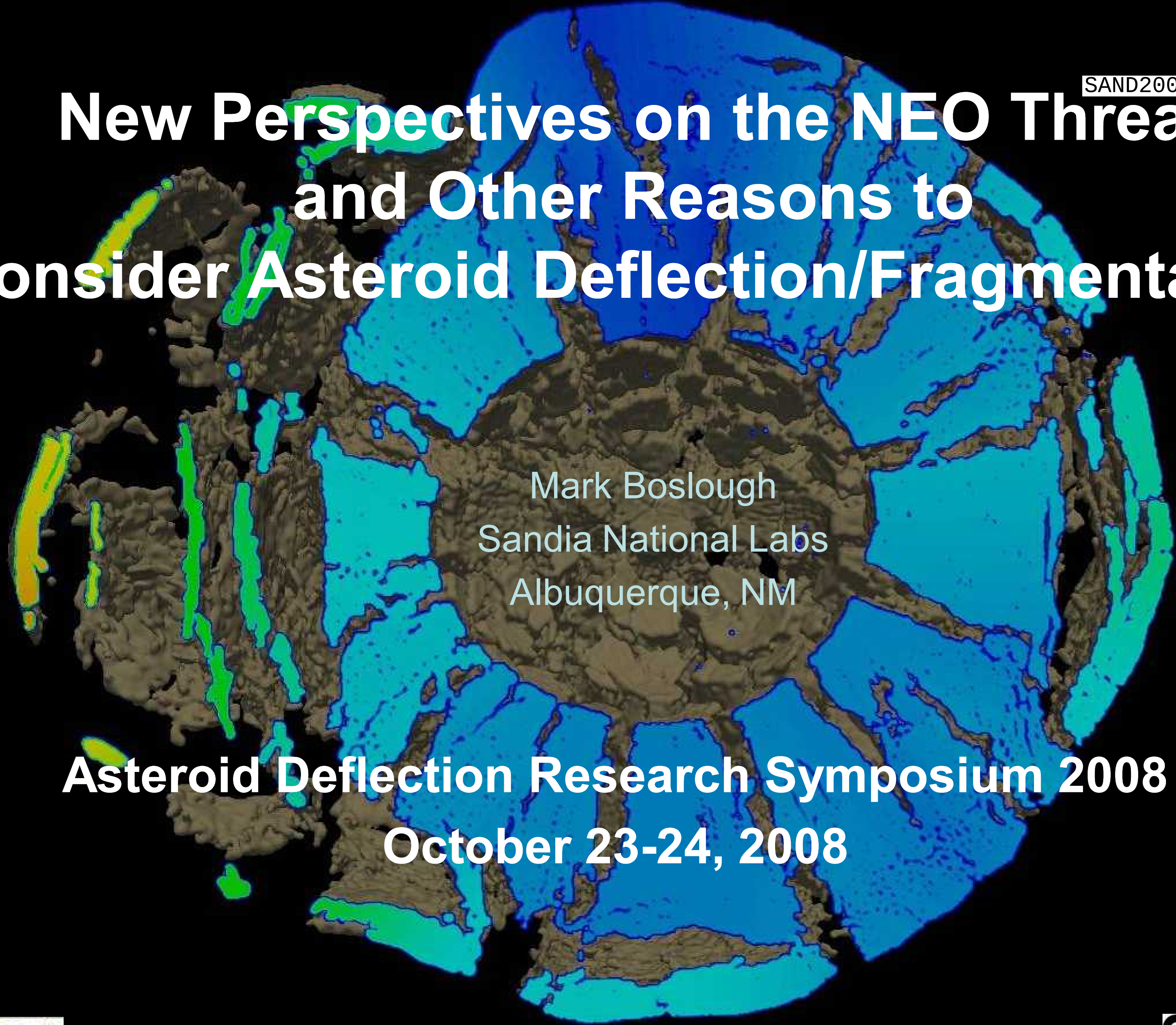
SAND2008-7238C



New Perspectives on the NEO Threat and Other Reasons to Consider Asteroid Deflection/Fragmentation

Mark Boslough

Sandia National Labs

Albuquerque, NM

Asteroid Deflection Research Symposium 2008

October 23-24, 2008

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Red Storm simulation

New perspectives on the impact threat

1. Some nuclear deflection strategies are better:
   Multiple low-yield shallow bursts are best.
2. Low-altitude airbursts dominate residual threat:
   Mitigation should be for ~hundred m asteroids.
3. Recent controversies in impact science:
   Credibility of community requires solid research.
4. Total asteroid threat is diminishing:
   Mitigation not justified for NEO protection alone.
5. Better reasons to consider asteroid deflection:
   Geo-engineering and space resources.

1. Nuclear deflection

- Best way to couple energy and momentum is buried nuclear burst (direct consequence of scaling laws)
- For a given total yield, multiple bursts are better than single burst (direct consequence of scaling laws)
- Non-weaponizable impact-triggered fission device is possible in principle
- Impact-triggered fusion device would make multiple low-yield shallow bursts feasible

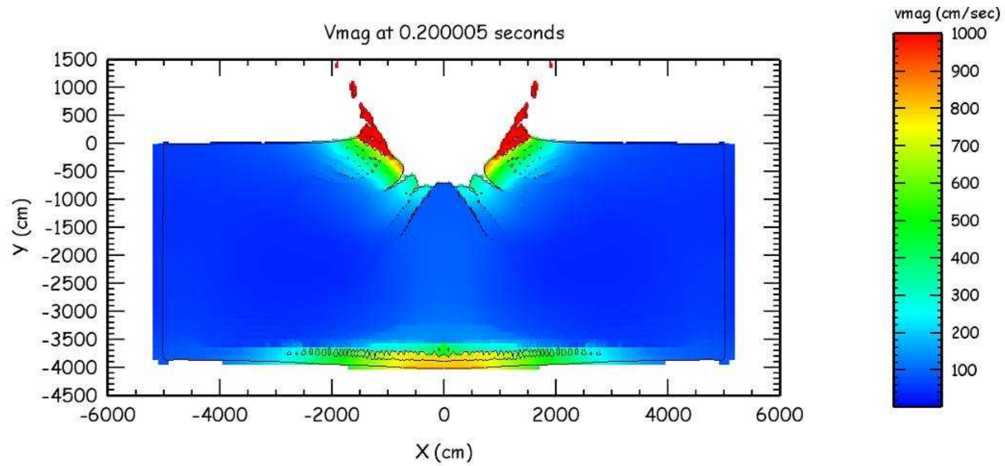
Numerical simulations of momentum coupling

- Three prongs of analysis: <u>Numerical simulations</u>, analytic models, scaled experiments.
- 2D parameter studies, sensitivity analysis, and intuition (require workstation computing).
- 3D models quantify effects of heterogeneities, strength, fracture, and spallation that are not amenable to either scaled experiments or analytical models (require capability computing).

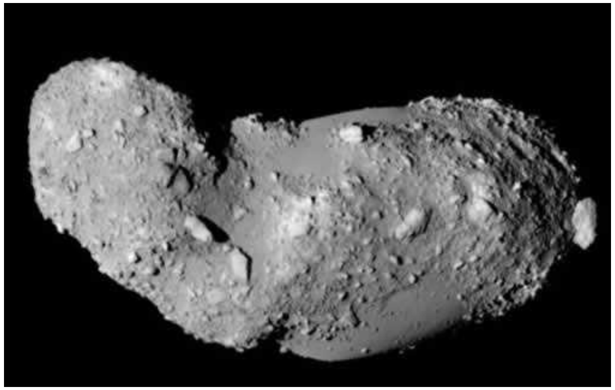
<u>2D workstation-class problem</u>

Example:

1 kiloton surface burst in an intermediate-strength 100-meter diameter dunite disk ($m=10^9$ kg) couples $3x10^8$ kg·m/s, but spalls material off the back surface.



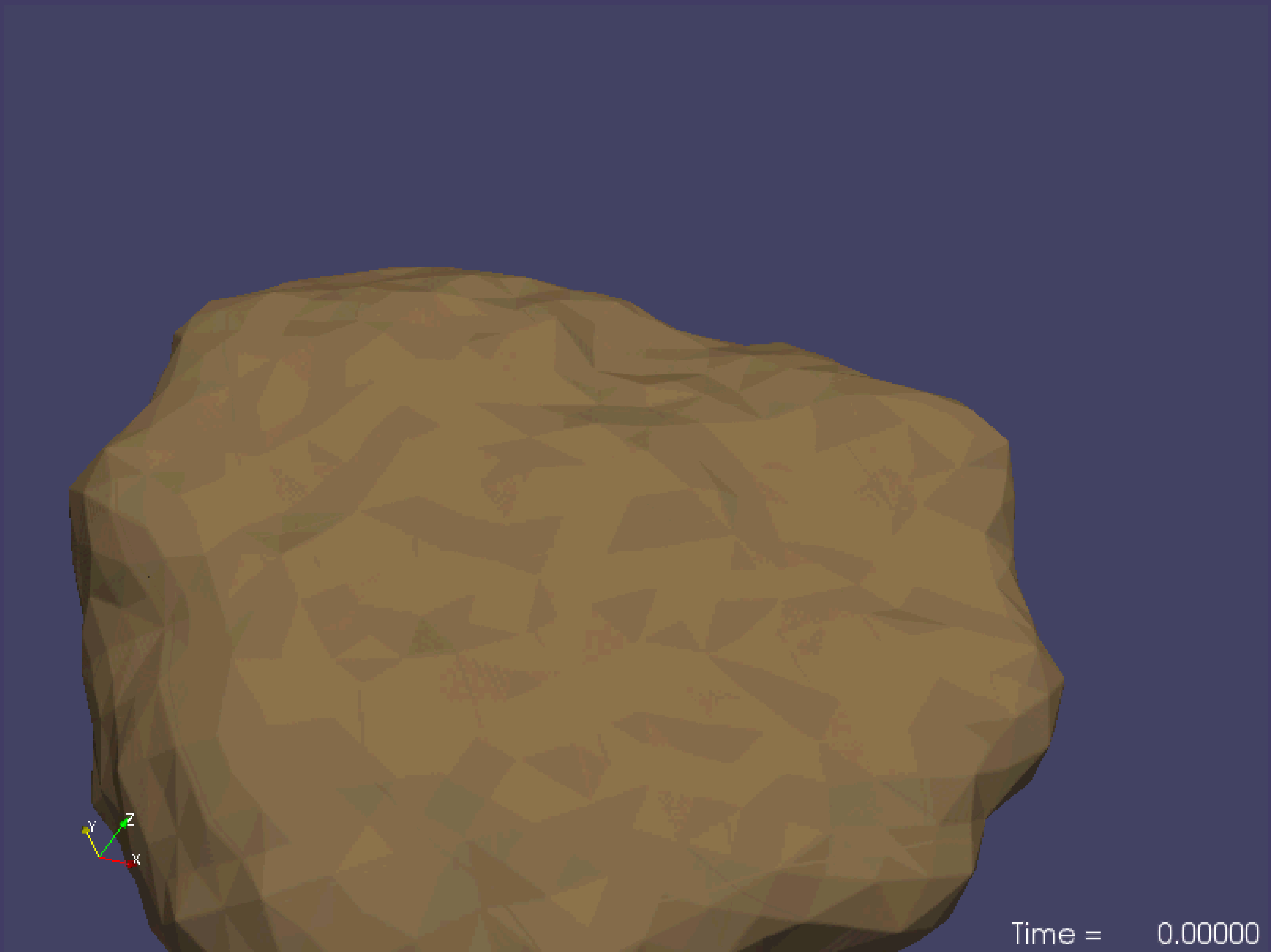
<u>3D capability-class problem</u>



Example:

For known 3D geometry, internal structure of Itokawa must be assumed. Over what range of parameters can momentum be coupled to Itokawa without breaking it?

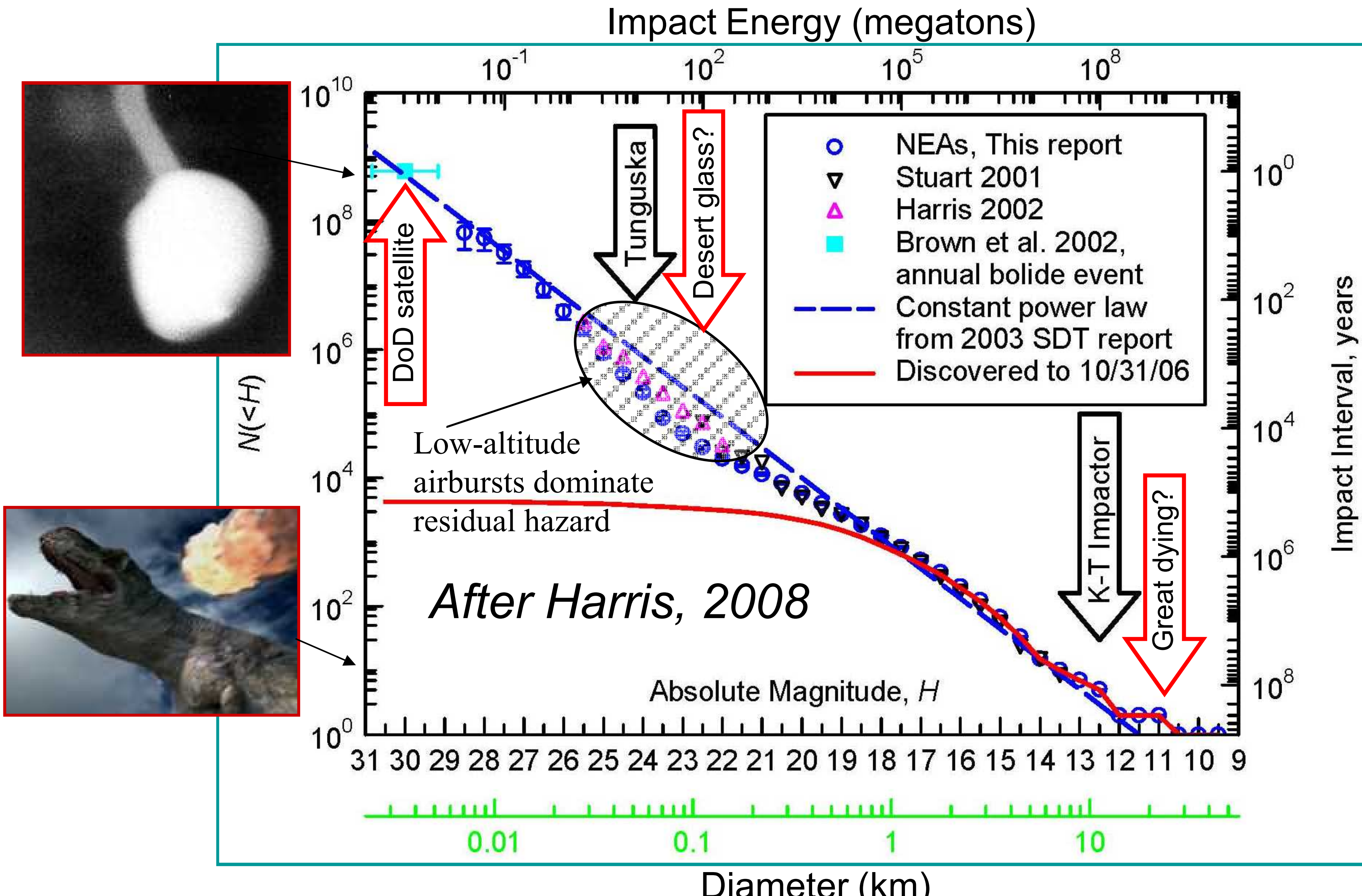
Golevka deflection: 100 kt explosion, 5 m deep
1 billion computational cells, Red Storm



2. Low-altitude airbursts

- The relative threat from low-altitude airbursts (LAAs) is increasing
- Our understanding of LAAs is improving
- The next destructive NEO will almost certainly be a LAA
- “100/100/100 event”: (~100 m, ~100 Mt, ~1/100 chance this century)
- 100/100/100 event will dominate threat after survey is complete
- Time for technology development is similar to threat reduction time
- There are other reasons to deflect/fragment small asteroids
- Technology should be focused small (~few hundred meter) asteroids

The nature of the impact threat is changing

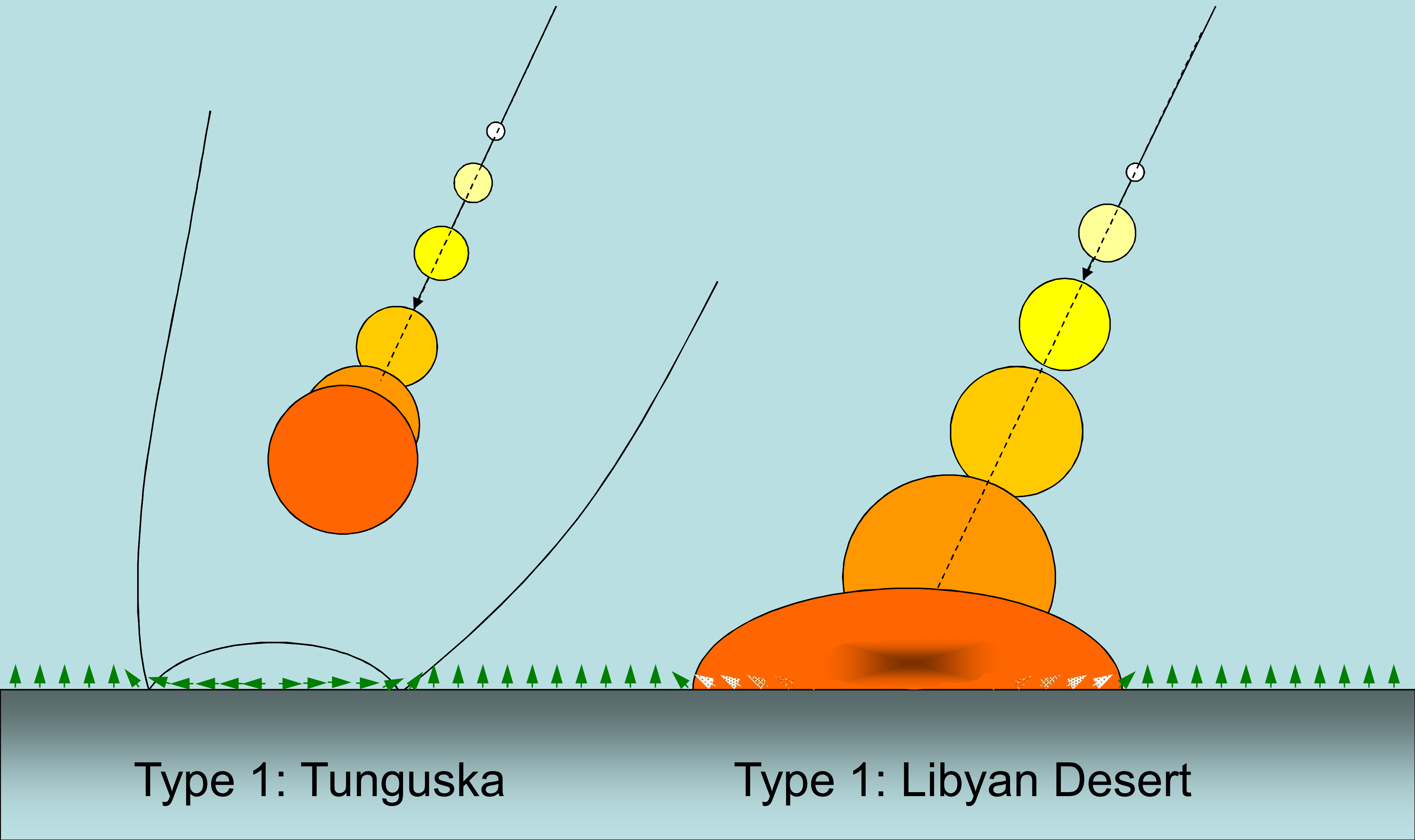


There are two types of Low-Altitude Airburst

1. The explosion generates a fireball that descends rapidly but does not reach the ground. Most of the damage at ground level is mechanical, due to the blast wave. This occurs for explosions between about 1 and 10 Mt, and may occur on time scales of several hundred years. The only known example is 1908 Tunguska event.

