

Flux of Kilogram-sized Meteoroids from Lunar Impact Monitoring

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Robert Suggs 1

William Cooke 2

Ron Suggs 1

Heather McNamara 1

Wesley Swift 5

Danielle Moser 4

Anne Diekmann 3

1 NASA Marshall Space Flight Center EV44

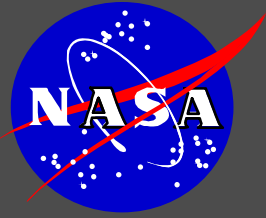
2 NASA Meteoroid Environment Office, Marshall Space Flight Center

3 Jacobs Technologies, MSFC

4 Morgan Stanley, MSFC

5 Raytheon/MSFC

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.



Flux of Kilogram-sized Meteoroids from Lunar Impact Monitoring

Bill Cooke

NASA Meteoroid Environment Office

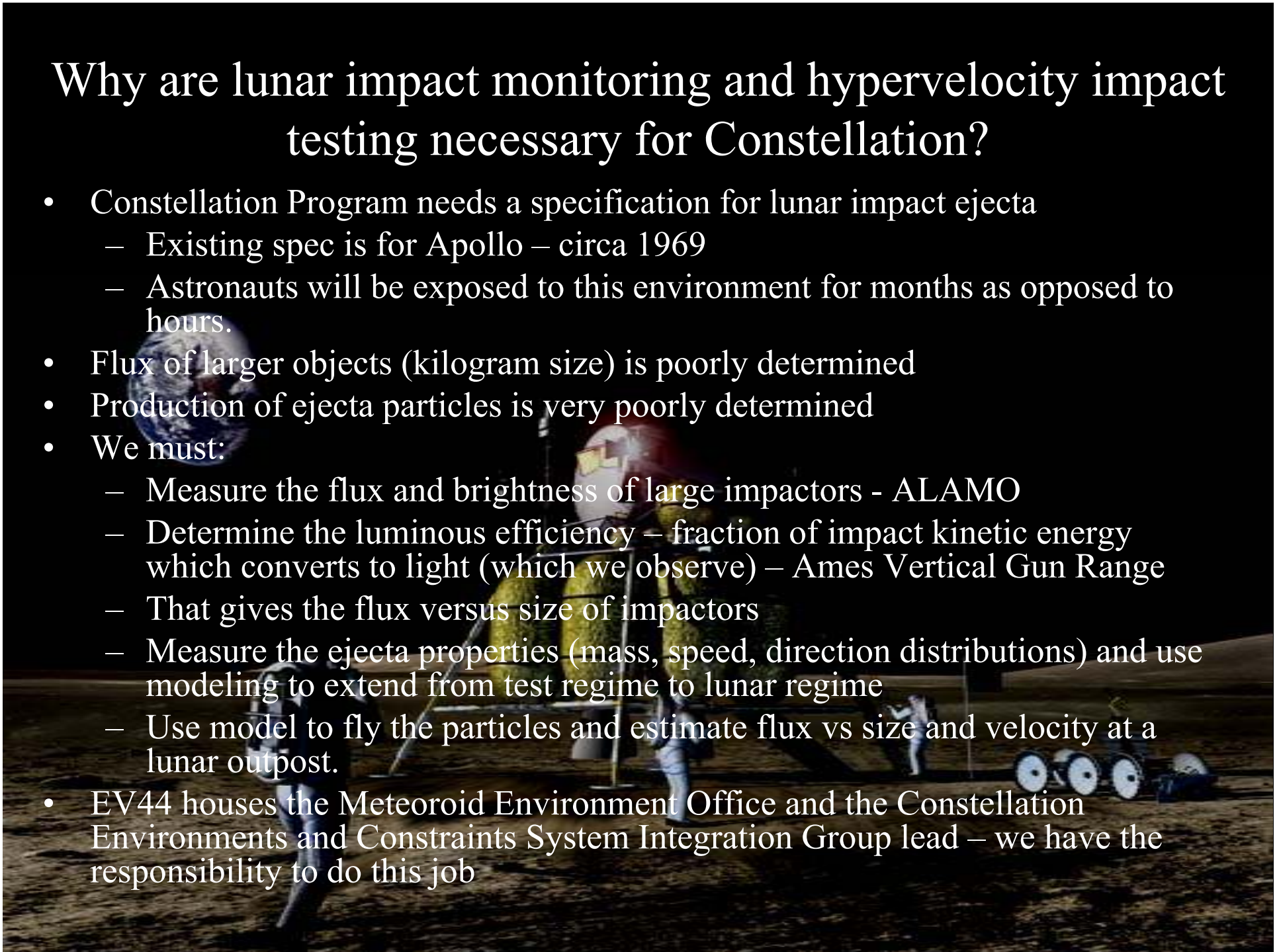
September 27, 2008

Why Lunar Impact Monitoring is Useful

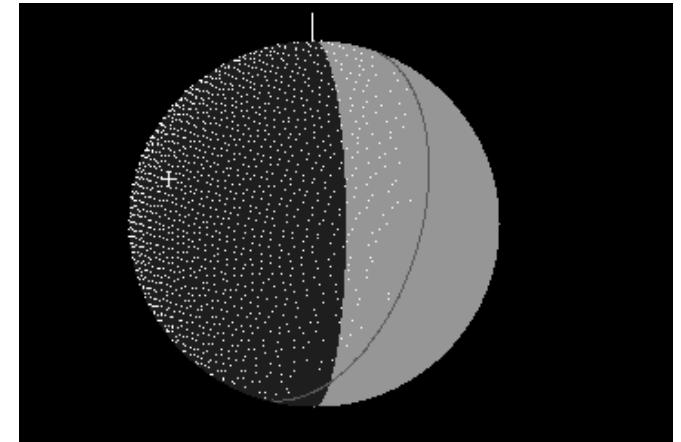
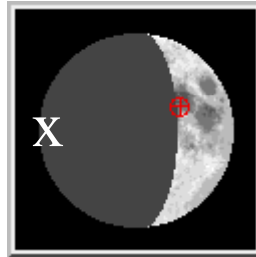
- We started this work in earnest 2 years ago to provide a better estimate of the ejecta environment for Constellation lunar elements.
- It turns out that it is also useful for calibration of MEM for large (kg) masses.

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



Jack Schmitt/Apollo 17 observation of lunar impact



"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.

