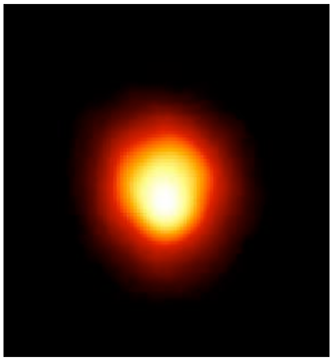
Betelgeuse



(Image Credit: HST/NASA, Observer: A. Dupree) (CfA)).

Betelgeuse is a red supergiant in the constellation of Orion. It is also the first star, other than the Sun, that's size can be directly measured from a telescope image.

In this Exploration, find out:

- Why are dying stars much bigger than their *main-sequence* counterparts?
- What are the relative sizes of dying stars, and stellar remnants, compared to objects in our solar system?
- Will the Sun ever go supernova?

Death of Stars

Most of the stars in the solar neighborhood shine by converting hydrogen to helium in their cores, and are therefore on the *main sequence*. Many of the brightest stars we see from the Earth are dying stars that have left the *main sequence*, meaning they no longer have hydrogen in the cores to convert to helium.

When a star begins to use helium for its fuel, the core is smaller than it was on the main sequence. But the outer layers of the star expand. This happens because the fusion reaction converting helium into carbon produces much more energy than the reaction that converts hydrogen to helium. The energy makes the star shine much more brightly than it did before. In fact, the star produces so much energy that gravity can't hold tightly on to the outer layers of the star. This extra energy puffs up the star. Relatively low mass stars will become giant stars, and high mass stars will become **supergiant** stars, like the star Betelgeuse shown above.

The Main Sequence and the Light We See

While on the main sequence, stars shine because they are converting the element hydrogen into the element helium in their cores. Energy is given off in the process, and that energy is what allows a star to shine:

4 hydrogen atoms

+

heat and pressure

=

1 helium atom
+ energy

© 2007 Dr Mary Urquhart, University of Texas at Dallas

Leaving the Main Sequence:

Dying Stars

When a star runs out of hydrogen in its core, it starts to collapse because of its own gravity. As it collapses, the core gets hotter and the pressure increases.

Stars about the mass of the Sun and bigger have higher pressures and temperatures so new fusion reactions can occur that release energy.

Once these reactions start, they keep the core of the star from collapsing further. The first new reaction converts helium to carbon:

3 helium atoms

+

heat and pressure

=

1 carbon atom

+ energy

How Dying Stars Change Classes

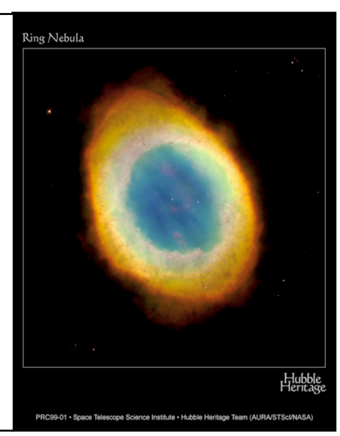
When the outer layers of a star puff up, they cool. A star that no longer shines by converting hydrogen to helium may be very bright compared with a star of the same mass that is still on the main sequence. But, its surface temperature may also be much cooler, and therefore its color will be redder. The *class* of a star depends on the *temperature of the surface* of the star.

Beyond Helium

The helium in the core of a star is converted to carbon much more rapidly than the hydrogen was converted to helium. What happens when the helium starts to run out? The core of the star will begin to collapse again. If the star has enough mass, it will begin converting carbon into oxygen. For very high mass stars with masses of about 8 times the mass of the Sun or larger (B and O class stars on the main sequence), this cycle will repeat until the element silicon has been converted to iron. Reactions involving iron do not produce extra energy, no matter how small the core becomes. When a star has used up its fuel, and has built up iron its core, it has reached the **iron limit**.

Each time the core collapses an outer layer of the core does not participate in the new reaction. The new elements created in the star build up around the core in an "onion-skin" structure, with lighter elements on the outside, and heavier elements on the inside. All of the elements that make up planets and everything on them (with the exception of hydrogen and some helium) are created in stars. Without the fusion reactions that produce energy in massive stars, the Earth and life would not exist.

This image of the Ring Nebula, taken by the Hubble Space Telescope, shows the expanding outer layers of the once red giant star surrounding the white dwarf that was once the star's core.



