Late Stages of Stellar Evolution, Problem Set 3

1 Channel maps

Consider a thin shell of radius R_s which is radially expanding with a velocity v_∞. If this shell is emitting line radiation in the radio/submm regime (for example a CO line), and you observe it with a radio telescope which resolves the shell, the channel maps will show rings of changing radius.
a) Explain why this is the case (use a sketch if you want).
The radius of the ring in the channel map at the frequency corresponding to the systemic velocity of the system $v_z = v_\mathrm{sys}$ will be largest, say θ_s, and in the channel maps corresponding to the velocities $v_z = v_\mathrm{sys} + v_\infty$ and $v_z = v_\mathrm{sys} - v_\infty$ it will be zero.
b) Show that between $v_\mathrm{sys} + v_\infty$ and $v_\mathrm{sys} - v_\infty$ the radius is given by

$$\theta(v_z) = \theta_\mathrm{s} \left[1 - (v_z - v_\mathrm{sys})^2 / v_\infty^2\right]^{1/2} \tag{1}$$

c) Assume that the line is the J=1-0 transition of CO at $\nu = 115.271$ GHz, that $v_\mathrm{sys} = 40$ km s^{-1} and $v_\infty = 15$ km s^{-1}. What frequency range should be observed?
d)* Find the corresponding line profile. For this assume that the shell has a thickness $\Delta\theta = 0.1\theta_\mathrm{s}$.

2 Line profile*

Consider a region with inner radius R_in and outer radius R_out, where $R_\mathrm{in} = 0.1 R_\mathrm{out}$, and assume it is expanding spherically with velocity v_∞. The line emissivity within this region is a function of radius, such that $j \propto r^{-3}$, and the line is optically thin everywhere.
a) Find the intrinsic line profile, normalized to the peak value.

3 Mass loss rate estimate

Say we are observing a probe X which emits radiation from a spherical shell of thickness ΔR_X within the CSE.
a) If we from the total intensity of the emission can estimate M_X, the total mass in probe X, and from chemical modelling the mass fraction of probe X so that we obtain the total mass in the shell, $M(\Delta R_X)$, and from the show that

$$\frac{M(\Delta R_X) v_\infty}{\Delta R_X} \tag{2}$$

gives an estimate of the mass loss rate $\dot{M}$ from the star.
b)* Argue that for this estimate we need the distance D to the star, and that the mass loss rate we derive will depend on D as $\dot{M} \propto D^2$.

4 Mass loss rate estimate

Study Sect. 7.7 (written by Hans Olofsson) from the Asymptotic Giant Branch book (copies added) and review the various methods through which the mass loss from an AGB star can be measured. What are the strong points and the weak points of each method? Can each of the methods be used for all AGB stars?