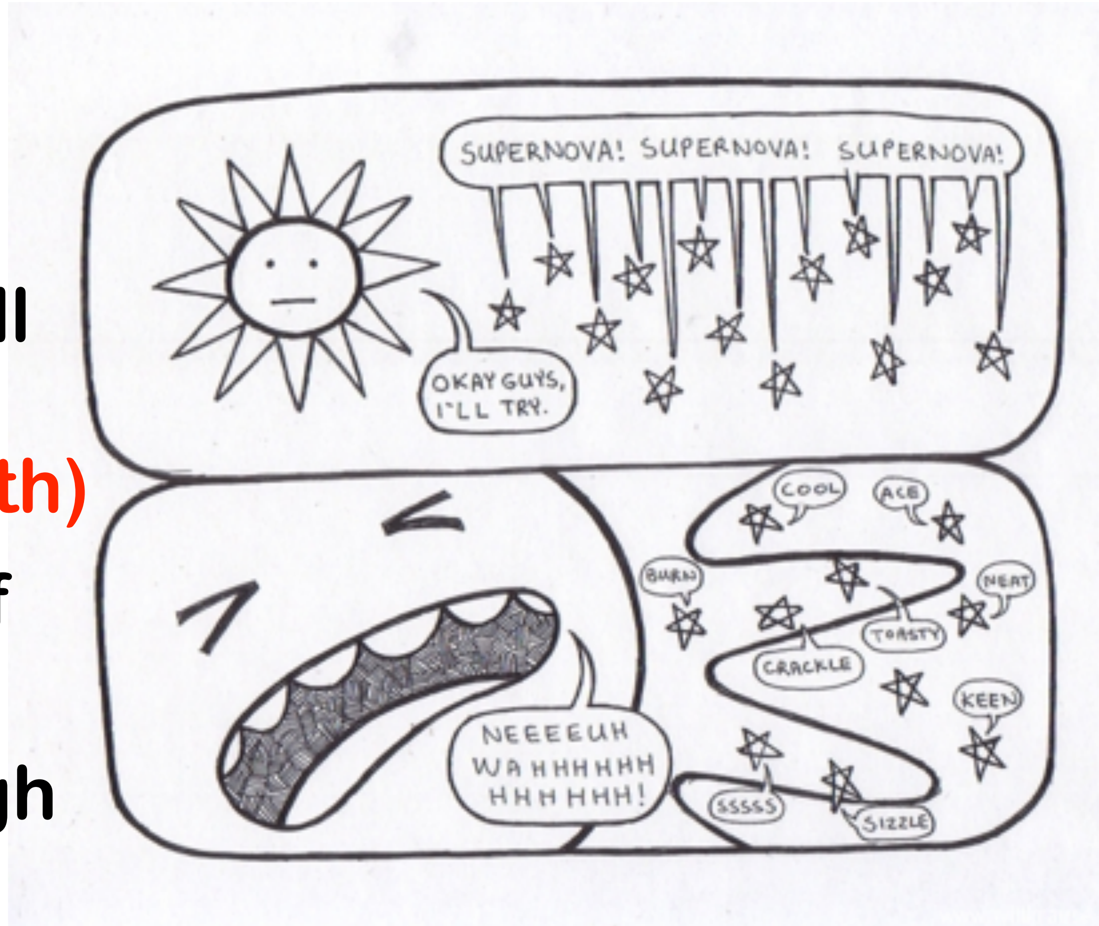
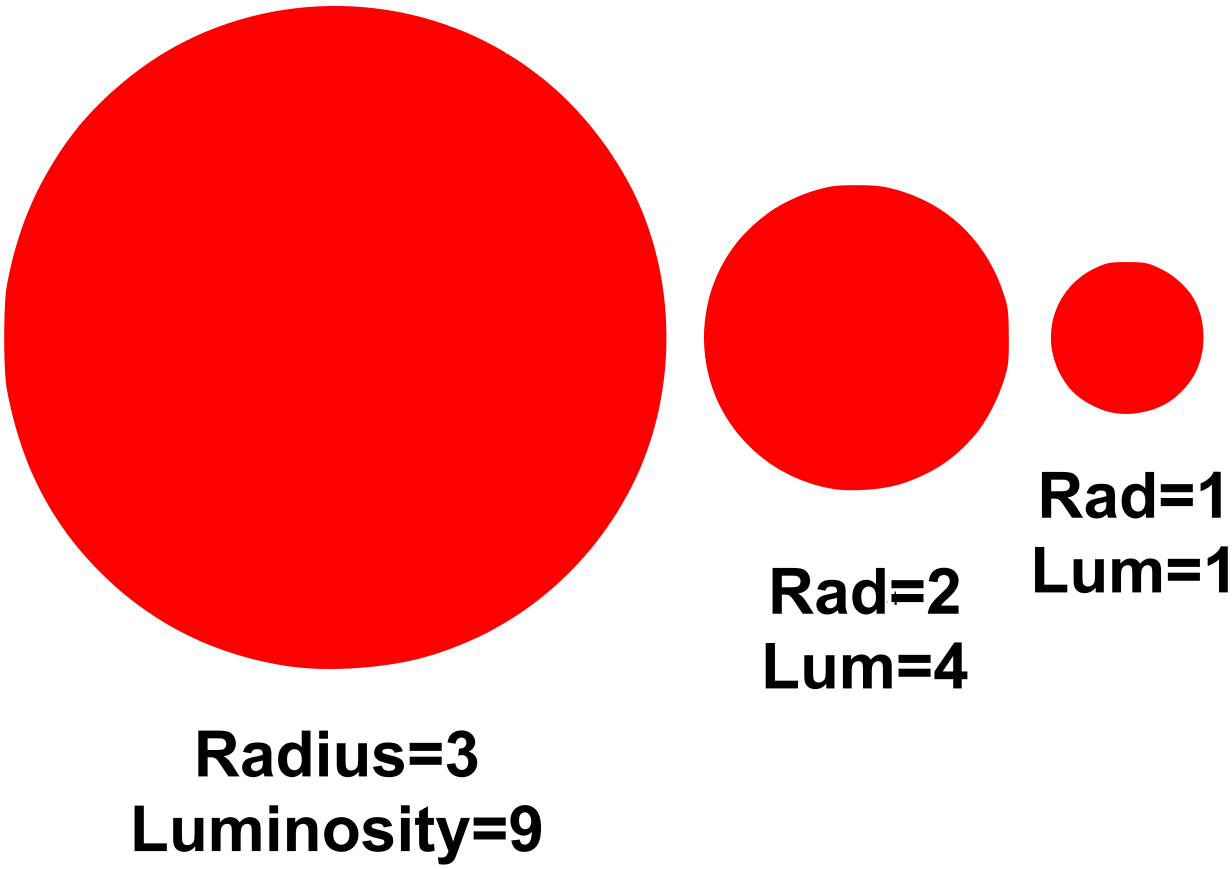
Killer Skies

- **Homework 6 due Monday**
- **Night Observing still need 1 more night (Report due Nov 15th)**
- **Last time: Nature of Stars 2**
- **Today: Death of High Mass Stars**



Music: *Champagne Supernova* – Oasis

Hotter and Bigger Objects are Brighter



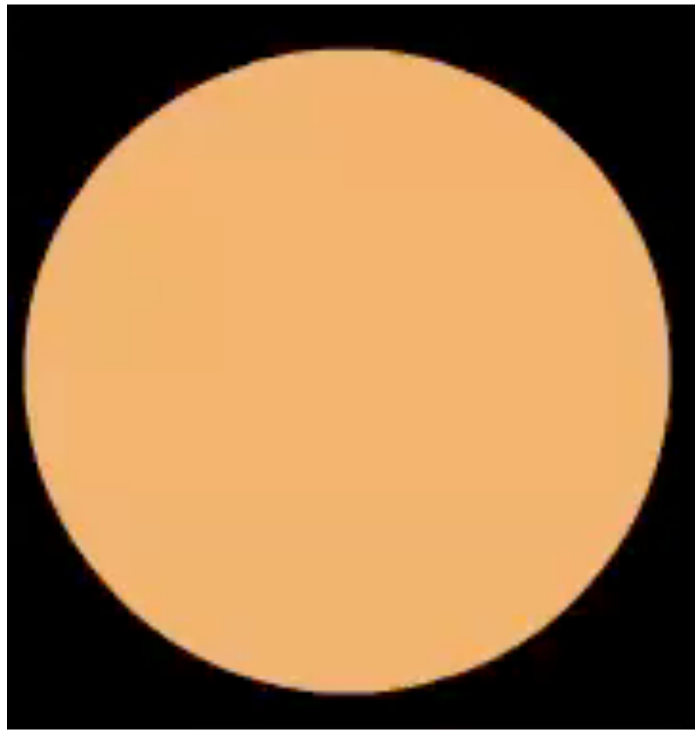
For stars of the same temperature, the larger the star, the greater the luminosity

Luminosity also depends on the surface area of the star. Bigger surface area means more energy radiated.

Thought Question

If a star's surface temperature increases while the luminosity remains the same, what is happening to the star's size (radius)?

A. It is increasing
B. It is decreasing
C. It is remaining the same
D. Not enough information



Answer B: If temperature goes up, but luminosity remains the same, the size MUST be decreasing.

Thought Question

Sirius A has a luminosity of 26 L_{Sun}. Deneb has a luminosity of 200,000 L_{Sun}. Both Sirius A and Deneb have the same temperature. Which star is **larger** in size?

A. Sirius A
B. Deneb
C. They are the same size
D. Not enough information

Answer B: Deneb is more luminous, but they have the same temperature. So, Deneb MUST be bigger.

Thought Question

Rigel and Regulus have similar radii. Rigel has luminosity of 66,000 L_{Sun} and Regulus has a luminosity of 150 L_{Sun}. Which star has the largest surface temperature?

A. Rigel
B. Regulus
C. They have the same temperature
D. Not enough information

Answer A: Since the same size, the hotter one is brighter.

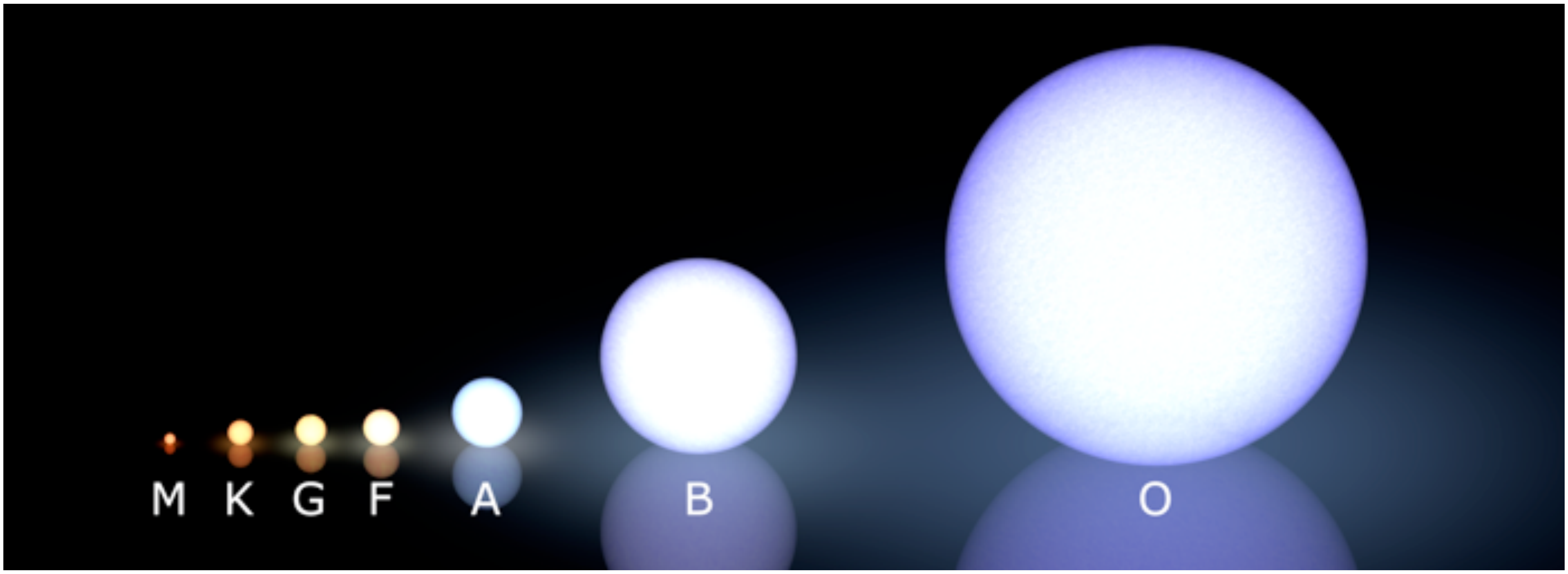
Thought Question

The stars Antares and Mimosa each have the same luminosity (about 35,000 L_{Sun}). Antares is cooler than Mimosa. Which star is **smaller**?

A. Antares
B. Mimosa
C. They are the same size
D. Not enough information

Answer B. To have the same luminosity as Mimosa and yet be cooler, Antares must be far larger.

