12.007 Geobiology
Spring 2009

A Search for Life on Earth from the Galileo Spacecraft

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Please see: Carl Sagan *et al* "A search for life on Earth from the Galileo spacecraft" *Nature* 365, 715 - 721 (21 October 1993).

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Please see: Table 1 in Carl Sagan *et al* "A search for life on Earth from the Galileo spacecraft" *Nature* 365, 715 - 721 (21 October 1993).

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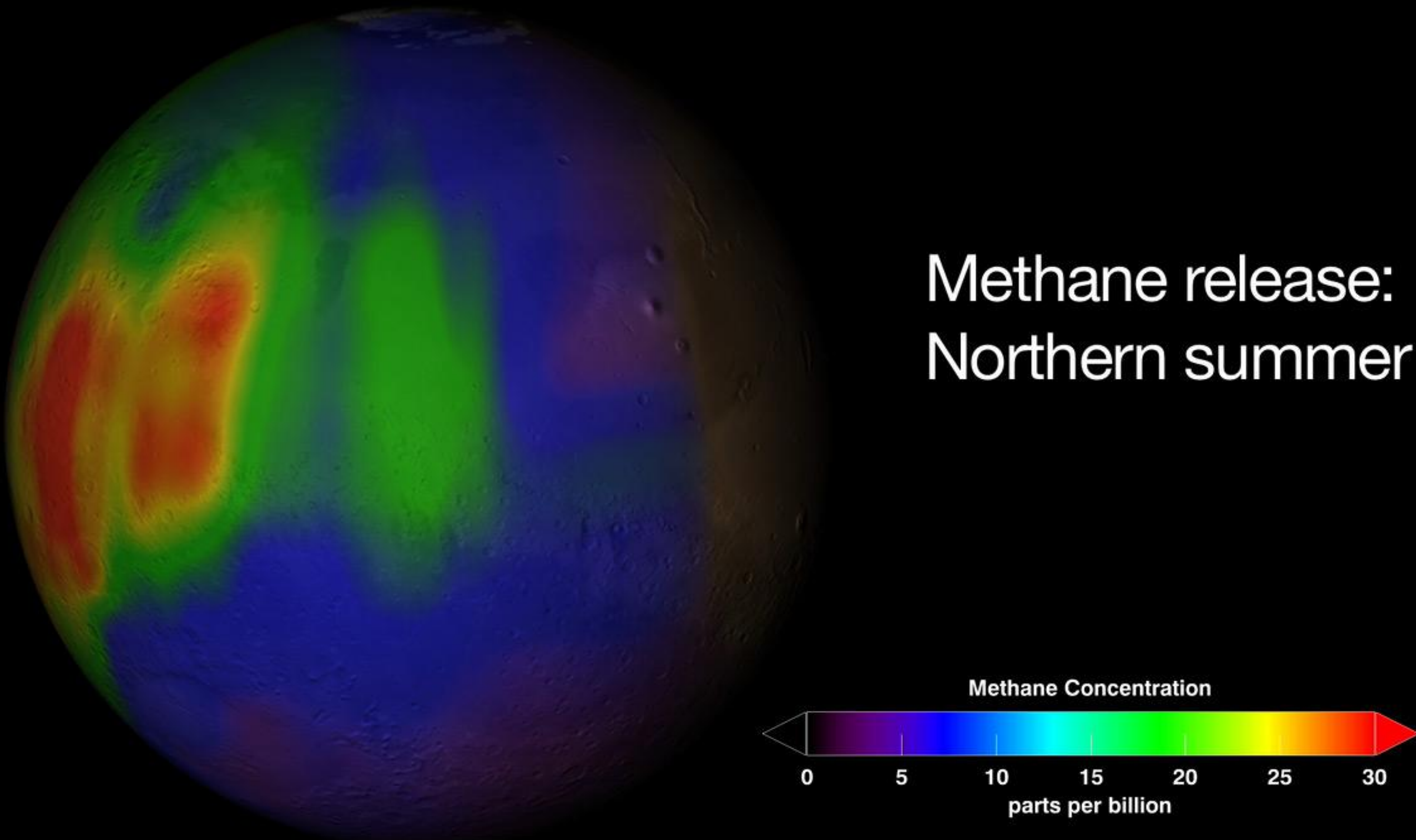
Please see: Figure 2 in Carl Sagan *et al* "A search for life on Earth from the Galileo spacecraft" *Nature* 365, 715 - 721 (21 October 1993).



http://www.nasa.gov/mission_pages/mars/news/marsmethane.html

SERPENTINIZATION

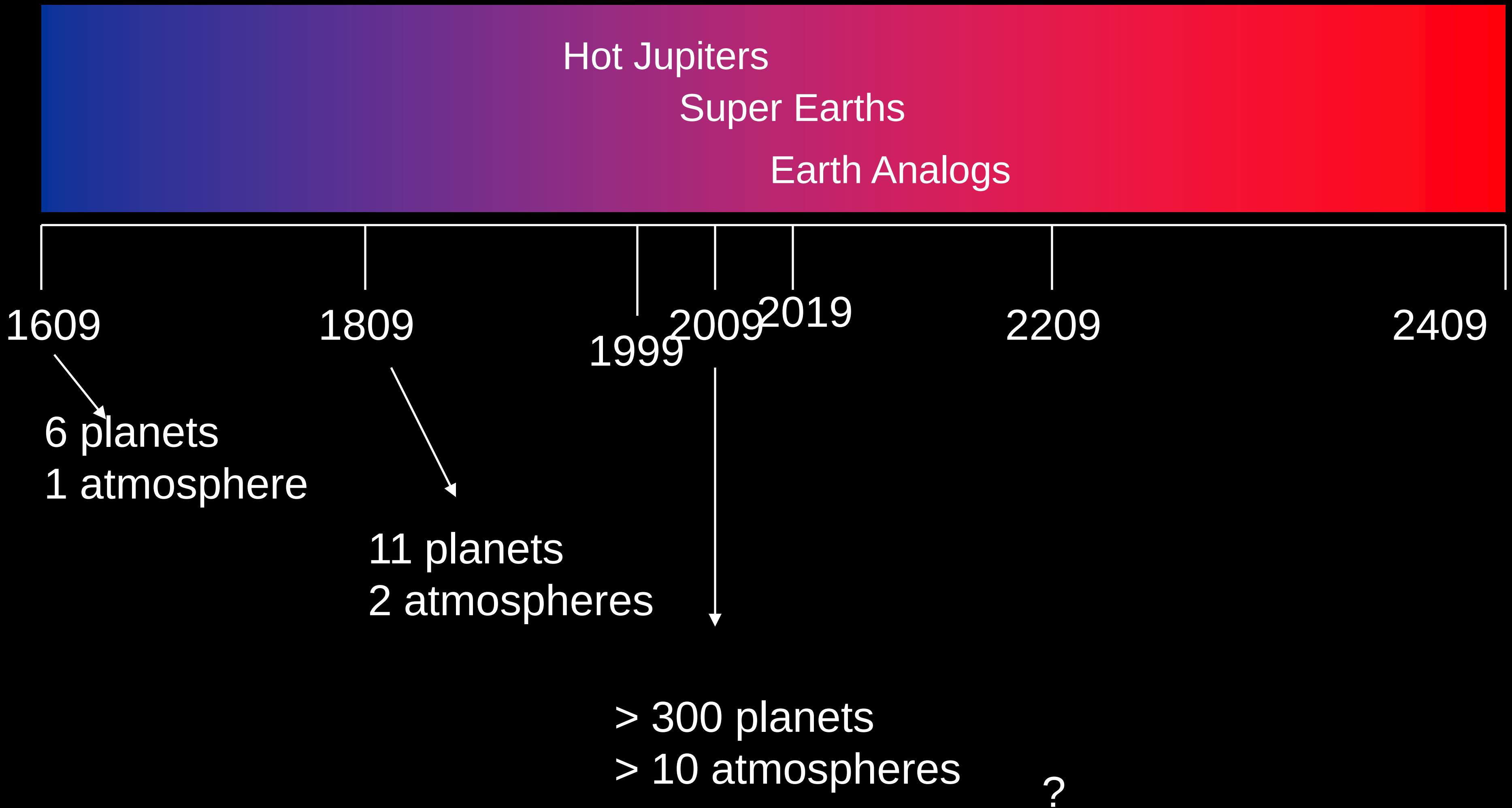
$$(Fe,Mg)_2SiO_4 + nH_2O + CO_2 \rightarrow Mg_3Si_2O_5(OH)_4 + Fe_3O_4 + CH_4$$

MICROBIAL METHANOGENESIS:

Life-sustaining planets in interstellar space?

