DENSITIES OF 5-15 μm INTERPLANETARY DUST PARTICLES; S. G. Love, D. J. Joswiak, and D. E. Brownlee, Department of Astronomy FM-20, University of Washington, Seattle, WA 98195.

We have measured the densities of about 100 5-15 μm stratospheric IDPs. Great care was taken to minimize selection bias in the sample population. Masses were determined using an absolute x-ray analysis technique with a transmission electron microscope, and volumes were found using scanning electron microscope imagery. Unmelted chondritic particles have densities between 0.5 and 6.0 g/cc. Roughly half of the particles have densities below 2 g/cc, indicating appreciable porosity, but porosities greater than about 70% are rare. IDPs with densities above 3.5 g/cc usually contain large sulfide grains. We find no evidence of bimodality in the unmelted particle density distribution. Chondritic spherules (melted particles) have densities near 3.5 g/cc, consistent with previous results for deep sea spherules.

Particle Selection and Compositions: Roughly 200 dark colored 5-15 μm particles were randomly selected from stratospheric cosmic dust collection surfaces U2-30 and U2012. The sample set represents well the extraterrestrial dust population in the stratosphere. To accurately represent the exoatmospheric population, density sorting by atmospheric fall speed (which may be partially offset by the tendency for low-density particles to stay entrained in the ram air stream and miss the collection plate) and atmospheric entry effects (although most IDPs of this size are relatively unaltered during atmospheric entry [1]) must be considered.

The particles were arranged on Nuclepore filters, and quantitatively analyzed for elemental composition in a SEM using a 20 kV beam, following the EDX method described by Schramm *et al.* [2]. The ≈100 particles that proved to be extraterrestrial formed the sample for this work.

Masses: Individual particle masses were found in a manner analogous to the synchrotron x-ray fluorescence technique of Flynn and Sutton [3], except that we used the 120 kV beam of a TEM to excite Fe Kα x-rays in each particle. For these small particles, the 120 kV beam illuminates the entire volume, and x-ray self-absorption is negligible, so the Fe Kα flux from a particle is proportional to the number of Fe atoms it contains. Using controlled beam raster areas and calibrating with stainless steel standard spheres of known size, mass, and iron abundance, we were able to determine the absolute Fe content of each particle from its Fe Kα emission. The inferred mass of iron in each particle, divided by its abundance of iron as found in the elemental analysis described above, yielded its total mass.

The mass determination technique was checked by examining the set of 1-6 μm stainless steel calibration spheres. Figure 1 shows Fe x-ray counts as a function of mass (as computed from density and measured volume) for the spheres. The number of counts is strictly linear with mass, with only one significant exception, which probably contained a void or air bubble. The relation shows no decline at the high end, the expected result if electron beam attenuation or x-ray self-absorption were important at these sizes. The method for finding masses is valid for particles up to at least 20 μm diameter if they have chondritic density and iron content.

An uncertainty in this method is the unknown oxidation state of iron in the particles. For chondritic particles, however, no reasonable oxygen abundance causes a large change in the derived mass. Another uncertainty is the carbon abundance, as carbon is not seen by the x-ray detector. Gross compositional inhomogeneity in a particle can add uncertainty if the 20 kV SEM EDX spectrum does not accurately represent the particle's bulk composition.

Volumes: Particle cross-sectional areas were measured by tracing outlines of their SEM photos into a computer, which measured the shape's area within a few percent. Particle heights were measured with the TEM in SEM mode, using high magnification and a configuration that yields a narrow depth of focus. The height was found using the difference in focus steps between the substrate and a representative point near the top of the particle. Calibration of focus steps to actual distance was performed using the standard spheres, and fell within 5% of the JEOL 1200 TEM factory calibration. The uncertainty in the height measurement was ± 0.5 μm. The heights of the particles were generally less than or nearly equal to their widths.

Volumes were computed using $V=0.7Ah$, where A is the cross-sectional area and h is the height. The leading factor 0.7 is adapted from a general formula for the volumes of regular solids [4]. The estimated uncertainty is no more than 20 percent for reasonable shapes. The possibility of embayments and shape irregularities out of the line of sight means that we tend to overestimate volume and underestimate density.

