Astronomy

April 27 – May 8th 2026

Semester 2 Weeks 16 - 17

Monday / Tuesday (May 4 & 5)

- T: 13 (C) evaluate the relationship between mass and fusion on stellar evolution;
- (D) compare how the mass of a main sequence star will determine its end state as a white dwarf, neutron star, or black hole;
- O: I will begin to explore the ideas about the life cycles of stars
- D: by taking notes, participating in a class discussion, and watching a video.
- A:
- Y: What are the major factors in determining the life cycle of a star?

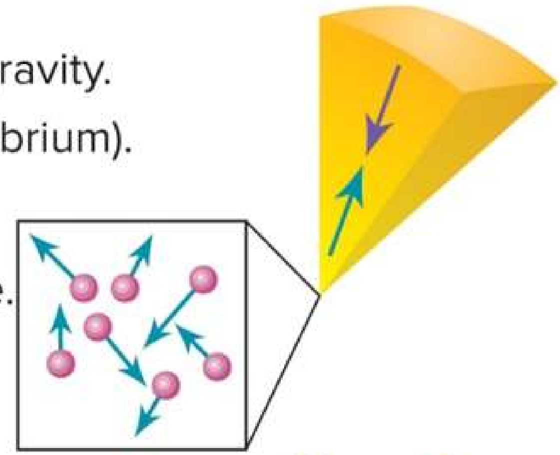
Stellar Evolution

- NASA, ESA, and M. Livio and the Hubble 20th Anniversary Team (STScI)

The Life of a Star

- Gravity holds a star together
- energy produced in its core by the conversion of hydrogen into helium.
- The hydrogen cannot last forever – consequently, the star must evolve (age).
- Once its fuel is exhausted, the star dies – quietly into a white dwarf or violently into a neutron star or black hole.

Principles Governing the Structure of a Star

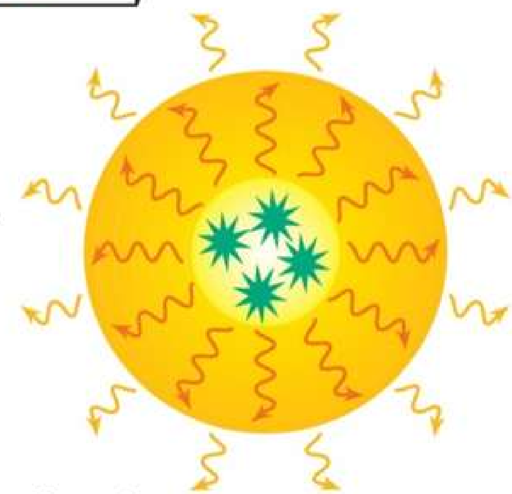


Gravity holds star together; *pressure* supports star against gravity.

Gravity and pressure forces must balance (hydrostatic equilibrium).

Pressure is created by high temperature in star's core.

High temperature causes heat to flow from core to surface, where it escapes into space as the star's *luminosity* (starlight).



Escaping heat is replenished by *nuclear fusion* in core. (Hydrogen fuses into helium, initially.)

Star eventually runs out of fuel.

Low-mass stars turn into **white dwarfs.**

High-mass stars explode, leaving **neutron star** or **black hole.**

Mass Is the Key

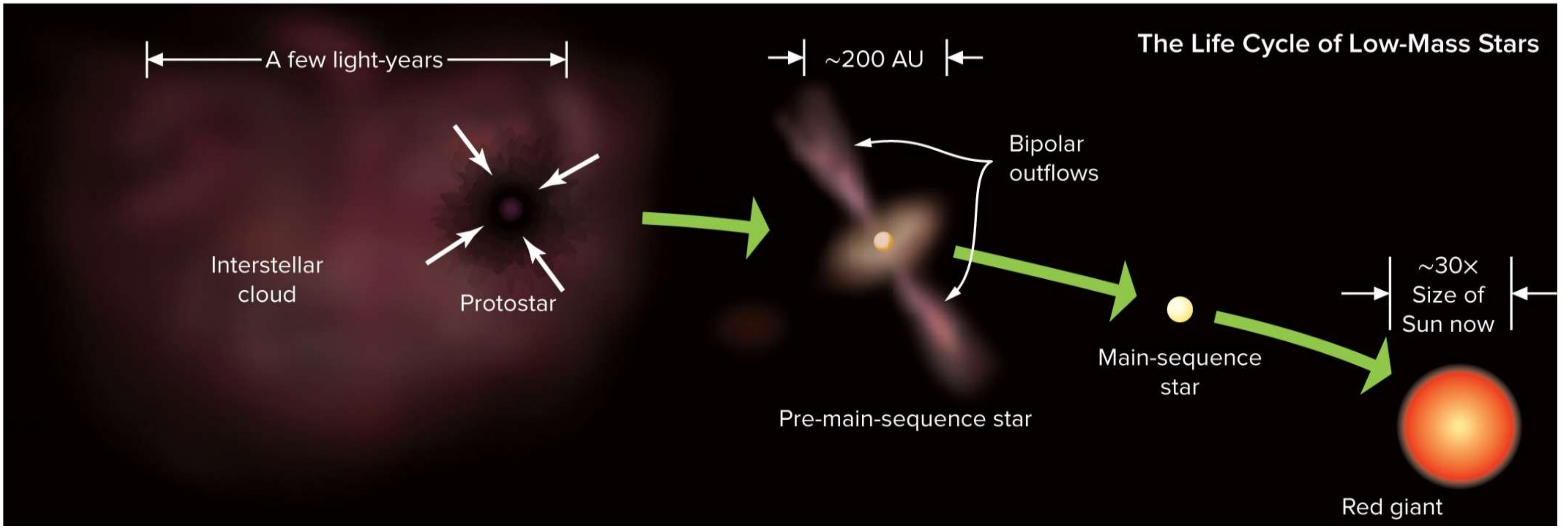
- Stars require millions to billions of years to evolve
- A star's evolution can be studied two ways:
  - Stellar models via computer calculations that take into account the relevant physics.
  - Observations – different stars represent different snapshots in the life of a star.
- Lifeline of star depends on mass
  - low-mass stars < 10 solar masses
  - high-mass stars > 10 solar masses

The Importance of Gravity

- Gravity drives stellar evolution from a star's formation out of a cloud to its final death.
- The collapsing cloud will heat because of gravity.
- The main-sequence star will sustain itself as gravity compresses and heat the core to fusion temperatures.
- Gravity will sculpt the final collapse of the star into a white dwarf, neutron star, or black hole.

