Towards Habitable Planetary Systems Using JWST…and ELTs

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This talk will discuss:

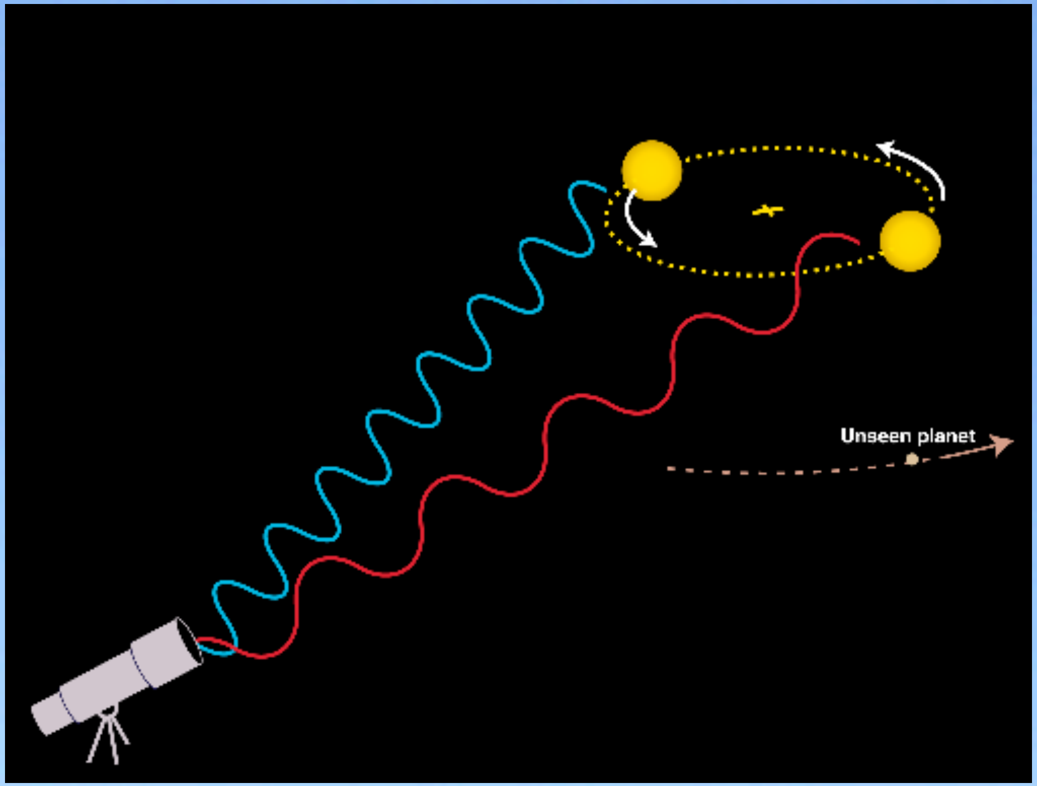
The landscape of extrasolar planets
…..and detection techniques

