THE INTERSTELLAR MEDIUM

"Omega" Nebula by
K.M. Merrill, SQIID

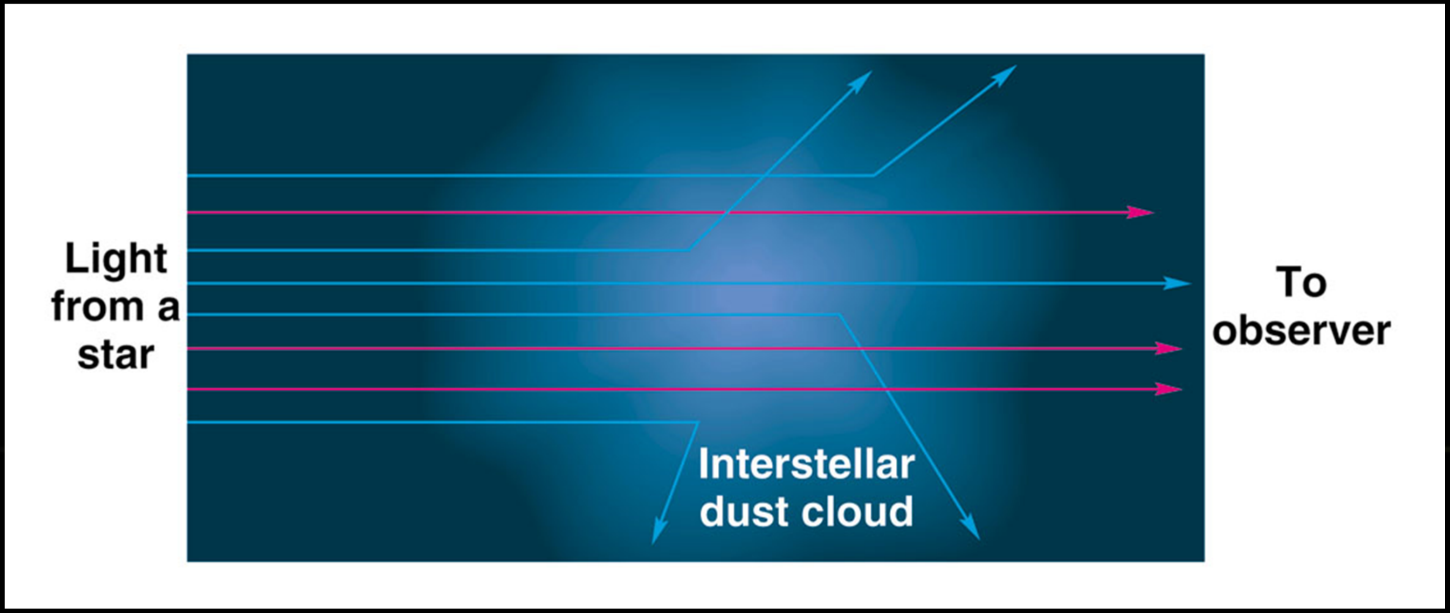
- An IR view of dust clouds
- In particular, light from polycyclic aromatic hydrocarbons (PAH's)
  - Little bit of carbon out there, forms hydrocarbons like car exhaust
  - Associated with dust
  - Easy to see

WHAT ARE DUST CLOUDS?

- Mostly hydrogen, helium (*of course!*)
- Tiny amount of carbon, nitrogen, oxygen etc.
  - Bonds with hydrogen
  - Forms molecules
  - Can accumulate into "dust"
- Cold – few tens of K!
- Big – few parsecs to tens of parsecs across
- Comparatively dense – maybe a million molecules per cm^3

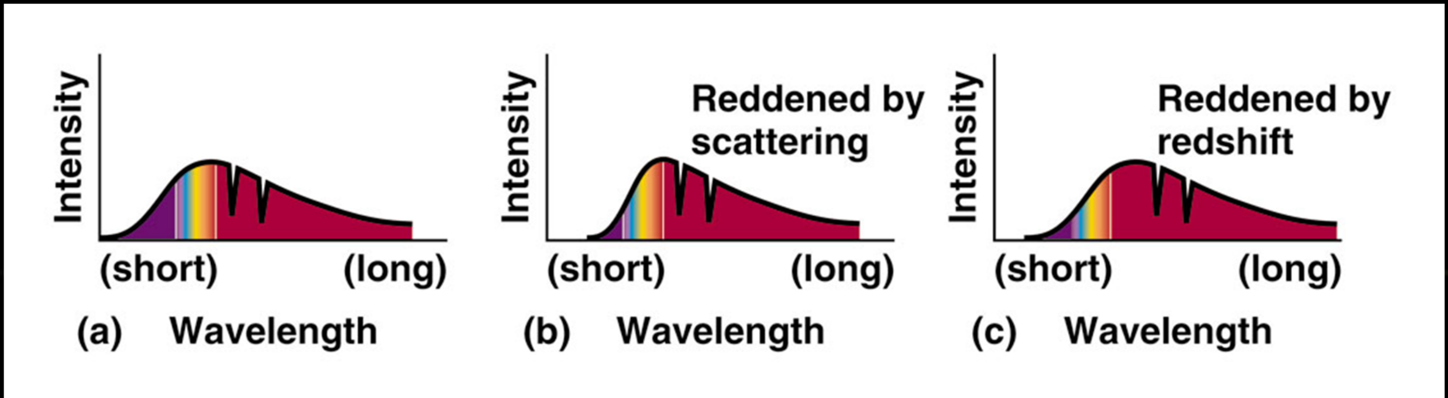
REDDENING

- Not all dust is in great globs
- A little bit most places
- Reddens starlight passing through
  - Same idea as a red sunset



DUST REDDENING VS. REDSHIFT

- Reddening by dust removes blue light and leaves red
  - Does not change the spectra, just the brightness of the continuum
- Doppler red shifts move everything to the red



REFLECTION NEBULAE

Photo by David Malin
with UKS

- Dust visible by the blue light which scatters off it
- Deep exposure of Pleiades good example
  - Bright blue stars provide plenty of blue light to scatter

MORE REFLECTION NEBULAE

NGC 1977

"Witch Head" +
M78

"Trifid"

NGC 2264 +
"Flaming Star"

