IN-SITU CHEMICAL ANALYSIS OF EXTRATERRESTRIAL MATERIAL CAPTURED IN AEROGEL:

G. J. Flynn[1], F. Horz[2], S. Bajt[3], and S. R. Sutton[3] (1) Dept. of Physics, SUNY-Plattsburgh, Plattsburgh NY 12901, (2) NASA Johnson Space Center, Houston TX 77058, (3) The University of Chicago, Chicago IL 60637

High-speed interplanetary dust and orbital debris can be collected non-destructively using aerogel capture cells on earth-orbiting spacecraft and the STARDUST comet sample return mission. In-situ chemical analysis of captured particles is highly desirable for initial classification as space debris or interplanetary dust, allowing quick determination of the dust to debris ratio, and selection of an appropriate analytical protocol for each particle based on a prior knowledge of its type. In a proof-of-principle experiment the X-Ray Microprobe at the National Synchrotron Light Source was used to analyze 50 micron diameter Allende fragments shot into 20 mg/cc silica aerogel at 3 to 6 km/s. A one-second data acquisition allowed determination of Fe/Ni ratios. Five minute data acquisitions allowed analysis of Fe, Ni, Cu, and Zn in Allende fragments as deep as 5 mm below the aerogel surface and Ca was detected in fragments up to 3.6 mm below the surface, demonstrating the ability to identify chondritic material, and distinguish it from orbital debris, by in-situ chemical analysis.

The intact capture of hypervelocity dust particles into aerogel has been demonstrated and aerogel collectors have been flown on earth-orbital space missions [1, 2]. The particles collected in earth orbit include both man-made space debris and interplanetary dust. In-situ chemical analysis of the captured particles would provide a preliminary characterization allowing: 1) rapid determination of the ratio of interplanetary dust to space debris in each size range, and 2) assignment of a specific analytical protocol to each particle based on a prior knowledge of its status as debris or interplanetary dust.

To simulate orbital capture, 43 to 56 micron fragments of the Allende carbonaceous chondrite were launched at 3 to 6 km/s into slabs of silica aerogel having a density of 20 mg/cc, using a 5mm light gas gun. Many of the initial projectiles fragmented during launch, causing a diversity of track lengths. The variable burial depth and fragment mass allowed determination of the feasibility and limitations of in-situ analysis.

The X-ray Microprobe at the National Synchrotron Light Source at Brookhaven National Laboratory, which uses a white-light x-ray beam of approximately 8 microns diameter for excitation, is suitable for in-situ chemical analysis of particles collected in aerogel [3]. Unlike electron microprobes, where the incident beam penetrates to only tens of microns, the highest energy x-rays in this incident beam penetrate several centimeters into low density aerogel. Thus, using the X-ray Microprobe, the detection of an element is dependent on the depth from which the fluorescence x-rays can escape the aerogel rather than on the depth to which the incident beam can penetrate. The X-ray Microprobe analysis is essentially non-destructive, and any sample alteration should be far less severe than that experienced during capture in the aerogel.

Chemical analysis was performed with the incident x-ray beam at a 45^{o} angle to the surface of the aerogel and with an energy dispersive x-ray detector at a 90^{o} angle to the incident beam (see Figure 1). A video microscope with a 5x, long-working-distance objective was located perpendicular to the surface of the aerogel. The sample was mounted on a 3-axis moveable stage, allowing vertical and horizontal motions to center individual particles in the x-ray beam, and motion parallel to the axis of the video camera.

The video system provided sufficient resolution to follow each track from the surface of the aerogel to its termination point. We examined six tracks which had Allende particles at their ends. The depth of each particle beneath the surface of the aerogel was measured by focusing the video microscope on the surface of the aerogel, then moving

Table 1: In-Situ Analyses - Allende Particles Captured in Aerogel

Particle	Depth Below Surface	Elements Detected
Allende 1	3.4 mm	Ca, Cr, Fe, Ni, Cu, Zn
Allende 2	3.0 mm	Ca, Cr, Fe, Ni, Cu, Zn
Allende 3	3.6 mm	Ca, Cr, Fe, Ni, Cu, Zn
Allende 4	4.5 mm	Fe, Ni, Cu, Zn
Allende 5	4.9 mm	Fe, Ni, Cu, Zn
Allende 6	1.1 mm	Ca, Ti, Cr, Fe, Ni, Cu, Zn

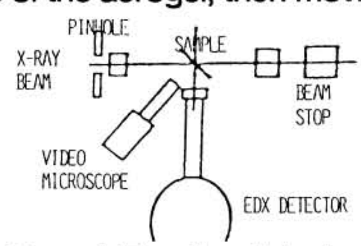

Figure 1: Experimental setup.

the sample in 0.01 mm increments until the Allende fragment came into focus. (The index of refraction of aerogel is sufficiently close to air that no correction was made.) The six fragments ranged in depth from 1.1 to 4.9 mm below the surface (see Table 1).

