The NASA Lunar Impact Monitoring Program

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and
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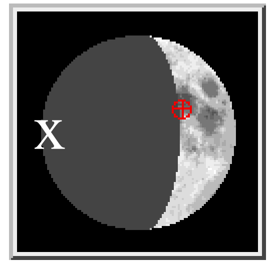
Why Lunar Impact Monitoring is Useful

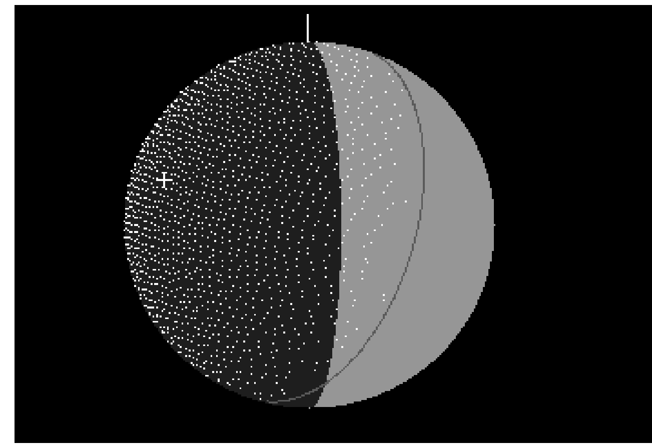
- We started this work in earnest 2 years ago to provide a better estimate of the ejecta environment for Constellation lunar elements.
- It turns out that it is also useful for calibration of MEM for large (kg) masses.

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

Jack Schmitt/Apollo 17 observation of lunar impact





Geminids 12/13/1972

"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.

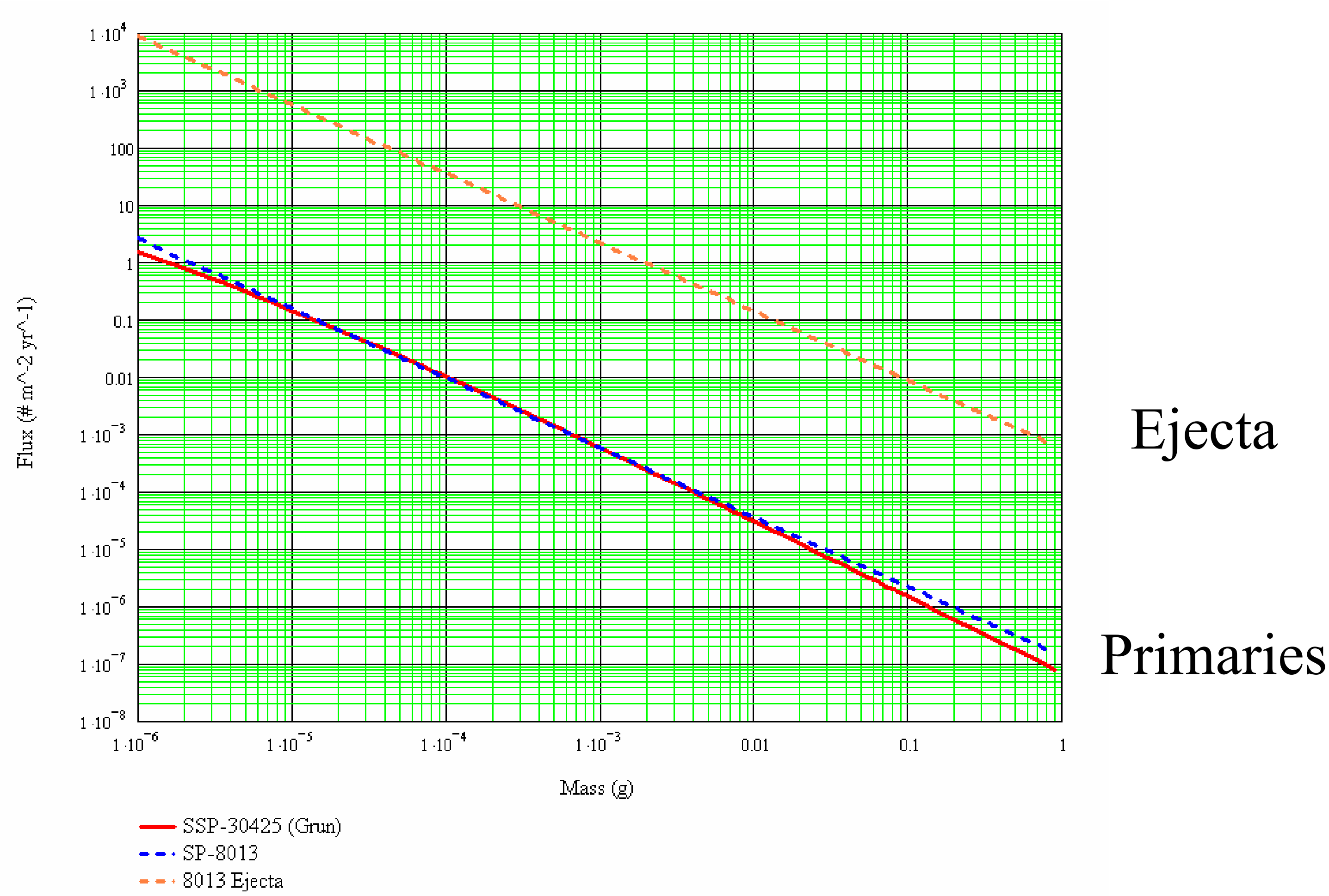
CC Okay. We'll check.