- The amount of mass (gravity) will also drive the duration of the evolution.

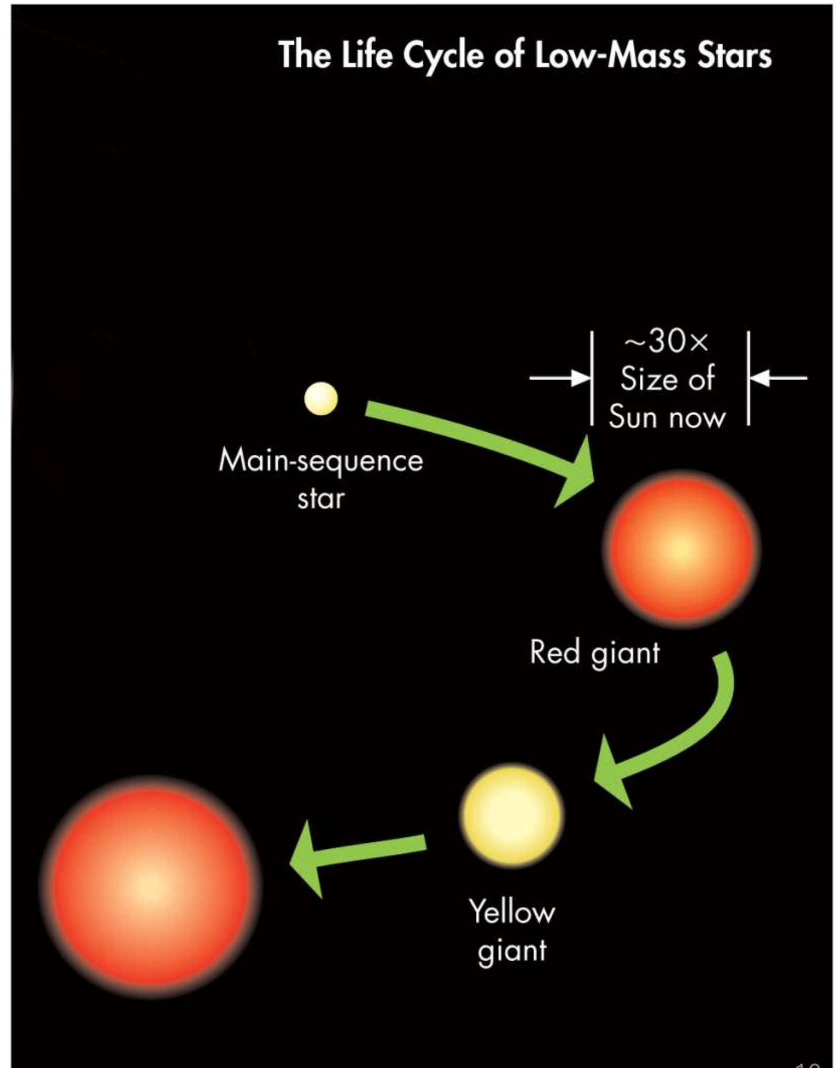
The Life of Our Sun



- The Sun was born out of a portion of an ***interstellar cloud*** that gravitationally collapsed over a time span of a few million years.
- Fusing hydrogen into helium in its core, the Sun will reside on the main sequence for 10 billion years and in the process convert 90% of its core hydrogen into helium.

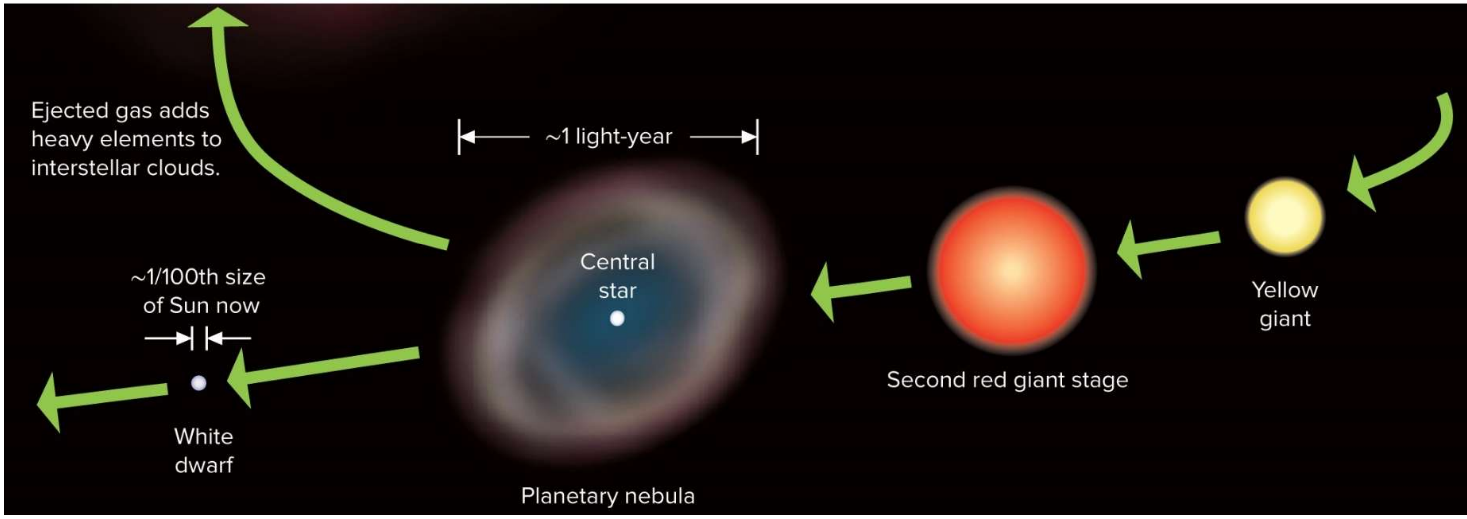
The Old Age of Our Sun

- Starved of fuel, the core will shrink and grow hotter as the outer surface expands and cools transforming the Sun into a red giant.
- After one billion years, the red giant's core will be hot enough to begin fusing helium.
- The Sun will then transform into a pulsating yellow giant.

