SPH Simulation of Bolide Entry

7th IAA Planetary Defense Conference

April 2021

Jason Pearl, Cody Raskin & Michael Owen

Lawrence Livermore National Laboratory

LLNL-PRES-821484

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Airburst Events

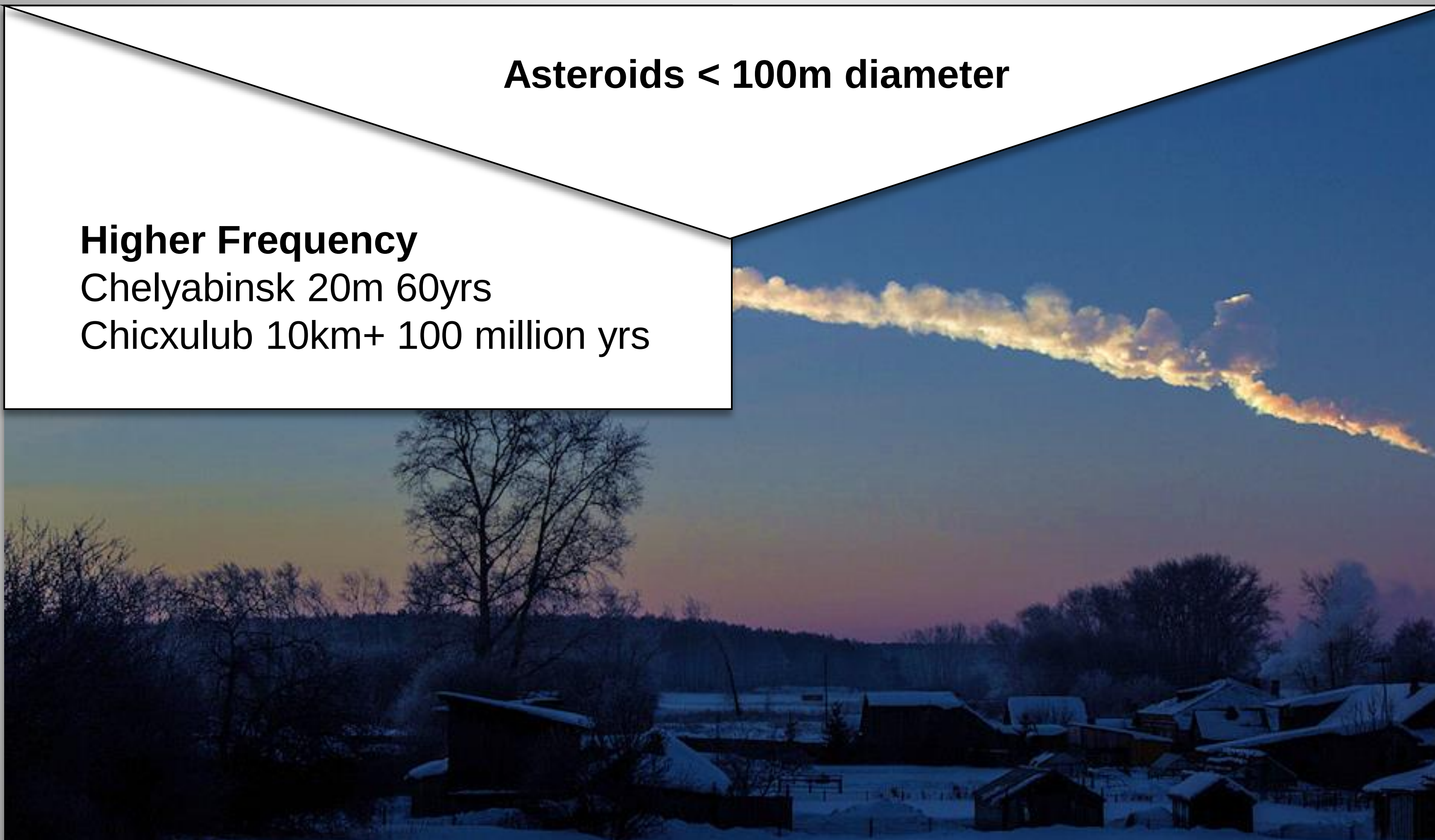
Airburst Events

Asteroids < 100m diameter

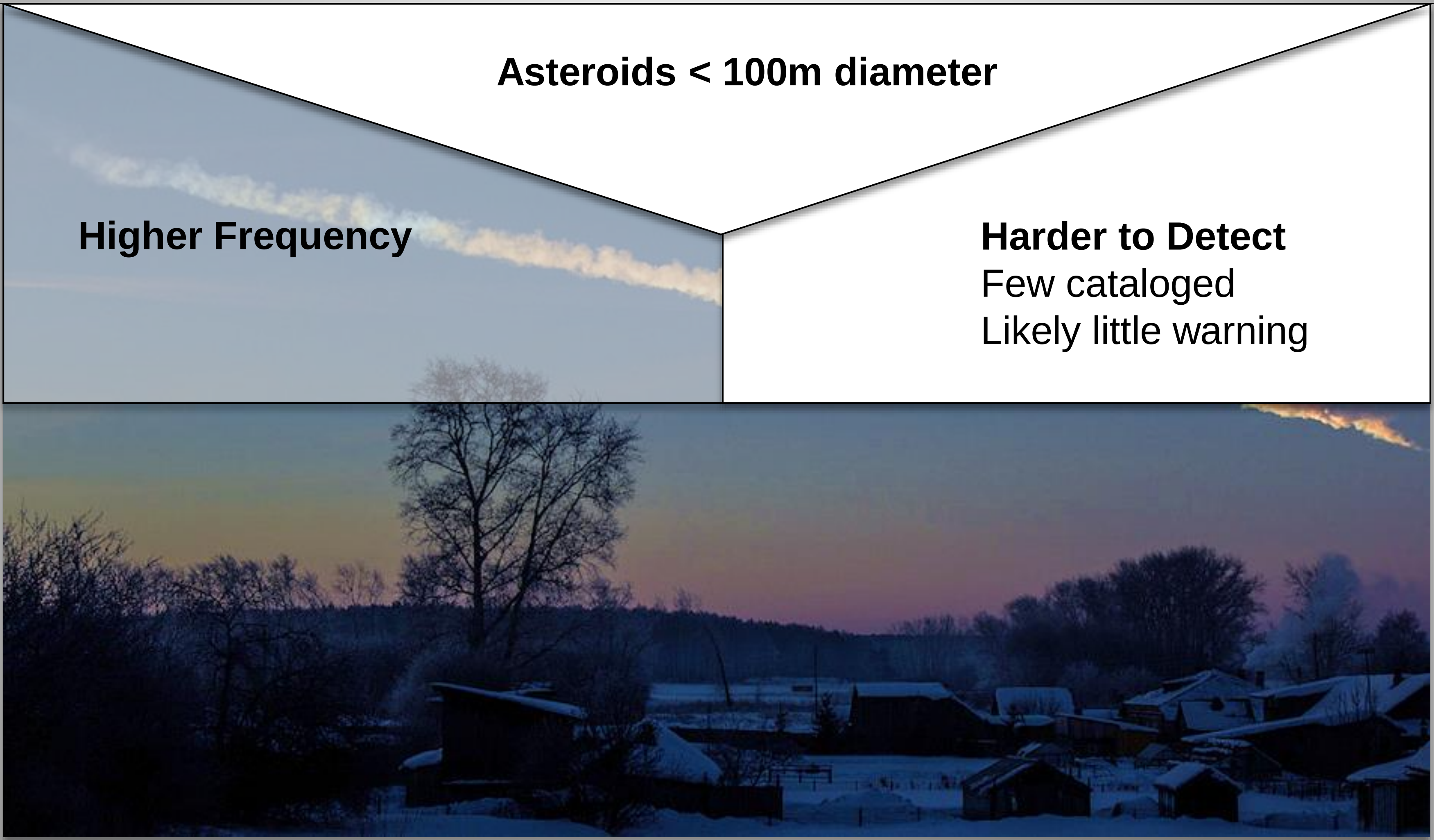
Airburst Events

Asteroids < 100m diameter

Higher Frequency
Chelyabinsk 20m 60yrs
Chicxulub 10km+ 100 million yrs



Airburst Events

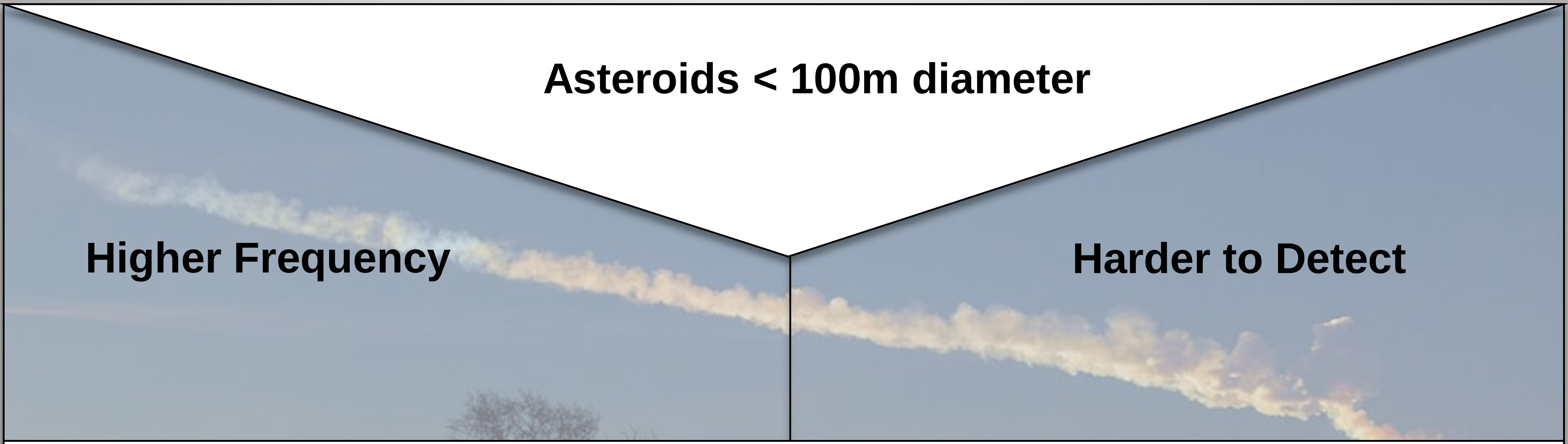


Asteroids < 100m diameter

Higher Frequency

Harder to Detect
Few cataloged
Likely little warning