During planet formation, rock and ice embryos of the order of Earth's mass may be formed, some of which may be ejected from the Solar System as they scatter gravitationally from proto-giant planets. These bodies can retain atmospheres rich in molecular hydrogen which, upon cooling, can have basal pressures of 10^2 to 10^4 bars. Pressure-induced far-infrared opacity of H_2 may prevent these bodies from eliminating internal radioactive heat except by developing an extensive adiabatic (with no loss or gain of heat) convective atmosphere. This means that, although the effective temperature of the body is around 30 K, its surface temperature can exceed the melting point of water. Such bodies may therefore have water oceans whose surface pressure and temperature are like those found at the base of Earth's oceans. Such potential homes for life will be difficult to detect.

Stevenson, 1999


Hot Jupiters
Super Earths
Earth Analogs
1609
1809
1999
2009
2019
2209
2409
6 planets
1 atmosphere
11 planets
2 atmospheres
> 300 planets
> 10 atmospheres
?

http://exoplanet.eu/catalog.php

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Exoplanet Update

Earth as an exoplanet

Hot Jupiter atmospheres

The fast track to habitable planets

NASA/EPOXI PI: M. A'Hearn Deputy PI: D. Deming

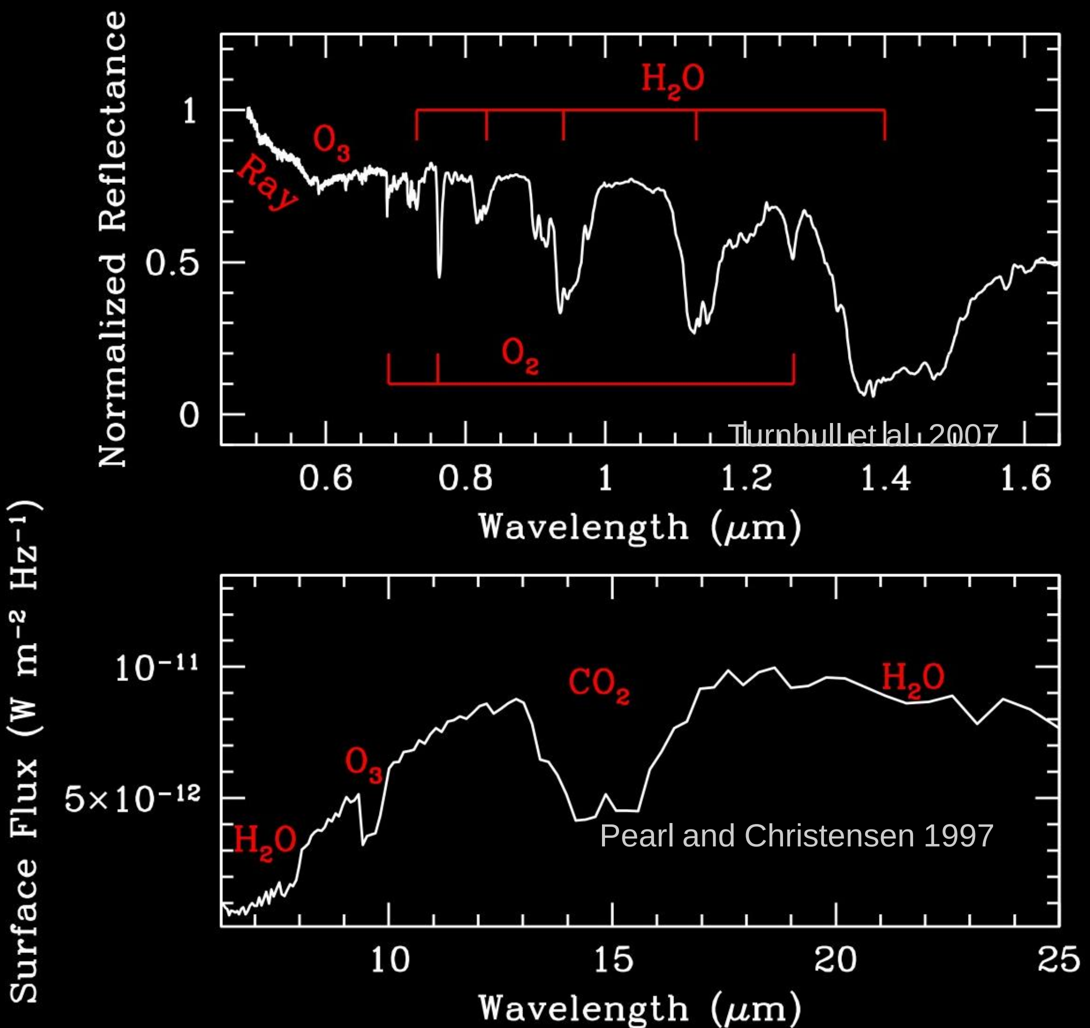
EPOCh + DIXI + = EPOXI

Don Lindler/GSFC

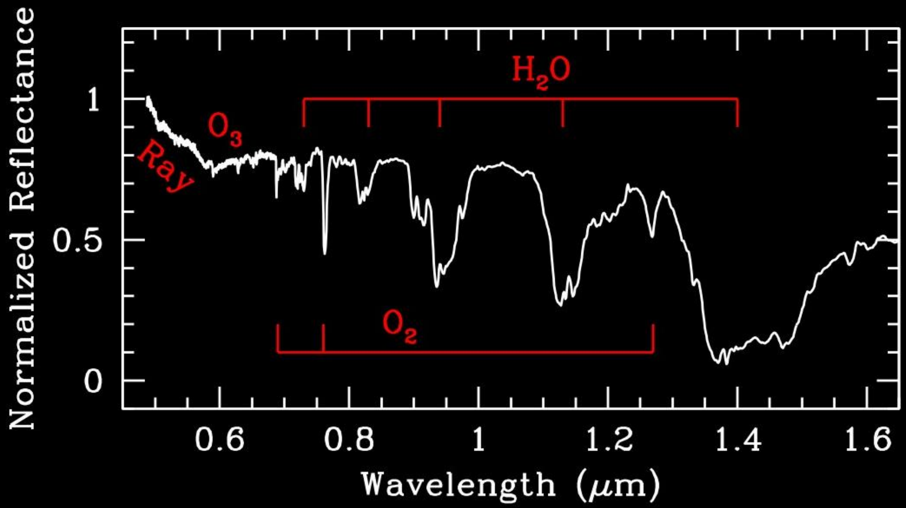
http://www.nasa.gov/topics/solarsystem/features/epoxi_transit.html

Earth as an Exoplanet

Earth as an Exoplanet



Earth as an Exoplanet



Turnbull et al. 2007

$$\frac{dI(s,\nu,\mu,t)}{ds} = j(s,\nu,\mu,t) - \kappa(s,\nu,t)I(s,\nu,\mu,t)$$

Summary #1

Goal: Find an Earth. Take spectra to find atmospheric composition and biosignatures. Study time variability to infer weather (and continents?)

