Detection and Characterization of Habitable Worlds … using JWST

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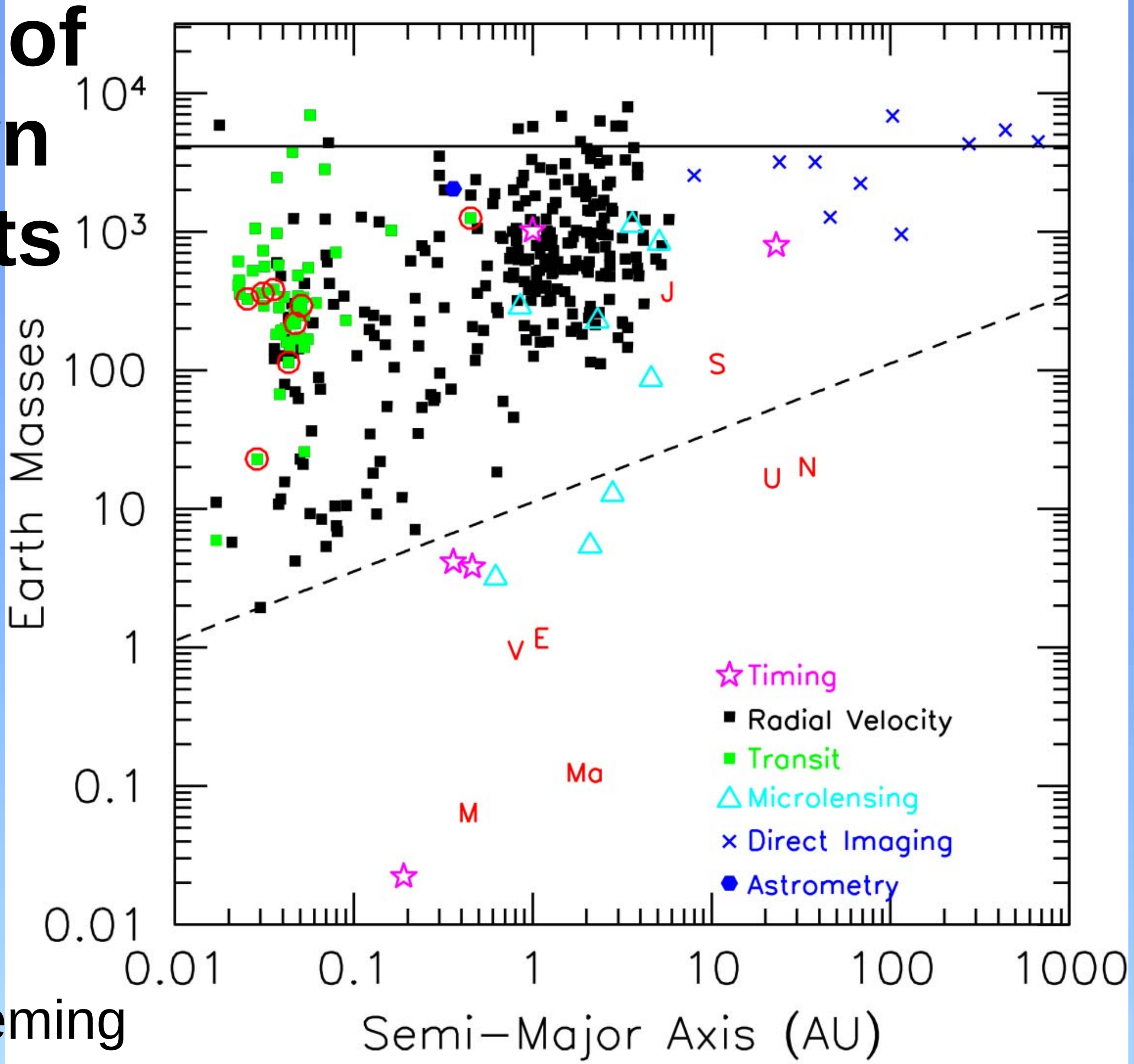
Summary of the known exoplanets



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

Also, Seager & Deming ARAA (2010)

We want to find:

a habitable, nearby, transiting, SuperEarth

***Finding them* with an all-sky survey**

***Characterizing their atmospheres using* JWST**

Based on PASP 883, 952 (2009)

Contributors: **Sara Seager, Josh Winn, Eliza Miller-Ricci, Mark Clampin, Don Lindler, Tom Greene, Dave Charbonneau, Greg Laughlin, George Ricker, Dave Latham, and Kim Ennico**

