Lab 11: Planetary Atmospheres

1. **Atmosphere as a planetary shield**

   A beneficial effect of a planet's atmosphere is that it protects the surface from impactors. Here you will calculate the maximum size of impactor (and subsequent crater diameter) that can occur on Venus and Earth.

   a) A useful term when analyzing a planet's atmosphere is the column density, σ, which is the total mass per unit area of the atmosphere (units of kg m^{-2}). What is the column density of Venus, given that is has a surface pressure of 9 MPa and surface gravity of 9 ms^{-2}? What about Earth (surface pressure 100 kPa and gravity 9.8 ms^{-2})? (*hint*: recall that pressure= force/area and that force=mass * acceleration).

   b) If a spherical impactor of radius *R* and traveling vertically downwards enters an atmosphere of column density σ, write down an expression for the total mass of atmosphere the projectile encounters assuming that it reaches the surface.

   c) Theoretical calculations show that an impactor will break up if the mass of atmosphere it encounters equals the mass of the impactor itself. Assuming an impactor density ρ, write down an expression for the radius *R* at which an impactor will break up for a given column density σ.

   d) For the case of Venus, what is the impactor radius at which break-up occurs if the impactor density is 2500 kg m^{-3}?

   e) We can approximate a relation between crater size D and impactor radius R with

   $$D \approx \left(\frac{2v^2}{g}\right)^{1/4} R^{3/4}$$

   Using this expression calculate the smallest size of impact crater you would expect to see on the surface of Venus. Assume an impact velocity of 15 km/s. How does your answer compare to the actual observations?

   f) Repeat parts (d) and (e) for Earth, using the same assumed values for impactor density and velocity.

   g) If the impactor came it at an oblique angle, rather than vertically, what would happen to the break-up radius (the minimum size of the impactor) and why?

   h) If the impactor was made of ice rather than rock, would the minimum crater size be bigger or smaller?

2. **Weather on a hot Jupiter Exoplanet**

   In our solar system the gas giants orbit out beyond the snow line (the distance from the Sun at which water condenses to ice) but in other systems things are very different. For example, the "hot Jupiter" HD80606b (in the constellation Ursa Major/Big Dipper) orbits its star at a distance of less than 1 AU.

   a) This planet has a mass four times that of Jupiter. Assuming that it has the same density as Jupiter

(~1.3 g/cm^3), what is the radius of HD80606b, given that Jupiter's radius is 70,000 km?

b) Given that Jupiter has a surface gravity of 25 ms^{-2}, what is the surface gravity on HD80606b?

c) What is the column density (in kgm^{-2}) at the point in the atmosphere where the pressure reaches 1 MPa? (*Hint*: look back at #1)

d) What is the total mass of atmosphere above the 1 MPa level?

e) We can approximate surface temperature by comparing the planet to the Earth-Sun system with the equation

$$T = \left(\frac{r_E}{r}\right)^2 \frac{F(1-A)}{4\varepsilon}^{1/4} \quad [\quad]$$

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where r_E is the Earth-Sun distance, r is the planet-star distance, F is the solar constant, ε is the emissivity, and ς is the Stefan-Boltzman constant.

The planet has an average distance from the star of 0.5 AU. Assuming that the star is identical to the Sun, calculate the average surface temperature of the planet. Take the albedo to be 0, the emissivity to be 1, solar constant 1300 Wm^{-2}, and the Stefan-Boltzman constant 5.7x10-8 $W\ m^{-2}\ K^{-4}$.

f) Because the planet is in a very eccentric orbit, it spends a short time very close to the star. If the closest approach distance is roughly 0.03 AU, what is the incident stellar flux (F) (in Wm^{-2}) it receives at this distance (remember that this star is identical to the Sun)?

g) Energy can be approximated as E=FA* t. Assuming that the planet spends one Earth day at a distance of 0.03 AU, what is the total energy that the planet receives over this period? (Hint: the surface area intercepting the stellar energy is πR^2).

h) Using the specific heat equation ($E=mC_p\ \Delta T$) and your answers to (d) and (g), how much does the temperature of the atmosphere above 1 MPa increase during the close approach to the star? Assume the specific heat capacity (C_p) of the atmosphere to be 4e3 $Jkg^{-1}K^{-1}$.

i) Because the planet is tidally-locked, one side will receive most of the energy during closest approach. What effect is this likely to have on the global circulation?

3. Is there any subject matter you'd be interested in covering over the next few weeks? This could be something we did in lab or Prof. Howard covered in lecture that you would like to know more about (examples: planetary accretion, exoplanets, etc)