Session 6: Stars and Their Lives

This presentation supports the "Background" material in Session 6 of the Afterschool Universe program.   This is the first of two sessions concerning the properties and workings of stars.

This opening slide shows a color photograph of a star-field. Something that can be noticed immediately is the variety of stars, both in terms of color (ranging from red to blue) and their brightness.

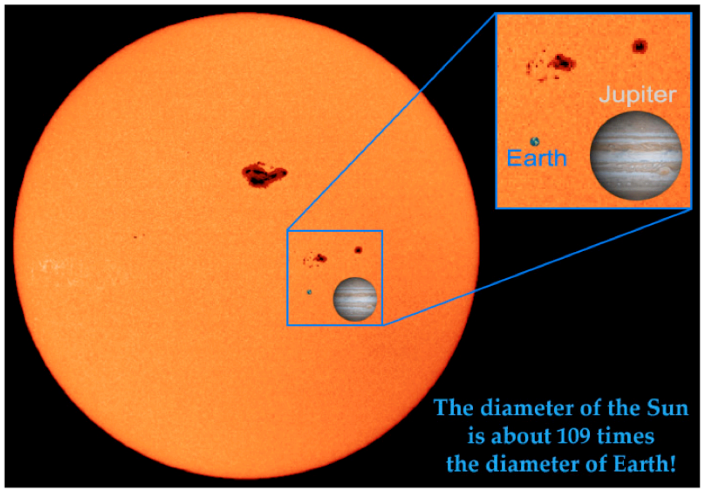
The Main Concepts…

1. The Sun is a pretty average star.

2. Stars are born, live and die… their life cycle depends on how big they are.

Let us summarize the main concepts in this Session. We will discuss these concepts in the rest of this presentation.

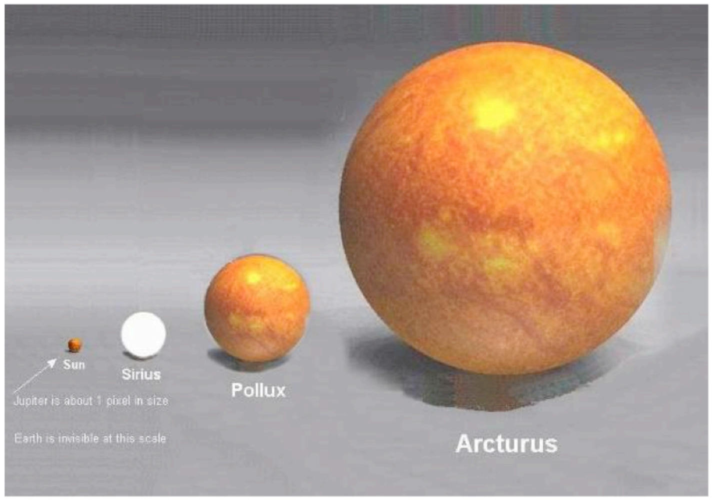
The Sun



The Sun is incredibly important to the Earth, providing all of our heat and light. As shown in this figure, it is a very impressive object with a diameter 109 times greater than the Earth's diameter, and a mass 330,000 times greater than the Earth's mass. The figure also shows the Sun in in comparison to Jupiter, the largest planet in the Solar System, and also in comparison to Earth.

However, it is important to realize that the Sun is just an average star. The only reason why the Sun appears so bright is that it is comparatively close to the Earth. At a distance of 93 million miles, the Sun is about 250,000 times closer than the next closest star (Proxima Centuri).

The Sun is an Average Star



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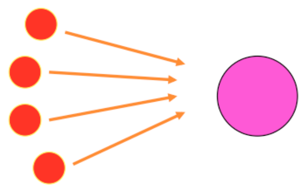
As we said before, the Sun is an average star. This figure compares the Sun to some other stars. Clearly some stars are much larger than the Sun, while others are smaller.

Let's now move on and talk about the how stars work and how they live their lives.

How Do Stars Work?

