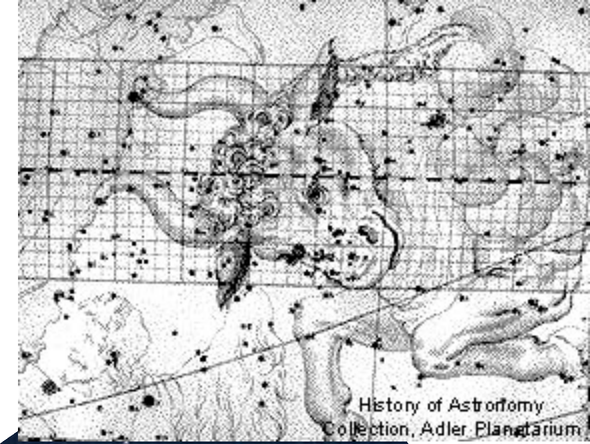
Star Formation

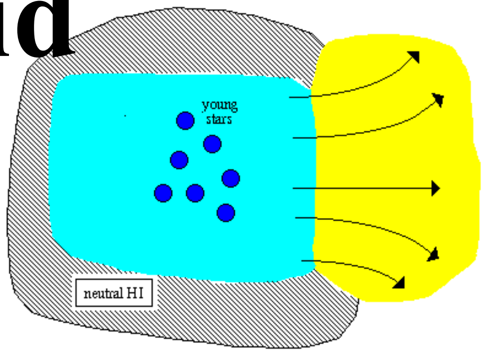


- Dust clouds
- Collapse
- Fragmenting
- Into star clusters

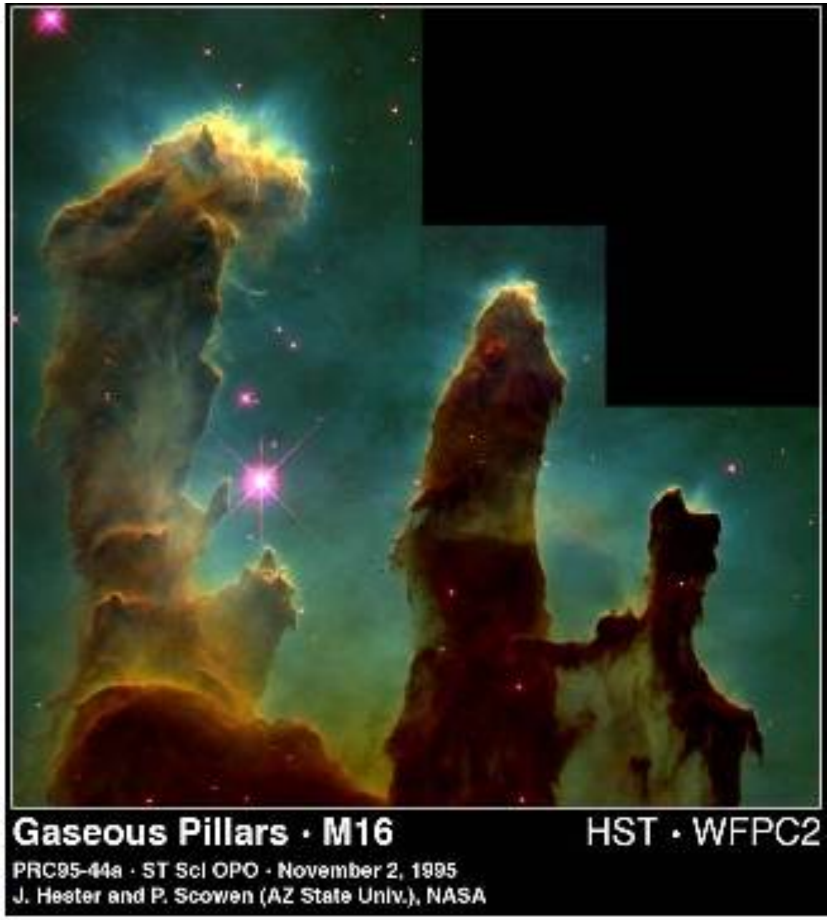
Stage 1. Molecular Cloud

- Large clouds of gas and dust
- Very cold and dense
- Most clouds supported by pressure

As the heated region grows, it will eventual breakthrough the clouds exterior to b
a visible HII region.

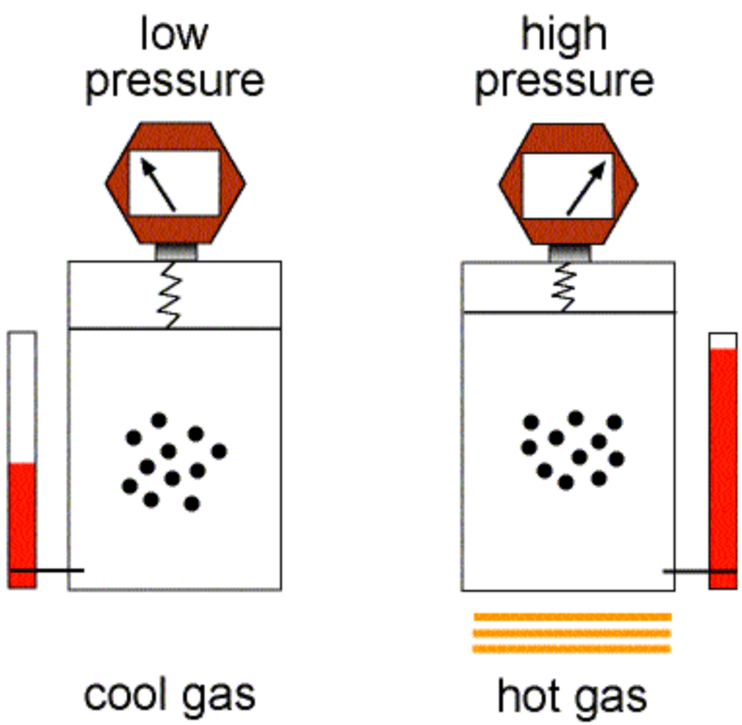


HST studied the three central pillars of the Eagle Nebula



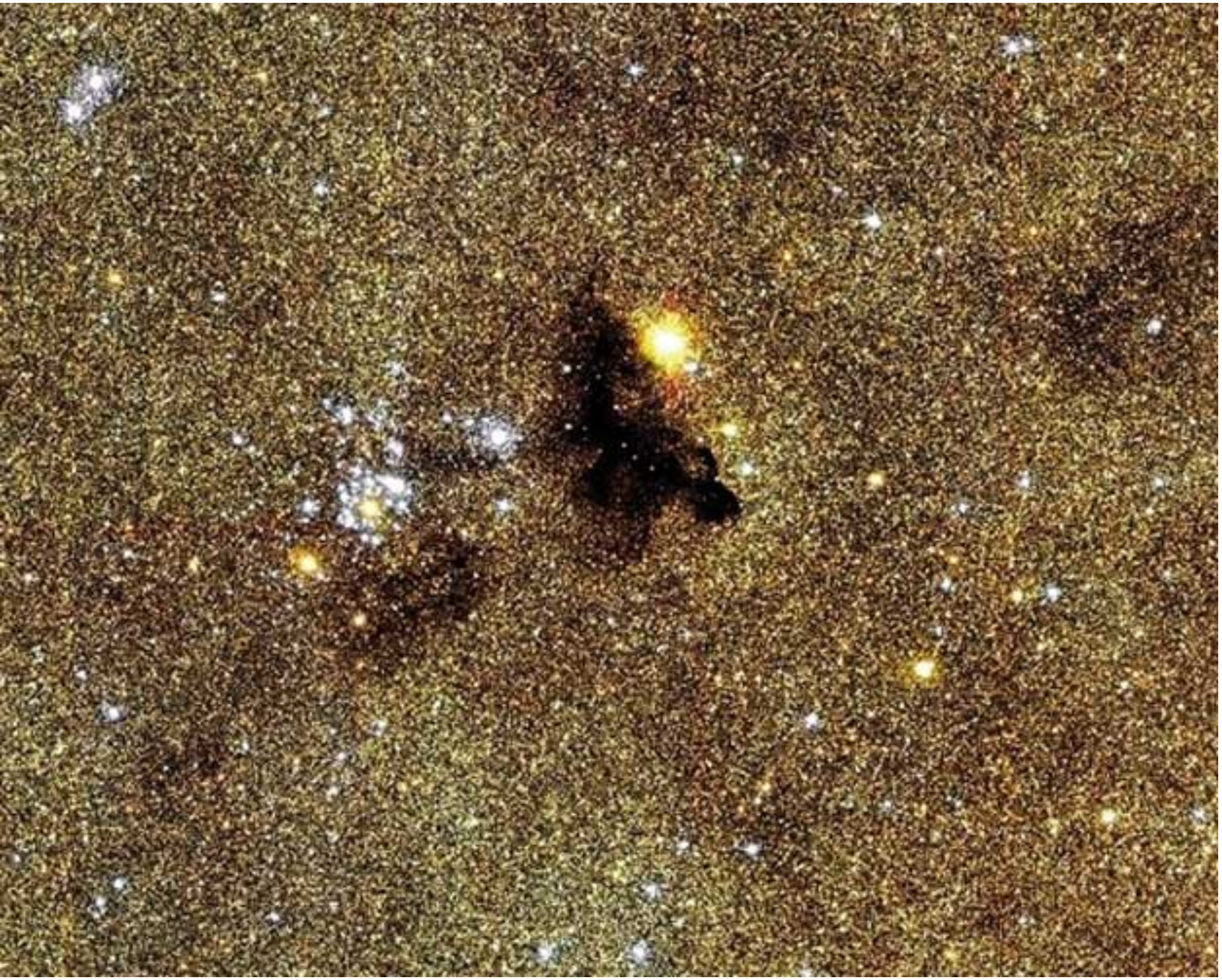
Gravity and Heat

- Speed/kinetic energy of particles depends on temperature
- 30K=>300meters/sec = 1000km/hour
- Pressure depends on Density & Temperature
- Pressure depends on number of particles & how fast they are moving



$$\text{pressure} = \frac{k \times \text{density} \times \text{temperature}}{\text{molecular weight}}$$

Collapse Triggered by Shock Waves: 1.Collisions of Molecular Clouds



- Molecular cloud Barnard 86
- Followed by the Open Cluster NGC 6520
- Seen against the background bulge of the galaxy

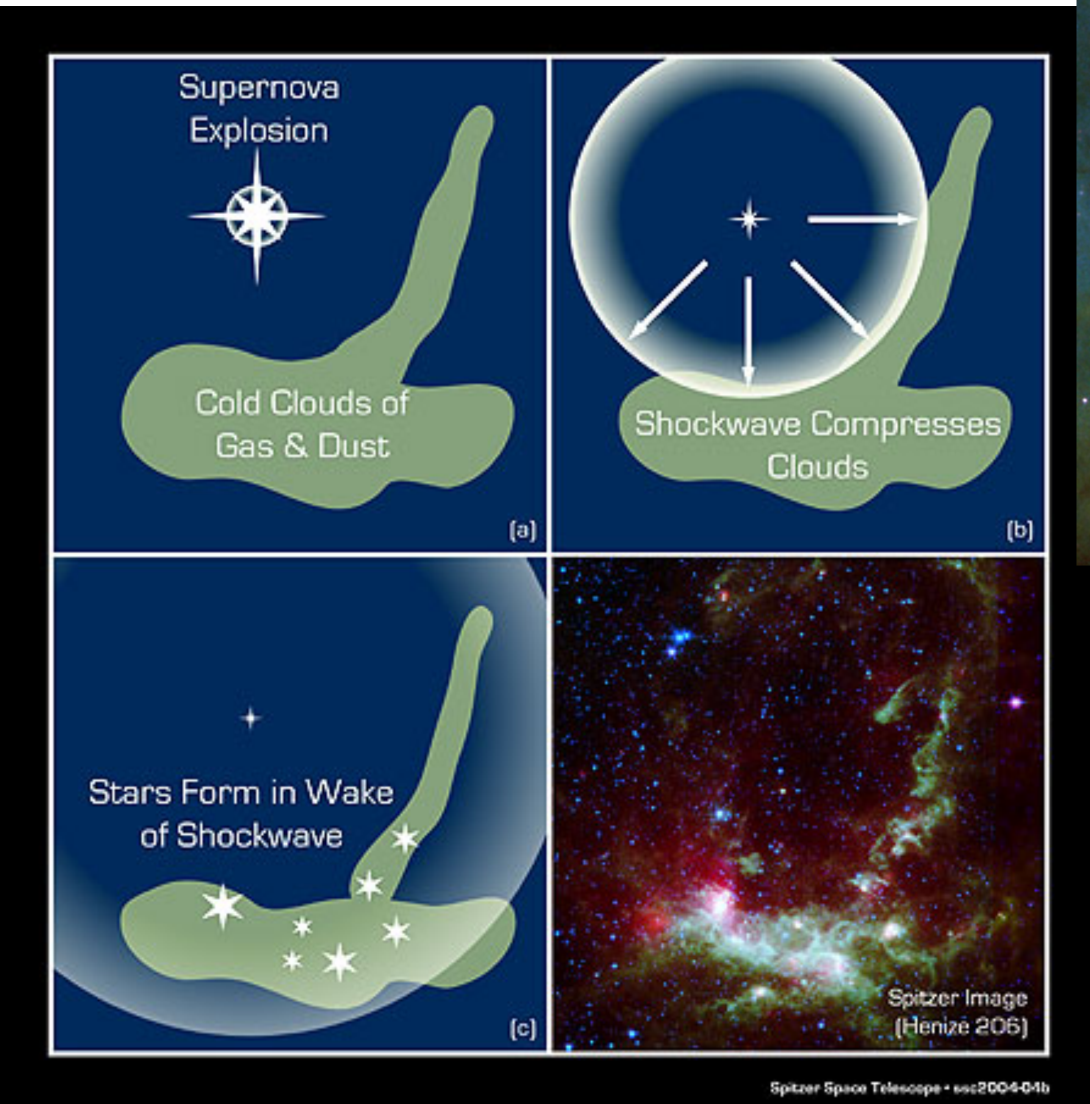
Collapse Triggered by: 2. Spiral Arms

- As the giant molecular cloud encounters a spiral arm it is compressed

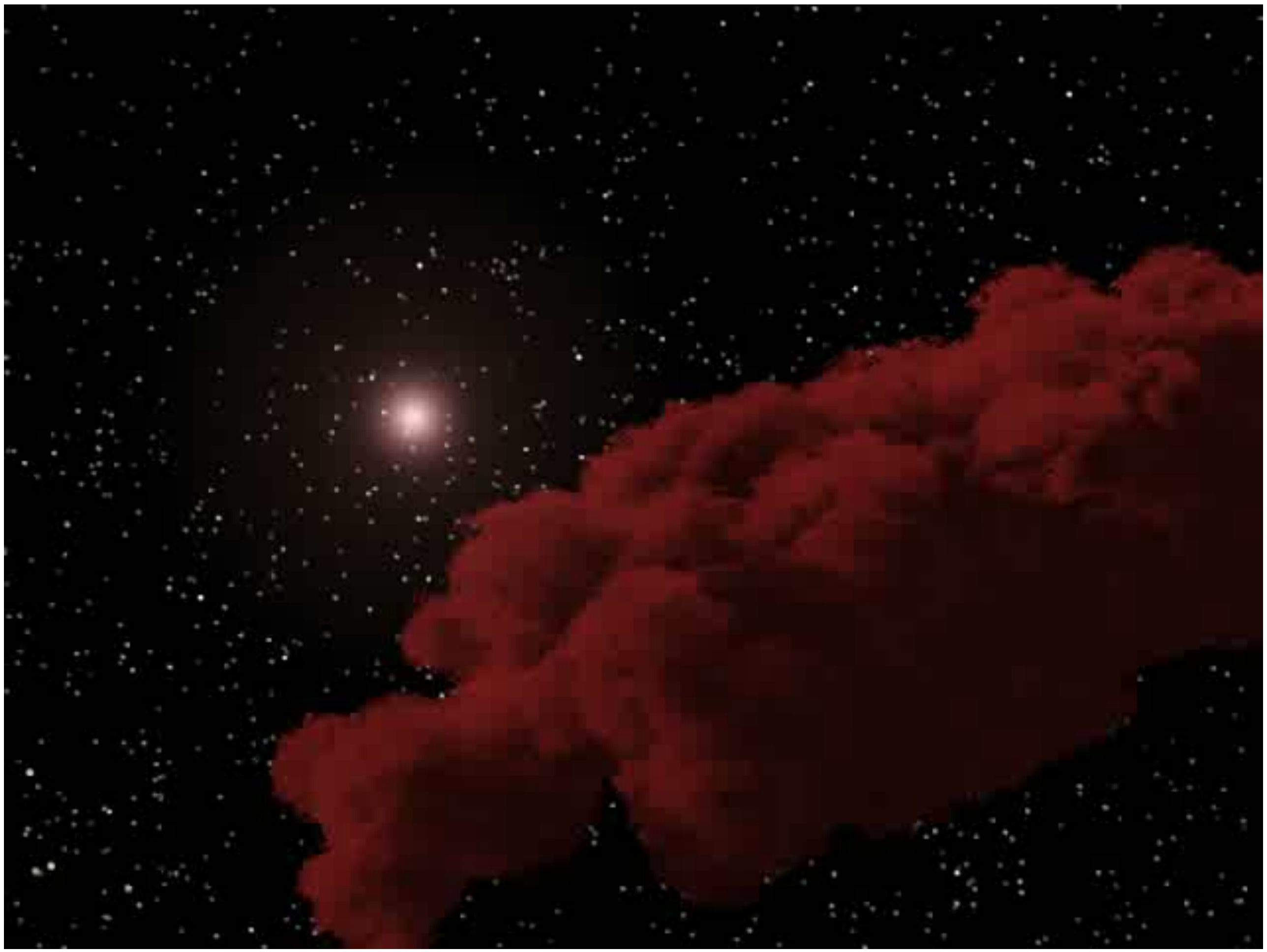
3.Collapse Triggered by Stellar Wind

- Bubble nebula forms where star' s supersonic wind hits molecular cloud forming shock

