CHAPTER 1 The Life Cycle of a Star

- Describe the life cycle of various size stars.

Rings of glowing gas encircling Supernova 1987A, about 179,000 light-years away in the Large Magellanic Cloud, one of the Milky Way's dwarf satellite galaxies.

The Life Cycle of Stars

Space may seem empty, but actually it contains thinly spread gas and dust, called **interstellar medium,** that gradually collapses over immense stretches of time and collects into denser clouds of gas and dust. The atoms of gas are mostly hydrogen and are typically about a centimeter apart. The dust is mostly carbon and silicon. In some places, this interstellar medium is collected into particularly dense clouds of gas and dust known as a **nebula**. A nebula is the birthplace of stars. Our sun was probably born in a nebula around 5 billion years ago.

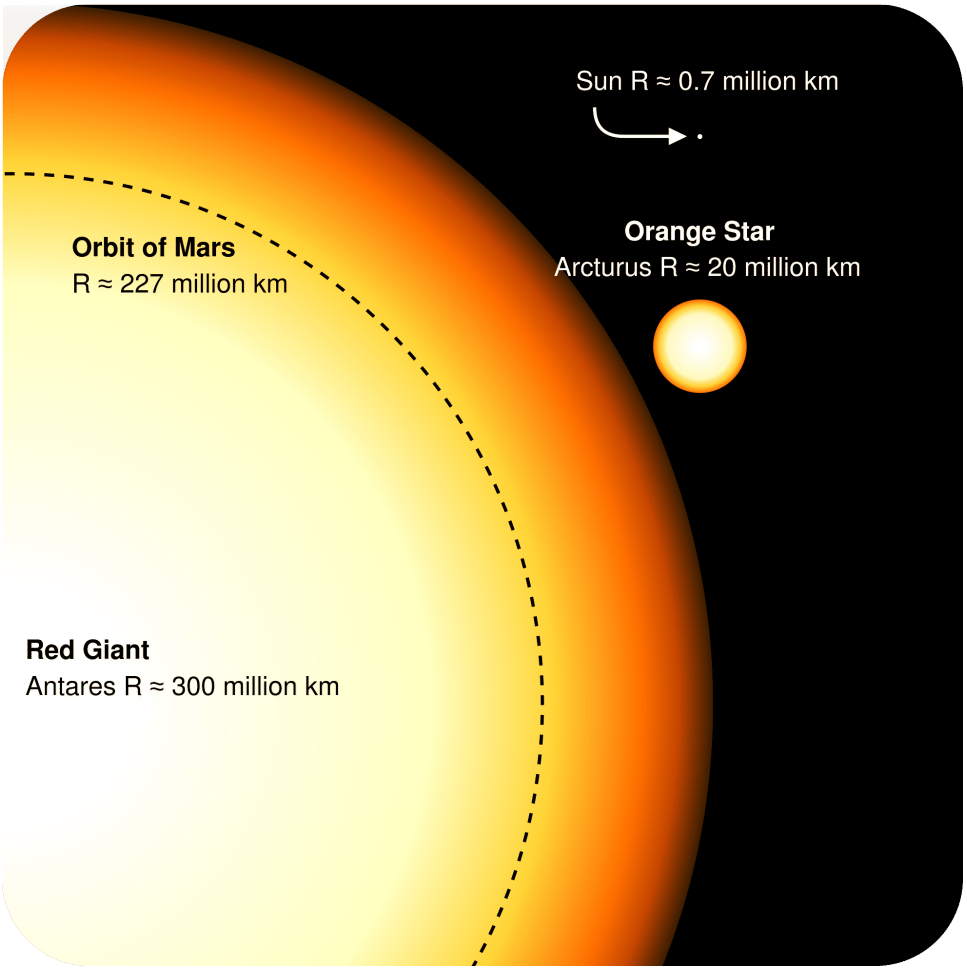
Within a nebula, there are varying regions where gravity has caused the gas and dust to clump together. The gravitational attraction of these clumps pull more atoms into the clump. As this **accretion** continues, the gas pressure increases and the core of the **protostar** gets hotter and hotter. If the protostar gets dense enough and hot enough, a fusion reaction will ignite and the star lights up. The minimum mass for the formation of a star is about 80 times the mass of Jupiter. A star is a very large, very hot ball of gas which has hydrogen fusing into helium in the core. Stars spend the majority of their life fusing hydrogen into helium. When the hydrogen is nearly used up, the star can fuse helium into heavier elements. Throughout this process, a battle goes on in the core of the star between gravity trying to collapse the star and temperature-produced gas pressure pushing the material in the star outward. During the life of a star, there is a balance between the gas pressure pushing out and gravity pushing in.

Once a star has achieved nuclear fusion in its core, it radiates energy into space. While the temperature-produced gas pressure balances gravity, the star attains a stable state and enters the main sequence phase of its life. The temperature of a main sequence star is about 15,000,000°C. For the major part of its life span, a star stays in this **main sequence** phase, with hydrogen being fused into helium and a balance between force pushing out and force pushing in.

How long a star lives depends on its initial size. Stars can live from many millions of years to many billions of years. The most massive stars (many times the size of our sun) become extremely dense and hot in the core and

therefore, have a very high fusion rate. The largest stars use up their hydrogen fuel fastest and therefore live for the shortest time, perhaps only millions of years. Stars that are the size of our sun fuse hydrogen much more slowly and therefore live much longer. Medium sized stars live billions of years.

