DOCUMENT RESUME

ED 260 910 SE 045 945

TITLE Lifestyles of the Stars.
INSTITUTION National Aeronautics and Space Administration, Cocoa Beach, Fla. John F. Kennedy Space Center.
PUB DATE 85
NOTE 9p.
PUB TYPE Guides - General (050)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Astronomy; Earth Science; *Science Education; Secondary Education; Secondary School Science; Space Sciences
IDENTIFIERS *Black Holes; *Stars

ABSTRACT

Some general information on stars is provided in this National Aeronautics and Space Administration pamphlet. Topic areas briefly discussed are: (1) the birth of a star; (2) main sequence stars; (3) red giants; (4) white dwarfs; (5) neutron stars; (6) supernovae; (7) pulsars; and (8) black holes. (JN)

Lifestyles of the Stars

The ability to place scientific instruments above the obscuring effects of the atmosphere has opened up so many new areas of study the collective effort is often called the "new astronomy." Radiation at energy levels higher than those of visible light penetrates the atmosphere poorly, or not at all. Many of the more interesting discoveries in modern astronomy are being made at these high energies, in the X-ray, gamma ray, and cosmic ray regions of the electromagnetic spectrum. Many fascinating new objects are being discovered. Others predicted by novel recent theories on the life cycles of stars are being sought, and found. These recent large increases in knowledge have led to new and fascinating theories on the highly varying life cycles of different types of stars.

Star Birth

Stars are believed to originate by the condensation of enormous clouds of cosmic dust and hydrogen gas; the latter is the lightest and most plentiful of the elements. There are many such clouds in our universe.

The motivating force behind the birth of a star is gravity. According to Newton's law of gravity, all bodies in the universe attract each other, in proportion to their mass and distance apart. The gas and dust particles in these vast interstellar clouds attract each other, and gradually draw closer together. Eventually, enough particles coalesce to form a clump which is massive enough that all parts are bound to each other by gravitation. At this point the edges of the cloud begin to collapse inward, separating it from the remaining gas and dust in the vicinity.

At first the cloud contracts rapidly, because the heat released by contraction is easily radiated outward. Then the cloud grows smaller and more dense, so that heat created at the center cannot immediately escape to the exterior. This causes a rapidly rising internal temperature, slowing down but not stopping the constant contraction.

At a certain point the interior of the star becomes so dense, and its temperature so high, that thermonuclear fusion begins. This is the actual "birth" of the star. In thermonuclear fusion two atoms of hydrogen are converted into one atom of helium, the second lightest element. Radiant energy is released in the process. The heat generated by nuclear fusion is greater than that produced by gravitation, and becomes the primary source of the cloud's energy. Gases heated by nuclear fusion at the cloud's center begin to rise, counterbalancing the inward pull of gravity on the outer layers. The star stops collapsing, and reaches a state of equilibrium between outward and inward pressures. It is now what astronomers call a main sequence star, like our own Sun. It will remain at this stage of its evolution for billions of years, until all of its readily available hydrogen has been converted into helium.

Are stars still being born today? Astronomers studying dense interstellar clouds with infrared telescopes have discovered an abundance of glowing objects, hidden from optical telescopes by the surrounding dust and gas. Since collapsing clouds radiate in the infrared until nuclear fusion begins, these are assumed to be developing stars.

Main Sequence Stars

How long a star remains on the main sequence, burning hydrogen for its fuel, depends largely on its mass. Our Sun has an estimated main sequence lifetime of about ten billion years, of which approximately five billion have now passed. Larger stars burn faster and hotter, and have main sequence lifetimes of as little as a million years. At some point all stars undergo major changes in their size and composition, with life cycles determined primarily by their original mass.

Red Giants

When the hydrogen fuel in a star's core has been consumed, the core starts to collapse. At the same time the hydrogen fusion process moves outward from the core into the surrounding regions, continuing the process of converting hydrogen into helium and releasing radiant energy.

