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

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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).
Meteor ionization increases with speed, and does not occur below $v_0 \sim 9 \text{ km s}^{-1}$.

Detections are complete to smaller masses at higher $v$.

We use the Jones ionization efficiency\(^1\) to de-bias the radar meteor speed distribution efficiency\(^2\)

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\(^1\)Jones, 1997; Thomas et al., 2016
\(^2\)Moorhead et al., 2017
Velocity distribution de-biasing

Relative flux

- Raw distribution
- Brown et al. (2004)
- Moorhead et al. (2017)

$v$ (km s$^{-1}$)
Velocity distribution sharpening

Measurement uncertainty has a blurring effect

- ionization-limited
- mass-limited

Relative flux vs. velocity graphs showing the effect of correction on observed data.
- We use meteor showers to characterize our observation "filter" ...
Next, we invert it (solve the $N \times N$ system of equations) to obtain the sharpened distribution.

Hyperbolic meteors disappear naturally.
Velocity distribution sharpening
Sharpening the de-biased distribution

![Graph showing velocity distribution sharpening](image-url)
Densities can be constrained by ablation modeling\textsuperscript{3}, 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 set\textsuperscript{4}

\textsuperscript{3}Campbell-Brown & Koschny, 2004; Borovička et al., 2007
\textsuperscript{4}Kikwaya et al., 2011
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 \( \text{does depend on } \rho \): 
  \[
  \text{depth} \propto \rho^{4/27}
  \]

- Ratio of radiation pressure to gravity also depends on \( \rho \): 
  \[
  \frac{F_r}{F_g} \propto \rho^{-2/3}
  \]

- Density affects the conversion of \( \beta \)-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 $\rho$ 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.