https://ntrs.nasa.gov/search.jsp?R=20140005786 2019-08-29T14:09:41+00:00Z

Lunar Meteoroid Impact Monitoring for LADEE

October 11, 2013

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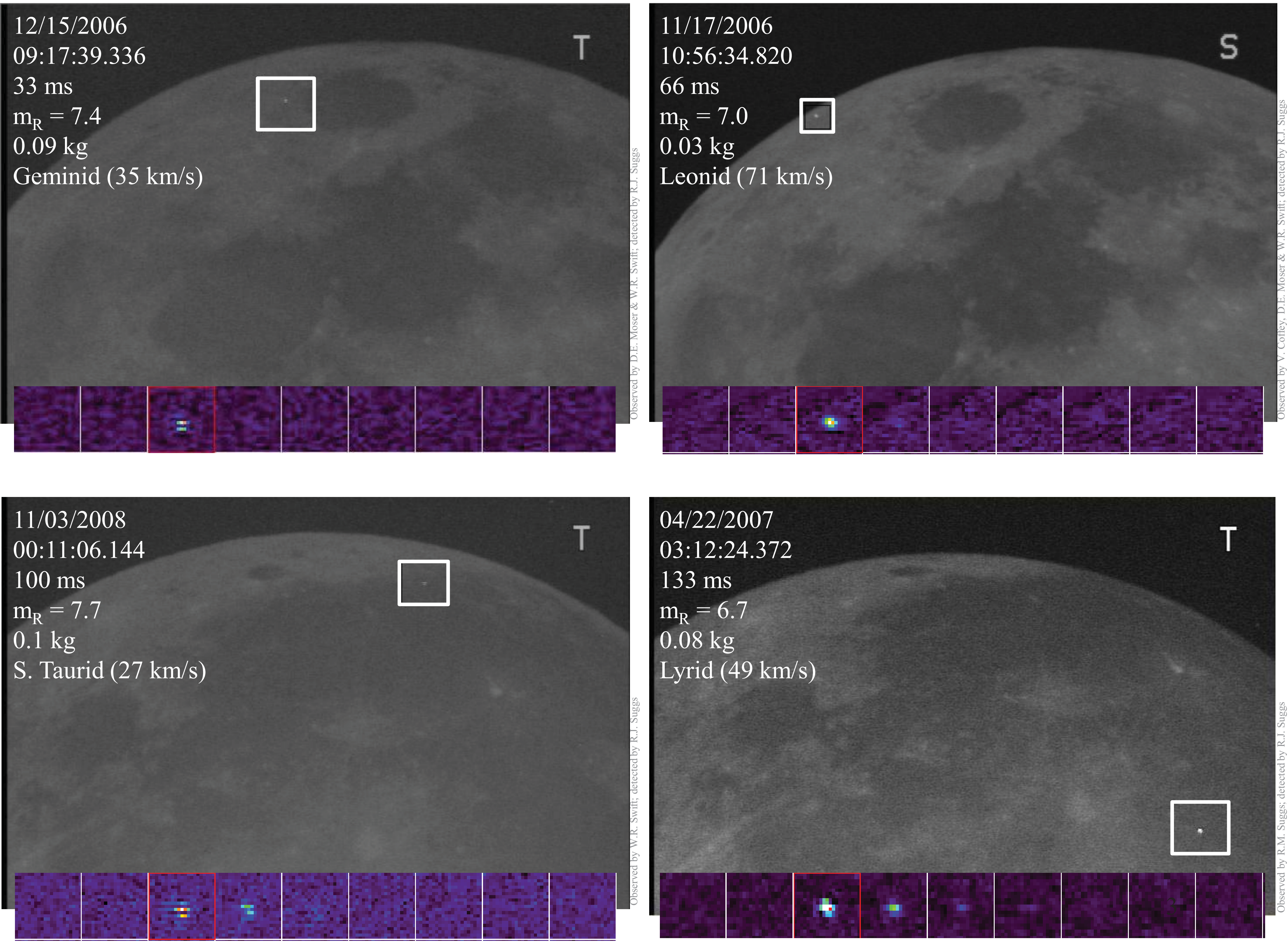
Why Monitor Lunar Impacts for LADEE?

- LADEE will be measuring dust and gases from low lunar orbit
- Meteoroid impacts eject dust and release gases which LADEE can measure
- It is important to know the time, location, and energy of the impact
  - These can be measured using relatively small ground-based telescopes WITH CAREFUL CALIBRATION
- Association with a particular meteor shower gives speed (meteoroid mass) and impact angle



12/15/2006
09:17:39.336
33 ms
m_R = 7.4
0.09 kg
Geminid (35 km/s)
T
Observed by D.E. Moser & W.R. Swift; detected by R.J. Suggs
11/17/2006
10:56:34.820
66 ms
m_R = 7.0
0.03 kg
Leonid (71 km/s)
S
Observed by V. Coffey, D.E. Moser & W.R. Swift; detected by R.J. Suggs
11/03/2008
00:11:06.144
100 ms
m_R = 7.7
0.1 kg
S. Taurid (27 km/s)
T
Observed by W.R. Swift; detected by R.J. Suggs
04/22/2007
03:12:24.372
133 ms
m_R = 6.7
0.08 kg
Lyrid (49 km/s)
T
Observed by R.M. Suggs; detected by R.J. Suggs

When to Observe

- Anytime the glare from the sunlit face doesn’t completely wash out the earthshine face
  - Typically between 10% illuminated (crescent) and 50% (quarter)
  - Morning observations are just as important
- Impact rate is higher during meteor showers but DON’T LET THAT BIAS WHEN YOU OBSERVE. Impacts can occur anytime and LADEE needs to know about them.
- Observe from twilight to moonset – evening
- Observe from moonrise to twilight – morning

Equipment

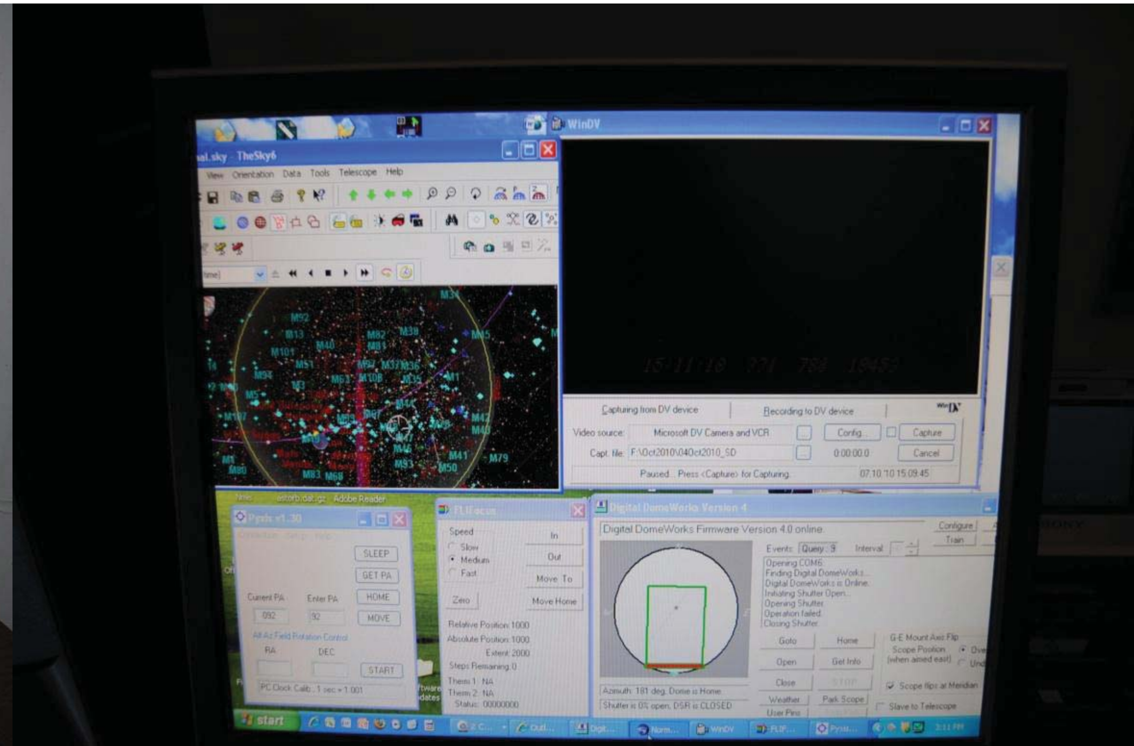
- Telescope – 8 – 14 inch preferred
- Larger scopes need focal reducer to give ~1m focal length and decent FOV (Optec, Meade, Celestron, etc.)
- Camera – B&W video 1/2inch Sony HAD EX chip (Watec 902H2 Ultimate)
- Digitizer – preferably delivering Sony CODEC .AVI files (Sony GV-D800, many Sony digital 8 camcorders, Canopus ADVC-110)
  - Others MAY work but must generate video compatible with LunarScan
- Time encoder – GPS (Kiwi or Iota)
  - May use WWV on audio channel with reduced accuracy
- Windows PC with ~500Gb fast harddrive (to avoid dropped frames)
  - Firewire card if using Sony or Canopus digitizers

Automated Lunar and Meteor Observatory (MPC H58)

- Telescopes
  - 3 14” (0.35m)
    2 Meade, 1 Celestron
  - RCOS 20 inch (0.5m)
- Detectors
  - Watec 902H2 Ultimate
  - Astrovid Stellacam EX
  - Gamma=0.45, man.gain

