Probabilistic Characterization of Tunguska-scale Asteroid Airbursts and Impact Frequencies

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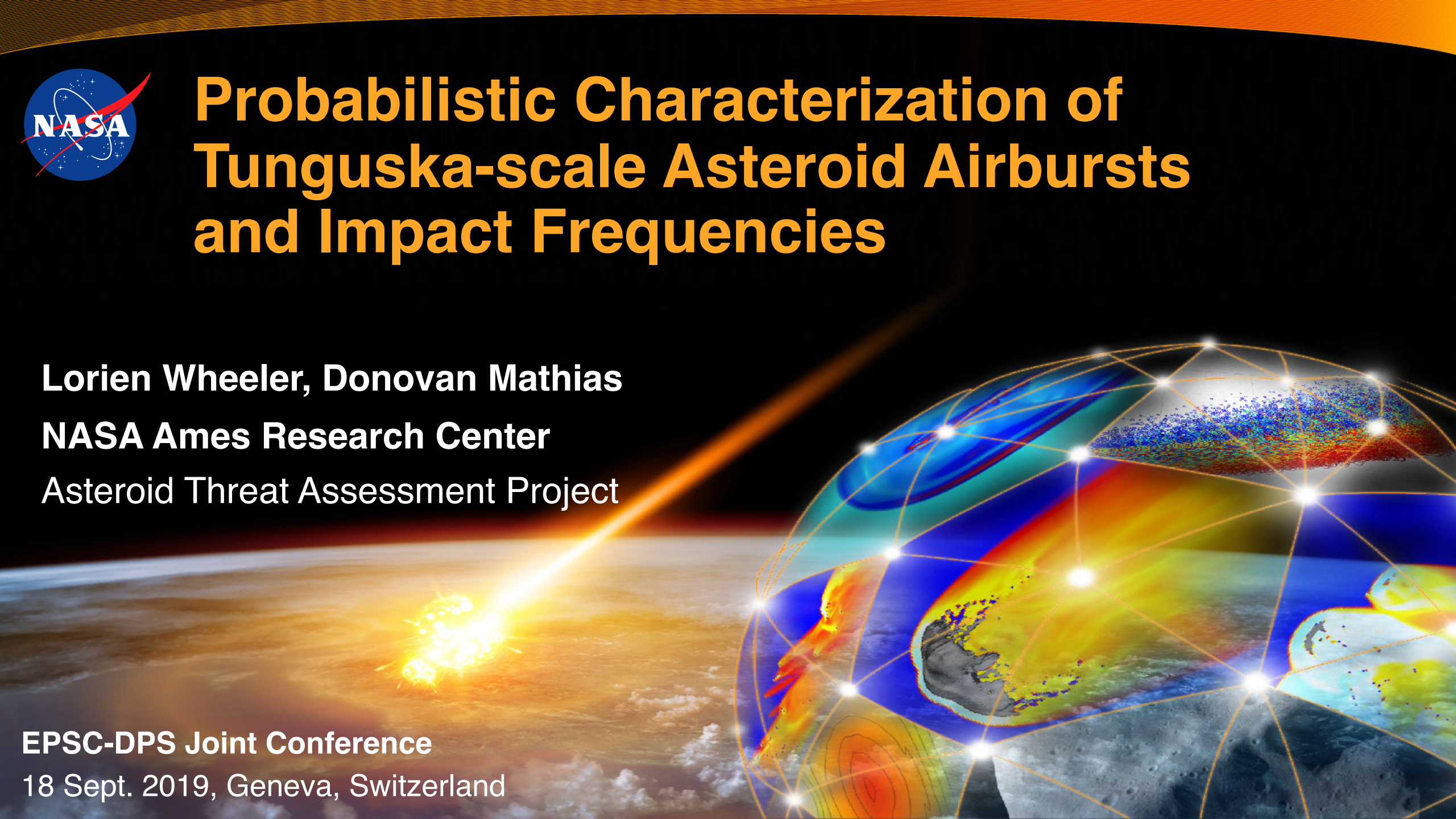
Asteroid Threat Assessment Project



EPSC-DPS Joint Conference

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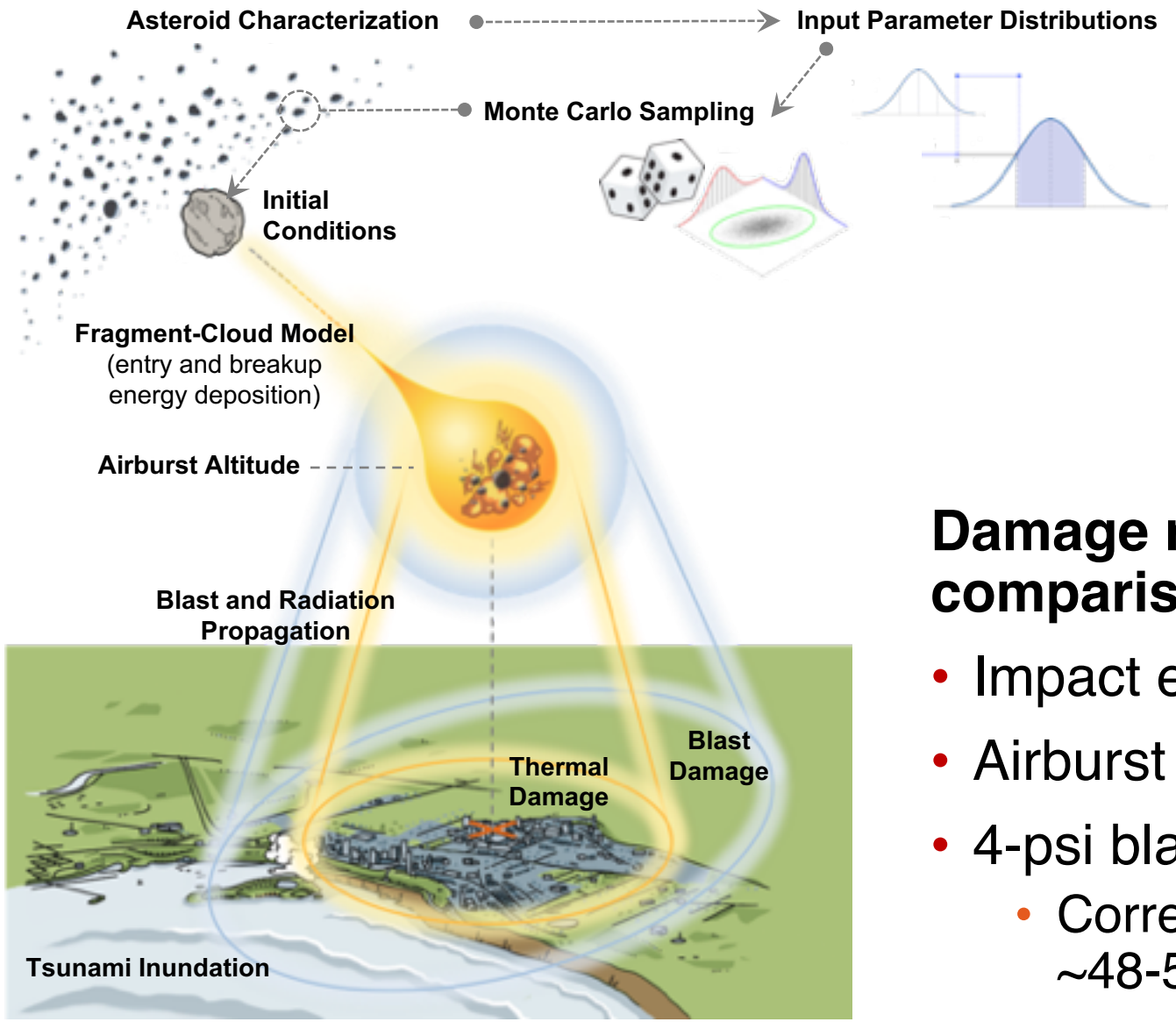
A Broader Characterization of Tunguska

