Physics 239: Homework 4
Fall 2016
Due by end of quarter

In this assignment, you are going to assemble the spectral energy distribution of a star forming galaxy from several different radiative processes.

1. Download the data table for the galaxy M82 from the website. The data have units of μm for wavelength and $L_\odot$/Hz for the monochromatic luminosity and its uncertainty. The distance to M82 is 3.6 Mpc.

2. The spectral energy distribution over this wavelength range has contributions from four main processes: starlight, dust emission, thermal free-free emission and synchrotron. You are going to write functions to generate spectra for these four processes. Then you can approximate by eye the needed parameters to match the observed M82 spectrum or do some sort of fitting - whatever you prefer.

   (a) For the starlight, I'd recommend starting from templates from the Starburst99 program (`http://www.stsci.edu/science/starburst99/docs/default.htm`). You can either run a simulation of your own on their website to generate a stellar population spectrum or download one of the spectra from the 1999 dataset. You should think about what sort of spectrum is reasonable for a galaxy like M82—a single burst of star formation or a continuous history? Describe your assumptions and procedure for obtaining an appropriate stellar spectrum. (Extra: figure out a way to account for the effects of dust extinction on the stellar spectrum). Over what range of wavelengths does the stellar emission dominate M82's spectrum? What stellar mass do you need for your selected star formation history to approximately match the M82 observations over that wavelength region? Don't worry about an exact match - order of magnitude here is fine.

   (b) For the dust, I give you permission to ignore the $5-40$ μm region where the features from polycyclic aromatic hydrocarbon vibrational bands dominate the spectrum (even though this is my favorite part). In thermal equilibrium, dust emits like a "modified blackbody"
$$S_\nu = \frac{M_{\rm dust}}{D^2}\kappa_\nu B_\nu(T_{\rm dust}) \tag{1}$$
where S_ν is the flux density (e.g. something with units comparable to [erg/s/cm^2/Hz]), $M_{\rm dust}$ is the dust mass, $B_\nu(T_{\rm dust})$ is the Planck function, D is the distance to the galaxy, and κ_ν is the absorption opacity. κ_ν can be derived from the composition of grains and Mie scattering cross section $Q_{\rm abs}$ as follows:
$$\kappa_\nu = \frac{3Q_{\rm abs}}{4a\rho} \tag{2}$$
where a is the grain size and ρ is the grain mass density. You can find the optical properties of various dust compositions here: `https://www.astro.princeton.edu/~draine/`

`dust/dust.diel.html`. Write a function that generates a spectrum for dust emission given a dust temperature, mass, and opacity (choosing some grain composition and size). What parameters does your model need to match the observed dust emission from M82? Over what wavelength range does dust emission dominate M82's spectrum?

(c) Write a function to generate a synchrotron spectrum given a power-law distribution of electron energies. The coefficients that relate the spectrum to the density of electrons and the magnetic field strength are out of the scope of this homework assignment, so just refer to equation 6.36 in your book and scale arbitrarily assuming fixed B and α. What power-law slope do you need to reproduce M82's synchrotron spectrum? Over what wavelength ranges does synchrotron dominate?

(d) Finally, write a function to generate a free-free spectrum for M82. Refer to the material in Chapter 5 of the textbook and the notes from class. Over what ranges does free-free make an important contribution to M82's spectrum?

3. Make script that generates one final plot with the spectra for all four radiative processes on top of the M82 data points. Push this to github with your functions and write up answering the questions above.