FLUX OF LARGE METEOROIDS FROM LUNAR IMPACT MONITORING AND INFRASOUND

Bill Cooke
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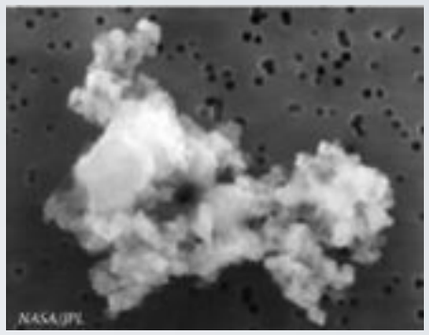
Meteoroid - small rocky/ icy debris out in space



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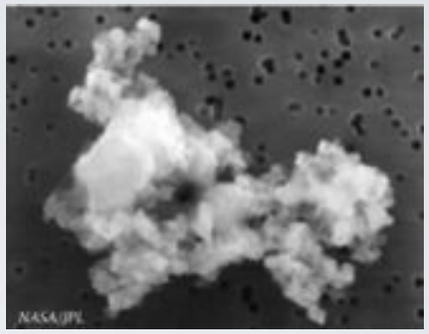

Meteor - streak of light/ionization produced by a meteoroid ablating in an atmosphere

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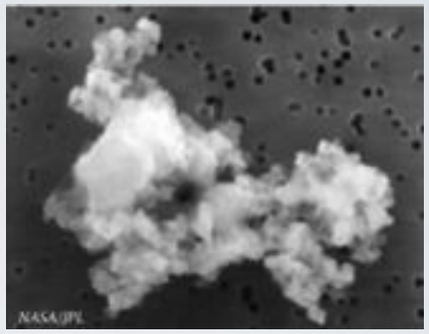
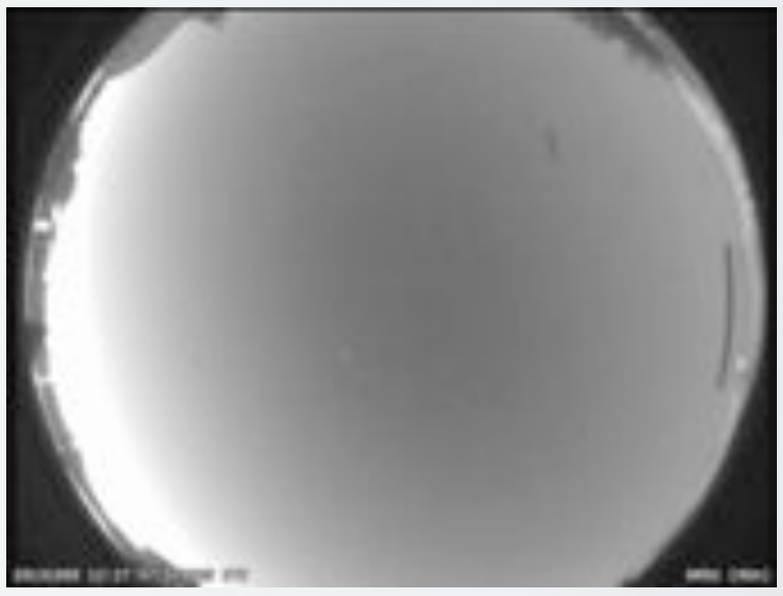


Meteor - streak of light/ionization produced by a meteoroid ablating in an atmosphere

Fireball - meteor with a peak brightness greater than the planet Venus (m_V -4). Also called a bolide



Super bolide - a meteor sufficiently energetic to be detected by seismic/other sensors (m_V ~-18)

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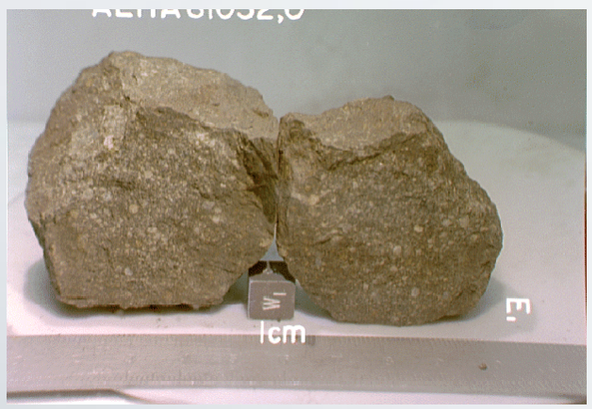

Meteorite - any part of a meteoroid/ asteroid that makes it to the surface

ASTEROID OR METEOROID?

Size is the discriminator, but no "official" boundary

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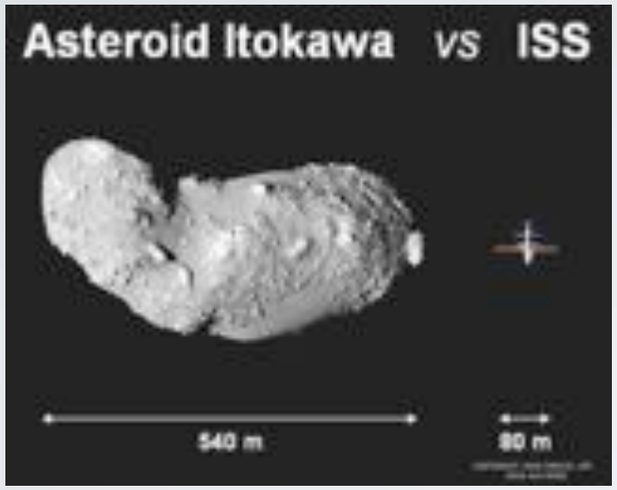
> International Astronomical Union definition: "A meteoroid is a solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger than an atom."

How NASA handles meteoroids, asteroids, and space junk



Earth-approaching asteroids

Near Earth Object Office (JPL)

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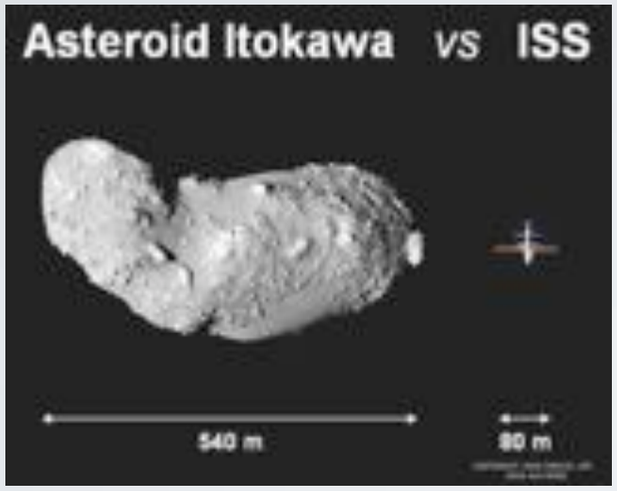

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Man-made orbital debris

Orbital Debris Program Office (JSC)

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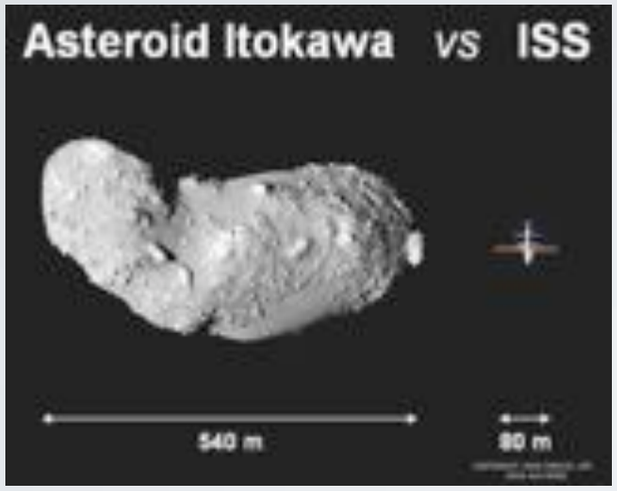

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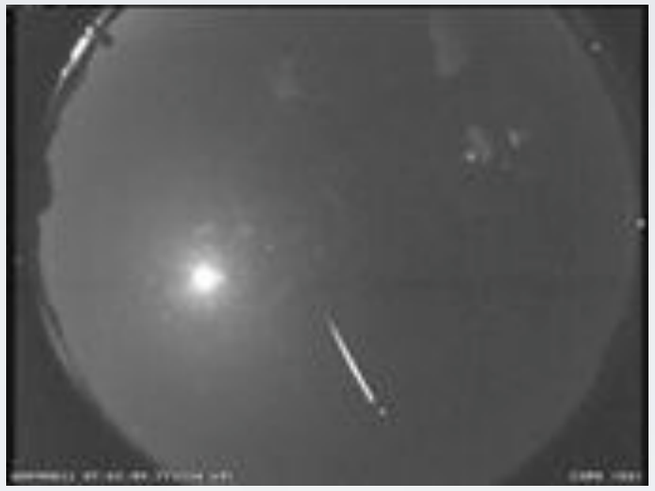

Meteoroids and meteors

Meteoroid Environment Office (MSFC)

Man-made orbital debris

Orbital Debris Program Office (JSC)

What does the Meteoroid Environments Office (MEO) do?

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Provide meteor shower forecasts to NASA/USG spacecraft operators

Monitor the meteoroid environment in near-Earth space (SSA)

Conduct and manage research to improve sporadic and shower meteoroid models

MAY CAMELOPARDALIDS

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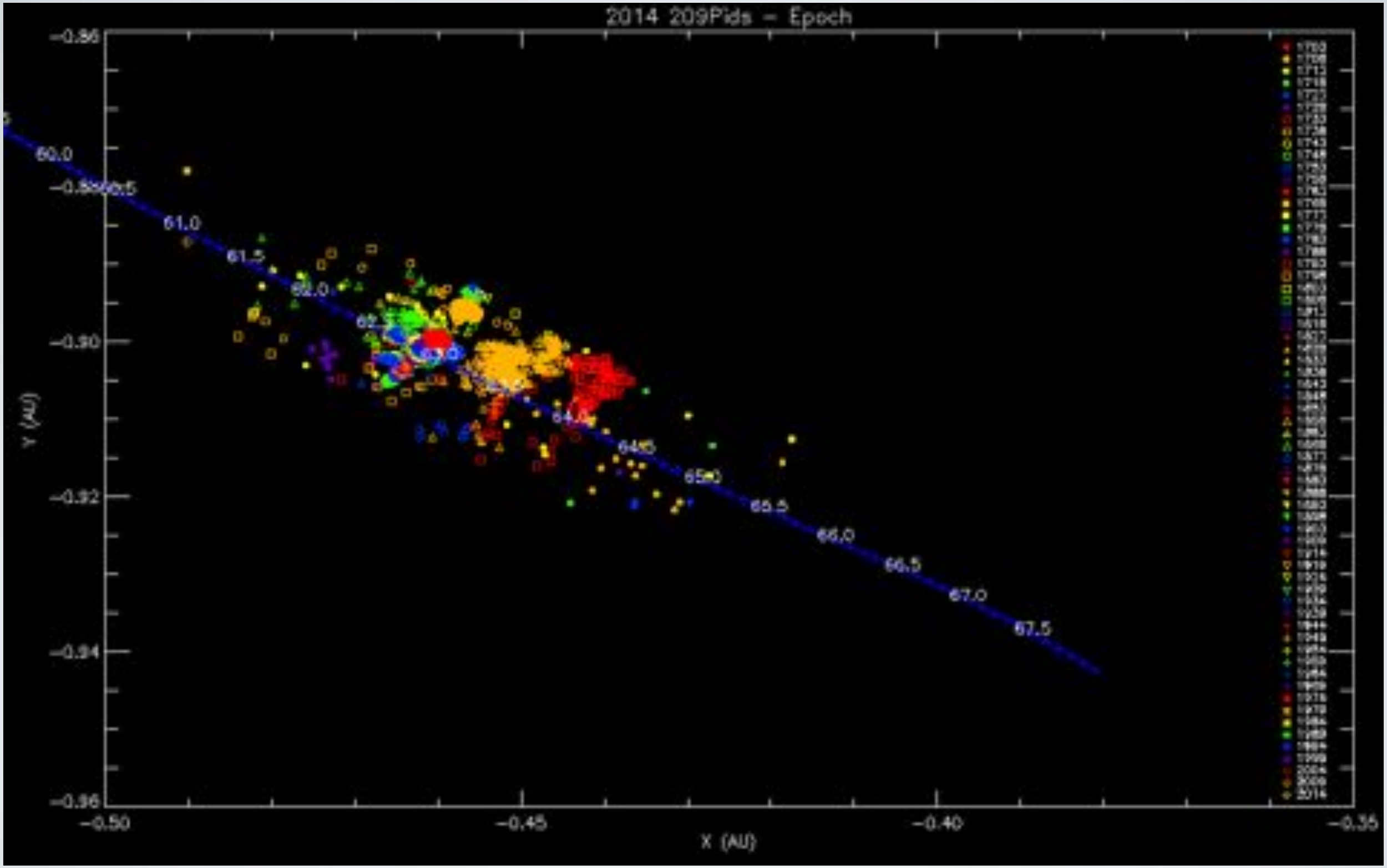
Models indicate mm size particles in stream, so potential risk to Earth orbiting spacecraft

Model	Time on May 24 (UT)	ZHR (#/hr)	RA, Dec (°)	V_g (km/s)
Lvytinen & Jenniskens (1929)	3:19			
Lvytinen & Jenniskens (1979)	6:04			
MSFC (peak 1)	6:11			
Lvytinen & Jenniskens (1818, 1853)	6:33			
MSFC (peak 2)	6:56			
Lvytinen & Jenniskens (1903, max)	6:59	15.86	125, +78	15.86
Lvytinen & Jenniskens (1909)	7:15			
Maslov (1898-1919; 1903)	7:18	200-300	122.8, +79.1	16.2
Maslov (max)	7:21	100	122.8, +79.0	
Vaubaillon	7:40	100-400	~125, +79	
Lvytinen & Jenniskens (1914)	7:49			
Maslov (1763-1783)	7:55	50-150	122.8, +79.0	16.2
MSFC (peak 3)	8:10			
Jenniskens (general)			123, +79	16


2014 209Pids – Epoch
−0.86
−0.88
−0.90
−0.92
−0.94
−0.96
Y (AU)
60.0
61.0
61.5
62.0
64.5
65.0
65.5
66.0
66.5
67.0
67.5
−0.50
−0.45
−0.40
−0.35
X (AU)


NASA
National Aeronautics and Space Administration
4347
ENGINEERING DIRECTORATE
Automated Lunar and Meteor Observatory

7-year observing program

Goal: Monitor the Moon for impact flashes produced by meteoroids striking the lunar surface.

