JAXA's Mission Instruments in the ISRO-JAXA Joint Lunar Polar Exploration (LUPEX) Project -Overview and Developing Status-. Y. Ishihara[1], T. Shimomura[2], R. Nishitani[2], M. Aida[2], and H. Mizuno[2], [1] Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, 252-5210, Japan (ishihara.yoshiaki@jaxa.jp), [2] Japan Aerospace Exploration Agency, 2-1-1 Sengen, Tsukuba, Ibaraki 305-0047, Japan.

Introduction: In recent years, analysis of various observation data from lunar exploration by Japan, the United States, India, and other countries has indicated the existence of water ice/frost that may have been supplied from outside in the low-temperature regions (polar regions) at high latitudes of the Moon where there is no direct solar irradiation [1-5]. However, no direct and conclusive information is available on whether water exists in the polar regions of the Moon, its quantity and form (hydrogen, hydroxyl groups, water molecules, etc., or adsorbed water, structural water, etc.), vertical and horizontal distribution (whether there are concentrated layers on the polar surface or in the subsurface, and their spatial extent). The knowledge of amount and distributions of water are important for not only scientific aspect but also planning and designing of future exploration (exp. manned exploration). In 2020s, as a first step, space agencies plan to do unmanned exploration for state and amount of water at lunar pole.

LUPEX: Japan Aerospace Exploration Agency (JAXA) and Indian Space Research Organisation (ISRO) is planned unmanned joint exploration, and that is named as "Lunar Polar Exploration (LUPEX) with the primary objective of obtaining data to assess whether water exists in the polar regions of the Moon, and if so, its potential as a future exploration resource." LUPEX spacecraft consists of a rover and a lander. JAXA is responsible for developing and operating the rover, and ISRO for developing and operating the lander. Nominal mission duration is from launch to 3.5 months after landing on the Moon.

LUPEX project status was as reported at 74th International Astronautical Congress [6]. The mission instruments were selected: JAXA's Resource Exploration Water Analyzer (REIWA) and Advanced Lunar Imaging Spectrometer (ALIS), ISRO's Ground Penetrating Radar (GPR) and Mid-Infrared Spectrometer (MIR), Permittivity and Thermophysical Investigation for Moon's Aquatic Scout (PRATHIMA), and Raman spectrometer integrated in REIWA, NASA's Neutron Spectrometer (NS) and ESA's Exospheric Mass Spectrometer for LUPEX (EMS-L). In addition to mission instruments, direct measurement of lunar water by conducting in-situ measurements to achieve the mission objectives, so the rover has a drilling system to excavate and sampling system to pick the regolith sample from a designated depth.

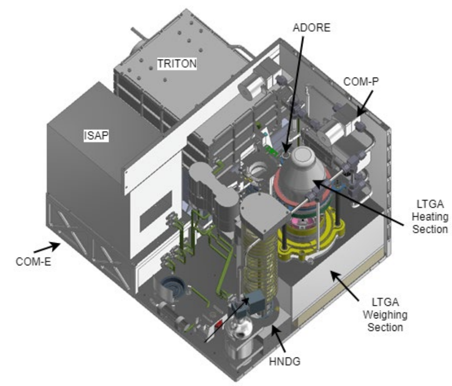

Figure 1 3D CAD Model of REIWA.

REIWA: REIWA is an integrated package instrument capable of weighing regolith samples received from the rover drilling mechanism while heating them and performing mass spectrometry and trace moisture measurement of the volatile components produced, as well as have a Raman spectrometer. REIWA consists of four measuring subsystems: the Lunar Thermogravimetric Analyzer (LTGA), Triple Reflection Reflectron (TRITON), Aquatic Detector using Optical Resonance (ADORE), and ISRO's Sample Analysis Package (ISAP), and three common subsystems as follows, Common Electronics (COM-E), Common Plumping (COM-P), and Sample Container Handling System (HNDG). (Figure 1).

LTGA can heat samples of 6-10 g mass from 100 K to 500 K in 30 minutes and weigh them with a resolution of 9.8×10^{-6} N (corresponding to a 0.1% weight change for a sample of 6 g mass).

TRITON is a reflective TOF mass spectrometer and can measure molecules and atoms in the mass range of m/z: 1-200. Three analysis modes with different flight path lengths are available, with a maximum mass resolution of $m/\Delta m > 120$.

ADORE is a cavity ring-down spectrometer. A laser beam is injected into the sample cell (optical resonator) of the ADORE, where volatile components are introduced, to resonate, and then the laser is shut off. The attenuation time of the light leaking out of the optical resonator after the laser is shut off makes it possible to quantify the absorption by water in the resonator with a mass accuracy of sub nanograms. By selecting wavelength, isotopes such as HDO can also be quantified.

