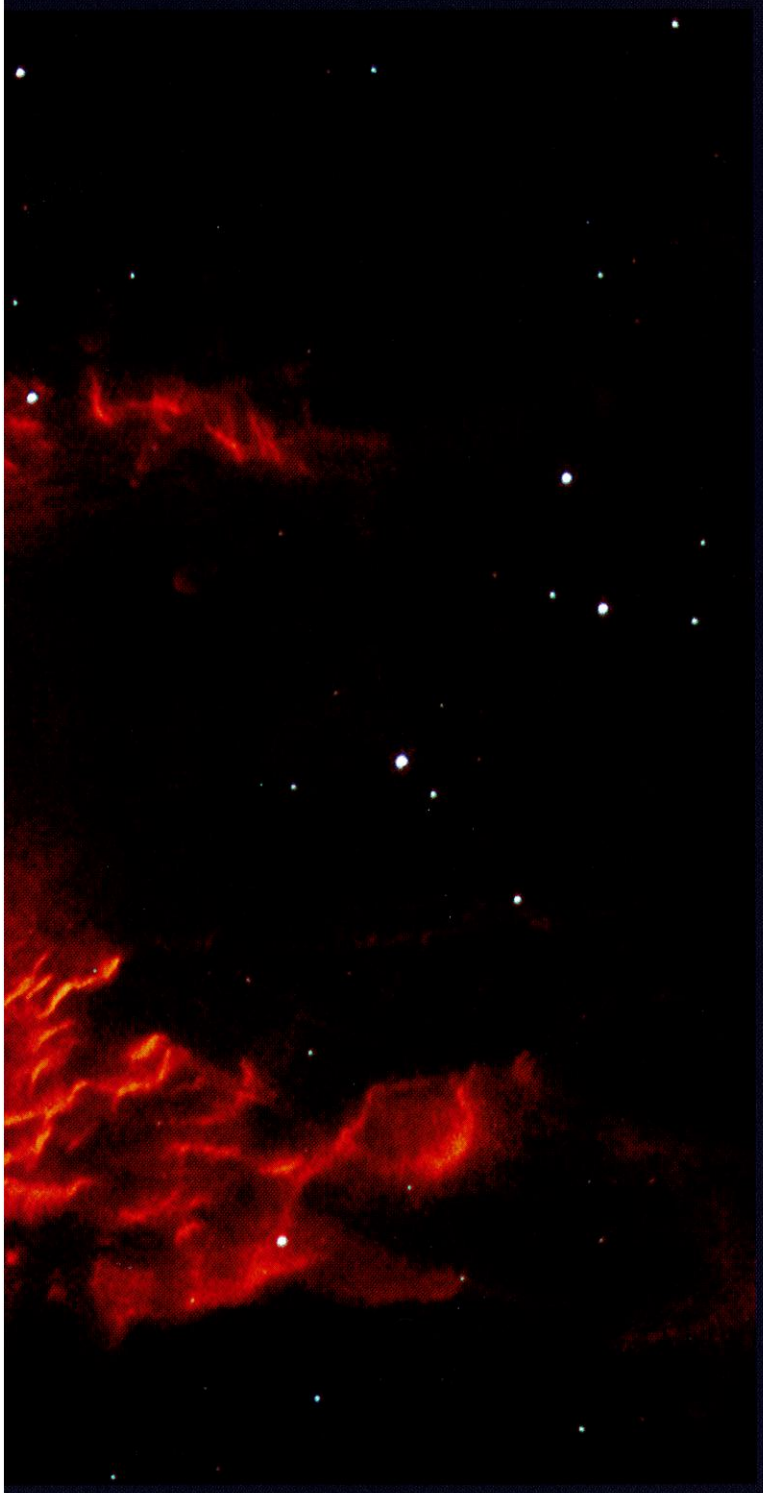
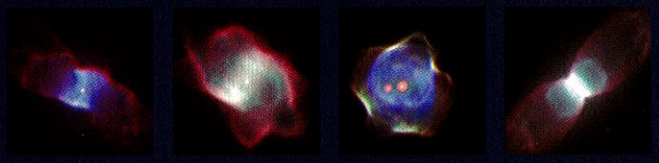
Butterflies

