

Lunar Impact Detections During the 2010 Geminid Meteor Shower

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Lunar video observations are routinely conducted at the NASA Marshall Space Flight Center in Huntsville Alabama for the detection of meteoroid impacts. Over 240 impacts have been detected since the start of the observing program initiated approximately 5 years ago. During this time it has been fairly rare that lunar observing conditions and the weather have been favorable during the peak of the major showers. However, observing conditions were marginally favorable during the peak of the 2010 Geminids. On Dec. 14, 2010 approximately 5.5 hours of video were recorded. Even though the lunar phase was just outside the constraints established for optimum lunar impact monitoring, the resulting video was of sufficient quality that 21 lunar impacts were detected yielding an average impact rate of approximately 4 per hour. This compares to 17 lunar impacts detected over 40 nights of observations (approximately 100 hours of lunar video) yielding an average impact rate of 1 per 6 hours for the whole of 2010, excluding Dec. 14. The results of the 2010 Geminid lunar impact detections will be discussed along with previous results from the 2006 Geminid shower that also coincided within the lunar observing window.

Lunar Impact Detections During the 2010 Geminid Meteor Shower



**NASA Meteor Video Observations and Analysis
Workshop Aug 4-5, 2011**

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Overview

Summary of Lunar Team's 5 years of lunar video observations

- Observation setup & constraints
- Observing statistics

Lunar observations during the Geminid 2010 shower

- Impacts observed
- Example video frames
- Comparison with 2006 Geminid shower observations

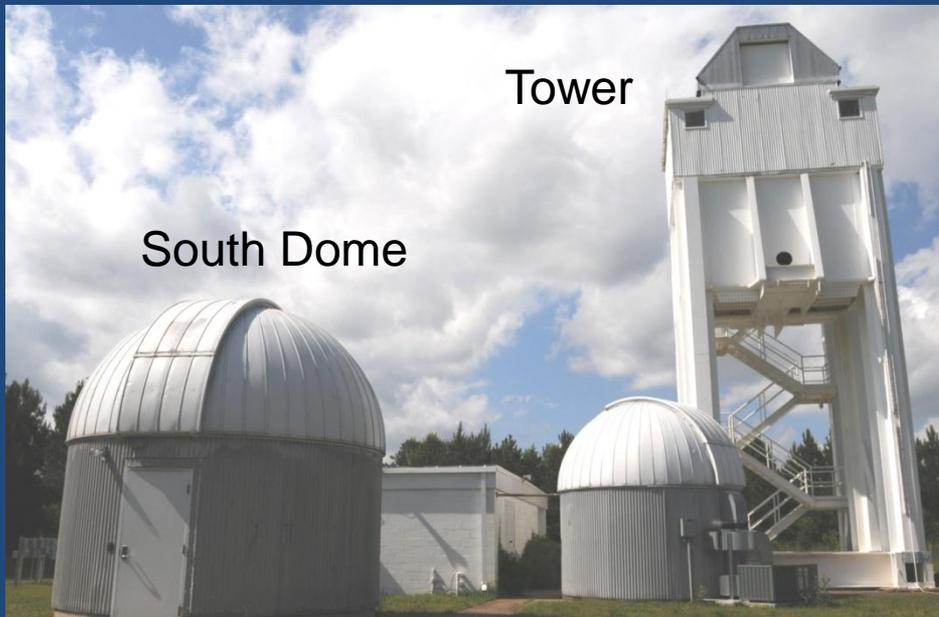
NASA MSFC Automated Lunar and Meteor Observatory



NASA MSFC, Alabama

- Telescopes
 - Three 14" (0.35m)
- Detectors
 - Watec 902H2 Ultimate
 - Astrovid Stellacam EX

Remote Observatory in Walker County Georgia near Chickamauga



Tower

South Dome



WCO

Observing Constraints

Field of View:

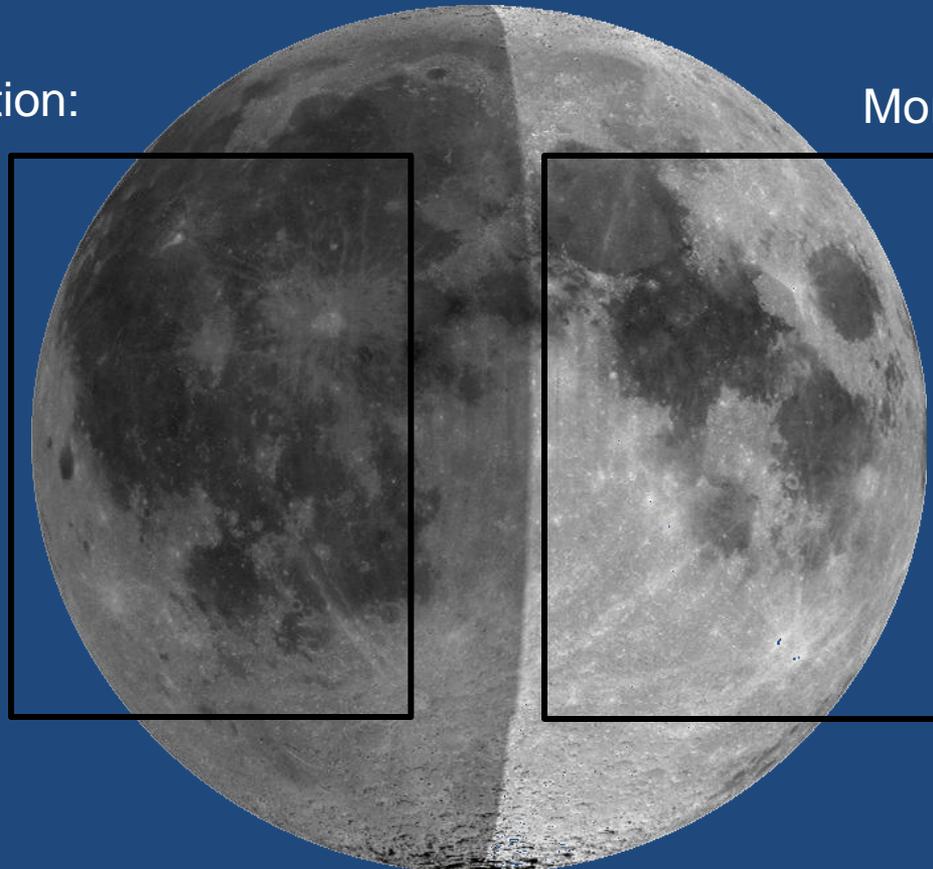
Balance between resolution, coverage area & phase constraints

Lunar Phase Constraint:

0.1 to 0.45 Illumination to reduce glare
Yields 8-9 nights per month

Evening Observation:

Waxing crescent
from twilight end
to moonset



Morning Observation:

Waning crescent
from moonrise
to twilight

Lunar Video Example Frame

9 Jan 2011 01:17:55 UTC

Tower Video



South Dome Video



Lunar Video Impact Detection

Peter Gural's Flash Detection
Software version 1.5

Tower & South Dome Videos are
each scanned

The screenshot displays the LunarScan software interface, which is divided into four main panels:

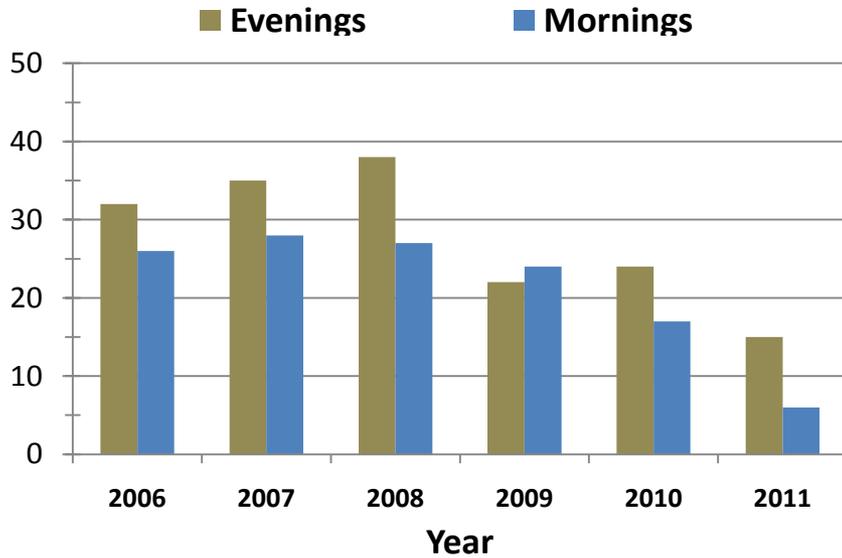
- Single Frame or Image Mean:** Shows a grayscale image of the Moon's surface. A white crosshair is visible on the left side, and a small white 'T' is in the top right corner.
- Movie Loop and Patch Sequence:** Displays a grid of small, dark, noisy images, likely representing individual frames or patches from a video sequence.
- Potential Shower Impact Region for Processing Date:** Shows a circular, textured area representing a potential impact region. A white crosshair is centered on the circle.
- LunarScan Console Window:** A text-based window displaying the program's main menu and options. The text is as follows:

```
##### LunarScan MAIN Menu Selection #####
#####
Options:  1 = MASK region definition
          2 = DARK field update from avi
          3 = SCAN avi file or built-in-test
          4 = CONFIRMATION of impacts
          5 = VIEW and EXTRACT confirmed impacts
          F = FUTURE prediction impact geometries
          P = PLAY digitized video file
          Q = QUIT Program

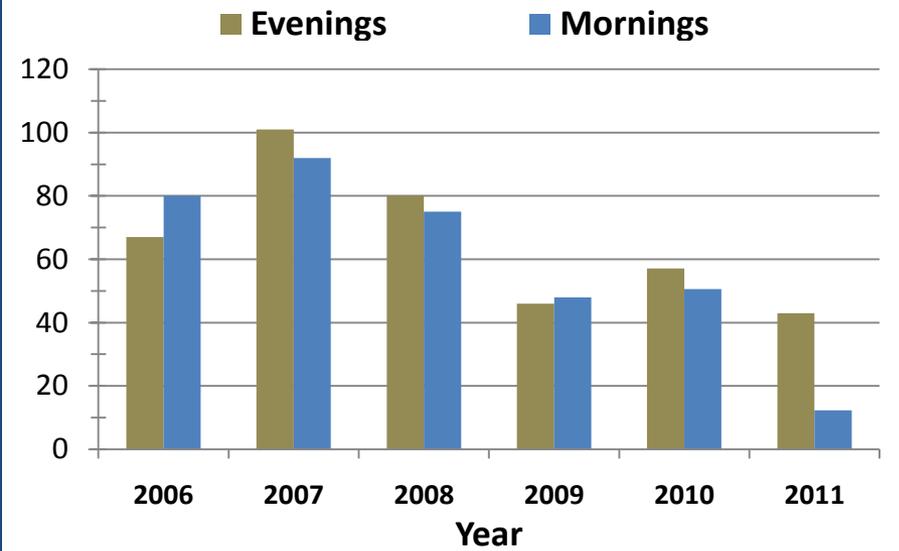
-----
Select a processing option:
#####
##### Review of Confirmed Data #####
#####
Enter the base filename:  8jan2011_t_vs150
-23  23:42:00.934  00:04:39.212  145   346  Frame#   8368
-62  00:28:00.616  00:50:30.894   161   673  Frame#   90836
-61  01:17:54.407  01:40:24.685   204    35  Frame#  180560
```

