



Overview of the Chelyabinsk Impact Event

Paul Chodas (JPL/Caltech), Peter Brown (Western University),
Mark Boslough (Sandia National Laboratories)

9th Meeting of the Small Bodies Assessment Group
10-11 July 2013, Washington, DC

Chelyabinsk narrowly escapes destruction in 2013!



REAL!

REAL!



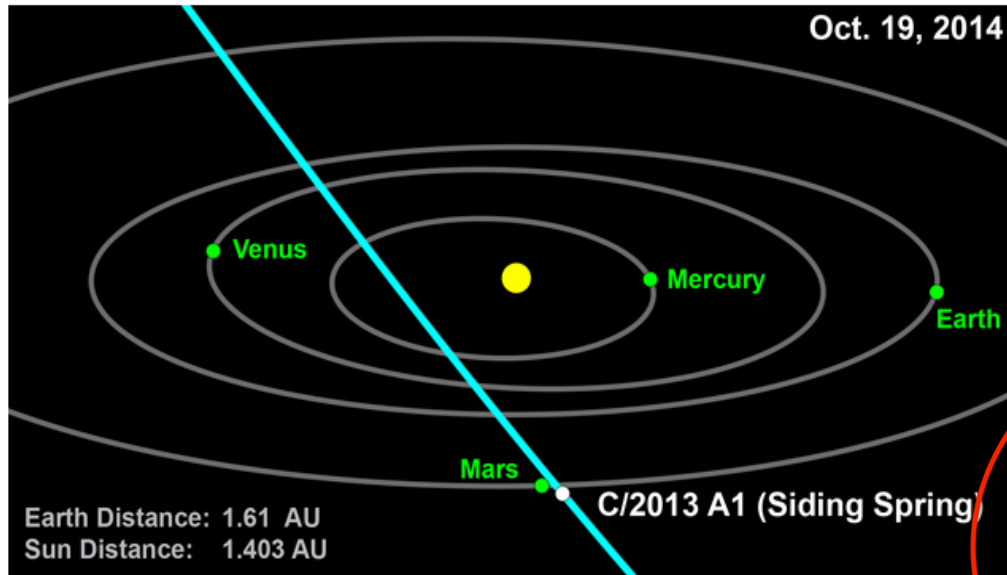


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Comet to Make Close Flyby of Red Planet in October 2014

New observations of comet C/2013 A1 (Siding Spring) have allowed NASA's Near-Earth Object Office at the Jet Propulsion Laboratory in Pasadena, Calif. to further refine the comet's orbit.

[Read more](#) (April 12, 2013)

Recent News



NASA Associate Administrator on Asteroid Initiative

The following are statements from the associate administrators of three NASA directorates.

[Read more](#) (April 10, 2013)

Archived Ustream Events

- [The Truth About 2012 - 12.08.11](#)
- [2005 YU55 Q & A - 11.01.11](#)
- [The Science of Vesta - 10.12.11](#)
- [Asteroid News from WISE - 09.29.11](#)

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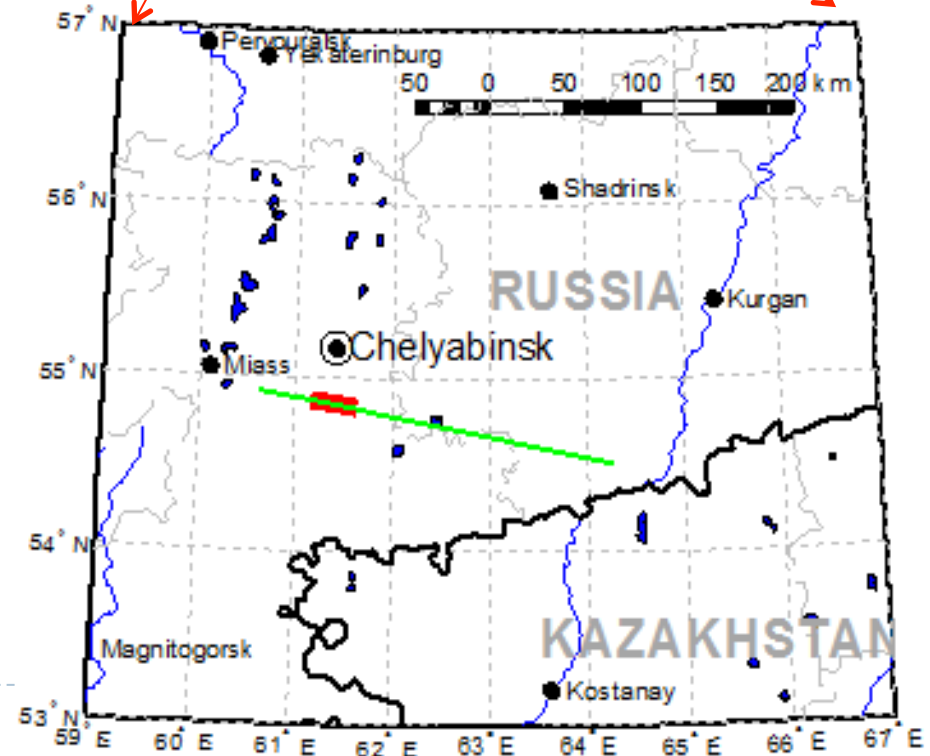


Early Radar Observations of Asteroid 2012 DA14

This 73-frame movie of asteroid 2012 DA14 was generated from data obtained by NASA's Goldstone Solar System Radar on the night of Feb. 15 to 16, 2013.

