The Chelyabinsk event – what we know one year later

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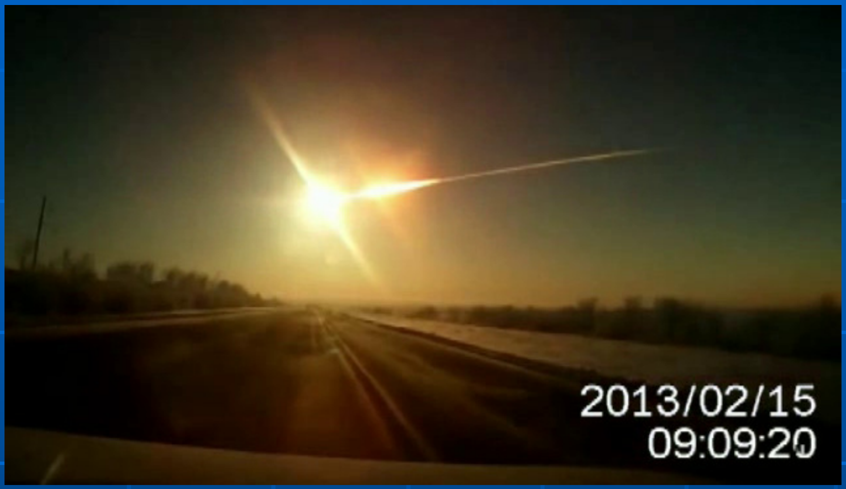


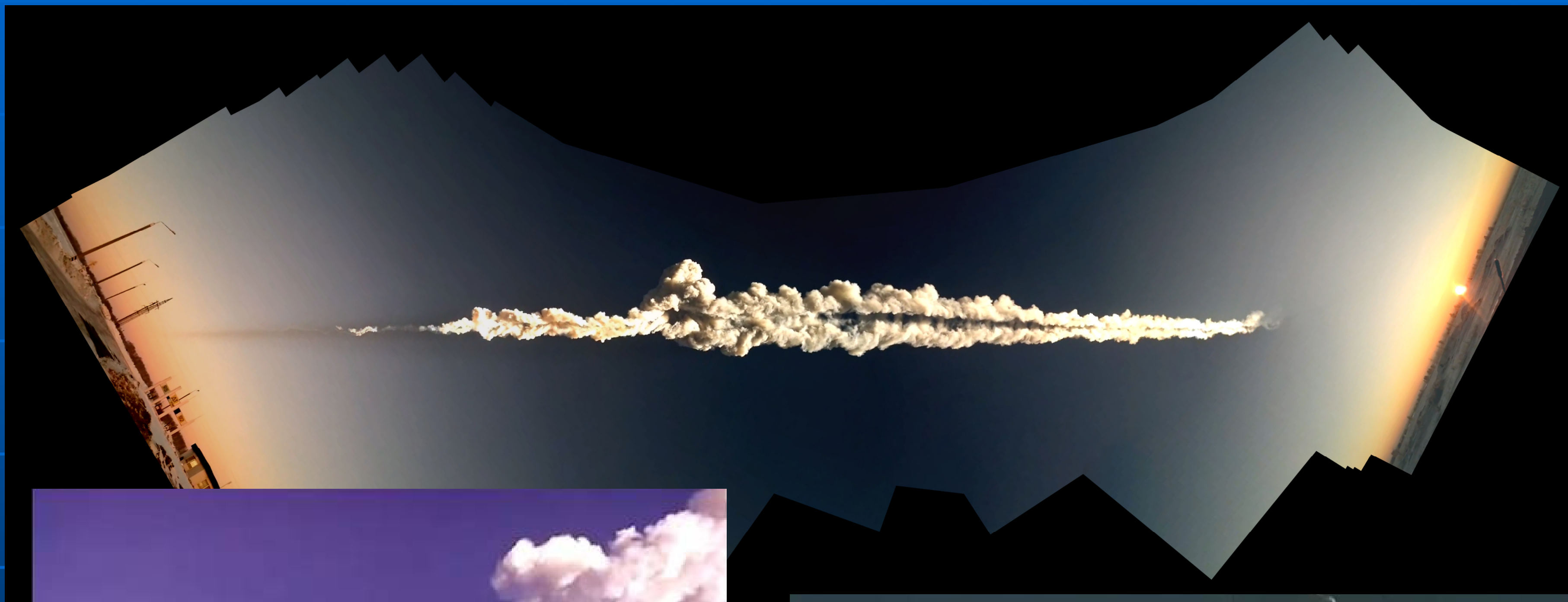
- Chelyabinsk and wide surroundings
- Extremely bright superbolide
- During local sunrise
- Damaging blast wave
- Massive dust trail

Damage by the blast wave

- Many windows broken
- ~ 1600 injured people

- Collapsed roof of a zinc plant

Dust trail in the atmosphere



Hole in ice, Chebarkul lake

- 70 km W of Chelyabinsk
- Diameter 8 m
- Impact observed by local fishermen and caught by a camera from distance

- Small meteorite fragments found in ice
- A 650 kg fragment recovered from the lake on October 16

Meteorites under the snow

- South of Chelyabinsk
- Thousands of mostly small meteorites, one big (1,8 kg)

- Totally > 100 kg
- Many other meteorites found in spring, including a 4 kg piece
- Ordinary chondrites, type LL5

Available data

- Videos (~700), including audio tracks
- Seismic records
- Infrasonic records from around the world (CTBTO's International Monitoring System)
- Satellite observations
  - US Government sensors
  - Meteorological satellites
- Recovered meteorites
- Damage on ground

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LETTER

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The trajectory, structure and origin of the Chelyabinsk asteroidal impactor

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LETTER

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A 500-kiloton airburst over Chelyabinsk and an enhanced hazard from small impactors

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Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization

Olga P. Popova,[1] Peter Jenniskens,[2,3]* Vacheslav Emel'yanenko,[4] Anna Kartashova,[4] Eugeny Biryukov,[5] Sergey Khaibrakhmanov,[6] Valery Shuvalov,[1] Yurij Rybnov,[1] Alexandr Dudorov,[6] Victor I. Grokhovsky,[7] Dmitry D. Badyukov,[8] Qing-Zhu Yin,[9] Peter S. Gural,[2] Jim Albers,[2] Mikael Granvik,[10] Läslo G. Evers,[11,12] Jacob Kuiper,[11] Vladimir Kharlamov,[1] Andrey Solovyov,[13] Yuri S. Rusakov,[14] Stanislav Korotkiy,[15] Ilya Serdyuk,[16] Alexander V. Korochantsev,[8] Michail Yu. Larionov,[7] Dmitry Glazachev,[1] Alexander E. Mayer,[6] Galen Gisler,[17] Sergei V. Gladkovsky,[18] Josh Wimpenny,[9] Matthew E. Sanborn,[9] Akane Yamakawa,[9] Kenneth L. Verosub,[9] Douglas J. Rowland,[19] Sarah Roeske,[9] Nicholas W. Botto,[9] Jon M. Friedrich,[20,21] Michael E. Zolensky,[22] Loan Le,[23,22] Daniel Ross,[23,22] Karen Ziegler,[24] Tomoki Nakamura,[25] Insu Ahn,[25] Jong Ik Lee,[26] Qin Zhou,[27,28] Xian-Hua Li,[28] Qiu-Li Li,[28] Yu Liu,[28] Guo-Qiang Tang,[28] Takahiro Hiroi,[29] Derek Sears,[3] Ilya A. Weinstein,[7] Alexander S. Vokhmintsev,[7] Alexei V. Ishchenko,[7] Phillipe Schmitt-Kopplin,[30,31] Norbert Hertkorn,[30] Keisuke Nagao,[32] Makiko K. Haba,[32] Mutsumi Komatsu,[33] Takashi Mikouchi,[34] (the Chelyabinsk Airburst Consortium)

