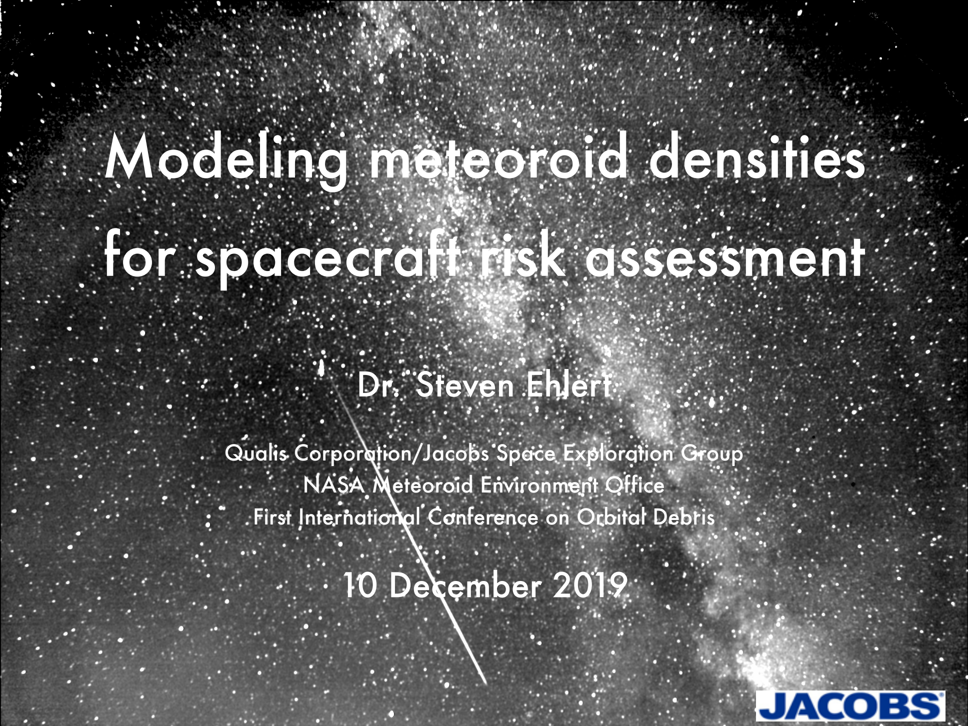

Modeling meteoroid densities for spacecraft risk assessment

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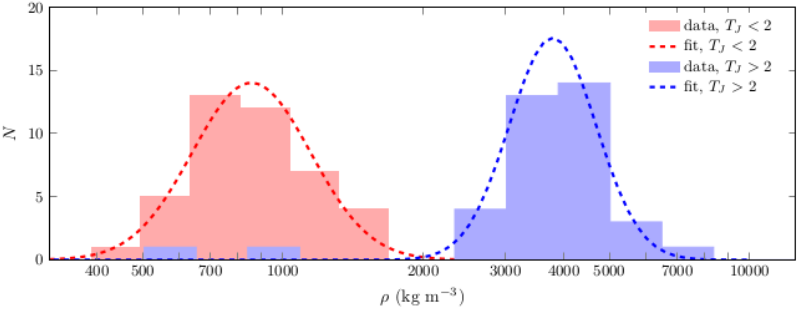
Overview

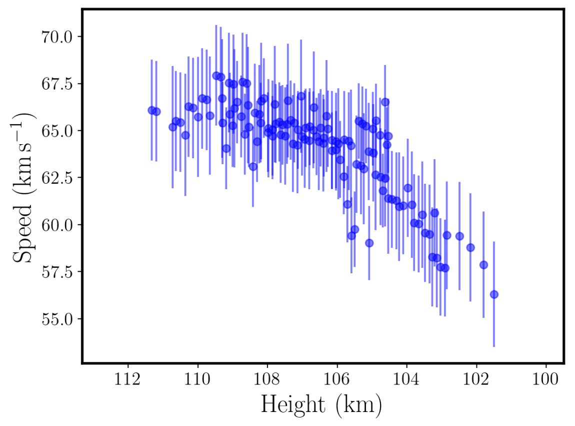
- Why are meteoroid densities so difficult to measure?
- The MEO's best efforts thus far.
- The need for better data in the future.

NASA's Meteoroid Engineering Model (MEM) 3 incorporates a new model of meteoroid densities based on the Tisserand parameter (with respect to Jupiter) of the meteoroid orbits. The data are taken from the 92 density measurements of Kikwaya et al. 2011.



