IS THE 3.5 μm INFRARED FEATURE ON ENCELADUS DUE TO HYDROGEN PEROXIDE?

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ABSTRACT

We use new and previously published measurements from our laboratory to examine the assignment of a 3.5 μm feature in the infrared spectrum of Enceladus. The spectral feature, taken with *Cassini*'s VIMS Spectrometer, has recently been interpreted as an absorption band from hydrogen peroxide on the surface. Such identification is important because it would imply an intense flux of magnetospheric particles, which are thought to be required to produce H_2O_2 from surface water ice. We compare the position and width of this feature with measurements of infrared spectra of water–hydrogen peroxide mixtures. We conclude that the reported feature from Enceladus does not correspond to hydrogen peroxide.

Key words: infrared: general – methods: laboratory – planets and satellites: individual (Enceladus and Saturn)

1. INTRODUCTION

The *Cassini* mission has made many striking discoveries around Saturn; among them is the spectacular fountain or plume of water vapor and icy particles emitting from the South Polar Region (SPR) of Enceladus (Hansen et al. 2006; Spahn et al. 2006; Porco et al. 2006). The origin of the plume is still a matter of dispute and therefore observations with multiple instruments have been made and are planned, especially during flybys. One of the observations is that of a weak, narrow feature at ∼3.5 μm in the infrared spectrum of the surface of Enceladus (Brown et al. 2006; Newman et al. 2007), superimposed on the strong O–H stretch band of water, by far the most abundant molecule on the surface ice (Cruikshank 1980; Brown et al. 2006). This feature was initially reported to be due to infrared absorption by light organics on the surface (Brown et al. 2006), but recently it was suggested that it is caused by the absorption of hydrogen peroxide (Newman et al. 2007). This molecule has been unequivocally detected by infrared spectroscopy only on Europa (Carlson et al. 1999) among the icy satellites, and it is believed to be formed by radiolysis of the surface water ice by the energetic component of the magnetospheric plasma. The identification is based on laboratory studies (Carlson et al. 1999; Moore & Hudson 2000; Gomis et al. 2004a, 2004b; Baragiola et al. 2005; Loeffler & Baragiola 2005; Loeffler et al. 2006a).

We are particularly interested in whether the 3.5 μm feature is due to hydrogen peroxide because it would indicate that the surface of Enceladus is subject to significant irradiation by energetic magnetospheric particles, in contrast with current expectations based on *Cassini*'s measurements of a low population of energetic particles at Enceladus orbit.

The concentration of hydrogen peroxide produced by irradiation of water is at most ∼1% (Loeffler et al. 2006a). At low temperatures typical of most of Enceladus, the H_2O_2 radiation product will form isolated trimers, $H_2O_2 \cdot 2H_2O$, which are unable to diffuse. At the relatively high temperatures of Enceladus SPR, diffusion allows the formation of equilibrium phases. At low H_2O_2 concentrations, these stable phases are pure water and the $H_2O_2 \cdot 2H_2O$ dihydrate compound (Foley & Giguere 1951), as follows from laboratory studies (Giguere & Harvey 1959; Loeffler & Baragiola 2005; Loeffler et al. 2006c). We note that precipitates of pure hydrogen peroxide can only exist at concentrations above ∼33% (Foley & Giguere 1951), unachievable by radiolysis, and thus cannot be present on Enceladus. Infrared spectroscopy can be used to identify these phases since the

position, shape, and full width at half-maximum (FWHM) of the 3.5 μm infrared absorption band are very sensitive to the environment of the H_2O_2 molecule.

In the present study, we compare the 3.5 μm feature on Enceladus with infrared spectra taken in the laboratory to determine whether this feature belongs to hydrogen peroxide.

