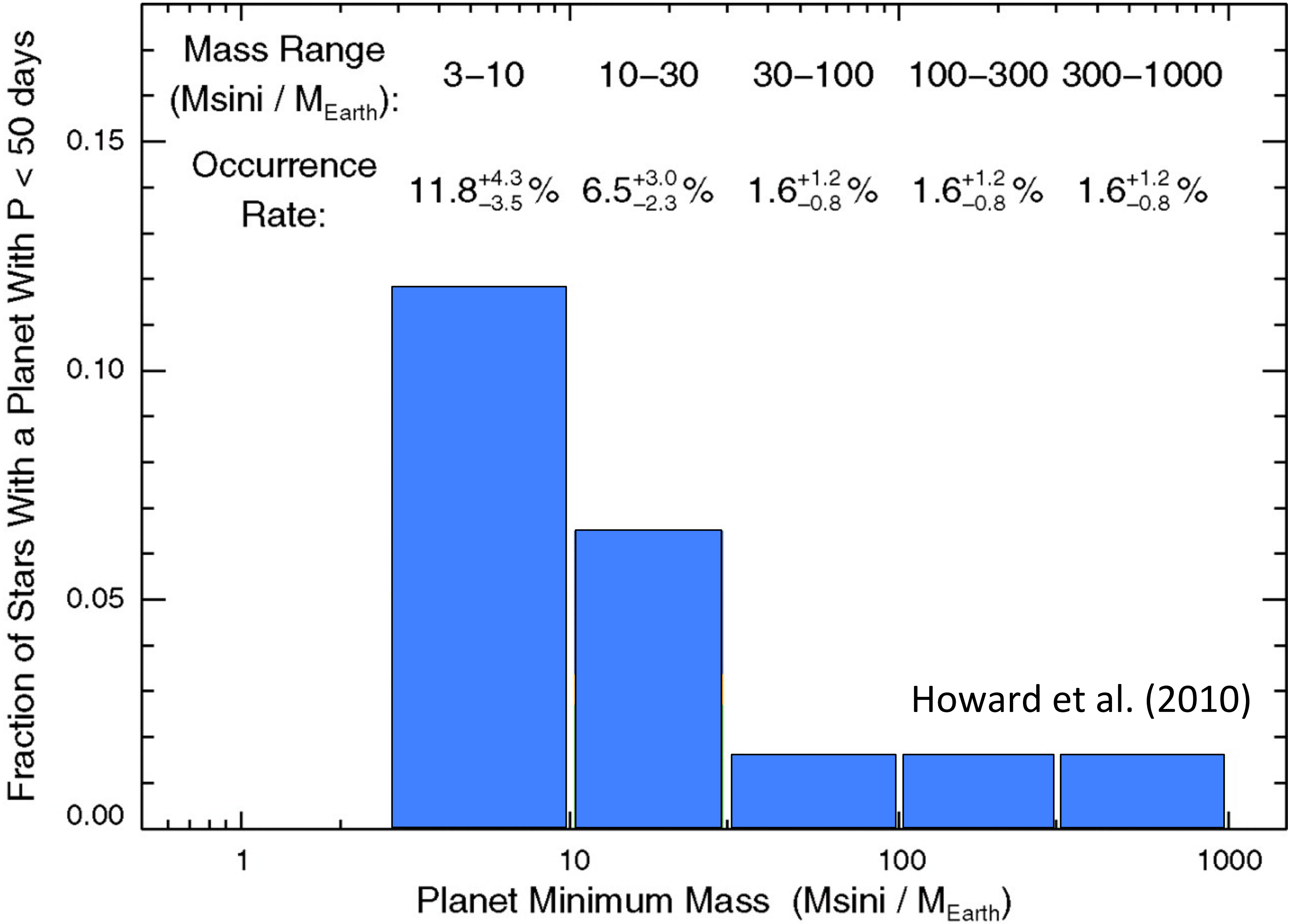
Beyond Hot Jupiters: Spitzer Observations of the Smallest Transiting Planets

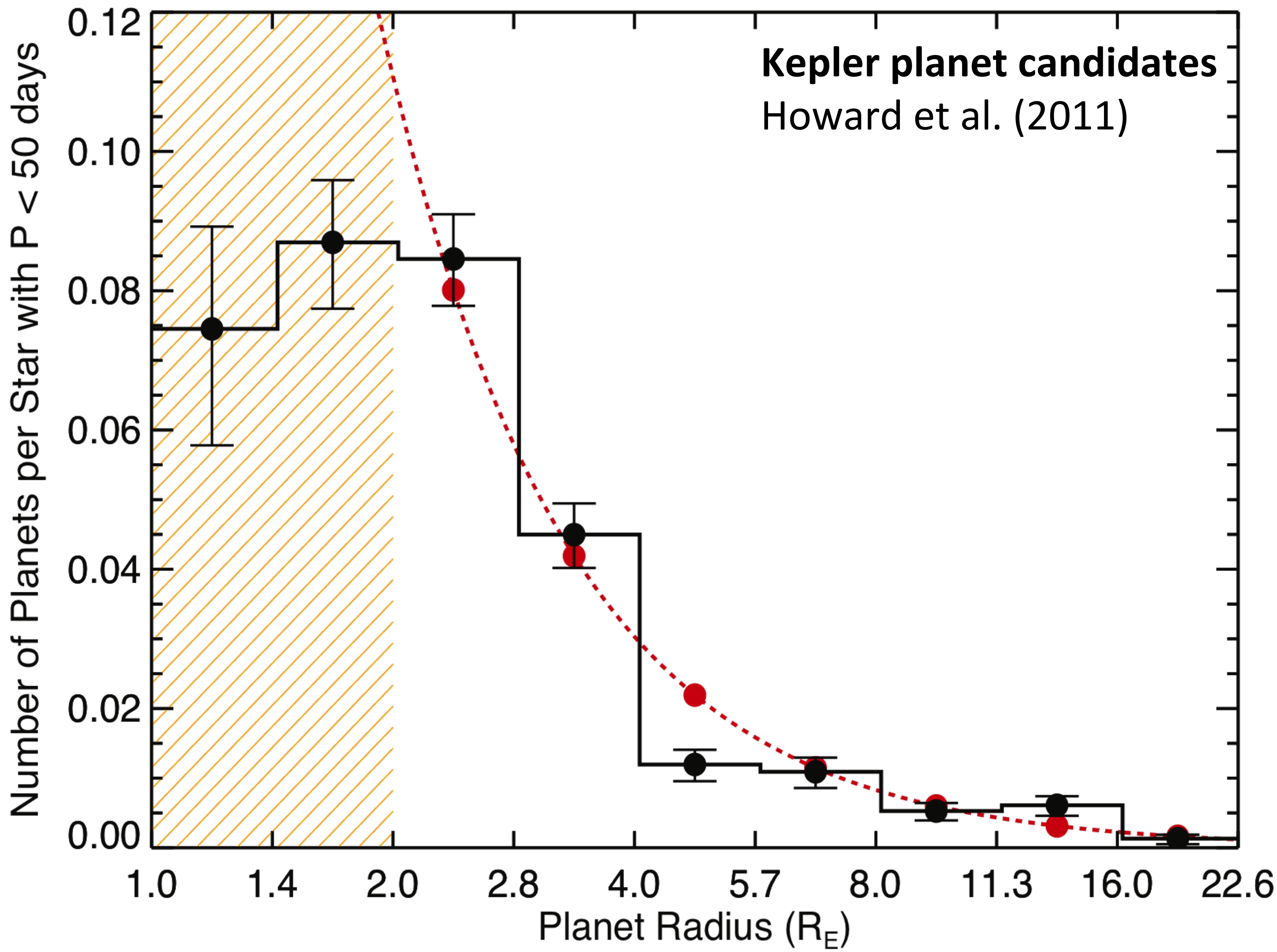
Heather Knutson, UC Berkeley

Image Credit: ESO/L. Calçada

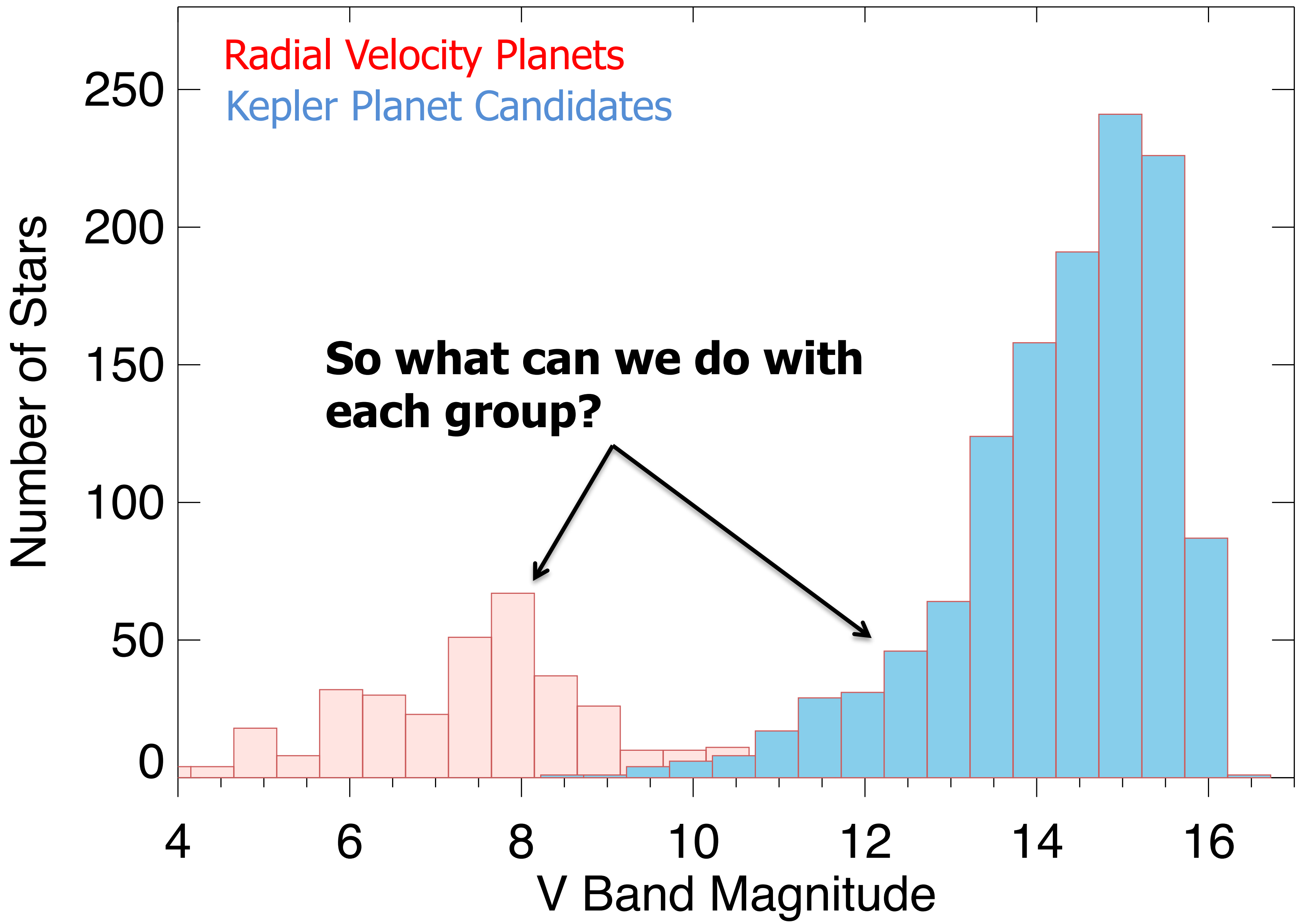
Good News: Radial Velocity Surveys Indicate Small Planets are Common



Kepler Planet Candidates Follow the Same Trend



Bad News: Most RV planets aren't transiting, and most Kepler planets are too faint for detailed study.

