

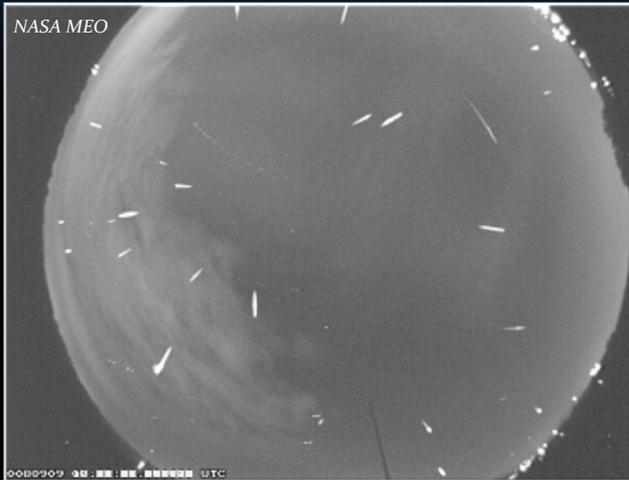
Bright Fireball Characterization and Modeling

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Terminology



Fireballs or Bolides

- Bright meteors.
- Peak magnitude brighter than Venus, $m_{\text{app}} = -4$.



Superbolides

- VERY bright meteors.
- Peak magnitude brighter than the full Moon, $m_{\text{app}} = -17$.

Why? Space Situational Awareness (SSA)

- The ability to view, understand and predict the physical location of natural and manmade objects in orbit around the Earth
- Support government agencies through the provision of timely and accurate information and data regarding the space environment
- Hazards to infrastructure in orbit & on the ground
 - Collisions between objects in orbit
 - Harmful space weather
 - Potential strikes by natural objects



And then came 9:20 AM on February
15, 2013...

2013/02/15 09:26:15







15.02.2019 7:22:56



Eye Witness Accounts

We saw a big burst of light then went outside to see what it was and we heard a really loud thundering sound.

We were exercising on the skating rink inside the building when we heard a deafening blast. The skating kids were knocked down.

Upon Chelyabinsk a huge fireball has exploded. It wasn't an aircraft.

My heart is still beating 200 heartbeats a minute! ... I saw this terrible flash, it was red-orange! My eyes are still hurting. I turned off all the lights, sat the kids on a couch and waited... Oh, my God, I thought the war had begun.

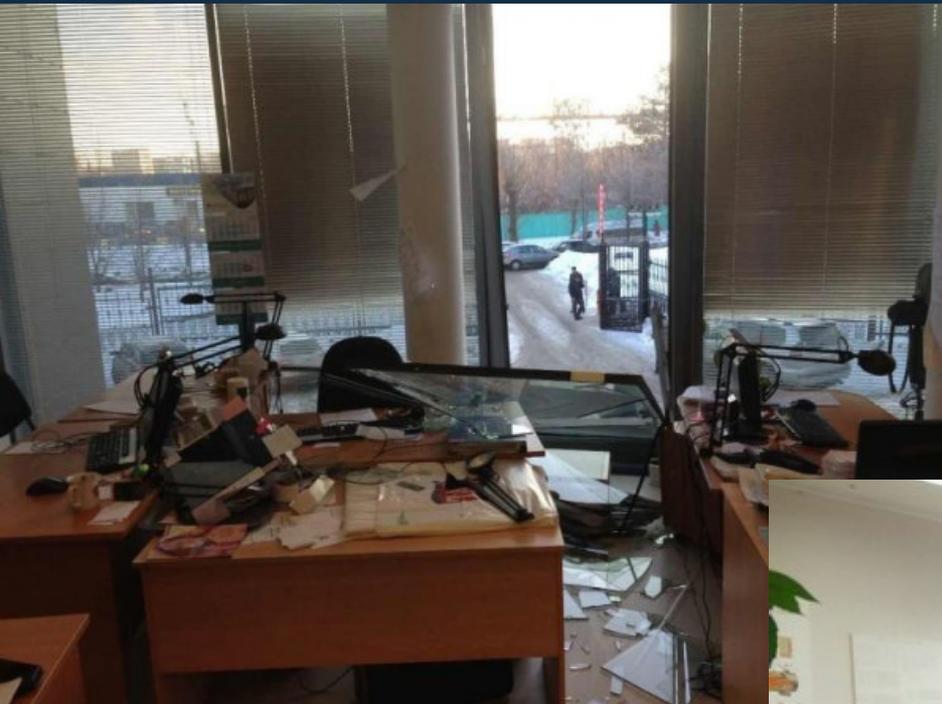
Windows were blown out, furniture was jumping, I am shaking now. What do I do? I first grabbed my cat and passport and ran outside, but then was told to come back home, get some water and sit here.

The light shone like 10 suns.

It was quite dark, but it suddenly became as bright as if it was day. I felt like I was blinded by headlights.

The most unusual morning ever – to wake up from the wind and the rumble, to yell hysterically while all the family is running around shocked.

