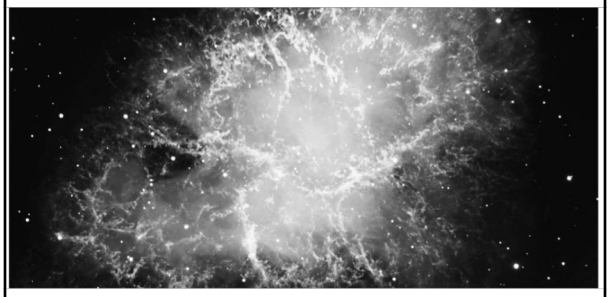
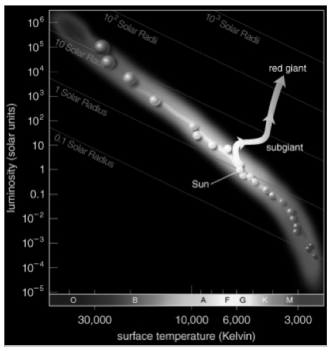
Chapter 17
Star Lives



1

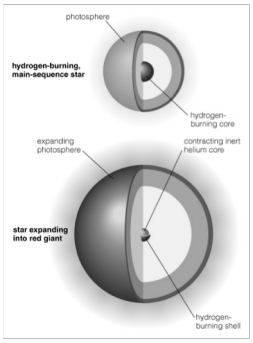
Low mass stars: post Main Sequence



- Observations of star clusters show that a star becomes larger, redder, more luminous after its time on the main sequence is over

2

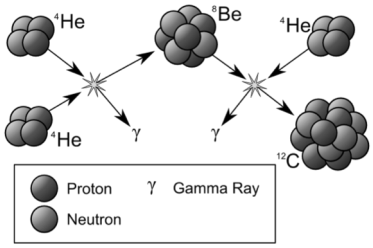
Mirror Principle: Core contracts, envelope expands



- After H burning, He ash remains in core
- As the core contracts, H begins fusing to He in a shell around core
- Luminosity increases: increasing fusion rate in shell does not stop the core from contracting

3

Next energy source: Helium burning



Helium fusion does not begin right away because it requires higher temperatures
(larger charge leads to greater repulsion);
Combine three He nuclei to make one carbon.

4

Thought Question

What happens in a low-mass star when core temperature rises enough for helium fusion to begin?

A. Helium fusion slowly starts up
B. Hydrogen fusion stops
C. Helium fusion rises very sharply

Hint: Degeneracy pressure is the main form of pressure in the inert helium core

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Helium Flash

- Thermostat is broken in low-mass red giant because degeneracy pressure supports core
- Core temperature rises rapidly when helium fusion begins
- Helium fusion rate skyrockets until thermal pressure takes over and expands core again to reach a balance

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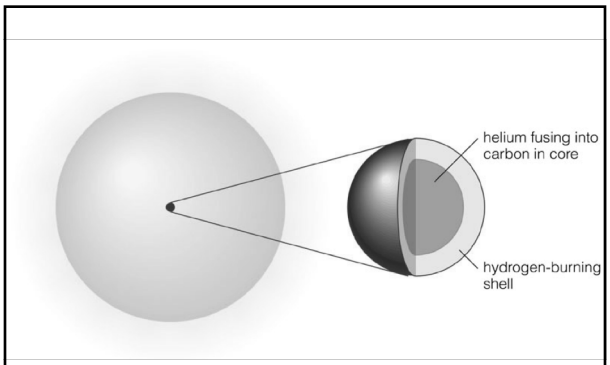

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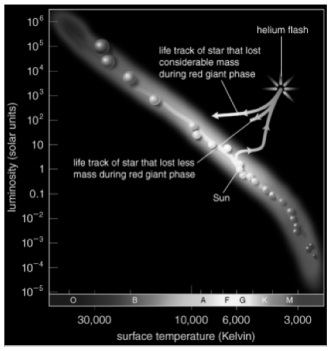
Life Track after Helium Flash



- Models show that a red giant should shrink and fade after He fusion begins in the core
- Mirror principle: core expands, envelope shrinks