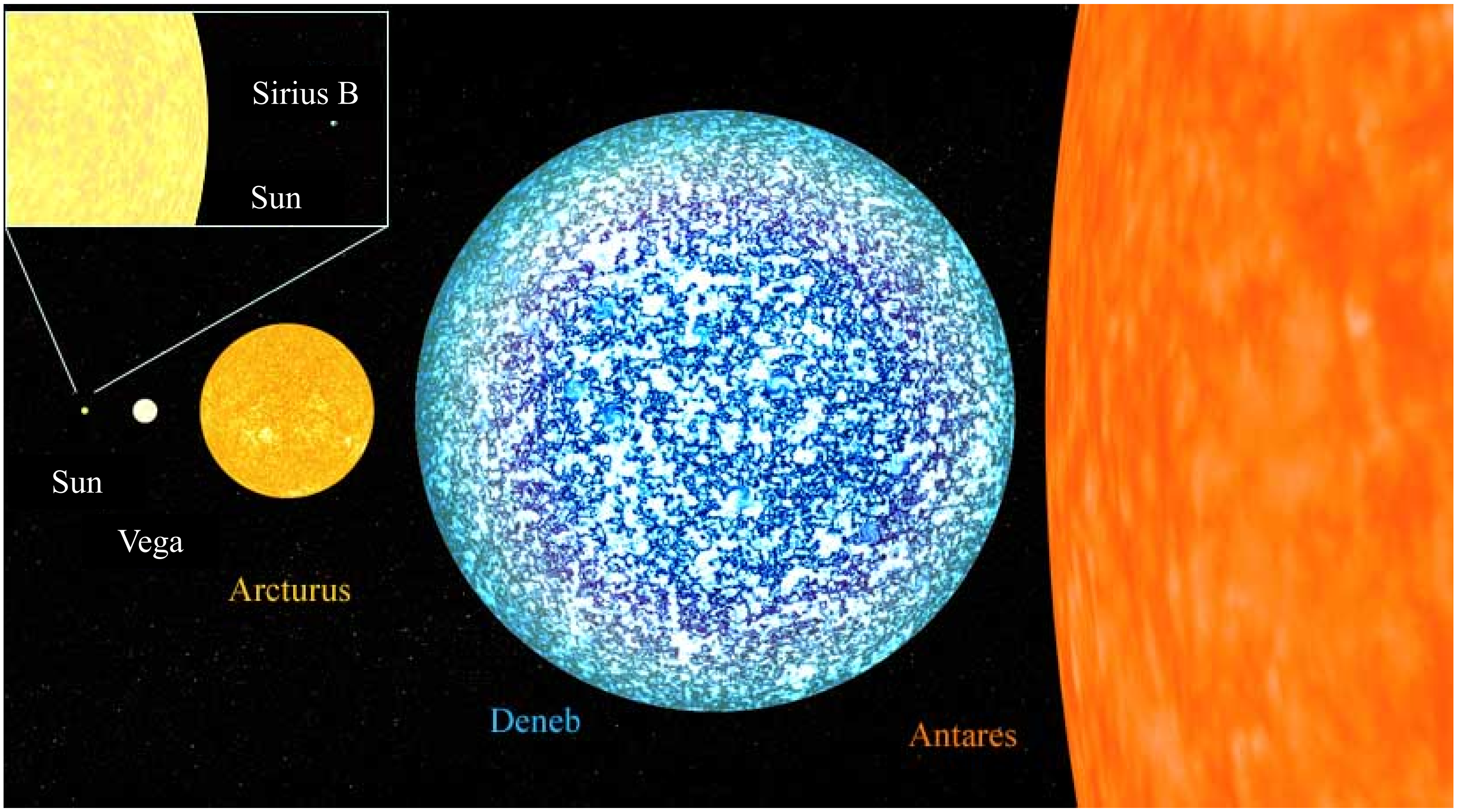
Sizes of Main Sequence Stars



This illustration shows the relative sizes and colors of main sequence stars, from smallest (Class M) to largest (Class O)
the Sun: class G

Now that we

Relative Sizes of Other Star Types



Sizes of the Sun (G main seq.), Sirius B (white dwarf), Vega (A main seq.), Arcturus (K giant), Deneb (A supergiant), and Antares (M red supergiant)

Sirius B: 0.0025 L_{Sun}, 0.008 R_{Sun} (about the size of the Earth).

Vega: 37 L_{Sun}, 2.5 R_{Sun}

Arcturus: 200 L_{Sun}, 25 R_{Sun}

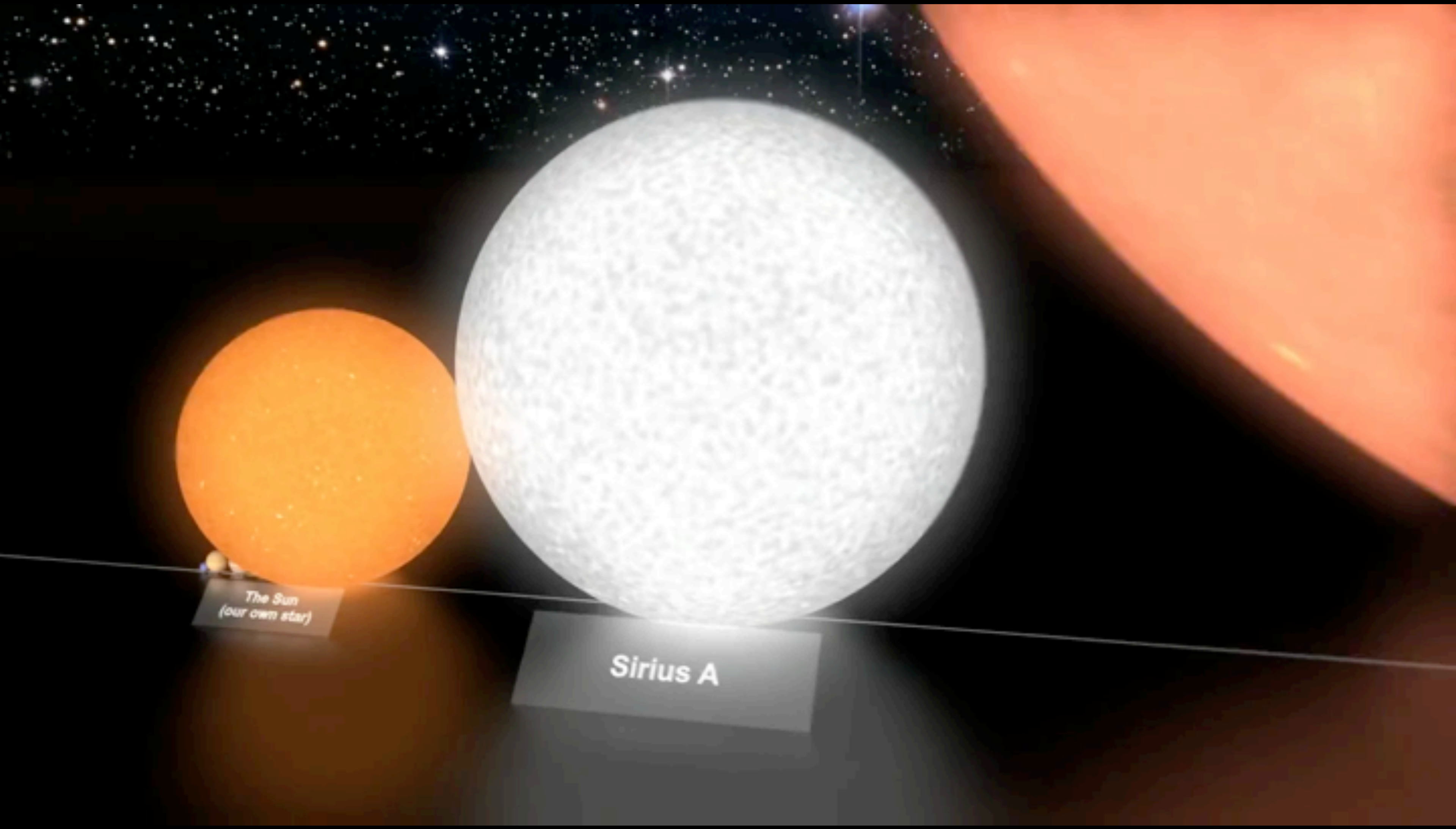
Deneb: 160,000 L_{Sun}, 200 R_{Sun} (2 AU across) – the size of Earth's orbit

Antares: 65,000 L_{Sun}, 700 R_{Sun} (7 AU across) – bigger than Mars' orbit!

THE LARGEST STARS ARE 1000 TIMES THE SUNS ORBIT.

http://www.youtube.com/watch?v=HEheh1BH34Q&feature=relate

A Tour of Size



http://www.youtube.com/watch?v=HEheh1BH34Q

Thought Question

Vote your conscience. Which star will have the longest lifetime on the main sequence?

A.  Spica: 11 M_{Sun} star

B.  Sirius: 2 M_{Sun} star

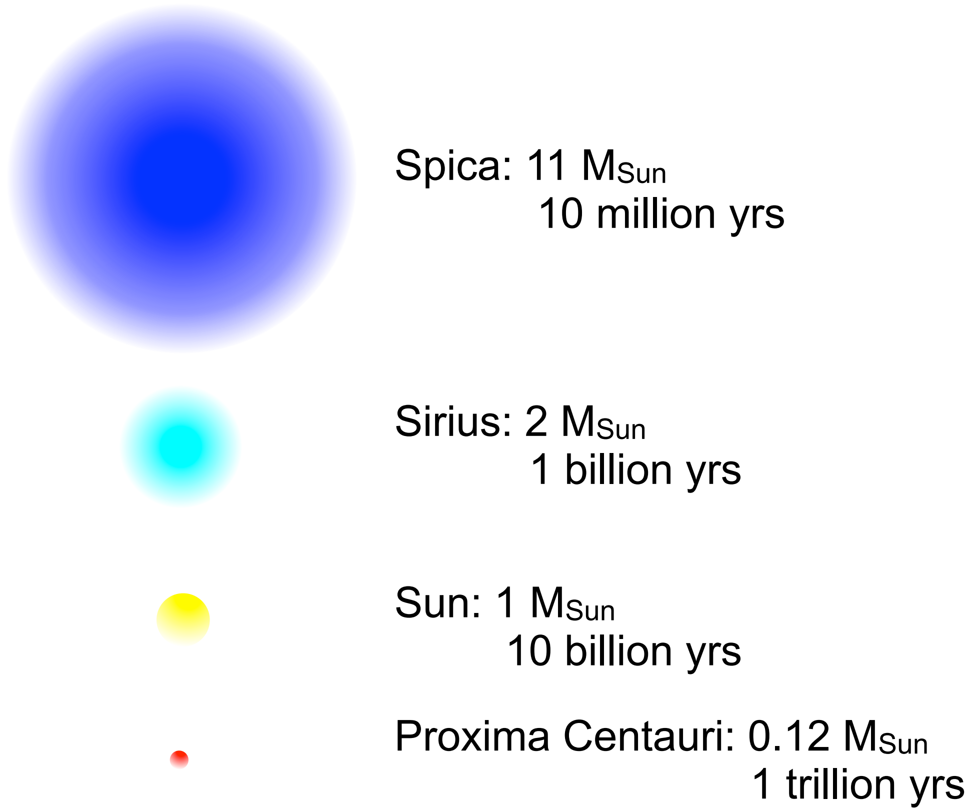
C. Sun: 1 M_{Sun} star

D.  Proxima Centauri: 0.12 M_{Sun} star

Answer: D The lowest mass star has the longest lifetime. It seems odd, doesn't it?

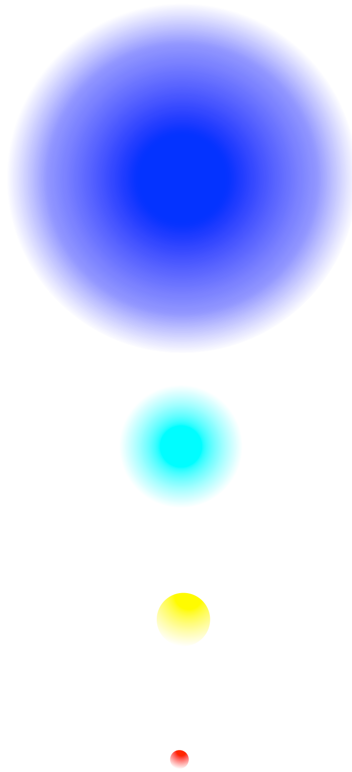
High-mass stars have dramatically *shorter* lifespans

- High mass star
  - More hydrogen fuel
  - But, MUCH greater luminosity
  - Luminosity ~ $Mass^{3.5}$
- High mass stars "burn" fuel MUCH faster than low mass stars
- Leads to short lives for high mass stars!



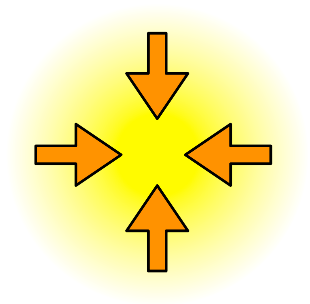
High-mass stars have dramatically *shorter* lifespans

- The mass-luminosity relation has a big effect on the lifespans of stars
- Consider a 10 M_{Sun} star:
    - 10 times as much fuel, uses it 10^4 times as fast
    - So a 10 M_{Sun} star will last only 10 **million** years
    - Compare to the 10 **billion** year lifetime of the Sun



What causes high-mass stars to live short lives?

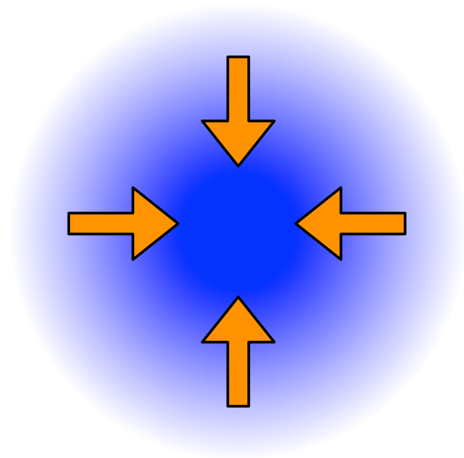
radius = 1 R_{sun}



<u>Low Mass Star:</u>

Lower Pressure
Lower Temperature
Slower Fusion
Lower Luminosity

radius = 1.5 R_{sun}



<u>High Mass Star:</u>

Higher Pressure
Higher Temperature
Rapid Fusion
Higher Luminosity

Pressure vs. gravity
A massive star has more mass to support.
The pressure and temperature in the center are very high.
Higher temperature boosts fusion rate.
Rapid fuel consumption.

High luminosity
A massive star has a stronger gravitational field and it has more mass to support.
So, the pressure needed to keep it from collapsing is very high.
That means the internal temperature must be high, which means the star will generate energy rapidly.

