Strength and Breakup Factors in Impact Scenario Risk Assessment

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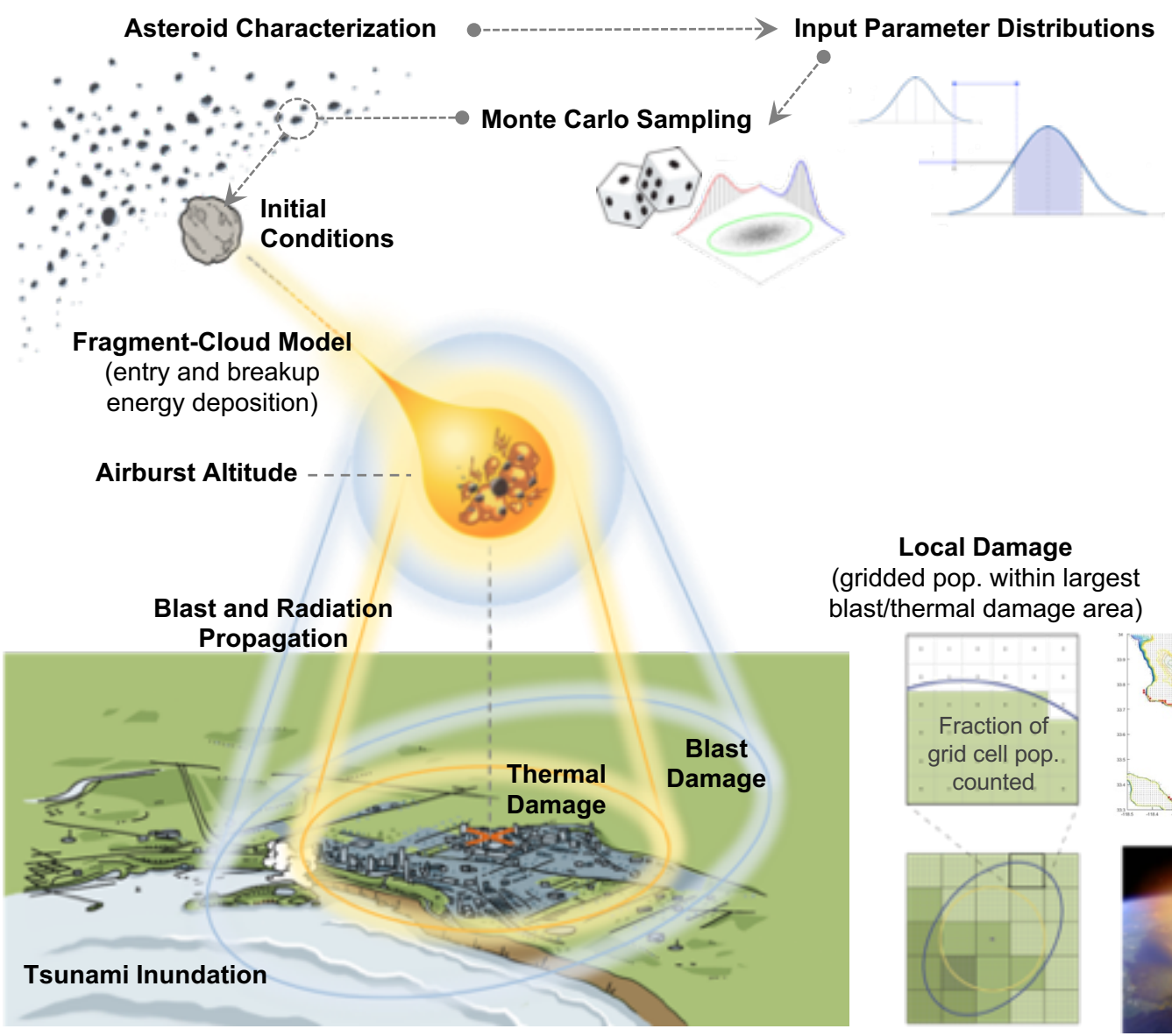
Probabilistic Asteroid Impact Risk (PAIR) Model