Observation from MSFC

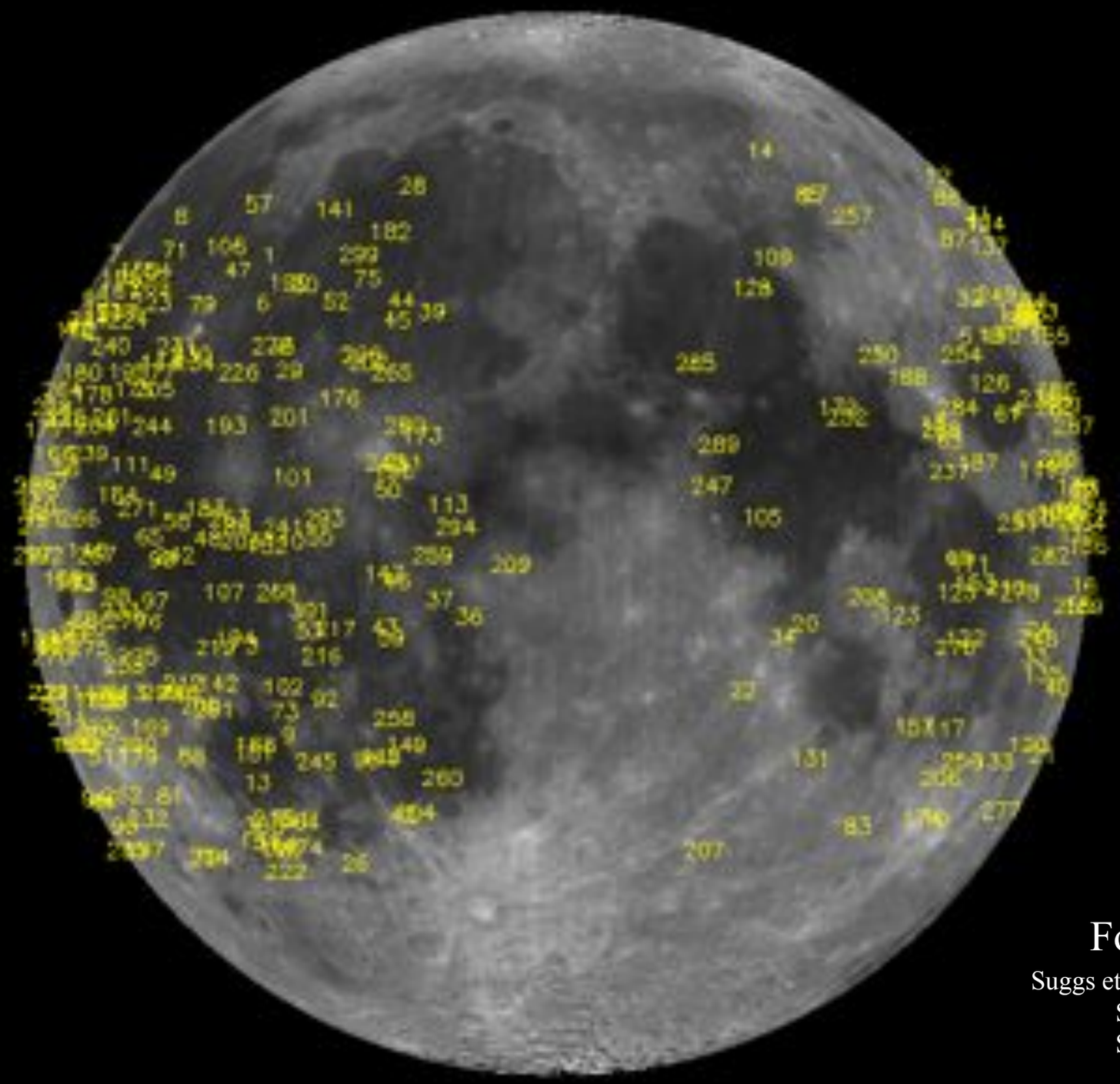
- Two 0.35m telescopes simultaneously
- Black & white CCD video cameras
- Interleaved 30fps video digitized, recorded
- Video analyzed with custom software

Field of View

- FOV covers approx. 20 arcmin
- 4×10^6 km^2 on the leading or trailing edge
- Observing when illumination 10-50%
- Maximum 10 observing nights/month

300+ lunar impacts observed

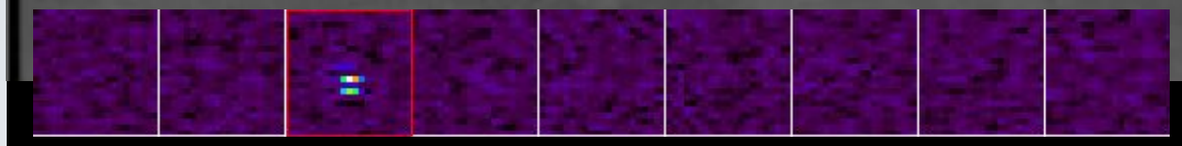
2005-present



For more info:

Suggs et al. (2013) to be submitted
Suggs et al. (2011)
Suggs et al. (2007)

12/15/2006
09:17:39.336
33 ms
m_R = 7.4
0.09 kg
Geminid (35 km/s)

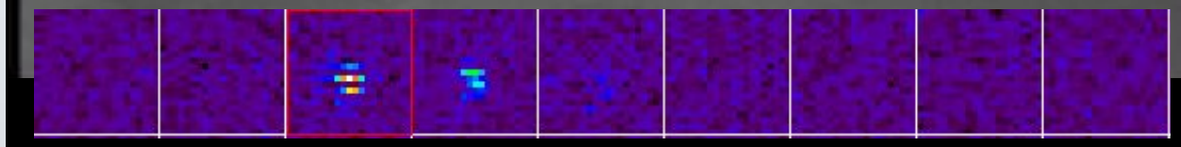


Observed by D.E. Moser & W.R. Swift; detected by R.J. Suggs

11/17/2006
10:56:34.820
66 ms
m_R = 7.0
0.03 kg
Leonid (71 km/s)

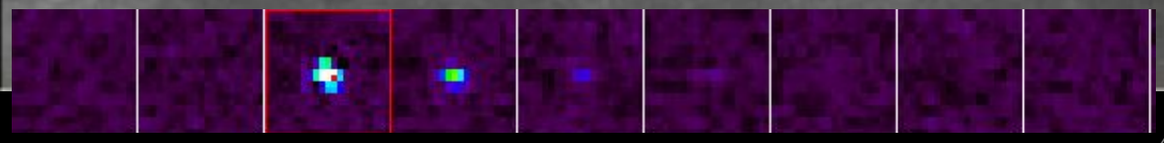
Observed by V. Coffey, D.E. Moser & W.R. Swift; detected by R.J. Suggs

11/03/2008
00:11:06.144
100 ms
m_R = 7.7
0.1 kg
S. Taurid (27 km/s)



Observed by W.R. Swift; detected by R.J. Suggs

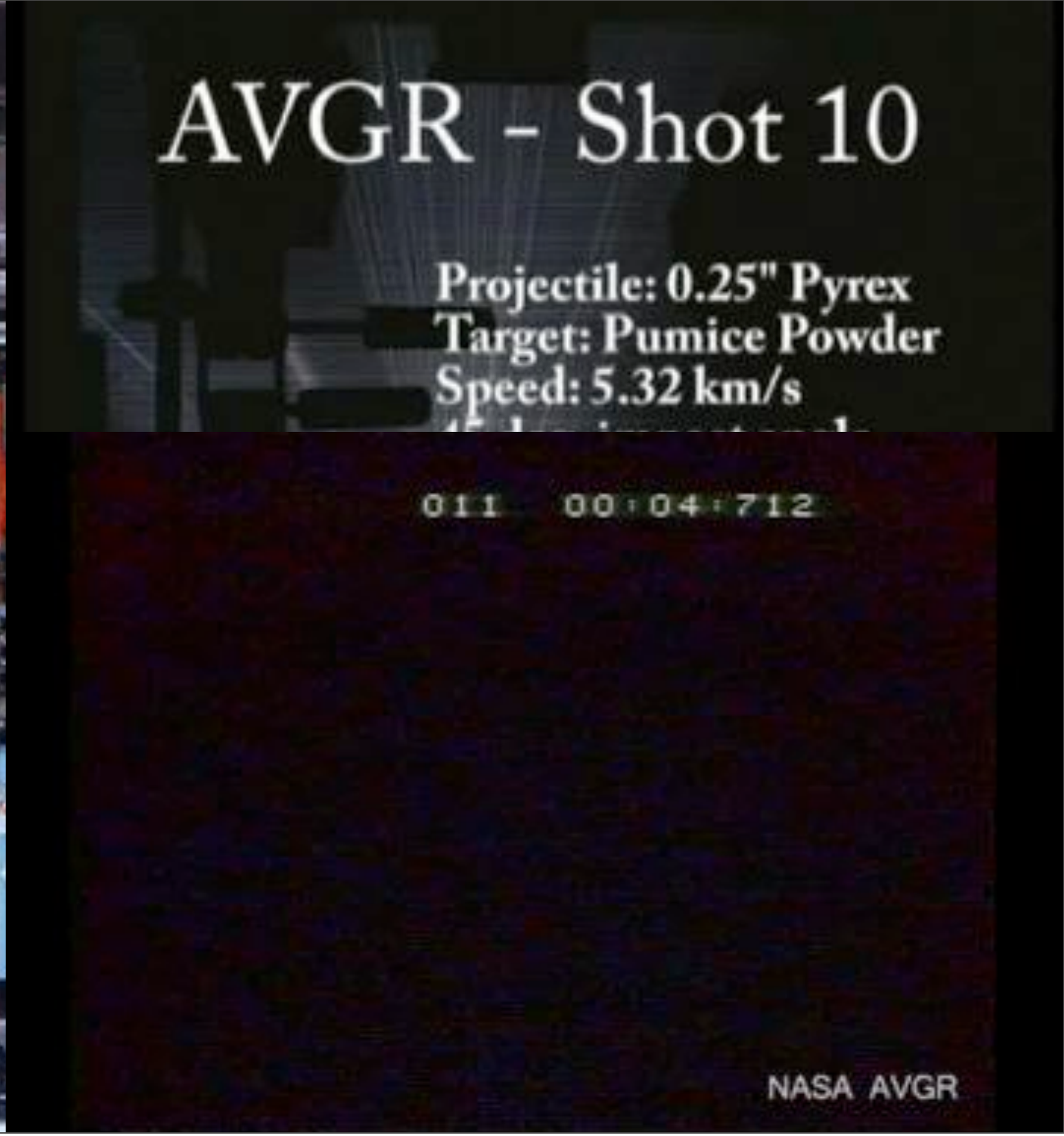
04/22/2007
03:12:24.372
133 ms
m_R = 6.7
0.08 kg
Lyrid (49 km/s)