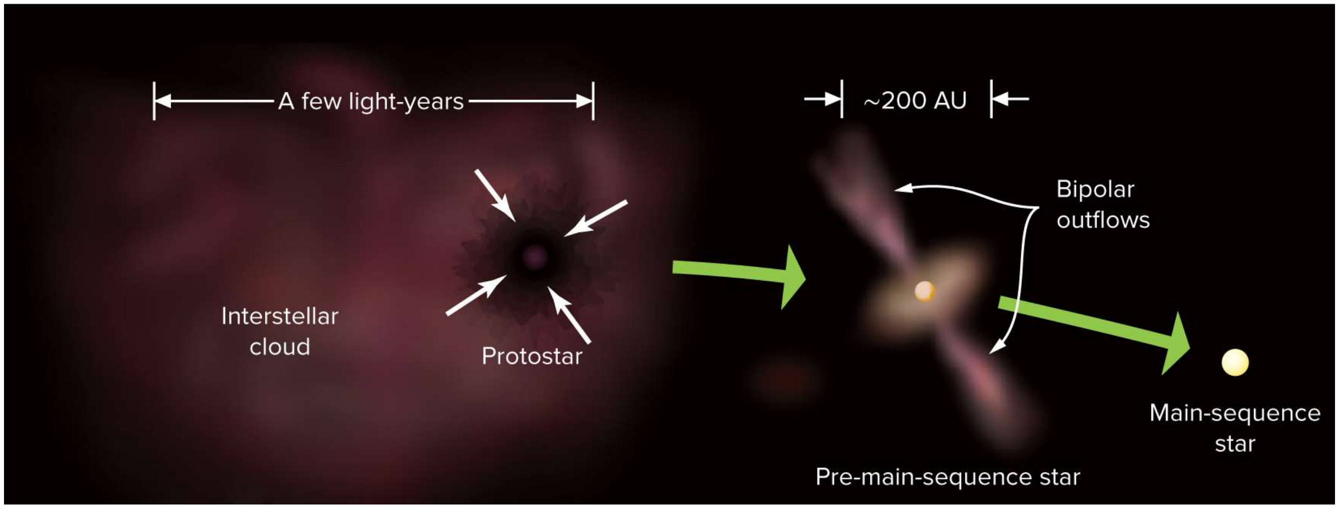


The Death of Our Sun

- As the core's helium fuel begins to expire, the Sun will once again transform into a red giant, but only bigger than before.
- The high luminosity of the red giant will drive the Sun's atmosphere into space leaving behind its core.
- The core will cool and dwindle into a white dwarf.



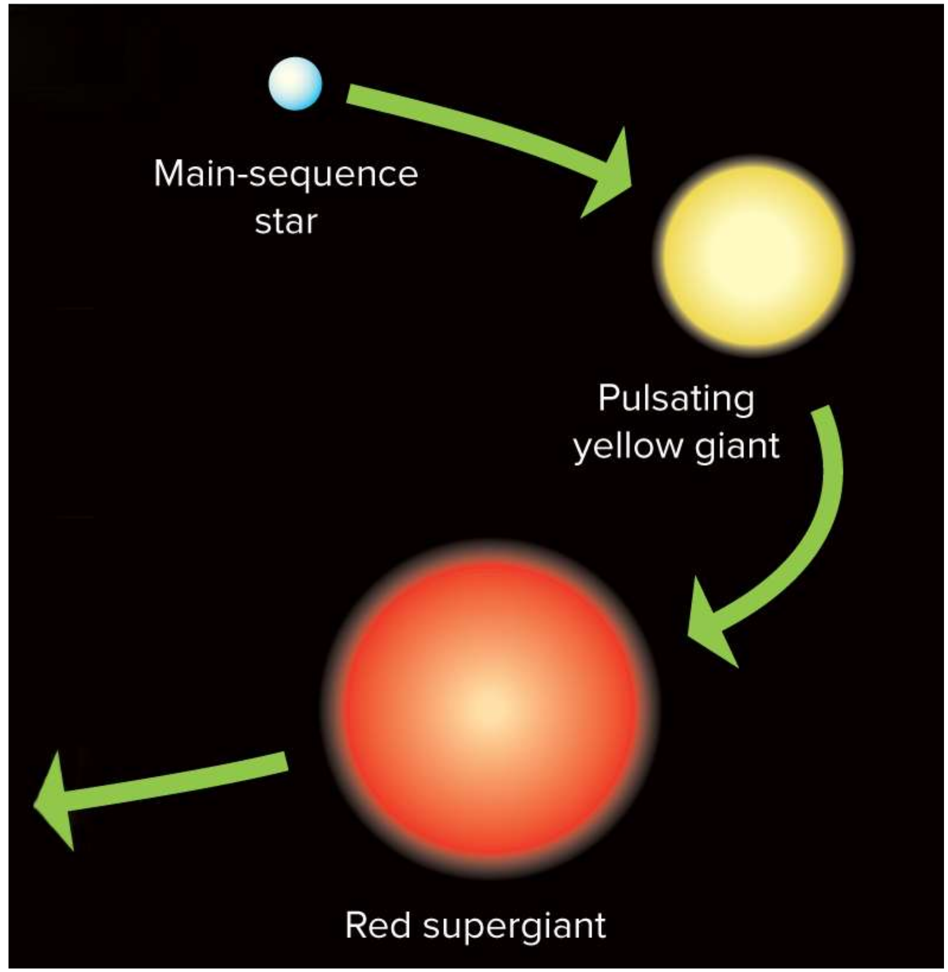
The Life of a High-Mass Star



- The early life of a high-mass star is similar to the Sun:
  - Collapses from an interstellar cloud and resides on the main sequence.
  - Proceeds through these stages much faster than the Sun, spending less than 100 million years on the main sequence.