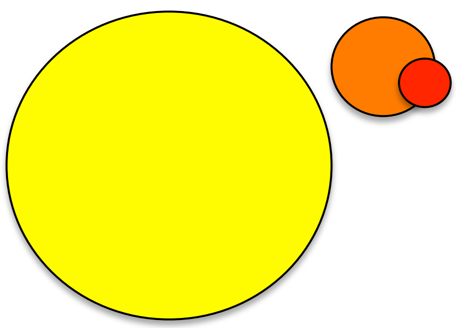


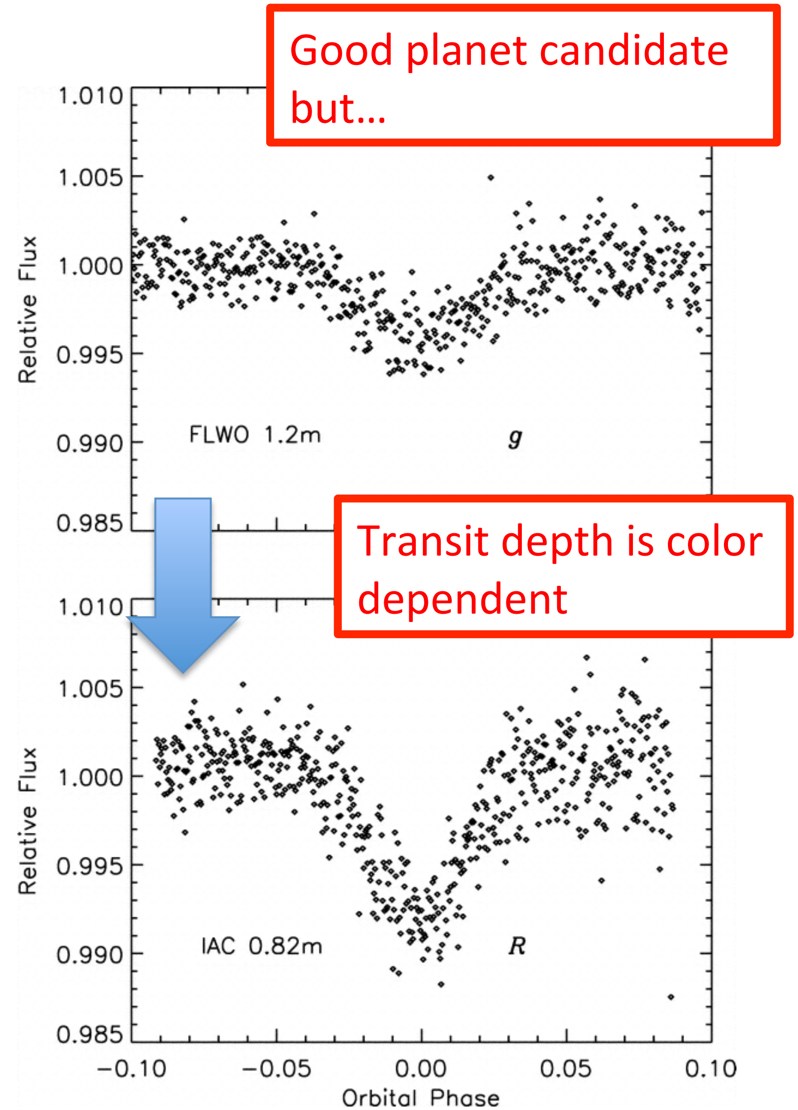
Project #1: Kepler Planet Candidate Verification

800-hour program (PI Charbonneau), work led by Jean-Michel Desert & Francois Fressin

- Change in Spitzer transit depth wrt Kepler measurement would indicate an astrophysical false positive

- Valuable for physically-associated triples for which Kepler will not detect shift of photocentroid

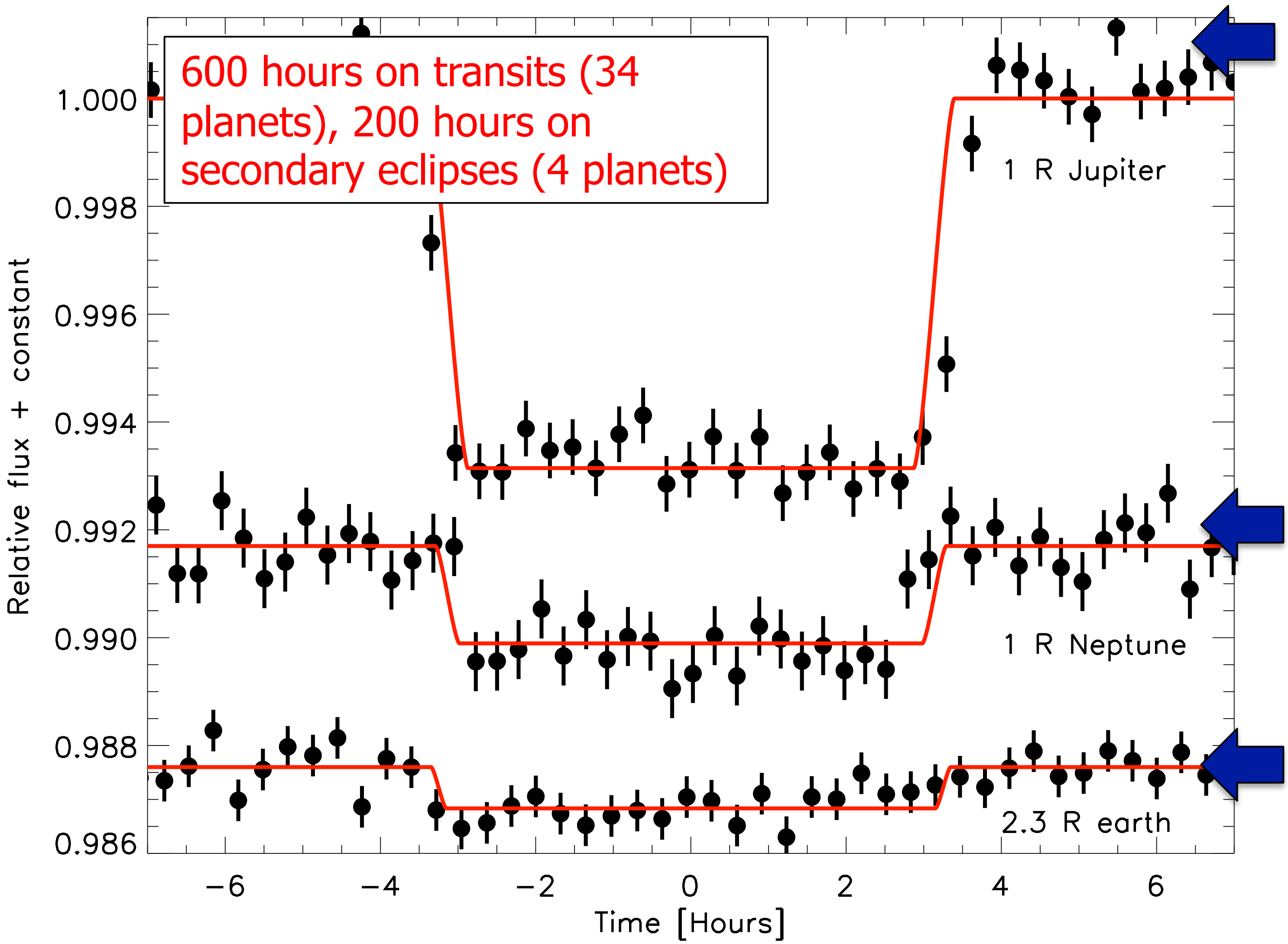




O'Donovan, Charbonneau, et al. 2006

Warm Spitzer Verification of Kepler Planet Candidates

800-hour program (PI Charbonneau), work led by Jean-Michel Desert & Francois Fressin

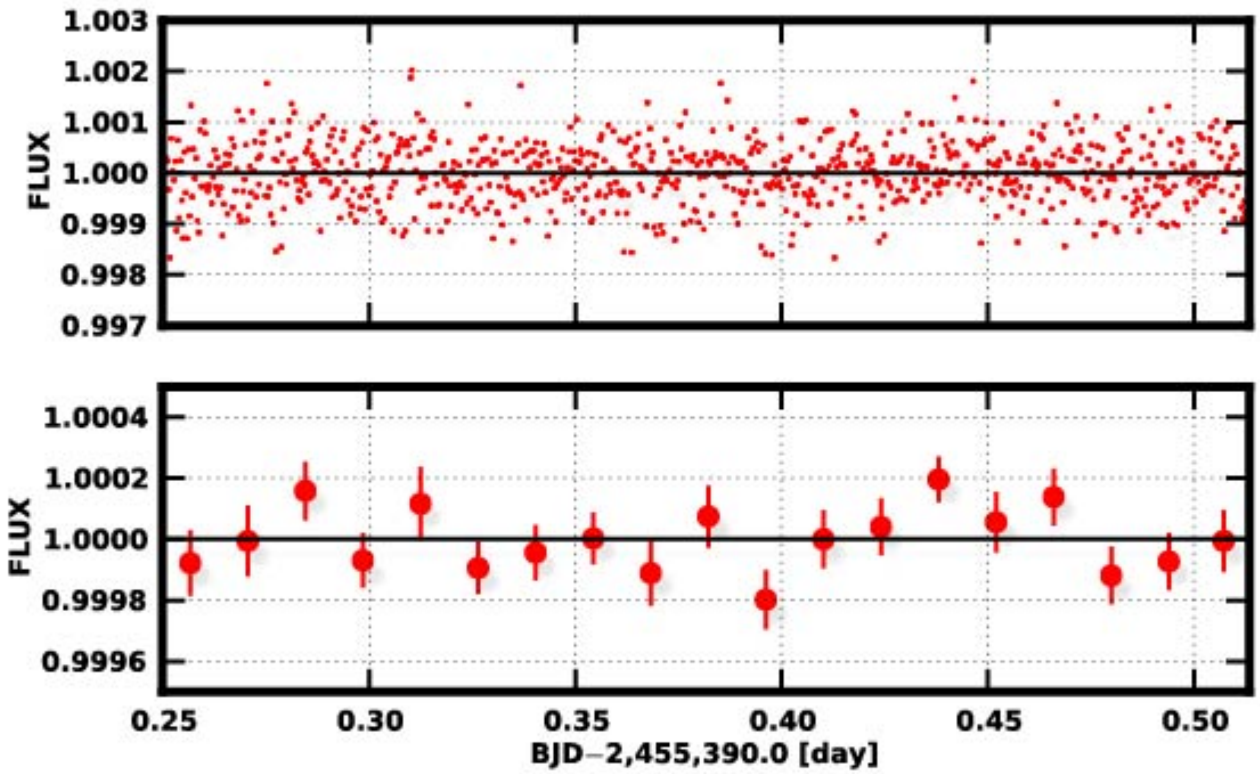


Jupiter-sized planet in an 18-day orbit around a rapidly rotating F star

Neptune-sized planet in 7-day orbit, Kepler centroids corrupted

Super-earth in an 80-day orbit around a low-mass star

Project #2: Search for Transits of Low-Mass RV Planets Orbiting Bright Stars



100 hours with warm Spitzer, PI Gillon

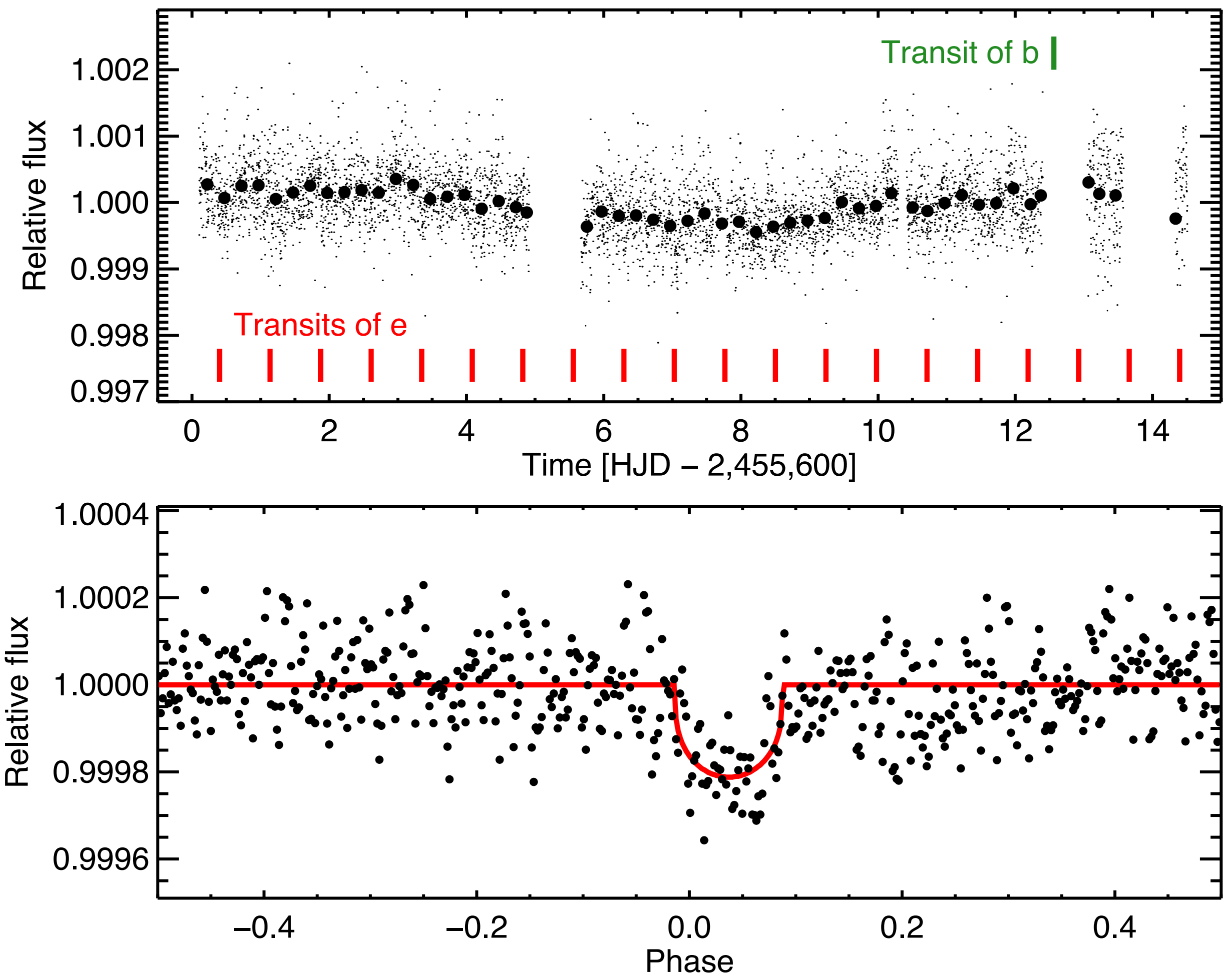
Need continuous, high-precision space-based monitoring for transit search.