- The 1908 Tunguska event provides a rare source of ground evidence for characterizing the potential damage from mid-sized asteroid airbursts.
  - Asteroid airburst that caused substantial tree-fall across 2,000 km^2 of forest (extending 15–35 km outward from the epicenter in a butterfly shape).
  - Estimated impact energies of 3–50 Mt (TNT equivalent) with 10–20 Mt as the most prevailing consensus, diameter of 34–190 m, and burst altitude of 5–15 km.
- Challenges of characterizing asteroid threats based on Tunguska:
  - Lack of knowledge about the properties of the initial object.
  - Many existing studies only consider a small subset of cases or assume or single representative property values to draw broad conclusions.
  - Does it represent a typical impact case or an outlier?
- Objective of this study:
  - Provide broader characterization of the range and relative likelihood of asteroid properties that could yield Tunguska-scale threats.

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

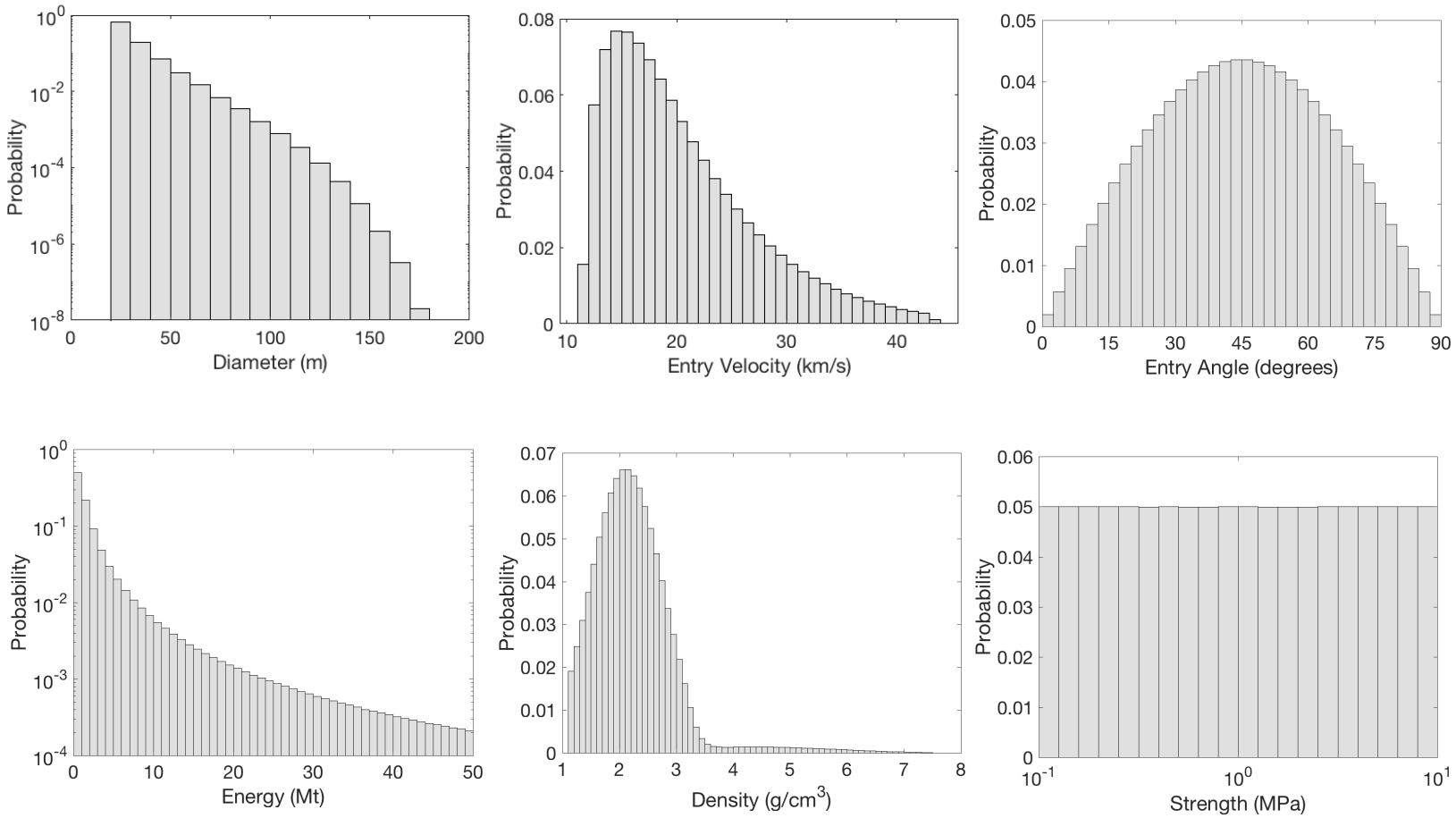
Damage results used for Tunguska comparisons:

- Impact energies (initial KE)
- Airburst altitudes from entry/breakup model
- 4-psi blast overpressure footprint
  - Correlates with tree-fall wind-speeds ~48-50 m/s

Probabilistic Impact Cases

- Modeled 50 million Tunguska-scale asteroid impact cases.
  - Diameters 20–180 m
  - Impact energies ≤50 Mt
- Probabilistic sampling accounted for:
  - Size frequencies: H-magnitude impact frequencies + NEOWISE albedo distribution
  - Distributions of asteroid and entry properties
  - Uncertainties in entry/breakup model parameters (ablation, breakup parameters)

