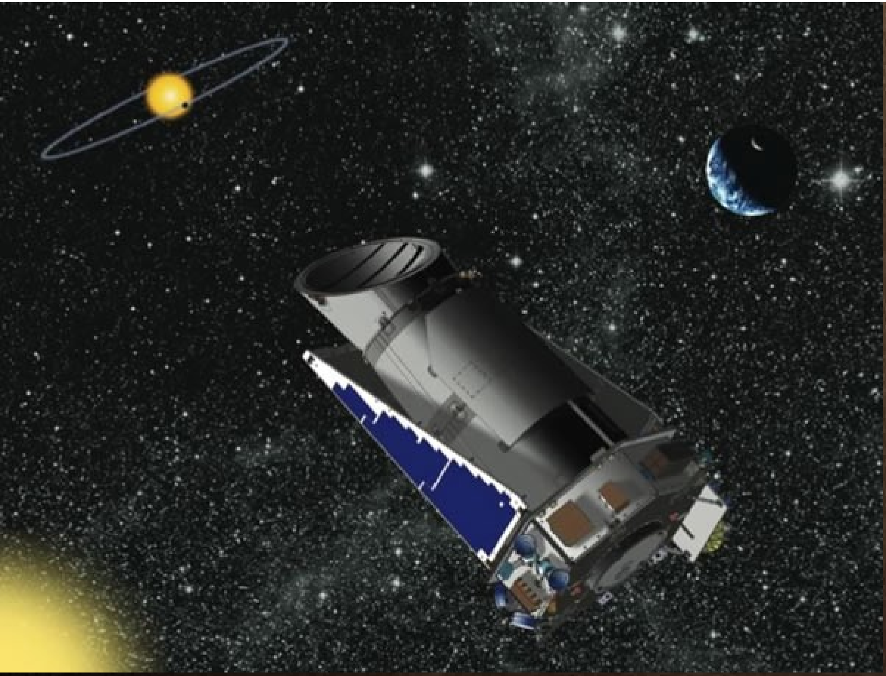


From 2009–2014, Kepler discovered over 4,000 planet candidates! Kepler used the transit method, while staring at 150,000+ stars.



This has been the tipping point.

There are now so many planets that we can do <u>some</u> statistics.

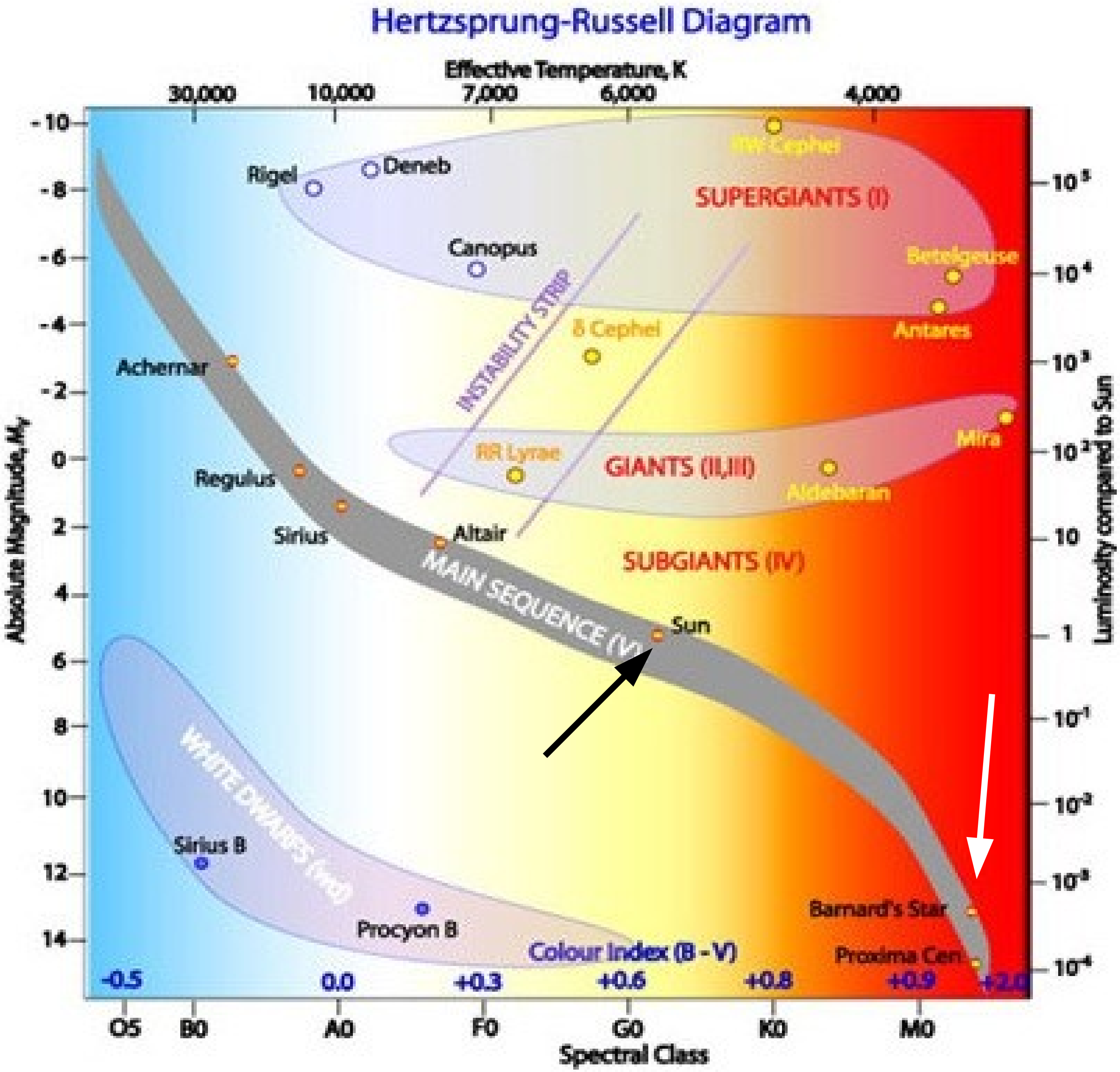


This has been the tipping point.

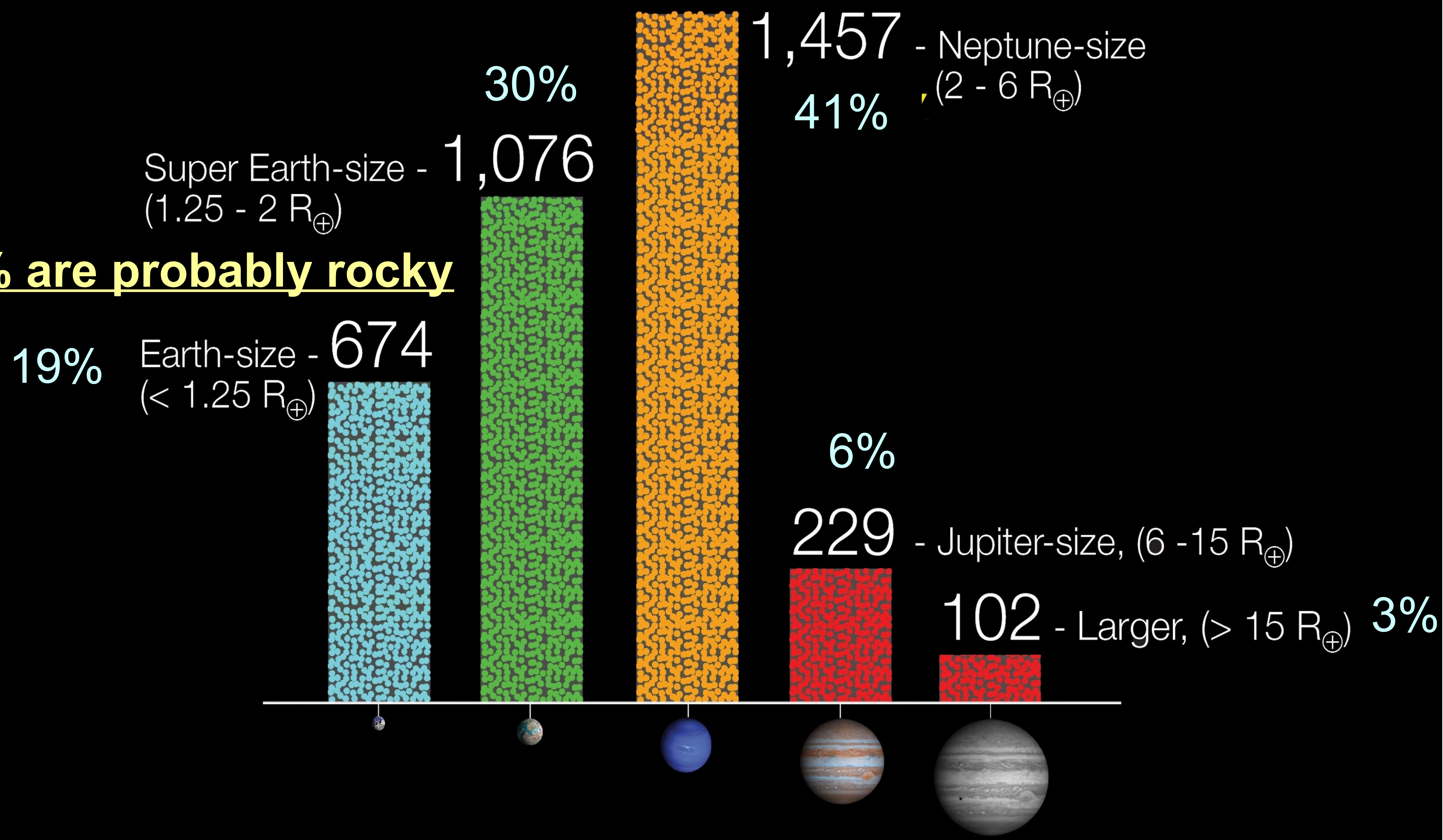
There are now so many planets that we can do <u>some</u> statistics.

**<u>Likewise, Kepler really could not detect solar system analogs (Venus, yes; Mercury, maybe)</u>**

Stars have a variety of sizes.



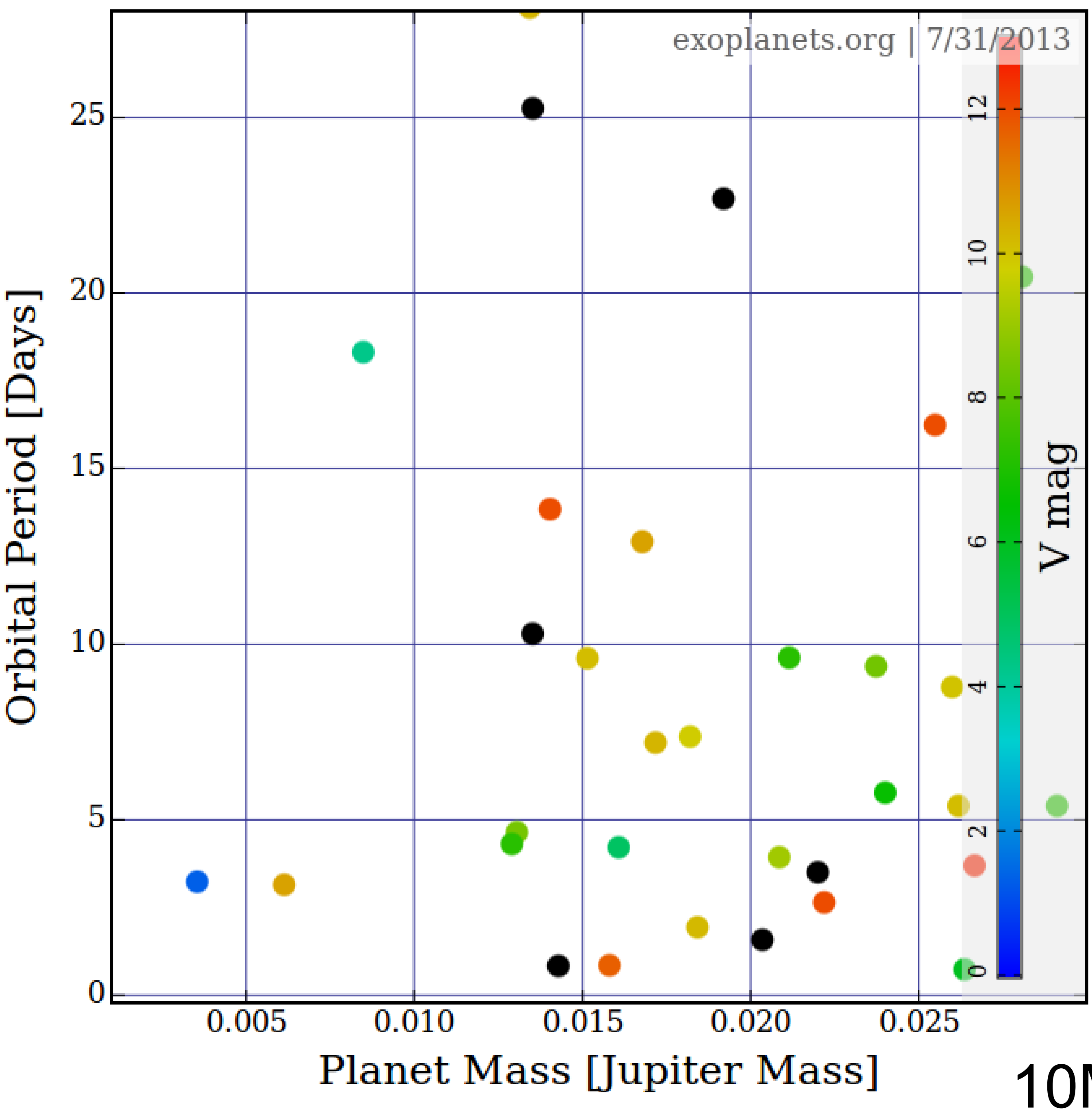
# Remember the biases!



## Sizes of Planet Candidates

*Totals as of November, 2013*

**49% are probably rocky**



Planets have been found with interesting masses, but usually in very short period orbits.

$10M_{Earth}$

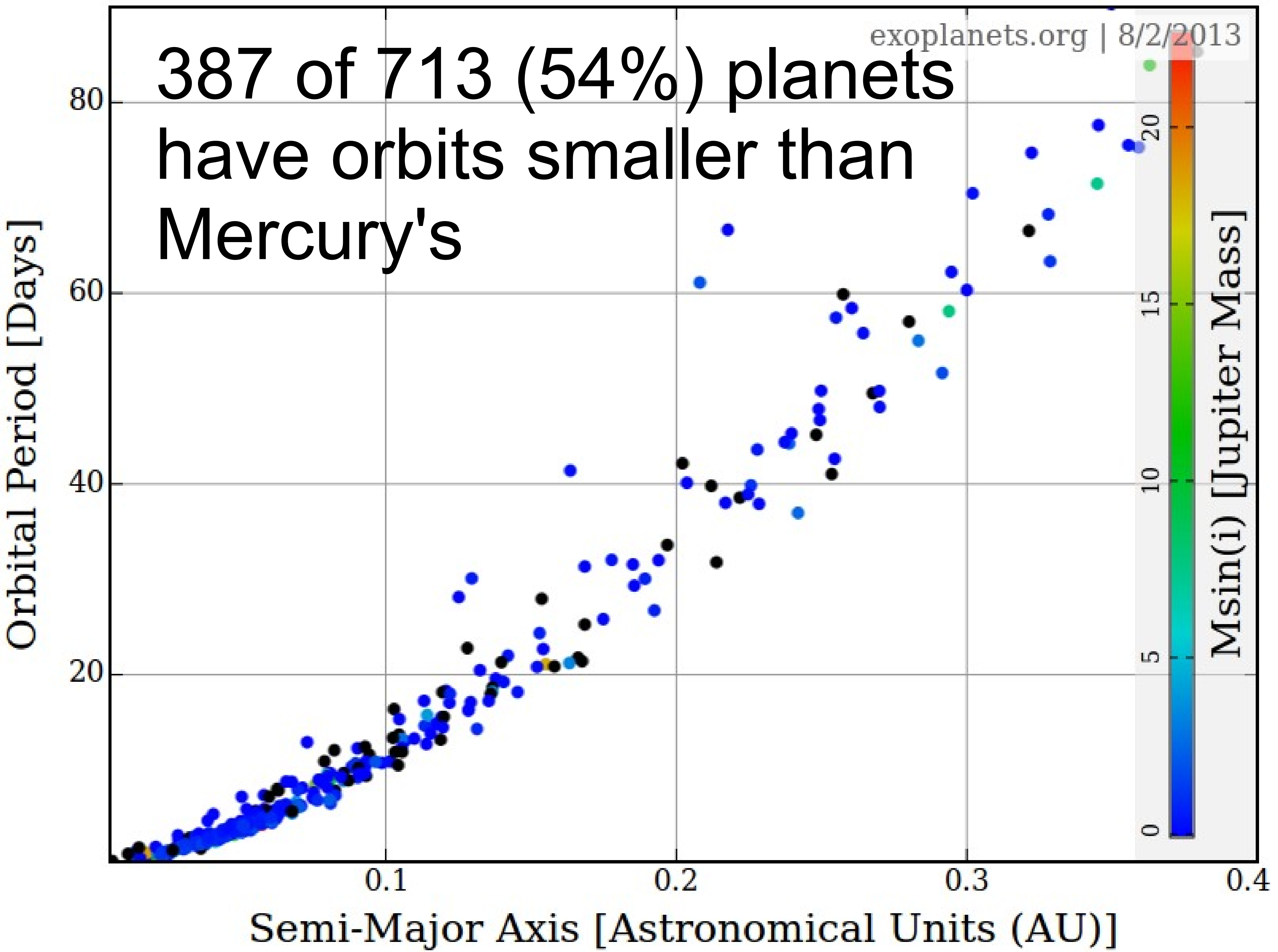
# Detections are biased to finding small planets in close orbits.

$P_{Orb}$= 13 21 40 days

$a_{AU}$= 0.10 0.14 0.21 AU

Mercury's orbit is 88 days at 0.39 AU.

387 of 713 (54%) planets have orbits smaller than Mercury's



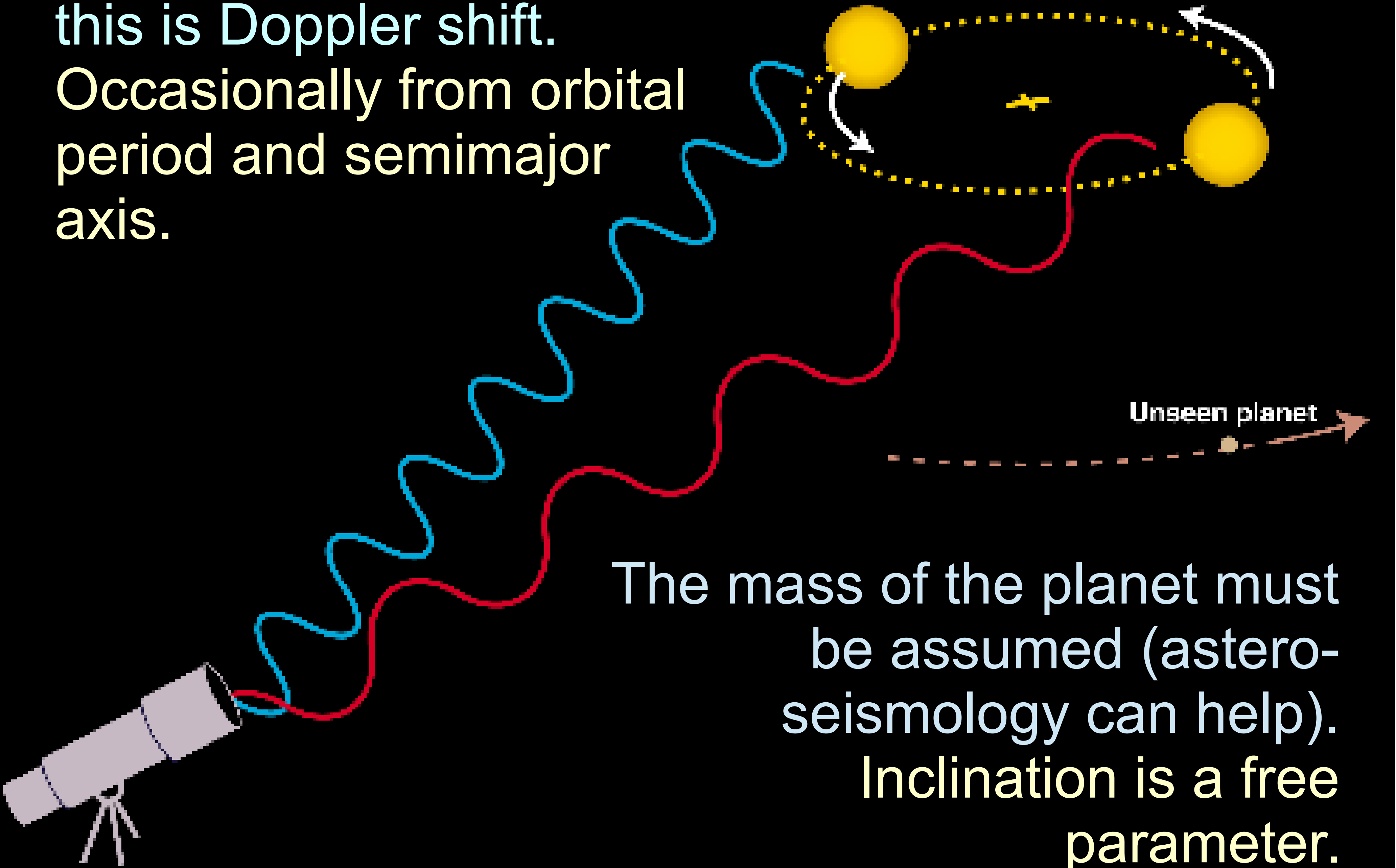
# Characterization Techniques

Orbit: Mass and Radius

Transmission Spectroscopy

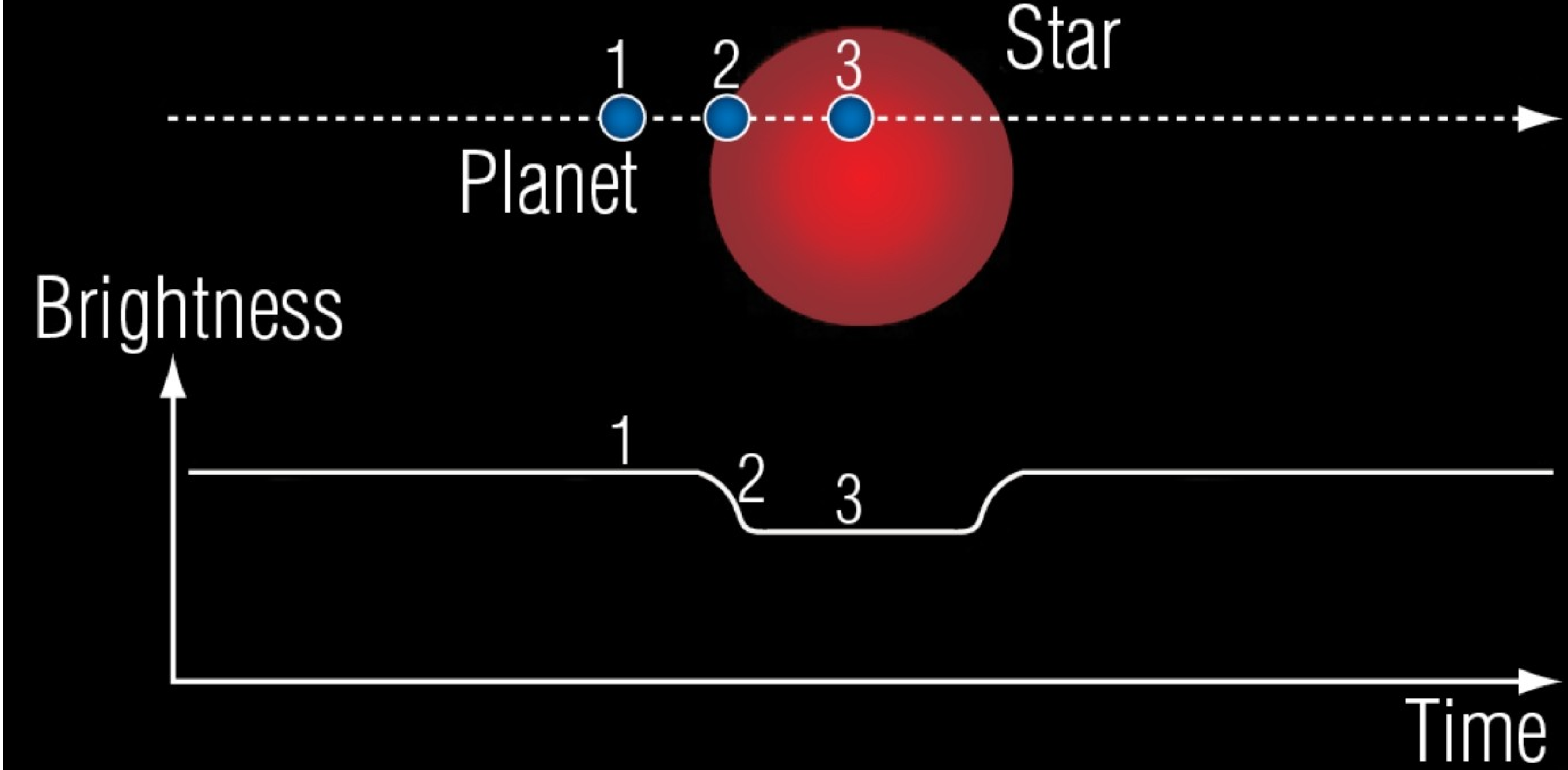
Reflection Spectroscopy (including broadband photometry)

Masses come from orbital mechanics only. Typically this is Doppler shift. Occasionally from orbital period and semimajor axis.

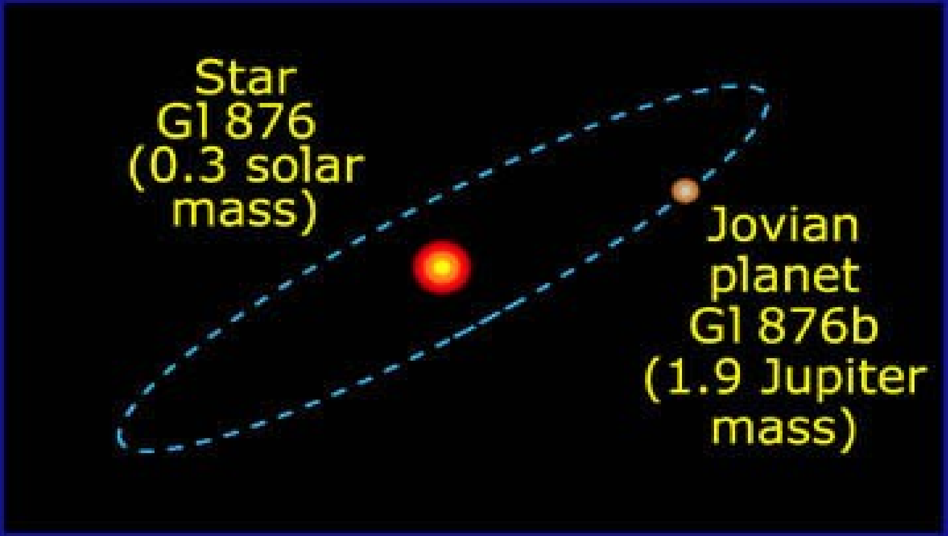


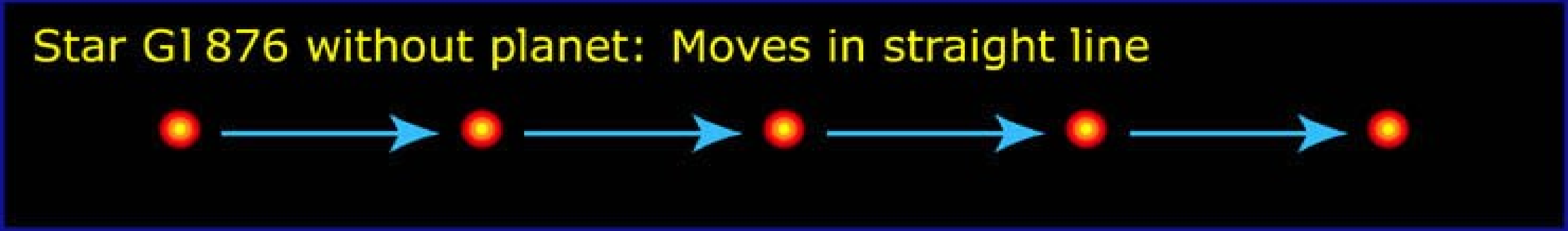
The mass of the planet must be assumed (astero-seismology can help). Inclination is a free parameter.