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

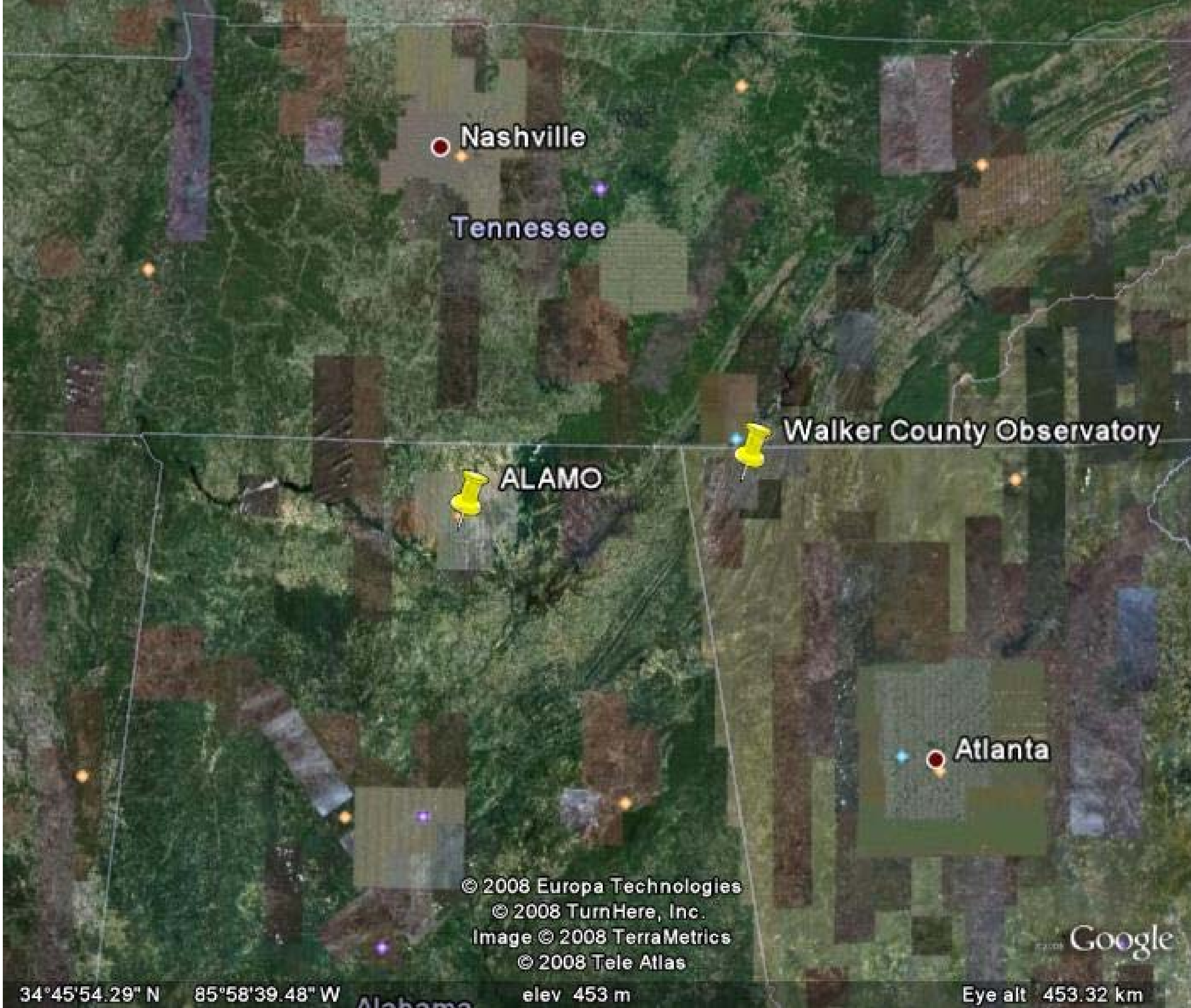

Nashville
Tennessee
Walker County Observatory
ALAMO
Atlanta
© 2008 Europa Technologies
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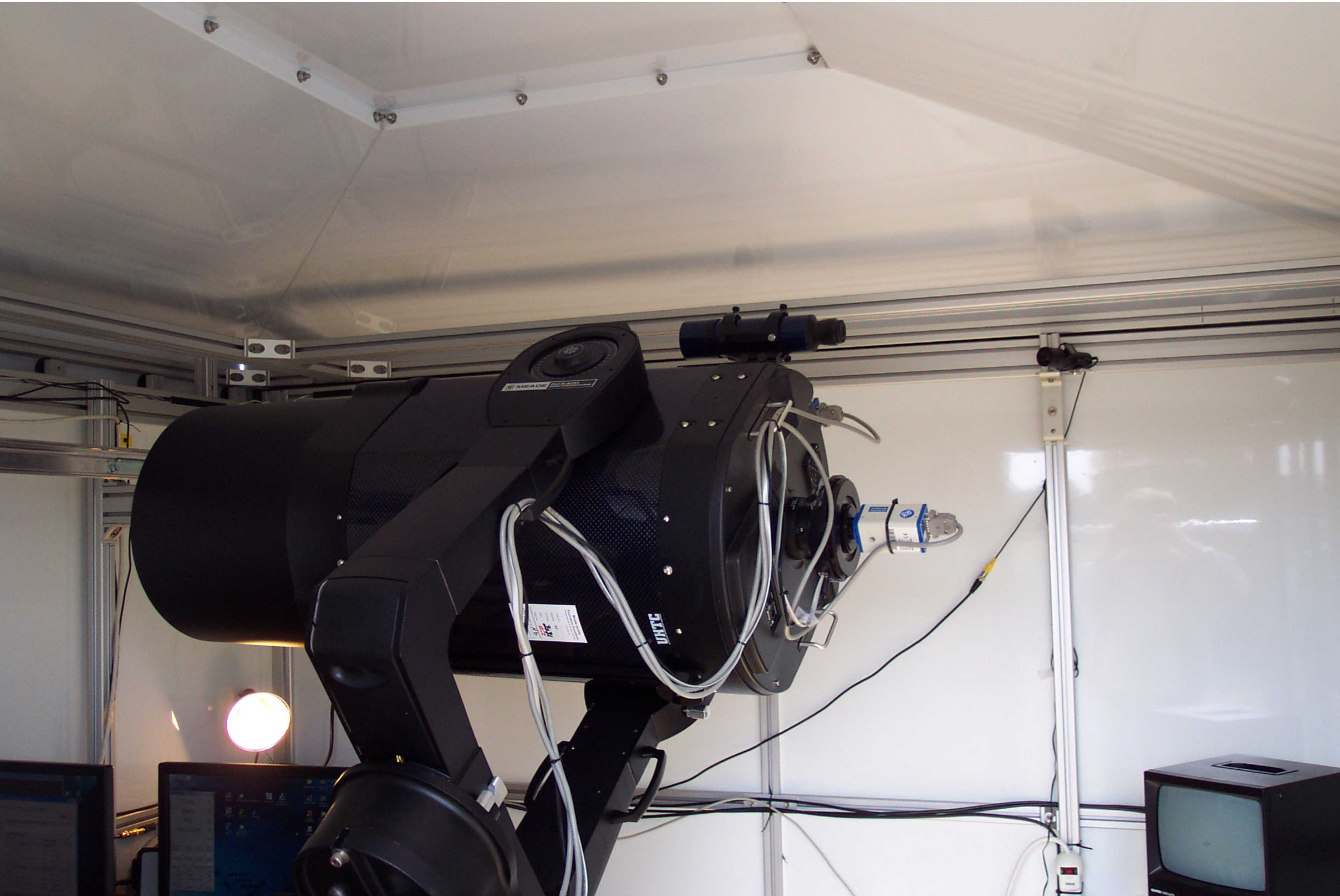
Image © 2008 TerraMetrics
© 2008 Tele Atlas
Google
34°45'54.29" N
85°58'39.48" W
elev 453 m
Eye alt 453.32 km

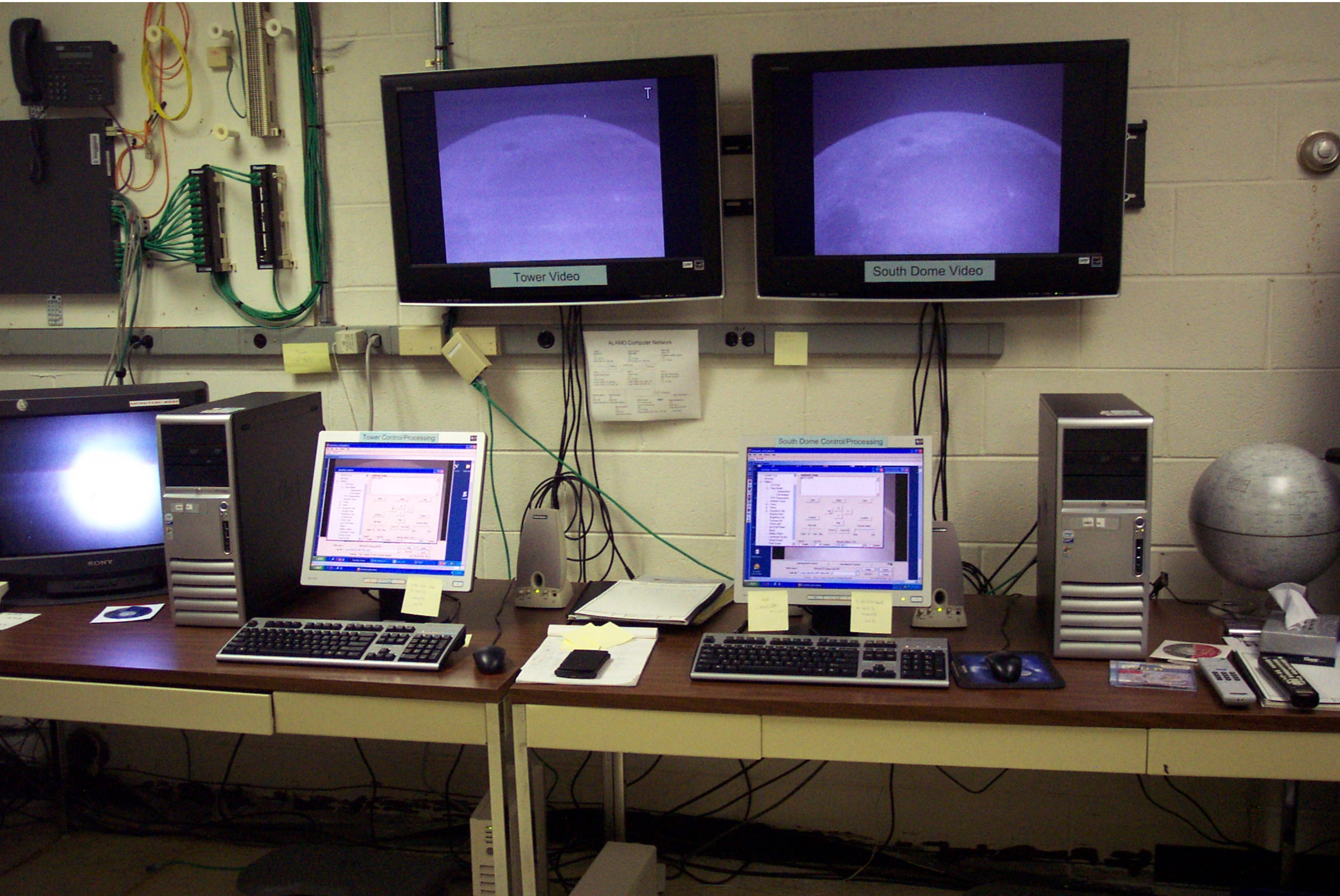
Walker County Observatory

Meade 14 in (0.35m)

