How do stars form and evolve?

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TOP: Thousands of sparkling young stars are nestled within the giant nebula NGC 3603. This stellar "jewel box" is one of the most massive young star clusters in the Milky Way, the galaxy that contains our solar system. NGC 3603 is a prominent star-forming region in the Carina spiral arm of the Milky Way, about 20,000 light-years away. This image shows a young star cluster surrounded by a vast region of dust and gas. The image reveals stages in the life cycle of stars. Photo from: NASA. BOTTOM: Novae typically originate in binary systems containing sun-like stars, as shown in this artist's rendering. Photo from: NASA's Goddard Space Flight Center/S. Wiessinger

Stars are the most fundamental building blocks of galaxies. The age, distribution, and composition of the stars in a galaxy trace the history and evolution of that galaxy. Moreover, stars are responsible for the manufacture and distribution of heavy elements such as carbon, nitrogen, and oxygen, and their characteristics are intimately tied to the characteristics of the planetary systems around them. Consequently, the study of the birth, life, and death of stars is crucial to the field of astronomy.

A Star Is Born

Stars are born within the clouds of dust scattered throughout most galaxies. Turbulence deep within these clouds causes the gas and dust to begin to collapse under their own gravitational attraction. As the cloud collapses, the material at the center begins to heat up. Known as a protostar, it is this hot core at the heart of the collapsing cloud that will one day become a star.

As the cloud collapses, a dense, hot core forms and begins gathering dust and gas. Not all of this material ends up as part of a star — the remaining dust can become planets, asteroids, or comets, or may remain as dust.

A star the size of our sun requires about 50 million years to mature from the beginning of the collapse of the cloud to adulthood. Our sun will stay in this mature phase for approximately 10 billion years.

Stars are fueled by the nuclear fusion of hydrogen to form helium deep in their interiors. The outflow of energy from the central regions of the star provides the pressure necessary to keep the star from collapsing under its own weight, and the energy by which it shines.

Main Sequence Stars

Stars that fuse hydrogen to form helium are called main sequence stars, and they make up 90 percent of the stars in the universe. These stars span a wide range of brightness and color, and they can be classified according to those characteristics. The smallest stars, known as red dwarfs, may contain as little as 10% the mass of the sun and release only 0.01% as much energy. Despite their smallness, red dwarfs are by far the most common stars in the universe and have lifespans of tens of billions of years.

On the other hand, the most massive stars, known as hypergiants, may be 100 or more times more massive than the sun. Hypergiants release hundreds of thousands of times more energy than the Sun, but have lifetimes of only a few million years. Although extreme stars such as these are believed to have been common in the early universe, today they are extremely rare. The entire Milky Way galaxy contains only a handful of hypergiants.

The Fate Of Stars

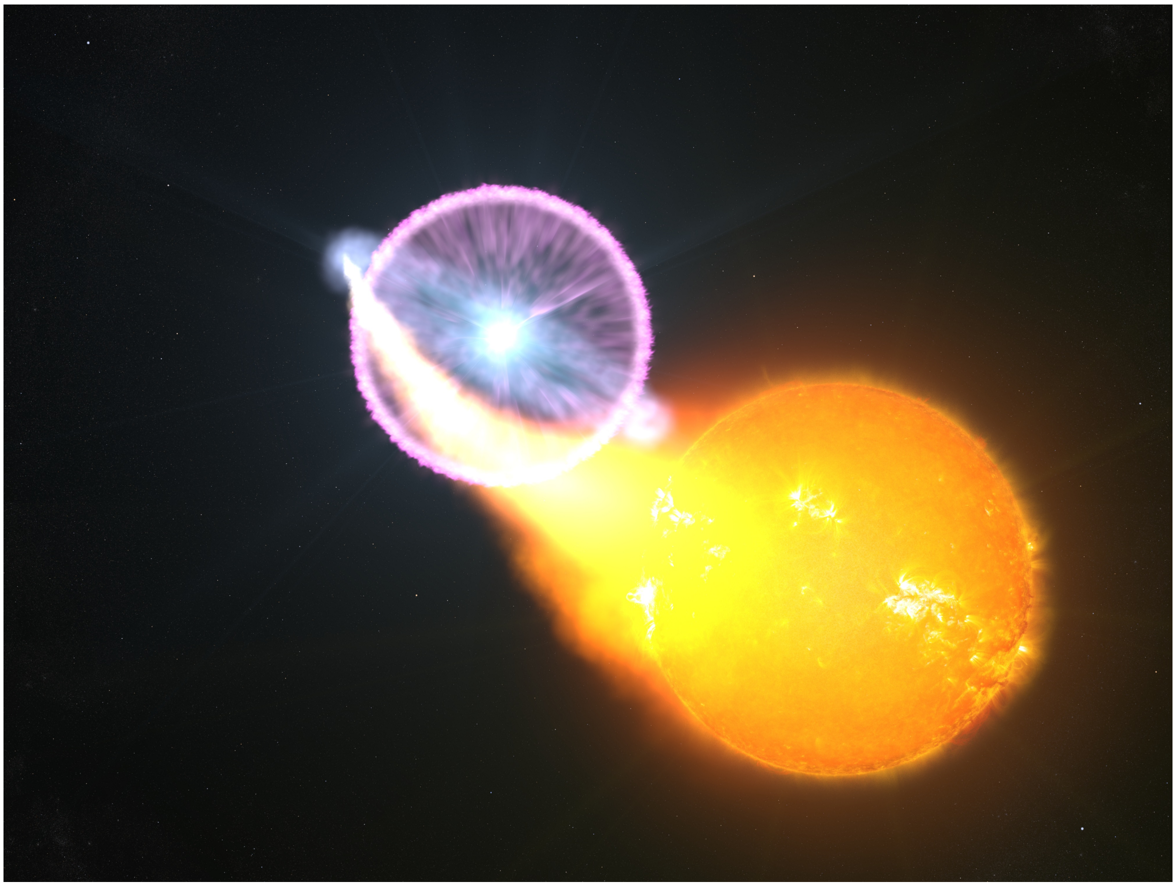
In general, the larger a star, the shorter its life, although all but the most massive stars live for billions of years. When a star has fused all the hydrogen in its core, nuclear reactions cease. Deprived of the energy production needed to support it, the core begins to collapse into itself and becomes much hotter. Hydrogen is still available outside the core, so hydrogen fusion continues in a shell surrounding the core. The increasingly hot core also pushes the outer layers of the star outward, causing them to expand and cool, transforming the star into a red giant.