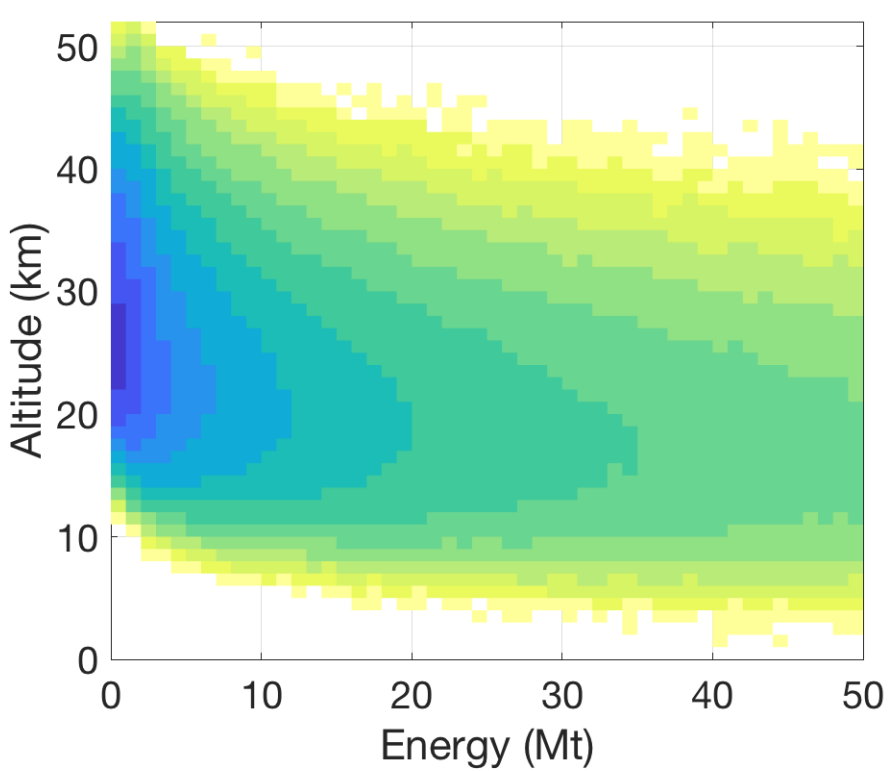
Sampled asteroid and entry property distributions

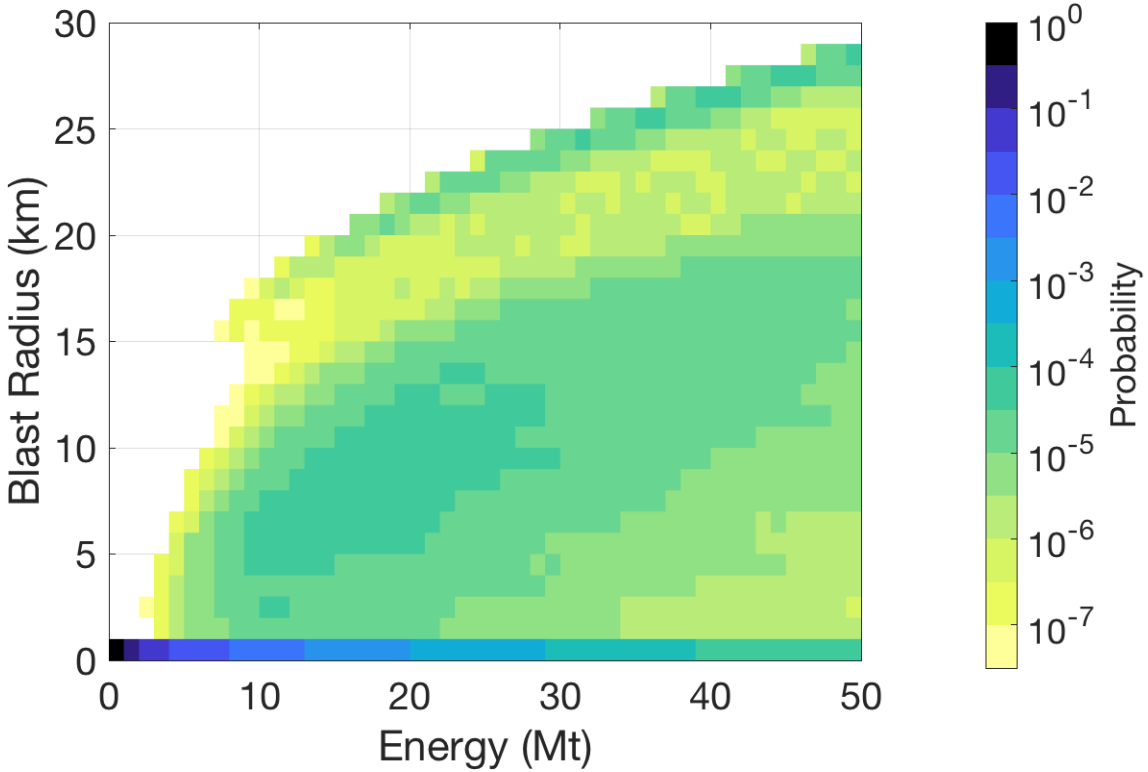


Airburst & Blast Damage Trends

- Results characterize relative likelihoods of various impact energy, burst altitude, and blast damage combinations across broad range of Tunguska-scale impactors.

Relative probabilities of airburst altitudes and blast damage radii as function of energy





