THE CHELYABINSK AIRBURST: OBSERVATIONS AND MODELS

Mark Boslough, Sandia National Laboratories, Albuquerque, NM mbboslo@sandia.gov

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On Feb. 15, 2013, an asteroid exploded about 40 km SSW of the Russian city of Chelyabinsk. Its proximity led to many injuries and widespread blast damage, but also yielded a plethora of data from security and dashboard cameras. Combined with seismic, infrasound, and satellite records, this provides a rich and multi-faceted means to determine the projectile size and entry parameters, and develop a self-consistent model. We present results of the first physics simulations to be initialized with accurate energy deposition derived from observations.

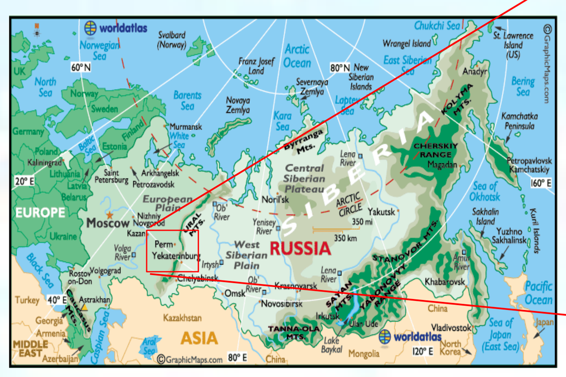
The best estimate of the explosive yield is 400-500 kilotons, making Chelyabinsk the most powerful such event observed since Tunguska (3-5 megatons). Analysis of video combined with subsequent on-site stellar calibrations enable precise estimates of entry velocity (19 km/s), angle (17° elevation) and altitude of peak brightness (29 km). This implies a pre-entry diameter of ~20 m and mass of ~1200 tonnes. Satellite sensors recorded the emission peak at 03:20:33 UT, with a total radiated energy of 3.75 · 1014 J (~90 kilotons). A typical bolide luminous efficiency of 20% implies a total energy of ~450 kilotons, consistent with infrasound and other observations. The maximum radiant intensity was 2.7 · 1013 W/ster, corresponding to a magnitude of -28.

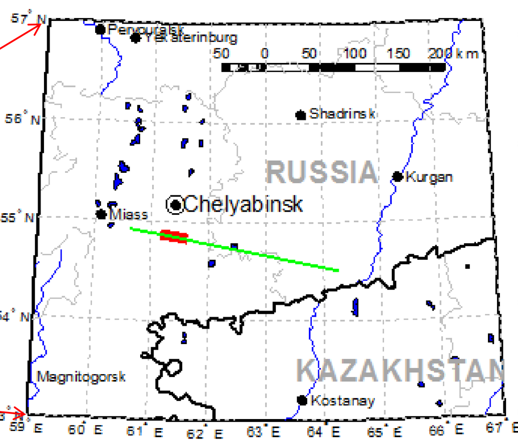
The shallow entry angle led to a long bolide duration (16.5 s) and energy was deposited over 100s of km leading to an extended, near-horizontal, linear explosion. The blast was distributed over a large area, and was much weaker than for a steep entry and a more concentrated explosion closer to the surface. The orientation also led to different phenomena than expected for a more vertical entry. There was no ballistic plume as observed from SL9 impacts (45°) or calculated for Tunguska (~35°). Instead, buoyant instabilities grew into mushroom clouds and bifurcated the trail into two contra-rotating vortices.

Chelyabinsk and Tunguska are "once-per-century" and "once-per-millennium" events, respectively. These outliers imply that the frequency of large airbursts is underestimated. Models also suggest that they are more damaging than nuclear explosions of the same yield (traditionally used to estimate impact risk). The risk from airbursts is therefore greater than previously thought.