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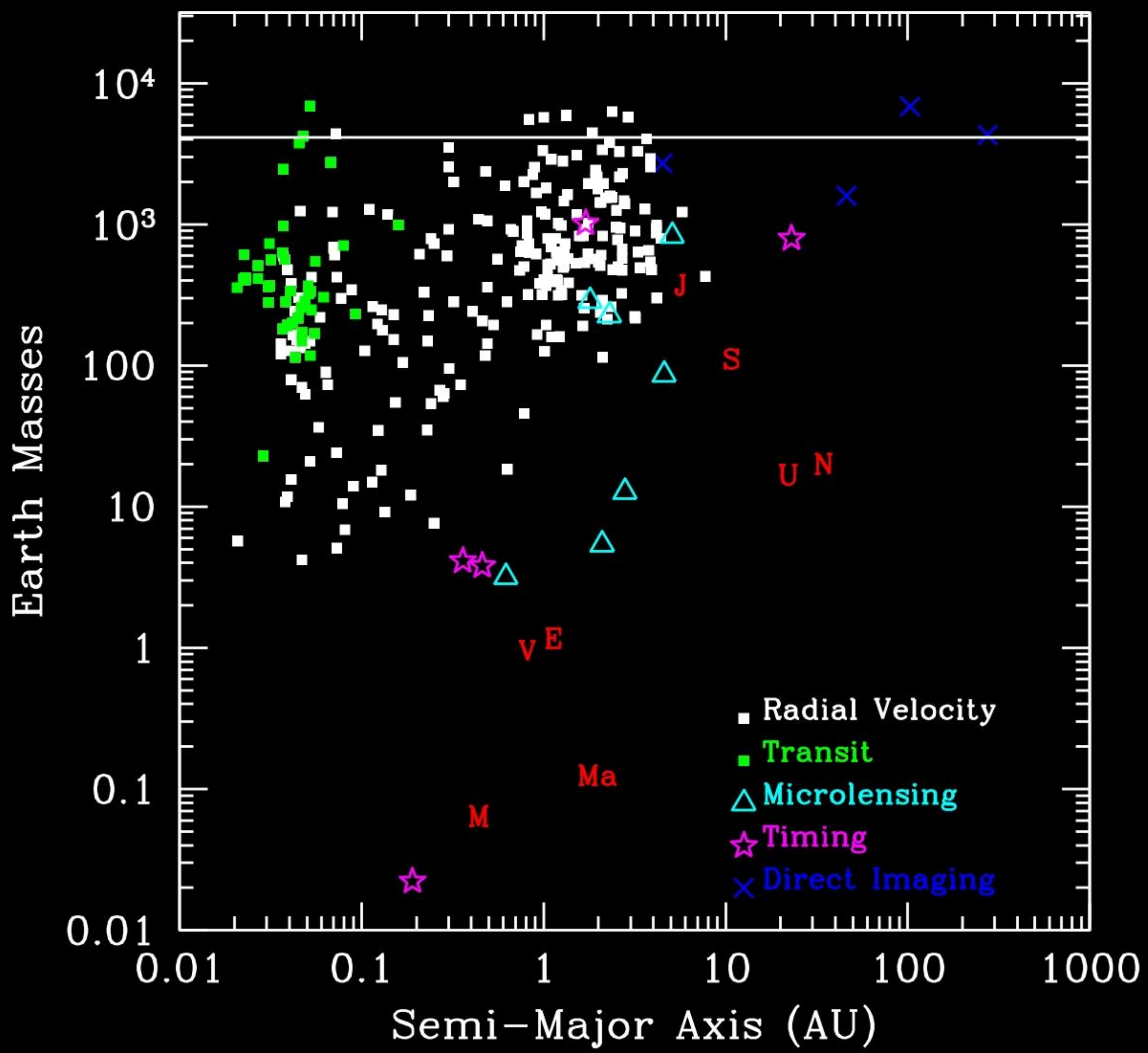
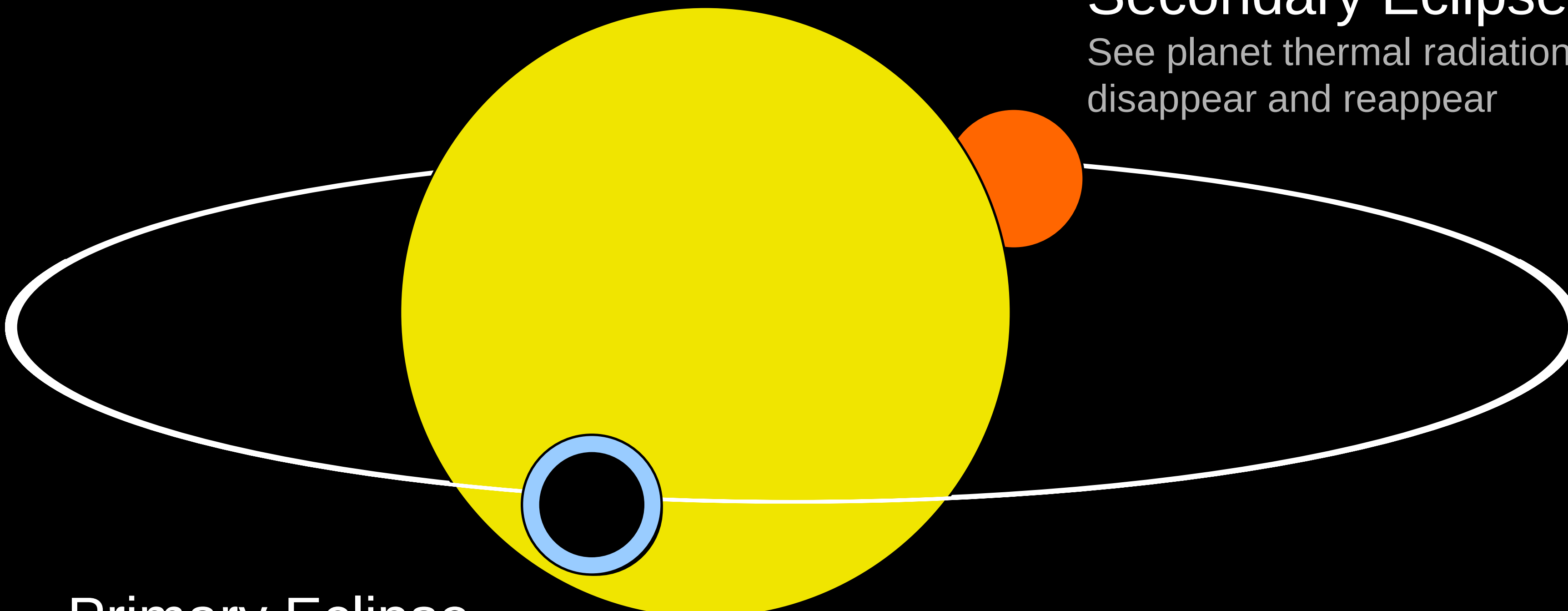
Known Planets 2008



Based on data compiled by J. Schneider

2. Transiting Planets



Secondary Eclipse

See planet thermal radiation disappear and reappear

Primary Eclipse

Measure size of planet
See star's radiation transmitted through the planet atmosphere