GJ 3634b: 8 Mearth planet in a 2.6 day orbit around a M2.5 dwarf, 6.0 K mag

Bonfils et al. (2011)

7% a priori transit probability, Spitzer observations reduce this to 0.9% (1σ)

55 Cancri e:
A Super-Earth Transiting a Naked-Eye Star



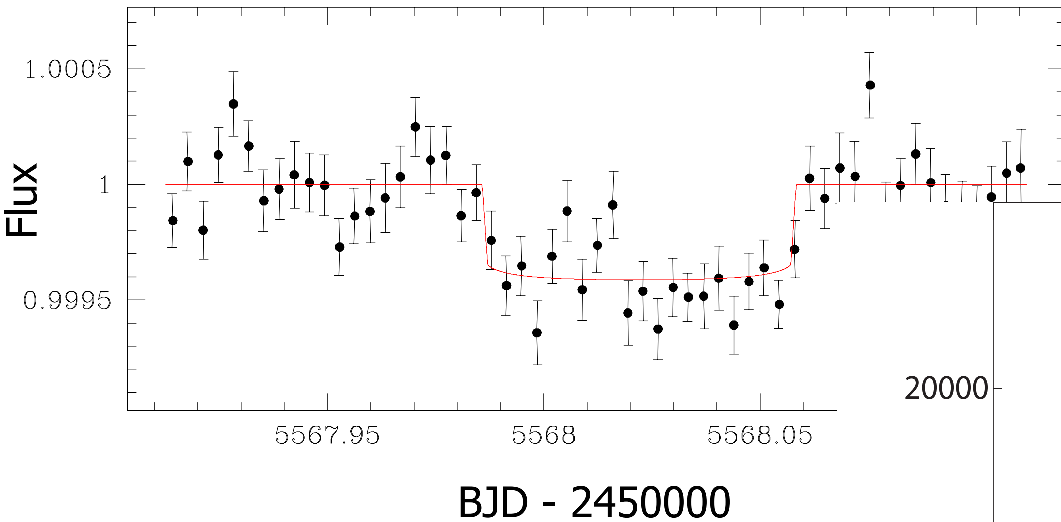
Sun-like star, V mag of 6.0, five known planets

Winn et al. (2011): Two weeks of monitoring in visible light with MOST

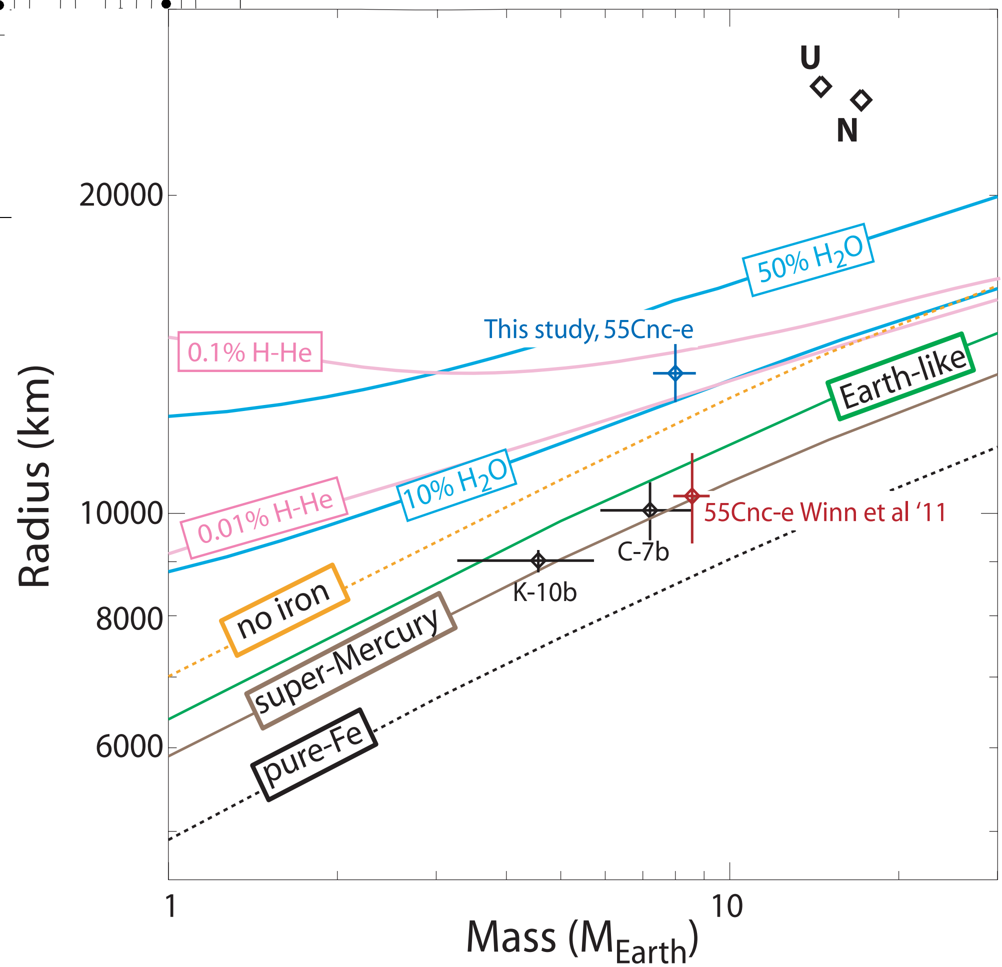
0.02% transit with 0.74-day period, corresponding to 1.6 R_{earth}

Density consistent with rock/iron composition.

Spitzer Confirmation of 55 Cancri e Transit

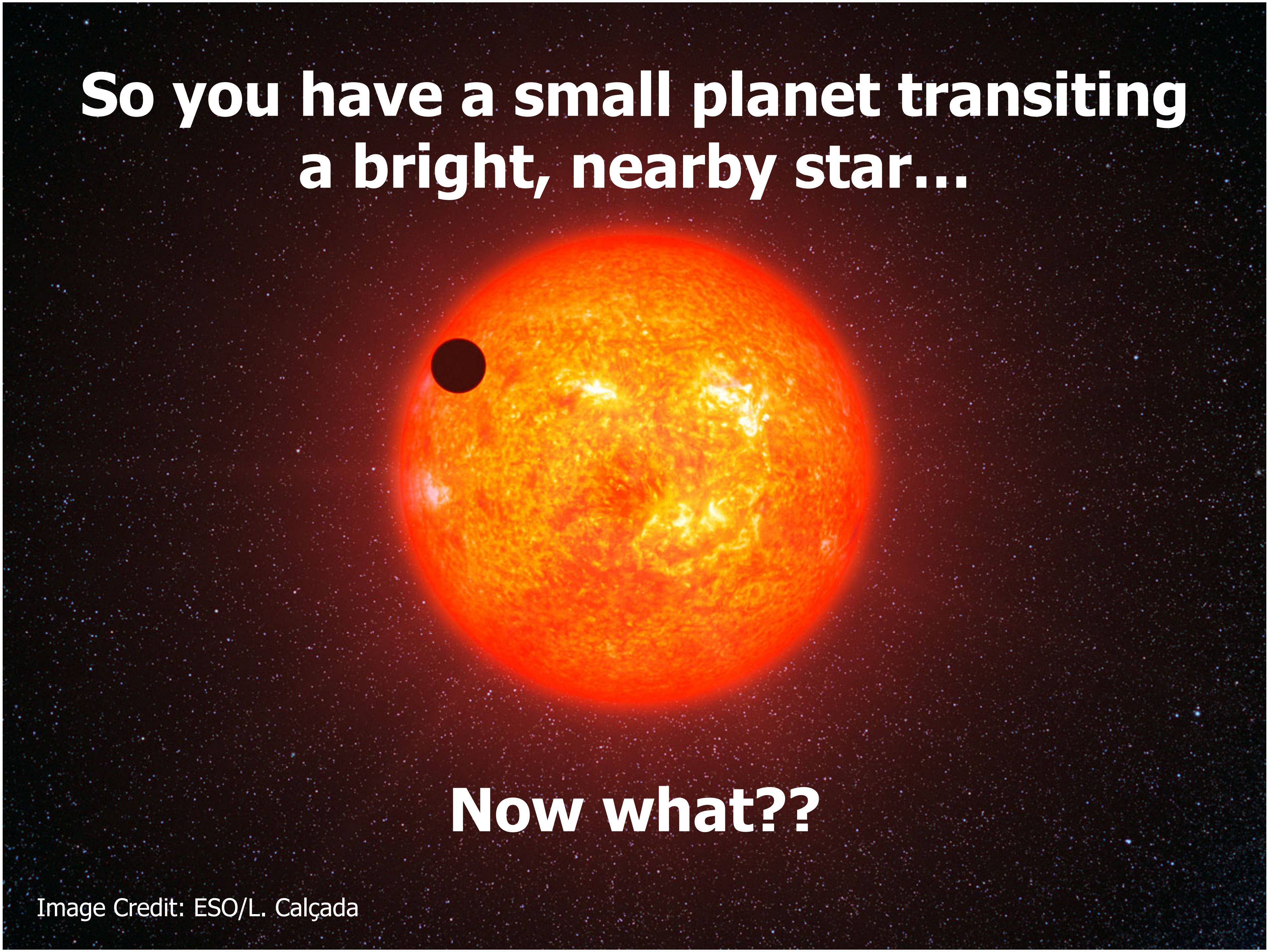


New result by Demory et al. (2011, astro-ph/1105.0415)

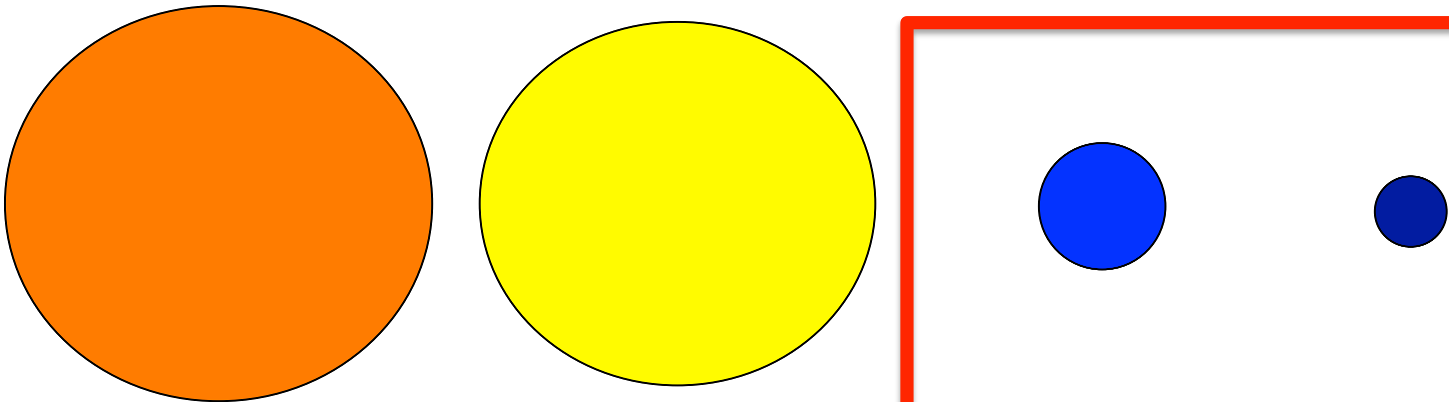


Problem: MOST and Spitzer radius estimates disagree (1.6 vs. 2.3 R_{earth})**.**

Can also do a blind search for additional transits in systems with one known transiting planet (e.g., GJ 436 and GJ 1214).


So you have a small planet transiting
a bright, nearby star…
Now what??
Image Credit: ESO/L. Calçada

Project #3: Atmosphere Studies for Small, Cool Planets



Planets drawn to scale.

