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Submicrometer Oxygen Isotopic Imaging With the NanoSIMS Ion Probe: Application to Returned Cometary Dust Samples

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Comets are considered to be the least altered remnants of the starting materials from which the solar system formed. The Stardust mission will return the first direct samples of cometary dust for laboratory study in January 2006. The spacecraft is expected to return ~1,000 particles in the 10 – 20 µm size range embedded in a silica aerogel collector. Extracting and analyzing these grains will pose serious technical challenges. Anhydrous interplanetary dust particles (IDPs) collected in the stratosphere share many of the inferred properties of cometary materials including fine grain size (100 – 1000 nm), high porosity, unequilibrated mineralogy, and high abundances of carbon and volatile elements [1]. The study of these particles has proven to be invaluable preparation for the practical and scientific issues to be addressed in the future study of returned cometary materials.

The Cameca NanoSIMS 50 ion microprobe has revolutionized the study of interstellar grains, with its fine spatial resolution (50 nm), high transmission, and simultaneous detection of 5 masses. These capabilities facilitated the discovery of interstellar silicates in meteorites and IDPs, which had not been previously been identified owing to their small size (200 – 500 nm) [2,3].

Johnson Space Center has recently established the Robert M Walker Laboratory for Space Science, an international facility dedicated to expanding the frontiers of extraterrestrial materials research. Two newly developed instruments funded by the NASA SRLIDAP program will serve as the centerpiece of our laboratory: a JEOL field emission transmission electron microscope (described in a companion abstract [4]) and the next generation NanoSIMS 50L ion microprobe. The NanoSIMS 50L builds upon the strengths of the original instrument, increasing the number of ion detectors from 5 to 7 while equipping each detector with a cylindrical electrostatic lens that will enable simultaneous detection of adjacent mass lines up to 60 u. A dedicated NMR probe has been added to stabilize the magnet at low field settings for H isotopic mapping. All mechanical adjustments (slits, apertures) are now motorized and under computer control to facilitate the tuning procedures. Stray magnetic fields have been mitigated where possible and corrective coils have been improved to optimize reproducibility of isotopic measurements. These enhancements will enable new kinds of science to be investigated on the smallest size samples (200 – 1000 nm) that may be entirely consumed during the course of a single measurement.

The new capabilities of the NanoSIMS 50L will benefit high priority science goals of the Stardust mission, including determining the relative proportions of interstellar and solar system materials in the returned samples and evaluating whether interstellar molecular cloud materials are associated with these grains. Interstellar grains are distinguished from solar system materials by their exotic isotopic compositions, as shown in Figures 1 and 2. Figure 1 compares the O isotopic compositions of presolar silicates with submicrometer grains in IDPs that are isotopically solar within measurement error. Several presolar silicates with moderate ^{17}O enrichments have been identified by Cameca 1270, which has poorer spatial resolution than the NanoSIMS (1 µm), but similar sensitivity

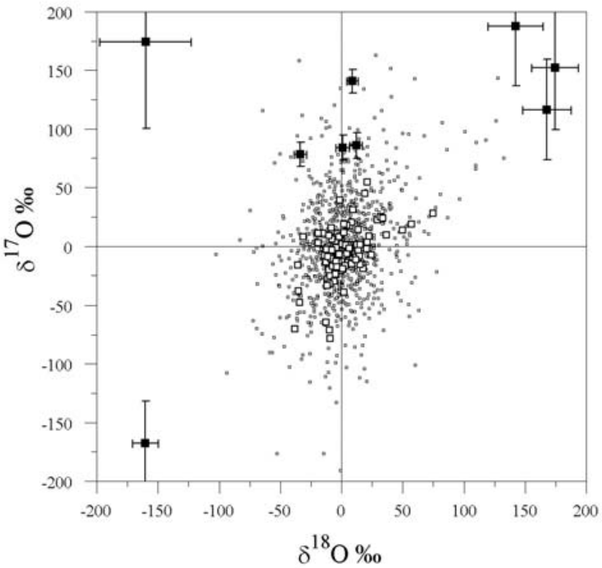

Figure 1: O isotopic compositions of presolar silicates (black symbols) compared with 1,000 isotopically solar sub-μm grains in IDPs measured by NanoSIMS. Four presolar silicates with high precision measurements were measured with a Cameca 1270. [2,3,6,7,8]

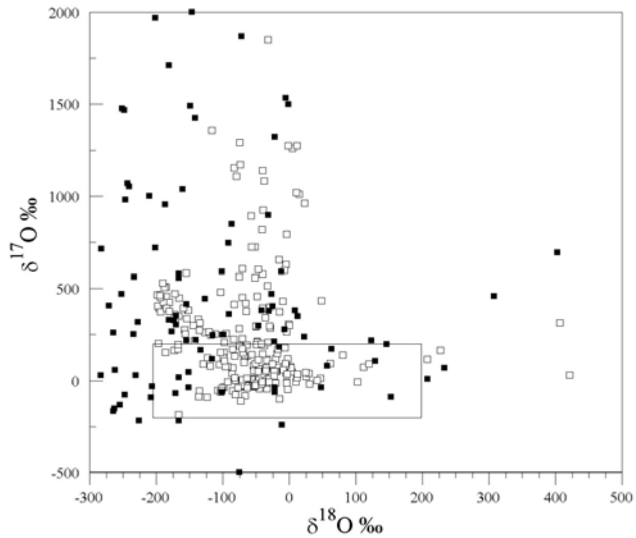

Figure 2: O isotopic compositions of presolar oxides (black squares) and of those grains diluted 80% with isotopically solar O (empty squares) simulating the effect of measuring grains ½ the size of spatial resolution in isotopic imaging. Rectangular region shows the range plotted in Fig 1 (-200‰ to +200‰) [9 & *refs therein*]

and superior precision [5]. These data show that improving the reproducibility of isotopic measurements by NanoSIMS will enhance our ability to identify presolar materials. Figure 2 illustrates the effect of isotopic dilution by surrounding material where presolar silicates are ~1/2 the size of the spatial resolution achieved in imaging. Although most presolar oxides become indistinguishable from solar (within the current precision of NanoSIMS measurements), many ^{17}O-rich grains are still detectable. The addition of two mobile detectors will now enable simultaneous measurements of C, (H or N), and O isotopes, a capability that will facilitate the coordinated search for stardust (with exotic C or O isotopic compositions) and molecular cloud material that may be enriched in ^{15}N and/or deuterium (Fig 3).

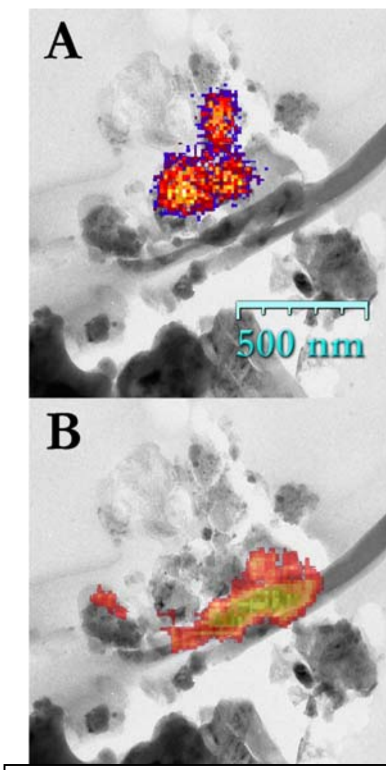

Figure 3: TEM image of IDP thin section containing (A) ^{18}O-rich supernova silicate grain and (B) ^{15}N-rich interstellar organic matter shown by overlaying NanoSIMS isotopic images. [10]

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