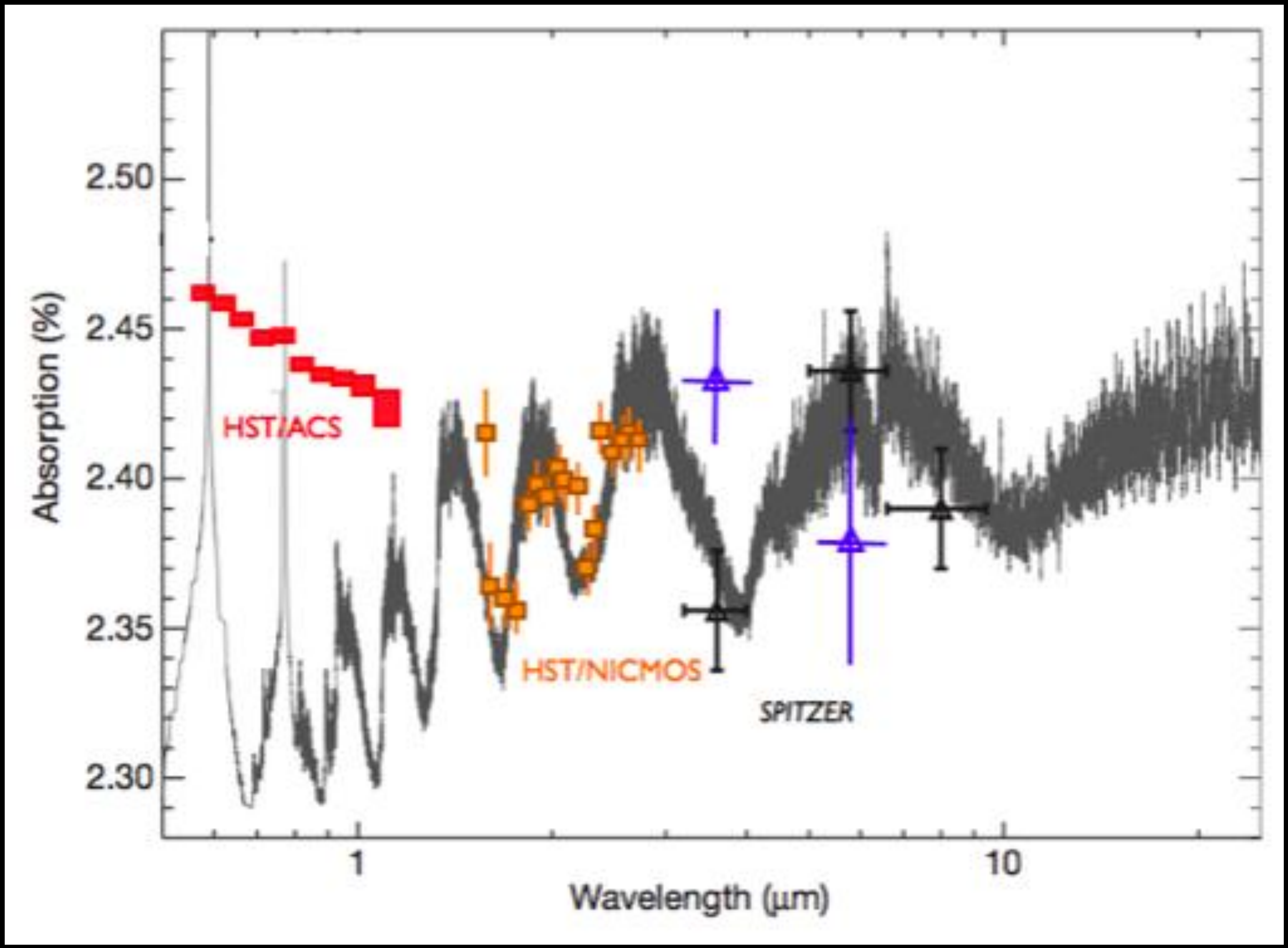
Learn about atmospheric circulation from thermal phase curves

Transit Transmission Spectrum

Image removed due to copyright restrictions.

Water vapor detection: a second confirmation of the basic picture of hot Jupiters. At T ~ 1000 - 2000K water vapor is unavoidable (unless C/O > 1).

Identification of Atoms and Molecules and Solids



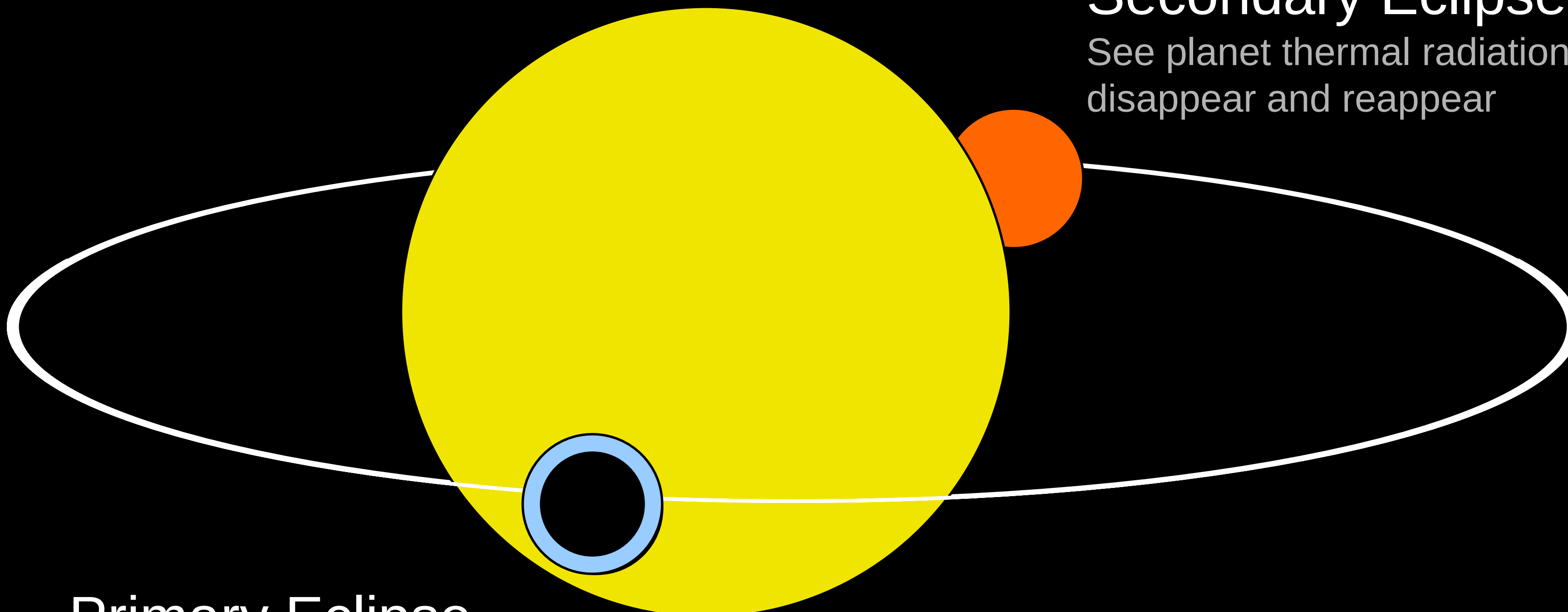
<u>HD 189733b</u>
Na, H_2O, CH_4
Hazes

<u>HD 209458b</u>
Na, H_2O
-detection of exospheric escape via H Ly α

Approximate limb P/T profile

Courtesy F. Pont

2. Transiting Planet Science



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Spitzer Photometry of TrES 4

