Cosmic Butterflies: Planetary Nebulae Explained

Planetary nebulae, left behind by stars like our Sun, come in chimerical shapes. New observations confirm that many of these shapes may have a common explanation.

The ESO's Very Large Telescope captured this image of planetary nebula Fleming 1. Inside the glowing gas cocoon, a pair of stars whirl around each other every 1.2 days. The interaction between the two stars creates the nebula's S-shaped symmetry.
ESO / H. Boffin

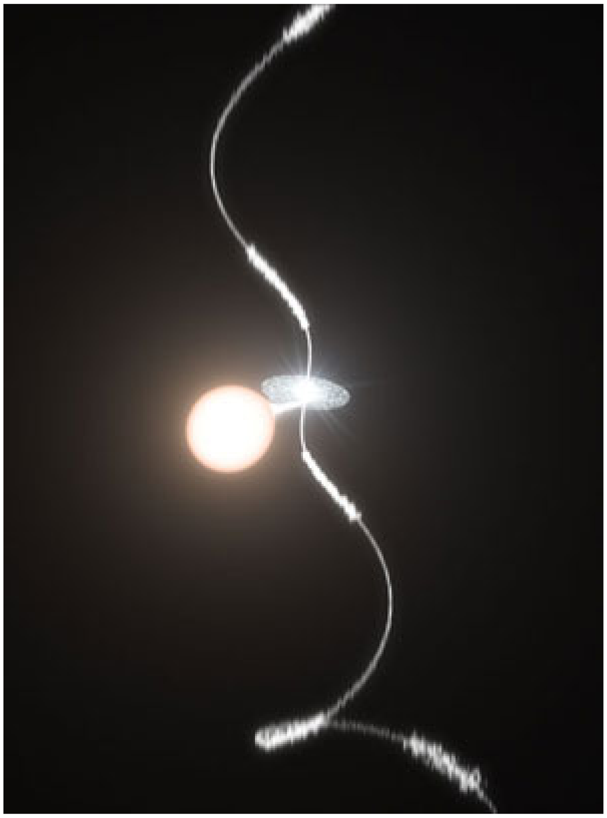
Do not go gentle into that good night,
Old age should burn and rave at close of day;
Rage, rage against the dying of the light.
— Dylan Thomas

Dying stars seem to pay heed to poetry. When stars roughly the mass of the Sun near the end of their lives, they shed their outer layers like trees in autumn. The glowing gas shells, called *planetary nebulae*, come in a colorful variety of shapes. The spectacular structures are all the more mysterious because stars are largely spherical. Determining how these shapes form used to be a matter of fierce debate, but one now-mainstream theory has found firm footing in a study published in today's *Science*.

Henri Boffin (European Southern Observatory, Chile) and his colleagues present new observations taken with ESO's Very Large Telescope of Fleming 1, a butterfly-shaped planetary nebula renowned for its spectacular set of S-shaped jets. The jets shoot out in two arcs from the dying star at the nebula's center. Theorists have long suggested the presence of a second star might explain such jets' characteristic shape. Observations carried out by Boffin's team confirm this theory with definitive evidence of not one but two stars in the nebula's heart, whipping around each other every 1.2 days.

In an unusual twist, both stars are white dwarfs, the glowing cinders of what were once Sunlike stars. The two stars might initially have been similar in size, evolving to the white dwarf phase roughly simultaneously — a rare occurrence in planetary nebulae. The stars currently weigh 0.5 to 0.86 and 0.7 to 1.0 times the mass of the Sun, where the ranges reflect the errors associated with the mass measurements.

The larger star was likely responsible for the S-shaped jets, which span 9 light-years from tip to tip. Symmetrical knots line both jets, suggesting episodic activity between 16,000 years ago — about the time when humans crossed the Bering Strait from Asia to North America — and 6,000 years ago.



This artist's illustration demonstrates how interaction between two stars can create an S-shape to the jets. One star feeds off the other, and the whirling buffet of gas wobbles in response to the stars' close orbit, creating bipolar jets that wobble too.
ESO / L. Calçada

Theorists have argued for 30 years that a binary would best explain the jets' kinks. First, the smaller star blew a stellar wind, which the larger star gathered into a whirling cloak of gas called an accretion disk. When the companion's tight orbit caused it to "bump" the cloak, the whole thing wobbled like a spinning top. The jets, powered by the disk, wobbled too. Once the disk grew too large, it engulfed both stars in a "common envelope," cutting off accretion to the larger star.

The discovery of the binary system in Fleming 1 cements this theory. Not only that, but the team also discovered a ring of bright knots surrounding the stars in their plane of orbit, which might also have resulted from interaction in the binary system.

"It took more than a decade, sometimes with fierce fighting, to convince the planetary nebula community that single stars cannot lead to such morphologies," says Noam Soker (Technion – Israel Institute of Technology), who was not involved in the study.

"This finding puts the binary model on very strong ground, such that it should go beyond the planetary nebula community," Stoker suggests. "The shaping of planetary nebulae is at the crossroads of many astrophysical objects, from core collapse supernovae to clusters of galaxies."

Boffin and his colleagues agree — the conclusion of the paper relates Fleming 1 to other planetary nebulae such as the Necklace Nebula, but they don't stop there. Similar structures can be found in systems that have nothing to do with planetary nebulae. Supernova 1987A, for example, formed a knotty ring structure about 30,000 years before it blew up, although observations have been unable to distinguish whether that particular exploding star had a companion. And symbiotic stars and massive stars sometimes fling out S-shaped jets. Though it's too soon to draw definitive conclusions, binary interaction may be the common thread that binds these disparate systems.

Posted by Monica Young, November 8, 2012
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