© 2007 Dr Mary Urquhart, University of Texas at Dallas

The End of a Sun-like Star:

When a star like the Sun can no longer sustain fusion, its core collapses for a final time. The outer layers of the star are lost, and surround the core in a cocoon of glowing gas. The core of the star is now a white dwarf - a hot, but very dim object that is no longer producing new energy. Like a hot coal taken out of a fire, it will slowly cool, becoming more dim and red. The outer layers of the star will also cool and fade, but before they do they will shine as a planetary nebula. (A planetary nebula has nothing to do with planets, but gets its name from the round shape.)

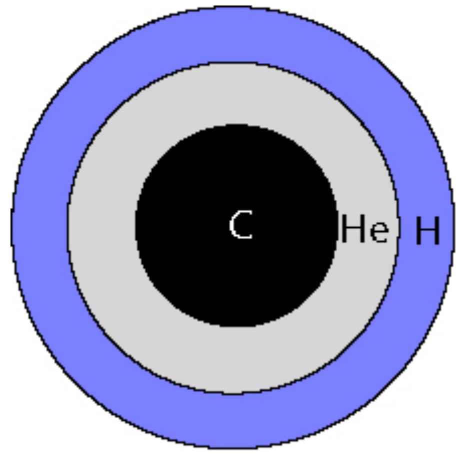
The End of a High-Mass Star:

Stars with masses of about 8 times the mass of the Sun experience a much more dramatic demise than lower mass stars like the Sun. When these stars run out of fuel by reaching the iron limit, the core collapses very fast (*perhaps in only a few seconds!*), and the outer layers of the star (and part of the core) are blown off in a massive explosion known as a **supernova**. **Supernovae** explosions release an almost unbelievable amount of energy.

In 1054 A.D., Chinese astronomers recorded a supernova explosion that was seen as a star so bright that it was visible during the day for more than three weeks. Today, the **Crab Nebula**, a supernova remnant, can be seen in the location of that mysterious new "star" seen nearly 1000 years ago.

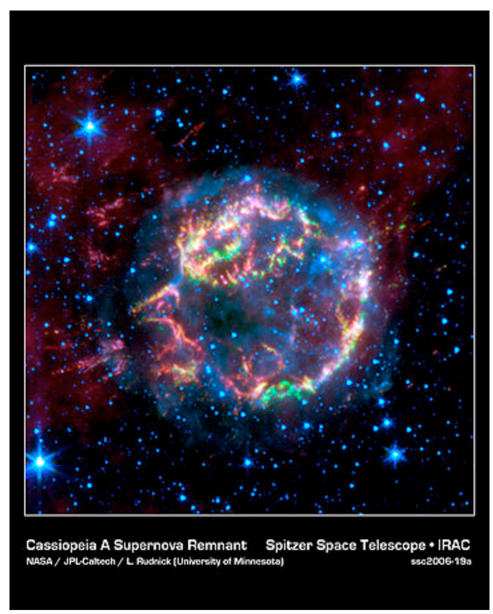
The fate of the remaining part of the core of the high mass star is also much more exciting than what happens to the core of a lower mass star. And exactly what that fate will be depends on the final mass of the core. If the core has a mass greater

Onion Skin Model



The onion skin model illustrates the layered structure of the cores of dying stars. As lighter elements are made into heavier elements inside stellar cores through the process of nuclear fusion, layers of different material build up, with the heaviest elements closest to the center of a star.

In a massive star, like Cassiopeia A was before it exploded, layers of successively higher mass elements build up, with iron forming as the final product of normal fusion reactions in the core.

