

Abstract for Meteoroids 2007 – Barcelona, Spain
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NASA's Lunar Impact Monitoring Program

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NASA's Meteoroid Environment Office has implemented a program to monitor the Moon for meteoroid impacts from the Marshall Space Flight Center. Using off-the-shelf telescopes and video equipment, the moon is monitored for as many as 10 nights per month, depending on weather. Custom software automatically detects flashes which are confirmed by a second telescope, photometrically calibrated using background stars, and published on a website for correlation with other observations. Hypervelocity impact tests at the Ames Vertical Gun Facility have been performed to determine the luminous efficiency and ejecta characteristics. The purpose of this research is to define the impact ejecta environment for use by lunar spacecraft designers of the Constellation (manned lunar) Program. The observational techniques and preliminary results will be discussed.



The NASA Lunar Impact Monitoring Program

Dr. Rob Suggs

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and

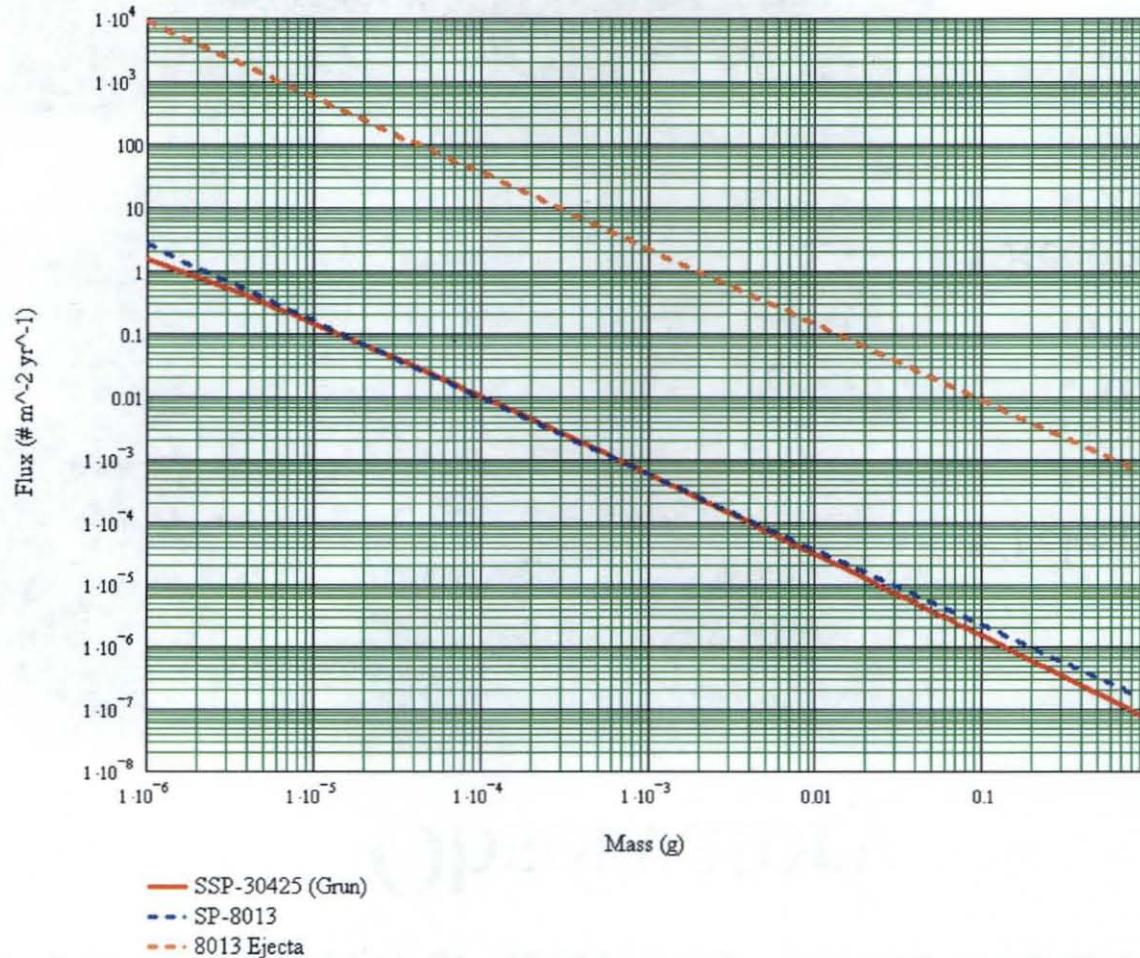
NASA Meteoroid Environment Office

11 June, 2007

Why are lunar impact monitoring and hypervelocity impact testing necessary?

