

APPLYING EARTH AND PLANETARY ATMOSPHERE MODELS TO EXOPLANETS

AN INTER-DISCIPLINARY STUDY SUPPORTED BY
THE SCIENCE INNOVATION FUND

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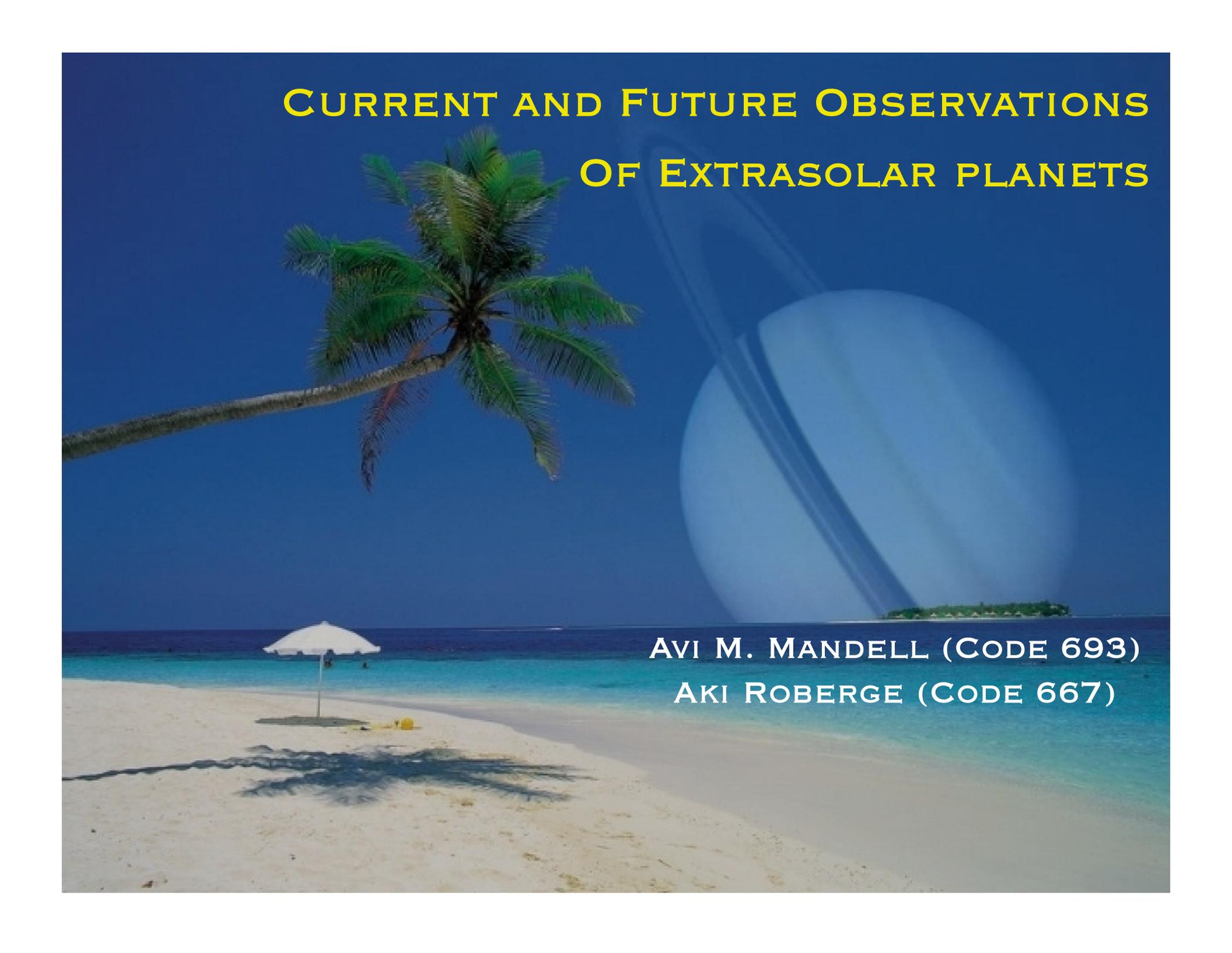
Aki Roberge (667)

Luke Oman (614)

Jose Rodriguez (614)

Lazaros Oreopoulos (613)

Warren Wiscombe (613)



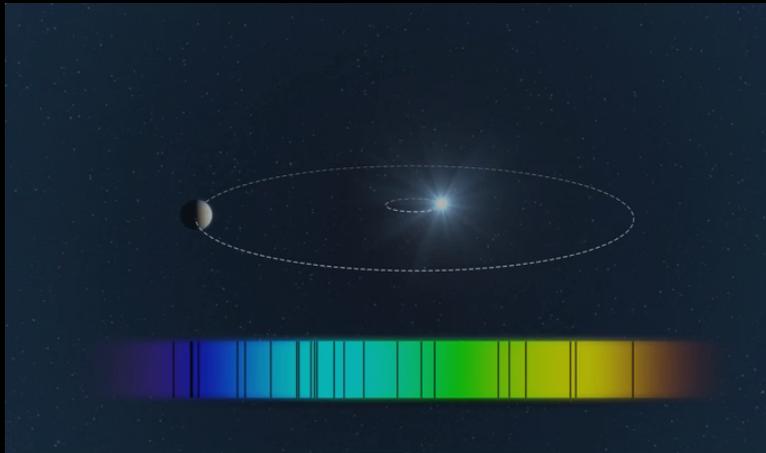
CURRENT AND FUTURE OBSERVATIONS OF EXTRASOLAR PLANETS

AVI M. MANDELL (CODE 693)

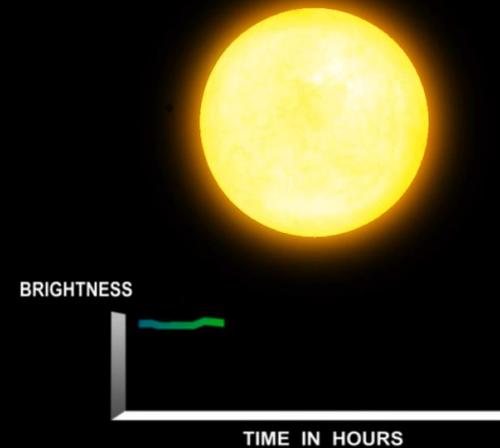
AKI ROBERGE (CODE 667)