As a star begins to run low on hydrogen, since the initial quantity has been fused into the denser helium gas, the core will contract due to gravity. The collapsing core increases temperature to the point that the star can begin to fuse helium into carbon. When that happens, the outer portion of the star expands greatly due to the higher temperature. The star can expand to 1000 times the diameter of the sun. At this point, the star is called a **red giant**. If our sun became a red giant, its surface would expand out past the orbit of Mars. Red giants are red because the surface of the star is cooler than white or blue stars, but remain highly visible because of their gigantic size.



After a star becomes a red giant, it will take one of several different paths to end its life. Which path is followed by a star after the red giant phase depends on its mass. During the fusion life of a star, its size is the result of a competition between fusion heat pushing the material out and gravity pulling the material in. At the end, gravity always wins. After the star has lived through its red giant stage, the fusion essentially ends (the star runs out of fuel) allowing gravity to collapse the star. Some of the outer layers of material will be blown away and the core becomes smaller and denser. The core will become either a neutron star, a white dwarf, a black dwarf, or a black hole.

Low-mass stars (less than 0.5 times the mass of our sun) become a red giant and then blow off some outer material which dissipates in the interstellar medium after a few hundred thousand years. The remainder of the star shrinks to a white dwarf. After a few billion years, **white dwarfs** cool to become **black dwarfs**.

Medium-mass stars (less than 3 times the mass of our sun) become a red giants and eventually become a **supernova**. A supernova is the massive explosion of a star accompanied by emission of light and matter so intense that it can outshine an entire galaxy. After a supernove, when all the accessible fuel in a medium-mass star is exhausted,

the iron core collapses and proton-electron pairs are converted into neutrons. Such stars are called **neutron stars**. Neutron stars might spin rapidly giving off light and X-rays or they might emit pulses of energy regularly and be known as **pulsars**.

The largest-mass stars become **black holes**. These extremely large stars end their life in the same way as a medium-mass star in that they become a supernova. After the outer layers are blown away in the supernova, however, the core of the star shrinks down in volume but still has a huge mass. The density of this object is extremely high, even denser than neutron stars. This dense object will have a gravitational force so large that not even light can escape from the body. (A companion topic to this occurs in *The General Theory of Relativity* where we see than extremely strong gravitational attraction can even attract light.) These objects appear black because light cannot leave them, that is, they pull all light back to their surface. Black holes capture everything nearby due to their massive gravity and so they grow in size. Black holes are a common topic for science fiction but keep in mind, they are simply a very dense ball of matter with intense gravitational attraction.

Summary

- A star begins its life in a nebula, struggles to balance gravitational pull and internal pressure during its main sequence period, and ends its life in an explosion to eventually become a white or black dwarf, or a neutron star, or a black hole.

Review

1. All stars begin as
    1. red giants
    2. nebulae
    3. supernova
    4. white dwarf
2. The correct life cycle for a very large mass star is
    1. main sequence, red giant, white dwarf
    2. black hole, supernova, red giant, nebulae
    3. main sequence, red giant, supernova, black hole
    4. main sequence, red giant, supernova, neutron star
3. Which of the following is the fusion occurring in our sun?
    1. lithium to beryllium
    2. helium to hydrogen
    3. hydrogen to helium
    4. helium to carbon
4. During its main sequence life time, a star is kept from collapsing by
    1. the strong nuclear force
    2. heat that produces gas pressure
    3. the fact that stars are made up of very lightweight hydrogen gas
    4. the weak nuclear force
5. Which type of star has the shortest life span?
    1. the smallest ones
    2. the middle sized ones
    3. the most massive ones
6. Medium-sized stars end their life as a

1. neutron star
2. white dwarf
3. black dwarf
4. black hole

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/186206

1. Where and how is a star born?
2. How does a star's size affect its life cycle?
3. What causes a supernova? A black hole?

- **interstellar medium:** Material, mostly hydrogen gas, other gases, and dust, occupying the space between the stars and providing the raw material for the formation of new stars.
- **nebula:** A visible, thinly spread cloud of interstellar gas and dust. Some nebulae are the remnants of a supernova explosion, others are gravity-induced condensations of the gases in the interstellar medium which in certain cases may become a site for the formation of new stars. The term was formerly used of any hazy, seemingly cloud like object, including what are now recognized as other galaxies beyond the Milky Way; it is restricted now to actual clouds of gas and dust within our own galaxy.
- **accretion:** The accumulation of dust and gas into larger bodies such as stars, planets and moons.
- **protostar:** A cloud of interstellar gas and dust that gradually collapses, forming a hot dense core,and evolves into a star once nuclear fusion can occur in the core.
- **red giant:** A red giant is a star in an intermediate stage of evolution, characterized by a large volume, low surface temperature, and reddish hue.
- **supernova:** The explosion of a star, possibly caused by gravitational collapse, during which the star's luminosity increases by as much as 20 magnitudes and most of the star's mass is blown away at very high velocity, sometimes leaving behind an extremely dense core.
- **neutron star:** A star that has collapsed under its own gravity to a diameter of about 10 to 15 km. It is composed mostly of neutrons, has a mass of between 1.4 and about 3 times that of the sun, and a density in excess of 1×10^{17} kilograms per cubic meter.
- **pulsar:** One of several hundred known celestial objects, generally believed to be rapidly rotating neutron stars, that emit pulses of radiation, especially radio waves, with a high degree of regularity.
- **black hole:** A black hole is a region of space from which gravity prevents anything, including light, from escaping.
- **white dwarf:** A star, approximately the size of the earth, that has undergone gravitational collapse and is in the final stage of evolution for low-mass stars, beginning hot and white and ending cold and dark (black dwarf).
- **black dwarf:** See definition for white dwarf.

References

1. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Supernova1987A.jpg .
2. User:Sakurambo/Wikipedia. http://commons.wikimedia.org/wiki/File:Redgiants.svg .