Flux of Kilogram-sized Meteoroids from Lunar Impact Monitoring


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Routine lunar impact monitoring has harvested over 110 impacts in 2 years of observations using 0.25, 0.36 and 0.5 m telescopes and low-light-level video cameras. The night side of the lunar surface provides a large collecting area for detecting these impacts and allows estimation of the flux of meteoroids down to a limiting luminous energy. In order to determine the limiting mass for these observations, models of the sporadic meteoroid environment were used to determine the velocity distribution and new measurements of luminous efficiency were made at the Ames Vertical Gun Range. The flux of meteoroids in this size range has implications for Near Earth Object populations as well as for estimating impact ejecta risk for future lunar missions.
The Flux of Kilogram-sized Meteoroids from Lunar Impact Monitoring


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Abstract

Routine lunar impact monitoring has translated over 150 impacts in just over 2 years of observations with the Lunar Video Camera. The near-synchronous orbit of the Next-Generation Lunar Observatory (NextGen) over the Moon permits monitoring impacts at the lunar surface. Imaging and digital processing techniques used to determine the velocity distribution and character of the impact ejecta. The flux of meteoroids in size range that has implications for near Earth Object populations as well as for estimating impact energy for future lunar landers.

Background

Measuring the flux of large meteoroids requires a large collecting area due to their relatively low density. Large field-of-view cameras can provide the necessary exposure times to detect the impact flashes at the expected rates. The technique of the previous program has recorded over 150 impacts in just over 2 years of operation. The primary purpose of this program is to improve the understanding of the lunar impact environment in support of the Constellation Program plans to return astronauts to the Moon. The size of kilogram-sized meteoroids is an important implication for the population of near Earth Objects. The poster describes the observational techniques and data analysis processes used to determine the velocity distribution of the impactors. The luminous efficiency and derived terrestrial impact rates are presented. A comparison of the derived mass flux with that of Grün (1985) shows good agreement within the margin of error. In this case it is suggested that the flux may be higher due to significant shower contamination in these data. The implication for the luminous efficiency of hypervelocity impacts and derived terrestrial impact rates are presented.

Impact Data and Determination of Flux

The image above shows the total number of impacts used in the calculations. A single camera observes the lunar surface in July 2005. The data is compared to the 10-hr video data from July 2007. The number of impacts recorded drops at a rate of 3%/month, and this is caused by the "missing" events. The average luminous area per video is 3.3 x 10^4 km^2. This is approximately 9% of the total lunar surface.

Determination of the Luminous Efficiency and Mass Limit

To determine the limiting mass for these observations we must first determine the luminous efficiency. In the case of meteoroids of sufficient size the impact flash may be visible to the naked eye. One approach to determine the mass limit is to model the impact flash with a hemispherical source. The luminous efficiency can be approximated with the equation:

\[ \eta = \frac{3.3 \times 10^4 \text{km}^2}{10 \text{hr}} = 6 \times 10^9 \text{km/s} \]

Where \( \eta \) is the luminous efficiency and \( \eta \) is the luminous flux.

Comparison with Other Flux Determinations

The derived mass flux is compared with that of Grün (1985) using good agreement within the margin of error. In this case it is suggested that the flux may be higher due to significant shower contamination in these data.

References


Examples of references include:

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Bill Cooke
NASA Meteoroid Environment Office
September 27, 2008
Why Lunar Impact Monitoring is Useful

• We started this work in earnest 2 years ago to provide a better estimate of the ejecta environment for Constellation lunar elements.

• It turns out that it is also useful for calibration of MEM for large (kg) masses.
Why are lunar impact monitoring and hypervelocity impact testing necessary for Constellation?

• Constellation Program needs a specification 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 (kilogram size) 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 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.
• EV44 houses the Meteoroid Environment Office and the Constellation Environments and Constraints System Integration Group lead – we have the responsibility to do this job
"NASA Apollo 17 transcript" discussion is given below (before descent to lunar surface):

---------------------03 15 38 09 (mission elapsed time)
(10 Dec 1972, 21:16:09 UT – possible Geminid)

LMP Hey, I just saw a flash on the lunar surface!

CC Oh, yes?

LMP It was just out there north of Grimaldi [mare]. Just north of Grimaldi. You might see if you got anything on your seismometers, although a small impact probably would give a fair amount of visible light.

CC Okay. We'll check.

LMP It was a bright little flash right out there near that crater. See the [sharp rimed] crater right at the [north] edge of [the] Grimaldi [mare]? Then there is another one [i.e., sharp rimed crater] [directly] north of it [about 50km]- fairly sharp one north of it. [That] is where there was just a thin streak [pin prick] [flash?] of light.

CC How about putting an X on the map where you saw it?