"Iris" +
Merope

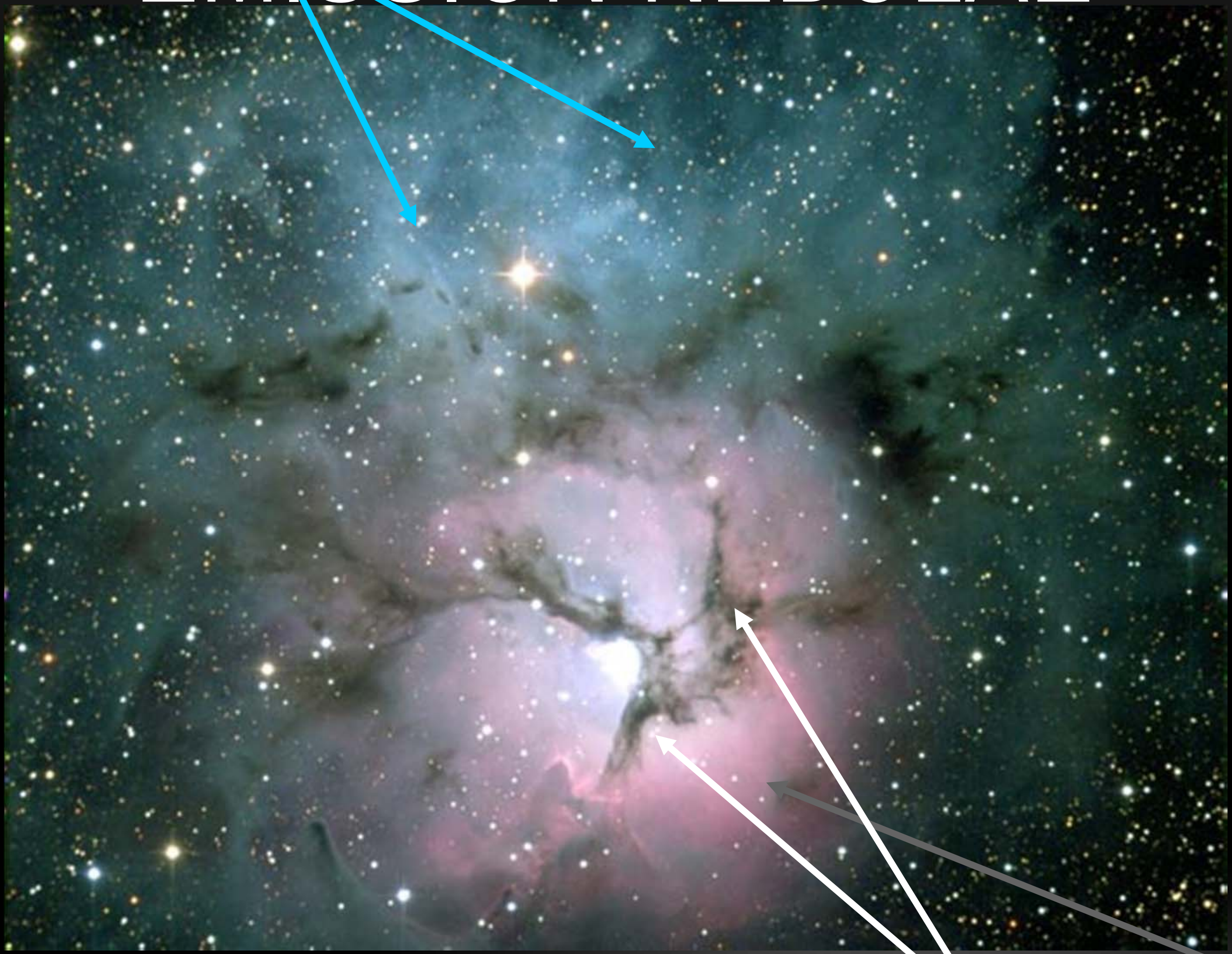
NGC 2023
(*near "Horsehead*")

Photos by
Robert Gendler

INTERSTELLAR GAS

- Stuff is mostly H, He
  - Dust is hydrocarbons, nitrates, etc.
  - only ~10% of the mass
- Rest is just H, He gas!
  - Cold gas (“HI”) mostly invisible
  - 21 cm radio emission lets us map the galaxy, however
  - Absorption lines from cold gas between us and stars are seen in stellar spectra
  - Hot gas (“HII”) glows like a neon sign

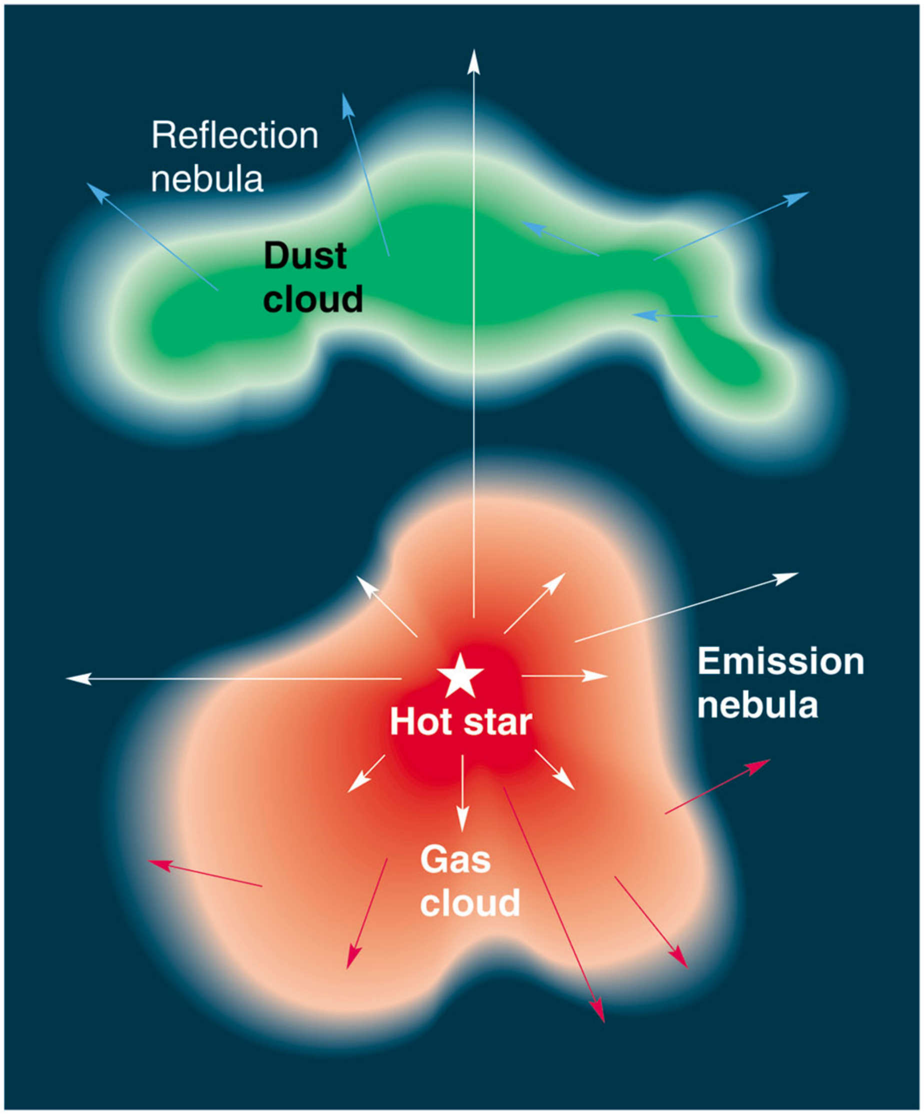
EMISSION NEBULAE



- UV light from nearby hot bright star excites gas
- Electrons fall from excited energy level to lower ones, emit light
  - Like a neon sign

Photo of M20 (“Trifid” Nebula)
By Todd Boroson, NOAO

SCHEMATIC OF THE "TRIFID" NEBULA



- Hot star excites nearby gas cloud
  - Causes the H to fluoresce
- Separate dust cloud reflects blue light from main star plus others

EMISSION NEBULAE

- Temperatures of ~ 10,000 K
- Total mass 100 to 10,000 solar masses
- But still mostly empty space – a few thousand molecules per cm^3 at most
  - In this room, $2x10^{19}$ molecules/cm^3
- Powered by central hot star(s)

THE "ESKIMO" NEBULA

- A "planetary nebula"
  - Named because through early scopes they looked planet-ish
  - Central star is a white dwarf – hot, UV emitter, not very bright
  - Gas is what used to be the atmosphere of the star which became the white dwarf
- Also an emission nebula

HST photo by Andrew Fruchter

HOW MUCH STUFF?