Science, Nov 29, 2013

Trajectory parameters

Length of luminous path: 272 km

Observed height span: 95.1 – 12.6 km

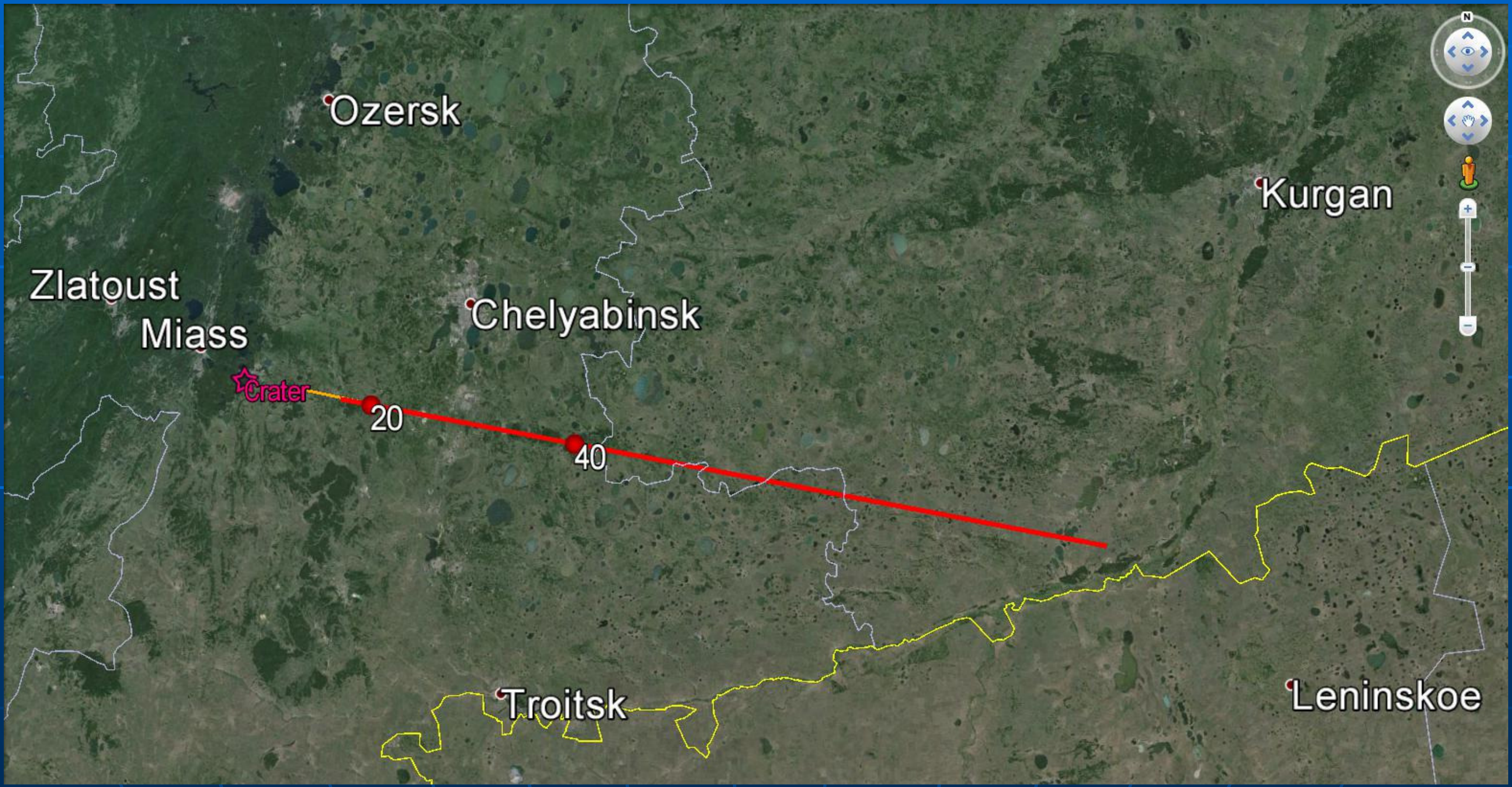
Slope: 18.5° at the beginning
17° at the end

Initial velocity: 19.03 ± 0.13 km/s

Terminal velocity: 3.2 km/s

Duration of the bolide: 16 seconds

Bolide trajectory



Energy and Size

- Energy from infrasonic, seismic, and US Government sensor data:

  500 (±100) kt TNT

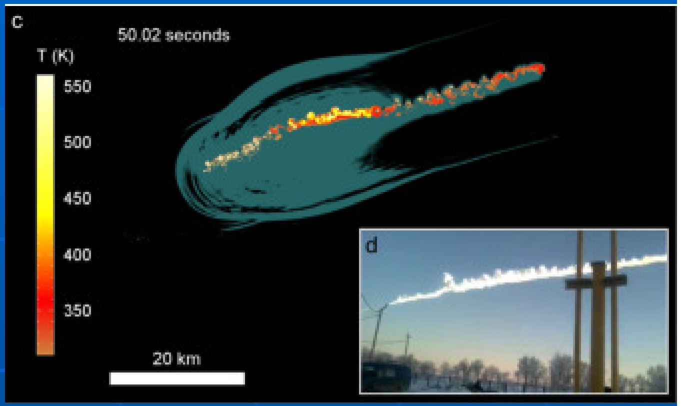
- Initial mass of the asteroid from known energy and speed:

  12,000 metric tons

- Initial size, using meteorite density (3300 kg/m^3):

  19 meters (17 – 20 m)

