



Publication Year	2019
Acceptance in OA @INAF	2024-02-05T14:45:30Z
Title	Temperature-dependent VNIR spectroscopy of sodium sulfates
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Handle	http://hdl.handle.net/20.500.12386/34712
Series	GEOPHYSICAL RESEARCH ABSTRACTS
Number	21



Temperature-dependent VNIR spectroscopy of sodium sulfates

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The surfaces of the icy Galilean satellites Europa, Ganymede and Callisto, dominated by water ice, also show substantial amounts of non-water-ice compounds both at regional and local scales. These satellites will be the subject of close exploration by the ESA JUICE mission and the NASA Europa Clipper mission, which will focus on Ganymede and Europa, respectively.

Among non-water-ice compounds thought to exist on the surfaces of the Jovian icy satellites, hydrated salt minerals have been proposed to exist as a by-product of endogenic processes. In particular, Europa and Ganymede's non-ice material appears to be a complex mixture of sulfate hydrates and other materials. Seasonal cycles of hydration-dehydration at Martian Polar Caps boundaries have also been suggested for Na-sulfate compounds mirabilite and thénardite. Safe detection of these minerals shall rely on laboratory spectroscopic analysis of these materials carried out under appropriate environmental conditions.

Following the selection of a Europlanet Transnational Access (TA) 2020 Research Infrastructure proposal, we took advantage of the Cold Surfaces Spectroscopy (CSS) facility at the Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) to acquire visible to near-infrared spectral profiles of anhydrous sodium sulfate or thénardite ($\text{Na}_2\cdot\text{SO}_4$) and sodium sulfate decahydrate or mirabilite ($\text{Na}_2\text{SO}_4\cdot 10\text{H}_2\text{O}$). The samples were measured under cryogenic conditions representative of real planetary surfaces.

The sulfates were first sieved in three different grain size ranges: $<50\ \mu\text{m}$, $75\text{-}100\ \mu\text{m}$, and $125\text{-}150\ \mu\text{m}$. Each grain size was measured with the SHINE Spectro-Gonio-Radiometer facility in the overall $0.5\text{-}5.0\ \mu\text{m}$ spectral range, with spectral resolution decreasing with increasing wavelength. For each sample, the overall $80\text{-}275\ \text{K}$ temperature range was acquired in 12 steps.

In the case of anhydrous sodium sulfate (thénardite), our spectral profiles reveal absorption features at 1.9 and $\sim 3\ \mu\text{m}$, due to a weak but unavoidable hydration of the sample, although this has always been optimally preserved prior to the measurements. On the other hand, the main absorption of sodium sulfate in the considered spectral range is centered at about $4.5\ \mu\text{m}$, and shows a clear dependence on the grain size, whereas the dependence on temperature is weaker.

The spectral profiles of sodium sulfate decahydrate (mirabilite) are significantly different. Given the high level of hydration of this mineral, in the $1\text{-}3\ \mu\text{m}$ range we mainly observe the spectral signatures due to combinations and overtones of the fundamental vibration modes of the water molecule, together with $\text{SO}_4^{2-}\text{-H}_2\text{O}$ complexes vibrations; the shape and intensity of these bands show a marked dependence both on the grain size and on the temperature, with low temperatures revealing a fine structure.

We analyze the spectral behaviour of the diagnostic signatures of these minerals as a function of both grain size and temperature, deriving trends related to specific spectral indices such as band center, band depth, band area, and bandwidth.

We plan to develop this work in the near future by measuring VIS-NIR spectra of magnesium chlorides following the same approach.