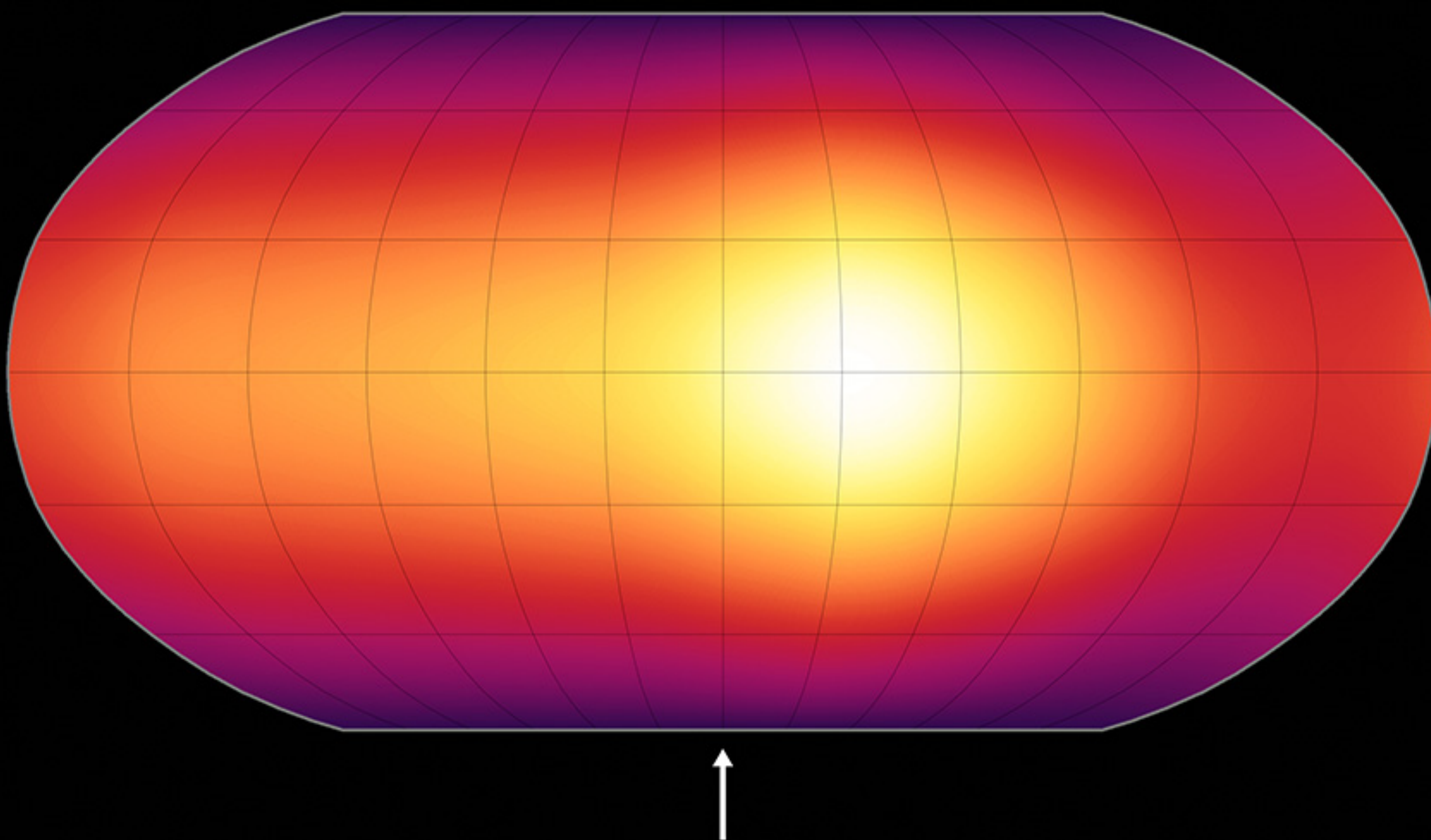
Spitzer's Exoplanets: From Hot Jupiters to Earths

David Charbonneau (Harvard-Smithsonian Center for Astrophysics)

28 October 2009



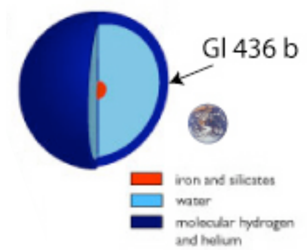
Statement about the Astronomy & Astrophysics 2010 – 2020 Decadal Survey

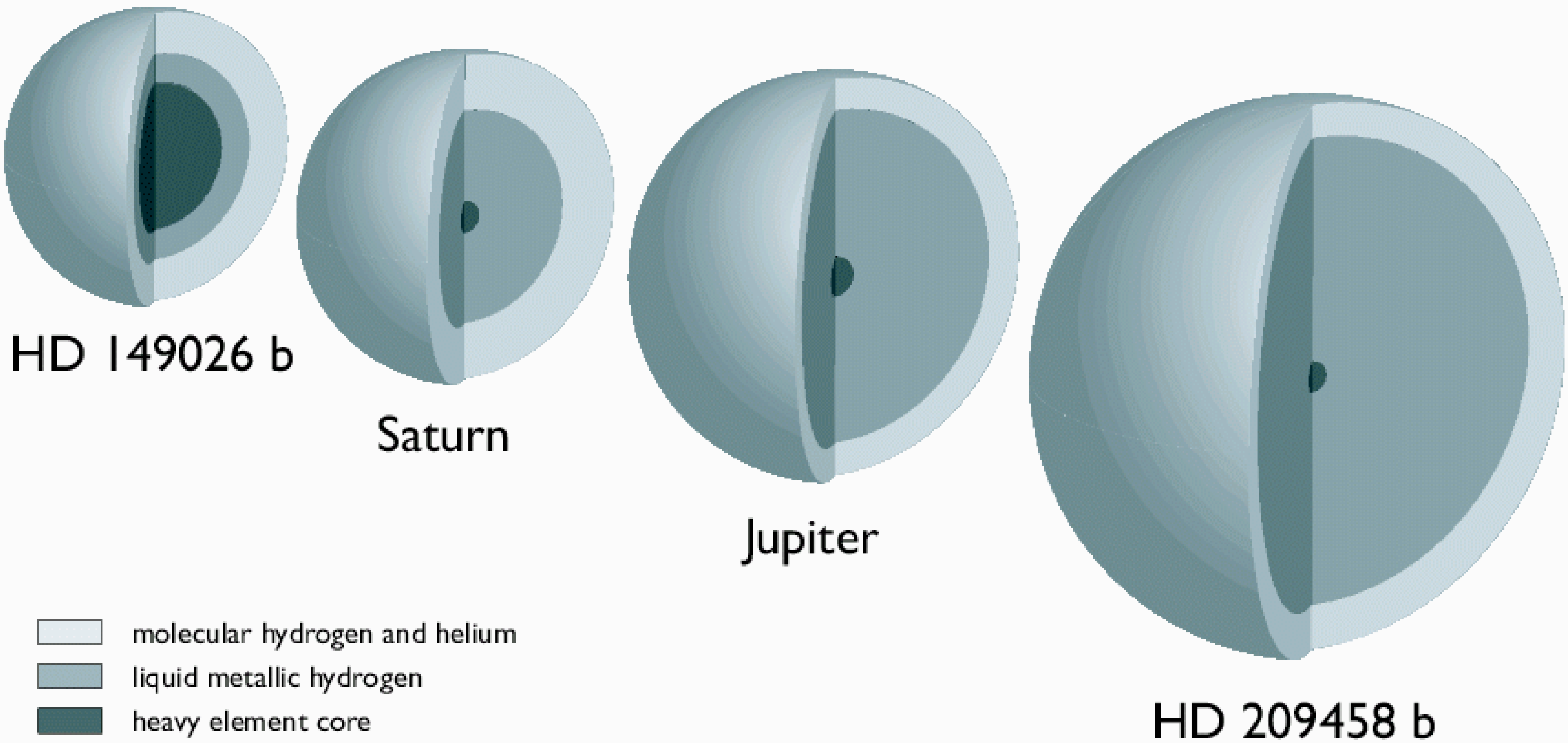
The Question:

What is the Exoplanet Legacy of the Spitzer Space Telescope?

Legacy: Something received from an ancestor or from the past

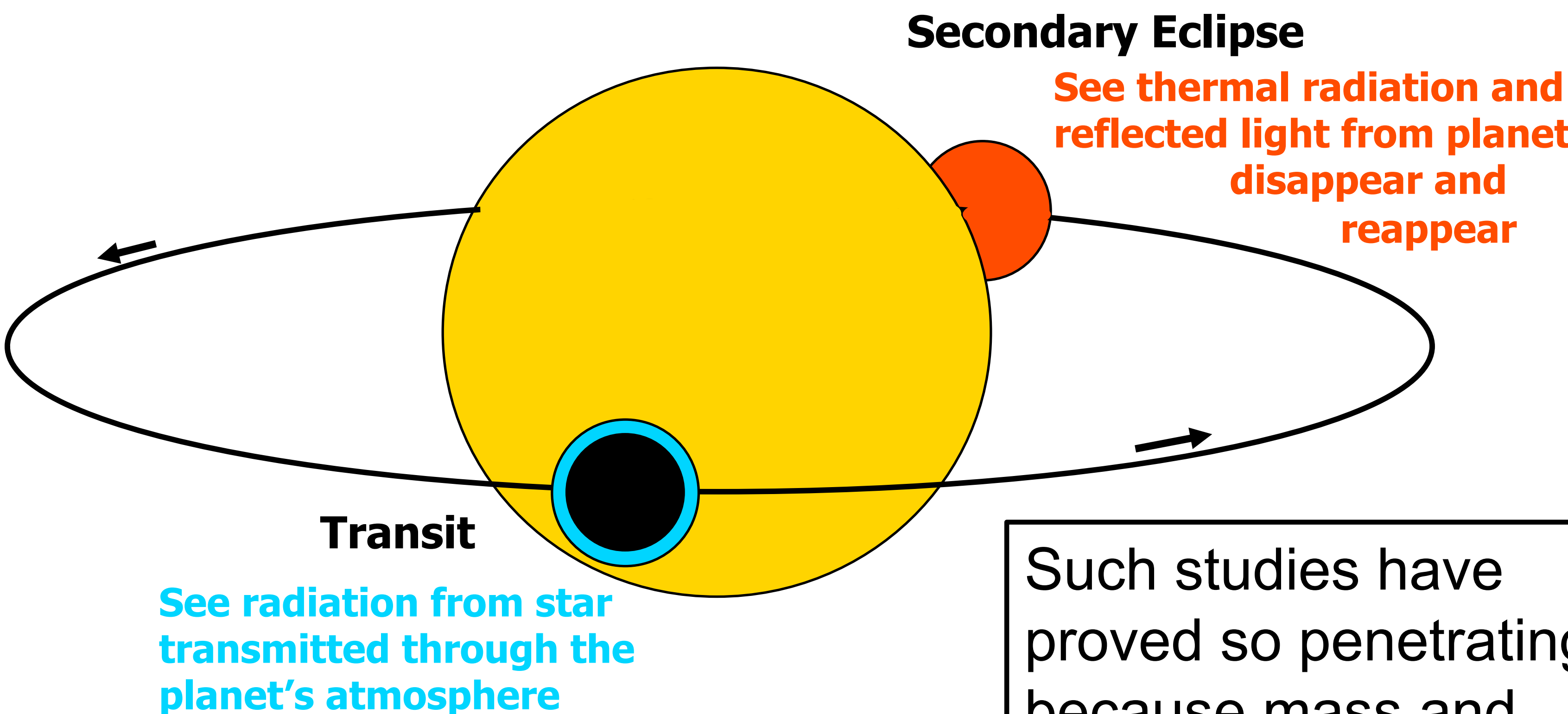
Transits Permit Direct Estimates of Masses and Radii