2. The fireball is much larger and descends all the way to the surface. The damage is dominated by high-temperature thermal radiation. The threshold yield is about 10 Mt, depending on other parameters, and they recur on time scales of several thousand years. The best putative example is the Libyan Desert Glass event, 29 million years ago.

There are two types of Low-Altitude Airburst



Type 1 airburst simulation: 5 megaton

Type 2 airburst simulation: 15 megaton

Type 1 LAA: “Tunguska-Type”

Type 1 LAA: “Tunguska-Type”

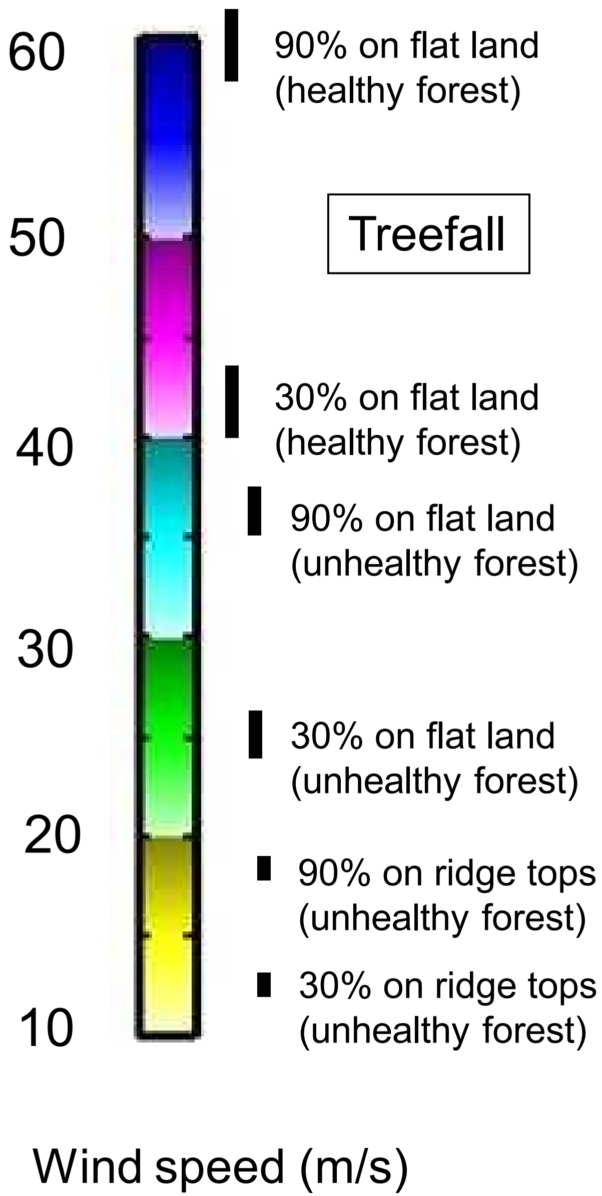
Florenskiy: 1961 Expedition

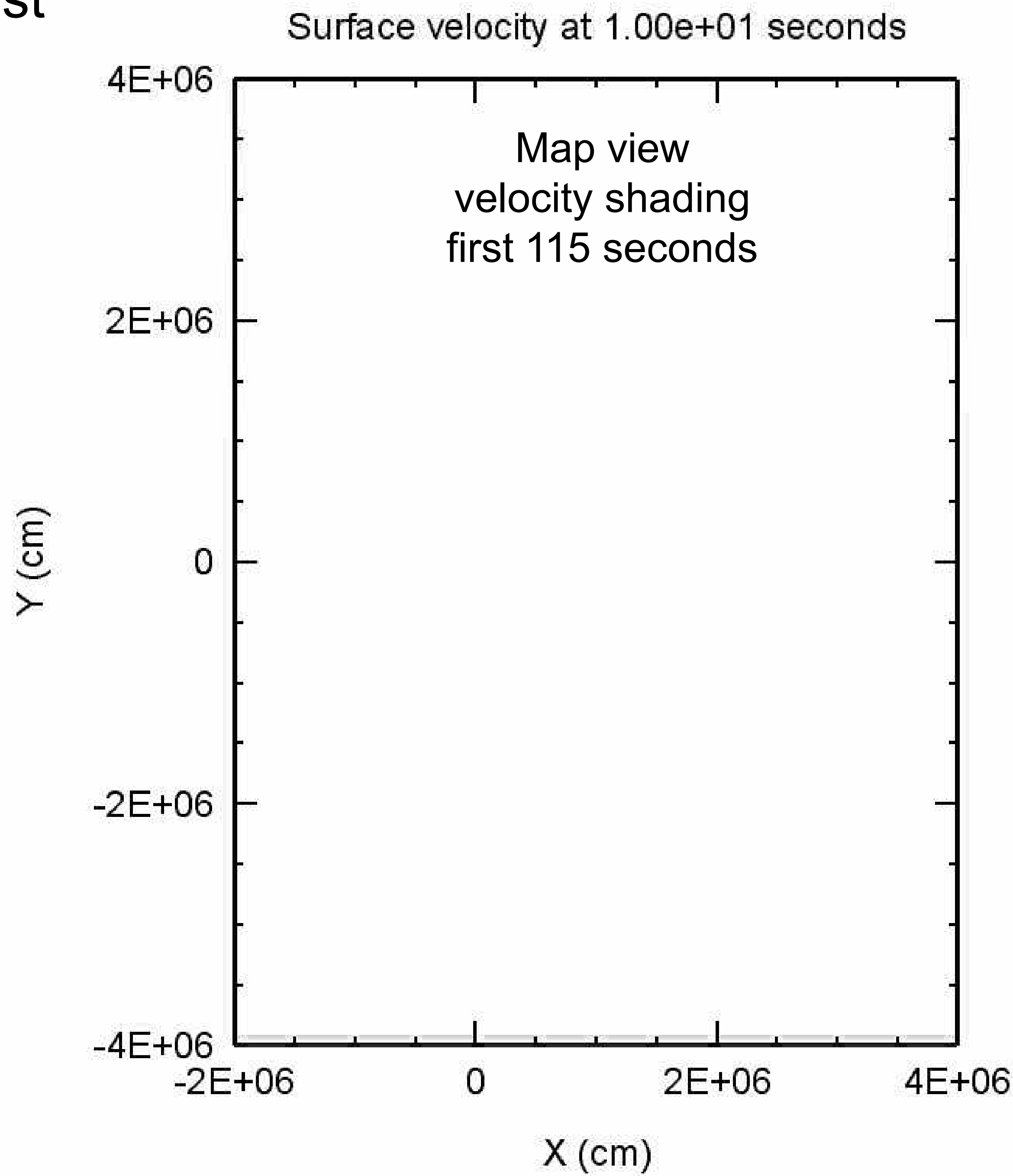
Consequences of Type 1 airburst

Krinov, 1963

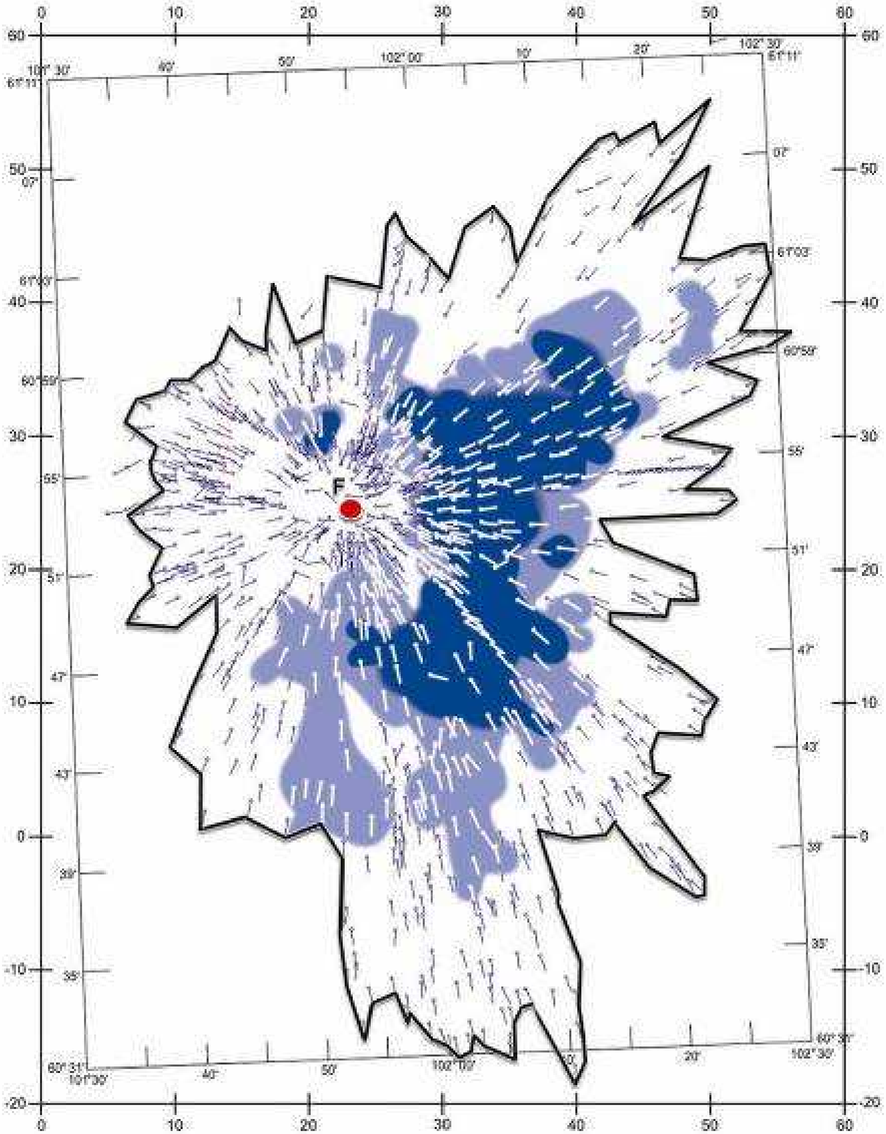
Fig. 485 — THE SIBERIAN FOREST DEVASTATED BY THE BLAST FROM THE METEORITE OF 30 JUNE 1908.

Modeling Type 1 airburst

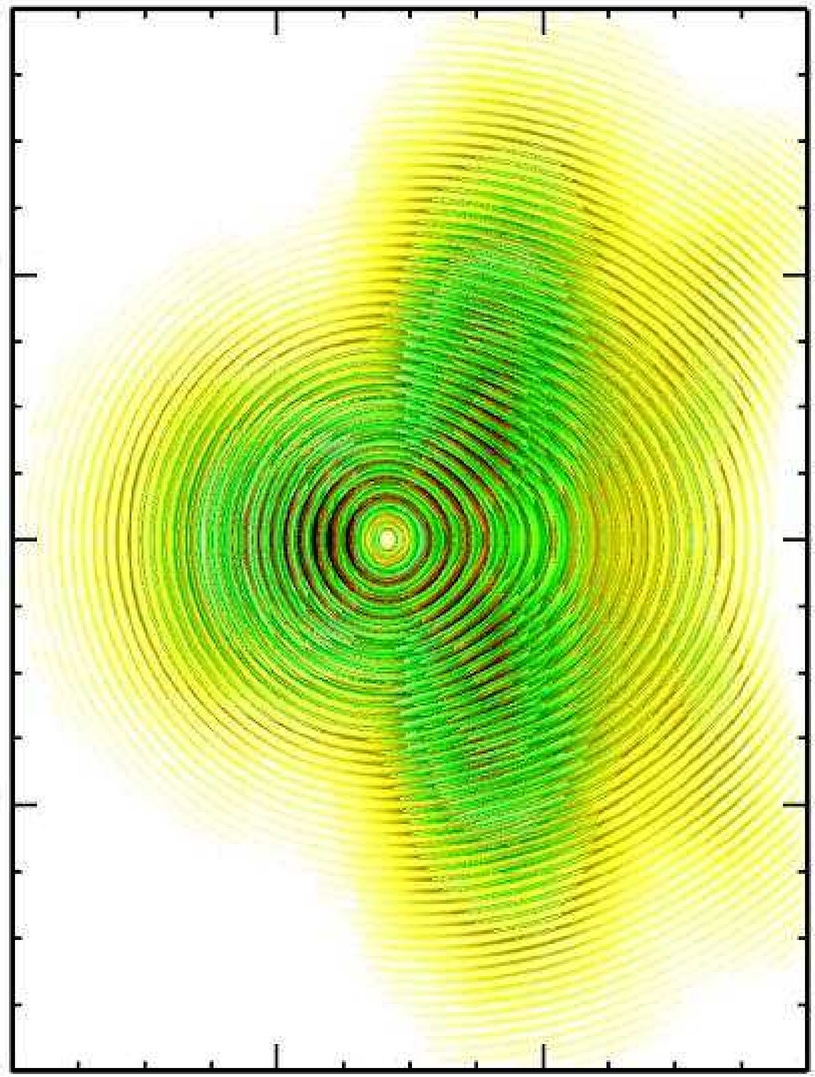




5 Mt explosion at 12 km above surface, 35° entry angle



Tunguska treefall map (Longo et al, 2005)

