ASTR 120 Problem Set 11: Due Thursday, November 30, 2017

General reminders: You must show all your work to get full credit. Also, if any website was useful, you need to give the URL in your answer. Note that any website is fair game; you just have to cite it. If any book including our textbook was useful, you need to indicate where in the book you used a particular fact. This will be true in all homeworks.

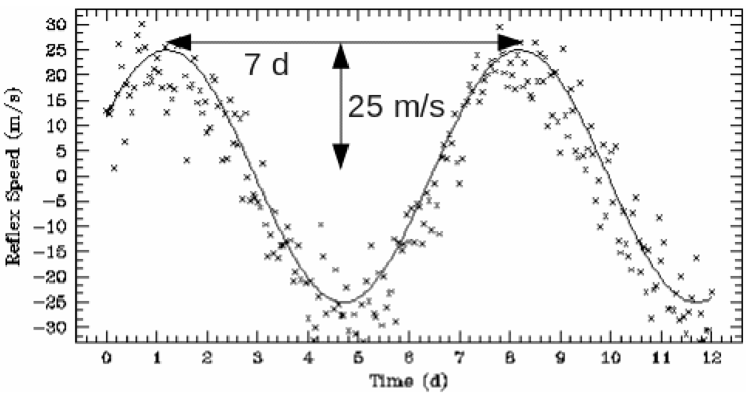
1. [5 points] In this problem we will work out more quantitatively why sunspots are cooler than the surrounding photosphere. We indicated that in sunspots, the magnetic field strength is large enough to resist gas motion, and therefore they suppress convection. To determine whether gas or magnetic fields win, we can compare pressures: the gas pressure is $P_{\rm gas} = nkT$, where in the top part of the photosphere $n \approx 10^{23}$ m^{-3}, and the magnetic pressure is $P_{\rm mag} = B^2/8\pi$ (if the magnetic field strength B is measured in Gauss, then P is in units of 0.1 J m^{-3}).

a. [1 point] Compute the gas pressure in units of J m^{-3}.

b. [1 point] Look up the average magnetic field strength of the Sun in Gauss, and use that to compute the average magnetic pressure in units of J m^{-3}; is the average magnetic pressure enough to inhibit gas motions?

c. [3 points] Calculate the magnetic field strength that is sufficient to significantly inhibit gas motions (i.e., such that $P_{\rm mag} = P_{\rm gas}$). Look up the typical magnetic field strength in a sunspot; is that enough to suppress convection?

2. [15 points] Consider the exoplanet data below, then answer the questions that follow.



- The star mass, radius, and effective temperature are identical to the Sun.
- There is a transit event, which is observed to block 1% of the light from the star.

a. [3 points] Calculate the semimajor axis of the exoplanet orbit, in AU.

b. [2 points] Two different researchers draw different conclusions about the orbit: one says that the eccentricity is $e = 0.01$, the other says the eccentricity is $e = 0.9$. Give a concise reason for why one or the other should be preferred.

c. [2 points] Calculate the exoplanet mass, in units of Jupiter masses.

d. [2 points] Assuming the entire planet crossed the face of the star, calculate the radius of the exoplanet, in meters. **Note:** as part of this calculation you need to make an assumption related to the temperature of the exoplanet. Indicate what this assumption is, and why you need to make it.

e. [2 points] Compute the average density of the exoplanet and make a comment about your answer; is it reasonable?

f. [2 points] Suppose that the exoplanet reflects all of the light that it receives from its host star, and does not have any other source of light. Calculate the ratio of the luminosity of that reflected light to the luminosity of the star.

g. [2 points] Look up the angular resolution of the Hubble space telescope. Calculate the distance, in parsecs, that this system would need to be from Earth so that at maximum extent the exoplanet is angularly separated from its host star by Hubble's angular resolution, and compare that with the distance to the nearest star to the Sun.

3. [5 points] Estimate the radial range of our solar system's habitable zone by computing the distances from our Sun at which the effective temperature for a planet with zero albedo ranges from 243 K to 343 K (30 degrees less than the freezing and boiling points of water at 1 atmosphere pressure, respectively, to account for a moderate greenhouse effect). Repeat the exercise for red dwarf Gliese 667C, which radiates only 1.4% of the Sun's luminosity, and confirm that exoplanet Gliese 667Cc (semimajor axis 0.12 AU) lies in the star's habitable zone. Also, given that the mass of Gliese 667C (the red dwarf) is 0.31 $M_\odot$, calculate the *ratio* of the tidal force on a planet at the 273 K orbital radius around Gliese 667C, to the tidal force on a planet at the 273 K orbital radius (again, with zero albedo) around our Sun. **Hint:** ratios are your friends!

Bonus Question [2 points]

Another method of exoplanet detection is gravitational microlensing. Find a website about this method, and summarize how it works.