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Hypervelocity Capture of Meteoroids in Aerogel

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1. Introduction

Micrometeoroids of cometary or asteroidal origin constitute a unique repository of information concerning the formation and subsequent processing history of materials in the solar nebula. One of the current goals of planetary science is to return samples from a known primitive extraterrestrial body for detailed laboratory analysis (NASA Solar System Exploration Committee, SSEC 1983). Planetary flyby orbital motions dictate that dust particles will approach the spacecraft at relative speeds up to tens of km/s. It has always been thought that these hypervelocity particles could not be captured without melting or vaporizing. We have developed the intact capture technology that enables flyby sample return of these hypervelocity particles. The STARDUST comet sample return mission, selected as the fourth NASA Discovery mission, capitalizes on this technology (Brownlee et al. 1996).

2. Intact Capture Technique

For decades, it was accepted that projectiles traveling faster than a speeding bullet could not be captured intact. After a decade of effort, the development of a passive collection technique suitable for intact capture of hypervelocity particles was successfully demonstrated under laboratory simulations for iron particles 0.1 *mu*m in size traveling at speeds up to 20 km/s (Tsou & Albee 1992).

2.1. Laboratory development

In 1983, initial laboratory experiments were performed with 3.2-mm-diameter aluminum projectiles impacting expanded polystyrene foam of 18 mg/ml density at a speed of about 6 km/s using NASA Ames' Vertical Two-Stage Light-Gas Gun (Tsou et al. 1984). This resulted in the startling discovery that more than 75% of the original projectile mass was captured intact. Subsequently, to generate a good database of intact capture, systematic and extensive simulation experiments were performed with a two-stage light-gas gun, a plasma drag gun and an electrostatic accelerator (Tsou et al. 1988). The light-gas gun simulation experiments consisted of launching projectiles with known mass and integrity at known speeds into various capture media under vacuum and at room temperature. The captured projectiles were then characterized by measuring the mass recovered, perimeter profiles, and surface erosion features. The capture media were examined for track profile, mass loss and surface composition. Methods of analysis included optical and electron microscopy and x-ray diffractometry.

To assess the effects of projectile size selected experiments with projectile sizes ranging from 0.1 μm to 6.35 mm were performed. To better characterize the influence of projectile material on intact capture, iron, copper, lead, glass, meteorites, and even lunar sand grains were used (Tsou et al. 1991). To investigate the mesostructural effects of capture media, polymer foams, films, fibers, microspheres, and high density gas were tested. Many polymer foams, including polystyrene, polyurethane, polyethylene, and polyamide, were tested with densities ranging from 9 to 100 mg/ml. Thus far, the highest intact mass recovery in the 6 km/s range, 98% recovered at 1.6 mg, has been obtained using foams made from polystyrene with mesostructure in the range of microns (Tsou et al. 1989).

2.2. Effective capture media

As more hypervelocity intact capturing experiments were performed, a clear set of capture media material properties, producing good intact capture results began to emerge, i.e., the capture media must be extremely underdense, that is the bulk density becomes considerably less than the parent material. Our experiments have shown that intact recovery does not follow the reduction of capture media density indefinitely. In fact, below a threshold of low densities, the mesostructure of the capture medium dominates the effectiveness of intact capture (Tsou et al. 1992). That is, a capture medium with considerably lower bulk density produces less intact capture than one with higher bulk density, but with a finer mesostructure.

Since our objective was the development of an intact capture technique for acquiring cosmic dust in the 0.1 μm to 100 μm size range, the ability to locate and remove captured particles was nearly as important as their capture. Not finding a captured particle in an opaque capture medium is equivalent to no capture at all.

3. New Capture Media

The search for a better intact capture medium focused on low density, fine mesostructure and high transparency materials. Beginning in early 1986, silica foam, metallic smoke, water glass, and other exotic laboratory novelties were explored as possible transparent capture media. Not until January 1987, was silica aerogel discovered to be an ideal intact capture medium. The mesostructure was in the range of tens of Ångströms, and it can be made very transparent! Lawrence Livermore National Laboratory (LLNL) initially provided aerogel samples for our intact capture experiments. They continued to improve their low density aerogel by increasing it's clarity, minimizing it's defects, and lowering it's densities. Since no amount of laboratory simulation can substitute for capturing actual hypervelocity particles in space, a concerted effort was made to gain space access. This turned out to be a decade long pursuit which was finally realized in 1992. We have flown aerogel in space every year since.