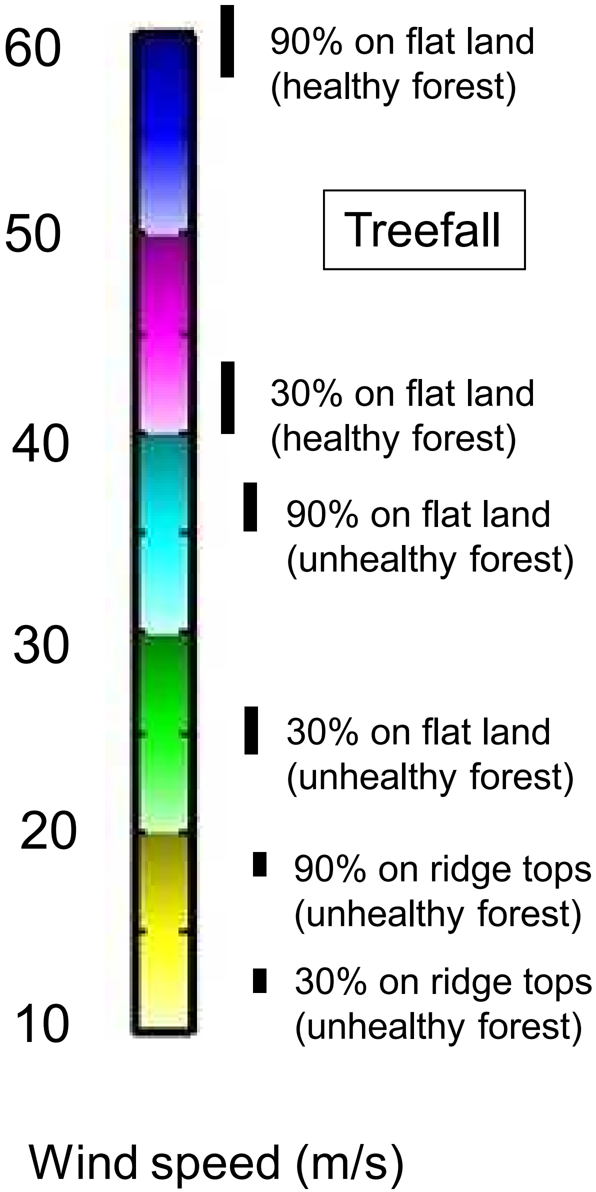


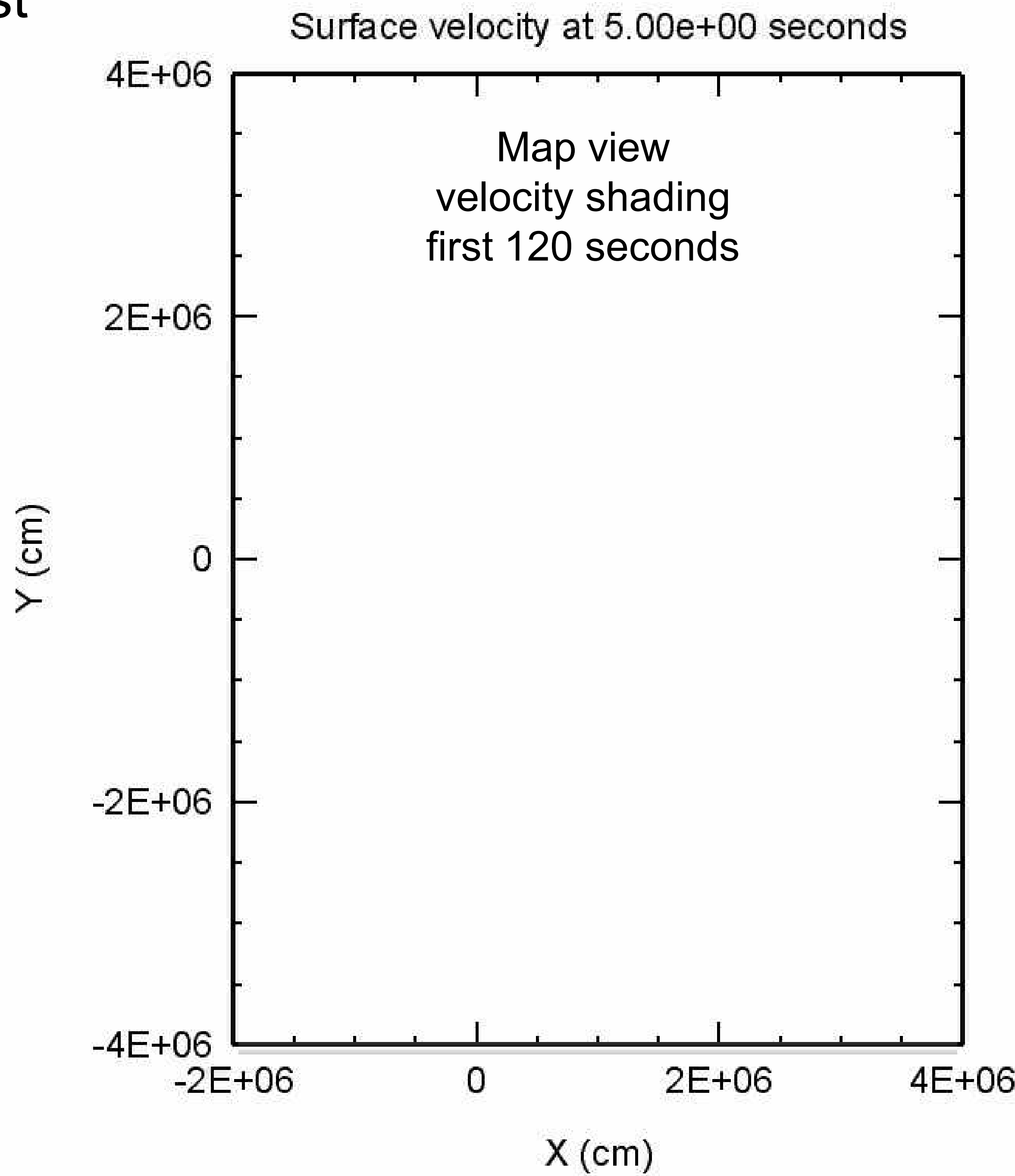
Wind speed map (this study)

Type 2 LAA: “Libyan-Desert-Type”

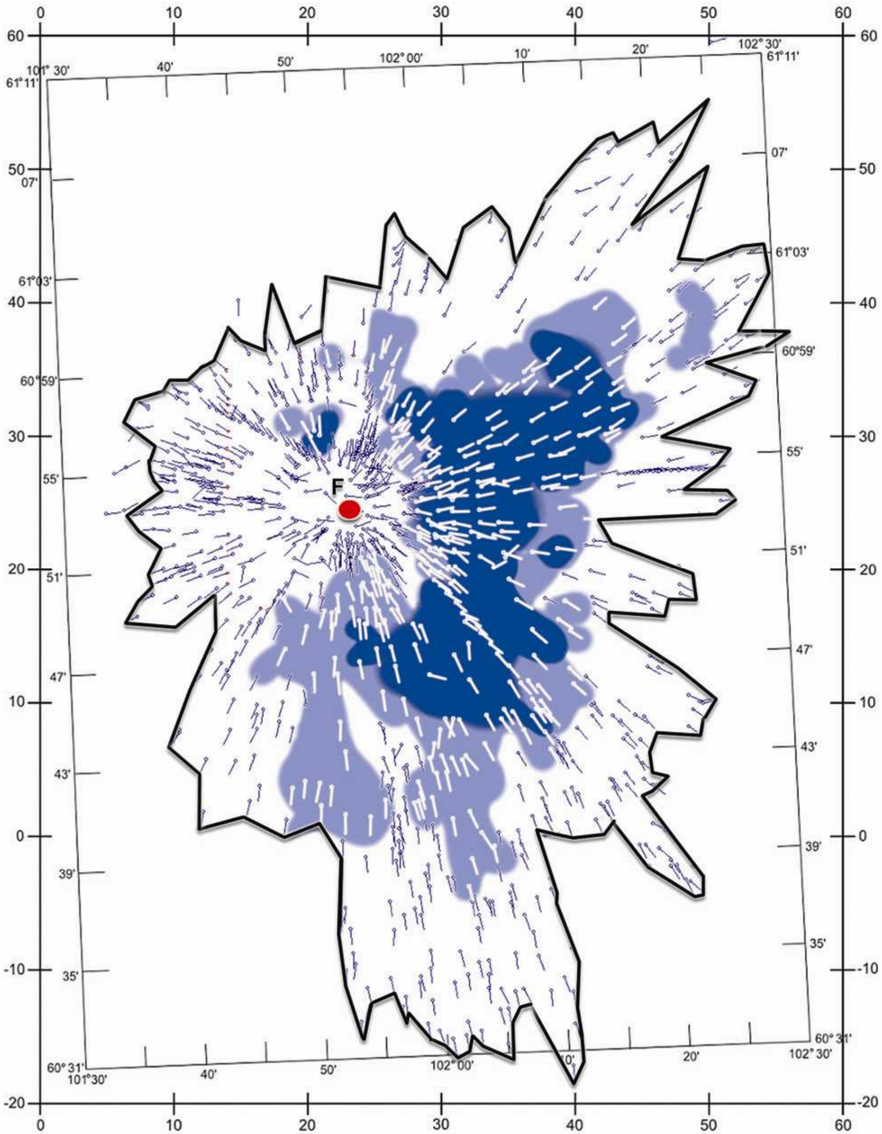
Consequences of Type 2 airburst

Modeling Type 2 airburst

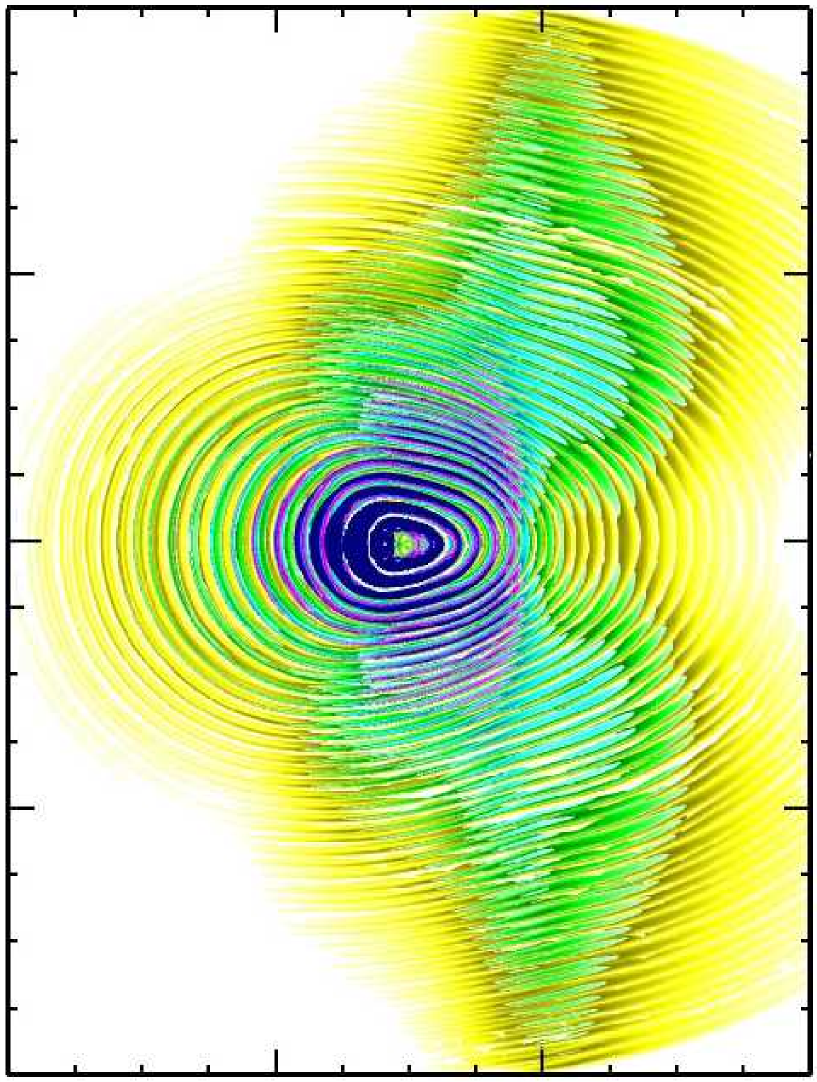




15 Mt explosion at 18 km above surface, 35° entry angle

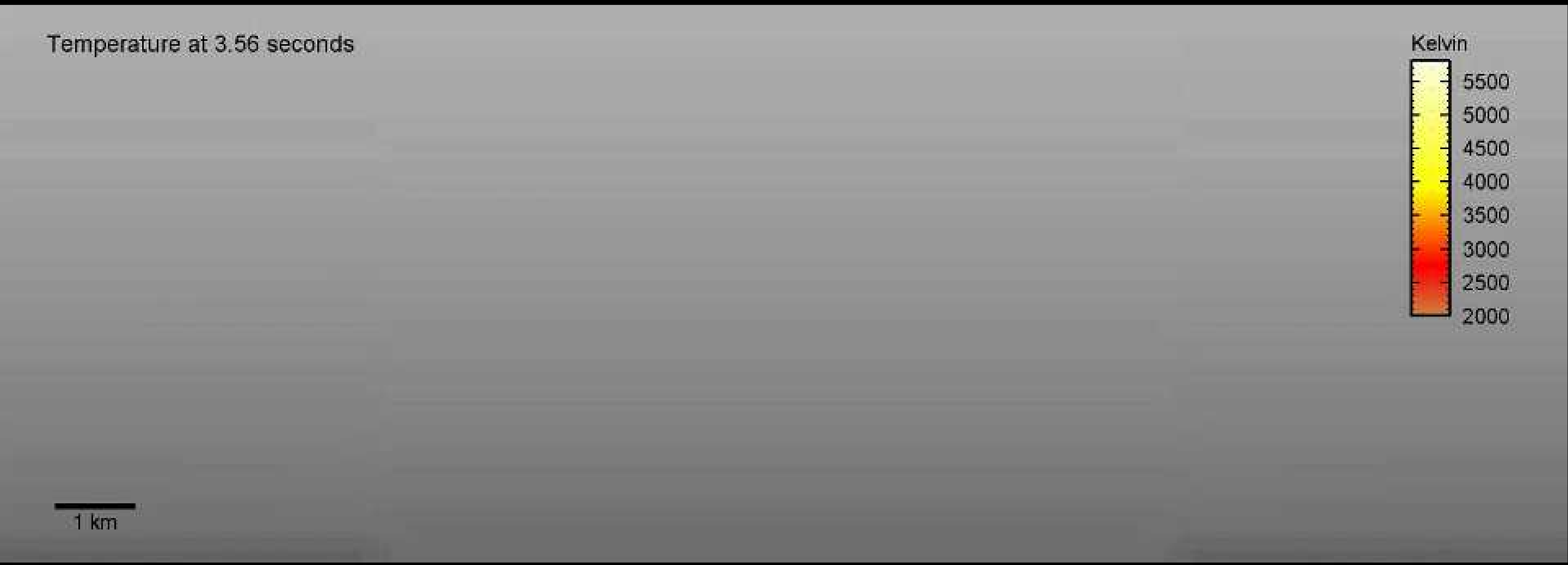


Tunguska treefall map (Longo et al, 2005)



Wind speed map (this study)

100 Mt explosion, 90° entry angle



Temperature shading

100 Mt explosion, 90° entry angle

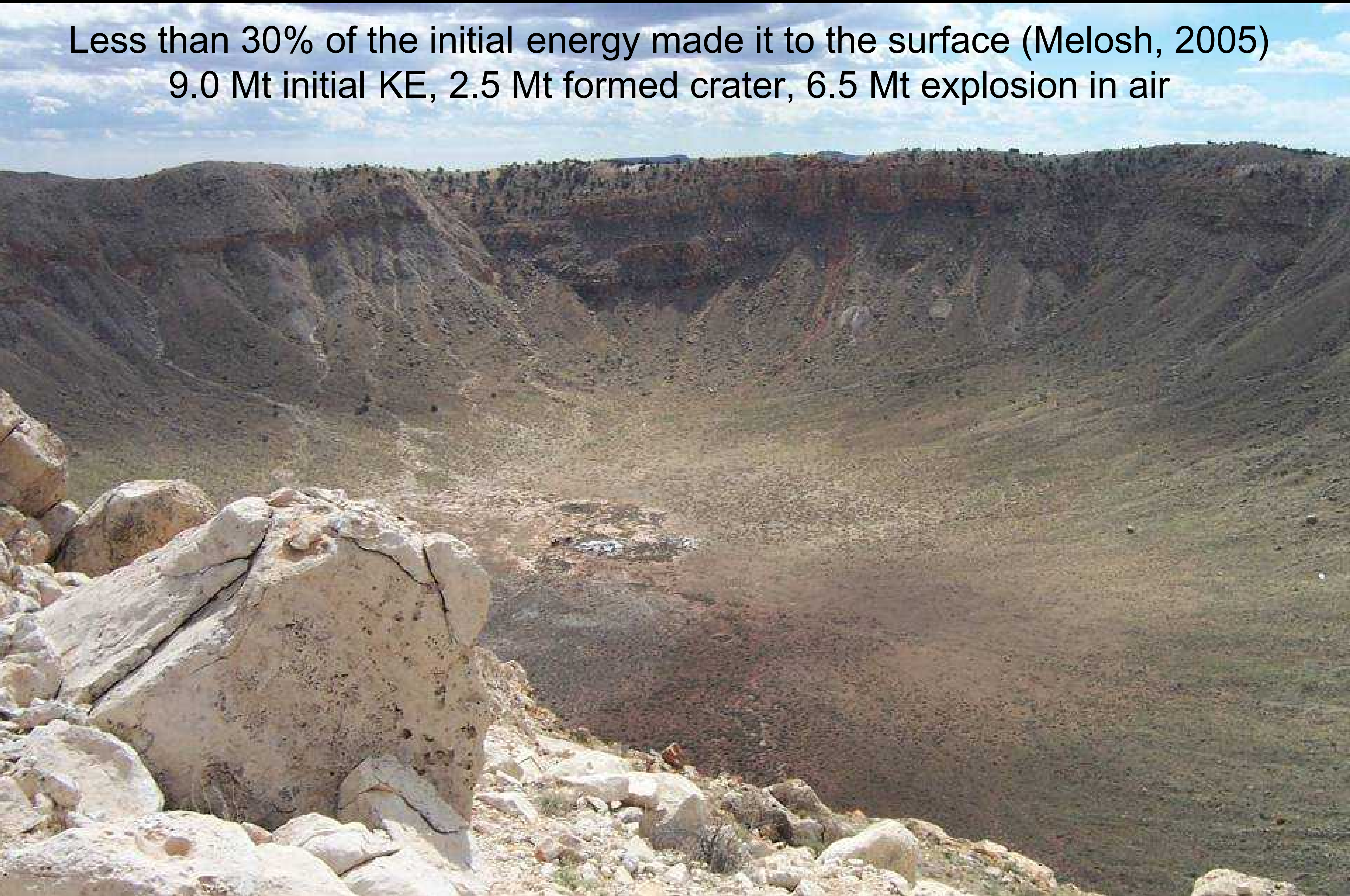
Wind speed shading

Animated version for National Geographic documentary “Ancient Asteroid”

Tutankhamun’s Fireball (Ancient Asteroid)

