

# Transmission spectroscopy of a warm neptune

**Near-infrared transmission spectrum of the warm-uranus GJ 3470b  
with the Wide Field Camera-3 on the *Hubble Space Telescope***

D. Ehrenreich<sup>1</sup>, X. Bonfils<sup>2</sup>, C. Lovis<sup>1</sup>, X. Delfosse<sup>2</sup>, T. Forveille<sup>2</sup>, M. Mayor<sup>1</sup>, V. Neves<sup>2,3,4,5</sup>, N. C. Santos<sup>3,4</sup>,  
S. Udry<sup>1</sup>, & D. Ségransan<sup>1</sup>

**arXiv:1405.1056**

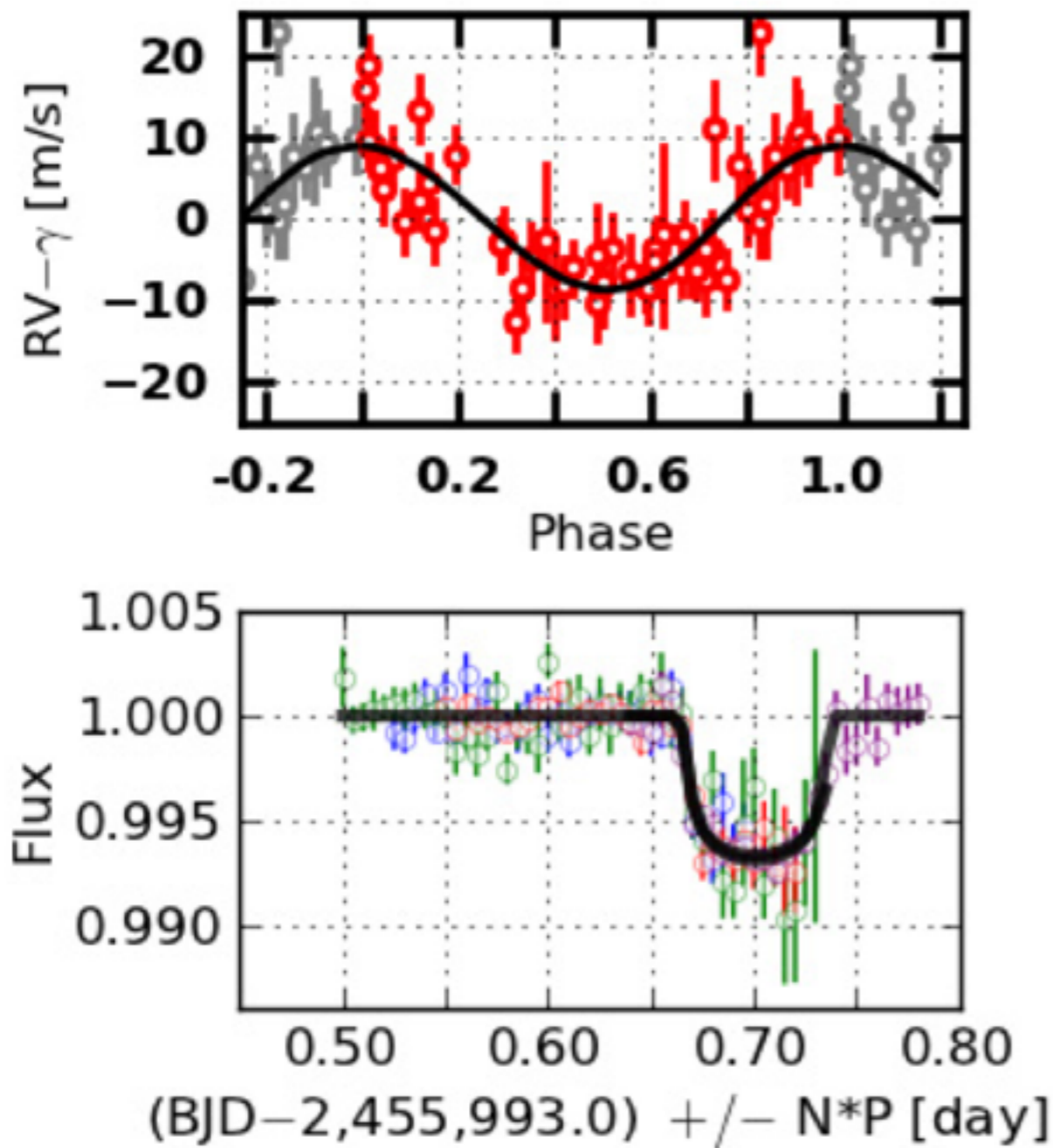


# Search for exoplanets around **M dwarfs**

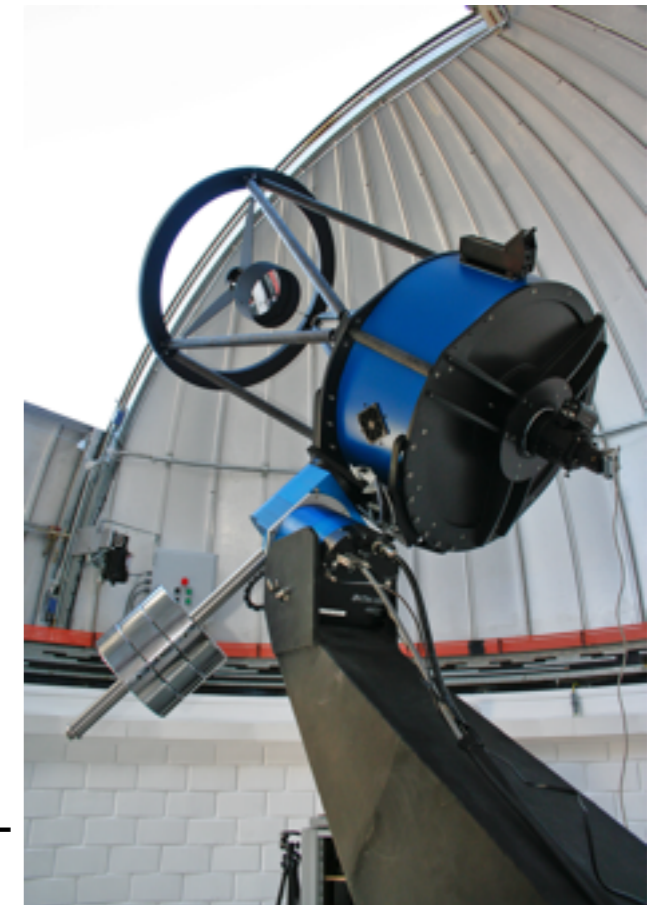
*("The shortcut to happiness")*

# Discovery of GJ 3470b

Bonfils+2012



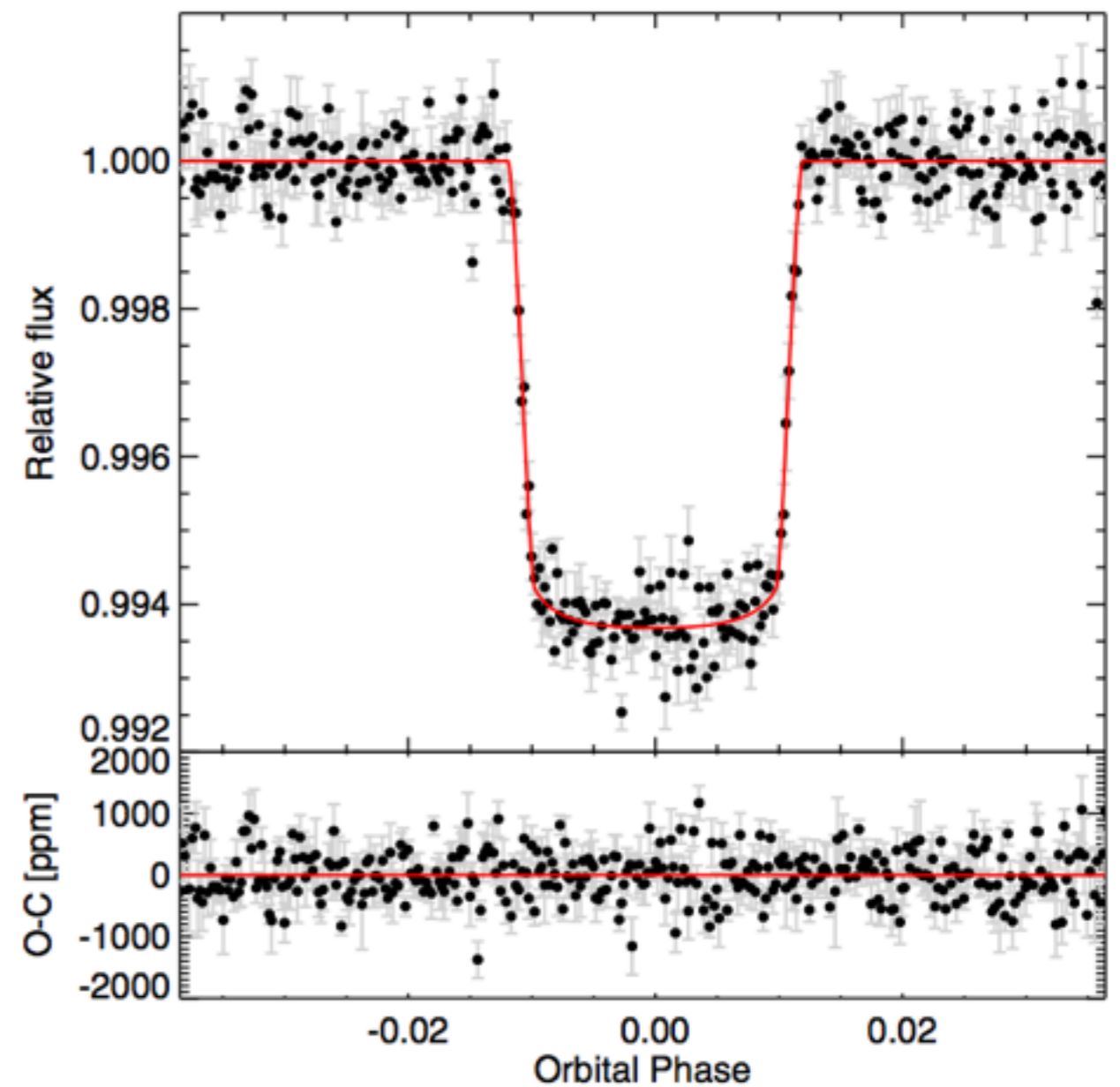
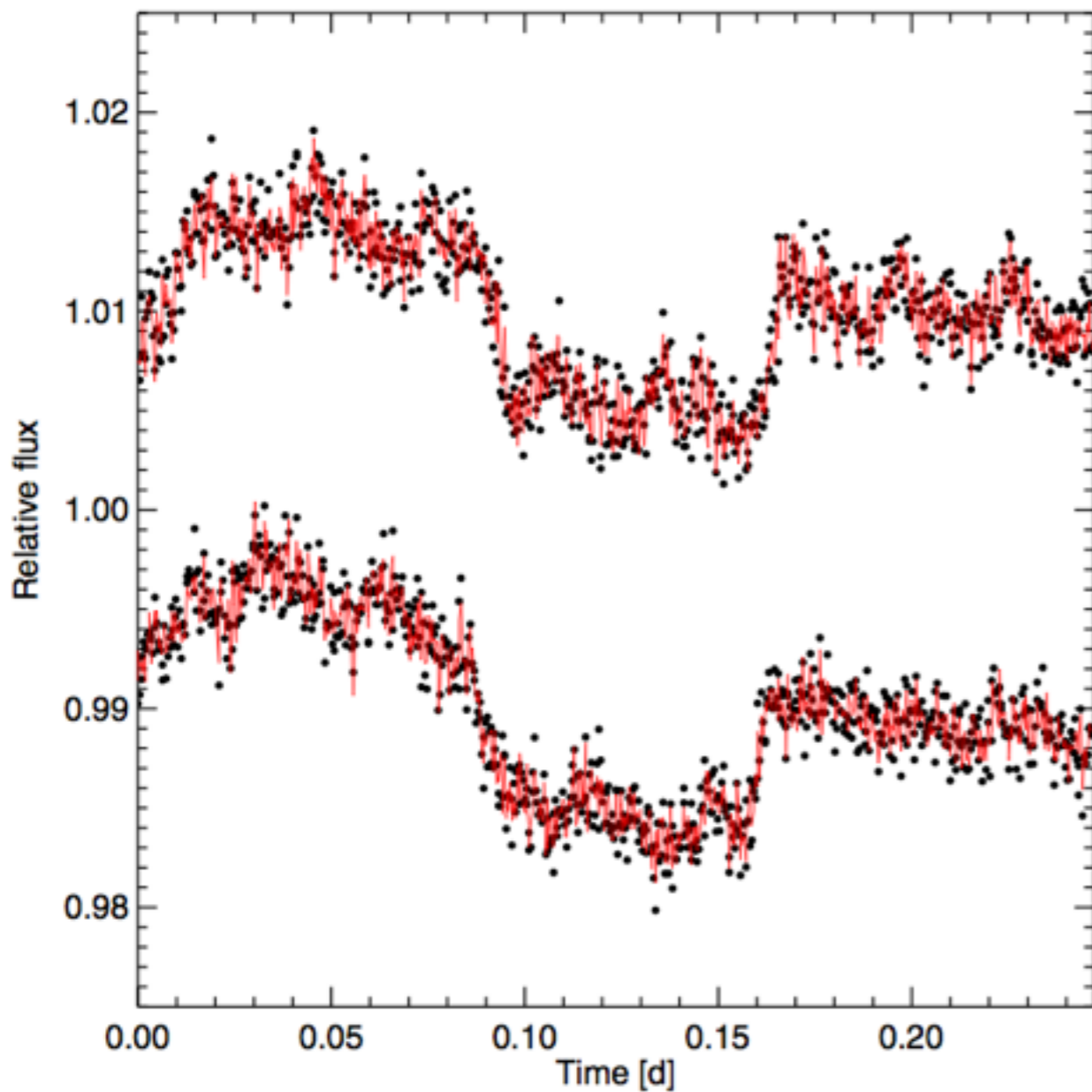
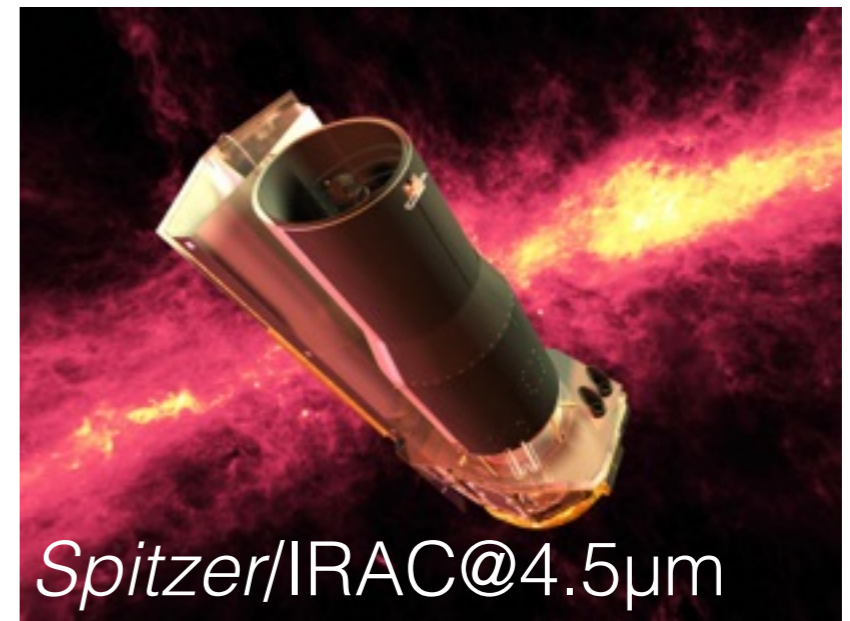
HARPS@ESO 3.6m



