The Life Cycles of Stars

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I. Star Birth and Life

Imagine an enormous cloud of gas and dust many light-years across. Gravity, as it always does, tries to pull the materials together. A few grains of dust collect a few more, then a few more, then more still. Eventually, enough gas and dust has been collected into a giant ball that, at the center of the ball, the temperature (from all the gas and dust bumping into each other under the great pressure of the surrounding material) reaches 15 million degrees or so. A wondrous event occurs.... nuclear fusion begins and the ball of gas and dust starts to glow. A new star has begun its life in our Universe.

So what is this magical thing called "nuclear fusion" and why does it start happening inside the ball of gas and dust? It happens like this..... As the contraction of the gas and dust progresses and the temperature reaches 15 million degrees or so, the pressure at the center of the ball becomes enormous. The electrons are stripped off of their parent atoms, creating a plasma. The contraction continues and the nuclei in the plasma start moving faster and faster. Eventually, they approach each other so fast that they overcome the electrical repulsion that exists between their protons. The nuclei crash into each other so hard that they stick together, or *fuse*. In doing so, they give off a great deal of energy. This energy from fusion pours out from the core, setting up an outward pressure in the gas around it that balances the inward pull of gravity. When the released energy reaches the outer layers of the ball of gas and dust, it moves off into space in the form of electromagnetic radiation. The ball, now a star, begins to shine.

New stars come in a variety of sizes and colors. They range from blue to red, from less than half the size of our Sun to over 20 times the Sun's size. It all depends on how much gas and dust is collected during the star's formation. The color of the star depends on the surface temperature of the star. And its temperature depends, again, on how much gas and dust were accumulated during formation. The more mass a star starts out with, the brighter and hotter it will be. For a star, everything depends on its mass.

Throughout their lives, stars fight the inward pull of the force of gravity. It is only the outward pressure created by the nuclear reactions pushing away from the star's core that keeps the star "intact". But these nuclear reactions require fuel, in particular hydrogen. Eventually the supply of hydrogen runs out and the star begins its demise.

II. Beginning of the End

After millions to billions of years, depending on their initial masses, stars run out of their main fuel - hydrogen. Once the ready supply of hydrogen in the core is gone, nuclear processes occurring there cease. Without the outward pressure generated from these reactions to counteract the force of gravity, the outer layers of the star begin to collapse inward toward the core. Just as during formation, when the material contracts, the temperature and pressure increase. This newly generated heat temporarily counteracts the force of gravity, and the outer layers of the star are now pushed outward. The star expands to larger than it ever was during its lifetime — a few to about a hundred times bigger. The star has become a red giant.

What happens next in the life of a star depends on its initial mass. Whether it was a "massive" star (some 5 or more times the mass of our Sun) or whether it was a "low or medium mass" star (about 0.4 to 3.4 times the mass of our Sun), the next steps after the red giant phase are very, very different.

III. The End

A. The Fate of Sun-Sized Stars: Black Dwarfs

Once a medium size star (such as our Sun) has reached the red giant phase, its outer layers continue to expand, the core contracts inward, and helium atoms in the core fuse together to form carbon. This fusion releases energy and the star gets a temporary reprieve. However, in a Sun-sized star, this process might only take a few minutes! The atomic structure of carbon is too strong to be further compressed by the mass of the surrounding material. The core is stabilized and the end is near.

The star will now begin to shed its outer layers as a diffuse cloud called a planetary nebula. Eventually, only about 20% of the star's initial mass remains and the star spends the rest of its days cooling and shrinking until it is only a few thousand miles in diameter. It has become a white dwarf. White dwarfs are stable because the inward pull of gravity is balanced by the electrons in the core of the star repulsing each other. With no fuel left to burn, the hot star radiates its remaining heat into the coldness of space for many billions of years. In the end, it will just sit in space as a cold dark mass sometimes referred to as a black dwarf.

B. The Fate of Massive Stars: Supernovae! and Then...

Fate has something very different, and very dramatic, in store for stars which are some 5 or more times as massive as our Sun. After the outer layers of the star have swollen into a red supergiant (i.e., a very big red giant), the core begins to yield to gravity and starts to shrink. As it shrinks, it grows hotter and denser, and a new series of nuclear reactions begin to occur, temporarily halting the collapse of the core. However, when the core becomes essentially just iron, it has nothing left to fuse (because of iron's nuclear structure, it does not permit its atoms to fuse into heavier elements) and fusion ceases. In less than a second, the star begins the final phase of its gravitational collapse. The core temperature rises to over 100 billion degrees as the iron atoms are crushed together. The repulsive force between the nuclei overcomes the force of gravity, and the core recoils out from the heart of the star in an explosive shock wave. As the shock encounters material in the star's outer layers, the material is heated, fusing to form new elements and radioactive isotopes. In one of the most spectacular events in the Universe, the shock propels the material away from the star in a tremendous explosion called a supernova. The material spews off into interstellar space — perhaps to collide with other cosmic debris and form new stars, perhaps to form planets and moons, perhaps to act as the seeds for an infinite variety of living things.

So what, if anything, remains of the core of the original star? Unlike in smaller stars, where the core becomes essentially all carbon and stable, the intense pressure inside the supergiant causes the electrons to be forced inside of (or combined with) the protons, forming neutrons. In fact, the whole core of the star becomes nothing but a dense ball of neutrons. It is possible that this core will remain intact after the supernova, and be called a neutron star. However, if the original star was very massive (say 15 or more times the mass of our Sun), even the neutrons will not be able to survive the core collapse and a black hole will form!