Yearly Observing Statistics

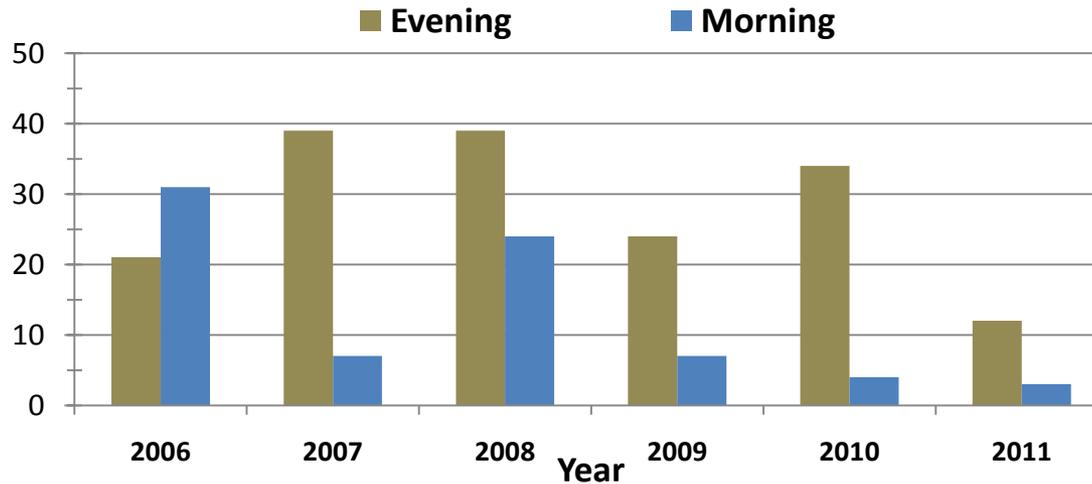
Nights Observed



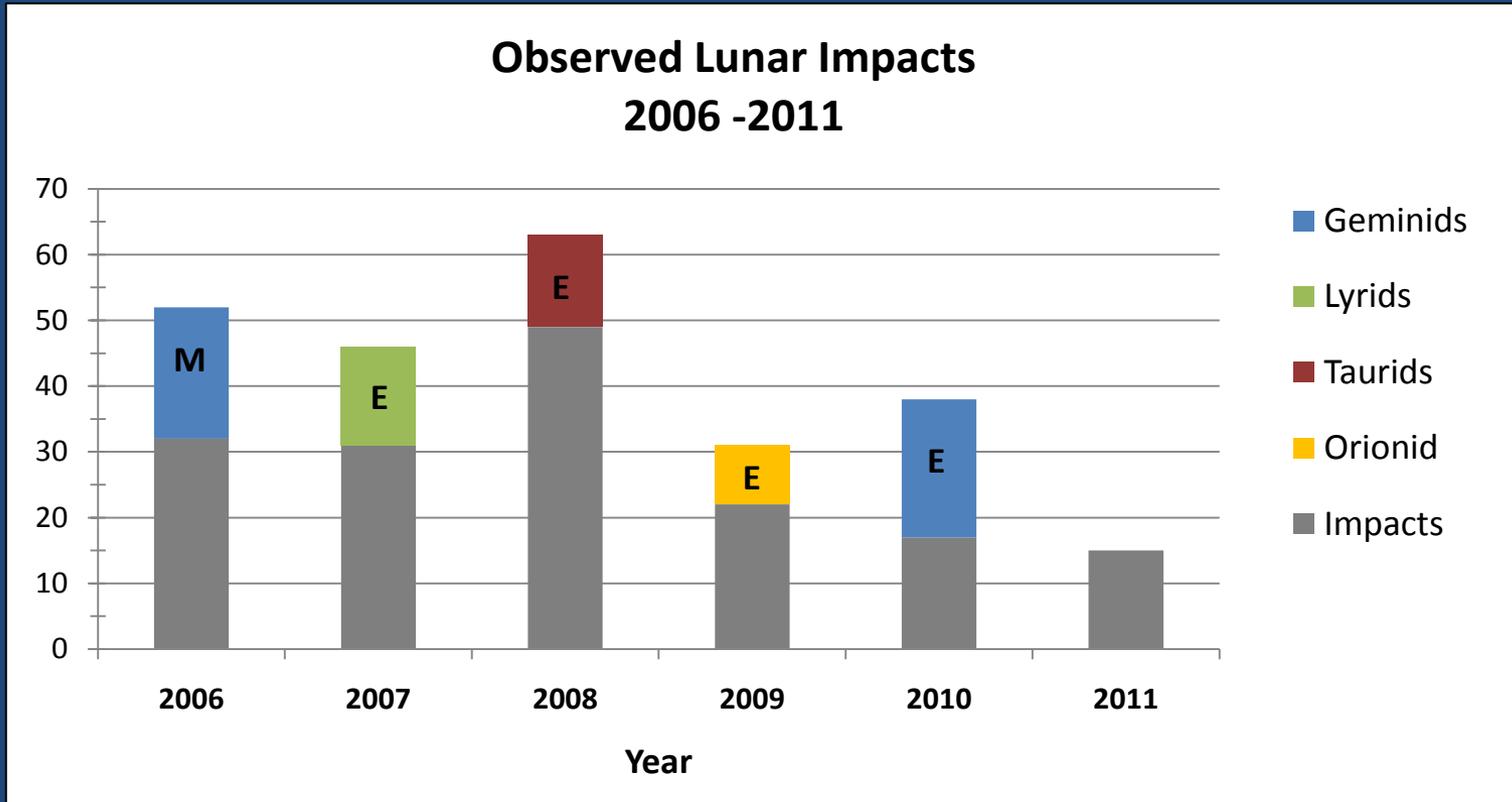
Hours Observed



Impacts Observed



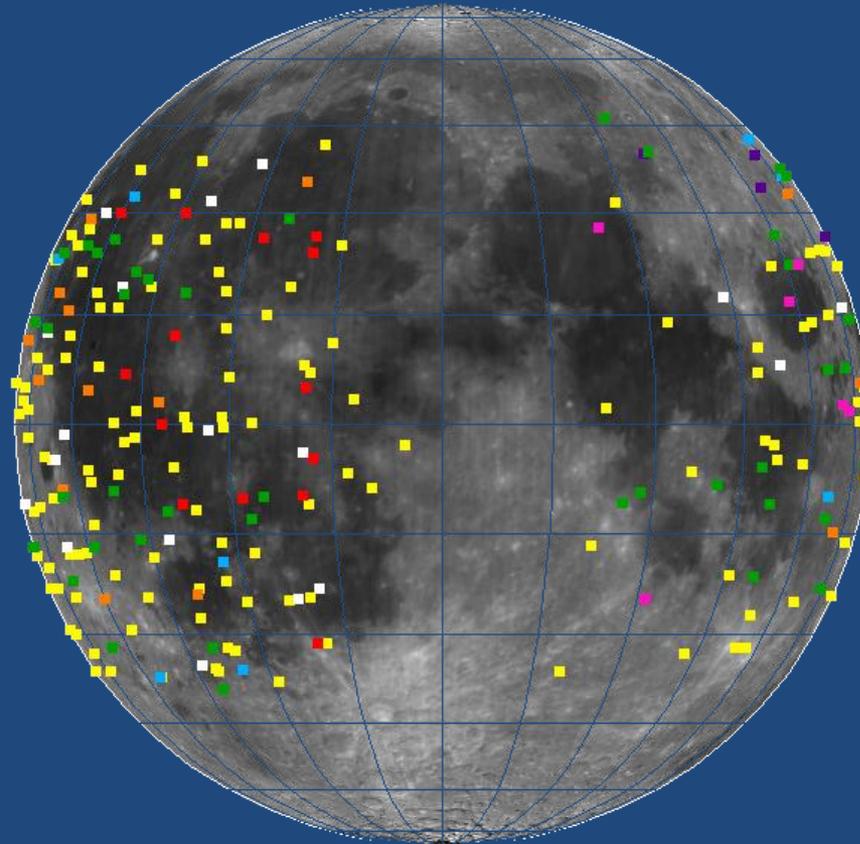
Significant Shower Events



5 Years of Lunar Observations

- 600 Nights Scheduled
- 294 Nights of Observations
- 752 hours of Video
- 245 Impacts Detected