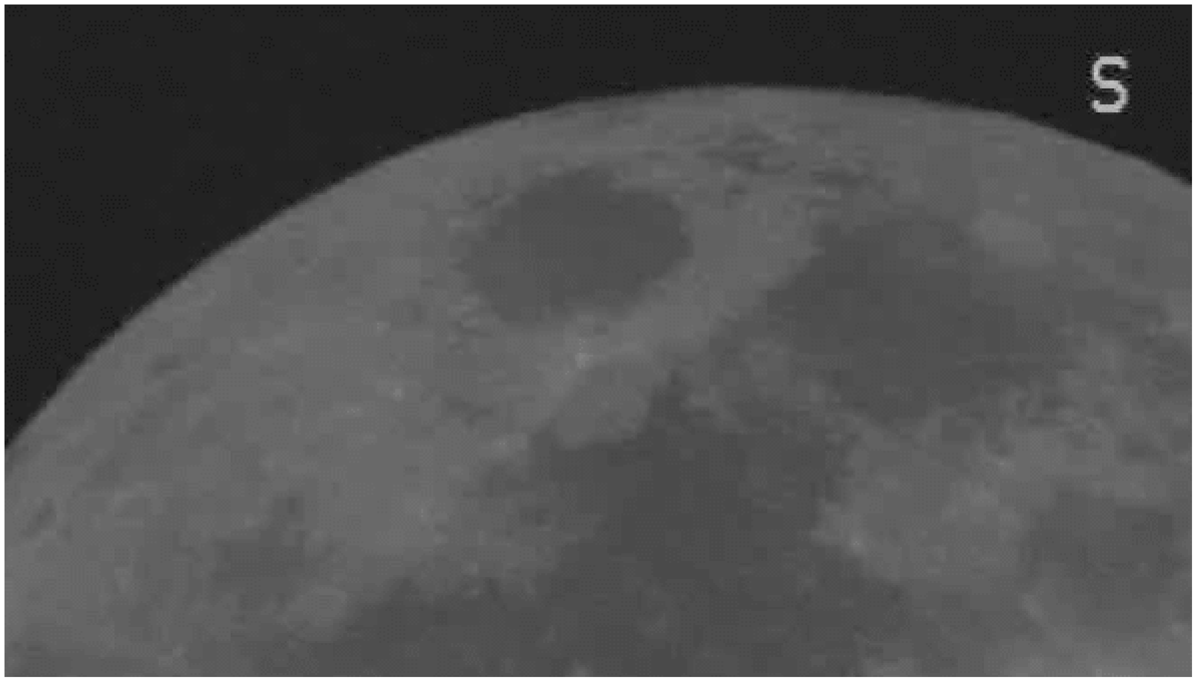


Control Room

Operator position



Probable Leonid Impact
November 17, 2006

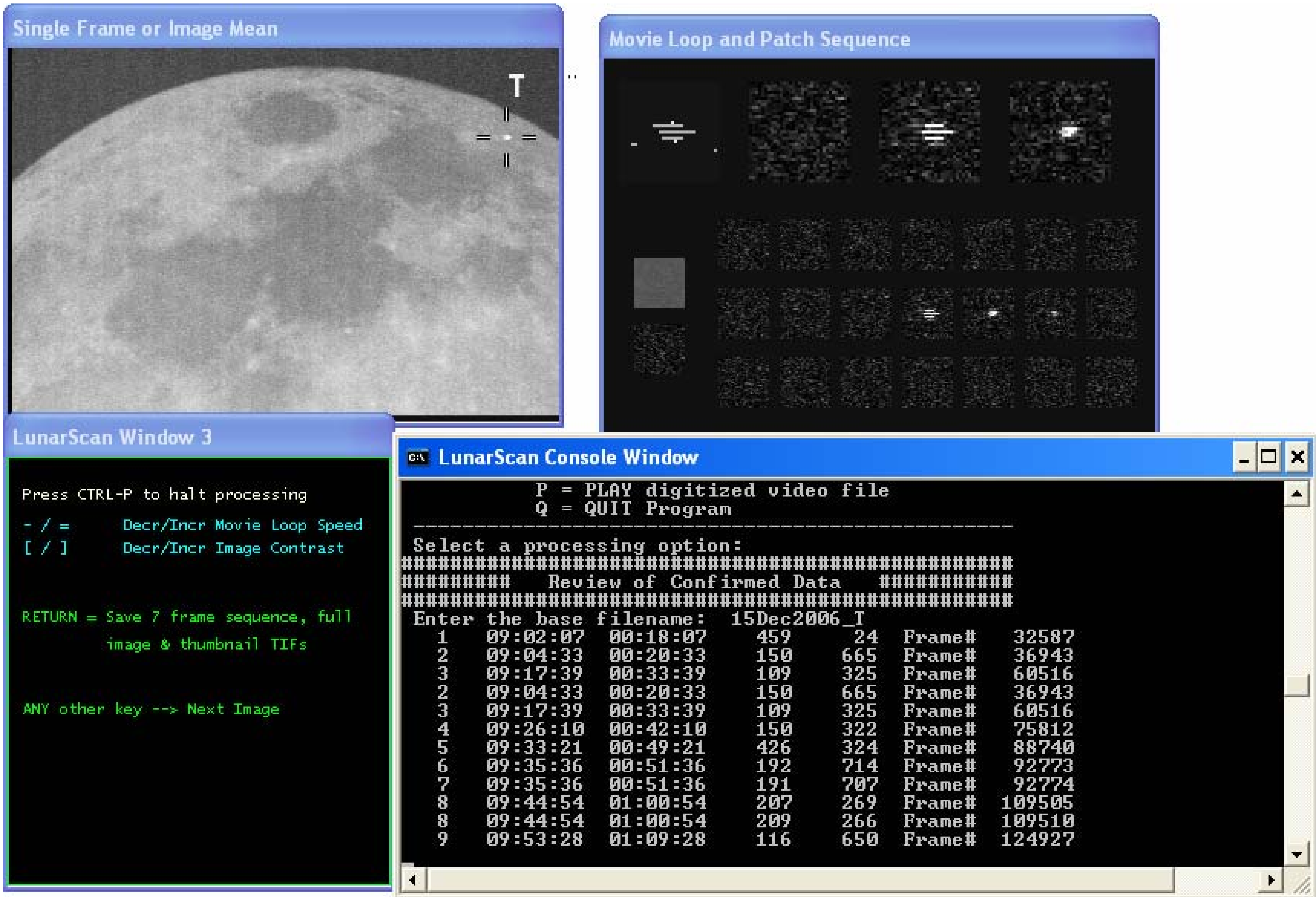


Video is slowed by a factor of 7

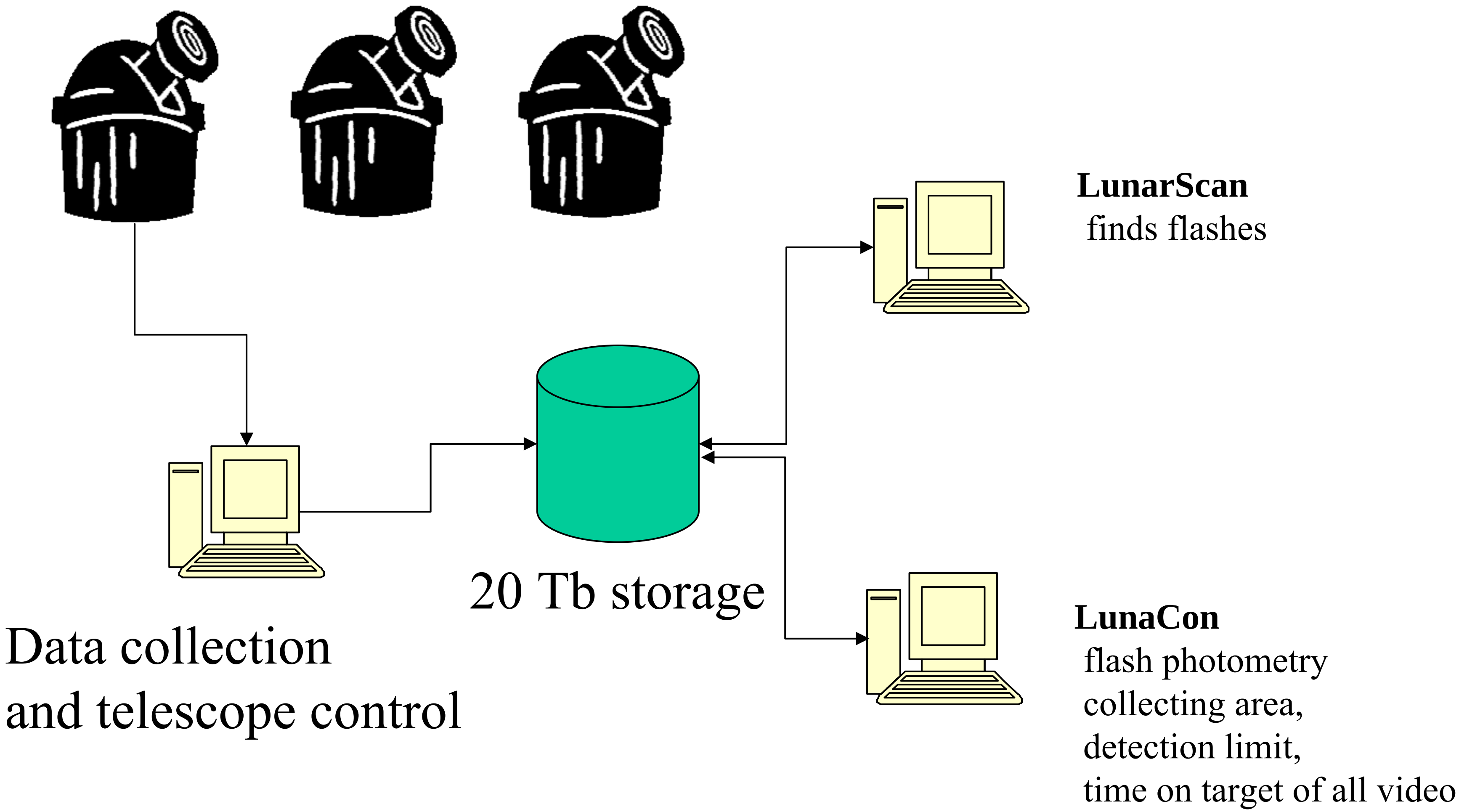
Video of multiple impacts

LunarScan (Gural)