Observed by R.M. Suggs; detected by R.J. Suggs

AVGR - Shot 10

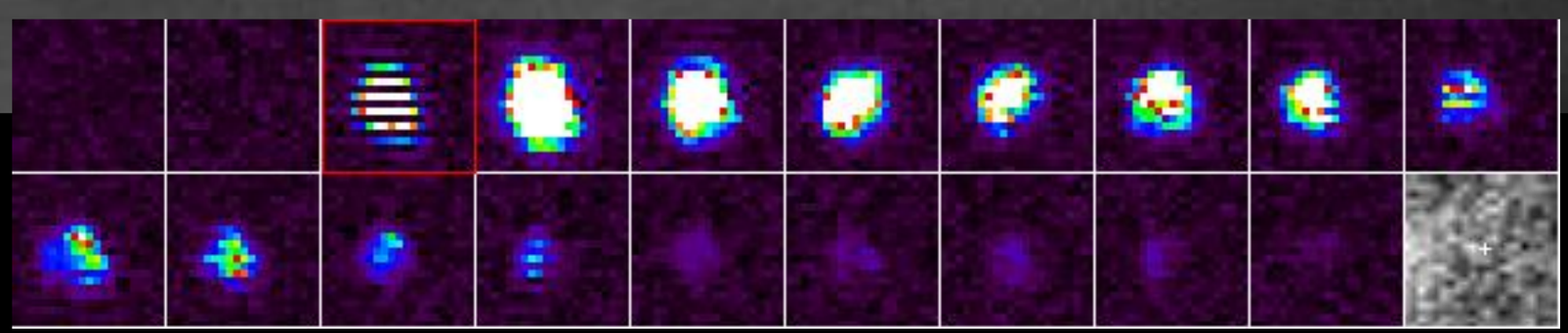
Projectile: 0.25" Pyrex
Target: Pumice Powder
Speed: 5.32 km/s
45 deg. impact angle


AVGR - Shot 10
Projectile: 0.25" Pyrex
Target: Pumice Powder
Speed: 5.32 km/s
011 00:04:712
NASA AVGR

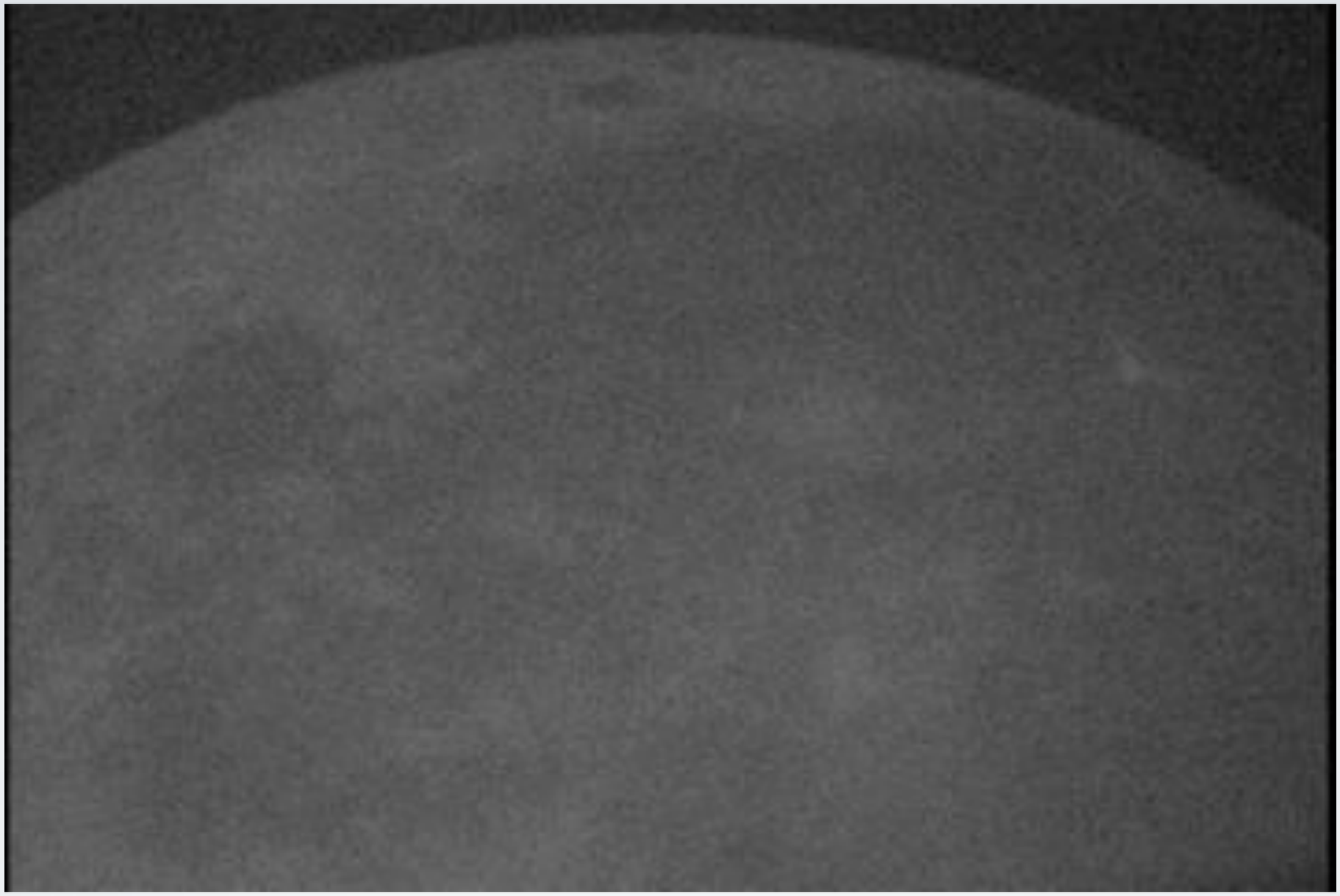
March 17, 2013 3:50:54 UTC

03/17/2013
03:50:54.312
1.03 s
m_R = ?
Impactor mass?
Meteor shower association?

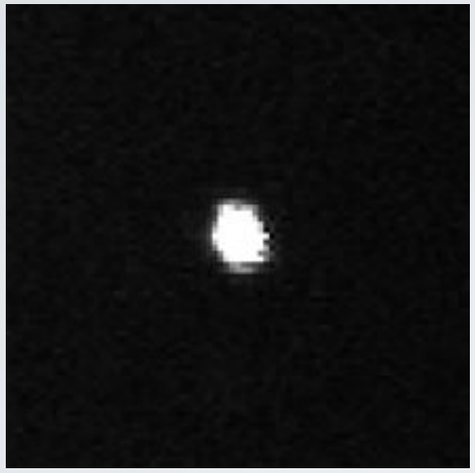
Observed by A. Kingery & R.M. Suggs; detected by R.J. Suggs

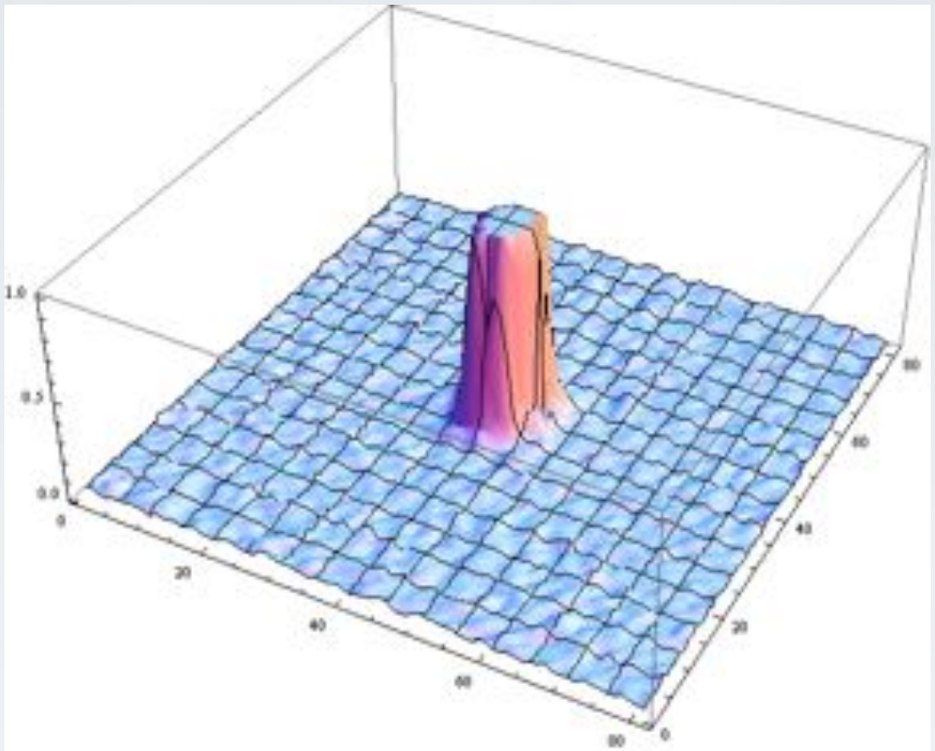


The brightest meteoroid impact flash detected in NASA's 7 year lunar observing program.



Estimating the magnitude

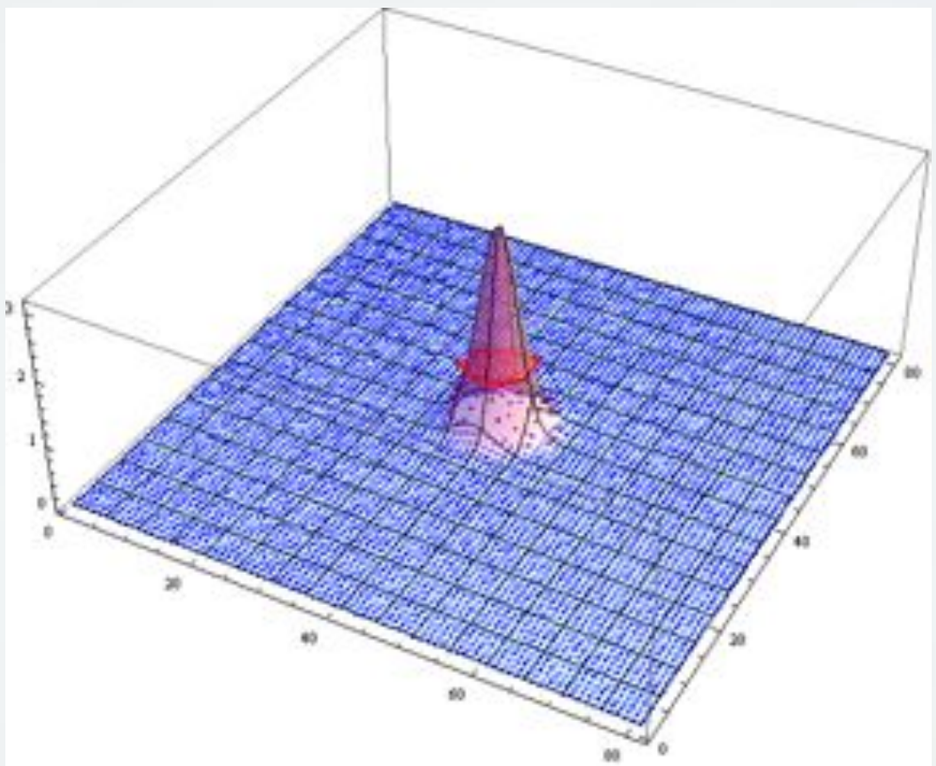




Saturated

Peak $m_R = 4.9$

Photometry performed using comparison stars



2D elliptical Gaussian fit to the unsaturated wings

Peak $m_R = 3.0 \pm 0.4$

Similar results for 2D elliptical Moffat fit

Preliminary energy estimate

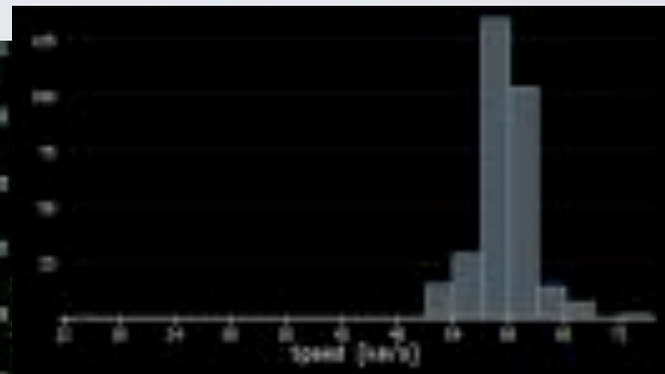
Luminous efficiency (η_λ) relates how much of the impactor's kinetic energy (KE) is converted to luminous energy (LE) in a wavelength range λ

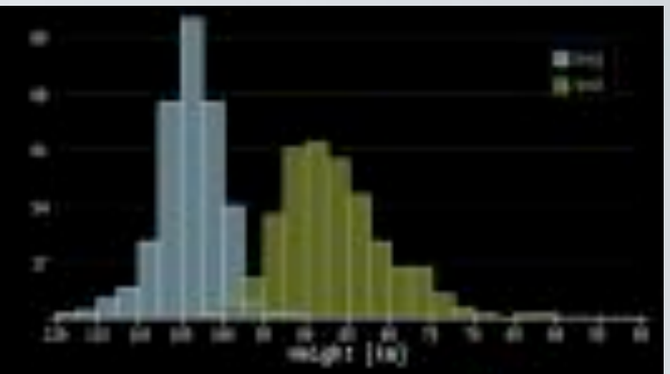
$$LE_\lambda = \eta_\lambda \, KE_\lambda$$

