Transit Spectroscopy

G. Vasisht

Photon Limited

$$\sigma^2 = N_s\tau \quad S \propto D^2$$

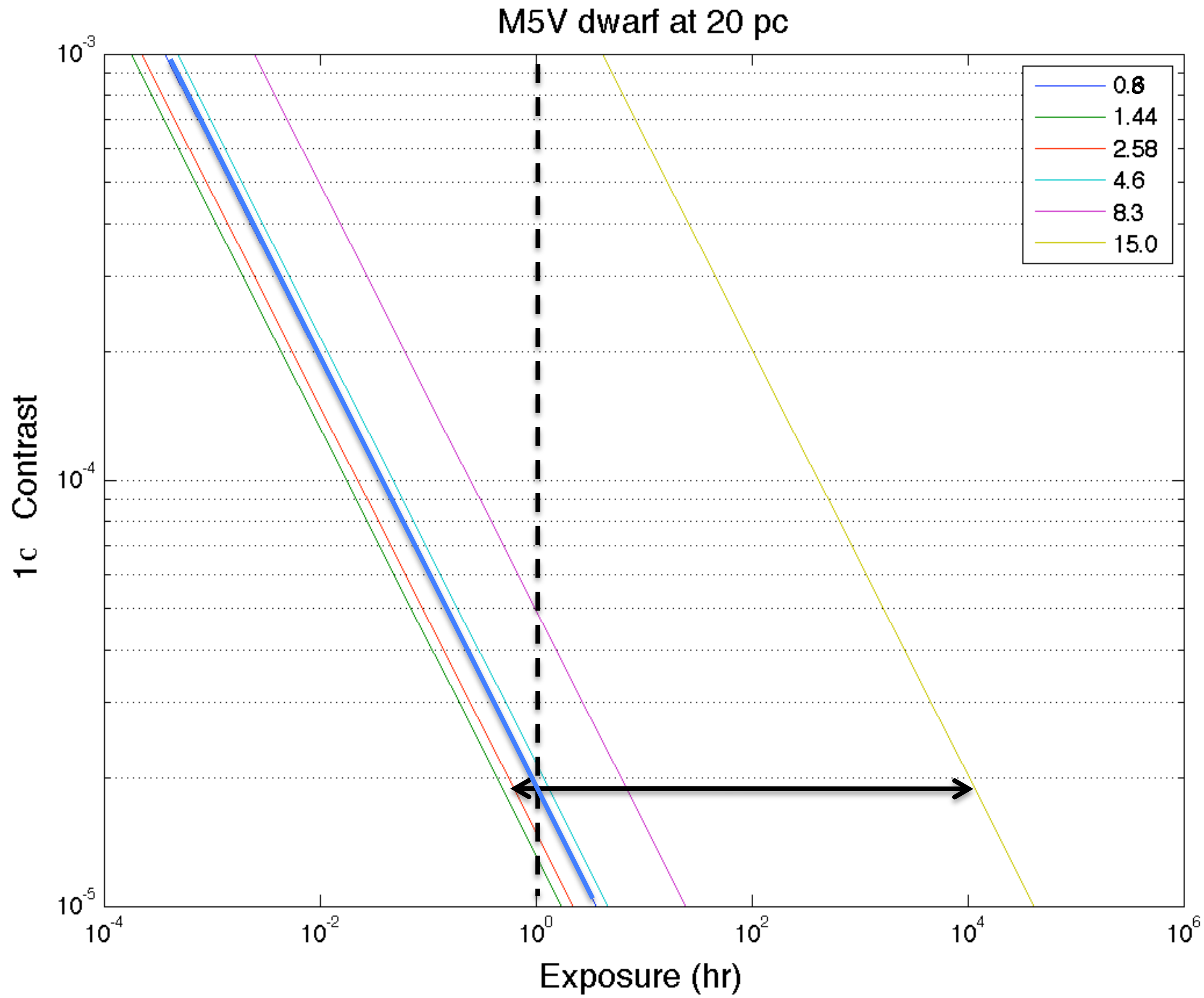
Makes small telescopes reasonably competitive!

Background Limited

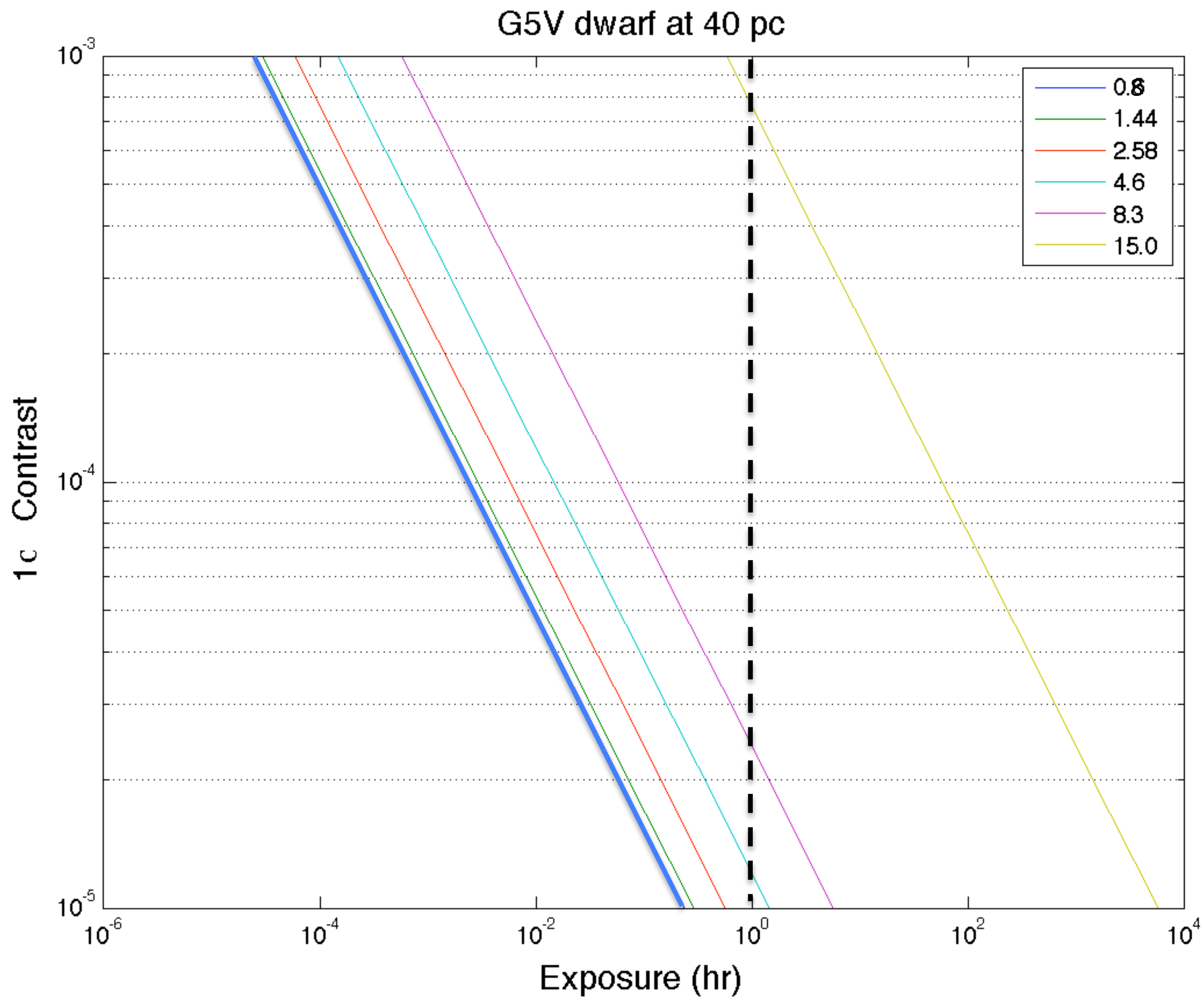
$$\sigma^2 = B\,\tau \quad S \propto D^4$$

Limits imposed by Systematics

$$\sigma^2 = cN_s^2\left(\tau/\tau_d\right) \quad S \propto D^0$$



M5V dwarf at 20 pc
0.8
1.44
2.58
4.6
8.3
15.0
1σ Contrast
Exposure (hr)

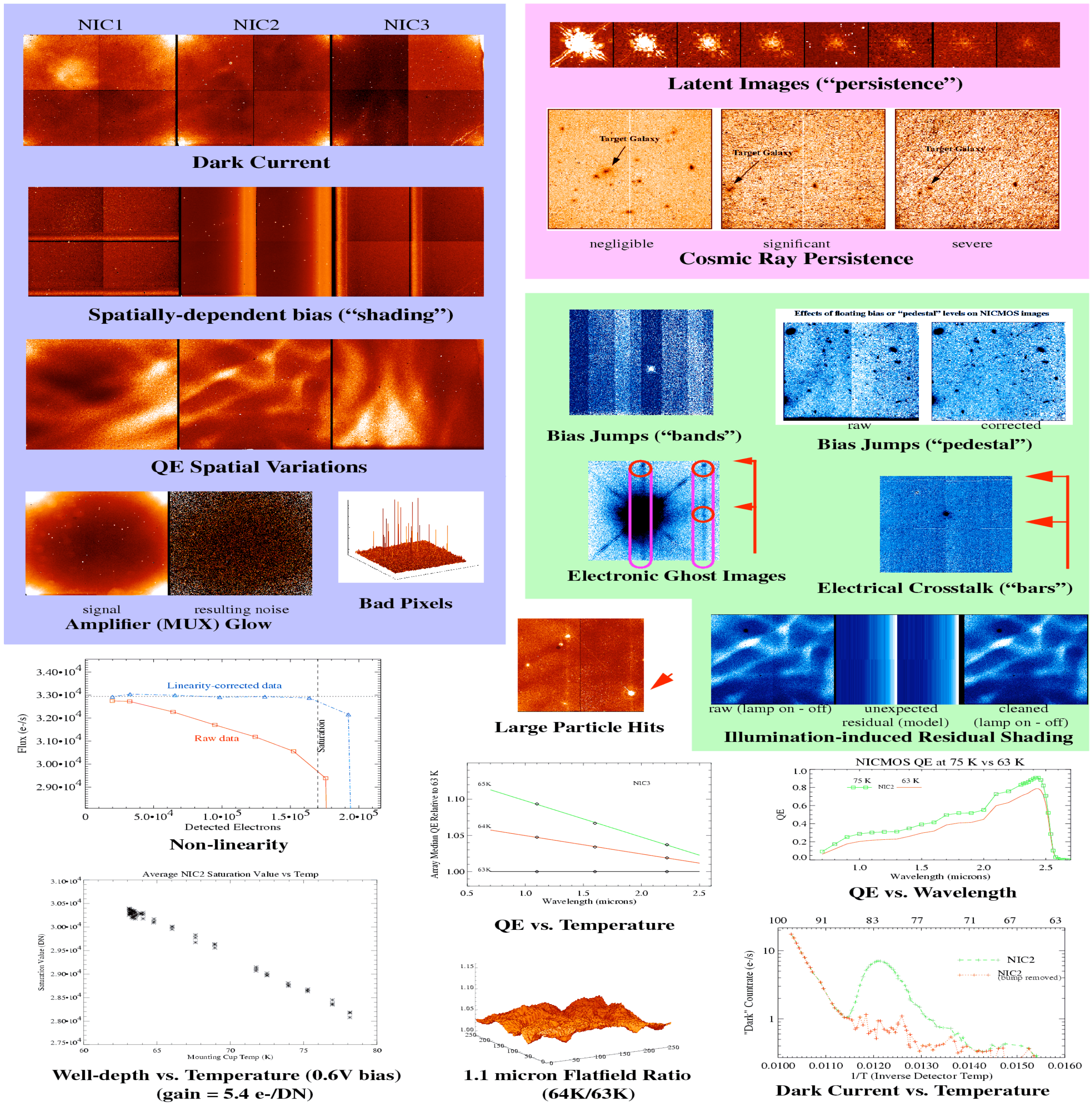


G5V dwarf at 40 pc
0.8
1.44
2.58
4.6
8.3
15.0
1σ Contrast
Exposure (hr)

State-of-the-art (20 ppm)