>> The windblown ripples of NGC 6537, a 12th-magnitude planetary nebula in Sagittarius, take on a butterfly shape in this dramatic image from the Hubble Space Telescope. Crablike claws extend more than 2 arcminutes from the unseen central star. Strong winds streaming outward at 2,000 to 4,500 kilometers per second sculpt the surrounding nebular gases and excite them to incandescence. Courtesy European Space Agency and Garrelt Mellema (Leiden University).

and Crabs of the Southern Sky



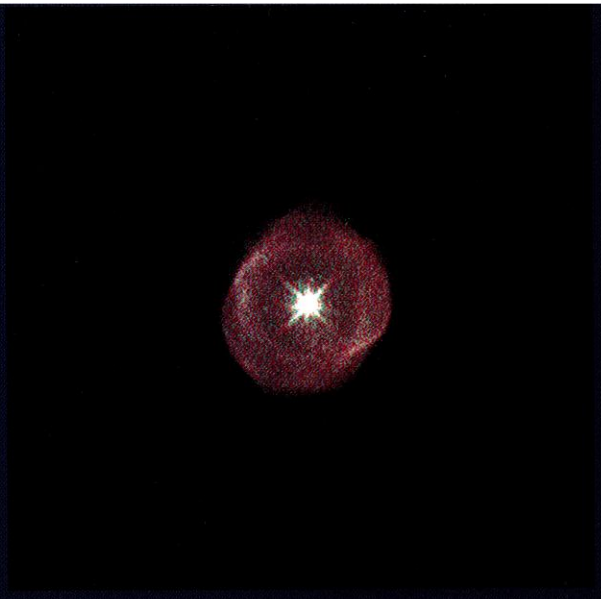
NO LONGER BORING ROUND BUBBLES, PLANETARY NEBULAE ARE CHALLENGING LONG-HELD NOTIONS OF STELLAR EVOLUTION.



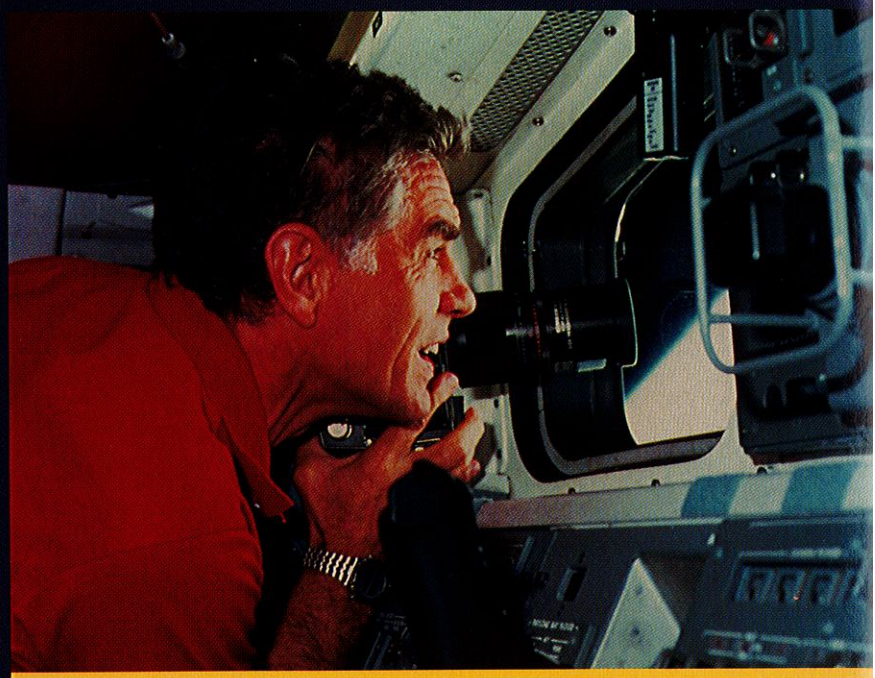
BY SUN KWOK

Of all the spectacles in our galaxy, few are as colorful or captivating as the ethereal bubbles of glowing gas known as planetary nebulae. Bright and easy to see, many rank among the most popular targets for telescopic observers at all levels. Yet planetary nebulae have nothing at all to do with planets — William Herschel coined the term because through his telescopes they had much the same size, shape, and color as Uranus, the planet he discovered in 1781. And even though Herschel soon convinced himself that they were actually globs of incandescent gas, the misnomer stuck.