- Constellation Program needs a spec for lunar impact ejecta
 - Existing spec is for Apollo – circa 1969
 - Astronauts will be exposed to this environment for months as opposed to hours.
- Flux of larger objects is poorly determined
- Production of ejecta particles is very poorly determined.
- We must:
 - Measure the flux and brightness of large impactors - ALAMO
 - Determine the luminous efficiency – fraction of impact kinetic energy which converts to light (which we observe) – Ames Vertical Gun Range
 - That gives the flux versus size of impactors
 - Measure the ejecta properties (mass, speed, direction distributions) and use hydrocode modeling to extend from test regime to lunar regime
 - Use model to fly the particles and estimate flux vs size and velocity at a lunar outpost.
- EV13 houses the Meteoroid Environment Office and the Constellation Environments and Constraints System Integration Group lead – we have the responsibility to do this job

Current (1969) Ejecta Model from SP-8013



Ejecta particles are 10,000 times as abundant as primaries of same size!
This curve is probably overly conservative.

Automated Lunar and Meteor Observatory



- Telescopes
 - 2 Meade RCX400 14" (355 mm)
 - Meade or Optec 0.33x focal reducer giving $\sim f2.6$
- Recording Devices
 - Astrovid Stellacam EX
 - Sony Digital 8 recorder as digitizer
 - Firewire to PC harddisk

Observing the Moon

- Dark (not sunlit) side only
 - Earthshine illuminates lunar features
 - FOV is approximately 20 arcmin – covering 4.5 to 5 million square km ~ 12% of the lunar surface
 - 12th magnitude background stars are easily visible at video rates
- Crescent and quarter phases – 0.1 to 0.5 solar illumination
 - 5 nights waxing (evening)
 - 5 nights waning (morning)
- Have taken data on about 55% of the possible nights. > 190 hours in the past year. Cirrus is our enemy.
- Observing procedure
 - Aim scope at Moon
 - Record video from StellaCam EX to hard drive
 - Wait and reposition – working on software to improve tracking of Meade scopes