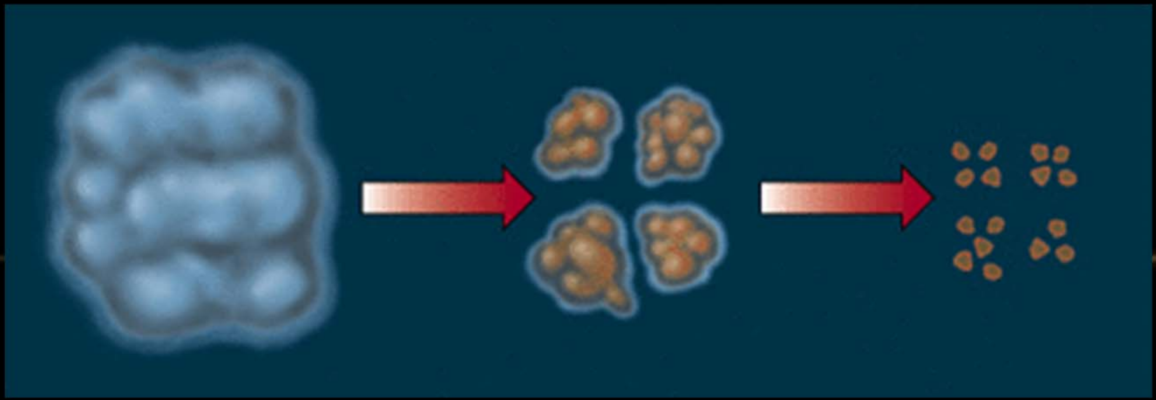
- An inventory of the Sun's neighborhood (where we can get a pretty good look) shows:
  - Interstellar dust and gas makes up 15-30% of the mass
  - Most of the rest is stars
  - Not counting so-called "dark matter" which we'll talk about in the cosmology section

GIANT MOLECULAR CLOUDS

- Very large - ~50 parsecs
- Cold - ~20 K
- Still mostly H, He, but cold enough for molecules and dust to form
  - ~200 molecules/cm^3
- Very massive
  - Up to a million solar masses

GRAVITATIONAL CONTRACTION

- All those particles attract each other
  - Get closer
- Gravitational force is stronger the closer you are ($1/r^2$ again), so closer stuff gets even closer yet
- Cloud fragments into smaller, denser “Bok Globules”

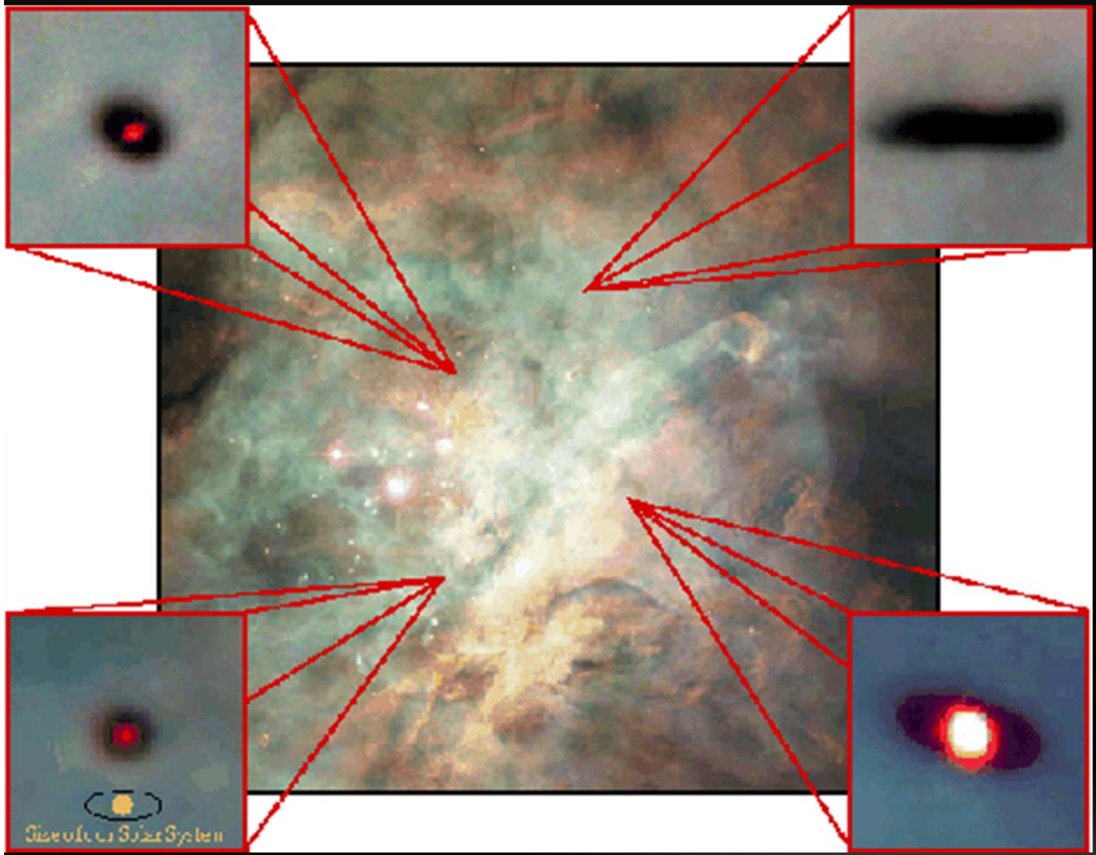


PROTOSTARS

Proplyds (infant solar systems) forming in Orion nebula (HST image)

- The globs get smaller yet
  - Angular momentum conservation spins them up - solar system formation
- Compression heats them
  - Fusion stars in the core
- And “solar systems” form (as we talked about in Ch.6)
  - So all that stuff applies here too