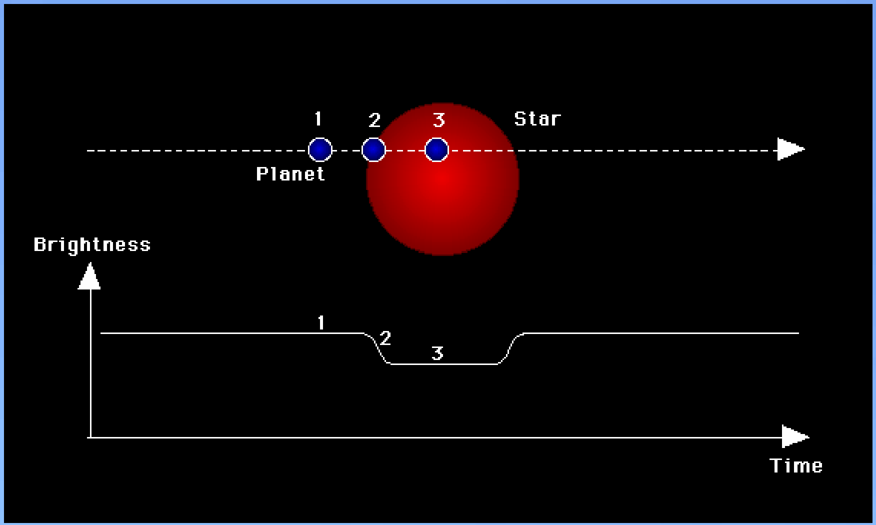
~ 30% of FGKM stars host superEarths, based on:
Microlensing (Gould et al. 2006, ApJ 644, 237)
Radial Velocity Surveys (Mayor et al. 2009, ApJ 493, 639)

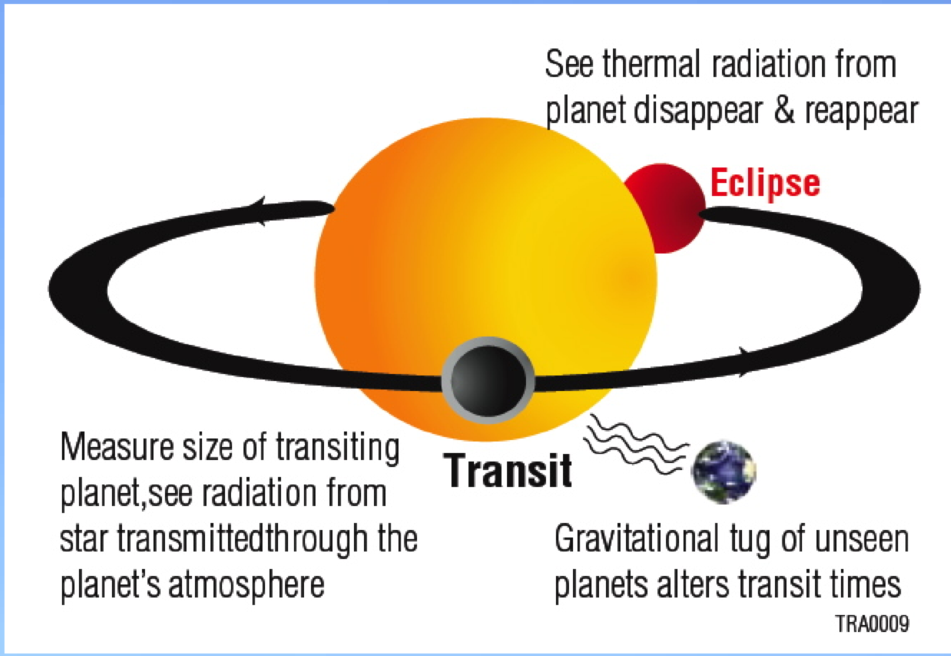
Their atmospheres initially contain: H_2, H_2O, CO, CO_2

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… so we here adopt the intermediate H_2 case of Miller-Ricci et al.

Exploit transits to characterize SuperEarth Atmospheres…



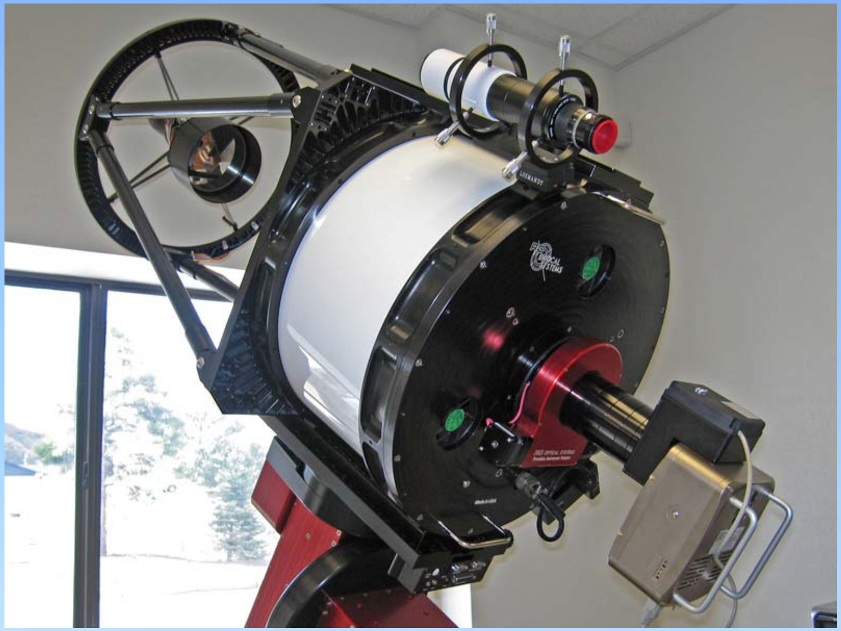


Can we characterize the Atmosphere of a SuperEarth using transits…? A habitable one??

