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MODELING THE ATMOSPHERIC BREAKUP OF VARIED ASTEROID STRUCTURES: INFERENCES FOR THE CHELYABINSK METEOR AND RISK ASSESSMENT APPLICATIONS

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ABSTRACT

Asteroid airbursts can produce damaging blast overpressures on the ground, as exemplified by the 2013 Chelyabinsk meteor. To assess the severity and extent of the ground damage from such airbursts, risk models require estimates of the energy deposited in the atmosphere during entry and breakup. This energy deposition depends upon how rapidly the bolide breaks apart and how the resulting fragments or debris interact with the atmosphere. These factors, in turn, could vary significantly depending on the initial asteroid properties and structures, which could range from coherent monoliths to loosely bound rubble piles. In order to effectively capture the ranges and likelihoods of potential damage, asteroid risk assessments require models that are fast enough to compute millions of impact cases, but are also able to capture how key asteroid characteristics may affect the energy deposition process.

We present an anlytic fragment-cloud model (FCM) that represents the atmospheric breakup and energy deposition of asteroids with a range of internal structures. The modeling approach combines successive fragmentation of larger independent pieces with aggregate debris clouds released during each break. The model can vary the number and masses of fragments produced, the debris mass released, and the fragment strength scaling that determines the successive fragmentation rate. The initial asteroid body can be seeded with a distribution of independent fragment sizes amid a remaining debris mass to represent loose rubble pile conglomerations, or can be defined as a monolith with an outer regolith layer. This approach enables the model to represent a range of breakup behaviors and reproduce detailed energy deposition features such as multiple flares due to successive burst events, high-altitude regolith blow-off, or initial rubble disruption followed by more energetic breakup of the constituent boulders. Matching these features in observed meteor light curves can support inferrences about pre-entry asteroid properties or breakup beviors, and can also be used to refine modeling assumptions or determine appropriate ranges for uncertain modeling parameters.

We have applied the FCM to reproduce observational data from the Chelyabinsk meteor, and present the results of the matches obtained. The model is able to produce very good matches to the observed light curve along with reasonable ranges of landed fragment mass. Inferrences about the bolide's initial mass, density, porosity, and structure are discussed, along with implications for airburst risk modeling applications.

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