# WIDESPREAD $CO_2$ AND OTHER NON-ICE COMPOUNDS ON THE ANTI-JOVIAN AND TRAILING SIDES OF EUROPA FROM GALILEO/NIMS OBSERVATIONS.

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**Introduction:** The Near Infrared Mapping Spectrometer (NIMS) on the Galileo Jupiter orbiter observed the Jovian system in the infrared spectral range from 0.7-5.3 µm. Absorption bands found in the 4-µm region of the reflectance spectrum of the icy Galilean satellites have been attributed to bond vibrations of simple radicals and compounds such as $CO_2$, SO, SH, CN and CH {1, 2, 3]. These discoveries were made first on Ganymede and Callisto only, because of the large density of radiation spikes in the early data from Europa prevented any useful analysis of this spectral region. Towards the end of the prime mission, some distant, low spatial resolution (200-300 km per NIMS pixel) observations of the trailing hemisphere of Europa were made with spike densities comparable to typical Callisto and Ganymede observations. Analysis of these data revealed $CO_2$, $SO_2$, [4] and $H_2O_2$ [5] compounds. The best analysis of the abundant hydrated compounds (salts) found on the trailing side of Europa [6] yielded a noisy, low reflectance spectrum from 3.3 to 5.3 µm.

**Observation Details and Calibration:** The NIMS builds up spectral images by building a spectrum over 20 mirror positions (Nyquist sampled) and up to 408 wavelengths (Nyquist sampled for all 408). These wavelengths are sensed by 17 discrete detectors, each of which covers a small region of the spectrum. The third dimension of the spectral image is filled out by scanning the instrument field-of-view slowly perpendicular to the mirror motion [7]. Each such scan is called a swath, and many NIMS observations are built up of two or more swaths, generally acquired in a raster mode.

The NIMS observations of the icy satellites are now being reexamined and recalibrated using new techniques [8]. This involves determining the best dark values and radiometric calibrations for each observation. The Europa observations awaited an improved technical processes: to determine the best values for the spectra longer than 3 µm, where the good data is outnumbered by radiation spikes by a ratio of 2:1 or more. The first Europa observation to be processed was on the E6 orbit that was known to have fewer spikes overall than many other orbits. The first observation in this orbit was named TERINC (Terra Incognito), and consisted of two NIMS swaths (downloaded) covering the central latitudes of Europa between about 140 and 260 degrees western longitude with a phase angle of 36 degrees (see Fig. 1). The southern swath was taken in a higher gain state and exhibits some saturation from 1.1–1.45 µm near the sub-solar point. This observation used half the available wavelengths and one detector (2.40–2.67 µm) was not working by this time (giving a total of 192 wavelengths).

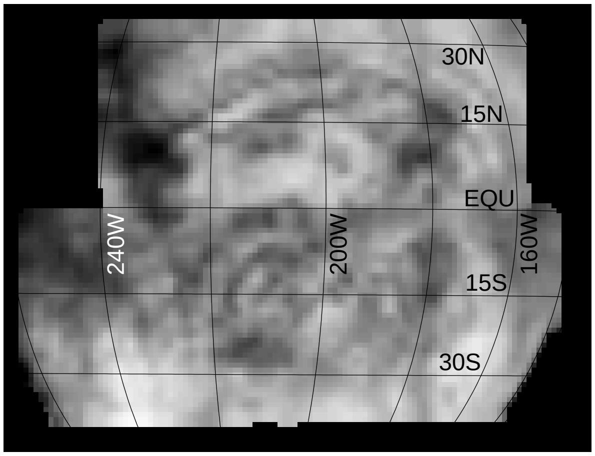


Figure 1. Approximate albedo image of the first wavelength of the E6 TERINC observation. The albedo ranges from 56% (hydrate) to beyond 80% (ice).

The observation was dark-corrected and radiometrically calibrated using the best dark and calibration values and wavelength list. The wavelengths up to 2.4 µm were despiked using our usual procedure (see [2] for information on wavelengths and despiking). The standard despiking uses a 3x3x3 NIMS pixel analysis that throws out outliers until a good fit to a 3-D hyper surface can be made; this hyper surface is used to predict the actual value at the center if it is a spike. The parameters to the procedure are a percentage of large outliers to eliminate on the first pass, then three passes to identify outliers with varying criteria. The short wavelength process yielded about 20% spikes.

For the wavelengths longer than about 2.75 µm the same despiking was used with much tighter first-pass parameters. This despiking was repeated three times to remove most of the visible spikes. Then a few hundred remaining small spikes were manually removed up to 4.4 µm. Beyond this wavelength the instrument only has a few digital numbers (DN) of signal, and contains no information other than general level. These wavelengths were further processed by averaging and smoothing the spectrum over 4x4 NIMS pixels, and constraining all the spectra in that block to match this average within 1.5 DN. The final frequency of spikes in

