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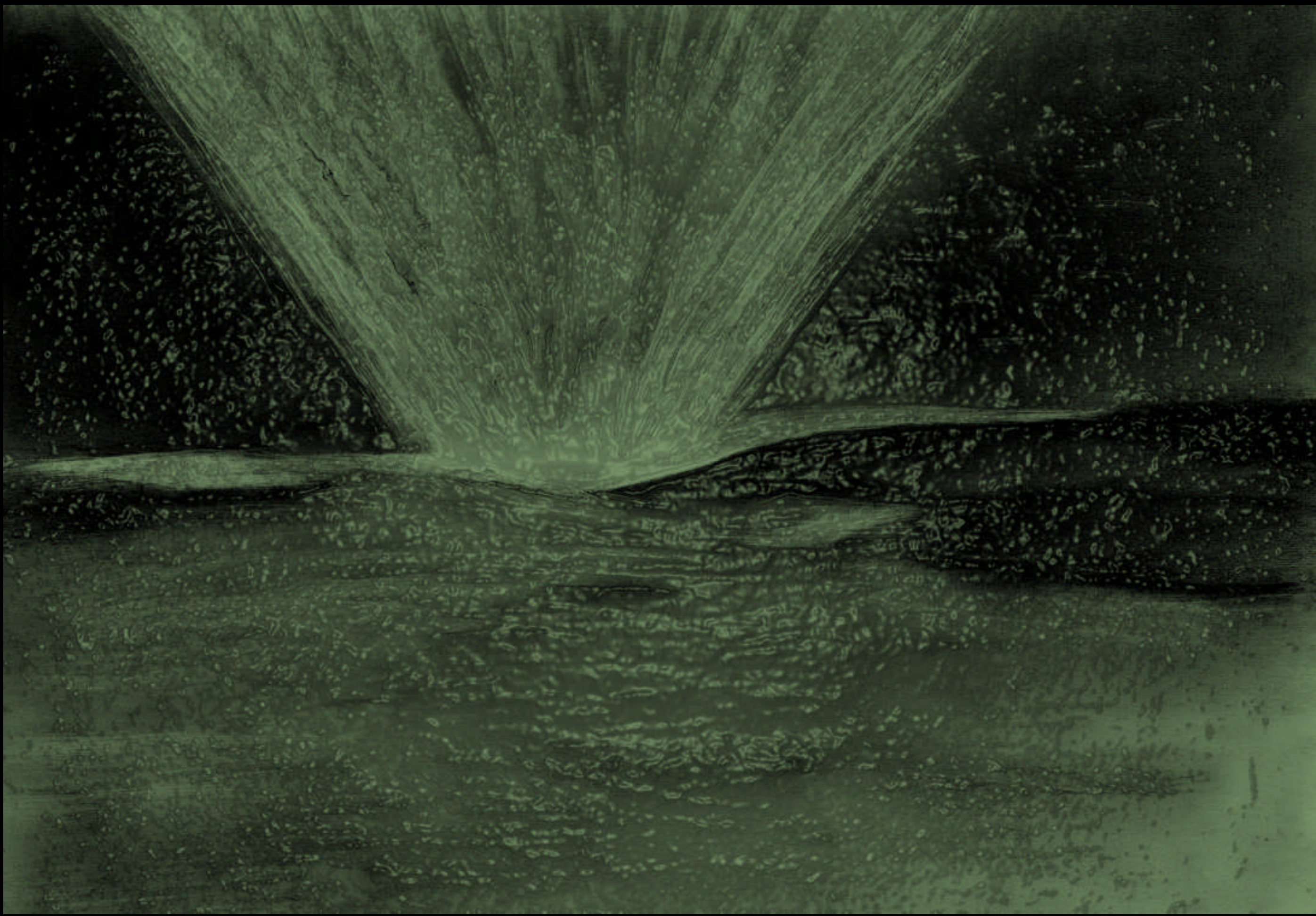

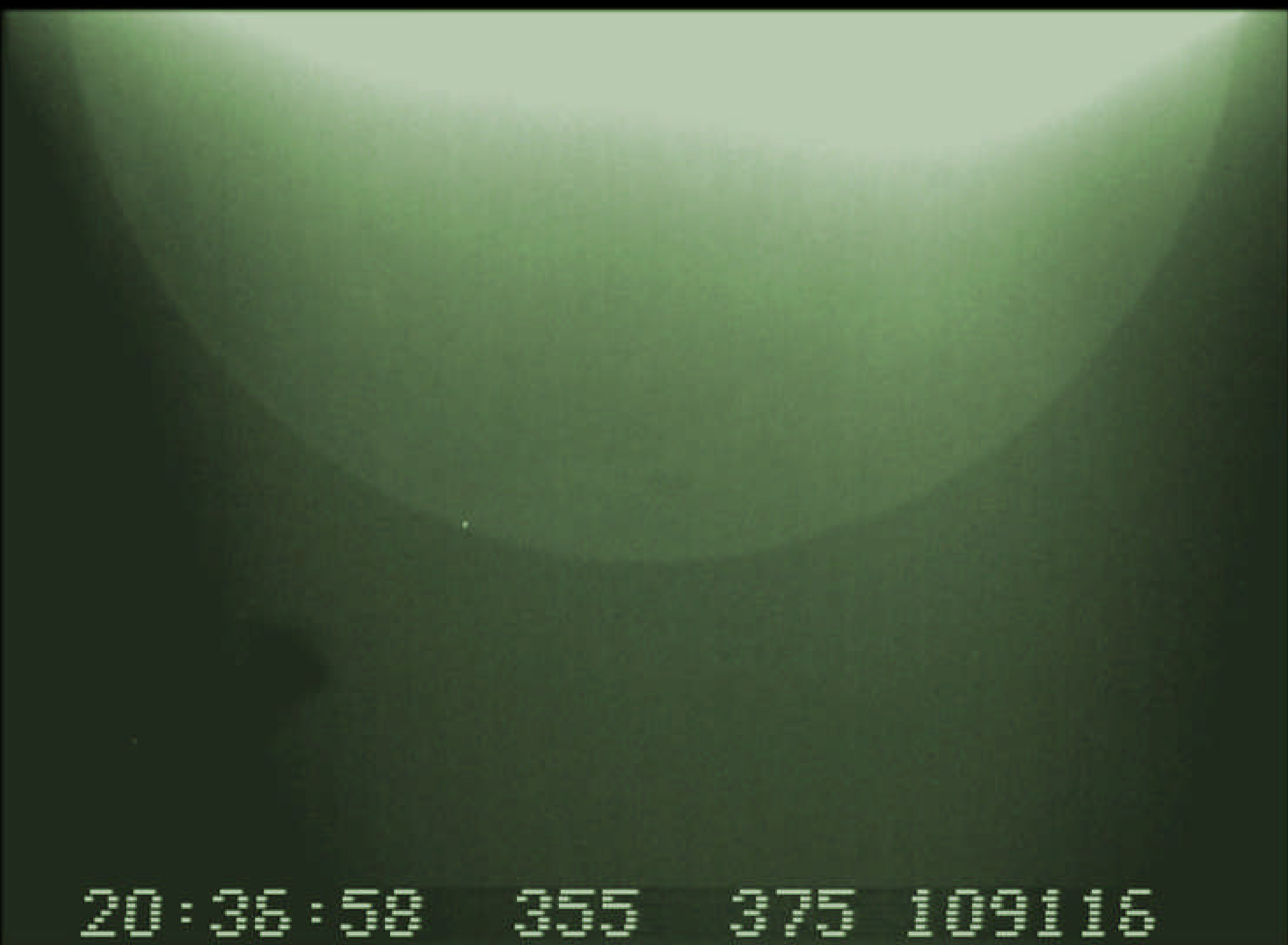

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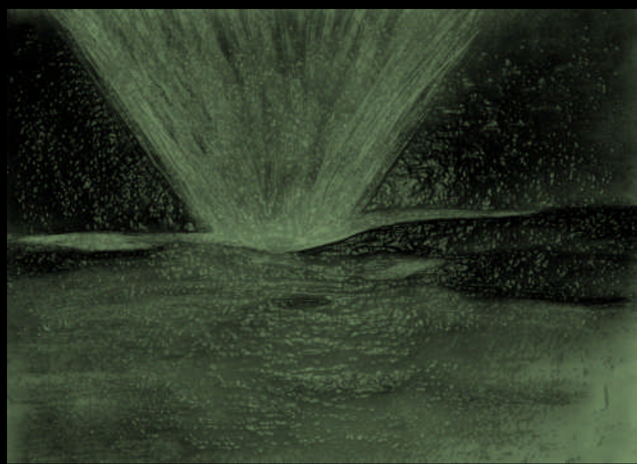

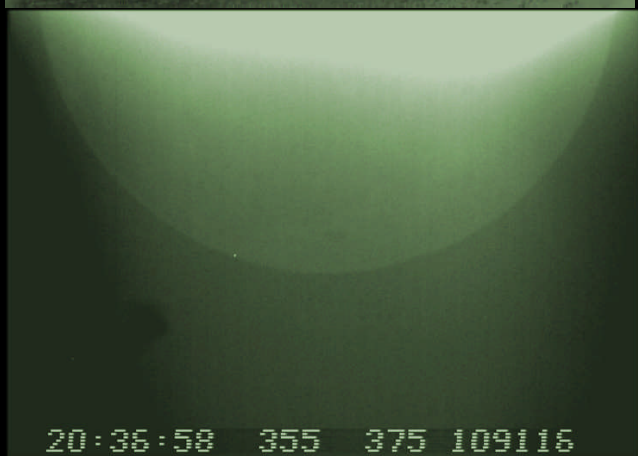

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Detection of a meteoroidal impact on the Moon

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Abstract

In this article we report data about a lunar flash detected on February 11, 2011 which very likely resulted from an impact. It was simultaneously detected by two independent observatories. The brightest impact flash reached a peak brightness of 8.1 ± 0.3 magV and had a long lasting afterglow. The selenographic coordinates of the lunar impact flash are determined to 88° ± 2° W and 16° ± 1° S. In addition we examine the flash characteristics in order to exclude further lunar flash sources, e.g cosmic rays, noise, meteors and artificial satellite glints. The examined impact flash probably corresponds to a sporadic event because no major meteor showers were active or exhibit favourable impact geometry on the impact date. Based on a modelling analysis, the mass of the impactor is estimated assuming a conversion efficiency from kinetic to optical energy of 2×10^{-3} *and* 2×10^{-2}*. The results show that the meteoroid is likely to range in size from about 6 to 8 cm in diameter and produced a crater of about 4-5 m in diameter.*

1. 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 (Cudnik et al., 2003). The development and widespread use of videorecording equipment has recently made it possible to conduct surveillance for flashes of light associated with lunar meteorite impacts in real time (Dunham et al., 2000; Cudnik et al., 2003). Since these initial successes, other meteor swarms have been shown to produce lunar impacts (Yanagisawa et al., 2006; Ortiz et al. 2002, 2006).