The intense heat of the nuclear reactions now occurring in a shell around the core causes the star's outer envelope to expand. As they move further from the center the outer layers cool, and the star's surface changes from white to red. When this happens to our Sun it will grow into a vast sphere, engulfing Mercury and Venus, and possibly Earth and Mars. It will then be a red giant.

As the star grows the contracting core may become so hot that it ignites and burns nuclear fuels other than hydrogen, beginning with the helium already created. The subsequent behaviour of such a star is complex, but in general it can be characterized as a continuing series of gravitational contractions and new nuclear ignitions. Each new series produces a succession of heavier elements, in addition to releasing energy. For example, the burning of helium produces carbon, and then the burning of carbon produces oxygen.

The number of available nuclear fuels is limited, and the star cannot indefinitely continue making heavier elements and then consuming them to make still heavier ones. Eventually, the star must undergo a great transformation. Depending on its mass, it may finally become a White Dwarf, a Neutron Star, or a Black Hole.

White Dwarfs

When it has burned all the nuclear fuels available to it, a star like our Sun contracts to a white hot sphere as small as a planet. This is the fate believed to await most stars. Such an object is called a White Dwarf. Its atoms are packed so tightly together that a fragment the size of a sugar cube would weigh thousands of kilograms. Over several more billion years, the White Dwarf cools and gradually turns into a black cinder. This is the future for our Sun, and the majority of all other stars.

Neutron Stars

In a star more than about 1½ times the mass of the Sun, gravitational forces are so great that they overcome the collective electron pressure which halts the collapse of smaller stars. The compression of the core may continue until its density is so high that its electrons are driven into the atomic nuclei, which are thereby transmuted into neutrons. In effect this creates an atomic nucleus of astronomical proportions – a neutron star.

A neutron star may be as small as 20 kilometers (12 miles) in diameter, but have a density billions of times that of lead. A cubic centimeter would weigh billions of kilograms. This is because all space between the parts of each atom, and between adjacent atoms in each molecule, has been eliminated. In normal matter these atomic parts occupy only a small portion of the space in which they exist. An often-used analogy compares our Sun to the nucleus of an atom and the planets to electrons circling around it. The volume occupied by the Sun and all the planets is a very minute percentage of the total amount of space involved.

Most astronomers today associate the astronomical phenomena called supernovae and pulsars with neutron stars and their evolution.

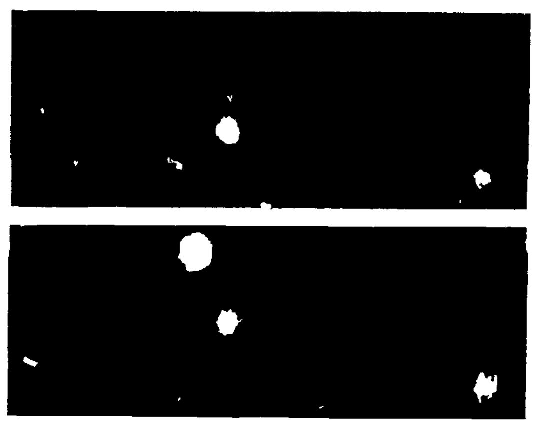
Supernovae

The final collapse of a star to the neutron stage may give rise to physical conditions that cause its outer portions to explode, producing a supernova. Such an explosion can produce so much energy the supernova will temporarily outshine all the hundreds of millions of ordinary in a galaxy.

A regular nova, which occurs more frequently, is far less violent and spectacular. One common class, called recurrent novae, is due to the nuclear ignition of gas being drawn from a companion star to the surface of a White Dwarf. Such binary systems, where two stars revolve around each other, are quite common, and sometimes they will have orbits that regularly bring them close enough for one to attract gas from the other.

