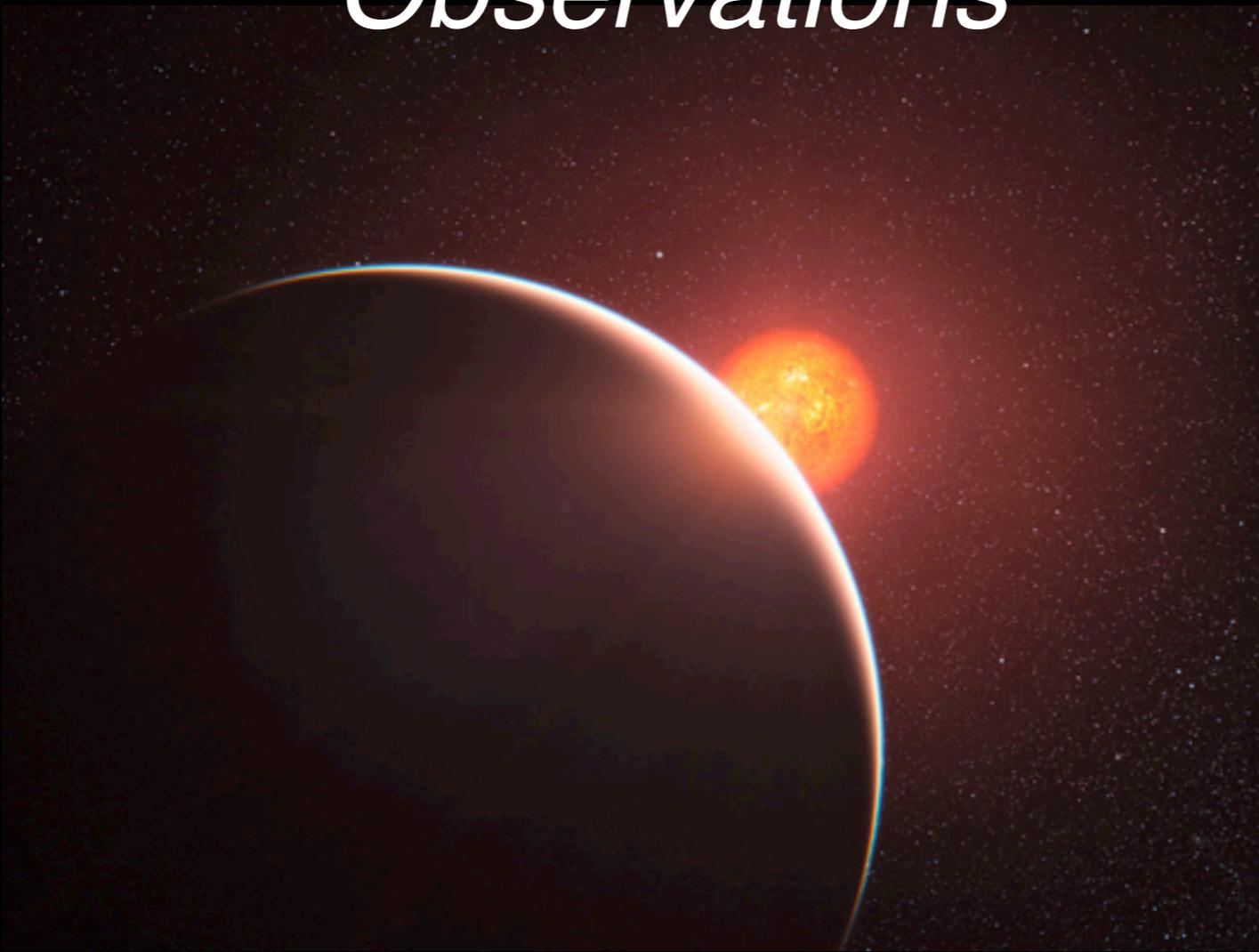


Atmospheric Characterization of Transiting Extrasolar Planets

Observations



Jean-Michel Désert

Caltech - Sagan Fellow

EXOPAG 6, Reno
October 13th 2012

New Frontiers



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**Comparative
exoplanetology
of hot-Jupiters**



New Frontiers

**Comparative
exoplanetology
of hot-Jupiters**

**Super-Earths
around low
mass stars**



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**Kepler
Transiting
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New Frontiers

**Comparative
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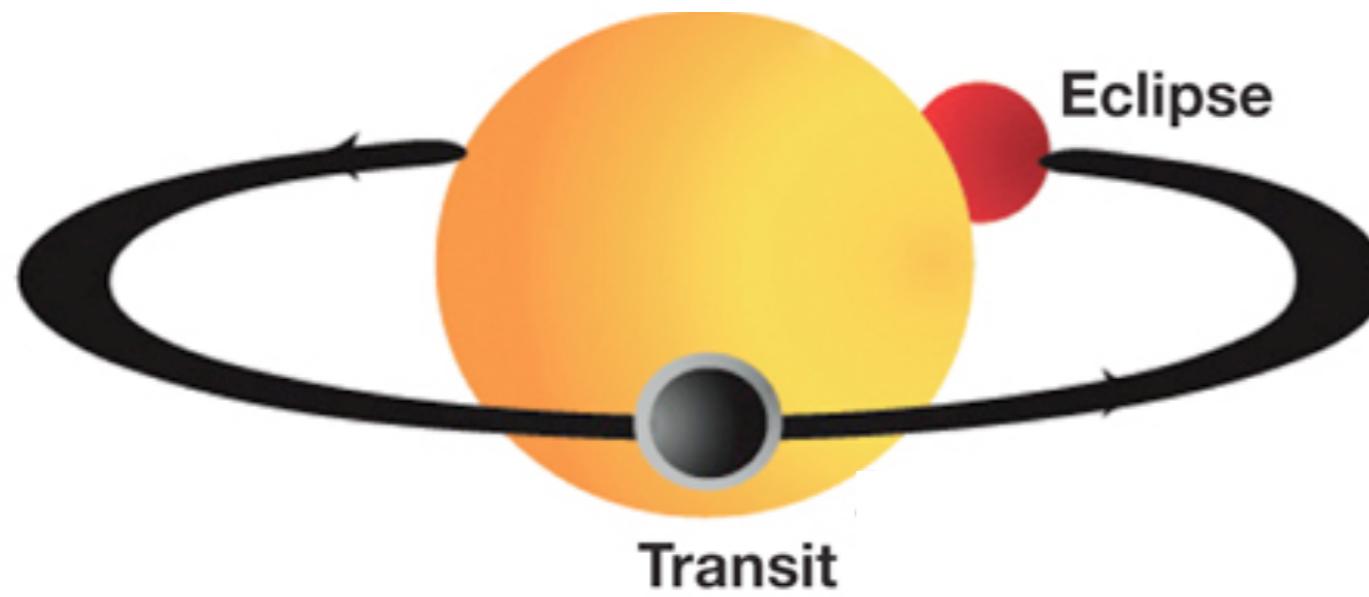
**Super-Earths
around low
mass stars**

**Kepler
Transiting
planets**

**Transiting
planets in front
of bright stars**

- I) A Decade of Transiting Planets' Atmospheres
- II) Comparative Exoplanetology
- III) Ground Based Challenges
- IV) New Astrophysical Opportunities

Transits Allow Studies of Atmospheres That Are Not Possible for Non-Transiting Exoplanets



$$\text{Reflected: } \frac{F_p}{F_*} = A_g \left(\frac{R_p}{a} \right)^2$$

$$\text{Emitted: } \frac{\Delta f}{f} \simeq \frac{T_p}{T_*} \left(\frac{R_p}{R_*} \right)^2$$

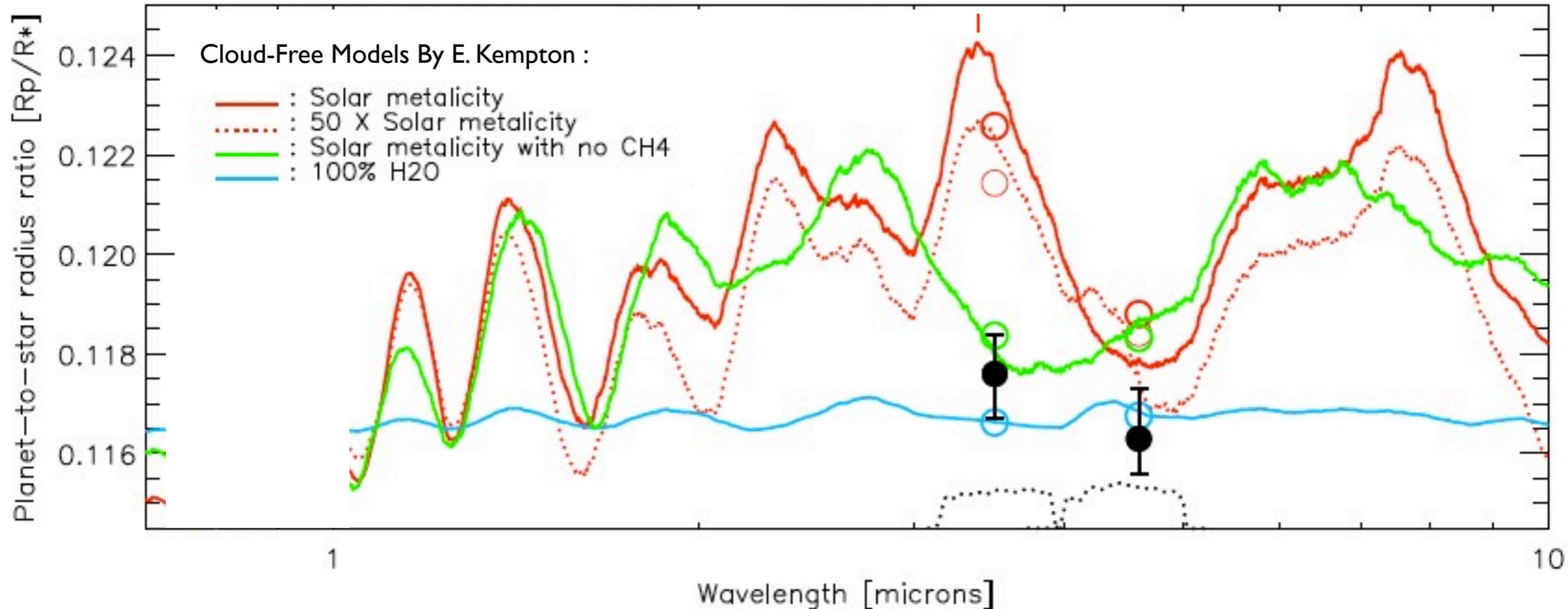
$$\text{Transmitted: } \Delta D \sim \frac{2HR_{\text{pl}}}{R_*^2}$$

$$H = \frac{kT}{\mu_m g}$$

Transmission Spectroscopy of GJ1214b

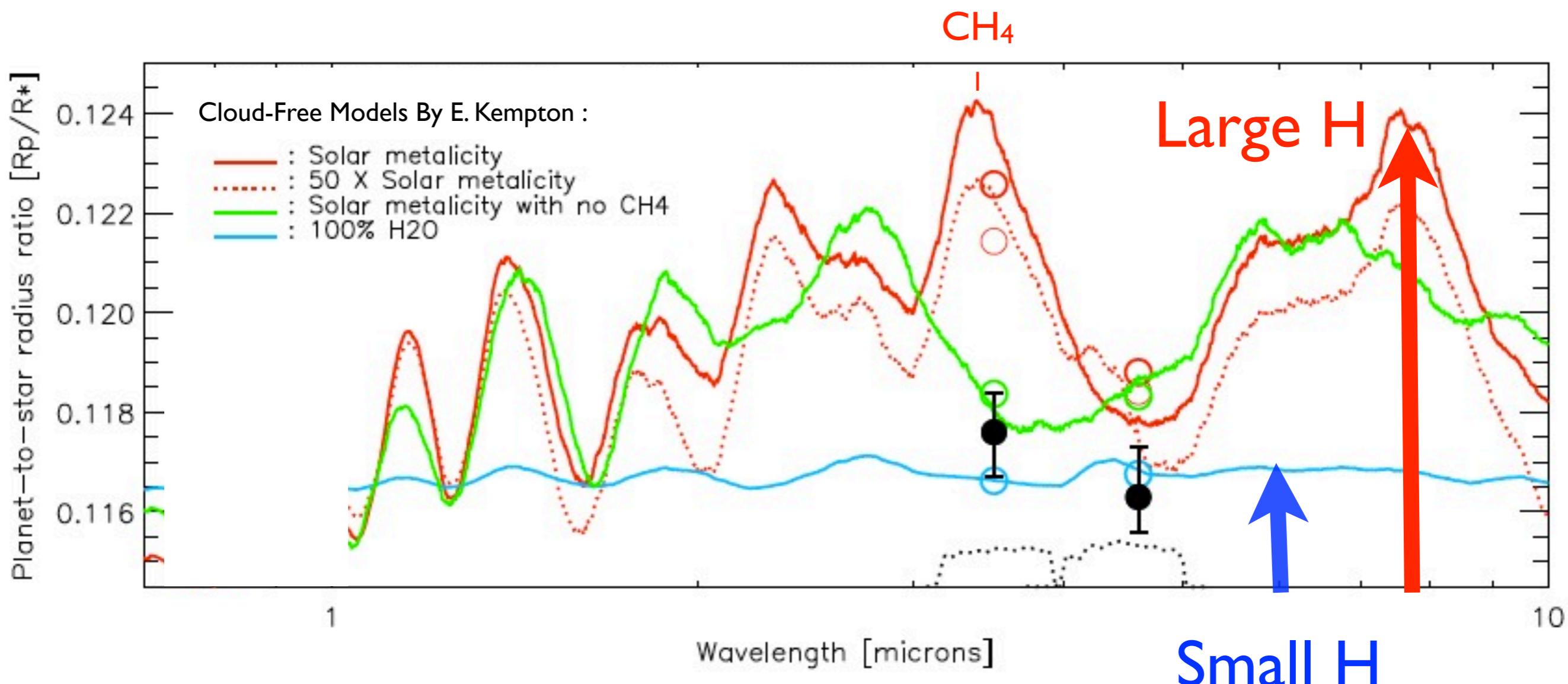
Désert et al. (2011)

CH₄



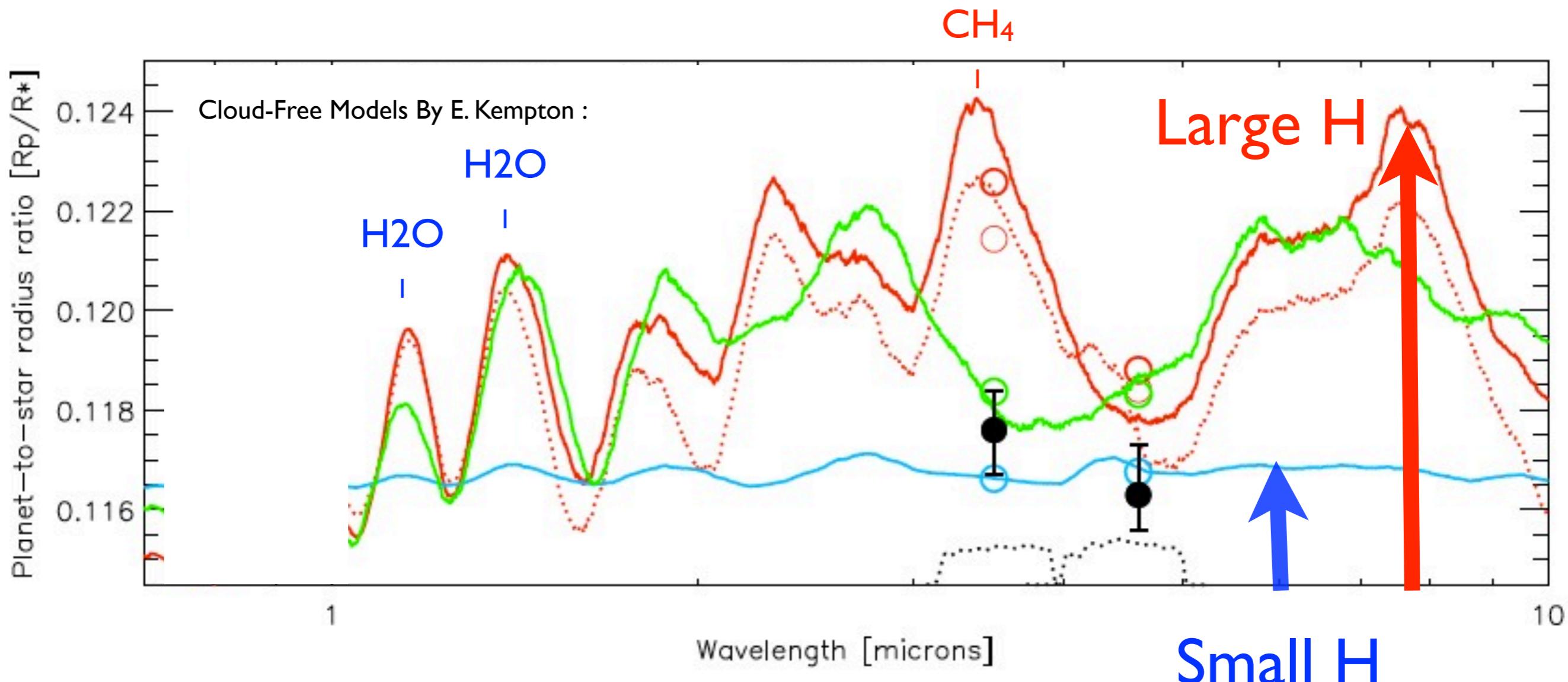
GJ1214b: Distinguishing H-rich/H-poor atmospheres

Désert et al. (2011)



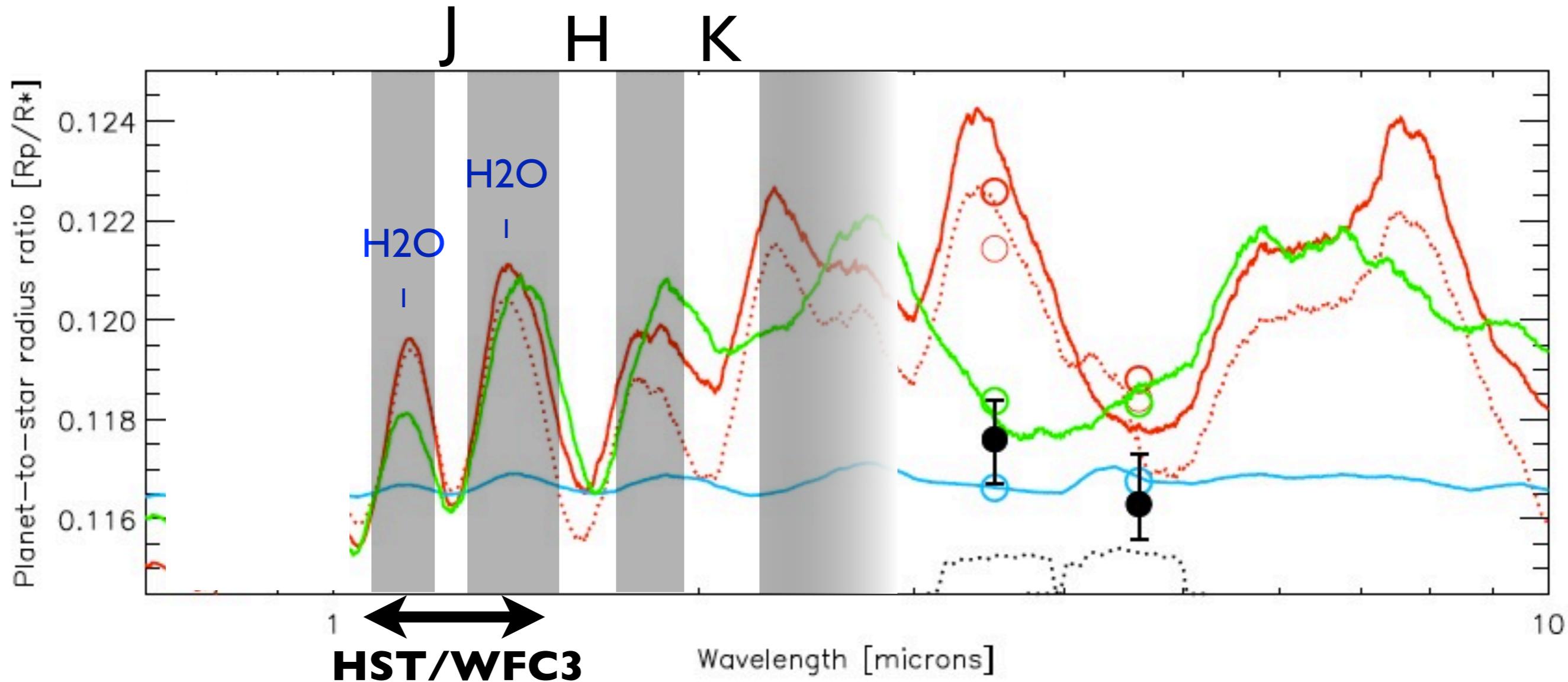
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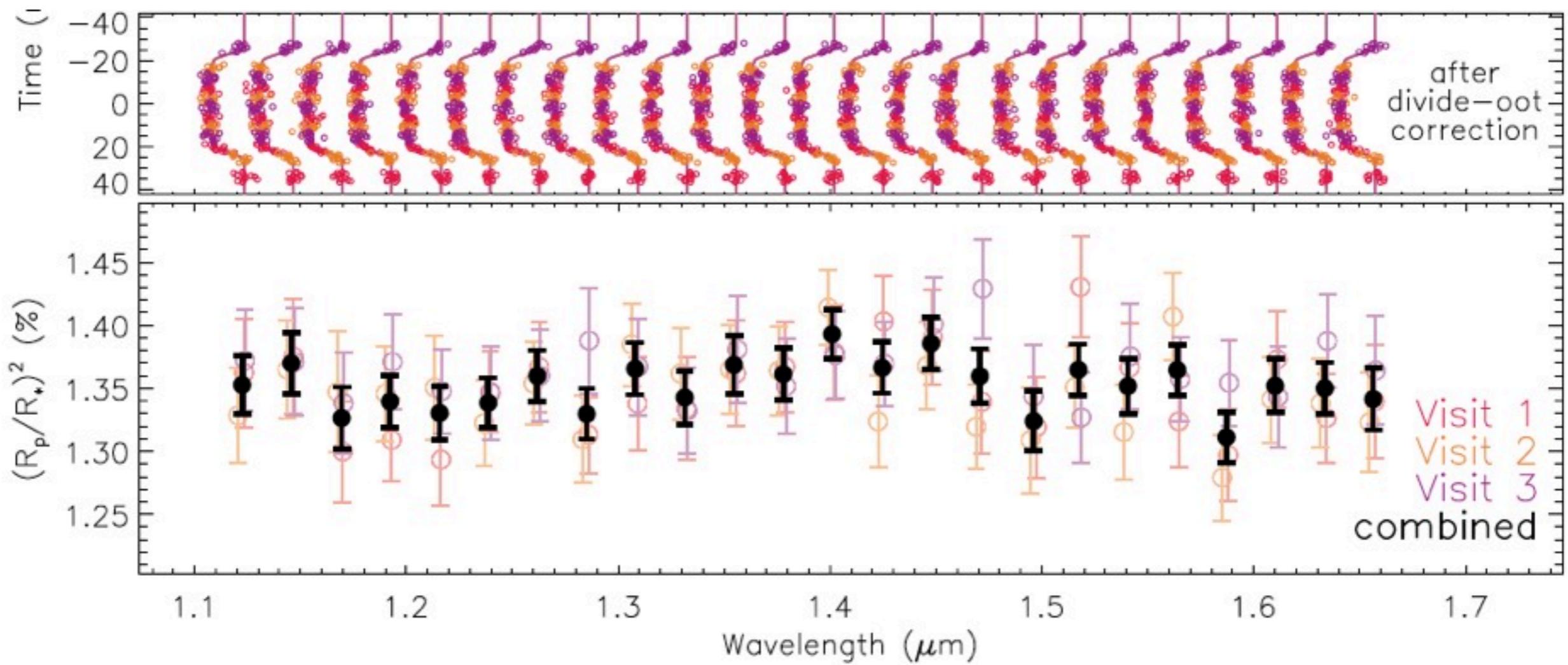
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Wavelength-Dependent Transit Depths

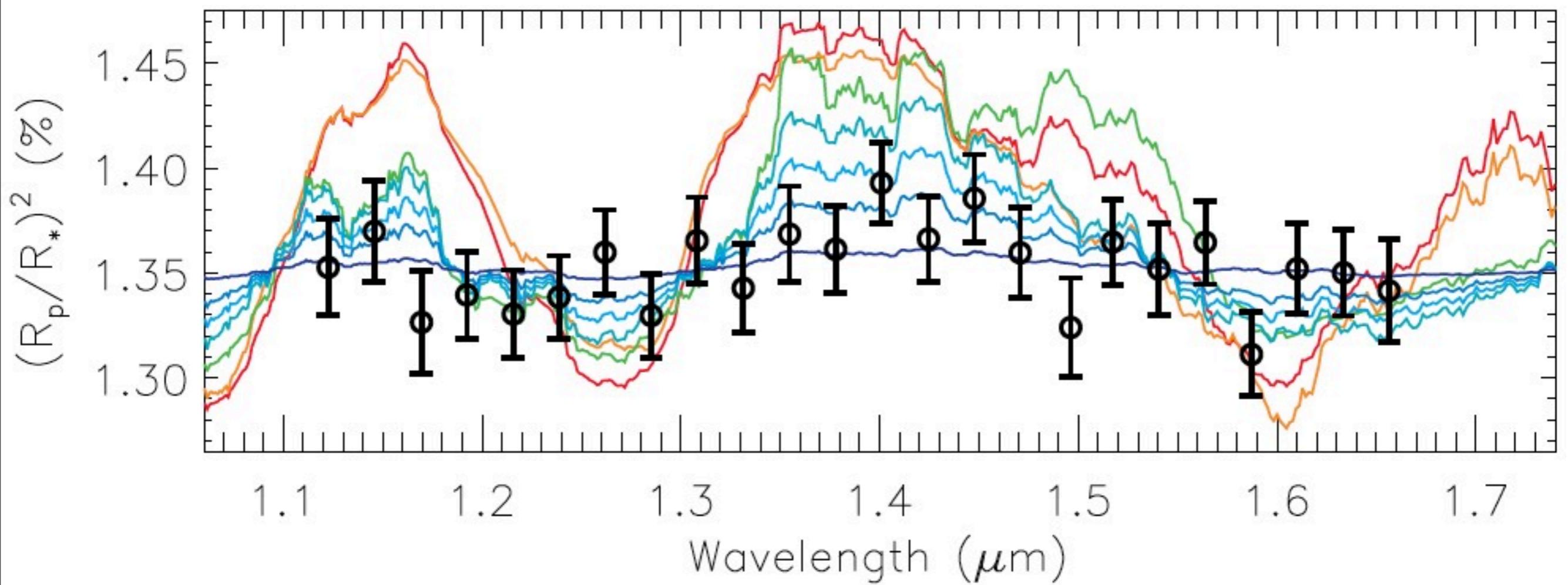
GJ 1214b



Berta et al. (2011)

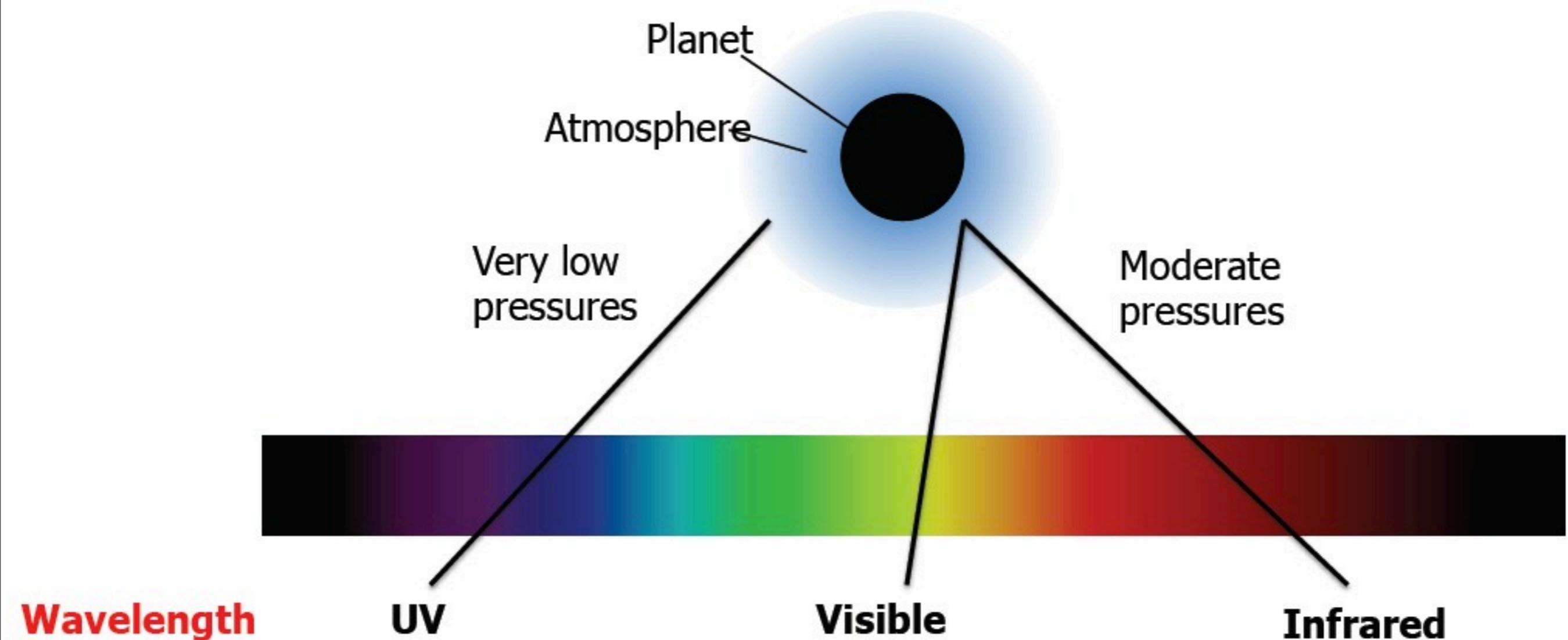
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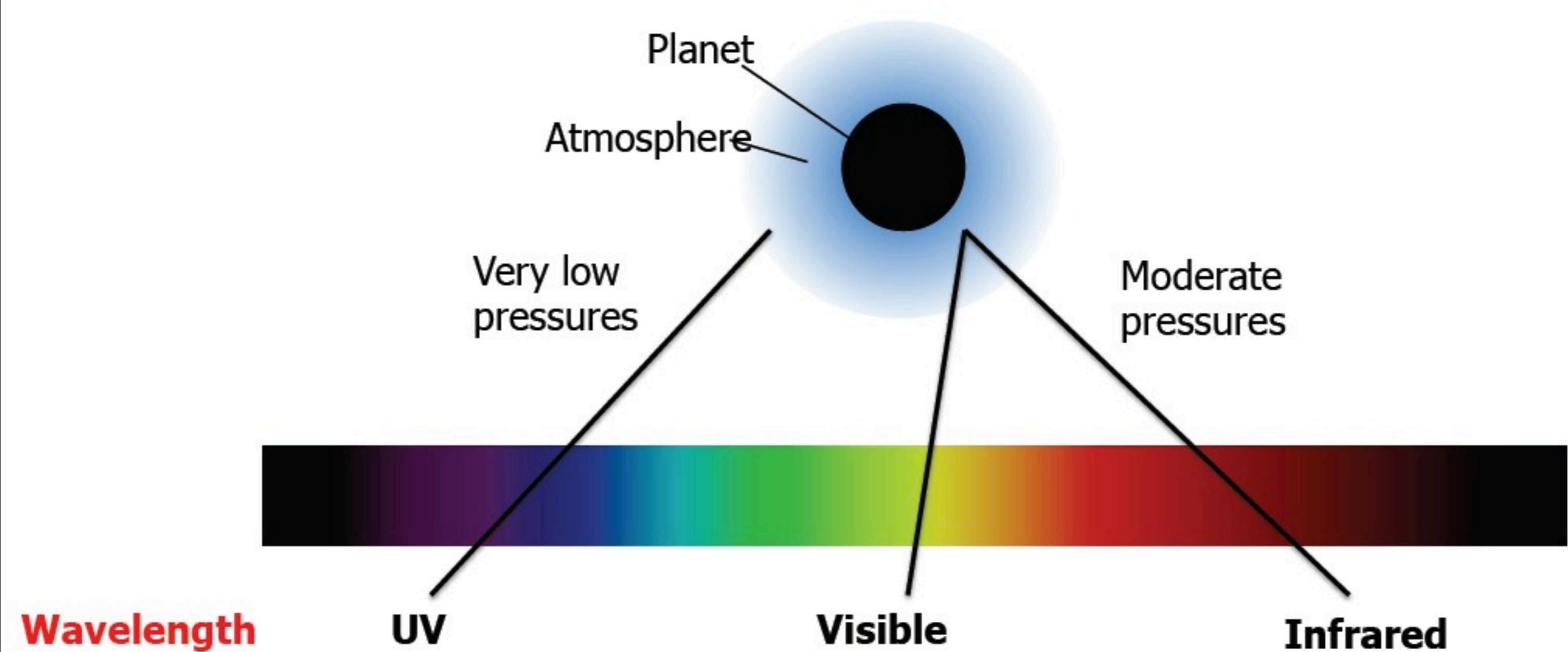