Chelyabinsk Airburst – Feb 15, 2013

- ▶ Bright fireball at 03:20:33 UT (09:20:33 local) near Chelyabinsk.
- ▶ Large number (hundreds) of videos >400 catalogued to date, 49% show direct fireball or lightflash.
- ▶ Observed trajectory: 250 km in 16s.
- ▶ Airblast damaged windows over several thousand km²; 1500 persons injured, mainly due to flying glass.
- ▶ Roof collapse at Zinc plant.
- ▶ Hundreds of ordinary chondrite meteorites (LL5) recovered.



Very Shallow Entry Angle: ~17 deg to Horizontal



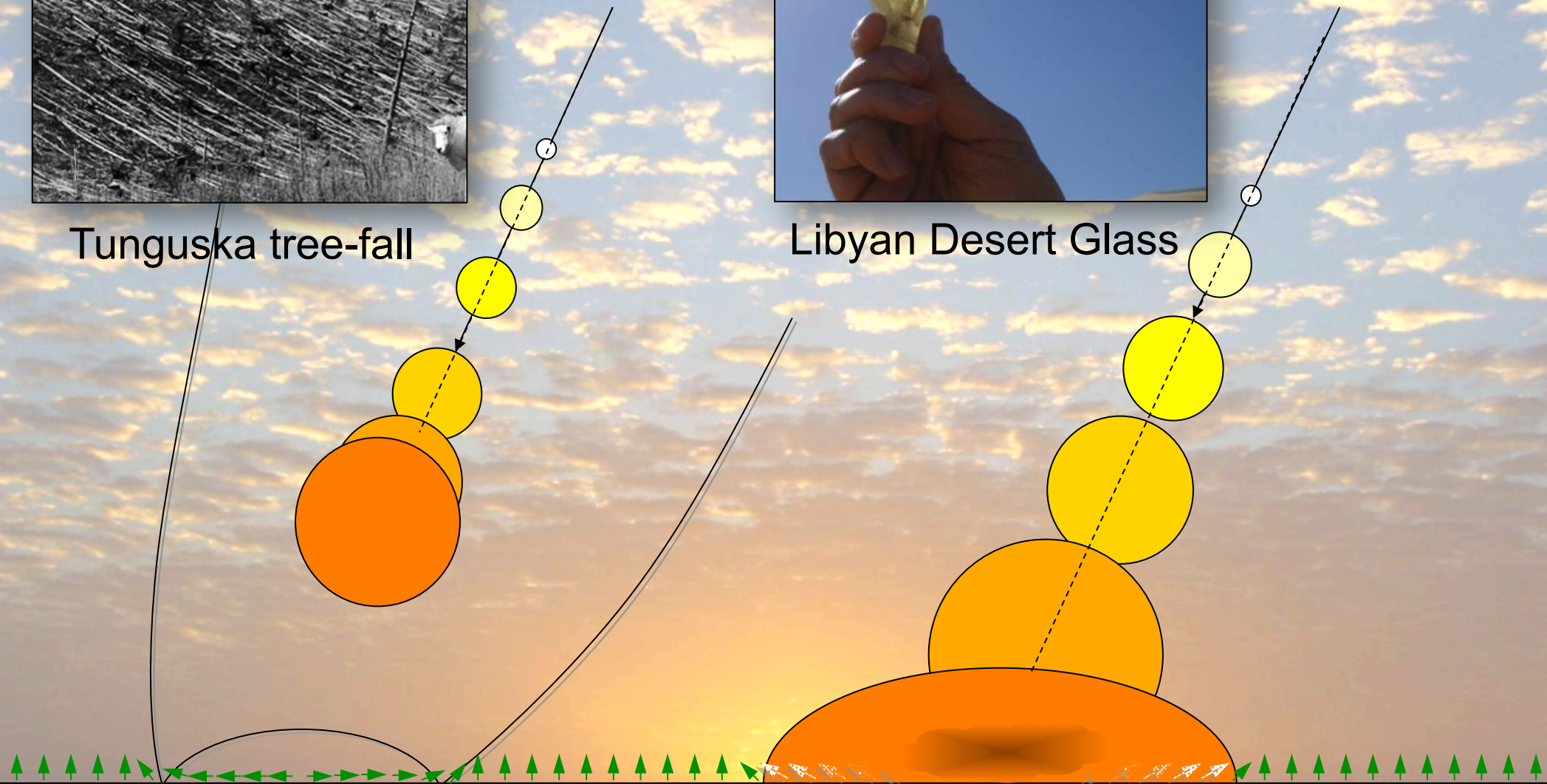
Two types of Low-Altitude Airburst



Tunguska tree-fall



Libyan Desert Glass