TRAPPIST

# Characterisation of the transit light curve

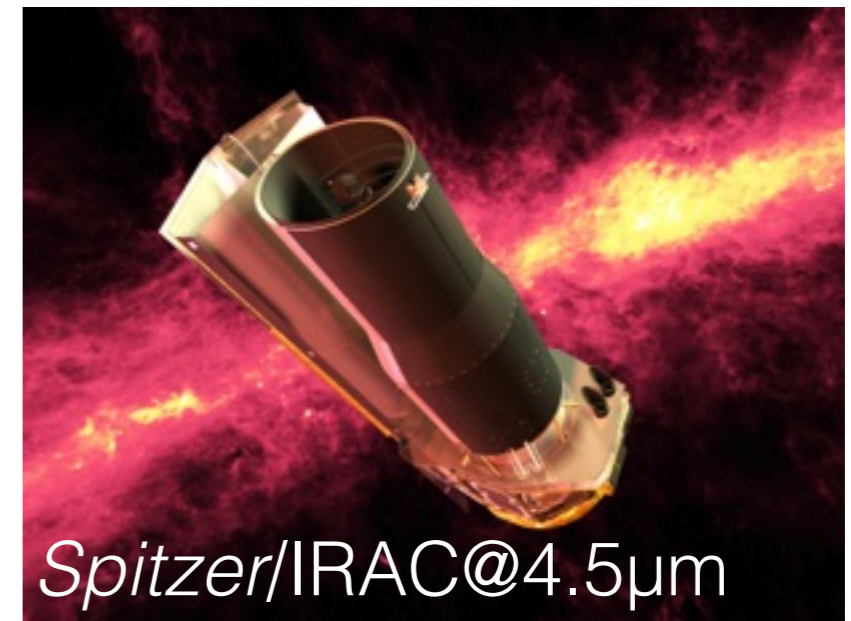
Demory+2013





# Characterisation of the transit light curve

Demory+2013

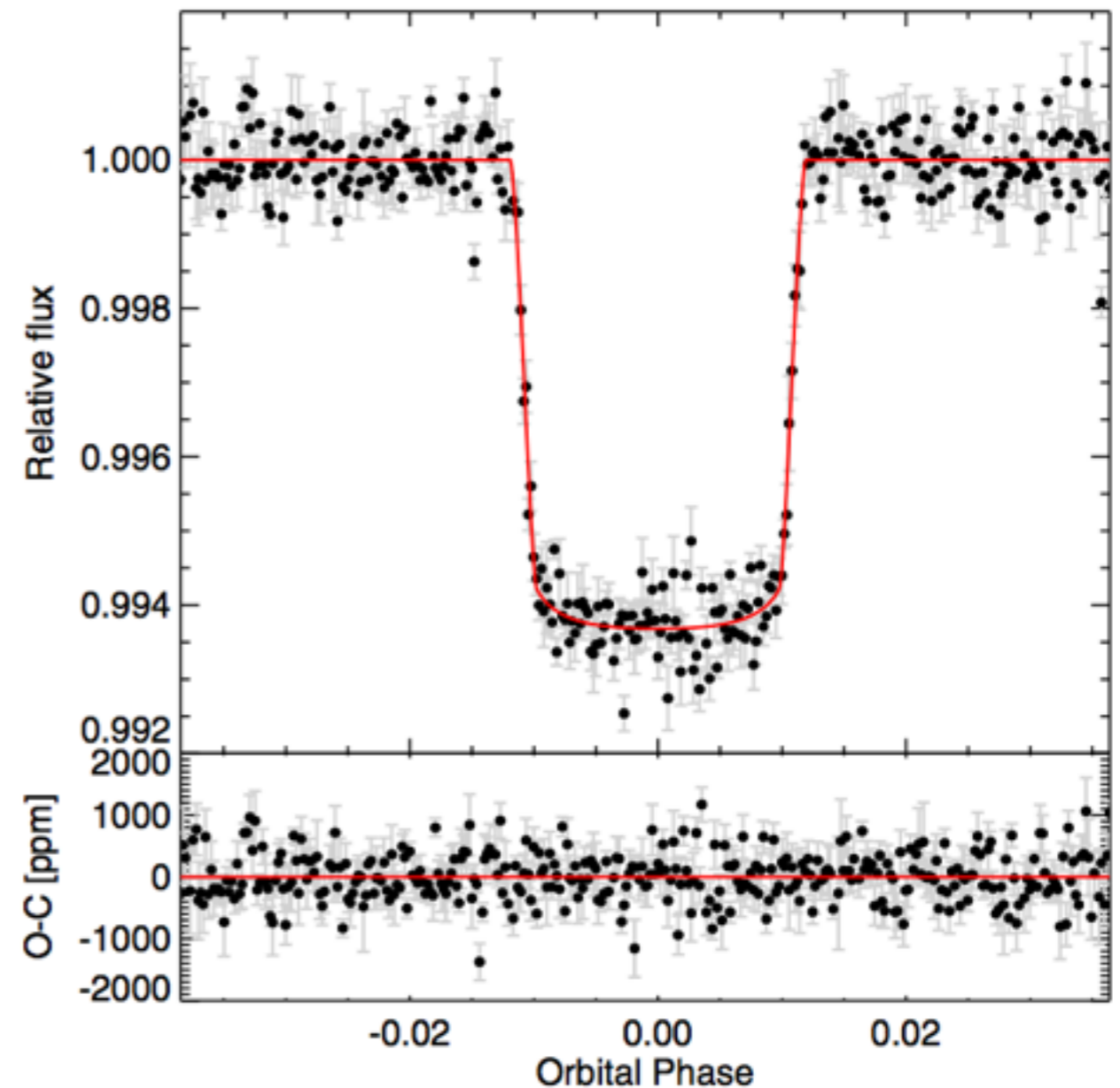


## Stellar parameters

$u_1$	$0.033 \pm 0.015$
$u_2$	$0.181 \pm 0.010$
Mean density $\rho_*$ ( $\rho_\odot$ )	$2.91^{+0.37}_{-0.33}$
Surface gravity $\log g_*$ (cgs)	$4.658 \pm 0.035$
Mass $M_*$ ( $M_\odot$ ) <sup>b</sup>	$0.539^{+0.047}_{-0.043}$
Radius $R_*$ ( $R_\odot$ ) <sup>b</sup>	$0.568^{+0.037}_{-0.031}$
Parallax $\pi$ (mas) <sup>b</sup>	$32.4^{+2.1}_{-1.9}$
Distance (pc) <sup>b</sup>	$30.7^{+2.1}_{-1.7}$
Effective temperature $T_{\text{eff}}$ (K) <sup>b</sup>	$3600 \pm 100$
Metallicity [Fe/H] (dex) <sup>b</sup>	$+0.20 \pm 0.10$

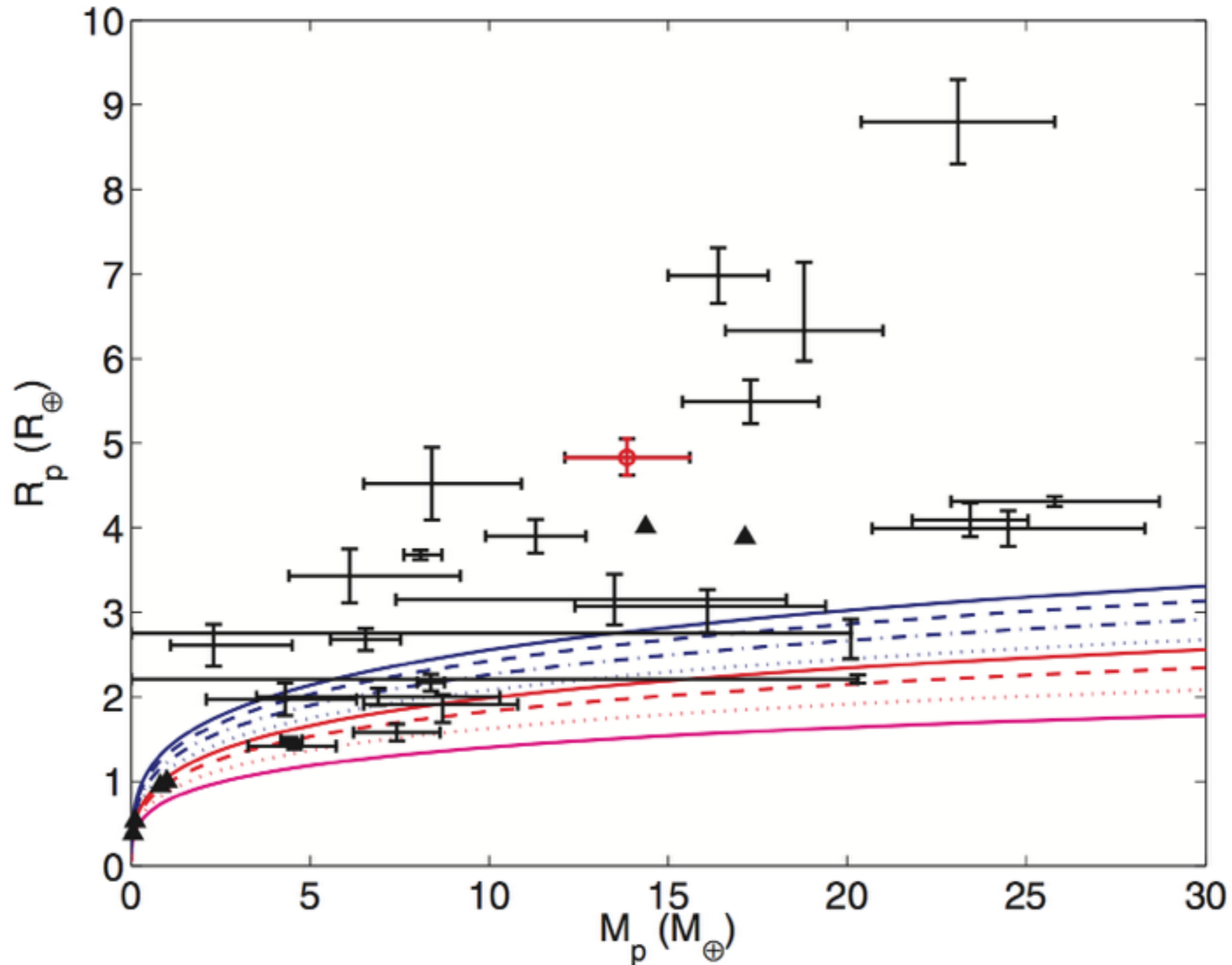
## Planetary parameters

RV semi-amplitude $K$ ( $\text{m s}^{-1}$ )	$8.9 \pm 1.1$
Orbital semi-major axis $a$ (AU)	$0.03557^{+0.00096}_{-0.00100}$
Orbital inclination $i$ (deg)	$88.3^{+0.5}_{-0.4}$
Mean density $\rho_p$ ( $\text{g cm}^{-3}$ )	$0.72^{+0.13}_{-0.12}$
Surface gravity $\log g_p$ (cgs)	$2.76^{+0.06}_{-0.07}$
Mass $M_p$ ( $M_\oplus$ )	$13.9^{+1.5}_{-1.4}$
Radius $R_p$ ( $R_\oplus$ )	$4.83^{+0.22}_{-0.21}$

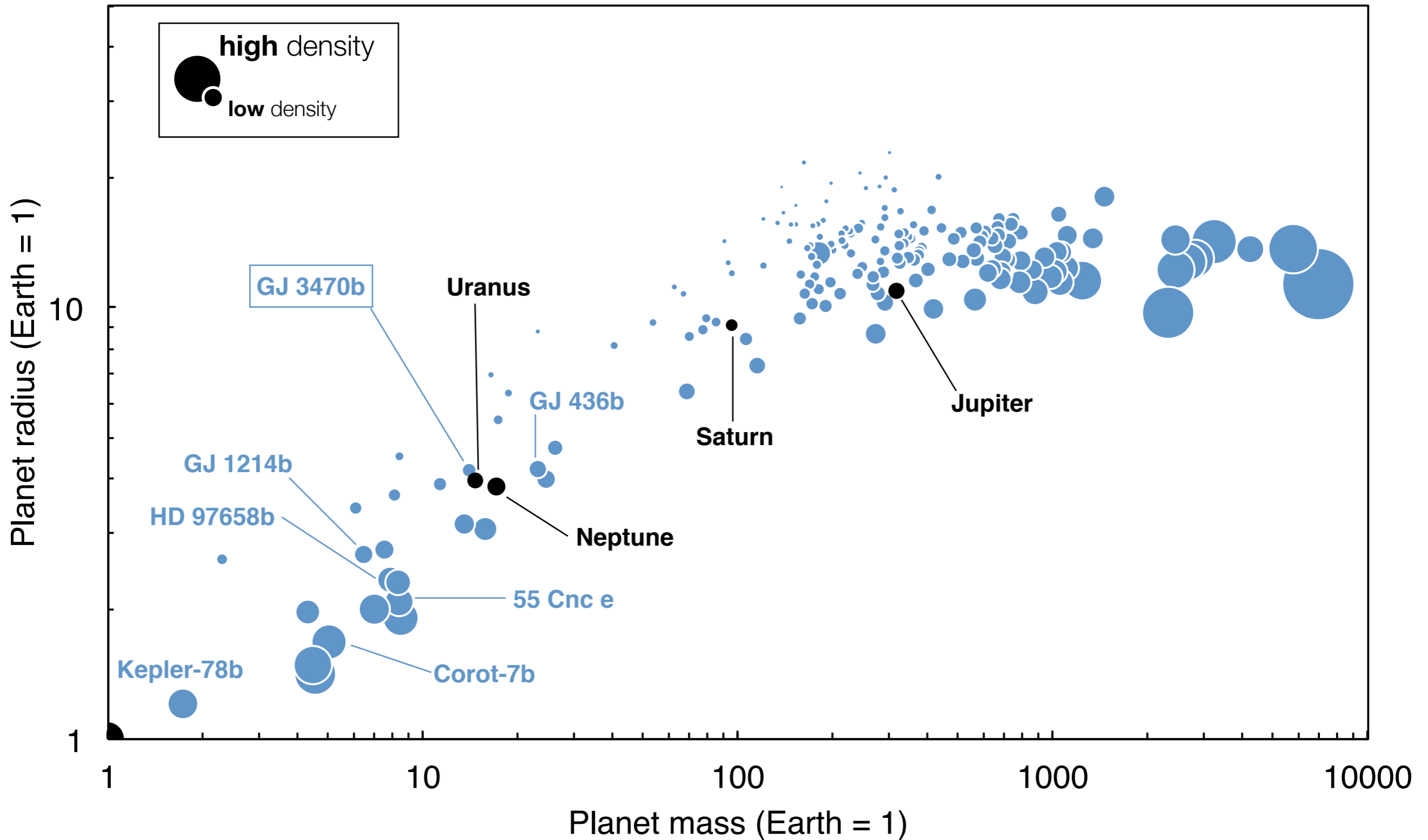


# Mass-radius diagram

Demory+2013



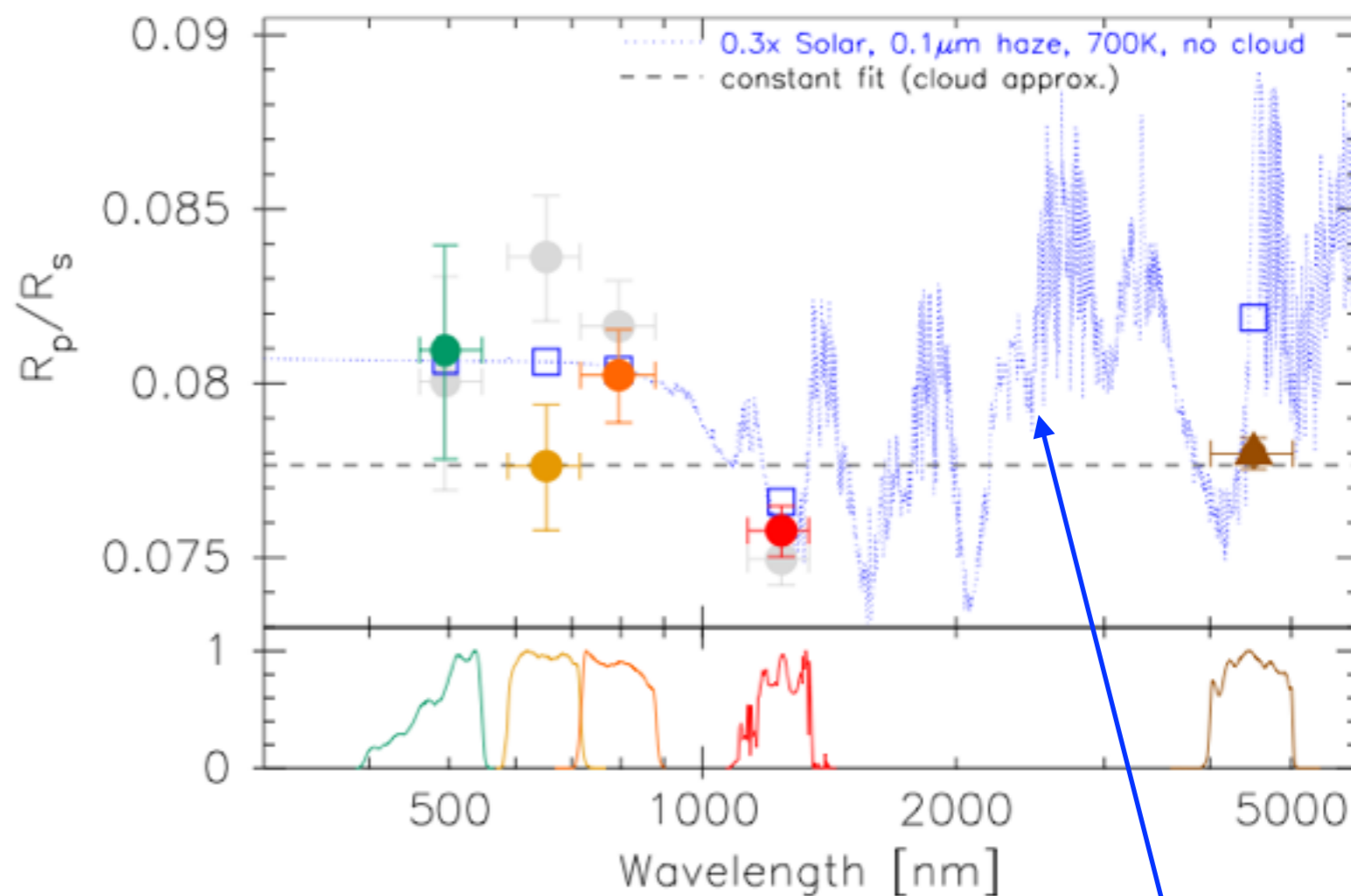
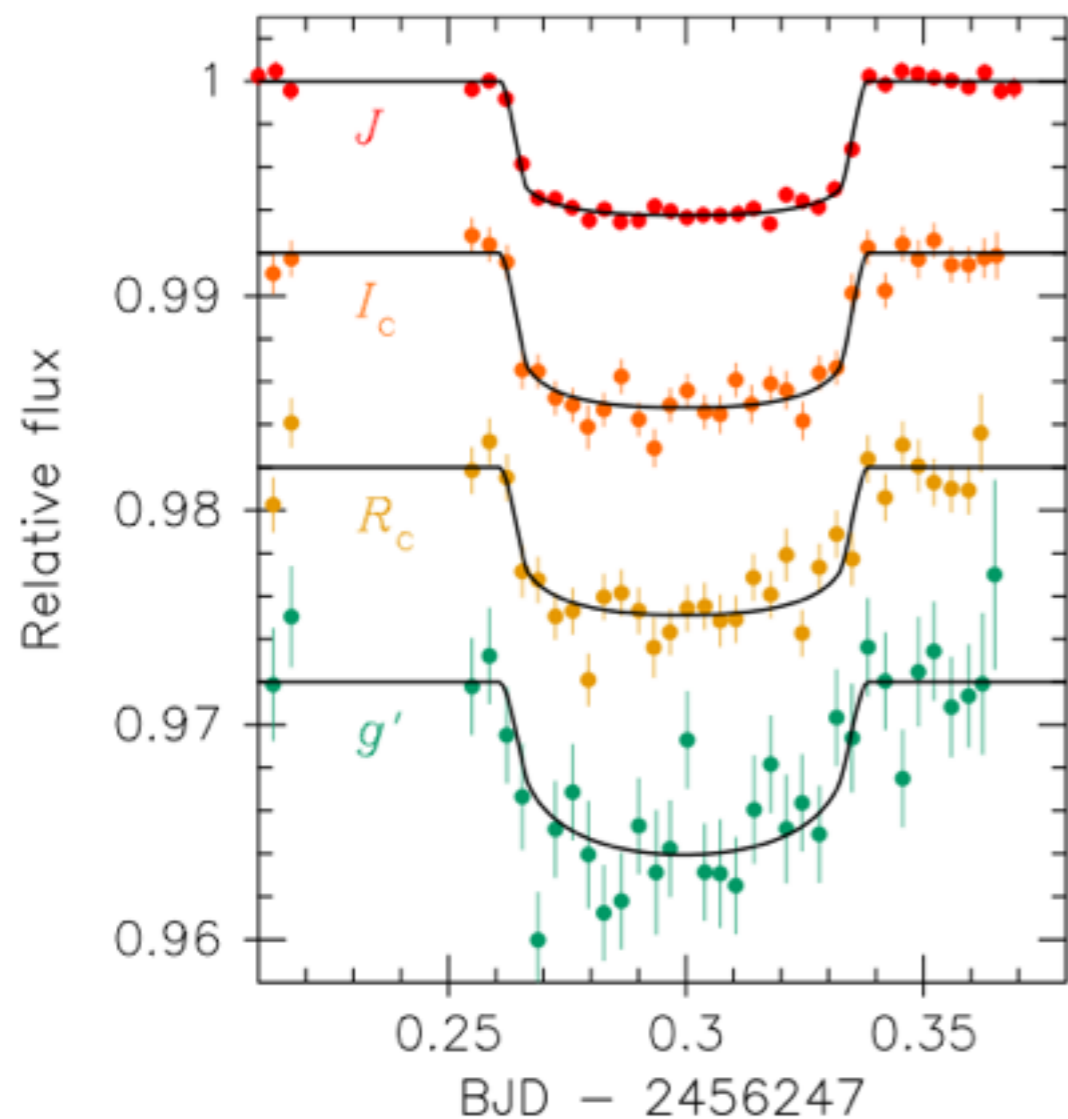
# A rare, warm-blooded animal



