PRINCIPAL-COMPONENT ANALYSIS OF THE CONTINUOUS 3-µm SPECTRA OF LOW-ALBEDO ASTEROIDS OBSERVED WITH THE AKARI SATELLITE. N. Okamura[1], S. Sugita[1], S. Kamata[2], F. Usui[3], T. Hiroi[4], T. Ootsubo[5], T. G. Müller[6], I. Sakon[3], S. Hasegawa[7], [1]Dept. of Complexity Sci. and Eng., The Univ. of Tokyo, Kashiwa, Chiba 277-8561, Japan (okamura@astrobio.k.u-tokyo.ac.jp), [2]Dept. of Earth and Planetary Sci., UC Santa Cruz, CA 95064, U.S.A., [3]Dept. of Astron., The Univ. of Tokyo, Hongo, Tokyo 113-0033, Japan, [4]Dept. of Geol. Sci., Brown Univ., Providence, RI 02912, U.S.A., [5]Astron. Inst, Tohoku Univ., Aoba, Sendai, Miyagi 980-8578, Japan, [6]Max-Planck-Institut für Extraterrestrische Physik, Garching 85748, Germany, [7]Inst. of Space and Astron. Sci., JAXA, Sagamihara, Kanagawa 252-5210, Japan.

Summary: We analyzed continuous near-infrared (NIR) spectra (2.6–3.1µm) of low-albedo asteroids observed with the first Japanese infrared astronomical satellite AKARI using the Principal-Component Analysis (PCA). The analyses revealed that the first principal component in the 3-µm range (3-µm PC1), which has very large contribution (~42%) to the total variance of the 3-µm spectra, resembles antigorite (a serpentine-group mineral) spectrum very well. The 3-µm PC1 also exhibits a good correlation with 0.7 µm absorption, which is widely considered as evidence of serpentine. These lines of evidence suggest that the shape and depth of the deep absorption band around 2.7 µm on many low-albedo asteroids may be controlled by serpentine.

Introduction: Many lines of evidence support that extensive aqueous alteration processes occurred in low-albedo asteroids, which may be parent body of carbonaceous chondrites. Aqueous alteration processes within small bodies are very important for understanding the both thermal history of planetary bodies and delivery of water in the inner Solar System. Spectroscopic observations of the 3-µm absorption bands of low-albedo asteroids would be extremely important for understanding the nature of such aqueous alteration processes, because almost all hydrous minerals exhibit strong absorption bands in this wavelength range with a great variety.

However, because the spectral region in 2.5-2.85 µm is severely affected by the Earth's atmosphere, it has not been observed from the Earth. The Japanese infrared astronomical satellite AKARI [1] observed continuous spectra of 33 low-albedo asteroids covering the 2.6 - 3.1 µm range uninterruptedly. The purpose of this study is to analyze the continuous 3-µm spectra by AKARI to characterize hydrous minerals on these asteroids.

3-µm Spectral Data and Analyses: The details of the AKARI satellite, data reduction protocols, and its spectral data of low-albedo asteroids are given in [2-4].

In this study, we conducted both direct comparison of spectra in the 3-µm range between the observed asteroid spectra and carbonaceous chondrites, and PCA in order to understand the nature of the 3-µm absorption bands of low-albedo asteroids, which exhibits a great variety in both shape and depth [3,4].

Spectral Comparison with Carbonaceous Chondrites: A great variety in observed asteroid spectra [3,4] may be comparable to the large spectral variation among carbonaceous chondrites. We attempted to find good matching pairs between published laboratory reflectance spectra of carbonaceous chondrites of 25 different samples [5,6] and the 33 dark asteroids observed in this study. The PCA we conducted is essentially the same as that used often in the visible and NIR wavelength range [e.g., 7,8]. A few good matching pairs were found. For example, 121 Hermione turned out to have very good similarity with a Murchison spectrum. Some other CM chondrites, such as ALH83102, also exhibit spectral shapes similar to that of 121 Hermione. The 121 Hermione reflectance decreases from 2.65 µm to 2.8 µm and then starts to increase, which is more typical of serpentine-rich CM chondrites rather than saponite-rich CI chondrites. However, we could not find any matching meteorite spectra for most of the observed asteroids.

