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

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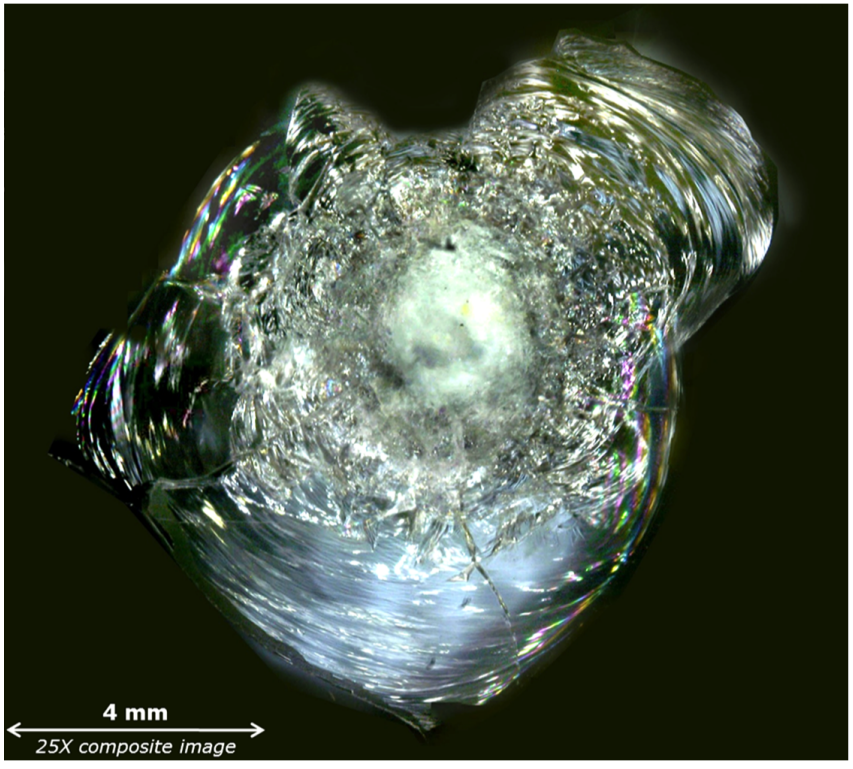
Meteoroid environment models



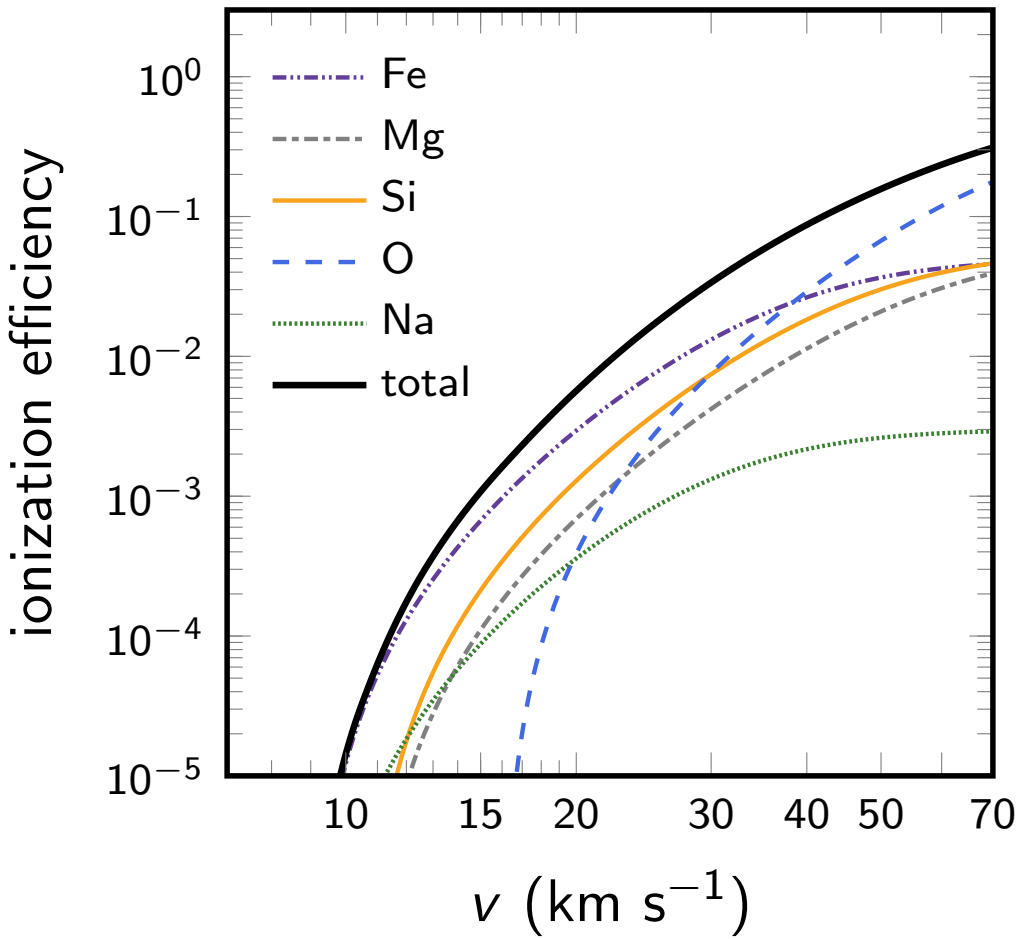
Meteoroid impact crater on shuttle window. Image provided by the NASA/JSC Hypervelocity Impact Technology (HVIT) Team.