Berta et al. (2011)

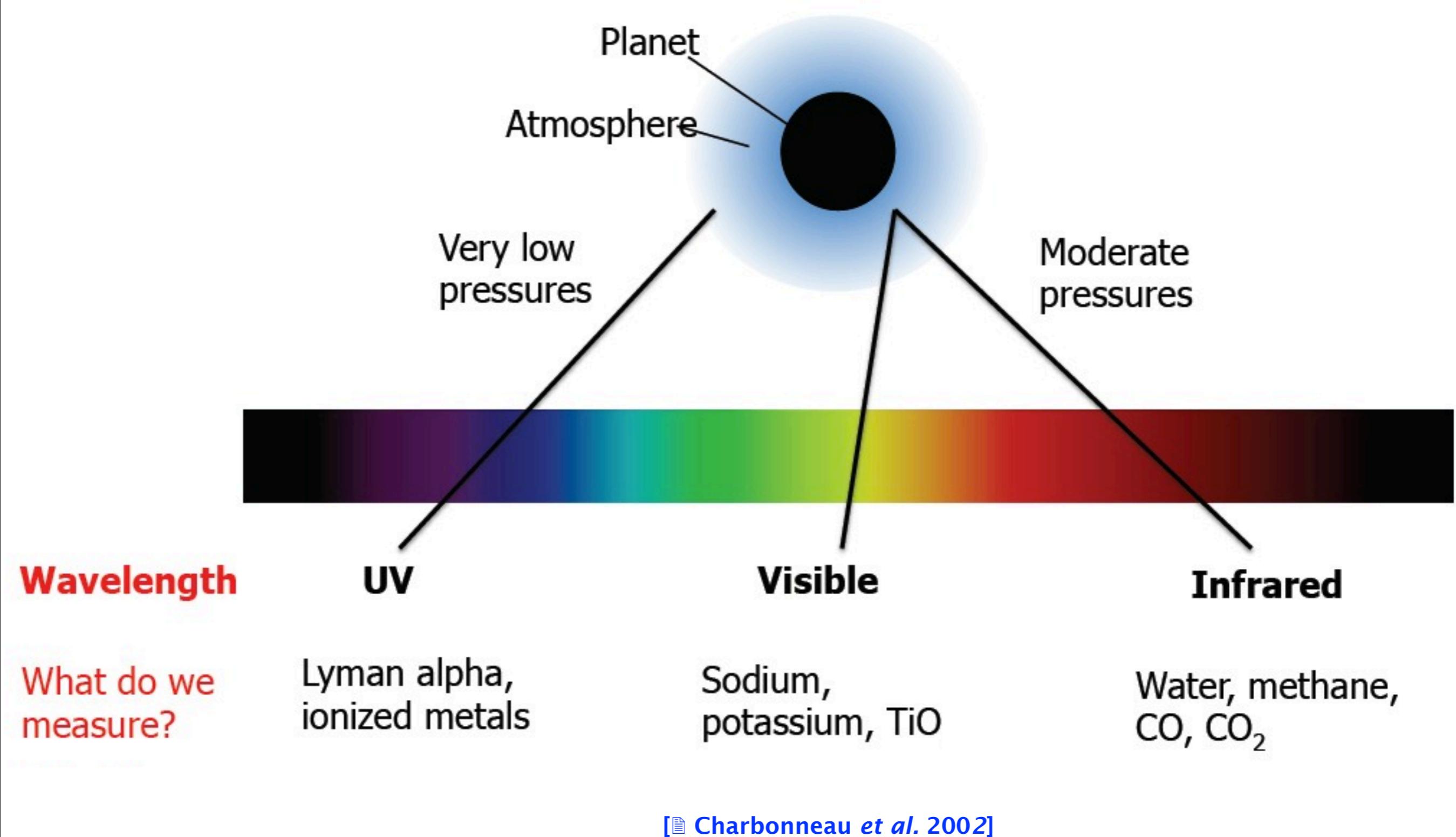
Necessity of a Multi-Wavelength Approach



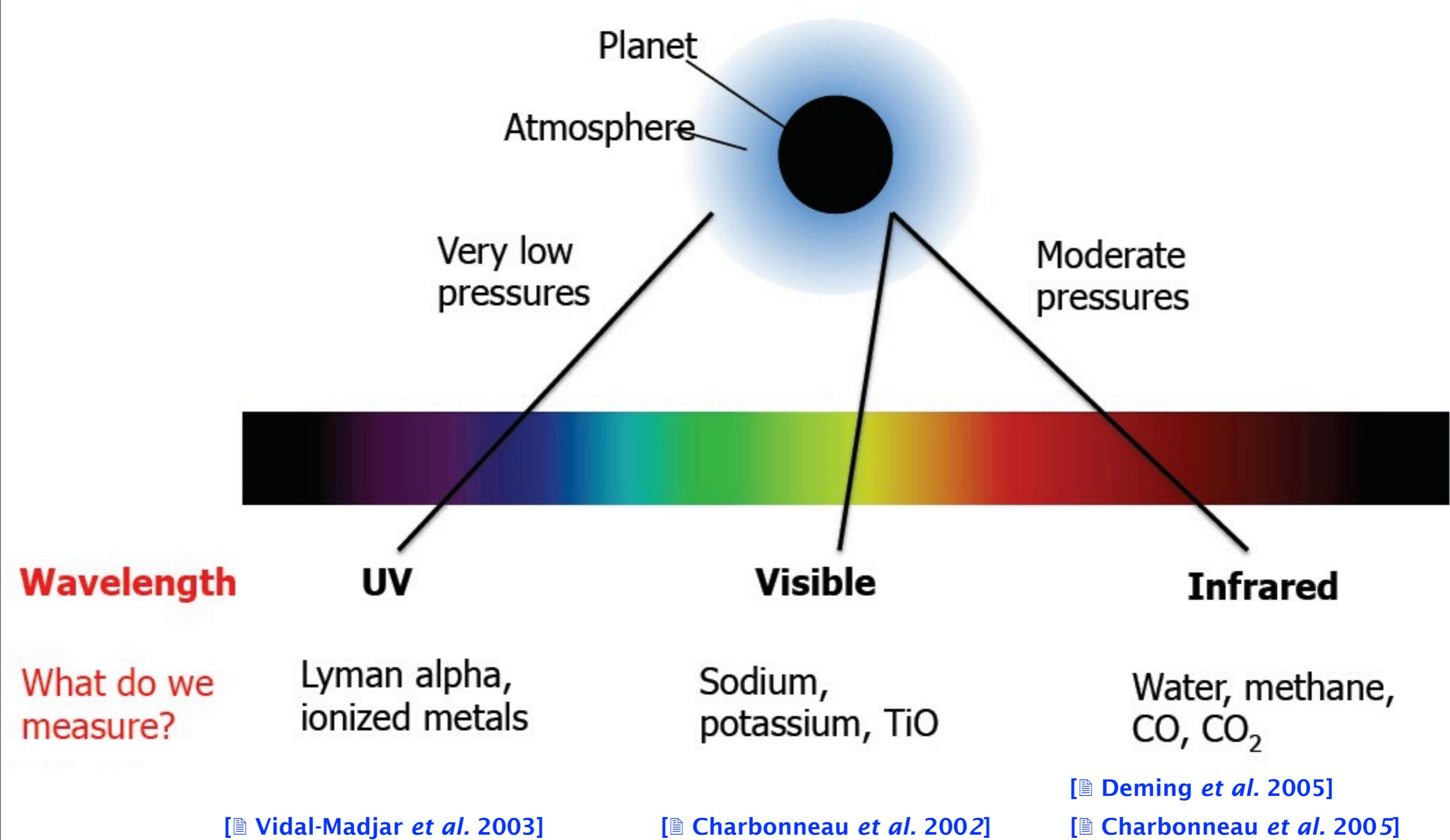
Transiting Exoplanet's Atmospheres : 10 Years of Breakthrough



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Transiting Exoplanet's Atmospheres : 10 Years of Breakthrough



A Decade of Transiting Planets Atmospheres: What Have We Learnt ?

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Diversity of hot-Jupiter Atmospheres

A Decade of Transiting Planets Atmospheres: What Have We Learnt ?

Diversity of hot-Jupiter Atmospheres:

- Temperature and Thermal inversion for a subset of planets

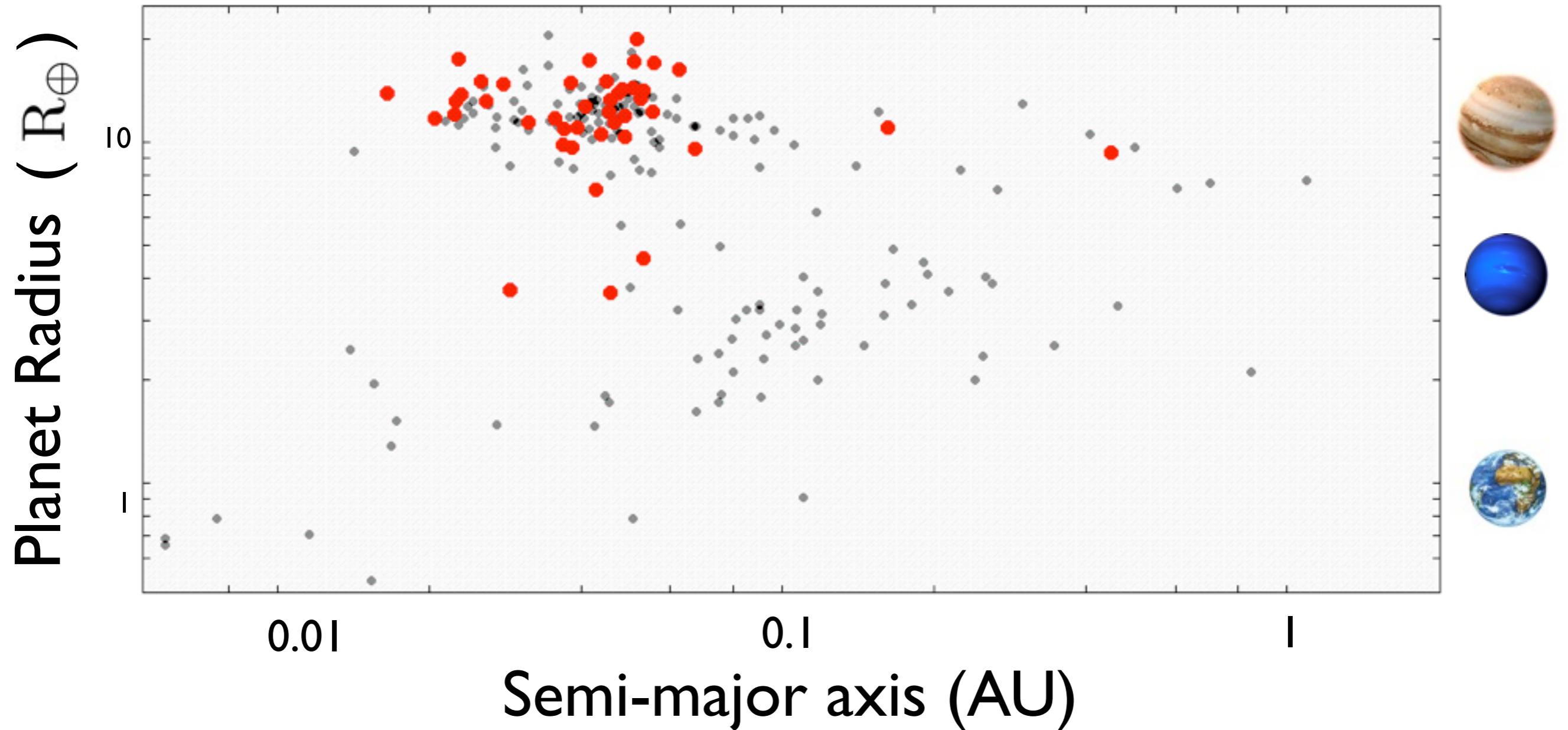
A Decade of Transiting Planets Atmospheres: What Have We Learnt ?

Diversity of hot-Jupiter Atmospheres:

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 - Spitzer Giant Exoplanet Surveys (Eclipses)
 - Joseph Harrington's program
 - Heather Knutson's program



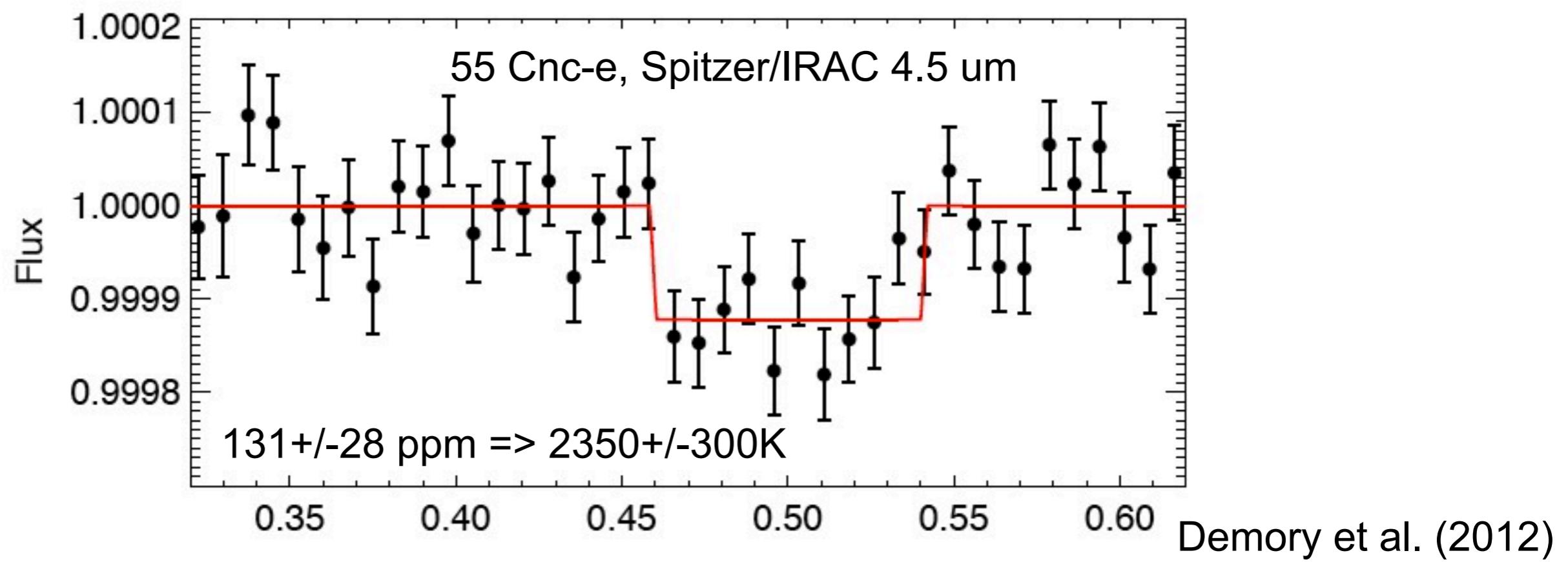
Emission Measurements (IR)



A Decade of Transiting Planets Atmospheres: What Have We Learnt ?

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A Decade of Transiting Planets Atmospheres: What Have We Learnt ?

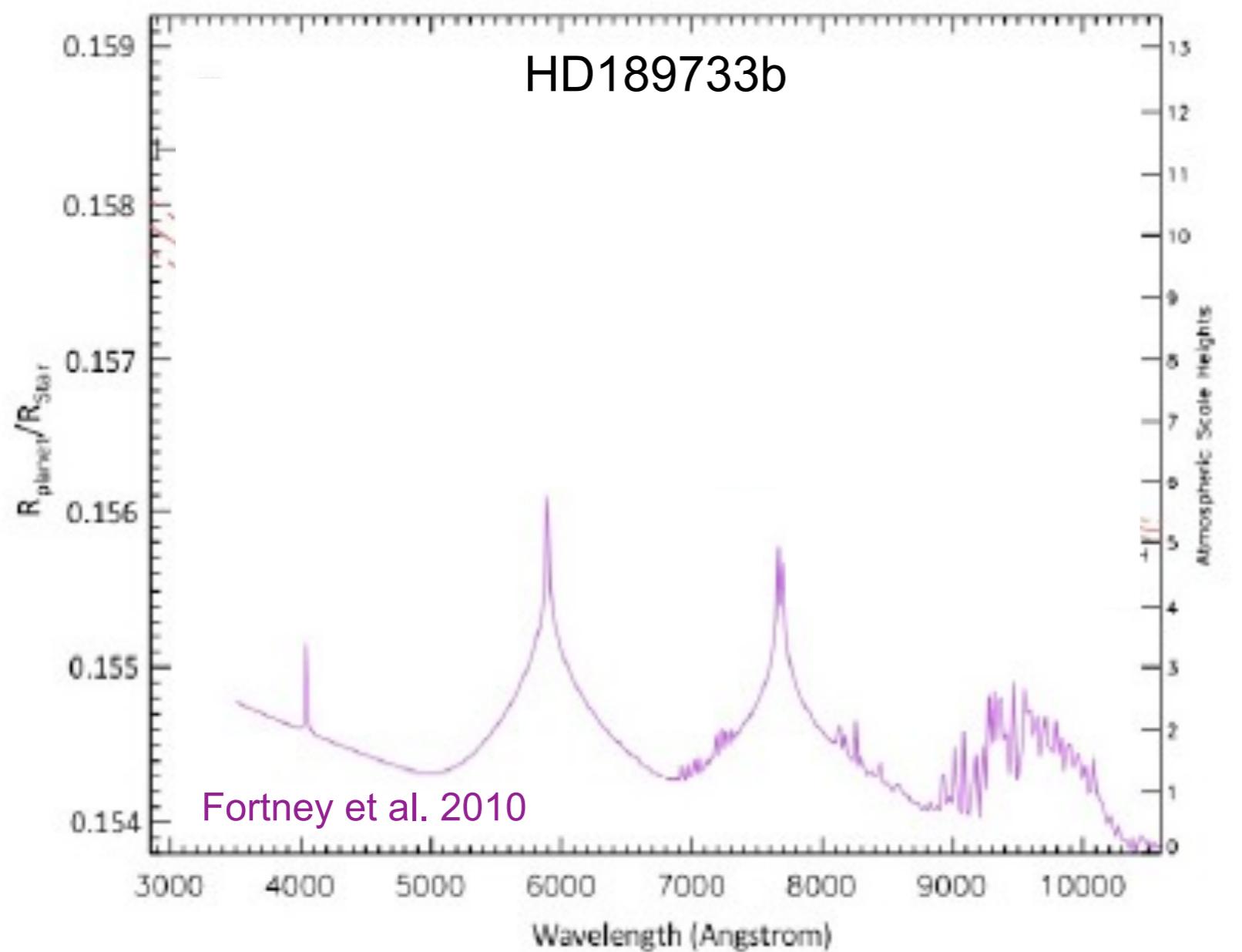
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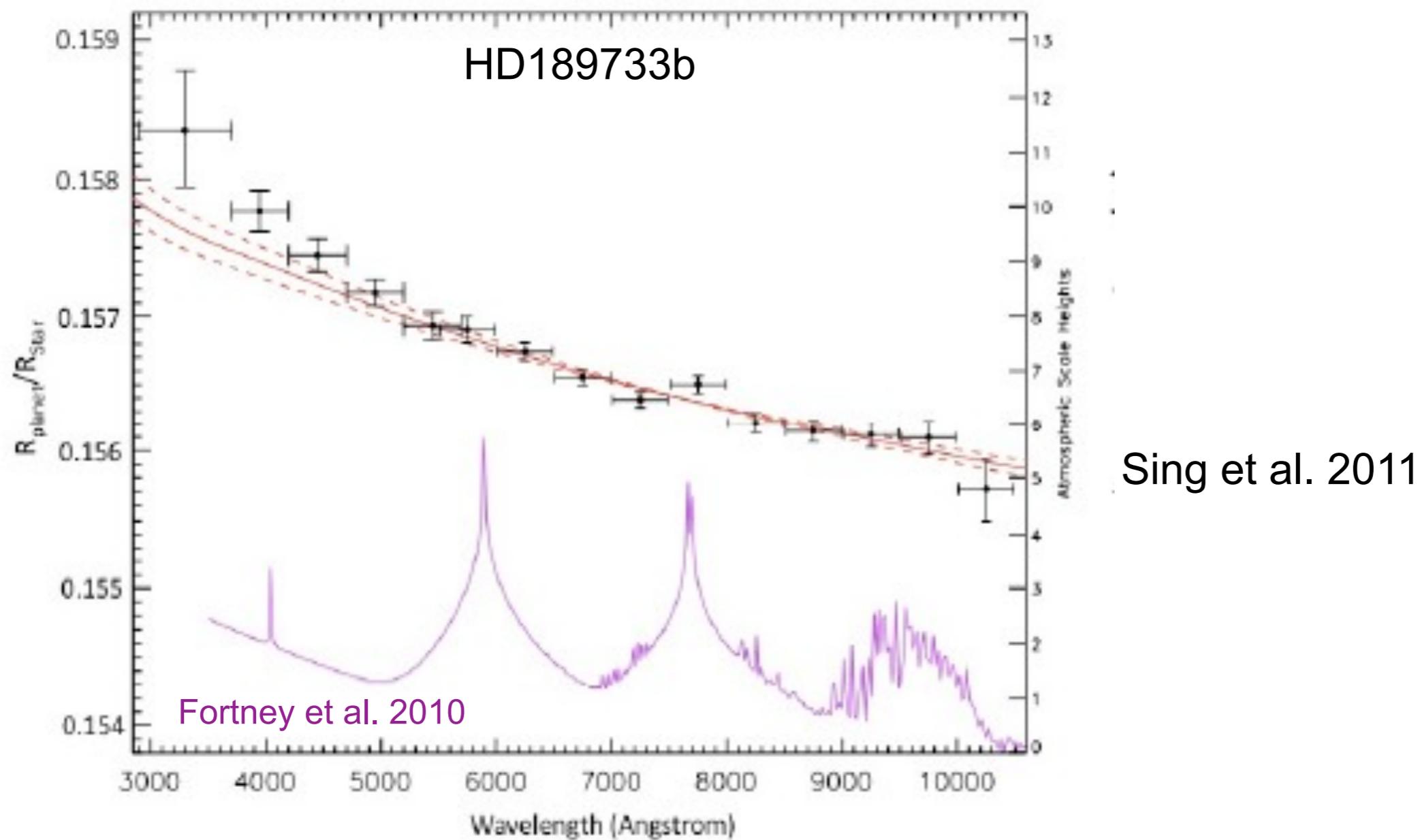
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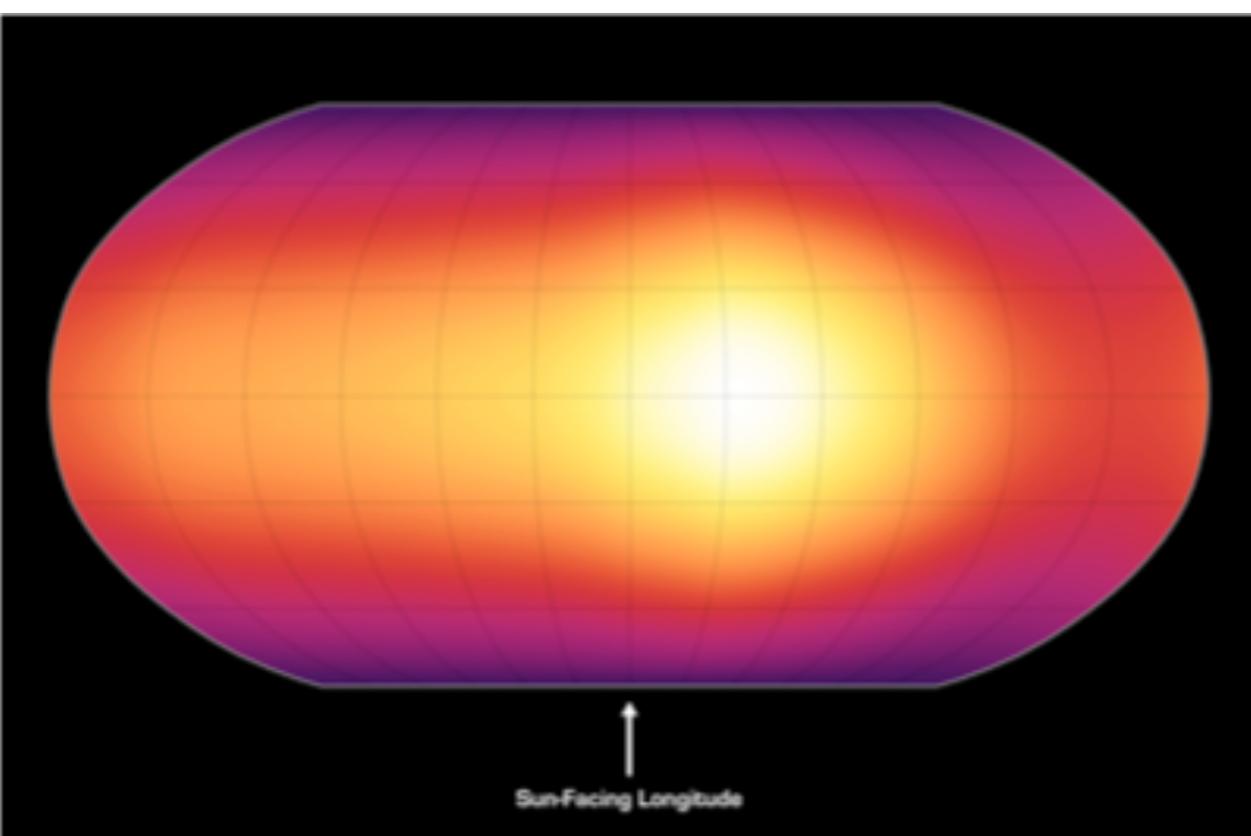
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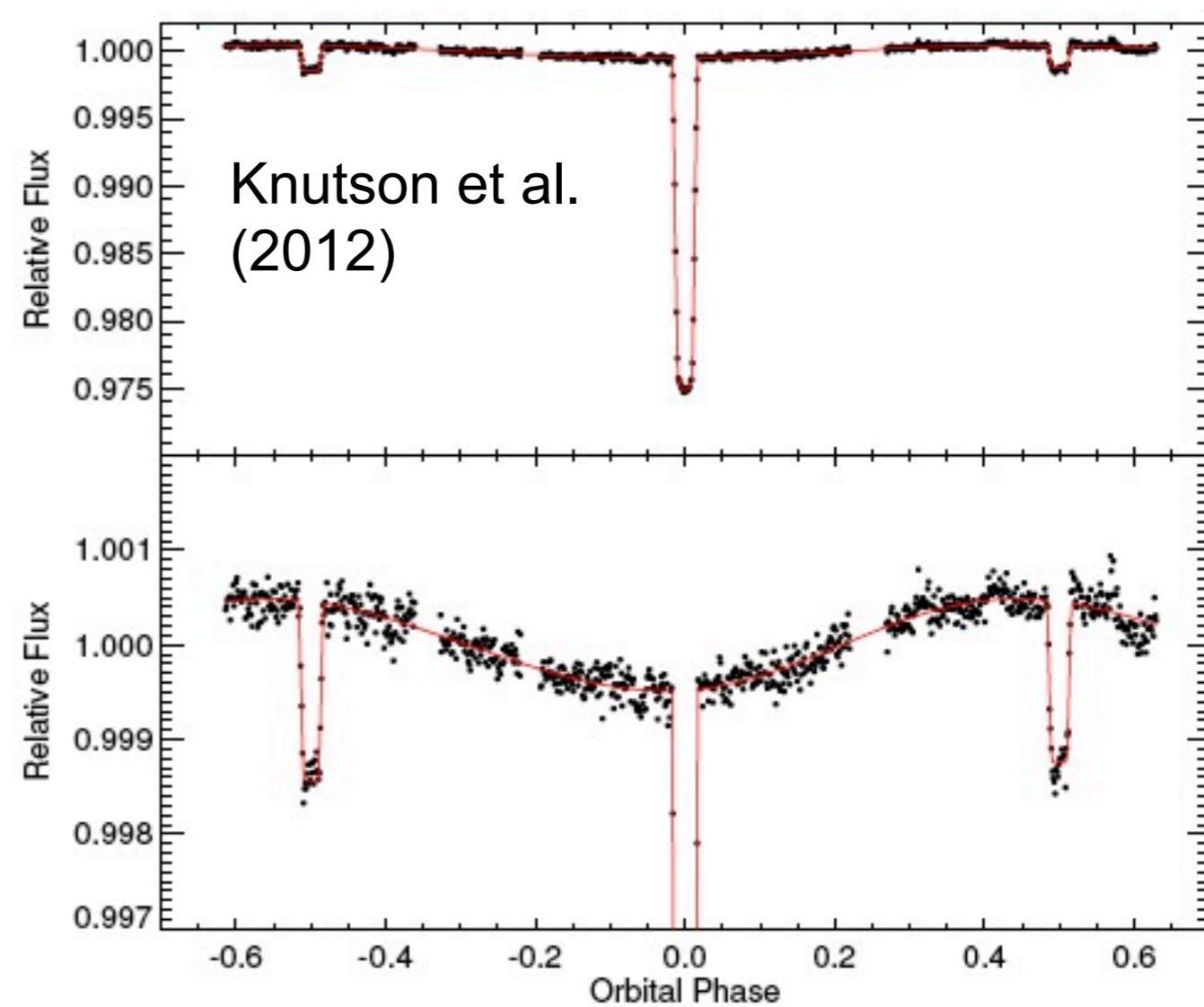
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HD189733b, Knutson et al. 2007



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- Instrumental and observational systematics
- Several “firsts” molecular detections in NIR challenged
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Diversity of hot-Jupiter Atmospheres:

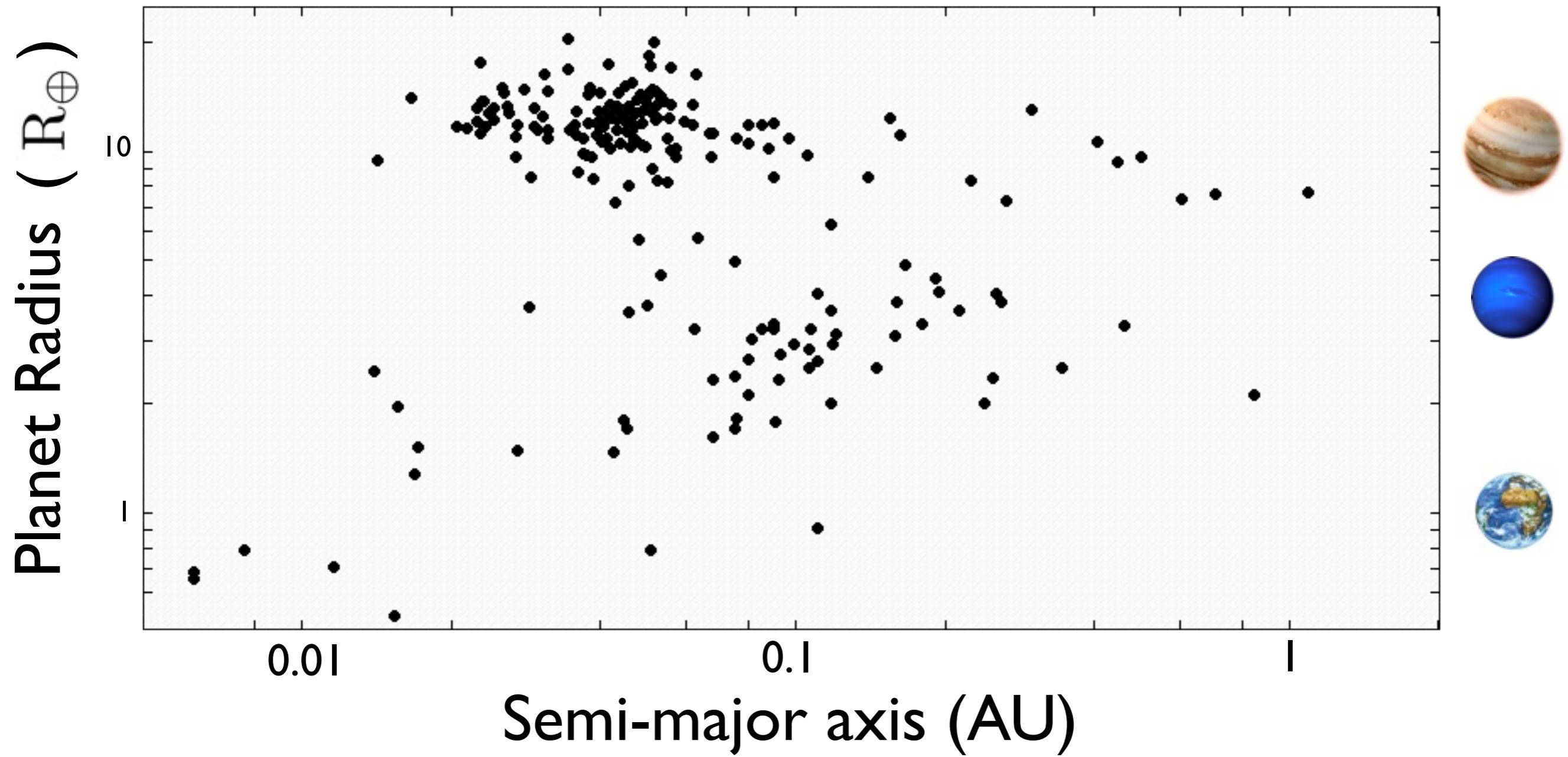
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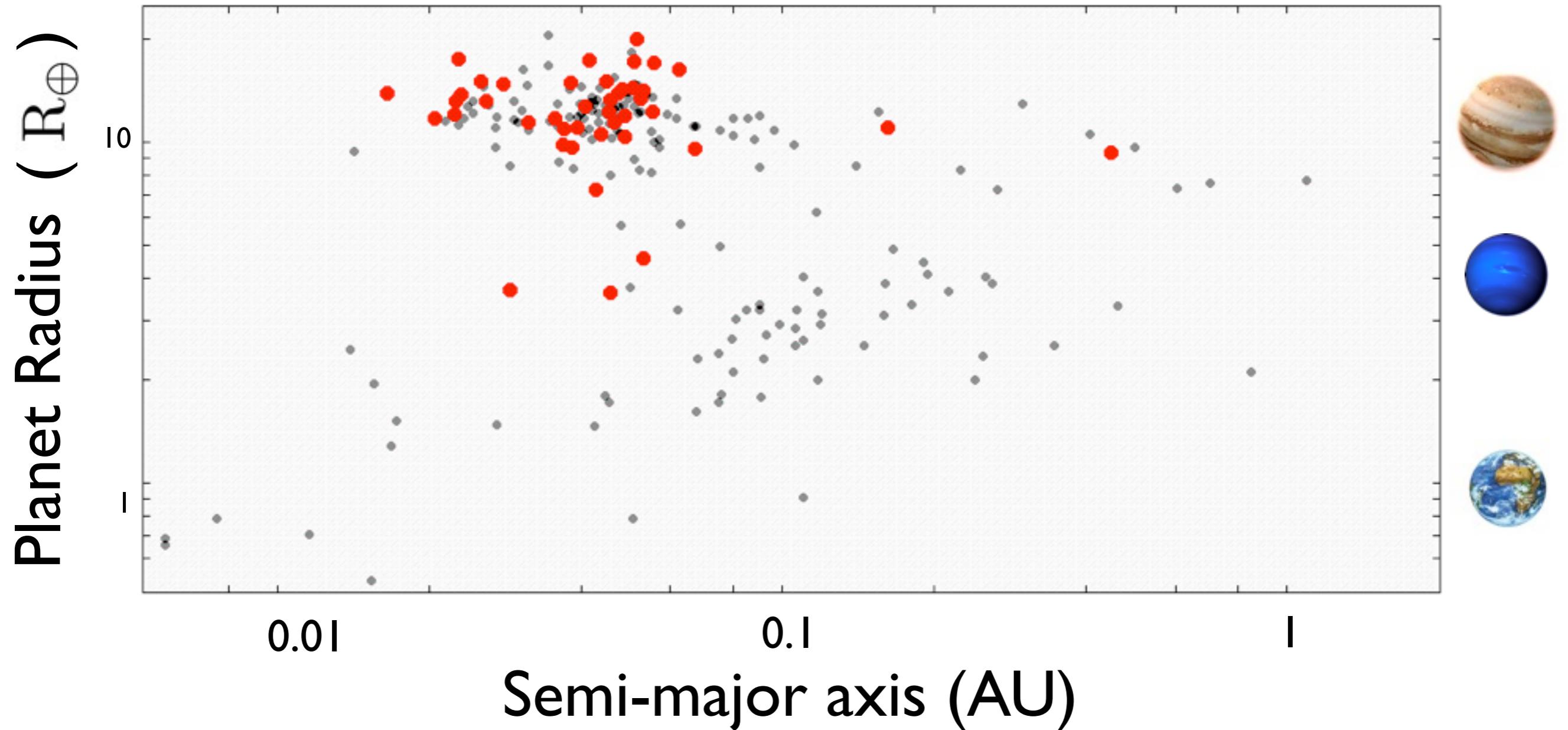
=> Multi-Wavelength Surveys Are Required

Transiting Exoplanets

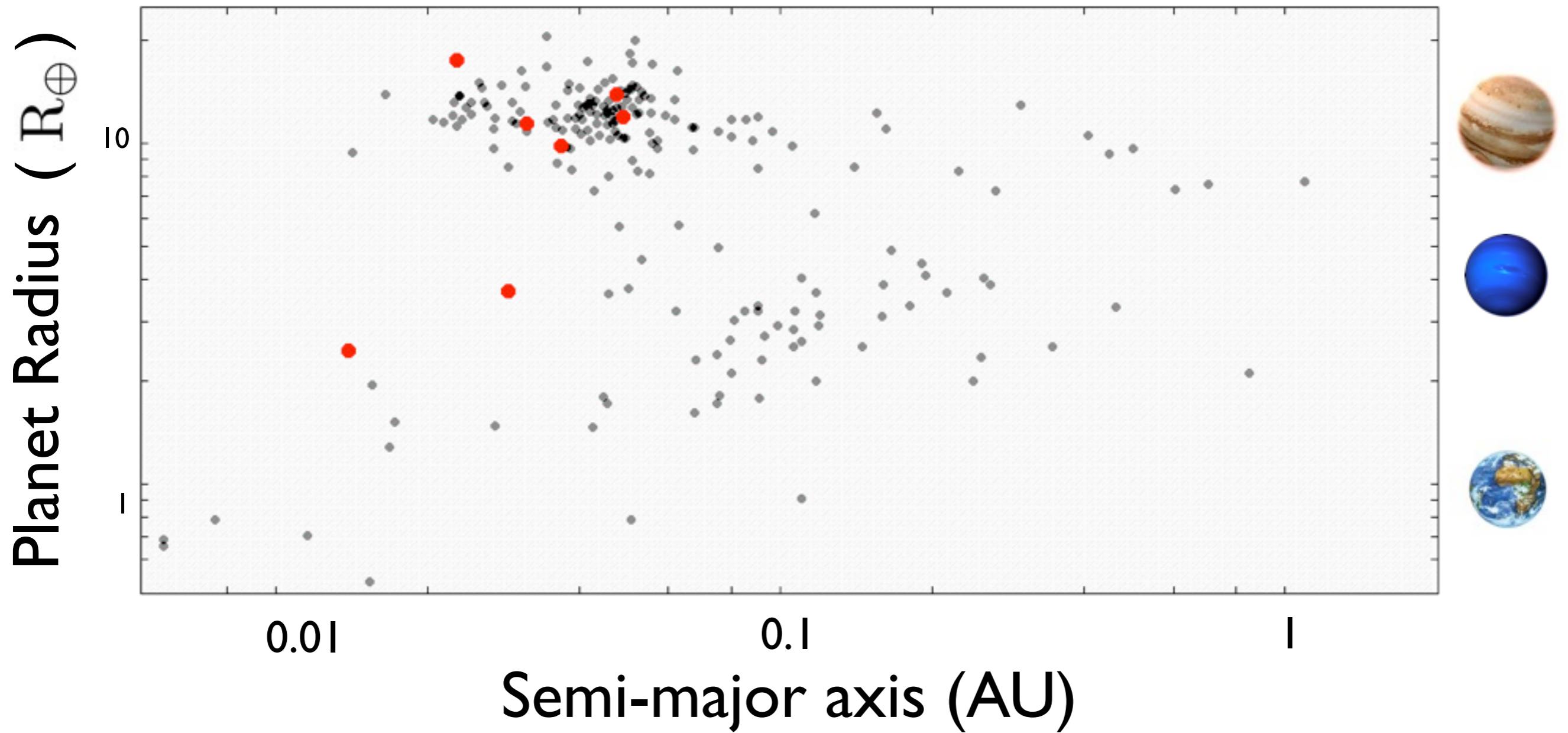




Emission Measurements (IR)



● Transmission Measurements (XEUV -> IR)



Hot-Jupiters Survey

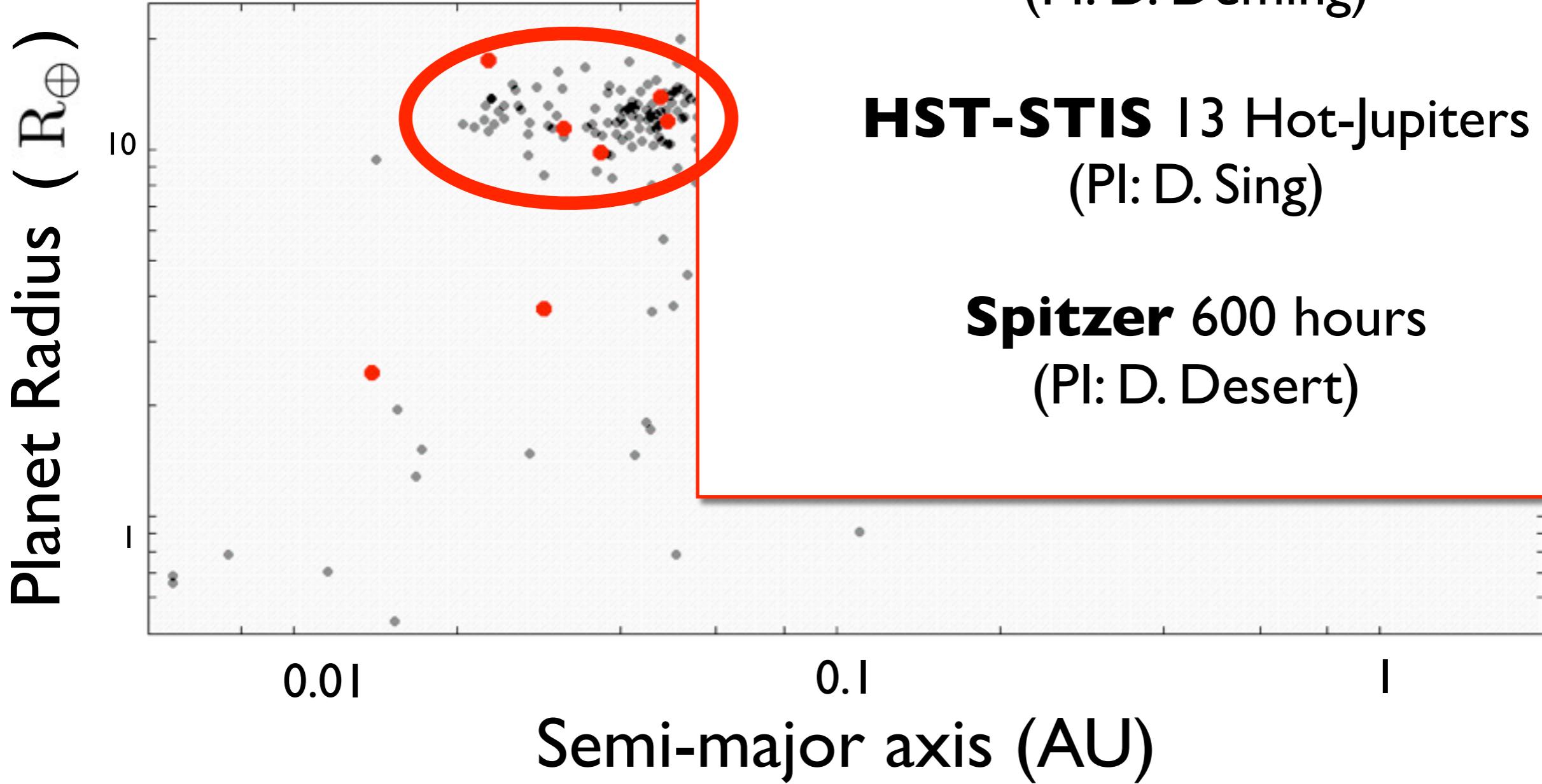
Transmission

Space-based Surveys:

HST-WFC3 13 Hot-Jupiters
(PI: D. Deming)

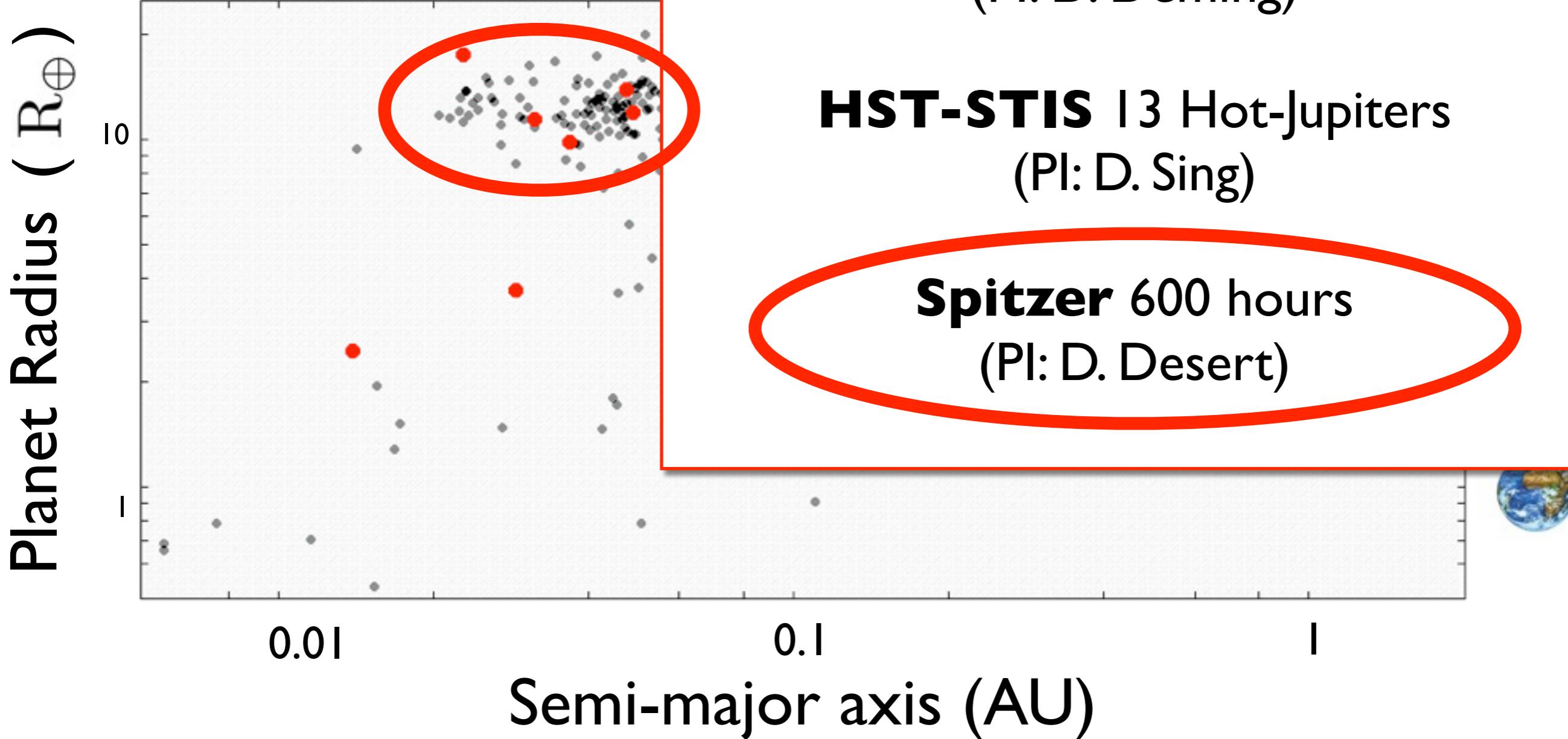
HST-STIS 13 Hot-Jupiters
(PI: D. Sing)

Spitzer 600 hours
(PI: D. Desert)



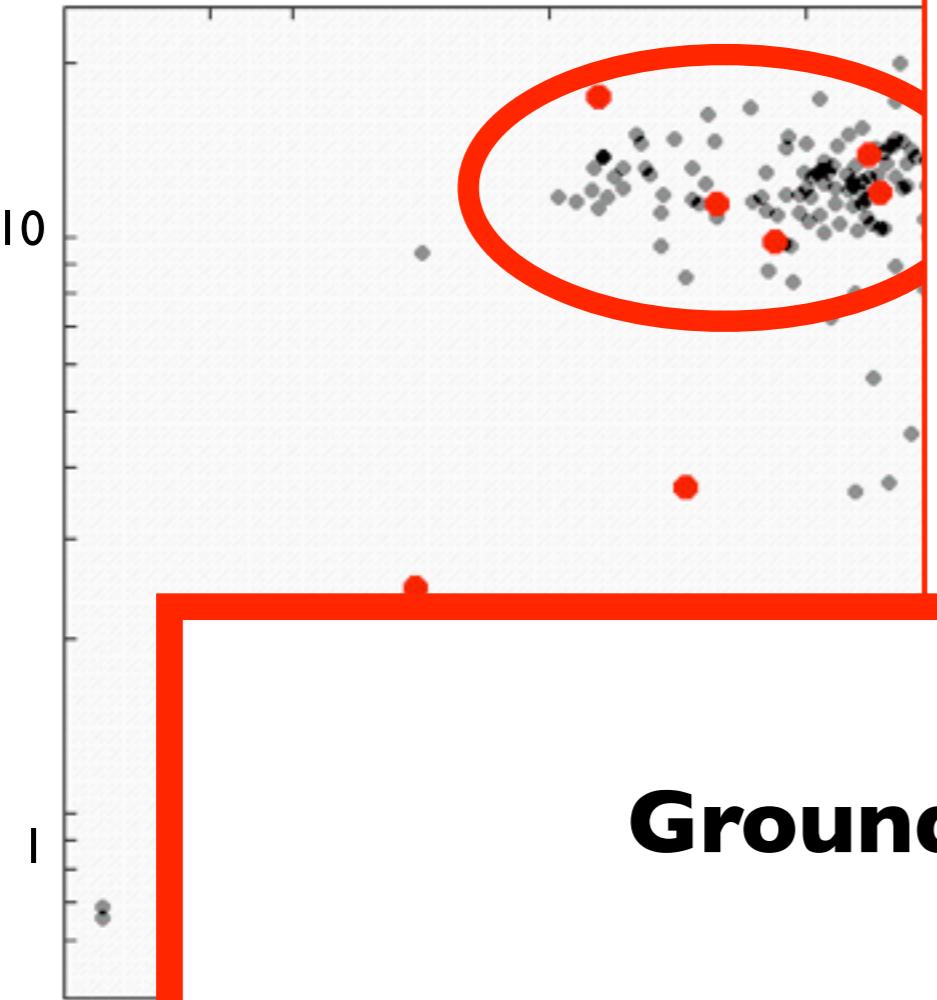
Hot-Jupiters Survey

Transmission



Hot-Ju Transmis

Planet Radius (R_{\oplus})



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HST-WFC3 13 Hot-Jupiters
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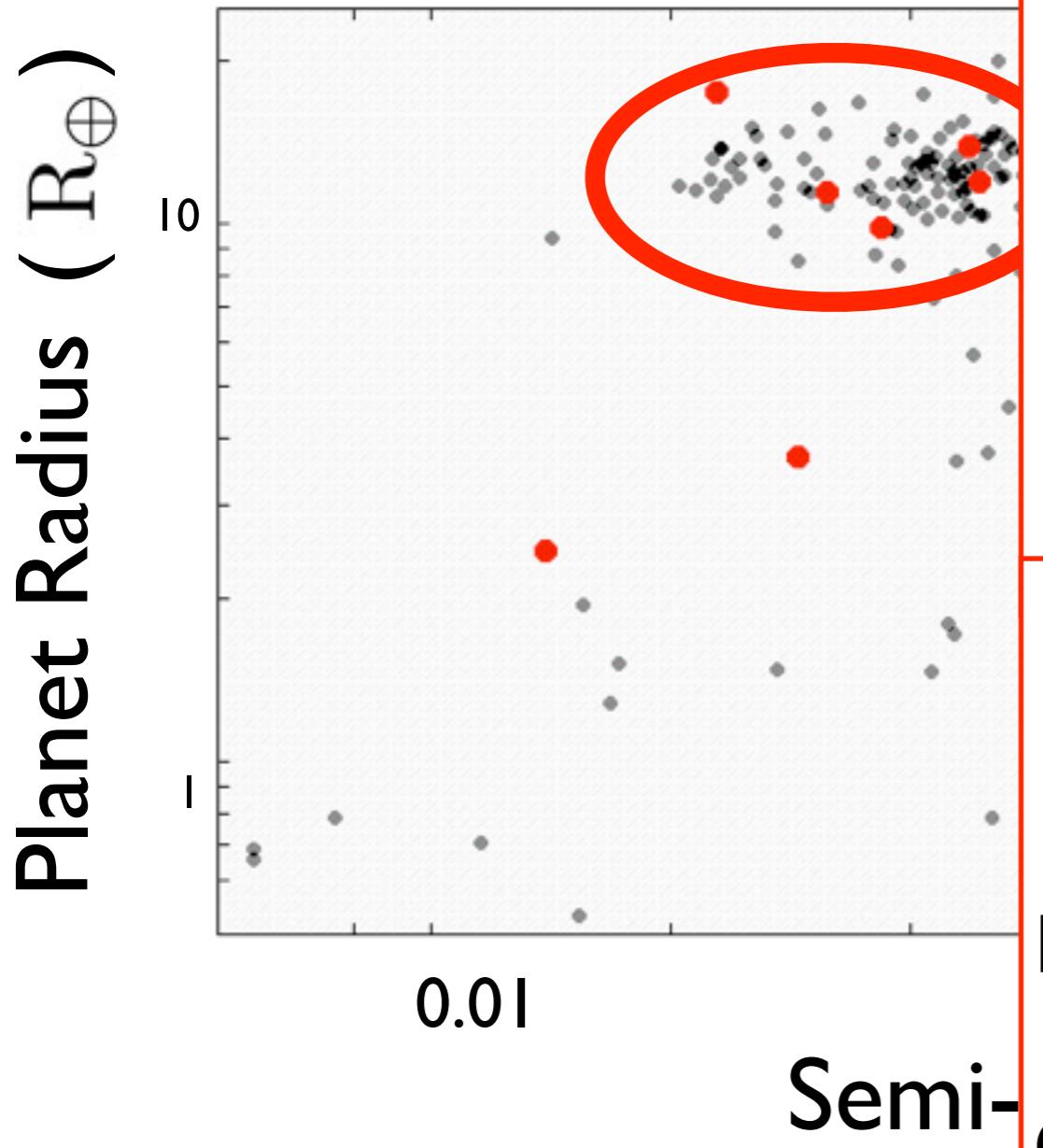
Ground-based Surveys:

NIR: Magellan (PI: JM Désert / J. Bean)

Optical: Gemini (PI: JM Désert)



Hot-Ju Transmis



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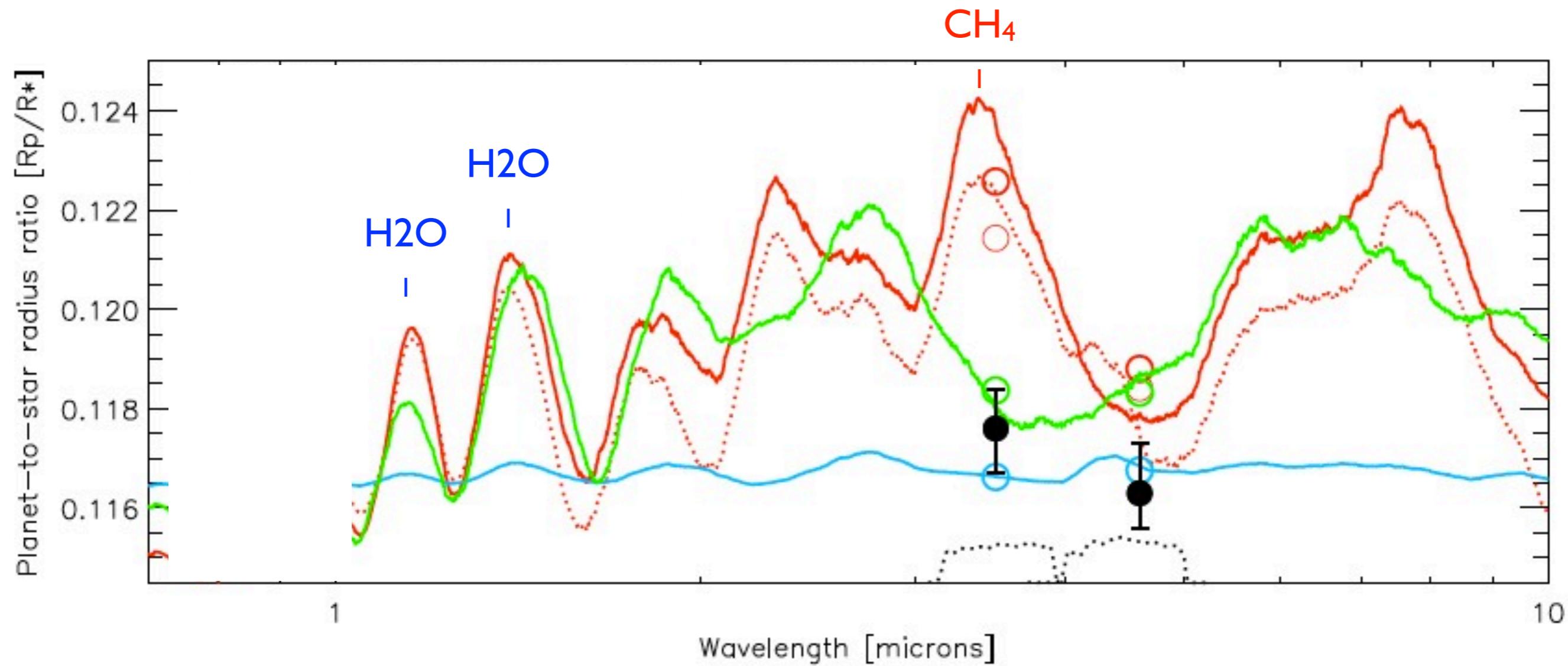
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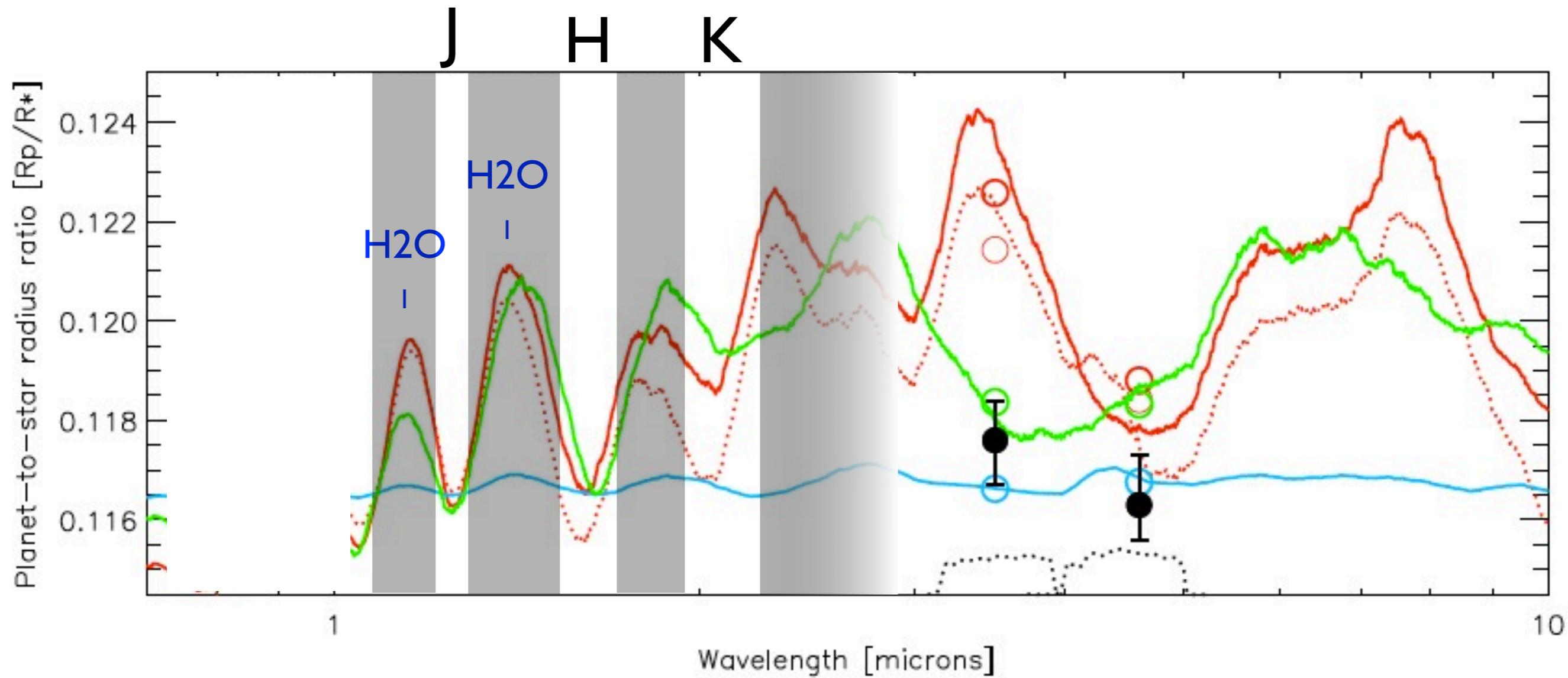
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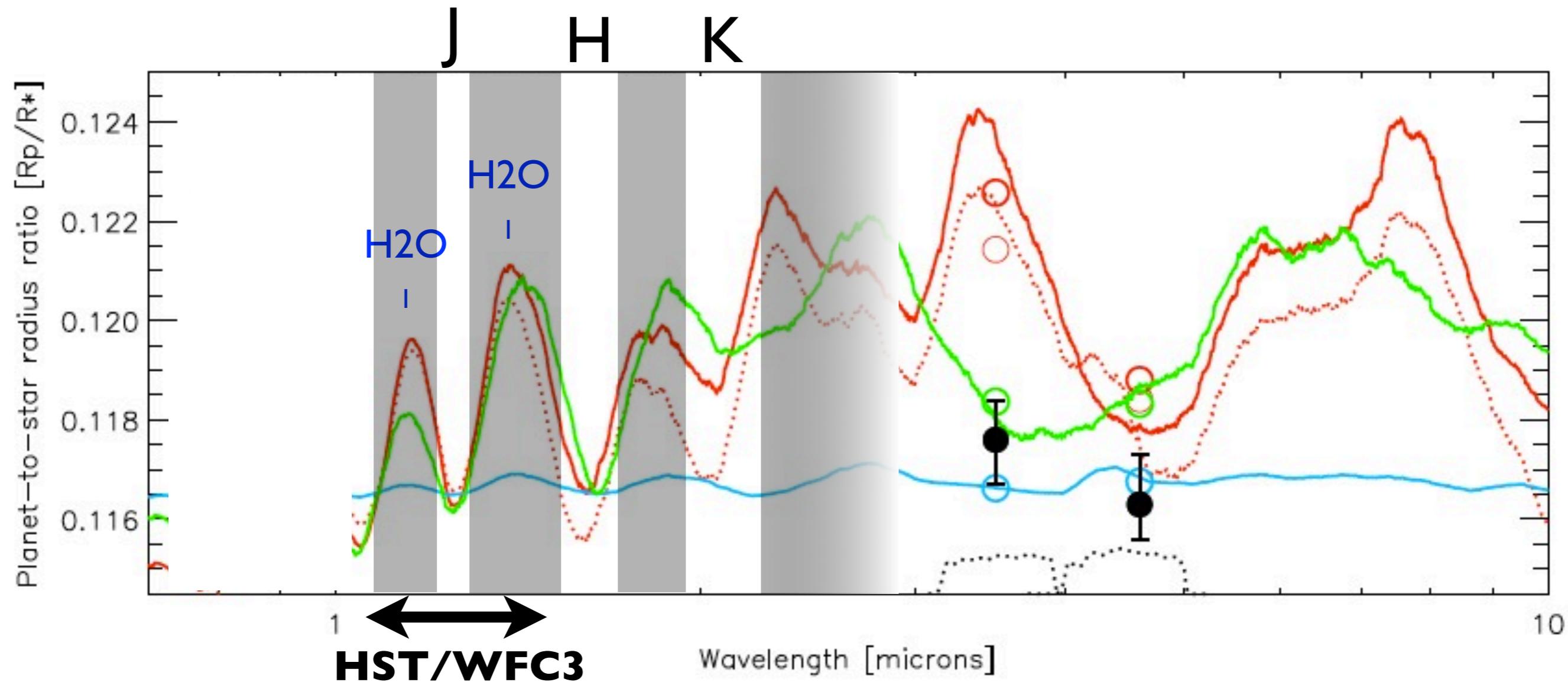
Transmission Spectroscopy of GJ1214b



