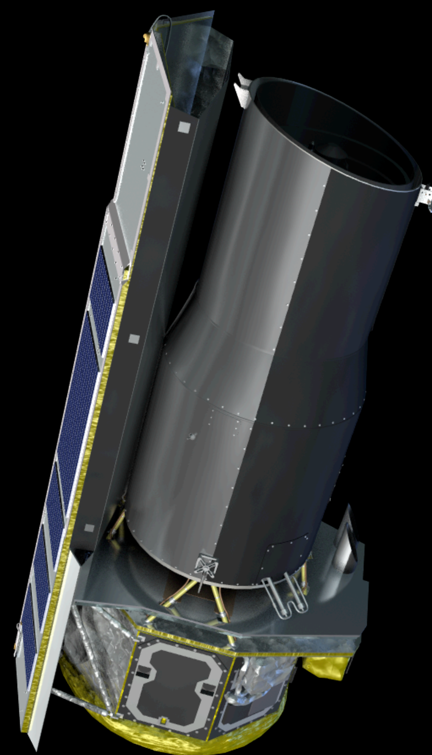
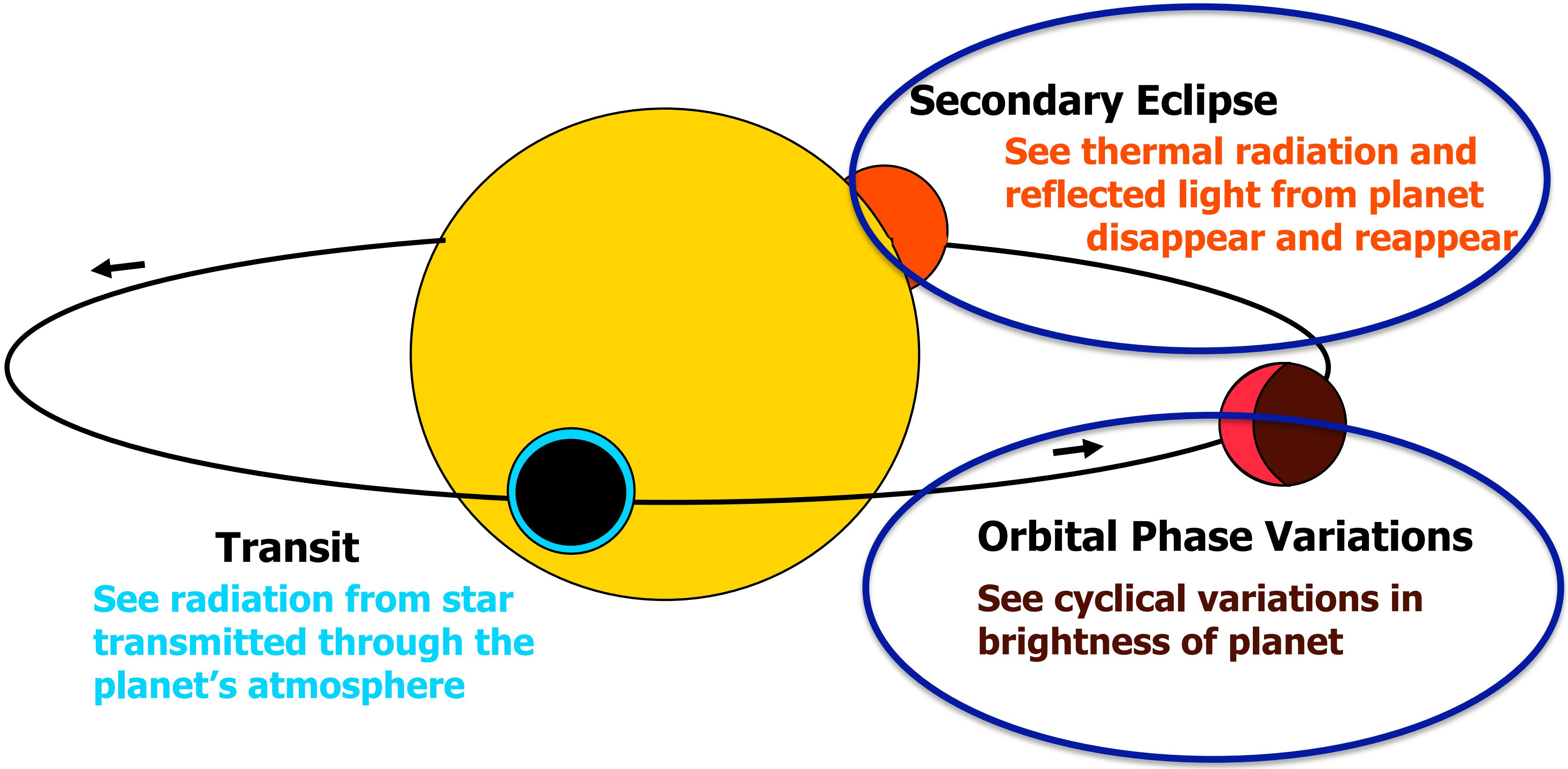
Warm Spitzer: Plans for Exoplanets



Jonathan Fortney, UC Santa Cruz
(with *much* help from H. Knutson and D. Charbonneau)

