

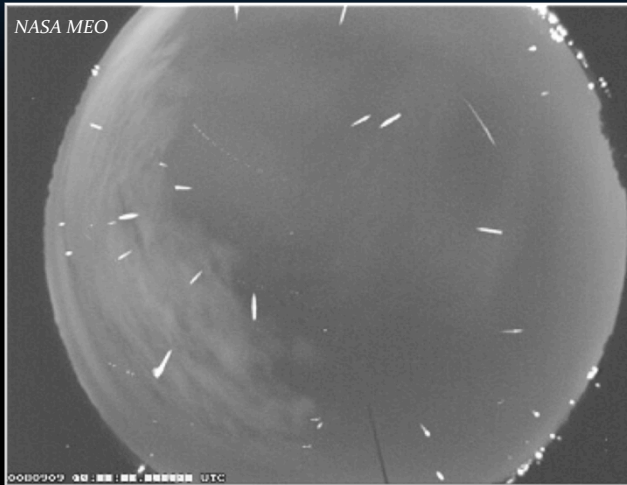
# Bright Fireball Characterization and Modeling

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# Terminology



## Fireballs or Bolides

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

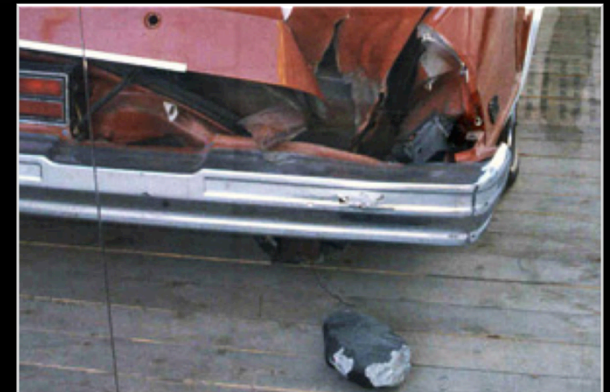


## Superbolides

- 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.

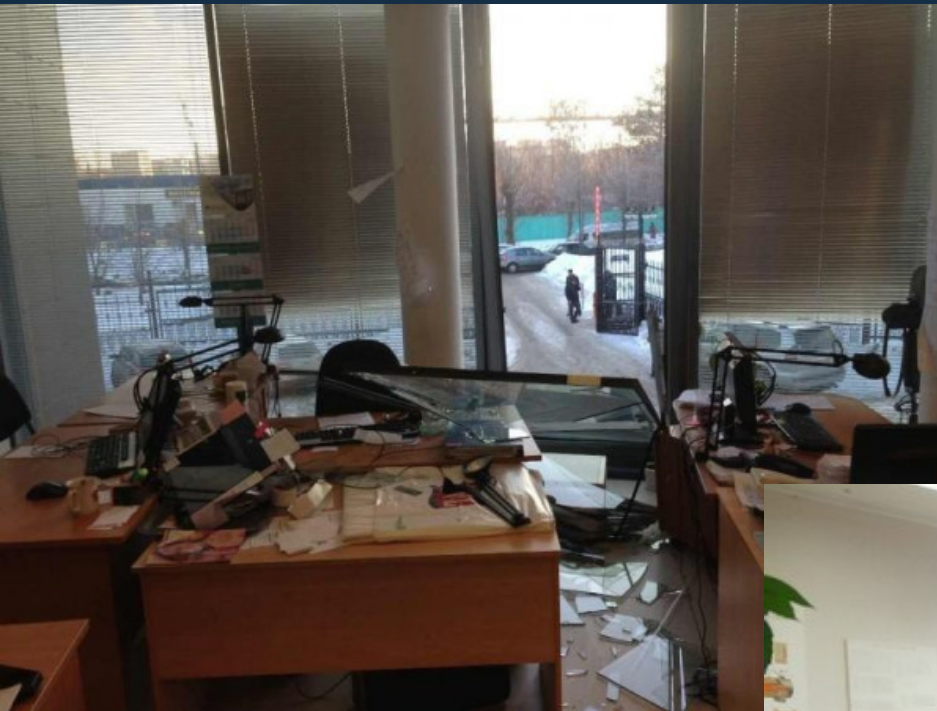
The light shone like 10 suns.

