HYDROGEN AND NITROGEN ISOTOPIC IMAGING OF INTERPLANETARY DUST. Larry R. Nittler, *Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road NW, Washington DC 20015, USA, lrn@dtm.ciw.edu*, Scott Messenger, *McDonnell Center for Space Sciences and Physics Department, Washington University, 1 Brookings Drive, St. Louis MO 63130, USA (current address: NIST, Building 222, Room A113 Gaithersburg, MD, 20899, USA, srm@email.nist.gov)*.

Many interplanetary dust particles (IDPs) have been observed to have large H and N isotopic anomalies [1,2], most commonly occurring as excesses in D and ^{15}N, relative to terrestrial standards. These excesses are usually ascribed to partially preserved presolar molecular cloud material, although the carrier phases are presently unknown [3]. Previous studies have shown that excesses in D and ^{15}N are more common in cluster IDPs than in non-cluster IDPs [4]. Furthermore, D/H and ^{15}N/^{14}N ratios are often strongly variable between different sub-fragments of a given IDP. Ion imaging studies have also shown that in some IDP fragments, the D is spatially concentrated in small "hotspots," with very high inferred D/H ratios [1,4]. We report here results of a preliminary isotopic survey of both individual and cluster IDPs, using microbeam imaging with the IMS-6f ion microprobe at the Carnegie Institution. The primary goal of this work is to investigate the degree of H and N isotopic heterogeneity in IDPs on smaller spatial scales and with higher precision than obtained in previous studies. Microbeam imaging has been previously used to obtain D/H images of one IDP [5]. This work extends the technique to a larger number of particles and to ^{15}N/^{14}N, C and O imaging as well as D/H imaging.

Seven individual IDPs and nine fragments of one cluster were picked off of small area collector W9019 with a W needle. Silicone oil was removed with a hexane rinse. The particles were dry-transferred to a gold foil and pressed in with a quartz disk. They were analyzed by scanning microbeam ion imaging. In this method, a small primary ion beam is rastered over the sample surface. The collection of secondary ions is synchronized with the primary beam raster, so the original position of each ion is known and a mass-filtered ion image is thus recorded. Images of different isotopes are alternately acquired and isotopic ratios are determined by image processing techniques. This microbeam imaging method has several advantages over the direct (microscope) ion imaging method used in most previous studies [1,4]. First, the spatial resolution depends only on the size of the primary beam and can in principle be considerably better than the best ($\sim$1–2μm) resolution obtained by direct ion imaging. Second, ions are counted directly by an electron multiplier, eliminating the need for complicated correction procedures relating microchannel plate/CCD image intensities to secondary ion intensities. Third, images can be obtained at high mass resolution with no added image aberrations or reduction in spatial resolution. This enables imaging of certain isotopic ratios, such as ^{15}N/^{14}N, that require high mass-resolving power to resolve isobaric interferences.

Images were acquired in two series. In the first series, H^- and D^- were imaged at low mass resolution with a 0.1 nA Cs^+ primary beam of diameter (and hence spatial resolution) $\sim$1μm and counting times per image of 2 and 60 seconds, respectively. In the second series, images of $^{12}C^-$, $^{16}O^-$, $^{12}C^{14}N^-$ and $^{12}C^{15}N^-$ were acquired at a mass-resolving power of 6000, with a somewhat higher spatial resolution ($\sim$0.7μm). Counting times were 4, 1, 4 and 60 seconds, respectively. The second series was only performed on those particles which had sufficient material following the H measurement. Each mass series was usually repeated ten times for a given measurement. The ion images were processed using new software developed for this study. This software allows the user to generate and display pixel-by-pixel isotopic ratio images and to quantitatively determine isotopic ratios for any selected subset of image pixels (for example, a sub-region of a particle). Figure 1 shows example images (H^- and D/H) of three fragments of the cluster (IDP #3); a one micron scale bar is shown for each fragment.

Our results are summarized in Table 1. IDP #7, a Fe-S-Ni-rich IDP, is not included in Table 1, since it was not analyzed for D/H and had a terrestrial ^{15}N/^{14}N ratio. Fragment I of the cluster was too small for analysis. The second and third columns of Table 1 give the bulk isotopic ratios of each particle. The fourth column indicates the degree of isotopic heterogeneity of a given IDP or cluster fragment. If an isotopic ratio was clearly heterogeneous across the particle, the IDP is listed as having one or more "hotspots," with the maximum inferred delta value given in parenthesis.

