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# Lunar impact flashes: Results from 56 hours of video survey data observed by using one telescope

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## Abstract

Primarily observations are performed during 2013 and 2014 at AGM observatory of Marrakech by using one SC telescope in the aim of observing sporadic meteoroids impacting the lunar dark side. Here, we report results from 56 hours of video survey.

## 1. Introduction

The impact of hyper-velocity centimeter-sized meteoroids on the moon yield moonquakes, melt the rocks, produce meter size craters and generates a plasma/vapor plume as bright and brief flash, which enhances eventually the lunar atmosphere. All these physical effects are now technically observable (e.g. Apollo, LROC, LADEE). Lunar impact detection provides the time and the position of the impact site with the best accuracy; and allows to estimates the energy, and the size of meteoroids and the craters produced. Future lunar explorations (lunar crust, atmosphere, new crater identification) will be more profitable if the independent determinations of the different parameters deduced are made in conjunction with more than one technique. Besides, the large monitored area provided by our Moon is favorable to better constraint the current impact rate on Earth-Moon environment and to characterize the upper size limit of meteoroids swarms. Moroccan observatories (Oukaimeden and AGM) are now involved in this research context, first detections from 2013 have been already presented and implications in lunar seismology are also discussed [1].

## 2. Observations and detections

A large part of observations was made during the first 4 months of 2013 and the latest four months of 2014. Several factors have prevented us to observe at the peak of meteor showers; including: unfavourable lunar phase and inadequate orbital encounter with most of the meteoroids swarms during the last two years, plus weather. More than 97% of our data was carried out in the best conditions. We monitor the night side of the lunar disc with a sensitive video camera working at interlaced mode (1 half-frame per 20 ms ; 1 frame per 40 ms) attached to a (0.33x or 0.63x) focal reducer + (35 or 20 cm) SC telescope. More details about the instrumental setup can be found in [1, 2,3]. The LunarScan software [4] is used on recorded videos to perform automated detections. The automatically detected transient events are then manually examined to eliminate false detections. Within the 56 hours data analysis; we have rejected several tens of hundreds of false detections.

Obviously, the most false detections are single half-frame duration (20ms) "cosmic ray and electronic noise". Otherwise, they show motion across the field of view "sun glints from satellite and orbital debris", or it is just a brilliant feature of the lunar surface (fig.1). Majority of lunar impacts are one frame flashes, and these flashes must be confirmed by at least two different observatories, other flashes can be easily identified based on typical characteristics of impact flashes in terms of intensity, spatial extension and duration. By using one telescope, we estimate to have missed more than tree one-frame flashes. Among the several hundreds of false detections, only four events were lasted more than one frame (20 ms) and simultaneously shown adequate brightness changes at the same pixels. Examining their light curves profile (sudden signal increase followed by a sharp decrease) plus photometric analysis one can notice undoubtedly that they are really impact flashes. The identification criteria and our survey results are consistent with more reliable statistics from NASA-MSFC [5].

**Figure 1**: Snapshots of typical false detections.

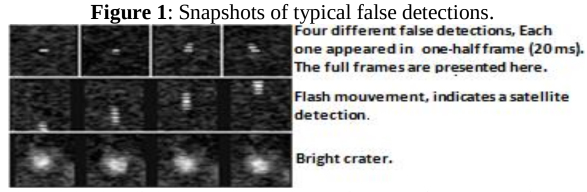
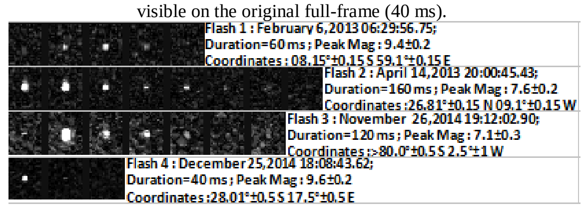



**Figure 2**: Sub-frames and characteristics of detected flashes. Each field present 20ms. Flashes 2 & 3 are not clearly visible on the last field, but visible on the original full-frame (40 ms).




## 3. Analysis and Results

Characteristics of each flash are given in Figure 2 and derived parameters in Table 1. We noticed that the last three flashes have been observed very close to the equator. All Magnitudes and durations showed a consistency on the trend revealed in the work of [6] (the most luminous flashes persist more). Except that the photometric analysis indicated that Flash 3 was brighter than flash 2 which is the longest one. This can be explained by the fact that fastest meteoroids have capacity to produce bright and short flashes as clarified at the same work [6] in the case of the Leonid meteoroids impacts. So, we consider that the object producing the flash 3 was faster; however the other caused flash 2 is larger and more massive. This is consistent with light curves analysis, the flash 2 has required more time during its expansion phase (this can be directly noticed in the Fig.2); while the flash 3 has quickly reached its maximum intensity. Since it is this phase that is considered in the calculation of energy, the flash 2 was found more energetic, subsequently generated with a more massive projectile.