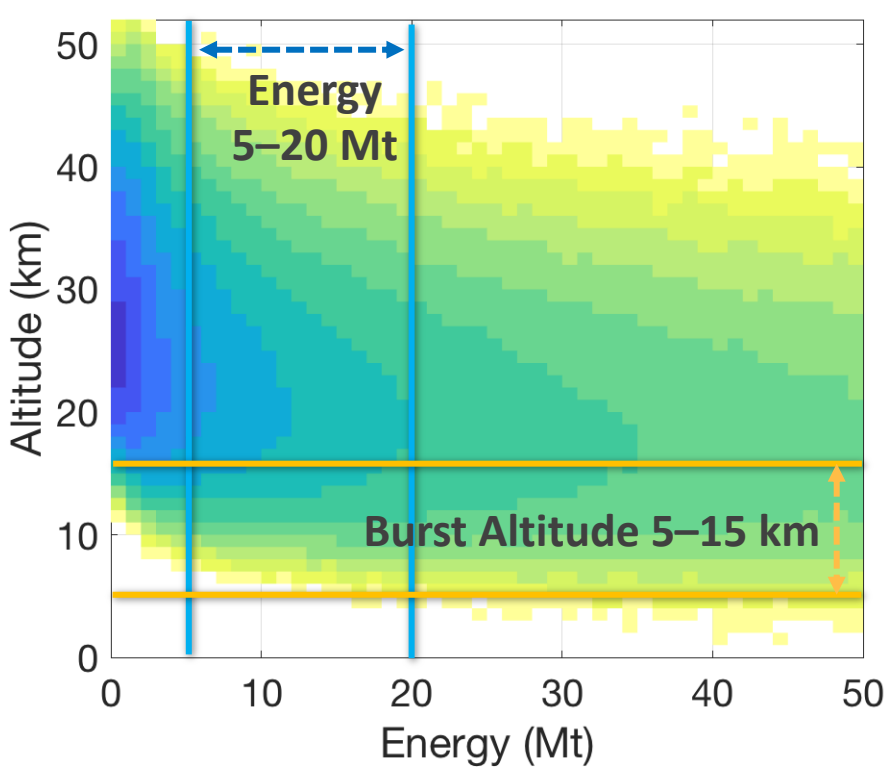
Airburst & Blast Damage Trends

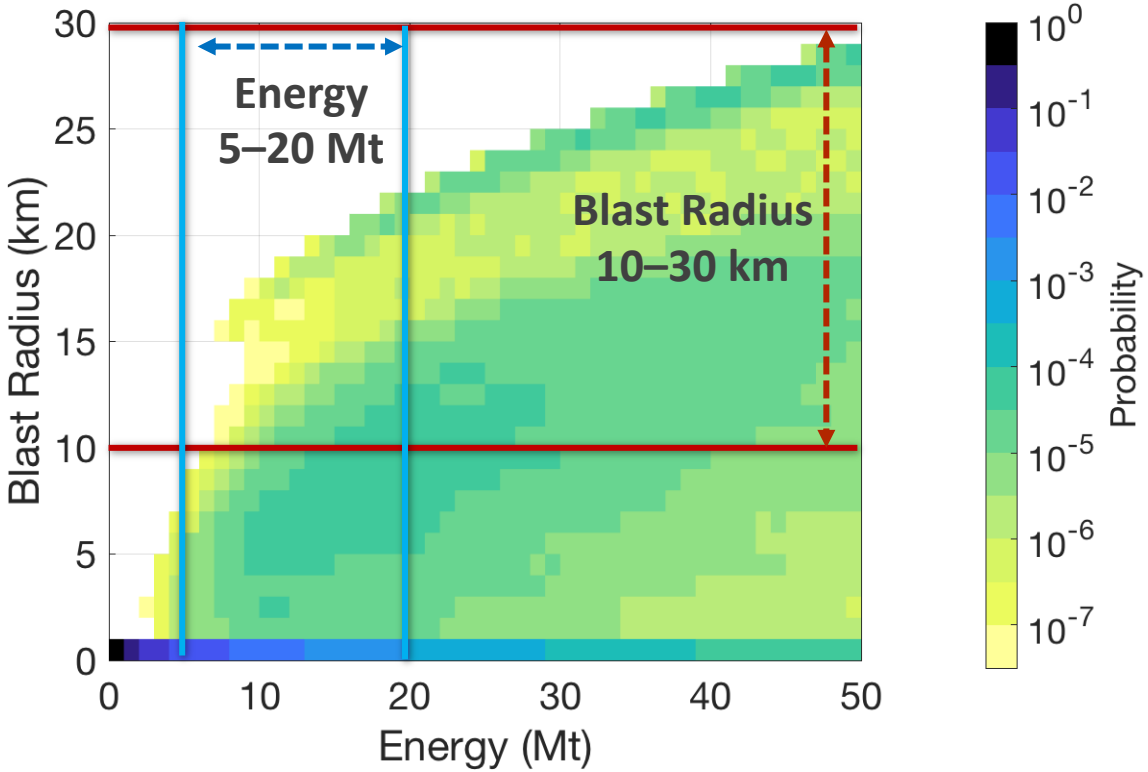
- Can then consider the relative probabilities among subsets of cases meeting of more specific Tunguska-like constraints

Tunguska-like Criteria

- Energy 5-20 Mt
- Altitude 5-15 km
- Blast Radius 10-30 km (4 psi)

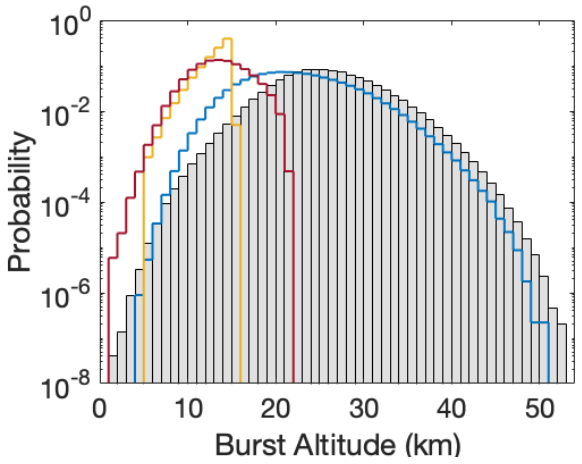
Relative probabilities of airburst altitudes and blast damage radii as function of energy

