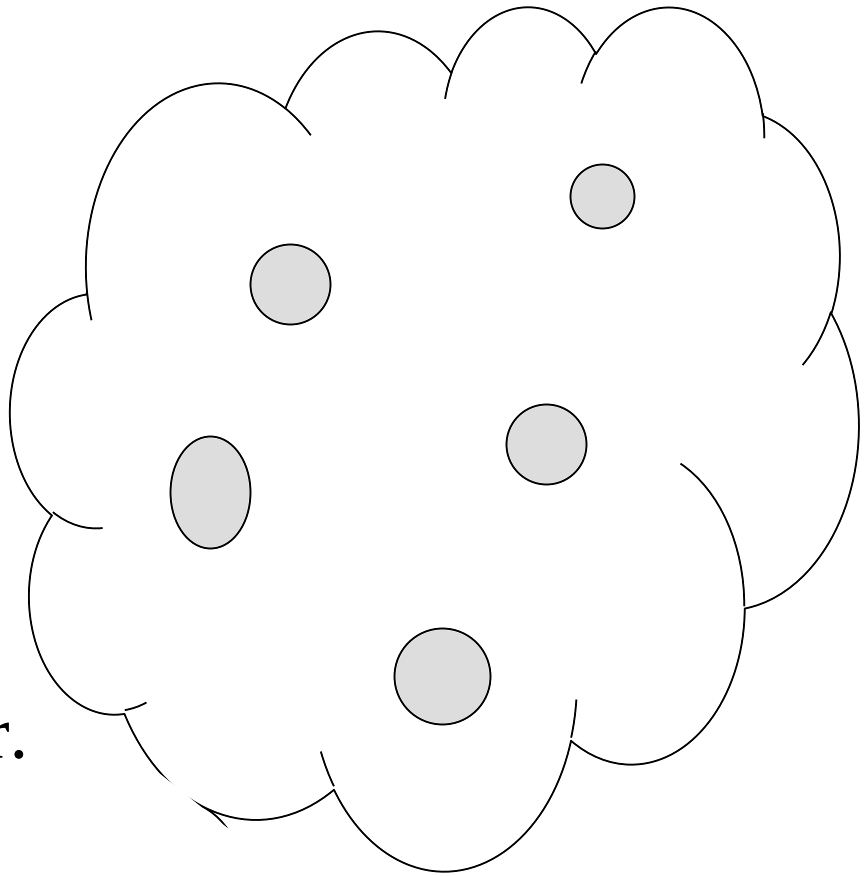
Lecture 21
Formation of Stars

November 14, 2018

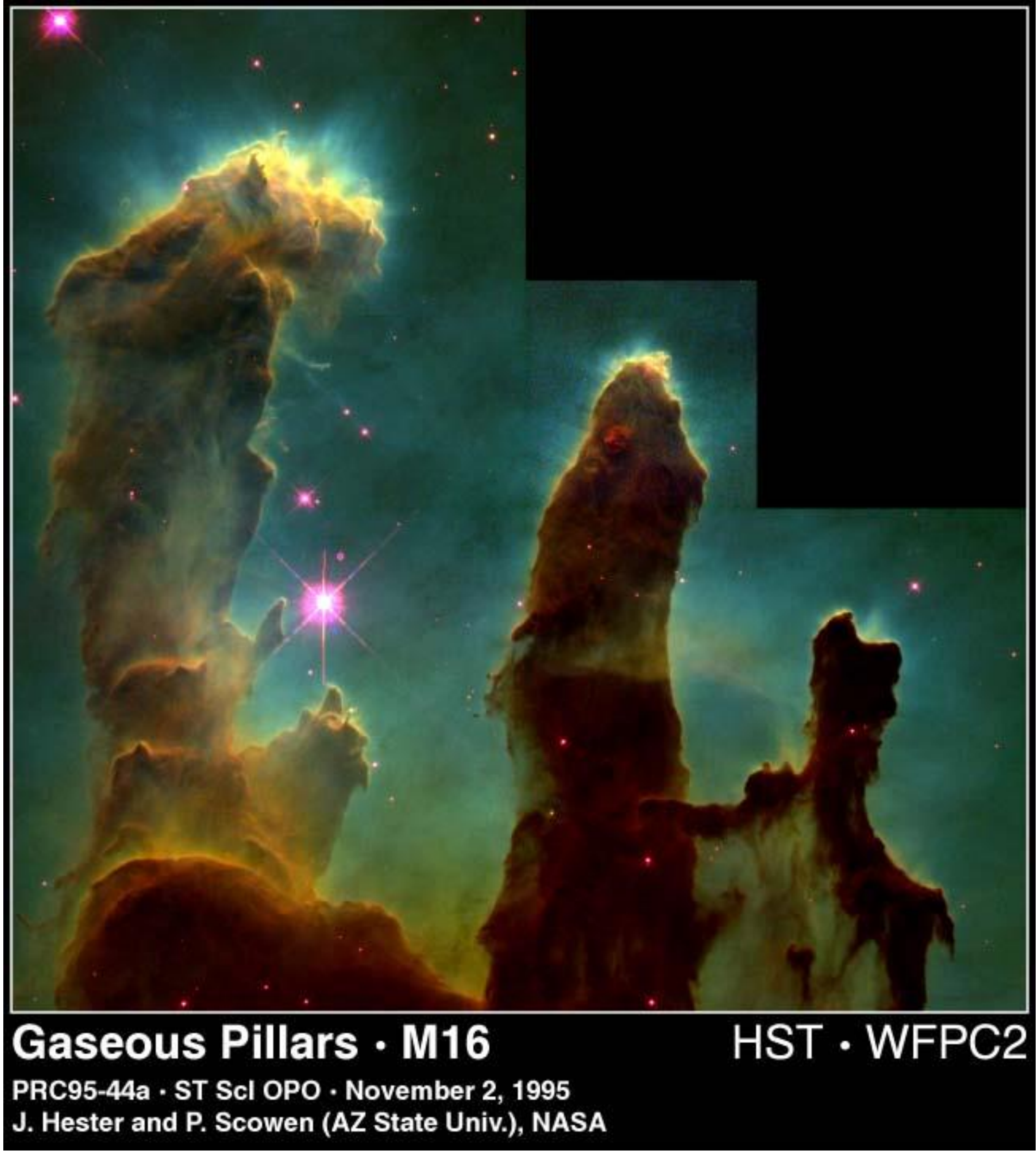
Birth of Stars

- Stars originally condense out of a COLD, interstellar cloud
  - composed of H and He + trace elements.
  - cloud breaks into clumps (gravity)
  - Each clump will make a star.