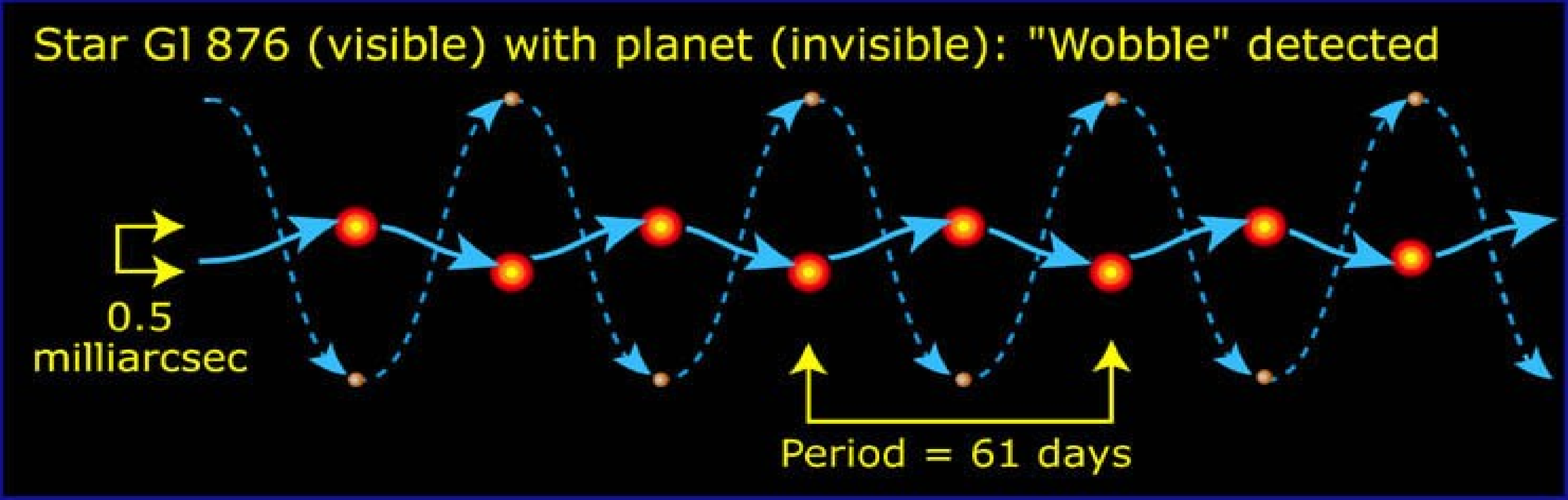
# Transits also constrain the inclination: but for *very* short period planets, the constraints decrease.



# Doppler plus astrometry can constrain the inclination. Extremely rare

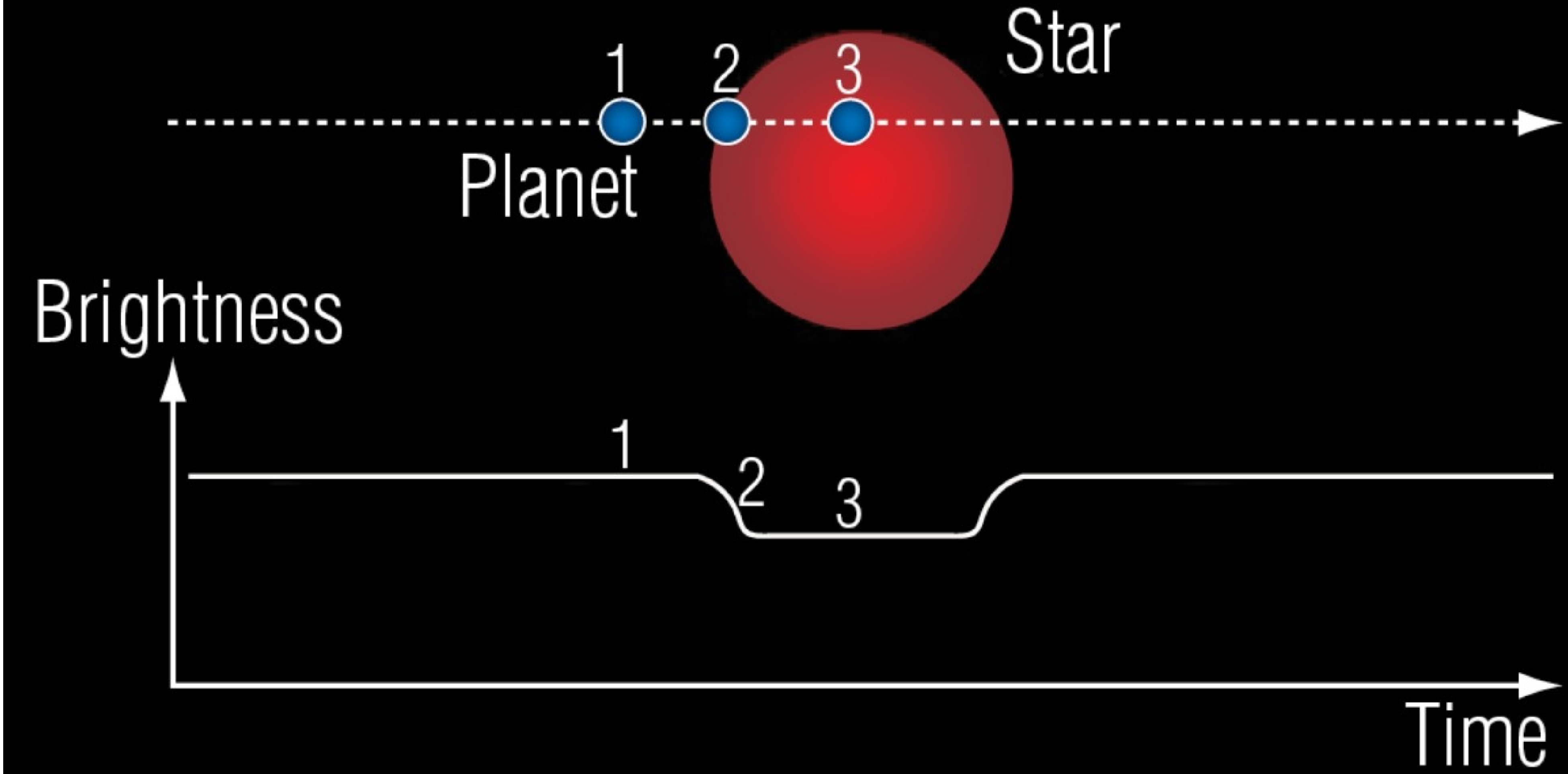




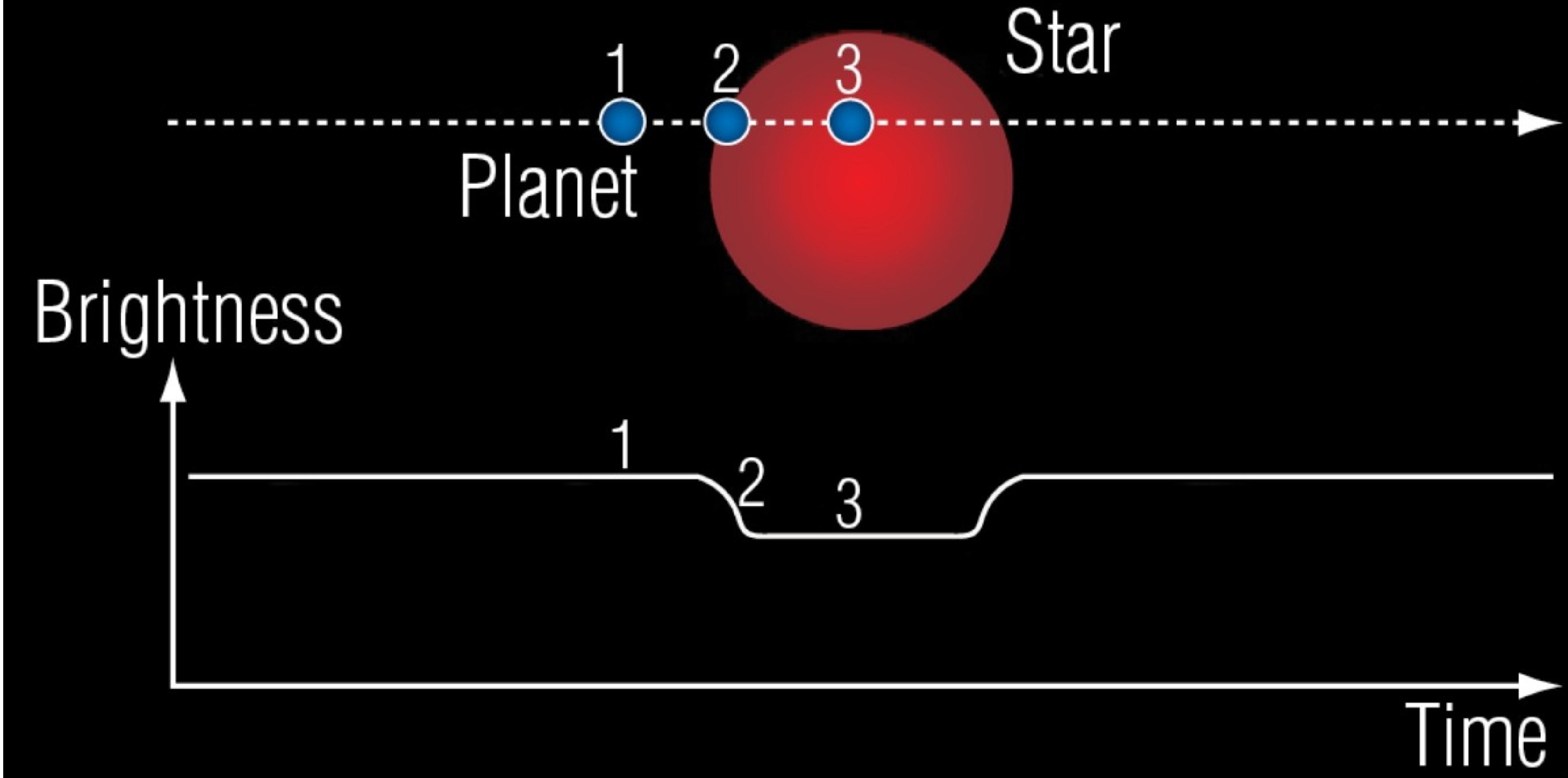


Transits also give the planet's radius.

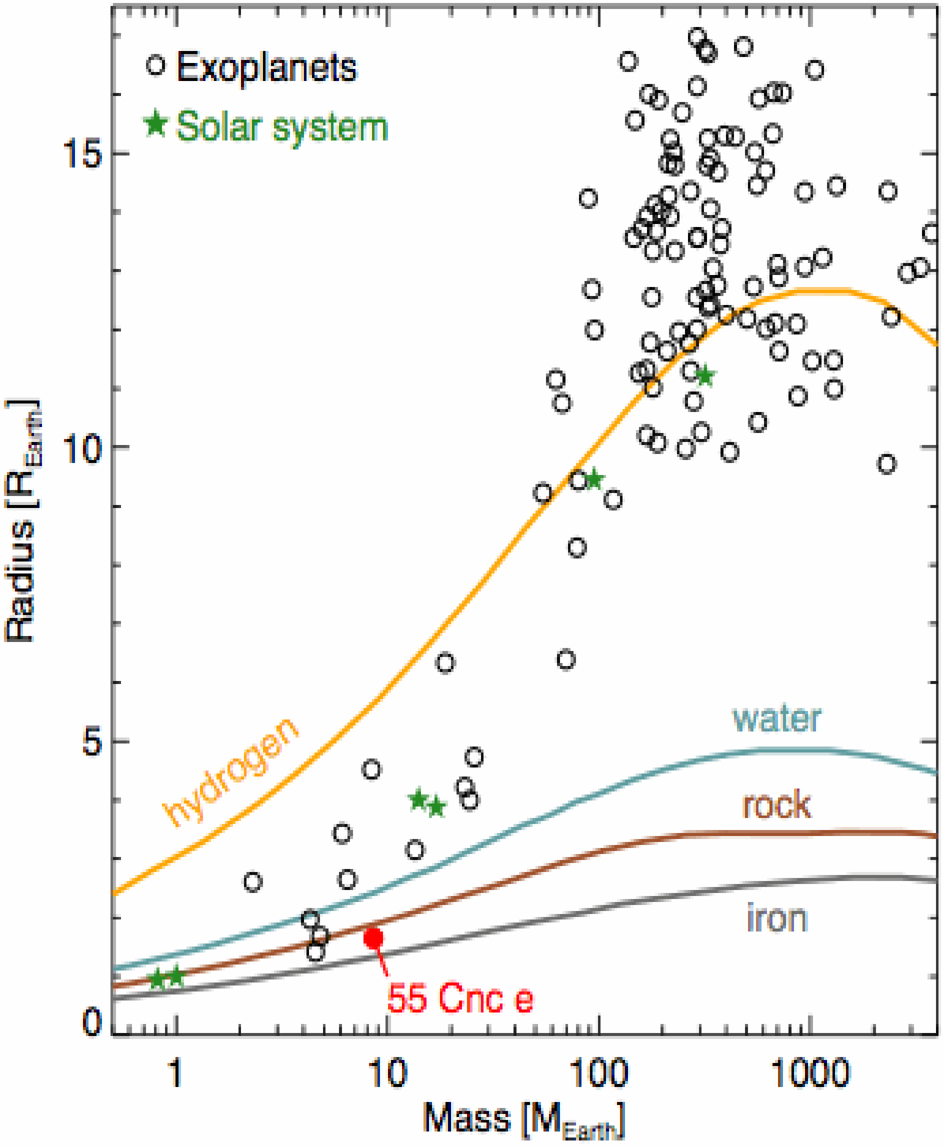
Again asteroseismology can help.

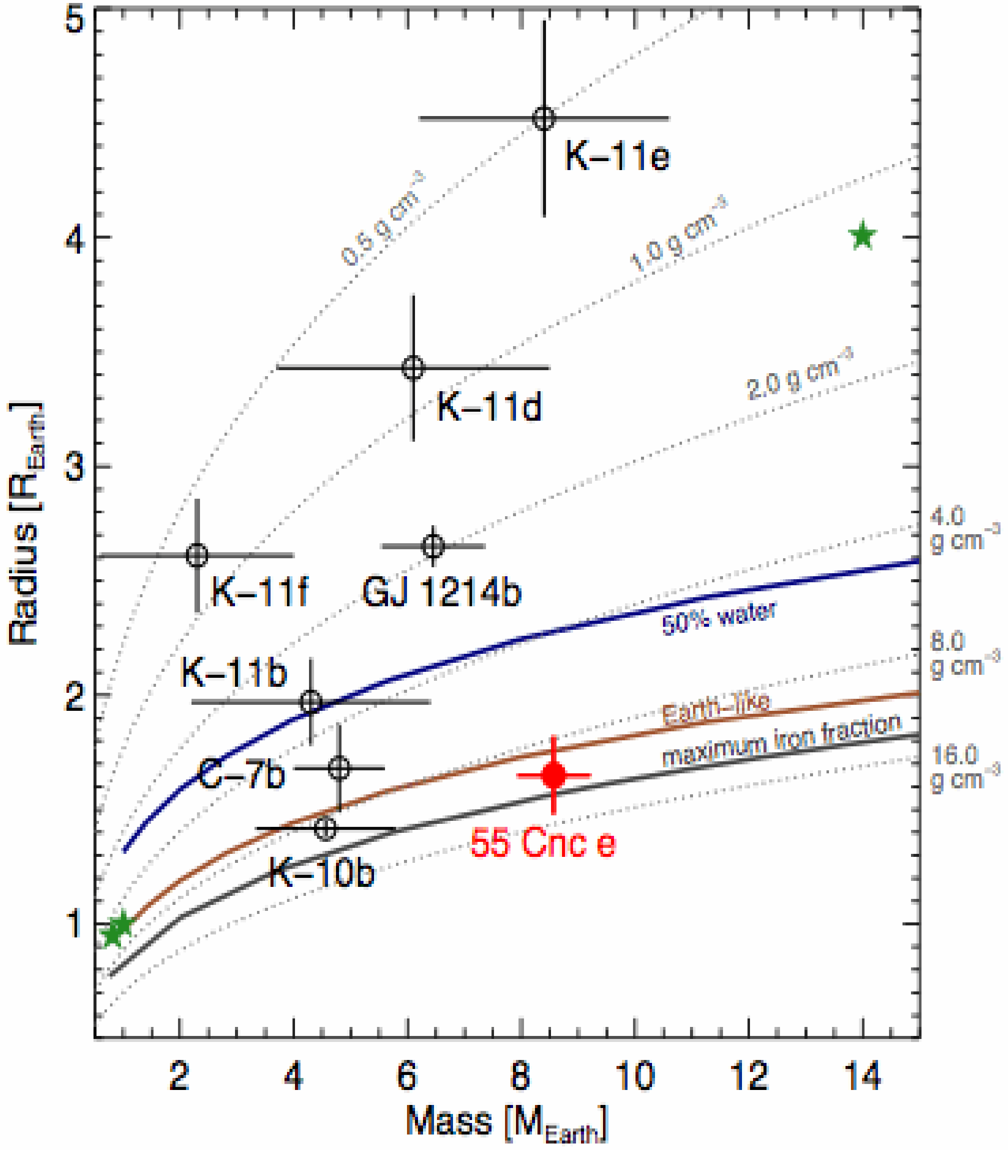


# With sufficient transit precision (ingress/egress timings), inclination can be determined too (and more precise radii).

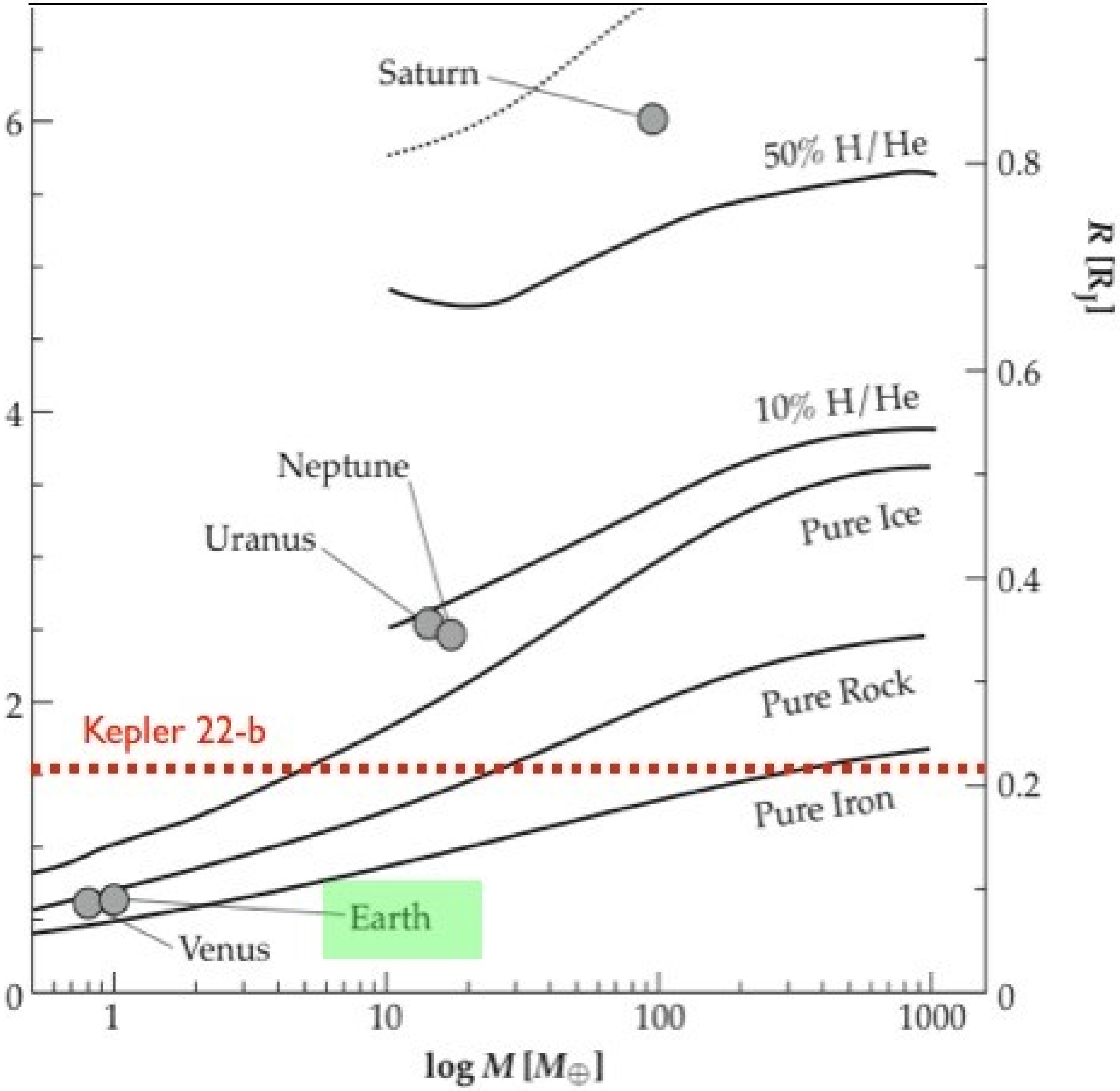


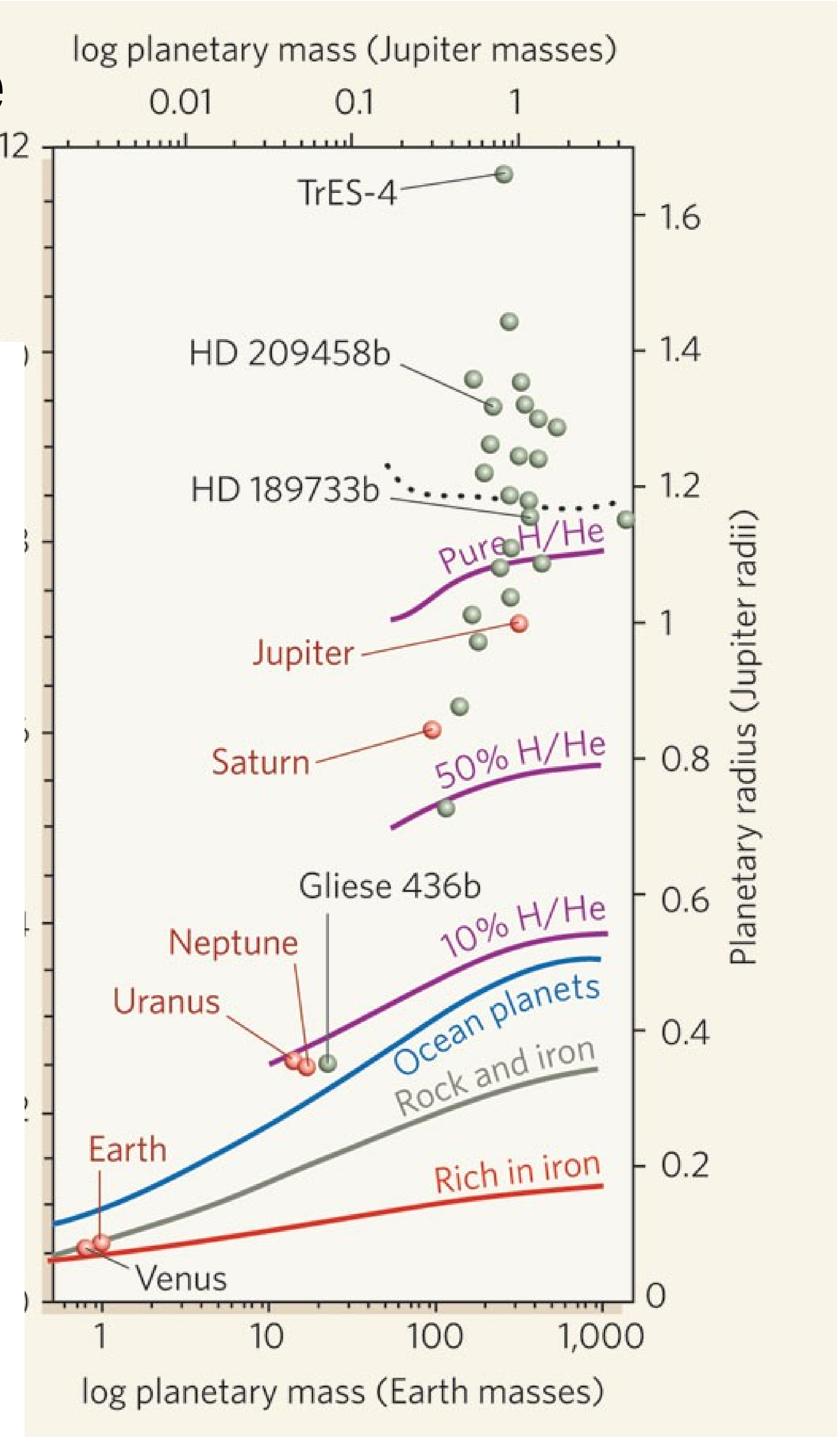
# With mass and radius come density. Model comparisons can be used to infer bulk compositions.



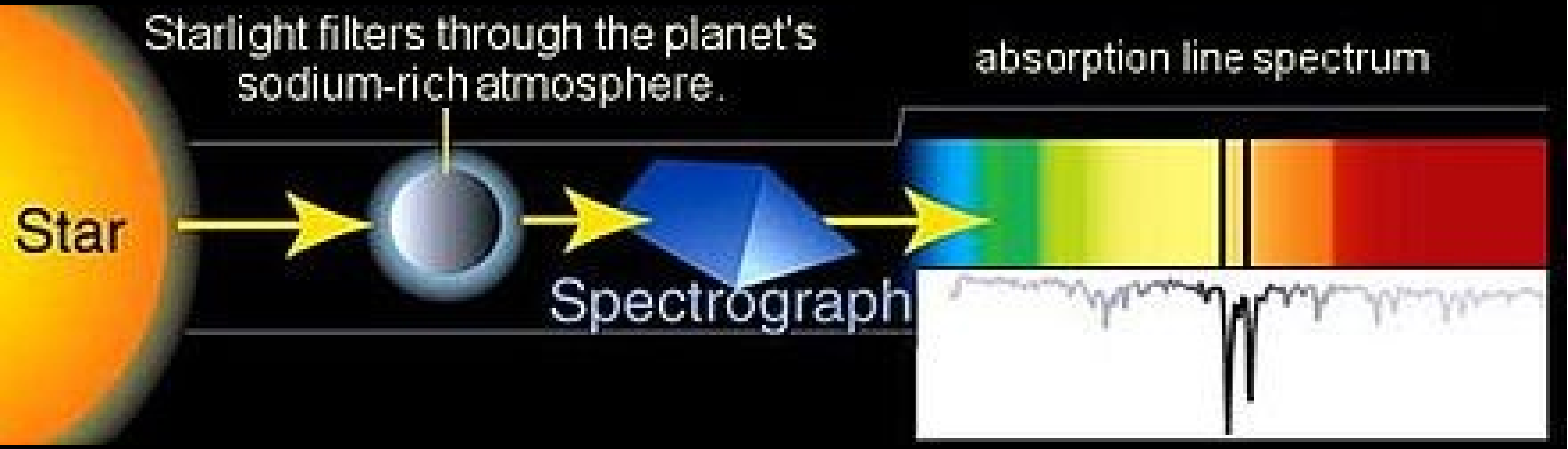


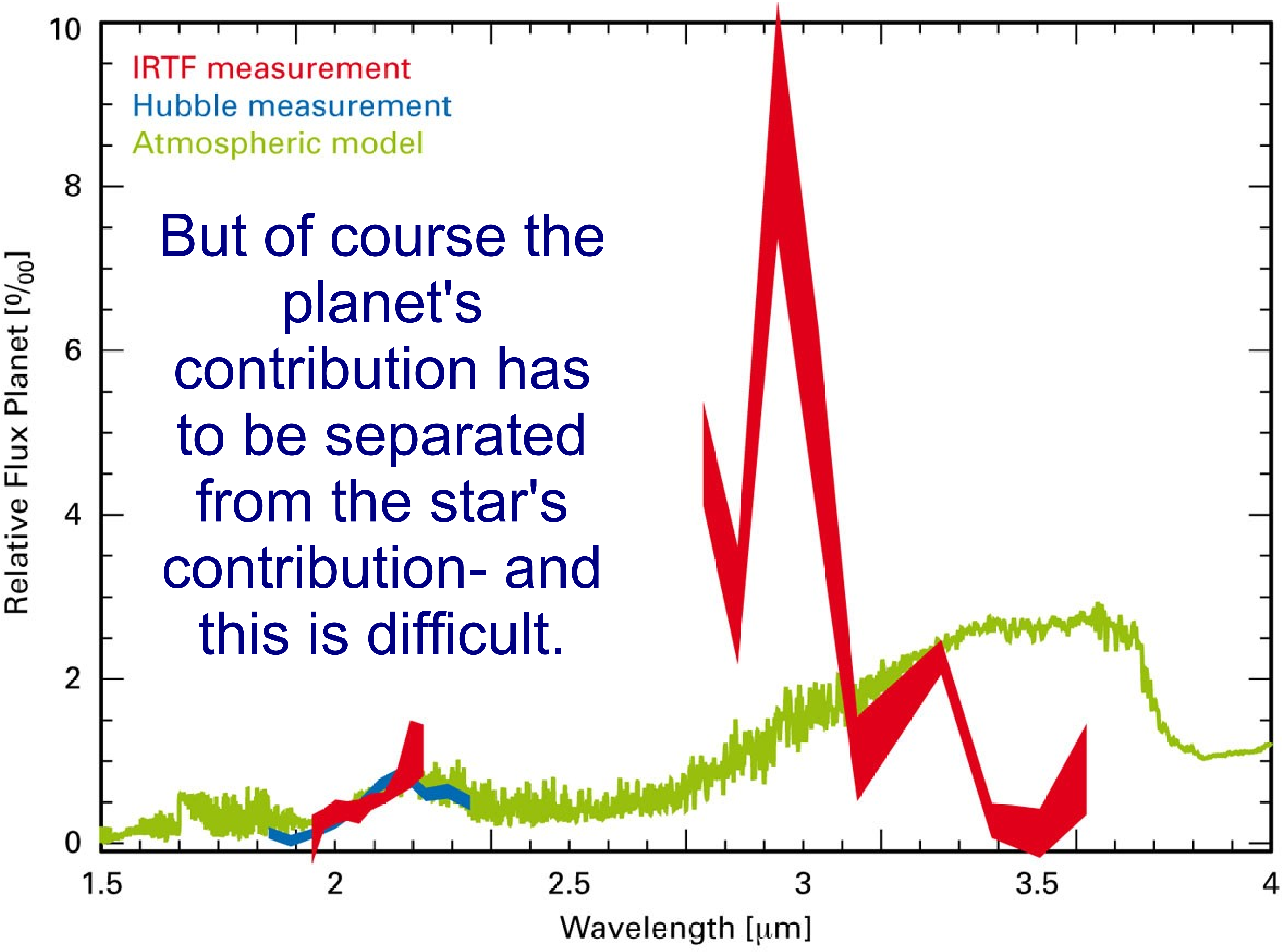
# But the model dependence is large and there are many, many degeneracies.