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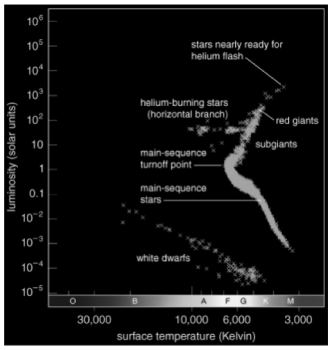
Life Track after Helium Flash



- Observations of star clusters agree with models
- Helium-burning stars are found in a *horizontal branch* on the H-R diagram

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Last stages of nuclear burning

- After core He fusion runs out,
  He fuses into C in a shell around the C core,
  H fuses into He in a shell around the He layer
- Double-shell burning stage never reaches equilibrium—fusion rate periodically spikes upward in a series of *thermal pulses*
- Star becomes large, luminous, and unstable (Sun will grow out nearly to Earth's radius)

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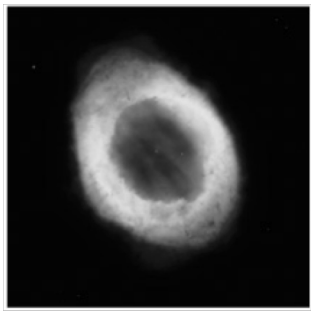
Planetary Nebulae



- Ends with a pulse that ejects the H and He envelope into space as a *planetary nebula*
- The core left behind becomes a white dwarf (supported by degeneracy pressure)

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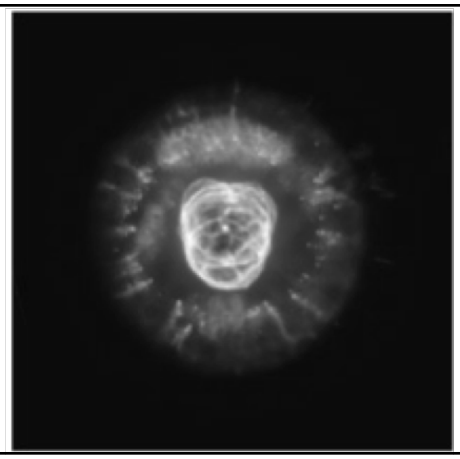

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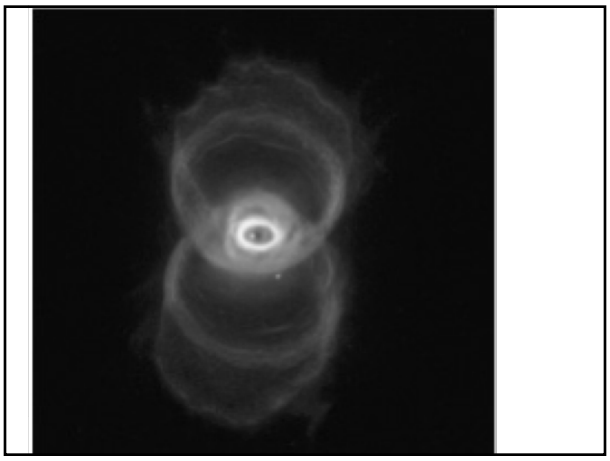

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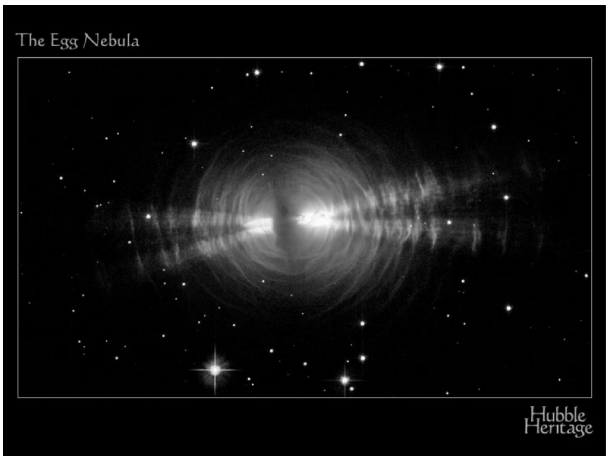