FOUR WAYS TO FIND & STUDY EXOPLANETS

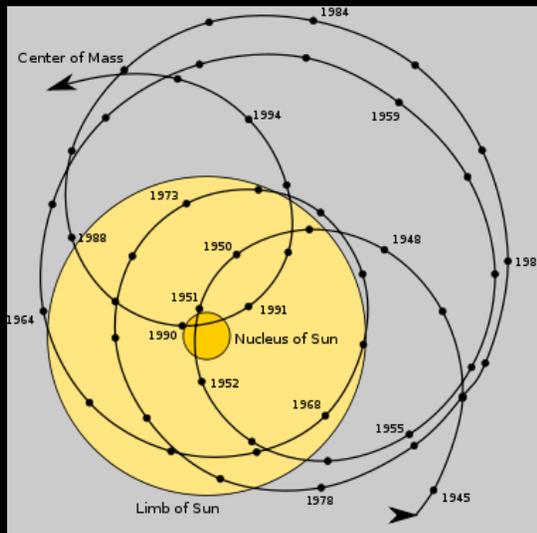
Precision Radial Velocity



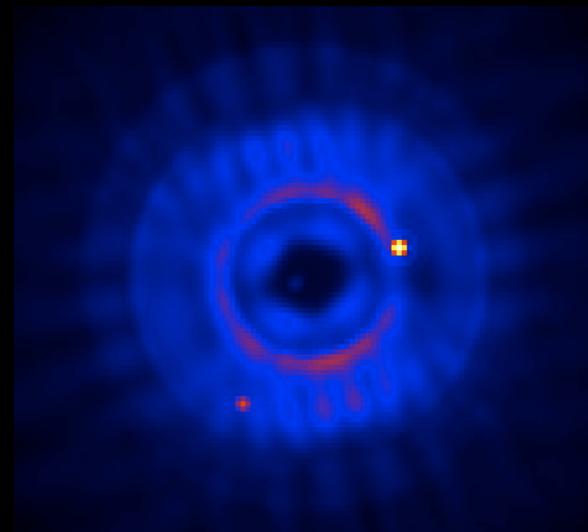
Transit & Occultation



Astrometry

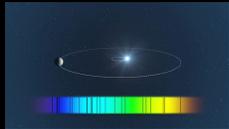


Direct Imaging



FOUR WAYS TO FIND & STUDY EXOPLANETS

Precision Radial Velocity



Information Gained:

- Orbital period
- Mass
- Eccentricity
- Multiple planets
- Stellar obliquity (R-M)
- * Easier for short-period planets

Transit & Occultation



Information Gained:

- Orbital Period
- Radius
- Inclination
- Nearby companions (TTV)
- Atmospheric opacity (trans/ecl)
- Atmospheric radiance (ecl)
- Albedo (very hard)
- * Easier for short-period planets

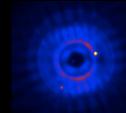
Astrometry



Information Gained:

- Orbital period
- Mass
- Eccentricity
- Inclination (w/ RV)
- Multiple planets
- * Easier for long-period planets

Direct Imaging



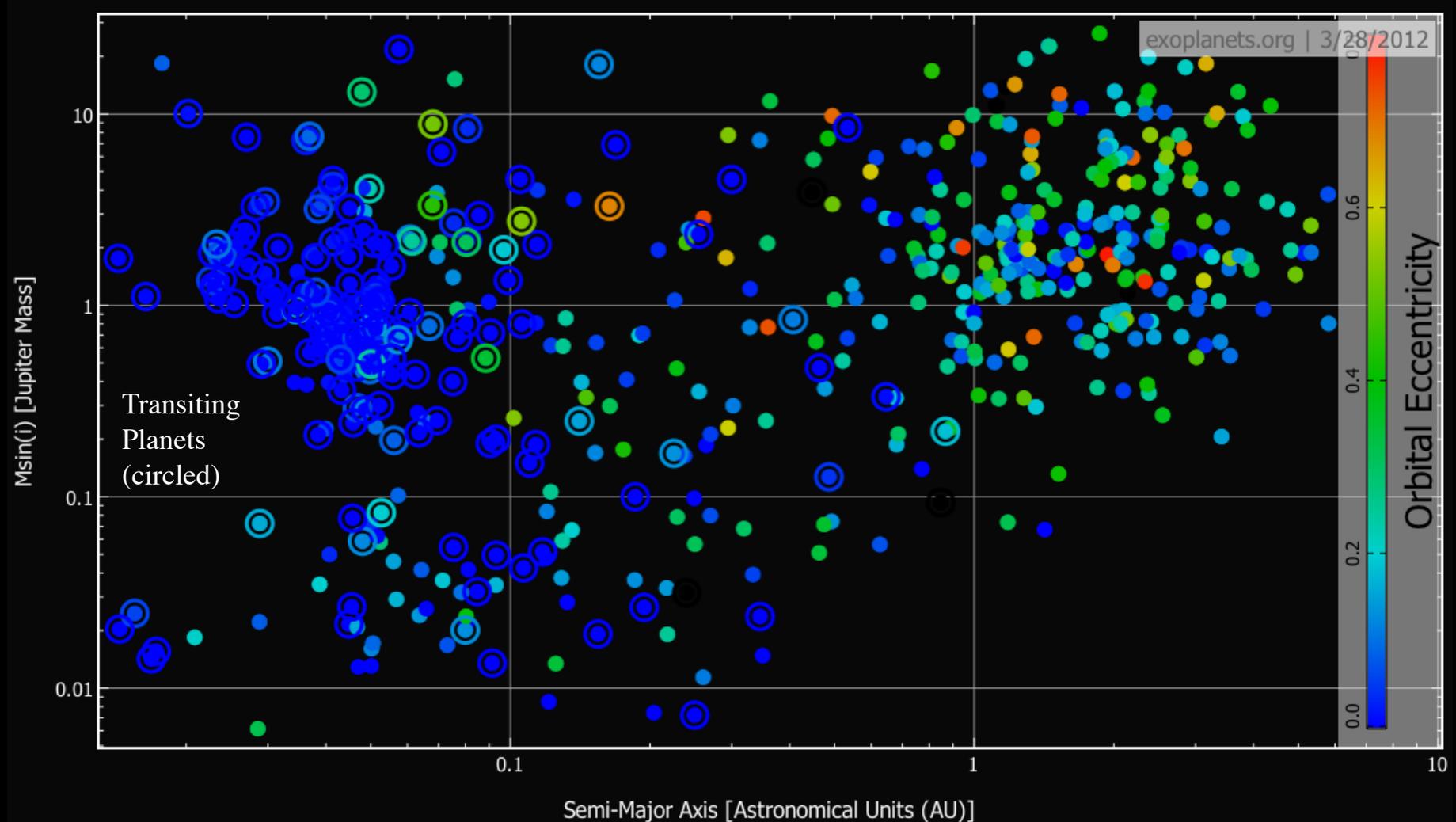
Information Gained:

- Orbital period (w/ long b.l.)
- Eccentricity (w/ long b.l.)
- Atmospheric radiance
- Atmospheric opacity
- Albedo
- Mass & Radius
(model-dependent)
- * Easier for long-period planets

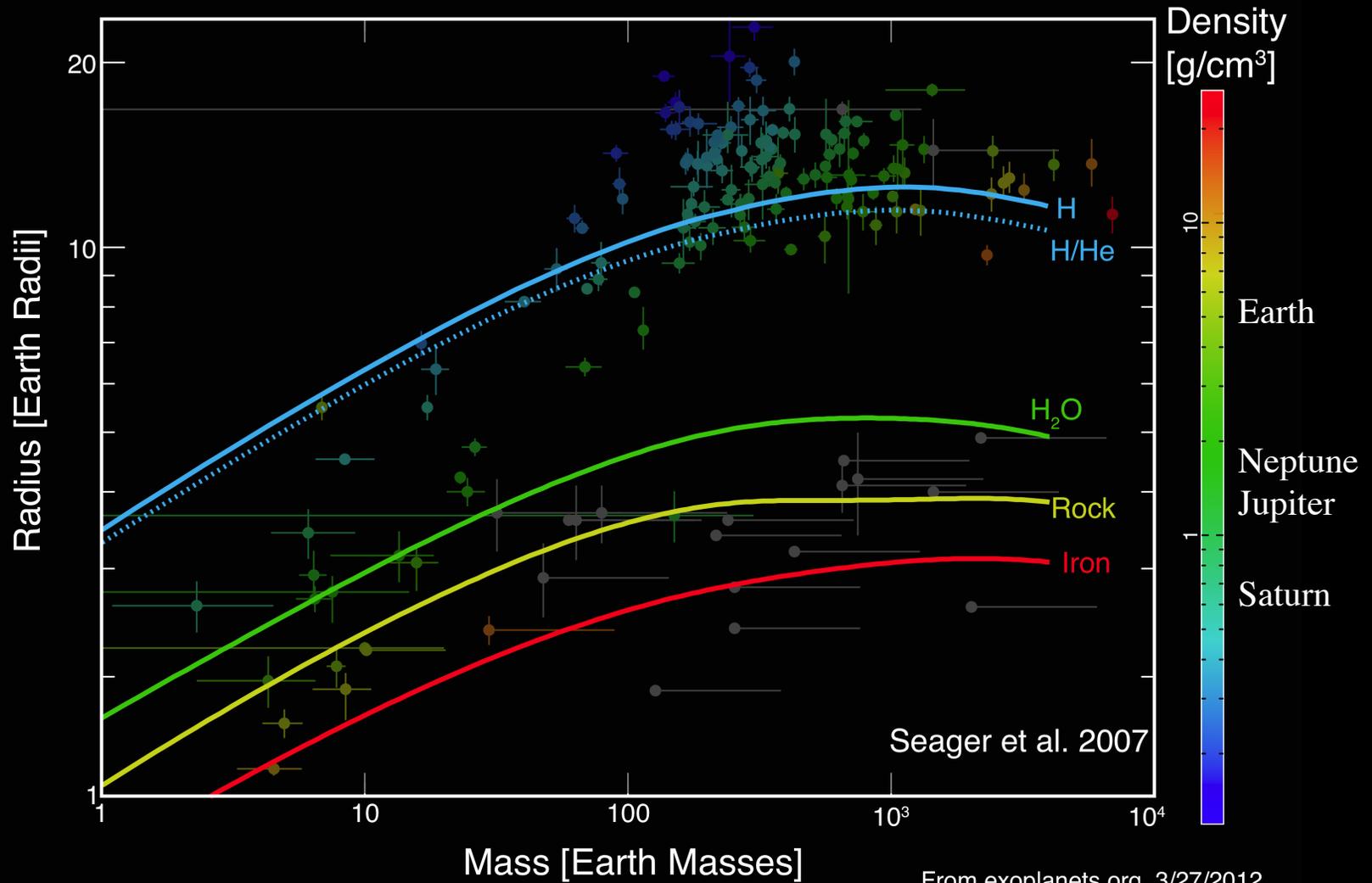


WHERE WE ARE TODAY: RV & TRANSITS

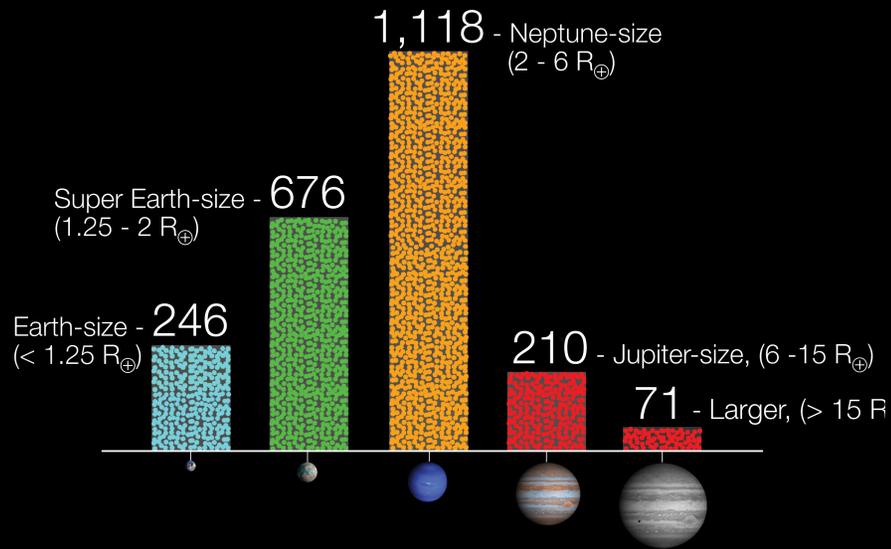
Known Exoplanets, 2012: 579



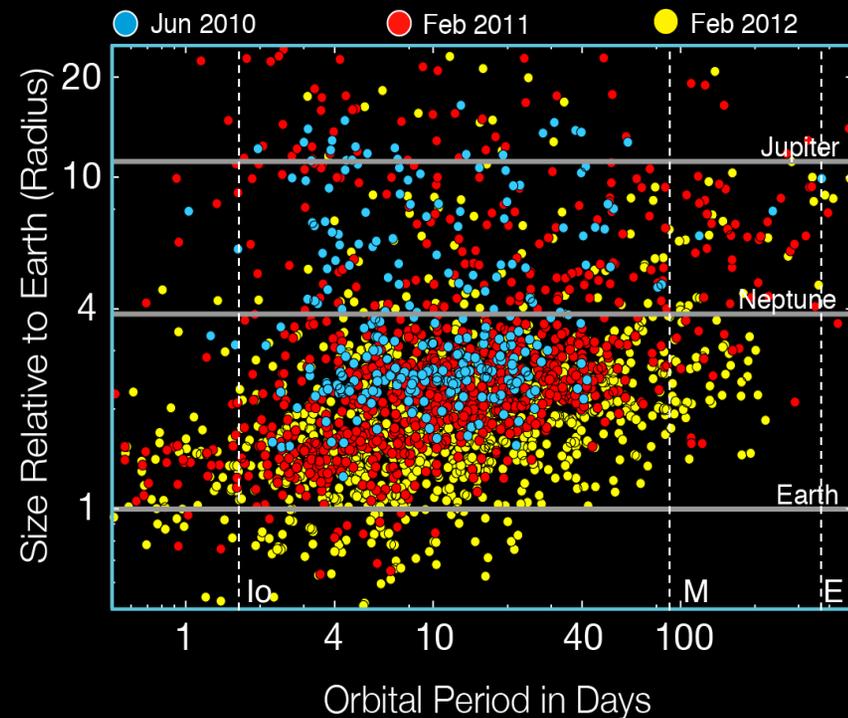