Some history

How to find and characterize a habitable world
……using transits

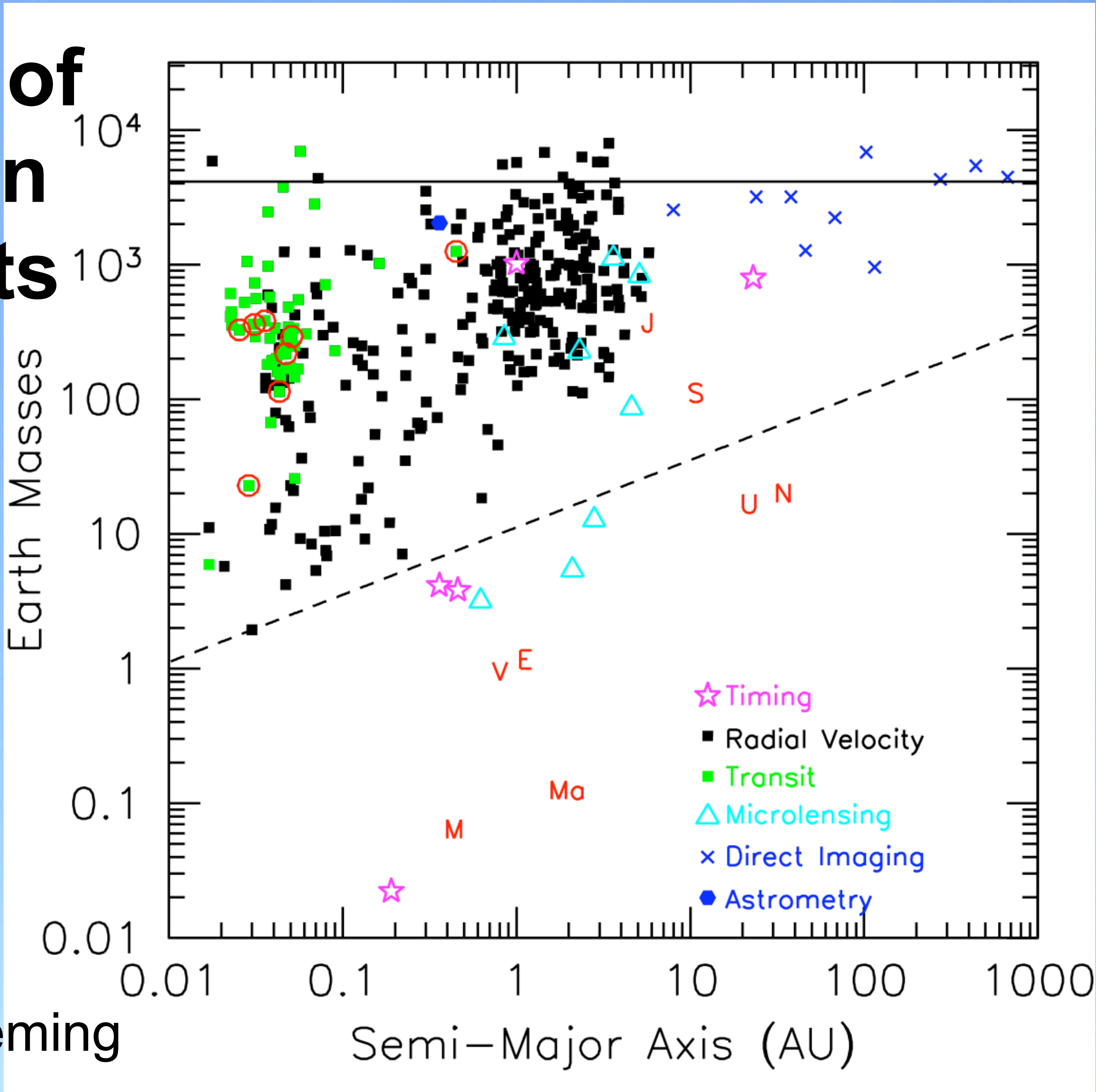
Roles of JWST vs. ELTS

Most of the > 450 exoplanets have been detected using radial velocities



…an *indirect* detection:
light from the planet is not measured

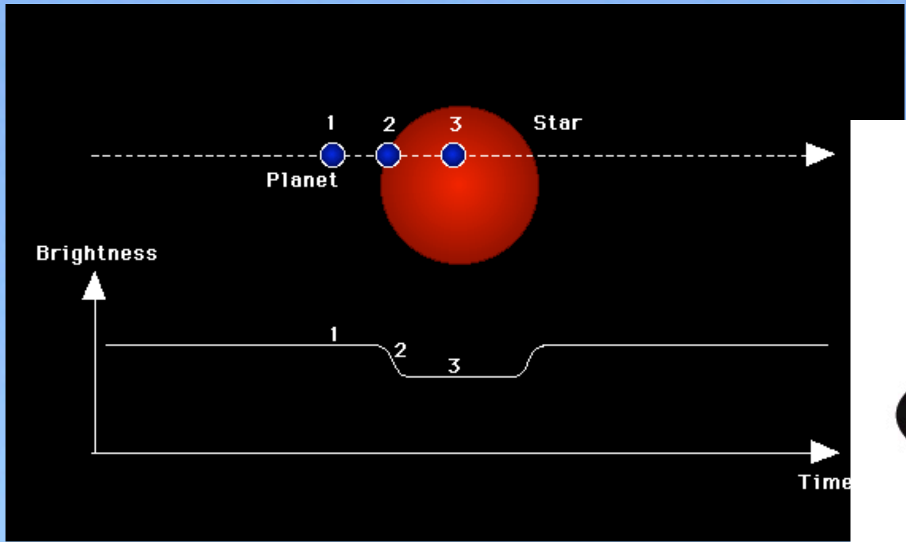
Summary of the known exoplanets



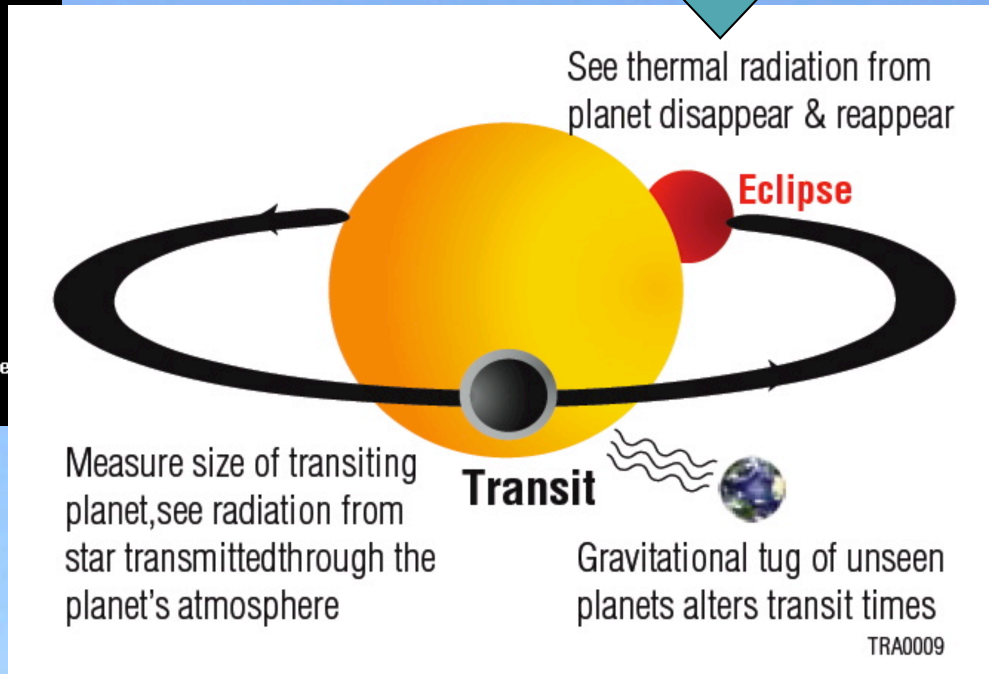
Deming & Seager review in Nature 462, 301 (2009)

Also, Seager & Deming ARAA (2010)

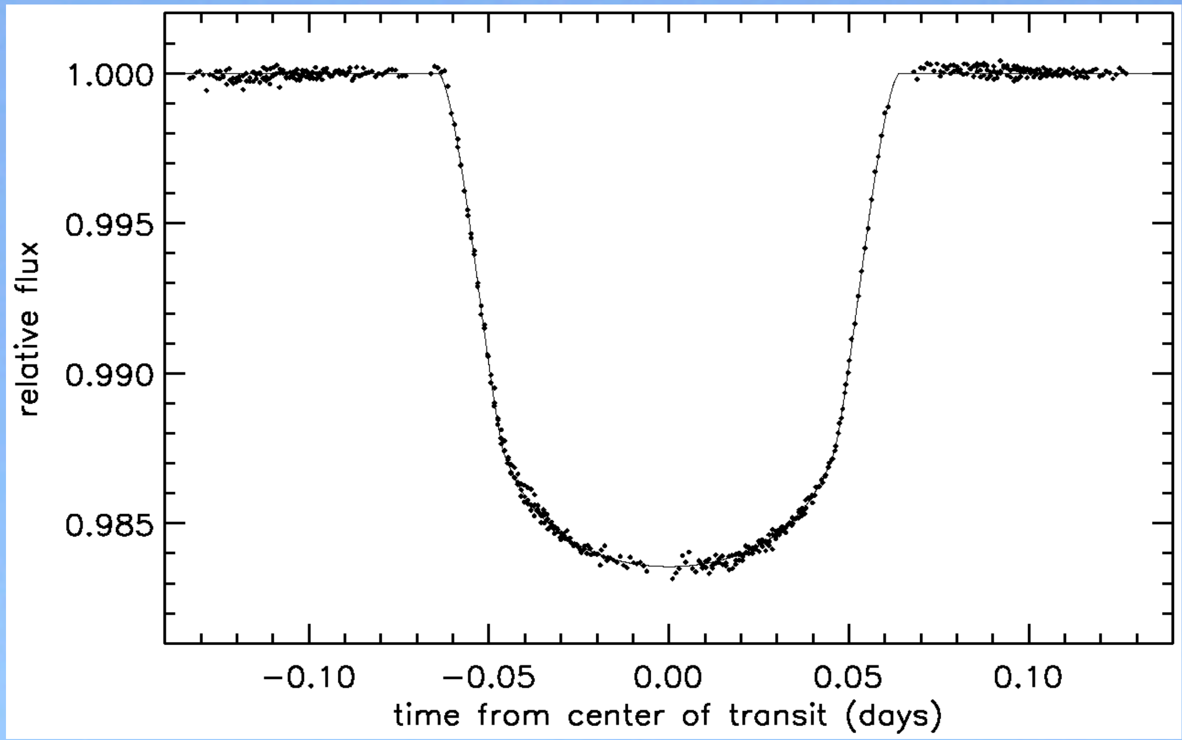
Exploit transits to characterize SuperEarth Atmospheres…



Direct detection
of light from the planet



Can we characterize the atmosphere of a SuperEarth using transits…? A habitable one??

