Lunar Calibration for Planetary Explorers using SELENE/SP Lunar Reflectance Model. T. Kouyama[1], Y. Yokota[2], Y. Ishihara[3], R. Nakamura[1], S. Yamamoto[4], T. Matsunaga[4], M. Yamada[5], S. Kameda[6], H. Sawada[3], H. Suzuki[7], R. Honda[8], T. Morota[9], C. Honda[10], K. Ogawa[11], and S. Sugita[12], [1]National Institute of Advanced Industrial Science and Technology (1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan, t.kouyama@aist.go.jp), [2]Tsukuba planetary science group, [3]Japan Aerospace Exploration Agency(Yoshinodai, Sagamihara, Kanagawa), [4]National Institute for Environmental Studies(Onogawa, Tsukuba, Ibaraki), [5]Chiba Inst. Tech. (Tsudanuma, Narashino, Chiba), [6]Rikkyo Univ. (Nishi-Ikebukuro,Toshima, Tokyo), [7]Meiji Univ. (Higashimita, Tama, Kawasaki, Kanagawa), [8]Kochi Univ. (Nangoku, Kochi), [9]Nagoya Univ. (Chikusa, Nagoya, Aichi), [10]Aizu Univ. (Aizu Wakamatsu, Fukushima). [10]Univ. of Tokyo (Hongo, Bunkyo, Tokyo).

Introduction: Reliable and stable quality control of data products is a key factor to obtain valuable scientific information from the data. Radiometric calibration in space is one of essential issues for image and spectroscopy data quality. Because of the long-term stability of the lunar surface reflectance (less than 1% variation during 1 million year [1]), the Moon is an ideal calibration source for the radiometric calibration in space.

Recently, hyperspectral lunar surface reflectance models covering lunar surface globally have been proposed based on hyperspectral observation data obtained by Moon orbiters [2, 3]. Spectral Profiler (SP) onboard SELENE, a Japanese Lunar orbiter, has provided one of such hyperspectral Moon reflectance and photometrical models [2], which enables to simulate any Moon observation. For planetary explorers, it is important that the reflectance models has global coverage to allow us to compare between observed and simulated radiances under any observation condition, since planetary explorers can observe not only the nearside of the Moon, but also the farside, which cannot be observed from the Earth,.

Japanese planetary spacecraft, Hayabusa and Hayabusa2 observed the Moon with their ultraviolet, visible and near infrared multi-band sensors when they approached the Earth for obtaining gravity assist to go to their targets in 2004 and 2015, respectively [4, 5]. Comparing observed and simulated Moon images, sensor sensitivity can be investigated.

Hyperspectral Lunar Reflectance Model based on SELENE/SP data: In this study we used a lunar reflectance model (SP models) based on SP hyper-spectral data, covering a wavelength range from 500 nm to 1600 nm with 6-8 nm spectral sampling interval [2, 6]. The SP model describes Moon surface reflectance globally, so that one can simulate not only observation of the nearside of the Moon but also the farside (Figure 1) [7]. The possibility of simulating both sides of the Moon is one of important advantages of SP model for simulating Moon observation, because planetary explorers can observe both nearside and farside of the Moon depending on their observation geometry.

Figure 1. Examples of simulating observations of the nearside and the farside of the Moon using SP model.

Moon observations by Hayabusa/AMICA and Hayabusa2/ONC: Both Hayabusa and Haybusa2 have multi-spectral cameras (Asteroid Multi-band Imaging Camera (AMICA) and Optical Navigation Camera Telescope (ONC-T), respectively) with 2-dimensinal charge-coupled devices (CCD's) and filters for ultraviolet to near infrared wavelength bands for investigating surface condition of their target asteroids [2, 7]. Table 1 summarizes AMICA and ONC-T observations (date, sub observer latitudes and longitudes on the Moon). In Table 1, sub Earth latitudes and longitudes are also listed for emphasizing the difference of the geometries of AMICA and ONC-T observations from observations from the Earth.

As described in previous section, considering above geometry information, we can simulate both Moon observations of AMICA and ONC-T (Figure 2 and 3) using SP model. In Figure 2 and 3, the resolution of simulated images are set to be higher than those of observations for showing Moon appearance clearly.

Table 1. Geometries of Moon observation by AMICA and ONC. Sub Earth points on the Moon are also listed.