Observations

Chelyabinsk Fireball
Feb 15, 2013

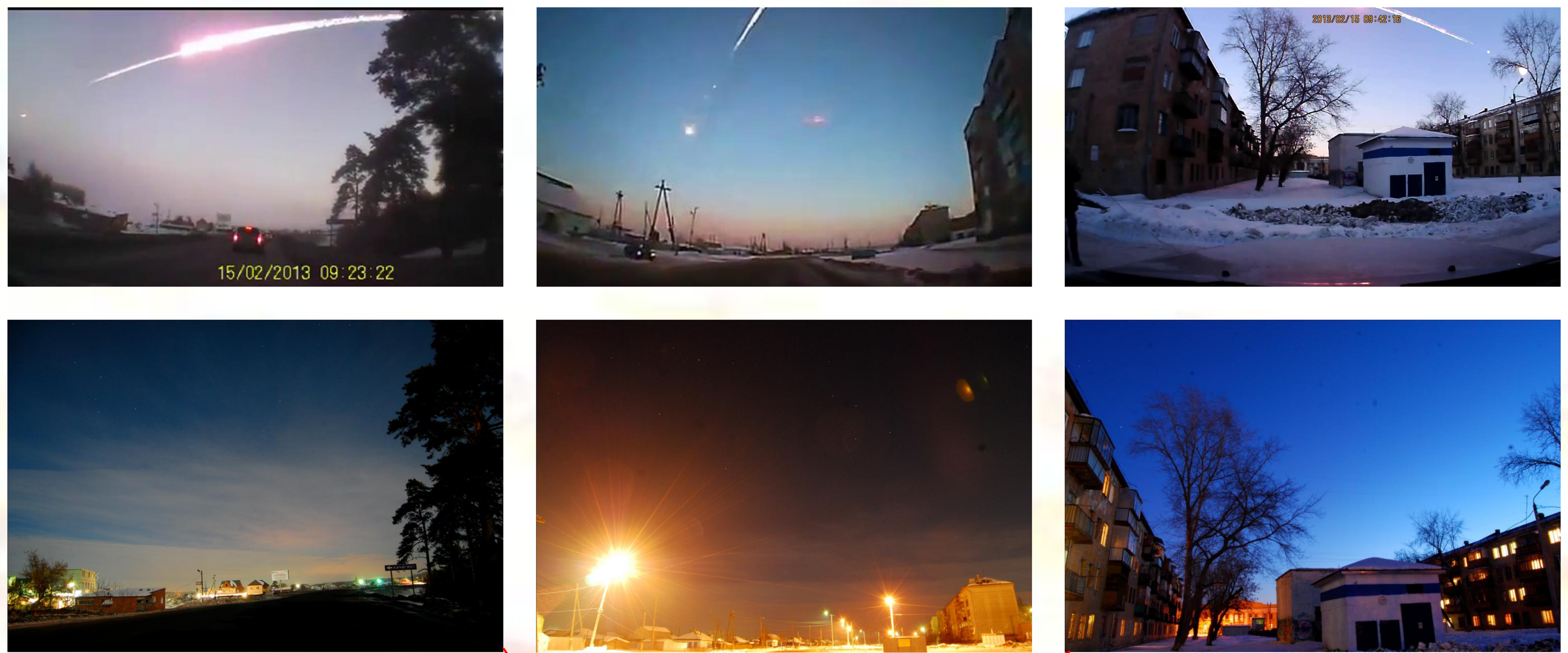




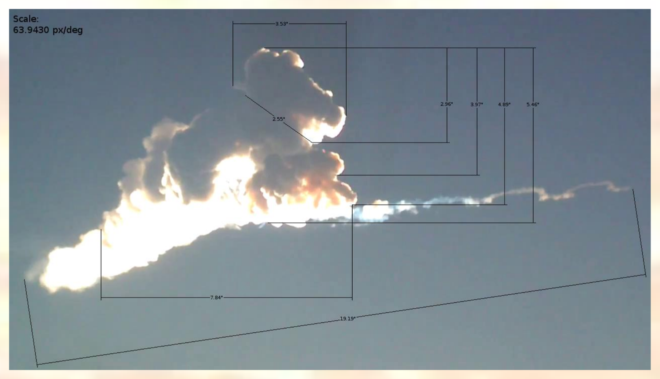
- Bright fireball occurs at 03:20:33 UT (09:20:33 local) just S. of Chelyabinsk, Russia
- Airblast damaged windows over several thousand km^2; ~1500 persons injured, mainly due to flying glass
- Large number of videos – 528 catalogued to date, 49% show direct fireball or light flash
- Ordinary chondrite (LL5) meteorites recovered