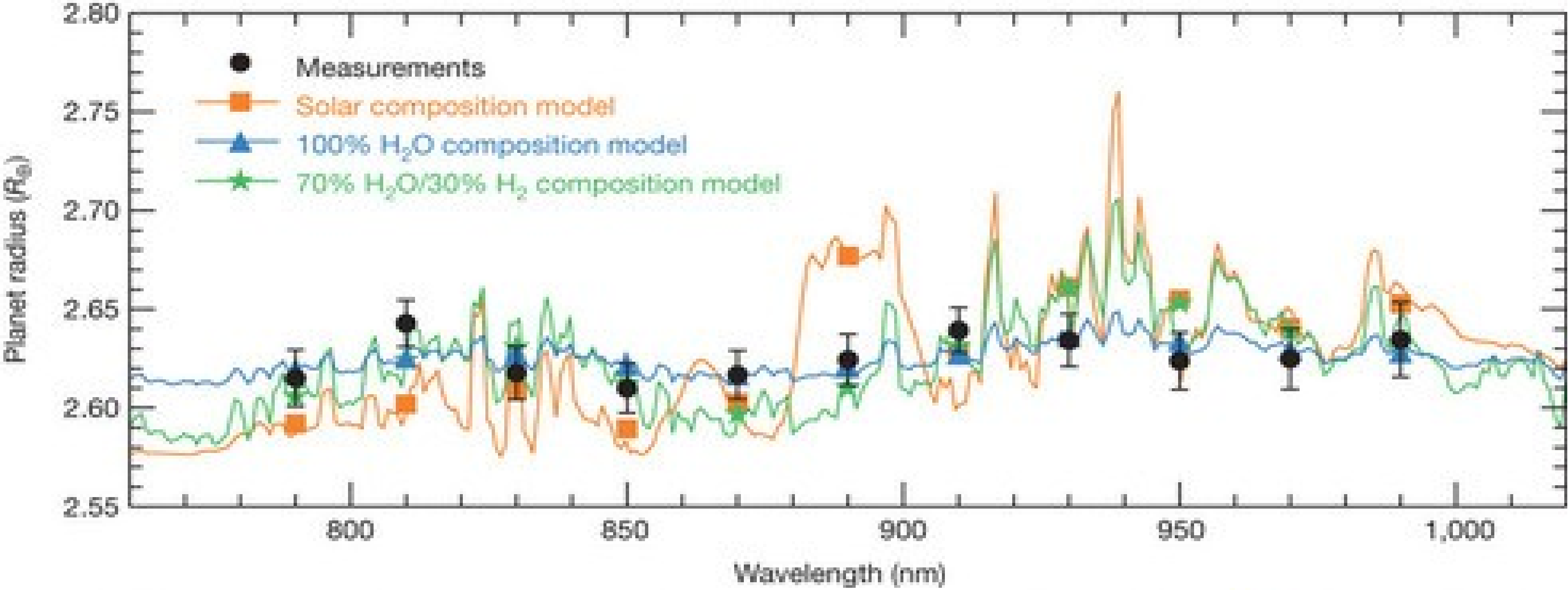


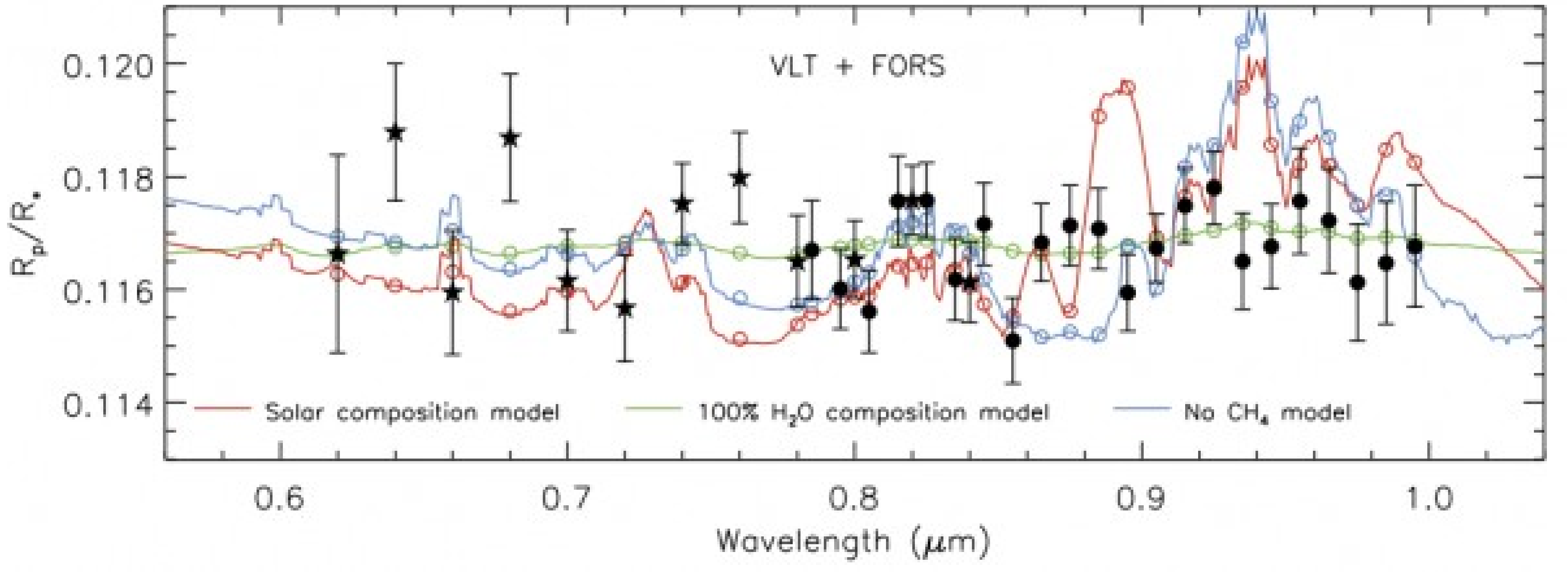
# Transmission spectroscopy is a more direct means of detecting the planet- but only the atmosphere.

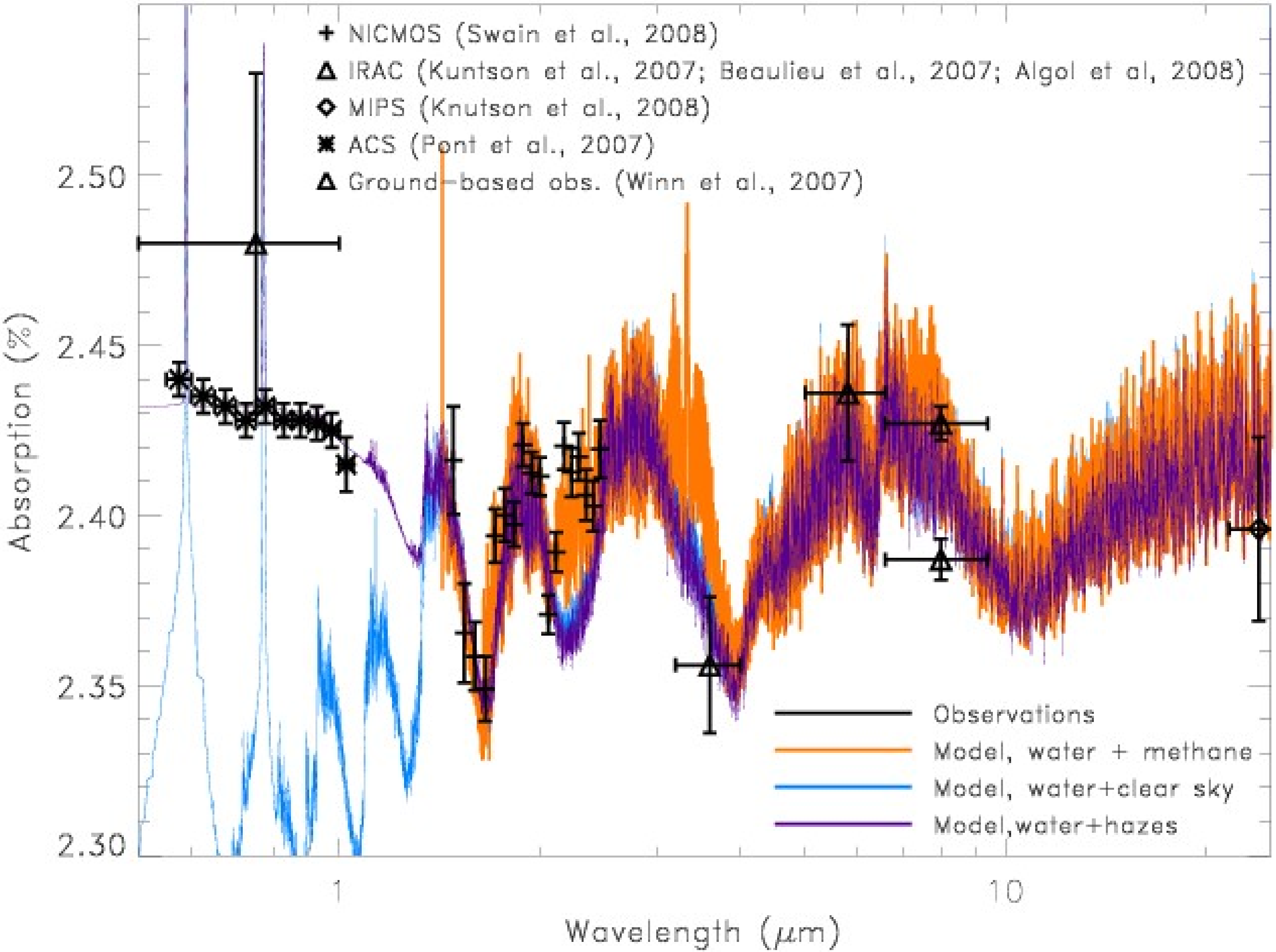




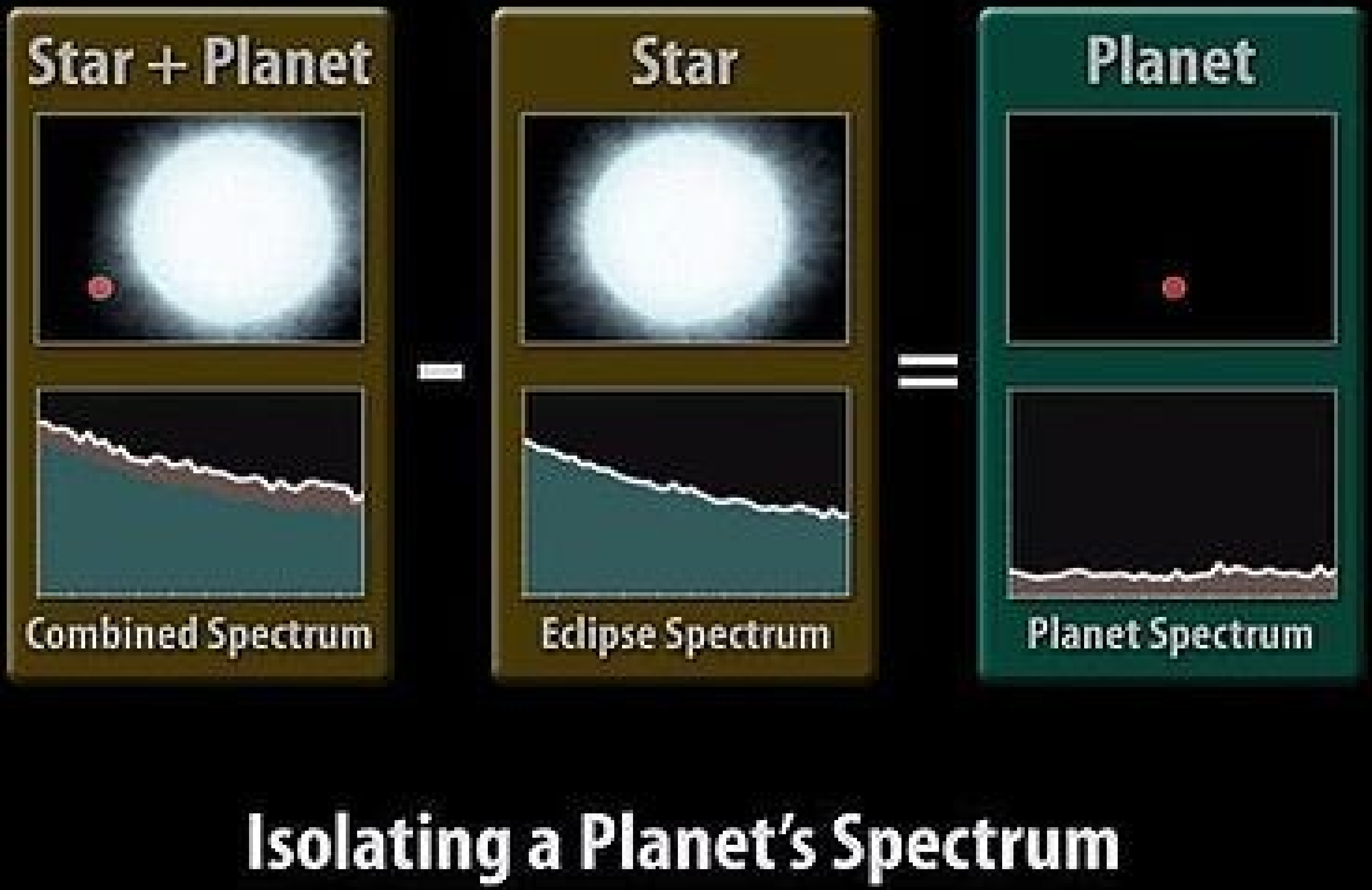
But of course the planet's contribution has to be separated from the star's contribution- and this is difficult.

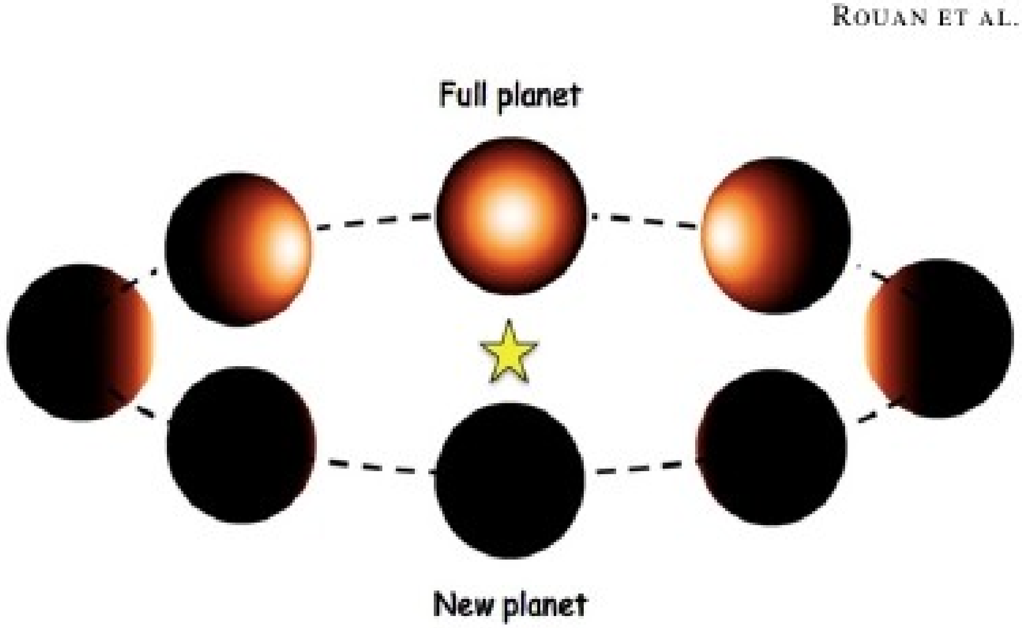

Measurements
Solar composition model
100% $H_2O$ composition model
70% $H_2O$/30% $H_2$ composition model
Planet radius ($R_⊕$)
2.80
2.75
2.70
2.65
2.60
2.55
800
850
900
950
1,000
Wavelength (nm)


VLT + FORS
$R_p/R_*$
0.120
0.118
0.116
0.114
Solar composition model
100% $H_2O$ composition model
No $CH_4$ model
0.6
0.7
0.8
0.9
1.0
Wavelength (μm)


+ NICMOS (Swain et al., 2008)
△ IRAC (Kuntson et al., 2007; Beaulieu et al., 2007; Algol et al, 2008)
◇ MIPS (Knutson et al., 2008)
✱ ACS (Pont et al., 2007)
△ Ground-based obs. (Winn et al., 2007)
Observations
Model, water + methane
Model, water+clear sky
Model,water+hazes
Absorption (%)
2.50
2.45
2.40
2.35
2.30
1
10
Wavelength (μm)

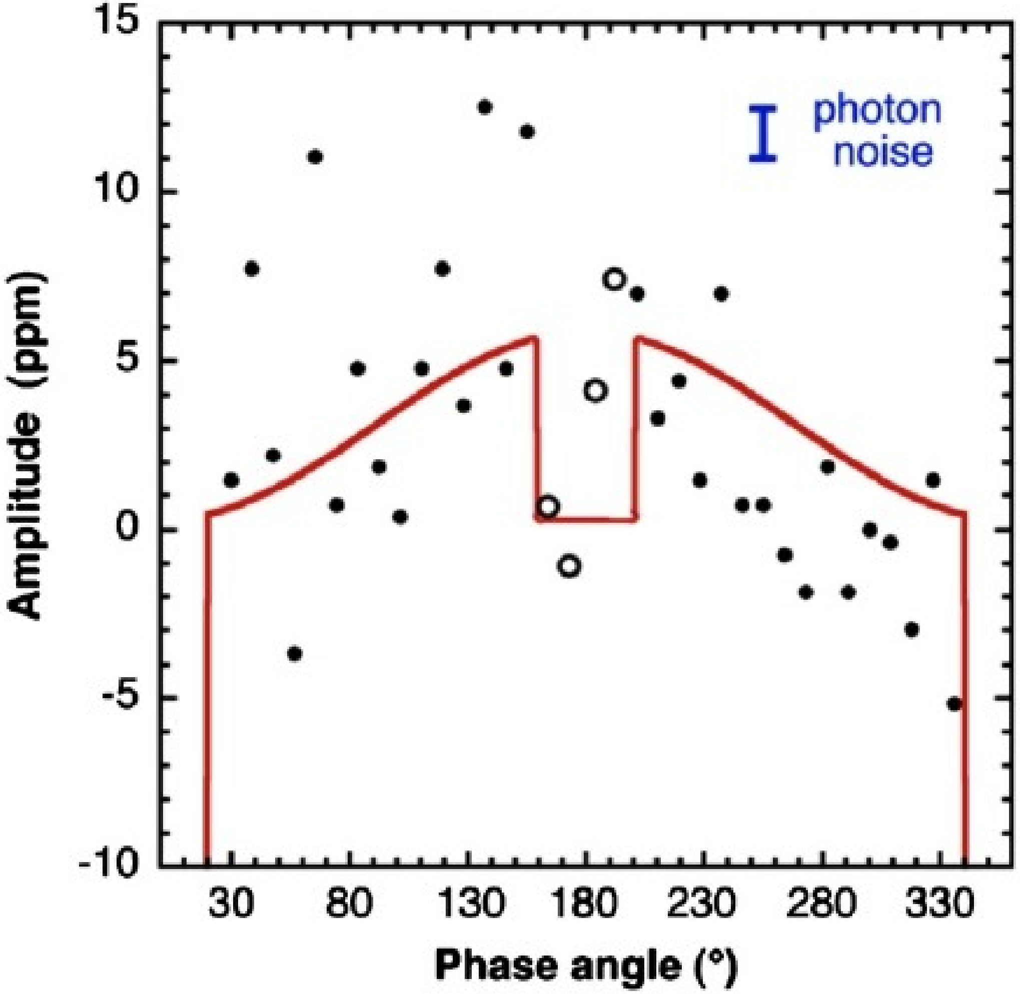
# Reflection Spectrum: Differenced from the star.



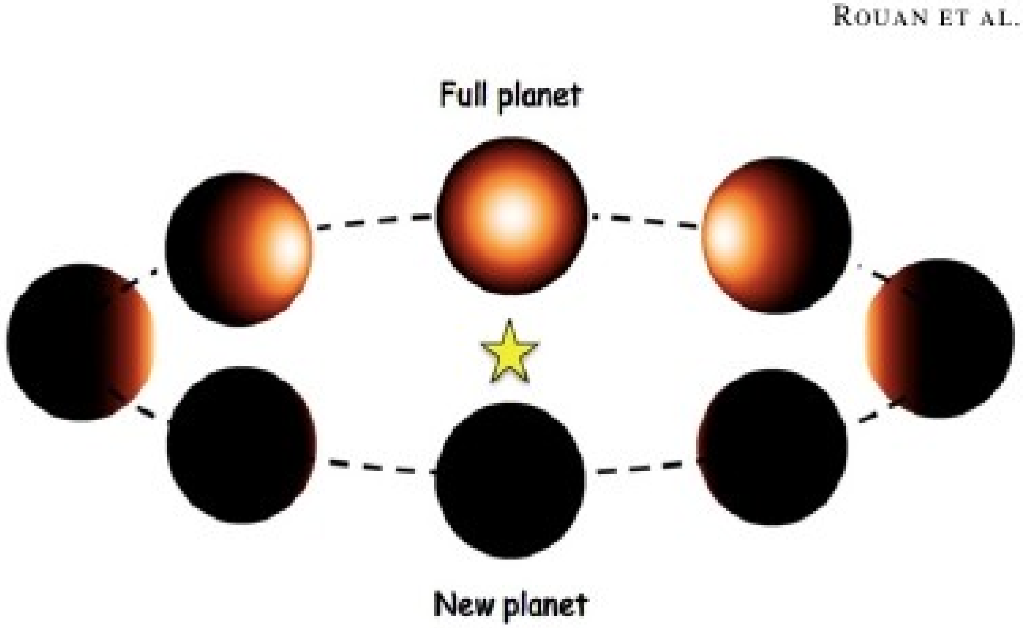


At different orbital phases, the amount of light received from the planet changes.

Each *filter*, which is a summed portion of the spectrum, will depend on the amount of reflected starlight (albedo) and the planetary contribution (blackbody + emission).

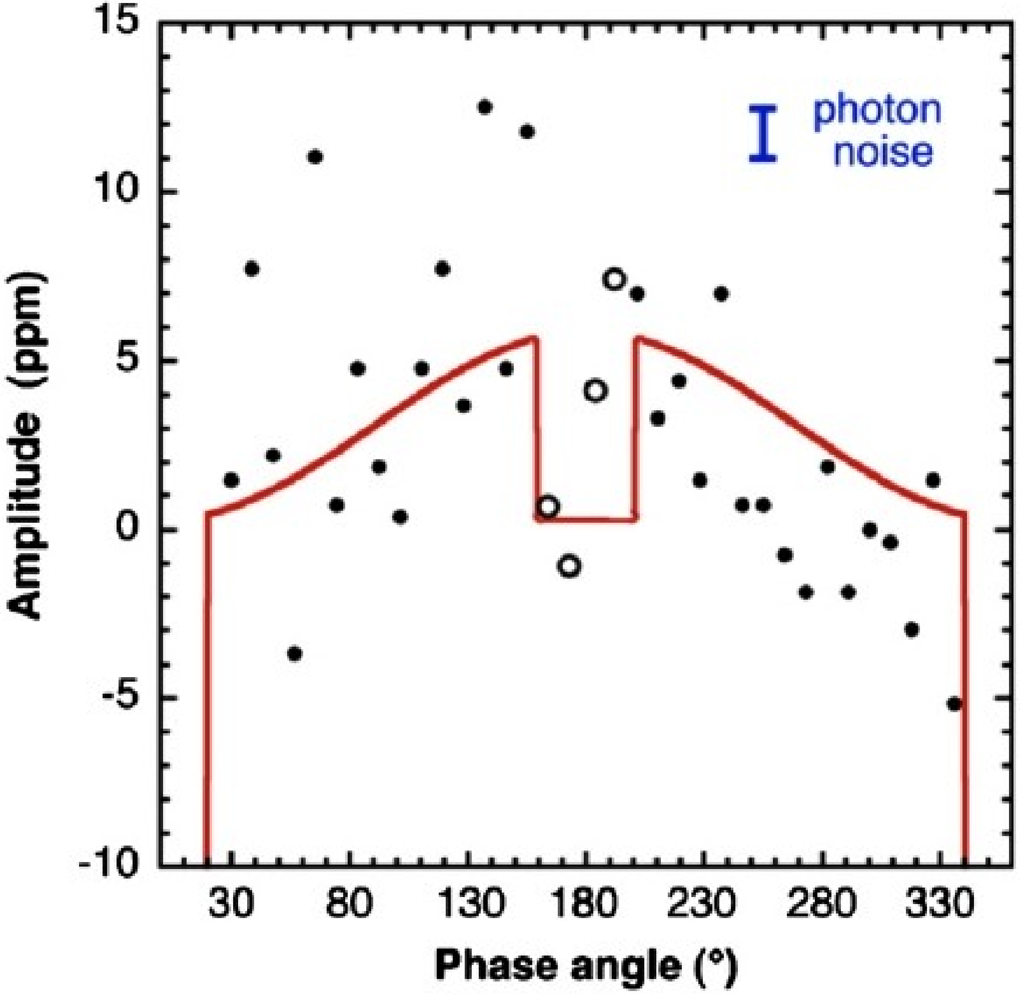


Rouan et al. 2011



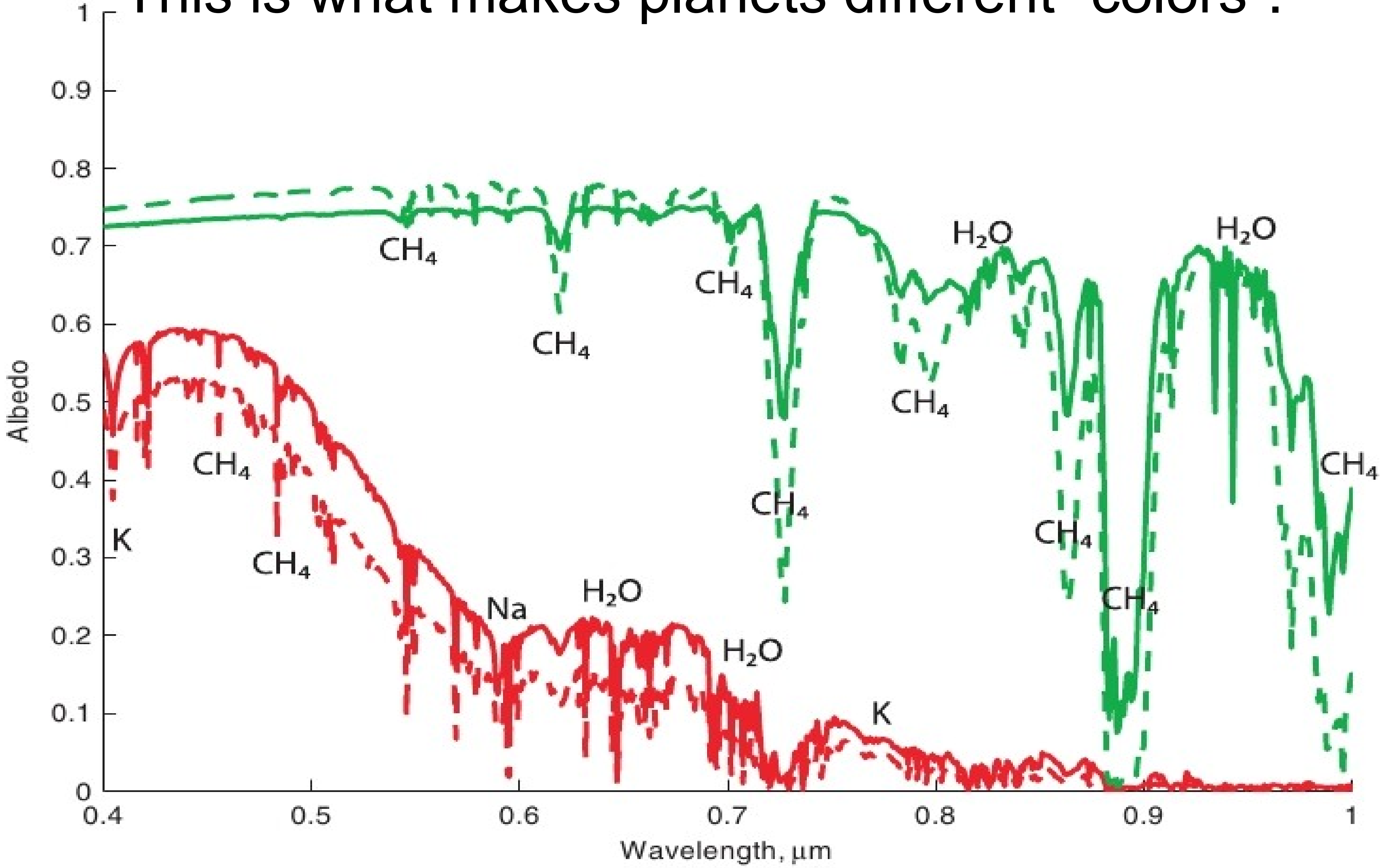
At different orbital phases, the amount of light received from the planet changes.