NASA's Meteoroid Environment Office is conducting a survey of meteoroids striking the lunar surface. Rates and distribution of impactors, shower and sporadic, have been discussed by Cooke et al. (2007). However light flashes can be caused spuriously by a number of factors including camera noise, cosmic rays, glints coming from space debris and satellites, and terrestrial meteorites with trajectories toward the observer. Methods have been developed by various groups that are intended to prevent spurious flashes being interpreted as being genuine (Lena and Evans, 2008; Lena, 2009). The standard approach is to have an impact recorded simultaneously by at least two observers located a minimum of 20-30 km from each other, or meet the following criteria: (a) The flash is confirmed by two or more independent observers. The flash on several subsequent video frames and exhibits a decreasing light curve. There is no indication of flash movement. (b) The flash lasts 3 or more video frames and exhibits a decreasing light curve. The flash is obvious in all frames and there is no indication of flash movement. (c) The flash lasts 2 frames. It is easily identifiable (bright) in the second frame and there is no indication of flash movement. After the successful lunar monitoring experience of the 1999 and 2001 Leonids, a systematic search and detection for sporadic impact flashes was conducted by Ortiz et al. (2006). During a video monitoring carried out on February 11th 2011, Sposetti and Iten detected a simultaneous flash of light on the rim of the lunar disk and preliminary results have been presented in a previous work (cf. Sposetti, 2011 and the corresponding video animation therein). In this article we report our final analysis and further conclusions that can be drawn from the data.

2. Instrumental setup

Two specific instrumental setups were used for the lunar impact flash survey. The telescopes consisted of a Borg 125 mm ED refractor and a 280 mm Schmidt–Cassegrain reflector equipped with high sensitivity WAT-902H2 Ultimate CCD video cameras. Further data concerning the two observatories are reported in Table 1. The distance between them is 12.9 km, measured with Google Earth.

3. Time of the flash

A time stamp was added to each video using a time inserter. The time of the flash was determined to be 20:36:58.365 UTC ± 0.010s by Iten (maximum intensity of half-frame no. 109116 of the original AVI file). The frame was deinterlaced (cf. Fig.1).The corresponding time of the flash in Sposetti's video was determined to be 20:36:58.360 UTC ± 0.020s (maximum intensity of frame no. 258556 of the original AVI file). This result matches very well the time of occurrence of the flash in Iten's AVI.

4. Moon data

The Moon data (TheSky©, Software Bisque) for the Sposetti observatory at the detection time are described in Table 2. Because the Lunar altitude was +47°07', the "parallax" distance (i.e. the projected distance as seen from the Moon) between the two observatories is reduced from 12.9km to 9.4km.

5. The sky position of the two detections

The celestial situation at the moment of the detection as seen from Sposetti observatory is shown in Fig. 2 (TheSky©, Software Bisque). We extracted 20 BMP frames from the original AVI centred on the time of the flash, 9 before the flash, the one of the flash and 10 after the flash (total integration time = 0.800s). The frames were stacked using the astronomical software IRIS© by Christian Buil (http://www.astrosurf.com/buil/us/iris/iris.htm). From the final image we extracted the XY-plane coordinates of the stars "A" and "B" and of the flash "F" using the psf-fitting method. We obtained FWHM values for the stars between 2 and 4 pixels, and about 4 pixels for the flash.

We thus determined the XY-plane distances AB, AF and BF. The ratios of the distances, ie. AF/AB and BF/AB, were also calculated (Fig. 3 and Table 3). The ratios of the position of F relative to A and B in the recordings by Sposetti and Iten are the same within 0.1%. Accordingly, the XY-plate location of F is the same in the video recordings by Sposetti and Iten with an error of 0.4 pixels relative to the two stars A and B. This procedure was repeated with only 5 BMP images (2 frames before, the frame of the flash, and 2 frames after) to estimate our previous result with 20 frames. The plate coordinates matched the ones calculated previously. Notably, the three objects A, B and F are "unfortunately" aligned, so this small error is especially valid along that line.

We did not try an estimate of the consistency of the 2 positions along the direction perpendicular to that line, corresponding to 5 arcsec, because of the E-W parallax between the two observatories. One can visually confirm that F is just inside the lunar border in both recordings by a few pixels (Fig. 4).

On Sposetti's frames, the sampling is 2.0 arcsec/pixel. At a distance of about 390,000 km the resolution is thus 3.8km/pixel. On Iten's images the sampling is higher and the resolution is 5.3 km/pixel. In Sposetti's frame it is apparent that the flash was spread over

6x3 pixels (Figs. 5-6). The psf-fitting method yields a FWHM of 4.2x3.6 pixels, corresponding to 8.4x7.2 arcsec (see Fig. 6). We electronically removed the high gradient from the image using a polynomial fit (the “Remove gradient function” in IRIS© software). The final image (Fig. 7a) shows the lunar albedo features fairly well and was used to estimate the impact region on the Moon. The selenographic coordinates were computed using the image shown in Fig. 7a, 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 image, a coordinate map was superimposed on the flash image. This procedure was performed using the LTVT software package by Mosher and Bondo (2006). The coordinates of the flash correspond to 88° ± 2° W and 16° ± 1° S, in the region near the crater Einstein (Fig. 7b).

6. Exclusion of other flash sources

6.1. Cosmic ray

Previous observing sessions have shown that certain profiles are characteristic of cosmic rays (Fig. 8-9) appearing round or nearly round on the screen, but occasionally also a short streak is recorded. Most often, cosmic ray flashes appear as doublets but we have also seen them as triplets, 1 pixel in size. This is because, at ground level, cosmic rays occur in little showers precipitated by a single event in the upper atmosphere. Although cosmic ray is the generic term for these phenomena, in this context it means any type of ionising radiation, including ground sources (trace amounts of uranium and other unstable elements). A decay of any of these nuclei can produce a cosmic ray indication in a frame. They are not usually seen on the same horizontal video line, unless by chance. Flashes of a type that usually appear on the same horizontal video line are instrumental noise, which lasts longer than a cosmic ray hit.

6.2. Meteors

The only possibility to mismatch a true lunar impact flash with a terrestrial impact is when the latter comes directly towards the observer. We have never detected such a head-on meteor. Fig. 10 displays a bright streak probably produced by a meteor.

6.3. Satellites

We used Calsky© (http://www.calsky.com/) to search for artificial satellites in the line-of-sight. No satellites within a circle of 3° diameter were found. Jan Manek also confirmed the absence of satellites in that sky region (Manek, private communication). In a previous session we detected the transit of the space debris FENGYUN 1C DEB (1999-025-AHJ). It appears as a bright flash that trailed for three frames, in direction from west to east. The first flash shown in Fig. 11 is located at centroid X 418 Y 168 in frame 168 and is detectable in the next frame 169 (separation of 0.03 sec) at centroid X 418 Y 278, with a track across the Y axis. In the third frame 170, a faint flash is detectable at centroid X 429 Y 410, which could also be a random noise peak. Moreover, if a typical geostationary satellite of 36,000km above the Earth surface was in the FOV, its resulting parallax from the two observatories would be 54 arcsec. This would give a difference of 27 pixels in Sposetti's or 19 pixels in Iten's recording. Because the two positions of the flash agree within 0.4 pixels along the Flash – star A – star B line, we can exclude the possibility of a geostationary satellite flash. An example of an artificial satellite glint detected in a previous observing session of February 9 2011 at 17:40:42 UTC is shown in Fig. 12a. Figure 12b displays the flash detection using the software Lunarscan©. The satellite is the geostationary Comstar 3 Rocket (1978-068B) and was at an height of 33716 km. Like a typical geostationary object it was co-moving with the earth. In the images the satellite was slowly moving from West to East and was briefly flashing every 11s.

7. Determining the brightness of the flash

The two recordings lack in calibration stars as well as in dark frames. A visual inspection of the sky transparency determined that evening was evaluated "fair-good", meaning the sky was not transparent. The photometry was done using the stars moving in the FOV during the 4 hours integration time. Unfortunately these few stars are all fainter than 9 mag. At the end we chose the only 3 visible and "measurable" stars (Fig. 13 and Table 4). Stars A and B were in the FOV at the moment of the flash. Star C had the highest V magnitude of the three but was in the FOV only 1 hour after the flash (at airmass 1.6).

We performed the method of aperture photometry and used the software Tangra© v.1.1.0.360 by Hristo Pavlov (http://www.hristopavlov.net/Tangra). This software yields "signal minus background" values. The intensity of the Flash F was measured in the frame of the maximum intensity, i.e. in the corresponding 40 ms interval. The intensities of the stars were measured and evaluated over several frames. We used the V magnitude values of the stars (Table 5). Because no stars brighter than the flash were found, our photometric measurement must be taken with a certain degree of uncertainty. Hence, the resulting V magnitude estimated from our computation is 8.1 ± 0.3. The corresponding light curves for this event are also shown in Figs. 14 and 15. The light curve of the flash was traced two times. First we used individual frames of 40 ms integration (see Fig. 14). The resulting curve gives a first idea of the evolution of the flash over time. A better result can be obtained by deinterlacing the frames into their two fields, which yields a doubled time resolution and a better light curve (see Fig. 15).

8. Results and discussion

The whole duration of the flash corresponds to 0.10 s ± 0.02 s in Sposetti's video. We observe that the half-frame of maximum intensity was preceded by an half-frame showing about one-third of the maximum intensity. Also note that Iten's light curve of the fields shows a strange up-and-down behaviour probably caused by some electronics behaviour, we currently don't understand. The brightness of the flash was estimated to 8.1 magV ± 0.3.

Specular reflection of sunlight from artificial satellites could cause very brief flashes. However, the lack of a 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 flash is present in a number of frames 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 time as seen from two observatories. The intensity of the flash is well above the noise level, the event covers several video frames, and the final confirmation comes from the fact that it was detected by two independent distant observers. Naturally occurring dark limb meteoroid impact flashes currently are the subject of professional research and professional-amateur cooperative observing campaigns. Artificial satellite collision tests showed that much more energy can be converted to light than was expected from standard collision theories (cf. Cudnik et al., 2003). The meteoroids that caused the observed 1999 lunar Leonid impacts may be smaller by one or two orders of magnitude than previously indicated, making them more compatible with the expected Leonid stream size/mass distribution. Numerical simulations have determined that a magnitude 3 flash could be produced by an object of 3 kg mass travelling at the Leonid impact velocity of 72 km s^{-1} (cf. Cudnik et al., 2003 and references therein). However, the meteoroidal mass can only be estimated if the optical efficiency is known, which is the fraction of the kinetic energy that is emitted in the visible. Bellot-Rubio et al. (2000a) provide an analytic model for determining the luminous energy reaching the Earth from lunar meteor impacts viewed at various angles. Numerical simulations of the impact of a cometary projectile into solid granite at 72 km s^{-1} yield a luminous efficiency of (1–2) x 10^{-3} (Artemieva et al., 2000). Through comparison of several of the 1999 Leonid lunar flashes with those of meteors observed on the ground, Bellot Rubio et al. (2000a, 2000b) estimate the luminous efficiency of lunar impacts to be 2 x 10^{-3} with an uncertainty of 1 order of magnitude. They also compute a constant luminous efficiency of 2 x 10^{-3} for these 72 km sec^{-1} impacts, i.e. two-thousands of the impact's kinetic energy is converted into light between 400 and 900 nm. However, the impact flash in this study probably corresponds to a sporadic event because no major meteor showers were active or exhibit favourable impact geometry on the impact date. Hence, the luminous efficiency may be very different between sporadic meteoroids and Leonid-Perseid impactors regarded in previous works (cf. Ortiz et al., 2002; Yanagisawa et al., 2006; Cudnik et al., 2003). In this study, the same formalism and equations as in the works by Bellot Rubio et al. (2000), Ortiz et al. (2002), and Carbognani (2000) was followed, including the kinetic energy that is translated into impactor mass assuming a typical sporadic impactor speed. According to the statistics of a large meteoroid orbit database (Steel, 1996) this speed is approximately 20.2 km s^{-1} on Earth and 16.9 km s^{-1} on the Moon, after correcting for the different escape velocities of the Earth and the Moon.