Atmospheric  
characterisation  
of GJ 3470b

## OPTICAL-TO-NEAR-INFRARED SIMULTANEOUS OBSERVATIONS FOR THE HOT URANUS GJ3470b: A HINT OF A CLOUD-FREE ATMOSPHERE

AKIHIKO FUKUI<sup>1</sup>, NORIO NARITA<sup>2</sup>, KENJI KUROSAKI<sup>3</sup>, MASAHIRO IKOMA<sup>3</sup>, KENSHI YANAGISAWA<sup>1</sup>, DAISUKE KURODA<sup>1</sup>,  
YASUHIRO SHIMIZU<sup>1</sup>, YASUHIRO H. TAKAHASHI<sup>2,4</sup>, HIROSHI OHNUKI<sup>5</sup>, MASAHIRO ONITSUKA<sup>6</sup>, TERUYUKI HIRANO<sup>7</sup>,  
TAKUYA SUENAGA<sup>6</sup>, KIYOE KAWAUCHI<sup>2</sup>, SHOGO NAGAYAMA<sup>2</sup>, KOUJI OHTA<sup>8</sup>, MICHITOSHI YOSHIDA<sup>9</sup>,  
NOBUYUKI KAWAI<sup>10</sup>, AND HIDEYUKI IZUMIURA<sup>1</sup>

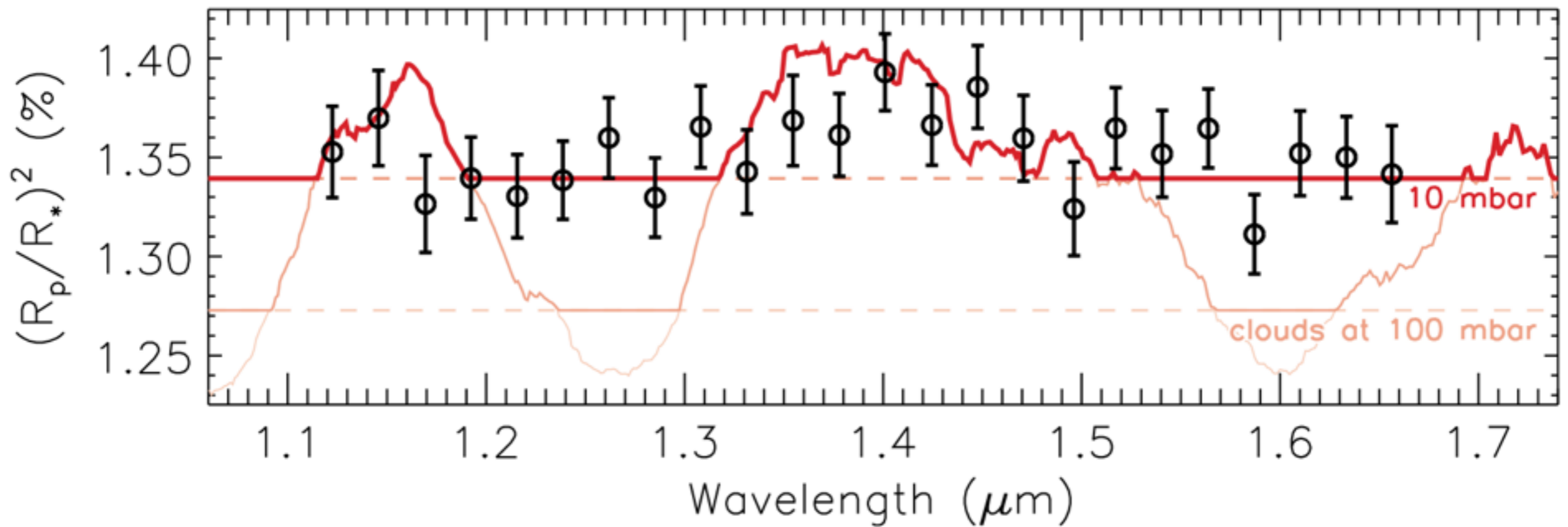


**scaled** from Howe & Burrows (2012)  
700-K “cloudless” atmosphere w/ 0.1-μm *tholins* (1000 cm<sup>-3</sup>)



# “Observer’s” clouds

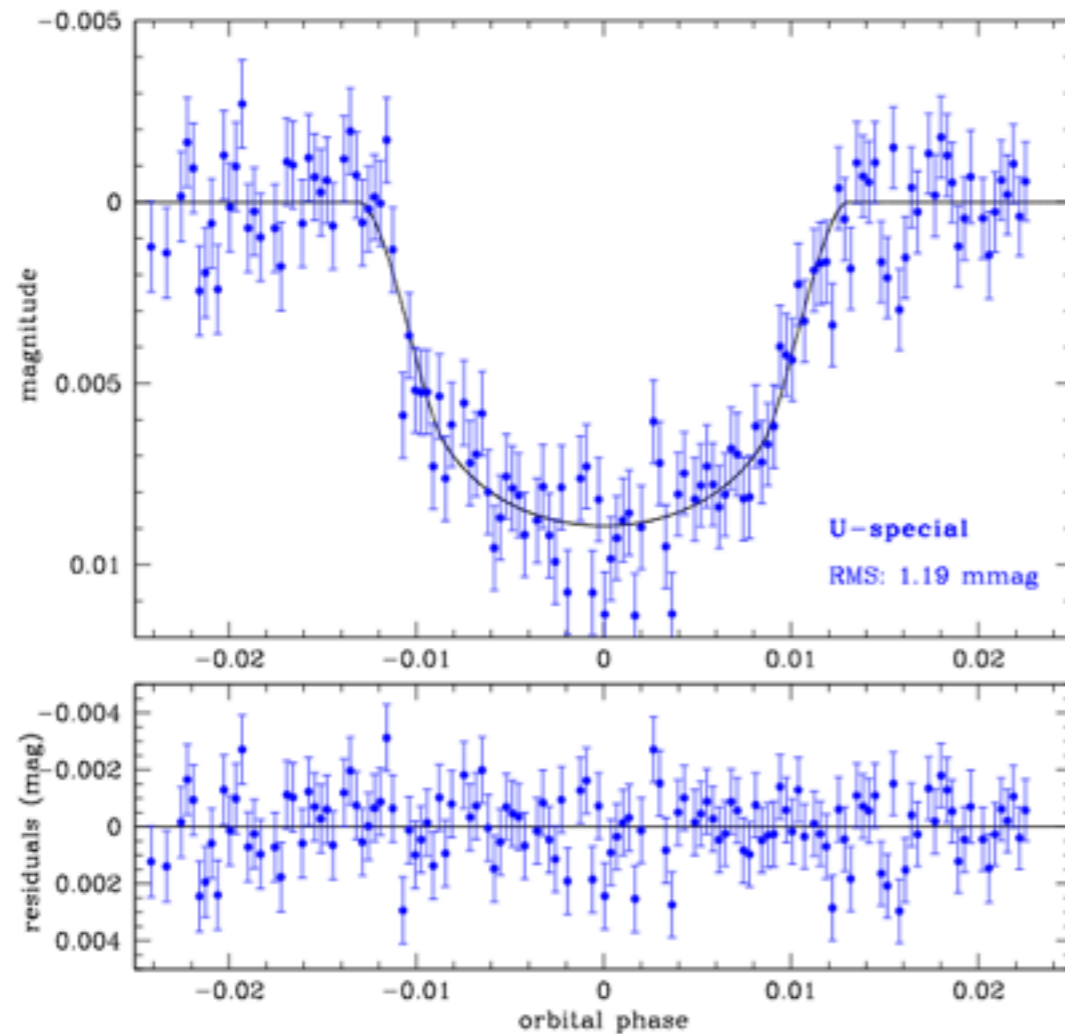
e.g., Berta+2014



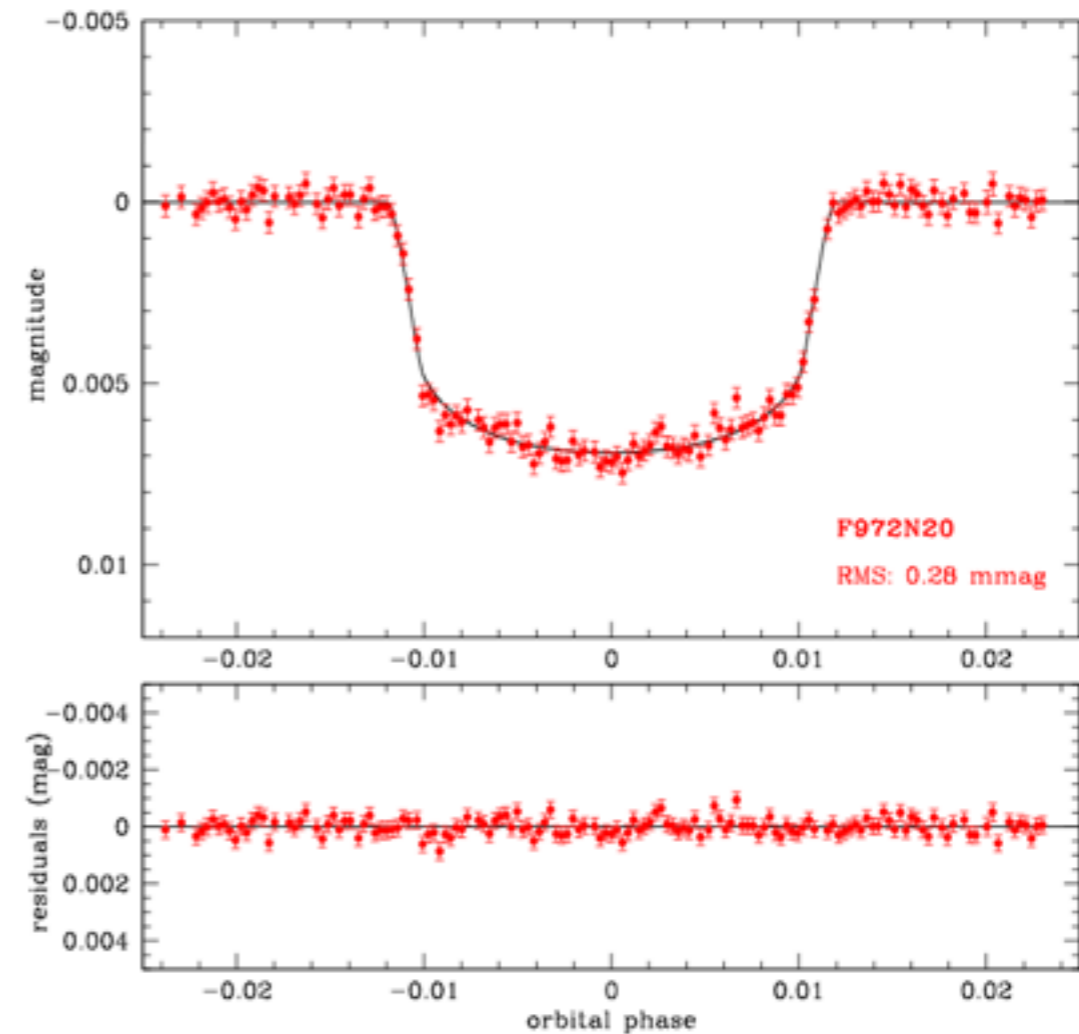
# Dual-band transit photometry

Nascimbeni+2013

LBT *U* band



LBT Narrow NIR band



# Dual-band transit photometry

Nascimbeni+2013

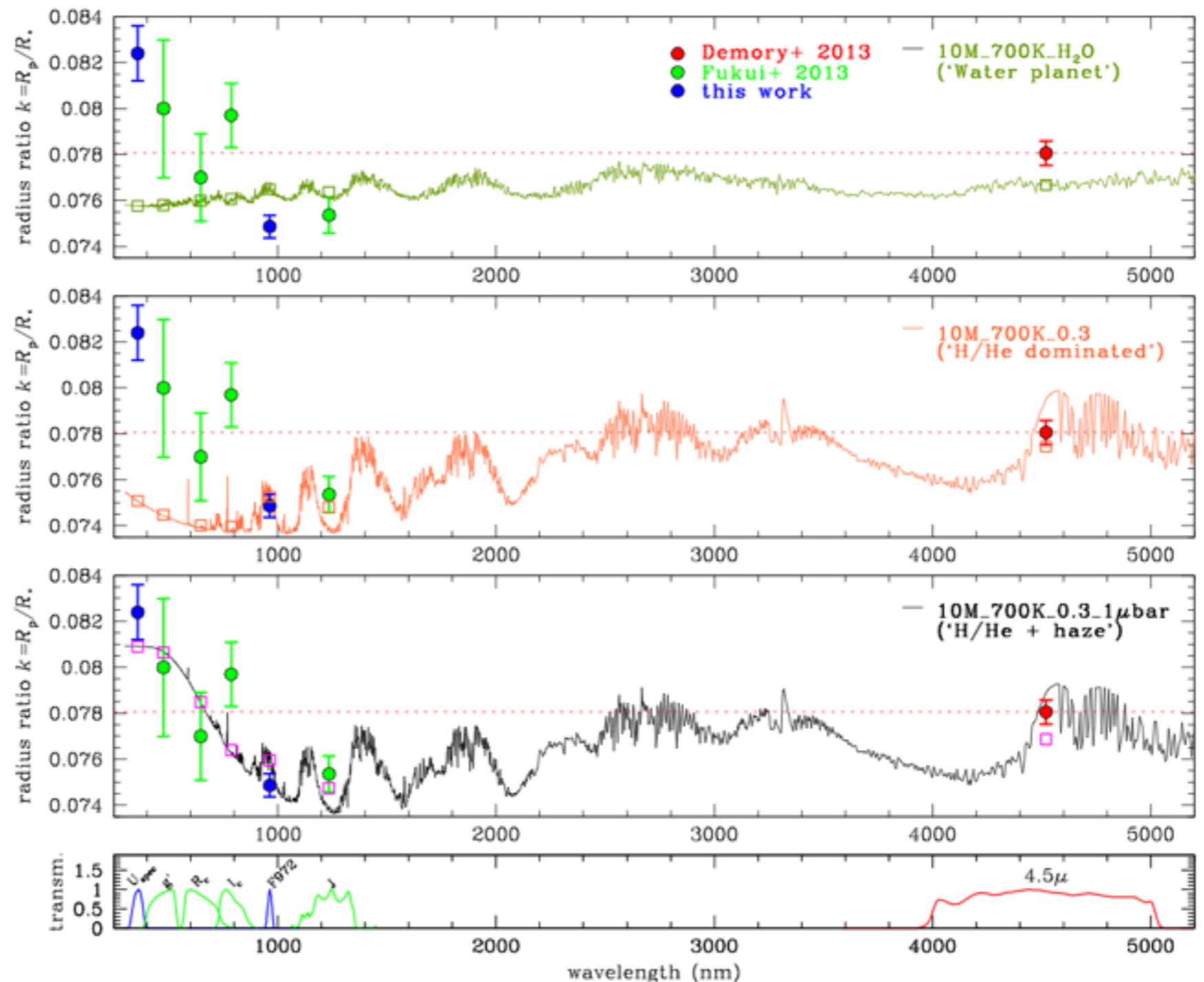
Models **scaled** from  
Howe & Burrows 2012

-Perfect gas  
-Hydrostatic equilibrium

$$H = kT / \mu g$$

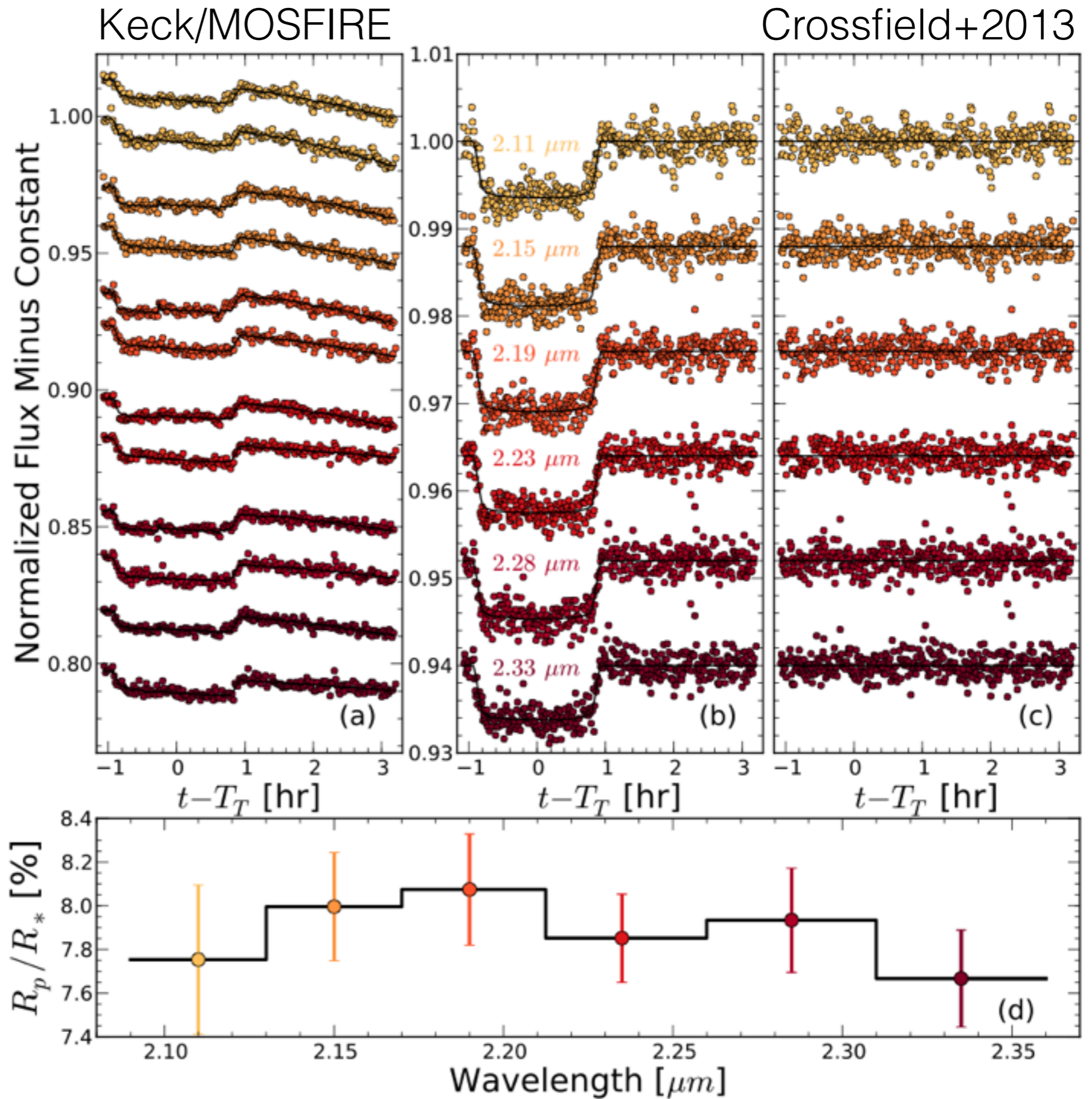
$$g = G M_p / R_p^2$$

-Dust/haze particles  
vertical, size distribution  
& number density???