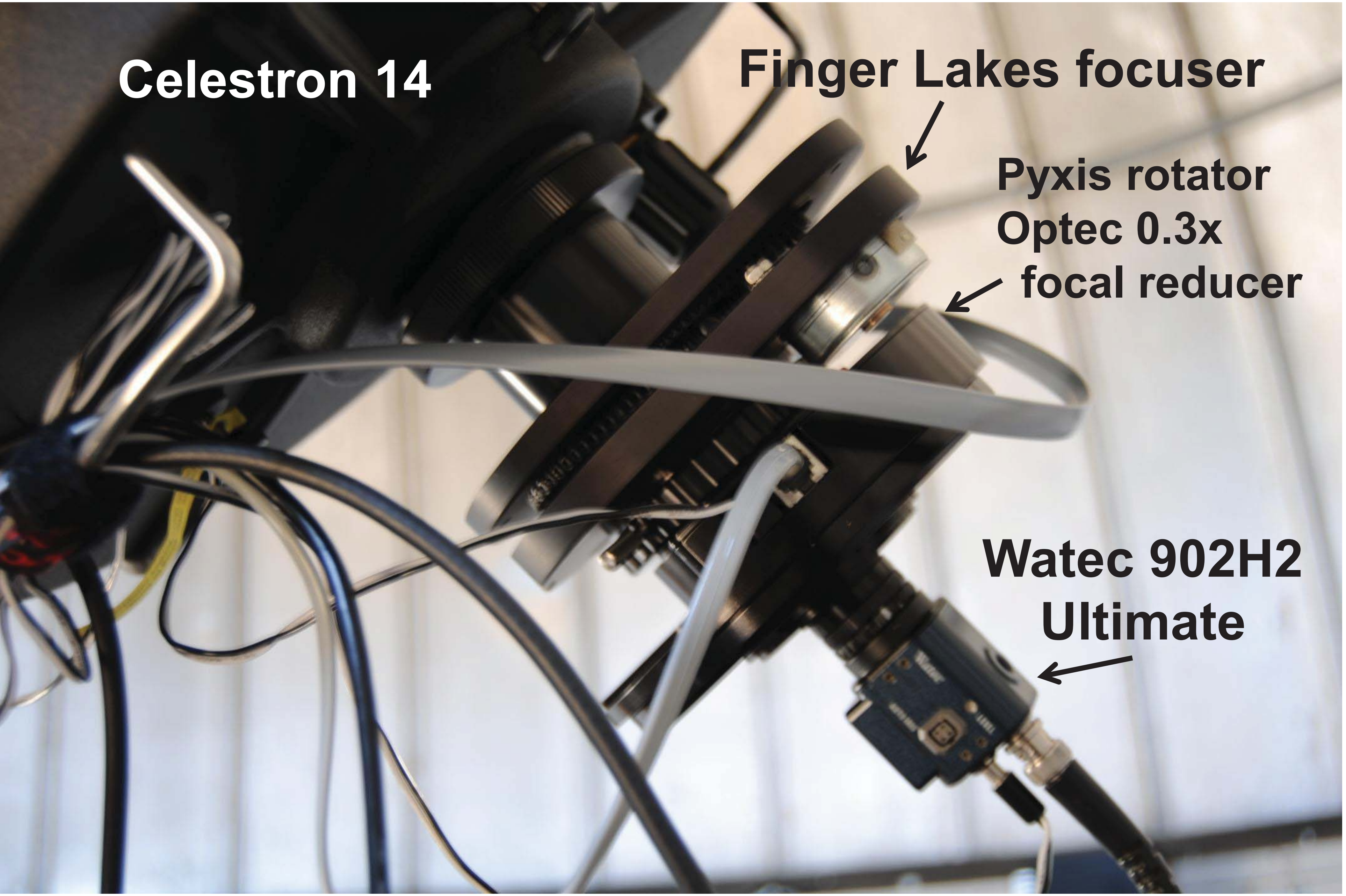
Huntsville, Alabama

Chickamauga, Georgia

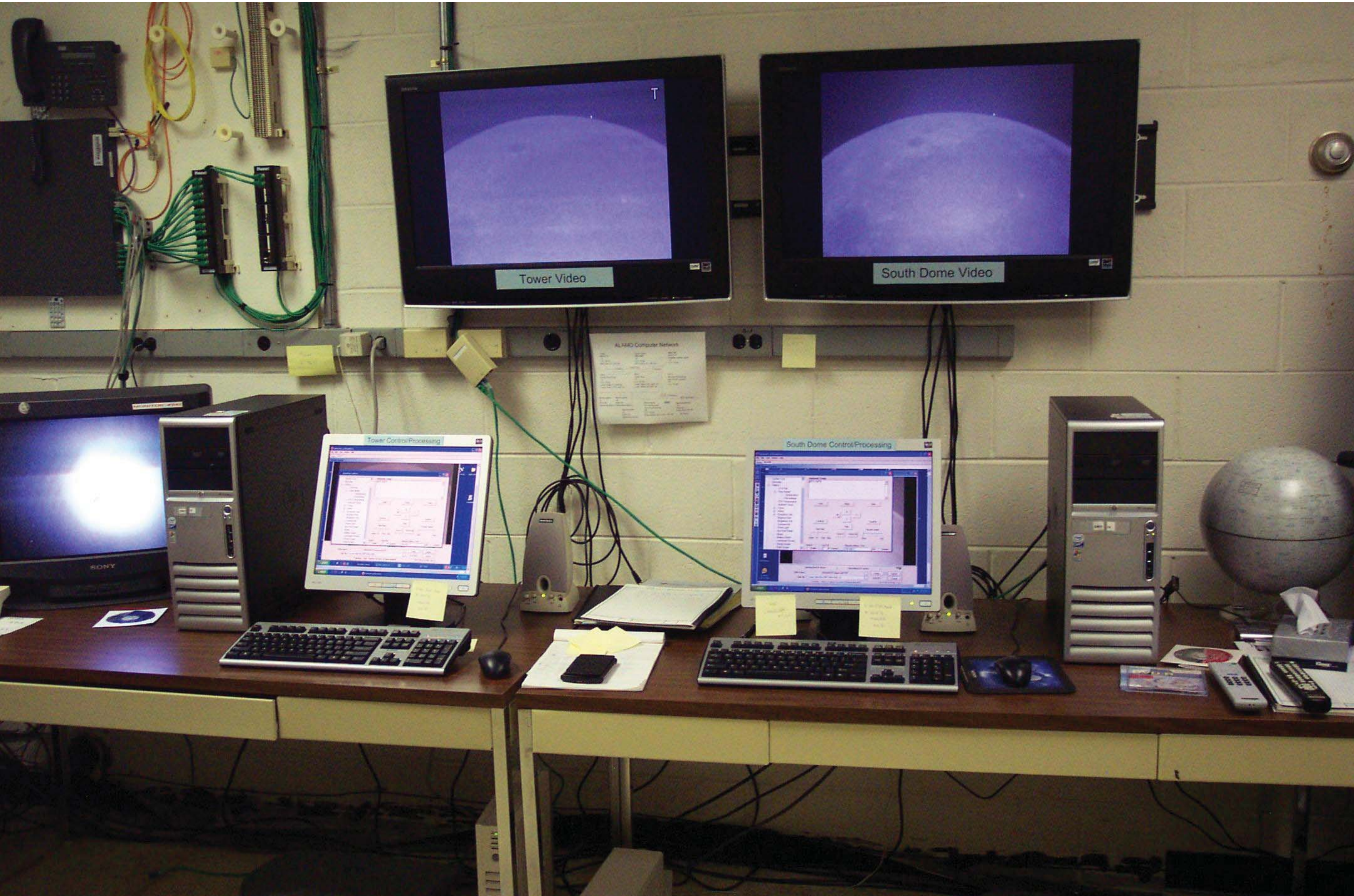


Telescope Control and Recording

TheSky X (Paramount/C14)
or Autostar (Meade)
WinDV to record via
Firewire from Sony DV or Canopus
deck/digitizer
Kiwi or IOTA GPS time stamper
Pyxis rotator control
Finger Lakes focuser control
DDW dome control
DLI power control


Celestron 14
Finger Lakes focuser
Pyxis rotator
Optec 0.3x
focal reducer
Watec 902H2
Ultimate

Operator position



Glare is a huge challenge

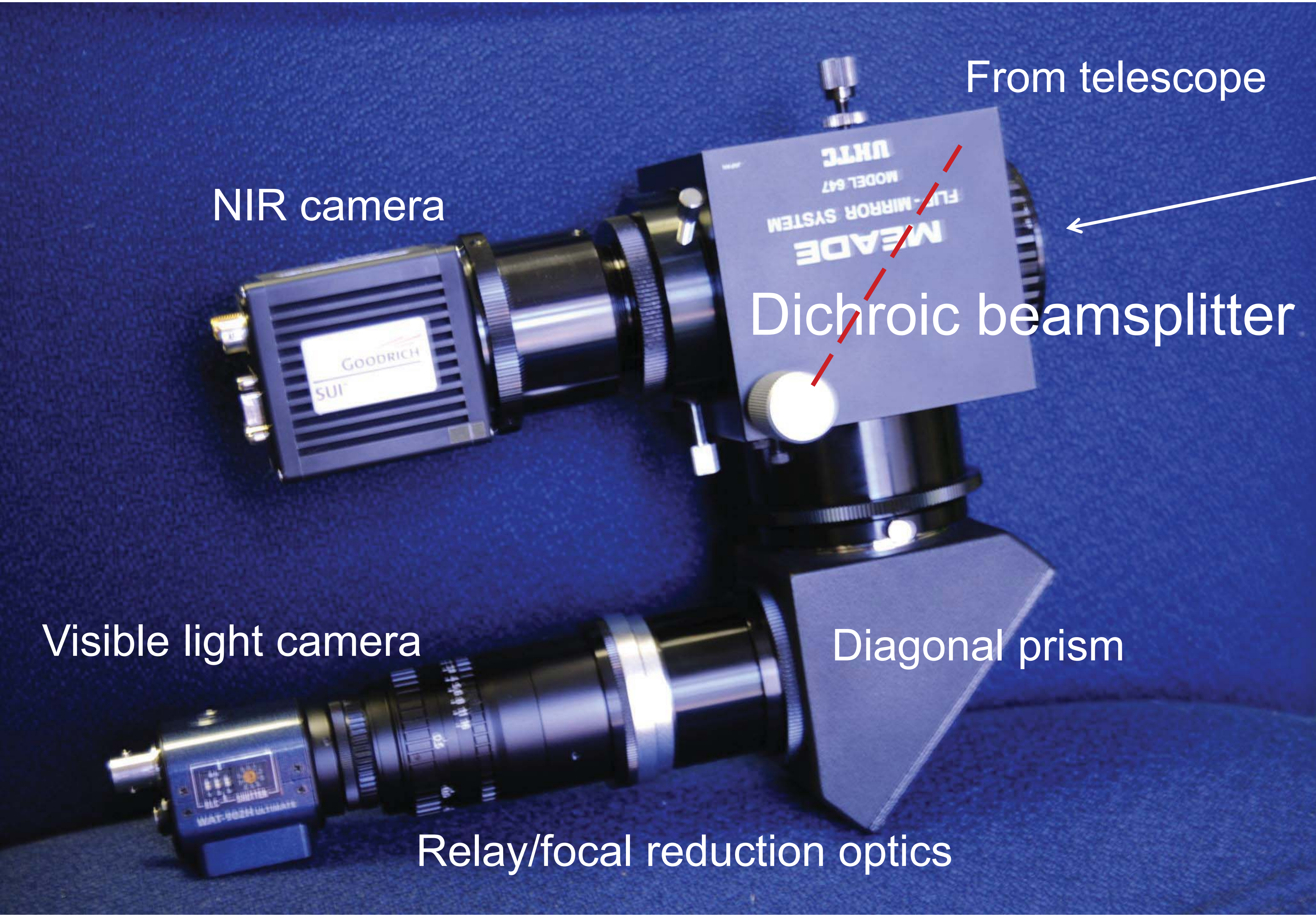
- You are trying to detect a 9^{th} – 10^{th} magnitude flash a few arcminutes from the sunlit Moon
- Glare sources and their mitigation
  - cirrus clouds and contrails
  - dirty optics – keep them clean
  - inadequate baffles – telescope design
  - internal reflections in the optics – use flocking paper

2 Cameras Needed

- Cosmic ray flashes in the CCD can look like impact flashes. 2 cameras can help reject those.
  - Cosmic rays are single frame so any multiframe flash is possibly real
- Orbital debris flashes can look like impact flashes. 2 widely separated (10s of km) telescopes can reject those.
  - We ran a telescope 100km from our primary observatory for 4 years and only saw one flash that would have fooled us.
  - LEO debris moves very fast so multiframe flashes would show motion. GEO is slower but still moving. Check many frames (2 or 3 seconds) either side of the flash all over the FOV.
- Observe even if you have only one camera
  - Another observer may see the same flash
  - You may capture a multi-frame flash

Possible solution for 2 cameras with one telescope: Dichroic beamsplitter

- Dichroic passes 90% of near infrared light to SU640 NIR camera and reflects 90% of visible light to Watec
- This also gives "2 color" data if cameras are gen-locked
- Main problem is different chip sizes and the need for focal reduction optics for the Watec
- Beware of persistence in NIR camera pixels


From telescope
NIR camera
Dichroic beamsplitter
Visible light camera
Diagonal prism
Relay/focal reduction optics

Flash Parameters Required for LADEE Science

- Date/Time – GPS time encoder
- Location – must be able to see lunar features in earthshine
- Energy – requires stellar calibration
  - Standard stars (or field stars) to determine extinction, color correction, zero point
  - $R = -2.5 \log_{10}(S) - k' X + T (B-V) + ZP$
  - $S = DN^{1/0.45}$ (DN is data number = pixel value) if camera gamma set to 0.45
  - See Suggs et al. (submitted to Icarus) for details

Don't throw your data away!!! Terabytes are cheap.