Collapse Triggered by 4. **Supernova**

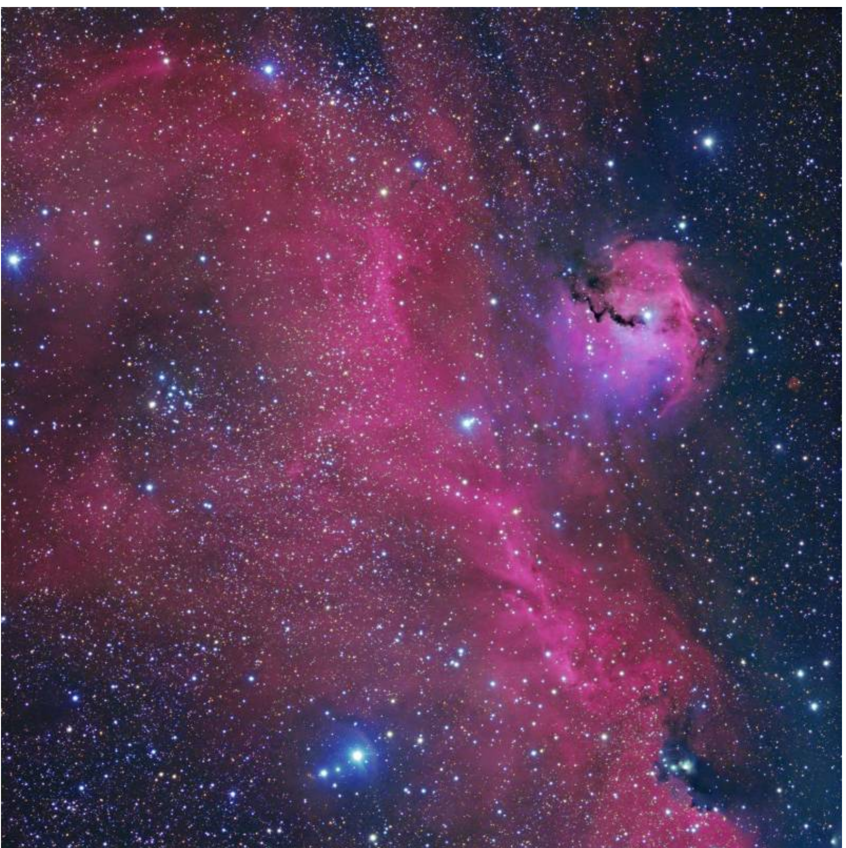


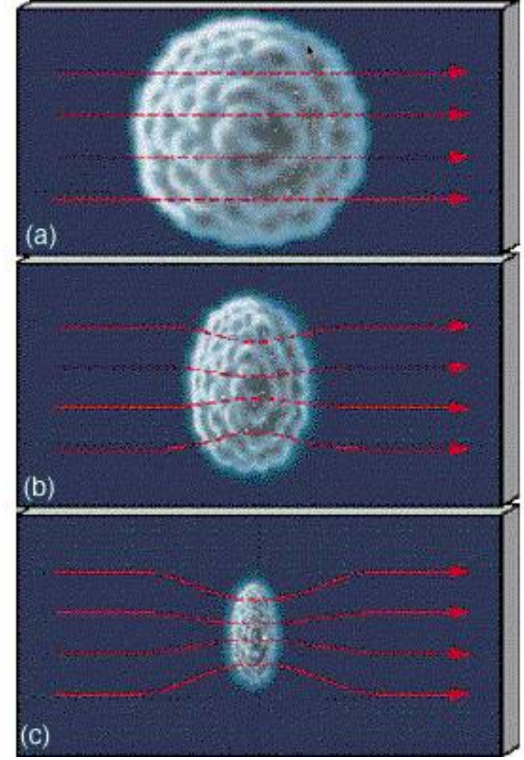
Supernova Triggers Star Formation

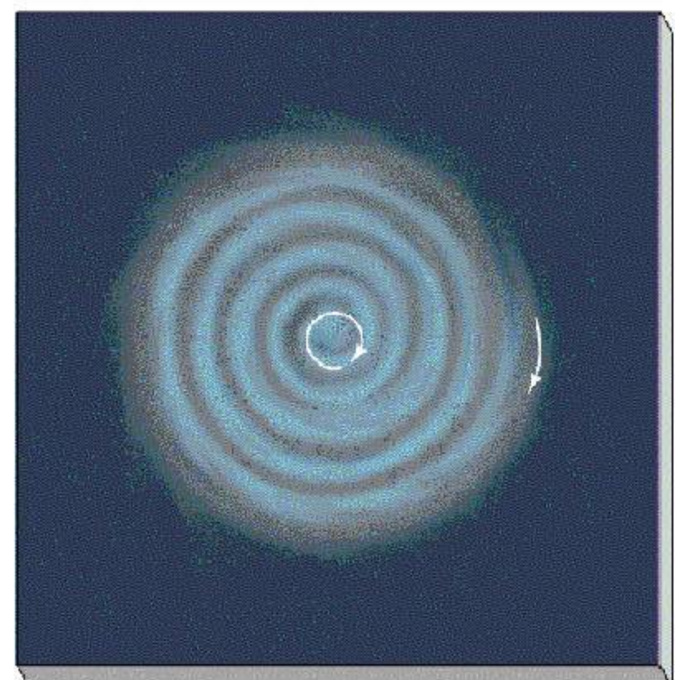


Collapse Resisted by:

- Thermal Pressure @30K velocity=0.3km/sec
- Spin – gas & dust forms protostellar disk
- Magnetism - ionized atoms can not cross magnetic field lines
- Turbulence

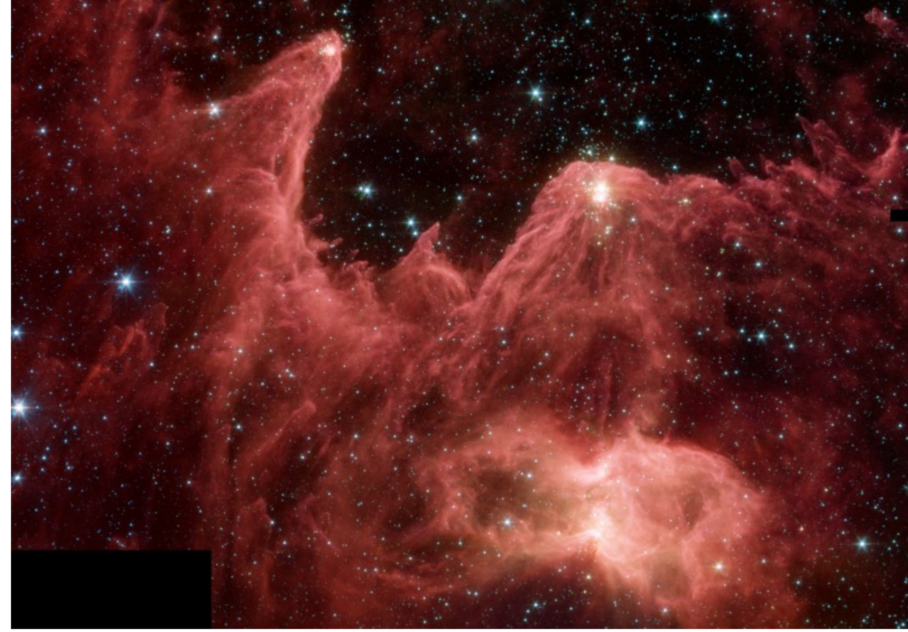


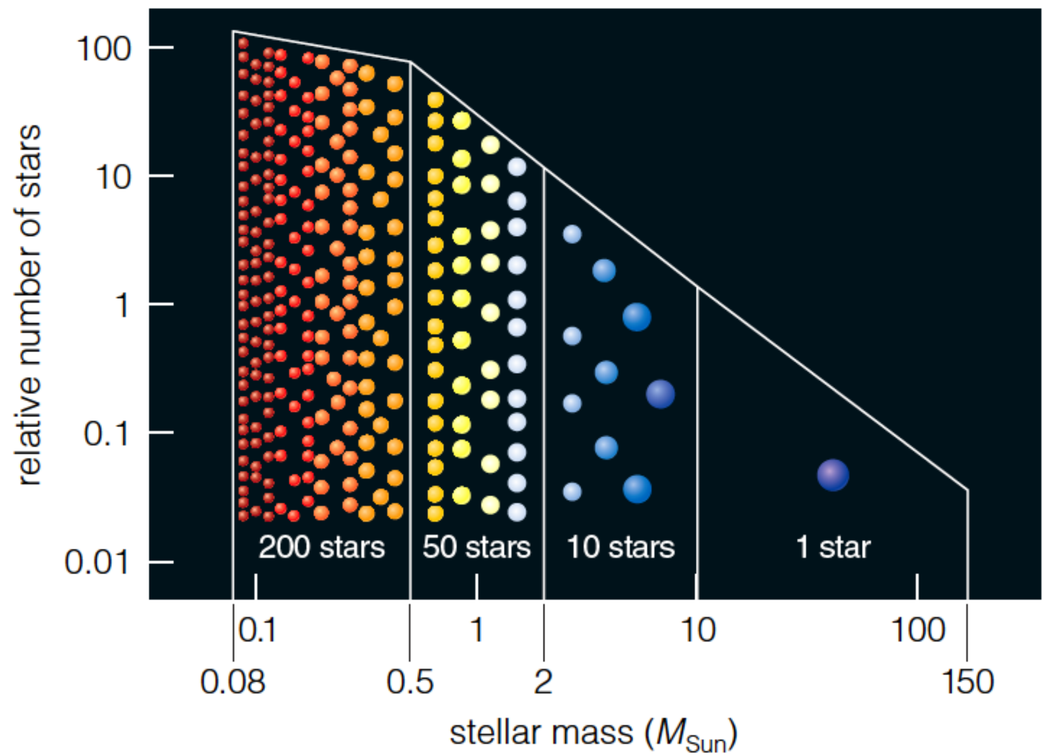


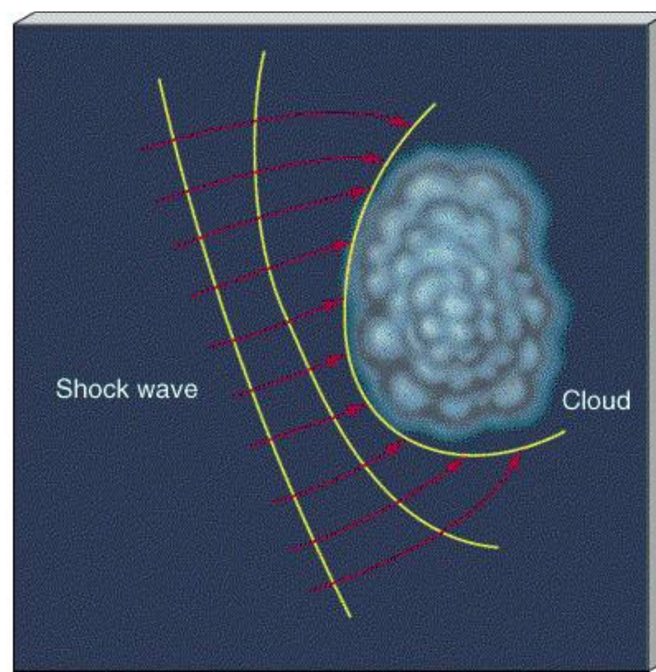


Stage 2. Cloud Fragments

- Initially the gas is tenuous = transparent cool
- Non-uniform collapse – the rich get richer

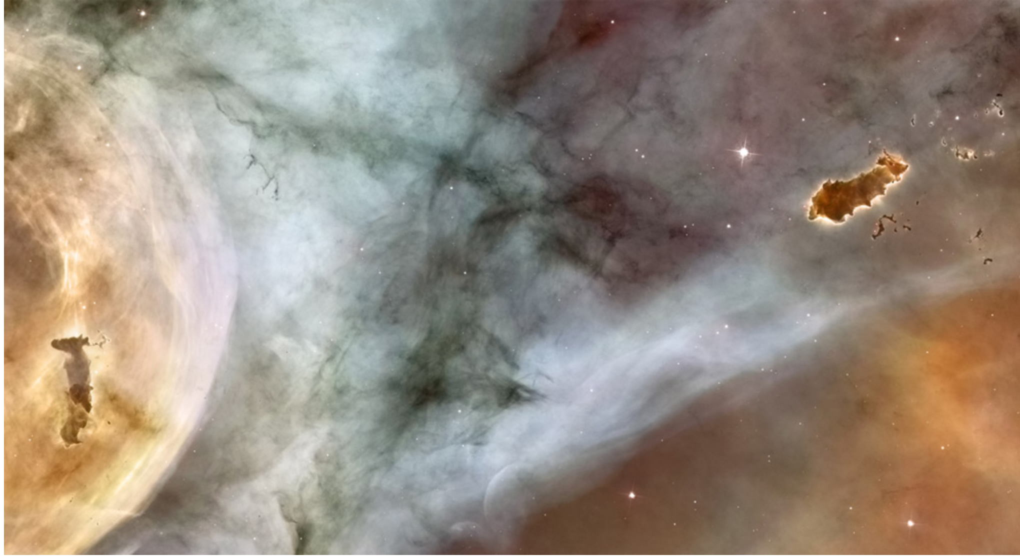


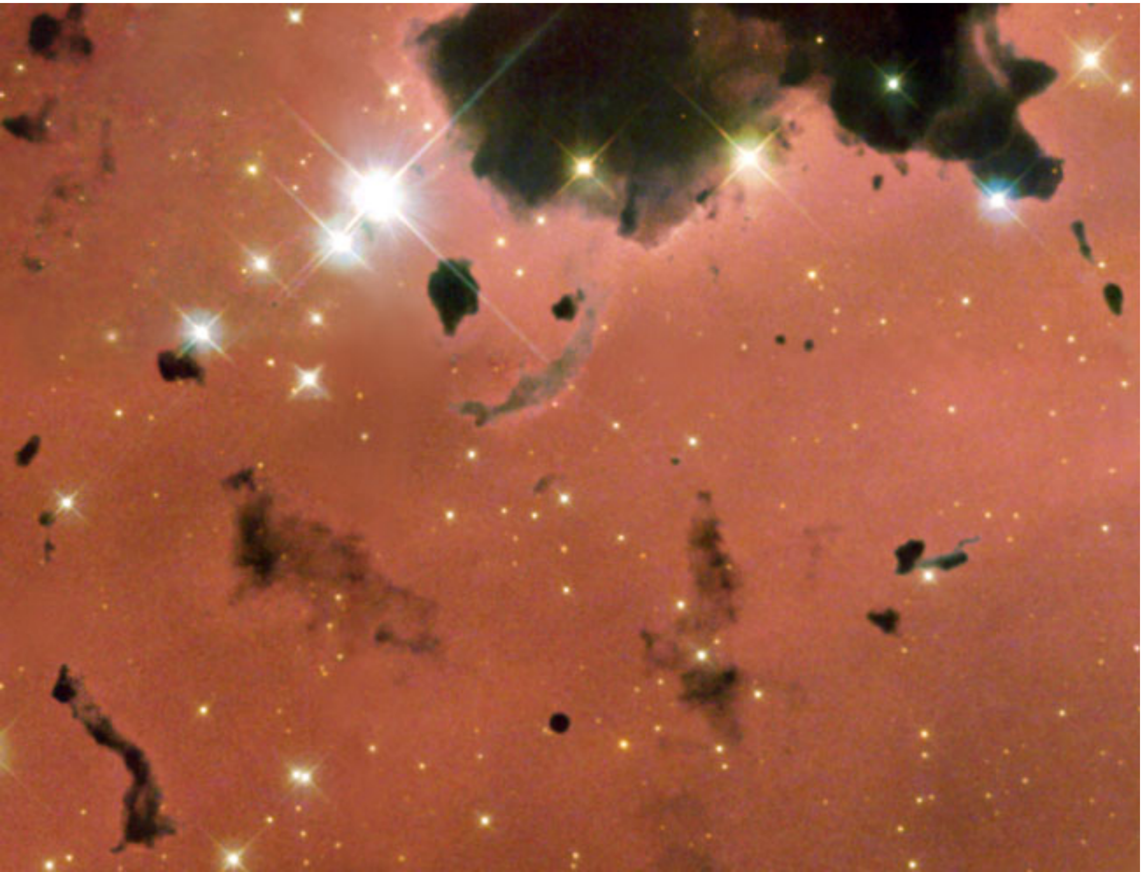


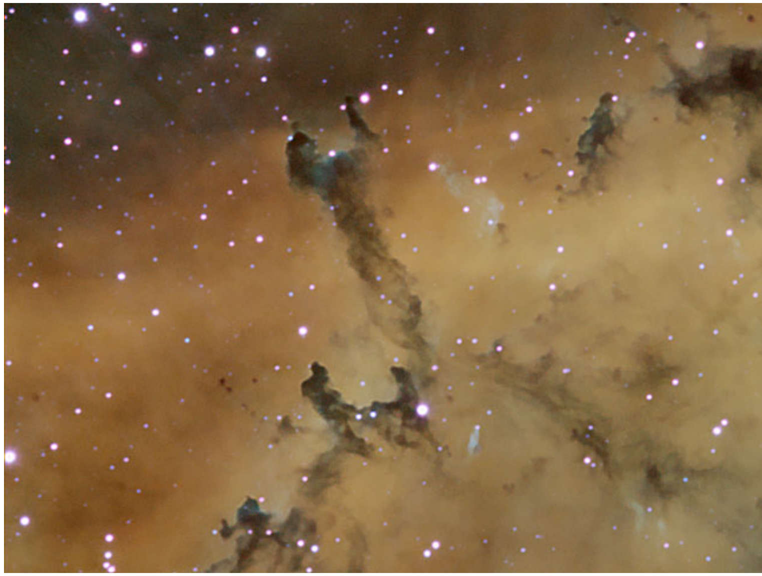


Bok Globules

- Giant Molecular Cloud's collapse to form globules with protostars inside cocoons of dust and gas





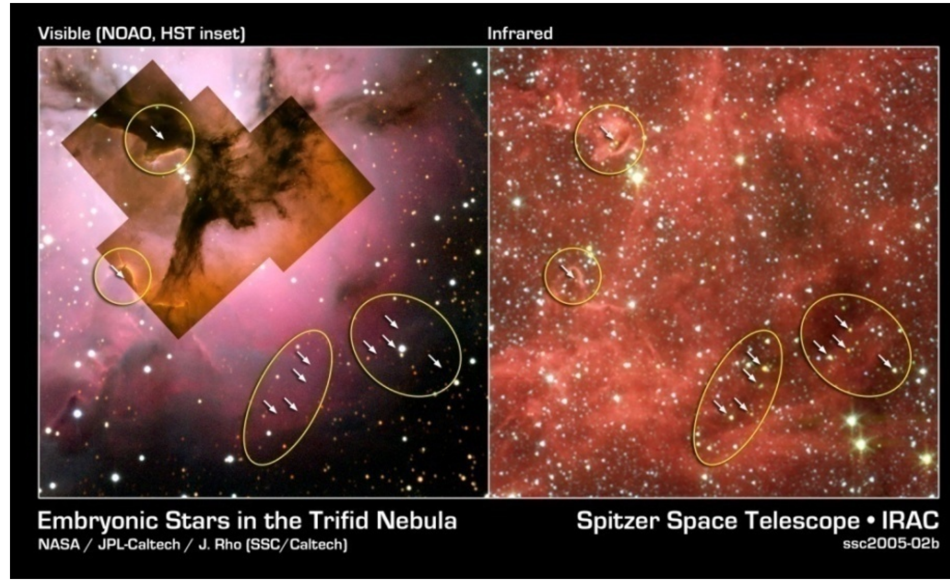


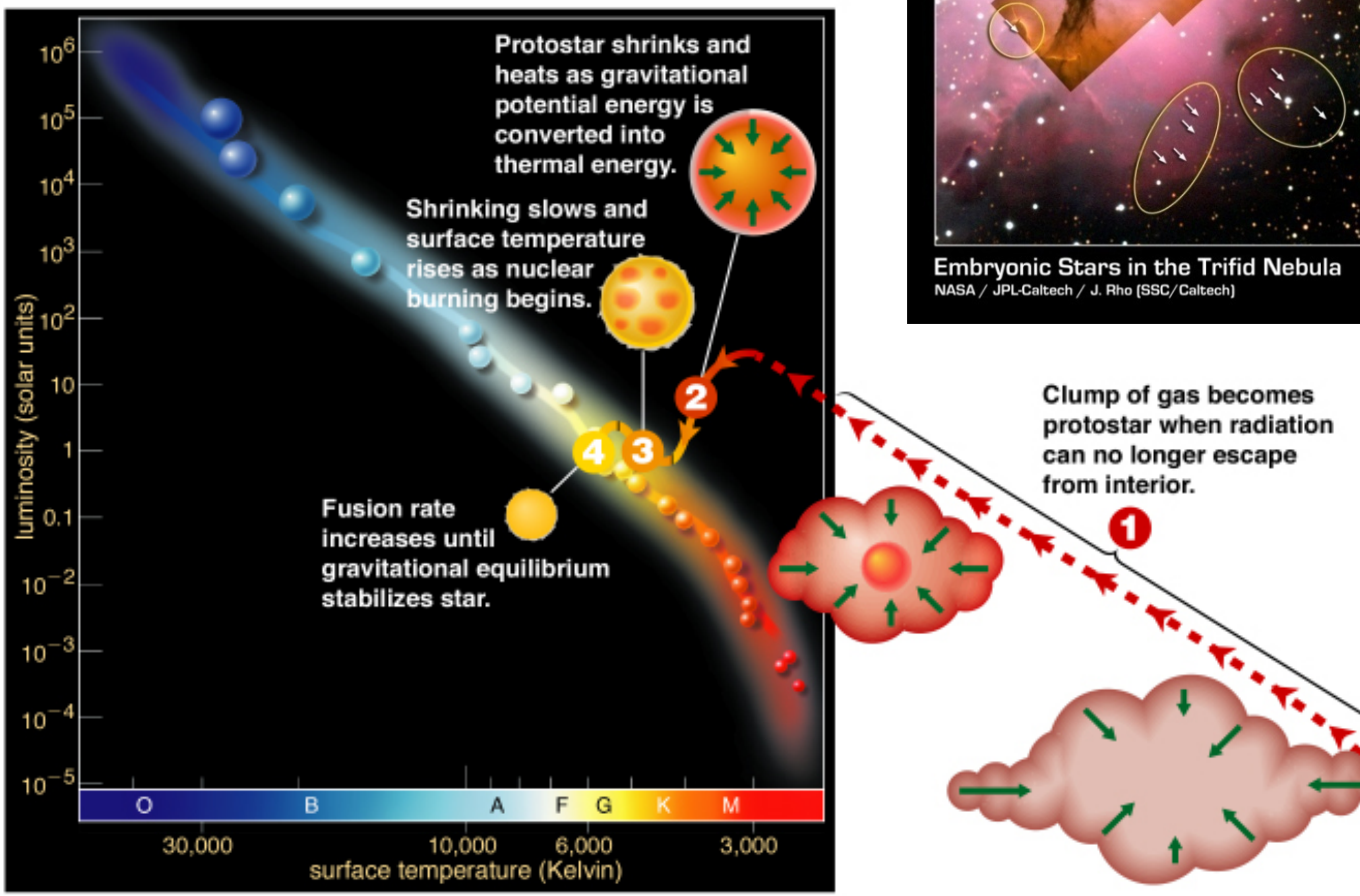
Stage 3. Fragmentation Ceases

- Energy from free-fall collapse heats cloud fragment
- Gravitational energy converted to thermal energy
- Gas & dust radiate so collapse continues until
- Cloud becomes opaque = a protostar