Transiting Planets as a Tool for Studying Exoplanet Atmospheres

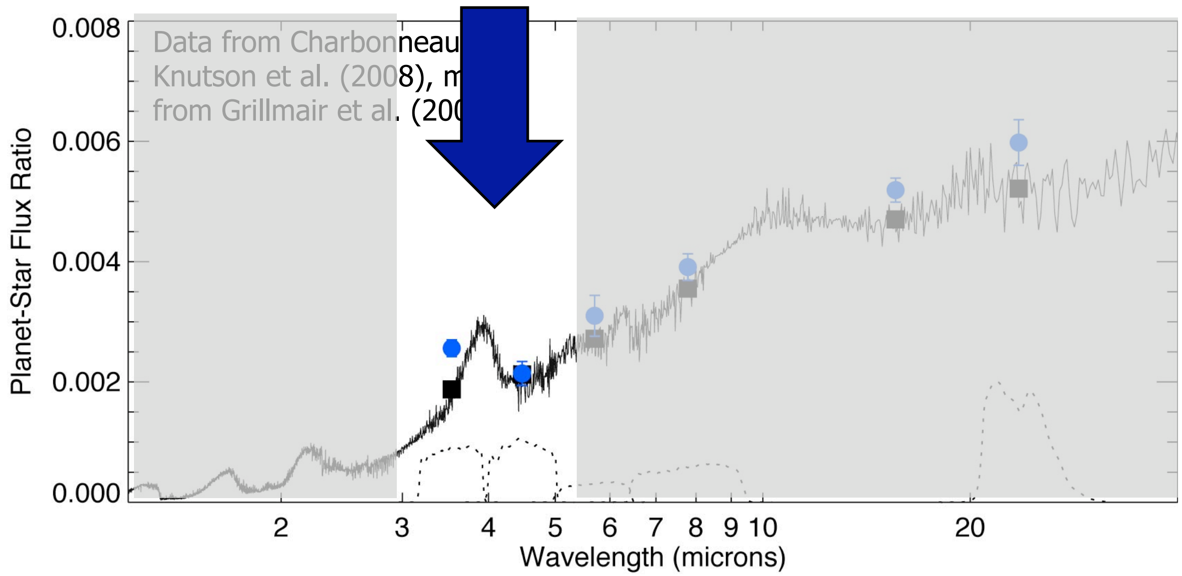


***Spitzer* Exploration Science Program 60021**
(1138 hours)
PI H. Knutson

(At Least)
Two Classes of Hot Jupiter Atmospheres

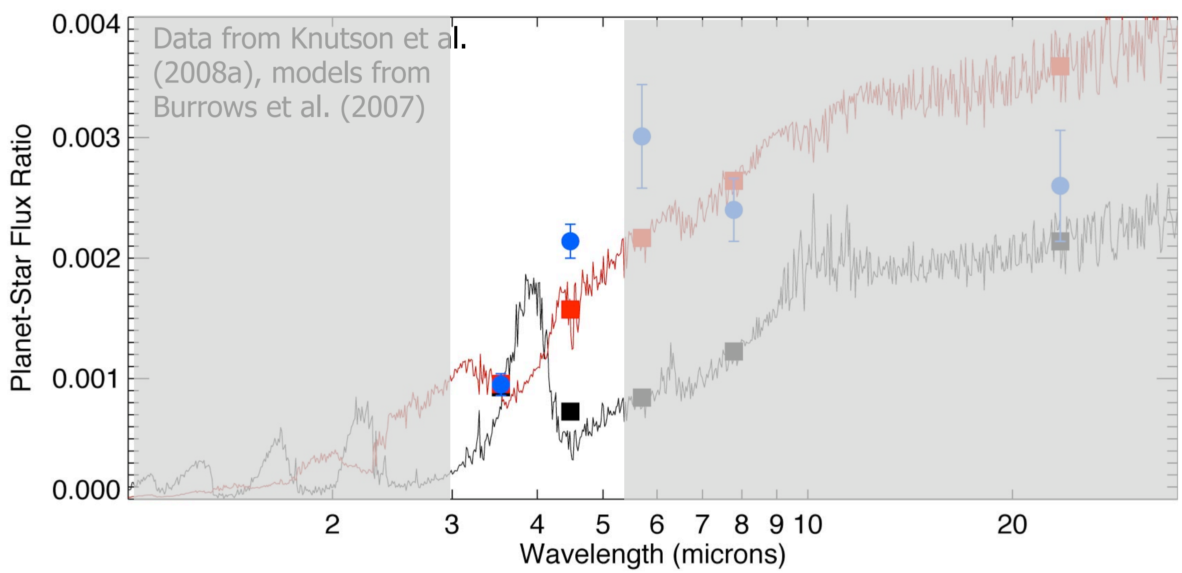
Observations in the 3.6 and 4.5 μm channels may be used to determine whether or not a given planet has an inversion.

HD 189733b is well-described by a model with water and CO bands in absorption.