- 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

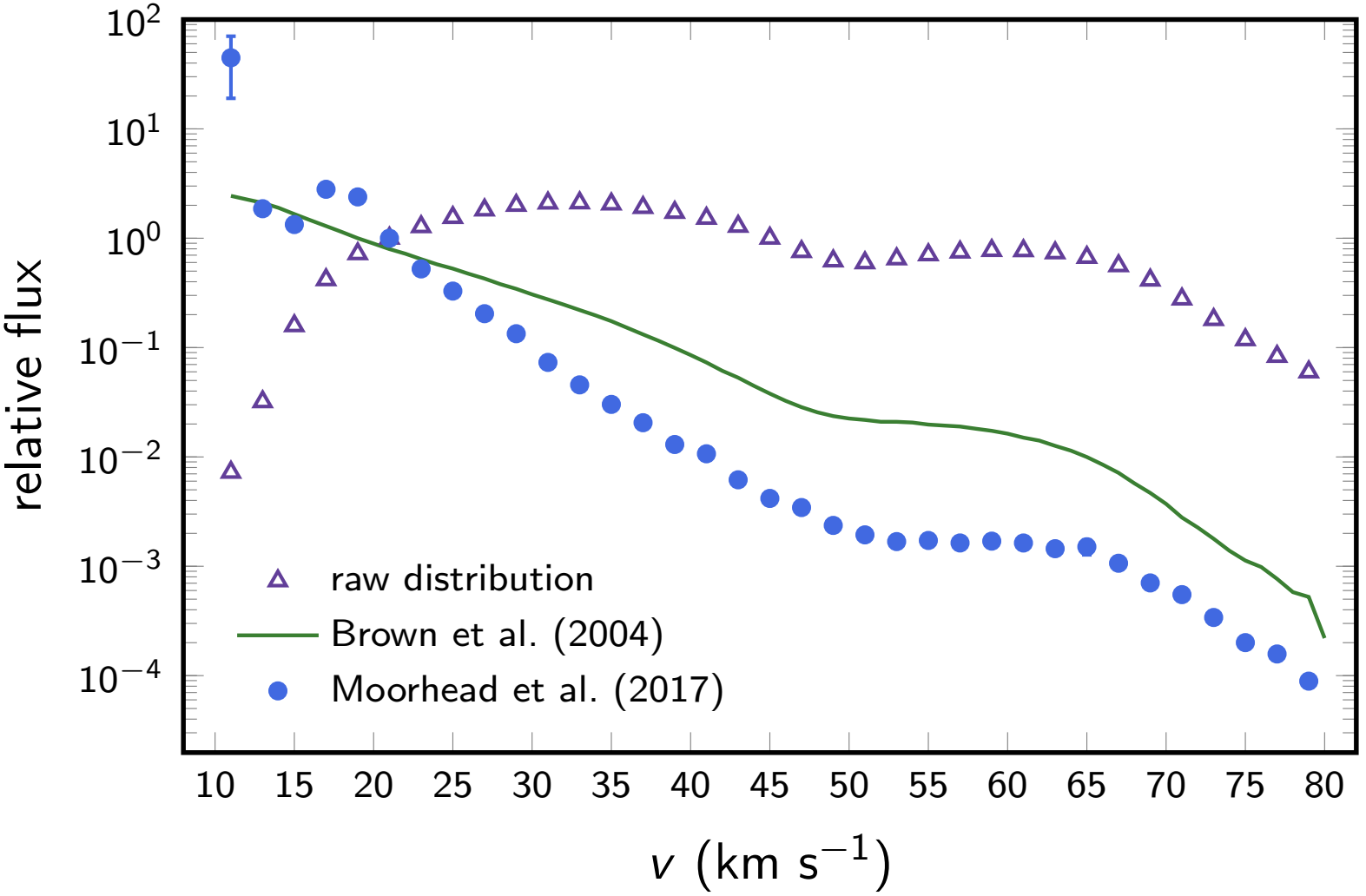
- Meteor ionization increases with speed, and does not occur below $v_0 \sim 9$ km s^{-1}.
- Detections are complete to smaller masses at higher v.
- We use the Jones ionization efficiency[1] to de-bias the radar meteor speed distribution efficiency[2]