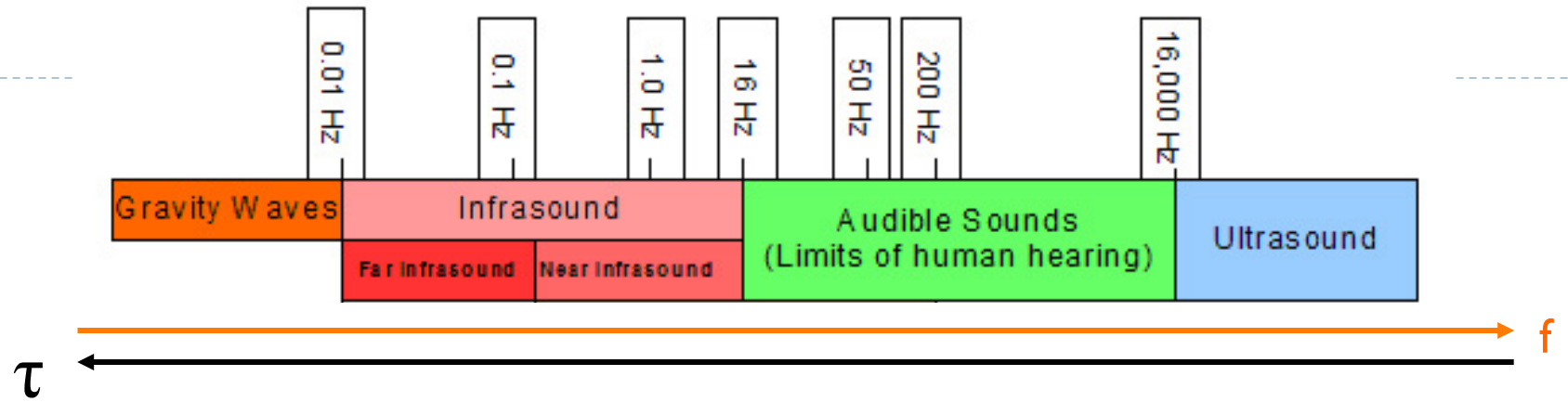
Type 1: Tunguska

Scorches and blows down trees

Type 2: Libyan Desert

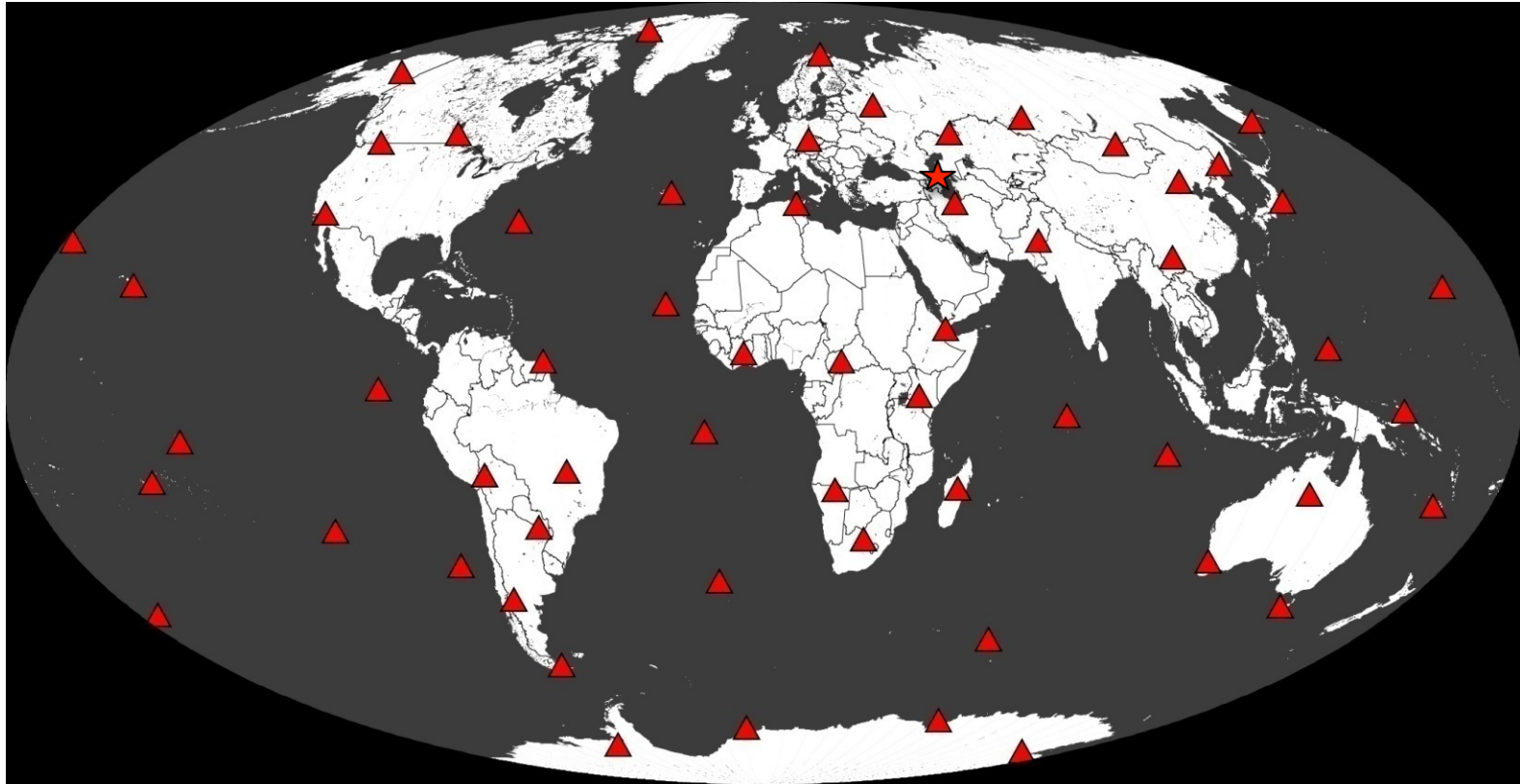
Vaporizes trees and melts rocks

Energy estimate from Infrasound



- ▶ Region of the acoustic spectrum below threshold of human hearing
- ▶ Lower frequencies attenuate slowly in the atmosphere than more familiar audible frequencies
- ▶ Dominant frequency of meteor signal indicates energy
 - ▶ lower $f \sim$ larger E
- ▶ Chelyabinsk infrasound peaked below 0.03 Hz - detectable by infrasound stations for several days – airwave circled the world multiple times