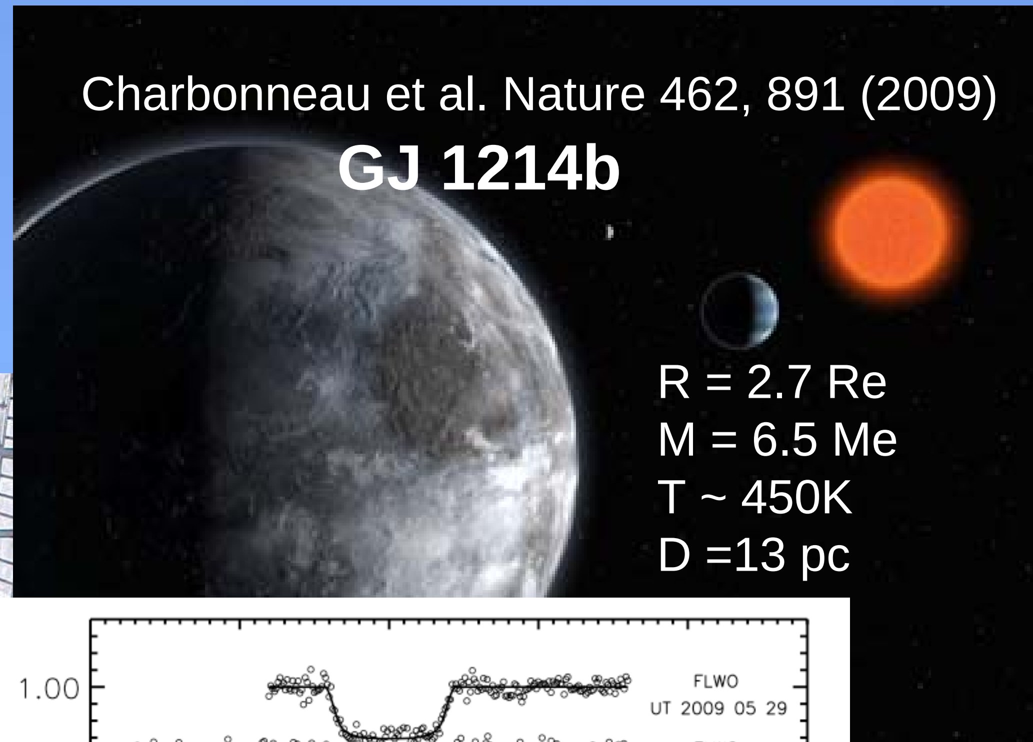
The MEarth Project

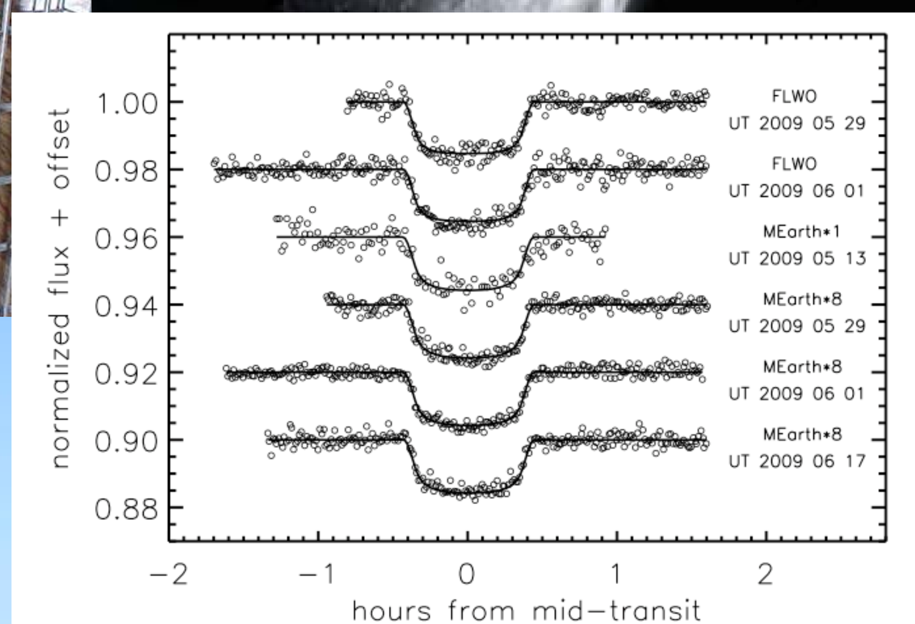
Charbonneau et al.