Meteor Crater impact was a low-altitude airburst

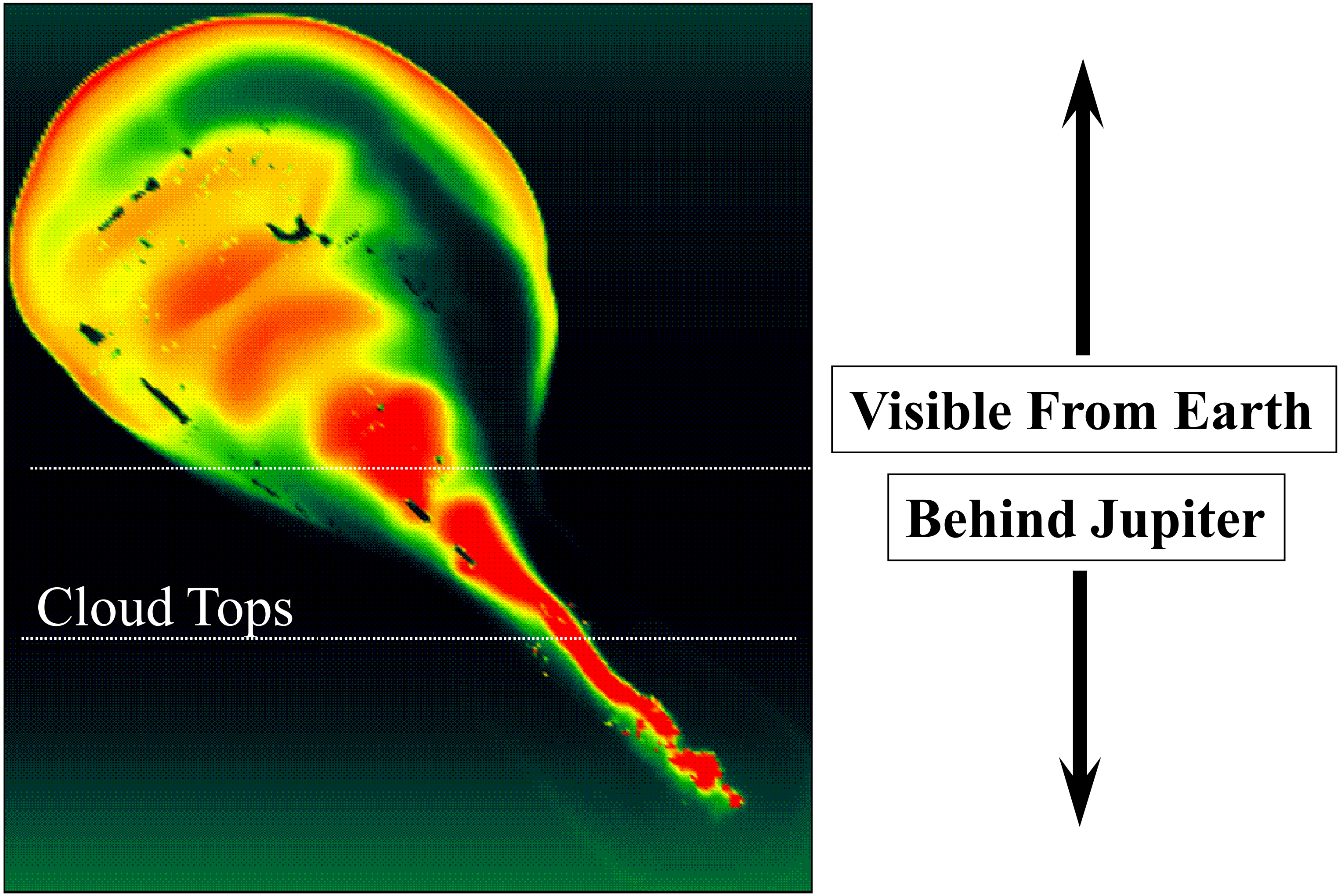
Less than 30% of the initial energy made it to the surface (Melosh, 2005)
9.0 Mt initial KE, 2.5 Mt formed crater, 6.5 Mt explosion in air



The physics of airbursts

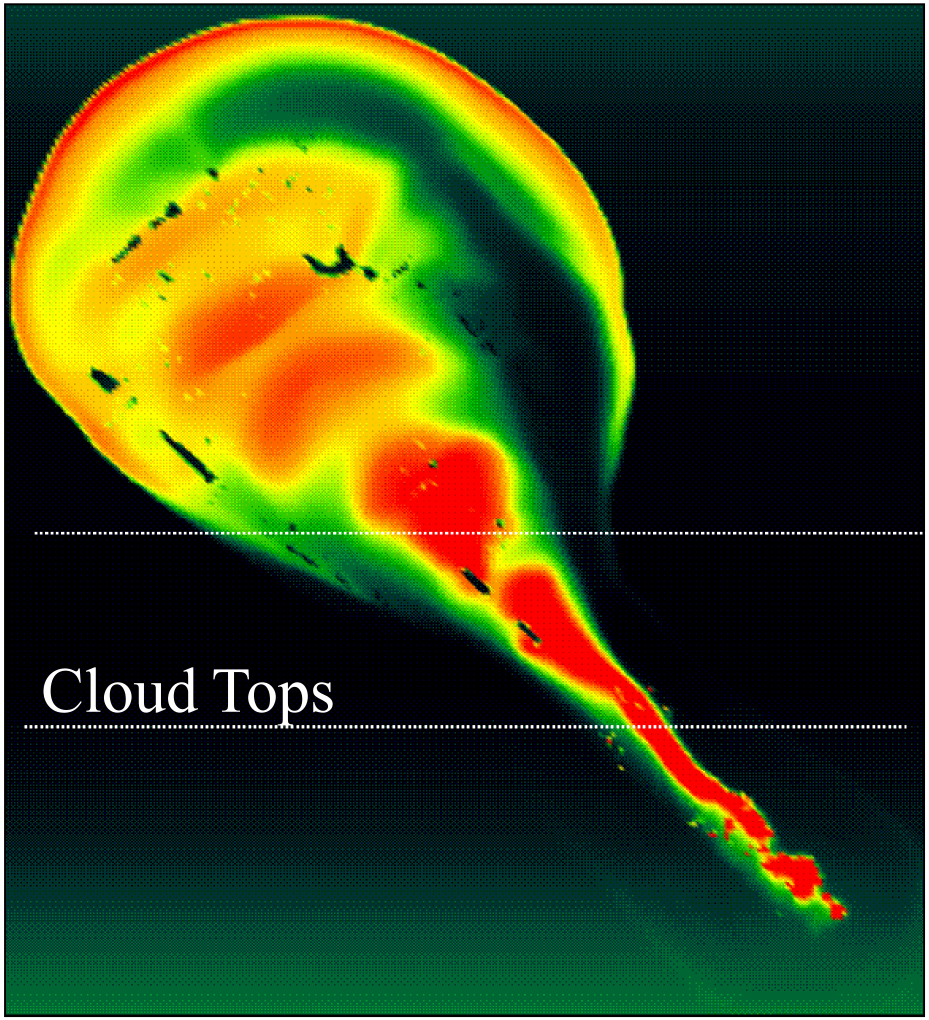
Shoemaker-Levy 9 comet crash: Jupiter, 1994

Shoemaker-Levy 9 impact, July 1994

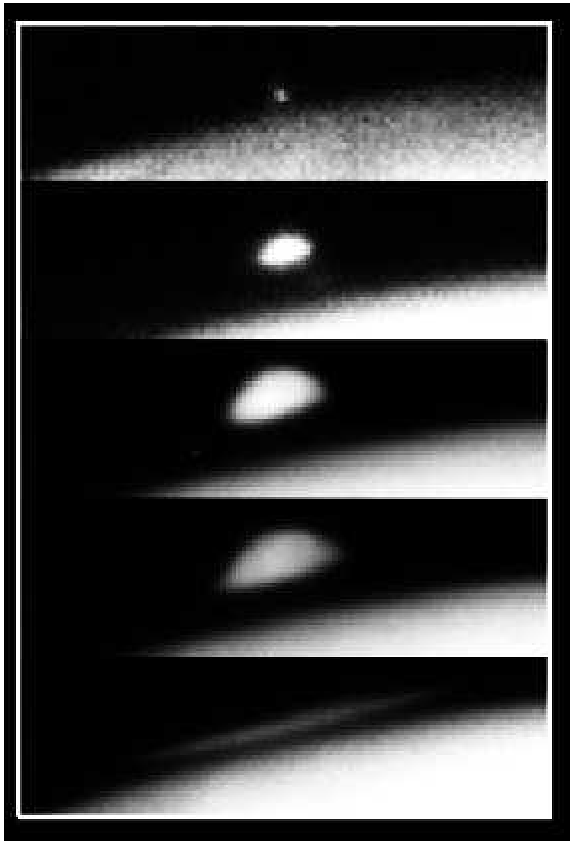


This is a *robust* result

Shoemaker-Levy 9 impact, July 1994



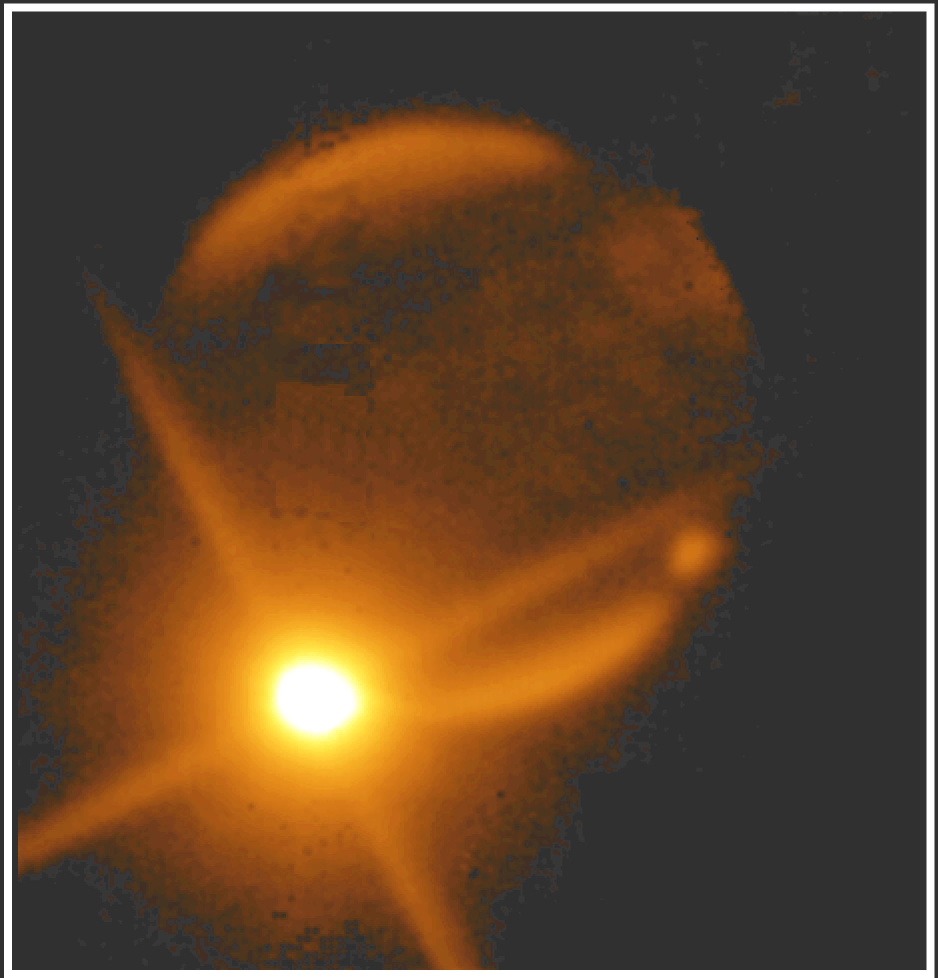
Impact G



Hubble Space Telescope Image

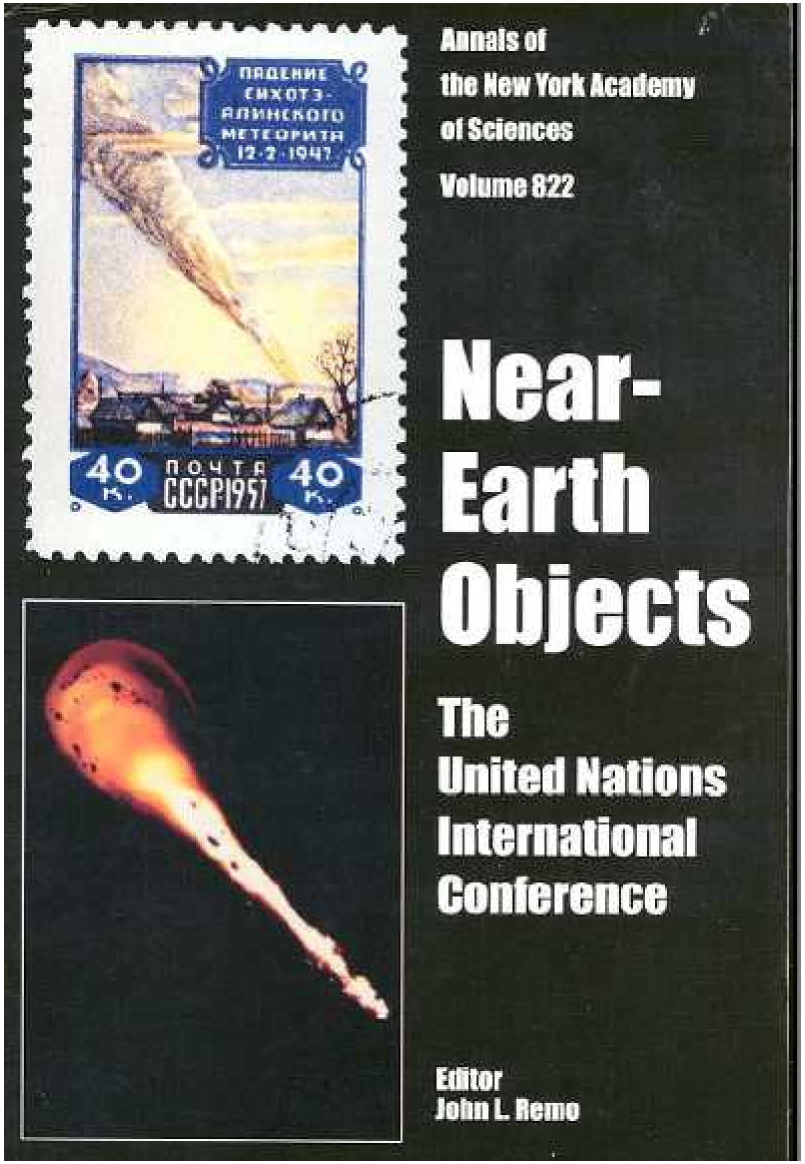
This is a *validated* result

View from Earth



Shoemaker-Levy 9 comet crash: Jupiter, 1994

Plumes and line explosions on Earth



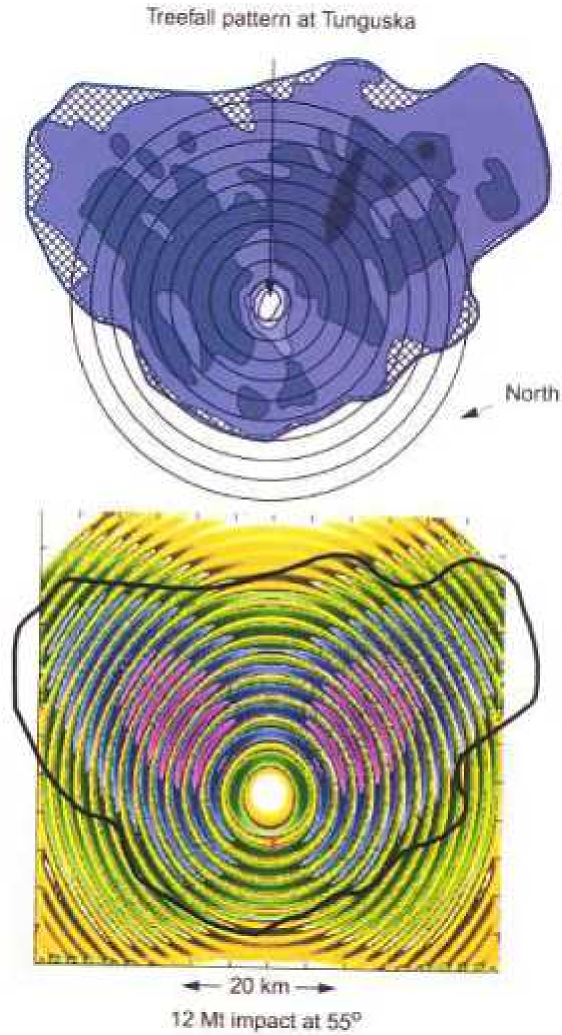
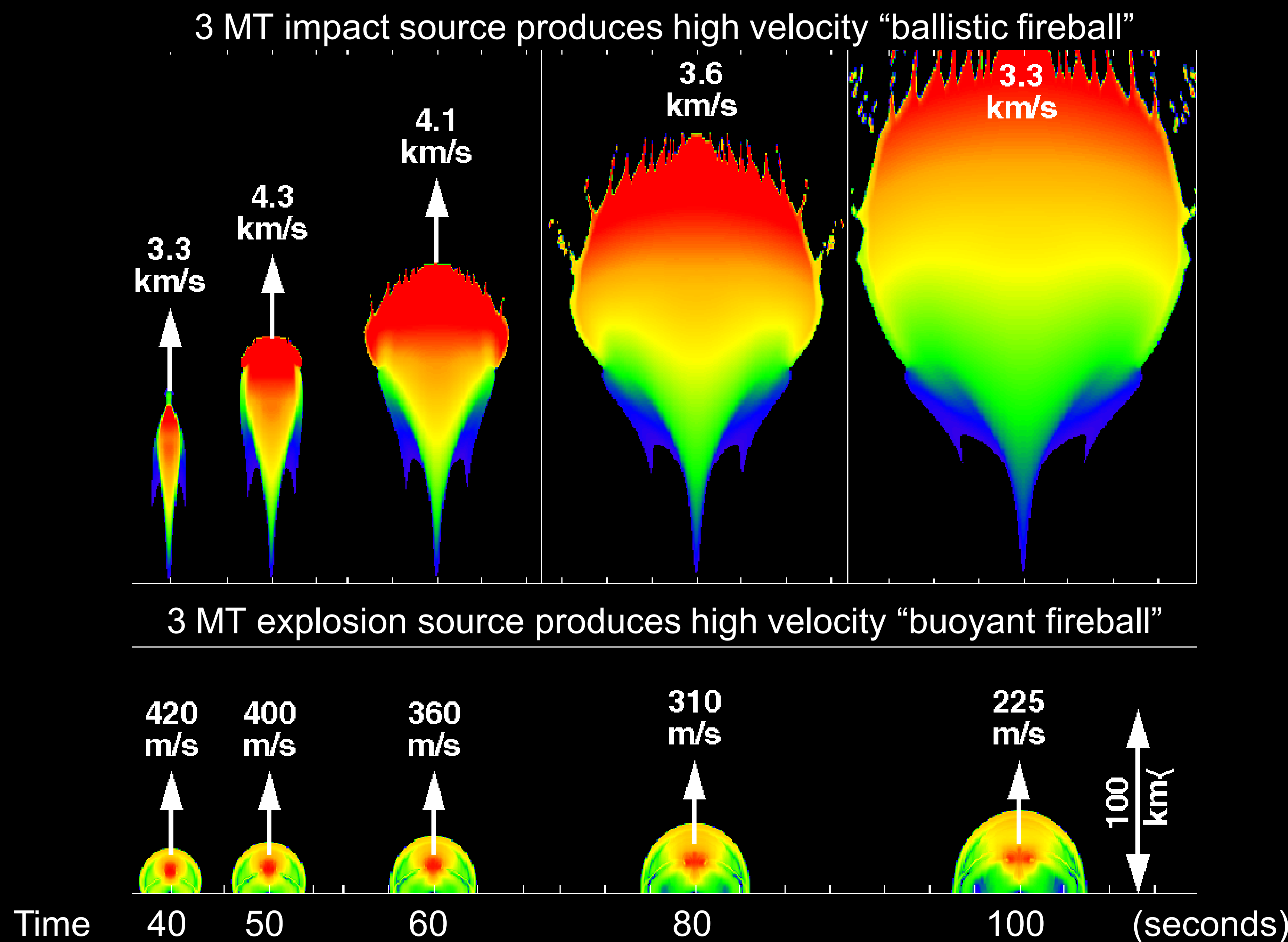


FIGURE 16. Comparison of butterfly-shaped treefall pattern at Tunguska [17] to map of peak surface windspeeds calculated from the collision of a 12 megaton object entering the atmosphere at an oblique angle, 55° from the zenith.