- 166 Evenings
- 394 Hours
- 169 Impacts



- 128 Mornings
- 358 Hours
- 76 Impacts

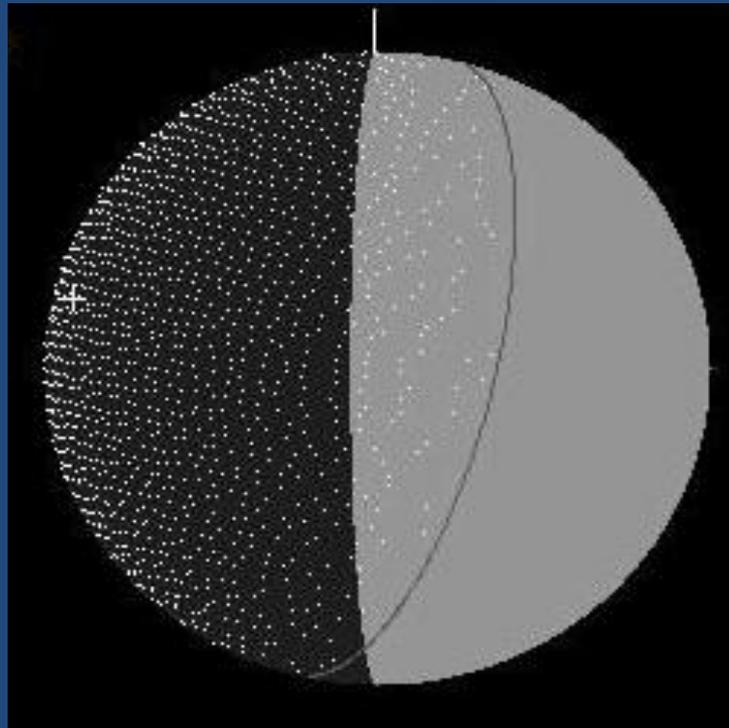


Lunar Observations During 2010 Geminids

Scheduled Lunar Observations :
Evenings of 9–13 Dec UTC

Lunar Impact Geometry

14 Dec. 00:00:00 UTC



Observed Lunar Impacts

Video Duration = 6.06 hrs

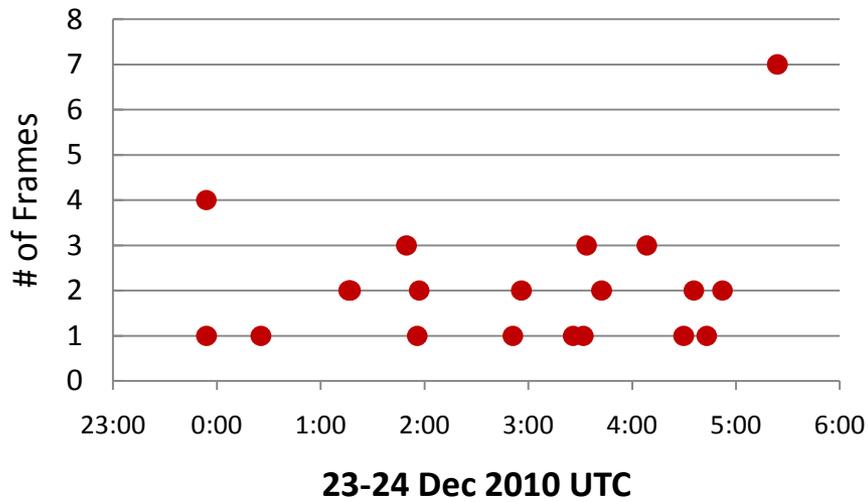
D = Detected C = Confirmed O = Obscured / Unresolved

13/14 Dec2010

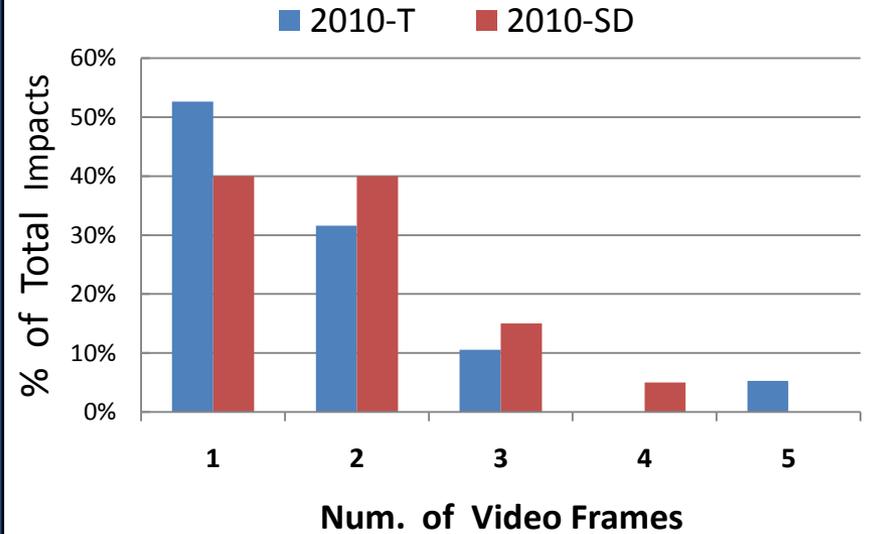
| Flash # | UT | Lon | Lat | Region | Observation Status | | | # Video Frames | | | Flash Quality | | |
|---------|------------|-------|-------|------------------|--------------------|----|---|----------------|----|---|---------------|------------|------------|
| | | | | | Tower | SD | W | Tower | SD | W | Tower | SD | W |
| 1 | 23:53:51.6 | -47.0 | -16.0 | Billy | D | D | O | 3 | 4 | x | bright | very brt. | x |
| 2 | 23:53:56.9 | -58.0 | -17.0 | Fontana | D | C | O | 1 | 1 | x | faint | very faint | x |
| 3 | 00:25:25.5 | -75.0 | 24.0 | Eddington | D | C | O | 1 | 1 | x | mod. brt. | mod. brt. | x |
| 4 | 01:16:14.6 | -39.0 | -32.0 | Lee | D | D | O | 2 | 2 | x | bright | bright | x |
| 5 | 01:16:42.0 | -27.0 | -13.0 | Darney C | O | D | O | x | 2 | x | x | mod. brt. | x |
| 6 | 01:17:08.8 | -25.0 | -10.0 | Eppinger | O | D | O | x | 2 | x | x | faint | x |
| 7 | 01:49:31.5 | -66.0 | 25.0 | Briggs | D | D | C | 2 | 3 | 1 | bright | bright | faint |
| 8 | 01:55:48.1 | -41.0 | -12.0 | Letronne | D | D | O | 2 | 1 | x | faint | bright | x |
| 9 | 01:56:51.5 | -64.0 | -10.0 | Grimaldi | D | C | O | 1 | 2 | x | faint | faint | x |
| 10 | 02:51:00.7 | -86.0 | -17.0 | Kopff B | D | D | O | 1 | 1 | x | bright | mod. brt. | x |
| 11 | 02:55:57.6 | -41.0 | -39.0 | Lacus Excellence | D | D | O | 3 | 2 | x | very brt. | brt. | x |
| 12 | 03:25:50.9 | -58.0 | 26.0 | Zinner | C | D | O | 2 | 1 | x | faint | mod. brt. | x |
| 13 | 03:31:47.3 | -62.0 | 24.0 | Schiaparelli | D | D | O | 1 | 1 | x | faint | faint | x |
| 14 | 03:33:38.7 | -71.0 | 13.0 | Cardanus | D | D | C | 2 | 3 | 1 | bright | bright | faint |
| 15 | 03:42:19.7 | -39.0 | 18.0 | Bessarion A | C | D | O | 1 | 2 | x | faint | mod. brt. | x |
| 16 | 04:08:31.1 | -68.0 | -22.0 | Darwin H | D | D | O | 2 | 3 | x | bright | bright | x |
| 17 | 04:29:48.1 | -78.0 | 14.0 | Vasco Da Gama | D | C | O | 1 | 1 | x | faint | very faint | x |
| 18 | 04:35:39.8 | -89.0 | -17.0 | Kopff | C | D | C | 1 | 2 | 1 | faint | faint | very faint |
| 19 | 04:43:03.5 | -47.0 | 20.0 | Aristarchus F | C | D | O | 1 | 1 | x | faint | mod. brt. | x |
| 20 | 04:52:12.1 | -50.0 | 21.0 | Herodotus | D | D | O | 1 | 2 | x | faint | mod. brt. | x |
| 21 | 05:23:56.1 | -65.0 | -32.0 | Lagrange L | D | x | O | 7 | x | x | very brt. | x | x |