High mass stars = Hummers
Low mass stars = Priuses

- High-mass stars: **"gas guzzlers"**
  - High luminosity, large, blue
  - Live short lives, millions of years
- Low-mass stars: **"fuel efficient"**
  - Low luminosity, small, red
  - Long-lived, hundreds of billions of years

High Mass: High Luminosity, Short-Lived, Large Radius, Blue

Low Mass: Low Luminosity, Long-Lived, Small Radius, Red

Stellar Lifestyles

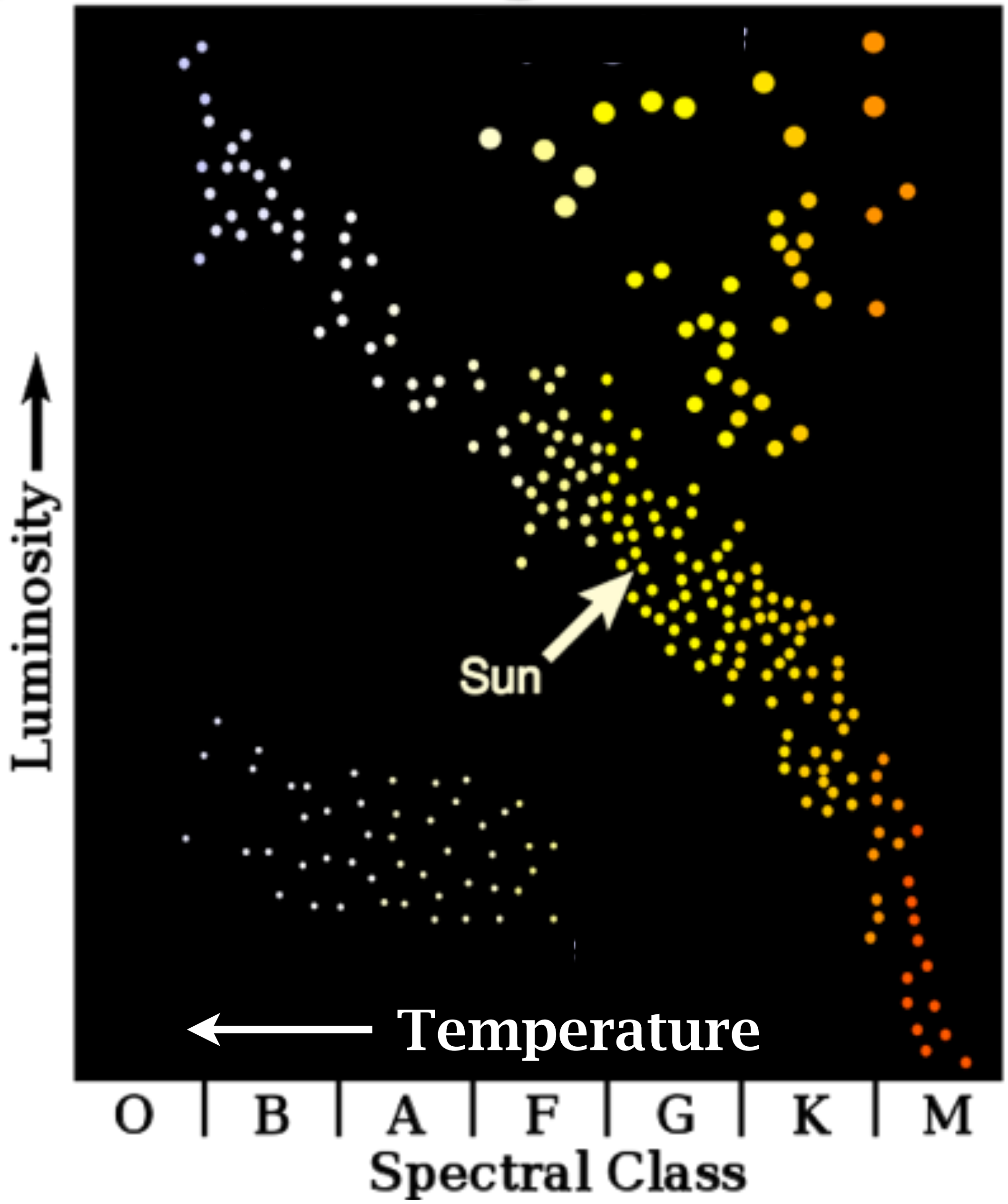
Low-mass stars

High-mass stars

Hertzsprung-Russell Diagram

A Luminosity vs. temperature plot is called the HR Diagram and it tells us a lot about stars.

Note: T plotted backwards! Hot at left, cool at right! Sorry!



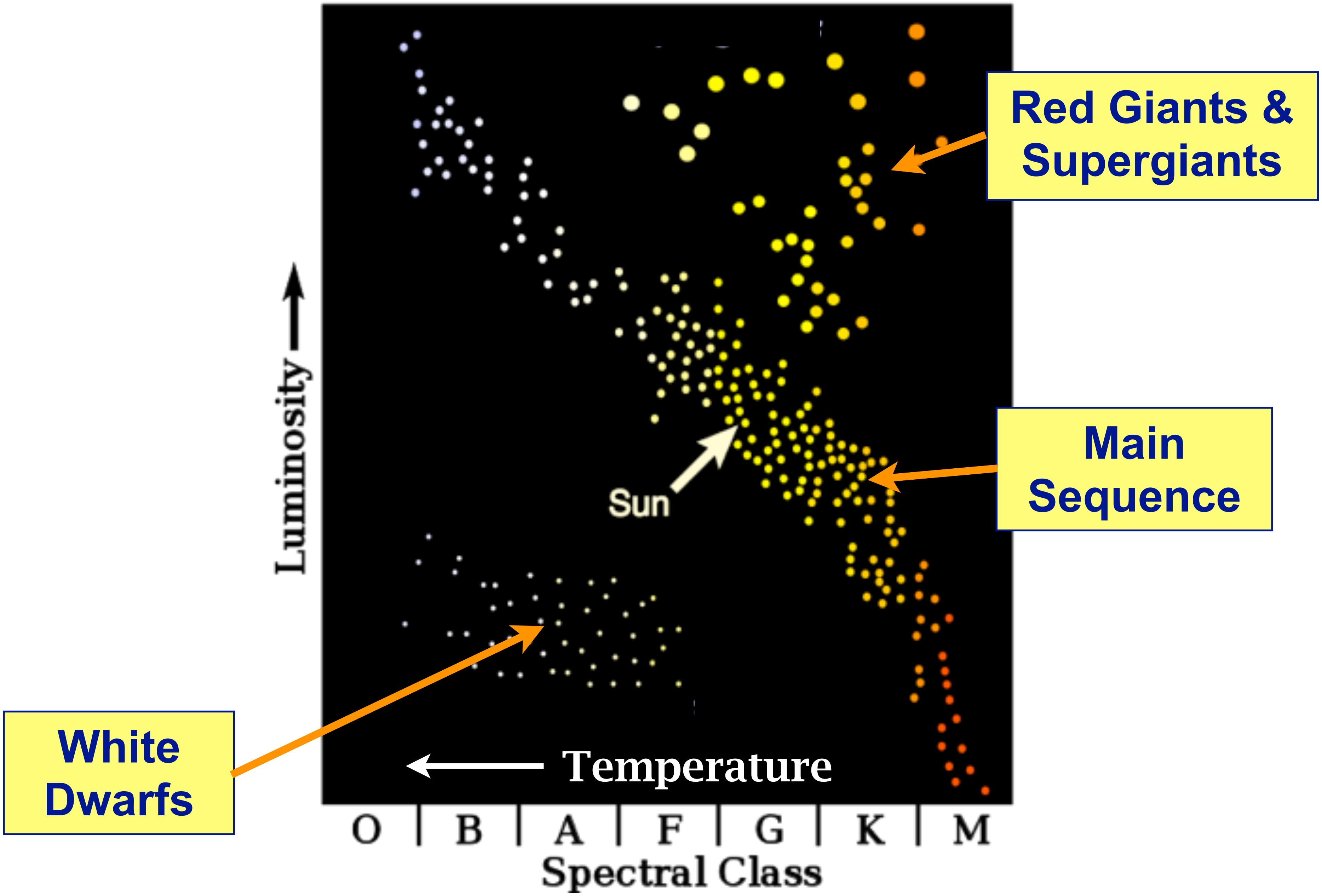
http://commons.wikimedia.org/wiki/File:HR-sparse.svg

Plots stellar luminosities vs. surface temperatures (or spectral classes) to study correlations between luminosity and temperature. Also enables astronomers to sort the stars by their sizes.

The diagram is named after its originators:Ejnar Hertzsprung in the Netherlands, and Henry Norris Russell in the United States.

Note, temperature decreases to the right (unlike most graphs)!!! Historical now, so we can't change it.

Red giants, white dwarfs, oh my!



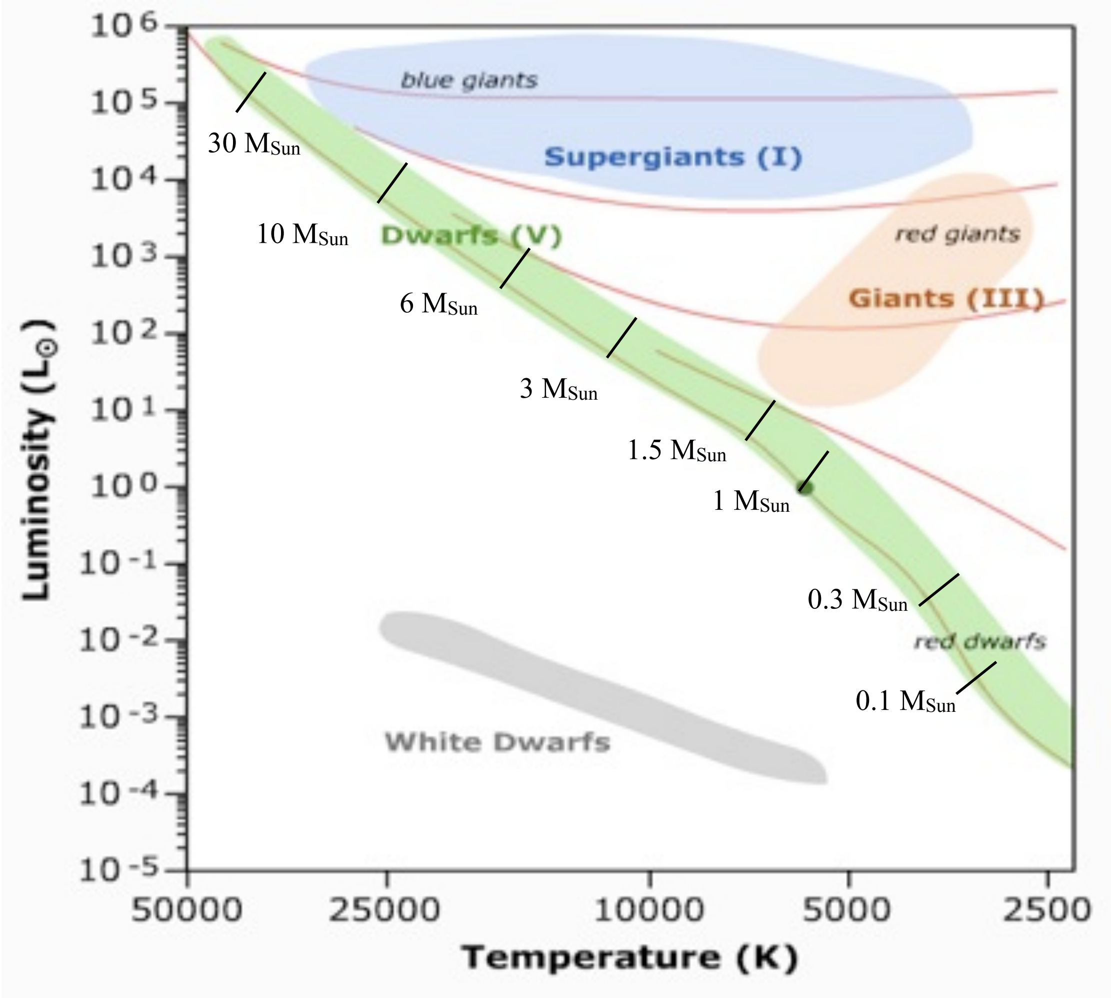
90% of all stars are on the main sequence. Runs from upper left (hot and luminous) to lower right (cool and dim). Includes the Sun.

Stars in the upper right are called red giants – Luminous but cool.

Stars in the lower left are called white dwarfs – Hot but dim.

A star's mass is its most important property!

- The main sequence is a ***mass sequence***
  - More massive stars are hotter, brighter, and bluer
  - Less massive stars are cooler, dimmer, and redder
  - Much larger range in luminosity than in mass



Much larger range in luminosity than in mass

Main Sequence: Properties Summarized

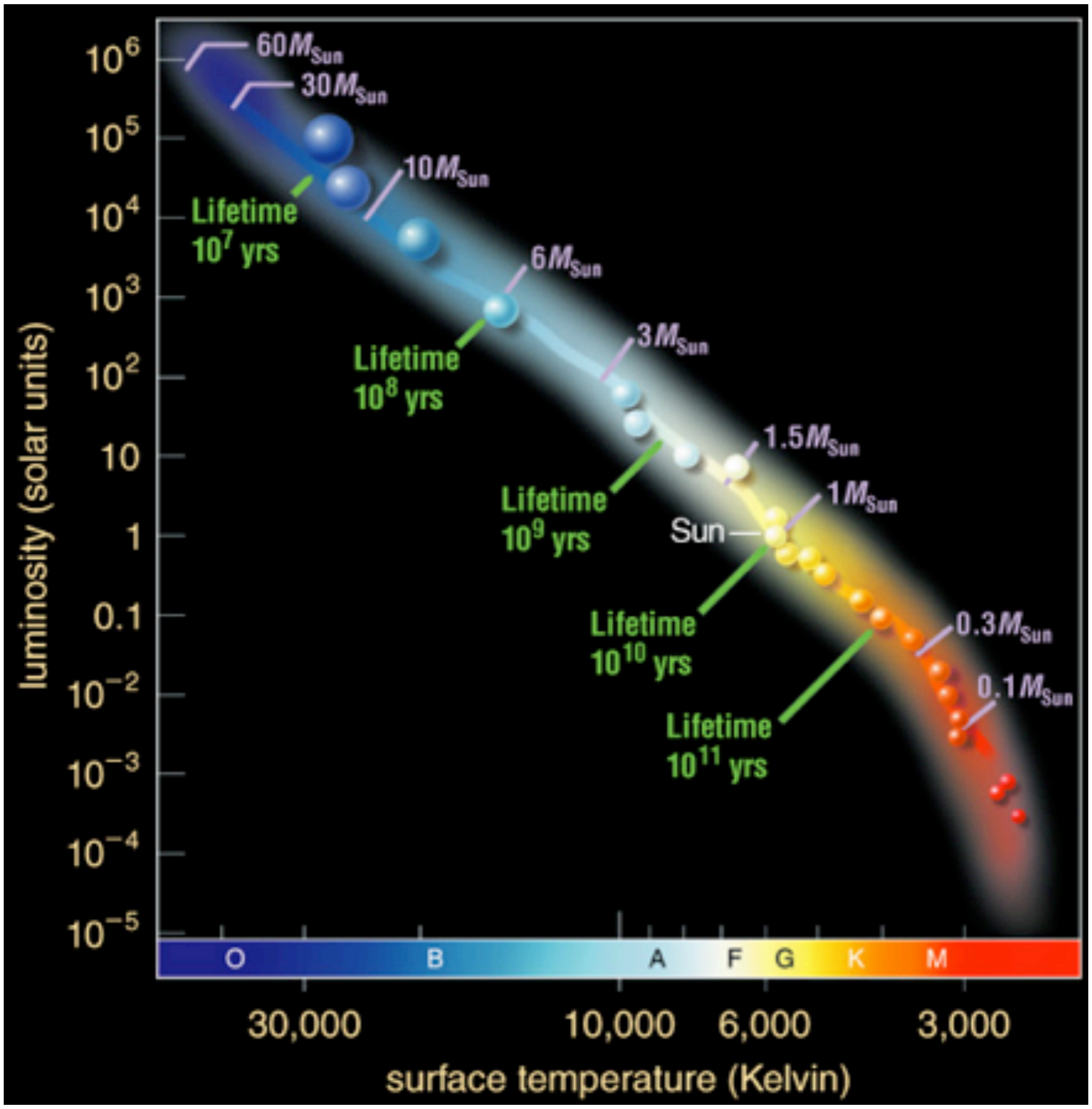
Main sequence is a sequence in star mass

high T:

- high luminosity
- high mass
- large size
- short lifespan

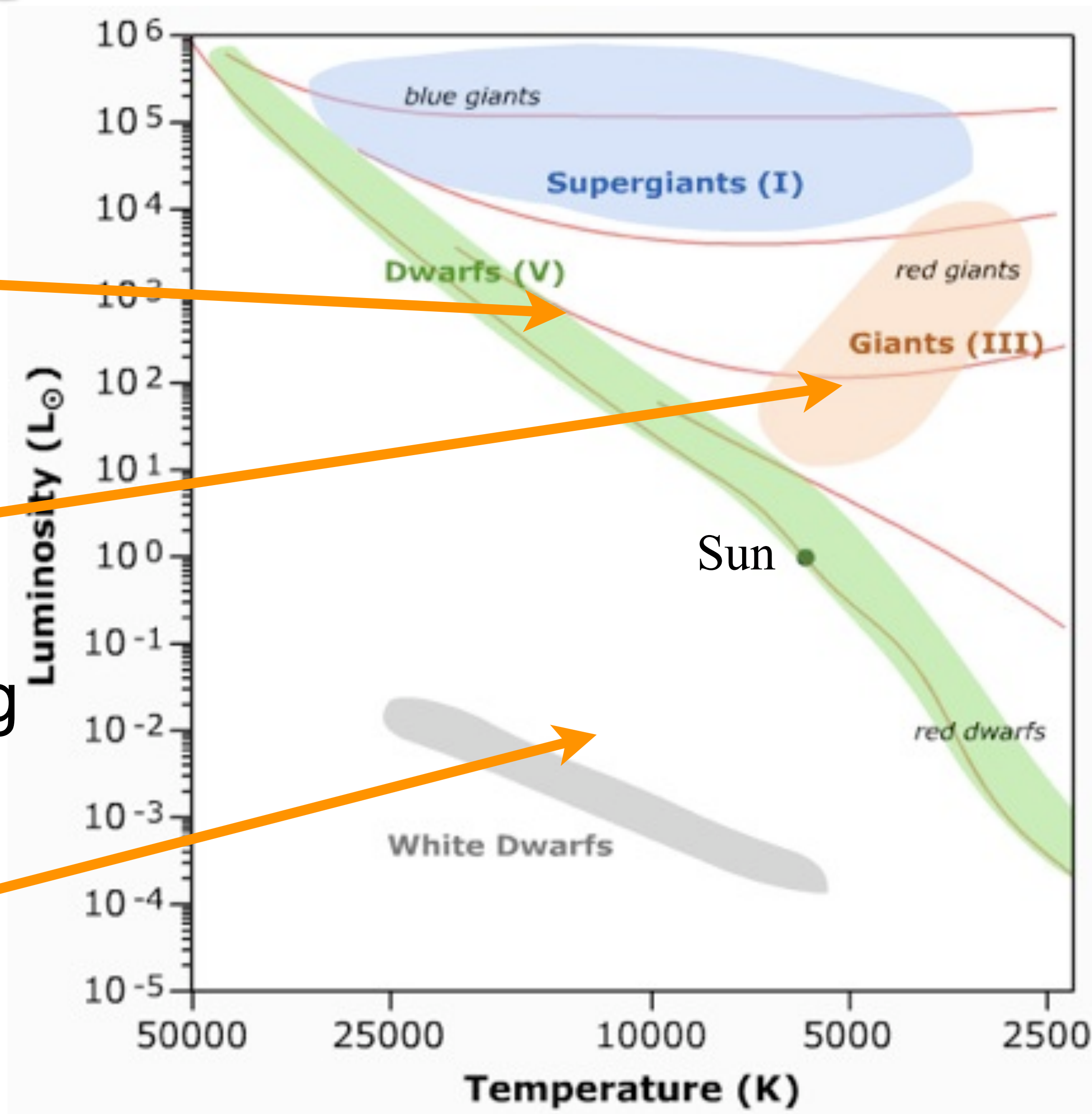
low T:

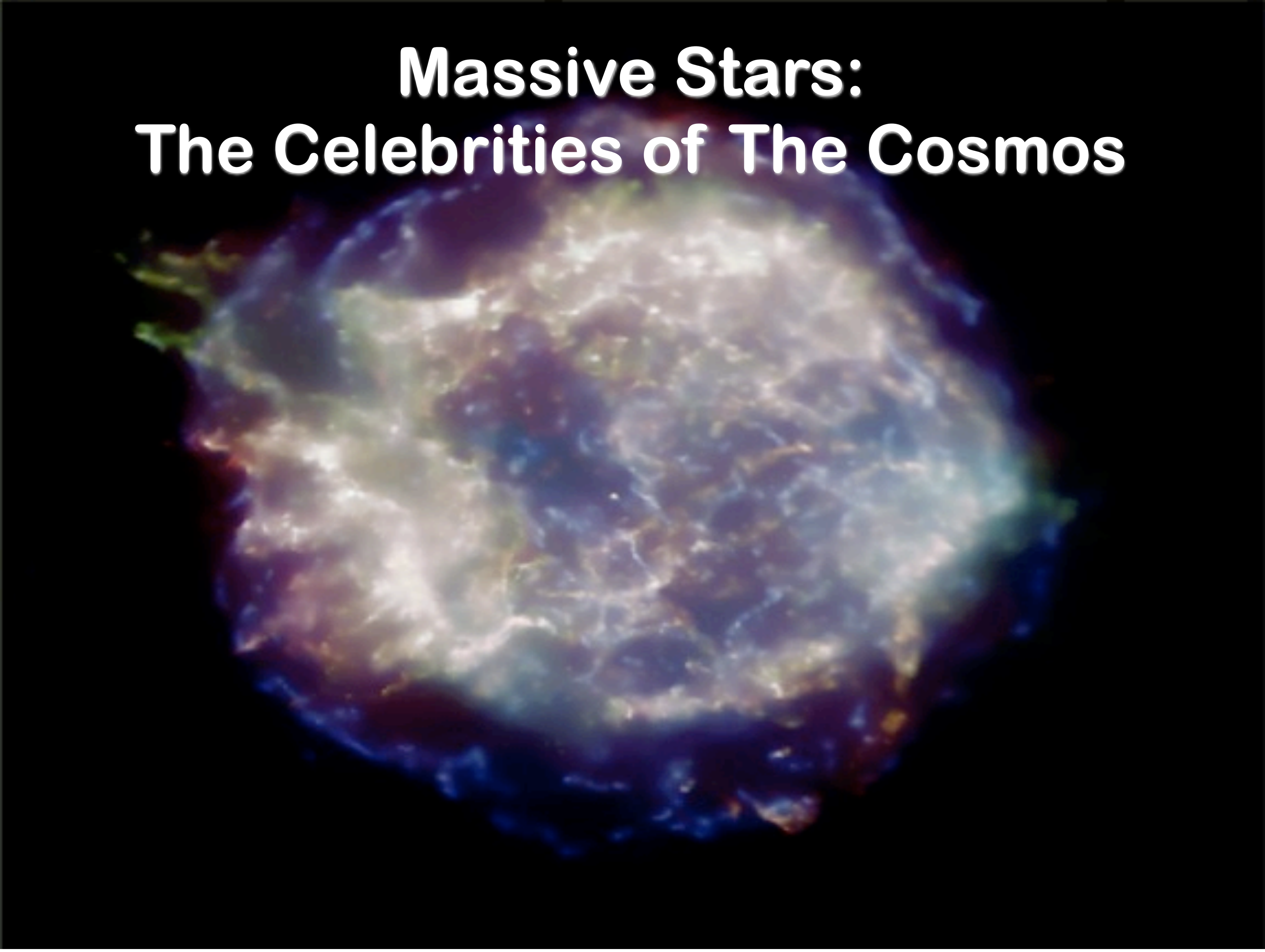
- low luminosity
- low mass
- small size
- long lifespan



What do the regions of the H-R diagram mean?

- States of stellar evolution (aging)
- **Main sequence** stars are 'adult stars'
- **Giants and supergiants** are 'aged stars' (nearing the end of their lives)
- **White dwarfs** are 'dead stars'

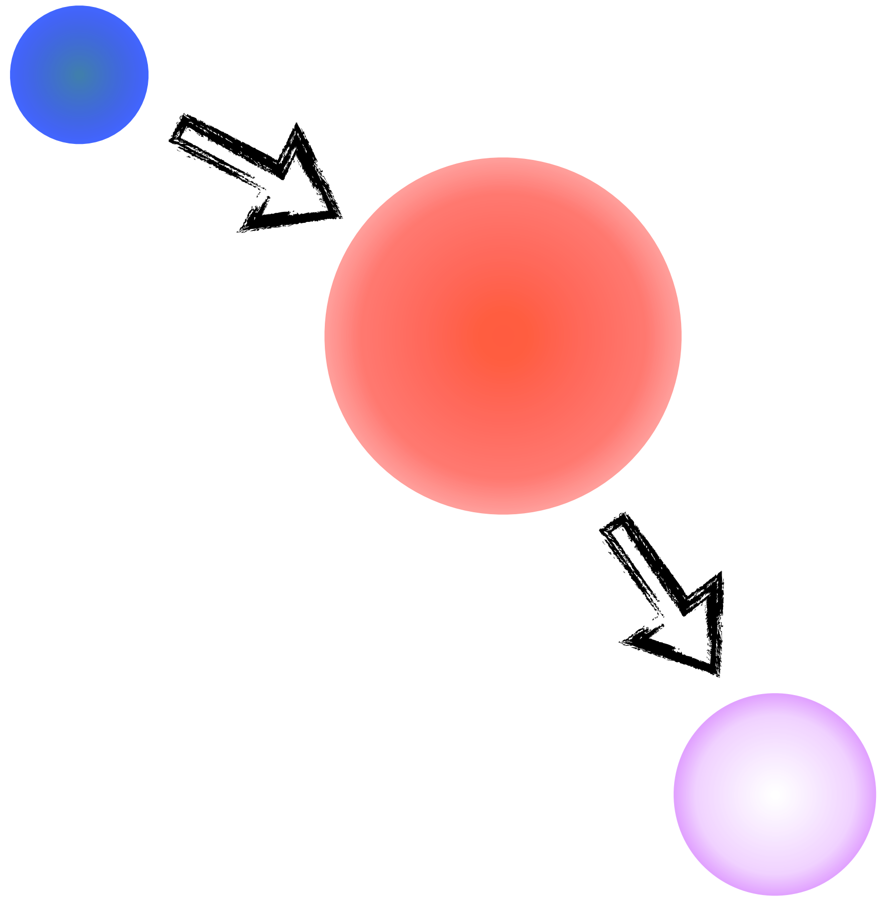



Massive Stars:
The Celebrities of The Cosmos

The fate of a massive star

Initial stages are similar to those of Sun-like star:

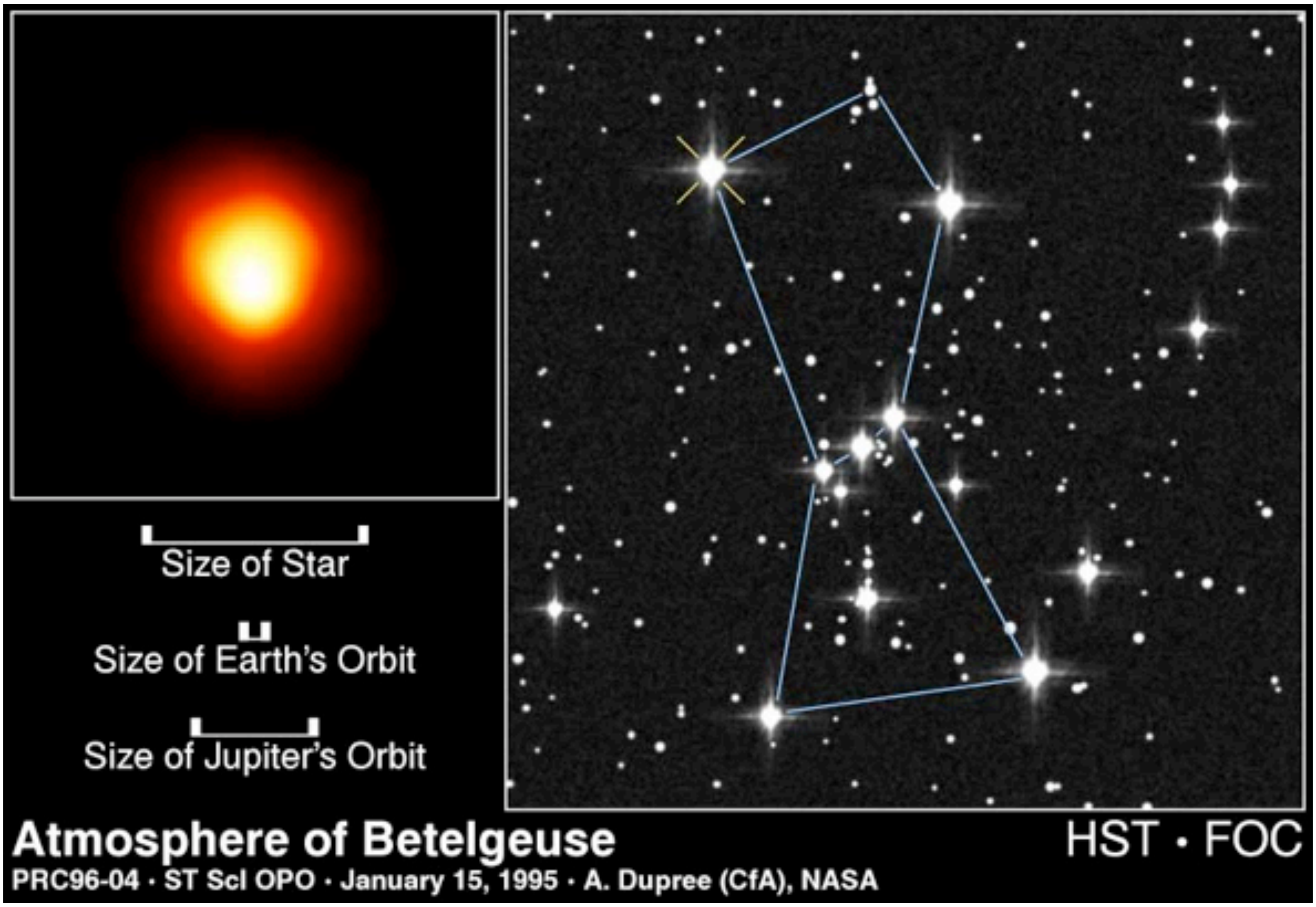
- **Main Sequence:** H fuses to He in core
- **Red Supergiant:** H fuses to He in shell around contracting He core
- **Blue Supergiant:** He fuses to C in core



**Top - Blue main sequence star.
Middle - Red supergiant,
Bottom - Blue supergiant**

Stars on the upper main sequence have too much mass to die as white dwarfs. However, their evolution begins much like that of their lower-mass cousins. They consume the hydrogen in their cores, ignite hydrogen shells, and become giants or, for the most massive stars, supergiants. Their cores contract and fuse helium first in the core and then in a shell, producing a carbon-oxygen core.

