ASTRONOMY 191 - Fall 2024
Homework Assignment #1
DUE by Friday, September 27, 2024
250 points

1. **Problem 1** [40 points]

Assuming 100% efficient solar cell material ($\epsilon = 1$), what area do you expect to need to cover with it to replace the power output of a nuclear power plan ($P_{\text{nuclear}} = 10^9$ W) on a clear day? What are would you need for a more realistic solar cell material (with an efficiency $\epsilon \approx 0.1$)? Compares your results with the surface area of the city of Somerville (MA), $\sim$10.9 km^2. Assume the luminosity of the Sun to be $L_\odot = 4 \times 10^{33}$ erg s^{-1}; the Earth-Sun distance to be 1 AU = 1.5$\times$10^{13} cm.

2. **Problem 2** [50 points]

Consider two astronomical objects: the Earth with $T \approx 300$ K and the Sun with $T \approx 5800$ K. Use the Stefan-Boltzmann Law to estimate the surface flux (F, in [erg s^{-1} cm^{-2}]) of each object. Estimate the total luminosity (L, in erg s^{-1}) of each object. Use the Planck Blackbody function to calculate and plot the surface brightness (i.e., the intensity, B_ν) for the two objects on the same axes as a function of wavelength. (Note that all plots should have the axes and scales labeled, units specified, and can be either linearly or logarithmically scaled on either axis; for this plot, your plotting range should extend at least from 0.2 to 20 μm on the x axis, and your y axis will need to be logarithmic to show both spectra at the same time).

3. **Problem 3** [70 points]

Consider two astronomical objects: an Earth-size planet with $T \approx 300$ K and a Sun-like star $T \approx 5800$ K. Assume that both objects radiate as blackbodies. Recalling that $F_\lambda = \pi I_\lambda (R/d)^2$, from Eq. 1.13 in the textbook, where R is the object's radius and d is the distance from the object's center. Plot the flux density, F_λ, at the surface of each of these objects. Plot the flux density, F_λ, at a distance of 10 parsecs (pc) from each of these objects. Plot the wavelength-dependent planet-star flux ratio, $F_{\lambda,\ planet}/F_{\lambda,\ star}$, of these two blackbody spectra. What does this plot suggest about the best wavelengths to look for radiation emitted by Earth-like planets in other exoplanetary systems? Calculate the bolometric (wavelength-integrated) planet-star flux ratio, F_{planet}/F_{star}.

4. **Problem 4** [50 points]

A supernova remnant has an angular diameter $\theta = 4.3$ arc minutes and a flux at 100 MHz of $F_{100} = 1.6 \times 10^{-19}$ erg cm^{-2} s^{-1} Hz^{-1}. Assume that the emission is thermal (even though it actually isn't). What is the brightness temperature T_b? What energy regime of the blackbody does this correspond to? (i.e., compare the energy of the 100 MHz photonts to the thermal energy kT_b), and determines whether the Rayleigh-Jeans limit is applicable. At what frequency (and wavelength, in nm) will the radiation peak, if the emission is blackbody?

5. Problem 5 [40 points]

Venus has a thick cloud layer that reflects light very well (albedo $\sim$0.75). At IR wavelengths these clouds are opaque and the temperature measured at this wavelength is only 225 K. However, radio waves with wavelengths $\lambda > 30$ cm can easily propagate through the atmosphere of Venus (but they are still absorbed and emitted by the soil at the planets surface). The radio flux received at the Earth from Venus at 30 cm is $F_\nu \approx 0.23$ Jy (1 Jy=10^{-23} erg cm^{-2} s^{-1} Hz^{-1}) when Venus is at quadrature. Calculate the temperature of Venus at its surface (use the radius of Venus $R_{\rm Venus} = 6052$ km; Earth-Sun distance 1 AU; Venus-Sun distance 0.72 AU). If the total power detected in a receiver of diameter D is $P = \pi(D/2)^2 \times F$, with F specific flux integrated over the frequency bandwidth of the receiver, estimate the total power detected by a receiver observing Venus with a 25 m dish radio telescope and with a bandwidth $\Delta\nu$=5 MHz.

TIPS:

$\star$ For Problems 4 and 5, you will need to write a code to produce the requested figures. You can use whatever language you want for the coding, but I would strongly recommend Python. Save the plot figures as PDF or PNG and submit them with the rest of the homework assignment.

$\star$ Do not hesitate to reach out to me for any questions you may have!