Project 5 - Radiation from Planets

Part 1.

When observing a distant exoplanet, the only quantity we can measure is the radiation coming from the planet. In this exercise we explore the relationships among the planet flux, temperature, and albedo. We also derive planet-to-star ratios which are key for assessing what kind and size of telescope and instrumentation are required to detect an exoplanet - and whether or not an exoplanet is detectable by any means.

1. a) Compare the incident energy from stellar radiation to the internal energy for a hot Jupiter exoplanet. Use $T_{eq} = 1600\,K$ for the planet's equilibrium temperature. Use $T_{eff} = 120\,K$ for the planet's interior energy (equivalent to Jupiter's interior energy). b) Compare the Earth's received energy from the Sun to its interior energy. The former can be taken as 270 K and the latter is known to be $44 \text{x} 10^{12}$ W.

2. Derive the radiation constant σ in the Stefan-Boltzmann Law equation by integrating the black body over frequency. Hint: use the identity

$$\int_0^\infty du \frac{u^3}{e^u - 1} = \frac{\pi^4}{15}. \tag{1}$$

3. Let us make some rough estimates on the temperature effect of the bond albedo which is, for Earth, about $A_B = 0.31$. Note: $T_{eq} = 253\,K$ for Earth. a) How much would the equilibrium temperature change if the Bond albedo was much larger: $A_B = 0.7$, e.g. due to more reflection by aerosols from volcanoes in the high atmosphere, more reflection from clouds or/and large ice surfaces at the poles? b) Calculate the same for much lower albedo: $A_B = 0.15$, e.g. if there are much less clouds.

4. A solid body (e.g. comet) in interstellar space with no nearby radiation source will have an effective temperature T = 3 K in thermal equilibrium with the cosmic micro-wave background (CMB). How far from the sun must such a body be located, so that the irradiation from the sun is equal to the irradiation from the CMB (i.e. $T_{eq} = 3\,K$), if a bond albedo of $A_B = 0.3$ is assumed. Can we hope to detect Oort cloud (a hypothesized spherical cloud of icy asteroids and comets at 50 000 AU around the Sun) bodies based on their thermal emission?

5. What is the planet-star flux ratio of a Lambert sphere at $\alpha = 90°$? Use the phase curve of the Lambert sphere. Show that the flux ratio at $\alpha = 90°$ is less than 1/2 of the flux ratio at $\alpha = 0°$.

6. How does the Lambert sphere phase curve equation depend on orbital inclination?

7. Planets both emit light (in the form of thermal radiation) and reflect starlight. Here, we make some estimates as to what flux contrasts can be expected for reflecting planets. For this, we look at three different kinds of planets: The Earth, Jupiter, and a young, massive planet, for example HR8799e (assume $R = 1.3\,R_J$, $T_{eff} = 1000\,K$). Calculate an estimate of the contrast in scattered light, assuming the respective semi-major axes (Earth: 1 AU, Jupiter: 5.2 AU, HR8799e: 14.5 AU) and geometric albedos at visible light (you can assume HR8799e to have a geometric albedo similar to Jupiter).

Part 2.

If you have (random) questions about exoplanet atmospheres that you've always wanted to have answered, please send them to me via your group's submission and I will get into (some) of those during the next exercise class. Happy exercising!

Note *All constants that are not explicitly given in the exercises are to be taken from the lecture script and clearly stated in the exercise submissions. To receive feedback on your project work please upload it as a PDF-file to the moodle-course. In case you have any questions, please contact Komal Bali (kobali@phys.ethz.ch), Janina Hansen (jahansen@ethz.ch), and Sean Jordan (jordans@ethz.ch).*