*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



Reuters



CHELYABINSK.RU

# Injuries

Over 1600 people injured by glass & debris



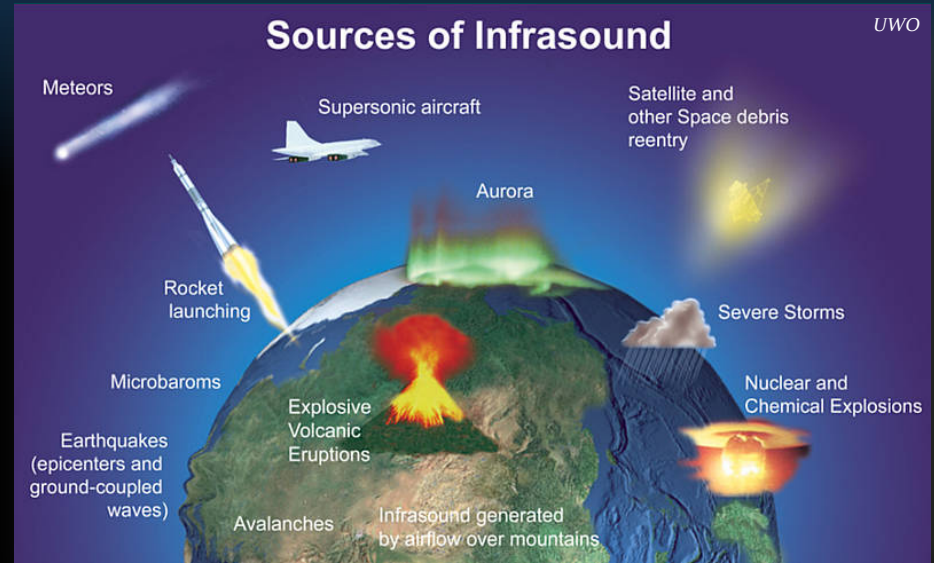
# Fireball Properties

<b>Energy</b>	Determined from infrasound and satellite measurements.
<b>Speed</b>	Calculated from angular rate in video and directly calculated from satellite observations.
<b>Mass/size</b>	Estimated from brightness in video once the speed is known. Also determined from the energy.
<b>Composition</b>	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

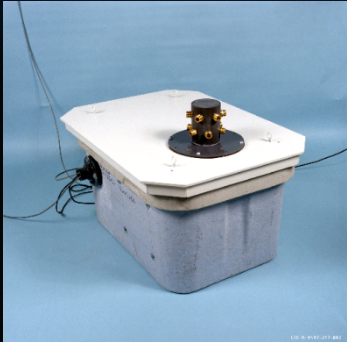
Microbaroms  
Weather systems  
Man-made explosions  
Supersonic aircraft / Missile launches  
Auroral electrojet

Occasional signals

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.