Impact Flash Duration

Flash Duration vs. Impact Time



Impact Flash Duration



Impact #1

23:53:52 UTC 12Dec

SD Video



Tower Video



Impact #3

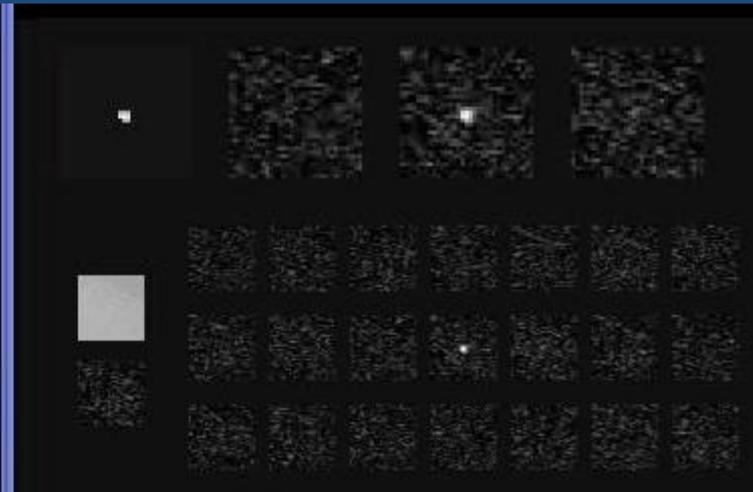
00:25:25 UTC

SD Video



Impact not detected
by Lunarscan in SD
Video

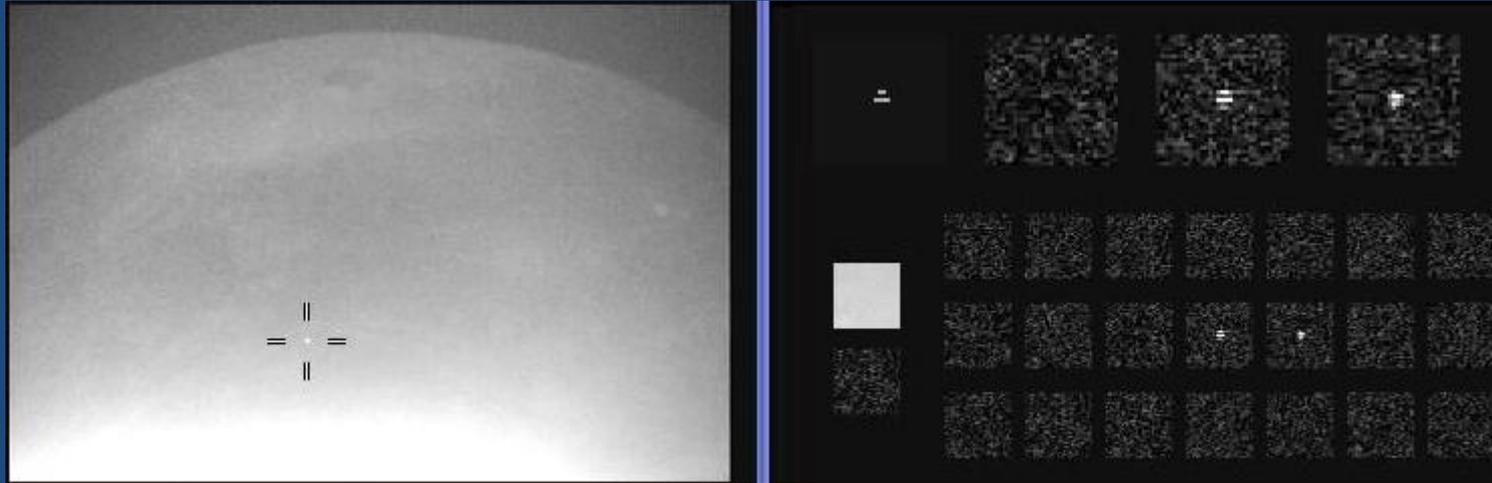
Tower Video



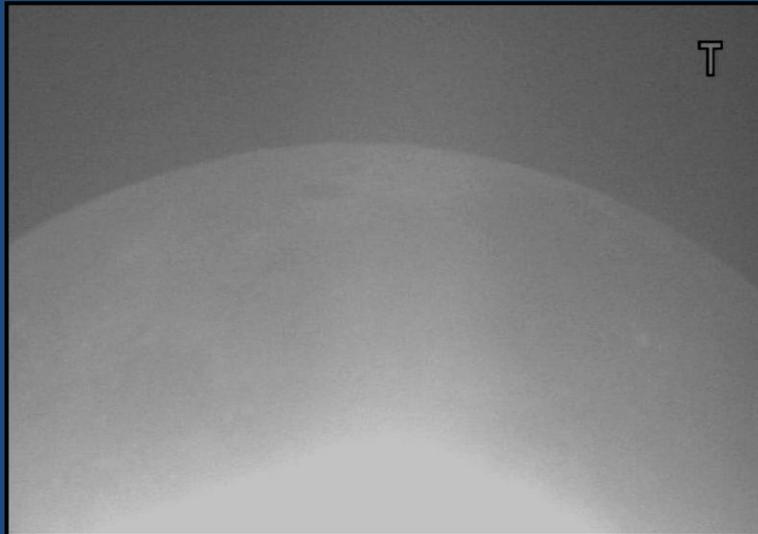
Impact #5

01:16:42 UTC

SD Video



Tower Video



Impact Obscured by Glare
No Confirmation

Impact #16

04:08:31 UTC

SD Video



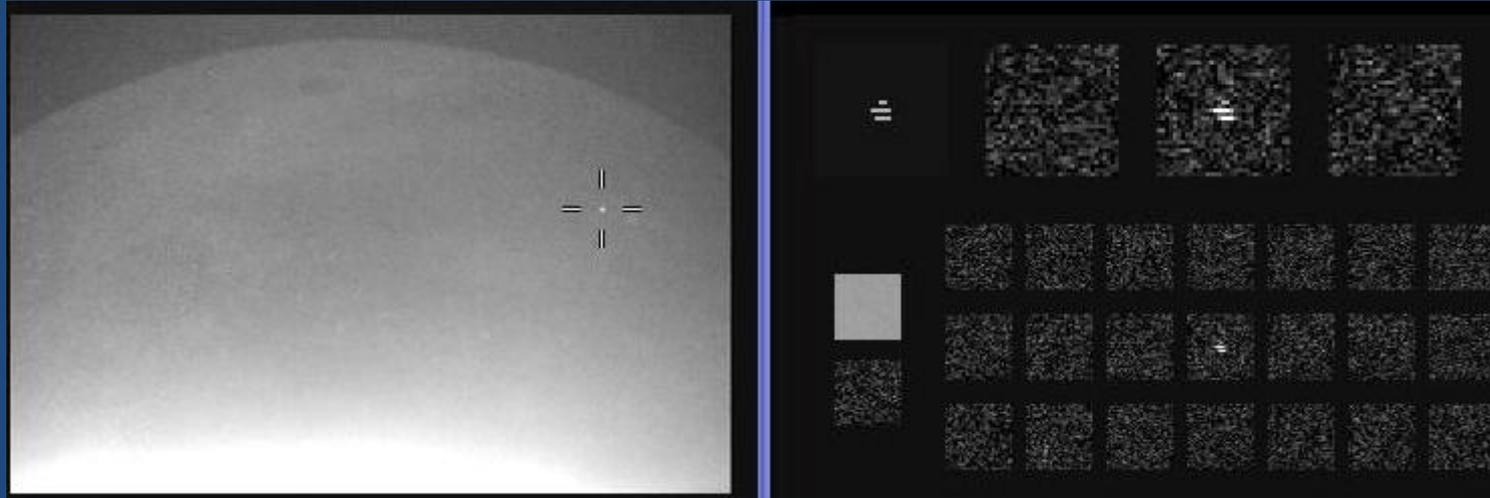
Tower Video



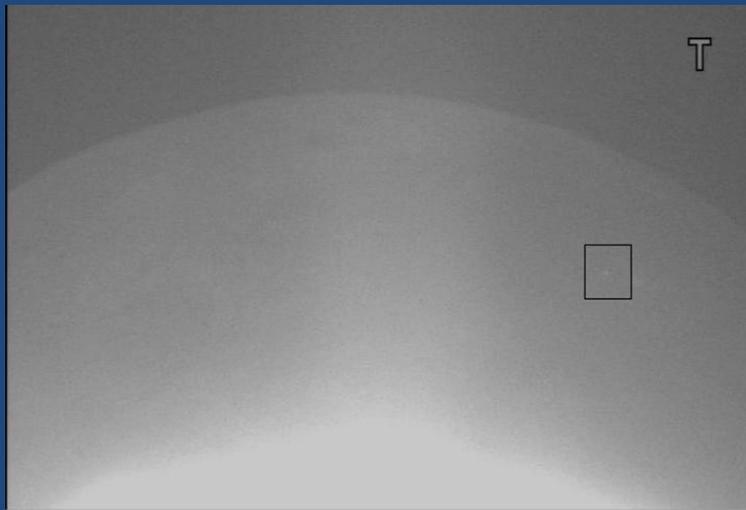