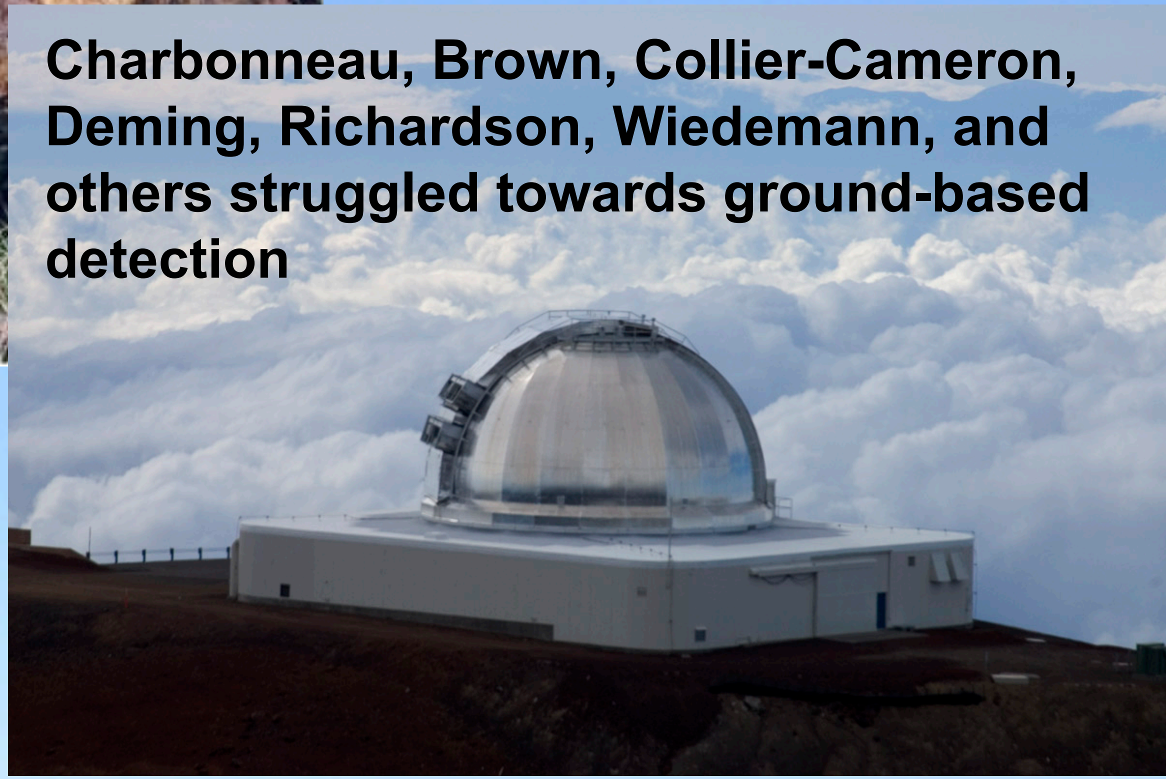


Brown et al. 2001, ApJ 552, 699

Transit data immediately yield the planet's bulk properties - mass (0.69 M_J) and radius (1.35 R_J)

→ Can we characterize the atmosphere?

Emitted/reflected spectra of hot Jupiters in the paleolithic age (1999-2003)

