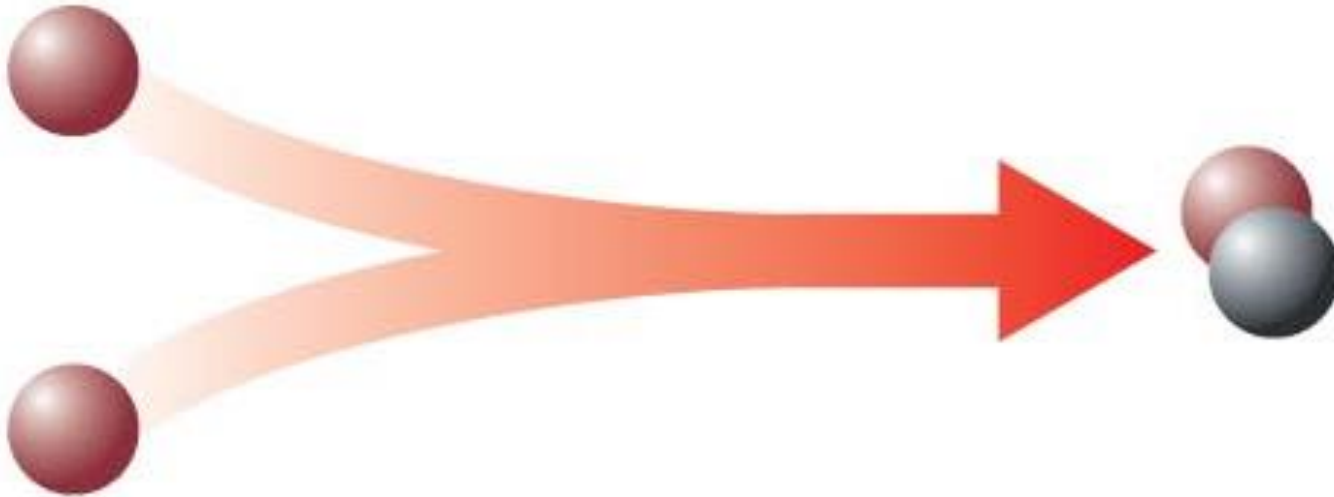


Evolution of a Protostar

fusion

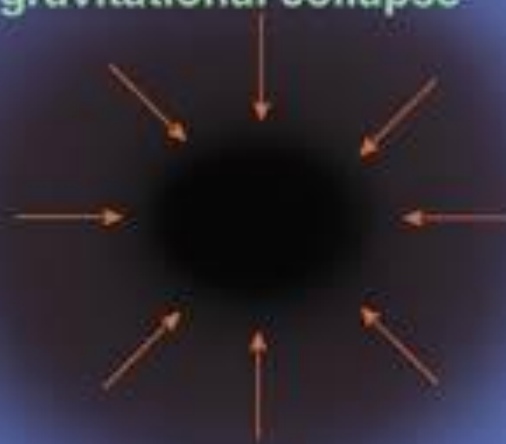


a dark cloud

dense core

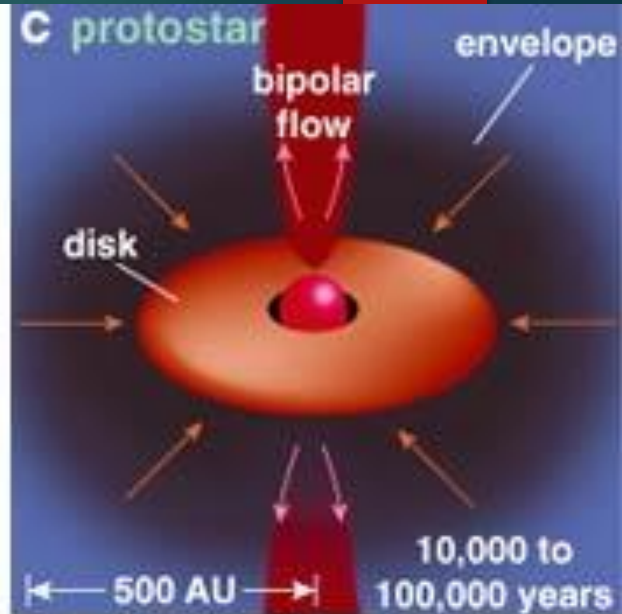
← 200,000 AU →

b gravitational collapse



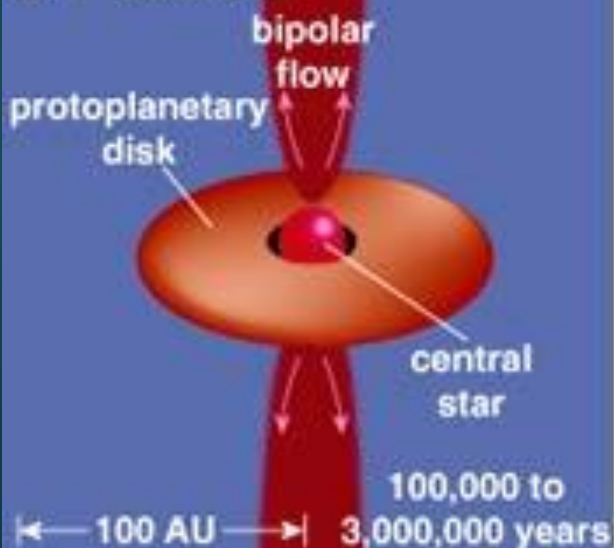
← 10,000 AU → time = 0

c protostar



← 500 AU → 10,000 to 100,000 years

d T Tauri star



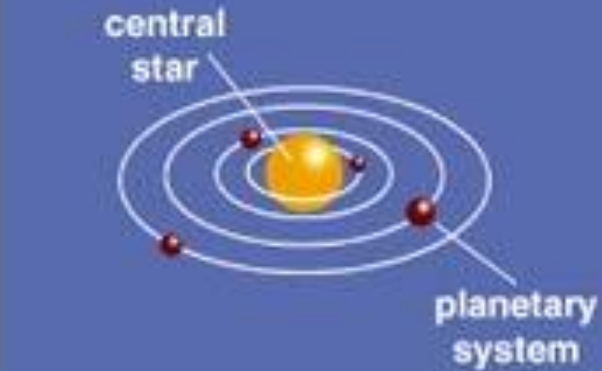
← 100 AU → 100,000 to 3,000,000 years

e pre-main-sequence star



← 100 AU → 3,000,000 to 50,000,000 years

f young stellar system

