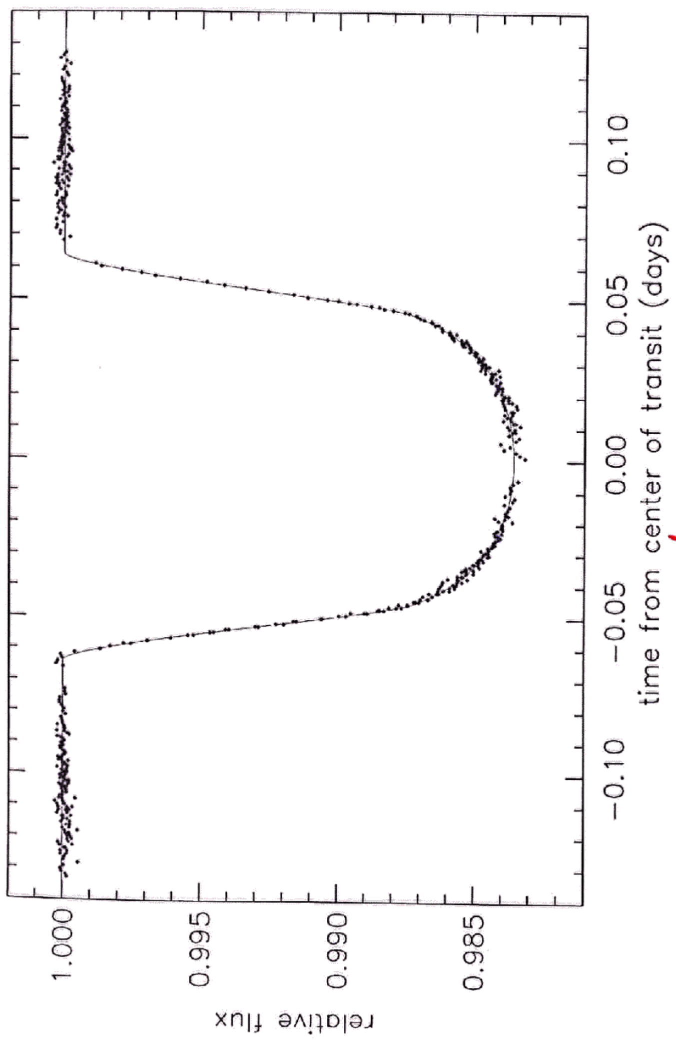


Transit HD 209458

STIS - HST

Brown et al 2001 Astrophys. J.

PROPERTIES OF HD 209458 b

- Orbital characteristics

$a = 0.045$ AU, $P = 3.525$ da, ecc. $= 0.03$

- Stellar characteristics

SpT = G0 V, Mass= $1.1 \pm 0.1 M_\odot$, Radius= $1.15 \pm 0.05 R_\odot$, Metallicity [Fe/H] = 0.0

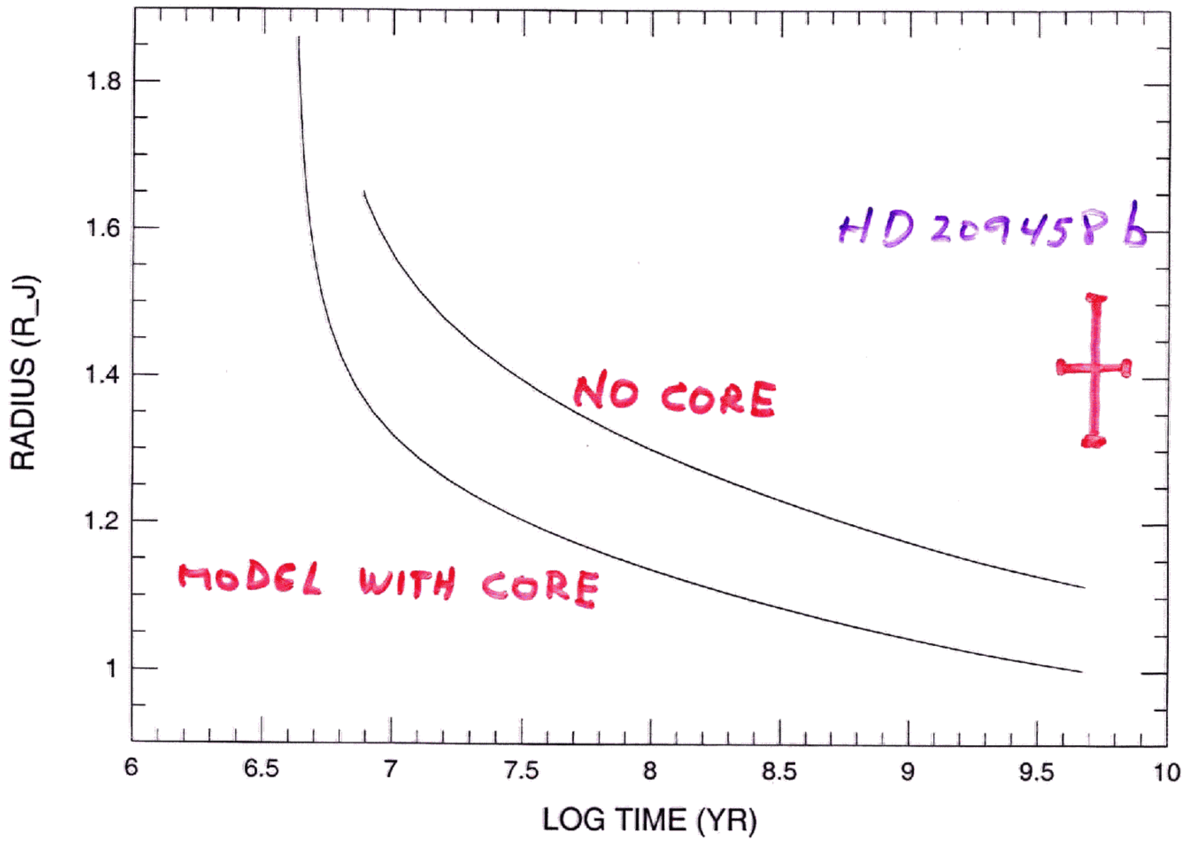
- Planetary characteristics (Jupiter units)