[1] Jones, 1997; Thomas et al., 2016

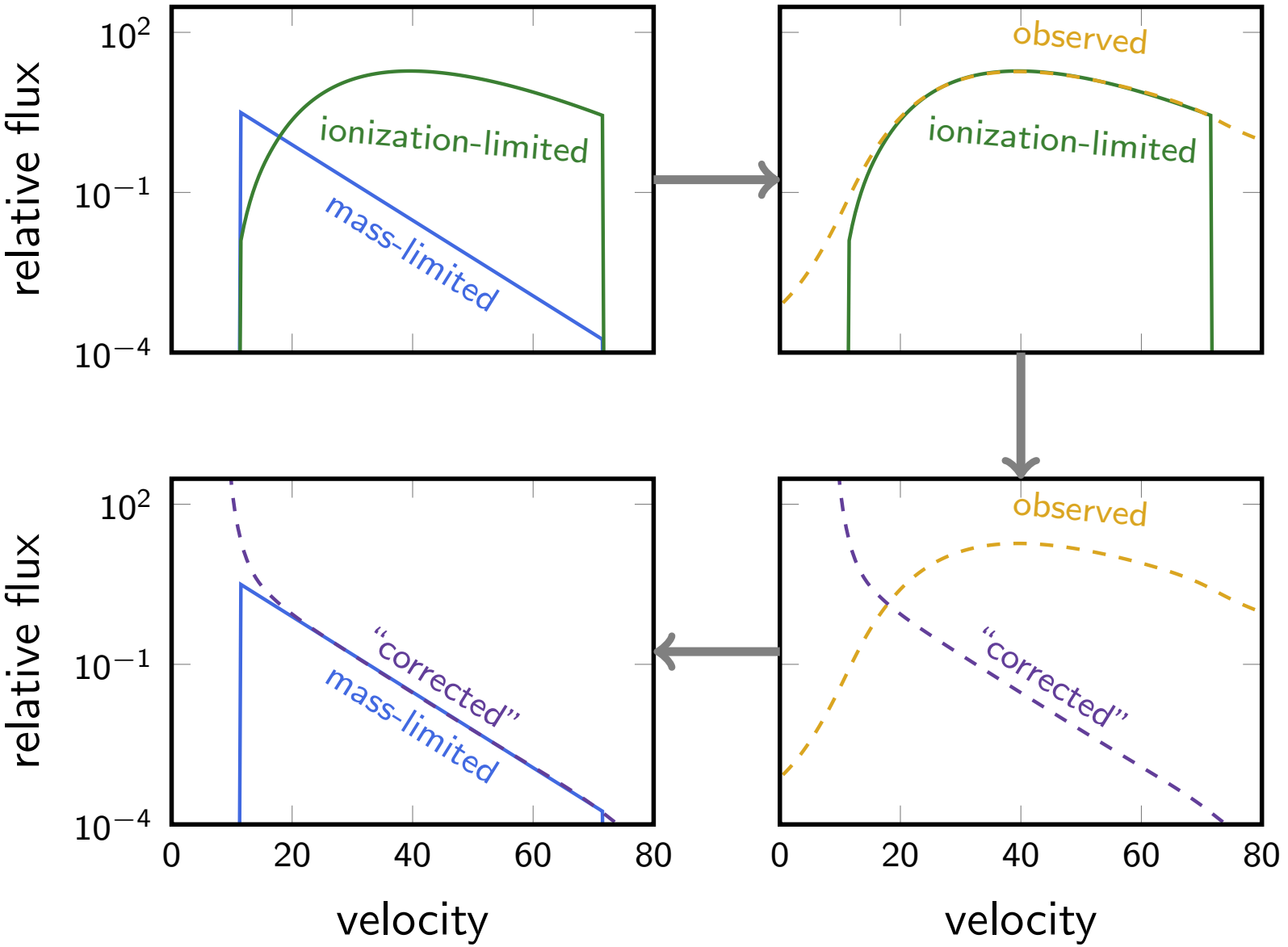
[2] Moorhead et al., 2017

Velocity distribution de-biasing



Velocity distribution sharpening

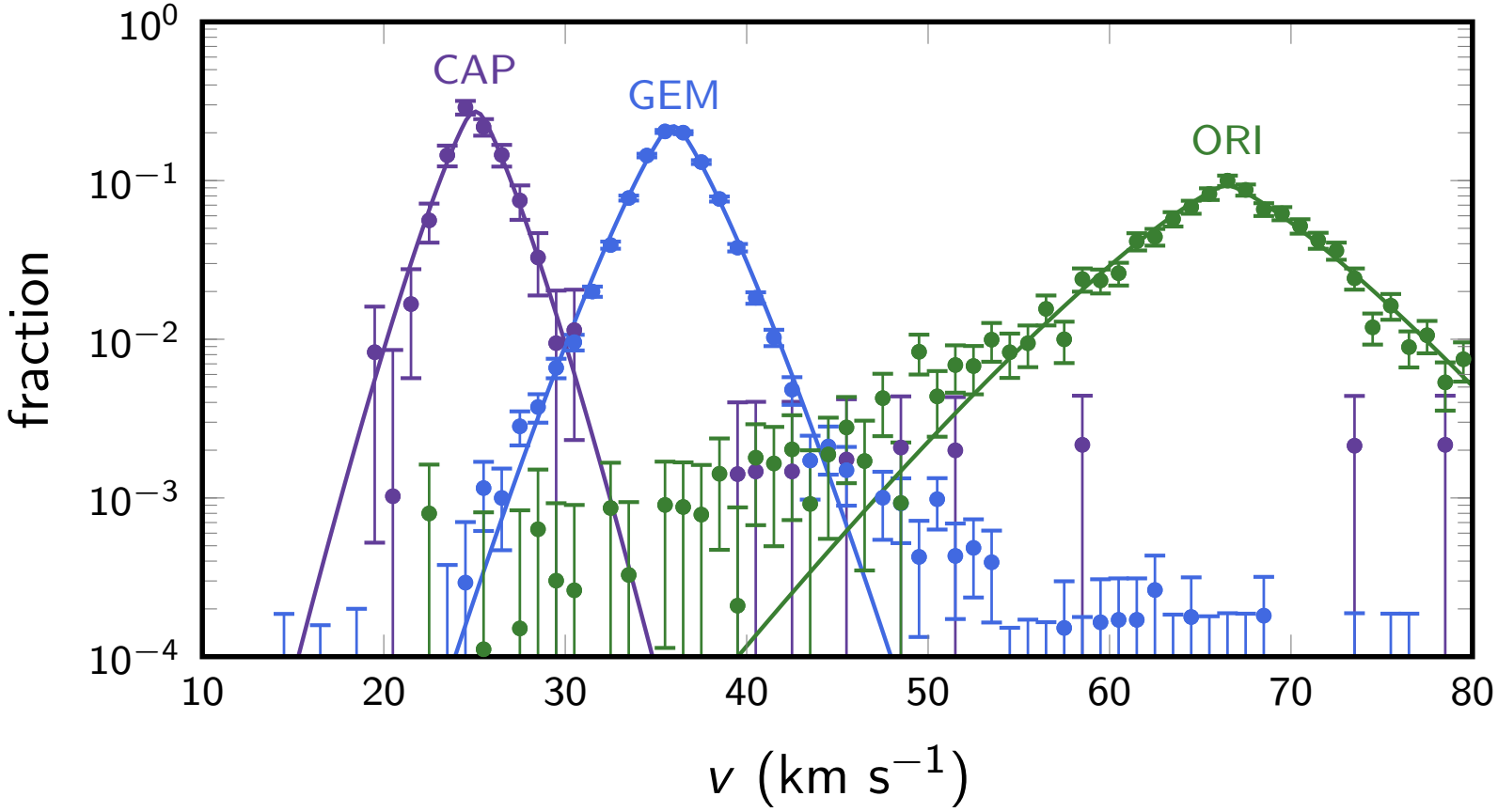