3 MT impact source produces high velocity “ballistic fireball”
3.3 km/s
4.3 km/s
4.1 km/s
3.6 km/s
3.3 km/s
3 MT explosion source produces high velocity “buoyant fireball”
420 m/s
400 m/s
360 m/s
310 m/s
225 m/s
100 km
Time
40
50
60
80
100
(seconds)

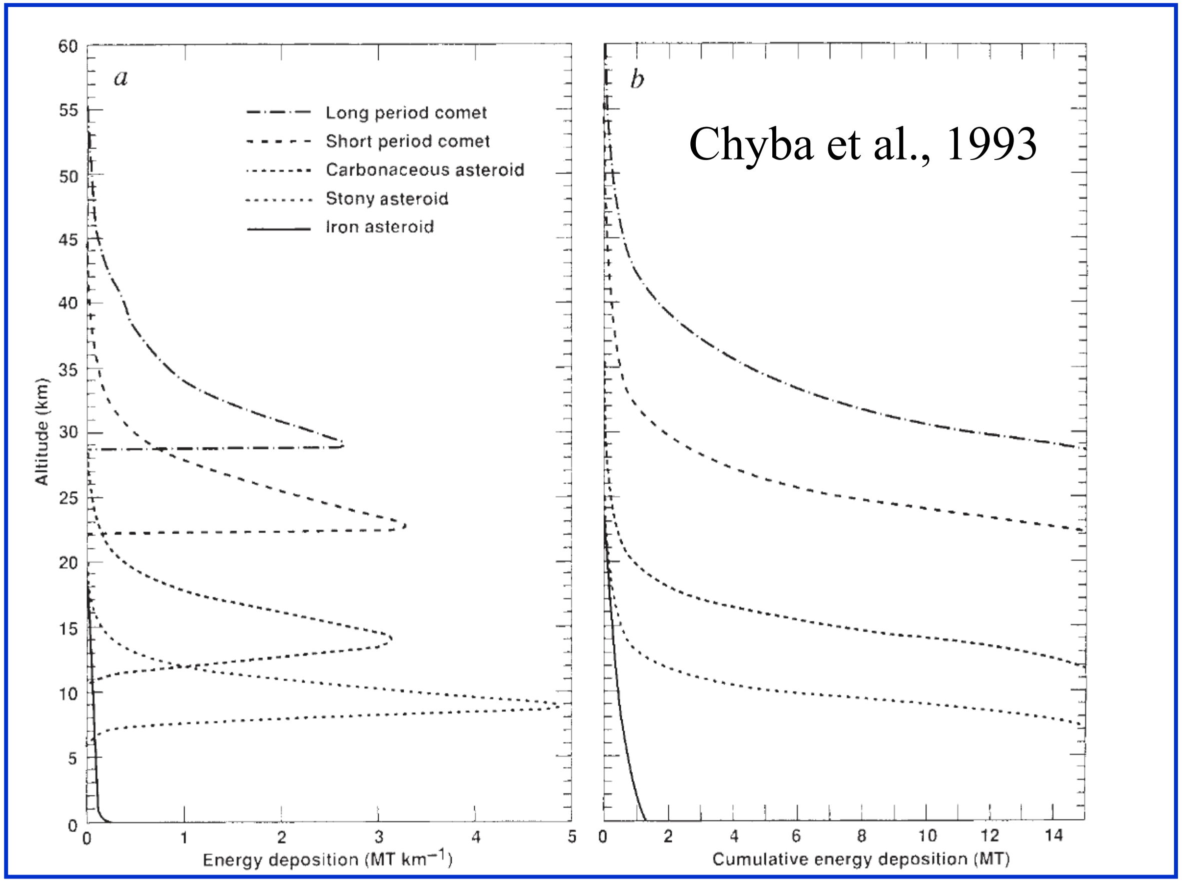
Pancake model: Earth's atmosphere protects us from low-altitude airbursts

Chyba et al. (1993), "The 1908 Tunguska explosion: atmospheric disruption of a stony asteroid" *Science*.

$$m\frac{dv}{dt} = -\tfrac{1}{2}\, C_D \rho A v^2$$

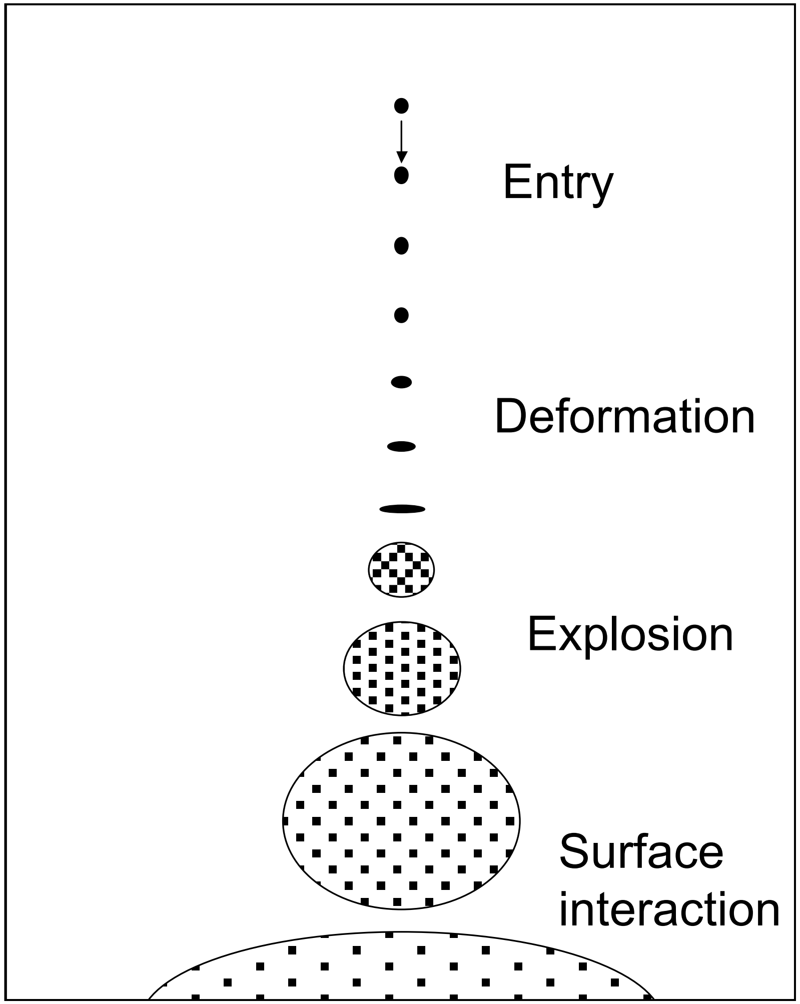
$$q\frac{dm}{dt} = -\tfrac{1}{2}\, C_H \rho A v^3$$

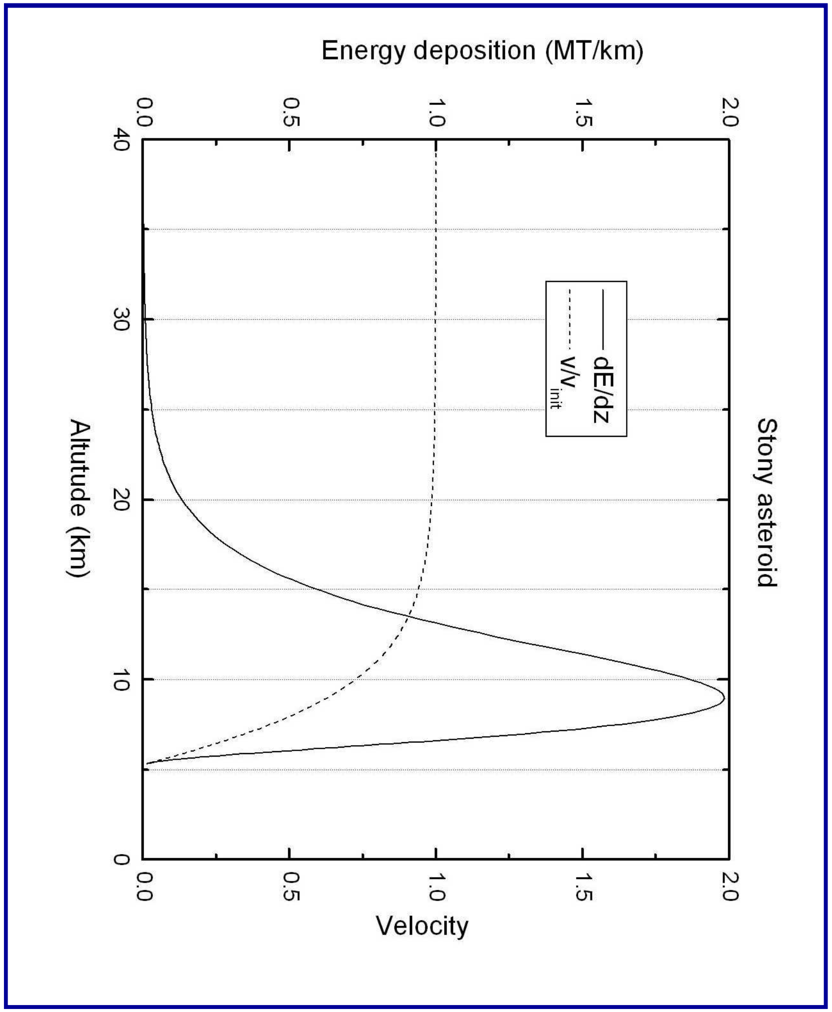
$$r\frac{d^2r}{dt^2} = -\tfrac{1}{2}\, C_D \frac{\rho}{\rho_m} v^2$$



A stony asteroid deposits essentially all of its kinetic energy above 7 km. In this model the energy deposition curve is sharply peaked because of the mutually-reinforcing effects of atmospheric drag and deformation. Subsequent modeling has been based on point-source explosions and nuclear weapons effects.

Pancake model revisited: Earth's atmosphere is actually penetrated by hot vapor jet

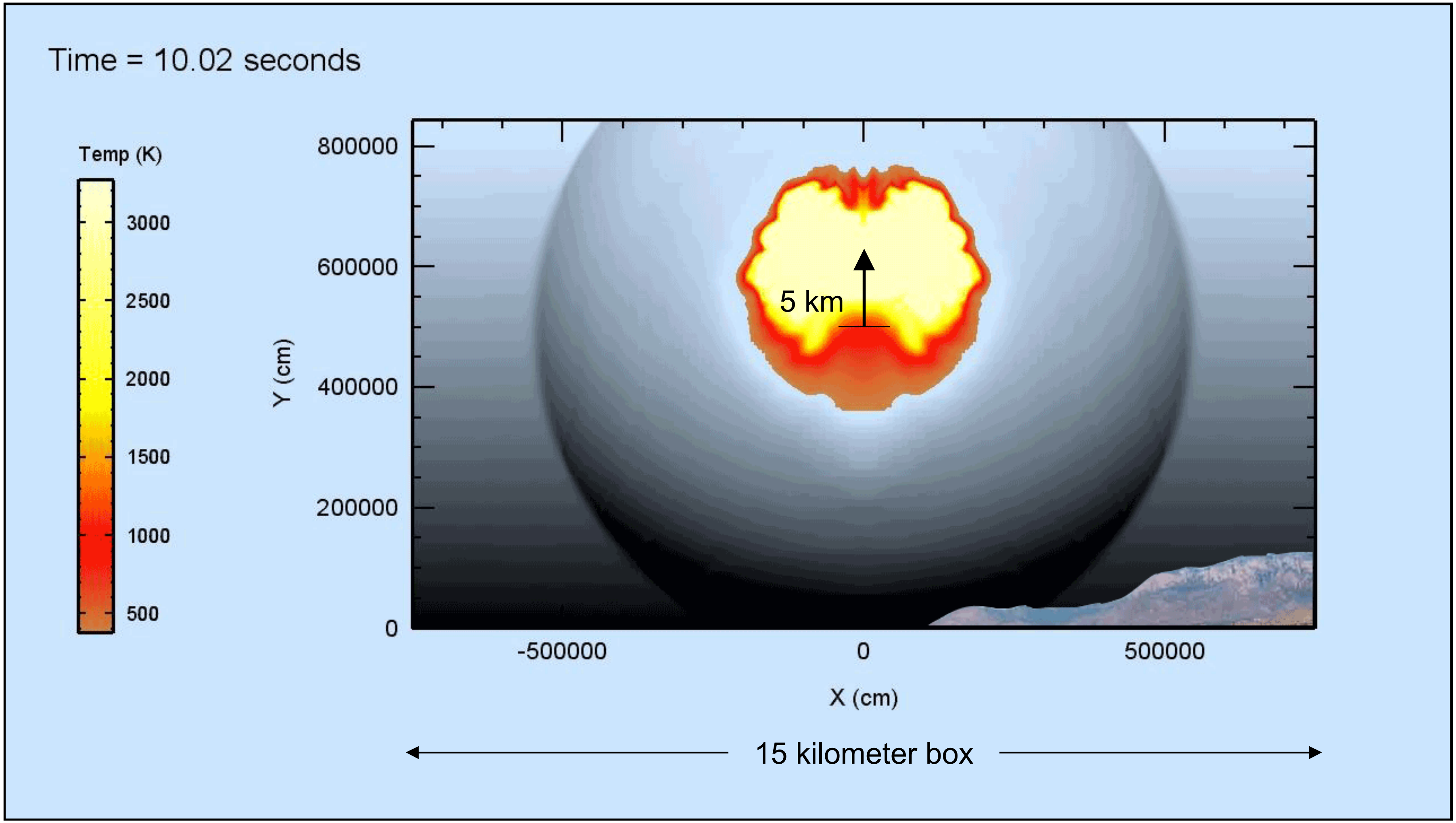




The "point source explosion" model is a poor approximation.