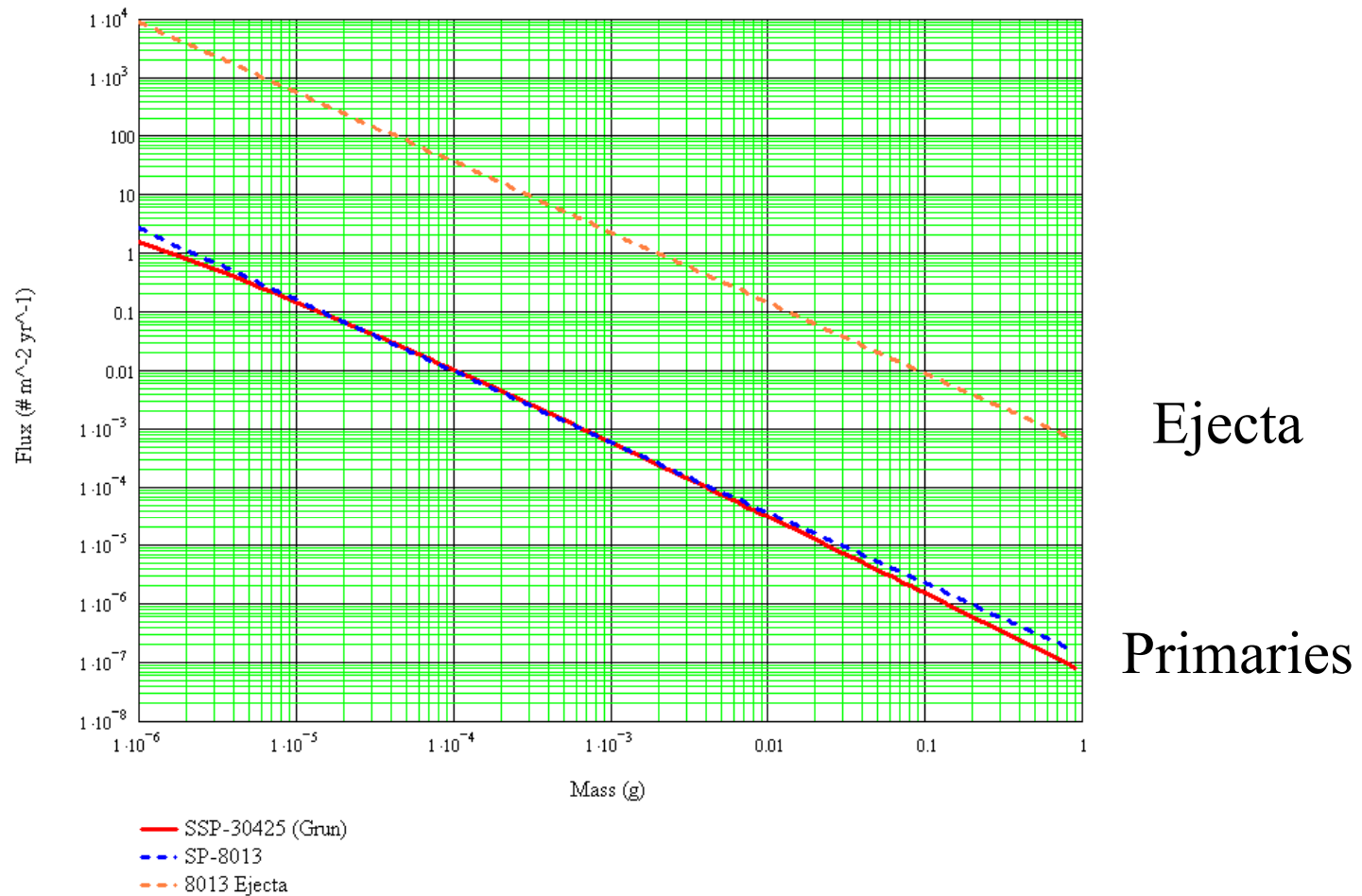
LMP It was a bright little flash right out there near that crater. See the [sharp rimed] crater right at the [north] edge of [the] Grimaldi [mare]? Then there is another one [i.e., sharp rimed crater] [directly] north of it [about 50km]- fairly sharp one north of it. [That] is where there was just a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