Measurement uncertainty has a blurring effect



Velocity distribution sharpening

Constructing a filter

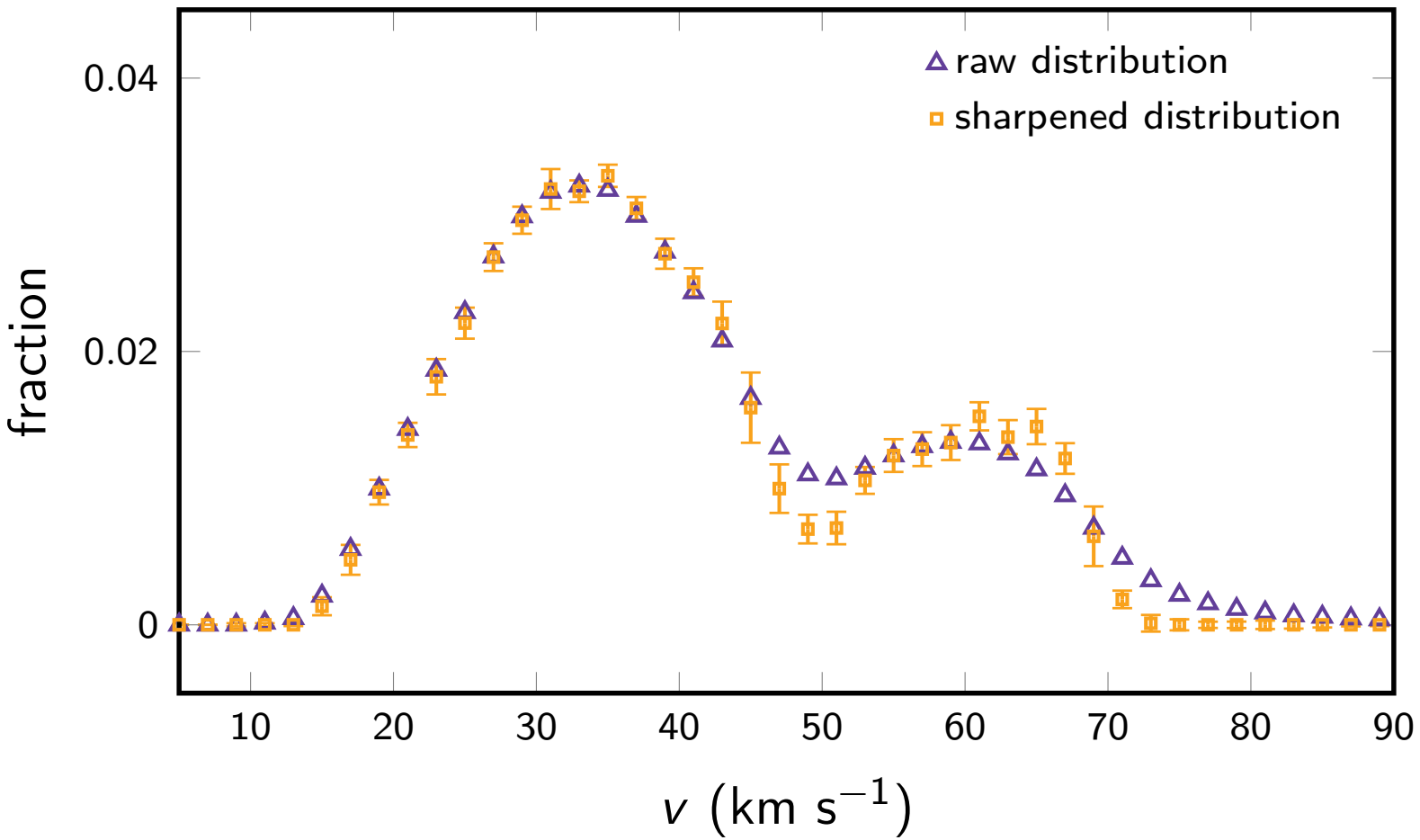
- We use meteor showers to characterize our observation "filter" ...