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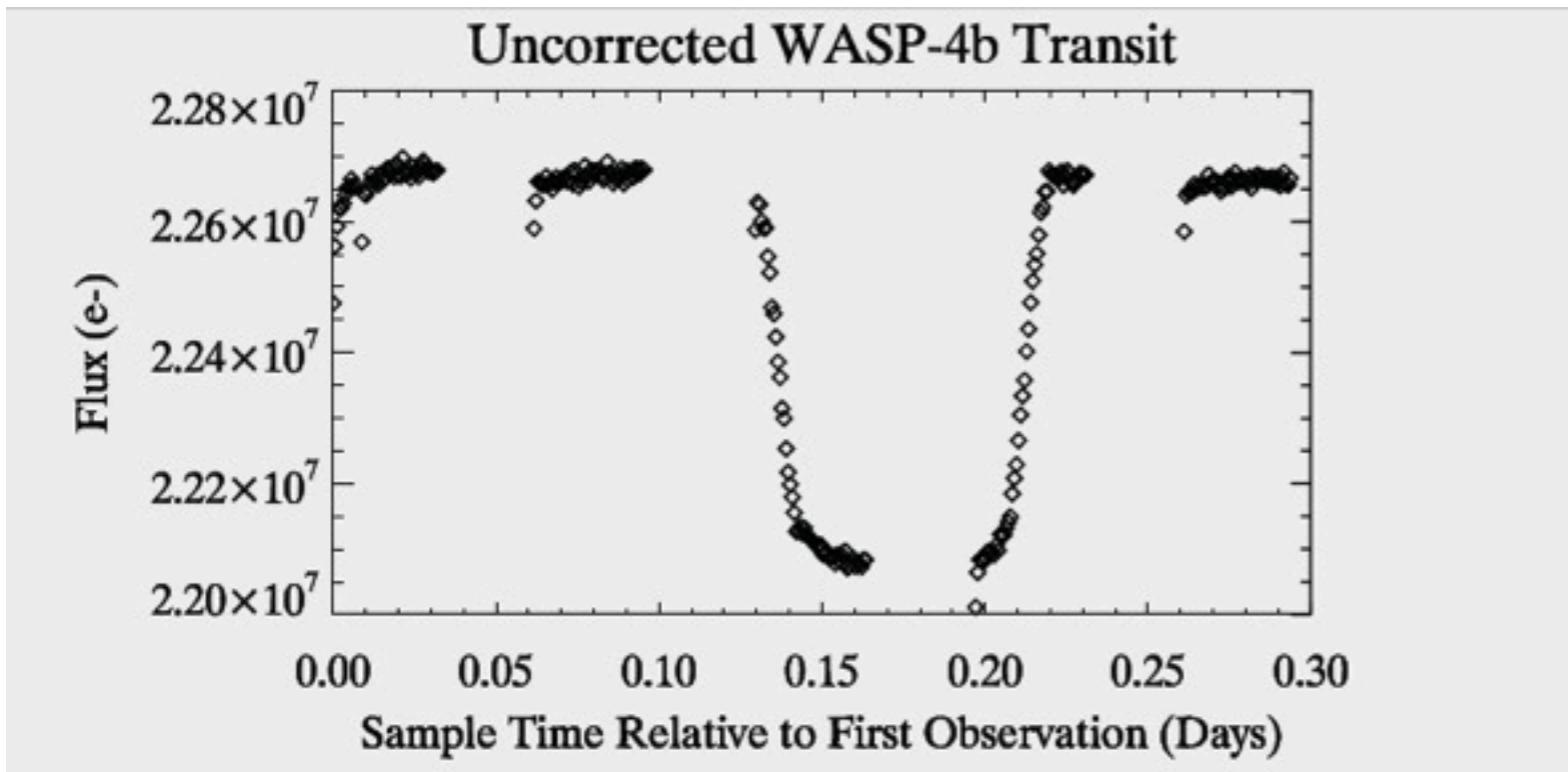


Transmission Spectroscopy of GJ1214b



Hot-Jupiters Survey with HST/WFC3

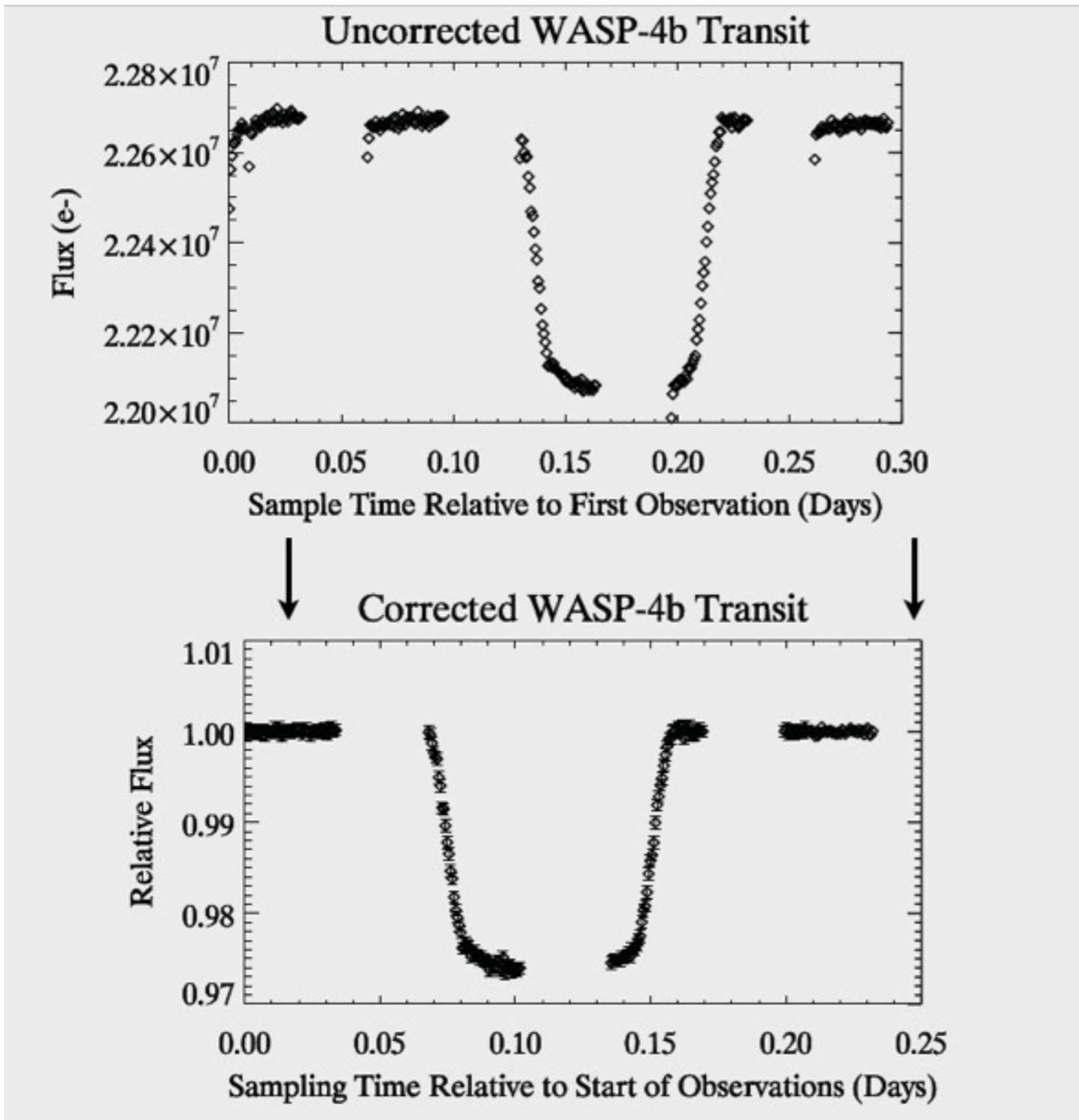
Sukrit Ranjan (CfA)



Ranjan et al. (in prep)

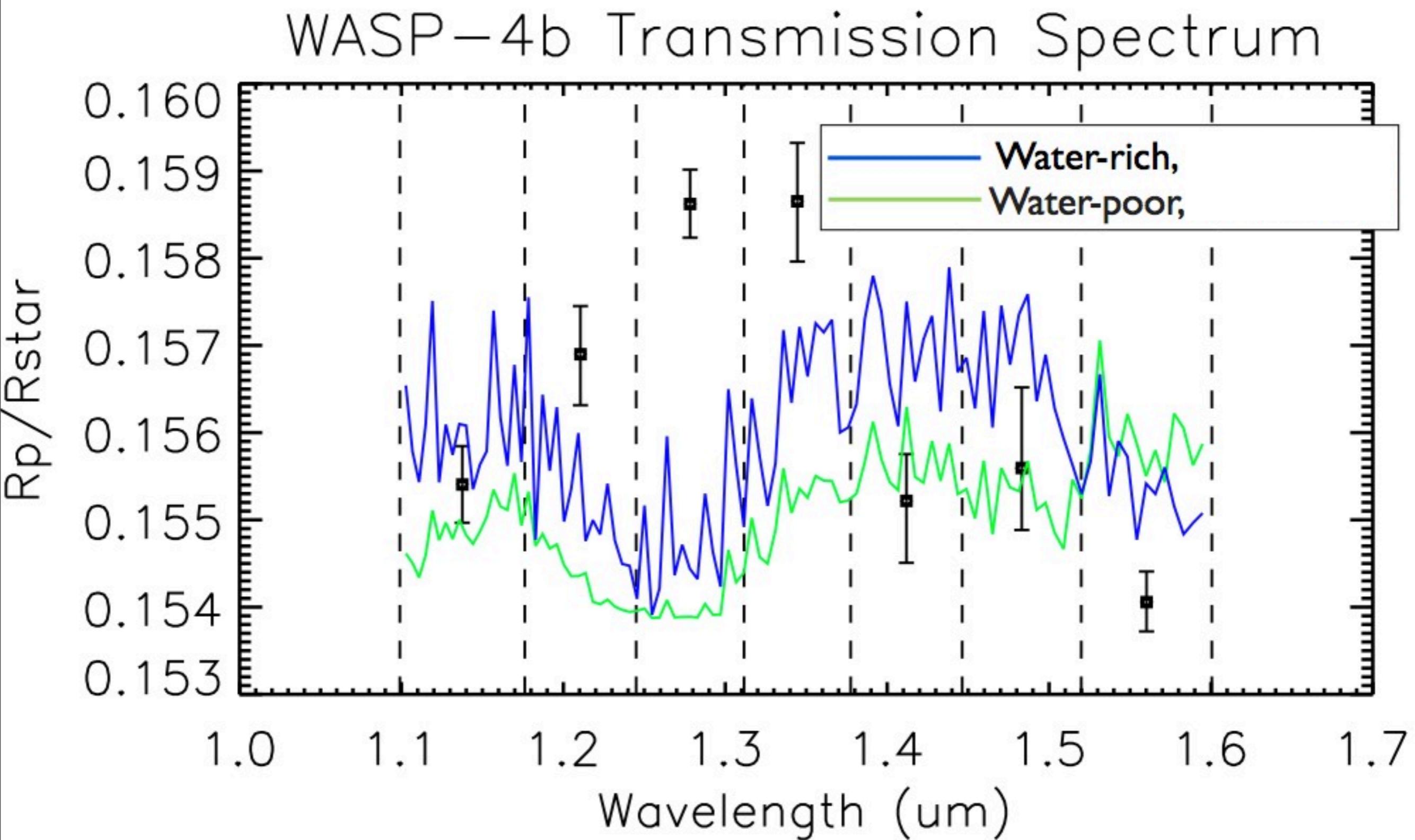
Hot-Jupiters Survey with HST/WFC3

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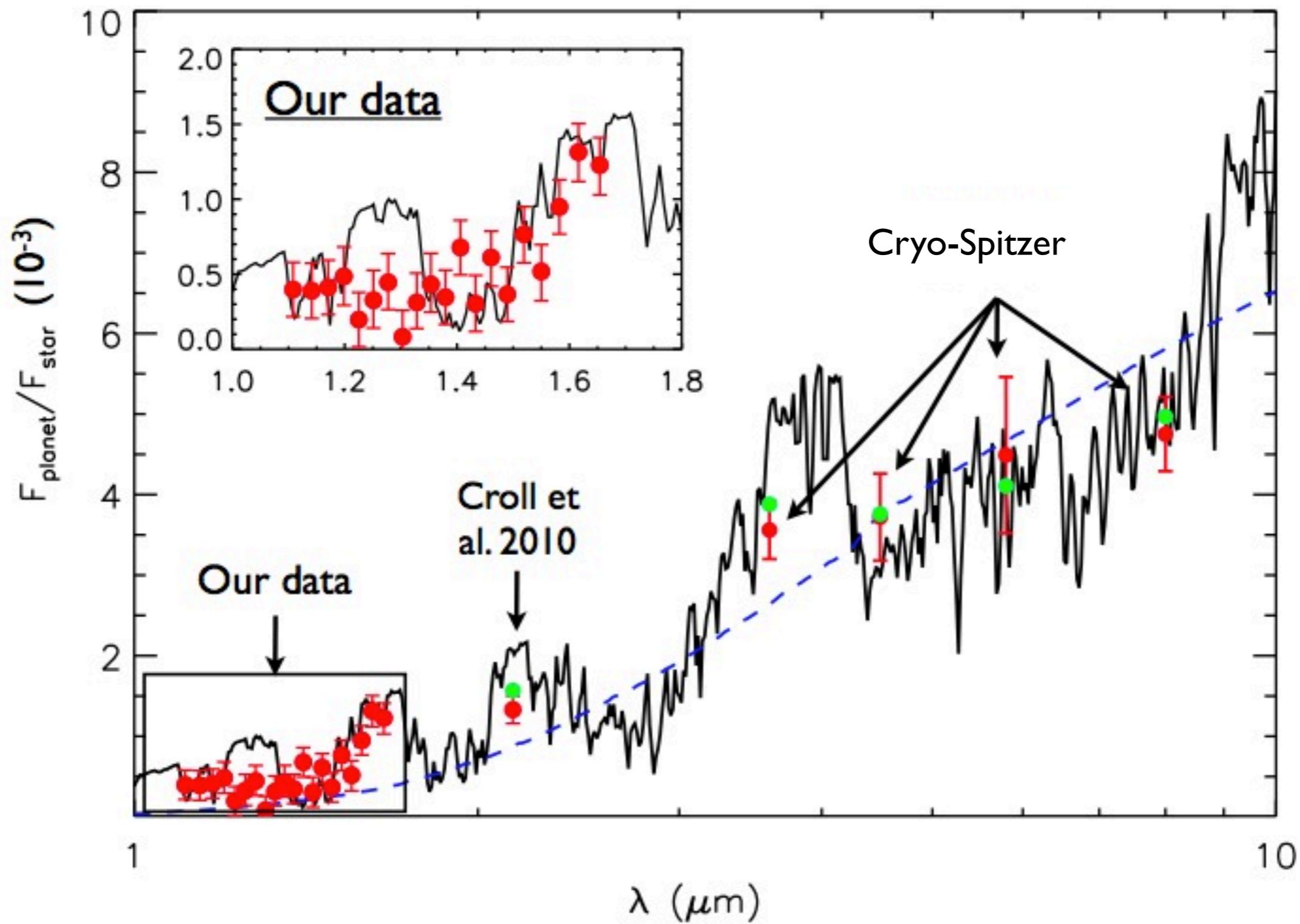


Ranjan et al. (in prep)

WASP-4b Transmission



TrES-3b Emission



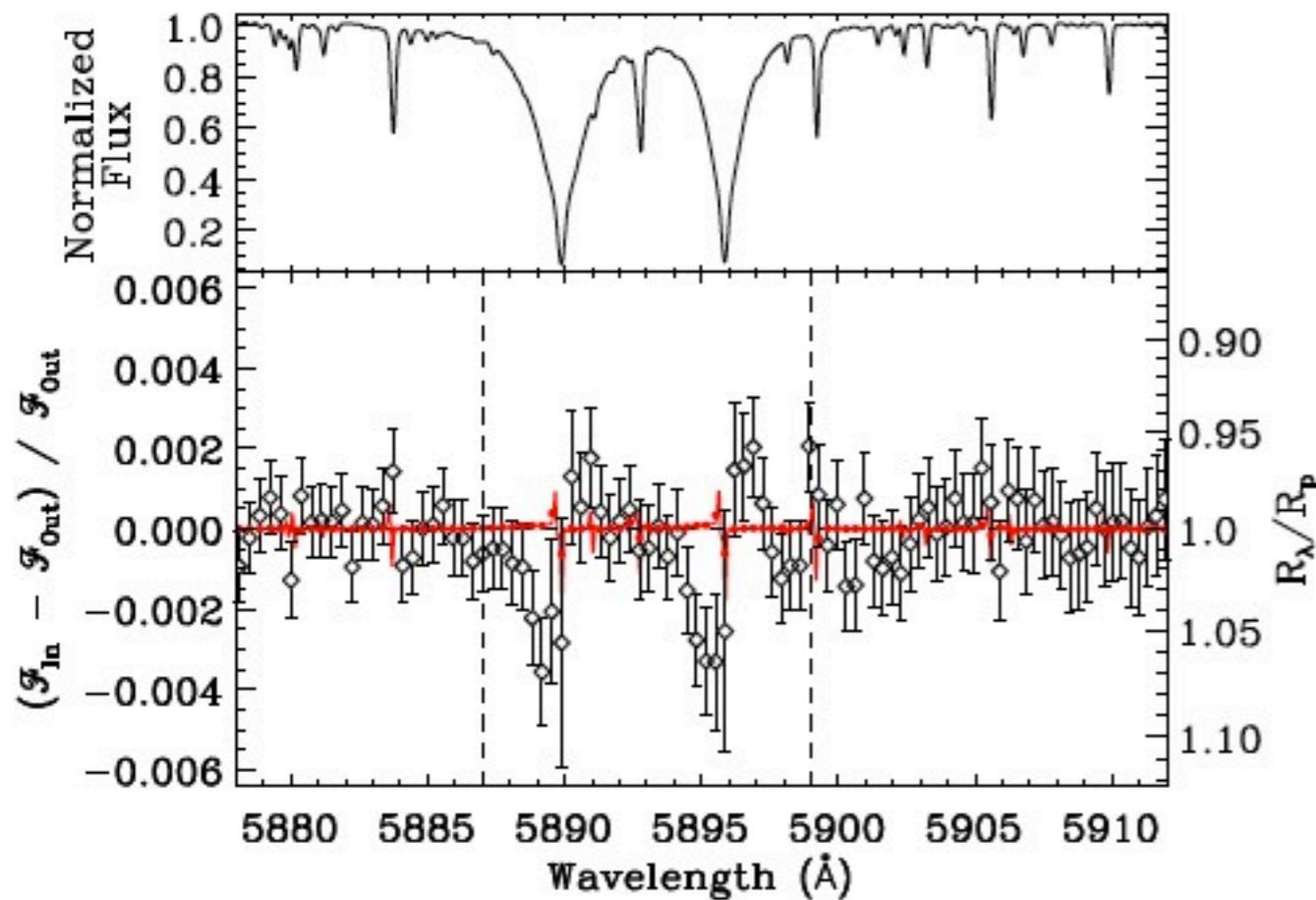
Ground-based Survey Of hot-Jupiters

- **Optical:** Gemini (PI: JM Désert)
- **NIR:** Magellan (PI: JM Désert / J. Bean)

Ground-Based Observations

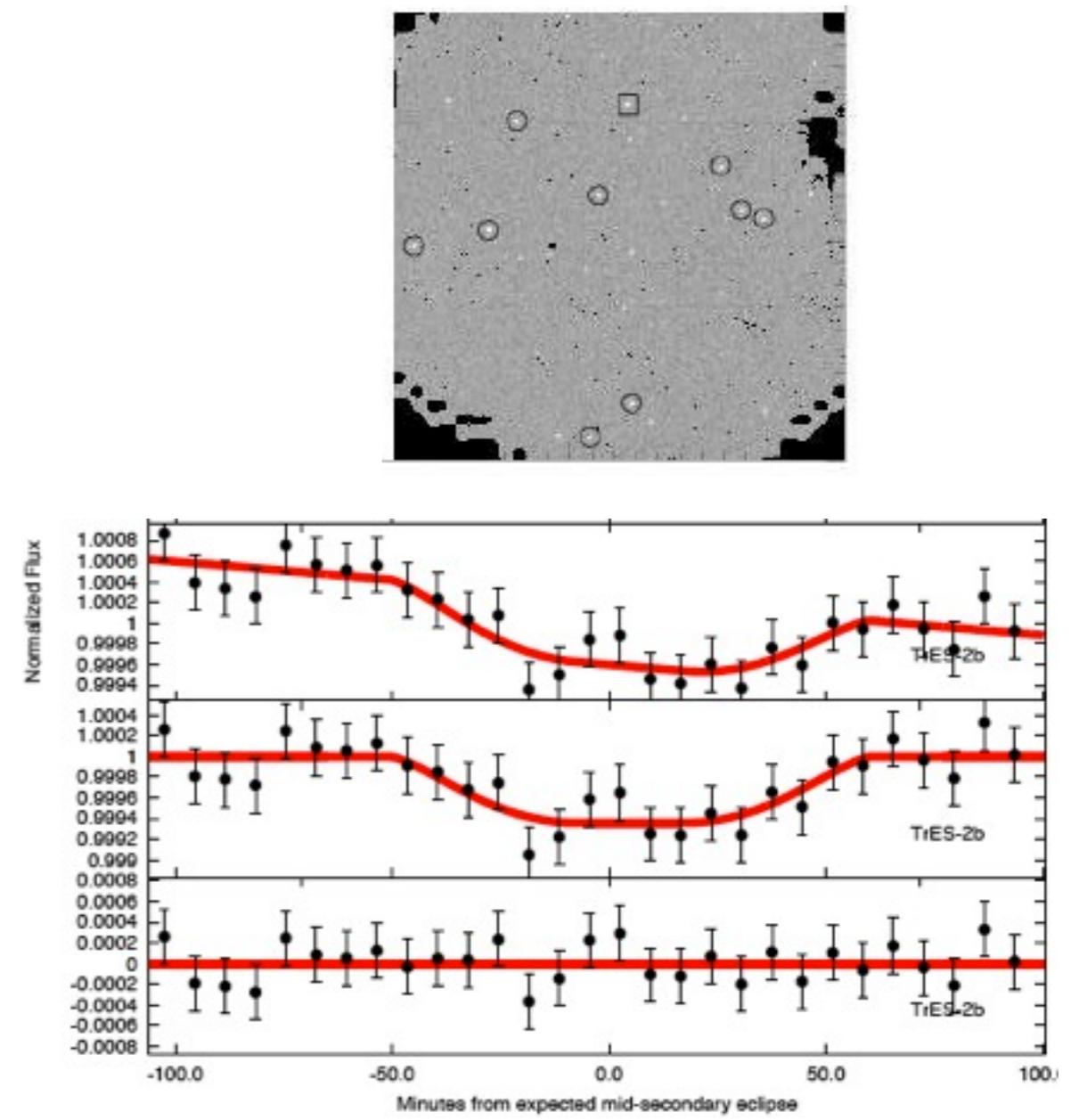
Redfield et al. (2008)

Transit HD189733b

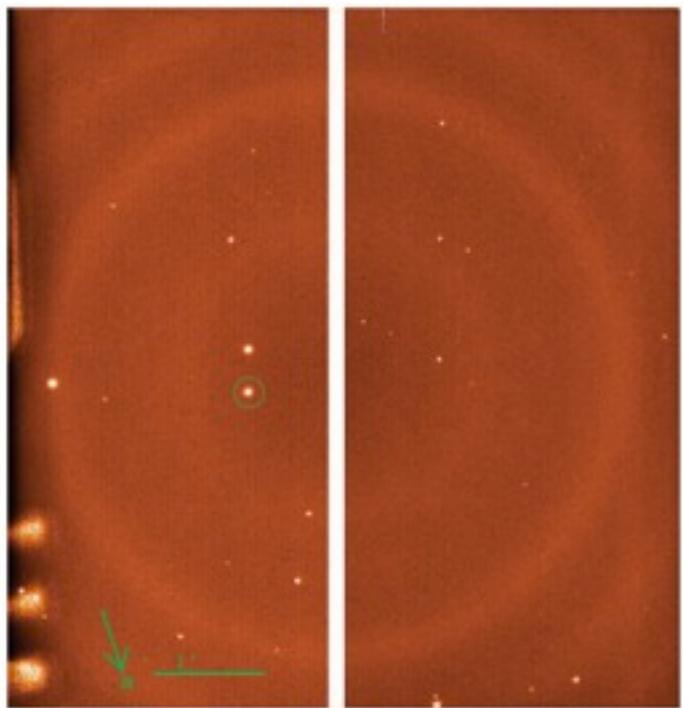
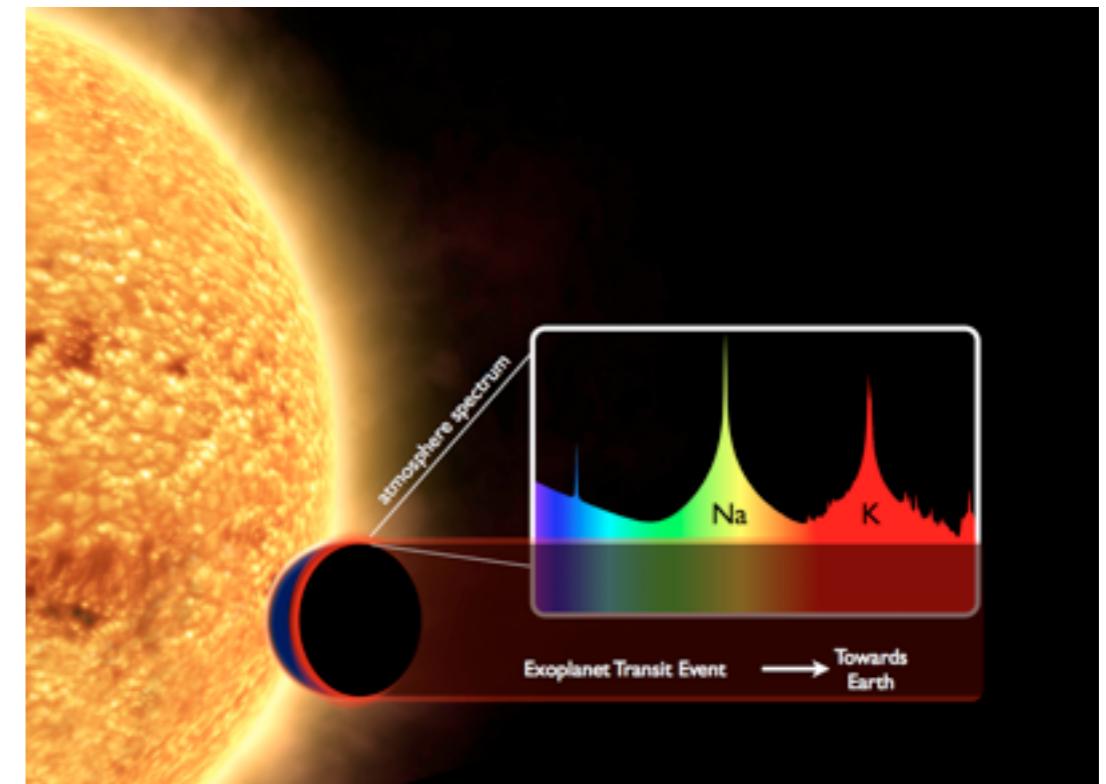


Croll et al. (2010)

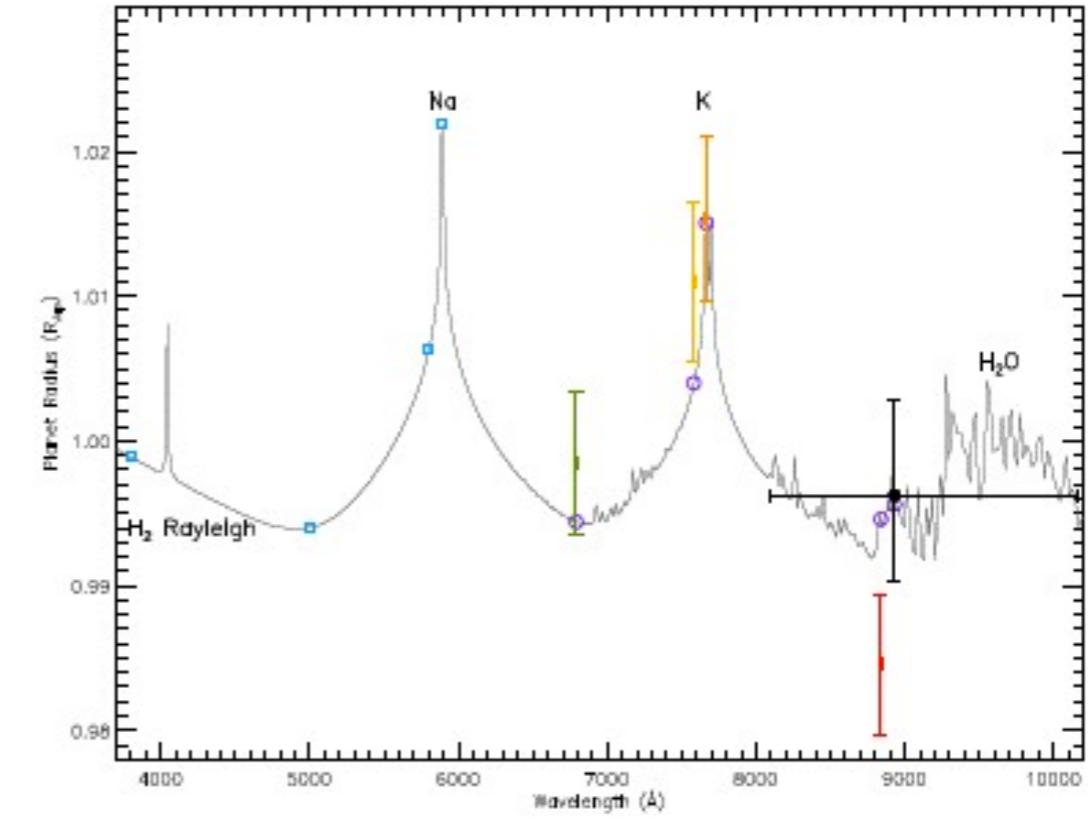
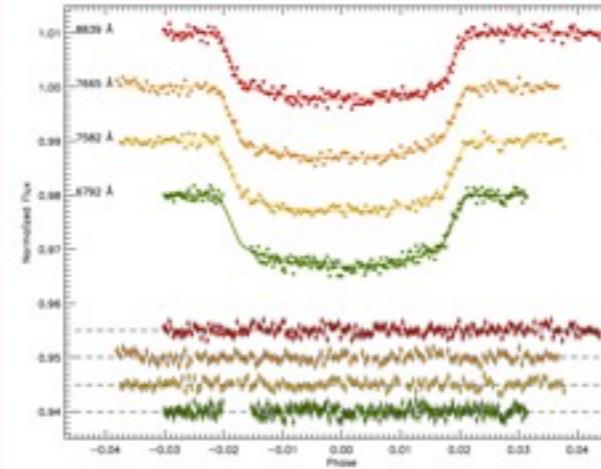
Eclipse TrES-2b