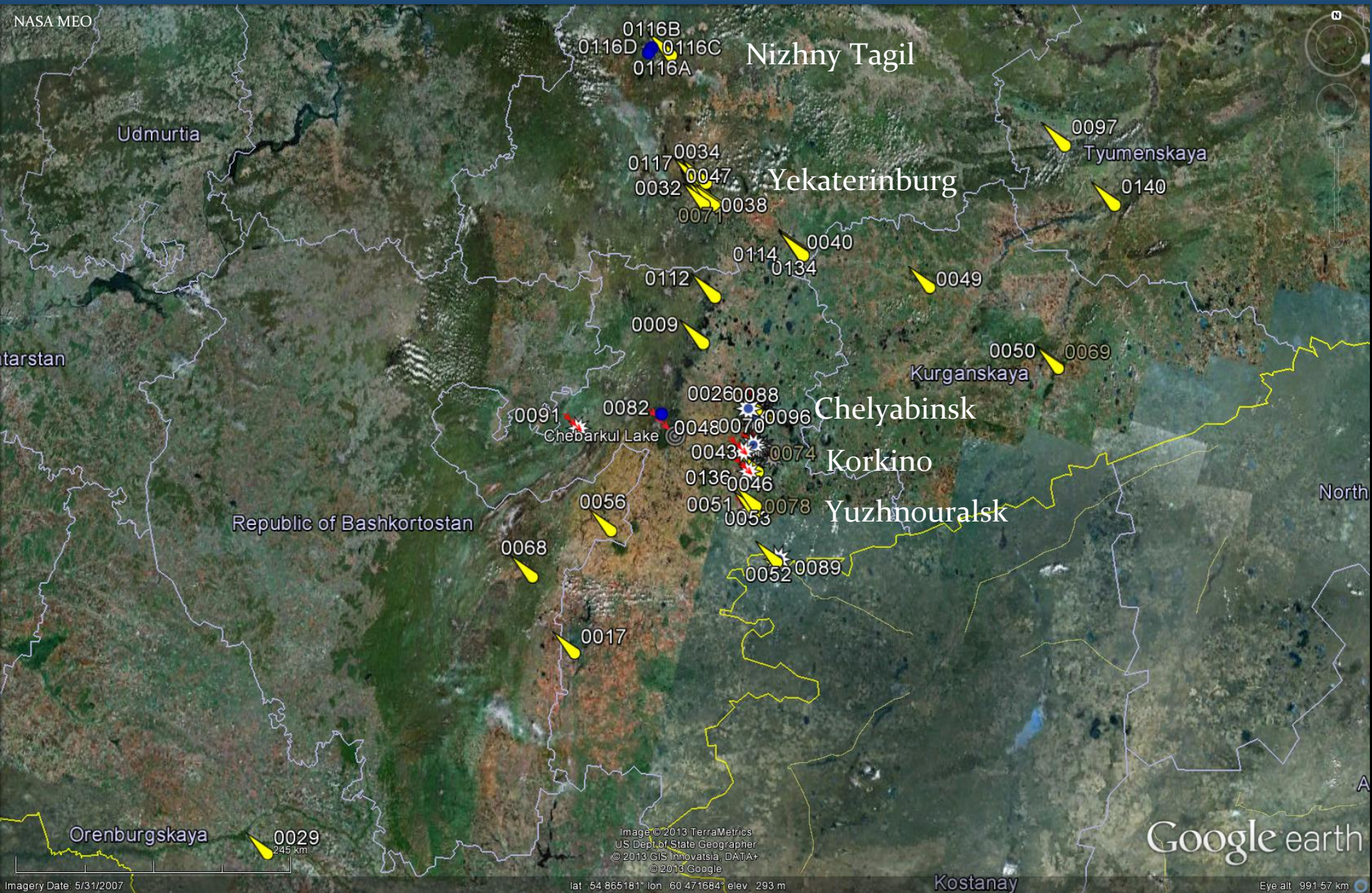






# Infrasound Monitoring Advantages

- 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



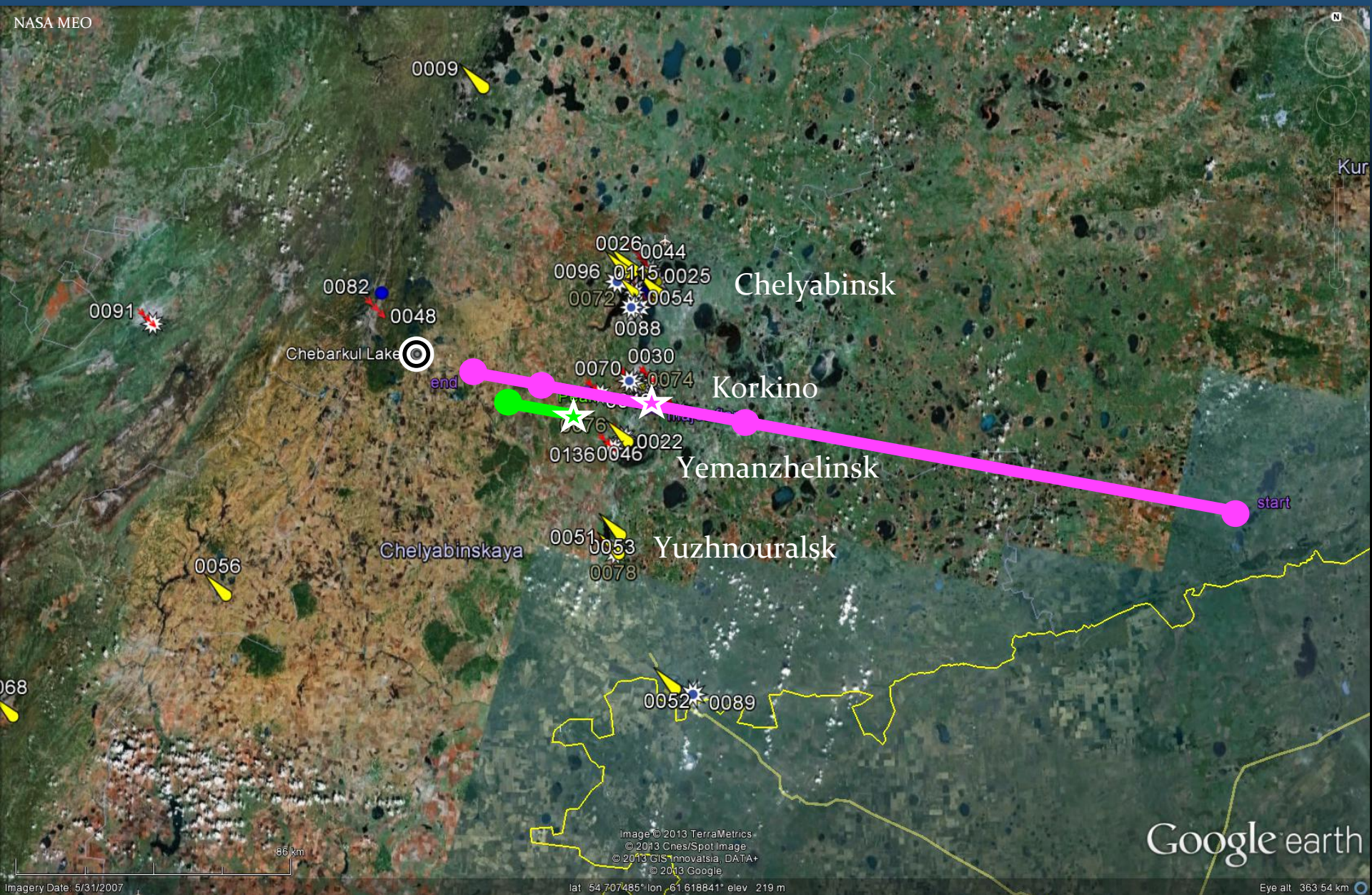
# Video Calibration



UWO