When a supernova occurs the explosion fills vast regions of space with matter which may radiate energy (including visible light) for hundreds or even thousands of years. This matter leaves the parent star with such tremendous force that it is not likely ever to be drawn back to it, unlike the smaller novae. An example of a supernova explosion is the Crab Nebula, which is illustrated here.

The debris created by a supernova explosion will eventually cool into dust and gas again, become part of an interstellar cloud, and may once more be condensed into a star. Most of the heavier elements found on Earth are believed to have originated in supernova explosions, since the normal nuclear processes in a star cannot produce them. The terrible power of the supernova explosion, however, can combine lighter elements into the heaviest ones found in nature. Therefore both our Sun and its planets may have formed out of clouds enriched by infusions of materials from some ancient supernova explosion.



A pulsar so dim it is hardly visible (top) and at maximum brightness (bottom).
Courtesy of Lick Observatory

Pulsars

The pulsar, which was discovered by radio astronomers and so named because its radio signal regularly turns off and on (or pulses), is thought to be a rapidly spinning neutron star. A pulsar may also give off energy at X-ray and other wavelengths. It is not likely that a pulsar actually turns its radiation on and off. Scientists believe it more likely the energy is emitted from a point on the star that faces toward and then away from Earth as the star spins, so that we receive the signal for only a small part of each revolution.

One pulsar is located in the center of the Crab Nebula, where the vast cloud of gas is still glowing from the heat produced by the original explosion. Both the pulsar and nebula are remnants of the supernova of 1054, which was observed and recorded by ancient Chinese astronomers.

Crab Nebula courtesy of the Hale Observatories

Black Holes

Physicists believe that if a star has more than about three times the mass of our Sun, its fate at the end of the gravitational collapse and nuclear burning cycle is to become that strange oddity called a "black hole." A large dying star shrinks into such incredible density that its gravity becomes so great in proportion to its size that nothing, not even light, can escape its surface. Therefore it literally becomes a "black hole" in space. Any matter or light that approaches such a star is sucked downward to its surface and vanishes.

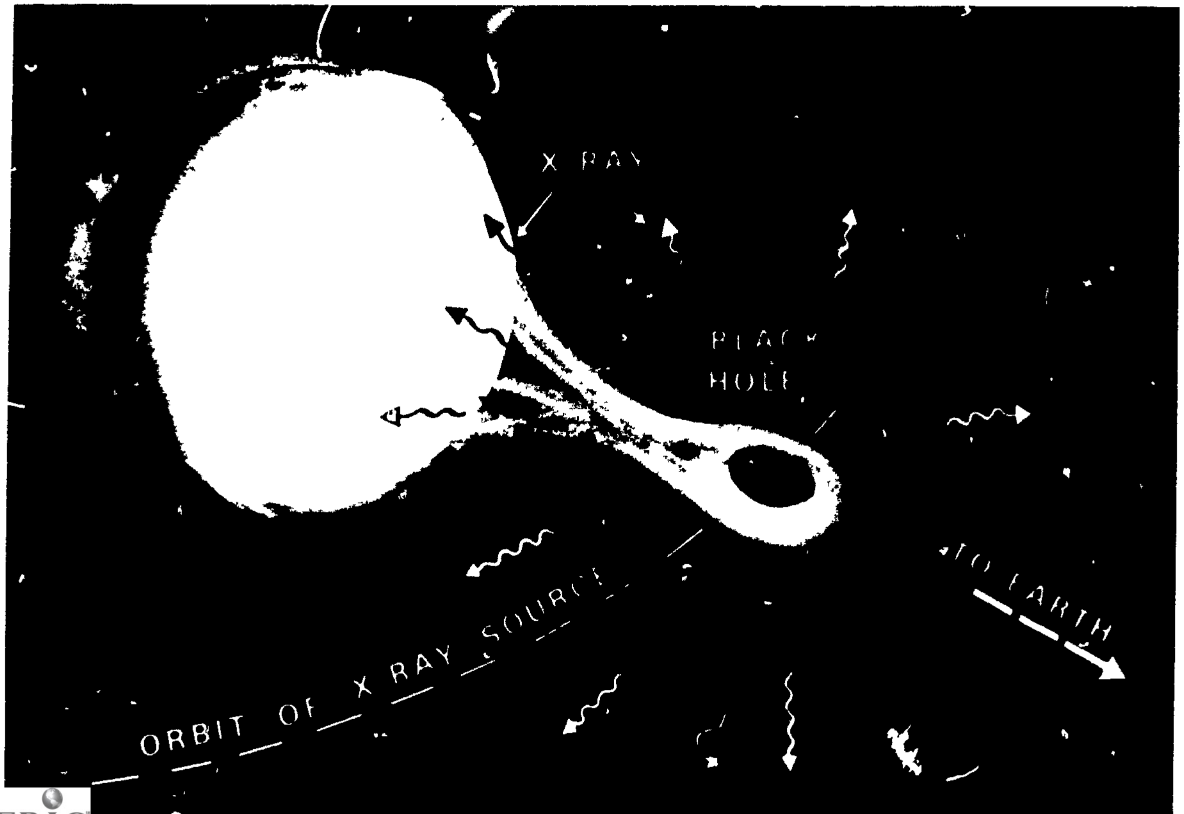
A black hole is invisible by its nature, but may sometimes be detected by indirect means. If it is a partner in one of the common binary systems, its gravity will affect the path of the companion star about which it orbits. A study of the movements of the visible star would reveal the influence of an invisible companion. If the two pass relatively close to each other in their orbits, a substantial amount of gas from the visible star may regularly be pulled into the black hole. Theorists believe that in the process some of this matter would be converted into soft X-rays, hard X-rays, and gamma rays. These would be radiated into space before the matter reaches the point of no return, and could be detected.

