CURRENT STATUS OF THE PLANNED LUNAR POLAR EXPLORATION MISSION JOINTLY STUDIED BY INDIA AND JAPAN.
M. Ohtake[1,2], Y. Karouji[1], Y. Ishihara[1], R. Nomura[1], H. Inoue[1], H. Shiraishi[1], H. Mizuno[1], T. Hoshino[1], and D. Asoh[1], [1] Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, 252-5210, Japan, [2]University of Aizu, Tsuruga, Ikki-machi Aizu-Wakamatsu, Fukushima, 965-8580, JAPAN (makiko-o@u-aizu.ac.jp).

Introduction: Multiple remote sensing dataset (e.g., visible and near-infrared [1], Layman-α [2], and neutron [3] observation of the lunar surface) derived from recent lunar exploration missions suggested that water ice might be widely present in the lunar polar region. For example, data from neutron spectrometer indicates that hydrogen abundance is much more abundant at latitude higher than 85° in both north and south poles compared with that in the lower latitude. Moreover, the estimated water equivalent hydrogen in the top ~1 m layer of the lunar regolith is up to ~0.5 wt.% [4]. In addition, measurement results from near-infrared spectrometry of the ejecta induced by artificial-impact in the permanently shadowed region reported that there is ~6 wt.% water abundance at the impact site [5].

However, currently, the actual origin, abundance, condensation mechanism, and lateral and vertical distribution of water remain unclear. This information will enable us to understand the transportation mechanism with supply flux of water to the Earth-Moon region in the solar system. In addition to the scientific interest, there is growing interest in using water ice (if present) as an in-situ resource. Specifically, using water ice as a propellant will have a significant impact in future exploration scenarios and activities, since the propellant generated from water can be used for ascent from the lunar surface and can reduce the mass of the launched spacecraft of lunar landing missions. To assess the abundance and distribution of water in the lunar polar region, the Japan Aerospace Exploration Agency (JAXA), in collaboration with the Indian Space Research Organisation (ISRO), is planning the lunar polar exploration mission (LUPEX; a tentative name). Herein, we discuss the objective and current status of the mission planning, including selected Japanese instruments.

Mission objective: Several studies that focus on searching water in the lunar polar region reported positive results, as nicely reviewed in [6]. However, each of the currently available datasets has limitations. In addition, there are also negative reports regarding the presence of water [7, 8]. Therefore, currently, the abundance, condensation mechanism, and lateral and vertical distribution of water at the lunar polar region remain unclear.

To solve these problems, JAXA is planning the lunar polar exploration mission [9] within the framework of international collaboration with ISRO. The objective of this mission is to obtain information regarding the abundance, distribution, and condensation mechanism of water at the lunar polar region in order to evaluate the possibility of using water as a resource in future missions. To achieve this objective, we need to land on the lunar surface at the polar region (latitudes > 80°) and directly measure and asses the presence of water by conducting in-situ measurements. If water is present, we also need to know its quantity (how much), quality (content of other phases such as CO_2 and CH_4), and usability (how deep do we need to drill or how much energy is required for drilling the regolith to derive the water) to assess if it can be used as a resource.

Mission configuration: In this mission, the ISRO and JAXA plan to develop a lander and a rover, respectively. The rover weights around 350 kg (including payloads), and it will carry multiple instruments both developed by JAXA and ISRO to carry out the objective of the mission. The rover can drill the surface regolith as deep as 1.5 m, bring up the regolith sample from the drilled depth, and transfer it to the instruments. The rover is designed to move and carry out measurements at the shadowed area for a short period of time. The biggest challenge in a technology's viewpoint is how to explore the large permanent shadowed region which was previously thought to be the major host of water ice [10]. However, recent computer simulation [11][12] suggested that water ice is possibly present at the subsurface (up to ~1 m) or in micro cold traps (scales from 1

Table 1 LUPEX Mission Instruments (including candidates)

Instrument	Observation target
Ground Penetrating Radar (GPR)	Underground radar observation up to 1.5 m during rover traverse
Neutron Spectrometer (NS)	Underground neutron (hydrogen) observation up to 1 m during rover traverse
Advanced Lunar Imaging Spectrometer (ALIS)	H_2O/OH observation of the surface and drilled regolith
REsourceInvestigation Water Analyzer (REIWA)	Instrument package of the four instruments
Lunar Thermogravimetric Analyzer (LTGA)	Thermogravimetric analyses of the drilled samples for water content
TRIple-reflection reflecTrON (TRITON)	Identification of chemical species of the volatile component in the drilled samples based on mass spectrometry
Aquatic Detector using Optical Resonance (ADORE)	Water content measurement in the drilled samples based on cavity ring-down spectrometry
ISRO Sample Analysis Package (TBD)	Mineralogical and elemental measurement of the drilled samples
ExosphericMassSpectrometer for LUPEX (EMS-L)	Surface gas pressure and chemical species measurement

km to 1 cm) on the Moon, and majority of these traps are located at latitudes > 80°, which is the target of the LUPEX mission. And the rover may be able to explore one of the micro cold traps.

