The unusual molecular and isotopic content of planetary nebulae

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Observations of planetary nebulae have revealed unusual molecular content and surprising enrichments of rare isotopes, challenging both chemical models as well as our current understanding of stellar nucleosynthesis.

Using the Arizona Radio Observatory 12-m and submillimeter telescopes and the IRAM 30-m telescope near Granada, Spain, astronomers at the University of Arizona discovered an unexpected chemical inventory in planetary nebulae. These results, presented at the 236th meeting of the American Astronomical Society by Deborah Schmidt (now at Swarthmore College), suggest that planetary nebulae play a vital role in supplying interstellar space with material rich in molecules, not just atoms.

Further, the molecular data have revealed unusual enrichments of rare isotopes of common elements such as carbon, oxygen, and nitrogen, including 13C, 15N, and 17O. The high abundances of these unusual isotopes in planetary nebulae cannot be explained by our current understanding of how most stars die, suggesting additional processes, even violent explosions, may be occurring.

Planetary nebulae represent the last gasps of dying Sun-like stars. At the end of their lives, these stars eject their outer layers, forming a brilliantly fluorescing envelope which expands away from the remnant core. This ejecta mixes in with the low-density matter that exists between stars, known as the interstellar medium, where it may later be incorporated into newly forming stellar systems.

The vestigial core, called a white dwarf, emits copious amounts of high-energy radiation as its temperature increases into the planetary nebula phase. As a result, it was long thought that the nebular material should be elemental in composition, with any molecules remaining from earlier stages in the star's life being destroyed by the energetic photons from the white dwarf.

At complete odds with these model predictions, observations conducted by Schmidt as part of her dissertation work at the University of Arizona unearthed a wealth of unusual molecular species in over 25 planetary nebulae.

These results unambiguously demonstrate that molecules are important components of the composition of planetary nebulae, and they may subsequently be "polluting" the diffuse interstellar medium. Historically, astronomers have struggled to explain the abundances of the polyatomic molecules observed in diffuse gas, as there is not enough dense material to create them on a realistic timescale. The discoveries of Schmidt et al. suggests a novel solution for this ongoing dilemma.

The molecular observations of these planetary nebulae also offer unique insight into the nuclear reactions that occurred in the progenitor star, and the elements and their different nuclei that were produced. This is because observations at radio and millimeter wavelengths are conducted with the highest spectral resolution, allowing molecules with different elements and isotopes to be clearly distinguished.

Schmidt and colleagues discovered that the molecules they have found indicate whether the progenitor star was rich in carbon, for example. Furthermore, they have been able to measure abundance ratios between the main element and its rarer forms, such as 12C/13C or 14N/15N. Such ratios are known to be sensitive probes of the processes that occurred deep within the star before it died, and have been used as one of the few "benchmarks" for testing stellar modeling. Now, for the first time, they can be accurately measured in planetary nebulae, giving a "snapshot" of the star's final stages.

What did the observations reveal in planetary nebulae? Lots of carbon, first of all, along with high abundances of 13C, and in one nebula, K4-47, hugely elevated amounts of 15N and 17O—higher than observed anywhere else in the universe (Schmidt et al. 2018). The high concentrations of 13C, 15N, and 17O observed in planetary nebulae have not been predicted by models of dying stars.

Specifically, Schmidt and collaborators suggest that the progenitor stars of these planetary nebulae may have undergone an unexpected event as they made their last "gasps"—a helium shell flash, in which hot carbon from deep within the star is blown out to the stellar surface. In the violent explosion that occurs, 13C, 15N, and 17O are created and ejected from the star. Such an energetic process can also explain the unusual bipolar and multipolar geometries typically exhibited by planetary nebulae, giving them their "hourglass" and "cloverleaf" shapes.

Dying stars also produce dust grains. Some of these grains have actually made their way to our solar system, where researchers such as collaborator Thomas Zega extract them from pristine meteorites. Elemental isotopes can be measured in these so-called "presolar" grains, providing a Rosetta Stone of their history. Some of these grains have been found to exhibit consistently low 12C/13C, 14N/15N, and 16O/17O ratios—a puzzle for cosmochemists, as these ratios cannot be explained by normal models.

For lack of a better explanation, it has been speculated that these atypical grains originated in novae, a type of thermonuclear explosion which occurs on the surface of the low-mass stellar remnants in binary systems. Their unusual ratios, however, match those found in K4-47, suggesting that planetary nebulae are their true birthplaces.

Planetary nebulae supply most of the matter found in interstellar space, which subsequently leads to stellar systems like our own. The work of Schmidt and colleagues has shown that these objects contain hidden molecules and elemental isotopes, invisible in the colorful images that portray them. Exploring these new, unexpected facets of planetary nebulae is crucial to our understanding of the history of stars and the evolution of matter that formed our solar system.

More information: D. R. Schmidt et al. Extreme 13C,15N and 17O isotopic enrichment in the young planetary nebula K4-47, *Nature* (2018).

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The Unexpected Molecular Complexity of Planetary Nebulae as Revealed by Millimeter-Wave Observations. repository.arizona.edu/handle/10150/634282

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