# Barbara Ryden: Making Stars

# Star timeline

| | | |
|---|---|---|
| ★☆☆ | 1. dark nebula | collapsing and cooling |
| ★★☆ | 2. protostar | collapsing and heating |
| ★★★ | 3. star | nuclear fusion |

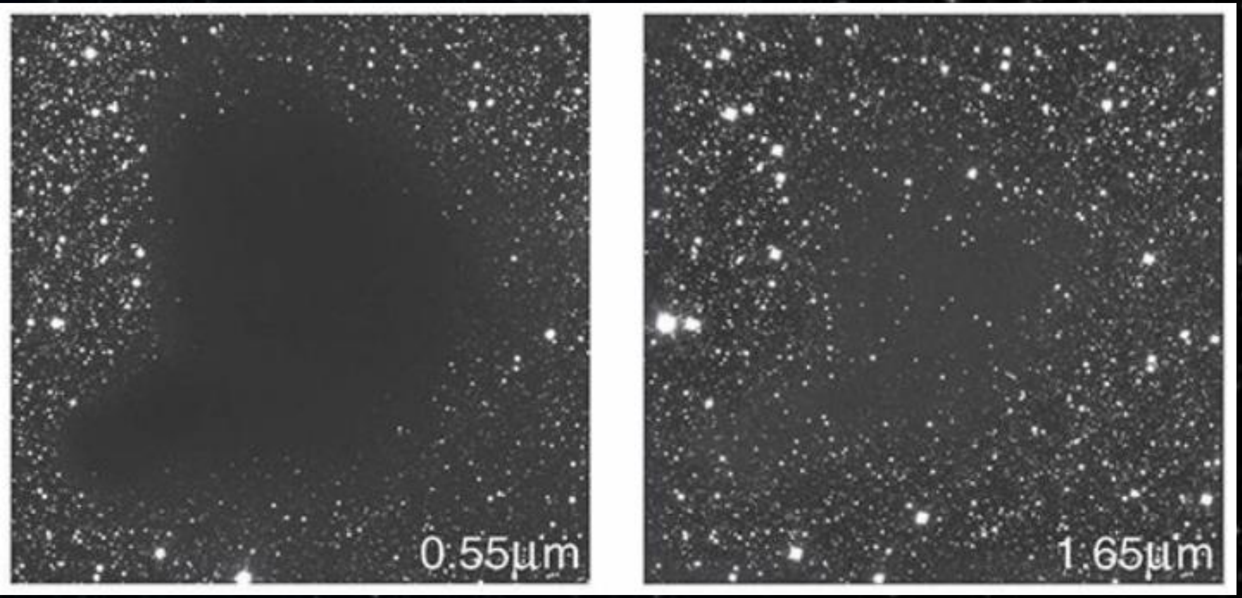
# 1. Dark nebula

- cold (20 K) & dense
- primarily Hydrogen
- some Oxygen, Carbon
- $M_J \sim \sqrt{\frac{T^3}{\rho}}$
- cooling through fir luminosity

$$L_{iso} \approx \frac{2E}{t_{dyn}} \approx 0.015\, L_{solar} \left(\frac{M}{15M_{solar}}\right) \sqrt{\frac{\rho}{10^{-15} kgm^{-3}}}$$

# 1. Dark nebula – luminosity correction

- different opacity at different wavelengths
  - 100 nm dust grains




- $L = f_e L_{bb} = 4\pi R^2 f_e \sigma_{sb} T^4$

# 1. Dark nebula – hierarchical fragmentation

- $M_J \sim \sqrt{\frac{T^3}{\rho}}$
  - T = const, ρ increases
    - $M_J$ decreases
    - 15 $M_{solar}$ object splits in 2 7.5 $M_{solar}$ fragments when $\rho \rightarrow 4\rho$
- power law distribution
  - 1% failure rate

# 1. Dark nebula – hierarchical fragmentation

- 100 objects
  - 1 collapses -> 1 star M
  - 99 split -> 198 fragments $\frac{M}{2}$
    - 2 collapse -> 2 stars $\frac{M}{2}$
    - 196 split -> 392 fragments $\frac{M}{4}$
      - …

- $2^n$ stars with mass $\frac{1}{2^n}M$ and $2^{2n}\rho$

# 1. Dark nebula – stop fragmentation

- $L_{iso}$ equal for every fragment
  - $M \sim \frac{1}{2^n}$ $and$ $\sqrt{\rho} \sim 2^n$
- smaller fragments have lower actual $L$
  - $L \sim R^2$
  - at some point, luminosity cooling is not enough -> $\frac{L_{frag}}{L_{frag}^{iso}} < 1$
  - $\frac{L_{frag}}{L_{frag}^{iso}} \approx 73\,000\ f_e \frac{1}{2^{2n}}$
  - fragmentation stops, T rises -> $M_J$ rises

=> protostar

# 2. Protostar

- contracting -> density inreases
- not nough luminosity cooling -> temperature increases

- if $M > 0.08\ M_{solar}$

=> star

# 3. star

- nuclear fusion

- early stars: only hydrogen -> low in dust
  - low $f_e$ -> no sufficient cooling
    - no/ little fragmentation
    - massive stars $(\sim M_J)$

- other factors
  - magnetic field
  - turbulence
  - angular momentum increases as object contracts
    - protostar (lower angular momentum) + protoplanetary disk (->planets)

# Jeans Mass

- $t_{dyn} = \frac{1}{\sqrt{4\pi G\rho}} \approx 1.1 * 10^{12}s\sqrt{\left(\frac{10^{15}m^3\rho}{kg}\right)}$
- $c_s = \sqrt{\frac{kT}{\mu}} \approx 270\frac{m}{s}\sqrt{\frac{T}{20K}}$
  - mean molecular mass $\mu = 2.3\, m_p$
- $\lambda_J = 2\pi c_s t_{dyn} \approx 1.9 * 10^{15}m\sqrt{10^{15}\rho\frac{m^3}{kg}\frac{T}{20K}}$
- $M_J = \frac{4\pi}{3}\rho\lambda_J^3 \approx 15\, M_{solar}\sqrt{\frac{10^{(-15)}kgm^{-3}}{\rho}}\sqrt{\frac{T}{20K}}^3$

# Isothermal Luminosity

- $L_{iso} = -\frac{dE}{dt}$
- $E = \frac{3}{2} NkT$
- $\frac{dE}{dt} = -P\frac{V}{dt} = -\frac{NkT}{V}\frac{V}{dt} \sim -3NkT\left(\frac{1}{R}\frac{dR}{dt}\right) = -2E\left(\frac{1}{R}\frac{dR}{dt}\right)$
- freely collapsing core: $\frac{dR}{dt} \approx \frac{R}{t_{dyn}}$

$$\boxed{L_{iso} \approx \frac{2E}{t_{dyn}} \approx 0.015\, L_{solar} \left(\frac{M}{15M_{solar}}\right)\sqrt{\frac{\rho}{10^{-15}kgm^{-3}}}}$$