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COSMIC DUST - LABORATORY ANALYSES OF EXTREMELY SMALL PARTICLES

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In order to learn something about the origin, the history, and the composition of our solar system, there are a number of different approaches that can be used. One can make theoretical calculations, computer simulations, astronomical observations, active and passive space craft experiments. A different approach involves the laboratory analyses of extraterrestrial material. The results of such measurements may give some information on the history and origin of that individual extraterrestrial sample. This information can then be added to the overall picture we have of our solar system. Unfortunately there are only few classes of extraterrestrial material available for laboratory research. Among them are lunar samples from the Apollo missions and meteorites, which have been an object of scientific research for a long time already. Compared to meteoritics, the laboratory study of cosmic dust particles has long been neglected. However, this was not due to little interest in this class of extraterrestrial material, but was a consequence of the enormous experimental difficulties in the analyses of 10 micron size dust particles. Only when advances in the field of micro analysis made it possible to gain meaningful results from a few nanograms of sample material, more effort was focused on cosmic dust particles.

Where do these cosmic dust particles come from and how are they collected? Most of the extraterrestrial dust particles in the vicinity of the Earth are probably produced in the asteroid belt or stem from comets. These particles then form a dust cloud that covers the entire inner part of our solar system. By its gravitational force the Earth attracts several tons of these dust particles every day, which then decelerate on atmospheric entry. Although some particles burn up, others survive atmospheric entry and can then be collected for laboratory analyses. Currently cosmic dust particles are routinely collected at a number of different sites, like, e.g, Antarctica, Greenland, and the stratosphere. The major advantage of collecting particles in the stratosphere is the fact that these dust particles have not been exposed to weathering as much as cosmic dust particles collected on the surface. The dust collection in the stratosphere is done by NASA, using high-flying aircraft at a height of 20 kilometers. All measurements reported here were made on these stratospheric dust particles.

Cosmic dust particles are sometimes also called 'micrometeorites', which may be a somewhat misleading term, since it seems to imply that these dust particles are basically meteorites, only smaller. Although many properties of cosmic dust particles are still unknown, one thing can be said for sure: These particles do not fit straight away into the standard classification scheme that has been developed for the 'classical' meteorites. This means that cosmic dust particles really represent their own class of extraterrestrial material, that is distinctly different from everything else that is available for laboratory research. This is exactly the reason why so

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much effort is put on the analyses of these tiny particles. Hopes are that we might learn something from these dust particles, that we could not learn from other classes of extraterrestrial material.

Most problems arising in the experimental work with cosmic dust particles can generally be attributed to one of two major difficulties: contamination and size. Contamination with terrestrial dust particles is a problem, since even in clean environments, such as the stratosphere, more than 50 % of all captured dust particles may be of terrestrial origin. It is therefore necessary to identify cosmic particles before meaningful results can be obtained. There are no easily-recognizable distiguishing marks of a cosmic dust particle; in fact, cosmic dust looks very much like terrestrial dust. An indication for a cosmic origin is, e.g., an anomalous isotopic composition. In theory this identification has to be done for each dust particle individually, but in most cases this is impractical and an identification depending on second-order characteristics is prefered. However, this procedure may lead to incorrect assumptions on whether an individual dust particle is of cosmic or terrestrial origin.
Size-related problems are for the most part obvious. Many analytical measurement techniques can not at all be used for the analysis of dust-size particles. And some other techniques may require so much material, that analyses are restricted to one single measurement per particle. This is especially disadvantageous, since it turned out that cosmic dust particles are a heterogeneous class of extraterrestrial material. Therefore it is desirable to use analytical techniques that make a number of complementary measurements on the same particle possible.

All measurements on stratospheric dust particles presented here were made with secondary ion mass spectrometry SIMS , which is a destructive technique, i.e., the sample is "used up" during the course of measurements. However, the amount of sample material used for each individual measurement is so small, that several different analyses can be made with each individual dust particle. The SIMS technique turns out to be an extremely useful tool in the study of very small particles and in the work presented here it made a number of "firsts" possible: The nitrogen isotopic compositions of cosmic dust particles have been measured for the first time. It was also the first time that it was possible to measure the abundances of the Rare Earth elements in these particles. However, the most important advance this work represents is the fact, that both trace elemental and isotopic abundances have been sucessfully measured in the same particles. Thus it is, for the first time, possible to compare isotopic and trace element abundance data of the same cosmic dust particles.

Significant hydrogen and nitrogen isotopic anomalies have been found in several cosmic dust particles. These anomalous isotopic compositions probably originated in cold interstellar molecular clouds that predate the solar system. Material from these interstellar clouds must later have been incorporated in these dust particles or their parent body, which were able to retain some kind of isotopic memory to those early stages. When the oxygen isotopes were measured, most cosmic dust particles turned out to have normal,

i.e. terrestrial, compositions. Only in one particle a clearly different, anomalous oxygen isotopic composition has been observed, that strongly resembled the oxygen measured in refractory inclusion in chondritic meteorites. At least this one particle might have a direct relationship with some meteoritic inclusions. In order to investigate this further, it was very helpful that the trace elemental abundances were also measured in the same particles.
Trace elemental abundances of extraterrestrial material can be compared with "cosmic abundances", i.e., average solar system abundances. When a sample contains all trace elements at cosmic abundances then it is assumed that the sample consists of unaltered, "primitive" material. Most of the analyzed cosmic dust particles have compositions that identify them as such primitive material. However, there is one notable exception; the particle with the oxygen isotopic anomaly has very different trace element abundances, which are similar to those found in refractory meteoritic inclusions. It looks like this one cosmic dust particle has an interesting story to tell. A small amount of material from this particle is still left and will be used for mineralogical analyses.

Although cosmic dust particles are extremely small samples of extraterrestrial material, they contain a great deal of information about the conditions at the time when they were formed and about their history. The real problem is not that these samples are too small, but that many measurement techniques are still not sensitive enough. Every advance in the field of micro analyses will most likely broaden our knowledge about these particles' real origins. Thus, every piece of information gathered in the laboratory can contribute to the overall picture we have of our solar system.