Outline

- Go over problem 4-9, 4-10, exam problem #4
- Star forming regions and molecular clouds
- Jeans instability
- Energy dissipation
- Star clusters
- Initial mass function

Interstellar Medium

- Interstellar medium (ISM) contains:
  - gas in molecular, atomic, ionized forms
  - dust
  - cosmic rays

- Molecular clouds are the densest region and where stars form
  - mass ~ $10^2 – 10^5$ solar masses
  - size ~ 10-100 parsecs
  - density ~ $10^2 – 10^4$ cm^{-3}
  - temperature ~ 10-100 K

Orion

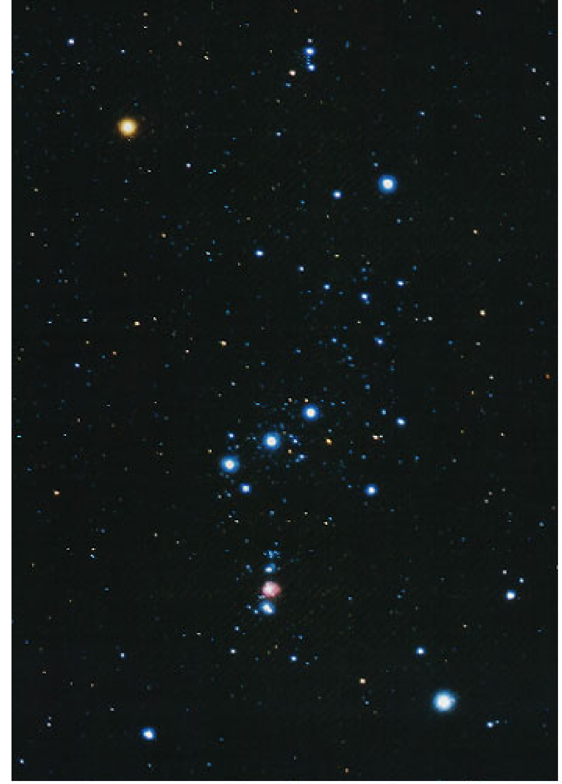
Top: optical image without (left) and with (right) map of CO molecular emission.

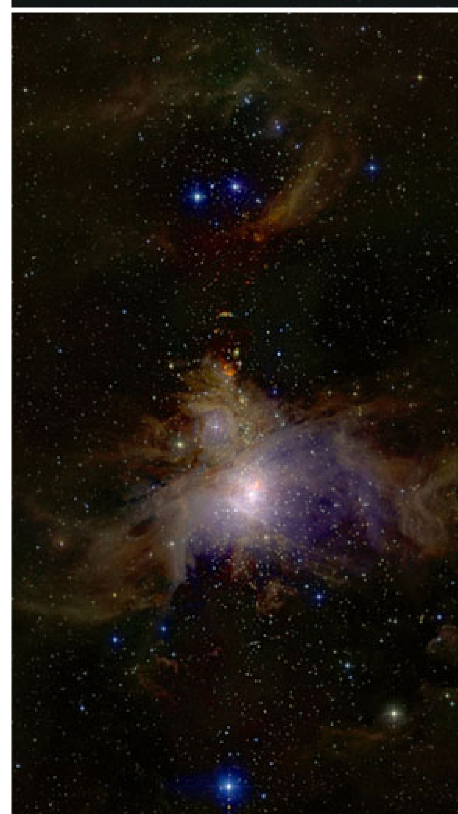
Bottom:

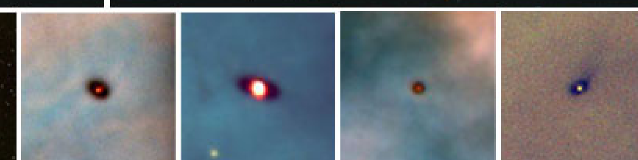
Left: Near-infrared image zoomed in on sword.