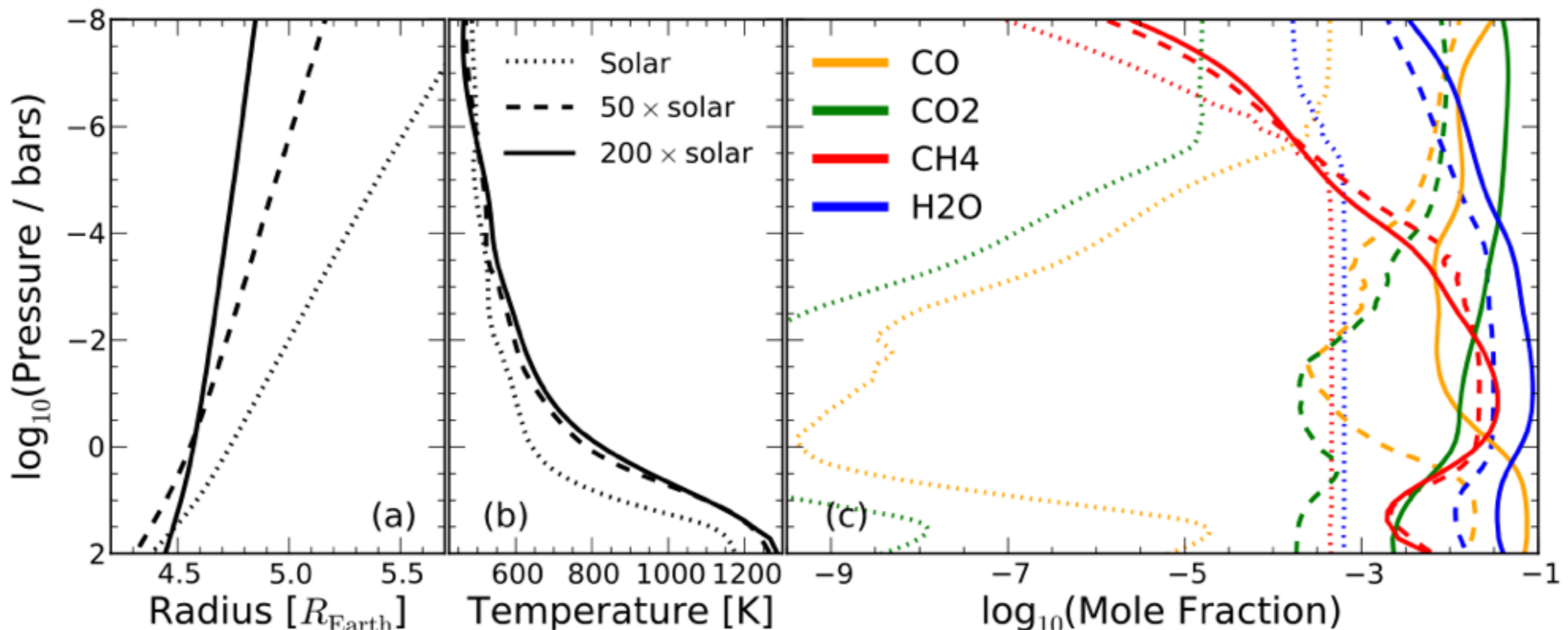
# NIR spectroscopy



# NIR spectroscopy+models

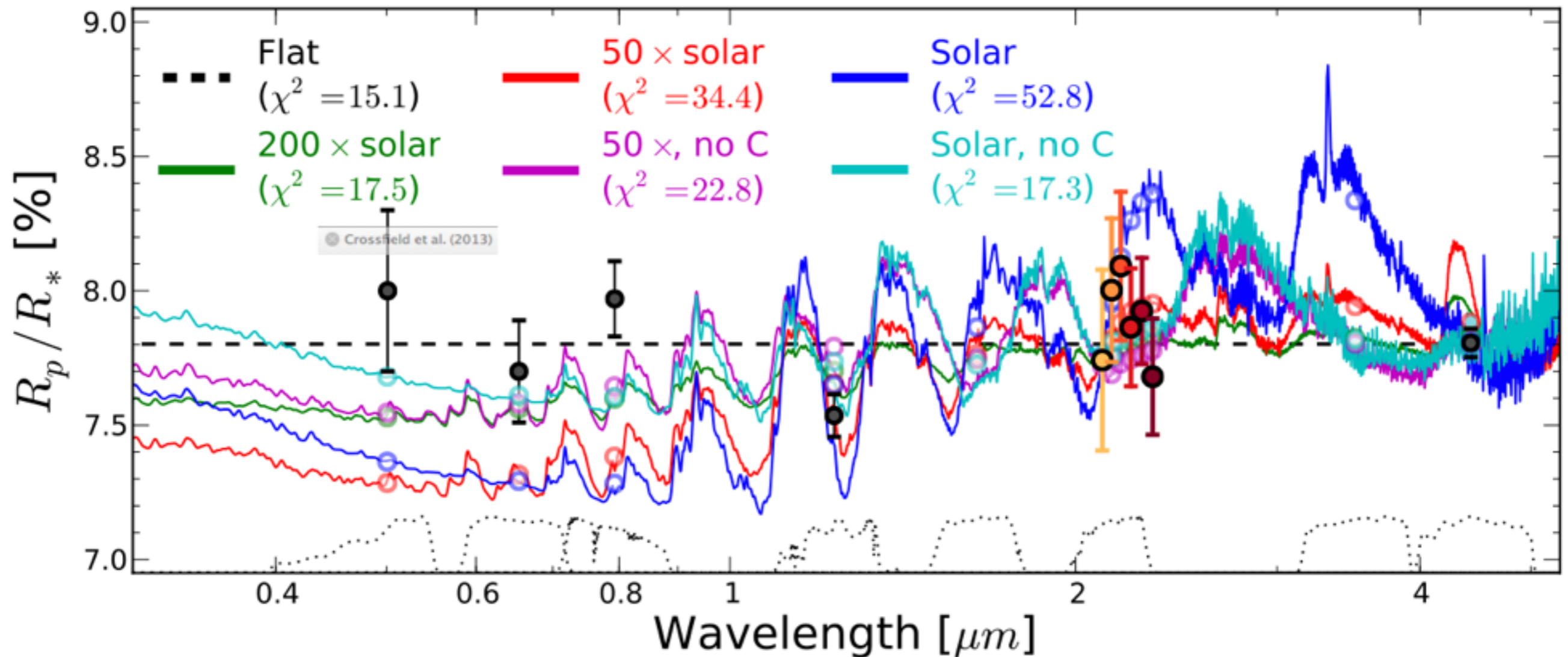
Crossfield+2013

Cloud-free PHOENIX models in chemical equilibrium  
or w/ carbon abundance set to 0