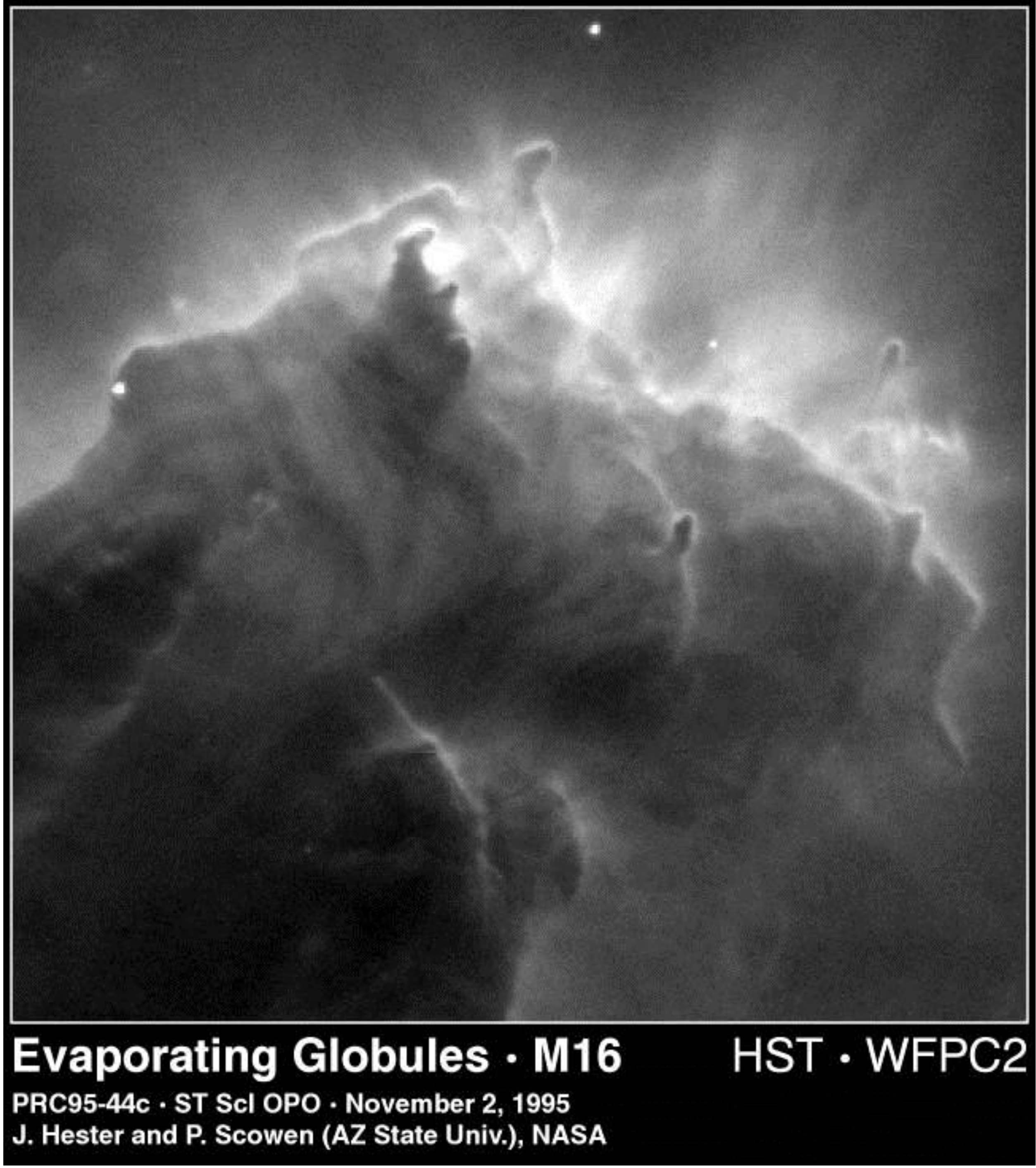


Eagle Nebula

Hubble Space Telescope (HST)



Eagle Nebula – HST



http://messier.seds.org/Pics/Png/m16habw.png

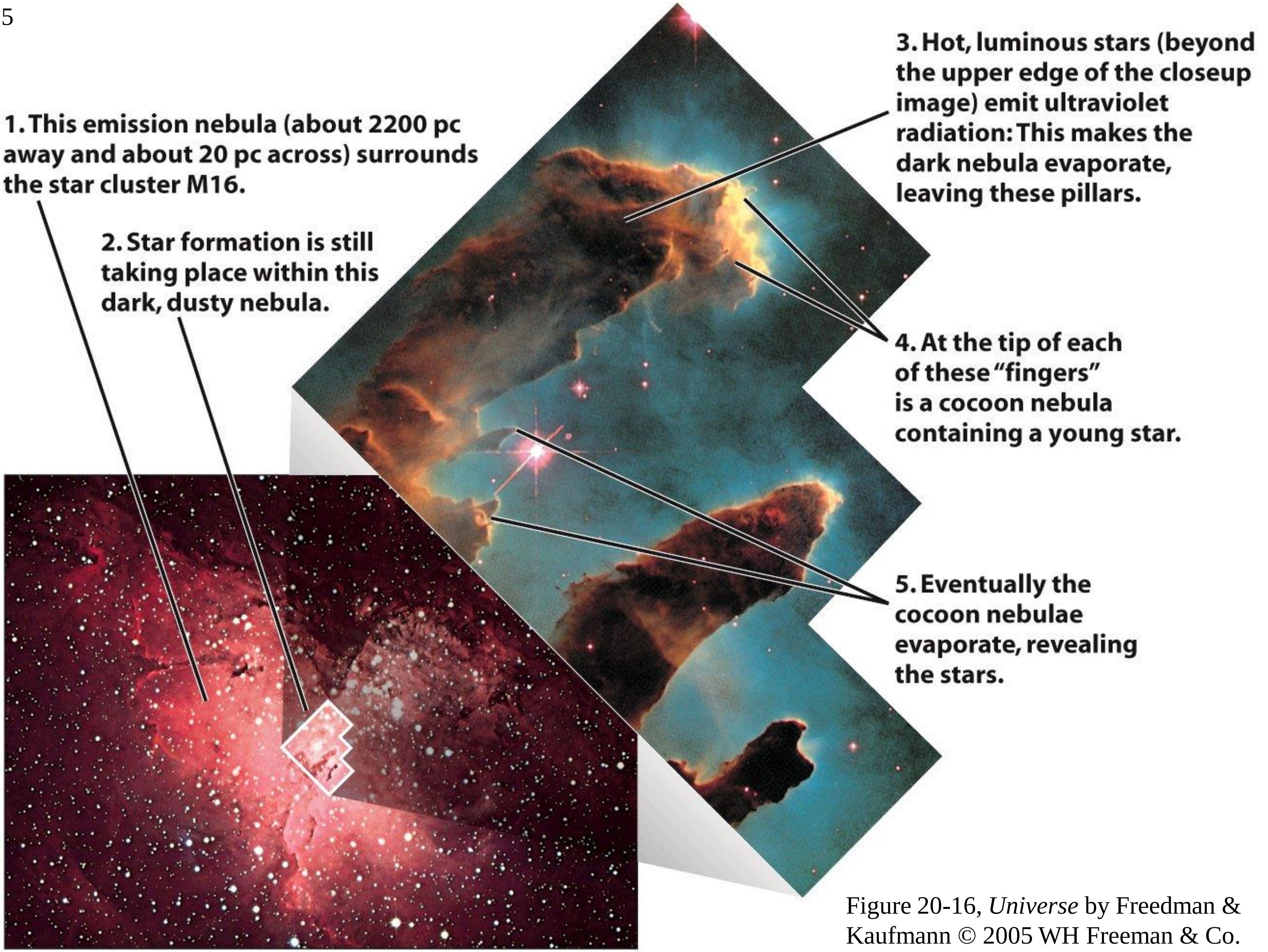
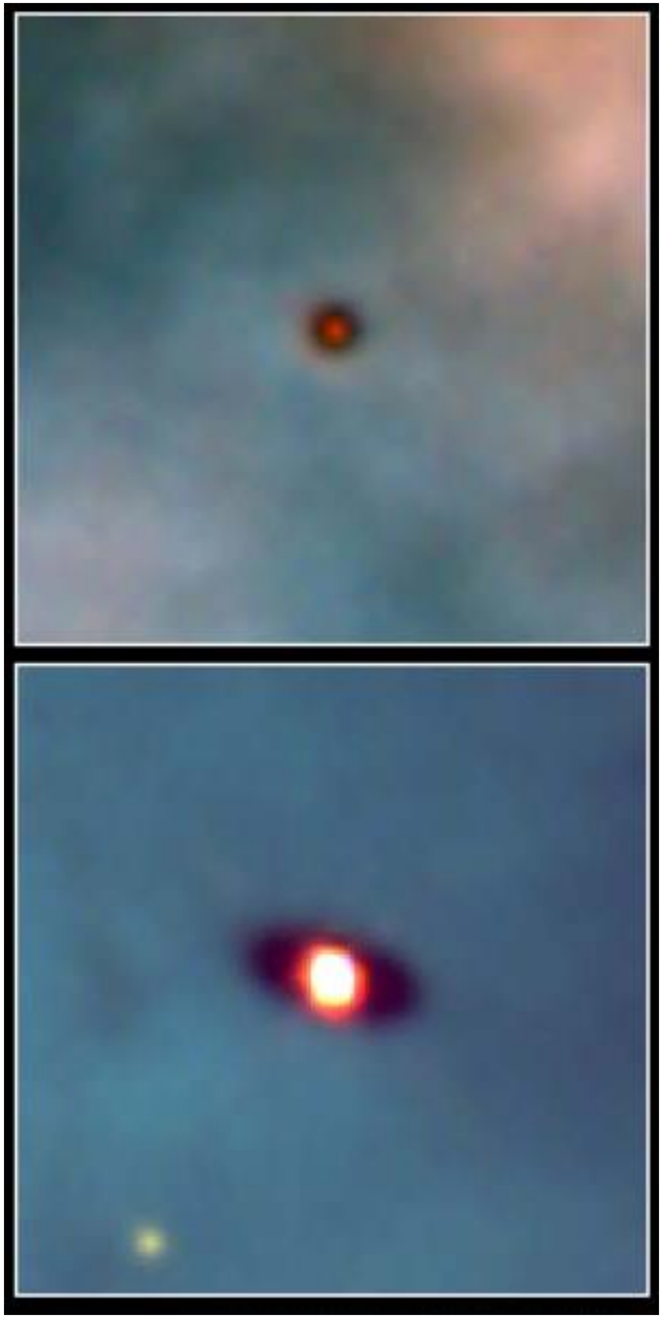


Figure 20-16, *Universe* by Freedman & Kaufmann © 2005 WH Freeman & Co.

