Interstellar Materials in Interplanetary Dust

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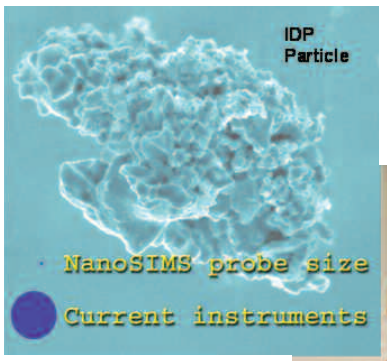
Largely unnoticed, the Earth accretes about 40,000 tons of interplanetary dust each year. These interplanetary dust particles (IDPs) originate from the disintegration of comets as they pass through the inner solar system, as well as by collisions among asteroids. This dust is so abundant in the inner solar system that it is easily visible to the naked eye – occurring just above the horizon, shortly after sunset in the west and before sunrise in the east – and is known as the Zodiacal light. NASA collects these IDPs in the stratosphere using high-altitude aircraft.

Most IDPs are clearly different from meteorites in both their physical properties and their chemical and mineralogical compositions. Typical IDPs are about 20 µm in size, and they are extremely fine grained and highly porous, with building blocks ranging in size from ~0.1 to 1 µm. In comparison to meteorites, IDPs are rich in volatile elements, carbon, and nitrogen, and have peculiar mineral assemblages. Many IDPs have never interacted with liquid water and are full of microscopic glassy silicate grains. These properties point to their most likely sources: comets.



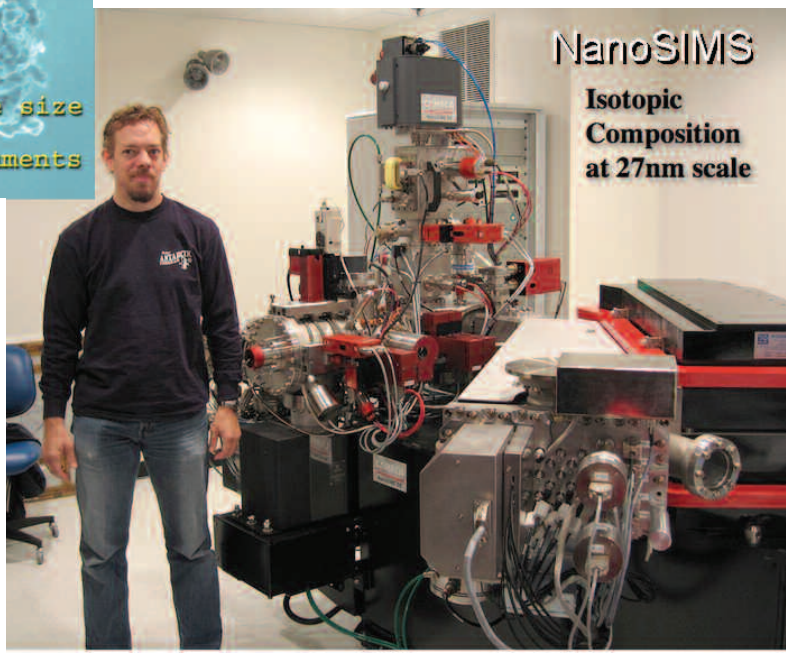
IDPs are of great interest because they have preserved the original building blocks of the solar system, including grains that formed in the solar nebula, and still older dust grains from other stars and organic matter from cold interstellar dust clouds. Although incredibly tiny (about 1 µm), these materials are direct samples of diverse astrophysical environments that are far beyond the reach of spacecraft and have hitherto been studied only with telescopes. By having these samples in hand, we gain valuable insight into the lifecycle of matter in the galaxy and the origin of the solar system.

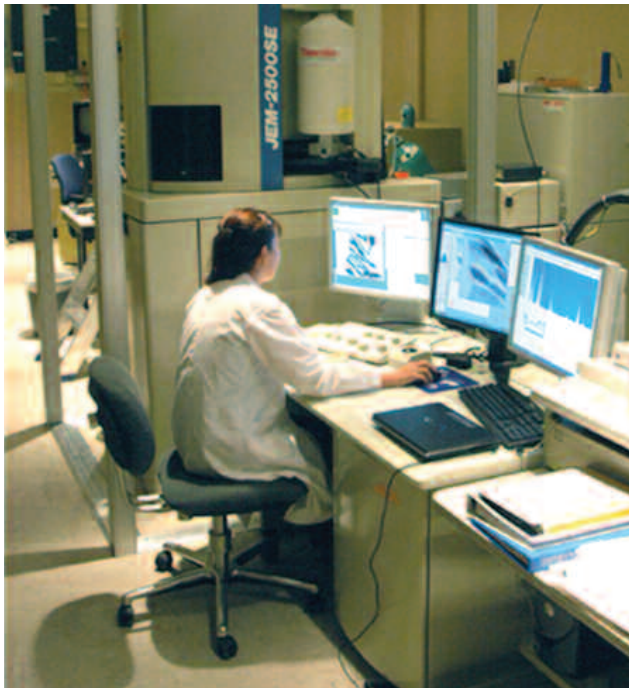
Our research on IDPs is focused on two topics: the nature and histories of ancient stardust; and the origin and evolution of interstellar molecular cloud organic matter. These interstellar materials are rare, microscopic, and remain hidden within a sea of materials that formed in the solar system. They are also far too small for age dating, so we must use a different way to distinguish them from solar system material.