Transmission GTC

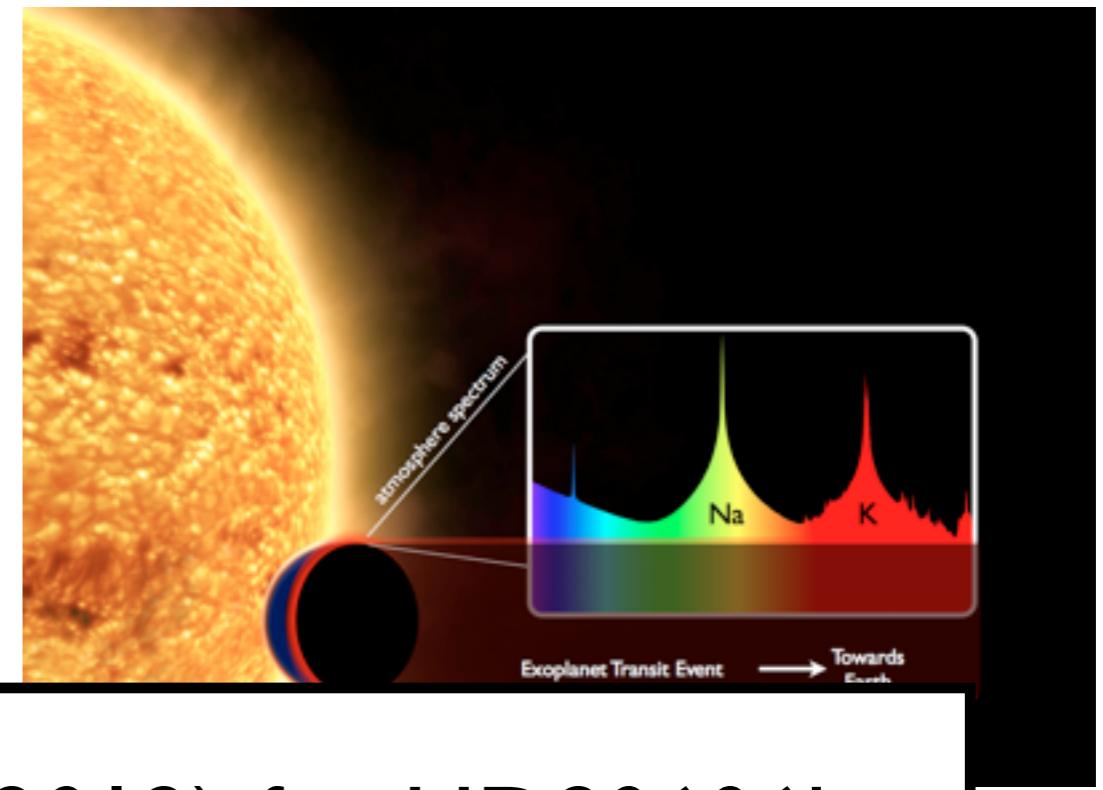


XO-2b

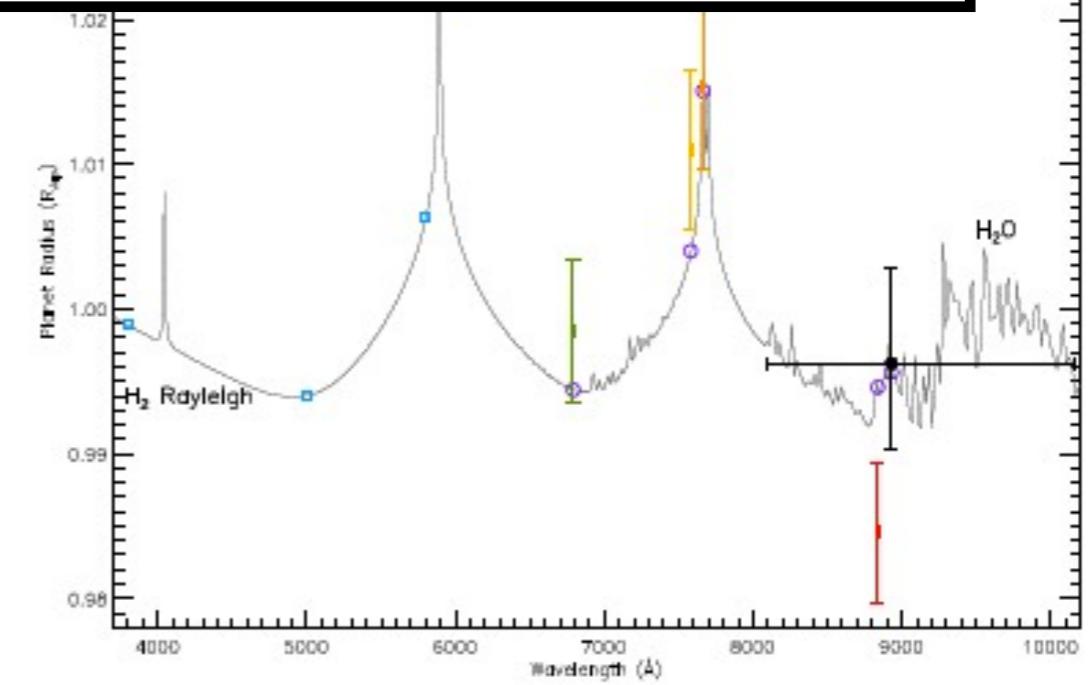
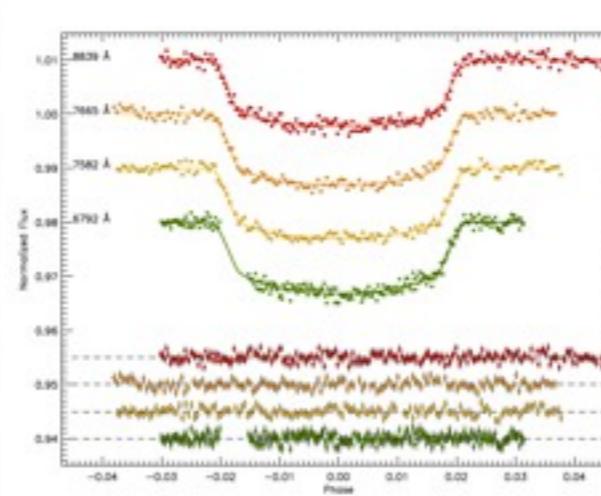
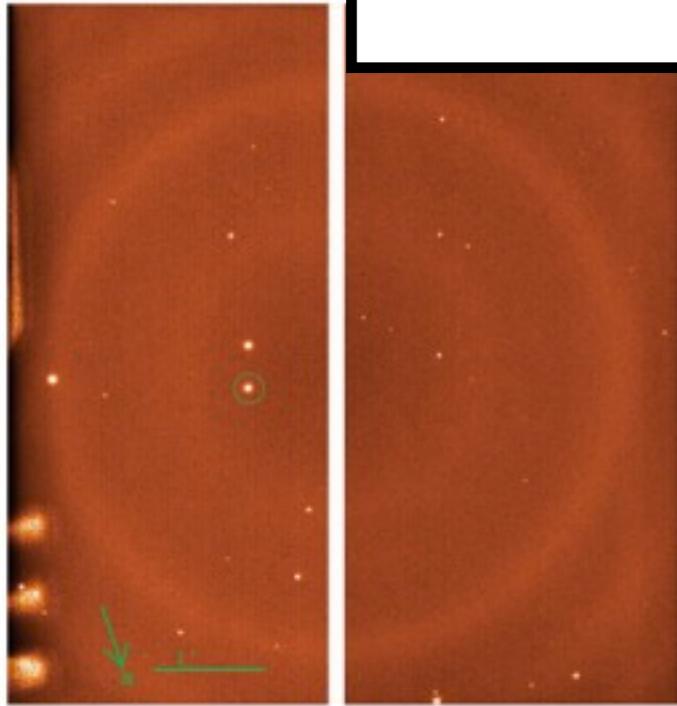


Sing, Désert et al. (2011)

Transmission GTC



See also Colon et al. (2012) for HD80606b

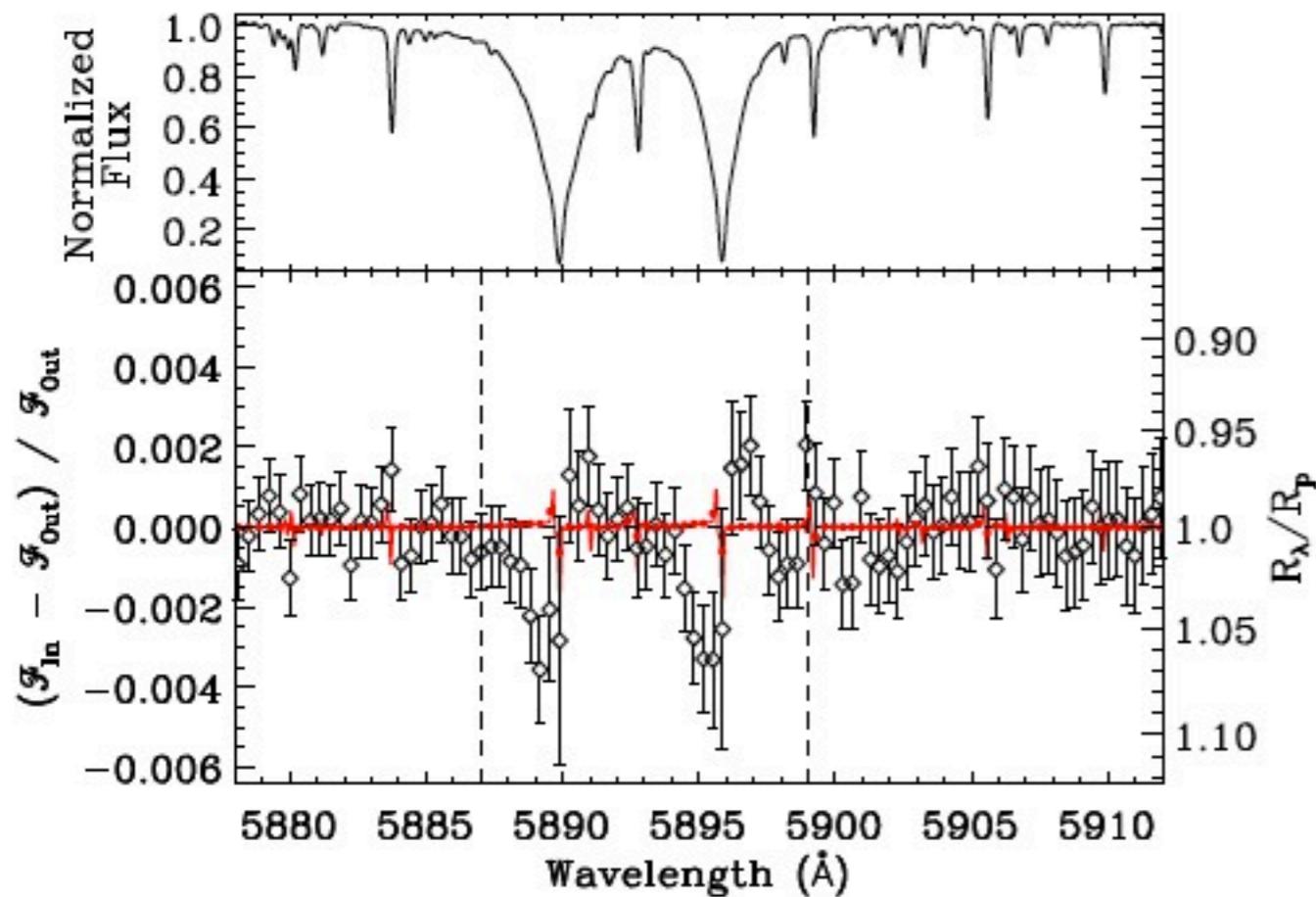


Sing, Désert et al. (2011)

Ground-Based Observations

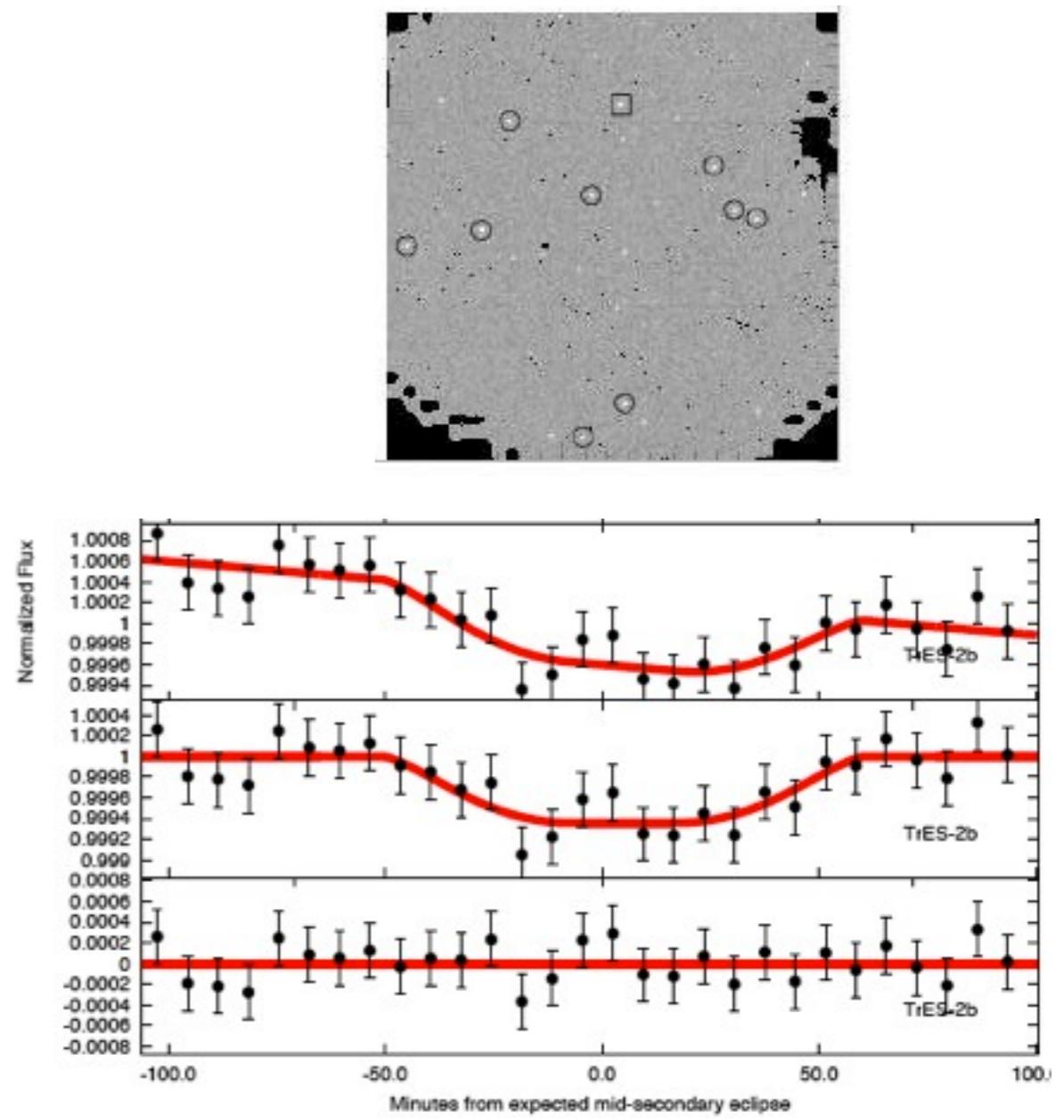
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Transit HD189733b



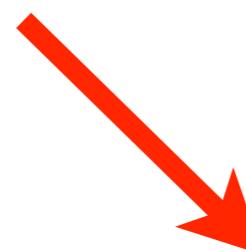
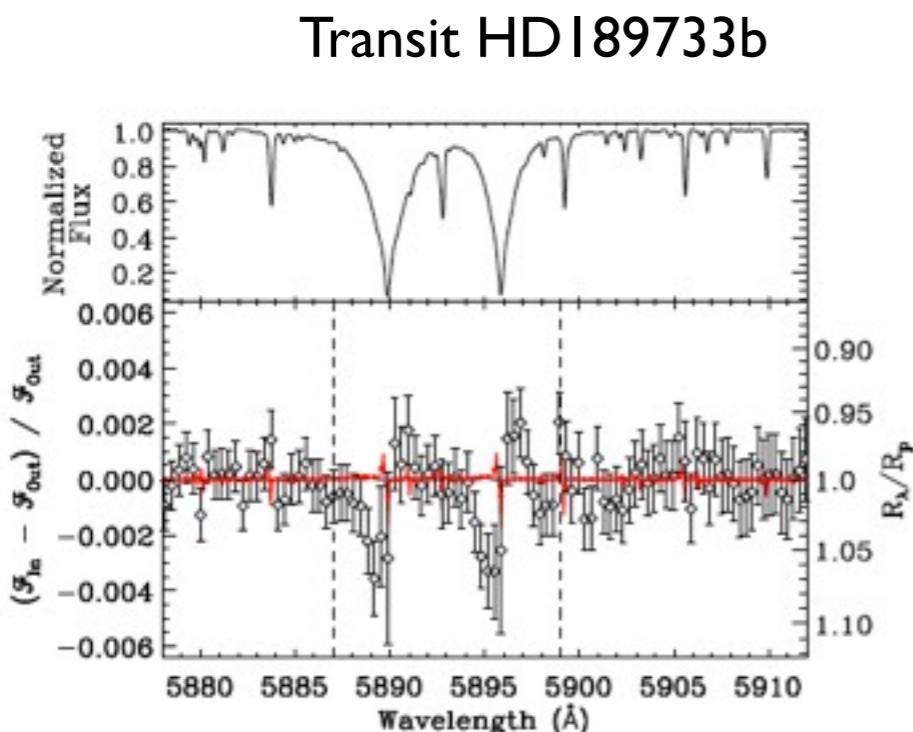
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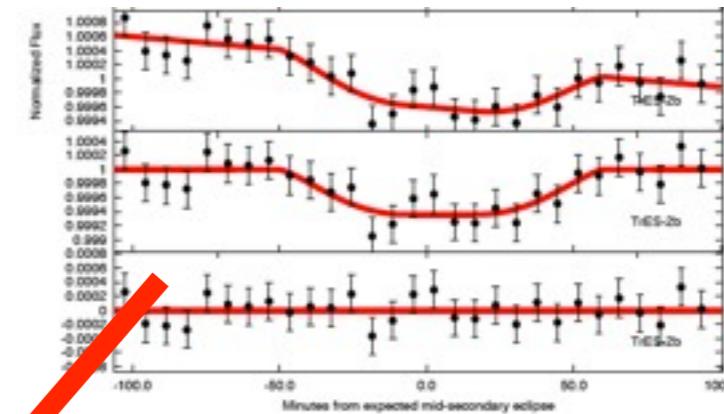
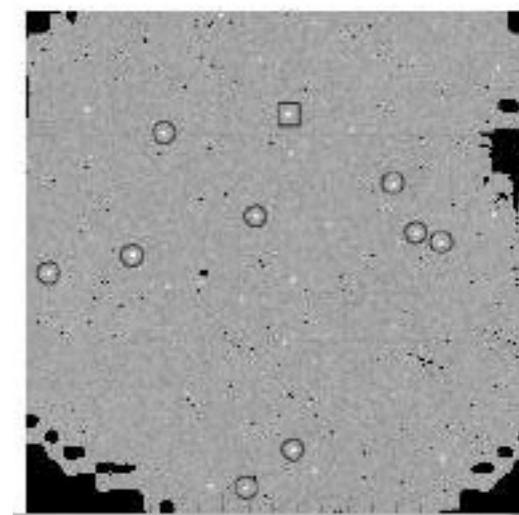


Ground-Based Observations

Redfield et al. (2008)



Croll et al. (2010)
Eclipse TrES-2b

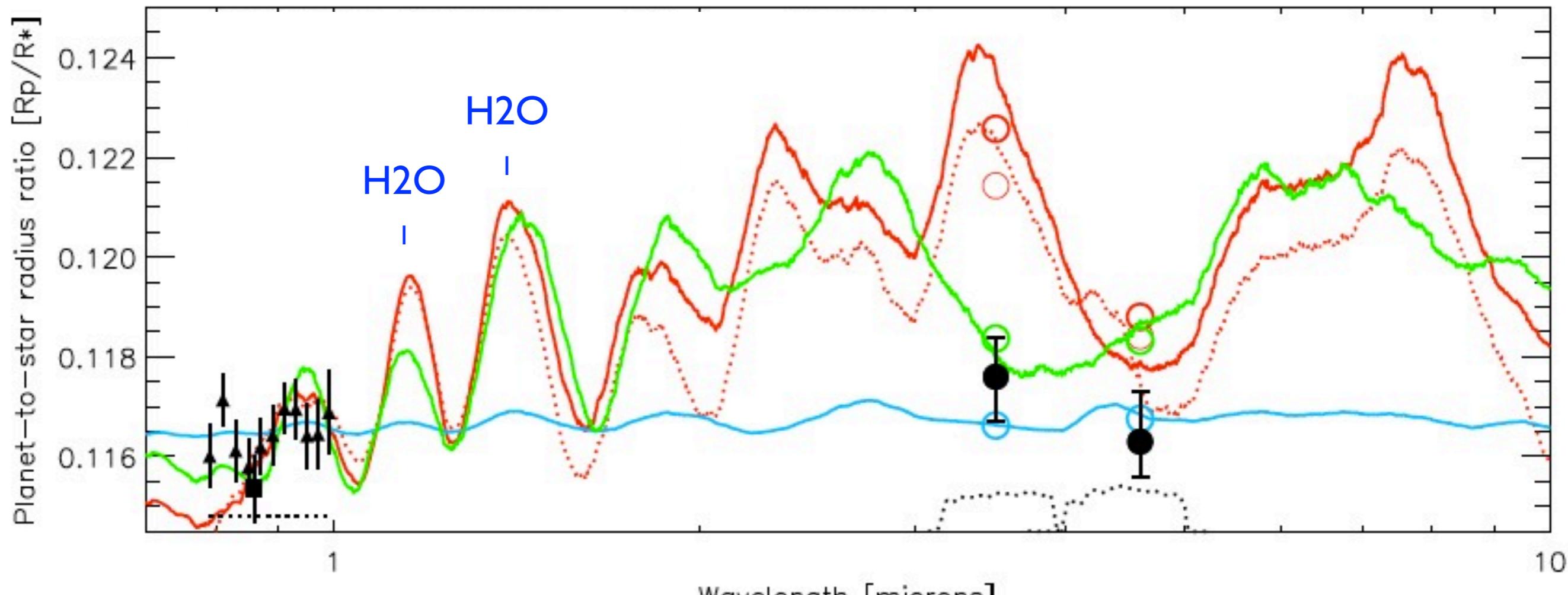


The Multi-Object Spectroscopy Technique

VLT/FORS Bean et al. (2010)

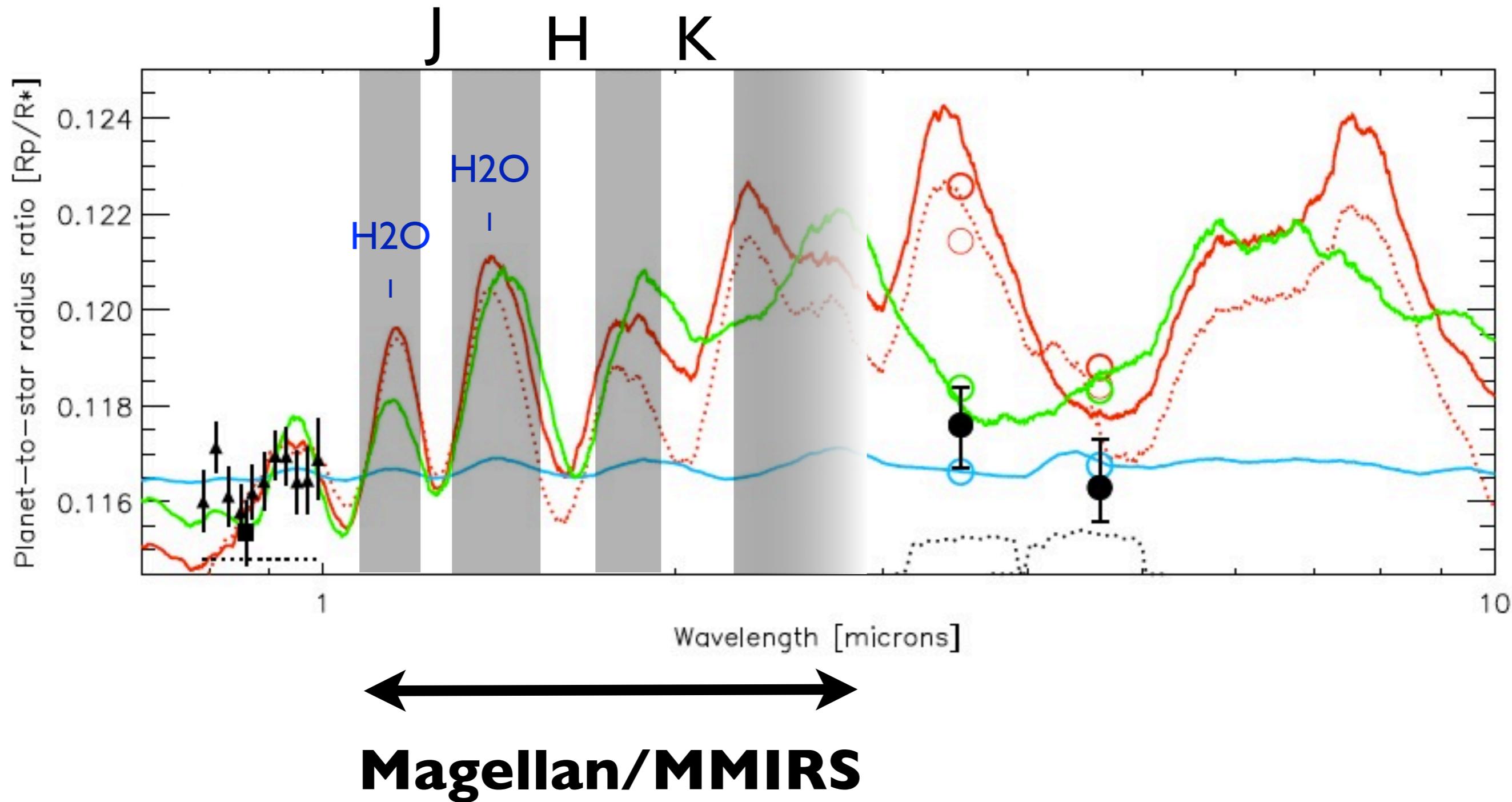
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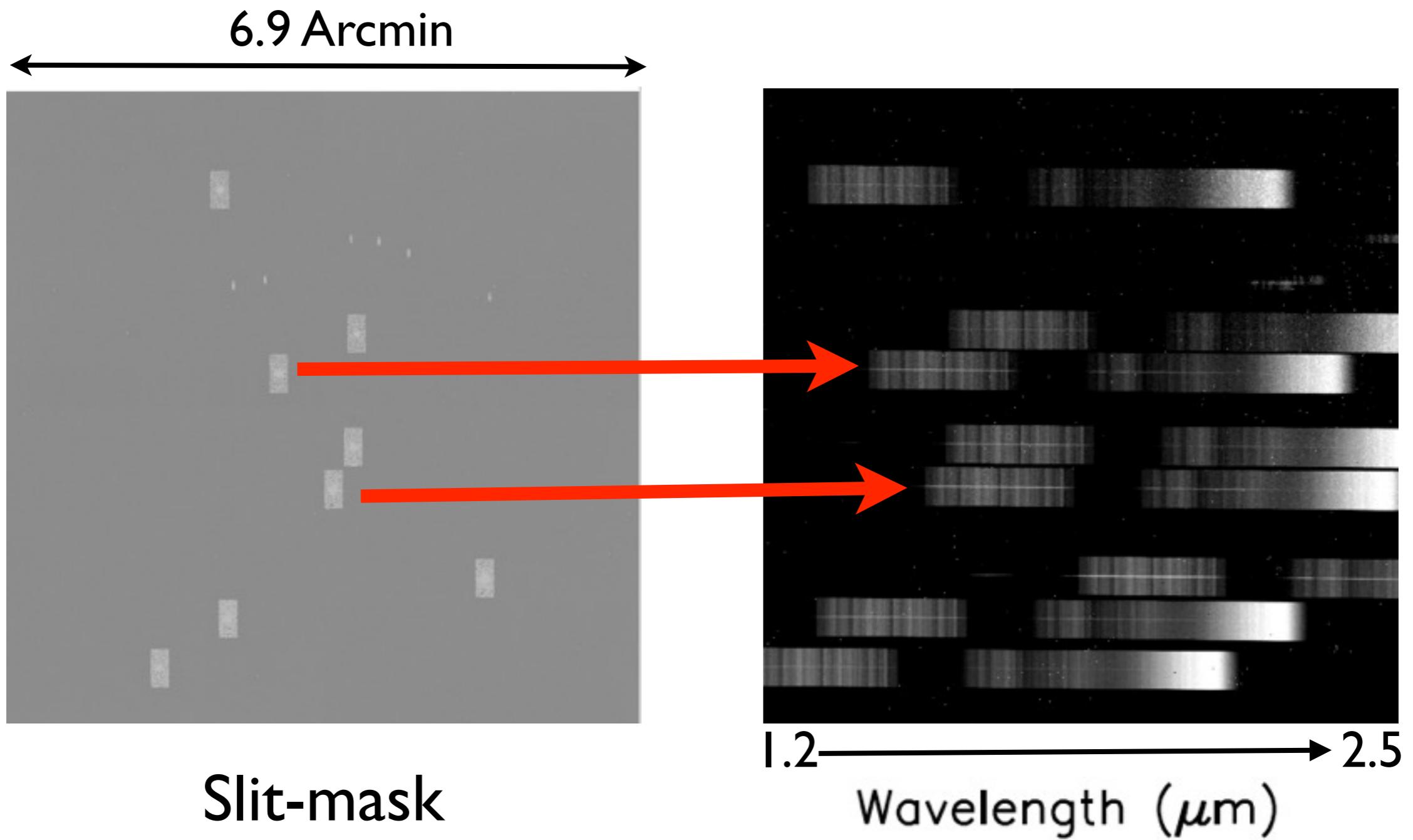
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Multi-Object Spectroscopy

(GJ 1214b, Magellan/MMIRS)

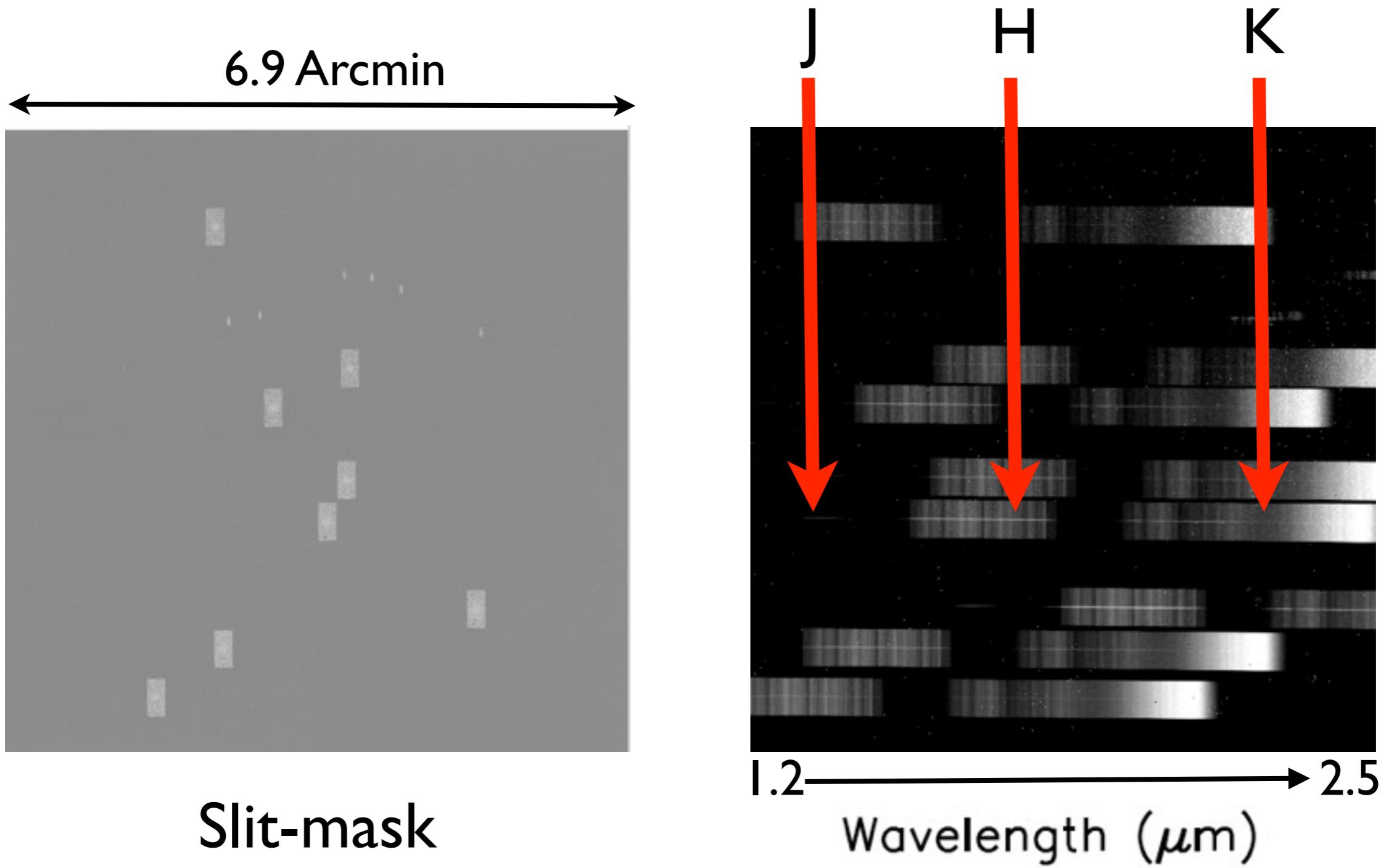
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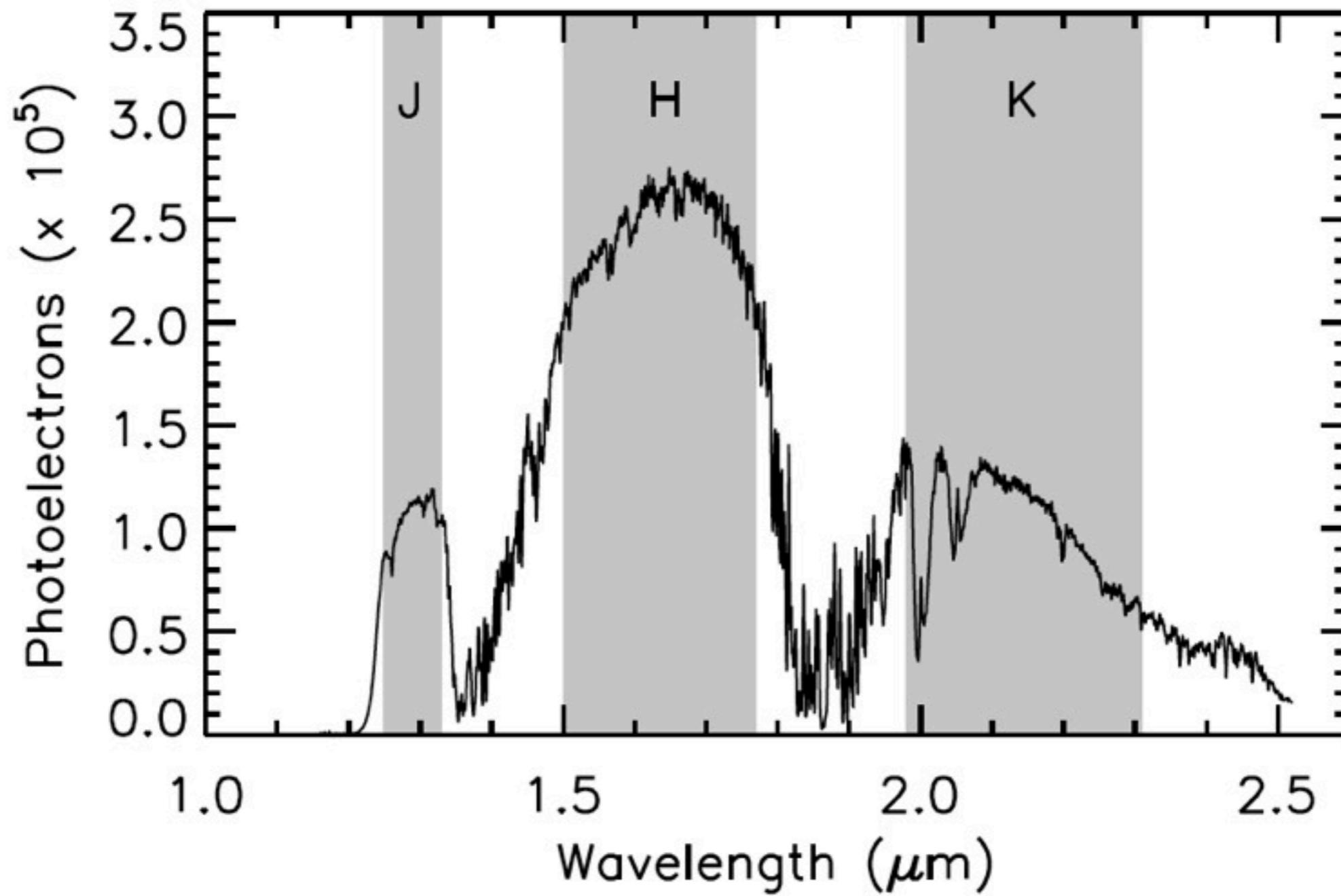