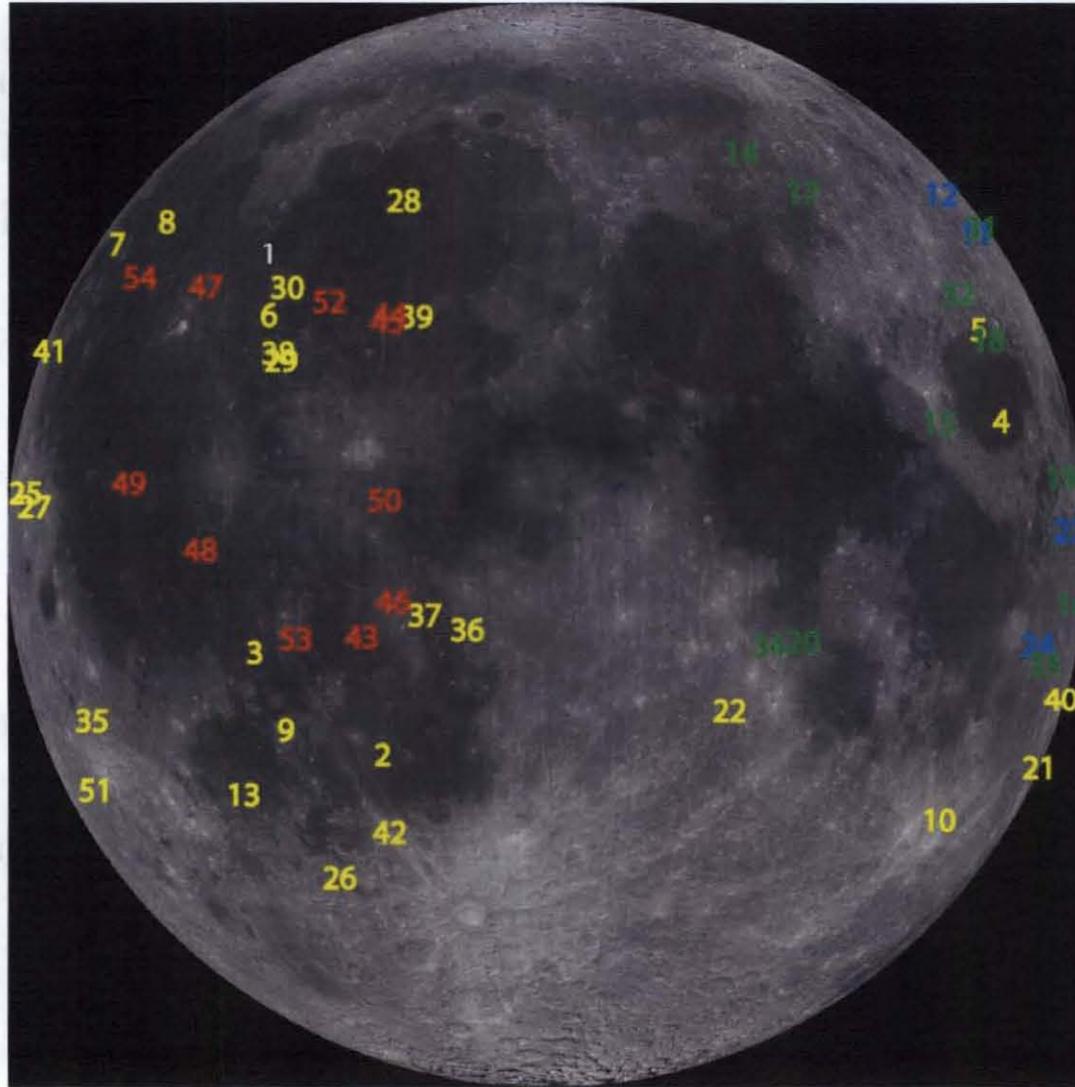


Probable Leonid Impact November 17, 2006



Video is slowed by a factor of 7

Impact Candidates

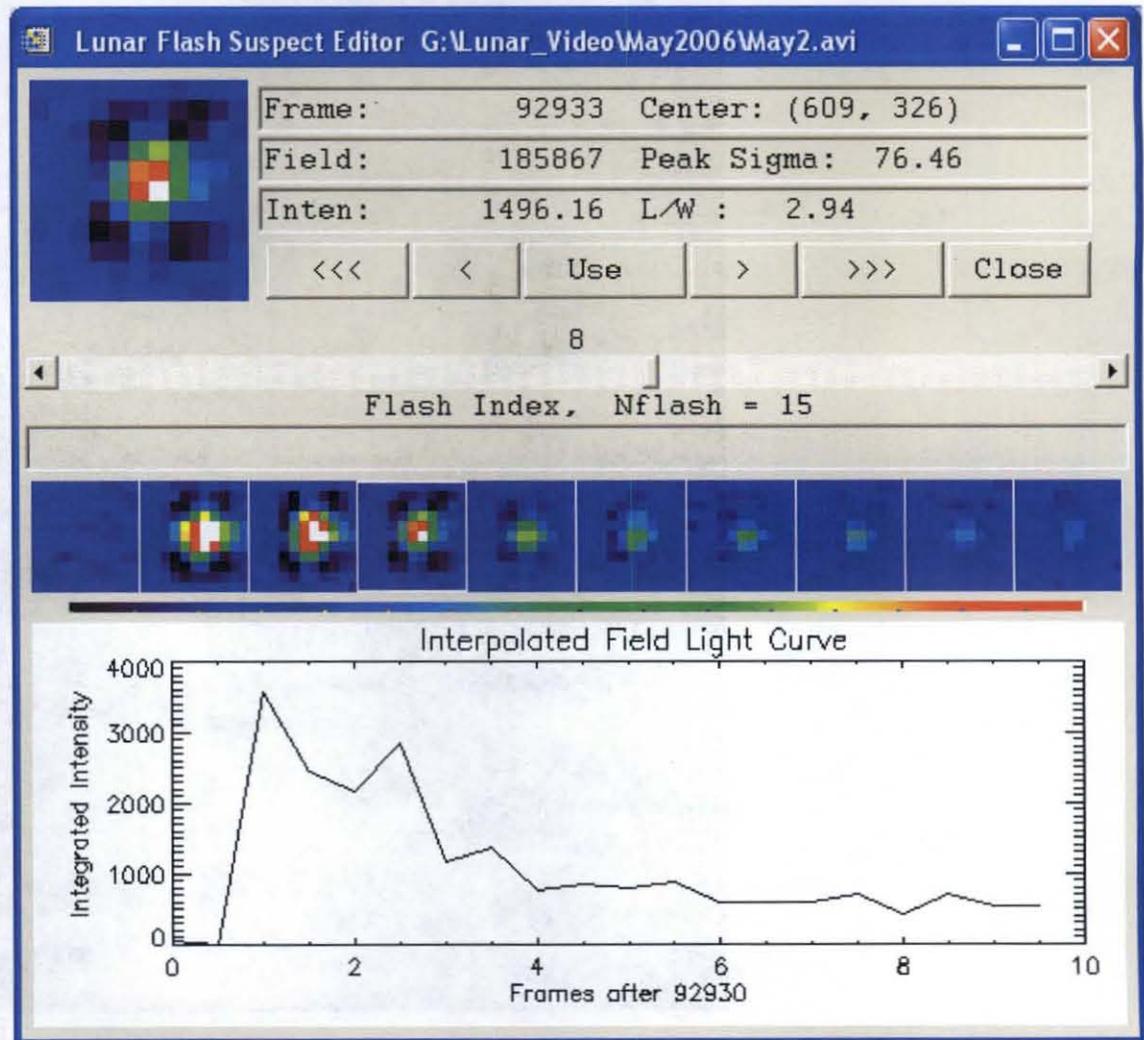


Yellow are sporadic background meteoroids

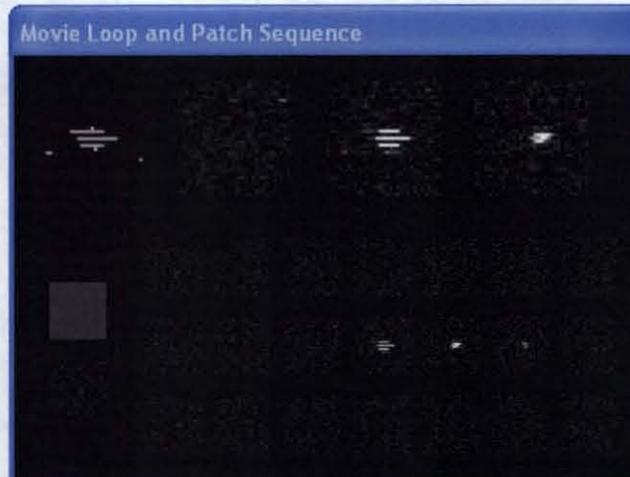
White is likely Taurid, green Geminids, blue Leonids, red Lyrids

The Usual Suspects

- Noise/cosmic rays
- Boundaries
- Stars
- Satellite glints
- Impacts !
- Establishing 2nd site to discriminate faint glints from orbital debris



LunarScan (Gural)



Impact 15 Dec 2006

```
LunarScan Window 3

Press CTRL-P to halt processing
- / =   Decr/Incr Movie Loop Speed
[ / ]   Decr/Incr Image Contrast

RETURN = Save 7 frame sequence, full
        image & thumbnail TIFs

ANY other key --> Next Image