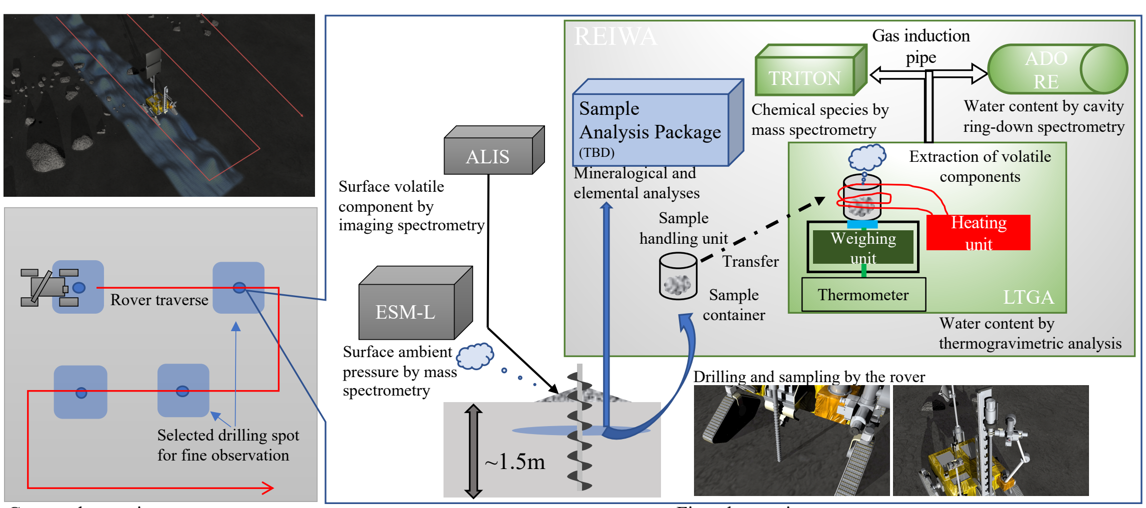
Current status: Since December 2017, JAXA and ISRO have been conducting feasibility studies on the mission. In early 2020, JAXA selected Japanese mission instruments for the LUPEX. Table 1 describes the selected Japanese instruments along with the candidate instruments of India and the invited international collaborator by JAXA. One of the instruments is called resource investigation water analyzer (REIWA), which will be developed as an instrument package to conduct suites of direct volatile measurements of the surface/subsurface regolith samples. REIWA consist of four subunits, namely, lunar thermogravimetric analyzer (LTGA), triple-reflection reflectron (TRITON), aquatic detector using optical resonance (ADORE), and ISRO sample analysis package (currently, this is a candidate instrument).

For the rover, JAXA has also conducted rover development and carried out several tests such as a wheel system test using regolith simulant and drilling test under the vacuum and low temperature condition. After the instrument selection, JAXA recently finished domestic system requirement review (SRR) for the rover with the JAXA's mission instruments, and it is planned to be a Phase B mission within this year (2021). The launch will be by JAXA's H3 rocket in around 2023.

Operation: JAXA and the selected instrument teams are conducting operation planning of the lunar surface observation based on the rover specification and estimated duration required for each measurement to carry out measurements. The overall mission duration is estimated to be more than 3.5 months after landing onto the lunar surface based on the current operation plan.

After landing on the lunar surface, deploying, and checking out of the system, the rover will start coarse observation of the predefined exploration area using ground penetrating radar (GPR), neutron spectrometer (NP), and advanced lunar imaging spectrometer (ALIS) (Figure 1). These instruments will measure the surface (by ALIS) and subsurface (by GPR and NP) water distribution and estimate their amount. Based on the coarse observation data, an area where water ice may exist will be identified, and then spot for drilling and depth selection will be carried out for fine observation. After the drilling, the regolith sample from the drilled depth is put into a sample container. The instrument package REIWA has a sample container handling system, which transfers the container to the weighing stage of the LTGA and also provides different portion of the regolith sample to the ISRO sample analysis package. The LTGA heating unit extracts volatile gas and derives water content based on the loss of weight. The extracted gas will be transported to the TRITON and ADORE through the induction pipe and will then be measured to identify their chemical species and water content.

References: [1] Li S. et al. (2018) *Proc. Natl. Acad. Sci.*, 201802345. [2] Gladstone G. R. et al. (2012) *J. Geophys. Res. 117*, E00H04, doi:10.1029/2011JE003913. [3] Mitrofanov I. G. et al. (2010) *Science 330*, 483-486. [4] Sanin, A. B. et al. (2017) *Icarus 283*, 20-30. [5] Colaprete, A. et al. (2010) *Science 80*, 463-468. [6] Lawrence D. J. (2017) *J. Geophys. Res., 122*, 21-51. [7] Fa W. and Cai Y. (2013) *J. Geophys. Res., 118*, 1582-1608. [8] Eke V. R. et al. (2014) *Icarus, 241*, 66-78. [9] Hoshino T. et al. (2017) *68th IAC*, IAC-17-A3.2B.4. [10] Paige D. A. et al. (2010) *Science, 330*, 479-482. [11] Schorghofer N. and Aharonson O. (2014) *The Astrophys. J. 788*, 169. [12] Hayne P. O. et al. (2020) *Nat. Astron.* https://doi.org/10.1038/s41550-020-1198-9.



Coarse observation　　　　Fine observation

Figure 1 Schematic image of the coarse and fine observation sequence by LUPEX