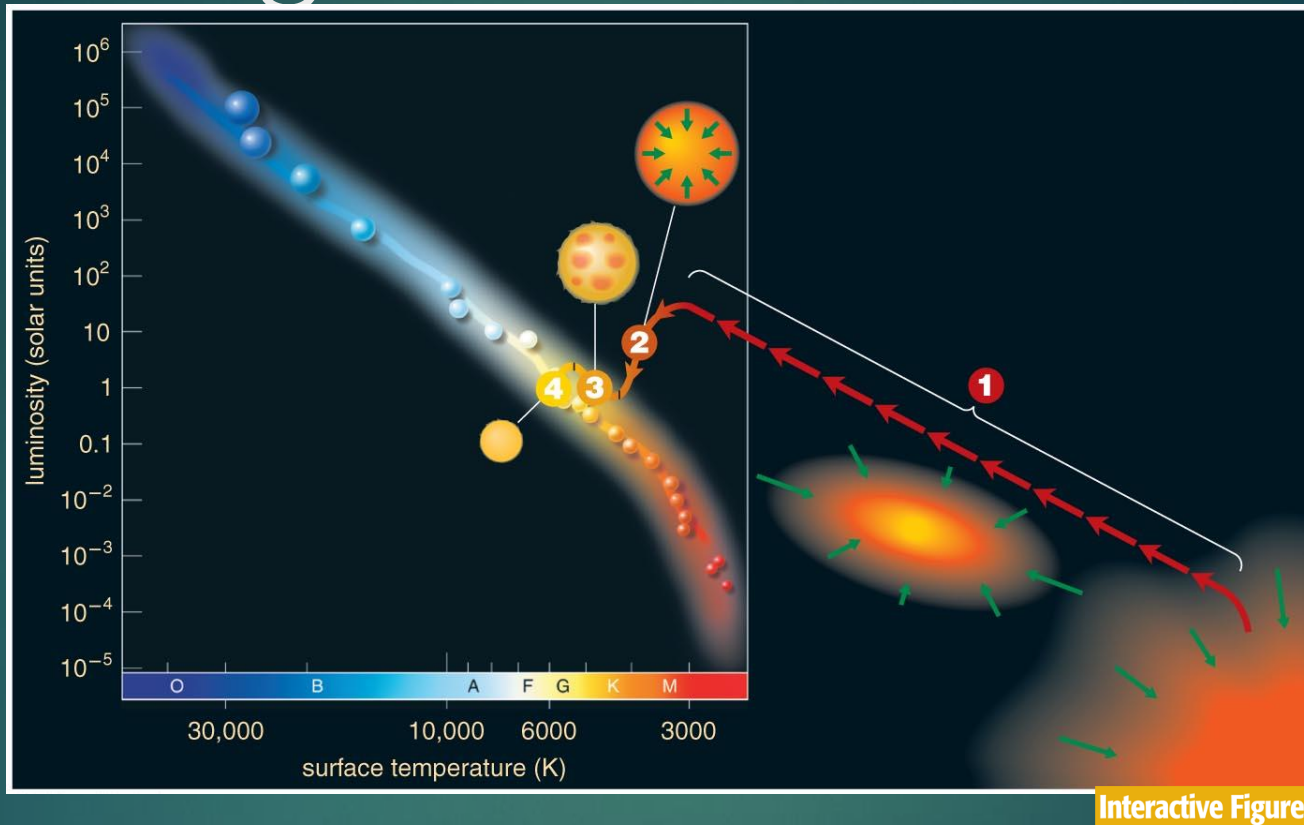


← 50 AU → after 50,000,000 years

From Protostar to Main Sequence

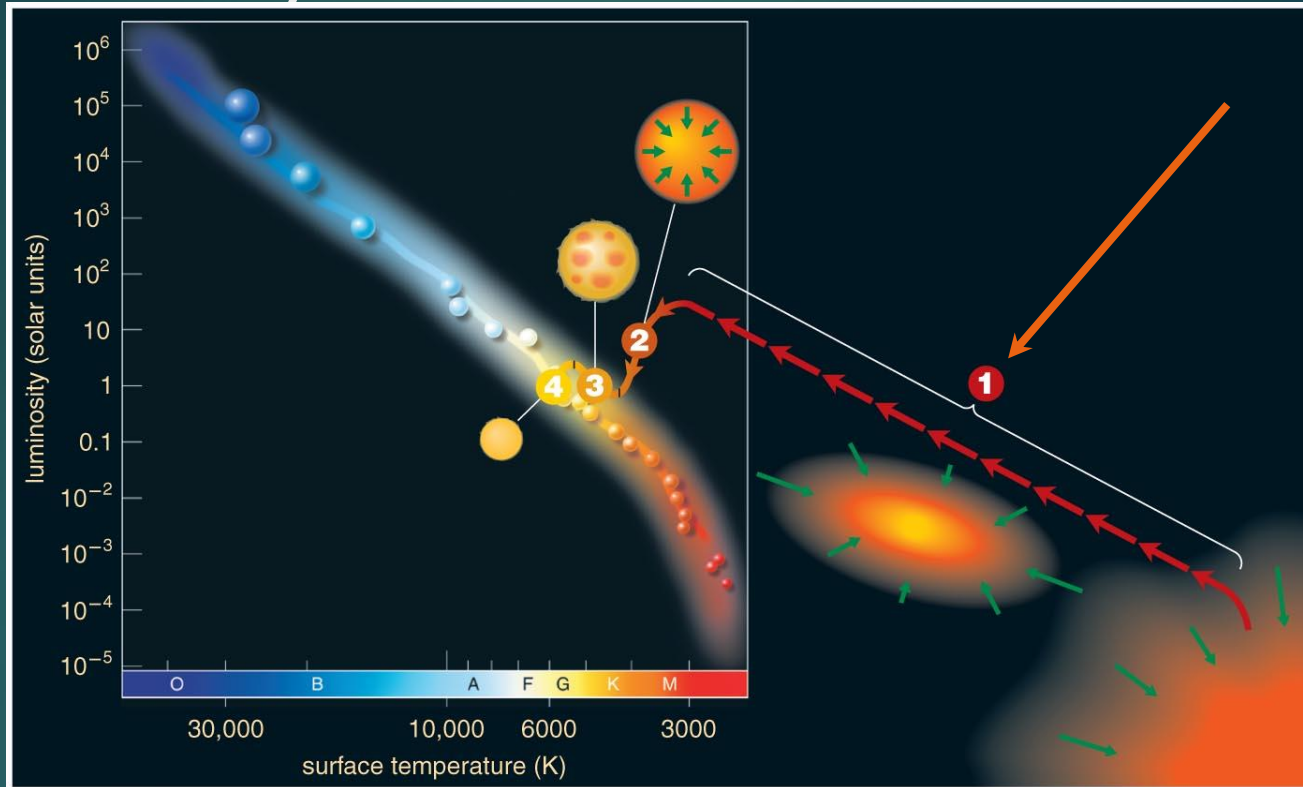
- ▶ A protostar looks starlike after the surrounding gas is blown away, but its thermal energy comes from gravitational contraction, not fusion.
- ▶ Contraction must continue until the core becomes hot enough for nuclear fusion.
- ▶ Contraction stops when the energy released by core fusion balances energy radiated from the surface—the star is now a *main-sequence star*.