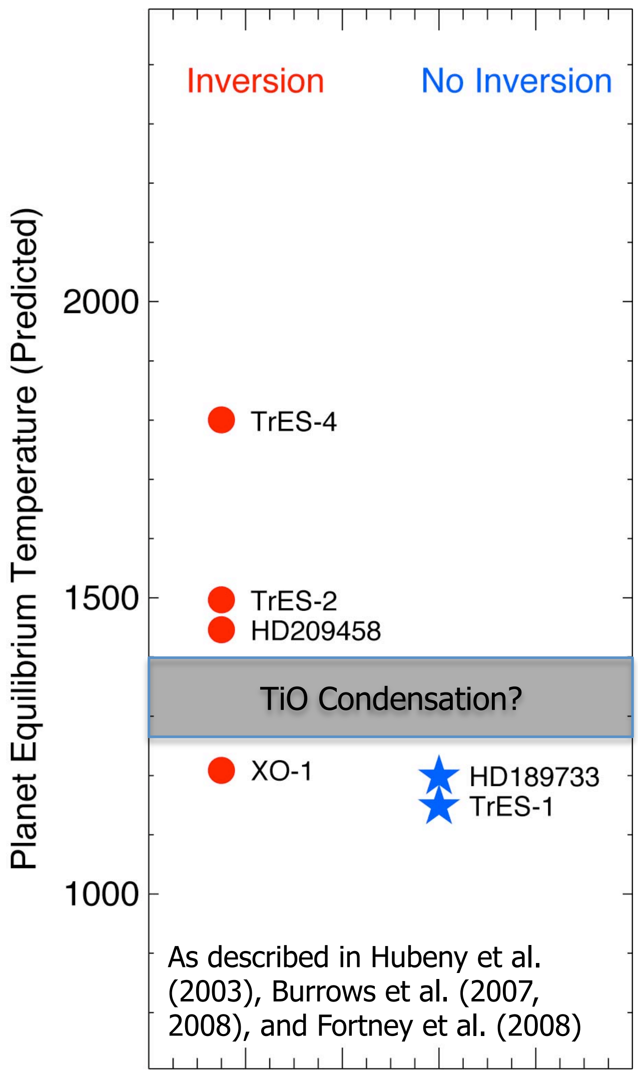
HD 209458b is NOT well-matched by this model.

Requires the addition of a high-altitude absorber, leading to the formation of a temperature inversion and water in emission.



Exploring the Origin of Temperature Inversions

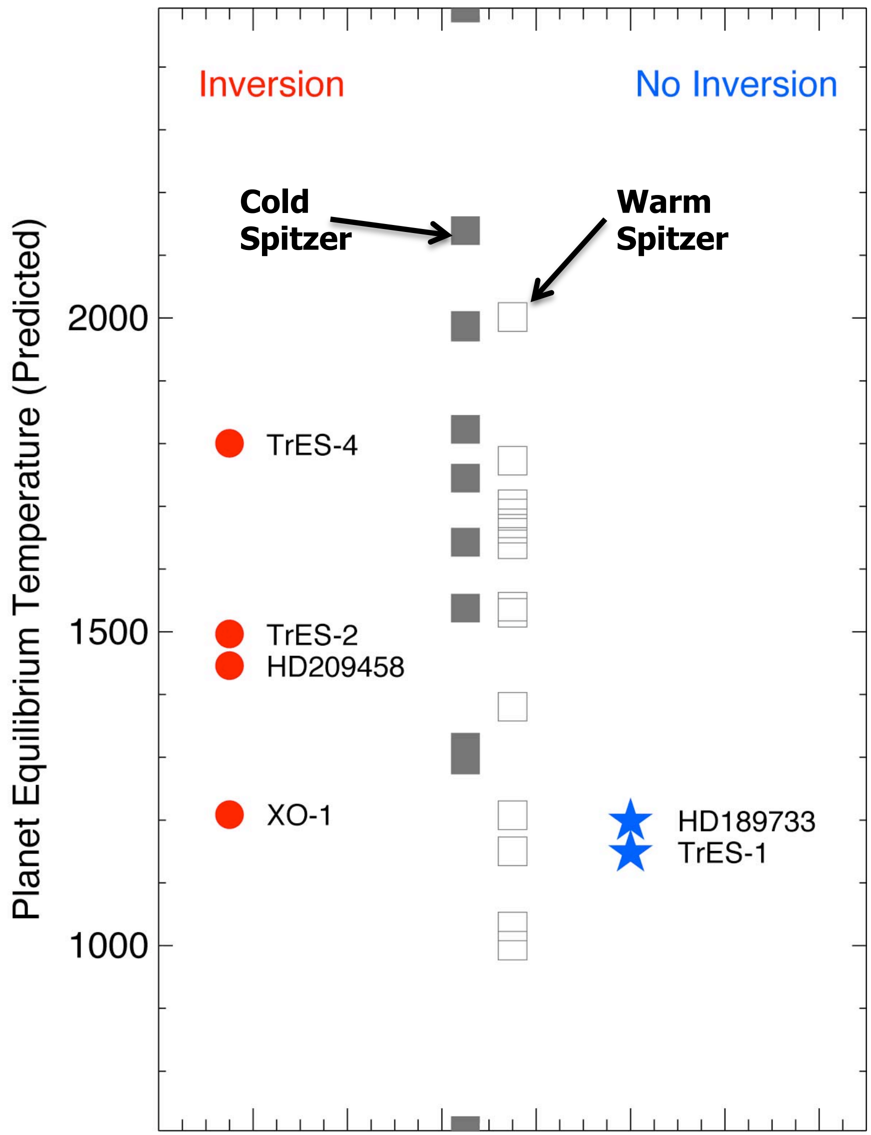
Theory: Gas-Phase TiO/VO



Need better statistics!