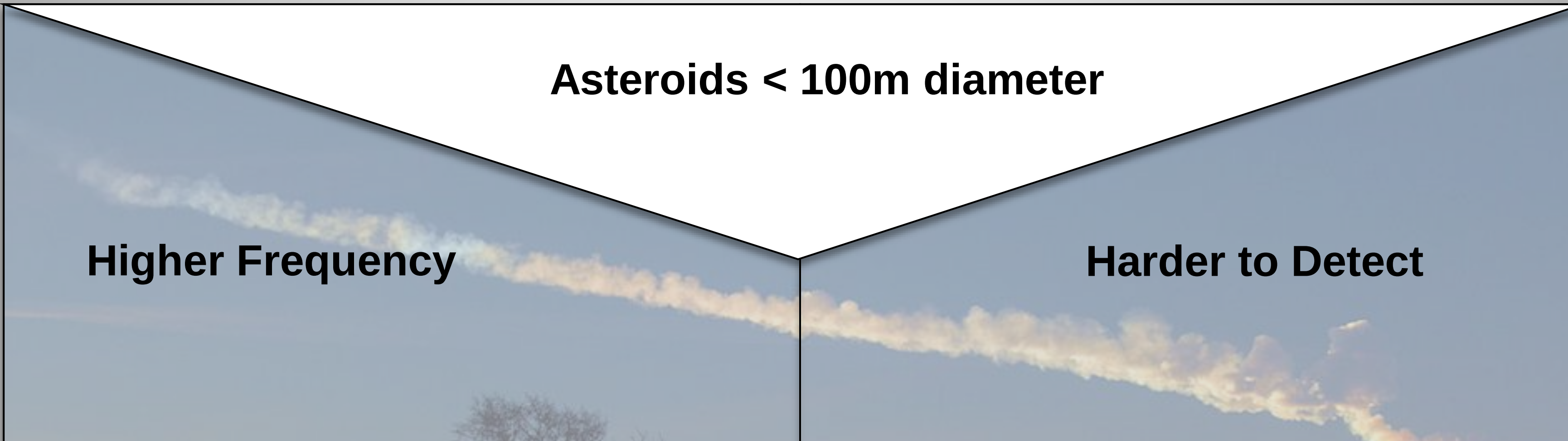
Airburst Events



Evacuate / Shelter in place?
Prepare infrastructure?
Scale of emergency response?
Scale of financial relief?

Airburst Events

Asteroids < 100m diameter



Evacuate / Shelter in place?
Prepare infrastructure?
Scale of emergency response?
Scale of financial relief?

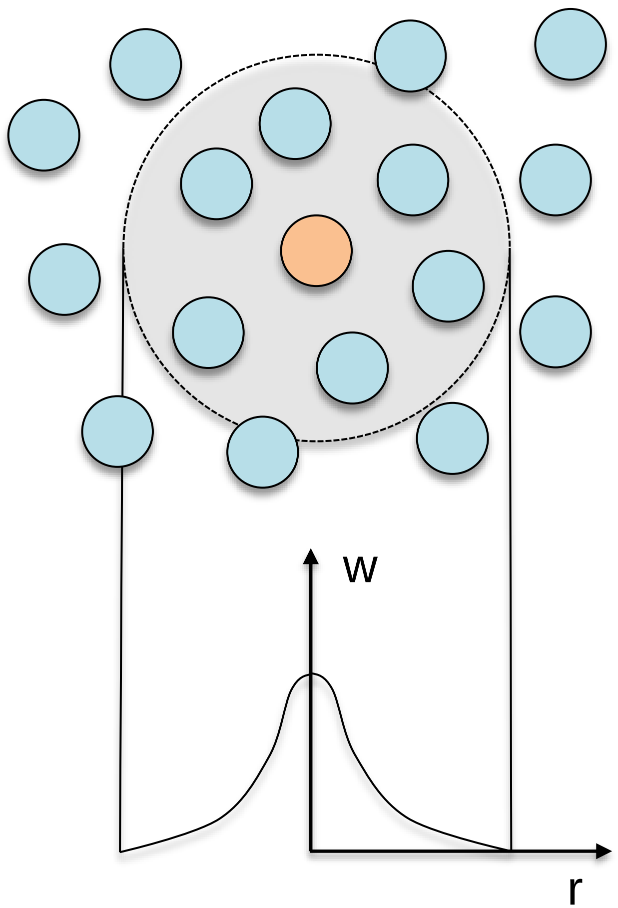
yield?
Height of burst?
Geometry of burst?

Smoothed Particle Hydrodynamics

Summary: Lagrangian meshless method, computational nodes interact with a dynamic neighbor set

Why SPH for Bolides?

- Naturally handles large deformations and interface tracking
- energy/momentum conservation
- Complement grid-code results