CTBTO – International Monitoring System Infrasound Network



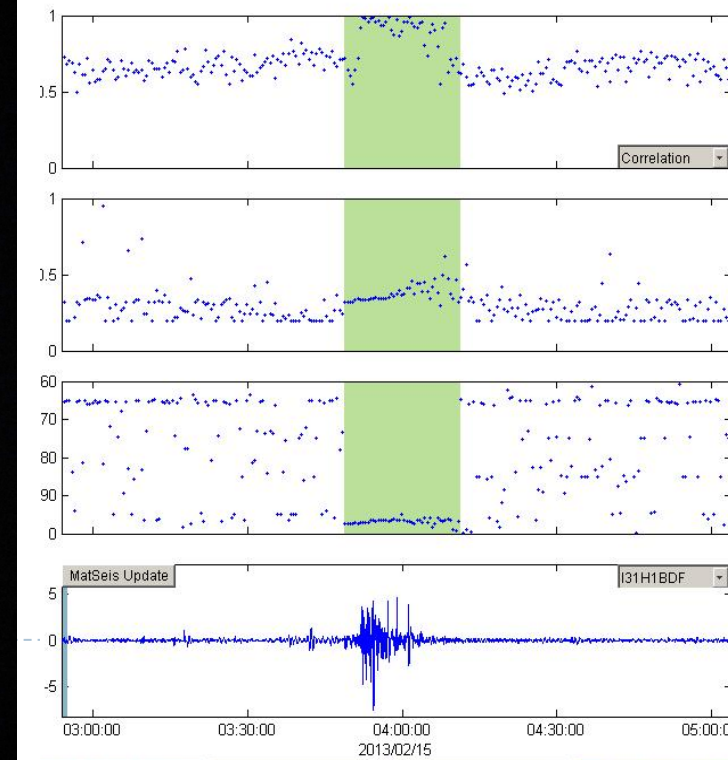
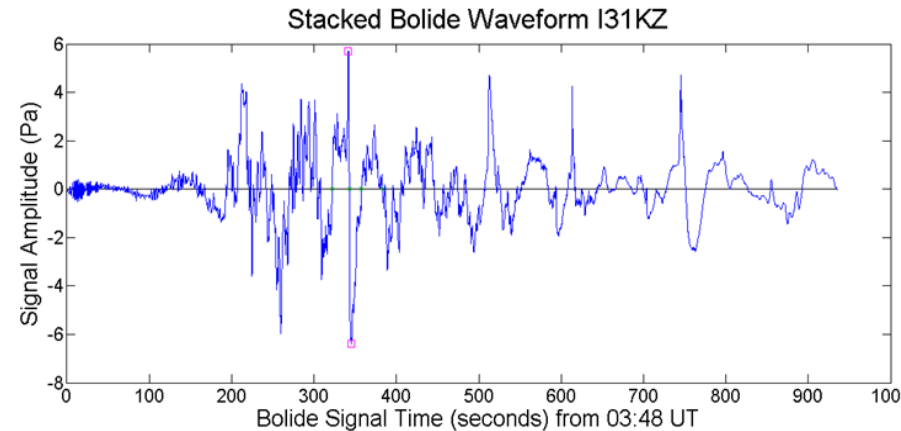
Courtesy M. Hedlin, UCSD

60 Stations planned
45 currently operating
~20 detected the Chelyabinsk airblast

Chelyabinsk Infrasound

- ▶ Highest amplitude – I53US in Alaska (6500 km range) – 13 Pa
- ▶ Closest station (I31KZ) shows similar amplitude and period of 38 sec

Courtesy PBS-NOVA





Near Earth Object Program

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Fireball and Bolide Reports

Fireballs and *bolides* are astronomical terms for exceptionally bright meteors that are spectacular enough to be seen over a very wide area. The following table provides a chronological data summary of fireball and bolide events provided by U.S. Government sensors. Ground-based observers sometimes also witness these events at night, or much more rarely in daylight, as impressive atmospheric light displays. This website is not meant to be a complete list of all fireball events. Only the brightest fireballs are noted.

A meteoroid is generally defined as an asteroid or comet fragment that orbits the Sun and has an approximate size between ten microns and a meter or so. Meteors, or "shooting stars," are the visible paths of meteoroids that have entered the Earth's atmosphere at high velocities. A *fireball* is an unusually bright meteor that reaches a visual magnitude of -3 or brighter when seen at the observer's zenith. Objects causing fireball events can exceed one meter in size. Fireballs that explode in the atmosphere are technically referred to as *bolides* although the terms fireballs and bolides are often used interchangeably.

During the atmospheric entry phase, an impacting object is both slowed and heated by atmospheric friction. In front of it, a bow shock develops where atmospheric gases are compressed and heated. Some of this energy is radiated to the object causing it to ablate, and in most cases, to break apart. Fragmentation increases the amount of atmosphere intercepted and so enhances ablation and atmospheric braking. The object catastrophically disrupts when the force from the unequal pressures on the front and back sides exceeds its tensile strength.

