The velocity and density distribution of Earth-intersecting meteoroids: implications for environment models

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Meteoroid environment models



Meteoroid impact crater on shuttle window. Image provided by the NASA/JSC Hypervelocity Impact Technology (HVIT) Team.

- Damage done by a meteoroid impact depends on:
 - mass
 - velocity
 - density
 - impact angle
- We are revisiting each of these components for the next version of our Meteoroid Engineering Model (MEM).

Velocity distribution de-biasing Ionization efficiency

- ► Meteor ionization increases with speed, and does not occur below v₀ ~ 9 km s⁻¹.
- Detections are complete to smaller masses at higher v.
- We use the Jones ionization efficiency¹ to de-bias the radar meteor speed distribution efficiency²
 - ¹Jones, 1997; Thomas et al., 2016 ²Moorhead et al., 2017



Velocity distribution de-biasing



Measurement uncertainty has a blurring effect



Constructing a filter

We use meteor showers to characterize our observation "filter" ...



Sharpening the raw distribution

- ► Next, we invert it (solve the N × N system of equations) to obtain the sharpened distribution.
- Hyperbolic meteors disappear naturally.



Sharpening the de-biased distribution



Density distribution

- Densities can be constrained by ablation modeling³, but there are few measurements to work with.
- We looked for a density proxy:
 - K_B was a poor proxy in all data sets examined
 - T_J was a good proxy for one data set⁴



³Campbell-Brown & Koschny, 2004; Borovička et al., 2007
⁴Kikwaya et al., 2011

Density distribution

- We fit log-normal distributions to the two density groups:
 - $T_J < 2 HTCs$, NICs apex and toroidal
 - $T_J > 2 JFCs$, asteroids helion/antihelion



Density de-biasing

Observations



- Density does not affect peak brightness (L); denser meteors simply peak at lower heights (see plot).
- Thus, no significant density bias in observations.

Density de-biasing

Numerical simulations and spacecraft impacts

Impact crater depth *does* depend on *ρ*:

depth $\propto
ho^{4/27}$

Ratio of radiation pressure to gravity also depends on ρ:

$$F_r/F_g \propto
ho^{-2/3}$$

Density affects the conversion of β-limited to mass-limited distributions, or mass-limited to crater-limited distributions.

Meteoroid directionality

Crater-limited, de-biased



- We have revisited the velocity distribution and density distribution used by meteoroid environment models.
- Our velocity distribution is:
 - derived from radar (CMOR) observations,
 - de-biased using modern ionization efficiency, and
 - sharpened to remove uncertainty smoothing.
- Our density distribution is based on Kikwaya et al. (2011).
 K_B was not well-correlated with *ρ* in any data set we examined.
- 38% of radar meteors are associated with the helion/ antihelion sources.

After de-biasing, we find that up to 93% of craters are associated with these sources.