Velocity distribution sharpening

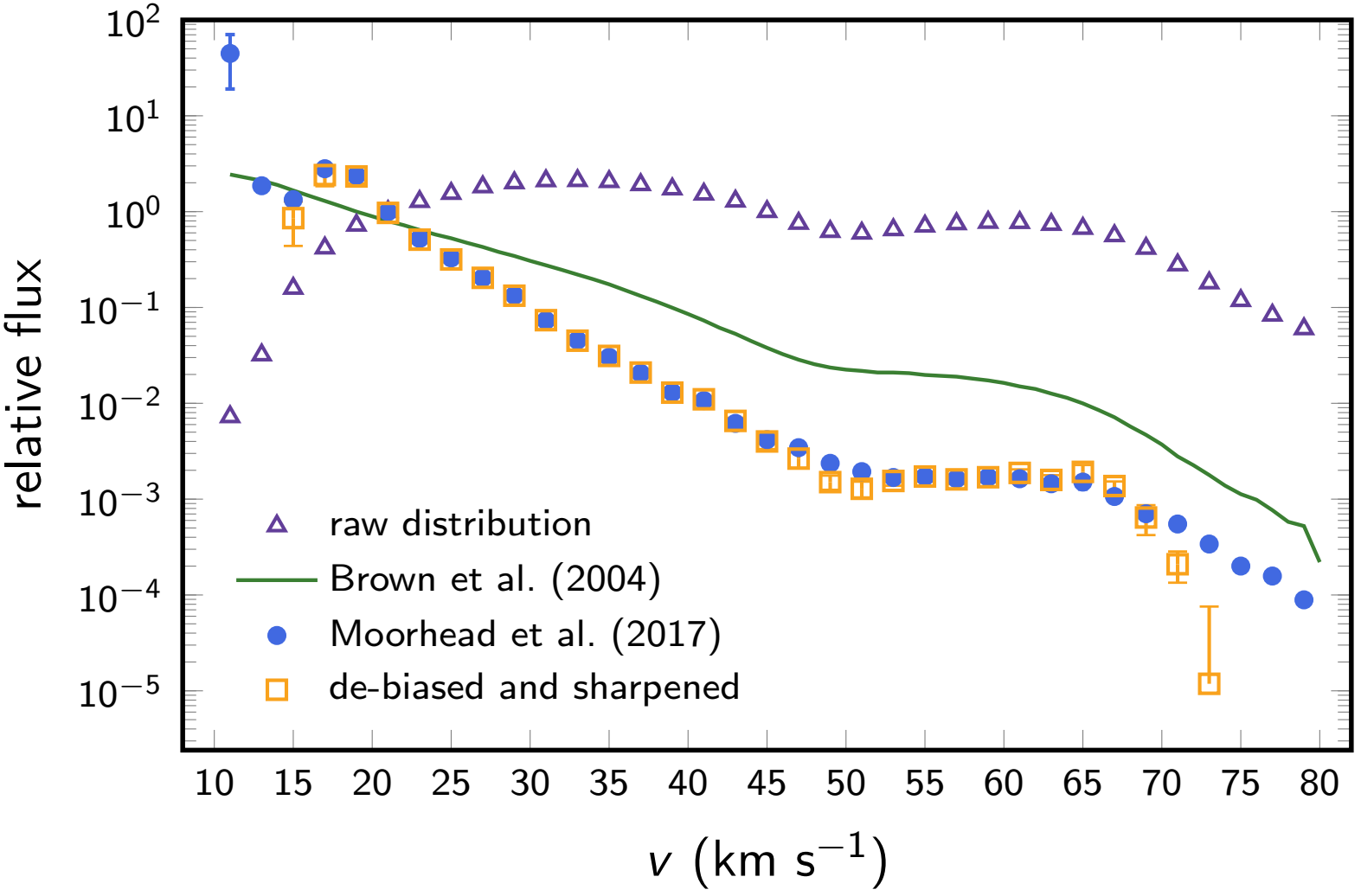
Sharpening the raw distribution

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



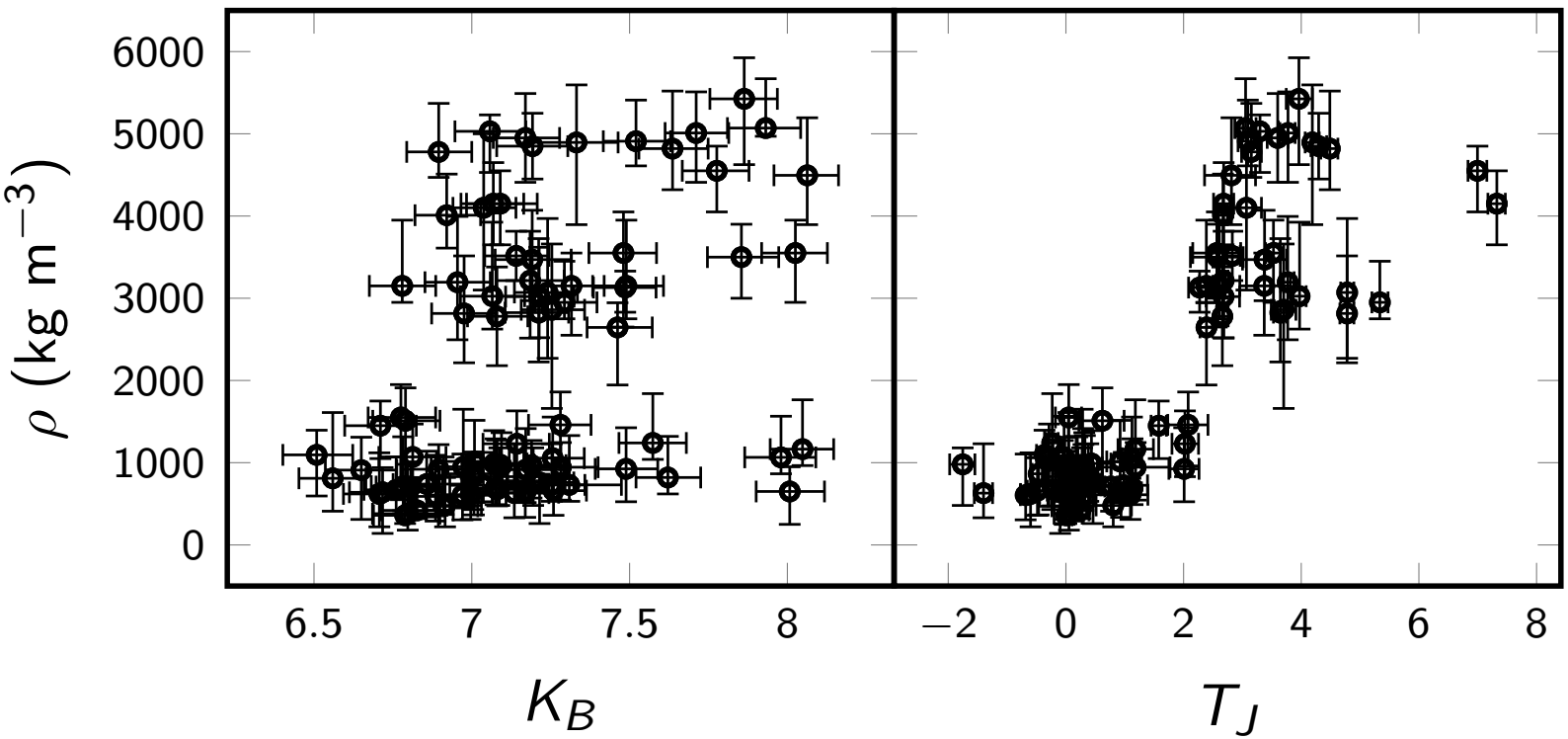
Velocity distribution sharpening

Sharpening the de-biased distribution



Density distribution

- Densities can be constrained by ablation modeling[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[4]