Although the nature of planetary nebulae was not understood for almost 200 years, we now realize that these glowing clouds have been ejected by red-giant stars nearing the ends of their lives (see the diagram on page 53). The process begins as the red giant sheds its atmosphere into space, creating a broad, diffuse cloud of matter. Eventually the star's outer layers completely dissipate, exposing its core. The stellar winds, now energized by light pressure from the hot core, race away at much greater speed and plow into the slower, outer envelope. The light we see marks the pileup zone.



^^ To ground-based telescopes, He2-131 in the southern constellation Apus appears completely starlike. But when viewed by the Hubble Space Telescope, He2-131 proved to be a tiny, round planetary nebula only 3 arcseconds across. Unless otherwise noted, the HST observations were obtained by Raghvendra Sahai (Jet Propulsion Laboratory) and processed at the University of Calgary's Space Astronomy Laboratory.



Karl G. Henize (1926–93) became a NASA astronaut in 1967 after distinguishing himself as a discoverer of planetary nebulae in the southern sky. He had hoped to fly to the Moon but eventually got only one flight assignment: the Spacelab 2 mission (pictured here) in 1985.

>> He2-86 is a planetary nebula in the constellation Musca. Under HST's scrutiny, the small (5-arcsecond) feature resolves into an enigmatic butterfly shape.

Just when astronomers thought they were making progress in understanding these perplexing objects, new HST observations posed further challenges.

Unlike stars, which radiate in all colors from violet to red interspersed by dark lines due to absorption by atoms in the stellar atmosphere, planetary nebulae emit predominantly in specific colors like neon signs. In addition to the red (H-alpha) light of hydrogen atoms, the spectra of planetary nebulae show the characteristic green line of doubly ionized oxygen atoms. It is through the detection of these lines that new planetary nebulae are discovered.

Although we usually think of them as extended objects with symmetrical shapes, most of the 1,500 known planetary nebulae in our galaxy look unassumingly starlike. In fact, planetary nebulae are usually identified as such by their emission-line spectrum, rather than by appearance. This is particularly true for those in the southern hemisphere. Many of them lie in the direction of the galactic center and are too distant and too small to have their nebulosities resolved by ground-based telescopes.

This all changed with the launch of the Hubble Space Telescope (HST). From its orbit high above Earth, HST does not suffer from the image-degrading effects of atmospheric turbulence and thus can routinely achieve much higher resolution than ground-based telescopes. In recent years, astronomers have exploited this advantage to observe an increasing number of "stellar" planetary nebulae, especially those at southern declinations.

Some of the newly resolved objects, such as the one known as He2-131, show round shells reminiscent of the most famous planetary, the Ring Nebula (M57) in Lyra. Others, like He2-86, have two-lobed (bipolar) shapes similar to NGC 6302, the well-known Butterfly Nebula. Although bipolar planetary nebulae have been observed for almost a century, they were dismissed as rare and exotic — just a deviation from the normal ringlike structures seen among their siblings. Recent studies, however, have revealed that these winged forms are more common than previously thought. In fact, the Ring Nebula itself may be a butterfly viewed down its long axis (*S&T*: July 2000, page 32).

Just when astronomers thought they were making progress in understand-

The Origin of "He" Planetary Nebulae

Many of the planetary nebulae in the southern sky were discovered during an emission-line survey undertaken by Karl G. Henize in 1949, while he was still a graduate student. He used a 10-inch telescope at the Lamont-Hussey Observatory in Bloemfontein, South Africa. By placing a prism in front of the telescope, he was able to detect the H-alpha line at 656.3 nanometers (6563 angstroms) and distinguish emission-line stars from normal stars. Carrying out such an ambitious observing program alone in a foreign land was by no means trivial, but Henize did so with love and dedication. When not observing at night, he played rugby with friends, organized a small baseball league, hiked extensively, and generally had a good time. By July 1951 he had completed a survey of the entire sky south of –25° declination; his doctoral thesis detailed 171 previously known and 137 newly discovered emission-line objects.

Although the H-alpha line is a good indicator of nebulosity, Henize wanted proof. So he photographed some of these objects using 40- and 60-inch reflectors. He found that seven of his emission-line "stars" were indeed enmeshed in nebulosity. Encouraged by this success, he compiled observing data for 459 emission-line objects — a survey published in 1967 and known today as the Henize second catalog, or "He2."