Stage 4. **Protostar**

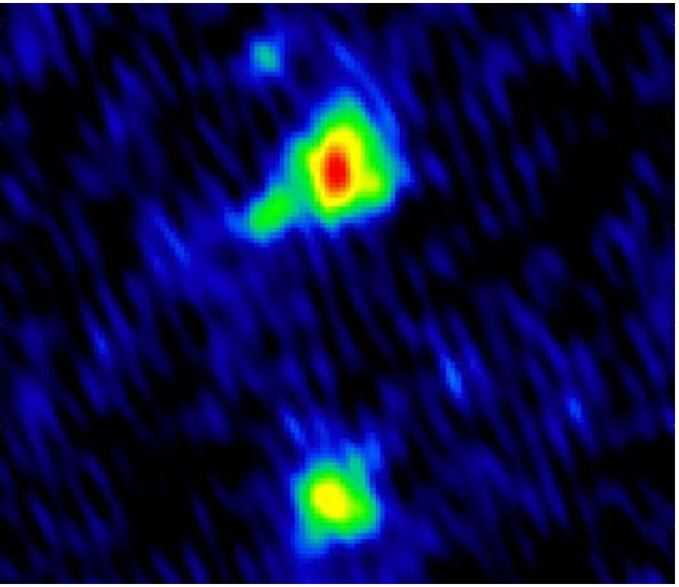
- 100,000 years – size of Mercury's orbit – cool surface
- Luminosity 100 times sun
- Fully convective

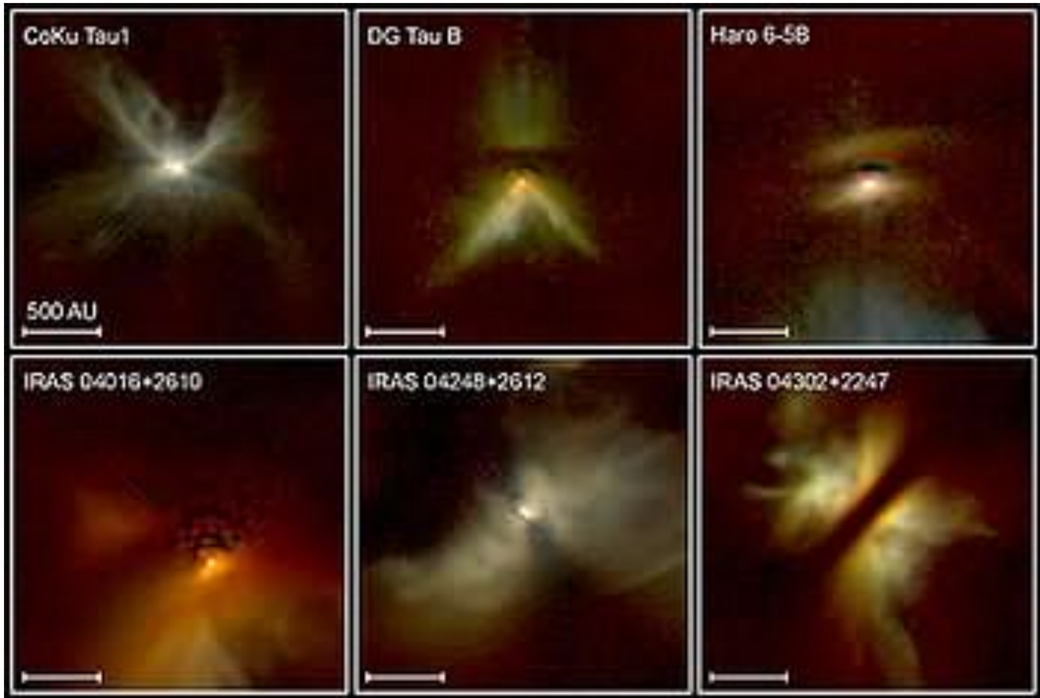


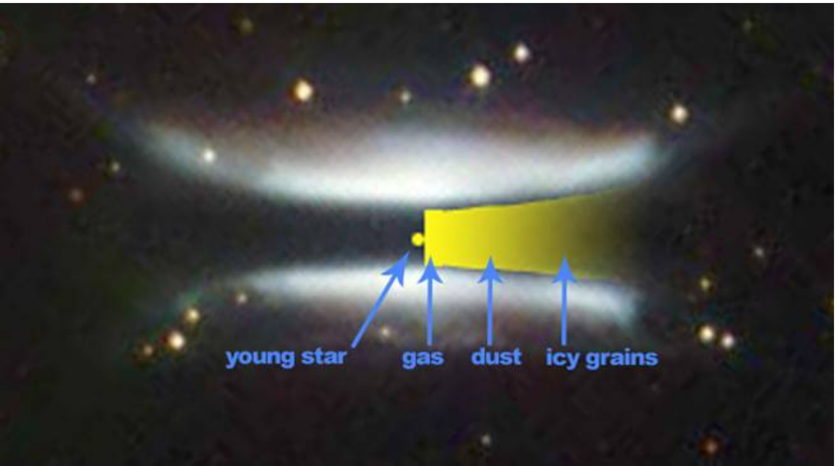


Protostar: **ProtostellarDisk**

- As protostars collapse they spin faster and form disks
- VLA images of two protostars and their disks reveal third component

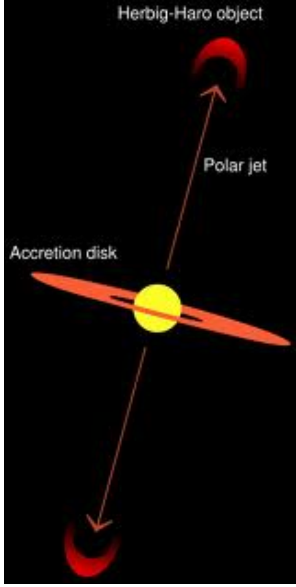


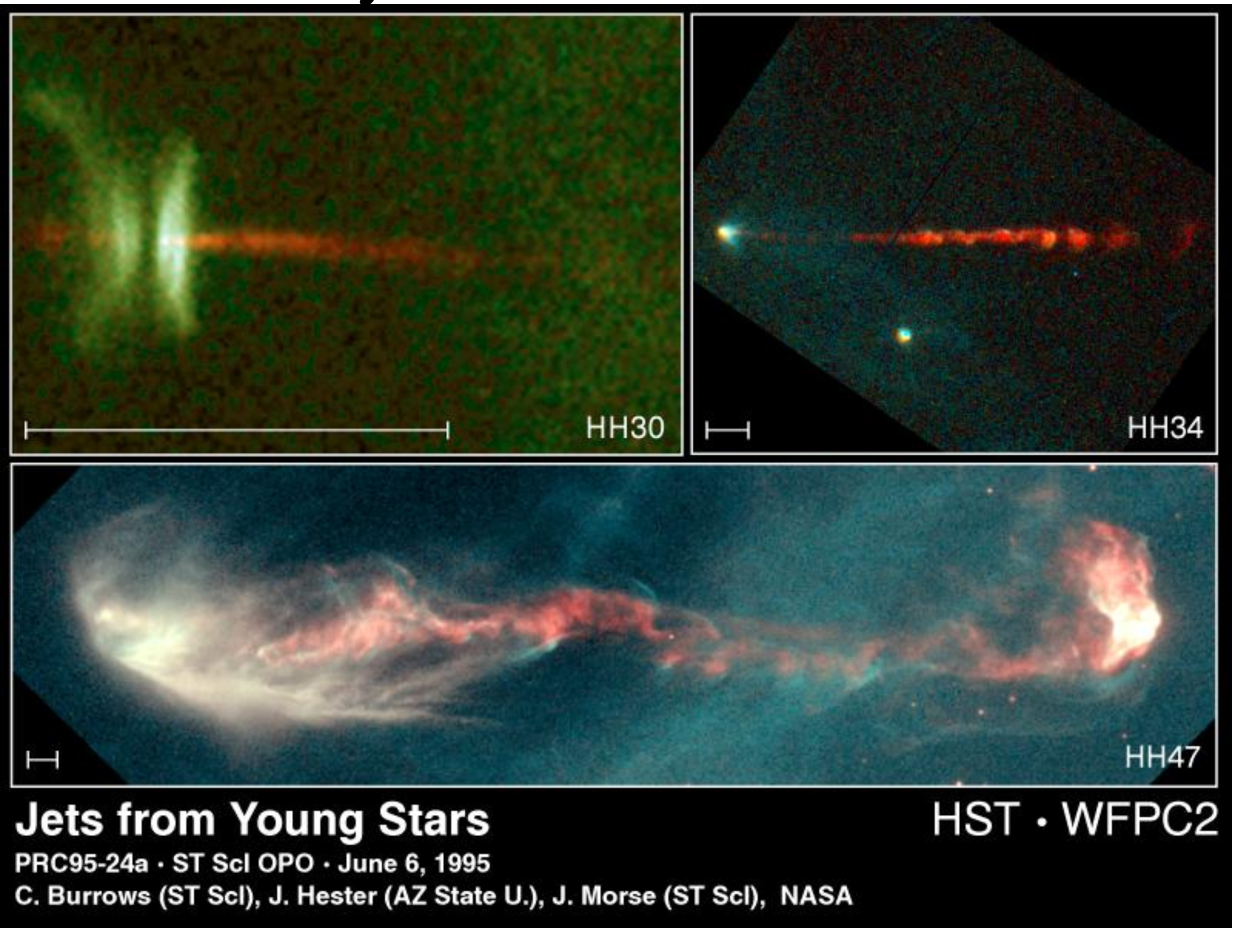


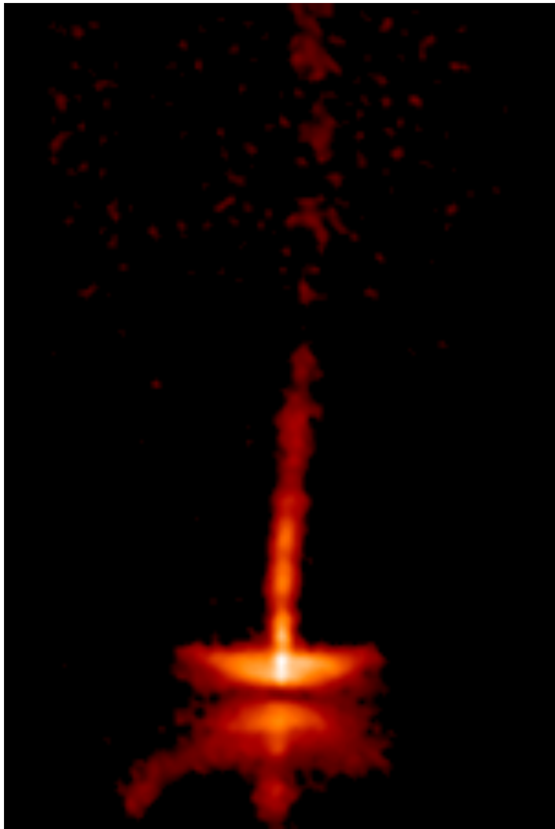


Protostar: **Bipolar Flow**

- Opposing jets of gas expelled by protostar focused by protostellar disk
- 30 ~500ly distant & 450AU diameter





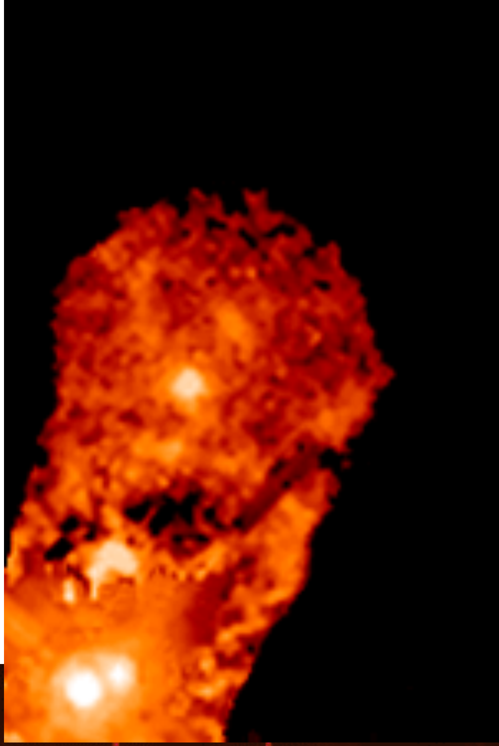


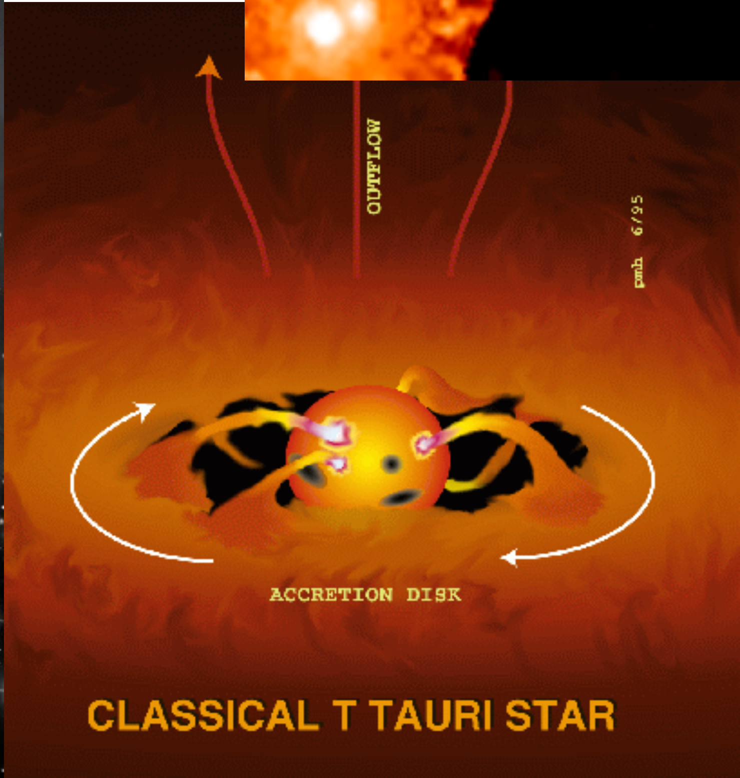
Protostar: **Cocoon**

- Hot star above left evaporates/blows away **cocoon** revealing slower evolving cooler stars
- Globule shields gas from hot star' s stellar wind and radiation pressure
- Creating a star formation pillar

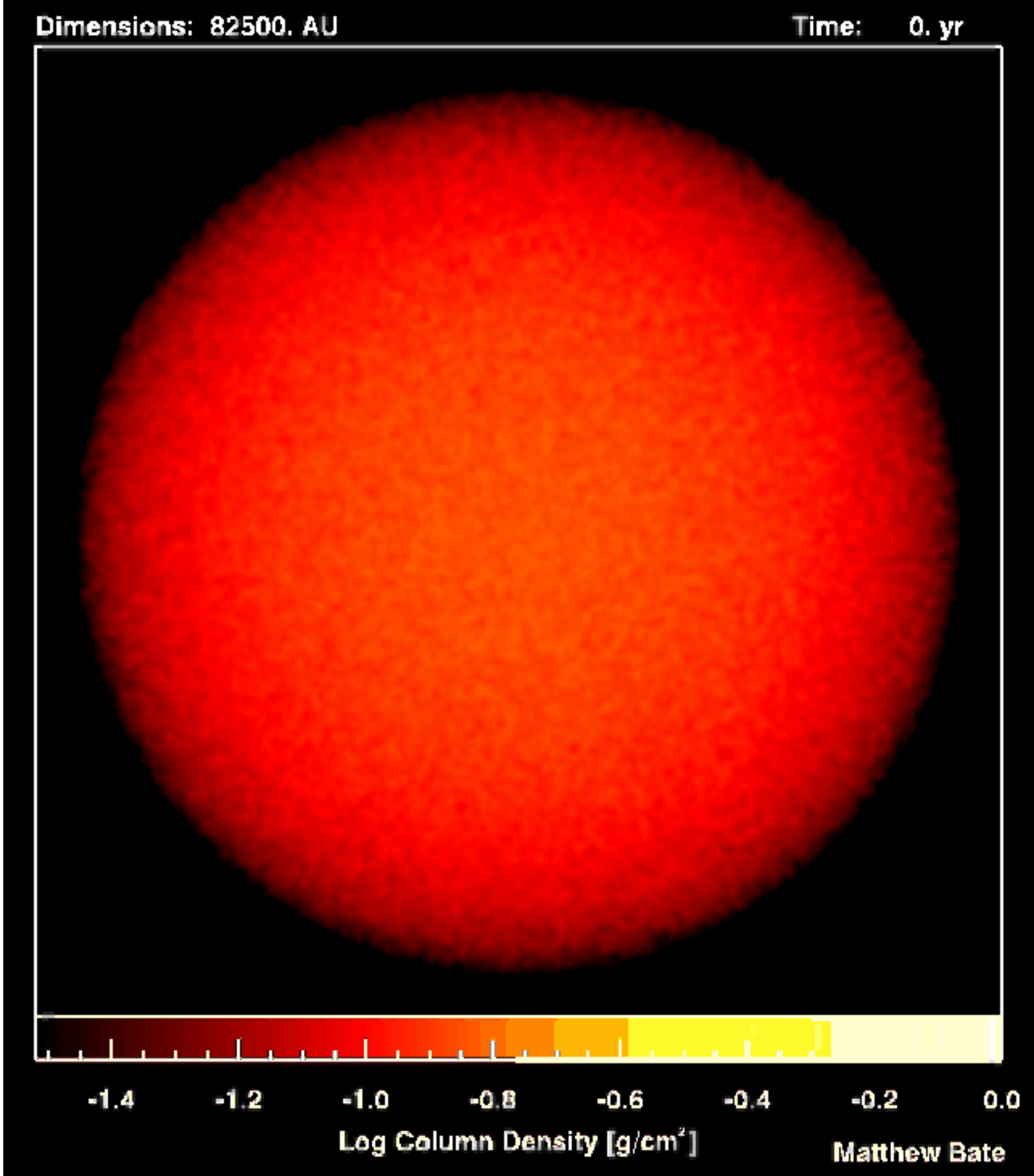
Protostar: **T Tauri** Stars

- Young star just after emerging from cocoon & before Main Sequence
- XZ Tauri; binary; HST frames 96,98, 2000
- T Tauri changes brightness & reflection nebula changes too