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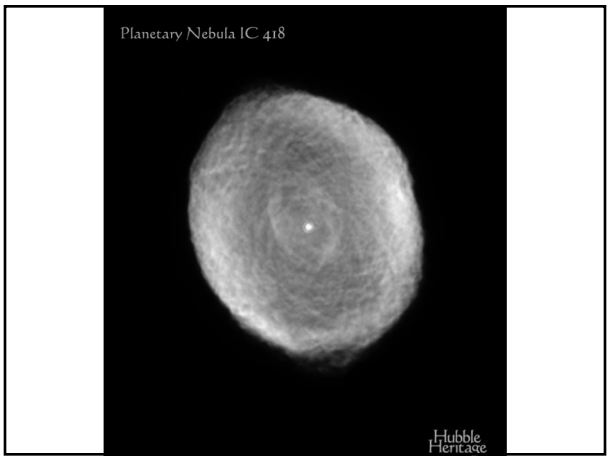

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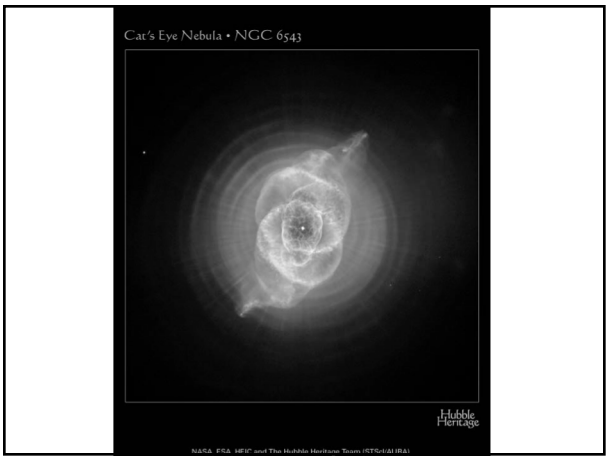

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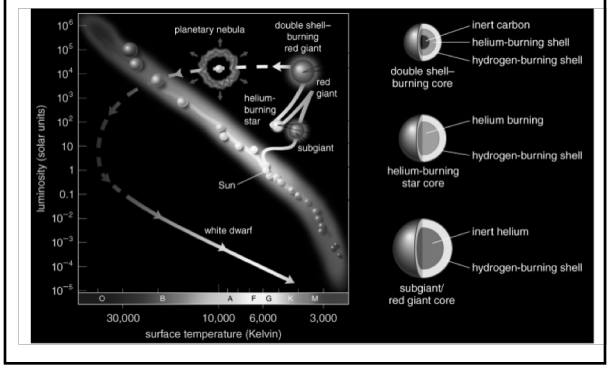
Life Track of a Sun-Like Star



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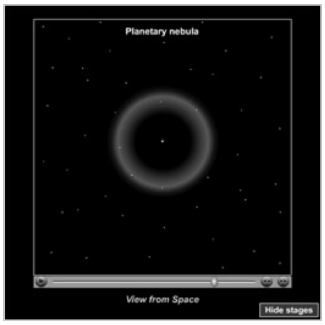

Life stages of a low-mass star like the Sun

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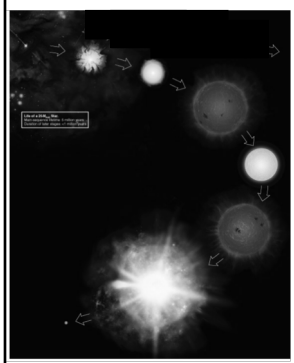

Not to scale!

Life Stages of <u>High-Mass Star</u>

1. Main Sequence:
   H fuses to He in core
2. Red Supergiant: H fuses to He in shell around He core
3. Helium Core Burning:
   He fuses to C in core while H fuses to He in shell
4. Multiple Shell Burning:
   Many elements fuse in shells
5. Supernova leaves neutron star or black hole behind

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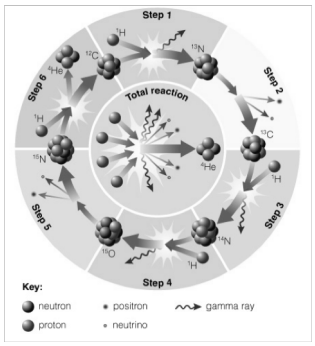
H to He by the CNO Cycle



- High-mass main sequence stars fuse H to He at a higher rate using carbon, nitrogen, and oxygen as catalysts
- He fuses to C in core
- Then He can fuse with C and heavier atoms …