LMP I keep looking for -- yes, we will. I was planning on looking for those kind of things....
Current (1969) Ejecta Model from SP-8013

Ejecta particles are 10,000 times as abundant as primaries!
This curve is unphysical.
Impact Observation Technique

• Dark (not sunlit) side only
  • Earthshine illuminates lunar features

• Crescent and quarter phases – 0.1 to 0.5 solar illumination
  • 5 nights waxing (evening)
  • 5 nights waning (morning)

• 4-6 nights of data a month, weather dependent

• 3 telescopes
  • 20 inch (0.5m) and 2 x 14 inch (0.35m)
  • StellaCam EX and Watec H2 cameras

• Observing procedure
  • Aim scope at Moon
  • Record video to harddrive
    • CCD camera → Digital 8 recorder → hard drive
  • Wait and reposition
Automated Lunar and Meteor Observatory
0.5m in dome on left, 0.35m in tower
20 inch (0.5m) RCOS
Walker County Observatory
Meade 14 in (0.35m)
Control Room
Operator position
Probable Leonid Impact
November 17, 2006

Video is slowed by a factor of 7
Video of multiple impacts
LunarScan (Gural)

Impact 15 Dec 2006
Data Analysis Pipeline

LunarScan finds flashes

LunaCon
flash photometry
collecting area,
detection limit,
time on target of all video

Data collection and telescope control

Must detect flash in all operating telescopes
The Usual Suspects

- Noise
- Boundaries
- Stars
- Satellite glints
- Impacts
- Established WCO site to discriminate faint glints from orbital debris
Atlas-Centaur Debris
16 Dec. 2006
Half real-time
Impact Candidates – over 100 now

Yellows are sporadic meteoroids
Other colors are probable shower meteoroids
Sporadics Only thru March 08

Evening obs
45 impacts
in approx.
93 hours

Morning obs
14 impacts
in approx.
99 hours
Lunar Viewing and Impact Geometry from 3 In-plane Sporadic Sources

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

First Quarter
- 0.48 sporadic impacts/hour
- 93.6 hours of good video
- 48.6% of observing time

New
- 0.14 sporadic impacts/hour
- 98.8 hours of good video
- 51.4% of observing time

Anti-Helion 24 km/s

Full

New

Helion 24 km/s

“No see-ums”
Example of a Moderate-Sized Impactor - May 2, 2006

Duration of flash: ~500 ms

Estimated peak magnitude: 6.86

Peak power flux reaching detector: $4.94 \times 10^{-11}$ W/m²

Total energy flux reaching detector: $4.58 \times 10^{-12}$ J/m²

Detected energy generated by impact: $3.394 \times 10^7$ J

Estimated kinetic energy of impactor: $1.6974 \times 10^{10}$ J (4.06 tons of TNT)

Estimated mass of impactor: 17.5 kg

Estimated diameter of impactor: $32$ cm ($\rho = 1$ g/cm³)

Estimated crater diameter: 13.5 m
Ames Hypervelocity Impact Testing

• Purposes
  – Determine impact luminous efficiency – fraction of kinetic energy converted to light (completed 2 sessions of tests for this)
  – Determine size and velocity distributions of ejecta produced in cratering process
• Fired pyrex projectiles into pulverized pumice and JSC-1A simulant at various speeds and angles
• Preliminary testing completed in October ‘06
  – Recorded impacts with our video cameras and Schultz’s high speed photometer using ground pumice
• Second test sequence completed August ’07
  – True neutral density filters on our video cameras using JSC-1A simulant
Ames Vertical Gun Range

Camera ports
AVGR - Shot 10

Projectile: 0.25" Pyrex
Target: Pumice Powder
Speed: 5.32 km/s
45 deg. impact angle
AVGR Run 070823
Crater in JSC-1A Simulant
Preliminary Results
using “not so neutral” density filters

![Graph showing speed vs. luminous efficiency for different datasets: Nemtchinov et al. LPSC XXIX, Bellot-Rubio et al. 2000, and MSFC AVGR tests 9/06.](image-url)
Next Step – Measure Ejecta Properties

- Designers need speed, size, and direction distributions to optimize meteoroid shielding designs
- Very high speed camera or sheet laser measurements of hypervelocity shots are needed to determine these characteristics
- Modeling to scale from AVGR tests to lunar sizes and velocities
Stopping time: watching craters grow
170 millionths of second

Schultz, et al.
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)
Plans

• Continue impact monitoring into the foreseeable future
  – Perhaps add an infrared camera since flashes peak redward of 1 micron
• Observe LCROSS impact from Apache Point Observatory
  – 3.5m and one of our 14 inch scopes to measure ejecta plume
• Complete analysis of observational data and present at DPS this October
• Analyze latest AVGR photometric data to determine luminous efficiency at low speed/size
  – Previous data was taken with “non-neutral” neutral density filters
• If/when Constellation funding becomes available, begin ejecta characterization and modeling tasks and develop engineering model of the ejecta environment
Summary

• We have a fruitful observing program underway which has significantly increased the number of lunar impacts observed
• 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 properties
• We are working to have a more accurate ejecta environment definition to support lunar lander, habitat, and EVA design
• Data also useful for validation of sporadic model at large size range
Useful Links

- **MEO**  [http://meo.nasa.gov](http://meo.nasa.gov)