

Burnout

New images from Hubble preview the death of our sun: swift, colorful, and surprisingly tempestuous

By Robert Kunzig

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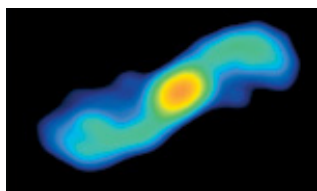
Time, even astronomical time, is made of moments. The universe began in a moment around 13.7 billion years ago. The sun was born in a moment some 4.6 billion years ago, when hydrogen atoms began fusing into helium. At another moment, some 5 billion years from now, the sun will exhaust its fuel and begin a slow death. Somewhere in the Milky Way galaxy, a star like our sun dies roughly every month. When that happens, it briefly exhales an extraordinarily beautiful, complex puff of gas known as a planetary nebula.



At the center of the Red Spider nebula lies a white dwarf that is nearly 1 million degrees Fahrenheit. A wind of fragmented atoms blows off it at millions of miles per hour. This star is a recent corpse: The surrounding gas, fluorescing and whipping into waves, was once the star's atmosphere but was cast off when fusion reactions stopped in its core. The nebula's spidery shape is a perspective illusion. "The 3-D structure is somewhat like an hourglass," says astronomer Garrett Mellema of Leiden University in the Netherlands.

Image Courtesy of ESA

The term is a misnomer: Observing a number of vaguely round, cloudlike objects in the sky during the late 18th century, Sir William Herschel thought they resembled faint planets. Planetary nebulas are the inevitable fate of the run-of-the-mill stars that account for more than 90 percent of the population of the Milky Way. Stars more than eight times as massive as our sun explode as brilliant supernovas, but such events happen just a few times a century in our galaxy. Planetary nebulas are the 15 minutes of fame granted to lesser stars.



Courtesy of NRAO/AUI/NSF



Courtesy of NASA/Hubble/STScI/Aura



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The Garden Sprinkler (center) is an aging star, not yet a white dwarf, that is shedding its atmosphere in pulsing jets, like the arcs of water that hang in the air as a lawn sprinkler twirls. K3-35, seen as a radio image (top left), also has precessing gas jets. The dark “patty” in Gomez’s Hamburger (top right) is a disk of dust that conceals a dying star; the “bun” is dust that reflects the hidden star’s light. In the Egg nebula (bottom right), high-speed jets from the central star have burst through another disklike cocoon of dust. The Calabash nebula (bottom left), illustrates what happens when high-speed winds of stellar gas (yellow) create shock waves as they ram into clouds of interstellar hydrogen and nitrogen (blue).

The death of a sunlike star was long thought to be a gentle, orderly process, every star more or less the same. But over the past decade, the Hubble Space Telescope-along with a group of powerful new observatories on the ground-has allowed astronomers to watch this dying stage with new understanding. “With the Hubble, we’ve been able to see things we simply couldn’t see before,” says C. Robert O’Dell of Vanderbilt University, who as project scientist oversaw the construction of the space telescope and has observed many nebulas with it since.

When a star runs out of hydrogen fuel in its center, the core contracts and heats up, inflating the star into a bloated red giant. The sun, in this phase, will reach past the orbit of Venus and may well engulf Earth. Meanwhile, the core becomes hot and dense enough to fuse helium, a flukier fuel. The star starts to pulse ominously. And over the next hundred thousand years, it blows most of its atmosphere off into space like so many smoke rings. What remains behind is a nearly naked core of carbon and oxygen, which collapses to form a white dwarf star, roughly the size of Earth but 100,000 times

as dense.

The dwarf is not hot enough to fuse carbon or oxygen, so it no longer burns like a star, but for a time it is still plenty hot enough-more than 50,000 degrees Fahrenheit-to expel the remnants of its atmosphere and to blast all that departed gas with ultraviolet light. The ultraviolet rays shred the molecules and atoms in the blown-off atmosphere, and that causes the gas to glow brightly. That glow is what we see as a planetary nebula.

