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The Life Cycle and Classification of Stars

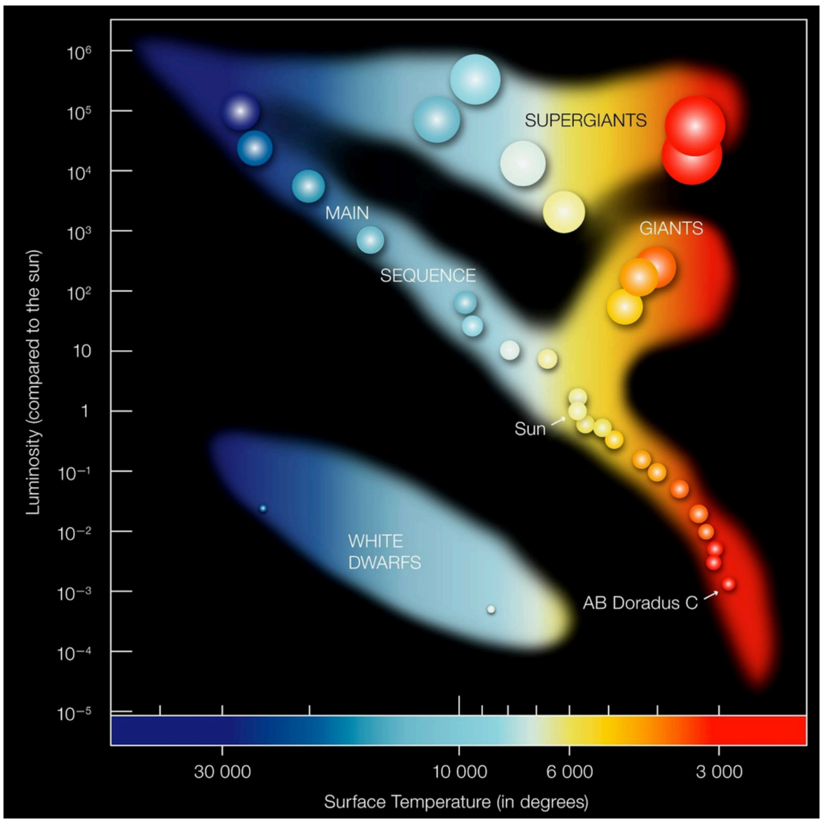
On a clear night, the sky above us fills with thousands of tiny points of light. For most of human history, these stars seemed mysterious and unchanging. Today, however, scientists know that each of those distant lights is a massive object with its own story; one that includes a birth, a life, and eventually a dramatic ending.

When you look up at the night sky, billions of stars shine back at you. Our Sun is just one of those stars, but many, like our Sun, lie at the center of their own ***planetary systems***.

Although it is estimated that there are 200 billion trillion (yes, that’s a real number!) stars in the Universe, all that we see from Earth are located within the Milky Way Galaxy.

To understand where these stars exist, we first need to understand the structure they live in- the galaxy. A galaxy is a massive structure consisting of stars, planets, and vast clouds of gas and dust, all bound together by gravity. The Milky Way Galaxy, in which our solar system lies, is just one of an estimated two trillion galaxies in the ***observable universe***. Estimates on how many stars exist within the Milky Way lie between 100 billion and 400 billion, and it is only these stars that we can see in the sky above us.

Even within our own galaxy, these stars are incredibly diverse. They vary in size, temperature, brightness, and lifespan. Because of this diversity, scientists have developed ways to classify stars and understand their life cycles. One of the most important tools astronomers use to do this is the Hertzsprung-Russell diagram. To organize what they knew about stars between 1910 and 1913, Danish astronomer Ejnar Hertzsprung and American astronomer Henry Norris Russell created the Hertzsprung-Russel diagram.



Hertzsprung-Russell Diagram; Image Credit: European Southern Observatory (ESO)

But before we learn about how stars are classified, let’s first talk about what a star is.

To begin, a star is a massive sphere of hot gas, or ***plasma***, held together by gravity and fueled by a process called ***nuclear fusion***. Through nuclear fusion, stars convert hydrogen into helium, producing energy. This process releases heat and light out into the universe.

A single star can remain stable for billions of years due to gravity pulling inward and energy pushing outward. This balance of forces allows a star to keep its shape and continuously fuel itself.

However, not all stars are the same. Some are hot and bright, while others are cool and faint.

The Hertzsprung-Russell Diagram Explained

Astronomers often classify stars based on two main categories: temperature and ***luminosity***. It is these two categories that intersect on the Hertzsprung-Russell diagram.

