NATURAL WATER EJECTION FROM THE LUNAR SURFACE IDENTIFIED AT THE POLAR REGIONS. M. Ohtake[1], Y. Nakauchi[2], S. Tanaka[2], M. Yamamoto[2], K. Onodera[3], H. Nagaoka[4], and R. Nishitani[2], [1] The University of Aizu, Tsuruga, Ikki-machi Aizu-Wakamatsu, Fukushima, Japan, makiko-o@u-aizu.ac.jp, [2]Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, Japan, [3]Earthquake Research Institute, The University of Tokyo, Yayoi, Tokyo, Japan, [4]Cluster for Pioneering Research, RIKEN, Wako, Saitama, Japan.

Introduction: Multiple recent remote sensing data demonstrated water ice condensation in the lunar polar region [1][2][3]. Possible sources of water in the lunar polar region are comets, asteroids, solar wind implantation, and volcanic gas. Most of the previous reports suggested water ice presence at the surface of the Moon in its permanently shadowed regions (PSRs) (e.g., [4]). Moreover, an artificial impact experiment conducted by Lunar Crater Observation and Sensing Satellite (LCROSS) suggested water presence at a depth of several meters in the impacted site [5]. However, the origin, amount, and input/output flux of volatile materials at the lunar surface remain unknown and obtaining information about migration mechanism is important to understand the current and possibly ancient delivery system of water (the origin, amount, and input/output flux of water) to the Earth-Moon system. Thus, we investigated the migration of volatile materials in the lunar polar region.

Data: In this study, we analyzed data obtained by Spectral Profiler (SP) (https://data.darts.isas.jaxa.jp/pub/pds3/sln-l-sp-4-level2c-v3.0/) [6][7] onboard the SELENE (Kaguya) [8]. The SP data includes visible and near infrared wavelengths with a spatial resolution of 500 m. The spacecraft's altitude was 100 ± 30 km during the one-year nominal mission, and it was reduced to ~15 km in the extended mission. We used SP data because the higher signal-to-noise (S/N) ratio at wavelength range of 513-1644 nm (≥ 1000 at 5% reflectance) is highly advantageous for spectral analyses at the darker polar region. SP essentially observed the daytime (day side) lunar surface, and in some orbits, SP further continued observation toward the nighttime at ten degrees or more with the aim of taking dark revel signal data. Enough nighttime observations are available in most of the polar region (≥ ± 80°).

Data Screening and Absorption Identification: First, the nighttime SP data observed in the polar region was selected because identifying the weak absorption signals of volatile materials can be easier with nighttime data. Afterward, we performed data screening to identify the data with enough signal and low noise in the analyzed wavelength range. Then, absorption identification was conducted by using the data of wavelength range of 955.4-1644.2 nm, which corresponds to the near-infrared shorter wavelength (NIR 1) sensor range of SP due to the absorption of the volatile materials located in this wavelength range.

Results: We identified water gas/ice absorptions in more than 10,000 spectra both in PSRs and non-PSRs during nighttime when no illumination reached the lunar surface, while nearly horizontal solar light at these regions could illuminated the sky (Fig. 1). Ray trace analyses suggested that spectrum observed at the directly illuminated P1 position exhibited a normal regolith spectral shape similar to the representative lunar highland soil (regolith) spectra obtained at the laboratory. The P2 spectrum of the completely unilluminated (ray trace analyses suggested that P2 was unilluminated by direct solar light nor by a reflected light from surroundings) location was clearly different from the representative lunar highland soil and P1 spectrum, as it is kinking around 1000 nm and

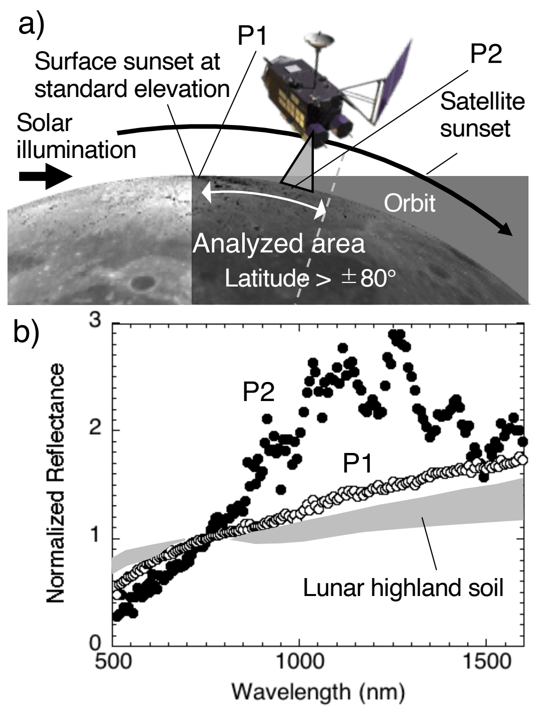

Fig. 1 Observational configuration and examples of the derived spectra. a) Schematic observation configuration. Position 1 (P1) data were obtained when the location was directly illuminated by the Sun. Position 2 (P2; 86° S, 45° E) data were obtained when the satellite was located between the surface sunset and the satellite sunset. At P2, the instrument will not receive a signal from the lunar surface. b) Reflectance spectra observed at P1 and P2 with representative laboratory spectra of the lunar highland soil obtained by Apollo 16 [9]. Spectra were normalized at 750 nm.