By all rights, such a nebula should be spherical, like the original star itself. Some are: Abell 39, for instance. But look at some of the pictures made with the Hubble over the past decade and simple, glowing gas rings is not what you see. You see a Hamburger and a Garden Sprinkler. You see a Butterfly and an Ant. And inside some of the nebulas-the Helix or Eskimo, say-you see peculiar knots and clumps of gas that look like comets plunging in toward the star. A couple of longtime students of planetary nebulas, Bruce Balick of the University of Washington and Adam Frank of the University of Rochester, recently summed up the impact of the Hubble images. "Each new image was greeted with a combination of aesthetic delight and interpretive apprehension, if not terror," they wrote. Researchers who thought they had these nebulas figured out discovered how little they knew.

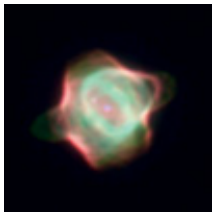


Courtesy NASA/Hubble/STScI/Aura

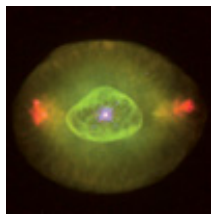
Menzel 3 looks like two comets colliding or like the head and thorax of an ant-hence its nickname, the Ant nebula-but astronomers say it is really two bubbles of gas expanding away from a central source. Each bubble is roughly 40,000 Earth-sun distances, or 3.7 trillion miles, long. The white spot at the center may be two stars locked in a tight orbit. One is probably a red giant that is still blowing off its atmosphere; the other is most likely a white dwarf stealing gas from its giant companion and lighting up the surrounding nebula. And somehow, two narrow jets of gas are streaming from this binary system at 200 to 300 miles per second or more, slamming into older, slower-moving clouds of star stuff. The shocked gas emits X rays that astronomer Joel Kastner recently detected using the orbiting Chandra X-ray Observatory. The jets seem to be inflating the bubbles, which are only a millennium old-a celestial moment. "Something has been going on very recently that has caused the jets to emerge," Kastner says. But what exactly that something might be is hidden within the white spot.

As Balick and Frank continue to struggle with what they're seeing, one thing has become clear about how stars die: Many perfectly ordinary ones do not go gently. As they near the end of their lives, they revert to the aggressive behavior they showed billions of years earlier in their vigorous youth. They emit focused jets of gas that travel at hundreds of miles per second. Those jets catch up with the more lazily drifting

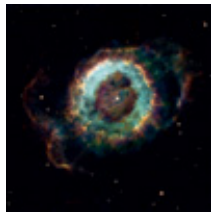
star smoke and knock it about, which may help explain the weird shapes.



Courtesy Matt Bobrowsky/
Orbital Sciences Corp/NASA

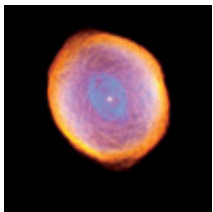


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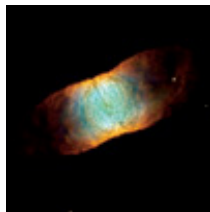


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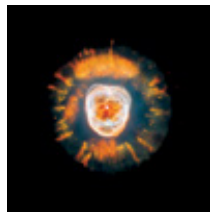
The Stingray nebula (left) is even younger than the Ant; its central star got hot enough to light up the surrounding gas and make it visible just within the past 25 years. The central star in the Blinking Planetary Nebula (middle) is shedding mysteriously bright clumps of gas, which glow red. The Little Ghost (right) is a more classic planetary nebula: Its doughnut is the steadily expanding ring of star gas that has been ionized and set aglow by ultraviolet light from the central white dwarf. (middle photo courtesy of Bruce Balick (University of Washington), Jason Alexander (University of Washington), Arsen Hajian (U.S. Naval Observatory), Yervant Terzian (Cornell University), Mario Perinotto (University of Florence, Italy), Patrizio Patriarchi (Arcetri Observatory, Italy), and NASA)



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The Spirograph nebula (left) contains enigmatic internal filaments. Similarly, the Retina nebula (middle), which is shaped like a doughnut seen from the side, exhibits light-absorbing dust and gas that have been swept into dense, dark lanes, seen silhouetted against the expanding doughnut of ionized gas. The Eskimo nebula (right) is older than the Retina, says astronomer C. Robert O'Dell. Here, the bright orange lanes have been whittled away by ultraviolet radiation from the star, turning them into knots with cometlike tails.