```

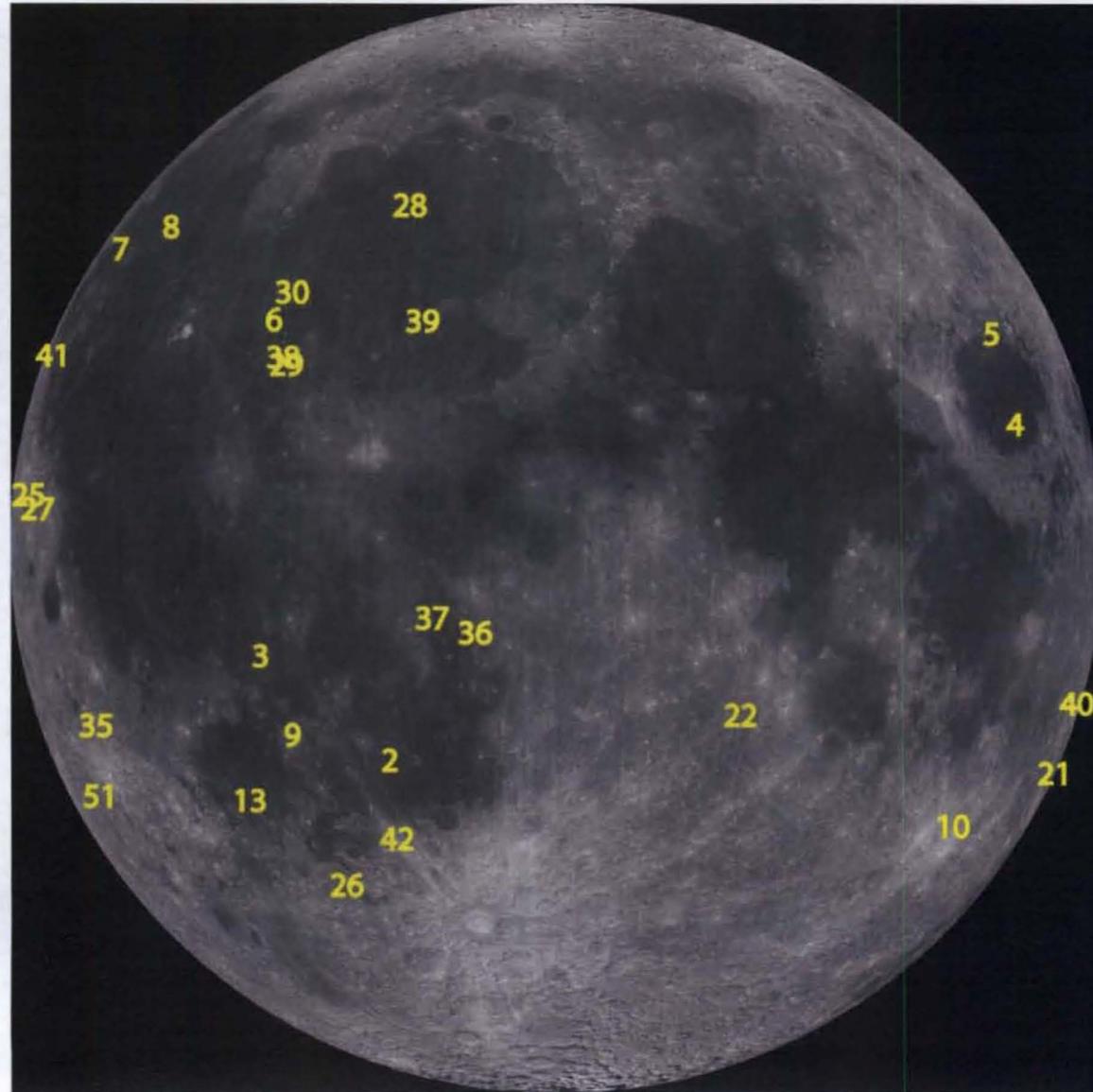
```
LunarScan Console Window

P = PLAY digitized video file
Q = QUIT Program

-----
Select a processing option:
#####
##### Review of Confirmed Data #####
#####
Enter the base filename: 15Dec2006_T
1 09:02:07 00:18:07 459 24 Frame# 32587
2 09:04:33 00:20:33 150 665 Frame# 36943
3 09:17:39 00:33:39 109 325 Frame# 60516
2 09:04:33 00:20:33 150 665 Frame# 36943
3 09:17:39 00:33:39 109 325 Frame# 60516
4 09:26:10 00:42:10 150 322 Frame# 75812
5 09:33:21 00:49:21 426 324 Frame# 88740
6 09:35:36 00:51:36 192 714 Frame# 92773
7 09:35:36 00:51:36 191 707 Frame# 92774
8 09:44:54 01:00:54 207 269 Frame# 109505
8 09:44:54 01:00:54 209 266 Frame# 109510
9 09:53:28 01:09:28 116 650 Frame# 124927
```

