Asteroid Threat Assessment

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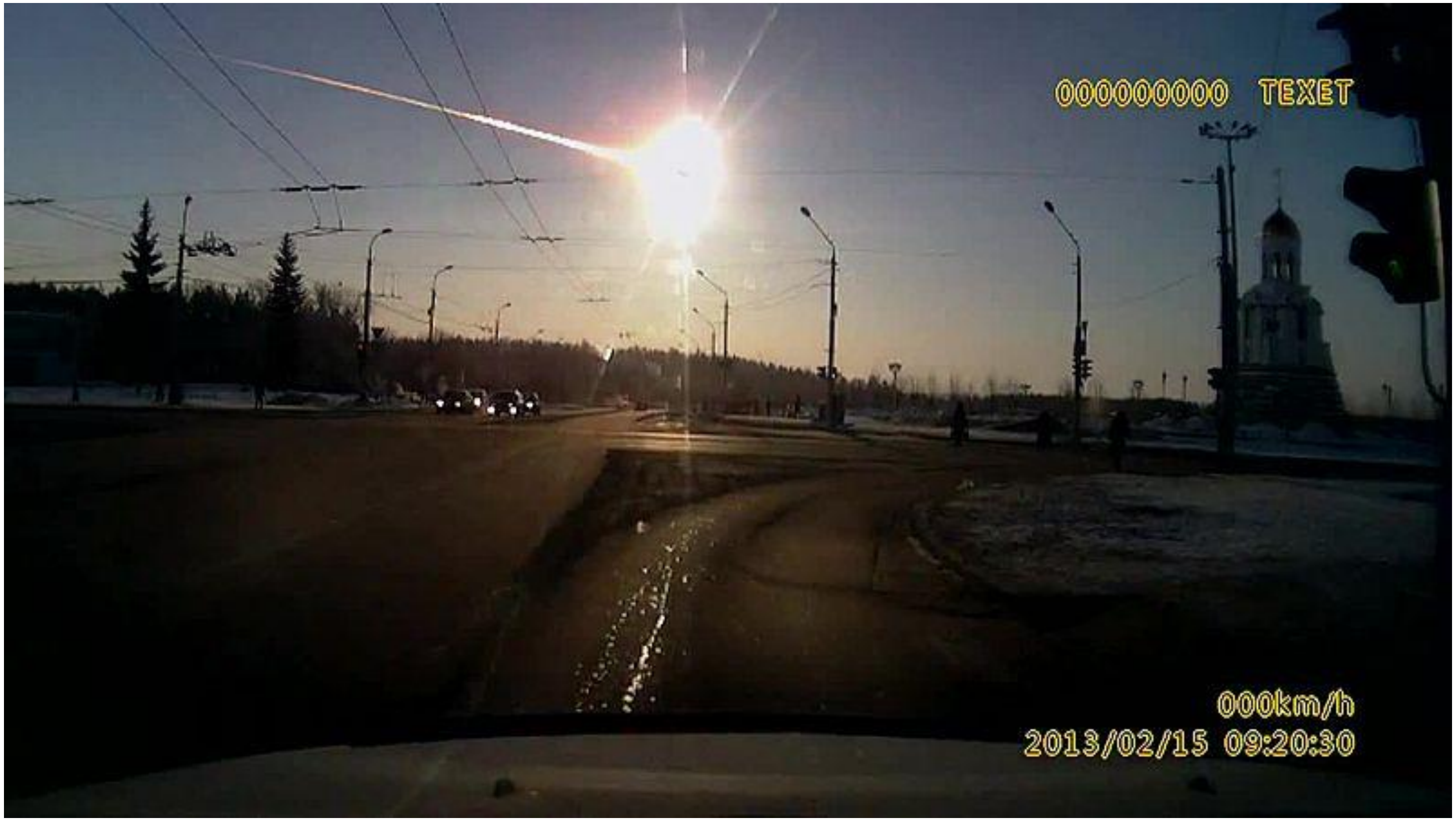
Overview

- Motivation
- Physics-Based Impact Risk Model
  - Airburst & Overpressure Threat
  - Surface Impact Threat
  - Frequency of Interactions
- Results

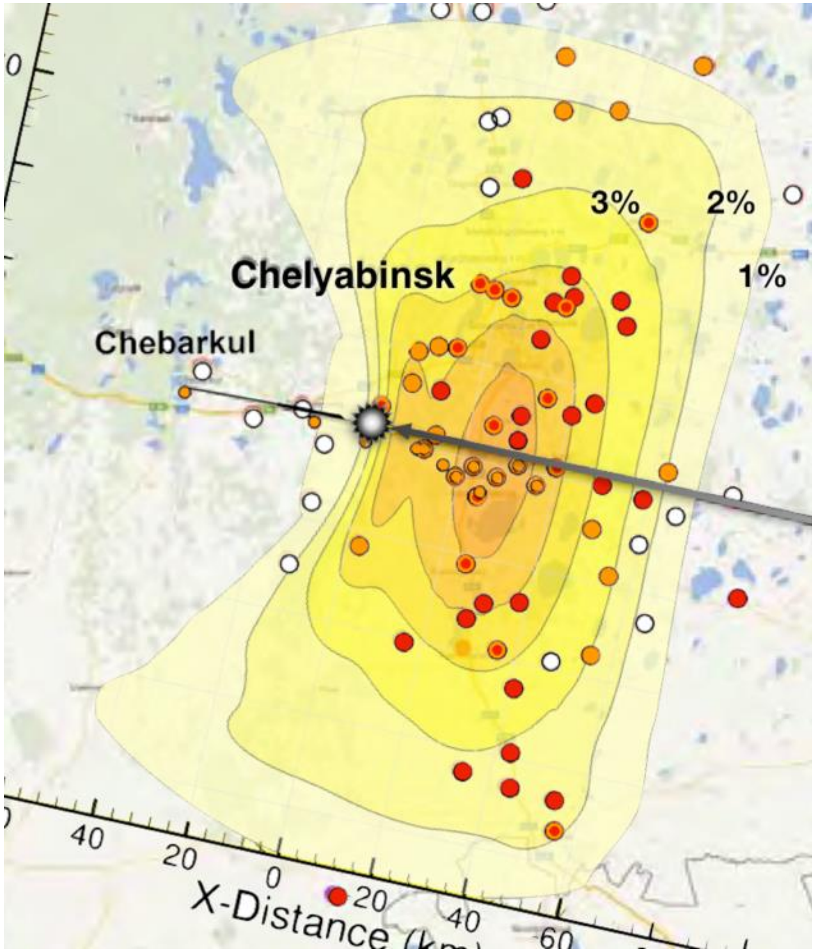
Credit: anosmicovni

Chelyabinsk (Feb. 2013)