2. EXPERIMENTAL DETAILS

All experiments were performed in a stainless steel ultra high vacuum (UHV) chamber on a radiation-shielded cryostat (base pressure ∼10^{-10} Torr), and are described in detail elsewhere (Loeffler et al. 2006b). For the new experiments reported here, we vapor deposited hydrogen peroxide and water mixtures from a glass manifold at near normal incidence at 110 K onto the mirror gold electrode of a quartz-crystal microbalance (QCM) that measures accurately the mass deposited per unit area, which can be converted to film column density (molecules cm^{-2} or thickness if the density is known; Sack & Baragiola 1993). The glass doser and manifold were chosen to prevent the highly reactive H_2O_2 from decomposing before growth; more details are given elsewhere (Loeffler 2007). Since the microbalance gives the total mass deposited per unit area rather than film thickness (which depends on density), we report the column densities in the films and use as a unit the monolayer, defined here as 1 ML = 10^{15} molecules cm^{-2}. The infrared reflectance of the films on the gold mirror was measured at an incident angle of 35° with a Thermo-Nicolet Nexus 670 Fourier transform infrared spectrometer at 2 cm^{-1} resolution.

We quantified the column density of H_2O_2 by calculating the band area of the 3.5 μm absorption feature and dividing it by the effective band strength A^* and the path length of light in the film. The effective band strength depends on film thickness due to interference effects present in thin film experiments (Loeffler et al. 2006a; Teolis et al. 2007). For our 1.9 μm films, $A^* = 4.9 \times 10^{-17}$ cm molecule^{-1} at 110 K (Loeffler et al. 2006a).

The quantification of this absorption band is difficult since it lies on a curved continuum originating from the O–H stretch vibration of water ice. To obtain an accurate band shape, area, and FWHM, one should use a baseline that matches the curved continuum; this becomes more crucial as the concentration of H_2O_2 decreases below a few percent. To choose an accurate baseline, one can either fit the continuum at both sides of the band with a nonlinear function, such as a high-order polynomial,
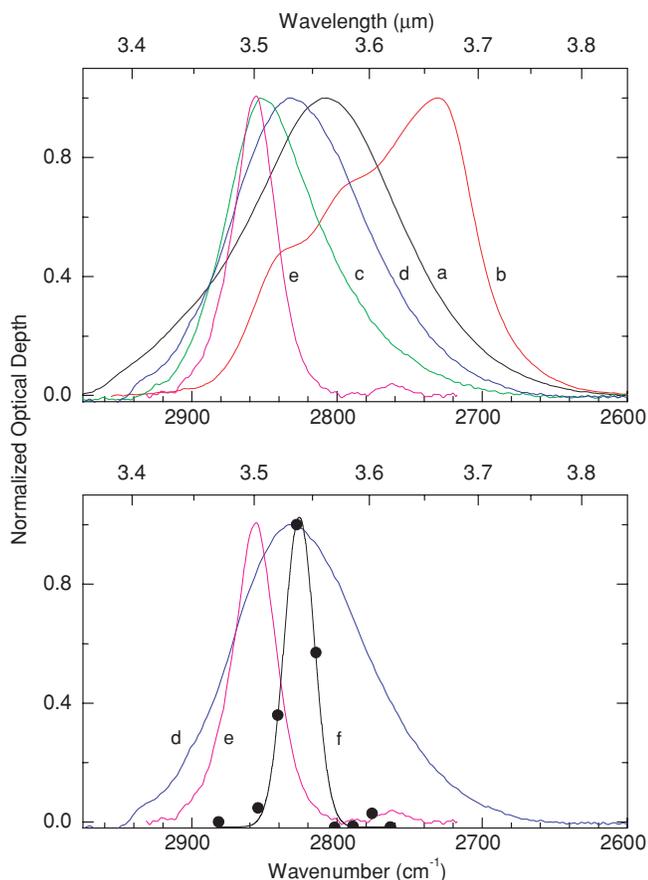
Figure 1. Infrared absorption spectra of H$_2$O$_2$ in different environments, taken from Loeffler & Baragiola (2005). (a) Pure (>97%) amorphous H$_2$O$_2$ at 110 K, (b) pure (>97%) crystalline H$_2$O$_2$ at 110 K, (c) 6.5% H$_2$O$_2$ dispersed in water ice grown at 110 K, (d) pure H$_2$O$_2$ precipitates obtained with alternate 10 ML layers of H$_2$O$_2$ and 100 ML of water at 110 K, (e) crystalline mixture of 3% H$_2$O$_2$ in water ice at 110 K, and (f) baseline subtracted spectrum of Enceladus shown in Newman et al. (2007). The solid line is a fit of a Gaussian to their data.

