Synchrotron X-ray Microprobe *In Situ* Trace Element Analysis of "Swarm" Particles Collected in Aerogel on the MIR Space Station: Evidence for a CI-Like Composition

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FIG. 1. Particle collector tray exposed on the MIR Space Station (NASA photo).

Introduction

Low-density silica aerogel collectors were flown on the Space Shuttle and the MIR Space Station to collect orbital debris and interplanetary dust particles (IDPs). Most 5 to 25 µm IDPs collected from the Earth's stratosphere by NASA have chondritic compositions. In particular, the Fe/Ni ratio (~17 in chondritic material) distinguishes IDPs from most man-made orbital debris, including plastics, paint flakes, solar cells, and metals. Distinguishing IDPs from orbital debris allows determination of the flux of both types of particles and identification of specific particles suitable for further characterization.

Methods and Materials

Chemical analysis of particles captured in aerogel has previously required the extraction of particles from the aerogel, a tedious and time-consuming procedure. Particle extraction also increases the likelihood of particle contamination or loss. We developed an *in situ* analysis technique[1] and performed *in situ* chemical analyses of particles captured in aerogel, using the Fe/Ni ratio as a preliminary screen to distinguish potential extraterrestrial particles from orbital debris.[1] The particles with approximately chondritic Fe/Ni ratios were analyzed further to compare their contents of moderately volatile elements to meteorites.

We reported the *in situ* chemical analysis of particles captured in aerogel exposed for 18 months on the MIR space station (Fig. 1),[1] performed using an ~15 µm analysis beam, with the x-ray microprobe on beamline X26A of the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. Two aerogel pieces contained a series of parallel tracks, most having identifiable particles at the end, indicating a "swarm" or stream of local, collisionally produced particles struck the aerogel simultaneously (Fig. 2).[2]

Results

The GSECARS x-ray microprobe at the Advanced Photon Source (APS) produces an analysis beam several orders of magnitude more intense and significantly smaller than the NSLS x-ray microprobe. These two characteristics result in a sensitivity ~100 times better than the NSLS microprobe, allowing the detection of volatile elements including Ga, Ge, and Se at CI concentrations in particles as small as ~1 µm. In addition, the smaller beam spot of

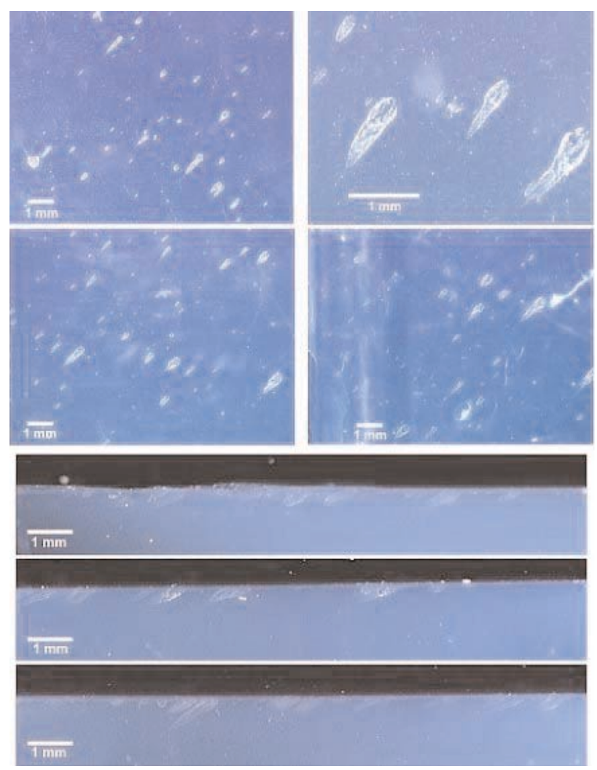

FIG. 2. Swarm particle tracks in MIR aerogel (NASA photo).

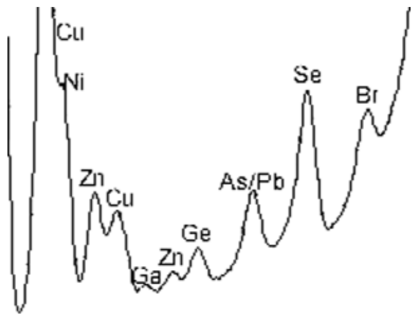

FIG. 3. Portion of the XRF spectrum for a 3 µm particle in aerogel from the swarm. The gallium concentration is 8 ppm.

the GSECARS x-ray microprobe reduces fluorescence from the cylindrical volume of aerogel analyzed along with the particle, decreasing the relative contribution of aerogel to the spectrum, which we hoped would allow detection of Cu and Zn in the particles. Four of the swarm particles, previously analyzed using the NSLS x-ray microprobe, were analyzed with an ~4 µm beam spot using the GSECARS x-ray microprobe. One-hour analysis was sufficient to obtain good quality spectra, allowing detection of Cr, Mn, Ga, Ge, and Se (Fig. 3).

We estimated the size of the largest swarm particle as ~3 µm using the NSLS x-ray microprobe data.[1] By comparing the Fe count rate in the GSECARS microprobe of each of the three smaller swarm particles with that of the larger swarm particle, we infer the other three particles are 1.8, 1.0, and 1.1 µm in size.

In each of the four swarm particles the concentrations of Cr, Mn, Ni (in all but one particle), Ga (in 3 particles where Ga was detected), and Ge (in 2 particles where Ge was detected) are within a factor of 3 of the CI meteorite value, the range of variation we observe in measurements on chondritic IDPs collected from the Earth's stratosphere. The good agreement between the CI meteorite, chondritic IDP, and swarm particle compositions suggests that these swarm particles are chondritic in composition

We established only upper limits on Cu and Zn because of the high Cu and Zn in the aerogel. The Cu and Zn limits provide no useful information, except for the largest swarm particle, because they exceed the Cu and Zn contents of CI material in the other three particles. This demonstrates the importance of insuring that *aerogel flown for particle collection must be relatively clean of elements of interest*. The upper limit on the Zn content of the largest swarm particle is only 40 ppm, approximately one-eighth of the CI value, while the contents of the other volatile trace elements (Mn, Ga, and Ge) are all close to CI. This pattern of low-Zn accompanying chondritic abundances of other moderately volatile elements has previously been reported in IDPs from the stratosphere and attributed to Zn loss during atmospheric entry. The low Zn may indicate this particle was heated above the Zn-loss temperature during deceleration in the aerogel.

Conclusions

These measurements demonstrate the x-ray microprobe on the GSECARS beamline can perform useful, *in situ* chemical analyses of particles as small as ~1 µm captured in aerogel. *In situ* analysis eliminates the time-consuming, physical recovery of particles, and may be particularly important for preliminary characterization of the 1,000 comet fragments, ~10 µm in size, to be returned by the STARDUST spacecraft.

The *in situ* analyses of four particles from a collisionally produced swarm[2] captured in aerogel exposed on the MIR Space Station demonstrates that the swarm particles have compositions similar to the CI carbonaceous chondrites, indicating an extraterrestrial in origin. The largest swarm particle has a Zn content <1/8 the CI value, while the other moderately volatile elements we analyzed were present at ~CI value. This suggests capture of the largest swarm particle may have resulted in moderate heating, although compositional heterogenity cannot be excluded. The thermal effects of hypervelocity aerogel capture on IDPs need to be explored further.

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