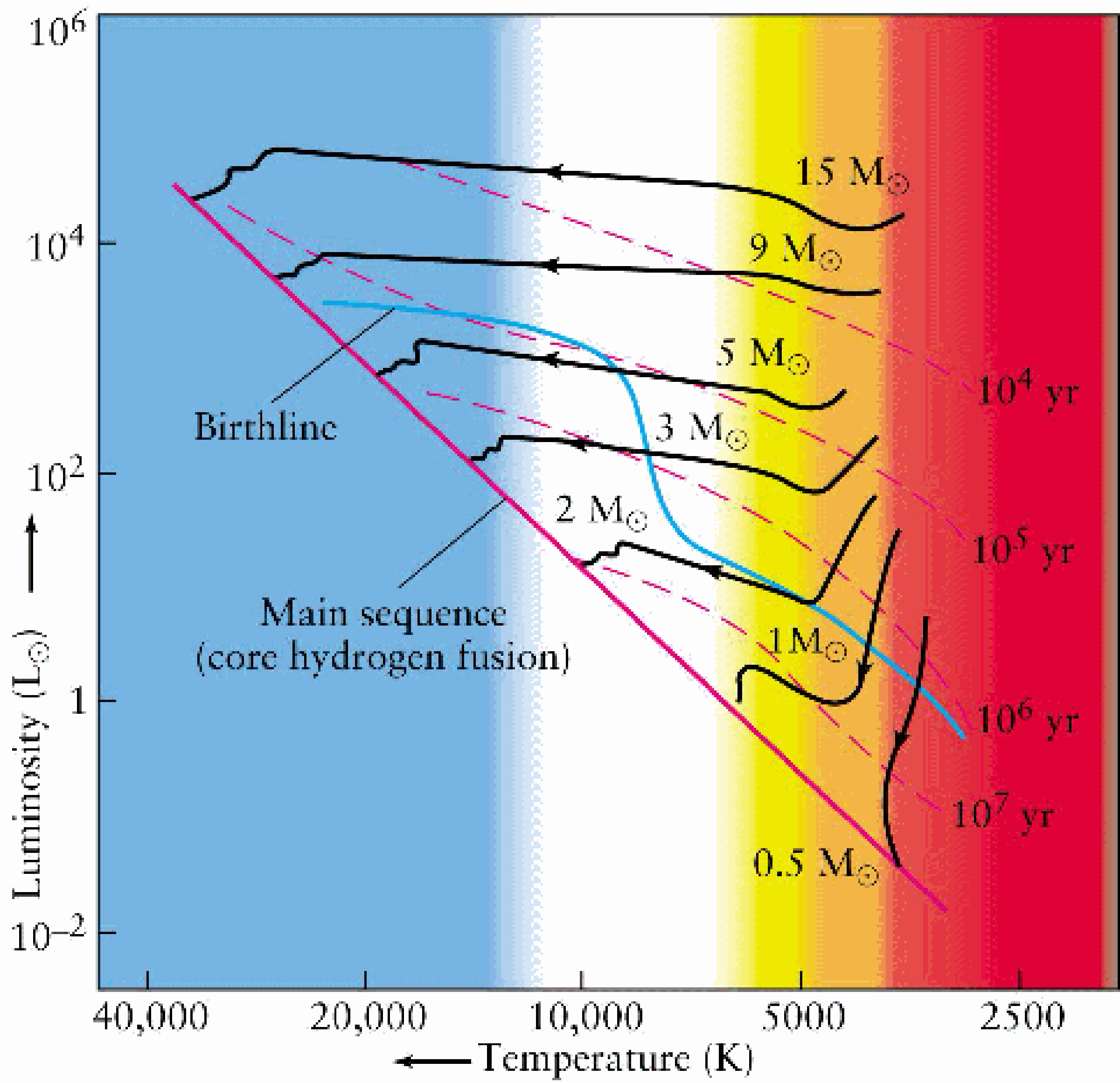
Protostars

- Protostar Forms
  - inner part of fragment becomes Proto-star continues to grow as mass falls on it
  - density and temperature increase
  - center ~1,000,000 K
  - gravity is stronger than the outward pressure of the heat, so the protostar continues to condense



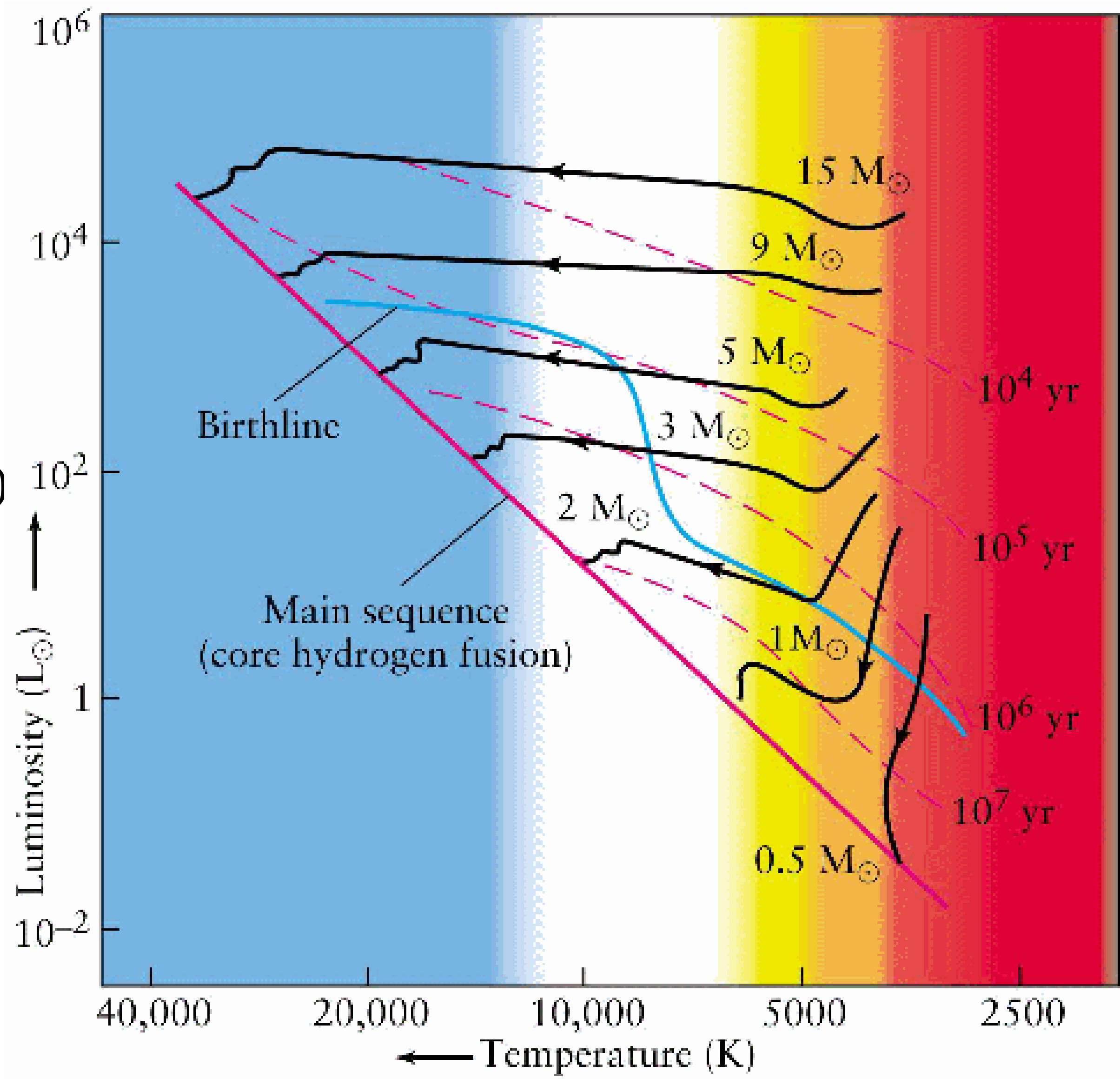
Protostar Evolution

- Protostar
  - shrinks
  - becomes hotter
  - less luminous
- Protostar stops accreting mass
  - solar wind prevents more particles from arriving
  - Now a pre-main-sequence star
  - crosses blue line