If v is the speed of the meteoroid of mass M, the kinetic energy of the body is given by:

$$E_c = \frac{1}{2} M v^2 \qquad (1)$$

The average magnitude of the flash observed from Earth is given by :

$$\overline{m} = m_o + 2.5 \cdot Log_{10}\left[\frac{4\pi \cdot \Delta t \cdot S_o}{\tau M}\left(\frac{d_{TL}}{v}\right)^2\right] \qquad (2)$$

where τ is the fraction of the kinetic energy converted to optical radiation and d_{TL} the Earth-Moon distance. Moreover, m_o = - 26.8 and S_o= 1.36 x 10^3 W m^{-2} are the apparent magnitude of the Sun and the solar constant, respectively.

Therefore the following equation is used :

$$\overline{m} = -2.5 \cdot Log_{10} M + f(\tau, v, \Delta t) \qquad (3)$$

with

$$f(\tau, v, \Delta t) \equiv m_{\circ} + 2.5 \cdot Log_{10}\left(\frac{\Delta t}{\tau v^2}\right) + 2.5 \cdot Log_{10}\left(4\pi S_{\circ} d_{TL}^2\right) \qquad (4)$$

where M is measured in grams and the quantities v (velocity) and Δt (duration of the flash) are known. From the scaling law of Gault the diameter of the crater that is formed is given approximately by:

$$D \approx E_c^{0.28} / 43 \qquad (5)$$

where E_c is the kinetic energy of the meteoroid measured in Joules, while D is the diameter of the crater in meters.

Moreover a short routine provided by Melosh and Beyer (1999) was used to evaluate the scaling equations to determine the diameter of a crater given details on the nature of the projectile, conditions of impact, and state of the target. The transient crater diameter is evaluated by three independent methods, yield scaling, pi-scaling and Gault's semi-empirical relations supplemented by rules on how crater size depends on gravity and angle of impact. Assuming a luminous efficiency of order 2 x10^{-3}, the mass required to generate the signal of the February 11th impact is 5 kg if we adopt the average velocity of sporadic meteoroids (16.9 km s^{-1}). The diameter of the crater formed on the lunar surface can be estimated using Gault's formula for craters of less than 100 m in diameter formed in loose soil or regolith (cf. Melosh, 1989). The parameters used in the calculation are the projectile density (2000 kg m^{-3}), the target density (2000 kg m^{-3}), the impact velocity (16.9 km s^{-1}), and the meteoroid mass previously inferred. The diameter of the crater was thus calculated to be 4.5 m. Based on the above data and assuming a spherical projectile the diameter of the impactor was inferred to be approximately 8 cm. It stroke the target with an energy of about 8 x 10^7 Joules. However, the kinetic energy is only affected by the luminous efficiency adopted. According to numerical models (Nemtchinov et al., 1998; Melosh et al., 1993) or hypervelocity impact flash experiments (Ernst and Schultz, 2005; Kadono and Fujiwara, 1996; Eichhorn, 1975), the luminous efficiency of 2 x 10^{-3} is already an optimistically high value. Besides, the value 2 x 10^{-3} was derived from 71 km s^{-1} impacts, whereas at 16.9 km s^{-1}, a different luminous efficiency would be expected. According to Ortiz et al. (2006), for sporadic impact flashes on the Moon a luminous efficiency of 2 x 10^{-2} is expected, yielding a mass of the impactor of considerably less than 5 kg. In this case, assuming the same parameters as those used in the previous computation, the impact flash appears to have been produced by a 0.5 kg body with a diameter of approximately 6 cm when assuming a spherical projectile. Using Gault's scaling law in regolith for crater sizes, the size of the lunar impact crater was computed to be 4 m. This value is similar for different impact angles of the meteoroid. Using the Pi-scaled law for transient craters, the final crater is a simple crater with a rim-to-rim diameter of 3.9 m. This impactor would strike the target with an energy of 3.23 x 10^{7} Joules (corresponding to 7.72 x 10^{-9} Megatons). The results show that the meteoroid is likely to range in size from about 6 to 8 cm in diameter producing a crater of about 4-5 m in diameter. Figure 16 (WAC M102722785 ME) shows the region of interest, determined in this work. The positioning uncertainty is fairly large because the event occurred near the limb of the lunar disk where especially longitude uncertainty is large. The Lunar Reconaissance orbiter (LRO) is continuously acquiring new images. Hence, it will be interesting to compare LRO high resolution images (NAC images with their resolution of ~1 m on the ground) of the impact area taken before and after the event. Also if the impact region can be large, the high resolution of the NAC images would in principle allow the detection of the small crater.

9. Summary and Conclusion

In this study we have described a lunar impact detected simultaneously from two independent video recordings. The meteoroidal impact occurred at 20:36:58.360 UTC ± 0.020s on February 11, 2011. We have examined the flash characteristics in order to exclude further lunar flash sources, e.g. cosmic rays, noise, meteors and artificial satellite glints. The selenographic coordinates of the lunar impact flash are determined to 88° ± 2° W and 16° ± 1° S, and the flash had a V magnitude of 8.1 ± 0.3. The duration of the flash corresponds to 0.10 s ± 0.02 s in Sposetti's video. The mass of the impactor is estimated to have been 5 kg based on a nominal model with conversion efficiency from kinetic to optical energy of 2x 10^{-3}.

The examined impact flash probably corresponds to a sporadic event because no major meteor showers were active or exhibit favourable impact geometry on the impact date. Based on a modelling analysis, the mass of the impactor is estimated to has been 0.5 kg assuming a luminous efficiency of 2×10^{-2}.

The results show that the meteoroid is likely to range in size from about 6 to 8 cm in diameter and produced a crater of about 4-5 m in diameter. Future high-resolution orbital data, e.g., from LRO spacecraft (NAC images) could allow the detection of the small crater.

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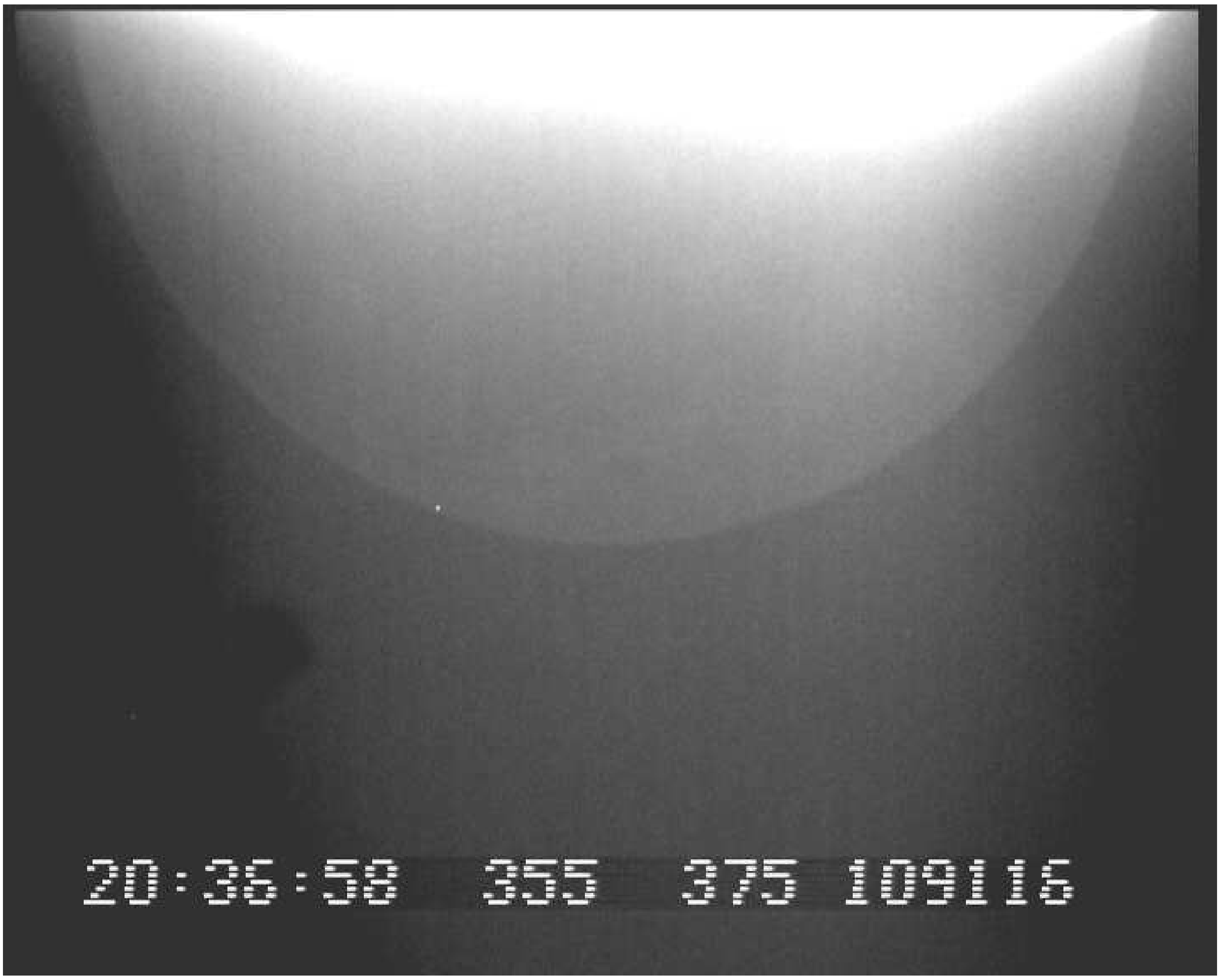

Figure 1. Video by Iten (flash detection).

