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Ice phase detection tools applied to Cassini VIMS data

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Abstract

We present a technique to measure the relative amounts of crystalline and amorphous H_2O-ice in spectra of fairly low spectral resolution and low signal precision. The technique was designed to work on Cassini VIMS hyper-spectral data cubes. We demonstrate is effectiveness with an application to the Saturn satellites.

1. Introduction

Amorphous and crystalline H_2O ices have been found combined on the surface of Quaoar [2], and Europa [4] and might be present on the surface of other icy bodies in the outer Solar System. From laboratory work [7; 5] it is well known that the prevalence of one over the other is usually characterized by shifts in the position of the 1.5- and 2.0-μm bands, but most obviously by the strength of the band at 1.65 μm and by variations in the shape, position and even presence of the Fresnel peak at 3.1 μm.

In an extensive study of H_2O ice Grundy et al [3] showed that the 1.5- and 2.0-μm bands can be fitted with Gaussians with different width and position (see Figure 1). While the 1.5-μm band is a complicated combination of several Gaussians, the 2.0-μm band is composed of three Gaussians, of which one is predominant in its contribution to the total absorption. Variations in ice phase affect the relative strength of the Gaussians that compose the 2.0-μm band [6].

2. Data analysis

Cassini VIMS hyper-spectral cubes offer a wealth of information on the surface of the icy Saturn satellites. Unfortunately, one of the instrument's filter junctions falls on the 1.65-μm band [1] and often the quality of the data at the 3.1-μm Fresnel peak is not sufficient to detect variations in its shape. Furthermore, the spectral resolution is often too coarse to allow detection of subtle shifts.

To demonstrate our technique, we make use of a grid of synthetic reflectance spectra calculated with a code based on the Shkuratov et al. [8] radiative transfer theory for atmosphere-less bodies and optical constants from Mastrapa et al. [6]. We fit a single Gaussian to the bulk of the 2.0-μm band (Table 1), corresponding to Grundy's dominant Gaussian at 2.02 μm. The fact that the fit is done to several (about 10 on average) data points will make the approach stable even for noisy observations. We ratio the synthetic spectra by the Gaussian fit to obtain a function, shown in Figure 2, that varies systematically, in the range shown in red in the figure, with changes in the relative amounts of crystalline and amorphous ice. The advantages of applying this technique to the Cassini VIMS data are twofold: the technique is independent of the spectrum resolution and is stable even when applied to fairly noisy data. We demonstrate its effectiveness on the Saturn satellites spectra.

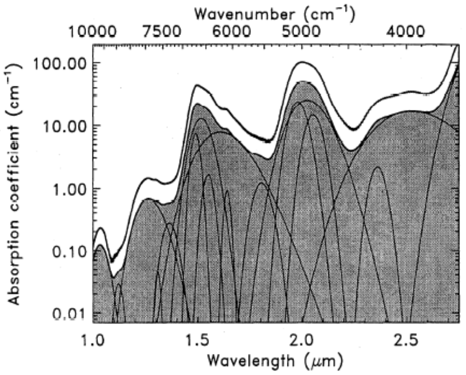

Figure 3. Example of an absorption coefficient spectrum (isolated curve) and the Gaussian fit (shaded region, shifted down by a factor of 2), showing the contributions of the 17 individual Gaussian curves. Although the maximum errors between fit and data approach 20%, they are very difficult to discern at this plotting scale, covering several orders of magnitude in absorption coefficient. This particular spectrum is for H_2O ice at 210 K.

Figure 1: Grundy et al. [3] figure illustrating the

Gaussian components of a section of the spectrum of crystalline H_2O ice.

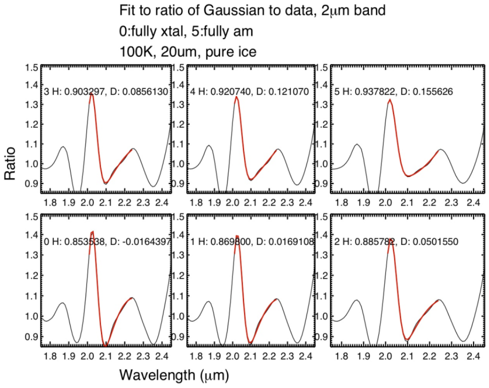

Figure 2. Ratio of synthetic spectrum to Gaussian fit for a variety of amorphous and crystalline mixtures illustrates the variations in the shape of the 2-μm band to be expected as the relative amounts of crystalline and amorphous ice varies.

3. Tables

Table 1: Grundy et al [3] table illustrating the position of the centers of the Gaussians contributing to the section

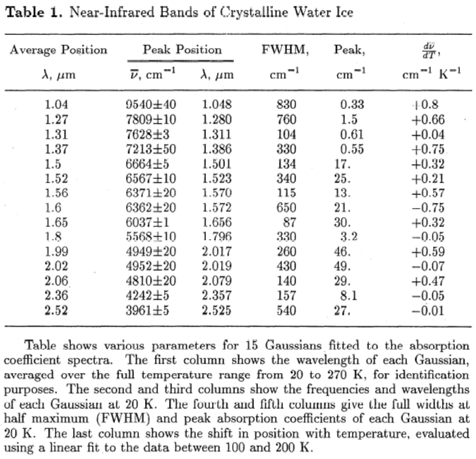

Table 1. Near-Infrared Bands of Crystalline Water Ice

Average Position	Peak Position		FWHM,	Peak,	$\frac{d\bar{\nu}}{dT}$,
λ, μm	$\bar{\nu}$, cm^{-1}	λ, μm	cm^{-1}	cm^{-1}	cm^{-1} K^{-1}
1.04	9540±40	1.048	830	0.33	+0.8
1.27	7809±10	1.280	760	1.5	+0.66
1.31	7628±3	1.311	104	0.61	+0.04
1.37	7213±50	1.386	330	0.55	+0.75
1.5	6664±5	1.501	134	17.	+0.32
1.52	6567±10	1.523	340	25.	+0.21
1.56	6371±20	1.570	115	13.	+0.57
1.6	6362±20	1.572	650	21.	−0.75
1.65	6037±1	1.656	87	30.	+0.32
1.8	5568±10	1.796	330	3.2	−0.05
1.99	4949±20	2.017	260	46.	+0.59
2.02	4952±20	2.019	430	49.	−0.07
2.06	4810±20	2.079	140	29.	+0.47
2.36	4242±5	2.357	157	8.1	−0.05
2.52	3961±5	2.525	540	27.	−0.01

Table shows various parameters for 15 Gaussians fitted to the absorption coefficient spectra. The first column shows the wavelength of each Gaussian, averaged over the full temperature range from 20 to 270 K, for identification purposes. The second and third columns show the frequencies and wavelengths of each Gaussian at 20 K. The fourth and fifth columns give the full widths at half maximum (FWHM) and peak absorption coefficients of each Gaussian at 20 K. The last column shows the shift in position with temperature, evaluated using a linear fit to the data between 100 and 200 K.

4. Summary

We present a technique to measure the relative amounts of crystalline and amorphous ice on the surface of icy bodies making use of their reflectance spectra 2.0-μm band. The technique is independent of spectral resolution and stable for relatively noisy data.

We illustrate the effectiveness of the method with an application to Cassini VIMS cubes of the Saturn satellites.

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