**THE ESTIMATE OF THE AMOUNT OF EJECTA IN LCROSS MISSION.** N. Okamura[1], S. Sugita[1], P. K. Hong[1], H. Kawakita[2], Y. Sekine[1], H. Terada[3], N. Takatoh[3], Y. Hayano[3], T. Fuse[3], D. H. Wooden[4], E. F. Young[5], P. G. Lucey[6], R. Furusho[3], J. Watanabe[3], J. Haruyama[7], R. Nakamura[8], K. Kurosawa[1], T. Hamura[1], and T. Kadono[9], [1]Dept. of Complexity Sci. & Eng., Univ. of Tokyo (Kashiwanoha, Kashiwa, Chiba 277-8561, JAPAN, okamura@astrobio.k.u-tokyo.ac.jp ), [2]Dept. of Phys., Kyoto Sangyo Univ., [3]National Astronomical Obs. of Japan, [4]NASA Ames Research Center, [5]Southwest Res. Inst., [6]Hawaii Inst. of Geophys. and Planetology, Univ. of Hawaii, [7]JAXA/ISAS, [8]National Inst. of Advanced Industrial Sci. and Tech., [9]Inst. of Laser Eng., Osaka Univ.

**Introduction:** The goal of Lunar Crater Observation and Sensing Satelite (LCROSS) mission is to investigate whether there is water in the regolith of permanently shadowed areas (PSA's) in the moon or not. We observed ejecta throw by LCROSS impacts over the rim of Cabeus crater, the target of the LCROSS impacts, by using the Subaru telescope. In this study, we estimate the amount of ejecta thrown above the Cabeus crater rim at Subaru telescope.

We observed ejecta by using the Infrared Camera and Spectrograph (IRCS), which can observe 2-dimensional images (1024 × 1024 pixels) simultaneously with spectroscopic observation. Using this slit viewer imaging system, we observed ejecta from LCROSS impacts. In order to reduce the effect of atmospheric water absorption blight, we chose $K_p$ band for the ejecta imaging observation. Each image was obtained one second of exposure time every ~4 seconds.

**Search for an ejecta plume:** Because the Moon moves on the sky sphere at different rate from regular stars, precise tracking is a challenging task. The Subaru telescope follow the Moon with its adaptive optics system very accurately. However because there is significant tracking error, we evaluated its amount. We calculated the root mean square (RMS) difference around the slit between consecutive two images with different amounts of translational shifts in both horizontal and vertical directions of an image of the pair. Results of the shifted differential analysis indicate that the RMS difference of the images is minimized for about one pixel of shift, indicating that the tracking is about one pixel (i.e., 0.05" and 100 m on the Moon).

Although translational shift analysis indicates that the tracking error was very small, matching between two consecutive images was not always very good. The boundary between a dark region and a bright region is sometimes very sharpe but some other time rather diffuse. This may be caused by scattering by the telluric atmosphere, probably cirus cloud seen in the sky in the night of LCROSS impacts. In order to quantify the atmospheric degree, we calculated the slope on the boundary between a dark region and a bright region. We chose two on the boundaries areas (A and B) as shown in Fig.3. The slopes on the boundaries is shown in Fig. 4, indicating that there is a good correlation between the two boundary areas. High slopes correspond to high contrast between bright and dark region; i.e., clear sky. Fig.4 also shows that the small slopes are seen that more frequently after the impact than before the impact, suggesting that atmospheric scattering increased as we observed. In order to minimize the influence of scatter, we pick up the data with high slope values. In this study we chose the data with slopes higher than 220 count/pixel for region A. There are 10 images meeting this condition.

Fig.3 shows an example of the imaging data before and after impact with high slope values. If a large amount of regolith was ejected by the impact, an ejecta plume would be seen above the slit position in post - impact images. Although we compared the imaging data before and after impact carefully with different contrasts, we could not find an ejecta plume.

Then, we subtracted imaging data before the impact from it after the impact and exaimned carefully whether there is ejecta. However we were not able to identify significant ejecta in the subtraction images.

Next, we defined the region "ejecta" and "sky" as Fig.1. The region "ejecta" is expected to observe ejecta and the region "sky " is a dark region that is little affected by light from the bright areas on the Moon.
The light intensity $I$ in these regions is the following,

$$I_{ejecta} = \left(F_{ejecta} + F_{sky}\right) \times trans \quad , \tag{1}$$

$$I_{sky} = F_{sky} \times trans \quad , \tag{2}$$

where *trans*, $I$, and $F$ stand for atmospheric transmittance, light observed on the ground and light reflected by ejecta (W).

In order to derive $F_{ejecta}$ from eq. (1) and (2), we need to remove *trans*. We used a near-by B-type star BS1140 as the standard star to estimate *trans*. Fig. 5 shows the intensity of reflected light from ejecta as a function of time after impact indicating that $F_{ejecta}$ is bound between $6.0 \times 10^{-12}$ W and $1.5 \times 10^{-11}$ W. If we observe ejecta we should see a peak between 0 second and 90seconds. However, there is no obvious peak during this period of time; a significant amount of ejecta was not observed.