Credit: Aleksandr Ivanov

Chelyabinsk Damage



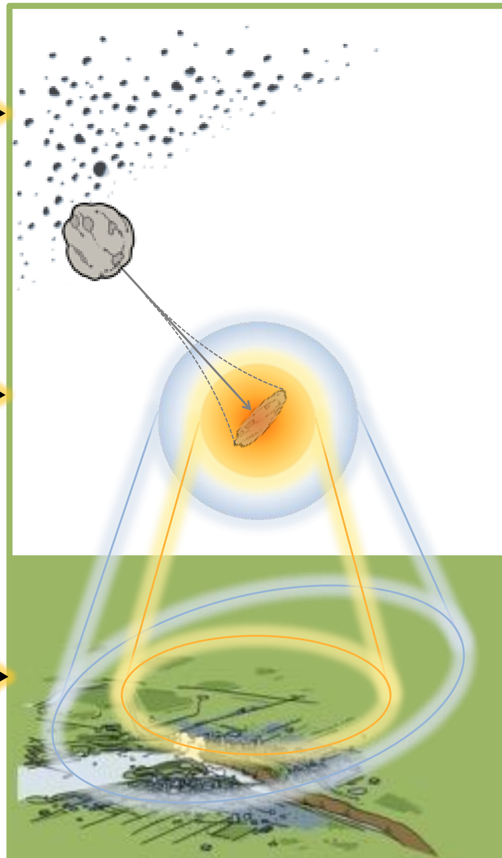
Asteroid Threat Assessment Project

Characterization
- Physical Properties
- Orbital Trajectories

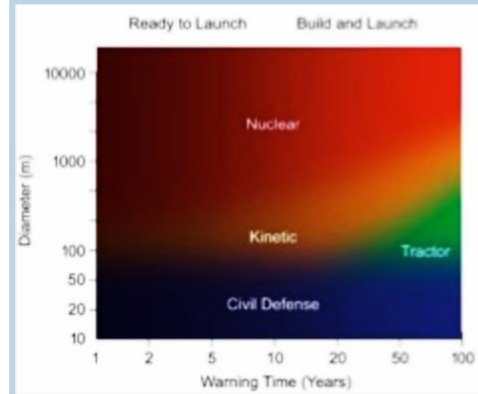
Atmospheric Entry & Airburst Modeling
- Entry Trajectories/Ablation
- Energy Deposition

Surface Impact Effects Modeling
- Ground Damage
- Tsunami Propagation

Physics-Based Impact Risk Modeling
- Quantitative Risk Metrics
- Sensitivity to Uncertainty



Impact Risk Assessment Tools

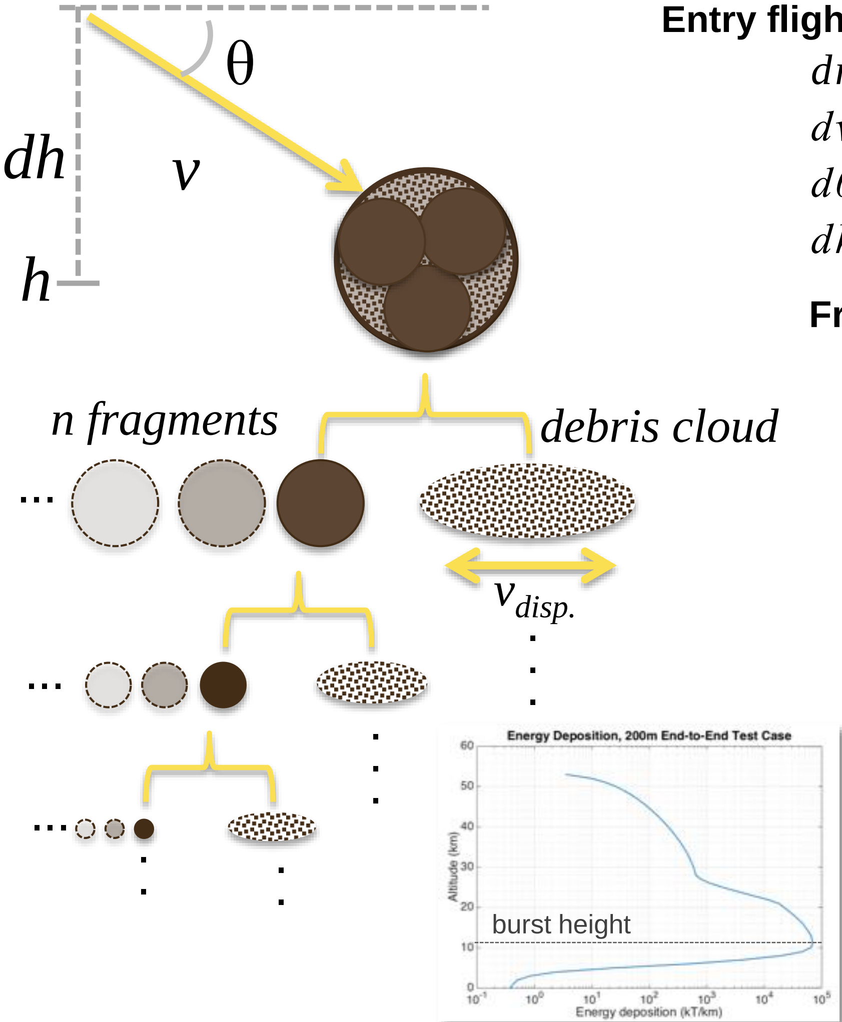


Credit: Tim Warchocki

Risk-Informed Decision Support
- Mitigation Planning
- Defense Strategies
- Response Decisions
- Policy Development

Energy Deposition Modeling

- Analytic model of asteroid entry/breakup to estimate energy deposited in the atmosphere
- Combines progressive breakup of independent fragments and “pancaking” debris clouds.



Entry flight: integrates meteor equations of motion and ablation

$$dm/dt = -0.5\rho_{air}v^3A\sigma$$
$$dv/dt = \rho_{air}v^2AC_D/m - g\sin\theta$$
$$d\theta/dt = (v/(R_E+h) - g/v)\cos\theta$$
$$dh/dt = v\sin\theta$$

Fragmentation when pressure > strength

$$\rho_{air}v^2 > strength$$

Each break yields:

- Multiple independent, identical fragments (baseline 2)
- Debris cloud of specified mass fraction (baseline 50%)

Fragment strengths increase with decreased size

$$S_2 = S_1(m_1/m_2)^\alpha$$

Clouds broaden and slow under common bow shock

$$v_{dispersion} = v_{cloud}(3.5\rho_{air}A/\rho_{cloud})^{1/2}$$

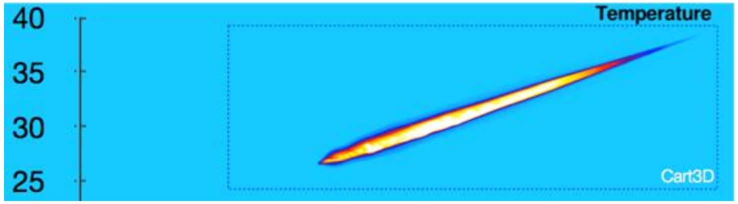
Energy deposition computed as change in total KE of all fragments/clouds as a function of altitude.

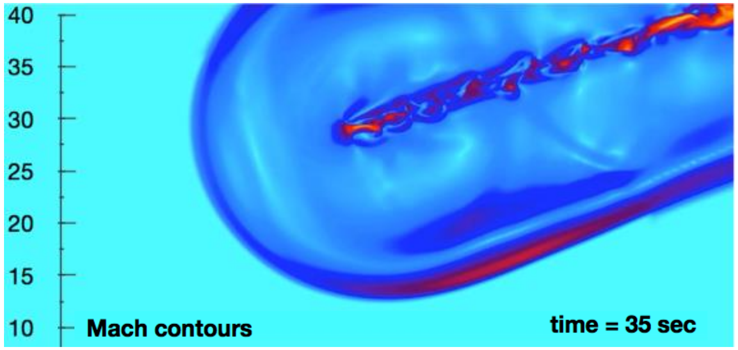
Airburst at altitude of peak energy deposition.