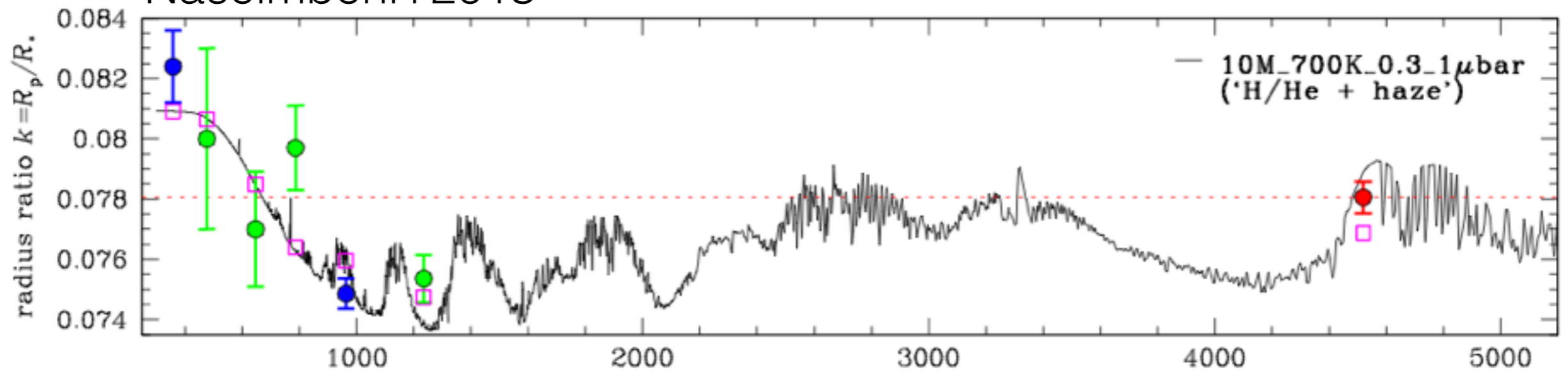
# NIR spectroscopy+models

Crossfield+2013

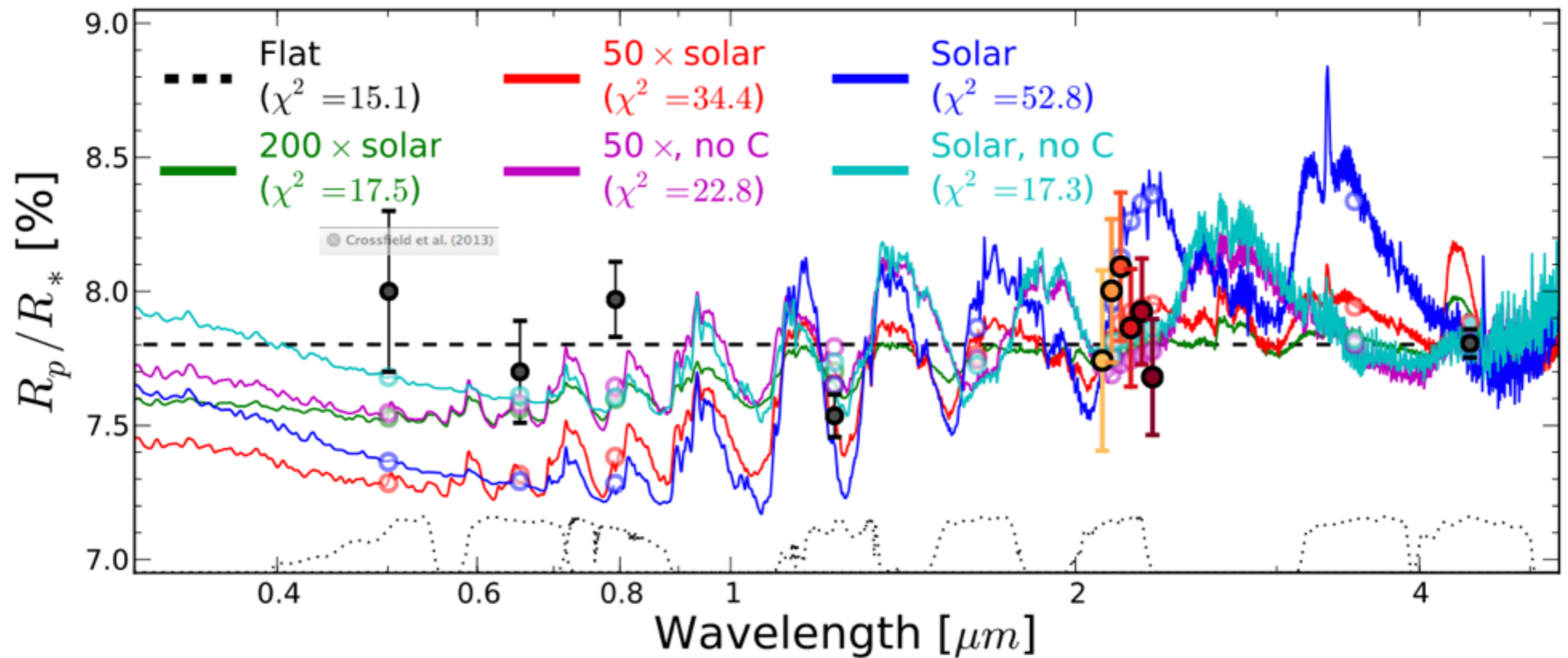


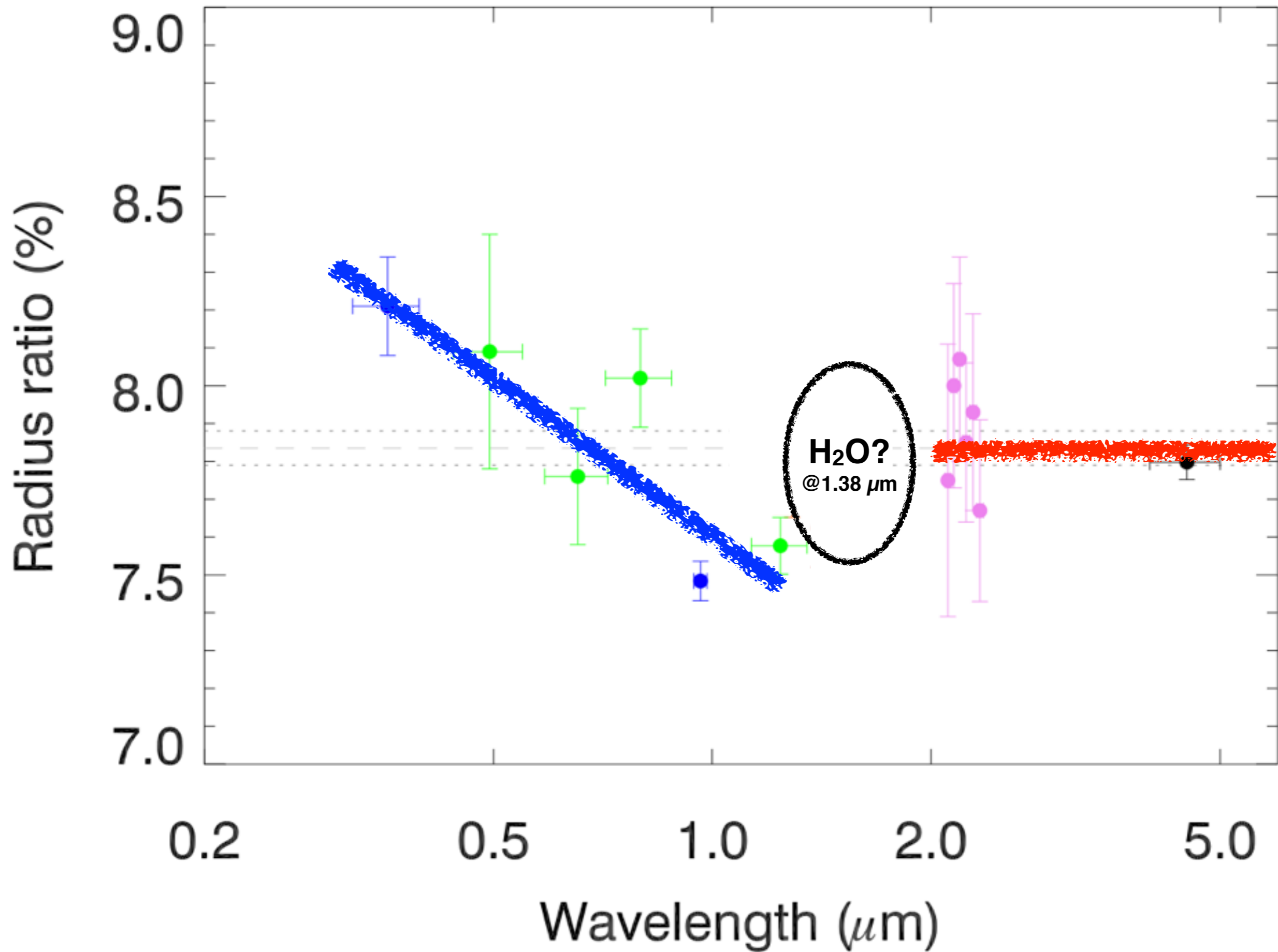


## Nascimbeni+2013



## Crossfield+2013



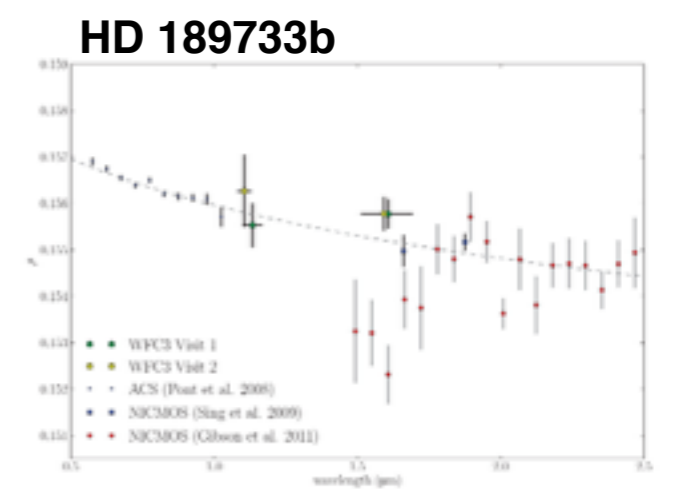
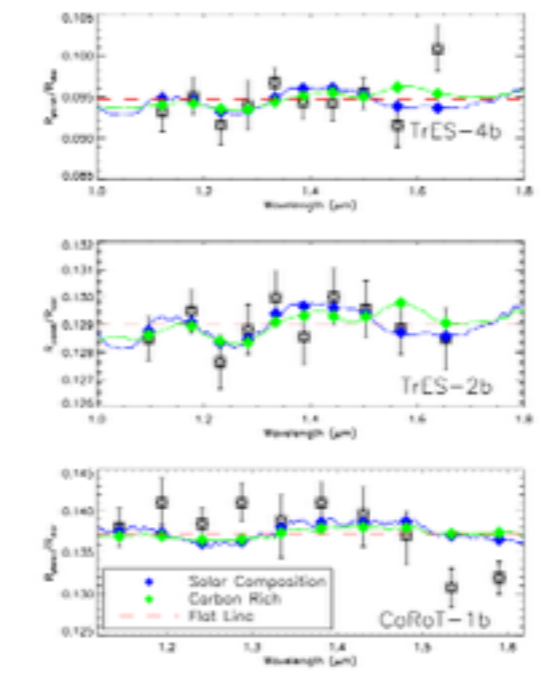
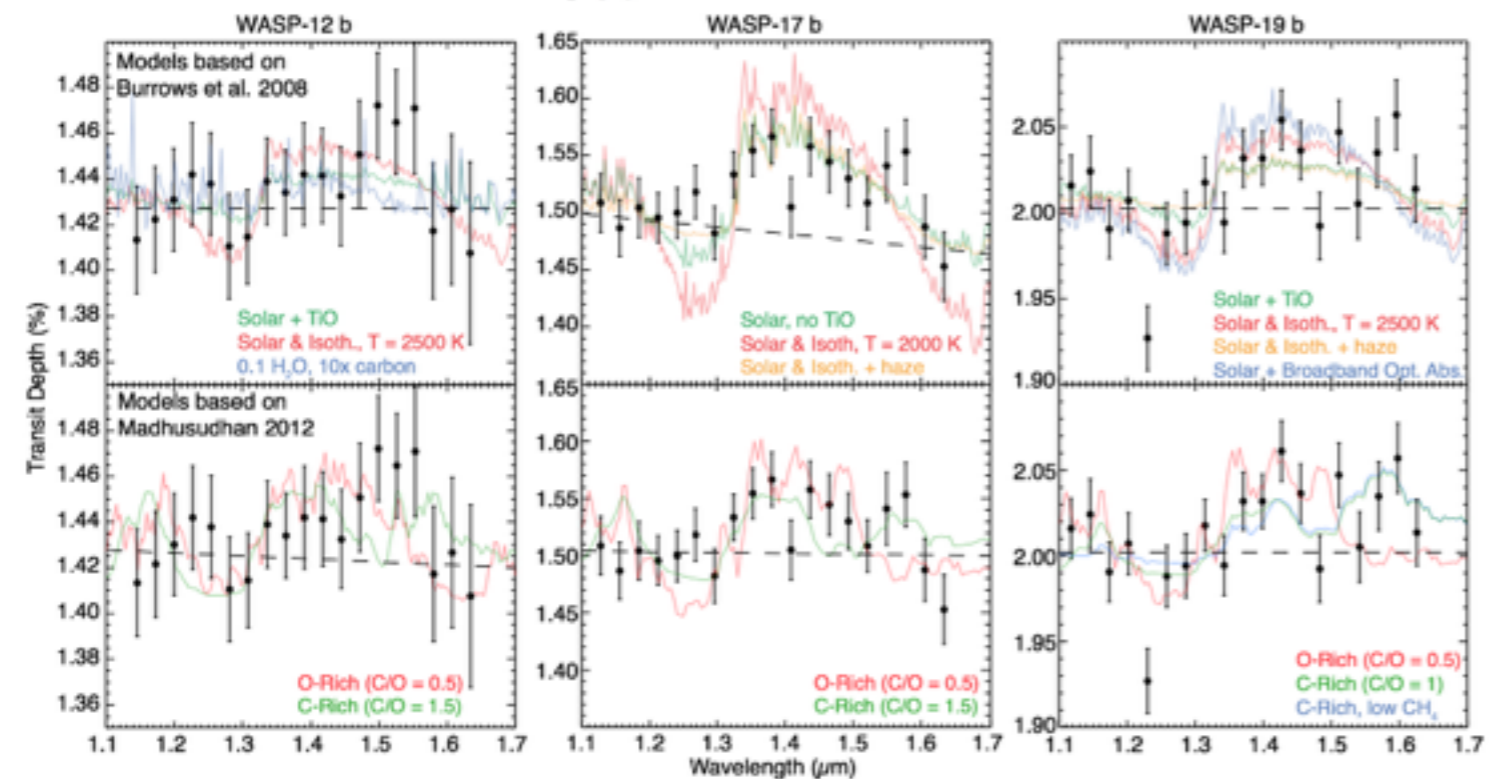
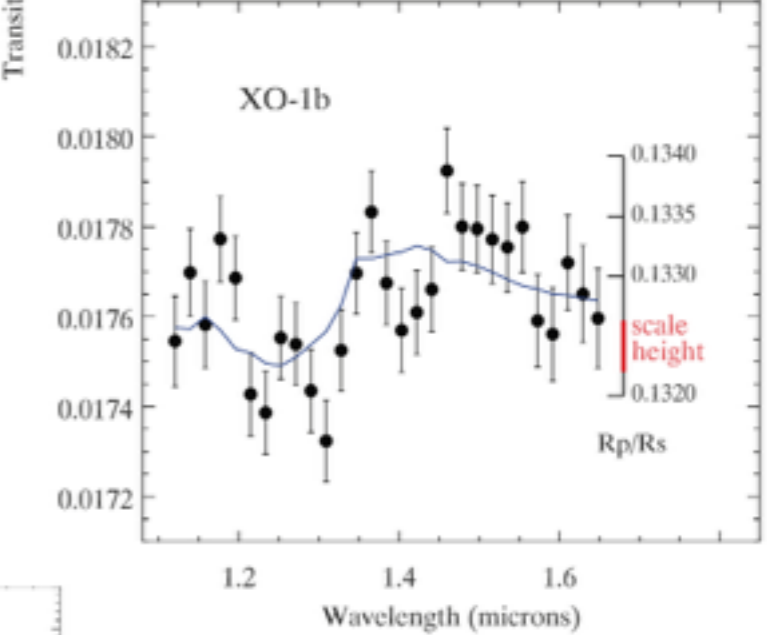
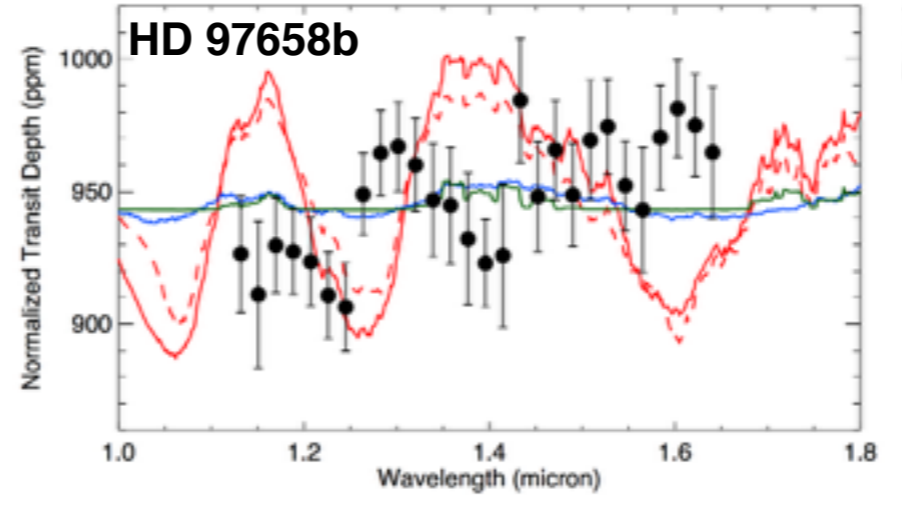
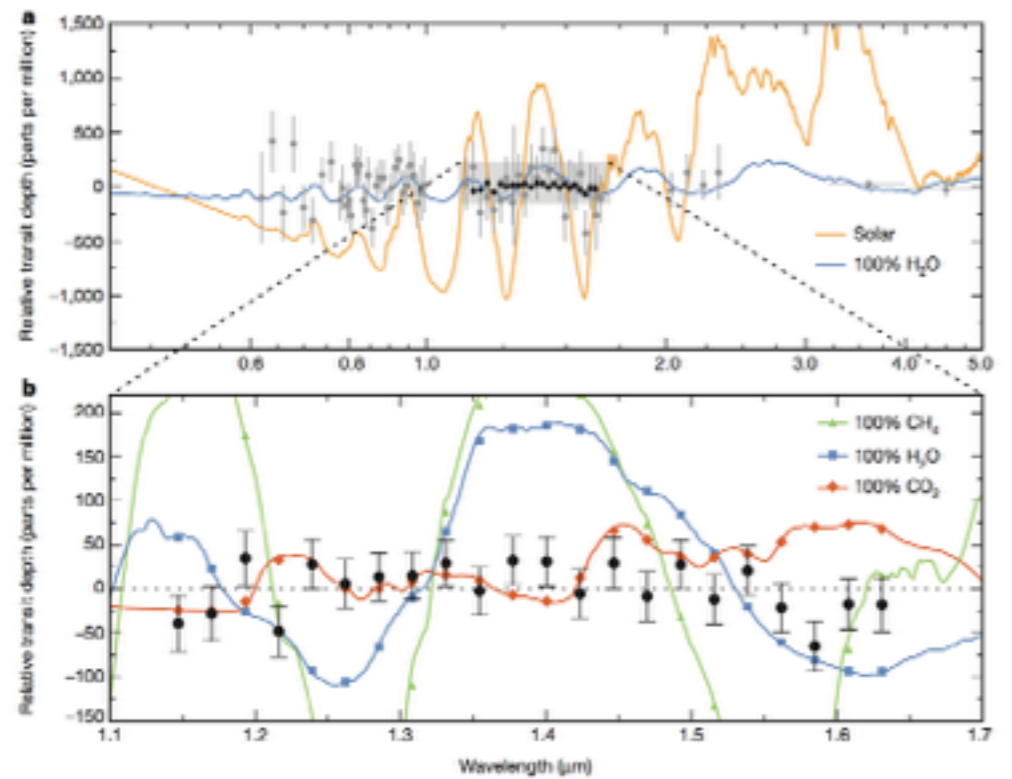
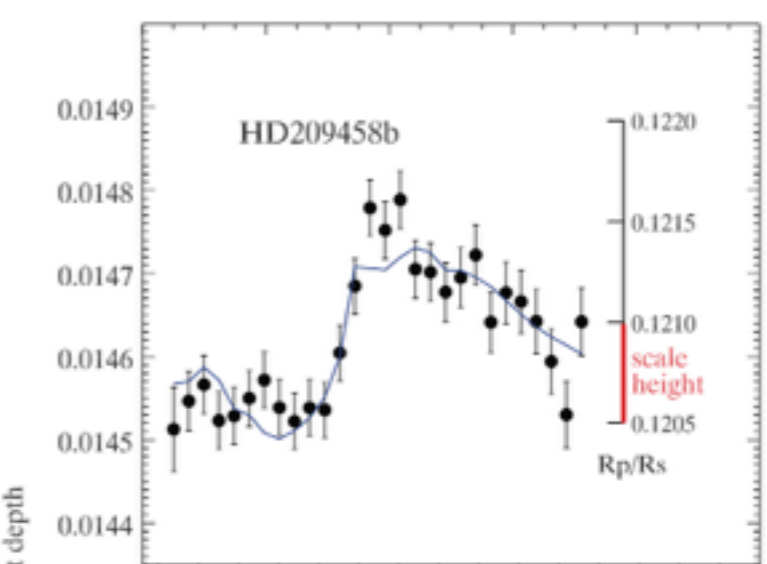
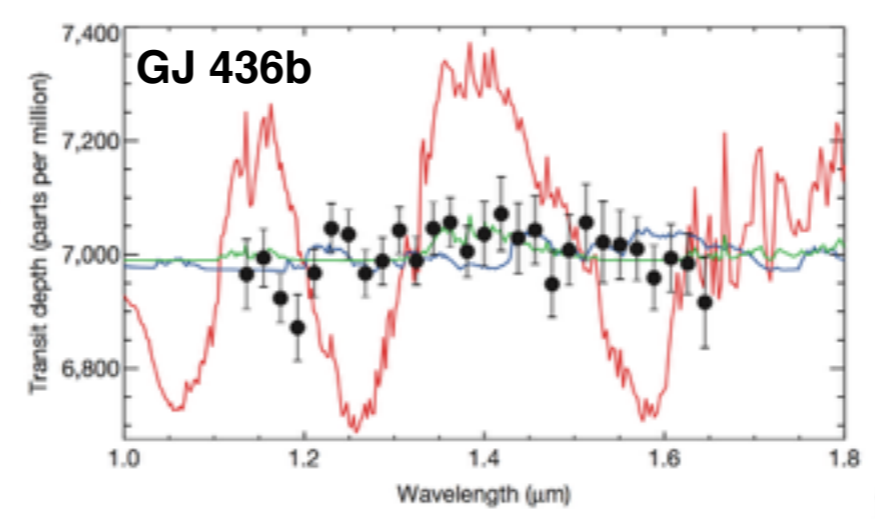
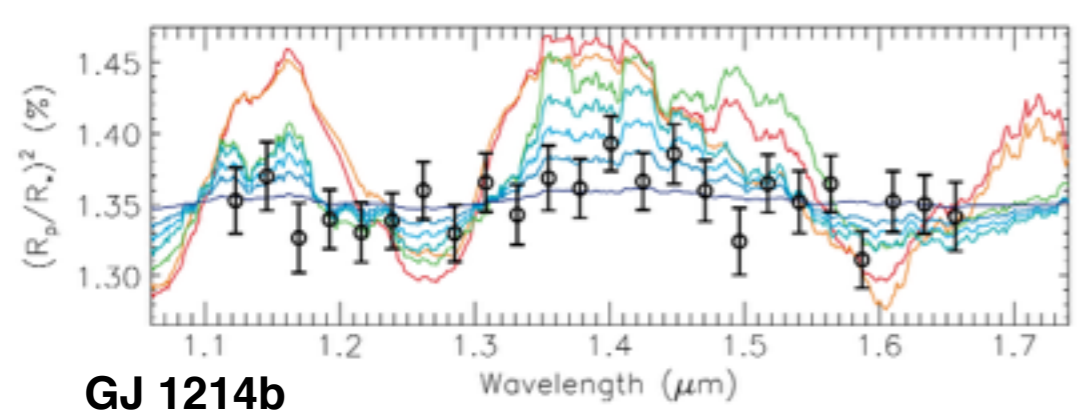


*“What is the nature of GJ 3470b, the missing link between super-earths and neptunes?”*

*Hubble Space Telescope  
Wide Field Camera-3 (WFC3)  
Slitless spectroscopy 1.1–1.7  $\mu\text{m}$*



