THE SEARCH FOR HYDROGEN PEROXIDE ON ENCELADUS.

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Introduction: The discovery of a dynamic, active plume emanating from the south pole of Enceladus has left scientists with many more questions than it has answered. What is causing the hot spot underneath the south pole? How are the water vapor particles formed? How does Saturn's magnetosphere interact with these particles? What is the nature of the surface and subsurface environments of the south pole? One way to explore these questions is to study the surface ice with photometric and spectral data. Using observations from the Visual and Infrared Mapping Spectrometer (VIMS) aboard the spacecraft Cassini, we have searched for the presence of H_2O_2 on Enceladus. Our preliminary results indicate a tentative detection of H_2O_2 in a condensed form. The presence or absence of H_2O_2 is indicative of the radiolytic environment of a surface or the surrounding atmosphere. In addition the depth and position of H_2O_2 bands are useful for determining grain size, porosity and thermal history [1].

Production of H_2O_2: High energy radiation, such as UV photons or H^+ ions, has been shown to convert water ice to H_2O_2 [1,2]. Energetic plasma dissociates H_2O into H + OH, and H_2O_2 either forms from the combination of two OH radicals or by reactive scattering of H and OH by water [3]. In irradiation experiments, less H_2O_2 is detected after radiolysis at higher temperatures, however, the addition of O_2 or CO_2 to water ice can counter this effect [1]. CO_2 acts as an electron scavenger, removing free electrons that can break up H_2O_2, and O_2 provides an additional pathway for the formation of H_2O_2 through H-atom addition. [1] detected H_2O_2 after irradiation of pure water ice films with 0.8 MeV H^+ ions at 16 K, but not at 80 K. When O_2 or CO_2 was deposited with the water ice prior to irradiation, H_2O_2 was detected at 80 K.

Spectral Signature: H_2O_2 can be identified in near- to mid-infrared ice spectra. Only three H_2O_2 absorption bands in this region can be distinguished from water ice bands: a combination band around 3.5 µm, a symmetric bending mode at 6.86 µm, and an asymmetric bending mode at 7.2 µm [2]. Of these, the 3.5 µm band is the strongest, but its position is somewhat variable. [4] examined the spectra of thin films of crystalline and amorphous H_2O_2 at 4 and 80 K. In general, the crystalline H_2O_2 had more defined peaks, whereas the amorphous bands were broader and rounder, due to hydrogen bonding and disorder. For condensed amorphous H_2O_2, the combination band was found at 3.559 µm, and for crystalline H_2O_2, it moved to 3.52 µm. In addition, deposition of H_2O and H_2O_2 together results in an upward shift in the wavelength of absorption bands due to intermolecular frequencies [4].

H_2O_2 produced by irradiation of H_2O displays the combination band at 3.501 µm or 3.511 µm with FWHM ranging from 0.02 to 0.12 µm [1,2]. Addition of O_2 to H_2O before irradiation results in a shift of the absorption band from 3.501 µm to 3.52 µm, and a CO_2/H_2O mixture produces a band at 3.508 µm [1]. Other factors affect the position of this band, including the concentration of H_2O_2 (a larger concentration shifts the band to higher wavelengths), grain size, porosity, and thermal history of the ice [1]. There is also a H_2O_2 absorption feature in the UV from around 300 nm to shorter wavelengths [3].

H_2O_2 on Europa: H_2O_2 has previously been detected on the surface of Europa with a concentration of 0.13% [3]. This detection includes analysis of the 3.5 µm band, in addition to absorption in the UV. Scientists believe that the H_2O_2 is produced by the bombardment of high energy particles from the Jovian magnetosphere [3]. A smaller H_2O_2 signal has also been detected on Ganymede and Callisto, where the strength of the radiative bombardment is weaker [5].

Enceladus Results: We have tentatively identified H_2O_2 on Enceladus with data from the VIMS, using the 3.5 µm absorption band as an indicator. This band appears in slightly different positions in the spectra of different regions of Enceladus (Fig. 1). For the spectrum of the south polar "tiger stripes", the band is located at 3.547 µm. For the region between the stripes, the band is at 3.563 µm. A global spectrum of Enceladus (minus the signal from the south pole) shows the band at 3.530 microns.

In general, the 3.5 µm band is stronger and shifted to higher wavelengths in the south polar region of Enceladus. The wavelength shift could be due to a higher concentration of H_2O_2 in this region, or a higher degree of amorphous as opposed to crystalline H_2O_2 ice. [6] found a higher concentration of amorphous water ice at the south pole of Enceladus relative to the rest of the satellite, thus a higher concentration of amorphous H_2O_2 ice in this region would be in agreement with this result.