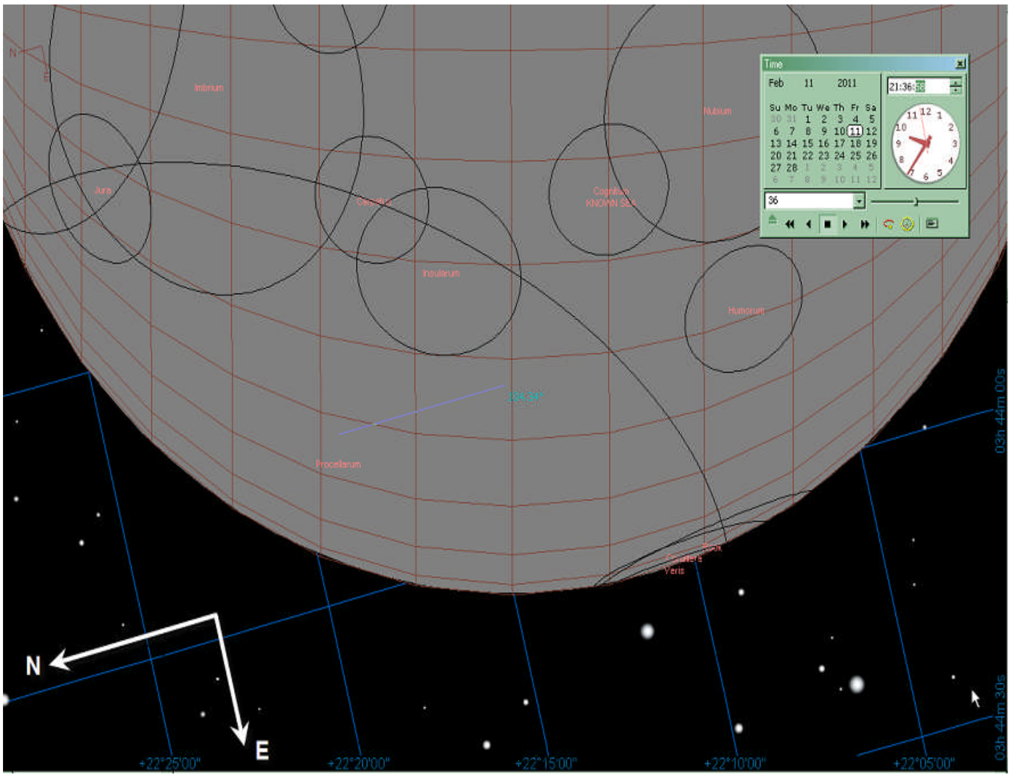

Figure 2. Celestial situation at the moment of the detection as seen from Sposetti's observatory.

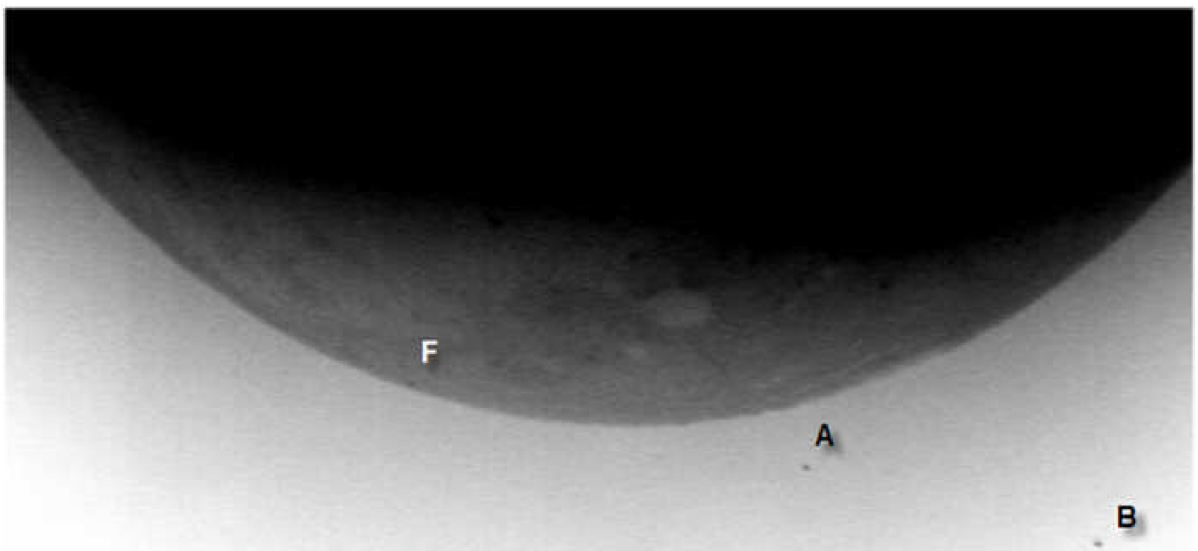

Figure 3. The Flash and the two stars.

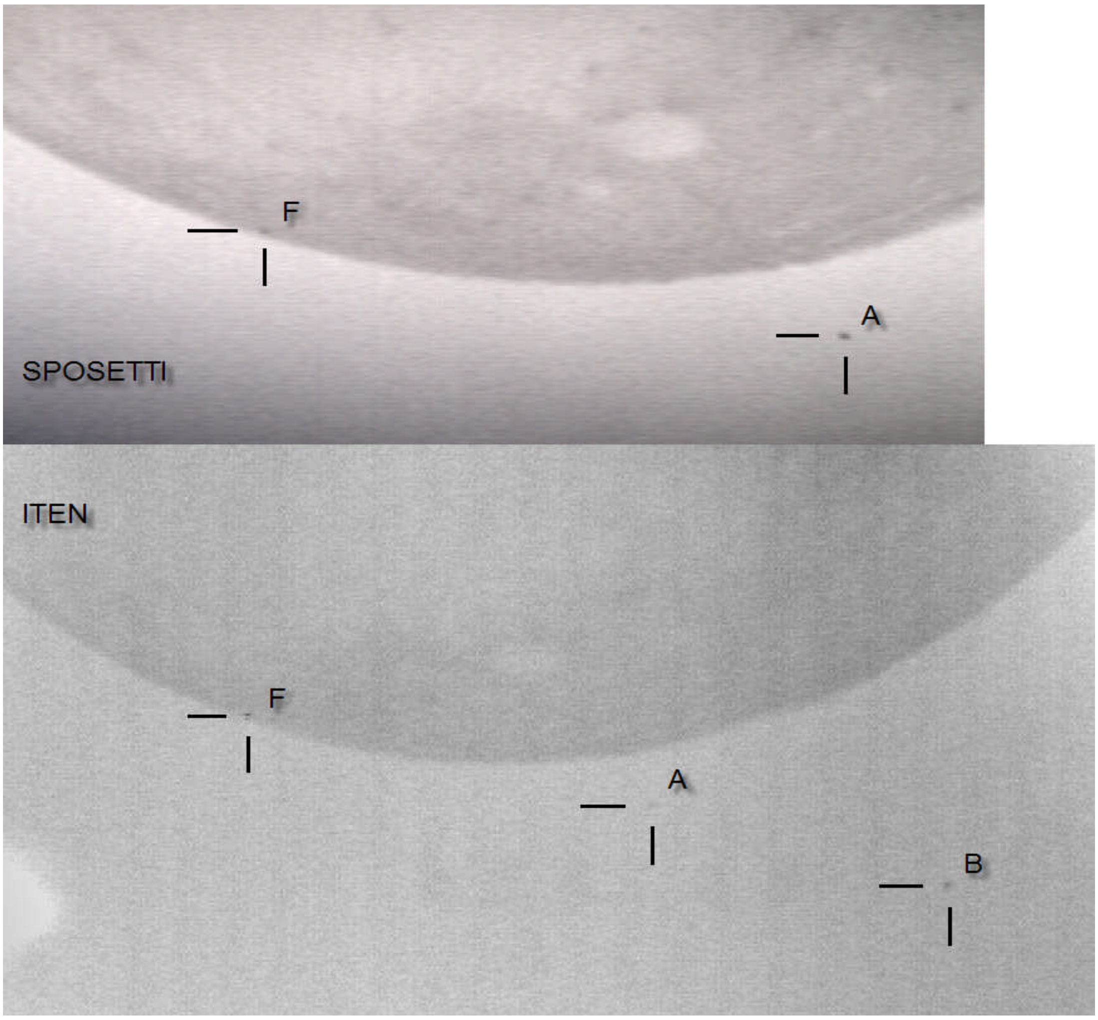

Figure 4. Note in the above image that F lies just inside the lunar border. There is also a very small parallax shift of the A star relative to the Moon border (in the vertical direction of the image) of 5arcsec (about 2 pixels) because of the two distant observatories.

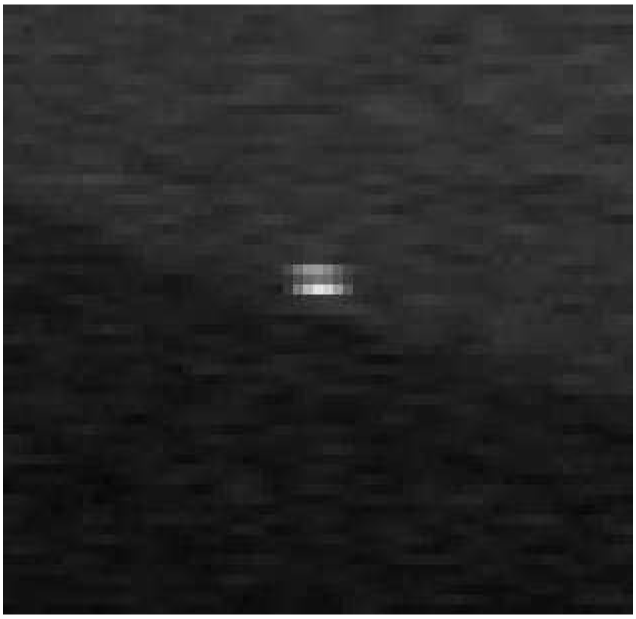

Figure 5. The flash at its maximum, 5x enlarged.

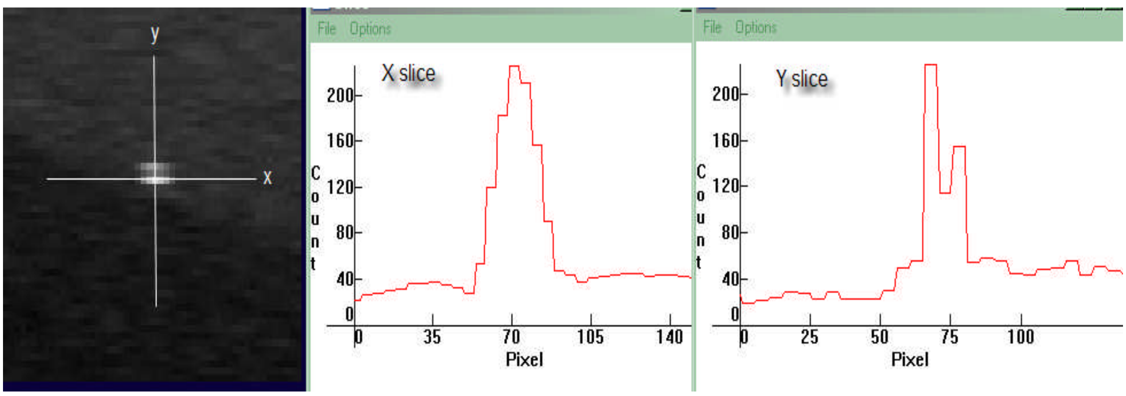

Figure 6. The xy-profiles-intensities of the flash at its maximum.