PCA Results: The above fact that there are not many matching pairs between low-albedo asteroids and carbonaceous chondrites does not necessarily indicate that these asteroid spectra have no similarity with meteorite spectra. There may be common spectral components shared by both asteroidal and meteoritic spectra. Such a common component could be extracted with PCA. In fact, our preliminary PCA results indicate that the first principal component (PC1) turned out to be very similar to antigorite spectrum (a serpentine-group mineral) as shown in Fig. 1. The sharp shoulder at 2.6 µm and an absorption peak at 2.75 µm seen in PC1 also distinguish itself from saponite spectra, which tend to have a round band shape. Furthermore, the PC1 spectral shape is much closer to that of Murchison (CM2) than that of Ivuna (CI). This is consistent with the fact that CM chondrites are rich in serpentine and contains no clay, such as saponite and that CI chondrite contains saponite.

Another important finding is that 3-µm PC1 accounts for ~ 42% of the total variation of the AKARI spectra analyzed in this study. This contribution is far greater than those by 3-µm PC2 (~ 11%) and by 3-µm

PC3 (~ 7%) as shown in Fig. 2. Thus, 3-µm PC1 may be the controlling factor for the overall strength of the absorption band in the 3-µm range seen on low-albedo asteroids.

Furthermore, comparison between 3-µm principal components (PC's) and visible PC's based on SMASS II [7] reveals that 3-µm PC1 exhibits significant correlation with visible PC2'; higher 3-µm PC1 values appear to be associated with higher visible PC2'. In other words, a deeper 2.7 µm absorption is associated with a deeper 0.7 µm absorption. In addition, a good correlation between the 3-µm PC's and visible spectral types are seen in Fig. 3. First, it is noted that Ch and Cgh, which exhibit 0.7 µm absorption, tend to have higher 3-µm-PC1. In other words, low-albedo asteroids with 0.7 µm absorption possess large 3-µm PC1 values. In fact, among the 8 asteroids with 3-µm PC1 > 0.3, 7 are either Ch or Cgh. There is no Ch or Cgh among 24 asteroids with 3-µm PC1 < 0.3. Such a clear separation strongly supports a close association between 3-µm PC1 and 0.7 µm absorption.

Implications for Low-Albedo Asteroids: The above results that the 3-µm PC1 of low-albedo asteroids resembles a serpentine spectrum and that it has a correlation with 0.7 µm absorption, which has been widely considered as evidence for serpentine, strongly suggest that the 3-µm PC1 may represent serpentine spectra on low-albedo asteroids. If this is the case, the dominance of 3-µm PC1 in the total spectral variance may imply that the strength of the 2.7 µm absorption band may be controlled by the serpentine abundance. The prevalence of 3-µm PC1 and 0.7 µm absorption band on low-albedo asteroids is consistent with the wide-spread presence of serpentine in carbonaceous chondrites.

Such insights on these absorption bands would also be extremely valuable for interpreting visible and NIR observations of 162173 1999JU$_3$ with upcoming HAYABUSA 2 mission [e.g., 10,11].

References: [1] Murakami H. et al. (2007) *PASJ, 59*, S369-S376. [2] Onaka et al. (2007) *PASJ*, *59*, S401-S410. [3] Okamura N. et al. (2014) *LPSC XXXXV,* Abstract #1375. [4] Okamura N. et al. to be submitted to *ApJ*. [5] Hiroi T. and Hasegawa S. (2003), *Antarct. Meteorite Res., 16,* 176-184. [6] Salisbury J. W. et al. (1991) *Icarus*, *92*, 280-297. [7] Bus S. J. and Binzel R. P. (2002) *Icarus, 158*, 106-145. [8] DeMeo F. E. (2009) *Icarus, 202*, 160–180. [9] Lazzaro D. et al (2004) *Icarus, 172*, 179-220. [10] Sugita S. et al. (2013) *LPSC XXXXIV,* Abstract #3026. [11] Iwata T. et al. (2013) *LPSC XXXXIV*, 1908.

