

Identification of the 23.5 μm Feature in Astronomical IR Spectra Through Synchrotron-Based FTIR Measurements of Interplanetary Dust

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Abstract No. Kell8036

Beamline(s): U10B

Introduction: The chemistry and mineralogy of dust grains in circumstellar and interstellar space are inferred largely from astronomical spectroscopic observations, with additional constraints provided by analyses of analogue materials in the laboratory. In infrared (IR) spectra of some YSOs and evolved stars, as well as comet Hale-Bopp, there is an excess flux between 20 μm and 26 μm that cannot be accounted for with either amorphous silicate grains, which peak below 20 μm , or crystalline silicates which exhibit much narrower peaks in the infrared spectrum. This feature has been attributed to FeO based upon calculated spectra derived from experimentally determined optical constants combined with theoretically modeled grain shapes and sizes. However, FeO (the mineral wüstite) is thermodynamically metastable and is extremely rare in meteoritic materials. Fe-rich sulfides are an alternative candidate for the “23 μm ” feature because they are ubiquitous constituents of IDPs and chondritic meteorites and they were detected in comet Halley’s dust.

Methods and Materials: We used the intense infrared beamline (U10B) at the National Synchrotron Light Source at Brookhaven National Lab to measure the infrared spectral properties of sulfide-rich IDPs and mineral standards. The FTIR instrument is sensitive over the 2.5–28.5 μm (4000–350 cm^{-1}) wavelength range. IR spectra were collected from 1) ultramicrotome thin sections (~ 70 nm thick) of IDPs that had been sectioned in sulfur and supported on a carbon-film transmission electron microscope (TEM) grids, and 2) ultramicrotome thin sections of terrestrial pyrrhotite, troilite, synthetic wüstite and magnetite that were sectioned in epoxy and supported on carbon-film TEM grids. We used an aperture of 32x32 μm for the measurements because smaller apertures resulted in spectral artifacts from diffraction effects at long wavelengths. Final baseline corrected (and smoothed) spectra were obtained by subtracting the background from the sample spectrum. Between 256 and 1000 scans (interferograms) were collected from each specimen with 4 cm^{-1} resolution.

Results and Discussion: We obtained laboratory infrared (IR) spectra of Fe-sulfide grains within individual interplanetary dust particles (IDPs) and compared them with astronomical IR spectra of circumstellar dust disks, young stellar objects (YSOs), and comet Hale-Bopp. We used the intense infrared beamline (U10B) at the National Synchrotron Light Source at Brookhaven National Lab to measure the infrared spectral properties of sulfide-rich IDPs and mineral standards. Pyrrhotite ($[\text{Fe,Ni}]_{1-x}\text{S}$) grains in IDPs, as well as pyrrhotite and troilite (FeS) mineral standards, produce a broad Fe-S stretch feature centered at ~ 23.5 μm (Figure 1). A similar broad feature centered ~ 23.5 μm is observed in the ISO spectra, implying that sulfide grains are an important, previously unrecognized component of circumstellar dust. In cold, dense interstellar molecular clouds, the nursery of YSOs like the solar nebula, sulfur is observed to be highly depleted from the gas phase, presumably because it is in Fe-sulfide grains. These results provide insight into how sulfur, an important biogenic element, is incorporated into planetary systems.

Acknowledgments: This work was supported by NASA RTOP 344-31-40-06, NASA Cosmochemistry Grant NAG5-9393, NASA Exobiology Grant NAG5-469101, and the JSC Astrobiology Institute Grant NAG9-1109.

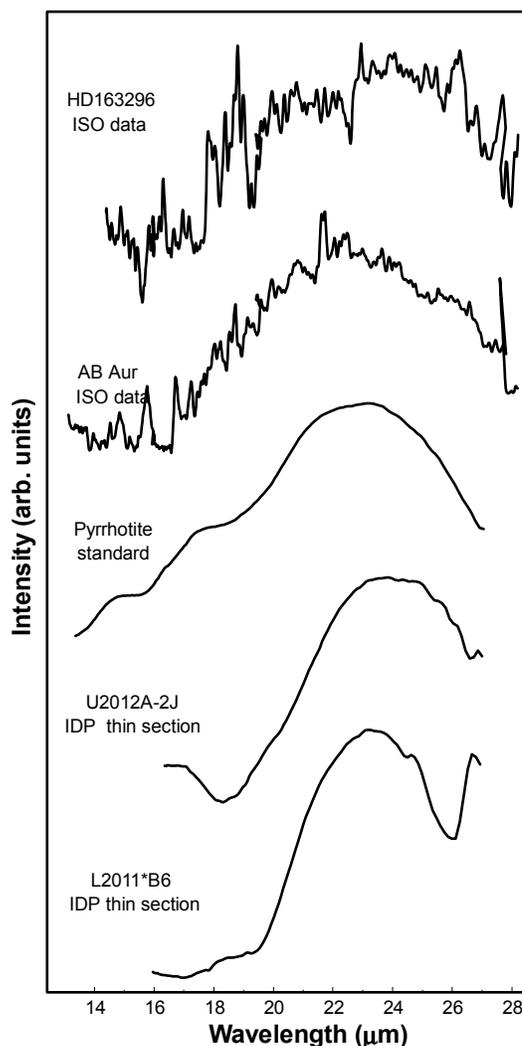


Figure 1. Infrared spectra of sulfide standards and sulfide-rich IDPs compared to “23 μm ” features in two Herbig stars showing similar peak positions, shapes, and bandwidths