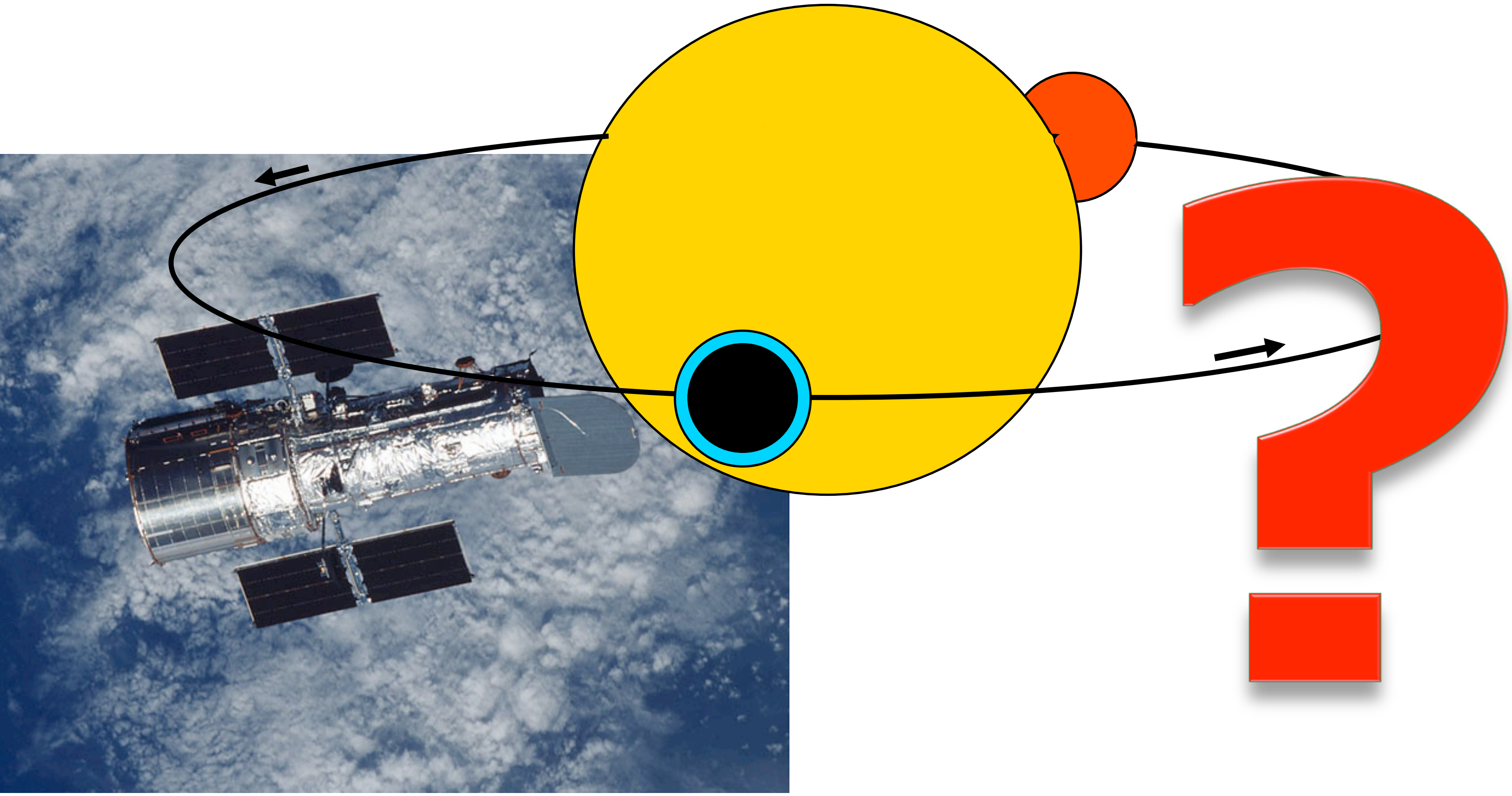
Figures courtesy G. Laughlin

Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets

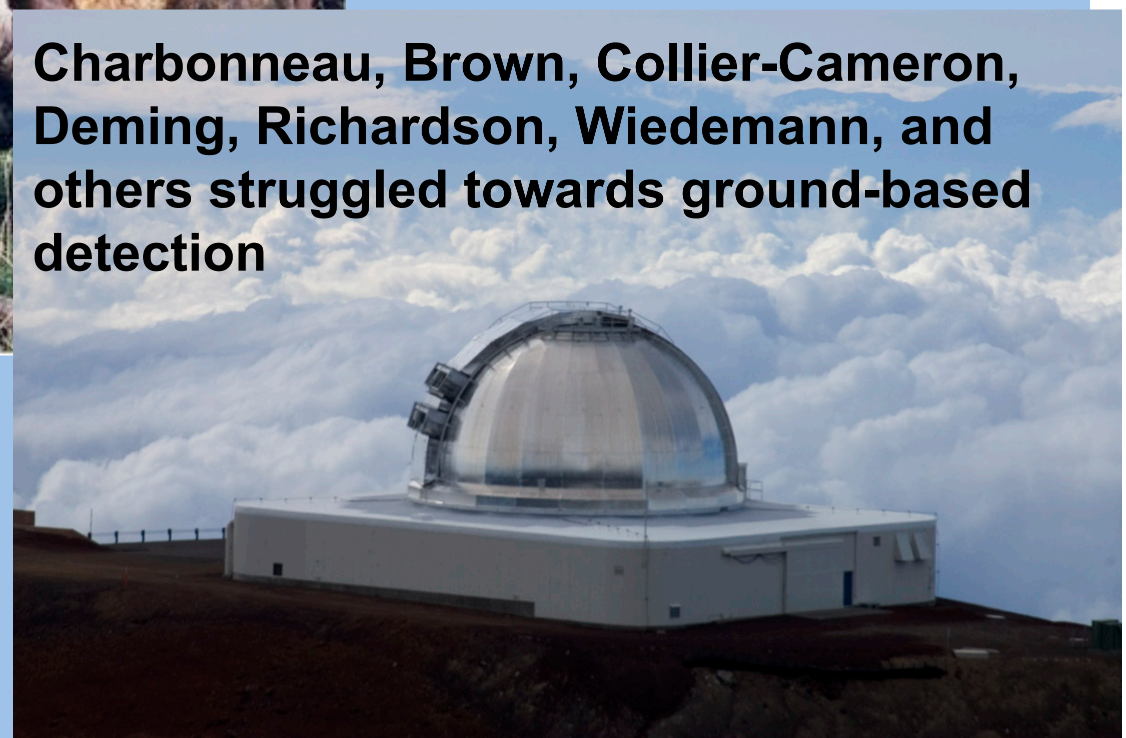


Such studies have proved so penetrating because mass and radius are known.

Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets

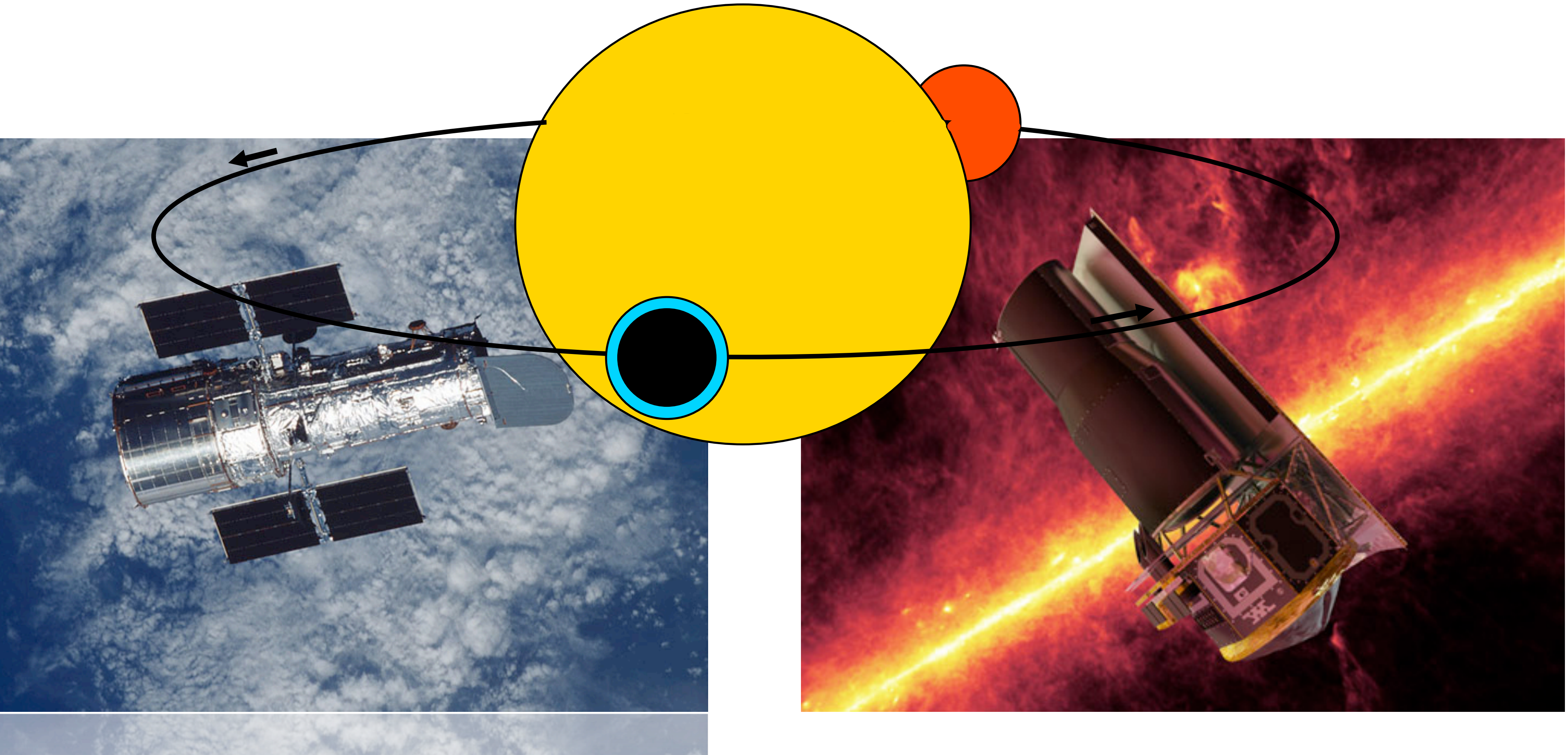


Emitted/reflected spectra of hot Jupiters in the paleolithic age (1999-2003)



Slide courtesy D. Deming

Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets



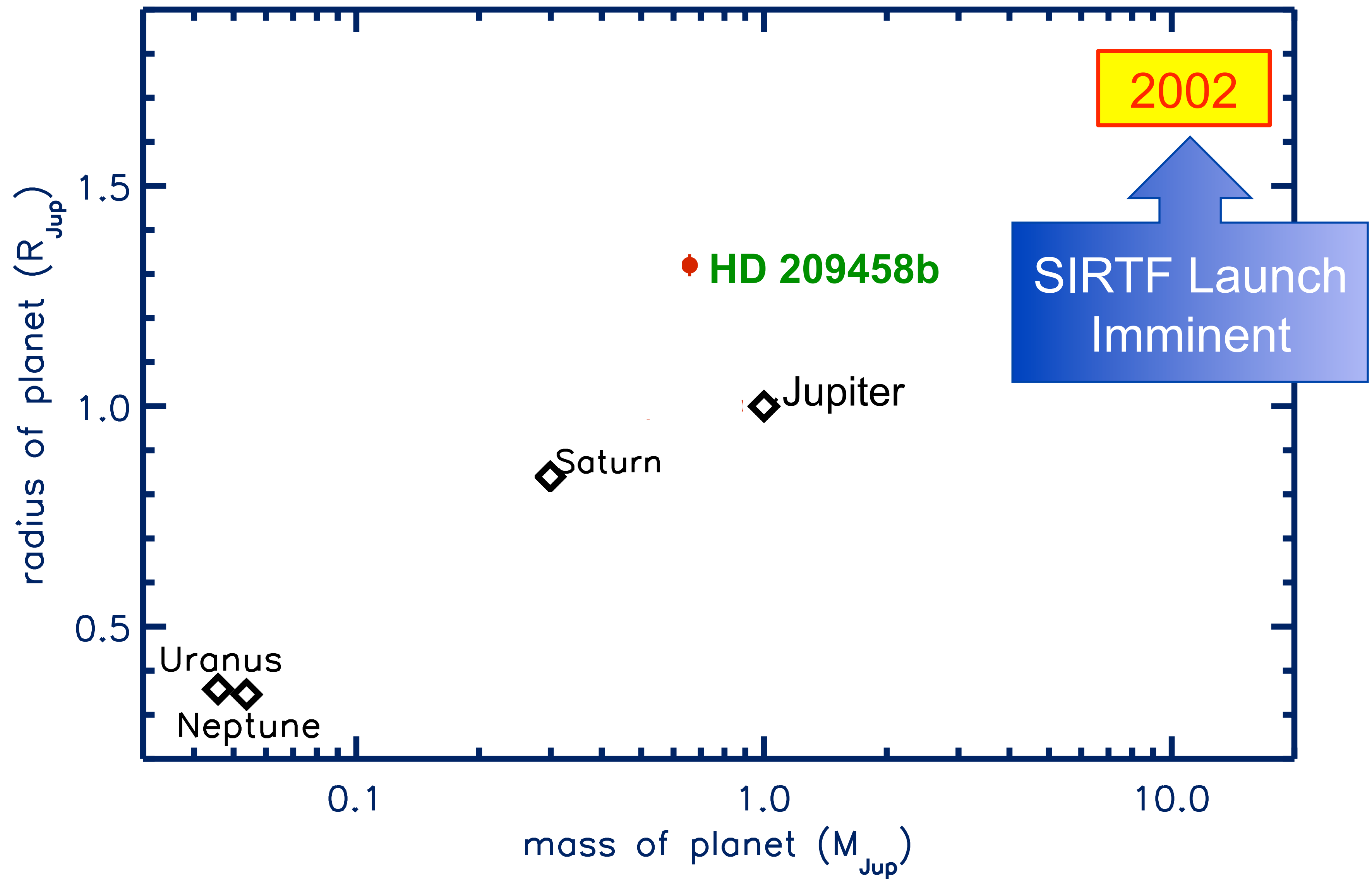
Important Guideline for Atmospheric Studies:

You need to know of the existence of a planet

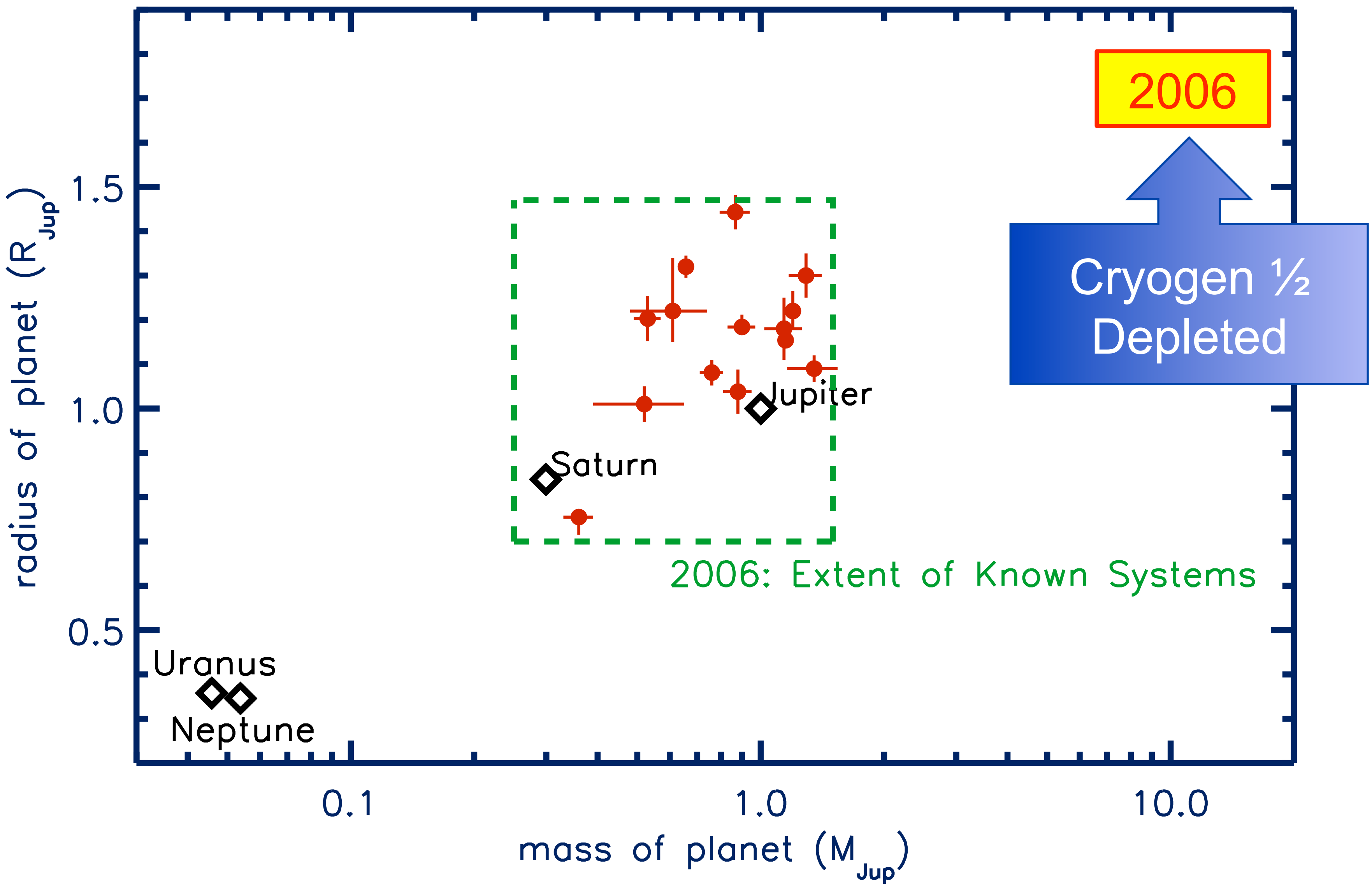
prior to

characterizing its atmosphere

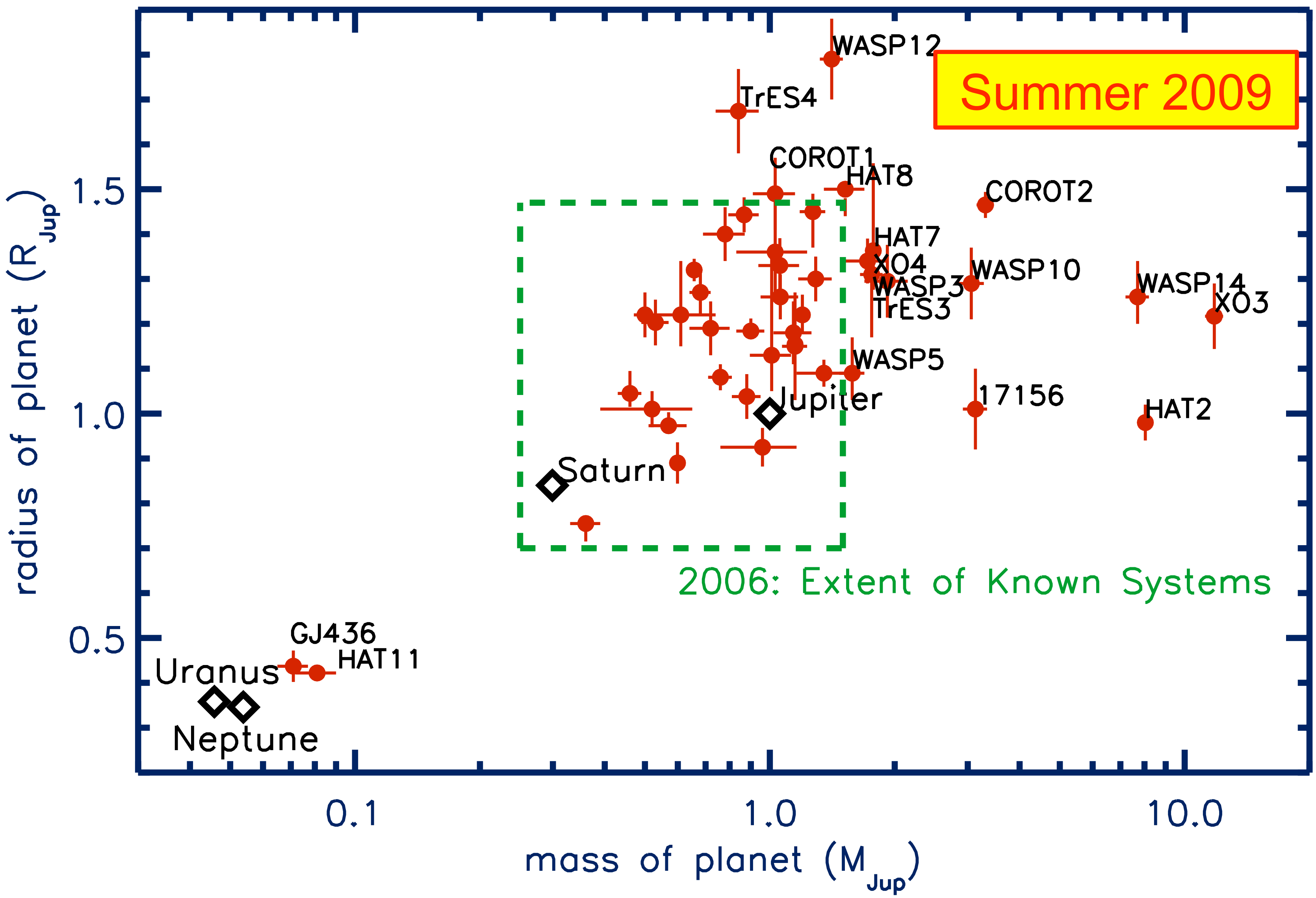
Exoplanet Masses and Sizes (Entire Universe)