- 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; southern version planned
- **These planets will be amenable to spectroscopic follow-up to search for atmospheric biomarkers**



The First MEarth Super-Earth





Everything from here on is *simulation….* *of TESS and JWST*

Stars in 2000 pc^3 centered on the Sun

F5-M8, 200 pc scale height in Z

number density varying with spectral type

One planet per star, from Earth to Jupiter in size

Equal numbers per log R

half water-dominated, half silicate

Equal numbers per log *a*

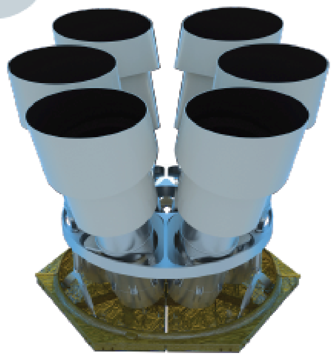
(with stellar luminosity scaling)

Record the coordinates and transit probability

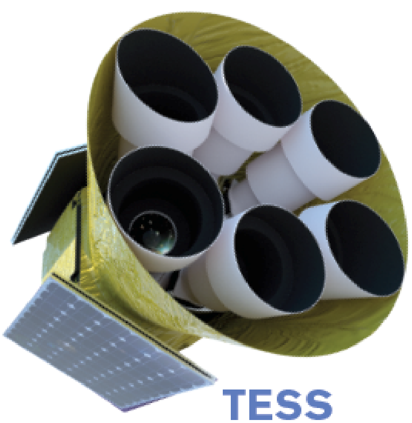
… and each planet's equilibrium temperature

Find them with TESS

5. TESS Instrumentation Fulfills Science Requirements



Six Camera Ass’y



TESS
“all-dressed up”

TESS Characteristic	Value or Range
CCD Detectors	Quad MIT/LL CCID-68s (4000x4000 imaging array @ 15µm/pixel)
CCD Mode	Shutterless: 2 s integrate, 2 ms frame transfer
CCD Space Flight History	6 years operation on HETE-2 (as CCID-20) Very low hot pixel rate in equatorial orbit
Lens Aperture	12.7 cm
Pixel Scale	16.3" $pixel^{-1}$
Camera Field-of-View	18° x 18°
Number of Cameras	6
Ensemble Field-of-View	54° x 36° = 1944 deg^2
Pass Band	600-1000 nm
Data Downlink Rate	10 Gbytes day^{-1}
Launch Date	Late 2012
Survey Duration	2 years for All Sky