Truly Supergiant Stars...



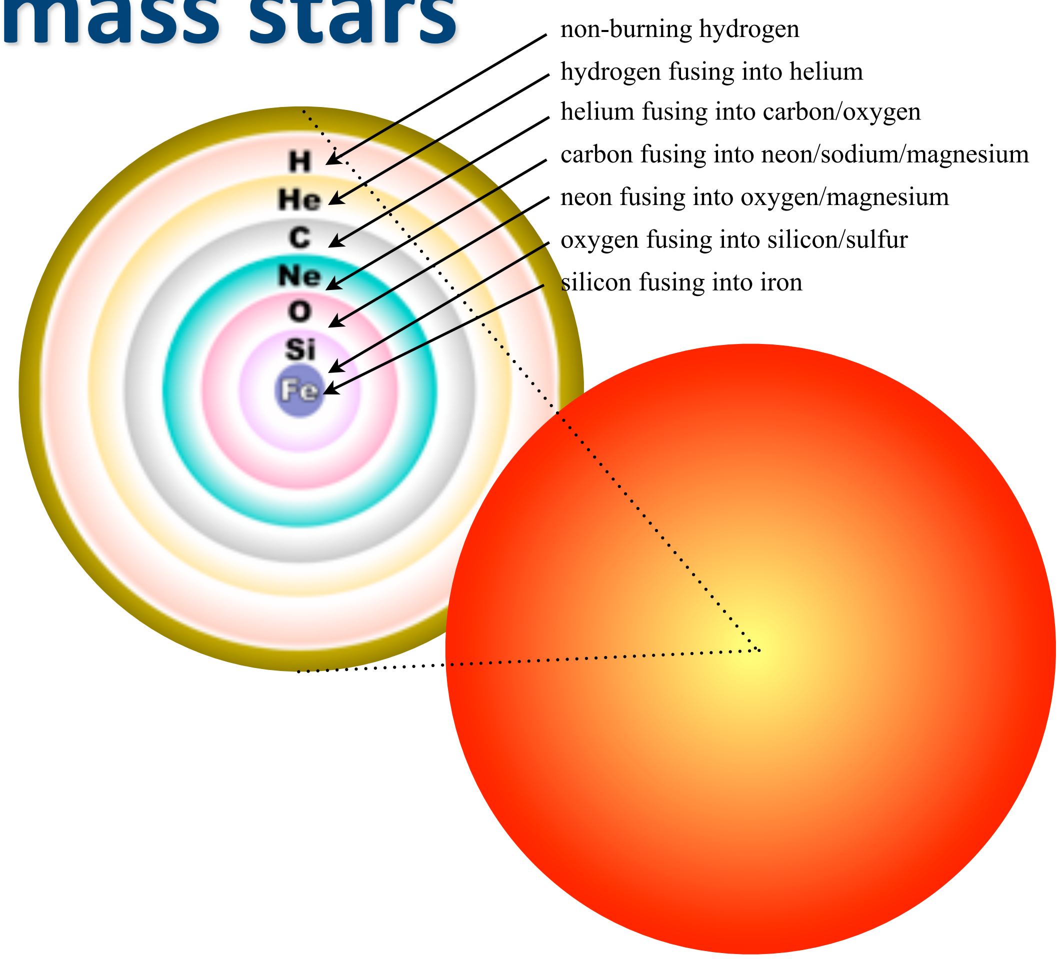
Andrea Dupree (Harvard-Smithsonian CfA), Ronald Gilliland (STScI), NASA and ESA

Big Betelgeuse! Red Supergiant.

A big star.

Helium fusion is not the end for high mass stars

- Massive stars can fuse heavier elements--since they are hotter
- Cycles of core fusion, core contraction
  - Shell fusion occurs in layers around the core
  - Ash of one fusion becomes fuel for the next



The onion-like layers inside a supergiant star in the final stages of its life

Unlike medium-mass stars, massive stars finally can get hot enough to ignite carbon fusion at a temperature of about 1 billion Kelvin. This pattern of core ignition and shell ignition continues with a series of heavier nuclei as fusion fuel. At higher temperatures than carbon fusion, nuclei of oxygen, neon, and magnesium fuse to make silicon and sulfur. At even higher temperatures, silicon can fuse to make iron. Thus, the star develops a layered structure. There is a hydrogen-fusion shell surrounding a helium-fusion shell surrounding a carbon-fusion shell, and so on.

Each stage of core fusion is shorter than the last...

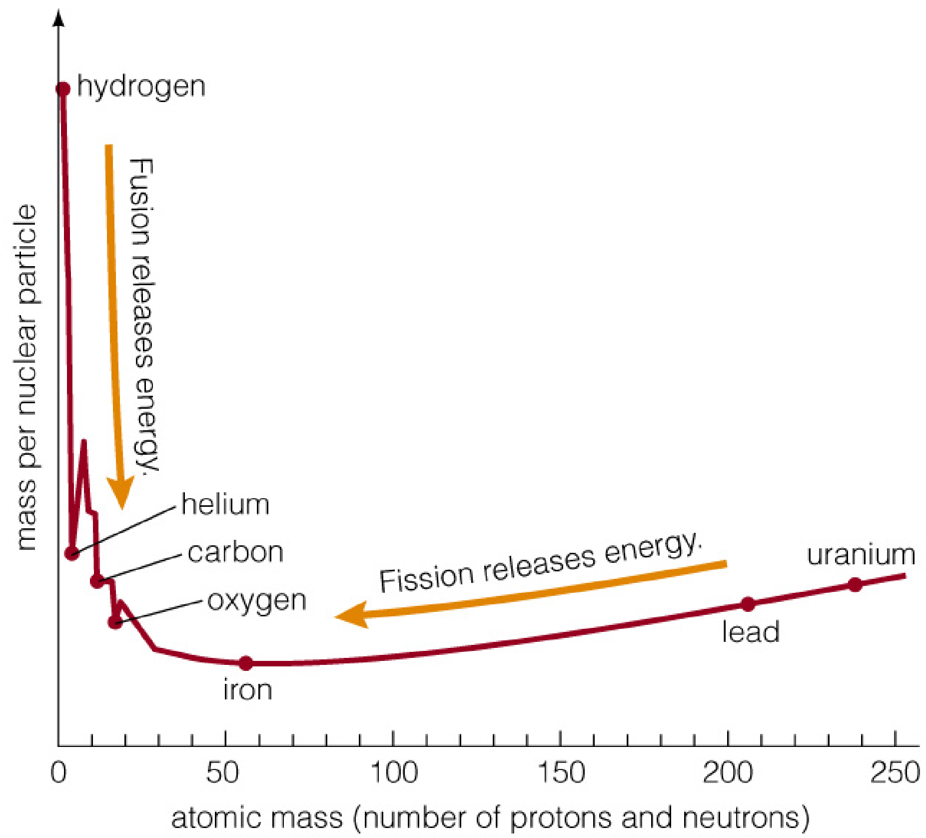
Stage	Temperature	Duration
H fusion	40 million K	7 million yr
He fusion	200 million K	500,000 yr
C fusion	600 million K	600 yr
Ne fusion	1.2 billion K	1 yr
O fusion	1.5 billion K	6 mo
Si fusion	2.7 billion K	1 day

A 25 M_{Sun} star will fuse over an entire solar mass of silicon into iron in about 1 day!

The fusion of the nuclear fuels in this series goes faster and faster as the massive star evolves rapidly. The amount of energy released per fusion reaction decreases as the mass of the types of atoms involved increases. To support its weight, a star must fuse oxygen much faster than it fused hydrogen. Hydrogen fusion can last 7 million years in a 25-solar-mass star. The same star will fuse its oxygen in 6 months and its silicon in just one day.

Iron - Dead End

- Final stage of core fusion: Silicon fusion produces iron
- The iron core is a dead end in the evolution of a massive star
- Nuclear reactions involving iron do not release energy
- They consume it!

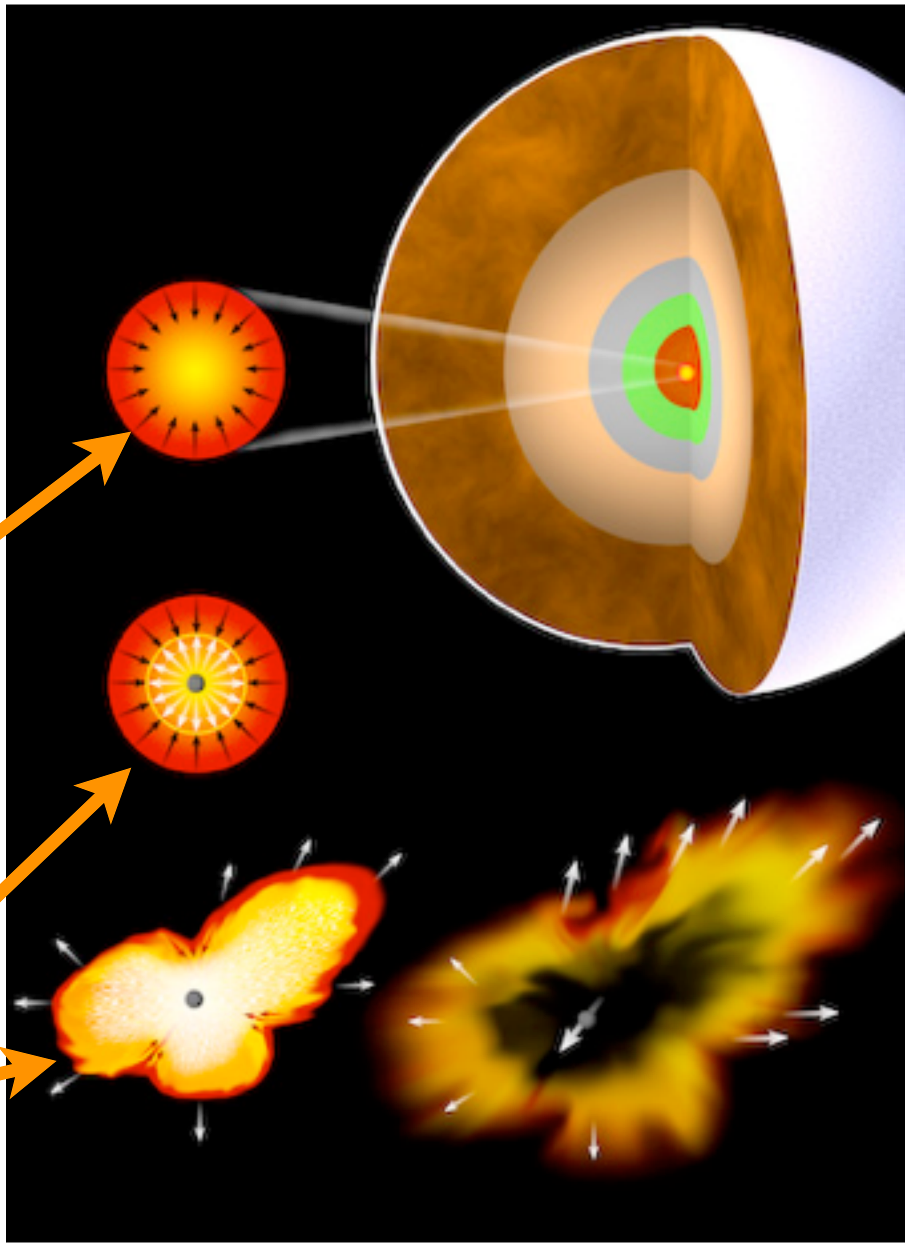


Neither fusion nor fission releases energy from iron

Once the material in the core of the star has been converted to iron, there are no further nuclear reactions that can release energy. As a star develops an iron core, energy production declines, and the core contracts. Iron builds up in core until degeneracy pressure can no longer resist gravity

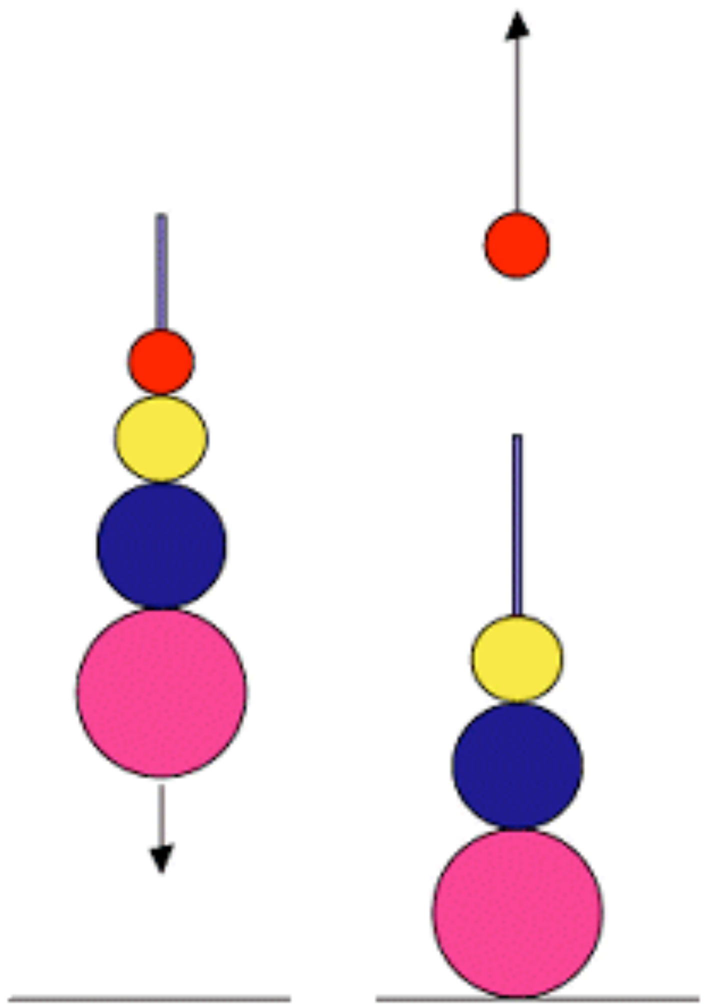
Supernova!

- Nuclear reactions cease at the center of the star's core
  - Gravity > Pressure
- The core **collapses** in less than 1/10th of a second
- Triggers an intensely energetic **rebound**
- Shatters the star in a **supernova**



The star's iron core collapses inward in less than 1/10th of a second. Inner part of the core is compressed into a ball of neutrons. Core collapse releases an enormous amount of energy, more than a hundred times what the Sun will radiate over its entire 10-billion-year lifetime. Energy released by collapse of core drives outer layers into space sends the star's former surface zooming outward at a speed of 10,000 kilometers per second.