Impact 15 Dec 2006



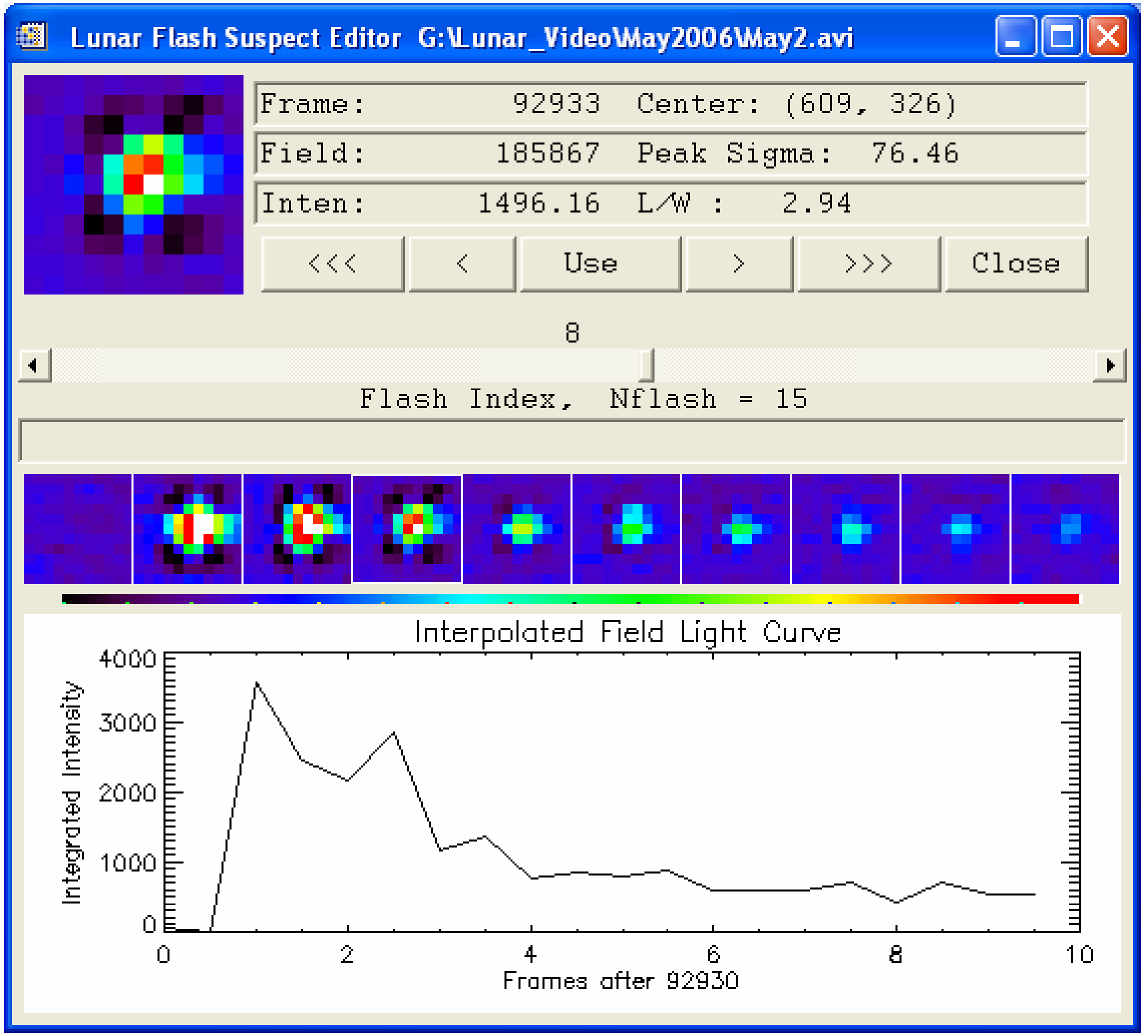
Data Analysis Pipeline



Must detect flash in all operating telescopes

The Usual Suspects

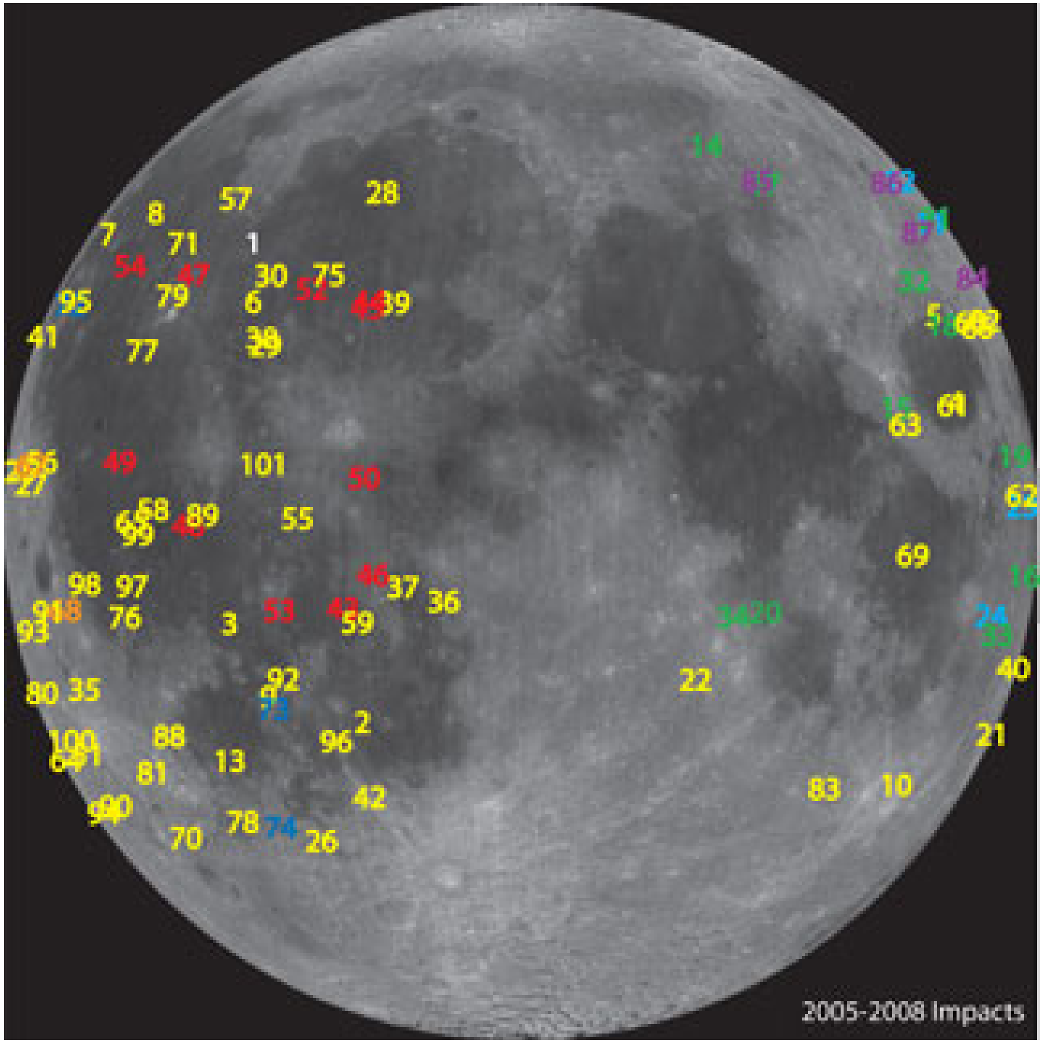
- Noise
- Boundaries
- Stars
- Satellite glints
- Impacts
- Established WCO site to discriminate faint glints from orbital debris



