Fingerprints of Stardust Tell Secrets of the Origin of Earth Elements

Challenge

Where did all the elements that are found on the Earth come from? How were they made? After the Big Bang, about 14 billion years ago, the universe contained only hydrogen and helium, which then combined in the first stars to form the elements we know today, such as carbon, oxygen, and nitrogen. Neutrons are added to these lighter elements in a process that takes place in dying and exploding stars. The process, called nucleosynthesis, creates more complex elements (Figure 1).

Argonne's Role

By using an instrument that is available nowhere else in the world, scientists from Argonne and The University of Chicago analyze grains of interstellar dust with a technique called resonance ionization mass spectrometry that measures elements to a tenth of a part per billion. These measurements identify different isotopes, or varieties of an element that differ only in the number of neutrons at their core. Because these atoms were created in stars that lived and died before the sun was born, the mass spectrometer is like a listening device that hears back billions of years.

Figure 1. Top: A dying star (faintly visible in the center of the ring) has expelled up to half its mass, much of which condenses into dust grains. Bottom: This column of cool molecular hydrogen gas and dust is an incubator for stars. Dust expelled from dying stars combines with fresh gas in clouds like these to form the next generation of stars. (Hubble Space Telescope photos from NASA.)

Approach

- Small pieces of meteorites are dissolved in acid, leaving behind the stardust dust grains for study (Figure 2).
- Many interstellar grains are mounted on a piece of soft gold, then mapped with a scanning electron microscope.
- A laser, focused through an optical microscope, vaporizes part of a stardust grain, releasing about ten thousand atoms. Two or more laser beams, each tuned to a specific wavelength (Figure 3), then intercept the expanding cloud of atoms, ionizing one or two atoms of the element of interest and leaving the rest behind. The ions then pass through the mass spectrometer, which separates the isotopes by mass and counts each one individually. Because the atoms of interest are so rare, most laser shots produce clouds that contain none of them at all. After as many as a million laser shots (at 1,000 per second), a spectrum is built up that measures the abundance of each isotope in the one specific element under study.

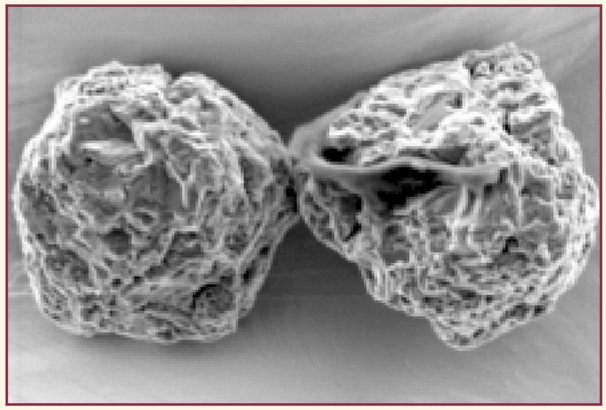

Figure 2. The Murchison meteorite, which fell in Australia on September 28, 1969, is suspected to have originated in a comet because it contains a high percentage of water (12%). At left is a piece of the meteorite, along with a vial containing some of the stardust isolated from Murchison. At right is an electron micrograph of two stardust grains, each much smaller than the width of a human hair.

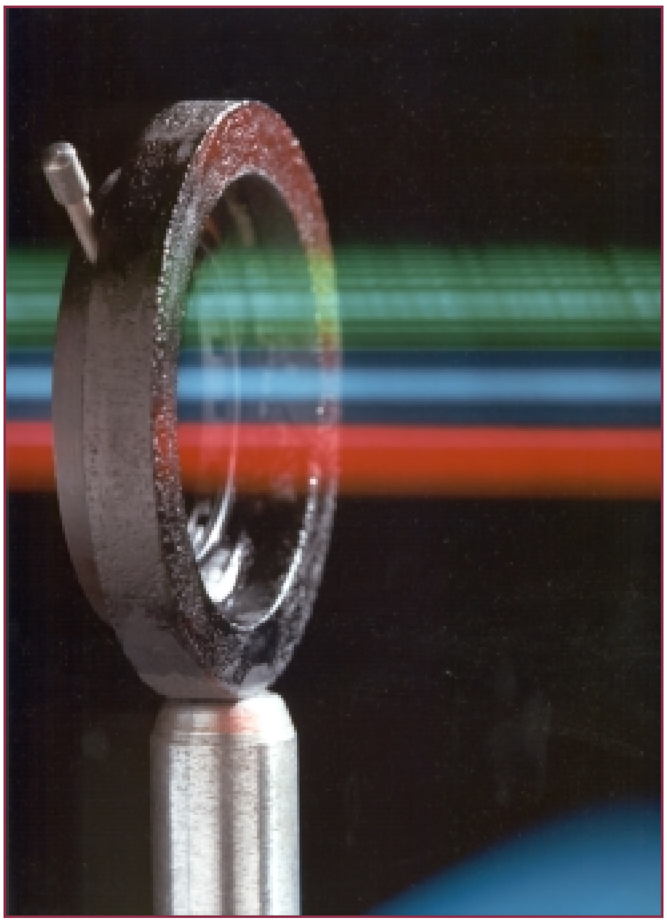

Figure 3. Material atomized from the grains is photoionized with a tunable laser system. The system must be tuned over a wide range because each element requires very specific colors.

Accomplishments

- Three types of interstellar grains have been identified, the most interesting being made of silicon carbide and graphite. Most plentiful is diamond.
- Some grains contain isotopes so strange, they can come only from other stars; each star leaves behind a unique isotopic fingerprint.
- The Argonne-Chicago team has found a pattern of neutron capture that has not been seen before. It matches neither the slow (*s*-process) nucleosynthesis that occurs over 1,000,000 years or longer, deep inside dying red giant stars, nor the rapid (*r*-process) nucleosynthesis that lasts perhaps only a few seconds in exploding supernovae.

Collaborator

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Sponsors

U.S. Department of Energy, Basic Energy Sciences —
Materials Sciences
National Aeronautics and Space Administration

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