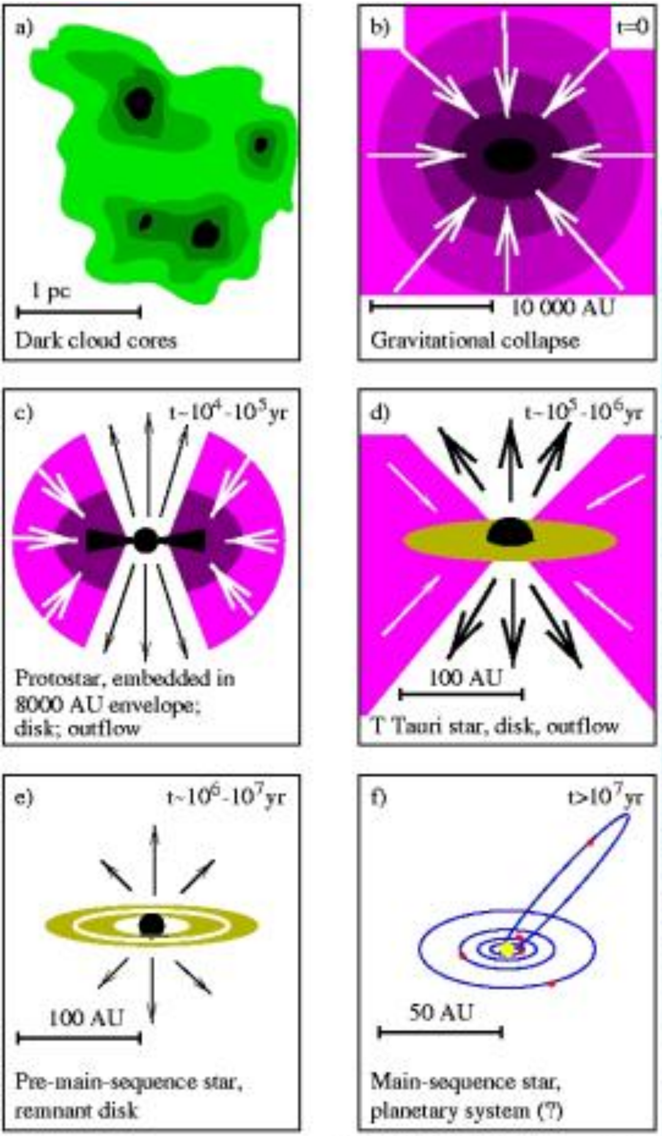




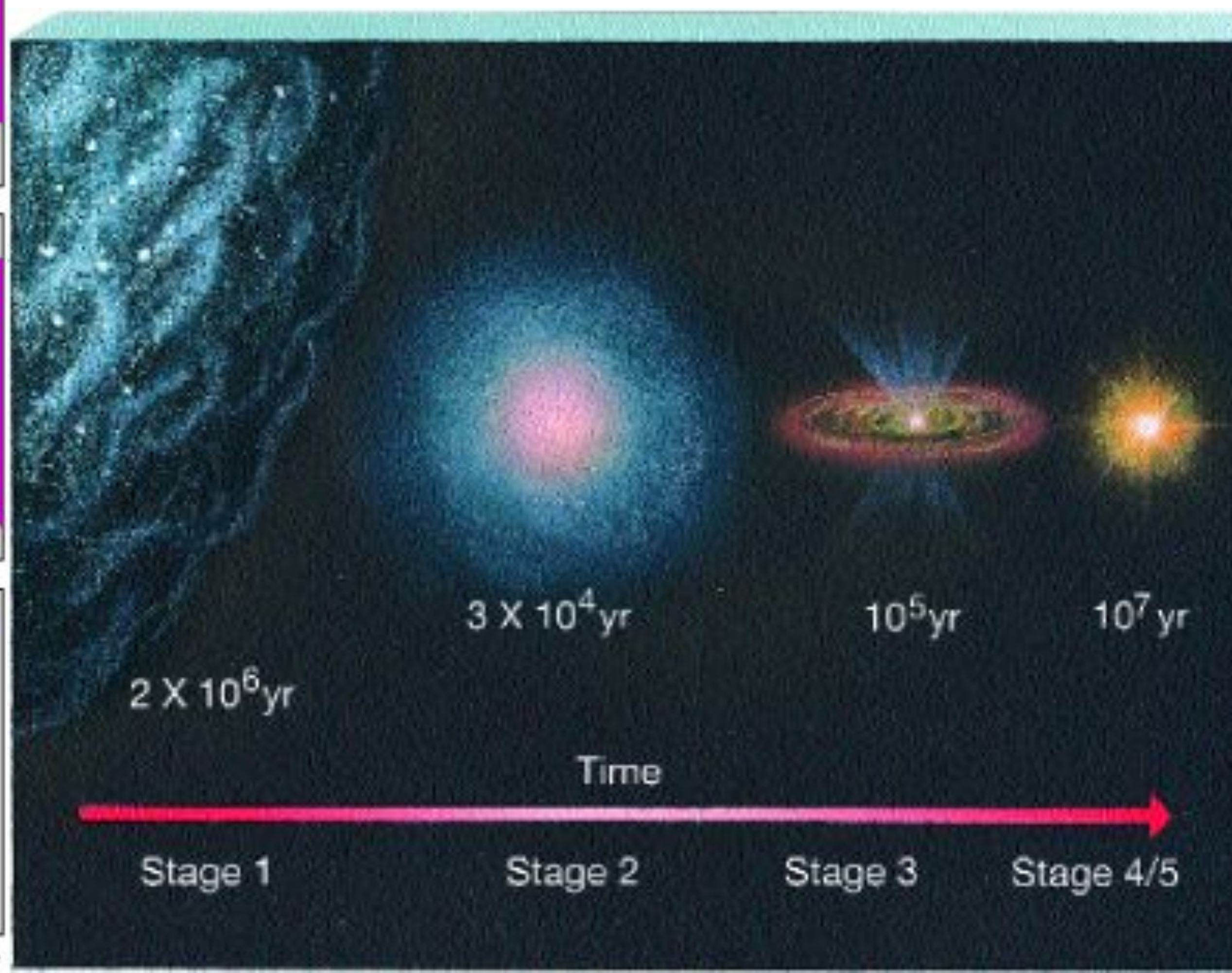
Theory: Star Formation



Giant Molecular Cloud, Fragmentation, Protostar, Protostellar Disk, T Tauri Star

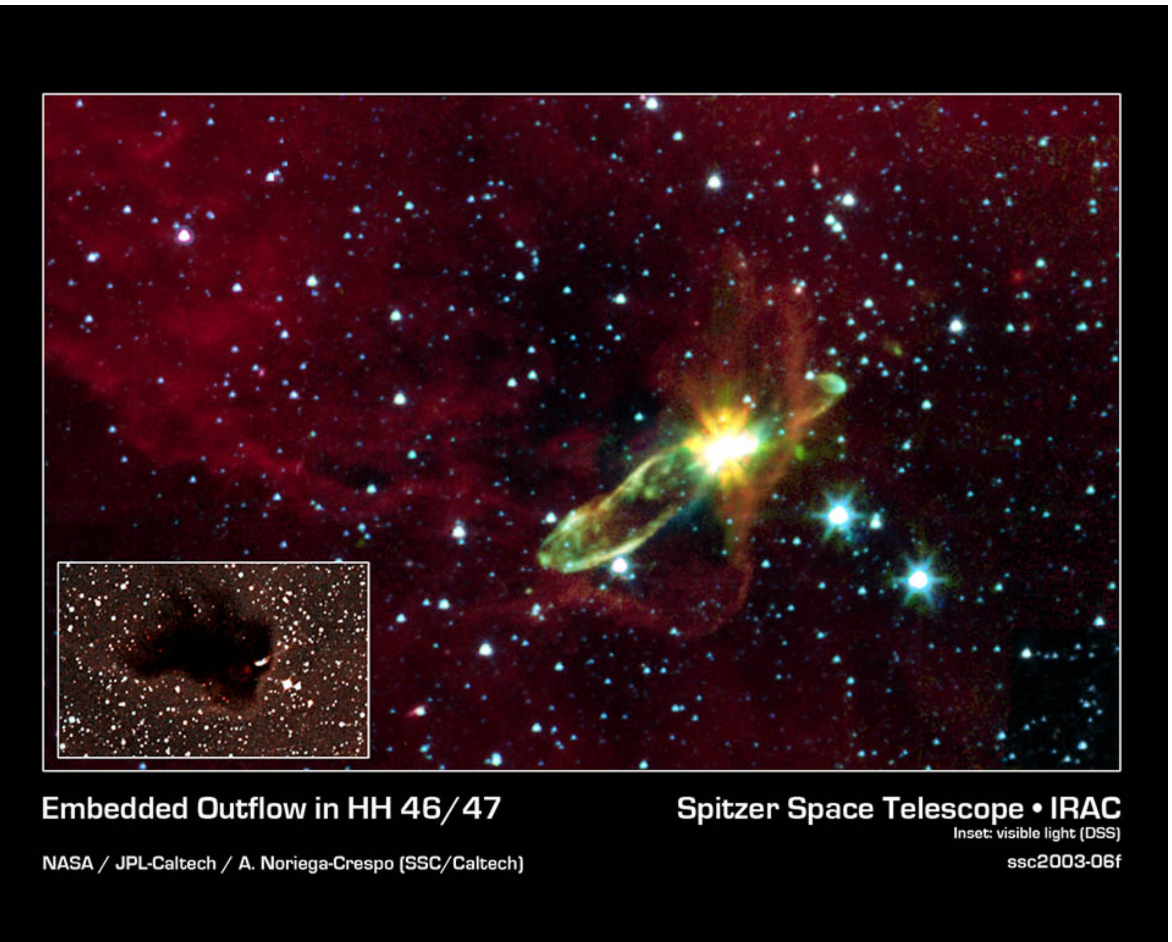


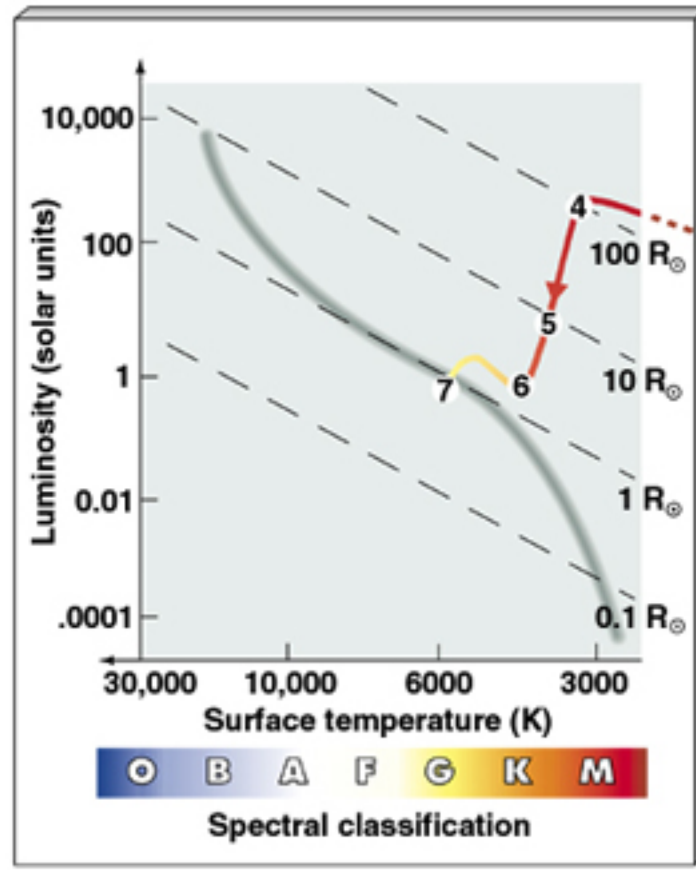
Hogerheijde 1998, after Shu et al. 1987



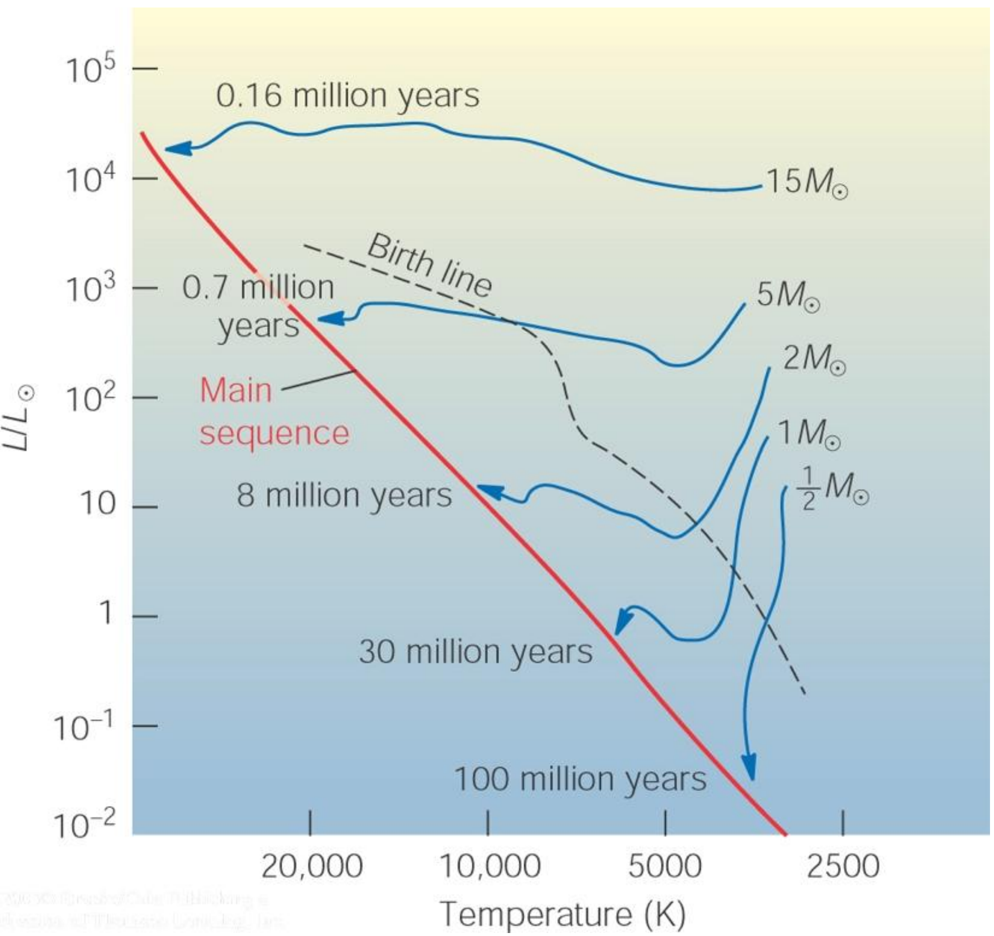
Protostar: **Evolutionary Track**

- Stage 5. Protostar shrinks; Luminosity decreases
- Stage 6. Core hot enough to begin fusion – A Star is Born
- Stage 7. Star joins main sequence





Zero Age Main Sequence = ZAMS

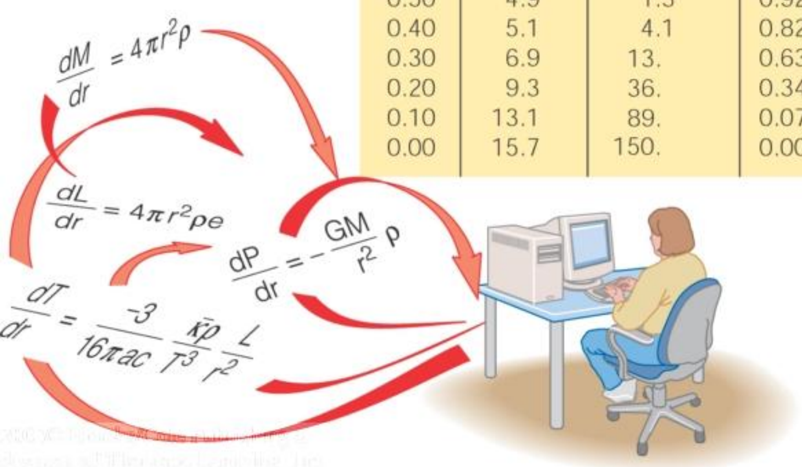


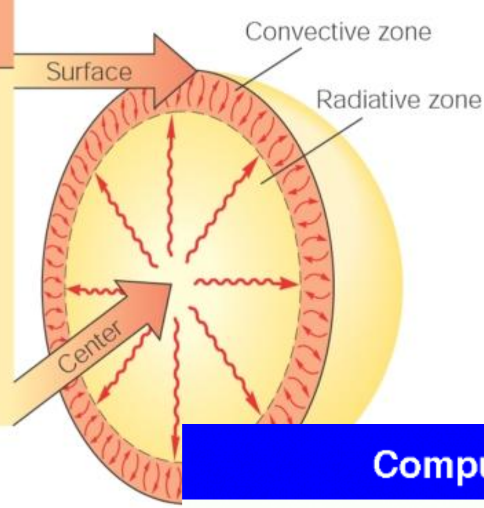
- More massive stars evolve to ZAMS more quickly than low mass stars
- Millions of years for Molecular cloud to form a star
- Mass determines position on ZAMS

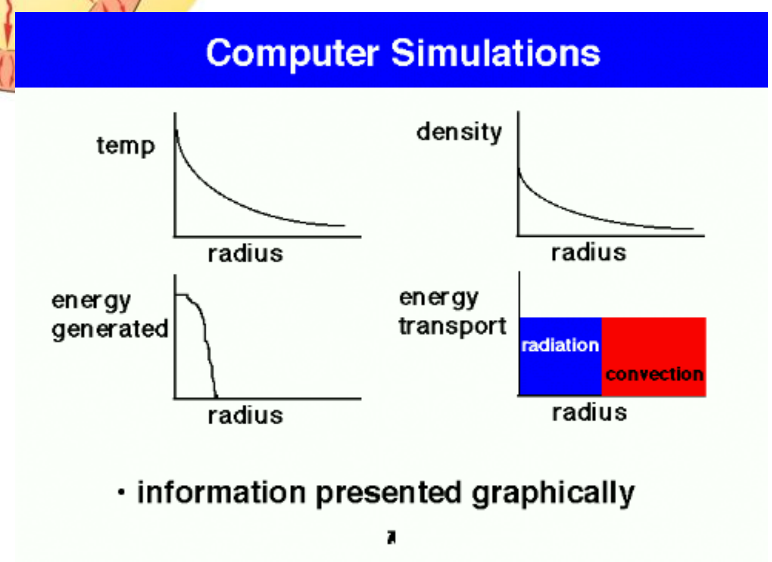
Four Laws of Stellar Structure

- Hydrostatic Equilibrium
- Energy Transport
- Conservation of Energy
- Conservation of Mass

$R/R_\odot$	T (10^6 K)	Density (g/cm^3)	$M/M_\odot$	$L/L_\odot$
1.00	0.006	0.00	1.00	1.00
0.90	0.60	0.009	0.999	1.00
0.80	1.2	0.035	0.996	1.00
0.70	2.3	0.12	0.990	1.00
0.60	3.1	0.40	0.97	1.00
0.50	4.9	1.3	0.92	1.00
0.40	5.1	4.1	0.82	1.00
0.30	6.9	13.	0.63	0.99
0.20	9.3	36.	0.34	0.91
0.10	13.1	89.	0.073	0.40
0.00	15.7	150.	0.000	0.00