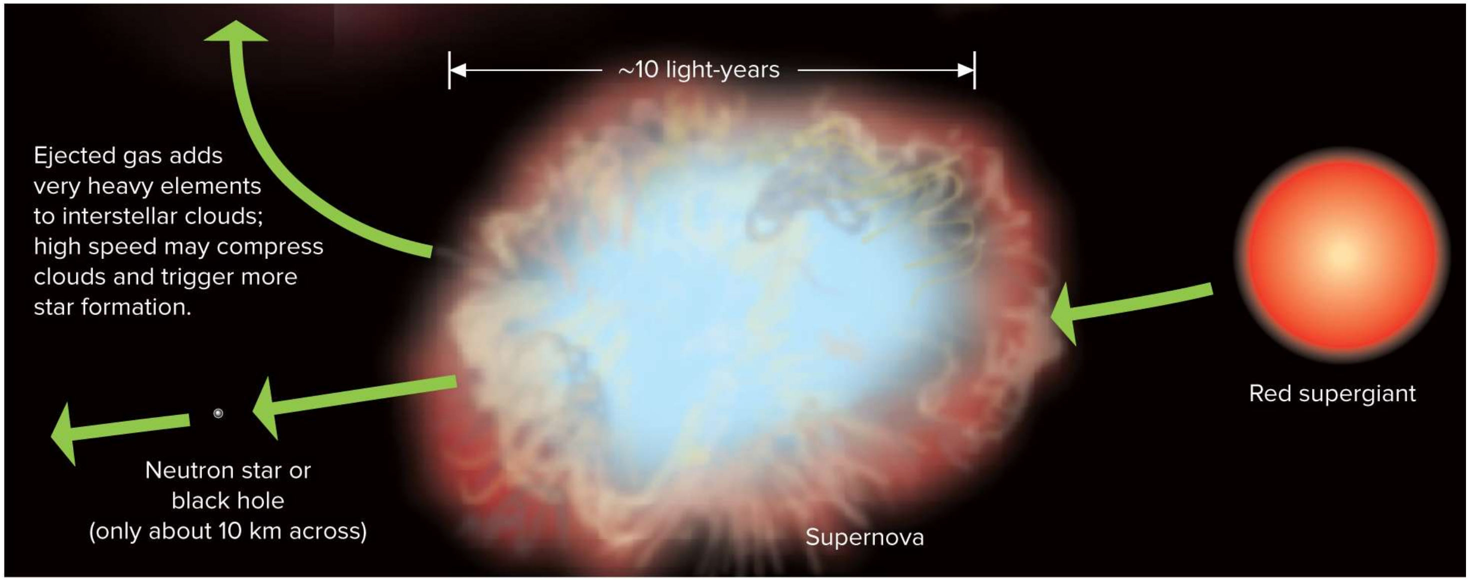
The Old Age of a High-Mass Star

- A high-mass star then passes through the pulsating yellow giant stage before it turns into a red supergiant.
- In the red supergiant phase, the core begins to fuse one element into another creating elements as massive as iron.



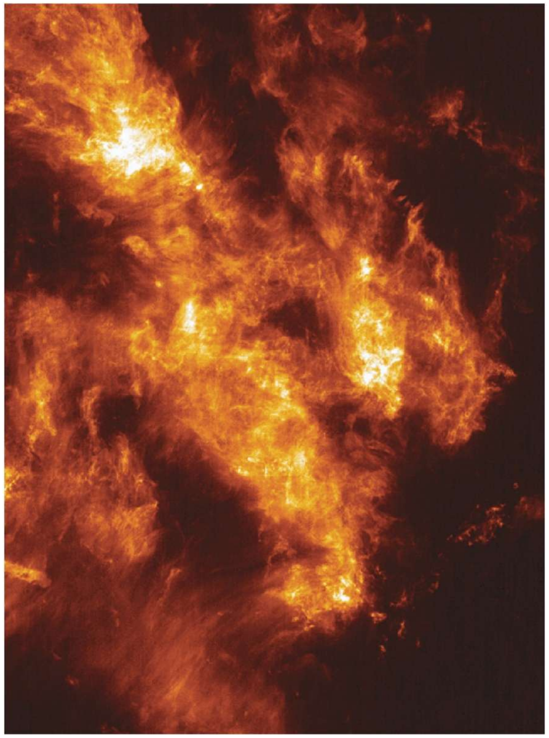
The Death of a High-Mass Star

- Once iron is reached, the core is out of fuel and it collapses.
- The star's heavy elements are blown into space along with its outer layers.
- A neutron star or black hole is left behind.

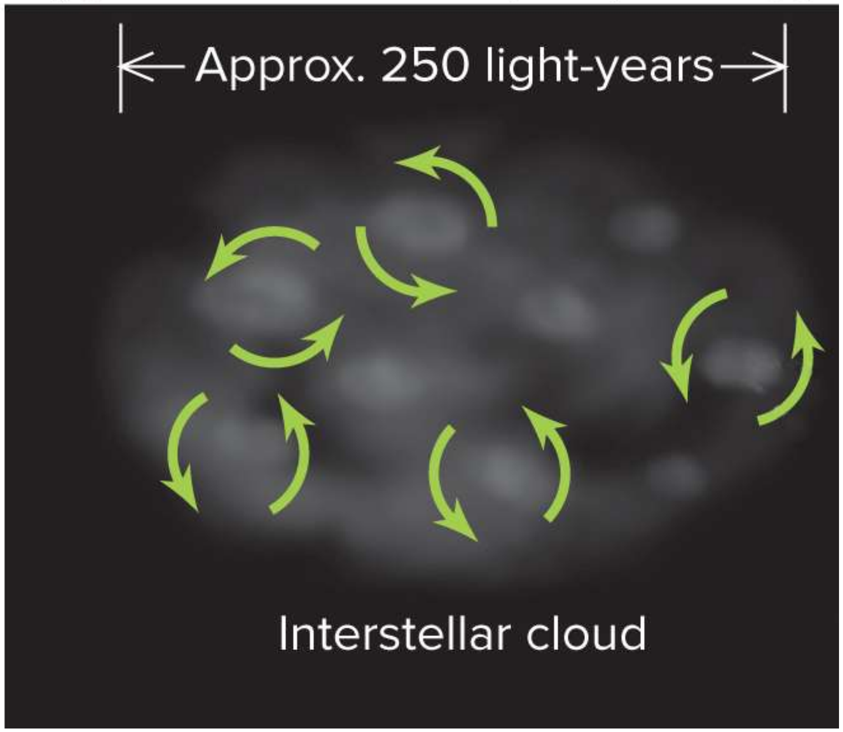


Interstellar Gas Clouds

- General Characteristics.
- Gas: hydrogen (71%), helium (27%), others.
- Dust: microscopic particles of silicates, carbon, and iron.
- Temperature: Around 10 K.