- Stars must have an <u>energy source</u> to shine
  - Nuclear fusion!
  - Combine small atoms (for example, hydrogen) to form larger atoms (for example, helium)
  - This process releases energy



Stars must have an energy source to shine. They generate this energy via nuclear fusion, the process by which two or more atoms (or more precisely, the nuclei of atoms) come together to form a new atom.

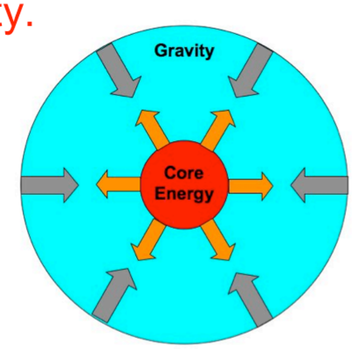
The graphic illustrates a particularly important process, the fusion of 4 hydrogen atoms (small red circles) to produce 1 helium atom (larger magenta circle). During this process, energy is released. The Sun converts 600 million tons of hydrogen into helium every second.

<u>Advanced Note</u> : the actual process by which 4 hydrogen atoms are converted into a helium atom is a little more complicated than that represented above. There are several steps, starting with the fusion of two hydrogen atoms to form deuterium.

A Balancing Act

Energy released from nuclear fusion counter acts inward force of gravity.

Throughout its life, these two forces determine the stages of a star's life.



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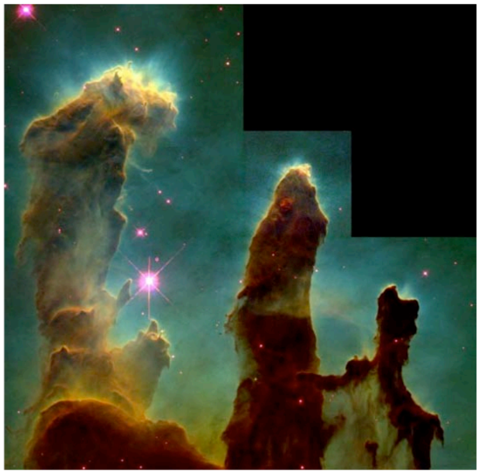
The energy generated in the core of the star flows outwards towards the surface where it is radiated into space. This outward flow of energy balances the inward pull of gravity and keeps the star in balance.

The Birth of Stars



- Stars are born in giant clouds of gas in deep space.
- Gravity causes gas to clumps. Clumps continue to collapse.
- A star is born once the center of the clump gets hot enough for nuclear fusion!

Let us now talk about the life cycle of stars.

Stars are born in large gas clouds in space known as nebulae.

The figure shows the Eagle Nebula (also known as M16) as seen by the Hubble Space Telescope (http://oposite.stsci.edu/pubinfo/PR/95/44.html).   This is a cloud of dust and gas in space where stars are currently forming.   Gravity causes the gas cloud to break up into clumps. The clumps collapse, becoming hotter and hotter, until they eventually become stars.

Another Star Forming Cloud

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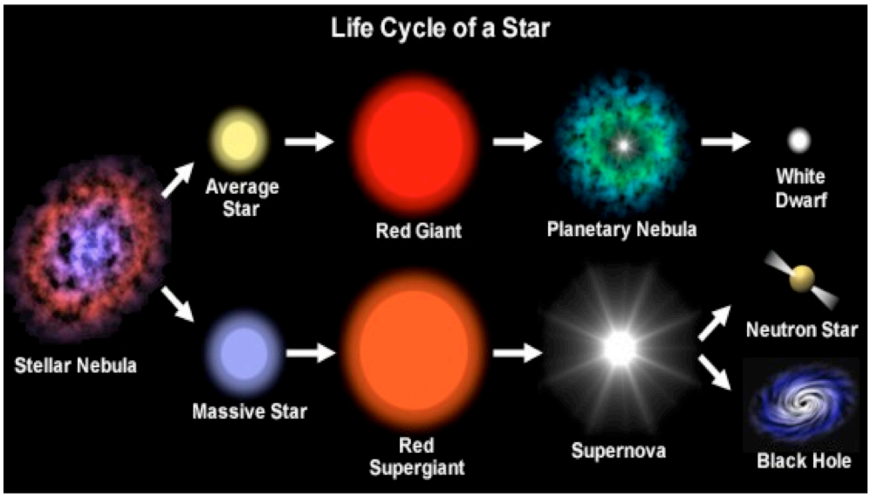
This is another star forming cloud, the Orion Nebula, which can be seen by the unaided eye in the sword of the constellation of Orion.

