OBJECTIVES, INSTRUMENTS, AND OPERATION PLAN OF THE LUNAR POLAR EXPLORATION MISSION JOINTLY PLANNED BY INDIA AND JAPAN.

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Introduction: Multiple remote sensing dataset derived from recent lunar exploration missions suggested that water ice might be widely present in the lunar polar region [1]-[3]. 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 (PSR) reported that there is ~6 wt.% water abundance at a depth of several meters below the surface at the impact site [5]. Further, visible and near-infrared spectrometry observation of the lunar surface reported presence of water ice not only at the subsurface but at the surface in PSR [1]. These multiple remote sensing results inferred presence of water ice as a stable phase at the PSR. However, recent study of similar visible and near-infrared spectrometry observation reported possibility of active sublimation and condensation phenomena of water ice molecules identified as intermittent uplift of water ice/gas mixture at latitude higher than 85° in both poles at non-PSR [6]. As these reports indicate, the reported location and abundance of water in the lunar polar region varies among studies and even currently unknown process might be working.

However, currently, the actual origin, abundance, condensation mechanism, and lateral and vertical distribution of water remain unclear because no landing mission and no in-situ measurements have been conducted at latitude higher than 85°. This information will enable us to understand the supply flux of water to the Earth-Moon region in the solar system and the migration process at the surface of an airless planetary body. In addition to the scientific interest, there is growing interest in using water ice 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).

Mission objective: As discussed in the previous section, many parameters regarding water presence at the lunar polar region, remain unclear up to now.

To solve these issues, JAXA is planning the lunar polar exploration mission [7] 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 to evaluate the possibility of using water as a resource in future missions (Table 1 describes the planned instruments). In addition, we are also going to measure chemical composition and abundance of other volatile species to assess required purifying process and energy for extracting water to use as a resource. To achieve these objectives, we are planning 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. We are

Table 1 Mission Instruments on the LUPEX Rover

Mission Instruments	Observation Target
Resource Investigation Water Analyzer (REIWA)	
(1) Lunar Thermogravimetric Analyzer (LTGA)	Thermogravimetric analyses of the drilled samples for water contents
(2) Triple-Reflection Reflectron (TRITON)	Identification of chemical species of the volatile component based on mass spectrometry
(3) Aquatic Detector using Optical Resonance (ADORE)	Water content measurement in the drilled samples based on cavity ring down spectrometry
(4) ISRO's Sample Analysis Package (ISAP)	Mineralogical and elemental measurement of the drilled samples
Advanced Lunar Imaging Spectrometer (ALIS)	H_2O/OH observation of the lunar surface
Ground Penetrating Rader (GPR)	Underground radar observation up to 1.5 meter during rover traverse
Mid-Infrared Imaging Spectrometer (MIR)	Infrared spectral range observation of the lunar surface including 3 μm -H_2O/OH absorption band
Permittivity and Thermophysical Investigation for Moon's Aquatic Scout (PRATHIMA)	Detection and quantification of regolith bound water-ice in the lunar surface/sub-surface
Neutron Spectrometer (NS)	Underground neutron (hydrogen) observation up to 1 meter during rover traverse
Exospheric Mass Spectrometer for LUPEX (EMS-L)	Surface gas pressure and chemical species measurement

going to conduct measurements 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. Furthermore, these measurements are going to be conducted under different temperature condition to assess migration and condensation process for estimate water distribution not only at the investigation site by the LUPEX but in a polar region in a global sense.

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 (Figure 1). The rover can drill the surface regolith as deep as 1.5 m, bring up the regolith sample from the 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 [8]. However, recent computer simulation [9]-[11] suggested that water ice is possibly present at the subsurface (up to ~1 m) or in micro cold traps (scales from 1 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.

Status: Evaluation and validation of the rover design are underway in various test environments using engineering models. Resource Investigation Water Analyzer (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. Manufacturing EMs of REIWA system has finished and testing and evaluating them in the subsystem level has been underway and the REIWA system level test will start from January 2025. Manufacturing of Advanced Lunar Imaging Spectrometer (ALIS) EM was completed, and its functional performance test has started. A series of EM tests will continue to the end of February 2025.

Operation: ISRO/JAXA and the 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 ALIS (Figure 1). These instruments will measure the surface (ALIS) and subsurface (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 selection for drilling site and will be carried out for fine observation. After the drilling, the regolith sample from the 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 portions 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.

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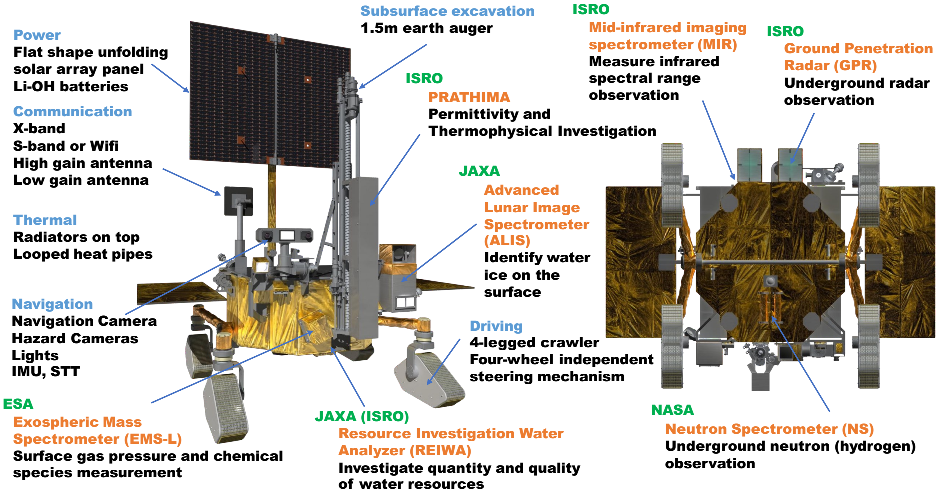

Figure 1 LUPEX Rover Overview