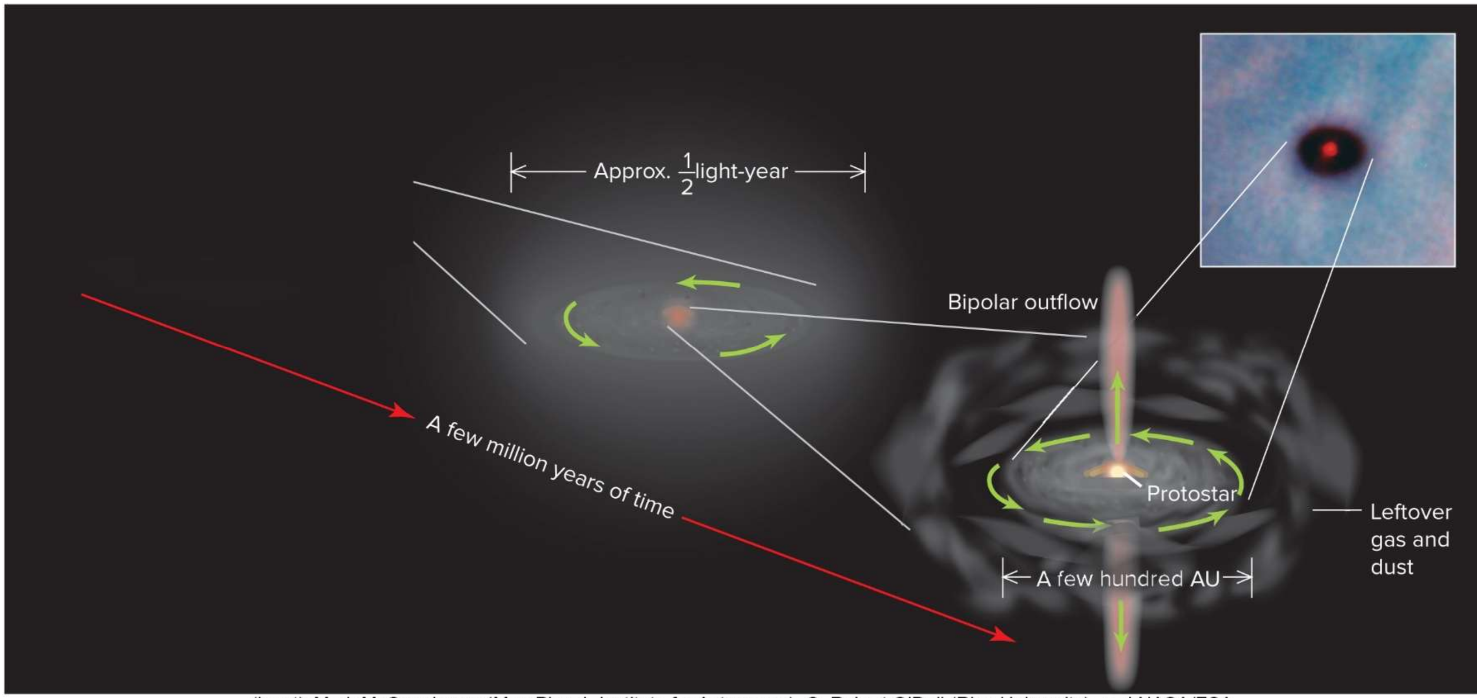


Initial Collapse



- Low temperature leads to too low pressure to support cloud against gravitational collapse.
- Collapse may be triggered by collision with another cloud, a star explosion, or some other process.
- Non-uniformity, clumpy nature of gas leads to formation of smaller, warmer, and denser clumps.

To the Protostar Stage



(inset): Mark McCaughrean (Max-Planck-Institute for Astronomy), C. Robert O'Dell (Rice University), and NASA/ESA

- Rotating dense clumps flatten into disk.
- About one million years: small, hot dense core at center of disk forms – a ***protostar***.
- Stars generally form in groups – similar age.

Protostars

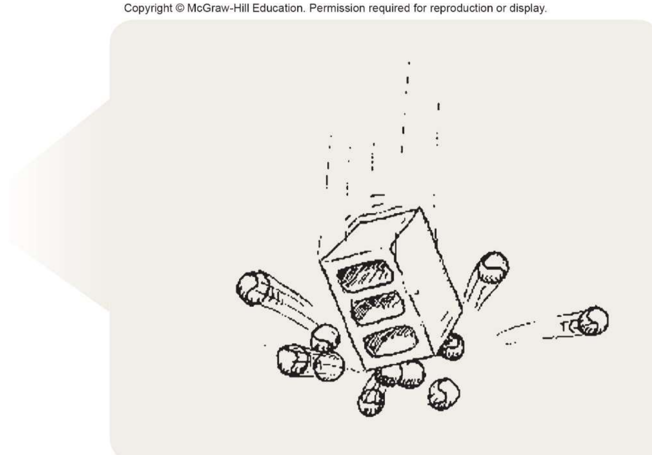
- Characteristics
- Temperature: About 1500 K.
- Shine at infrared and radio wavelengths.
- Low temperature and obscuring dust prevents visible detection.
- May be found in “Bok globules”, dark blobs 0.2 to 2 lys across with masses of up 200 solar masses.

(a,b): NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

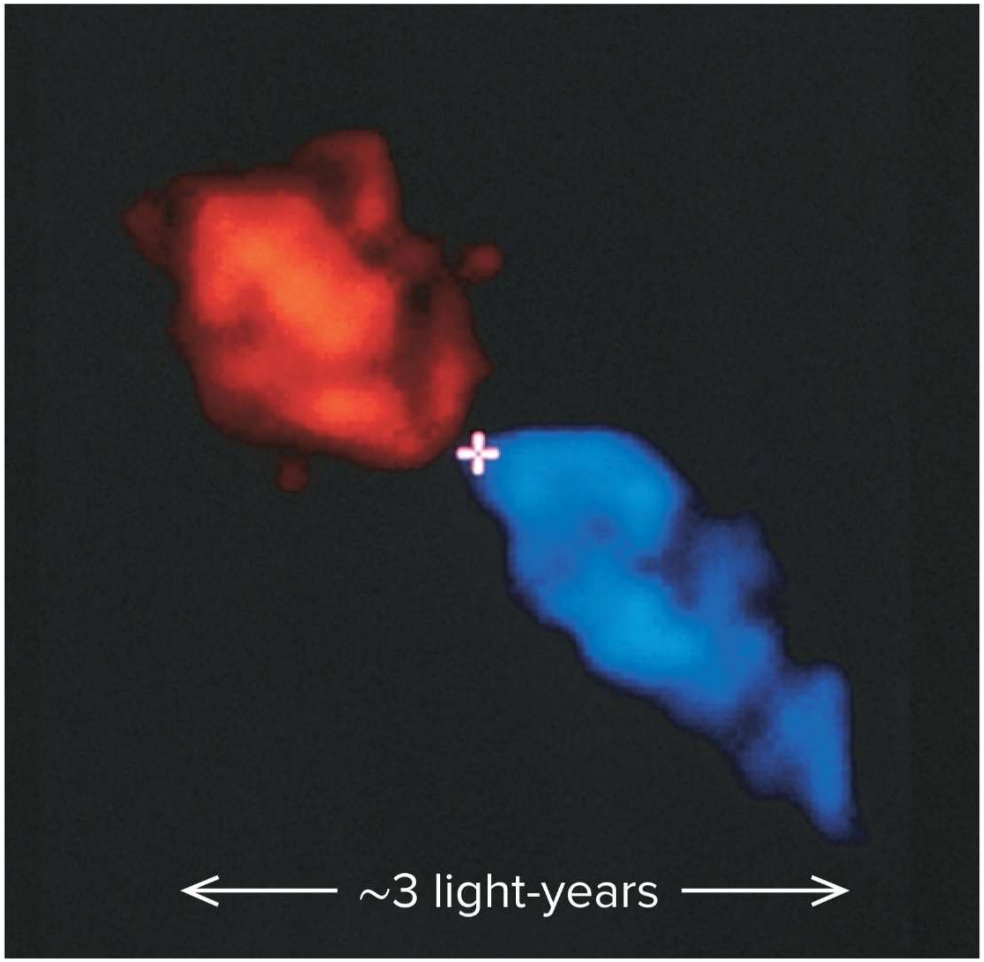
• (a, b): NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