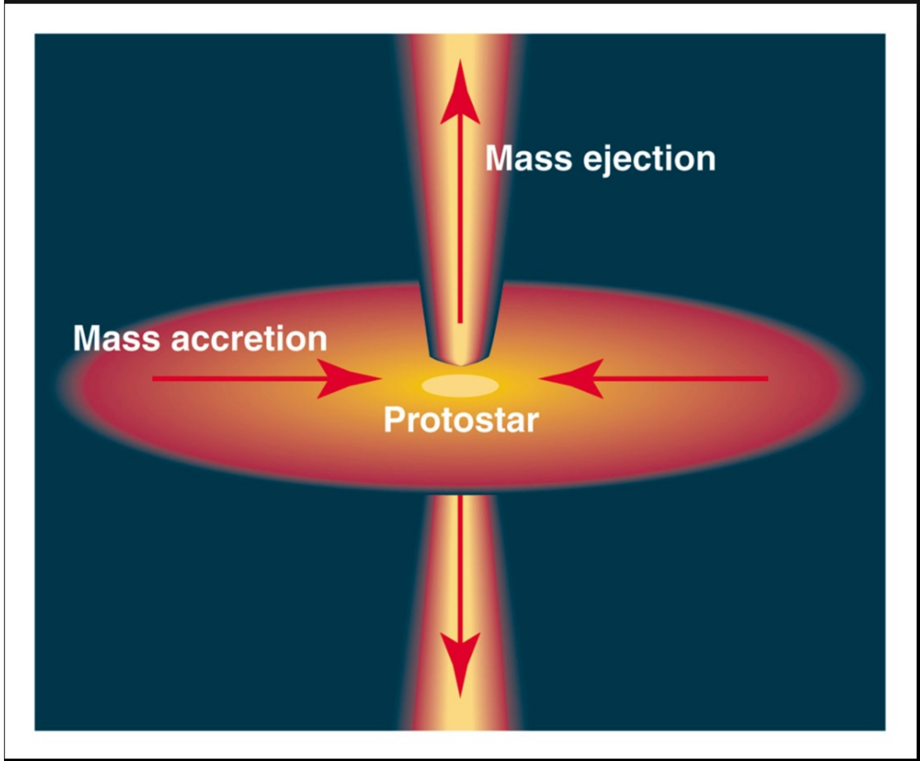
COCOON NEBULAE



- There is still a cloud of gas and dust around the protostar
  - Called a cocoon nebula
- The new starshine heats this up, we see them in the IR

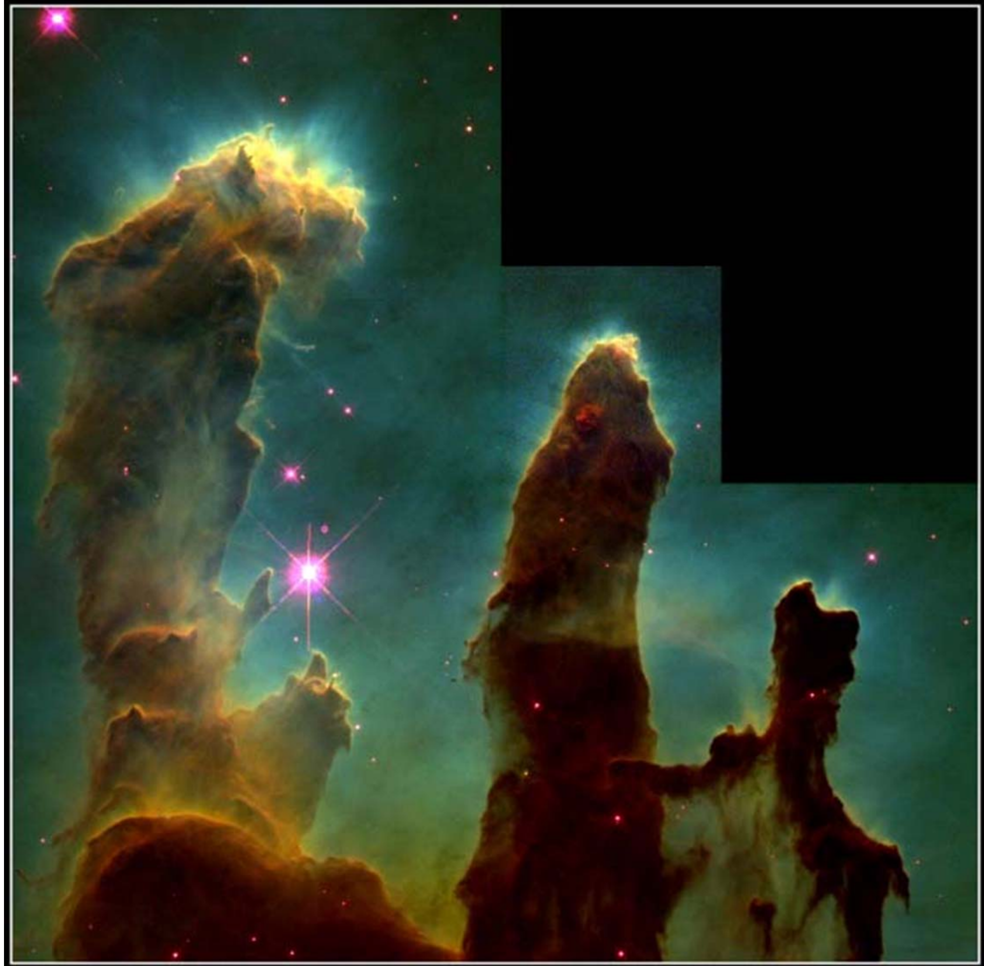
Protostars in Orion

BUSTING OUT



- The new star's "stellar wind" blows away the dust and gas
  - Except what has already stuck together as planets
- "Bipolar outflow" makes jets
  - Carry away excess angular momentum

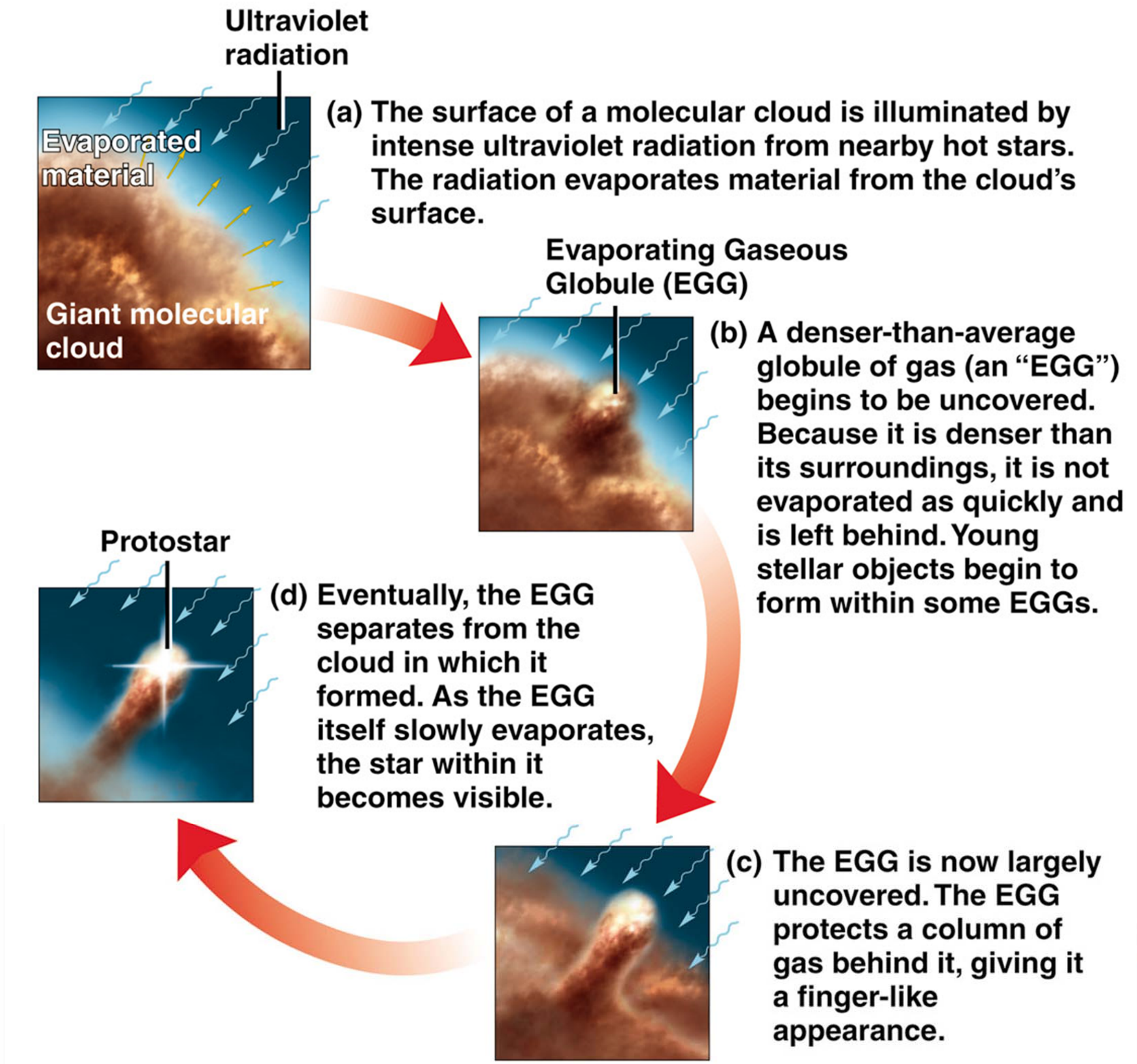
PILLARS?


