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Non-Destructive Chemical and Mineralogical Analysis of Nanogram-mass Interplanetary Dust

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Beamline(s): X26A

Introduction: Interplanetary dust particles (IDPs), which are nanogram-mass fragments from asteroids and comets, are recovered from the Earth's stratosphere by NASA aircraft, curated at the NASA Johnson Space Center, and made available to the scientific community for analyses. These IDPs include: 1) the most primitive samples of extraterrestrial material available for laboratory study -- dust that has not been altered by aqueous processing or noticable heating since the formation of our Solar System, and, 2) the only samples of comets, which are believed to have preserved in cold-storage samples of the dust out of which the planets formed, currently available for laboratory study. The analysis of these primitive dust particles is likely to constrain the chemistry, temperature, pressure, and oxygen fugacity of the Solar nebula at the time dust was forming. However, many of the techniques for analyzing nanogram-mass particles are destructive, making it necessary to develop non-destructive analysis techniques to fully characterize each particle prior to the destructive examination.

Methods and Materials: We use the micro-focused x-ray beam at beamline X26A to determine the chemistry, mineralogy, and Fe-bonding state of individual, nanogram-mass IDPs. The x-ray beam at X26A is focused to an ~15 micrometer spot using Kirkpartrick-Baez focusing mirrors. Using this x-ray beam, we have performed x-ray fluorescence chemical analysis, x-ray diffraction mineralogical analysis, and Fe-X-ray Absorption Near Edge Structure (Fe-XANES) spectroscopy on more than 20 individual IDPs.

Results: The x-ray fluorescence measurements provide element to Fe ratios for most elements having fluorescence energies from 6 to 16 keV, including the K-shell fluorescence of elements from Cr through Sr, with a detection limit of ~3 ppm for nanogram-mass particles. Most of the IDPs examined had element/Fe ratios for the refractory elements that are within a factor of three of the "solar" composition, as determined from the CI-meteorites. However, we measured a mean enrichment by about a factor of 2 to 3 of the IDPs compared to the CI-meteorites for the volatile elements (Mn, Cu, Zn, Ga, Ge). Using Fe-XANES we were able to distinguish particles dominated by Fe^{2+}, consistent with the anhydrous minerals olivine and pyroxene, from particles dominated by Fe^{3+}, dominated by hydrated minerals. Using X-ray diffraction we identified magnetite, which is believed to be produced on atmospheric entry, pyrrhotite (FeS), and olivine. The x-ray diffraction pattern also provides information on the size distribution of the minerals in each IDP, with large grains producing a spot pattern while abundant, small grains produce a ring pattern.

Conclusions: The high mean abundances of the moderately volatile elements indicate that either: 1) the CI meteorites are not representative of the "solar" composition, or, 2) the IDPs formed at a location or time in Solar System history when the more refractory elements had partially condensed. By performing X-ray fluorescernce, x-ray diffraction, and XANES measurements on the same nanometer-mass IDPs we are able to characterize the chemistry and mineralogy of each particle in a non-destructive manner, preserving the fully-characterized particle for subsequent analysis by other techniques.

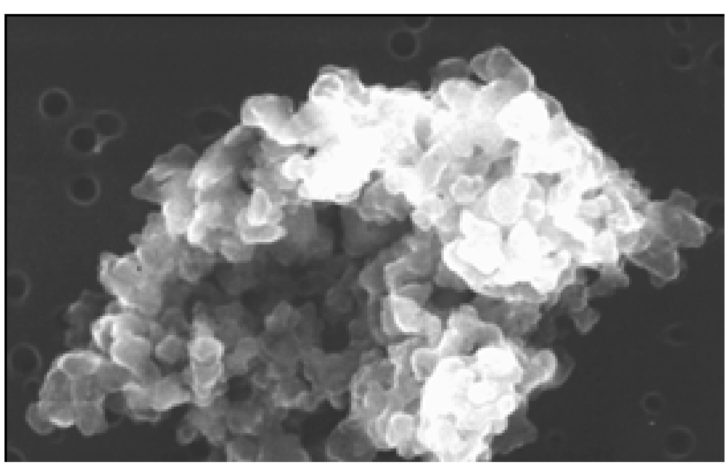

Figure 1: SEM image of a typical, porous IDP measuring ~11 micrometers in its largest dimension.