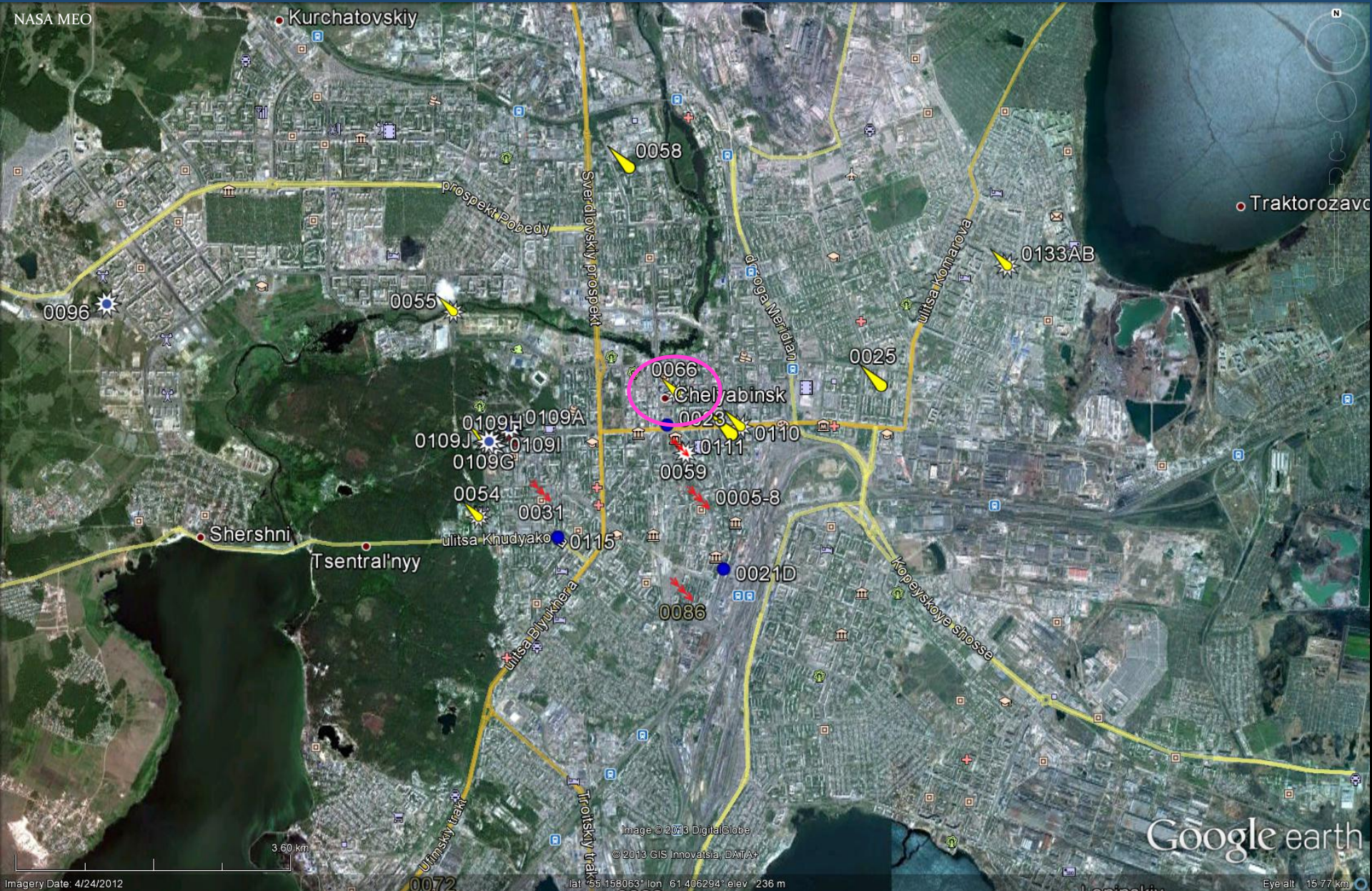
# Preliminary Trajectories



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



# Chelyabinsk: Vid #0066



Key:  fireball  trail  blast  shadow