Date and Time

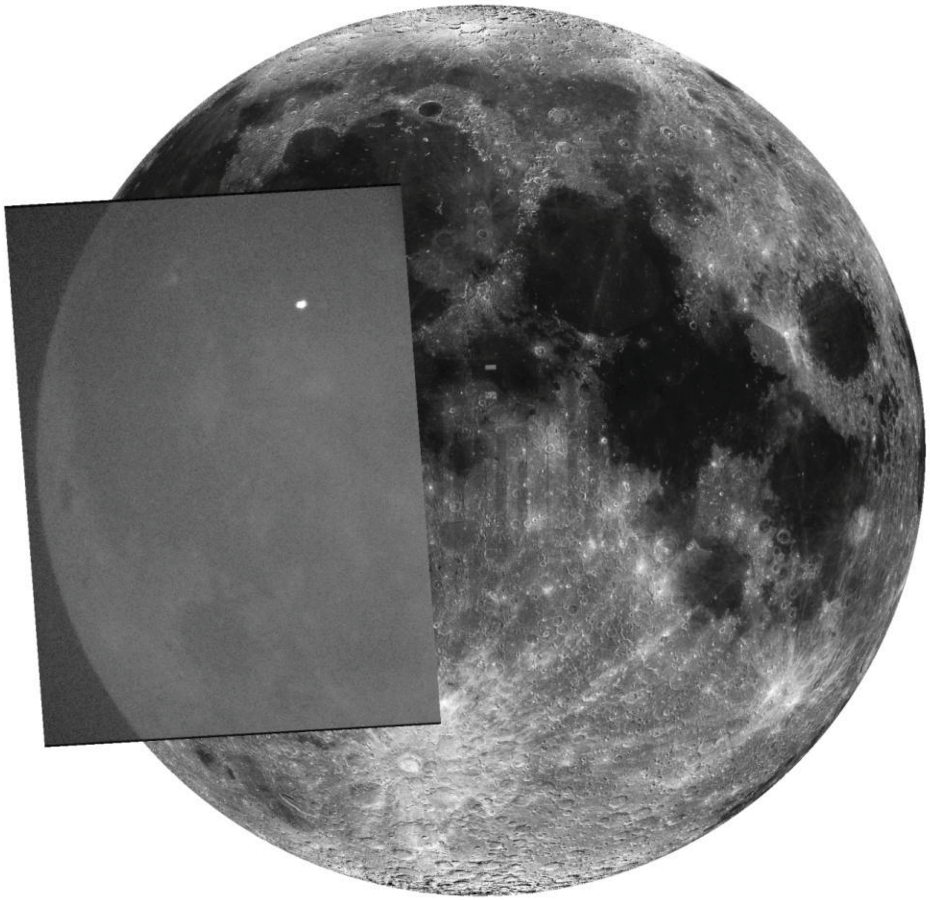
- Must be accurate to less than an second in order to facilitate correlation with other observers
- On-screen time is best
  - Kiwi is no longer available
  - Iota-VTI is available videotimers.com/home.html

- WWV, CHU or any other shortwave time signal recorded on audio channel of .AVI file can be used.

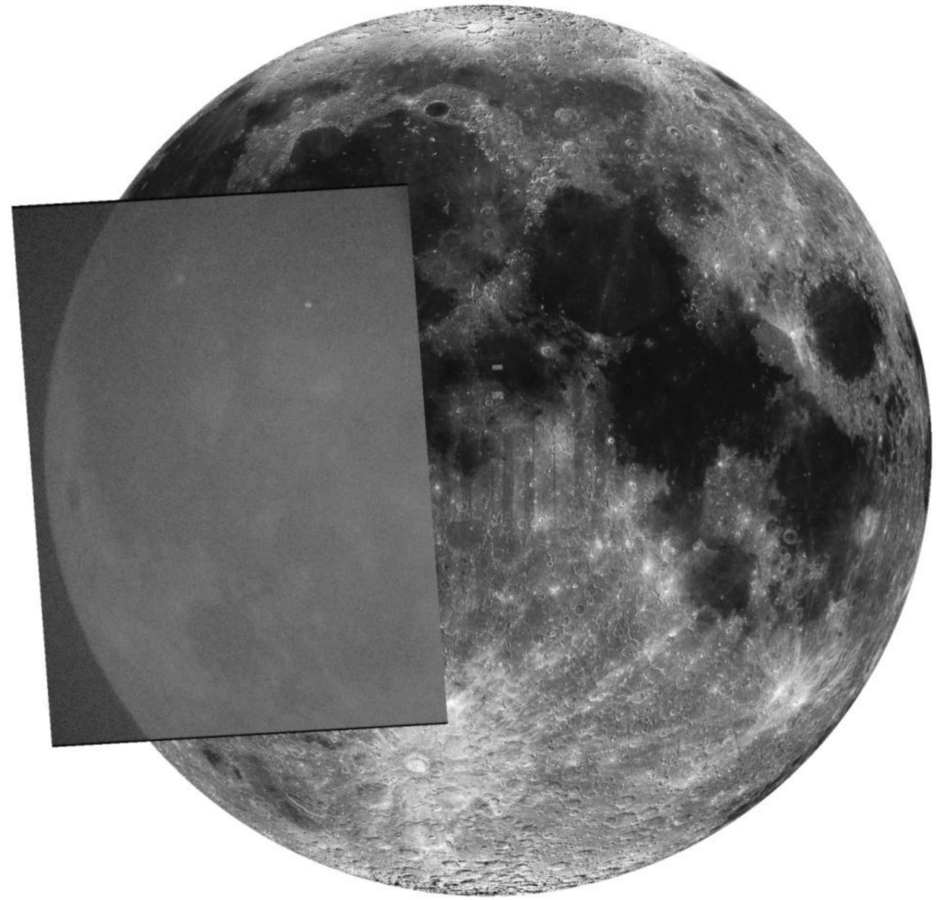
Location

- Use Virtual Moon Atlas and “eyeball it” using features visible in earthshine
  - www.ap-i.net/avl/en/start
- Use ArcMap (Arc GIS 10)
  - Many universities have this in geology or civil engineering departments
  - NASA has a site license

Mapping the impact location



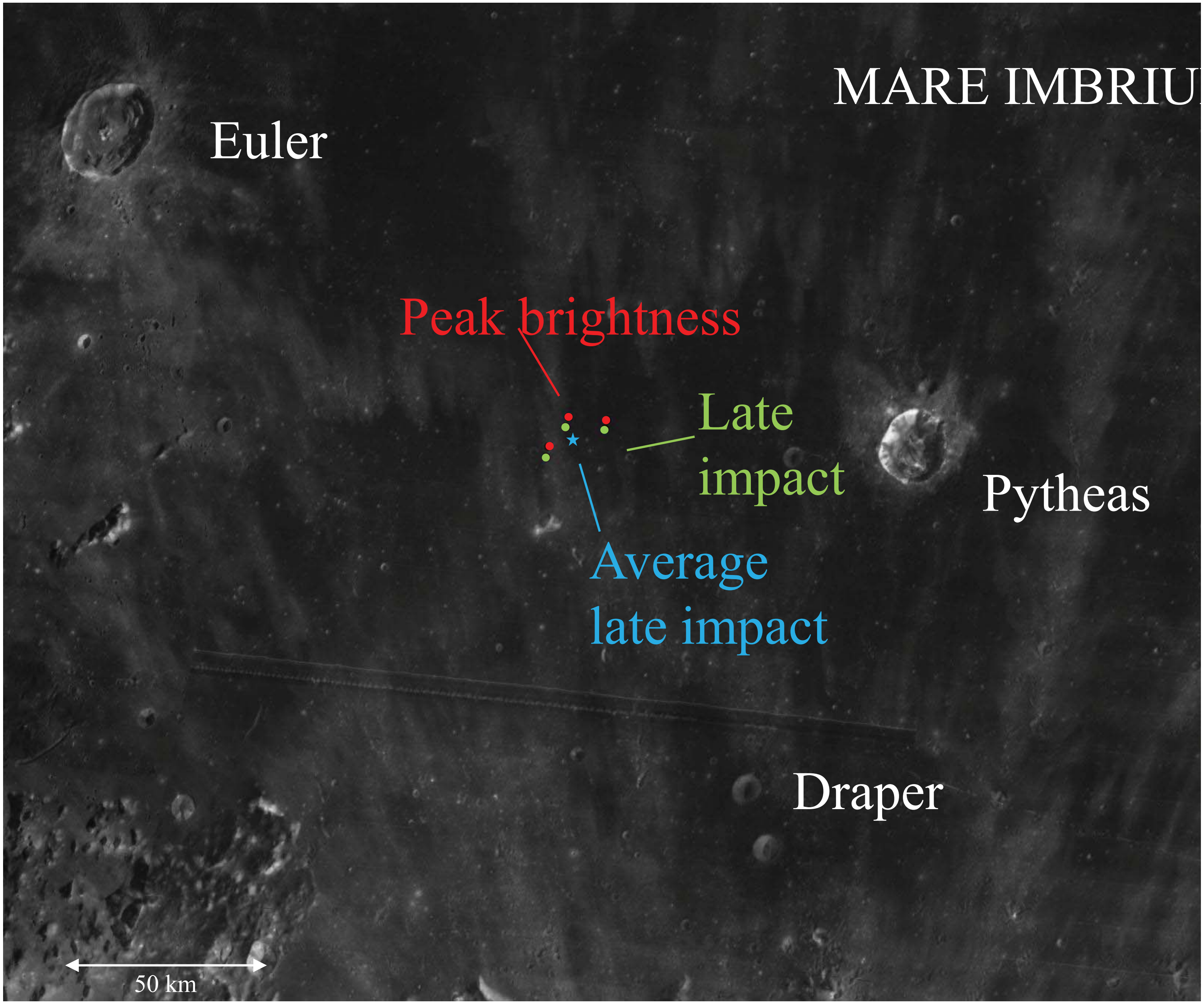
Flash at peak brightness



Flash 10 frames (333 ms) after the peak

ArcMap (ArcGIS 10) was used to georeference the lunar impact video

Results of several attempts with different features and frames



Average location: 20.599 ± 0.172° N, 23.922 ± 0.304° W

Magnitude Equation

see Brian Warner's book "A Practical Guide to Lightcurve Photometry and Analysis"

$$R = -2.5 \log_{10}(S) - k' X + T (B-V) + ZP$$

R = Johnson-Cousins R magnitude

k' = extinction coefficient

X = airmass (zenith = 1.0)

