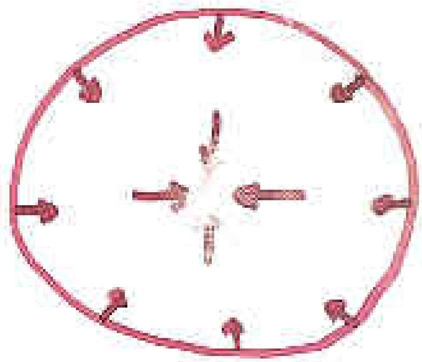
Collapse of a proto-star

Source of energy : gravity only.

- Gravitationally unstable cloud
  Cool, large, low luminosity
  Dust enshrouded, need IR



when collapses, some p.e. heats cloud
some radiated away (optically thin)
(some cooling so collapse continues)

- Inner region collapses more rapidy, pre-stellar core forms

Timescale for collapse

Think of the early stages of collapse of the gas cloud

Can ignore pressure at this stage because density is so low.

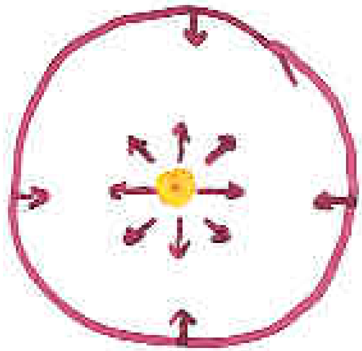
Even if cloud starts with roughly uniform density, this changes fast

$\boxed{Q}$ Why?

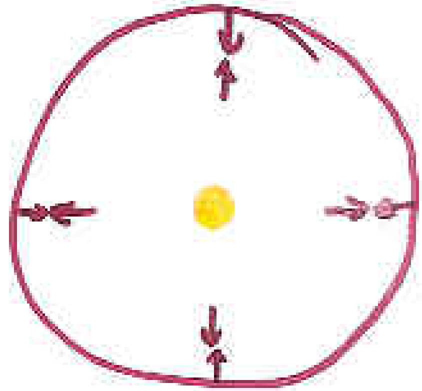
- Particles close to the center collapse inward ~~faster~~ first (less distance to travel) and density increases faster there
- as it becomes denser, gravitational forces are larger so collapse time shorter

...... etc

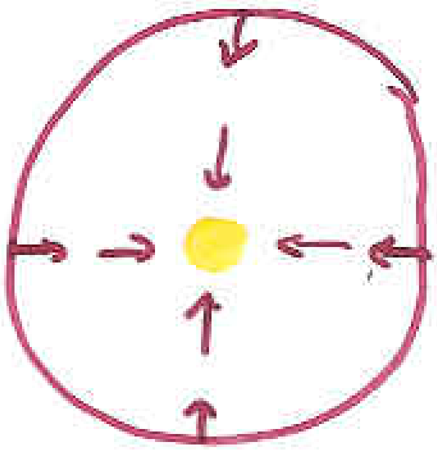
- core 'bounce' : pressure builds up & core expands



- interaction between infalling & expanding material
bounce stops, collapse proceeds



- core density increases until photons can't escape (optically thick)



Free-fall time :

little m

Consider particle, mass m, @ edge of cloud, mass M, radius R, initial density ρ_0.

Particle falls straight to center

Follows ellyptical orbit with $e = 1$

and semi-major axis $a = R/2$

$$M = \frac{4}{3}\pi R^3 \rho_0 = \frac{32}{3}\pi a^3 \rho_0$$

Kepler's third law :

$$\frac{P^2}{a^3} = \frac{4\pi^2}{GM}$$

$$P = \left(\frac{3\pi}{8G\rho_0}\right)^{1/2}$$

$$\boxed{\text{Free-fall time} \propto \rho^{-1/2}}$$

For a giant molecular cloud

$$\rho \simeq 10^{-15}\ \mathrm{kg/m^3}$$

Free-fall time is $\sim 10^5$ years.