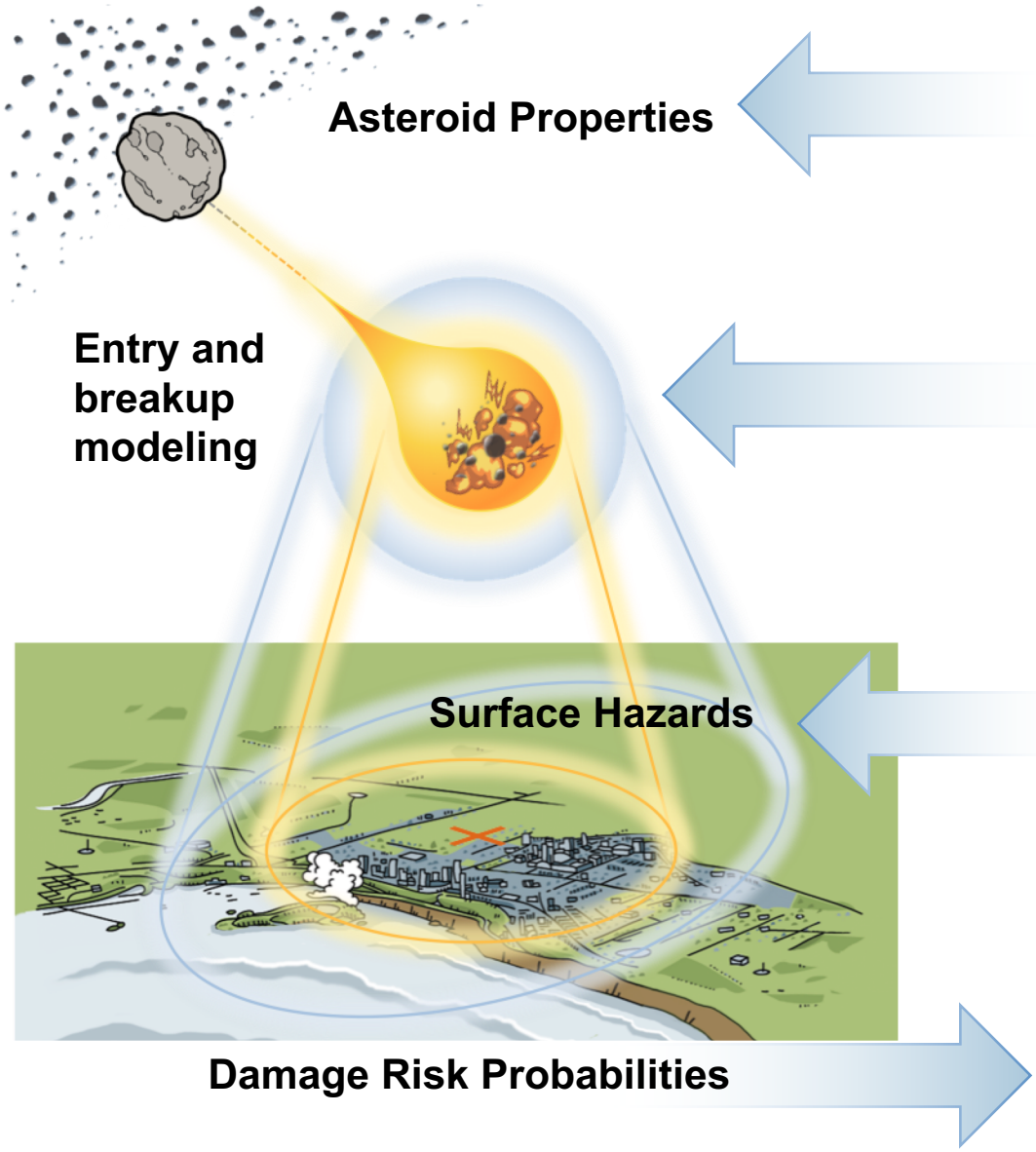
PHA Measurements

- H-magnitude
- Albedo
- Orbital trajectory
- Asteroid class
- Composition

Impact Parameters

- Diameter
- Density
- Strength
- Luminous efficiency
- Velocity
- Entry angle
- Azimuth angle
- Impact coordinates

Strength and Breakup Factors



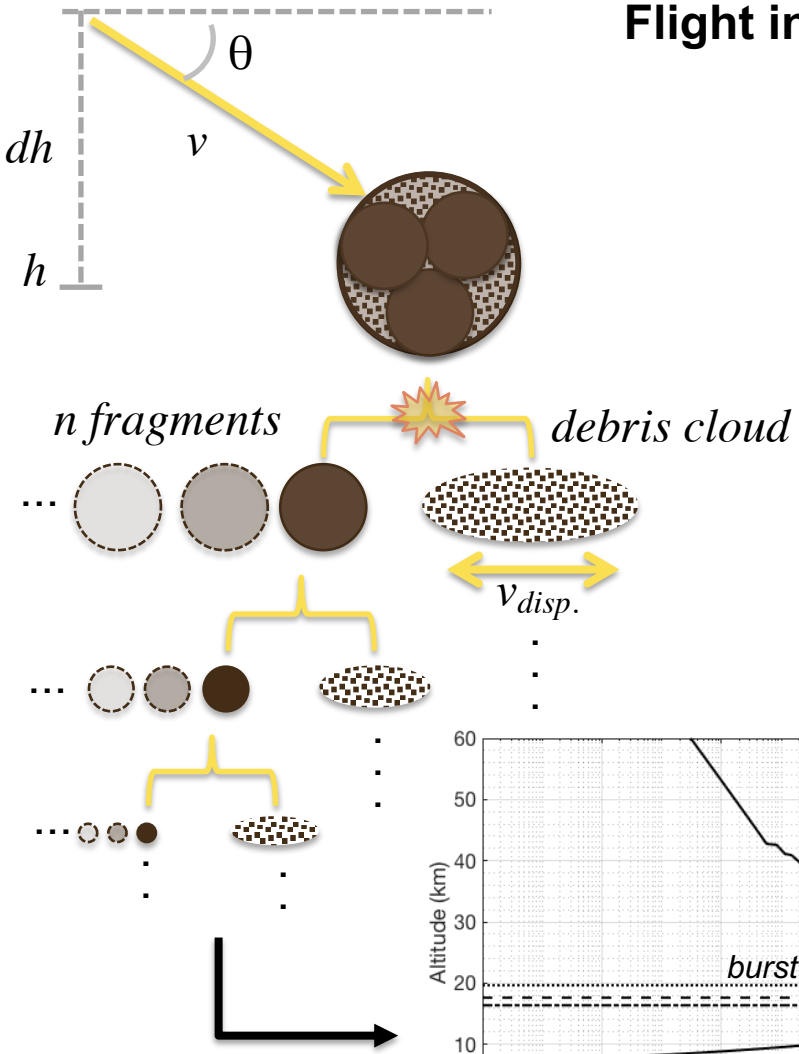
Strength ranges, distributions, and correlation with other observable properties

Different breakup behaviors, Resulting energy deposition, Airburst altitudes

Blast propagation, ground footprint estimation

How do these factors affect damage assessment trends? Where are the sensitivities?

Fragment-Cloud Model (FCM)



Flight integration:

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

Fragmentation occurs when stagnation pressure exceeds strength

$$\rho_{air}v^2 > Strength\ (S)$$

Fragment strengths increase with decreased size

$$S_1 = S_0(m_0/m_1)^\alpha$$

Debris clouds broaden and slow under common bow shock

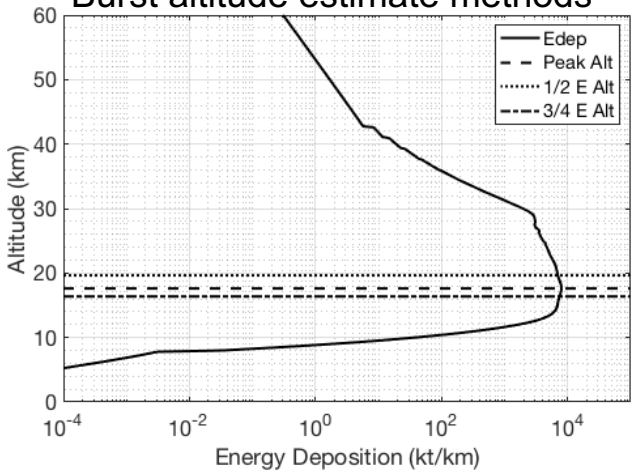
$$v_{disp.} = v_{cloud}(C_{disp}A\rho_{air}/\rho_{debris})^{1/2}$$