T = color response correction term

(*B-V*) = color index

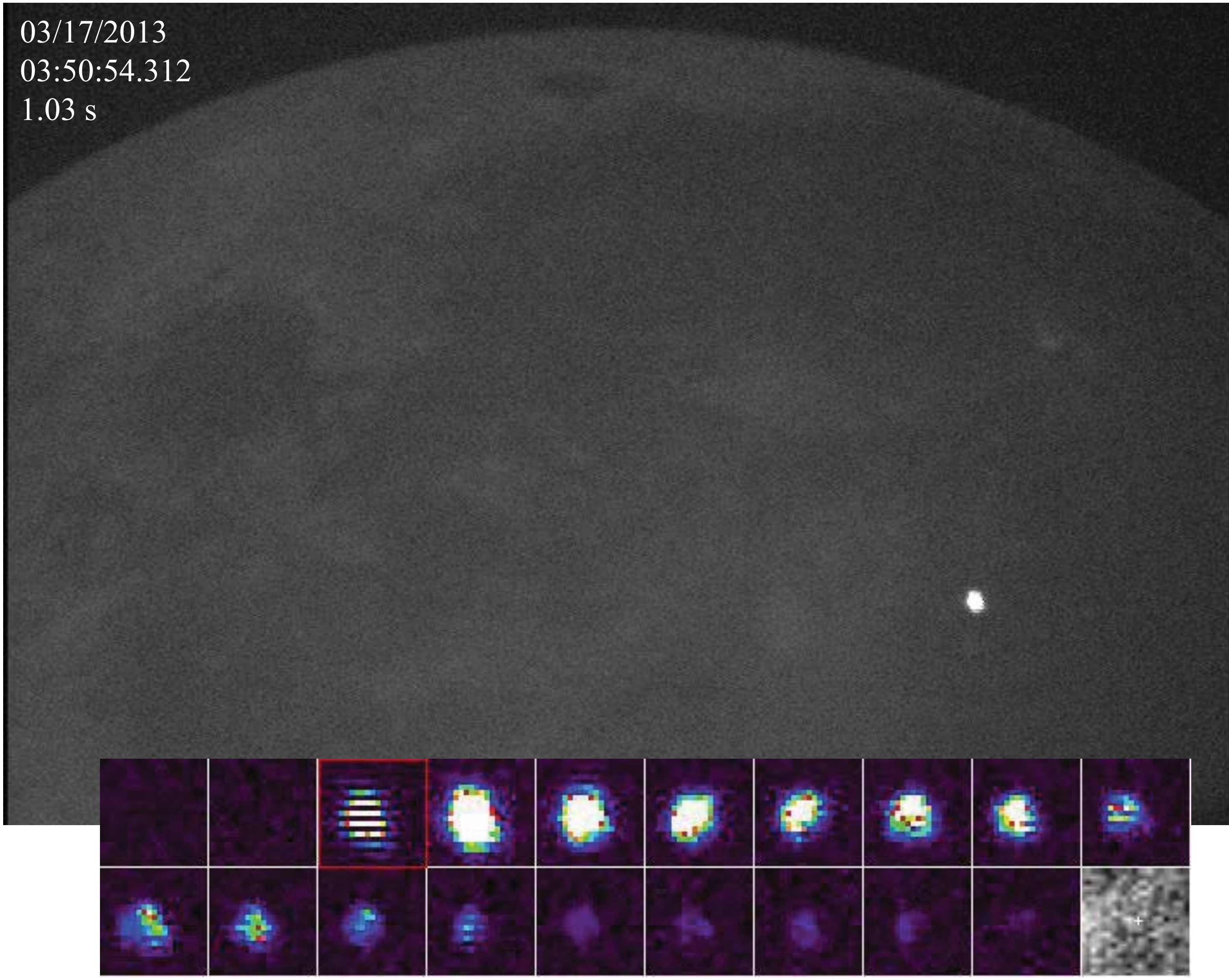
ZP = zero point for the night

$S = DN^{1/0.45}$ if camera gamma set to 0.45 which extends dynamic range (faintest flash to saturation)

DN = pixel value 0 – 255

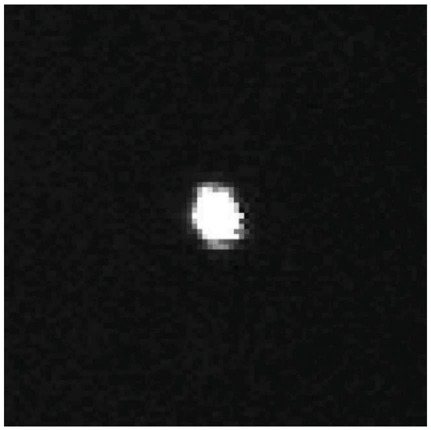
Must use Manual Gain Control (no AGC), no ELC (rightmost switch on the side down) and adjust gain to balance sensitivity and glare/earthshine

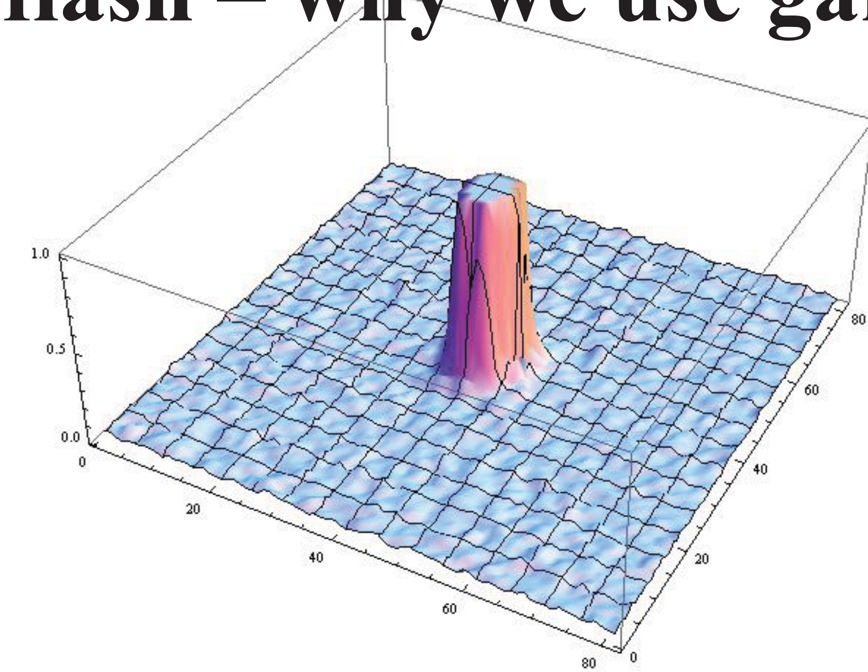
Saturated Image: Largest Impact in 7 years
March 17, 2013 3:50:54 UTC



Observed by A. Kingery & R.M. Suggs; detected by R.J. Suggs

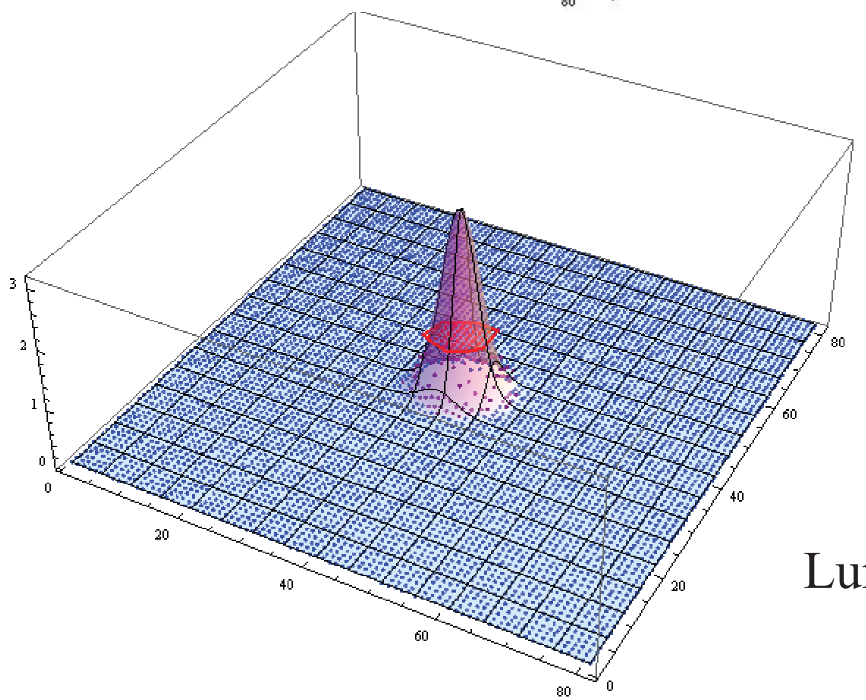
Preliminary magnitude estimate for a saturated flash – why we use gamma=0.45





Saturated

Peak $m_R = 4.9$



2D elliptical Gaussian fit
to the unsaturated wings

Peak $m_R = 3.1 \pm 0.4$
Luminous energy = 4.8×10^6 J

Similar results for
2D elliptical Moffat fit

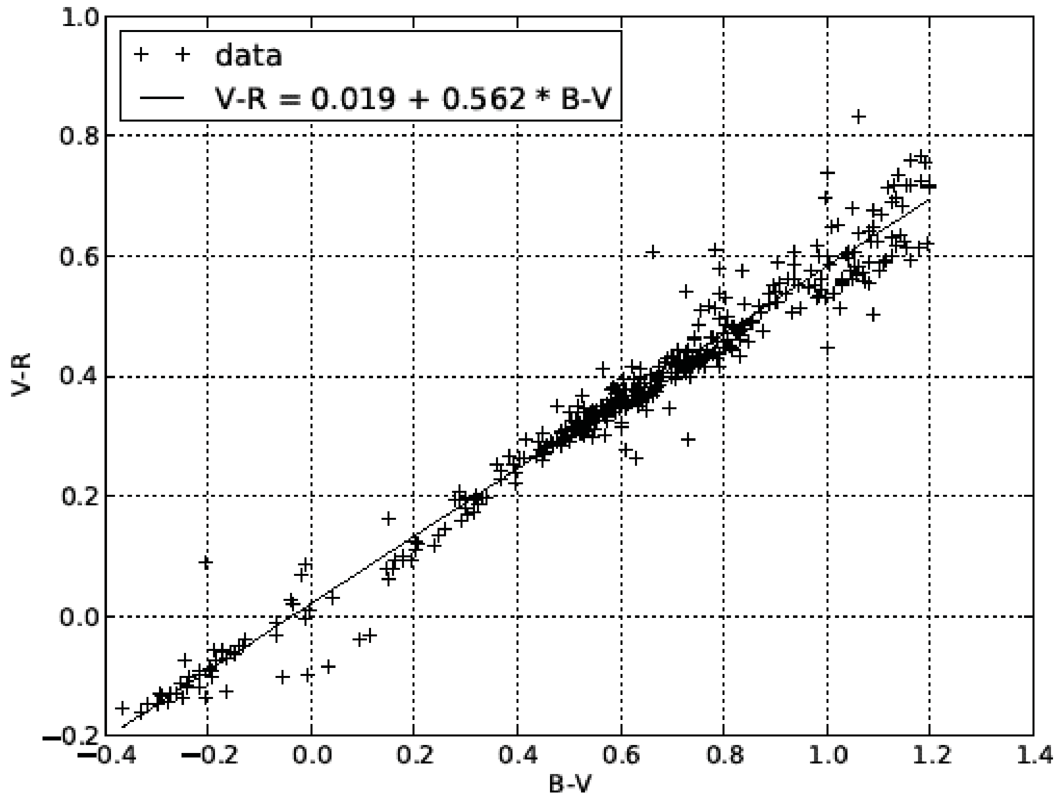
Comparison Stars

- Stars will pass through the field of view during observations, but
  - you don't typically know the R magnitude
  - they are seldom in the FOV at the time of the flash
    - this means you must do "all sky" photometry rather than "differential" (i.e. must account for extinction as a function of airmass)
  - flat field must be very good because vignetting is worse near the edge of the FOV where the field stars will be seen
- Cartes du Ciel is excellent for star identification www.ap-i.net/skychart/start
- So it is better to observe some "standards" at various airmasses after evening observations and before morning ones
- Build a standards list using SIMBAD for stars that are bright enough but don't saturate the system (8 – 9 R mag for 14in) that pass through your zenith simbad.u-strasbg.fr/simbad/
  - Must have published R and B-V mag and not be a variable

$$R = -2.5 \log(S) - k' X + T (B-V) + ZP$$

See Warner's book "A Practical Guide to Lightcurve Photometry and Analysis" for details