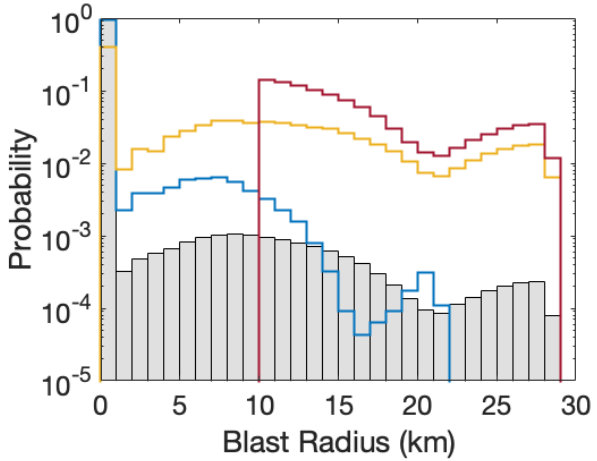


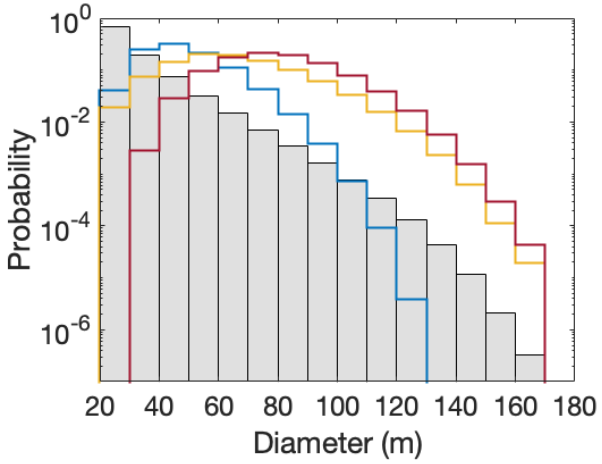


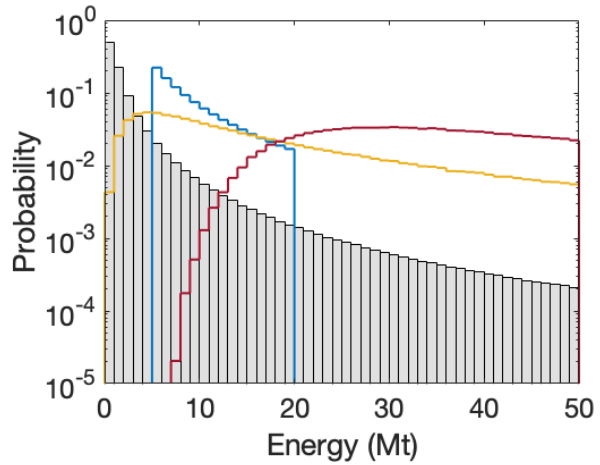
Tunguska-like Criteria Probabilities

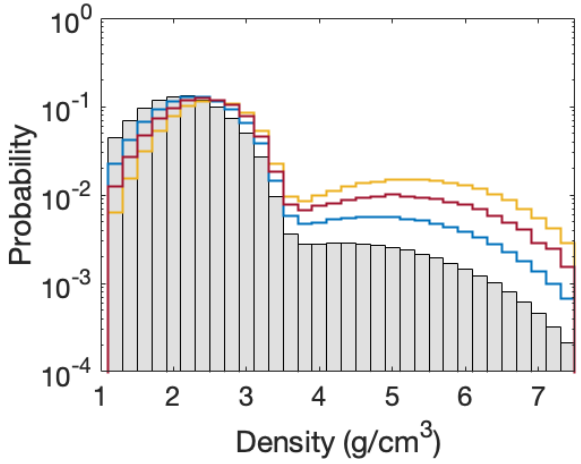
- Results show relative probabilities of properties among cases meeting each criterion, compared with the baseline distribution of all cases.
- Tunguska-like events can be produced by a broad range of asteroid and entry properties.

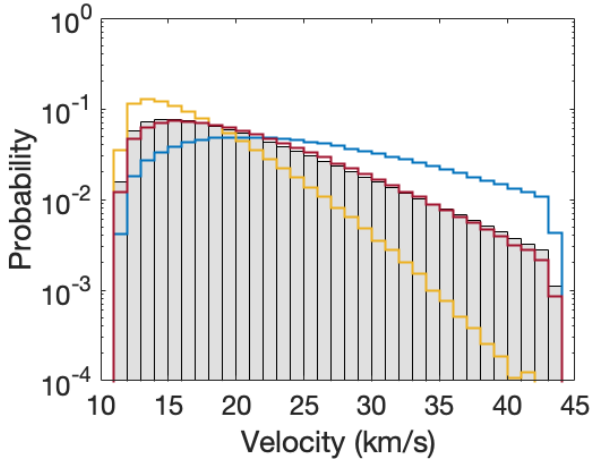


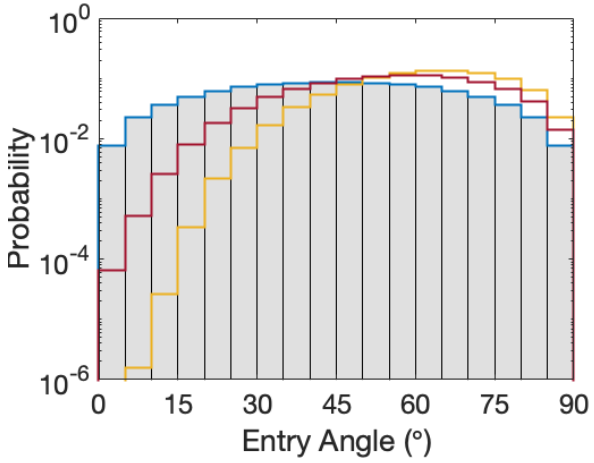








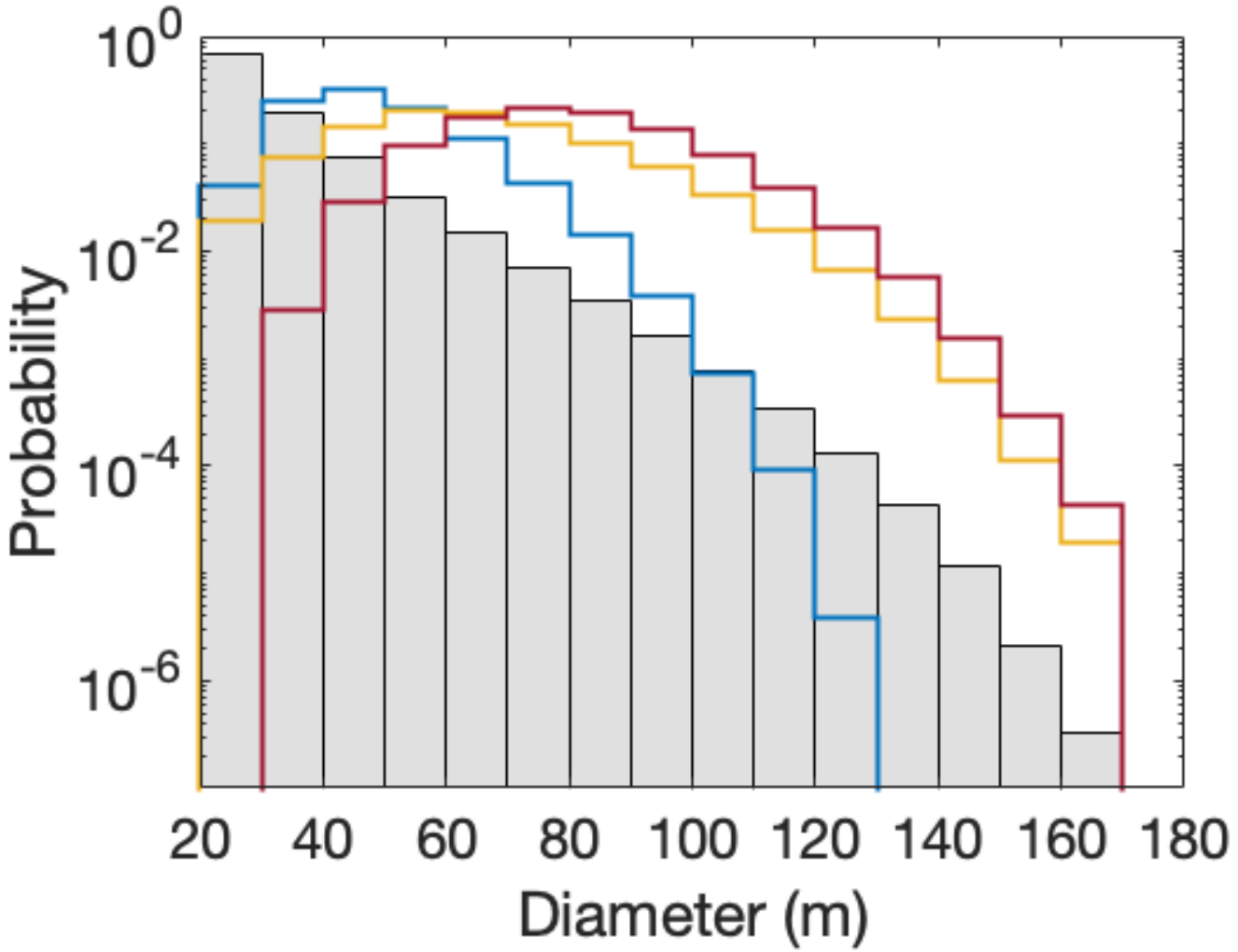




Tunguska-like Criteria

All (20-180 m, E $\leq$ 50 Mt)
Energy 5-20 Mt
Altitude 5-15 km
Blast Radius 10-30 km (4 psi)