Atmospheric energy deposition rates used to estimate airburst altitude

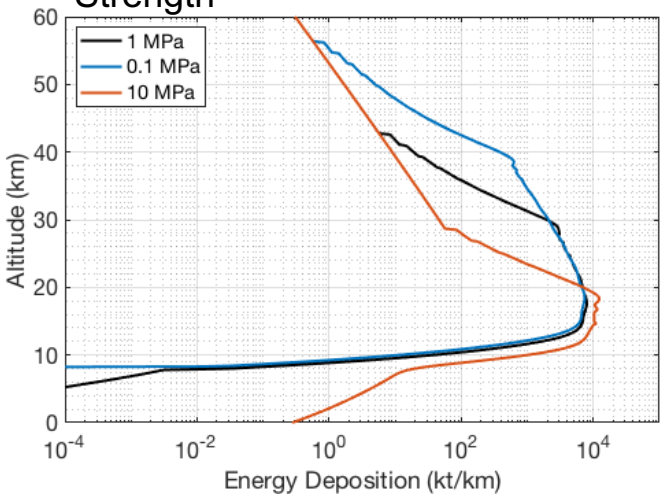
FCM Energy Deposition Variation

100 Mt, 120 m diameter, stony type asteroid, entering at 20 km/s and 45°

Burst altitude estimate methods

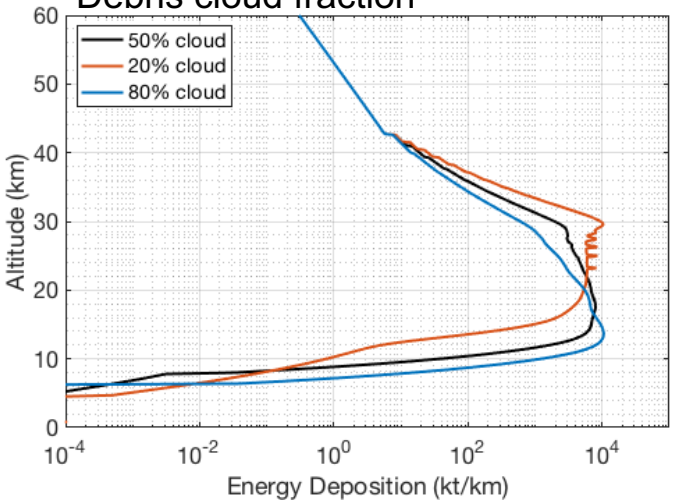


Strength

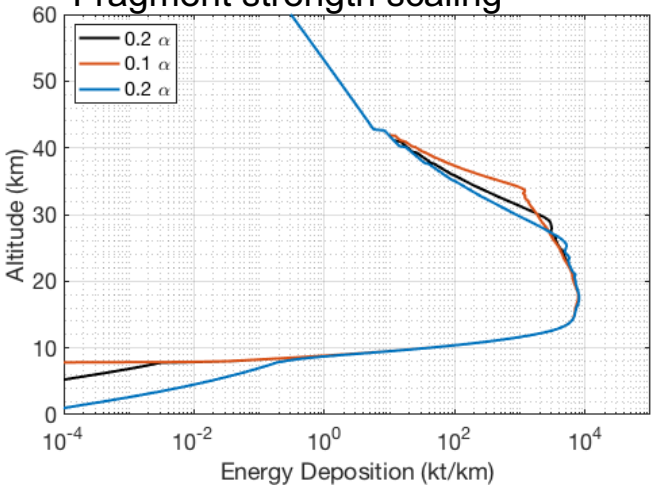


Model provides varied energy deposition curves that can represent uncertainties in breakup behavior and effective burst altitudes