Further Collapse

- Gravity continues to draw material inward.
- Protostar heats to 7 million K in core and hydrogen fusion commences.
- Collapse of core ceases, but protostar continues to acquire material from disk for 10^6 years.
- In-falling material creates violent changes in brightness and ultimately a strong outflow of gas.



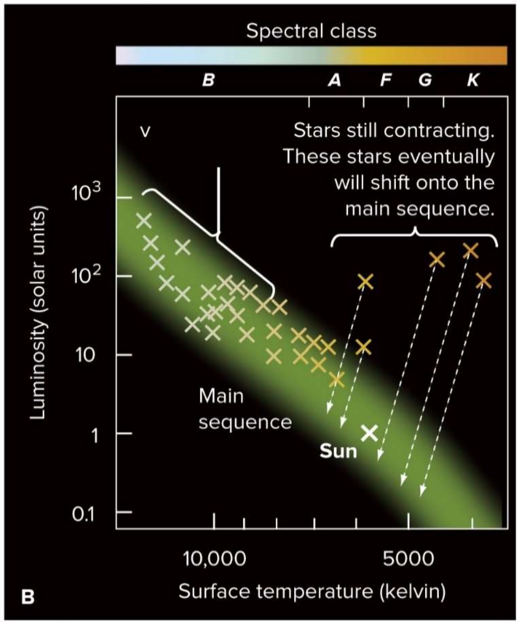
Bipolar Outflows



- Jets also create ***bipolar outflows*** around protostar.
- Easily seen at radio wavelengths.
- Clears away most gas and dust around protostar.

- Courtesy of Ronald Snell, FCRAO

T-Tauri Stars



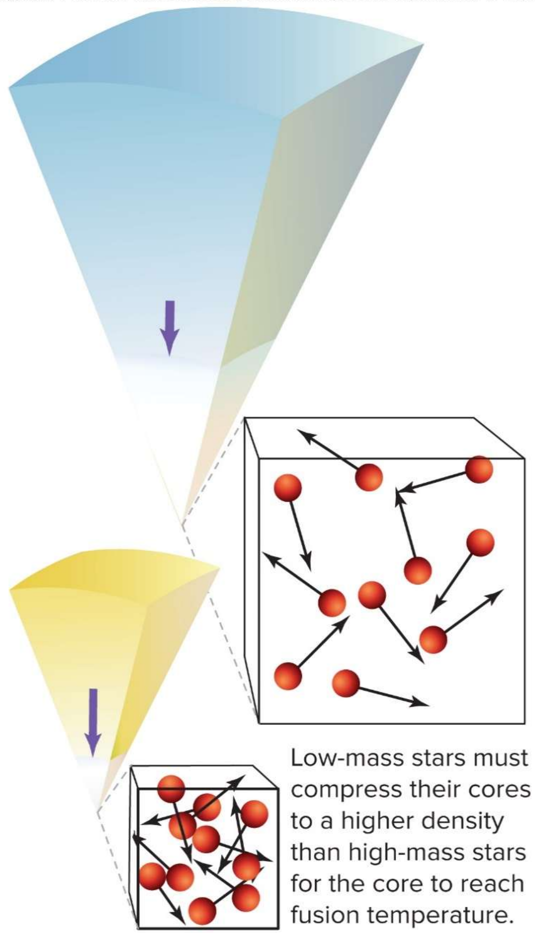
- Young stars still partially immersed in interstellar matter.
- Vary erratically in brightness, perhaps due to magnetic activity.
- Intense outward gas flows from surfaces.
- Occupy H-R diagram just above main-sequence.

- a: © Robert Gendler/Subaru Telescope (NAOJ) & DSS/ Assembly and Processing

Stellar Mass Limits

- Stars smaller than 0.1 $M_{¤}$ are rarely seen since their mass is too small for their cores to initiate fusion reactions.
- Objects with masses between planets and stars are called brown dwarfs, “failed stars” extremely dim and difficult to observe.
- Upper mass limit of stars (about 30 $M_{¤}$) due to extreme temperatures and luminosity preventing additional material from falling on them - intense radiation may even strip off outer layers of star.