Life Cycle of Stars



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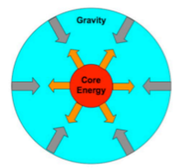
After stars are born, they follow one of two paths depending upon their mass.

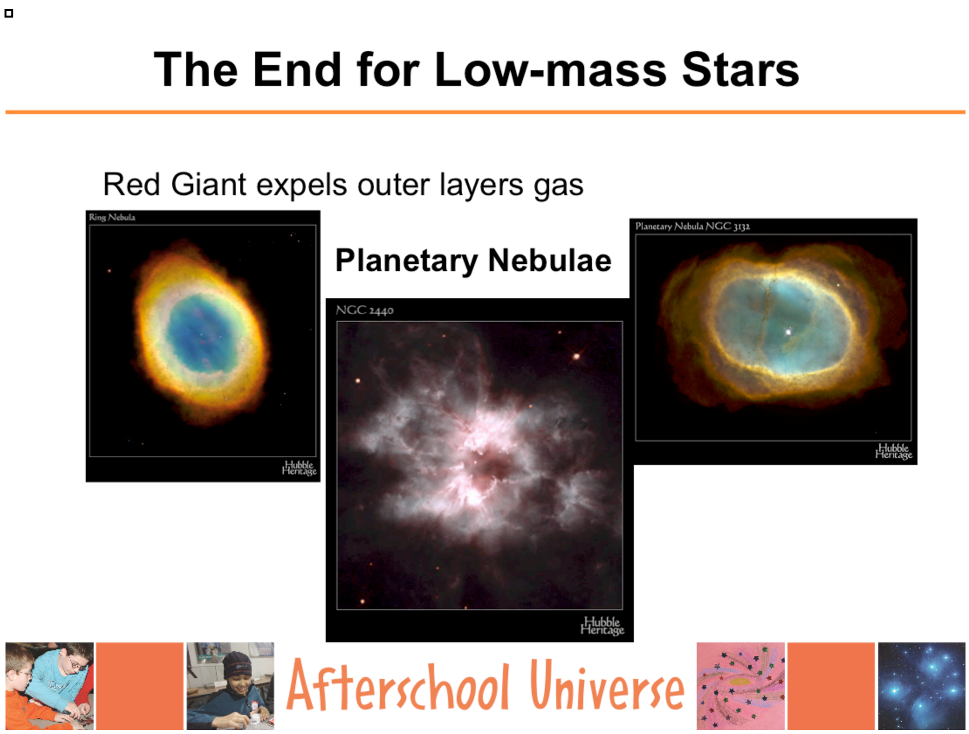
The graphic summarizes these two paths. The top path is followed by relatively small stars (stars with a mass less than 8 times that of the Sun). The bottom path is followed by more massive stars. Both paths start in a similar way… after being born in a nebula, the star enters a long-lived phase during which energy is being generated via the conversion of hydrogen into helium in the core of the star. This long-lived part is called the “main sequence” phase of a star’s life.