HD 209458b
Mass: 0.66 M_{Jup}
Radius: 1.32 R_{Jup}
T_{eqil}=1360 K

HD 189733b
Mass: 1.15 M_{Jup}
Radius: 1.15 R_{Jup}
T_{equil}=1130 K

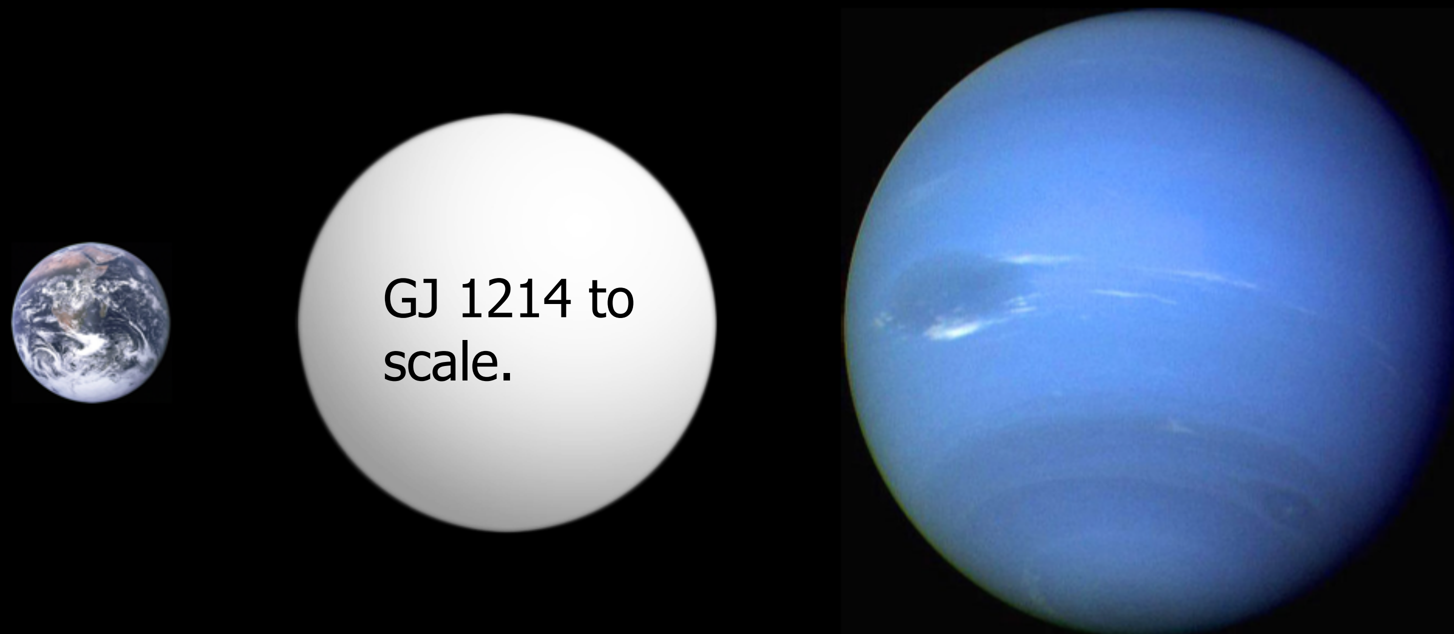
GJ 436b
Mass: 0.07 M_{Jup}
Radius: 0.44 R_{Jup}
T_{equil}=700 K

GJ 1214b
Mass: 0.02 M_{Jup}
Radius: 0.24 R_{Jup}
T_{equil}=560 K

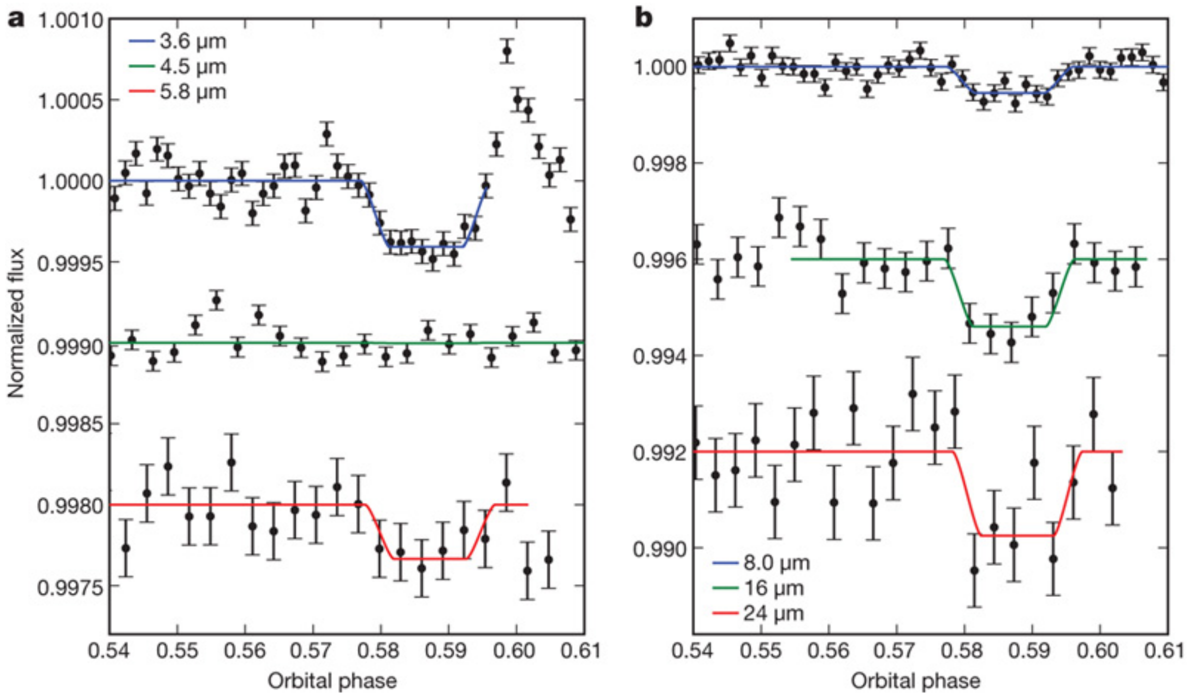
Smaller radius and lower effective temperature both reduce size of signal for transmission spectroscopy and secondary eclipse observations.

Ideal targets are small planets transiting bright, nearby M dwarfs

GJ 1214b & GJ 436b: A Distinctly Different Breed of (Exo)Planets

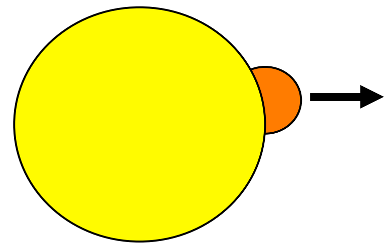


- Metal-rich (large solid rock/ice cores), hydrogen atmospheres(?)
- Methane dominates over CO in equilibrium chemistry.
- Cool enough for clouds? 500-800 K temperatures.
- M dwarfs have high UV fluxes, is photochemistry important?



A Dayside Emission Spectrum for GJ 436b

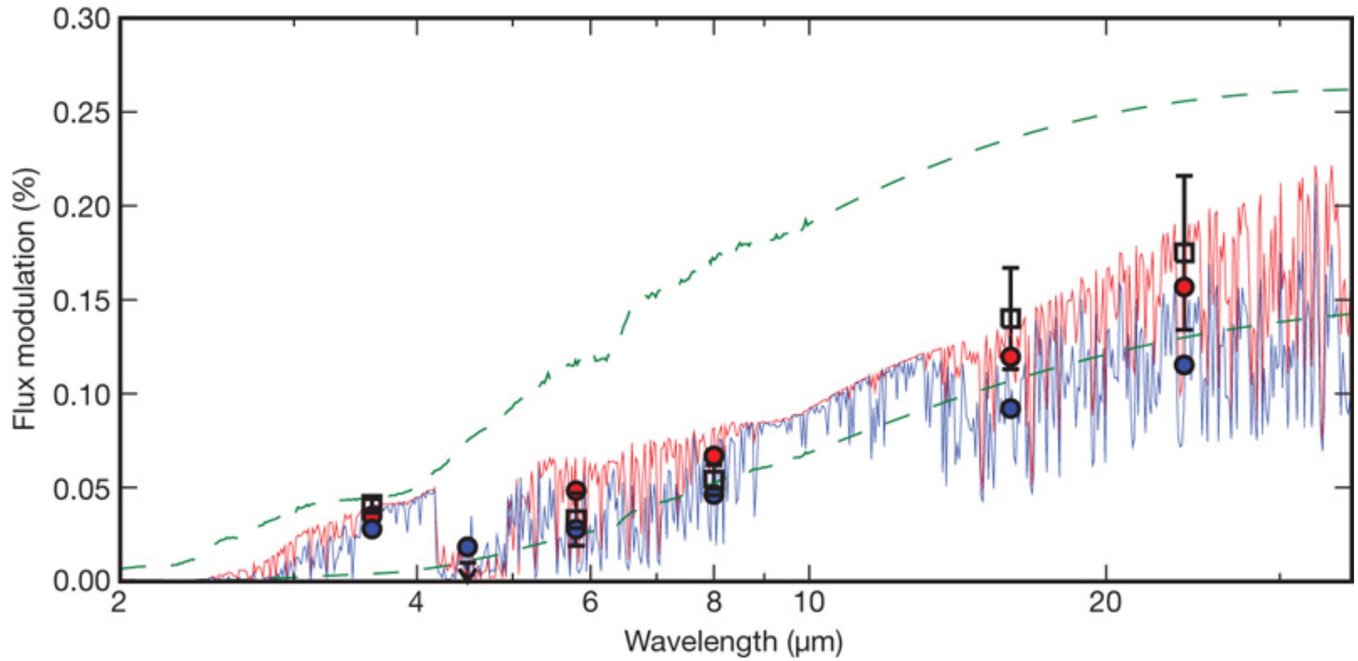
Stevenson et al. (2010)



CH$_4$ / CO Ratio:

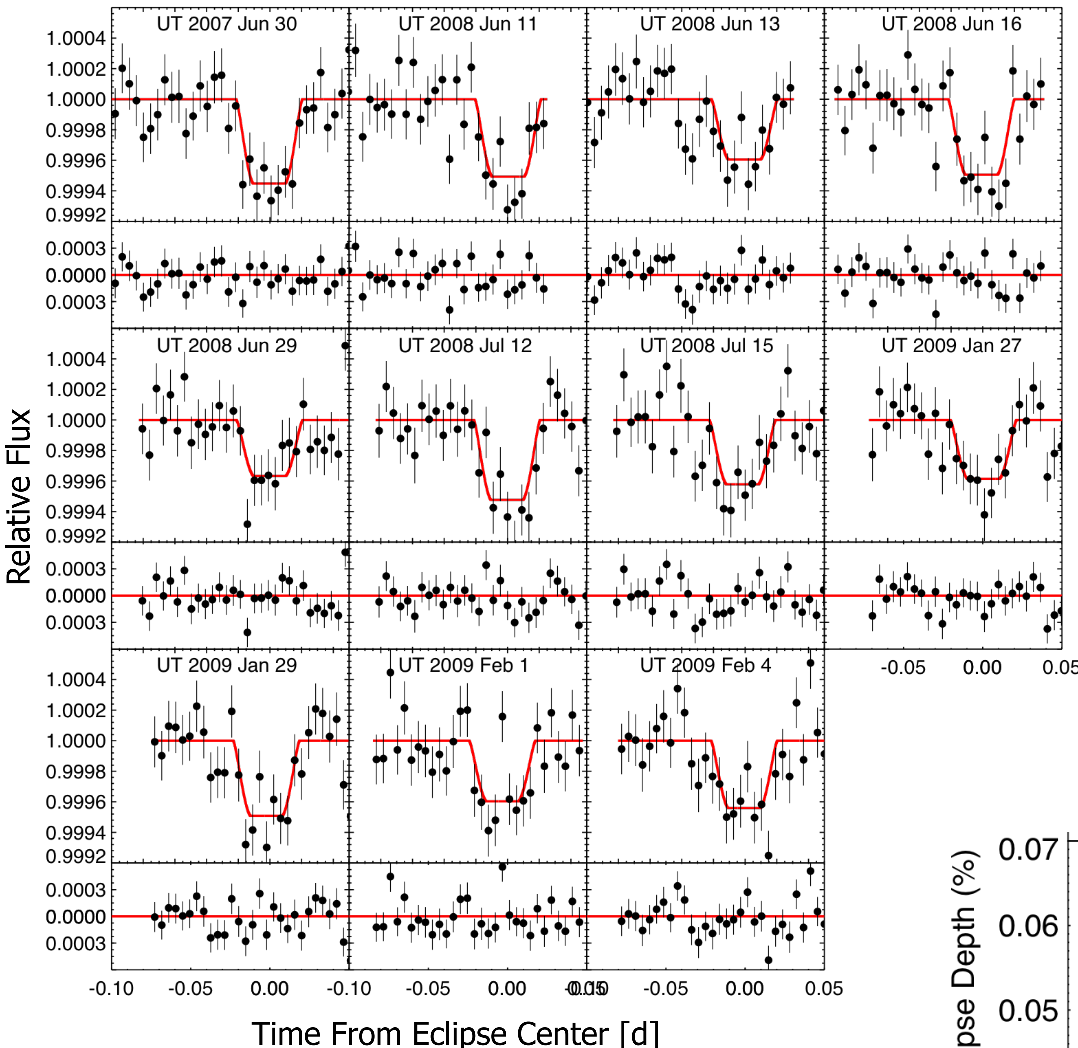
Predicted: 100

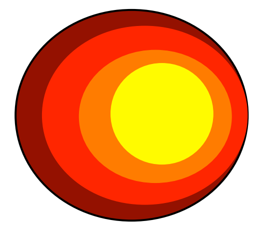
Measured: <0.001

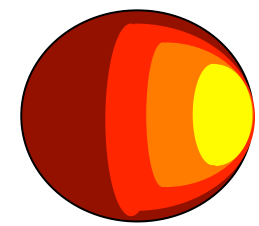


Constraints on Atmospheric Variability for GJ 436b

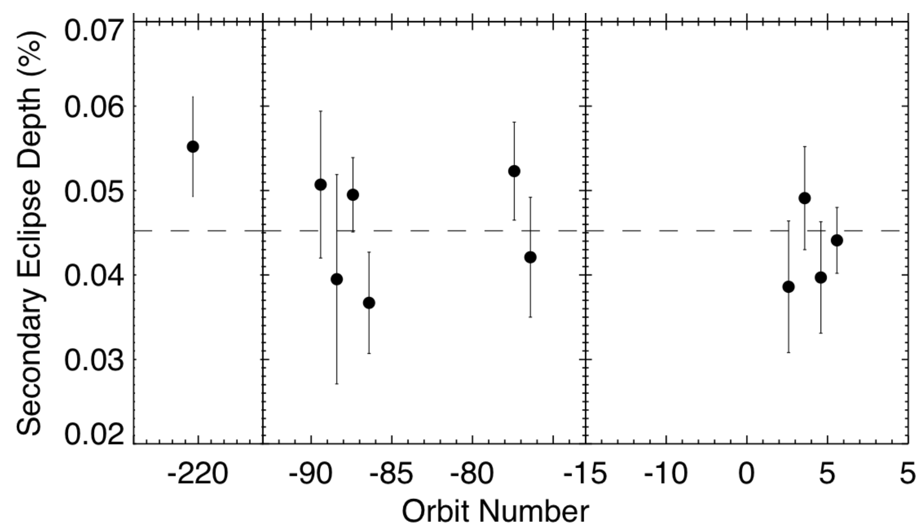
Knutson et al. (2011)