**Figure 3**: Light curves of recorded flashes.

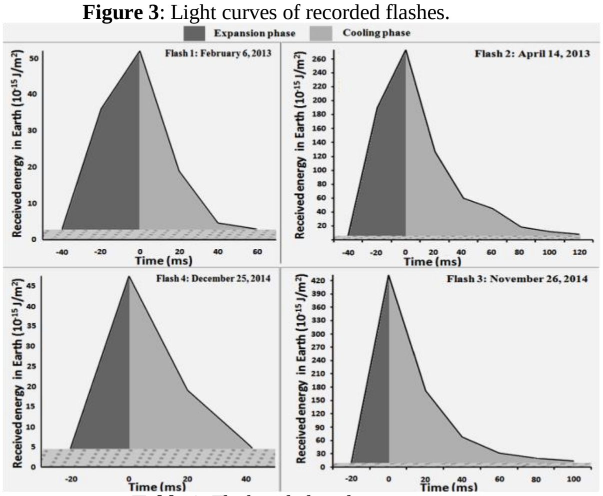



**Table 1**: Flashes deduced parameters.

| | F 1 | F 2 | F3 | F4 |
|---|---|---|---|---|
| Impact luminous Energy ($10^4$ J) | 8.2 | 43 | 35 | 4.5 |
| Estimated impact Energy ($10^7$ J) | 5.4 | 28.7 | 23.1 | 3.0 |
| Estimated mass of impactor (kg) | 0.4 | 2.1 | 1.2 | 0.15 |
| Estimated crater diameter (m) | 2.6 | 4.4 | 4.2 | 1.8 |

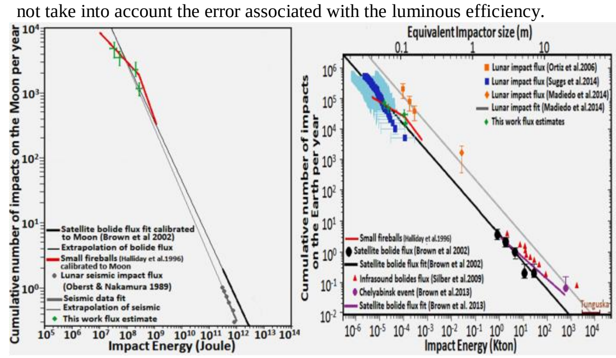
"Meteoroid speed of 16 km/s, a luminous efficiency of 1.5 $10^{-3}$, projectile density of 1.5 g/cm$^{-3}$ and target density of 2.2 g/cm$^{-3}$ are used in the calculation".

# 4. Implications for the impact rate

Lunar impact rate can be reached by considering the total survey time and the average surface monitored. Then, the terrestrial impact flux is obtained by calibrating the lunar rate in terms of Earth collecting area and correcting the impact energy by considering gravitational focusing [2, 3, 7].

New and old results of Earth-lunar system data flux are plotted in the figure 3. Our derived flux is relatively compatible with the extrapolation of lunar impact data given by Apollo seismic station [8]. We have converted bolides explosions rate in Earth to the lunar rate. Our data are more consistent with small fireballs flux [9] and a little compatible with extrapolation of large bolides flux [10]. Compared to other lunar flashes fluxes, our data are consistent with flux derived from [2] at low energy, but higher with a factor of 3 in energy between $10^8$ and $10^9$J. With the same differences approximately, our data are low in comparison with the rate obtained by [3, 11], note that this last rate supports the annual flux indicated by large impact events such as Tunguska and Chelyabinsk. The present discord may be simply due to difference in the approach taken to determine the energy of the impact in each work, something that can be minimized in the future.

**Figure 4**: our data rate (green dots) plotted with recent lunar flashes flux and different datasets presented in the lunar & terrestrial scale (error bars do not take into account the error associated with the luminous efficiency.




Impact flashes allows to monitor low-energy impacts (in the $10^7$J range; provoked by~ 5 cm meteoroid; resulting~ 1.5 m crater). In addition, given the large monitored area, it helps also to keep an eye on the big explosions as the largest flash (8s, 15.6 TNT) observed by [3]. With more datasets, especially, if detections are matched with other techniques (seismic detection, new craters characterization); improvements and accurate estimation of the present impacts and characterization of the meteoroid impact hazards danger will certainly achieved, this will allow as well calibration of the partitioned energies, improve the energy calculation procedure and calibrate the scaling laws used.

# 5. Conclusion

Primarily results from our survey are discussed, and summarized characteristics of our detections are also presented. Our estimates indicate that about 12±3 craters that are larger than 1.5 m in diameter are created daily on our moon. Our first attempts were satisfactory, it allowed us to make confidence on our current progress in observational and analysis techniques, and to check whether our detection rate is consistent or not with other datasets. Given the time-consuming workload required to registering and analyzing the videos data, which is the main limitation to our capabilities, we wish to automate our instrumental setup in order to increase our detections and be in rendezvous with future lunar exploration.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