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Hot bands observation of water in ejecta plume of LCROSS impact using the Subaru telescope

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Recent epithermal neutron measurements by Lunar Prospector (LP) reveals that hydrogen abundances in lunar soils within the depth of 10 cm from the surface ranges from 2 x $10^2$to 4 x 10^4 ppm, corresponding to ~0.2 to 40 wt% H_2O, in the permanently shadowed areas (PSAs) near the lunar poles [Lawrence et al 2006,Feldman et al 2001]. However, the terrain camera on-board the Selenological and Engineering Explorer (SELENE) did not find any exposed water-ice on the surface of the PSAs in the Shackleton crater near the lunar south pole [Haruyama et al 2008]. Thus, although H atoms exist in very shallow depths of the lunar regolith within the PSAs, both its molecular form (water-ice, hydrated minerals and/or organic matter) and depth distribution remain highly uncertain.

The LCROSS Mission is to attempt to directly investigate the presence of water on the Moon by excavating surface materials in a PSA inside Cabeus crater through two hypervelocity impacts of 2000 kg and 700 kg projectiles at 2.5km/s of velocity and >70 degrees of incident angle. Smooth-particle hydrodynamics (SPH) calculations suggest that the amount of water ejected over the 2.5 km height of the rim of Cabeus crater would reach ~150 kg if water content in the excavated lunar soils is 1 wt% [Korycansky et al 2009]. This amount would be observable with a large ground-based telescope, such as the Subaru telescope. Because ground-based telescopes would look at LCROSS impact plume from the side, unlike the LCROSS spacecraft looking from above, they would provide important information to constrain the depth distribution of water in the lunar regolith.

We observed infrared spectra during the LCROSS impact events with the Infrared Camera and Spectrograph (IRCS) Echelle spectrometer of the Subaru telescope on Mauna Kea, Hawaii. We targeted H2O emission lines in non-resonance fluorescence bands (hot bands) near 2900nm wavelengths because these emission lines are absorbed much less efficiently by atmospheric water vapor than fundamental water band emission [e.g. Kawakita et al 2006]. Although the Adaptive Optics (AO) system of the Subaru telescope reduced wobbles of the slit during observation, hot band emission lines have not yet been found in any spectra. The estimated upper limit of the H2O mass ejected over the height of the slit from the crater floor (~2.5km) is ~40 kg by the noise around one of the strong hot band wavelengths.

However the SPH calculation shows that the H_2O mass ejected over the 2.5km height is ~150 kg. The large difference between our observation results and pre-mission SPH calculation results would suggest three possibilities. The first possibility is the lack of water in the shallow regions in the PSA. The second possibility is that ice grains excavated by the Centaur impact had a very large average size, slowing the rate of sublimation greatly. However these would be inconsistent with the observation of the significant amount of water vapor observed by the Shepherding Spacecraft (S-S/C), which could see the ejecta as low as about 1 km above the floor of Cabeus crater. The third interpretation is that the amount of high-speed ejecta reaching the height of the slit of the Subaru telescope was much smaller than the theoretical estimates. The IRCS imaging observation results also support this possibility. There are two possible mechanisms for this possibility. (1) The amount of ejecta was much small immediately after the ejection velocity exceeds a specific cut-off velocity. (2) The ejection angle of the Centaur impact was much smaller than that of standard impact cases (~45 degrees). Thus our observation results suggest that we could get a new knowledge about an impact beyond the boundary of the assumption of laboratory impact experiments and cratering theory.

Keywords: impact, permanently shadowed areas, lunar water, spectroscopy