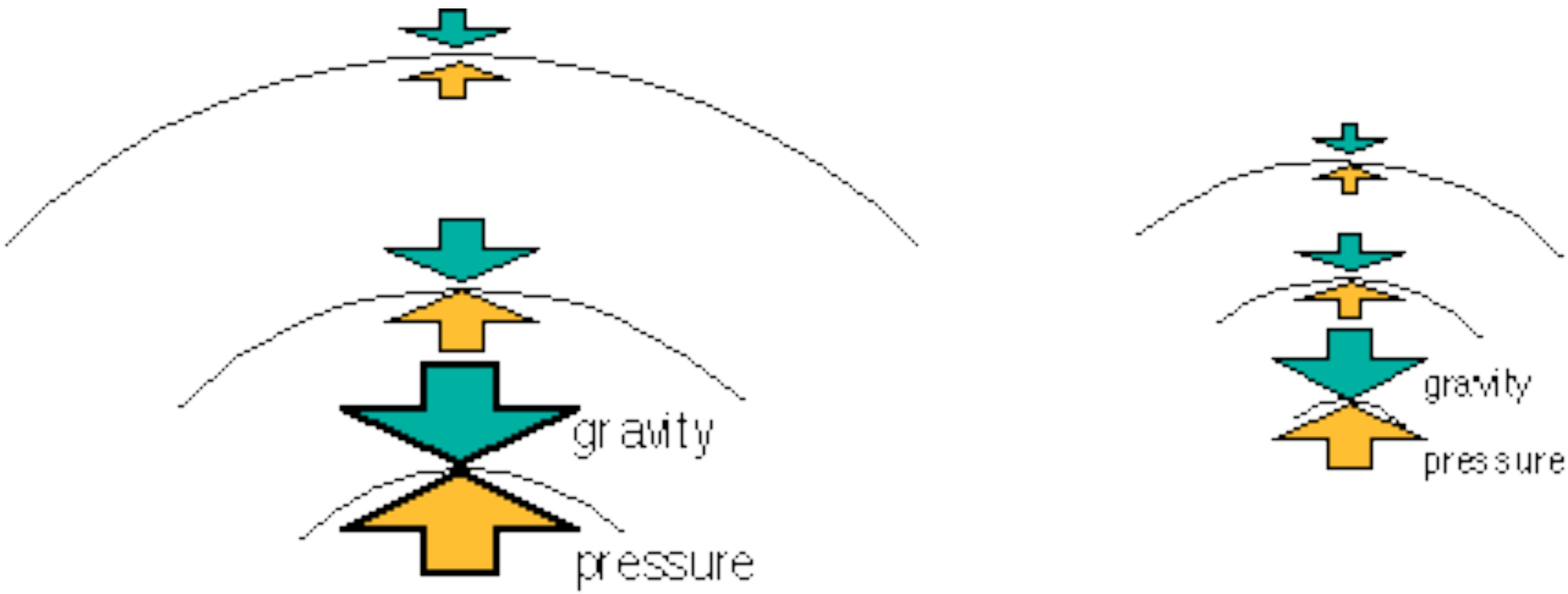






Hydrostatic Equilibrium

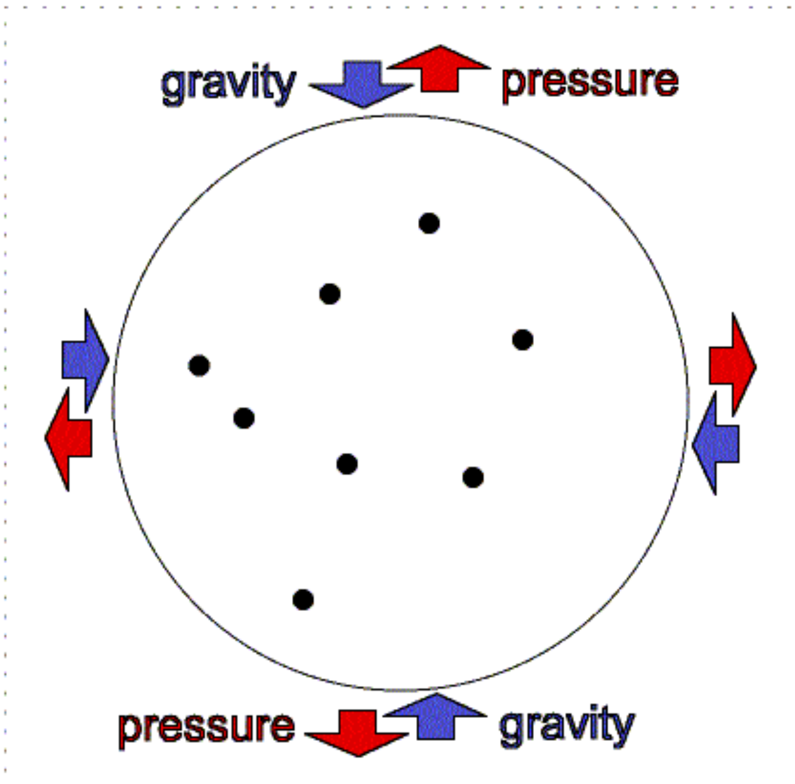
- Why doesn't the Sun's gravity just crush it into nothing?
- Gas pressure equals Gravity/Weight pulling down

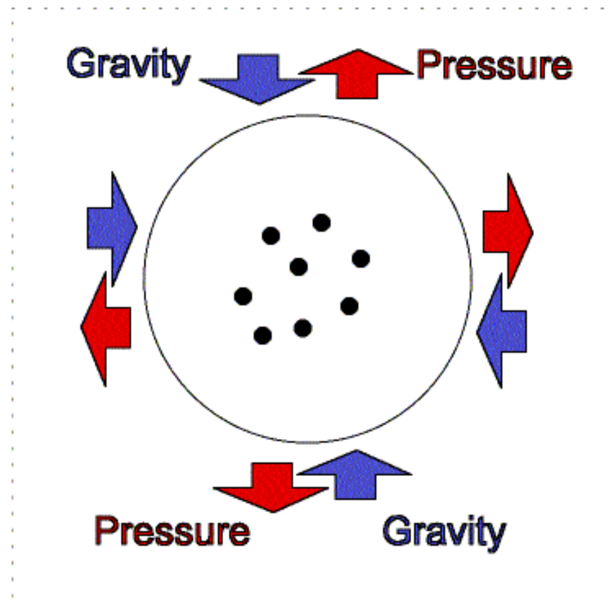


More massive stars have greater gravity compression. They need higher core temperatures to be stable and have very many more nuclear reactions. A slight change in mass produces a large change in luminosity.

Pressure and Gravity

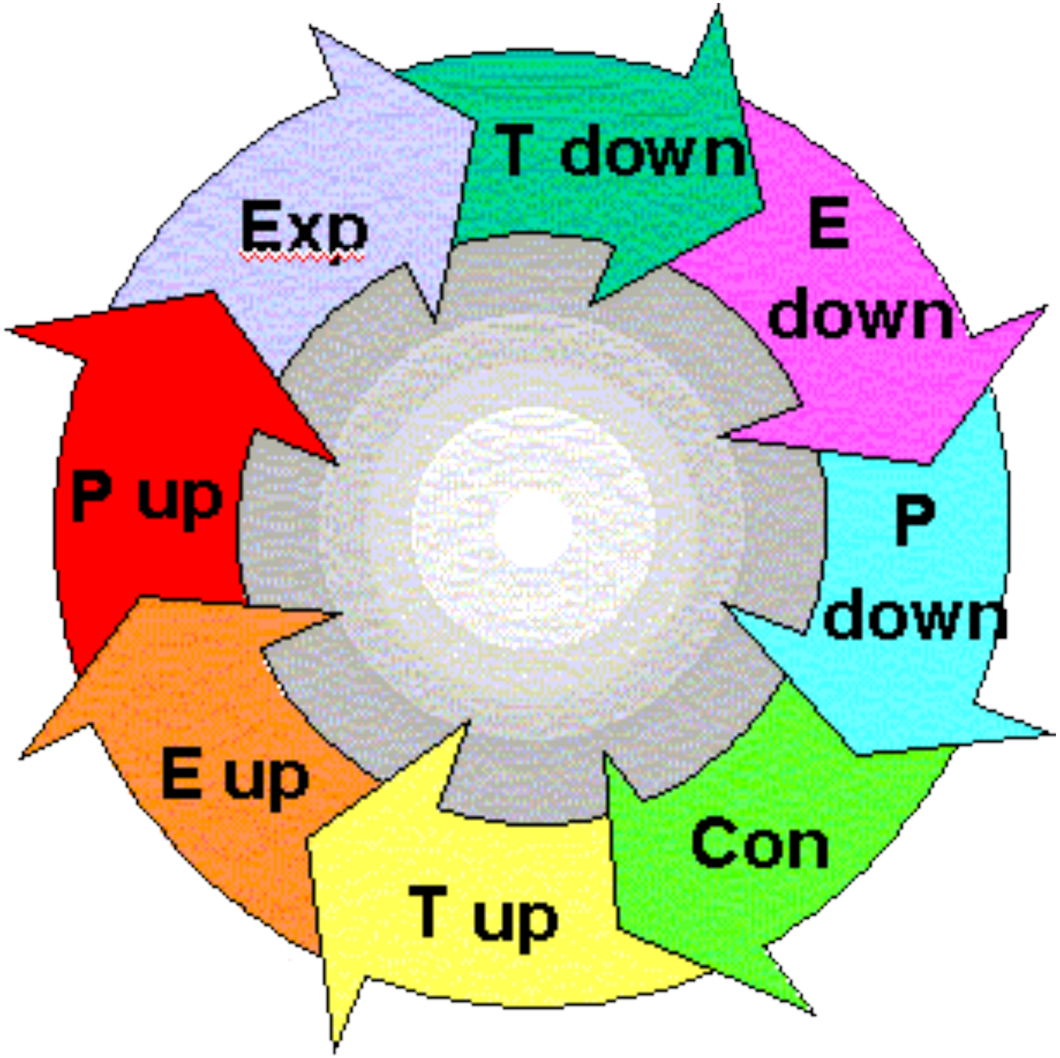
- Pressure depends on temperature = speed/kinetic energy
- Pressure depends on density (number of particles per volume)
- Gravity pulls gas together but is resisted by pressure of gas





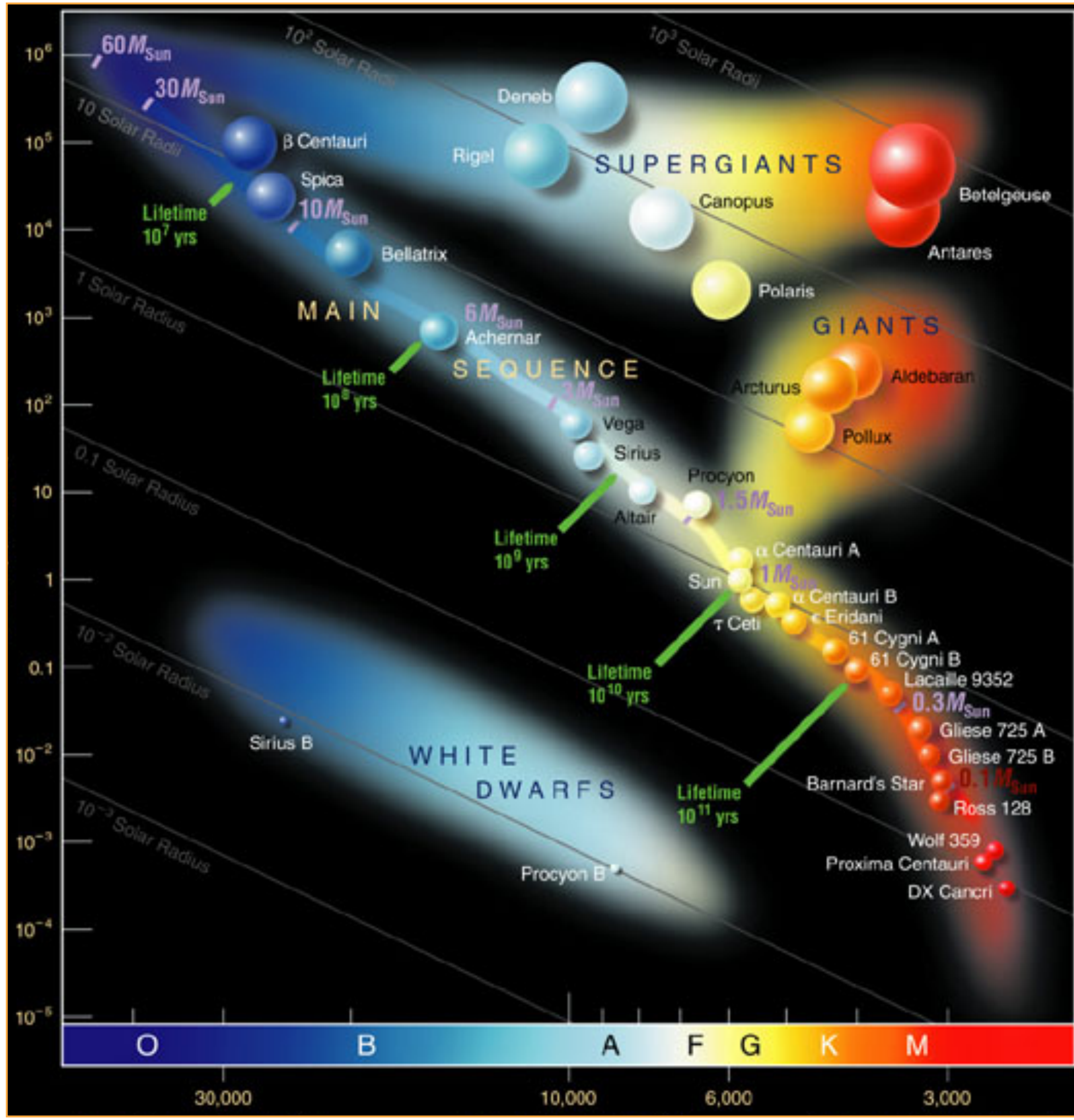
Pressure-Temperature Thermostat

- Con = core contracts
- T = temperature
- E= Energy production rate
- P = Pressure
- Exp = core expands



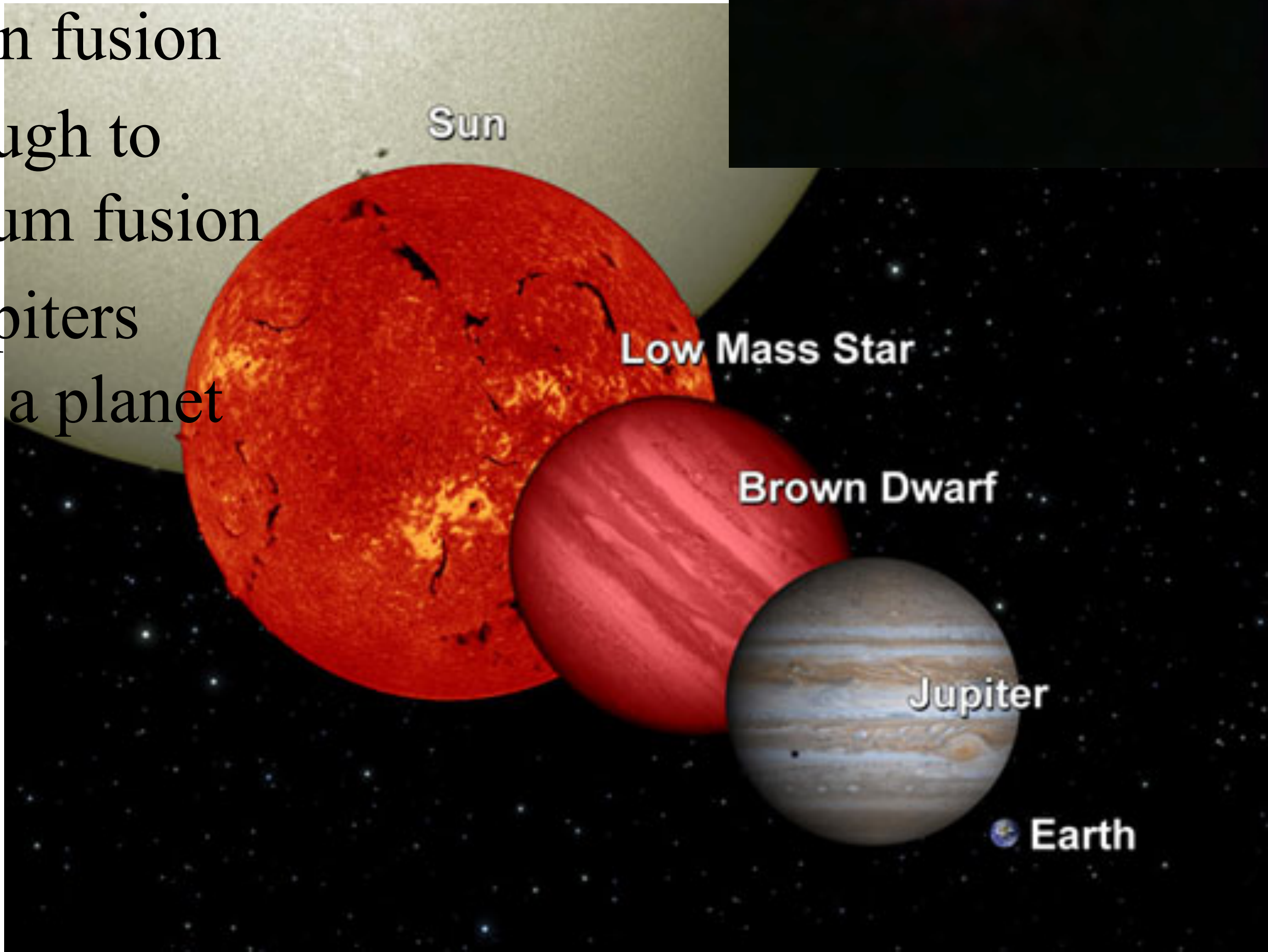
More Massive Stars–More Luminous

- The more massive the star
  – The more pressure needed to hold it up
- The hotter the core temperature must go
- The faster the protons go - the more fusion reactions
- More reactions- brighter star = Mass-Luminosity Relation



Brown Dwarfs

- Mass $< 0.08 M_{\odot}$ Core temperature too small to start Hydrogen fusion
- Mass big enough to ignite deuterium fusion
- Mass > 12 Jupiters Too big to be a planet
- Billions??