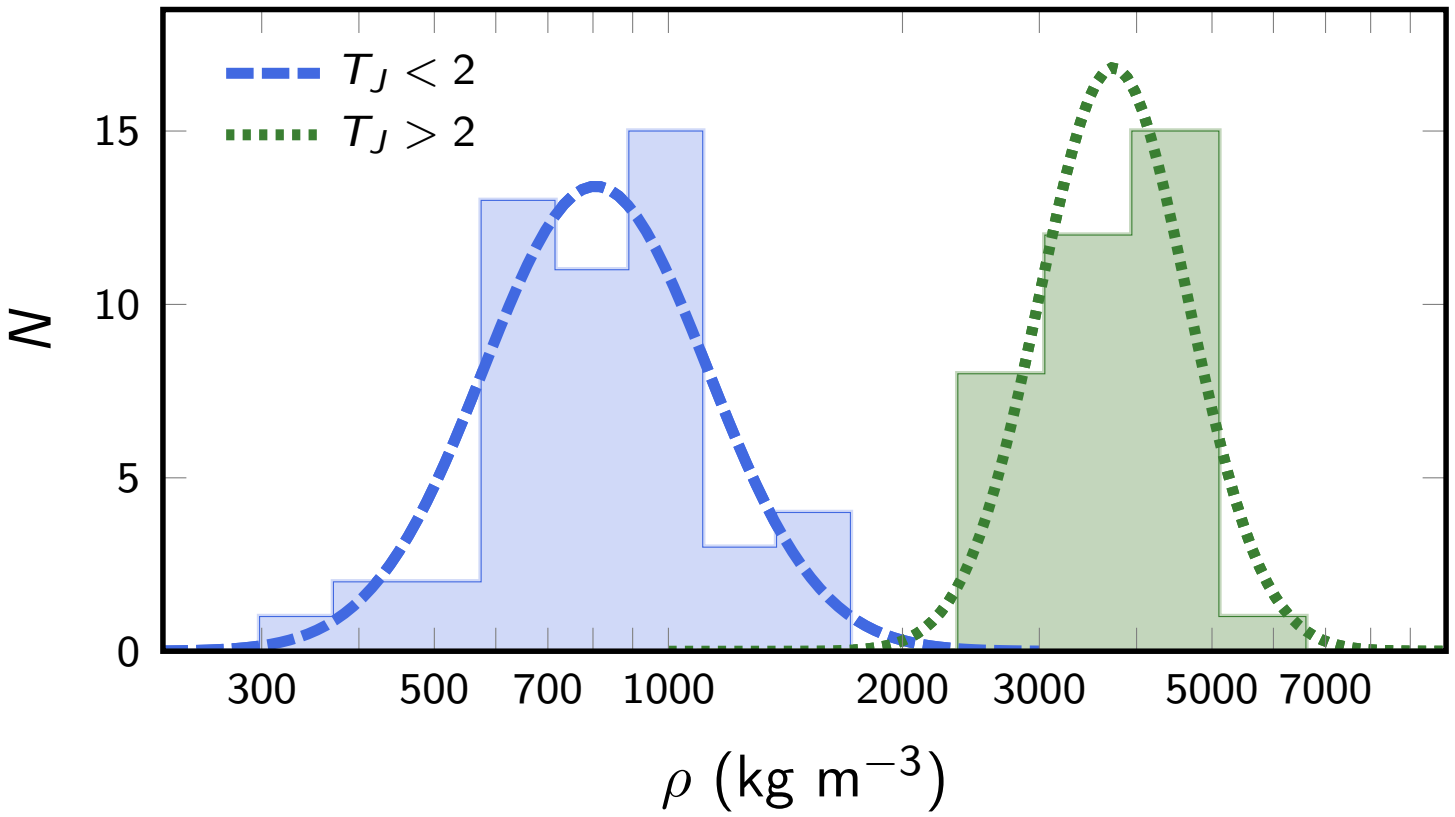


[3] Campbell-Brown & Koschny, 2004; Borovička et al., 2007

[4] Kikwaya et al., 2011

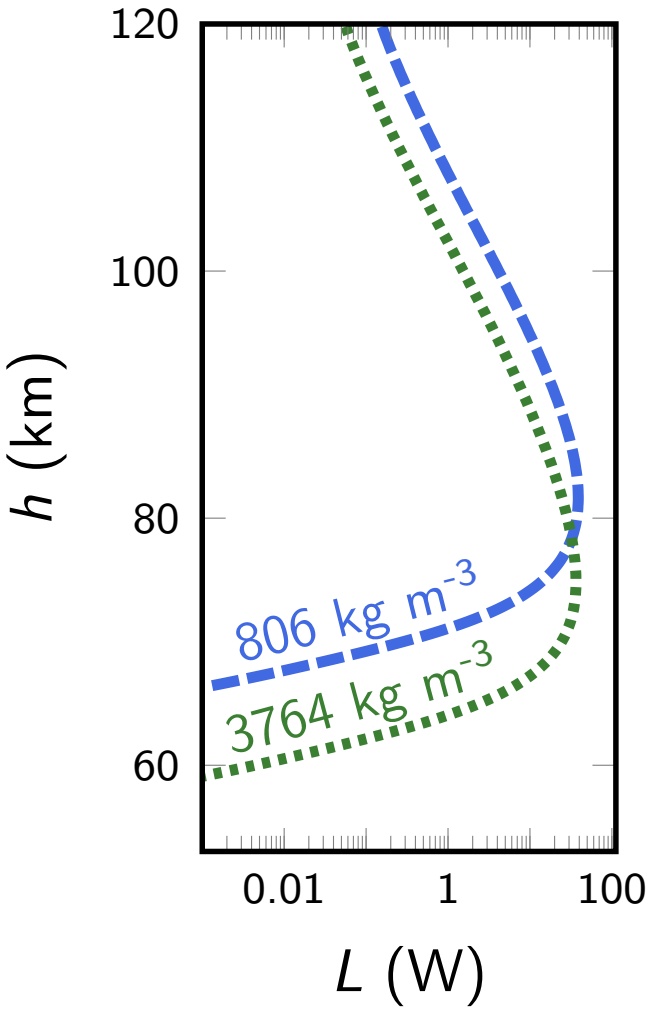
Density distribution

- 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:

$$\text{depth} \propto \rho^{4/27}$$

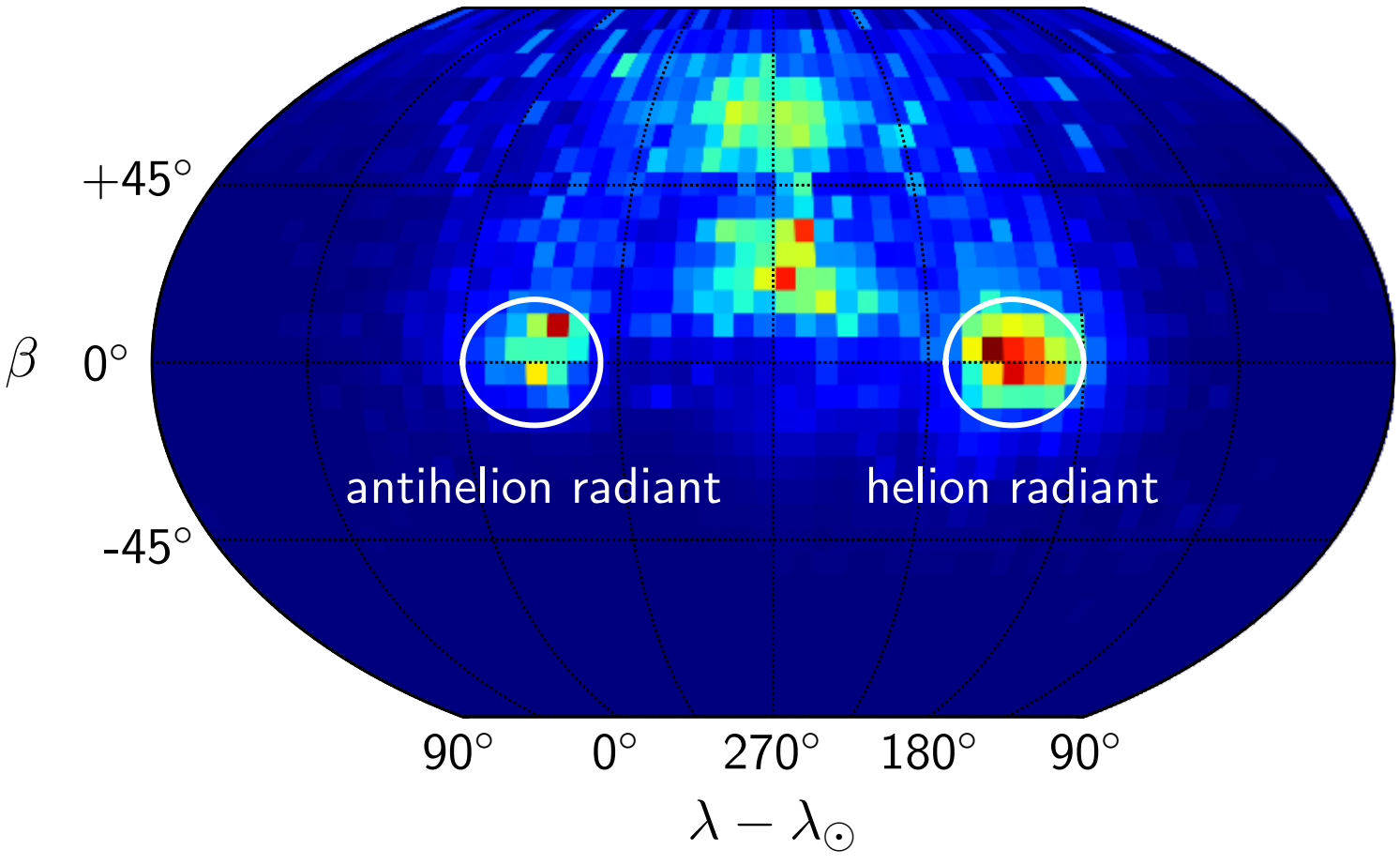
- Ratio of radiation pressure to gravity also depends on ρ:

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

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

Meteoroid directionality

Crater-limited, de-biased



Summary

- 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.