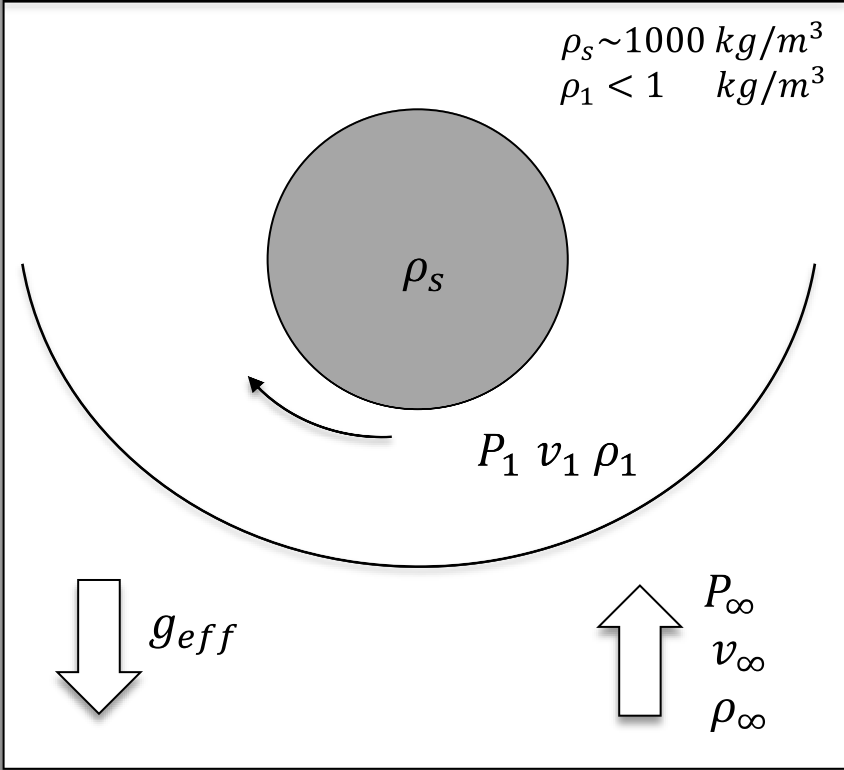


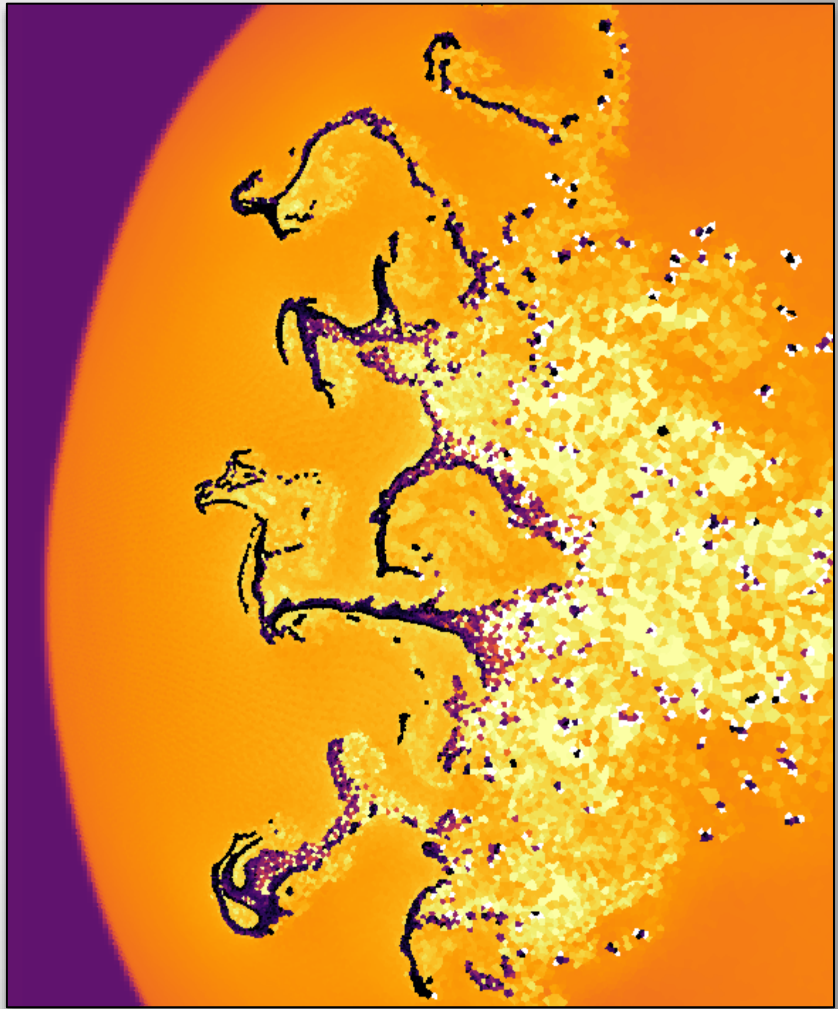
Physics

- 2D Planar
- Euler equations
  - No radiation
  - No heat transfer
  - Zero-strength
- Tillotson EOS for granite
- Gamma-Gas law for air ($\gamma = 1.4$)