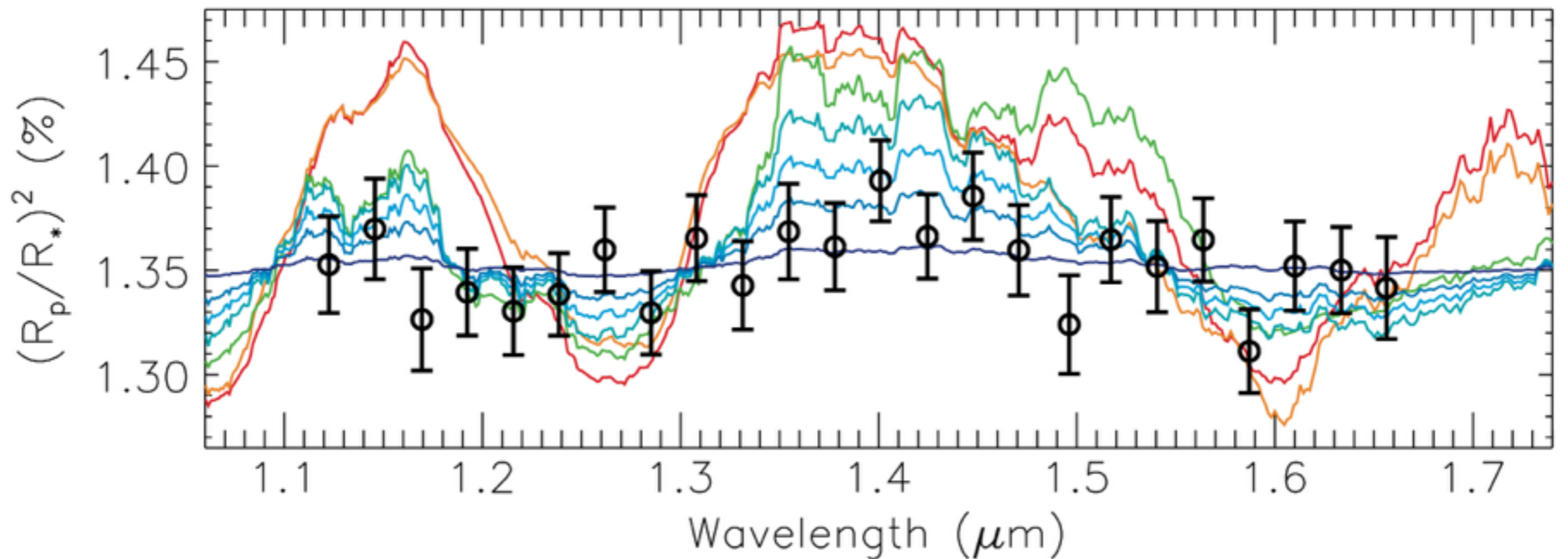




# Transmission spectrum of GJ 1214b

Berta+2012

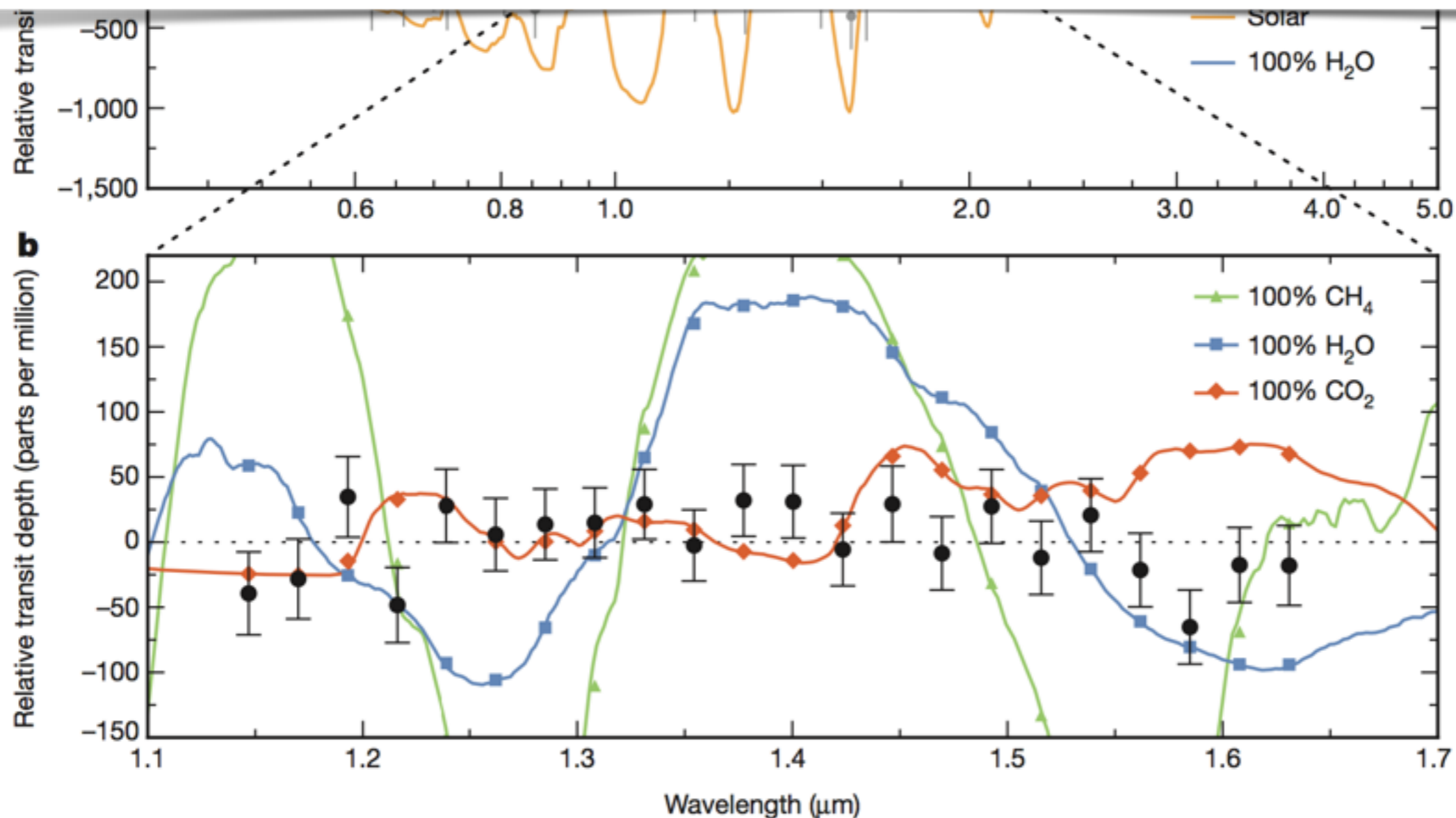
3 transits



- solar:  $\chi^2=126.2$
- solar with 50X metals:  $\chi^2=113.2$
- solar with no  $\text{CH}_4$ :  $\chi^2=88.9$
- 10%  $\text{H}_2\text{O}$ :  $\chi^2=47.8$
- 20%  $\text{H}_2\text{O}$ :  $\chi^2=25.5$
- 40%  $\text{H}_2\text{O}$ :  $\chi^2=15.3$
- 100%  $\text{H}_2\text{O}$ :  $\chi^2=16.7$

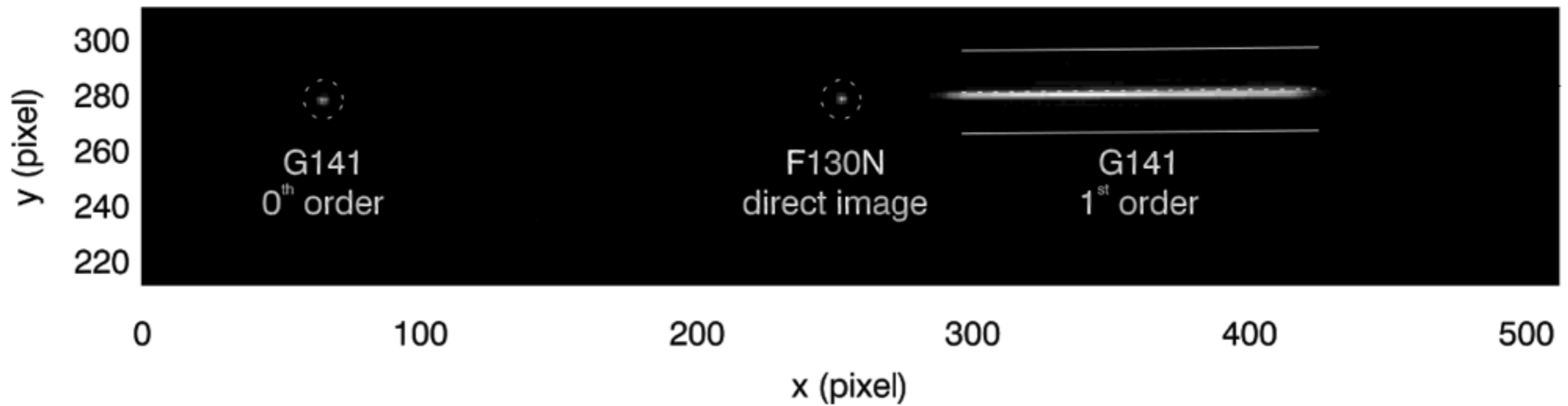
# Clouds in the atmosphere of the super-Earth exoplanet GJ 1214b

Laura Kreidberg<sup>1</sup>, Jacob L. Bean<sup>1</sup>, Jean-Michel Désert<sup>2,3</sup>, Björn Benneke<sup>4</sup>, Drake Deming<sup>5</sup>, Kevin B. Stevenson<sup>1</sup>, Sara Seager<sup>4</sup>, Zachory Berta-Thompson<sup>6,7</sup>, Andreas Seifahrt<sup>1</sup> & Derek Homeier<sup>8</sup>

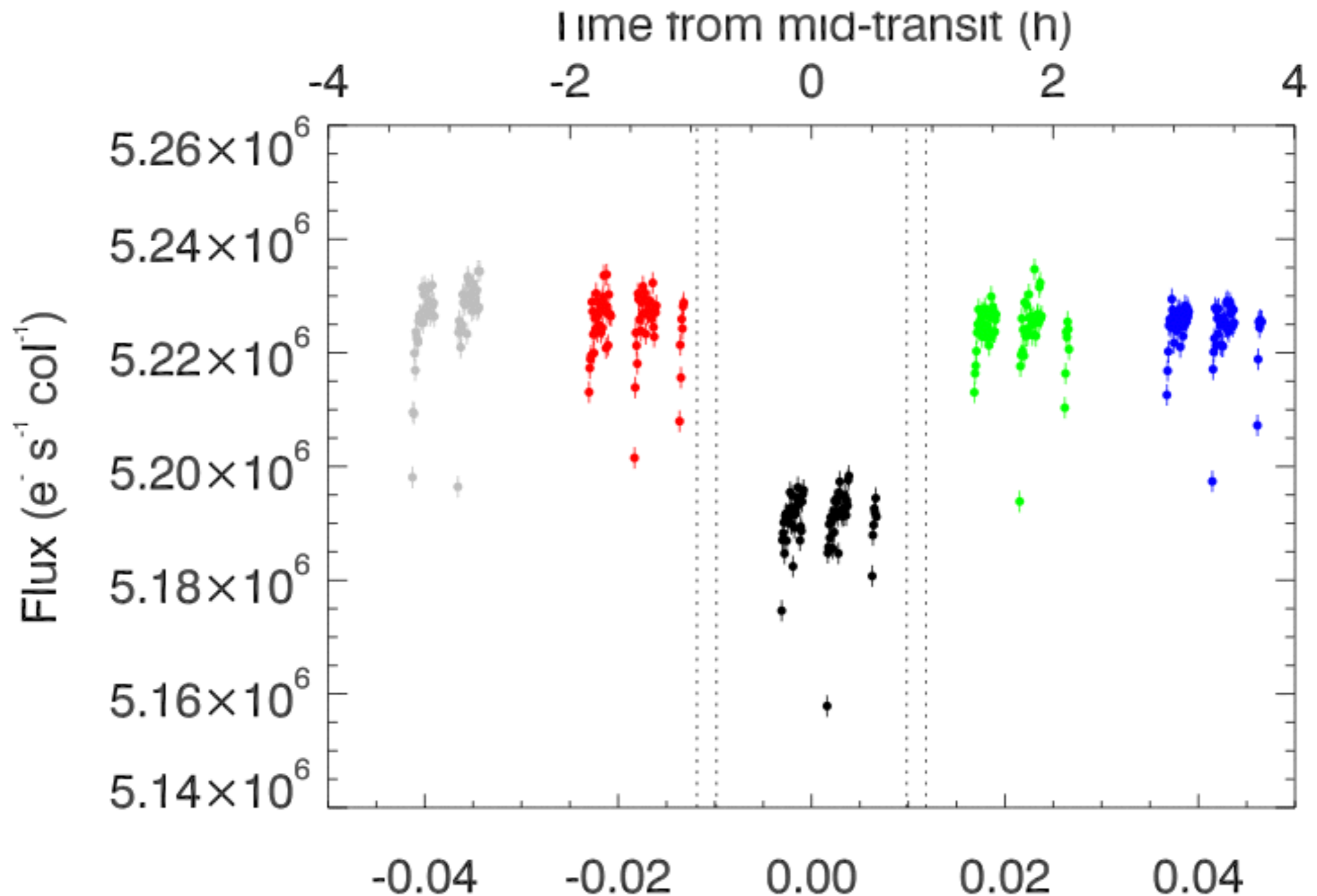




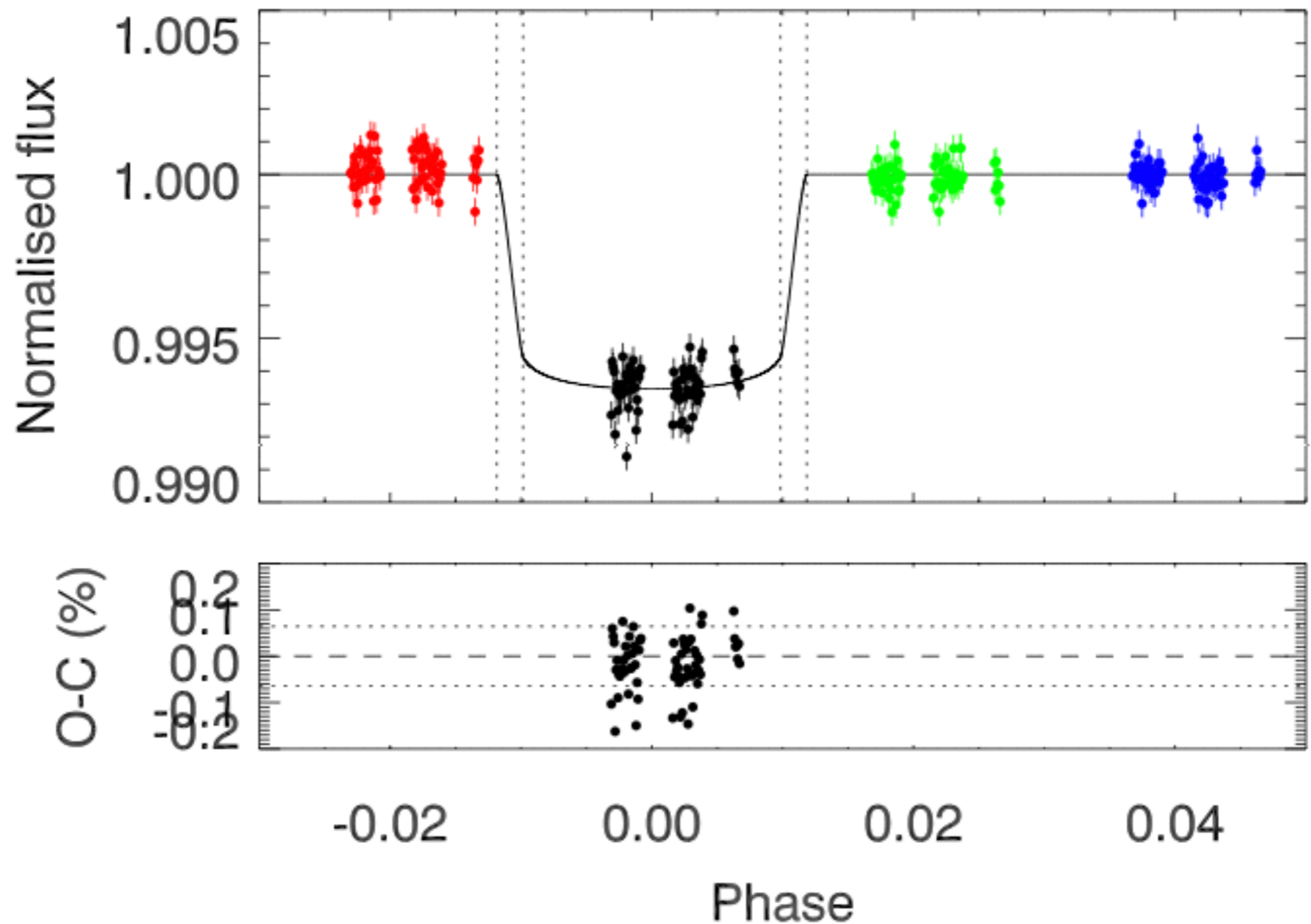
# *HST/WFC3* data ("stare mode")



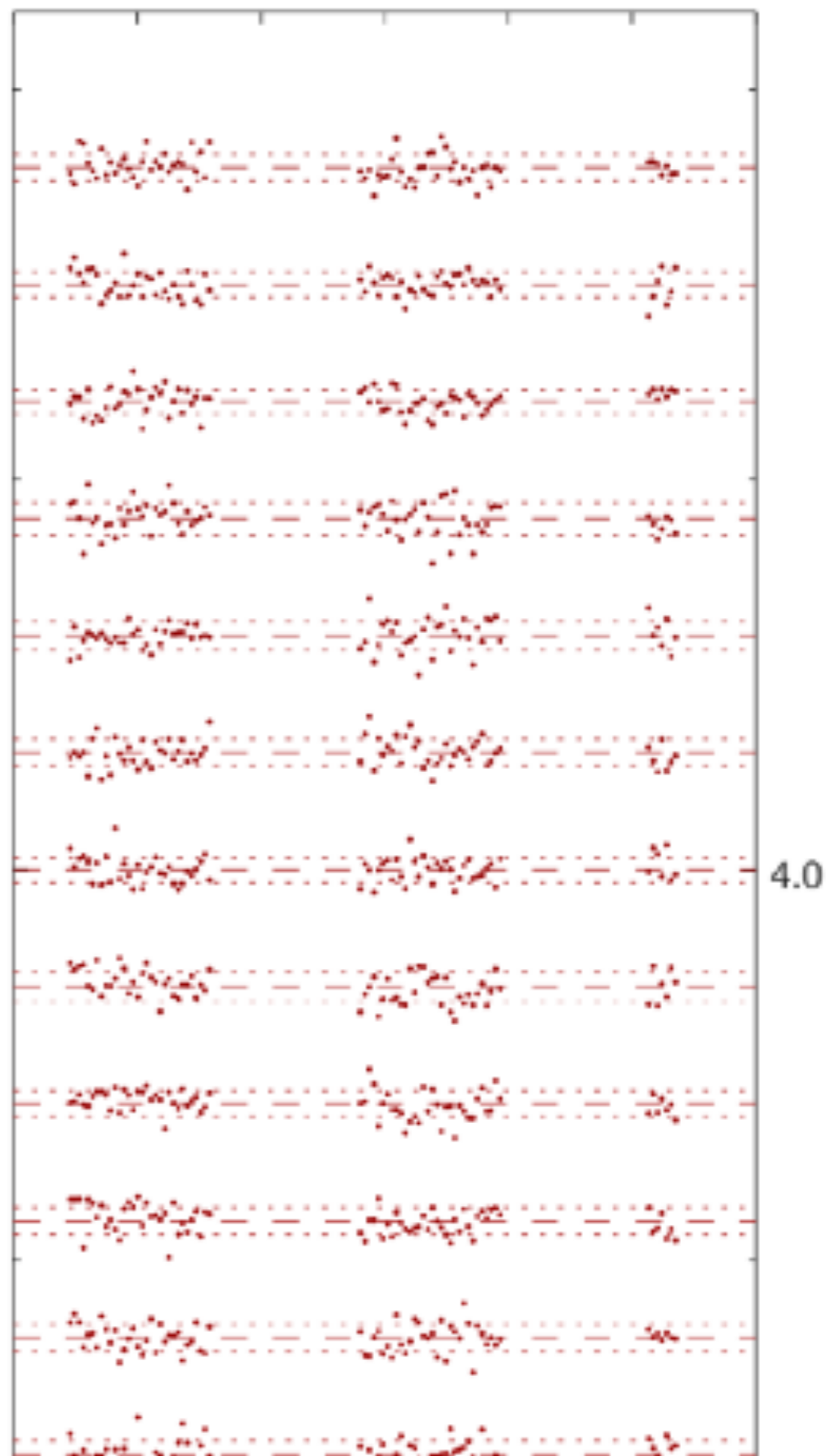
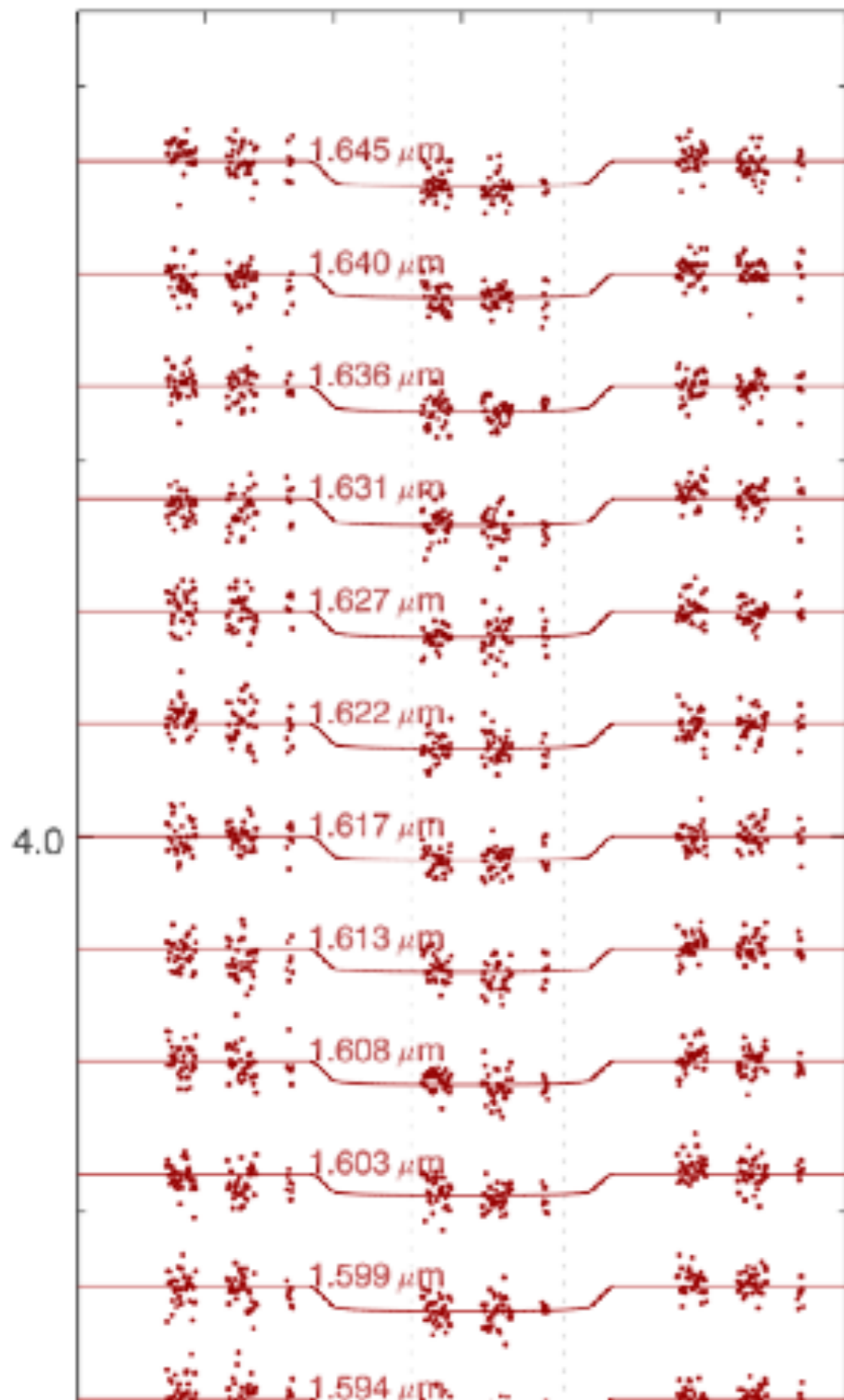
# *HST*/WFC3 “white” light curve

