Mem. S.A.It. Suppl. Vol. 6, 41

Memorie della
Supplementi

Databases of Mid and Far IR Spectra for the analyses of the Cassini mission data

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Abstract. InfraRed spectra of ices, minerals and organic compounds have been collected. The data provide spectra in reflectance, absorbance and transmittance of different materials (at different grain size, temperatures) and also the optical constants (k and n), which are useful to understand emission and absorption mechanisms of solid materials. This work will be useful to analyze and interpret the data coming from space missions and in particular from CIRS, the Composite Infrared Spectrometer on board the Cassini-Huygens probe, with a spectral range between 7 and 1000 μm. In particular, our aim is to analyze spectra on icy satellites of Saturn.

Key words. MIR and FIR spectra, databases, Cassini mission

1. Introduction

The Cassini-Huygens mission has been succesfully launched from Kennedy Space Center on 15th October 1997. It is composed of an orbiter (Cassini) and a probe (Huygens), which has succesfully descended Titan's atmosphere, on 14th January 2005. This mission is a collaboration between NASA, the European Space Agency (ESA) and the Italian Space Agency (ASI). The Cassini-Huygens mission has been idealyzed to study the entire saturnian system, composed by the planet itself, the icy moons, the ring system, the magnetosphere, and the atmosphere.

We focus on one of the instruments on board the Cassini probe, the Composite InfraRed Spectrometer (CIRS).

CIRS is a remote sensing Fourier Transform Spectrometer, which operates from 10 to 1400 cm^{-1}, that is in the spectral range between 1 mm and 7 μm, with a spectral resolution that can be set from 0.5 to 15.5 cm^{-1}.

CIRS will provide 3D maps of temperature, gas composition and aerosol condensates of the atmospheres of Titan and Saturn with a good resolution. It is composed of 2 interferometers. The Far-InfraRed region (10-600 cm^{-1}, called Focal Plane FP1) is measured with a polarizing interferometer having thermopile detectors, with a common 4-mrad field of view. The middle InfraRed region is measured with a traditional Michelson interferometer, having two focal planes (600-1100 cm^{-1}, FP3, and 1100-1400 cm^{-1} FP4), each

Send offprint requests to: A. Migliorini having ten HgCdTe detectors, with 0.273 mrad field of view per pixel.

We concentrate our attention to study by CIRS the icy moons of Saturn. In fact, at these wavelenghts, from the thermal spectra provided by CIRS, it is possible to derive a thermal map for the icy moons of Saturn, their general characteristics and in particular their surface composition. From the spectral features detected on the CIRS spectra, we could investigate the composition and distribution of the surface materials of the icy moon of Saturn, with a particular attention to the dark, organic-rich materials and condensed ices with low melting point.

2. Spectra in the Mid and Far InfraRed

From the previous observations, we know that the icy moons of Saturn are composed by ices (like water ice, carbon dioxide, carbon monoxide, metan, ammonia, ...), organic compounds, and minerals (like carbonates, silicates, olivines and piroxenes in different forms). There will probably be many other still undetected compounds, which could be detected for the first time during the Cassini-Huygens mission.

We have started to compile a complete spectral database, which could be of a great use during the reduction and interpretation of CIRS data. We have selected different databases, containing principally the optical constants of interesting compounds, and their principal spectral features.

In the following sections we report the most well known spectral features for ices, organic compound and silicates.

2.1. Solar System ices

The major part of the common vibrational features in the minerals spectra are due to water and OH ions. The principal water features in the InfraRed are at 1.9 and 6.27 μm; there exist also other two characteristic features of water, at 2.9 and 6.1 μm, which are due to the bending vibrational mode of H-O-H.

Recent works by Sylvester et al. (1999) have recorded, from observations with the Short- and Long- Wavelength spectrometers on board the Infrared Space Observatory, features of OH at 34.6 μm, and one at 62.0 μm; another water ice feature has been identified at 43.0 μm by Dartois et al. (1998). An interesting work on Solar System ices have been performed by Johnson & Atreya (1996). They have derived, from laboratory esperiments, the spectra and the optical constants for CO_2 and H_2O ices at temperatures from 77 to 150 K over the spectral range 50 to 500 cm^{-1}.

As regarding NH_3 ice, the main InfraRed features detected up to now are located at 2.96, 6.14, 9.0, 9.46, 12.7 μm (see works by Wong (2004), Gibb et al. (2000) and Lacy et al. (1998)).

Here we have reported only some of the features detected for water ices, ammonia ices, methan ices.

2.2. Organic Compounds

The *organic compounds* are molecular solids composed by C, H, O and N. Their fundamental vibrations are:

- ν_1 (symmetric stretching) at 1063 cm^{-1} (9.40 μm)
- ν_2 (bending out of the plane) at 879 cm^{-1} (11.40 μm)
- ν_3 (asymmetric stretching) at 1415 cm^{-1} (7.06 μm)
- ν_4 (bending in the plane) at 680 cm^{-1} (14.70 μm)

2.3. Silicates

The *silicates* are the most studied minerals, because they are very abundant on planetary surfaces. They are characterized by the SiO_4^{4-} elementar group, and they are classified in several "families" depending on the number of ossigen atoms which are placed in common between two elementar groups.
Pyroxenes and olivines are two of the most common silicats forms on planetary surfaces.