A Star’s Mass Determines Its Core Temperature

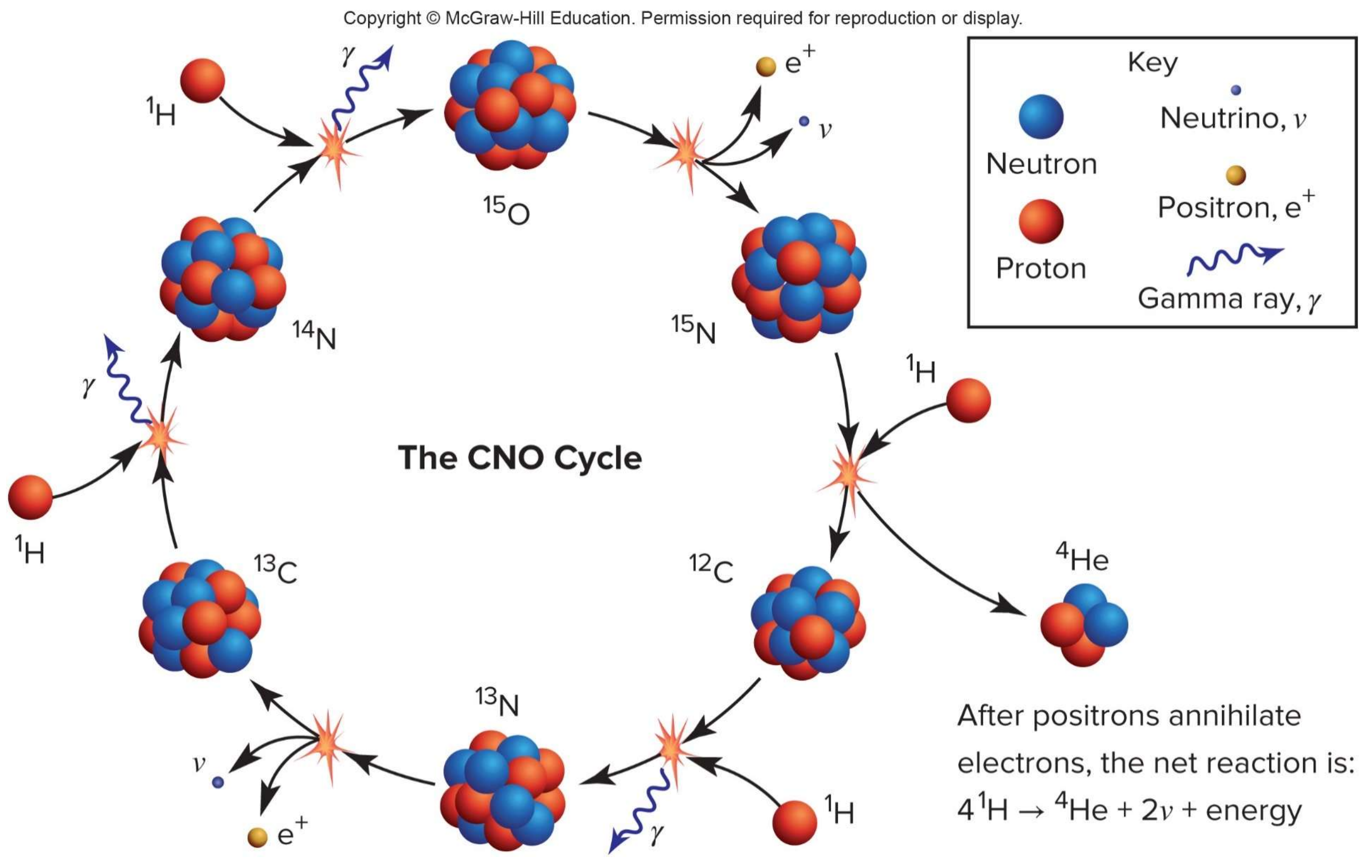


Low-mass stars must compress their cores to a higher density than high-mass stars for the core to reach fusion temperature.

Fusion Cycles of High- and Low-Mass Stars

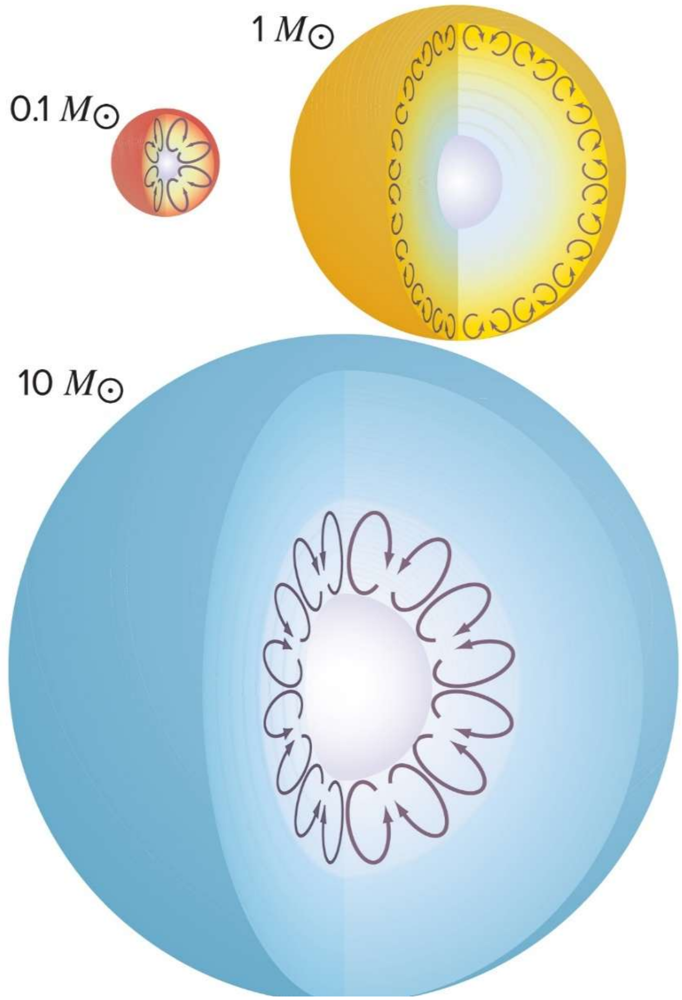
- Fusion in the core
- Low mass stars: proton-proton chain.
- High mass stars: C N O cycle – carbon, nitrogen, and oxygen act as catalysts for H fusion at higher core temperatures.

The C-N-O Cycle



Structure of High- and Low-Mass Stars

- Low mass stars: Inner radiative zone, outer convection layer.
- High mass stars: Inner convection zone, outer radiative layer.
- All stars: Outer layers of hydrogen gas are unavailable for fusion reactions in the core.



Stellar Lifetimes

- The time a star stays on the main sequence is called the ***main-sequence lifetime.***
- The amount of time t_{lms} a star will spend on the main sequence depends on its available fuel (mass M) and how fast it consumes it (luminosity L).