Gaseous Pillars · M16 HST · WFPC2
PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

- Famous picture in "Eagle" Nebula
- "Pillars" are part of a Giant Molecular Cloud
- Stars nearby have already formed
  - Hot, bright, strong UV radiation and stellar wind

EGGS

- An ringside seat for star formation



ALL SORTS GOING ON IN ORION

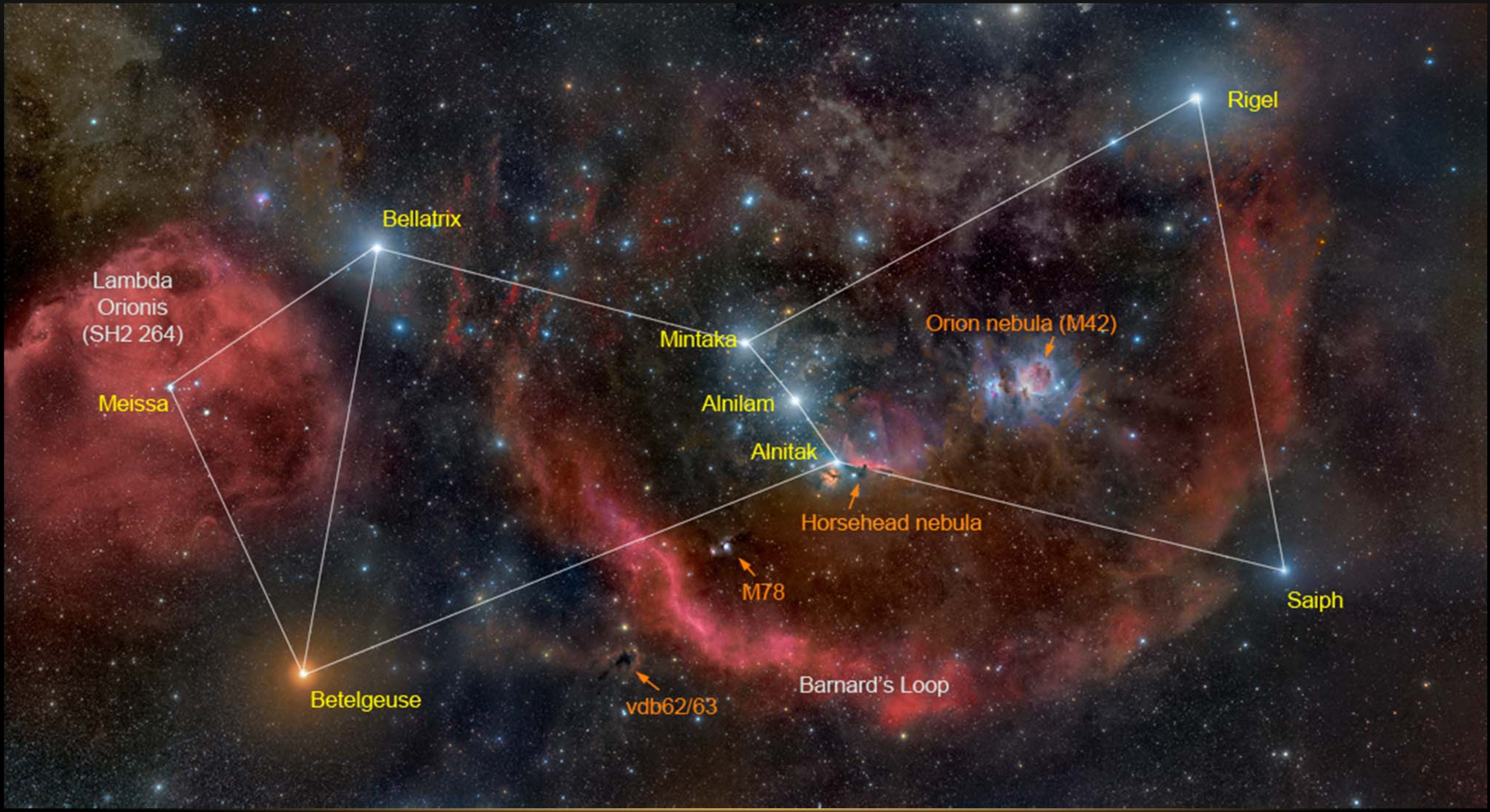


Image by Rogelio Bernal Andreo (DeepSkyColors.com)