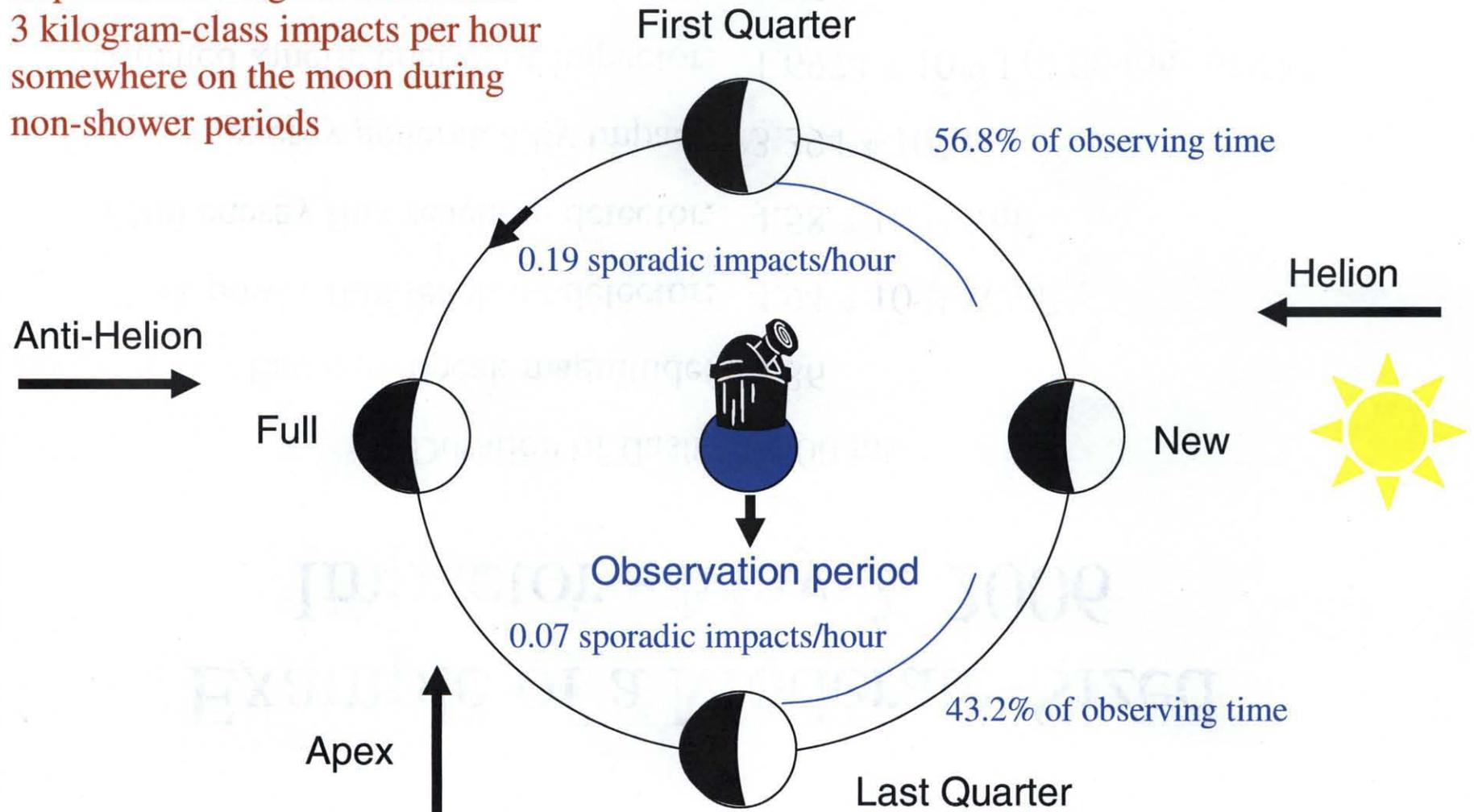
Photometric analysis is performed by LunaCon (Swift, poster paper)
Currently adding collecting area and “limiting magnitude” determination to
LunaCon