IV. More about the Stellar Endpoints

A. White/Black Dwarfs

A star like our Sun will become a white dwarf when it has exhausted its nuclear fuel. Near the end of its nuclear burning stage, such a star expels most of its outer material (creating a planetary nebula) until only the hot ($T > 100{,}000$ K) core remains, which then settles down to become a young white dwarf. A typical white dwarf is half as massive as the Sun, yet only slightly bigger than the Earth. This makes white dwarfs one of the densest forms of matter, surpassed only by neutron stars.

White dwarfs have no way to keep themselves hot (unless they accrete matter from other closeby stars); therefore, they cool down over the course of many billions of years. Eventually, such stars cool completely and become black dwarfs. Black dwarfs do not radiate at all.

Many nearby, young white dwarfs have been detected as sources of soft X-rays (i.e. lower-energy X-rays); soft X-ray and extreme ultraviolet observations enable astronomers to study the composition and structure of the thin atmospheres of these stars.

B. Neutron Stars

Neutron stars are typically about ten miles in diameter, have about 1.4 times the mass of our Sun, and spin very rapidly (one revolution takes mere seconds!). Neutron stars are fascinating because they are the densest objects known. Due to its small size and high density, a neutron star possesses a surface gravitational field about 300,000 times that of Earth.

Neutron stars also have very intense magnetic fields - about 1,000,000,000,000 times stronger than Earth's. Neutron stars may "pulse" due to electrons accelerated near the magnetic poles, which are not aligned with the rotation axis of the star. These electrons travel outward from the neutron star, until they reach the point at which they would be forced to travel faster than the speed of light in order to still co-rotate with the star. At this radius, the electrons must stop, and they release some of their kinetic energy in the form of X-rays and gamma-rays. External viewers see these pulses of radiation whenever the magnetic pole is visible. The pulses come at the same rate as the rotation of the neutron star, and thus, appear periodic. Neutron stars which emit such pulses are called pulsars.

C. Black Holes

Black holes are objects so dense that not even light can escape their gravity and, since nothing can travel faster than light, nothing can escape from inside a black hole. Nevertheless, there is now a great deal of observational evidence for the existence of two types of black holes: those with masses of a typical star (4-15 times the mass of our Sun), and those with masses of a typical galaxy. This evidence comes not from seeing the black holes directly, but by observing the behavior of stars and other material near them!

Galaxy-mass black holes are found in Active Galactic Nuclei (AGN). They are thought to have the mass of about 10 to 100 billion Suns! The mass of one of these supermassive black holes has recently been measured using radio astronomy. X-ray observations of iron in the accretion disks may actually be showing the effects of massive black holes as well.

The Electromagnetic Spectrum as a Probe of the Universe

All objects in our Universe emit, reflect, and absorb electromagnetic radiation in their own distinctive ways. The way an object does this provides it special characteristics which scientists can use to probe an object's composition, temperature, density, age, motion, distance, and other chemical and physical characteristics. Astronomers can time events (for instance, recording exactly when a binary star system is eclipsed and for how long), can obtain the energy distribution of a source (by passing its electromagnetic radiation through a prism or grating to break it into component colors), or can record the appearance of a source (such as taking an image of the source). These three methods are by no means exclusive of each other, but each reveals different aspects of a source and each method gives the astronomer slightly different information.

While the night sky has always served as a source of wonder and mystery, it has only been in the past few decades that we have had the tools to look at the Universe over the entire electromagnetic (EM) spectrum and see it in all of its glory. Once we were able to use space-based instruments to examine infrared, ultraviolet, X-ray, and gamma-ray emissions, we found objects that were otherwise invisible to us (e.g., black holes and neutron stars). A "view from space" is critical since radiation in these ranges cannot penetrate the Earth's atmosphere. Many objects in the heavens "light up" with wavelengths too short or too long for the human eye to see, and most objects can only be fully understood by combining observations of behavior and appearance in different regions of the EM spectrum.

We can think of electromagnetic radiation in several different ways:

- From a physical science standpoint, all electromagnetic radiation can be thought of as originating from the motions of atomic particles. Gamma-rays occur when atomic nuclei are split or fused. X-rays occur when an electron orbiting close to an atomic nucleus is pushed outward with such force that it escapes the atom; ultraviolet, when an electron is jolted from a near to a far orbit; and visible and infrared, when electrons are jolted a few orbits out. Photons in these three energy ranges (X-ray, UV, and optical) are emitted as one of the outer shell electrons loses enough energy to fall down to the replace the electron missing from the inner shell. Radio waves are generated by any electron movement; even the stream of electrons (electric current) in a common household wire creates radio waves ...albeit with wavelengths of hundreds of kilometers and very weak in amplitude.

Electromagnetic radiation can be described in terms of a stream of photons (massless packets of energy), each traveling in a wave-like pattern, moving at the speed of light. The only difference between radio waves, visible light, and gamma-rays is the amount of energy in the photons. Radio waves have photons with low energies, microwaves have a little more energy than radio waves, and infrared has still more, then visible, ultraviolet, X-rays, and gamma-rays. By the equation $E = h\nu = hc/\lambda$, energy dictates a photon's wavelength and frequency.

Conclusion: The human life given to us is an effect of cosmology or GOD , or something which is beyond our perception. The world has to be explored to understand the mysteries and this may lead us to understand the mind of CREATION.

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