AstroBlaster Demo



The gravitational collapse of the dying star is illustrated by the AstroBlaster™ falling to the surface. The shock wave accelerating outward through the star is illustrated by a wave of increasing speed as the result of the impact which is felt by the lighter balls nearer the top. The supernova explosion is illustrated by the rapid departure of the top ball at high speed.

IClicker Question

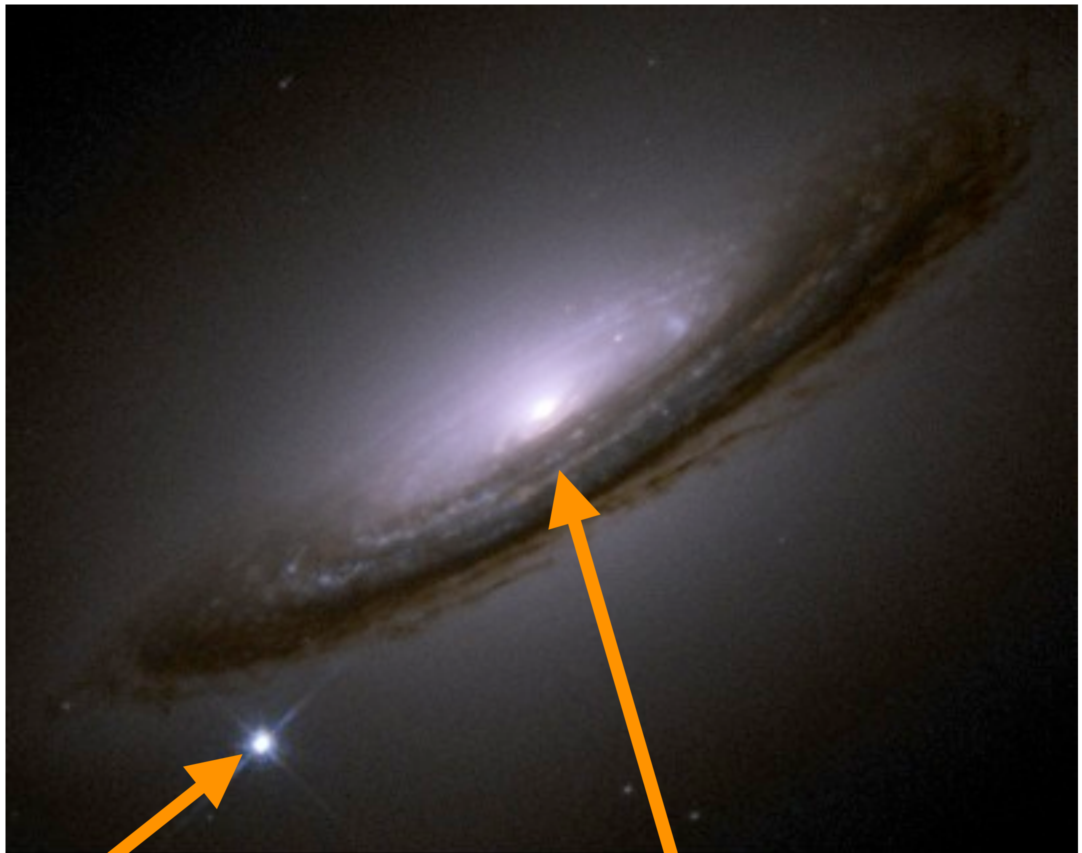
In the astroblaster demo, what did the little red ball represent?

a) **The inner core of the massive star**
b) **The envelope of the massive star**
c) **A low-mass stellar companion to the high mass star.**
d) **Iron.**

Answer B

Luminosity of 1 BILLION SUNS!

- Supernovae are **luminous**
- Luminosity increases 10,000 times!
- Rivals that of a moderate-sized galaxy!
- Freaky-bright!



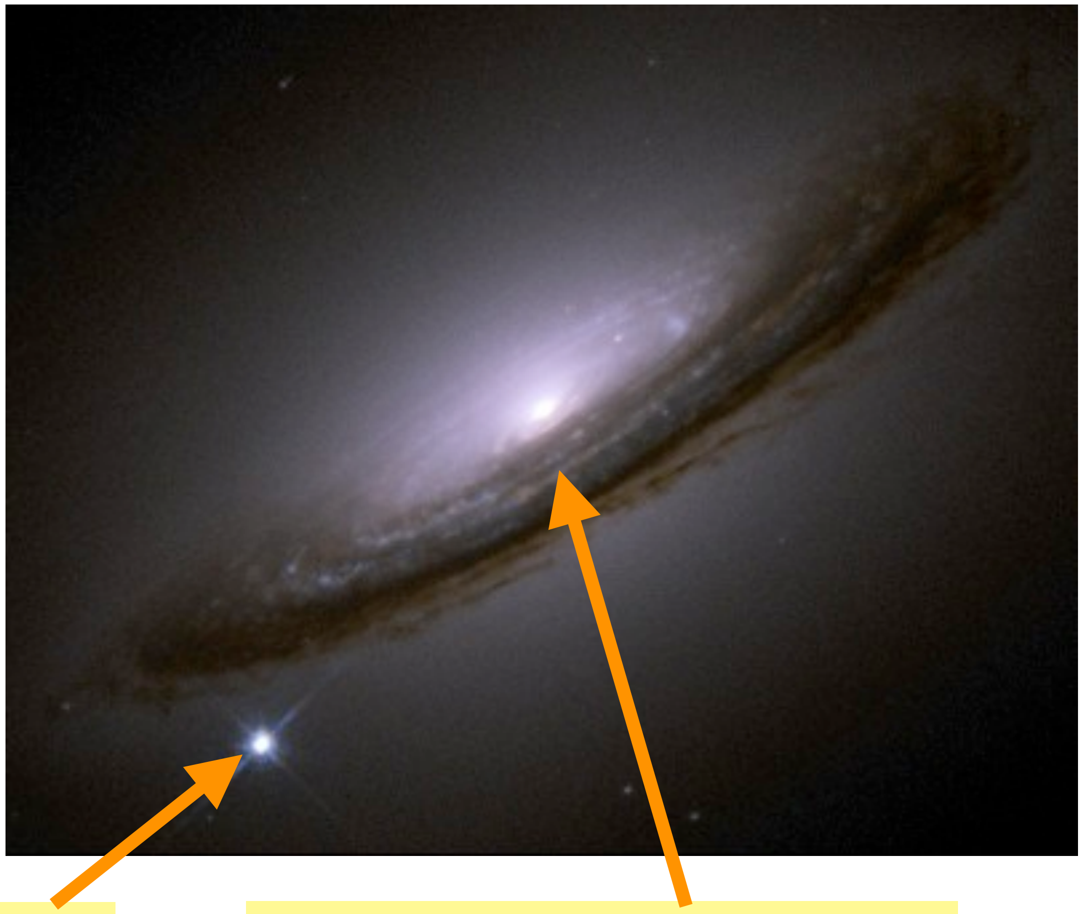
NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team

Light from a single supernova

Combined light of billions of stars

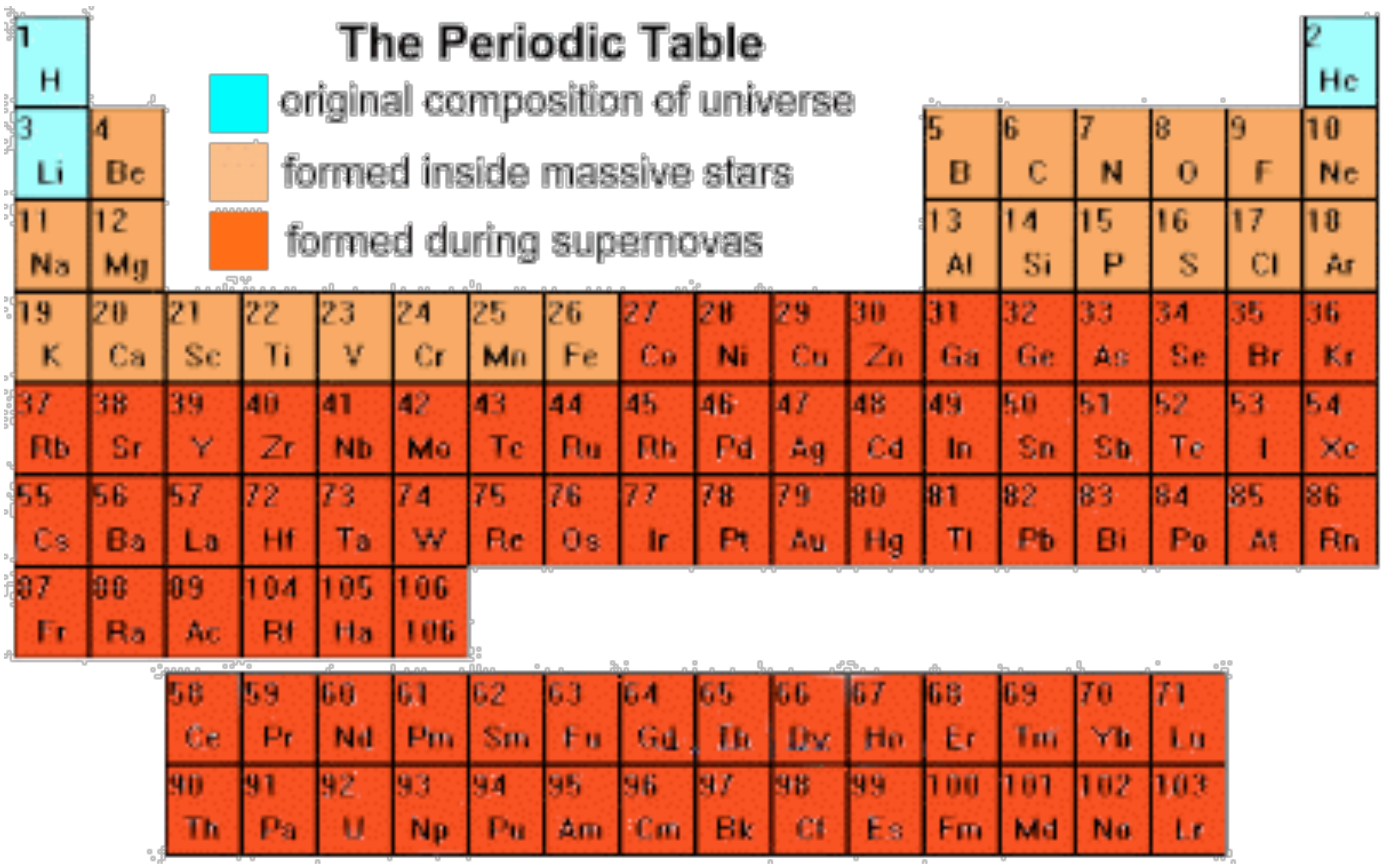
Luminosity of 1 BILLION SUNS!

- During the supernova, many elements are forged
- Lots of spare energy so even reactions that require energy can occur



NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team

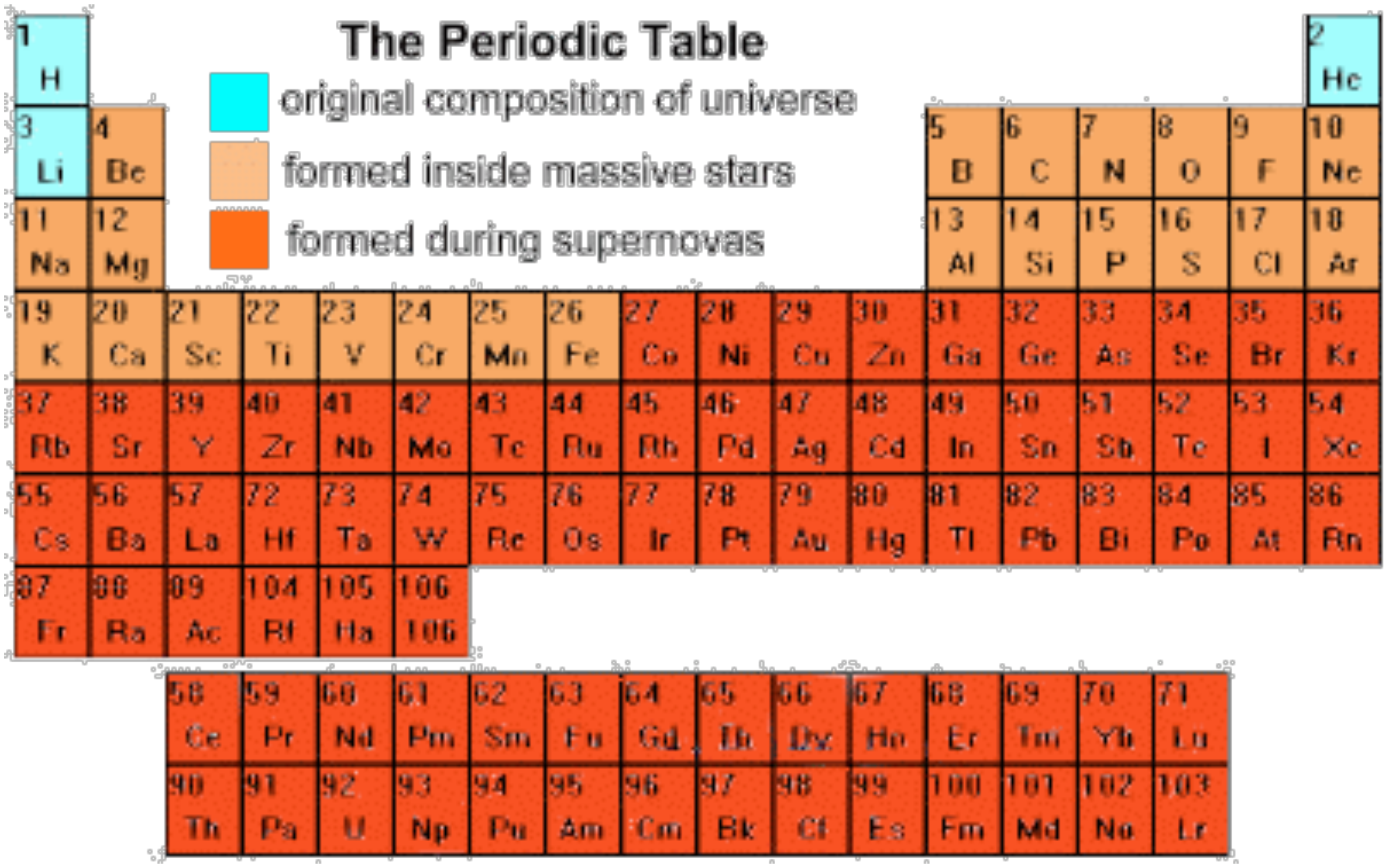
We are made of star stuff



The atoms we are made of were formed within the cores and supernovae of massive stars

Big Bang made 75% H, 25% He – stars make everything else. Helium fusion can make carbon in low-mass stars. Core fusion can make C, N, O, Ne, Mg, Si, S, Ca, Fe, etc., in high-mass stars. Energy and neutrons released in supernova explosion enables elements heavier than iron to form supernova explosions seed the created elements into space, for the next generation of stars and planets. Carl Sagan says it well.