**Upper limit for ejecta mass:** In order to investigate why ejecta was not observed, we estimated an upper limit for the mass of ejecta above 2 km. The total area $A$ (m$^2$) and total mass $M$ (kg) of ejecta can be given by using $D$, the diameter of a particle, and $n(D)$, the number of particles whose diameter is $D$. We used the maximum diameter (1mm) and minimum diameter (1 $\mu$ m) of particle respectively. Here, we use the size distribution of lunar regolith outside PSA's [5],

$$n(D) = CD^{-3.94}, \tag{3}$$

where we can estimate the constant $C$ from the following equation,

$$F_{ejecta} = L\ A\ Sr\ \frac{\varepsilon}{2\pi} \tag{4}$$

Where $L$ is the unit reflection from the Sun (W/m$^2$) and $\varepsilon$ = 0.1 is albedo, and $Sr = 3.49 \times 10^{-16}$ is solid angle of the telescope aperture viewed from the Moon. From the observational results, we obtain $M = 1 \times 10^3$ kg from eq. (3) and (4).

**Discussion & Conclusions:** In this paper, we investigated the ejecta mass of LCROSS impact from the imaging data obtained by the Subaru telescope. Since a significant amount of ejecta has not been detected from the data, we estimate upper limit for the ejecta mass

The obtained upper limit for the ejecta mass beyond 2.5 km is only 1/20 of a pre-impact the theoretical estimate [1]. Although this estimate for the upper limit of ejecta mass is still preliminary, it is important in discuss the possible mechanisms for this small amount of ejecta from LCROSS impacts.

A first possibility is that the average grain size of the impact ejecta is so large that light scattering was very inefficient. A second possibility is that resulting crater was much smaller than pre-impact prediction, perhaps because of the strength of materials within the PSA. A third is that the cut-off velocity, above which ejecta mass is greatly reduced, is much lower than theoretical estimate [e.g., 1]. Fourth possibility is that the ejecta plume was ejected a much lower angle than stardand 45°. Then much less mass of ejecta can reach the field of view of our observation than standard impact theoretical predictions. Among the four possibilities, the first two conflict with LCROSS Shepherding Spacecraft (S-S/C) observations. More specifically, S-S/C has observed a clear image of ejecta plume above the Sun horizon at 1 km above the crater floor. If the grain size of the ejecta is extremely large, the ejecta plume should not be detected easily by the S-S/C. Also, S-S/C has observe a rather large crater using its mid - IR camera. Such a large diameter of crater can not be formed if the cratering was controlled by the strength of the target material. Consequently, a low cut-off ejecta velocity and a very shallow ejection angle are capable accounting for the lack of strong ejecta light above 2 km of height without conflicting with S-S/C observations. Because both possibilities involve impact mechanics, further impact studies are needed to resolve this problem. In other words, our observation results suggest physical processes induced by the LCROSS collisions may involve impact mechanisms that we have not understood yet.

**References:** [1] Korycansky D.G. et al. (2009), *MAPS*, *44*, 603. [2] Clabon W.A. (2000) *Allen's Astrophysical Qquantities, 4th ed.*, The Athlone Press, London. [3] Goldstein, G.B. et al. (2001), *JGR, 106 (E12), 32*,841. [4] Pieters, C.M. et al. (2009) *Science, 326*,558. [5] Heiken, G.H. et al. (1991), *Lunar Sourcebook,* Cambridge Univ. Press

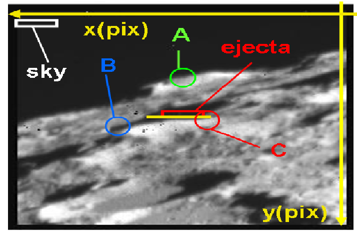


**Fig. 1.** This figure shows regionA, regionB, region "ejecta" and region "sky".

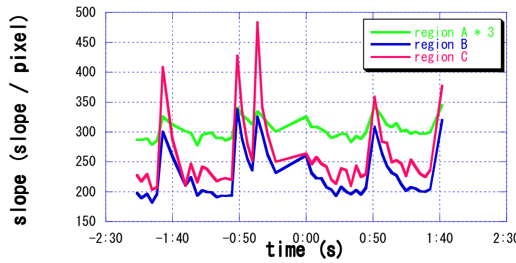


**Fig.2**. The slope of count at the boundaries between bright and dark regions in the field of view as a function of time.

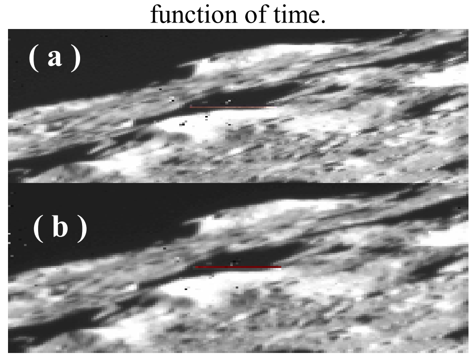


**Fig.3.** Slit viewer images around the LCROSS impact, (a) before the impact. and (b) after the impact.

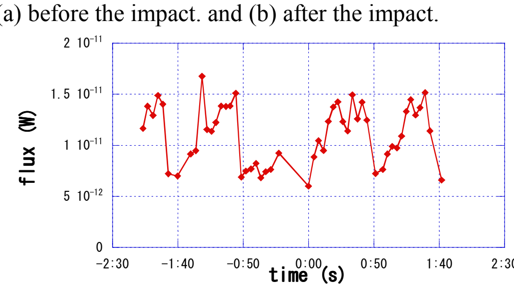


**Fig.4.** The relation between the reflection (W) and time (s) after impact.