Observation of Lunar Impact Flashes with the SPOSH Camera: System Parameters and Expected Performance

R. Luther (1,2), A. Margonis (1), J. Oberst (1,3), F. Sohl (3) and J. Flohrer (3)

(1) Technische Universität Berlin, Germany, (2) Humboldt Universität zu Berlin, Germany, (3) Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany. (robert.luther@hu-berlin.de)

Introduction

Observations of meteors in the atmosphere of the Earth have a long tradition and brought up knowledge of meteoroid population and streams in near Earth space. Only recently, observations of meteoroid impacts on the dark hemisphere of the Moon became technically possible. Since the first confirmed Earth based observation of a lunar impact flash in 1999 [e.g. 1] more than 200 impact flashes have been registered [2]. Meteoroids bombarding the Moon are not slowed down by an atmosphere and impact with high velocities of up to 70 km/s, causing a light flash of about 10 to 100 ms duration.

Continuous observations of the dark hemisphere of the Moon improve our knowledge of near-Earth meteoroid population. Meteoroid Impacts release a portion of their pre-impact energy in the form of seismic energy, which can be recorded by seismometers. From known impact locations and times, we have the unique opportunity to improve seismic data analysis and studies of interior structure. Therefore, it is important to study the various system parameters that determine the possibility of a successful lunar impact flash detection, which we have done by numeric simulations. In particular, we want to evaluate the performance of the camera head of the SPOSH camera system [3] attached to a telescope.

System Parameters

In order to determine the limiting magnitude of an observing system we simulate the background signal seen during an observation in the visible wave length that consists mainly of sunlight reflected from Earth to the Moon and back to Earth, called Earthshine, using the following equation [cf.4] :

$$P^{CCD}_{Earthshine} = \frac{L_{Sun}(\lambda)\,\Omega_{Earth}\; f\; A_{Earth} A_{Moon}\; O_{Moon} \cos(\alpha)\, r^2 Q(\lambda)}{2\pi\, R^2 E(\lambda)} \quad (1)$$

with P as the power of Earthshine in electrons per second and pixel, sun radiation at Earth distance L_{sun}, solid angle Ω of the Earth and the fraction f of the sun-lit Earth, both seen from the Moon, the Albedos of Earth and Moon A_{Earth} and A_{moon}, the lunar surface O_{Moon} per Pixel, radiation incident angle α, Aperture r, CCD quantum efficiency Q, Earth-Moon distance R and energy E of any light quantum.

Field of View: The amount of background radiation depends on the background emitting area on the Moon that is determined by focal length f of the telescope and the number of pixels and the pixel size d_{Pixel}. For one pixel, the area is calculated by the instantaneous field of view (IFOV):

$$\mathrm{IFOV} = 2 * \arctan\left(\frac{d_{Pixel}}{2\,f}\right) \quad (2)$$

Greater focal length and smaller pixel size result in a smaller IFOV, hence, in a smaller surface area covered by one detection unit and less background radiation. In this way, instrumental set-up influences the limiting magnitude for lunar impact flash detection. However, smaller IFOV results in a smaller coverage on the lunar surface and therefore in a lower probability of detecting lunar impacts.

CCD Integration Time: Fastest observations are done by systems with frame rates of up to 60 half-frames per second [e.g. 5]. Slower systems collect more background signal instead of impact flashes and, thus, suffer from reduced signal-to-noise ratios. Binning of CCD's can increase frame rates on cost of resolution, but increases also the lunar surface per detection unit by the binning factor and thus compensates the lower integration times (see eq. 2 and 3).

$$\frac{S}{N} = \frac{\mathrm{Flash\,(aperture)}}{\sqrt{\mathrm{Flash\,(aperture)} + \mathrm{Earthshine\,(t, IFOV, aperture)}}} \quad (3)$$

Aperture: A larger aperture has an effect on the signal-to-noise ratio by increasing the amount of collected photons per detection unit. The Poisson-distributed noise increases by the square root of the increased signal. Thus, doubling the diameter will approximately double the signal-to-noise ratio (eq. 3).

Table 1: Telescope and camera data.