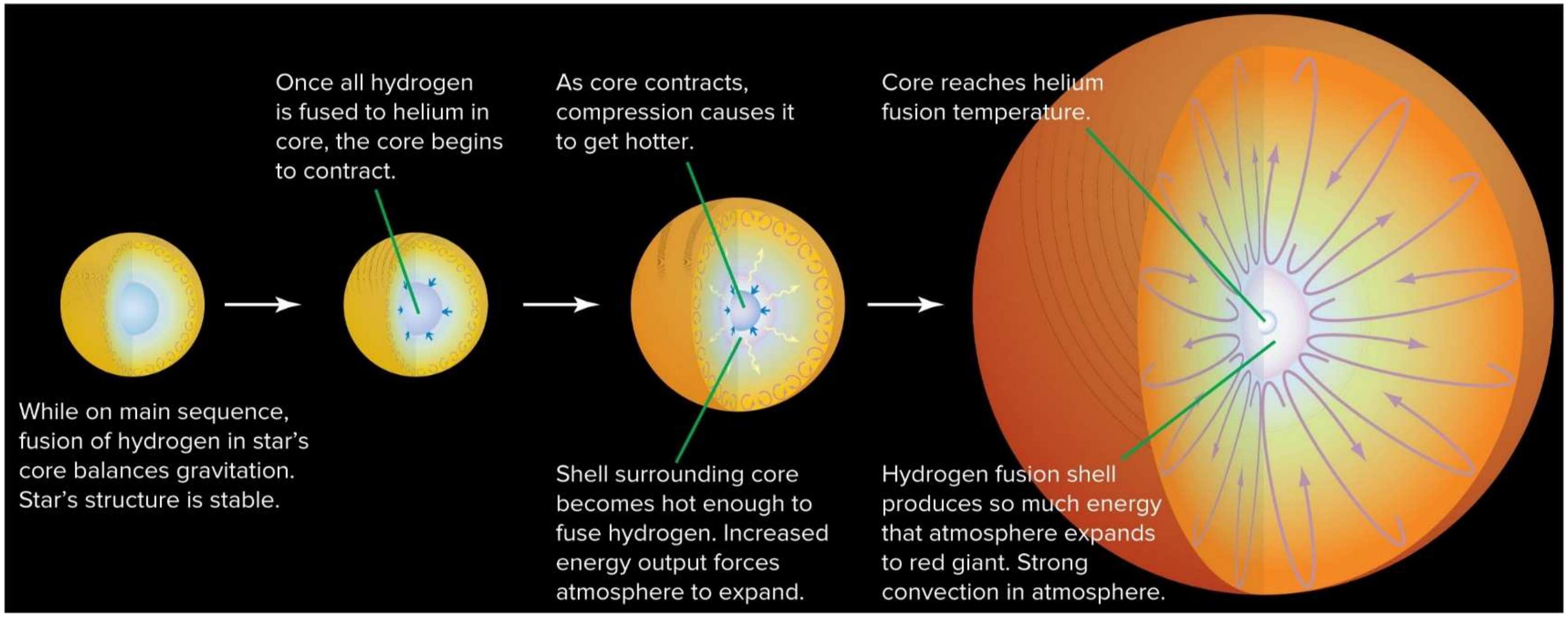
$$t_{lms} = 10^{10}\left(\frac{M}{L}\right) years$$

Stellar Lifetime Examples

- Some lifetimes:
- 1 $M_{¤}$ star with 1 $L_{¤}$:10 billion years.
- 2 $M_{¤}$ star with 20 $L_{¤}$:1 billion years.
- 30 $M_{¤}$ star with 10^5 $L_{¤}$:3 million years.

Leaving the Main Sequence

- When a main-sequence star exhausts its fuel, the core drops its pressure, is compressed by gravity, and heats up.
- The increasing temperature of the core eventually ignites hydrogen gas just outside the core in a region called the ***shell source.***



Becoming a Red Giant

- The shell source increases the pressure around the core and pushes surrounding gases outward.
- The star expands into a red giant as the radius increases and the surface cools.
- The size of red giant depends on initial mass of star.

Structure of a Red Giant

- Most of a giant star's volume is in its huge outer envelope, while most of its mass is in its Earth-sized core.
- Convection carries energy through the outer opaque envelope to the surface.

Wednesday / Thursday (April 29 & 30)

Journal 6.2

- What are some personal obstacles that you want to overcome in the next few years?

- T:13 B) describe and communicate star formation from nebulae to protostars to the development of main sequence stars;
- (D) compare how the mass of a main sequence star will determine its end state as a white dwarf, neutron star, or black hole;
- O: I will begin my project about the life cycles of stars
- D: by researching, designing, and beginning to implement my project.
- A: white dwarf, main sequence, red giant, nebula, neutron star, protostars
- Y: What is the first factor to consider when determining the life cycle of a star?

Friday (May 1)

- C-day
- Continue Projects

Monday / Tuesday (May 4 & 5)

- Finish Projects

- T:13 B) describe and communicate star formation from nebulae to protostars to the development of main sequence stars;
- (D) compare how the mass of a main sequence star will determine its end state as a white dwarf, neutron star, or black hole;
- O: I will continue working on my project about the life cycles of stars
- D: by researching, designing, and finalizing my project.
- A: white dwarf, main sequence, red giant, nebula, neutron star, protostars
- Y: What is the first factor to consider when determining the life cycle of a star?

Wednesday / Thursday (May 6 & 7)

- Project Presentations

- T:13 B) describe and communicate star formation from nebulae to protostars to the development of main sequence stars;
- (D) compare how the mass of a main sequence star will determine its end state as a white dwarf, neutron star, or black hole;
- O: I will finish and present my project
- D: by participating in a gallery walk and grading of my peers.
- A: white dwarf, main sequence, red giant, nebula, neutron star, protostars
- Y: How will you determine if a project met the requirements and was correctly explained?

Category	2 - Excellent	1 - Needs Improvement	0 - Missing/Incomplete	Score
Content Accuracy	Information is accurate, well-explained, and covers all stages of the star from birth to death.	Some information is inaccurate, unclear, or missing key details. Not all stages are represented.	Information is mostly missing or completely inaccurate.	
Visual Presentation	Poster/visual is neat, organized, colorful, and creatively represents the topic.	Poster/visual is somewhat messy or lacks detail.	Poster/visual is difficult to read, very messy, or not turned in.	
Clarity & Engagement	Project is easy to understand, and the presenters explain concepts clearly and confidently.	Presentation is somewhat unclear or lacks confidence.	The presenters are unprepared or do not explain the project.	

Friday (May 8th)

- C-day
- Anyone that was absent last class will need to present their projects.