Astr 118, Physics of Planetary Systems Discussion Week 8: Atmospheres

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1. The possible shapes of temperature structures

An approximate expression for the temperature structure of an atmosphere is

$$T(\tau)^4 = \frac{3}{4}T_{\text{int}}^4\left(\tau + \frac{2}{3}\right) + \frac{3}{4}T_{\text{irr}}^4\left[\frac{2}{3} + \frac{1}{\gamma\sqrt{3}} + \left(\frac{\gamma}{\sqrt{3}} - \frac{1}{\gamma\sqrt{3}}\right)\exp\left(-\gamma\tau\sqrt{3}\right)\right]$$

This is a mess, so let's try and get something sensible out of it!

- τ is "optical depth": this is about proportional to pressure – it's small high up and large lower down. When coding, we'll just pretend this is pressure whenever it's convenient.
- T_{int} and T_{irr} are the internal and irradiation temperatures of the atmosphere: the amount of heating we get from the planet interior and the stellar radiation respectively.
- γ is something like "efficiency of planet heating"/ "efficiency of star heating". If it's < 1, star heating permeates the atmosphere more, and if it's > 1, planet heating permeates more.

In pairs, implement and plot this in Python. Let τ range from 10^{-8} to 10^3 log-spaced, and use $T_{\text{int}}, T_{\text{irr}}, \gamma$ (gamma) as free parameters. I highly recommend implementing this as a function that takes in the three free parameters and returns the T array, so you can overplot many results at once. **Use this visualization to answer the following questions.**

a. In a free-floating planet, what does the temperature structure look like?

b. In a highly irradiated atmosphere where $T_{\text{irr}} \gg T_{\text{int}}$, what happens for $\tau \ll 1$ (upper atmosphere) and $\tau \gg 1$ (lower atmosphere)?

c. What's likely to be true about planets that exhibit *thermal inversions*, where the atmosphere gets colder and then warmer again as you're going up?

2. Horizontal wind speed

There's a lot to cover in 1D analysis of atmospheres, but there are also some effects that need us to consider the 3D structure. Let's look at just one: zonal winds. These are described by the partial differential equation

$$\frac{2\pi}{P_{\text{rotation}}}\frac{\partial u}{\partial \ln p} = -\frac{\partial (RT)}{\partial x}$$

where the wind speed is u, the length of the planet's day is P_{rotation}, and p, T, x describe variation across the planet in the horizontal direction. Approximating $\frac{\partial y}{\partial x} \approx \frac{\Delta y}{\Delta x}$ for reasonable choices of Δy, Δx, how fast are Earth's winds? Plug this into WolframAlpha (R = "specific gas constant of air") to avoid a bunch of tedious unit-chasing! What might change in the exoplanet context?

3. Converting to $T(z)$ with pair programming!

I have a Jupyter notebook with a P-T profile loaded. Talk me through the steps I need to do to convert the independent axis from pressure [$T(P)$] to altitude [$T(z)$]! The ideal gas law $P = \rho RT/\mu$ and hydrostatic equilibrium $\mathrm{d}P/\mathrm{d}z = -\rho g$ may be useful.