- *Key factors in differential performance of the Kepler mission*
  - *Differential Spatial (Ensemble) Photometry (✗)*
  - *Differential Temporal Photometry (✔)*
  - *Prevention and Decorrelation of Image Motion (✔)*
  - *Optimal weighting of pixels for maximization of signal-to-noise (✔)*
  - *Operation at large fraction of well depth (✔)*
  - *Keep illumination (images) fixed on the detector for months (✗)*
  - *Thermal control (selection of a proper orbit) (✗✔)*

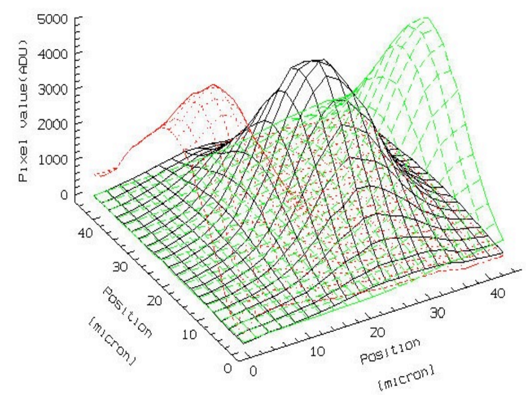
Nicmos 3 detectors

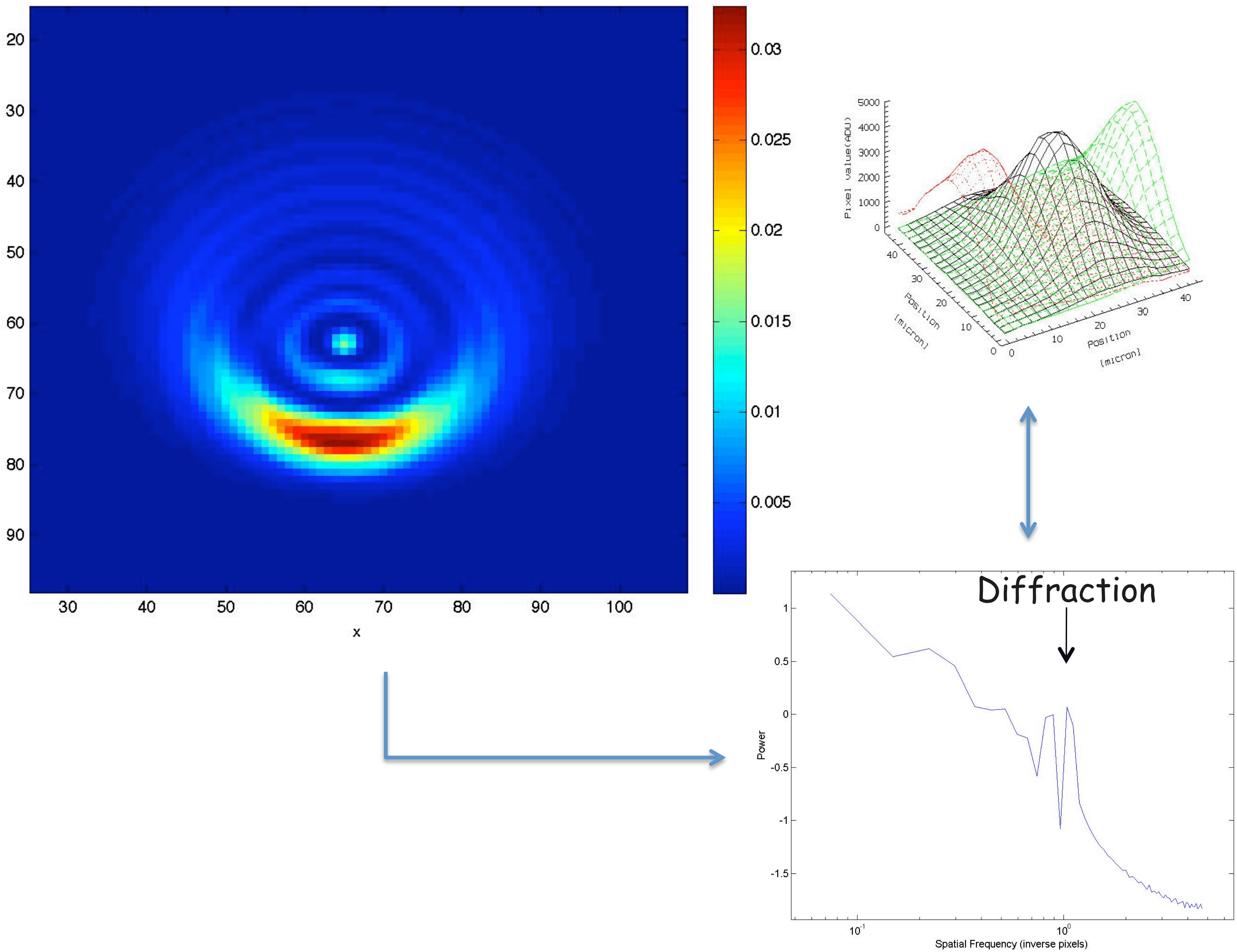


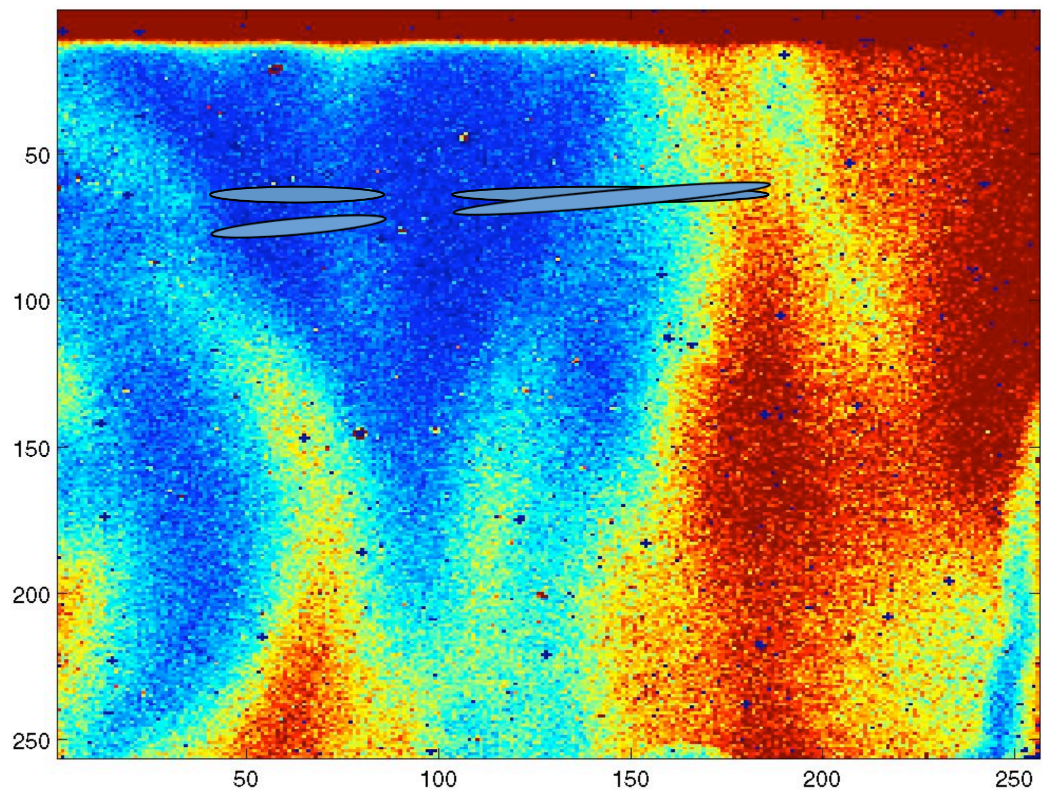
Figer et al. 2002

… *Secondly, the point spread functions are not critically sampled*

$$\lambda/D \approx \text{pixel pitch}$$




x
Pixel value(ADU)
Position [micron]
Position [micron]
Diffraction
Power
Spatial Frequency (inverse pixels)