We are made of star stuff



Your body, your phone, your computer-- all from the death of stars!

Supernova 1054

- In 1054, Chinese and Arab astronomers recorded a 'guest star'
  - Visible in daylight for 23 days
  - Took two years to vanish from sight
- Also pictured in rock paintings and pottery of Native Americans

The 'guest star' was visible in the sky for over 650 nights

Supernovae are rare—only a few have been seen with the naked eye in recorded history. Arab astronomers saw one in AD 1006. The Chinese saw one in AD 1054. European astronomers observed two—one in AD 1572 (Tycho's supernova) and one in AD 1604 (Kepler's supernova). In addition, the guest stars of AD 185, 386, 393, and 1181 may have been supernovae.

Supernova 1054 Today

- The Crab Nebula is a **supernova remnant**
- The remains of Supernova 1054
- Comparing its size with its speed of expansion reveals an age of nine or ten centuries
- Just when the “guest star” made its visit

NASA, ESA, J. Hester, A. Loll (ASU)

When modern astronomers turned their telescopes to the location of the guest star, they found a peculiar nebula—now known as the Crab Nebula. The Crab Nebula is called so for its many-legged shape. The ‘legs’ are filaments of gas that are moving away from the site of the explosion at about 1,400 km/s. Comparing the nebula’s radius, 1.35 pc, with its velocity of expansion reveals that the nebula began expanding nine or ten centuries ago. That is just when the guest star made its visit.

High-Mass Stars:
The James Dean of Stars

Live Fast

Star life is struggle vs gravity

Nuclear fires keep hot, stable

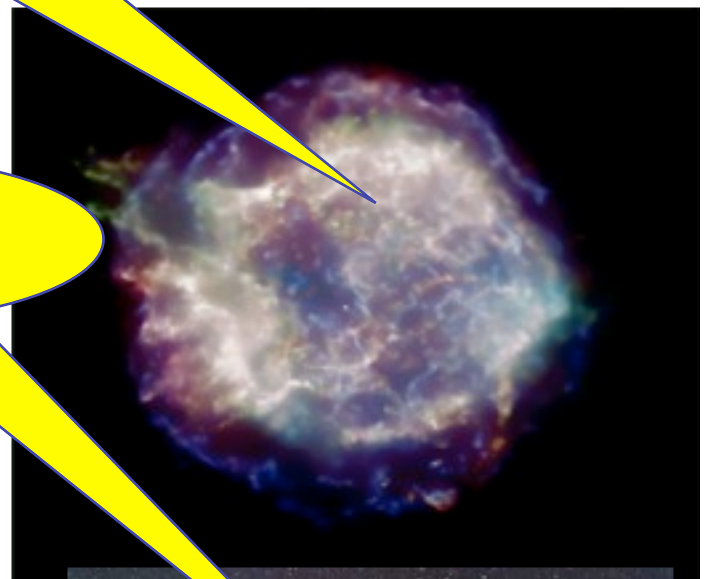
Die Young

- Fuel exhaustion ⇨ collapse
- Core becomes dense, “bounce”
- Shock wave launched ⇨ explosion!

Leave a Beautiful Corpse

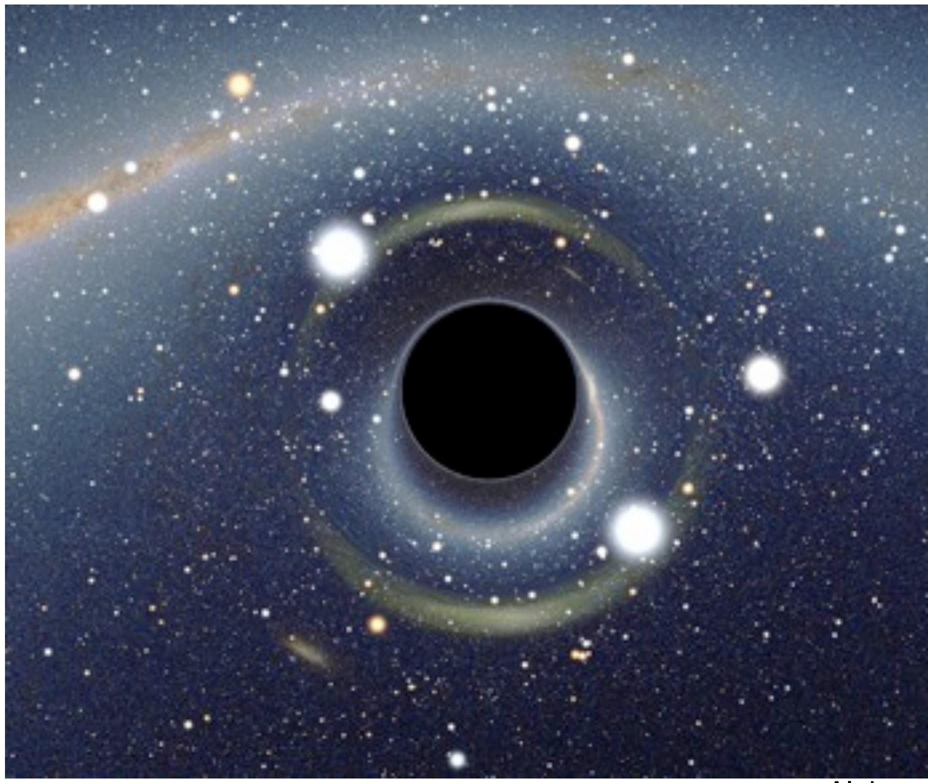
- Ultradense “cinder”

  neutron star/black hole
- Most material ejected at high speed



What's left of the star's core after the supernova explosion?

- A **neutron star**
  - About 1.5 – 2 M_{Sun}
  - Very compact – around 20 km across!
  - Composed almost entirely of neutrons
- ...or a **black hole!**
  - a region of space from which nothing, not even light, can escape
  - Gravity's ultimate victory!

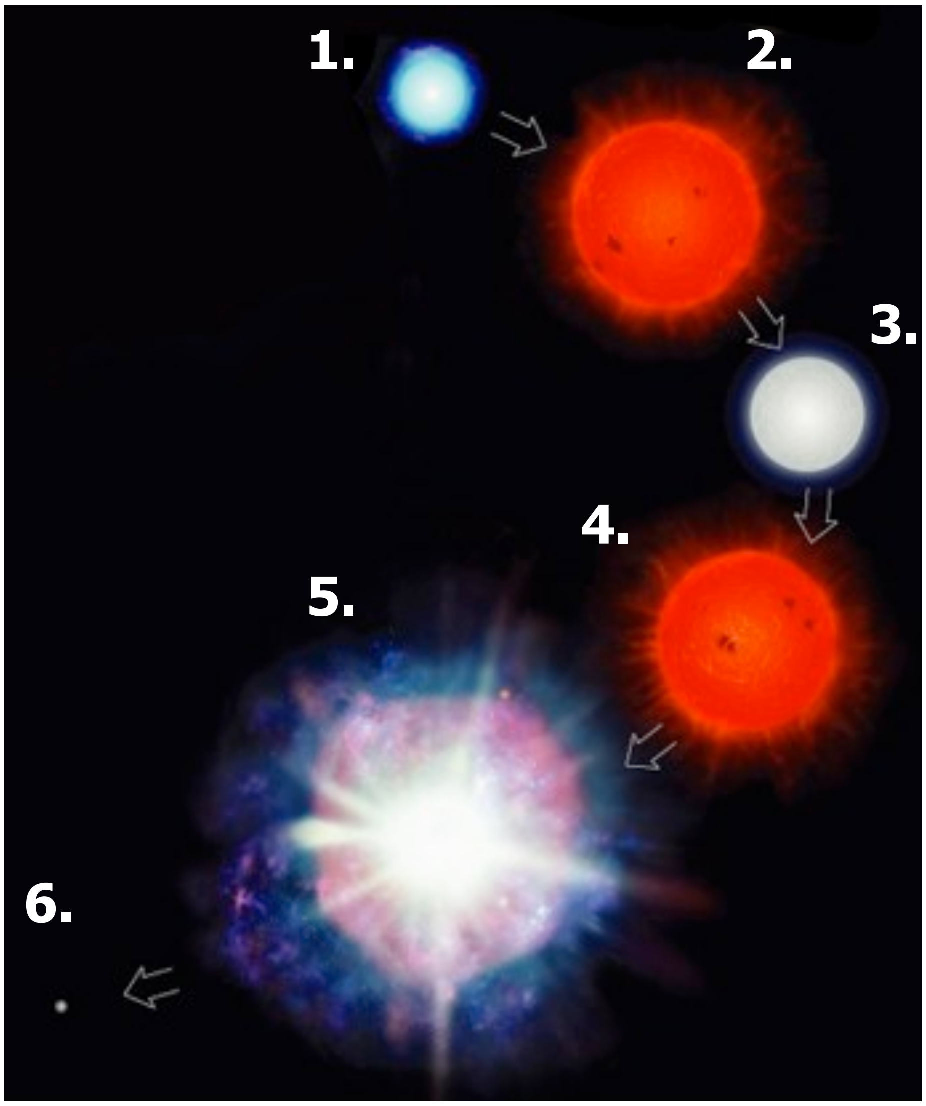


Alain r

Black hole affects light.

The Fate of a Massive Star

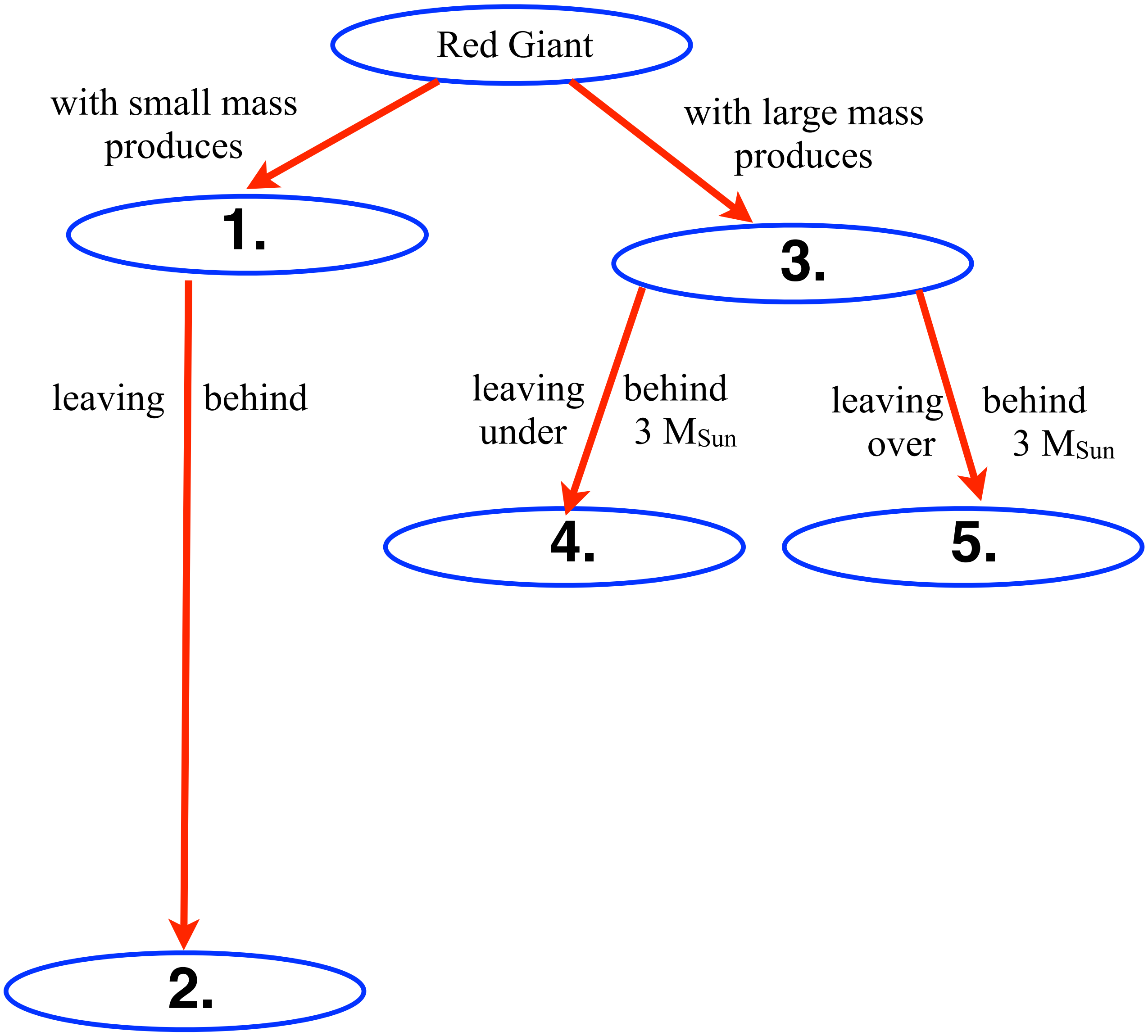
1. Main Sequence
2. Red Supergiant
3. Blue Supergiant
4. Red Supergiant II
5. Supernova!
6. Neutron star or black hole



Stellar Evolution Review

Which term best fits oval #1?