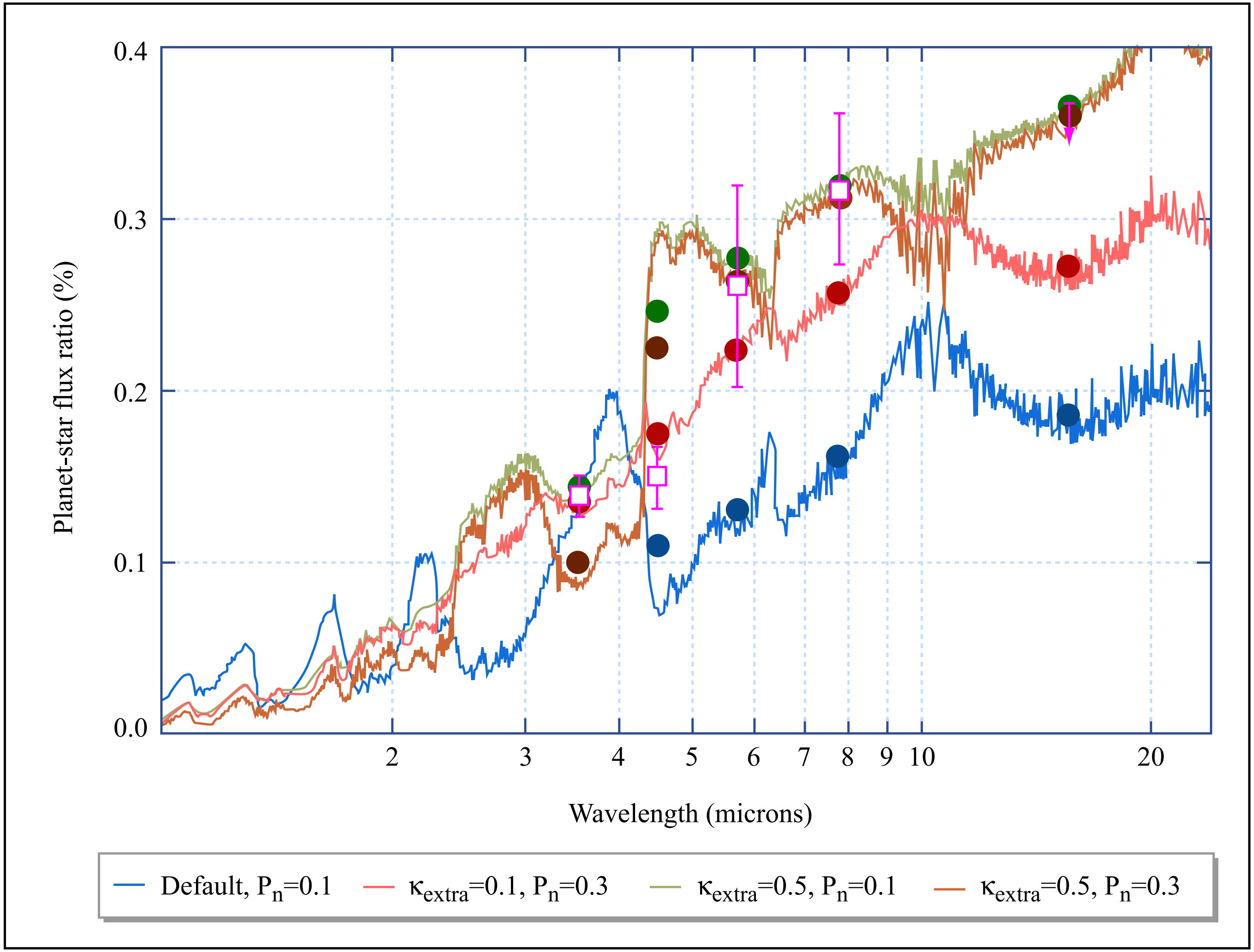
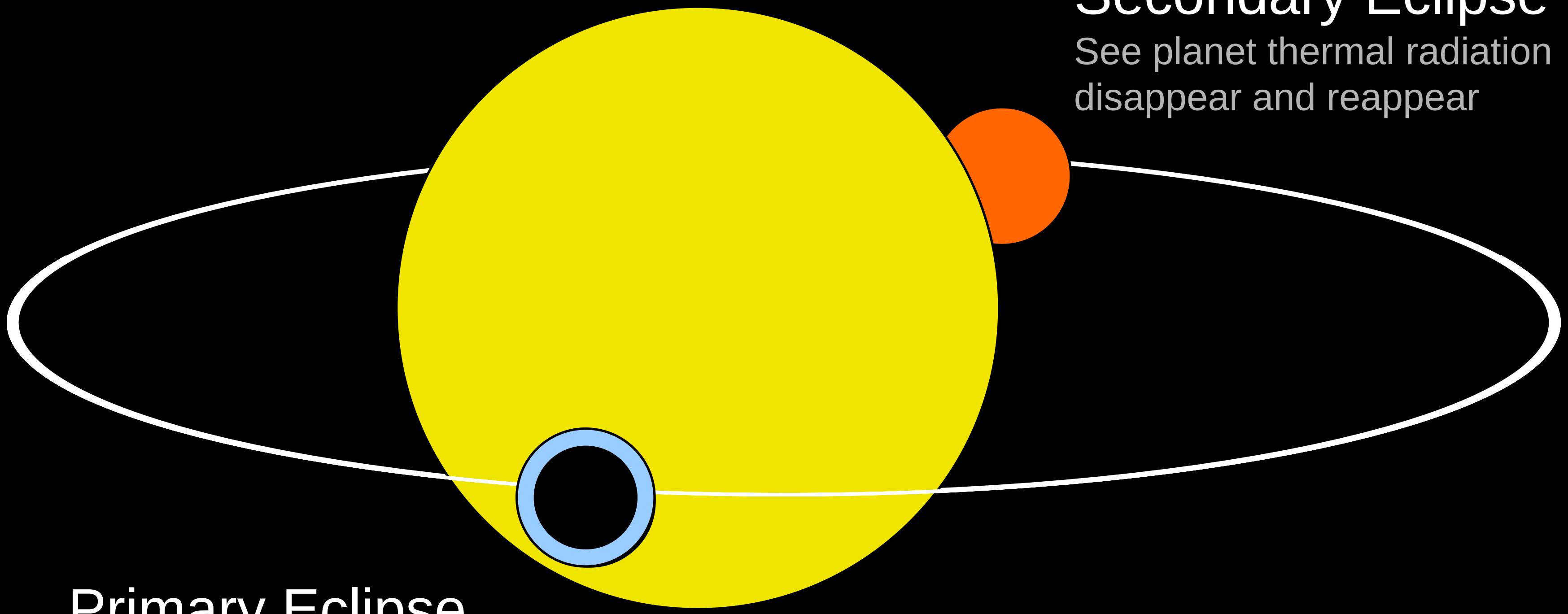


Figure by MIT OpenCourseWare.

Knutson et al. (2008);

Transiting Planet Science



Secondary Eclipse

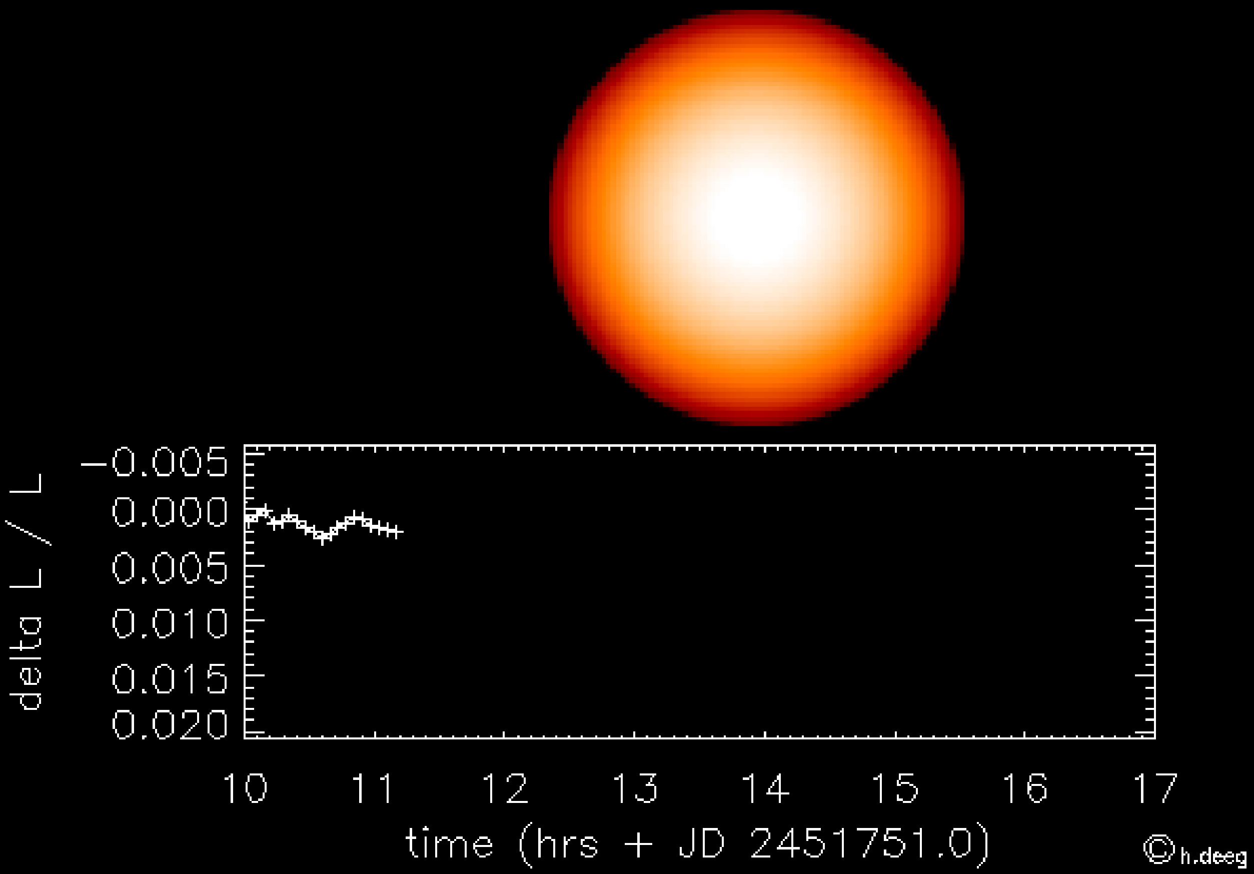
See planet thermal radiation disappear and reappear