Atlas-Centaur Debris
16 Dec. 2006

Half real-time

Impact Candidates – over 100 now



Yellows are sporadic meteoroids
Other colors are probable shower meteoroids

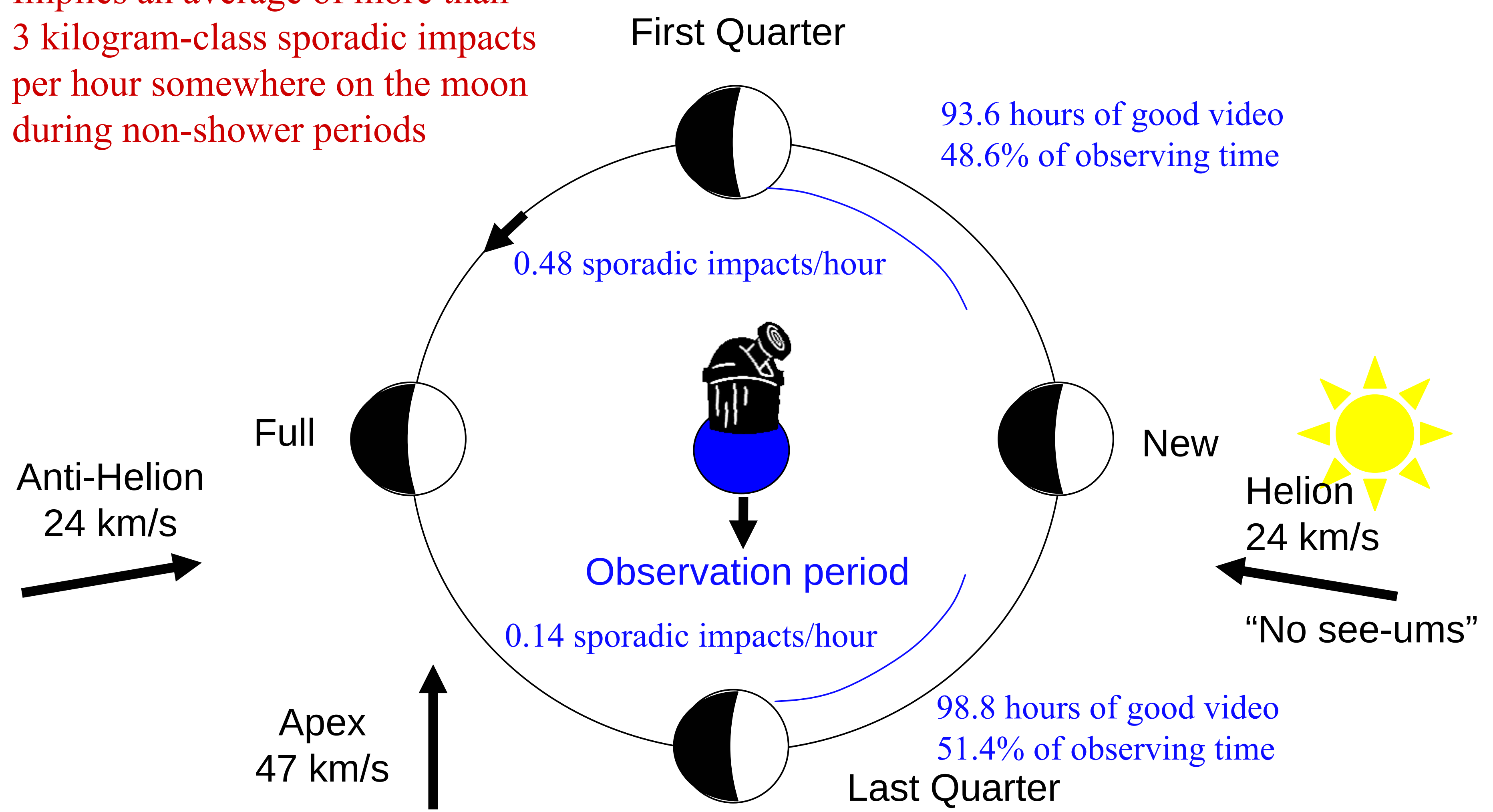
Sporadics Only thru March 08

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



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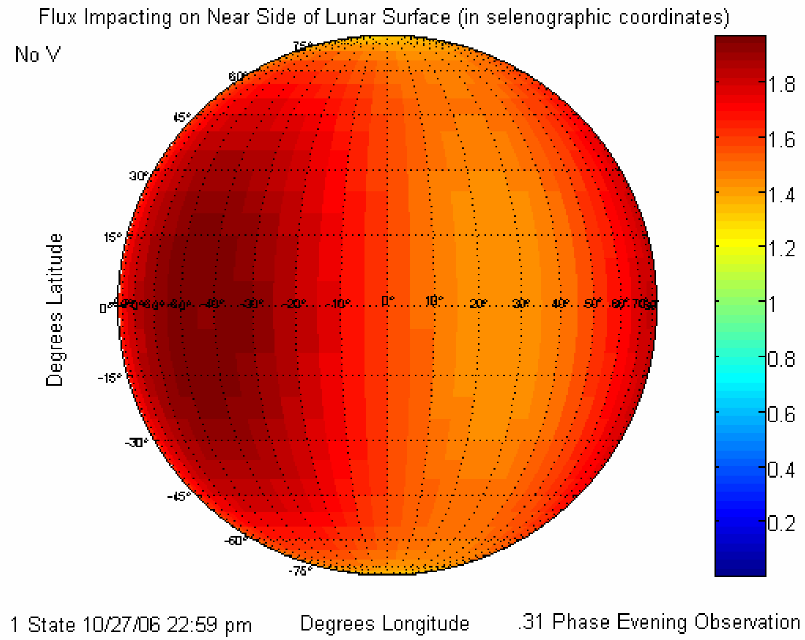
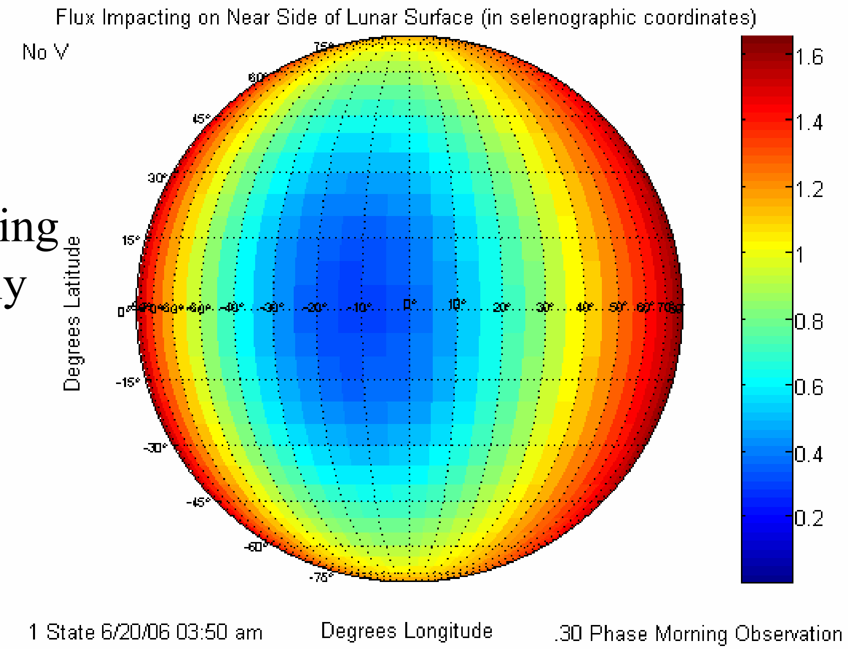
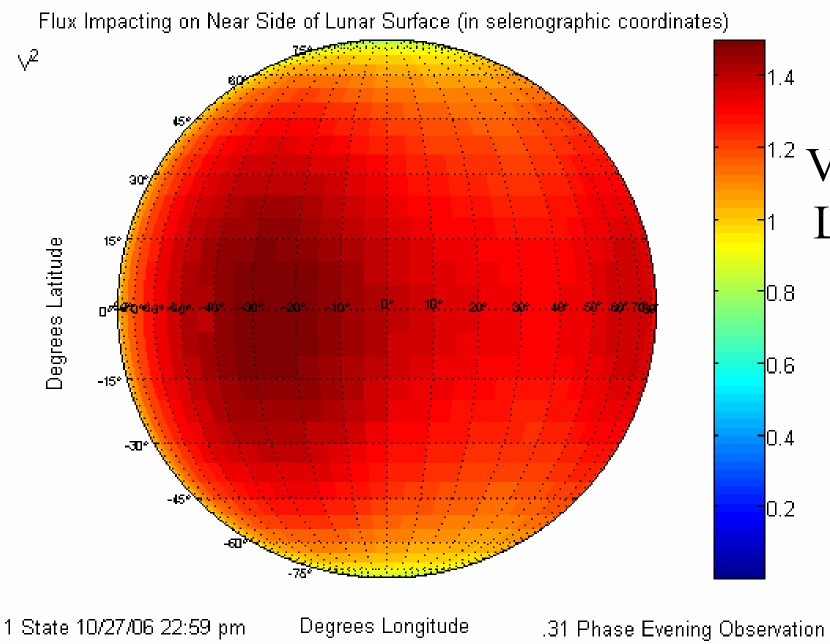