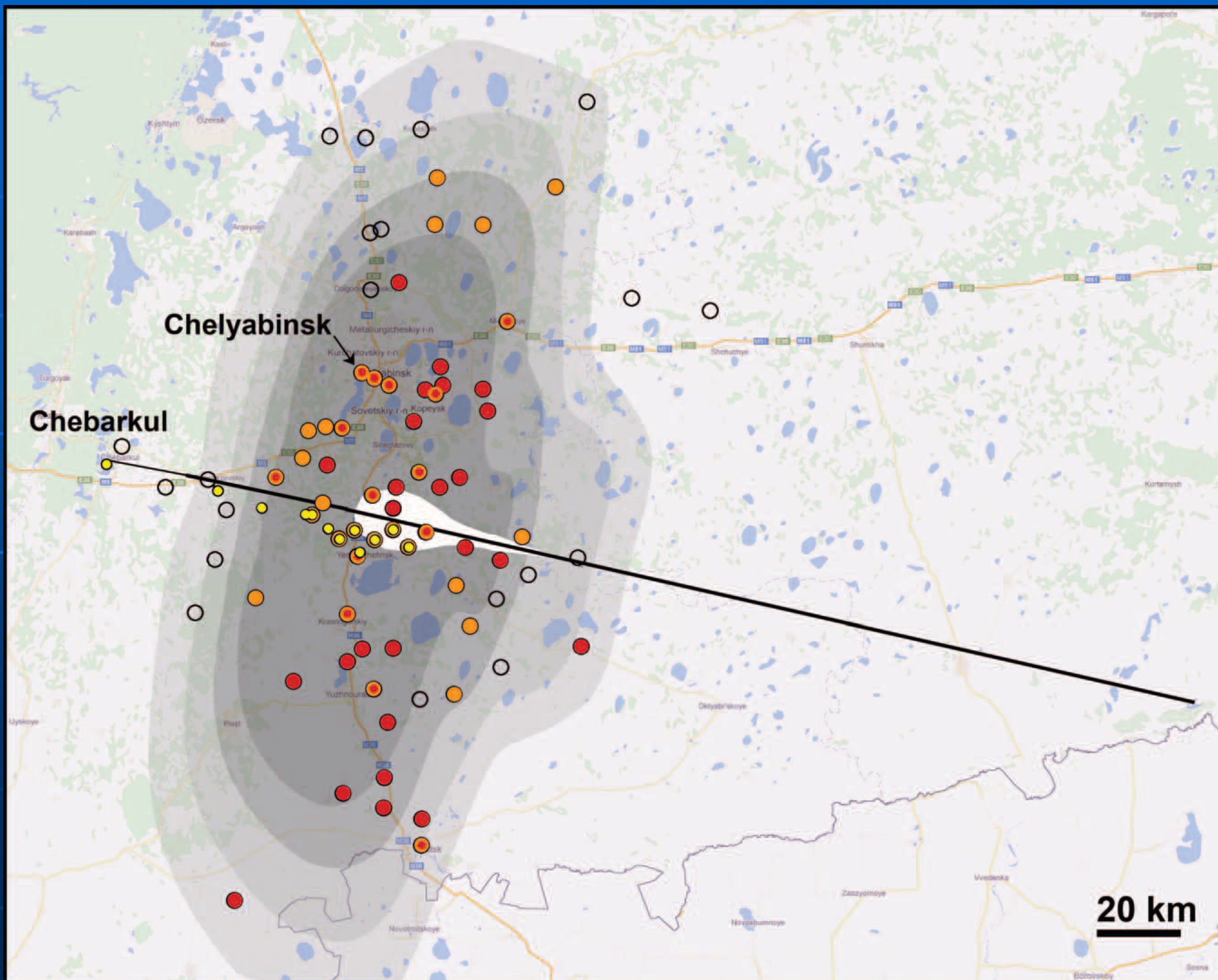
Shock wave – Cylindrical or Spherical?



- Shock wave causing damage was cylindrical not spherical
- Ray tracing establishes origin height – arrivals are from various heights, not single point
- Secondary, weaker shocks after main arrival are spherical from fragmentation

Brown et al.

Map of glass damage with models of overpressure

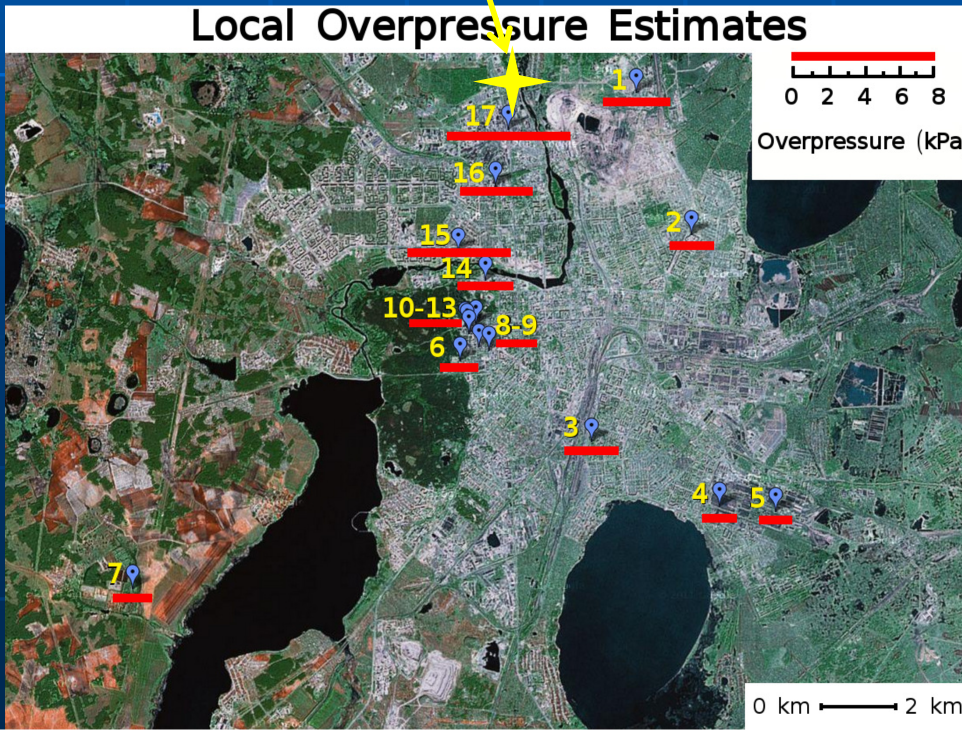


7, 230 buildings affected

Popova et al.

Airblast Damage in Chelyabinsk

- Of >5000 windows examined, ~10% broke due to initial shock
- 40% of buildings affected
- Window glass velocity 7 – 9 m/s
- Shock is a few percent atmospheric pressure
- Zinc factory roof collapse near focusing?



