# Laboratory far-IR spectroscopy of minerals: providing the data for IR missions analysis

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Mineral spectra in the far-IR region are highly characteristic of mineral group, crystal structure and chemical composition. For slightly more than 10 years has far-IR spectroscopy become useful for identifying the mineralogy of cosmic dust populations. Now attempts to identify some common minerals having prominent far-IR features within the dust associated with various astronomical objects, such as the circumstellar dust of AGB stars, that of Young Stellar Objects, Planetary Nebulae, protoplanetary and debris discs, and comets, are being undertaken. In addition to the currently operating far-IR/sub-mm Herschel Space Observatory, several others, both past and planned, IR space missions, such as ISO, Spitzer, SOFIA, SPICA, and Millimetron, are to be mentioned. To support the analysis of data return from those missions, the building of a database of laboratory far-IR spectra of terrestrial mineral analogs, representing a wide range of mineral groups, especially at conditions relevant to those in space (e.g. at cryogenic temperatures) is desirable and timely.

In this connection, we have collected mass absorption coefficient spectra of micron-sized powders for more than 150 naturally occurring astrophysically-relevant terrestrial minerals in the wavelength range 15 - 250 µm. These include over 20 oxides and hydroxides; a variety of sulfides of $Me_{(1-x)}S$ and $MeS_{(1-x)}$ families; carbonates (e.g. Fig.1 (right)); garnets; phenakites; olivines over the full compositional range from fayalite $Fe_2SiO_4$ to forsterite $Mg_2SiO_4$; pyroxenes including jadeite $NaAlSi_2O_6$, aegirine $NaFe^{3+}Si_2O_6$ and the enstatite $MgSiO_3$ – ferrosilite $Fe^{2+}SiO_3$ and the diopside $CaMgSi_2O_6$ - augite $Ca(Mg,Fe)Si_2O_6$ – hedenbergite $CaFeSi_2O_6$ series; pyroxenoids; amphiboles; multiple phyllosilicates, including the serpentines (antigorite, chrysotile, amesite, etc.), smectites (beidellite, montmorillonite, nontronite, hectorite, saponite, chlorite, clinochlore, etc.), micas (clintonite, illite, vermiculite, pyrophyllite, talc, etc.) (see example of the spectra on Fig. 1 (left)), kaolinites (dickite, kaolinite, nacrite, halloysite, palygorskite, and sepiolite, etc.); soro- and cyclosilicates (see example on Fig 2 (right)); a range of compositions across both plagioclase- and alkali- feldspars, as well as several representatives of the silica group. Most of the minerals examined possess prominent and characteristic features in the far-IR range (Figs. 1, 2). For many minerals, ours are the first far-IR spectra out to 250 µm, according to literature review. Far-IR peak frequencies and mass absorption coefficient values are tabulated. The prepared mineral powders will be available for further mid-IR or reflectance studies. Currently

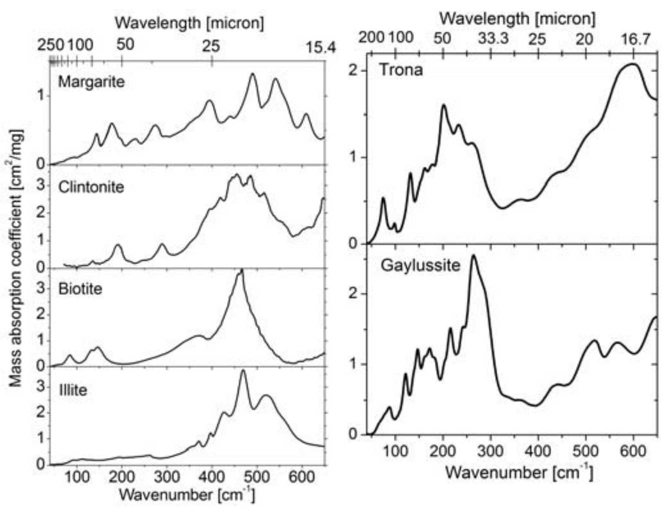


**Fig.1** (**left**) spectra of the phyllosilicates, mica subgroup; (**right**) examples of spectra for hydrated and acid carbonates.

all the data are being prepared for publication and submission to the Planetary Data System (PDS) database.

