

Chemical analysis of individual interplanetary dust particles

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Introduction

Interplanetary dust particles (IDPs) decelerate in the Earth's upper atmosphere generally without melting. IDPs from 2 to 35 micrometers in size are collected by NASA from the Earth's stratosphere using high-altitude aircraft. These IDPs are fragments of asteroids and comets; thus, their compositions provide a direct measure of the compositions of asteroids and comets. Each IDP is an individual micrometeorite and may sample a different parent body. Thus, IDPs must be analyzed individually for maximum information return.

Some IDPs are extremely primitive, having experienced little thermal or aqueous alteration since they formed. These IDPs better preserve the record of early Solar Nebula conditions than the most primitive meteorites collected on Earth. Thus, these primitive IDPs provide the most significant constraints on the composition, temperature, pressure, and other properties of the Solar Nebula during the time of dust formation.

We have performed chemical analyses of IDPs using the x-ray microprobe installed on beamline X26A of the National Synchrotron Light Source (NSLS) since 1987 [1]. However, the flux and minimum achievable beam spot of the NSLS x-ray microprobe impose a practical limit of about 10 micrometers (estimated mass ~1 nanogram) on the minimum size of an IDP in which the trace elements from Cu through Sr can be detected.

Since the degree of heating and thermal alteration (element loss and mineralogical transformation) experienced by an IDP during atmospheric deceleration increases with particle mass, examination of the smallest IDPs collected by NASA may provide the best constraints on Solar Nebula conditions and on the compositions of asteroids and comets.

Methods and Materials

We performed trace element analysis of IDPs using the GSECARS (sector 13) microprobe at the Advanced Photon Source (APS). This x-ray microprobe uses an undulator as its x-ray source. A Si(220) water-cooled, channel-cut, scannable monochromator provided a monochromatic analysis beam which was focused to an ~3 micrometer beam spot using Kirkpatrick-Baez focusing mirrors. The flux density of this APS system exceeds that available using the NSLS x-ray microprobe by about three orders of magnitude, significantly reducing the minimum size of particles that can be analyzed.

In this initial effort to analyze smaller IDPs, we first examined three IDPs that had previously been analyzed at the NSLS. We then analyzed several IDPs in the 4 to 7 micrometer size range (minimum estimated mass ~0.1 nanogram), too small for meaningful trace element analysis with the NSLS x-ray microprobe.

Results

The comparison of the NSLS and APS analyses of the same particles generally showed good agreement between the two instruments [2]. We obtained high-quality spectra of the ~0.1 nanogram mass IDPs with the APS x-ray microprobe in ~60 to 90 minute analysis times. This compares to a typical analysis time of 180 to 240 minutes for ~1 nanogram mass IDPs using the NSLS x-ray microprobe.

The analysis beam energy at the NSLS is limited by the decreasing flux with increasing energy. IDP analyses at the NSLS are generally performed with an analysis beam of 16.5 keV, just above the Sr K-alpha fluorescence line. The higher energy of the APS x-ray microprobe allowed us to extend our analyses of IDPs to the K-lines of elements heavier than Sr. These APS measurements were performed at 21.7 keV, allowing the detection of Y, Zr, Nb, and Mo in addition to the elements normally detected at the NSLS (see Figure 1).

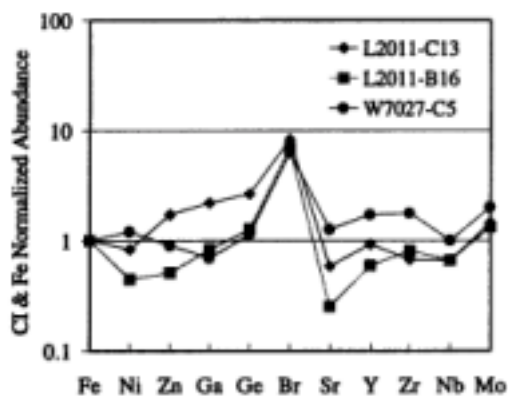


Figure 1: CI and Fe normalized abundance patterns for three chondritic IDPs collected from the Earth's stratosphere. A particle matching the bulk composition of the CI carbonaceous chondrite meteorites would plot as a horizontal line at 1. These IDPs are similar to the CI meteorites except that all three IDPs show large excesses of Br, and W7027C5 is enriched in the volatile elements Zn, Ga, and Ge relative to CI.

Discussion

The initial measurements on IDPs using the GSECARS x-ray microprobe at the APS demonstrated a substantial enhancement in element sensitivity over the x-ray microprobe at the NSLS. These first results demonstrate that the APS x-ray microprobe can be used to perform trace element chemical analyses of IDPs down to ~2 to 3 micrometers in size, the minimum size currently being collected from the Earth's stratosphere by NASA. The higher analysis beam energy available at the APS has extended the set of trace elements detectable in IDPs to include Y, Zr, Nb, and Mo, and use of a higher analysis beam energy may extend this range further.

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References

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