A FLUORESCENT AEROGEL FOR CAPTURE AND IDENTIFICATION OF INTERPLANETARY AND INTERSTELLAR DUST.

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Aerogels are extremely low-density solids whose superiority as capturing media for hypervelocity ($v > 0.5$km/s) grains has been well established [2, 7, 8]. A prominent example is the use of silica aerogel as the collecting medium for cometary and interstellar grains on NASA's Stardust mission [3].

Aerogel collectors have been deployed in low-earth orbit, but severe background from anthropogenic orbital debris has so far prevented the identification of more than a handful of interplanetary particles [7]. No interstellar particles have been identified so far. Since they are on hyperbolic orbits, extraterrestrial particles are faster than orbital debris, so could in principle be identified on that basis, but existing aerogels give little information on impact velocity. With this in mind, we have developed a novel calorimetric aerogel which passively records the kinetic energy of captured hypervelocity particles.

The capture of a hypervelocity dust particle in aerogel produces a shock wave that deforms, heats, and vaporizes the aerogel material in the vicinity of the projectile's trajectory, resulting in the formation of a permanent track. The correlation between captured projectile velocity and track characteristics (e.g., track length, track volume, etc.) is poor [8]. This behavior is expected theoretically [1, 11, 4]. The amount of local heating, however, is nearly linearly proportional to the projectile kinetic energy [1]. If this local heating alters some property of the aerogel in the vicinity of the track, then this property could be used as a calorimeter. We chose to focus on inducing a fluorescence signal. We have observed fluorescence resulting from the thermal alteration of aerogels previously in various doped aerogel systems, which fluoresce weakly in their amorphous state and strongly when baked at high temperatures ($\simeq 1000^\circ$C) for extended periods of time ($\sim$ 1hr). A simple example of such a system is alumina aerogel doped with chromium (III). The amorphous, unheated phase is only very weakly fluorescent under UV illumination (254 nm or 365 nm). Heating the aerogel to 1450° C causes it to crystallize to the well-known luminescent phase α-Al_2O_3:Cr, known in Nature as ruby, which glows red ($\lambda_{max} \simeq 700$nm) under UV illumination. More complex systems include alumina gels co-doped with Gd and Tb. Gd acts as a sensitizer by absorbing UV light at certain wavelengths and nonradiatively transferring energy to Tb, which emits at several wavelengths, principally in the green.

Local heating that results from the capture of hypervelocity projectiles is rapid and confined to small regions in the aerogel. However, the inducement of a fluorescent state as a result of rapid (t$< 200\mu$s), local heating (within $< 100\mu$m of the particle track) in an aerogel has previously not been reported. To test whether local heating in an aerogel could induce an irreversible phase transformation into a fluorescent phase, the effects of hypervelocity projectile capture were first simulated by exposing samples of Cr-doped and (Gd,Tb)-doped alumina aerogels ($\rho \sim$170 mg/cc) with a pulsed CO_2 laser (300 Hz, 50μm spot size, pulse width=50μs, power=0.25-0.50 W). The energy per pulse is approximately the energetic equivalent of a glass sphere 10 microns in diameter impacting at 10 km/s. Some of these aerogels displayed brilliant green fluorescence in the regions of local heating. This was encouraging evidence that the capture of hypervelocity dust particles could induce a fluorescent phase in alumina aerogels. These alumina aerogel samples were selected for shots with hypervelocity projectiles (a mix of powdered meteorite and glass beads) at the Advanced Vertical Gun Range at NASA Ames Research Center. Two of these samples showed intense green fluorescence in the heated material surrounding the particle tracks, thus establishing that the phase transformation occurs in alumina aerogels (See Fig. 1). Quantitative measurements with these shots were precluded because of the large spread in particle sizes and the unknown effect of particle ablation. These shots were followed more recently, again at Ames, with projectiles consisting of a mixture of monodisperse glass spheres. This allowed us to do quantitative measurements of the fluorescence yield as a function of particle size and velocity.