Protostar Evolution

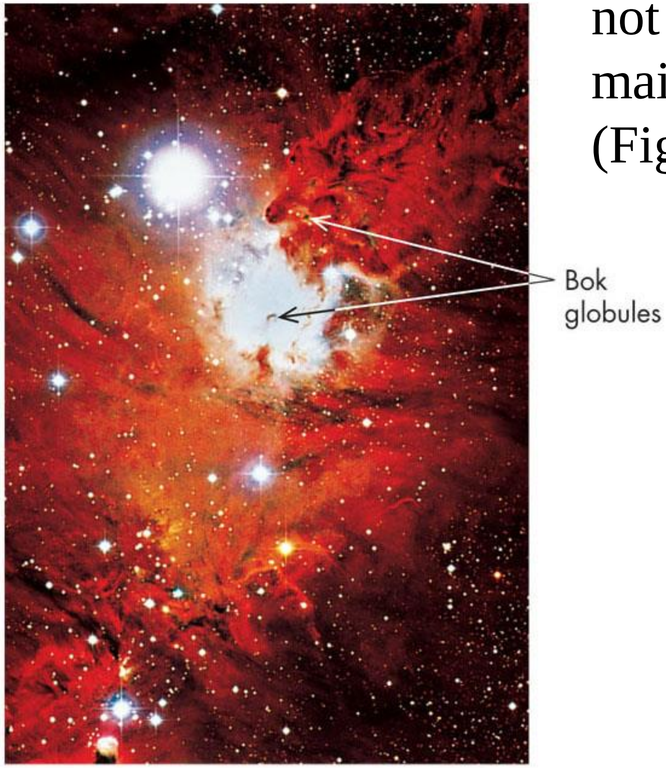
- Pre-main-sequence star
  - collapses slowly
  - becomes hotter
  - If $<0.1M_{\Theta}$ it stays a **brown dwarf**, a cool, dim object with insuf-ficient mass to begin hydrogen fusion
- Fusion begins
  - high temp. (10 million K) and pressures in core
  - Can take 10^5 - 10^7 years
  - Now a true star
  - Massive stars $>7M_{\Theta}$ start fusing so early they are never pre-main-sequence
- Star moves to Main Sequence, achieves *hydrostatic equilibrium*



Main Sequence Stars

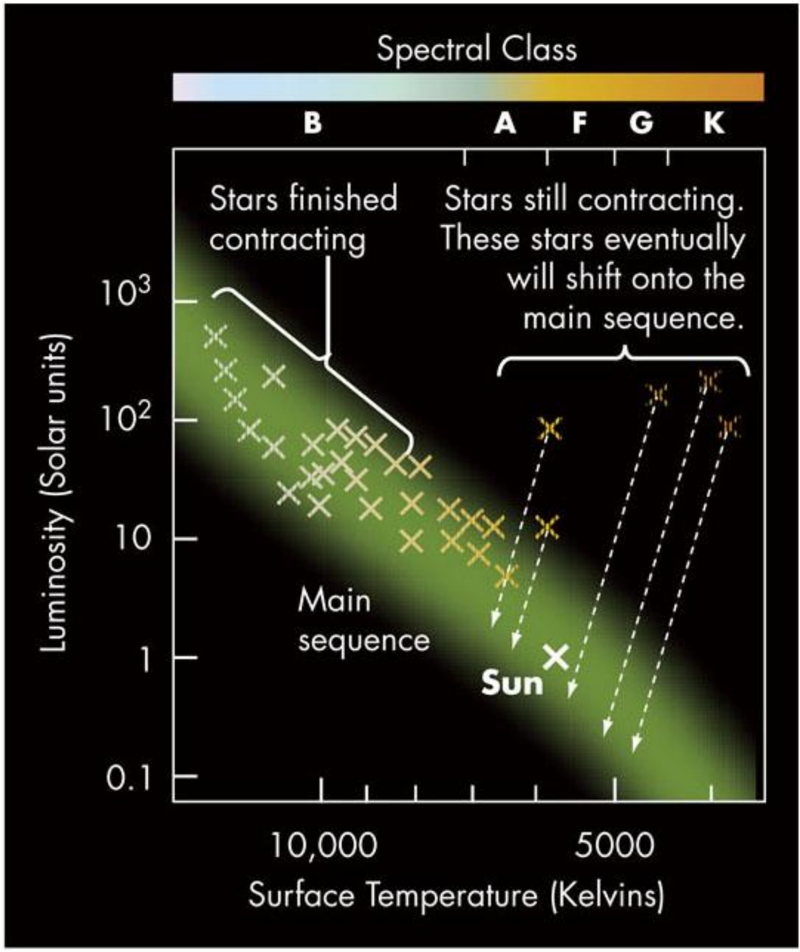
- Stars are in hydrostatic equilibrium
  - fusing Hydrogen into Helium.
- Stars do not move along the main sequence.

This star cluster is so young that the cool, low-mass stars have not yet arrived at the main sequence (Fig. 13.9 p. 392)



A

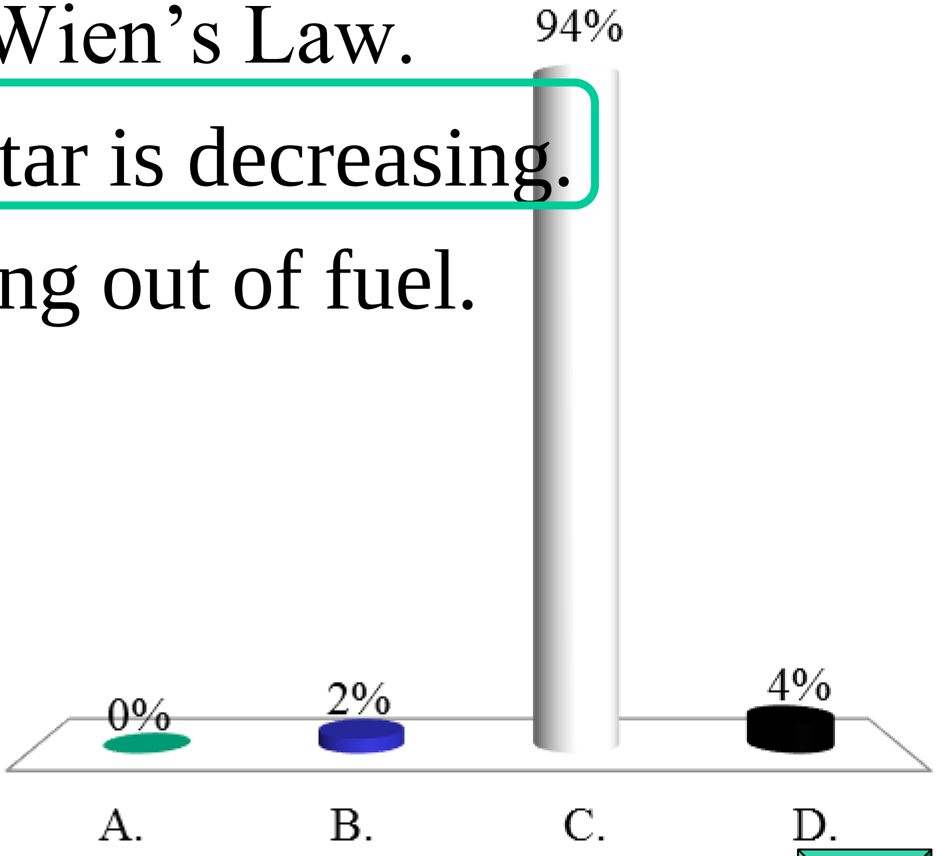
Courtesy of Anglo-Australian Observatory; photograph by David Malin



B

While a protostar is forming, it typically becomes hotter and less luminous. Why?

A. Warmer objects are always less luminous.
B. Because they follow Wien's Law.
C. The size of the protostar is decreasing.
D. The protostar is running out of fuel.



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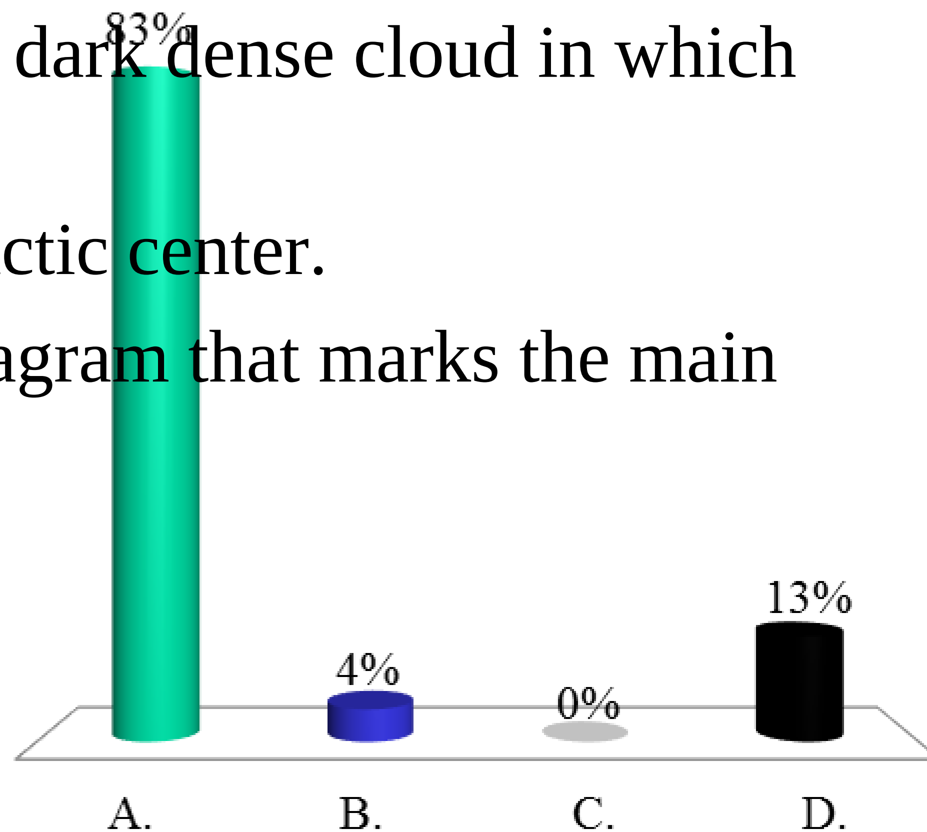
A star's evolutionary track is

