Space science discoveries are being made in earthly labs

Research with isotopes

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Reaching for the stars isn't so out of reach these days.

With the development of increasingly sophisticated instruments, researchers not only are able to get more detailed information about circumstellar and interstellar dust from afar by using advanced telescopes, but they also are now able to study actual stardust right in their own labs.

Since the discovery two decades ago that primitive meteorites contain microscopic grains of preserved stardust, physicists, chemists, astrophysicists and astronomers have taken advantage of this interstellar material that falls to Earth.

With new and ever-improving instruments to analyze these grains in the laboratory, researchers around the world are gaining new insights into the formation of the elements and the evolution of stars.

And with the successful January 2006 completion of NASA's seven-year 2.88 billion mile round-trip Stardust mission to collect cometary and interstellar dust particles, researchers worldwide will be busy analyzing these samples for years to come looking for answers to fundamental questions about comets and the origin of the solar system.

Ernst K. Zinner, Ph.D., research professor of physics and of earth and planetary sciences, both in Arts & Sciences, at Washington University in St. Louis, provided an overview of the study of "Stardust in the Laboratory" Monday, Feb. 20, 2006, at the annual meeting of the American Association for the Advancement of Science (AAAS), held in St. Louis. He also participated in the AAAS "Exploring a Dusty Cosmos" press briefing that morning.

Zinner, the recipient of both the National Academy of Sciences' J. Lawrence Smith Medal and the Meteorological Society's Leonard Medal, is a pioneer in the analysis of stellar dust grains found in primitive meteorites.

In 1987, Zinner and colleagues at Washington University and a group of scientists at the University of Chicago found the first stardust in a meteorite. Those presolar grains were specks of diamond and silicon carbide.

Since then, Zinner and other members of WUSTL's Laboratory for Space Sciences' research group have played leading roles in analyzing these grains in the laboratory and interpreting the results. The Laboratory for Space Sciences is part of the departments of Physics and Earth and Planetary Sciences and the McDonnell Center for the Space Sciences, all in Arts & Sciences.

It is generally believed that these grains were formed billions of years ago in the atmospheres of dying stars. "As a star dies," Zinner explains, "its atmosphere begins to expand and cool. Then ions turn into atoms, atoms form molecules and, eventually, molecules condense into grains."

The dust then is ejected into outer space, where it collects with gas and dust from other stars to form cold, dark clouds.

More than 4.5 billion years ago, one such cloud collapsed to form our solar system, and the dust -- literally pieces of distant and long-dead stars -- was preserved in meteorites.

By studying the isotopic composition of these grains, researchers are gaining new information on nuclear and chemical processes in stars and on conditions during the formation of the solar system.

Advancements in instrumentation

Using a microanalytic instrument called an ion microprobe to measure the proportions of specific isotopes, Zinner and his colleagues in the late 1980s and '90s identified three types of interstellar grains -- silicon carbide, graphite and aluminum oxide -- and two important stellar sources of the grains.

The researchers determined through signature isotopic compositions that the grains came from red giant stars of low to medium mass during late stages of their evolution and from supernovae, massive stars that exploded at the end of their evolution.

These grains, Zinner explains, condensed when the envelope of red giants cooled during expansion or when supernovae exploded, thus preserving the elemental and isotopic composition of their stellar sources.

Zinner adapted the microprobe to permit precise isotopic measurements in samples weighing as little as a millionth of a millionth of a gram.

Isotopes are versions of an element that have different numbers of neutrons and, consequently, different masses. In the same way that a zoologist studies a set of footprints to learn about the animal that made them, Zinner and his colleagues study the isotopes in a grain to learn about the parent star -- its mass, age, composition and other characteristics.

The latest ion microprobe on the scene is the NanoSIMS (SIMS is short for Secondary Ion Mass Spectrometer), which can resolve objects smaller than a micrometer -- one millionth of a meter -- or 1/100th smaller than the diameter of a human hair.

Zinner and Frank J. Stadermann, Ph.D., senior research scientist in the Department of Physics in Arts & Sciences, helped design and test the NanoSIMS, which is made by CAMECA in Paris. At a cost of $2 million, Washington University acquired the first NanoSIMS in the world in 2000. There are now some 16 worldwide.

Ion probes direct a beam of ions onto one spot on a sample. The beam dislodges some of the sample's own atoms, some of which become ionized. This secondary beam of ions enters a mass spectrometer that is set to detect a particular isotope. Thus, ion probes can identify grains that have an unusually high or low proportion of that isotope.

Unlike most other ion probes, however, the NanoSIMS can detect five different isotopes simultaneously. The beam can also travel automatically from spot to spot so that many hundreds or thousands of grains can be analyzed in one experimental setup.

Using the NanoSIMS, Ann Nguyen, Ph.D., at the time a WUSTL graduate student under Zinner, persevered -- after a WUSTL team had already sifted through 100,000 grains looking for a particular type of stardust without success -- and found the first silicate stardust in a meteorite.

In the March 5, 2004, issue of Science, Nguyen and Zinner describe nine specks of silicate stardust -- presolar silicate grains -- from one of the most primitive meteorites known. Silicate is a compound of silicon, oxygen and other elements such as magnesium and iron. Nguyen is now a postdoctoral research associate in the Department of Terrestrial Magnetism at the Carnegie Institution in Washington, D.C.

"Finding presolar silicates in a meteorite tells us that the solar system formed from gas and dust, some of which never got very hot, rather than from a hot solar nebula," Zinner says. "Analyzing such grains provides information about their stellar sources, nuclear processes in stars and the physical and chemical compositions of stellar atmospheres.

"The NanoSIMS was essential for this discovery," Zinner says. "These presolar silicate grains are very small -- only a fraction of a micrometer. The instrument's high spatial resolution and high sensitivity made these measurements possible."

This detailed information about stardust proves that space science can be done in the laboratory, Zinner says. "Analyzing these small specks can give us information, such as detailed isotopic ratios, that cannot be obtained by the traditional techniques of astronomy," he adds.

Other instrumentation being used for studying very small particles include various kinds of mass spectrometers for chemical and isotopic analysis and radioactive dating, electron microscopes for chemical and structural analysis, and chemical and physical apparatus geared to the processing of microscopic material.

Zinner and Stadermann's current project will be analyzing the three slices of a cometary dust particle they recently received from the Stardust mission -- the first U.S. mission since Apollo 17 in 1972 to bring back extraterrestrial material.