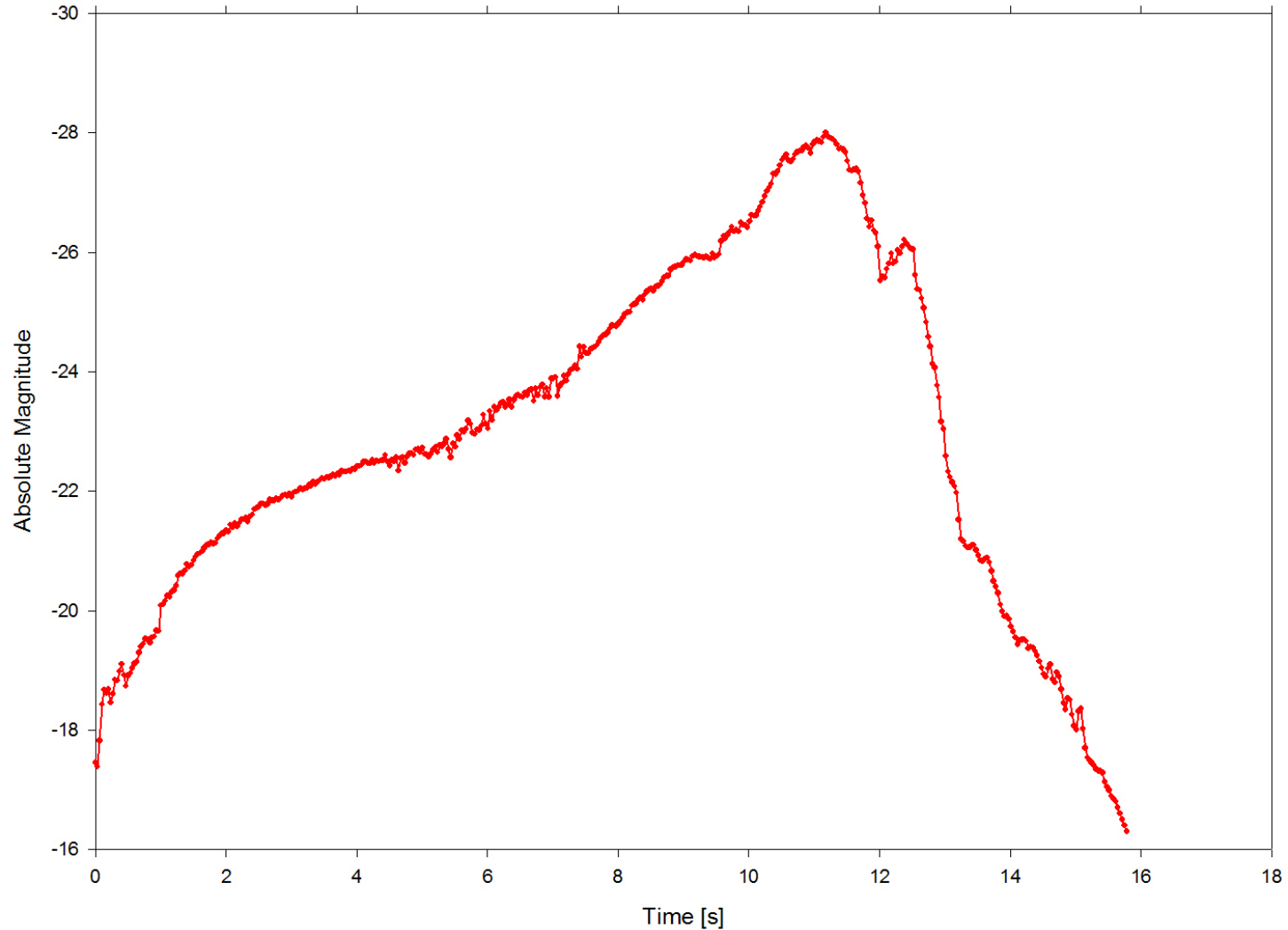
Mass/size



2011.09.27 17:26:35



# Preliminary Light Curve (6 Videos)





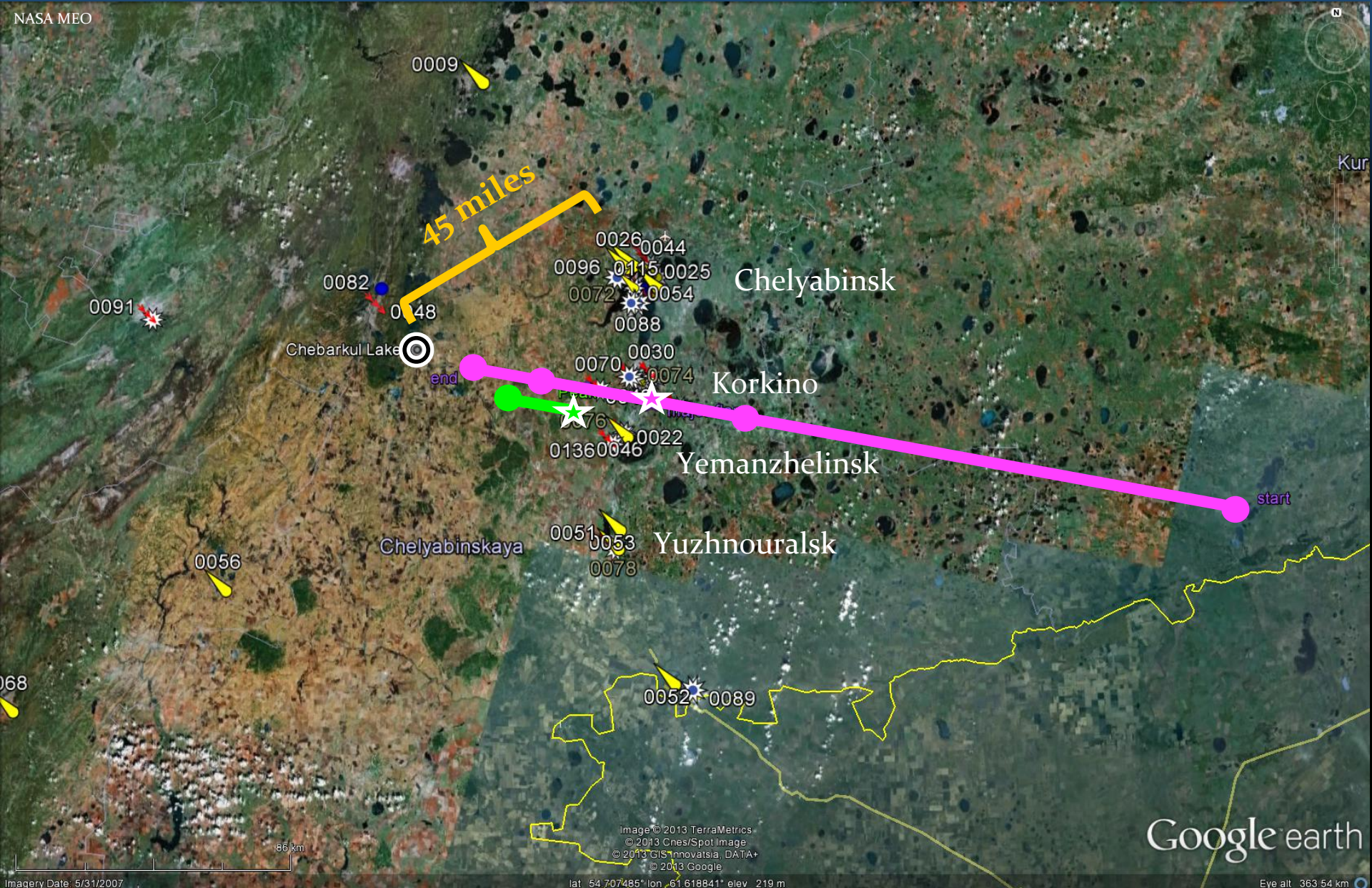
# Chebarkul Lake



6 m (20 ft)



