Development of Two Types of NIR Spectral Camera for Lunar Missions SLIM and LUPEX.

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Introduction: A hyperspectral camera is a camera that cuts two dimensions from a three-dimensional cube of two-dimensional information of an image x one-dimensional information of wavelength. There are two types of instantaneous field of view to be captured by the image sensor of the camera: one is to select a two-dimensional image, and the other is to select one line of spatial information x wavelength information.

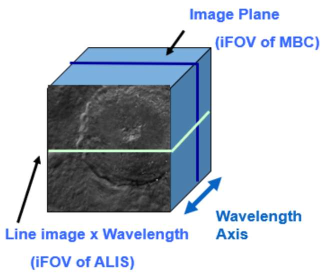

Fig.1 Two types of data acquisition methods from hyper-spectral three-dimensional data.

We are currently developing two spectroscopic cameras for the lunar missions Smart Lander for Investigating Moon (SLIM) project and Lunar Polar Exploration (LUPEX) project. We use two types of spectroscopic cameras according to each exploration purpose.

SLIM project is ongoing at Japan Aerospace Exploration Agency (JAXA). It was approved in 2016 and will be launched in fiscal year 2022 as Japan's lunar-landing mission [1]. The main purpose of this project is to demonstrate various techniques for pinpoint landing within a hundred meters in radius on the moon. Demonstration of the SLIM landing technology will cause a paradigm shift from "exploring where it is easy to land" to "exploring where we want to land." After landing, the SLIM project plans to operate Multi-Band Camera (MBC) to observe around the landing site. This is one of the two spectroscopic cameras we are developing.

As a landing site for SLIM mission, one of the small fresh craters just outside of the Theophilus crater is selected. This crater (diameter ~200 m) locates 13.3º S, 25.2º E outside the southwest rim of Theophilus and named "Shioli". There is olivine-rich lithology, which is probably mantle (or the lower part of the crustal) origin excavated by the Nectaris basin forming impact [2] as suggested by the global distribution of the olivine-rich sites [3], well before the formation of the Theophlius .

In order to identify this unknown lithology and estimate its origin, MBC has a spatial resolution (1.3 mm/pixel at 10 m) that distinguishes plutonic rock texture and a band combination that identifies mineral species. And most importantly, MBC has plan to estimate Mg # (=Mg/(Mg+Fe) atomic ratio) of olivine.

Another mission is LUPEX. It is concept by Indian Space Research Organization (ISRO) and JAXA. In 2017, JAXA and ISRO signed an implementation arrangement for a joint lunar polar exploration mission in which a spacecraft will land in an area close to Permanently Shaded Regions (PSRs). After landing, it will perform neutron spectroscopic and underground radar observations while moving on a rover to identify a location where water ice is likely to exist. In February 2020, JAXA made an open call for proposals for observation equipment for lunar polar exploration missions. In this open call, JAXA set 0.5 wt% as the threshold weight percent concentration to determine if water is present. In June 2020, the visible NIR imaging spectrometer named Advanced Lunar Imaging Spectrometer (ALIS) proposed by us was selected as one of the candidate devices for rover-equipped ice detectors. This is another spectroscopic camera mentioned earlier and detects water ice using absorption of water ice around 1500 nm.

Camera Details: The development members of MBC and ALIS are shown in Table 1. There are several members involved in the development of both cameras. Currently, MBC's development status is in the manufacturing stage of the flight model. On the other hand, ALIS is just before the specifications are finalized. The block diagrams and specifications of MBC and ALIS are shown in Fig. 2 and Table 2. For MBC, we selected a type of acquiring a two-dimensional image as iFOV. This is because it is necessary to find mantle rock candidate around the lander within a short lifetime of MBC. On the other hand, for ALIS, we selected a type of acquiring a line x wavelength image as iFOV. This is because we want to observe the slight NIR absorption of water ice during a short lighting time.

Table 1. Member List for MBC and ALIS Development Team.