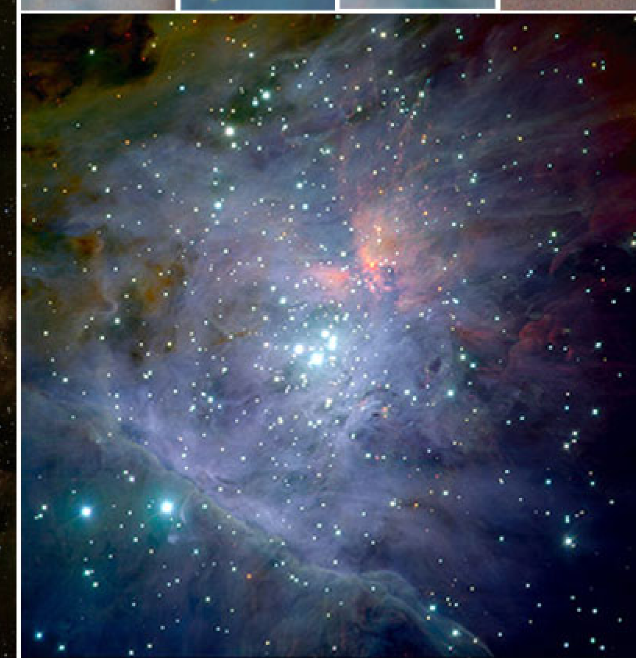
Right: Near-infrared image zoomed in on Trapezium cluster within sword.

Center: Protoplanetary disks around young stars.









Jeans Instability

- When is a gas cloud unstable to collapse?
- Consider a spherical cloud of constant (initial) density and temperature with particles of mean mass *m*. The cloud has a mass *M* and radius *r*.
- The cloud undergoes a radial compression *dr*.
- Gravitational energy:

$$E_g \approx -\frac{GM^2}{r} \rightarrow dE_g = -\frac{GM^2}{r^2}dr$$

- Volume decrease $dV = 4\pi r^2 dr$, causes thermal energy increase $dE_{\text{th}} = PdV$.
- Use equation of state for ideal gas

$$dE_{\text{th}} = nkT\,4\pi r^2 dr = \frac{M}{\bar{m}\frac{4}{3}\pi r^3} kT\,4\pi r^2 dr = 3\frac{M}{\bar{m}} kT \frac{dr}{r}$$

Jeans Instability

- Cloud is unstable to collapse if total energy decreases when compressed

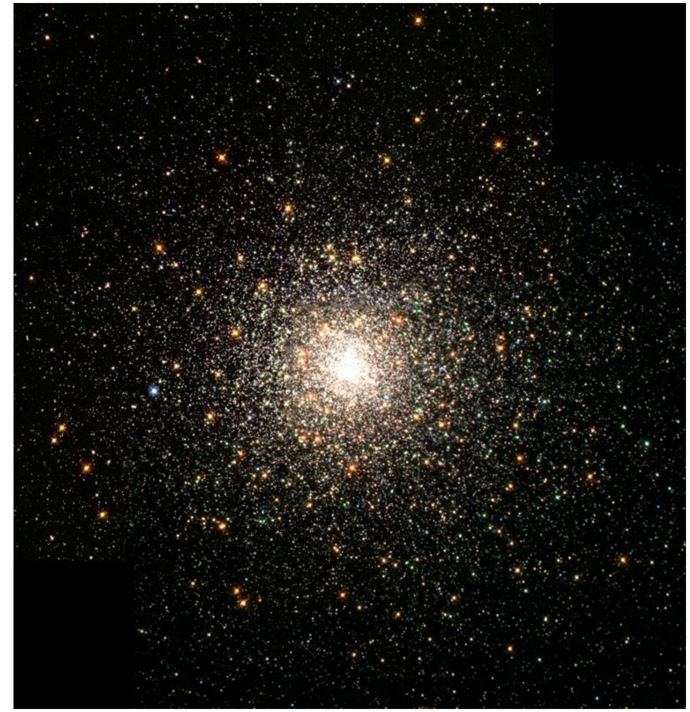
$$dE_g + dE_{\mathrm{th}} < 0 \rightarrow 3\frac{M}{\bar{m}}kT\frac{dr}{r} < \frac{GM^2}{r^2}dr$$

- Gives the Jeans mass, radius, and density

$$M > M_J = \frac{3kTr}{G\bar{m}} \qquad r < r_J = \frac{G\bar{m}M}{3kT} \qquad \rho > \rho_J = \frac{3}{4\pi M^2}\left(\frac{3kT}{G\bar{m}}\right)^3$$