Size Probabilities for Tunguska Criteria

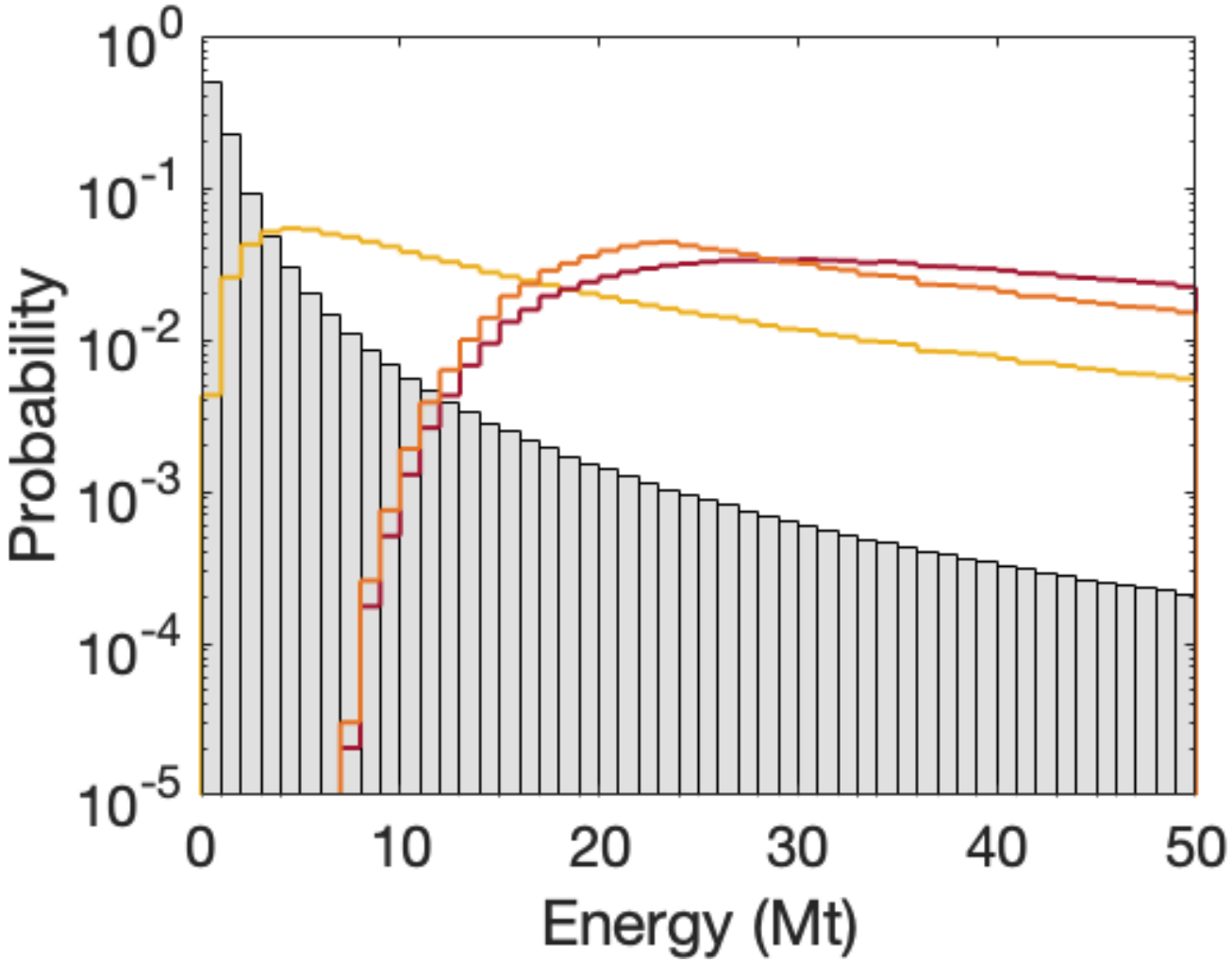


Tunguska-like Criteria

- All (20-180 m, E $\leq$ 50 Mt)
- Energy 5-20 Mt
- Altitude 5-15 km
- Blast Radius 10-30 km (4 psi)

- Diameter probabilities peak around:
  - 45 m for the energy criterion
  - 55 m for the altitude criterion
  - 75 m for the blast damage criterion

Size Probabilities for Tunguska Criteria



Tunguska-like Criteria

- All (20-180m, E $\leq$ 50 Mt)
- Altitude 5-15 km
- Blast Radius 10-30 km (4 psi)
- Altitude + Blast Radius

- Energy probabilities peak around:
  - 6 Mt for the altitude criterion
  - 20–30 Mt for the blast damage criterion
  - 23 Mt for blast damage and altitude criteria together

Summary

- Tunguska-like events can be produced by a broad range of impact scenarios and asteroid properties.
- Larger objects of 20–30 Mt or 70–80 m are more likely to cause Tunguska-scale ground damage than sizes on the smaller end of Tunguska estimates.
  - Greater damage potential of larger objects outweighs their rarity (lower impact frequency).
  - Smaller objects, while more frequent, are much less likely to cause Tunguska-scale ground damage.
- References:

  - Wheeler L. and Mathias D., 2019. Probabilistic assessment of Tunguska-scale asteroid impacts. Icarus, Vol. 327. https://doi.org/10.1016/j.icarus.2018.12.017
  - Wheeler L. and Mathias D., 2019. Effects of asteroid property distributions on expected impact rates. Icarus, Vol. 321. https://doi.org/10.1016/j.icarus.2018.12.034
  - Mathias D., Wheeler L., Dotson J., 2017. A probabilistic asteroid impact risk model: assessment of sub-300m impacts, Icarus, Vol. 289. https://doi.org/10.1016/j.icarus.2017.02.009