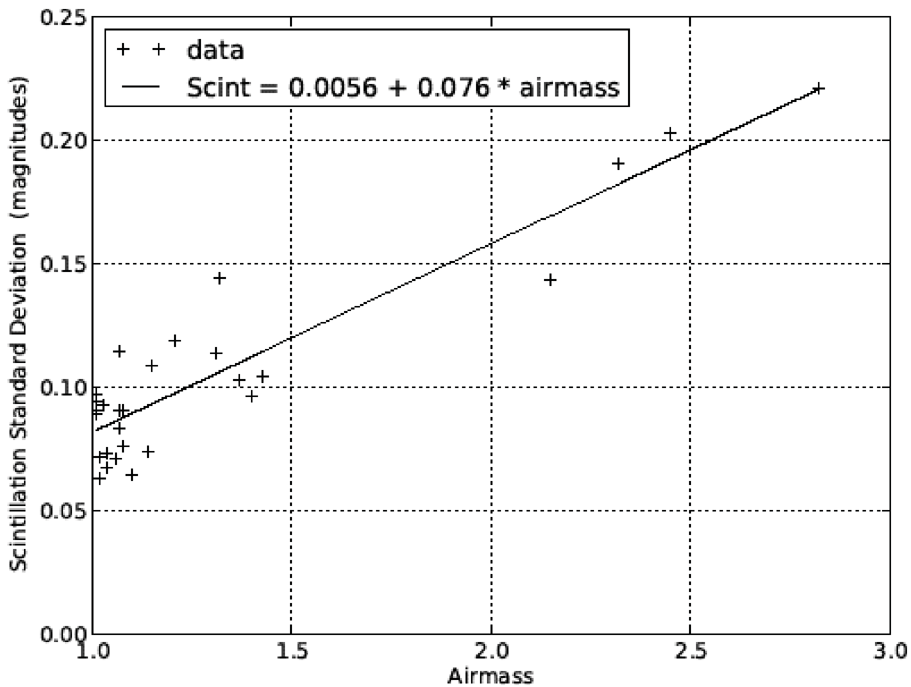
If you don't have an R magnitude but do have V and B-V use this correlation between V-R and B-V for Landolt Standards



$$R = V - 0.019 - 0.562\,(B\text{-}V)$$

Only for stars bluer than B-V = 1.2

Error due to atmospheric scintillation is a function of airmass X
You may want to determine this for your site by measuring field-to-field instrumental magnitude deviation at various airmasses



$$\sigma_{scint} = 0.0056 + 0.076\, X$$

$$\sigma^2 = \sigma_{scint}{}^2 + \sigma_{fit}{}^2$$

Camera FOV and Tracking

Optimize FOV for LADEE

Long axis of camera parallel to equator which is LADEE's orbit plane

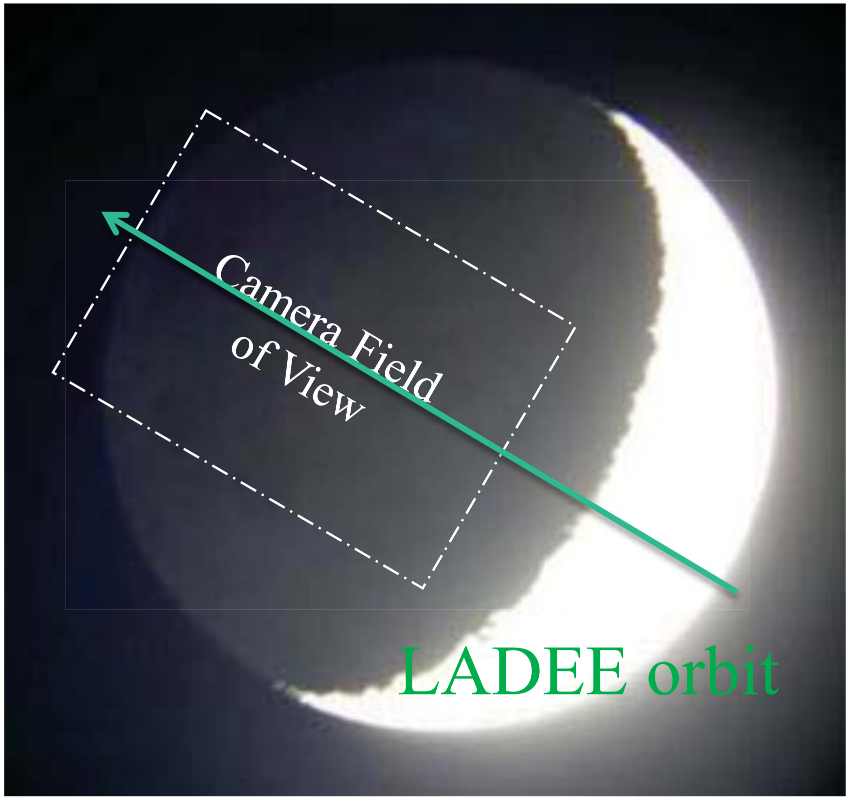
May have to move FOV away from terminator to avoid glare as phase progresses

Fewer field stars will be visible due to little sky visibility

Make sure your optics are clean

Use lunar rate on your telescope mount

- Most have average rate in RA, none in Dec
- Aristarchus and Proclus are easy to see and use as tracking targets



Software we have used

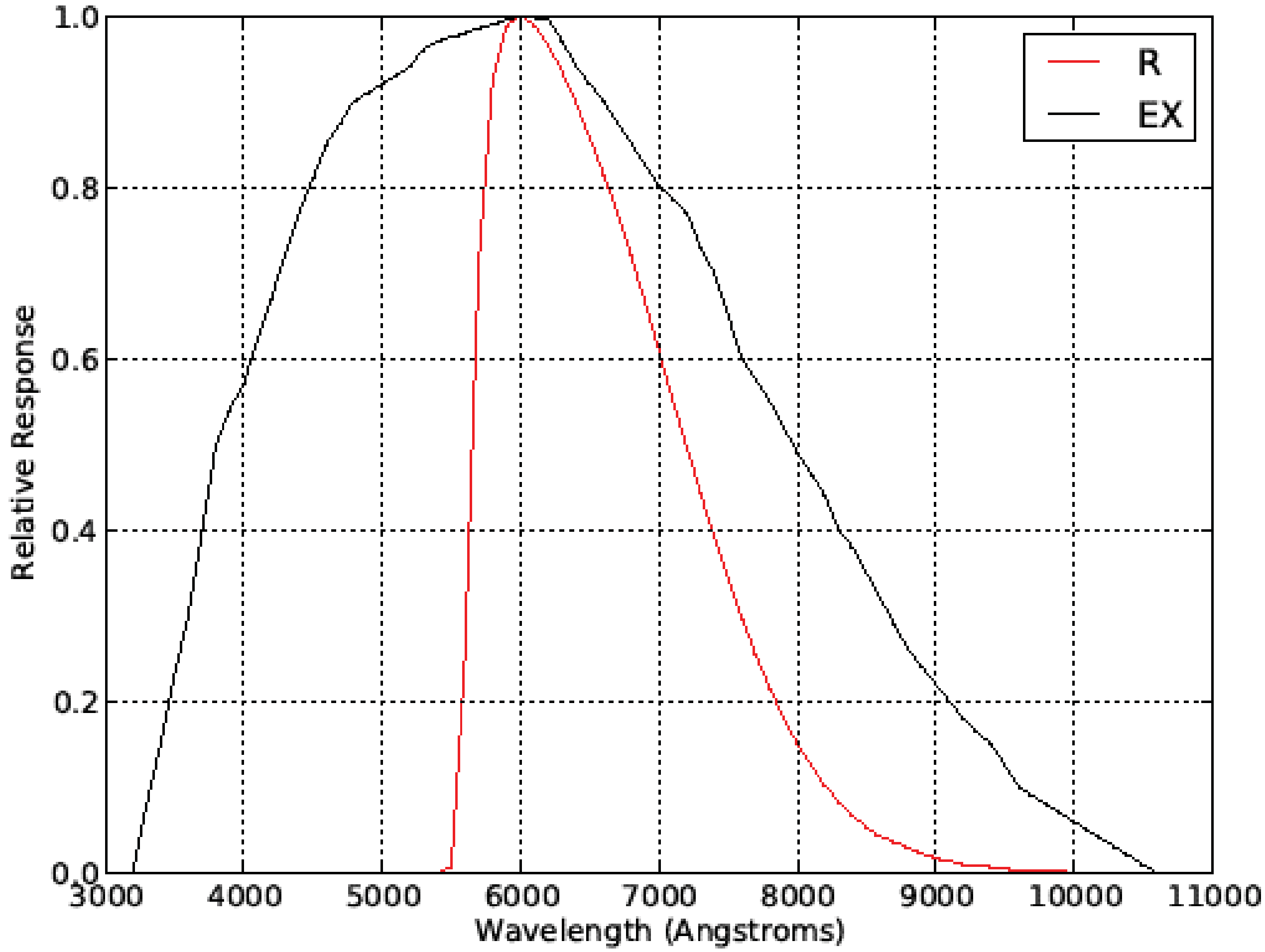
- WinDV for recording windv.mourek.cz
- LunarScan detection software (Gural will discuss) www.lunarimpacts.com/lunarimpacts.htm
- VirtualDub for slicing out relevant sections of video and converting to “Old AVI” for reading into Limovie www.virtualdub.org/download.html
- Limovie for photometry of flashes and calibration stars www005.upp.so-net.ne.jp/k_miyash/occ02/limovie_en.html
- MaximDL can convert video segments to FITS
  - Don’t use the aperture photometry tool until after each pixel is gamma corrected by $S = DN^{1/0.45}$ if camera gamma set to 0.45
- Python and Pyraf may be used for aperture photometry www.stsci.edu/institute/software_hardware/pyraf/current/download