# Chebarkul Lake



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

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

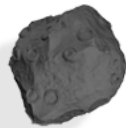
## Comparative Sizes



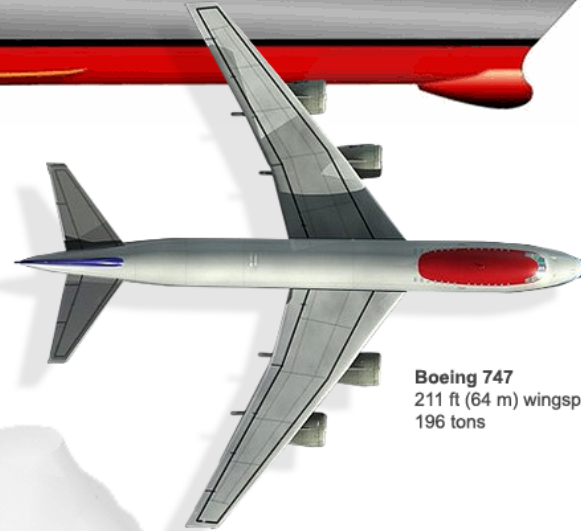
**Ticonderoga Class Cruiser**  
560 ft (169 m) length  
9,800 tons



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



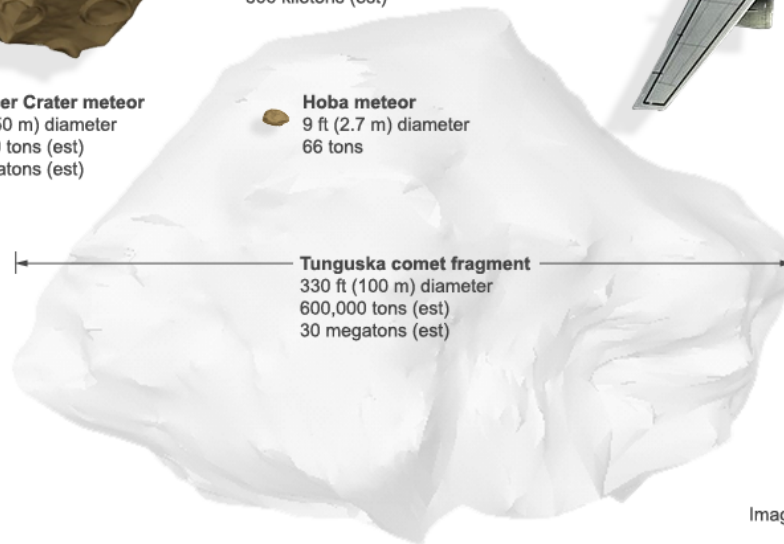
**Chelyabinsk meteor**  
56 ft (17 m) diameter  
10,000 tons (est)  
500 kilotons (est)



**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)

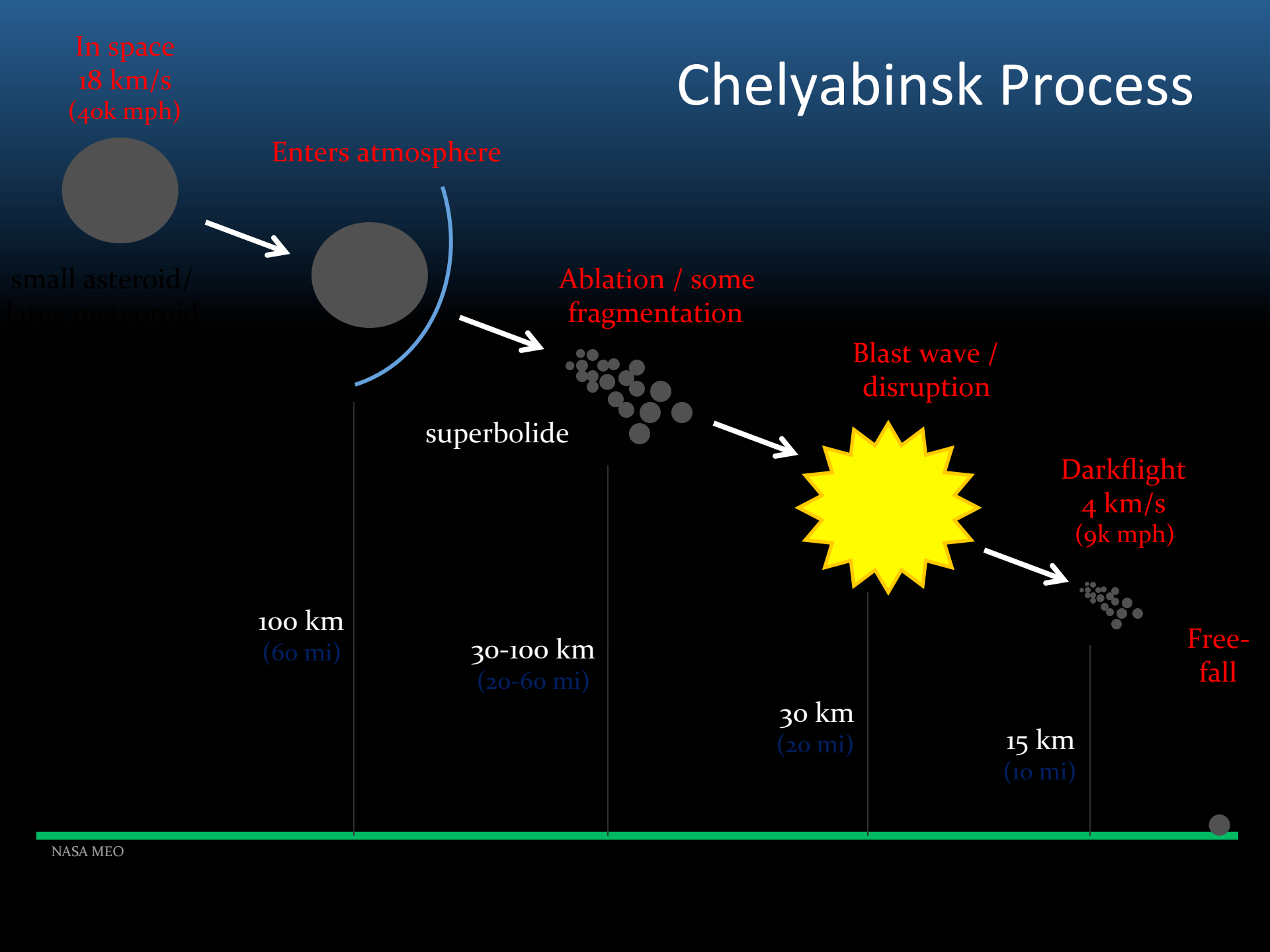
30-100 km  
(20-60 mi)

