Algorithms for Lunar Flash Video Search, Measurement, and Archiving

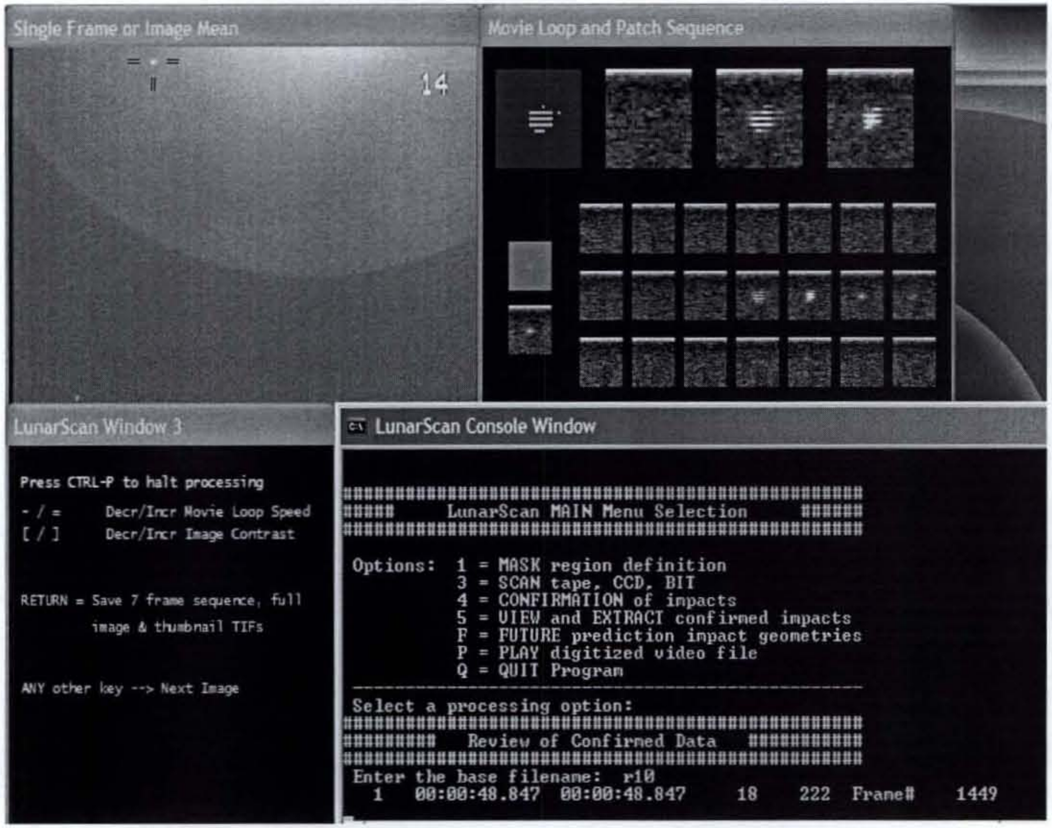
Wesley Swift[a], Robert Suggs[b], Bill Cooke[b]

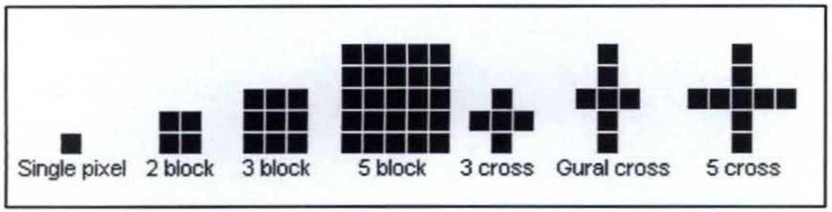
Abstract

Lunar meteoroid impact flashes provide a method to estimate the flux of the large meteoroid flux and thus their hazard to spacecraft. Although meteoroid impacts on the Moon have been detected using video methods for over a decade, the difficulty of manually searching hours of video for the rare, extremely brief impact flashes has discouraged the technique's systematic implementation. A prototype has been developed for the purpose of automatically searching Lunar video records for impact flashes, eliminating false detections, editing the returned possible flashes, and archiving and documenting the results. The theory and organization of the program is discussed with emphasis on the filtering out of several classes of false detections and retaining the brief portions of the raw video necessary for in depth analysis of the flashes detected. Several utilities for measurement, analysis, and location of the flashes on the moon included in the program are demonstrated. Application of the program to a year's worth of Lunar observations is discussed along with examples of impact flashes as well as several classes of false impact flashes.