The silicates present typical features at 8-15 μm (stretching mode) and at 18-25 μm (bending mode).
In Jager et al. (1998), prominent emission and

absorption features due to silicates have been found around 9.3, 13.6, 13.8, 14.6, 18.3, 20.8, 24.7, 26.1, 43.3, 45.0 and 65.7 μm. Previous works by Molster et al. (1998) have been identified emission and absorption features around 10.1, 11.2, 13.8, 16.3, 19.5, 21.5, 23.7, 27.9, 33.6, 35.5, 36.5, 40.5, 43.0 and 69.5 μm, marking the presence of crystalline olivines and pyroxenes.

3. Analyses of Phoebe and Iapetus

CIRS has started to observe Phoebe on June 2004 during the Cassini's approch to Saturn, Dione on December 2004 and Iapetus on January 2005. Numerous spectra of Phoebe and Iapetus on the three focal planes were acquired. However, since these are rather cold objects (peak temperatures of around 115 K for Phoebe), their thermal emissions are faible with peak emissions at ~200 cm^{-1}. As a consequence, there is hardly any signal left on the spectral range of FP4 and most of the individual spectra of FP3 and FP1 have S/N less than optimal for feature identification. To overcome this, all spectra for each object are co-added, producing an average spectrum. To accomplish this, the thermal emission for each acquired observation is modeled and them removed by division from the observed spectrum. The resulting spectra should reproduce the emissivity variations, which can be used for compositional analysis. These are then summed up to produce and average spectrum. A possible problem here comes from the fact that the peak emissions for the saturnian satellites lie well within the spectral range of FP1. This means that any mismatch between the model and the actual emission may introduce broad features in the emissivity spectrum. To avoid this accurate thermal modeling must be used, taking into account the real morphology of the surface of each body. This is particularly true for the irregular surface of Phoebe (Fig. 1), for which most of the thermal emission variations are controlled by local topography. Such a model is being implemented using the shape model obtained by the observations of Imaging Science Subsystem (ISS) on board the Cassini spacecraft.

The preliminary analysis, we did so far, consists on a fit of each spectrum with two black bodies; the final result is then analyzed taking into account the noise level of the instrument.

3.1. Phoebe

Up to now Phoebe is the only satellite observed at very close distance. During the Cassini close approch (~ 2100 km), more than 600 spectra of Phoebe have been taken by the FP1 of CIRS. Many other spectra have been provided by the FP3 and FP4, with a worse S/N ratio. Water ice has been detected at shorter wavelenghts by the Visible and Infrared Mapping Spectrometer (VIMS) and other instruments on board the Cassini probe, and we know that water ice has to be present at around 200 cm^{-1} (50 μm). This signature is not evident on our spectra. Probably, this feature could be under the noise level, and hence not detectable. On the other hand, there could be a contamination by dark compounds, and hence water feature would not be evident. We are now working to understand why water ice feature is not visible at longer wavelenghts.

3.2. Iapetus

Iapetus is the third moon met by the probe. Fig. 2 shows the moon as seen by Cassini's camera. For Iapetus we have more than 400 spectra taken with FP1. Due to the difference of its surface (the diffence in albedo between the two faces is of a factor 10), we need carefull thermal models to better analyse the spectra. Also in this case, the signal is very low and we are trying to improve the quality co-adding more data.

4. Conclusions and Future Plans

Many spectra of interesting materials are available at short spectral range (up to 50 μm) and few spectra are also available up to 200 μm. Very few data exist up to 1 mm. It has been found that emissivity feature profiles of silicate dust depend on temperature, with differences between materi-

Fig. 1. Phoebe's picture, taken by the camera on board the Cassini probe during the close flyby with the moon, on 23rd June 2004. (Credits: NASA/JPL/Space Science Institute).

Fig. 2. The two faces moon of Saturn, Iapetus, taken by the camera on board the Cassini probe, on 15th July 2004. (Credits: NASA/JPL/Space Science Institute).

als (Mennella et al. 1998). Furthermore, dependency of spectroscopic properties of surfaces on parameters like chemical composition (silicates, carbonaceous materials and ices), structure (amorphous, crystalline), morphology/dimension (grain size distribution, fractal aggregates, or packing) and processing (UV, ion irradiation) are not well known at typical CIRS spectral ranges. This lack of reference information on the candidate materials, analysed in proper physical conditions and spectral range, strongly limit data interpretation. From another point of view, laboratory data can allow the identification of possible carriers of the observed emission features, also on the basis of compatibility of specific analogue material with the specific object observed and comparison with surface properties inferred from different instrument on board of Cassini-Huygens mission. Spectroscopic analysis will take advantage from the laboratory activity of particulate analogues which are performing in Cosmic Physics and Planetology Laboratory of INAF Naples in support of the mission. Mixtures of ices (water and organic molecules) with Titan tholin and silicates will be obtained at cryogenic temperatures and reflectrance spectra in far-infrared region (up to 2 mm) acquired and compared with the observed emissivities by using appropriate thermophysical models. The material we collected up to now is only partially usefull for analysis and interpretation of CIRS data. We need to enlarge our spectral databases, and for this we need new appropriate laboratory measurements.

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