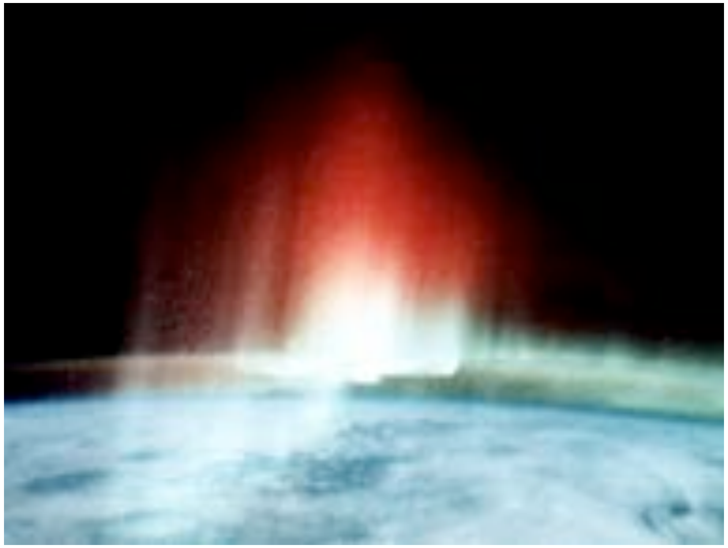
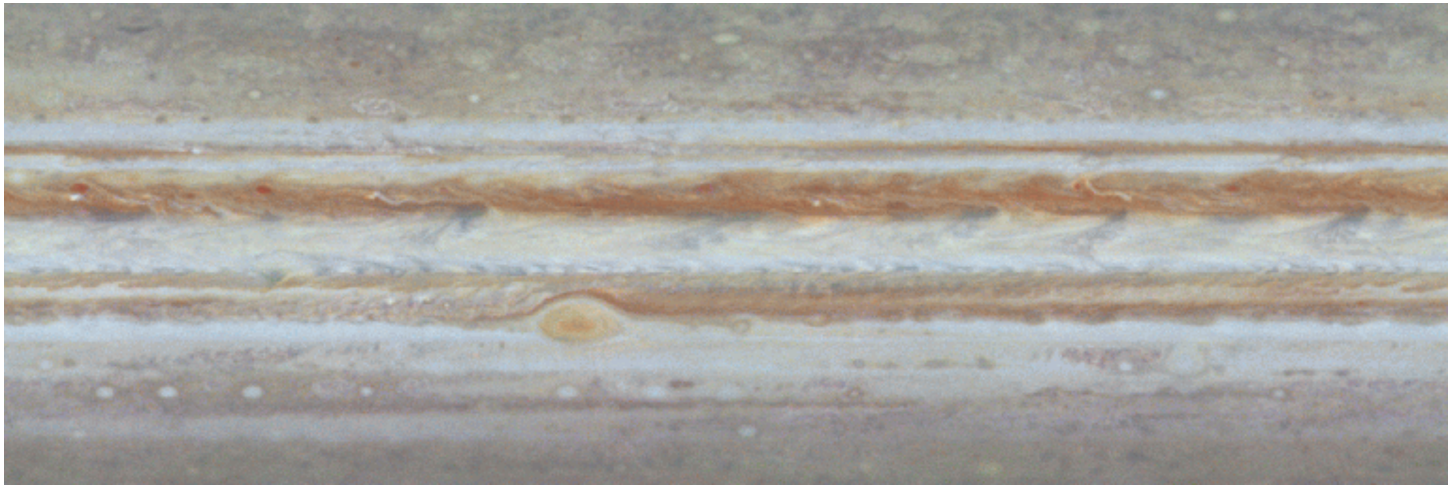
Planetary Atmospheres

- Structure
- Composition
- Clouds
- Photochemistry
- Meteorology
- Atmospheric Escape





Structure

Generalized Hydrostatic Equilibrium

$$P(z) = P(0)e^{-\int_0^z dr/H(r)} \qquad \rho(z) = \rho(0)e^{-\int_0^z dr/H^*(r)}$$

Generalized Pressure Scale Height

$$H(z) = \frac{kT(z)}{g_p(z)\mu_a(z)m_{amu}}$$

Generalized Density Scale Height

$$\frac{1}{H^*(z)} = \frac{1}{T(z)}\frac{dT(z)}{dz} + \frac{g_p(z)\mu_a(z)m_{amu}}{kT(z)}$$