	TMB Apo Refractor	SPOSH	
focal length in mm	1400	1024 x 1024	pixel
aperture in mm	203	13.3	pixel size in µm
focal ratio	6.9	90% (peak)	quantum efficiency

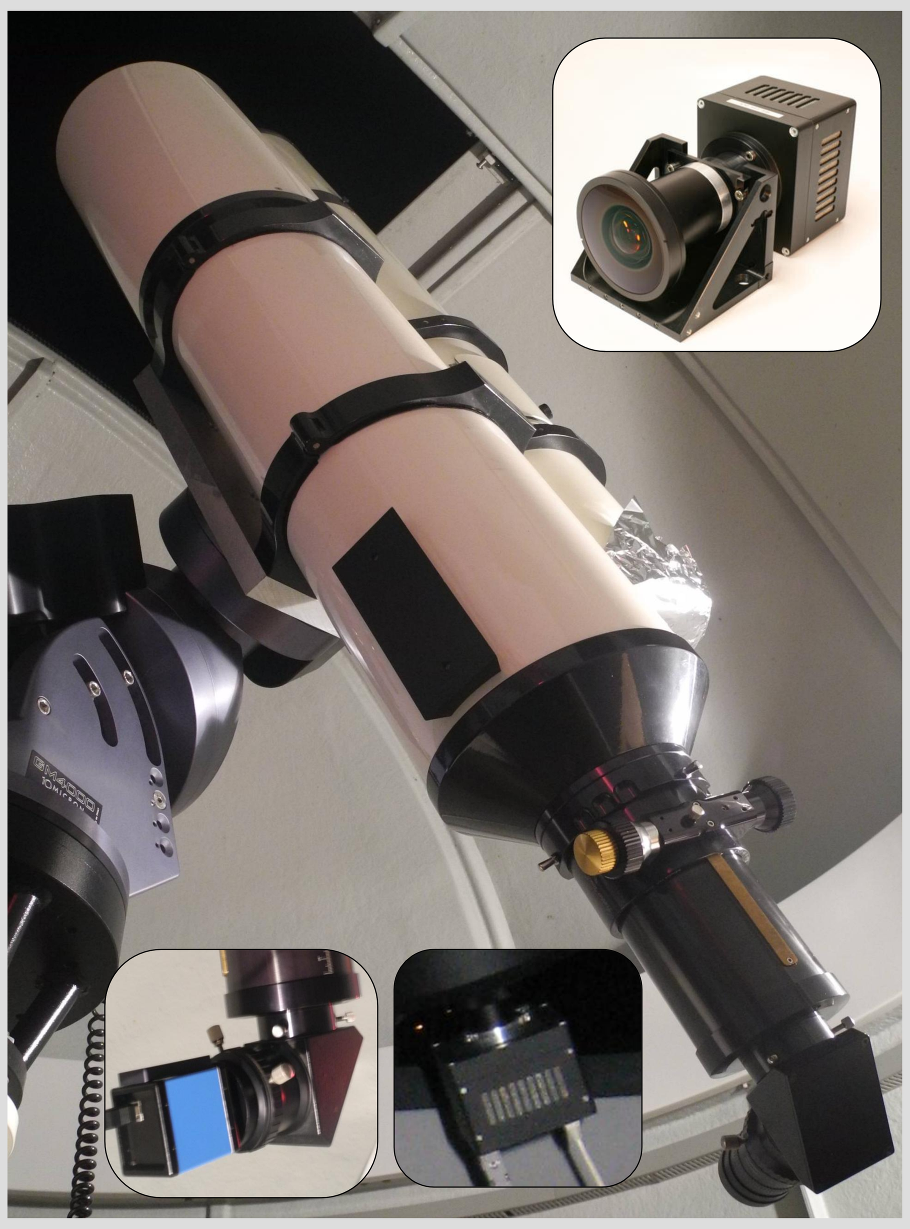

Fig. 1: Observing System: TMB-Refractor and our two cameras (left: DFK 21AU04, right and top: SPOSH camera with and without fisheye lense).