Filters and Photometric Calibration

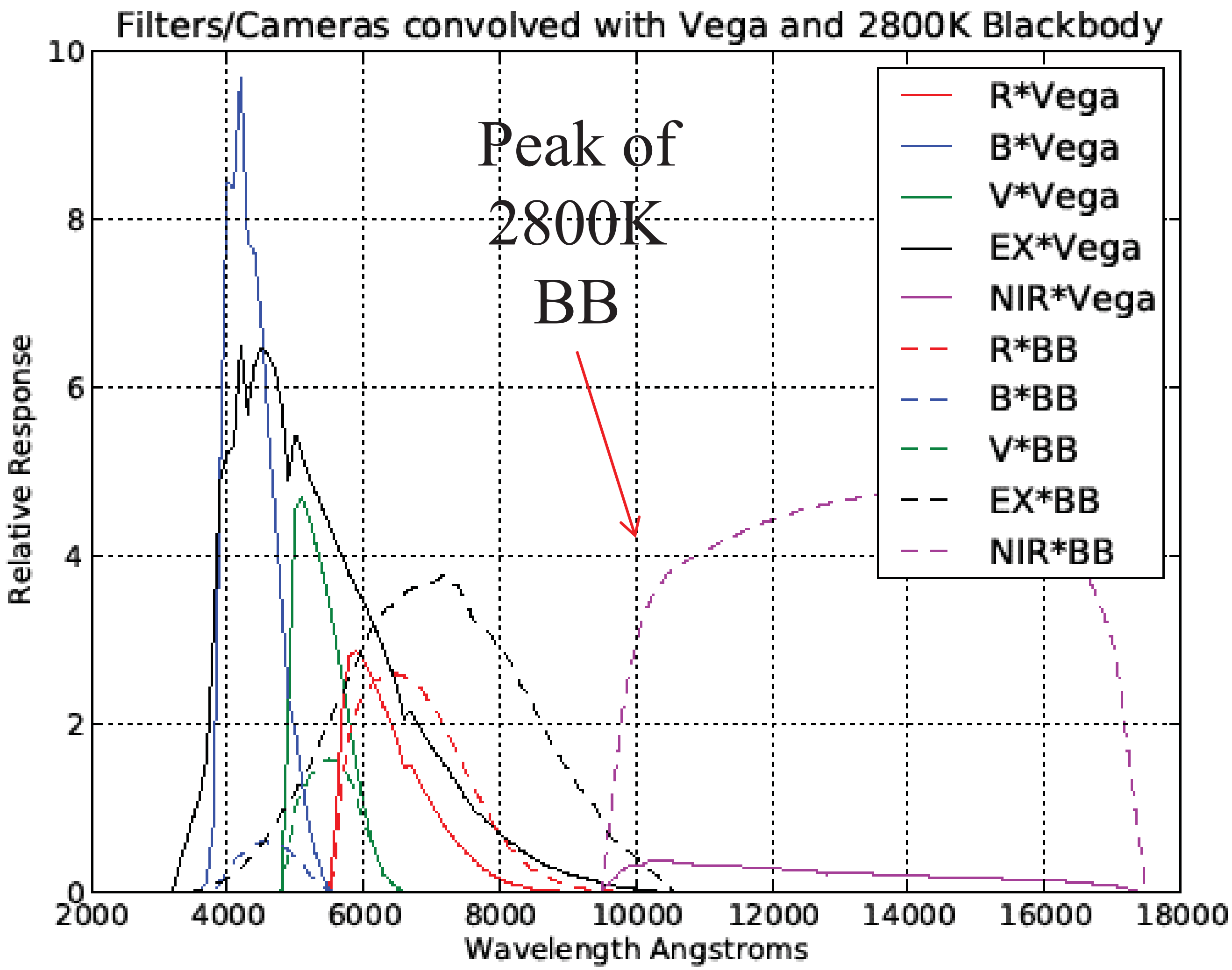
- Use the camera unfiltered to give maximum sensitivity
  - Wider spectral response
    - near infrared where the flash is brightest
    - blue and green where earthshine is brightest (to see features)
- Calibration should be done with R magnitudes of comparison stars
  - Peak sensitivity of HAD EX and R filter is at the same wavelength
  - Need the color term T (B-V) = EX-R in the magnitude equation

$$R = -2.5\ \log(S) - k'\, X + T\,(B\text{-}V) + ZP$$

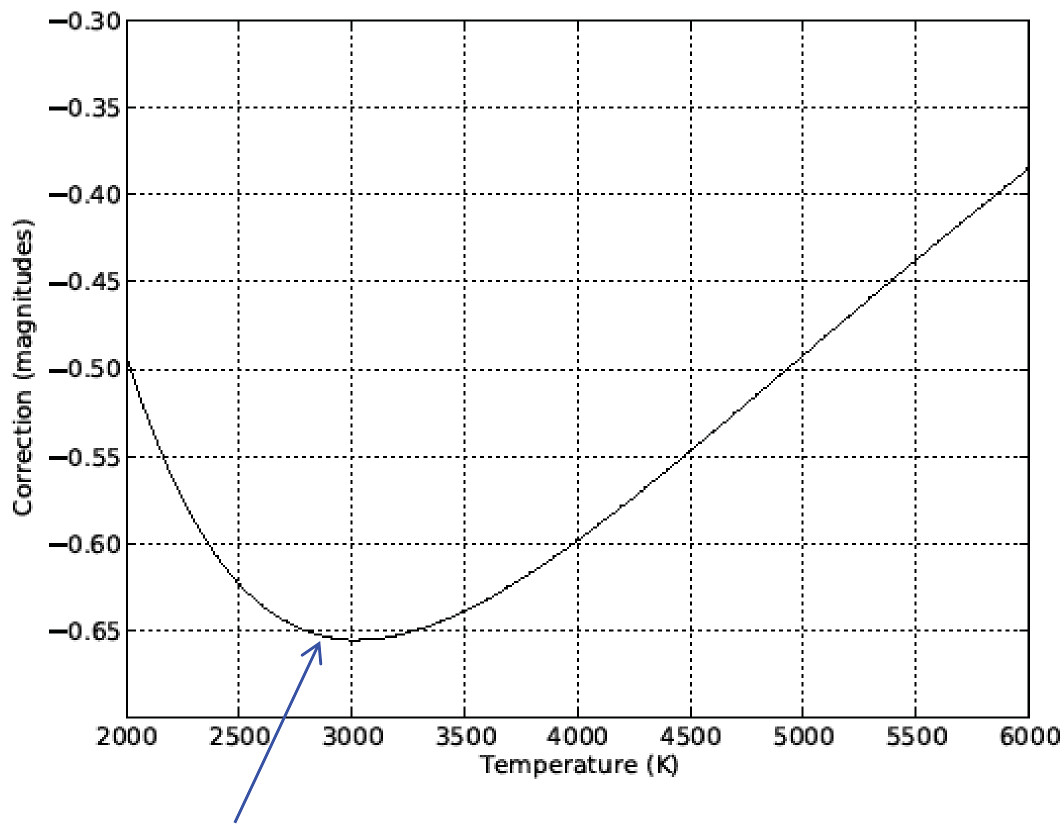
Sony HAD EX response compared to Johnson-Cousins R filter



Filter and camera responses depend on temperature of object



Correction from HAD EX to R filter vs blackbody temperature
R-EX replaces T(B-V)



Theoretical peak flash temperature 2800K Nemtchinov et al.

To compute energy from impact magnitude

- $E_{lum} = f_\lambda \, \Delta\lambda \; f \; \pi \; d^2 \; t$ Joules

  E_{lum} = luminous energy

  $\Delta\lambda$ = filter half power width, 1607 Ångstroms for R

  f = 2 for flashes near the lunar surface

  d = distance from Earth to the Moon

  t = exposure time, 0.01667 for a NTSC field

$f_\lambda = 10^{(-R + 21.1 + zp_R) / 2.5}$ J cm^{-2} s^{-1} Å^{-1}

R = the R magnitude

zp_R photometric zero point for *R* (not the same as *ZP* in magnitude equation)

To compute mass of the impactor if you know the impact speed (from shower association)