Figure 2. FWHM of the 3.5 μm absorption band of H$_2$O$_2$ mixed in water ice as a function of concentration.

or use the spectrum of a pure water ice sample grown under the same conditions to the same thickness as the reference spectrum. In these experiments, we verified that both methods gave us the same band shape and band area if the concentration was around 1%. However, for lower concentrations we used pure water ice as our reference, since the continua in this region were so similar for the two samples. For concentrations above 1% we used a nonlinear polynomial fit to approximate the baseline, as the continuum in those samples was slightly altered in comparison to pure water ice (Loeffler et al. 2006a).

3. RESULTS AND DISCUSSION

3.1. Comparison of Infrared Spectra of H$_2$O$_2$ to the 3.5 μm Feature on Enceladus

The position of the infrared feature reported on the surface of Enceladus is closest to an absorption band of H$_2$O$_2$ if this molecule is in a pure precipitate. However, not only is pure H$_2$O$_2$ unlikely, as discussed above, but the FWHM of the Enceladus 3.5 μm feature, 0.02 ± 0.01 μm, is seven times smaller than the absorption band of H$_2$O$_2$ in pure precipitates.

Figure 1 (top) shows spectra for H$_2$O$_2$ in a variety of environments taken from our previous reports (Loeffler & Baragiola 2005). Figure 1 (bottom) compares the feature observed on the surface of Enceladus with the absorption bands that best fit
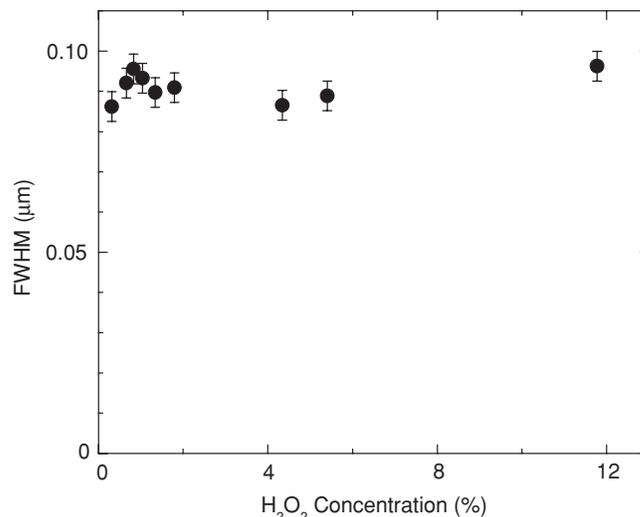
the position or the width individually but, clearly, the match is unsatisfactory when both parameters are considered.

Newman et al. (2007) interpreted the laboratory data of Moore & Hudson (2000) and Loeffler & Baragiola (2005) to conclude that the H$_2$O$_2$ absorption band narrows when the concentration of H$_2$O$_2$ in a mixture with water is decreased, and thus a narrow width only meant that the concentration was low. To test this possibility, we measured the concentration dependence of the FWHM of the absorption band of hydrogen peroxide mixed in water, grown at 110 K. The results in Figure 2 show that the FWHM remains constant over a change in concentration of a factor of 40. We note than in a previous report we showed that the FWHM changes with phase, not with concentration (see Table 1 in Loeffler & Baragiola 2005). For instance, the band narrows by a factor of $\sim$2 upon crystallization of a mixture.

Finally, we tested for the possibility that CO$_2$, which has been detected on the surface of Enceladus (Brown et al. 2006), could affect the FWHM or band position of hydrogen peroxide. We found no detectable changes in the shape and position of the hydrogen peroxide band when we grew a mixture of CO$_2$ and hydrogen peroxide in a water matrix. Thus, based on the new and previously published laboratory data, we conclude that the 3.5 μm absorption feature on Enceladus is unlikely due to hydrogen peroxide.

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