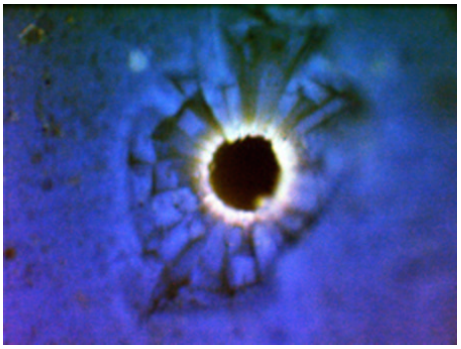

Fig. 1: Fluorescent track mouth of a captured hypervelocity dust particle, v$\simeq 4.72$km/s.

The fluorescence yield was measured using a standard fluorescence microscope with an attached cooled color CCD video camera. The fluorescence was excited at 365 nm. When analyzed, we found that the fluorescence yield, I_g , appears to be consistent with being a single-valued function of the particle kinetic energy, $I_g \propto E_k^{0.69}$, over the range from 2μm to 20μm (three orders of magnitude in mass). Details of the image analysis can be found in [5] (See Fig. 2).

The Stardust spacecraft, whose primary mission is to return samples of cometary dust to Earth for laboratory study, has exposed aerogel collectors to the interstellar dust stream during two periods of its cruise phase. The Stardust collectors will be returned in 2006. Models of the IS dust flux in the inner solar system indicate that the Stardust collectors will capture $\sim$ 10 1-μm particles, and perhaps one 2-μm particle. An array of calorimetric aerogel, with collecting area of 3 m^2 deployed in low earth orbit for two years, would have enough collecting power to collect several hundred 1-μm particles IS particles [9]. A collector deployed on the wake side of a spacecraft in low-earth orbit could collect IS dust at moderate velocites ($<$ 10 km/s) during periods of the year when the earth's motion is most parallel to that of the IS dust stream [6]. Furthermore, the largest particle expected to be captured by such an array would be $\sim$30 times more massive than the largest particle expected to be collected by Stardust [9] (see Fig. 3). These particles would be large enough to apply multiple chemical, mineralogical, and isotopic analysis techniques to each particle [12].

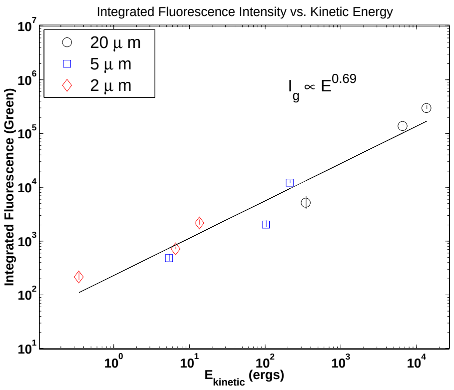

Fig. 2 I_g^{net} vs. Kinetic Energy of Hypervelocity Projectiles. The error bars are statistical only.

Interplanetary dust particles could also be captured and identified using calorimetric aerogel collectors. A single collector that is large enough to capture, in space, several 100 μm particles — characteristic of AMMs — along with IDPs could clarify the relationship between them. The origin of AMMs in particular is important since they constitute the greatest contemporary mass input to the earth [10], and could have contributed a significant amount of water and organics to the early earth.

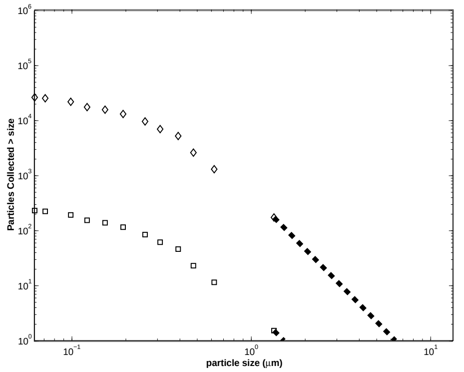

Fig. 3: Cummulative number of interstellar dust grains vs. size expected to be collector in low-earth orbit (◊) compared to the Stardust mission (□). The collecting area of the low-earth orbit collector is assumed to be =3 m^2, exposed for 3 years. The extrapolated portion of the calculation assumes an IS flux that falls off as $m^{-1.1}$.

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