(a) Raytheon NASA/MSFC USA, (b) NASA / MSFC EV13 USA

Lunar Flash Video Search - Method

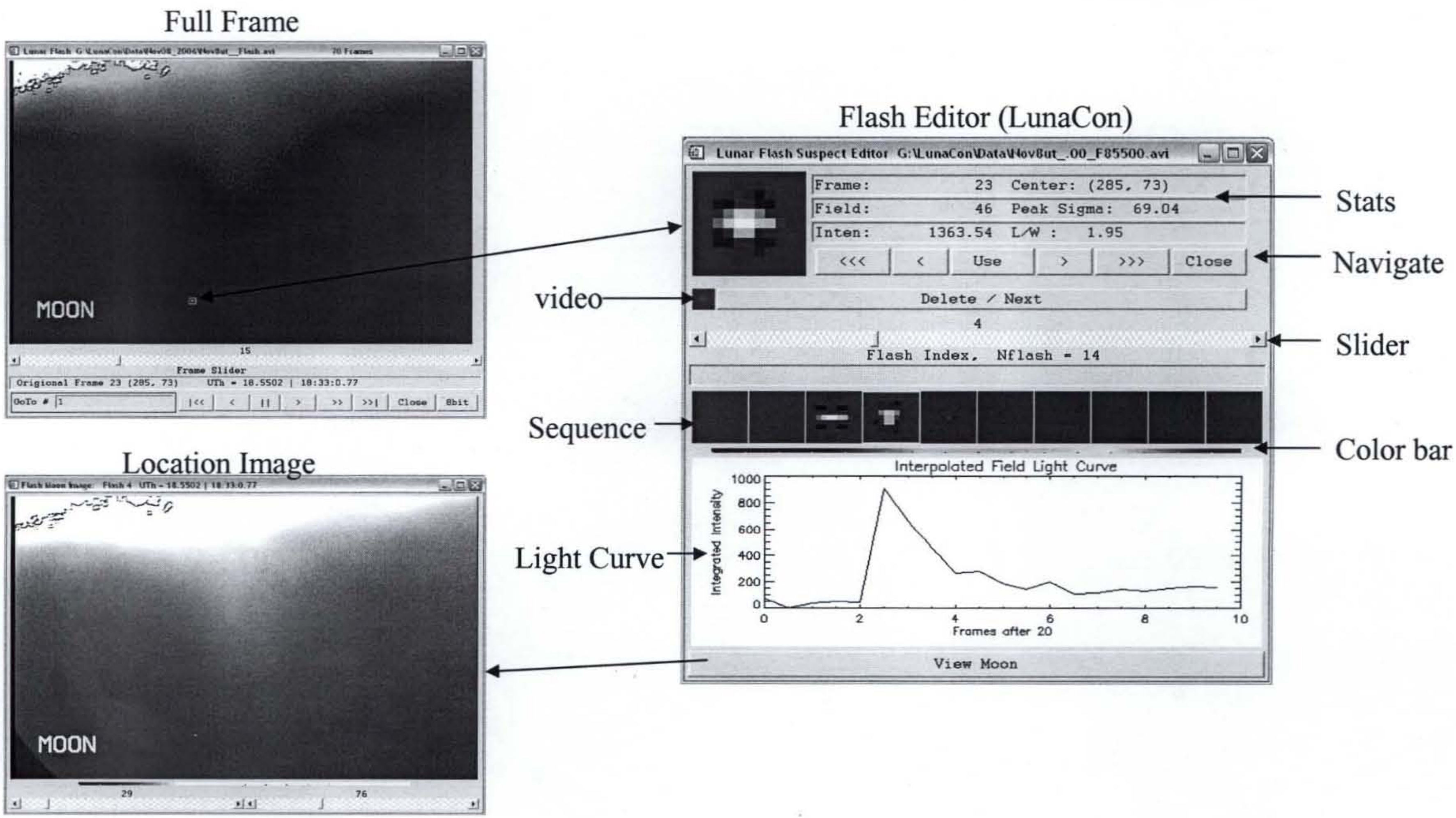




Pixilated point spread function search patterns

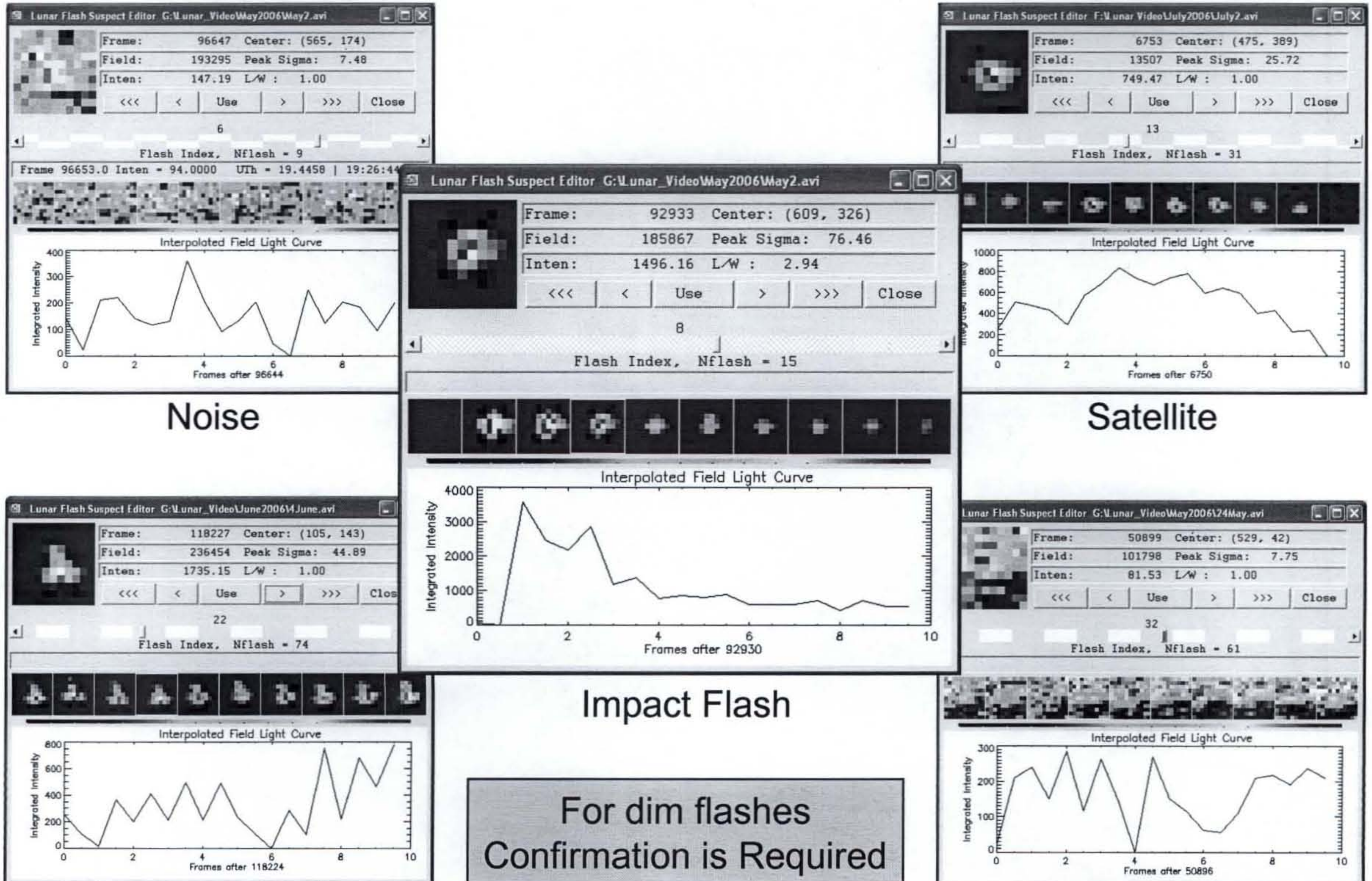
- Detection based on assumed instrument point spread function (PSF)
- Complete PSF pattern must exceed chosen local statistics
- At least one pixel in the PSF must exceed a chosen peak sigma
- Lunar masking & dark sky masking used to limit search and define statistical parameters
- Prototype software, LunaCon, was developed by W. Swift in IDL
- Current software, LunarScan, independently developed by Peter Gural, is fast and flexible.