Damage



Injuries

Over 1600 people injured by glass & debris

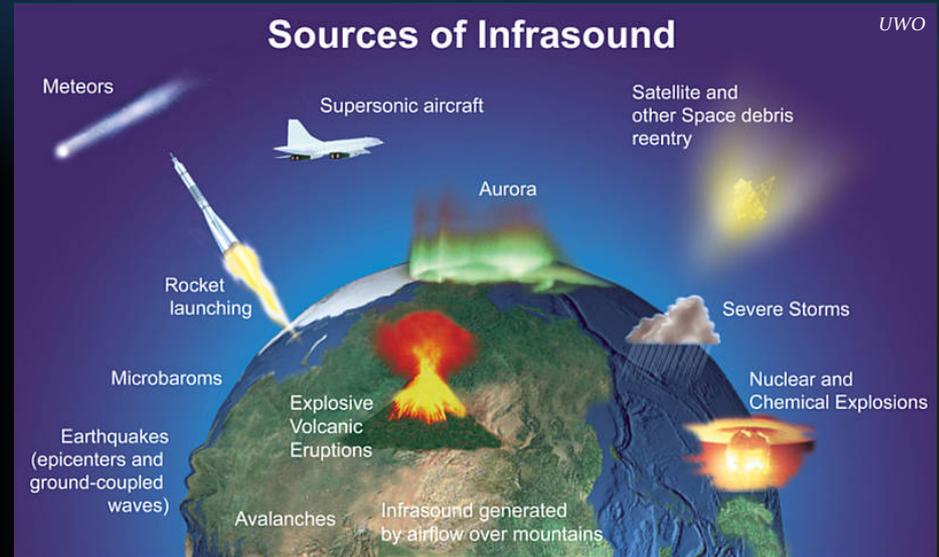


Fireball Properties

Energy	Determined from infrasound and satellite measurements.
Speed	Calculated from angular rate in video and directly calculated from satellite observations.
Mass/size	Estimated from brightness in video once the speed is known. Also determined from the energy.
Composition	Ascertained from laboratory study of meteorites found.

Infrasound

- Low frequency sound waves (0.01-20 Hz).
- Any mechanism generating coherent acoustic signal in the atmosphere can generate infrasonic waves.
- Travels great distances.
- Cannot be heard by the human ear.
- Amplitude & period enables energy determination.



Signals regularly detected

Occasional signals

Microbaroms
Weather systems
Man-made explosions
Supersonic aircraft / Missile launches
Auroral electrojet

Meteors/bolides (~20/year)
Earthquakes
Volcanic
Re-entering spacecraft

Typical Infrasound Array Equipment



Photos of vault housing the sensor, digitizer and RF modem.



Fielded equipment: solar panels, met station and batteries at one of the array positions.

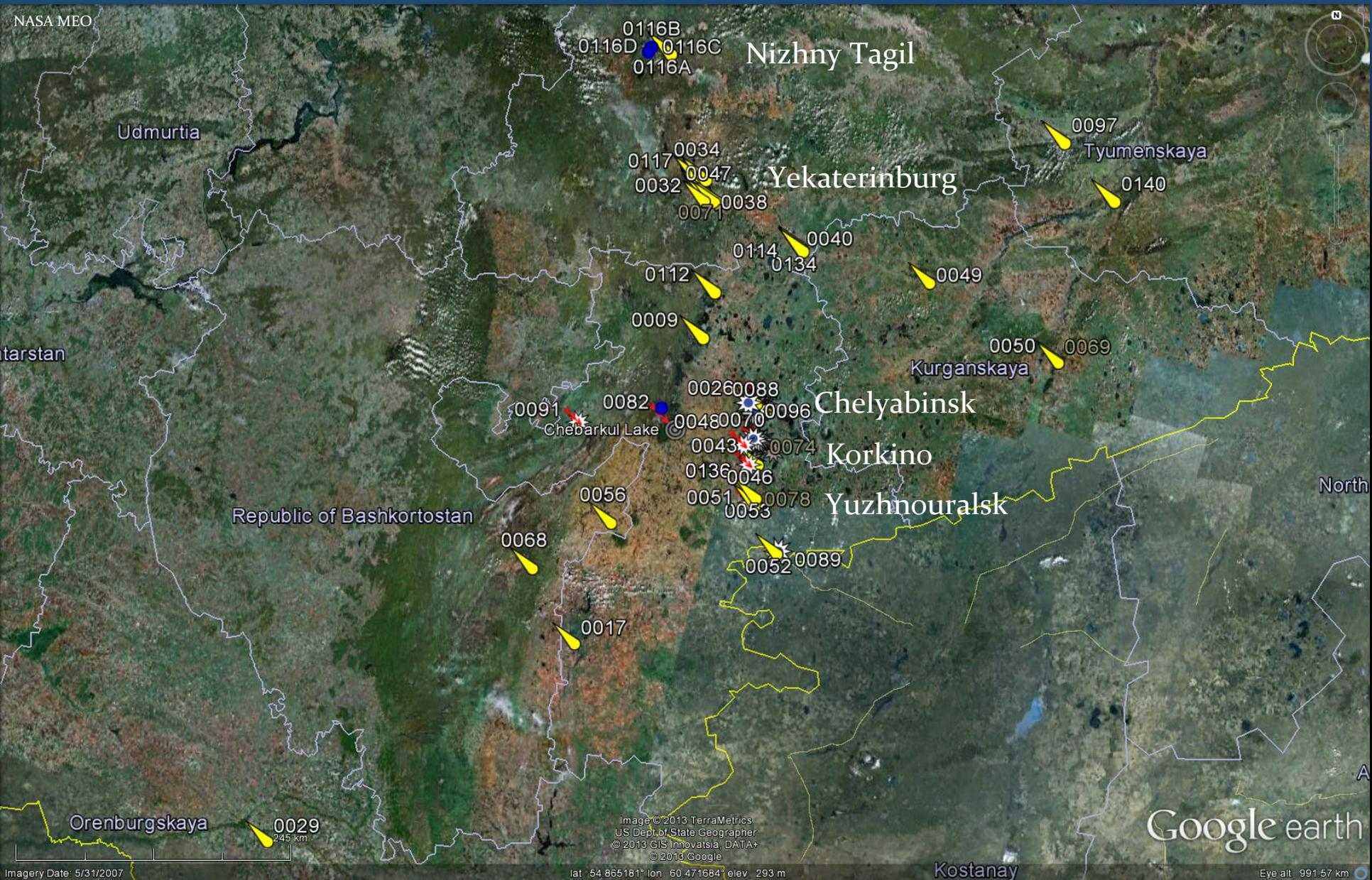
Deployed vault and sensor showing noise reduction hoses. This and three other sites make up the array.