Note that data are not provided in real-time and not all fireballs are reported.

Date/Time - Peak Brightness	Latitude (Deg)	Longitude (Deg)	Altitude (km)	Velocity (km/s)	Velocity Components (km/s)			Total Radiated Energy (J)	Calculated Total Impact Energy (kt)
					vx	vy	vz		
2013-02-15 03:20:33	54.8N	61.1E	23.3	18.6	+12.8	-13.3	-2.4	3.75E+14	440

Chelyabinsk Fireball Total Energy and Impactor Mass and Size

- ▶ Total energy is determined by taking the observed optical yield (E_r) and dividing by efficiency (η)
 - ▶ $E_t = E_r / \eta$
 - ▶ Gives 450 – 700 kT for total energy
- ▶ The largest recorded event since the 1908 Tunguska explosion.
- ▶ With total yield (=energy = kinetic energy of impactor) known, mass is found from $E_t = 1/2 mv^2$
 - ▶ Use velocity = 18.6 km/s to give 11000 T < m < 17000 T
- ▶ Size is found using mass and assuming a spherical shape and bulk density
 - ▶ Bulk density of 3400 kgm⁻³ gives 18m < D < 21m

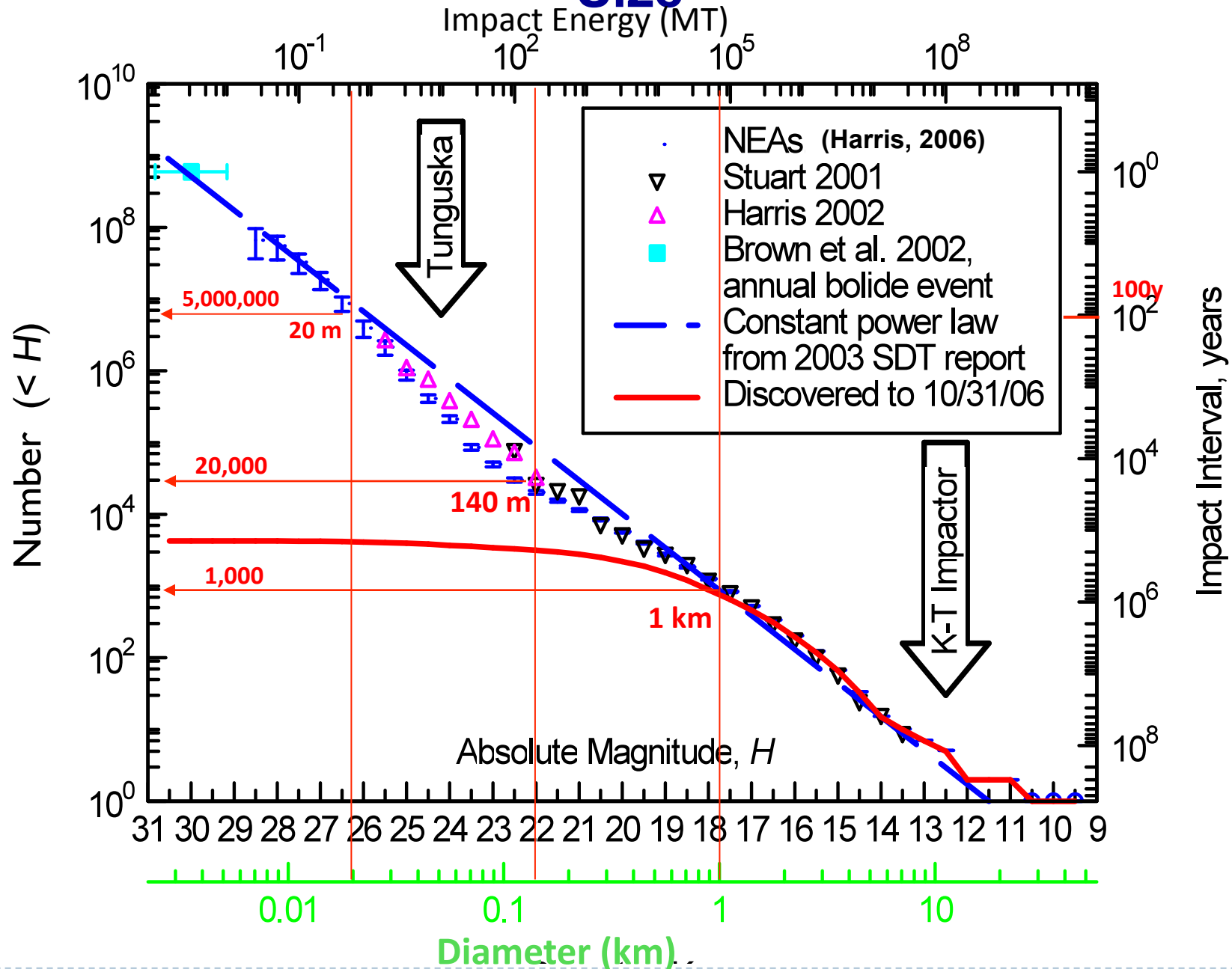


Pre-Entry Heliocentric Orbit

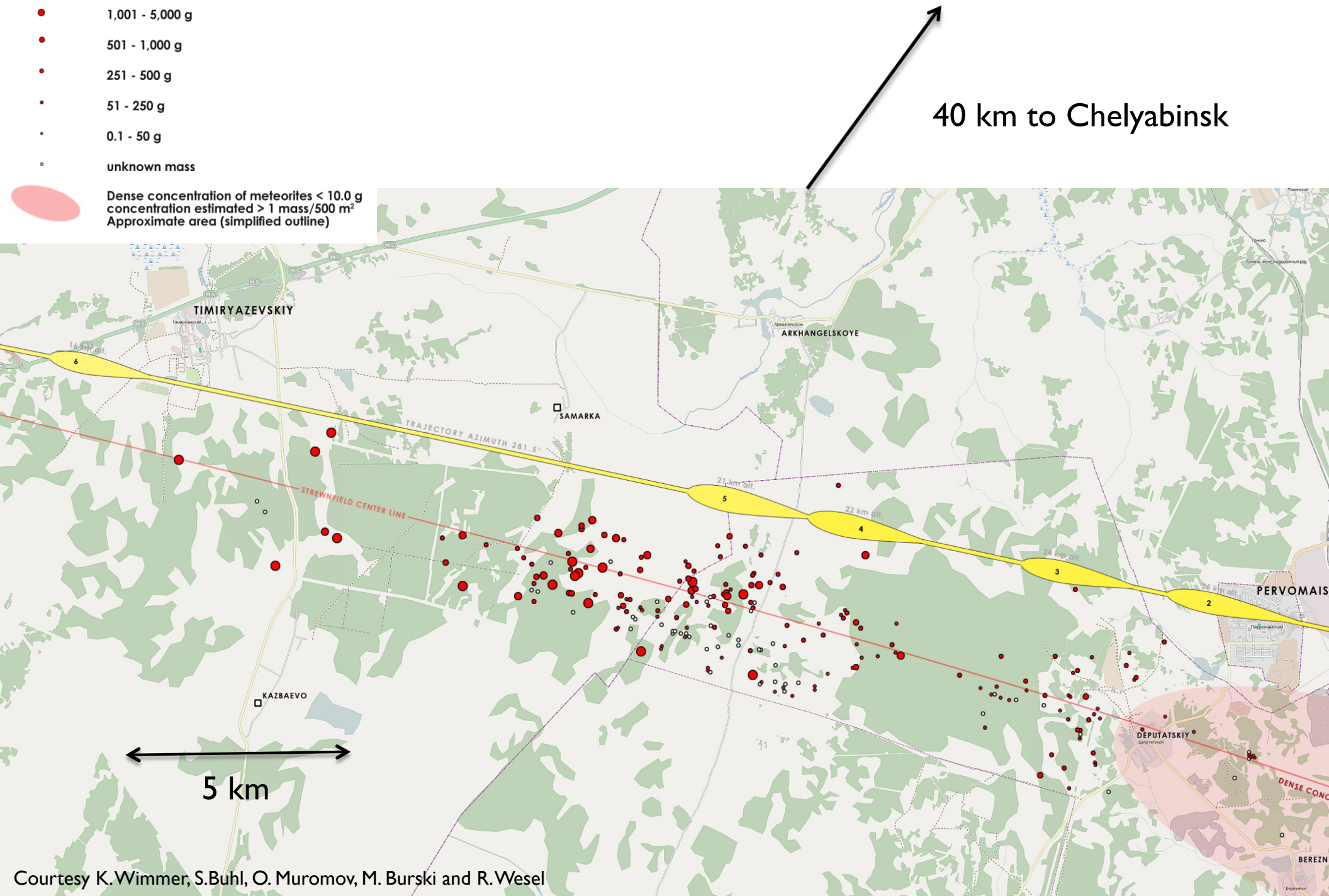
- ▶ From detailed analyses of video records, Borovicka et al. calculated the trajectory and pre-entry orbit of the impactor:
- ▶ Entry velocity: 17.5 ± 0.5 km/s
- ▶ Heliocentric orbital elements:
 - ▶ $a = 1.55 \pm 0.07$ AU $e = 0.50 \pm 0.02$
 - ▶ $q = 0.768 \pm 0.011$ AU $Q = 2.33 \pm 0.14$ AU
 - ▶ $\text{Peri} = 109.7 \pm 1.8$ deg $\text{Node} = 326.41$ deg
 - ▶ $i = 3.6 \pm 0.7$ deg