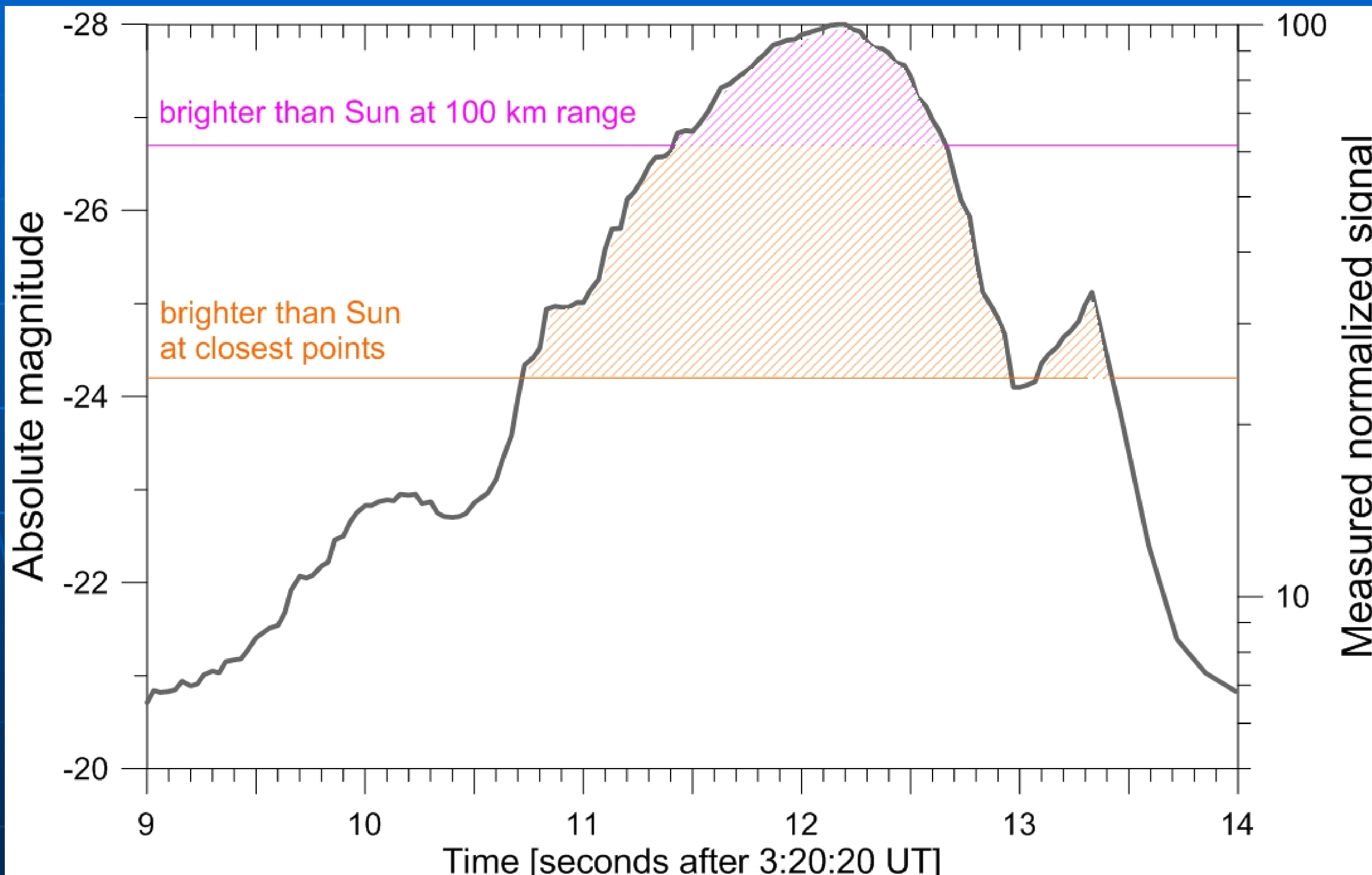
Brown et al.

Injuries

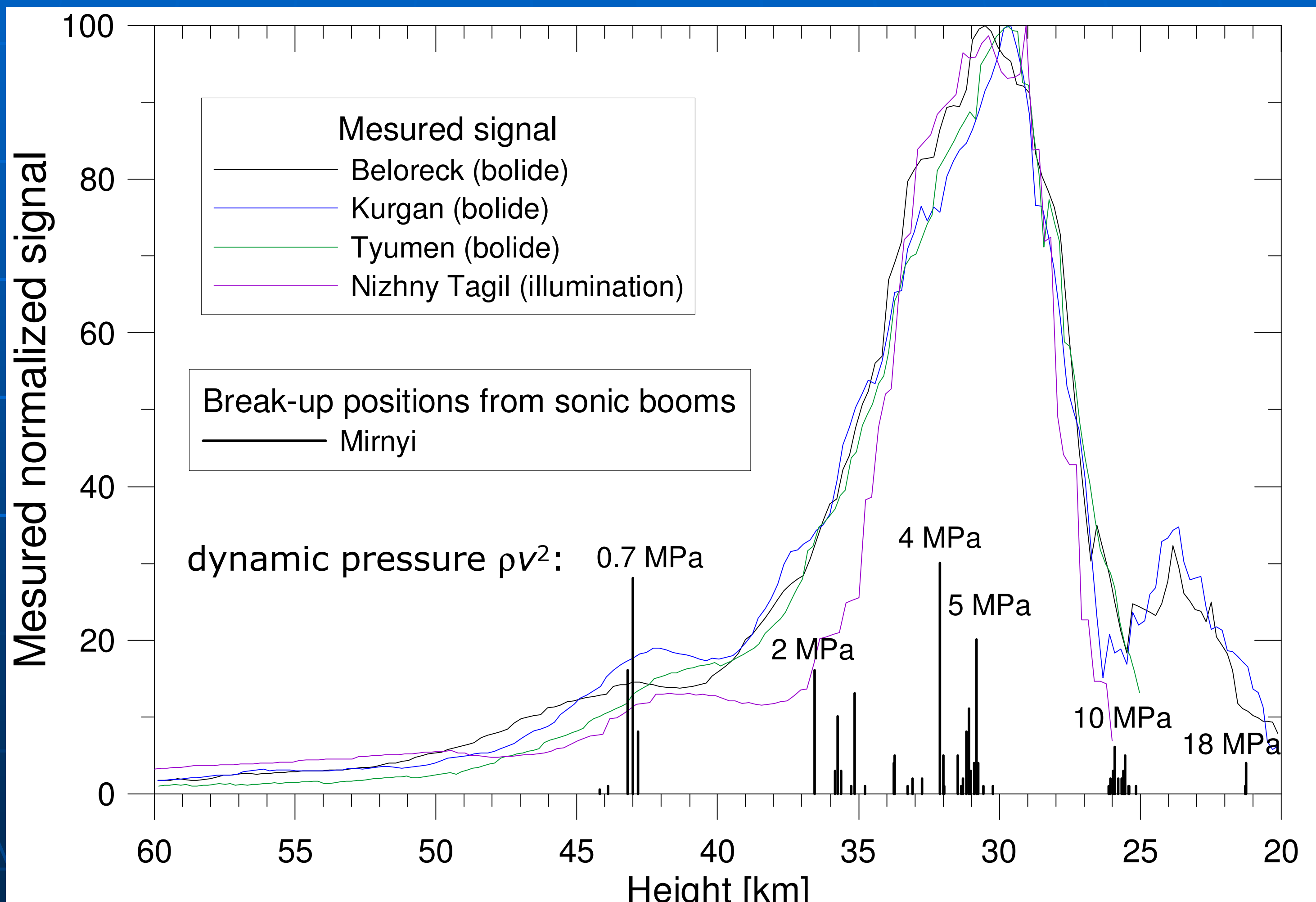
- 1,613 people asked for medical assistance at hospitals, 112 people were hospitalized, 2 in serious condition; no fatalities
- Injuries were from broken glass
- Other inconveniences reported: heat, sunburn, painful eyes, temporal deafness, stress
- No significant damage or injuries from falling meteorites

Popova et al.