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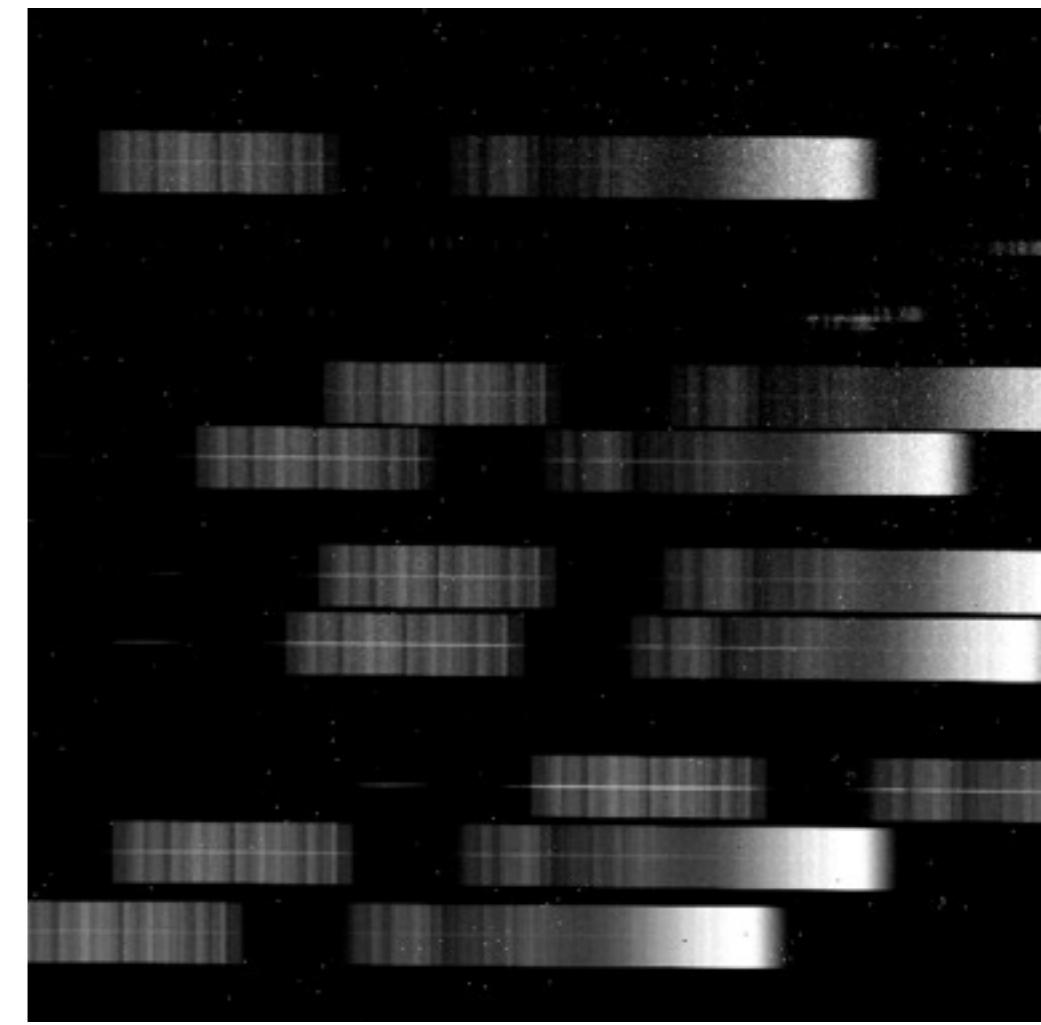
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Control systems



1.2 → 2.5
Wavelength (μm)

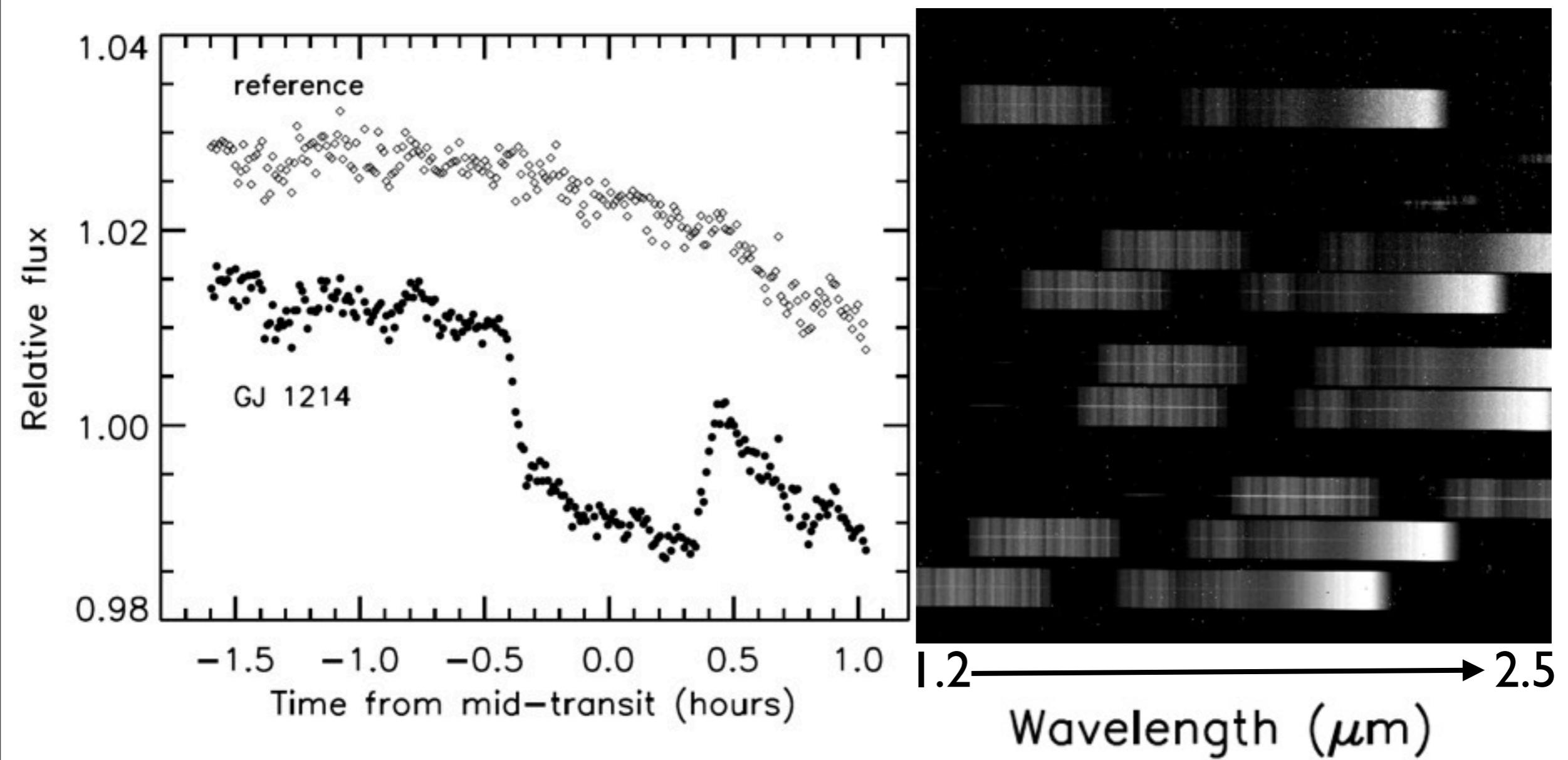
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Control systematics



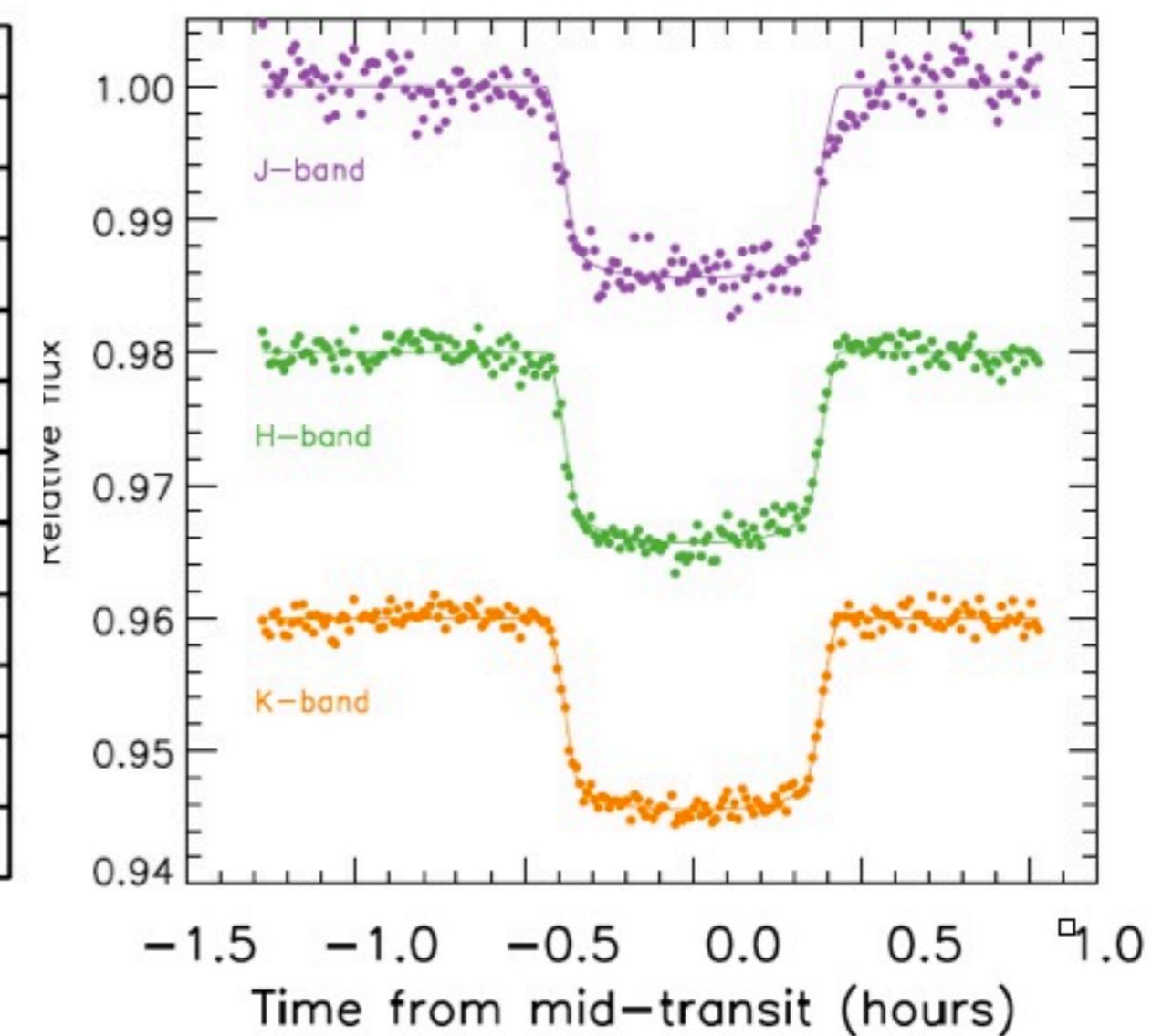
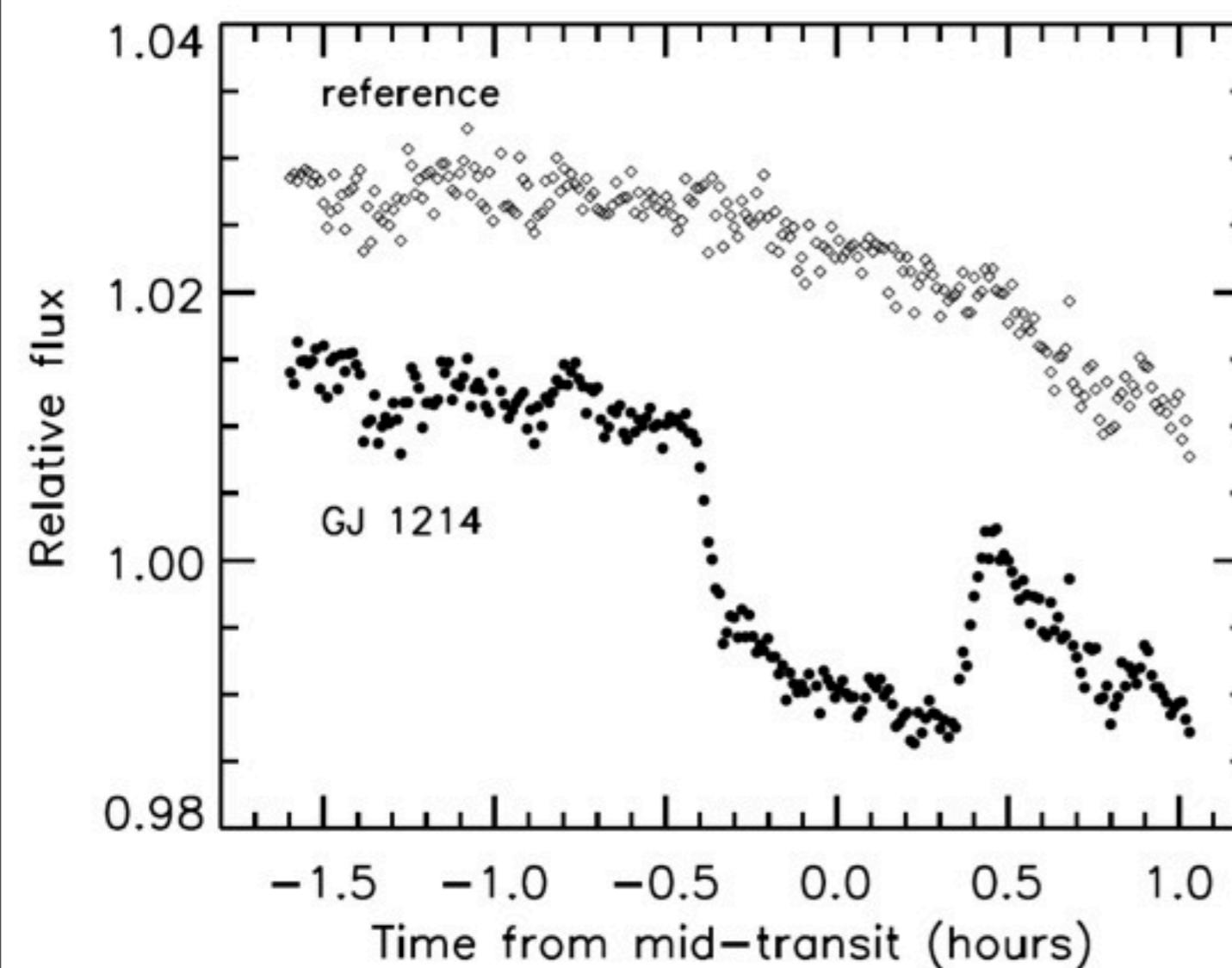
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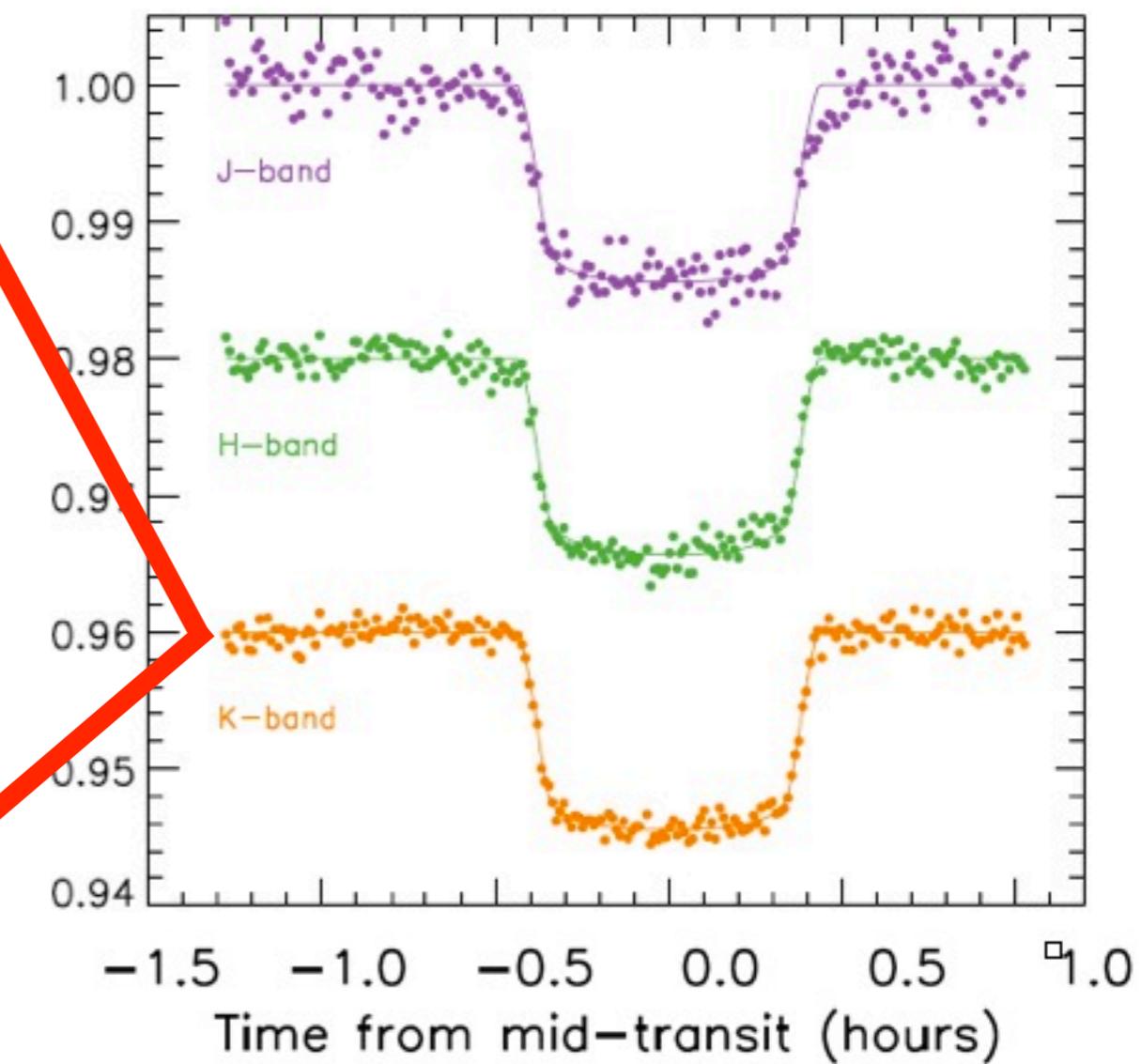
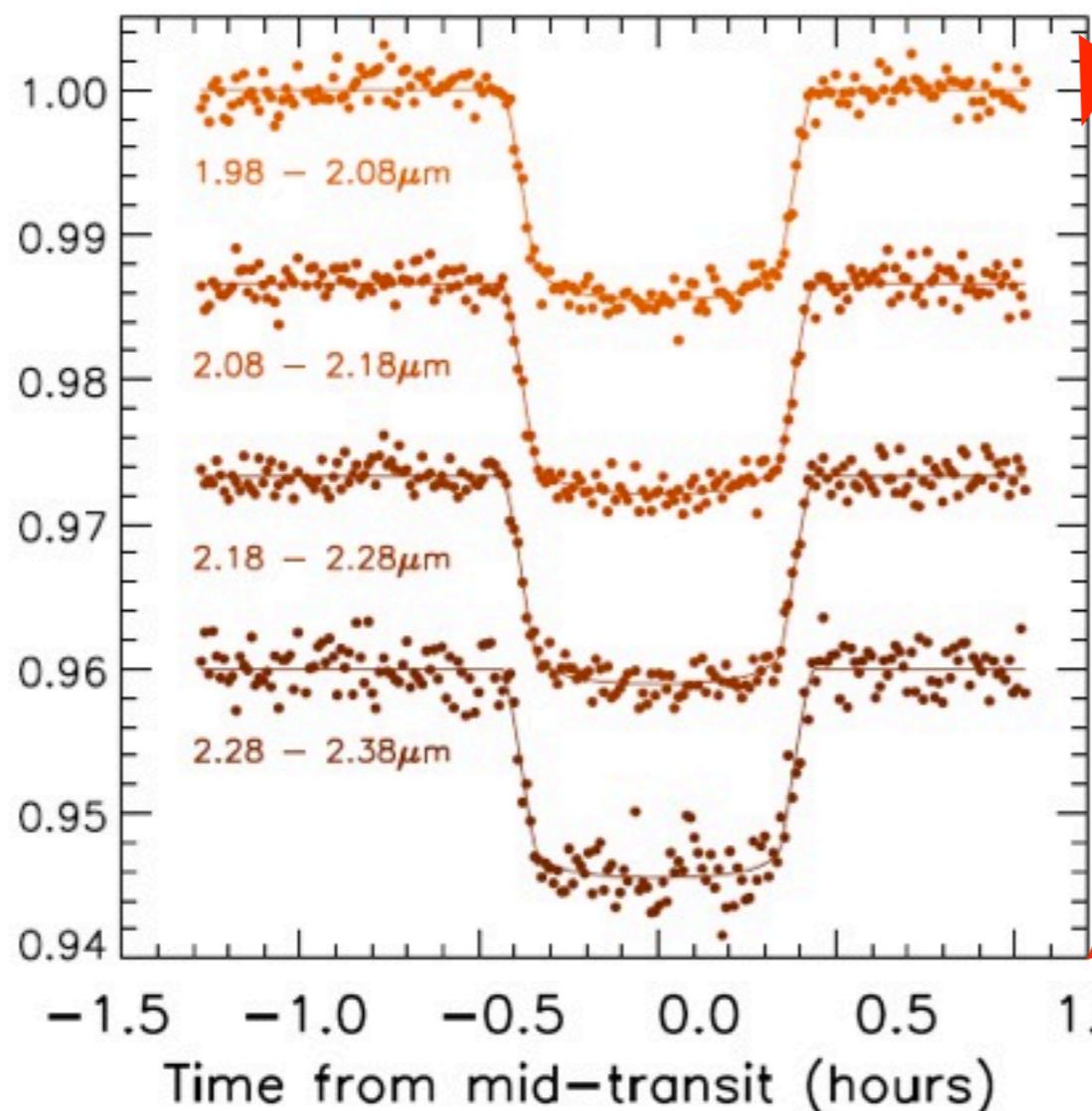
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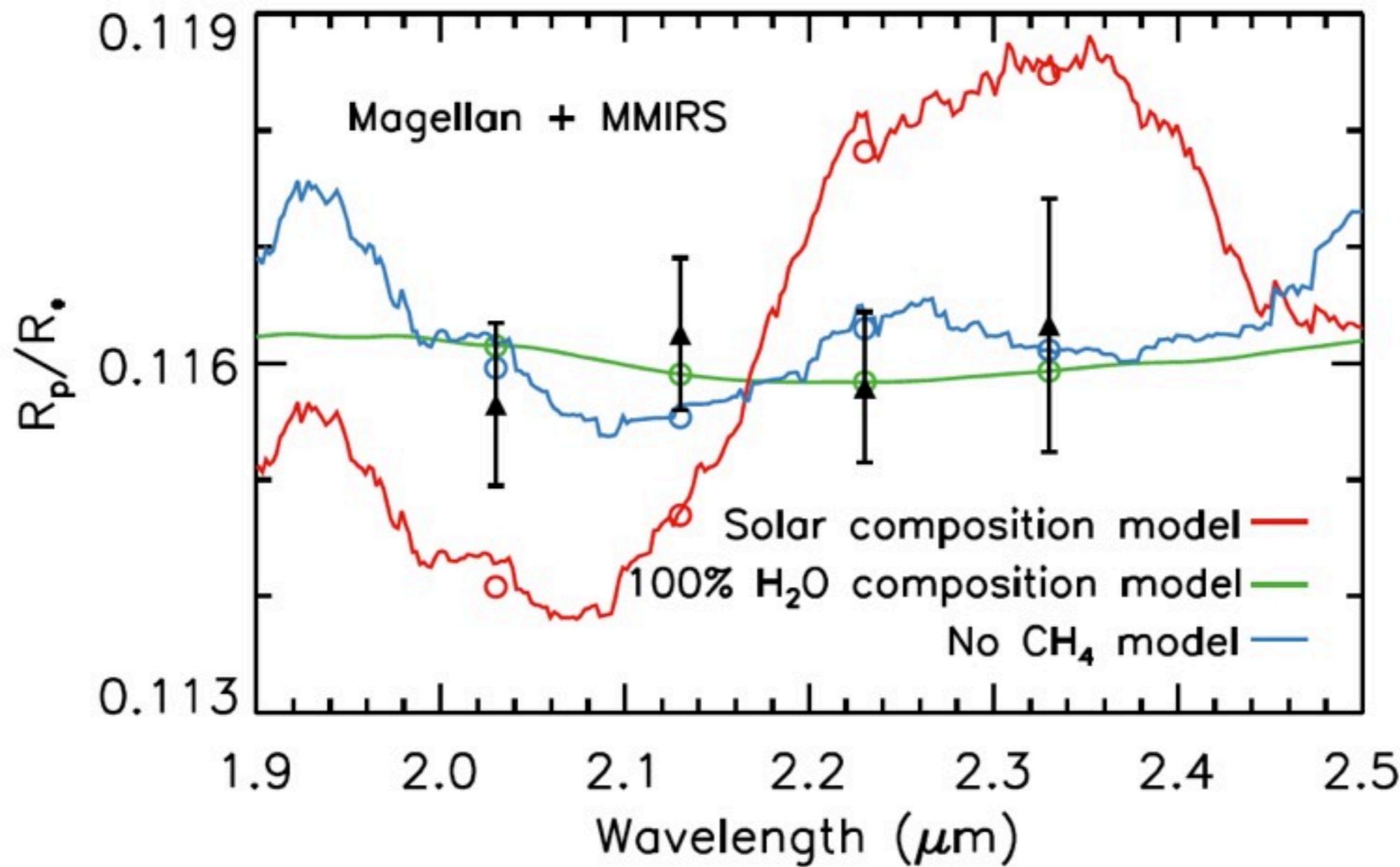
Bean, Désert et al. (2011)



K-band

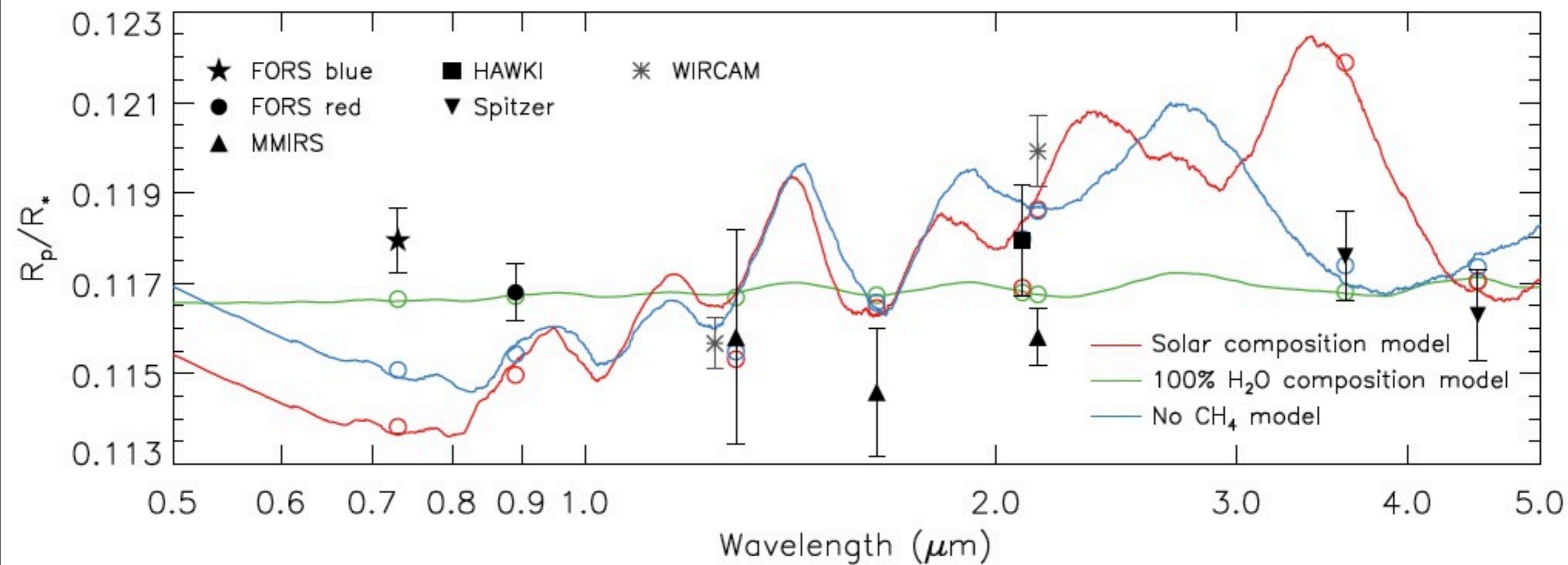


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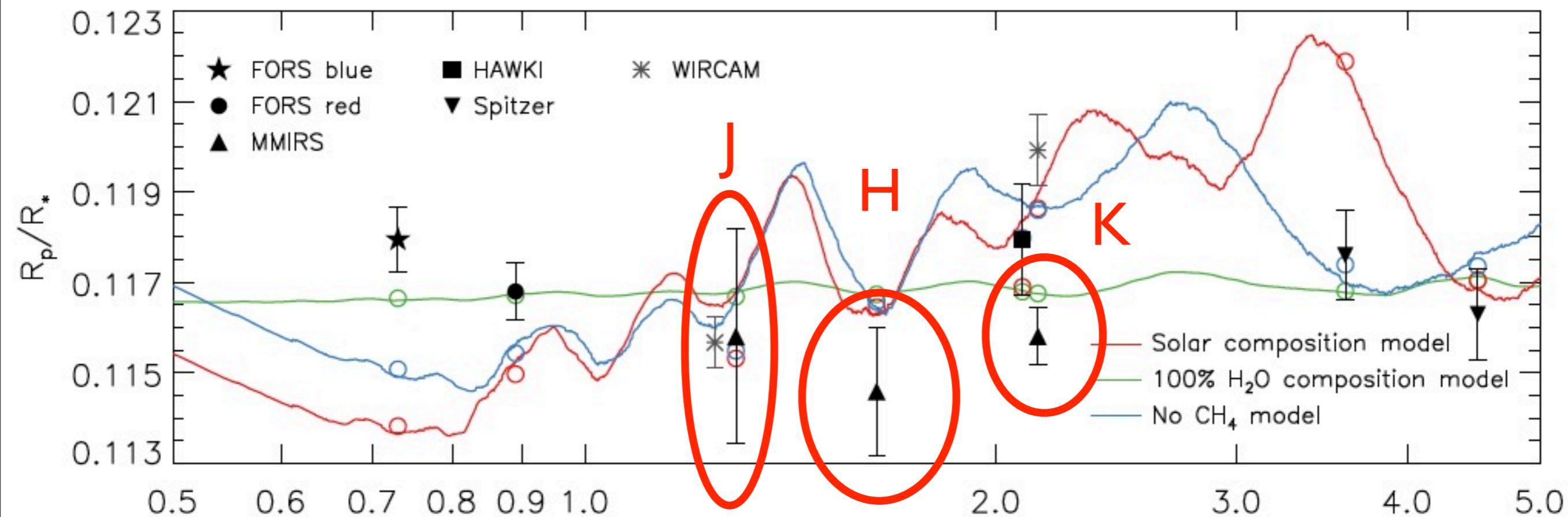
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Bean, Désert et al. (2011)