Gradually, the star's internal nuclear fires become increasingly unstable, sometimes burning furiously and at other times dying down. These variations cause the star to pulsate and throw off its outer layers, surrounding itself in a cocoon of gas and dust. What happens next depends on the size of the core.

White Dwarfs Are The Size Of Earth

For average stars like the sun, the process of ejecting its outer layers continues until the core is exposed. This dead but still ferociously hot stellar cinder is called a white dwarf. White dwarfs are roughly the size of our Earth, despite containing the mass of a star. Billions of years from now, our own sun will be a white dwarf. White dwarfs are intrinsically very faint because they are so small and, because they lack a source of energy production, they fade into nothing as they gradually cool down.

This fate awaits only those stars with a mass up to about 1.4 times the mass of our sun. Bigger stars suffer a different fate.



If a white dwarf forms in a double or multiple star system, it may experience a more eventful end as a nova. Nova is Latin for "new." Novae were once thought to be new stars, but today we understand that they are in fact very old white dwarf stars. If a white dwarf is close enough to a companion star, its gravity may drag matter from the outer layers of that star onto itself, building up its surface layer. When enough hydrogen has accumulated on the surface, a burst of nuclear fusion occurs, causing the white dwarf to brighten substantially and expel the remaining material. Within a few days, the glow fades and the cycle starts again. Sometimes, particularly massive white dwarfs may build up so much mass this way that they collapse and explode completely, becoming what is known as a supernova.

The Formation Of A Supernova

Main sequence stars that are over eight solar masses, or eight times the size of the sun, are destined to die in a titanic explosion called a supernova. In a nova, only the star's surface explodes. In a supernova, the star's core collapses and then explodes. In just a matter of seconds, the core shrinks from roughly 5,000 miles across to just a dozen miles across, and the temperature spikes 100 billion degrees or more. The outer layers of the star initially begin to collapse along with the core, but rebound with the enormous release of energy and are thrown violently outward. A supernova releases an almost unimaginable amount of energy. On average, a supernova explosion occurs about once every hundred years in a typical galaxy. About 25 to 50 of them are discovered each year in other galaxies. Most are too far away to be seen without a telescope.

If a supernova is just the right size, the collapse continues until electrons and protons combine to form neutrons. This produces a neutron star. Neutron stars are incredibly dense. Because they contain so much mass packed into such a small volume, the gravitation at the surface of a neutron star is immense.

Enter The Black Hole

If a supernova is big enough - larger than three solar masses - it collapses completely to form a black hole, the universe's densest object. The gravity of a black hole is so strong that nothing nearby can escape, not even light. Since our instruments see light, black holes can only be detected indirectly. Indirect observations are possible because the gravitational field of a black hole is so powerful that any nearby material is caught up and dragged in. As matter spirals into a black hole, it forms a disk that is heated to enormous temperatures, releasing high quantities of radiation.

The dust and debris left behind by novae and supernovae eventually blend with the surrounding gas and dust, enriching it with the heavy elements that are produced when a star dies. Eventually, those materials are recycled. They will provide the building blocks for a new generation of stars and accompanying planetary systems.

Quiz

1 Which idea is BEST supported by the selection below from the section "Main Sequence Stars"?

> *Although extreme stars such as these are believed to have been common in the early universe, today they are extremely rare. The entire Milky Way galaxy contains only a handful of hypergiants.*

(A) Hypergiants have very short lifespans compared with more common stars.

(B) Stars can help astronomers understand how the universe changes.

(C) The early universe was almost completely made up of only much larger stars.

(D) The Milky Way galaxy offers little information about the early universe.

2 Which of the following selections BEST supports the idea that stars influence the planetary systems around them?

(A) Gradually, the star's internal nuclear fires become increasingly unstable, sometimes burning furiously and at other times dying down.

(B) If a white dwarf is close enough to a companion star, its gravity may drag matter from the outer layers of that star onto itself, building up its surface layer.

(C) Not all of this material ends up as part of a star — the remaining dust can become planets, asteroids, or comets, or may remain as dust.

(D) Hypergiants release hundreds of thousands of times more energy than the Sun, but have lifetimes of only a few million years.

3 The CENTRAL idea of the article is developed by:

(A) explaining the heavy elements that come from stars

(B) describing the physical characteristics of a star

(C) describing how a star influences other objects in space

(D) explaining the birth, life and death of a star

4 Which of the following selections from the article is MOST important to the development of the MAIN idea of the article?

(A) Known as a protostar, it is this hot core at the heart of the collapsing cloud that will one day become a star.

(B) In general, the larger a star, the shorter its life, although all but the most massive stars live for billions of years.

(C) Stars that fuse hydrogen to form helium are called main sequence stars, and they make up 90 percent of the stars in the universe.

(D) For average stars like the sun, the process of ejecting its outer layers continues until the core is exposed.