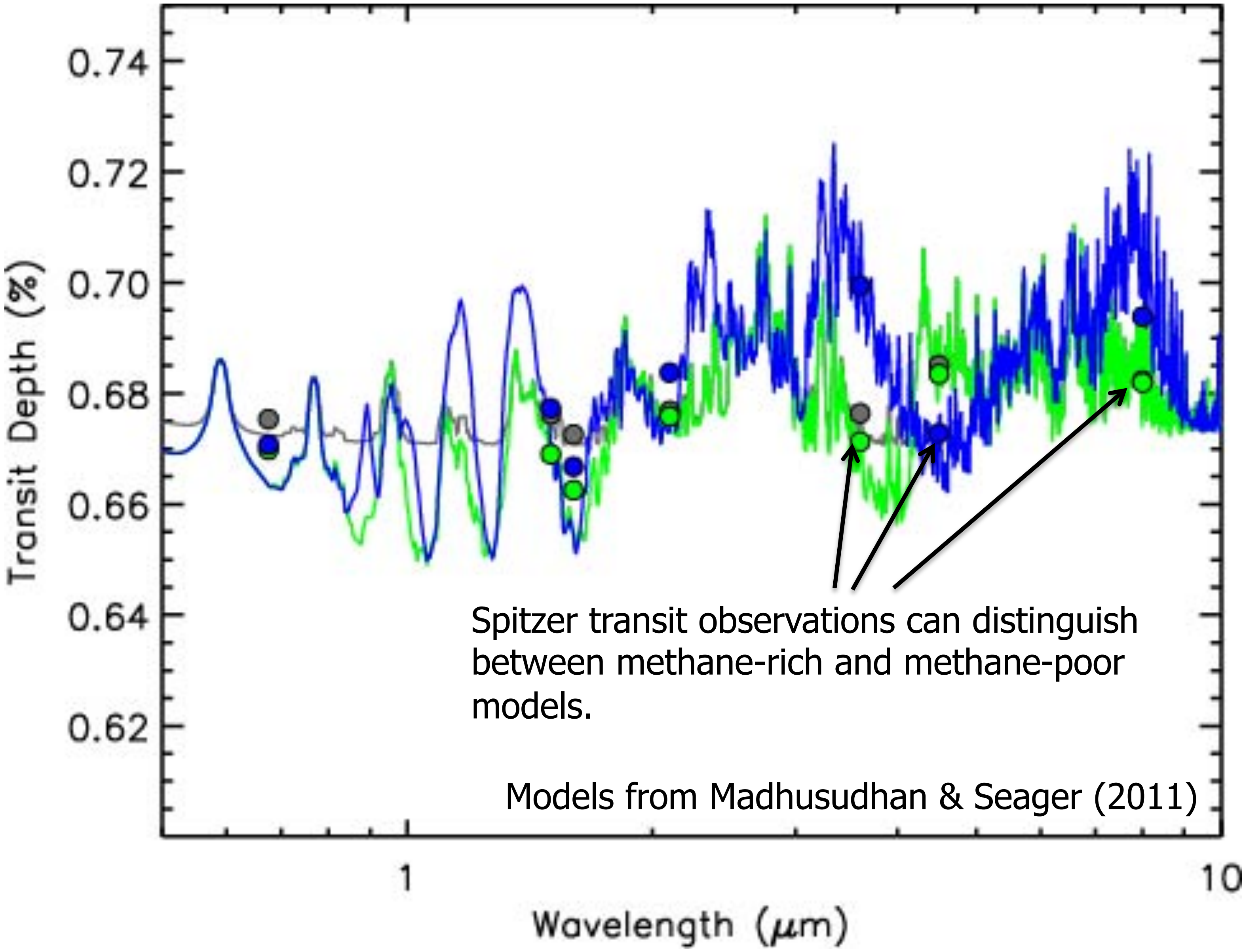


Shifting weather patterns could cause variability in dayside flux.

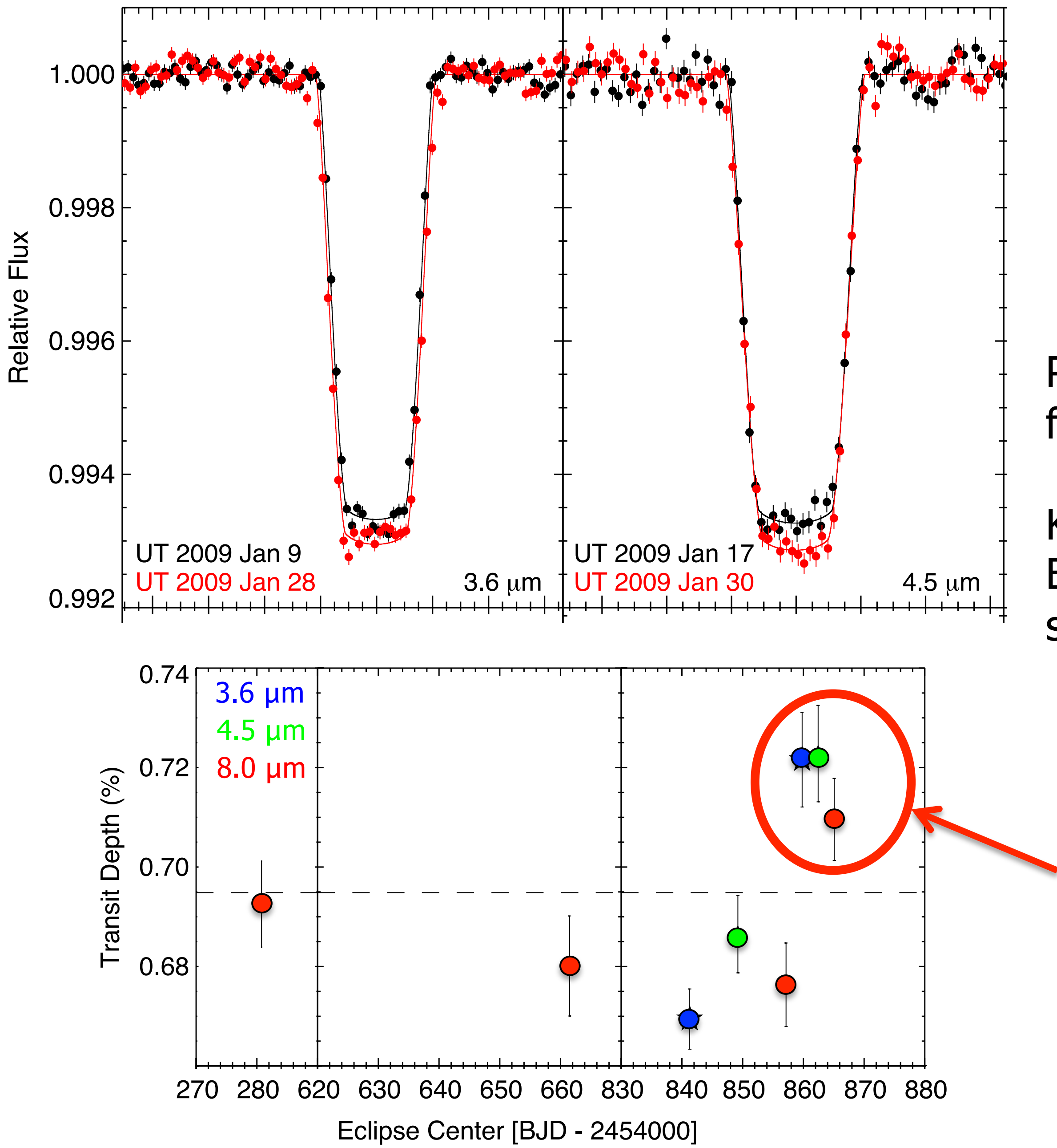


Dayside flux varies by <17% (1σ), consistent with predictions from Lewis et al. (2010).

Transmission Spectroscopy of GJ 436b



Eight Spitzer Transit Observations of GJ 436b

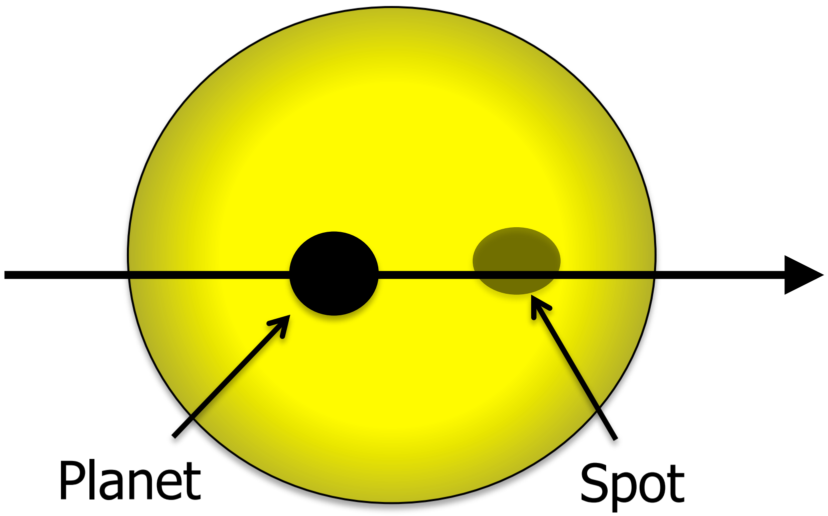


Problem: Transit depths vary from one epoch to the next!

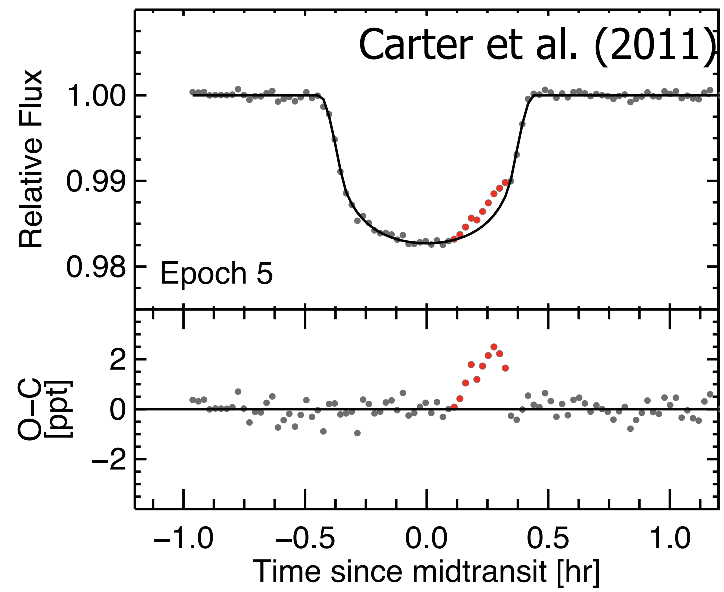
Knutson et al. (2011), Beaulieu et al. (2011) find the same result

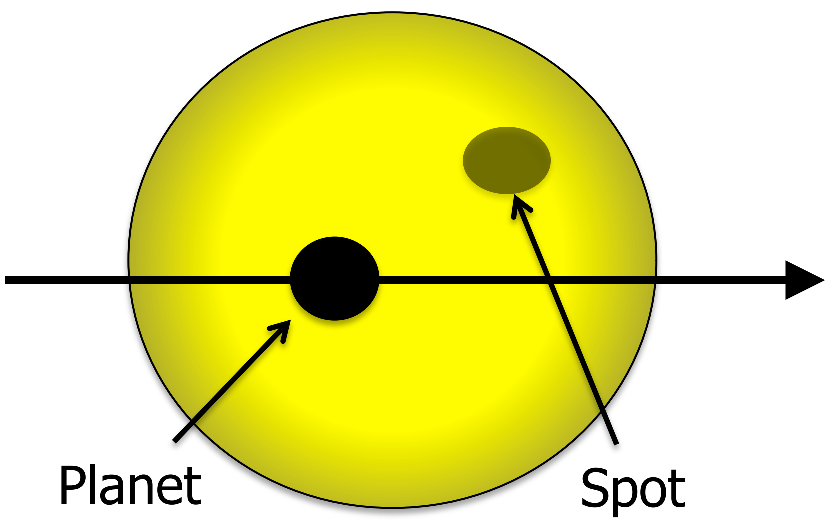
Abrupt transition from shallower to deeper transits… perhaps **indicative of increased stellar activity**?