Stellar calibrations provide trajectory verification

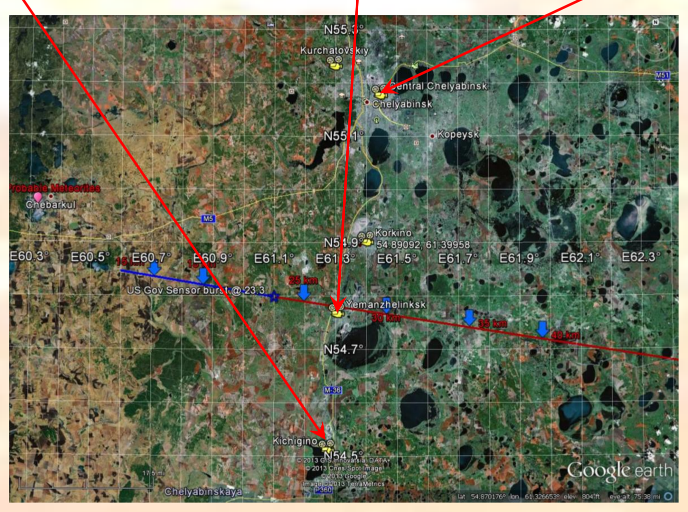
At widely-spaced locations, dashboard camera images (upper row) were calibrated using a stationary camera to image the stars (lower row)



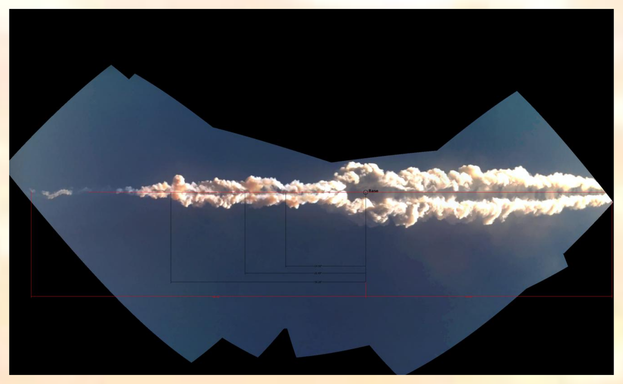
Kichigino   Yemanzhelinksk   Central Chelyabinsk



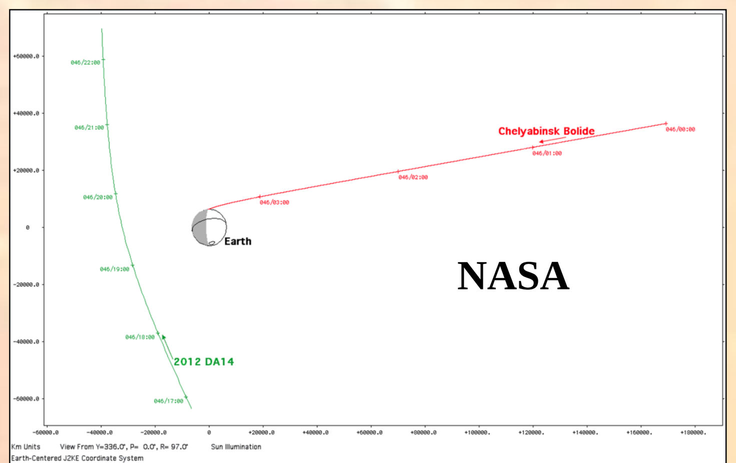
Mushroom cloud at 28 km height, cloud 5 km in diameter risen to 35 km altitude after ~2 minutes



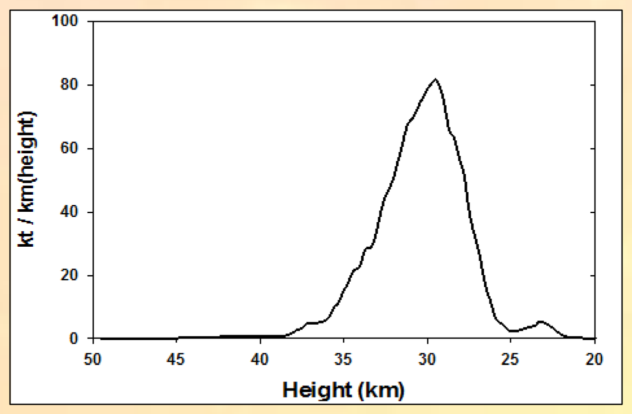
Stellar calibration locations relative to trajectory