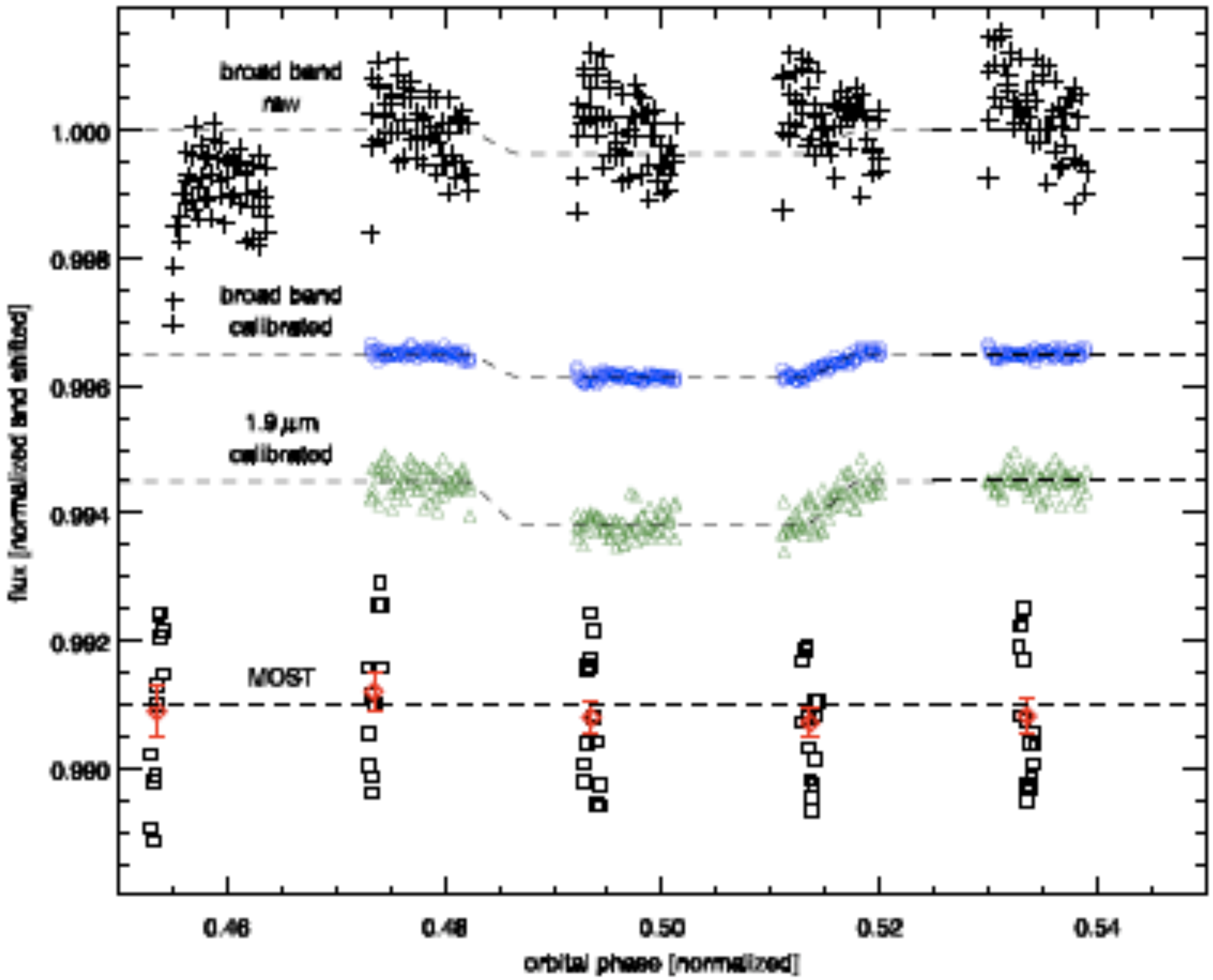


50
100
150
200
250
50
100
150
200
250

Methods in spectrophotometry

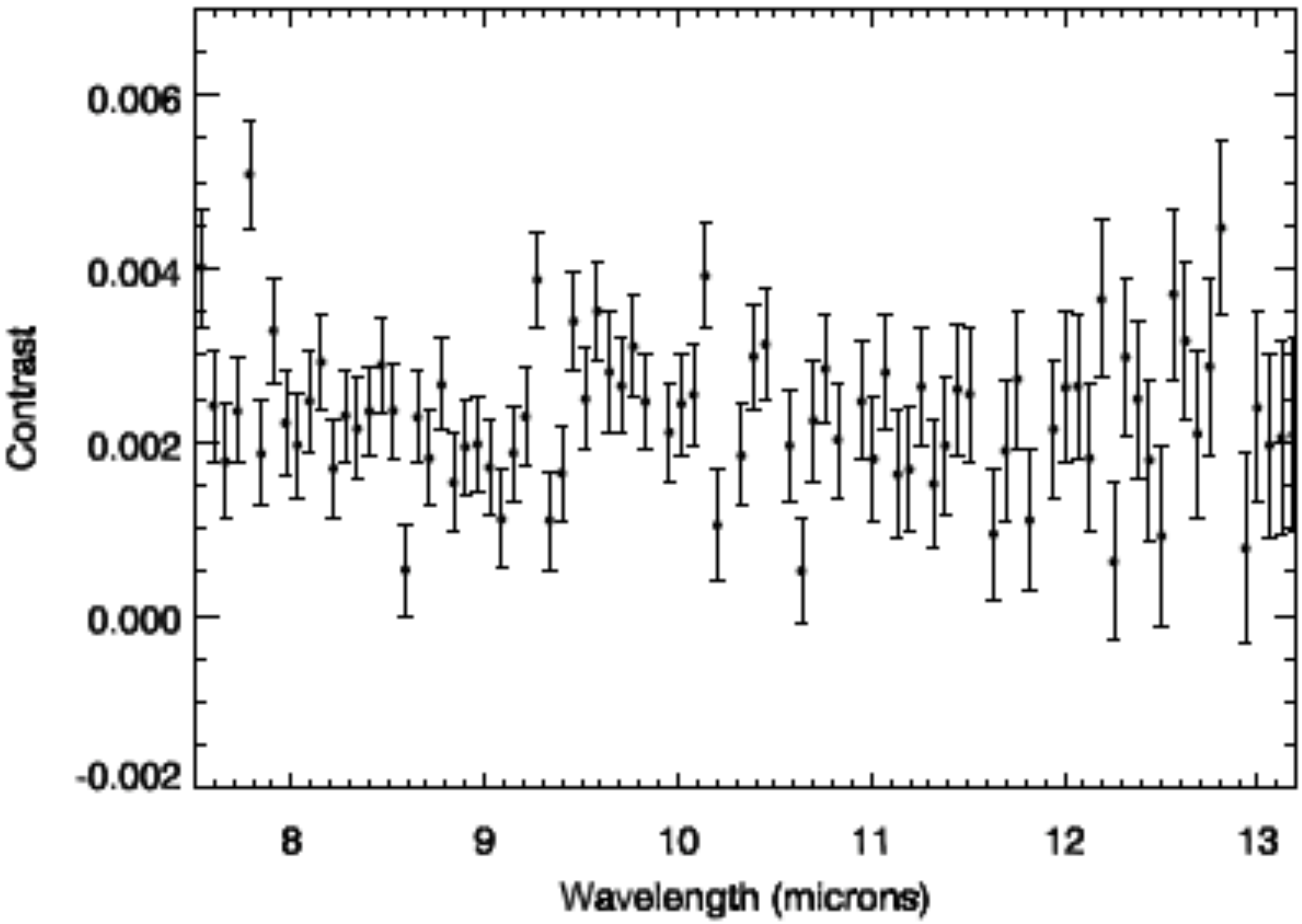
- *To approach shot-noise limited spectroscopy, one needs to dig beneath a systematics floor*
- *For this, knowledge of the instrument is key*
  - *Image motion is observable with high signal-to-noise (when rigid)*
  - *Similarly ILS structure changes are observable*
  - *When small, the effects of these can be modeled and removed*

HD 209458b Lightcurves



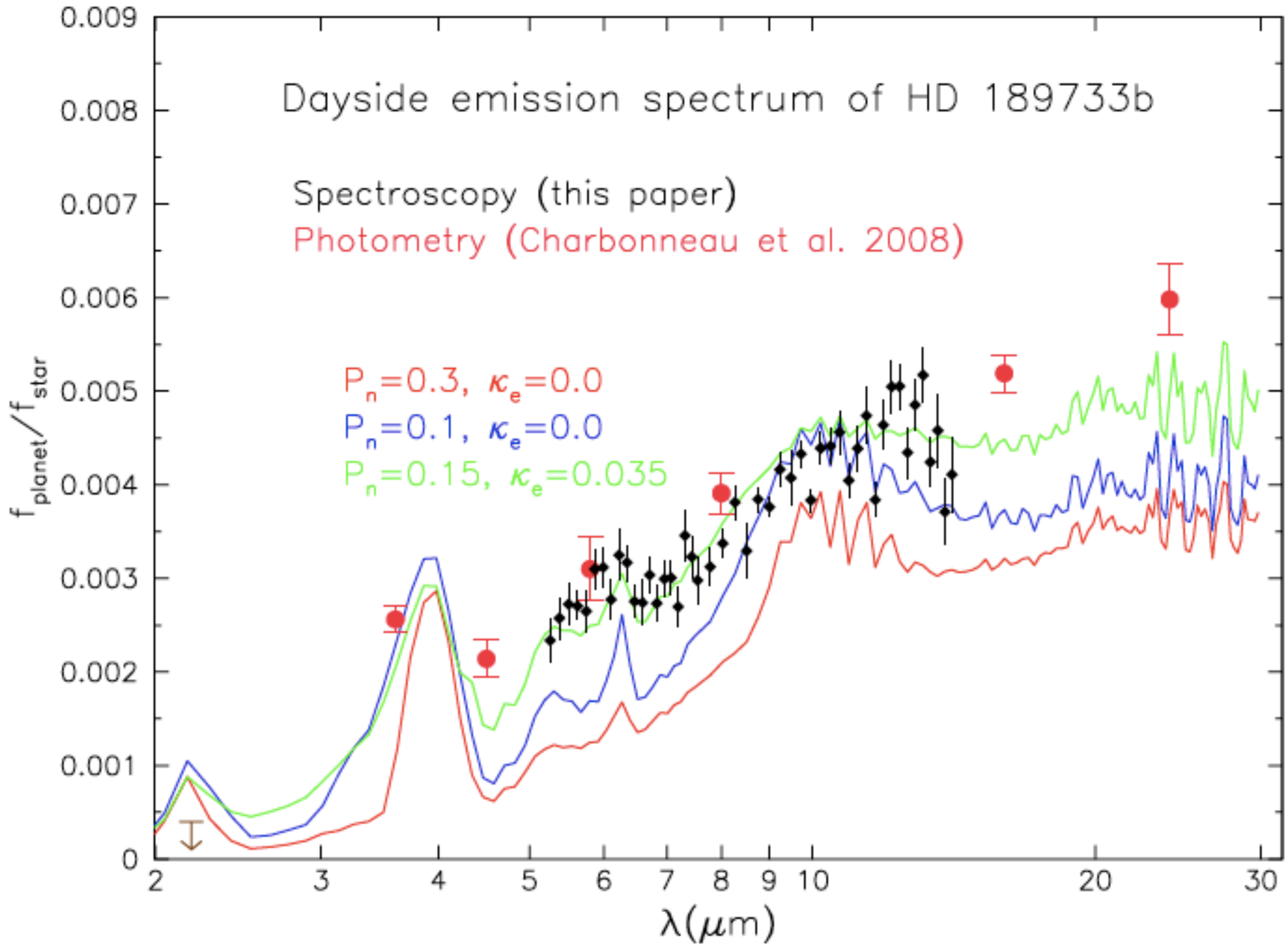
Spectra…

HD 209458b



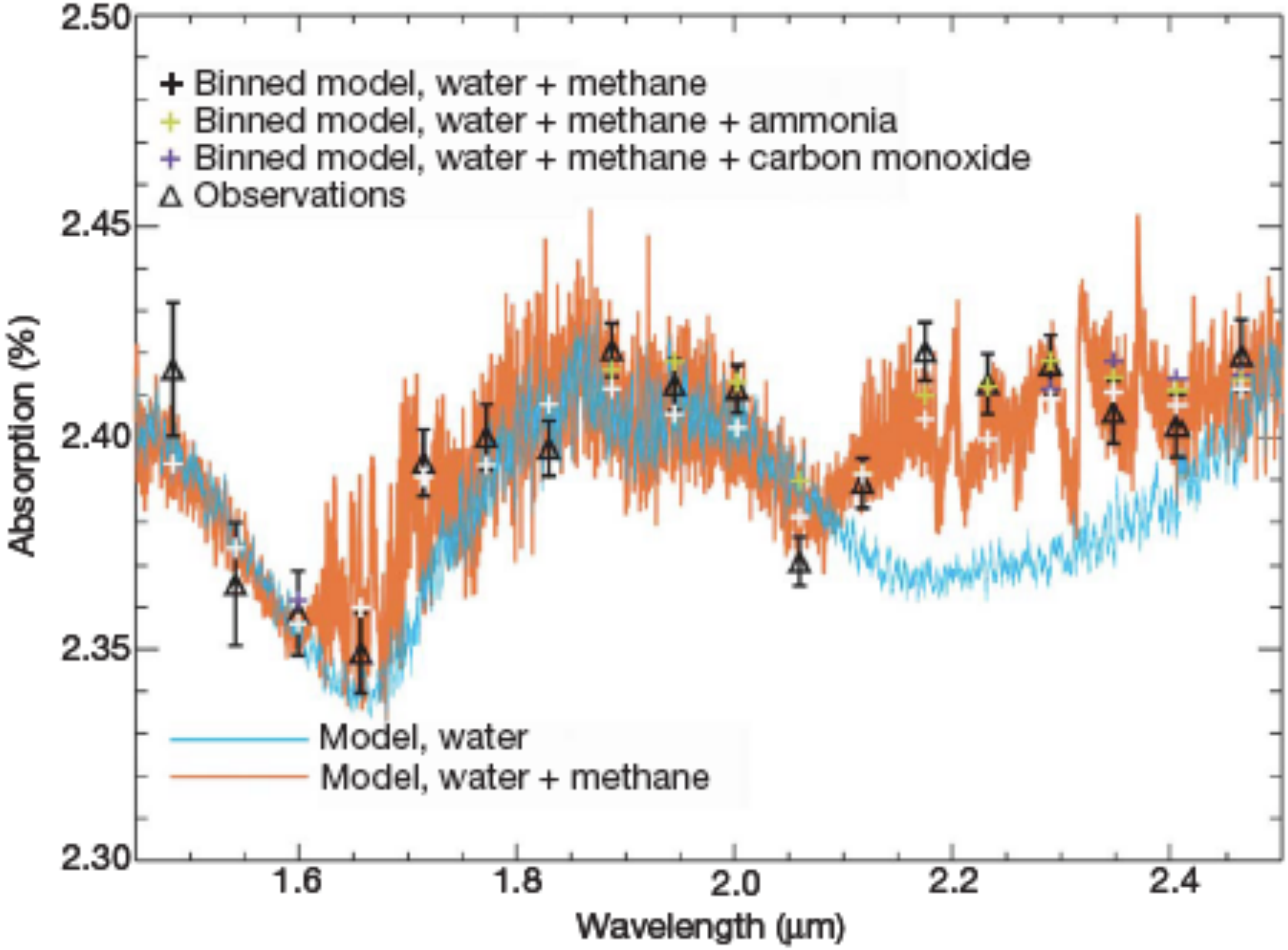
Richardson et al. 2007
Swain et al. 2008