Primary Eclipse

Measure size of planet
See star's radiation transmitted through the planet atmosphere

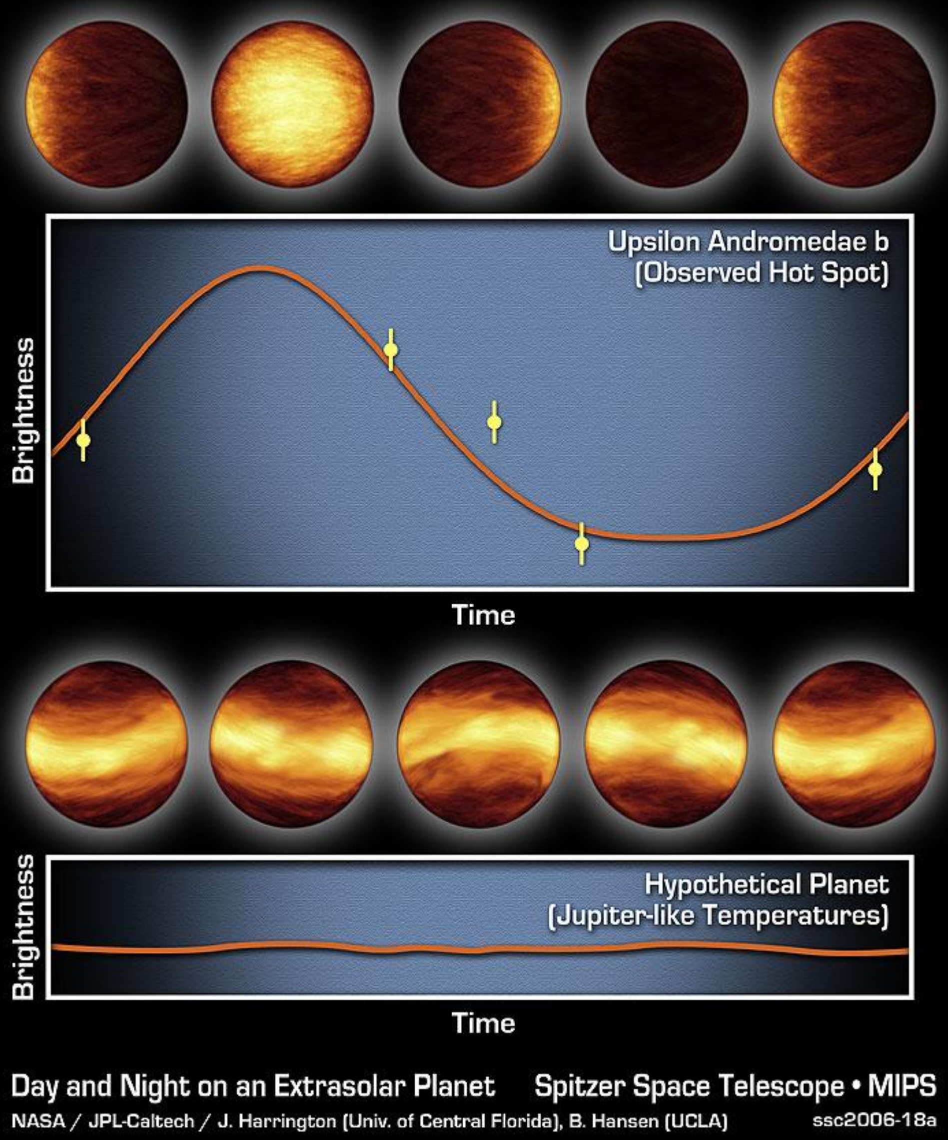
Learn about atmospheric circulation from thermal phase curves

Hot Jupiters



NASA/ESA/G. Bacon
Spitzer Space Telescope

Hot Jupiters



Summary #2

Dozens of hot Jupiter atmospheres have been observed. Interpretation includes: id of molecules; thermal inversions; day-night gradients of different magnitudes.