The Beginning of the End: Red Giants

- Energy released from nuclear fusion of hydrogen balances stars against gravity
- But the hydrogen eventually runs out!
  - Core of star collapses and releases heat
  - This heat expands the outer layers
  - Star puffs up to form a Red Giant



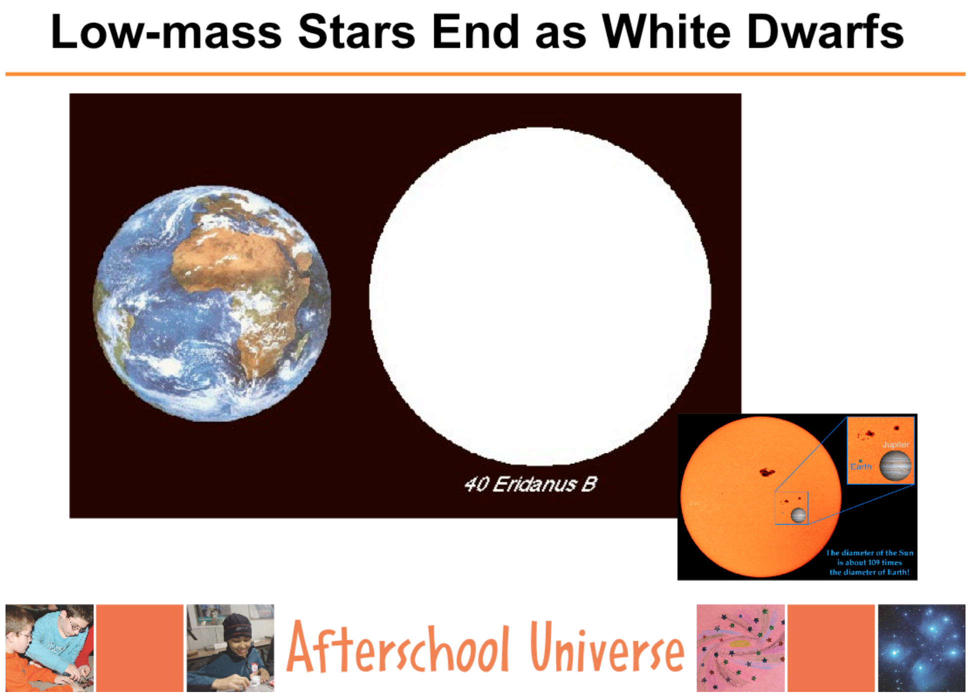
This long-lived phase of the star comes to an end when the core of the star runs out of hydrogen. The reduction in energy generation upsets the balance of forces (gravity vs. energy flow) inside of the star. As a result, the core of the star contracts and releases extra heat. This causes the outer layers of the star to puff up, forming a Red Giant (for a low mass star) or a Red Supergiant (for a high mass star).



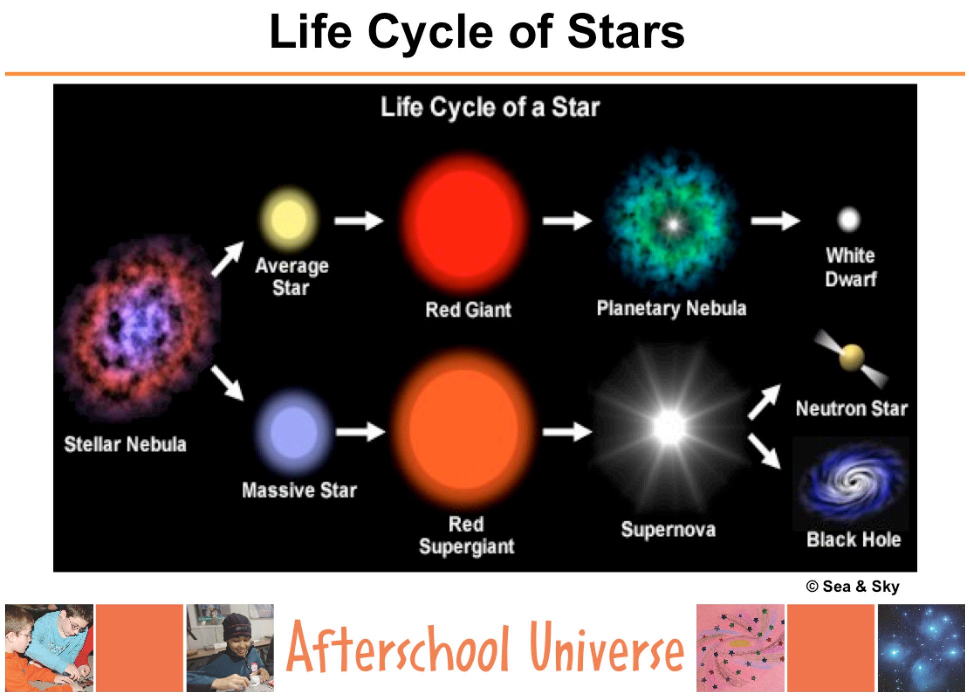
At this point, low mass stars and high mass stars follow very different routes.