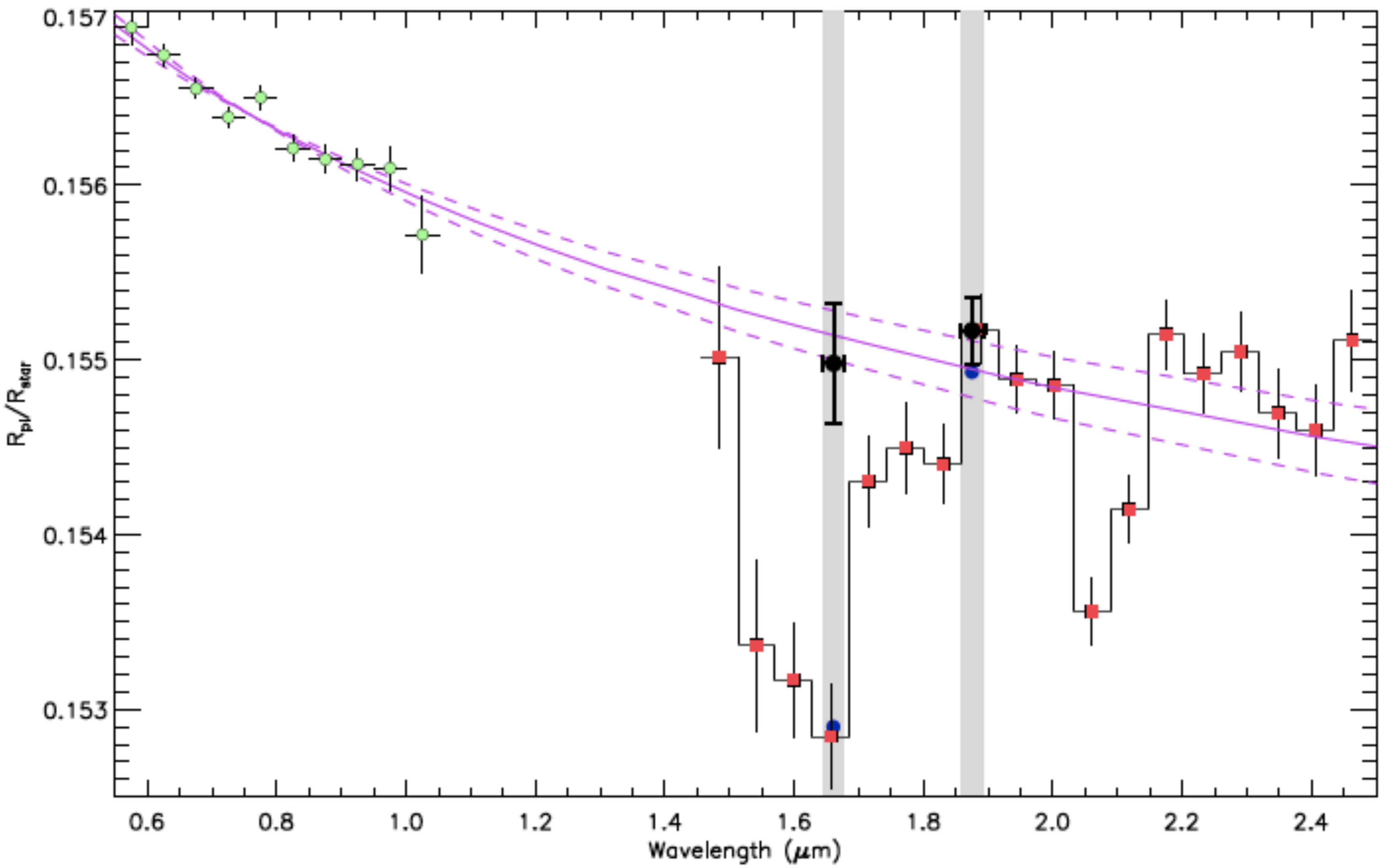
Grillmair et al. 2009



The black points show the mean flux ratios for six 2nd-order spectra (5-8 μm) and four 1st-order spectra (7.5-14 μm).

