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A New Hydrocode Pipeline for Assessing Ground effects of Chelyabinsk- to Tunguska-Sized Asteroid Airbursts

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Super-bolides are of particular interest to planetary defense since they can release vast amounts of energy (500 kton to >10 Mton) during atmospheric entry. Super-bolides such as Chelyabinsk (20m, 2013) and Tunguska (50m, 1908) are two contemporary examples of the effects airburst phenomena have, ranging from minor structural damage to prominent land devastation. Smaller scale celestial objects responsible for airbursts exist in greater numbers in our solar system and are significantly harder to detect. These factors underscore the necessity of developing a robust understanding of how entry characteristics affect localities and regions on the ground.

High-fidelity simulations of ground effects, given asteroid properties and entry characteristics could contribute to this understanding. Unfortunately, the atmospheric breakup and blast propagation are characterized by different length and time scales, necessitating separate simulations and an intermediate handoff. We approached this

modeling challenge by developing a hydrocode pipeline which consists of two parts, initialized by explicitly calculating the energy deposition and momentum loss during the bolide breakup. This deposition is then handed-off into an atmospheric blast propagation code to estimate ground overpressures and wind speeds.

The airburst is modeled using the FSISPH package of the Smoothed Particle Hydrodynamics (SPH) code Spheral++. Aspects of the physical problem, such as entry angle, velocity, geometry, strength, damage, etc., are readily modeled and the fragmentation and breakup of the asteroid is tabulated as a total energy loss of the asteroid 'system.' This simulation strictly models the airburst event, which lasts several seconds. The tabulated energy, momentum, and mass change, as a function of altitude and time, are then utilized as input parameters in the Eulerian blast propagation code, Miranda. In an Eulerian domain, the airburst 'zone' is modeled as a moving point source with a gaussian distribution of the energy rate at each respective time-step. This zone is then advanced along the trajectory that the asteroid takes in space and the blast solver propagates the generated pressure wave to longer end states.

We apply our new pipeline by utilizing the data generated from a previous SPH simulation of the Chelyabinsk airburst case. We deposit the tabulated energy, mass, and momentum within a 3-dimensional cartesian domain within Miranda with complex ground geometry representative of a realistic landscape, such as an urban setting. Simulating the Chelyabinsk event via this pipeline allows us to perform a satisfactory comparison of the estimated to the observed ground overpressures, given some static set of SPH input parameters based on the literature. Furthermore, informed by the results of this specific study, we can begin an analysis of how slight variations in the entry characteristics of a similar scenario, such as entry angle, would affect the response on the ground.

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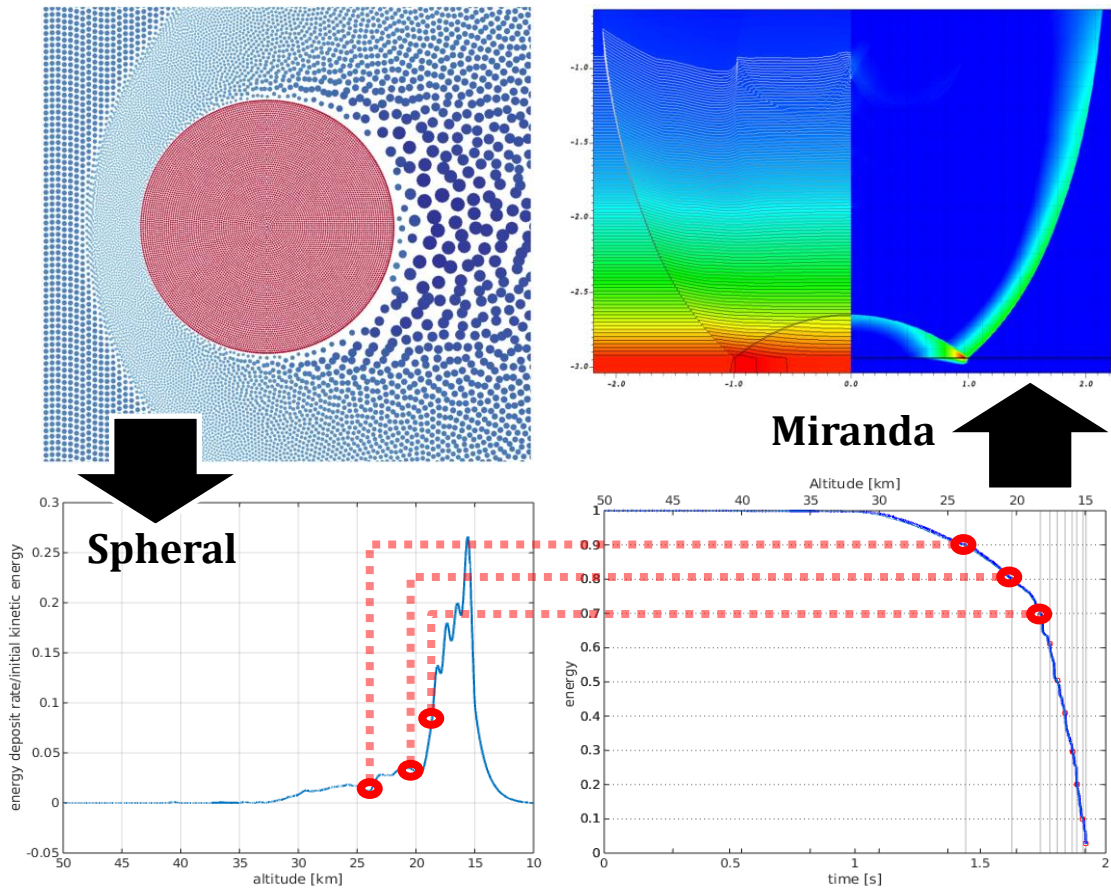


Fig 1.: In counter-clockwise motion, this figure visualizes the hydrocode pipeline process: 1. initialize the asteroid with specific size, geometry, and material configurations in a hypervelocity environment in air through the FSISPH solver, 2. Tabulate the energy deposition from the fragmentation and breakup of the asteroid, and 3. Input the energy deposition as a moving energy source term in the blast solver, Miranda, to propagate the pressure wave out to longer time steps and quantify the ground consequences of the modeled airburst.