Geminids 12/13/1972

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

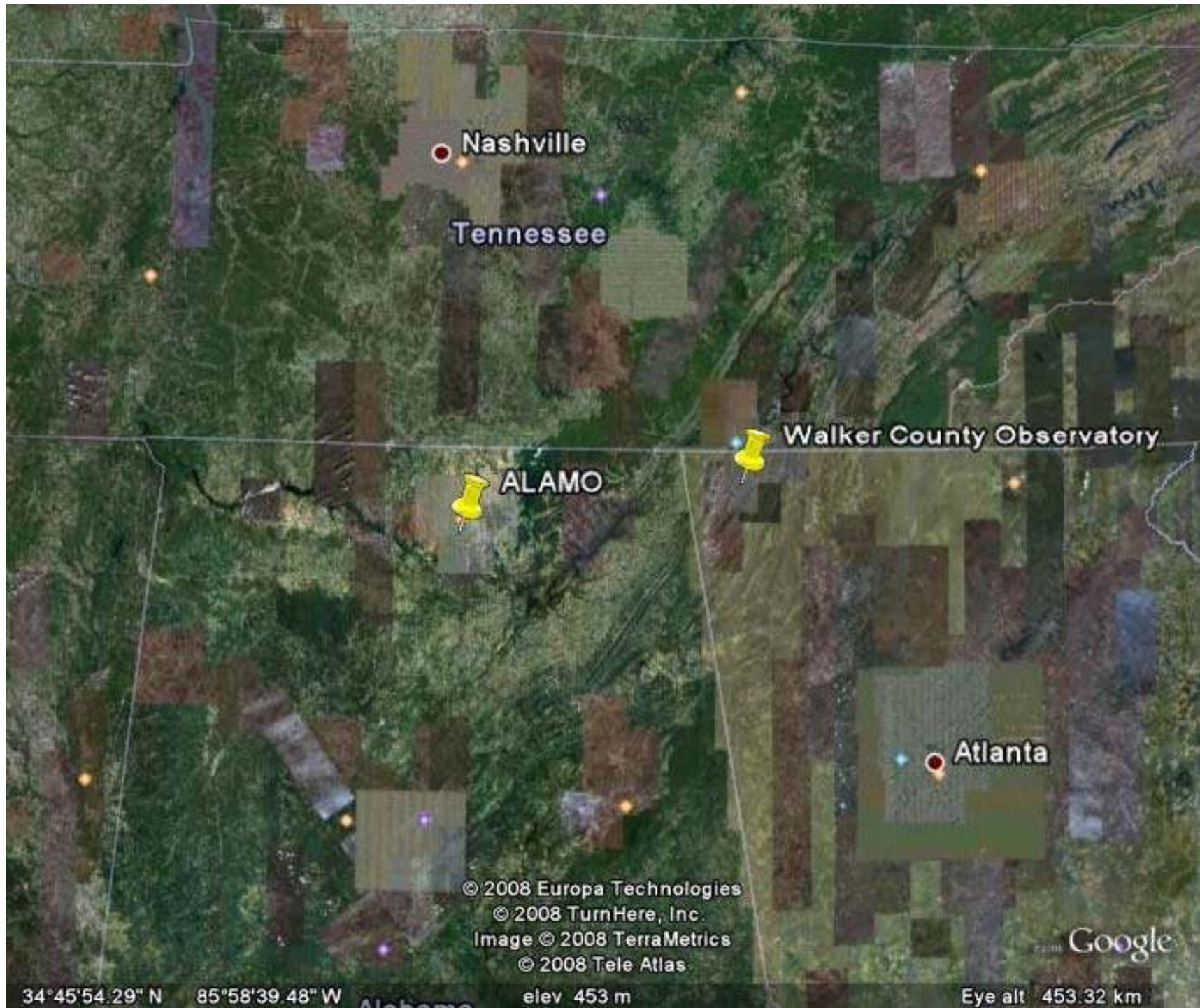


0.5m in dome on left, 0.35m in tower



20 inch (0.5m) RCOS





Nashville

Tennessee

Walker County Observatory

ALAMO

Atlanta

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© 2008 Tele Atlas

Google

34°45'54.29" N 85°58'39.48" W