Those things that look like curved metal arms in the Garden Sprinkler are really pulsing jets of gas, emitted by some kind of nozzle close to the central star that is wobbling like the axis of a top, says Angels Riera of the Polytechnic University of Catalonia in Spain. The jets in another nebula, K3-35, are so powerful, reports Luis Miranda of Spain's Astrophysical Institute of Andalusia, that they are squashing clouds of water vapor at their tips, 450 billion miles from the star, and causing the water to mase-emit laserlike beams of microwaves. Water masers also line the jets that Hiroshi Imai of the Joint Institute for Very Long Baseline Interferometry in Europe has traced to W43A, a red giant that appears to be on the verge of shedding its atmosphere. In the Ant nebula, Joel Kastner, a young astronomer at the Rochester Institute of Technology, and his collaborators have mapped what seem to be X-ray-emitting jets that extend from the center of the nebula to the tips of its bizarre, bright lobes. "It looks like we're seeing the nozzles that are inflating the two bubbles," Kastner says.

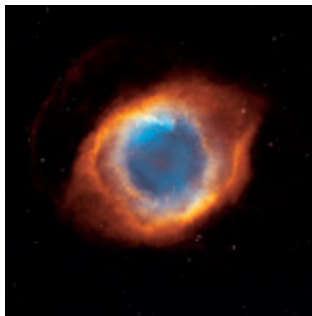
The nozzles themselves are hidden in the nebula's bright central blob of light. Whatever things are creating the jets, they are too small for even Hubble to pick out. Debate rages as to their nature. One possibility is that the central star is really two stars, one sucking an equatorial disk of matter out of the other, perhaps a white dwarf stealing from a distended red giant. As the space around the equator grows overcrowded, other stuff spewed by the dying giant would tend to get funneled into jets along the polar axis. Another possibility is that the central star has a powerful magnetic field that twists up into polar funnels as the star's interior gurgles to the surface and becomes exposed. Combinations of the two mechanisms are also possible.

Abell 39 is an ancient planetary nebula that has been spreading out for thousands of years. It now stretches six light-years across. Whatever violence it knew in its early years is long forgotten. The cloud is so diffuse that distant galaxies can be seen through it. Astronomers once would have called the orderly, spherical Abell 39 a textbook example of a planetary nebula—but the Hubble Space Telescope has forced scientists to rewrite the textbooks.



Courtesy of WIYN/NOAO/NSF

To O'Dell, who has been observing planetary nebulas for more than 40 years, all those beautiful shapes are a confounding diversion. "They're overly fascinating," he says. "They have such a wealth of detail. We can hope to understand the gross features, but the better we observe them, the more it seems there is an endless series of finer and finer problems. The challenge becomes to distinguish the important ones." He admits to being fascinated by the fine, comet-shaped knots recently observed inside the Helix nebula—they are clumps of molecular gas that escaped being ionized by the star's ultraviolet blast—but only because they relate to the big picture. Those blobs of dead star stuff may survive intact and become a part of the next generation of stars. "It's an ecological situation," O'Dell says.



Courtesy of NASA/Hubble/STScI



Courtesy of NASA/NOA/Hubble/STScI/NRAO



Courtesy of NASA/NOA/Hubble/STScI/NRAO

The Helix nebula (top), so near Earth it can be seen with binoculars, shows a late stage in the evolution of the cometlike knots present in some planetary nebulas. The knots, clearly shown in the Hubble close-ups (bottom left and right), are clumps of dust and molecular gas so dense that energetic radiation from the star swept by without shredding them. A typical one is larger than our solar system and weighs as much as Earth. “What we’re trying to figure out is whether they will survive,” says astronomer C. Robert O’Dell. If they do, the knots would most likely become a part of a very different kind of nebula, called a giant molecular cloud, that will eventually give birth to a new generation of stars.

Ecology is important, but so are the lives of individuals. The big picture is important, but so are the details. In stellar affairs, as in human ones, they help make the big picture interesting. The planetary nebula that Miranda has been observing, K3-35, may or may not reveal a general principle of star death-but he calculates that it was born no more than 20 years ago. In planetary nebulas, the timescale of astronomical moments intersects with the timescale of human ones. “Probably these jets will disappear in my lifetime,” says Imai, who is 32, talking about W43A, which could become a planetary nebula any day now. “If we don’t continue to observe it, we will miss that special moment.”