INTERIOR COMPOSITION: THE MASS-RADIUS RELATION



STATISTICS OF PLANETARY SYSTEMS: THE KEPLER SPACE TELESCOPE



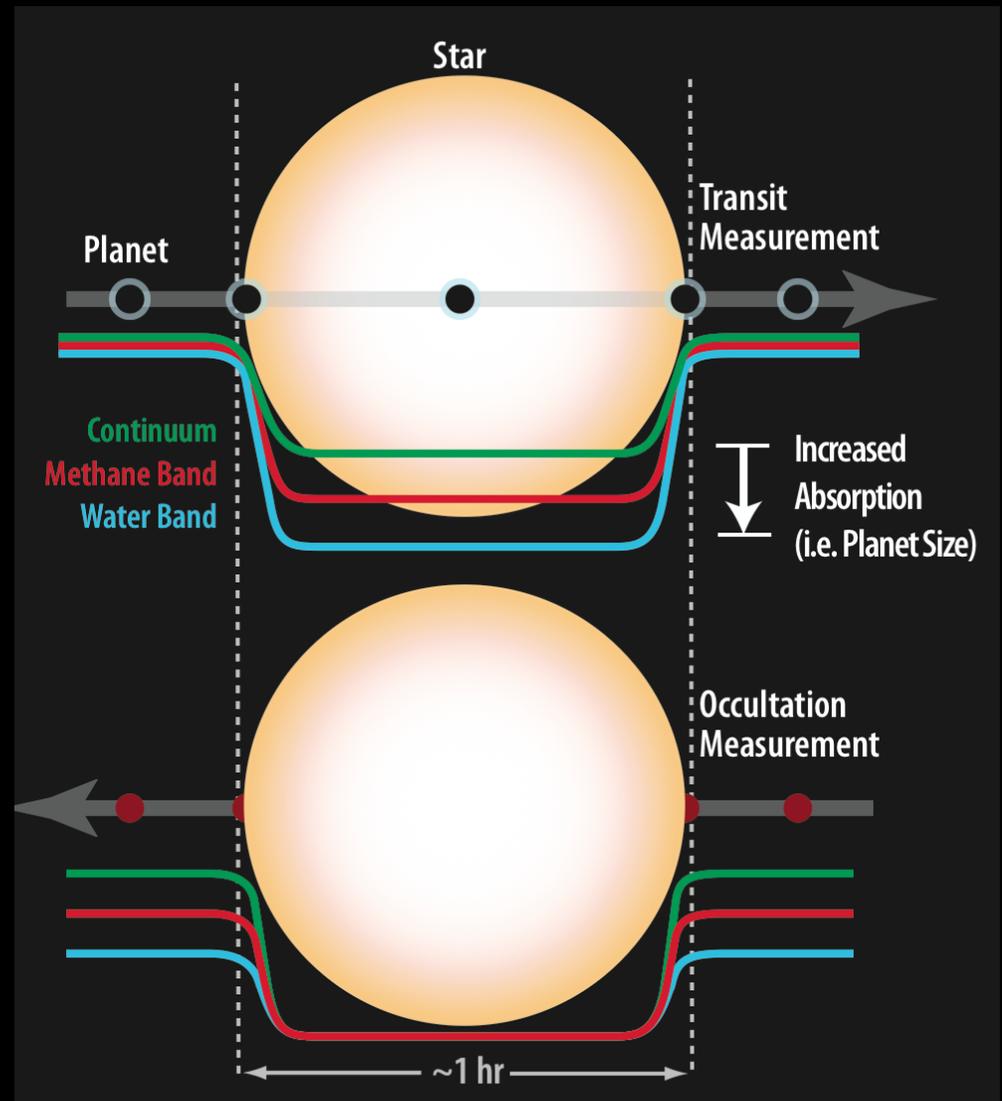
Candidate Planets
Feb 2012



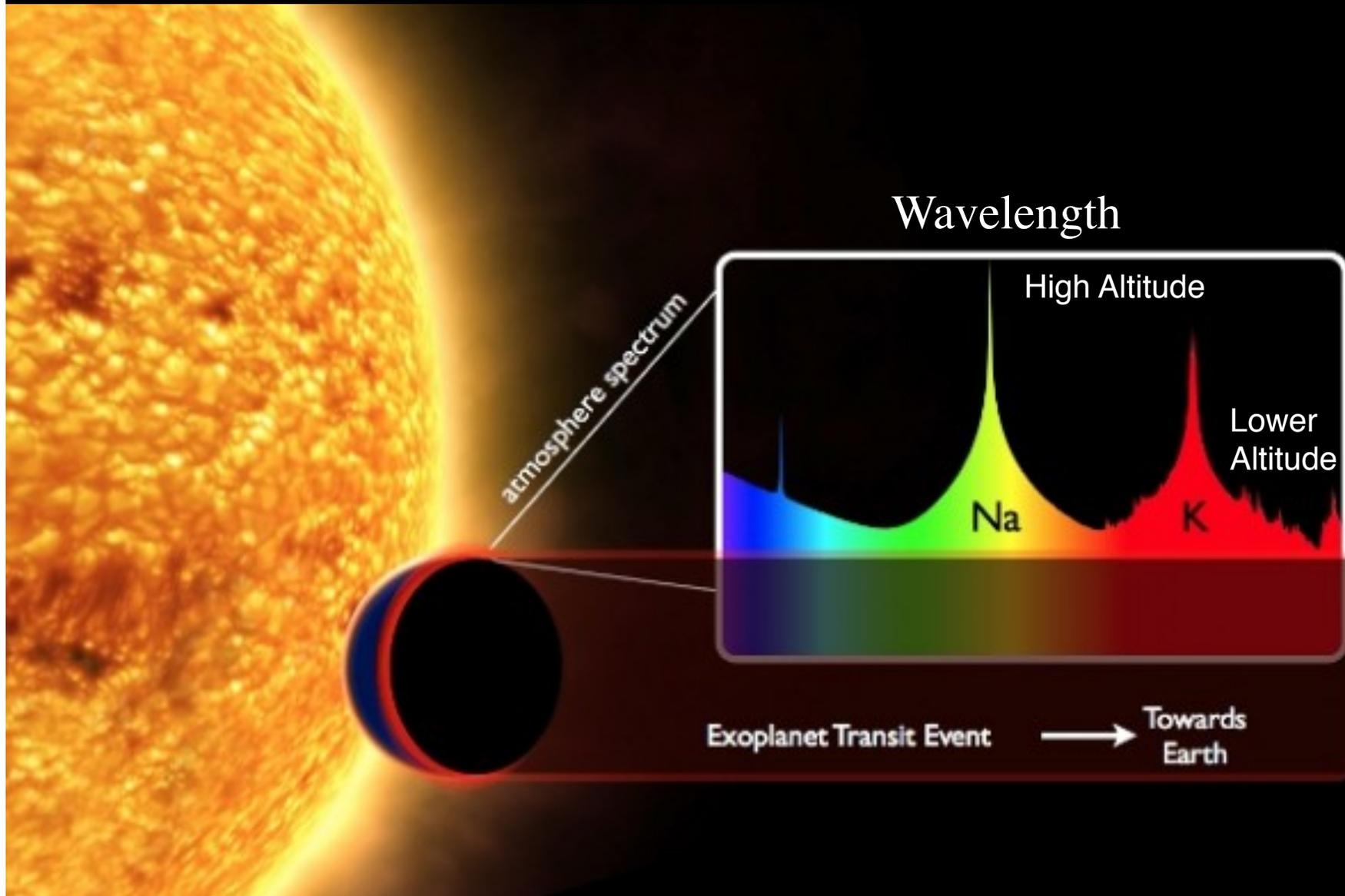


BUT HOW DO WE LEARN ABOUT ATMOSPHERES?

- Transits provide the opportunity to probe the absorption in a planet's atmosphere
 - As starlight passes through the atmosphere of a planet, atoms and molecules absorb at different wavelengths
