ASTRO 402. Computer Assignment # 2

March 22 2005. Due Apr 1 2005

This assignment deals with the transfer of radiation from a central star through a surrounding dust envelope. As it propagates through the envelope, the radiation is absorbed by the dust grains, which are heated and which radiate. The result is an astronomical source which radiates primarily in the infrared.

There's a radiative transfer code for you to play with in gk/A402/dust.f on astro. The code is *very* simple. (It is also atrociously badly written in archaic f77. I will not be the least offended if anyone rewrites it). It assumes that the central star is a black body and that the surrounding spherically symmetric envelope is produced by mass loss at constant outflow speed V_o, so that at distance r from the star the dust density is

$$n_d(r) = \frac{\dot{M}_d}{4\pi r^2 V_o m_d}$$

where $\dot{M}_d$ is the dust loss rate, V_o the outflow speed and m_d the mass of a dust grain. The dust grains are assumed to be spheres of radius a_d with material density ρ_d. The radiation is assumed to propagate radially and scattering is ignored.

What this code does is divide the circumstellar shell into radial zones. In each zone the amount by which the incident radiation is attenuated is calculated as is the temperature of the dust. We then find the dust equilibrium temperature and calculate the emission for each shell. This calculation is repeated between r_o, the inner radius of each shell, and R, the outer radius. The inner radius can either be specified or is calculated as the location where the dust grains condense out of the gas phase.

The emergent spectrum F_λ at R is then convolved with the filter functions R_λ of the IRAS satellite to calculate the flux density which that satellite would have observed at its four operating bands centered at 12μ, 25μ, 60μ and 100μ:

$$S_\lambda = \frac{\int F_\lambda R_\lambda d\lambda}{\int R_\lambda d\lambda}$$

(see the IRAS explanatory supplement, ed. C. Beichman *et al.* 1988; it's on the reserve shelf in the library).

Here's what I want you to do. Several authors (e.g. van der Veen and Habing 1988, Astronomy and Astrophysics 194, p125: "The IRAS Two- Color Diagram as a Tool for Studying Late Stages of Stellar Evolution") have shown that the two-color diagram shown in their Figures 5a and 5b, reproduced here, can be explained by the properties of circumstellar material and can be used as a diagnostic of mass loss. See what you can do with the program "dust.f" to reproduce the features of this diagram. In particular, make calculations of the infrared colors as a function of mass loss rate and see if you can reproduce the sequence shown by the dotted line in Figure 5b.

The colors in Figure 5 are in magnitudes and defined as follows:

$$[12] - [25] = 2.5 \log \frac{S_{25\mu}}{S_{12\mu}}$$

etc. The flux densities S are in Jy.

As well as "dust.f" you'll need several input files. First is "input", which on one line contains the input parameters for the model, as follows:

1) the stellar surface temperature in K.
2) the stellar luminosity in $L_\odot$.
3) The outer radius of the shell in cm

4) the inner radius. set this equal to 0 to set the inner radius as the place where the dust condenses.
5) the dust loss rate in $M_\odot$ yr^{-1}.
6) the outflow speed of the wind in km s^{-1}.
7) the distance to the source in pc
8) flag. 0 = silicate grains, 1 = carbon grains
9) the grain radius a_d in cm
10) the grain material density in gm cm^{-3}. It has the value 2.25 for carbon grains and 3.5 for silicate grains
11) the grain emissivity index β at long wavelengths. The grain effective cross section is $\pi a_d^2 Q_\lambda$ where

$$Q_\lambda = Q_o \left(\frac{\lambda}{\lambda_o}\right)^{-\beta}$$

(Q is very much less than 1 at long wavelengths because of diffraction effects).
12) ignore these last. (12) should always be set to 0.0.

You also need files “tbl2.sil”, containing the optical properties for silicate grains, “tbl2.graph” containing the optical properties of graphite grains, and “filter.dat” the IRAS response functions.

Notes. Evolved stars are cool, with temperatures in the range 2000 to 3500 K, and highly luminous (5000 to 50,000 $L_\odot$). They have either fairly normal abundances with the oxygen abundance greater than the carbon abundance, in which case the grains are silicates, or are “carbon stars”, with the carbon abundance greater than the oxygen abundance. The grains are graphite or amorphous (soot) in this case.

The files will also be placed on the web page.