Light curve (the brightest part)



Heights of fragmentations

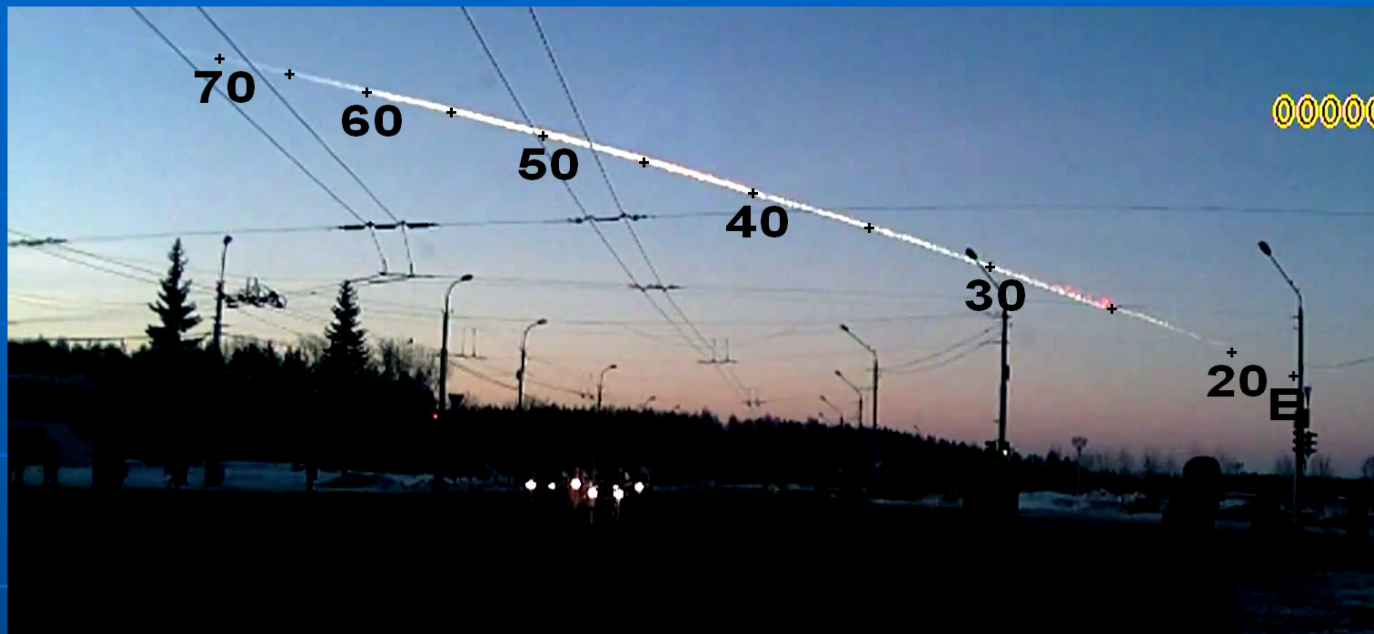


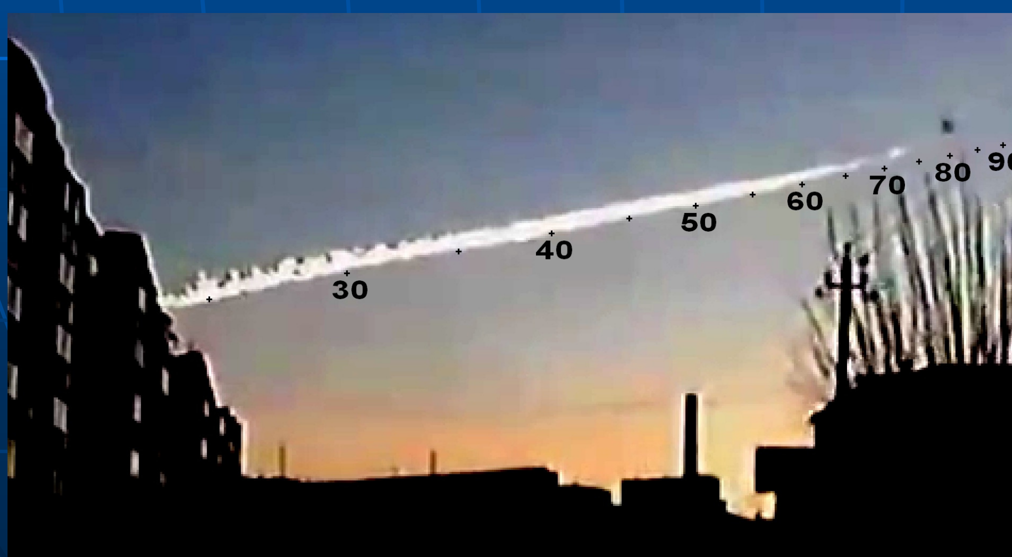
Fragmentation sequence

- First fragmentation at height ~ 45 km under P ~ 0.5 MPa (1% mass loss)
- Large scale disruption (95% mass loss) at 39 – 30 km under P = 1 – 5 MPa
- By 29 km object was 10 – 20 boulders of sizes 1–3 m
- These boulders break again at 26–22 km under P ~ 10–18 MPa

Normal tensile strength of meteorites is ~ 50 MPa
Fractures in the body decreased the bulk strength

