From massive star to supernova remnant

Among the exotic species found in the galactic zoo, Wolf-Rayet stars are both rare and distinctive. Believed to be massive stars in a late stage of their stellar evolution, these intensely luminous objects are born with about 20 to 100 times the sun's mass. Over a period of just a few million years, strong stellar winds carry away nearly half their mass. Eventually, they probably end their lives in a violent supernova explosion. Until now, however, astronomers lacked direct observational evidence for this evolutionary path.

Joy Nichols-Bohlin of the Computer Sciences Corp. in El Segundo, Calif., and Robert A. Fesen of the University of Colorado at Boulder started by looking at Wolf-Rayet stars surrounded by a ring nebula — a shell of expanding gas very close to the star. About 5 to 10 percent of all Wolf-Rayet stars have ring nebulas.

Working with ultraviolet light measurements obtained by NASA's International Ultraviolet Explorer satellite, the researchers discovered three Wolf-Rayet stars that also appear to lie within and near the center of wispy, much more distant, expanding gaseous shells. In one case, for instance, the ring nebula surrounding the star is about 20 light-years across while the large dust shell is 160 light-years across. Each huge, distant shell may be the remnant of an earlier supernova explosion that shattered the now-invisible binary companion of each Wolf-Rayet star, the researchers said at an American Astronomical Society meeting this week in Kansas City, Mo.

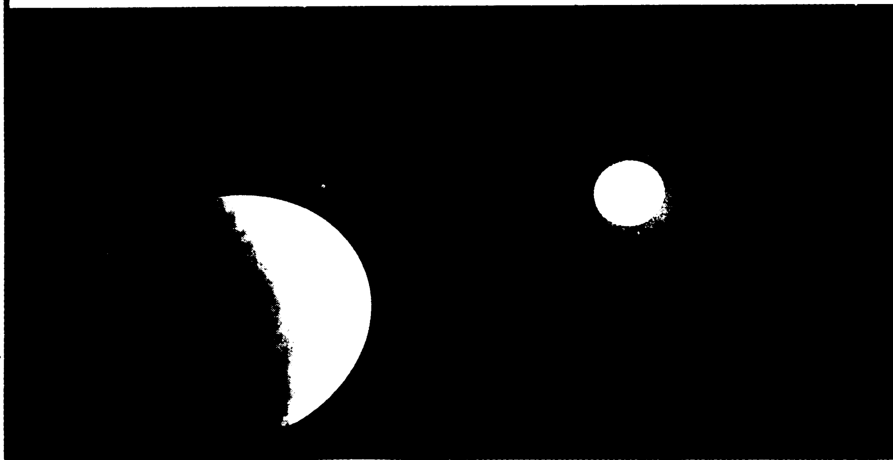
The observations fit a model for the evolution of a binary star system consisting of two massive stars orbiting each other. The more massive and faster-evolving of the two stars is the first to shift into the Wolf-Rayet phase. Within 200,000 years or so, it explodes in a supernova, sending off a gaseous cloud and collapsing into a neutron star. Its companion also soon becomes a Wolf-Rayet star and then undergoes a supernova explosion. The result is a binary system consisting of two neutron stars.

"If these huge shells that have been detected are indeed old supernova remnants, then the three Wolf-Rayet stars might be members of massive binary star systems, having entered their Wolf-Rayet phase relatively soon after the supernova explosion of one of the stars in the system," says Nichols-Bohlin. "Obviously, a great deal more work needs to be done to confirm that these are highly evolved supernova remnants rather than interstellar bubbles ejected by a single star."

Nevertheless, postulating that a binary system rather than a single star is responsible for the supernova remnant provides a tidy explanation for the presence of a ring nebula around these Wolf-Rayet stars. Such a star loses mass to its neutron-star companion, but the flow is so great that the neutron star can't accept all the material. Some forms into a gaseous cloud, which is swept out into a ring by the stellar winds. The formation of ring nebulas in massive binary systems may be an example of the same kind of phenomenon that leads to the association of planetary nebulas with binary systems consisting of less massive stars — but on a much larger scale (see box).

"Only around those Wolf-Rayet stars that show nicely formed ring nebulae do we find any evidence that there was a supernova," says Fesen. These ring nebulas appear to signal both a violent past and an explosive future. — *I. Peterson*

A cosmic egg wrapped in a gaseous shell



Dana Berry/Space Telescope Science Institute

Artist's impression of binary star system at the center of planetary nebula K 1-2 shows distorting and heating effects of a small, hot star on its cooler companion.

Like Laurel and Hardy, the two whirling stars at the heart of a fuzzy patch of light known as Kohoutek 1-2 (K 1-2) are a mismatched pair. The smaller, hotter star tugs at its flabby, relatively cool companion, pulling it into a shape reminiscent of an egg. Its intense radiation heats the companion's facing side to a bluish-white color, while the opposite, cooler side stays reddish-orange. With its distinctive coloration, the companion star resembles a giant Easter egg.

"We believe this is the largest such [heating] effect yet found," says astronomer Howard E. Bond of the Space Telescope Science Institute in Baltimore. Bond's discovery came in the course of a systematic study of variations in the brightness of stars surrounded by expanding clouds of gas, or planetary nebulas. He reported his findings to an American Astronomical Society meeting this week in Kansas City.

K 1-2 is a very faint object about 7,000 light-years from earth in the direction of the southern constellation Pyxis. Bond's measurements show that the two stars making up this binary system are so close together — just one or two stellar diameters apart — that they appear as one. "They're almost but not quite touching," says Bond. The two stars orbit their center of mass every 16 hours. They lie enveloped in a glowing shell of gas made visible by the hotter star's intense radiation.

Out of roughly 40 planetary nebulas studied so far, Bond and his colleagues have discovered about half a dozen in which the central stars prove to be close pairs of stars. "This surprisingly high incidence of close binaries is starting to suggest that at least some planetary nebulae are actually ejected because of the interaction of binary stars," Bond says.

Until recently, astronomers thought red giant stars were the main source of planetary nebulas. Toward the end of its life, a red giant would become so large and its surface gravity so low that its outer layers could easily become detached. However, the exact mechanism by which a red giant could slough off its skin wasn't clear.

Bond proposes that the ejection of gaseous matter is a way in which a binary system can give off its excess energy as its two stars spiral closer together and as one draws matter from its companion in an act of stellar cannibalism. "It's always been a mystery not only where planetary nebulae come from but also where very close binary stars come from," Bond says. This mechanism allows widely separated binaries to evolve into close binaries.

The presence of a planetary nebula is a clue showing the violent interactions that can take place when two stars approach each other, says Bond. In a few billion years, the stars will get close enough to coalesce, setting the stage for a nova explosion. — *I. Peterson*

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