During the formation of the solar system, virtually all preexisting materials were obliterated and homogenized. Consequently, the relative abundances of the isotopes of all elements are very uniform throughout the solar system on scales ranging from micrometers to astronomical units. Thus, materials from beyond the solar system are easily recognized since their isotopic compositions stand out among the uniformity of solar system materials. We are then faced with the challenge of measuring isotopic compositions on scales far smaller than a single cell.

Johnson Space Center space scientist Scott Messenger recently installed a revolutionary new instrument, the

Scott Messenger with NanoSIMS. Inset shows SEM image of interplanetary dust particle.





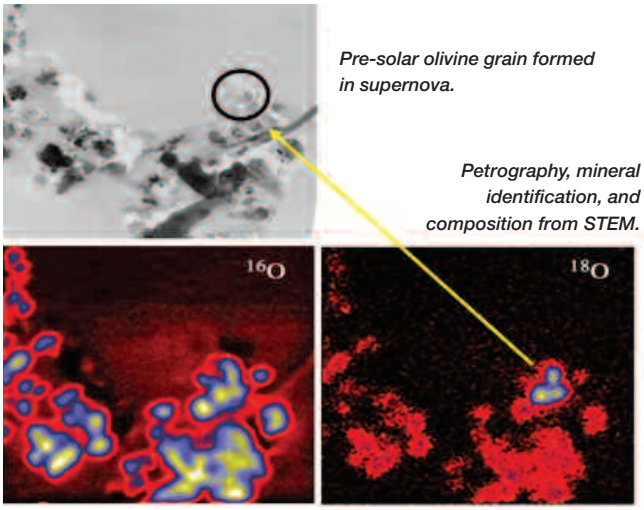
Keiko Nakamura-Messenger using scanning transmission electron microscope (STEM).

NanoSIMS 50L, that is one of the few instruments capable of making these isotopic measurements at submicrometer scales. For the past decade, Messenger has coordinated his isotopic measurements with colleague Lindsay Keller's transmission electron microscope (TEM) studies of the same materials. Keller's TEM analyses provide the essential chemical and mineralogical information necessary to understand the histories and formation conditions of the target materials. The coordination of these two instruments on the same samples can yield a compelling story, if we find the right sample.

One recent success story involves the discovery of a grain (found in an IDP) with isotopic abundances so exotic it is, thus far, unique. Measurements from the NanoSIMS showed the 500-nanometer grain to have 13 times more ^{18}O and one-third the ^{17}O, relative to ^{16}O, compared with solar system materials. This strange oxygen isotopic composition leaves no doubt that it was a true grain of stardust. By comparing the isotopic ratios with models of stellar nucleosynthesis, the origin was clear: This was a grain from a type II supernova. Fortunately, we had several slices of this supernova grain to work with since we had sliced the parent IDP into 70-nanometer-thick sections. Keller's analysis of other slices of the supernova grain showed that it was an olivine mineral grain containing a fair amount of iron.

The result was exciting because this was the first silicate mineral ever found from a supernova. But it was also surprising because, under normal circumstances, silicates that form from high-temperature gases contain very little iron. Of course, we realized that an exploding star is not a normal circumstance. We turned to our colleague Dante Lauretta at the University of Arizona. Lauretta models the formation of minerals. By combining our knowledge of our grain's elemental abundances, mineralogy, and isotopic compositions, and by comparing this with supernova models, he was able to show that our novel olivine grain could form by invoking particular mixtures of material within the supernova explosion. Amazingly, from the analysis of one submicrometer grain, we had shown that complex, large-scale turbulence and mixing must occur in supernova explosions.

Keller took the analysis of our supernova grain one step further and showed that it had no signs of the extensive radiation damage we would expect for a typical interstellar grain. Our conclusion is that this grain spent much less than the average amount of time roaming the galaxy – perhaps less than 10 million years. This is rather a cosmic blink of the eye, and is such a short lifetime that we speculate that the parent star exploded within the stellar nursery from which our solar system formed.



Oxygen isotope maps from NanoSIMS.