Many IDPs in the 5µm to 15µm size range contain extraordinarily high abundances of He. In a project to measure IDP entry velocities [1] with the Nier/Schlutter stepped He method [2], we have observed IDPs with He concentrations in excess of 10 cc(STP)g⁻¹. This corresponds to 0.2 wt % He averaged over the particle! The origin of this He is somewhat of a mystery. In addition to high concentration, it often occurs with ³He/⁴He ratios that significantly differ from solar wind values. In many cases the ratio is lower than SW and consistent with an appreciable SEP component [3].

In TEM studies of microtome thin-sections of He-rich IDPs we have noted vesicles that we believe are He bubbles. We have seen these in olivine, amorphous silicate and pyrrhotite. They were most prominent in sulfides, an observation possibly related to the defect structure of Fe(1-x)S. The bubbles range in size from a few nm up to 50 nm in diameter with 25 nm being a common size. In the sulfides we have seen remarkable regions of euhedral voids showing crystallographic alignment. The form of these aligned euhedral bubbles is very similar to that observed in metal foils that have been implanted with noble gases at doses above 10¹⁵ cm⁻² and then heat treated [4,5]. Extensive laboratory studies of He-implanted metal foils have demonstrated that with heating, bubbles grow due to He diffusion and defect migration. In unheated foils, bubbles are indistinct and only a few nm in size but with heating, the bubbles coarsen, become more distinct and grow to 10's of nm in size. In metals, appreciable bubble enlargement occurs when the matrix metal is heated to approximately one half of its melting temperature. As bubbles grow, their internal pressures decrease from the kbar range and ultimately they begin to coalesce. Futagami et al. [6] have observed surface fractures due to bursting of bubbles in irradiated and heated olivine samples. In some of the IDP samples, we believe that pulse heating during atmospheric entry causes the He bubbles to grow and become more apparent. In a sense the pulse heating "develops" the He bubbles, enlarging them so that they can be readily seen in the TEM.

The ability to image He bubbles provides a variety of new types of information. They provide yet another heating indicator useful for identifying strongly heated IDPs, they provide information on the nature of irradiation and, with the depth distribution, they may provide insight to the energy and penetration depth of He. Because He bubbles can be imaged on very small scales, their presence may provide a means to visualize He distributions at the submicron level. This might be used to detect episodes of irradiation of IDP component grains prior to their accretion to form aggregates. Potentially, this technique could be applied to Lunar and other meteoritic materials if they were heated in the laboratory to enlarge (develop) the He bubbles. This might also be done in a heating stage where bubble growth could be dynamically observed in real-time.

We believe that we have directly seen He bubbles in IDPs, although to be cautious it is possible that the voids have other origins. The high He concentration, bubble distribution near grain edges and the thermal history of the particles, all suggest that the observed voids are He bubbles. Void structures reported by Akai [7] in olivine from thermally metamorphosed carbonaceous chondrites were also described as "most likely" due to irradiation damage, although other sources such as metamorphism, shock effects, sample preparation and other alteration processes were not ruled out. We have observed euhedral vesicles in terrestrial pyrrhotite that was heavily irradiated with 4 kev He ions in a special facility at the University of Minnesota. Bubbles were seen in heated samples but not in unheated or non-irradiated samples. Support for the "tiny He Bubble" interpretation of the voids also comes from EELS observations at MVA Inc. A 200 keV transmission electron microscope was used to
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determine whether He could be detected in the bubbles using parallel electron energy loss spectroscopy (PEELS). An under-saturated electron beam with an energy spread of ~0.8 eV (measured on the zero-loss peak at FWHM) was positioned on individual bubbles. To minimize He loss resulting from irradiation damage, acquisition times were kept to a minimum. Small edges superimposed on the plasmon-loss peak at ~22 eV were observed in spectra from several bubbles. The position of the edges (22 eV) is consistent with the He-K (1s→2p) core scattering edge, although additional PEELS measurements of implanted standards are required to confirm the observations.

The He bubbles in IDPs are not the only small voids in IDPs and there is potential for confusion with other artifacts. Small vesicles are commonly seen in amorphous carbon regions in IDPs although they appear to occur in a much wider range of sizes than He bubbles. The vesicles in carbon range up to micron-size and are most likely made by escaping volatiles other than He [8]. We have also seen small voids in phyllosilicates. These are more erratically shaped than He bubbles and most likely they are products of result of dehydration processes during atmospheric entry heating. The general characteristics of the purported He bubbles is a high concentration of nm to 50nm bubbles near grain edges.


Figure 1 Noble gas bubbles in a Ni film that was implanted with a 4\times10^{16} \text{ cm}^{-2} dose of Kr ions and then thermally annealed at 650 C. This TEM image is from Birtcher 1991 [4].

Figure 2 He bubbles in pyrrhotite from the IDP U2-12A2J. The stepped He release profiles indicate that this particle was heated to 900 C during atmospheric entry heating. This is a TEM image of a microtome section with the exterior of the particle on the right. Scale bar = 100 nm.