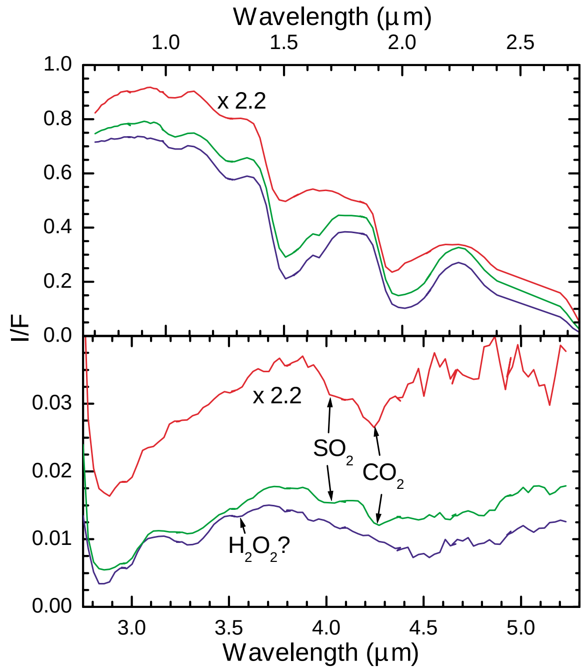


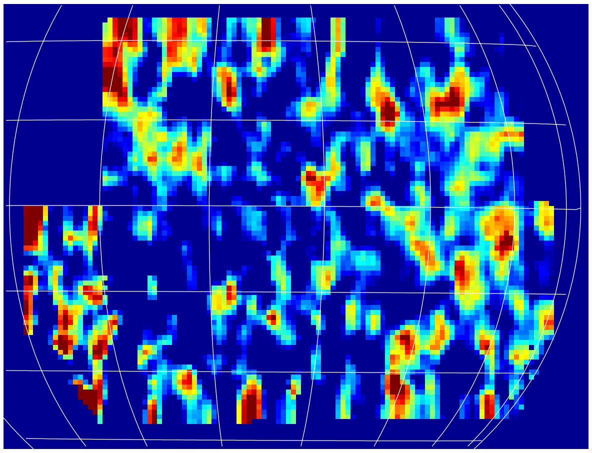
Figure 2. Example spectra from E6 TERINC.

this region was 70-80%. Because of this aggressive approach, there is undoubtedly some averaging over adjacent pixels or wavelengths that occurs that must be taken into account when comparing to observations of the other satellites.

**Results:** Average spectra from three locations are shown in Fig. 2. One is from an almost pure hydrate region (red) while the other two are from more ice-rich areas (blue and green). The longwave portion (bottom graph) shows a smooth rise to a possible inflection near 4.0 µm ($SO_2$) and a band at 4.25 µm ($CO_2$) for the hydrate. The icy spectra have a Fresnel peak near 3.1 µm and a smooth peak at 3.6 and dip at 4.5 µm characteristic of fine-grained snow. On some ice-rich spectra there are additional bands centered near 4.0 and 4.25 µm, and a band near 3.5 µm attributed to $H_2O_2$ [5].

Since the 4.25-µm band ($CO_2$) is contained within one NIMS detector and is not affected by detector overlap offsets (like e.g. the 4.0-µm band), it was simple to map its distribution using methods described by Hibbitts *et al.* [2]. This map is shown in Fig. 3 and shows band depths exceeding 30%. Compared to the image in Fig. 1, it appears that the strong bands are concentrated in the hydrate-rich areas, and this is shown most clearly in a plot showing the fraction of all pixels of a given albedo that have band depths greater than a given level. Here it can be seen that nearly all the darkest pixels have band-depths greater than 15%, and a quarter of them have band-depths greater then 25%.

A preliminary map of the 4.0-µm band shows weaker absorption and a different distribution. This analysis requires data from two detectors to define the continuum and will take more work to do correctly.



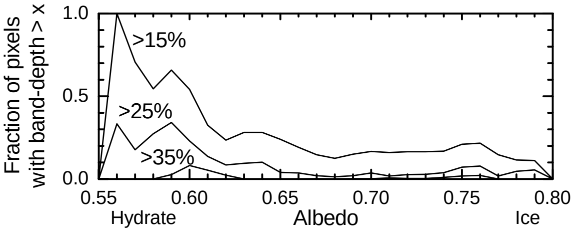


Figure 3. (top) Map of 4.25 µm band depths from 0 (blue) to 30% (dark red).

Figure 4. (bottom) The frequency of different band-depths as a function of albedo

**Conclusions:** Absorption bands attributed to $CO_2$ and $SO_2$ have been found on the anti-Jovian and trailing sides of Europa for the first time. A first analysis shows that the $CO_2$ appears to be associated with the darker hydrate (salt) materials, as it has also been shown to occur mainly in the non-ice materials on Callisto and Ganymede [2, 3]. Since the hydrate seems to be associated with the interior of Europa [6], the source of the $CO_2$ may be internal, rather than produced by some radiolytic processes on the surface.

**References:**

[1] McCord T.B. *et al.* (1997) *Science*, *278*, 271–275; McCord T.B. *et al.* (1998) *JGR*, *103*, 8603–8626. [2] Hibbitts C.A. *et al.* (2000) *JGR*, *105*, 22541–22557. [3] Hibbitts C.A. *et al.* (2003) *JGR*, *108(E5)*, 5036. [4] Smythe W.D. *et al.* (1998) *BAAS*, *30*, Abs. 55P.07, 1448. [5] Carlson R.W. *et al.* (1999) *Science*, *283*, 2062–2064. [6] McCord T.B. *et al.* (1998) *Science*, *280*, 1242–1246; McCord T.B. *et al.* (1999) *JGR*, *104*, 11827–11852. [7] Carlson R.W. *et al.* (1992) *Space Sci. Rev.*, *60*, 457–502. [8] Hansen G.B. and T.B. McCord (2004) *JGR*, *109*, E01012; Hansen G.B. *et al.* (2006) *Eos*, *87(36)*, Abs. P41B-05; Hansen G.B. *et al.* (2006) *BAAS*, *38*, 540.