A. its change of position on the H-R diagram over time.

B. its motion through the dark dense cloud in which it was born.

C. its orbit about the galactic center.

D. the line on the H-R diagram that marks the main sequence.



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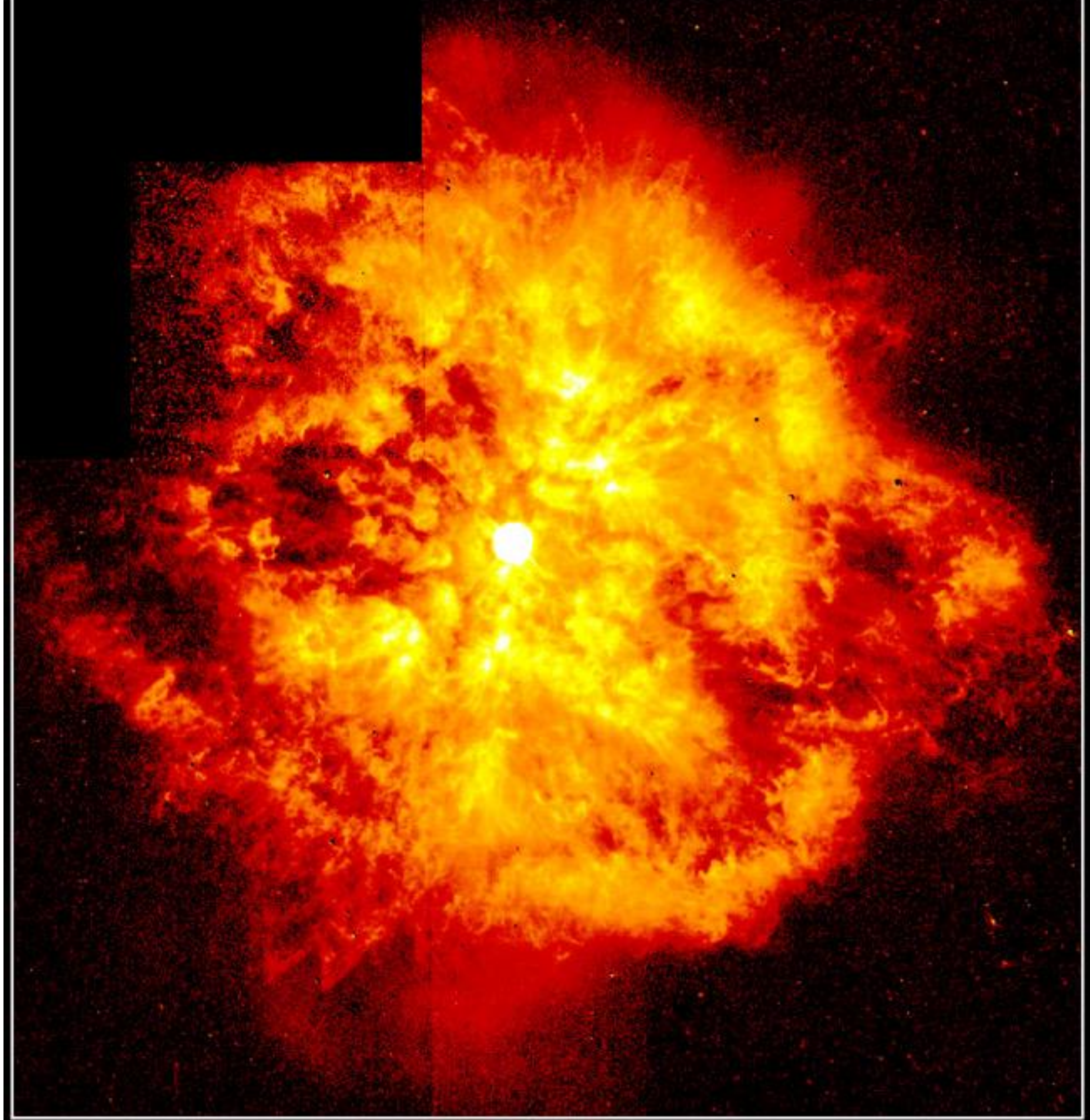
Stars Emit Gas

- ✓ Extremely hot "Wolf-Rayet" star (50,000 K) emitting huge amounts of material
- ✓ Shows how bright stars make huge winds
- ✓ Ejected material forms clumps

NASA link to this photo



Nebula M1-67 around Star WR124 **HST • WFPC2**

PRC98-38 • STScI OPO • November 5, 1998

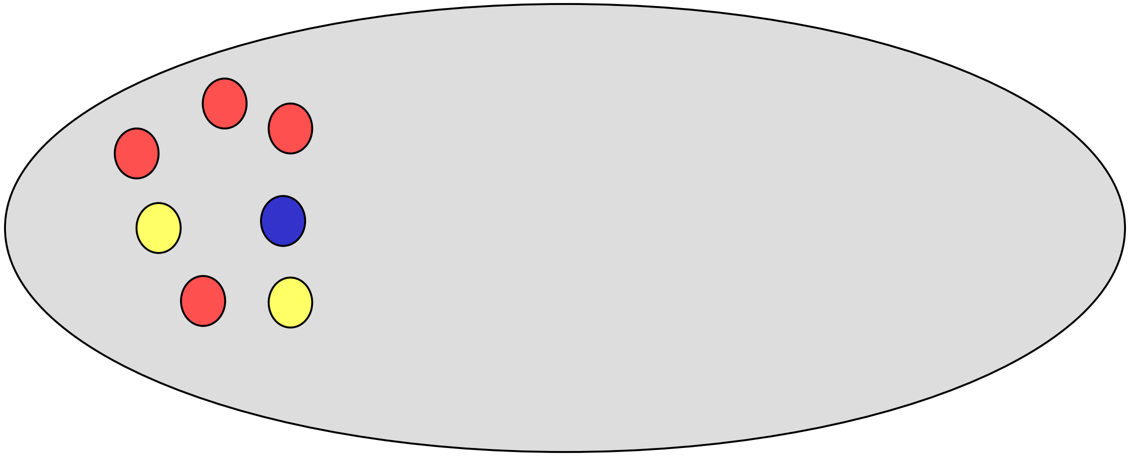
Y. Grosdidier and A. Moffat (University of Montreal) and NASA

Making Stars with Shock Waves

This image shows a bow shock forming around LL Orionis due to fast stellar winds from beyond the right edge of the photo.

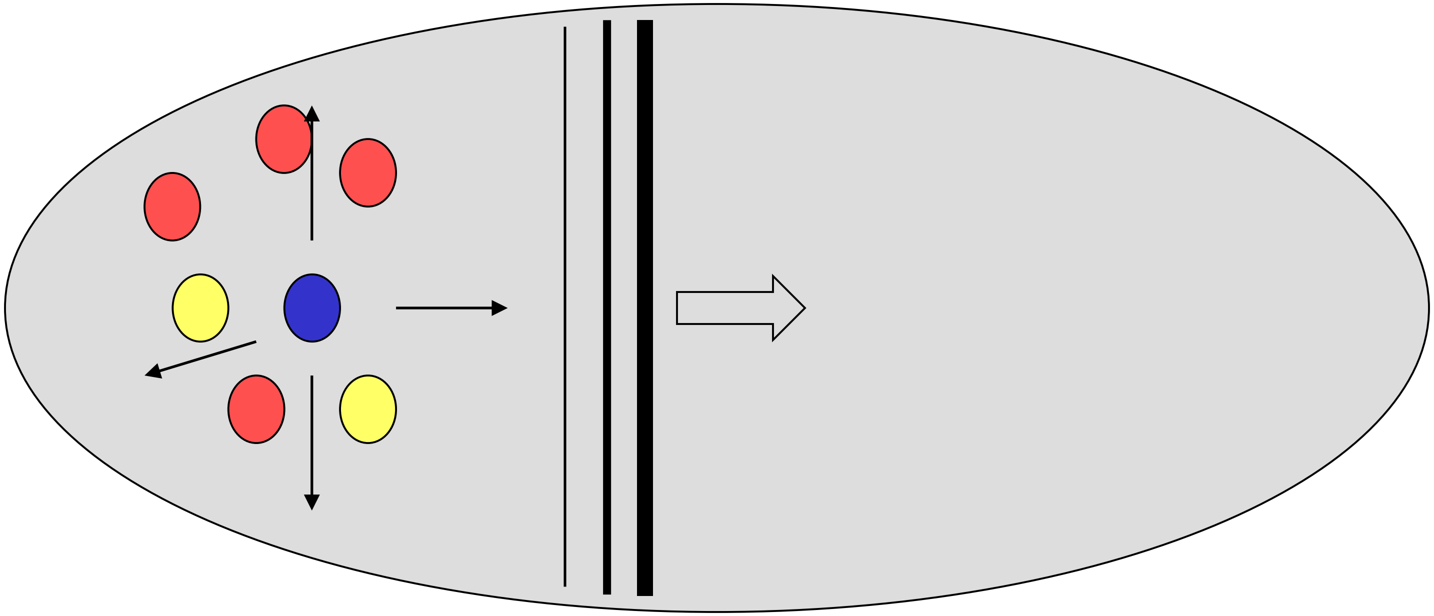
Star Clusters and New Star Formation

- Groups of stars form and condense in part of a giant gas cloud
  - All types of stars form
  - More M-type (red) than O-type (blue) stars form