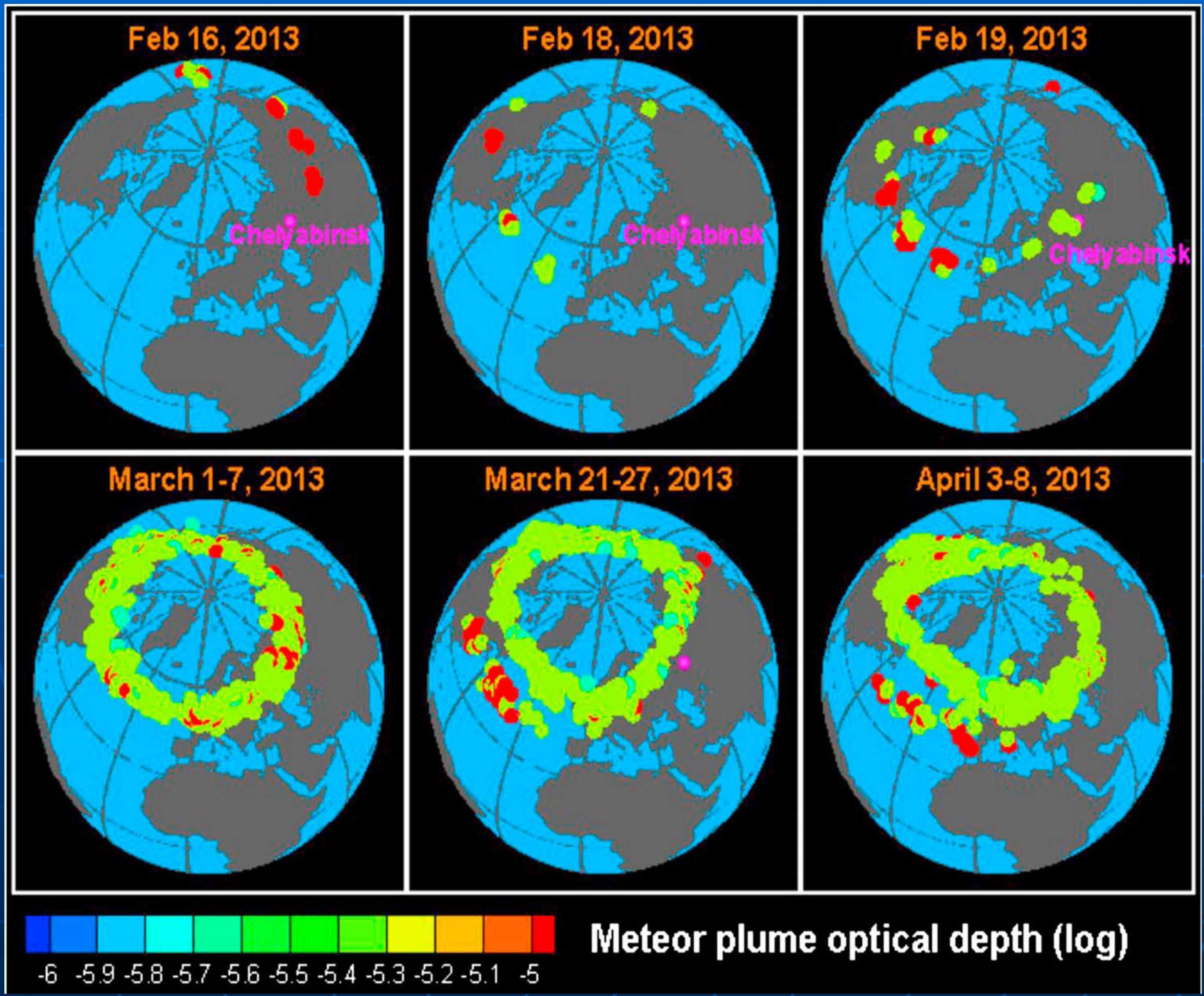
Initial extent of the dust trail





- starting at height ~70 km
- diameter 2–3 km between heights 60–25 km
- volume ~600 km^3

Within days, the dust circled the globe



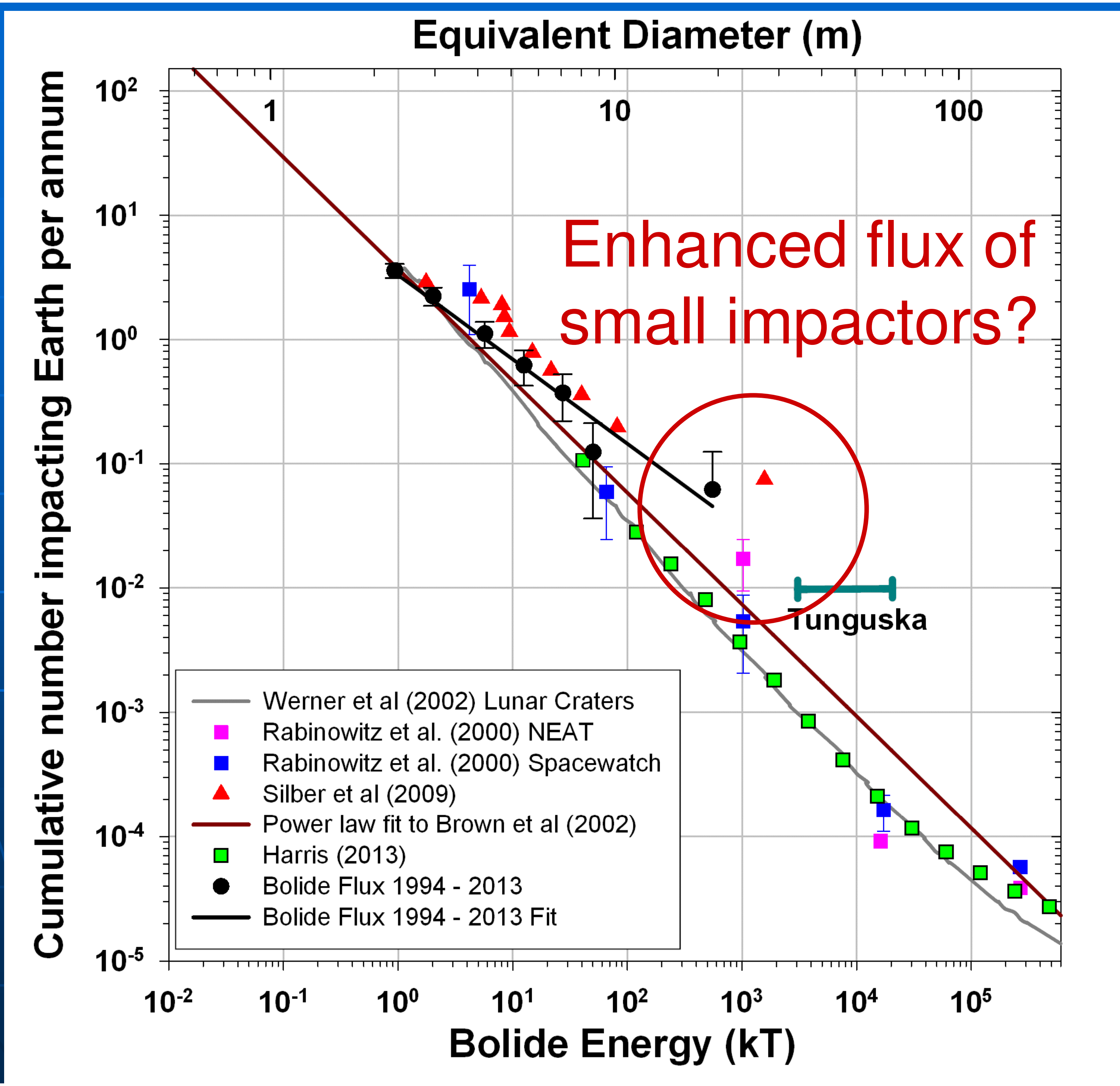
Gorkavyi et al. (2013)