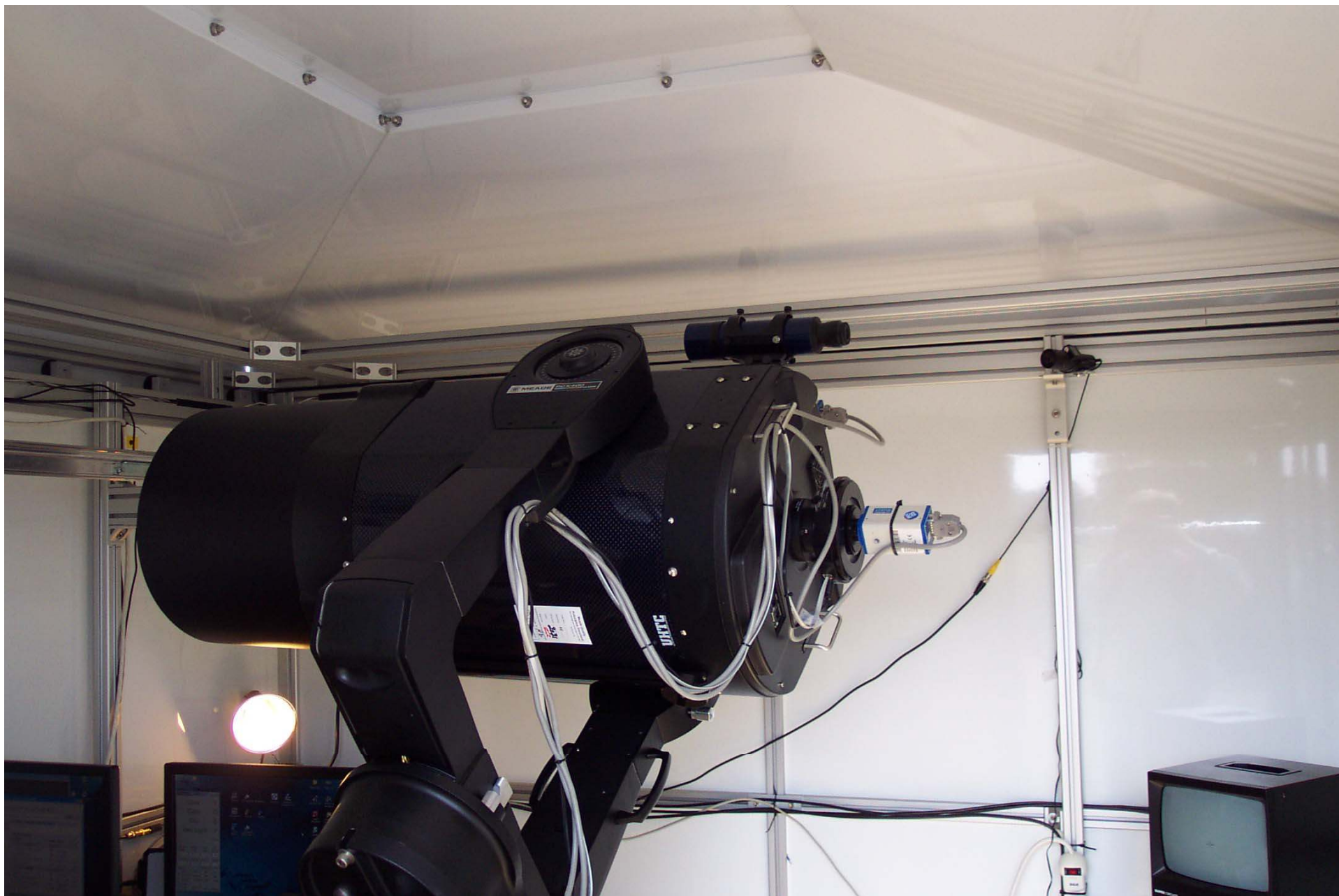
elev 453 m

Eye alt 453.32 km

Walker County Observatory



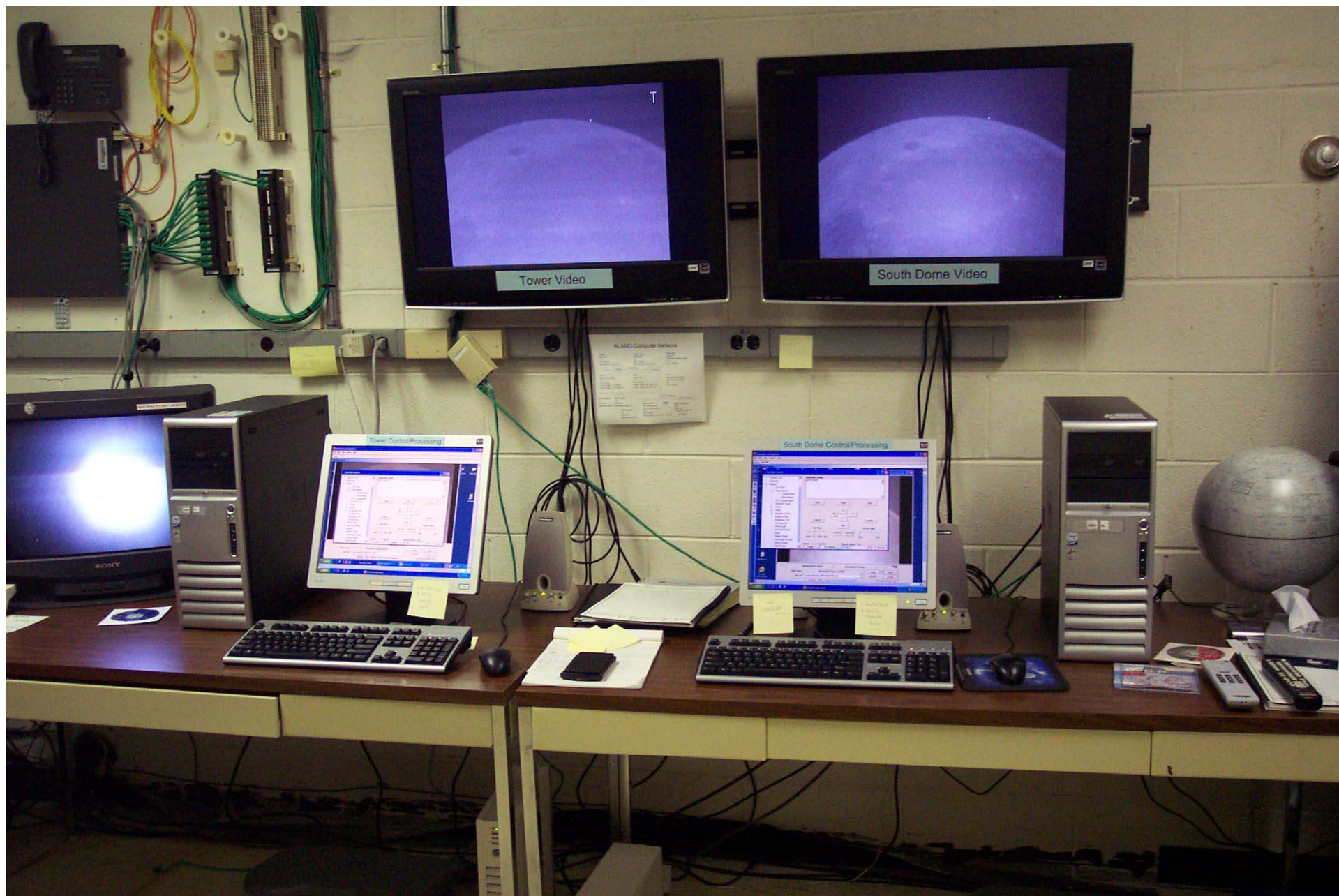
Meade 14 in (0.35m)



Control Room



Operator position



Probable Leonid Impact November 17, 2006

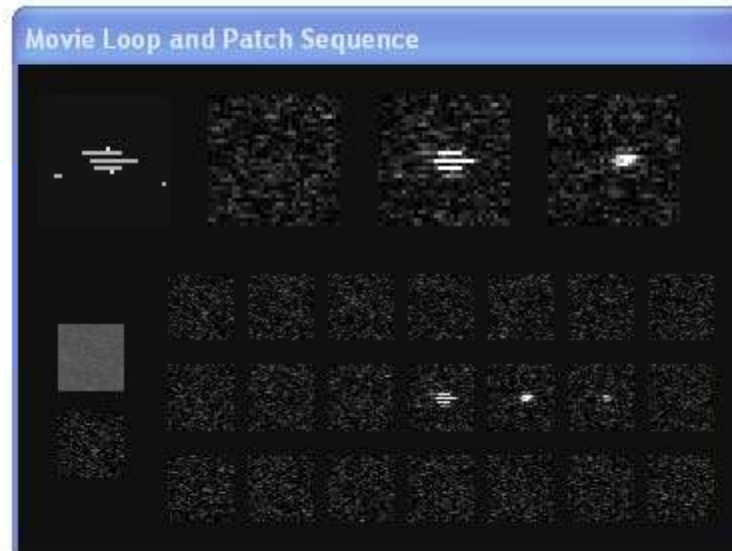


Video is slowed by a factor of 7

Video of multiple impacts

LunarScan (Gural)