In November 1973, a team of astronomers at London's University College reported a powerful X-ray source of the type described above, called Cygnus X-1.[1] The data they analyzed was obtained by an X-ray experiment aboard NASA's Orbiting Astronomical Observatory-3 (named Copernicus, after the great Polish astronomer). The astronomers concluded the X-ray source was a black hole.

The London team identified Cygnus X-1 with the binary supergiant star system HDE (for Henry Draper Extension catalog) 226868, which is in our Milky Way galaxy, some 8,000 light years[2] from Earth. Optical observations indicate that the system consists of a visible star thirty times as massive as our Sun, and an invisible companion.

[1]An X-ray source is defined as a celestial phenomenon that radiates more X-rays than any other form of electromagnetic radiation, including visible light, infrared rays, gamma rays, ultraviolet light, or radio waves. X-rays are only a small part of the electromagnetic radiation of normal stars, such as our Sun. Cygnus X-1 is so named because it is the first X-ray source discovered in the constellation Cygnus, the Swan.

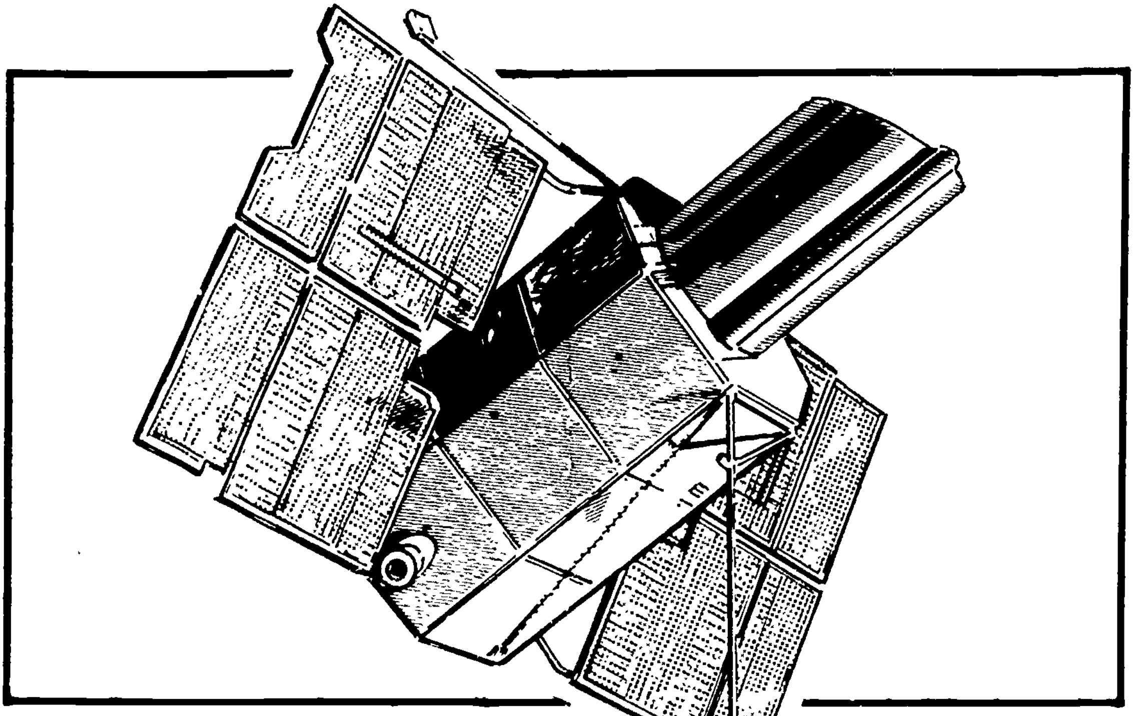
[2]A light year is the distance that light, traveling at 186,000 miles per second, moves in one year; about 9.6 trillion kilometers, or 6 trillion miles.



According to the astronomers, vast clouds of matter are flowing from the visible star to its invisible companion. A good part of this matter is being converted into the predicted X-rays, which are being detected here.

As further evidence, the data from Copernicus show interruptions in the soft X-ray emissions from the system that apparently coincide with the time intervals when the visible star would be in front of the black hole, relative to Earth. Such soft X-rays would be absorbed by the atmosphere of the visible star. Hard X-rays, however, would penetrate the star's atmosphere and still reach Earth. This is in fact what seems to be happening.