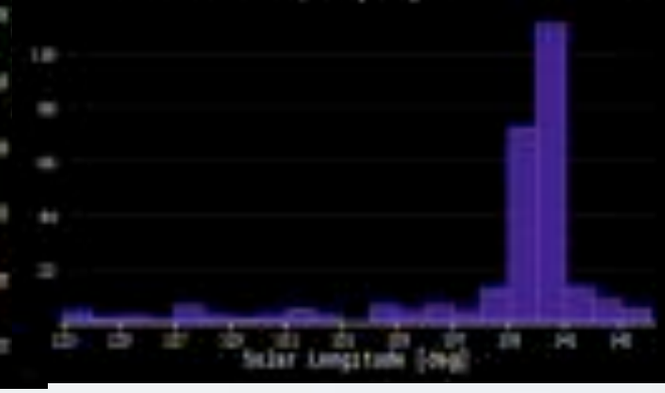
	Const. $\eta = 2 \times 10^{-4}$		**Vel. dep. $\eta = 1.3 \times 10^{-3}$** (Moser et al. 2011)	
	Average	Range	Average	Range
Luminous energy (J)	7.1×10^6	$4.7 \times 10^6 – 1.1 \times 10^7$	7.1×10^6	$4.7 \times 10^6 – 1.1 \times 10^7$
Kinetic energy of impactor (J)	3.6×10^{10}	$2.4 \times 10^{10} – 5.5 \times 10^{10}$	5.4×10^9	$3.6 \times 10^9 – 8.4 \times 10^9$
Impactor mass (kg) (assuming $v_g = 25.6$ km/s)	108	72 – 168	16	11 – 26

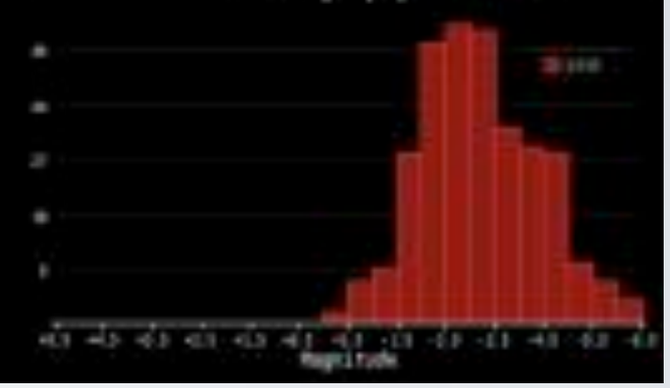
Why did we assume $v_g = 25.6$ km/s?

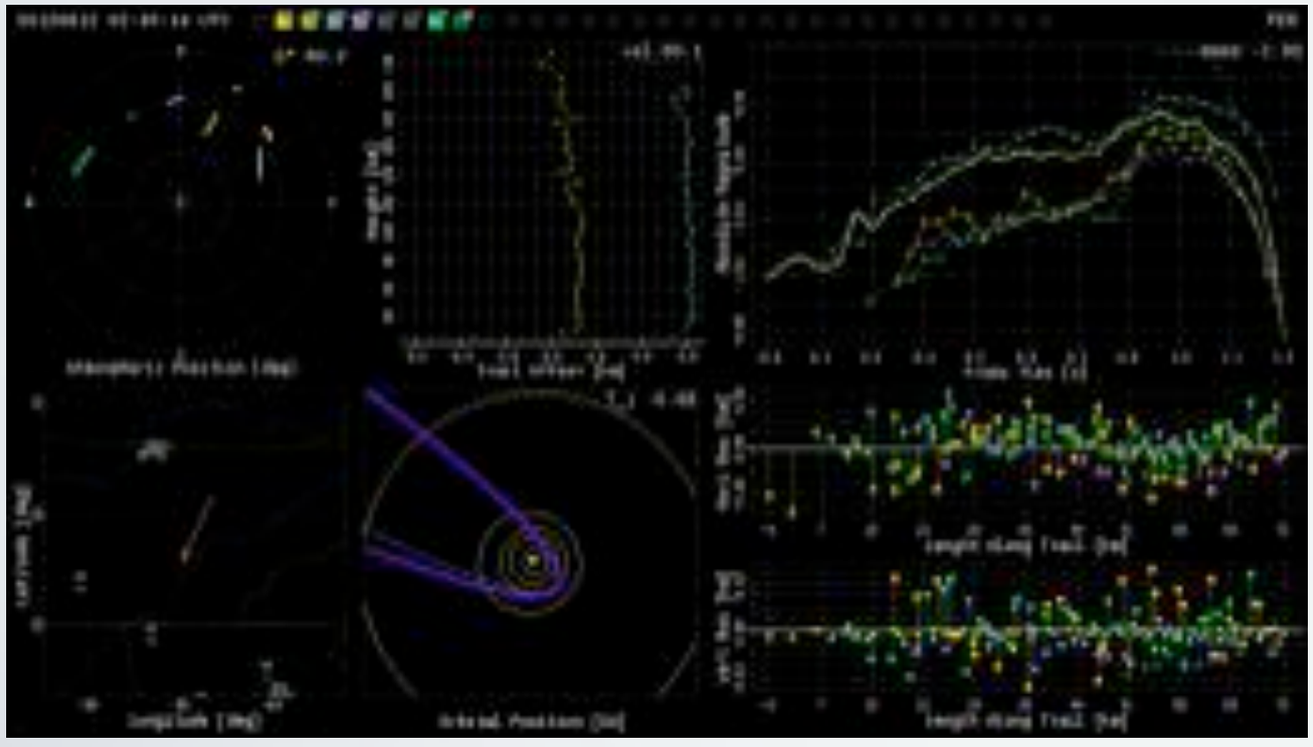

Latitude [deg]
Longitude [deg]

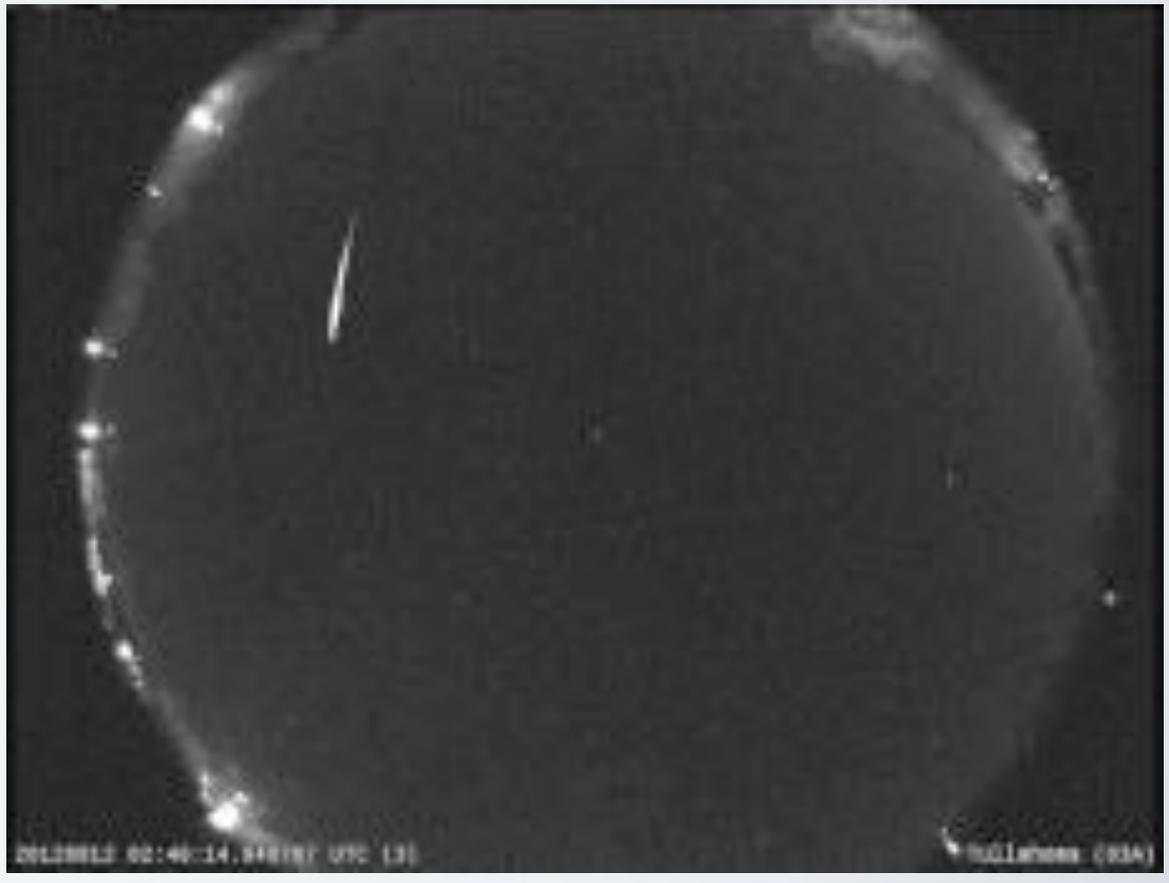

Speed [km/s]


Height [Rs]


Solar Longitude [deg]