Birth Stages on a Life Track



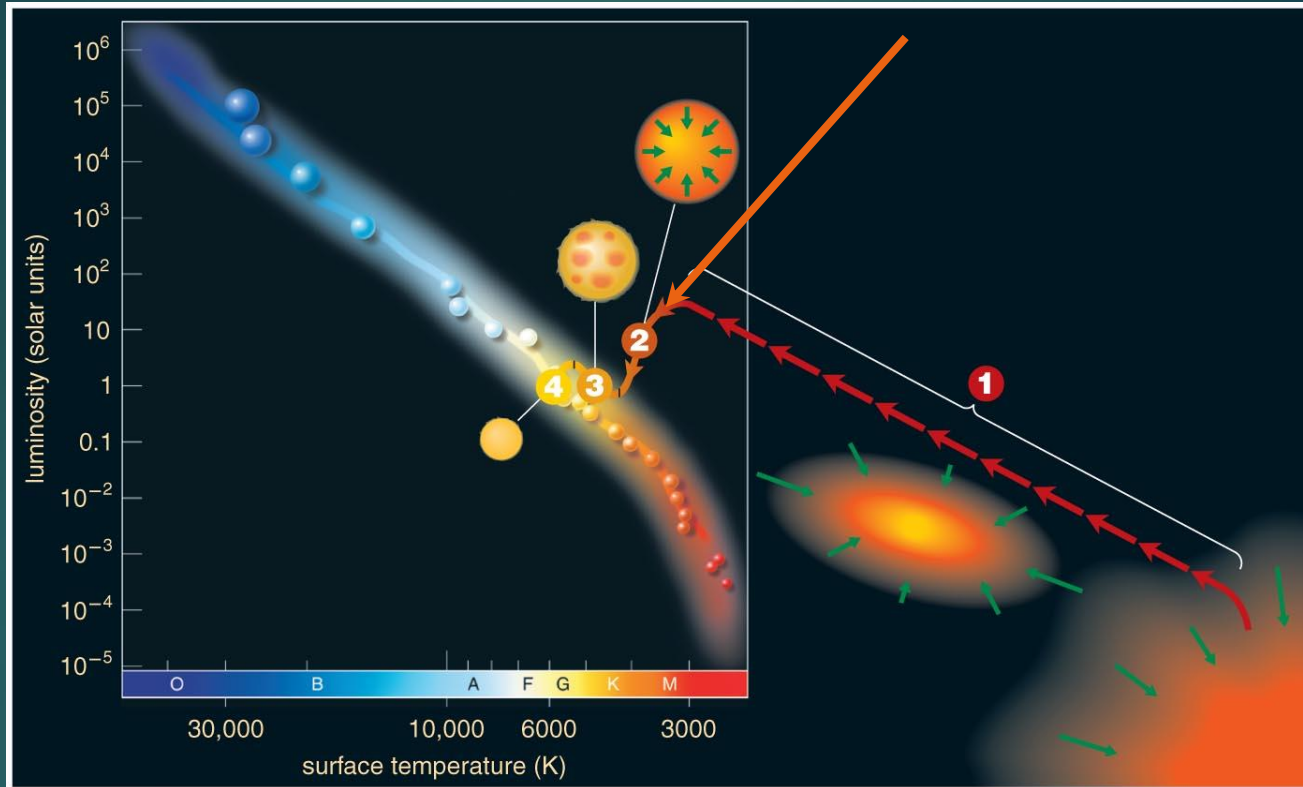
- ▶ A life track illustrates a star's surface temperature and luminosity at different moments in time.

Assembly of a Protostar



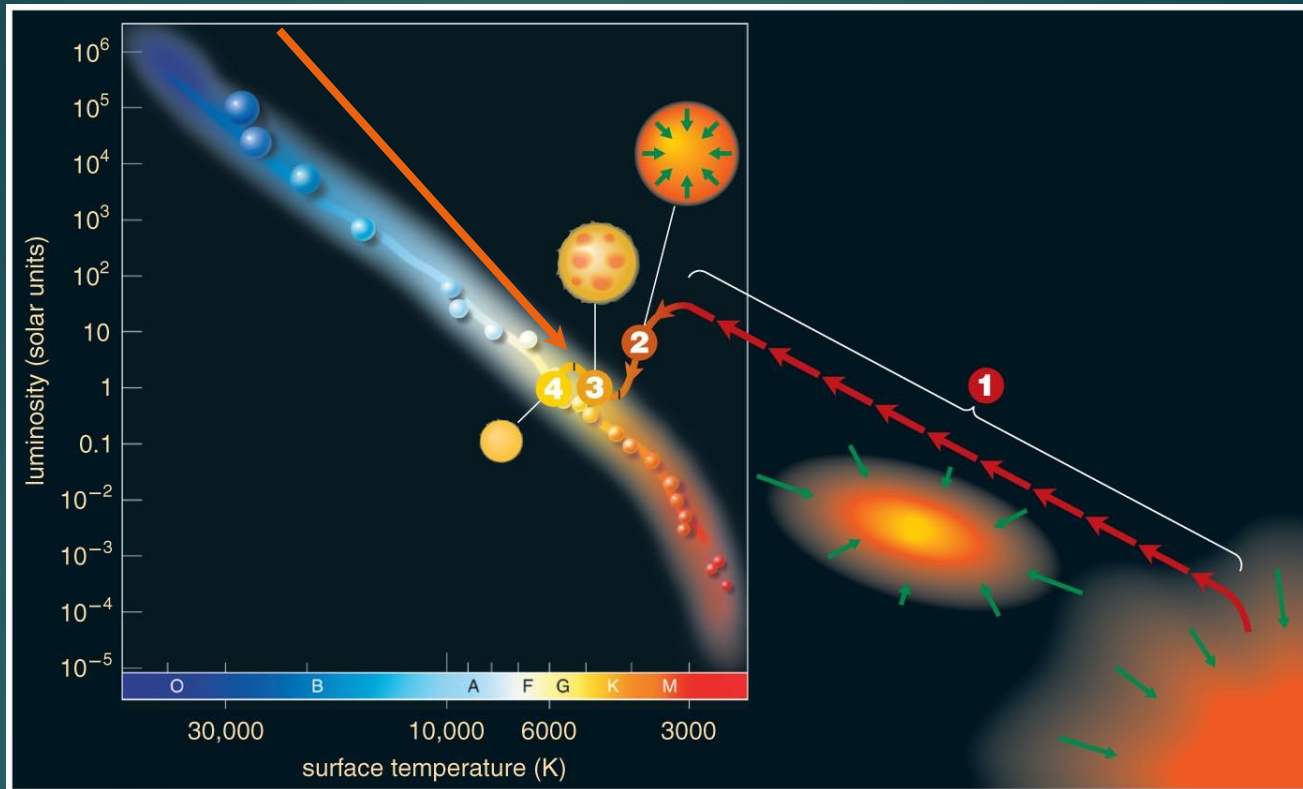
- ▶ Luminosity and temperature grow as matter collects into a protostar.

