PLANETARY SCIENCE RESEARCH PSRD Discoveries

Hot Idea

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Analyzing Next to Nothing

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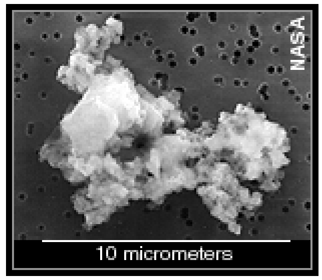


Interplanetary Dust
Collected in the stratosphere.

Analytical techniques have advanced so far that it is possible to slice up a sample only 10 micrometers across (with a mass of only a billionth of a gram) so that a dozen microanalytical techniques can be used to extract fascinating, crucial information about the sample's history. This astonishing ability is useful in analyzing interplanetary dust collected in the stratosphere, tiny interstellar grains in meteorites, sparse and wispy weathering products in Martian meteorites, and samples to be collected and returned to Earth by current and future sample return missions from comets, asteroids, Martian moons, and Mars. The importance of the array of techniques available to cosmochemists has been documented by Michael Zolensky (Johnson Space Center), Carlé Pieters (Brown University), Benton Clark (Lockheed Martin Astronautics, Denver), and James Papike (University of New Mexico), with special attention to sample-return missions.

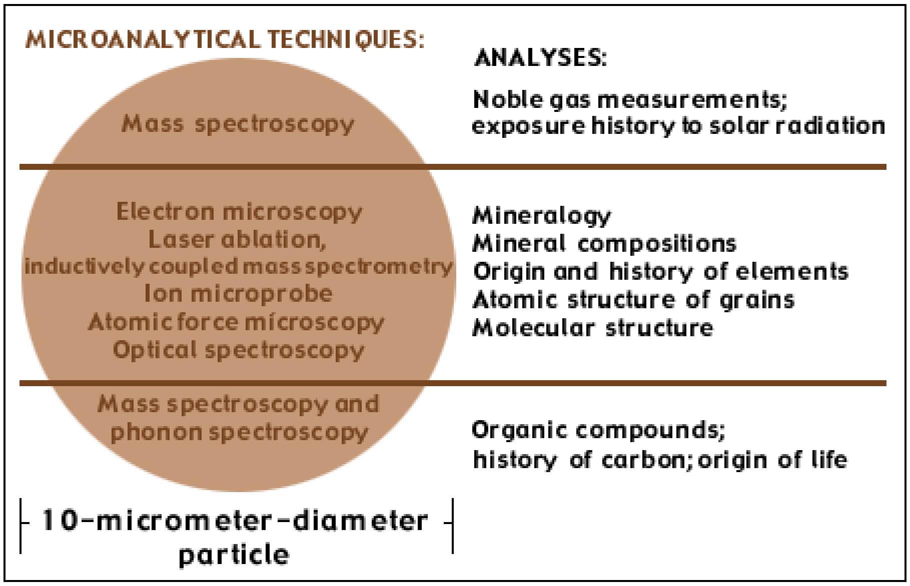
Reference:

Zolensky, M. E., Pieters, C., Clark, B., and Papike, J. J. (2000) Small is beautiful: The analysis of nanogram-sized astromaterials. *Meteoritics and Planetary Science,* v. 35, p. 9-29.

Tiny Samples Require High-Powered Analyses

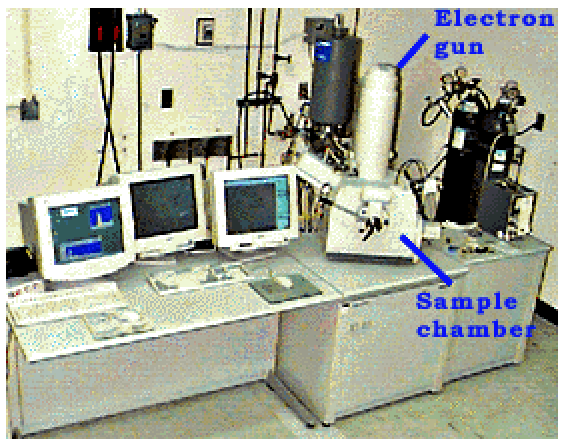
Zolensky and his co-authors point out how many studies of extraterrestrial materials absolutely require analytical techniques that can make precise measurements of particles that are only a few micrometers across, or even smaller. They give an informative example of the multitude of techniques that can be applied to a single interplanetary dust particle only ten micrometers across. Such a particle has a mass of only one billionth of a gram! (High-flying ER-2 aircraft, the civilian equivalent of the famous U-2 spy plane, collect interplanetary dust particles.) The particles enter the atmosphere and, although heated somewhat during entry, they slow down mostly undamaged and fall very slowly through the upper atmosphere.