Multi-Object Spectroscopy (GJ1214b, Magellan/MMIRS)

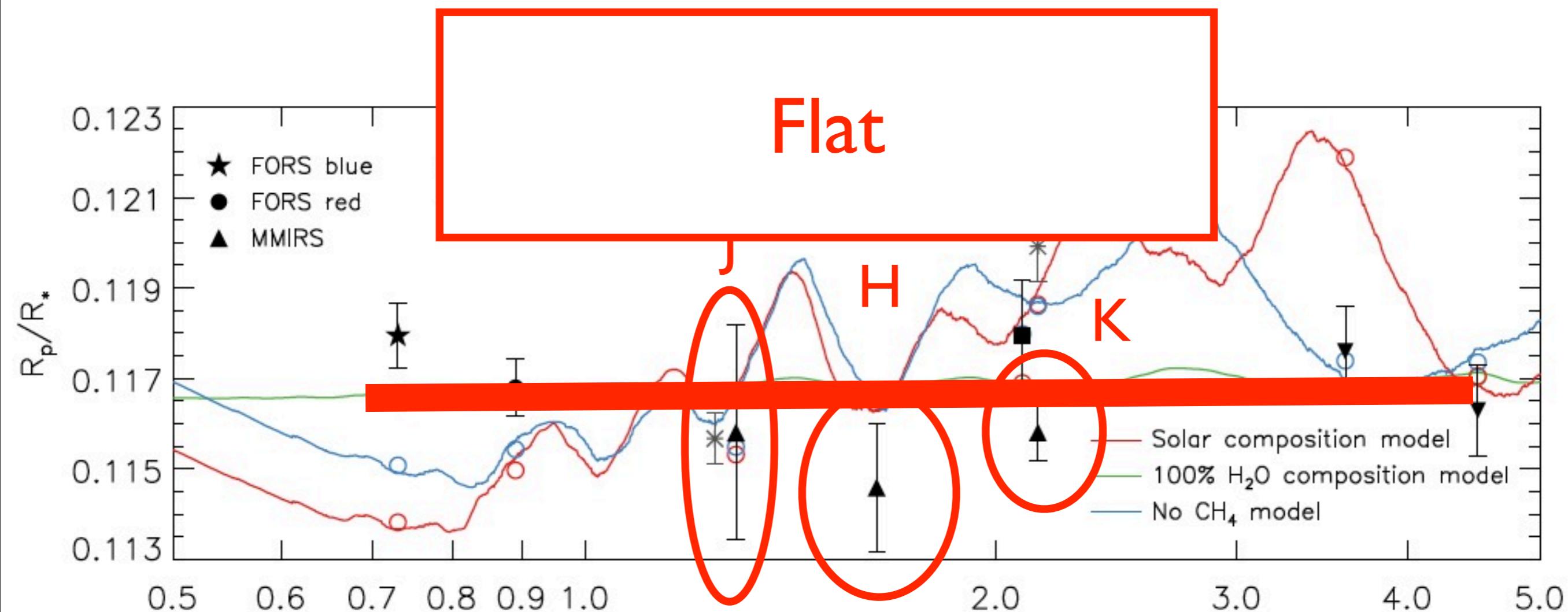


- 500 ppm / min in K-band
- 3 times photon noise (K-band) , or greater
- Uncontrolled systematics

Bean, Désert et al. (2011)

Multi-Object Spectroscopy

(GJ 1214b, Magellan/MMIRS)



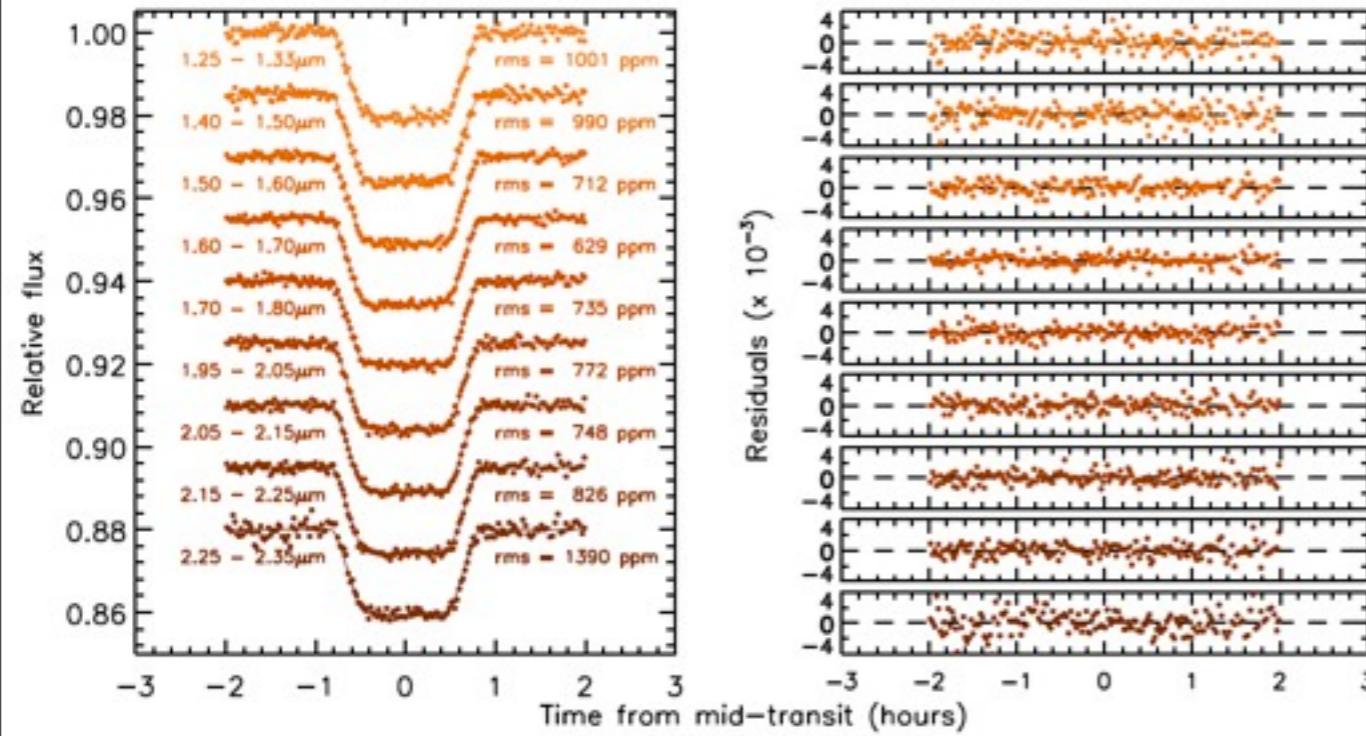
- 500 ppm / min in K-band
- 3 times photon noise (K-band) , or greater
- Uncontrolled systematics

Bean, Désert et al. (2011)

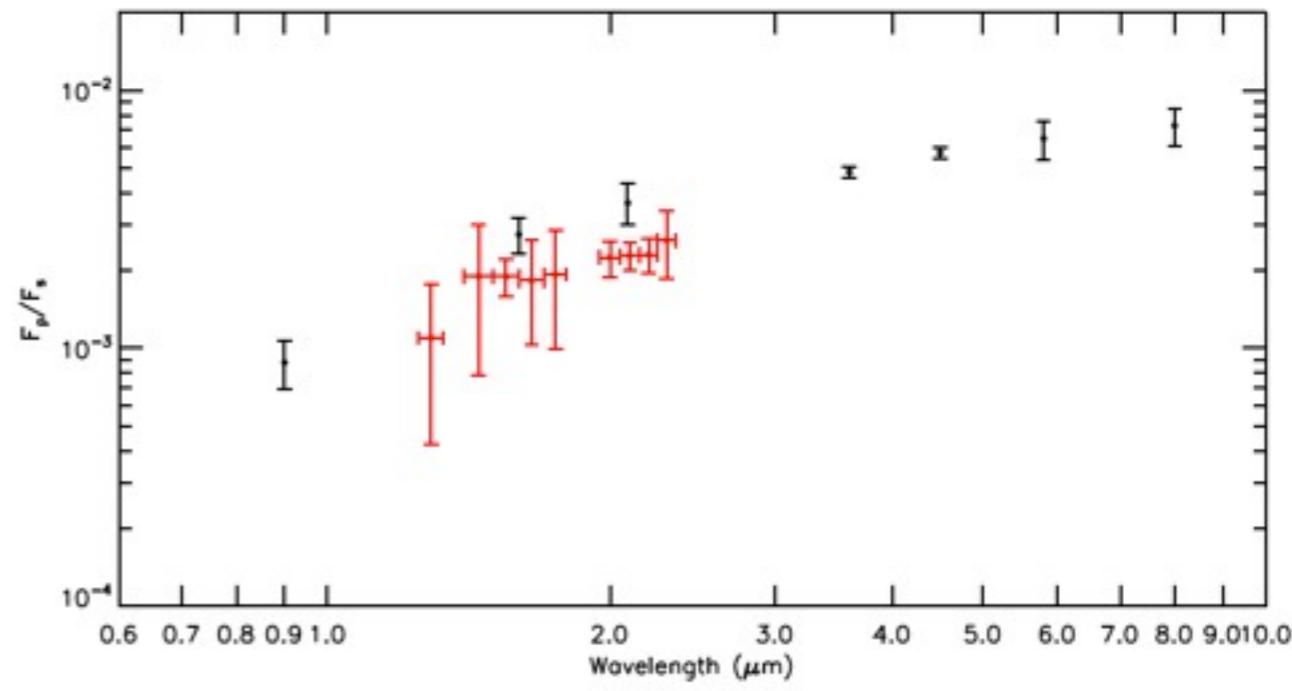
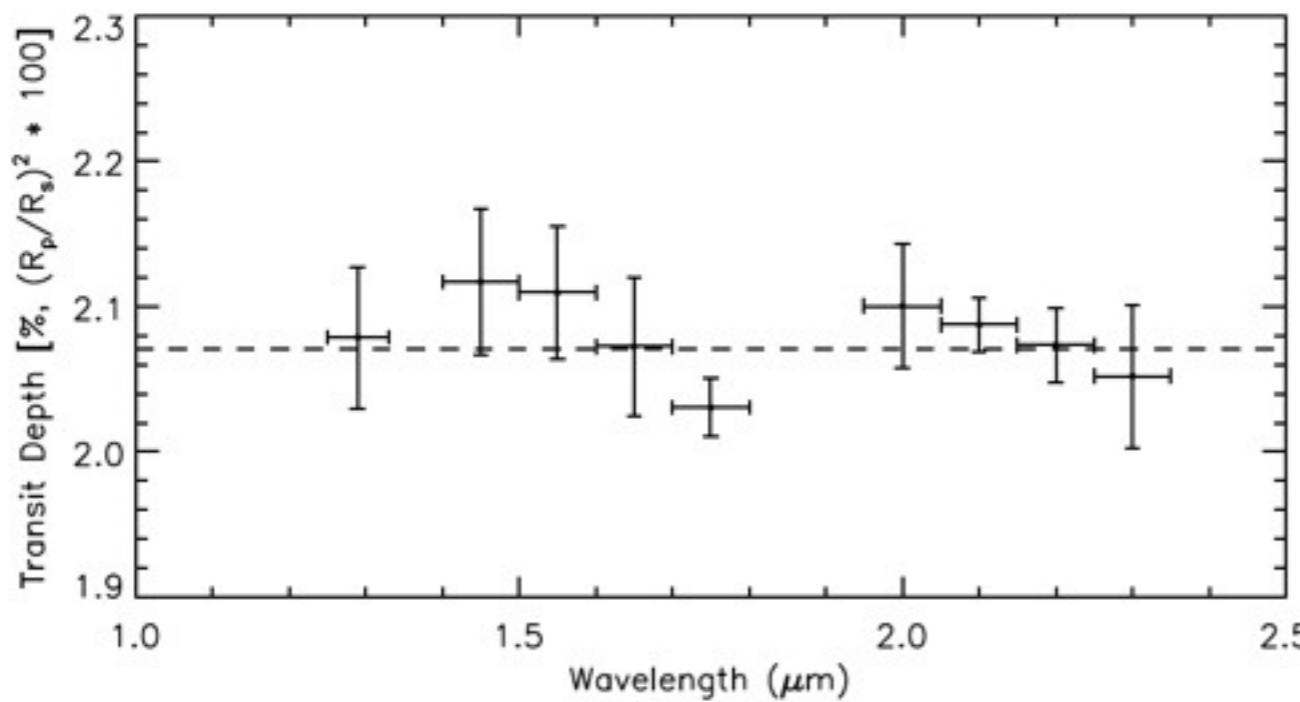
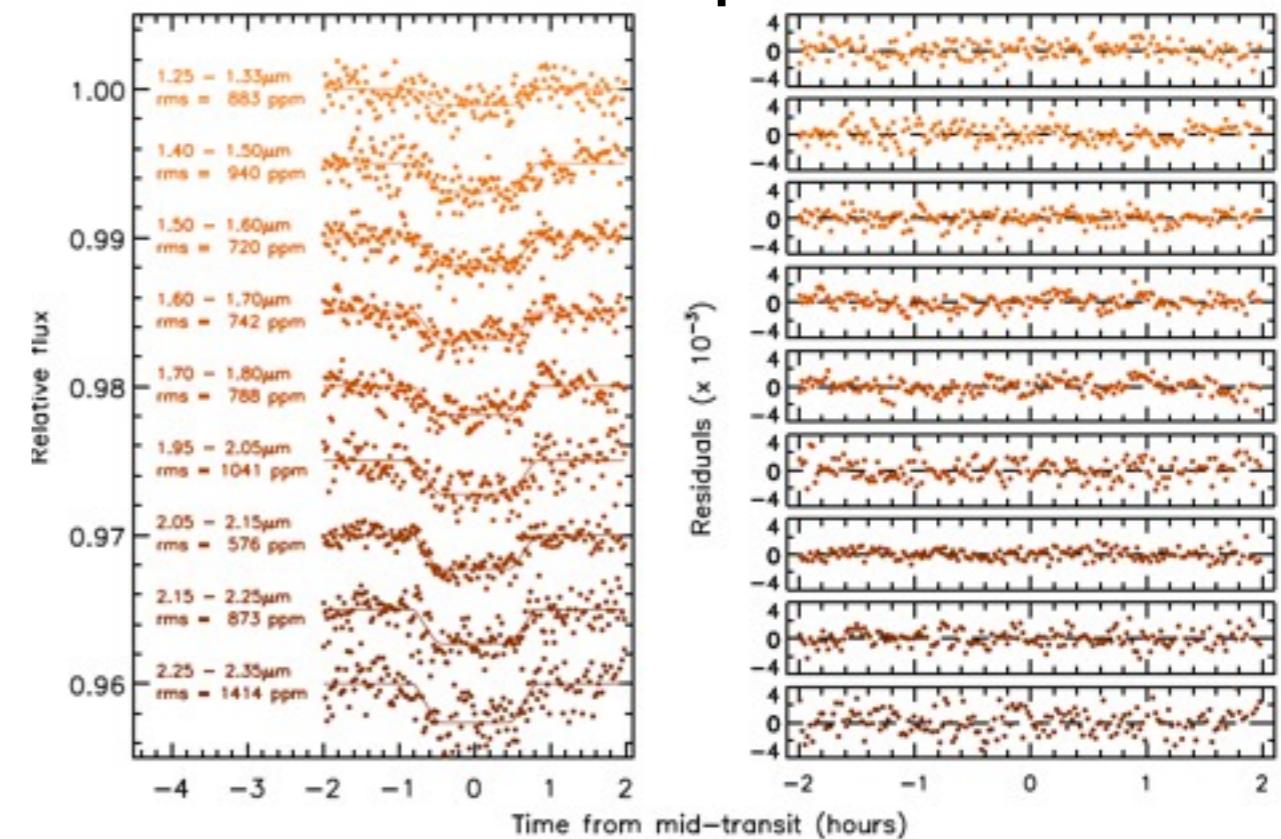
WASP-19b with Magellan/MMIRS (NIR)



2xTransits



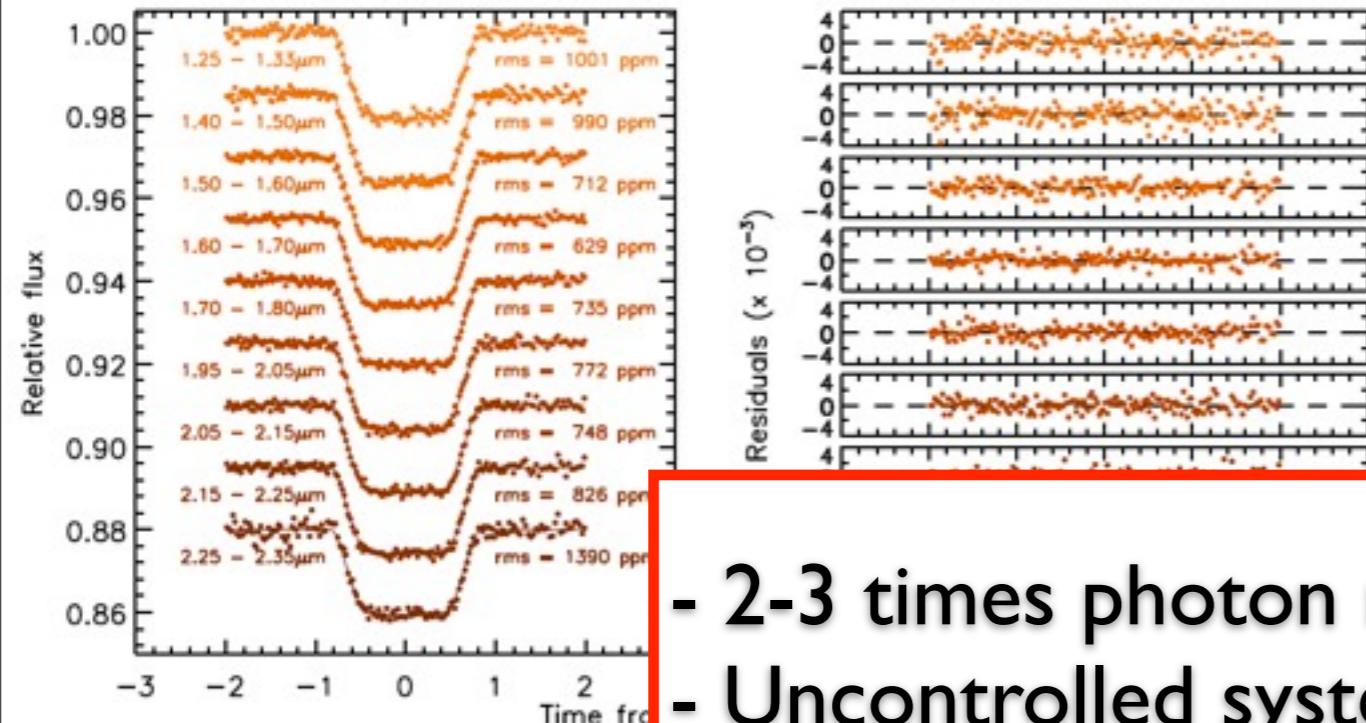
2xEclipses



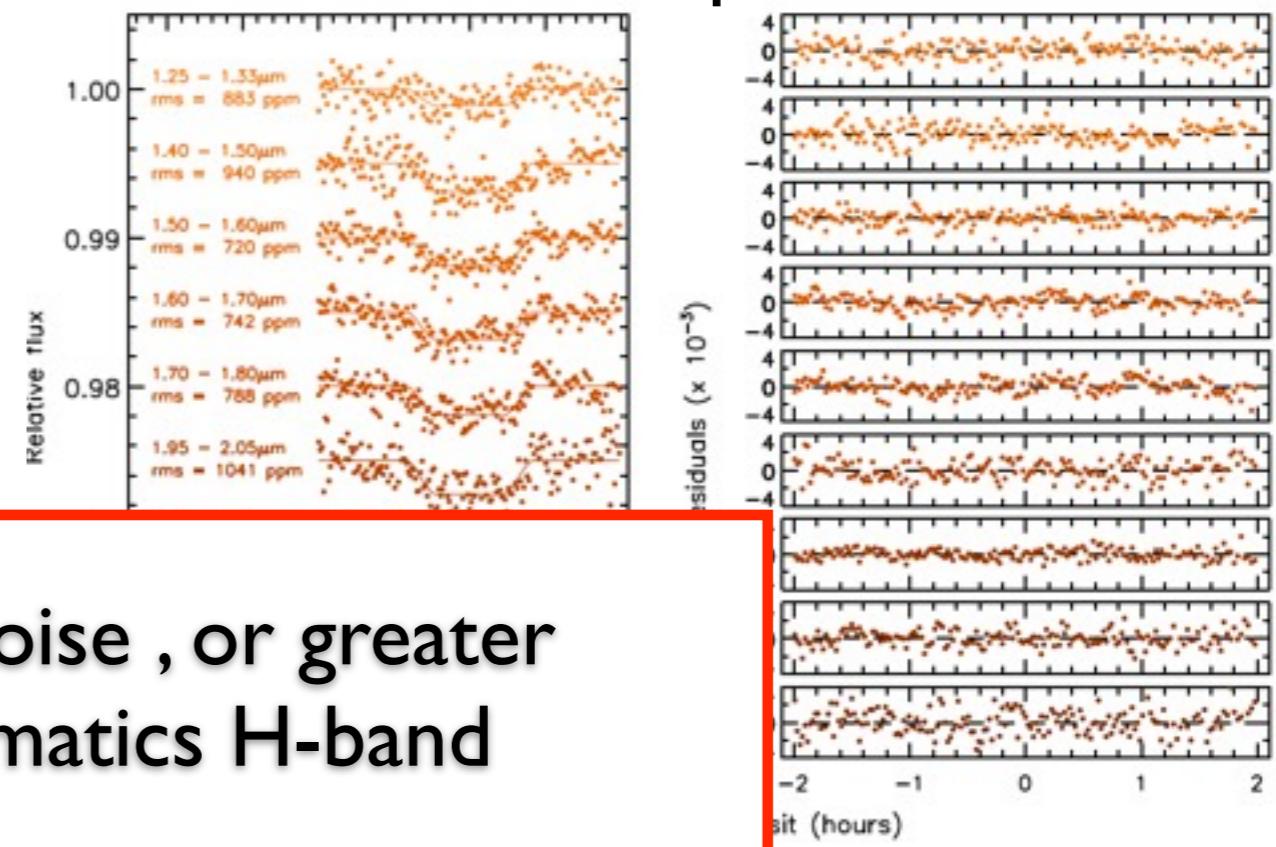
WASP-19b with Magellan/MMIRS (NIR)



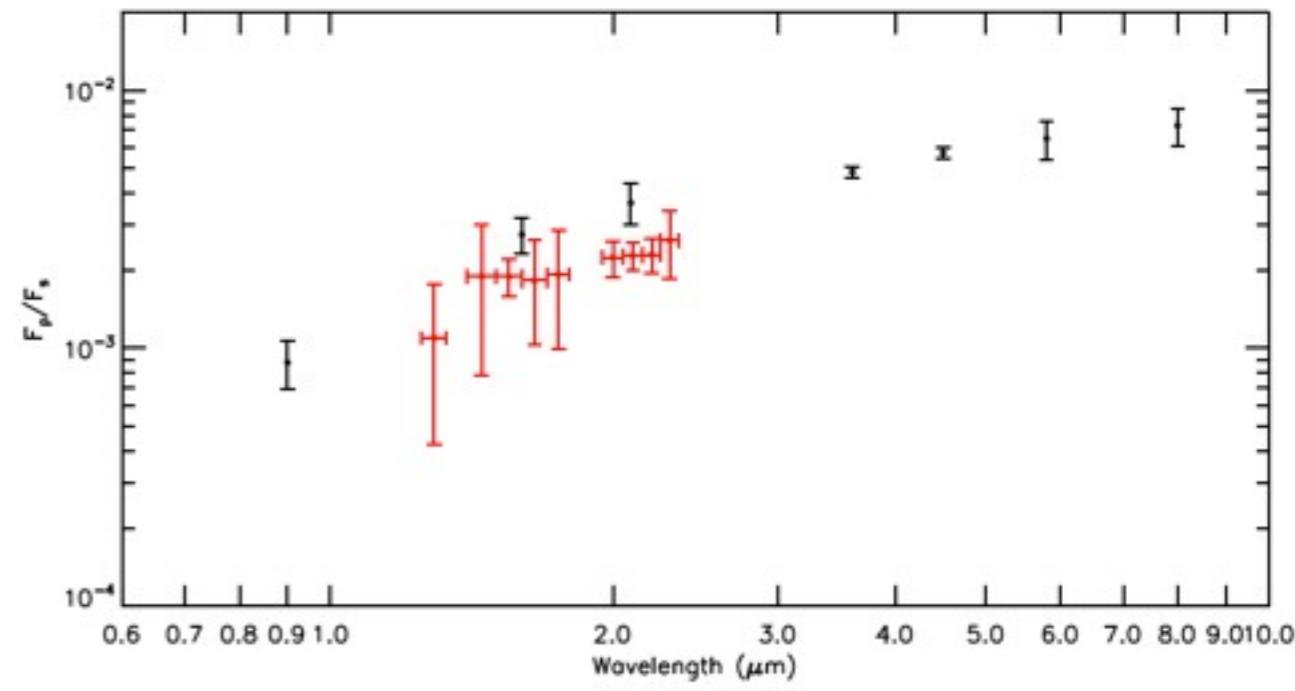
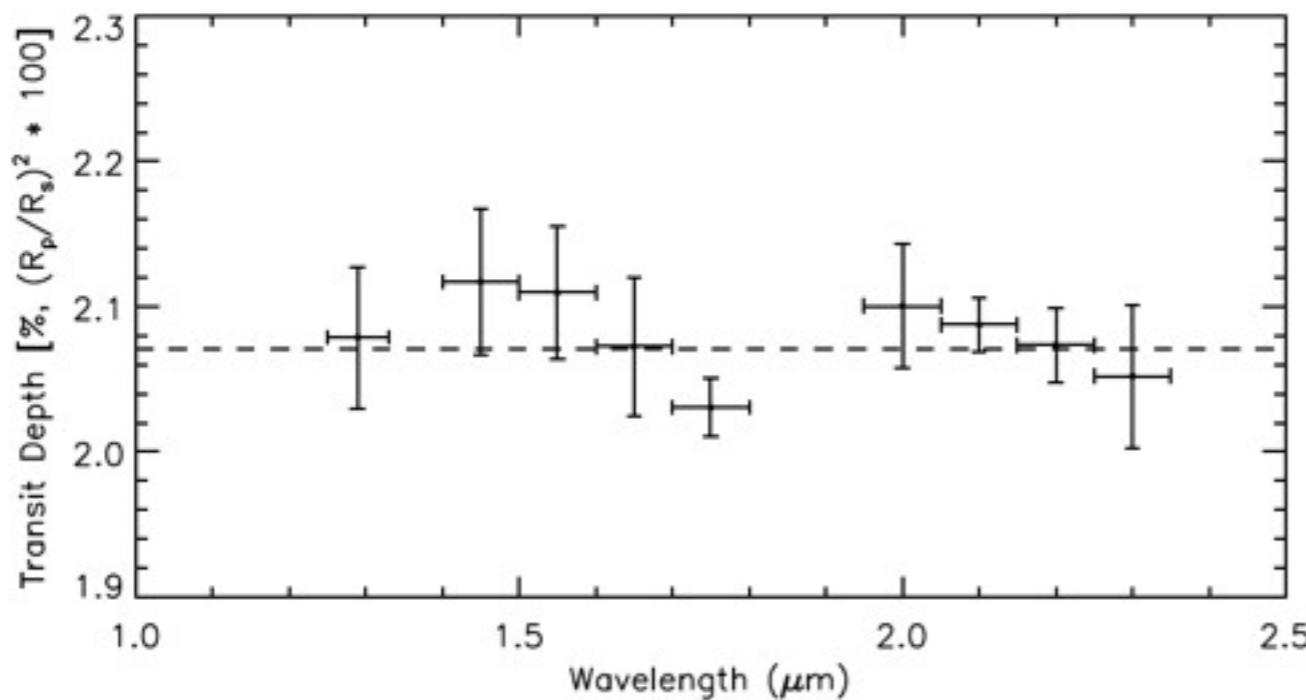
2xTransits



2xEclipses



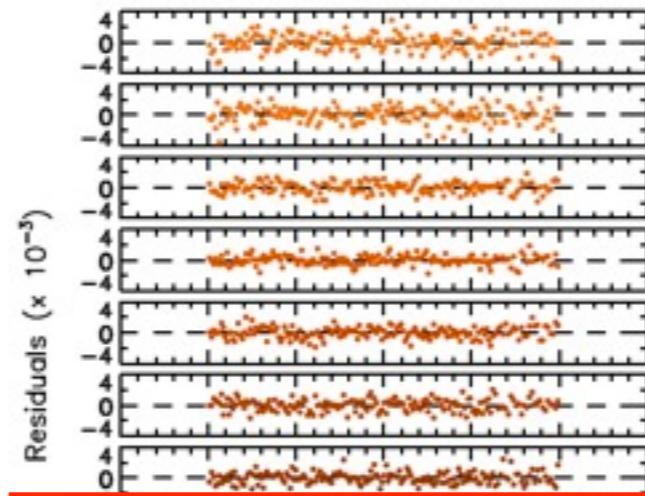
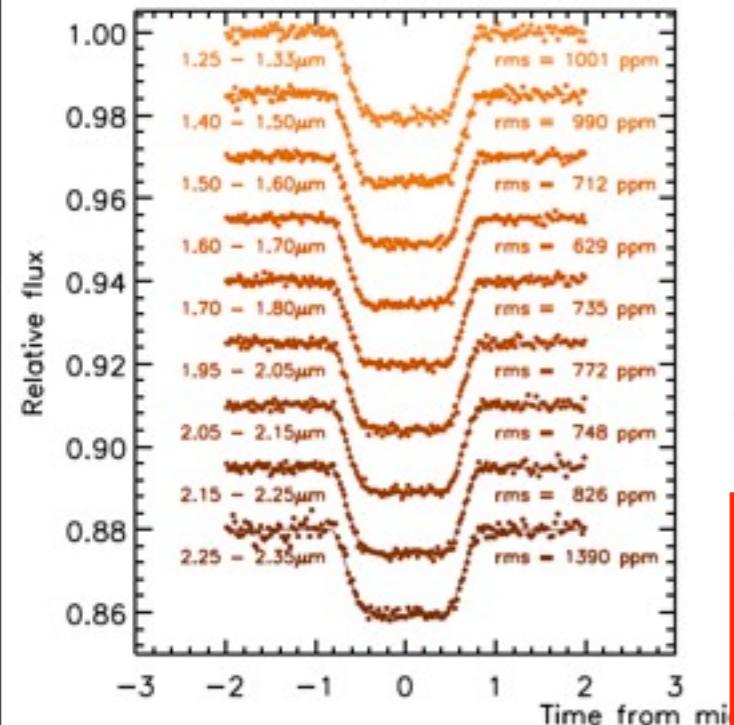
- 2-3 times photon noise , or greater
- Uncontrolled systematics H-band