After the Red Giant phase, low mass stars blow off their outer layers. The expelled gas forms a nebula, often called a planetary nebula (although they have nothing to do with planets). Here we show three examples of these planetary nebulae:

From Left to Right, Ring Nebula, NGC2440, and NGC3132 (all images from Hubble Heritage: http://heritage.stsci.edu/public/gallery/galindex.html)



After the star blows off its outer layers, the core of the star collapses to form a White Dwarf. While it can have the mass of the Sun, a white dwarf is only the size of the Earth. The graphic in the lower right reminds us of how big the original star (like the Sun) was before compared to the Earth.



Now let us consider high-mass stars (the lower route in the graphic).

When the core converts all of its hydrogen into helium, it doesn't stop there. The helium is converted into carbon, the carbon to magnesium and so on. This process eventually stops when the core has been turned into iron.

Supernova!

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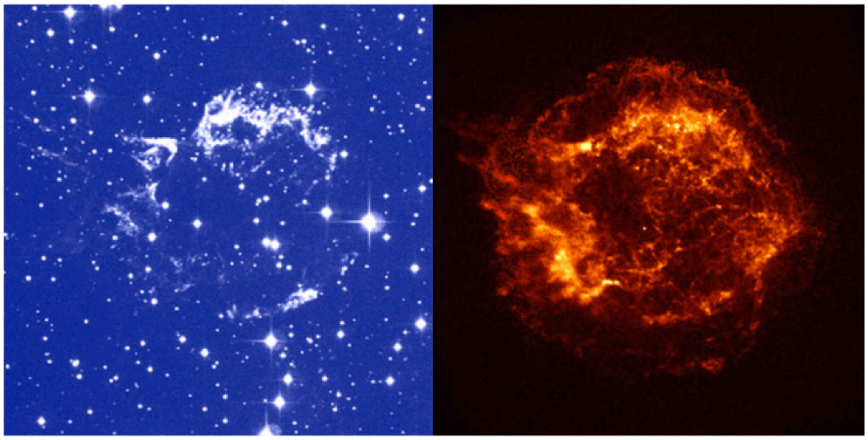
When the core is converted into iron, energy generation stops. The core of the star collapses under the unchecked force of gravity. After this catastrophic collapse, the core “bounces”, and the bounce blows the star apart in a spectacular explosion known as a supernova.

This graphic shows a real picture of a supernova in 1987. The right-hand picture is taken before the explosion, and the left hand picture was taken shortly after the explosion. Supernovae are very bright and can briefly outshine the galaxy that they are in!

Supernova Remnants: Cas A

Optical X-ray



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We see the debris of these explosions around us; they are called supernova remnants. This figure shows one particular example, Cassiopeia-A, which exploded 300 years ago. The X-ray image shows hot gases associated with the supernova explosion.

Cas A x-ray and optical images from http://chandra.harvard.edu/photo/0237/

What’s Left After the Supernova

Neutron Star (if original star < 20 x Solar)

- Under collapse, protons and electrons combine to form neutrons.
- Only 10 Km across, very dense

Black Hole (if original star > 20 x Solar)

- Not even compacted neutrons can support weight of very massive stars.

The supernova doesn’t completely blow the star apart - the very core has collapsed to a very compact object.

If the original star is between 8 and 20 solar masses, we are left with a neutron star. A very very dense star with the mass of the Sun but only the size of a city.

If the original star has greater than 20 solar masses, we get a black hole.