A single particle can be divided into numerous tiny pieces. For example, the diagram below shows what can be done by dividing a sample into three pieces. One piece can be used to determine the exposure history to solar radiation, important in figuring out its path in space. Measuring the noble gases (e.g., helium, neon) by mass spectrometry would do this. A second piece would characterize the chemistry, mineralogy, and structure of the particle to learn more about its origin and history. Scientists would use a variety of techniques to image components within and across the grain and to probe its compositional diversity at both the elemental and isotopic level. Non-destructive surveys would also be made using spectroscopy that records how the particle interacts with visible, near-infrared, and mid-infrared radiation. A third piece would be analyzed to determine the history of carbon and hints about the origin of life. This involves determining the organic compounds present by mass spectroscopy and other spectroscopic techniques.



(Adapted from Zolensky, *et.al.*, 2000.)

Numerous techniques (listed in left column) allow state-of-the-art analyses (shown in right column) of one minuscule sample of extraterrestrial material that is cut by an ultramicrotome (a microscopic knife).

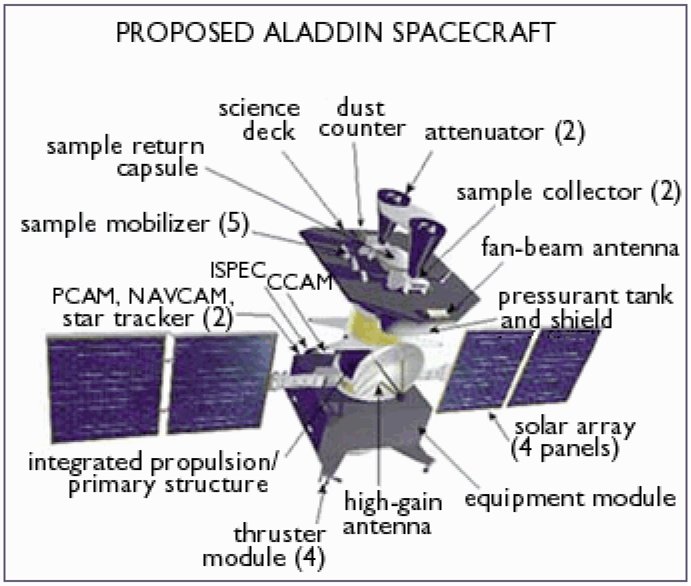


Modern scanning electron microscopes can see features only billionths of a meter in size. Other instruments are also capable of analyzing grains invisible to the unaided eye.

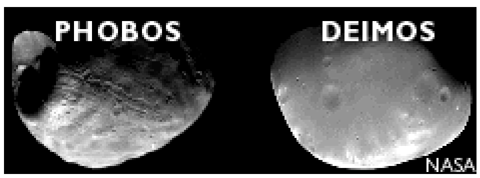
Since 1981, about 1520 grains of interplanetary dust have been analyzed, although not all by multiple techniques. According to Zolensky, who is curator of the cosmic dust collection at the Johnson Space Center, the total mass of these particles is only 0.52 micrograms! He points out that these tiny particles have such complex histories that we can begin to understand them only by applying multiple analytical techniques to each one.

Gathering Samples Throughout the Solar System

The original motivation for this study by Zolensky and co-authors was to document how much information could be gleaned from a proposed launch-and-catch sample from the two Martian moons, Phobos and Deimos. Carlé Pieters was Principal Investigator on such a proposed mission, called *Aladdin,* which would have sent a projectile into a few carefully selected places on each moon, and then collected the ejecta that would be kicked off. The projectiles would not have been rocket powered and would have hit at about 1 kilometer per second, not fast enough to damage the ejected materials. About 1100 particles greater than 10 micrometers in size would have been collected. Clearly, very special analytical techniques would be required to study such small samples.



Artist's drawing of the Aladdin spacecraft, with key scientific components labled.

