# Astronomy 210 Spring 2011
# Homework Set #5

Due in class: Friday, March 4 Total Points: 50

1. *A Newly Discovered Planet.* The NASA *Kepler* mission is an orbiting telescope designed to find planets around other stars ("exoplanets") and right now is in the midst of making revolutionary discoveries. In January 2011, *Kepler* announced a new planet, known as Kepler-10b (10=10th star for which *Kepler* has a confirmed planet, b=first planet found around this star). The host star of Kepler-10b is almost exactly identical to the Sun, with a similar radius and surface temperature, and identical luminosity. So for the purposes of this problem, assume the host star is exactly identical to the Sun.

   (a) [**5 points**] Kepler-10b is found to have an orbital period of just 0.837 days! Calculate the semimajor axis of Kepler-10b, in AU and in meters. Compare your answer to the semimajor axes of Mercury, and to the radius of Kepler-10b's host star, and comment.

   (b) [**5 points**] Kepler-10b is found to have a mass $M = 4.6 M_\oplus$, and a radius $R = 1.4 R_\oplus$, where $\oplus$ =Earth. Find the average density of Kepler-10b in kg/m$^3$. What do you conclude about the composition of Kepler-10b?

   (c) [**5 points**] Kepler-10b is the first exoplanet for which the average density is confirmed to be larger than 3000 kg/m$^3$ Comment on why this is significant.

   (d) [**5 points**] Find the acceleration $g$ of gravity on the surface of Kepler-10b, in m/s$^2$. Compare your result to $g_\oplus$, and comment.

   (e) [**5 points**] Calculate the equilibrium temperature of Kepler-10b, assuming it is a fast rotator. Assume an albedo $A = 0.1$.

   On a planet's surface, all rocks melt at temperatures $\approx 1200°\text{C} \approx 1500$ K. Compare your result to this, and comment.

   (f) [**5 points**] Find the minimum molecular weight $\mu$ a gas must have to be retained in the atmosphere of Kepler-10b. Express your answer in units of the proton mass, i.e., find $\mu/m_p$. Can Kepler-10b retain an atmosphere of oxygen ($O_2$, molecular weight $\mu = 32 m_p$)?

2. *The Habitable Zone.* In our search for exoplanets, there is a special interest in finding worlds which could support life. Of course, we have no idea how biology and biochemistry would evolve elsewhere in the cosmos, so we must take an open mind about what extraterrestrial environments could support life. Still, it seems hard to imagine life developing in regions which lack liquid water. Thus, planets which can support liquid water are said to be in the "habitable zone" around their host star.

   Until recently, no exoplanets have been found in the habitable zone of their stars. However, on Feb. 2, 2011, the *Kepler* team announced that they are currently monitoring 54 stars which are likely to harbor planets in their habitable zones! *Kepler* will soon be able to confirm whether these candidates are real planets, and is expected that $> 80\%$ will be. Then for the first time we will know the location of new worlds which may harbor life!

   Here we will make a simple (in fact, oversimplified) estimate of the size of the habitable zone.

   (a) [**5 points**] The temperatures at which water is liquid depend on a planet's atmospheric pressure. However, for simplicity we will simply use the temperature range for the Earth's atmospheric pressure, namely water exists for $0°\text{C} < T < 100°\text{C}$; be sure to convert this to Kelvin units.

   For planets orbiting the Sun, find the range of orbital radii for which the equilibrium temperature can support liquid water; express your answer in AU. For simplicity assume Earth's albedo $A = 0.4$, and fast rotation.

   Does the habitable region seem large or small to you?

(b) **[5 points]** Your answer to part (a) should find that 1 AU orbits are not in the Sun's habitable zone! Clearly this is not correct. The reason, as we will soon see, is that the Earth's surface is hotter than the naive equilibrium temperature, due to the greenhouse effect which arises from the Earth's atmosphere. Indeed, we would expect greenhouse effects to also be present in exoplanets as well.

The greenhouse effect always makes a planet's surface temperature *higher* than the naive equilibrium value we have been using. In light of this, how should realistic evaluations of the habitable zone compare to your result from part (a)? That is, how are the inner and outer boundaries changed?

(c) **[5 points]** Other stars generally have radii, surface temperatures, and luminosities different from the Sun's. Thus the size of a star's habitable zone will generally be different from the Sun's. Moreover, most are which are significantly cooler, smaller, and less massive than the Sun. For a star with $L = 0.1L_\odot$ (that is, only 10% as luminous as the Sun) find the naive estimate of the habitable zone, as you did in part (a). Comment on the result. *Hint*: it will be useful to think about how the star's luminosity depends on its temperature and radius.

(d) **[5 points]** If the star in part (c) has a mass $M = 0.5M_\odot$, find the planetary orbital periods would correspond to the habitable zone range you estimated in part (c). Express your answer in years, and comment.