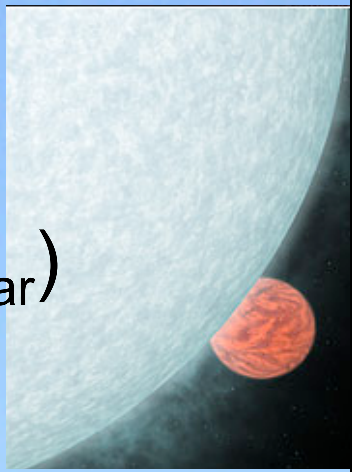


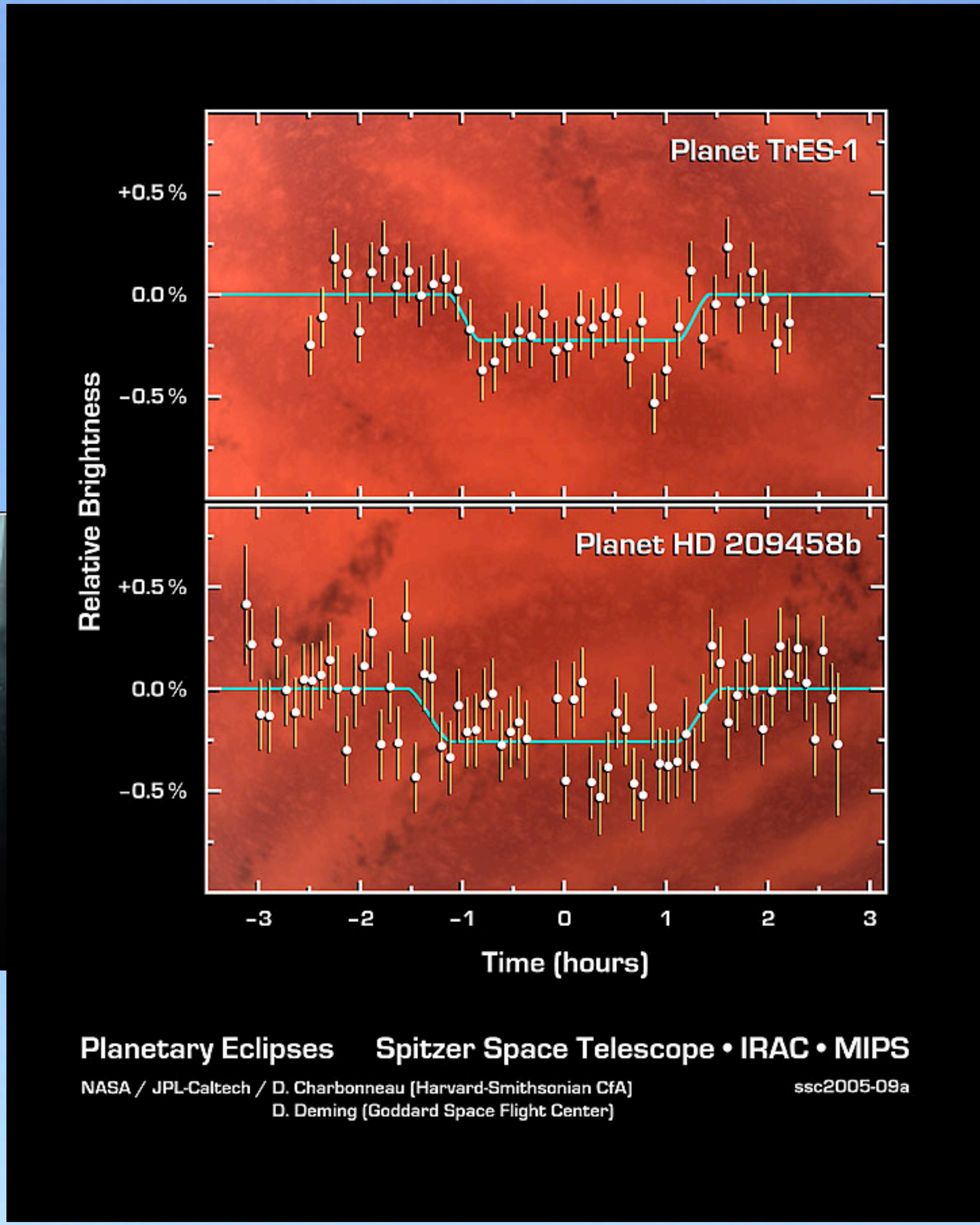
"First Light" Thermal Emission

Spitzer enables direct detection of IR light from the planets

eclipse depth ~ $(R_p/R_{star})^2(T_p/T_{star})$

yields T ~ 1100K



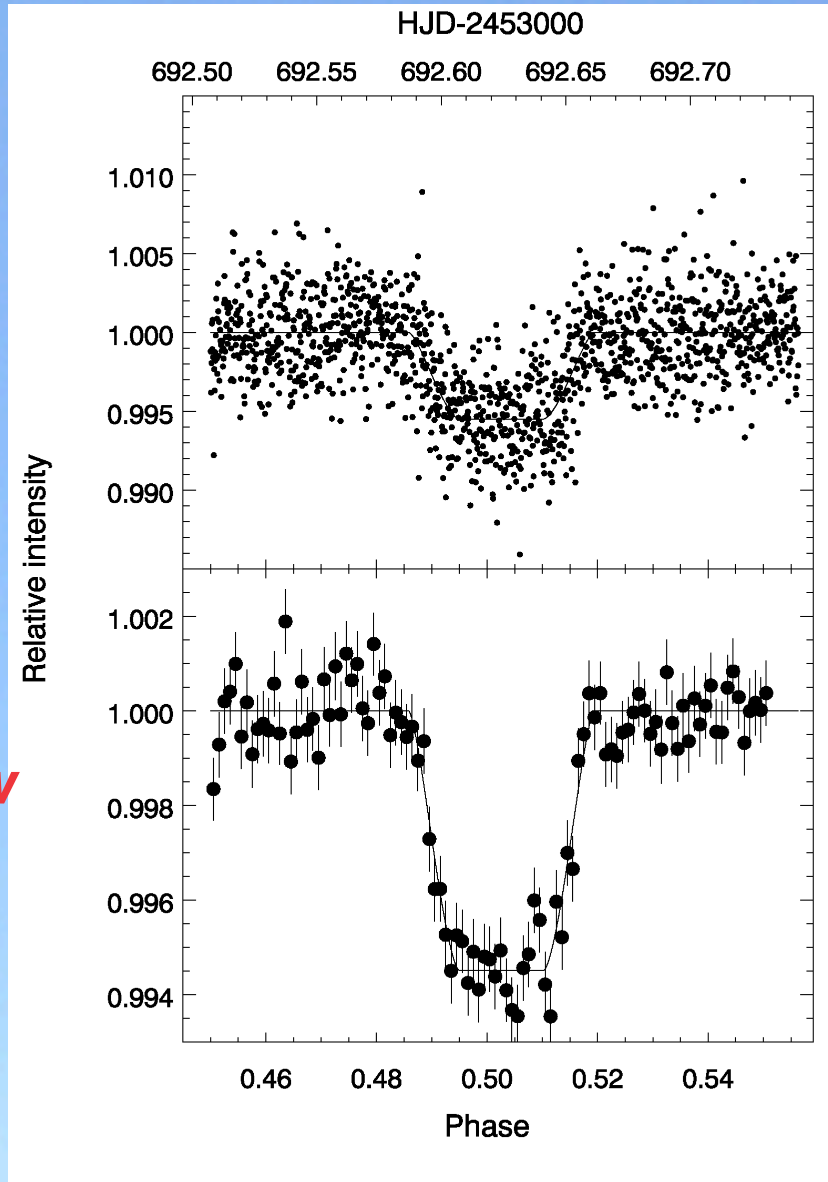


Six Spitzer photometric bands can give a low resolution spectrum of the planet

Eclipse of HD 189733B

eclipse depth ~ $(R_p/R_{star})^2(T_p/T_{star})$

Dominant term



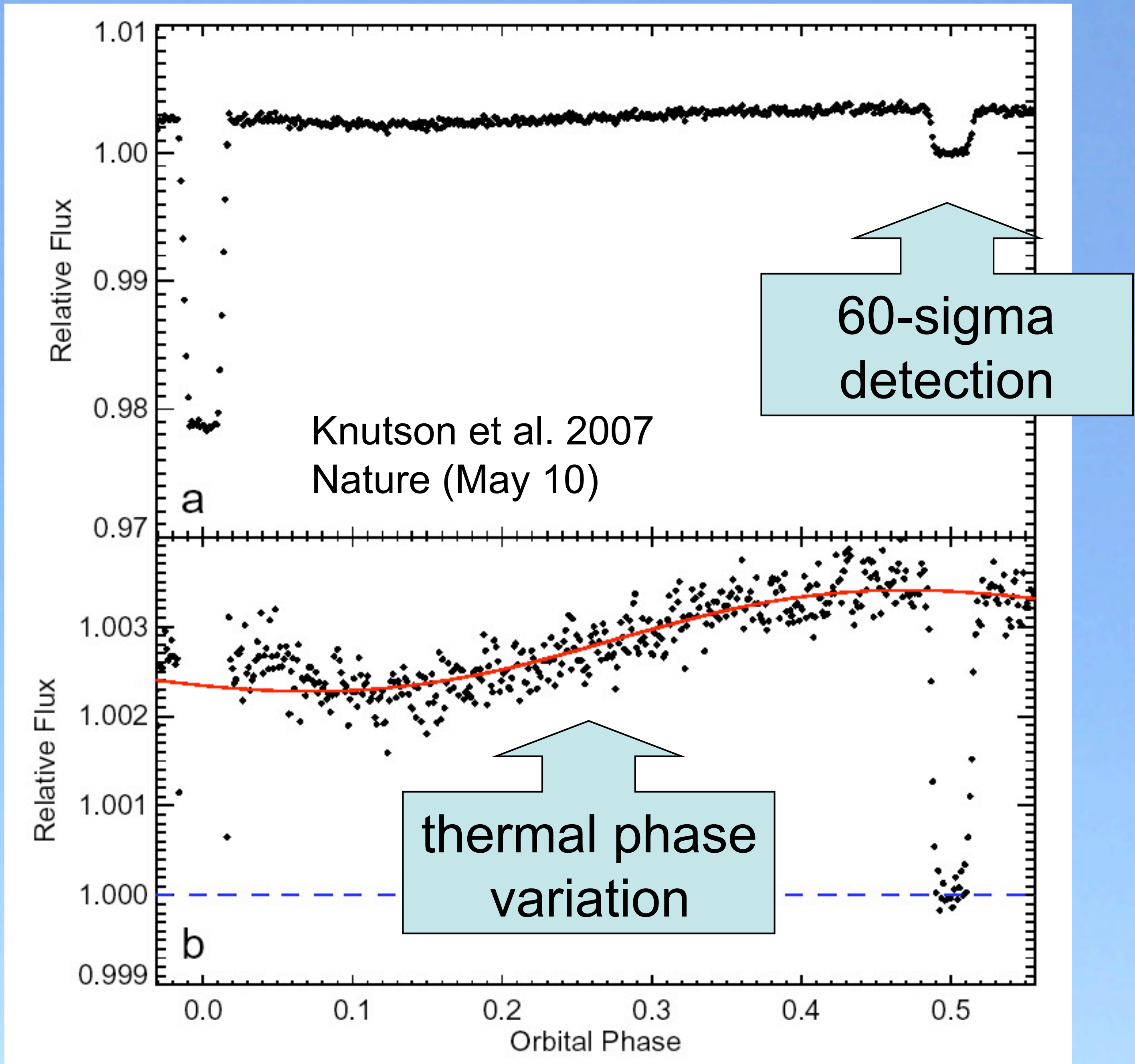
$T_p \sim T_{star}\, \Delta^{0.5}$

lower main-sequence stars allow high S/N planet detection

HD 189733b (K3V)