 - The more absorption, the larger a planet's radius appears, and the higher the altitude that the transmitted light passes through
 - The same is true for planetary occultations – except now the planet's thermal radiation is self-absorbed by upper atmospheric layers

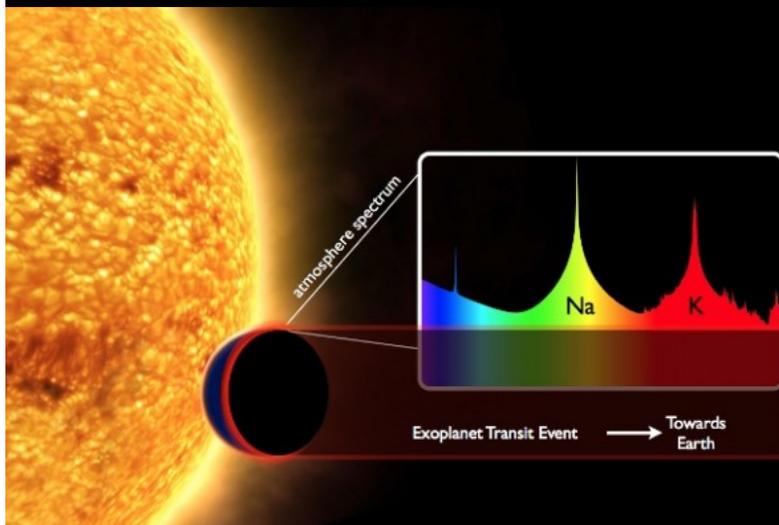
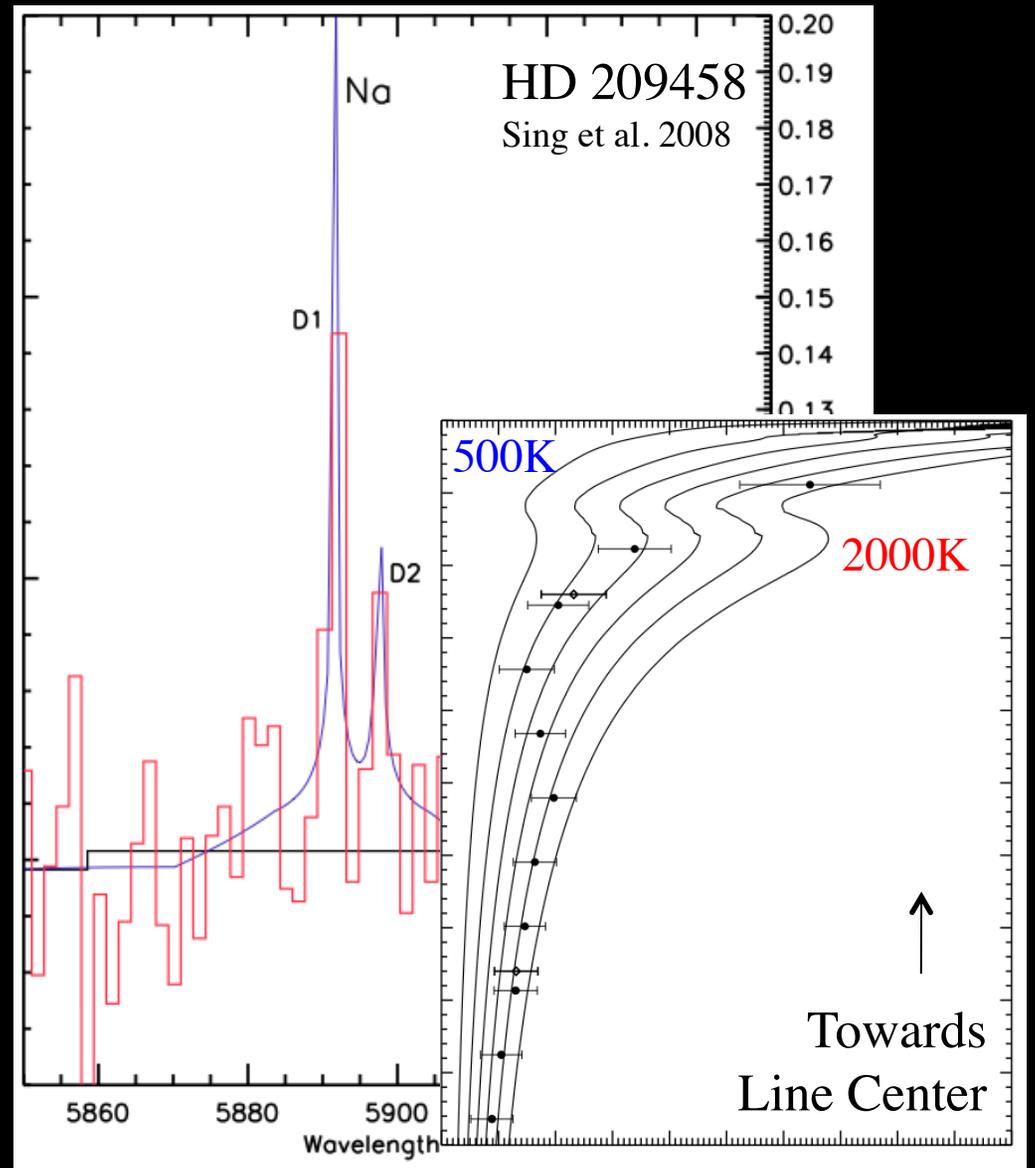