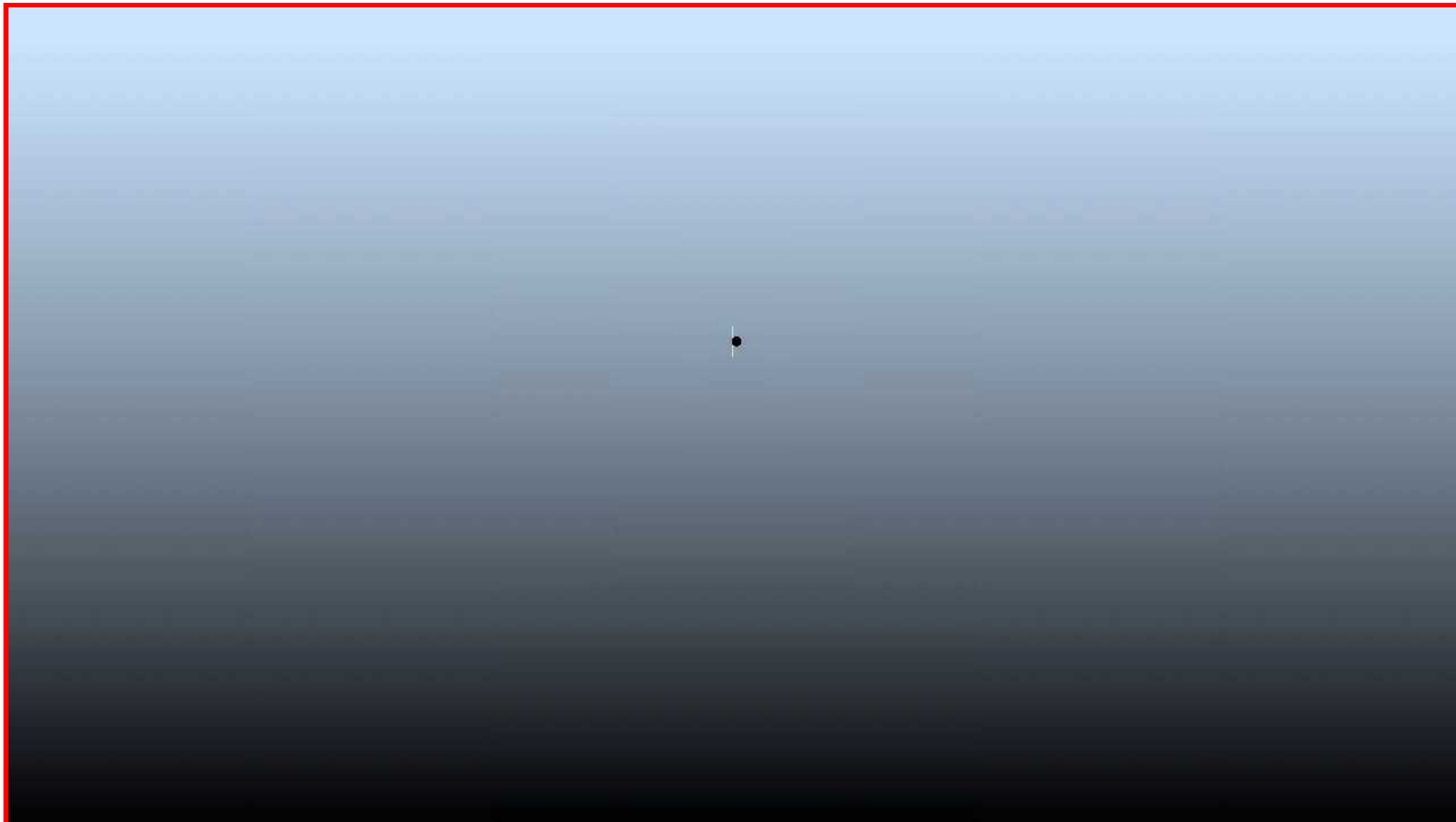
Movies: Difference between explosion and impact

5 megaton point explosion at 5 km altitude: first 20 seconds



Movies: Difference between explosion and impact

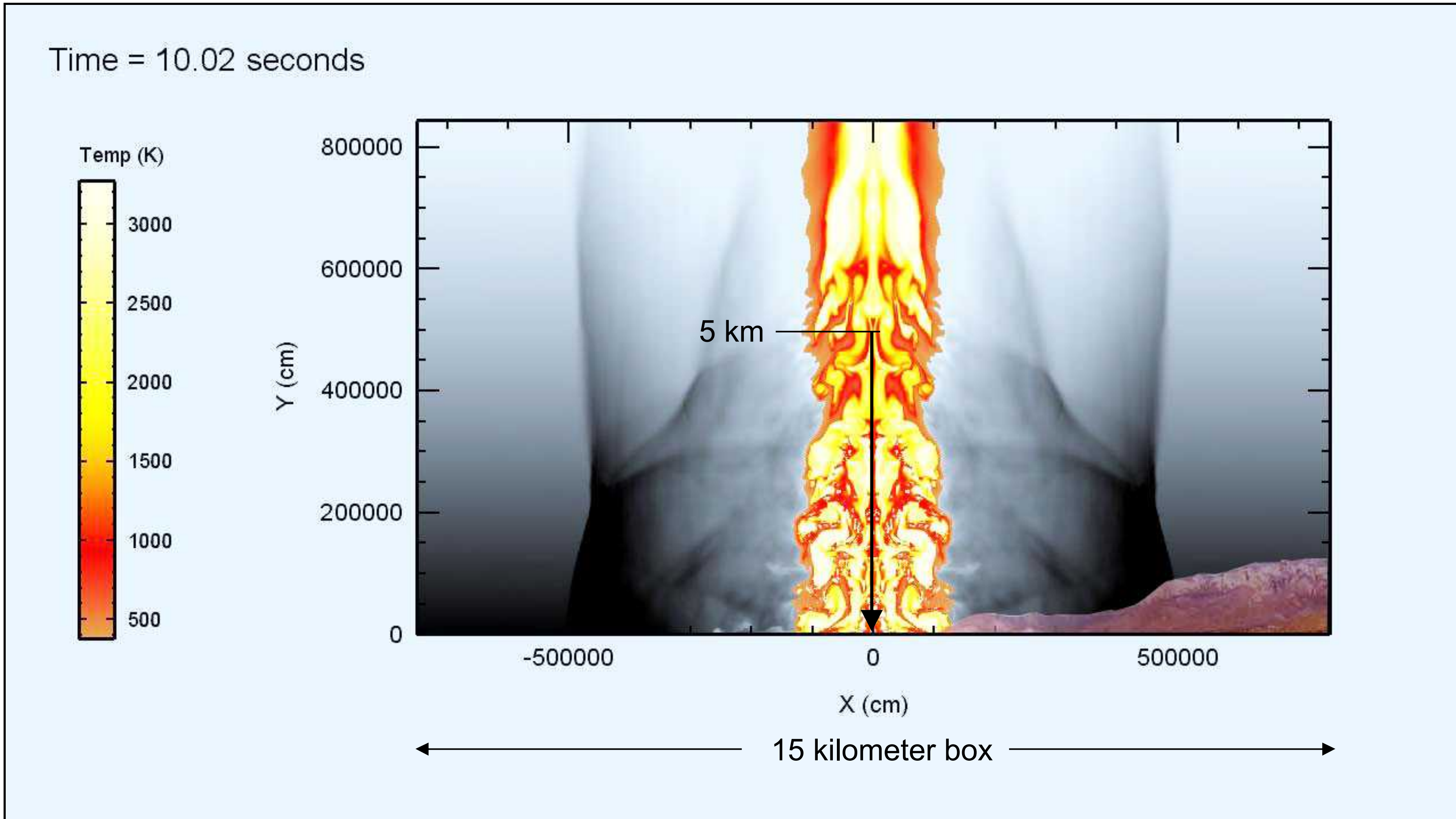
5 megaton point explosion at 5 km altitude: first 20 seconds



Box dimensions: 8.4 x 15 km

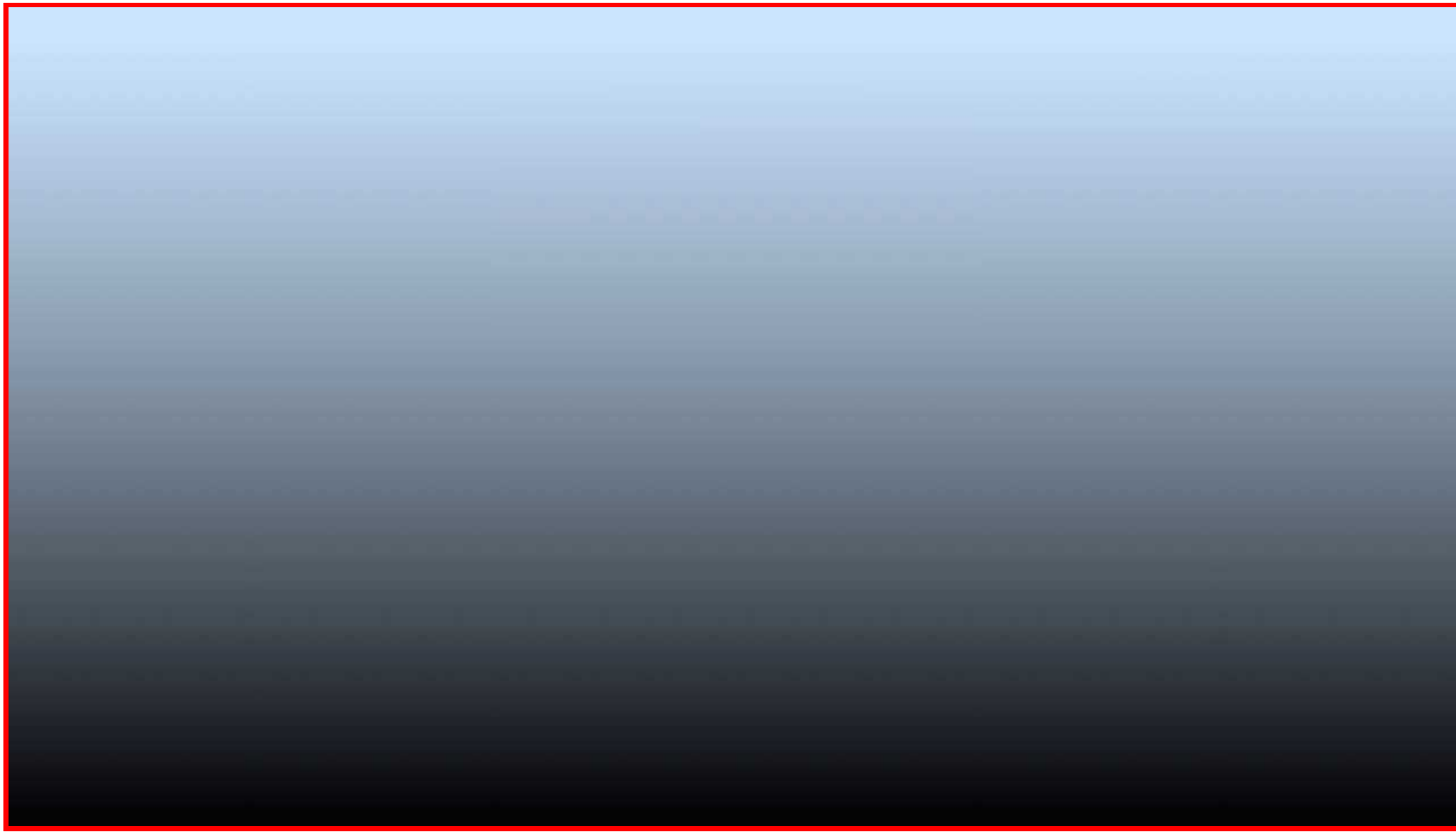
Movies: Difference between explosion and impact

5 megaton impact airburst at 5 km altitude: first 20 seconds



Movies: Difference between explosion and impact

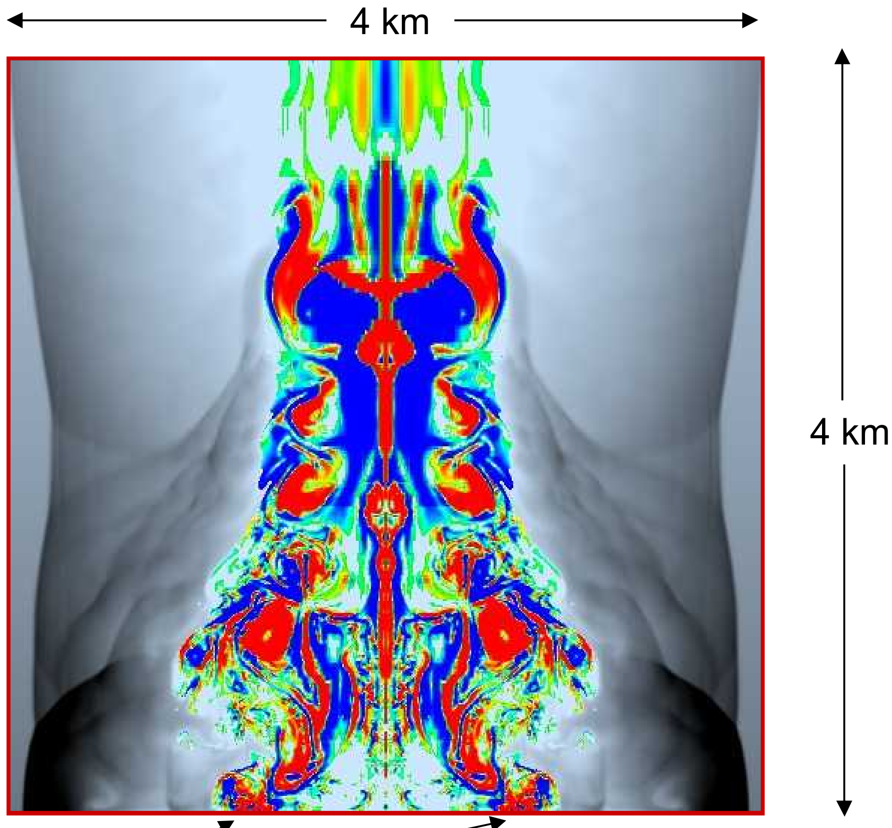
5 megaton impact airburst at 5 km altitude: first 20 seconds



Box dimensions: 8.4 x 15 km

Impact-Induced Vortex Rings

5 megaton impact airburst at 5 km altitude
generates stack of supersonic white-hot “mega-tornado” rings



Red: inward rotation
Blue: outward rotation

Sustained supersonic flow
melts and ablates surface

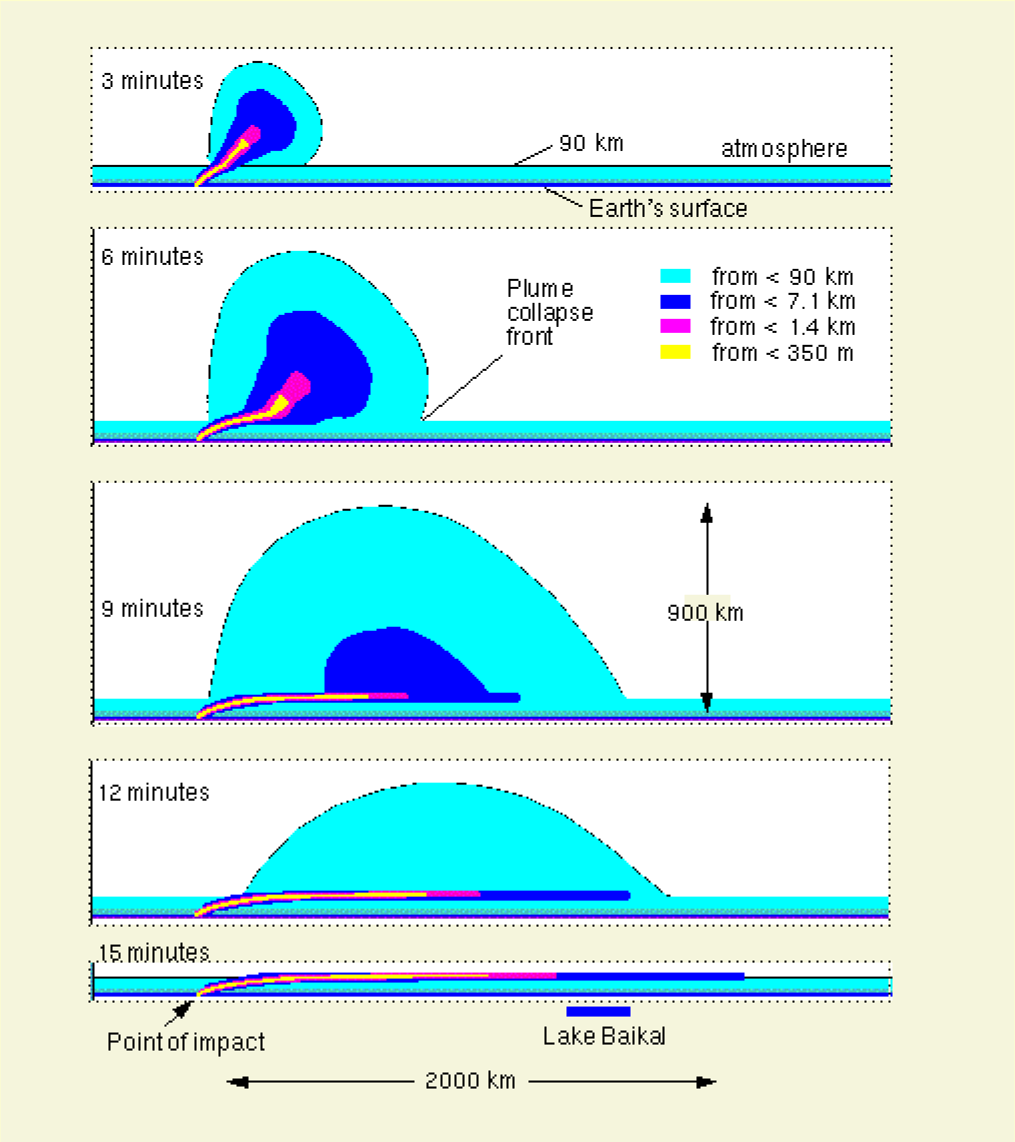
Impact-Induced Vortex Rings

5 megaton impact airburst at 5 km altitude

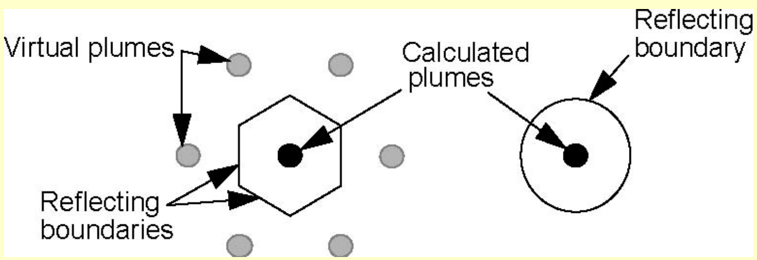
Box dimensions: 3 x 4 km

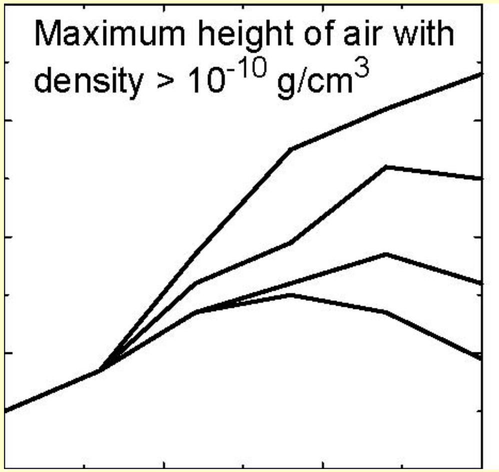
Bologna, Italy 1996

Tunguska96



Silica96





Animated version for National Geographic documentary “Ancient Asteroid”

This video was shown as justification for Younger-Dryas extinction impact hypothesis at 2007 Spring AGU, Acapulco.