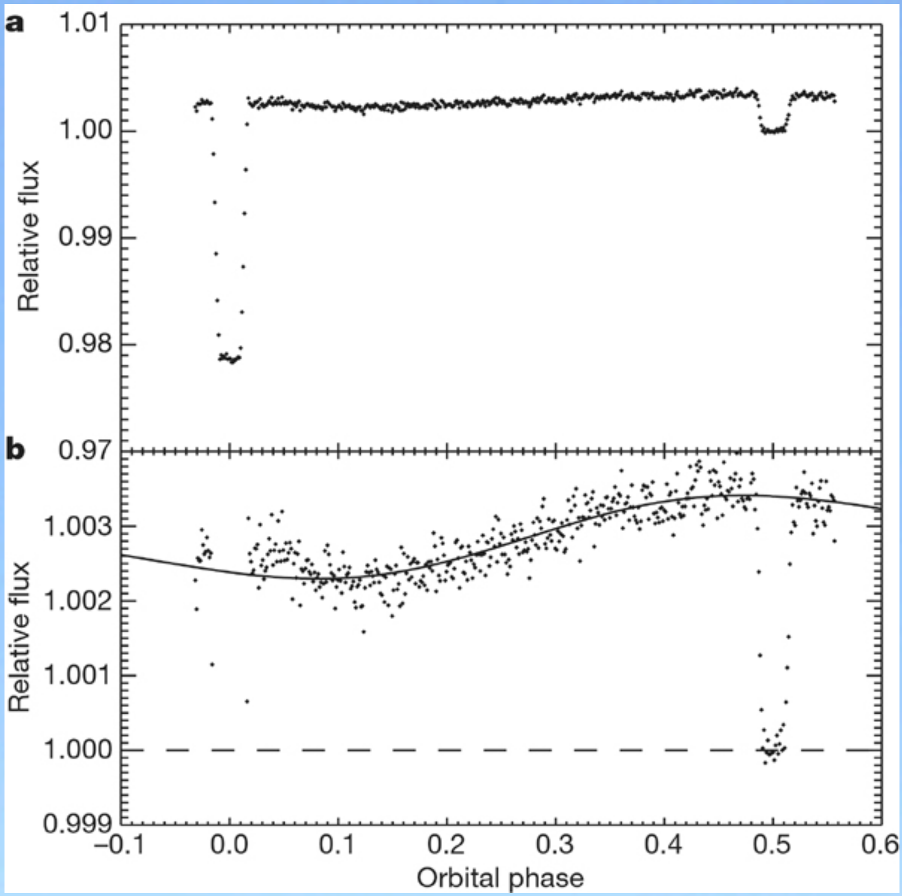
32σ detection at 16 μm

Deming et al. 2006, ApJ 644, 560

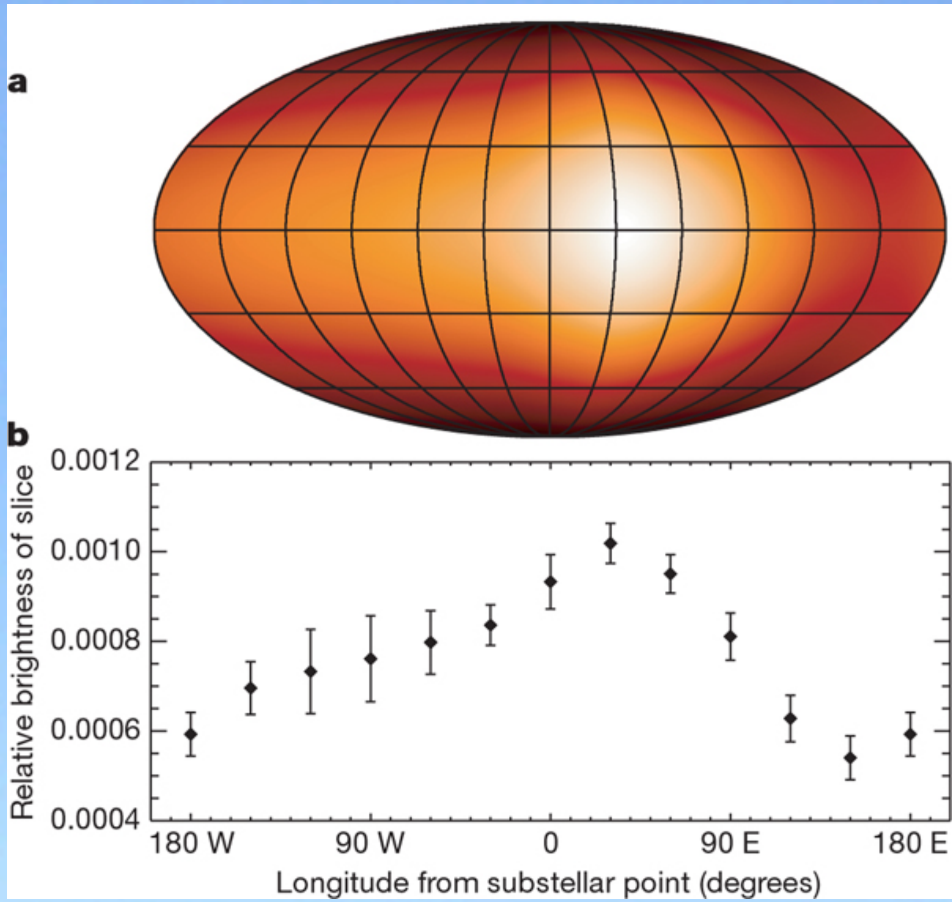

1.01
1.00
0.99
0.98
0.97
Relative Flux
a
Knutson et al. 2007
Nature (May 10)
60-sigma
detection
1.003
1.002
1.001
1.000
0.999
Relative Flux
b
thermal phase
variation
0.0
0.1
0.2
0.3
0.4
0.5
Orbital Phase

A Surface Emission Map of an Exoplanet

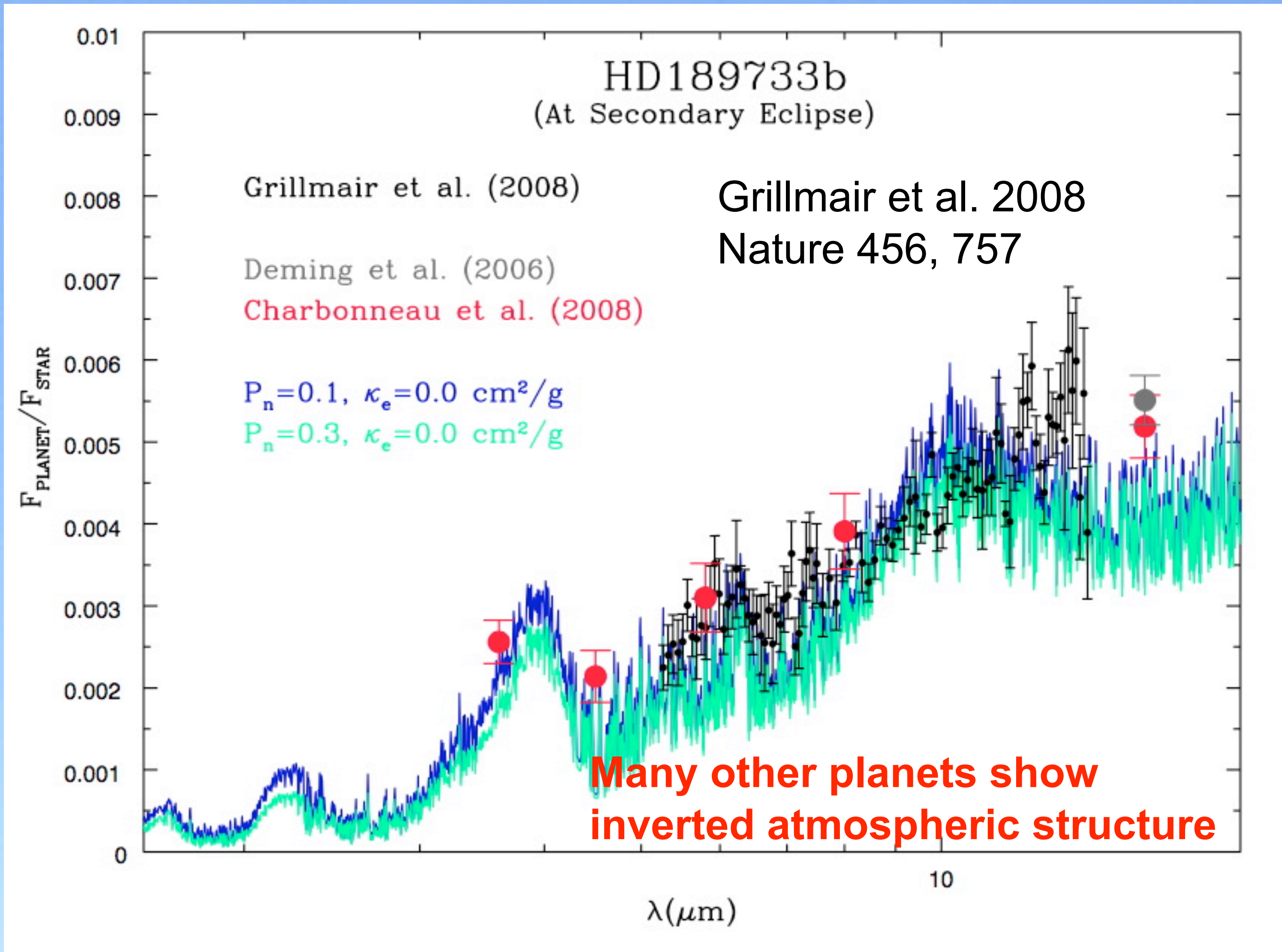
implies significant redistribution, with a phase lag in longitude (winds)