Impact #19

04:43:04 UTC

SD Video



Tower Video



WCO Video



Impact #21

05:23:56 UTC

Tower Video

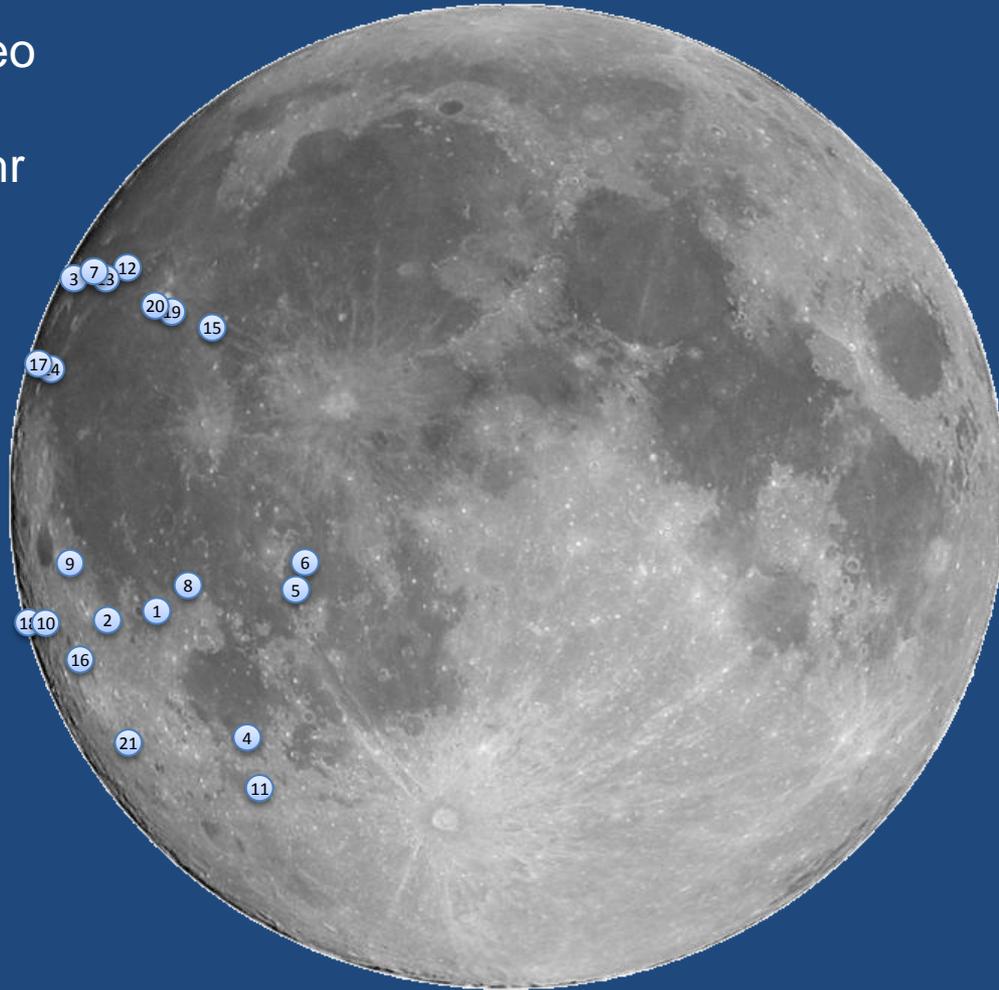


7 Video Frames



2010 Geminids Observed Lunar Impacts

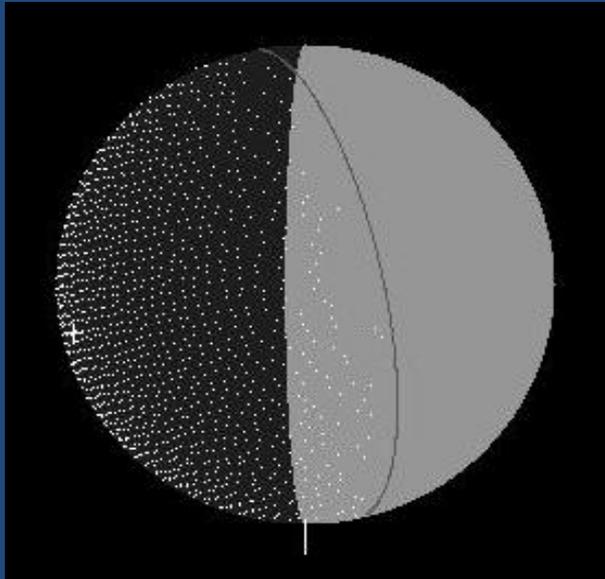
- 6.1 hrs of video
- 21 Impacts
- 3-4 impacts / hr



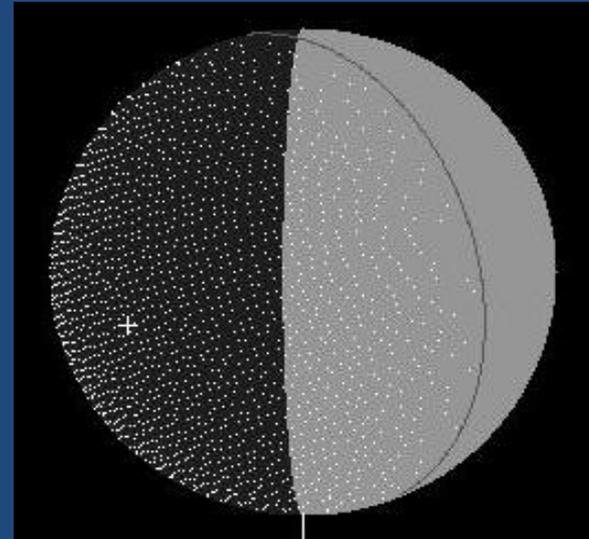
Minor Showers During December

14 Dec 2010

Monocerotids



sigma-Hydrids

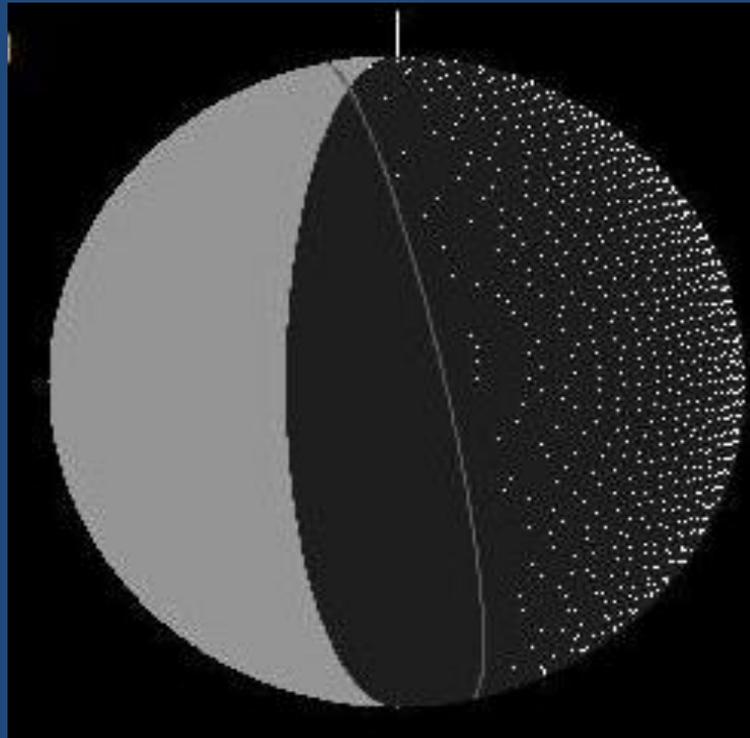


2006 Geminid Shower

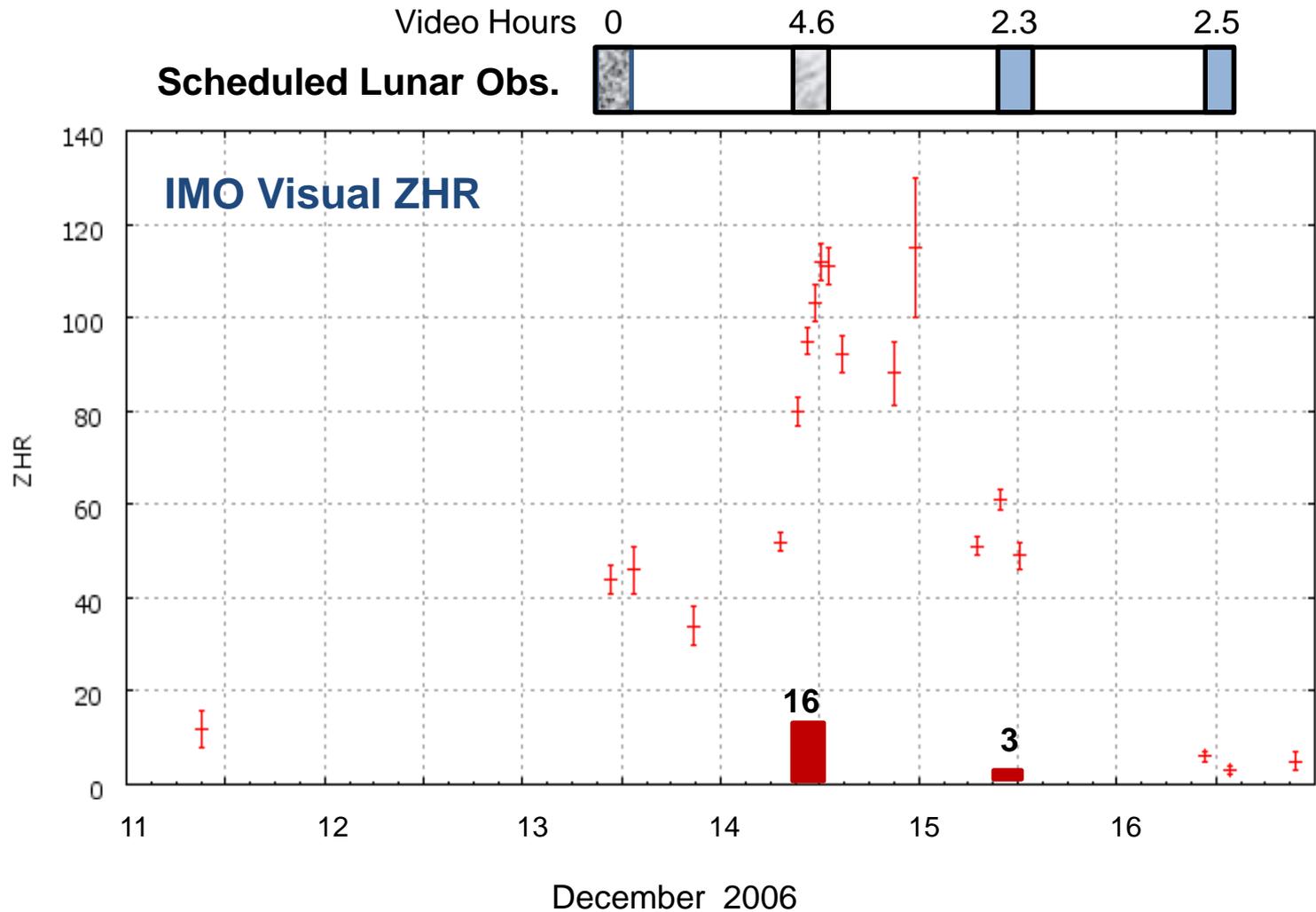
Scheduled Lunar Observations:
Mornings 13–17 Dec UTC