MBC	ALIS
Payload Manager	**Lead**
Makiko Ohtake	Kazuto Saiki
MBC leader	**Sub-Lead**
Kazuto Saiki	Yusuke Nakauchi
Co-leader	**Member**
Hiroaki Shiraishi	Masahiro Kayama
Sub-leader	Hiroshi Nagaoka
Chikatoshi Honda	Hirohide Demura
Member	Kouhei Kitazato
Yusuke Nakauchi	Yoshiko Ogawa
Yoshiaki Ishihara	Takashi Mikouchi
Hiroyuki Sato	Teruyuki Hirano
Takao Maeda	
Hiroshi Nagaoka	**Grating Development Sub-Team**
ChihiroYamanaka	Noboru Ebizuka
	Minoru Sasaki
	Takayuki Okamoto

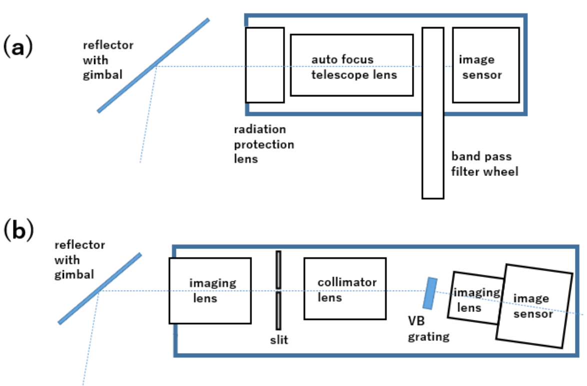

Fig.2 Block diagrams of Multi-Band Camera (a) and Advanced Lunar Imaging Spectrometer (b).

Table 2. Specifications of MBC and ALIS.

Name	Multi-Band Camera	Advanced Lunar Imaging Spectrometer
Purpose	Onboard SLIM	Onboard LUPEX rover
Type of Spectrometer	Band Pass Filters 750, 920, 950, 970, 1000, 1050, 1100, 1250, 1550, 1650 (nm)	Volume Binary Grating 750 ~ 1650 nm
Band Width	30 nm	Less than 5 nm
Image Sensor	Xenics FPA0.9-1.7_640_4_TE1 pack sensor	SONY IMX990
F-number	10	2 or brighter
Focus	Auto Focus	Single Focus
iFOV	4° x 3.2°	2 m x 1 cm @ 2 m distance

Ongoing work: For successful spectroscopic observations on the moon, it is important to conduct operational tests under observation conditions that are close to actual conditions.

We are observing natural rocks with the Engineering Model of MBC. In order to detect peak wavelength of absorption band from discrete spectral data obtained by band-pass filters, we use spline fitting method. First, the continuous spectrum data is generated from discrete data of 10 bands of MBC using spline fitting. Next, the continuum connecting the reflectance of 750 nm and the reflectance of 1550 nm was removed. After the continuum removal, we determine the peak wavelength where the value of the first derivative of the spline function became 0 near 1000 nm.

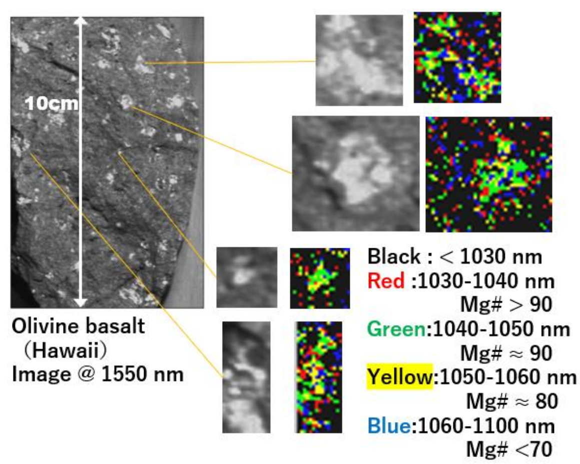

Fig.3 Example of full pixel peak search analysis of MBC data for a natural rock.

Looking at the results shown in Fig.3, most of the pixels show the correct Mg # value, although there are some misrecognitions. We continue to collect such empirical data.

For ALIS, we have developed a micro-ice production apparatus and are continuing the observation verification test by a BBM of ALIS. We estimate SNR value of the detector required to detect 0.5 wt% ice as to be ~220 for olivine and ~120 for plagioclase [4].

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References: [1] Sakai S. et al. (2015) *Low-Cost Planetary Mission Conference.* [2] Ohtake M. et al. (2019) *50th LPSC*, #2342. [3] Yamamoto S.et al. (2010) *Nat. GeoSci*., 3, 533-536. [4] Ogishima & Saiki (2021) Icarus, 357, in press.