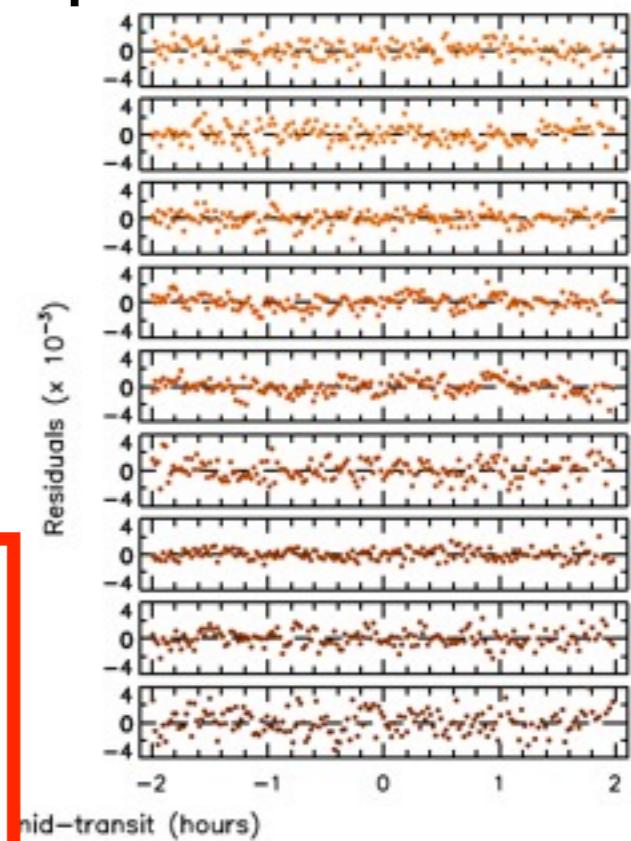
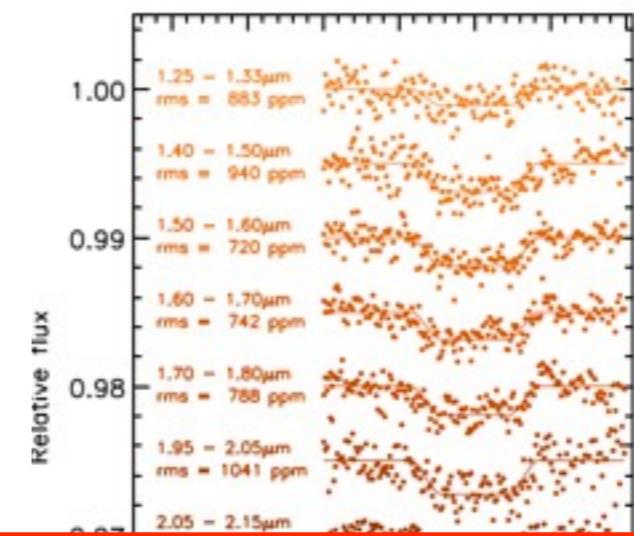
WASP-19b with Magellan/MMIRS (NIR)



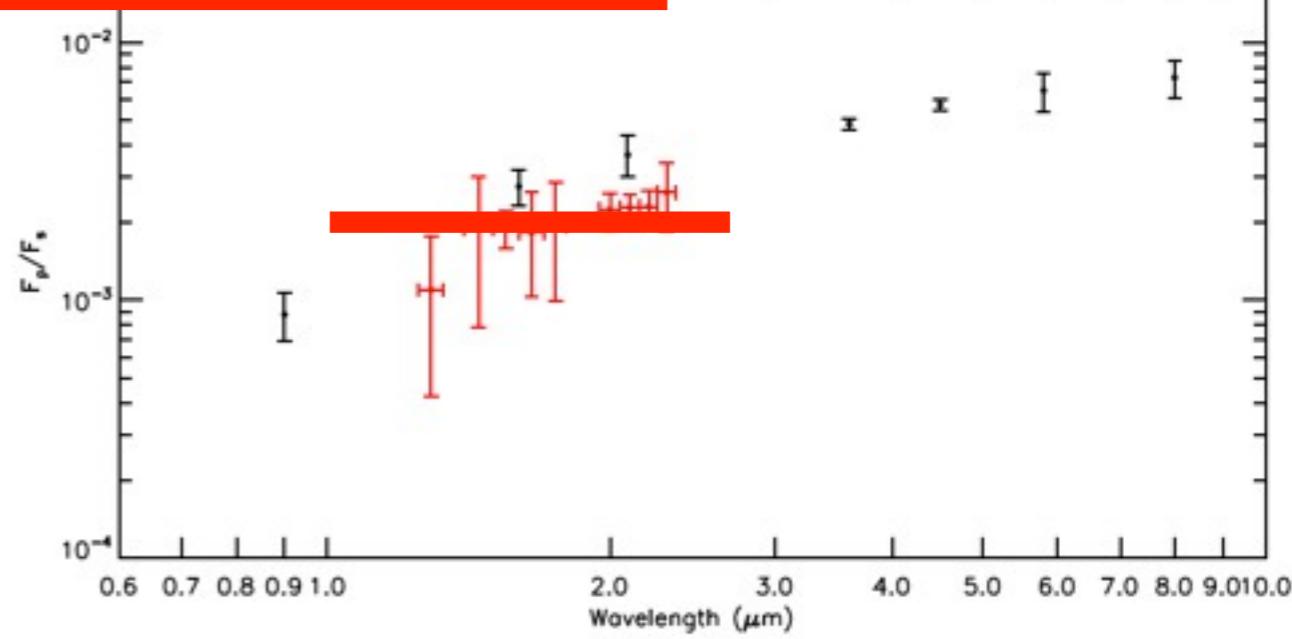
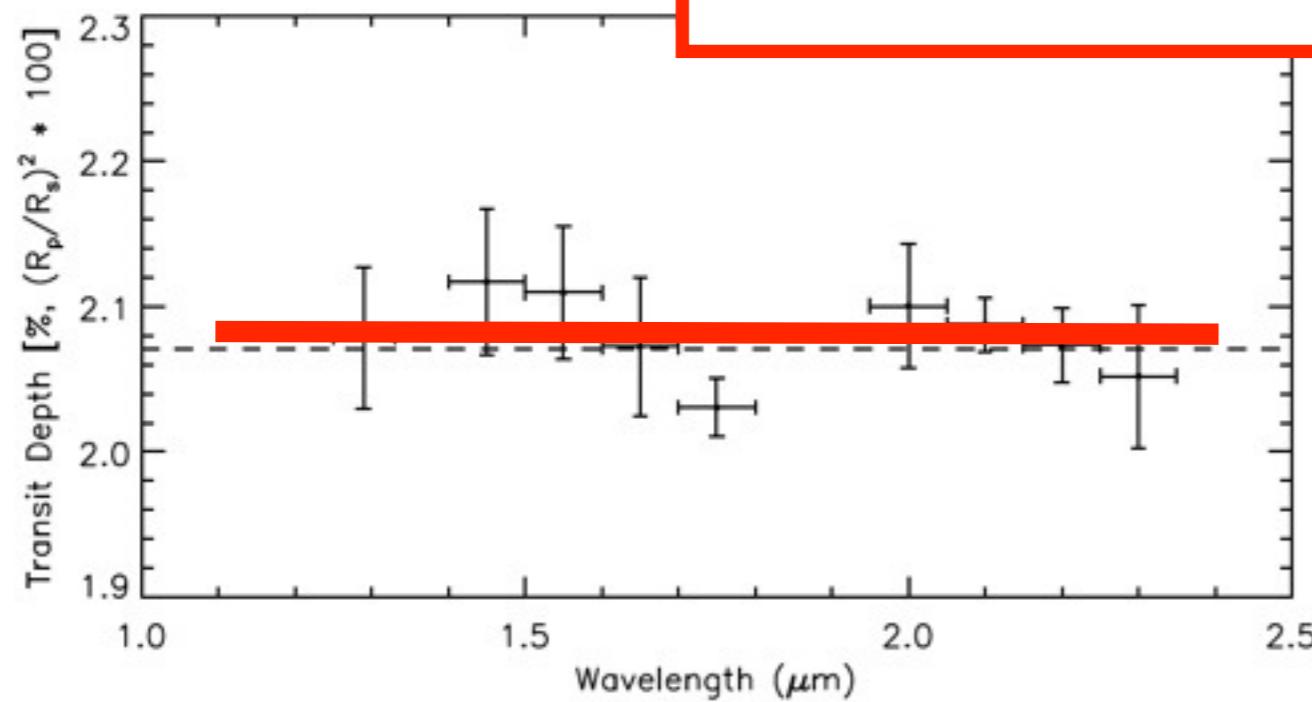
2xTransits



2xEclipses



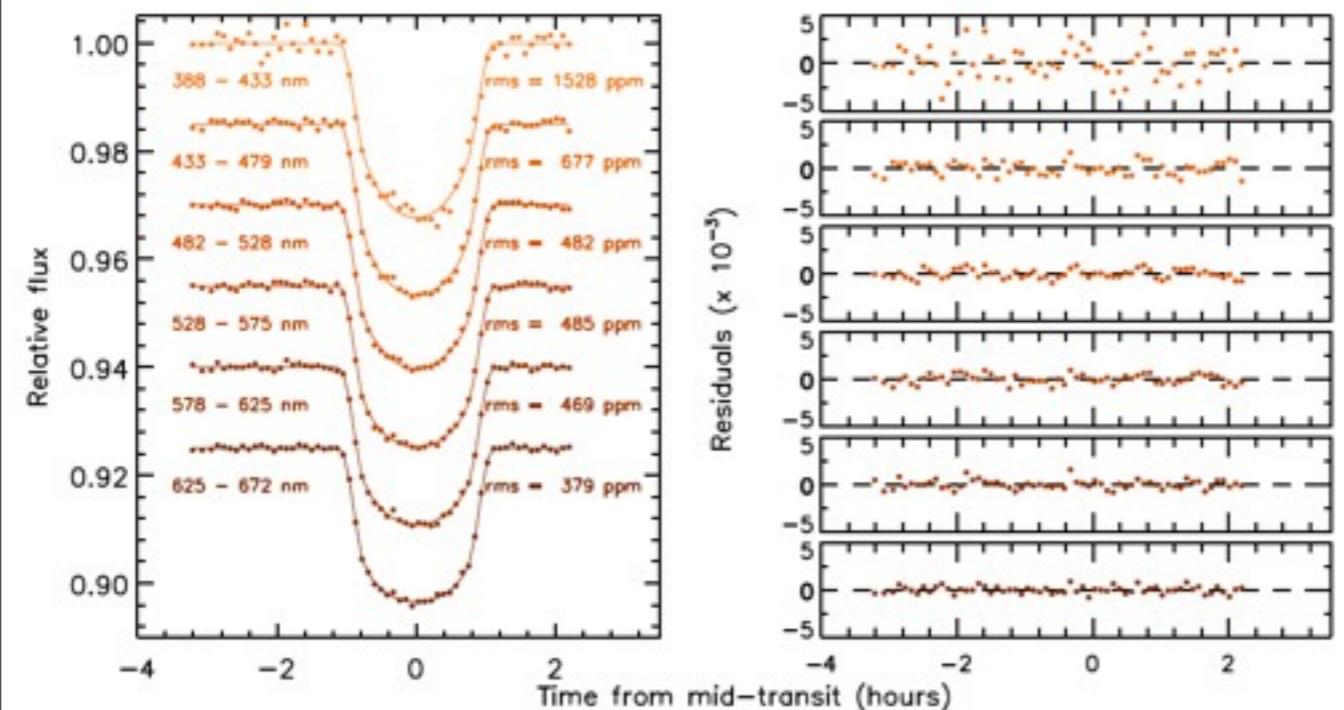
Flat again! Always Flat!



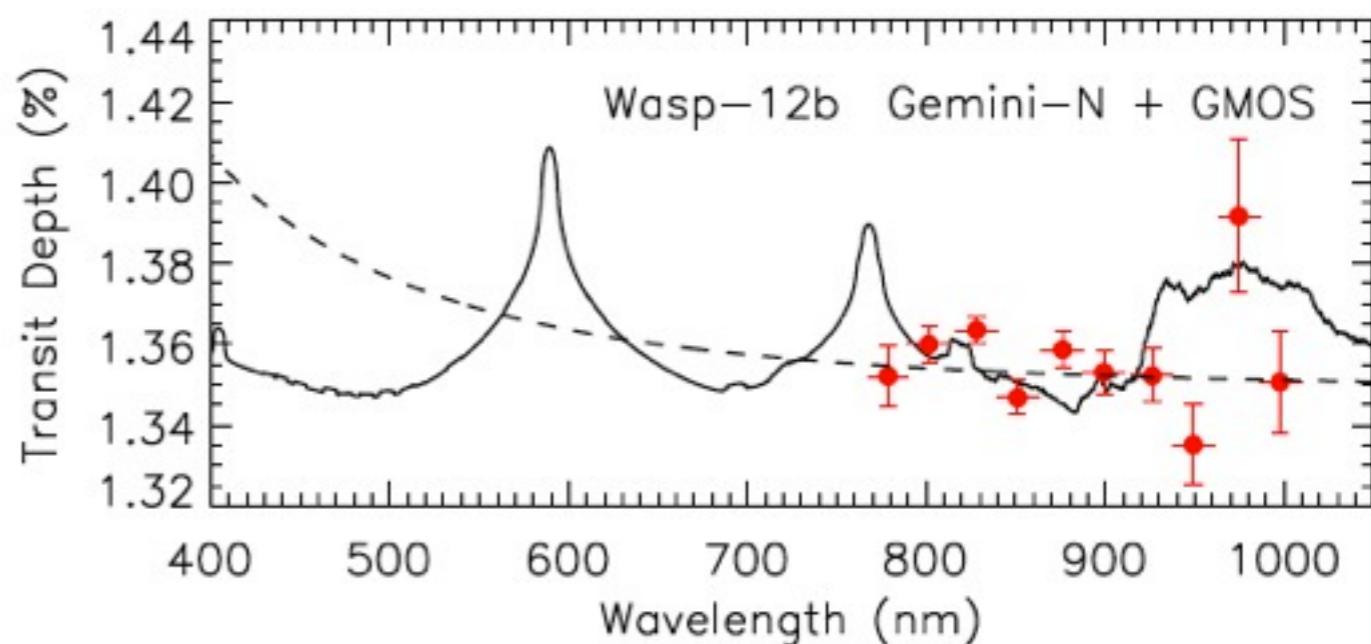
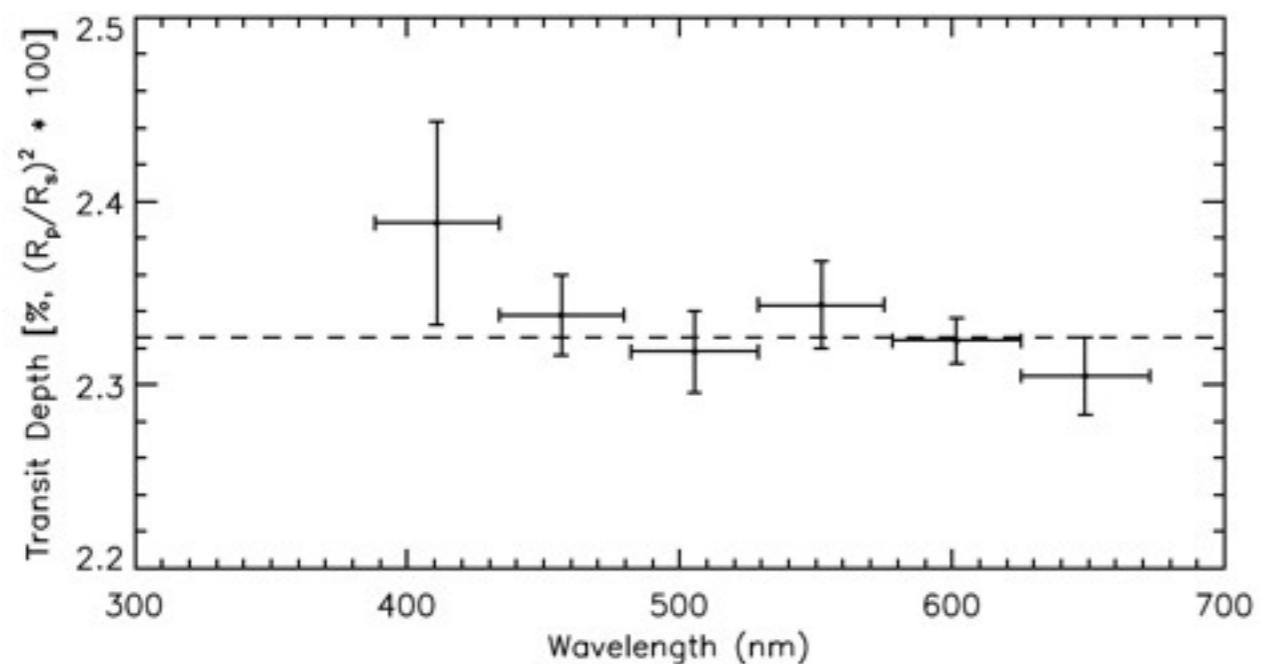
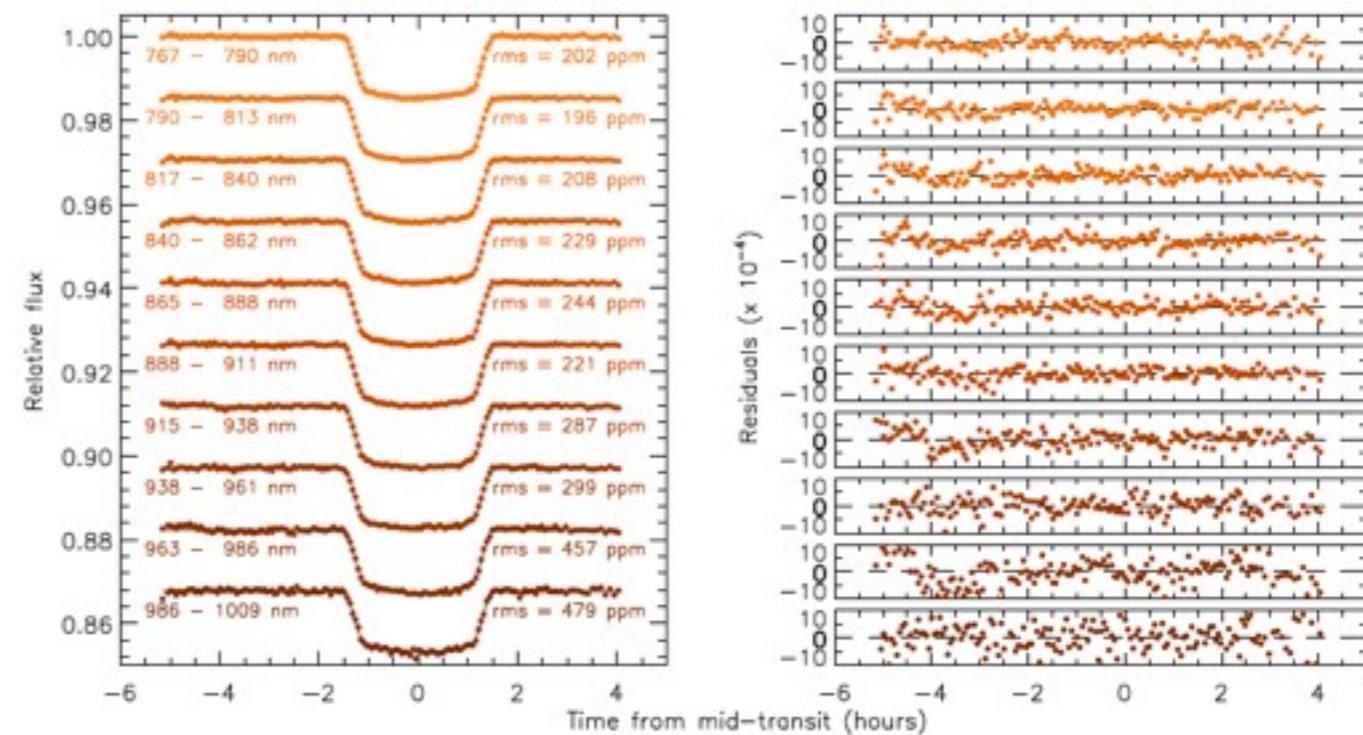
GEMINI North & South /GMOS (Optical)



WASP-4b



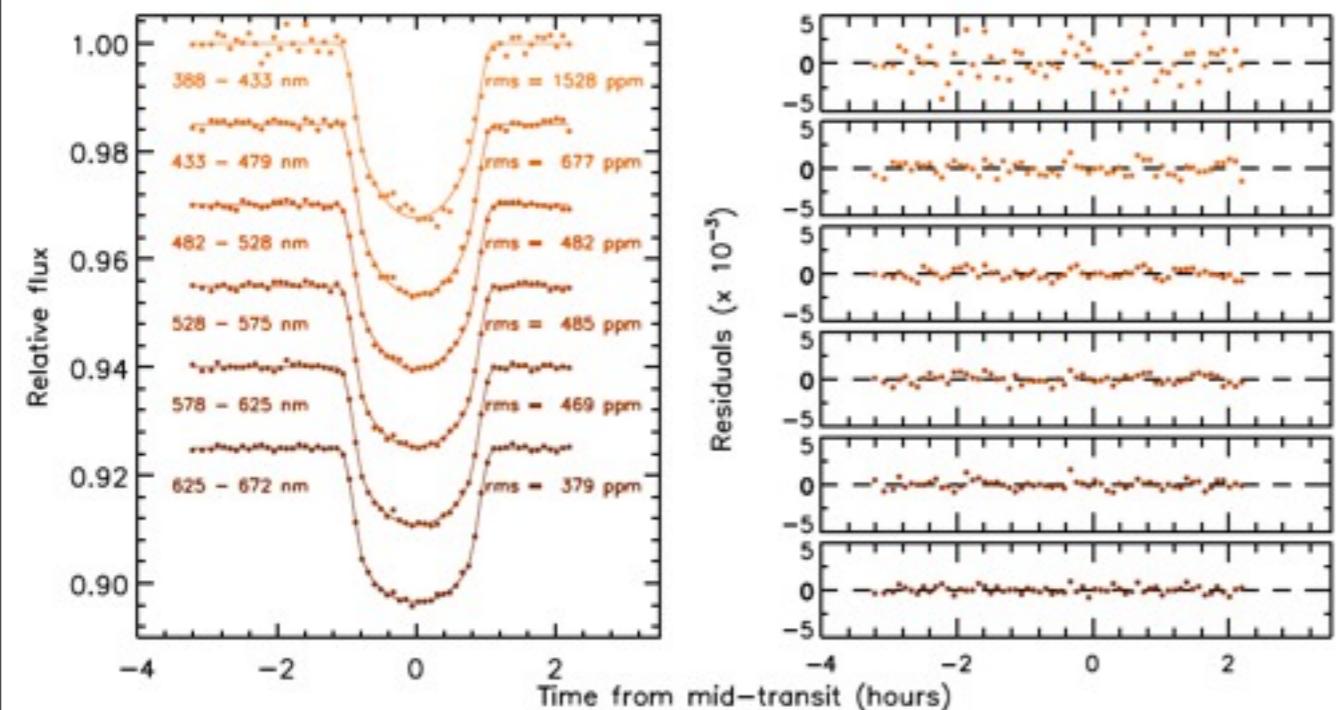
WASP-12b



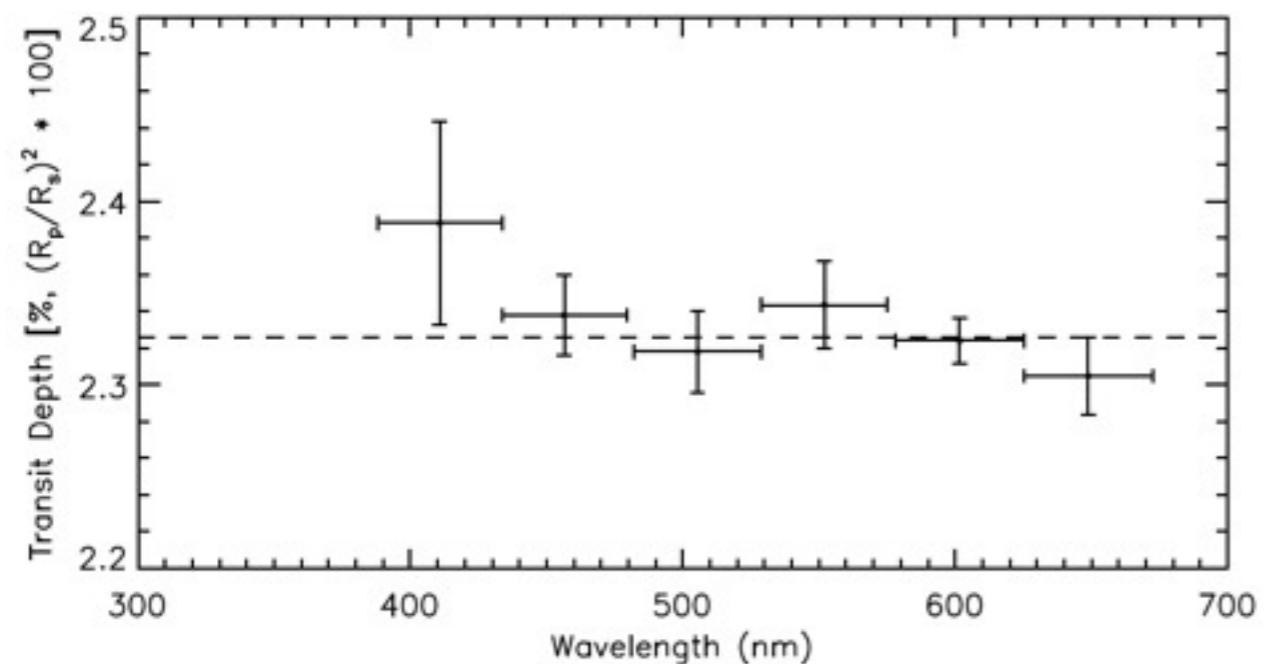
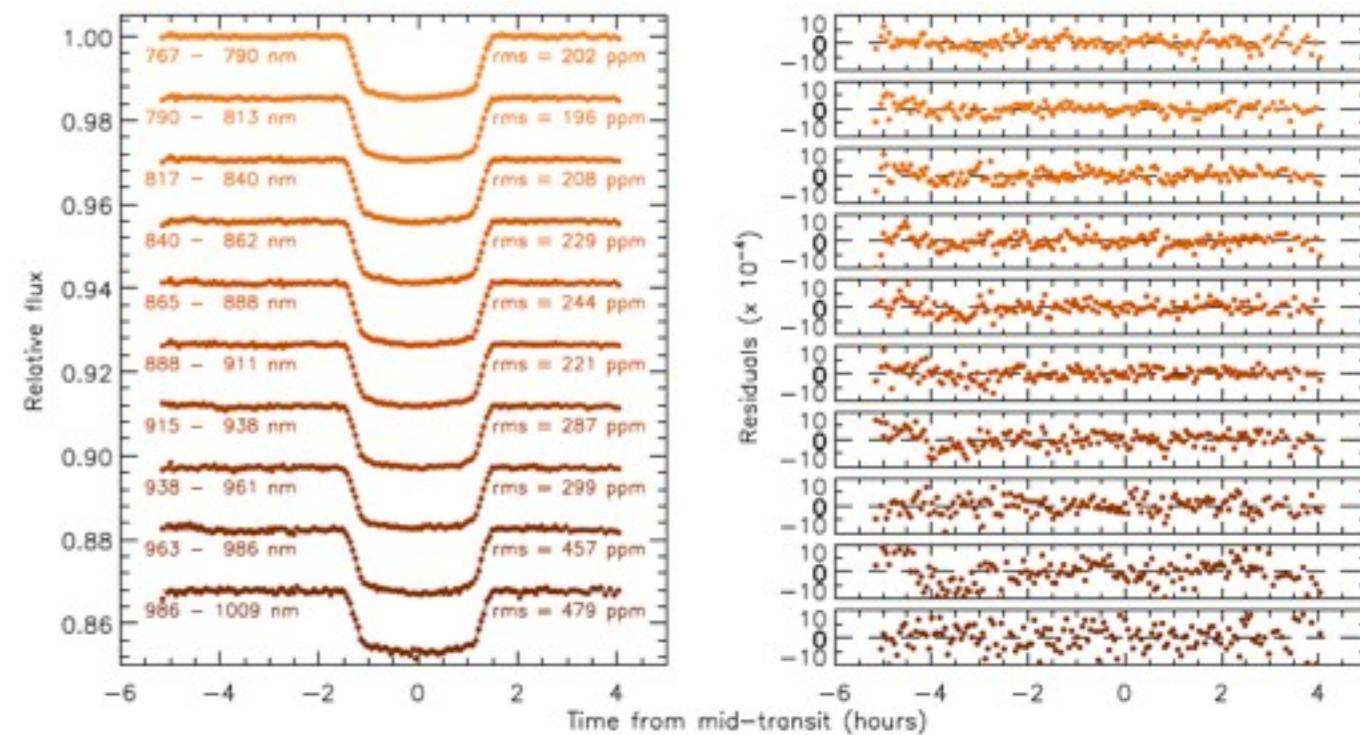
GEMINI North & South /GMOS (Optical)



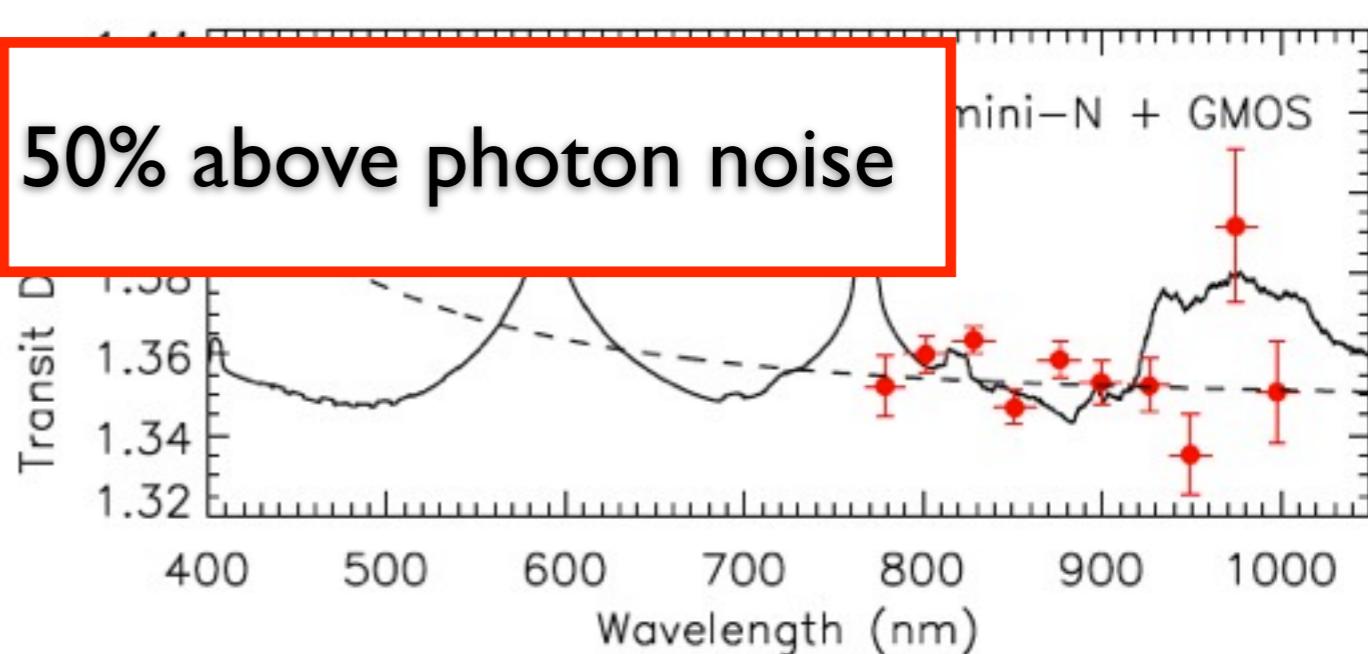
WASP-4b



WASP-12b



50% above photon noise



Ground-Based Surveys

Immediate Goals:

Comparative exoplanetology of Hot-Giants:

Surveys of a dozen objects on Magellan (NIR) and Gemini (Visible)

Ultimate Goals:

Low-Mass Planets Around Low-Mass-Stars

Main Challenges:

Understanding and Controlling Instrumental and
Astrophysical Systematics.

IV) New Astrophysical Opportunities

New Frontier For Atmospheric Studies in the Era of CoRoT/Kepler

- Hot Jupiters (Reflected light, Phase-curves, etc...)
- Combining IR+Vis. : (Désert et al. 2011c,d, Fortney et al. 2011)
- Hot Super-Earth (e.g. Batalha et al. 2010: Kepler-10b)
- Gas giants at larger orbital distances than HJs

Finding transiting planets around bright stars

- MEarth
- MOST
- KELT (KELT 2Ab :Beatty et al. 2012), TERMS,Spitzer
- e.g. MASCARA (PI Snellen)
- ExoplanetSat (S. Seager)
- TESS / PLATO

Finding transiting planets around bright stars

- MEarth

Unlikely to apply the MOS technique!

- e.g. MASCARA (PI Snellen)
- ExoplanetSat (S. Seager)
- TESS / PLATO

Transit Exoplanetology in the Next Decade

CoRoT/Kepler
Spitzer
HST

TESS/PLATO
FINESSE/ECHO

JWST

2012

2016?

2020

Ground-based
with MOS:

Gemini, Magellan,
Keck, VLT, LBT

GMT/TMT

The End