Results and Discussion: The distribution of densities for unmelted particles is presented in Fig. 2. The mean density of unmelted chondritic stratospheric IDPs is 2 g/cc, and the range is 0.5 to 6.0 g/cc. The mean density of chondritic spherules in this sample is 3.5 g/cc, comparable to the 3.0 g/cc result of Murrell *et al.* [5] for deep sea spherules.

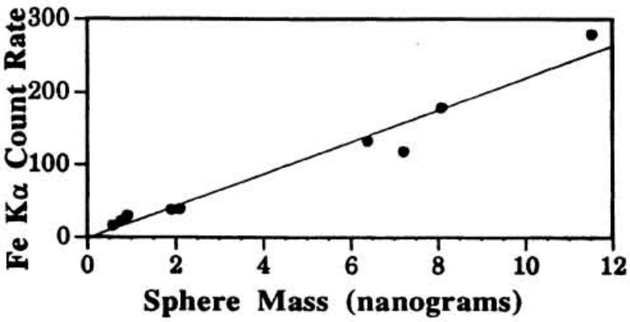

Fig. 1. Steel Sphere Counts vs. Mass

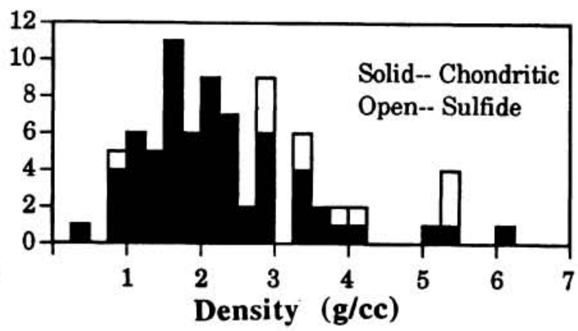

Fig. 2. Unmelted Particle Density Distribution

Flynn and Sutton [3] found a mean density of 1.2 g/cc for unmelted IDPs, a significantly lower value than ours, but consistent with the results of Zolensky *et al.* [6] who used an INAA method. Both studies found a large proportion of particles with densities below 1.0 g/cc. Fraundorf *et al.* [7] found an average IDP density similar to ours, using more direct techniques for measuring mass and volume. A standard NASA micrometeoroid model [8] assumed an average density of 0.5 g/cc based on meteor studies.

In our sample, we find no particles with densities below 0.5 g/cc. This is not an absolute statement, as three very porous and fluffy particles which fragmented during capture or analysis were not measured. They could have had very low densities, but in view of the fact that they comprise only 3% of our sample, we must conclude that particles with very low densities (and porosities in excess of 70%) are rare.

Flynn and Sutton have suggested that the IDP density distribution contains two clearly distinct populations, on the basis of 25 particles' measured densities [3]. We see no indication of a bimodal distribution, finding instead a single broad peak around 2 g/cc with a high density tail. Possible explanations for the discrepancy include the fact that many previous studies' particles were selected from a catalog of SEM photographs, and may thus be more subject to selection biases (based on shape and consistency) than the particles studied here. We also examined smaller particles. In addition, the present study took greater care to measure particle compositions completely.

The results of this work have implications for the assessment of meteoroid collisions with spacecraft and with one another, the effects of Poynting-Robertson orbital decay on interplanetary dust motes, theoretical models of the zodiacal light, and calibration of micrometeoroid detectors. This study also affects the treatment of meteoroid flight in the atmosphere. The difference in mean density between melted and unmelted particles indicates that micrometeoroid densities change upon melting, an effect which has not been treated in atmospheric entry calculations.

References: [1] Love, S. G., and D. E. Brownlee (1991) Icarus **89**, 26-43. [2] Schramm, L. S., *et al.* (1989) Meteoritics **24** 99-112. [3] Flynn, G. J., and S. R. Sutton (1990) LPS XXI, 375-376. [4] Hodgman, C. D., ed. (1957) CRC Mathematical Tables, Chemical Rubber Publishing Co., Cleveland. [5] Murrell, M. T., *et al.* (1980) Geochim. Cosmochim. Acta **44**, 2067-2074. [6] Zolensky, M. E., *et al.* (1989) LPS XX, 1255-1256. [7] Fraundorf, P., *et al.* (1982) LPS XII, 225-226. [8] Cour-Palais, B. G. (1969) NASA SP-8013.