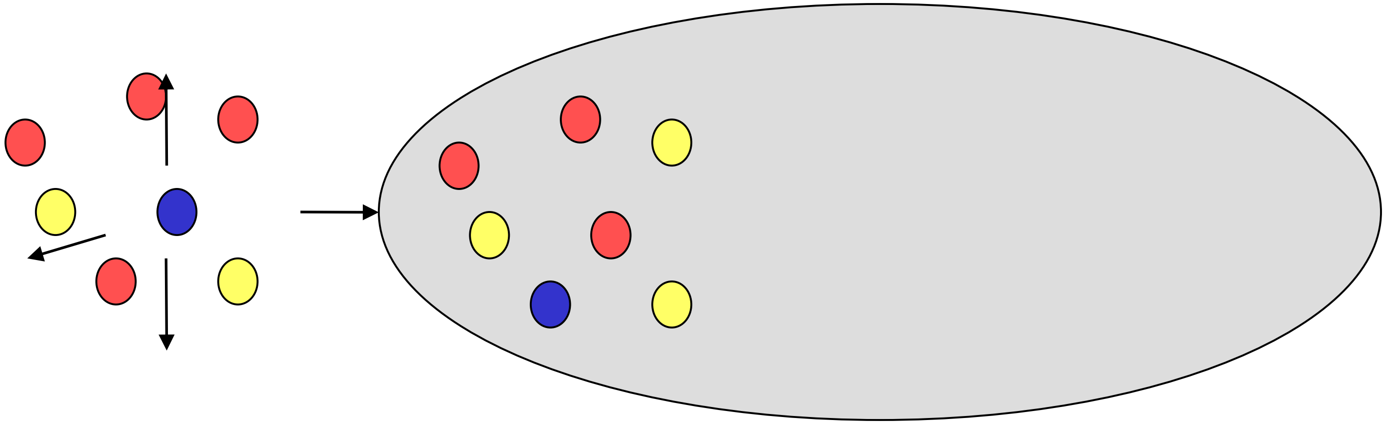
The Shock Wave

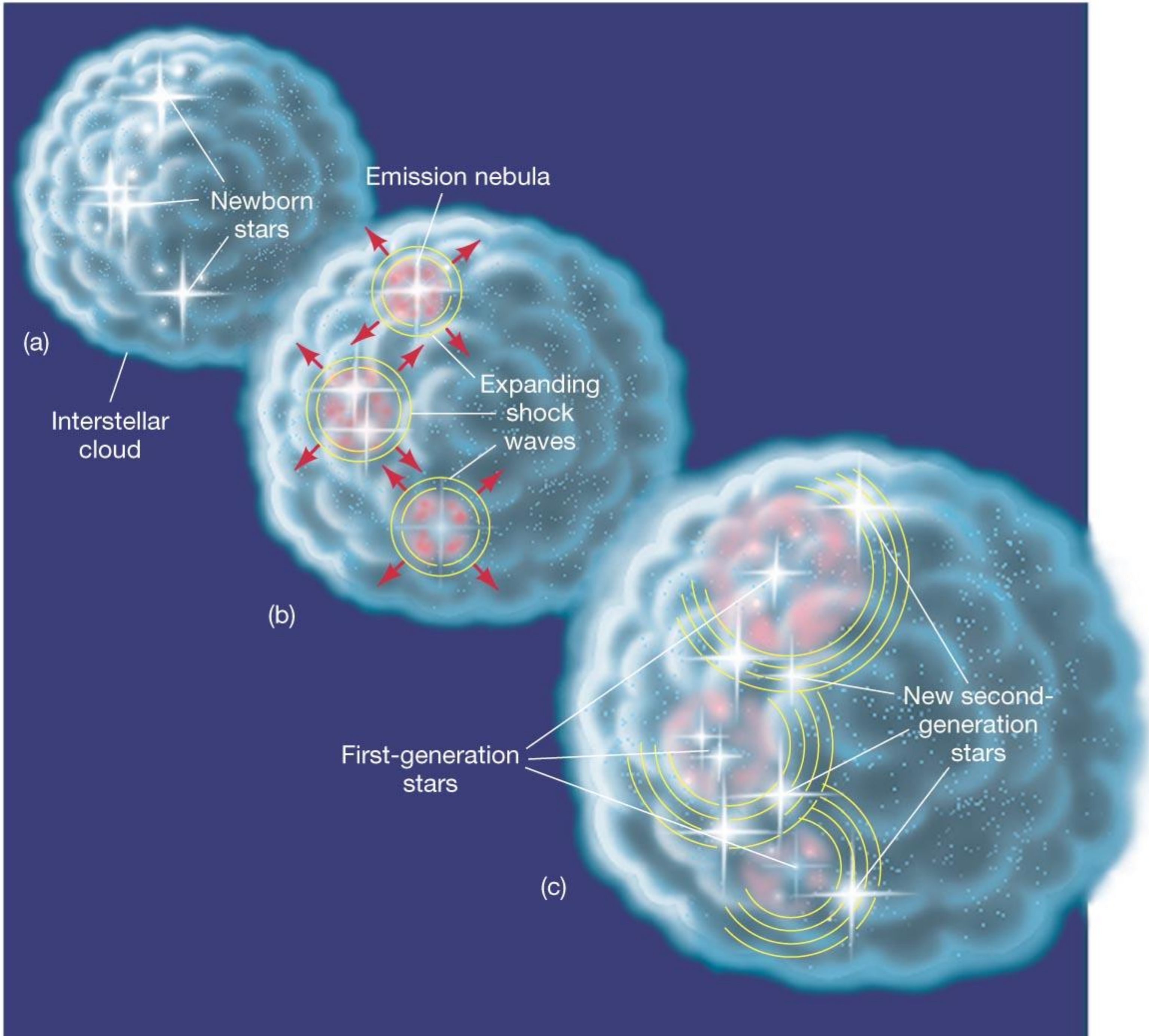
- O and B stars give off huge stellar winds
  - Winds push gas away in a shock wave
  - Shock wave compresses nearby gas