Infrasound Monitoring Advantages

- Small fireball (10's of kg TNT equivalent) up to 100-200 km
- Kiloton explosions- Nominal detection at 2000-3000 km ranges
- Megaton explosions - global coverage
- Multiple station detections can provide location for bolides

Mapping Video Locations



Key:  fireball  trail  blast  shadow

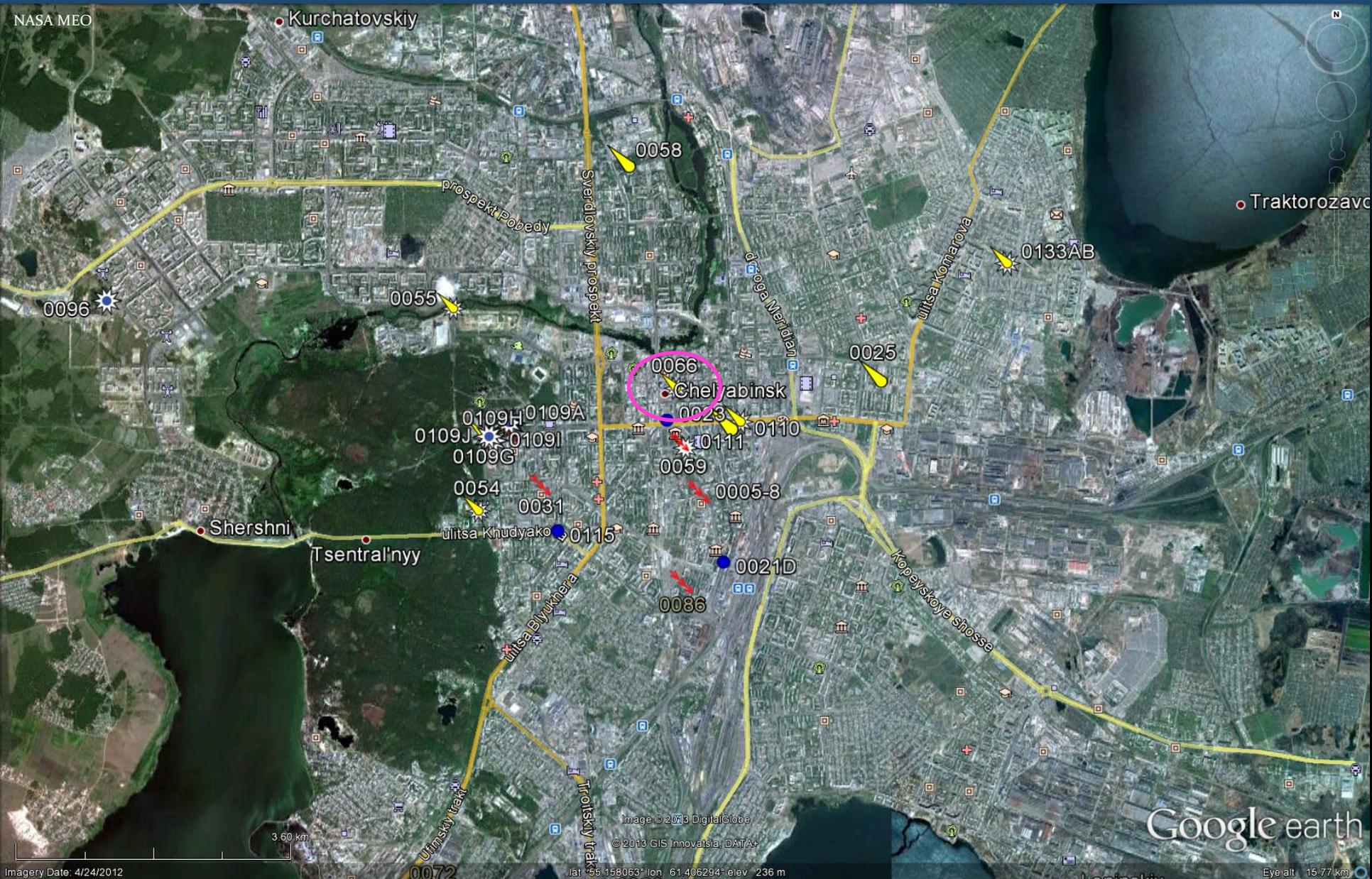
Speed

Video Calibration



UWO

Chelyabinsk: Vid #0066



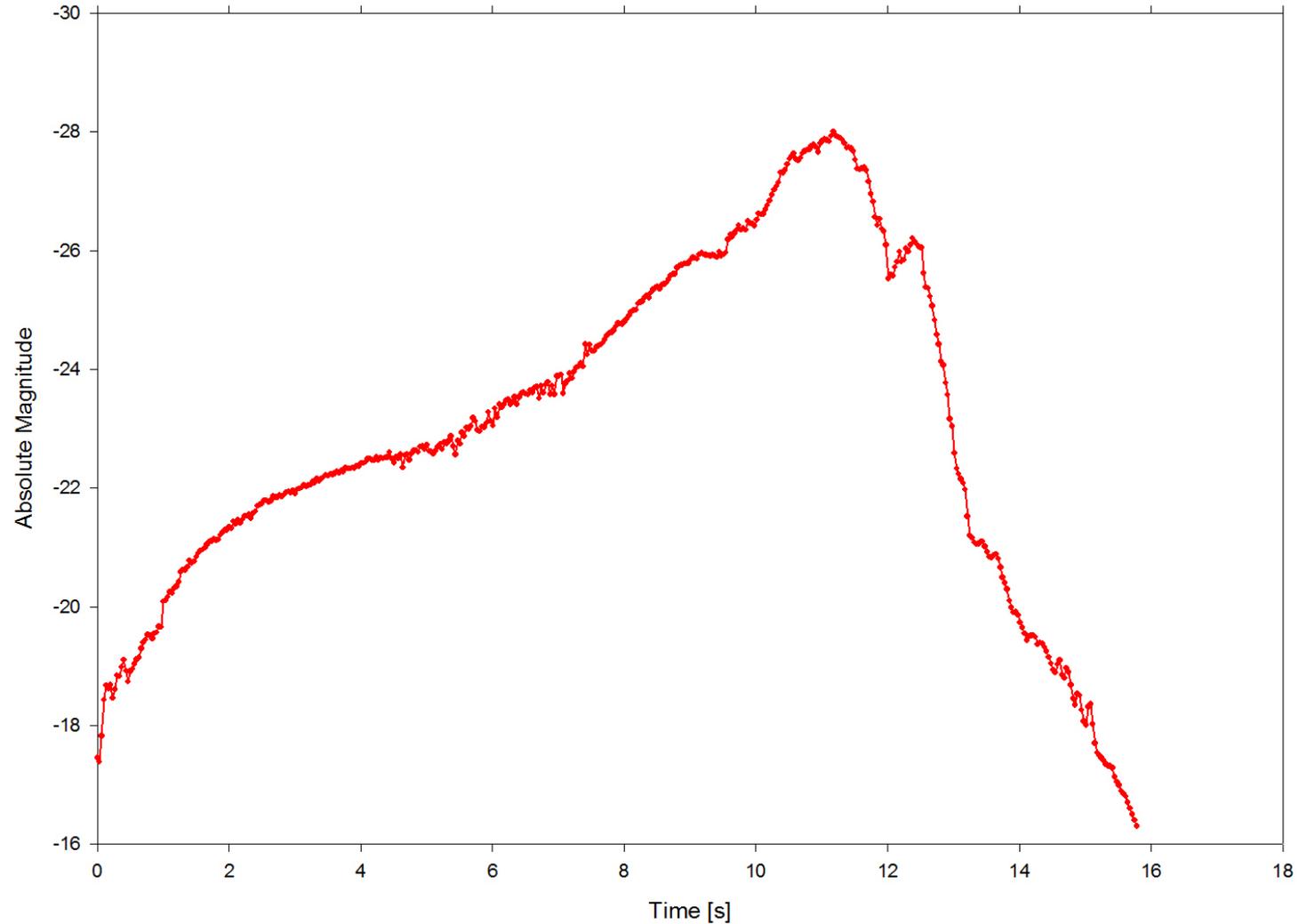
Key:  fireball  trail  blast  shadow

Mass/size

2011.09.27 17:26:35



Preliminary Light Curve (6 Videos)