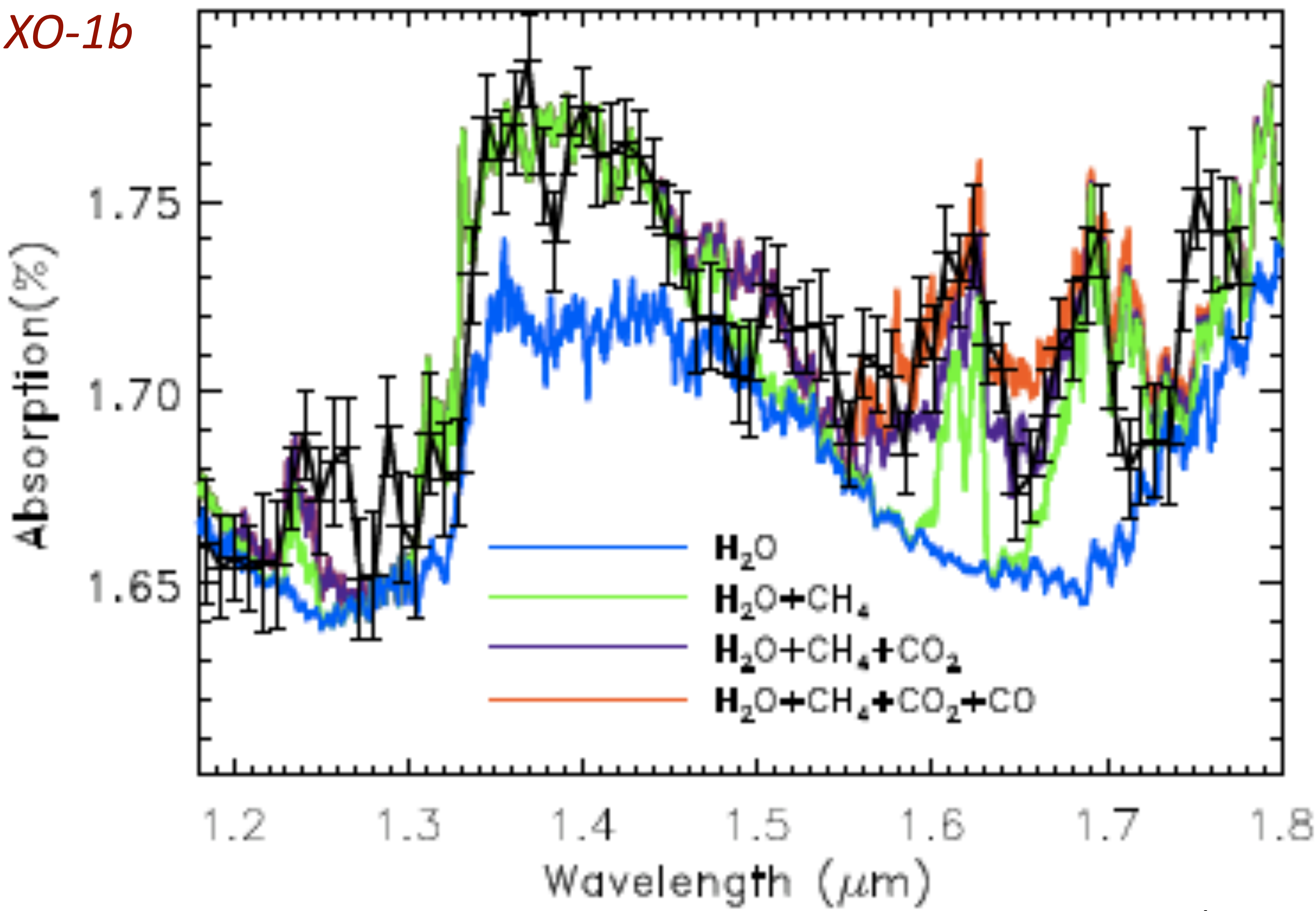
Swain, Vasisht & Tinetti 2008





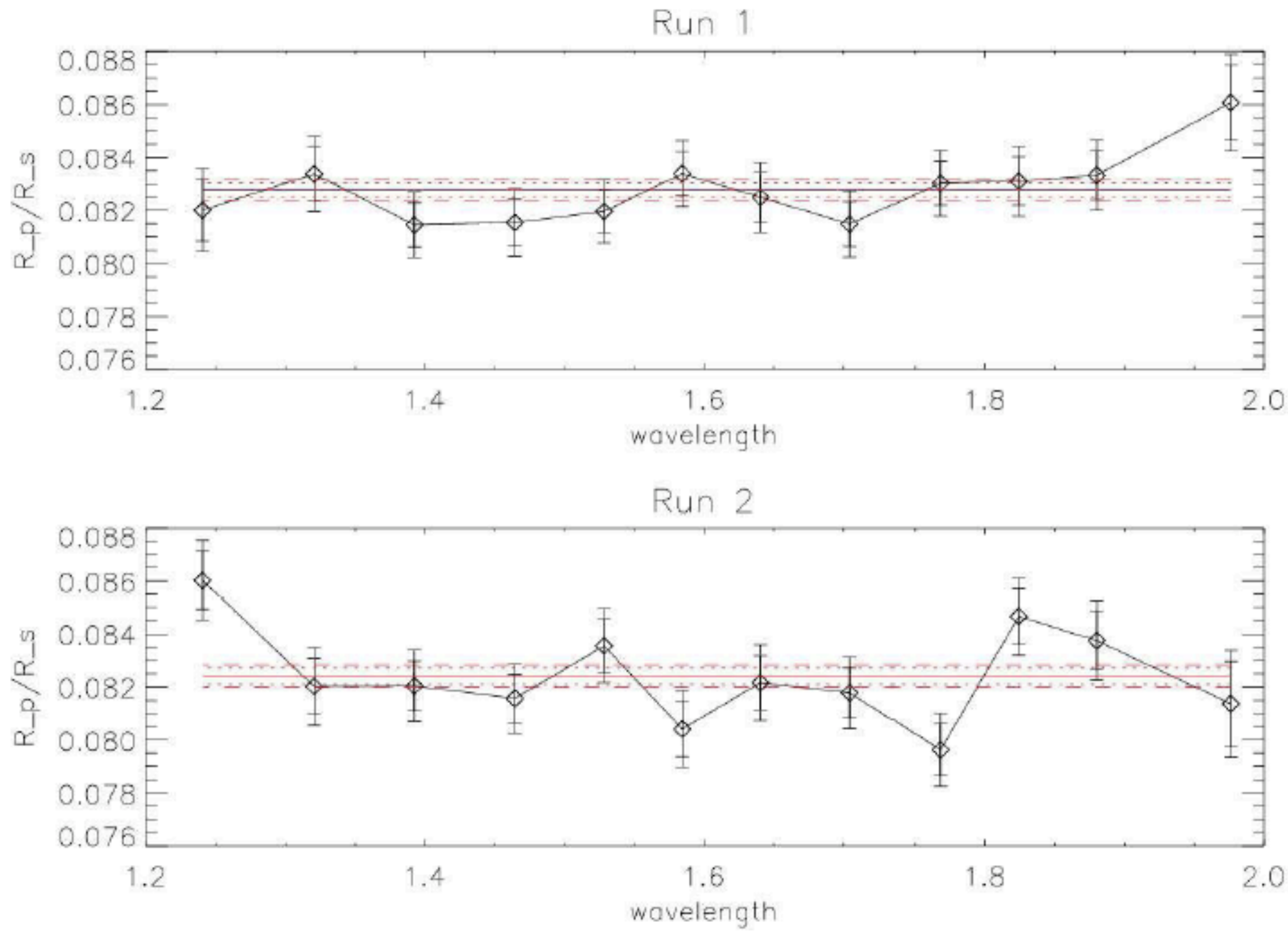
Sing et al. 2009

XO-1b

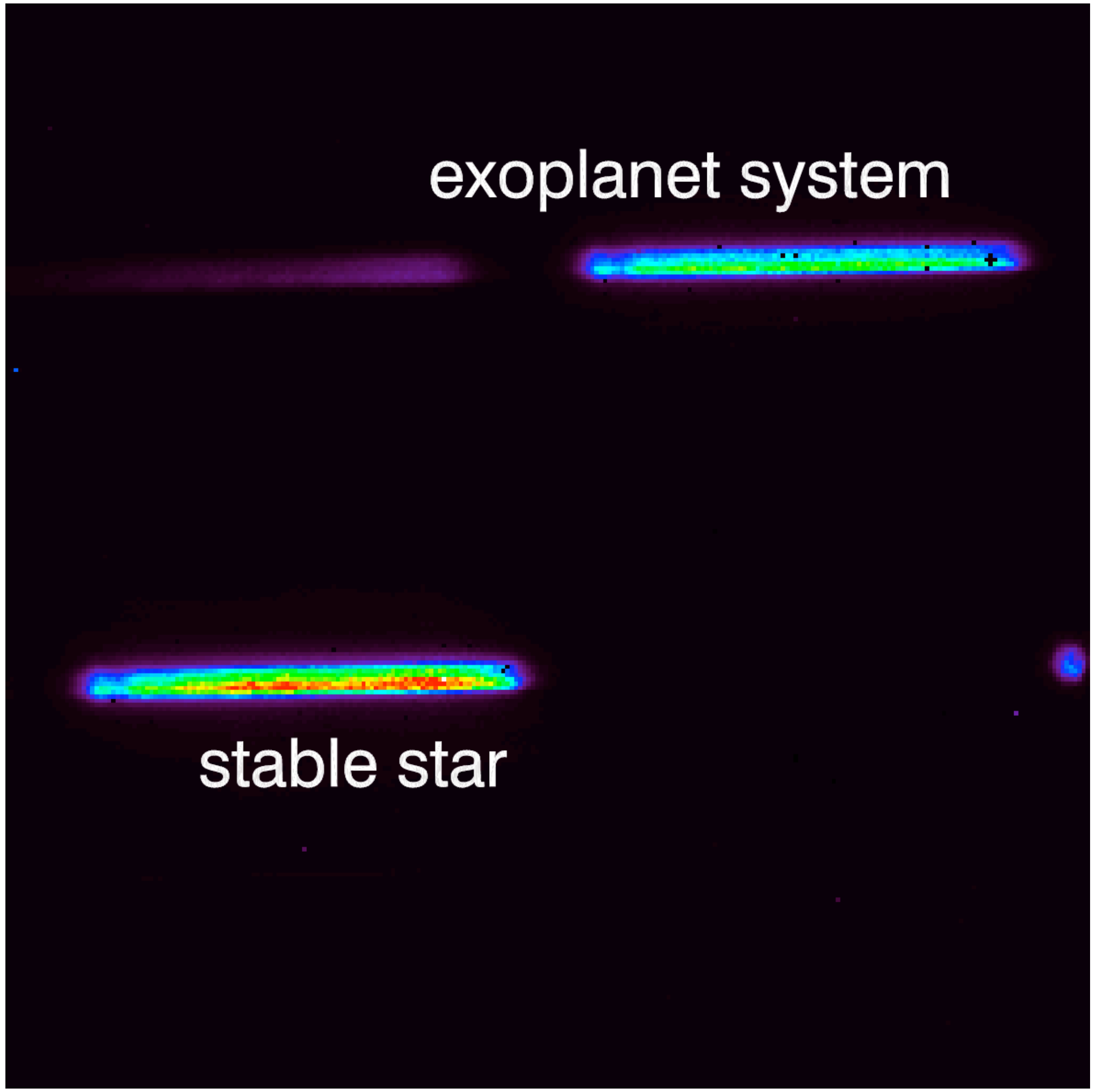


Tinetti et al. 2010

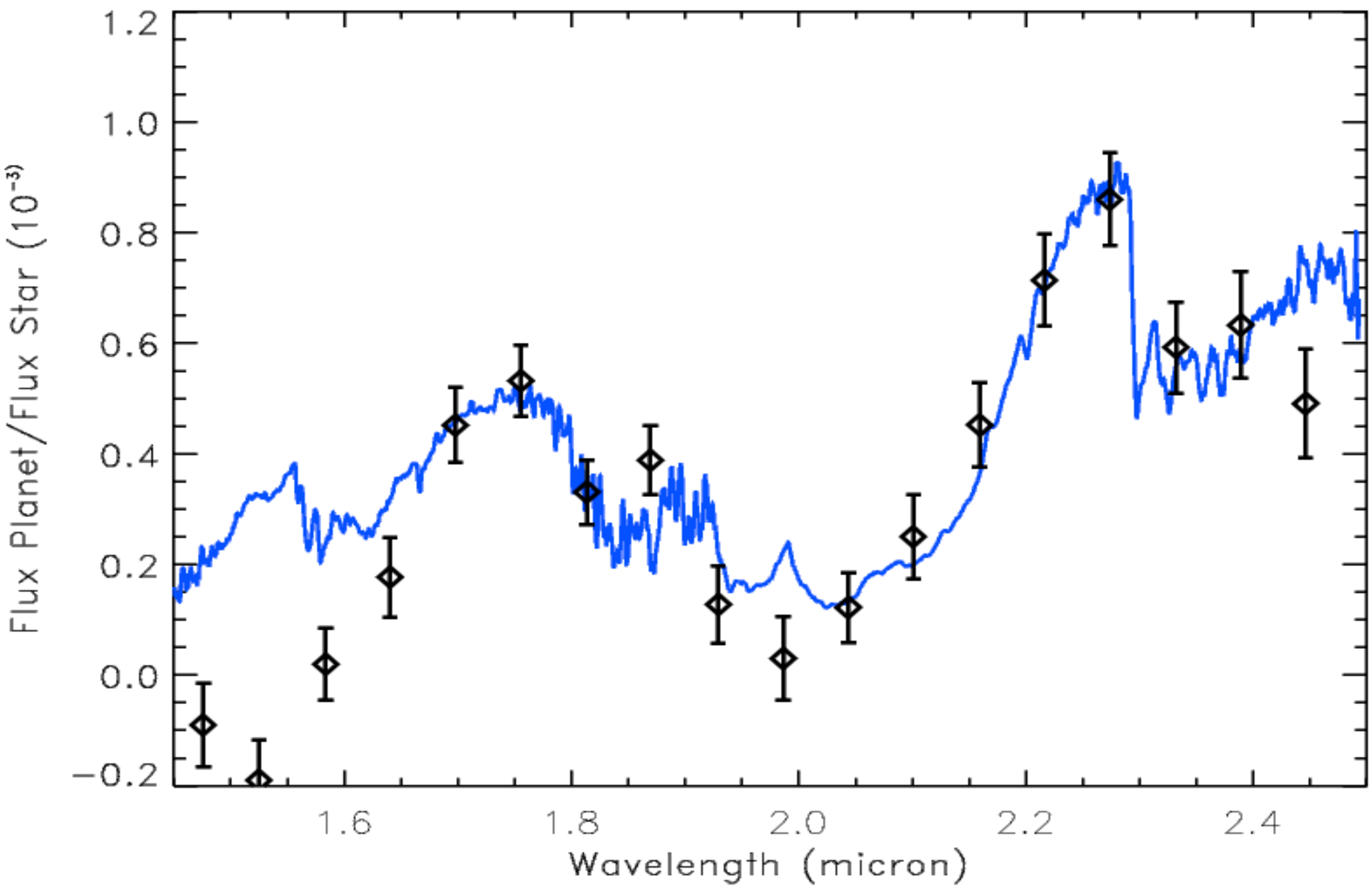
GJ 436b



Pont et al. 2009
Angerhausen et al. 2010

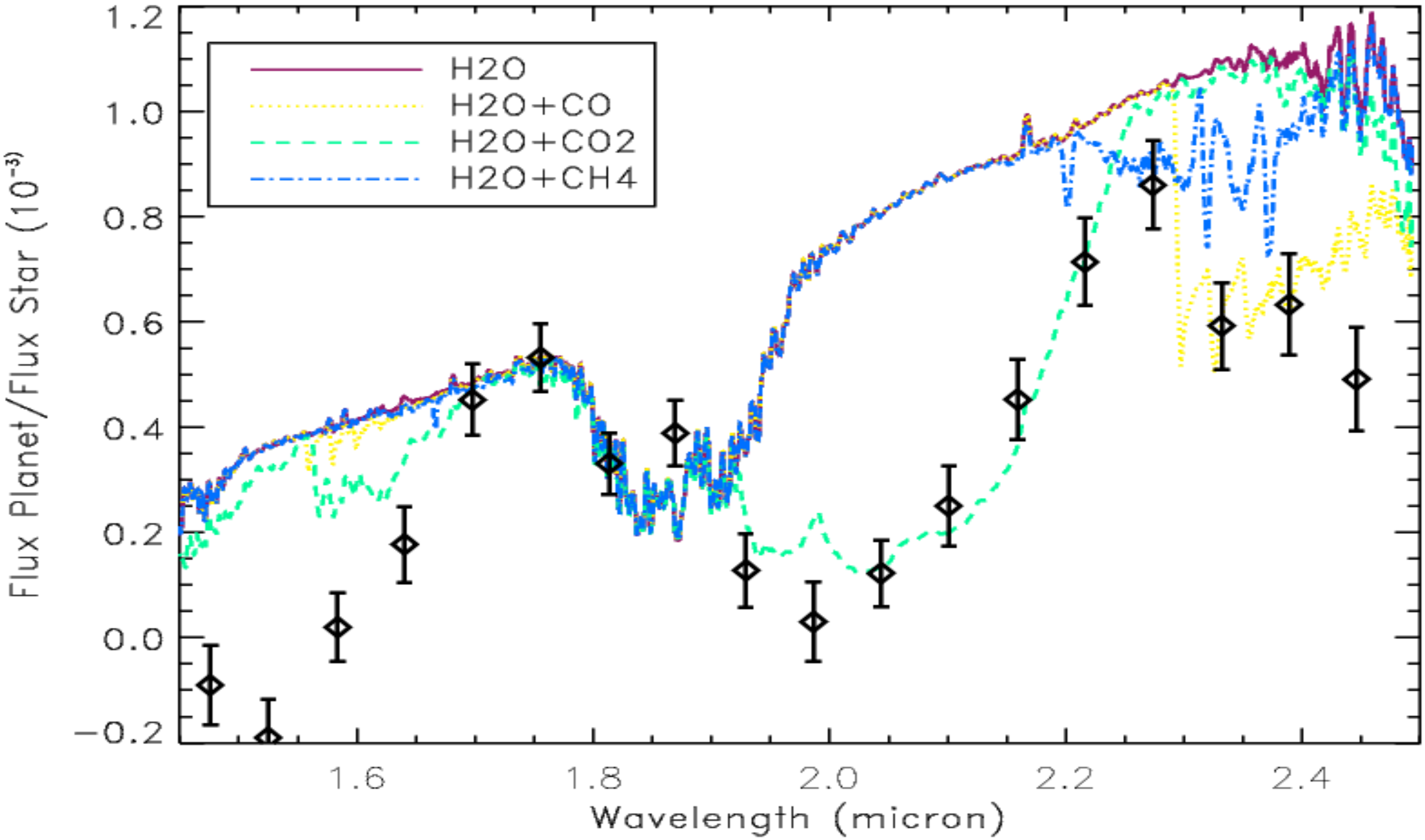

exoplanet system
stable star

HD 189733b NIR Emission



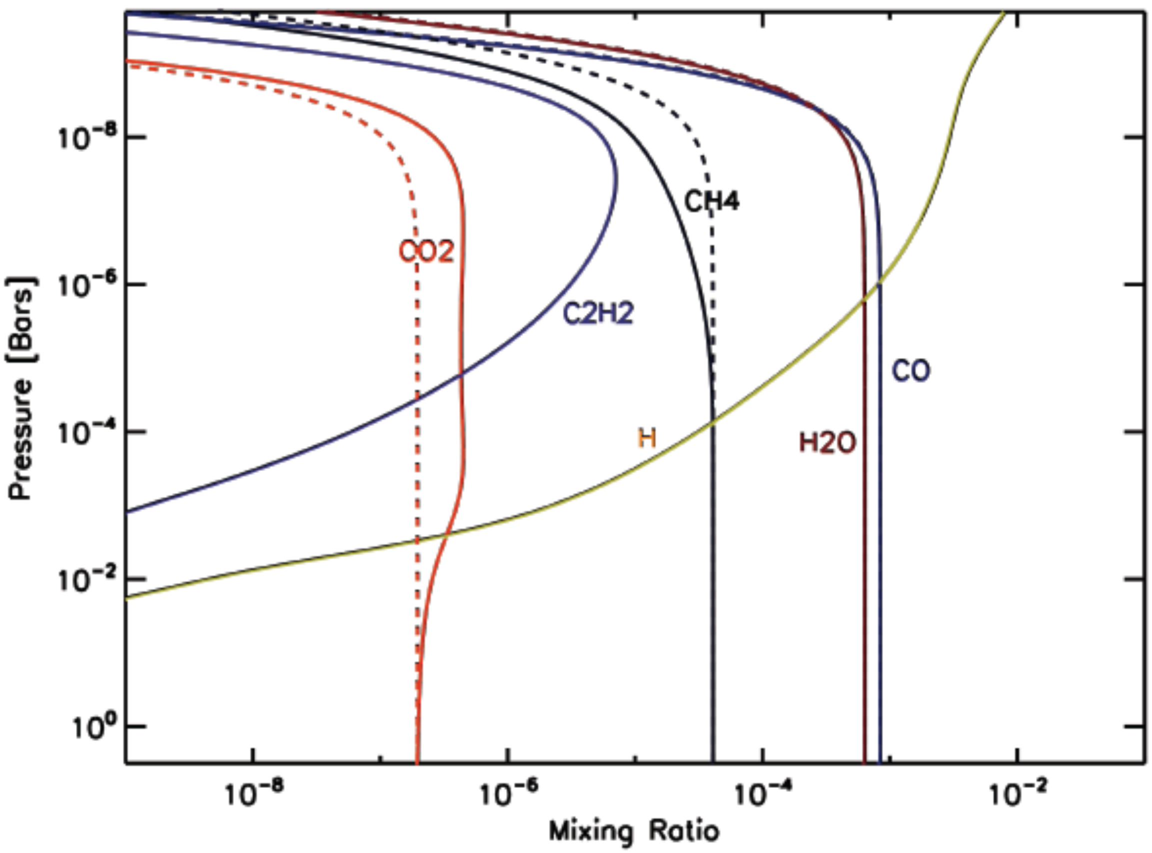
Swain et al. 2009

