Detection of Meteoroidal Impacts on the Moon. S. Sposetti[1], R. Lena[2] and M. Iten[3]. [1] Gnosca observatory, In Fun I Vign 7, CH-6525 Gnosca, Switzerland; stefano@sposetti.ch; [2] Geologic Lunar Research (GLR) group, via Cartesio 144, sc. D, 00137 Rome, Italy; r.lena@sanita.it; [3] Garden observatory, via Terriciole 15, CH-6596 Gordola, Switzerland; mitensa@ticino.com

Introduction: On November 18, 1999, the first confirmed lunar meteoritic impacts were recorded in the form of flashes that resulted from the collision of the Moon with debris within the Leonid meteoroid stream [1]. Since these initial successes, other meteor swarms have been shown to produce lunar impacts [2-5]. Rates and distribution of impactors, shower and sporadic, have been discussed in [6].

During our surveys carried out on February 11, 2011 and April 9-10, 2011 four impacts were simultaneously recorded by two independent and distant (13 km apart) observatories (Table 1).

Methods and instruments: The selenographic coordinates (Table 1) of the flashes were computed using our images displaying several lunar features that were of very low contrast on the dark limb of the imaged lunar surface.

After alignment with the edge of the lunar disk, computation of the libration and overlay of the rotated Moon's surface matching the imagery, a coordinate map was superimposed on the flash images (Fig.1). Images of the impacts #2 and #3 are shown in Fig. 2.

We performed the method of aperture photometry using the software Tangra which delivers "signal minus background" values. The intensity of the flashes were measured in the field of the maximum intensity, i.e. in the 0.020s interval. The intensities of the stars were measured and evaluated over several frames.

The intensity of the flashes are well above the noise level and the events cover several fields. The lack of trail and the absence of another flash in the same frame or in other frames indicate that the feature is not likely to be due to a satellite, nor to space debris. In addition, the flashes are present in a number of fields at a stationary position, which again rules out cosmic rays, noise, or even artificial satellite glints. Besides, the positions of all geostationary satellites were checked and none was within a few degrees of the Moon at the impact times as seen from two observatories.

Analysis: The brightest impact flash 1 reached a peak brightness of 8.1 ± 0.3 magV and had a quite long lasting afterglow. The duration of the event corresponds to 0.10 s ± 0.02 s. The impact occurred in the western lunar border in the region near the crater Einstein. All the other flashes #2-4 were dimmer than 8 mag and all were 60ms long.

The impacts occurred in Mare Humorum (at about 110 km from Liebig crater), and in the western shore of Mare Imbrium near the craters Diophantus and Fedorov, respectively.

#	Date and Time UT	Location	Mag.(V)	Telescope
1	February, 11, 2011 20:36:58.36 ± 0.02	16°N ± 1° 88°W ± 2°	8.1±0.3	(A-B)
2	April, 9, 2011 20:52:44.65 ± 0.01	27°S ± 1° 45°W ± 1°	8.4± 0.5	(A-B)
3	April, 10, 2011 19:28:00.13 ± 0.01	28°N ± 1° 38°W ± 1°	8.2±0.5	(A-C)
4	April, 10, 2011 19:47:02.38 ± 0.01	28°N ± 1° 40°W ± 1°	8.5±0.5	(A-C)

Table 1: Date, impact times, selenographic coordinates, magnitudes of the detected impacts, observatory and instruments used (A: M. Iten Gordola with a Borg 125 ED refractor equipped with a Watec-902H2 Ultimate CCD camera; B: S. Sposetti Gnosca with a Schmidt Cassegrain 280 mm telescope and Watec-902H2 Ultimate CCD camera; C: S. Sposetti Gnosca with a Newtonian 420 mm reflector and Watec-902H2 Supreme). Photometry carried out using the software *Tangra* by Pavlov (http://www.hristopavlov.net/Tangra).