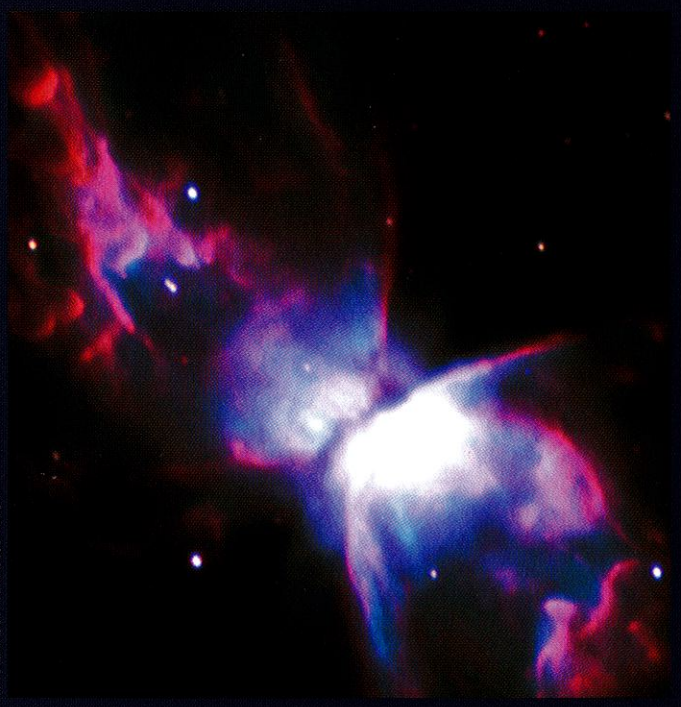
Henize hoped that an even larger telescope might detect nebulosity around his more elusive objects. During 1961 and 1962, while a guest observer at Mount Stromlo Observatory in Australia, Henize used the facility's 1.88-meter (74-inch) reflector to hunt them down. But many remained unresolved and starlike. Ultimately, confirmation came from the spectroscopic work of Louise Webster at Mount Stromlo, who detected the distinctive green emission at 500.7 nanometers (5007 angstroms) due to oxygen ions.

In 1967, at the age of 40, Karl Henize became a NASA astronaut and moved to Houston. A true astronomer-astronaut, he would have flown on either Apollo 20, 21, or 22 had the program continued. Instead, Henize worked in support roles for NASA year after year. Finally, after 18 years of waiting, he served as mission specialist for Space Shuttle mission 51-F, which carried the Spacelab 2 astronomy platform into orbit on July 29, 1985. At the age of 58, he was at that time the oldest person to have flown in space.

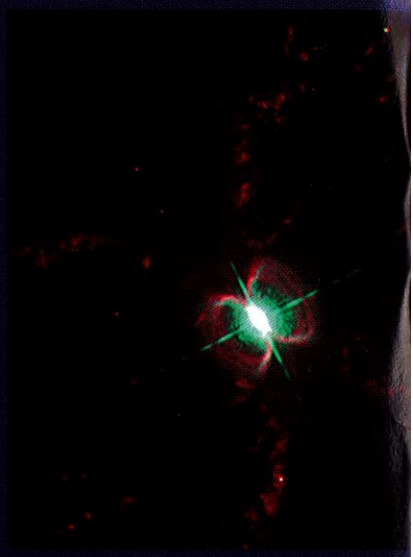
Unfortunately, Henize did not have the chance to see the wonderful HST pictures of the planetary nebulae he discovered. On October 5, 1993, 12 days short of his 67th birthday, he died while attempting to climb Mount Everest. Henize was buried near the Changste Glacier, at an altitude of some 5,500 meters (18,000 feet) — a dramatic end to a life spent reaching for the heavens.

NASA/JOHNSON SPACE CENTER

One of the most beautiful planetary nebulae in the southern sky, NGC 6302 spans more than 45 arcseconds in the constellation Scorpius. A view from the European Southern Observatory's Very Large Telescope *(lower left)* shows a textbook case of bipolar lobes. In a Hubble composite image obtained in February 2000 *(lower right)*, the eastern lobe is separated from the western lobe (toward upper left) by a dark torus of dust. This dust collar conceals the hot central star, whose surface temperature is about 380,000° Kelvin, but the effects of the star's wind blowing into the lobes are clearly seen.