Probable Sporadic Impacts



Lunar Viewing and Impact Geometry from 3 Strongest Sporadic Sources

Implies an average of more than 3 kilogram-class impacts per hour somewhere on the moon during non-shower periods



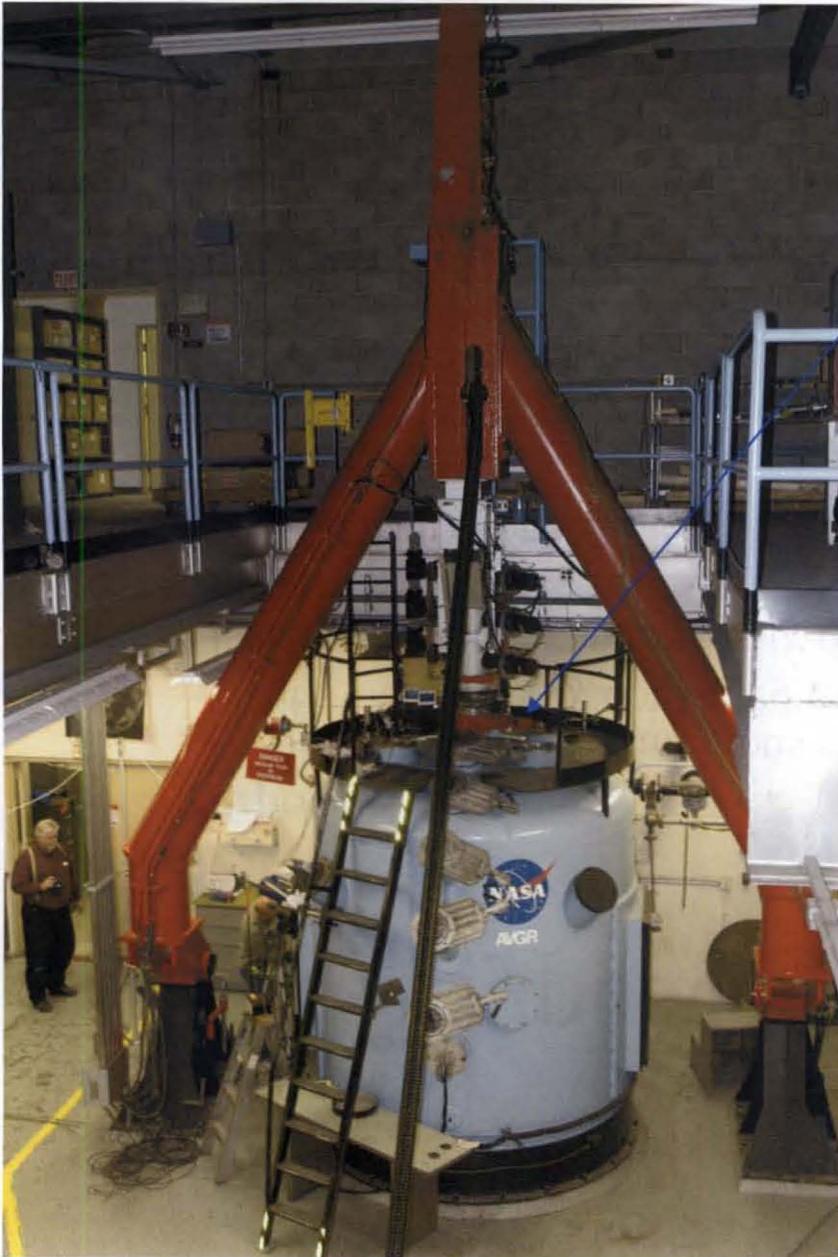
Example of a Moderate-Sized Impactor - May 2, 2006