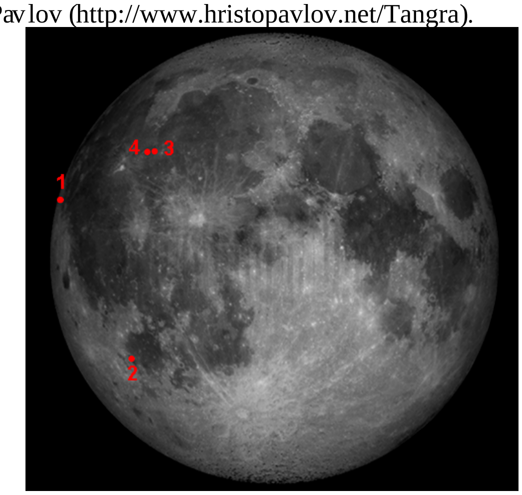

Fig. 1. Lunar Meteor Impact Locations (cf. Table 1).

The examined impact flashes correspond probably to sporadic events because no major meteor showers were active or exhibit favourable impact geometry on the impact dates. The masses of the impactors are estimated to have been about 2-5 kg based on a nominal model with conversion efficiency from kinetic to optical energy of 2×10^{-3}.

For sporadic impact flashes on the Moon a luminous efficiency of 2×10^{-2} yields a mass of the impactors considerably less than the preceding inferred values by a factor of 10 [7].

It should be noted, however, that these values are nominal, since the results includes uncertainties in projectile density, meteoroid mass and luminous efficiency adopted. These results are obtained assuming a typical sporadic impactor speed which is approximatively 16.9 km s^{-1} according to [8]. The diameters of the craters excavated by the impacts are calculated by Gault's formula [9] assuming the density of both meteoroids and lunar material to be 2000 kg m^{-3}. Based on a modelling analysis these meteoroids are likely to range in size from about 6 to 14 cm in diameters and produced craters of about 3-10 m in diameter. Future high-resolution orbital data, e.g., from LRO spacecraft (NAC images) could allow the detection of these small craters.

References: [1] Cudnik et al. (2003) *Earth, Moon and Planets 93*, 145-161; [2] Yanagisawa et al. (2006) *Icarus 182*, 489–495; [3] Ortiz et al. (2000) *Nature 405*, 921-923; [4] Ortiz et al. (2002) *Astrophys. J. 576*, 567–573; [5] Cooke et al. (2006) *LPSC XXXVII*, Abstract #1731 [6] Cooke et al. (2007) *LPSC XXXVIII*, Abstract #1986; [7] Ortiz et al. (2006) *Icarus 184*, 319-326; [8] Steel (1996) *Space Sci. Rev. 78*, 507–553; [9] Melosh (1989). Impact Cratering: A Geologic Process. Oxford Univ. Press, New York