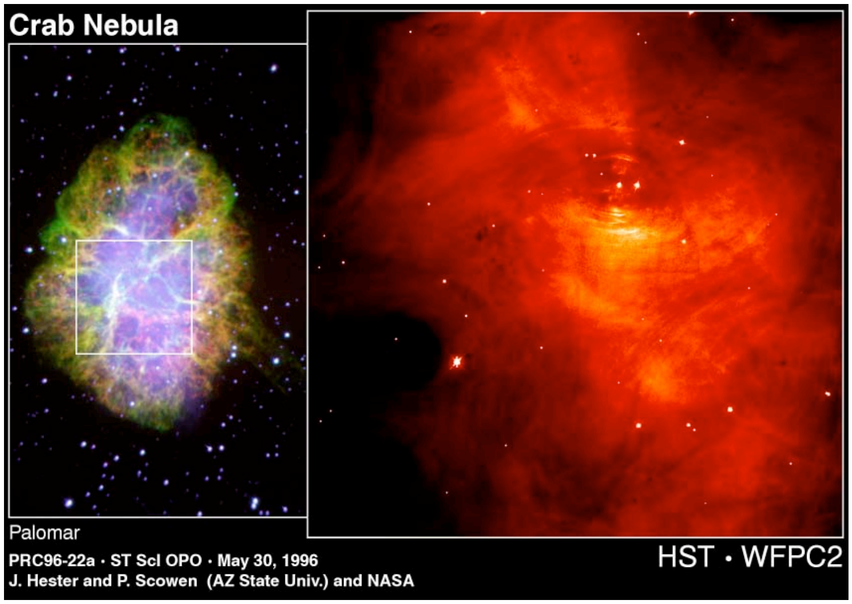


Cassiopeia A as seen by Spitzer Space Telescope in 2006. The infrared telescope actually saw the onion skin layers that were blown off when the star went supernova.

(See image and story at http://www.spitzer.caltech.edu/Media/releases/ssc2006-19/release.shtml.)

© 2007 Dr Mary Urquhart, University of Texas at Dallas

than 1.4 times the mass of the Sun, then the core's own gravity will be strong enough to squeeze all of the empty space out of the core's atoms. If the mass is less than about 3 times the mass of the Sun, what is left is a very small, extremely dense object known as a **neutron star**. When the collapsing core is more massive than this limit, it continues collapsing and becomes one of the strangest objects in our universe: a **black hole**.



© 2007 Dr Mary Urquhart, University of Texas at Dallas

Death of Stars Exercises:

Exercise 1:
Using the diameter of the Sun and the scale factor of 1:10 billion, complete Table 1.

Table 1: Red Giants and Supergiants

	Mass	Diameter/ Diameter of the Sun	Actual Size (in billions of meters)	Scaled Size (in meters)
Red Giant (future Sun)	1 x M_{Sun}	~200		
Red Supergiant (Betelgeuse)	~18 x M_{Sun}	~1000		

The diameter of the Sun is 1.392 billion meters.

Exercise 2:
Compare the scaled sizes for a red giant and a red supergiant to the distances of the planets in the solar system. (Hint: divide the diameter by two to get the radius to make your comparison easier.)

- When the Sun becomes a red giant, it will reach closest to the orbit of which planet? ____
- If the supergiant star Betelgeuse replaced the Sun, it would extend out to the orbit of which planet? ____

Exercise 3:
Using the scale factor of 1:10 billion, complete Table 2.

Table 2: Sizes of White Dwarfs, Neutron Stars, and Black Holes

	Mass	Diameter	Scaled Size (in mm)
White Dwarf	0.7 x M_{Sun}	~10,000 km	
Neutron Star	1.4 x M_{Sun}	~30 km	
Black Hole	~3 x M_{Sun} or more	~18 km or more	

* The "diameter" of a black hole is not actually a real size, but represents the region around the black hole that has such intense gravity that even light can't escape.

© 2007 Dr Mary Urquhart, University of Texas at Dallas

Exercise 4:

Compare the size of a typical white dwarf, as shown in **Table 1** to the sizes of the planets using the **Size Table** from the **Scale Model Solar System** activity.

- Which planets are closest to the size of a white dwarf?

  ____

- What object could you use to represent a white dwarf in a scale model that uses the scale factor of 1:10 billion?_______________________________________

Exercise 5:

Compare the size of the neutron star and black hole in **Table 2** to the sizes of the planets.

- Would you be able to see an object the size of either a neutron star or a few solar mass black hole on the scale model?__________________________________

  Why or Why not?

Things to Think About:

- If a blue-white B class star leaves the main sequence, and its outer layers swell and turn red. What is the new class of that star?

- When the Sun becomes a red giant, its mass will not go up. (In fact, the Sun will lose mass). How will the density of the future red giant Sun compare with the density of the main sequence Sun shining today?

- Imagine if a planet orbiting a very massive star somehow managed to survive the star going supernova without its orbit being affected by the powerful explosion. Would this planet be pulled in to the black hole left behind by the supernova because of the black hole's gravity?

© 2007 Dr Mary Urquhart, University of Texas at Dallas