Infrared Radiation from an Extrasolar Planet

- A dozen or so detected extrasolar planets appear to be Jupiter-sized with orbits only 0.5 AU from their host star, with 4 to 7 day periods.
- These “hot Jupiters” should emit significant IR radiation, but separating it from the host star is difficult.
- Luckily, the planet HD 209458b (of the star HD 209458, no b) was observed to transit its host star!
HD 209458b transit gives information about radius and inclination (unknown through radial velocity measurements)

Fig. 3.—Solid contours are the 1, 2, and 3 σ confidence levels for the planet radius and orbital inclination, assuming $R_p = 1.1 \, R_\odot$ and $M_p = 1.1 \, M_\odot$. The minimum occurs at $R_p = 1.27 \, R_\odot$ and $i = 87.1^\circ$. The dashed and dotted contours are the confidence levels in the cases of $(R_p, M_p) = \{1.0 \, R_\odot, 1.0 \, M_\odot\}$ and $(R_p, M_p) = \{1.2 \, R_\odot, 1.2 \, M_\odot\}$ respectively. The dominant modeling uncertainty is that in the stellar radius.

Fig. 2.—Shown are the data from Fig. 1 binned into 5 m averages, phased according to our best-fit orbit, plotted as a function of time from $T_e$. The rms variation at the beginning of the time series is roughly 1.5 mmag, and this precision is maintained throughout the duration of the transit. The increased scatter at the end of the time series is due to increasing air mass which occurred at roughly the same time for both transits, since the two occurred very nearly 1 week apart. The solid line is the transit shape that would occur for our best-fit model, $R_p = 1.27 \, R_\odot$, $i = 87.1^\circ$. The lower and upper dashed lines are the transit curves that would occur for a planet 10% larger and smaller in radius, respectively. The rapid initial fall and final rise of the transit curve correspond to the times between first and second and between third and fourth contacts, when the planet is crossing the edge of the star; the resulting slope is a function of the finite size of the planet, the impact parameter of the transit, and the limb darkening of the star. The central curved portion of the transit is the time between second and third contacts, when the planet is entirely in front of the star.
Radius!? Mass!? What now!?
(!? means excited confusion)

- Well, now we can predict the IR emission it should give off based on models
- Take a closer look, and maybe detect some IR photons known to come from the planet
- That's direct detection baby! (well...sort of)
Jupiter-size Planet SED Models
Not exactly Planck functions!

Class I: Jovian ~5AU
150 K -> ice, reflection

Class II: Water ~1-2 AU
methane, water & ammonia produce strong absorption

Class III: Clear ~0.5 AU
strong ro-vibrational molecular absorption, gaseous water and methane

Sudarsky et al. 2003
Secondary Eclipse

- When the planet goes behind the star, should see a dip in the IR flux
- Using IRAC 4.5 and 8 µm bands, Charbonneau et al. 2005 best fit shows a dip in IR flux during secondary eclipse
- The ratio of the dips correspond to a blackbody at $T = 1060 \pm 50$ K
- At thermal equilibrium with star:

$$T_{eq} = T_* (R_*/2a)^{1/2} [f(1 - A)]^{1/4} \approx 1163 [f(1 - A)]^{1/4} \text{ K},$$
Constrains Orbital Eccentricity

- Non-zero eccentricity would produce a shift in the difference between the center of the primary (tI) and secondary eclipse (tII), compared to the half-period
- \( \omega \) is the longitude of periastron (node angle)
**HD 209458b Atmosphere**

- Seager & Sasselov 2000 first predicted atmospheric absorption by HD 209458b
- Ratio of transparent atmosphere area to star $\sim 10^{-3}, 10^{-4}$
- Using models, they predicted the K1 and NaI resonance doublet lines would have the deepest flux changes during transit.
Charbonneau et al. 2002 detected planet's Na I doublet lines

Looked at differences in fluxes of a series of bands

Concluded flux dip was due to a high cloud deck and/or a low atomic sodium abundance
References

• Collier-Cameron, A. 2002. Astron Geophys, 43, 421-425
• Seager, S. 2003, ASO, 294, 2003