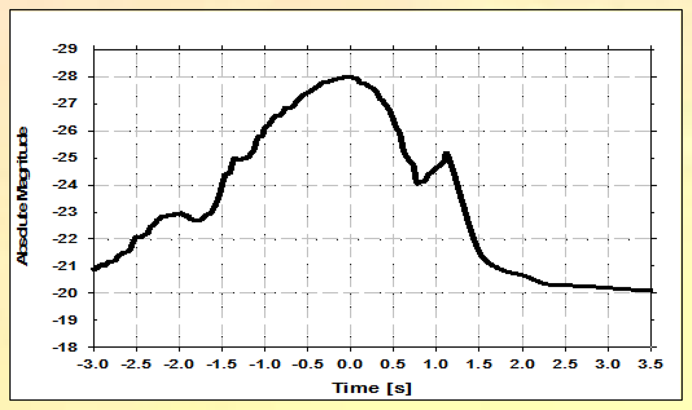


Twin vortices (2D moving mushroom cloud feature) 2-3 km separation, 1-km wide after 1 minute



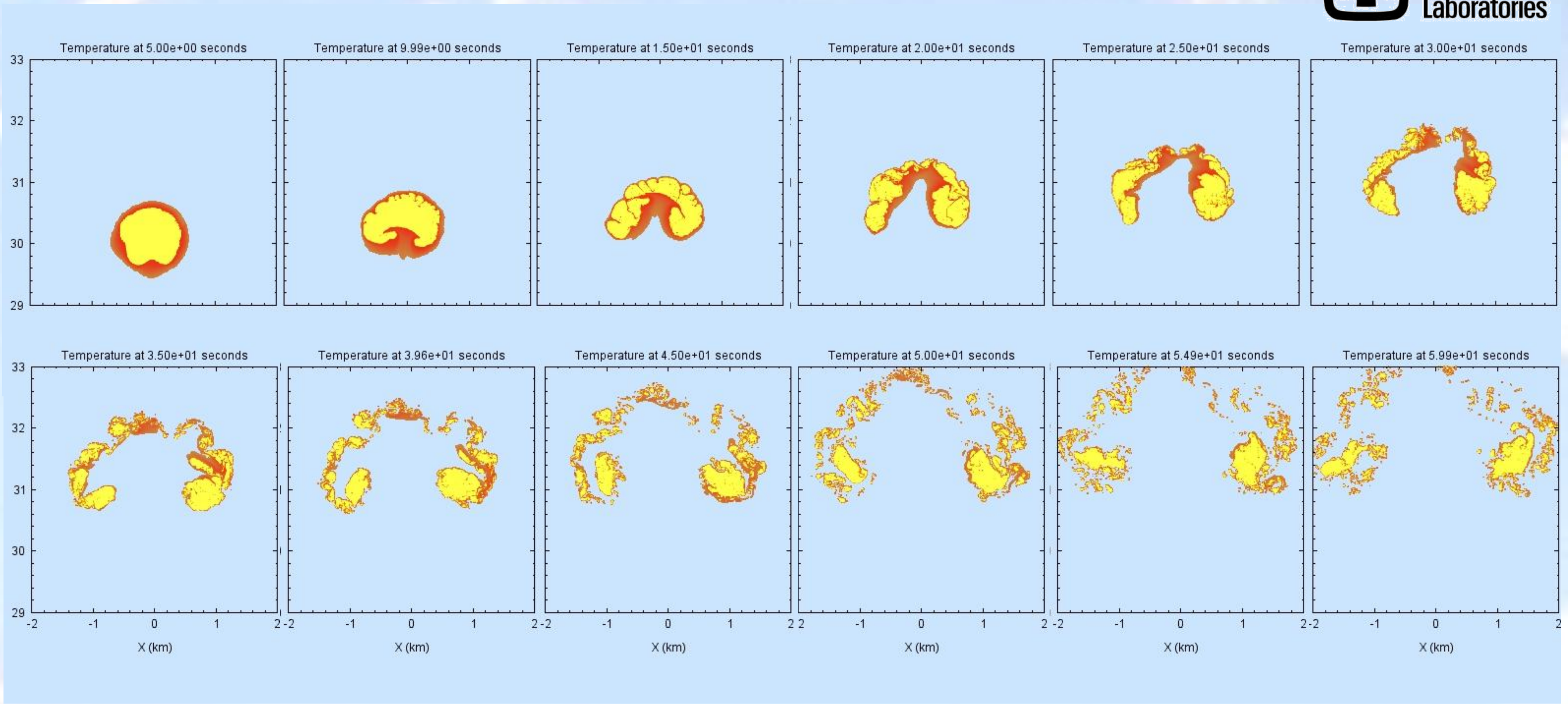
The two Feb 15, 2013 events were not related