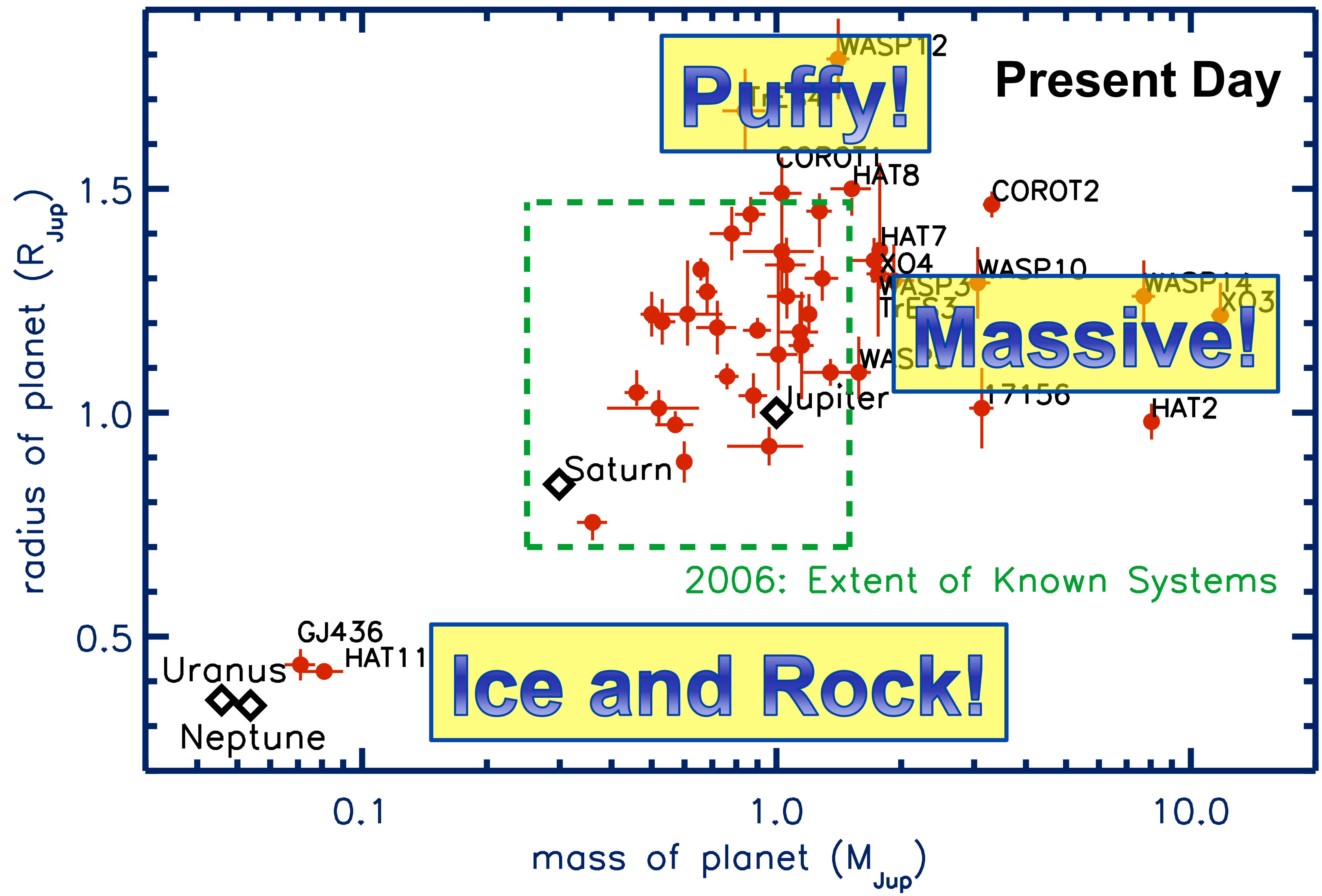
Exoplanet Masses and Sizes



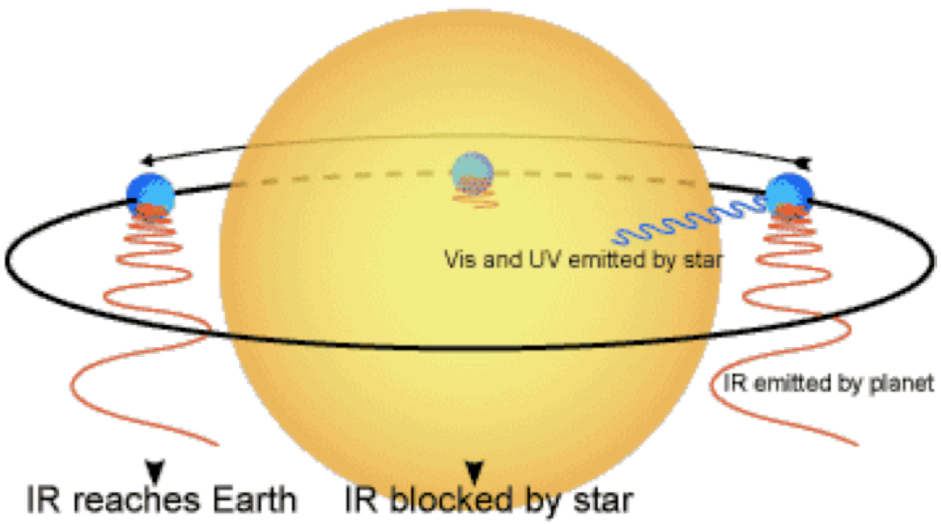
Exoplanet Masses and Sizes

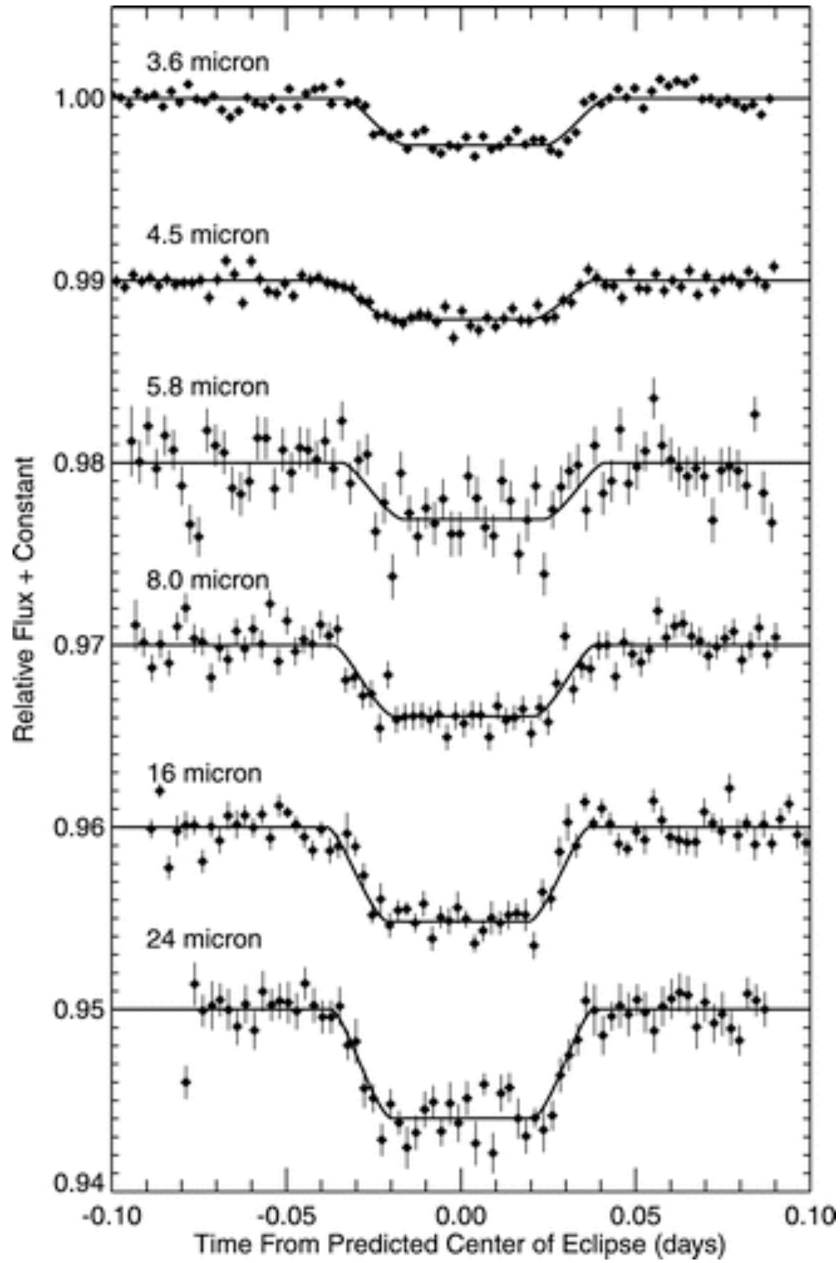


Exoplanet Masses and Sizes



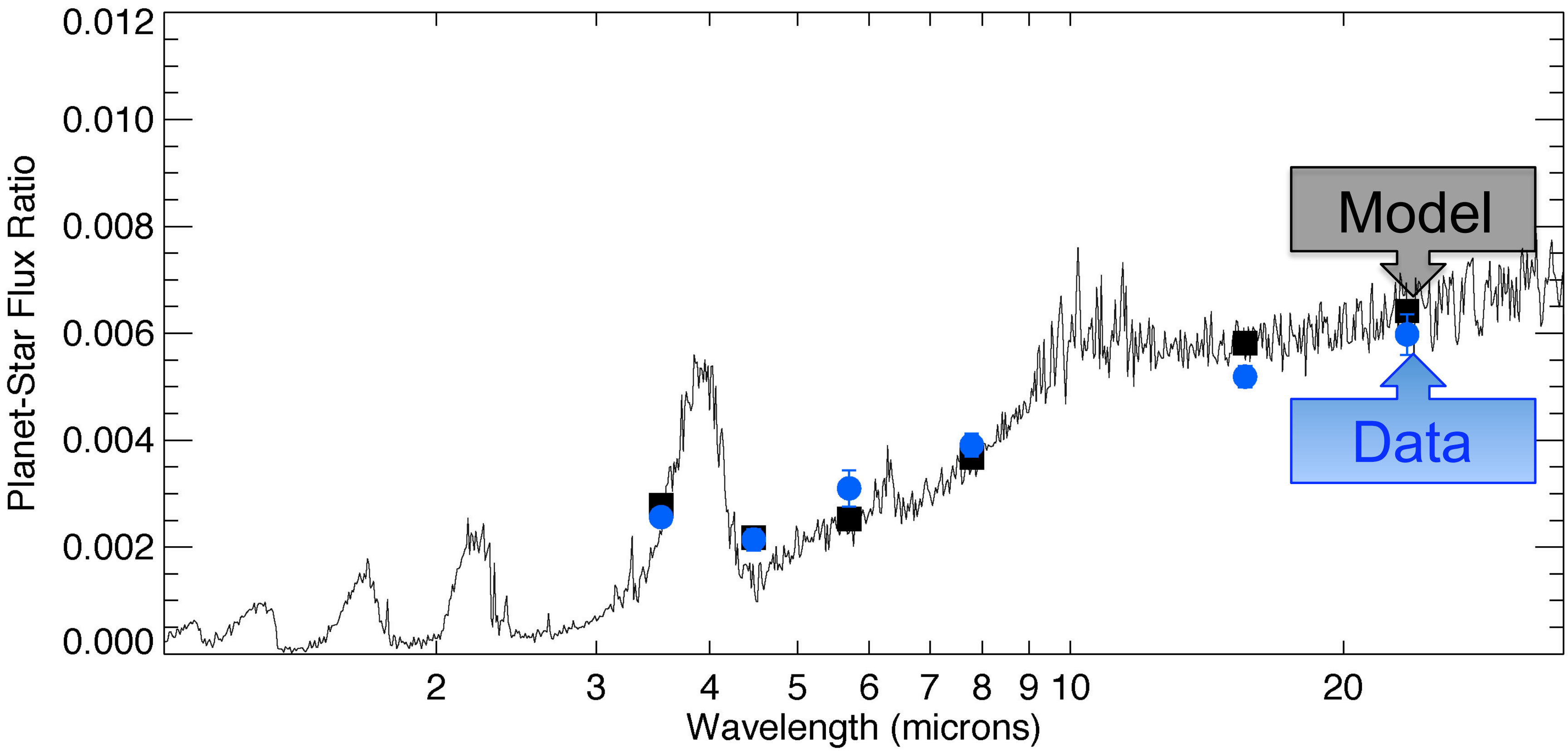
Spitzer Photometry of an Exoplanet Passing ***Behind*** Its Star





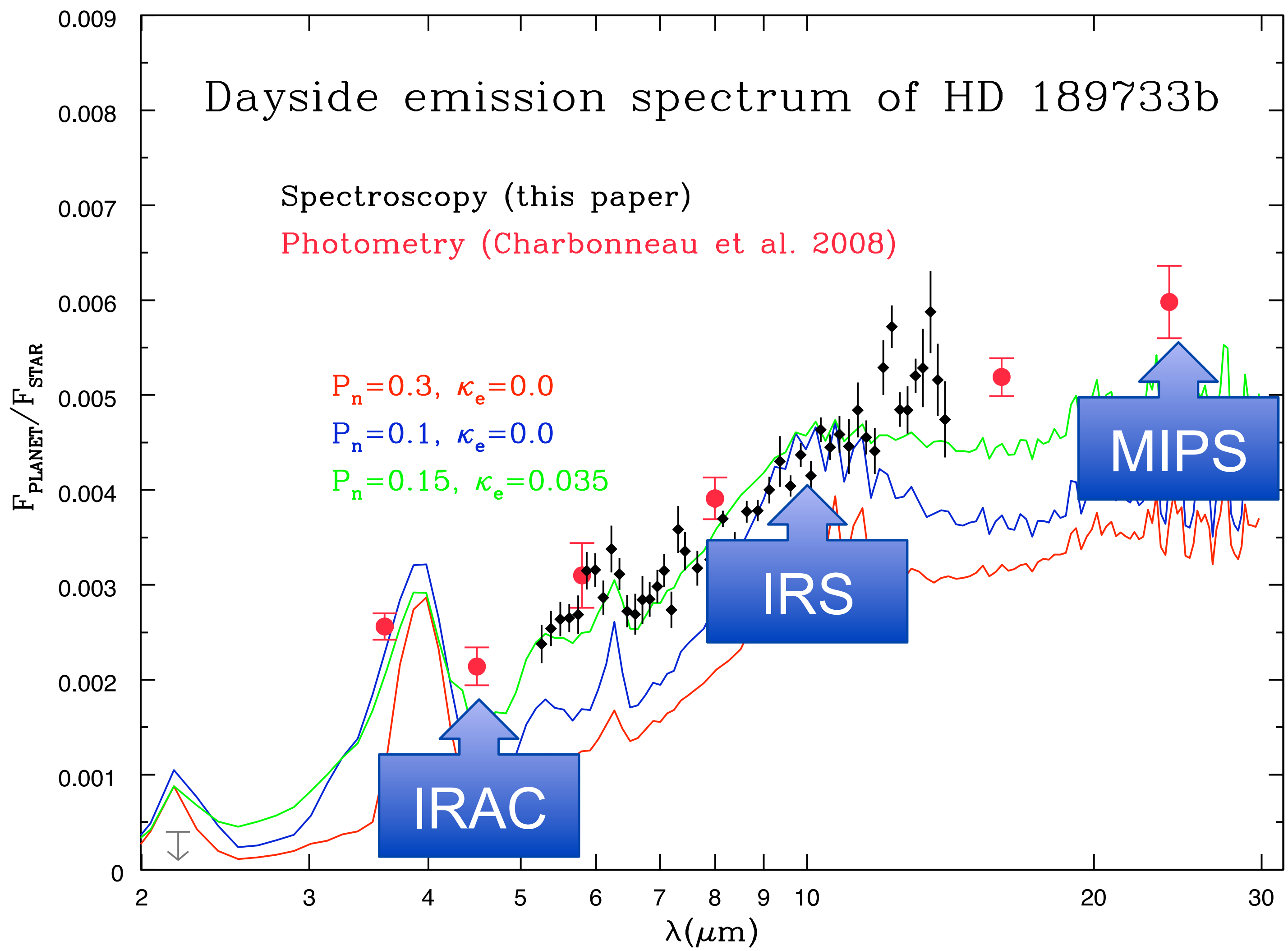
Charbonneau, Knutson et al. 2008

These Observations Permit Us to Study the Temperature and Chemistry of Exoplanet Atmospheres