Knutson, Charbonneau, et al. (2007)



An Exoplanet Spectrum (R ~ 100)



~ 30% of FGKM stars host superEarths, based on:
Microlensing (Gould et al. 2006, ApJ 644, 237)
Radial Velocity Surveys (Mayor et al. 2009, ApJ 493, 639)

Their atmospheres initially contain: H_2, H_2O, CO, CO_2

Elkins-Tanton & Seager 2008
ApJ 685, 1237
Schaefer & Fegley 2009,
astro-ph/0909.4050
Miller-Ricci et al. 2009,
ApJ 690, 1056

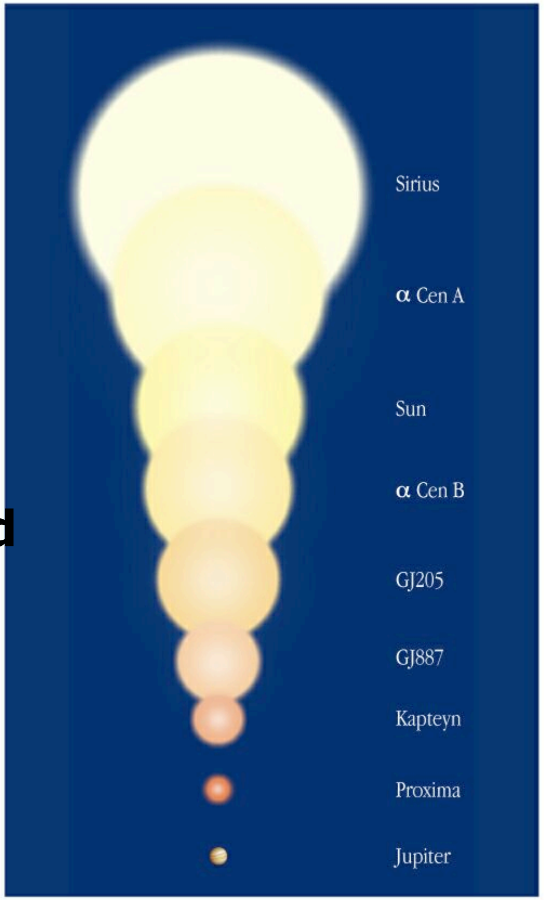
Both thermal and non-thermal atmospheric escape rates are uncertain… but the atmospheres can contain residual H_2
…making their detection easier

The M-dwarf Opportunity

The lowest mass stars (M4V and later) are attractive targets for 3 simple reasons:

1. They are VERY numerous (they outnumber Sun-like stars 10:1).
2. The habitable zone lies close to the star implying short orbital periods (~10 days) and a higher probability of transits.
3. The small stellar size means that rocky planets can be detected with ground-based precision.

- D. Charbonneau



Relative Sizes of the Alpha Centauri Components and Other Objects

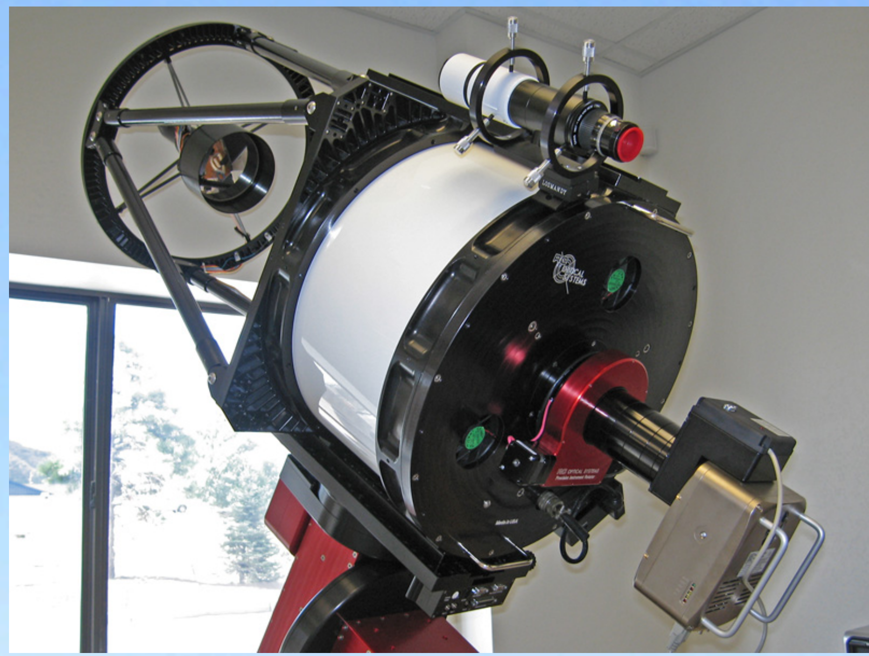
ESO PR Photo 07b/03 (15 March 2003)