TRANSLATING TRANSIT DEPTH TO STRUCTURE

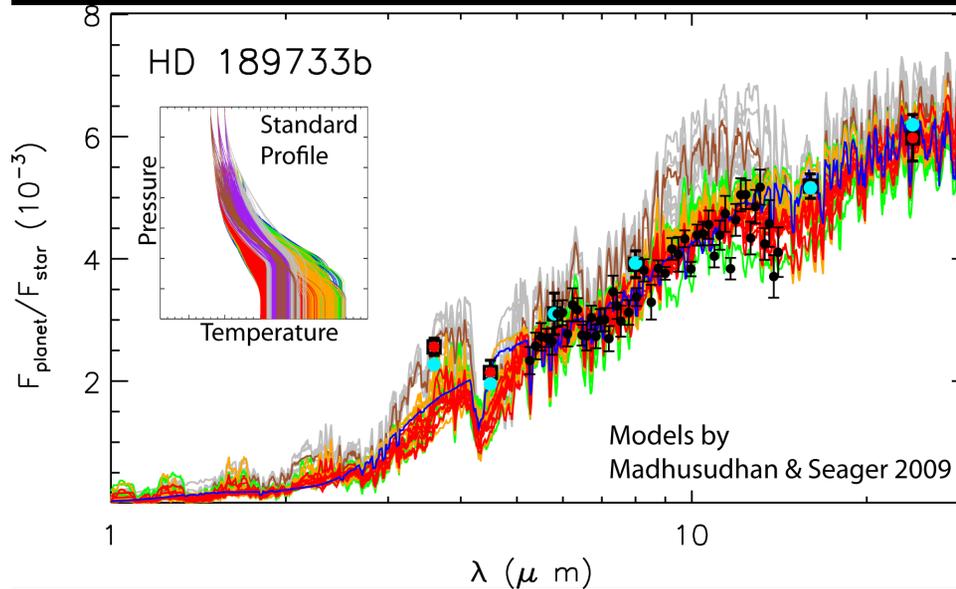


TRANSLATING TRANSIT DEPTH TO STRUCTURE

- Optical & UV wavelengths:
Sensitive to atomic species such as Na, K, ionized C (HST/STIS, HST/COS, ground-based telescopes)



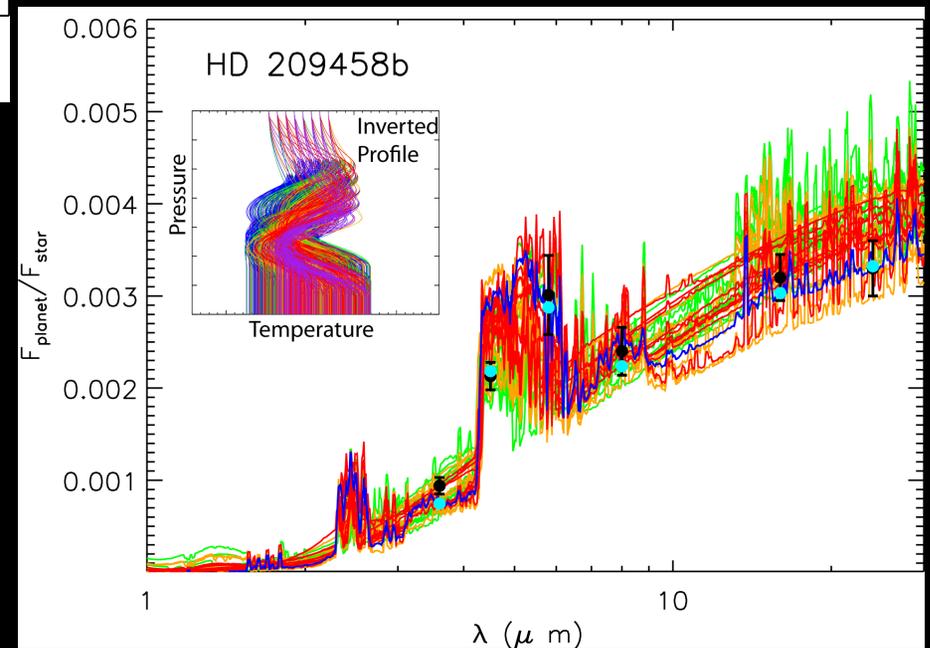
SPITZER: REVEALING MOLECULES IN THE IR



The data is sparse, but some planets appear to fit standard models quite well...