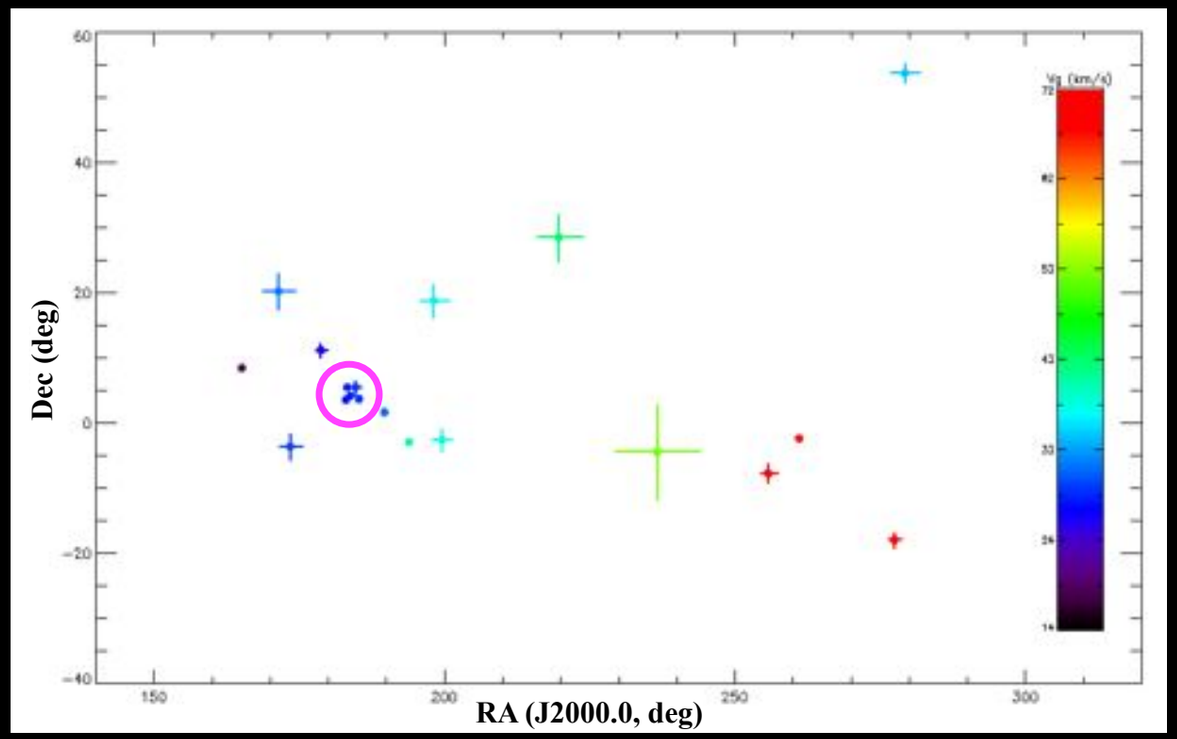

Magnitude





Meteor shower association

19 fireballs seen on Mar 17, 2013



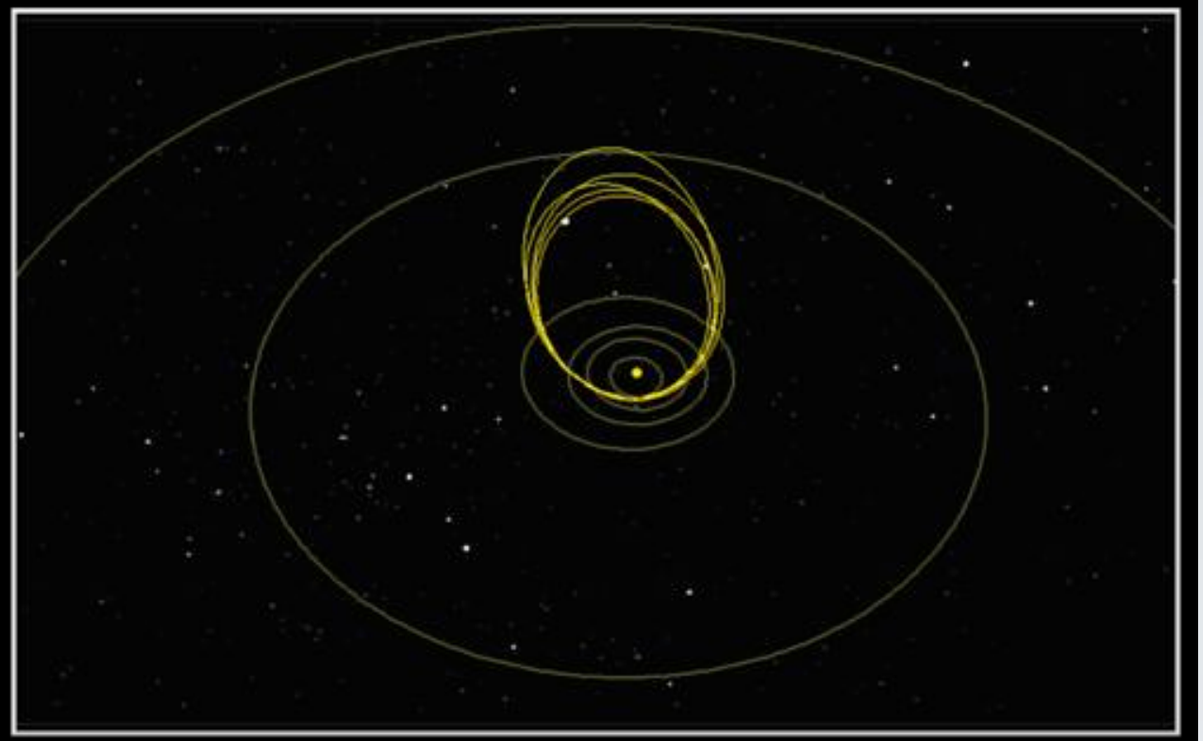
Geocentric meteor radiants color-coded by speed with a tight cluster of 5 with

Virginid Complex

	meteors	NVI[1]	EVI[2]
α_g (°)	184.1 ± 1.0	185.7	183.6
δ_g (°)	4.4 ± 0.9	2.3	3.7
v_g (km/s)	25.6 ± 0.8	23.0	28.9
λ_{sun} (°)	356.6	354	354

[1](Sekanina, 1973), [2](Whipple, 1957)

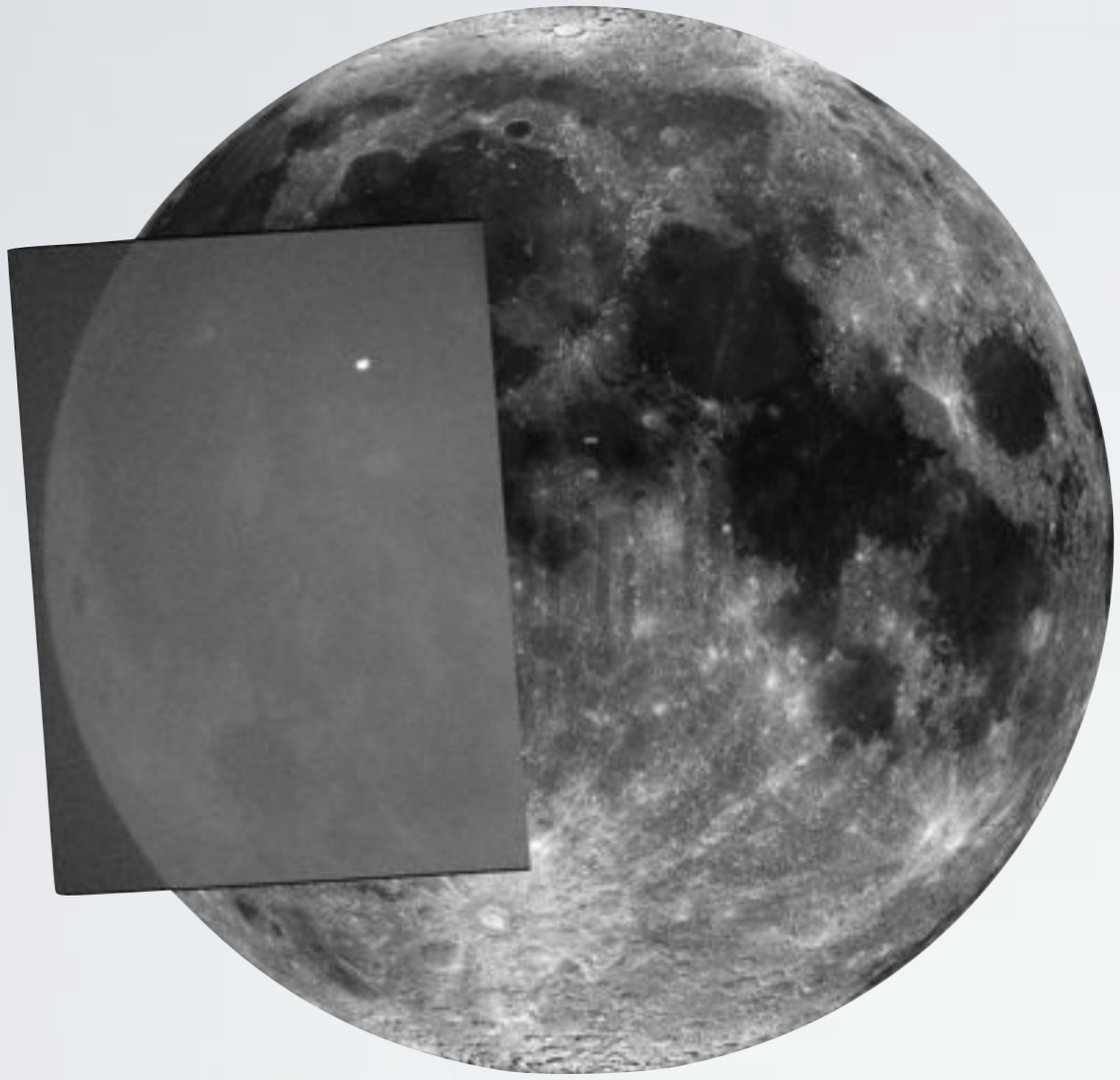
Cluster of 5 seen on Mar 17, 2013



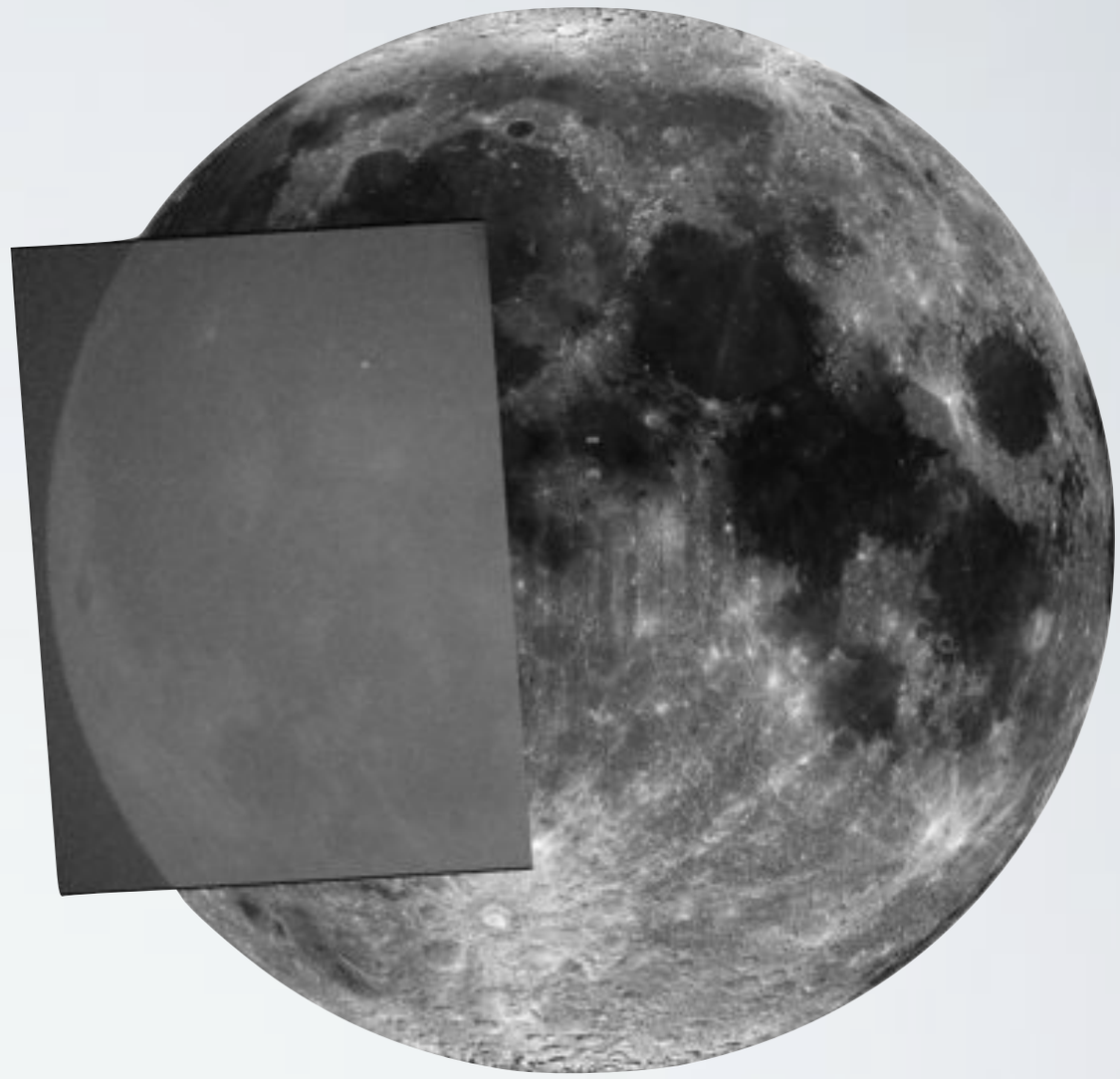
Orbits of the cluster of 5 were very similar with the following average orbital elements

	meteoroids	NVI	EVI
a (AU)	2.25 ± 0.17	1.69	2.82
e	0.79 ± 0.02	0.71	0.86
i (°)	5.26 ± 1.02	3.7	5.2
ω (°)	280.32 ± 2.11	282.4	285.8
Ω (°)	356.65 ± 0.07	358.0	355.1
q (AU)	0.48 ± 0.02	0.496	0.40
Q (AU)	4.0 ± 0.3	2.89	5.25
Tj	3.1 ± 0.2 →	Indicates asteroidal body	