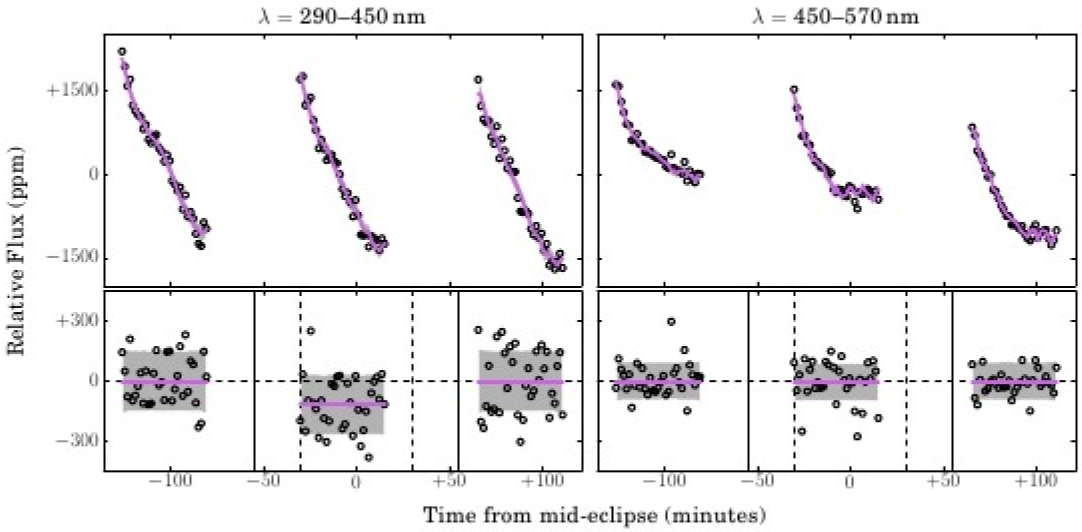
In transiting systems, at some phases (secondary eclipse), there is starlight only (the planet is behind the star), which can be compared to other phases, where the planet contributes.



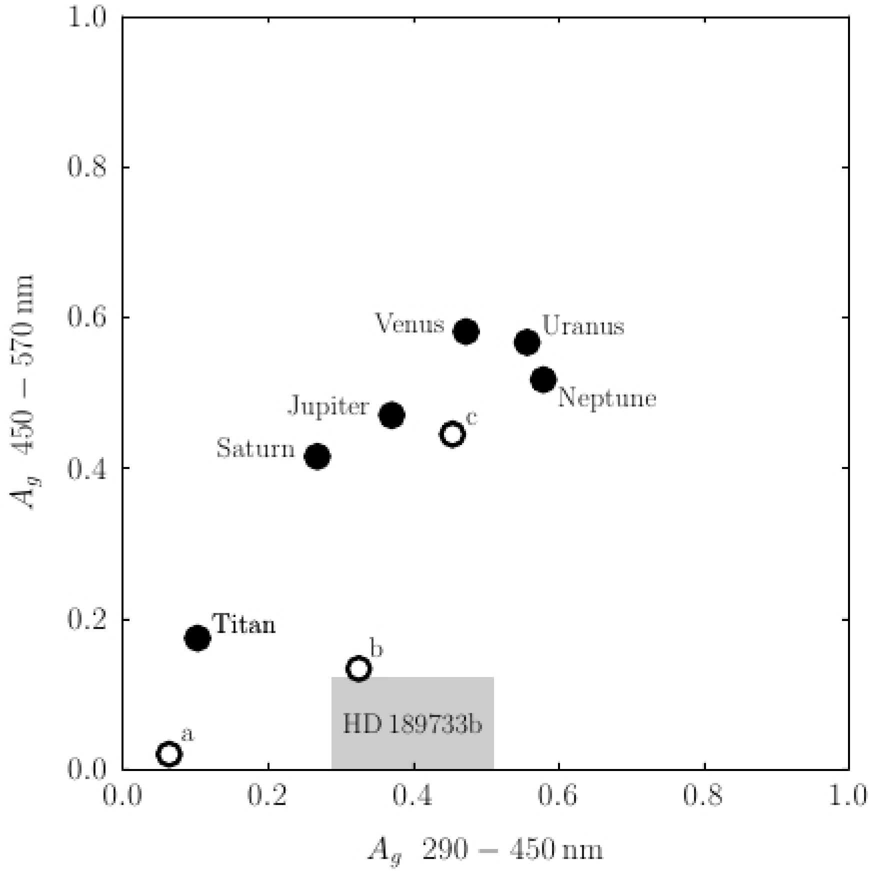
Rouan et al. 2011

# Then there is wavelength-dependent albedo. This is what makes planets different “colors”.



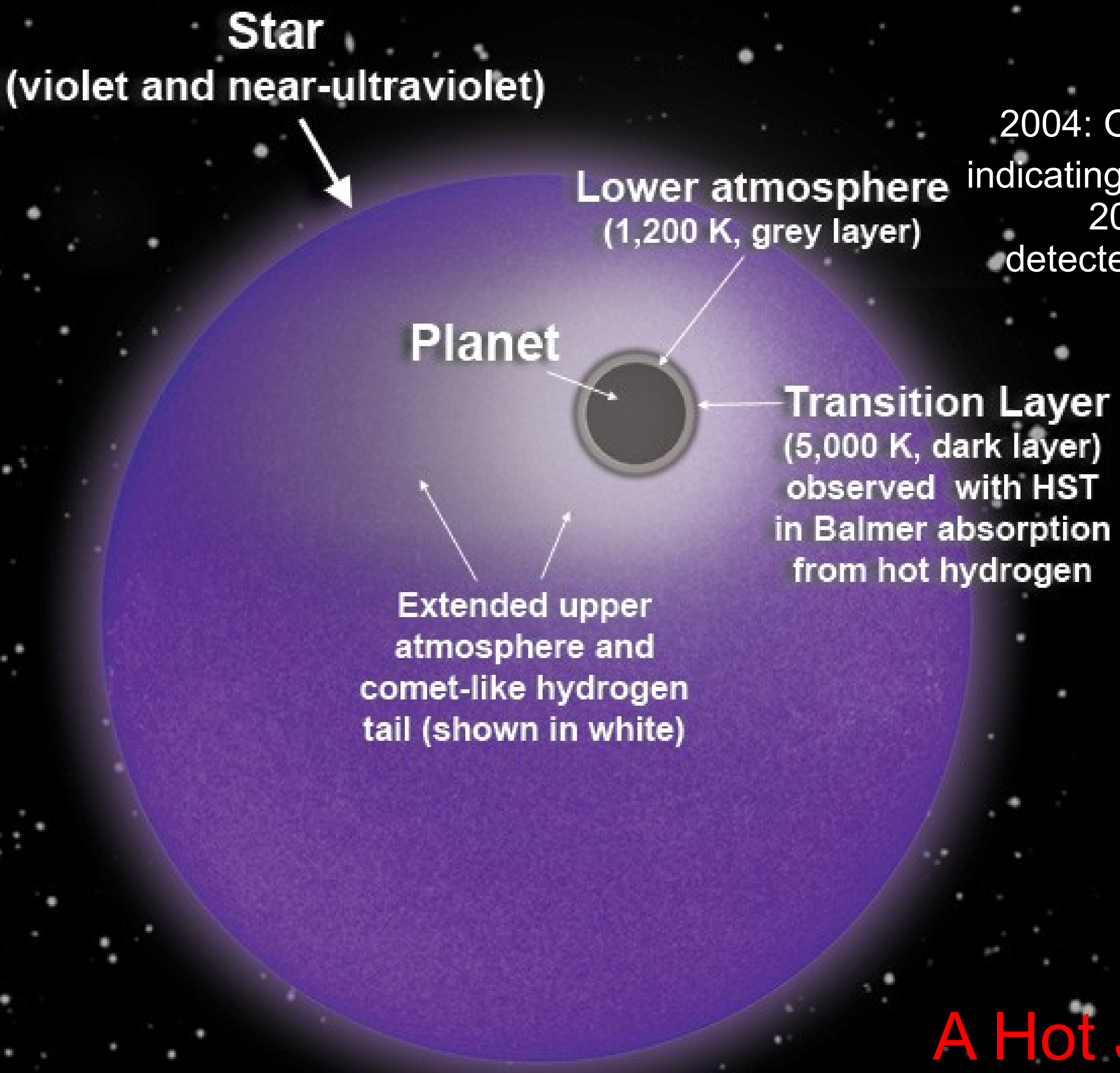


Actual measurements



Conclusions

from
Evans et al. 2013



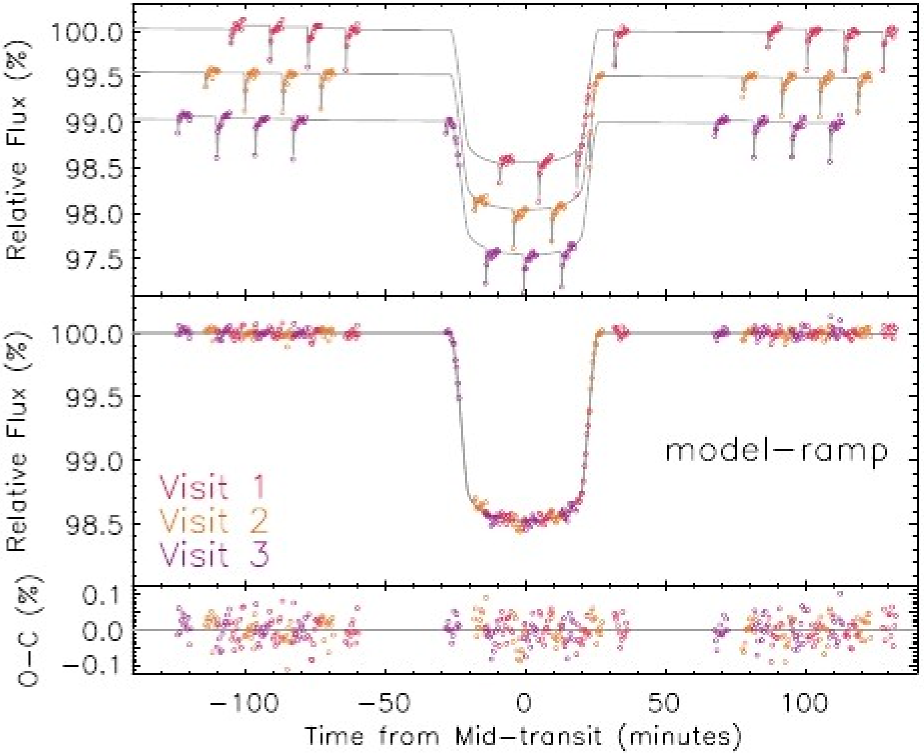
2002: Sodium detected
2003: $H_2$ detected
2004: $O_2$ & C & $3R_p$ atmo and tail indicating evaporating atmosphere.
2007: Balmer series & jump detected, providing the picture at left.

All HST UV/nUV transmission spectroscopy.

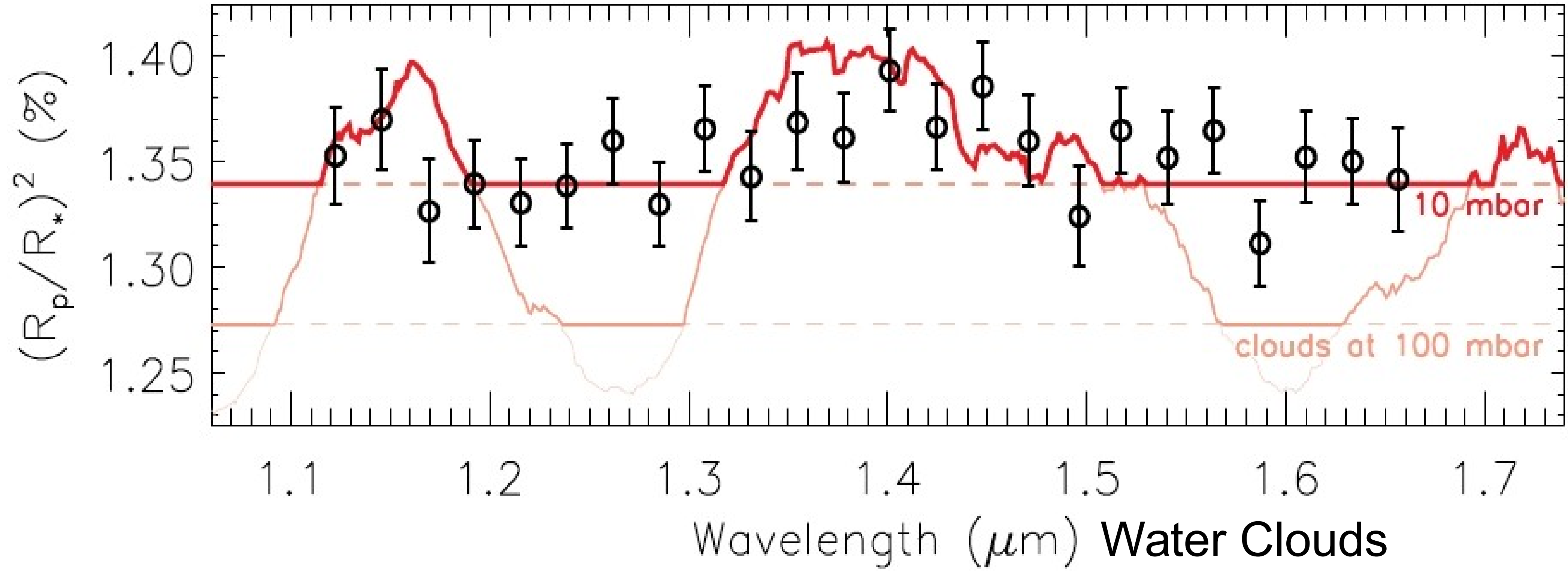
# A Hot Jupiter

*Image Credit: L. McKibben and G.E. Ballester (UA-LPL)*

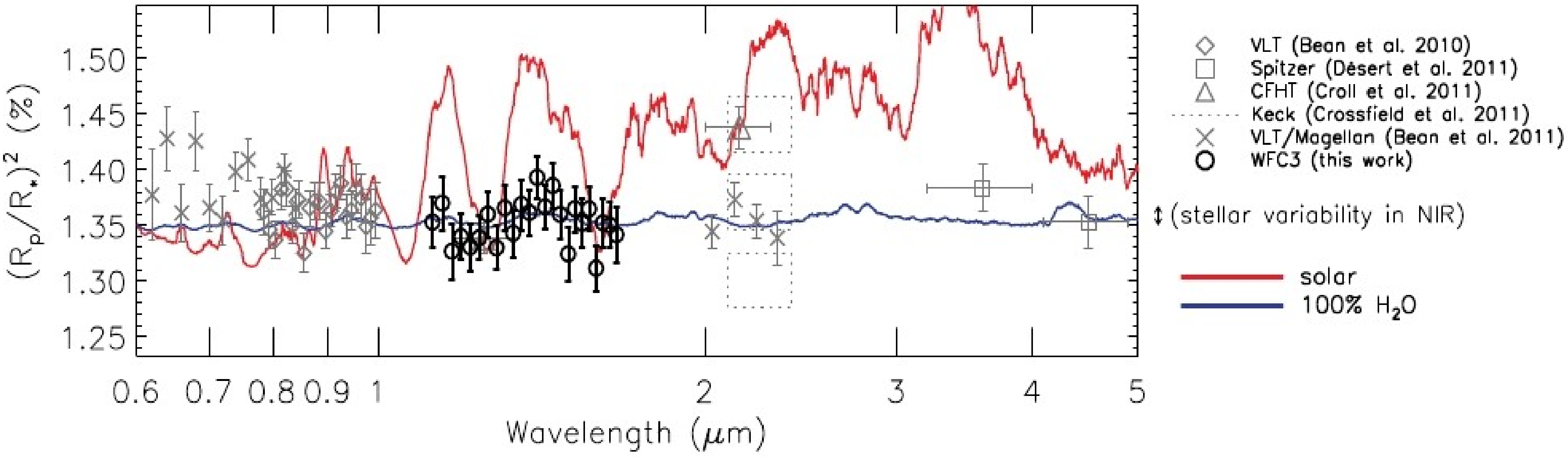
# Findings and speculations for hot (super)Earths that we're interested in.



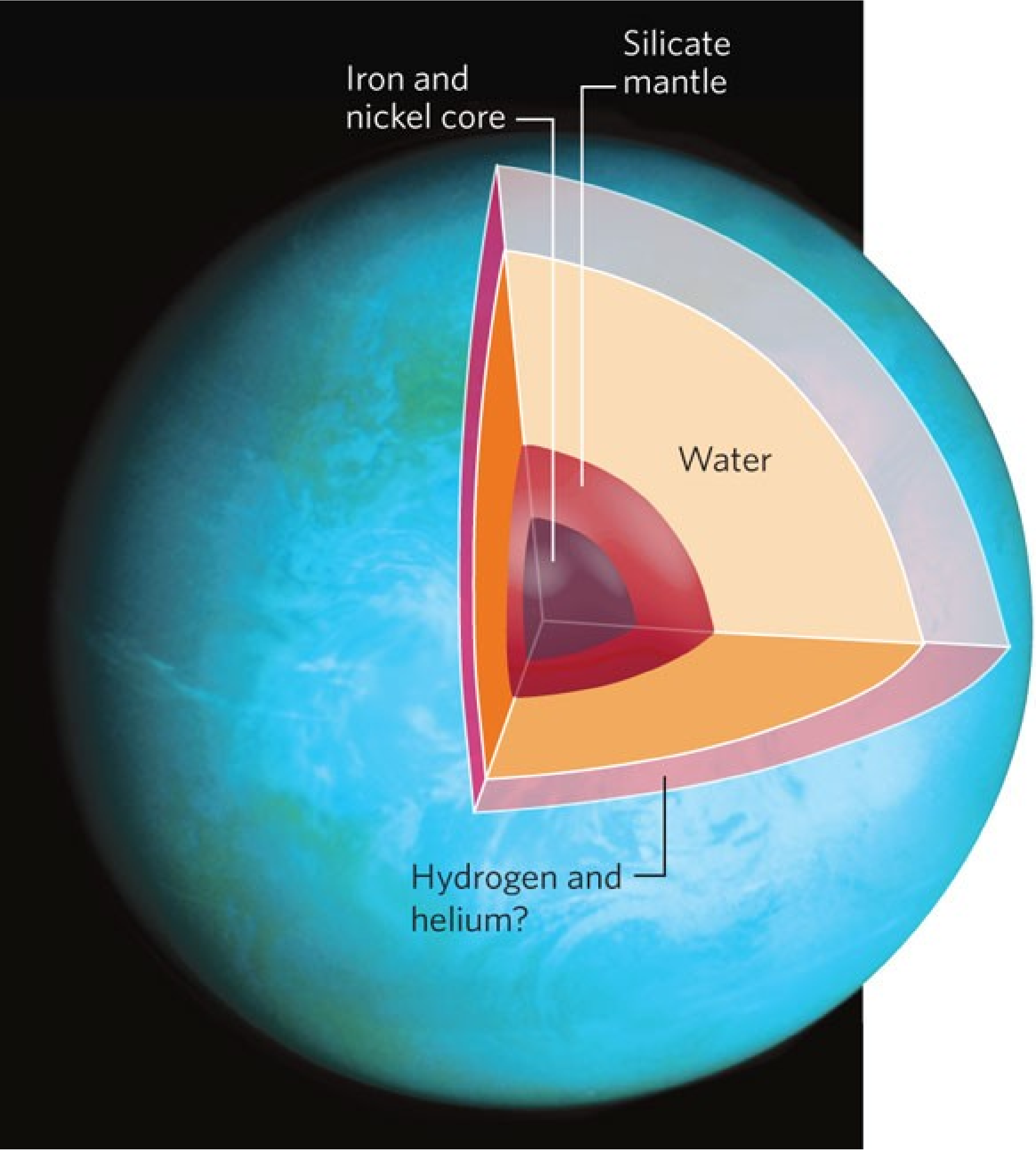
HST transmission spectroscopy determined that the atmosphere is optically thick for GJ1214b ($R=2.7R_{Earth}$ Berta et al. 2011)



Water Clouds



Overall, GJ1214b's IR transmission spectrum is consistent with $H_2O$ (doesn't mean that's what it is though!).



# GJ1214b is a hot Super-Earth:

Mass = 6.5 $M_{Earth}$

Radius = 2.7 $R_{Earth}$

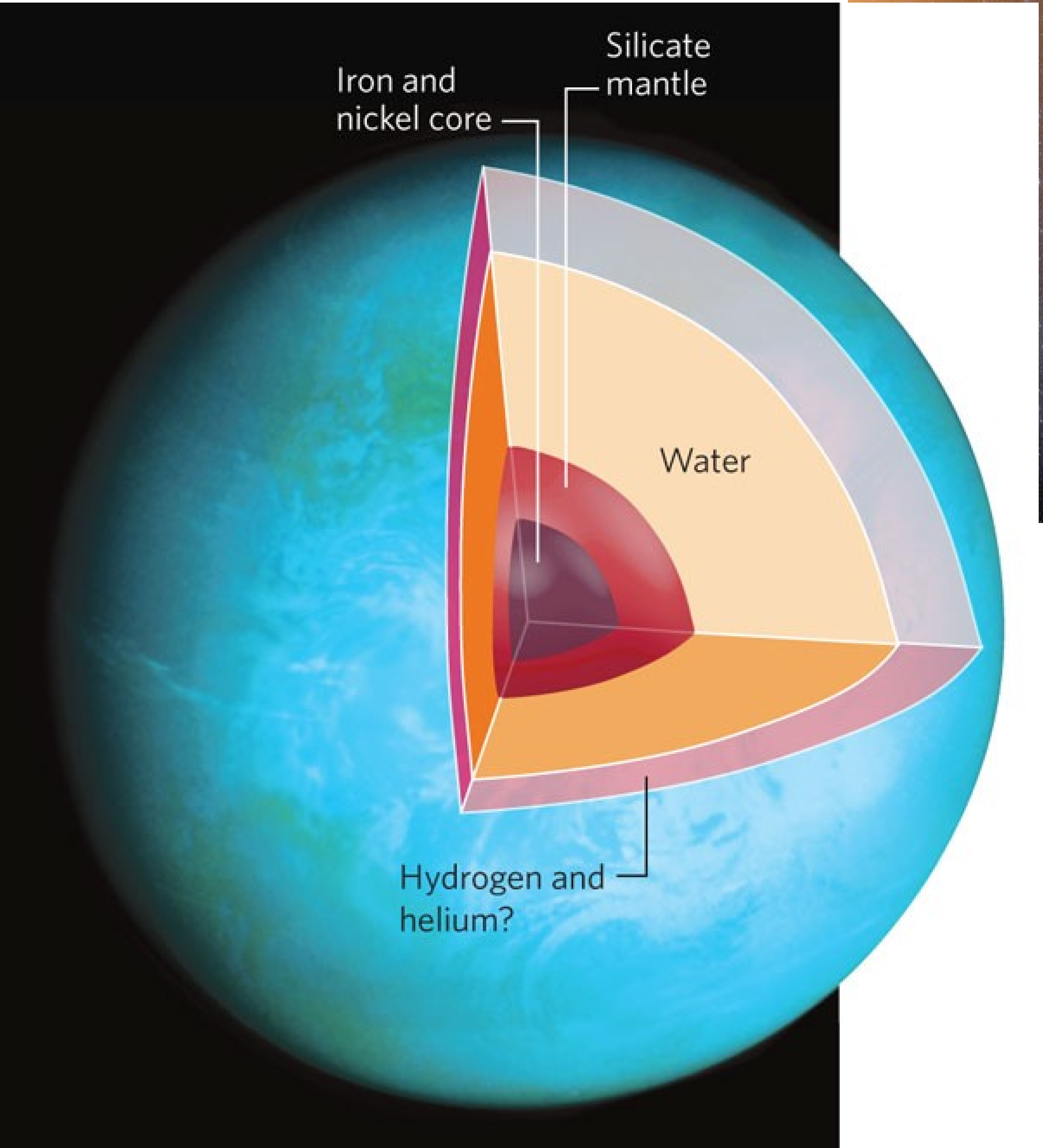
$\rho$ = 1.6 +/- 0.6 g/cc

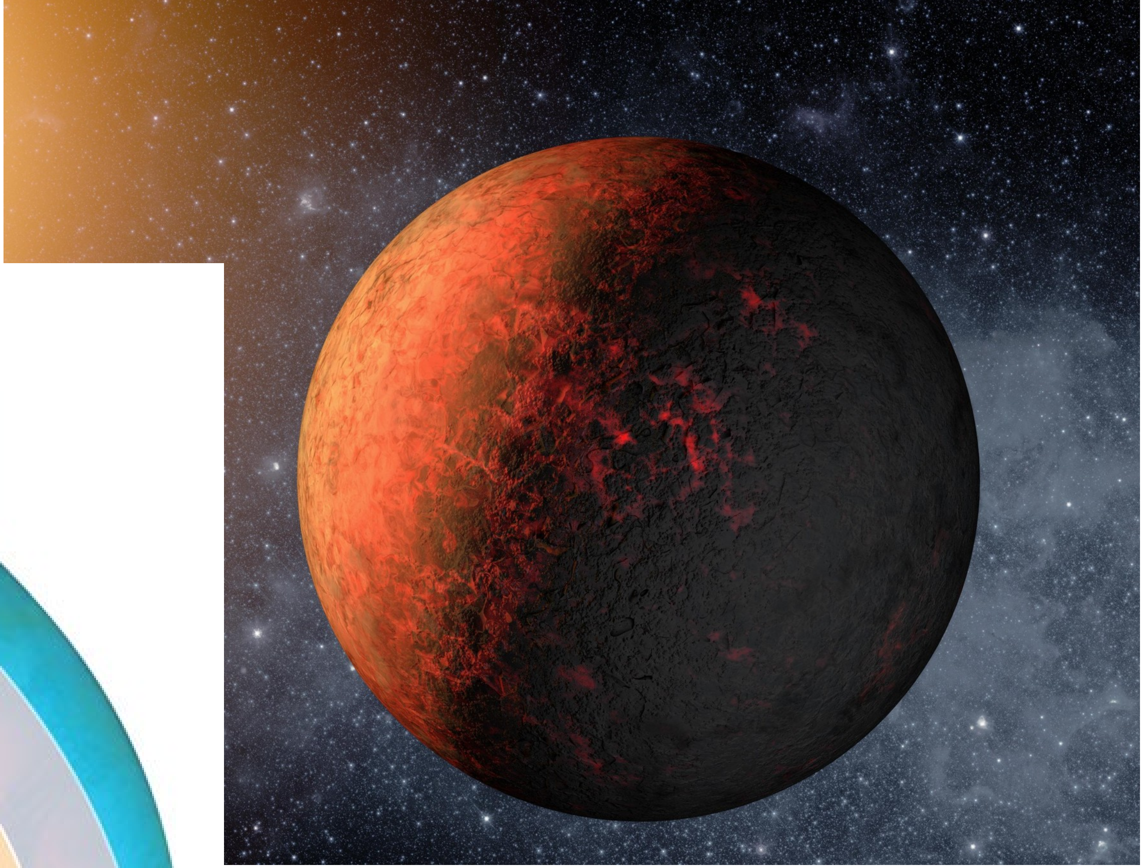
(Anglada-Escude et al. 2013)

BUT... a side note that CFHT WIRCam observations indicate a H/He atmosphere inconsistent with a water world. (Croll et al. 2011; transmission spectra)

# 55 Cnc e

$M=7.8M_{Earth}$ $R=2.17R_{Earth}$

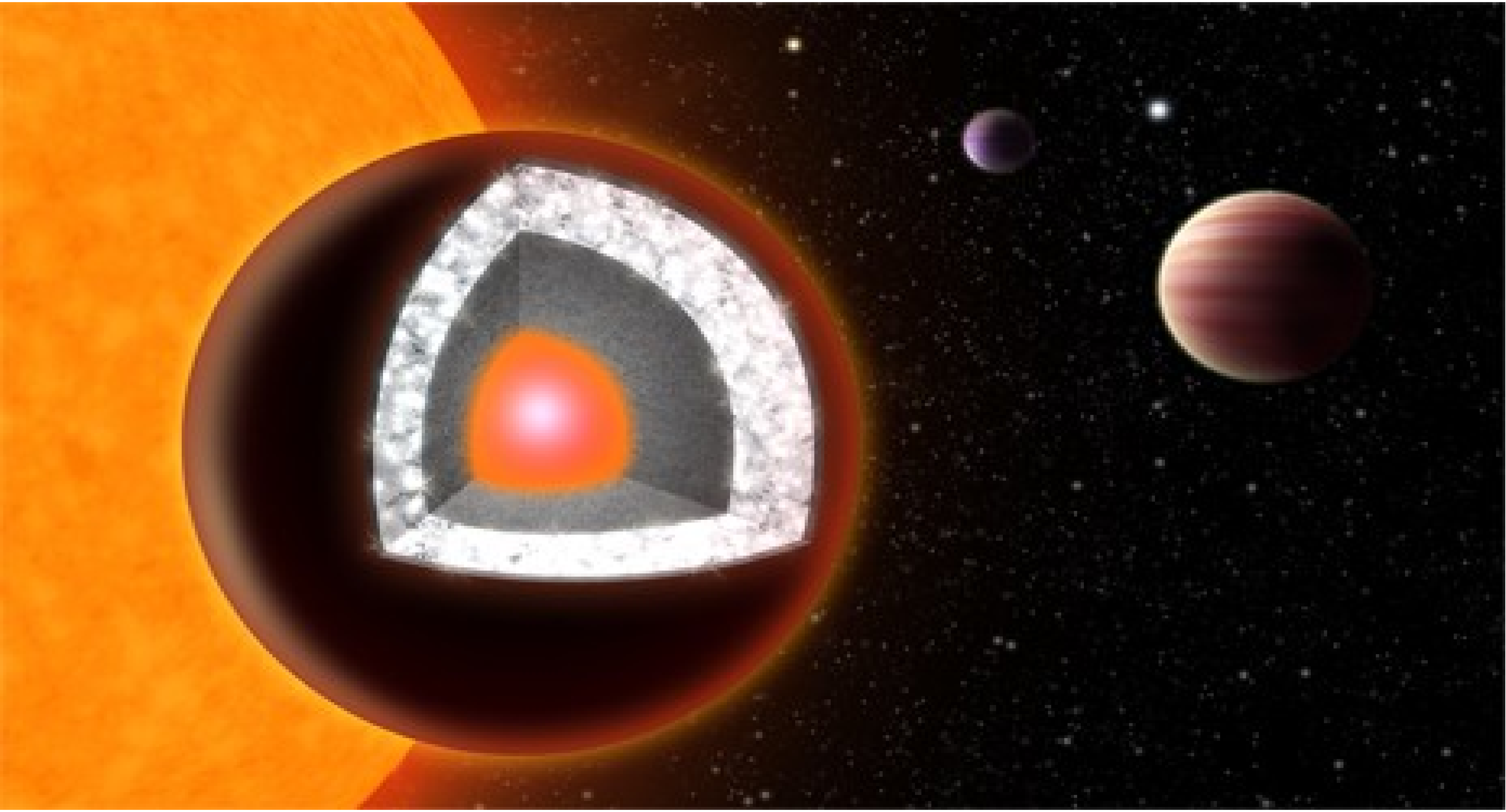




Originally a hot rock, then the density was downgraded to $4.78^{+1.31}_{-1.20}$g/cc (Demory 2011)

Steamy water atmosphere?