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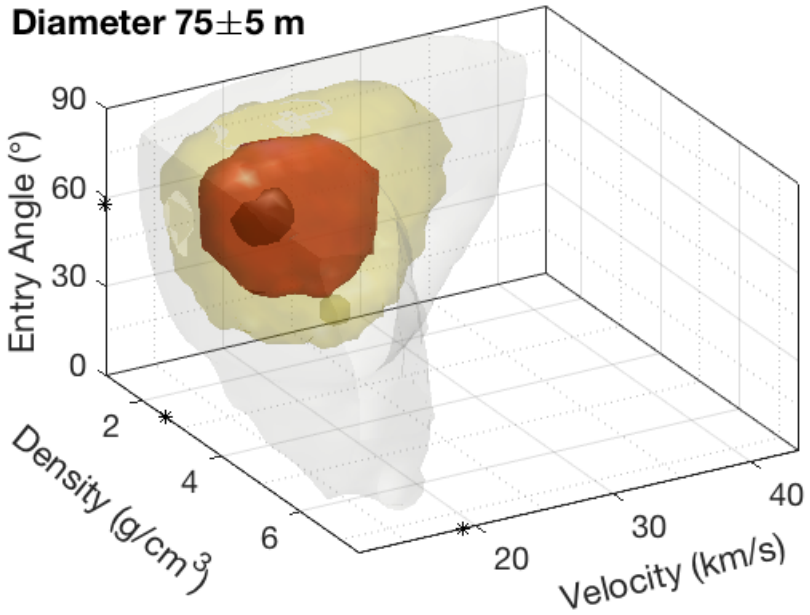
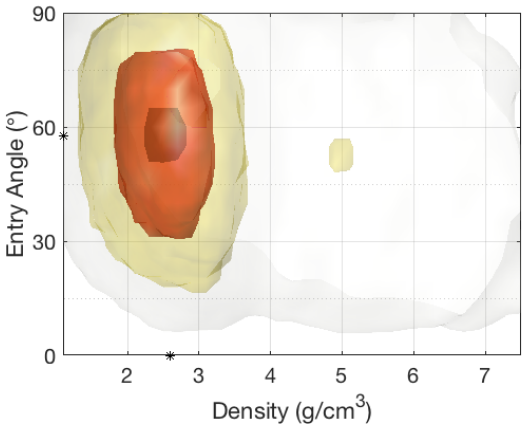
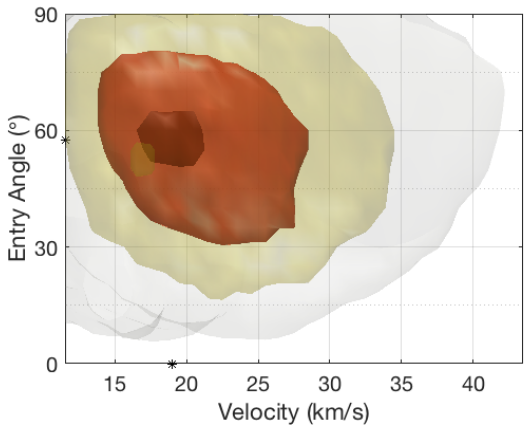
Backup

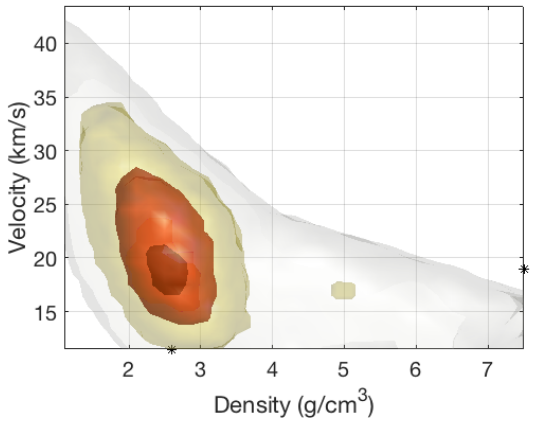
Property Combinations Most Likely to Cause Tunguska-Scale Blast Damage



- Individual property probabilities do not necessarily
- What **combinations** of properties altogether are most likely to cause Tunguska-scale blast damage?
  - Diameter 70–80m
  - Energy 19–32 Mt (mean/mode ~25 Mt)
  - Density 2.5–2.7 g/cm^3
  - Entry 18.5–19.5 km/s at 55–60 degrees
  - Burst altitude 10–20 km (mean/mode ~12–13 km)
  - Blast radii 10–25 km (mean/mode ~12–14 km)