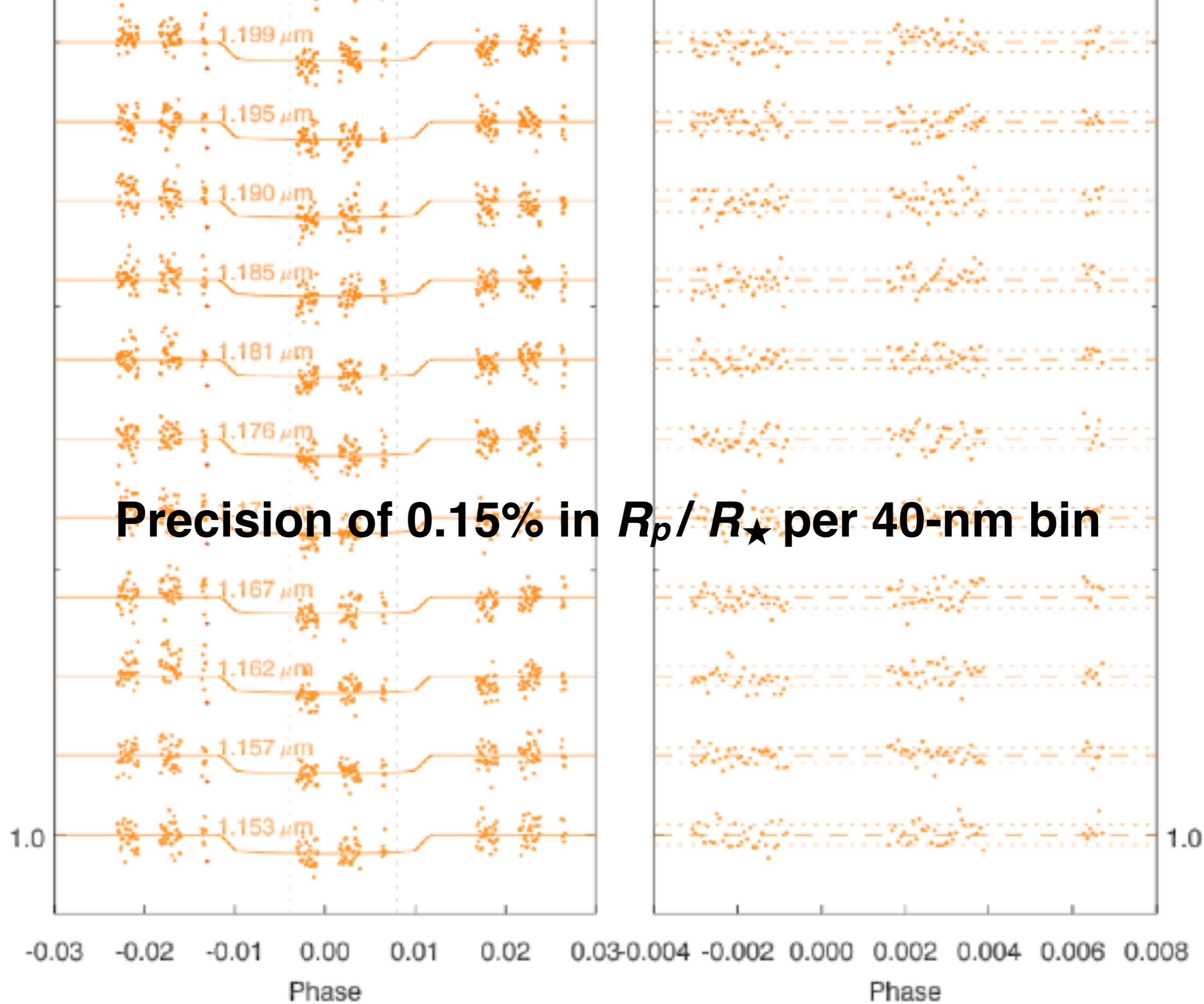


# *HST*/WFC3 “white” light curve



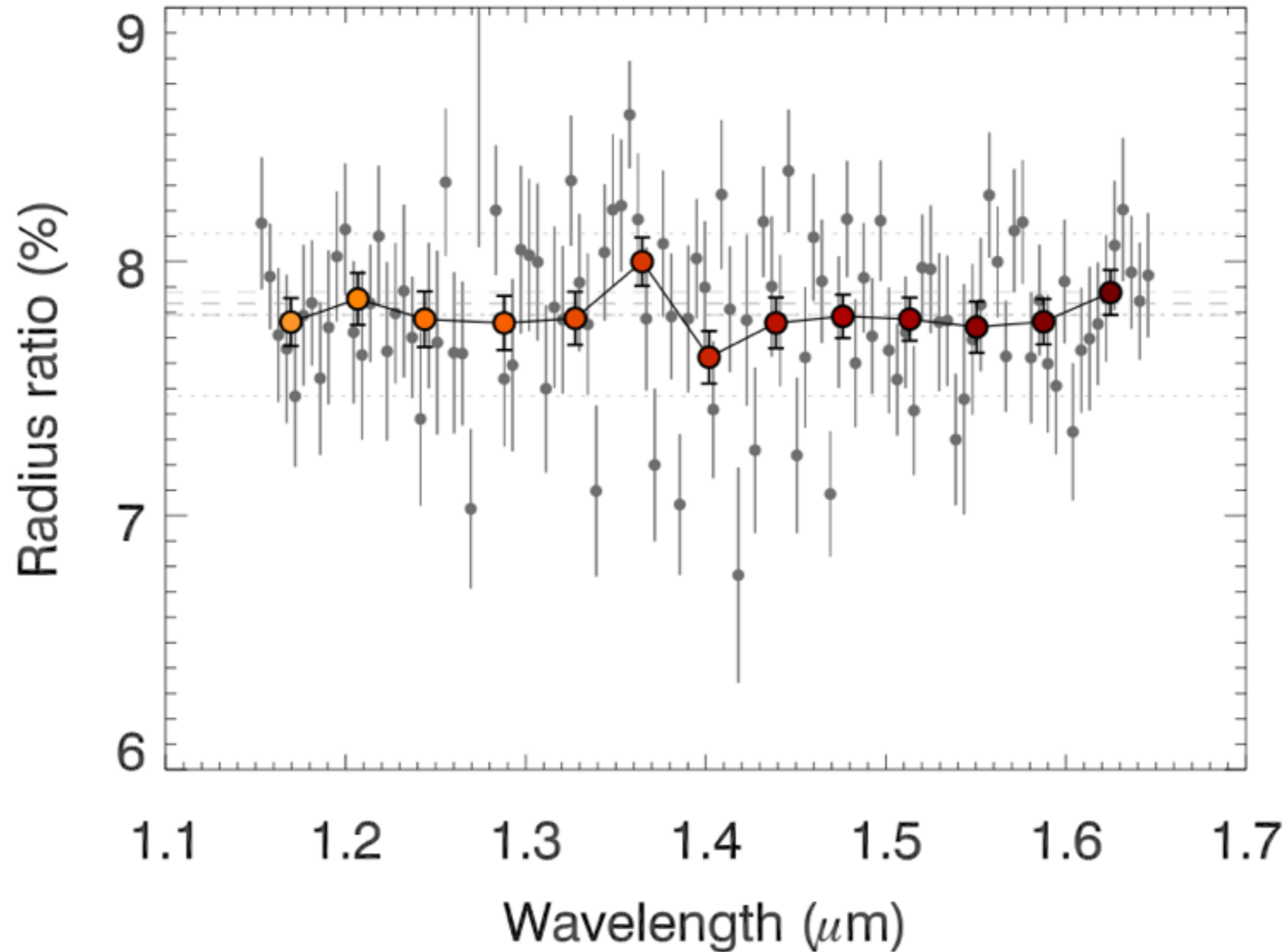




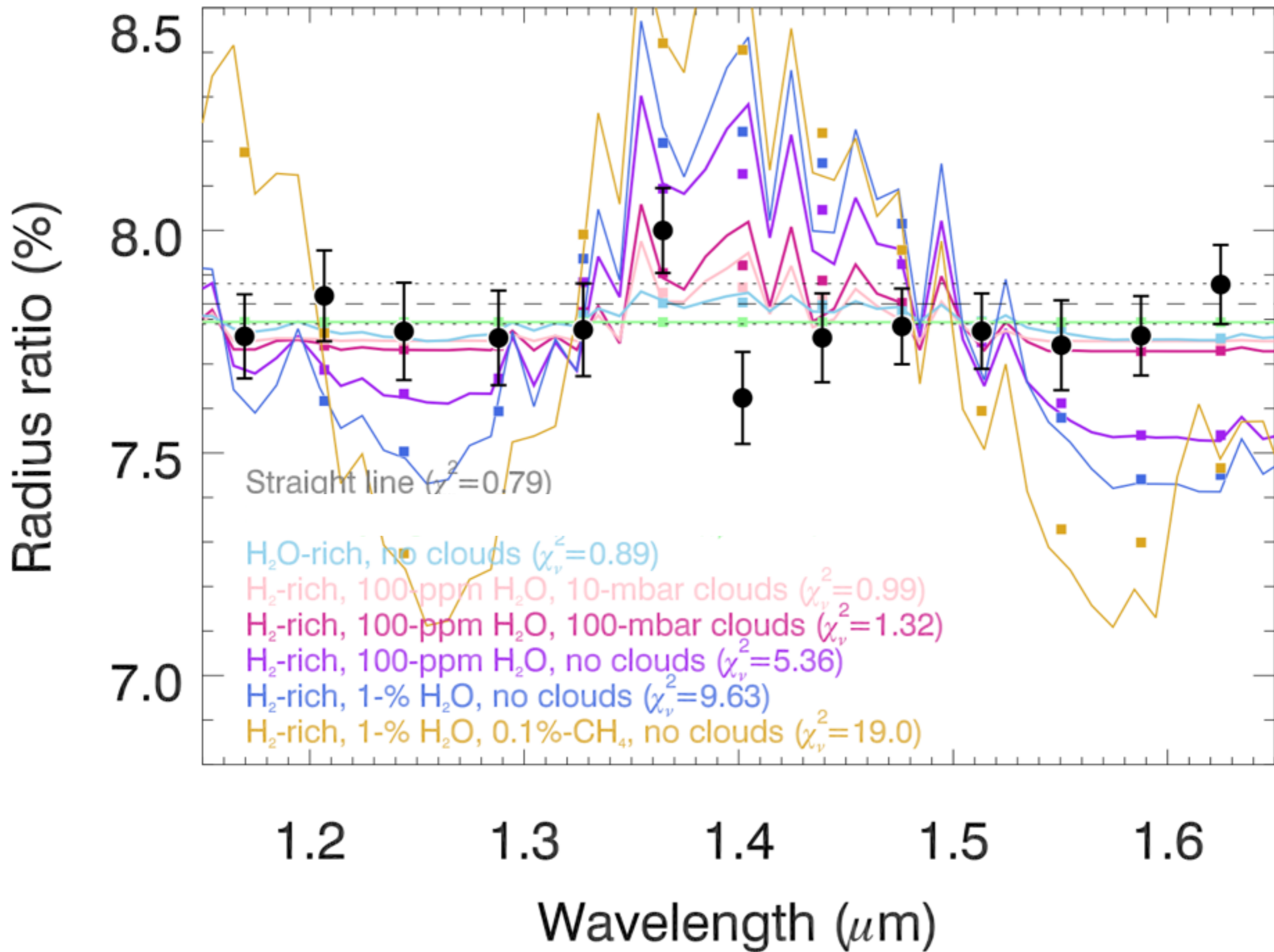


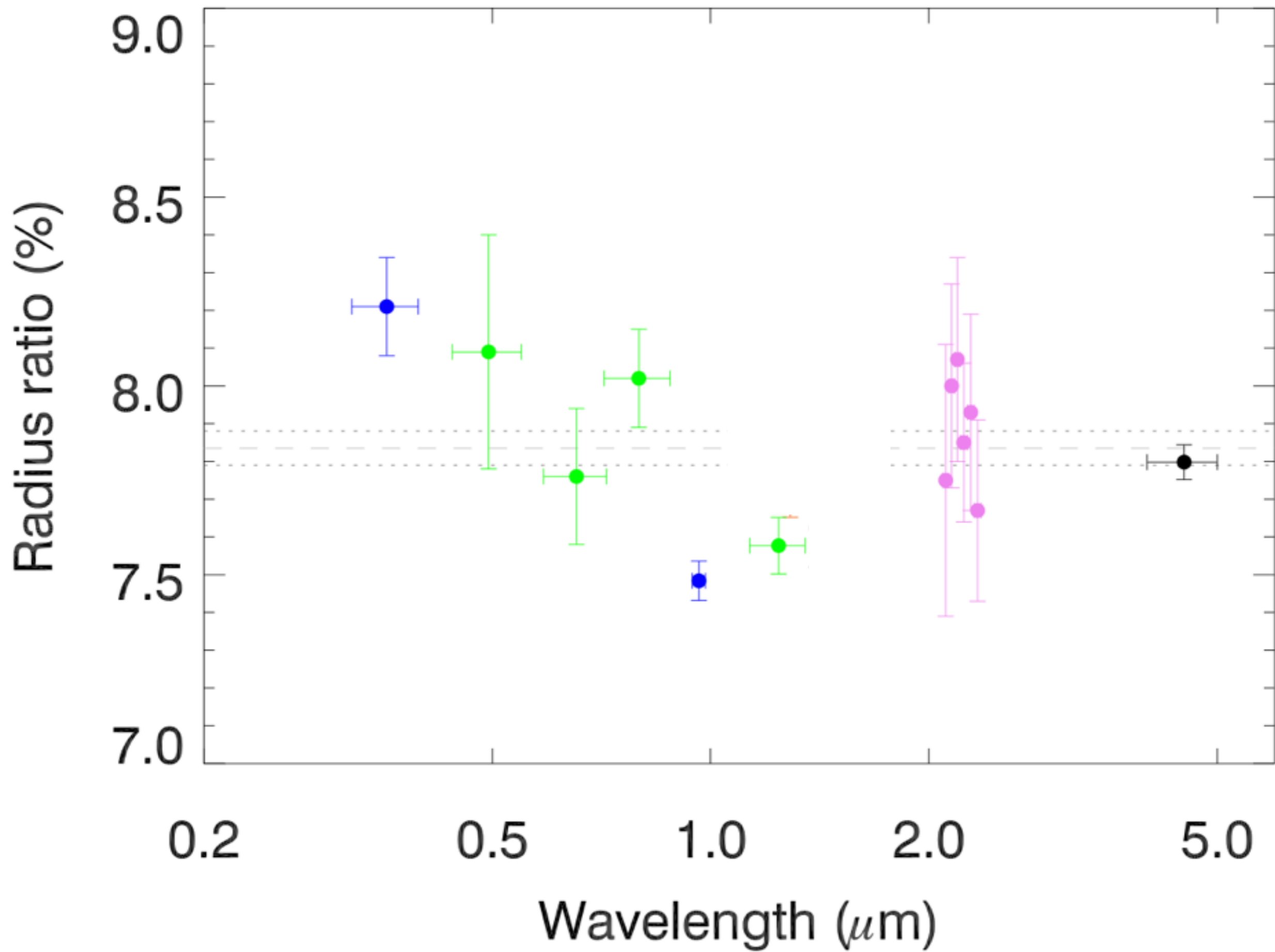
# Transmission spectrum of GJ 3470b

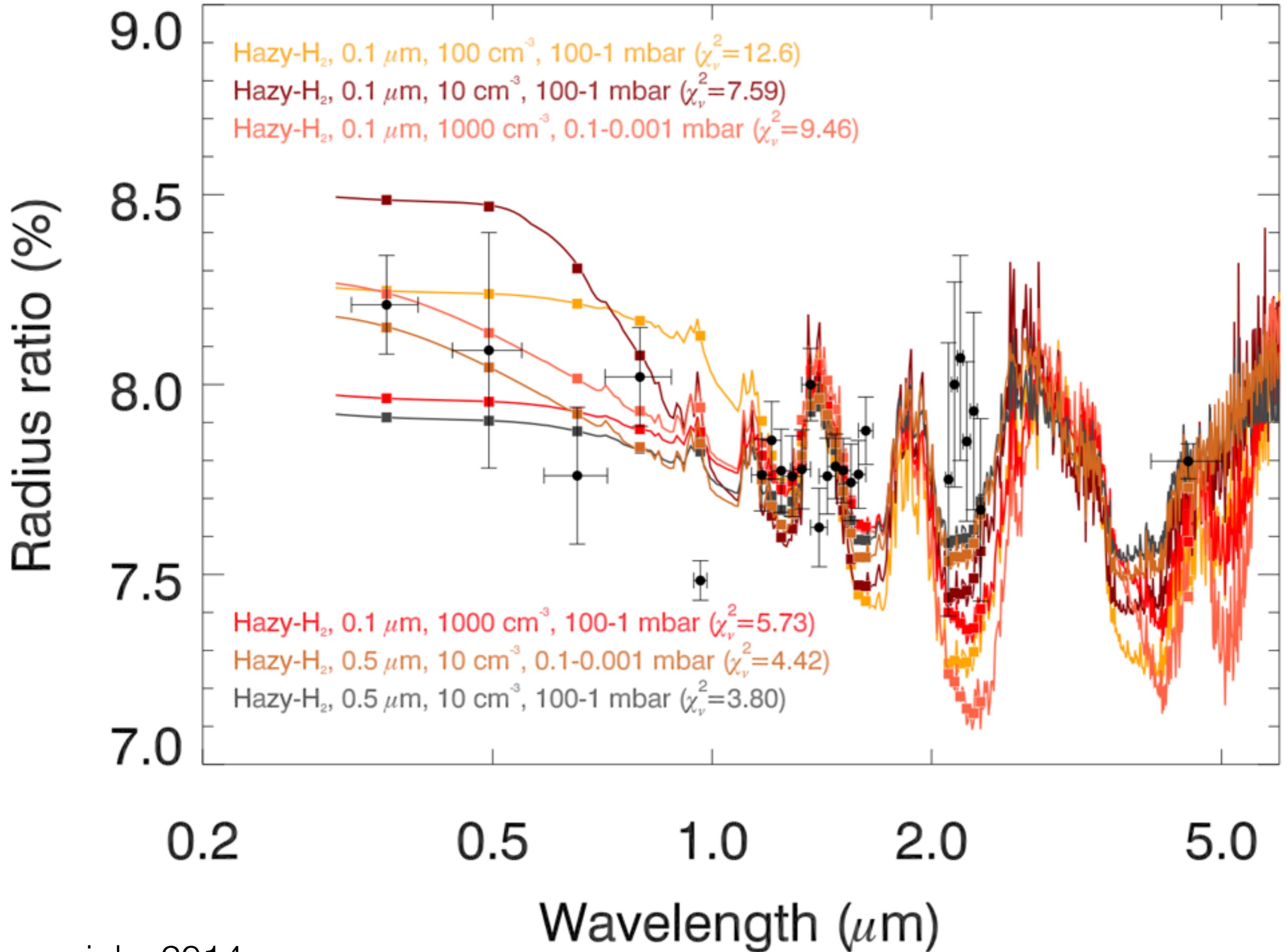
Ehrenreich+2014



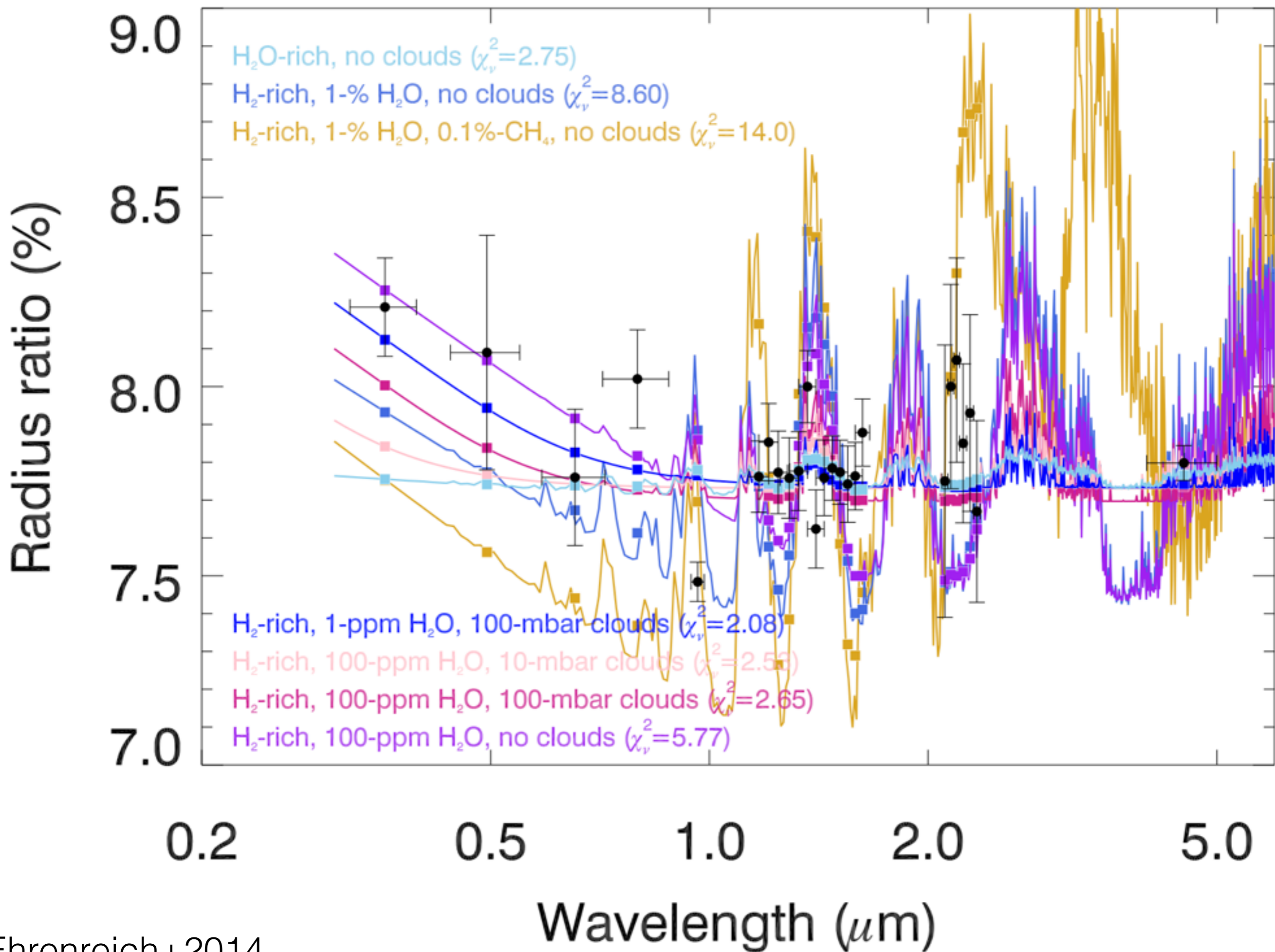


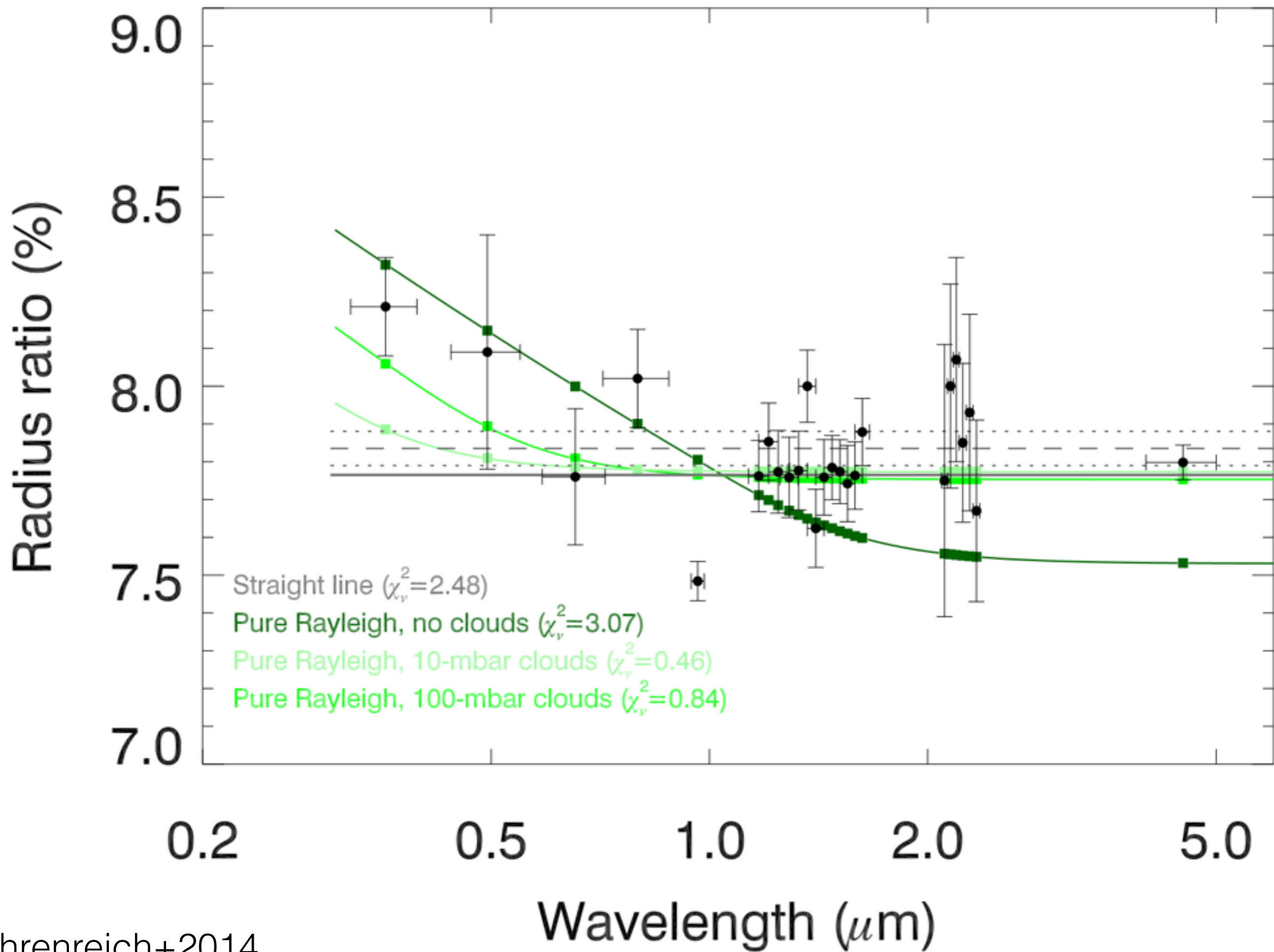












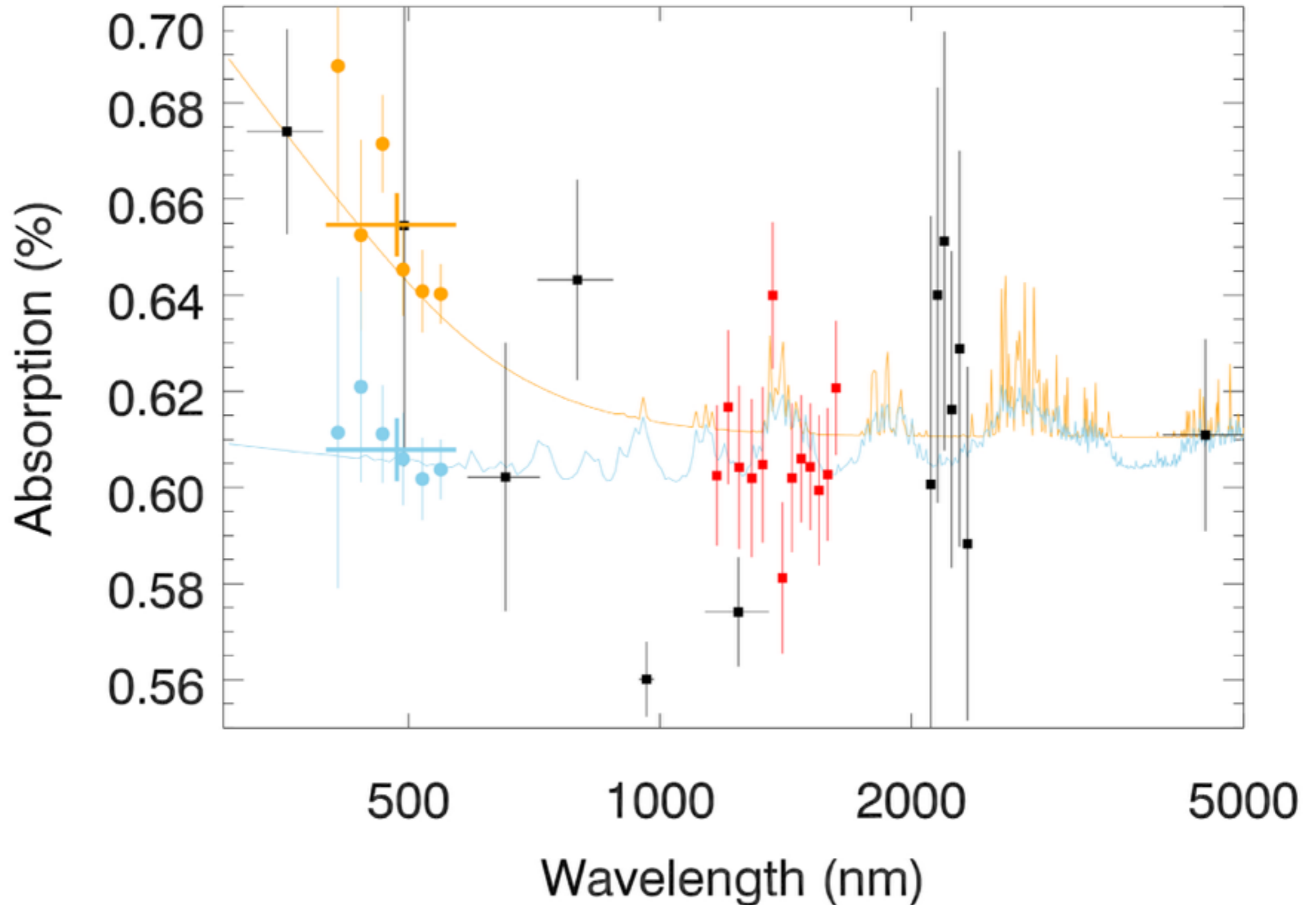


# Summary

- **Transmission spectrum of GJ 3470b from 0.4 to 5  $\mu\text{m}$**