HD 189733b NIR Emission: Model Components

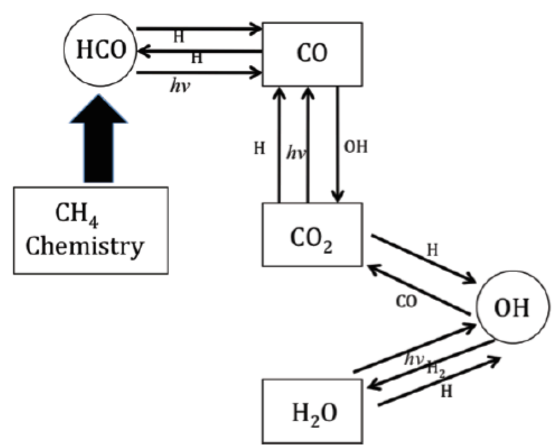


Swain et al. 2009

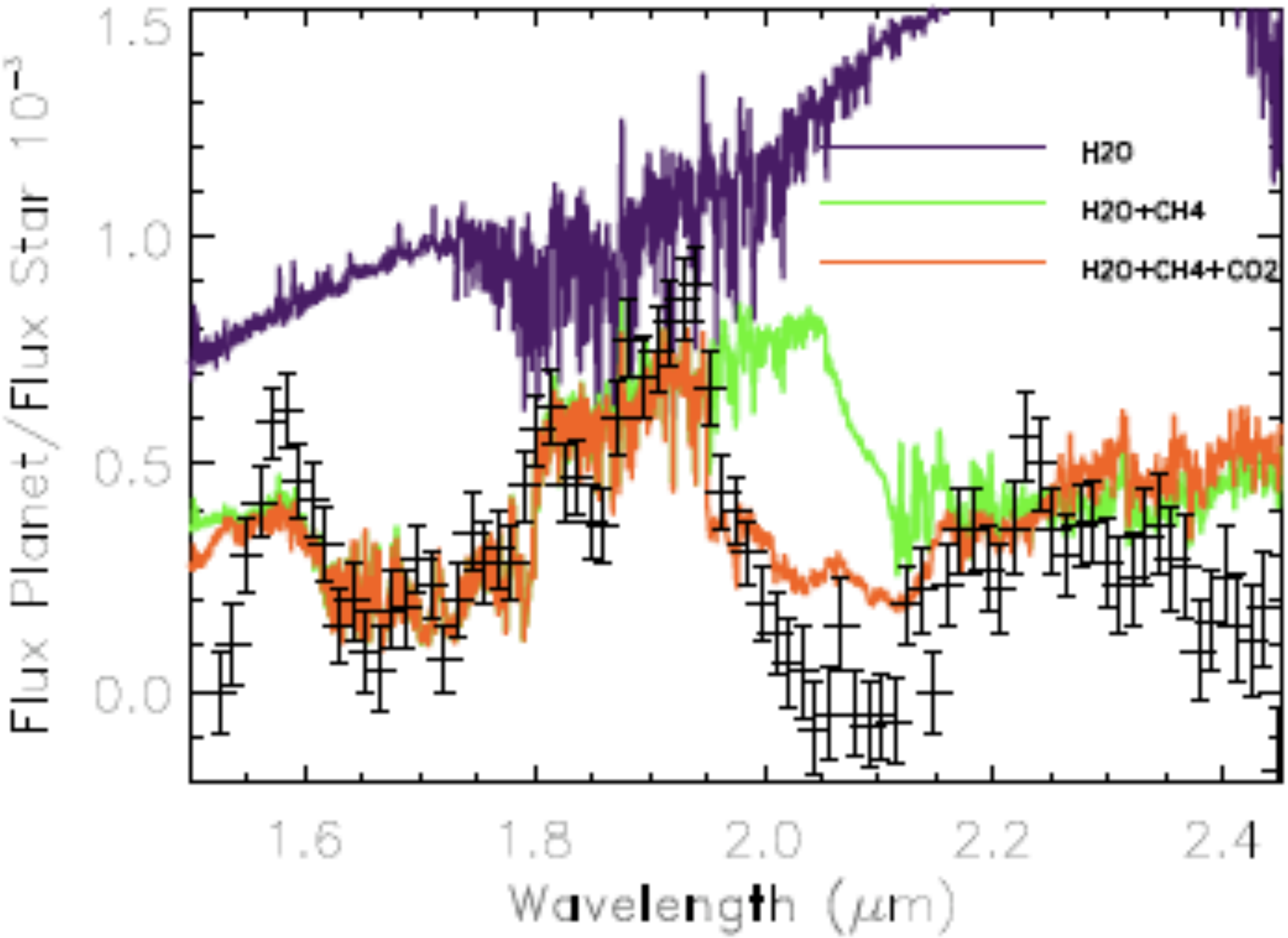
HD 189733b Chemistry



Line et al. 2010

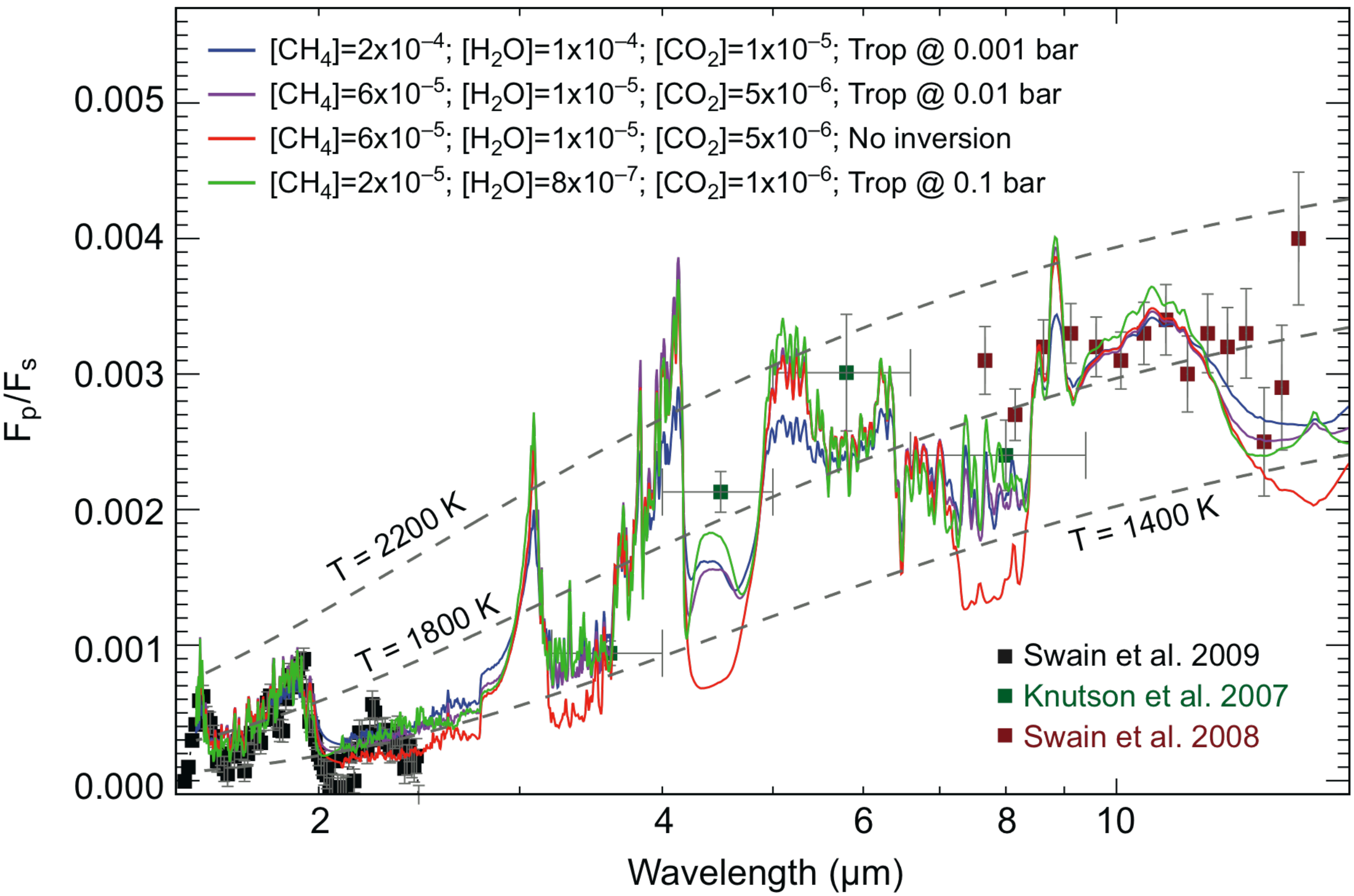


HD 209458b NIR Emission



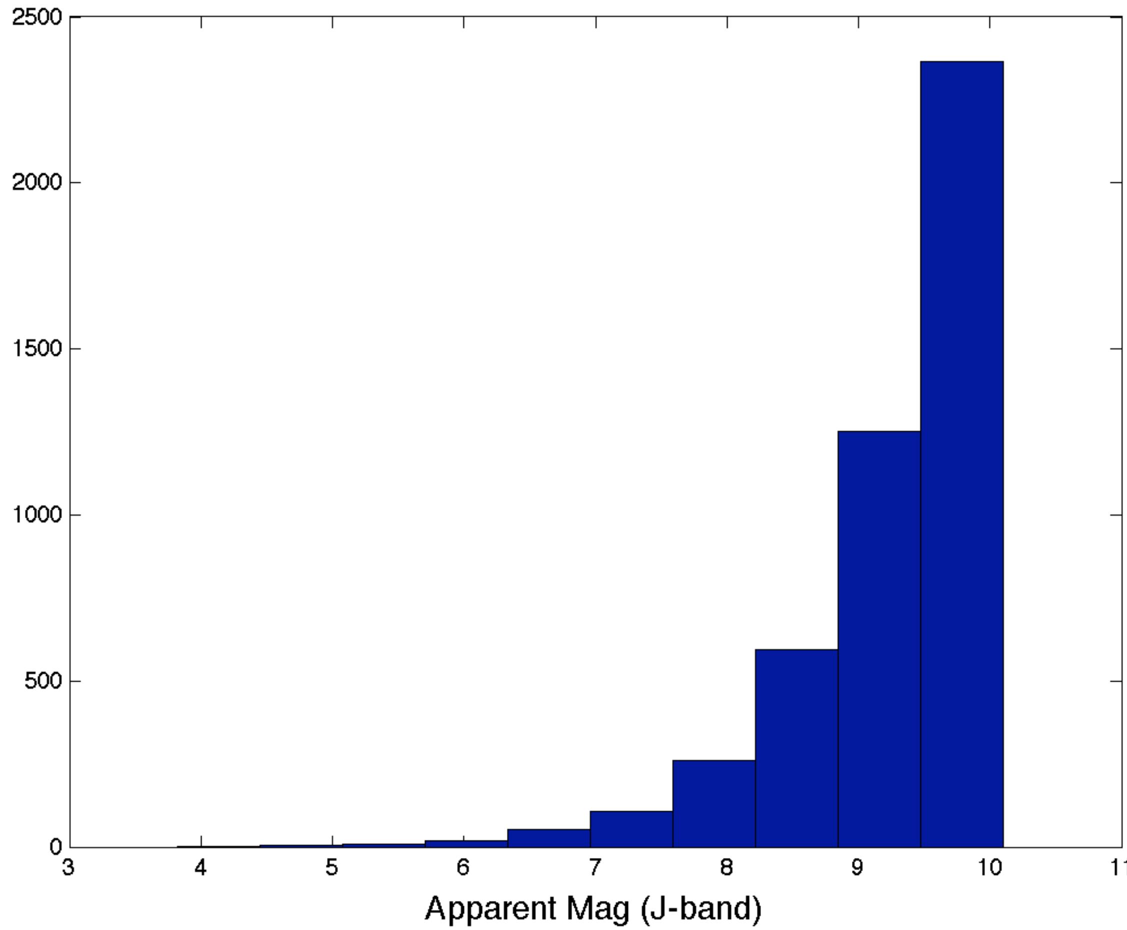
Swain et al. 2009

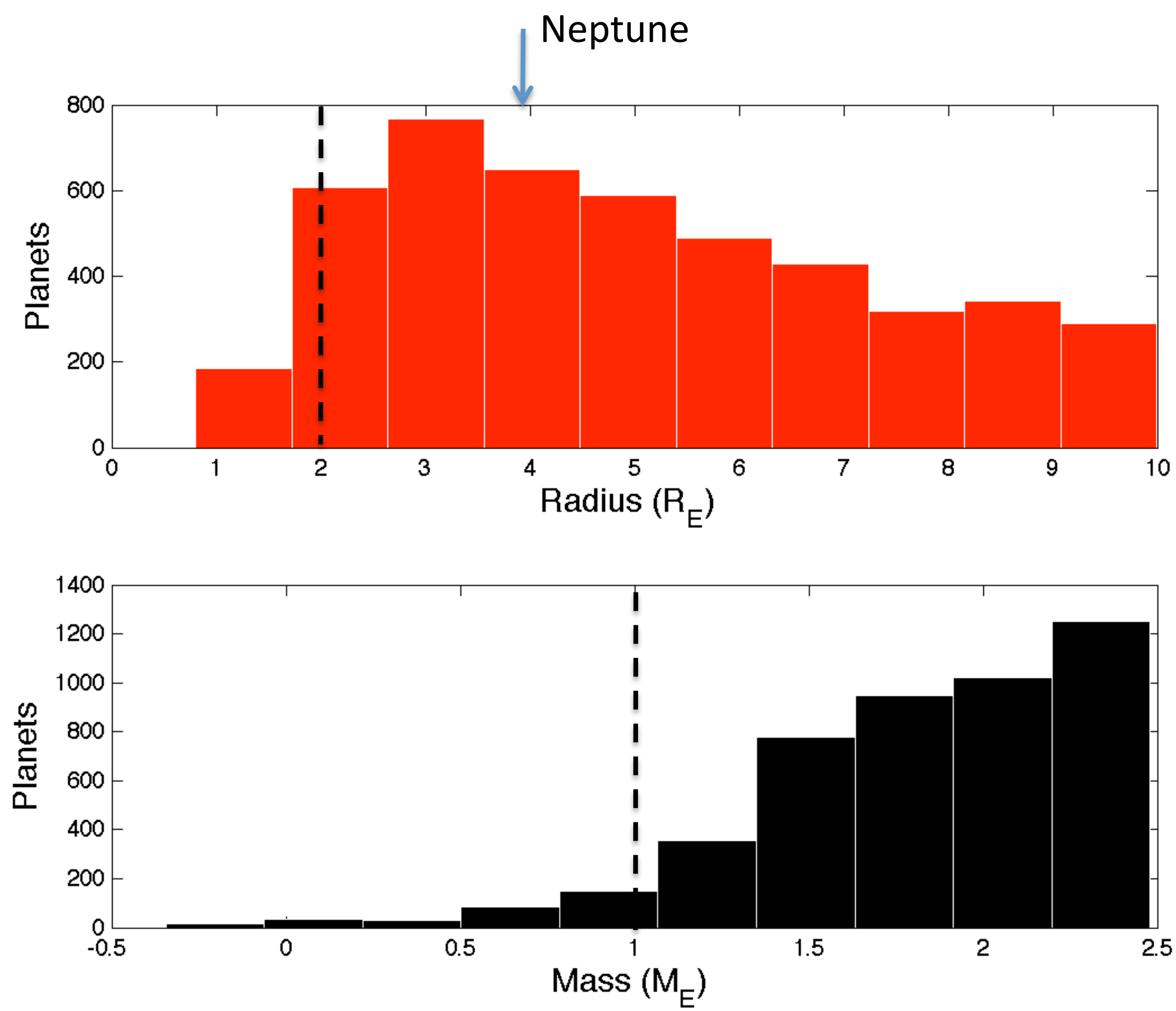
HD 209458b Emission



Also Madhusudhan & Seager 2009

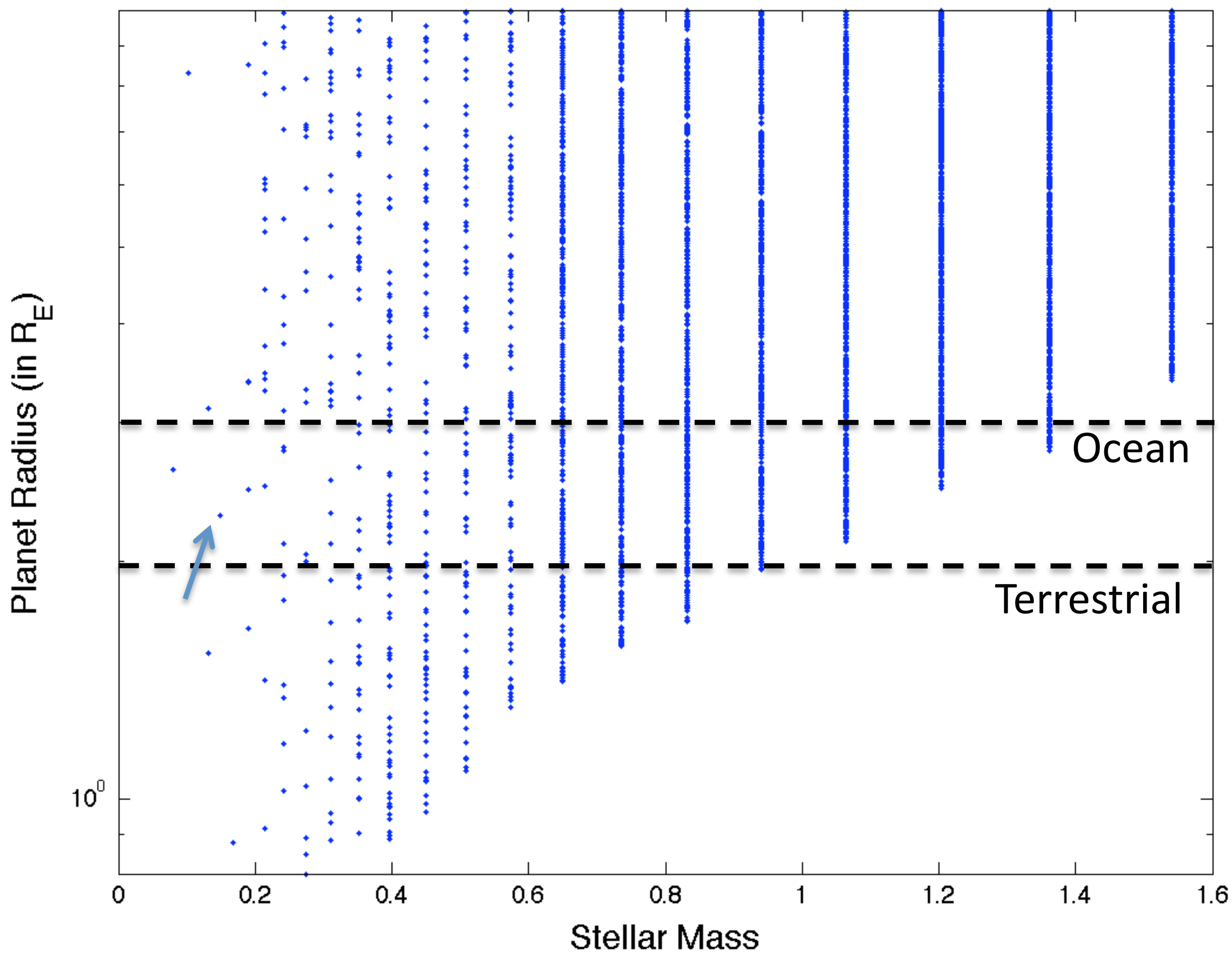
Future