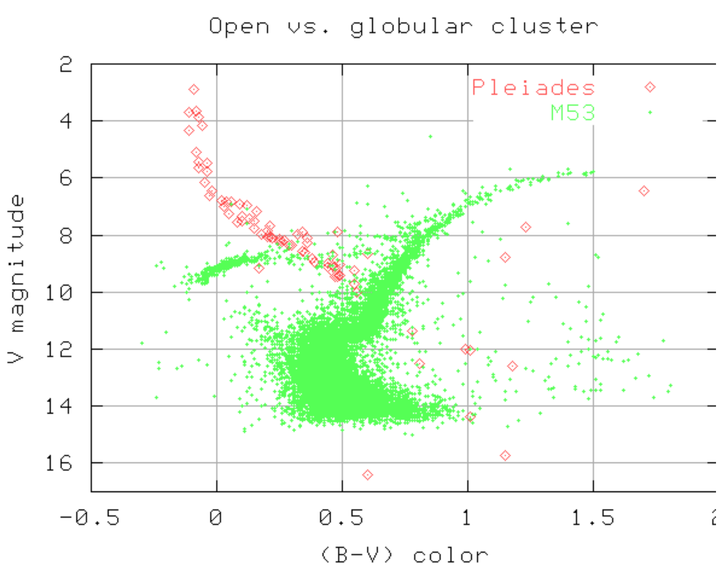
Open Clusters & Associations

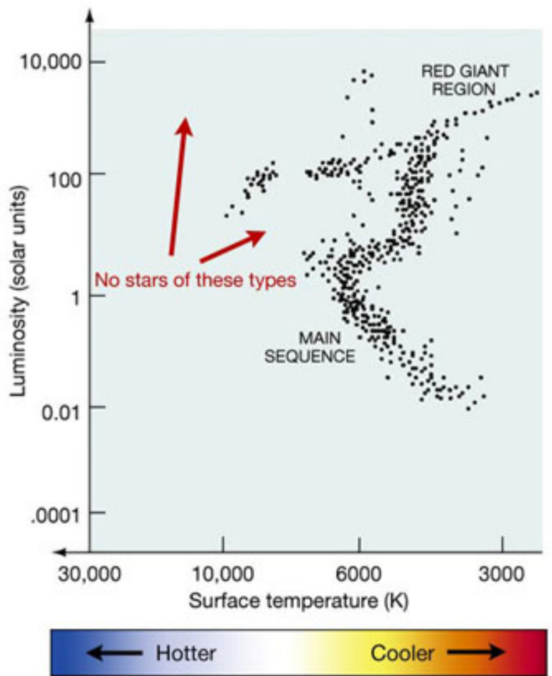
Stars form together in Open Clusters; lasting ~a billion years

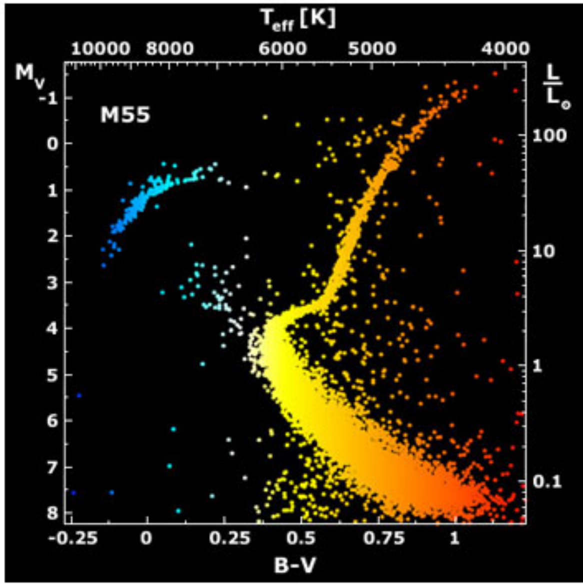
- Associations-not gravitationally bound; lasting ~million years
- NGC869,M35, NGC2158

Globular Clusters

- Million stars formed 13 billion years ago

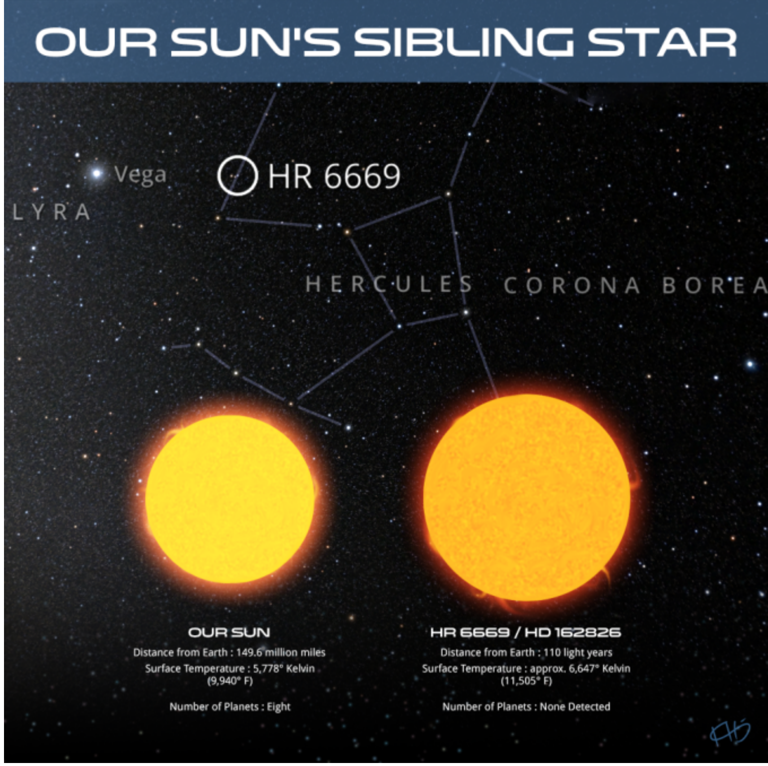


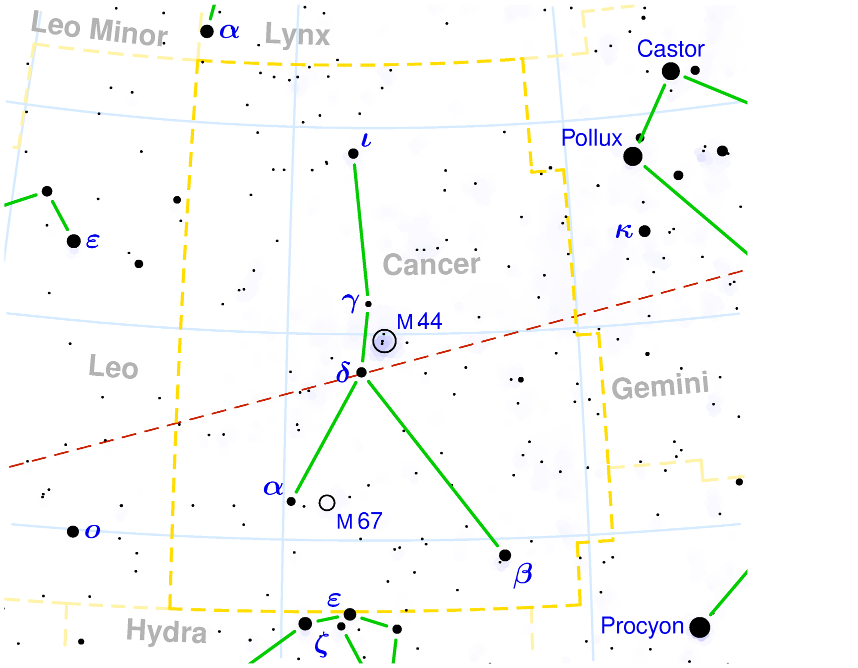




Sun's Birth Cluster?

- Sun would have been born in a cluster of stars maybe M67??
- Julio Navarro says No – correct age but wrong space motion
- Or maybe HD162826 is sibling?



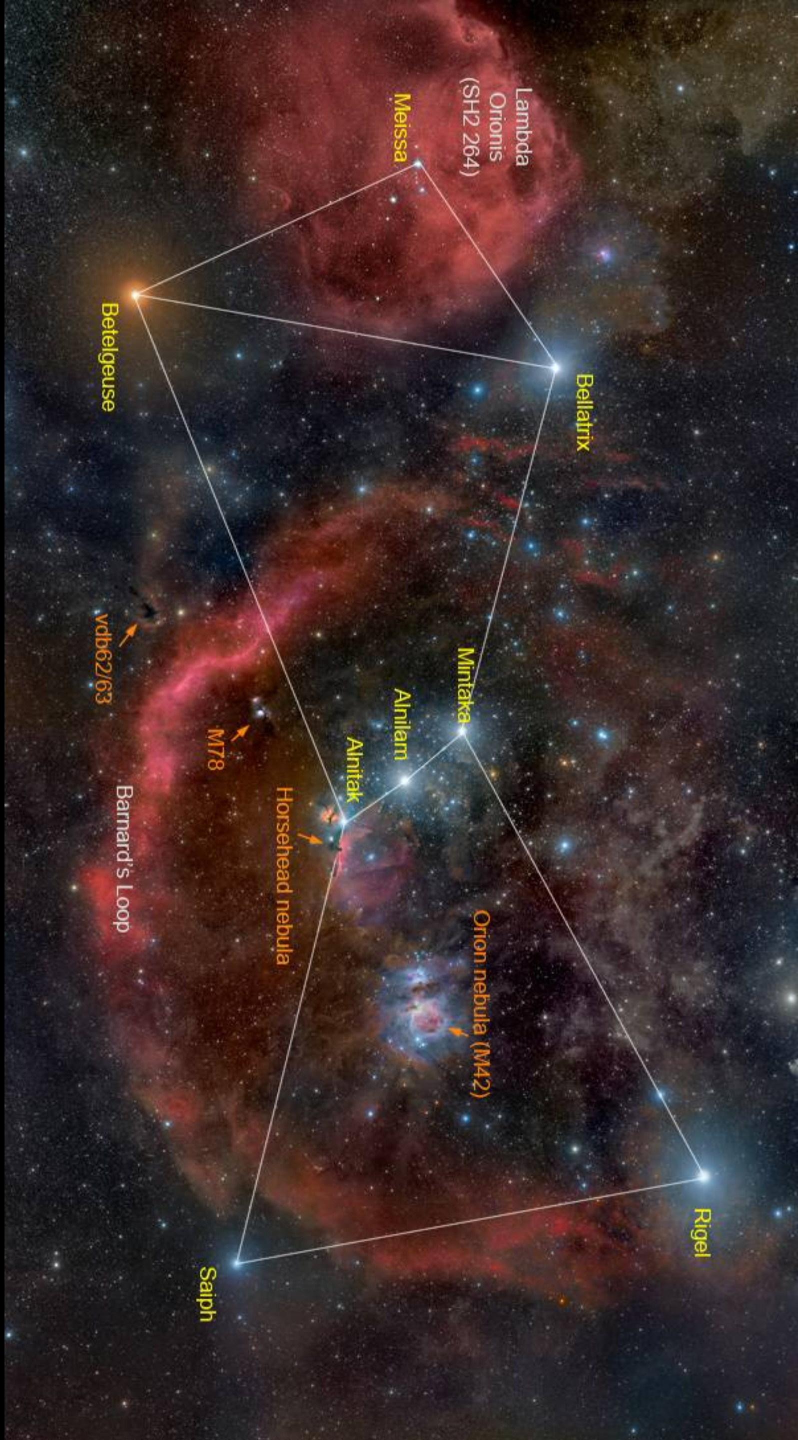


Stars form:

a. In Giant Molecular clouds
b. When a shock like a supernova explosion compresses a giant molecular cloud
c. With more massive stars forming first
d. In Open Clusters or Globular Clusters
e. All of these are correct

Orion Constellation

- Orion the Hunter



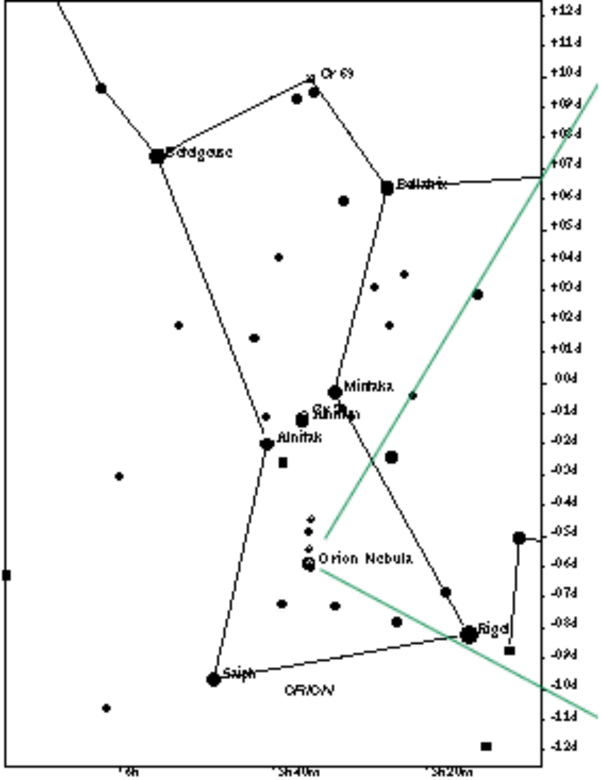
Examining a Star Forming Region

Oldest stars in shoulders, then belt, then sword

M78, Belt and Sword of Orion

Orion's Belt

- Alnitak, Alnilam, Mintaka light up the ISM (red, blue, black?)
- Three O and B supergiants formed a few millions years ago
- Show interstellar absorption lines of wrong radial velocity
- IR shows Horse Head



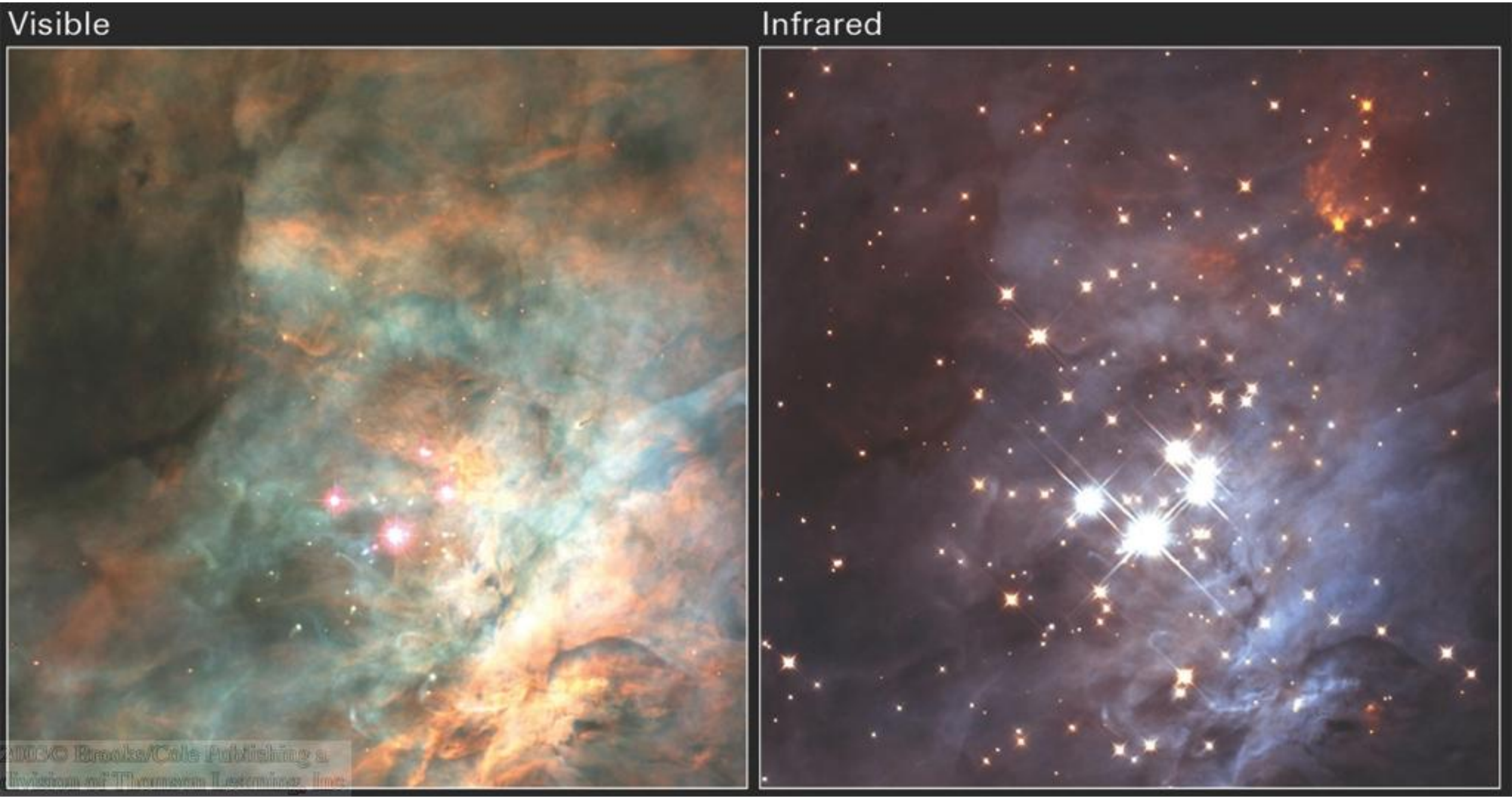
Orion Nebulae

- 1500 light years distant
- ~100 ly across
- Reflection nebula is blue
- Emission nebula is red