Lunar Impact Geometry

14 Dec. 08:00:00 UTC



2006 Geminid Observations



Observed Lunar Impacts

14 Dec 2006

Video Duration = 4.6 hrs

D = Detected C = Confirmed

| Impact # | UT | Lon | Lat | Region | Observation Status | | Video Frames | | Peak Mag | |
|----------|------------|------|-------|---------------|--------------------|----|--------------|----|----------|------|
| | | | | | Tower | SD | Tower | SD | Tower | SD |
| 1 | 08:12:40.0 | 33.5 | 46.5 | Lacus Somni | D | C | 1 | 1 | 9.5 | x |
| 2 | 08:16:46.4 | 51.5 | -21.0 | Biot B | D | D | 2 | 1 | 9.1 | 9.4 |
| 3 | 08:32:06.6 | 70.5 | 2.5 | Mare Undarur | D | C | 1 | 1 | 9.8 | x |
| 4 | 08:32:52.0 | 66.0 | 7.5 | Mare Undarur | C | D | 1 | 1 | 10.5 | 9.6 |
| 5 | 08:39:57.2 | 74.0 | -23.0 | Phillips B | D | C | 1 | 1 | 9.8 | x |
| 6 | 08:46:02.0 | 80.0 | 14.5 | Hansen B | D | C | 1 | 1 | 9.6 | x |
| 7 | 08:50:36.1 | 46.5 | 12.5 | Palus Somni | D | D | 1 | 1 | 8.5 | 9.4 |
| 8 | 08:51:20.6 | 51.5 | -11.0 | Mare fecundit | C | D | 1 | 1 | 10 | 9 |
| 9 | 08:56:43.0 | 84.0 | -5.5 | Mare Smythii | D | D | 1 | 1 | 8.8 | 8.7 |
| 10 | 09:00:22.1 | 39.0 | 40.0 | Maury P | D | D | 2 | 2 | 9.1 | 8.7 |
| 11 | 09:03:33.0 | 61.0 | 22.0 | Mare Crisium | C | D | 1 | 1 | 10.2 | 10.7 |
| 12 | 10:11:07.3 | 40.5 | -8.5 | Gutenberg | D | D | 2 | 2 | 10.2 | 10.3 |
| 13 | 10:28:51.1 | 83.5 | 36.0 | Gauss | C | D | 1 | 2 | x | 10.2 |
| 14 | 10:56:41.8 | 71.5 | 7.5 | Mare Undarur | D | D | 1 | 1 | 9.7 | 9.5 |
| 15 | 11:21:22.6 | 49.0 | -6.0 | Mare fecundit | C | D | 1 | 1 | x | 10.4 |
| 16 | 11:28:08.4 | 28.0 | -9.5 | Theophilus | D | D | 3 | 2 | 9.2 | 9.5 |

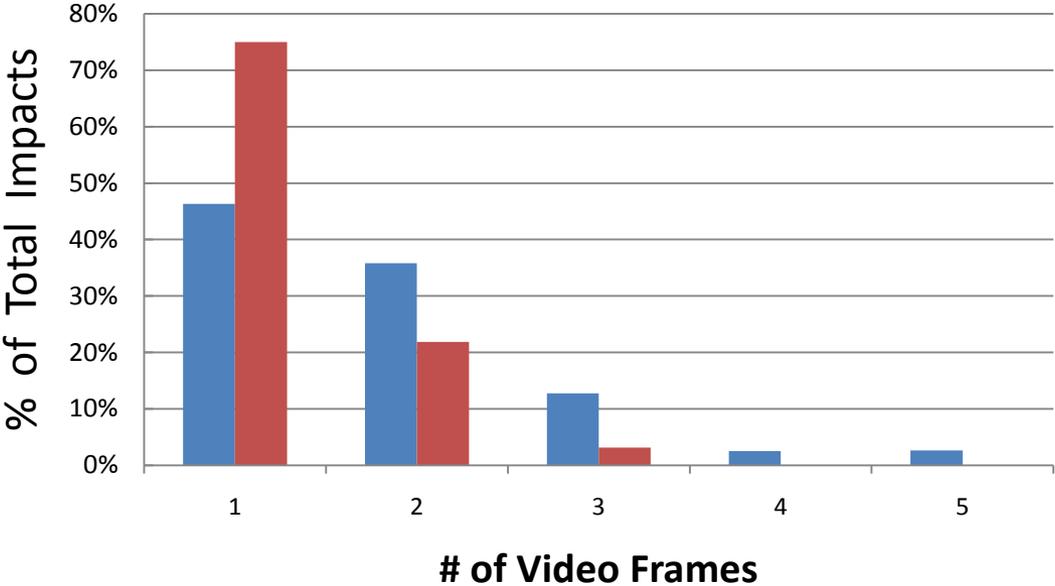
15 Dec 2006

Video Duration = 2.3 hrs

| | | | | | | | | | | |
|----|------------|------|-------|----------|---|---|---|---|------|-----|
| 17 | 09:15:14.0 | 85.0 | 37.5 | Beals | D | D | 1 | 1 | 10.1 | x |
| 18 | 09:17:39.0 | 60.0 | 26.5 | Delmotte | D | D | 1 | 1 | 7.7 | 8.3 |
| 19 | 09:53:28.0 | 67.0 | -13.0 | Lame N | D | x | 3 | x | 6.7 | x |