WE SEE MANY CLOUDS…

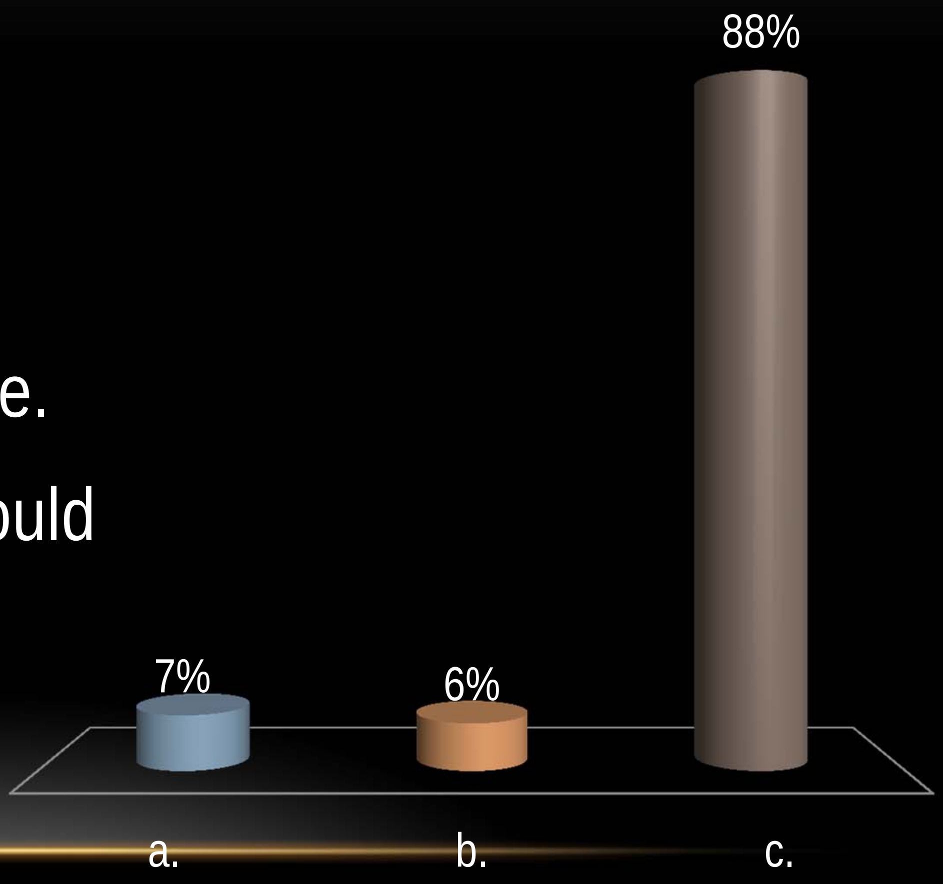
- We see a lot of these clouds, and they are not all turning into stars
  - So they must be stable: *ie*, resistant to gravity’s pull
  - How?

WHAT WOULD HAPPEN TO A CONTRACTING CLOUD FRAGMENT IF IT WERE NOT ABLE TO RADIATE AWAY ITS THERMAL ENERGY?

a. It would continue contracting, but its temperature would not change.

b. Its mass would increase.

c. Its internal pressure would increase. ✓



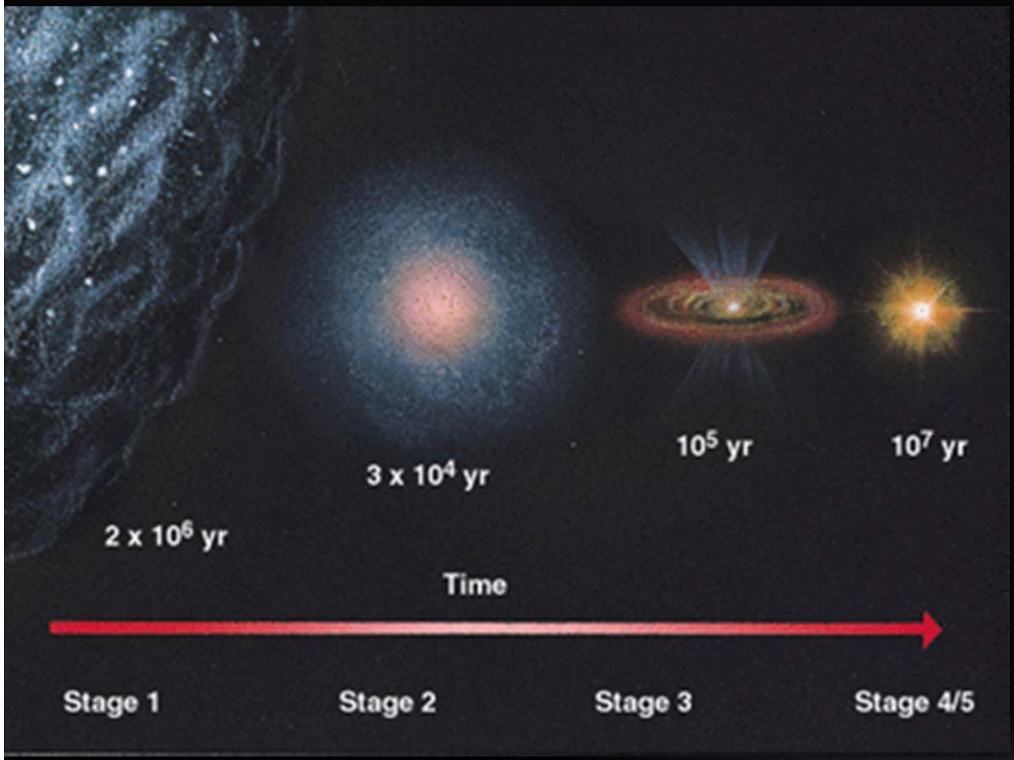
STABLE CLOUDS

- Pressure in cloud can balance out gravity's force and stop contraction
  - Same forces as work inside a star to hold it up (*only much less dense and hot in a cloud*!)
- If the cloud can radiate energy and cool off, pressure drops, can contract more

WHAT STARTS THINGS OFF?

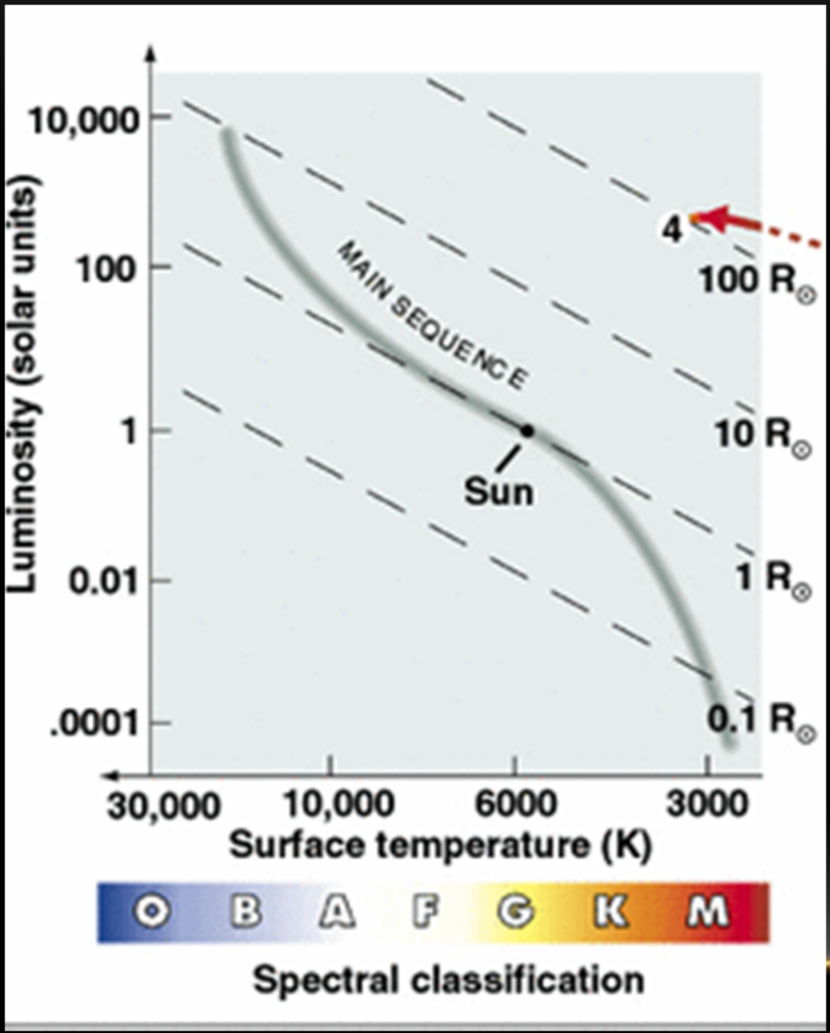
- If stable, Giant Molecular Clouds would need a kick to start collapsing
  - Nearby young stars with strong stellar wind
  - Old stars blowing off their outer atmospheres at the ends of their lives
  - Supernovae (exploding stars)
  - Colliding GMC's
  - Large-scale galactic spiral density waves

HOW LONG DOES IT TAKE?



