Time-Domain THz Spectroscopy of Astrophysical Dust and Ice Analogs in the Laboratory

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Summary

We address the need for laboratory research into the long-wavelength spectra of astrophysical dust and ice materials for the interpretation of data obtained by future far-infrared observatories. Our group has recently submitted a proposal to study the optical properties of astrophysical dust and ice analogs at long wavelength (from about 50 µm to 3 mm) using the technique of time-domain THz spectroscopy. There is a general lack of data in this spectral range for astrophysical materials. This technique has advantages over standard FTIR spectroscopy in that the optical constants of the materials will be measured directly. We will focus our studies on the mixtures of ices in the interstellar medium and in planetary environments as indicated by the most recent mid-infrared data (e.g., H_2O, CO, CO_2, CH_3OH, CH_4, and some others), as well as interstellar non-ice solids such as PAHs and silicates. This work will provide valuable physical data for the interpretation of data obtained by far-infrared missions such as Herschel and SOFIA as well as sub-mm observatories such as ALMA.

The Need for Laboratory Data

In the past two decades, great strides have been made in the area of infrared astronomy from space-based and ground-based observatories. Observations at near- and mid-infrared wavelengths (0.8-25 µm) have returned a wealth of data from the Hubble and Spitzer Space Telescopes as well as the European Infrared Space Observatory. The analyses of these data sets have benefited greatly from the large volume of spectroscopic studies of laboratory analog materials at these wavelengths.

Since one of the major goals of astronomy in the next decade will be to explore the spectral region spanning the far-infrared (far-IR) into the sub-millimeter, with anticipated data returns from missions such as Herschel and observatories such as SOFIA and ALMA, it is clear that sets of laboratory data will be needed in the long wavelength region from about 25 µm to 3 mm.

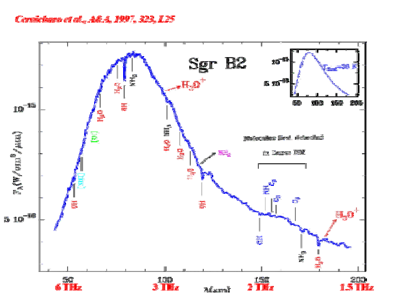


Figure 1: The far-infrared spectrum of the high-mass star forming region Sgr B2 as measured by the Infrared Space Observatory's Long-Wavelength Spectrometer (from Cernicharo et al. 1997). Clearly visible is the blackbody curve of the cold dust against which the ro-vibrational absorptions of many gas-phase species are present. There may also be weak, broad structures due to interstellar solid materials present, but these have not yet been identified.

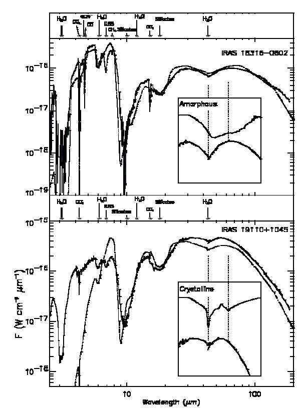


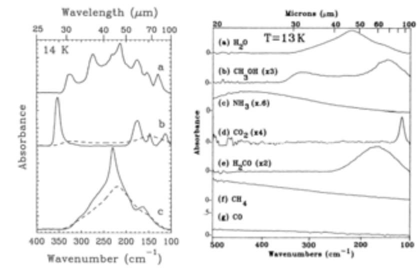
Figure 2: The ISO spectra from 2.5 to 200 µm of two IRAS sources (from Dartois et al. 1998). In both spectra, the broad absorption features of condensed volatiles (ices) are seen. The far-IR absorption of H_2O was indentified near 40 and 60 µm.

Current Laboratory Data Sets

To date, far-infrared studies of interstellar ice analogs have focused on the spectral properties of solid H_2O (such as those by Bertie & Whalley 1967; Hardin & Harvey 1973; Moore & Hudson 1992; Hudson & Moore 1993). These studies have used conventional FTIR techniques to achieve spectral of H_2O and other pure samples of frozen volatiles in the wavelength region from about 20µm to about 200µm. Studies that extend this spectral range to longer wavelengths, or those that include ice mixtures or solids are sparse in the literature. Most notably, Hudson & Moore (1993) demonstrated the sensitivity of far-IR spectra to the structure of an H_2O+CH_3OH ice mixture.

Figure 3:
(left panel) from Hudson & Moore (1993). (a) H_2O+CH_3OH mixture warmed from 13 K to 140 K and re-cooled; (b) pure amorphous and crystalline CH_3OH; (c) pure amorphous and crystalline H_2O.

(right panel) from Moore & Hudson (1994). Far-IR spectra (20-100 µm) of various pure amorphous ices at 13 K.



Proposed Set of New Lab Measurements

We are planning to study laboratory samples of ices and astrophysical solids listed in Table 1. using terahertz time-domain spectroscopy. We will employ coherent detection of the THz pulses using a standard electro-optic detector scheme in order to record the electric field of the transmitted THz pulse as a function of time. This direct measurement of the electric field allows us to determine the full complex transmission coefficient and recover both the real and the imaginary parts of the sample's refractive index. We will measure the transmission coefficient and determine the optical constants of the materials from 20µm to 3 mm (0.1-15 THz) with a resolution of 1-10 GHz (R ~ 1000 – 1500), sufficient for the broad absorptions of solids in this range. Samples will be created at a thickness of approximately 10µm. We should achieve wide spectral coverage over the THz range, depending on the material used as substrates and optical windows.

The primary goal is to provide a database of long-wavelength transmission spectra and optical constants for materials and ices that are relevant to the interstellar medium or planetary astronomy. The motivation for this study is the growing emergence of far-IR/THz astronomy, as evidenced by upcoming missions such as Herschel and SOFIA. The data we provide will allow for rigorous interpretation of long-wavelength spectra of interstellar and planetary environments from these missions and observatories such as ALMA.

Table 1. Ice compositions and temperatures to be studied

Composition		Temperature(s)
Pure Ices:		
H_2O		10-170 K
CH_3OH		10-150 K
CO_2		10-70 K
CO		10-30 K
CH_4		10-30 K
NH_3		10-90 K
N_2		10-30 K
Ice Mixtures:		
H_2O+CO_2	(10:1)	10-170 K
H_2O+CO	(10:1)	10-170 K
H_2O+CH_3OH	(10:1)	10-170 K
$H_2O+CH_3OH+CO_2$	(1:1:1)	10-170 K
N_2+CH_4	(10:1)	30-50 K
N_2+CO	(10:1)	30-50 K
N_2+CO_2	(10:1)	30-50 K
N_2+H_2O	(10:1)	30-50 K
Solids:		
Pyrene		10-300 K
Coronene		10-300 K
Forsterite (Mg_2SiO_4)		10-300 K

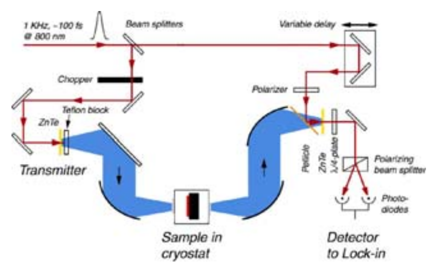


Figure 4: A terahertz time-domain spectrometer based on optical rectification in zinc telluride (ZnTe).

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