Mapping the impact location

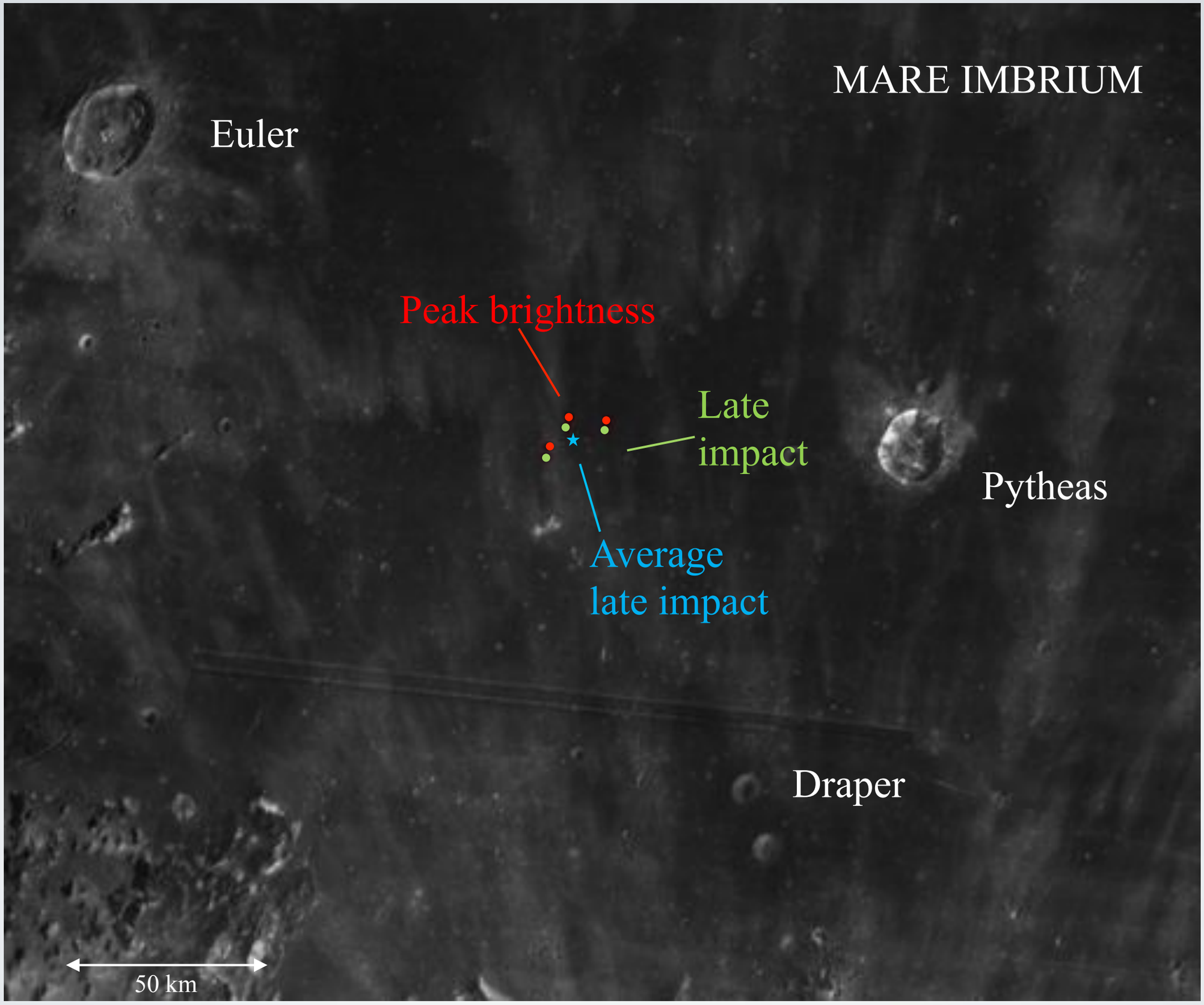


Flash at peak brightness

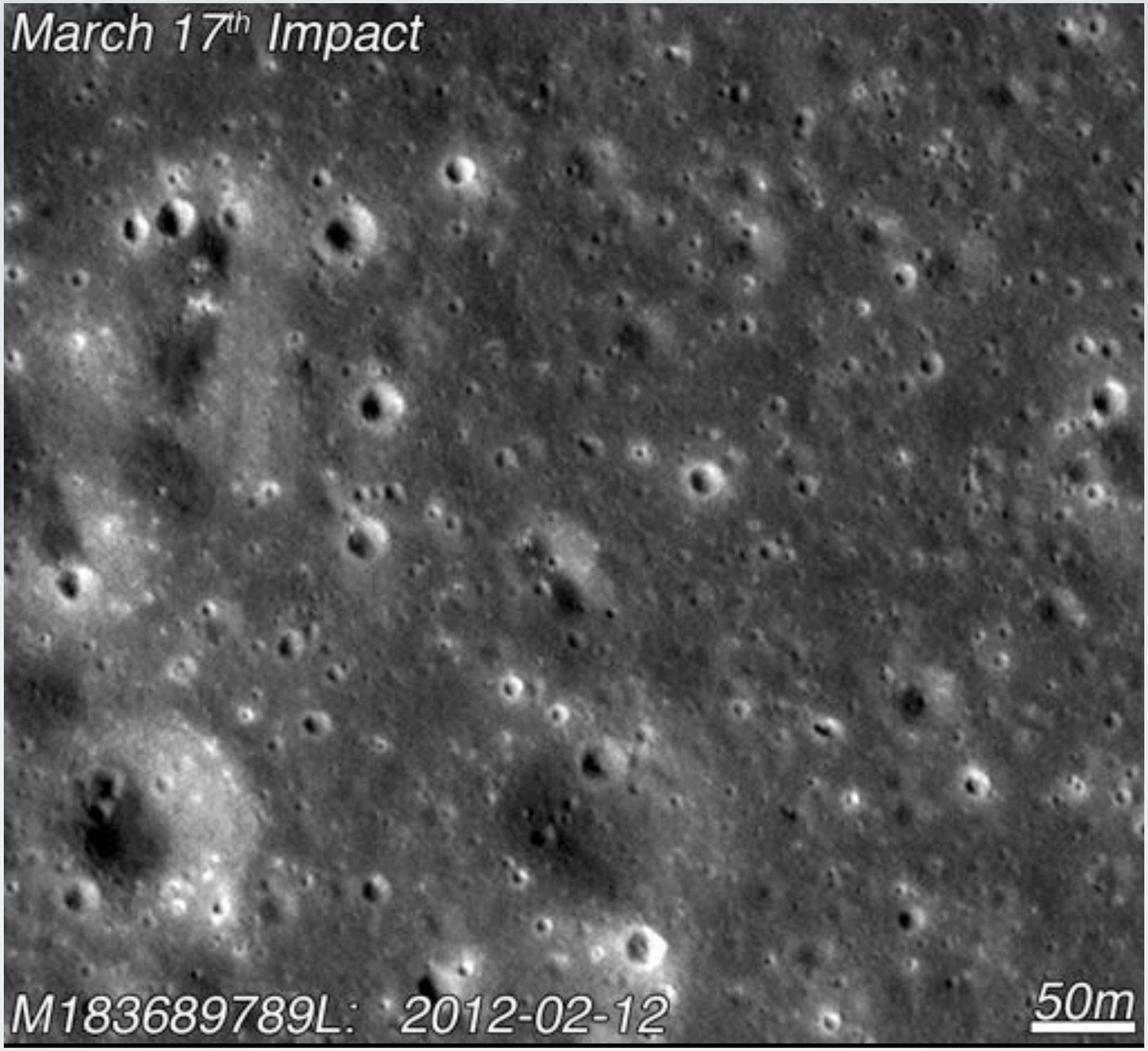


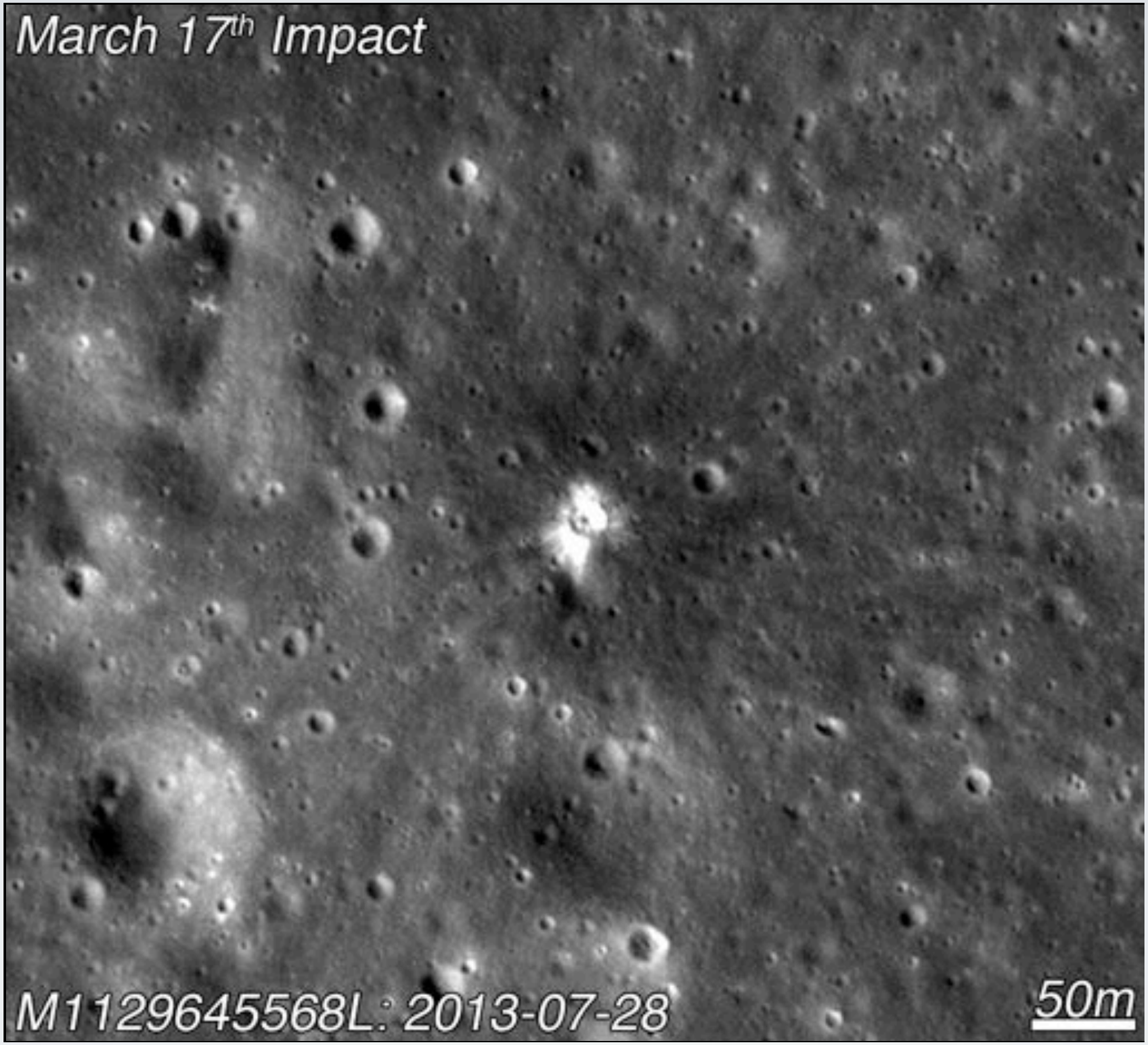
Flash 10 frames (333 ms) after the peak

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



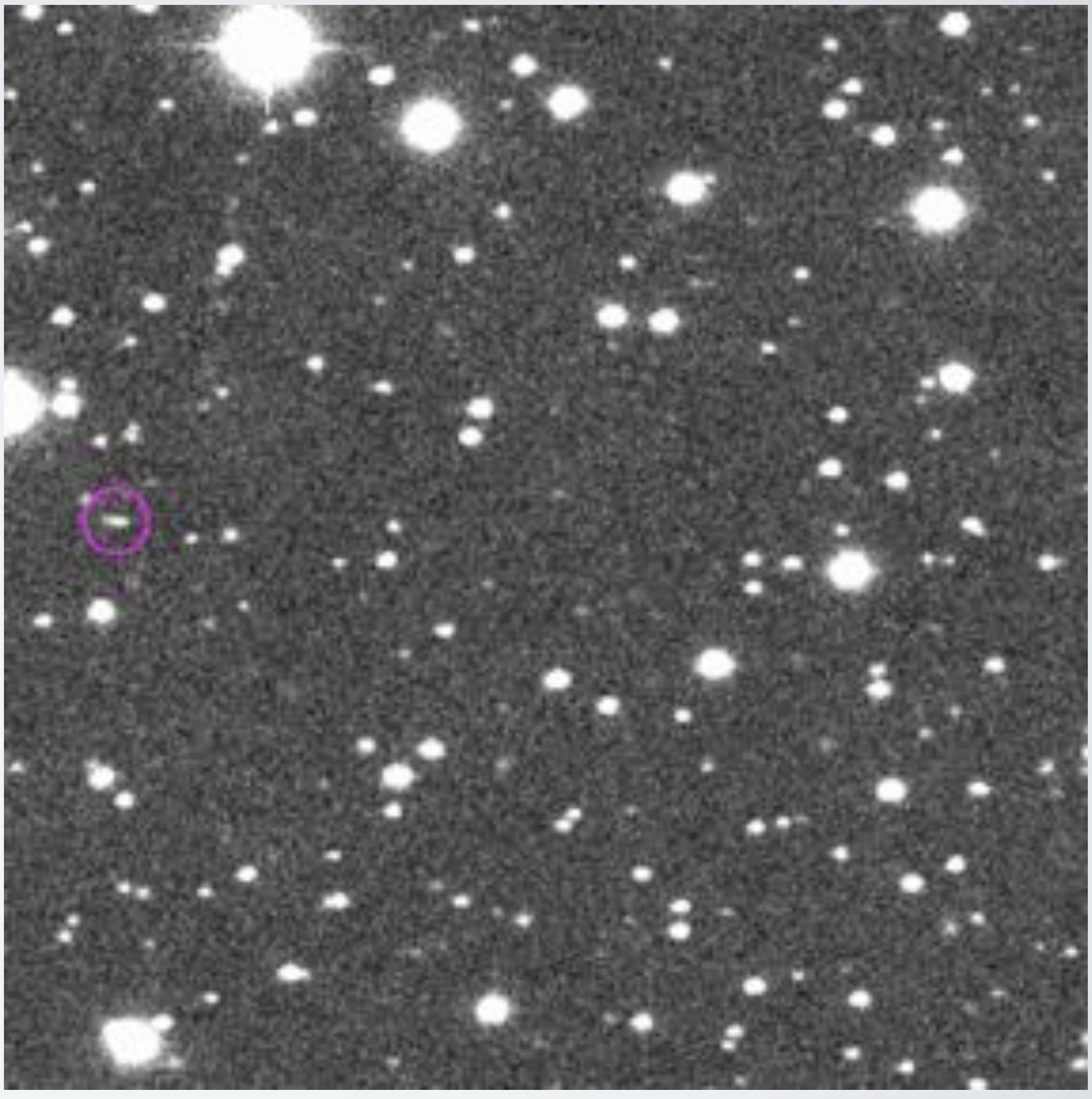
Average location: 20.599 ± 0.172° N, 23.922 ± 0.304° W


