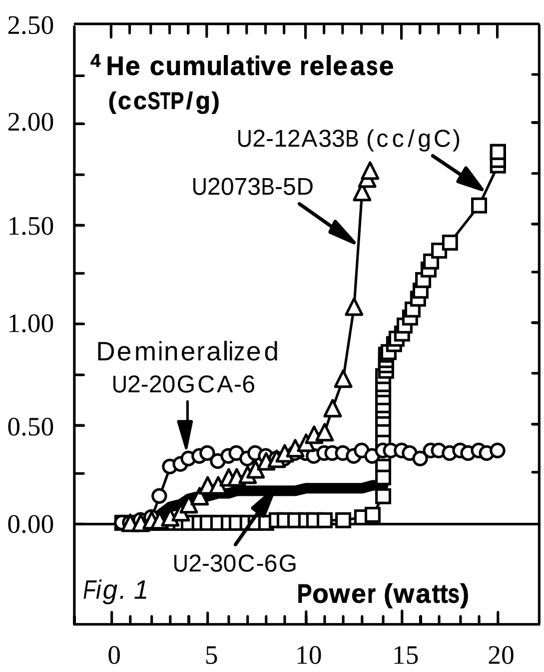
HELIUM AND NEON IN CARBON-RICH PHASES OF INTERPLANETARY DUST PARTICLES. R. L. Palma[1], D. J. Schlutter[2], R. O. Pepin[2], D. E. Brownlee[3], and D. O. Joswiak[3]; [1]Department of Physics, Sam Houston State University, Huntsville, TX 77341, [2]School of Physics & Astronomy, University of Minnesota, 116 Church St. S. E., Minneapolis, MN 55455, USA (e-mail: pepin001@tc.umn.edu), [3]Department of Astronomy, University of Washington, Seattle, WA 98195.

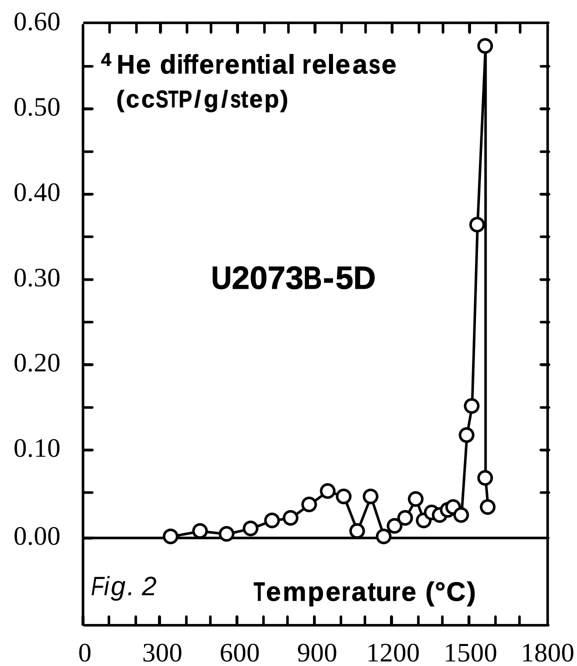
Interplanetary dust particles (IDPs) are exposed to solar wind (SW) and solar energetic particle (SEP) radiation as they spiral sunward by Poynting-Robertson drag. SW ions penetrate particle surfaces to depths of 10s of nanometers; implantation depths of SEP ions are poorly known but are probably on the order of ~1 µm. Saturation doses of SW-He are incident on grain surfaces in just a few centuries of exposure near 1 AU. One would therefore expect the He inventories of IDPs impacting the top of the Earth's atmosphere to be dominated by SW-SEP mixtures residing largely in surficial and thermally labile sites. Measured $^3He/^4He$ ratios do indeed fall between the SW and SEP compositions for the majority of IDPs [1] (others, however, display intriguing and as yet unexplained elevations of $^3He/^4He$ that cannot be due to solar corpuscular radiation [1,2]). Flash heating of IDPs during atmospheric drag deceleration depletes these SW-SEP reservoirs and shifts laboratory ^4He release profiles toward higher temperatures, to extents that depend on the intensities of drag-heating. These profile shifts have been used as relative measures of IDP atmospheric entry speeds and thus as a way to distinguish between probably asteroidal and probably cometary particles [3,4].