Role of Hydrodynamic Instabilities

- Coupled instabilities
  - Rayleigh-Taylor
  - Kelvin-Helmholtz





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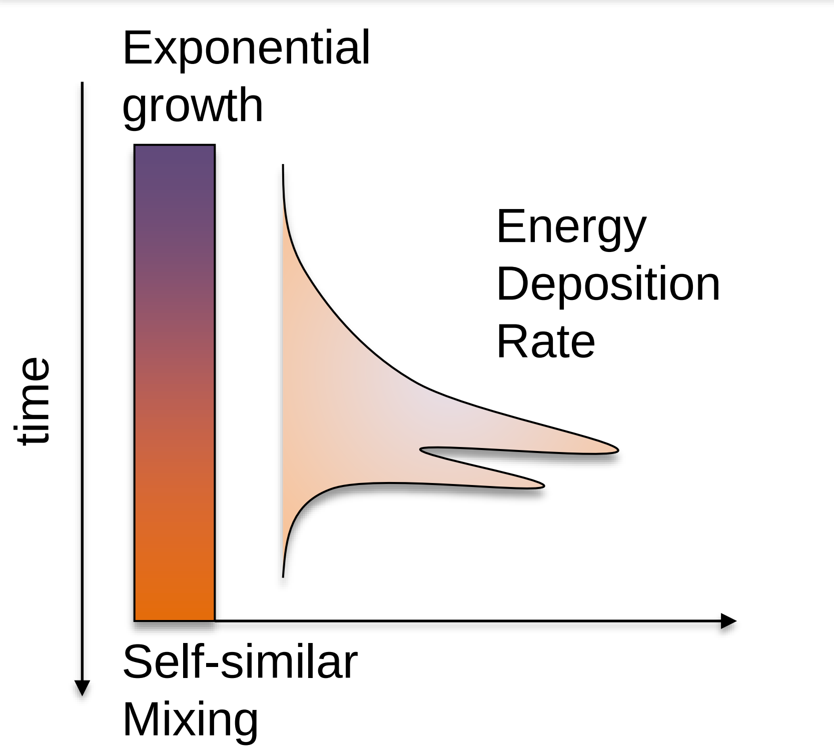
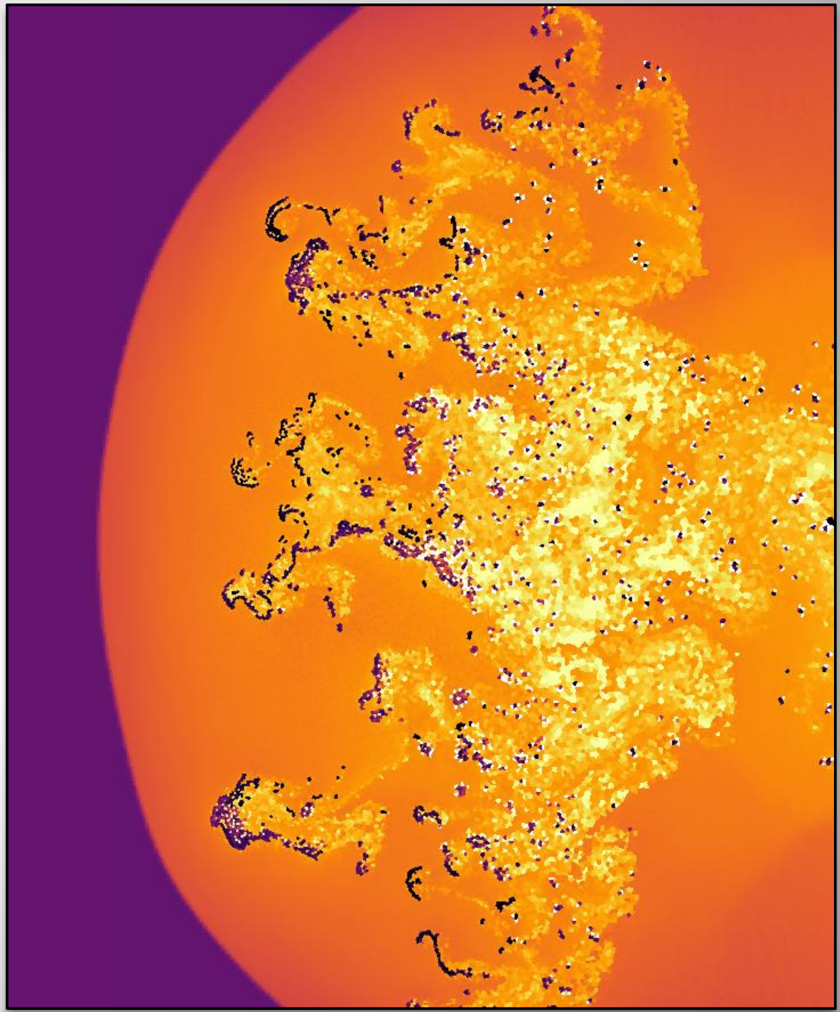
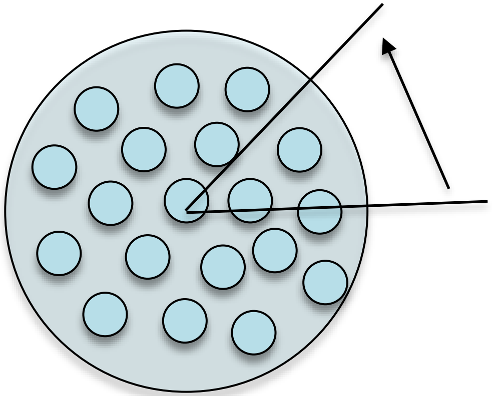