Debris cloud fraction

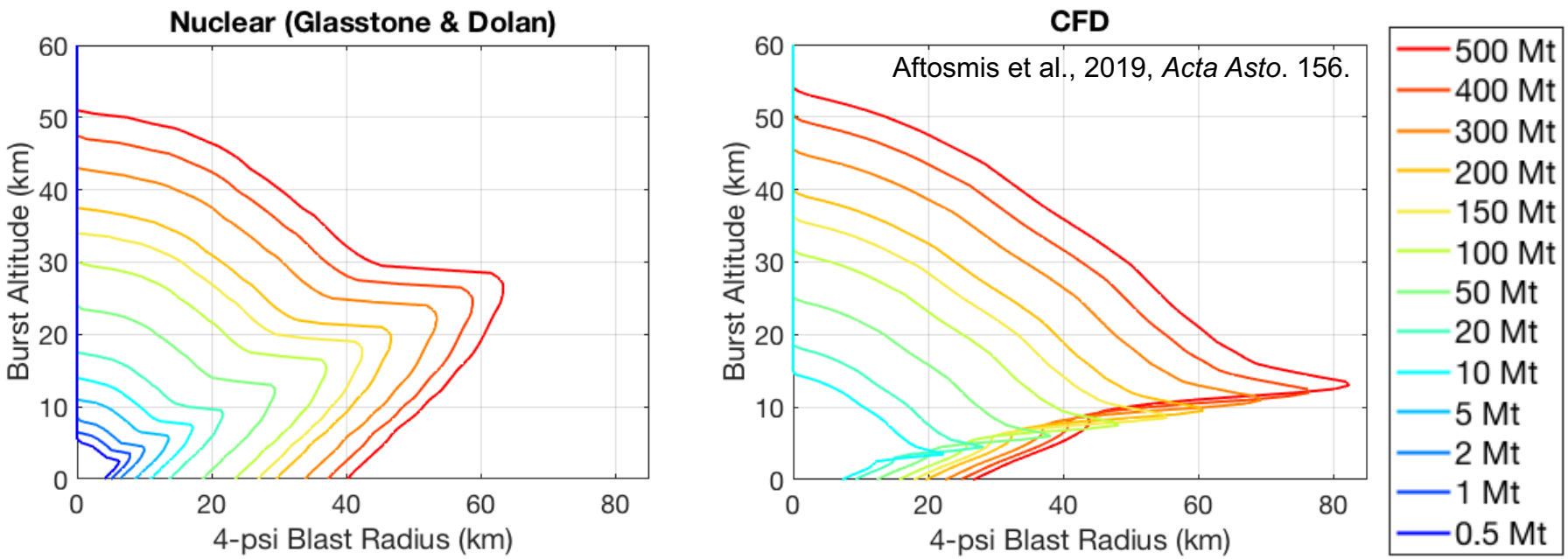


Fragment strength scaling



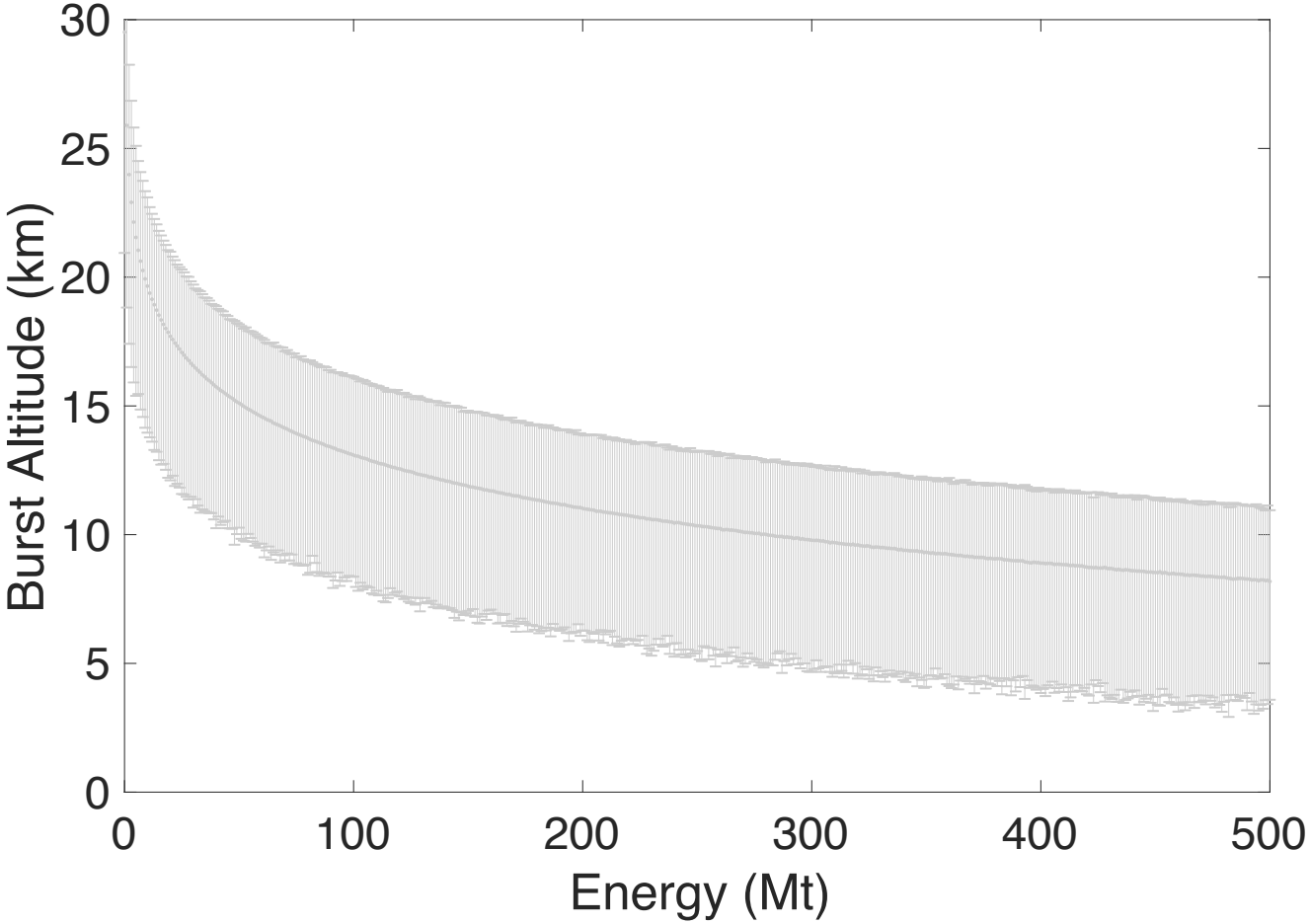
Height-of-Burst Maps

- HOB maps provide an efficient, but simplified approach for estimating blast overpressure ground radius as a function of energy (yield) and effective burst altitude.
- Nuclear-based HOB maps are based on small yields that cannot be accurately scaled to large asteroid yields due to effects of buoyancy and longer time-scales
- HOB maps based on CFD simulations of 250 Mt asteroid blasts (Aftosmis et al., 2019)
- PAIR interpolates between nuclear curves for E < 5 Mt and simulation curves for E > 250 Mt
- For a given yield and overpressure level, there is an "optimal" burst altitude the produces the largest ground radius



Modeled Burst Altitude Ranges

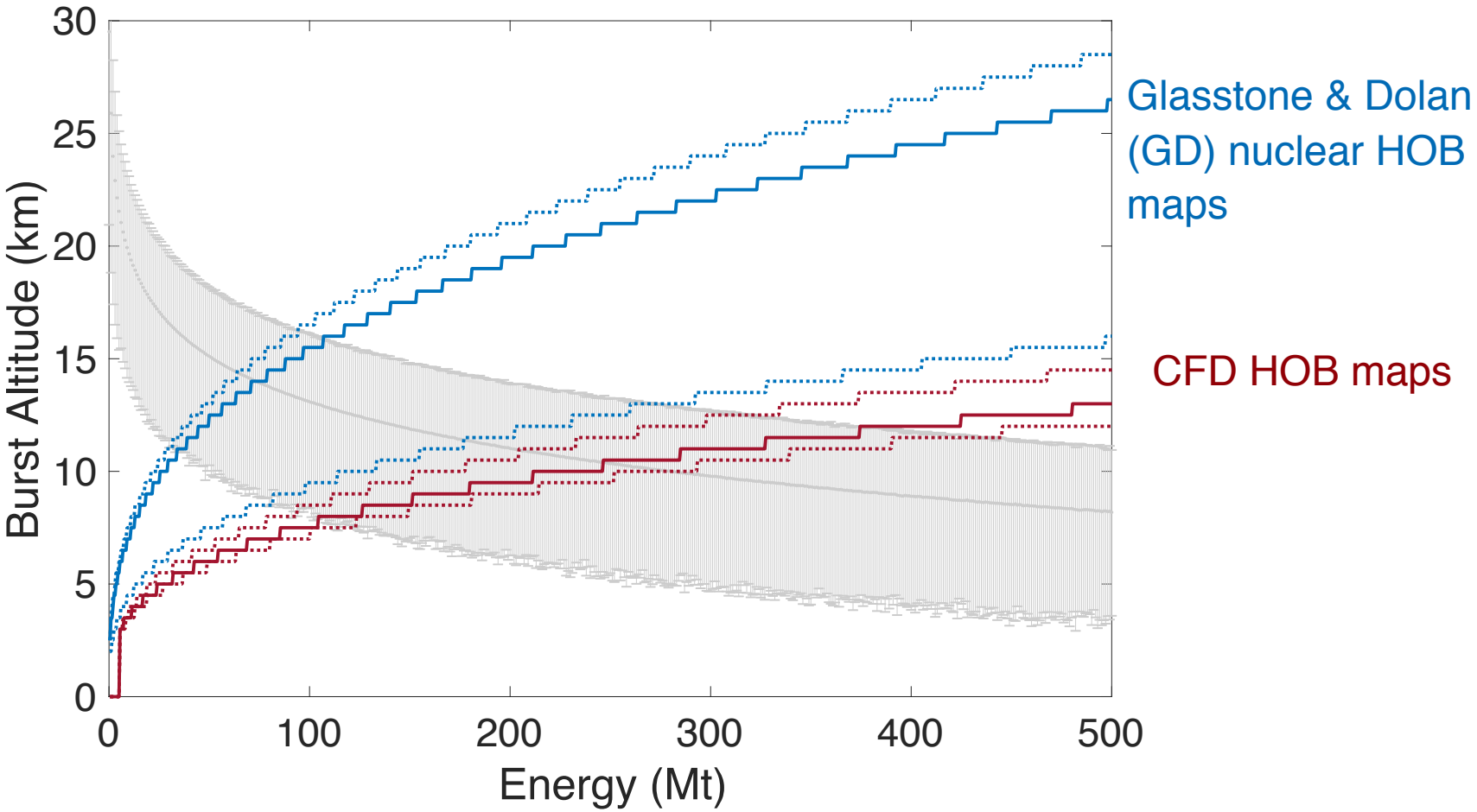
- Modeled burst altitude ranges (min/mean/max) as a function of energy for nominal entries at 19 km/s and 45°