Impact 15 Dec 2006



```
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

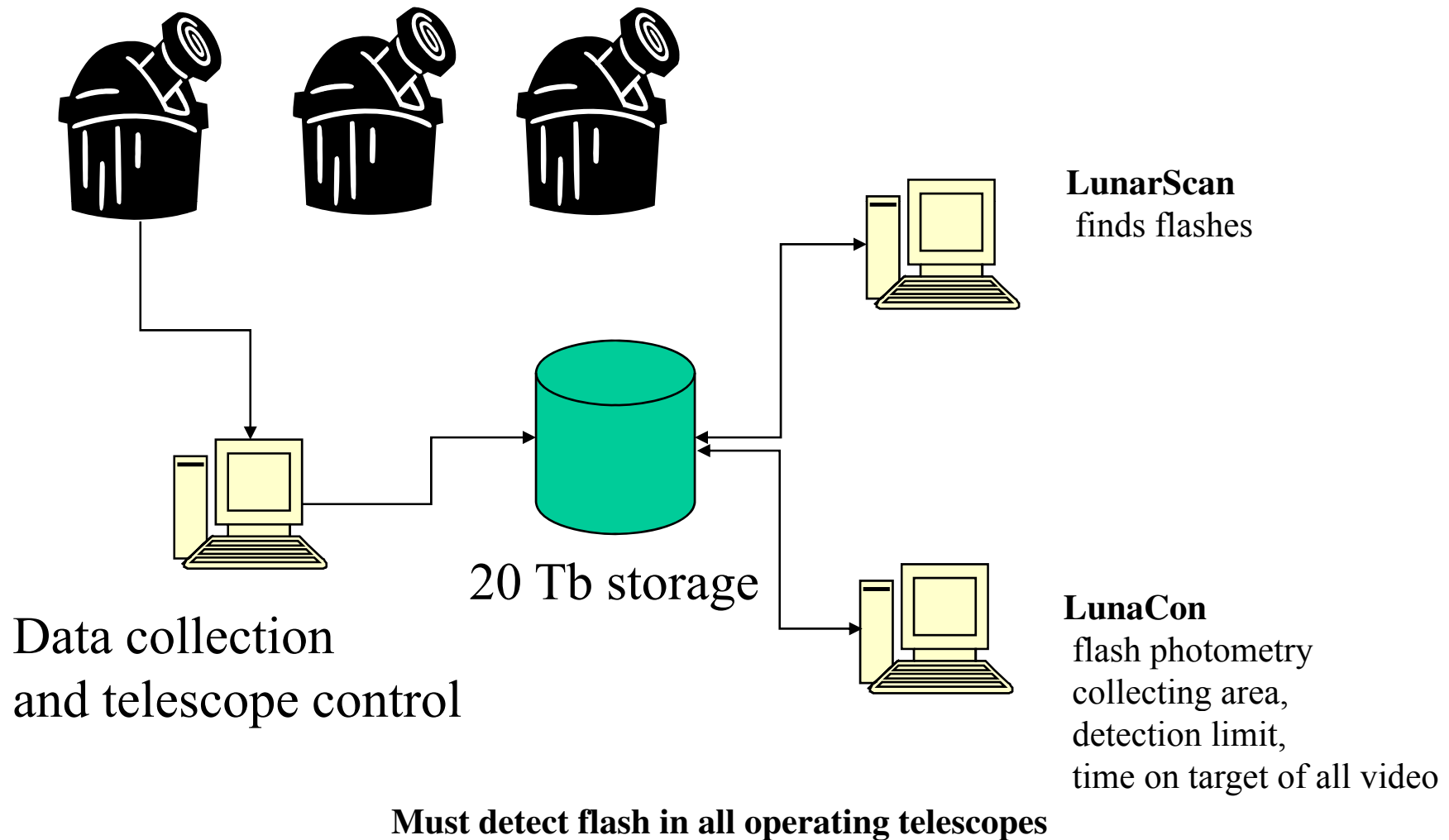
ANY other key --> Next Image
```

```
o:\ LunarScan Console Window

P = PLAY digitized video file
Q = QUIT Program

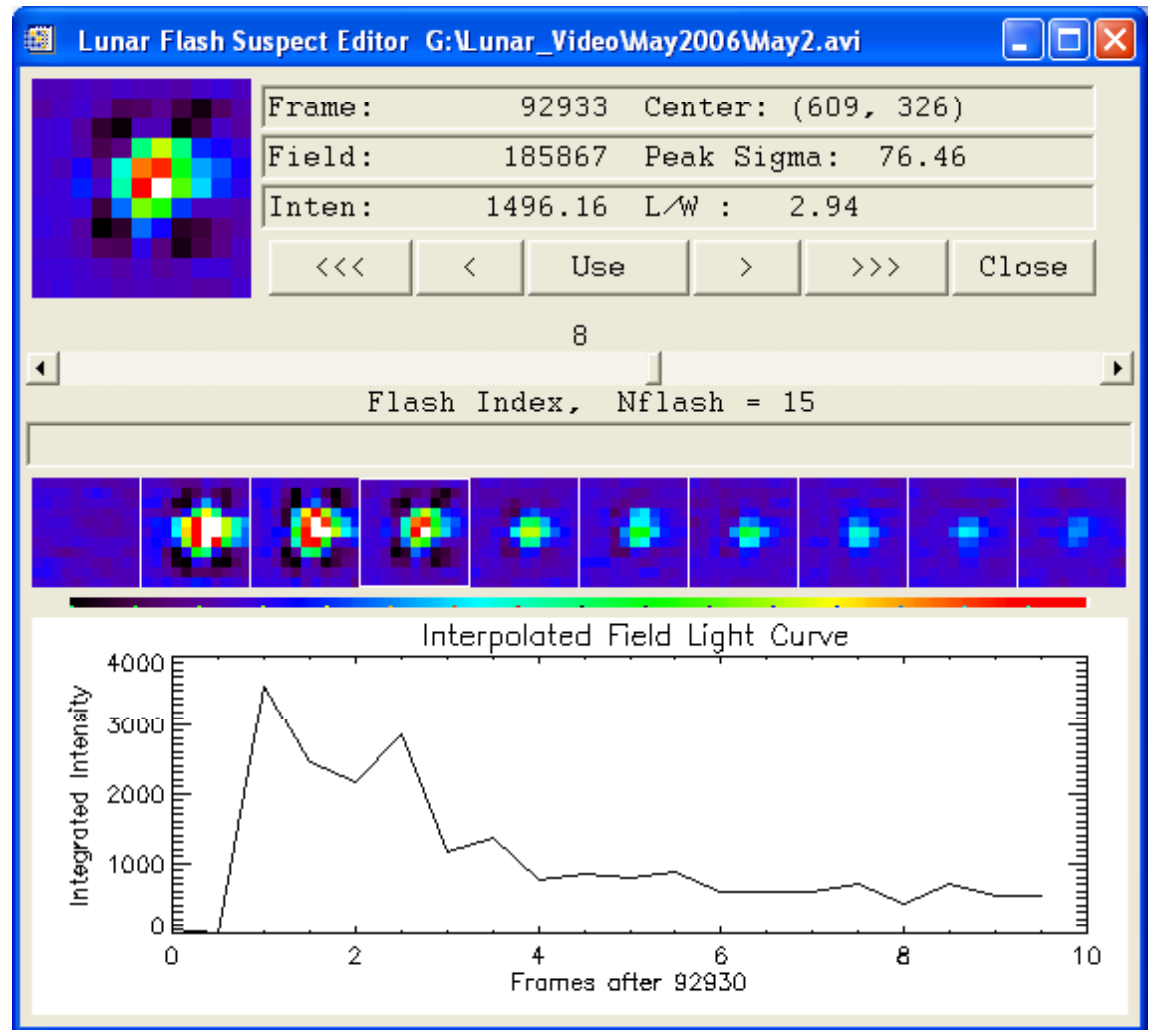
-----
Select a processing option:
#####
##### Review of Confirmed Data #####
#####
Enter the base filename: 15Dec2006_T
1 09:02:07 00:18:07 459 24 Frame# 32587
2 09:04:33 00:20:33 150 665 Frame# 36943
3 09:17:39 00:33:39 109 325 Frame# 60516
2 09:04:33 00:20:33 150 665 Frame# 36943
3 09:17:39 00:33:39 109 325 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
```