Virial theorem

For a system in equilibrium,

$$2\,E_{kinetic} = -U$$

potential energy

So if $E_{kinetic} + U = 0$

$$\text{Total energy} = \frac{U}{2}$$

Implications of virial theorem

E (total energy) $= \frac{p.e.}{2}$

So as cloud collapses, p.e decreases and E decreases

$\Rightarrow$ some of energy of cloud is radiated away

Since $k.e = -\frac{p.e.}{2}$, half of energy gained is lost, half goes to increasing kinetic energy (both infall & random motions)

Example on luminosity of protostar:

Virial Theorem says that amount of energy radiated is (current p.e)/2

Over 100 years, collapse of $1 M_\odot$ to $500 R_\odot$ gives $170 L_\odot$

The other half is available for heating cloud, speeding up collapse, etc.

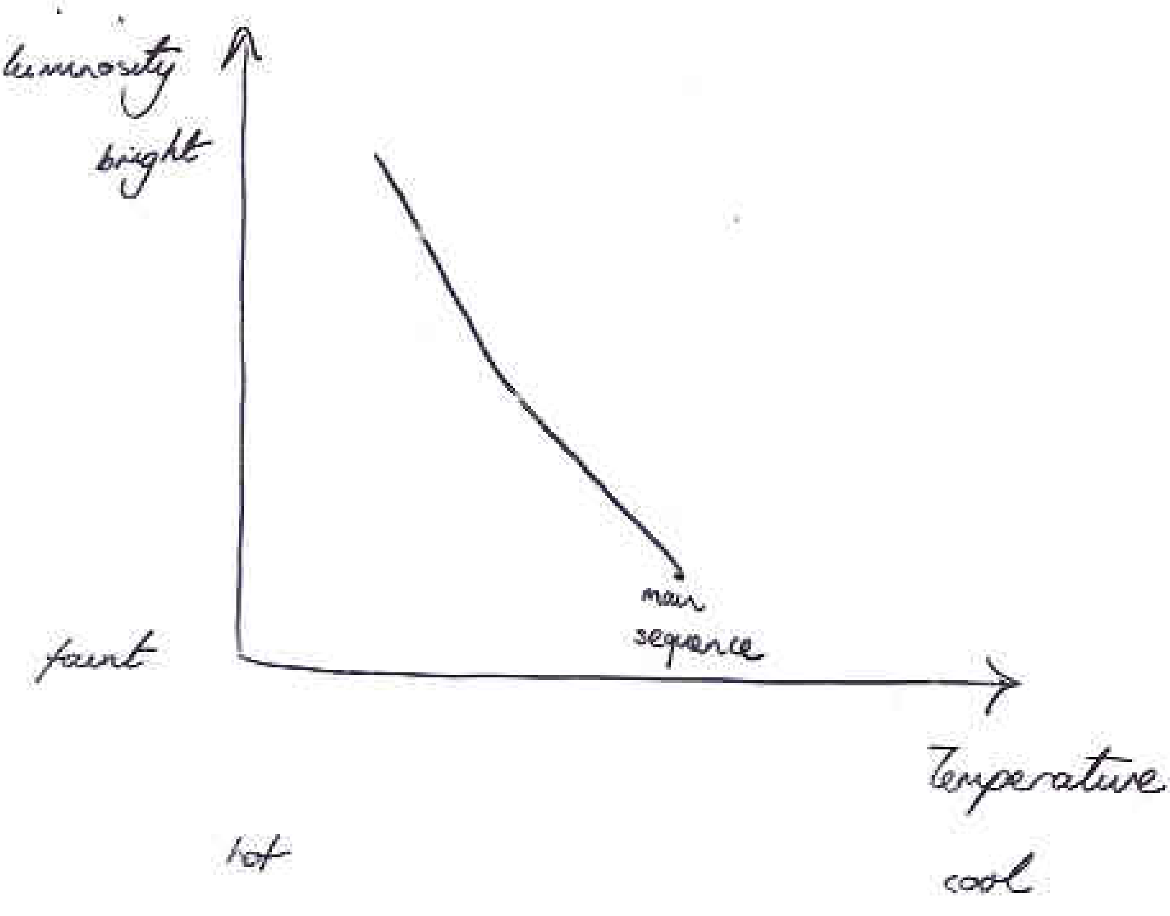
(note that a similar calculation can be made for the heating of a planet by accretion of planetesimals)