Past impactors

Event	Energy (kt TNT*)
Tunguzka (1908)	10 000
Indian Ocean (1963) - unconfirmed	(1 500)
Chelyabinsk (2013)	500
Brazil (1930) - unconfirmed	(100?)
Indonesia (2009)	50
Marshall Islands (1994)	20
Sikhote Alin (1947)	10

Largest nuclear explosion (USSR 1961)	50 000
Hiroshima bomb (1945)	15

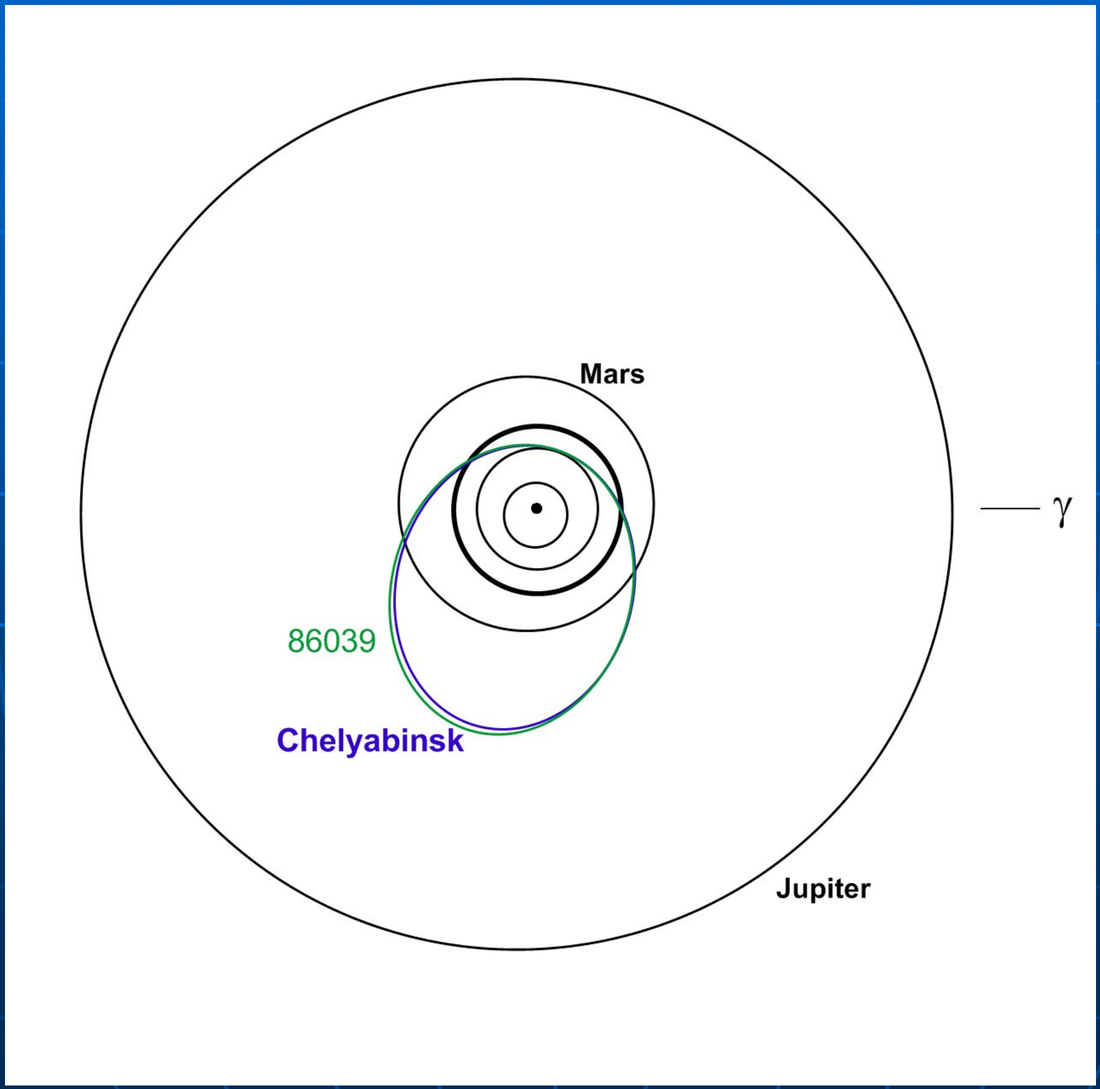
*1 kt TNT = $4{,}185 \times 10^{12}$ J



Equivalent Diameter (m)
1
10
100
Cumulative number impacting Earth per annum
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Enhanced flux of small impactors?
Tunguska
Werner et al (2002) Lunar Craters
Rabinowitz et al. (2000) NEAT
Rabinowitz et al. (2000) Spacewatch
Silber et al (2009)
Power law fit to Brown et al (2002)
Harris (2013)
Bolide Flux 1994 - 2013
Bolide Flux 1994 - 2013 Fit
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5
Bolide Energy (kT)

Brown et al.