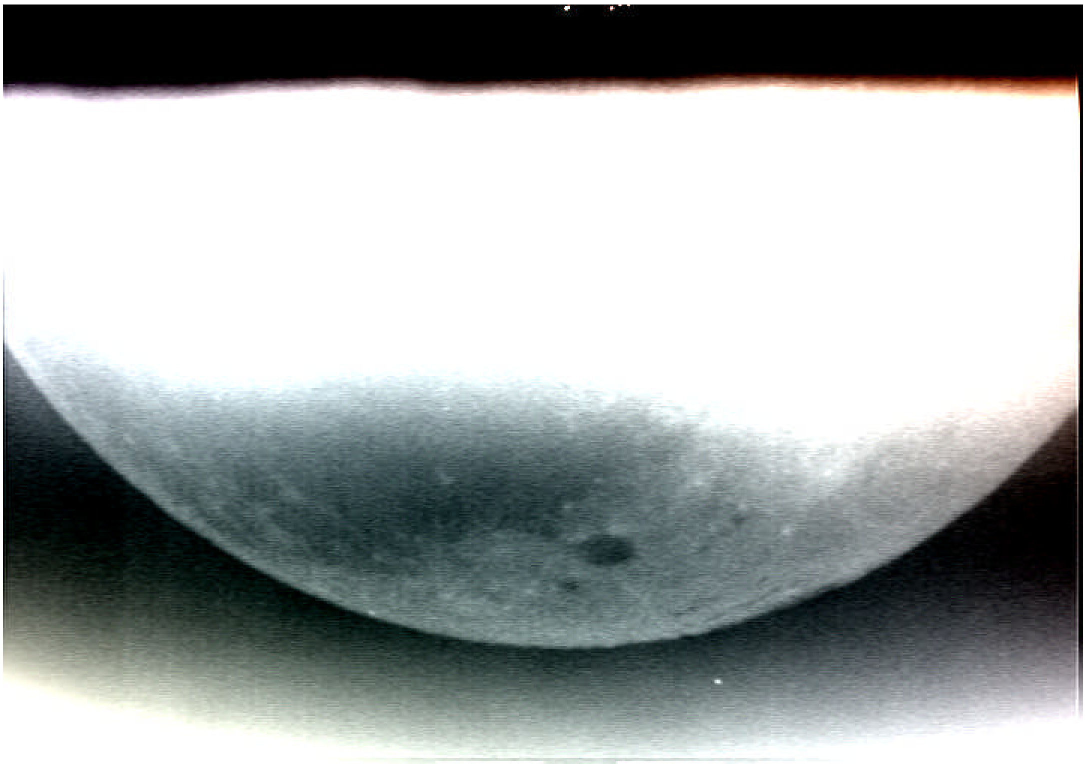

Figure 7a. Image after application of a polynomial fit in order to remove the high gradient.

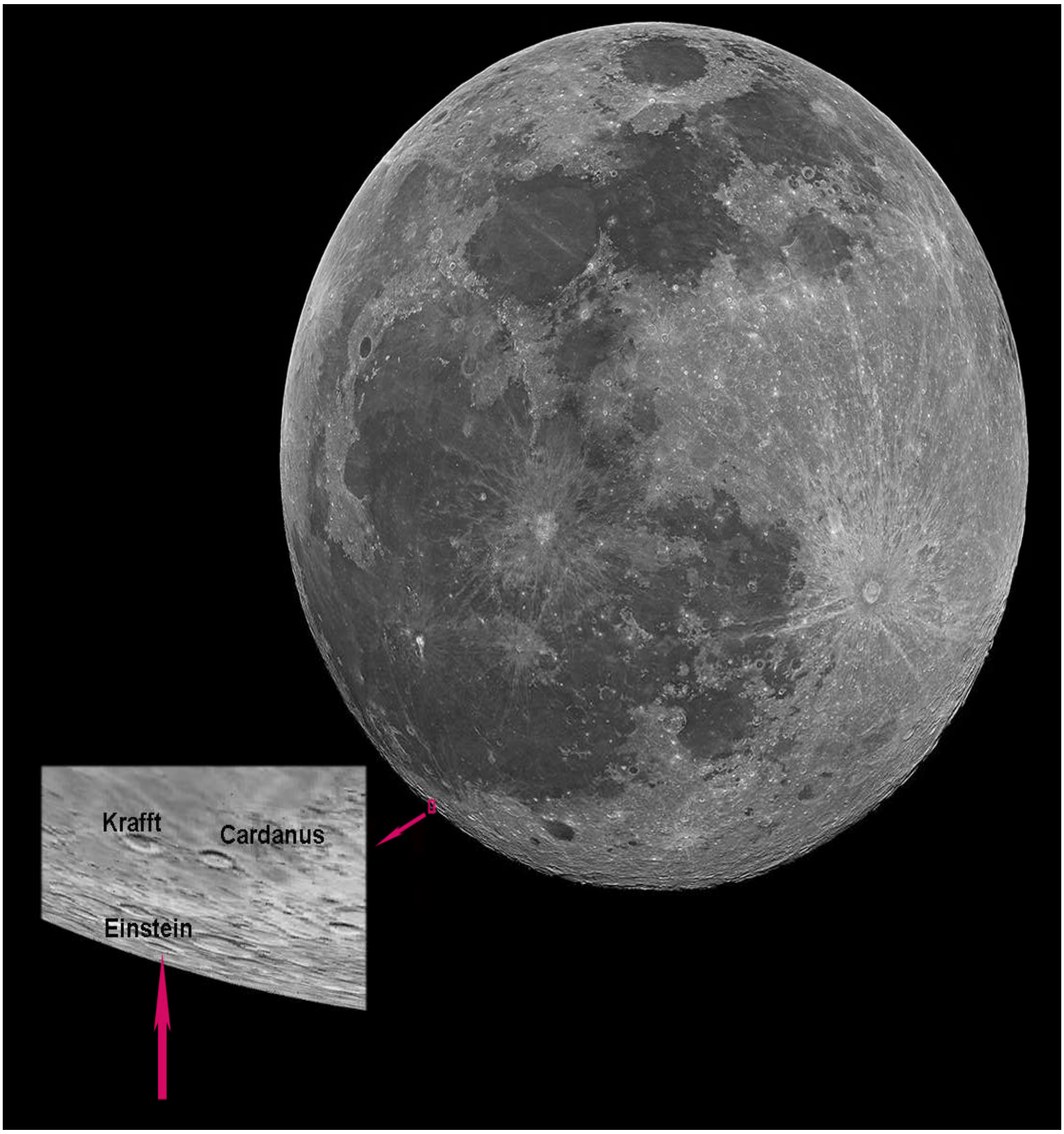

Figure 7b. Lunar map and the region in which the lunar flash was detected. North is to the left and West to the bottom.

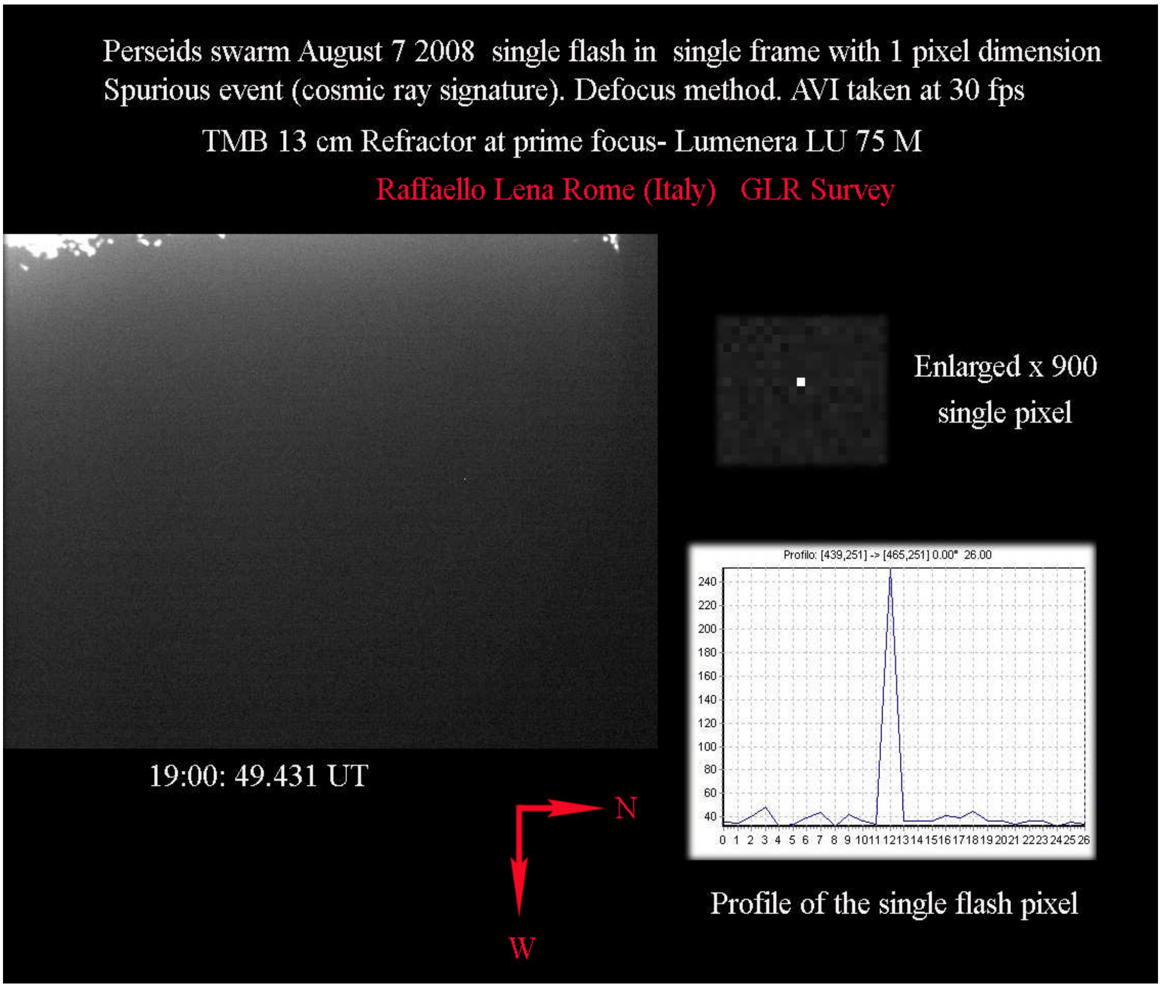

Figure 8. A cosmic ray signature.

