

Synchrotron FTIR Examination of Interplanetary Dust Particles: An Effort to Determine the Compounds and Minerals in Interstellar and Circumstellar Dust

G. J. Flynn

Dept. of Physics, SUNY-Plattsburgh, Plattsburgh, NY

L. P. Keller

NASA Johnson Space Center, Houston, TX

Abstract

Some interplanetary dust particles (IDPs), collected by NASA from the Earth's stratosphere, are the most primitive extraterrestrial material available for laboratory analysis. Many exhibit isotopic anomalies in H, N, and O, suggesting they contain preserved interstellar matter. We report the preliminary results of a comparison of the infrared absorption spectra of sub-units of the IDPs with astronomical spectra of interstellar grains.

1. Introduction

Astronomical spectroscopy provides information on the types and abundances of matter present in a variety of astrophysical environments. The infrared region of the spectrum is particularly useful in characterizing the dust. The Infrared Space Observatory (ISO) obtained spectroscopic data over the 2.5 to 200 μm wavelength range. To interpret these spectra it is necessary to have laboratory spectra of minerals in order to match the astronomical spectra to those of identified and well-characterized materials. We have focused our efforts on measuring the infrared spectra of minerals in the interplanetary dust particles (IDPs).

2. Interplanetary Dust Particles

The IDPs, fragments from asteroids and comets, range from about 5 to 50 μm in size. The IDP collection techniques are described in detail by Brownlee (4). Some of the IDPs are particularly interesting because they exhibit isotopic compositions distinctly different from Solar System materials. Messenger (9) reported that "cluster IDPs," which are so weak they break into many fragments on collection, frequently have non-solar D/H and ^{15}N contents. Messenger *et al.* (10) reported about 1% of the silicate grains in the first few cluster IDPs examined showed O isotopic anomalies consistent with them being interstellar. We have begun an infrared survey of the minerals in IDPs and a comparison of the spectra with the features detected by ISO and other infrared observing efforts.

3. Equipment

The infrared spectra were measured using two Fourier Transform InfraRed (FTIR) instruments, a Spectra-Tech IRus and a Nicolet Continuum, installed on the U4-IR and the U10B infrared beamlines at the National Synchrotron Light Source (NSLS). They have about 1,000

times the infrared flux of global instruments, providing about 100 times better signal to noise. Synchrotron FTIR allows us to compare the absorption features of the silicates, sulfide, and organic matter in the IDPs to infrared features detected in interstellar and/or circumstellar environments.

4. Silicates

The IDPs contain three types of silicates: anhydrous silicates (olivine or pyroxene), hydrated silicates, and glassy (non-crystalline) silicates. Bradley (2) suggested that the glassy silicates found in the IDPs might be the common silicate in the interstellar medium. These silicates, called GEMS (for Glass with Embedded Metal and Sulfide), are typically about $0.5 \mu\text{m}$ in diameter. We examined GEMS in L2011*B6, one fragment of a cluster IDP. L2011*B6 is dominated by Fe-sulfide, but contains two small lobes of GEMS and some associated carbonaceous material. The infrared spectrum of these GEMS is an excellent match to the broad $9.5 \mu\text{m}$ feature of the interstellar silicate (3). This is the first time any single, naturally-occurring material has matched the width and shape of the amorphous interstellar silicate feature. This result suggests that either the GEMS in this IDP are interstellar grains or that grain production in our Solar System was sufficiently similar to that in the environment where the interstellar silicates were produced that very similar material was produced in our Solar System. Bradley (2) noted that some GEMS contain small silicate crystals (olivine or pyroxene), and suggested that GEMS were produced by radiation damage and alteration of these anhydrous silicate grains. The infrared spectra of those GEMS that contain anhydrous silicates show the sharp absorption features of olivine or pyroxene superimposed on the broad amorphous silicate feature. The infrared signatures of these GEMS are a good match to the $10 \mu\text{m}$ features of dust in the comas of Comet Halley and Comet Hale-Bopp, and the dust surrounding the young star HD163296 (see (3)).

5. Sulfide

ISO spectra of some cold, dense molecular clouds show an excess flux from 20 to $26 \mu\text{m}$, attributed to FeO based on calculated FeO spectra (1). However, FeO is thermodynamically unstable and rare in meteorites, so it seems an unlikely candidate to explain this feature. Sulfur is known to be depleted in the gas phase in some cold molecular clouds, but the sulfur host was not known. Fe-sulfide, particularly pyrrhotite, is a common mineral in the IDPs and meteorites. Terrestrial pyrrhotite is a good match to the ISO feature (7), while the pyrrhotite in two IDPs exhibits a narrower absorption feature. The difference between IDP and terrestrial pyrrhotite absorption might be due to composition, since the pyrrhotite can span the range from FeS to $\text{Fe}_{0.8}\text{S}$. This result indicates that pyrrhotite is a previously unidentified component of the dust in many cold circumstellar environments. It may have significant implications for astrobiology, since Cody *et al.* (5) suggest sulfide grains may have served as catalysts in the synthesis of organic molecules.

6. Organic Matter

C-H stretching features, near $3.4 \mu\text{m}$, have been detected in interstellar grains. Li and Greenberg (8) proposed that the most abundant type of interstellar grain is a glassy silicate

mantled by refractory organic matter. Transmission Electron Microscope (TEM) examination of the IDP L2011*B6 shows carbonaceous material associated with the GEMS. Because the ultramicrotome section is only 70 nm thick, we have not obtained an infrared spectrum of this carbonaceous material. Other IDPs contain carbonaceous units large enough to be examined by infrared spectroscopy. These spectra show the C-H stretching features characteristic of aliphatic hydrocarbons (6).

Simple aliphatic molecules are chains of C-H₂ groups with C-H₃ groups on both ends. Thus the ratio of C-H₃ to C-H₂ absorption measures the length of the chain. The interstellar grains in Pendleton *et al.* (11) have a higher C-H₃ to C-H₂ ratio than IDPs, suggesting interstellar aliphatic chains are, on average, shorter than those in IDPs. However, we have not yet obtained spectra of the carbonaceous material spatially associated with GEMS in IDPs. That material may be different from the dominant organic matter in IDPs.

7. Future Work

Amorphous interstellar silicates have two strong features, the 9.5 μm feature matched by GEMS, and a feature near 20 μm . We have, thus far, been unable to measure the 20 μm absorption of the GEMS in L2011*B2. This remains a high priority. A new FTIR facility, that can measure spectra from 2.5 to 200 μm , has been constructed at the NSLS. This should allow us to compare the far-infrared features in IDPs to those measured by ISO.

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