	MASS	RADIUS
Charbonneau et al. 01	0.69 ± 0.05	1.35 ± 0.06
Cody and Sasselov 02	0.69 ± 0.05	1.41 ± 0.10

Model gives a radius of 1.03 R_J with a core and 1.13 R_J without a core.. The model includes surface heating of the planet by the star and therefore assumes that the planet migrated early in its history (by 10^7 yr) to its present position

To fit the actual radius an extra source of energy is required, such as tidal dissipation, with a rate of 2×10^{-8} $L_\odot$, or dissipation, at a relatively deep layer, of atmospheric flows ("kinetic heating".)

RADIUS OF HD 209458 b



QUESTIONS

- WHAT IS THE NIGHT-SIDE TEMPERATURE OF A SYNCHRONOUSLY ROTATING SHORT-PERIOD GIANT PLANET?
- CAN ATMOSPHERIC CIRCULATION GENERATE SHEAR LAYERS LEADING TO DISSIPATION OF ENERGY AND EXPANSION OF THE PLANET?

Estimate of Night-side Temperature

Day-side photosphere $\kappa_d P_d = \frac{2}{3} g$

Ideal gas density $\rho_d = \frac{P_d \mu}{R_g T_d}$

Density scale height $h_d = \frac{\rho}{\frac{d\rho}{dz}} = \frac{c_d^2}{g}$

Thermal energy per unit area

$$E_h = \rho_d h_d c_d^2 = P_d h_d = \frac{2 c_d^2}{3 \kappa_d}$$

Cooling time on night side

$$\tau_c = \frac{E_h}{\sigma T_n^4}$$

Equilibrium condition

Advection time (day → night)

= cooling time (night)

$$\frac{E_h}{\sigma T_n^4} = \frac{\pi R_p}{2 V_f}$$

$$\Rightarrow \quad T_n = \left(\frac{4 V_f c_d^2}{3 \pi \kappa_d \sigma R_p} \right)^{\frac{1}{4}}$$

