The international observation of lunar impact flashes and application of the results to future lunar seismic experiments.
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Introduction: The lunar impact flashes can be detected as luminous phenomenon caused by the meteoroid impacts on the lunar night side, and the 345 impact flashes have been detected in NASA lunar impact flash monitoring program from 2005 to 2015. The magnitude and frequency of impact flashes provide frequent distribution of meteoroid in small energy range; that corresponds to R-magnitude of 5.07-10.42 [1]. The combination of the flux and those estimated by other observations such as fireball detection and infrasound observations in larger energy range can derive accurate relation between the impact number and the magnitude. Moreover, meteoroid impacts play an important role in lunar seismology because those can be seismic source to investigate the lunar shallow structure like crust and upper mantle (e.g., [2]). Usually, three seismic stations are required to locate a seismic source. However, determining the exact impact locations and origin times from the ground observation allows us to investigate the lunar interior using only single seismic station. This will be very useful for future lunar seismic experiments because deployment of multiple seismic stations require much budget and the large content of the explorer.

In this study, we have tried first international observation of the lunar impact flashes in same days. Usually, the observation time of the Moon is limited less than 3-7 hours in one station. The continuous observation along longitude can elongate the observation time, and it can provide more detection of the impact flashes and the flux with higher resolution. In this presentation, we will report (i) the results of 2-years observations on Japanese ground stations, (ii) the results of the international observation conducted during the peak period of Geminids in 2018, (iii) application of these results to future seismic experiments.

The Stations and Equipment: For this international observation campaign, we have prepared for 6 ground stations; three in Japan, two in France and one in Taiwan. In Japan, the University of Electro-Communications (UEC), Nihon University and Institute of Space and Astronautical Science (ISAS) have joined the campaign. The telescope attached with thermal infrared camera was added to observation in Nihon University. In France, Paris University and Nice observatory have prepared for the telescopes to detect the flashes. As additional site, Lulin Astronomical Observatory has joined to our observations in Taiwan.

The equipment for monitoring of the impact flashes are different in each ground station. For basic configuration, the telescope whose aperture larger than 8", astronomical video camera (CCD and/or CMOS cameras), monitor and the recorder were set. As example, ZWO ASI174MM was used as the camera, and the software of Fire Capture was applied for monitoring and recording. The detection of lunar impact flashes in the recorded lunar images has been performed by some software such as Lunar Scan.

Results of Impact Flash Observations:

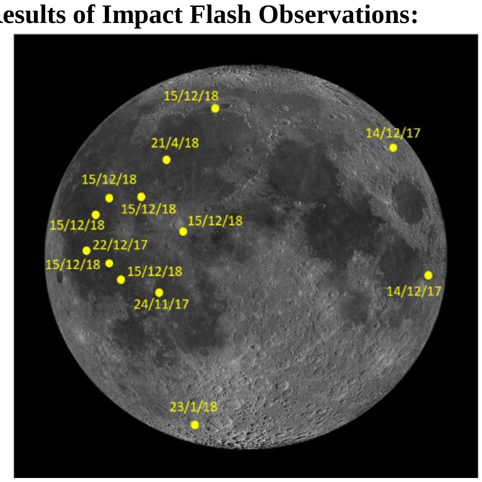

Fig.1. The approximate locations of 13 detected lunar impact flashes. The day/month/year is put in each event.

In Japanese side, we have continued the impact flash observations for 21 months . The flash can be detected in term when ratio of lunar illuminated area is in range of 10 -50 % on the lunar nearside, and the term is about 10 days in one month. Eventually, we have performed the observations at 30 nights in fine days, and the total observation time is about 60 hours. From the observations, we succeeded to detect 21 lunar impact flashes, and 3 flashes were detected in all Japanese sites. Among all of the flash events, 11 events were detected during about 5 hours observation in December 15, 2018. The approximate locations of detected 13 events are shown in Fig. 1. In the figure, we clearly find that more flashes are detected in the lunar westside compared with the eastside, and it is similar result to previous studies (e.g., [3]), though it may be due to bias in the observation time . For some flash events, physical parameters are determined. For the event detected at January 23, 2018, R-magnitude is 5.88 ± 0.18, the luminous energy is 24.5 ± 3.92E+4 J, the impact mass is 660 ± 150 g. Finally, we will summarize the locations and physical parameters of all flash events, the impact detection rate, the mass flux including results derived from other counties.

Application to Lunar Seismic Experiments: The lunar seismic experiment since Apollo-era is important topic to reveal the internal structure of the Moon. In addition to little information about region deeper than depth of about 1100 km, we still have uncertainty about the lunar crustal thickness from about 30 to 60 km [4, 5]. The accurate determinations of origin time and source location by impact flash detection and more travel time data in lunar shallow region enable better estimation of the crustal thickness.

We have evaluated the expected detection number of the impact seismic events located by the impact flash observation using method in [6]. As preliminary evaluation, we considered detection rate of the flash derived from results of the NASA lunar impact flash monitoring program; that is 0.234 (flashes/hour). In here, we assume that term of seismic experiment is 6 months and continuous observation of 24 hours in one day using global ground telescope network. Since the days when we can observe the impact flashes on the Moon is 10 in one month as described above, the estimated detection number of impact flash is 338 during the mission term. This corresponds to 345 flashes detected by only single station of NASA during about 10 years.

We have applied the locations of the 345 impact flashes which were detected by NASA ground telescope to source location of the impact seismic events. Then, the seismic waveforms of the impact events originated from the 345 sources are calculated at each location of the seismic station. The calculation method of the impact seismic waveform is referred from [7]. If maximum amplitude of an impact seismic event is larger than the detection limit of the seismometer in a station, we evaluate that the event can be detected at the station. In this study, we assume the seismometer loaded in the penetrator [8] in the future experiments, because the penetrator is important candidate to deploy geophysical network on the planetary surface by hard landing.

Fig. 2 shows the expected detection number of the impact seismic events originated from the 345 sources at each seismic station deployed with resolution of 3×3 degrees. The seismic stations are set within ±30 degrees in latitude, because it is thermal limitation which the penetrator can be deployed without additional heater. From Fig.2, we can expect detection of about 50 impact seismic events at maximum in lunar westside area. The asymmetry in Fig.2 is due to locations of impact flashes as shown in Fig.1. If travel times of all detected events can be applied to exploration of internal structure, the number will be sufficiently larger than that of the impact events (19 events) applied to derive current lunar internal model [5]. We will progress this seismic evaluation using results of our international observations, various calculation methods of seismic waveforms and various seismic and impact parameters.

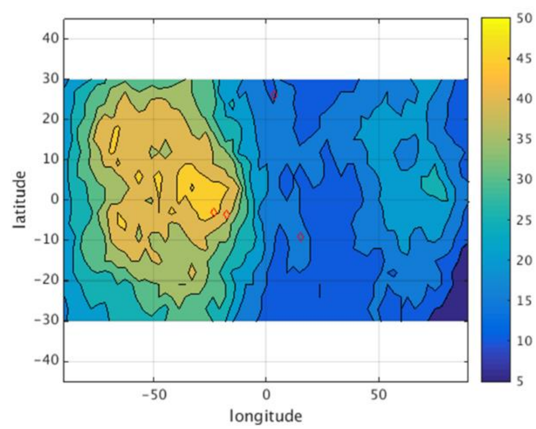

Fig.2. The expected detection number of the impact seismic events located by the impact flash observation with resolutions of 3×3 degrees during half of a year. The seismic stations are deployed within ±30 degrees in latitude.

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