Luminous efficiency

$$\eta = 1.5\times10^{-3} \exp\left(-9.3^2/v^2\right)$$

v = impact speed in km/s

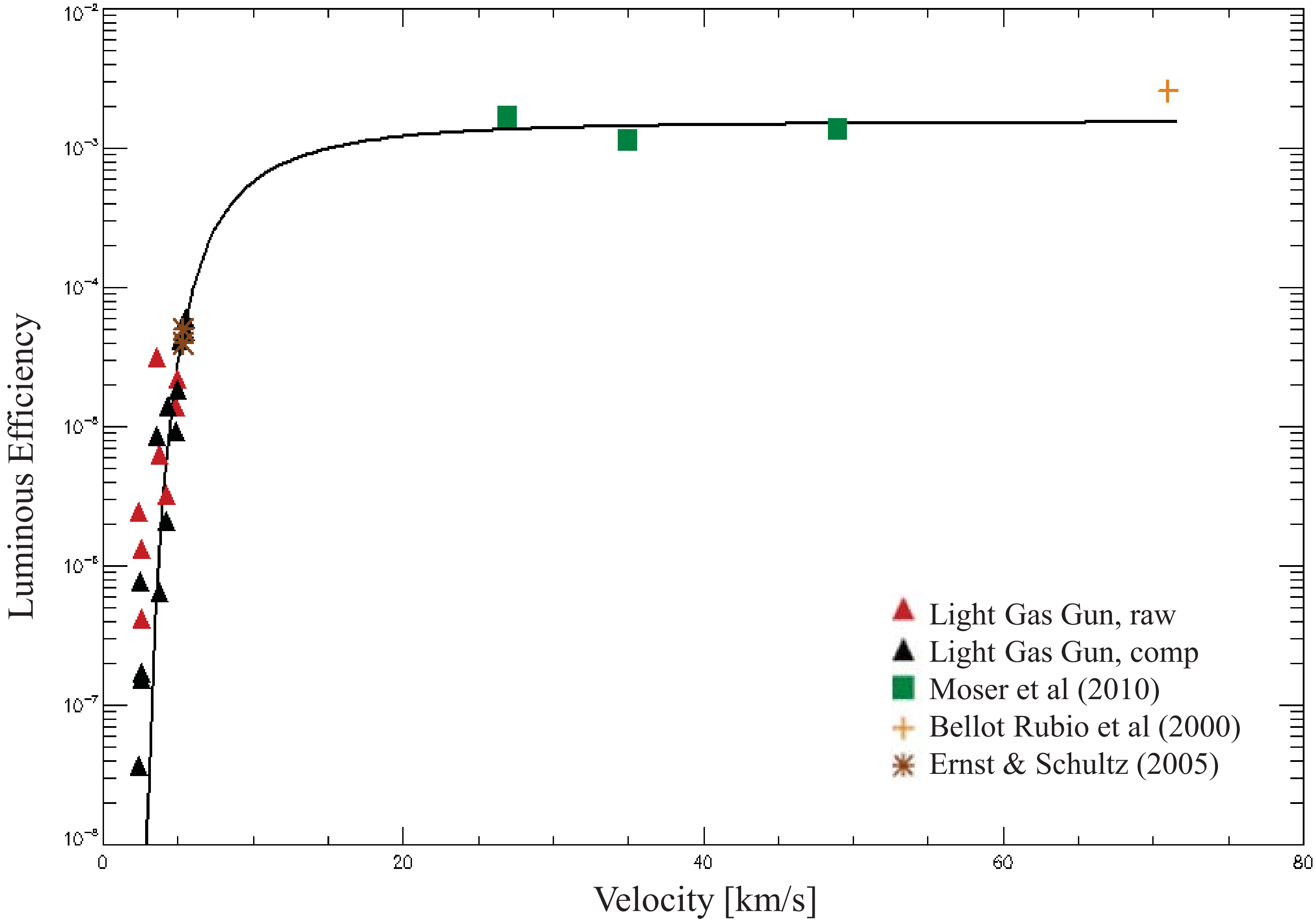
Kinetic Energy

$$KE = E_{lum} / \eta$$

Mass

$$M = 2\, KE / v^2$$

Luminous Efficiency from Swift et al. 2010



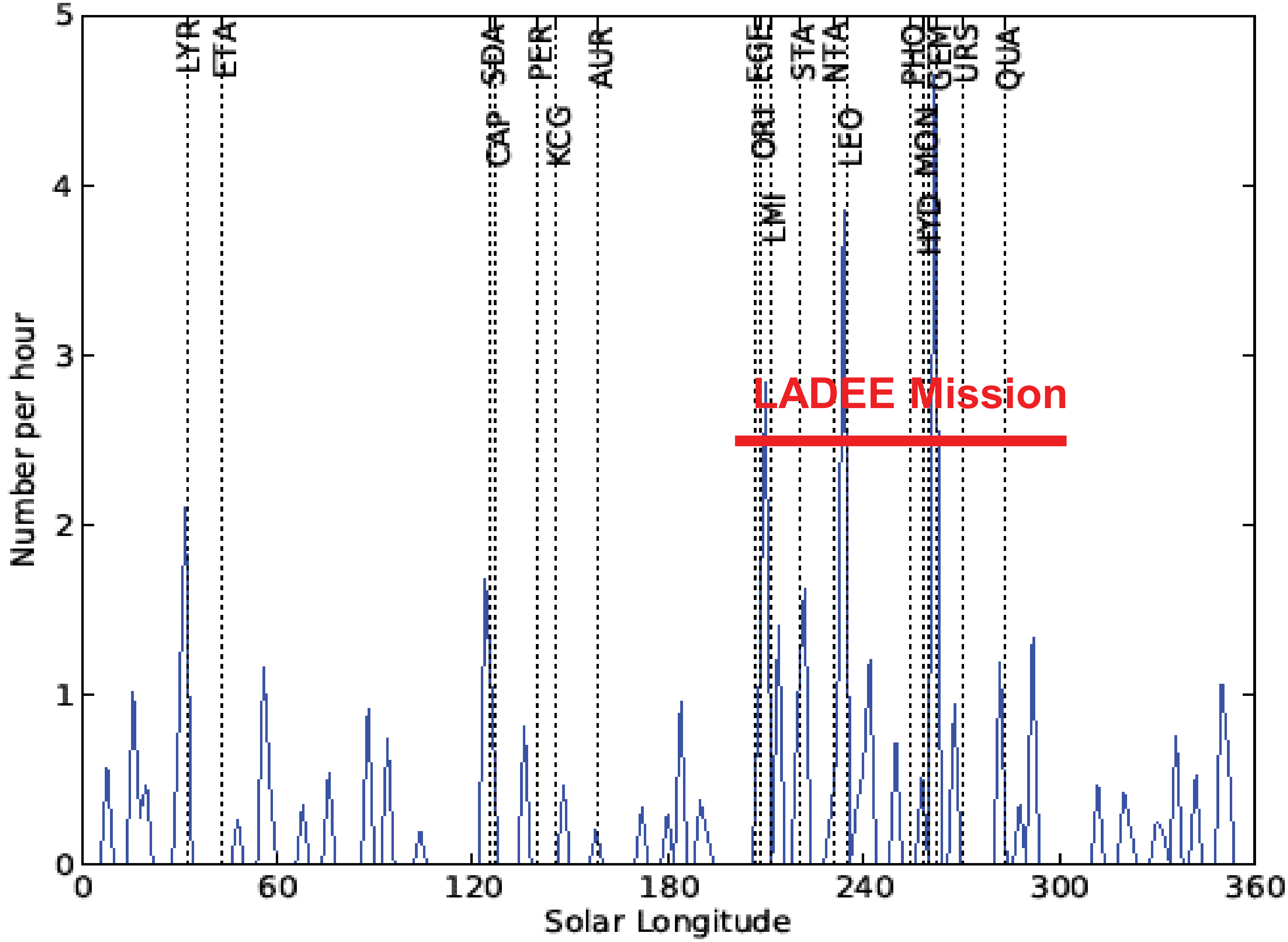
$$\eta_{cam} = 1.5x10^{-3}\, e^{-\left(\frac{9.3}{v}\right)^2}$$

- Fits both *Lunar Impact and Light Gas Gun data*

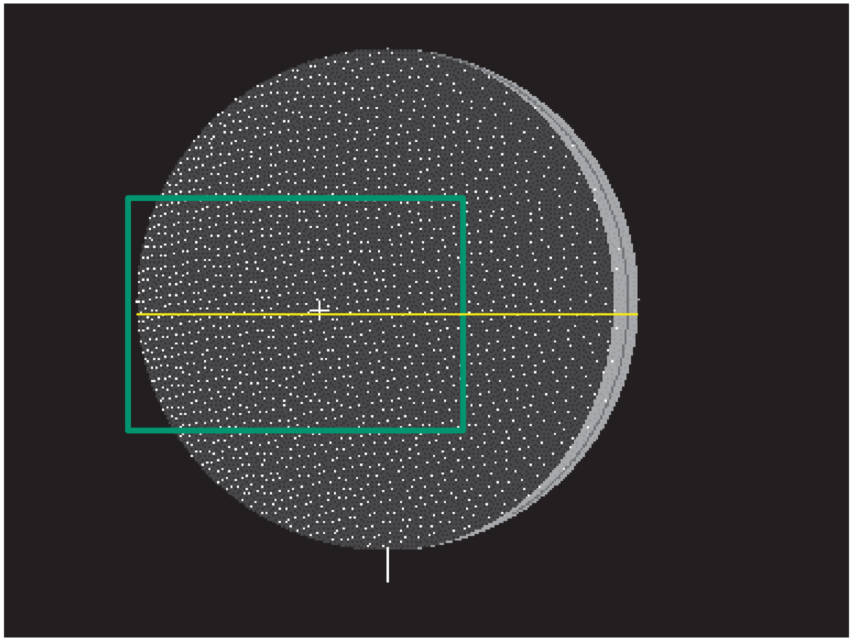
Shower visibility

but don’t let this bias your observation times

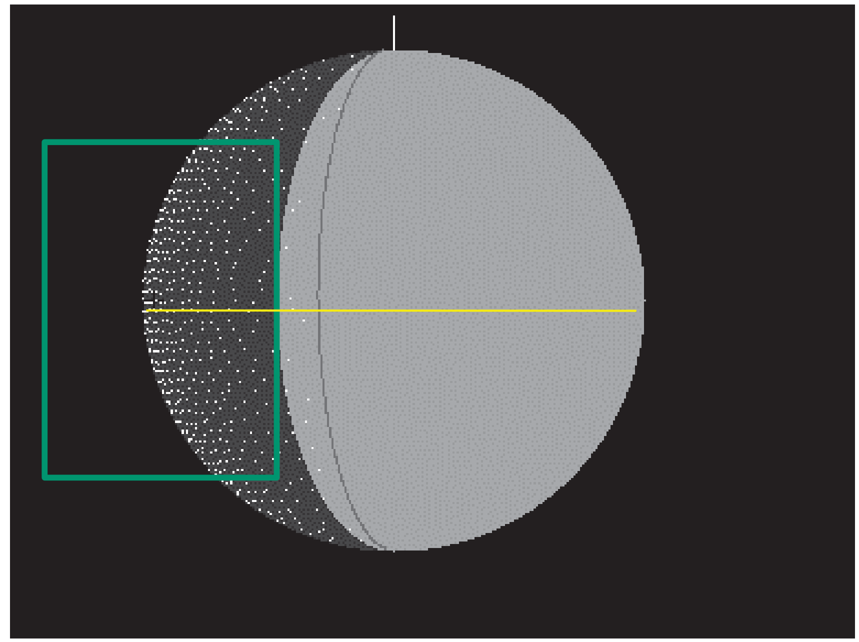
Impact Flash Rate with Meteor Showers
Must observe anytime to detect sporadics and minor shower meteoroids



Some decent showers during LADEE
Note the FOV orientation



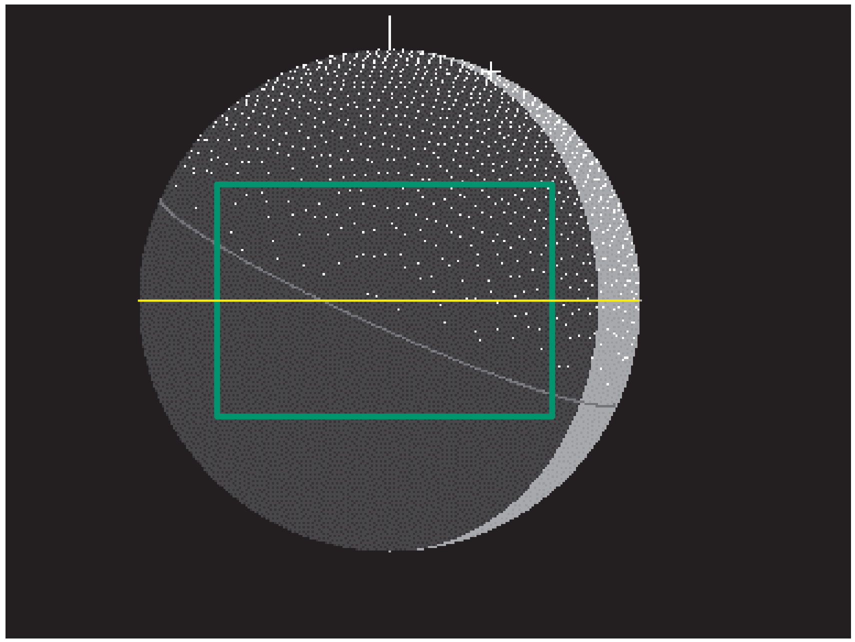
South Taurids Nov 5, 2013



North Taurids Nov 12, 2013

These are fairly long-lasting showers so observations either side of the peak should be fruitful

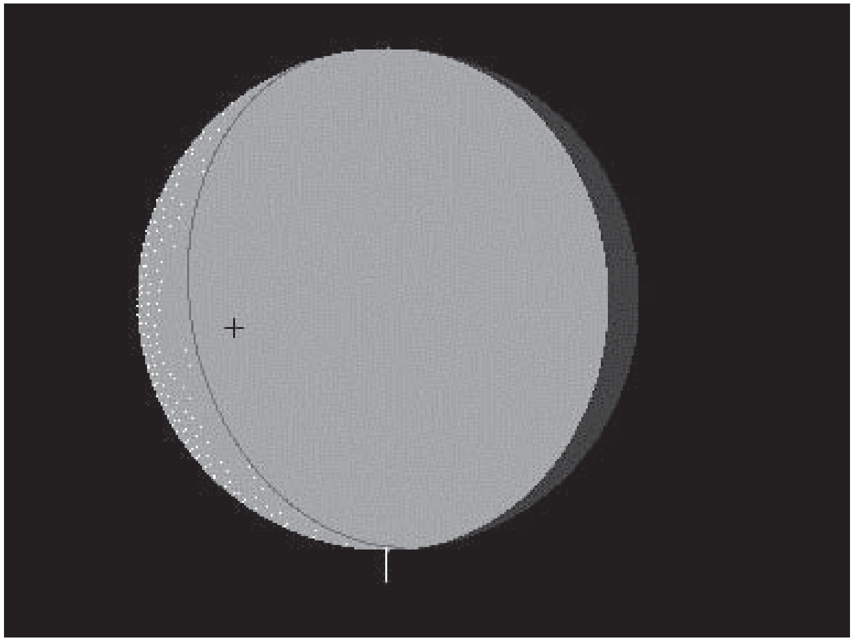
And in 2014



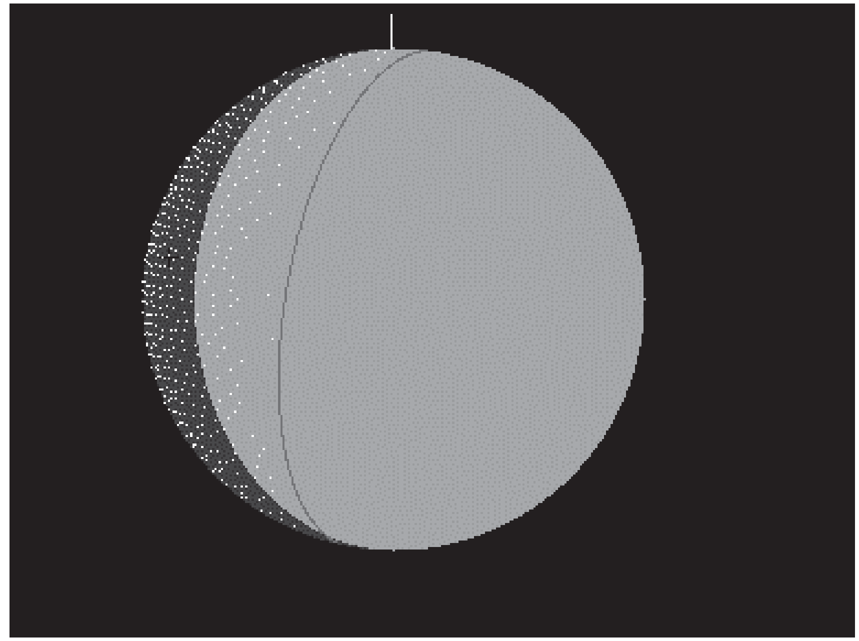
Quadrantids Jan 3, 2014

Note that west limb equator (LADEE orbit) is not visible from Quadrantid radiant so may want to bias FOV closer to sunlit hemisphere as glare allows.