Estimate for $\kappa_d = 1$, $V_f \approx c_d \sim 3 \times 10^5$

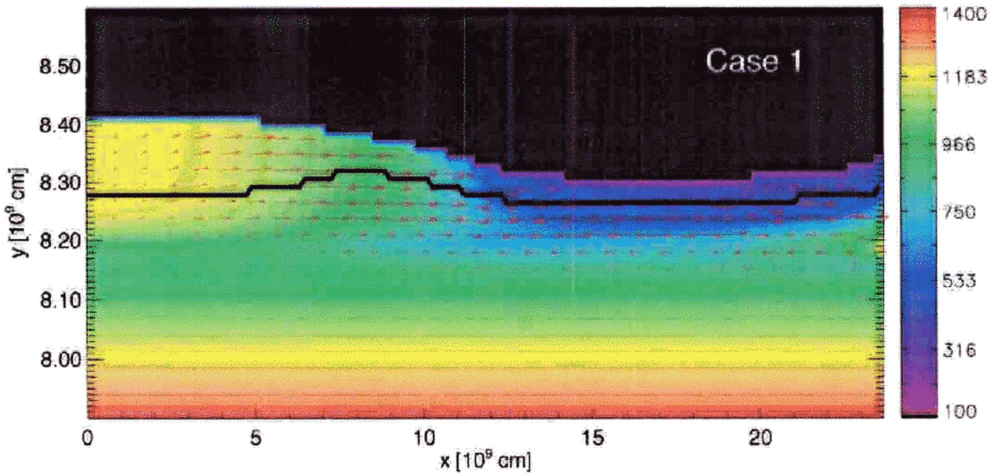
$$T_n \simeq 400 \text{ K}$$

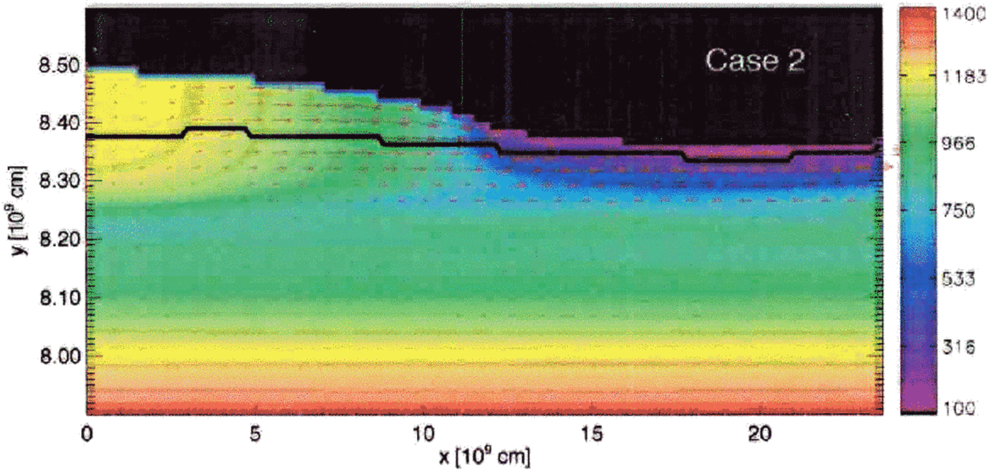
Reduce opacity by factor 100:

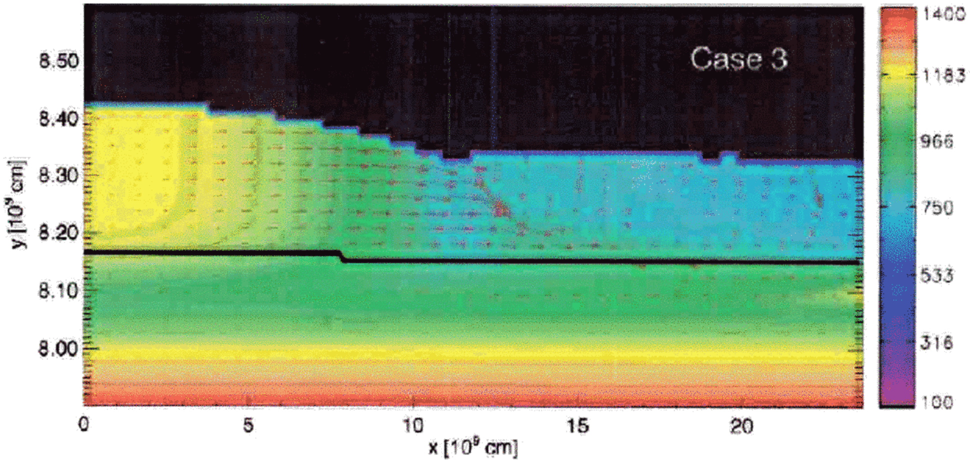
$$T_n \simeq 1200 \text{ K}$$

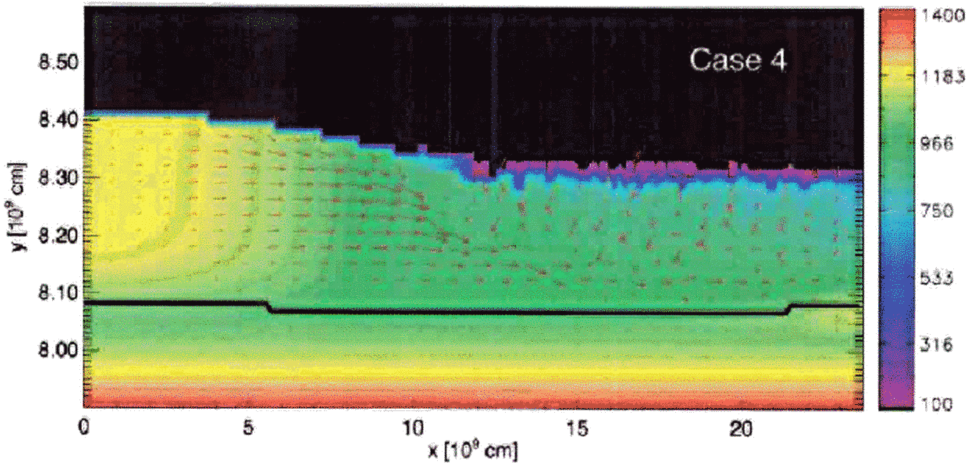
CALCULATIONS

- **Hydrodynamics in 2 space dimensions (depth and azimuth)**
- **Radiative transfer: flux-limited diffusion**
- **Planet heated on day side only: $T_{eq} = 1200$ K.**
- **Opacity is a parameter: high opacity (with grains); low opacity (without grains), range 5 orders of magnitude**
- **2-D grid extending through outer 5% of radius and 0 to 180 degrees in azimuth**
- **Initial conditions: spherical model for HD 209458b at age of 4.5 Gyr**
- **Calculation run to steady state, total time is orders of magnitude longer than hydrodynamic crossing time or radiative cooling time in outer layers**









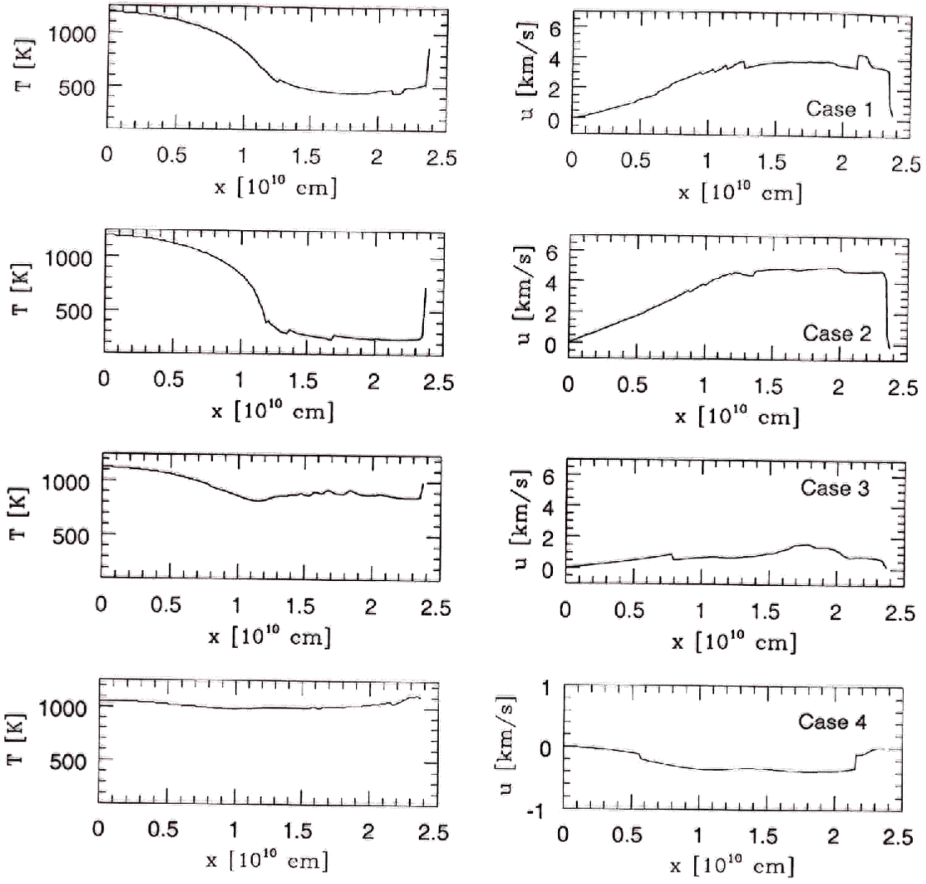


Fig. 4.– The left frames give the temperature as a function of x at the photosphere for the steady-state model. The right frames give the velocity in the x-direction as a function of x, also at the photosphere. *Top to bottom:* Cases 1, 2, 3, and 4.

CONCLUSIONS

- Atmospheric circulation is induced in short-period tidally locked giant planets
- Advective transfer of heat increases temperature on night side substantially
- Results depend on opacity
- High opacity: night side is 500 K cooler than day side
- Low opacity: night side and day side have about the same temperature
- Shear layer develops between the day-night flow and the return flow
- Shear layer is unstable and probably generates heat, but the location is too near the surface to result in significant expansion
- Detailed structure of outer layers has implications regarding cooling time and tidal dissipation function
- 3-dimensional calculations are needed.