* Balance between heating and energy loss means that star formation is possible *

- Theoretical calculations of gravitational collapse of protostars give evolutionary tracks which can be compared with observations of "young stellar objects"

Question

As a dense molecular cloud starts the collapse that will lead to the birth of a star, where should it be plotted on the H-R diagram?



• another core bounce

temperature ↑ and star ends up on HR diag

completeley convective now

all stars, whatever mass, end up at

about the same temperature now

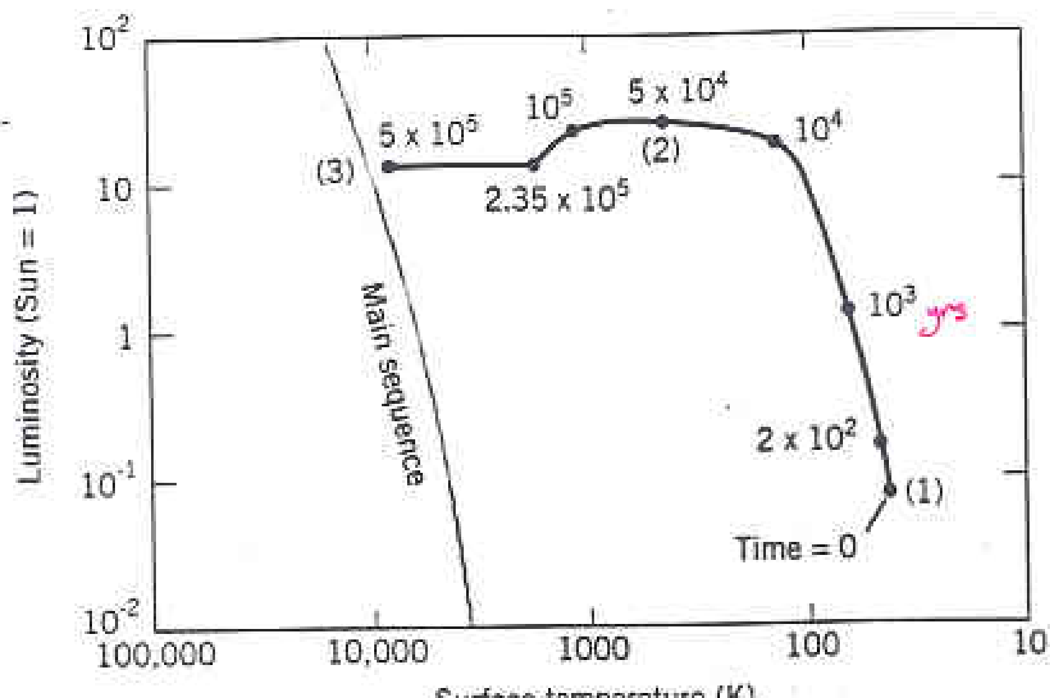


FIGURE 17–6. The path in the H-R diagram of a protostar during dynamical collapse.