Charbonneau, Knutson et al. (2008)

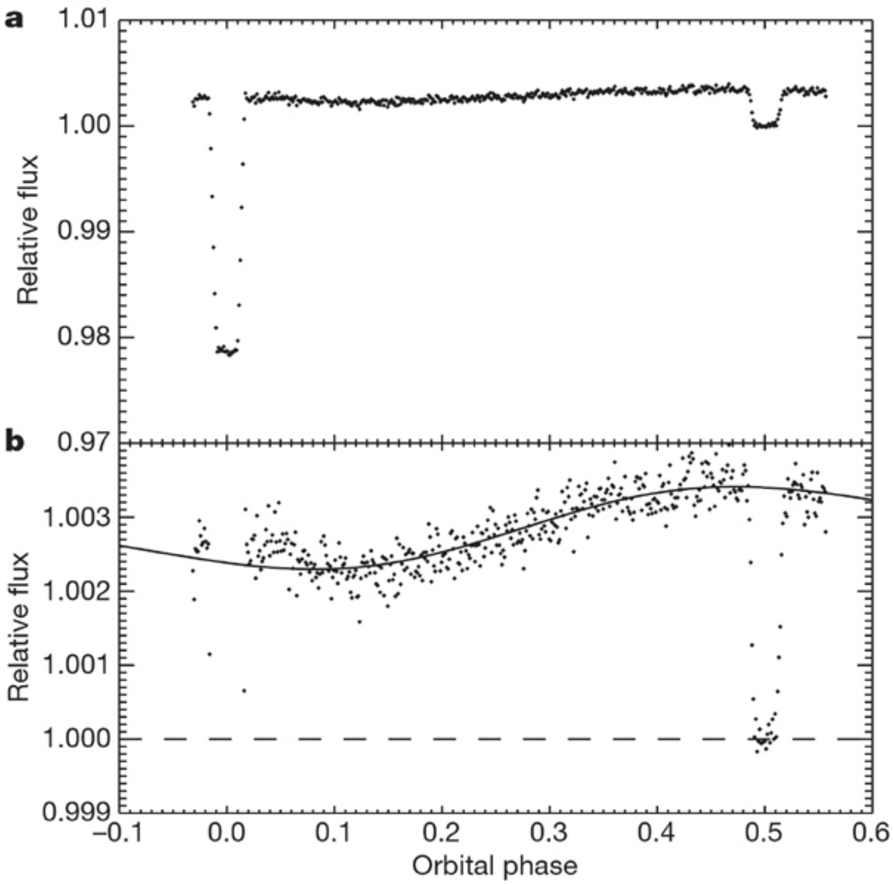
The Infrared Spectrum of the Dayside of a Hot Jupiter

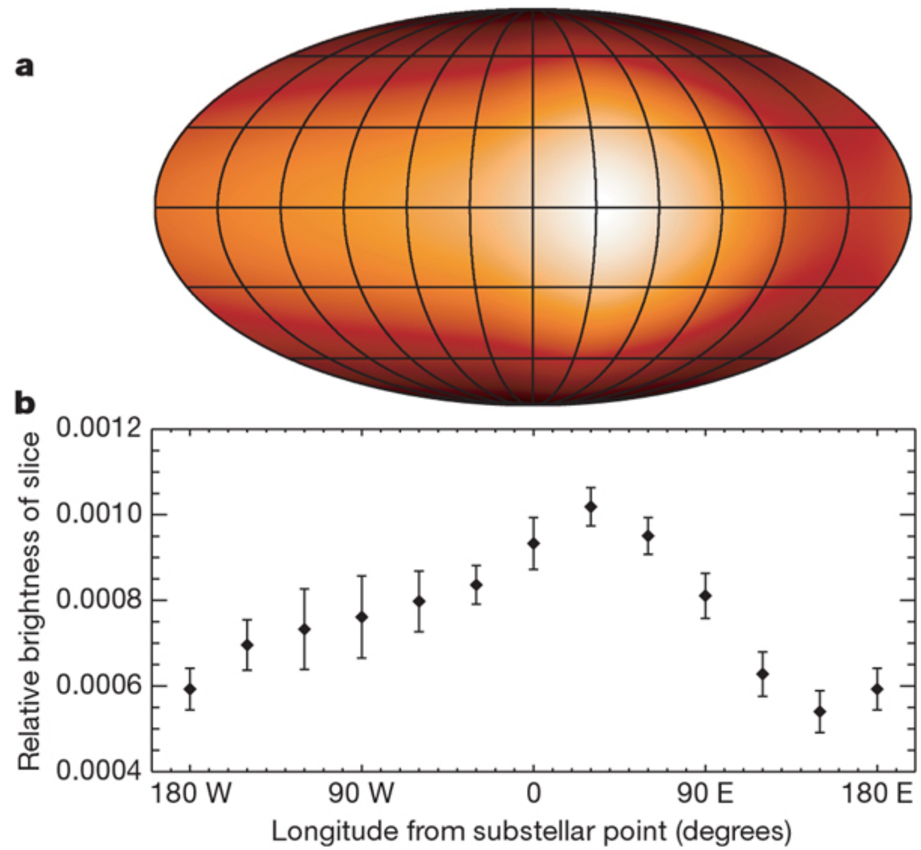


Grillmair, Burrows, Charbonneau, et al. Nature (2008)

Mapping the Surface Emission of an Exoplanet

Knutson, Charbonneau, et al. Nature (2007)

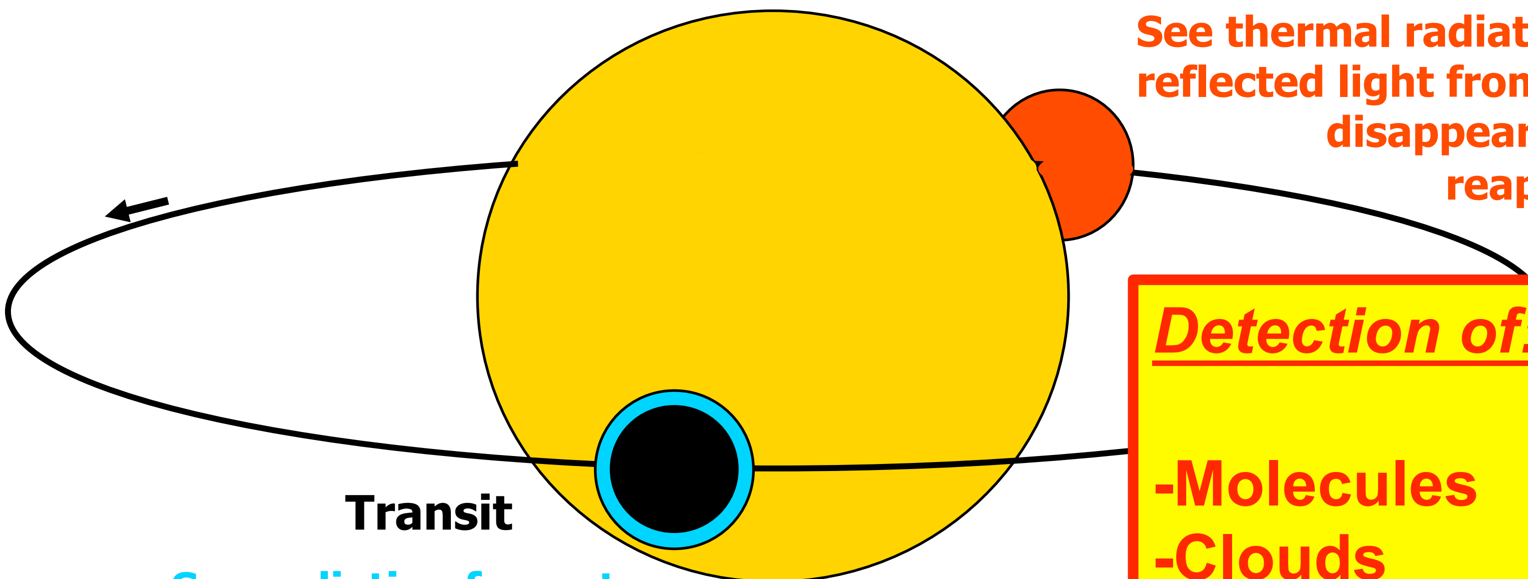




Modest day/night temperature difference indicates efficient heat redistribution.

Hottest point on planet lies east of "high noon", indicating winds.

Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets



<u>Detection of:</u>

-Molecules
-Clouds
-Temperature Inv.
-Day/Night Contrast

A Brief History of Progress in Comparative Exoplanetology

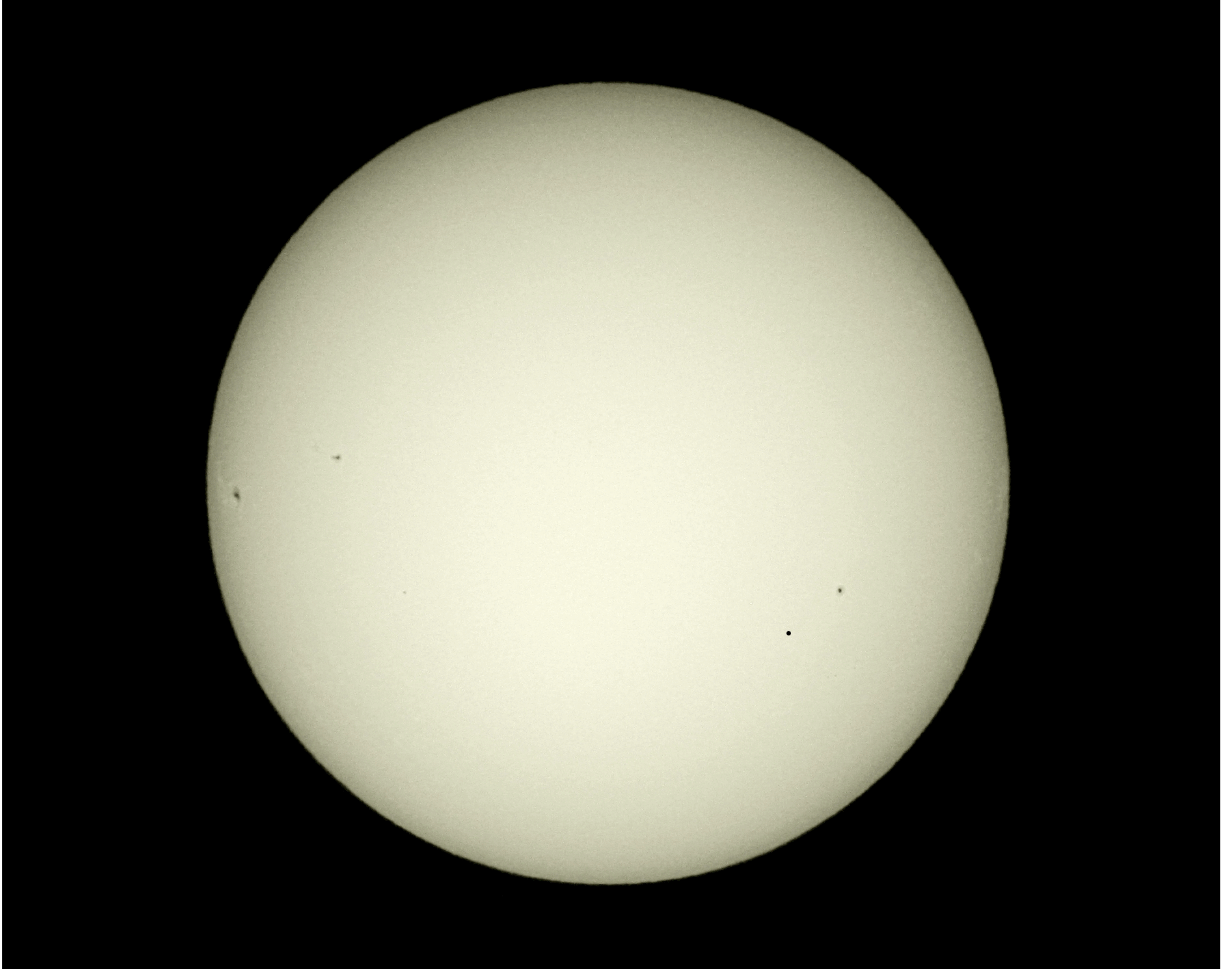
<u>1999 – 2009:</u> Hydrogen + Helium Worlds

Transit Detection → Atmospheric Characterization

Ground Based

Space Based

How did Spitzer
inform our quest
to study the atmosphere
of a habitable exoplanet?