The nearest habitable world orbits an M-dwarf

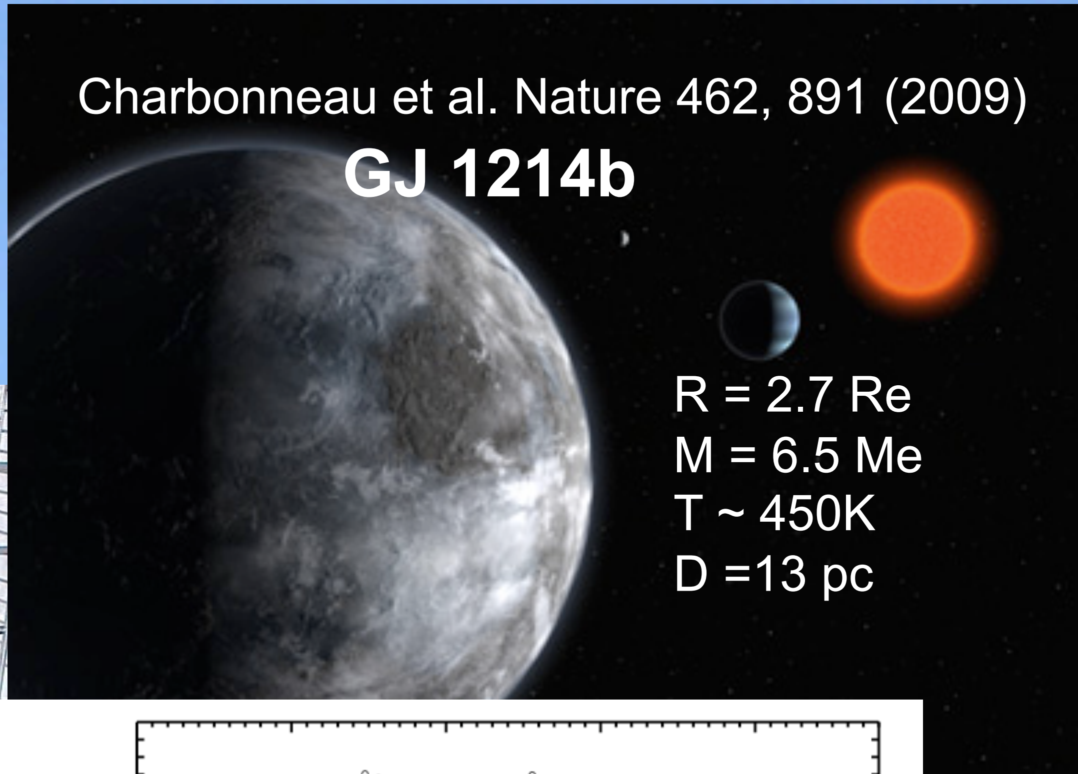
The MEarth Project

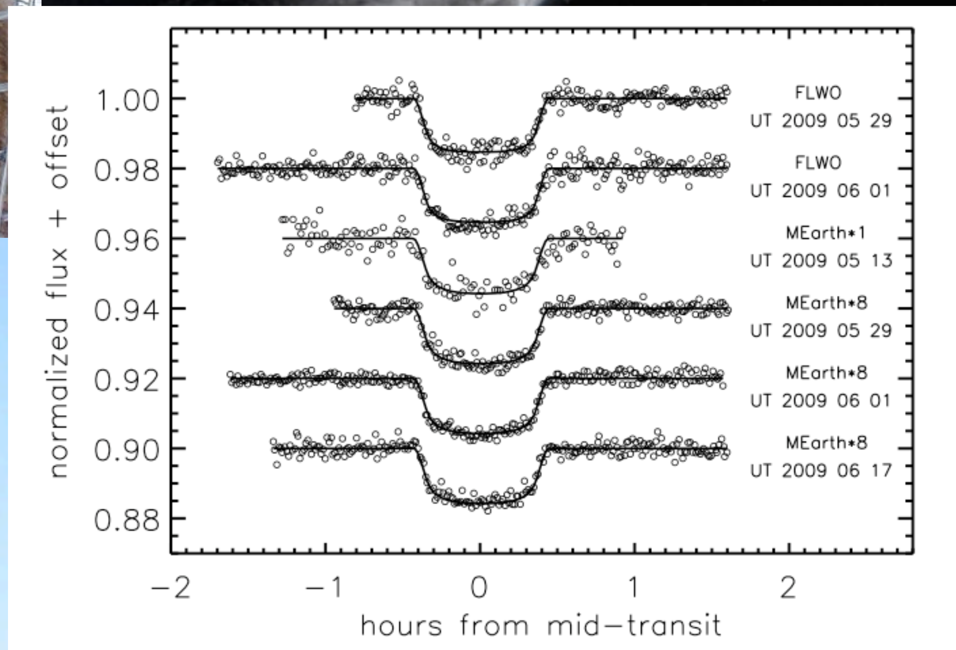
Charbonneau et al.

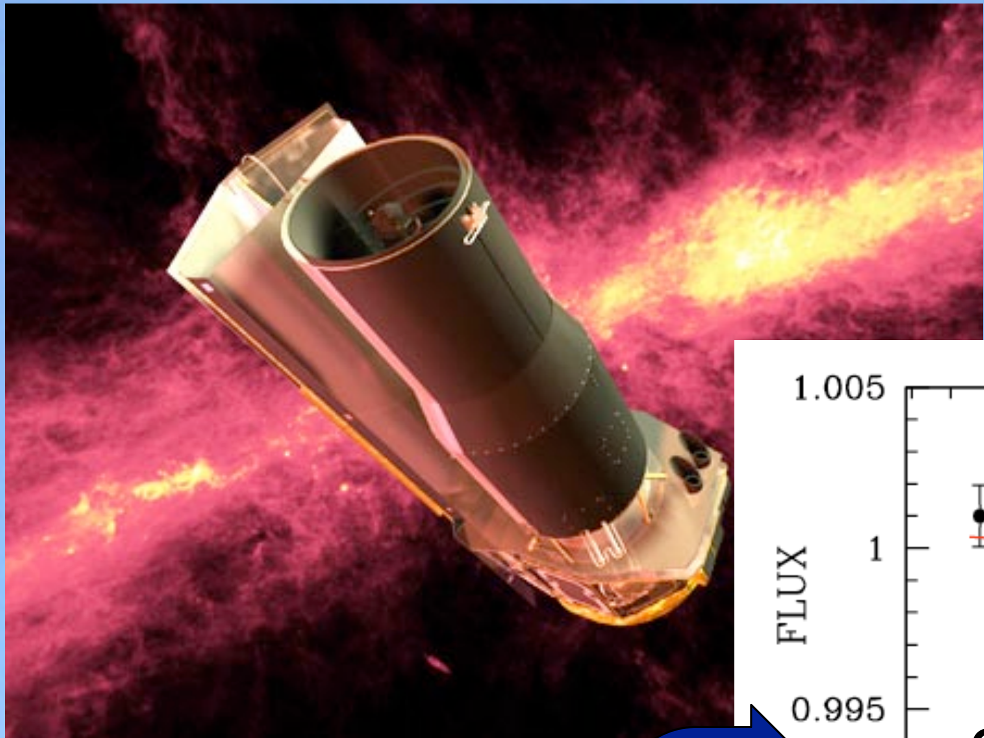
- Using 8 X 16-inch telescopes to survey the 2000 nearest M-dwarfs for rocky planets in their habitable zones
- Converted an existing abandoned building on Mt Hopkins, AZ
- Fully operational as of September 2008
- Southern hemisphere extension under development
- **These planets will be amenable to spectroscopic follow-up to search for atmospheric biomarkers**