Convective Contraction



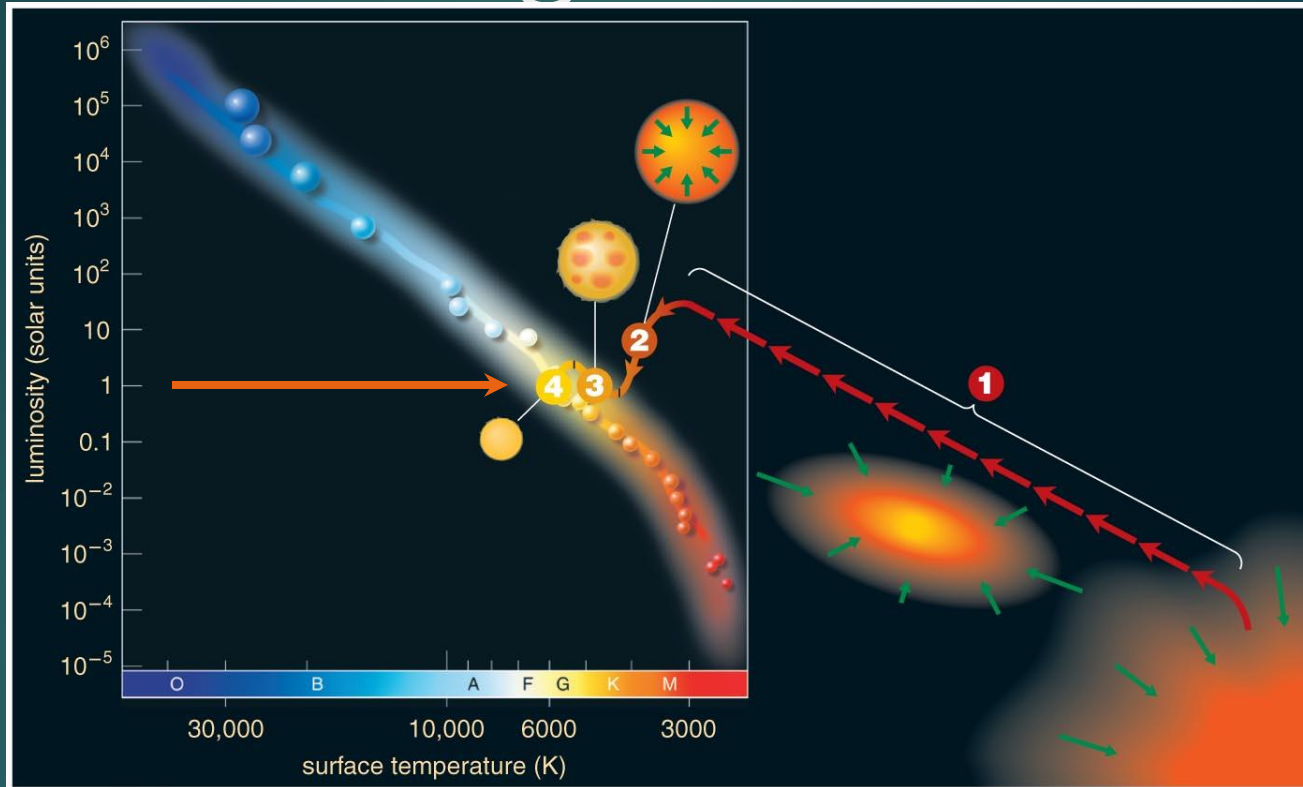
- ▶ Surface temperature remains near 3000 K while convection is main energy transport mechanism.

Radiative Contraction



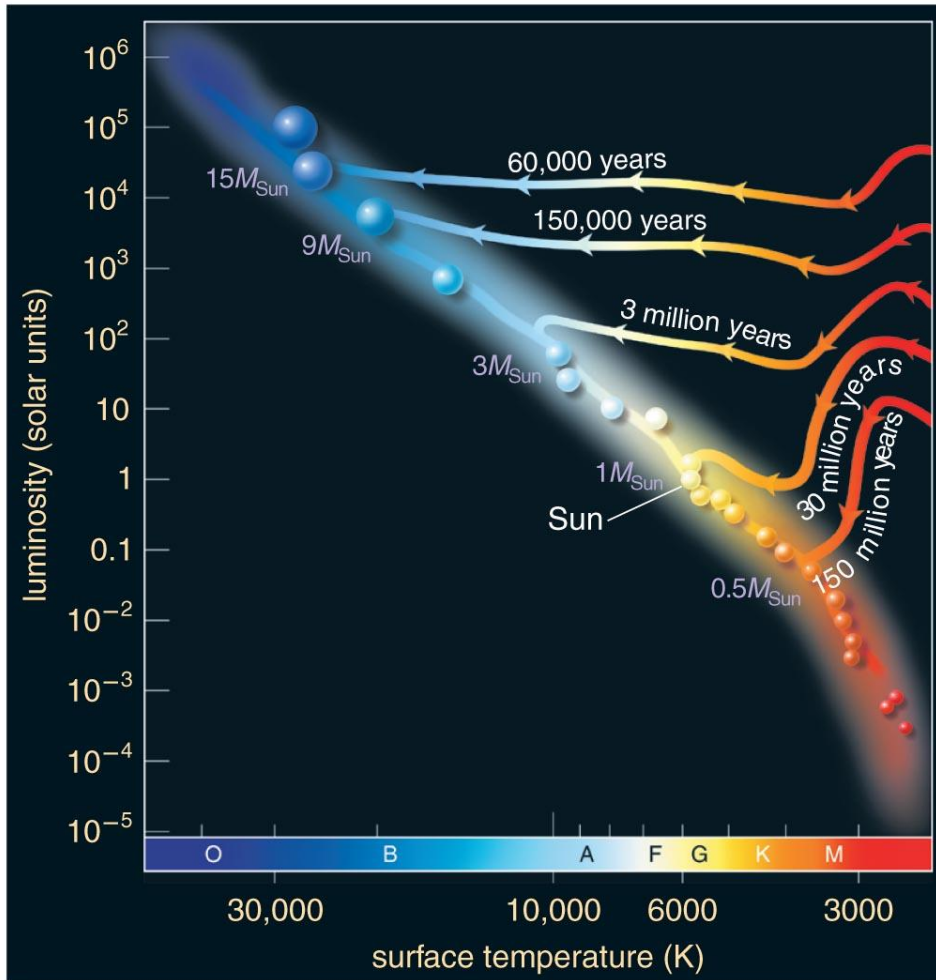
- ▶ Luminosity remains nearly constant during late stages of contraction, while radiation transports energy through star.