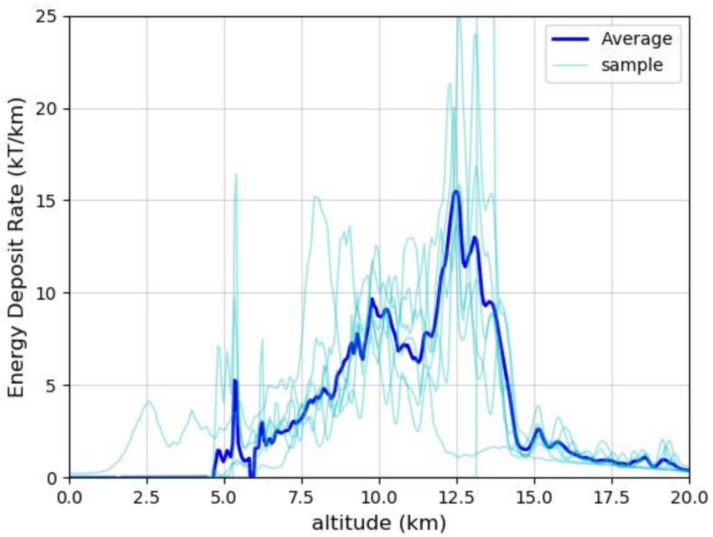


Sensitive Dependence on Initial Conditions

- Strengthless
- ρ = 2.68 g / cc
- Initial velocity = 1.5 km / sec
- Radius = 17.5 m

- 6 perturbed cases run
- Node distribution of bolide rotated to introduce perturbation
- [0.5,1.0,1.5, 2.0, 2.5, 3.0] radians