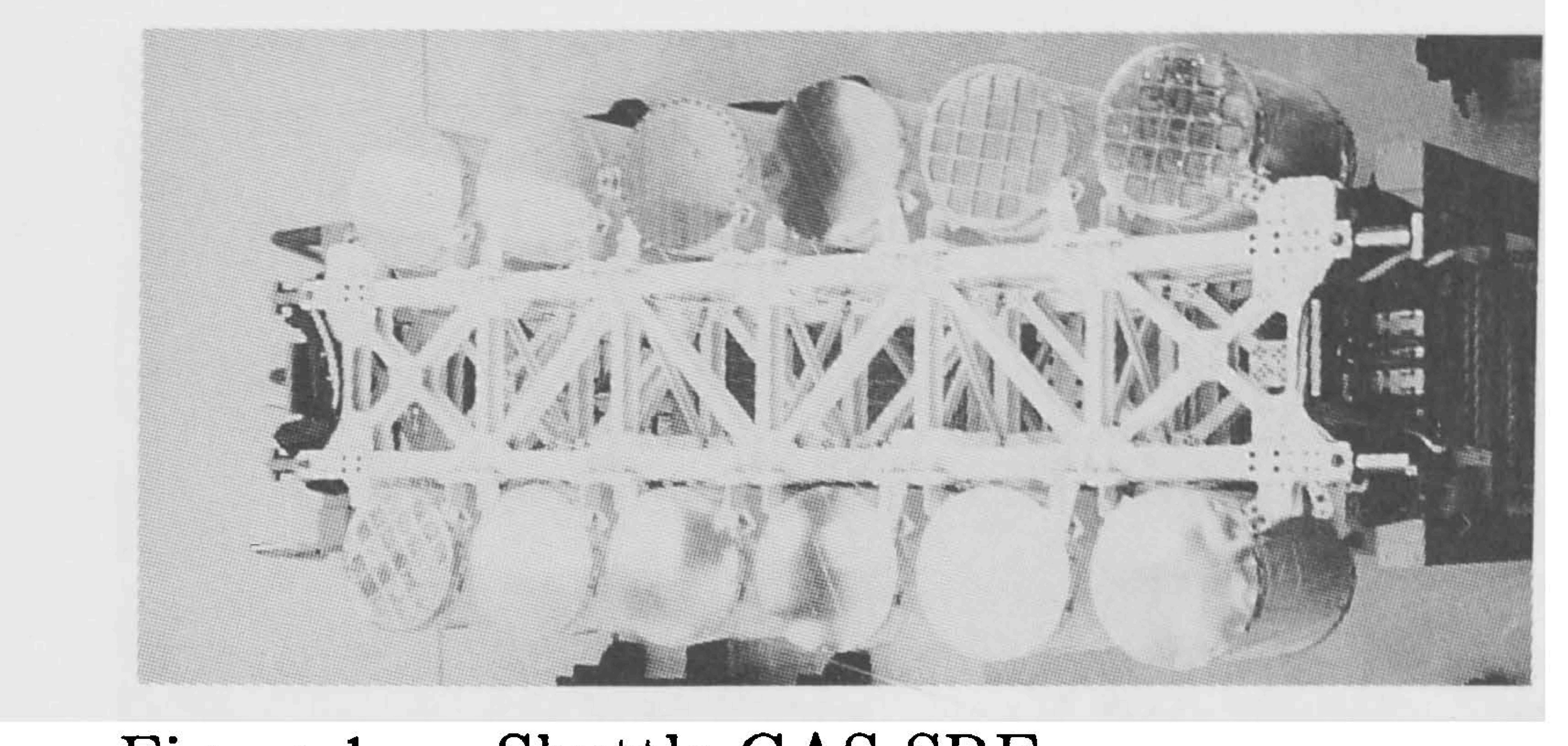


Figure 1. Shuttle GAS SRE

3.1. Shuttle GAS SRE

Space access was first accomplished via thermal insulated end covers flown on the Shuttle Get Away Special (GAS) payload canisters modified to hold our Sample Return Experiment (SRE) of aerogel capture cells (Tsou et al. 1993). These modified end covers containing our SRE were placed on top of the GAS payload canisters for exposure to open space. Each SRE is 57.6 cm in outer diameter, and contains twenty-one 10 cm × 10 cm × 1 cm silicon aerogel capture cells. The JPL fabricated silica aerogel capture cells had densities on the order of 20 mg/ml. Each of the aerogel capture cells was fabricated individually in the desired dimensions. Each GAS SRE provides a net total of 0.165 m^2 capture surface. Figure 1 shows our SRE mounted on the GAS bridge before integration into the Space Shuttle payload bay. To date, there have been five GAS SRE flights: STS-47, STS-57, STS-64, STS-68 and STS-72. The separate collectors with 27 aerogel cells were flown on the Wake Shield experiment onboard STS-69.

3.2. Shuttle Spacehab SRE

Spacehab is a commercial endeavor subscribed by NASA to facilitate space access flight for commercial businesses. On STS-60, two large modules with 80 silica aerogel capture cells per panel were flown resulting in a total exposed surface area of nearly 1.6 m^2. The silica aerogel capture cells were our standard 10 cm × 10 cm × 1 cm cell of 20 mg/ml density. Figure 2 shows the aerogel in flight aboard Spacehab with a view of Earth in the background.

3.3. ESA Eureka TiCCE

The first long duration aerogel space flight was flown aboard the Eureka TiCCE experiment (McDonnell 1994). It consisted of four 10 cm × 10 cm × 0.1 cm aerogel cells made by LLNL mounted on top of TiCCE tray modules. The total exposed area was 0.04 m^2 with a six months exposure time.

3.4. Results

All of our 313 space exposed aerogel cells were returned to Earth without any apparent damage. Upon initial examination, there were at least four large hypervelocity particles captured in three of the cells from STS-47 and more than two dozen from STS-60. More than ten carrot shaped tracks have been found in Eureka exposed samples (Brownlee et al. 1994). Initial optical examination of