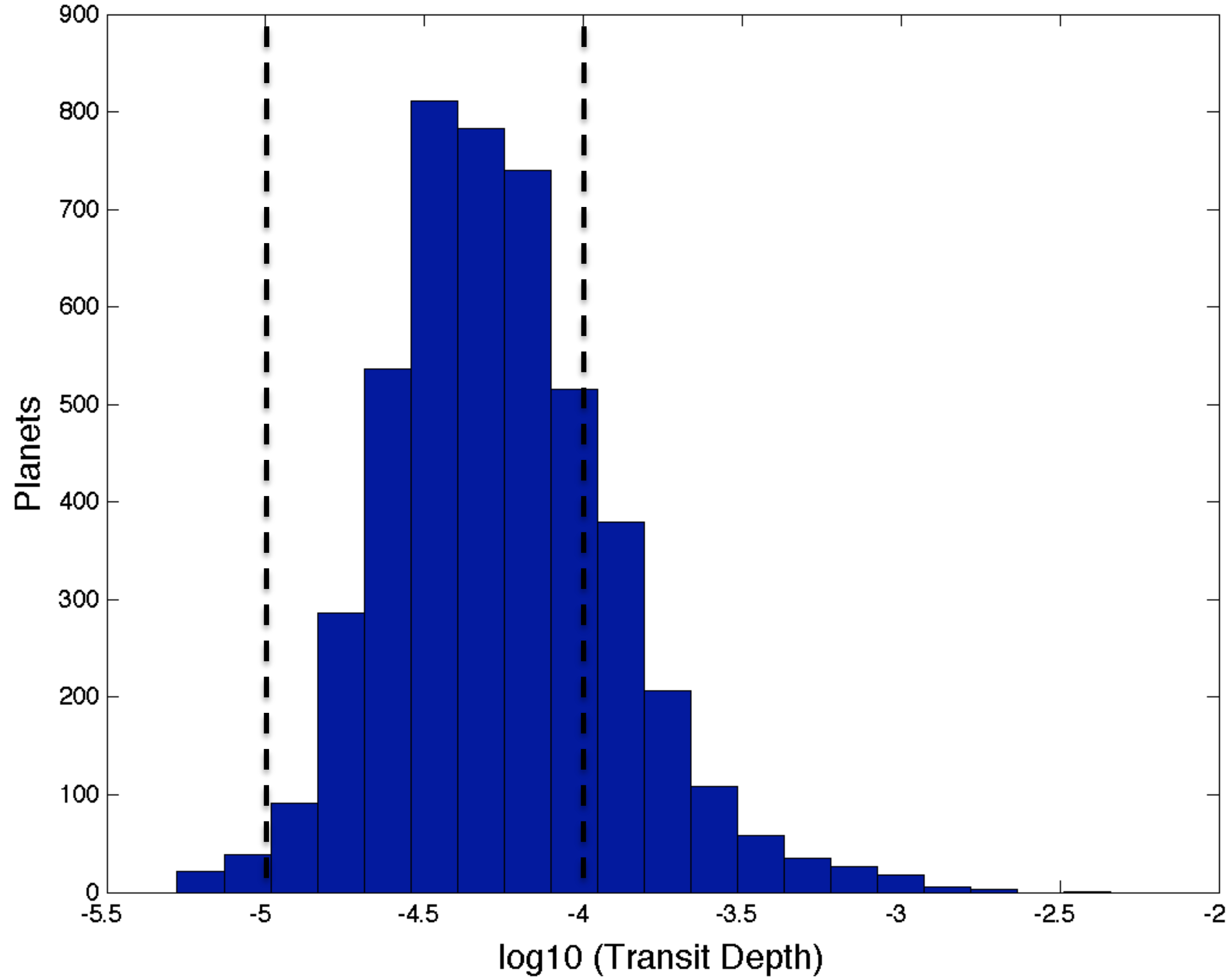


Mass radius relations from Seager et al. 2007

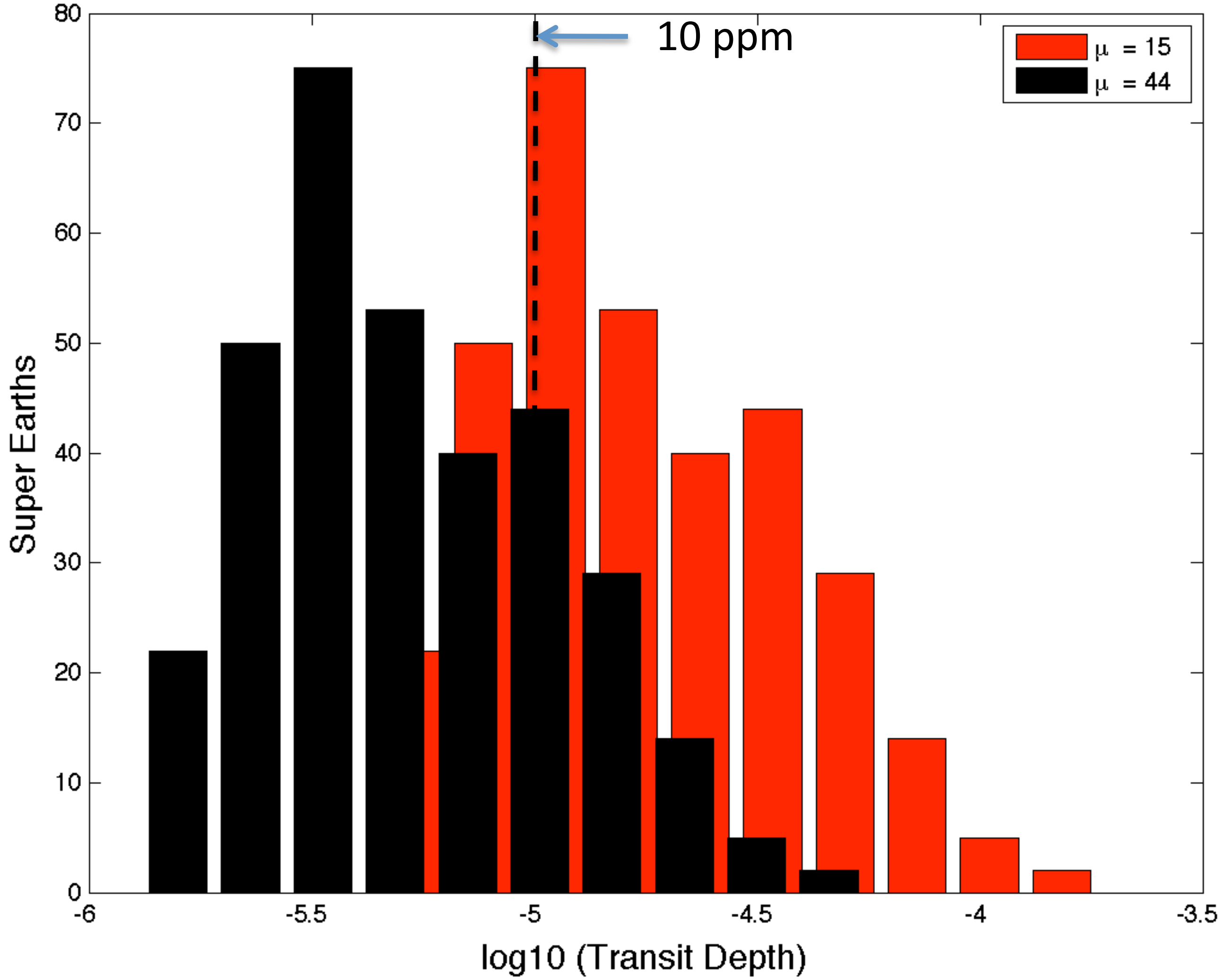
Planets and Host Stars



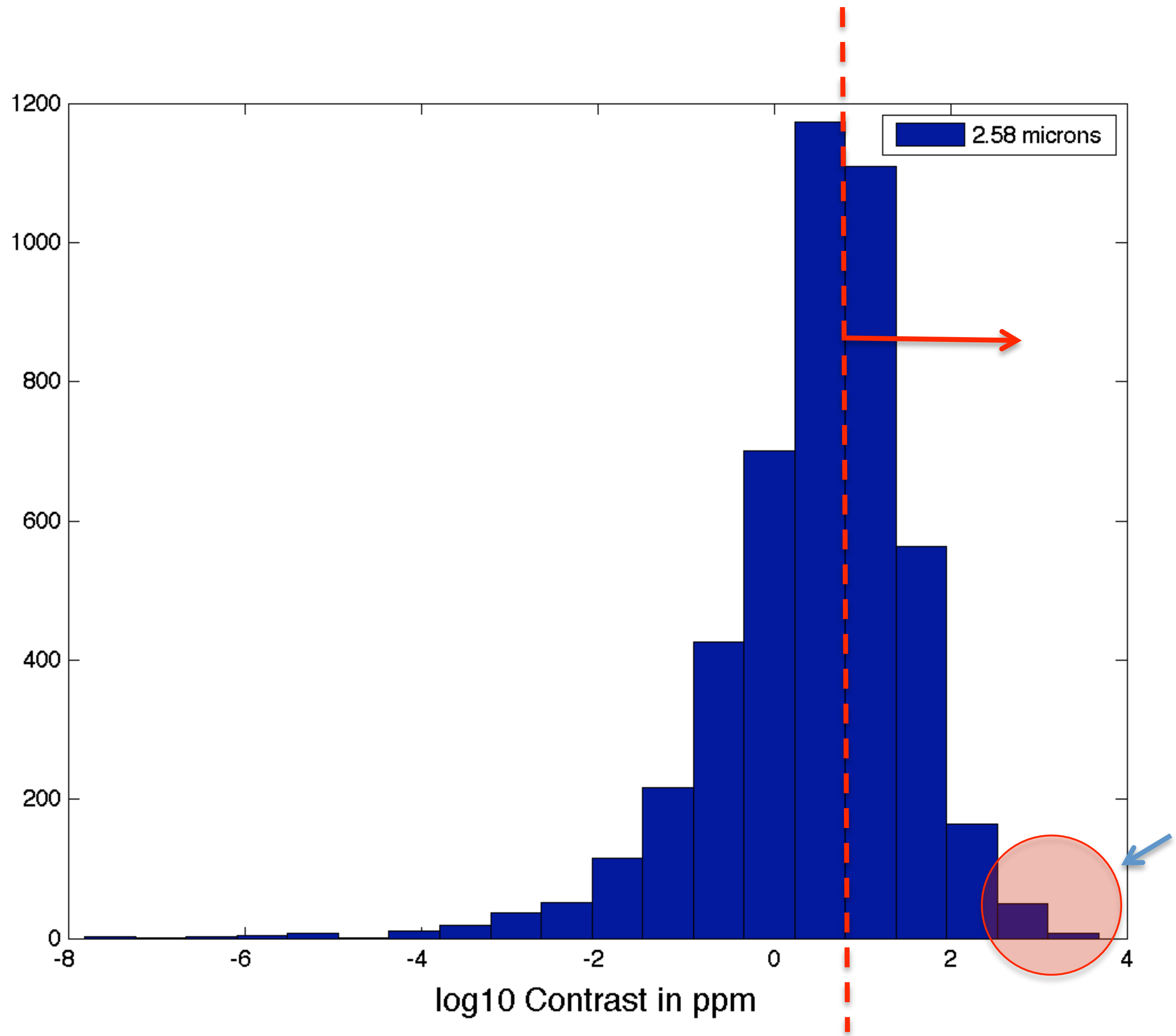
Transit Signal (5 Scale heights)



Transit Signal (5 Scale heights, SEs)

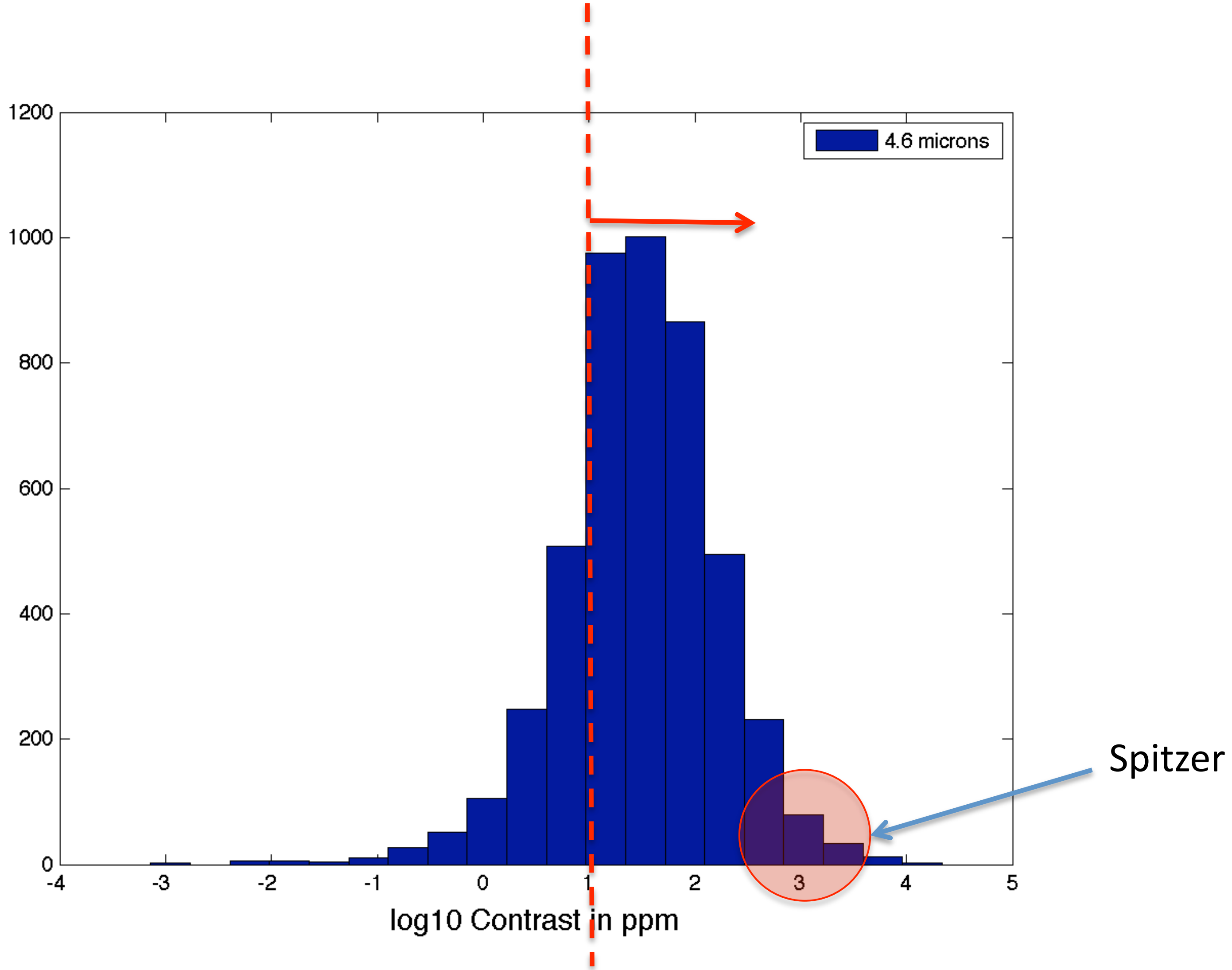


Near IR eclipse depths (H_2O band)



Planets being targeted with HST.

Near-to-Mid IR (CO_2 bands)



Summary

- *As of now, only the brightest, most favorable, exoplanetary systems have been targeted with spectroscopy.*
- *Signatures typically smaller than the raw measurement capabilty.*
- *Repeated measurements generally hard to obtain. Limited phase coverage and limited cadence.*
- *50 cm telescopes, with good/stable spectrographs would be invaluable. Optical to NIR (up to 5 microns) is most optimal. An ensemble of measurements, on a select group of bright exoplanets, would be scientifically invaluable.*