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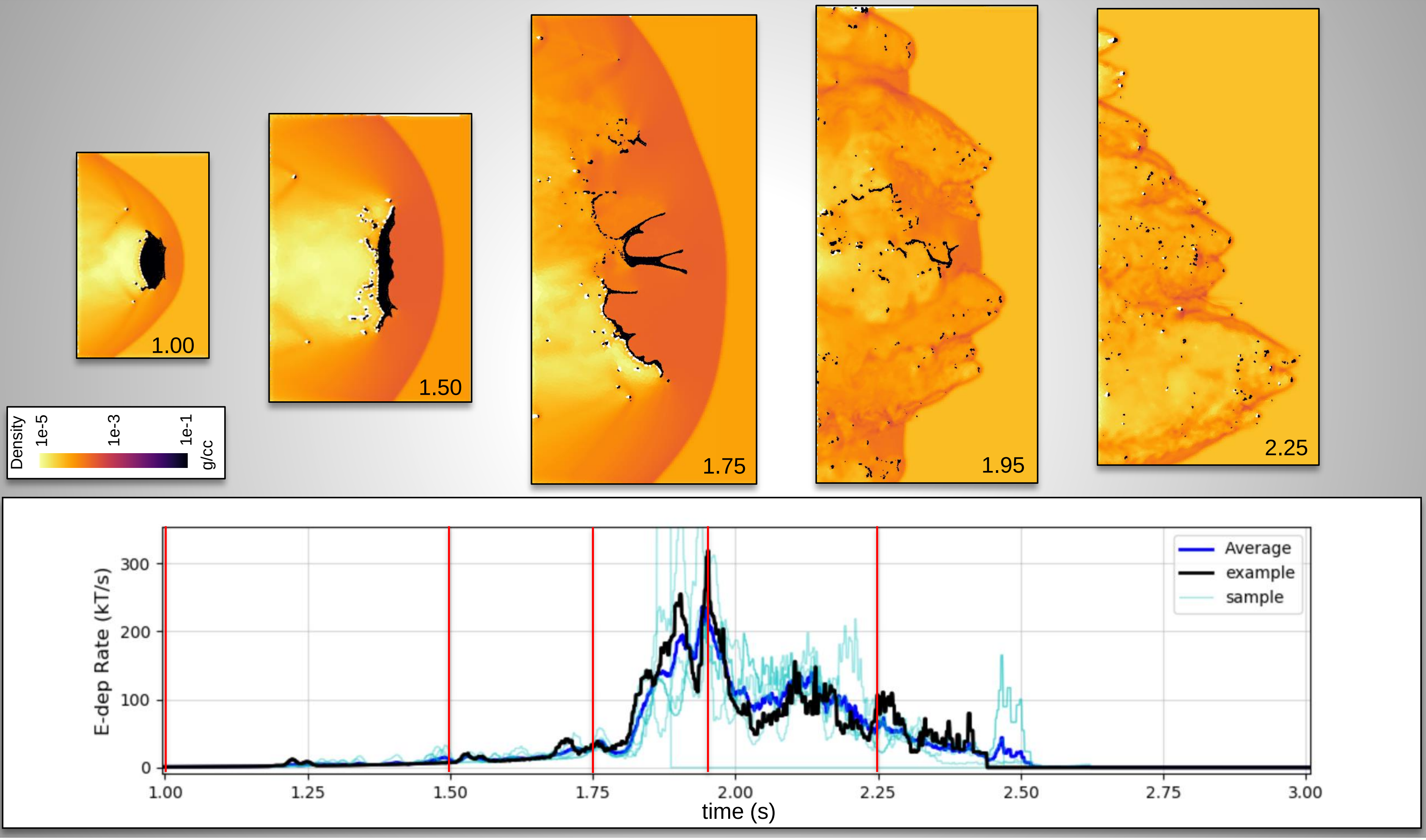
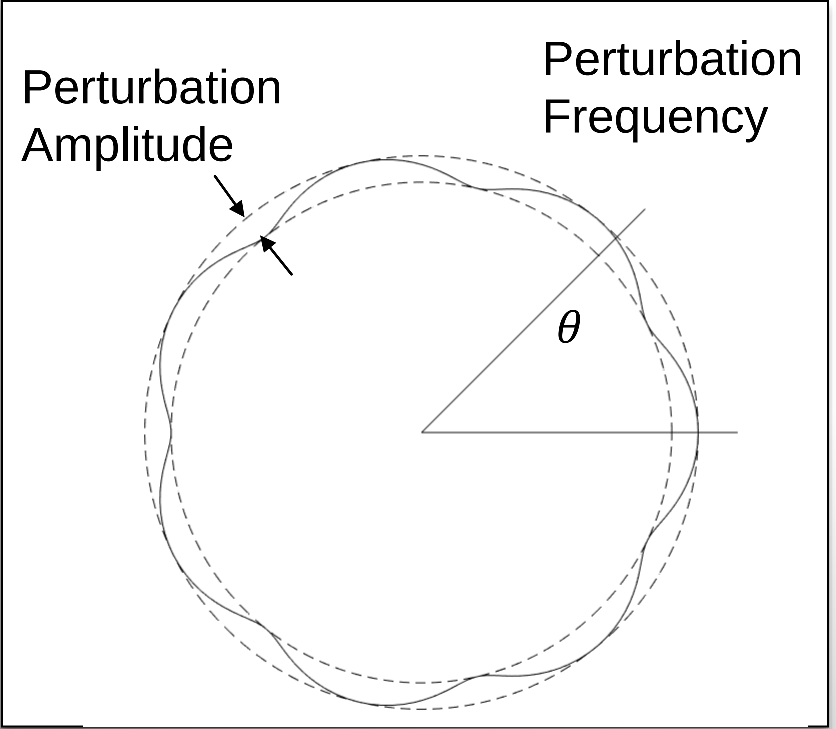
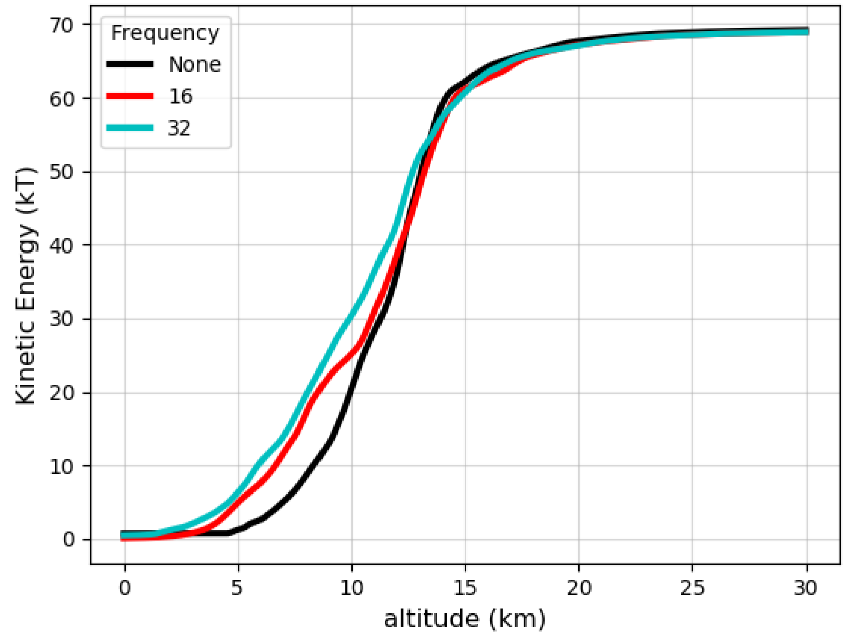


Effects of Surface Perturbations

- Strengthless
- ρ = 2.68 g / cc
- v0= 15.0 km / sec
- Radius ~ 17.5* m
- Constant mass
- Sinusoidal surface perturbations
- Amplitude = 0.1 Radius
- Plots averaged over 6 perturbed runs