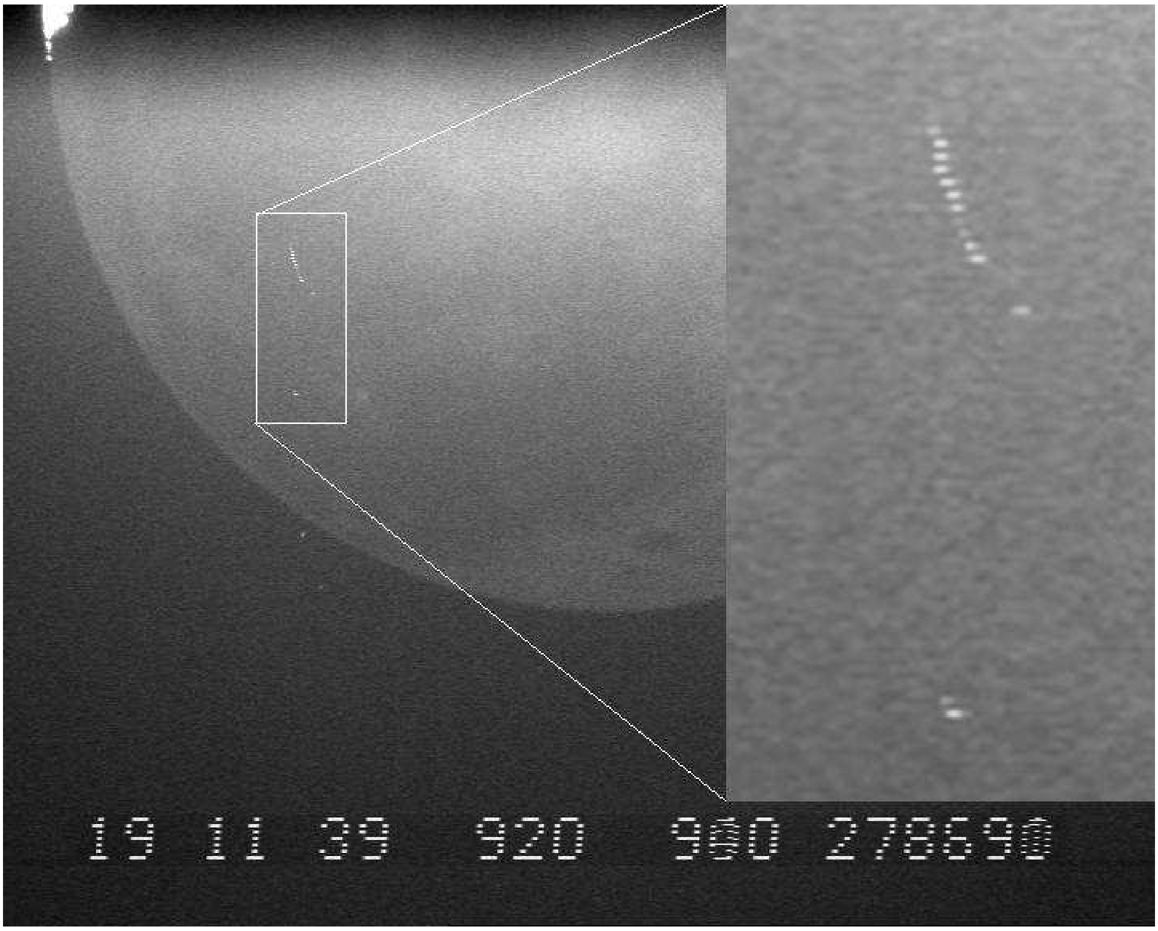

Figure 9. A cosmic ray signature.

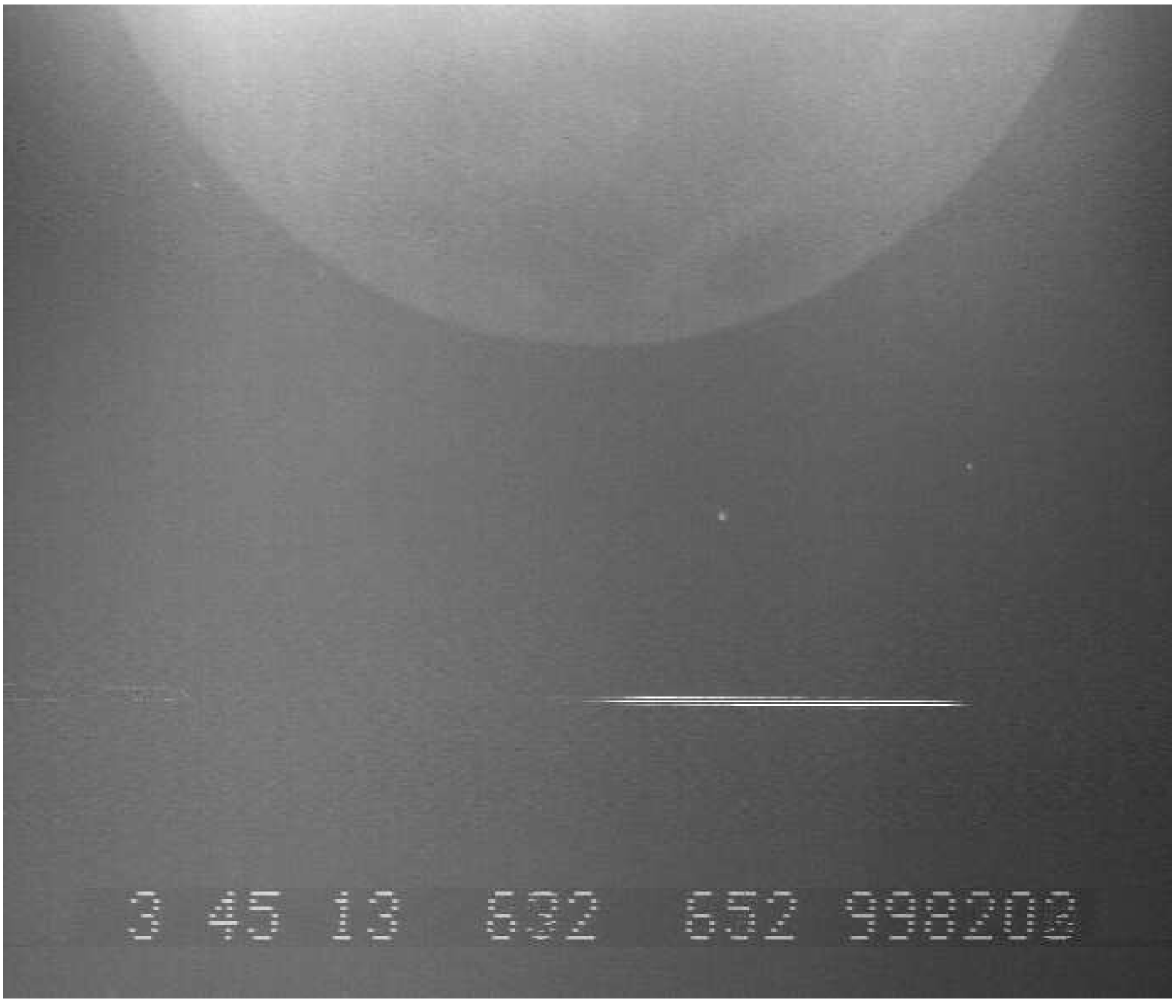

Figure 10. A bright streak probably produced by a meteor.

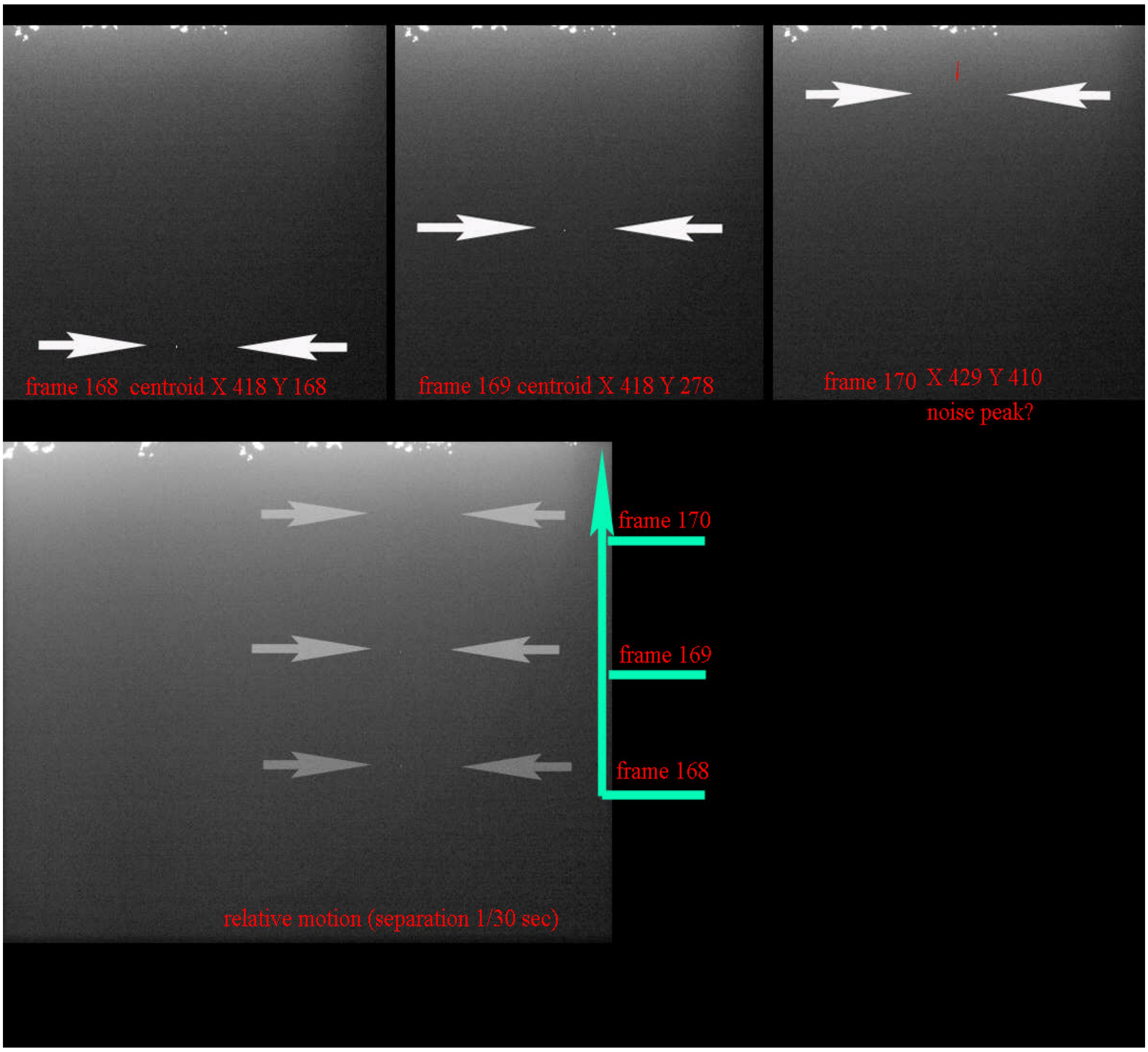

Figure 11. The track of the space debris FENGYUN 1C DEB(1999-025-AHJ) across the Moon detected on August 08, 2008, at 19:05:06 UTC.

