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Measuring the temperature of impact plumes from the analysis of lunar impact flashes

J. M. Madiedo[1,2], J. L. Ortiz[3]

(1) Facultad de Ciencias Experimentales, Universidad de Huelva, Spain (madiedo@uhu.es).
(2) Facultad de Física. Universidad de Sevilla. 41012 Sevilla, Spain.
(3) Instituto de Astrofísica de Andalucía, CSIC, Apt. 3004, Camino Bajo de Huetor 50, Granada, Spain.

Introduction

Different researchers have studied the impacts of meteoroids on the lunar surface by analyzing the flashes produced during these collisions (see e.g. [1] to [4]). In this way different parameters can be determined, such as the energy of the impactor, its mass, and the size of the resulting crater. From the frequency of these events, paramount information related to the impact hazard for Earth can be also derived [2, 3, 5]. However, the analysis of these impact flashes has so far been performed in the visible range. Our team started in 2009 a lunar impact flash monitoring program named MIDAS [5], which is the continuation of the lunar impact flash monitoring project started by the second author in 1999 [1]. Recently, in addition to the observations performed in visible band, we have also conducted a systematic monitoring of the night side of the Moon in the near-infrared (nIR). In this way, we can analyze the behaviour of these impact flashes in different spectral bands. The analysis of these events is providing the value of the emission efficiency for impact flashes in the nIR. Besides, the temperature of the impact plume and the evolution with time of this temperature can be obtained.

Instrumentation

We have employed three f/10 Schmidt-Cassegrain telescopes with diameters of 0.36, 0.28 and 0.24 m. Each telescope used a Watec 902H Ultimate CCD camera and a GPS time inserter. Focal reducers (f/3.3) were also used to increase the monitored area. A nIR filter was employed for the camera attached to the 0.24 m telescope. As a result, the images taken by this telescope corresponded to wavelengths raging from 685 to 1000 nm. The unfiltered telescopes provided images in the wavelength range between, approximately, 400 and 1000 nm.

Figure 1. Watec 902H Ultimate CCD video camera and one of the SC telescopes (0.36 m) employed to record the impact flash presented here.

Observations and results

On 25 March 2015 one impact flash was identified (Fig. 2) at 21h00m16.8s UT. Its peak apparent magnitude in visible band was 7.3±0.2 and 5.1±0.3 in the infrared. The impactor hit the Moon at the coordinates 11.3 ± 0.1 ºN, 21.6 ± 0.1 ºW (close to the NW wall of Crater Copernicus). The method developed in [6, 7] reveals that the most likely source (with a probability of ~88%) of the meteoroid is the sporadic component. So, we assumed a typical impact velocity of 17 km s^{-1} [2] and an impact angle of 45º.

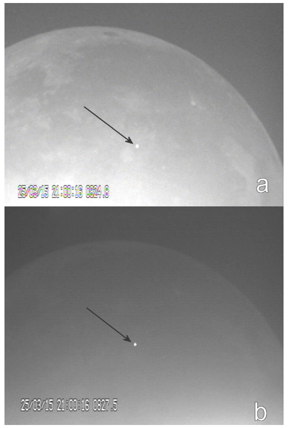

Figure 2. Impact flash recorded in visible band (a) and in nIR (b).

The event lasted 0.18 s in V band and 0.20 s in the nIR (Fig. 3). The integration of the radiated power [2] provided the energy radiated in visible band E_V=1.46·10^6 J and in the infrared E_I=1.44·10^6 J. The kinetic energy of the impactor by assuming a luminous efficiency in the visible of 3·10^{-3} [2] yields E_k = 4.86·108 J.

Once the kinetic energy is known, the emission efficiency in the nIR can be estimated from $\eta_I = E_I/E_k$, and this parameter yields η_I = 4.7·10^{-3}. So, the emission efficiency for sporadic events in this spectral band is higher than in V band by a factor of about 56%.

With an assumed impact velocity of 17 km s^{-1} the kinetic energy E_k corresponds to an impactor mass M = 3.4 ± 0.3 kg.

The main characteristics of the event are listed in Table 1.