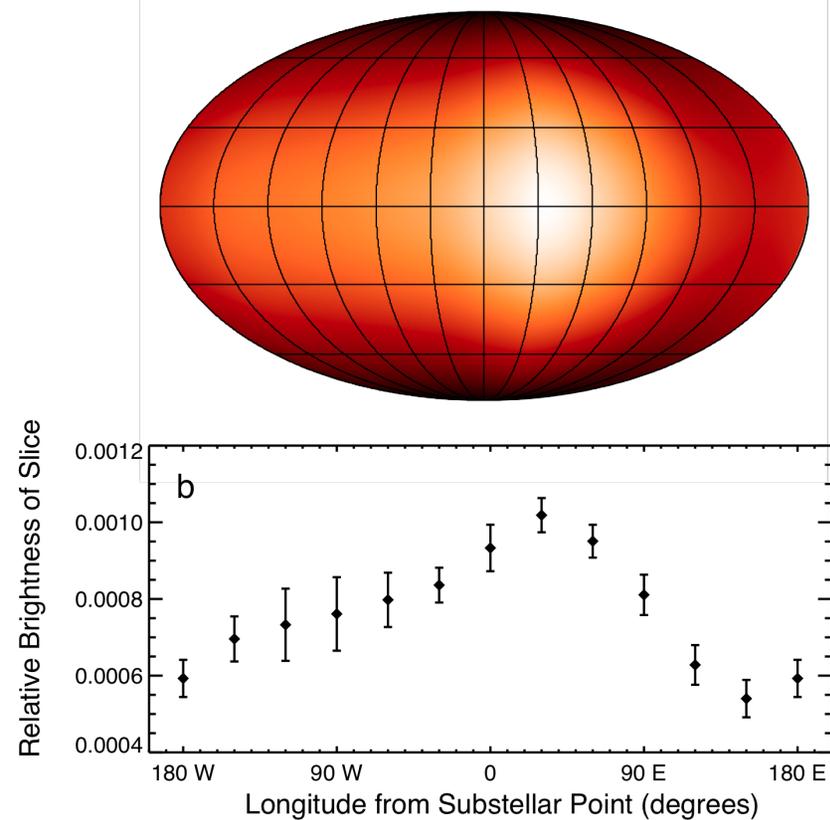
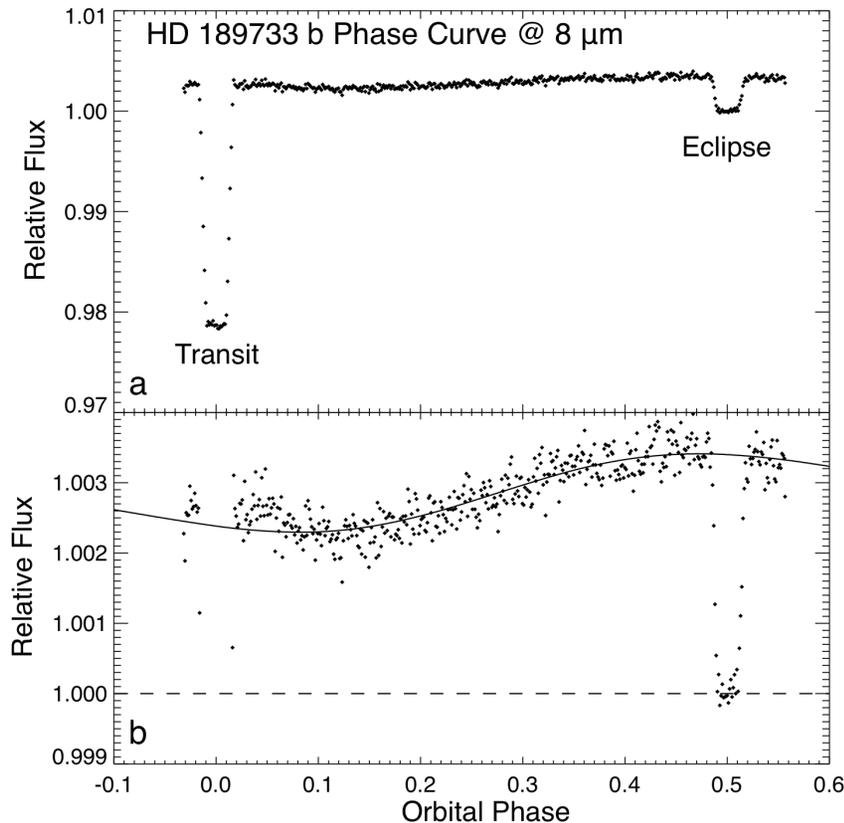
... while others require unexpected temperature profiles

Adapted from Madhusudhan & Seager 2009





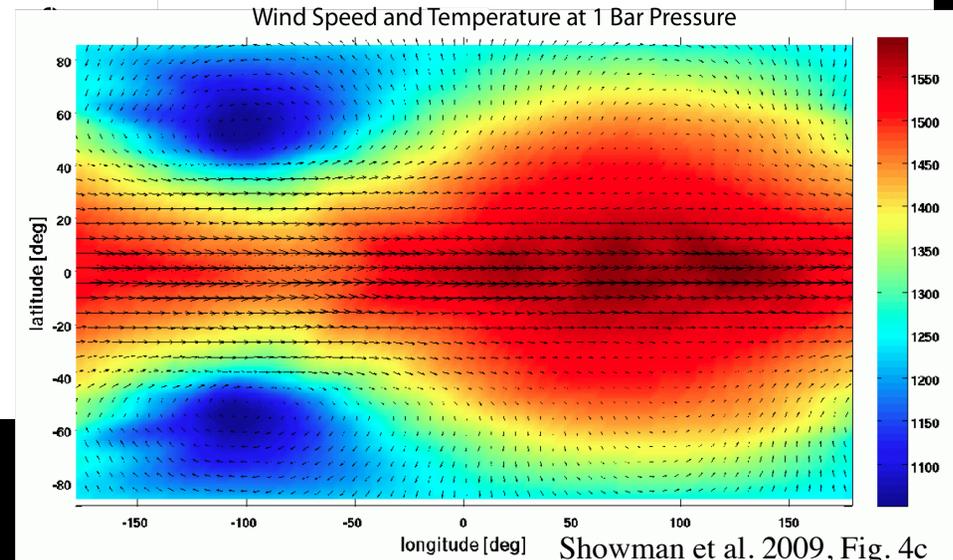
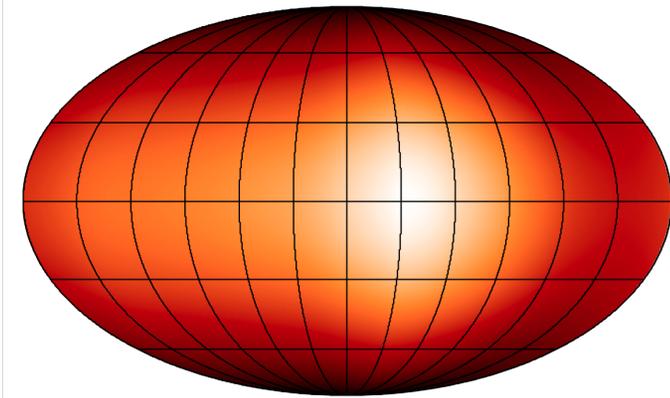
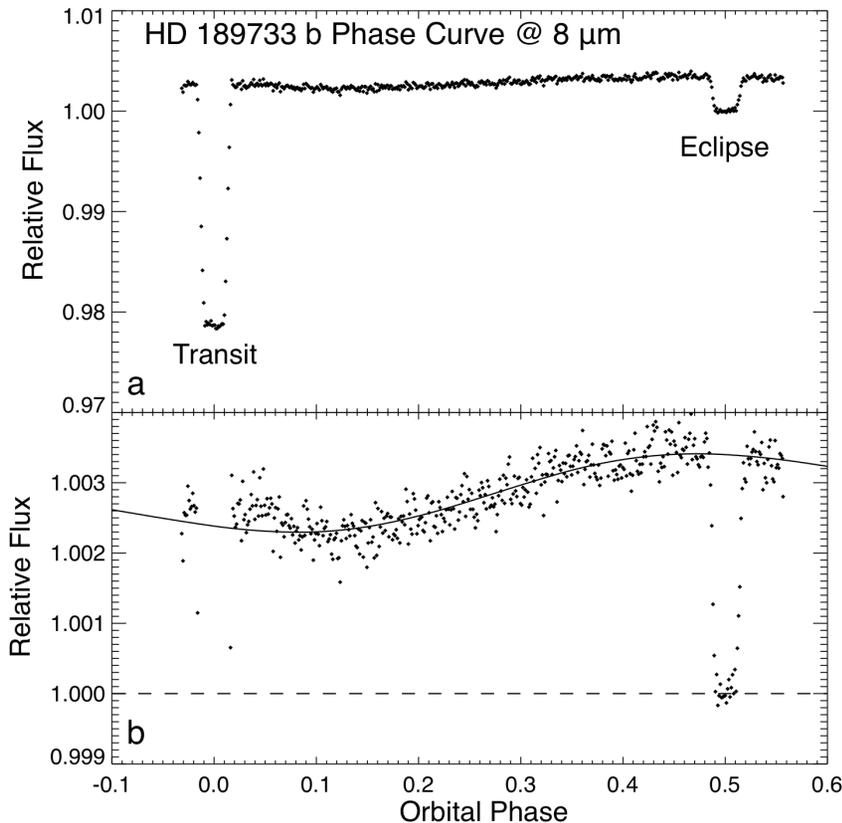
SPITZER: REVEALING MOLECULES IN THE IR