Furthermore, by analyzing the gradual cut-off of the soft X-ray emissions, and the time at which they reappear, the astronomers were able to estimate the unseen object's size. It is about one ten-thousandth that of our Sun. By calculating in detail how the gravity of Cygnus X-1 affects the visible star, the astronomers determined that the mass of X-1 is about six times that of our Sun. This



mass exceeds the theoretically predicted limits for a stable neutron star.

In summary, the invisibility of Cygnus X-1, its great mass, small size, and the hard and soft X-rays streaming from surrounding matter, all support the conclusion it is a black hole. The scientists theorize that in time it may completely swallow its visible companion, leaving no trace of the existence of either.

Cygnus X-1 has been the most extensively studied possible black hole, but in 1978 Copernicus located a second candidate, in the constellation Scorpio. The International Ultraviolet Explorer satellite, launched in 1978, soon located a third black hole possibility, at the center of a globular cluster some 15,000 light years from Earth. These two objects are now under study.

The New Astronomy

New instruments that operate above the atmosphere are bringing about changes …onomy as revolutionary as those wrought by Galileo, when he turned a telescope to the sky and for the first time far exceeded the resolving power of the human eye. (He was the first man to see the four largest moons of Jupiter, which are called the Galilean satellites in his honor.) The new astronomy is still in its infancy, and its significance cannot be fully determined at this time. Like all progress in knowledge, however, these advanced techniques for seeing into our universe will one day make their contribution to the benefit of mankind.

NASA

National Aeronautics and Space Administration

John F. Kennedy Space Center

☆U.S. G.P.O. 1985-547-127