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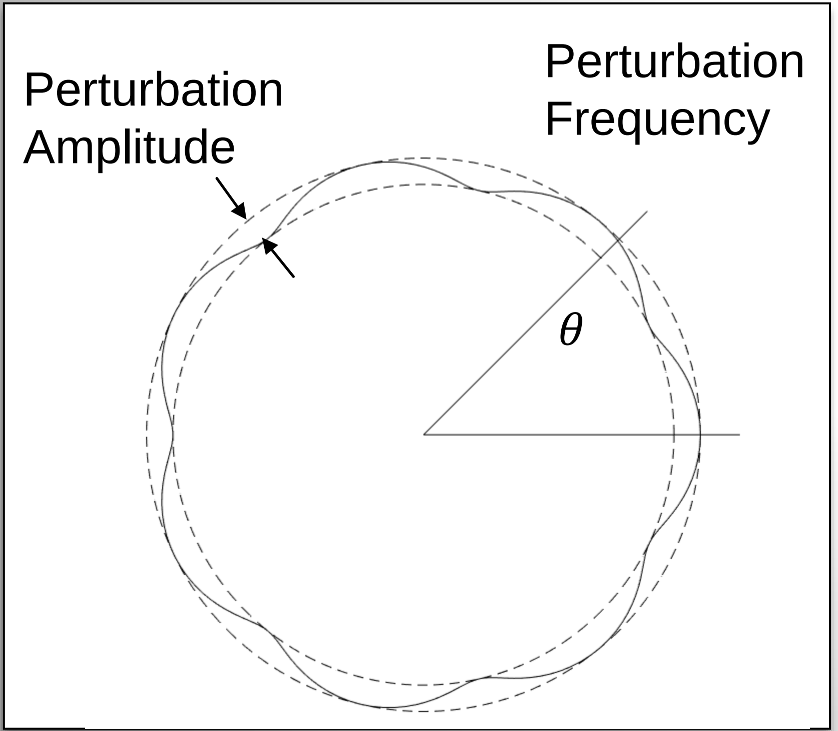

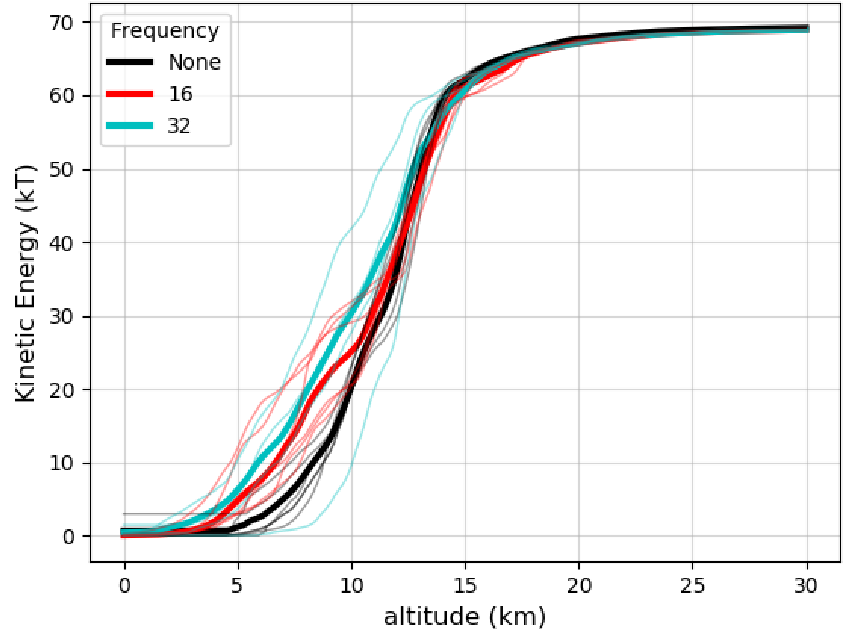

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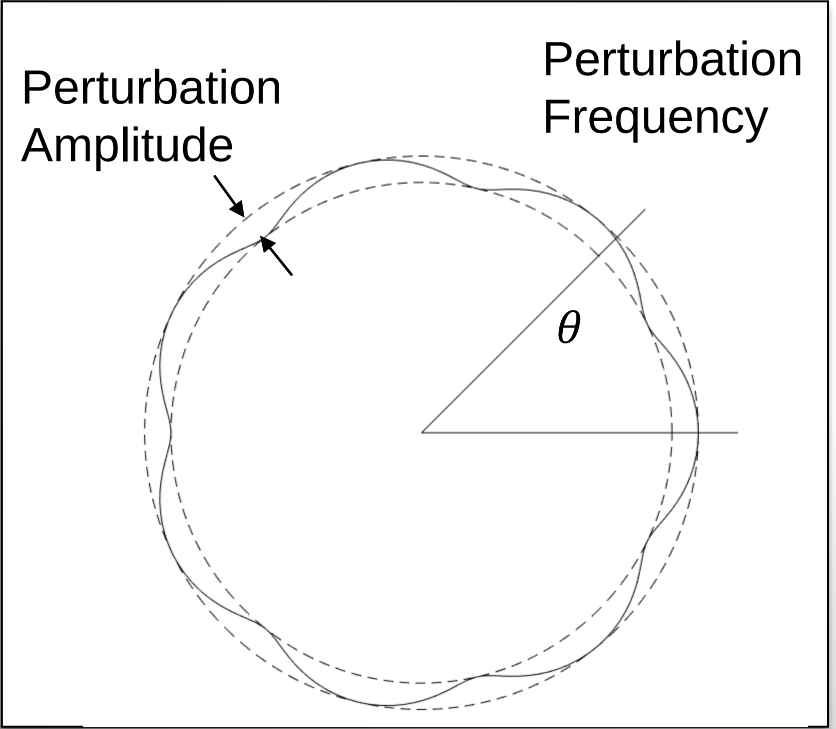

