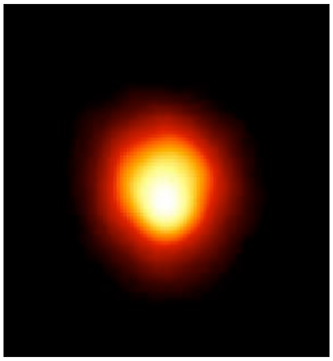
Betelgeuse



(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 Teacher Guide

In this exercise, students will model the sizes of dying stars (which have left the main sequence), and stellar remnants for the purpose of exploring the wide range of sizes of stellar objects. The lesson uses the same 1:10 billion scale factor as used in the Scale Model Solar System, Sizes of Stars, and Stellar Distances lessons for easy comparison to our own solar system and main sequence stars. (Main sequence refers to stars during the main part of their "lives" during which they convert hydrogen to helium in their cores).

Recommend Prerequisites: Scale Model Solar System, Sizes of Stars

Grade Level: 6-8

Curriculum Standards: The Death of Stars lesson is matched to:

- National Science and Math Education Content Standards for grades 5-8.
- National Math Standards 5-8
- Texas Essential Knowledge and Skills (grades 6 and 8)
- Content Standards for California Public Schools (grade 8)

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including a short introduction and follow-up.

Purpose: To aid students in understanding how stars are born, the relative numbers of stars of different masses born in interstellar clouds, and the lifetimes of stars.

Key Concepts:

- Dying stars can be much bigger than main sequence stars.
- The objects left behind when a star dies — a white dwarf, neutron star, or black hole — are the size of the Earth or smaller.
- Our own star, the Sun, will never go supernova.

Required Supplies:

- A copy of the student instruction sheet for each student
- Size table from the Scale Model Solar System activity
- Distance table from the Scale Model Solar System activity

Recommended Supplies:

- A large grapefruit or 14 cm diameter ball (for the present-day Sun)
- A cherry tomato or small red ball that is about 3 cm or about 1” in diameter (to represent a main sequence M class star)
- A blue candy sprinkle or planet card for the Earth from the Scale Model Solar System activity
- A white candy sprinkle (taped onto a black card to help make it visible.)
- A map of your city or region
- A metric ruler for every student or small group of students

Introduction:

Ask the students what they think happens to stars after they run out of hydrogen in their cores and leave the main sequence.

- What will be the final fate of a star like the Sun?
- Are main sequence stars the largest stars, smallest stars, or are they neither?
- What makes stars shine?

Concluding your introduction before passing out the student handouts for this activity will aid you in understanding the knowledge and misconceptions that the students already have. If the students will take the student sheet home to read, try to introduce the activity in a brief discussion before the end of the class in which you will make the assignment.

Review Scale Factors:

Review the usefulness of the scale factor in the Scale Model Solar System and/or Sizes of Stars activities. By using the same scale factor of 1:10 billion, the students will more easily be able to make comparisons to the sizes of objects in the solar system and to stars on the main sequence.

Note: The use of *italics* indicates information or instructions from the student version

Most of the stars in the solar neighborhood shine by converting hydrogen to helium, 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.

Discussing fusion with your students: As mentioned in the Sizes of Stars activity**,** the Benchmarks for Science Literacy recommend that students in grades 6-8 be introduced to the different types of atoms, but not to subatomic particles. The discussion of fusion included in the student handout is therefore very simplified.

In the Sizes of Stars activity, students may have asked where the heat inside a star comes from initially so that fusion can begin. Students may now wonder how a star can begin using heavier elements for fuel when they didn't before.

Once again, the answer is gravity. Without hydrogen fusion as a source of energy, the star begins to collapse. As it collapse it heats up. When the core is sufficiently dense and hot, fusion of elements heavier than hydrogen begins.

Effect on Class

As on the main sequence, star colors are a function of temperature, with blue for a hot star and red for a cool star. However, unlike stars on the main sequence, star colors for dying stars are not strictly a function of the mass of the star. Not all giants will be red. As they evolve, stars can shrink and expand, changing their colors. At their largest, however, they will be red.

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

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.*

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

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.

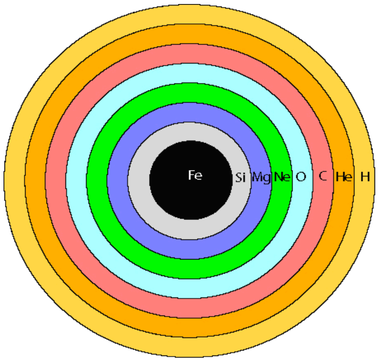
Once these reactions start, they keep the core of the star from collapsing further. The first new reaction converts helium to carbon:

3 helium atoms
+
heat and pressure
=
1 carbon atom
+ energy

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.