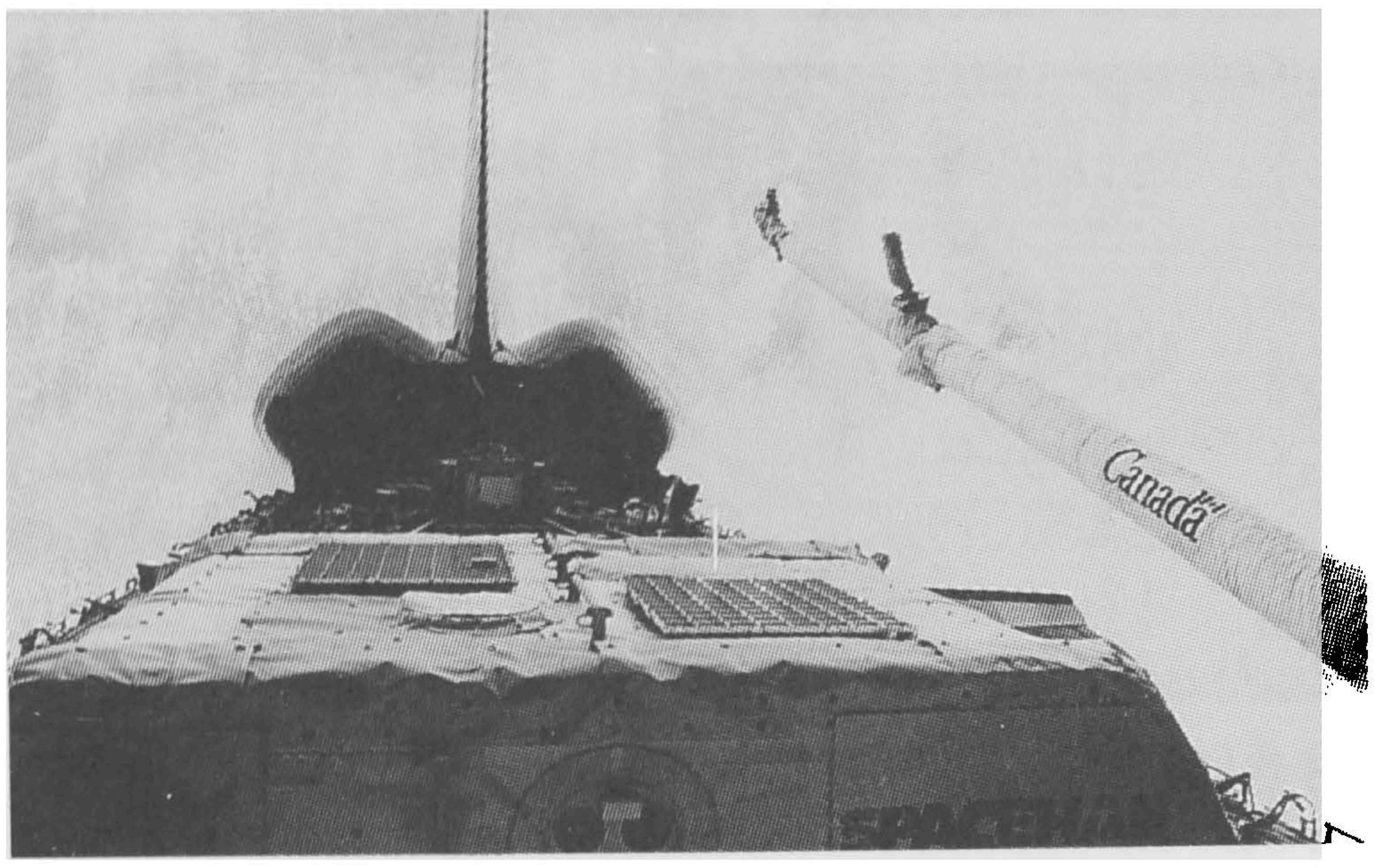


Figure 2. Shuttle Spacehab SRE

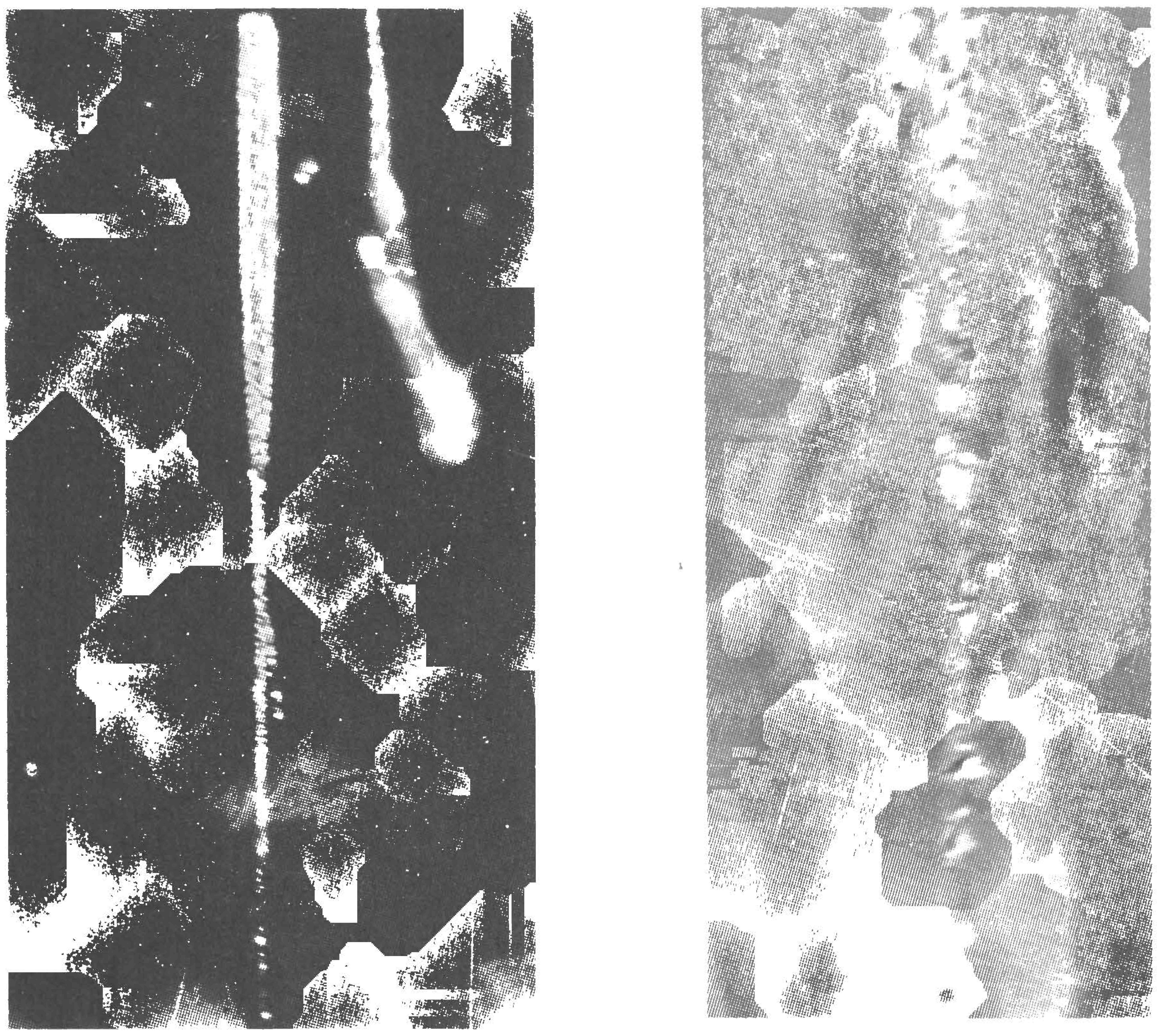
these tracks has been carried out showing captured hypervelocity particles being intact. Figure 3a shows a captured particle with a typical carrot track. The intact particle is lodged at the end of the track. The track length is typically 100 to 200 times the diameter of the captured particle and serves as an excellent pointer, thus essential in locating the particle. Figure 3b is an enlarged view of particles at the end of their tracks in Figure 3a. Six of these particles have been removed from aerogel and mounted for detailed study. Two of these particles are found to be 5 and 10 μm diameter spheres of Al_2O_3 as determined by scanning electron microscopy. They are most likely solid rocket fuel remnants. Other analytical techniques are used as required for specific studies. Ample evidence of the notorious Shuttle payload bay contamination has also been verified through captured debris on our aerogel cells.