EUROPEAN SOUTHERN OBSERVATORY



>> He2-299 in Sagittarius *(right)* has a nearly edge-on central ring and several twisting outer lobes. He2-447 in Vulpecula *(lower right)* is equally peculiar: its bright inner shell is surrounded by two pairs of skewed lobes.

SUN KWOK, KATE SU, AND RAGHVENDRA SAHAI

>> An HST composite image reveals two inner shells and a pair of unique pointed lobes in He2-320, a 4.2-arcsecond-long bubble of light in Corona Australis.

Further amazement awaited us as observers used HST to track down more southern planetary nebulae.

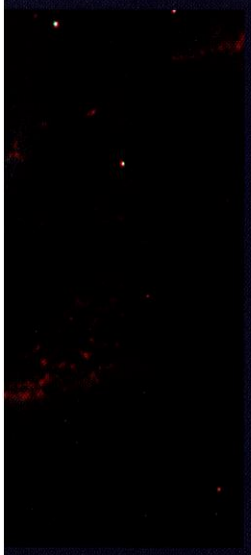
ing these perplexing objects, new HST observations posed further challenges. Consider the bizarre aspect of He2-320. Instead of the round-ended lobes commonly seen in NGC 6302 and elsewhere, He2-320 terminates in lobes that are pointed and sharp — as if guided and shaped by an unseen hand. Between the two lobes is a very tight waist. Astronomers conjecture that an unseen doughnut of dust wraps around the waist and channels the gas flow to create the bipolar lobes.

Other examples of HST's strange revelations are He2-447 and He2-299, which sport *two* and *three* pairs of lobes, respectively. Such structures are not expected in any of our current theoretical models. Nor are the crablike claws of objects like He2-104. Some astronomers have argued that He2-104 is not really a planetary nebula but rather a peculiar object with a hot-and-cool pair of central stars.

Further amazement awaited us as observers used HST to track down more southern planetary nebulae. He3-1475 defies all conventional wisdom in having an S-shaped structure. The two thin lobes seem to have been swung out from a slingshot. In contrast, He3-1357 has a disklike structure with a bubble bursting out on each side.

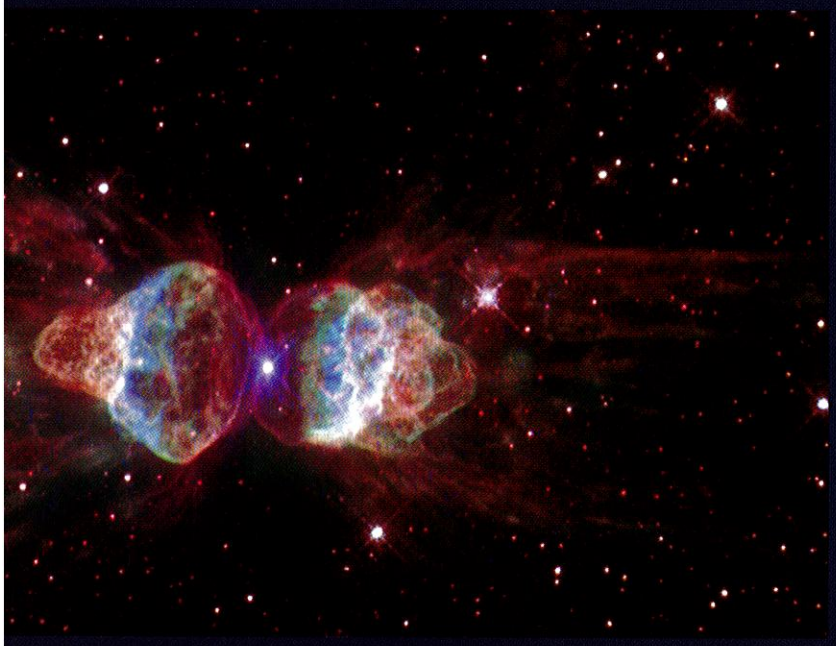
All these discoveries have raised new questions about the origin of the morphologies of planetary nebulae. As this issue of *Sky & Telescope* reaches subscribers, more than 200 researchers will be gathering in Canberra, Australia, for a symposium on planetary nebulae sponsored by the International Astronomical Union. Perhaps such a high-power brainstorming session will shed some new light on how these objects fashion their diverse and beautiful shapes.