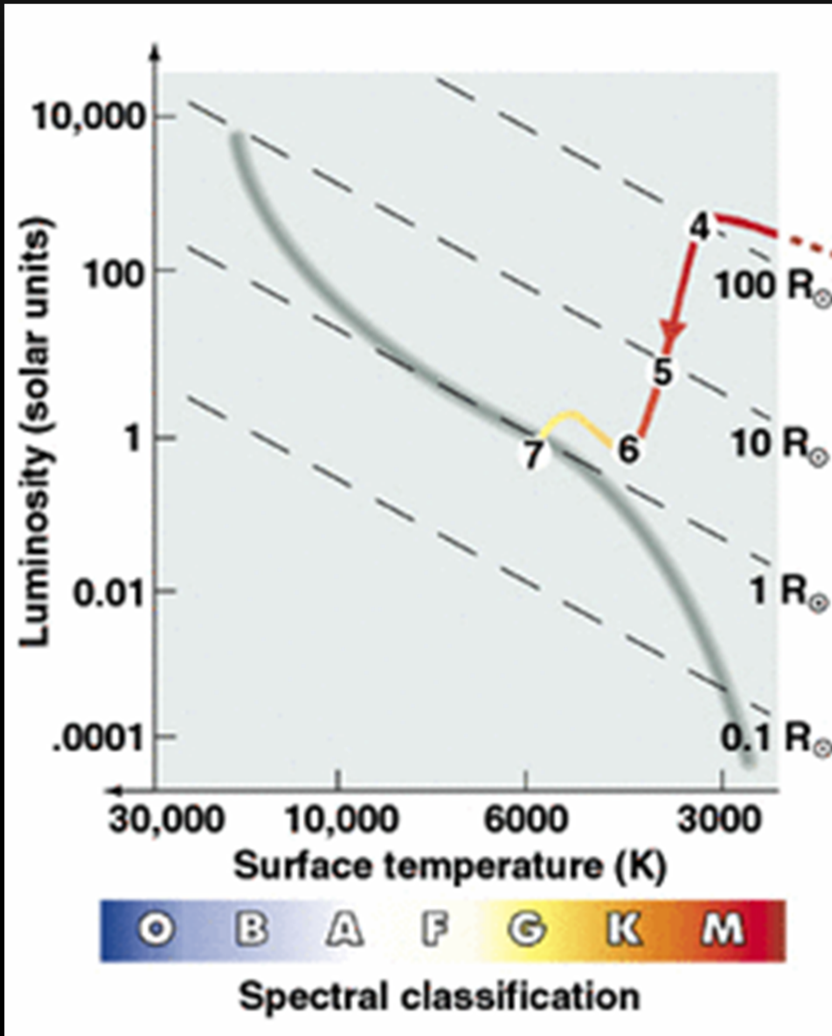
- Initial collapse could take a while on its own, faster if kicked
- Millions to hundreds of millions of years in total
  - 30 My for a sun-like star
  - More massive stars form much more rapidly, since more mass means more gravity

LUMINOSITY VS. TEMPERATURE



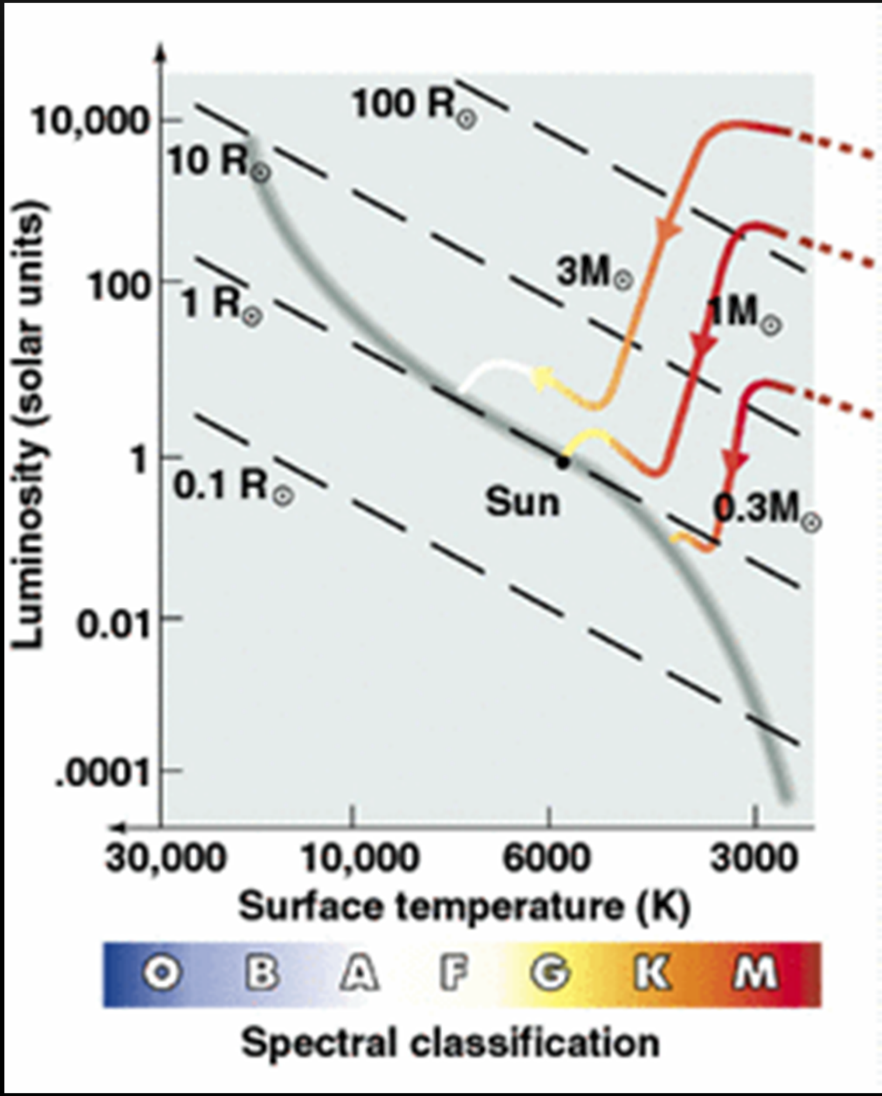
- Just before the protostar's fusion starts, it is already 1000x as Luminous as the sun (infalling stuff from the disk)
- But not very hot compared to a normal star
- Put it on the HR diagram