Meteoroid densities are EXTREMELY difficult to measure

Densities can only be determined when both a dynamical mass and photometric mass can be measured, which in turn requires observations of deceleration and light curves. The spatial resolution required to measure deceleration generally needs to be better than $\sim 100\,$m.



Modeling meteoroid ablation in the atmosphere requires solving a complex set of coupled, non-linear differential equations with a large number of free parameters. The most crucial of these parameters is the grain mass distribution, which cannot be constrained from the light curve and deceleration data.

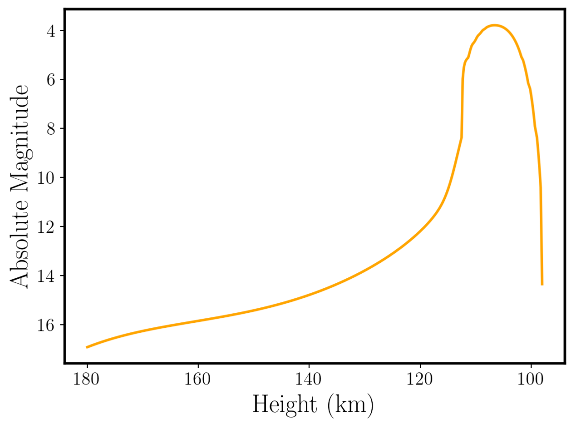
$$\frac{dv}{dt} = \frac{\Gamma \rho_a v^2}{m} A \left(\frac{m}{\rho_m} \right)^{2/3}$$

$$\frac{dH}{dt} = -v \cos z.$$

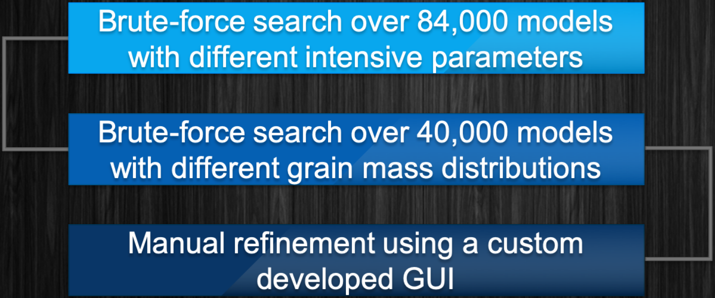
$$\frac{dT_m}{dt} = \frac{1}{c \times m} \left[A \left(\frac{m}{\rho_m} \right)^{2/3} \left(\frac{\Lambda \rho_a v^3}{2} - 4\sigma_B \epsilon (T_m^4 - T_a^4) \right) - L \frac{dm}{dt} \right]$$

$$\frac{dm}{dt} = A \left(\frac{m}{\rho_m} \right)^{2/3} \psi \frac{P_a \exp\left(\frac{L\mu}{k_B T_b} \right) \exp\left(\frac{-L\mu}{k_B T_m} \right) - p_v}{\sqrt{2\pi k_B T_m / \mu}} + \frac{P_{spall} \Lambda}{2L} A \left(\frac{m}{\rho_m} \right)^{2/3} \rho_a v^3$$

The thermal disruption model of ablation utilized in this work assumes that a meteoroid has a “dust-ball” structure - small grains bound together by a volatile organic “glue.” Speed, height, temperature, and total mass are calculated as a function of time. When the meteoroid temperature reaches a user-defined value, the “glue” vaporizes and the meteoroid fragments into multiple components.



The process we utilized to attempt new density measurements is almost identical to that in Kikwaya et al. 2011, which is the most thorough study of meteoroid densities performed to date.