Sun Kwok, *an astronomer at the University of Calgary, chairs the planetary nebula working group of the International Astronomical Union. He recently authored* The Origin and Evolution of Planetary Nebulae *and* Cosmic Butterflies, *both published by Cambridge University Press.*

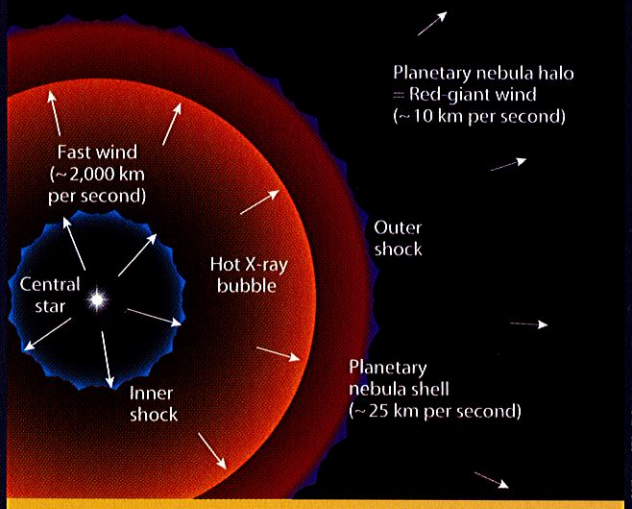


<< First observed with the Hubble telescope in 1999 by Romano Corradi (Institute of Astrophysics, Canary Islands), He2-104 in Centaurus *(left)* shows three pairs of rings near its core, and its outer lobes are made up of knots and filaments more than 1 arcminute across. One linear "jet," seen at upper right, consists of nine knots.

>> Distinct streamers also adorn the Ant Nebula (Menzel 3) in the constellation Norma *(below)*. Neither it nor He2-104 has the classic round shape of a planetary nebula, and researchers think magnetic fields or binary central stars may be driving and shaping the outflows.



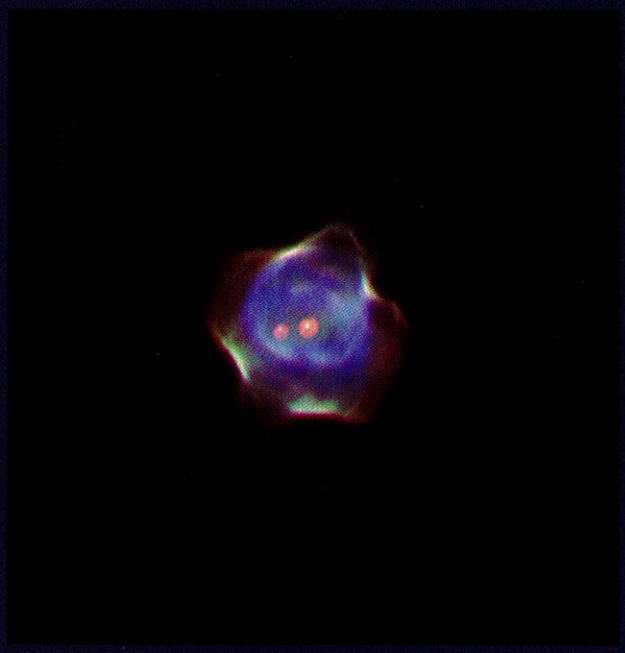
Interacting-Winds Theory



S&T ILLUSTRATION

A low-mass star like the Sun eventually swells to become a red giant that slowly "leaks" its atmosphere into space. Once the star's hot core is exposed, a fast stellar wind plows into the previously ejected material, creating a dense shell of excited gas — a planetary nebula.

>> He3-1357 in the constellation Ara was first imaged with HST by Matthew Bobrowsky (Challenger Center, Virginia), who dubbed it the Stingray Nebula. It shows a bright inner ring and an outer outflow axis not perpendicular to the plane of the ring. Two stars can be seen inside the nebula. It is unclear whether this object's binary nature has anything to do with its peculiar shape.



>> He3-1475 in Sagittarius has an elongated S shape that contradicts our preconceptions of what planetary nebulae should look like. It has a cometlike core (in white) and three pairs of knots (emitted by ionized nitrogen, shown in green) in the arms. Although cataloged by Karl Henize in 1976, its stunning bipolar nature was not recognized until seen by the Hubble Space Telescope during the 1990s.

SkyandTelescope.com

For more information about Sky & Telescope *magazine or to subscribe visit SkyandTelescope.com or phone 800-253-0245.*