Cumulative ^4He release profiles generated by stepped degassing of a suite of twelve mostly "chondritic" IDPs recently provided by D. Brownlee were, with one exception, characteristic of those observed in earlier experiments. An example is shown by the heavy line for IDP U2-30C-6G in the Fig. 1 plot of cumulative release vs. power delivered in each 20-heating step to the folded Pt foil



containing the sample. Its total ^4He loading of 0.19 ccSTP/g was somewhat higher than usual for "normal" IDPs but still not greatly above a typical concentration. Helium evolution from U2-30C-6G peaked at a power of ~3W. The corresponding maximum-release temperature of ~750•C was also typical, falling toward the lower end of the range of ~550-1200•C measured for a large number of IDPs [4].

The exceptional particle, U2073B-5D, was included in the suite as a long shot, since its morphology suggested entry heating to very high temperature (>1200•C) and thus one would not expect retention of any significant fraction of its pre-entry gas content. So much for expectations. As seen in Fig. 1, He in U2073B-5D was both >10-fold above a typical loading for IDPs and completely degassed only at high power levels. The Fig. 2 differential release spectrum vs. temperature is bimodal, with sharp release of ~70% of the total inventory in a narrow interval between ~1490 and 1570•C. Nothing like this has been seen before in an IDP. Retention of a normally thermally labile species to such temperatures points to tight trapping in a refractory carrier.



Since carbon was abundant in U2073B-5D, and its silicates and metal appeared to have partially melted (and thus presumably were largely degassed), the carbon seemed a plausible candidate for the refractory host phase of the high-temperature He component. To test this hypothesis we analyzed a fragment of U2-12A33B, a strongly heated IDP composed of a C-rich skeletal framework containing Fe-Ni metal or carbide beads, with attached partially-melted silicate spheres and Ni-Fe globules. From an electron back-scatter image we estimated a total mass of •4-5ng for this fragment, and a carbon content of •60 wt%. A large number of individual pulse-heating steps —not all of which are plotted— yielded the cumulative ^4He release profile shown in Fig. 1; the vertical segment at 14W reflects a sequence of 15 heating steps carried out at the same power (temperature) to provide data for estimating the diffusion parameter D/a^2. It is clear from Fig. 1 and the differential release profiles shown in Figs. 2 and 3 that the ^4He content of U2-12A33B was even larger than in U2073B-5D and even more closely

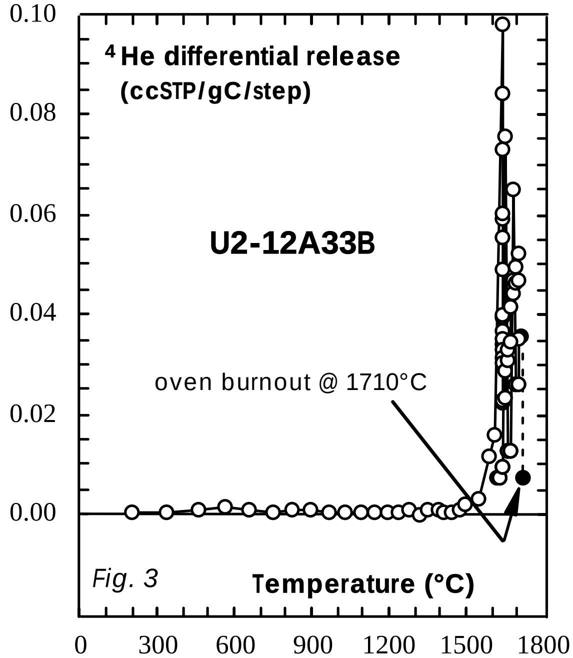


Fig. 3

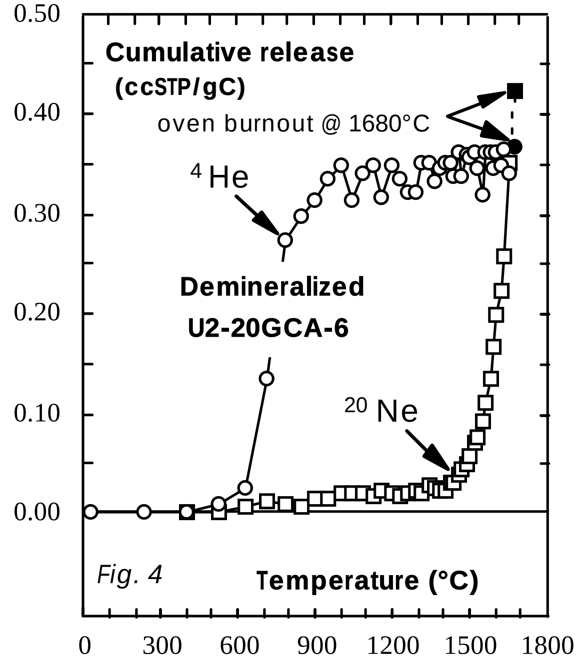


Fig. 4

associated with a highly refractory carrier. Remarkably, He extraction was still incomplete after 60 20-second pulse heatings at T •1645•C; the last full heating step released ~2% of the total accumulated up to that point before partial melting of the Pt foil at 1710•C ended the run (Fig. 3).