Better statistics will make it possible to search for correlations between inversions and other parameters…

Theory 1: Gas Phase TiO/VO



- Stellar metallicity
- UV incident flux
- Planetary surface gravity
- Rotation period

- Observe secondary eclipses for all systems with $m_K<12$

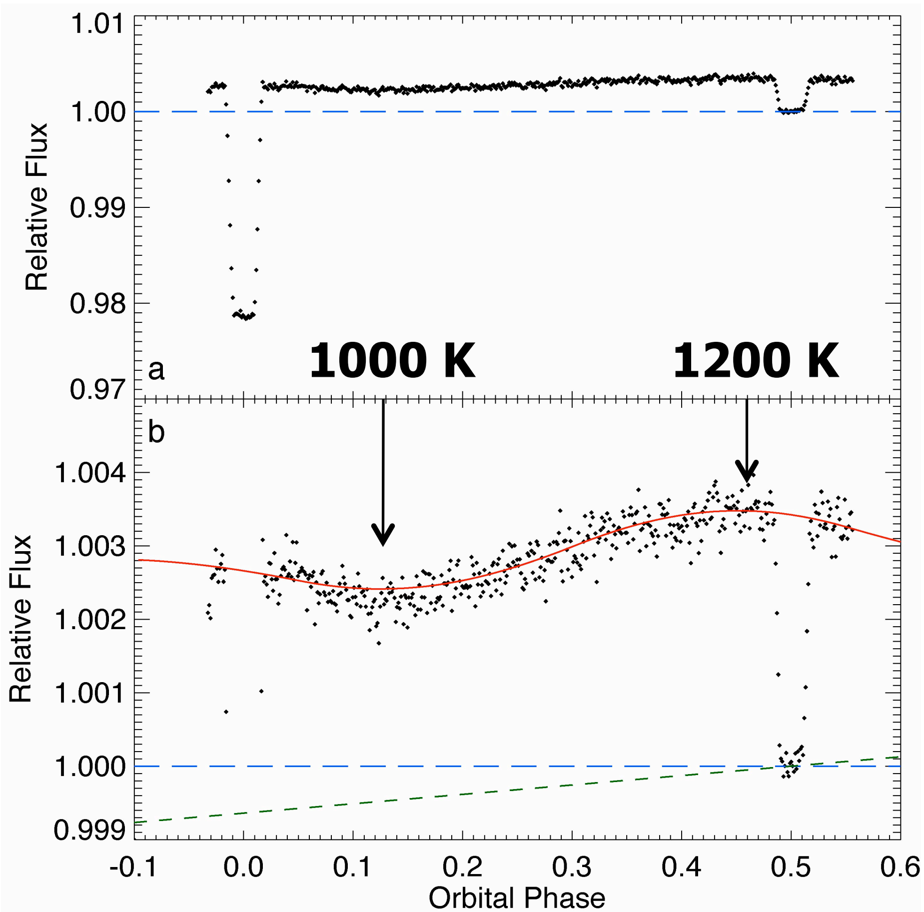
- Add 15 planets to the 19-planet cold Spitzer sample

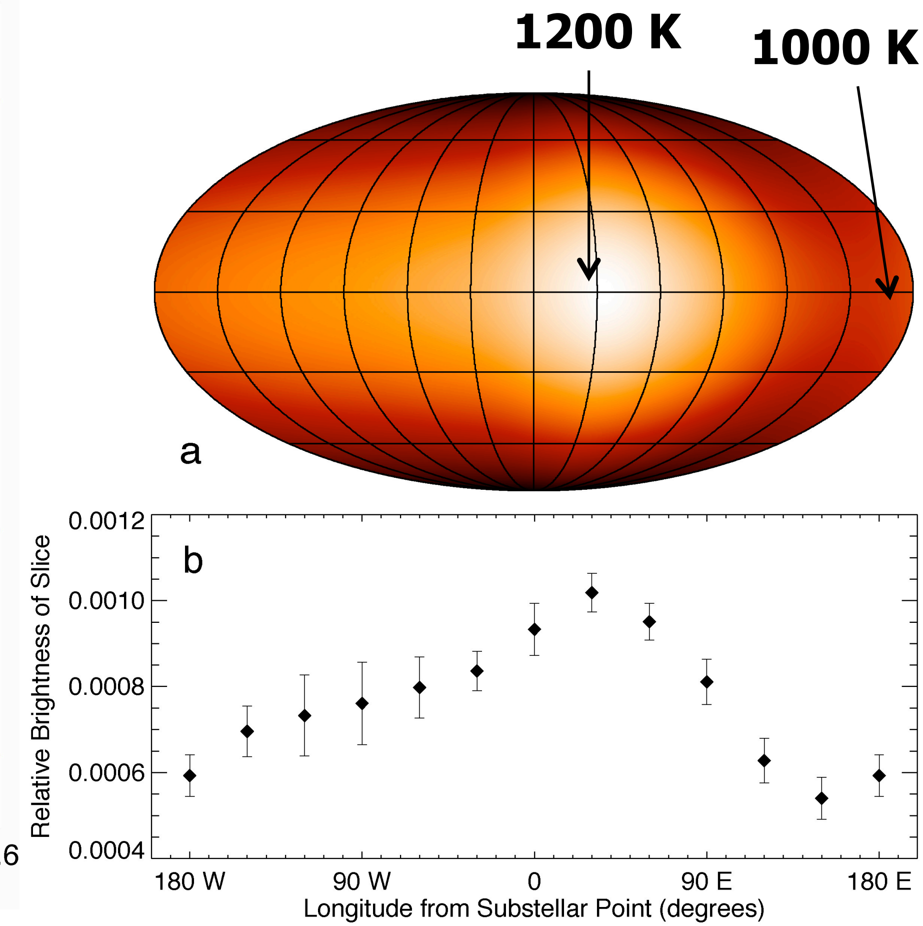
Not So Fast!
The Need for Spatially Resolved Information

Properties of tidally locked planets may vary substantially with longitude and latitude; secondary eclipse observations give us an average over the dayside hemisphere.