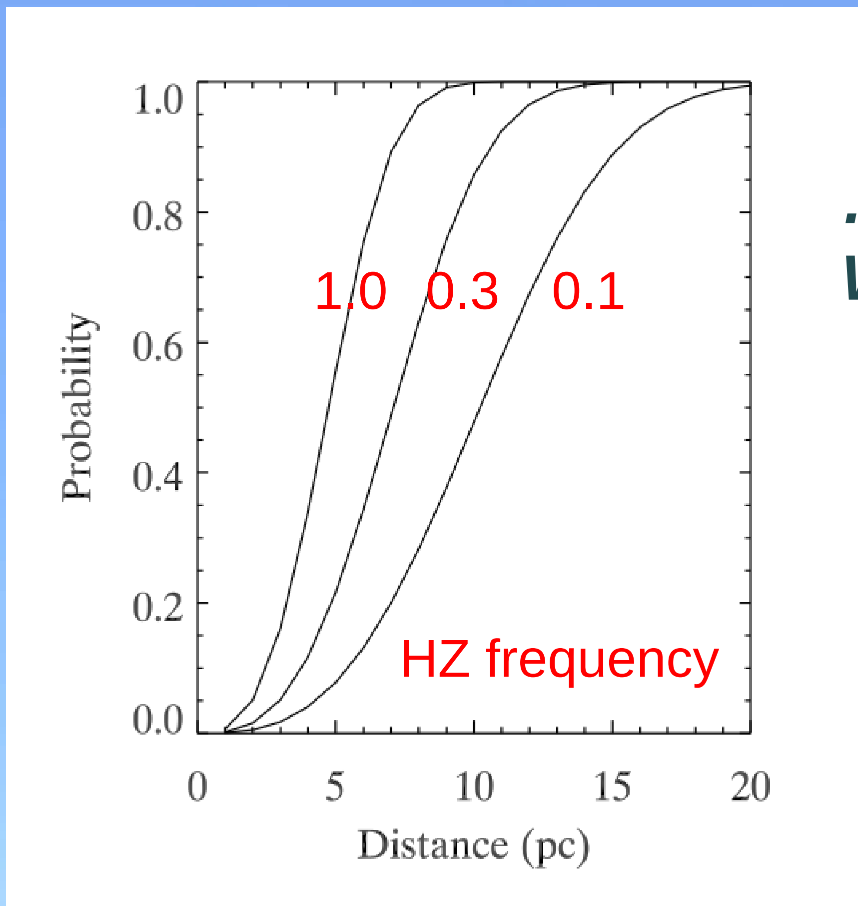
Rv assumed possible
For d < 35 pc

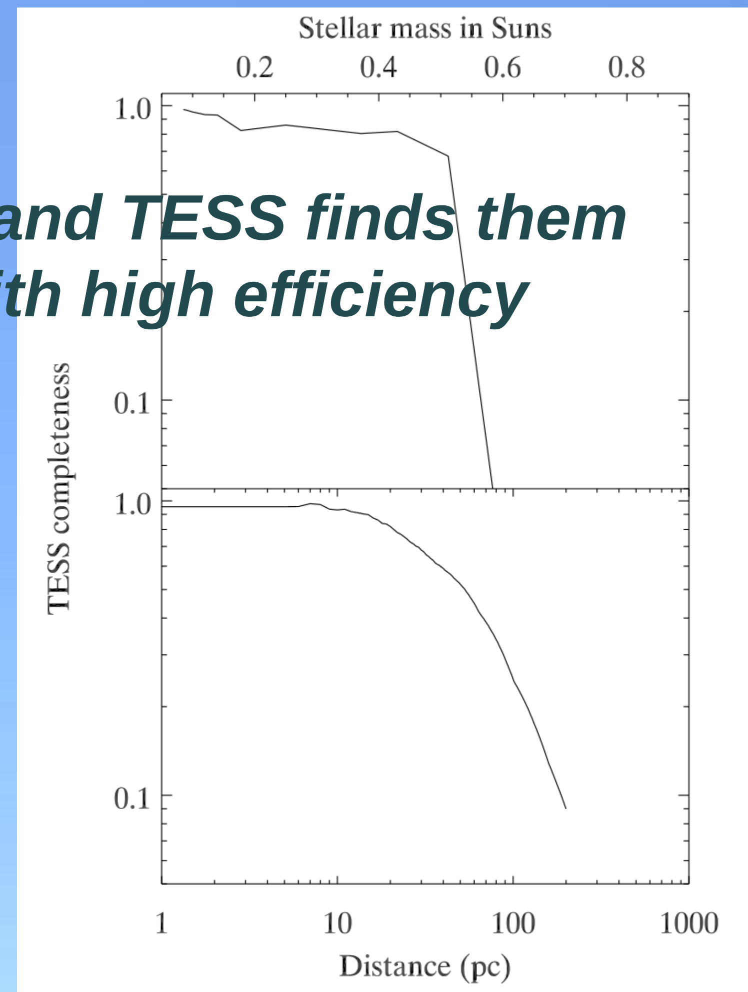
Simulate observations of each transit at 10-minute resolution, and 96-minute sampling

Two transits: P < 36 days

Apply S/N criteria

The nearest transiting habitable SuperEarth orbits an M-dwarf



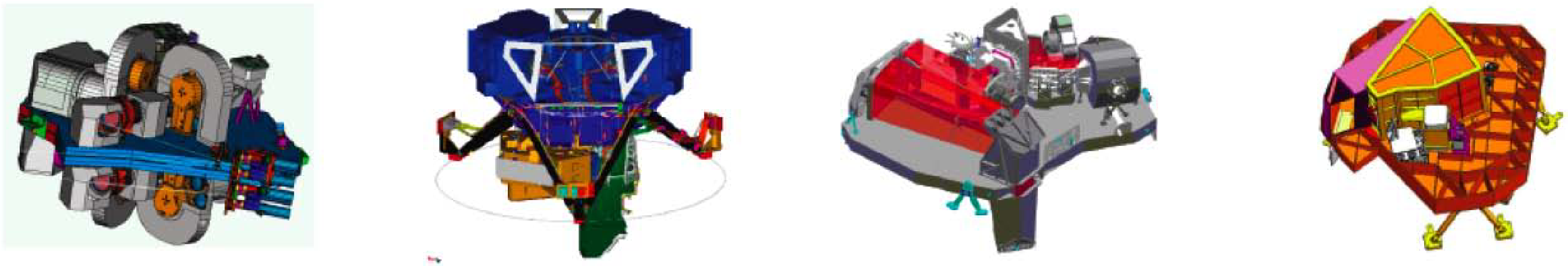


…and TESS finds them With high efficiency


The James Webb Space Telescope
6.5 m diameter
26 m2 collecting area
0.7 - 25 microns
© S. Seager

JWST Science Instruments

- **Near Infrared Camera (NIRCam) – Univ. of Arizona**
  - Deep, wide field imager (0.6 μm – 5 μm) R~ 5
- **Near Infrared Spectrograph (NIRSpec) – ESA**
  - Multi-Object Spectroscopy (0.6 μm – 5 μm) R = 100 - 3000
- **Mid-Infrared Instrument (MIRI) – JPL/ESA**
  - Mid-infrared imaging (5 μm – 28.5 μm) R ~ 2500
- **Fine Guidance Sensor (FGS) & Tunable Filter Imager – CSA**
  - Fine Guidance Sensor (0.6 μm – 5 μm)
  - Tunable Filter Imaging (1.6 μm – 4.9 μm



from Mark Clampin

Observe the systems with JWST….