# 55 Cnc e: Now fortified with Carbon!
# $M \sim 8M_{Earth}$, $R \sim 2.2R_{Earth}$, $P_{orb}=18$ hours $T \sim 2{,}400K$
# (Madhusudhan et al. 2012)



# CoRoT-7b

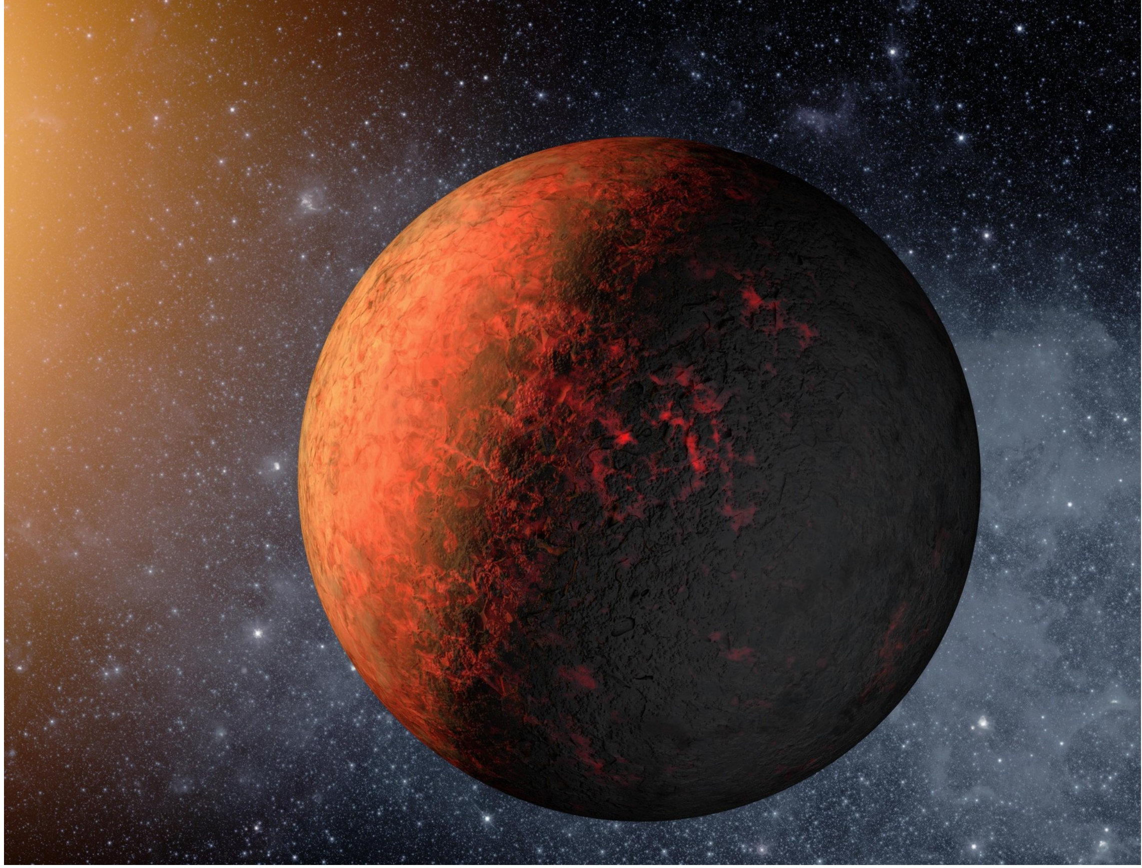
$M=7.42M_{Earth}$ $R=1.58R_{Earth}$

$\rho = 10.4\ ^{+}/_{-}\ 1.8$ g/cc

# Kepler 10b

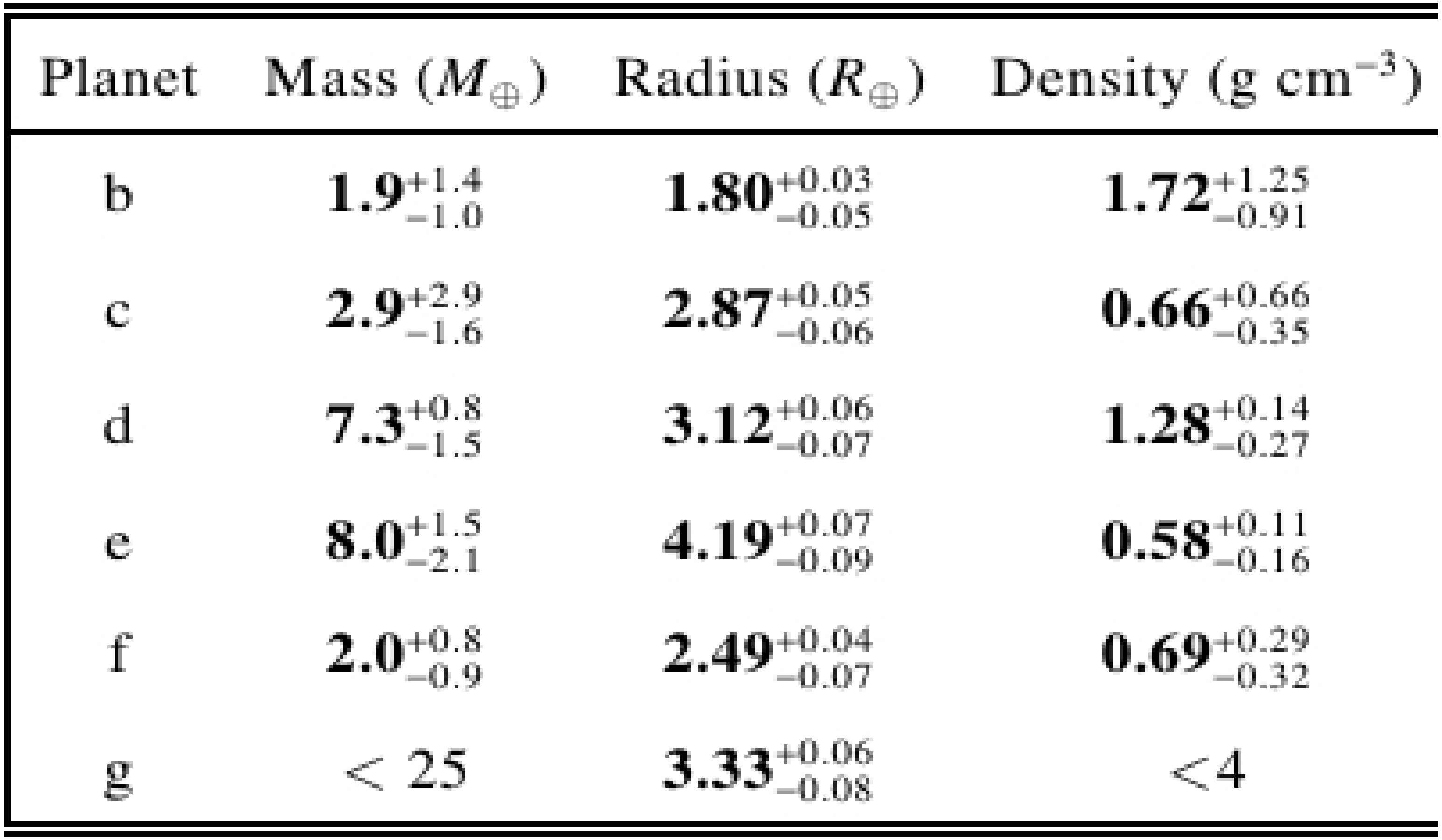
$M=4.5M_{Earth}$ $R=1.4R_{Earth}$

$\rho = 8.7$ g/cc



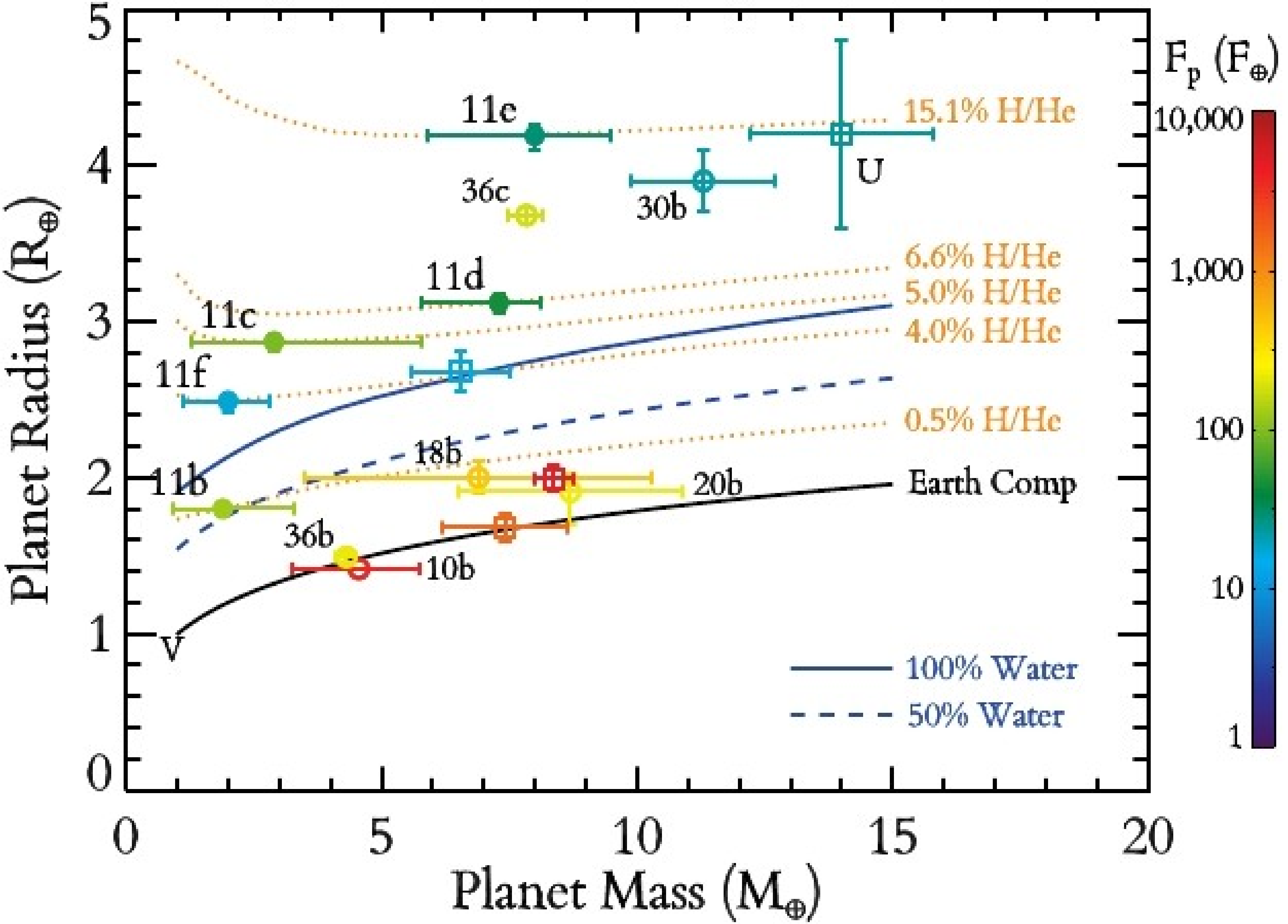
Both claimed as Fe-rich Mercury-like from structural models only (Gong & Zhou 2012 and Wagner et al. 2012).

# Kepler 11 has 6 planets, 5 with orbital periods under 50 days.

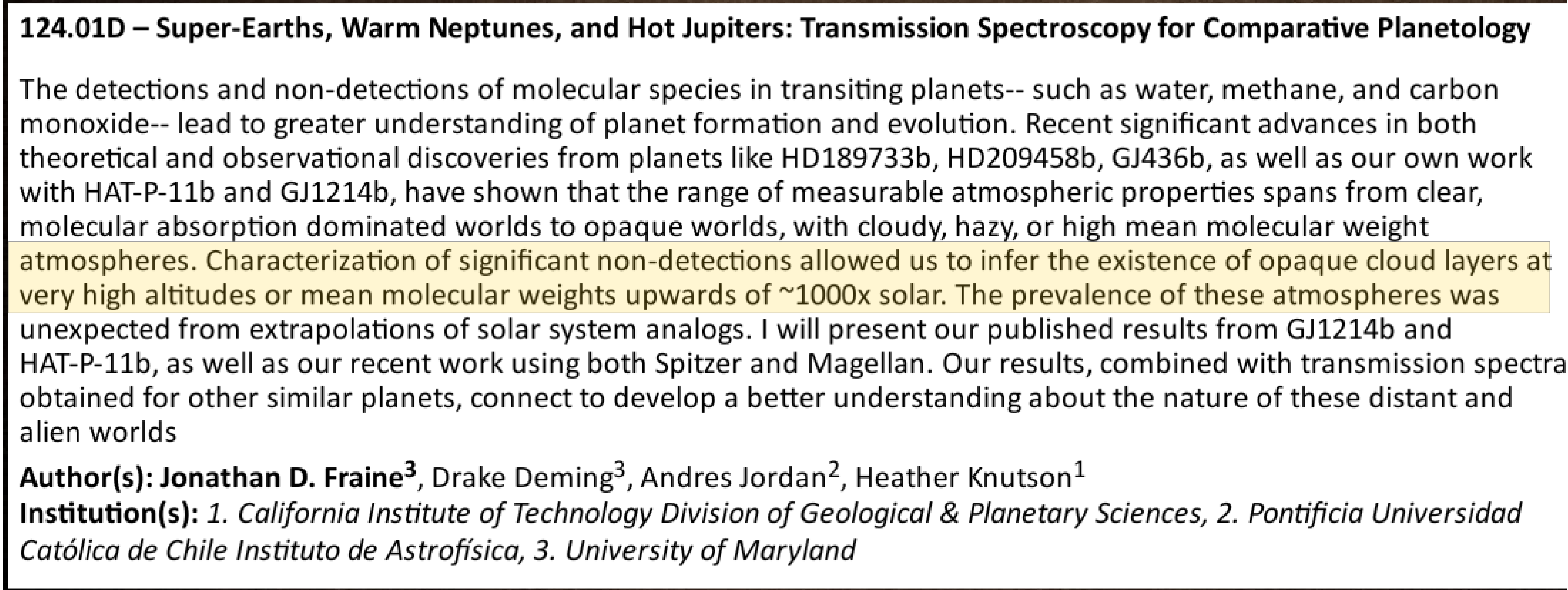


| Planet | Mass ($M_\oplus$) | Radius ($R_\oplus$) | Density (g cm$^{-3}$) |
|---|---|---|---|
| b | $\mathbf{1.9}^{+1.4}_{-1.0}$ | $\mathbf{1.80}^{+0.03}_{-0.05}$ | $\mathbf{1.72}^{+1.25}_{-0.91}$ |
| c | $\mathbf{2.9}^{+2.9}_{-1.6}$ | $\mathbf{2.87}^{+0.05}_{-0.06}$ | $\mathbf{0.66}^{+0.66}_{-0.35}$ |
| d | $\mathbf{7.3}^{+0.8}_{-1.5}$ | $\mathbf{3.12}^{+0.06}_{-0.07}$ | $\mathbf{1.28}^{+0.14}_{-0.27}$ |
| e | $\mathbf{8.0}^{+1.5}_{-2.1}$ | $\mathbf{4.19}^{+0.07}_{-0.09}$ | $\mathbf{0.58}^{+0.11}_{-0.16}$ |
| f | $\mathbf{2.0}^{+0.8}_{-0.9}$ | $\mathbf{2.49}^{+0.04}_{-0.07}$ | $\mathbf{0.69}^{+0.29}_{-0.32}$ |
| g | $< 25$ | $\mathbf{3.33}^{+0.06}_{-0.08}$ | $<4$ |

But all with low densities. (Lissauer et al. 2013)


Planet Radius (R⊕)
Planet Mass (M⊕)
0
1
2
3
4
5
0
5
10
15
20
Fp (F⊕)
10,000
1,000
100
10
1
15.1% H/He
6.6% H/He
5.0% H/He
4.0% H/He
0.5% H/He
Earth Comp
100% Water
50% Water
11e
11d
11c
11f
11b
36c
36b
30b
18b
20b
10b
U
V

# Reports as of Jan. 2015

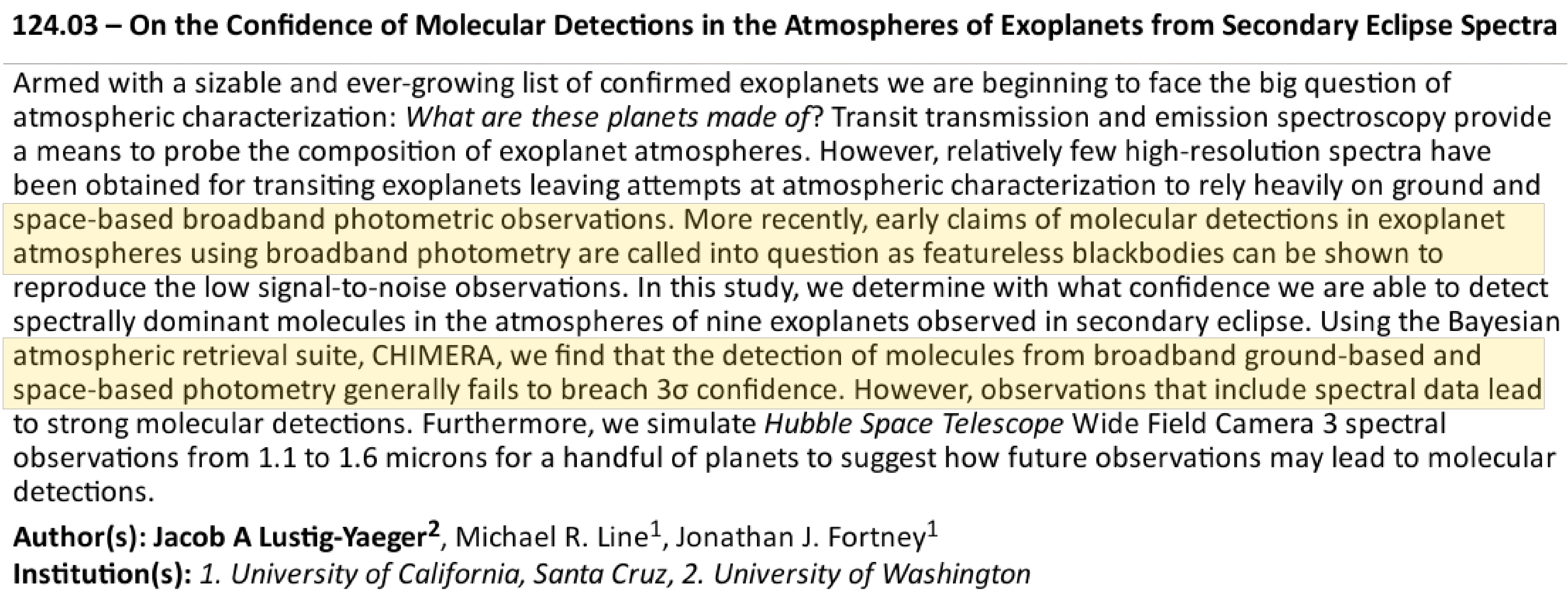


**124.01D – Super-Earths, Warm Neptunes, and Hot Jupiters: Transmission Spectroscopy for Comparative Planetology**

The detections and non-detections of molecular species in transiting planets-- such as water, methane, and carbon monoxide-- lead to greater understanding of planet formation and evolution. Recent significant advances in both theoretical and observational discoveries from planets like HD189733b, HD209458b, GJ436b, as well as our own work with HAT-P-11b and GJ1214b, have shown that the range of measurable atmospheric properties spans from clear, molecular absorption dominated worlds to opaque worlds, with cloudy, hazy, or high mean molecular weight atmospheres. Characterization of significant non-detections allowed us to infer the existence of opaque cloud layers at very high altitudes or mean molecular weights upwards of ~1000x solar. The prevalence of these atmospheres was unexpected from extrapolations of solar system analogs. I will present our published results from GJ1214b and HAT-P-11b, as well as our recent work using both Spitzer and Magellan. Our results, combined with transmission spectra obtained for other similar planets, connect to develop a better understanding about the nature of these distant and alien worlds

**Author(s): Jonathan D. Fraine[3]**, Drake Deming[3], Andres Jordan[2], Heather Knutson[1]
**Institution(s):** *1. California Institute of Technology Division of Geological & Planetary Sciences, 2. Pontificia Universidad Católica de Chile Instituto de Astrofísica, 3. University of Maryland*

# Reports as of Jan. 2015

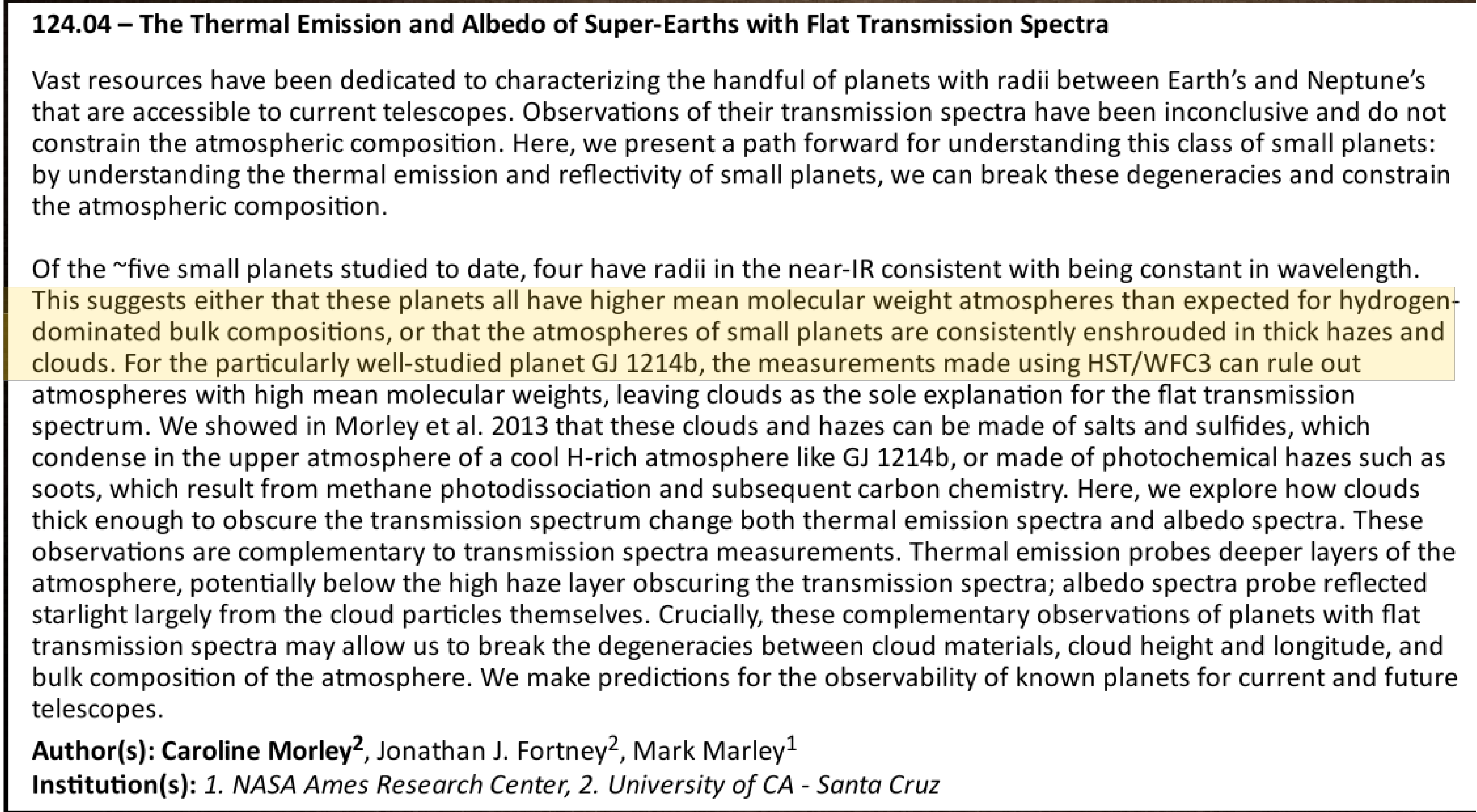


**124.03 – On the Confidence of Molecular Detections in the Atmospheres of Exoplanets from Secondary Eclipse Spectra**

Armed with a sizable and ever-growing list of confirmed exoplanets we are beginning to face the big question of atmospheric characterization: *What are these planets made of*? Transit transmission and emission spectroscopy provide a means to probe the composition of exoplanet atmospheres. However, relatively few high-resolution spectra have been obtained for transiting exoplanets leaving attempts at atmospheric characterization to rely heavily on ground and space-based broadband photometric observations. More recently, early claims of molecular detections in exoplanet atmospheres using broadband photometry are called into question as featureless blackbodies can be shown to reproduce the low signal-to-noise observations. In this study, we determine with what confidence we are able to detect spectrally dominant molecules in the atmospheres of nine exoplanets observed in secondary eclipse. Using the Bayesian atmospheric retrieval suite, CHIMERA, we find that the detection of molecules from broadband ground-based and space-based photometry generally fails to breach 3σ confidence. However, observations that include spectral data lead to strong molecular detections. Furthermore, we simulate *Hubble Space Telescope* Wide Field Camera 3 spectral observations from 1.1 to 1.6 microns for a handful of planets to suggest how future observations may lead to molecular detections.

**Author(s): Jacob A Lustig-Yaeger[2]**, Michael R. Line[1], Jonathan J. Fortney[1]
**Institution(s):** *1. University of California, Santa Cruz, 2. University of Washington*

# Reports as of Jan. 2015



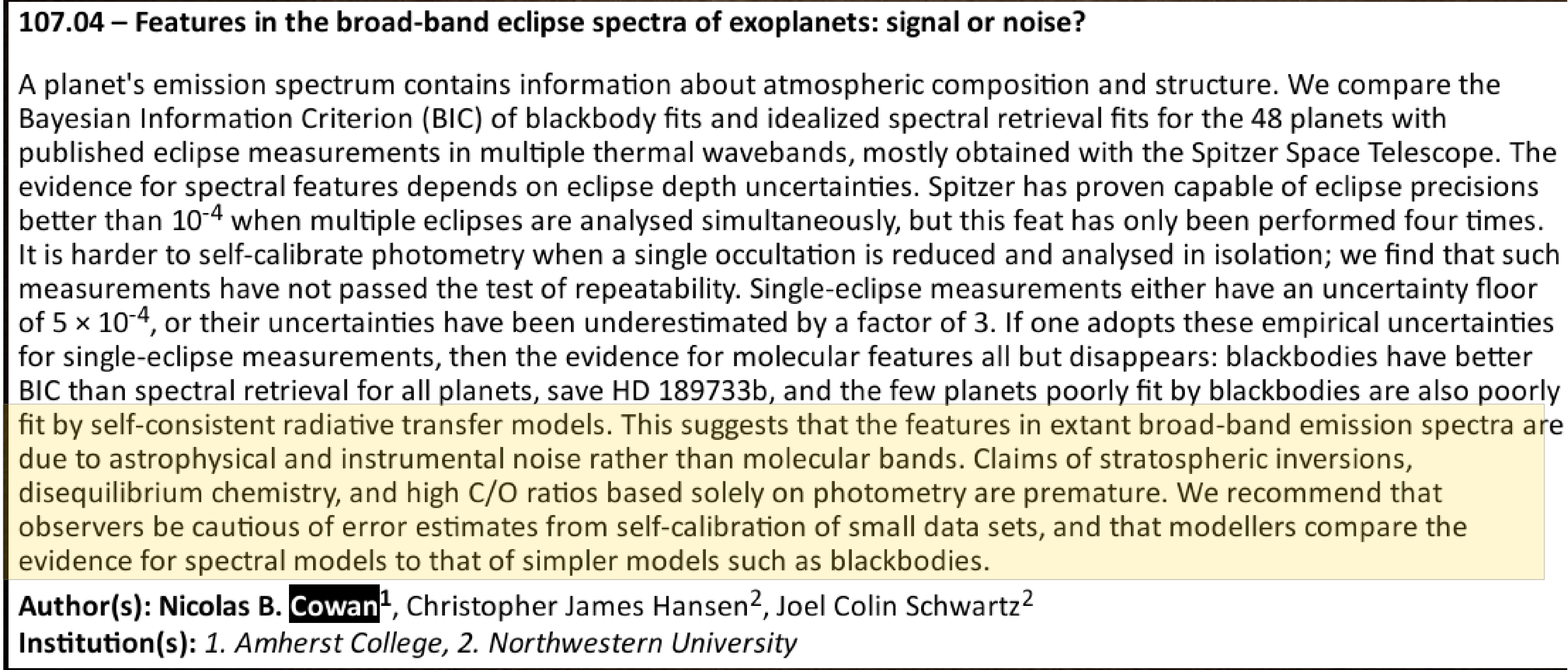
**124.04 – The Thermal Emission and Albedo of Super-Earths with Flat Transmission Spectra**

Vast resources have been dedicated to characterizing the handful of planets with radii between Earth's and Neptune's that are accessible to current telescopes. Observations of their transmission spectra have been inconclusive and do not constrain the atmospheric composition. Here, we present a path forward for understanding this class of small planets: by understanding the thermal emission and reflectivity of small planets, we can break these degeneracies and constrain the atmospheric composition.