A. neutron star
B. black hole
C. planetary nebula
D. white dwarf
E. supernova

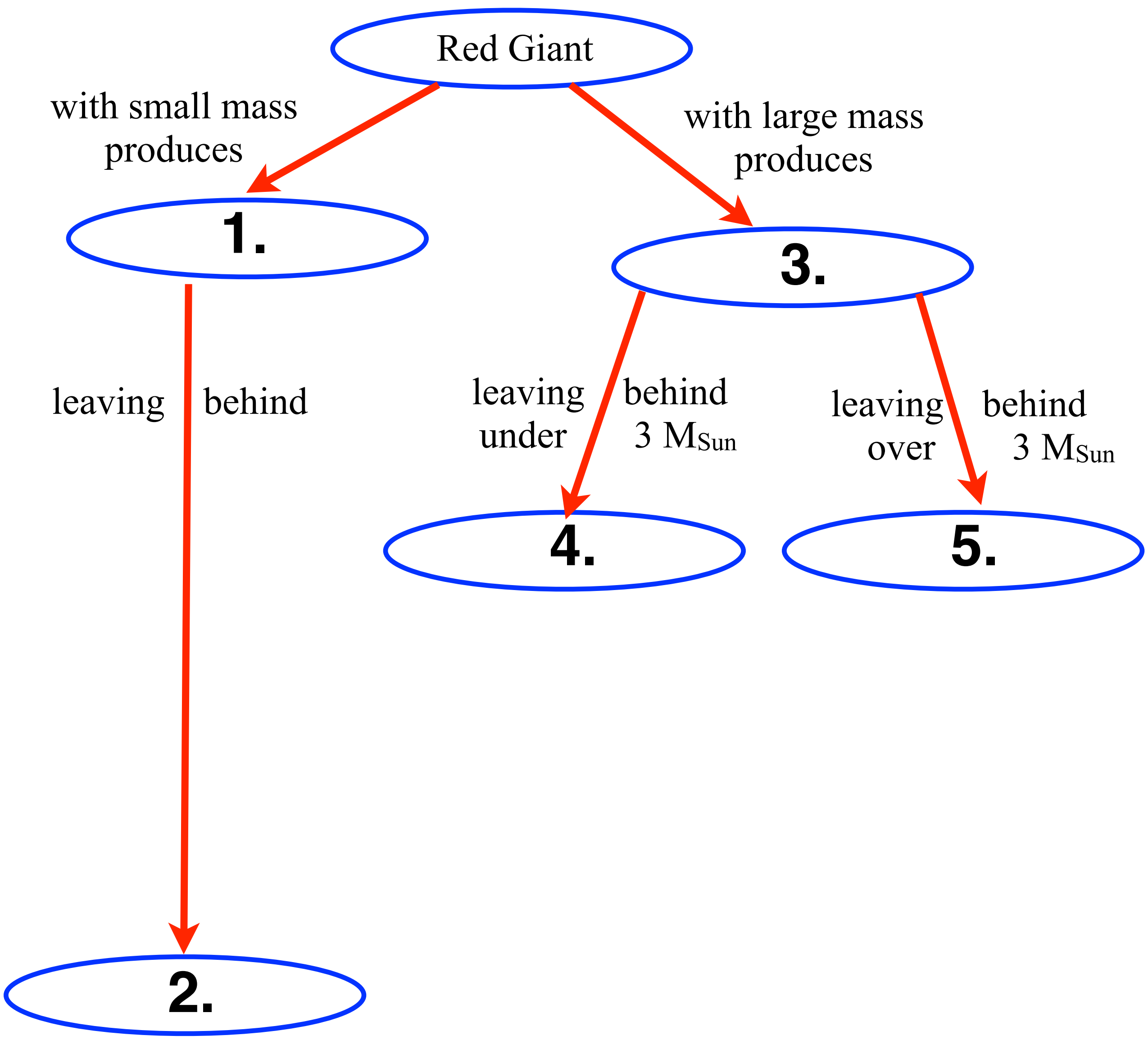


Answer: C. Low mass stars produce a planetary nebula, which has nothing to do with planets.

Stellar Evolution Review

Which term best fits oval #2?

A. neutron star
B. black hole
C. planetary nebula
D. white dwarf
E. supernova

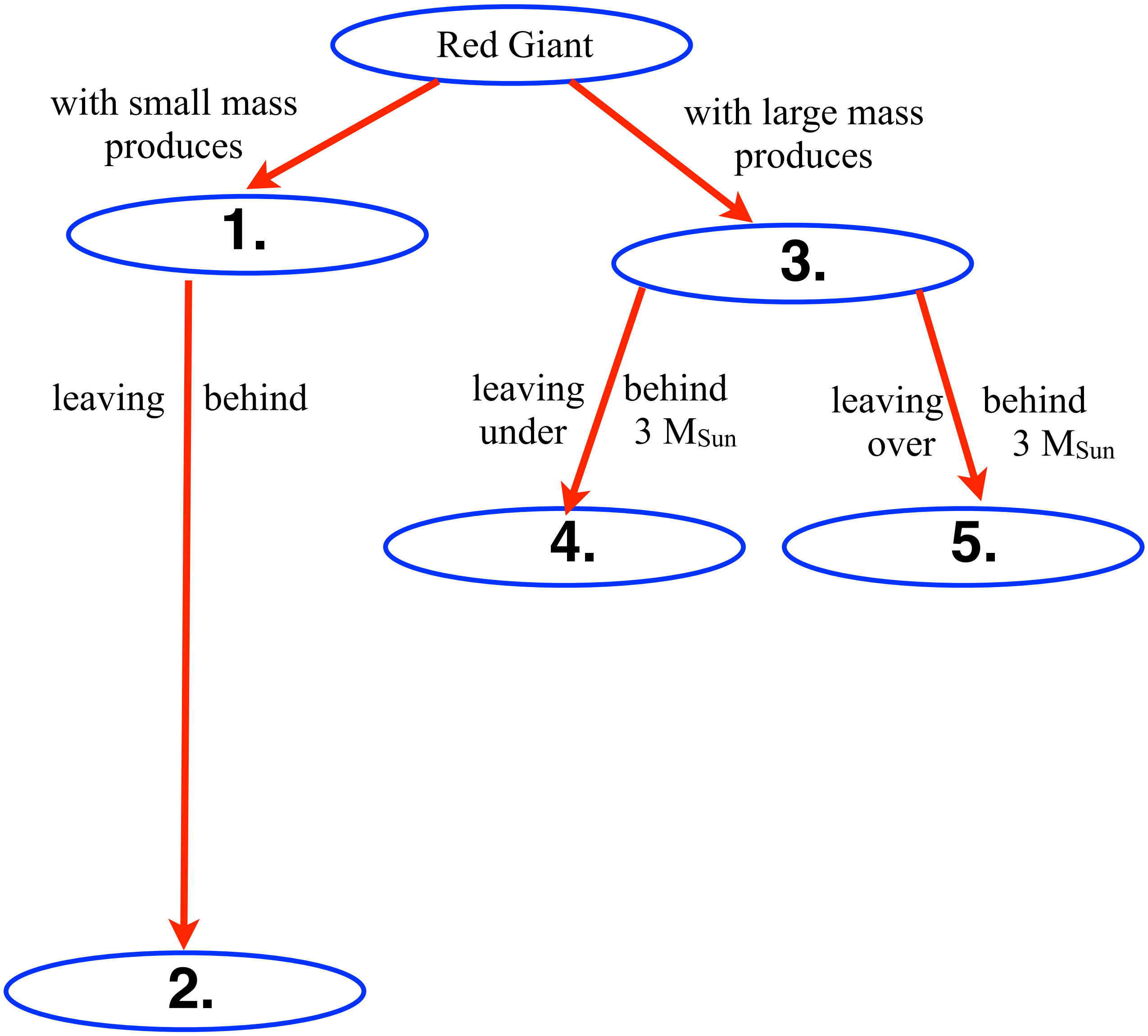


Answer: D. The death of a low-mass star is a white dwarf.

Stellar Evolution Review

Which term best fits oval #3?

A. neutron star
B. black hole
C. planetary nebula
D. white dwarf
E. supernova

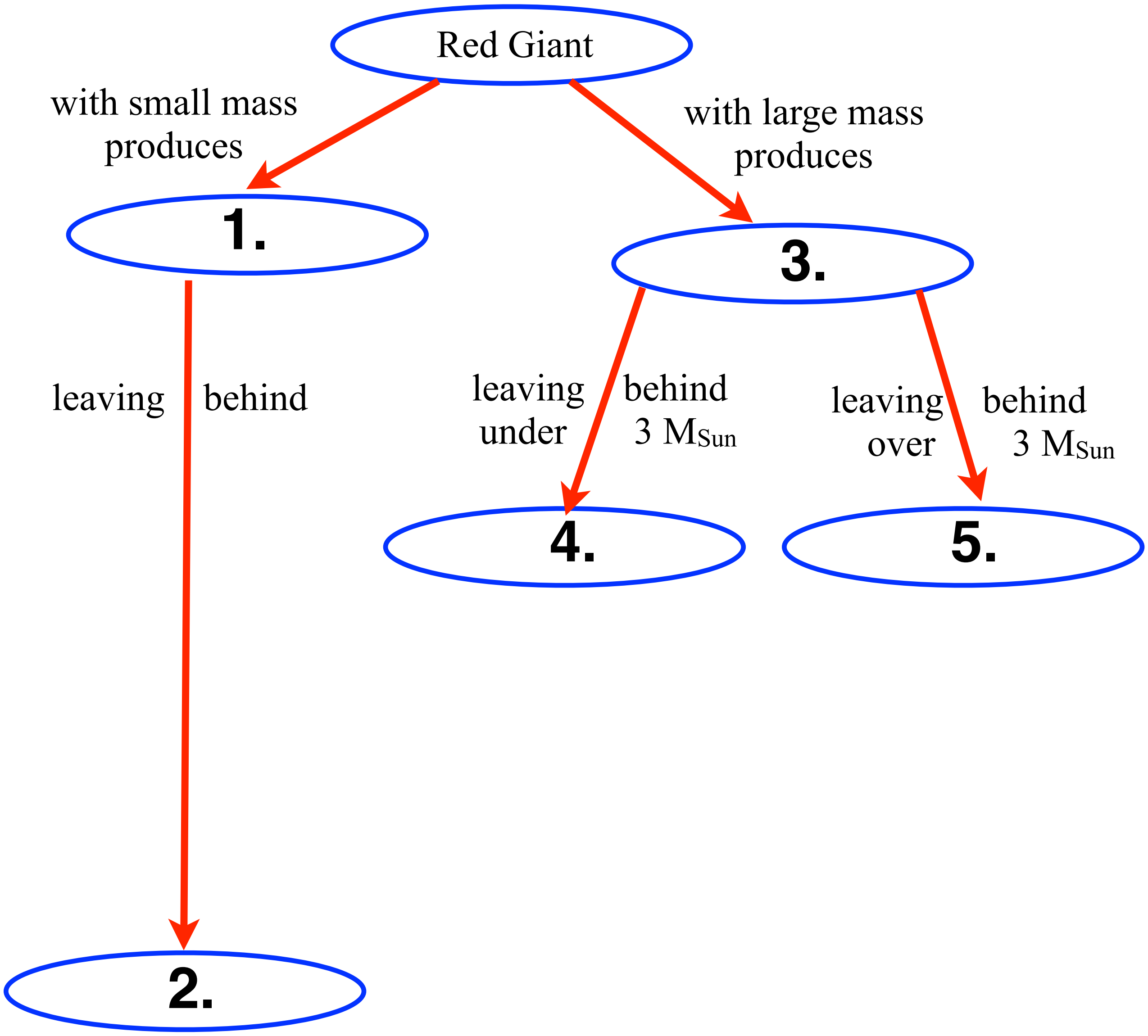


Answer: E. A high mass star has enough mass to explode.

Stellar Evolution Review

Which term best fits oval #4?

A. neutron star
B. black hole
C. planetary nebula
D. white dwarf
E. supernova

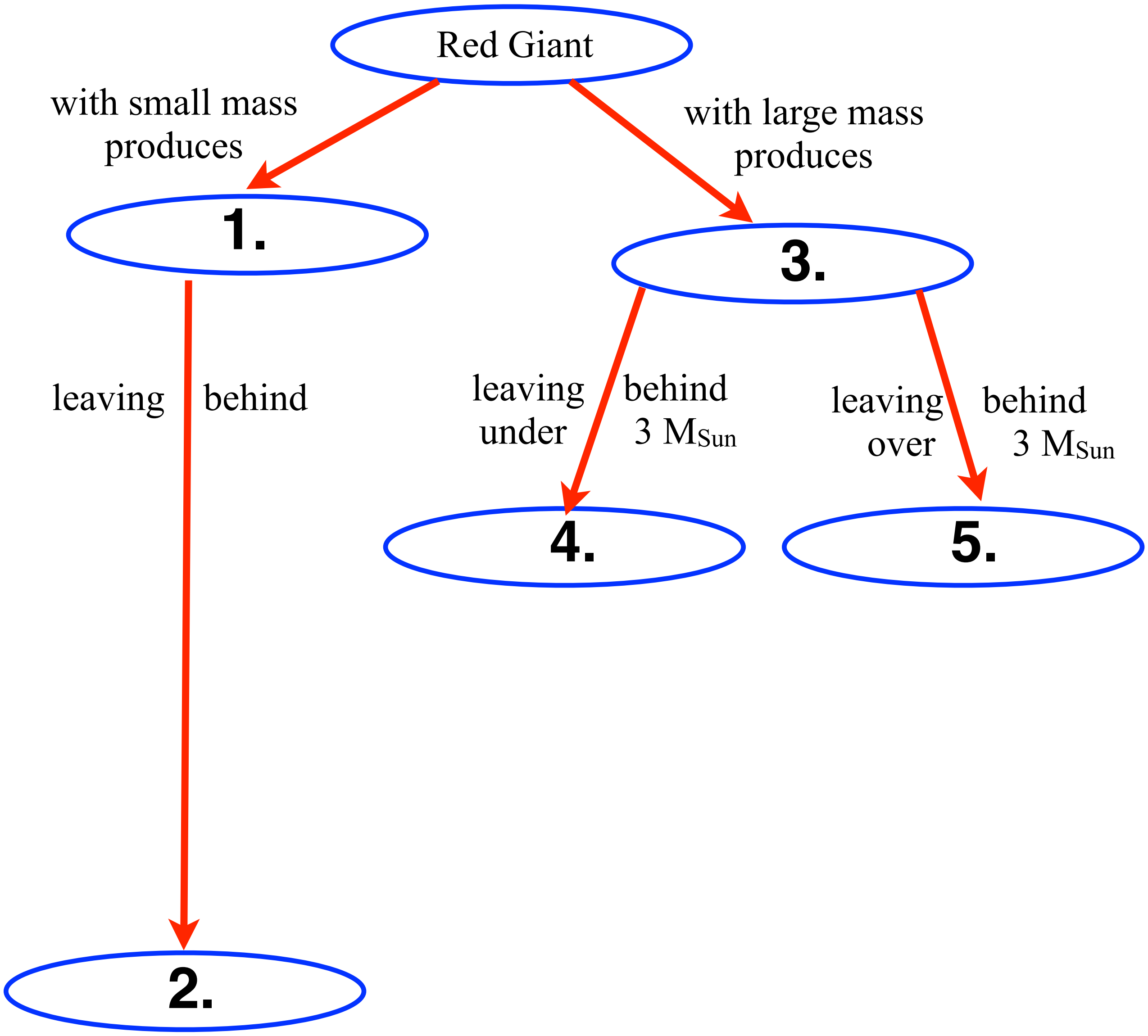


Answer: A. If the left over core mass is less than 3 solar masses, then the death is a neutron star.

Stellar Evolution Review

Which term best fits oval #5?

A. neutron star
B. black hole
C. planetary nebula
D. white dwarf
E. supernova



Answer: B. If the left over core mass is more than 3 solar masses, then the death is a neutron star.