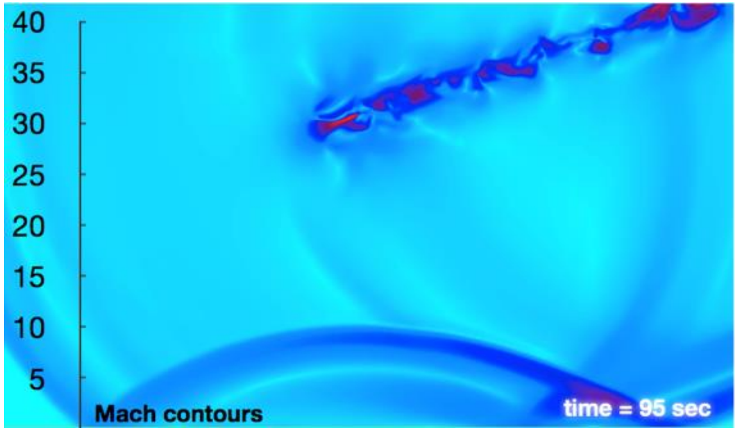
Blast Propagation

- Blast propagation through the atmosphere, simulated using Cart3D
  - Unstructured, Cartesian, Eulerian solver
  - Isothermal atmosphere
  - Energy added to flow in multiple ways
    - Static spherical charge
    - Line source
- Time-dependent pressures tracked on the ground
  - Peak pressure magnitude
  - Arrival times
- Computed results compared with Popova et. al (2013)
  - ~20m diameter
  - ~20 km/s entry velocity