Exoplanet Update

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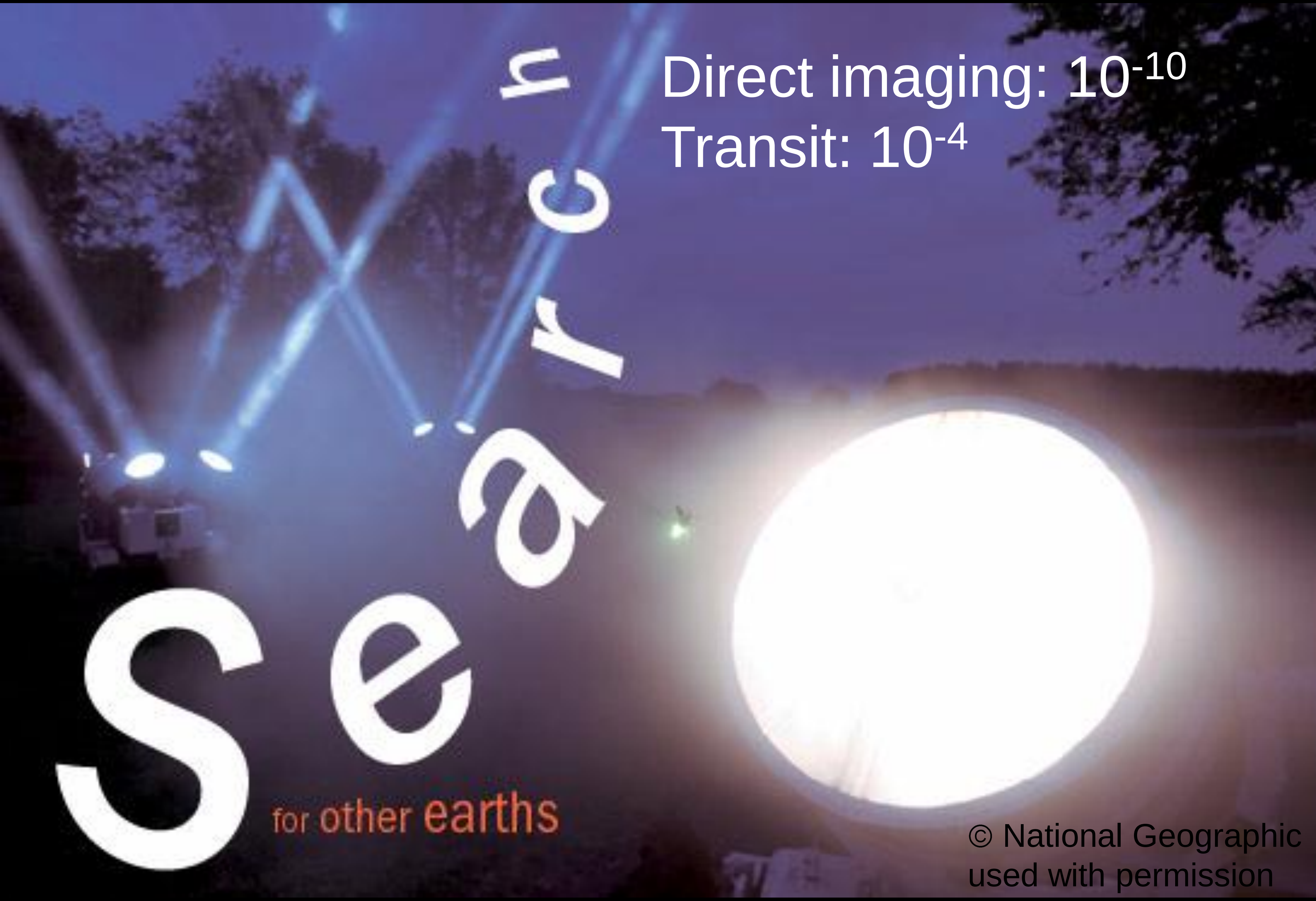
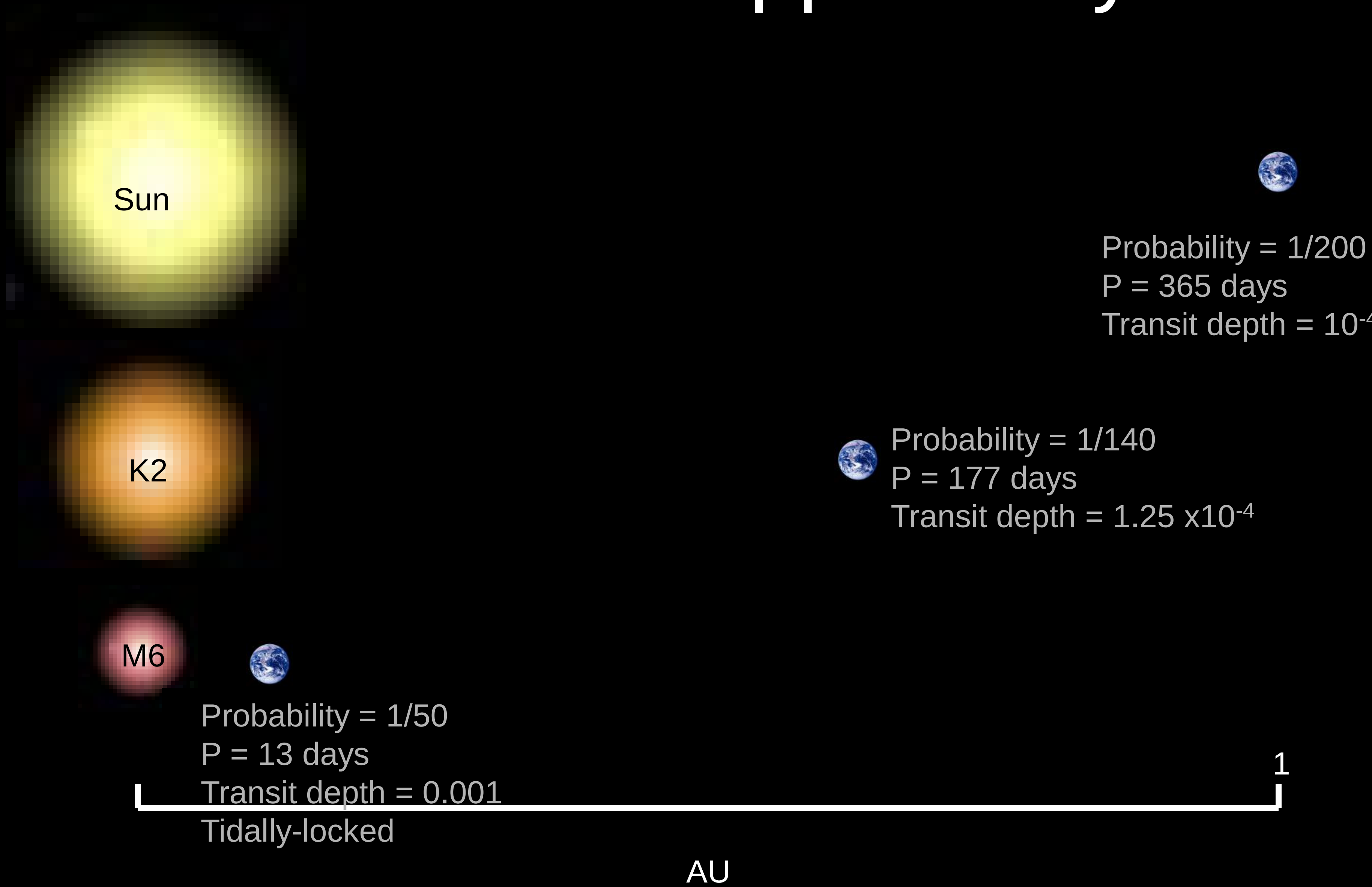
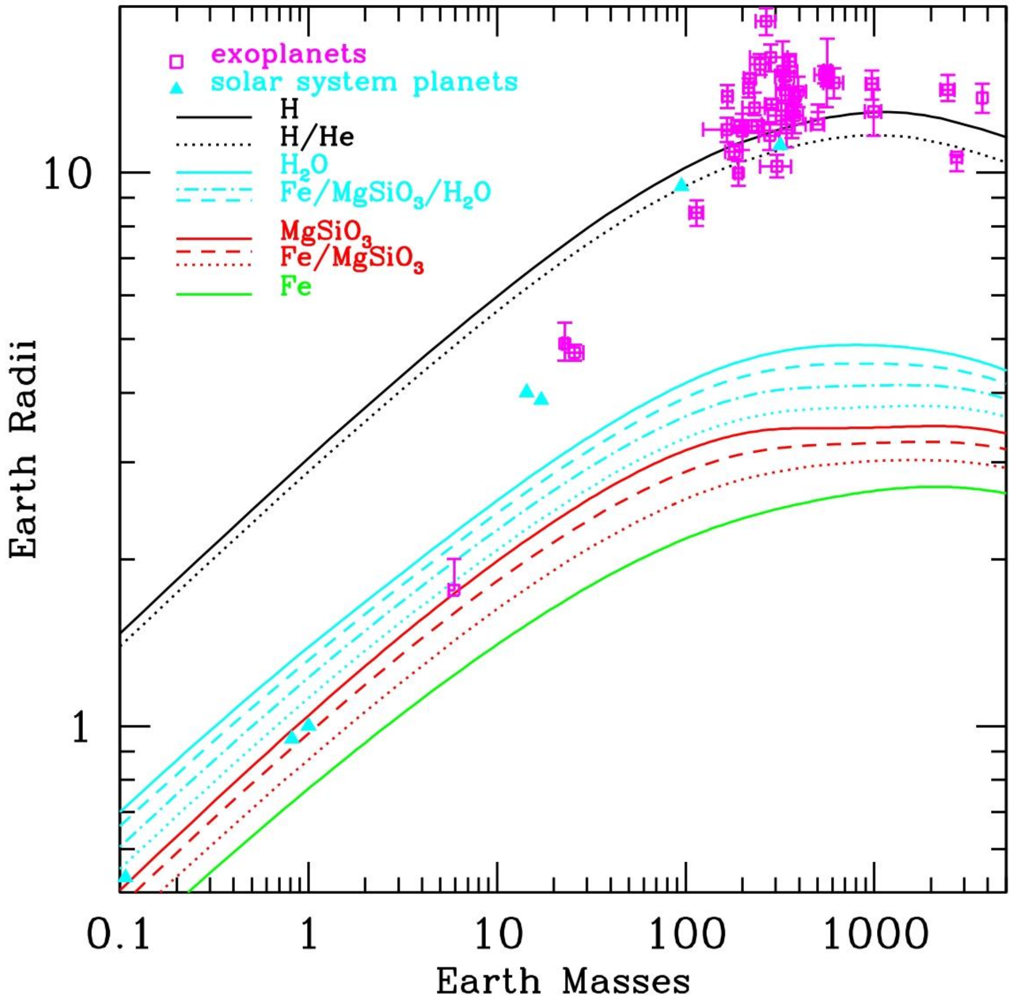
Direct imaging: 10^{-10}
Transit: 10^{-4}