ISAP is a Raman spectrometer provided by ISRO and it analyze regolith sample supplied by HNDG.

In the development of REIWA, some components (e.g., electric balance for LTGA) are developing using Commercial off-the-shell (COTS) and prototyping of each subsystem and testing of BBMs were conducted to apply COTS under the lunar environment and to solve various development issues. Based on these results, Preliminary Design Review (PDR) was conducted in December 2022 to confirm the results of the basic design of REIWA total system in terms of the mechanical, communication, thermal, volatile gas transfer systems, and etc. Engineering Model (EM) is being prepared and sub-component EM test is underway.

ALIS: ALIS is an instrument that observes lunar surface reflectance spectra (wavelengths from 750 to 1,650 nm), enabling spectroscopic identification of minerals constituting lunar regolith and rocks (mainly using absorption in the 1,000 nm band due to Fe^{2+}) and confirmation and quantification of the presence of water ice (using absorption in the 1,500 nm band due to water ice and absorption in the 1,400 nm band due to OH stretching vibration). ALIS will contribute to the direct measurement of water concentration, horizontal distribution of water, and identification of the morphology and species of hydrogen among the LUPEX observation objectives.

ALIS is composed of four components: a camera section (ALIS-C), which contains the main components such as image sensor, optical system, and electronics (Figure 2); a movable mirror section (ALIS-M), which changes the observation field of view in azimuth and elevation of two axis (Figure 2); a light source section (ALIS-L), for observation in shadow areas (in permanent shadow or with boulders) (Figure 2); and a standard diffuse reflector (ALIS-D), for calibration of the observation data. Figure 3 shows an overview of the optical system of ALIS, a line observation types continuous spectral imaging system with a 2-axis gimbal-driven movable mirror. The observation lines are dispersed in the wavelength direction by a transmission-type volume-binary (VB) diffraction grating, which has higher diffraction efficiency and wider full width at half-maximum than conventional transmission-type diffraction gratings with a staircase shape. By driving a movable mirror, it is possible to obtain a hyperspectral data cube of "two spatial dimensions" × "one wavelength dimension" by scanning the field of view.

ALIS has been developing based on the heritage of similar instruments, such as the movable mirrors of the Multi-Band Camera (MBC) [7,8], which is installed in SLIM. In order to solve the development issues, optical BBM prototypes and tests were conducted, etc. Based on these results, PDR was conducted from December 2022 to January 2023 to confirm the results of basic design of mechanical, thermal, communication, and optical design, and to confirm validity of total ALIS design. EM was prepared and EM test is underway.

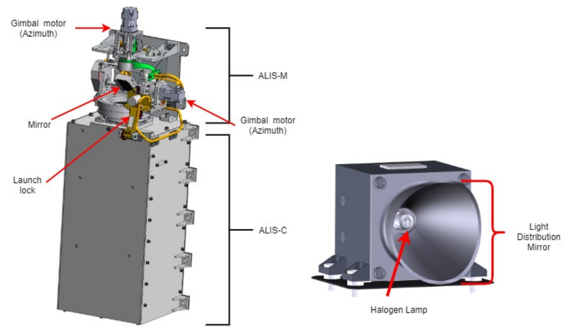

Figure 2 3D CAD Models of ALIS-C/M (left) and ALIS-L (right).

ALIS-M basically follows the design of the SLIM-MBC's movable mirror, but with modifications such as the harness arrangement of the movable section and the position of the launch lock actuator. ALIS-L has a specially shaped light distribution mirror projects halogen lamp light onto the observation area in front of the rover (an ellipse with an area of about 1 m^2 centered 4.5 m in front).

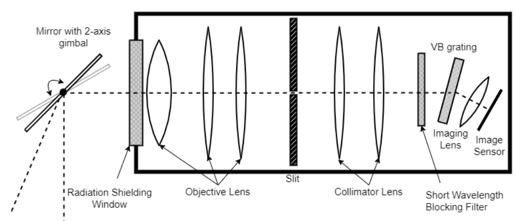

Figure 3 Schematic of ALIS optical system.
This is a conceptual diagram, and the number of lenses does not reflect the design results.

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References: [1] Li, S. et al. (2018) *PNAS*, 201802345. [2] Gladstone G. R. et al. (2012) *JGR*, *117, E00H04*. [3] Mitrofanov I. G. et al. (2010) *Science 330,* 483-486. [4] A. B. Sanin, et al. (2016) *Icarus 283*. [5] Colaprete, A. et al. (2010) *Science 80,* 463-468. [6] Mizuno, H. et al. (2023) *74th IAC*, IAC-23-A3. 2A.5. [7] Nakauchi, Y. et al.: (2019), *50th LPSC*, #1522. [8] Saiki, K. et al. (2021) *52nd LPSC*, #2303.