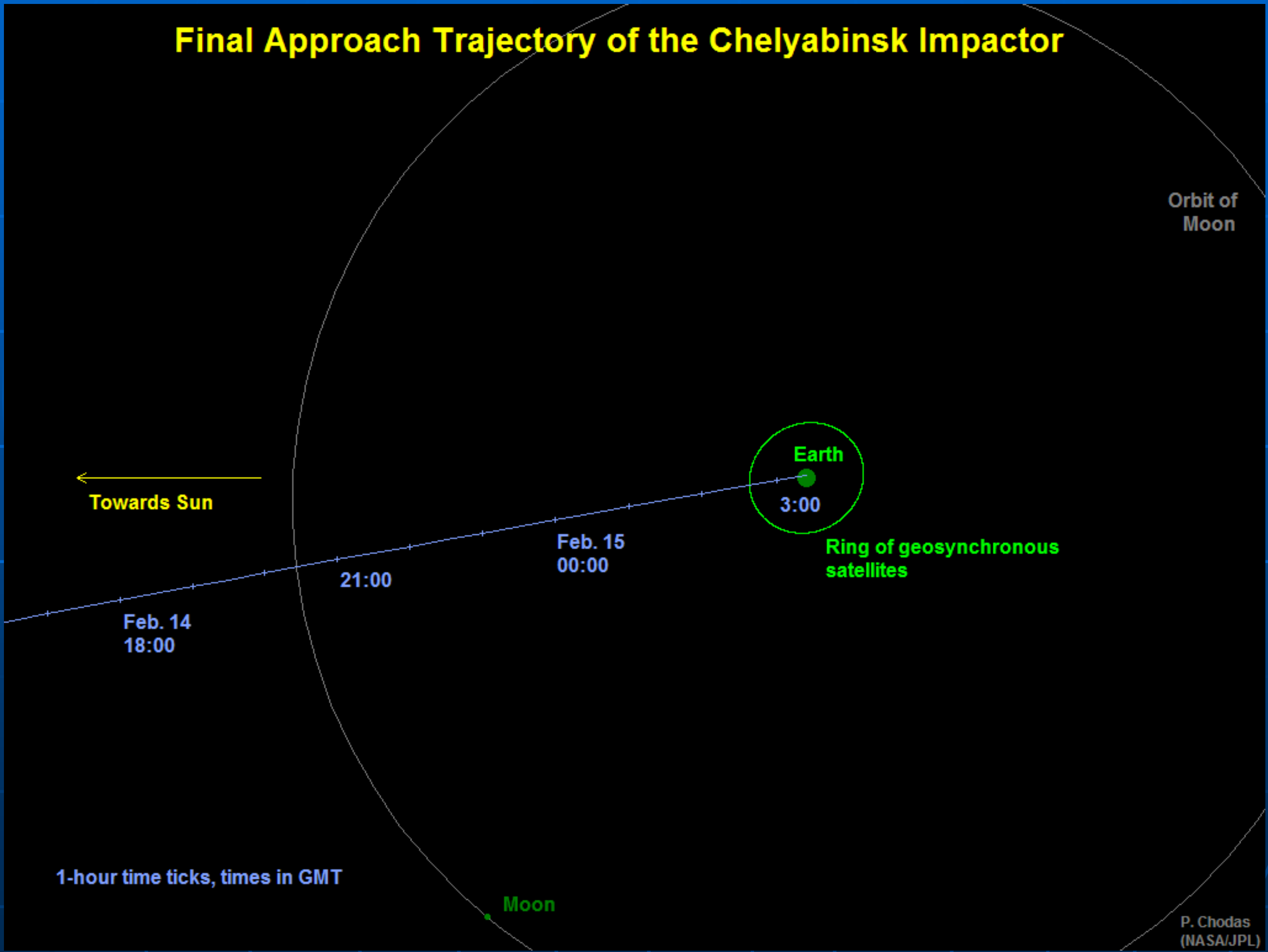
Orbits of Chelyabinsk and a 2-km asteroid 86039 (1999 NC43)



Hypothesis

- Recent ($<10^5$ yr) collision of 86039 with another asteroid created Chelyabinsk
- Such collision(s) may be the reason of more 10-50 m impactors existing than corresponds to the equilibrium

Why not discovered before impact?



Approached from the direction of Sun

Even in the opposite case, the chance of discovery would be slight with current telescopes

P. Chodas, NASA/JPL

Summary

- Chelyabinsk – the first asteroid disaster in (modern) history
- Damage was from the blast wave. If the body were stronger and penetrated deeper intact, the blast wave would be more damaging
- Chelyabinsk demonstrated that 20-m asteroids <u>are</u> dangerous
- Another potential risk – misidentification with military attack
- Asteroids of such size maybe more numerous than previously thought

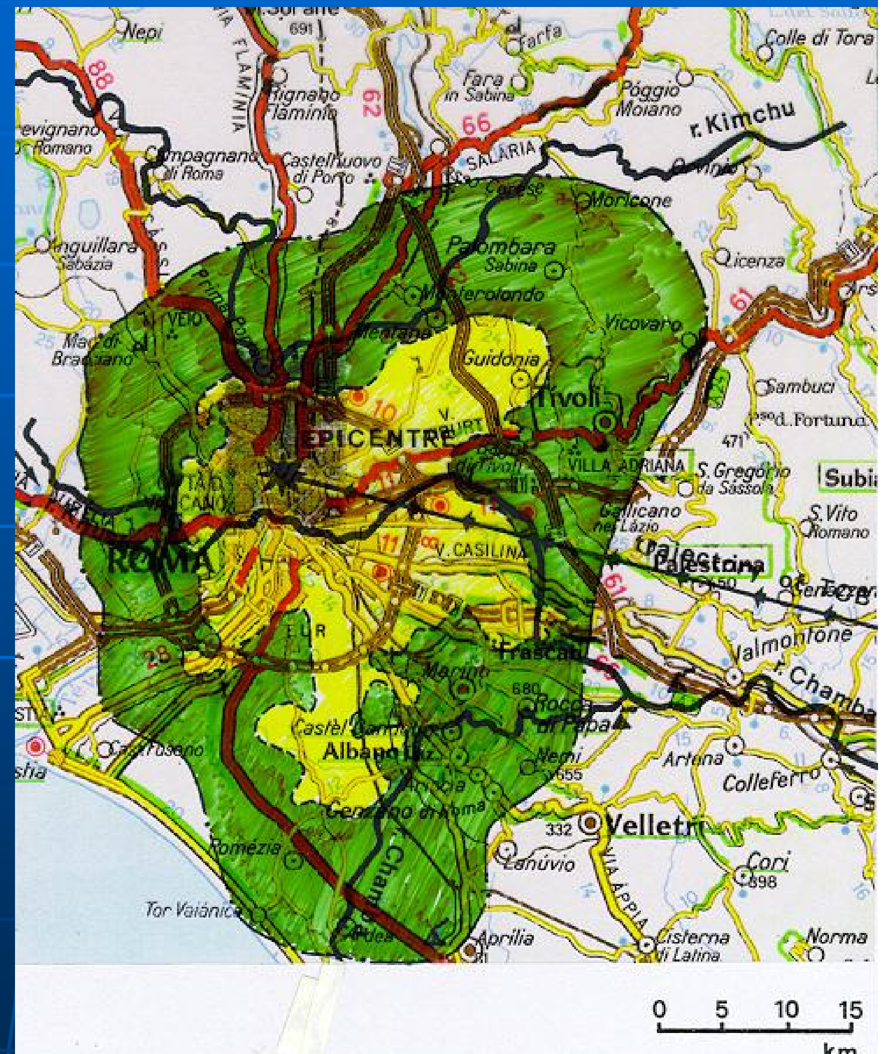
Mitigation of the risk of small asteroids

- Discover asteroid days to weeks before impact
- Compute the impact point. If it is in inhabited area, warn and evacuate people
- ATLAS initiative (Asteroid Terrestrial-Impact Last Alert System) of Univ. of Hawaii – small telescopes, cheap
- But only ~ 60% of sky is accessible from the ground – go to space

Tunguzka (Jun 30, 1908)

Kulik expedition, 1928

Region damaged by the blast wave: 60 x 40 km



comparison with Rome

Sikhote Alin (Feb 12, 1947)

~23 tons of iron meteorites
the largest piece 1700 kg
the larges crater ∅ 27 m

Carancas Crater (Peru)

15 Sep 2007

∅ 14 m

depth 3 m

ordinary chondrite

original meteoroid size 0.9 – 1.7 m only