Self-Sustaining Fusion



- ▶ Core temperature continues to rise until star begins fusion and arrives on the main sequence.

Life Tracks for Different Masses



- ▶ 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.

What have we learned?

- ▶ **What slows the contraction of a star-forming cloud?**

- ▶ The contraction of a cloud fragment slows when thermal pressure builds up because infrared and radio photons can no longer escape.

- ▶ **What is the role of rotation in star birth?**

- ▶ Conservation of angular momentum leads to the formation of disks around protostars.

What have we learned?

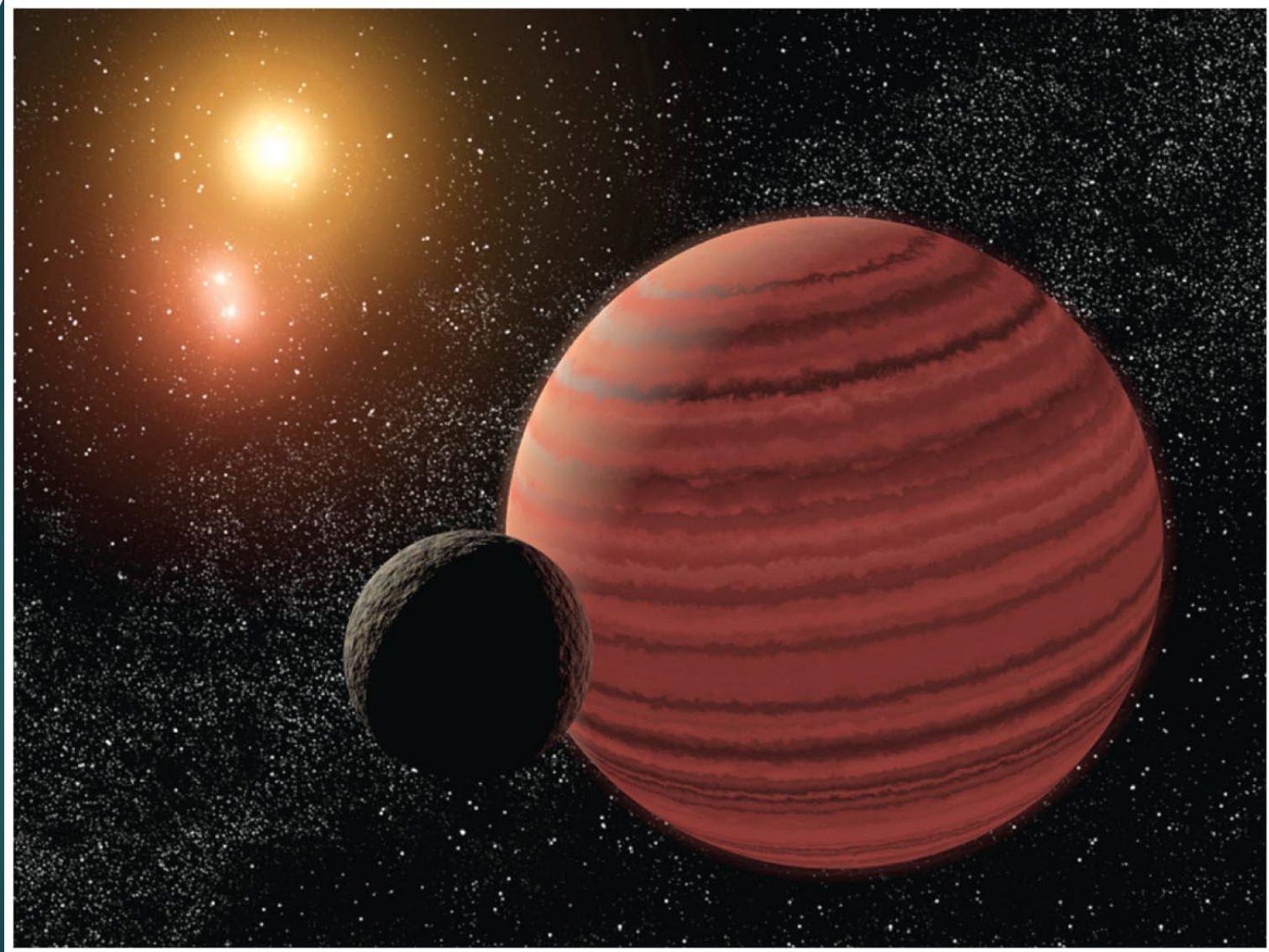
- ▶ **How does nuclear fusion begin in a newborn star?**

- ▶ Nuclear fusion begins when contraction causes the star's core to grow hot enough for fusion.

16.3 Masses of Newborn Stars

- ▶ Our goals for learning:
 - ▶ **What is the smallest mass a newborn star can have?**
 - ▶ **What is the greatest mass a newborn star can have?**
 - ▶ **What are the typical masses of newborn stars?**

What is the smallest mass a newborn star can have?