	AMICA	ONC-T
Date	2004.05.17	2015.12.05
Distance	341,224 km	764,658 km
Sub obs. lat.	20.85°	-56.37°
Sub obs. lon.	-132.65°	-96.25°
Sub Earth lat.	0.39°	-1.02°
Sub Earth lon.	3.96°	1.16°

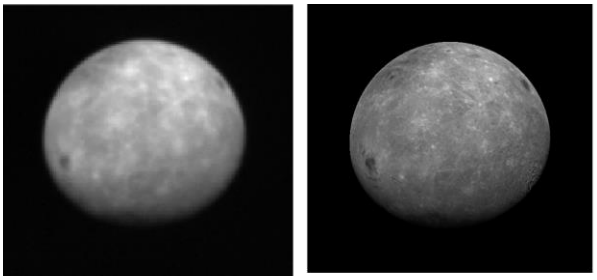

Figure 2. (Right) Moon image taken by Hayabusa/AMICA on May 17, 2004 and (left) its simulated image with SP model.

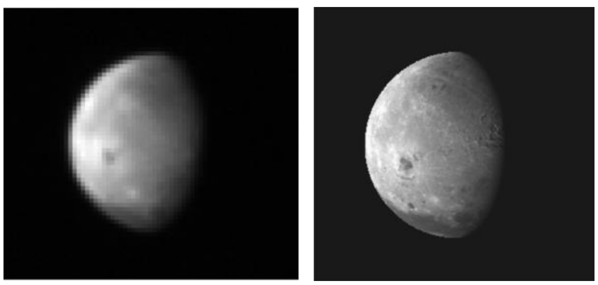

Figure 3. Same as Figure 2 but for Hayabusa2/ONC observation on December 5, 2015.

Comparison of irradiance between observed and simulated images: First, we focused on comparison of irradiance I (W/m^2/µm) between the observed and simulated Moon images, which is estimated from;

$I = \sum_i r_i \omega_{\text{pixel}}$,

where i indicates ith pixel included in Moon disk region in each Moon image, r_i is radiance at the ith pixel, and ω_{pixel} is steradian of a pixel. Since SP model covers wavelength range from 500 to 1650nm, we used Moon images observed by AMICA with 553, 700, 861, and 960nm bands, and by ONC-T with 549, 700, 859, and 950nm bands. The conversion factors from digital values to radiance are based on [4] and [8] for AMICA and ONC-T, respectively.

Irradiance comparison between Hayabusa/AMICA observation and model simulation based on SP exhibits good agreement between the two irradiance values, except for irradiance at 550 nm band (Figure 4). A possible reason for the discrepancy might be the calibration issue of SP reflectance in short wavelength range [9]. Therefore we have considered combining other lunar reflectance model would be useful for modifying the absolute magnitude of the simulated irradiance in the short wavelength range. Figure 4 also shows simulated irradiance whose absolute magnitudes are corrected with ROLO model, which are developed from ground-based multispectral lunar observations [10], exhibiting more consistent irradiance distribution with observations.

Irradiance comparison between Hayabusa2/ONC-T

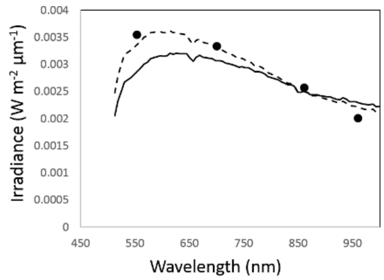

Figure 4. Comparison between observed Moon irradiance evaluated from AMICA images (black dots) and simulated irradiance based on SP model (solid line), and irradiance corrected with ROLO model (dashed line).

observation and simulation also suggests that ONC-T irradiance exhibits a similar agreement (not shown). However, these comparisons are still preliminary; more thorough examinations are necessary for decisive conclusion. Nevertheless, the comparison shown in this study clearly demonstrates that the SP model is useful for evaluating the spectral irradiance obtained by spacecraft that fly near the Earth and the Moon.

Summary: Since SP model enables us to simulate any Moon observation which includes both nearside and farside of the Moon, the model is useful for radiometric calibration of planetary explorers. We have simulated prior Moon observations conducted by Hayabusa/AMICA and Hayabusa2/ONC-T using SP model. From the comparison of simulated irradiance with AMICA and ONC-T observations, the simulated irradiance showed good agreement with the observations. Additionally, combining with other lunar reflectance model, more consistent simulated values with observations could be obtained. Further comparison between the SP model and ONC-T will help calibrate the radiometric accuracy of ONC-T for upcoming remote sensing observation of asteroid Ryugu in 2018.

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