Phase curve observations allow you to resolve these gradients, and to study the planet's atmospheric circulation patterns.

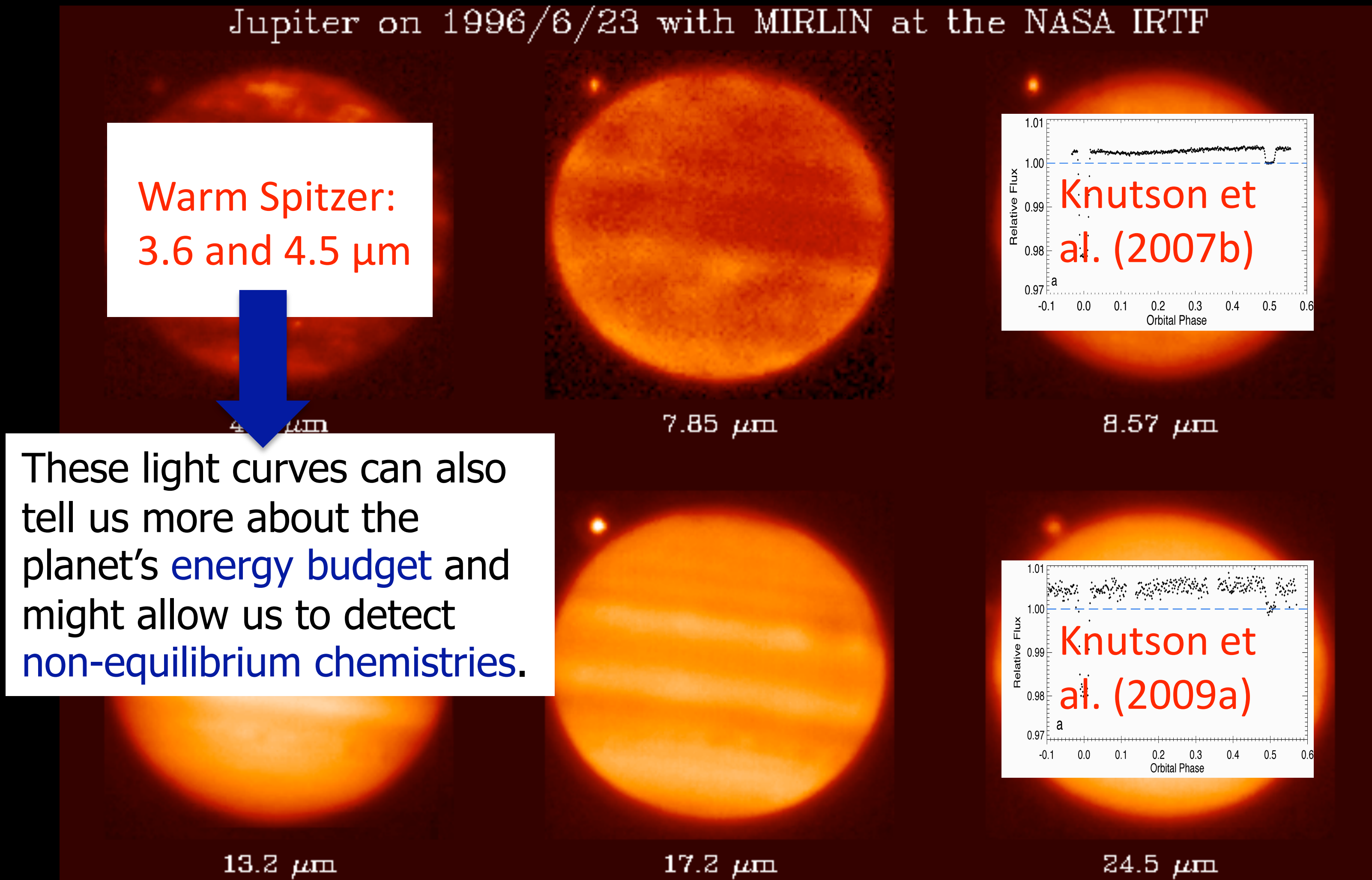
First Longitudinal Temperature Profile for an Extrasolar Planet





Spitzer 8 μm observations of HD 189733b
(Knutson et al. 2007b, *Nature* 447, 183).

Different Wavelengths Probe Different Depths in the Planet's Atmosphere.



Will have phase curves from 3.6-24 μm (four bands) for multiple planets.

A Survey of Atmospheric Circulation on Five Hot Jupiters

What about a 8 M_{Jup} planet with a highly **eccentric orbit**? →

HAT-P-2b
Mass: 8.0 M_{Jup}
Radius: 0.98 R_{Jup}
T_{equil}=1100-2200 K

What does the atmospheric circulation look like in the **high-flux limit**? Planet is also in the Kepler field. →