Onion Skin Model

For a high-mass star, the core will build up successively more massive elements, with iron (and nickel) building up in the center.



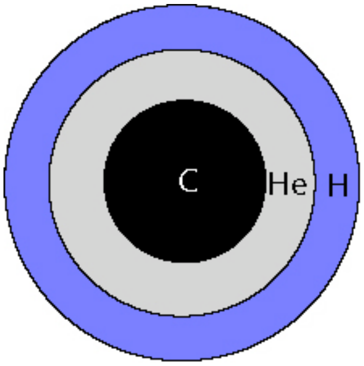
Onion Skin Model to Iron: In massive stars, the onion skin structure of the core builds in successive layers all the way to iron. The illustration shown for students is of a simplified version of the onion skin model representing a Sun-like star.

Elements Heavier Than Iron: Your students may ask where elements heavier than iron originate. They too, are produced in stars by a process called neutron capture. Understanding this process requires a discussion of subatomic particles, which is why it has not been described in the student reading. If your students ask, however, you may wish to discuss it.

In brief, the other nuclear reactions in the star produce high-energy neutrons. Sometimes an atom captures a neutron, changing the nature of the atom. A neutron can decay into a proton and electron, and so new elements can be produced. (An antineutrino is also produced in the process, but this is too much information for middle school.)

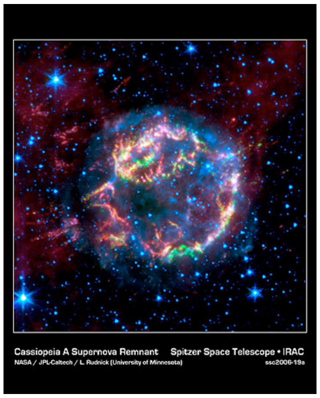
Elements produced in this way, like copper, silver, and gold, are much more rare than lighter elements like carbon, oxygen, silicon, or iron. Nickel, although heavier than iron

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 Supernova Remnant Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / L. Rudnick (University of Minnesota) ssc2006-19a

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.)

is an “iron family” element, and is produced by silicon fusion at the same time iron is being produced.

Background: A More Compete Story of Stellar Evolution

The actual evolution of stars off of the main sequence is more complex than given in this lesson for middle school students. The following information is provided to give the teacher a more complete picture of stellar evolution should questions arise:

As the core of a star begins to run out of each elemental fuel, the core collapses again. This collapse compresses the core, increasing its temperature and pressure. The area immediately surrounding the core is also compressed. As a star leaves the main sequence, but before helium fusion begins, a shell around the core will begin hydrogen fusion. It is during this time that the star begins to swell into a red giant or red supergiant, depending upon its mass. Once the core is sufficiently hot and dense (with a temperature of about 200 million K), helium fusion will begin. Helium fusion produces much more energy than hydrogen fusion, and the star heats up again, increasing in spectral class. A sun-like star will become an orange (K-class) or yellow (G-class) giant, before becoming a red giant again. A massive star may become a white or blue (A or B class) supergiant, before again returning to a red supergiant phase. Stars a few times more massive than the Sun will pass through a stage as a yellow giant star called a Cephid variable.

Each successive new “fuel” will require greater core temperatures and pressures. The gravity of stars provides the force that compresses their cores. Once carbon fusion begins, a massive star builds up the onion-skin of elements in its core very quickly, in mere hundreds of years. The internal changes happen so fast during the later stages of fusion that no change in spectral classes will be visible to astronomers observing the star.

Regardless of its surface temperature, a giant/supergiant star will be much larger and continue to shine with a tremendous amount of energy compared with its time on the main sequence. This stellar dying process is about 10% as long as a star’s main sequence lifetime.

For more information on stellar evolution check out the following Web resources:

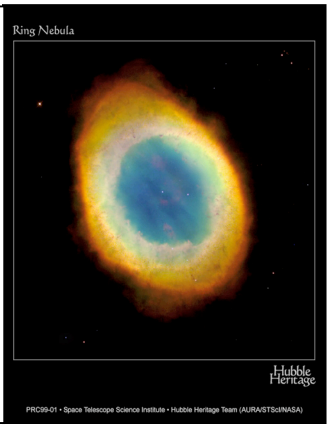
NASA’s Imagine the Universe Teacher Corner:
http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html

Australia Telescope Education and Public Outreach:
http://outreach.atnf.csiro.au/education/senior/astrophysics/stellarevolution_postmain.html

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.)

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.