Light curves were determined using indirect scattered light and corrected for autogain. Calibrated using both meteorite-fireball events and kiloton class and larger airbursts. Total deposited energy assuming η = 17% is >471 kT

Models

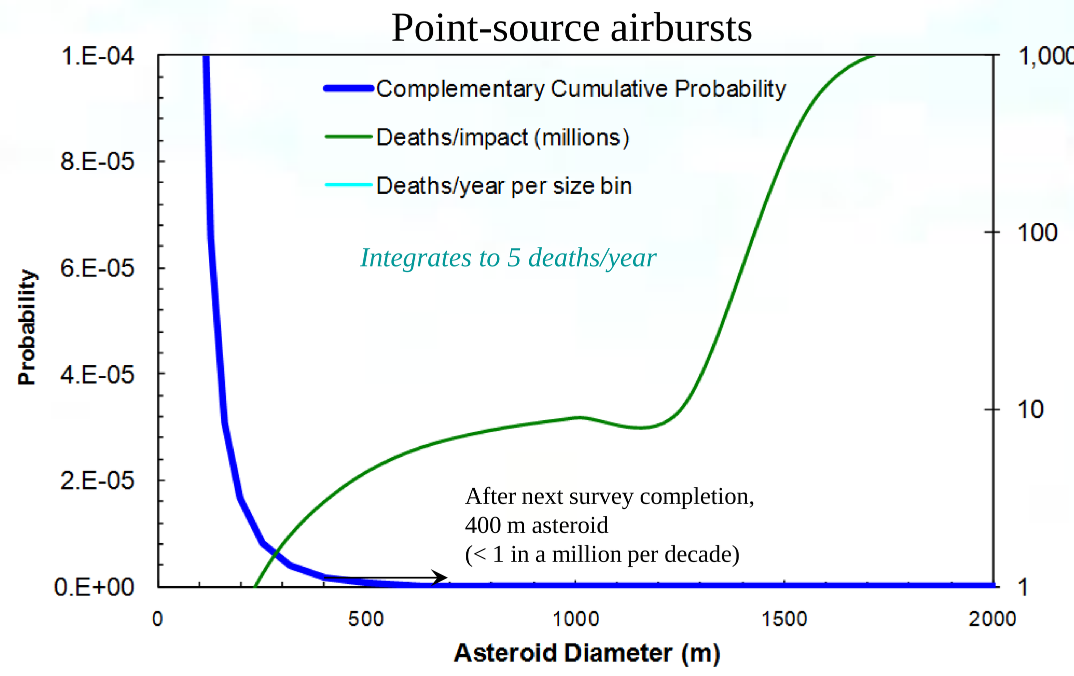


First minute of the wake in 2D cross-sections at 5 s intervals shows bifurcation into contra-rotating vortices, consistent with observations