Impact Flash Duration

2010 2006



Impact #10

9:00:22 UTC

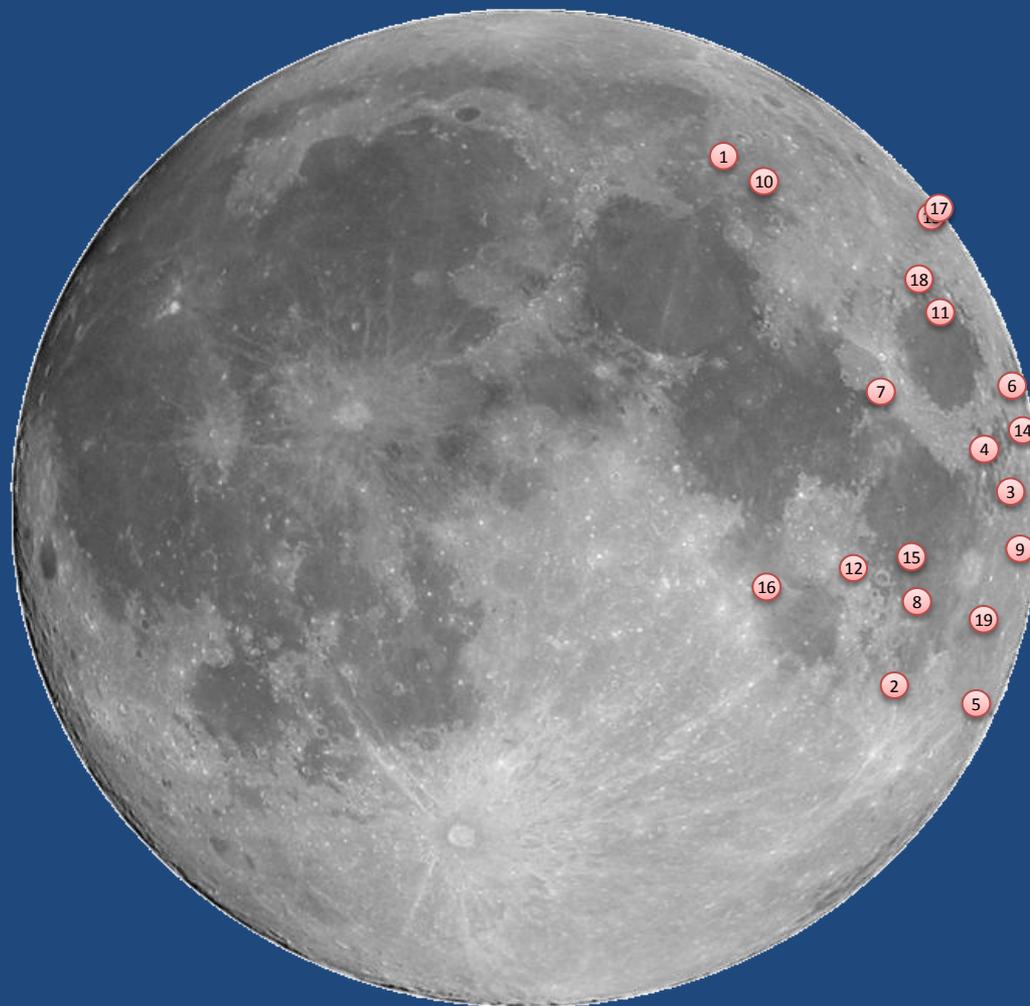
SD Video



Tower Video



2006 Geminids Observed Lunar Impacts



14 Dec 2006

- 4.6 hrs of video
- 16 Impacts
- 3-4 impacts / hr

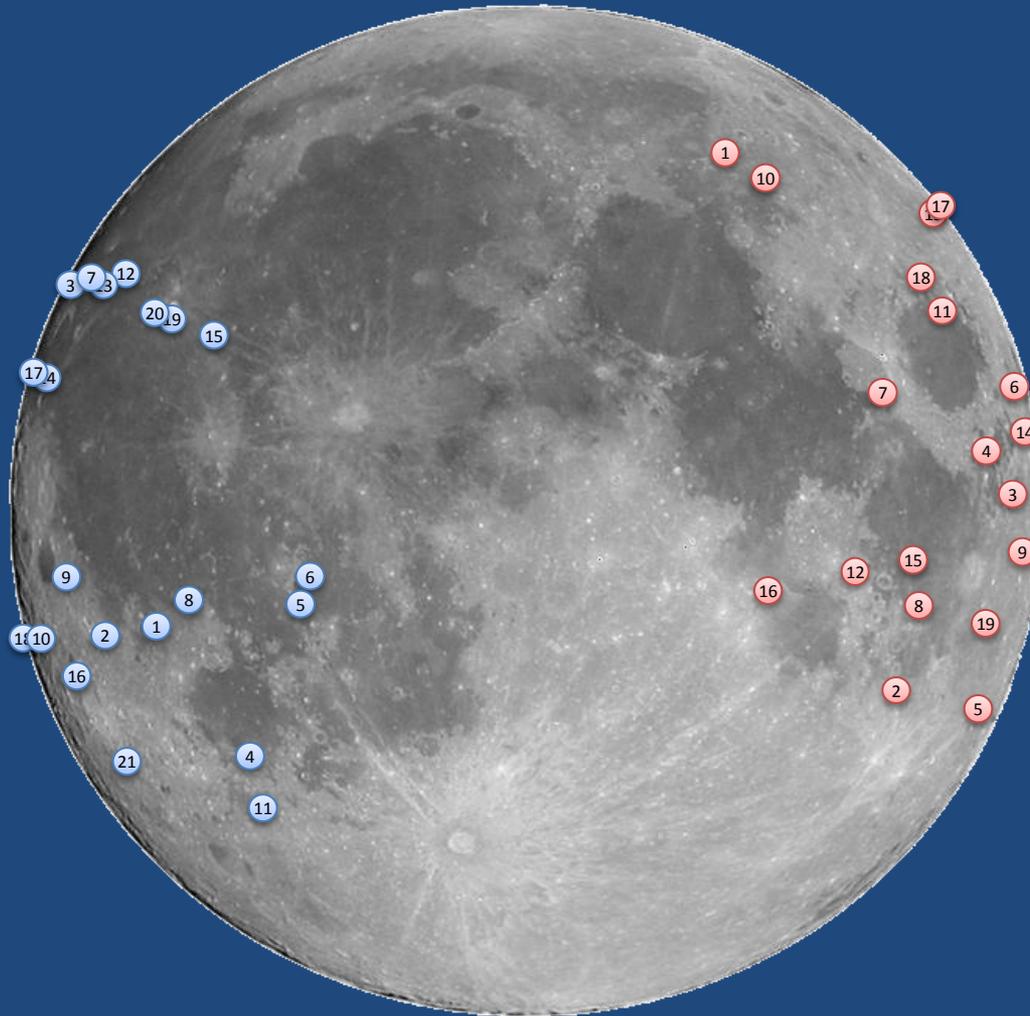
15 Dec 2006

- 2.3 hrs of Video
- 3 impacts
- 2-3 impacts / hr

Geminids 2006 & 2010 Lunar Impacts

14 Dec 2010

- 6.1 hrs of video
- 21 Impacts
- 3-4 impacts / hr



14 Dec 2006

- 4.6 hrs of video
- 16 Impacts
- 3-4 impacts / hr

15 Dec 2006

- 2.3 hrs of Video
- 3 impacts
- 1-2 impacts / hr

Summary

Lunar Observations were taken during the 2010 & 2006 Geminid showers.

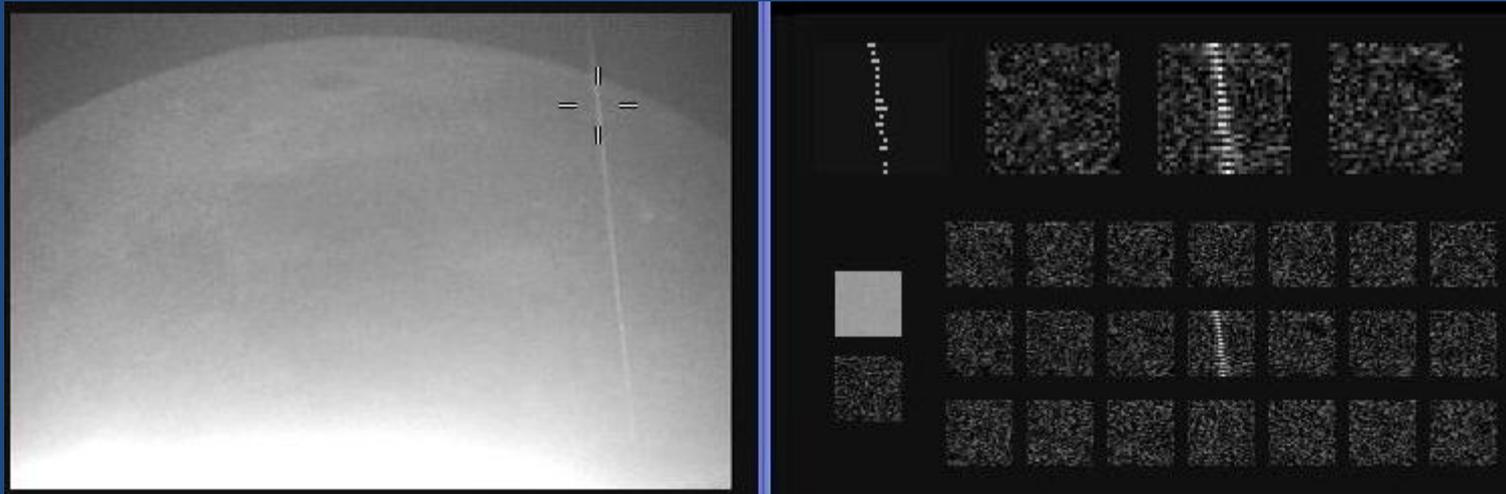
Similar Lunar impact rates were observed for both 2010 & 2006 Geminid showers.

Flash durations for the 2010 impacts were on average longer than the 2006 flash durations.

Lunar Meteor

14 Dec 2010

SD Video

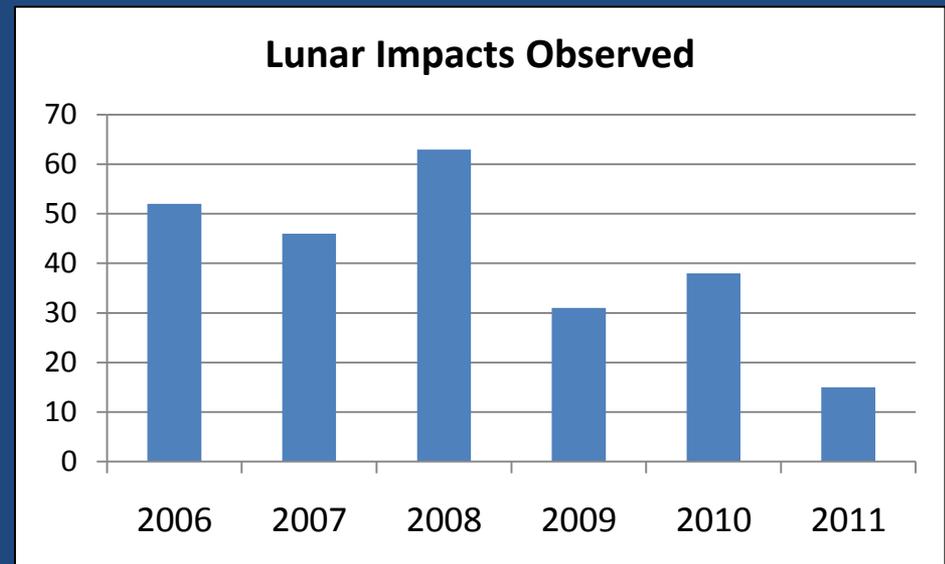
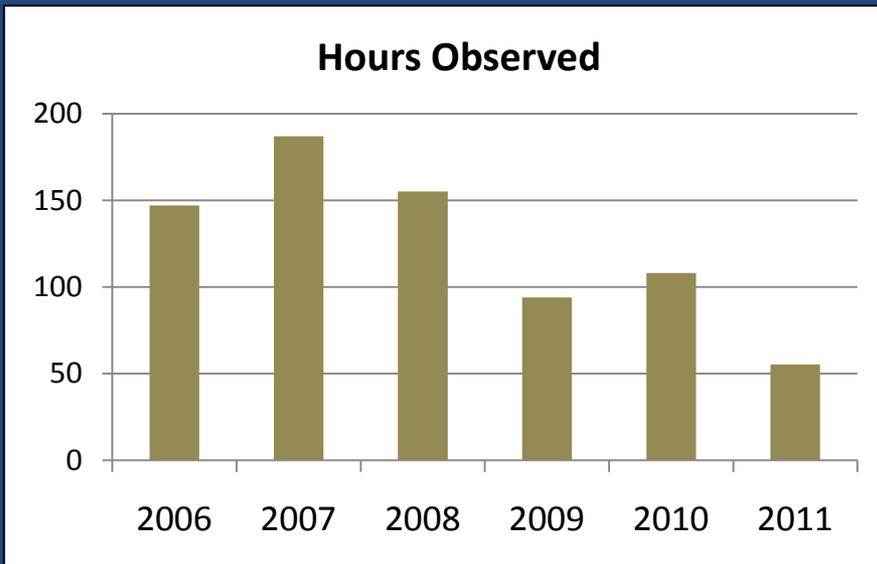
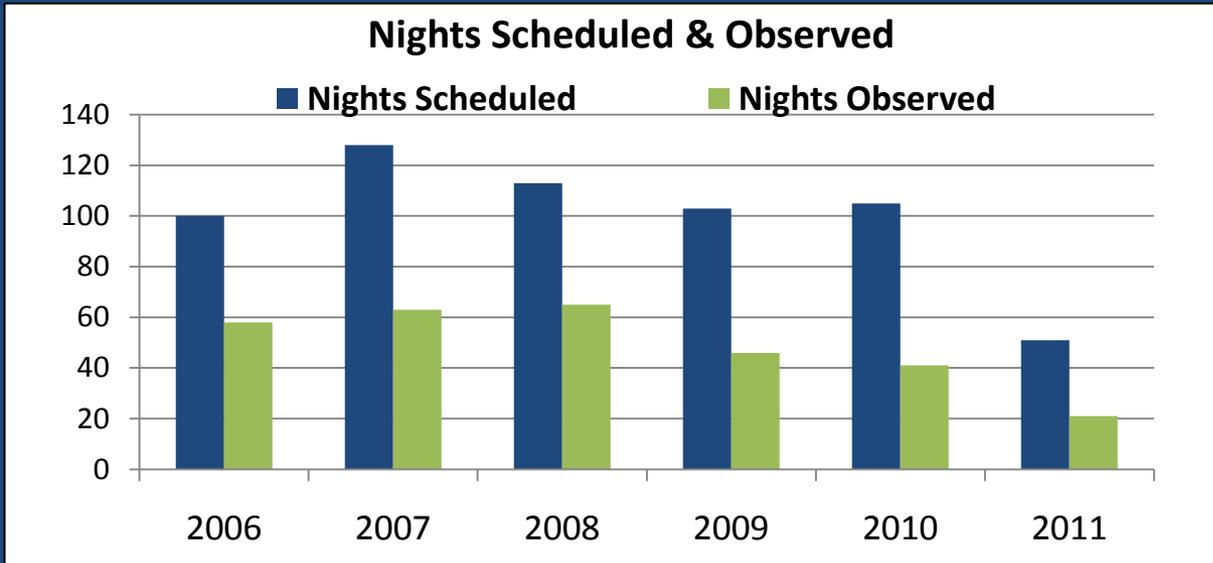