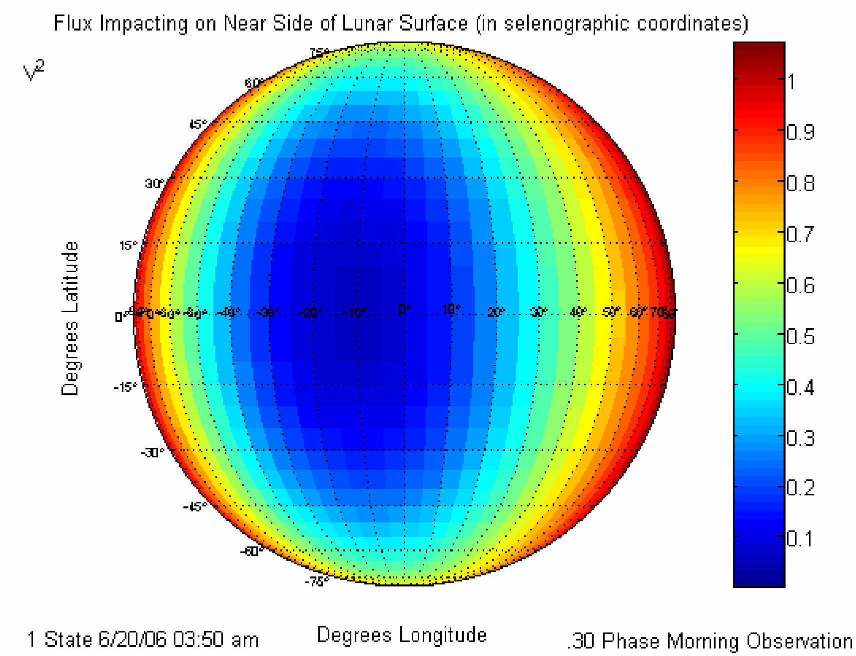
No V Scaling
Flux only



Preliminary MEM Flux Calculations by Heather McNamara



V^2 Scaling
Lum Eff =
constant



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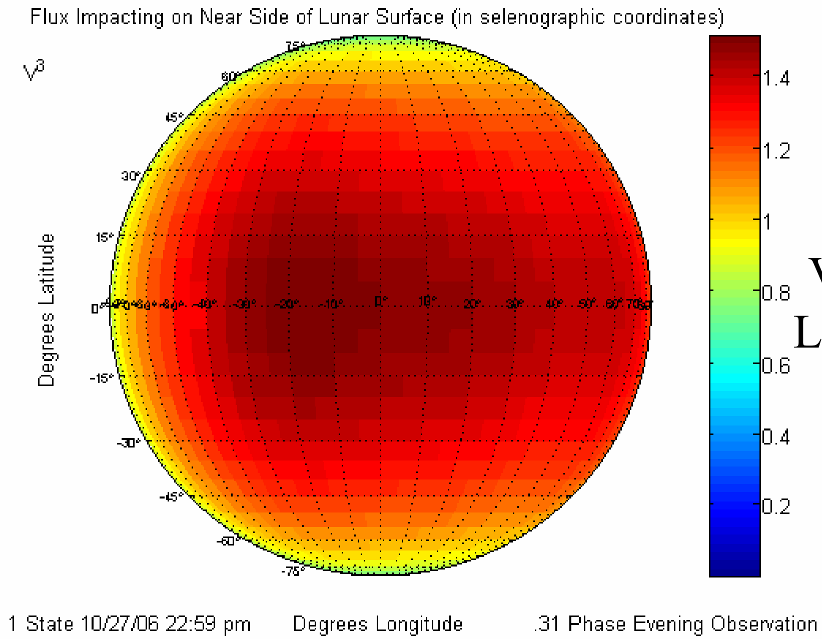
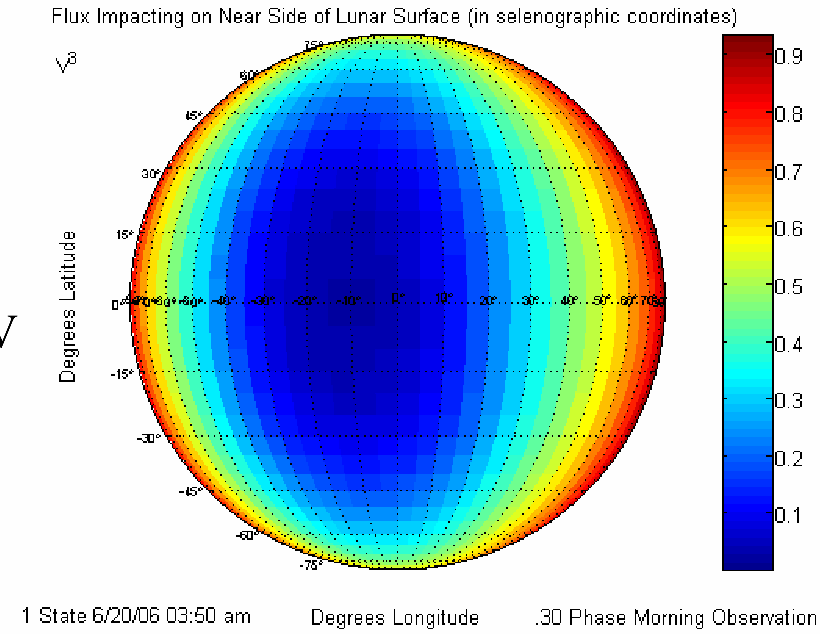


V^3 Scaling
Lum Eff ~ V



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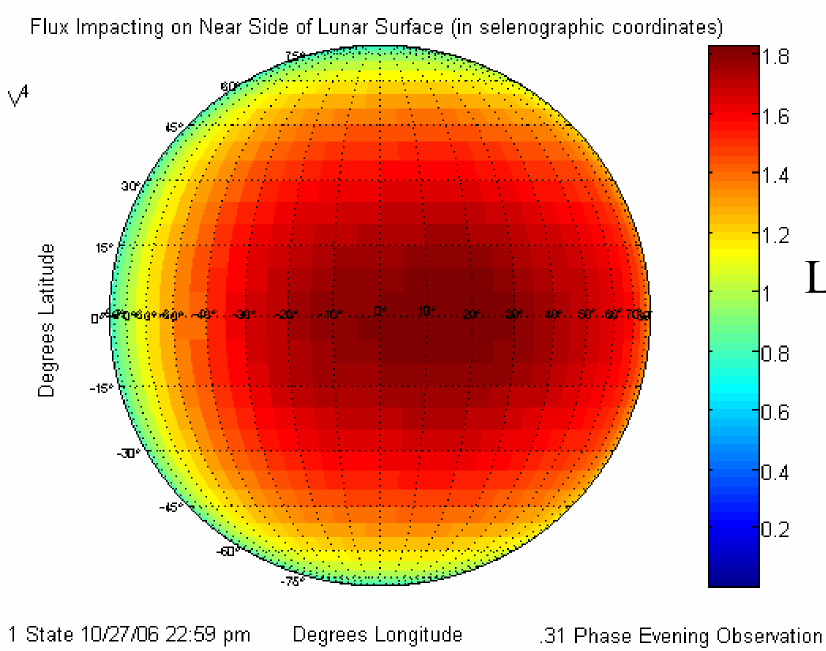
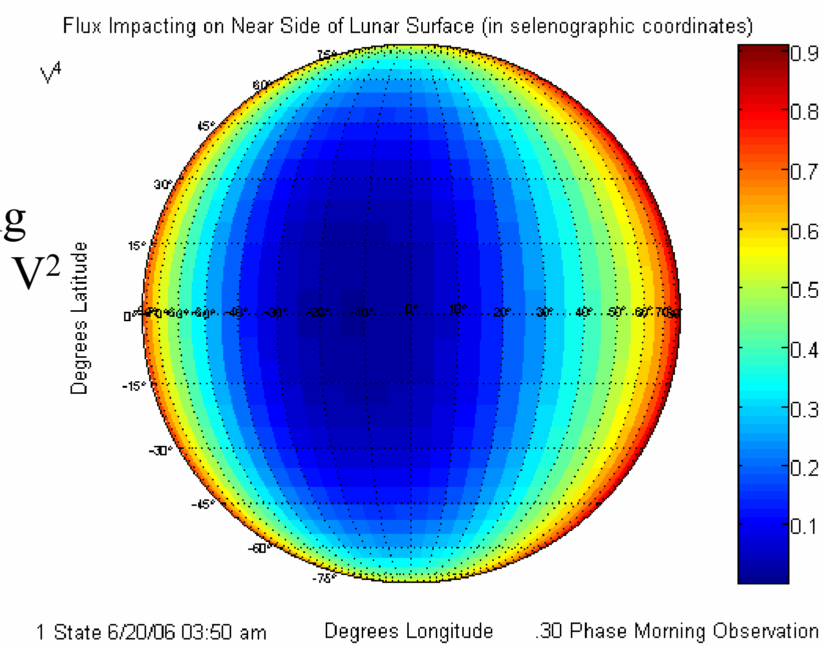