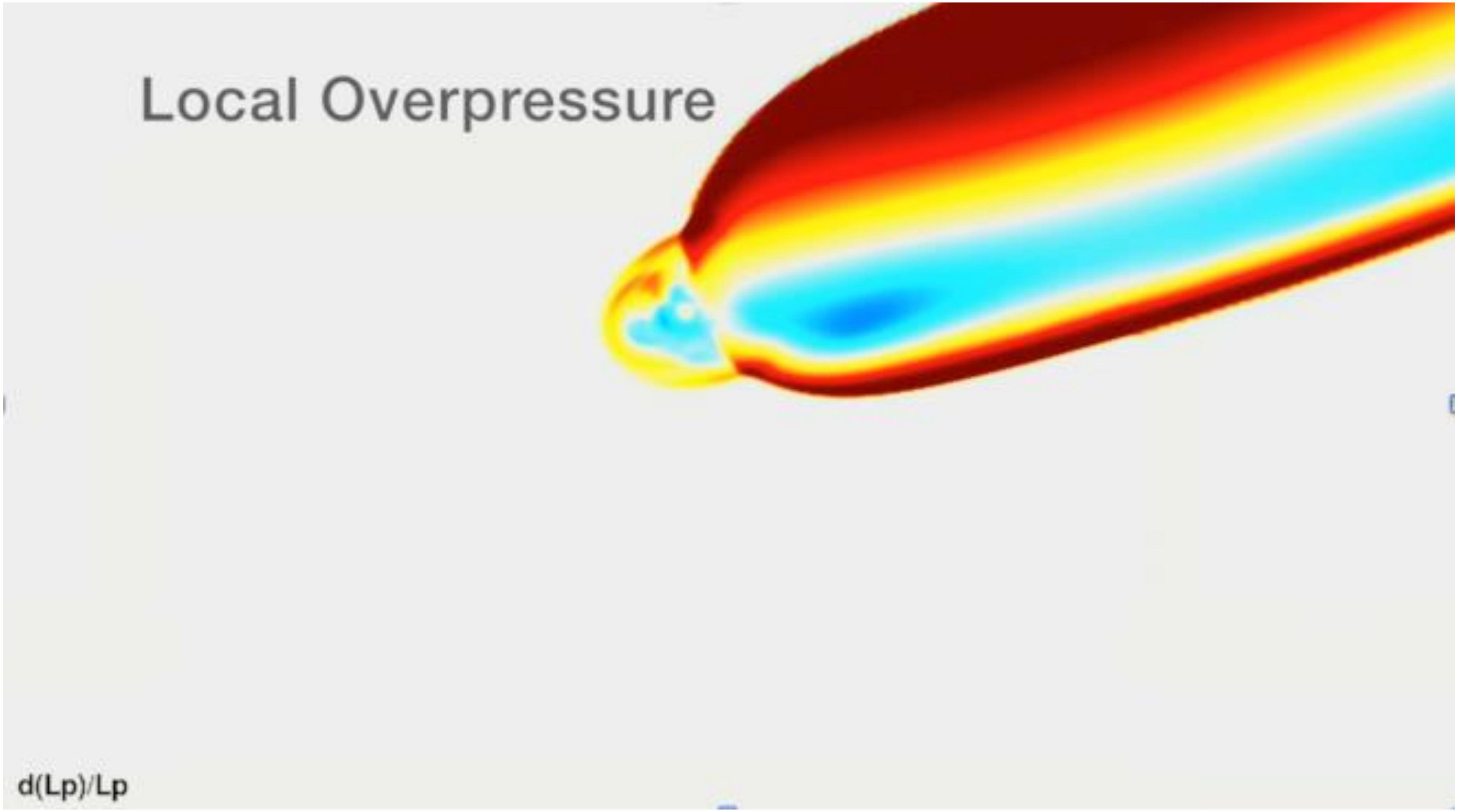
Cart3D asteroid entry modeling







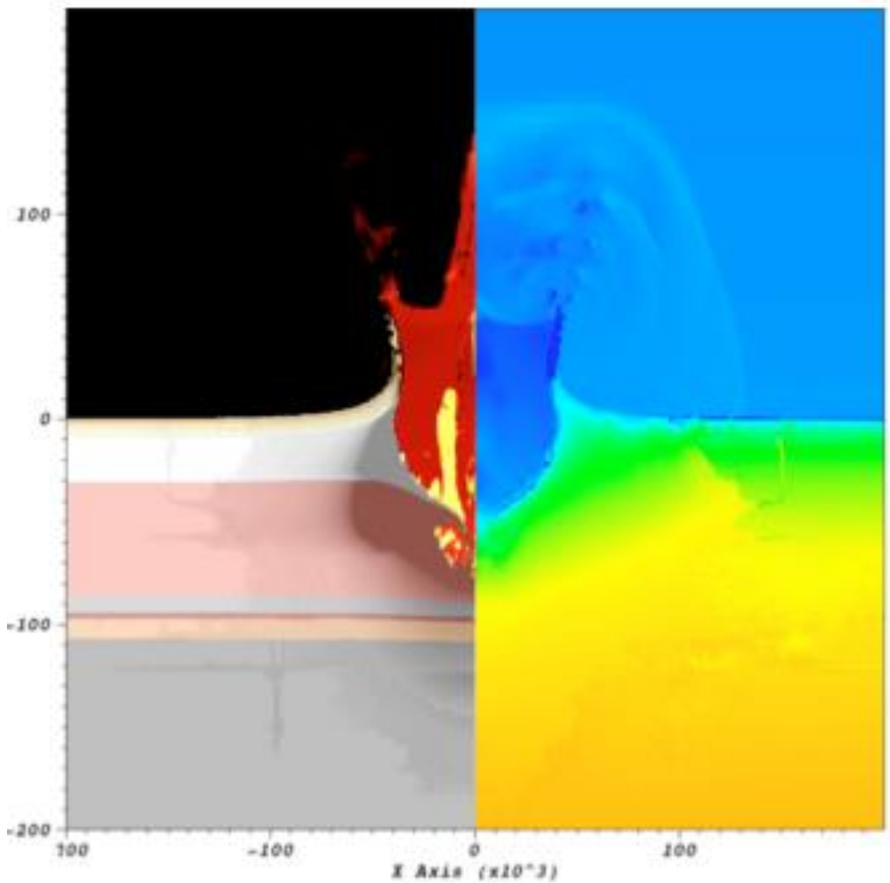
Blast Propagation



Land Impact Simulation

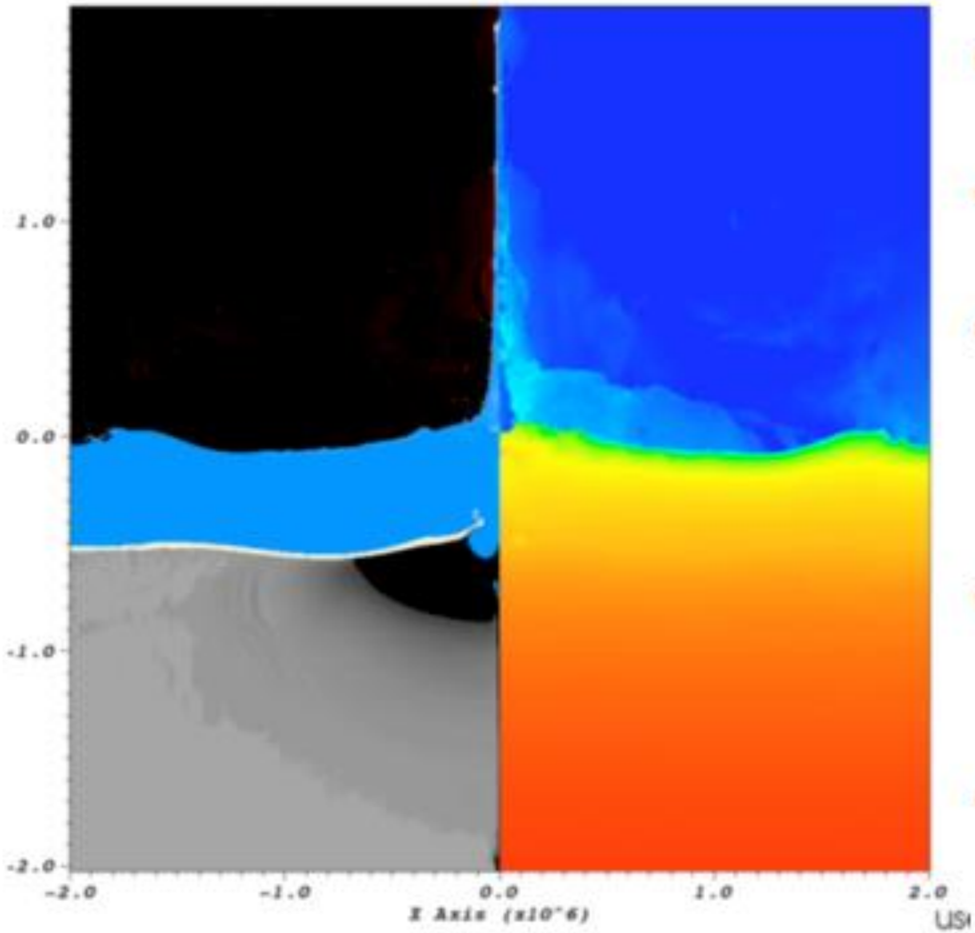
- Preliminary test: Ø40m Iron meteor, 15 km/s vertical impact

Preliminary Test Simulation.



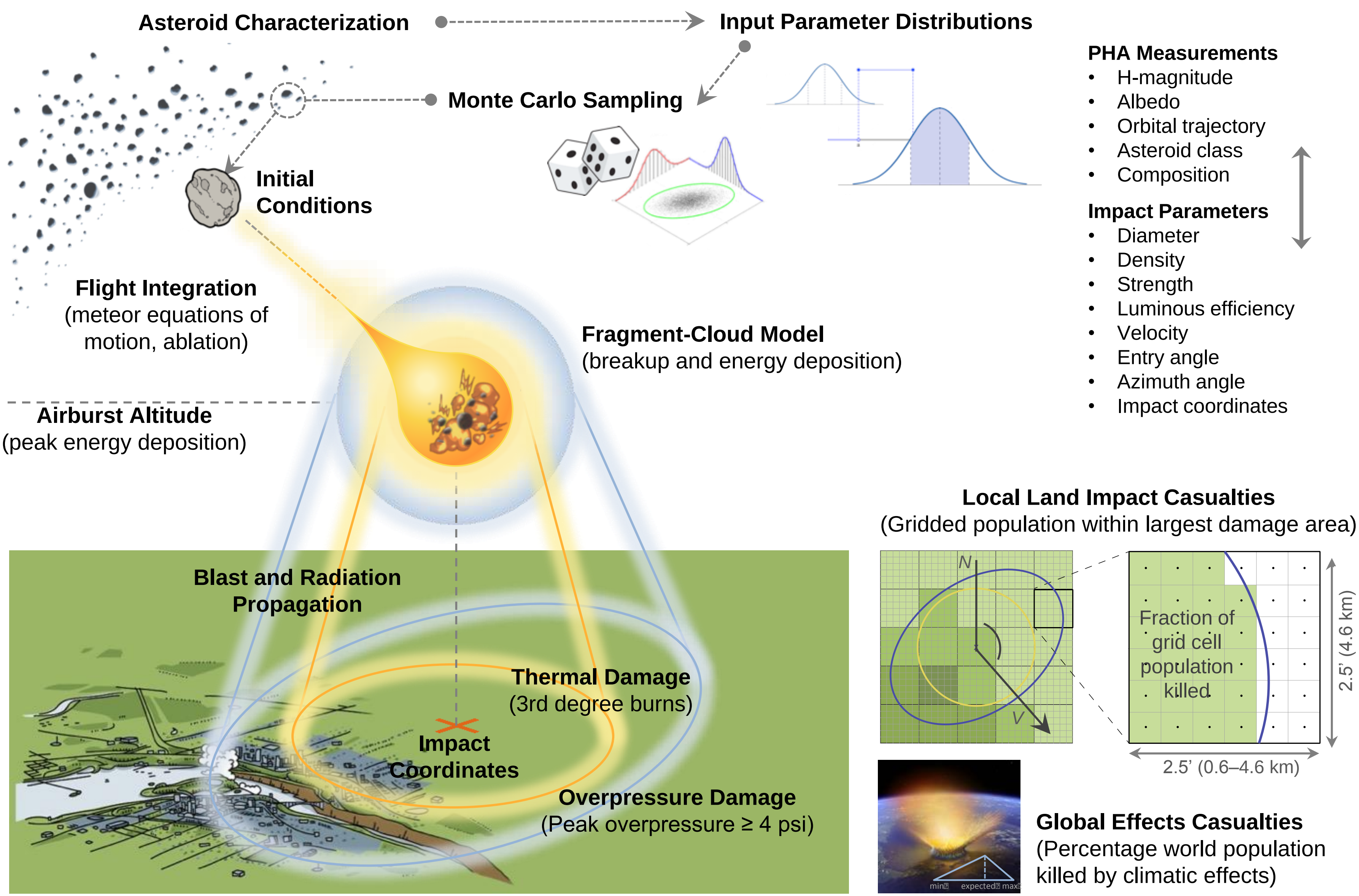
Ocean Impact Simulation

Preliminary Test Simulation.