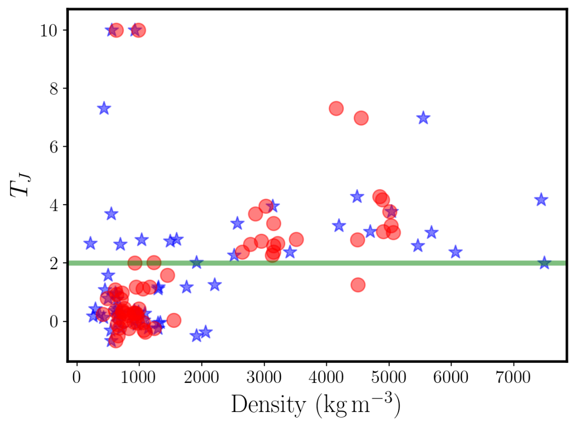


Brute-force search over 84,000 models with different intensive parameters

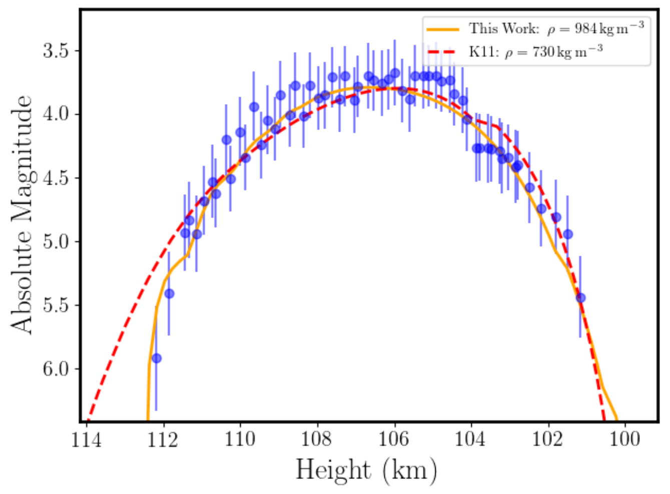
Brute-force search over 40,000 models with different grain mass distributions

Manual refinement using a custom developed GUI

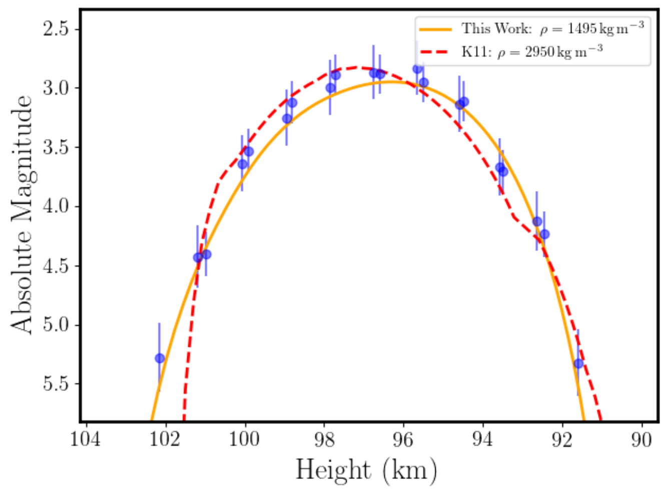
Tests utilizing 60 events with measurements from Kikwaya et al. 2011 showed that $\sim 20\%$ had final density values discrepant by more than a factor of two compared to past calculations. This is despite the fact that the data and ablation model were identical between the two analyses.



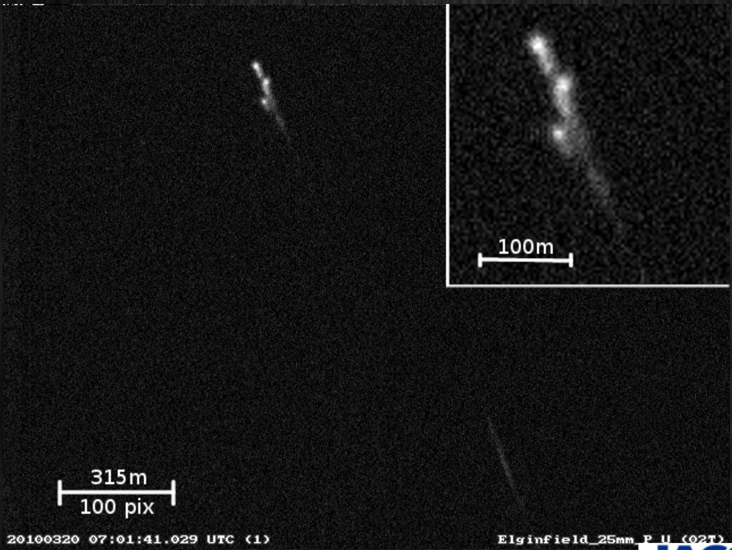
Most events showed small discrepancies (a factor of < 2) between old and new density measurements.



For events where there is a large discrepancy in the final density (a factor of > 2), both models are "good" fits to the data. The orange curve corresponds to the density of coal, while the red curve is the density of solid aluminum.



The most promising observational data for future work is taken by the University of Western Ontario's CAMO instrument. This extremely high resolution camera resolves the fragmentation process, with the distribution of light in the wake of the meteoroid providing new constraints on the grain mass distribution.



Conclusions

1. Densities are a key driver of risk posed to spacecraft by the meteoroid environment.
2. MEM 3 has incorporated a density distribution that utilizes measurements of 92 events.
3. Densities are extremely difficult to measure.
4. Greater need than ever for high resolution meteor imagery to break degeneracies.