Data Analysis Pipeline



The Usual Suspects

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



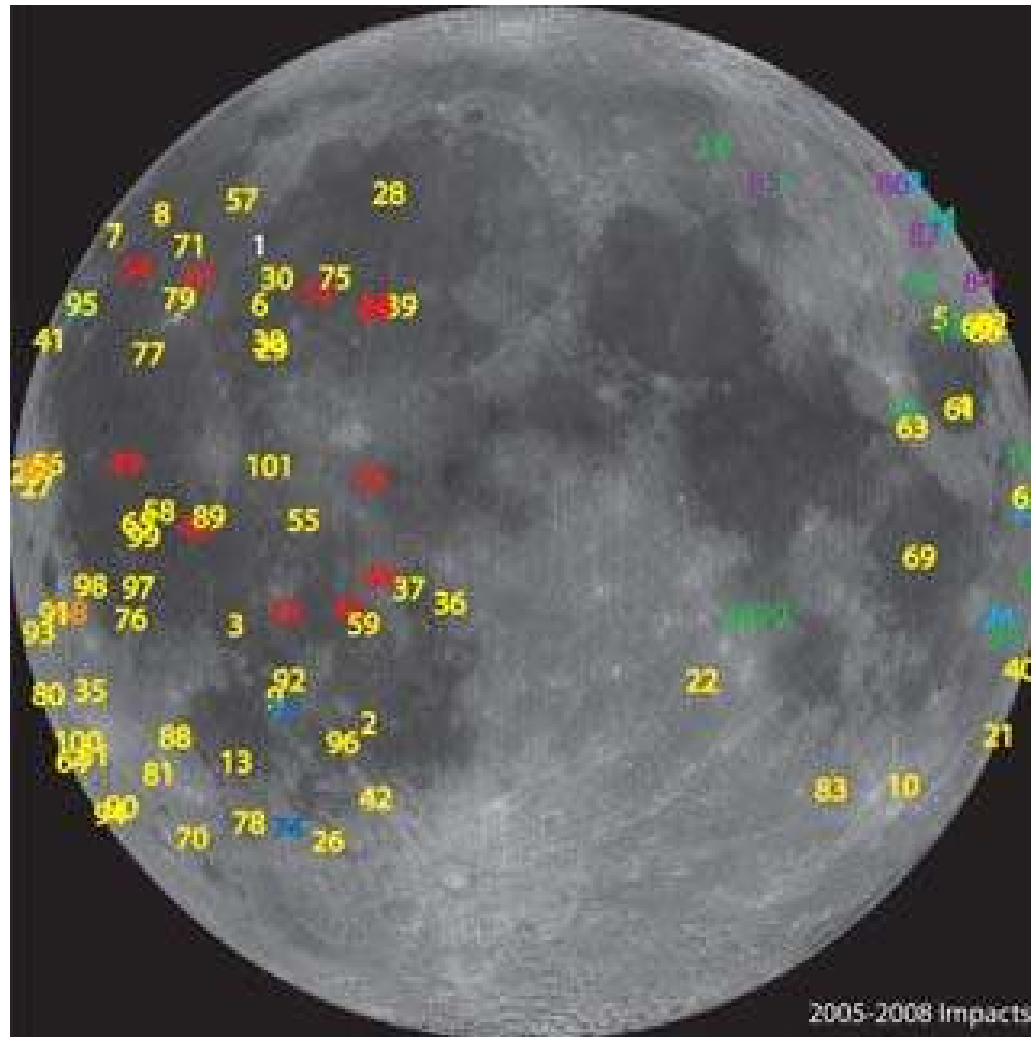
Atlas-Centaur Debris

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

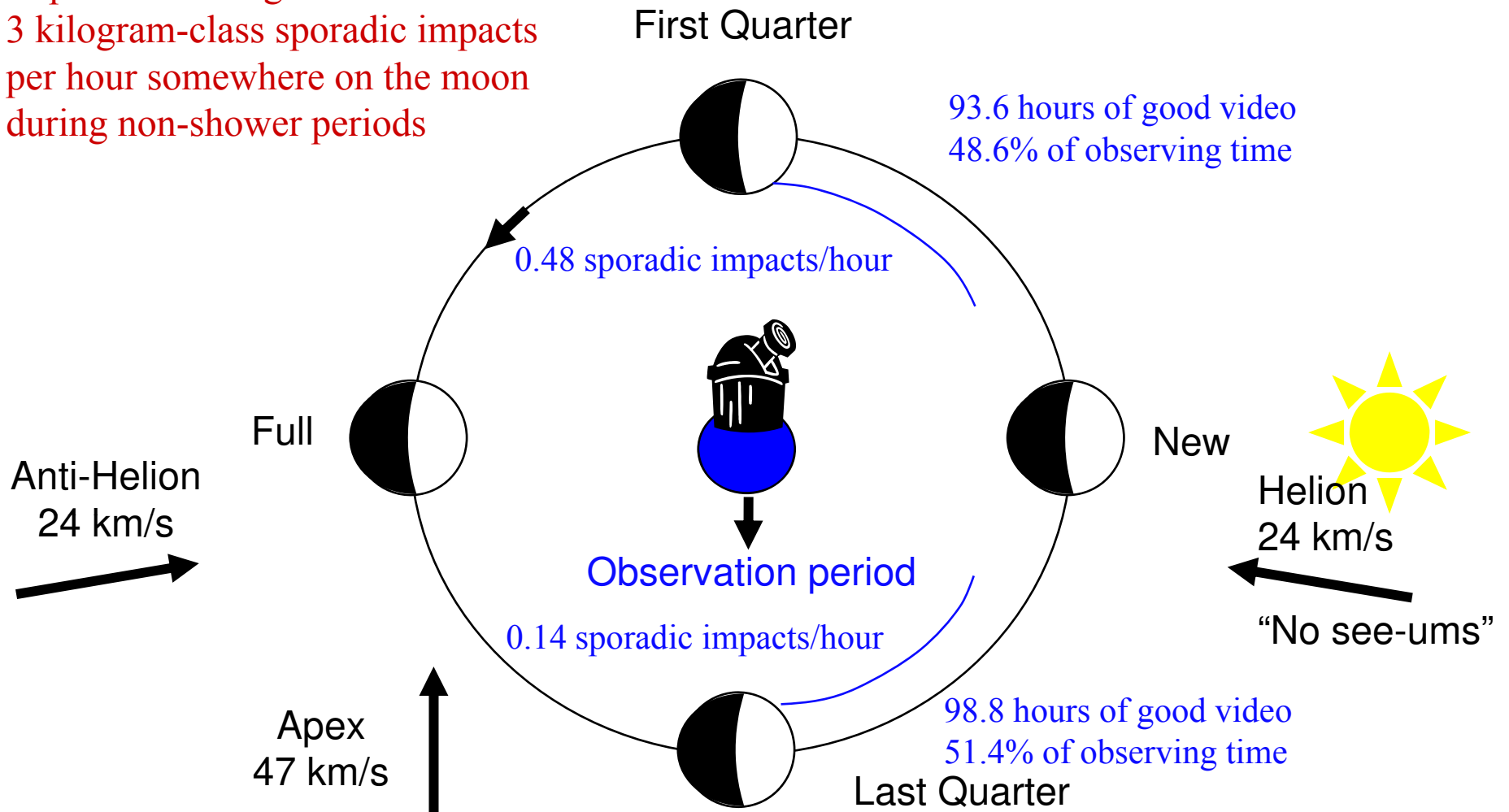


Evening obs
45 impacts
in approx.
93 hours