Fusion and Contraction

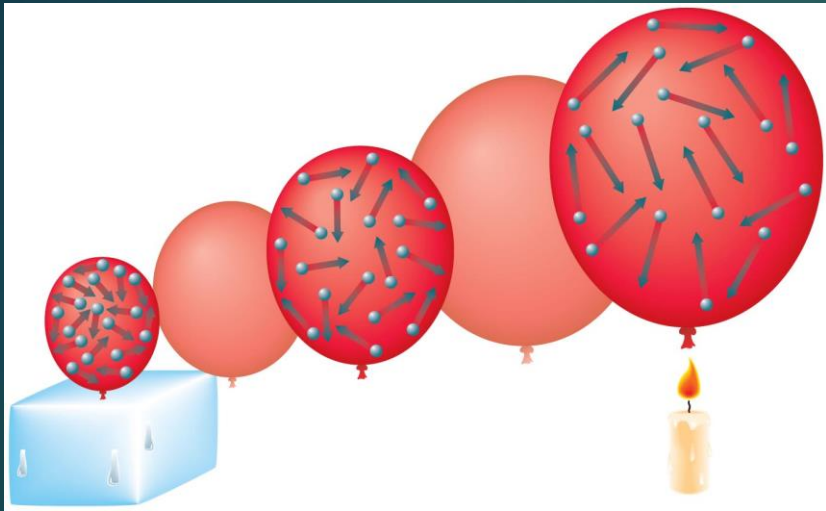
- ▶ Fusion will not begin in a contracting cloud if some sort of force stops contraction before the core temperature rises above 10^7 K.
- ▶ Thermal pressure cannot stop contraction because the star is constantly losing thermal energy from its surface through radiation.
- ▶ Is there another form of pressure that can stop contraction?



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▶ **Degeneracy Pressure:**

- ▶ The laws of quantum mechanics prohibit two electrons from occupying the same state in same place.



▶ Thermal Pressure:

- ▶ Depends on heat content.
- ▶ Is the main form of pressure in most stars.

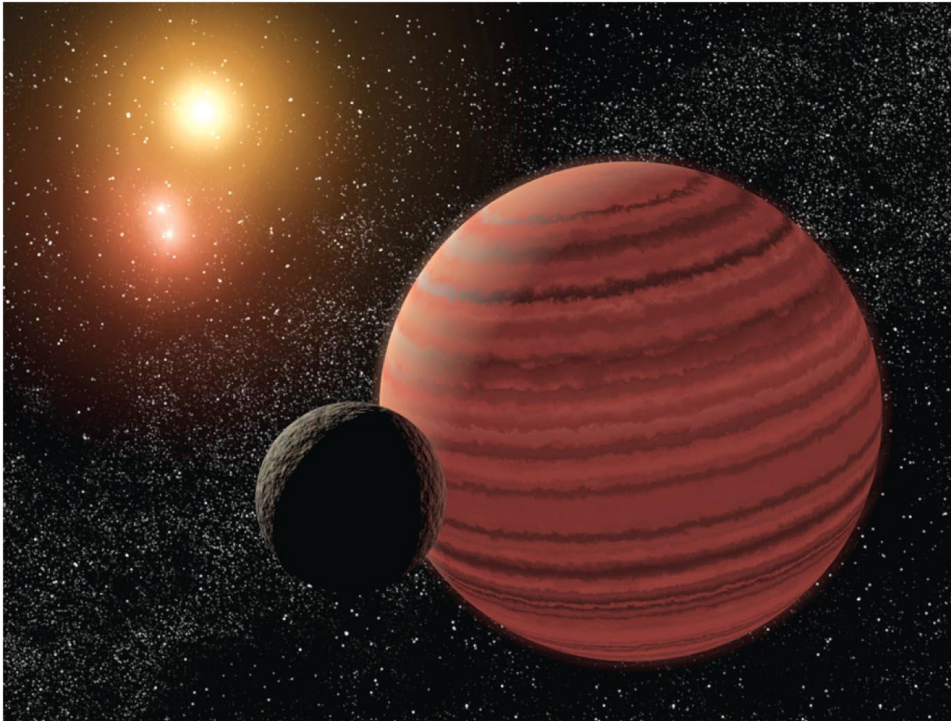
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▶ Degeneracy Pressure:

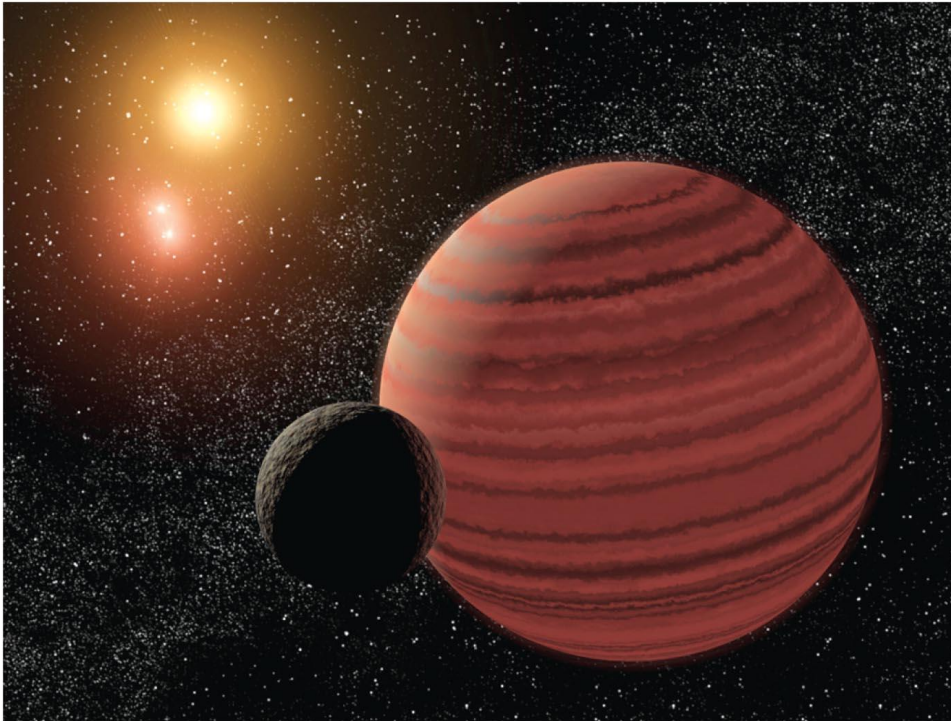
- ▶ Particles can't be in same state in same place.
- ▶ Doesn't depend on heat content.

Brown Dwarfs



- ▶ Degeneracy pressure halts the contraction of objects with $< 0.08M_{\text{Sun}}$ before core temperature becomes hot enough for fusion.
- ▶ Starlike objects not massive enough to start fusion are **brown dwarfs**.

Brown Dwarfs



- ▶ A brown dwarf emits infrared light because of heat left over from contraction.
- ▶ Its luminosity gradually declines with time as it loses thermal energy.