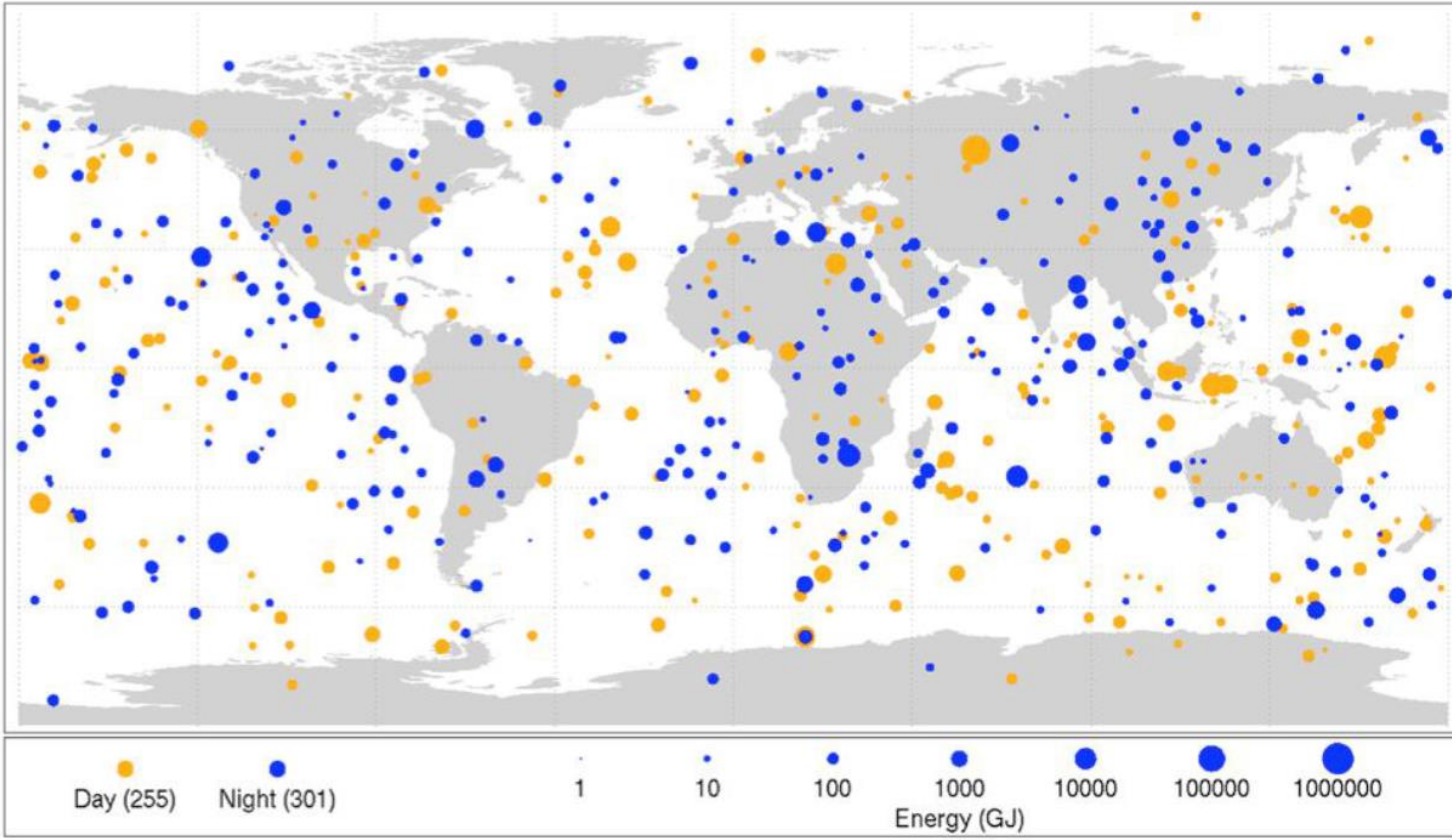
- 2.1 Million years ago in South-East Pacific Ocean
- Only known impact into deep Ocean Basin
- Evidence of mega-tsunami debris on coasts of Chile and Antarctica as well as drill cores from Bellingshausen Sea.
- Current estimates Ø750m rock at 12 km/s vertical (10 GT) or 18 km/s at 45° .
- 5000m deep ocean, 250m sediment, basalt crust.