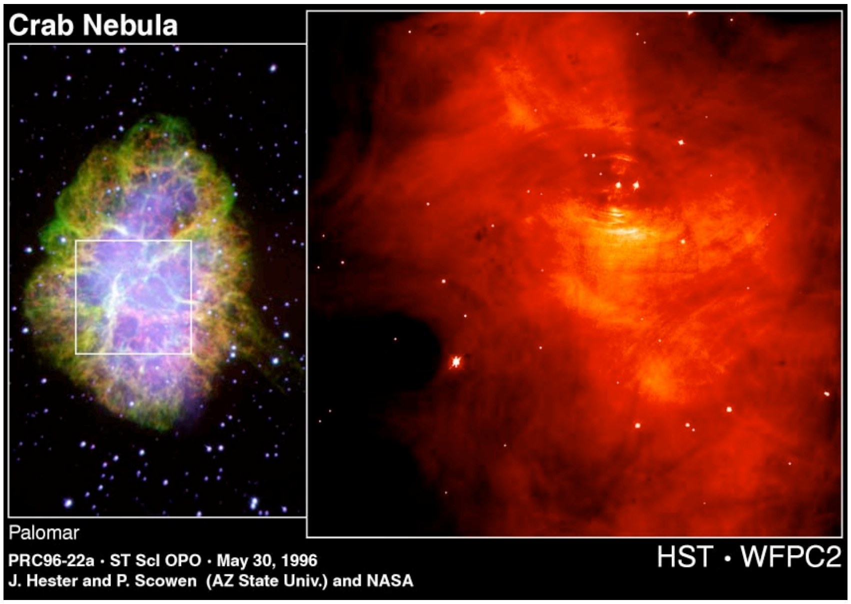


PRC99-01 • Space Telescope Science Institute • Hubble Heritage Team (AURA/STScI/NASA)

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 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.*



PRC96-22a · ST ScI OPO · May 30, 1996
J. Hester and P. Scowen (AZ State Univ.) and NASA

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 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****.*

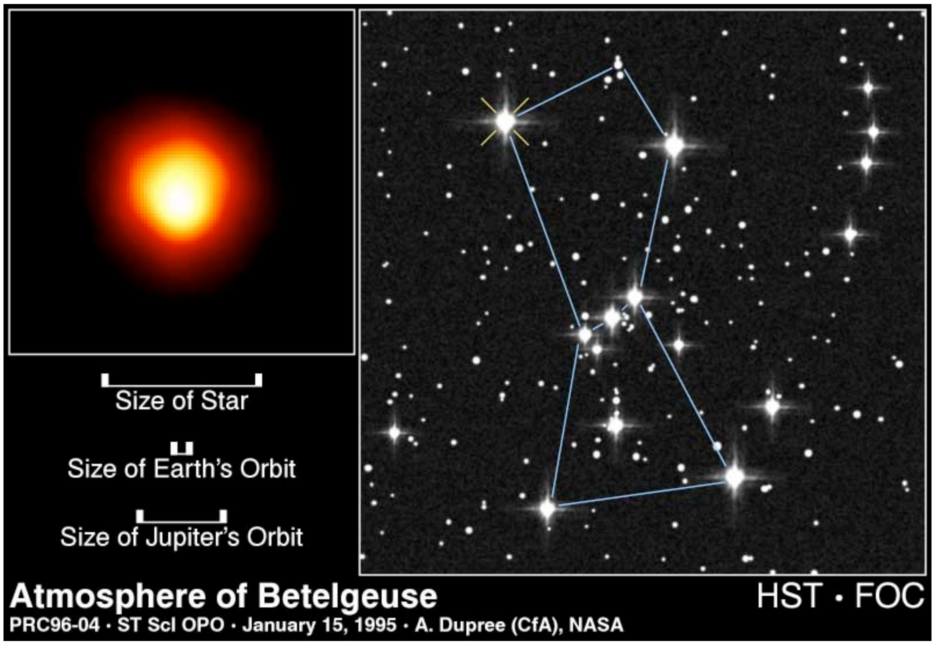
Death of Stars Exercises:

Have students complete the exercises either individually or in small groups.

Make sure the students have a copy of the Size Table and the Distance Table from the Scale Model Solar System activity handy.

The Sun will fill the present orbit of the Earth, and perhaps even Mars, during its final red giant phase. However, by that time the future Sun it will have also lost mass. Less mass means less gravity, and the Earth's orbit may expand to beyond the reach of the bloated star.

Giants, and especially supergiants like Betelgeuse, are the largest, and brightest stars. Betelgeuse is about 1400 light years away, but is one of the brightest stars in our sky.



Atmosphere of Betelgeuse

PRC96-04 • ST ScI OPO • January 15, 1995 • A. Dupree (CfA), NASA

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*	**~278 billion meters**	**~27.8 m**
Red Supergiant (Betelgeuse)	*~18 x* M_{Sun}	*~1000*	**~1390 billion meters**	**~139 m**

The diameter of the Sun is 1.392 billion meters.