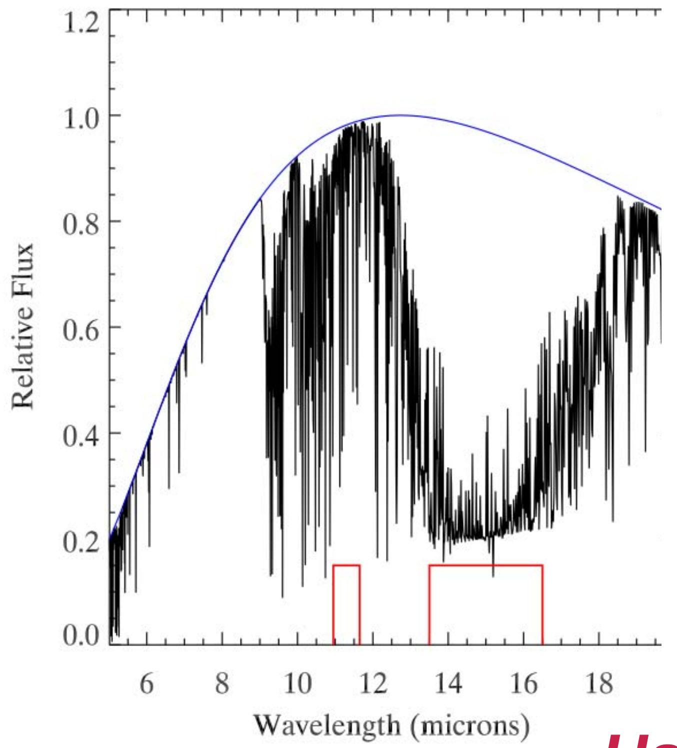
Transmission spectroscopy using NIRSpec (2-5 microns)
Emission filter photometry at eclipse (15 microns), MIRI
Miller-Ricci atmosphere models:
- **intermediate composition, with some hydrogen**

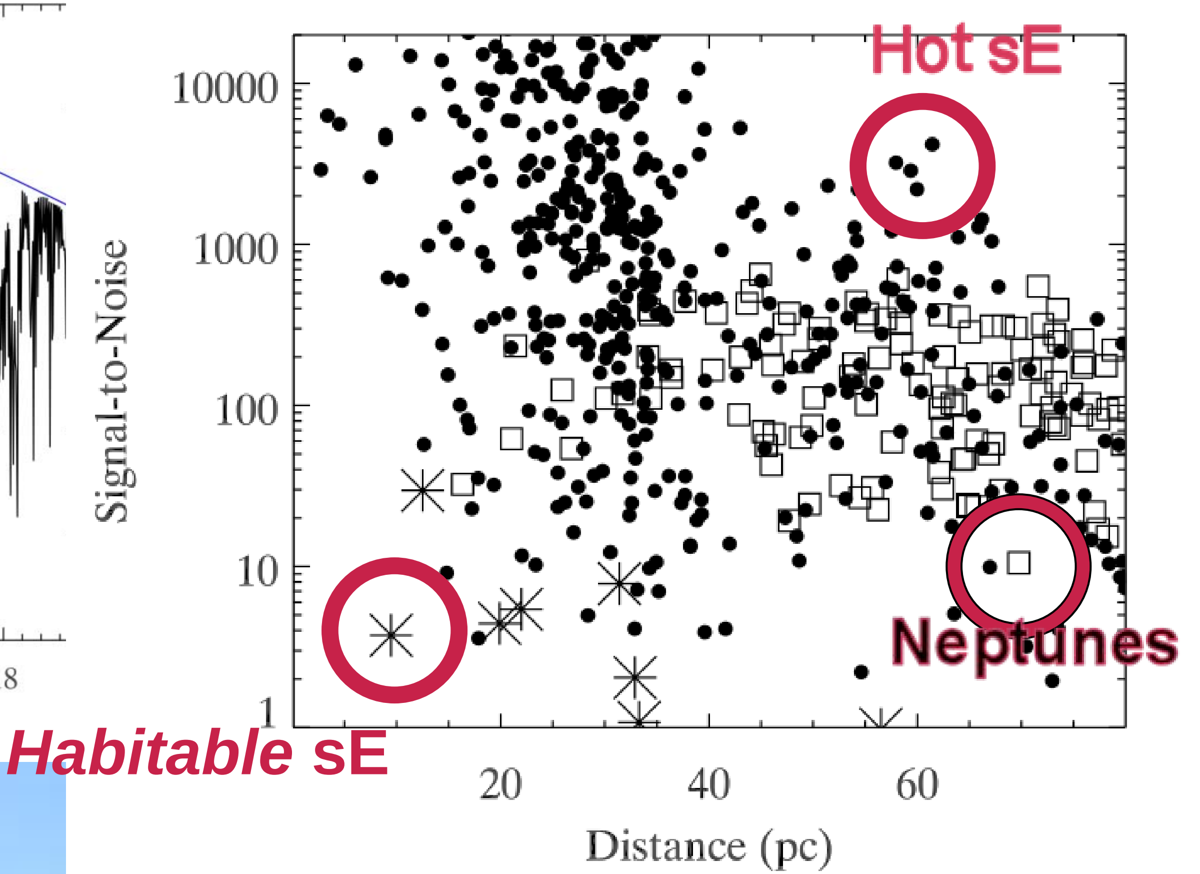
Sensitivity from instrument and telescope design review
- **photon noise, read noise, thermal background, etc.**
- **pointing jitter, intra-pixel effects, flat-fielding error**