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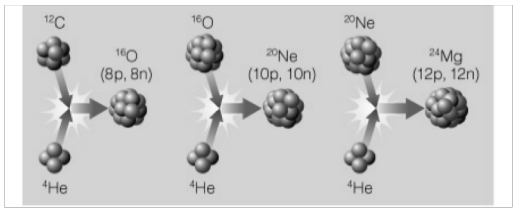
Helium Capture at High Temperature



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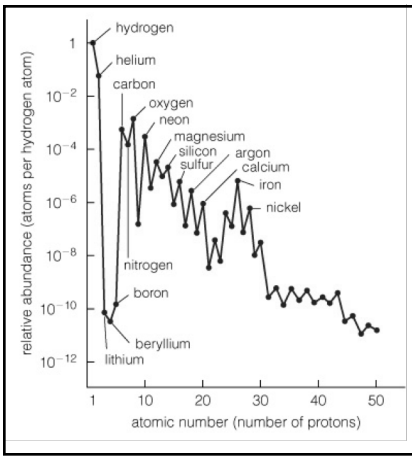

Evidence for helium capture:

Higher abundances of elements with even numbers of protons

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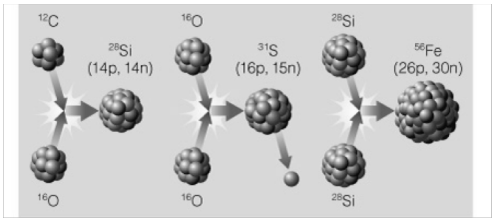
Advanced Nuclear Burning



- Core temperatures in stars with $>8M_{Sun}$ allow fusion of elements as heavy as iron

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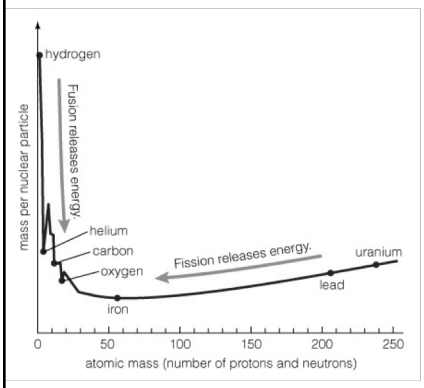

Iron is dead end for fusion because nuclear reactions involving iron *do not release energy*

(Fe has lowest mass per nuclear particle)

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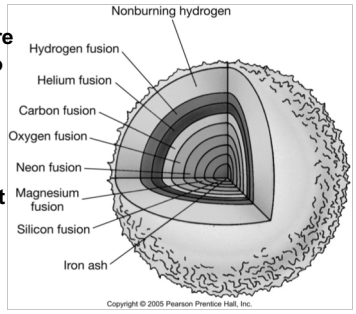
A high-mass star can continue to fuse elements in its core right up to iron ("onion" like shells).

As heavier elements are fused, the reactions go faster and the stage is over more quickly.

A 20-solar-mass star will burn carbon for about 10,000 years, but its iron core lasts less than a day.



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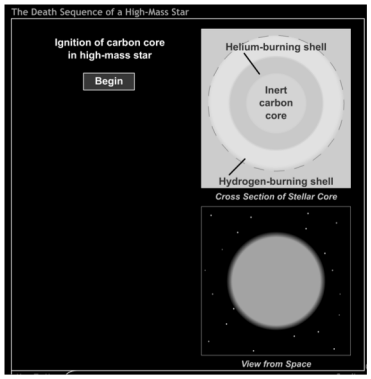

Life stages of a high-mass star

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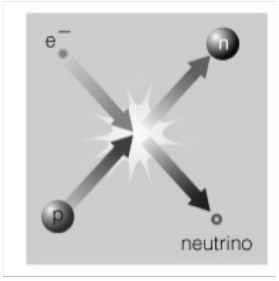
Supernova Explosion



- Core collapse causes electrons to combine with protons, making neutrons and neutrinos
- Neutrons collapse to the center, forming a **neutron star**
- Outer layers bounce off core and are ejected into space

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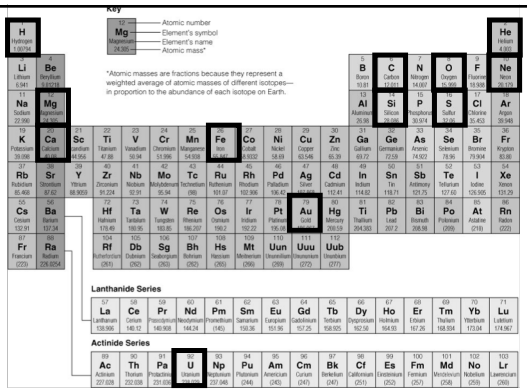

