ASTRONOMY

Labs Hold the Key to the 21-Micrometer Mystery

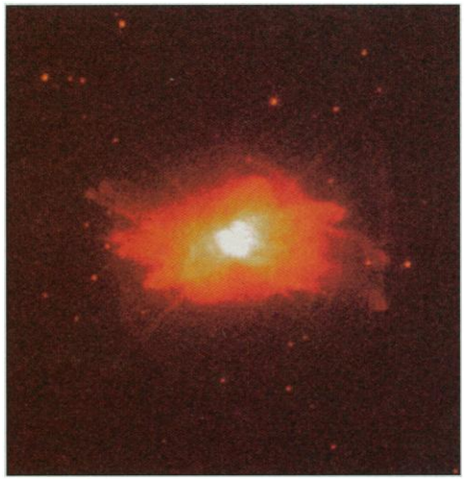
Some substance not usually associated with stars is glowing around 12 red giants. Researchers hope to find it at the lab bench

For more than a decade, a strange infrared glow coming from certain red giant stars has perplexed astronomers. Centered on a wavelength of 21 micrometers, the emission forms a wide band in the infrared spectrum, which implies that it comes from a large complex molecule or a solid and not from the atoms or simple molecules normally found around stars. Now an intense e-mail debate is raging over the nature of the source, with researchers proposing substances never before detected in space, including polymers, ball-shaped fullerenes, and even nanodiamonds.

The debate was touched off when the first detailed analysis of the feature, based on observations by the European Space Agency's Infrared Space Observatory (ISO), was published earlier this year. And this has spurred on astronomers who are working with infrared spectroscopists to try to find a substance that produces a matching spectrum. "It is a mystery," says Sun Kwok of the University of Calgary in Canada.

Kwok and his colleague Kevin Volk, along with Bruce Hrivnak of Valparaiso University in Indiana, announced the first four stars exhibiting this feature in 1988 using the Infrared Astronomical Satellite (IRAS). But the low resolution of IRAS's spectrometers made it hard to discern details of the emission feature. After the launch of ISO and its high-resolution spectrometers in 1995, however, the number of stars showing the feature grew to 12, and their nature became clearer. "The feature can only be observed in a very precise evolutionary stage, in the short transition between the red giant phase and the planetary nebula stage," says Pedro Garcia-Lario of the ISO Science Operations Centre near Madrid. Stars at that stage of their life smoke like an old lantern, blowing off dust that is rich in carbon compounds.

In March of this year, Garcia-Lario and his colleagues published a detailed study of the infrared spectrum of one of these stars, IRAS 16594-4656, in the *Astrophysical Journal*. This report, along with another high-resolution study of several similar stars published in this week's *Astrophysical Journal* by Kwok and his colleagues, has sparked a host of theories on the identity of this mysterious compound. "The feature is so strong that it has to come from a common element," says Kwok, and in such stars "carbon and hydrogen are the obvious ingredients." The ISO observations have shown that the profile of the emission feature—identical for all 12 stars—is almost 4 micrometers wide, ruling out small molecules as the source because they produce narrow emission lines. "It has to be either a mixture of similar kinds of molecules, like hydrogenated fullerenes, or a very large molecule complex, or a polymer, or even a solid," says Kwok.



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Shrouded star. IRAS 16594-4656, the Water Lily Nebula, which shows the 21-micrometer feature.

Now astronomers, spectroscopists, and theorists are joining forces to find a substance that produces the same infrared spectrum. And, as in all the best detective stories, suspects abound. Theoretical physicist Adrian Webster of the University of Edinburgh in the U.K. has proposed that the mysterious compound may be hydrogenated fullerenes. The basic fullerene consists of 60 carbon atoms arranged in a sphere, and anywhere from one to 60 hydrogen atoms can festoon it. "I calculated the general spectrum of a mixture of hydrites, and it turned out to be a broad feature centered on 21 microns," Webster says. Garcia-Lario says that fullerenes could well be produced by the decomposition of large hydrogenated amorphous carbon grains, together with so-called polycyclic aromatic hydrocarbons, ring-shaped molecules known to exist in red giant atmospheres.

However, some astronomers have put forward another, equally exotic candidate: nanodiamonds. Scientists had thought that diamonds could only form on the solid surface of a planet or other body, not in the atmosphere of a star. But Jo Nuth of Goddard Space Flight Center in Greenbelt, Maryland, cites work over the past few years by materials scientists Rustum Roy of Pennsylvania State University in University Park, Andrew Phelps of the University of Dayton in Ohio, and others, which showed that nanodiamonds could form straight from a carbon vapor without a substrate. "This broke the taboo that says that vapor deposition processes weren't directly applicable to circumstellar shells," says Nuth.

This proposal is supported by Hugh Hill, also at Goddard, who along with researchers from France studied nitrogen-doped nanodiamonds 1 to 3 nanometers in size, which they had extracted from a meteorite. When they studied the diamonds in the lab, they detected infrared emission at 21 micrometers. "We found a fascinating resemblance," says Hill. "We feel that the 21-micron feature represents the best evidence so far that nanodiamonds can be detected in the interstellar medium." However, Thomas Henning of the University of Jena in Germany is not convinced. The 21-micrometer feature in laboratory diamonds is too weak, he says. "You would have to have large amounts of nanodiamonds doped with nitrogen in these [circumstellar] environments" to produce the observed spectra, he says. Henning also believes that the technique used to extract the diamonds from the meteorites may contribute to the 21-micrometer feature.

Henning has his own candidate: silicon disulfide. "In silicon disulfide, there is a clear 21-micron feature which fits relatively well," he says, but he admits that, just as with nanodiamond, explaining the strength of the observed emission would require a lot more silicon disulfide than is usually found around stars. Nuth also points out that silicon disulfide has other emission features, for example near 10 micrometers, that are not observed in the 12 stars.

ISO's useful life ended in April last year, and no infrared observatory has yet been launched that could provide more detail about the 21-micrometer feature. So researchers are pushing forward with laboratory studies, testing candidate sources, and scrutinizing the ISO data for more clues: other emission lines in the infrared spectrum that are only found in the 12 stars. The quest won't be easy, says Kwok. "We are most likely looking at something we don't even have on Earth." **–ALEXANDER HELLEMANS**

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