4. Uniqueness of Aerogel for Space Flights

The initial motivation for using silica aerogel was for a transparent medium that possessed low density and a fine mesostructure. With increased aerogel space flight experience, we have learned of other exceptional aerogel properties such as: it has the lowest density solid and the widest density range, the highest surface area to mass ratio, has space launch robustness, thermal cycling stability, radiation tolerance and ionic stability (Tsou 1995).

4.1. Particle shielding

A unique feature is that melted aerogel sticks to the frontal surface of the projectile. This effectively reduces the projectile speed and protects the projectile from further physical erosion. The melted layer wrapping around the frontal portion of the projectiles seemed to be much more pronounced in silica aerogel than in polymer foams, as shown in Figure 4. This very useful effect increases intact capture, is especially beneficial for capturing tiny and fragile dust particles, and may further help in preventing the breakage of fluffy particles.



(a) (b)

Figure 3. Intact captured particle in Aerogel

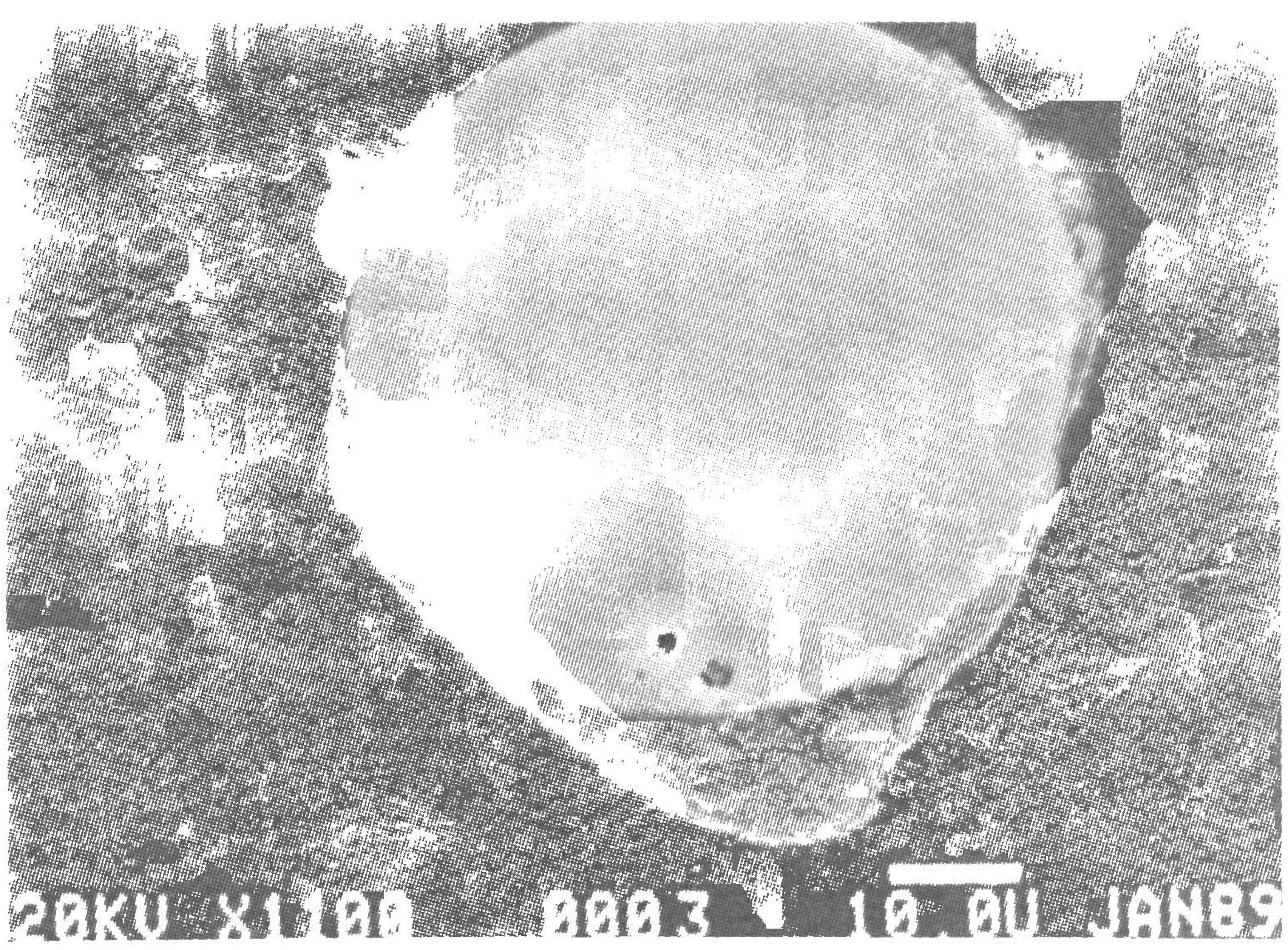


Figure 4. Aerogel wrapped particle

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4.2. Cleanliness