Tutankhamun’s Fireball (Ancient Asteroid)

3. Recent impact controversies

Two new papers

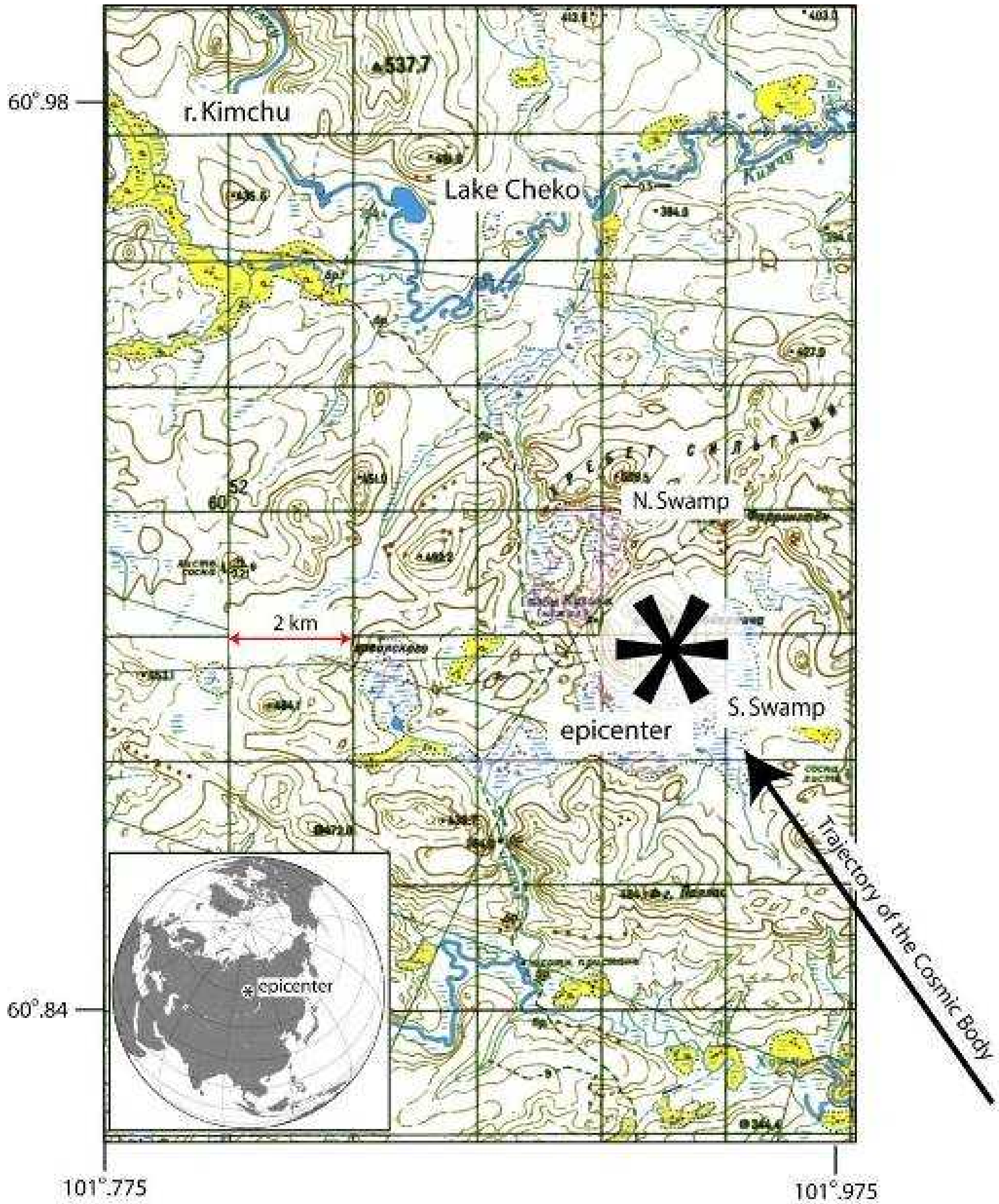
Gasperini et al. (2007) *"A possible impact crater for the 1908 Tunguska Event"*

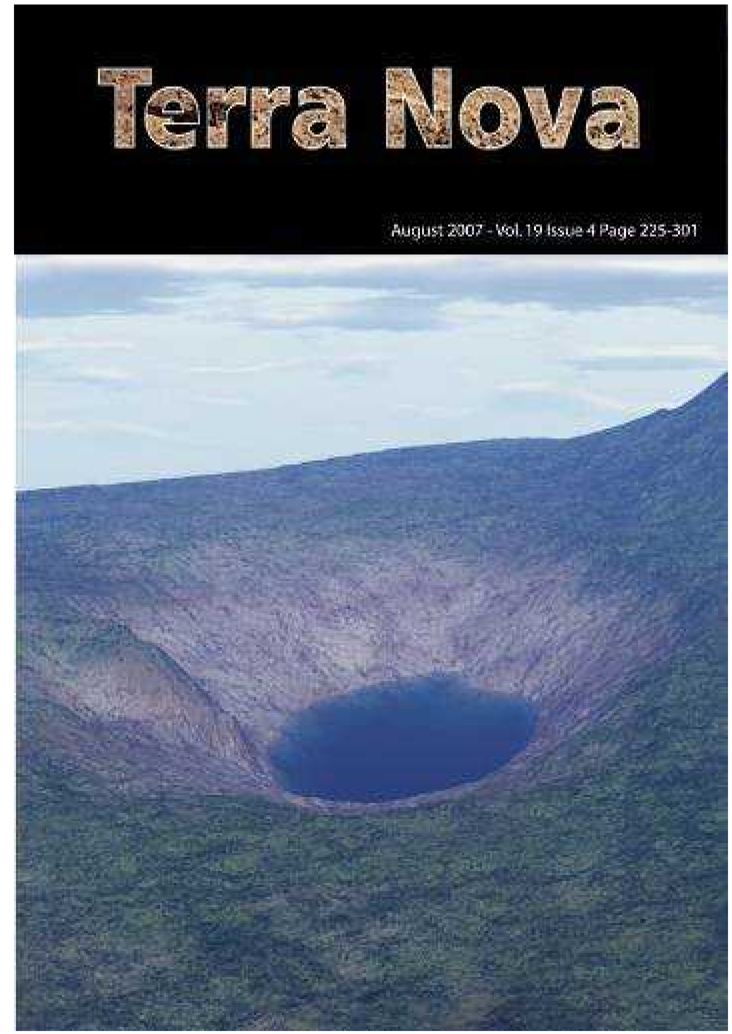
- Viable hypothesis
- Only evidence is circumstantial
- Have not found any theoretical support

Firestone et al. (2007), "*Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling*"

- Not a viable hypothesis
- Evidence is very weak
- Completely inconsistent with physics of impacts and airbursts

The Lake Cheko Controversy





"A possible impact crater for the 1908 Tunguska Event" Gasperini et al., 2007

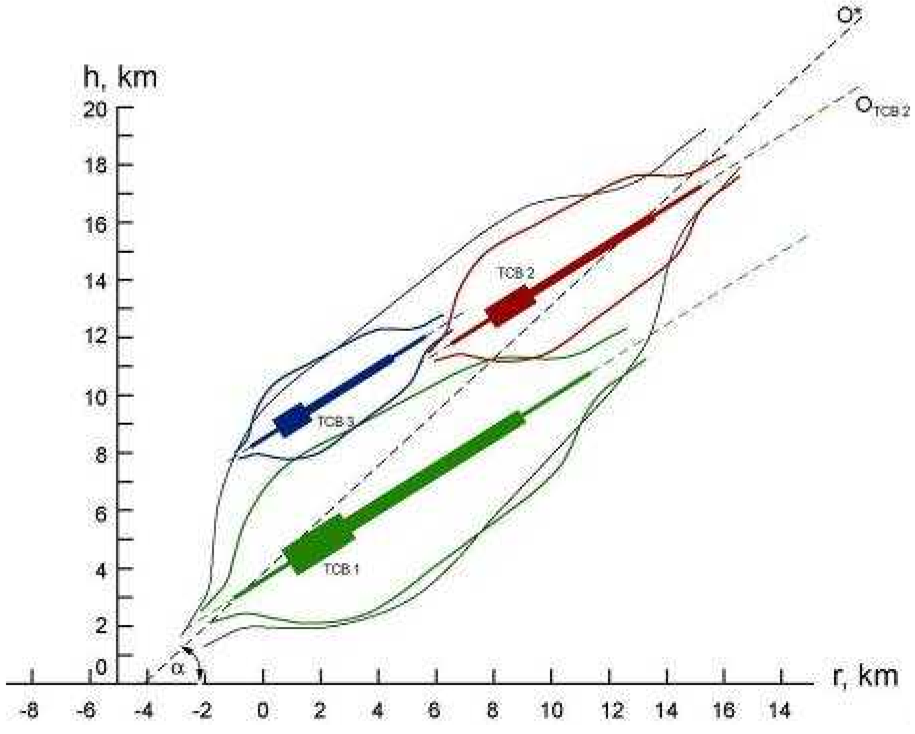
The Lake Cheko Controversy

Impact crater or just a lake?

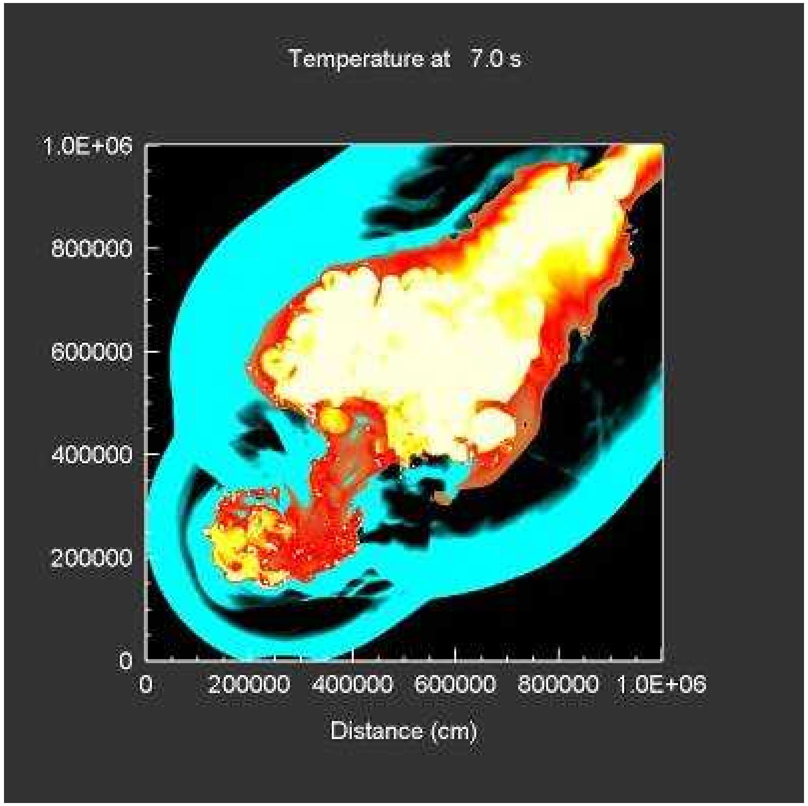
First post-expedition conference: Vanavara

First look: Submersible camera videos!

The Lake Cheko Controversy



"Anfinogenov spindles" (Anfinogenov, 1966)



Multiple explosions (Boslough, 2008)

The Holocene Impact Rate Controversy

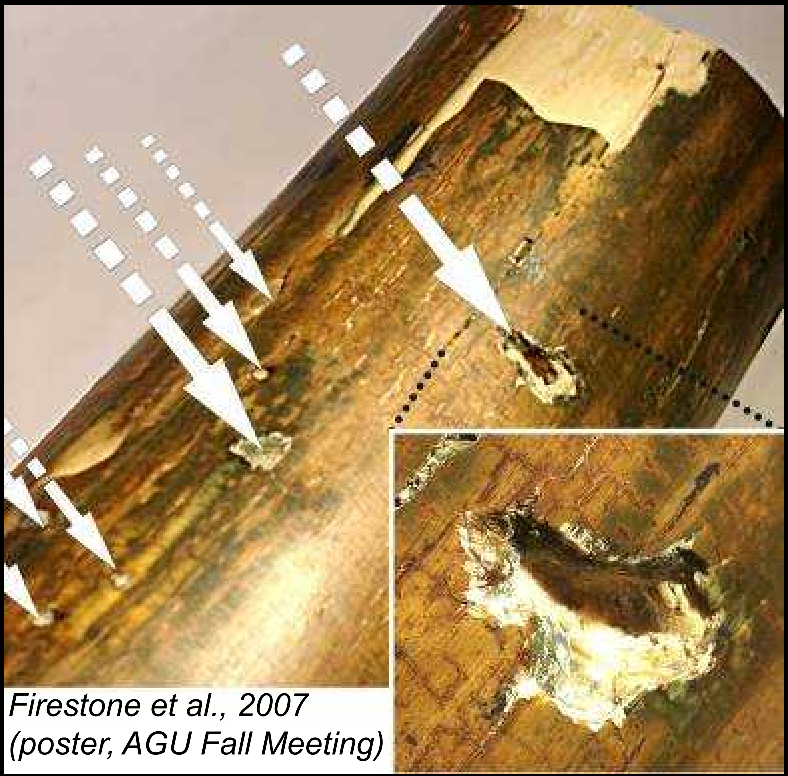
June 2008 Atlantic Monthly
"The odds that a potentially devastating space rock will hit Earth this century may be as high as one in 10. So why isn't NASA trying harder to prevent catastrophe?"
By Gregg Easterbrook

A team of researchers led by Richard Firestone, of the Lawrence Berkeley National Laboratory, in California, recently announced the discovery of evidence that one or two huge space rocks, each perhaps several kilometers across, exploded high above Canada 12,900 years ago.

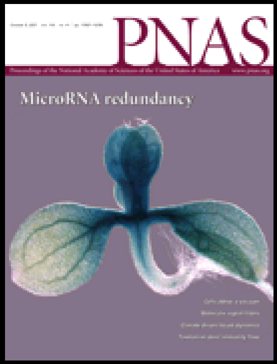
If, as Boslough thinks, most asteroids and comets explode before reaching the ground, then this is another reason to fear that the conventional thinking seriously underestimates the frequency of space-rock strikes—the small number of craters may be lulling us into complacency.

Given the scientific findings, shouldn't space rocks be one of NASA's priorities? You'd think so, but Dallas Abbott says NASA has shown no interest in her group's work: "The NASA people don't want to believe me. They won't even listen."

The Megafuana Extinction Controversy

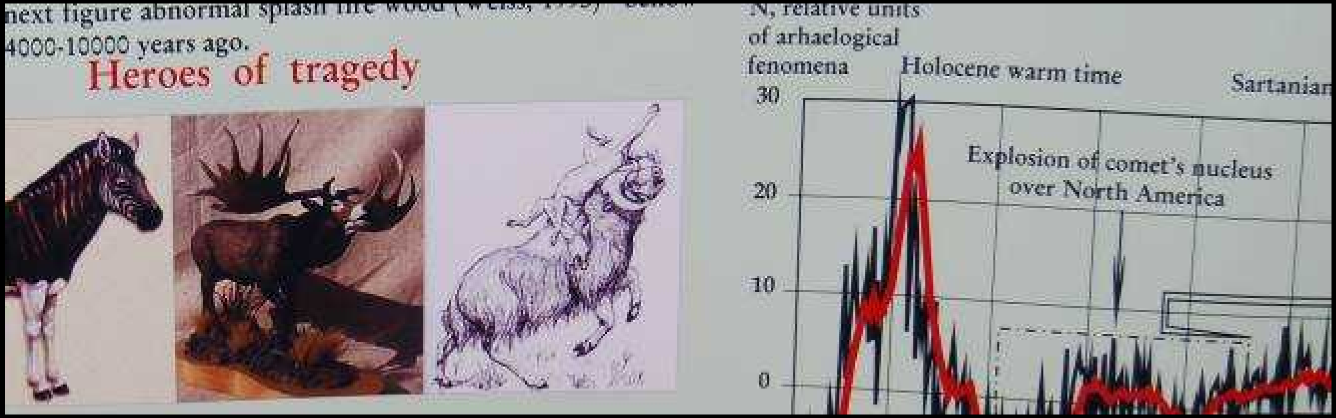


Firestone et al., 2007 (poster, AGU Fall Meeting)



R.B. Firestone et al. (2007), “*Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling*’

Bear skull, Krasnoyarsk

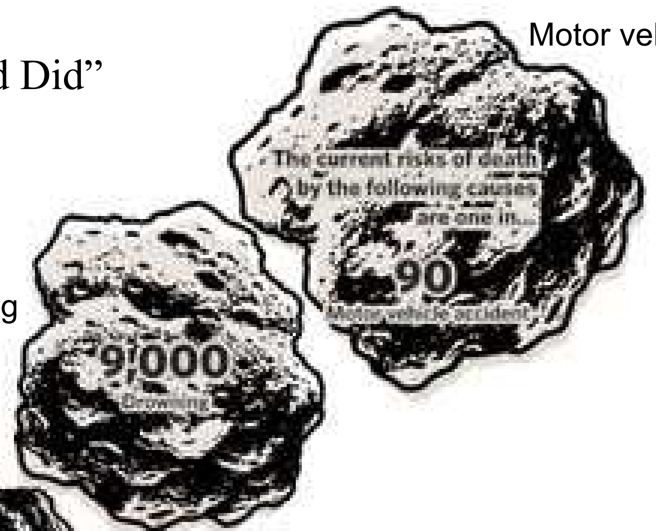


Russian poster at Tunguska 2008 conference, Moscow

4. The asteroid threat in perspective

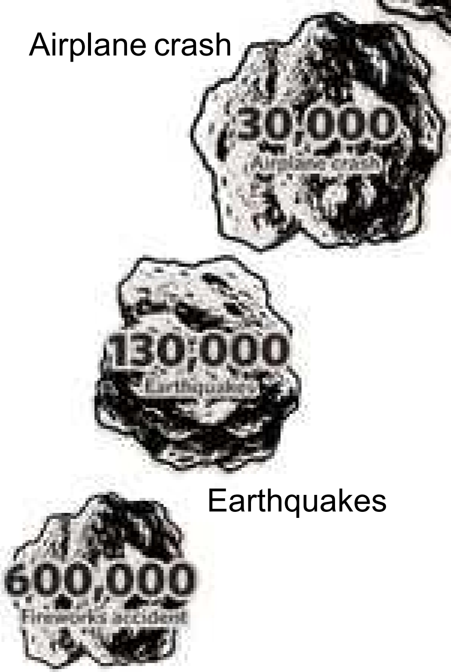
The asteroid threat in perspective

Alan Harris,
"What Spaceguard Did"
Nature 453, 2008



Motor vehicle accident

Drowning



Airplane crash

Earthquakes

Fireworks accident

Asteroid impact (all sizes)