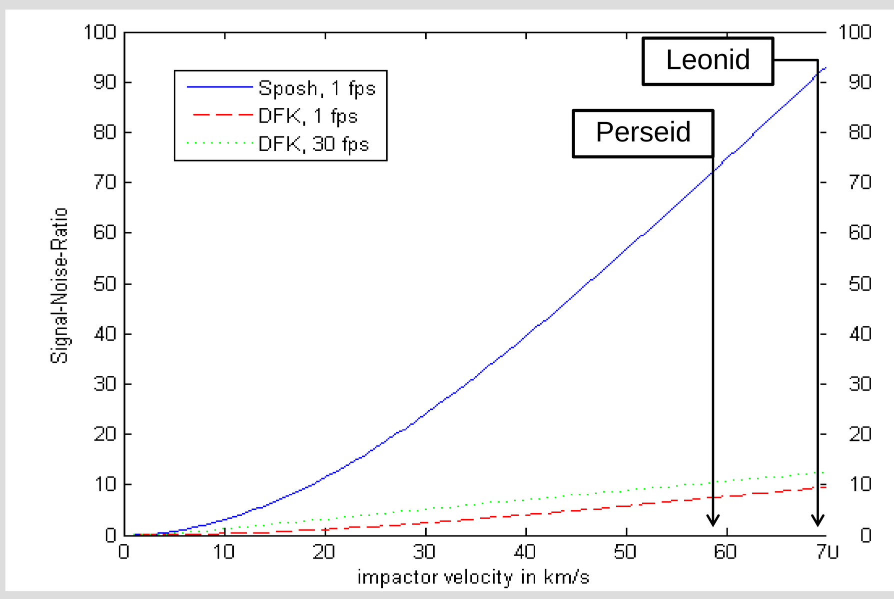

Fig. 2: Expected flash signal-to-noise ratios relative to the impactor velocity. The ratios were computed for our two cameras with 1 fps and for the DFK camera also with 30 fps with impacting meteoroids of 1 kg mass and an estimated plume temperature of 2000 K.

Signal-to-noise ratio (S/N): We calculate the S/N for our system by the kinetic energy of the impactor. As converting factor for radiation energy we use a luminous efficiency of about 0.0015 [4]. The percentage of energy detectable by our CCD is calculated by a black body spectrum with a flash plume temperature of 2000 K. Fig. 2 shows the S/N depending on the impactor velocity for an impactor with a mass of 1 kg for the SPOSH camera and our current DFK camera.

Observing System

Our observatory in Liebenhof (+52°33'6"N, +14°1'9"E) near Berlin is equipped with a TMB Apo Refractor (specifications see table 1, photo see figure 1) on which we plan to mount our SPOSH camera head. Our system reaches a field of view of 34 arcmin and thus can cover the complete dark hemisphere of the Moon. One pixel represents an area of about 14 km².

Figure 3 shows two composite images of the lunar dayside surface taken with the DFK camera mounted onto the TMB refractor. Since the SPOSH camera is much more sensitive than the DFK camera, we expect to see in a similar fashion lunar surface contours on the nocturnal hemisphere. We calculated the signal by equation 1 and reach an Earthshine signal of about 9400 electrons (~13 visual magnitude) with the SPOSH camera – in contrast to 120 electrons by the DFK camera. Thus, we will try to get precise locations of impact flashes, e.g. for later crater search. In addition, we expect the SPOSH camera to be more sensitive to impact flashes than the current DFK camera. Figure 2 reveals an increase by a factor of about 7 up to a S/N of 95 for Leonid meteoroids with a velocity of about 70 km/s.

Summary

We discuss the influences of system parameters on system performance and introduce our observing system in Liebenhof. With the SPOSH camera we expect to improve our system as shown by the S/N and plan to take images of the nocturnal hemisphere of the Moon that show clear surface structures for flash detection and localization. Thus, impact flash measurements will shed light on impact processes as well as on the properties of the impacting objects and for assessments of collision hazards. Successful observations rely on improving the signal-to-noise ratio and balancing of lunar impact probability which depends on the system limiting magnitude as well as lunar surface coverage.

Fig. 3: Composite images of the illuminated lunar surface each based on several hundred stacked high-quality single frames taken on 16.08.2013, 19:20:11 UTC, in Liebenhof with our TMB Refractor and the DFK camera: FOV: 8.8 x 6.6 arcmin², each pixel covers an area of 2.4 km². A darkframe is removed.

Acknowledgements

This research has been supported by the Helmholtz Association through the research alliance "Robotic Exploration of Extreme Environments".

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