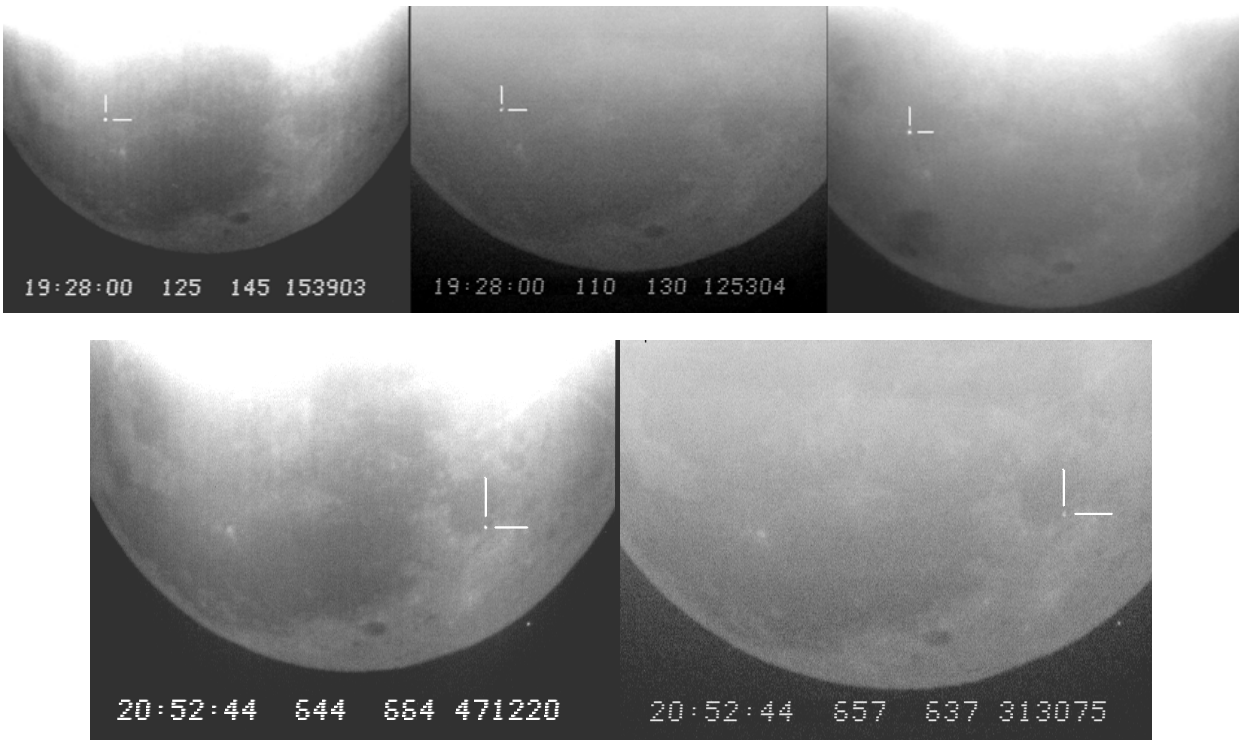

Fig.2. (top) Flash #3 April, 10, 2011 occurred at 19:28:00.13 ± 0.01 UT. (bottom) Flash #3 April, 9, 2011 occurred at 20:52:44.65 ± 0.01 UT. Both flashes were simultaneously recorded by two independent and distant (13 km apart) observatories (cf. Table 1).

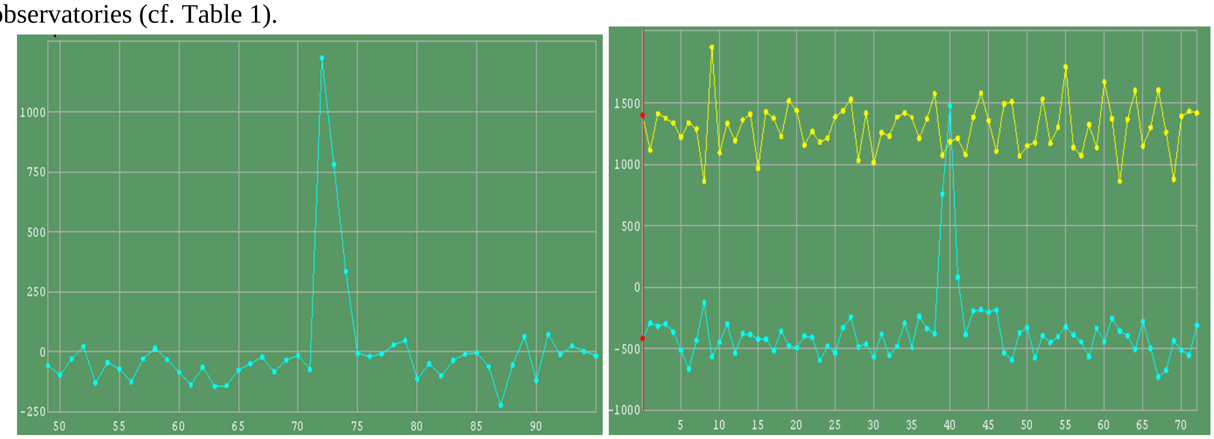

Fig.3. (left) Light curve of flash recorded on April, 10, 2011 at 19:28:00.13 UT. (right) Light curve of flash recorded on April, 9, 2011 at 20:52:44.65 UT. Time resolution 20ms.