Observe *every* transit/eclipse in JWST's 5-year mission
- **account for field-of-regard**

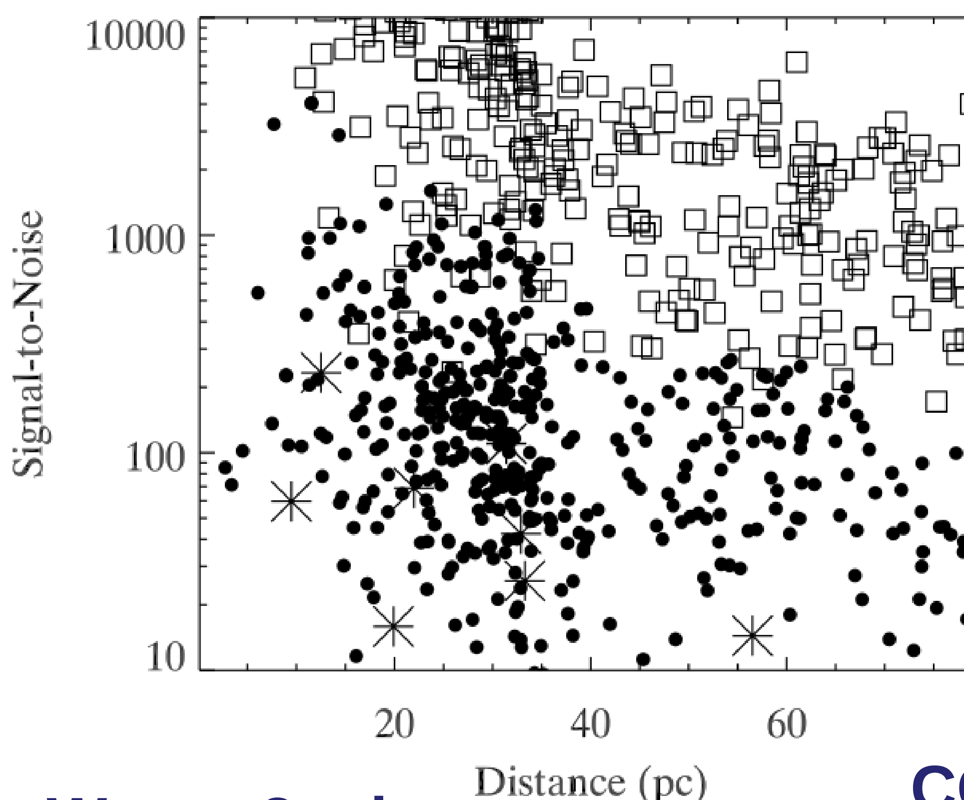
Compute total S/N for each SuperEarth in each mode

Results for 15 microns (CO_2)

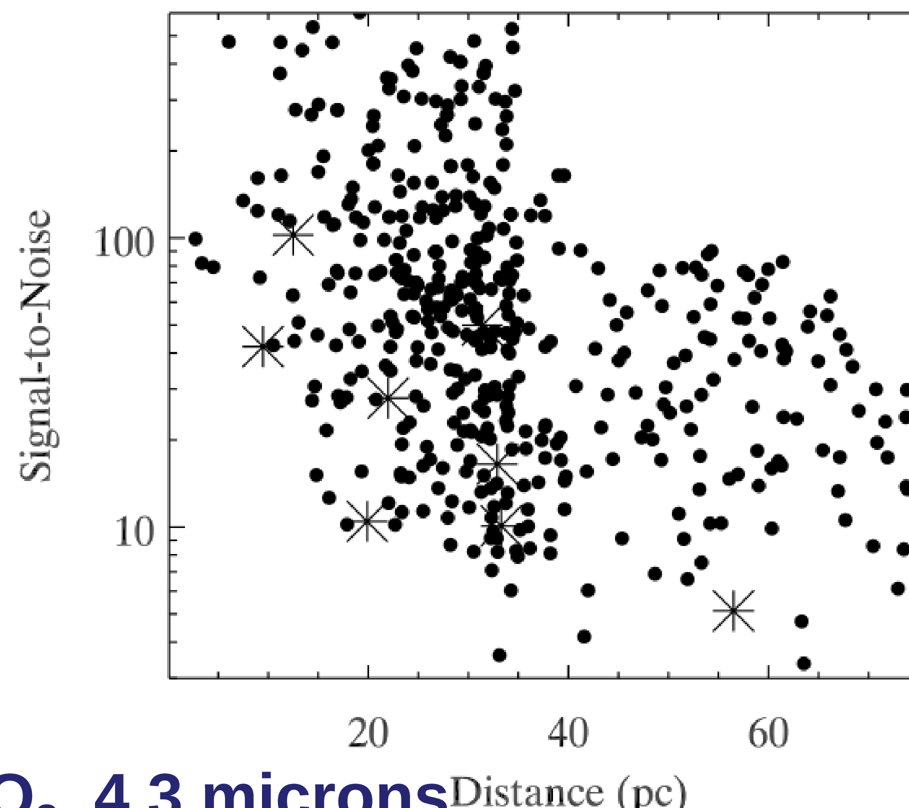




Results for 2-5 micron transmission spectroscopy (CO_2 and water)