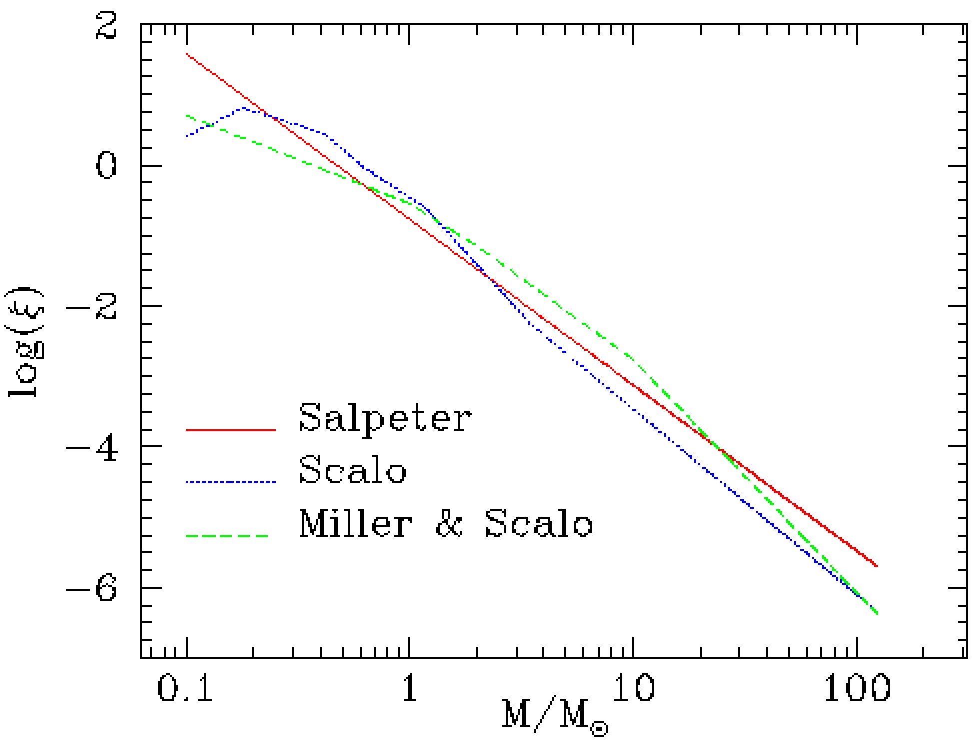
- Jeans density increases as clump mass decreases
  - collapse begins on large scales
  - sub-clumps start to independently collapse as density increases
  - leads to formation of star clusters

Star Clusters



- Pleiades (left) is an open star cluster at a distance of 136 pc with about 1000 stars and a total mass of 800 solar masses. Cluster is about 100 Myr old and is not gravitationally bound, so will dissipate in ~300 Myr.
- M80 (right) is globular cluster at a distance of 8.7kpc with a total mass of about 5×10^5 solar masses. Age is ~ 13 Gyr. Cluster is gravitationally bound.

Initial Mass Function



- Clusters form stars of a wide range of masses.
- The distribution is the "initial mass function" (IMF) and gives the relative probability of forming stars of different masses.
- Salpeter mass function is powerlaw with exponent of -2.35.
- More recent work shows turn over at sub-solar masses.

Cloud Collapse

- For 1000 solar mass cloud at 20 K ($m \sim 2\ m_H$ since gas is mostly H_2)
  - number density ~ 1 cm^{-3}
  - free-fall time scale ~ $(3\pi/32G\rho)^{1/2}$ ~ 40,000,000 years
- Anyone see a problem with this?

- Clouds that appear to be long lived have $n \sim 10^2 - 10^4\ cm^{-3}$
- Additional supported from supersonic turbulent motions of the gas and/or magnetic fields.
  - $u_K \sim nkT \sim 3\times10^{-15}$ erg/cm^3 for 1 cm^{-3}
  - $u_B \sim B^2/8\pi \sim 3\times10^{-13}$ erg/cm^3 for B ~ 1 μG typical in ISM
- Need $n > 10^2\ cm^{-3}$ to overcome magnetic field support.
- Often star formation is triggered by an external event that creates density perturbations.

Cloud Collapse

- To collapse, needs means to dissipate energy:
  - Radiation - depends on temperature, chemical composition, optical depth of core, surroundings of core.
  - Dissociation of H_2 gives 4.5 eV/molecule
  - Ionization of H gives 13.6 eV per molecule

- Process is too complex for accurate analytical calculations
  - need to do large-scale magnetohydrodynamic (MHD) simulations

- Collapse of 1 solar mass core requires 10^7-10^8 years.

Homework

- For next class:
  - Problem 5-1
  - Exam problem #5