Physics 688, From Brown Dwarfs to Giant Planets  
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**Problem Set 2**  
Due in class on Wednesday Mar 4, 2009

Each letter part of a problem is worth 5 points. Material covered: lectures 7–12.

1. **(10 points)** Finish problem 3 of Chapter 4 in Reid & Hawley. That is, complete parts (d) and (e).

2. **(15 points)** Problem 1 of Chapter 4 in Reid & Hawley.

3. **(25 points)** Using highly precise spectroscopy, an M3 V star has been observed to display a periodic radial velocity oscillation due to an unseen companion with a period of $P = 12.9$ days and a semi-amplitude of $v_r = 3.03$ m/s. The orbital eccentricity of the companion is found to be zero, i.e., its orbit is circular. Using the respective mass, temperature, and radius estimate for the primary from Table 4.1 in Reid & Hawley, answer the following questions:

   a) What is the value of the projected semi-major axis, $a$, of the system? Compare this figure to the distance of the planet Mercury from the Sun, and to the solar radius.

   b) What is the estimated minimum mass $M_2 \sin i$ of the secondary? ($i$ is the orbital inclination with respect to the line of sight; $i = 90^\circ$ for an edge-on orbit, $i = 0^\circ$ for a face-on orbit.) Compare this to the masses of Jupiter and Earth.

   c) What is the minimum value for the orbital inclination $i$ for which the companion still has a planet-like mass ($< 13 M_{\text{Jup}}$). At what values of $i$ would the companion be actually stellar ($>75 M_{\text{Jup}}$ or $>0.072 M_{\text{Sun}}$)?

   d) Assuming that the companion is a planet and has an Earth-like albedo ($A = 0.296$; i.e., 29.6% of incident light is immediately reflected back into space), what is the effective temperature on the planet? Would water be in liquid form (could the planet be habitable)?

   e) The distance to the host star is 6.2 pc. Assuming that we can measure any astrometric wobble in the absolute position of the primary to a precision of 50 micro-arc seconds (the best that can be done today with ground-based interferometry), is there an upper limit on the companion’s mass (lower limit on the orbital inclination $i$ that we can place in the absence of a detected astrometric wobble? (Neglect any complications due to possible distinction between the center of mass and the center of light in the system, in case the companion is massive enough to be self-luminous.) What is the minimum semi-major axis in which the planet would produce a detectable astrometric signal in the position of the primary for an edge-on orbit ($i = 90^\circ$)? With what period?

4. **(10 points)** Problem 3 of Chapter 7 in Reid & Hawley. (You may have to read over Chapter 7.3 in the textbook.)