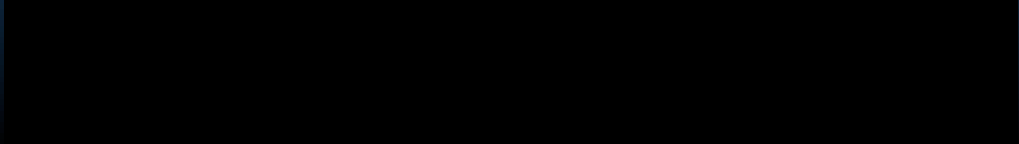
30 km  
(20 mi)

15 km  
(10 mi)

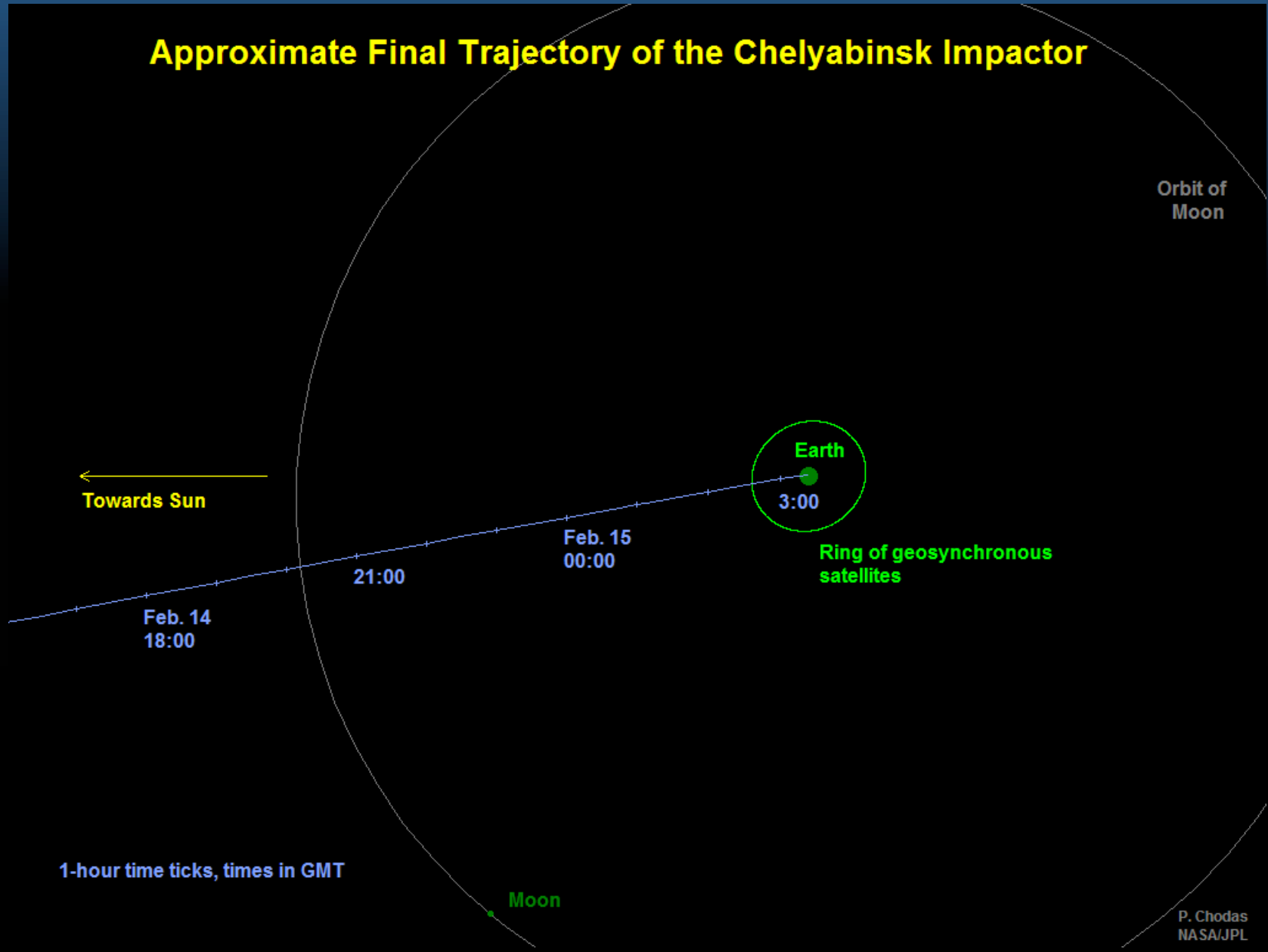
superbolide

small asteroid/  
large meteoroid



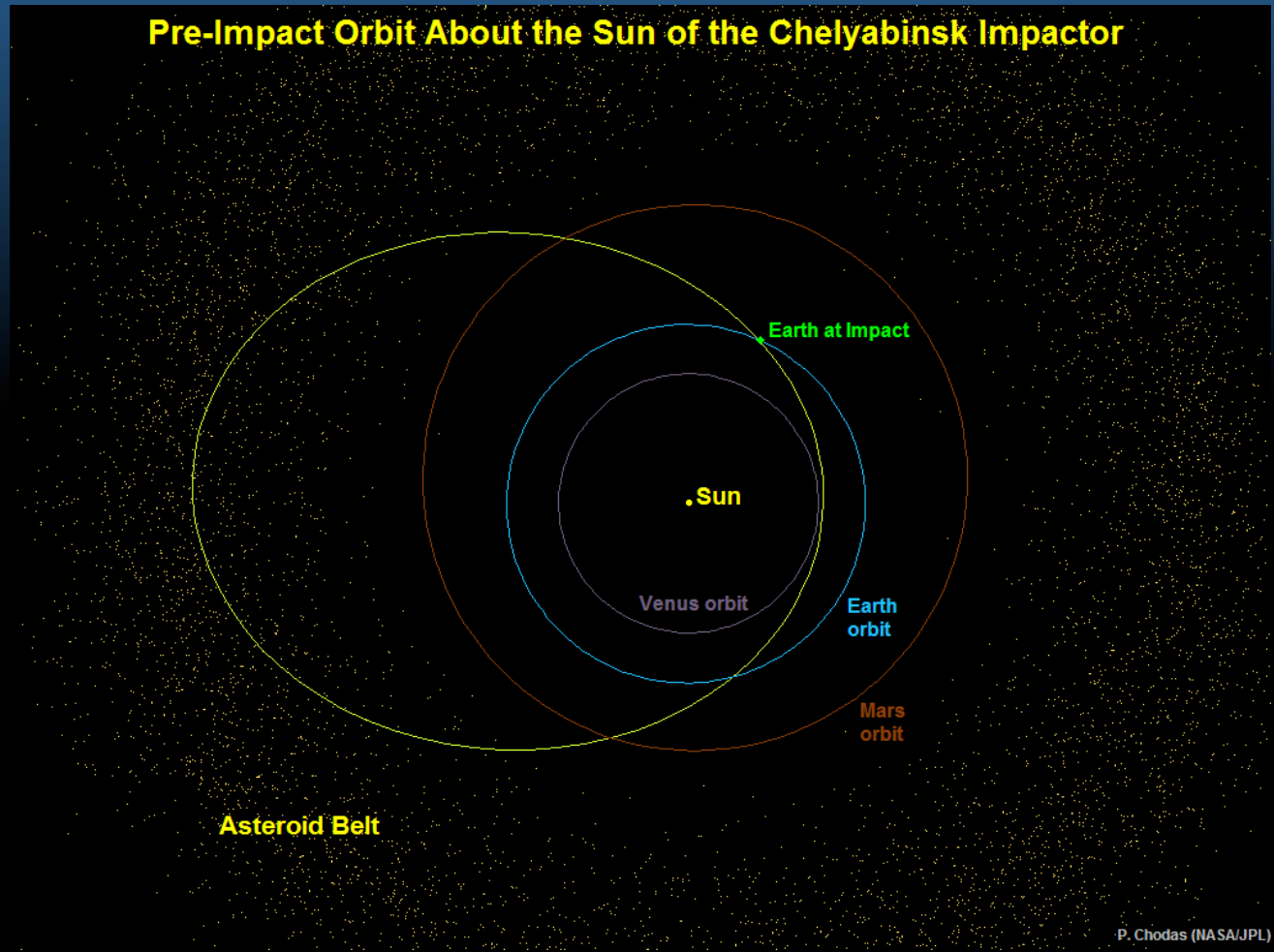


# Approximate Final Trajectory of the Chelyabinsk Impactor





# Orbit



P. Chodas (NASA/JPL)

Authors	Semimajor axis (AU)	Eccentricity	Inclination (deg)	Peri. (deg)	Node (deg)	Perihelion (AU)	Aphelion (AU)
Borovicka et al.	$1.55 \pm 0.07$	$0.50 \pm 0.02$	$3.6 \pm 0.7$	$109.7 \pm 1.8$	326.41	$0.768 \pm 0.011$	$2.33 \pm 0.14$
Zuluaga & Ferrin	$1.73 \pm 0.23$	$0.51 \pm 0.08$	$3.45 \pm 2.02$	$120.62 \pm 2.77$	$326.70 \pm 0.79$	$0.82 \pm 0.03$	$2.64 \pm 0.49$
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