Tower Video



Backup Charts

Yearly Observing Statistics

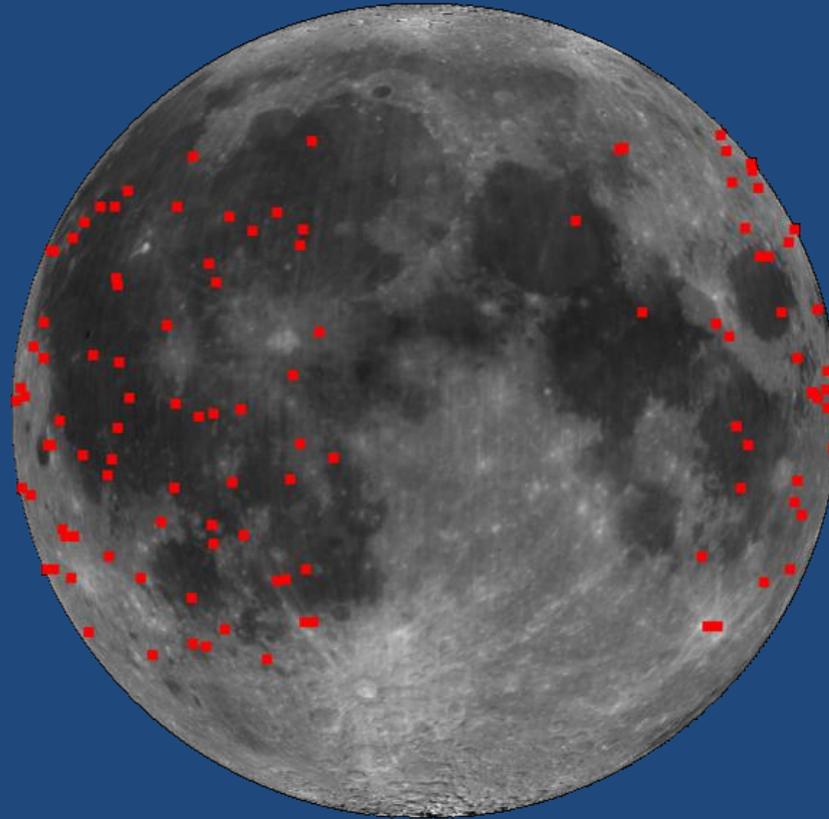


Approximately 3 Years of Analyzed Video Observations

- 548 hours of analyzed lunar video
- 212 hours of photometric quality
- 115 impacts retained out of 175

Evening Lunar Videos

- 277 hours total
- 118 hours retained
- 74 impacts retained out of 110



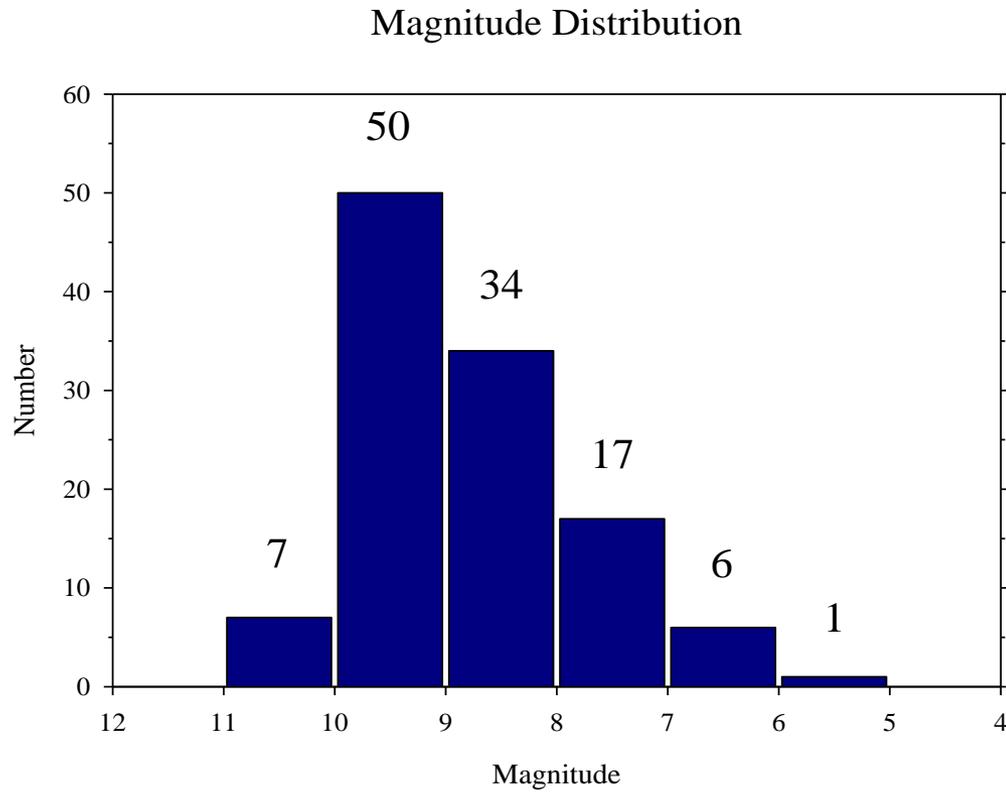
Morning Lunar Videos

- 271 hours total
- 94 hours retained
- 41 impacts retained out of 65

Summary of Analysis Results

- Total observing hours (photometric quality) = 212.4 hrs
- Total impacts in this period = 115
 - 108 to a magnitude completeness limit ~ 10th mag.
- Approximate detectable mass limit = 100g
- Average observing area = $3.8 \times 10^6 \text{ km}^2$
- Calculated Flux = $1.34 \times 10^{-7} \text{ km}^{-2} \text{ hr}^{-1}$
 - Evening $1.55 \times 10^{-7} \text{ km}^{-2} \text{ hr}^{-1}$
 - Morning $1.07 \times 10^{-7} \text{ km}^{-2} \text{ hr}^{-1}$
- Observed flux asymmetry = 1.45 : 1
- Modeled flux asymmetry from major and minor shower contributions during observation period = 1.57

Histogram of Flash Magnitudes



Shows completeness to approximately magnitude 10

MSFC Activities During the 2010 Geminids

NASA Web Chat

- NASA media event “Up All Night” chat.
- Allows public to ask questions of MSFC scientists through the night (3500+ questions).
- All-night chatters were Danielle Moser and Rhiannon Blaauw.
- Streamed live video of the shower to the web (~355,000 views)

Sky Observations

- Narrow Field Camera (Watec, 23° FOV)
 - UFO capture software
- All Sky Fireball Camera
 - ASGARD software

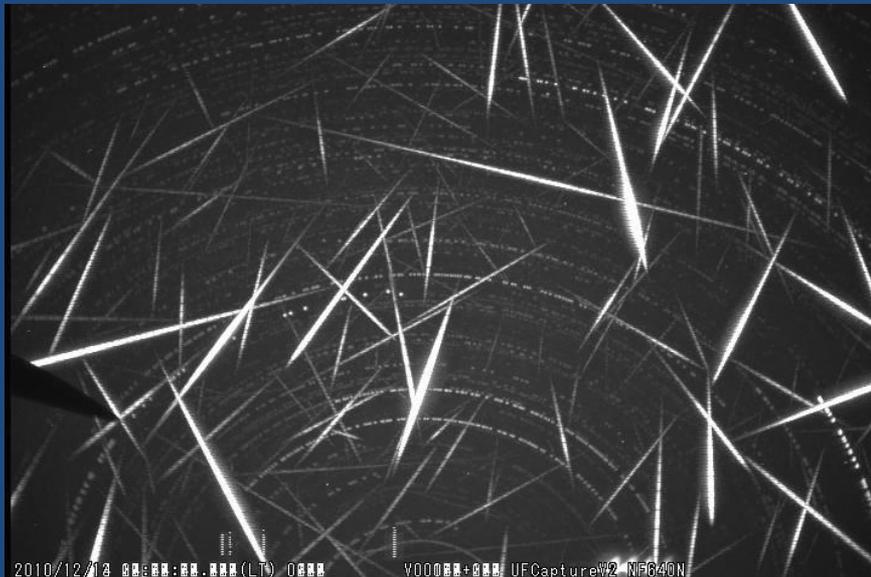
Lunar Observations

Sky Observations

14 Dec 2010

Intensified Camera

- 235 meteors
- 137 Geminids



All Sky Fireball Camera, Huntsville

- 102 single station meteors
- 18 double station Geminids