- **Hint of scattering in the visible**
- **Featureless in the NIR and IR**
- **Blue sky over a sea of clouds?**
- **Where is the water?**
- ***Observations of the integrated limb***



*“Searching for blue sky on a warm neptune”*  
submitted to *HST* Cycle 22

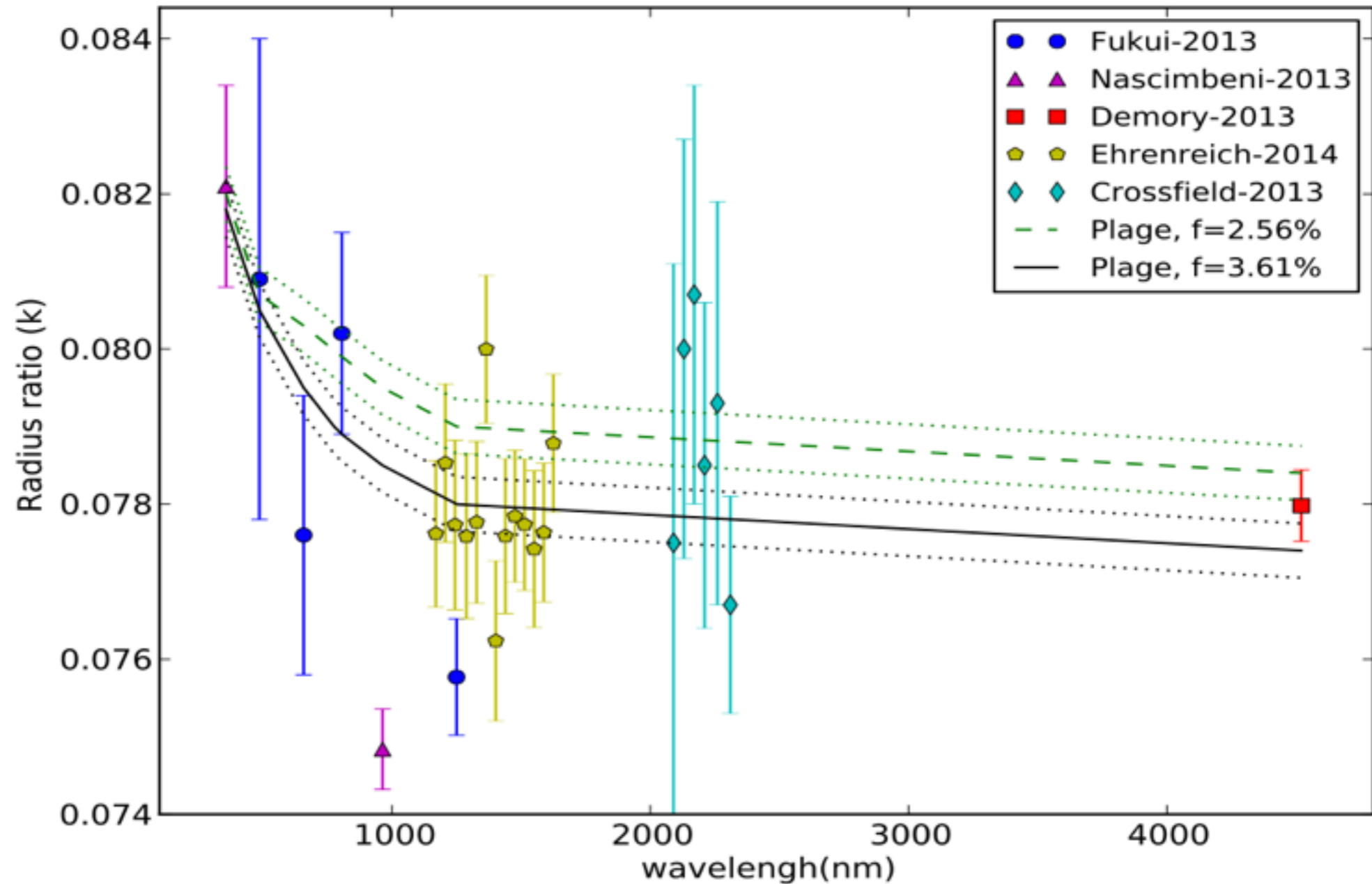


HOWEVER,

here's an alternative (ad-hoc) scenario

# Stellar activity?

Oshagh+2014, submitted



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