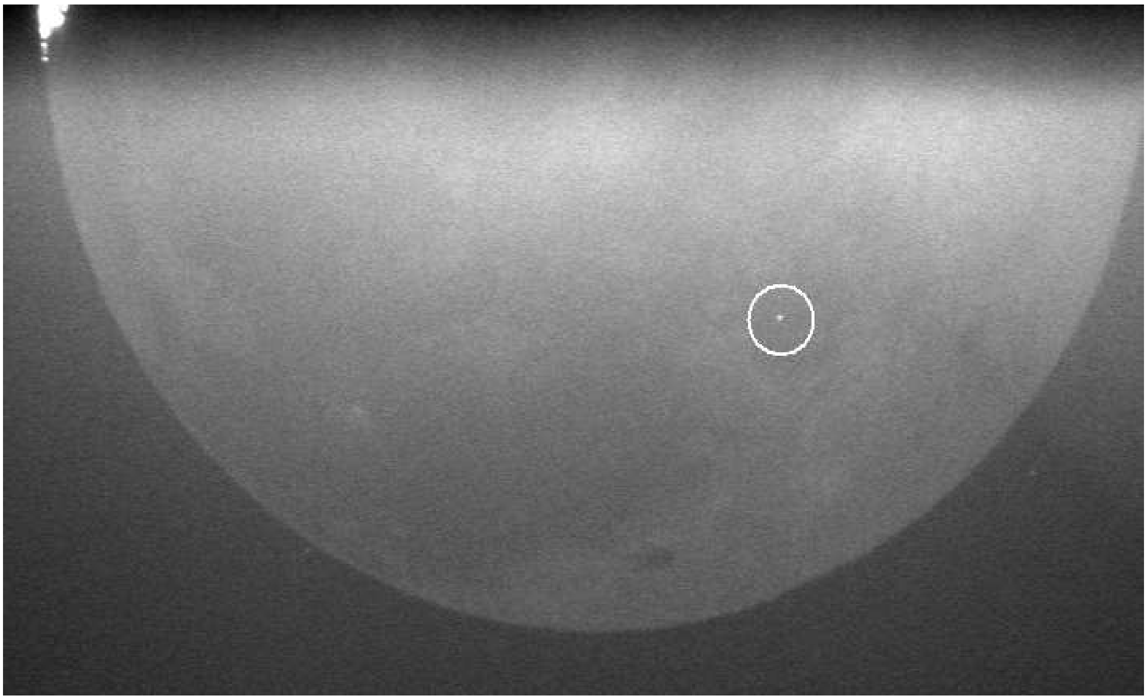

Figure 12a. The flash of the geostationary Comstar 3 Rocket (1978-068B)

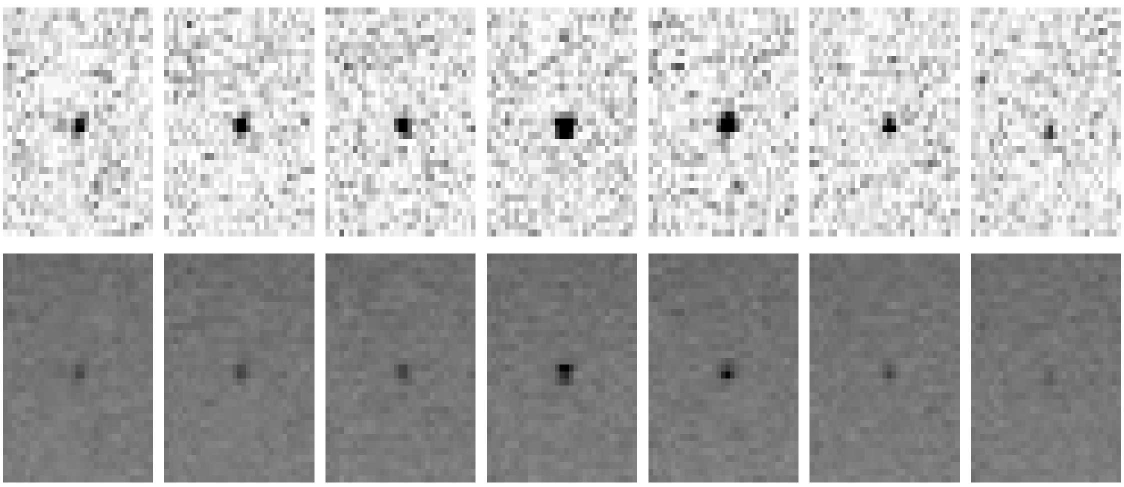

Figure 12b. The detection of the flash by Lunarscan©

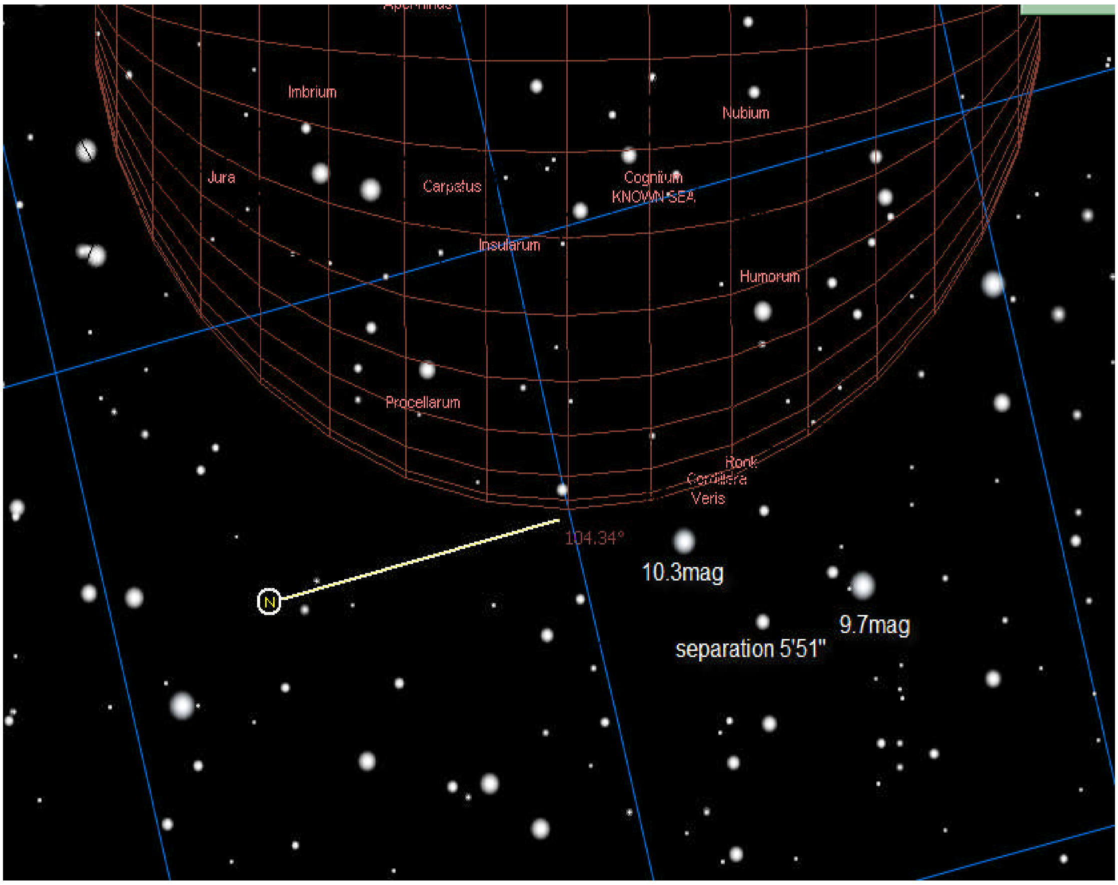

Figure 13. Stars A and B used for aperture photometry (TheSky©).

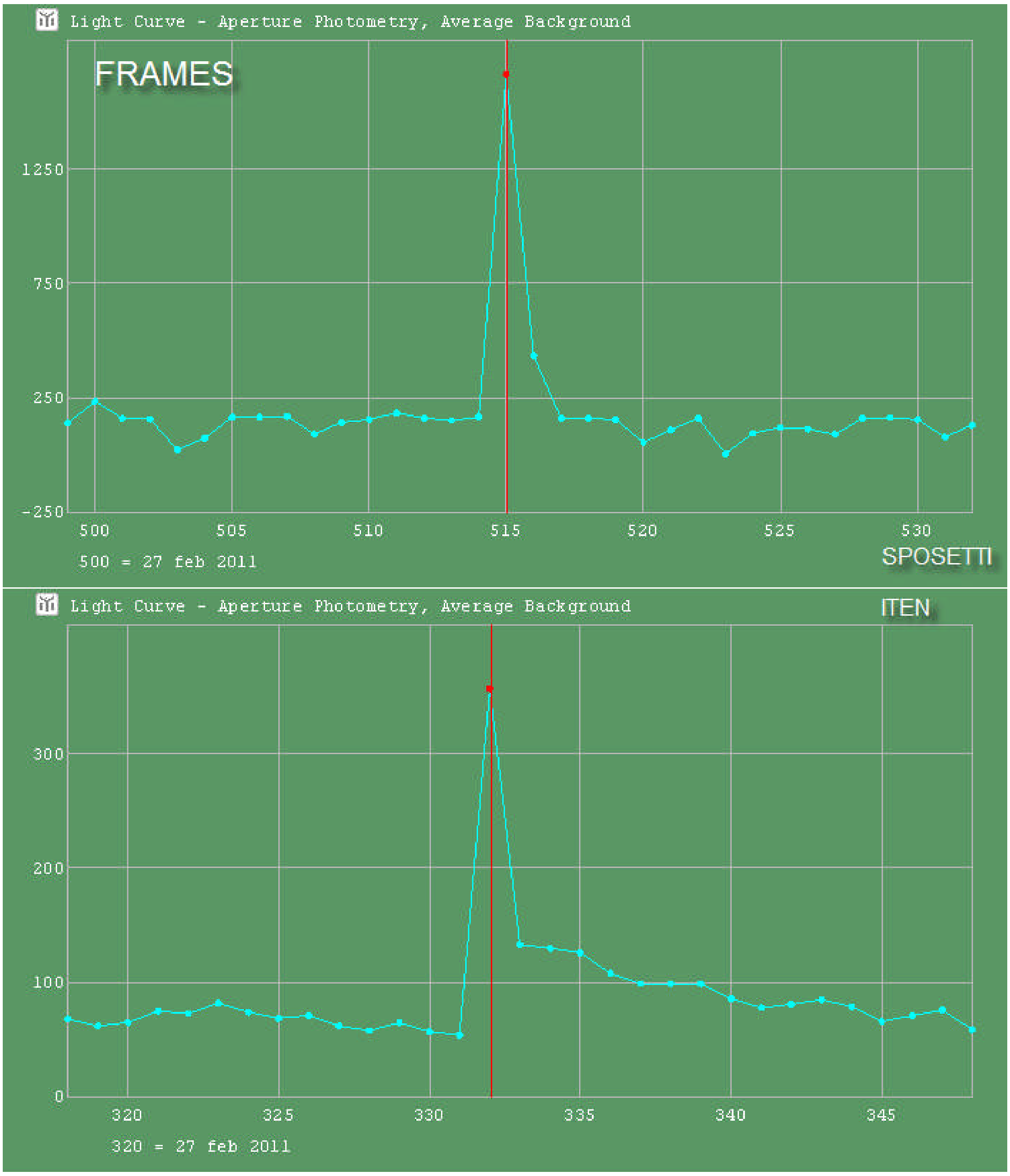

Figure 14. Light curves of the frames (1 frame = 40 ms) obtained in a circular diameter of 6 pixels (Tangra©).