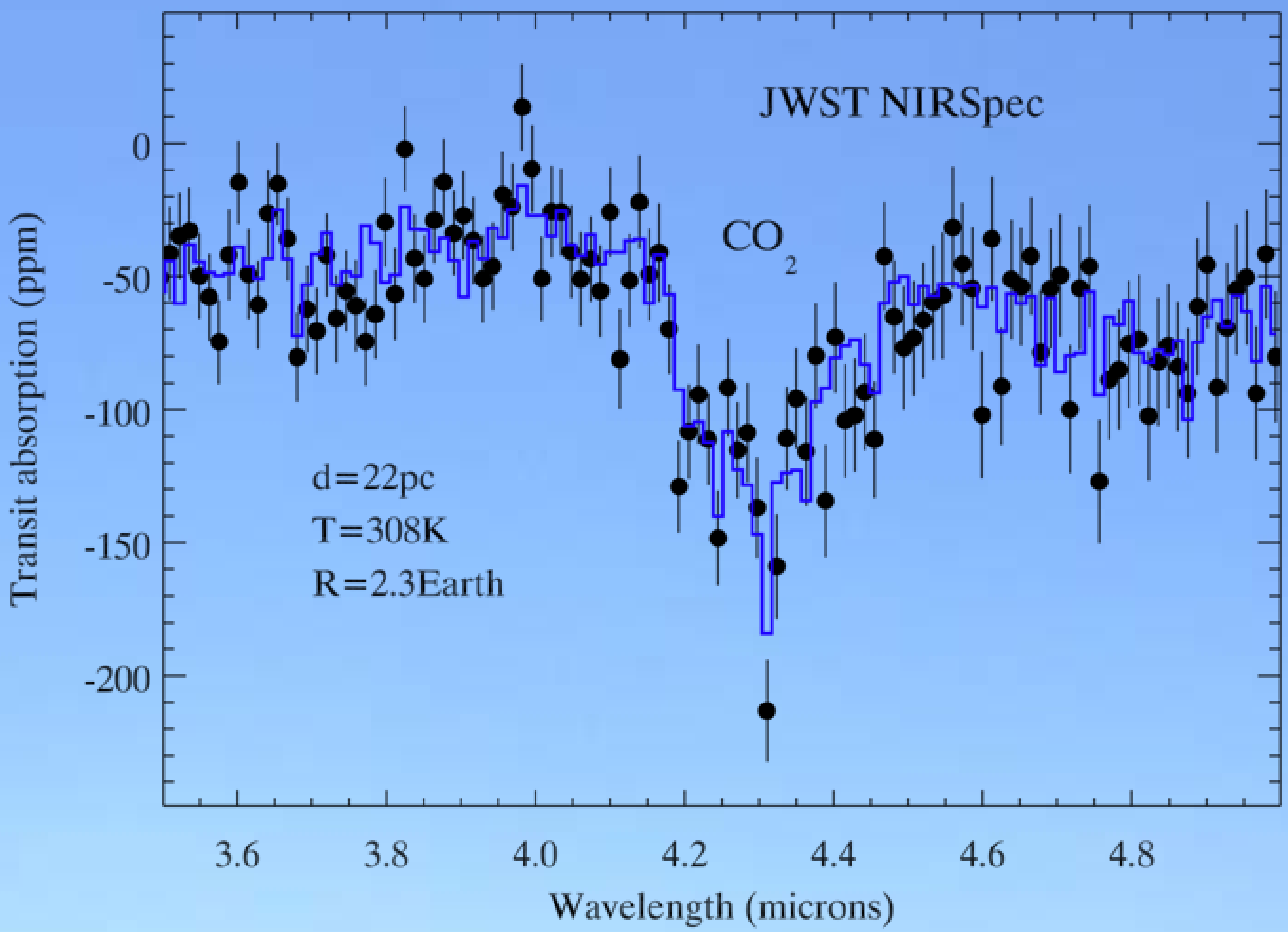


Water, 3 microns



CO_2, 4.3 microns

Example of carbon dioxide in a habitable SuperEarth



Conclusions and comments

- Uncertainties are primarily *astrophysical,* not technological
  - Nature of SuperEarth atmospheres
  - Frequency of HZ SuperEarths
- IR radial velocities are needed
- Some aspects of these simulations may be too pessimistic (don't allow for multi-planet systems)
- Other improvements are possible
  - Atmospheric composition from the bulk composition
- It will be difficult, but possible, to measure the temperature and molecular abundances in *one to four* habitable, transiting, superEarths