The phase curve for HD189733 b reveals that the hottest point on the planet appears to be shifted...



SPITZER: REVEALING MOLECULES IN THE IR



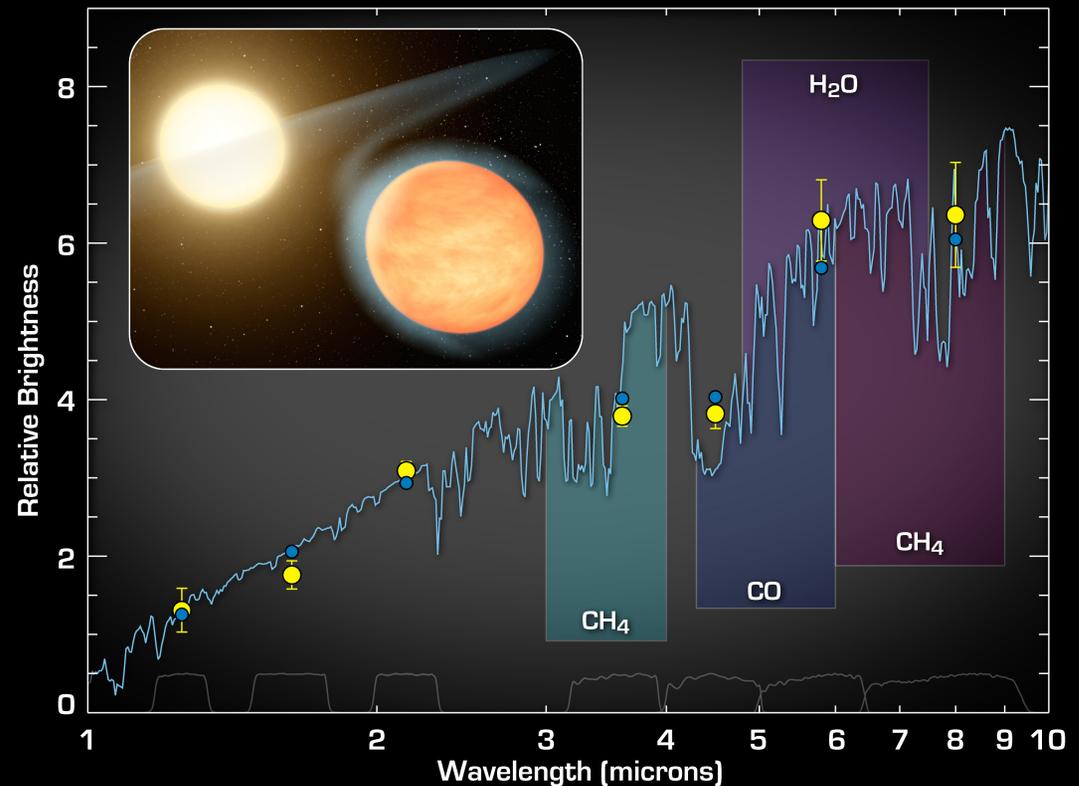
The phase curve for HD189733 b reveals that the hottest point on the planet appears to be shifted...

... which matches a remarkable prediction for zonal winds from 3D hydrodynamic models!

Adapted from Knutson et al. 2009

SPITZER: REVEALING MOLECULES IN THE IR

- First evidence of a planet with a radically different chemical composition from our Solar System
 - Best-fit model requires very little H₂O and significant CO and CH₄, suggesting $C/O > 1$
 - Carbon-dominated chemistry would lead to planets made of exotic solids such as graphite and carbides



Exoplanet WASP-12b

NASA / JPL-Caltech / N. Madhusudhan (Princeton University)

Spitzer Space Telescope • IRAC

ssc2010-10a



CURRENT AND IMPENDING CHALLENGES

- We have lost the capability for Cold Spitzer ($\lambda > 5$ microns), and we will be losing contact with Spitzer altogether sometime near the end of 2013
- Until JWST, characterization of molecular species in exoplanet atmospheres is restricted to the NIR (1 – 5 microns), primarily with HST or from the ground
- HST/NICMOS produced extremely interesting results, but the accuracy of the results have been thrown into doubt by recent re-analyses... but WFC3 can save us! (partly...)
- Ground-based observations are extremely challenging, and results have proved to be controversial...

A EXTREMELY INTERESTING CASE STUDY: GJ 1214 B

- GJ 1214 b is a Super-Earth-mass planet, with $M = 6.5 M_{\text{Earth}}$ and $R = 2.7 R_{\text{Earth}}$, orbiting an M-type parent star – an exciting new class of planets
- The proximity of the star, and the small size, make this planet ideal for follow-up characterization through transits – but the results have been ambiguous...