Structure

Note: For an Isothermal Atmosphere
(or region of an atmosphere):

$$H(z) = H^*(z)$$

Since $$\frac{dT(z)}{dz} = 0$$

Remember that $$g_p(z) = \frac{GM_p}{r^2} = \frac{GM_p}{\left(R_p + z\right)^2}$$

* So at small altitudes $r \Rightarrow R_P$ *and* $g_p(z) \cong g_p(R_p)$

Structure

Most planets have near-surface scale heights ranging between ~10-25 km due to the similar ratios of

$T/(g_p\mu_a)$

	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
T_{surf} (K)	737	288	215	165*	135*	76*	72*
Bond Albedo	0.75	0.31	0.25	0.34	0.34	0.29	0.31
H (km)	16	8.5	11	24	47	25	23

* Temperature at 1 bar pressure

Structure

Of course, temperature actually does vary with height

If a packet of gas rises rapidly (adiabatic), then it will expand and, as a result, cool

Work done in expanding = work done in cooling

$$VdP = \frac{m_{gm}}{\rho} dP \qquad\qquad C_p dT$$

m_{gm} is the mass of one mole, ρ is the density of the gas

C_p is the specific heat capacity of the gas at constant pressure

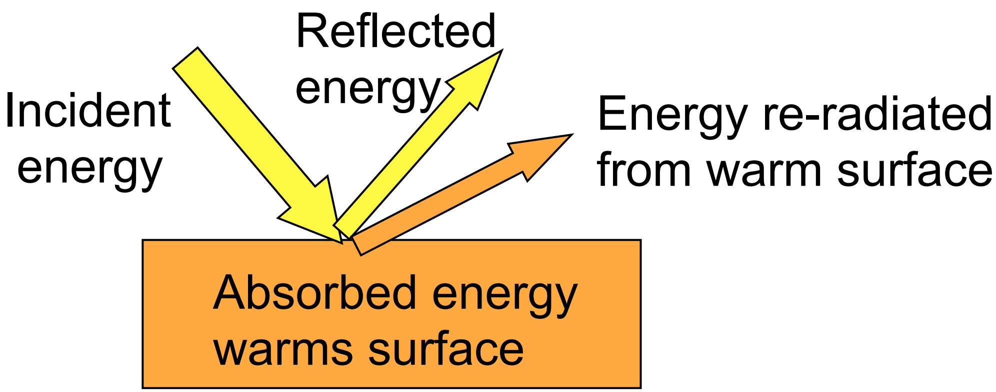
Combining these two equations with hydrostatic equilibrium, we get the dry adiabatic lapse rate:

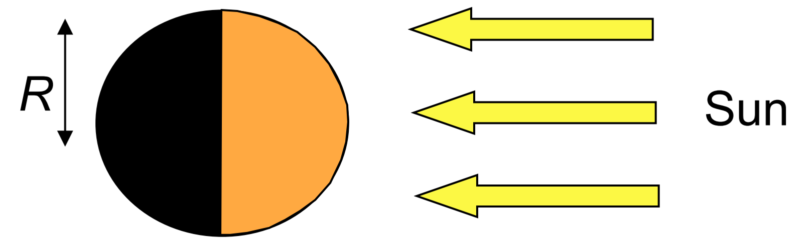
$$\frac{dT}{dz} = \frac{m_{gm} g_p}{C_p} = \frac{g_p}{c_p}$$

* On Earth, the lapse rate is about 10 K/km

Thermal Structure: Surface

What determines a planet's surface temperature?





$$P_{in} = (1 - A_b)\pi R^2 \frac{F_{\odot}}{r_{\odot AU}^2}$$

$$P_{out} = 4\pi R^2 \varepsilon \sigma T^4$$

A_b is Bond albedo, $F_{\odot}$ is solar flux at Earth's distance, $r_{\odot}$ is distance of planet to Sun, ε is emissivity, σ is Stefan's constant ($5.67\mathrm{x}10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$)

Balancing energy in and energy out yields:

$$T_{eq} = \left(\frac{F_{\odot}}{r_{\odot AU}^2} \frac{(1 - A_b)}{4\varepsilon\sigma} \right)^{1/4}$$

Thermal Structure: Surface

- Solar constant $F_{\odot}$ =1300 Wm^{-2}
- Earth (Bond) albedo A_b=0.3, ε=0.9
- Equilibrium temperature = 263 K
- How reasonable is this value?

Body	Mercury	Venus	Earth	Mars
A_b	0.12	0.75	0.3	0.25
T_{eq}	446	238	263	216
Actual T	100-725	737	288	215

- How to explain the discrepancies?
- Has the Sun's energy stayed constant with time?