Energy and neutrons released in supernova explosion enable elements heavier than iron to form, including Au and U

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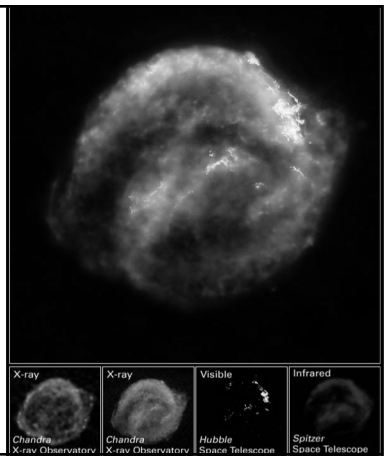
Supernovae are rare (last one in Galaxy observed by Kepler in 1604).
The SN remnant emits across the EM spectrum for 10,000 years.



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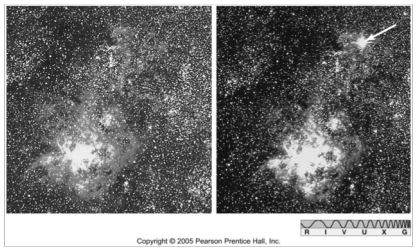
Supernova SN1987A occurred in the Large Magellanic Cloud in February 1987. Exploding star was a blue supergiant. Accompanied by a neutrino burst.



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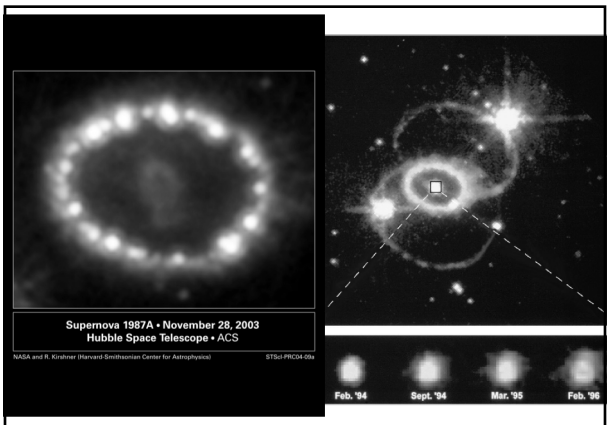

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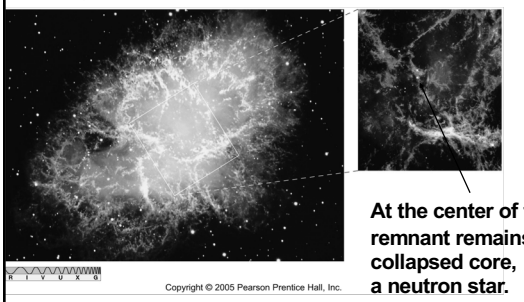
Crab nebula is a remnant of massive star (Type II) supernova explosion that occurred in the year 1054.



At the center of the remnant remains the collapsed core, a neutron star.

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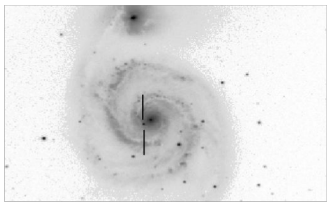
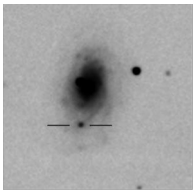
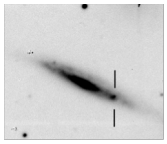
380 discovered by Tim Puckett, Mtn. Town, GA







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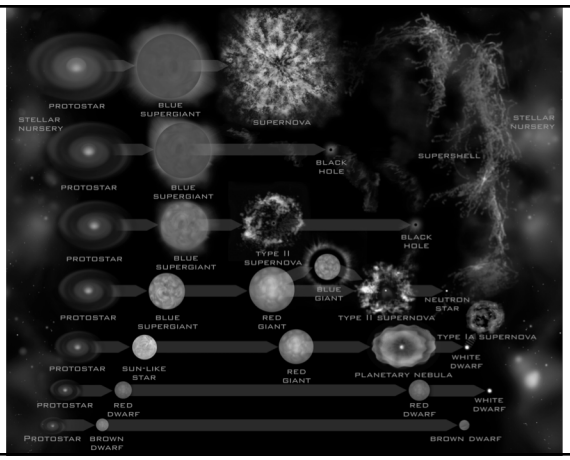

