Star Formation – HW #3

Due Wednesday Oct 17 at the beginning of class. Answer the following questions. Show all work.

1. **Altogether Now: GMCs, Clusters, Protostars and Outflow Feedback**

Consider a collapsing protostellar core that delivers mass to an accretion disk at its center at a constant rate $\dot{M}$. A fraction f of the mass that reaches the disk is ejected in an outflow, and the remainder goes onto a protostar at the center of the disk. The material ejected in the outflow is launched at a velocity equal to the escape speed from the stellar surface. The protostar has a constant radius R_* as it grows.

a) Compute the momentum per unit stellar mass ejected by the outflow in the process of forming a star of final mass M_*. Evaluate this numerically for $f = 0.1$, $M_* = 0.5M_\odot$. and $R_* = 3R_\odot$.

b) The material ejected into the outflow will shock and radiate energy as it interacts with the surrounding gas, so on large scales the outflow will conserve momentum rather than energy. The terminal velocity of the outflow material will be roughly the turbulent velocity dispersion σ of the ambient cloud. If this cloud is forming a cluster of stars, all of mass M_*, with a constant star formation rate $\dot{M}$ cluster, compute the rate at which outflows inject kinetic energy into the cloud.

c) Suppose the cloud obeys Larsons relations, so its velocity dispersion, mass M, and size L are related by $\sigma = 0.72(L/\mathrm{pc})^{0.5}$ km/s and $M = 100(L/\mathrm{pc})^2 M_\odot$. Assuming the turbulence in the cloud decays at a rate what star formation rate is required for energy injected by outflows to balance the energy lost via the decay of turbulence? Evaluate this numerically for $L = 1$, 10 and 100 pc.

d) If stars form at the rate required to maintain the turbulence, what fraction of the cloud mass must be converted into stars per cloud free-fall time? Assume the cloud density is $\rho = M/L^3$. Again, evaluate numerically for $L = 1$, 10 and 100 pc. Are these numbers reasonable? Conversely, for what size clouds, if any, is it reasonable to neglect the energy injected by protostellar outflows?

2. **Observing Dusty Protostars**

In this problem you will use the radiative transfer code, Hyperion, to model an embedded low-mass protostar. Download and install Hyperion from here: *http://www.hyperion-rt.org*. I suggest perusing Robitaille (2011) to get a sense for how the code works and what sorts of problems it can do.

a) Use the documentation example for setting up 'Analytical YSO Models' to initialize a model of a star with envelope and disk with the following properties:

- YSO: $L = 5L_\odot$, $R = 2R_\odot$, $T = 6200$ K
- Flared Disk: $M_d = 0.01M_\odot$, $R_{\rm d,min} = 10R_\odot$, $R_{d,max} = 200$ au, scale height $h = 5$ au, flaring power $\beta = 1.25$
- Envelope: $M_e = 0.4M_\odot$, $R_{\rm e,min} = 200$ au, $R_{\rm e,max} = 10^4$ au, $\rho \propto r^{-2}$
- Dust Model: Kim, Martin & Hendry 1994
- Spherical grid: 100 x 5 x 5

I suggest starting with 10,000 photons. Make a plot showing the SEDs of this source viewed from several different angles, assuming a distance of 300 pc. Explain any features of the SED. How does the SED change with viewing angle and why?[1]

b) Run the same model with properties as above but with envelope masses of 4, 0.04 and 0.004 $M_\odot$. What is the effective temperature of each of the 4 sources? What is the class is each?

c) Carry out your own "numerical experiment." Modify some of the Analytical YSO Model settings or add some extra parameter to the model. What do you find?

[1]You can also make 2D images as in Offner et al. 2012. Producing a well-sampled image usually requires 10 times more photons however.