HAT-P-7b
Mass: 1.78 M_{Jup}
Radius: 1.36 R_{Jup}
T_{eqil}=2100 K

How do **temperature inversions** affect the day-night circulation? →

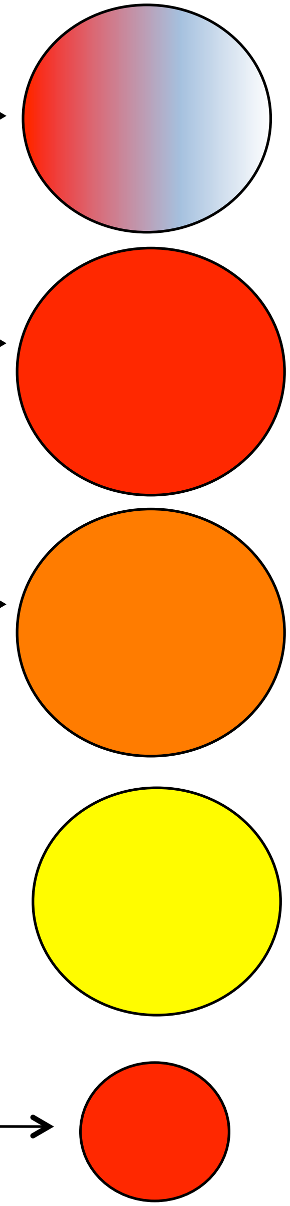
HD 209458b
Mass: 0.66 M_{Jup}
Radius: 1.32 R_{Jup}
T_{eqil}=1400 K

Benchmark system →

HD 189733b
Mass: 1.15 M_{Jup}
Radius: 1.15 R_{Jup}
T_{equil}=1100 K

Do **core-dominated planets** have qualitatively different circulation patterns? →

HD 149026b
Mass: 0.36 M_{Jup}
Radius: 0.76 R_{Jup}
T_{equil}=1700 K



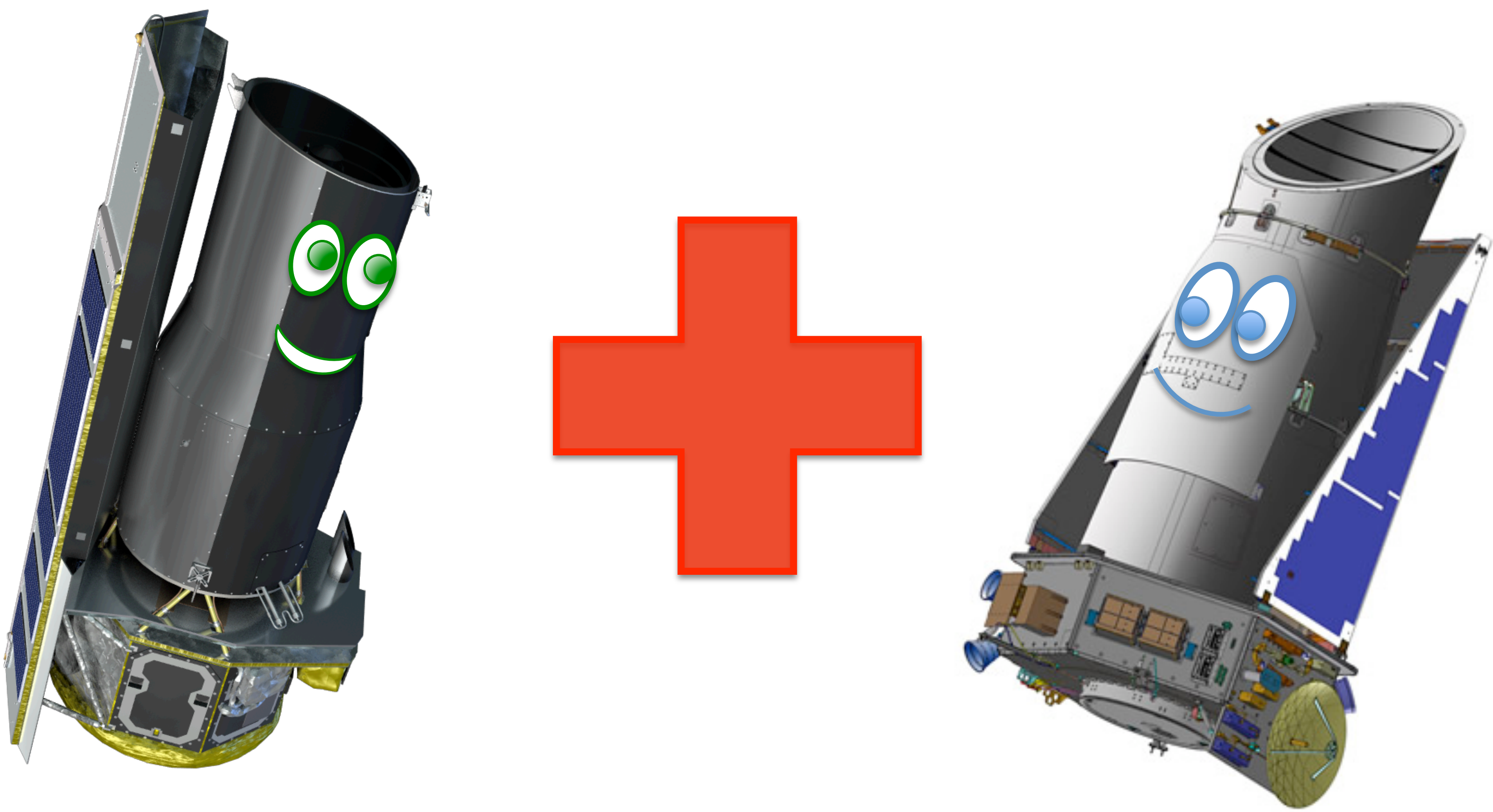
Knutson Program: Conclusions

Knutson program employs a two-pronged approach to advancing our understanding of hot Jupiter atmospheres.