Chemical analysis of the aerogel showed a major peak at Si, consistent with the composition of aerogel, and a large Ar peak due to Ar in the air along the incident beam path (see Figure 2a). Calcium and Fe were also detected in this aerogel. The Ca in this aerogel may be sufficient to preclude quantitative determination of the Ca contents of some of the Allende samples, emphasizing the importance of selecting aerogels which have a minimum of contamination for particle capture experiments [3, 4].

When an Allende fragment was centered in the incident x-ray beam, strong signals were detected at the Fe and Ni K-alpha and K-beta fluorescence energies. Zinc, and Cu were also detected in all six Allende particles. The volatile elements Cu and Zn provide an unambigous discrimination between most man-made NiFe (with low Zn contents) and chondritic material (with several hundred ppm of both Zn and Cu). Even the deepest particle, Allende 5 (analyzed at a depth of 4.9 mm below the surface), showed clear signals of the Zn and Cu (see Figure 2b). The high Zn and Cu contents suggest little loss of these moderately volatile elements during capture. The observed count rates indicate the current X-ray Microprobe could perform in-situ chemical analysis of particles as small as 5 microns in 15 to 30 minutes.

Fluorescence signals are attenuated during passage through the aerogel, thus the X-ray Microprobe can detect high-Z elements, such as Fe and Ni, at significantly greater depths than elements of lower Z, eg. Ca. Figure 2c shows Ca detection in Allende 6, 1.1 mm below the surface of the aerogel. Very small Ca signals were seen in Allende 1, Allende 2, and Allende 3, at depths of 3.0 to 3.6 mm, but no Ca was detected in Allende 4 or Allende 5, at depths of 4.5 and 4.9 mm below the surface of the aerogel. If the Ca contents of the 6 Allende particles are all similar, this result suggests our maximum sampling depth for Ca in aerogel of density 20 mg/cc is of order 4 mm.

Since typical meteoroids travel about 100 projectile diameters before stopping in 20 mg/cc aerogel [2], particles up to ~10 microns in diameter should stop within 1 mm of the aerogel surface, while 50 micron particles should stop within 5 mm of the surface.

To determine the minimum time required to identify a chondritic particle, one-second data acquisitions were performed on Allende 2 and on the aerogel about 300 microns from Allende 2. Both Ni and Fe were detected in Allende 2 in one-second, indicating we can identify a chondritic particle and determine its Ni/Fe ratio with a data acquisition time of less than one second. Thus a mapping experiment to locate all chondritic particles in an aerogel sample would require no longer than one second per pixel in the map.

These results demonstrate that the X-ray Microprobe can perform in-situ chemical analyses of interplanetary dust and orbital debris captured in aerogel. Chondritic material can be identified, and metallic debris containing iron, copper or other high-Z elements can be distinguished from chondritic material, at depths exceeding 5 mm in 20 mg/cc aerogel. The X-ray Microprobe can also provide in-situ chemical characterization of particles captured in aerogel on comet sample return missions, such as STARDUST.

References: 1) Tsou, P. et al. (1993) Lunar & Planet. Sci. XXIV, 1443-1444. 2) Brownlee, D. E. et al. (1994) Lunar & Planet. Sci. XXV, 183-184. 3) Flynn G.J. and Sutton, S.R. (1994) in Workshop on Particle Capture, Recovery, and Velocity/Trajectory Measurement Technologies, LPI, Houston, 36-37. 4) Barrett et al. (1992) Proc. 22nd Lunar Planet. Sci. Conf., LPI, Houston, 203-212.

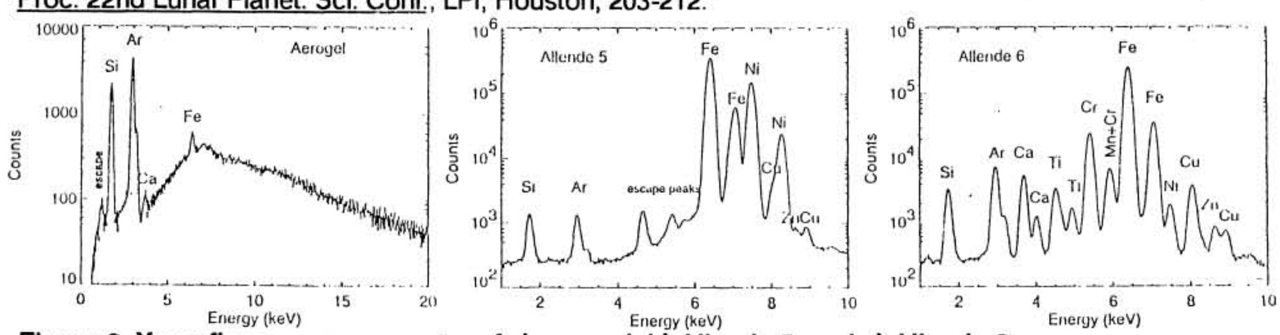

Figure 2: X-ray fluorescence spectra of a) aerogel, b) Allende 5, and c) Allende 6.