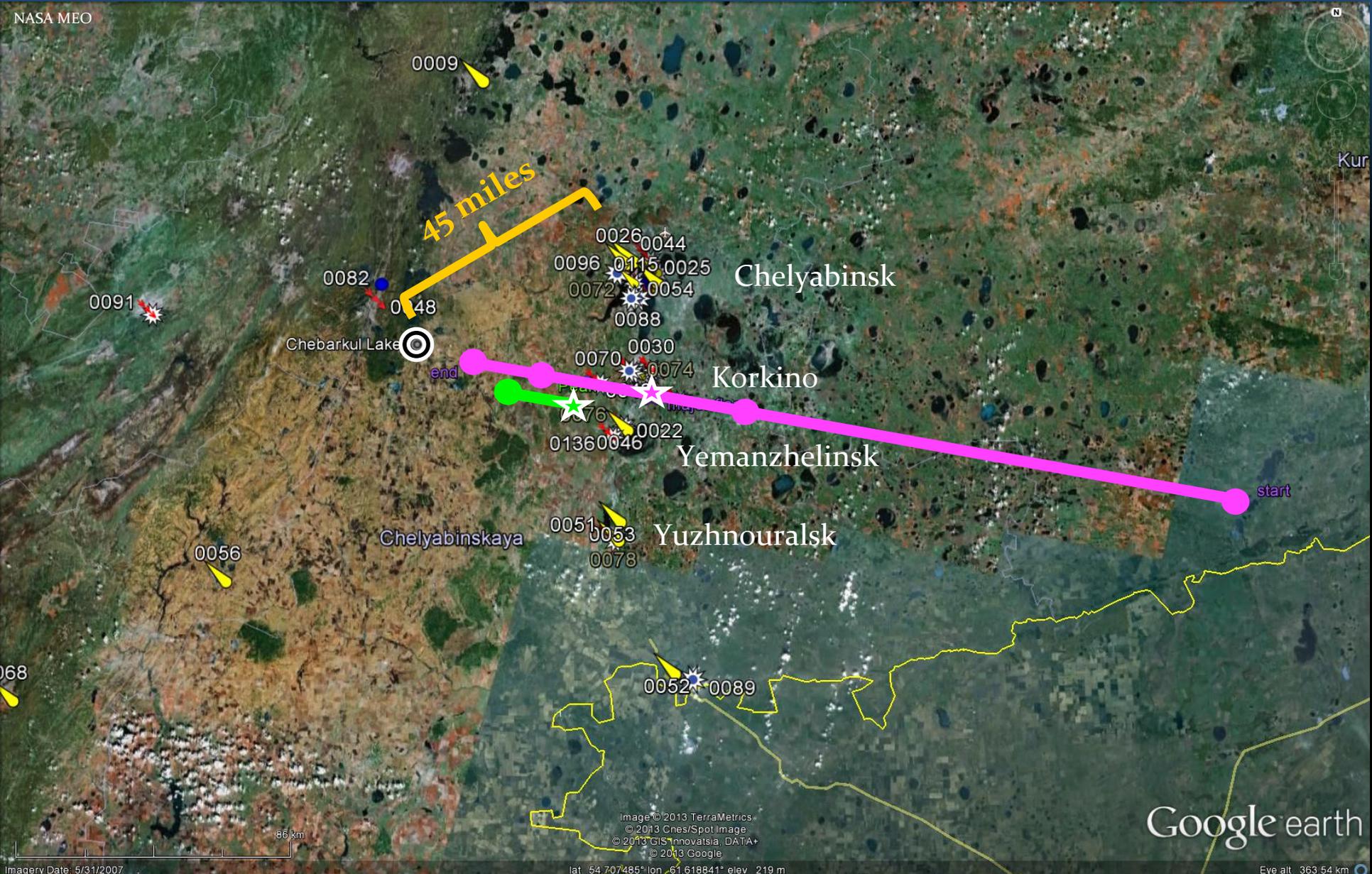
Chebarkul Lake



6 m (20 ft)



Chebarkul Lake



NASA MEO

Kur

start

45 miles

end

Imagery Date: 5/31/2007

lat 54.707485° lon 61.618841° elev 219 m

Eye alt 363.54 km

- Key:  fireball  trail  blast  shadow  US Gov  Czech-CBET Speed

Meteorites



RIA Novosti / Pavel Lysizin

Over 100 fragments of suspected meteorite material so far. Biggest piece ~4 lbs.

Chelyabinsk Properties

Energy	470 kilotons at altitude of 30 km (19 miles) near Chelyabinsk (54.8° N, 61.1° E)
Speed	18 km/s (40,300 mph)
Mass/size	~12,000 tons 20 m (66 ft)
Composition	Ordinary chondrite (LL5)

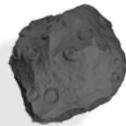
Comparative Sizes



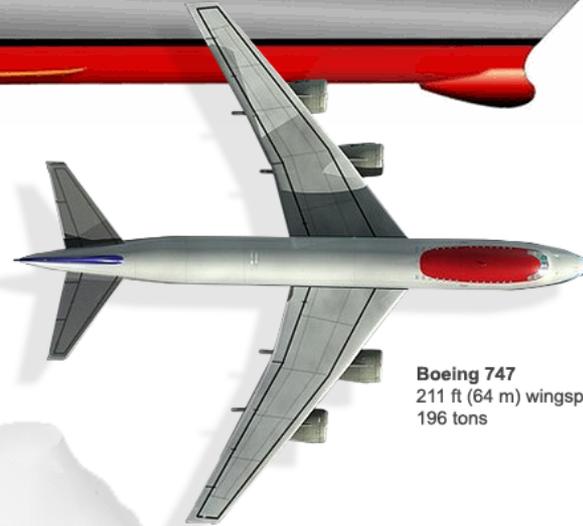
Ticonderoga Class Cruiser
560 ft (169 m) length
9,800 tons