Of the ~five small planets studied to date, four have radii in the near-IR consistent with being constant in wavelength. This suggests either that these planets all have higher mean molecular weight atmospheres than expected for hydrogen-dominated bulk compositions, or that the atmospheres of small planets are consistently enshrouded in thick hazes and clouds. For the particularly well-studied planet GJ 1214b, the measurements made using HST/WFC3 can rule out atmospheres with high mean molecular weights, leaving clouds as the sole explanation for the flat transmission spectrum. We showed in Morley et al. 2013 that these clouds and hazes can be made of salts and sulfides, which condense in the upper atmosphere of a cool H-rich atmosphere like GJ 1214b, or made of photochemical hazes such as soots, which result from methane photodissociation and subsequent carbon chemistry. Here, we explore how clouds thick enough to obscure the transmission spectrum change both thermal emission spectra and albedo spectra. These observations are complementary to transmission spectra measurements. Thermal emission probes deeper layers of the atmosphere, potentially below the high haze layer obscuring the transmission spectra; albedo spectra probe reflected starlight largely from the cloud particles themselves. Crucially, these complementary observations of planets with flat transmission spectra may allow us to break the degeneracies between cloud materials, cloud height and longitude, and bulk composition of the atmosphere. We make predictions for the observability of known planets for current and future telescopes.

**Author(s): Caroline Morley[2]**, Jonathan J. Fortney[2], Mark Marley[1]
**Institution(s):** *1. NASA Ames Research Center, 2. University of CA - Santa Cruz*

# Reports as of Jan. 2015



**107.04 – Features in the broad-band eclipse spectra of exoplanets: signal or noise?**

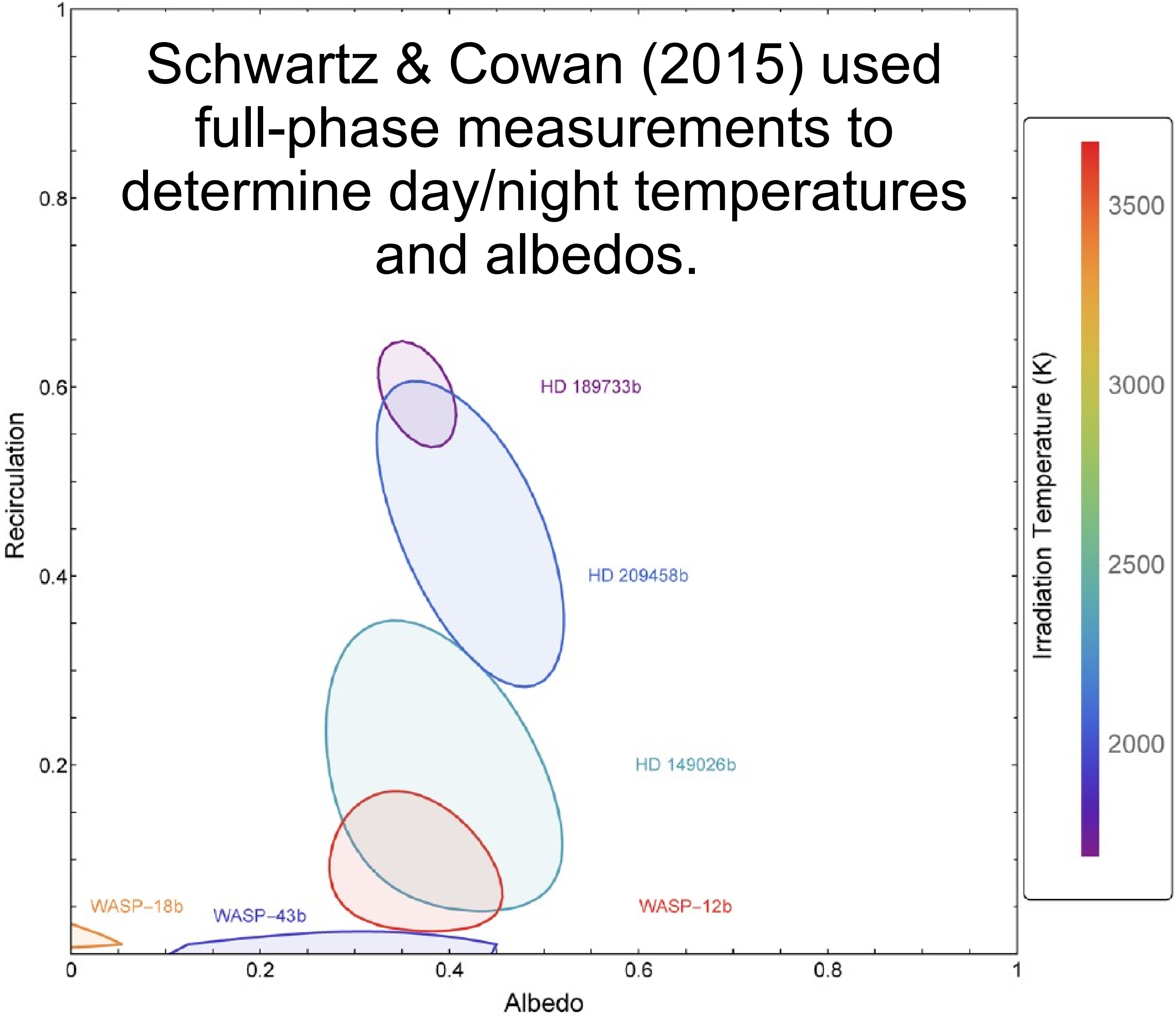
A planet's emission spectrum contains information about atmospheric composition and structure. We compare the Bayesian Information Criterion (BIC) of blackbody fits and idealized spectral retrieval fits for the 48 planets with published eclipse measurements in multiple thermal wavebands, mostly obtained with the Spitzer Space Telescope. The evidence for spectral features depends on eclipse depth uncertainties. Spitzer has proven capable of eclipse precisions better than $10^{-4}$ when multiple eclipses are analysed simultaneously, but this feat has only been performed four times. It is harder to self-calibrate photometry when a single occultation is reduced and analysed in isolation; we find that such measurements have not passed the test of repeatability. Single-eclipse measurements either have an uncertainty floor of $5 \times 10^{-4}$, or their uncertainties have been underestimated by a factor of 3. If one adopts these empirical uncertainties for single-eclipse measurements, then the evidence for molecular features all but disappears: blackbodies have better BIC than spectral retrieval for all planets, save HD 189733b, and the few planets poorly fit by blackbodies are also poorly fit by self-consistent radiative transfer models. This suggests that the features in extant broad-band emission spectra are due to astrophysical and instrumental noise rather than molecular bands. Claims of stratospheric inversions, disequilibrium chemistry, and high C/O ratios based solely on photometry are premature. We recommend that observers be cautious of error estimates from self-calibration of small data sets, and that modellers compare the evidence for spectral models to that of simpler models such as blackbodies.

**Author(s):** **Nicolas B. Cowan**[1], Christopher James Hansen[2], Joel Colin Schwartz[2]
**Institution(s):** *1. Amherst College, 2. Northwestern University*

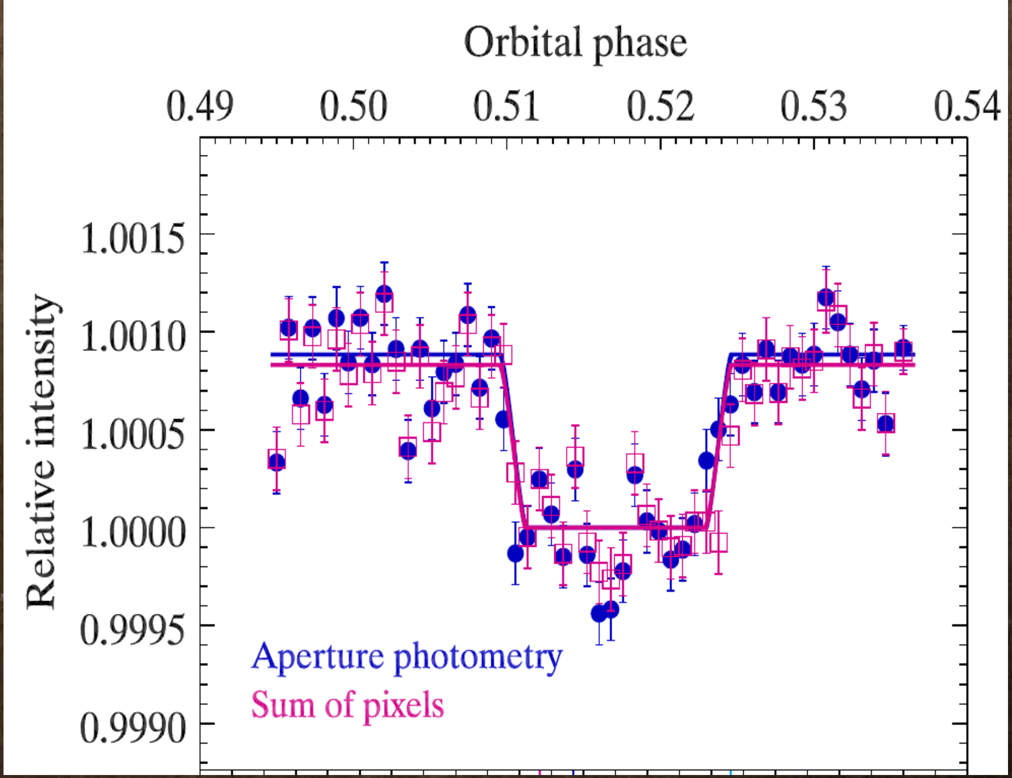
# Reports as of Jan. 2015

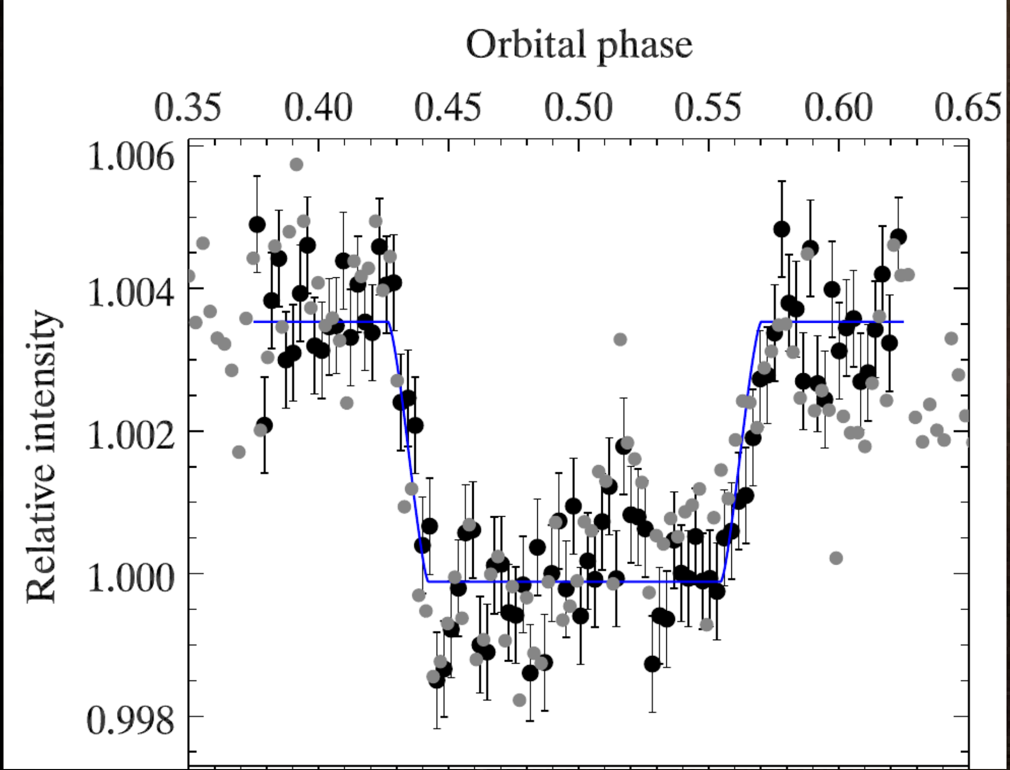
So transmission spectroscopy is not very useful, and reflection spectroscopy (albedo measurements) is the current 'best bet' for measuring something.

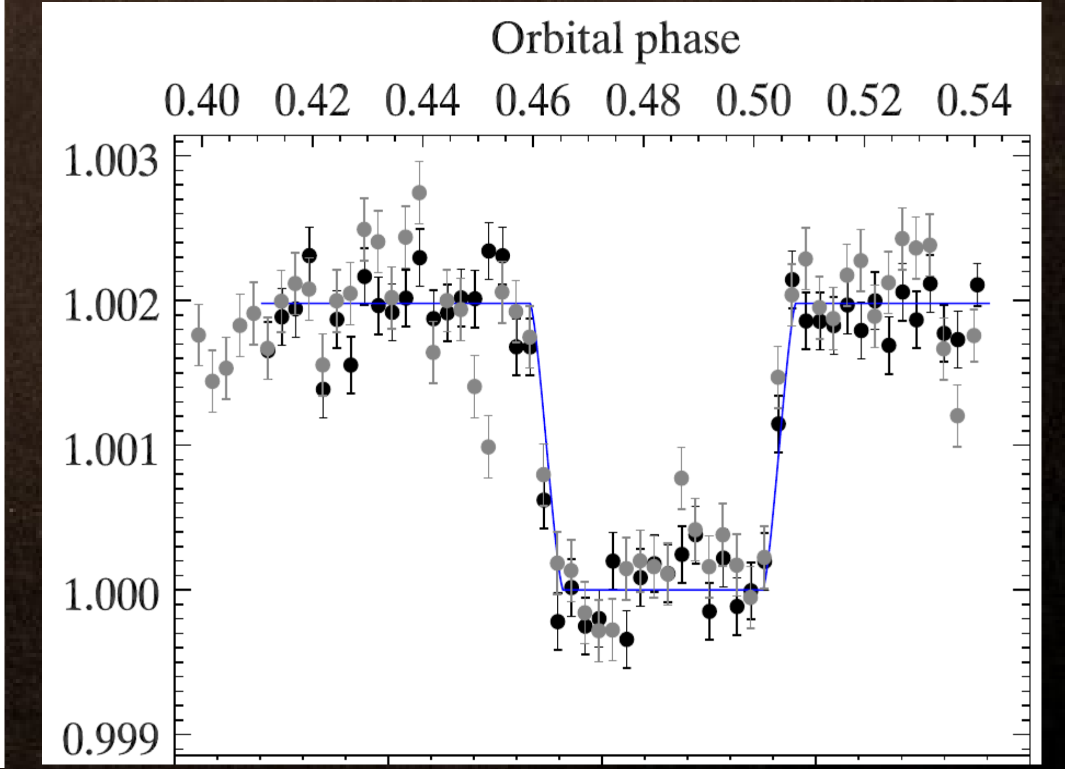
# Schwartz & Cowan (2015) used full-phase measurements to determine day/night temperatures and albedos.



Deming et al. (2015) have developed a new photometric technique and extracted secondary eclipses for several stars.

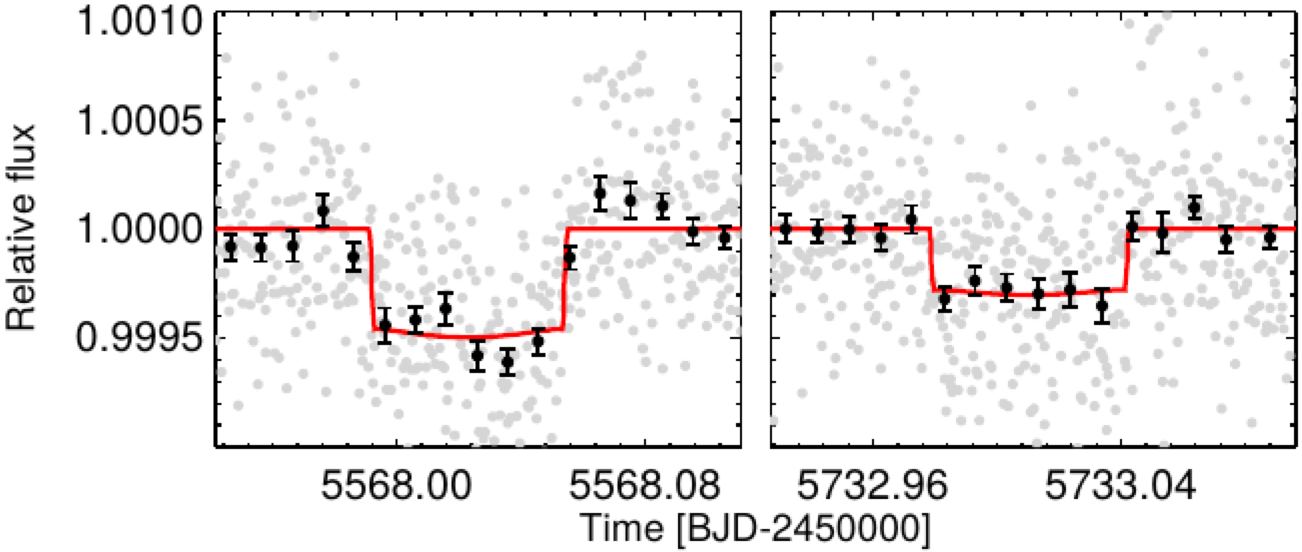


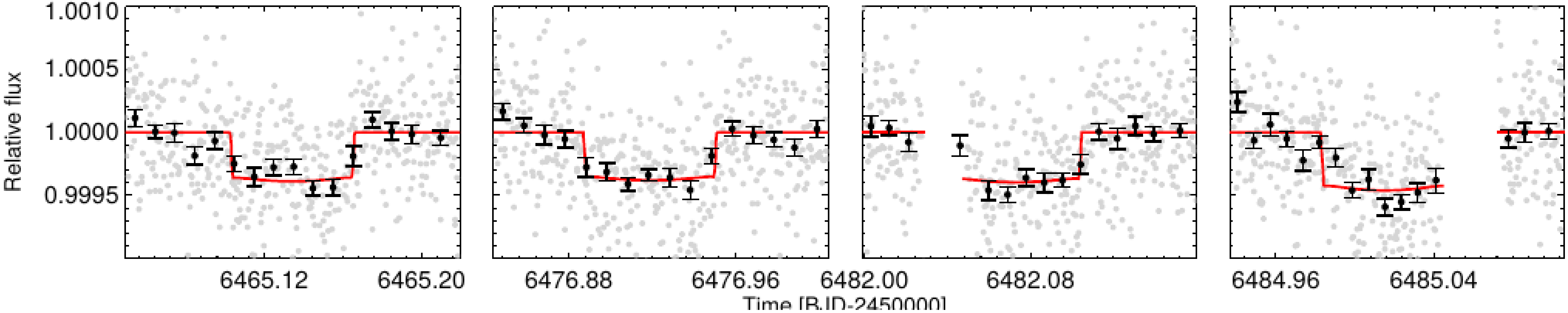


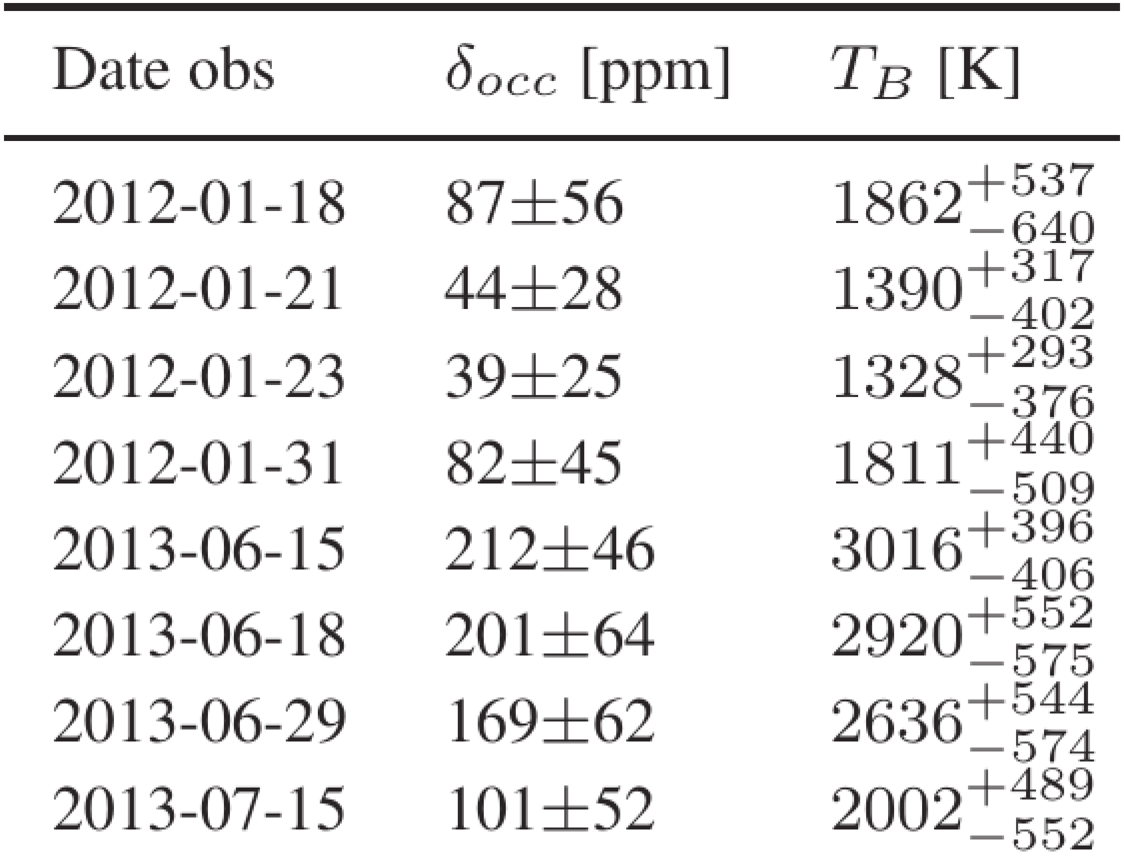


# Demory et al. (2015) looked again at 55 Cnc e (hot rock) and found variability in transit depths.

| Date obs | Transit depth [ppm] |
|---|---|
| 2011-01-06 | 484±74 |
| 2011-06-20 | 287±52 |
| 2013-06-21 | 325±76 |
| 2013-07-03 | 365±43 |
| 2013-07-08 | 406±78 |
| 2013-07-11 | 433±90 |

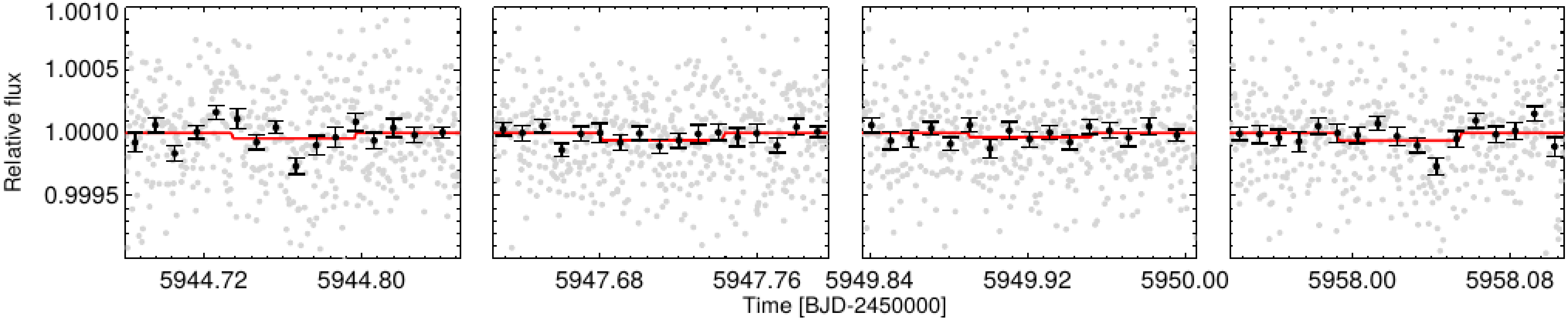






| Date obs | $\delta_{occ}$ [ppm] | $T_B$ [K] |
|---|---|---|
| 2012-01-18 | 87±56 | $1862^{+537}_{-640}$ |
| 2012-01-21 | 44±28 | $1390^{+317}_{-402}$ |
| 2012-01-23 | 39±25 | $1328^{+293}_{-376}$ |
| 2012-01-31 | 82±45 | $1811^{+440}_{-509}$ |
| 2013-06-15 | 212±46 | $3016^{+396}_{-406}$ |
| 2013-06-18 | 201±64 | $2920^{+552}_{-575}$ |
| 2013-06-29 | 169±62 | $2636^{+544}_{-574}$ |
| 2013-07-15 | 101±52 | $2002^{+489}_{-552}$ |

Likewise, they measured secondary eclipse depths, with possible changes.



All of these are Spitzer IR or HST observations. Much tougher from the ground.

# Break?

# Observational Efforts

## What we've done

# Observational Efforts

At our first meeting, we had observed 5 nights and processed very little data.

But we were only 6 months into the grant, so this was not so surprising.

# Observational Efforts

At our first meeting, we had observed 5 nights and processed very little data.

At our second meeting, we had observed about 45 additional nights and processed a fair fraction of the data.

But little of it was “done”