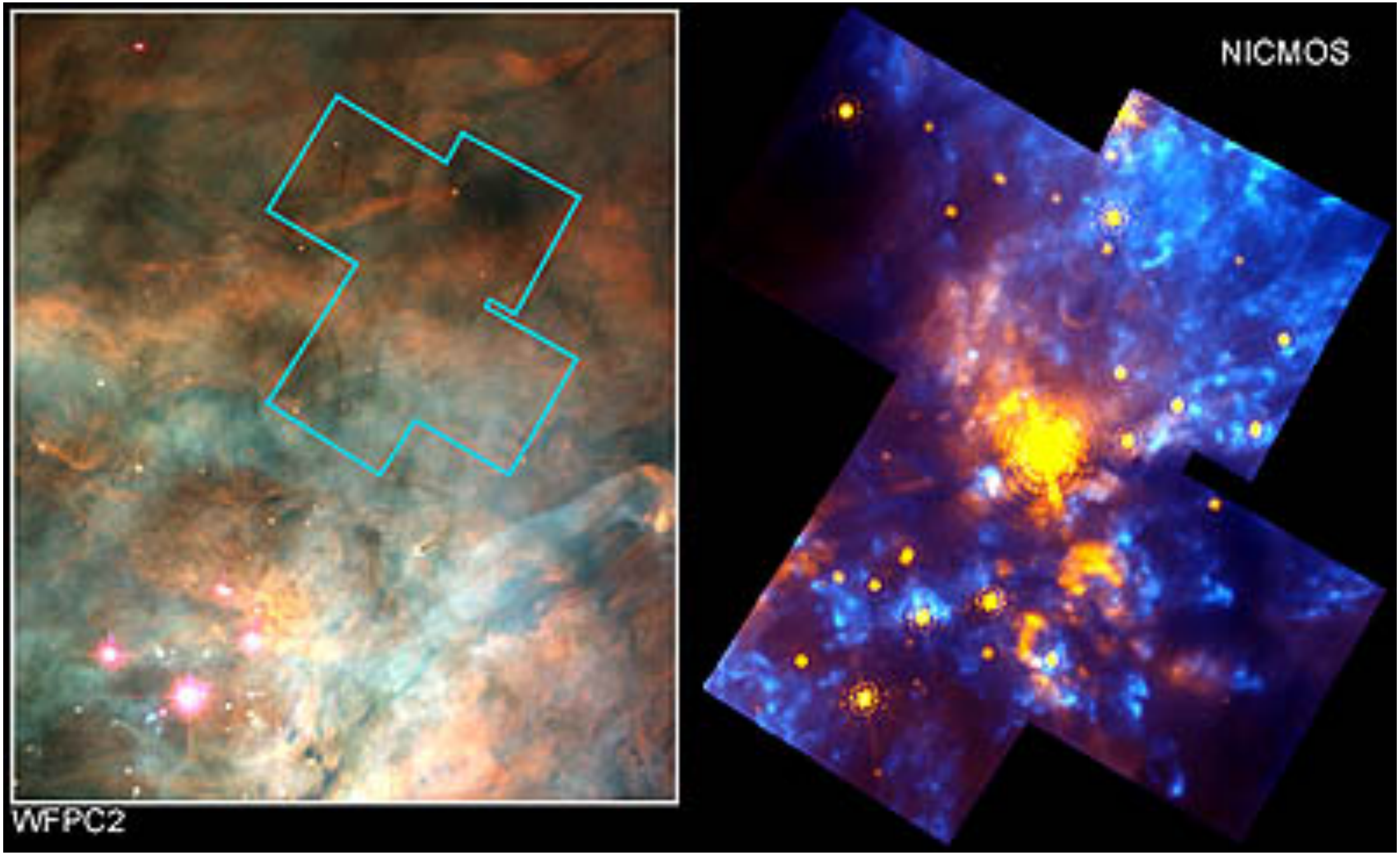
Trapezium

- One O3 star emits most of the UV powering the emission nebula (should be red

Near Infrared Reveals New Stars



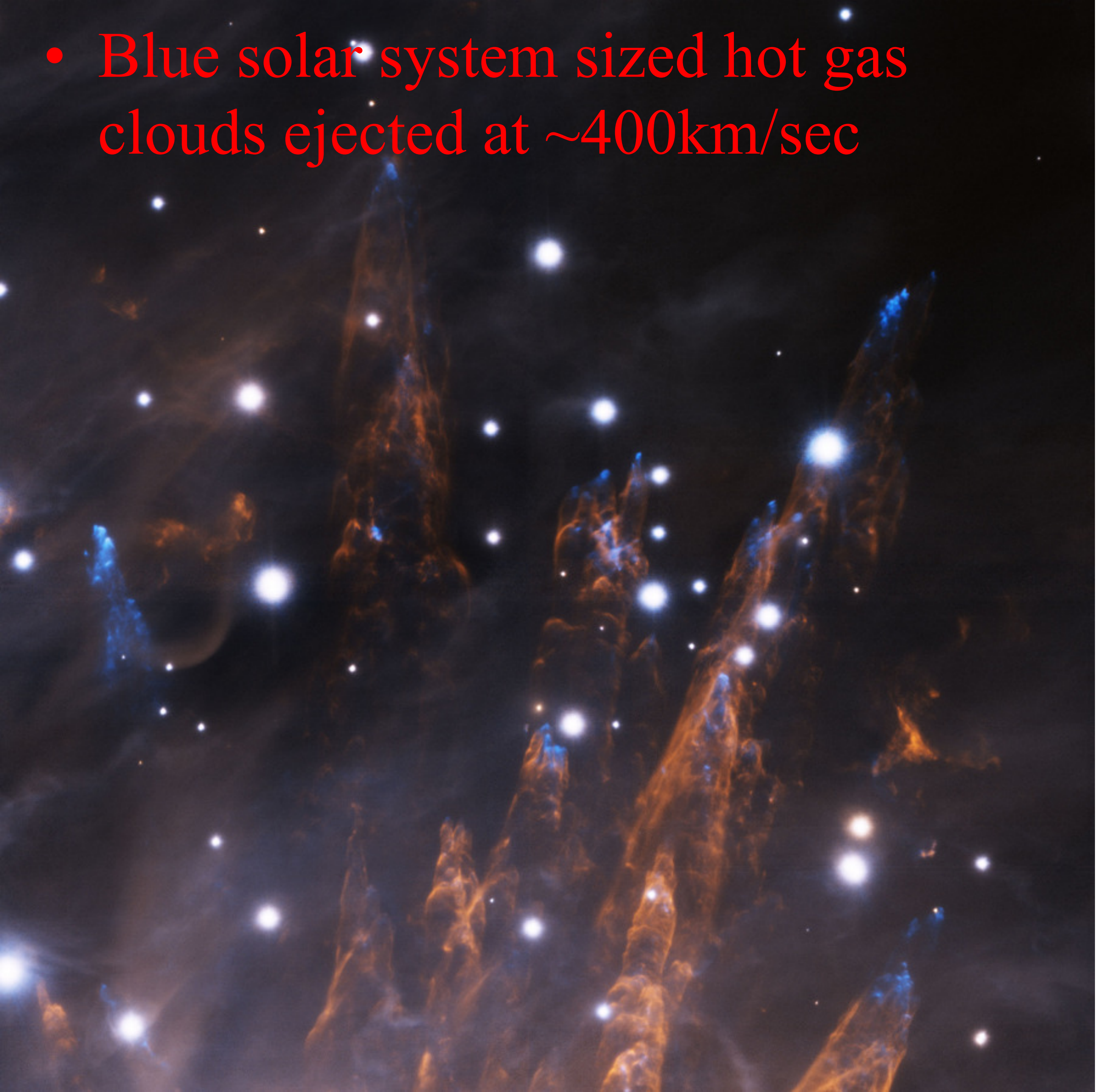
Protostars Revealed in Orion



Protostellar/planetary Disks

Orion Bullets

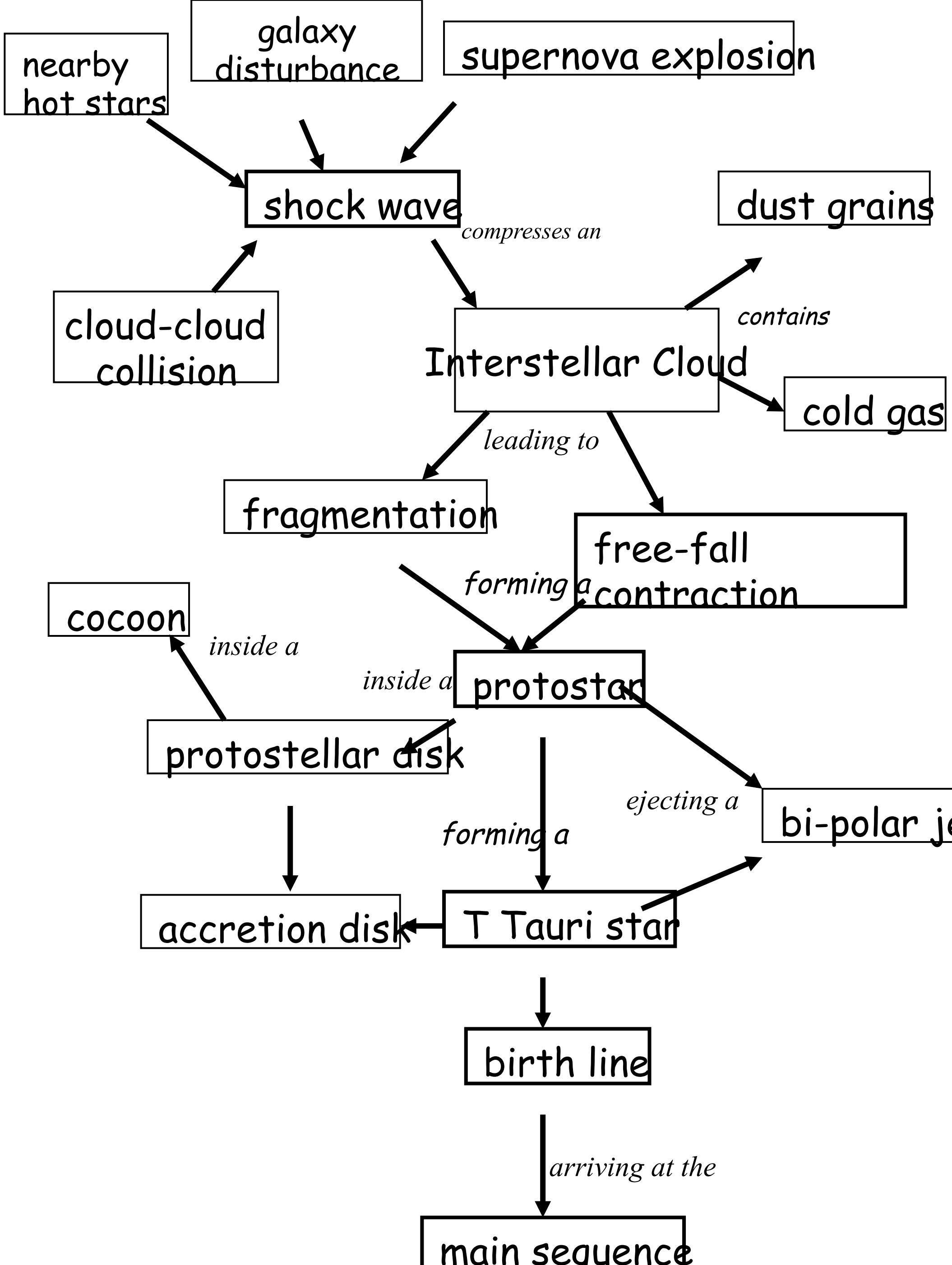
- Blue solar system sized hot gas clouds ejected at ~400km/sec

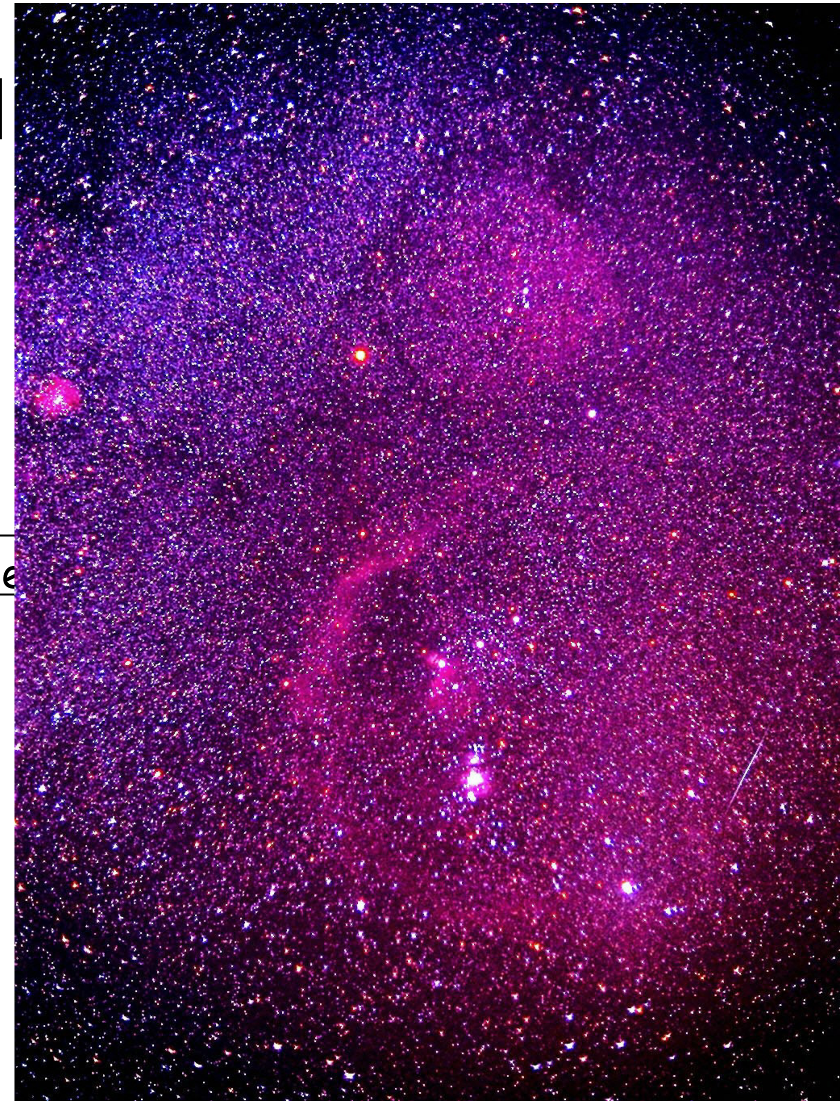


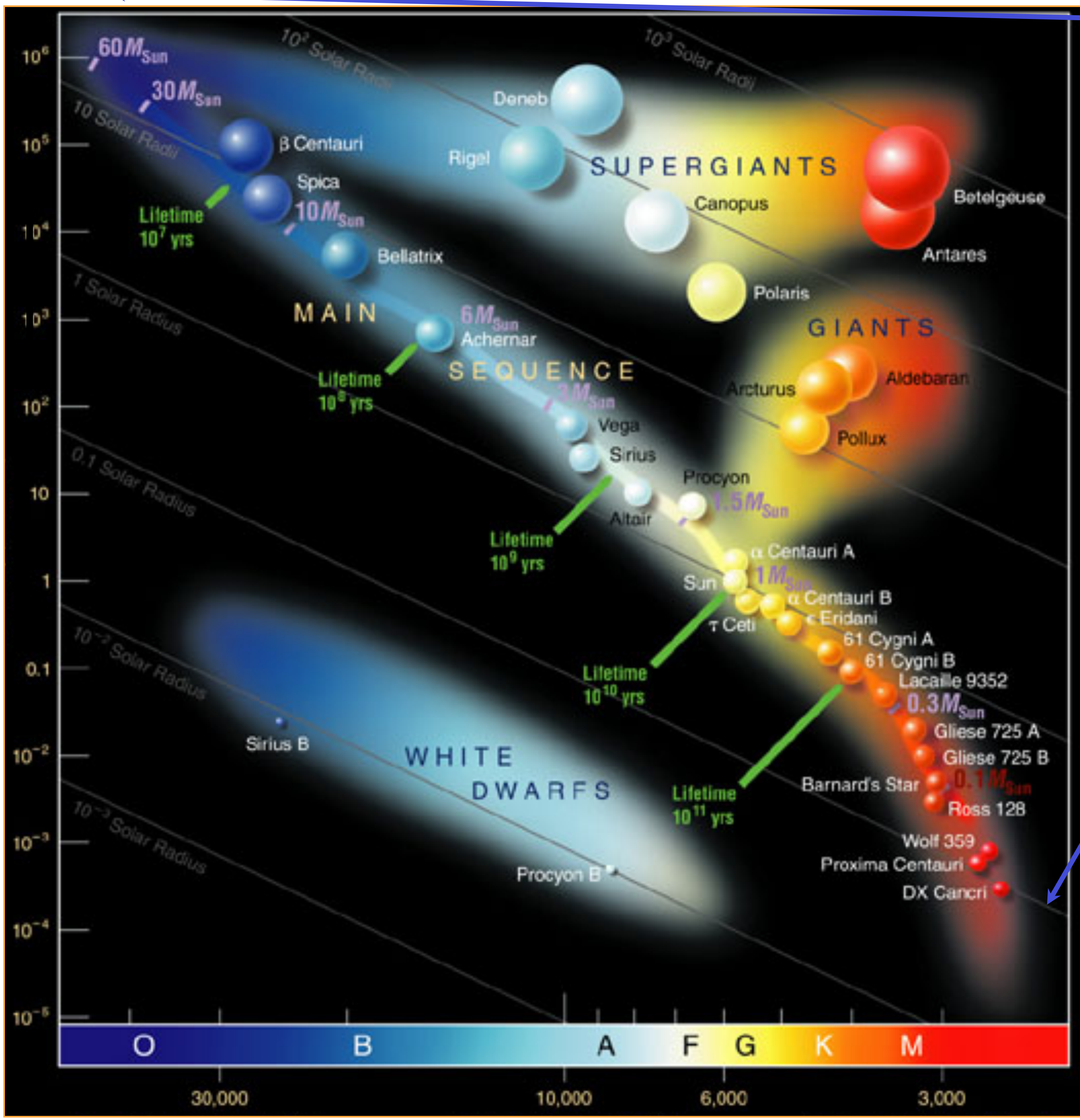
Orion Observational

Orion Simulation

Concept Map for Star Formation



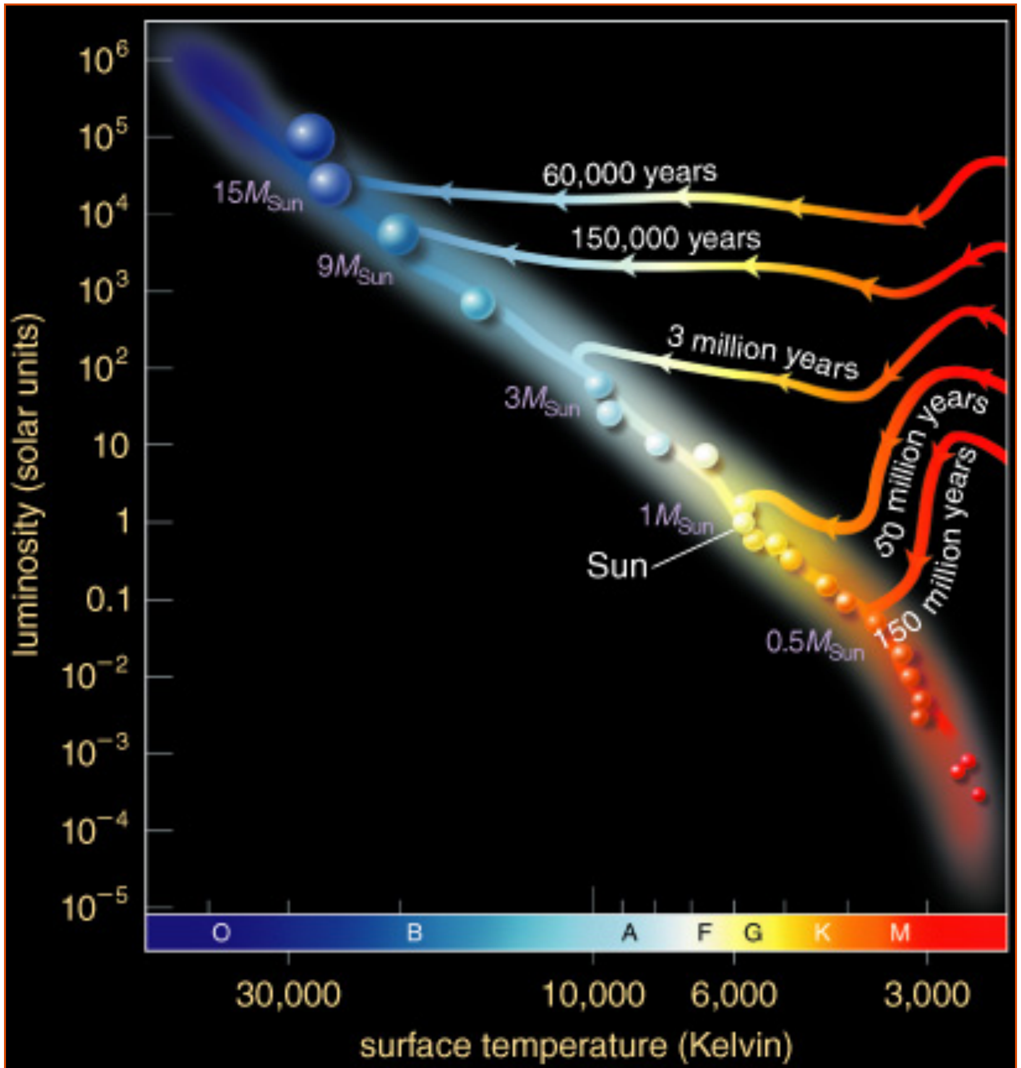




Stars more massive than $150 M_{Sun}$ would blow apart

Stars less massive than $0.08 M_{Sun}$ can't sustain fusion

Protostars Join Main Sequence

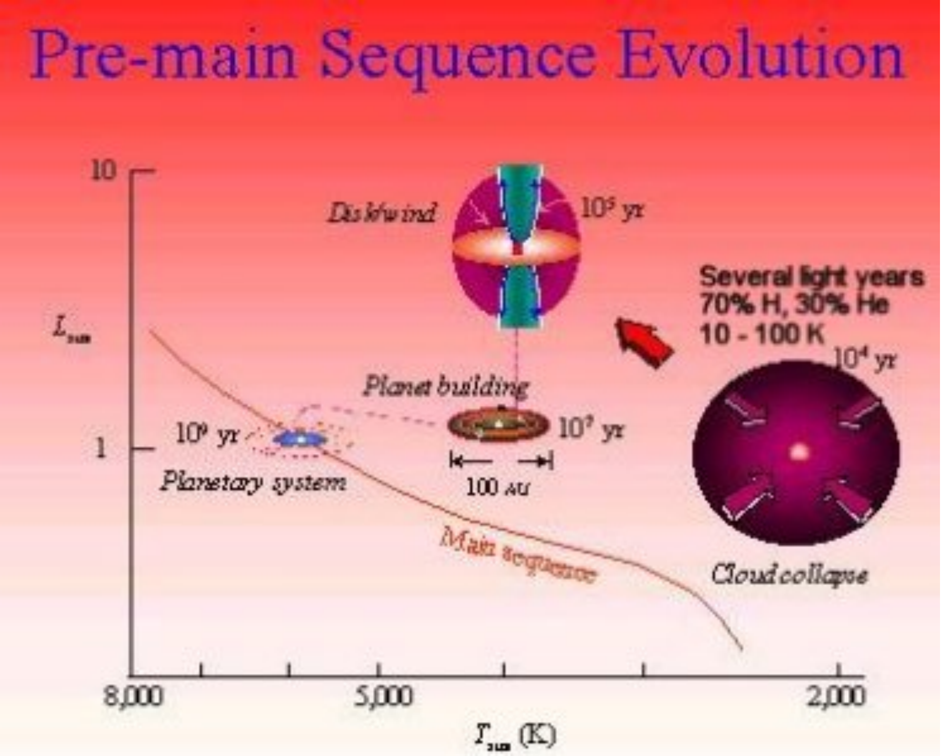


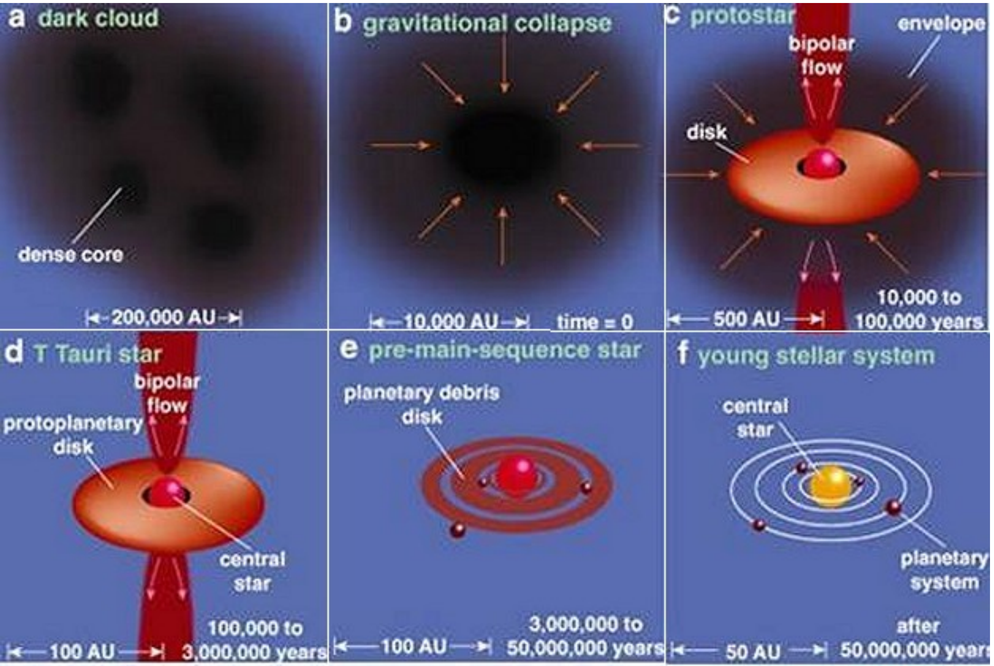
- Models show that Sun required about 30 million years to go from protostar to main sequence
- Higher-mass stars form faster
- Lower-mass stars form more slowly