Although the south pole as a whole contains water ice of a more amorphous nature, the tiger stripes have a higher degree of crystallinity than the region in between the stripes [6]. In our work, both the tiger stripes and the region between them display the H_2O_2 band very close to the amorphous position at 3.56 µm, although the position for the tiger stripe spectrum is shifted to a slightly lower wavelength. This inconsistency, between the forms of water ice and H_2O_2, could be reconciled by the fact that water ice is crystallized at 140 K, while H_2O_2/H_2O mixtures crystallize between 140-200 K [4]. Thus the tiger stripes may be hot enough to crystallize pure water ice, but cool enough such that condensed hydrogen peroxide could remain amorphous.

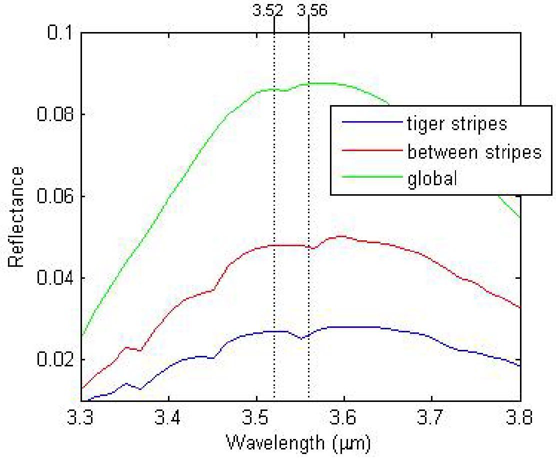

Figure 1. Enceladus spectra from several different areas of the satellite in the region of the 3.5 µm H_2O_2 absorption band. The blue line is from the "tiger stripes", the red line is from the region in between the stripes and the green line is a global spectrum. The vertical dotted lines highlight 3.52 and 3.56 microns, the positions of the band for crystalline and amorphous condensed H_2O_2 ice, respectively.

To examine the 3.5 µm band in more detail, we plot the spectrum of the south polar region of Enceladus and the expected continuum without this band (Fig. 2). The position of this band is 3.547 µm, with a FWHM of 0.04 µm. The position of the H_2O_2 combination mode band for all of the Enceladus spectra corresponds best to the lab spectra of condensed amorphous ice, condensed crystalline ice, or a mixture. In addition, it also matches somewhat well with the spectrum of an irradiated mixture of H_2O and O_2 [1].

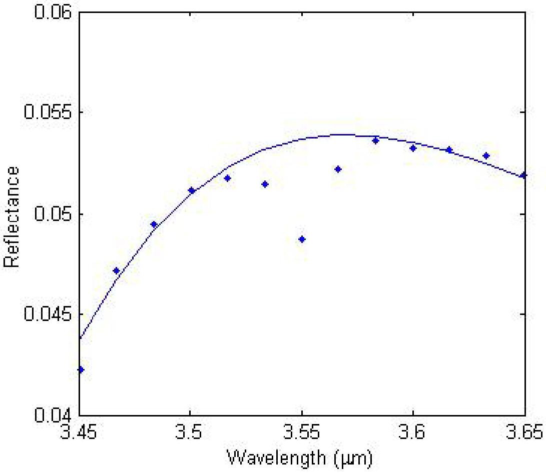

Figure 2. Spectrum of the south pole of Enceladus near 3.5 µm and the interpolated continuum without the absorption band. The Enceladus spectrum is shown in dots and the continuum is shown as a line.

Conclusions: We believe we have found evidence of H_2O_2 on Enceladus from initial analysis. It is most likely in a condensed form. The position of the band in our data suggests that the south polar region contains H_2O_2 ice of a more amorphous nature, whereas the rest of the surface of Enceladus contains more crystalline H_2O_2. We propose that the H_2O_2 has been transformed from H_2O through bombardment by high energy particles coming from Saturn's magnetosphere. Furthermore, the H_2O_2 band is stronger in the polar spectra, suggesting that the radiation at the poles is stronger, perhaps due to a magnetic field at Enceladus diverting the high-energy particles polewards. This explanation could also account for the distribution of more amorphous H_2O_2 at the poles and more crystalline H_2O_2 elsewhere, as radiative bombardment could disrupt the crystalline structure of H_2O_2 as it does with H_2O [7].

We would like to confirm our detection of H_2O_2 by looking for the absorption feature in the UV. We would also like to look for H_2O_2 on the other icy satellites of Saturn.

References: **[1]** Moore, M.H. and Hudson R.L. (2000) *Icarus 145,* 282-288. **[2]** Zheng, W., et al. (2006) *Astrophys. J. 639,* 534-548. **[3]** Carlson, R.W., et al. (1999) *Science 283*, 2062-2064. **[4]** Giguere, P.A. and Harvey, K.B. (1959) *J. Mol. Spectr. 3*, 36-45. **[5]** Hendrix, A.R. et al. (1999) *LPSC XXX*, 2043. **[6]** Newman, S.F. et al. (2007) *submitted to Icarus.* **[7]** Moore, M.H. and Hudson, R.L. (1992) *Astrophys. J. 401*, 353-360.