AY C10/L&S C70U **Name:** ______________________

Fall 2018

Worksheet 5

09/18/2018

This worksheet covers the physical intuition behind the greenhouse effect, tides, and extrasolar planet detection. There are 4 pages (including this cover page) and 3 questions. Accuracy is definitely desired, but effort and clear physical reasoning are far more important than the final answer, *especially* for the challenge problems.

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1. Consider a simplified model for the atmosphere of Venus, a flat plate that is completely transparent to light with a wavelength shorter than 1 micrometer, but which reflects *half* of all incident light with longer wavelengths.

   (a) **Would the incident sunlight** be allowed to pass through the atmosphere, or would it be reflected? How about **Venus's thermal emission**? Answer this question with minimal calculation.

   (b) Assume that the Sun is very far away and its rays come in parallel. **Draw a figure** illustrating the path of the light. **What happens to it** when it hits Venus's surface initially and how does that affect its subsequent trajectory?

   (c) In order to remain in thermodynamic equilibrium, the total radiative flux (ε in the lecture notation) absorbed by each square meter of the planet must equal the flux it emits. With our greenhouse atmosphere, **how does ε change** with respect to the no-atmosphere case? **Temperature**? Answer qualitatively.

(d) If instead of reflecting 50% of infrared light, the atmosphere blocked 10%, **what would happen** *(qualitatively)* to the change in temperature? **5%**? Use this result and whatever facts you know from lecture and reading to order the four inner planets (Mercury, Venus, Earth, Mars) by the strength of their greenhouse effect.

(e) **Explain in a sentence or two** how adding carbon dioxide to the atmosphere may contribute to global warming on Earth.

2. For this question, we investigate tidal forces using the example of a small moon in the orbit of Saturn. The satellite has a mass m and a radius r, and orbits around Saturn (a planet of mass M) at radius R.

   (a) **Draw a diagram** of the system, including accelerations from Saturn on both sides of the moon and the acceleration at the moon's center-of-mass.

   (b) **Compute the accelerations** at each point you indicated in the previous diagram. Now **subtract the center-of-mass acceleration** off of all accelerations in your picture. **Qualitatively compare** the *magnitudes* and *directions* of the accelerations on either side of the moon. **Describe** what effect you would expect this to have on the moon's shape.

(c) Besides being affected by tidal acceleration, the shape of the moon is also influenced by its own self-gravity. **Equate the acceleration due to self-gravity** with the tidal acceleration. **What happens** when tidal acceleration equals or exceeds self-gravitational acceleration, and what course concept does this connect to?

(d) Very qualitatively, **how might one adjust** m, M, r, or R to cause tidal disruption? **How does tidal disruption** explain why Saturn has rings?

(e) The *Cassini* space probe passed very close to Saturn and has a much smaller mass than any of Saturn's moons, and yet survived without being tidally disrupted. **Why**?

3. In this question, we investigate the two main methods of exoplanetary detection—the Doppler-wobble ("radial velocity") and transit techniques.

   (a) Suppose that a planet is orbiting a star of mass M at distance R, with peak velocity v_0. Assuming we are observing the star edge-on, **plot the Doppler wobble** in light of wavelength λ that we would measure as a function of time.

(b) Now let the the plane of the planet's orbit be actually inclined by a (not necessarily small) angle α with respect to our line of sight. **Modify your expression from the previous part** to incorporate the inclination and **qualitatively describes** what happens to the Doppler wobble as we see a planet's orbit more and more face-on.

(c) Now assume the star has a radius of r_* and the planet has a radius r_p. If the planet is orbiting edge-on, **sketch out the shape** of a transit. At transit peak, **what fraction of starlight** would be blocked?

(d) Transits can only be detected when the plane of the planet's orbit is edge-on or nearly so. **Explain** how this makes transiting planets comparatively rare.