SPECTRAL HETEROGENEITY OF RYUGU SAMPLES DUE TO SPACE WEATHERING REVEALED BY MICROMEGA. S. Furukawa1,2, T. Okada1,2, K. Yogata2, K. Hatakeda2,3, T. Yada2, A. Miyazaki2, K. Nagashima2, R. Tahara2, Y. Sugiyama2, A. Nakano2, T. Ojima2, Y. Hitomi2,3, K. Kumagai2,3, M. Nishimura2, M. Abe2, T. Usui2, J.-P. Bibring4, C. Pilorget4, V. Hamm4, R. Brunetto4, D. Loizeau4, L. Riu4, T. Le Pivert-Jolivet4, R. Kanemaru2, 1University of Tokyo, Japan (furukawa-32666@g.ecc.u-tokyo.ac.jp), 2Institute of Space and Astronautical Science, JAXA, Japan, 3Marine Works Japan, Yokosuka, Japan, 4Institut d’Astrophysique Spatiale, Universite Paris-Saclay, Orsay, France.

Introduction: Asteroids are primitive small Solar System objects and classified by their surface spectral profiles. The surface of asteroids is exposed to space and altered by space weathering effects by solar winds, UV rays, and micro-meteoritic impacts [1], so that it is necessary to understand the mechanism of changes in such spectral profiles.

C-type asteroid 162173 Ryugu is enriched in water and organic materials. JAXA Hayabusa2 has brought back 5.4 g of Ryugu samples (surface samples stored in Chamber A and subsurface samples in Chamber C) to Earth in 2020 after remote sensing and sample collection at the asteroid. To date, initial descriptions, and analysis of Ryugu samples have been continued at the JAXA’s Curation Center [2]. Among them, measurements by MicrOmega, the near-infrared hyperspectral microscope, have found spectral properties of Ryugu samples [3][4], and the common features to most of Ryugu samples are the slope around 2.0 µm and the absorption bands at 2.7 µm, 3.1 µm, and 3.4 µm [3,5,6].

A previous space weathering experiment on the carbonaceous meteorites showed that laser irradiation caused gentler slope of the continuum around 2.0 µm [7]. On the contrary, visible multi-spectral band observations using ONC observations around Ryugu reported that the surface of asteroid becomes redder invisible wavelength due to space weathering [8]. However, changes of the slope in near-infrared wavelength due to space weathering are poorly understood.

The 2.7 µm absorption band of Ryugu samples was also confirmed by near-infrared spectroscopy: NIR3 observations around Ryugu, and is thought to originate from hydroxyl (OH) groups within layered silicates [9]. The previous study of the 2.7 µm absorption band by fitting analysis of the short wavelength side reported that there is a diversity of peak positions and depths in the absorption band [5]. According to the report that the depth of the 2.7 µm absorption band decreases with dehydrogenation due to space weathering [10], the diversity of the absorption band is probably related to space weathering, but an integrated analysis of the entire 2.7 µm absorption band was lacking.

In this study, changes in the near-infrared spectral properties of Ryugu samples due to space weathering are investigated and mechanisms are proposed to account for these changes, especially for the slope around 2.0 µm and the entire 2.7 µm absorption band, which are common features of most Ryugu samples.

Methods: In this study, 157 spectra of Ryugu samples by MicrOmega (95 samples from Chamber A, 63 from Chamber C) were investigated. The spectra of sample A0009 as an example is shown in Figure 1.

The slopes around 2.0 µm are calculated by fitting a linear function. The 2.7 µm absorption band, after the baseline was estimated and extracted, were analyzed entirely by fitting multiple Gaussian functions to derive the peak position and depth.

![Figure 1](image1.png)  An example of the near-infrared spectrum obtained by MicrOmega measurement (sample A0009), orange area for the slope of the continuum around 2 µm, light-blue area for the entire of 2.7µm absorption band.

![Figure 2](image2.png)  An example of analysis results for the 2.7 µm absorption band (sample A0009), fitting with six Gaussian functions f1 to f6.
Results: An example of the results of the analysis of the 2.7 µm absorption band is shown in Figure 2. The absorption band is fit (ted?) with six gaussian functions f1 to f6.

The relationship between the peak position and the depth of the composite waveform (superpositions of f1 - f6) in the 2.7 µm absorption band is investigated as shown in Figure 3. The distribution of Chamber A samples is separated into two regions: a region with a shorter peak wavelength and another depth (α) and a region with a longer peak wavelength and a smaller depth (β). The distribution of Chamber C samples does not show such a trend but plotted in-between (C). The same trend has been reported in the previous study [5].

The slope of the continuum around 2.0 µm for the three groups (α, β, and C) in the 2.7 µm absorption band was compared. The slope becomes gentler in the order of α > C > β: (α: (6.09 ± 1.31) × 10^{-2} [%/cm^2]), β: (5.80 ± 1.46) × 10^{-3} [%/cm^2], and C: (6.06 ± 1.51) × 10^{-3} [%/cm^2]). Therefore, the peak position and depth of the 2.7 µm absorption band becomes longer and decreases as the slope around 2.0 µm becomes gentler.

![Figure 3. Relationship between peak position and depth of the composite waveform in the 2.7 µm absorption band.](image)

With these previous studies, the trend in the relationship between the peak around the 2.0 µm and the 2.7 µm absorption band investigated in this study indicates a possible difference of the degree of space weathering effects. In other words, the degree of space weathering effects is in the order of α < C < β.

A comparison of the f1 and f2 in the 2.7 µm absorption band confirms that the depth of f2 decreases significantly as f1 shifts to longer wavelength. From this, a following mechanism is proposed for the change in the 2.7 µm absorption band due to space weathering. First, the OH group corresponding to f1 is broken by space weathering. In particular, the micrometeorite impacts distort the crystal structure by melting the sample surface. Then, the vibrational modes of the OH group corresponding to f1 are diversified because of crystal distortion. As a result, the peak position and depth of f1 are shifted to longer wavelength and decreased.

We propose factors that explains heterogeneity of the Ryugu samples due to space weathering (estimated influence: α < C < β). First, for the Chamber A samples α and β, the asteroid Ryugu may have been affected by space weathering only a few hundred nm of the surface [10]. Thus, β is considered to be the particles in the top layer and α the particles in the layer below β. For the Chamber C samples, which may have been affected by space weathering to an intermediate degree between α and β, we propose several ideas. The first idea is that the Chamber C samples originated from the surface samples corresponding to β, which have been crushed by the SCI impact [12], exposing the unaffected interior corresponding to α. The second idea is that the Chamber C samples came from such particles corresponding to α that were ejected by the SCI impact and slightly affected by space weathering by Solar UV rays. The third idea is that the Chambers A and C samples are different materials from each other. We will report these potential mechanisms in detail.

Discussion: There is an example of a carbonaceous meteorite reported to have a gentler slope of the continuum around 2.0 µm due to space weathering [7]. NIRS observations of the asteroid Ryugu reported that the ratio of the 2.4 µm reflectance to the 2.2 µm reflectance, corresponding to a slope around 2.0 µm, is reduced due to space weathering [11]. It has been reported that the depth of the 2.7 µm absorption band of the Ryugu sample decreases due to space weathering [10].