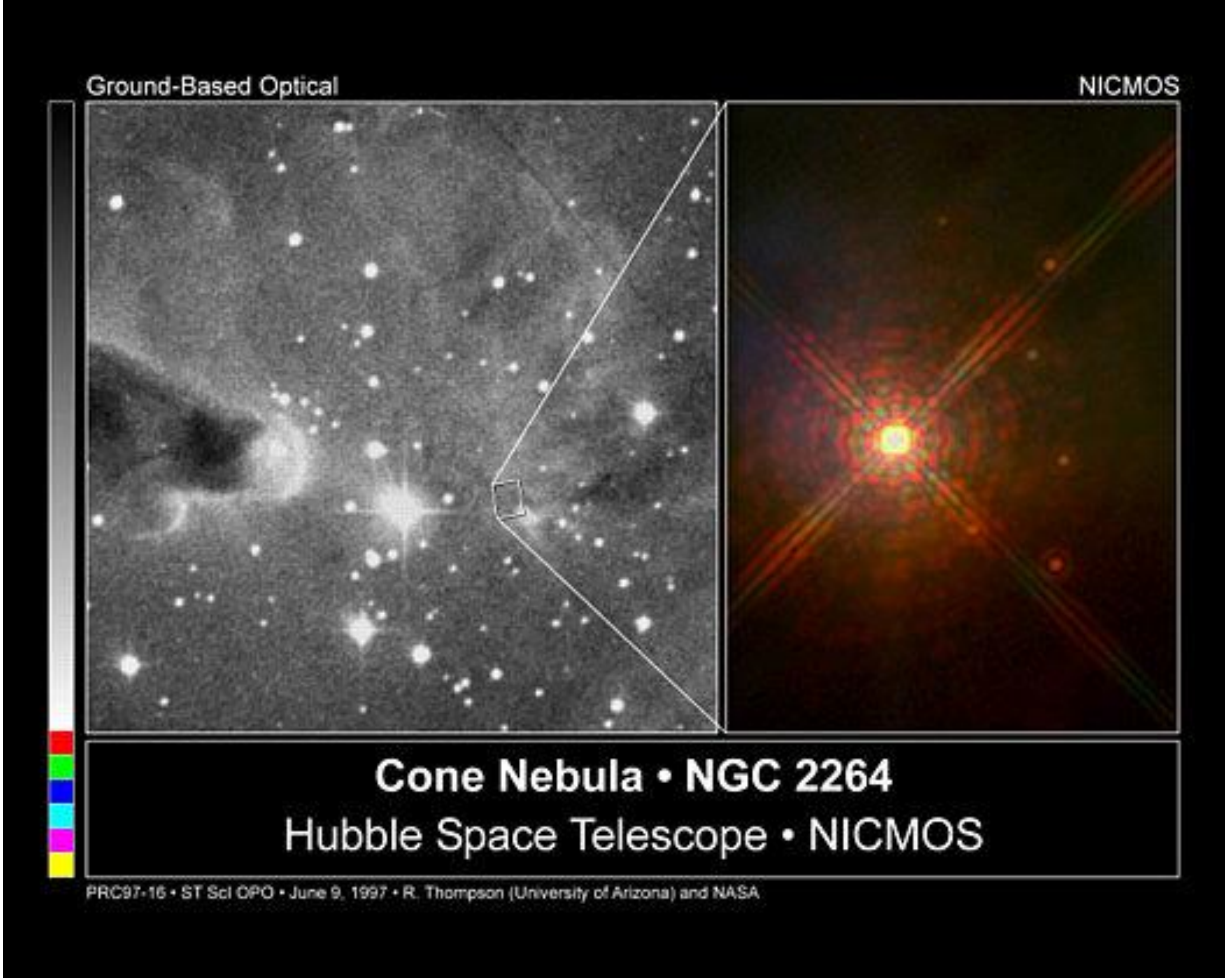


New Star Formation by Shock Wave

- Stellar winds sweep away gas and dust
- First stars are now outside of nebula.
- New stars form in compressed area
- Cluster may loosen up




Emission nebula
Newborn stars
(a)
Interstellar cloud
Expanding shock waves
(b)
New second-generation stars
First-generation stars
(c)

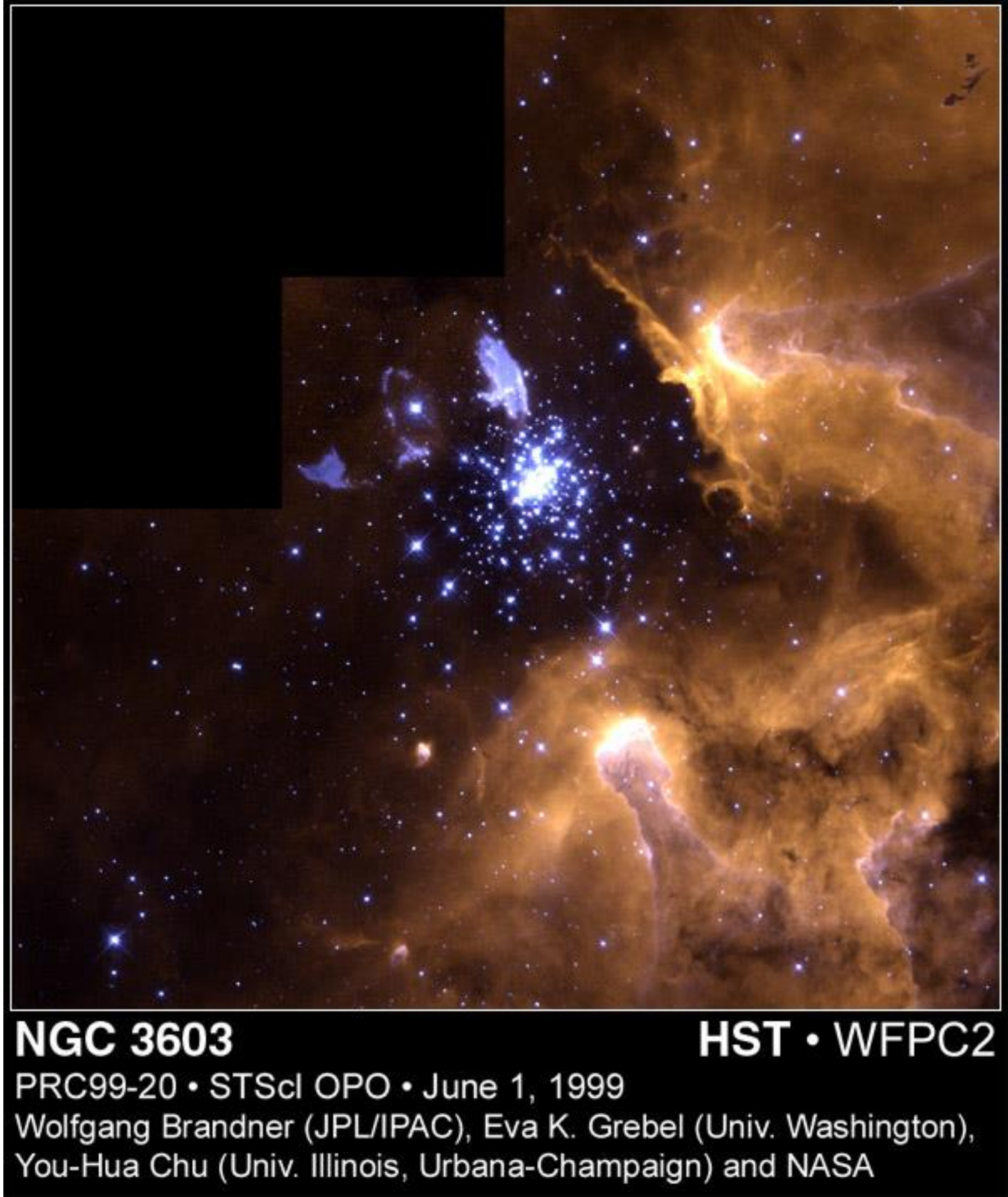


More information on this image

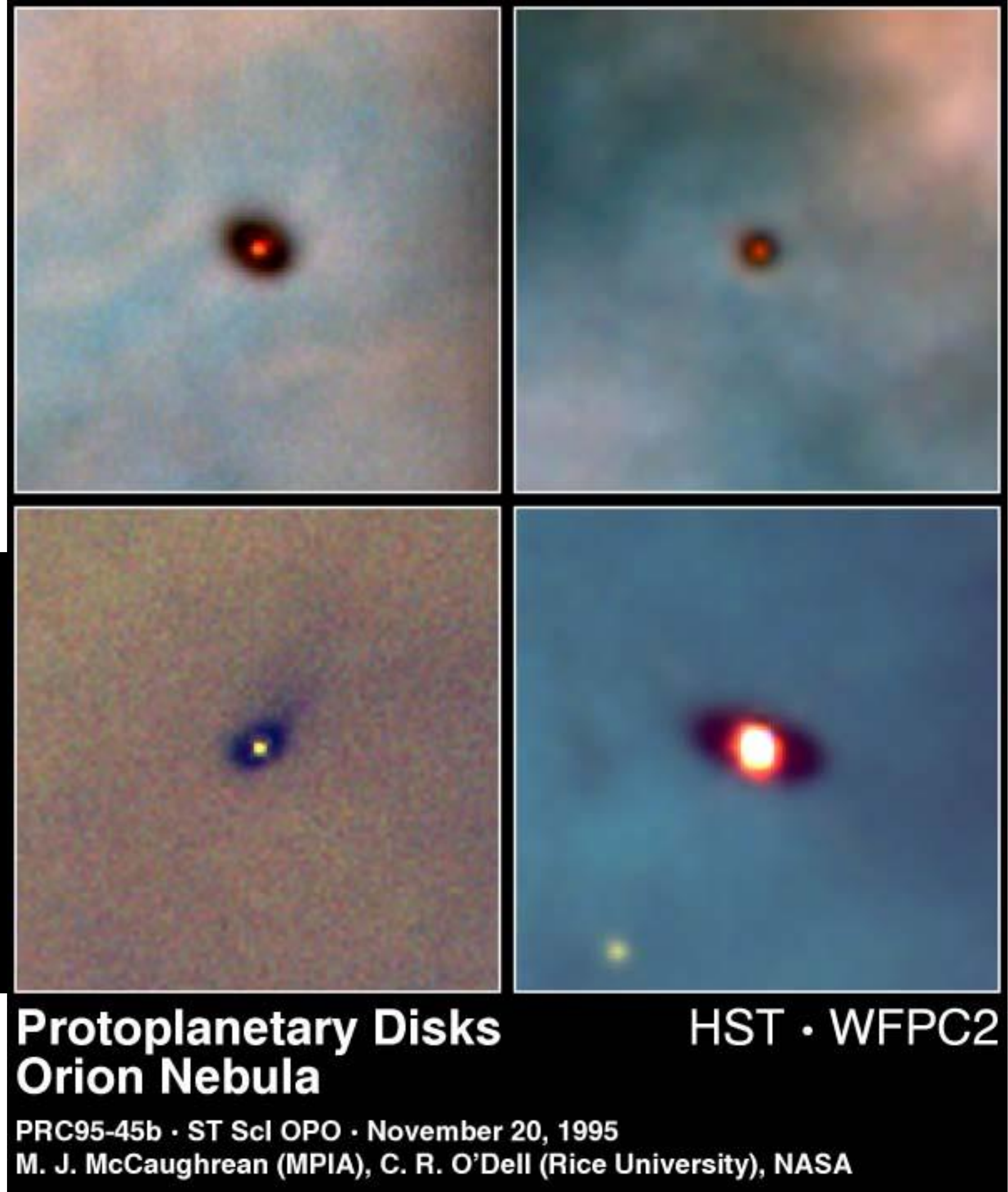
Note the features:

- ✓ Hot O and B star cluster
- ✓ Nebula sculpted by stellar winds
- ✓ Protostars forming in dense clumps of nebula
- ✓ Bok globules are dark, dense regions where stars may someday form.

NASA link to this photo



Proto-planetary Disks (Orion Nebula)



Animation

NASA image info

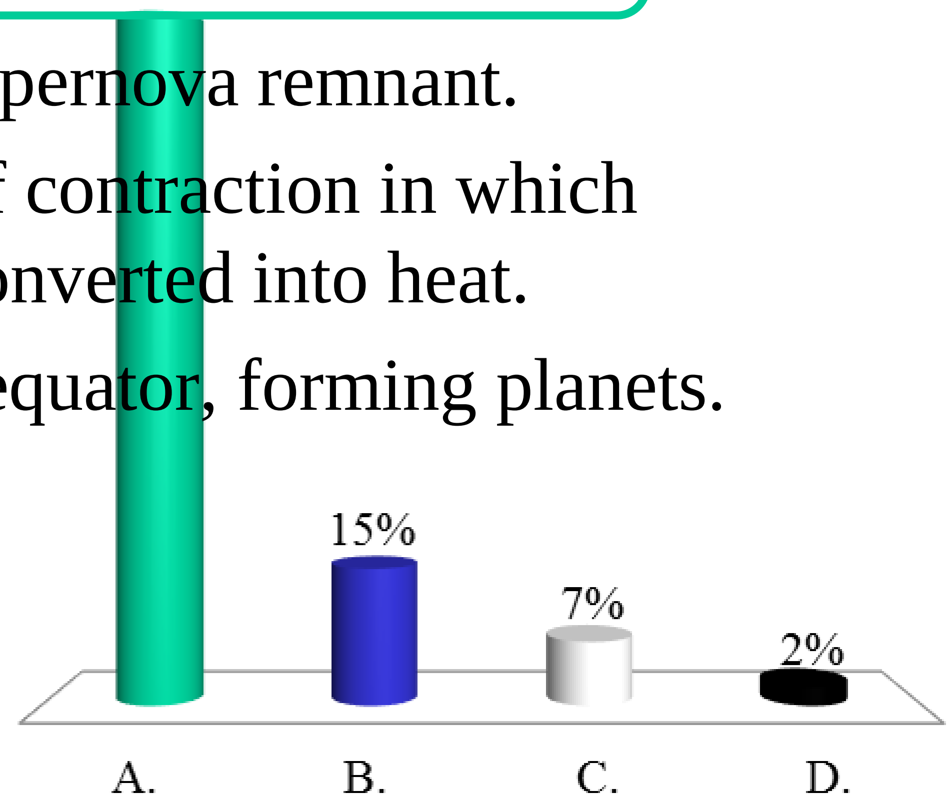
What event happens at the end of the protostar stage of a star's life?

A. Nuclear fusion begins, generating energy and increasing internal pressure.

B. It explodes, forming a supernova remnant.

C. It begins a long period of contraction in which gravitational energy is converted into heat.

D. Gas is spun off from its equator, forming planets.



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Lifetimes of Stars

- High mass stars
  - lots of fuel
  - most luminous (use fuel quickly)
- Low mass stars
  - Very little fuel
  - least luminous (use fuel slowly)

Relation between Lifetime and Mass

$$\text{Lifetime} \propto \frac{\text{Mass}}{\text{Luminosity}} \propto \frac{\text{Mass}}{\text{Mass}^3}$$

$$\text{Lifetime} \propto \frac{1}{\text{Mass}^2}$$

- As the mass increases, the lifetime of the star decreases
  - High mass stars have short lives
  - Low mass stars have long lives

Stellar Lifetimes

Type	Temp.	Mass	Lum.	Time on MS (myrs)
O	35,000	25	80,000	3
B	30,000	15	10,000	15
A	11,000	3	60	500
F	7,000	1.5	5	3,000
G	6,000	1.0	1	10,000
K	5,000	0.75	0.5	15,000
M	4,000	0.5	0.03	200,000 (greater than age of Universe)

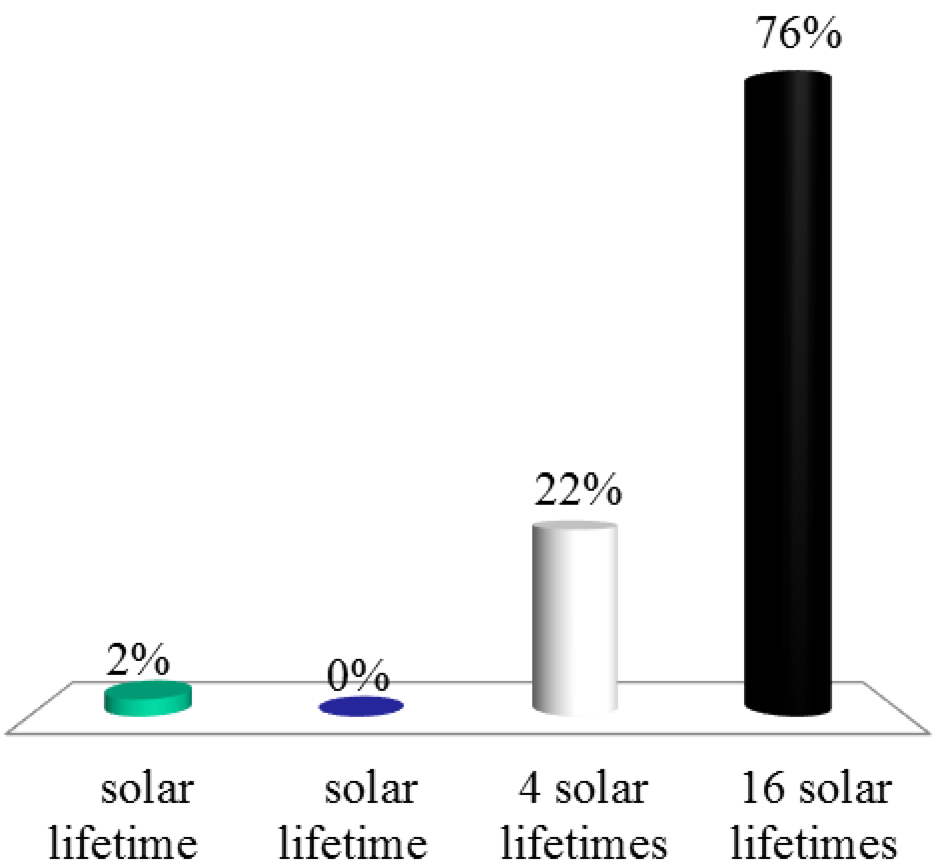
If a star has a mass of $0.25M_{\odot}$, about how long will it live?

A. $\frac{1}{16}$ solar lifetime

B. $\frac{1}{4}$ solar lifetime

C. 4 solar lifetimes

D. 16 solar lifetimes



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If a star has a mass of $0.25M_\odot$, about how long will it live?

A. $\frac{1}{16}$ solar lifetime

B. $\frac{1}{4}$ solar lifetime

C. 4 solar lifetimes

D. 16 solar lifetimes

$$\frac{\text{Life}_{\text{new}}}{\text{Life}_{\text{old}}} = \frac{\frac{1}{M_{\text{new}}^2}}{\frac{1}{M_{\text{old}}^2}} = \frac{M_{\text{old}}^2}{M_{\text{new}}^2} = \frac{M_{\text{Sun}}^2}{\left(0.25M_{\text{Sun}}\right)^2} = 16$$

$$\text{Life}_{\text{new}} = 16\text{Life}_{\text{old}} = \boxed{16 \text{ solar lifetimes}}$$