As in previous studies, the IDPs exhibit a wide range of D/H ratios, with generally larger δD values observed in cluster fragments than in individual IDPs. Spatial heterogeneity in D/H was observed in one individual IDP and in four of the six cluster fragments large enough to determine the degree of isotopic homogeneity. The images shown in Figure 1 illustrate the observed range in D/H heterogeneity. Fragment 3D has several regions of enhanced D/H ratio; fragment 3H is isotopically uniform except for one bright D hotspot and 3J is homogeneous. This study suggests that micron-scale variations in the D/H ratio are more common in IDPs, especially in cluster IDPs, than previously realized. Moreover, this study revealed some hotspots with relatively modest D/H ratios in particles with unremarkable bulk D enrichments, IDP #1 for instance. These likely would have been missed in previous direct imaging studies.

One IDP, #8, has a bulk ^{15}N enrichment at a 2σ significance level. However, the ion images revealed this ^{15}N to be concentrated into a $\sim$2μm hotspot. The ^{15}N enrichment of this hotspot (δ^{15}N=700$\pm$200) is among the largest ever observed in interplanetary dust. This is the first indication that N is also isotopically heterogeneous on a micron scale in IDPs. The fact that the bulk ^{15}N/^{14}N ratio for this IDP is only marginally anomalous suggests that previous measurements of IDPs might have missed particles with ^{15}N hotspots, but more or less normal N on average.

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Table 1

IDP	δD_{SMOW} (per mil)	$\delta^{15}N_{air}$ (per mil)	homogeneity (max. δ-value)
1	345 ± 69	49 ± 26	1 D hotspot (1150)
2	-150 ± 42	34 ± 17	homogeneous
3A	35 ± 226	not meas.	too small
3B	214 ± 139	not meas.	too small
3C	1155 ± 111	not meas.	1 D hotspot (1700)
3D	1734 ± 119	15 ± 30	4 D hotspots (2700)
3E	738 ± 75	not meas.	1 D hotspot (1000)
3F	95 ± 77	-58 ± 62	homogeneous
3G	149 ± 95	-131 ± 70	too small
3H	833 ± 73	25 ± 26	1 D hotspot (3100)
3J	418 ± 83	not meas.	homogeneous
4	-60 ± 82	-116 ± 76	homogeneous
5	93 ± 46	not meas.	homogeneous
6	145 ± 70	not meas.	homogeneous
8	848 ± 74	195 ± 92	1 ^{15}N hotspot (700)

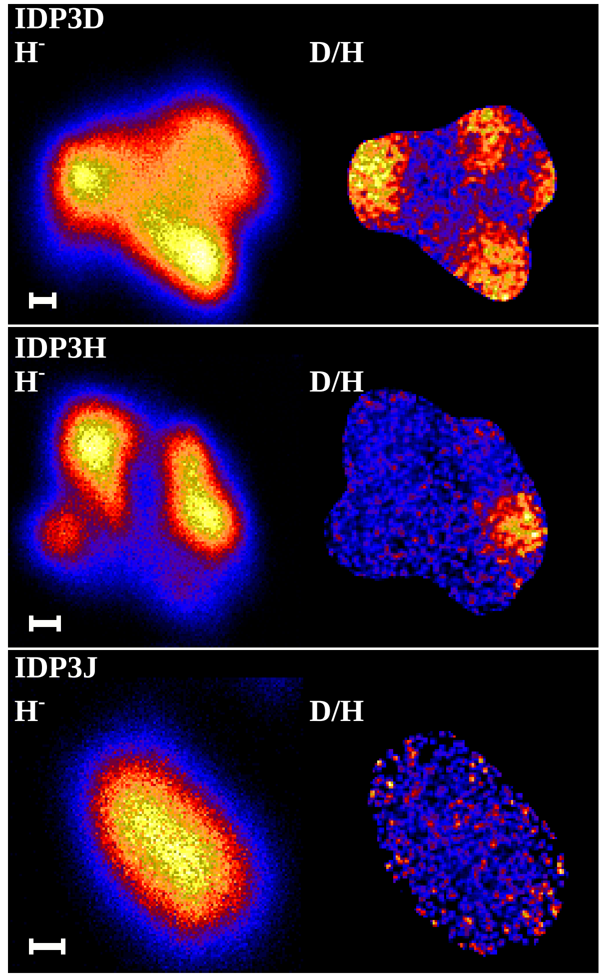

Figure 1: H^- ion images and D/H images for three fragments of cluster IDP #3. Scale bars are 1μm