The M Star Opportunity



Exoplanet Mass-Radius Diagram



$$\frac{dm(r)}{dr} = 4\pi r^2 \rho(r)$$

$$\frac{dP(r)}{dr} = \frac{-Gm(r)\rho(r)}{r^2}$$

$$\rho(r) = F(P(r), T(r))$$

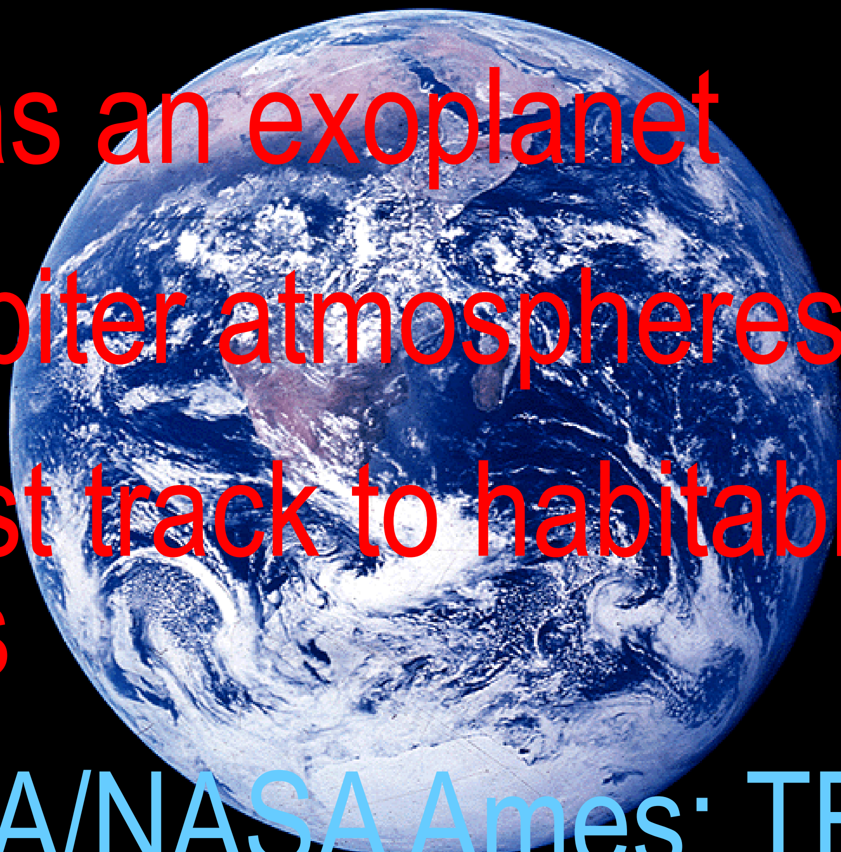
Seager, Kuchner, Hier-Majumder, Militzer 2007
Zapolsky and Salpeter 1969
Stevenson 1982, Hubbard 1984
Valencia et al. 2006, 2007
Sotin et al. 2007
Selsis et al. 2007
… and others

We infer an exoplanet's bulk composition from its M and R

Summary #3

Super Earths orbiting small stars is the current frontier. Unknowns abound.

Exoplanet Update



Earth as an exoplanet

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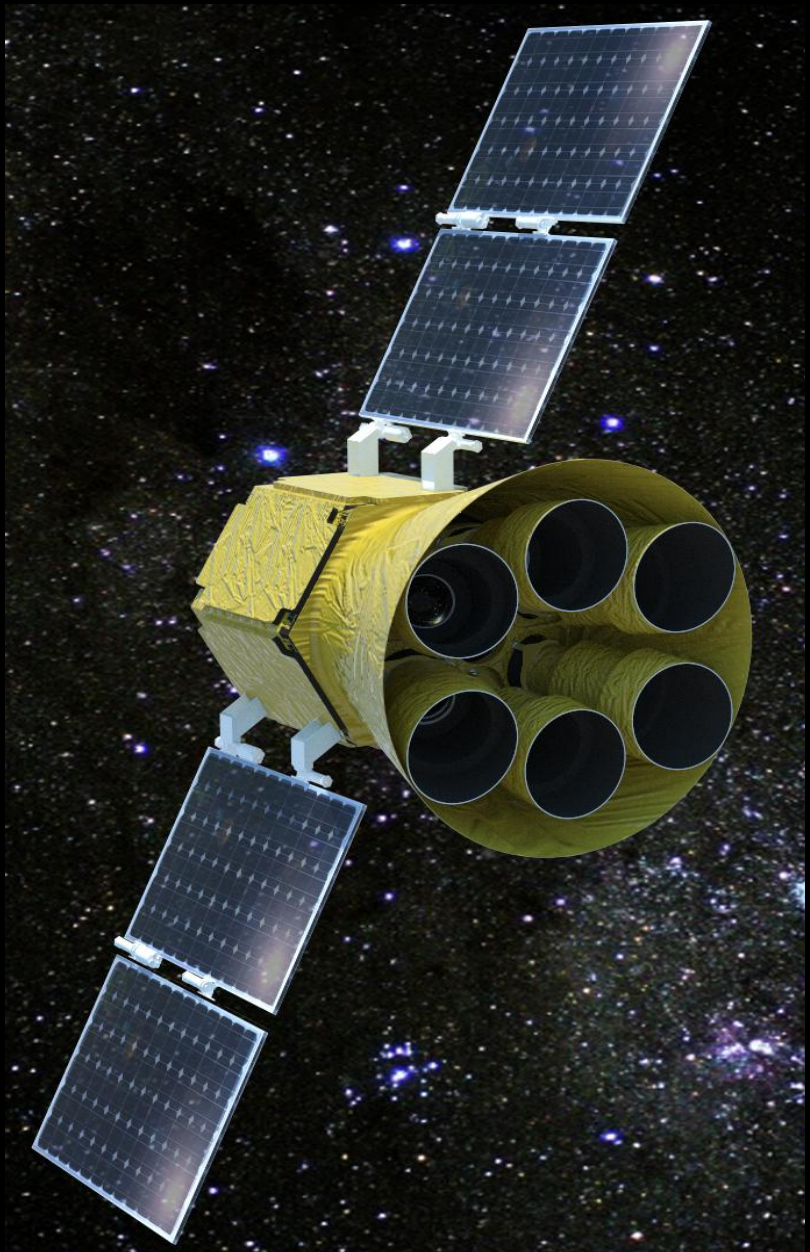
MIT/CfA/NASA Ames: TESS

TESS



Transiting Exoplanet
Survey Satellite (TESS)

- 6 wide-field optical cameras
- 0.3 mmag precision
- $> 2 \times 10^6$ bright stars $7 < I$ mag < 12
- Thousands of transiting planets with $P < 1$ month
- NASA/SMEX Phase A

PI G. Ricker (MIT) Co-Is: Seager, Elliot (EAPS), Winn, Burgasser (Physics)

Summary

Ultimate goal is to find and study Earth analogs.

At present we have a growing data set on hot Jupiter atmospheres.

As a fast track to habitable worlds we can find and study big Earths orbiting small stars--but there are many unknowns.

TESS is in phase A. Other space telescopes will be launched soon to forward progress in exoplanet studies.