By Hubble measurements, Betelgeuse is even bigger than the estimate given here!

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?* **Earth**
- *If the supergiant star Betelgeuse replaced the Sun, it would extend out to the orbit of which planet?* **Jupiter**

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*	**~1 mm**
Neutron Star	*1.4 x* M_{Sun}	*~30 km*	**~.003 mm**
Black Hole	*~3 x* M_{Sun} *or more*	*~18 km or more*	**~0.0018 mm**

** 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.*

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?* **Earth and Venus**
- *What object could you use to represent a white dwarf in a scale model that uses the scale factor of 1:10 billion?* **candy sprinkle (white)**

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?* **No.**

  Why or why not? **Both are too small for a 1:10 billion scale model.**

Things to Think About:

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

Why? Color, or more accurately, surface temperature, determines spectral class.

- 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?

Because the future red giant Sun will have the same amount of mass (or less) as the current Sun, but in a much greater volume, its density will be much less.

- 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? **No.**

Black holes and gravity are difficult concepts, for adults as well as children.

Black holes left behind when a star goes supernova always have **less mass** than the original star. That means they have **less gravity** at a given distance from the center of the black hole. Very close to the black hole the gravity is intense because all the matter is concentrated in tiny space. For example, a spacecraft could never get within 5 km of the center of a normal star, and even if it did, the mass of the star would surround the spacecraft.

Distance, as well as mass, matters for gravity. Because the spacecraft is *outside* the star, and therefore millions or billions of km away from the star's center of mass, the gravity the gravitational force on it would be **much less** than for a spacecraft near the event horizon of a black hole with the same mass as the star.

At a distance of billions of km from the center of mass of a 3 solar mass star, a spacecraft would not encounter the intense gravity that the same spacecraft would within a mere 5 km of a black hole 3 times the mass of the Sun.

Follow-up:

After the students have had a chance to read through the student sheet (individually or as a class), discuss the concepts presented in the information sheet.

When the exercises have been completed, discuss those results as well. Using objects such as the grapefruit for the present-day Sun, and the blue candy sprinkle or planet card for the Earth from the Scale Model Solar System activity as visual aids for the students may help them better understand how giants, supergiants, and white dwarfs relate to the sizes of objects in our solar system.

If possible, consider taking the students to an area such as the schoolyard or a long hallway with about 80 meters of space available, and walk the distance to that corresponds to the radius of a red giant and a red supergiant. To help your students compare evolved stars to their main class counterparts, consider bringing along

- the grapefruit that represents the present-day Sun on this scale and
- the cherry tomato or small red ball to represent a main sequence M class star

A map of your city or region can be used to help your students understand the actual sizes of a neutron star and the event horizon of a black hole. The size of a neutron star is often compared to the size of Manhattan Island.

Extension:

If you have Internet access for students working in small groups, or you can make high quality color printouts from the Web, consider having students look at some of the many planetary nebulae, a supernova remnant, and a lone neutron star imaged by the Hubble Space Telescope. For images of stellar remnants taken in non-visible wavelengths of light, try the galleries of these other two of NASA's four Great Observatories:

- Spitzer Space Telescope (infrared) at http://www.spitzer.caltech.edu/
- Chandra X-Ray Observatory at http://chandra.harvard.edu/.

Hubble Images:

- The Ring Nebula (M57), the most famous planetary nebula
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/01/
- The Glowing Eye of NGC 6751
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2000/12/
- Cat's Eye Nebula
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/27/
- Stingray Nebula: a very young planetary nebula.
  http://oposite.stsci.edu/pubinfo/pr/1998/15/
- The “Eskimo” Nebula: A Planetary Nebula
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2000/07/image/a
- The Hourglass Nebula, another planetary nebula (not spherical at all)
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1996/07/
- The "Rotten Egg" Nebula: A Planetary Nebula in the Making
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1996/05/
- Dying Sun-like Star
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1996/05/
- The Crab Nebula (A Supernova Remnant)
  http://www.seds.org/messier/more/m001_hst.html
- Nearby Supernova Remnant
  http://imgsrc.hubblesite.org/hu/db/2005/15/images/a/formats/web_print.jpg
- Hubble Sees a Neutron Star Alone in Space
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1997/32/

Comparison images with Hubble, Spitzer and Chandra:

- Kepler’s Supernova
  http://hubblesite.org/newscenter/archive/releases/2004/29/
- Super Massive Black Holes
  http://hubblesite.org/newscenter/archive/releases/2004/19/
- Cassiopeia A Supernova Remnant
  http://www.spitzer.caltech.edu/Media/releases/ssc2005-14/ssc2005-14c.shtml