Airburst damage potential has been underestimated

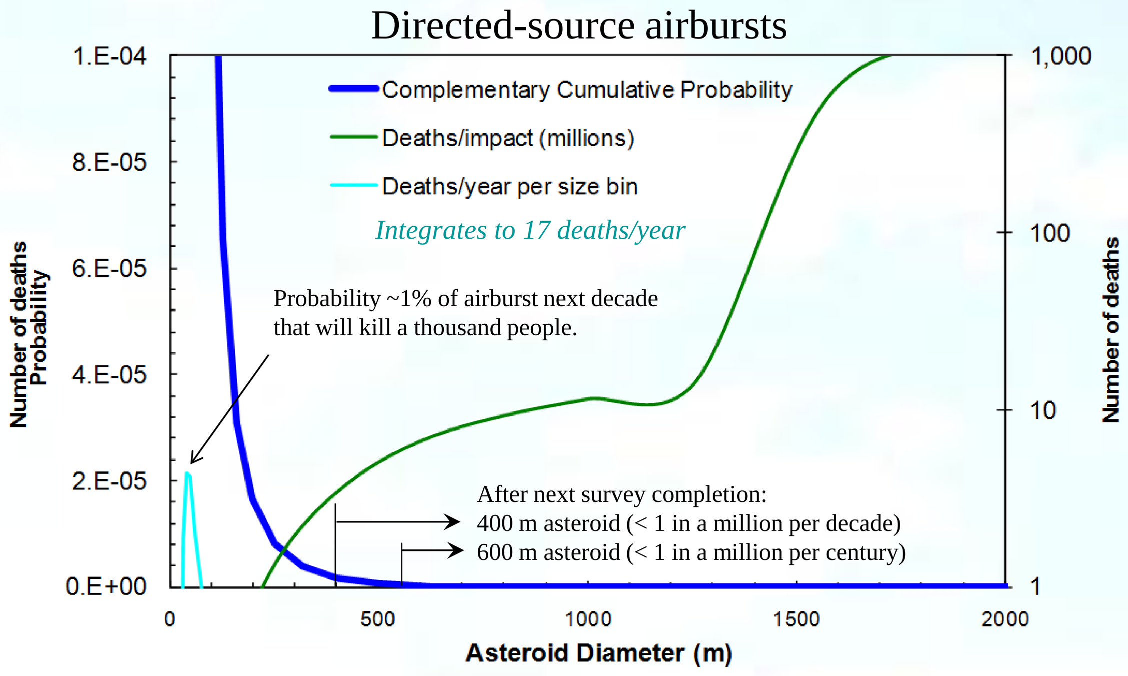
On time scales of significance, NEO orbits are deterministic. The probability of impact by a specific NEO in the next decade is either zero or one (with perfect knowledge, it is not a probabilistic problem). The *actual* risk is not the same as the *assessed* risk. *Actual* risk does not change, but *assessed* risk evolves as our state of knowledge improves. The graphs below represent two components of knowledge. The left hand graph is based on point-source airburst damage estimates, which is now known to underestimate the damage potential. The right-hand graph accounts for the significantly greater damage potential of collisional airbursts. Barring the extremely unlikely discovery of an NEO on a collision course, the assessed risk is expected to decline to an average of about 17 deaths/year worldwide after the next survey is complete. Most of these will be due to airburst events, for which the appropriate mitigation method is civil defense.

Point-source airbursts



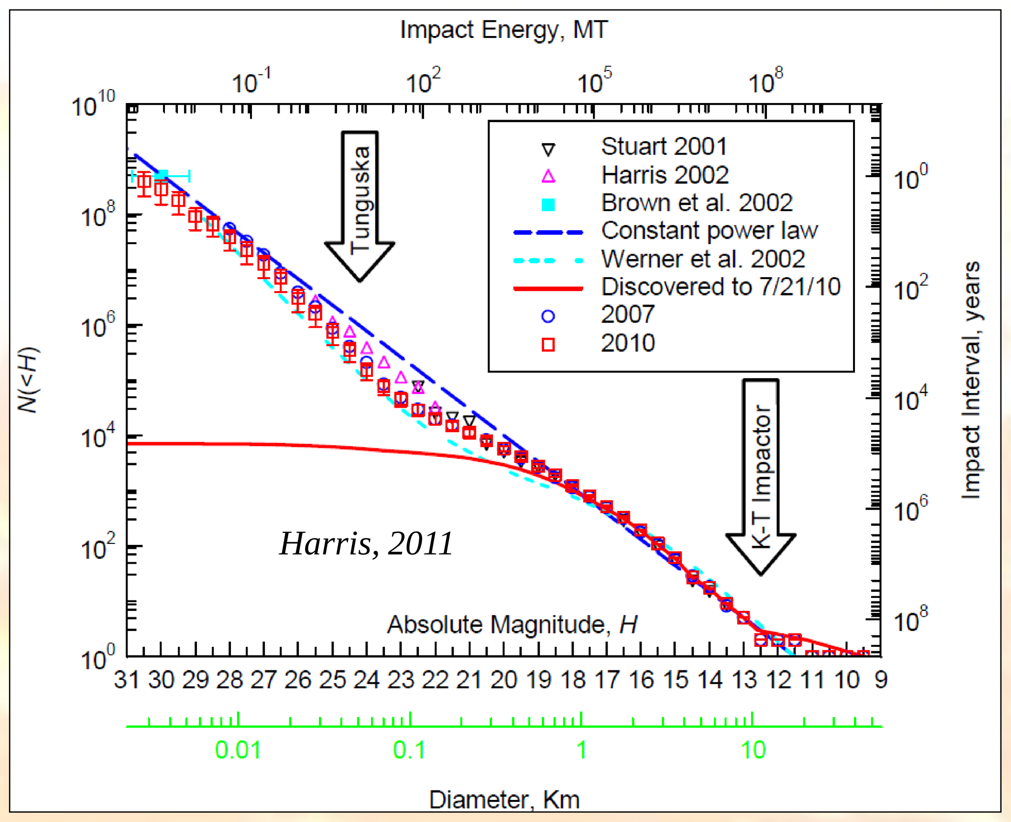
Future (after next survey) threat = 5 deaths/year