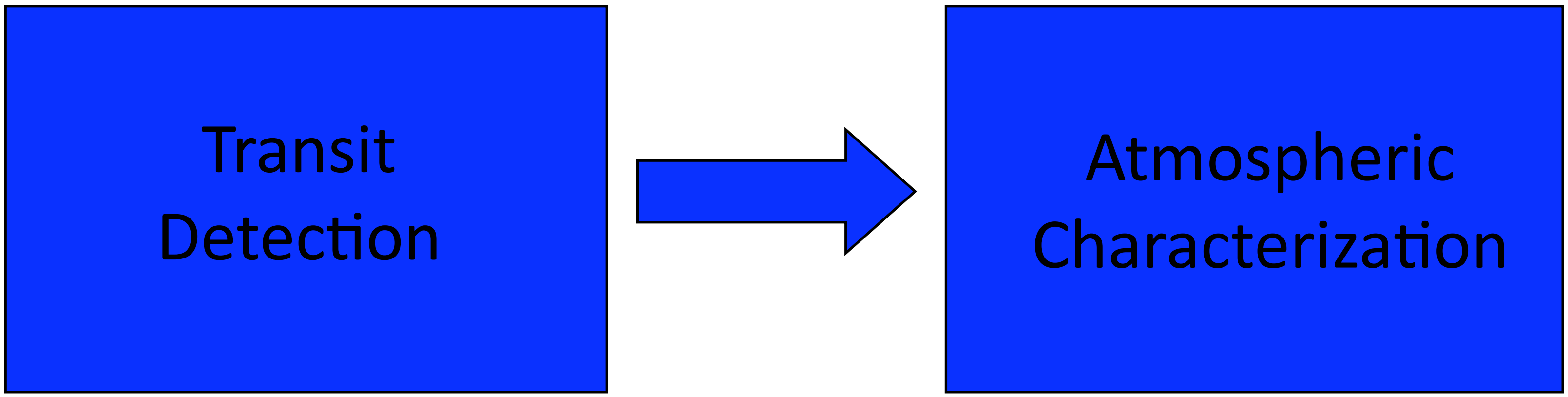
First we will conduct a comprehensive survey of the dayside emission spectra of hot Jupiters, and use this to investigate the processes that lead to the formation of temperature inversions.

Second, we will examine the spatially resolved properties and atmospheric circulation for five representative planets using phase curve observations.

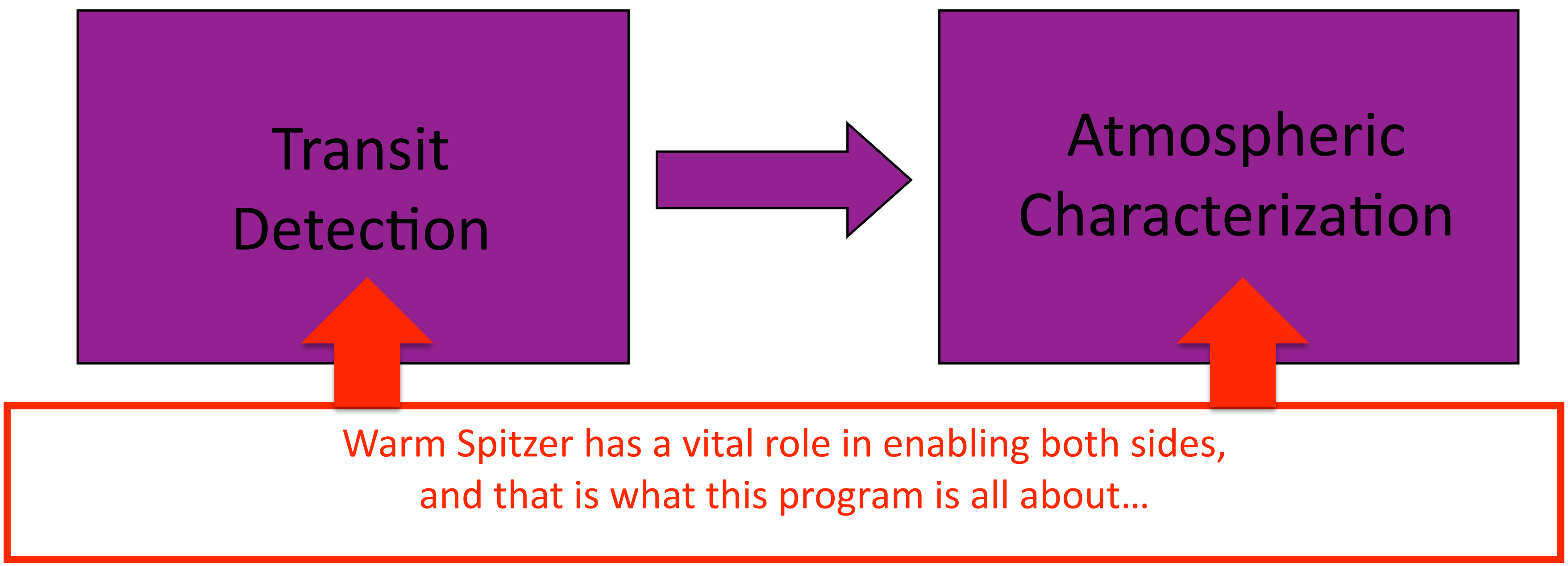
Warm Spitzer -- Confirmation and Characterization of Kepler Mission Exoplanets: The Era of Rock and Ice Exoplanets