Big ones that are terrible this year due to nearly full Moon



Orionids Oct 21, 2013



Geminids Dec 14, 2013

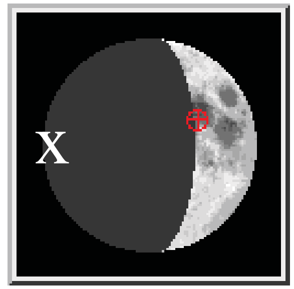
Amateur Contributions

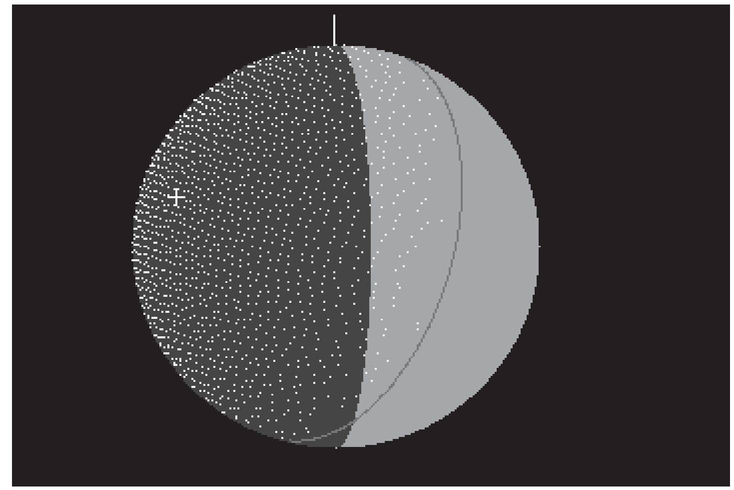
- A telescope of at least 8 inch diameter, a video camera, video digitizer, GPS time encoder and PC can provide useful data
- For details see www.nasa.gov/centers/marshall/pdf/166643main_MinimumSystemRequirements5.pdf
- Provide your observations to the Association of Lunar and Planetary Observers

alpo-astronomy.org/lunarupload/lunimpacts.htm

Backup

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.

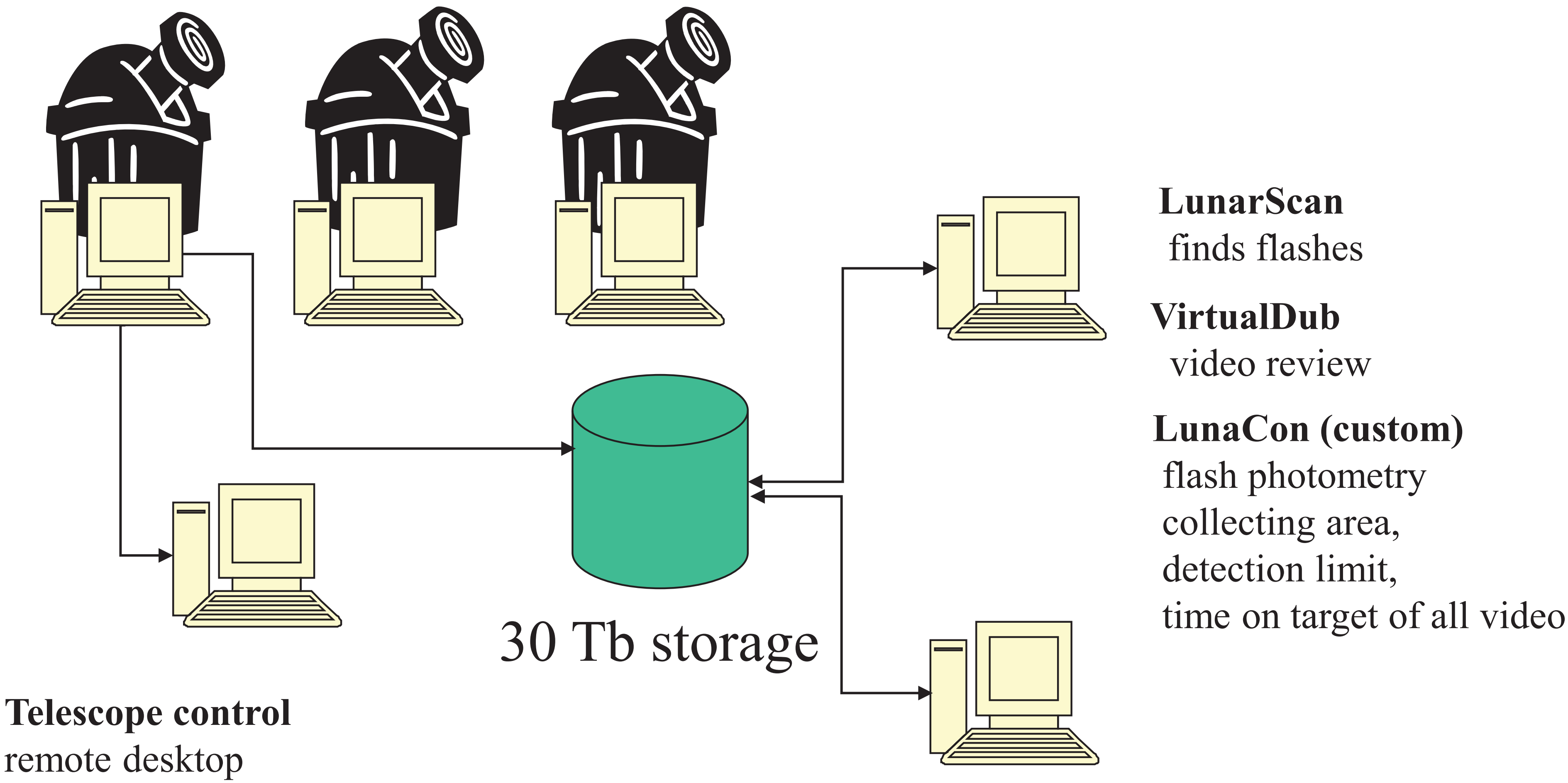
CC How about putting an X on the map where you saw it?

LMP I keep looking for -- yes, we will. I was planning on looking for those kind of things....

Automated Lunar and Meteor Observatory

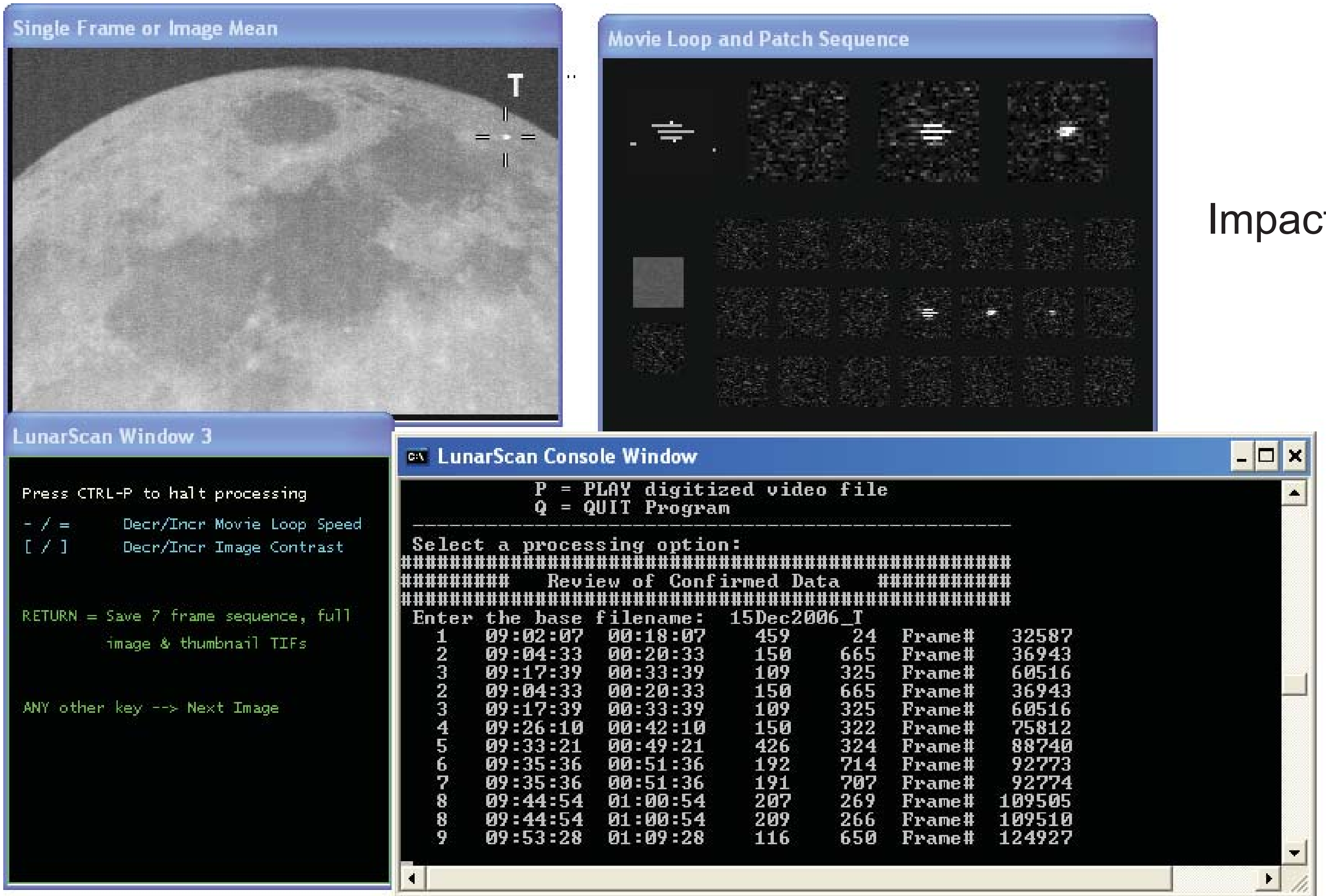
Meade 14 in (0.35m)

Data Pipeline



Must detect flash in all operating telescopes to discriminate cosmic rays and orbital debris unless flash is multiple fields with no apparent motion

LunarScan (Gural)



Impact 15 Dec 2006

Free download from http://www.lunarimpacts.com/lunarimpacts.htm