- Entries at 19 km/s and 45°
- Stoney type asteroid density ranges
- Diameters 10-270 m
- Aerodynamic breakup strengths 0.1-10 MPa
- Strength scaling α 0.1-0.3

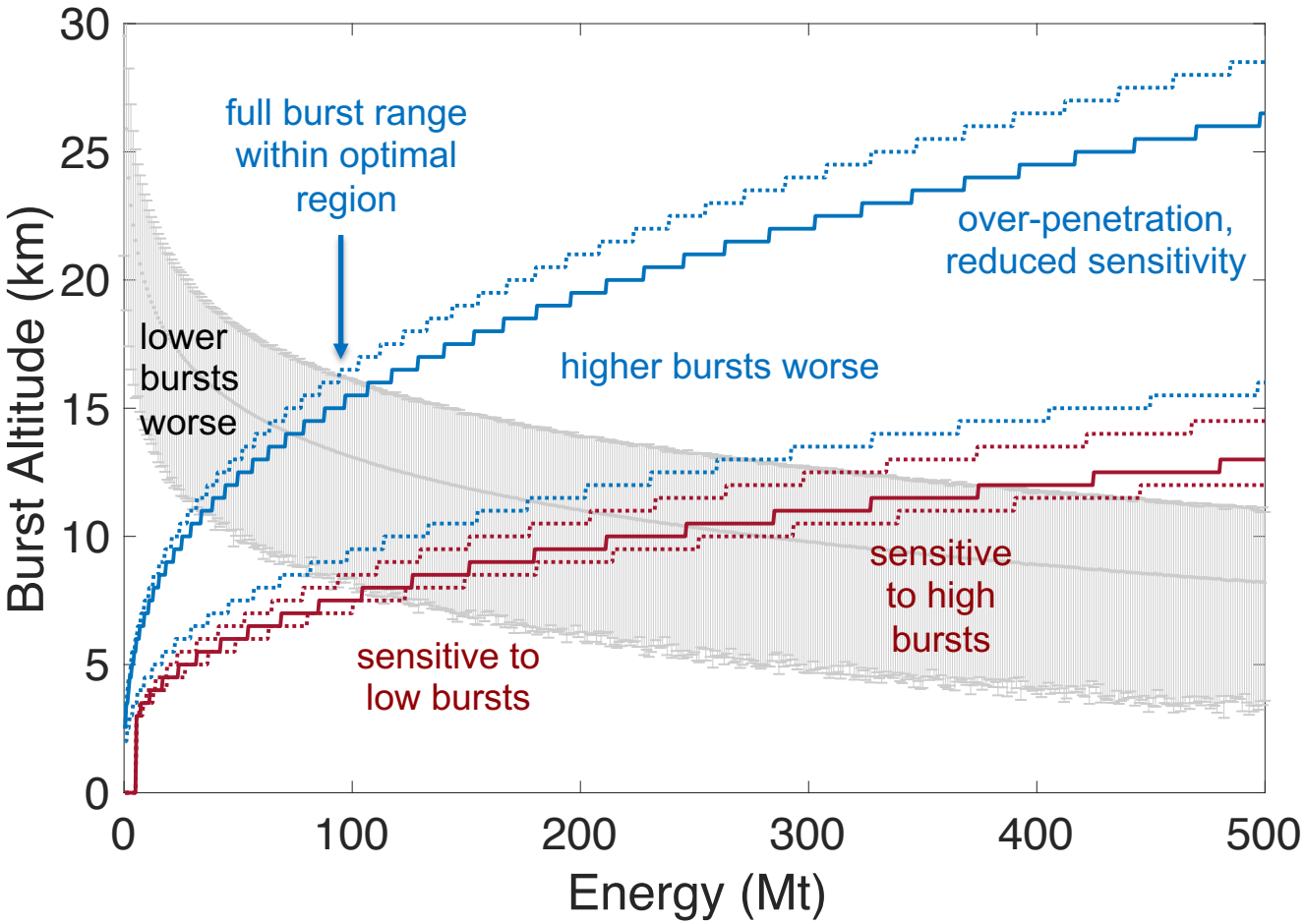
Modeled vs. Optimal Burst Altitudes

- Comparison with optimal HOB ranges (ranges give blast footprint radii within ±10% of max for each energy)



Modeled vs. Optimal Burst Altitudes

- Sensitivity to strength and breakup factors depends upon how the resulting burst altitudes coincide with optimal burst altitude for different yield energies.