Lunar Flash Video Search - Software



> ➢Software is semi-automated. Possible flashes need to be edited by operator

Lunar Flash Video Search - Artifacts



Noise

Satellite

Impact Flash

Star

Boundary

For dim flashes
Confirmation is Required

Lunar Flash Video Measurement - Lunar Area

- The Earth Shine area of the moon varies with **phase and position**.
- Area observed must be **accumulated**, pixel by pixel, throughout the observations. Lunar disc center pixel area, A_c, km^2 is determined by Lunar disc radius in pixels.
- **Surveyed area** is weighted by pixel distance, ***r/R***, from center of the Lunar disc to account for **spherical Moon** effects.
- Lunar disc center pixel area, A_c, km^2 is determined by Lunar disc radius in pixels.
- Observed **Area-Time product** (km^2-hr) , AT, is binned by "limiting magnitude".
- $Good_{magnitude}$ adjusts for clouds, dropouts, and the "limiting magnitude".
- Area-time product of **null observations** is part of flux estimate.
- Example: 355mm diameter f/8 telescope with 0.33 focal reducer operating at f = 950mm
  Surveys ~50km^2-hr / frame or 1 hour video => 5e6 km^2-hr

$$Flux_{magnitude} = \frac{N_{magnitude}}{\sum_{obs} (Area \times Time)_{magnitude}}$$

$$\text{PixelAreaWeight}, W = \frac{1.0}{Cos\left(A\sin\left(r/R\right)\right)}$$

$$\text{AT}_{magnitude}, \text{km}^2 \text{ - hours}, = \frac{\sum_{\text{frames}} good_{magnitude}\left[\sum_{lunarpixels} W \times A_c\right]}{frames/hour}$$

Lunar Flash Video Measurement - Photometry

Problem

- One has no choice of sky conditions or calibration stars
- Available star can be hours away and at different elevation
- Sky conditions can vary from frame to frame
- Observations are often continued to very low elevations with rapidly changing airmass

Solution

- Use mean lunar intensity, *Lmi*, as transfer standard
- Lunar sensitivity function, *Lsf,* includes extinction
- $Sen0_k$ can be determined for every $field_k$, IU
- Flash light curve, i_k, IU, using Circular Aperture Photometry
- Calibration using $Sen0_k$ removes atmospheric effects

$$Lsf = \frac{Sen0_0}{Apsf_0(Lmi_0 - Smi_0)} \Rightarrow Sen0_k = Lsf \times Apsf_0 \times (Lmi_k - Smi_k)$$

Lunar Flash Video Measurement- Moon

Definitions:

IU	Instrument Units
Lmi	Lunar mean intensity, IU
Smi	Sky mean intensity, IU
[Max, Min]	95th and 5th percentiles
PSF	Point Spread Function sigma
Apsf	*Area of PSF, $\pi(PSF)^2$*, pixels
Lpsfi	Lunar PSF intensity, IU
Lpsfm	Lunar PSF intensity, mag.
Sen0	*Sensitivity, sen0* = IU m_0 star
C	Contrast of lunar image [0,1]
range	*mean ($1\pm C$), see [Max, Min]*
$Range_{Lpsfm}$	Lunar PSF magnitude range
Lsf	*Lunar sensitivity factor*

$$Contrast, C \equiv \frac{Max - Min}{Max + Min}$$

$$range = Lmi\,(1 \pm C)$$

$$Lpsfm_{image} = -2.5Log_{10}\left(\frac{Lpsfi}{sen0}\right) - 5Log_{10}\left(\frac{PSF_{image}}{PSF_{star}}\right)$$

$$\mathrm{Range}_{\mathrm{Lpsfm}} = -2.5Log_{10}\left(\frac{Lpsfi}{sen0}\right) + \left[-2.5Log_{10}(1+C), -2.5Log_{10}(1-C)\right]$$

➢ *$Range_{Lpsfm}$* can be used as proxy for Limiting Magnitude for Highlands and Mare

Lunar Flash Video Measurement
Flash Characterization

- I_{Total} and maximum intensity, I_a often the only measurables of Lunar flash
- Measures are required that are **independent of camera**, exposure and sky
- Most flashes can be well approximated by **exponential** thermal decay curve
- **Thermal Decay** is specified by **Initial intensity**, i_0 and **Time Constant**, α
- For single frame flashes, $I_{Total} = I_a = i_0$ and $\alpha = 1$ (by definition)
- Flash **Initial magnitude** m_f and **Time Constant** α form ideal measures
- $m_f = 0 \Rightarrow i_0 = 5\times10^{-9}$ watts/m^2 so: $m_f = 6$, $\alpha = 0.10$ sec => 2×10^{-12} J/m^2

$$I_{Total} = \int_0^\infty i_0 e^{-\left(\frac{t}{\alpha}\right)} dt = i_0\alpha$$

$$I_a = \int_0^a i_0 e^{-\left(\frac{t}{\alpha}\right)} dt = i_0\alpha\left[1 - e^{-\left(\frac{a}{\alpha}\right)}\right] \Rightarrow \frac{I_a}{I_T} = 1 - e^{-\left(\frac{a}{\alpha}\right)}$$

$$\text{Time Constant, } \alpha = \frac{a}{\ln\left(\frac{I_T}{I_T - I_a}\right)} \Rightarrow \text{Initial Intensity, } i_0 = {I_T}/{\alpha}$$

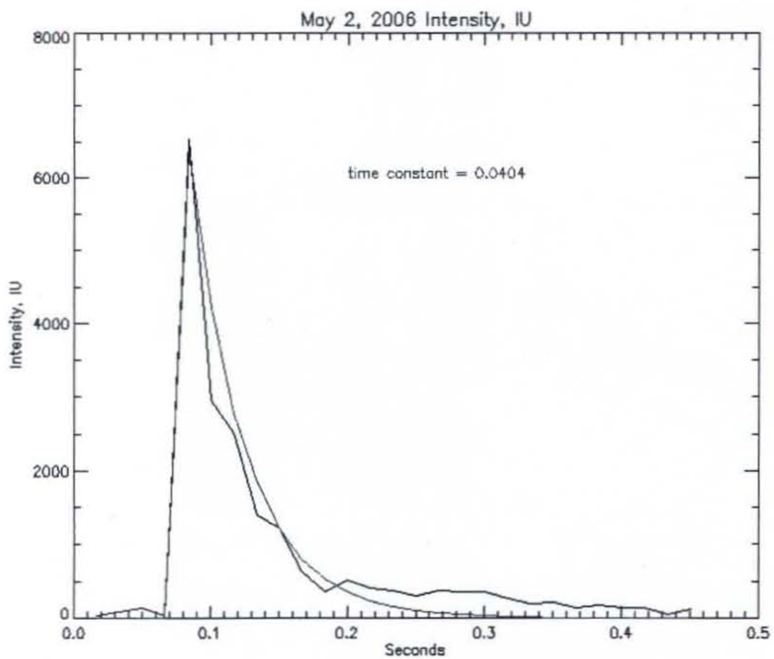
$$\text{Flash Initial magnitude, } m_f = -2.5 Log_{10}\left(\frac{i_0}{sen0_k}\right)$$