The minerals for study are selected from American Museum of Natural History mineral collection, verified by means of electron microprobe and XRD, ground to micron dimensions, and a micron particle size distribution is ensured by Stokes settling. For far-IR measurements the polyethylene pellets are made via hot pressing at controlled temperature. The absorption spectra are collected using Bomem Fourier spectrometer with globar source, mylar beamsplitter, and a 4 K bolometer. The useable spectral range is 40 - 650 $cm^{-1}$ (250 - 15.4 μm wavelength), with spectral resolution of 4 $cm^{-1}$. The transmittance $T$ is calculated as the ratio of the transmitted power spectra for two pellets, with and without mineral. The mass absorption coefficient $\kappa$ is calculated as $\kappa = (S/m) \ln (1/T)$, where $m$ – mineral mass in the pellet, and $S$ – pellet area.

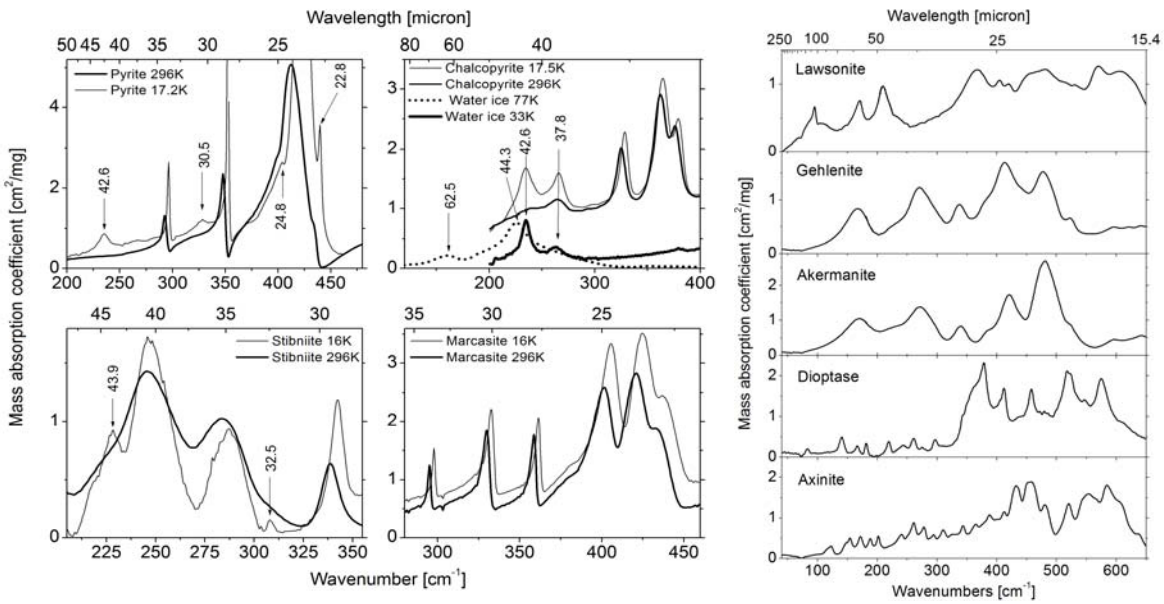


**Fig 2** (**left**) the temperature dependence of the sulfide spectra. Blue shifts, line sharpening, resolution of overlapping bands, and water ice peaks appear due to a thin layer of water ice that is collected on the pellet; (**right**) example of spectra for soro- (lawsonite, gehlenite, akermanite) and cyclosilicates (dioptase and ferroaxinite) groups.

Low-temperature measurements down to 15 K revealed sharpening and blue-shifts of the characteristic absorption lines, and in some cases, resolution of additional features not seen at room temperature. Water ice peaks are presented in the Fig. 2 (left), appearing around 62.5 and 42.6 - 44.3 μm. These agree well with the crystalline water ice peak for moderately-low temperatures at 62 μm, and with an amorphous water ice spectral feature at 44-46 μm in previous publications. In addition to these, another line at ~37.8 μm appears in many of our low temperature spectra, which we also attribute to water ice. There is a significant sharpening and blue-shift in the ice peaks when the temperature is reduced from 77 K to 33 K, e.g. 44.3 μm blueshifts to 42.6 μm.

As the nearest future prospective we, plan first: to expand this study by including several more astrophysically-important mineral groups (e.g. carbides, or water-bearing minerals as sulfates, phosphates, hydrated and acid carbonates (e.g. Fig.1, right), etc.); and second: similar far-IR studies of the extraterrestrial minerals, extracted from a variety of meteorites. Currently we are beginning such studies on ten of the martian meteorites and a series of achondrites.