Stellar Activity is Bad for Transits

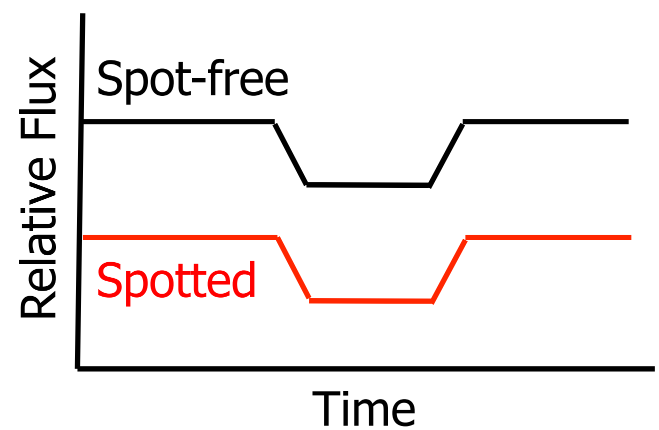


Scenario 1: Occulted Spot



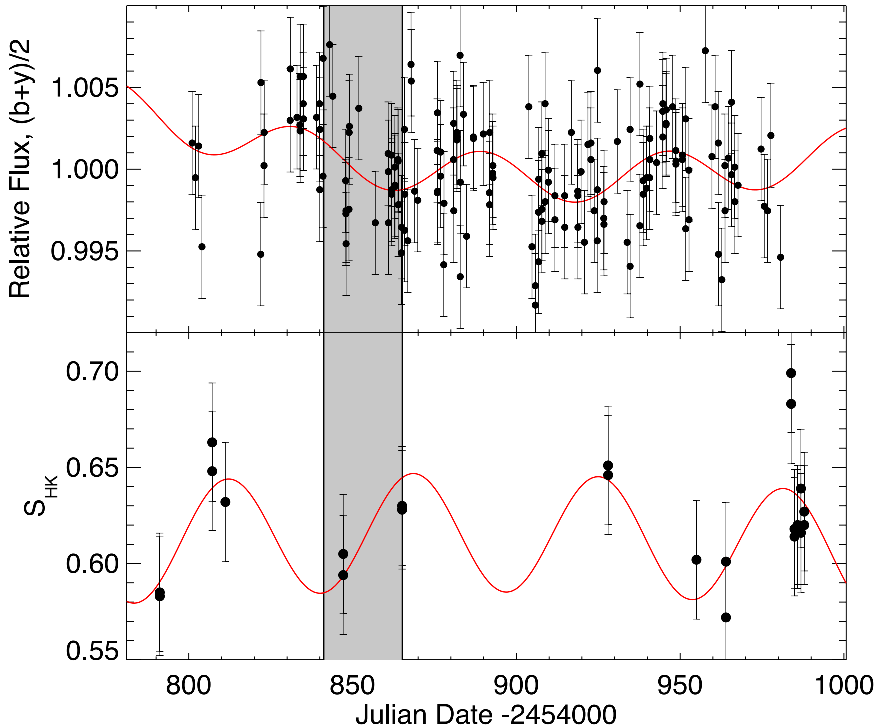


Scenario 2: Non-Occulted Spot



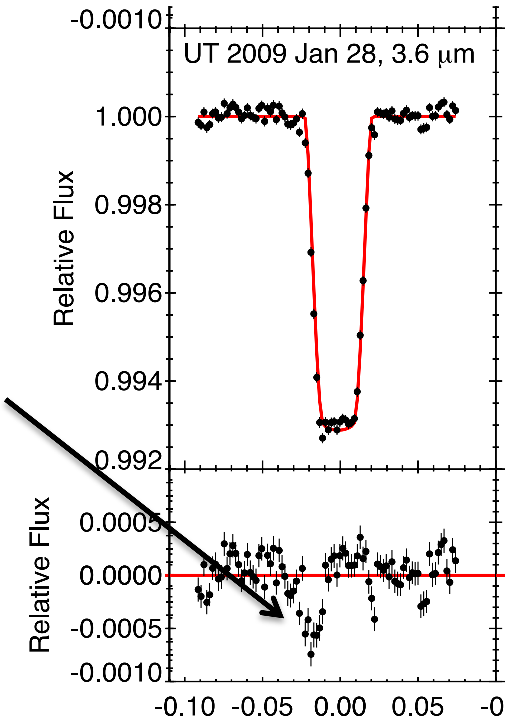
Evidence for Stellar Activity

Knutson et al. (2011)



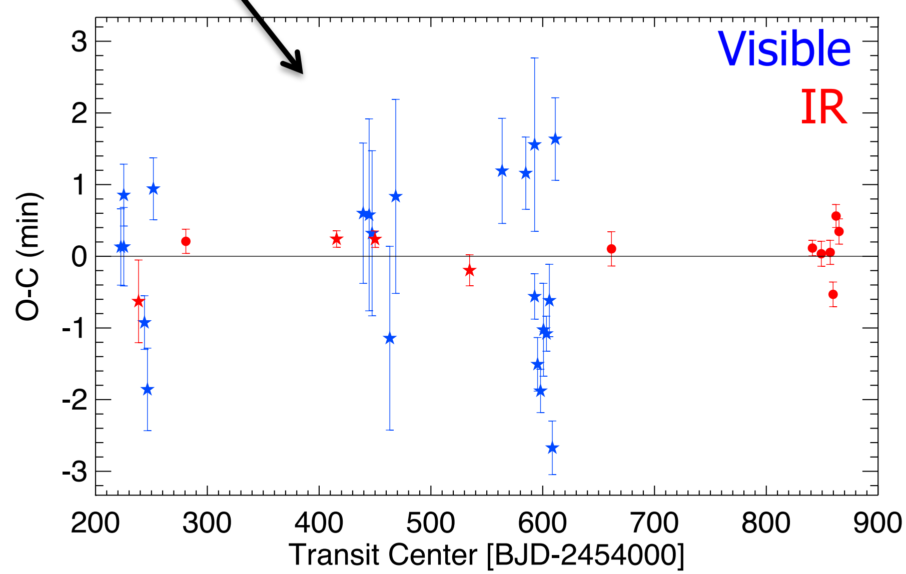
40-50 day rotation period w/small amplitude, consistent with relatively old/quiet early M spectral type

Conclusion: transit depth variations probably due to occulted spots, star likely viewed near pole-on