- Sensitive regions differ between nuclear HOB maps and CFD-based HOB maps for larger yields.
- Nuclear curves have higher, broader optimal altitude ranges
- Simulation-based curves have lower, narrower optimal range

Modeled vs. Optimal Burst Altitudes

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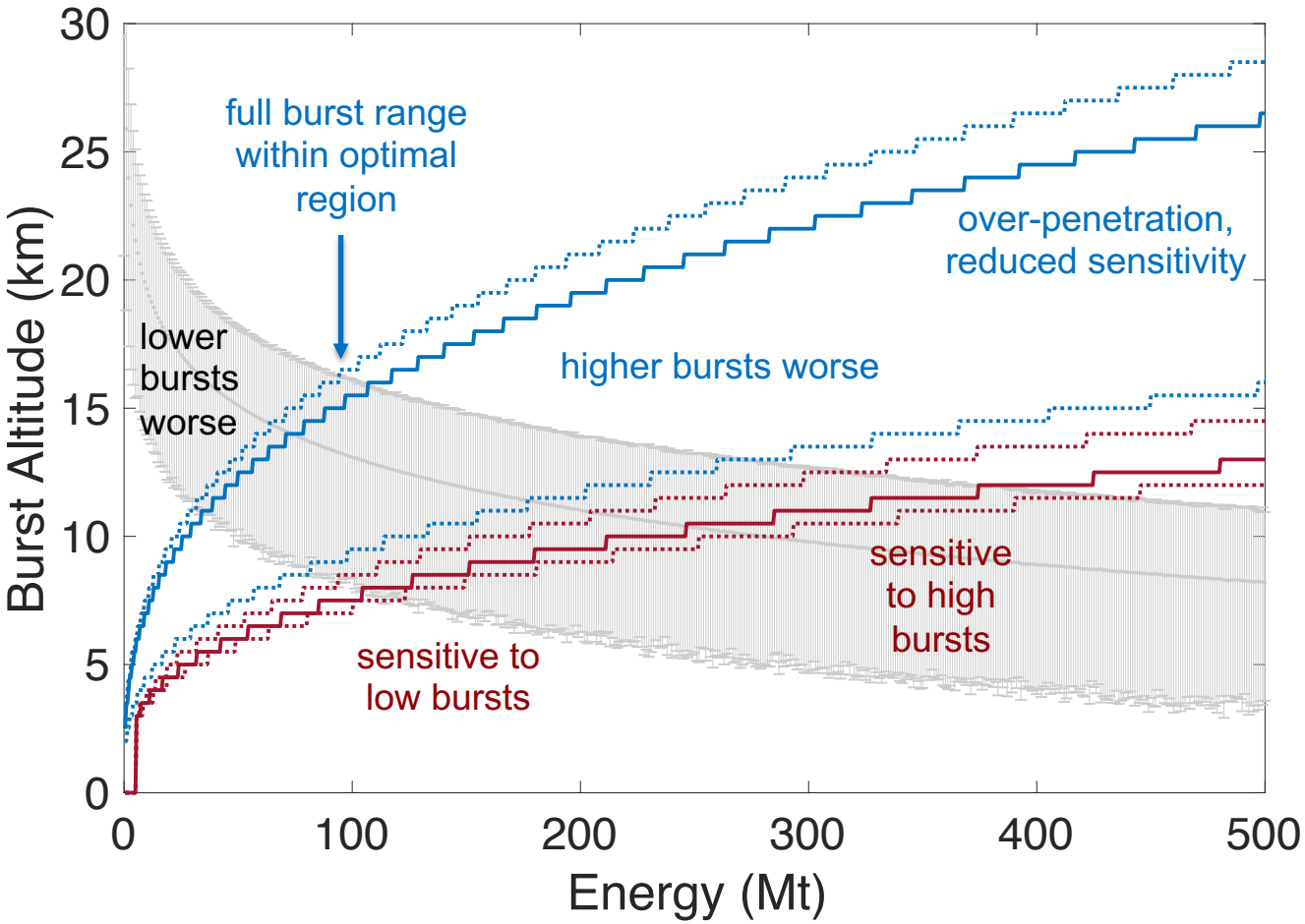
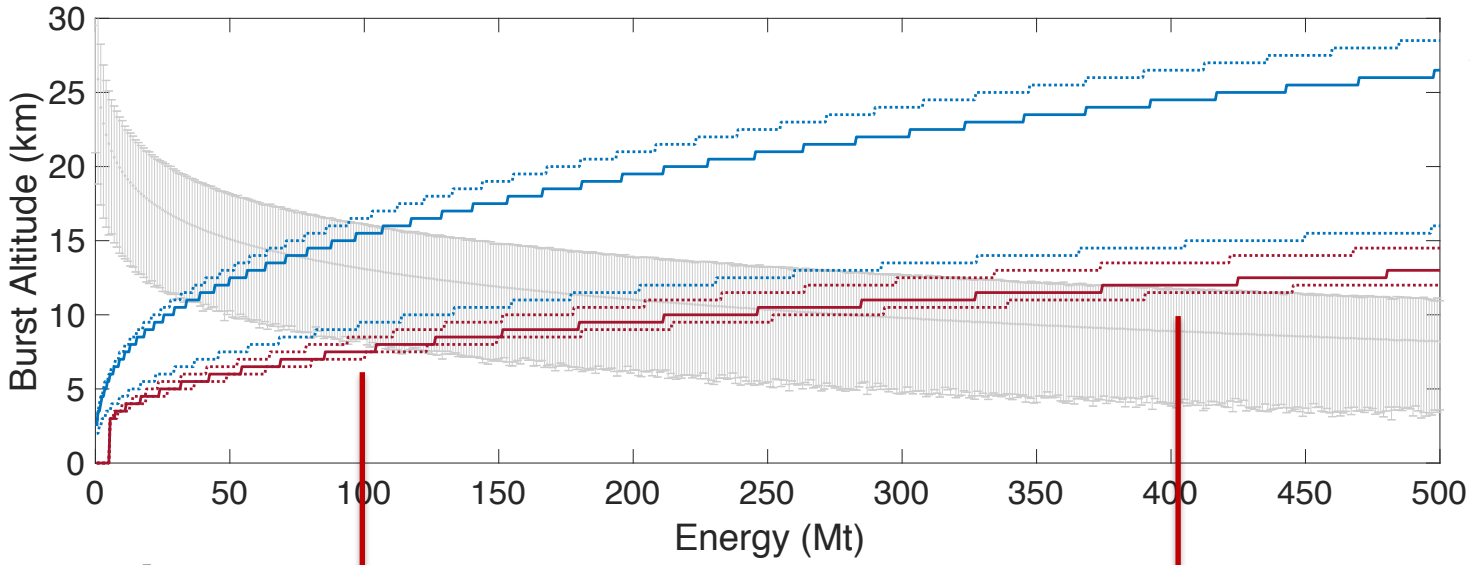
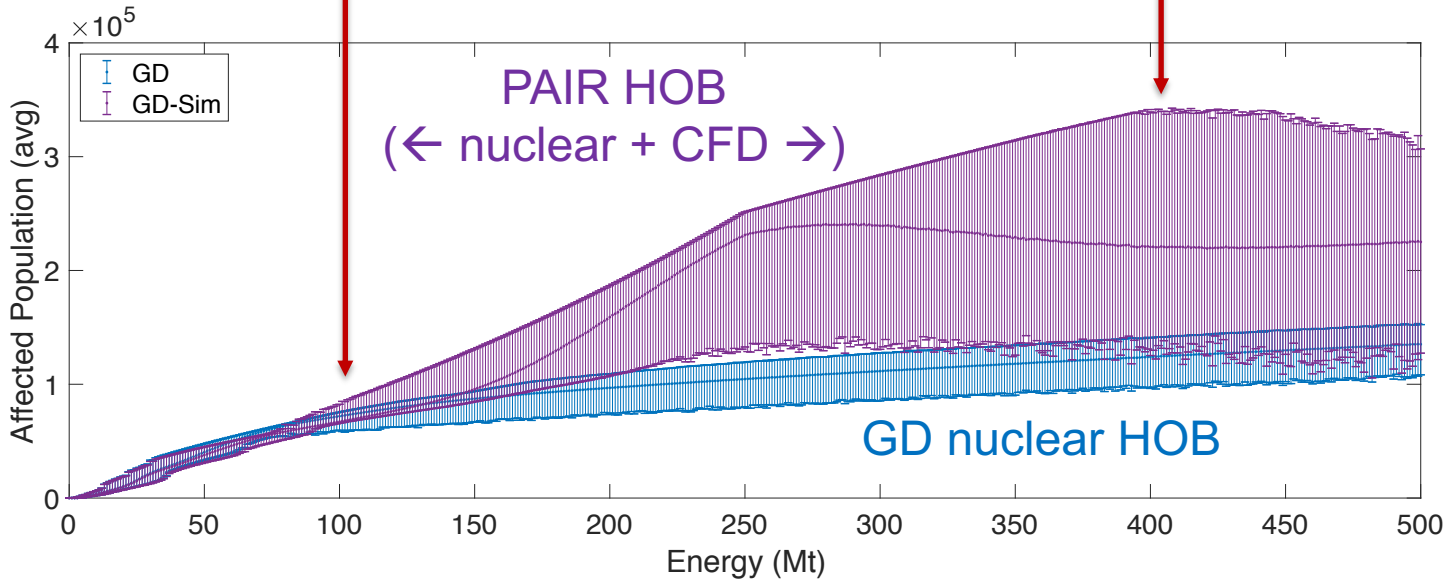