# Observing- Exoplanet 1

**Corot 7b**.

Period= 0.85 days

Transit depth = 0.00035 mag

$M \sim 5M_{Earth}$

$R \sim 1.7R_{Earth}$

$\rho \sim 8.8\ (+/-3)$ g/cc

Spectral class: K0V

V=11.7

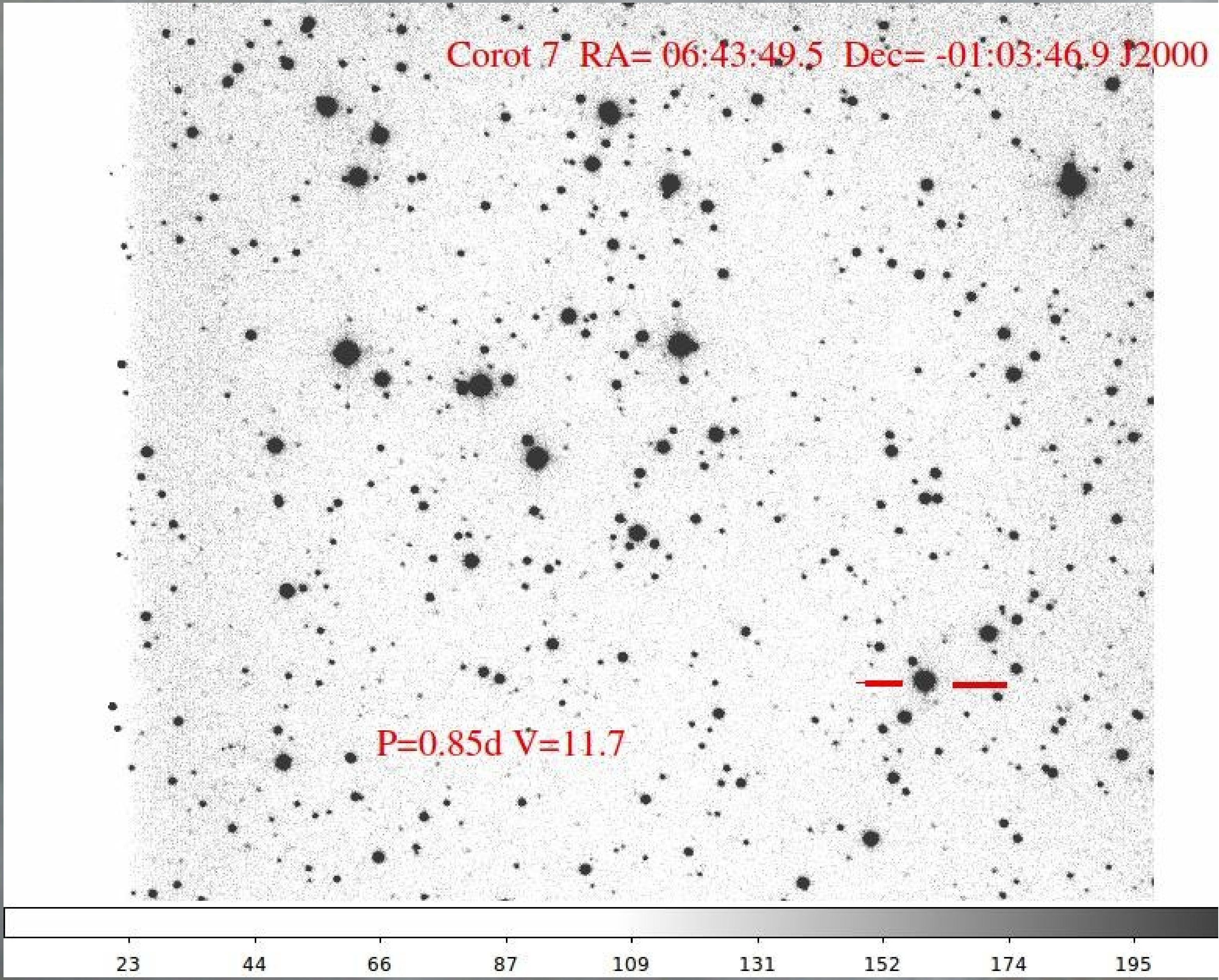
$R = 0.87R_{sun}$

$M = 0.93M_{sun}$

$T_{eff} = 5275$ K

# Corot7: A nice rich field with many comparison stars. 25.5 hrs over 5 nights.

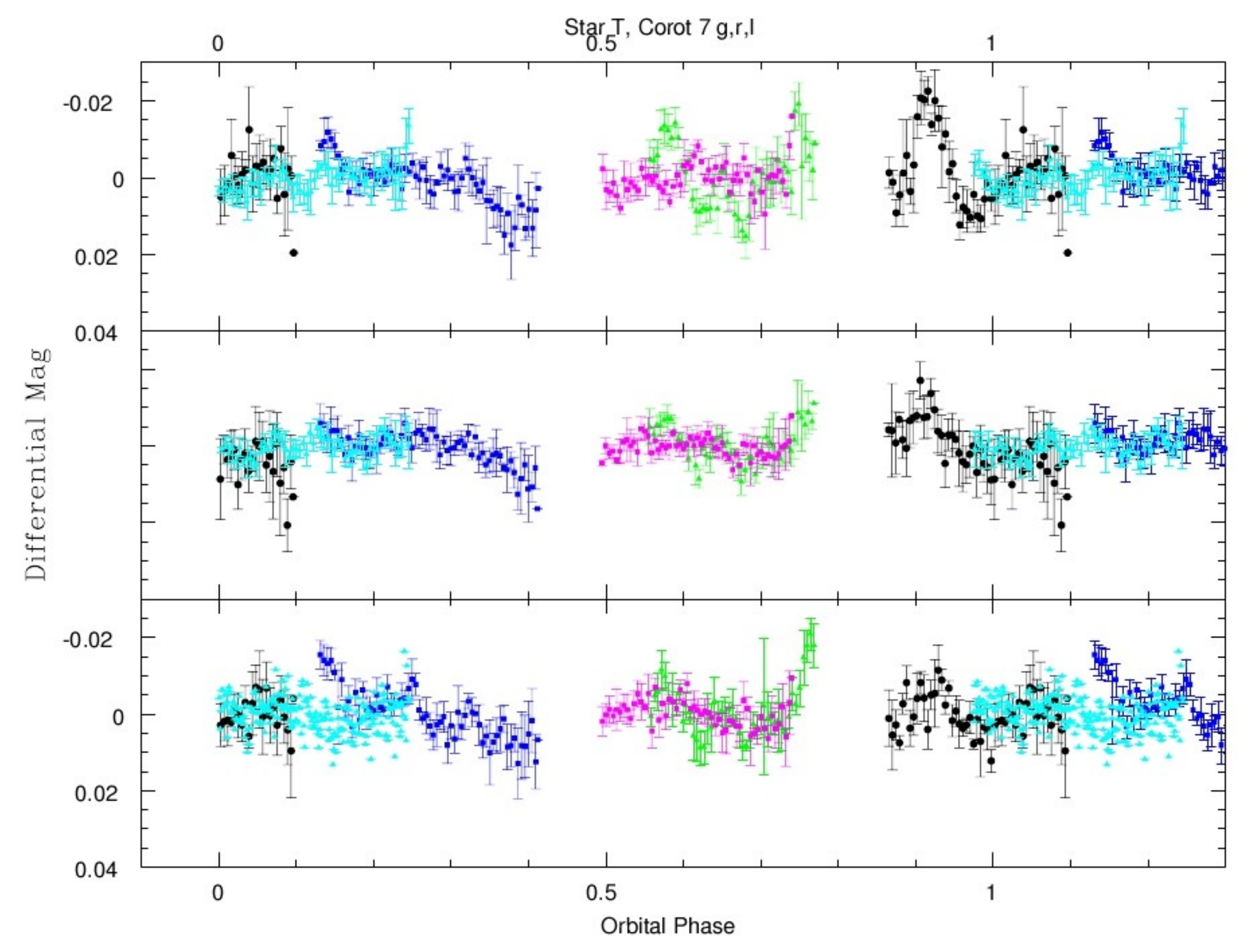
I showed this last year



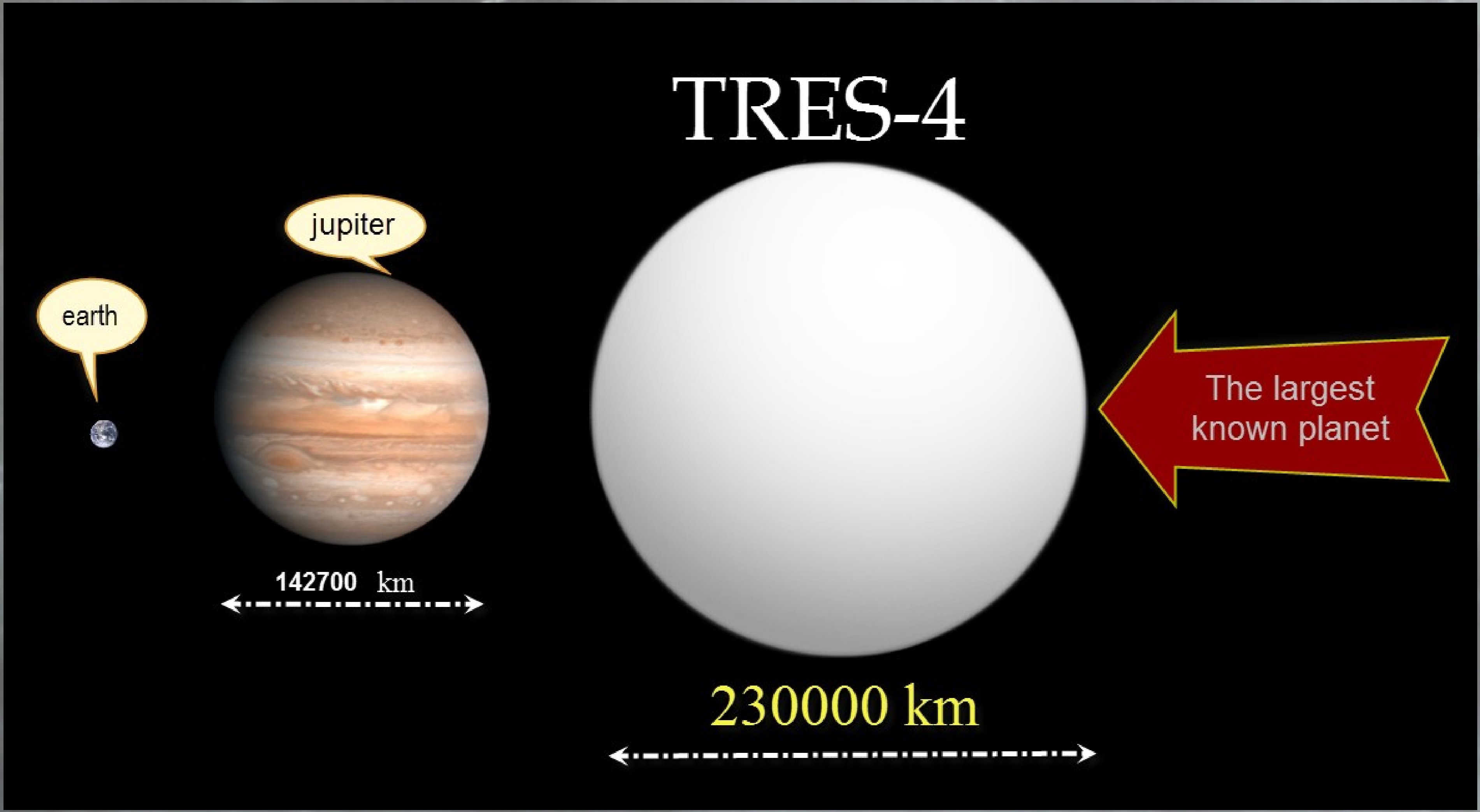
# After making all the corrections possible (position, airmass, comparison star color) the error is still much larger than what we hope to measure.

**But this was with the 'dirty' RS1340 camera, which we knew had issues.**

**So the extra work did not produce results, which was expected.**



# Observing- Exoplanet 2



# Observing- Exoplanet 2

**Tres-4b.**

Period= 3.55 days

$M \sim 0.9M_{Jupiter}$

$R \sim 1.78R_{Jupiter}$

$\rho \sim 0.2\ (+/-0.03)$ g/cc

Spectral class: F

V=11.6

$R = 1.82R_{sun}$

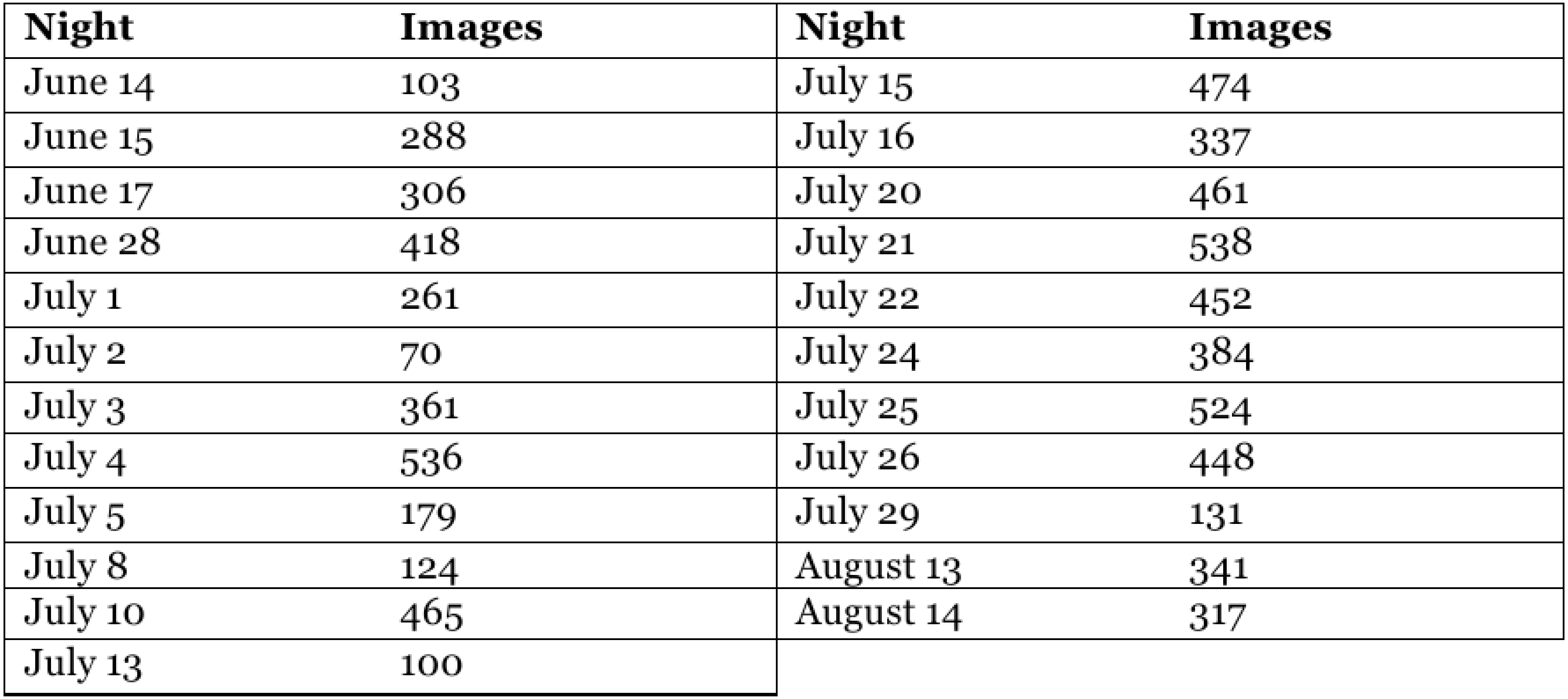
$M = 1.4M_{sun}$

$T_{eff} = 6200$ K

Transit depth = 0.00984 mag

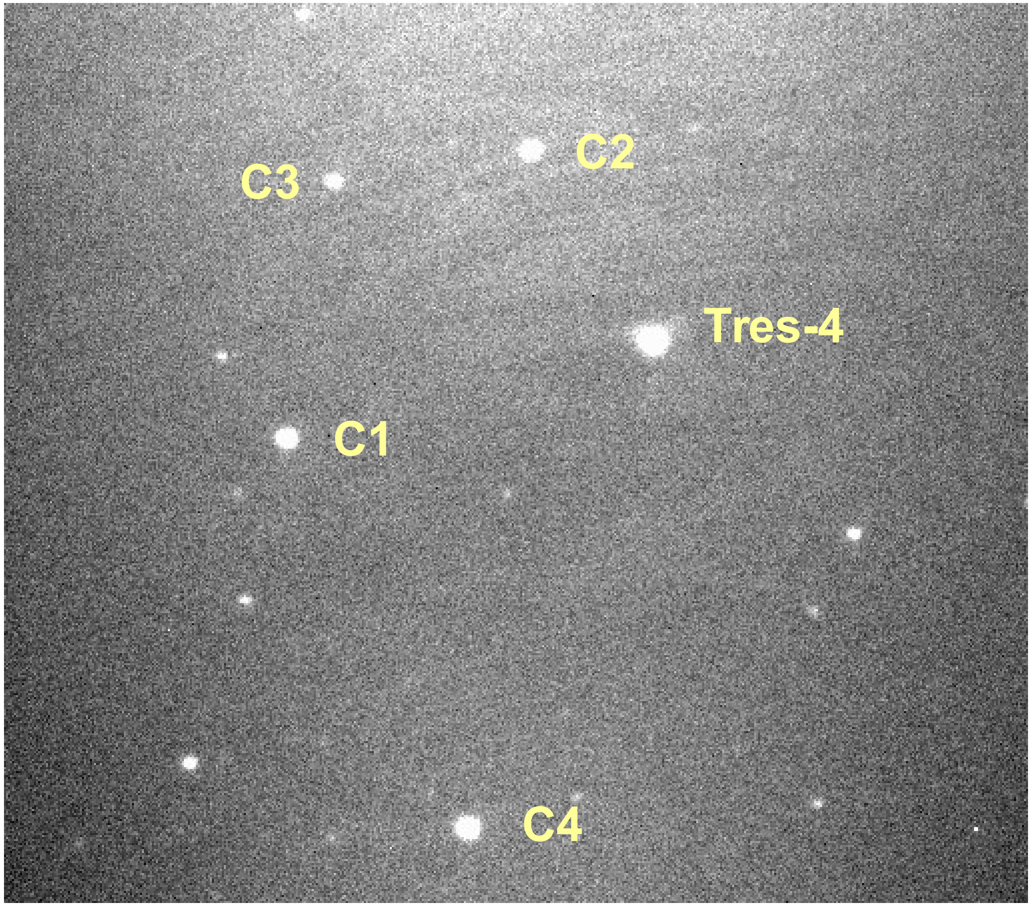
Secondary eclipse depth (IR) = 0.0014 mag

# 23 nights of data. 7618 images.
## But summer, lots of humidity, some clouds....

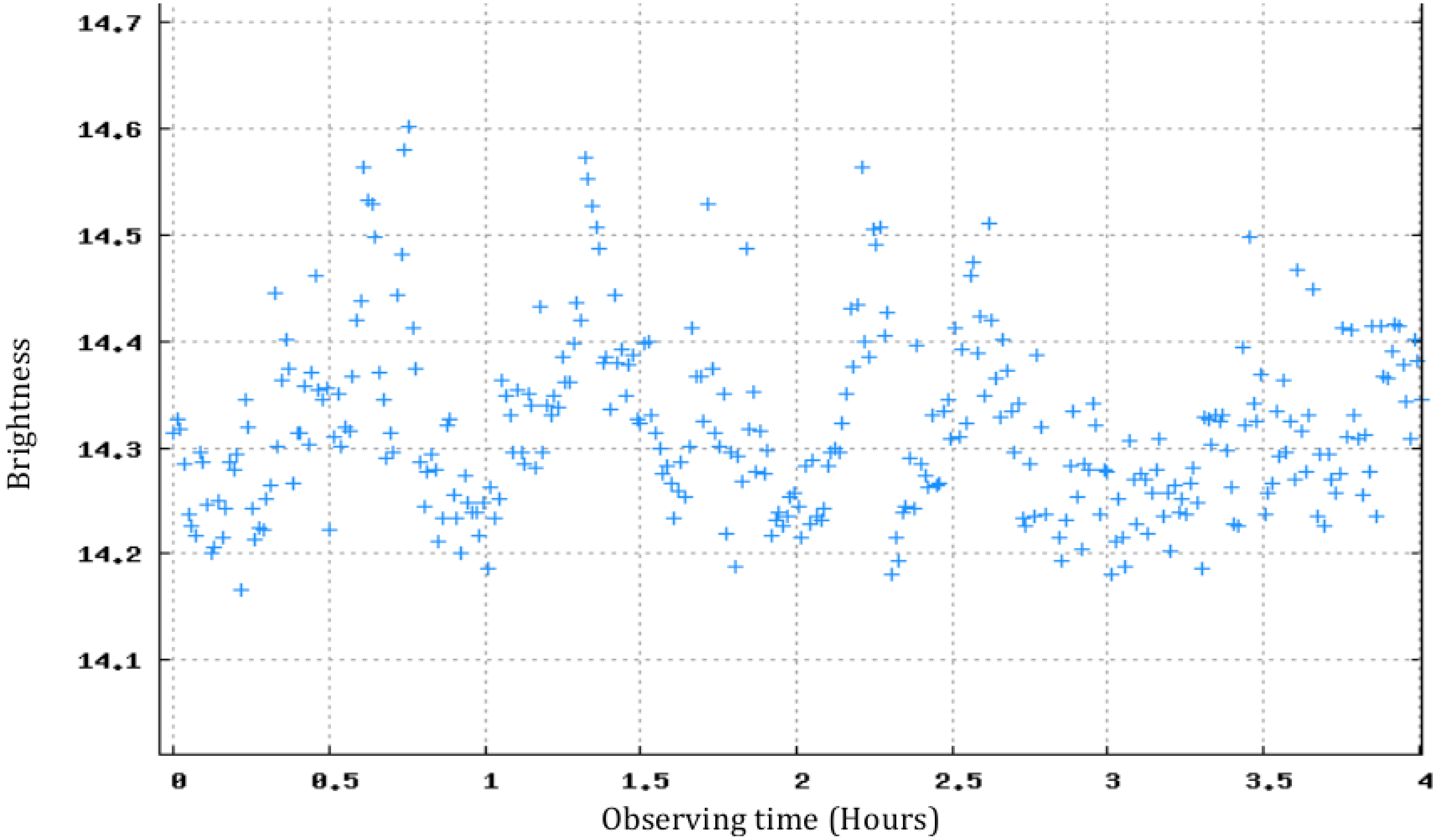


| Night | Images | Night | Images |
|---|---|---|---|
| June 14 | 103 | July 15 | 474 |
| June 15 | 288 | July 16 | 337 |
| June 17 | 306 | July 20 | 461 |
| June 28 | 418 | July 21 | 538 |
| July 1 | 261 | July 22 | 452 |
| July 2 | 70 | July 24 | 384 |
| July 3 | 361 | July 25 | 524 |
| July 4 | 536 | July 26 | 448 |
| July 5 | 179 | July 29 | 131 |
| July 8 | 124 | August 13 | 341 |
| July 10 | 465 | August 14 | 317 |
| July 13 | 100 | | |

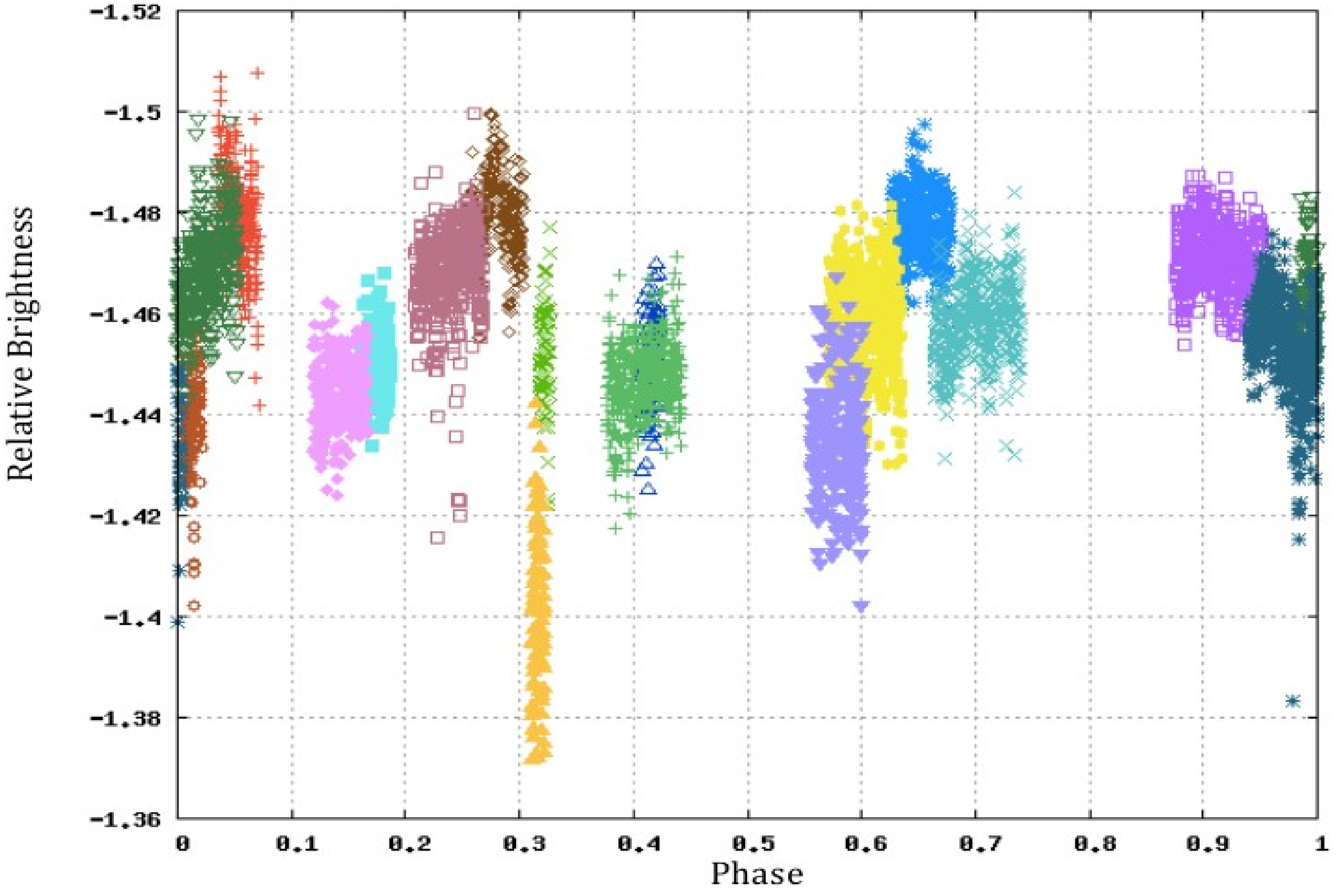
And few comparison stars... only one really.
C1 is a variable star, C3 is often too faint, and C4 drifts off the field, usually leaving only C2.



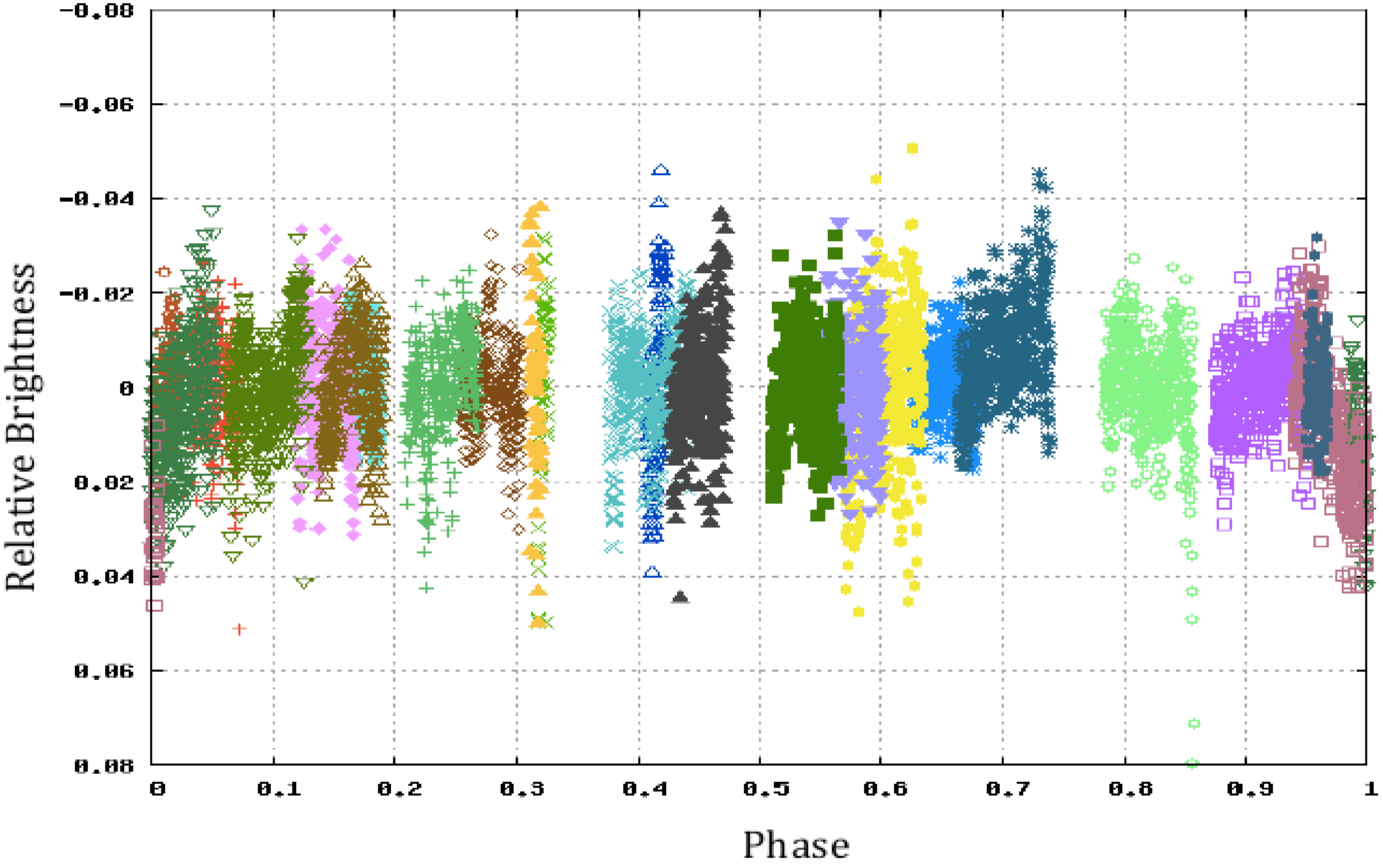
# Lightcurve of C1



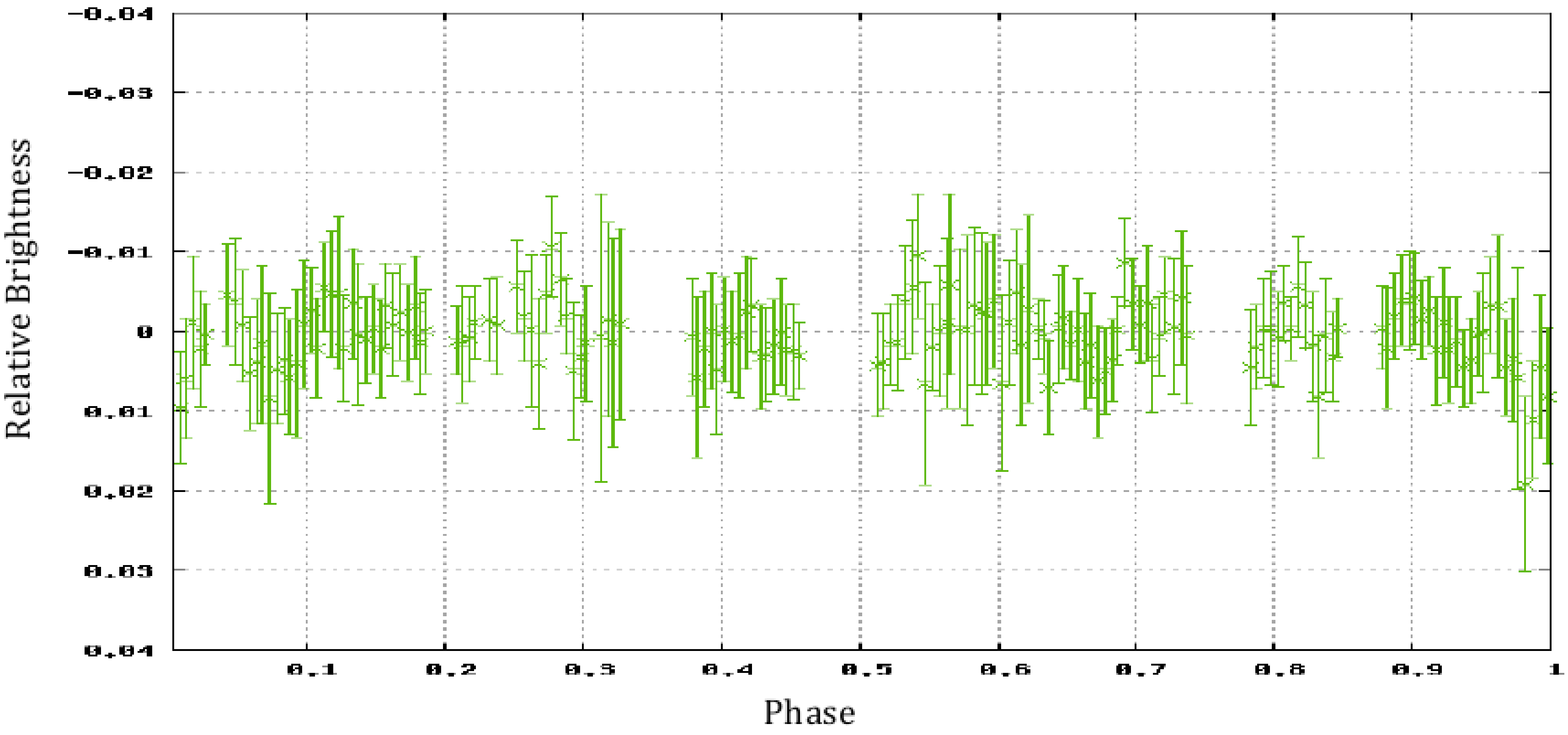
# Raw results folded over orbital phase.
# (Shannon's work, r filter)



