Quick notes on
Star Formation

Zach Meisel
Ohio University - ASTR4201 - Fall 2020

The Jeans Criterion (which is surprisingly not a fashion guide)

- Star formation results when a massive cloud of gas in space collapses. Whether or not collapse will occur is given by the Jeans Criterion.
- A conglomeration of gas will be in virial equilibrium when $2\langle K\rangle = -\langle \Omega \rangle$
  - $\langle K\rangle = \frac{3}{2} N k_B T = \frac{3}{2}\frac{M}{\mu m_H} k_B T$
  - $d\Omega = -\frac{Gm}{r} dm$ & for constant density $r = R\left(\frac{m}{M}\right)^{1/3}$, so $d\Omega = -\frac{GM^{1/3} m^{2/3}}{R} dm$,

    and $\langle \Omega \rangle = -\int_0^M \frac{GM^{\frac{1}{3}} m^{\frac{2}{3}}}{R} dm = -\frac{3}{5}\frac{GM^2}{R}$
- For collapse, the potential needs to overpower the kinetic: $-\langle \Omega \rangle > 2\langle K \rangle$
  - $\frac{3}{5}\frac{GM^2}{R} > 3\frac{M}{\mu m_H} k_B T \rightarrow \quad M > M_J \equiv \frac{5k_B}{\mu m_H G} TR = \sqrt{\frac{375 k_B^3 T^3}{4\pi G^3 n \mu^4 m_H^4}}$ since $\rho = \frac{M}{\frac{4}{3}\pi R^3} = n\mu m_H$
  - Rounding: $M_J \approx 100\sqrt{\frac{T^3}{\mu^4 n}} M_\odot$ [Some parts of Galactic disk, H_2 w/ ~10K, ~10^3cm^{-3}: M_J~25 $M_\odot$]

    Clouds fragment, forming smaller stars.
    - The early universe was hotter, so first stars must have been more massive
    - From the virial theorem, clouds heat-up when they contract. Cooling must happen for stars to form.

Cooling of Clouds

- From the virial theorem, clouds heat-up when they contract. Cooling must happen for stars to form.
- The mechanism is kinetic energy converting to radiation
  - Molecules (usually CO):
    Collisions result in an excitation [rotational, vibrational, electronic], followed by a de-excitation. Some fraction of those photons escape the cloud, cooling it.
  - Dust (few molecules to several microns):
    Collisions result in a dust grain getting heated, which then radiates thermally. This is only relevant at high enough densities.

Post-cloud, Pre-star: Hyashi Track Timescale

- Once H_2 is dissociated, cooling is inefficient and the collapse is no longer free-fall.
  (Recall, free-fall time is the dynamical time: $t_{ff} \sim \frac{1}{\sqrt{G\bar{\rho}}}$ ~1 hour for the sun)
  The object is now a proto-star, not yet fusing Hydrogen in the core.
- Energy is radiated away on the Kelvin-Helmholtz timescale:
  - $\tau_{KH} = \frac{-E}{L} \sim \frac{GM^2}{RL}$ …for the sun, ~30M years.
- Hand-wavy explanation for motion on HR-diagram:
  - We see the "surface", where the surface is the last place a photon scatters [the optical depth]
  - If a really large object expands a bit, R is increased, and T at what was the "surface" goes down.
  - But, the region near original "surface" also gets thinner, and we see deeper into the protostar (the new "surface"), where T is hotter than the outer layer.
    Thus, T_{eff} is ~constant and the Hayashi Track is ~vertical