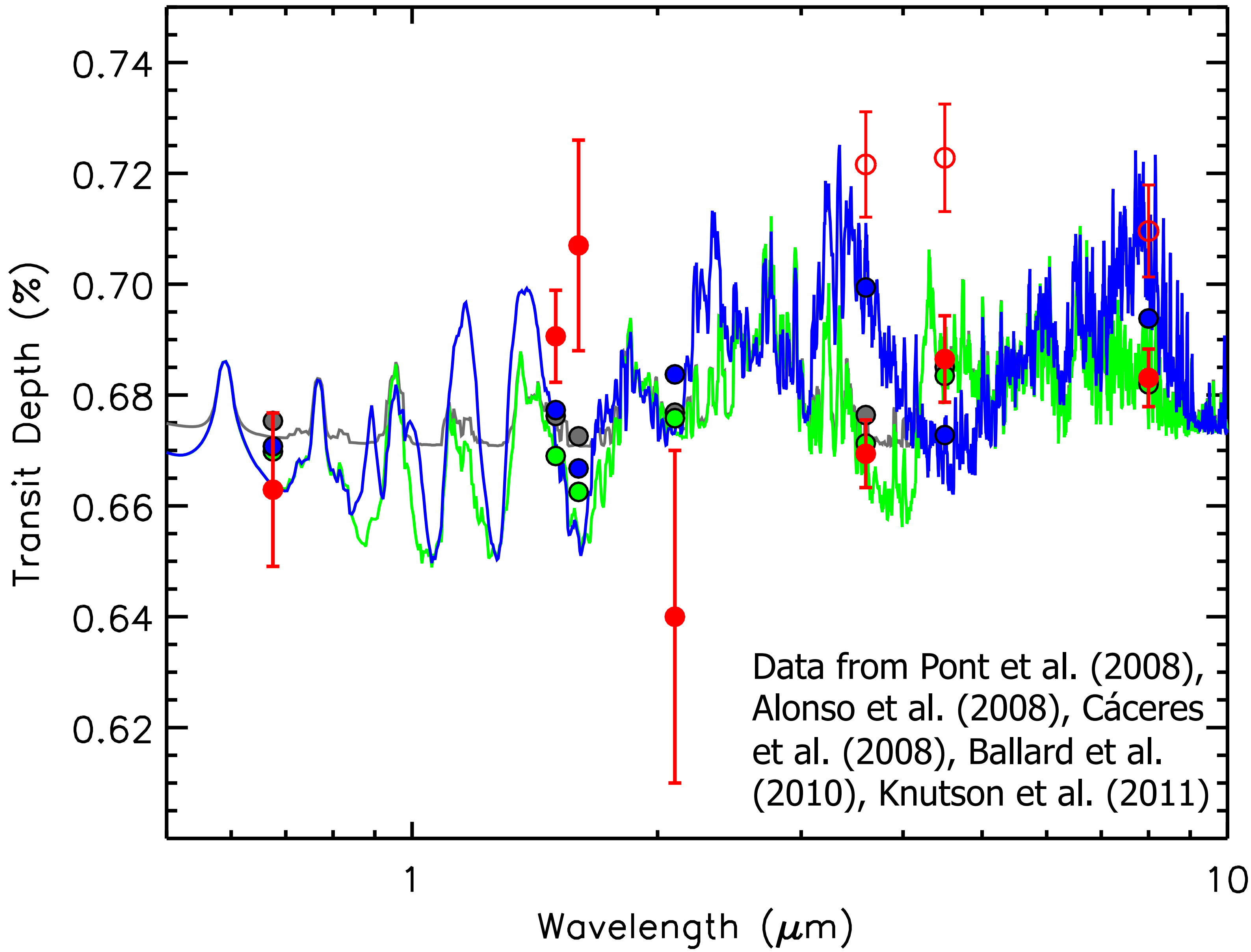


Occultation of bright region on star

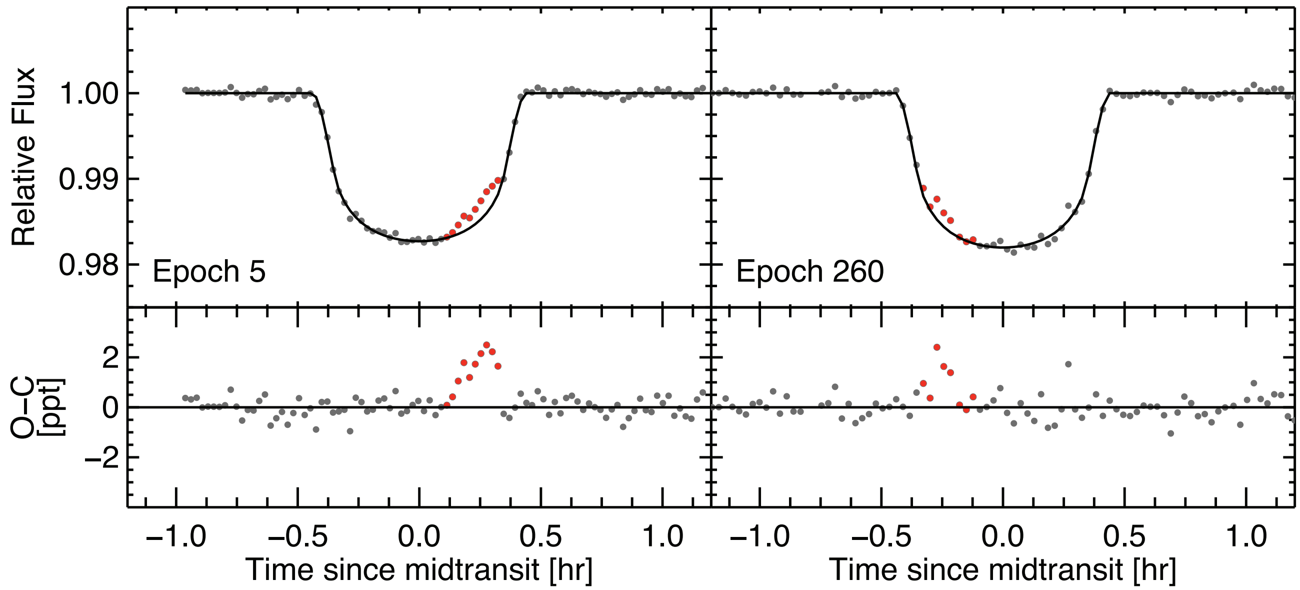
Color-dependent timing variations



Transmission Spectroscopy of GJ 436b

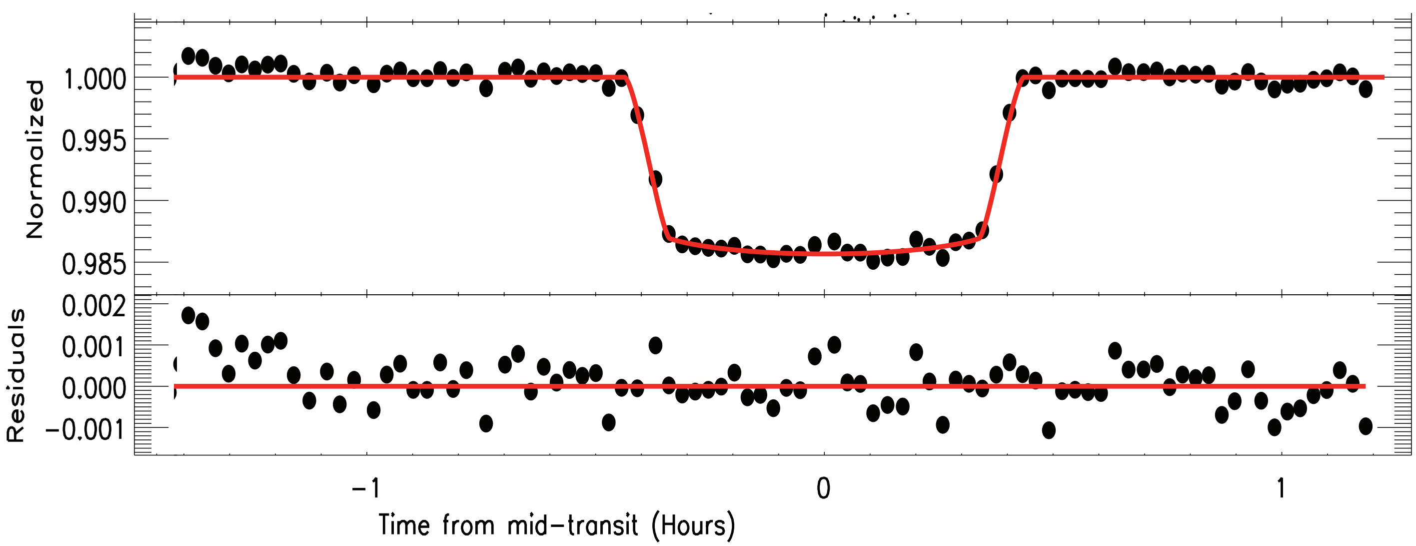


Will Stellar Activity Affect All Transiting Planets Orbiting M Stars?



GJ 1214 also has a slow, 52 day rotation period, Teff=3000 K (Berta et al. 2011; 3500 K for GJ 436)

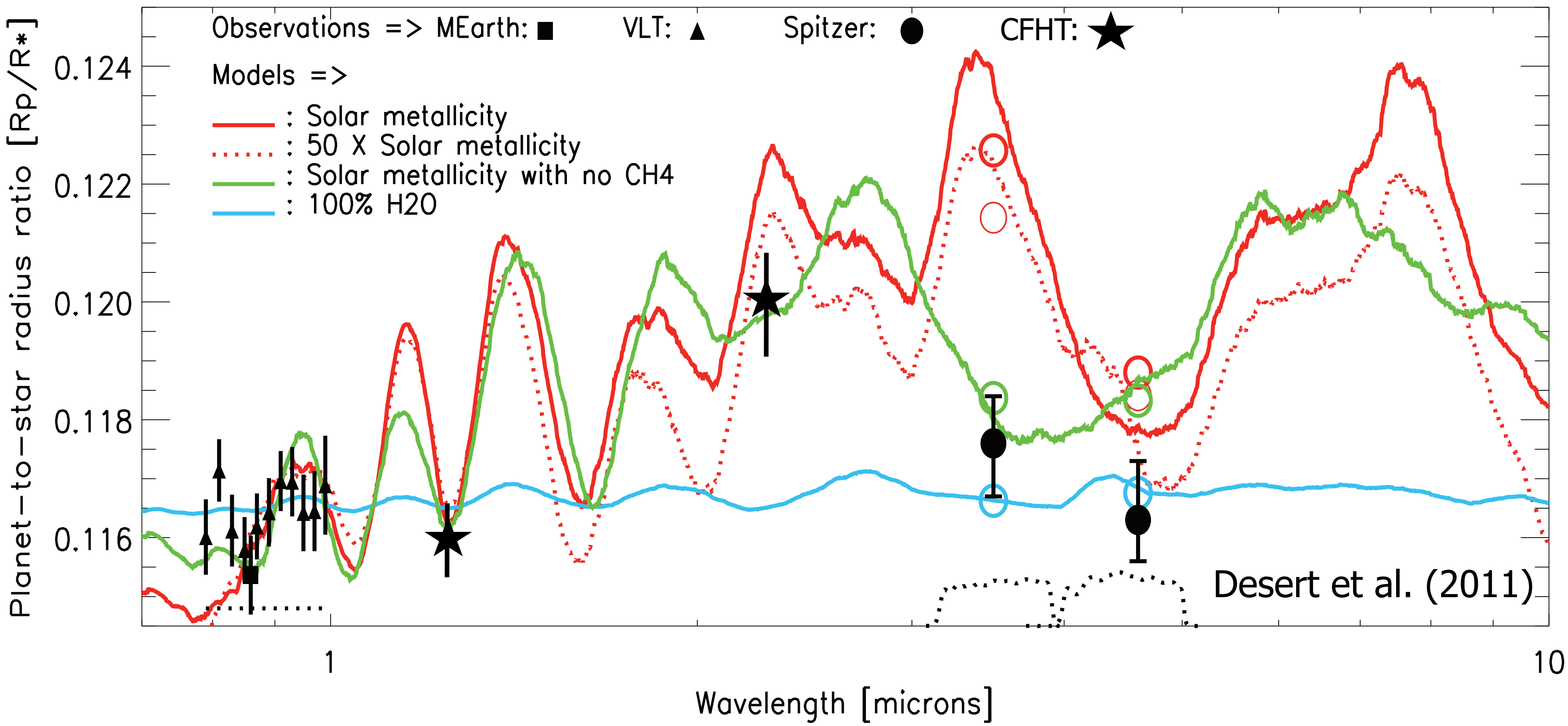
R′ band transits of GJ 1214b, 6.5 m Magellan Clay telescope (Carter et al. 2011)



Spitzer 4.5 μm transit
(Desert et al. 2011)

Infrared may be ok for this star.

Warm Spitzer Constraints on the Composition of GJ 1214b's Atmosphere

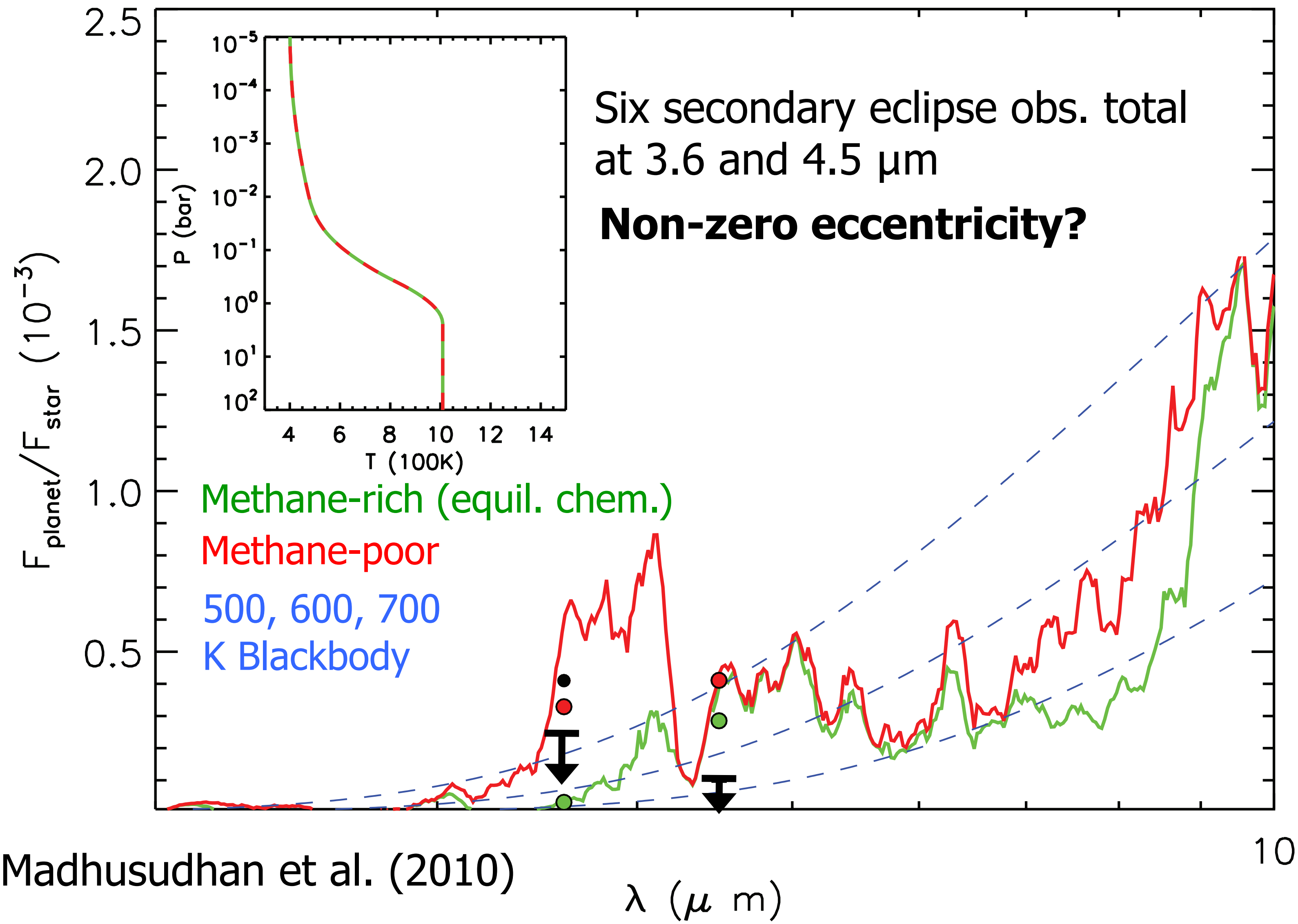


Based on data from Bean et al. (2010), Croll et al. (2011), Desert et al. (2011)

See poster by Jean-Michel Desert on Spitzer results!

Also talks by Eliza Kempton, Bryce Croll, & Jacob Bean, posters by Ian Crossfield.

Secondary Eclipse Constraints on the Composition of GJ 1214b's Atmosphere



Madhusudhan et al. (2010)

Conclusions

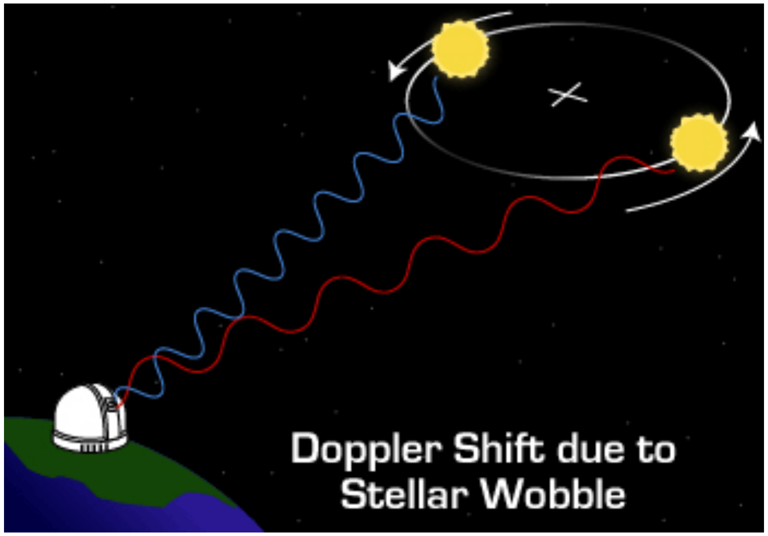
- Multi-wavelength photometry with warm Spitzer can be used to confirm planet candidates and search for new transiting systems.