Population & Impact Frequency vs. Abs. Magnitude & Size



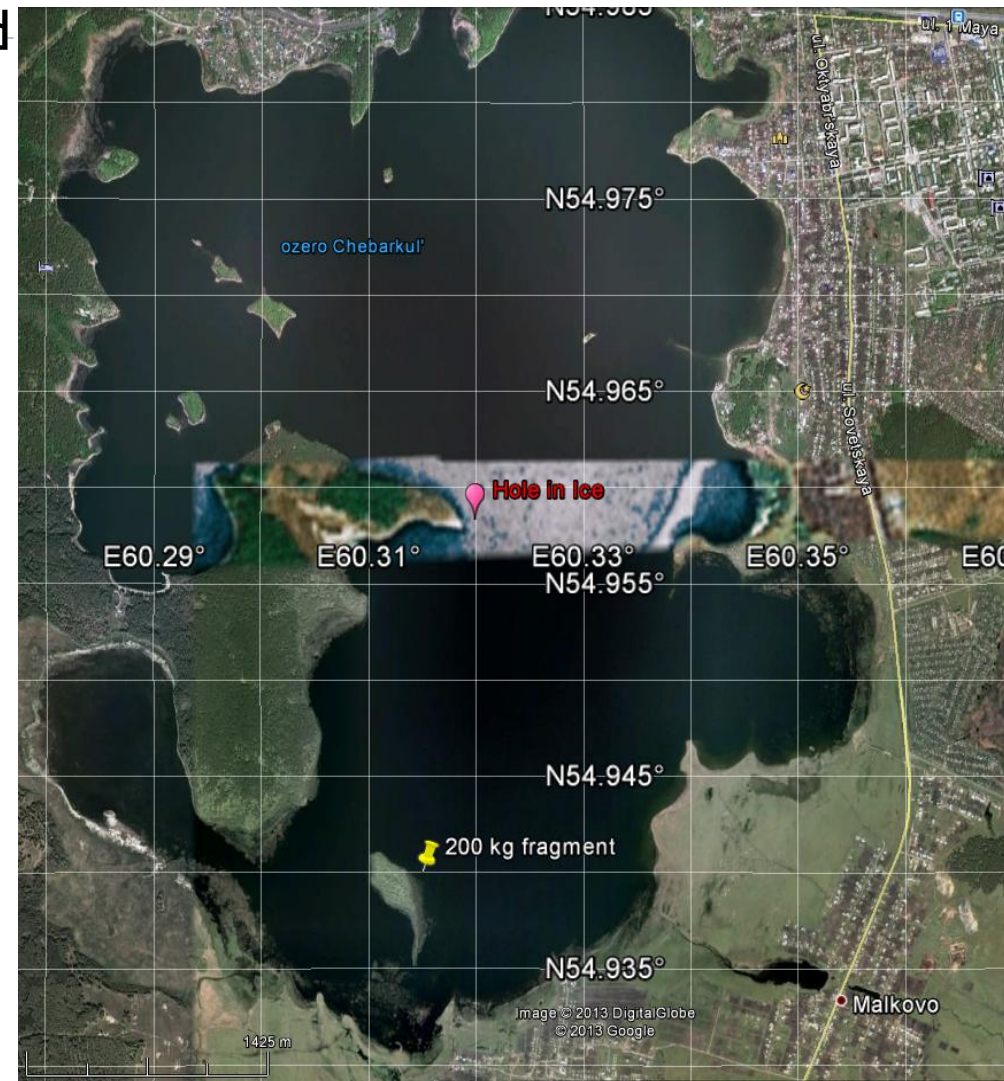
Meteorite Finds on the Ground



Courtesy K. Wimmer, S. Buhl, O. Muromov, M. Burski and R. Wesel

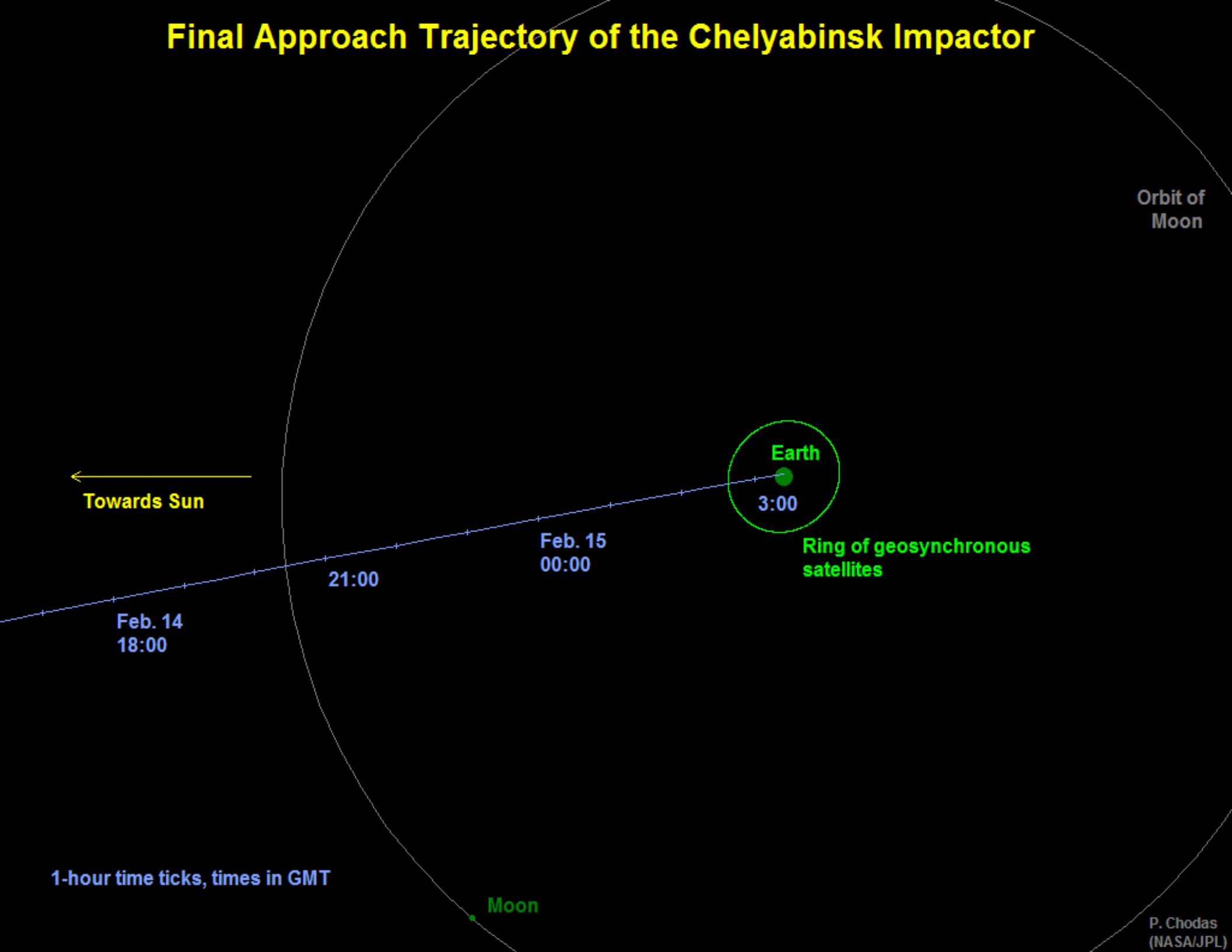
Main Mass is in Lake Chebarkul

- ▶ Final fragment ends ablation at ~ 15 km altitude - estimated to be 200-500 kg based on model comparisons to observed deceleration and brightness.