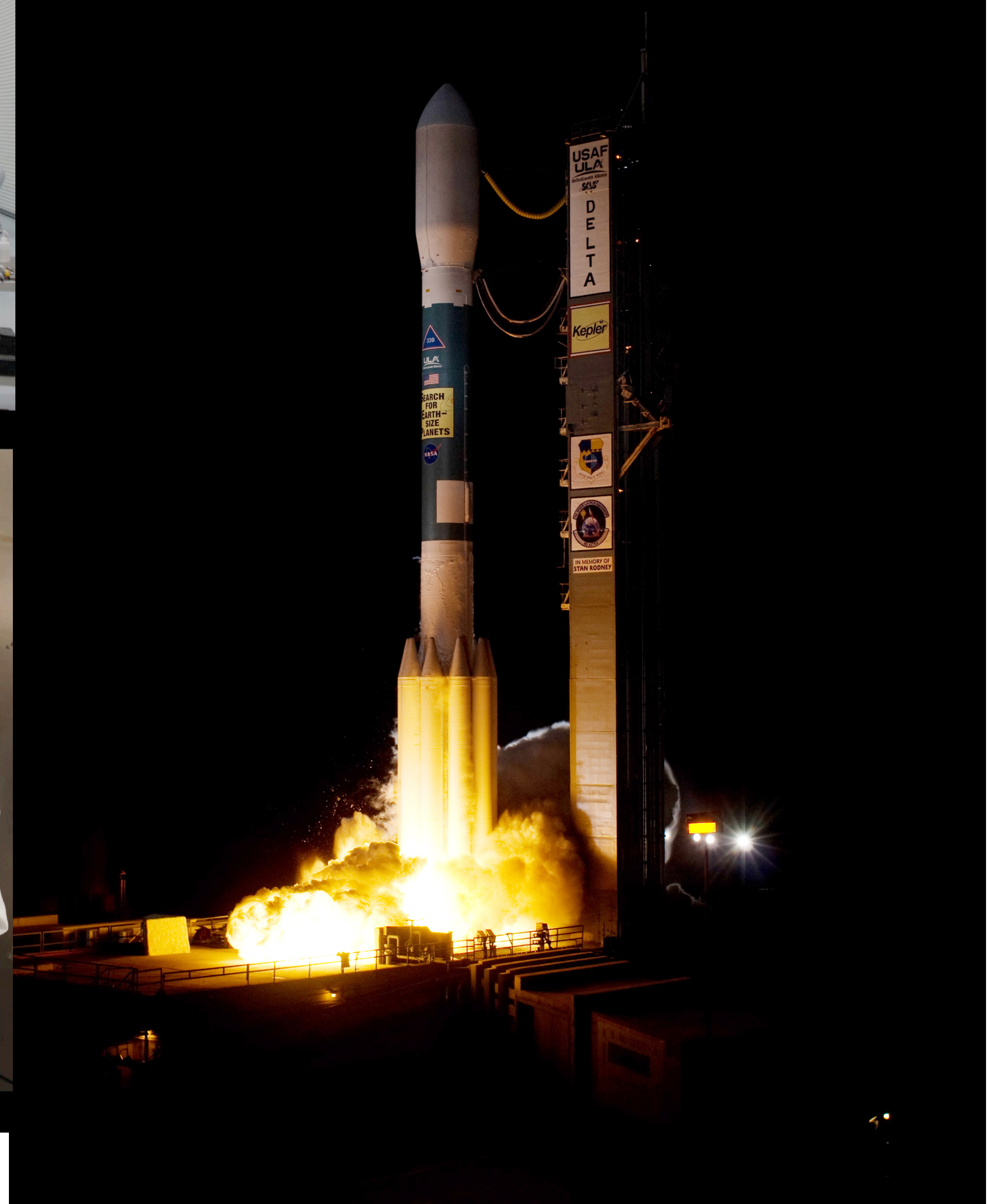


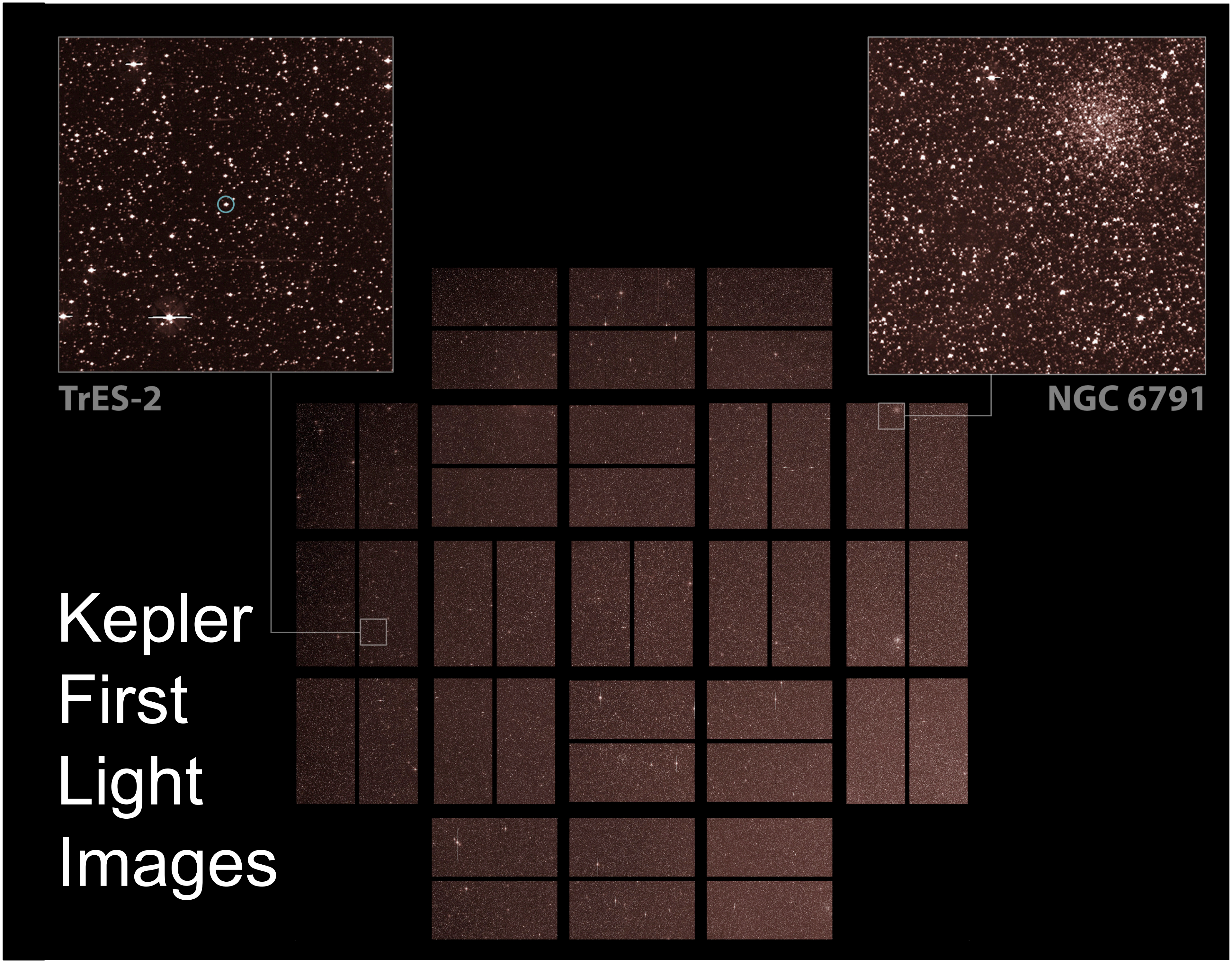
Space-based Searches for Transiting Rocky Exoplanets

- Will monitor 60,000 stars for 150 days
- Can detect Super-Earths

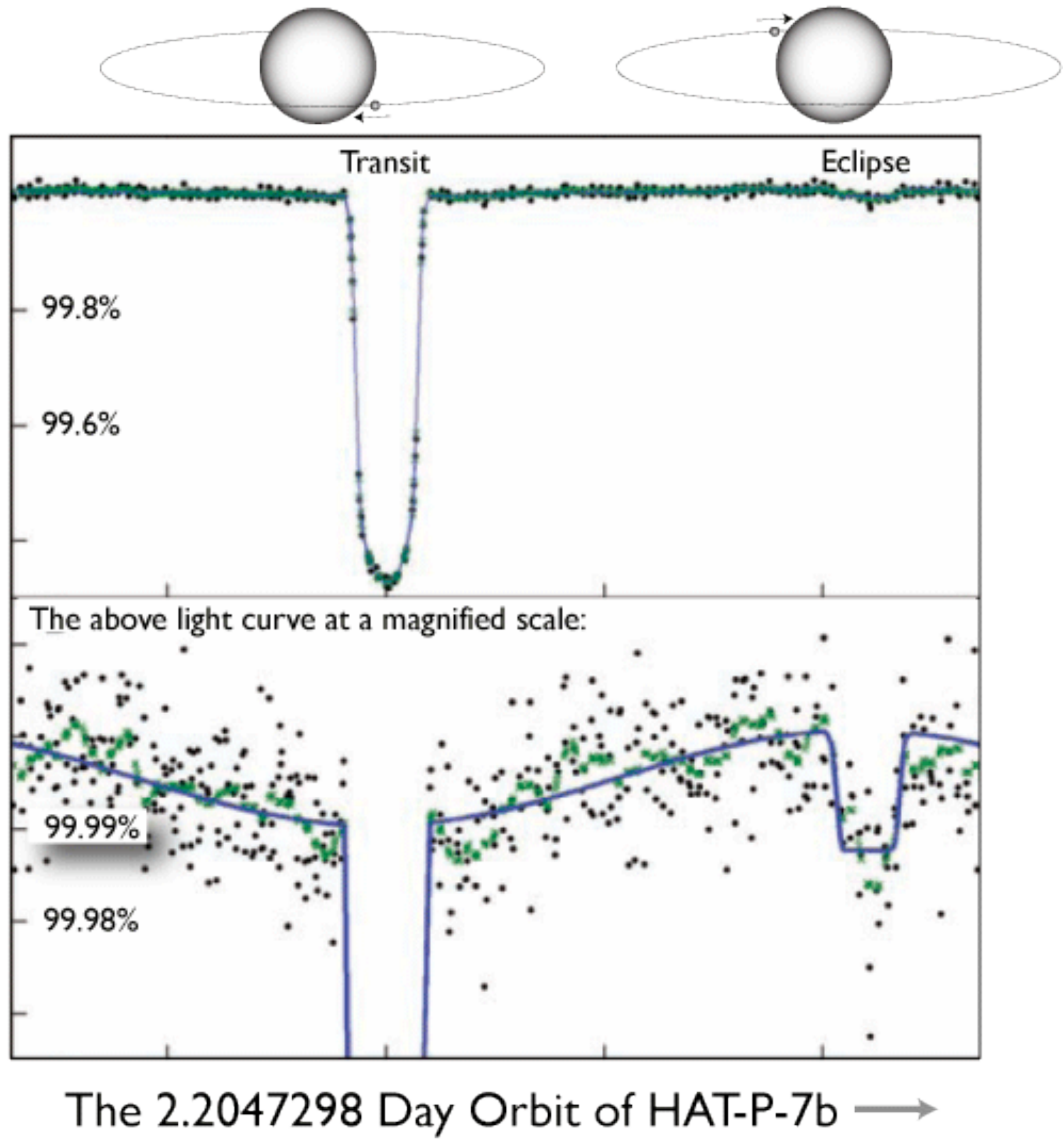
- Will monitor 150,000 stars for 3.5 years
- Will determine rate-of-occurrence of *true* Earth analogs

Kepler Mission Successful Launch March 6th, 2009




TrES-2
NGC 6791
Kepler First Light Images

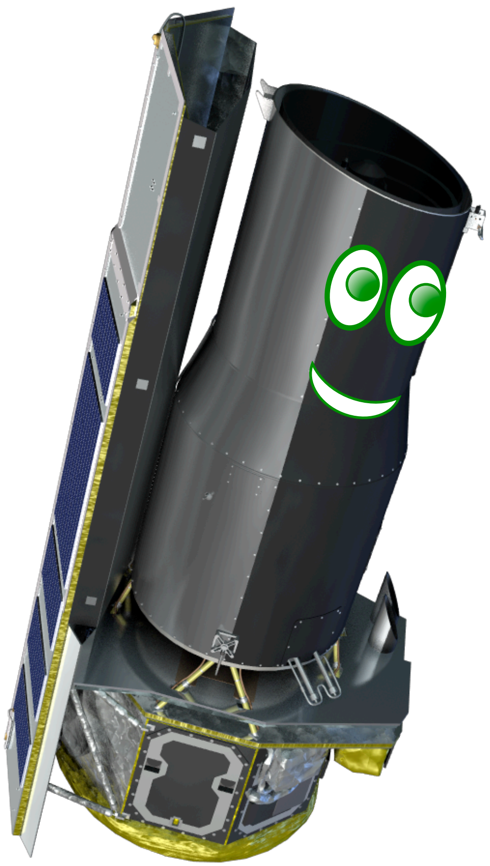
Kepler Mission Photometry of the Known Exoplanet HAT-P-7