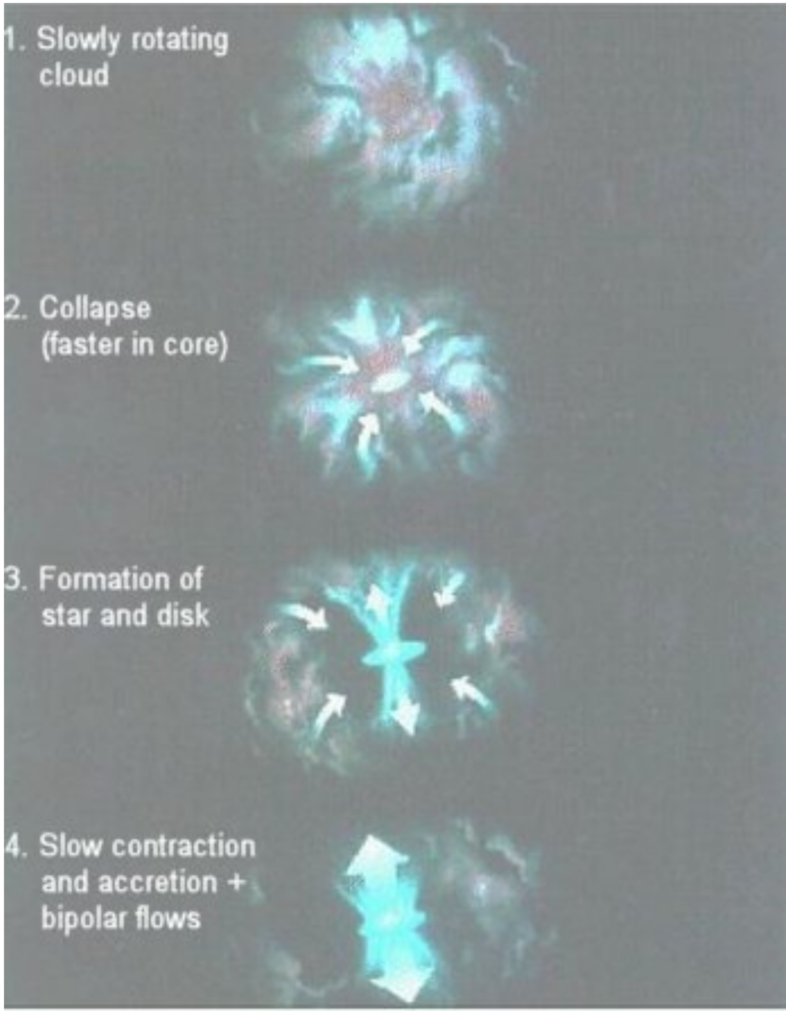
NGC 2264

- A star is born when Hydrogen fusion ignites
- At a core temperature > 10 million K
- And protons can overcome the Coulomb repulsion

Pre-main Sequence Evolution

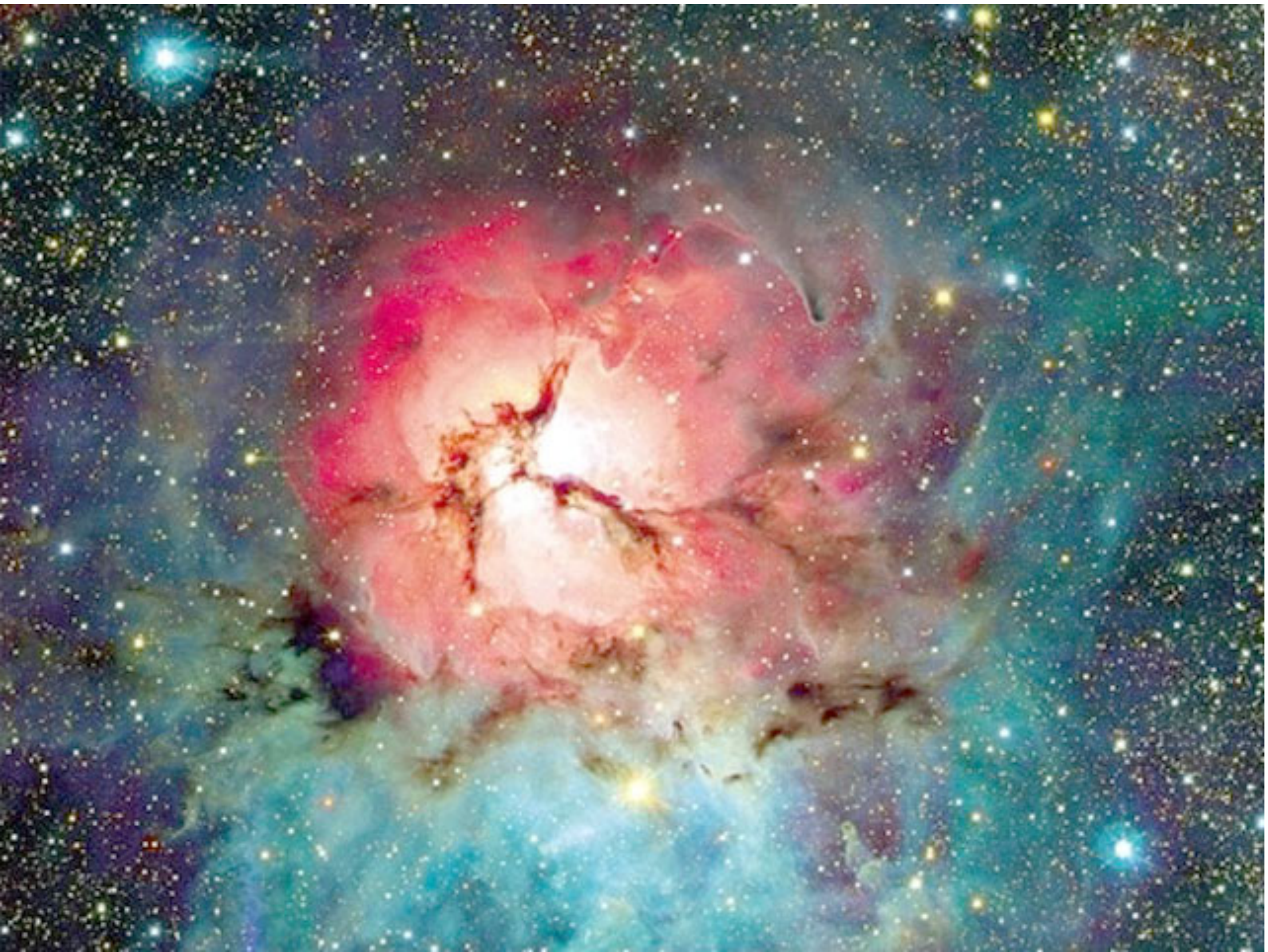






Review ISM

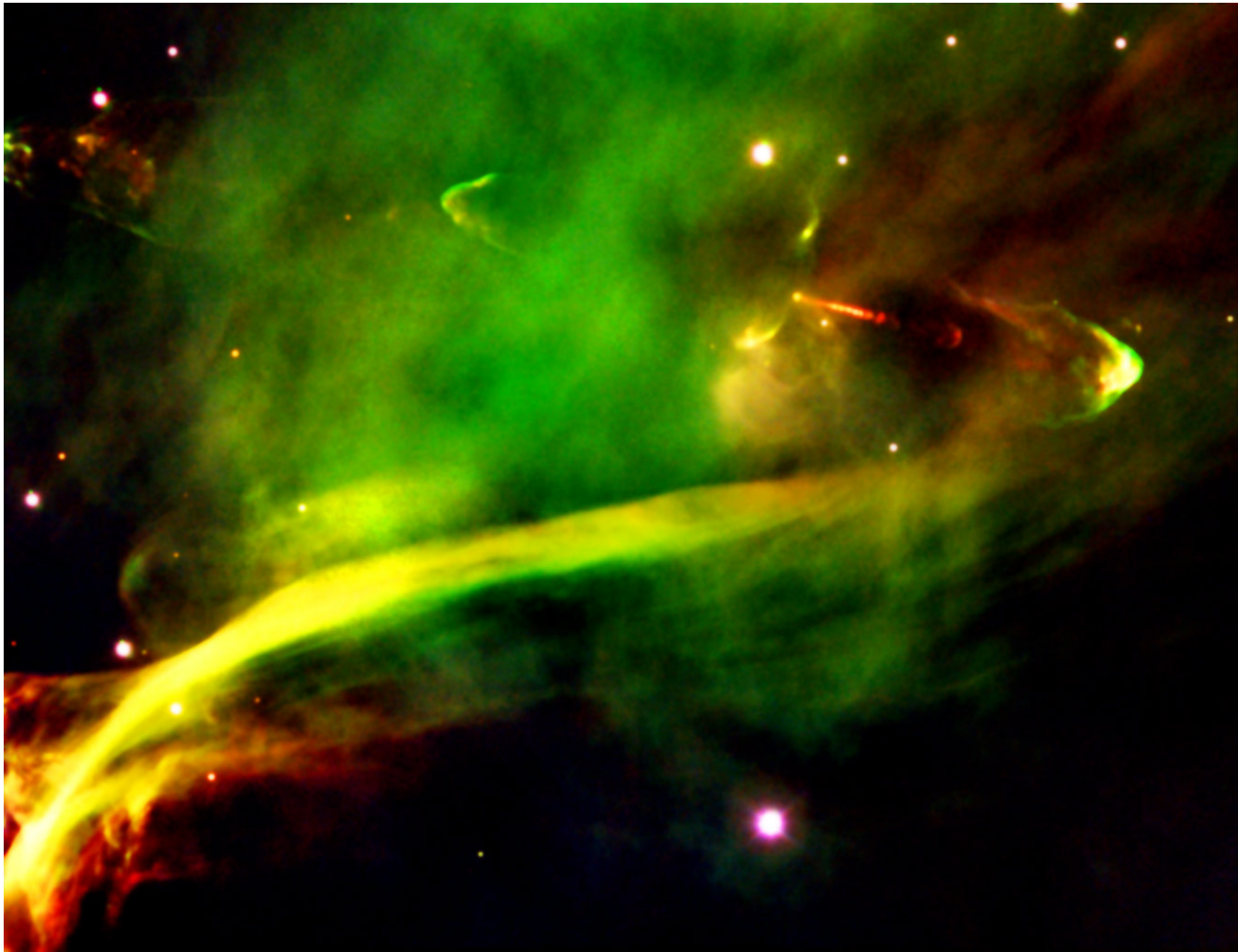
- Emission Nebulae: Red, H II, 10,000 Kelvin
- Reflection Nebulae, Blue, H I, 1,000 Kelvin
- Dark Nebula: Black, H_2 molecules, 10Kelvin



Stars seen through dust will seem fainter, redder have interstellar lines

Atomic hydrogen HI gas will emit 21-cm radio

HH34 is Bipolar Flow??

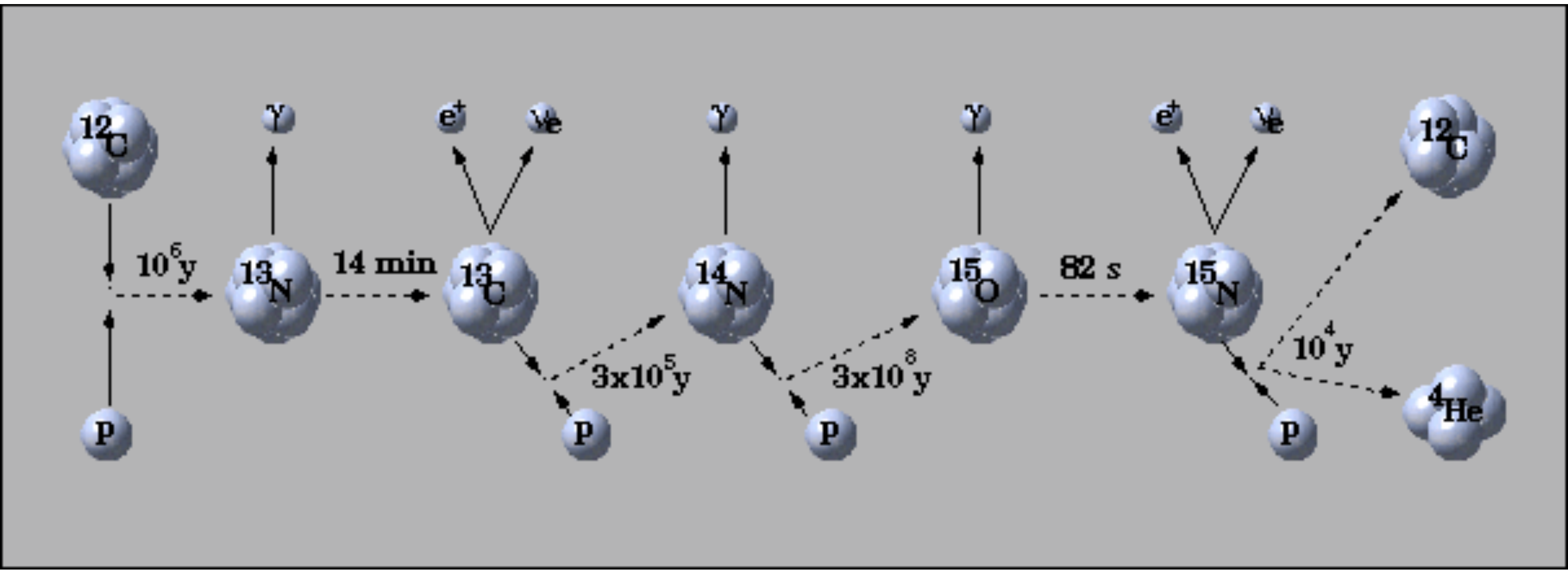


Star Formation in SMC

- A giant molecular cloud collapses due to cloud collision, spiral arm, supernova or stellar wind
- Overcoming thermal pressure, rotation, turbulence and magnetic fields
- Becoming hotter from gravitational contraction
- Blowing away dust to reveal the star

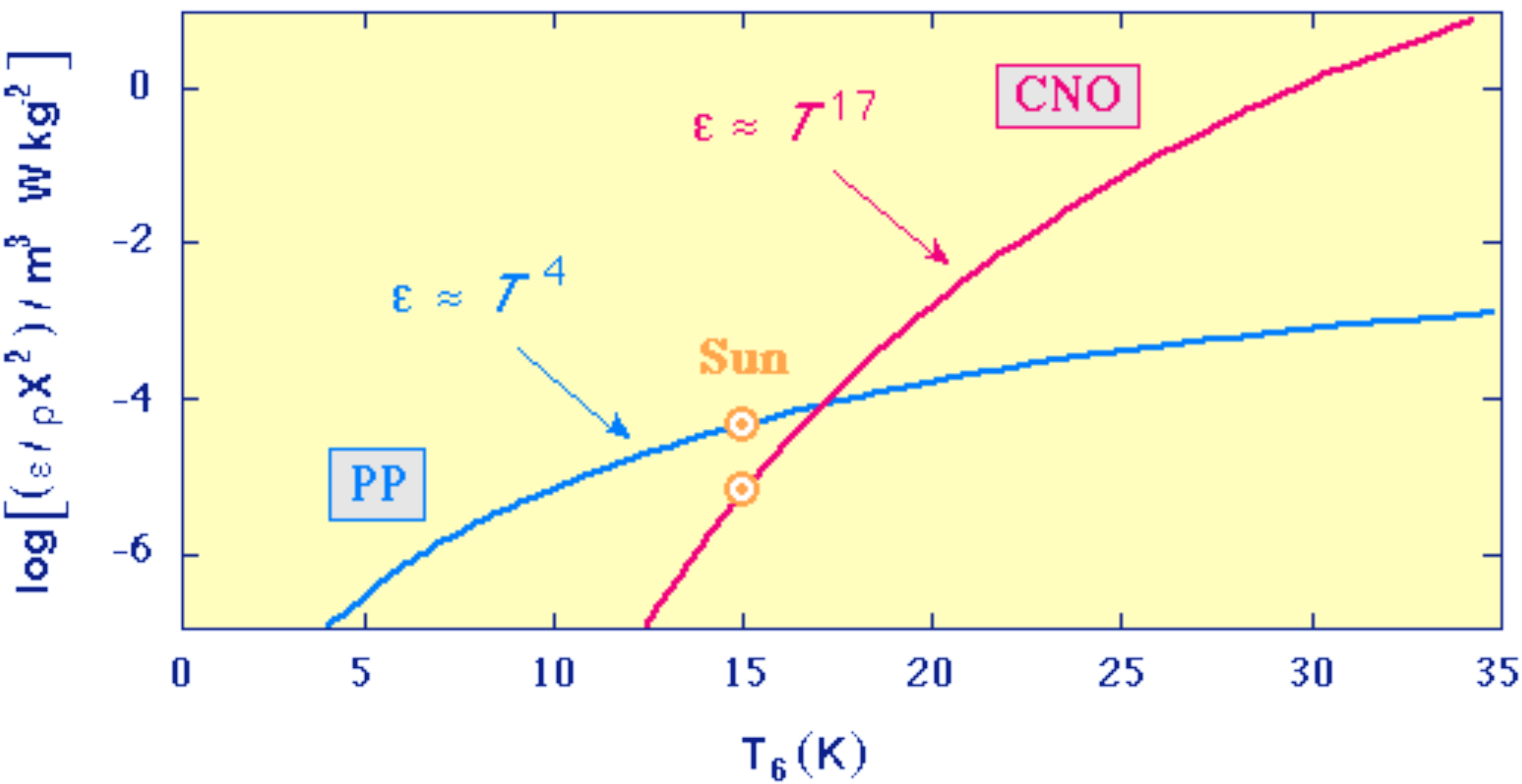
Carbon Nitrogen Oxygen=CNO Cycle

- At higher temperatures protons can penetrate higher coulomb barrier
- Carbon gains a couple protons to become Nitrogen
- Which gains a couple of protons to become Oxygen
- Which ejects a Helium to become Carbon plus energy



PP-CNO Temperature Dependence

- Efficiency ε depends on temperature T
- Central temperature depends on star's mass
- 10% increase in temp – PP increases 46% and CNO 350%



Protostars

- Energy from collapse (Free-fall contraction) heats cloud fragment
- Gravitational converted to thermal energy
- Gas & dust radiate so collapse continues until
- Cloud becomes opaque and thus a protostar