The evidence suggests —but not yet conclusively— that the host phase in both particles is some type of carbon. Pertinent questions are whether the He was initially present in the carbon or was somehow transported from other phases into refractory carbon trapping structures during entry heating, and whether such structures existed in the pre-atmospheric IDP or were themselves created in the heating episode. To address the first of these questions we measured release profiles from an HF-demineralized fragment, U2-20GCA-6, taken from a giant cluster (GC) particle that shows no similar morphologic evidence of strong heating. The •0.1ng of acid residue contained only carbon and traces of iron sulfide. The He release profile plotted in Fig. 1, and in Fig. 4 vs. temperature, shows that the residue was heavily loaded with ^{4}He which evolved at typical temperatures for IDP degassing—most of it between ~650•C and 850•C with little if any additional release up to 1680•C. So, at least in this GC fragment, carbon is a major carrier, and its He was not bound in high-temperature sites.

A striking result of the U2-20GCA-6 residue analysis was the release behavior of Ne shown in Fig. 4. The two profiles imply trapping of gas with a high ^{4}He/^{20}Ne ratio in low-temperature sites (a solar-like ratio of ~800 would have contributed too little Ne to be detected), and Ne trapping in refractory structures that either did not retain He or held it above 1680•C. Ne release just prior to oven burnout was still large, indicating incomplete extraction; the total Ne abundance shown in Fig. 4 is therefore a lower limit. An acid residue of another GC fragment is on hand but not yet analyzed. It will be important to see if He and Ne release profiles similar to those in Fig. 4, with their implications for the nature of noble gas trapping sites, are characteristic of carbon in this large cluster particle.

IDPs with high He abundances are commonly assumed to have acquired the bulk of their noble gases from exposure to SW-SEP radiation during their recent residence in space. There is nothing to counter this view in the isotopic distributions measured in this study. ^{3}He/^{4}He ratios in all 14 particles are intermediate between the SW and SEP compositions. The average of 37 measurements of ^{3}He/^{4}He made within the high-temperature release peak of U2-12A33B (Fig. 3) is $2.41 \pm 0.21 \times 10^{-4}$, close to the $2.17 \pm 0.05 \times 10^{-4}$ ratio for SEP [5]. The high-temperature Ne in U2-20GCA-6 (Fig. 4) is also SEP-like: ^{20}Ne/^{22}Ne = 10.60 ± 0.24 and ^{21}Ne/^{22}Ne = 0.0291 ± 0.0028, compared to SEP values of 11.2 ± 0.2 and 0.0295 ± 0.0005 respectively [5].

However recent implantation of solar ions into surfaces of IDPs at their pre-entry sizes is not the only possibility for gas loading. Small particles now welded into larger grains might have been irradiated separately in an earlier epoch. The GC particle allows an interesting test. Its pre-entry size was so large that much of the grain interior should have been shielded from recent SW-SEP radiation. If its gases derive entirely from implantation into surfaces of the parent IDP, most of its fragments should be gas-free.

The principal issue raised by this work is the physical nature of trapping sites capably of retaining He and Ne to such high temperatures. Carbon nanotube bundles are known to trap these two species with uniquely high binding energies [e.g., 6]. But whether such structures exist in IDP carbon, and if so in what astrophysical environment they might have formed, are unanswered questions.

References. [1] R. Pepin *et al.* (2000) *Meteorit. Planet. Sci.* **35**, 495. [2] R. Pepin *et al.* (2000) *LPS* **XXXI**, #1833. [3] A. O. Nier & D. J. Schlutter (1993) *Meteoritics* **28**, 675. [4] D. J. Joswiak *et al.* (2000) *LPS* **XXXI**, #1500. [5] J.-P. Benkert *et al.* (1993) *JGR* **98**, 13147. [6] G. Stan *et al.* (1998) *J. Low Temp. Phys.* **113**, 447.