V^4 Scaling
Lum Eff ~ V^2



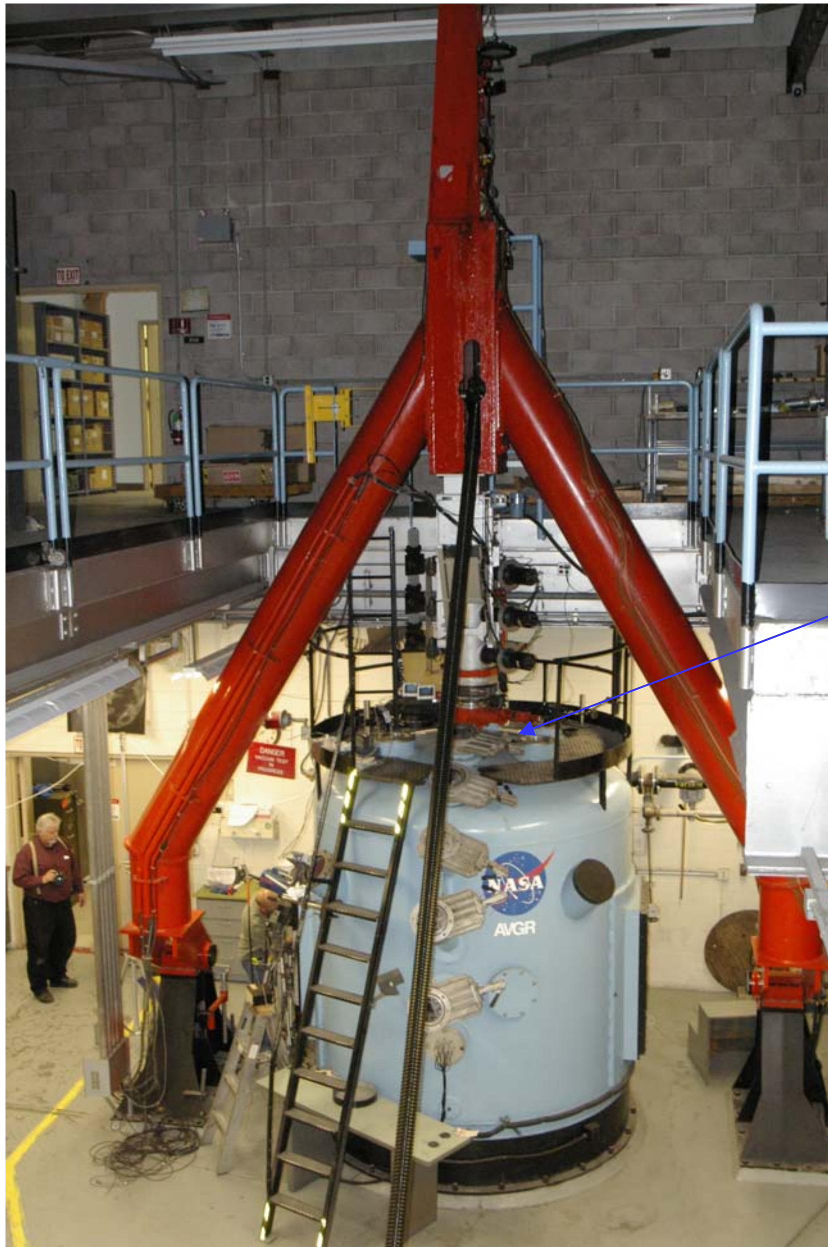
Example of a Moderate-Sized Impactor - May 2, 2006

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

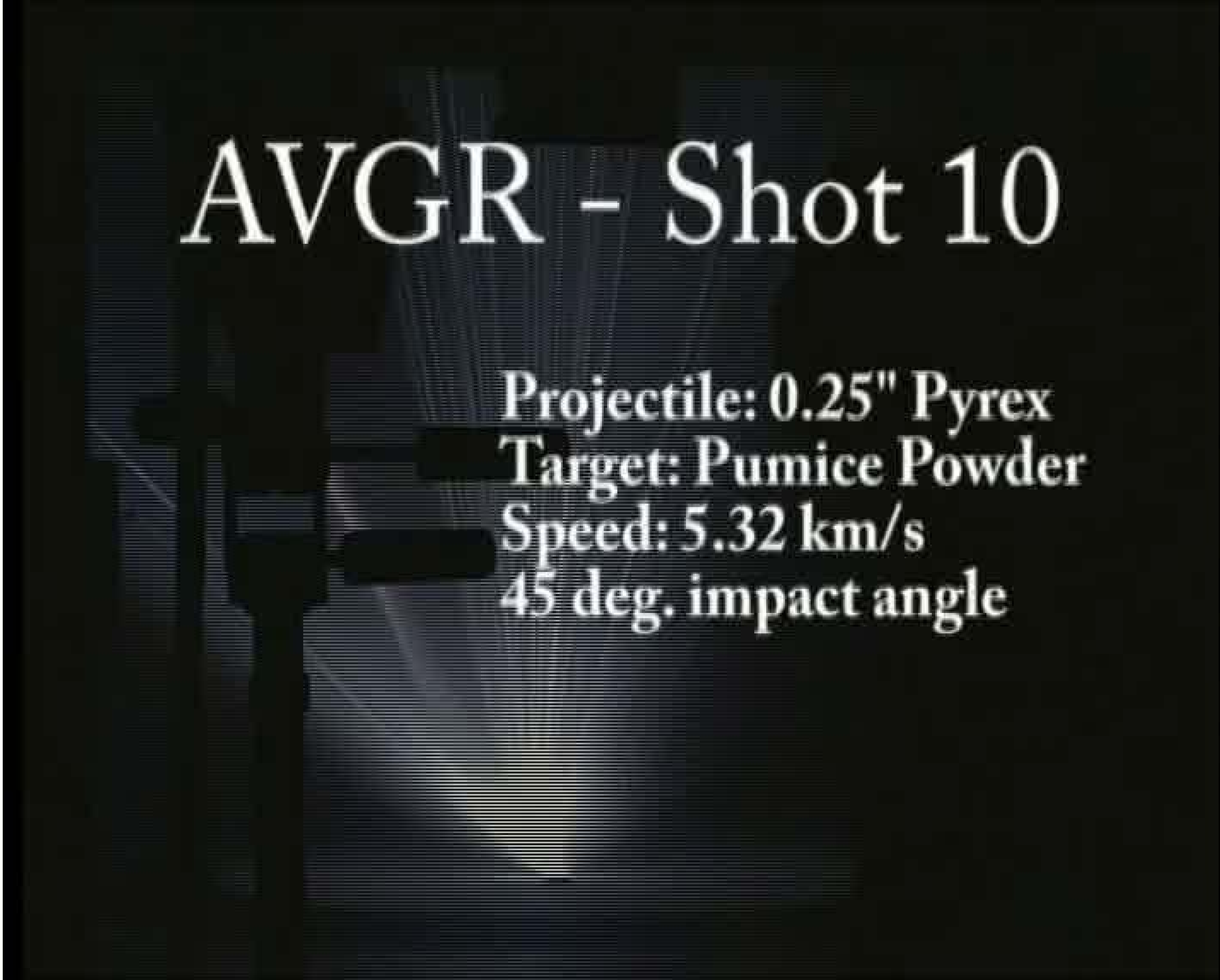
- Purposes
  - Determine impact luminous efficiency – fraction of kinetic energy converted to light (completed 2 sessions of tests for this)
  - Determine size and velocity distributions of ejecta produced in cratering process
- Fired pyrex projectiles into pulverized pumice and JSC-1A simulant at various 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