Duration of flash:	~500 ms
Estimated peak magnitude:	6.86
Peak power flux reaching detector:	$4.94 * 10^{-11}$ W/m ²
Total energy flux reaching detector:	$4.58 * 10^{-12}$ J/m ²
Detected energy generated by impact:	$3.394 * 10^7$ J
Estimated kinetic energy of impactor:	$1.6974 * 10^{10}$ J (4.06 tons of TNT)
Estimated mass of impactor:	17.5 kg
Estimated diameter of impactor:	32 cm ($\rho = 1$ g/cm ³)
Estimated crater diameter:	13.5 m

Ames Hypervelocity Impact Testing

- Purposes
 - Determine impact luminous efficiency (in our camera passband) – fraction of kinetic energy converted to light
 - Determine size and velocity distributions of ejecta produced in cratering process
- These parameters are essential in defining the lunar design environment
- Fired 1/4 inch pyrex projectiles into pulverized pumice at various speeds and angles (2 – 6 km/sec)
- Preliminary testing completed in October '06 – funded exclusively by Meteoroid Environment Office (HQ OSMA sponsored)
 - Recorded impacts with our video cameras and Schultz's high speed photometer

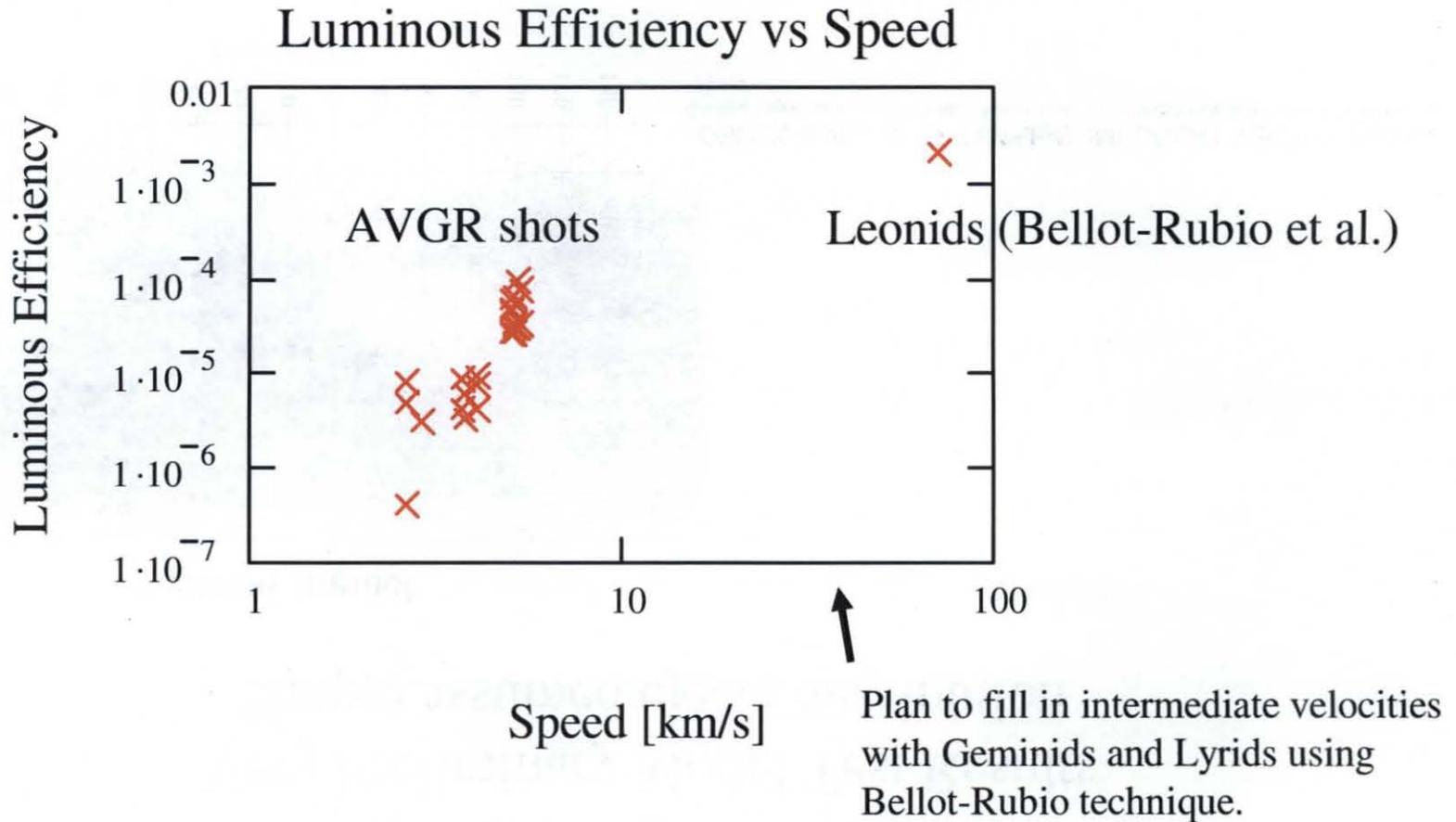
Ames Vertical Gun Range



Camera ports



Preliminary Results

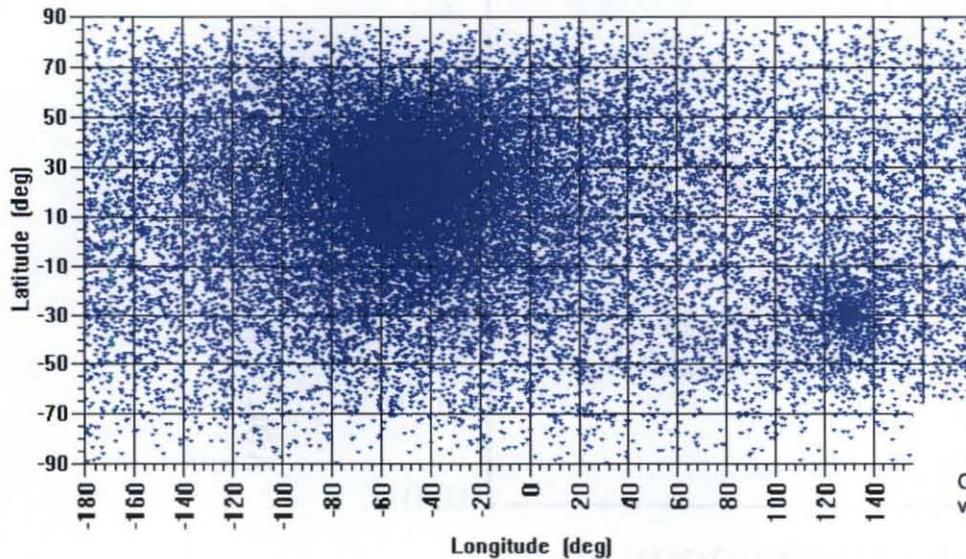


Ejecta Flight Model

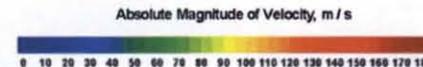
Very Preliminary Model Test Results

Simple assumed ejecta distribution

Vertical Impact



OBLIQUE VIEWS OF THREE-COMPONENT VECTOR PLOTS
Oblique impact captured at three different times. Vector colors indicate absolute magnitude of velocity



From Schultz et al. (2000)

Summary

- We have a fruitful observing program underway which has significantly increased the number of lunar impacts observed. We plan to continue for the foreseeable future.
 - Improving photometric analysis software
 - Adding 2nd site to discriminate geosynchronous orbital debris
 - Engaging amateur community by porting LunarScan to PC platform