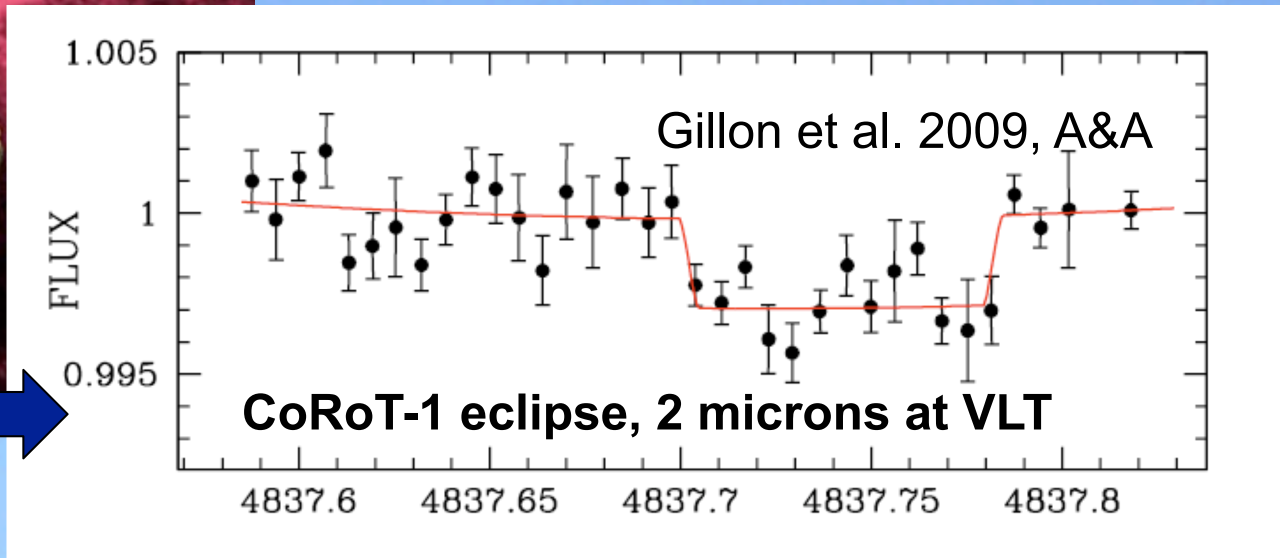
The First MEarth Super-Earth





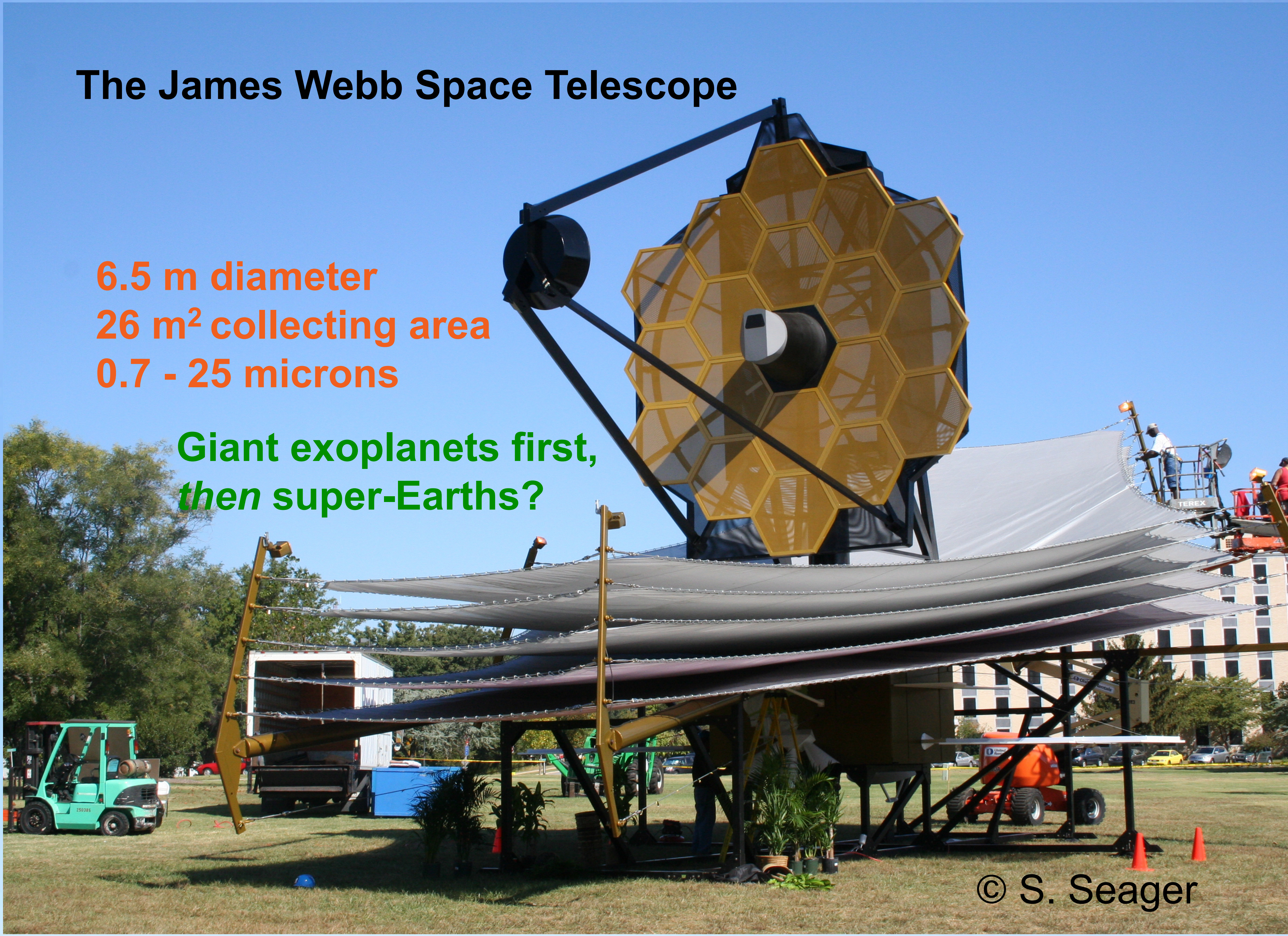


Spitzer brought us to the modern era of exoplanet characterization

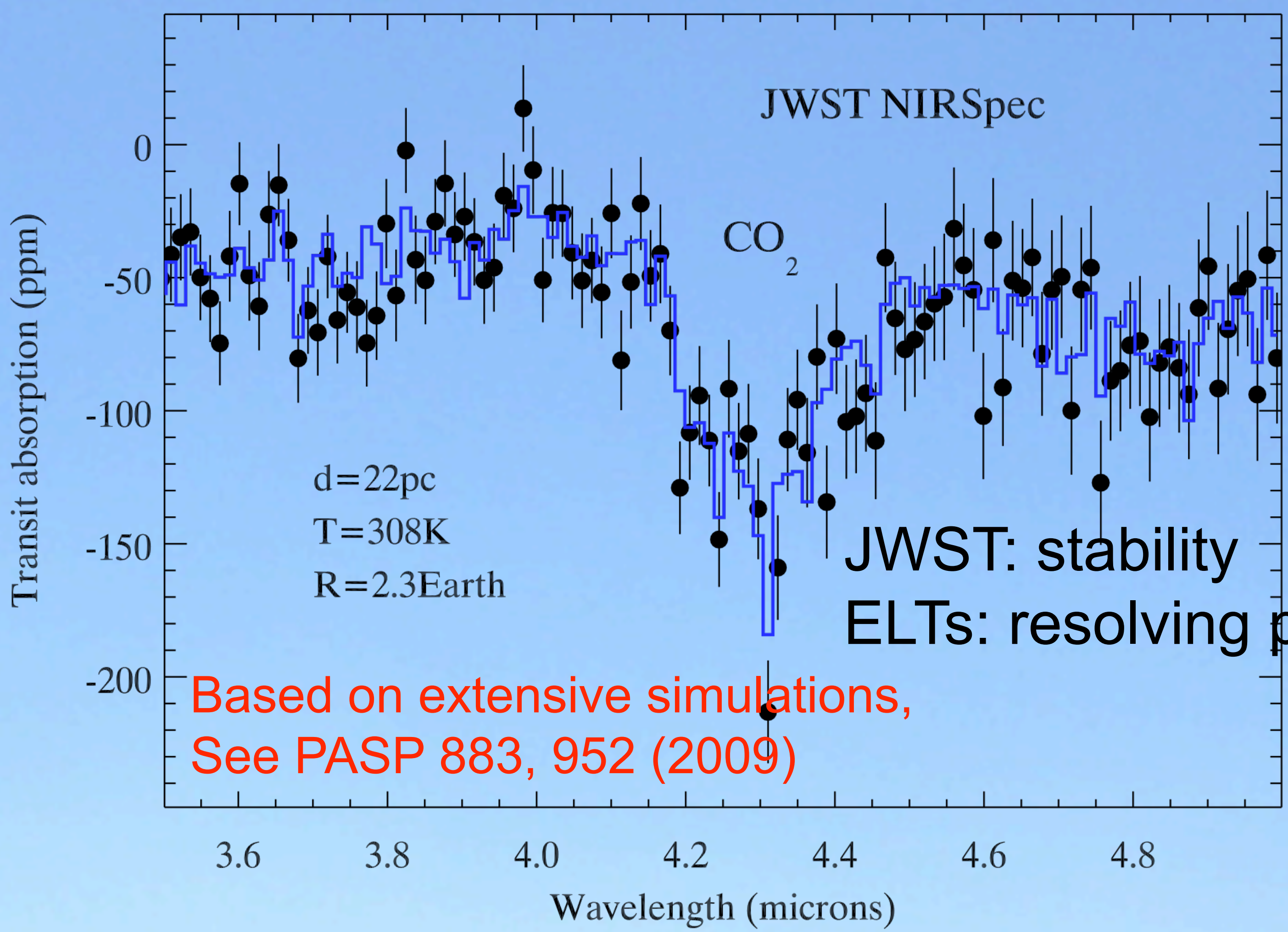


Ground-based detection is now easier because we *know* the nature of the signals from Spitzer detections

So…JWST first, then ELTs


The James Webb Space Telescope
6.5 m diameter
26 m^2 collecting area
0.7 - 25 microns
Giant exoplanets first,
then super-Earths?
© S. Seager

Example of carbon dioxide in a habitable SuperEarth



JWST: stability
ELTs: resolving power

Based on extensive simulations,
See PASP 883, 952 (2009)

Conclusions and comments

- Spitzer – and now ground-based observers – have detected light from transiting extrasolar planets
- A habitable world transiting a nearby M-dwarf can be characterized (major molecular constituents) using JWST
- JWST first, then ELTs
  - JWST stability will clarify the nature of the signals
  - ELTs will exploit their spectral resolution
- For true Earth analogs, we will need high contrast imaging from space (TPF)