A star’s temperature is measured from its surface. Scientists do this by observing the star through a telescope to see what color of light is coming from the star. A star’s color can tell a scientist how hot or cold the star is. Based on decades of observations, astronomers rank stars from hottest to coolest using the following formula:

The hottest stars in the universe emit blue light, while the coolest stars emit red. Our Sun is a yellow star, also known as a ***yellow dwarf***, and lies in the middle of the temperature range.

The second factor, luminosity, is a star’s ***true brightness***, or the total energy it produces. This is different from a star’s ***apparent brightness***, which is how bright it looks from Earth.

When astronomers plot temperature and luminosity together, a remarkable pattern appears.

Pause and Think:

How would you describe the difference between *true brightness* and *apparent brightness?*

On the Hertzsprung-Russell diagram, the horizontal axis represents temperature (hot to cool), and the vertical axis represents luminosity. However, the temperature scale on the H-R diagram works differently from most graphs. Instead of increasing from left to right, temperature actually decreases from left to right. This means the hottest stars appear on the left side of the diagram, while the coolest stars appear on the right.

There are three main regions on the H-R diagram: *Main Sequence, Giants and Supergiants, and White Dwarfs.*

The Main Sequence, which appears as a long, twisted band stretching from the upper left to the bottom right of the diagram is where most stars in the observable universe are found. A star located within the Main Sequence is at the most stable and longest period of its life. Our Sun is a Main Sequence star, having completed only half of its ten-billion-year life cycle.

Next, in the upper right corner of the diagram lie the giants and supergiants. These stars are the largest and brightest stars in the universe. However, they are also the coolest. This is because their heat is dispersed across a much larger surface area. Adversely, smaller, denser stars burn hotter because of a smaller surface area.

Finally, in the bottom left corner of the diagram, lie the white dwarfs. These stars are small and very dense. They are extremely hot yet faint.

The position of a star on the Hertzsprung-Russell diagram can tell astronomers what stage of life a star is in. To understand why stars appear in different regions of the diagram, we need to look at how stars form and evolve over time.

The Life Cycle of A Star: Birth

A star begins as a nebula - a vast cloud of gas and dust in space. At one point, gravity causes the nebula to collapse into what is known as a ***protostar***. At this point, 99% of the material from the nebula forms into a hot, dense ball in the center, while the remaining 1% scatters around the ball in a disk-shaped debris field. As the temperature of the material in the center rises, nuclear fusion begins, and the newly-birthed star becomes a Main Sequence star.

Life on the Main Sequence

A star spends most of its life in the Main Sequence phase. This phase begins the moment nuclear fusion begins turning hydrogen into helium and can last billions of years.

A star’s mass determines its life. Massive stars burn fuel quickly, causing shorter life spans, while smaller stars burn fuel more slowly, allowing them to survive longer. On the Hertzsprung-Russell diagram, large, hot stars can be found in the upper left, while small, cool stars appear in the lower right.

Due to limitations in our current technology, the Sun is the only star close enough for us to study and, because it is a Main Sequence star, we know more about this period of a star’s life than any other. Despite this, there is still much about stars that we do not yet understand.

Pause and Think:

Why might a larger star burn through its fuel faster than a smaller star?

The Death of A Star

By tracing where stars appear on the H-R diagram, astronomers can follow their entire life story, from birth to death.

As a star nears the end of its Main Sequence phase, its hydrogen supply begins to run out. The core collapses, and what happens next depends largely on the star’s mass.

A low-mass star will expand until it becomes a giant or a supergiant. Eventually, all the outer layers of the star will blow away, and from this material will be born a new planetary nebula. Once the star’s outer layers have been shed, all that remains is a hot, dense core called a white dwarf. This will be the fate of our Sun in approximately 5 billion years (NASA, 2025).

Massive stars, however, experience a more violent and dramatic death. As the star’s core collapses, an extreme amount of pressure builds up. Finally, the pressure becomes too much, and the star explodes, violently, becoming what is known as a ***supernova***. The core of the star survives but is so dense that it becomes a ***black hole*** or a ***neutron star*** (NASA, 2025). These celestial objects do not appear in the Hertzsprung-Russell diagram because they are no longer stars; they are simply remnants.

Reading the Life Cycle on the H-R Diagram

The Hertzsprung-Russell diagram has been an invaluable tool in the astronomer’s tool belt. With it, astronomers can classify newly-discovered stars and estimate size, temperature, and stage of life. In other words, the H-R diagram acts as a map of stellar evolution. The diagram shows us that each star has a beginning, a life, and an ending. It reveals the hidden patterns behind the night sky, where entire planetary systems are birthed and ended, in a seemingly endless cycle.

Our Sun is just one star currently living its Main Sequence life, but one day, long after we are gone, it too will meet its end.

Final Question:

What do you think will happen to Earth when the Sun dies out?

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