The Dependence of Spectral Features on Ice Content and Temperature for Vesta and Ryugu. T. Michalik[1], A. Maturilli[1], K. Otto[1], B. Schmitt[2], O. Poch[2], P. Beck[2], J. Helbert[1], [1]Institute for Planetary Research, German Aerospace Center DLR, Rutherfordstr. 2, 12489 Berlin, Germany, [2]Université Grenoble Alpes, CNRS, IPAG, Grenoble, France – alessandro.maturilli@dlr.de

Introduction: Our overall aim for this project is to characterize and interpret the diverse reflectance features of asteroids, comets and icy moons as well as revealing the composition of their near surfaces to constrain their evolution in the early solar system in particular in relation to their icy content. Studies have shown that icy analogue materials do not always exhibit the absorption features associated with pure ice [1, 2]. Instead, especially for dark materials intimately mixed with water ice, icy absorption features can be completely masked below 2.5 µm and significantly reduced above this wavelength. The quantitative understanding of this behaviour is essential for all solar system bodies that (could) contain ices, like asteroids, comets and the moons of the outer planets. Detectability of chemical compounds is also a crucial issue for planetary missions and its reliability is indispensable. Therefore, we developed a project to assist scientists in interpreting their data. We aim to determine the dependence of absorption features on ice content and temperature for the analyses of spectral features on two particular bodies for which orbital remote sensing data are or will be available (DAWN and HAYABUSA 2). The results of the laboratory study will then be compared to the missions' remote sensing data in order to constrain the surface composition and texture of these bodies from their spectral features and thus to understand the possible role of water ice in shaping their surface.

Spectral characterization of Vesta and Ryugu: On Vesta, diverse spectral features have been observed (Fig. 1) which have either been attributed to endogenic materials (HED meteorites) or to exogenic materials like ordinary and carbonaceous chondrites [3-7]. A broad area present in an equatorial to northern region exhibits an enrichment in hydroxylated materials (see bluish/purple area in Fig. 1), which is thought to be a product of contamination by carbonaceous chondrites [8]. Furthermore, evidence for volatile outgassing is present in the form of pitted terrains at specific localities [9, 10], however ice has not been identified by the spectrometer nor the Gamma Ray and Neutron Detector on board DAWN. The measurements undertaken within the proposed work will give us information about whether ice undetectable in the IR could be present on Vesta and possibly be responsible for the VIS spectral slope and morphological features we observe. The same is anticipated for the data of Ryugu.

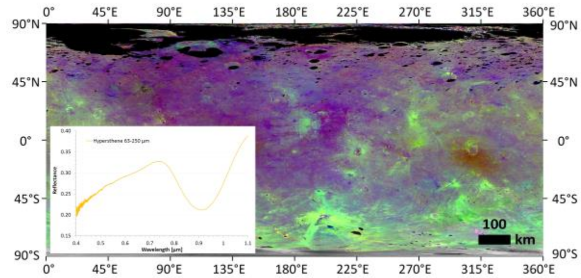

Figure 1: Equidistant projection of Vesta at the High Altitude Mapping Orbit (~60 m/px) as a false colour ratio mosaic (R= 965 nm/917 nm, G=750 nm/917 nm and B=438 nm/750 nm). The false colours give information about pyroxene band depth (G-band), pyroxene band position (R-band) and visual slopes (B-band). Lower left spectrum shows a hypersthene spectrum measured at the PSL at DLR in Berlin, which is used amongst others as analogue material for Vesta during the proposed measurements.

Set-up of laboratory experiment: At the PSL laboratory [11] we measured the reflectance of some analogue materials, at temperatures below 293 K. However, an exact determination of the temperature at which the samples are measured as well as a controlled generation of ice/sample mixtures without risking melting or alteration of the sample materials is not yet possible. With the measurements at the Cold Surfaces Spectroscopy Laboratory (CSS) in Grenoble at IPAG, where the SHINE spectro-gonio radiometer has very high absolute photometric accuracy (< 0.5%) [12] and the CarboN-IR cryogenic cell allows to control temperature down to 70K, we will enlarge our experimental assessments of the spectral properties of materials potentially present at the surface of the bodies of interest, as well as improve our understanding of laboratory technology and space-based remote observations of the cold bodies of interest.

The investigated samples comprise analogues for Vesta and Ryugu. For Vesta, hypersthene is used as an analogue for the endogenic HED meteorite suite and small amounts of Murchison (carbonaceous chondrite) is used as a darkening agent which is assumed for the Vestan regolith [3]. For Ryugu, we used a Tagish Lake-based simulant (UTPS-TB) produced at the University of Tokio (UT) by crushing Mg-rich phyllosilicates (asbestos-free serpentine), Mg-rich olivine, Magnetite, Fe-Ca-Mg carbonates, Fe-Ni sulfides into very fine particles, and then mixing them with carbon nano-particles and polymer organic materials [13]. The mixing happened as first under wet condition; the mixture was then successively completely dried to adapt the compressible strength to that of Tagish Lake. The analogue materials for Vesta and Ryugu is mixed with different proportions of ice as well as in part with different mixing modes. This allows us to investigate the dependence of the spectra on the mixing mode (inter- or intra-particle) of ice and rock particles, which is also unknown for the bodies' surfaces. The desired wavelength range (0.4 – 2.5 µm) covers the range of absorption bands for pyroxenes (~0.9 µm) as well as some of the water ice absorptions (e.g., 1.5 and 2.0 µm) and also allows the determination of the overall spectral slopes of the samples. For the inter-particle mixtures we selected a 63-125 µm grain size range, for the intra-particle mixture the dust powder selected is < 25 µm in size.

A total of 9 sample measurements at three different temperatures (100, 200, 270 K) are envisaged to be acquired. Table 1 shows the different samples, their ice contents as well as the temperatures and mixing modes.

Analogue Body	**Ice Content**	**Mixing Mode** (after [14])
Vesta	0 %	pure
Ryugu	0 %	pure
Ice	100 %	pure
Vesta	25 %	inter-particle
Vesta	50 %	inter-particle
Vesta	90 %	inter-particle
Vesta	90 %	intra-particle
Ryugu	50 %	inter-particle
Ryugu	90 %	inter-particle

Table 1. Samples measured at IPAG.

The viewing geometry is constant for all measurements. The focus of this work is to compare laboratory reflectance measurements with remote sensing data of a specific object, whose data was fully calibrated to match a phase angle of 30°, which is what we required for the proposed measurements as well. The measurements are performed over the 0.4-2.5 µm range at 10 nm spectral sampling, similar to the VIR/NIR instrument/channel.

Impact on icy bodies science: Our work will improve our understanding of surface properties of asteroidal, cometary and moon regoliths in relation to ice content and temperature, especially for Vesta and Ryugu. Constraints on the abundance of ice in planetary regoliths are one of the key questions we will derive with our measurements. This will have a major impact on research concerning missions like DAWN, ROSETTA, OSIRIS-REX, HAYABUSA 2 and CASSINI and will help to interpret their data. Furthermore, upcoming missions like LUCY and especially JUICE will explore even more bodies with possible icy regoliths.

Within one year of their recording all measured spectra and their associated sample information will be made available to the whole community through the SSHADE database infrastructure for solid spectroscopy (www.sshade.eu), also supported by the Europlanet 2020-RI programme.

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