Brown Dwarfs in Orion



- ▶ Infrared observations can reveal recently formed brown dwarfs because they are still relatively warm and luminous.

What is the greatest mass a
newborn star can have?



Radiation Pressure



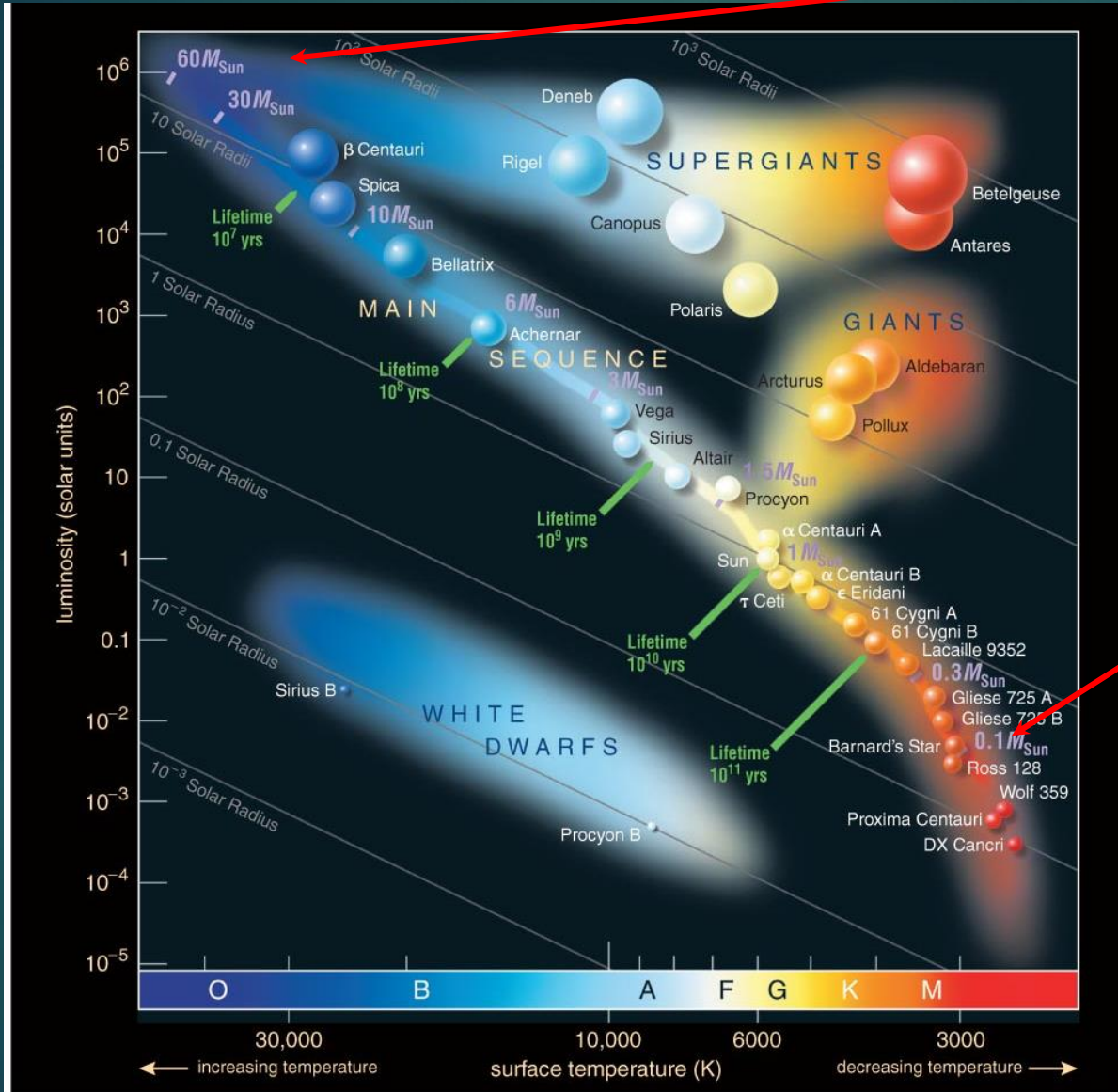
- ▶ Photons exert a slight amount of pressure when they strike matter.
- ▶ Very massive stars are so luminous that the collective pressure of photons drives their matter into space.

Upper Limit on a Star's Mass



- ▶ Models of stars suggest that radiation pressure limits how massive a star can be without blowing itself apart.
- ▶ Maximum thought to be around $150M_{\text{Sun}}$, but new observations indicate some may be even larger!

Luminosity ↑



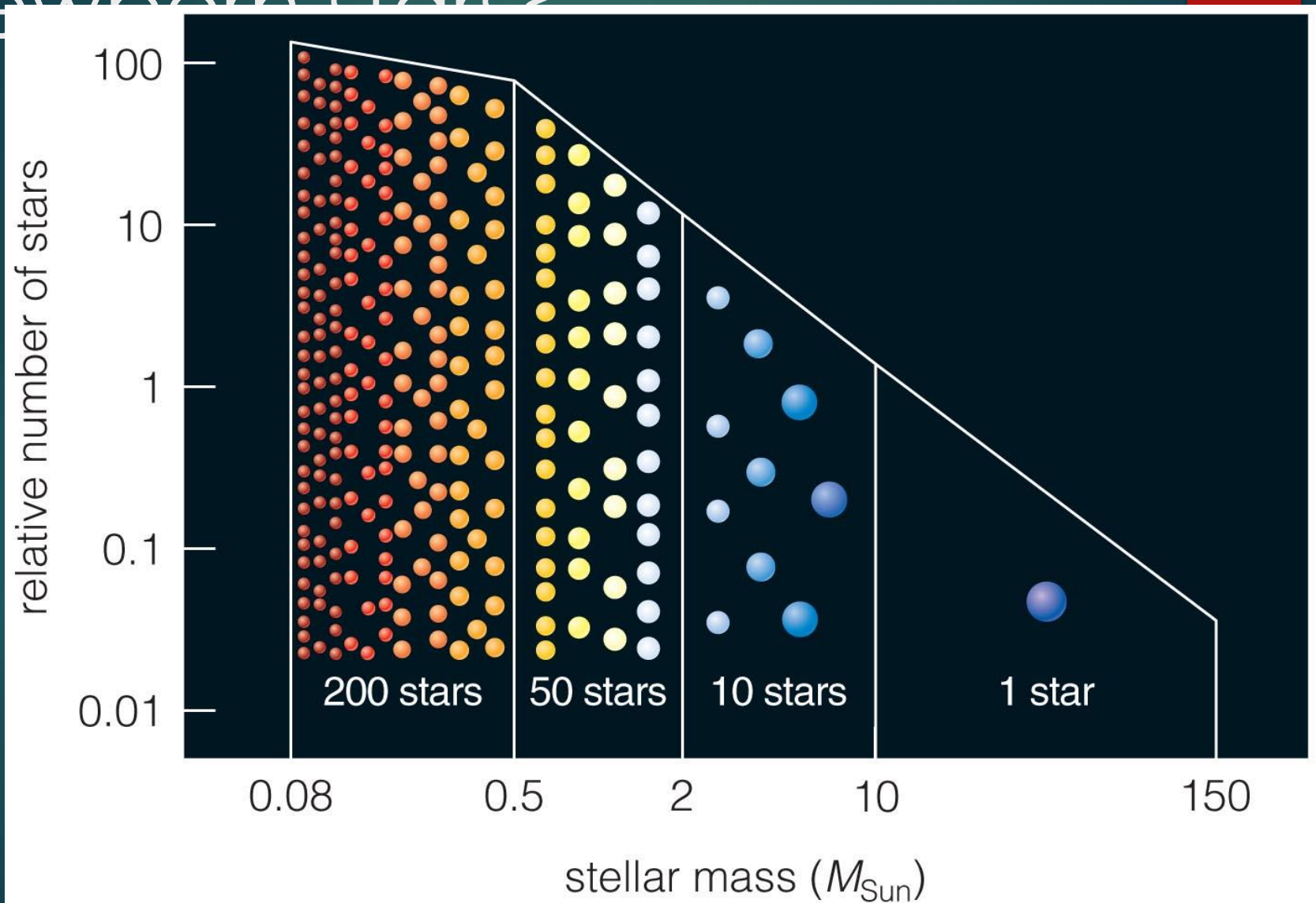
Stars more massive than $150M_{\text{Sun}}$ would blow apart.