Barringer Crater meteor
165 ft (50 m) diameter
300,000 tons (est)
10 megatons (est)



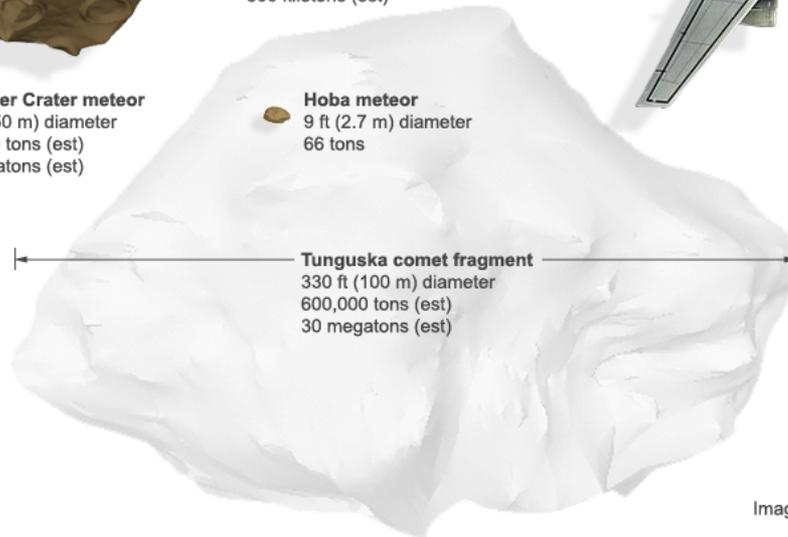
Chelyabinsk meteor
56 ft (17 m) diameter
10,000 tons (est)
500 kilotons (est)



Boeing 747
211 ft (64 m) wingspan
196 tons



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)

Chelyabinsk Process

In space
18 km/s
(40k mph)

Enters atmosphere

Ablation / some
fragmentation

Blast wave /
disruption

Darkflight
4 km/s
(9k mph)

Free-
fall

100 km
(60 mi)

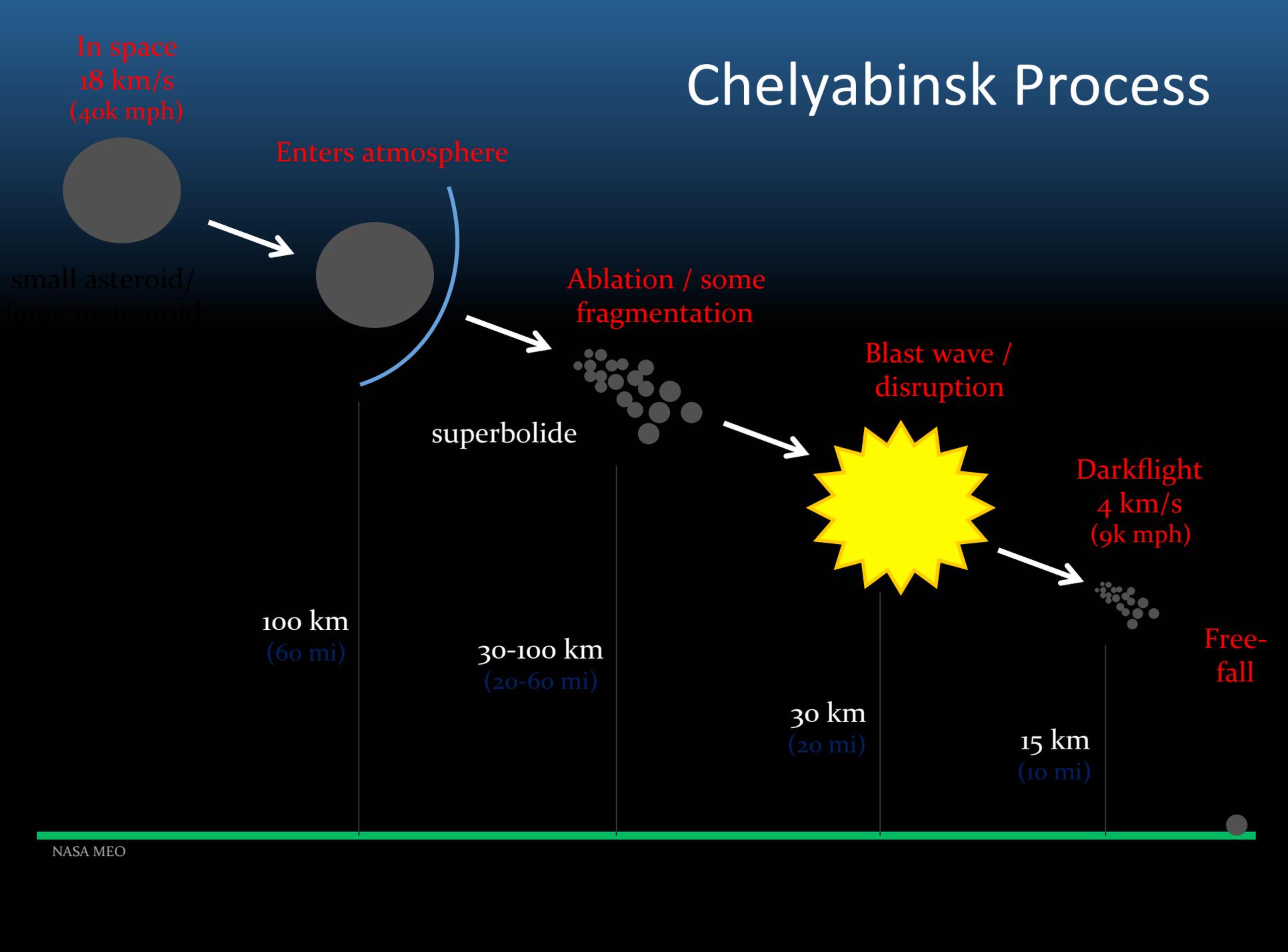
30-100 km
(20-60 mi)

