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Identification and Characterization of the Host of Interstellar Deuterium in Interplanetary Dust Particles

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Beamline(s): X1A

Introduction: Interplanetary dust particles (IDPs), which are ~5 to 35 μm fragments from asteroids and comets, have been collected from the Earth's stratosphere by NASA since the mid-1970s. The isotopic compositions of IDPs have been measured using Secondary Ion Mass Spectrometry (SIMS). Some of these IDPs contain excesses in D and ^{15}N consistent with the preservation of interstellar matter that formed in a cold environment. The likely host(s) of the D are organic matter or water.

Methods and Materials: Messenger has employed a Cameca 50 Ion Probe (nano-SIMS), with a spatial resolution of ~0.5 μm, to map the spatial distribution of D in individual IDPs pressed into gold. He identified several D-rich hot spots using a sputtering rate low enough to preserve some of the D-rich material for subsequent analysis by other techniques. Keller has developed a technique to ultramicrotome the nano-SIMS sample to the ~100 nm thickness required for the Transmission Electron Microscope (TEM) and the Scanning Transmission X-ray Microscope (STXM). We are employing the STXM at beamline X1A to map the carbon spatial distribution in ultramicrotome sections of IDPs on which Messenger has already located the D-rich spots. Our objective is to overlay the carbon maps on the D maps, to determine if the D-carrier is carbonaceous, and, if so, to perform X-ray Absorption Near-Edge Structure (XANES) spectroscopy to identify the carbon functional groups associated with the D.

L2009D11 is a D-rich IDP dominated by "track rich" crystalline silicate and also contains Fe-sulfide with some carbonaceous material. The presence of solar flare tracks, which anneal at ~600^{o} C, indicates the particle was not significantly heated on atmospheric entry. The bulk D in L2009D11 is +560 $^{o}/_{oo}$ enriched over mean terrestrial D/H. A D hot-spot ~3 μm in size is >1200 $^{o}/_{oo}$. Transmission electron microscope examination showed the D hot-spot to be fine-grained and C-rich. We also examined a D-poor IDP, L2005*A3, which is dominated by crystalline silicate with minor amounts of Fe-sulfide. The bulk D in L2005*A3 is -420 $^{o}/_{oo}$. This particle has a magnetite rim and has no solar flare tracks -- both indicating the particle experienced significant atmospheric entry heating.

Results: We mapped the carbon in L2009D11, by taking two transmission images of the sample with x-rays having an energy just below and an energy just above the C K-edge. We found a high concentration of C at the D hot-spot. This indicates that the D host is carbonaceous. We then performed C-XANES spectroscopy to identify the functional group(s) associated with the D. The strong absorption near 285 eV is from C-ring structure, which occurs in elemental and organic carbon. The strong absorption near 288.5 eV is carbonyl (C=O), identifying organic carbon at the site of the D hot-spot.

Conclusions: The D hot-spot in L2009D11 is spatially associated with organic carbon, not with water, indicating that a hydrocarbon is the D-carrier. Both the D-rich IDP and the D-poor IDP have essentially the same C-XANES spectra. The strength of the C-ring absorption is not correlated with D abundance, which suggests that aromatic hydrocarbon is not the D-carrier.

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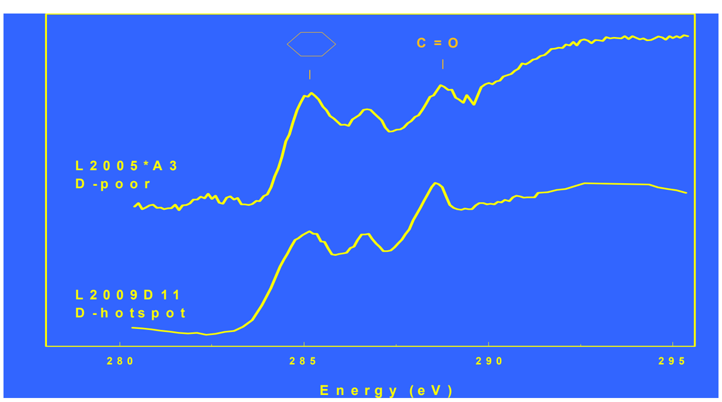

Figure 1: Comparison of the C-XANES spectra of L2011D11 and L2005*A3.