- Modeled altitudes pass through optimal range of nuclear curves sooner (smaller energies, higher altitudes)
- Modeled altitudes span simulation-based optimal altitudes over larger range of energies

Effects of Simulation-Based HOB on Affected Population Estimates





Altitude range of higher energy impactors coincides more with lower optimal bursts from simulation-based HOB

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Increases damage estimates and uncertainty range compared to scaled nuclear models

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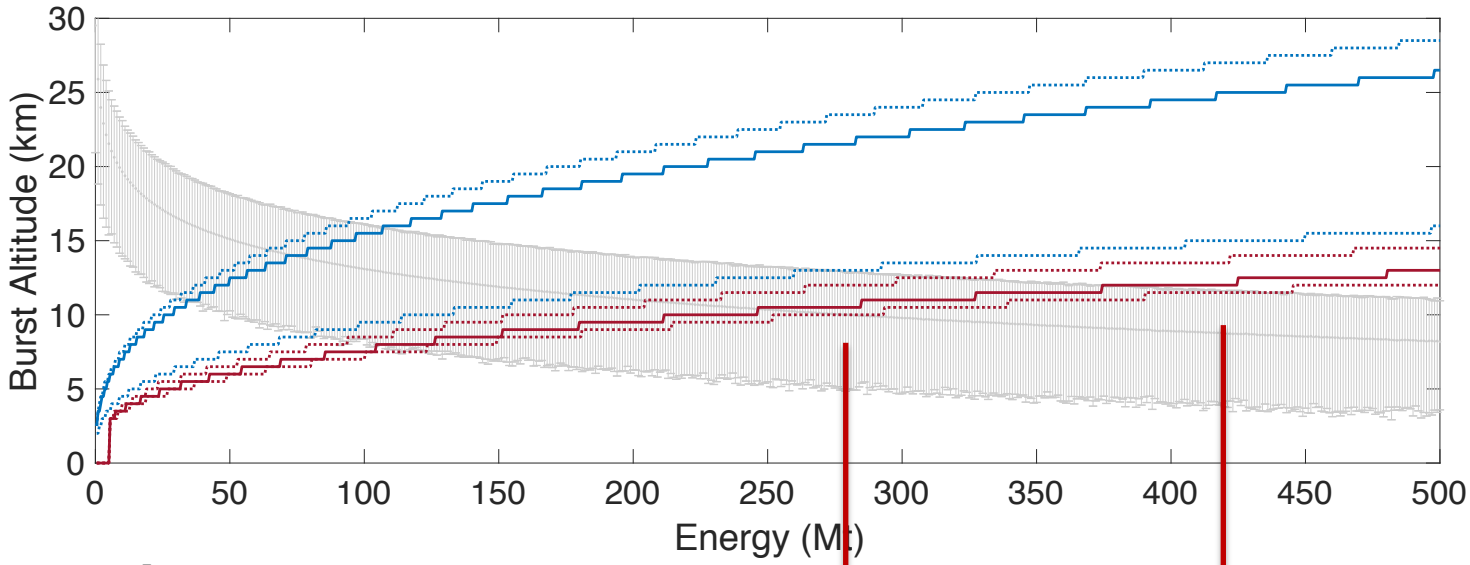
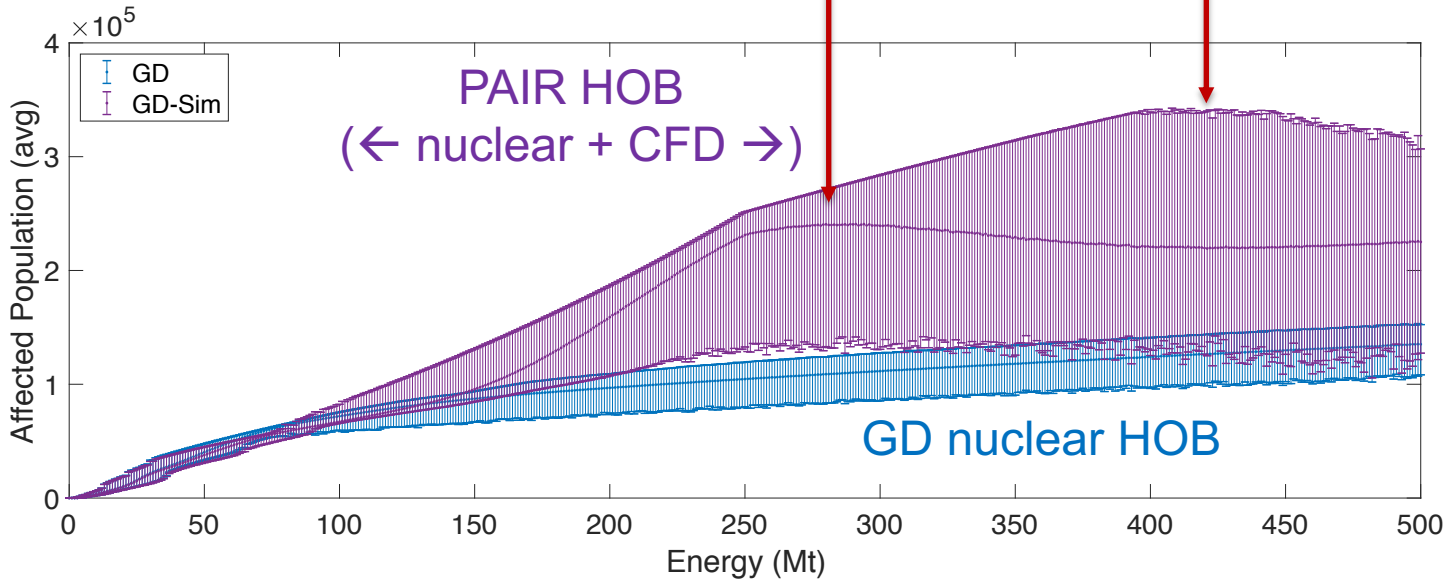