March 17th Impact
M183689789L: 2012-02-12
50m


March 17th Impact
M1129645568L: 2013-07-28
50m

2014 AA

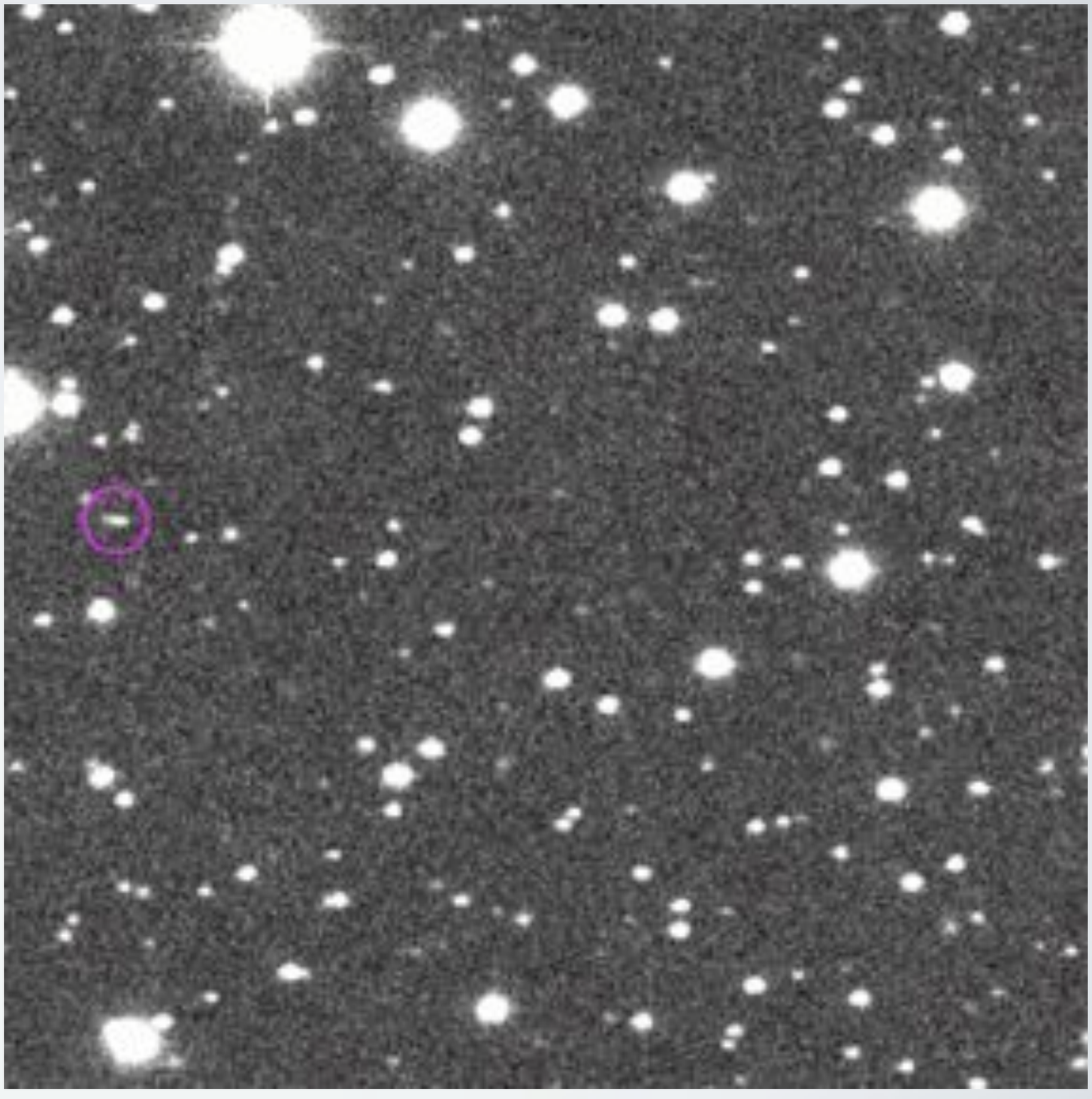
Discovered January 1 at 6:18 UT. 7 images taken over 70 minute interval