Asteroid impact (global)

Regional impact

Food poisoning by botulism

Impact mass extinction

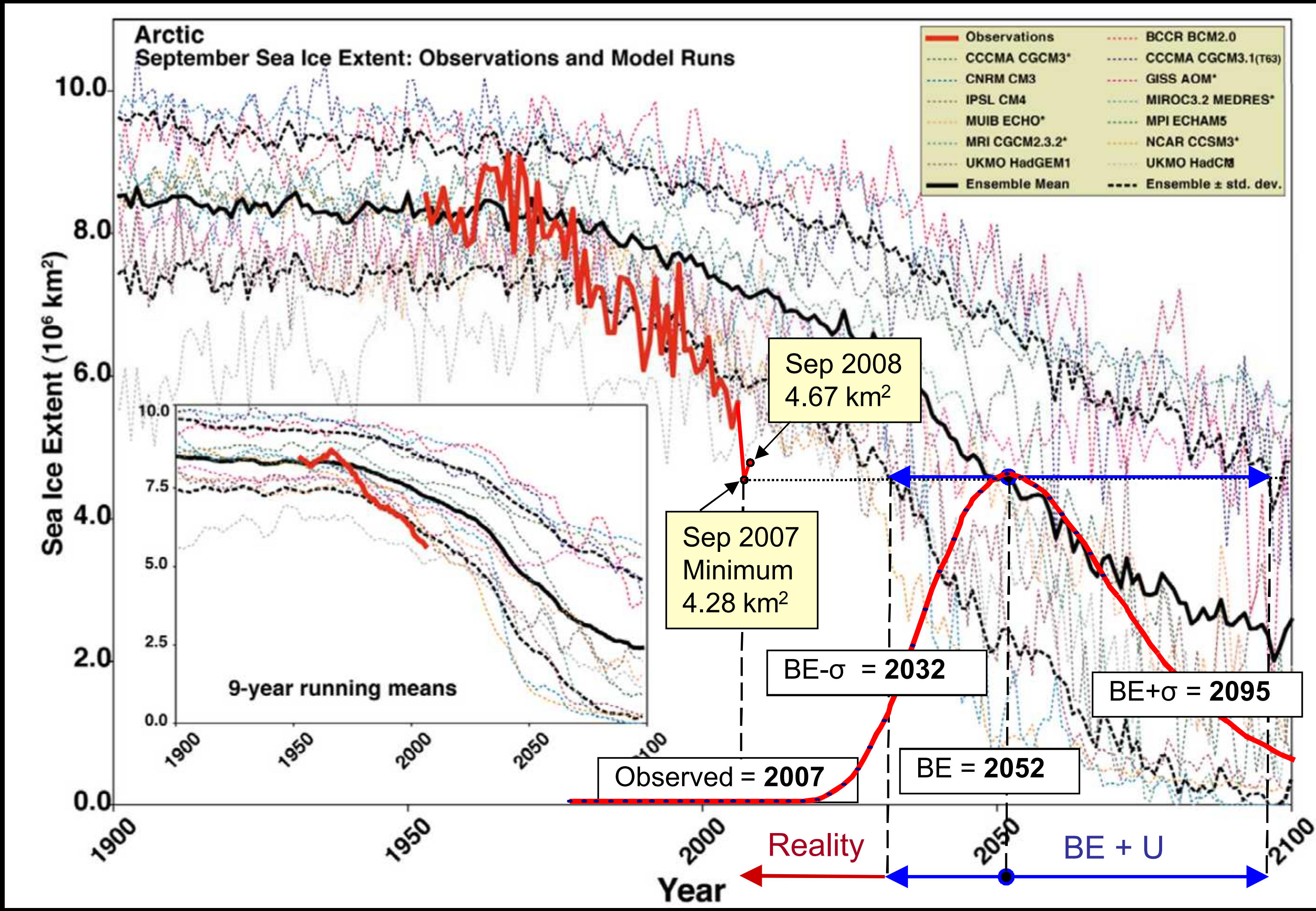
Tunguska

Shark attack

Cause	Expected deaths per year*
Type 1 airburst	10 (<1 per year in US)
All asteroids	80 (~4 per year in US)
Climate change	150,000 – 300,000
Air Pollution	600,000
Malaria	1,000,000
Traffic accidents	1,200,000
HIV/AIDS	2,100,000
Tobacco	5,000,000

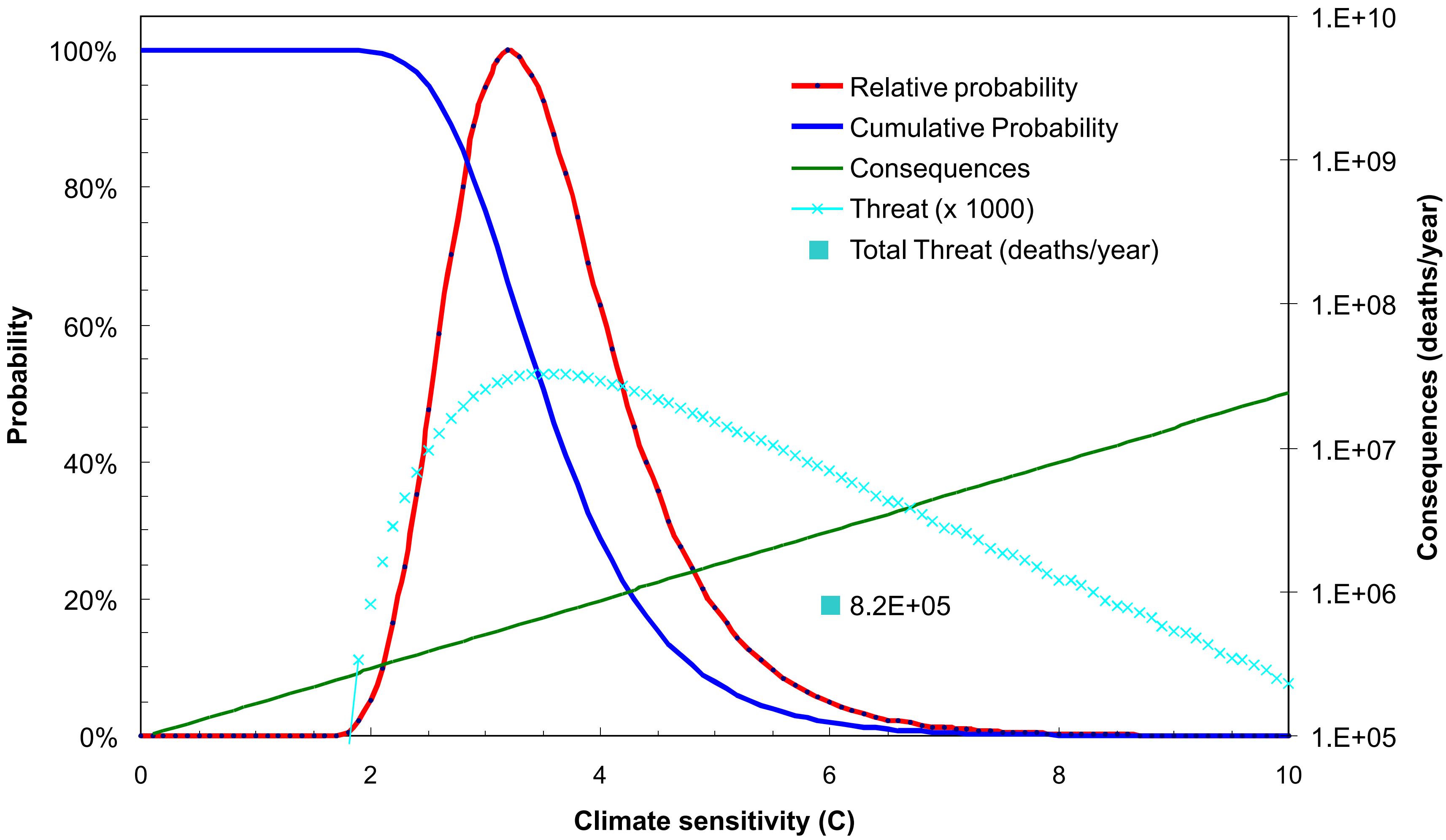
*Asteroid estimates from Harris (2008).
All other estimates from the World Health Organization.

5. Better reasons for NEO deflection



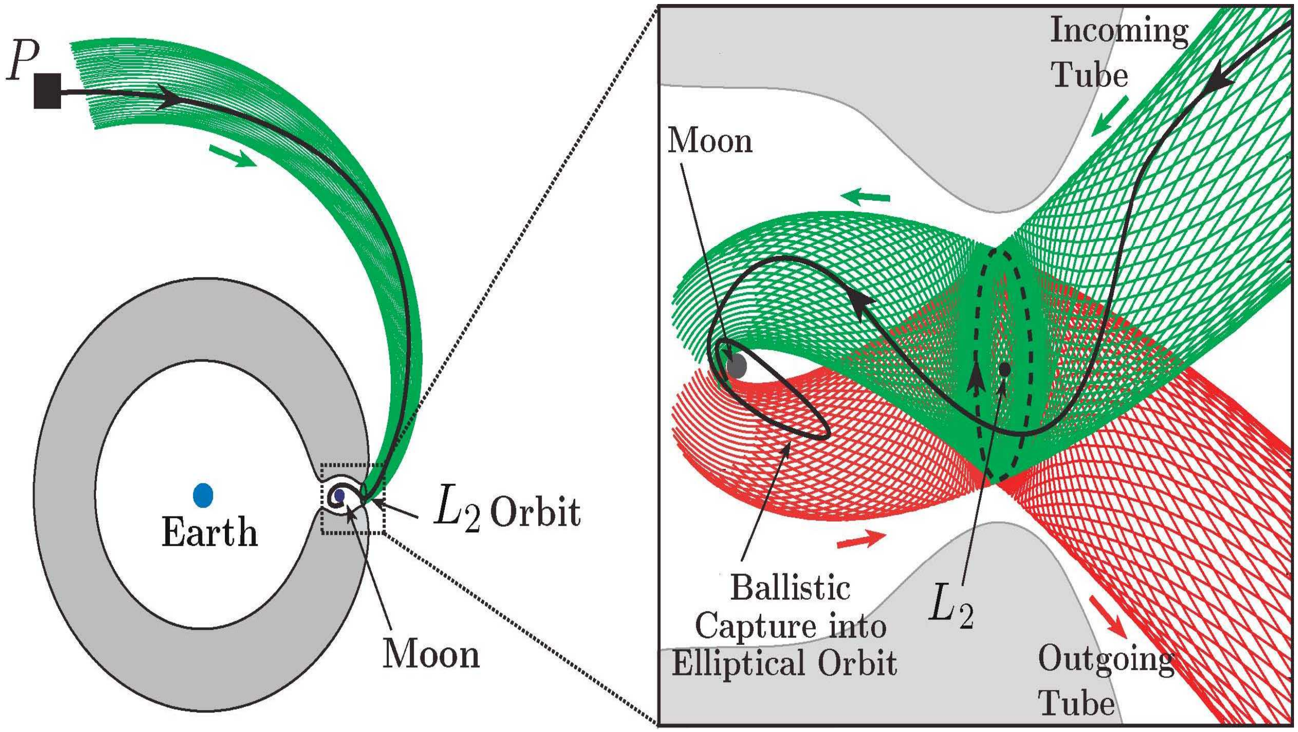
The rate of climate change is exceeding the most extreme expectations

Climate change threat is ~ 100,000 times greater



Threat = Probability · Consequences

NEO capture for space resources or geo-engineering

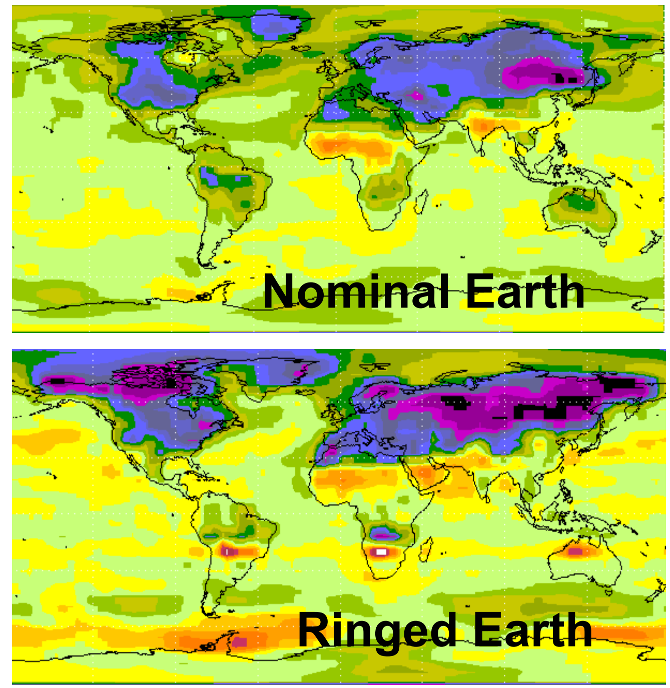


Low-energy pathways allow capture of object into Earth orbit (Marsden and Ross, 2005)

Global climate change mitigation: More urgent than impact mitigation by $\sim 10^5$

- Captured asteroids can be fragmented and used to created engineered orbital debris ring.
- Changes in incoming solar radiation and atmospheric opacity modify Earth's climate.
- Rapid changes in Earth's climate are observable in geologic record.

Climate simulations

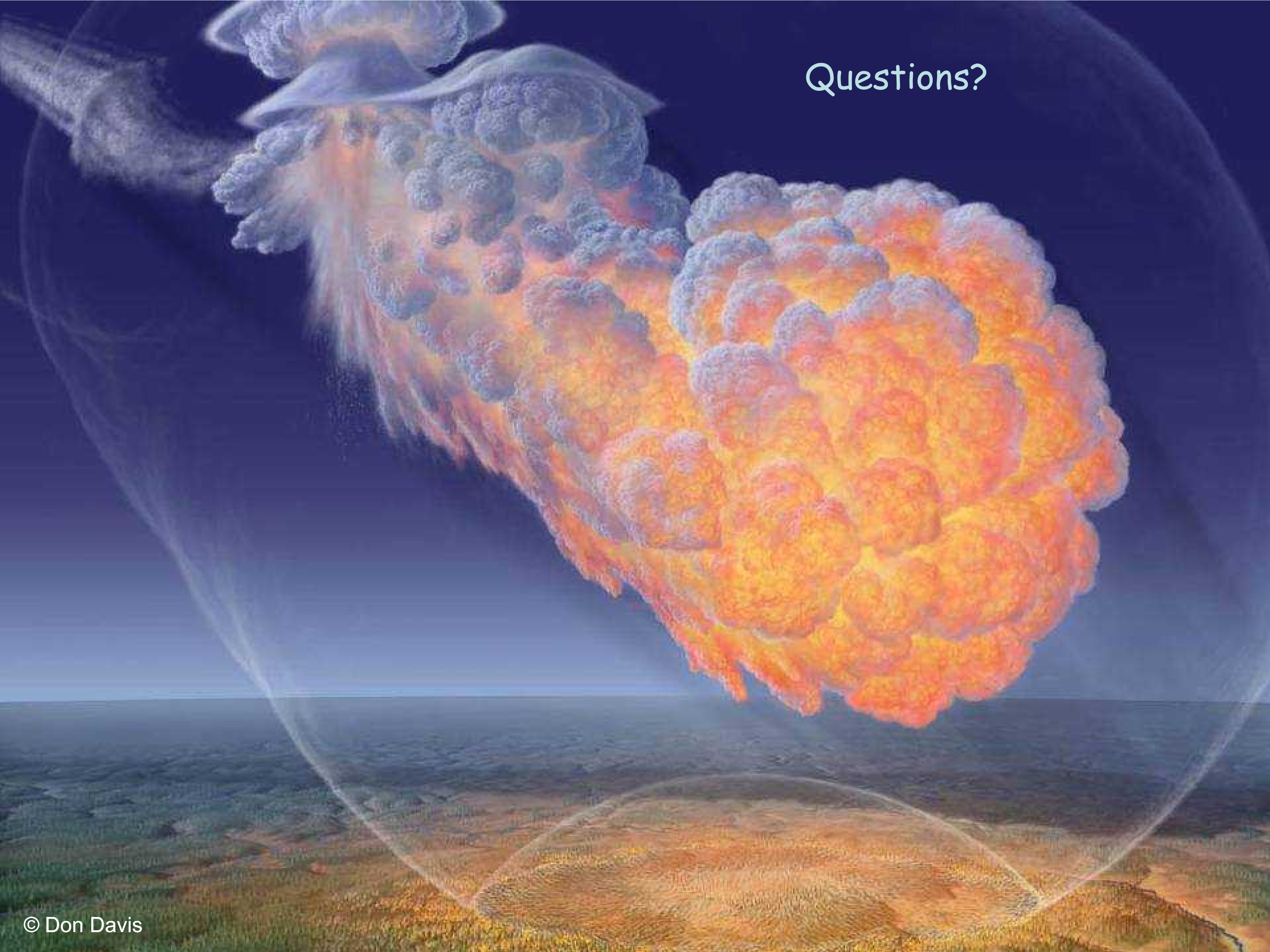


Difference in mean temperature (low vs. high obliquity)

Fawcett and Boslough (2002), "Climatic effects of an impact-induced equatorial debris ring", JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. D15, 10.1029/2001JD001230, 2002

Conclusions

1. Multiple low-yield shallow bursts are most effective nuclear deflection method.
2. Primary mitigation goal should be for Type 2 airburst prevention.
3. Credibility of community requires skepticism and solid research.
4. Deflection not justified for NEO protection alone.
5. Geo-engineering and space resources are vastly better reasons to develop deflection technology.


Questions?
© Don Davis