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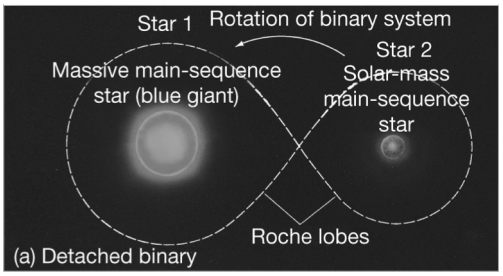
Evolution in Close Binary Stars

Mass transfer can radically change stars. Example: Algol ("eye of the Medusa")

Began as a detached binary



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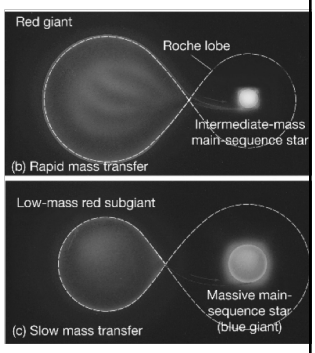
As the more massive star became a red giant, it began mass transfer onto the gainer star.

Eventually the mass gainer became the more massive star, leaving the mass donor as a red subgiant.
Algol Paradox



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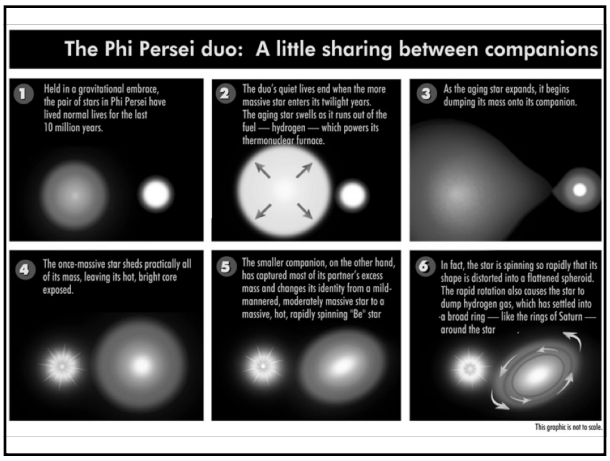
The Phi Persei duo: A little sharing between companions
1 Held in a gravitational embrace, the pair of stars in Phi Persei have lived normal lives for the last 10 million years.
2 The duo's quiet lives end when the more massive star enters its twilight years. The aging star swells as it runs out of the fuel — hydrogen — which powers its thermonuclear furnace.
3 As the aging star expands, it begins dumping its mass onto its companion.
4 The once-massive star sheds practically all of its mass, leaving its hot, bright core exposed.
5 The smaller companion, on the other hand, has captured most of its partner's excess mass and changes its identity from a mild-mannered, moderately massive star to a massive, hot, rapidly spinning "Be" star
6 In fact, the star is spinning so rapidly that its shape is distorted into a flattened spheroid. The rapid rotation also causes the star to dump hydrogen gas, which has settled into a broad ring — like the rings of Saturn — around the star
This graphic is not to scale.

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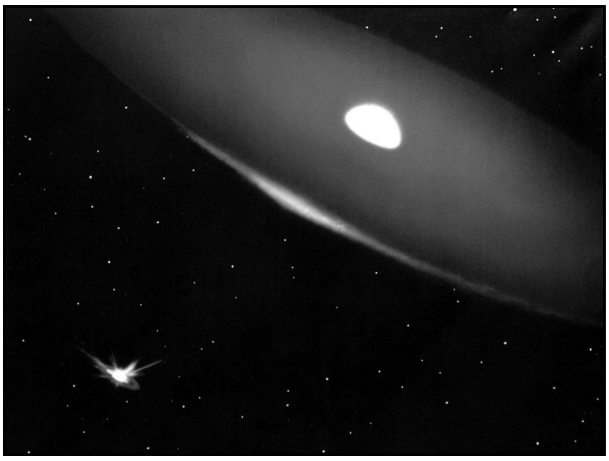

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