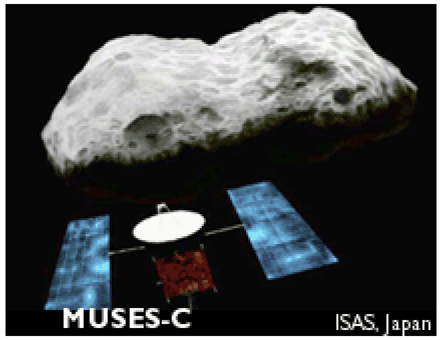


Samples would have been collected from Phobos and Deimos, the two moons of Mars, by the Aladdin mission. Phobos is about 22 km in diameter; Deimos is 12 km in diameter.

Unfortunately, the Discovery program did not select the mission. Nevertheless, the need to analyze such tiny samples remains. The Stardust mission, launched in February of 1999, will return particles from a comet and from interstellar space. This mission will return about 1000 particles, all less than 100 micrometers across (most only about 10 micrometers). They will be studied by the same techniques used in studies of interplanetary dust particles collected in the stratosphere.

Artist's conception of how the *Stardust* spacecraft will encounter comet Wild 2. The mission will collect dust from the comet and return the samples to Earth in 2006.

The Japanese space agency will launch a mission in early 2002, Muses-C, that will return huge samples, by the standards discussed by Zolensky and coworkers. It will collect a total of about three grams of powder and rock chips from a near-Earth asteroid. Although seemingly large, much of the sample will likely be very fine powder, and even the rock chips are likely to contain micrometer-sized components.



Muses-C is a sample return mission tentatively targeted to the asteroid Nereus, also known less poetically as 1989ML.

The most anticipated sample-return missions will be those that deliver pieces of Mars to us. These will enable us to understand the climate history of the Red Planet and to search for past and present life on it. The missions will return samples of the surface soils and of fresh rock chips or cores. We know from the Viking and Pathfinder missions that the surface materials are complex and fine grained, no doubt requiring the techniques Zolensky and colleagues describe. But even rock samples require capabilities to study extremely small samples because, like the martian meteorites, they will probably contain minute occurrences of weathering products that must be studied to understand the past climate history of Mars. The products will also be ideal places to examine for evidence of past or present life.

(Image from NASA's Planetary Photojournal, catalog # PIA01120.)

Samples from Mars will be returned with the help of an even more capable rover than the Sojourner rover carried in 1997 by Mars Pathfinder. Studying the fine grained material making up the soil on the Martian surface will require microanalytical techniques.

Too Small for their Own Good?

In many cases, we will be obtaining samples from bodies kilometers across. How representative are the ultra-tiny samples of the entire body? Can they be informative about the processes that operated before the body formed or inside it after its assembly? Does a hand full of fine-grained dirt tell us much about surface processes on all of Mars? Or its climate history? Have our analytical techniques gotten too good for our own good?

Probably not, if the problems are chosen carefully. A sample of an asteroid with properties similar to carbonaceous chondrites would be able to characterize it thoroughly with a few hundred particles. This is especially true because even small bodies are covered with some powdery materials, as shown by pictures of asteroids, Phobos, and Deimos. The fragmental surface materials will be mixed around the body, so the small samples will be meaningful.

Zolensky and co-authors argue that the tiniest grains on the surfaces of asteroids can be used to understand a long list of important problems:

1. The origin of minerals in the bodies.
2. The nature of the processes operating near the surface.
3. The bulk chemical composition of the surface.

4. Conditions of thermal and water-driven alteration of the materials.
5. The relationship of the surface materials to comets, asteroids, and meteorites (using isotopic analyses, especially of oxygen).
6. The abundance of water.
7. The abundance of organic compounds.
8. The history of volatile mobility in the body and its surface layers.
9. Searching for pre-solar and interstellar material.

These amazing techniques will also be needed to understand Mars. The important problems in Martian exploration require exquisite analytical sensitivity to understand the complex array of minerals expected, even if we brought back several kilograms of rock samples. So, as the title of Zolensky's paper reads, perhaps small is beautiful!

Additional Resources

Mars Exploration Program from the Jet Propulsion Lab.

Muses-C mission homepage.

Stardust mission homepage.

Zolensky, M. E., Pieters, C., Clark, B., and Papike, J. J. (2000) Small is beautiful: The analysis of nanogram-sized astromaterials. *Meteoritics and Planetary Science,* v. 35, p. 9-29.

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