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



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/m²

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

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

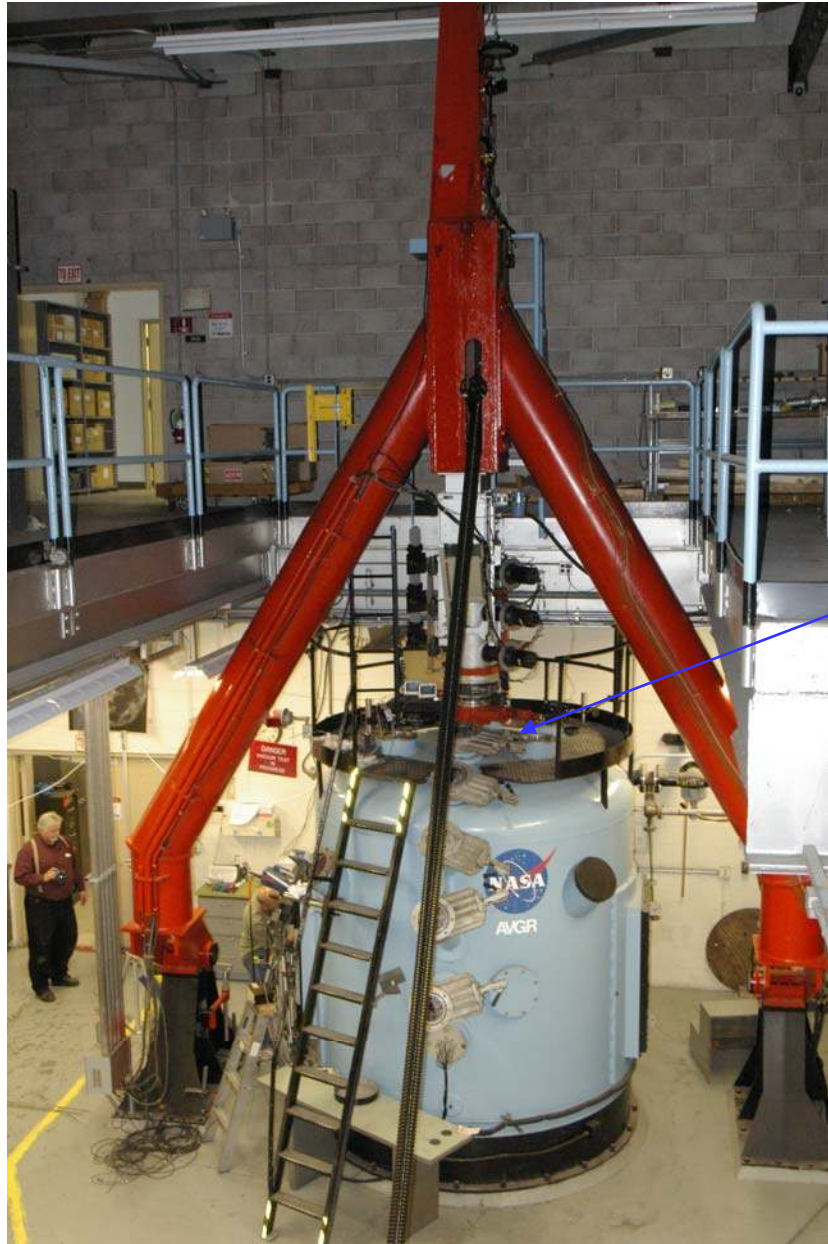
Estimated diameter of impactor: 32 cm ($\rho = 1$ g/cm³)