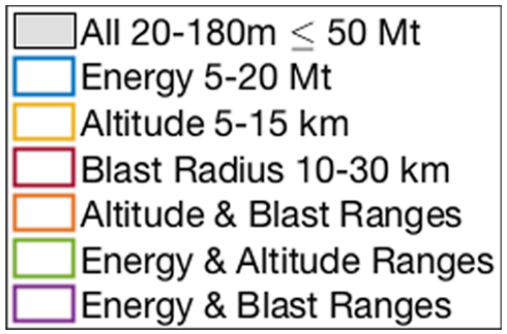
All blast criteria cases

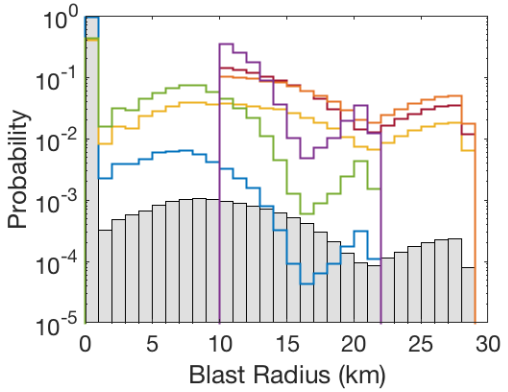
>10% max probability density

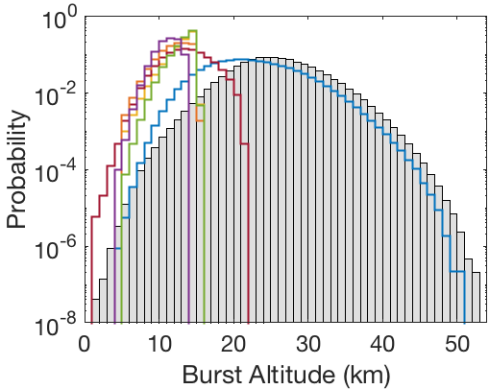
>50% max probability density

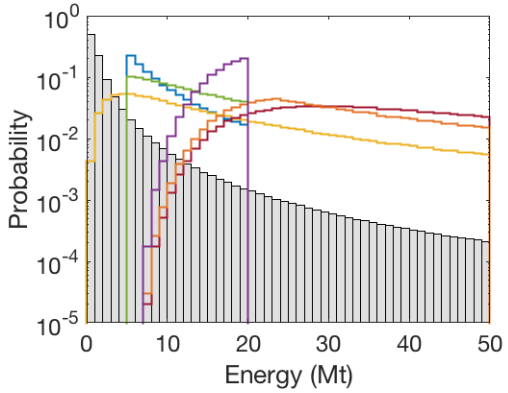
>90% max probability density

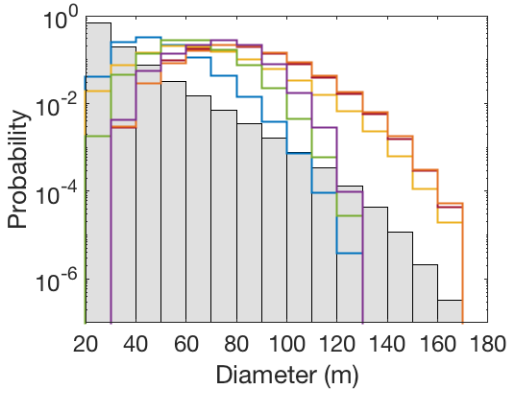
Tunguska-like Criteria Probabilities

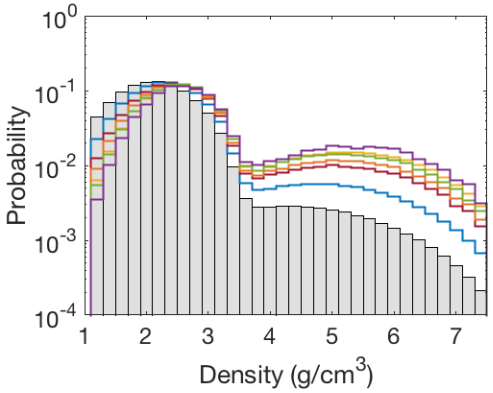


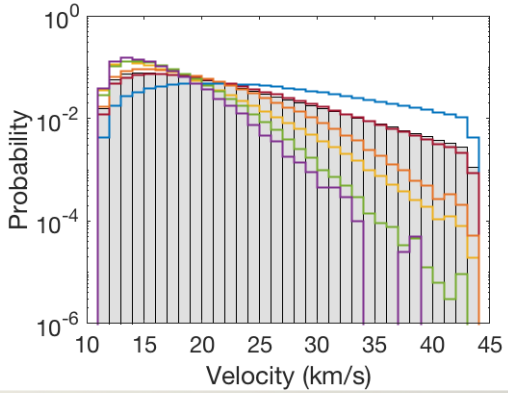


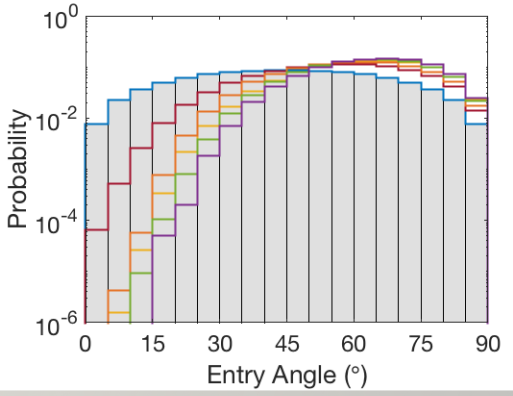


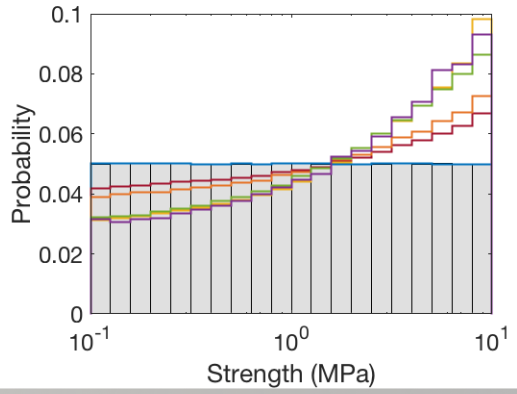






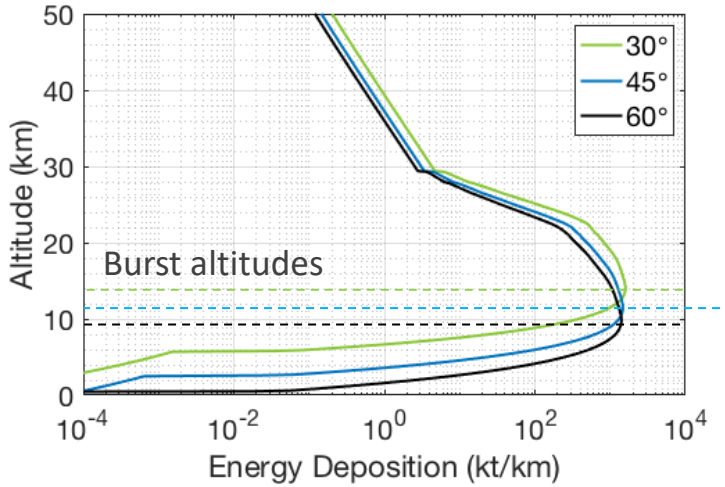




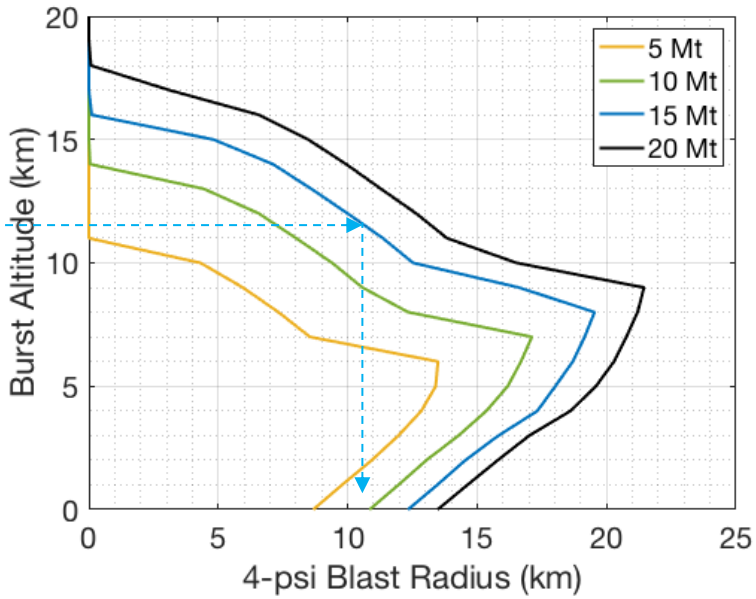


Airburst Blast Damage

- The Fragment-Cloud Model (FCM) models energy deposited in the atmosphere during entry and breakup.
- Effective airburst altitude is taken at peak energy deposition or a given energy fraction.
- Height-of-burst (HOB) maps used to estimate blast footprint radii as a function of burst altitude and total impact energy.



FCM energy deposition curves for nominal Tunguska-scale impactor
15-Mt, ~70 m diameter, 3 g/cm^3, 5 MPa, entry at 15 km/s, 30–60° from horizontal.



Height-of-burst (HOB) maps
4-psi blast footprint radii for Tunguska-scale energies.

Blast Overpressure Damage

- Blast radii on the ground are estimated using yield scaling and height-of-burst (HOB) maps

- Nuclear-based HOB maps (Glasstone & Dolan, 1977)

+

- Simulation-based HOB maps that account for buoyancy effects in larger bursts (Aftosmis et al., 2017)

- 4 psi overpressure level correlates with tree-fall wind-speeds ~48-50 m/s in CFD blast simulations (M. Nemec & M. Aftosmis)

4-psi HOB Curves for Tunguska-Scale Energies