has a negative slope at longer wavelength than 1000 nm. This shape of the P2 spectrum is not typical for lunar regolith and the zigzag shape is attributed to the absorptions of water and likely to other volatile species. Ray trace analyses and spectral shape both suggested that the observed volatile signal did not come from the lunar surface but from the sky (space).

SP is a line profiling instrument with a narrow swath (~500 m), and the satellite orbits the Moon every 2 hours, where the Moon rotates 33 km at the equator during one satellite orbit. Therefore, the footprints of SP rarely overlap. However, at a special location where the satellite orbit overlaps (crosses) each other, the duration and temporal spectral variation of an event can be checked. Figure 2 illustrates such a rare observation (we identified only one such event). A temporal variation of the volatile identified spectra observed in one example orbit is presented in, and it varied in signal strength (y-axis). However, all the volatile identified constantly have absorption at 1500 nm (corresponding to water ice), indicating the continuous presence of observed material in in the space (satellite altitude at the observation timing was ~20 km). This event continued for 44 hours in 22

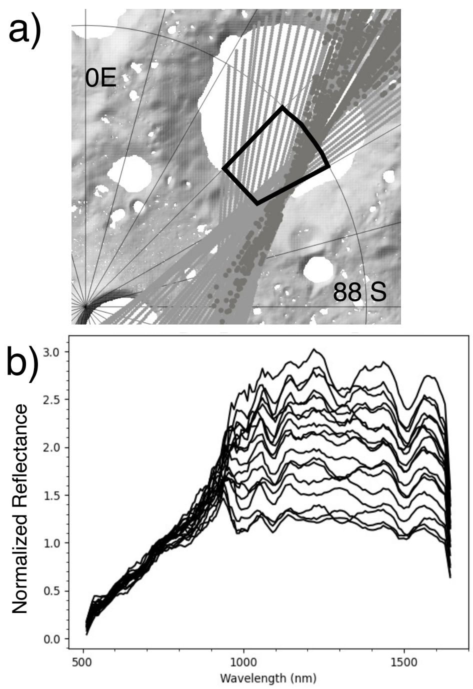

Fig. 2 Temporal variation of the absorption identified spectra. a) Observed location. Hatches are footprint of all SP observation (gray) and that of the identified absorption (dark gray). Multiple observation of one area (surrounded by black line; S88.0-88.5, E45-60) were achieved because of the satellite orbiter overlap. b) Normalized (at 750 nm) reflectance from one example orbit (rev. 6881; Data were obtained in 6 seconds are presented). Volatile absorptions were identified continuously as demonstrated by the fact that most of the spectra have similar absorption at 1500 nm, which originate from water though the spectral shape slightly changes in other wavelength with time.

orbits. Apparently, the event ceased its activity (absorption identification ends) after 44 hours although observation by SP continued after that.

Discussion: Because the SP data analyzed in this study is from nighttime observations, where basically no sunlight reaches the lunar surface and no signals are expected under normal circumstances, we conducted a careful evaluation to check if the absorptions identified in this study really originate from volatile materials, which might be located somewhere between the lunar surface and the spacecraft or might have artificial origins, such as calibration errors or stray light. The evaluation revealed that the identified absorption persists after divided by spectra from adjacent illuminated region and the geometric condition (angle) between the solar illumination and SP has no correlation to the timing of the absorption identified observations. Stray light originates from the solar light, even if it exists, cannot have an absorption similar to the absorption we identified. These results indicated that calibration errors or stray light origin are unlikely and that the identified absorptions are real.

As demonstrated in Fig.1, the lunar surface was not illuminated by direct or reflected solar light at the volatile identified location. Also, we confirmed that earthshine is too weak to explain the observed signal and many of the absorption identified spectra were observed during a period of no visibility of the Earth. Thus, the absorption signal we identified is not from the lunar surface and the natural conclusion is that the volatile materials must be lofted (ejected) from the lunar surface and reached to a higher altitude in space, where illuminated by the Sun.

The identified locations of the water ejection correspond to the high hydrogen concentration area reported previously [3]. Also, the identified location corresponds to a high sublimation rate area [10]. Most of the water ejection events did not coincide with the major meteoroid streams. The timing, duration, location, all suggest that impact events cannot be their main origin.

The identified water ejection events revealed that the lunar polar region is extremely active in terms of volatile migration.

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