- ▶ Darkflight modeling places impact 30 km from endpoint on Southern part of Lake Chebarkul about 2 km from hole in ice.
- ▶ Impact speed = ~ 200 m/s.

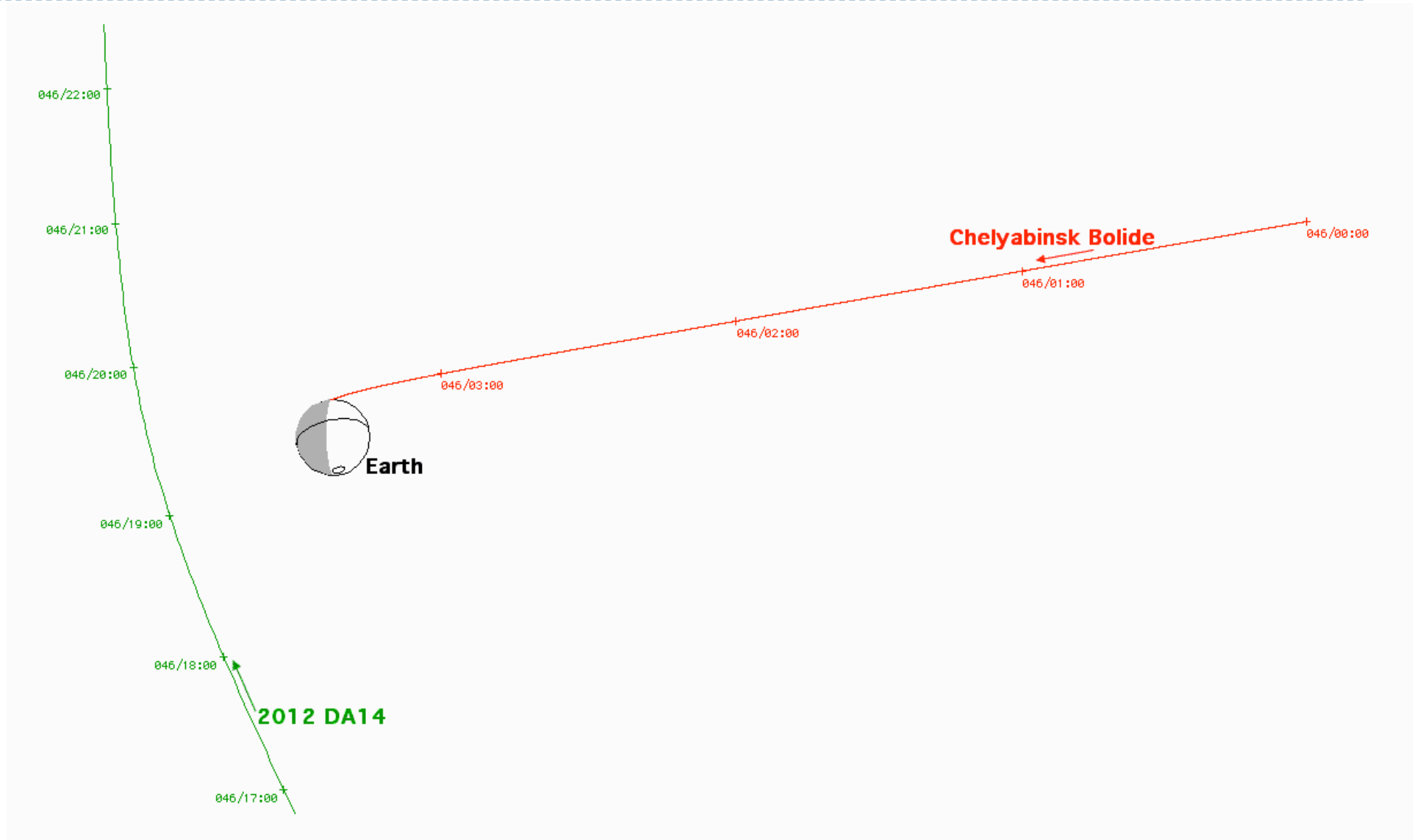


2 km

Final Approach Trajectory of the Chelyabinsk Impactor



Two Unrelated Extremely Close Approaches Only 16 hours Apart



Courtesy of Dan Adamo

Pre-Impact Orbit About the Sun of the Chelyabinsk Impactor