Physics-Based Impact Risk Model



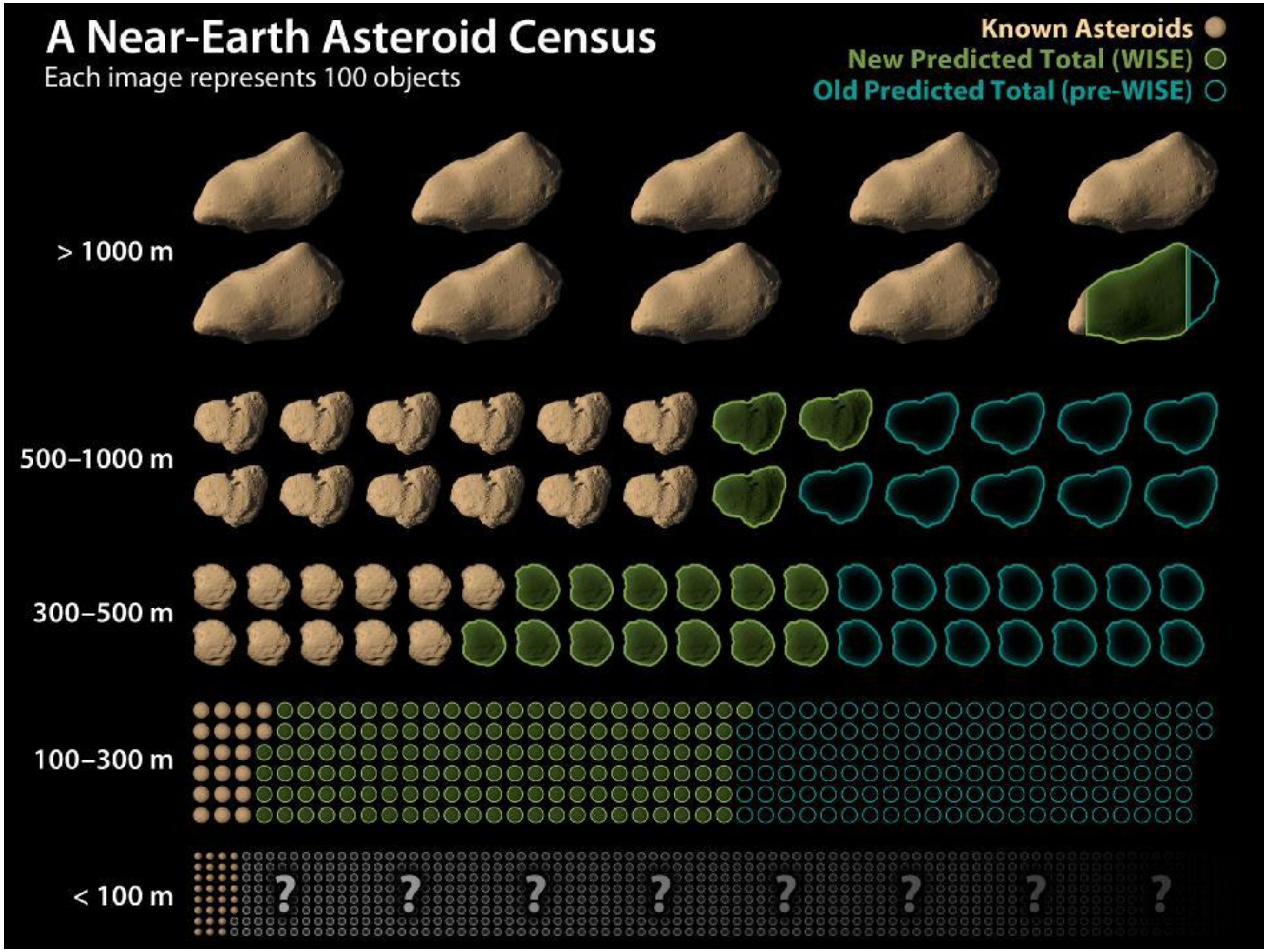
Bolide Events 1994 – 2013

Small Asteroids that Disintegrated in Earth's Atmosphere



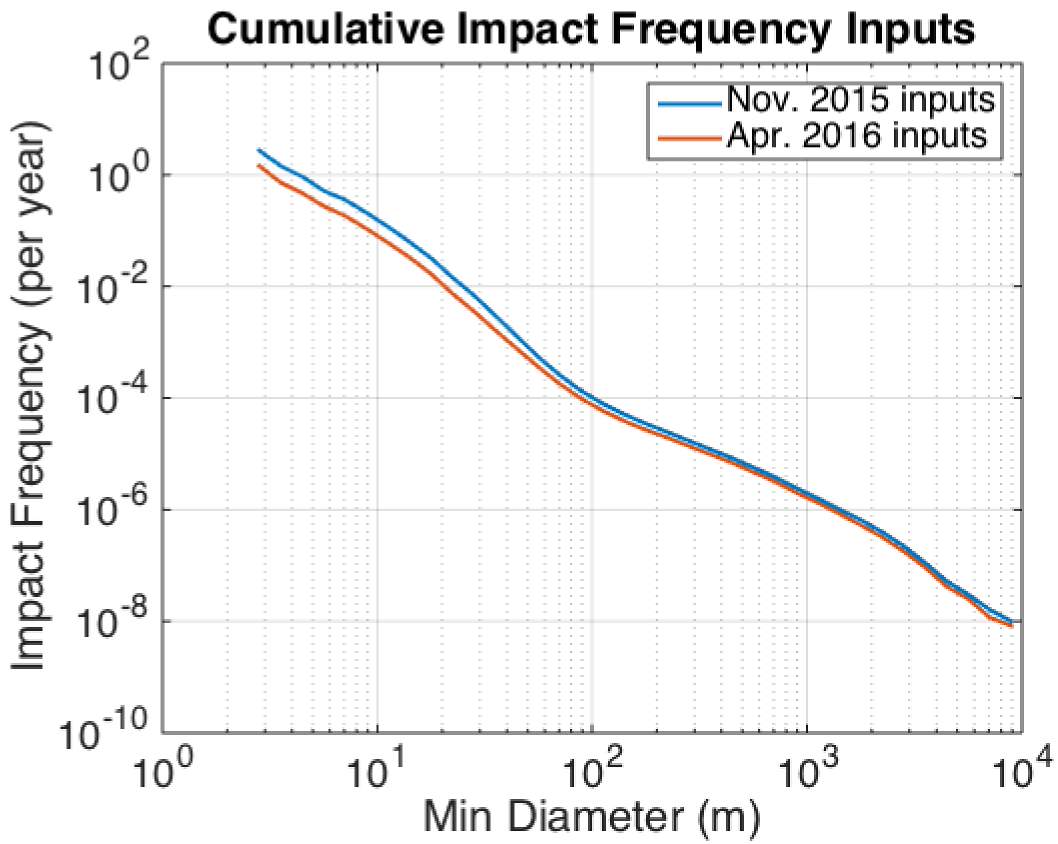
This diagram maps the data gathered from 1994-2013 on small asteroids impacting Earth's atmosphere and disintegrating to create very bright meteors, technically called "bolides" and commonly referred to as "fireballs". Sizes of orange dots (daytime impacts) and blue dots (nighttime impacts) are proportional to the optical radiated energy of impacts measured in billions of Joules (GJ) of energy, and show the location of impacts from objects about 1 meter (3 feet) to almost 20 meters (60 feet) in size.

Surveys to Detect Potential Hazards



Credit: NASA

Earth Impact Frequency

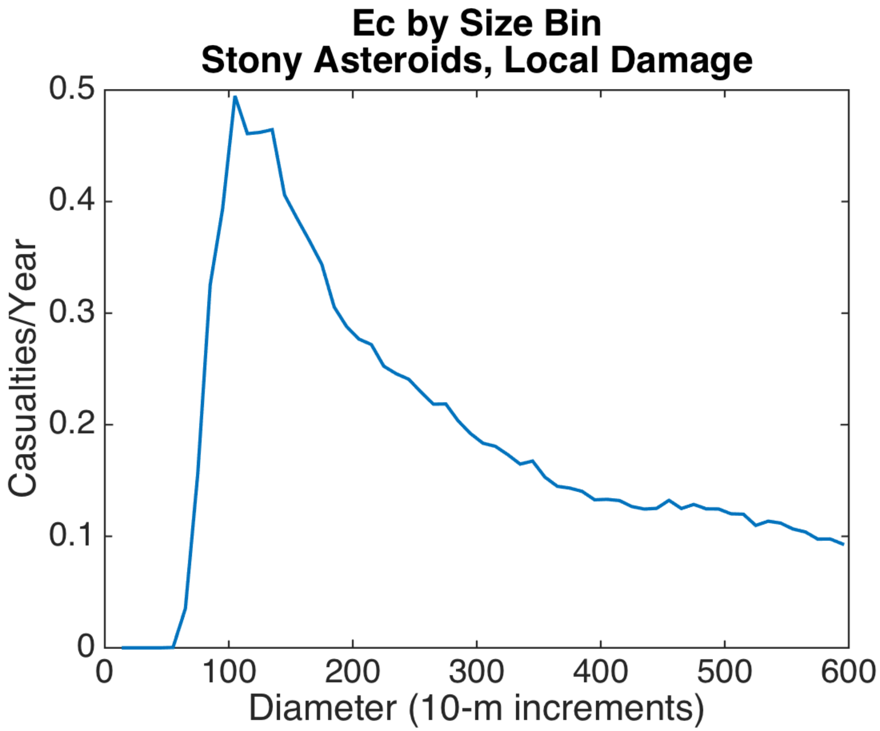


Source: Alan Harris

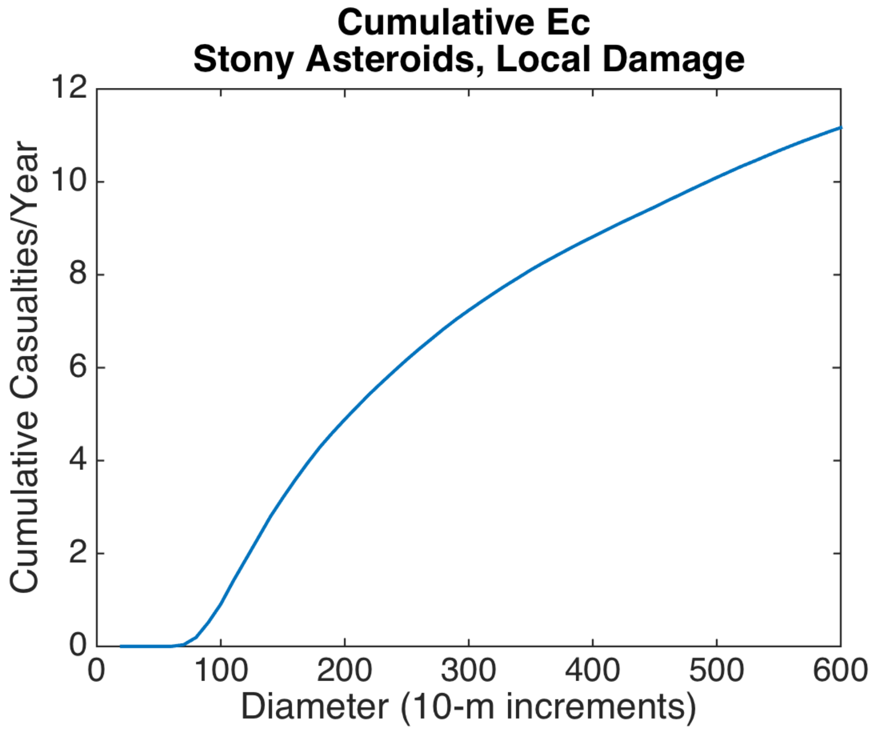
E_C: Estimated Casualties/Year

- Average potential casualties from impacts within a given size range, multiplied by the expected impact frequency/year of that size range.