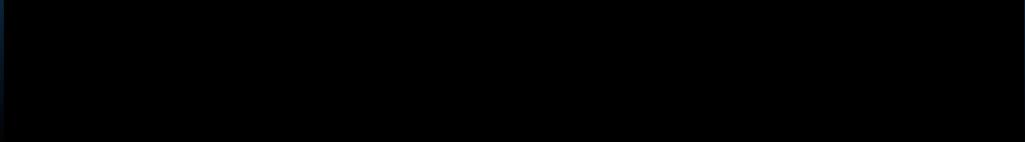
30 km
(20 mi)

15 km
(10 mi)

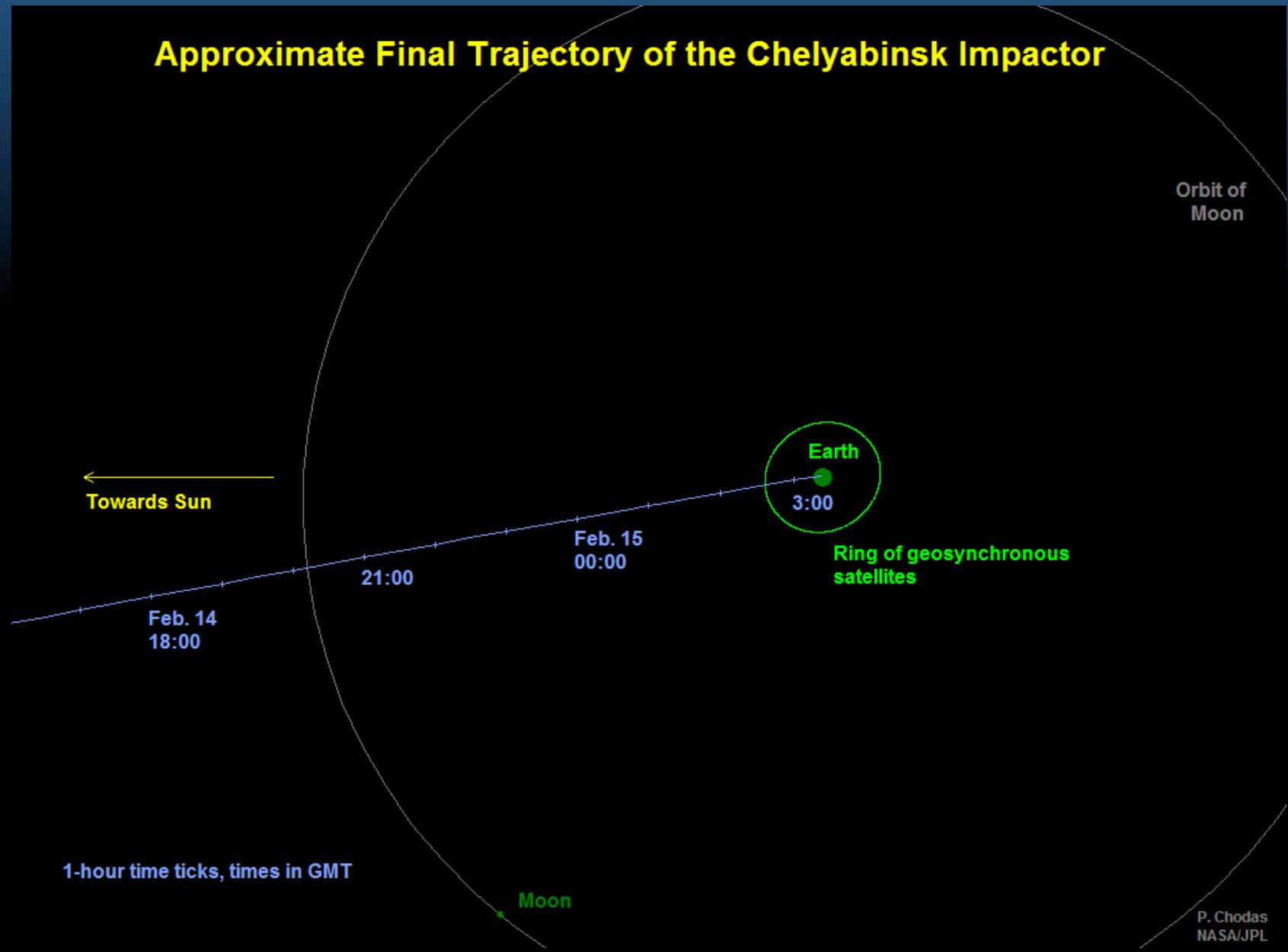
superbolide

small asteroid/
large meteoroid

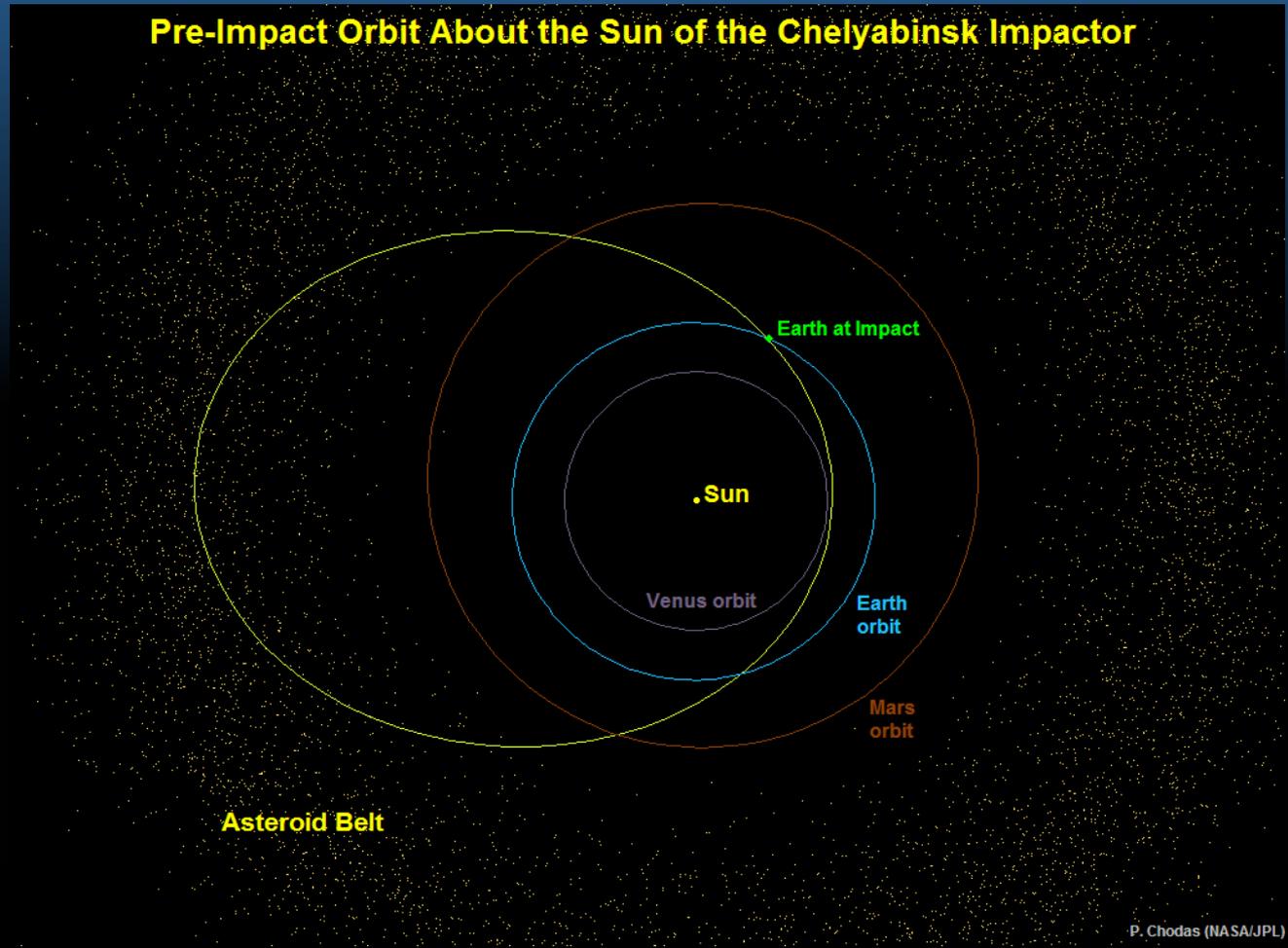




Approximate Final Trajectory of the Chelyabinsk Impactor



Orbit



P. Chodas (NASA/JPL)

Authors	Semimajor axis (AU)	Eccentricity	Inclination (deg)	Peri. (deg)	Node (deg)	Perihelion (AU)	Aphelion (AU)
Borovicka et al.	1.55 ± 0.07	0.50 ± 0.02	3.6 ± 0.7	109.7 ± 1.8	326.41	0.768 ± 0.011	2.33 ± 0.14
Zuluaga & Ferrin	1.73 ± 0.23	0.51 ± 0.08	3.45 ± 2.02	120.62 ± 2.77	326.70 ± 0.79	0.82 ± 0.03	2.64 ± 0.49
Chodas & Chesley	1.73	0.57	4.2			0.75	2.78
Lyytinen	1.66	0.52	4.05	116.0	326.43	0.80	2.53

Orbit Visualization