 - Already have one confirmed impact observed by amateur with 8 inch telescope
 - Website
 - www.nasa.gov/centers/marshall/news/lunar/index.html
- We have done initial test shots at the Ames Vertical Gun Range – obtained preliminary luminous efficiency values
 - More shots and better diagnostics are needed to determine ejecta velocity distributions
- Development has begun on a model to lash together the primary impactor flux and ejecta distribution models to give the ejecta flux and size/velocity distributions at any landing site
- We are working to have a more accurate ejecta environment definition to support lunar lander, habitat, and EVA design

References

- 1) Bellot Rubio, L. R., Ortiz, J. L., and Sada, "Observation And Interpretation Of Meteoroid Impact Flashes On The Moon", *Astron. Astrophys.* 542, L65–L68.
- 2) Cooke, W.J. Suggs, R.M. and Swift, W.R. "A Probable Taurid Impact On The Moon", Lunar and Planetary Science XXXVII (2006)), Houston, Texas, LPI, paper 1731
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- 4) Dunham, D. W. et al, "The First Confirmed Video recordings Of Lunar Meteor Impacts.", *Lunar and Planetary Science Conference XXXI* (2000), Houston, Texas, LPI, Paper 1547
- 5) Gural, Peter, "Automated Detection of Lunar Impact Flashes", 2007 Meteoroid Environments Workshop, MSFC, Huntsville, Alabama, January 2007
- 6) Ortiz, J.L. et al., "Detection of sporadic impact flashes on the Moon: Implications for the luminous efficiency of hypervelocity impacts and derived terrestrial impact rates", *Icarus* 184 (2006) 319–326
- 7) Swift, W. R. "LunaCon - Software to detect lunar impacts" ,2007 Meteoroid Environments Workshop, MSFC, Huntsville, Alabama, January 2007
- 8) McNamara, H. et al., "Meteoroid Engineering Model (MEM): A Meteoroid Model for the Inner Solar System", *Earth, Moon, and Planets* (2004), 95: 123-139.

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