Over-penetration below sharper optimal burst range of CFD-based HOB maps

Can begin decreasing damage levels more than increases due to additional energy

Sample Ground Damage Footprints

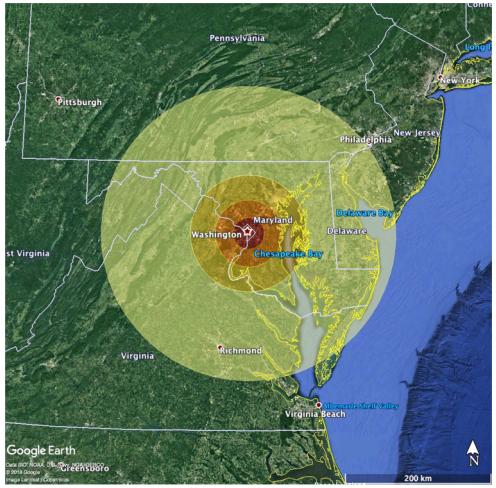
(placed over Washington D.C. for scale)

Entry:
19 km/s, 45°

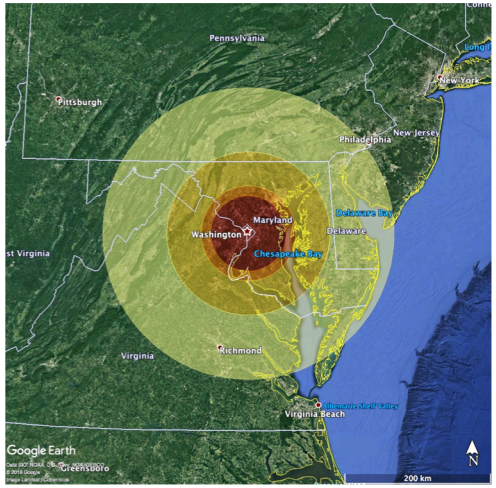
Typical Stony Type:
2.2 g/cm^3
1 MPa

60 m, ~11 Mt

200 m, ~400 Mt



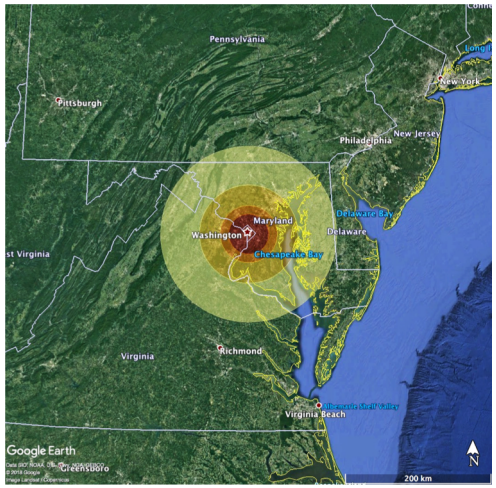
500 m, ~6 Gt



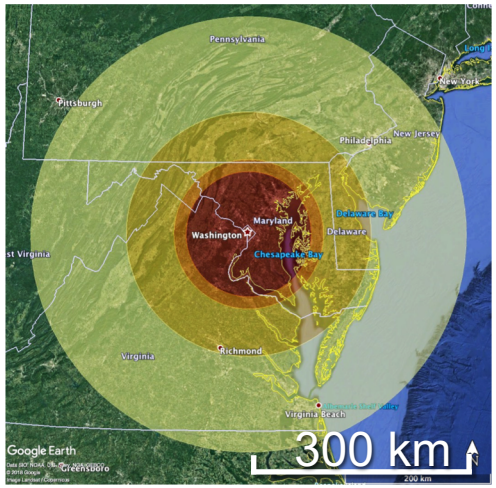
Strong, Dense Iron:
6.5 g/cm^3
non-breaking

60 m, ~32 Mt

200 m, ~1 Gt



500 m, ~18 Gt



- Serious
- Severe
- Critical
- Unsurvivable

Summary

- Strength parameters and breakup modeling factors can be important for assessing specific cases or transitional regimes
  - Cases where strength uncertainty spans or approaches optimal burst altitude
  - Transitional energy regimes between simulation models and nuclear data
  - Small sizes that only do damage if able to penetrate down closer to their optimal burst
- Ongoing work:
  - Parametric CFD blast propagation simulation studies to characterize blast footprints by energy deposition profiles beyond the simplified effective height of burst.
  - Sensitivity studies and improve characterization of strength distributions, ranges, and correlations.
  - Transitioning FCM debris cloud modeling from simplified pancake approaches to multi-body fragment spread rate models that can better tie breakup modeling to physical parameters

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Probabilistic Asteroid Impact Risk (PAIR) Model

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