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



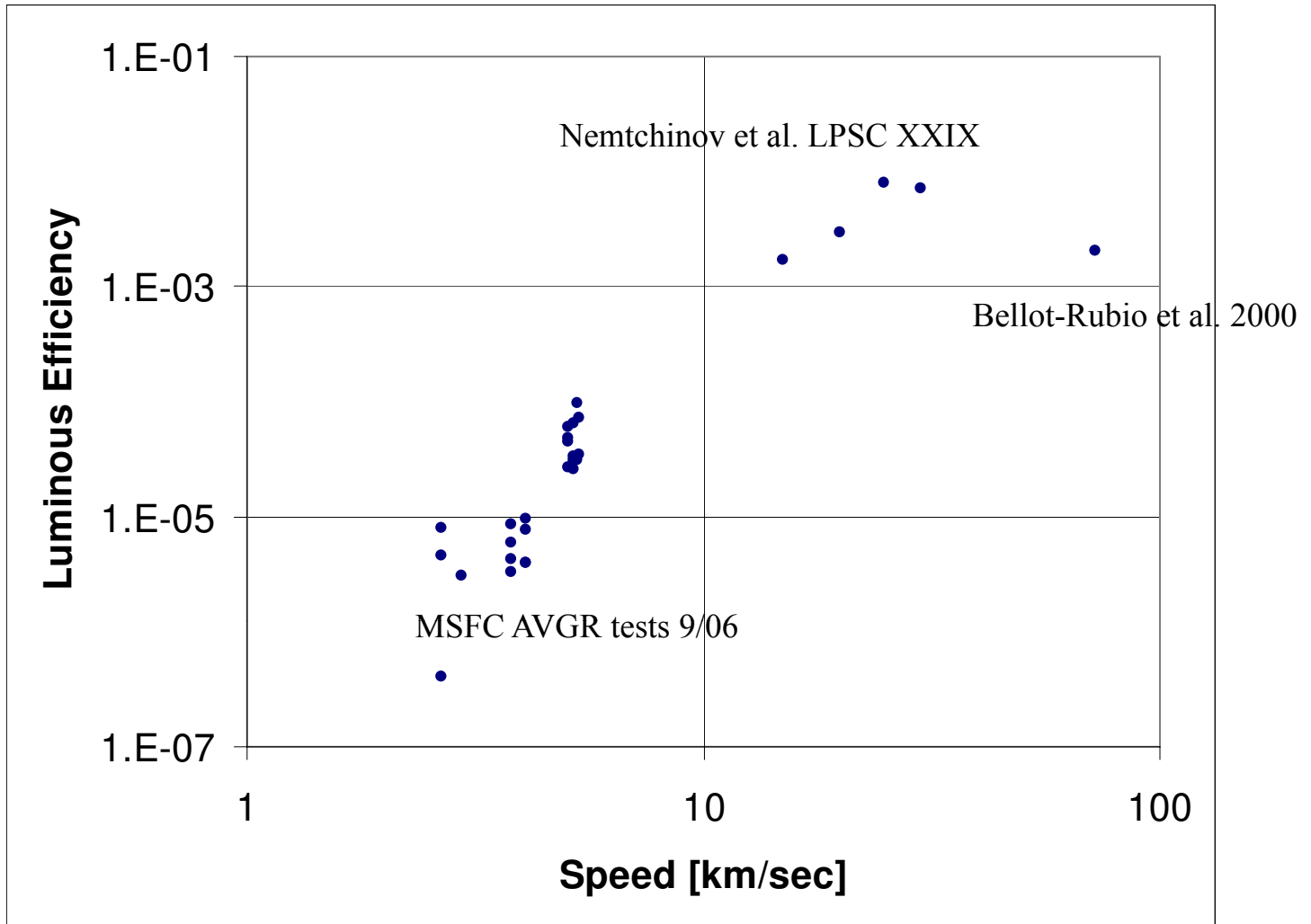
AVGR Run 070823

Crater in JSC-1A Simulant



Preliminary Results

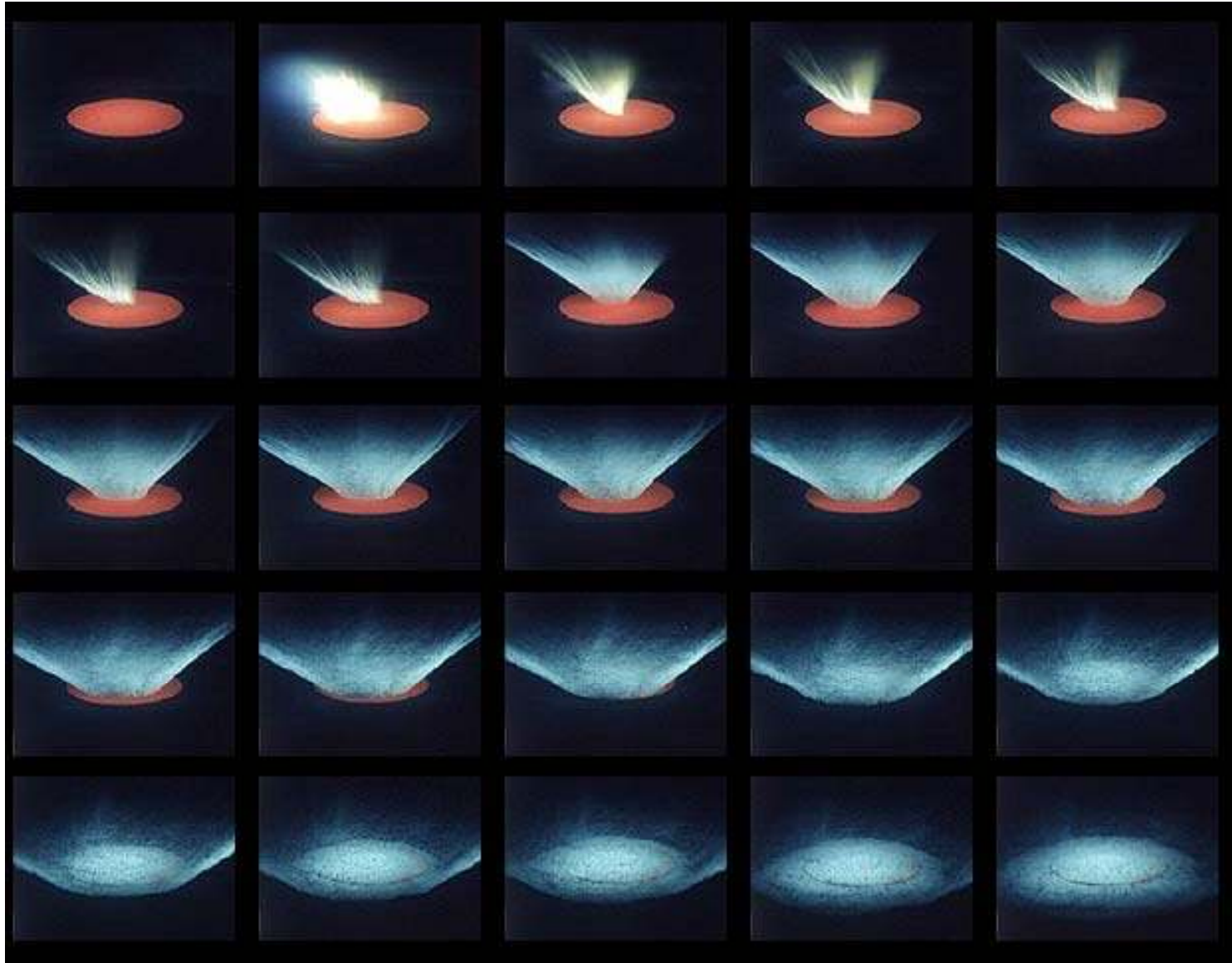
using “not so neutral” density filters



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



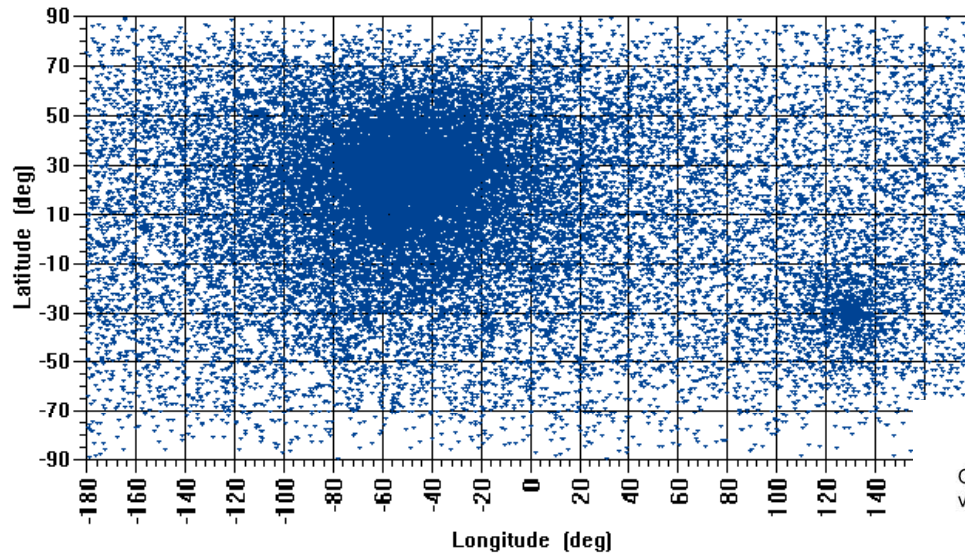
Schultz, et al.

Ejecta Flight Model

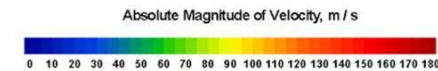
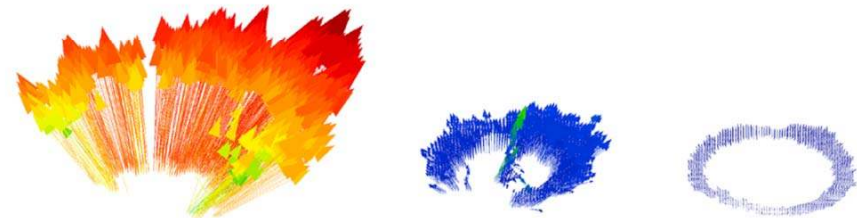
Very Preliminary Model Test Results

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>

- Impacts

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