The Interstellar Medium

Problem Set 7

Due **in class** Wednesday February 23, 2011

Readings: Chapter 12.1 to 12.2 of Tielens.

Homework Problems:

Population III Star Formation and Ionization of Globules

1. **Ionization of winds and accretion flows.** Derive equations (12.49) and (12.52) of Tielens.

2. **Application to Pop III star formation.** The models of Schaerer (2002 A & A 382, 28) predict that a $120M_{\odot}$ Pop III star emits $N_{Lyc} = 1.1 \times 10^{50}$ hydrogen-ionizing photons per second on its main sequence (duration 2.5 Myr). Since the stars are hot, massive, and nearly Eddington limited, $N_{Lyc} \propto M$ for $50 \leq M \leq 500M_{\odot}$, and the main-sequence lifetime is nearly independent of M. In CDM cosmology, the first Pop III stars form by the collapse of gas in small halos, cooled by H_2. The clumps from which the Pop III stars form have size $\sim$ 2 pc, and density $n_H \sim 10^3/\ \mathrm{cm}^3$ (cf Bromm et al 1999 ApJ 527, L5).

   a) Estimate the free-fall time of such a clump, and thus estimate the expected accretion rate dM/dt with which the last half of the star is accumulated. Also compare the free-fall time to the main sequence lifetime of the star.

   b) Estimate, in solar masses per year, the critical accretion rate for ionization (Tielens section 12.2.5) and the size of the HII region as a function of M around the forming Pop III star of mass M(t) in the range 50 to $500M_{\odot}$.

   c) Show that initially, the HII region is confined near the growing star, but that as its mass increases to a critical value, the HII region will encompass the entire clump from which the star is accreting.

   d) Compare the binding energy per unit mass of the clump with the thermal energy per unit mass in an HII region, and show that the clump will be destroyed when the HII region fills it, setting an upper limit to the mass of the Pop III star.

3. **Ionization of globules.** The cover of Tielens text shows an infrared image of the cometary globule IC 1396A, which is roughly 0.5 pc in radius, and is (in projection anyway) 4 pc from the O6.5 ionizing star HD 206267.

   a) CO measurements suggest the mass of the globule is $\sim$ 200 $M_{\odot}$, and the density $n_H \sim 2 \times 10^4/cm^3$. The density of the ionized gas is $\sim 600/cm^3$. Estimate the ionizing photon flux N required at the base of the flow to keep it ionized.

   b) Compare this flux to that expected from the ionizing star. What do you conclude?

   c) Estimate the mass loss rate from the globule, and its expected lifetime.