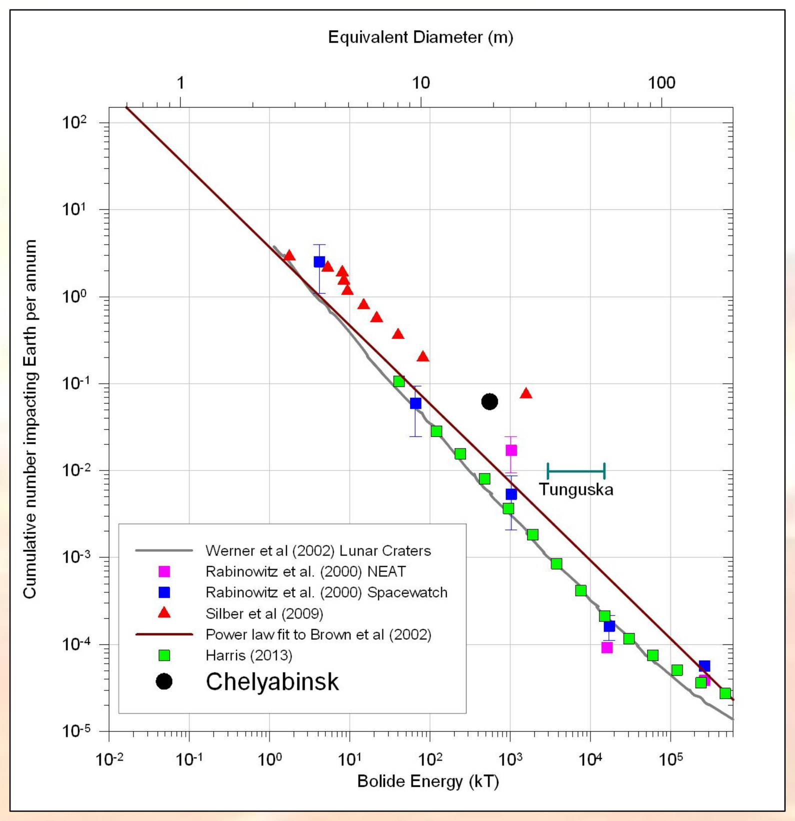
Directed-source airbursts



Future (after next survey) threat = 17 deaths/year (240% increase)

Airburst frequency may have been underestimated





Left: Telescope-based population curve suggests deficit of NEOs in the airburst size range relative to power law distribution

Right: Bolide-based population curve suggests surplus of NEOs in this size range, suggesting that airburst risk has been underestimated..

Chelyabinsk Consortium: Jelle Assink (CEA), Luciana Astiz (UCSD), R. Blaauw (NASA-MEO), M. Boslough (SNL), J. Borovicka (Ondrejov Observatory), Nicolas Brachet (CTBTO), David Brown (CTBTO), M. Campbell-Brown (UWO), Peter Brown (UWO), Lars Ceranna (BGR), D. Clark (UWO), W. Cooke (NASA-MEO), Catherine de-Groot Hedlin (UCSD), Douglas Drob (NRL), E. Duffy (UWO), Wayne Edwards (NRCan), Laslo Evers (KNMI), Milton Garces (ISLA), Michael Hedlin (UCSD), Aaron Kingery (NASA-MEO), Cale Kochenour (NASA-MEO), Zbyszek Krzeminski (UWO), Gabi Laske (UCSD), Alexis Le Pichon (CEA), Pierrick Mialle (CTBTO), D. Moser (NASA-MEO), Alex Saffer(NASA-MEO), E. Silber (UWO), Pieter Smets (KNMI), Richard Spalding (SNL), P Spurny (Ondrejov Observatory), Ed Tagliaferri (ETSS), D. Uren (UWO), R. Weryk (UWO), Rod Whitaker, (LANL), P. Wiegert (UWO)

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Below: First 30 s of the wake in 3D cross-sections at 5 s intervals, showing bow shock and early formation of mushroom clouds