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

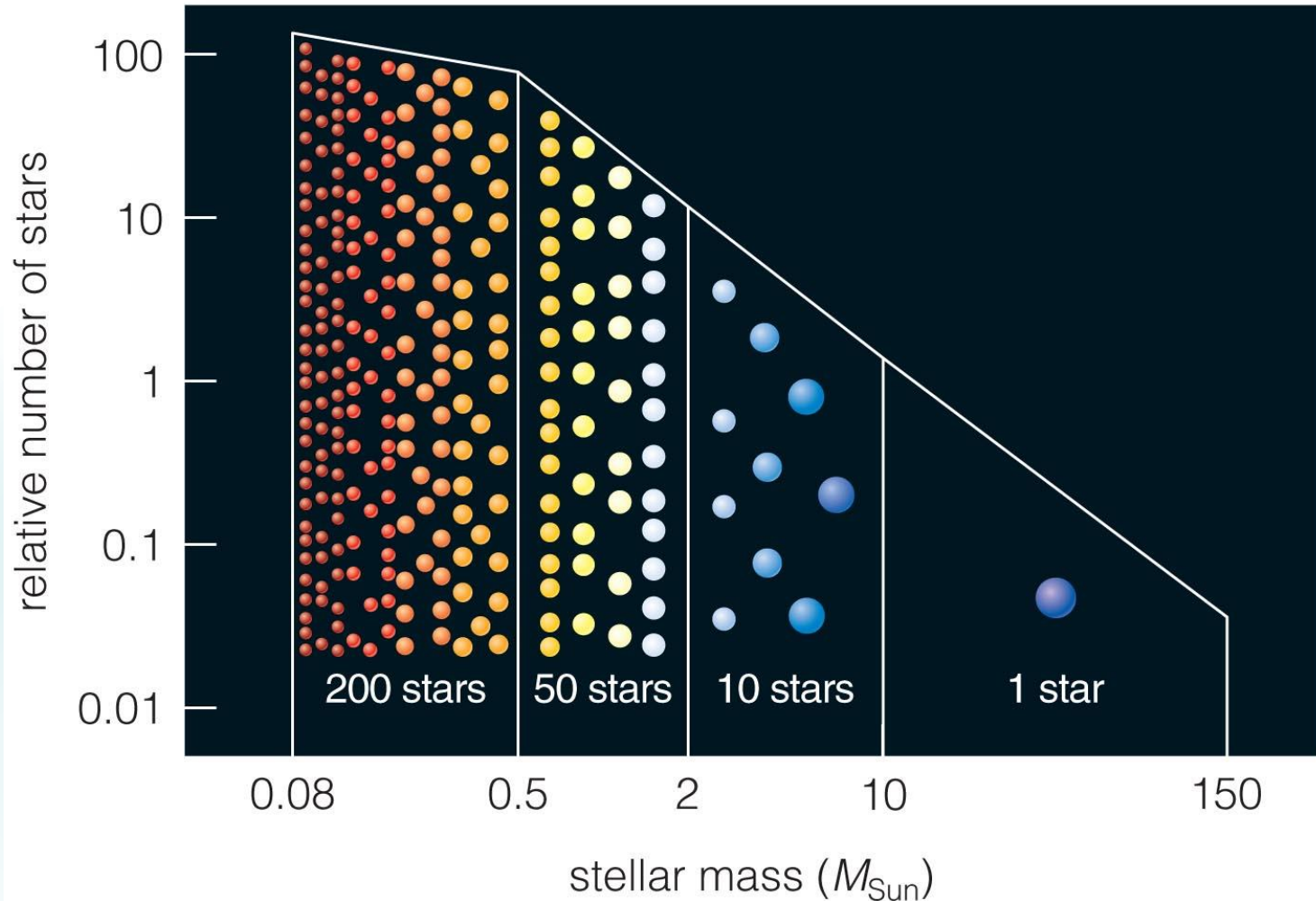
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← Temperature

What are the typical masses of newborn stars?



Demographics of Stars



- ▶ Observations of star clusters show that star formation makes many more low-mass stars than high-mass stars.

What have we learned?

- ▶ **What is the smallest mass a newborn star can have?**
 - ▶ Degeneracy pressure stops the contraction of objects $<0.08M_{\text{Sun}}$ before fusion starts.
- ▶ **What is the greatest mass a newborn star can have?**
 - ▶ Stars greater than about $150M_{\text{Sun}}$ would be so luminous that radiation pressure would blow them apart.
 - ▶ New observations may require raising this limit.

What have we learned?

- ▶ **What are the typical masses of newborn stars?**
 - ▶ Star formation makes many more low-mass stars than high-mass stars.