E_c for each given size range (changes with bin size)

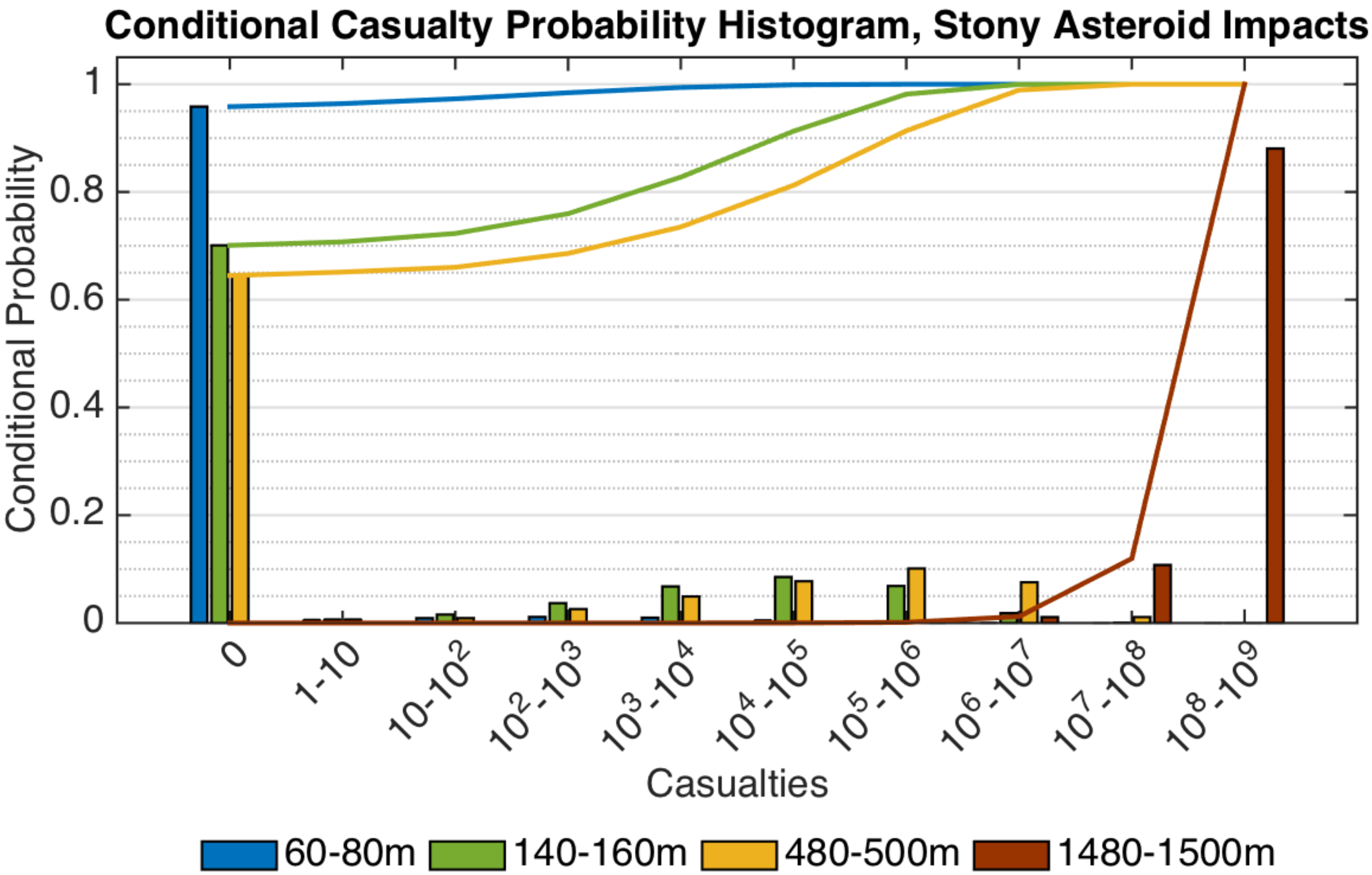


Cumulative E_c for impacts up to given size



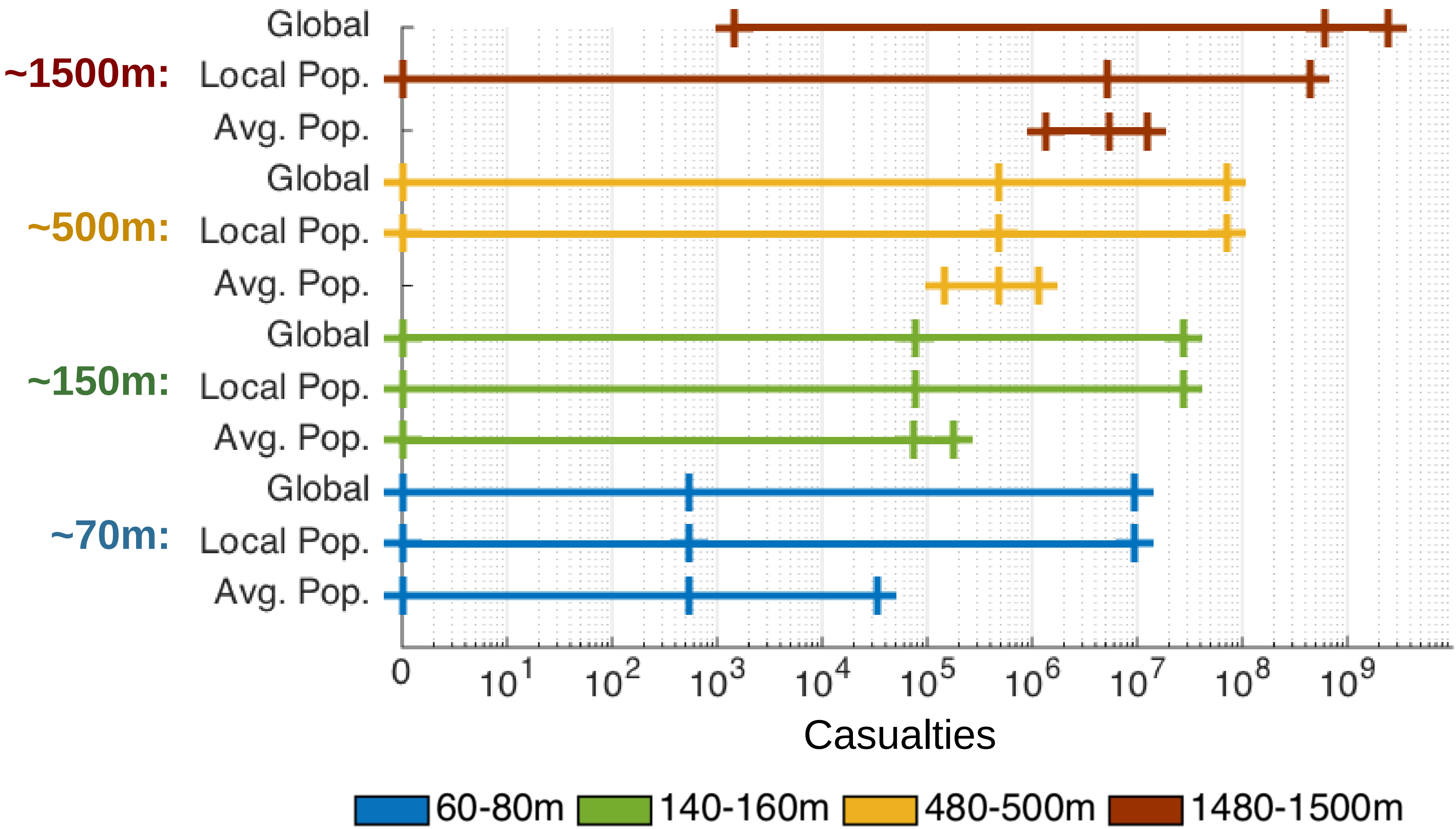
Beyond Average Casualty Rates

- Expected values based on averages misrepresent likely outcomes

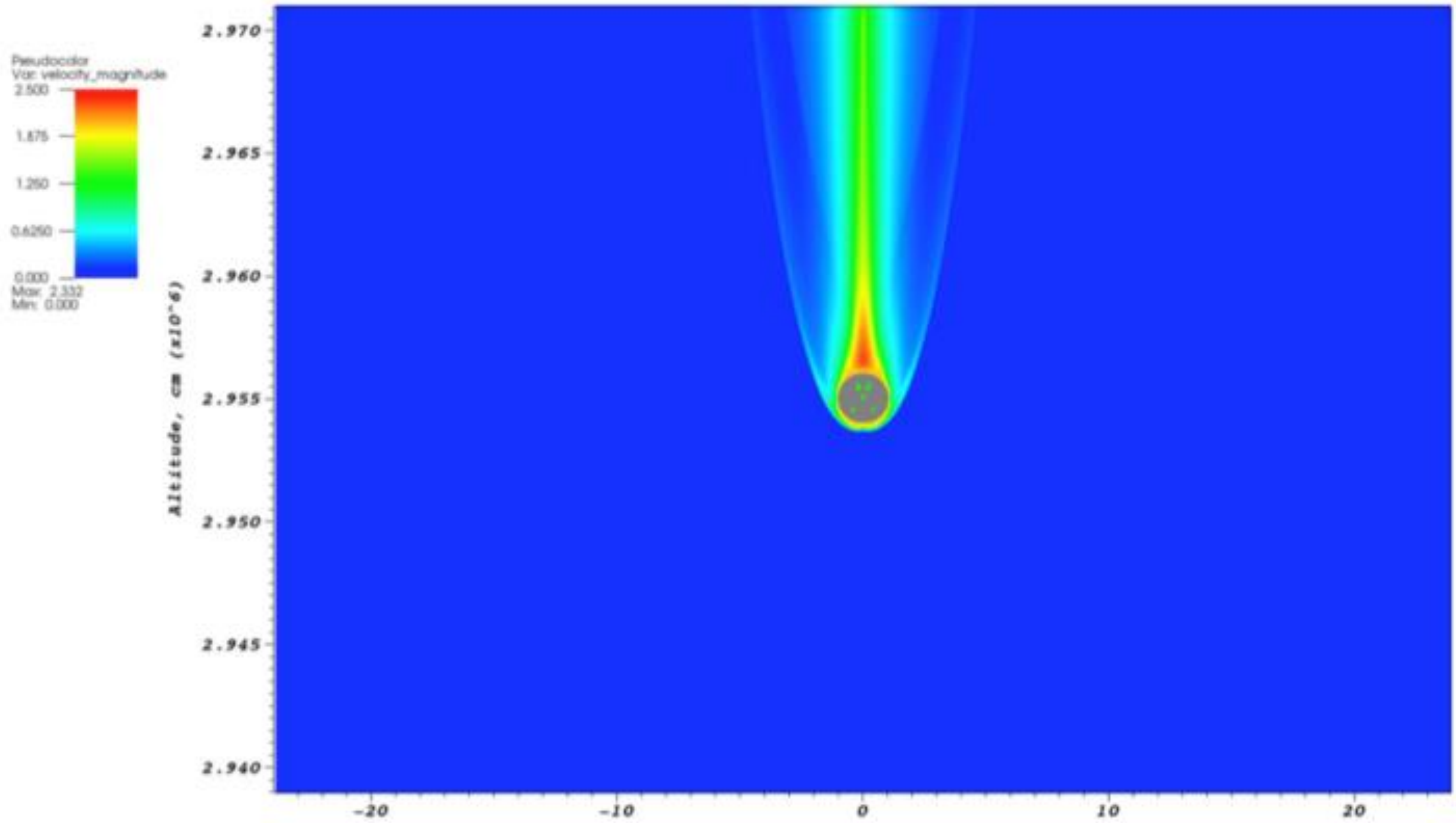


Impact of Population Distribution and Global Effects

- Impact location dominates until global effects phase in.



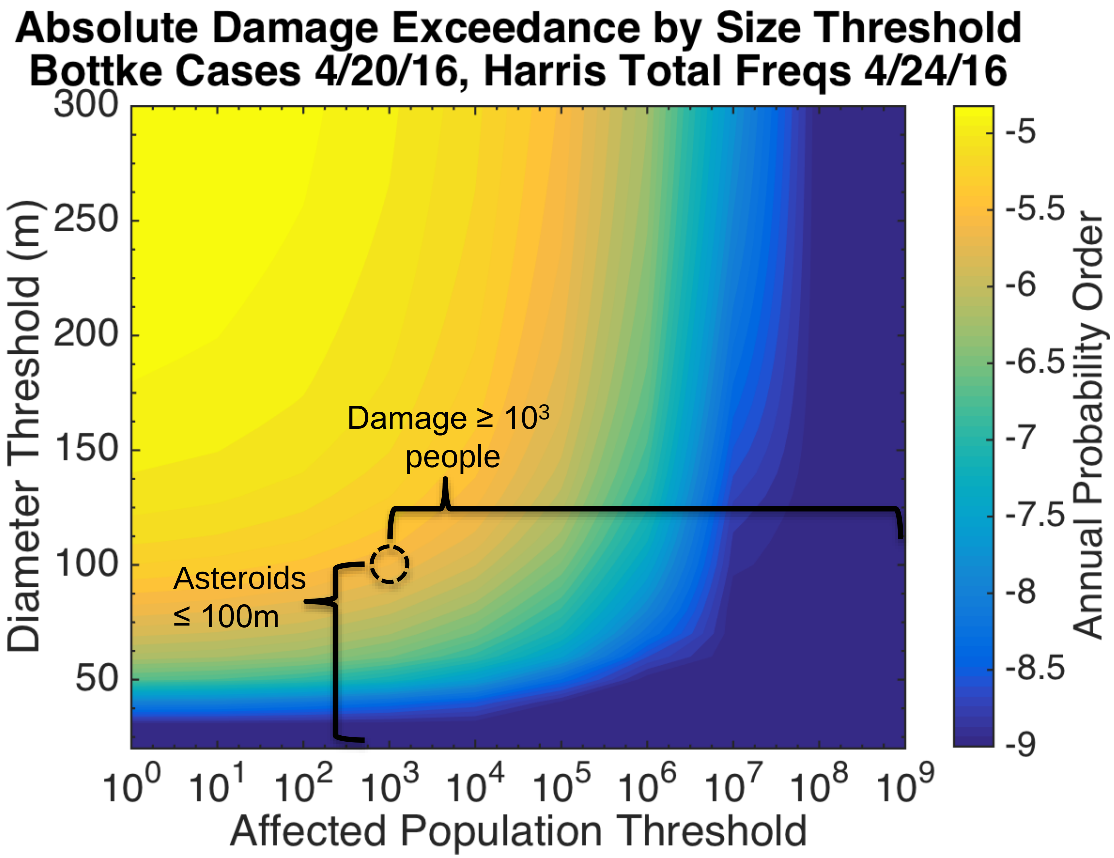
Questions?


Pseudocolor
Var: velocity_magnitude
2.500
1.875
1.250
0.6250
0.000
Max: 2.332
Min: 0.000
2.970
2.965
2.960
2.955
2.950
2.945
2.940
Altitude, cm (x10^6)
-20
-10
0
10
20

BACKUP

Annual Exceedance Probabilities by Maximum Size Threshold

- Annual probability of an asteroid ***up to a given size*** impacting Earth ***and*** affecting ***at least*** a given population threshold or greater.



- *e.g.*, contour color plotted at 100m diameter and 10^3 population gives the cumulative probability of an asteroid 100m or smaller affecting at least 1,000 people.
- Probabilities are shown on log-scale labeled by order of magnitude, *e.g.*, -6 = one-in-a-million (10^{-6}) chance per year.
- Cumulative probabilities are used to minimize result dependence on width of diameter and population bins.
- Affected population represents 100% of the population within a 4-psi blast damage radius.