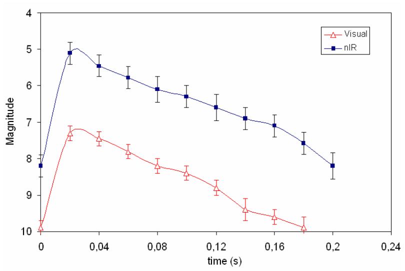

Figure 3: Lightcurve of the impact flash in visible light and in the nIR.

The temperature T of the impact plume was estimated by assuming that the intensity distribution follows Planck's law (Fig. 4). This plot shows that T reached a maximum value of around 4000 K at the beginning of the flash, and then after a sudden decrease to around 3200 K it remains practically constant for around 0.1 s. This suggests that during this phase the condensation process gives rise to equilibrium in the impact plume, so that the temperature remains constant as a consequence of the release of evaporation energy. After that time the plume temperature slowly decreases to a final value of ~2900 K by the end of the event.

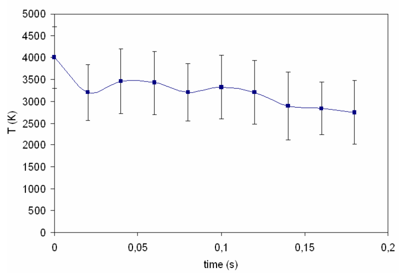

Figure 4: Evolution with time of the temperature of the impact plume.

Date and time	2015 March 25 at 21h 00m 16.80 ± 0.01s UT
Peak brightness (magnitude)	7.3±0.2 in V band; 5.1±0.3 in I-band
Selenographic coordinates	Lat.: 11.3±0.1 ºN, Lon.: 21.6±0.1 ºW
Duration (s)	0.18 (V band); 0.20 (nIR)
Impact kinetic energy	(4.86±0.04)·10^8 J (0.12±0.01 tons of TNT)
Meteoroid mass (kg)	3.4±0.3
Meteoroid diameter (cm)	15.3±0.4 (ρ_p=1.8 g cm^{-3})
Meteoroid impact velocity (km s^{-1})	17
Impact angle (º)	45.0
Crater diameter (m)	4.8±0.1 (?$_p$=0.3 g cm^{-3}); 6.8±0.2 (ρ_p=1.8 g cm^{-3}) 7.3±0.2 (ρ_p=3.7 g cm^{-3})

Table 1: Characteristics of the impact flash discussed in this work, by assuming η_V=3·10^{-3} and a sporadic source (the most likely one) for the projectile. ρ_p: impactor density.

Summary and conclusions

We are monitoring lunar impact flashes in different spectral bands. The event recorded on 25 March 2015 was observed in both the nIR and in the visible. The peak visual magnitude of this event was 7.3 ± 0.2 and the peak magnitude in I band was 5.1 ± 0.3. Our calculations show that the most likely origin of the source meteoroid is the sporadic background, with a probability of 88 %. By assuming a luminous efficiency in V-band of 3·10^{-3}, the impactor mass yields 3.4 ± 0.3 kg. And the estimated diameter D of the resulting crater would range from 4.8 ± 0.1 m (for meteoroid density ρ_p = 0.3 g cm^{-3}) to 7.3 ± 0.2 m (for ρ_p = 3.7 g cm^{-3}), with D = 6.8 ± 0.2 m for ρ_p = 1.8 g cm^{-3}. This fresh crater could be observed by means of probes orbiting the Moon, such as LRO.

The emission efficiency in the nIR for this sporadic event has been also inferred. The value of this parameter yields 4.7·10^{-3}, which is higher, by around 56%, than the luminous efficiency in visible band. This shows that presumably a large part of the electromagnetic energy radiated as a consequence of the impact is emitted in the infrared. The temperature of the impact plume, which has been obtained from the energy flux densities for V and I bands, is of around 3200 K during most of the light curve, which suggests that condensation gives rise to equilibrium in the impact plume during this stage. But the very initial flash is even hotter (about 4000 K), and this temperature decreases to ~2900 K by the end of the event.

References

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