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



The Kepler Era 2009+: Rock + Ice Worlds



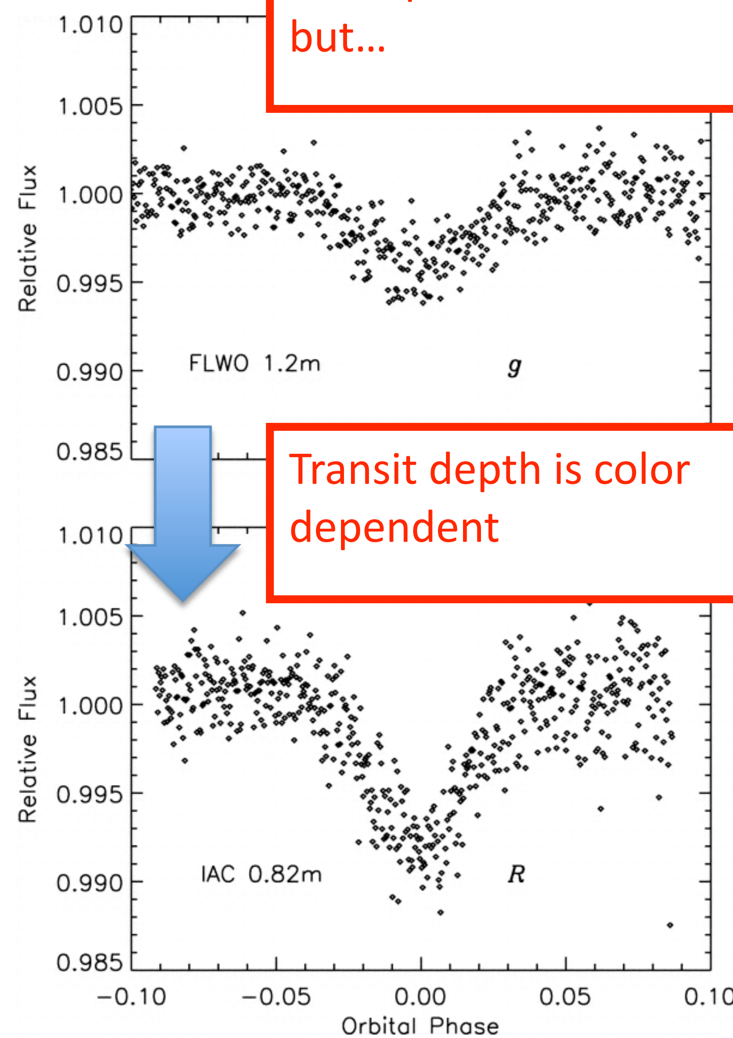
Rejection of Astrophysical False Positives

- Color dependence of transit depth is an important tool employed by ground-based surveys (eg. TrES, right image)
- **Spitzer/IRAC photometry can detect transits as small as 0.03% (perhaps smaller)**
- Change in Spitzer transit depth wrt Kepler measurement would indicate an astrophysical false positive
- Valuable for physically-associated triples for which Kepler will not detect shift of photocentroid

People are currently pursuing this for Corot-7, candidate 1.7 R_{Earth} exoplanet (F. Fressin et al.)

Good planet candidate but…

Transit depth is color dependent



O'Donovan, Charbonneau, et al. 2006

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 brightness temperatures
- 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

Team Membership

- Charbonneau (Spitzer Proposal PI, Kepler Participating Scientist)
- Borucki, Brown, Latham, Gilliland (Kepler PI and Team Members)
- Fortney, Ford, Seager (Kepler Participating Scientists; theory)
- Knutson, Deming (Non-Kepler co-Is providing Spitzer expertise)

Schedule and Path Forward

- Kepler FOV visibility to Spitzer:

  Window 1: 2009 May 02 – 2010 Jan 22 **(72% of year)**

  Window 2: 2010 May 11 – 2011 Jan 30 **(72% of year)**

- Delivery of Observing Requests to Spitzer Science Center:

  2009 Sep 30 (20% of total allocation): short period, high SNR systems

  2010 Apr 15 (60% of total allocation): based on 1 year of Kepler data

We expect to begin Spitzer observations of Kepler-detected systems as early as fall 2009.

Summary of All Exoplanet Programs I

Exploration Science Programs

Charbonneau, David Harvard University (800 hours)

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

Knutson, Heather UC Berkeley (1138 hours)

Dynamic Studies of Exoplanet Atmospheres: From Global Properties to Local Physics

DDT Programs

Harrington, Joseph University of Central Florida (200 hours)

The Spitzer Exoplanetary Atmosphere Survey

Gillon, Michael Observatoire de Geneve

Detecting the Transits of Nearby Super-Earths

Summary of All Exoplanet Programs II

GO Programs

Barry, Richard — NASA Goddard Space Flight Center
Exoplanet HAT-P-11b Secondary Transit Observations

Machalek, Pavel — Johns Hopkins University
Dynamic atmosphere of the eccentric and massive planet XO-3b

Maxted, Pierre — Keele University
WASP-17 - testing the paradigm of pM/pL class planets

Maxted, Pierre — Keele University
Lightcurves of two newly discovered ultra-short period planets

Burleigh, Matt — University of Leicester
Cool, spatially resolved substellar and exoplanetary analogues at white dwarfs

Langton, Jonathan — UC Santa Cruz
Two for the Show: Observing the Periastron Passages of HD 80606b

Luhman, Kevin — Pennsylvania State University
A Survey for Wide Substellar Companions in the Solar Neighborhood

Spitzer TACs *love* exoplanets, so be thinking about the next cycle