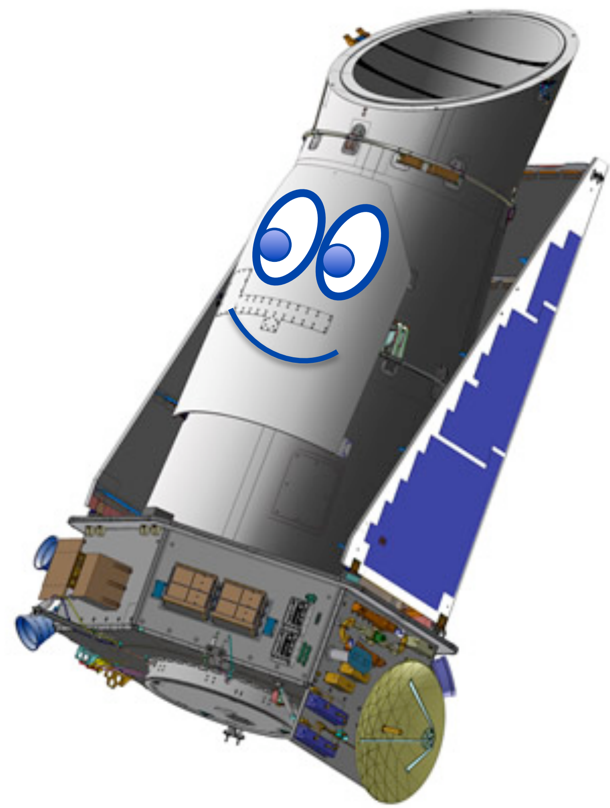


Borucki et al.
Science (2009)

Confirmation and Characterization of Kepler Mission Exoplanets: The Era of Rock and Ice Exoplanets

Warm Spitzer Exploration Science Program
(PI David Charbonneau)



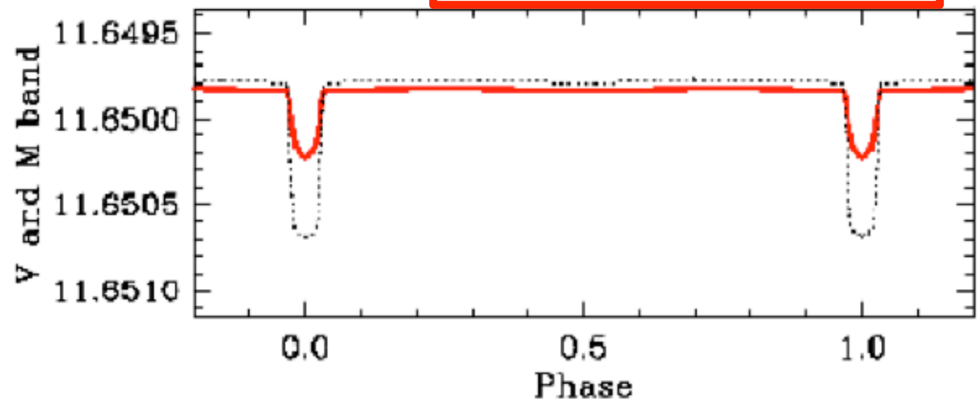


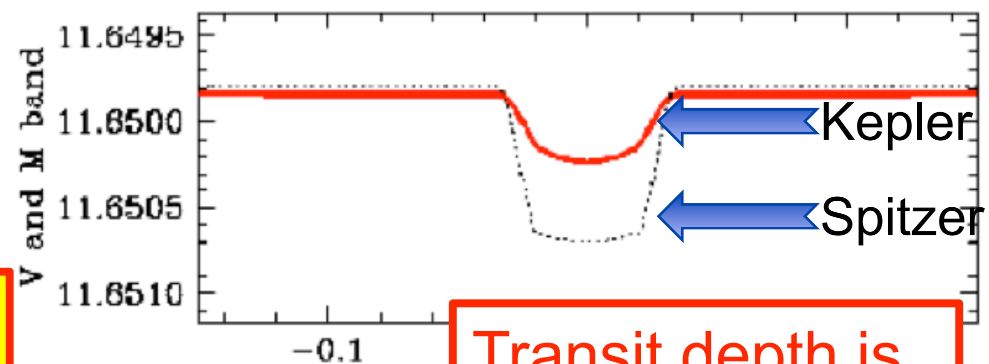
Rejection of Astrophysical False Positives

- If a Kepler candidate results from blend of eclipsing binary, transit will be color dependent.
- **Spitzer/IRAC photometry can detect transits as small as 0.03% (perhaps smaller)**
- Crucial for physically-associated triples for which Kepler will not detect shift of photocentroid

Spitzer has ALREADY done this for the first transiting Super-Earth, Corot-7b (DDT Program; F. Fressin et al.)

Good planet candidate but…





Transit depth is color dependent

Warm Spitzer Exploration Science Program
800 hours

Goal 1:

Directly detect photons from previously inaccessible classes of exoplanets, namely cool Jupiters, hot Neptunes and superhot SuperEarths.

- Dayside temperature
- Presence or absence of temperature inversion
- Determine if eccentricity is near zero

Study 20 planets at each of 3.6 & 4.5 μm (one 10 hour eclipse per band) for a total of 400 hours

Goal 2:

Transit photometry of candidate terrestrial planets to reject blends of eclipsing binaries.

- Confirm planetary nature of candidate by color-invariance of transit depth.

Study 40 candidates at 4.5 μm (one 10 hour transit) for a total of 400 hours

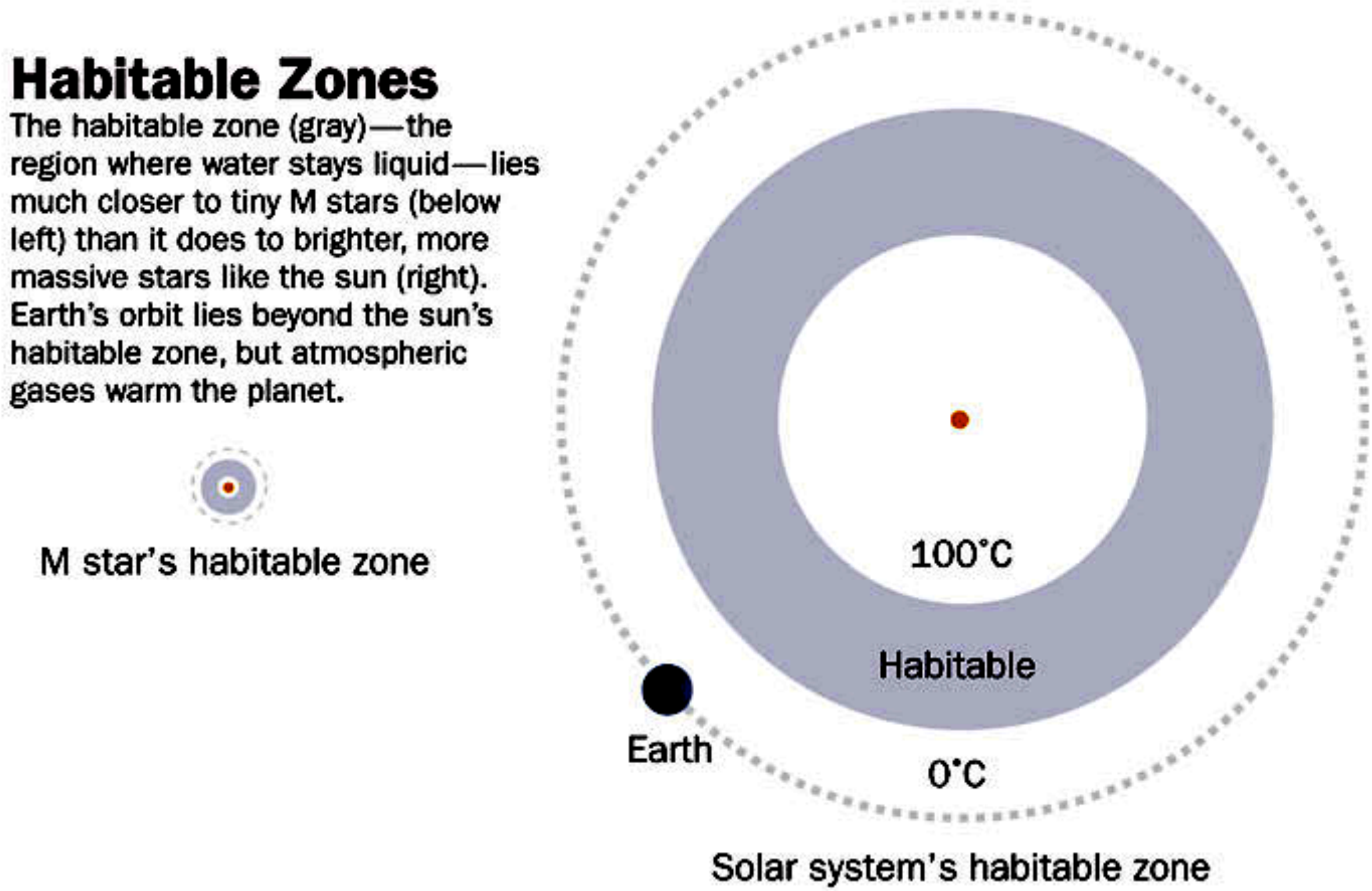
The Path Ahead for Kepler-Detected Rock + Ice Habitable Worlds

Transit Detection → Atmospheric Characterization

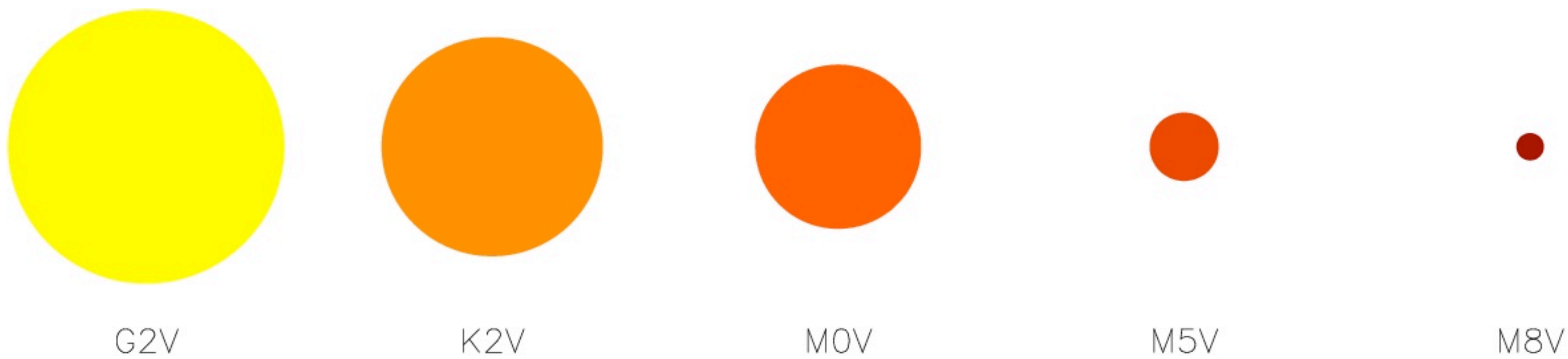
Space Based

?