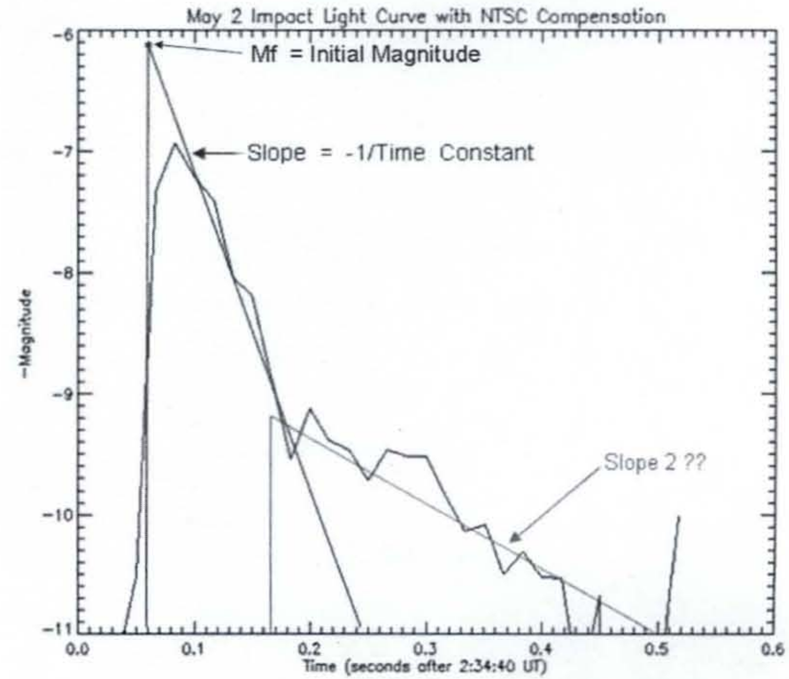
Lunar Flash Video Measurement Characterization Example

May 2, 2006 Impact:

Intensity Plot

- Time Constant, $\alpha = 0.04$
- Initial Magnitude, $m_f = 6.1$
- Maximum recorded, $m_a = 6.8$





May 2, 2006 Impact:

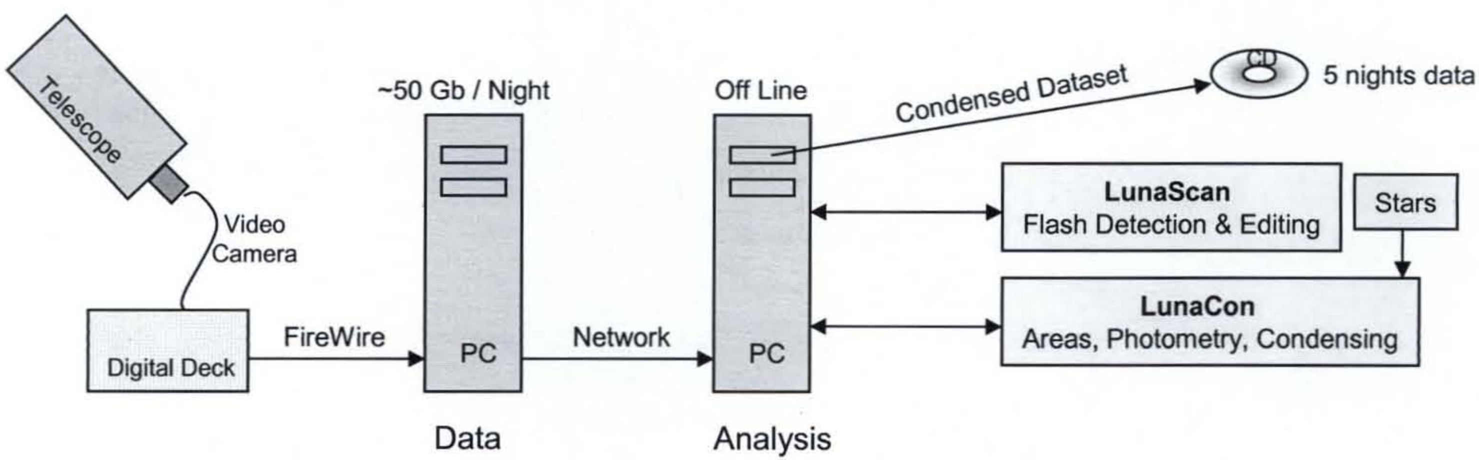
Magnitude Plot

- Decay linear in magnitude
- Slope yields the time constant
- Very bright flash can exhibit complex behavior.

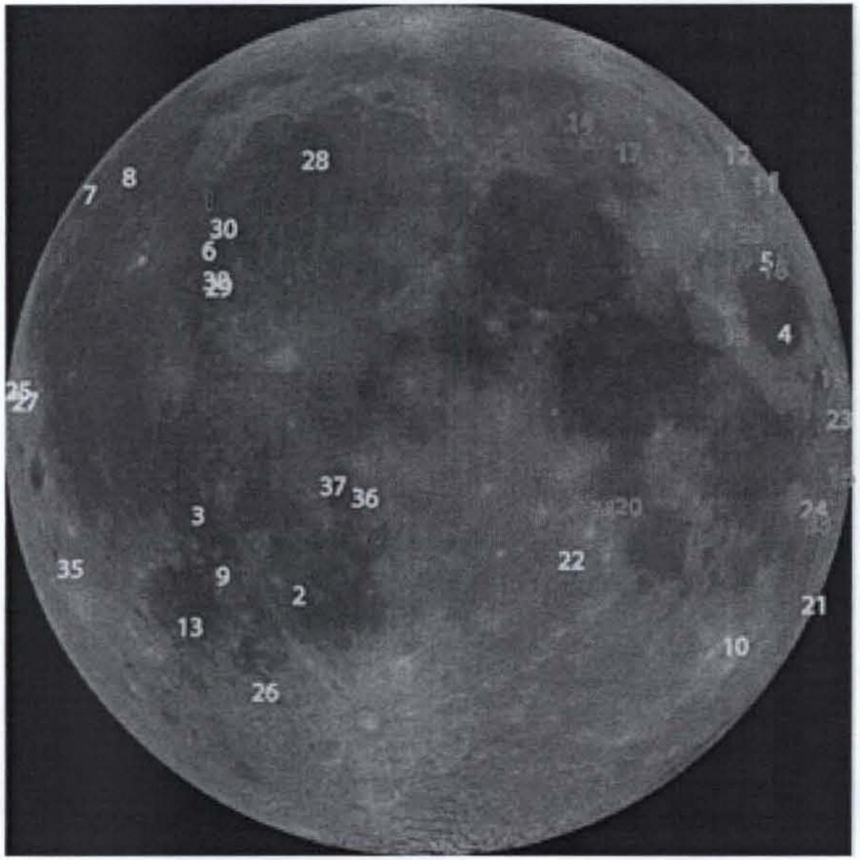
Lunar Flash Archiving – Condensed Data

Data Condensing

- One night's video is many Gigabytes of data, mostly empty of impacts
- Data compression tends to eliminate the short, dim flashes from video
- Data "condensing" is the process of removing all unnecessary video frames
- Lunar statistics, including $AT_{magnitude}$, *Lmi,* contrast, and *Lsf* found and saved
- Condensed data includes uncompressed flash video and auxiliary data
- Compressed data flashes can be reprocessed at some later date
- 4 hours uncondensed Lunar video: ~50 Gb, Condensed: ~100 Mb