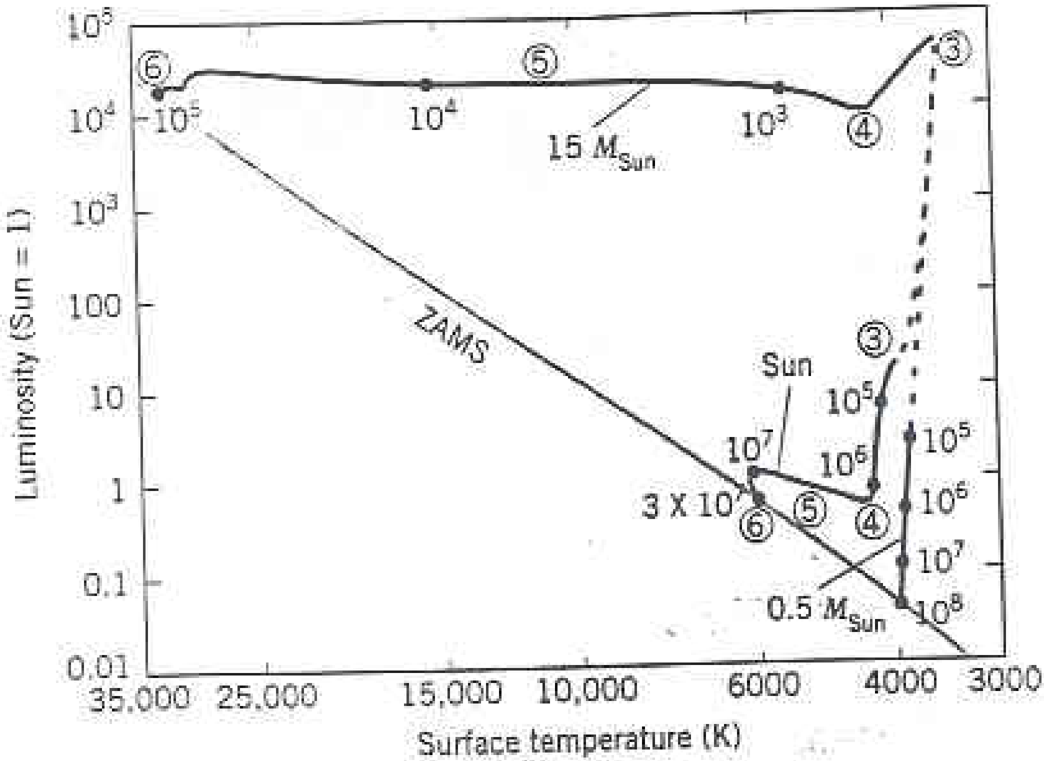


FIGURE 17–7. The path in the H-R diagram of protostars of different masses.

- completely convective ⇒ cooling keeps up with collapse

optically thick, no radiative cooling

"Hyashi track" Temperature almost constant

collapsing ⇒ $L \downarrow$ (cf $L \propto 4\pi R^2$)

- radiation takes over, surface temp $\uparrow$
  still collapsing but T balances R &
  L stays $\sim$ constant

- core temperature reaches $\sim 10^7$ K
  fusion reactions start
  star is on main sequence where it will spend most of its life

STAR FORMATION

The story so far ....

- importance of understanding how stars form
  - galaxy formation
  - cosmology

- Initial conditions : giant molecular cloud ($\sim 10^6 M_\odot$) of gas & dust
  - low density ($10^2 - 10^3$ H_2 molecules / cm^3)
  - cool ($\sim 10K$)

- Conditions for gravitational collapse
  - gravity vs pressure (ignore mag fields for the moment)
  - (cf hydrostatic equilibrium)

- Conditions for sphere to be gravitationally bound

$$k.e. + p.e. \leq 0$$

$$\frac{3}{2}\frac{M}{m}kT - \frac{3}{5}G\frac{M^2}{R} \leq 0$$

gives Jeans length $R_J \simeq \sqrt{\dfrac{kT}{Gm\rho}}$

Jeans mass $M_J \simeq 4\left(\dfrac{kT}{Gm}\right)^{3/2}\left(\dfrac{1}{\rho}\right)^{1/2}$

- Timescale for collapse :

free fall time $t_{ff} \simeq \dfrac{1}{\sqrt{G\rho}}$

- Virial theorem : in equilibrium

$$k.e. = -\frac{p.e.}{2}$$