# Corrected results folded over orbital phase. (Shannon's work, r filter, transits at the edges)



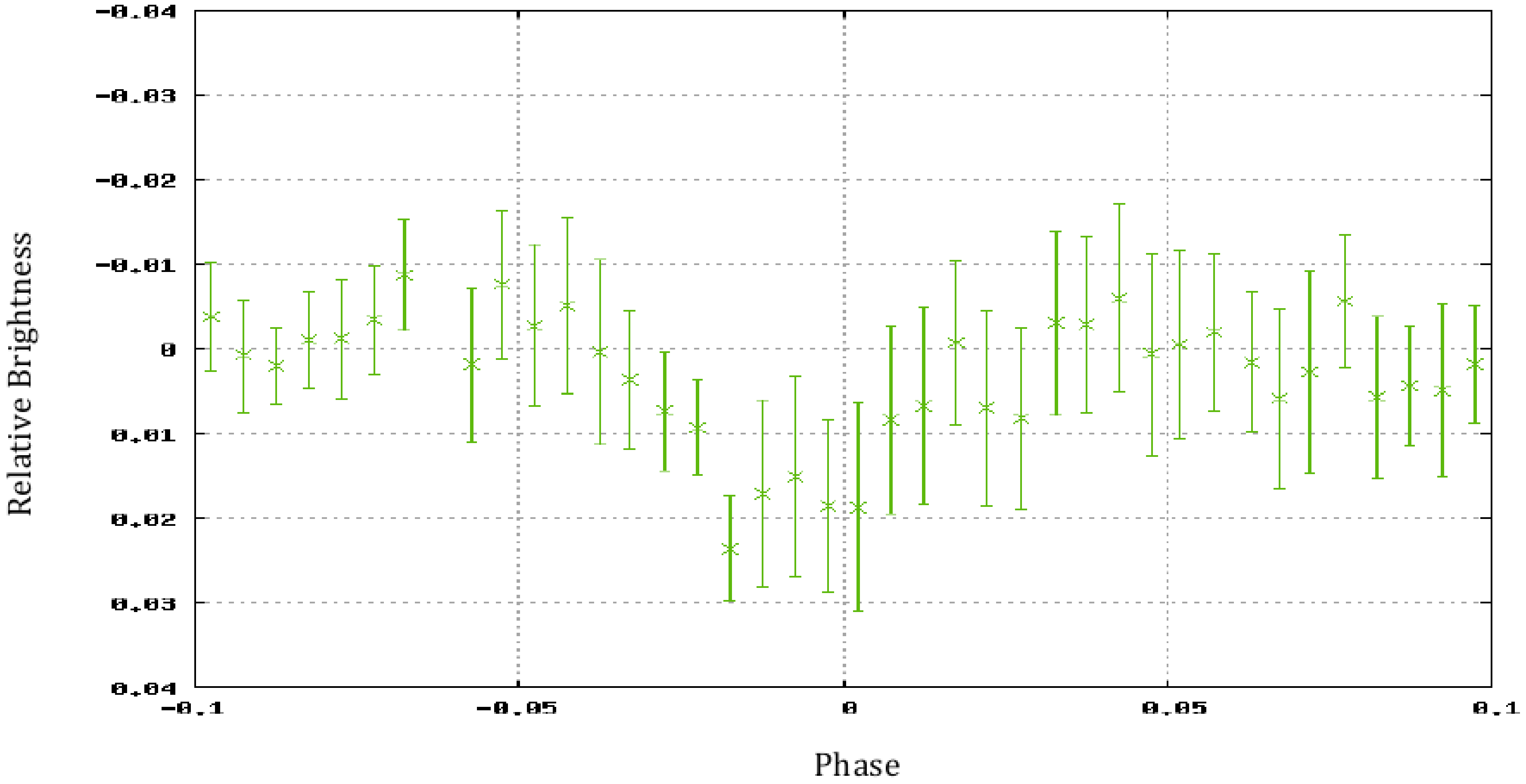
# Final binned results folded over orbital phase. (Shannon's work, r filter, transits at the edges) <σ>=6.8 mmag, transit depth = 9.8 mmag, secondary eclipse depth = 1.4 mmag

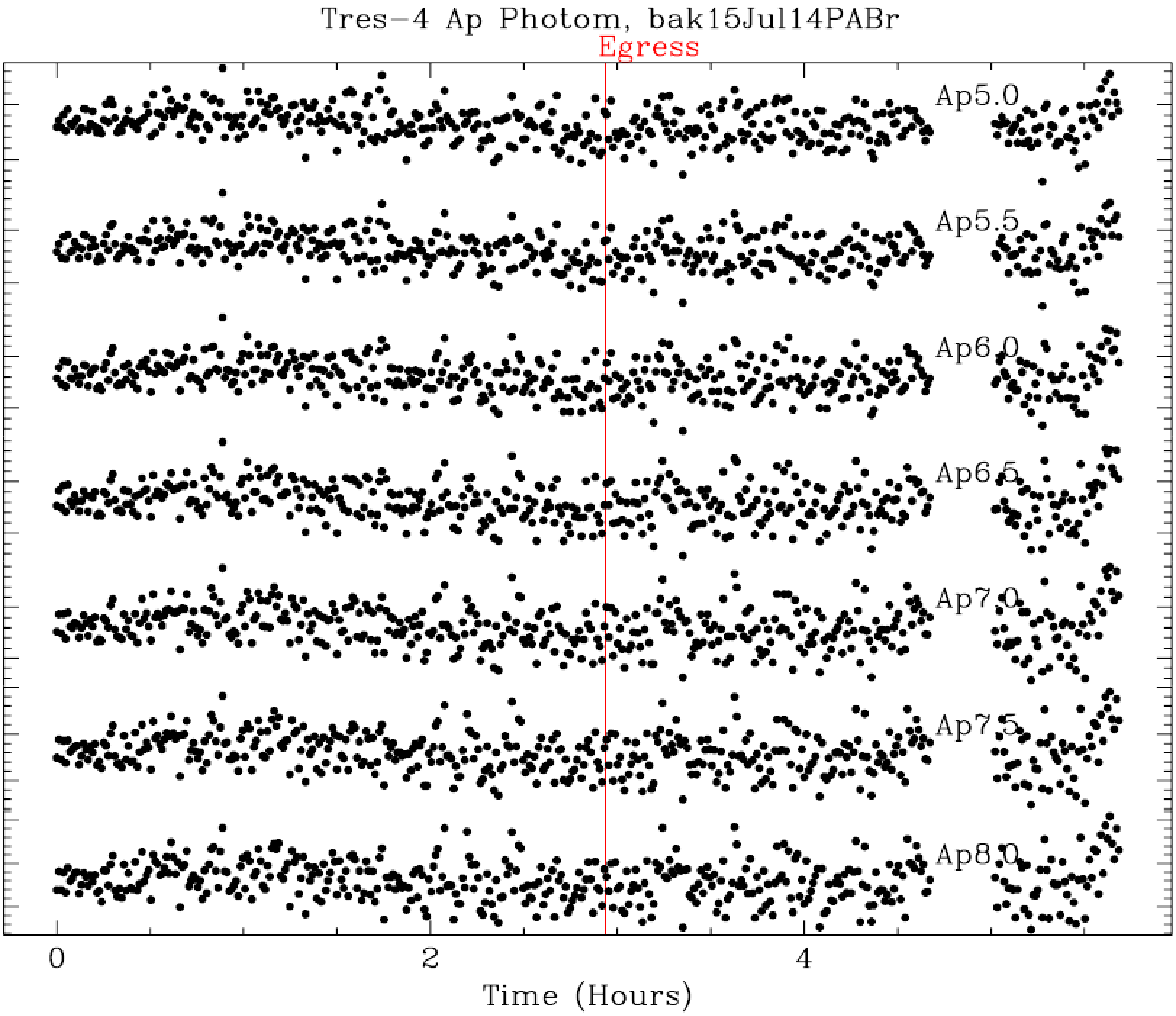


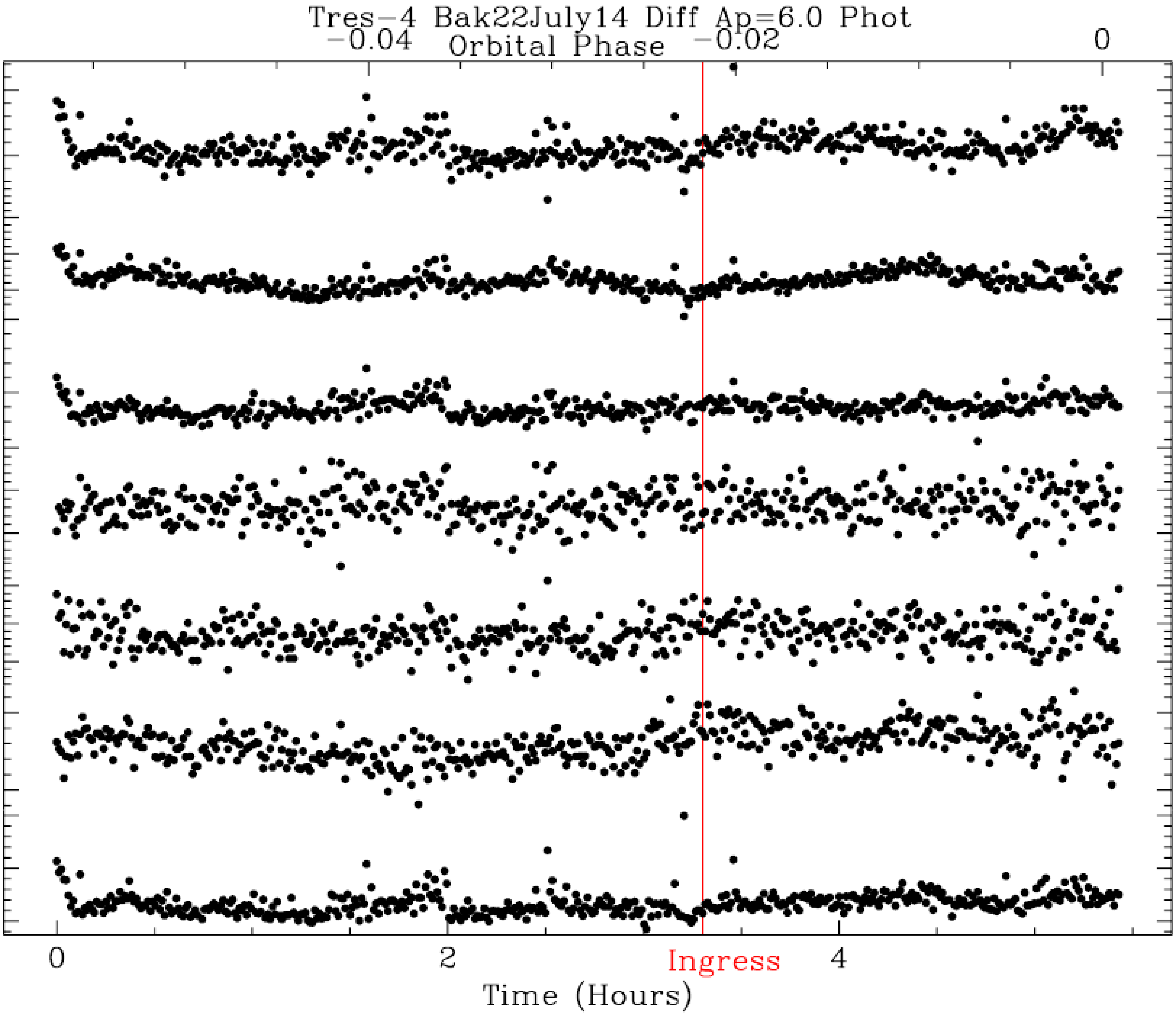
# Final binned results folded over orbital phase. (Shannon's work, r filter, transits at the edges)

During 3 nights, we observed parts of the transit.

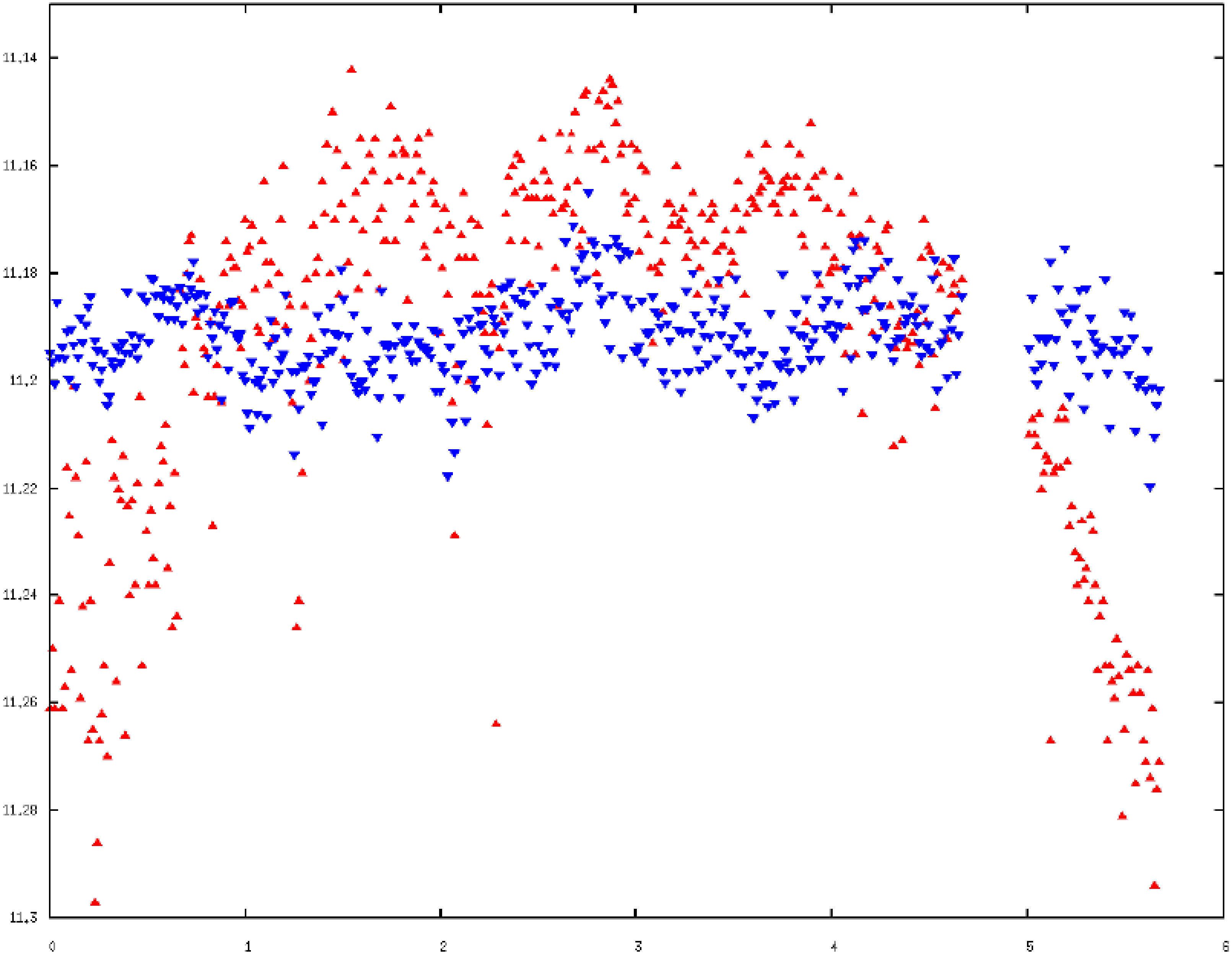
During no night did we get the entire transit.




Tres-4 Ap Photom, bak15Jul14PABr
Egress
Ap5.0
Ap5.5
Ap6.0
Ap6.5
Ap7.0
Ap7.5
Ap8.0
0
2
4
Time (Hours)


Tres-4 Bak22July14 Diff Ap=6.0 Phot
-0.04
Orbital Phase
-0.02
0
0
2
Ingress
4
Time (Hours)

# New tool: TFA



# Observing- Exoplanet 3

**Qatar 2b**.

Period= 1.34 days

Transit depth = 0.027 mag

$M \sim 2.5M_{Jupiter}$

$R \sim 1.1R_{Jupiter}$

Spectral class: KV

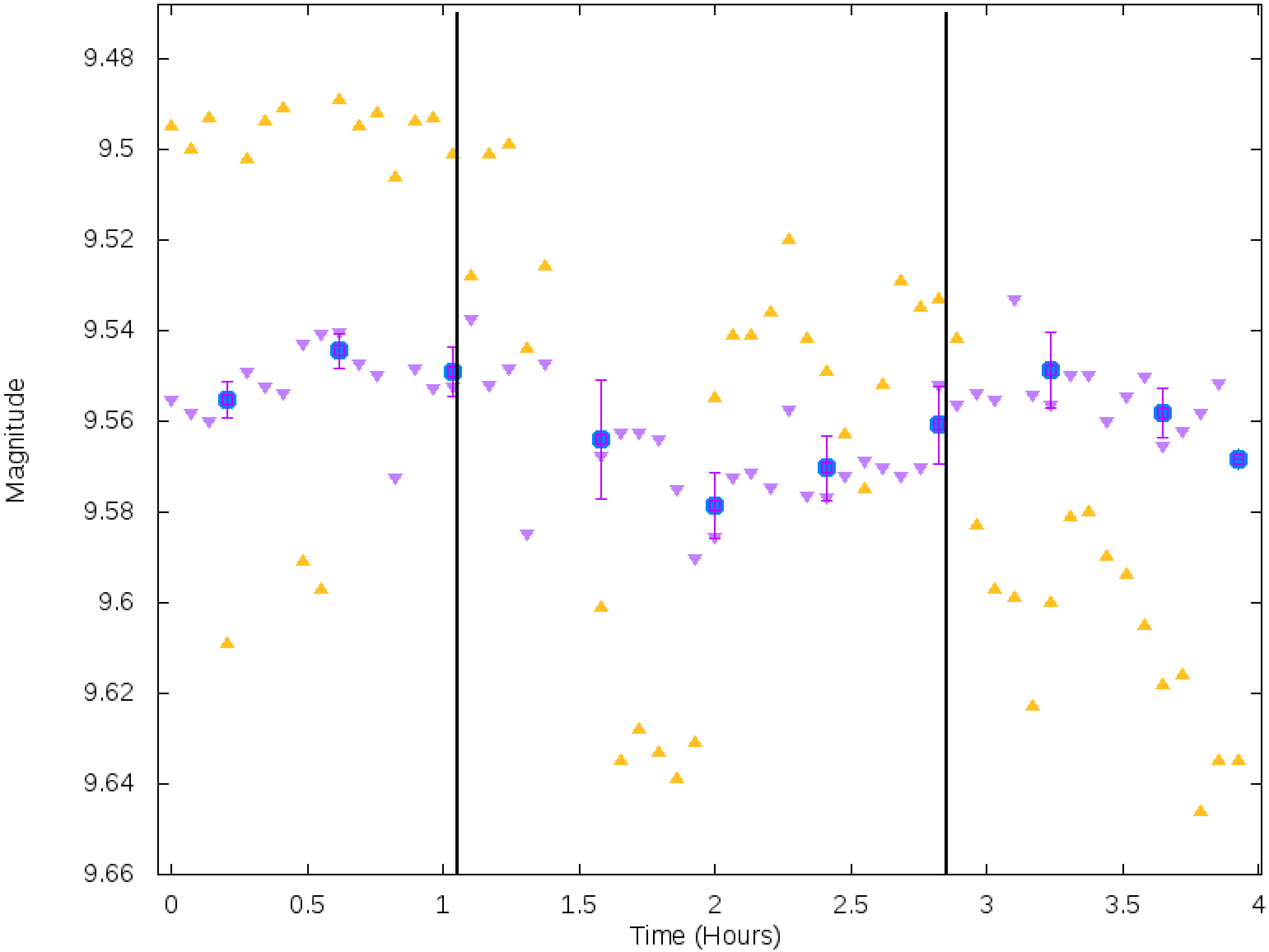
V=13.3

$R = 0.71R_{sun}$

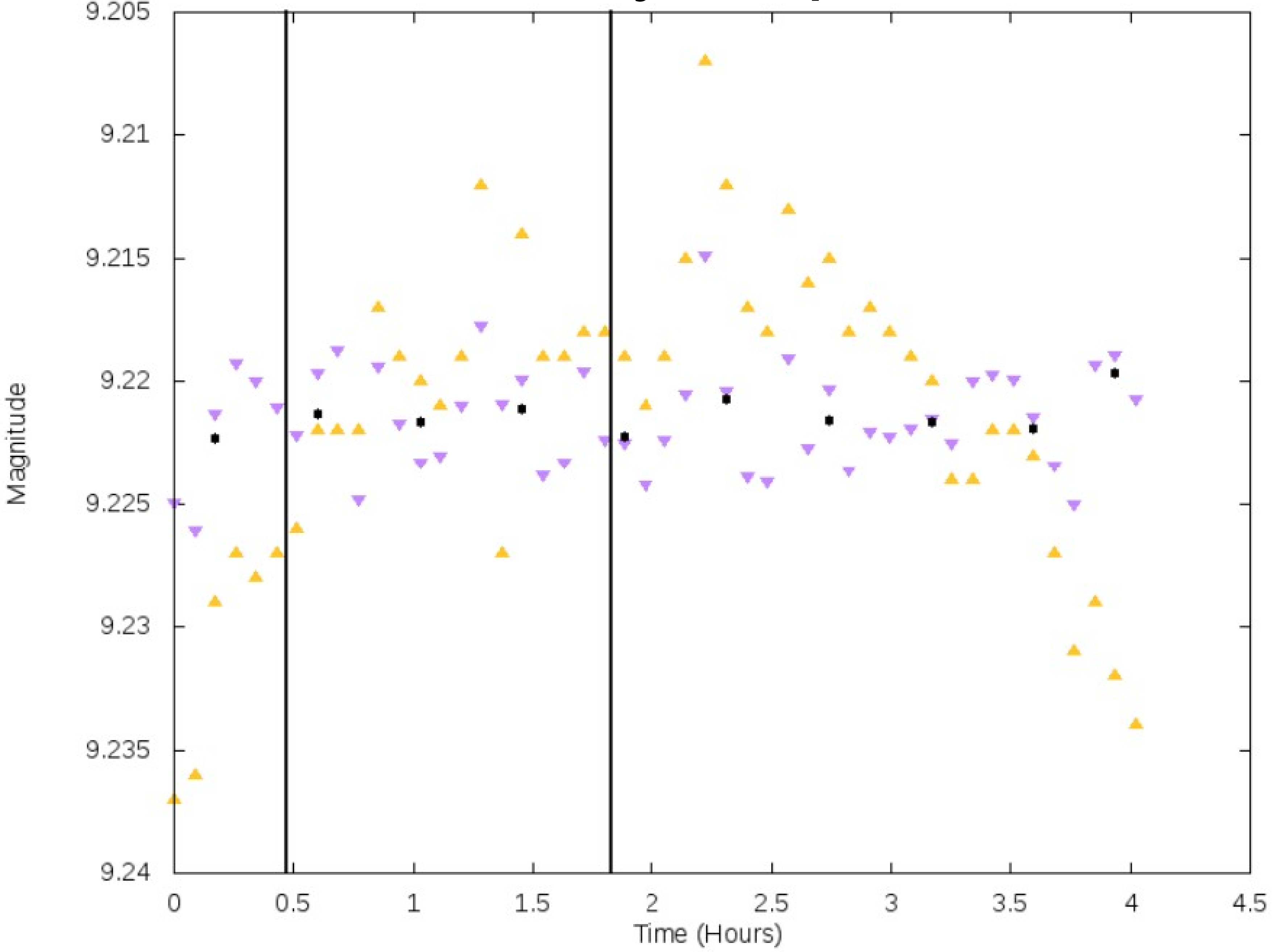
$M = 0.74M_{sun}$

$T_{eff} = 4645$ K

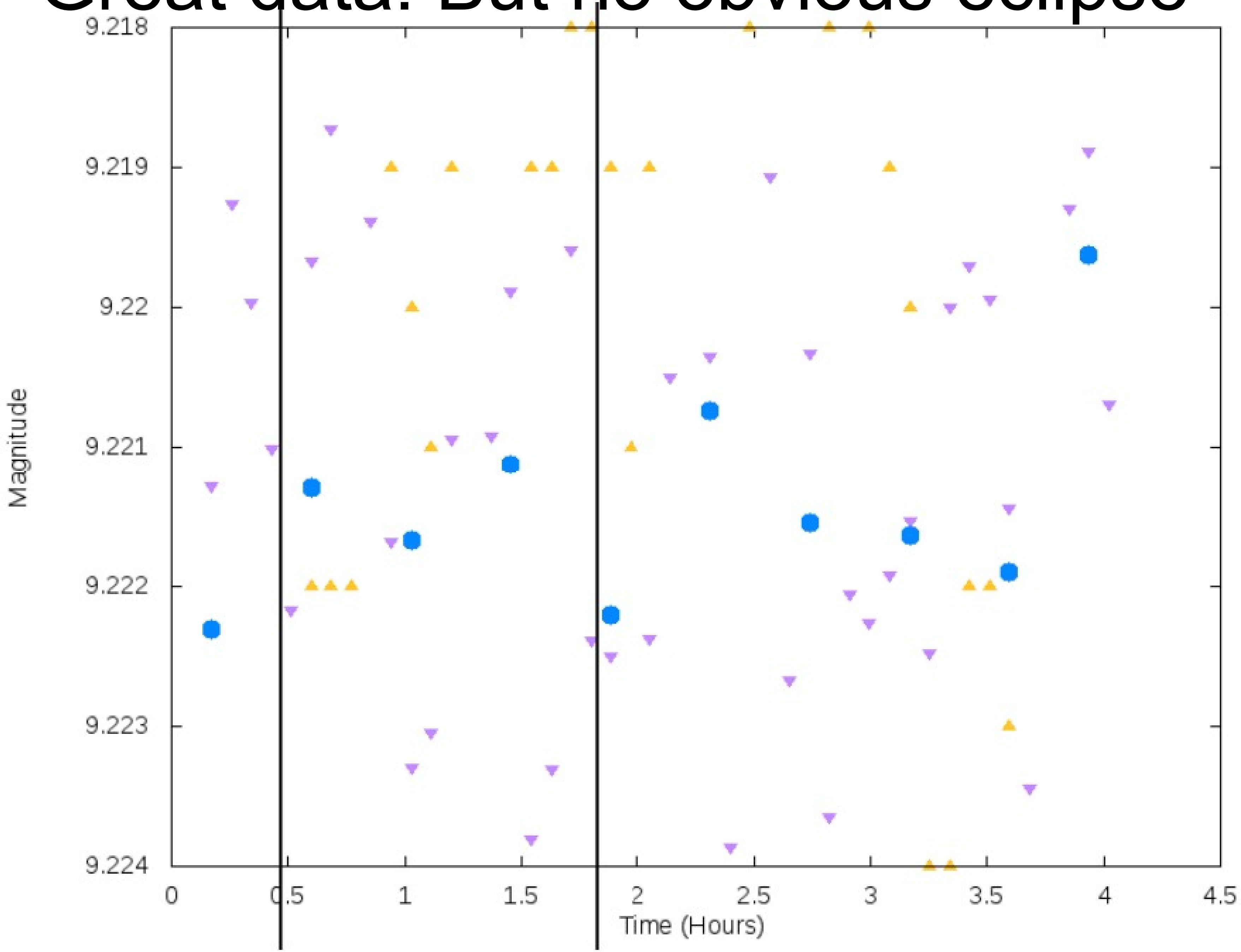
# MINERVA Engineering data- Transit



# Secondary eclipse.

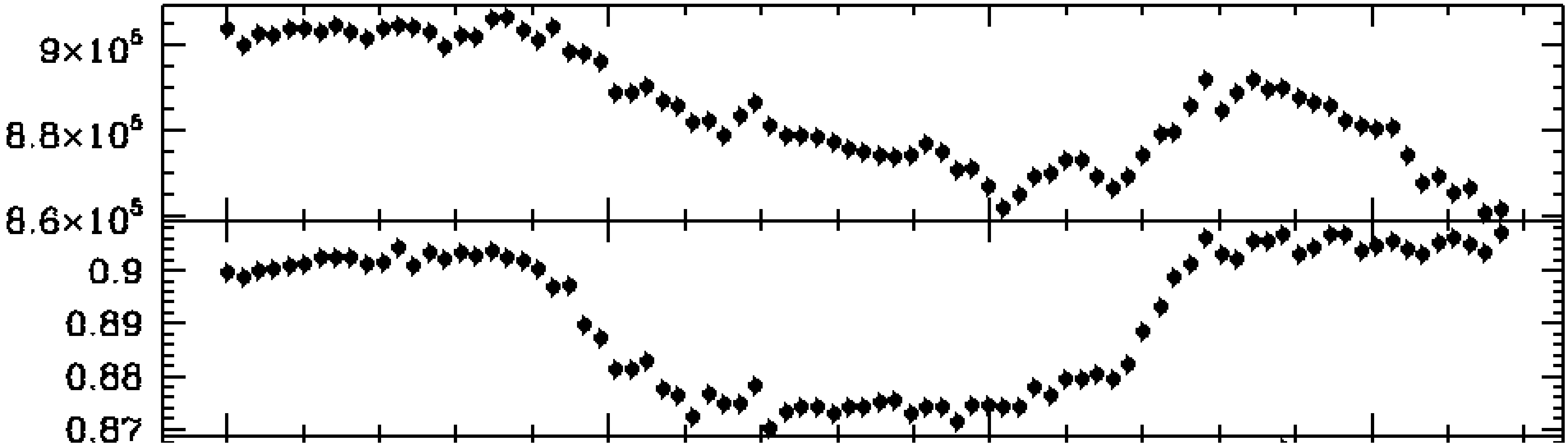


# Great data! But no obvious eclipse



# Better MINERVA transit data

## Top= raw, bottom= differential



# So what have we learned?

* We still need to have a 'best' data set to determine our real limitations, and we've not had that yet.

Best= cloud-free, little Moonlight, no instrument spots, many comparison stars, several orbits covered.

# So what have we learned?

* Our telescope/instrument is just not so good for this purpose.