THE EVOLUTIONARY TRACK



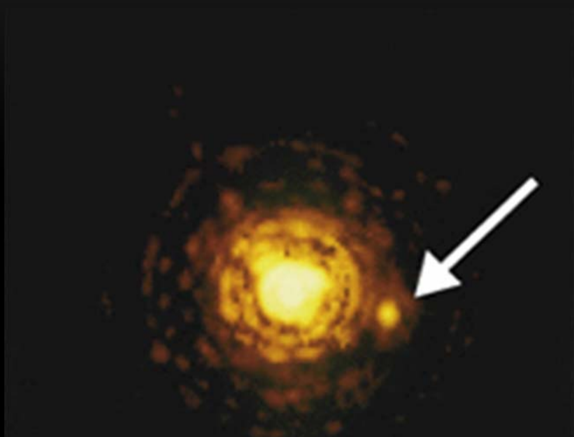
- The protostar keeps contracting
  - Less surface area, so less luminous
- Gets hotter
- So it's place on the HR diagram changes with time
- Fusion starts, and it settles into Hydrostatic Equilibrium on the Main Sequence

DIFFERENT MASS STARS?

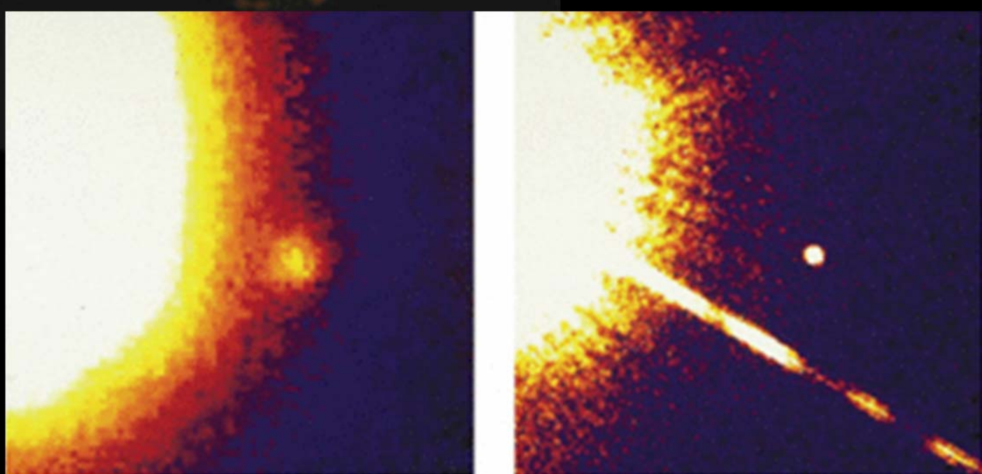


- More massive stars stay bigger and get hotter
- They end up on the Main Sequence at the appropriate place
- Then spend most of their lives sitting there happily fusing hydrogen into helium

BROWN DWARFS



Gliese 623 from HST

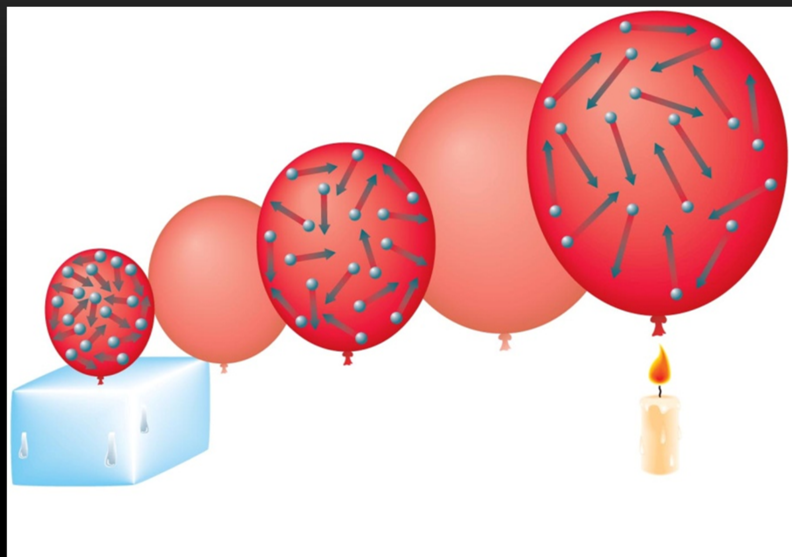


Gliese 229 in IR (left) and from HST (right)

- A protostar too small to get hot enough in the core to start fusion is a “Brown Dwarf” or a “failed star”
  - Need about 80 Jupiter-masses to start fusion
- These photos show very faint ($10^{-6}L_o$) companions of nearby red dwarf stars
  - ~ 50 Jupiter masses

WHAT STOPS BROWN DWARFS FROM BECOMING A STAR?

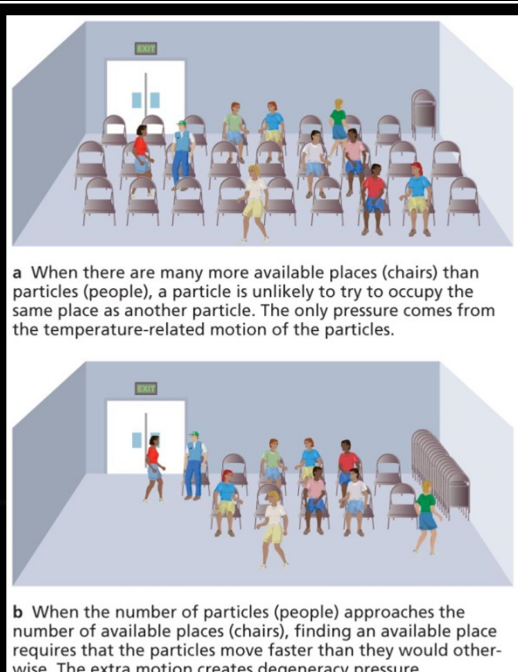
- Need 10^7K in core to start fusing H to He
- Regular thermal pressure should do it for things ~10 times Jupiter's mass
- Must be some other sort of pressure to stop contraction to that point



Thermal Pressure:

Depends on heat content

The main form of pressure in most stars



a When there are many more available places (chairs) than particles (people), a particle is unlikely to try to occupy the same place as another particle. The only pressure comes from the temperature-related motion of the particles.

b When the number of particles (people) approaches the number of available places (chairs), finding an available place requires that the particles move faster than they would otherwise. The extra motion creates degeneracy pressure.

Fig.13.8

Degeneracy Pressure:

Particles can't be in same state in same place

Doesn't depend on heat content

HOW BIG?

- The smallest a star can be is about 80 Jupiters
  - 0.08 $M_\odot$
- There is a maximum size too –
  - Above ~100 $M_\odot$, the cloud collapses so fast that it breaks up and makes smaller stars instead
  - Plus, that large a star is so bright that pressure from the light itself blows off the star's outer layers
    - Called the "Eddington Limit"
    - We have not observed stars more massive than this