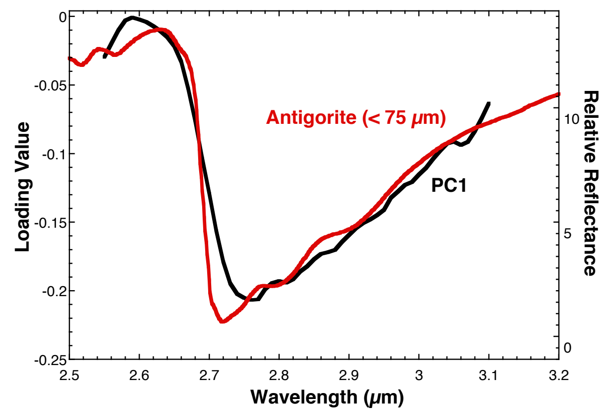

Fig. 1. Comparison between the first principal component (PC1) of low-albedo asteroid spectra observed by AKARI and antigorite (a serpentine-group mineral). The spectrum of antigorite, whose grain size is < 75 µm, is taken from Aster Spectral Library.

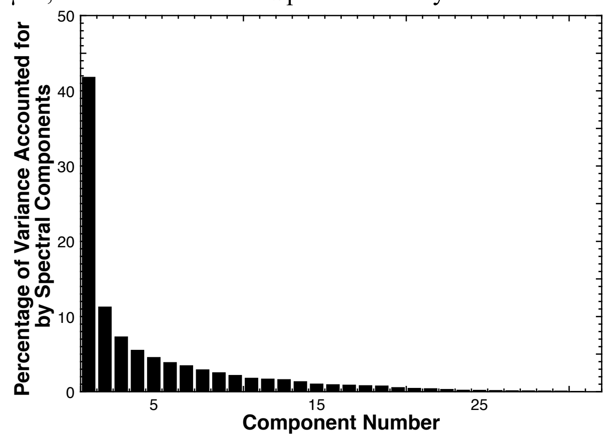

Fig. 2. Contribution of principal components (PC's) of low-albedo asteroid spectra observed by AKARI.

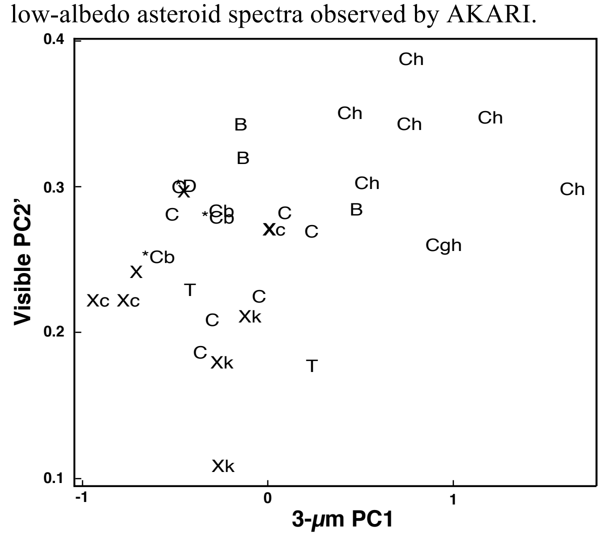

Fig. 3. Correlation between 3-µm PC1 and visible PC2' based on SMASS II dataset [7]. Spectral types by [7,9] are also shown in this Figure. The visible PC2' values of SMASS II have a good correlation with 0.7 µm absorption depths.