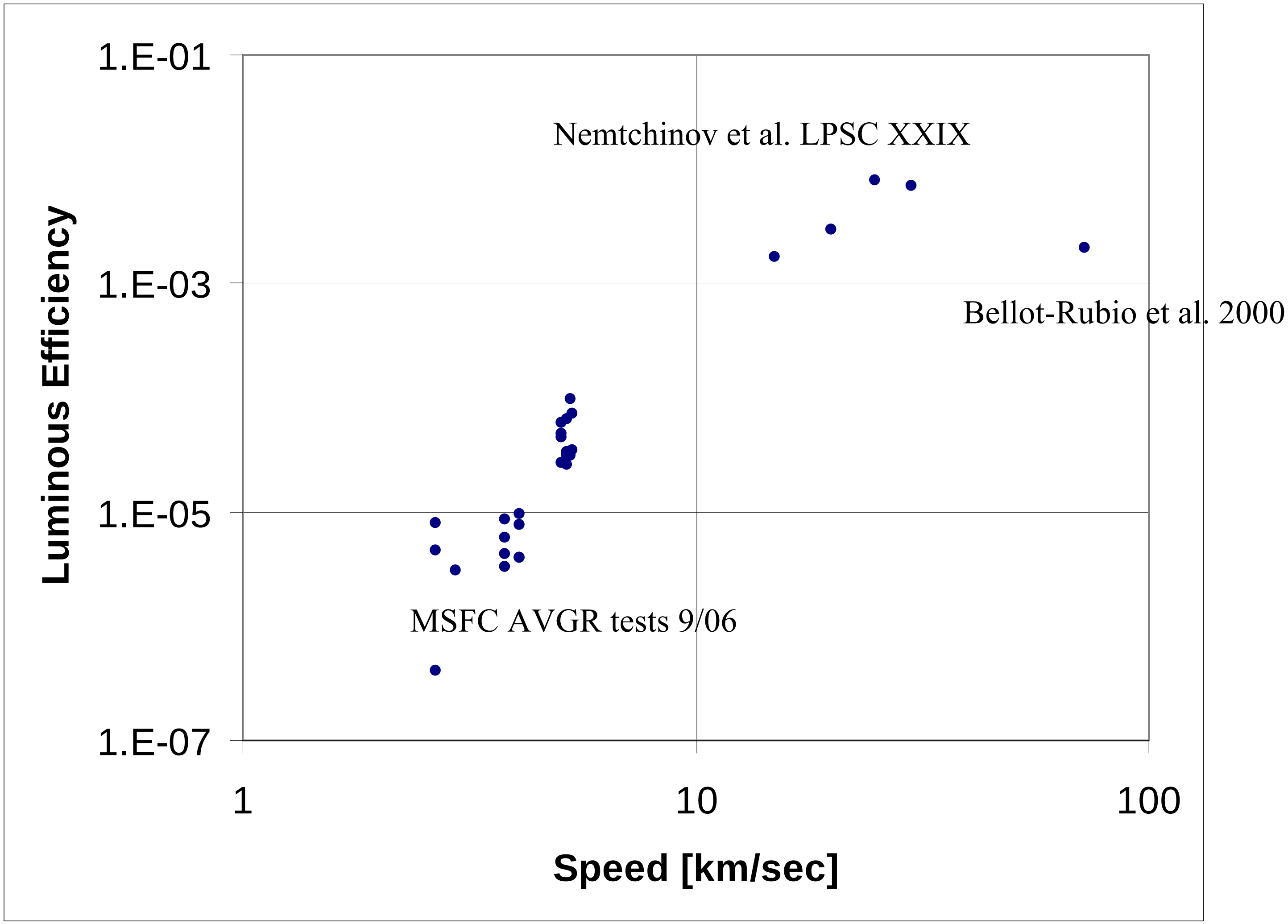

SONY


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

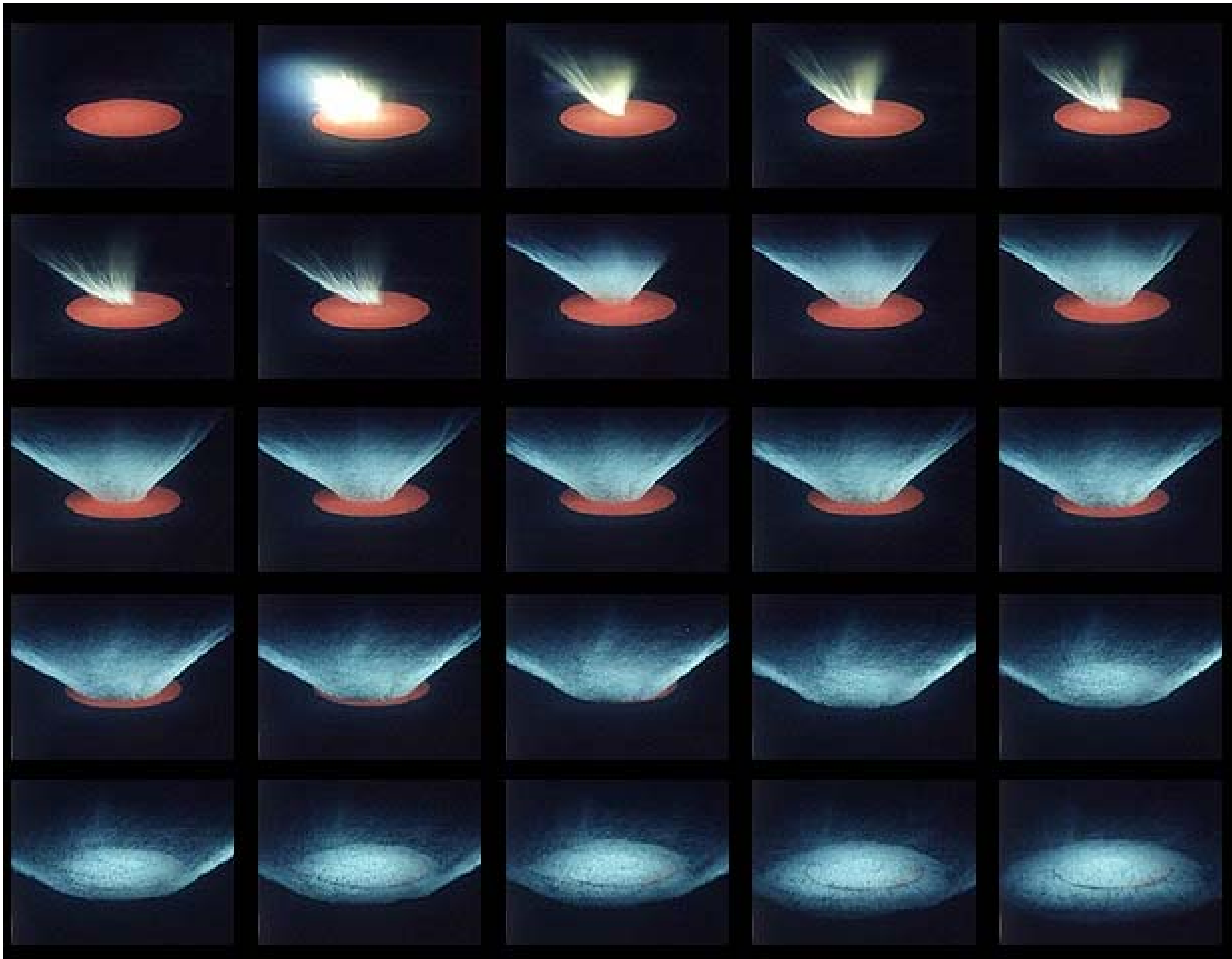
Preliminary Results
using “not so neutral” density filters



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

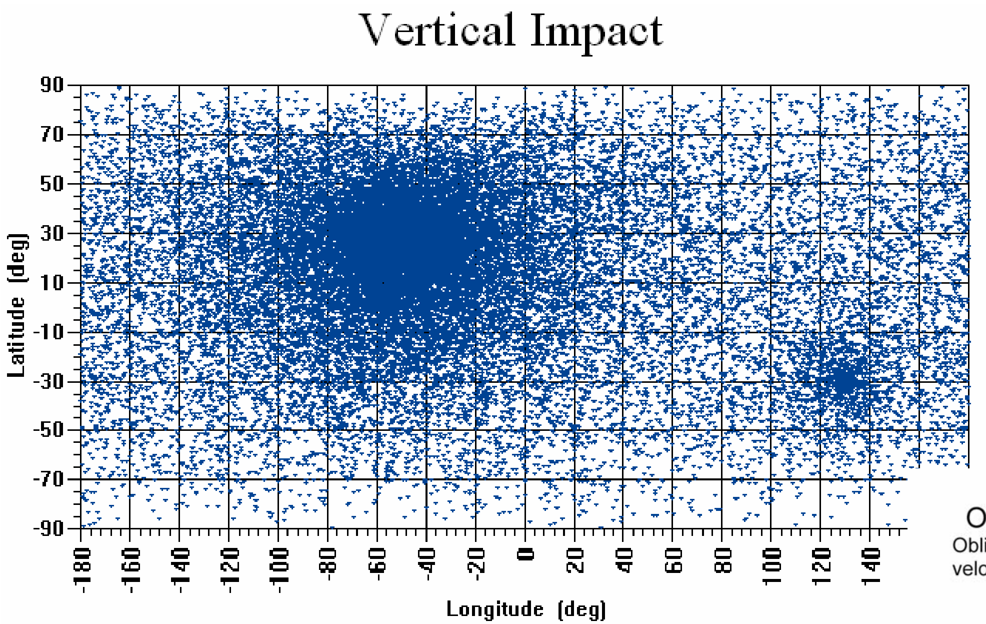


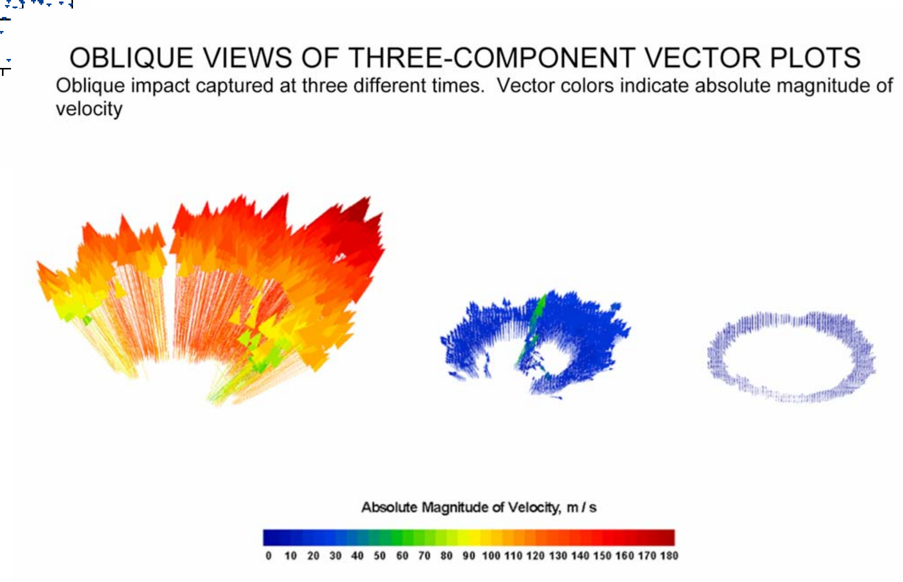
Schultz, et al.

Ejecta Flight Model

Very Preliminary Model Test Results

Simple assumed ejecta distribution





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
- Impacts

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