2014 AA

Discovered January 1 at 6:18 UT. 7 images taken over 70 minute interval

Magnitude of 19 indicated an object 2-4 meters in diameter

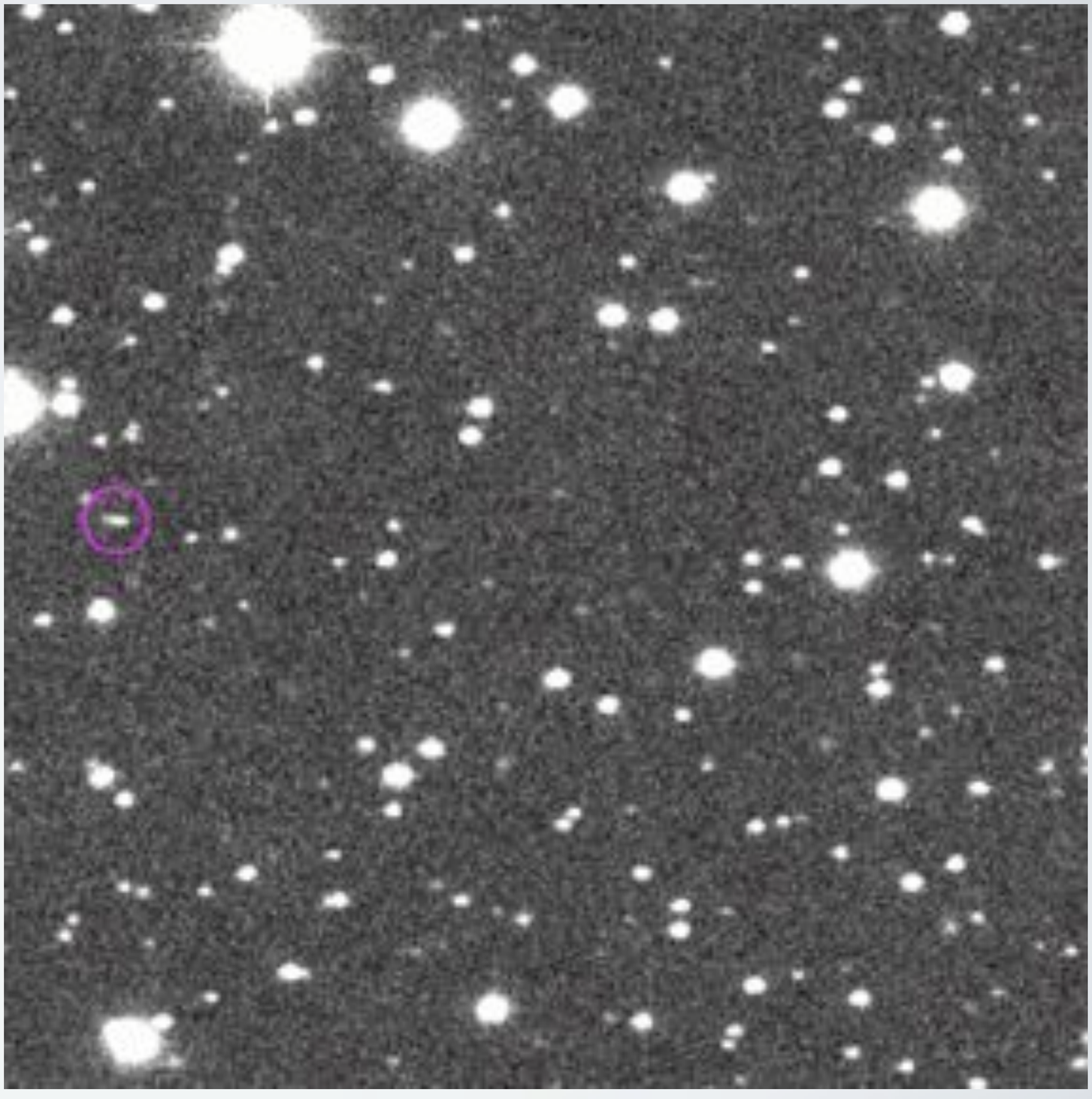


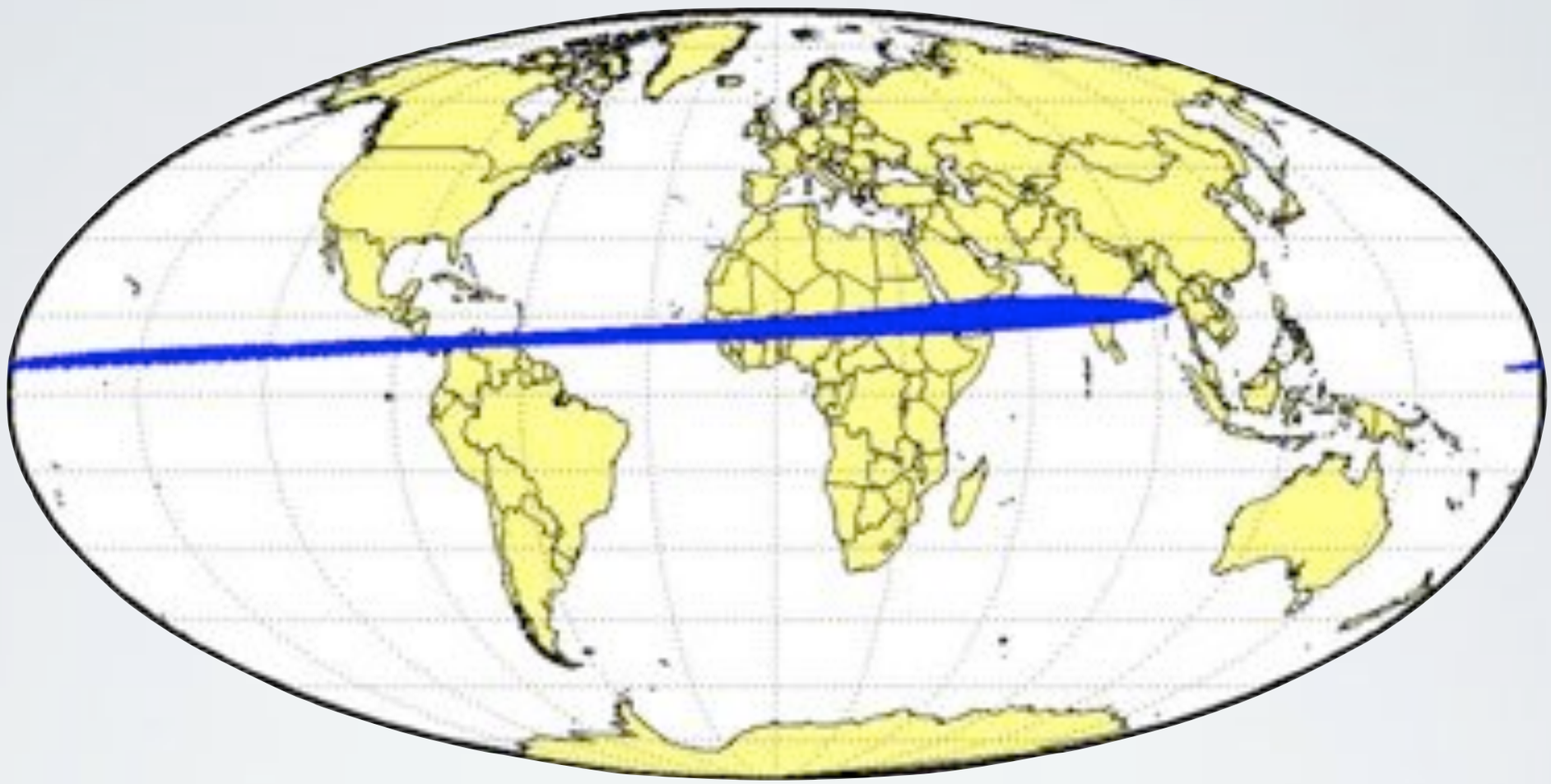
2014 AA

Discovered January 1 at 6:18 UT. 7 images taken over 70 minute interval

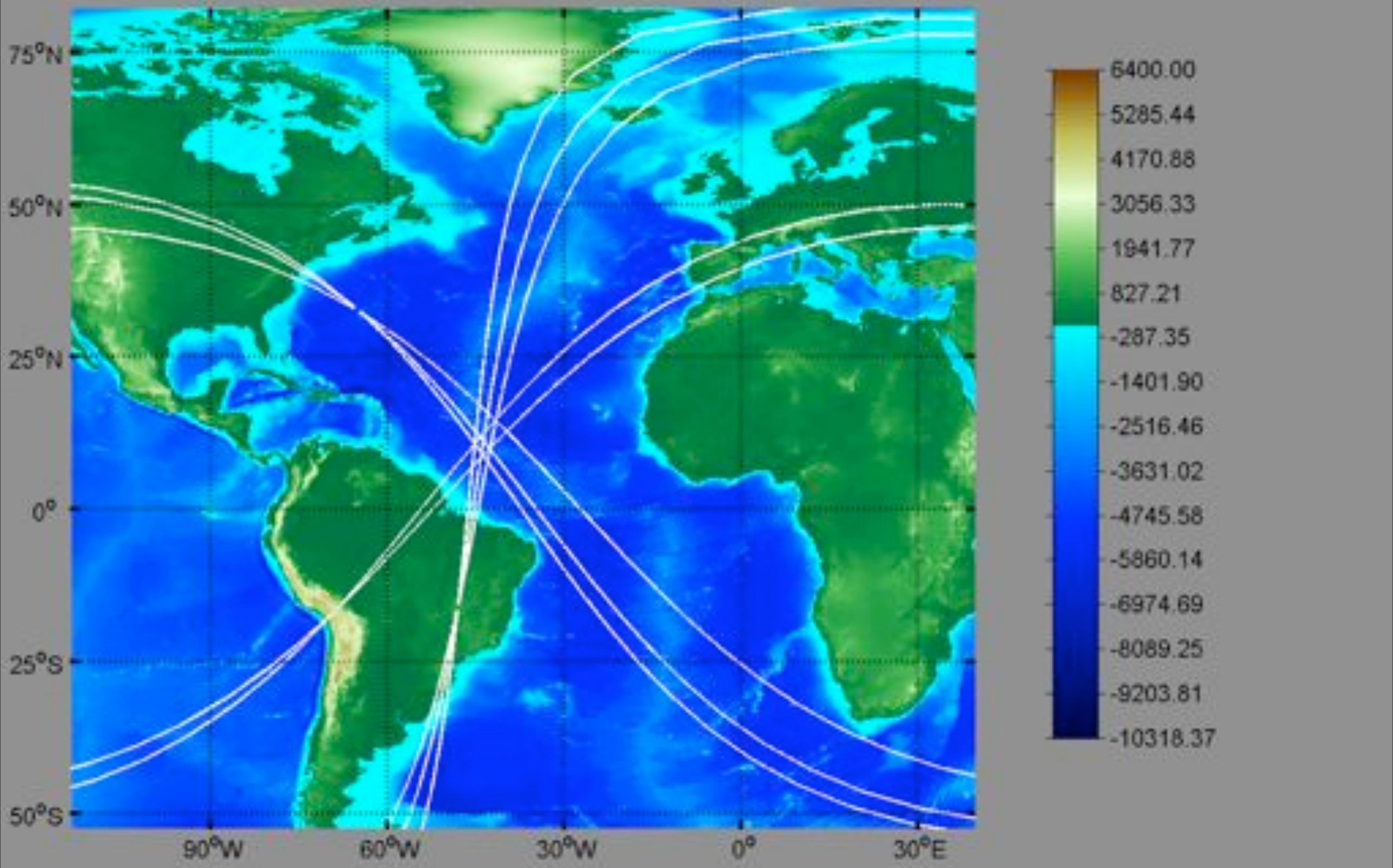
Magnitude of 19 indicated an object 2-4 meters in diameter

Positions submitted to the MPC, but no one realized object was on an impact course with Earth until just before impact





Projected impact time was Jan 2 2:25 UTC, just off coast of west Africa


75°N
50°N
25°N
0°
25°S
50°S
90°W
60°W
30°W
0°
30°E
6400.00
5285.44
4170.88
3056.33
1941.77
827.21
-287.35
-1401.90
-2516.46
-3631.02
-4745.58
-5860.14
-6974.69
-8089.25
-9203.81
-10318.37

Actual impact time was Jan 2 3:30 UTC +/- 30 minutes

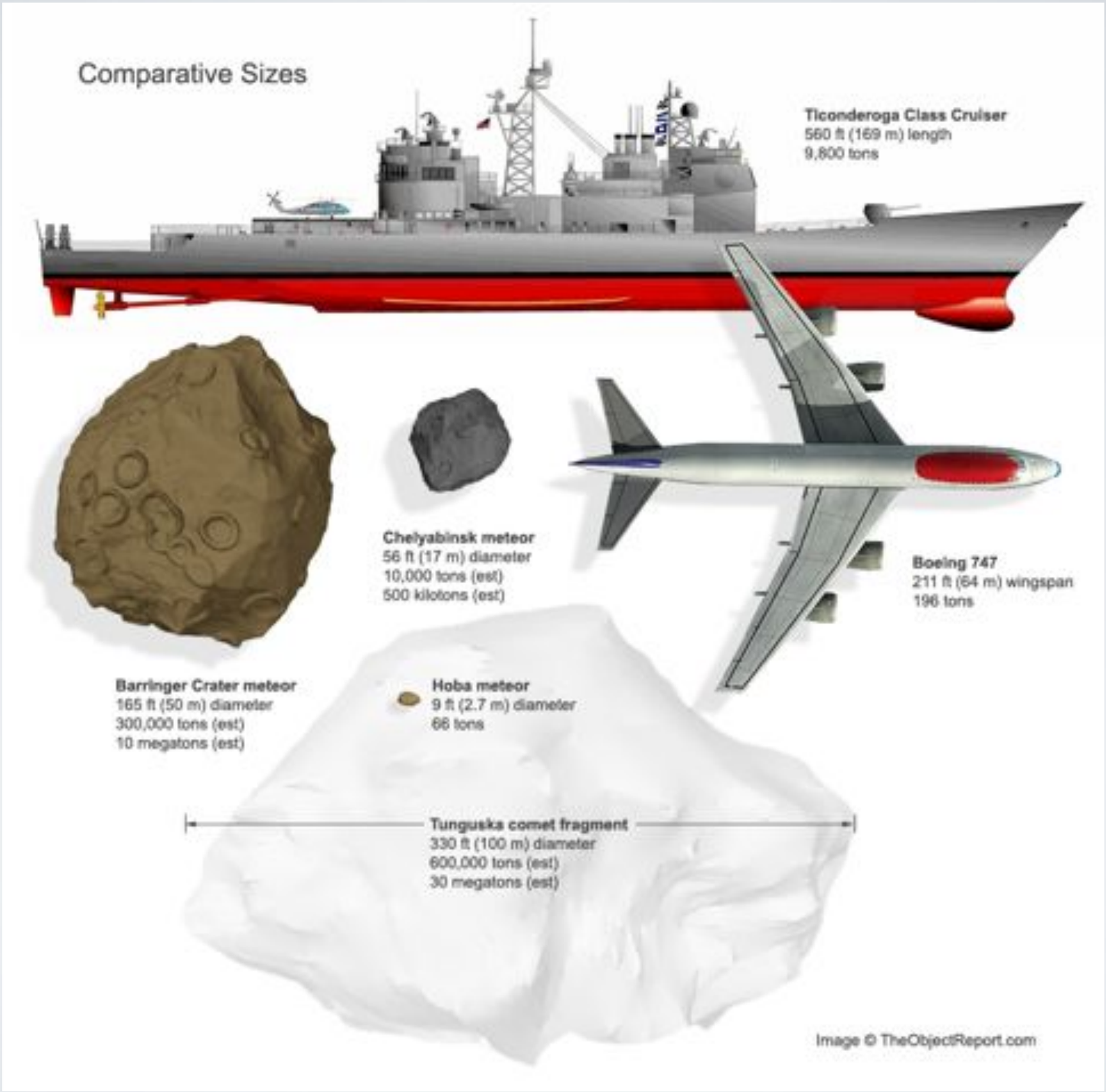
Actual impact time was Jan 2 3:30 UTC +/- 30 minutes

Impact energy of about 1 kiloton

CHELYABINSK

Fireball Properties

Energy	470 kilotons at altitude of 30 km (19 miles) near Chelyabinsk (54.8° N, 61.1° E)
Speed	19 km/s (42,500 mph)
Mass/size	~12,000 tons 19 m (62 ft)
Composition	Ordinary chondrite (LL5)

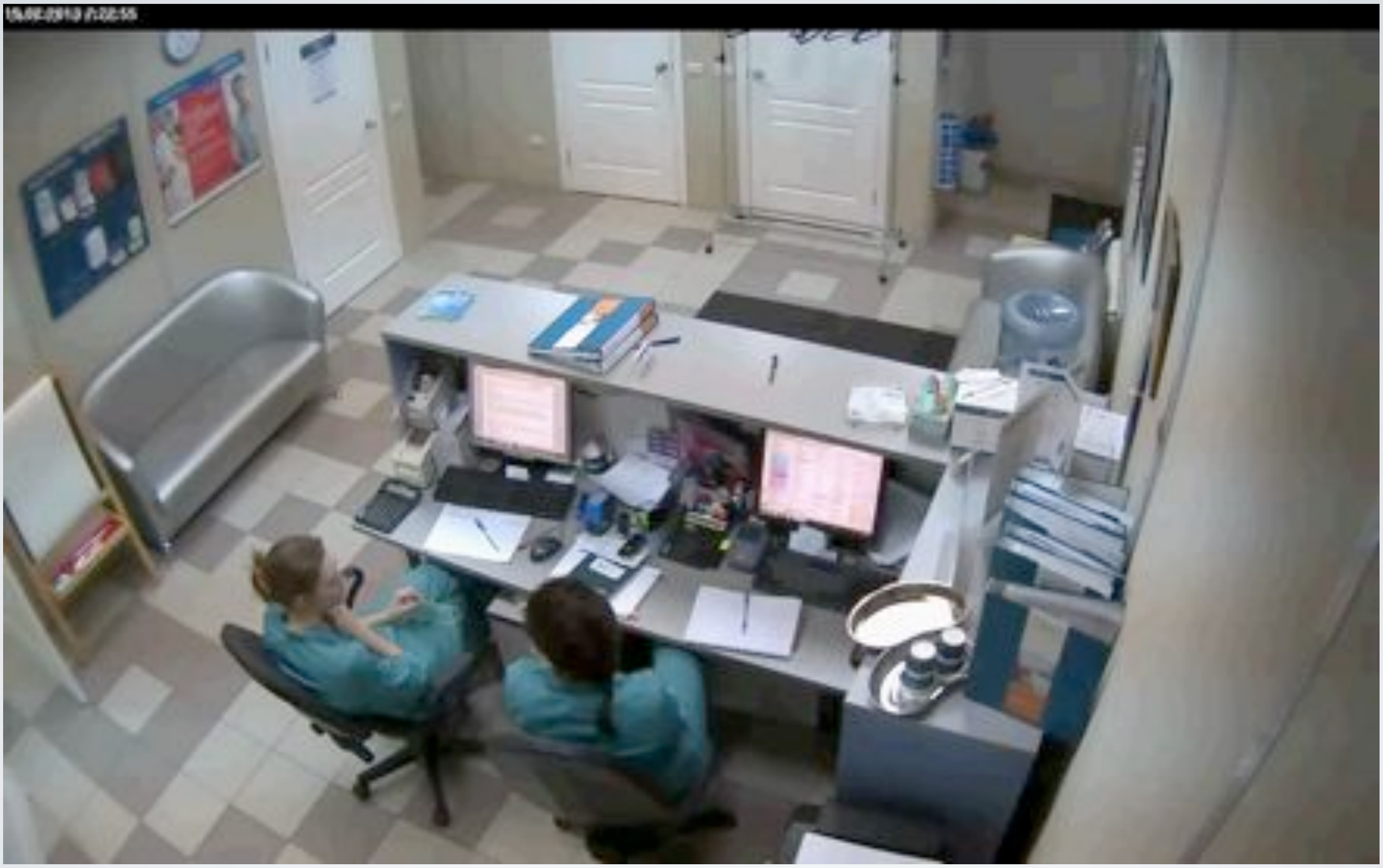

Comparative Sizes
Ticonderoga Class Cruiser
560 ft (169 m) length
9,800 tons
Chelyabinsk meteor
56 ft (17 m) diameter
10,000 tons (est)
500 kilotons (est)
Boeing 747
211 ft (64 m) wingspan
196 tons
Barringer Crater meteor
165 ft (50 m) diameter
300,000 tons (est)
10 megatons (est)
Hoba meteor
9 ft (2.7 m) diameter
66 tons
Tunguska comet fragment
330 ft (100 m) diameter
600,000 tons (est)
30 megatons (est)
Image © TheObjectReport.com


31.12.2012 16:30:40


Камера 2
8:44:56 15.02.2013


Камера 2
8:44:56 15.02.2013


Камера 2
8:44:56 15.02.2013




15/02/2013 09:22:32

Kiloton Airbursts Detected by Infrasound: 2000-2013