It is important that the capture medium be extremely pure and clean in order to minimize source uncertainty and cross contamination. The best commercially available clean materials are silicon wafers used in the production of semiconductors. We were pleasantly surprised to learn that the silica aerogel produced at JPL is of comparable cleanliness to semiconductor silicon. This results from the inherent thermal cleaning nature of the critical point extraction process.

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References

Brownlee, D., F. Hörz, L. Hrubesh, J.A.M. McDonnell, P. Tsou & J. Williams 1994, LPSC 25, 183

Brownlee, D.E., D. Burnett, B. Clark, M.S. Hanner, F. Hörz, J. Kissel, R. Newburn, S. Sanford, Z. Sekanina, P. Tsou & M. Zolensky 1996, these proceedings.

McDonnell, J.A.M. 1994, LPSC 25, 867

SSEC, NASA 1983, 149

Tsou, P., D.E. Brownlee & A.L. Albee 1984, LPSC 15, 866

Tsou, P., W. Kromydas & A.L. Albee 1988, LPI No. 88-01, 62

Tsou, P., D.E. Brownlee & A.L. Albee 1989, LPSC 20, 1132

Tsou, P., D.E. Brownlee & A.L. Albee 1991, LPSC 22, 1419

Tsou, P., D.J. Griffiths & D.J. Buettner 1992, "ASP Topical Conference on Shock Compression of Condenced Matter", 955

Tsou, P & A.L. Albee 1992, LPSC 23, 1453

Tsou, P., D.E. Brownlee & A.L. Albee 1993, LPSC 24, 1443

Tsou, P. 1995, J. Non-Cryst. Solids, 186, 415