Lunar Flash Archiving - Reporting



www.nasa.gov/centers/marshall/news/lunar/index.html

#	UT Date	UT Time	Video Frames (1/30 s)	Approx. Magnitude	Probable Type	Telescopes
1	07 Nov 05	23:41:52	5	7.3	Taurid	10"
2	02 May 06	02:34:40	14	6.9	Sporadic	10"
3	04 June 06	04:48:35	1.5	7.9	Sporadic	10"
4	21 June 06	08:57:17	2.5	8.3	Sporadic	10" & 14"
5	19 July 06	10:14:44	2	8.4	Sporadic	10" & 14"
6	03 Aug 06	01:43:19	3.5	6.7	Sporadic	14"
7	03 Aug 06	01:46:11	1.5	9.1	Sporadic	14"
8	04 Aug 06	02:24:57	2	7.1	Sporadic	10" & 14"
9	04 Aug 06	02:50:14	2	8.9	Sporadic	10" & 14"
10	16 Sep 06	09:52:53	1	8.7	Sporadic	two 14"
13	30 Oct 06	00:24:27	1.5	7.6	Sporadic	two 14"
21	13 Nov 06	11:03:14	3	9.3	Sporadic	two 14"
22	14 Nov 06	08:26:39	2	TBD	Sporadic	two 14"
12	17 Nov 06	10:46:27	1	9.4	Leonid	two 14"
11	17 Nov 06	10:56:34	1	8.2	Leonid	two 14"
23	17 Nov 06	11:02:28	2	8.2	Leonid	two 14"
24	17 Nov 06	11:09:11	1	8.7	Leonid	two 14"
25	24 Nov 06	23:24:05	1	6.4	Sporadic	two 14"
26	24 Nov 06	23:58:13	1	6.2	Sporadic	two 14"
27	25 Nov 06	00:55:54	1	7.0	Sporadic	two 14"
28	26 Nov 06	00:59:16	2	7.3	Sporadic	two 14"
29	26 Nov 06	01:28:43	1	9.1	Sporadic	two 14"
30	26 Nov 06	01:30:29	1	9.1	Sporadic	two 14"
14	14 Dec 06	08:12:40	1	9.4	Geminid	two 14"
15	14 Dec 06	08:50:36	1	8.5	Geminid	two 14"
16	14 Dec 06	08:56:43	0.5	8.6	Geminid	two 14"
17	14 Dec 06	09:00:22	1	8.5	Satellite?	two 14"
18	14 Dec 06	09:03:33	0.5	10.0	Geminid	two 14"
19	14 Dec 06	10:56:42	1	8.7	Geminid	two 14"
20	14 Dec 06	11:28:08	2.5	7.5	Geminid	two 14"
31	15 Dec 06	09:15:14	1	7.9	Geminid	two 14"
32	15 Dec 06	09:17:39	1	7.3	Geminid	two 14"
33	15 Dec 06	09:53:28	3	6.2	Geminid	14"
34	16 Dec 06	09:50:10	1	7.8	Geminid	14"
35	24 Dec 06	00:27:42	1	7.4	Sporadic	two 14"
36	23 Feb 07	00:11:36	2	TBD	Sporadic	14"
37	23 Feb 07	00:47:45	2	TBD	Sporadic	two 14"
38	23 Feb 07	04:02:44	1	TBD	Sporadic	two 14"

Summary

- Methods have been developed for semi-automated lunar impact flash detection.
- Software and techniques have been developed to edit suspected lunar impact flashes.
- Methods are described for finding Lunar survey area as a function of detection limits.
- Lunar intensity over the PSF is developed as a photometric calibration transfer standard.
- A system for characterization of impact flashes is developed independent of instrumentation.
- Lunar flash data archiving techniques are described and preliminary survey results shown.

References

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