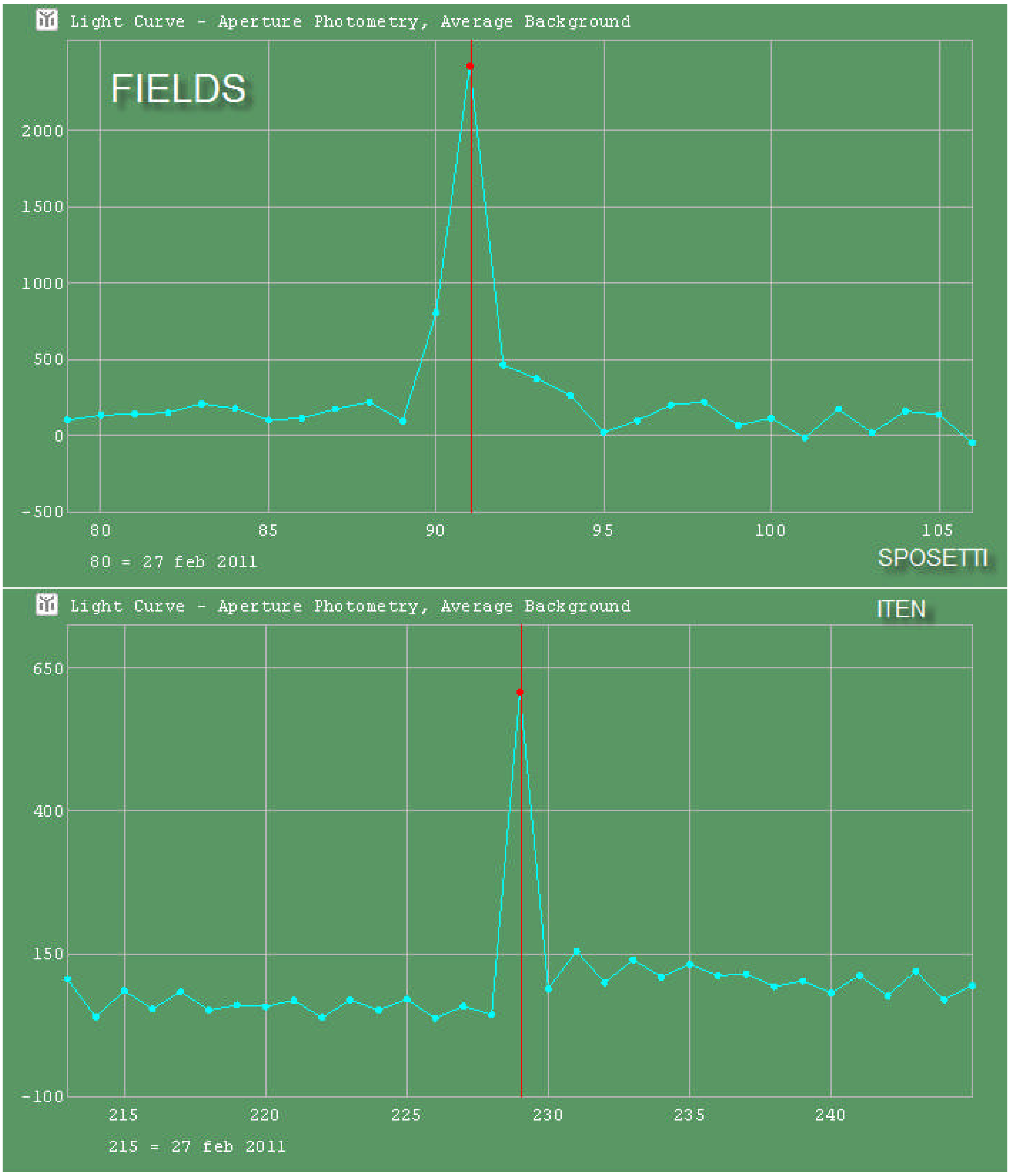

Figure 15. Light curves of the half-frames (1 half-frame = 20 ms) obtained in a circular diameter of 6 pixels (Tangra©).

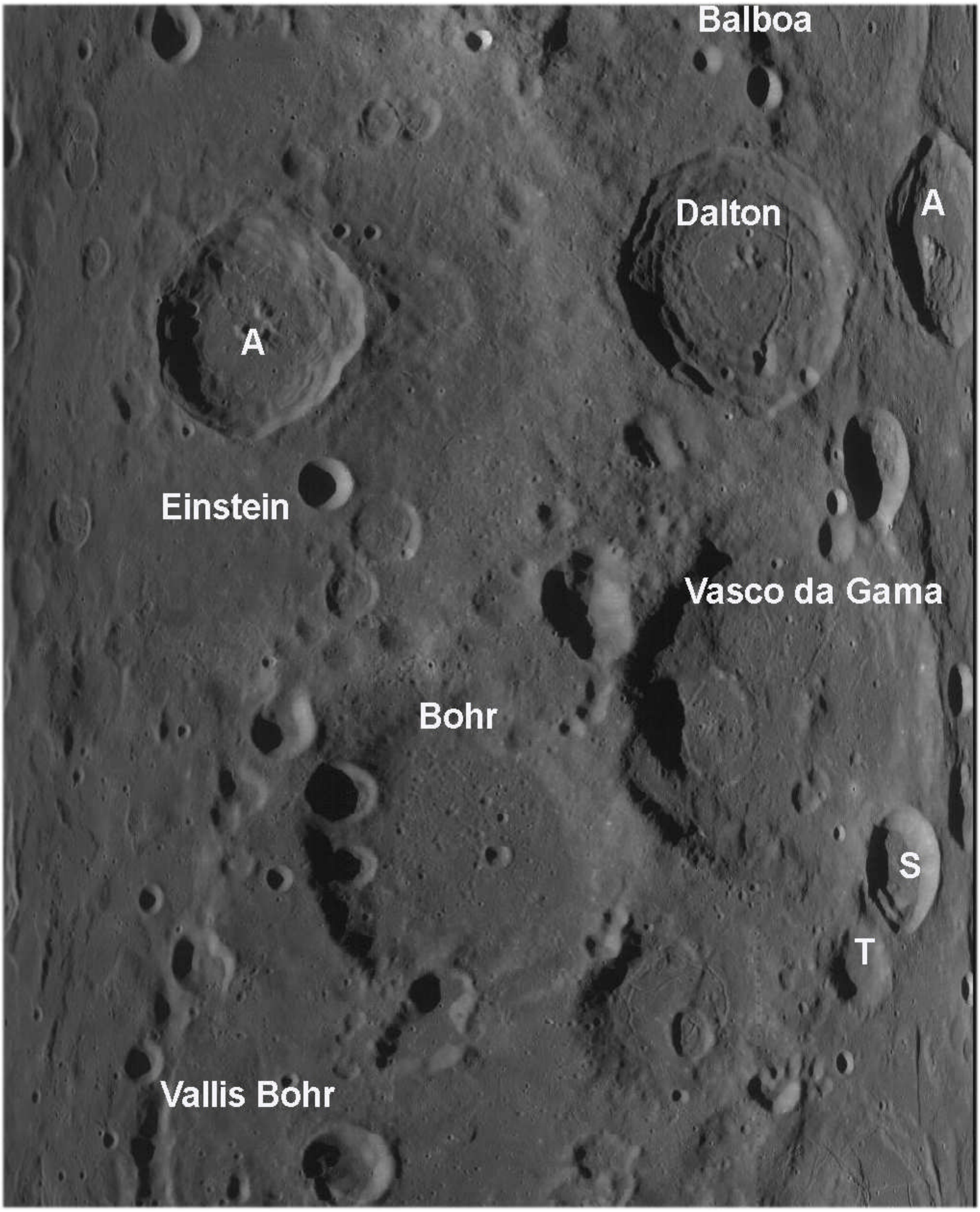

Figure 16. LRO imagery WAC M102722785 ME. North to the top and west to the left. Approximately the image covers 10° N -18° N and 83° - 90° W, the region of the examined lunar impact.

Table 1: Observer, observatory and instrument information.

Marco ITEN, Garden Observatory

Setup:

Telescope: Borg 125 ED refractor,
Telescope aperture: 125mm
Reducer/Flattener: Borg 0.83
Telescope focal length: 660mm
Autoguiding software: Nudger
Videocamera: WAT-902H2 Ultimate, 1/2" Sony CCD-Sensor ICX429ALL
Videocamera settings: AGC=LOW, GAMMA=LOW , BLC1,2,3=OFF
Video Format: 720x576 pixels
Field of view: 34x27arcmin
Sampling: 2.8arcsec/pixel
CCIR recording mode @ 25fps (Integration frame time=0.04s)
GPS time inserter: KIWI-OSD with GPS Garmin 18 LVC
Videograbber: Logilink EasyCap USB 2.0 Video Adapter, S-video input
Recording software: Virtualdub with Huffyuv v2.1.1. compression
AVI files saved on Hard Disk

Location (GPS measured):

Observatory E longitude: 08:52:28.6
Observatory N latitude: 46:10:43.7
Observatory height: 210m

Stefano SPOSETTI, Gnosca Observatory

Setup :

Telescope: Celestron C11 reflector,
Telescope aperture: 280mm
Reducer: Optec 0.33X
Telescope focal length: 950mm
Autoguiding software: Nudger
Videocamera: WAT-902H2 Ultimate, 1/2" Sony CCD-Sensor ICX429ALL
Videocamera settings: AGC=LO, GAMMA=OFF , BLC1,2,3=OFF
Video Format: 720x576 pixels
Field of view: 24x19arcmin
Sampling: 2.0arcsec/pixel
CCIR recording mode @ 25fps (Integration frame time=0.04s)
GPS time inserter: KIWI-OSD with GPS Garmin 18 LVC
Videograbber: TV-AV PCI-TV7130, S-video input
Recording software: Virtualdub with Huffyuv v2.1.1. compression
AVI files saved on Hard Disk

Location (GPS measured):

Observatory E longitude: 09:01:26.5
Observatory N latitude: 46:13:53.2
Observatory height: 260m

Table 2 Moon data, at the moment of the detection, as seen from Sposetti's observatory.

Equatorial 2000:	RA: 03h 42m 18s Dec: +22°09'00"
Horizon:	Azim: 251°13'00" Alt: +47°07'17"
Visibility:	Rise 10:43, Set 01:35 UTC
Transit time:	18:35 UTC
Phase:	55.63 %
Air mass:	1.36
Moon angular diameter:	00°30'25"
Moon distance:	392775.29 km
Moon altitude w/refraction:	47.1367°
Moon optical libration:	l: -6.8811 b: -3.5348
Moon physical libration:	l: -0.0183 b: -0.0129
Moon total libration:	l: -6.8994 b: -3.5477
Moon position angle:	-14.0966°
Moon phase angle:	83.5343°
Moon position angle of bright limb:	257.5143°
Sidereal time:	06:39

Table 3. xy-plane coordinates of the stars "A" and "B" and of the flash "F" (Fig. 3).

	SPOSETTI	ITEN
xF (pixels)	246.5	258.5
yF (pixels)	172.0	279.0
xA (pixels)	477.3	418.8
yA (pixels)	124.5	239.4
xB (pixels)	647.5	536.6
yB (pixels)	82.5	204.1
AB distance (pixels)	175.305562	122.975323
BF distance (pixels)	410.866462	288.029069
AF distance (pixels)	235.637200	165.138313
BF/AB	2.343716	2.342170
AF/AB	1.344151	1.342857
%error BF/AB	0.066	
%error AF/AB	0.096	

Table 4. Star data from Centre de Données astronomiques de Strasbourg (http://cdsarc.u-strasbg.fr).

	STAR A	STAR B	STAR C
Name	BD+21 508	HD 23159	HD 23327
Coord. J2000.0	03 43 31.12 +22 09 30.1	03 43 42.38 +22 04 16.3	03 45 07.43 +22 17 36.8
Spectral type	F8 D	F2 D	F5 D
B	11.12	10.1	9.57
V	10.47	9.67	9.19
R	10.33	-	-
J	9.09	8.41	8.18

Table 5. Intensities and magnitudes.

		FLASH F	STAR A	STAR B	STAR C
SPOSETTI	Signal minus Background	1409	200	300	500
	Error ±	-	50	50	100
ITEN	Signal minus Background	378	-	100	110
	Error ±	-	-	20	20
			F compared to A	F compared to B	F compared to C
SPOSETTI	Magnitude		8.35	8	8.05
	Error ±		0.3	0.2	0.3
ITEN	Magnitude		-	8.23	7.84
	Error ±		-	0.3	0.2