The Small Star Opportunity



The Small Star Opportunity

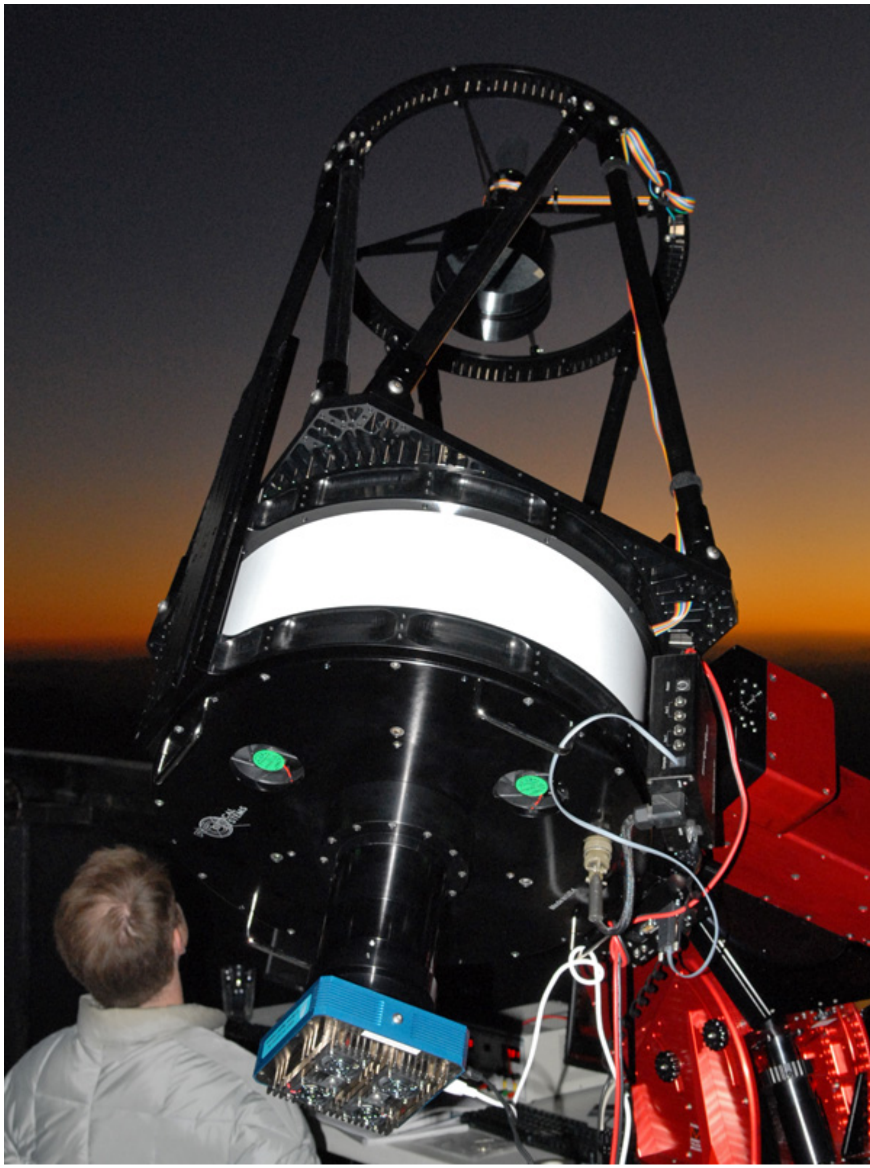


Consider a 7-M_{Earth} 2-R_{Earth} habitable zone planet:

✓ Transits are deeper	*Sun: 0.03%*	*M5V: 0.5%*
✓ Transits are more frequent	*Sun: 365 days*	*M5V: 15 days*
✓ Transits are more likely	*Sun: 0.5%*	*M5V: 1.6%*
✓ Greater Doppler Wobble	*Sun: 1.3 m/s*	*M5V: 10 m/s*

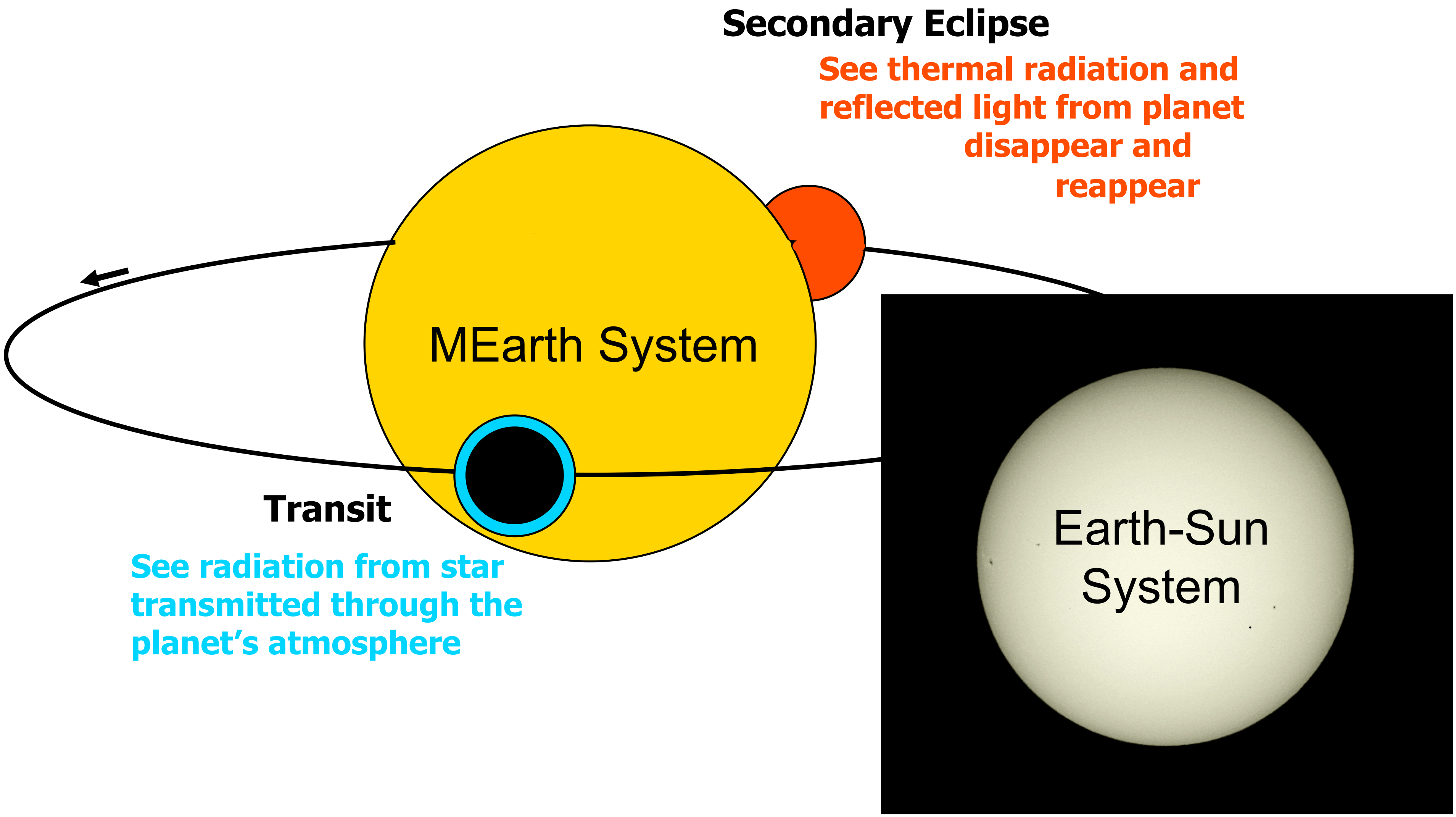
The MEarth Project

with P. Nutzman, J. Irwin, C. Burke, Z. Berta, and E. Falco



MEarth Project, Whipple Observatory, AZ

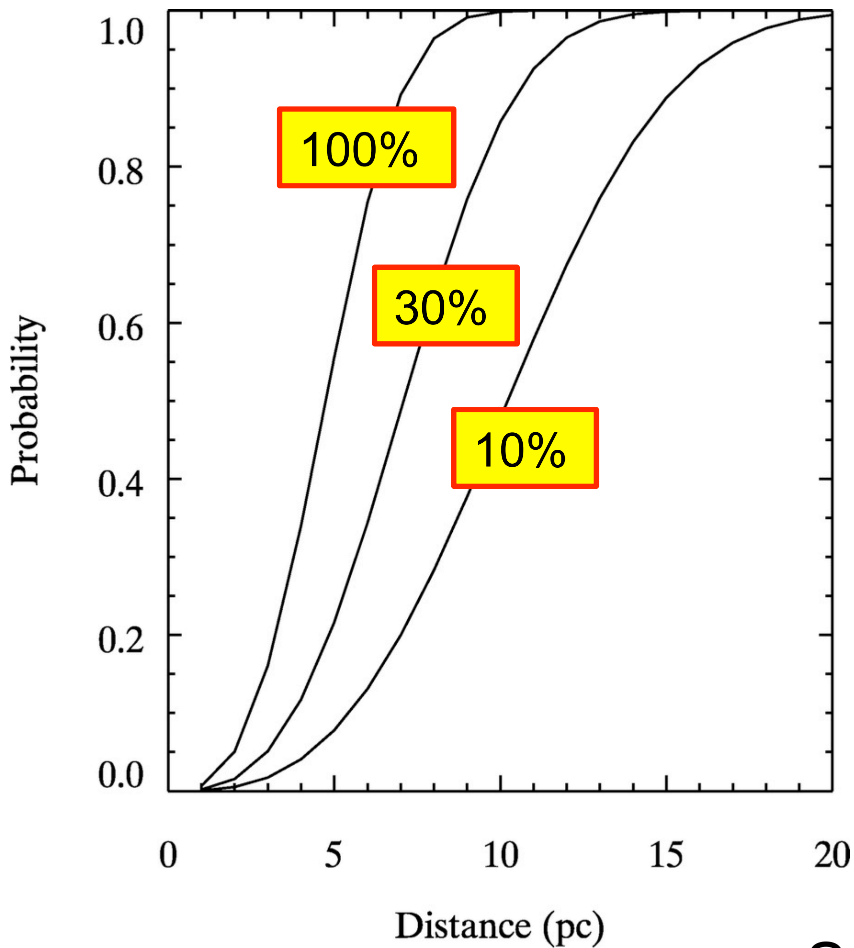
Transit Studies of the Atmospheres Are Facilitated by the Small Size of the Star

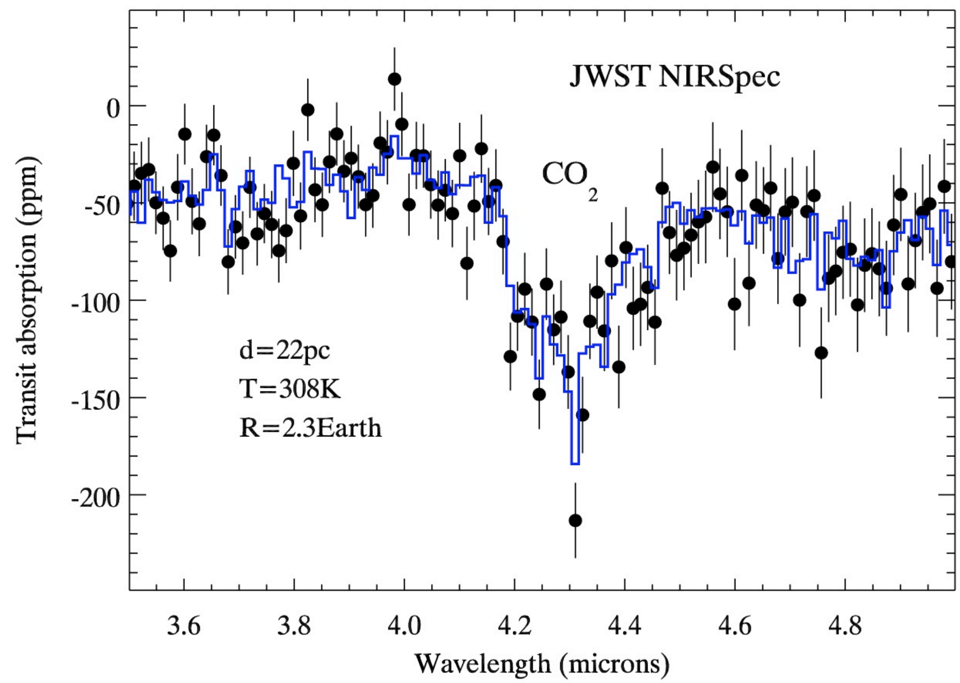


Habitable-Zone Planets Orbiting Low-Mass Stars
are Ideal Targets for Atmospheric Studies
to Search for **BIOMARKERS**

James Webb Space Telescope is scheduled for launch in 2014.

Planning for JWST Studies of Habitable Super-Earths





See Deming et al. (2009) for details

The Question:

What is the Exoplanet Legacy of the Spitzer Space Telescope?

<u>Legacy:</u> Something received from an ancestor or from the past

Spitzer’s Exoplanet Work:

<u>1999 – 2009:</u> Hydrogen + Helium Worlds

Transit Detection → Atmospheric Characterization

Spitzer’s Exoplanet Legacy:

<u>2009+ :</u> Rock + Ice Habitable Worlds

Transit Detection → Atmospheric Characterization

Spitzer's Exoplanet Legacy:

An entirely novel, fast-tack approach to the study of inhabited worlds beyond the Solar system.