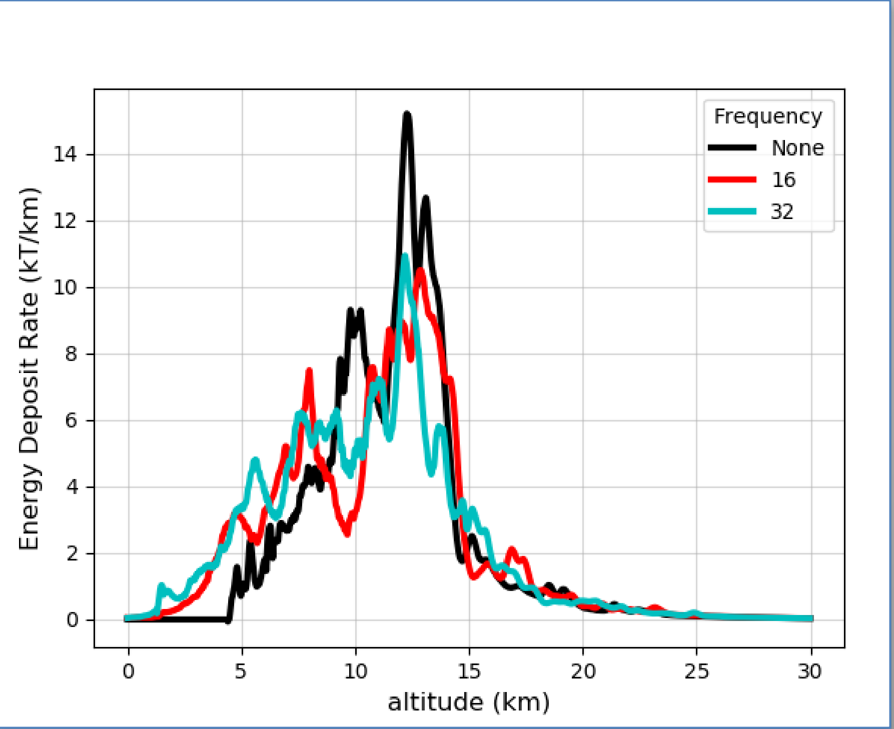

Conclusions

- **Sensitive dependence on initial conditions responsible for considerable spread in results.**

- **Surface perturbations flatten the curve?**
  - On average, cases with surface perturbations deposited energy at low altitudes with smaller peaks.
  - Variation in averages smaller than SDIC variation.

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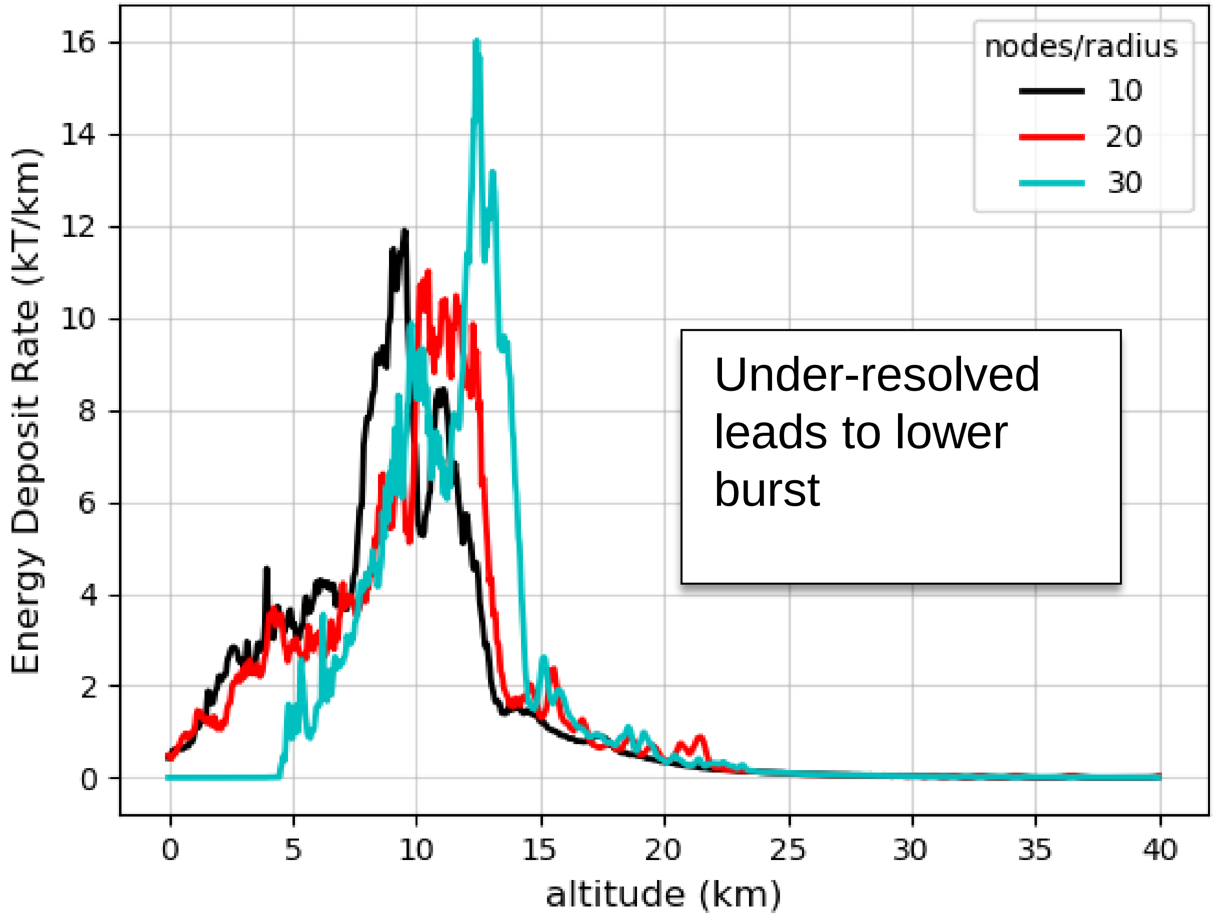
Resolution

- Strengthless
- ρ = 2.68 g / cc
- v0= 1.5 km / sec
- Radius = 17.5 m



*averages for 6 perturbed runs shown in plots

Reference

Korycansky, D.G. and Zahnle, K.J., Mac Law, M.M "High-resolution simulations of the impacts of asteroids into the venusian atmosphere" Icarus, 146, 387-403, 2000.