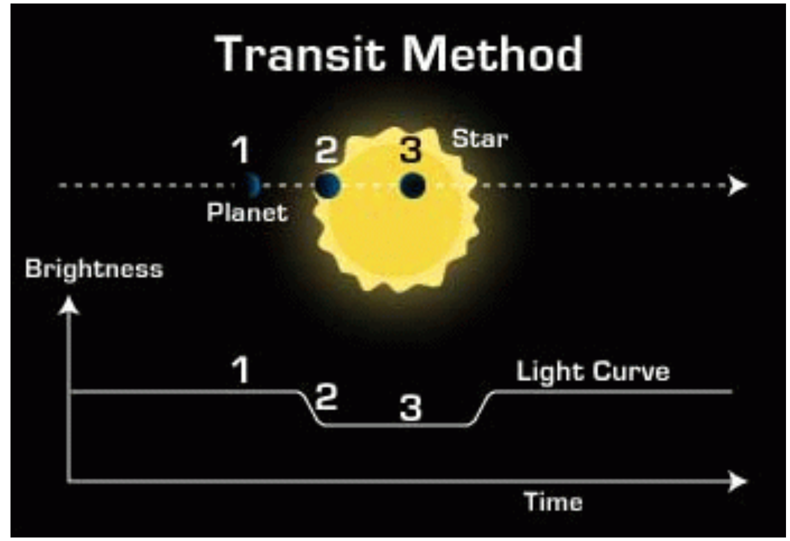
- For the present, atmosphere studies of super-Earths are focused on planets orbiting bright, nearby M dwarfs.

- Where is the methane??

- Devil is in the details– activity on M stars is poorly understood, and problematic for characterization.

Two Commonly Used Methods for Finding & Characterizing Exoplanets





Doppler Method

Determine Planet Mass

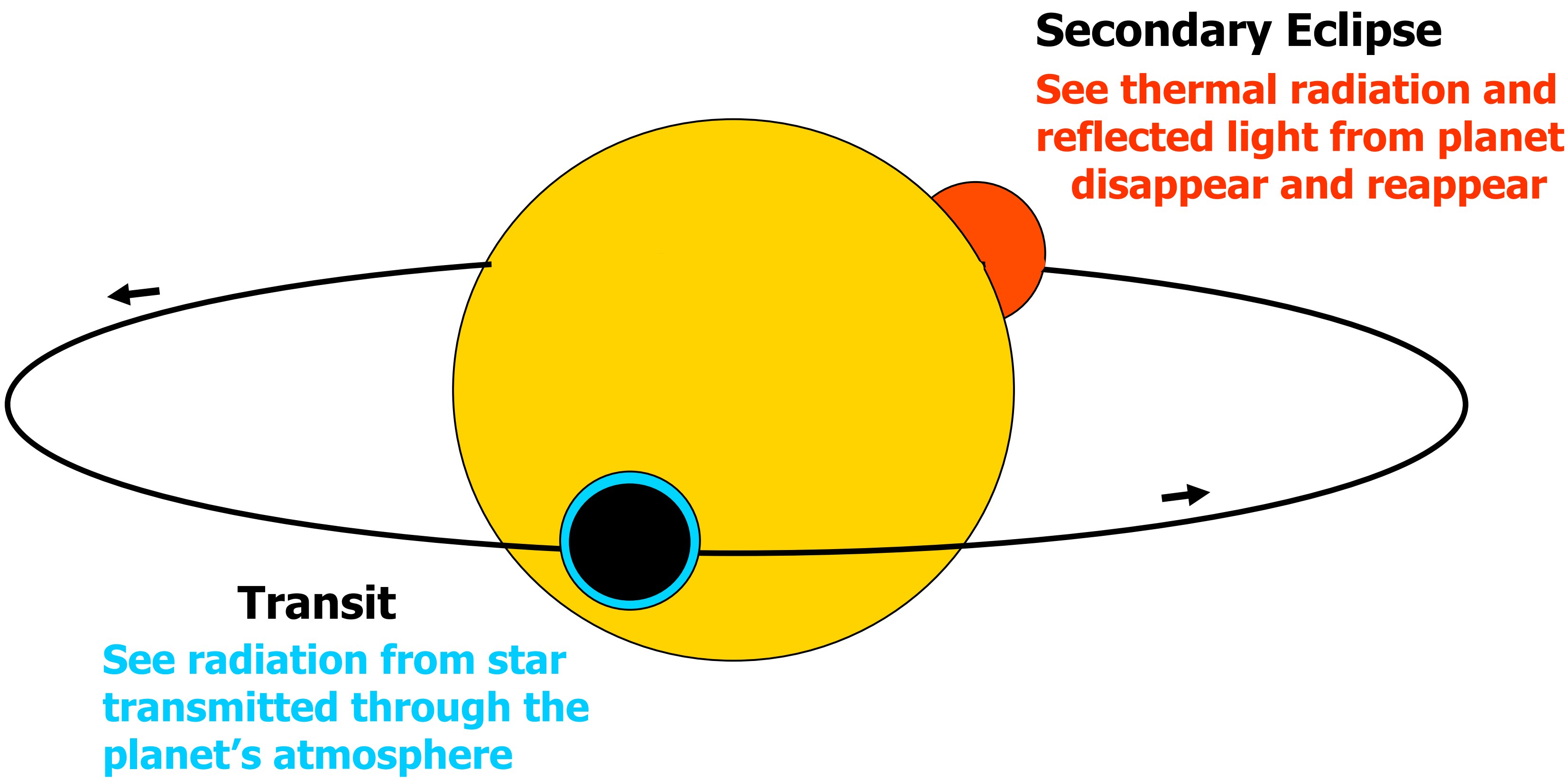
Transit Method

Determine Planet Diameter

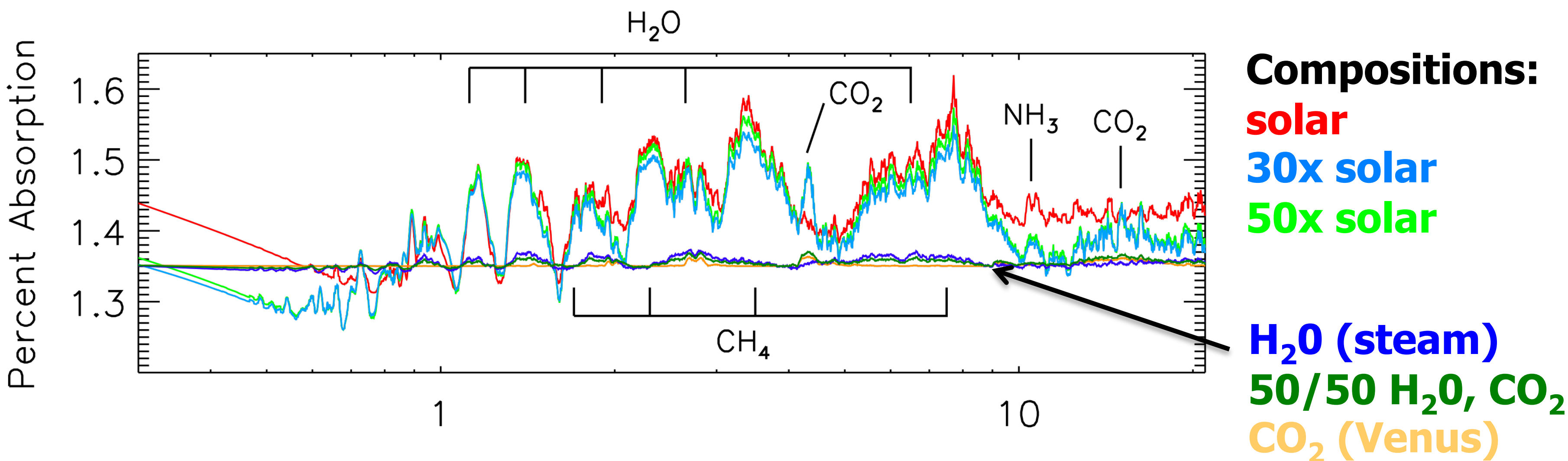
Calculate Planet Density and Infer Composition:

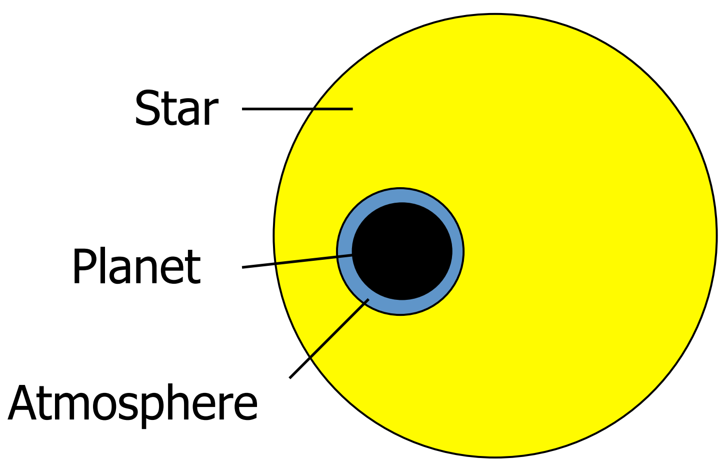
Gas giant (Jupiter), Ice giant (Neptune), or Rocky planet (Earth)

Transiting Planets as a Tool for Studying Exoplanetary Atmospheres



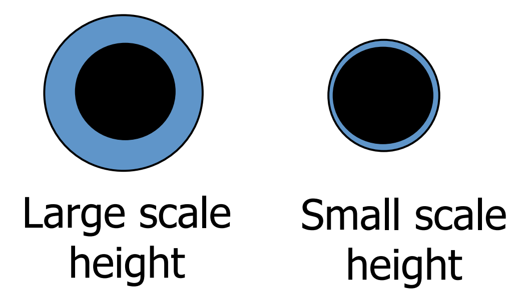
Determining the Composition of GJ 1214b's Atmosphere with Transmission Spectroscopy





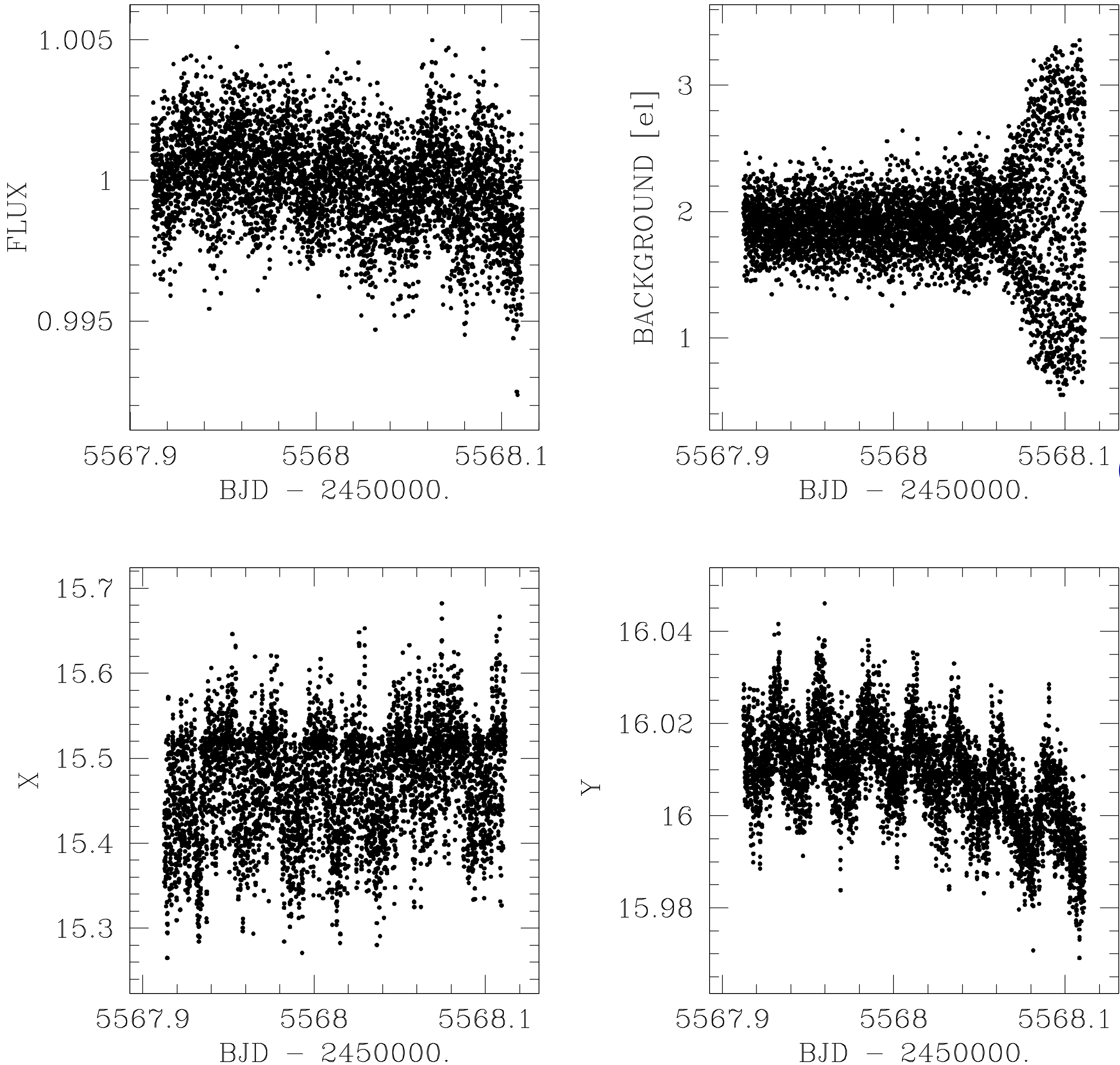
Scale Height

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



Miller-Ricci & Fortney (2010)

Spitzer Confirmation of 55 Cancri e Transit



Demory et al. (2011, astro-ph/1105.0415)