Velocity distributions from radar observations

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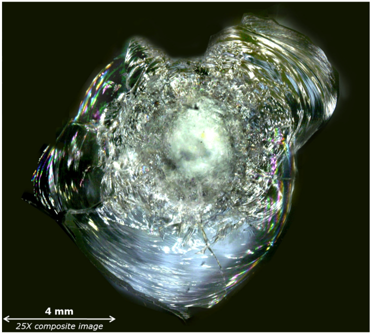
Meteoroid environment models: MEM

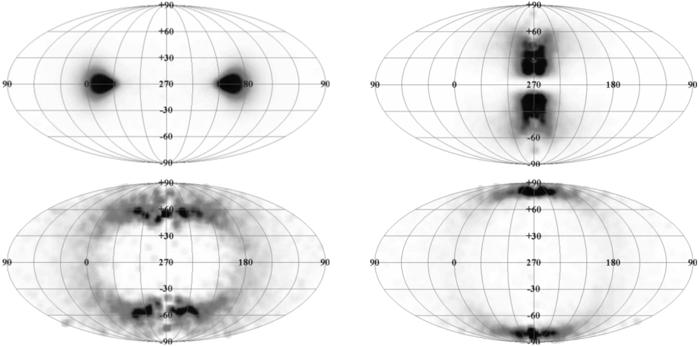


Meteoroid impact crater on shuttle window. Image provided by the NASA/JSC Hypervelocity Impact Technology (HVIT) Team.

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

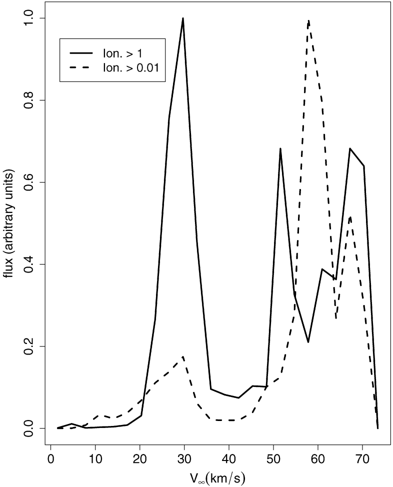
Meteoroid environment models: MEM

- Based on Jones SporMod model
- Has 4 populations derived from short-period, long-period, Halley-type, and asteroidal parents.
- Based on CMOR meteor obs. and Helios zodiacal light meas.



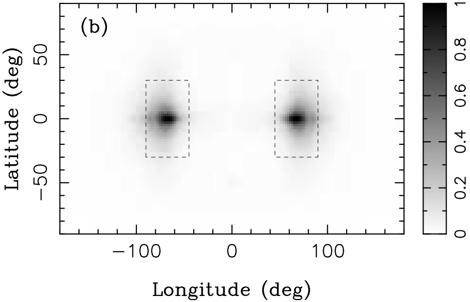
Meteoroid environment models: PRISM

- We are considering the Wiegert et al. (2009) dynamical model for MEMR3.
- Links environment to a few comets rather than entire population
- Tuned to match CMOR observations
- Predicts a faster speed distribution for more sensitive radars

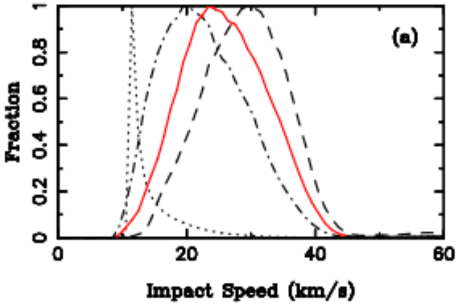


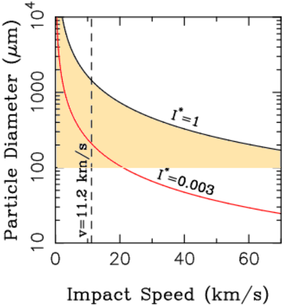
Meteoroid environment models: ZoDy

- Nesvorný et al. developed a model based on IRAS zodiacal light measurements
- They attribute the bulk of the environment to helion/antihelion particles coming from JFCs



Meteoroid environment models: ZoDy

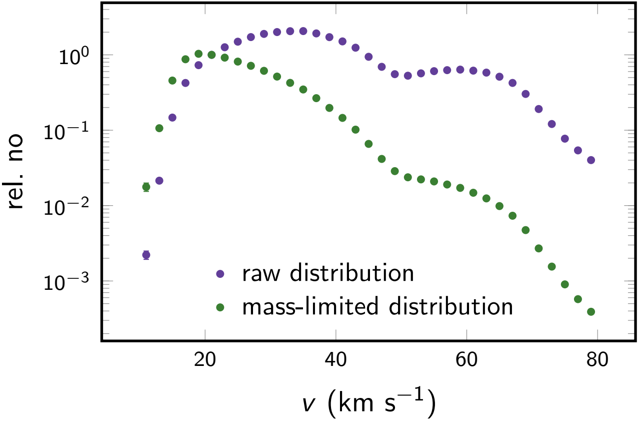




- Nesvorný et al. predict a meteoroid speed distribution that is sharply skewed towards slow material
- They also predict that the speed distribution is a function of the "ionization cutoff", but in the opposite direction
- (The form of this cutoff is a bit out-of-date, as I'll show here)

Correcting to a limiting mass

$$q \propto m^a v^b,\ \text{flux} \propto m^{-\alpha} \rightarrow N_{>m_{ref}} = N v^{-b\alpha/a}\ \text{(Taylor, 1995)}$$

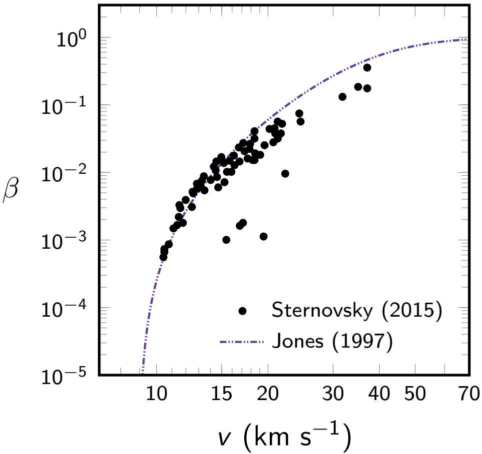


Ionization efficiency

- Jones (1997) predicts $q \not\propto v^b$
- Experiments confirm this for iron (Sternovsky, 2015)
- CMOR detections show a "cliff" near 9.5 km/s

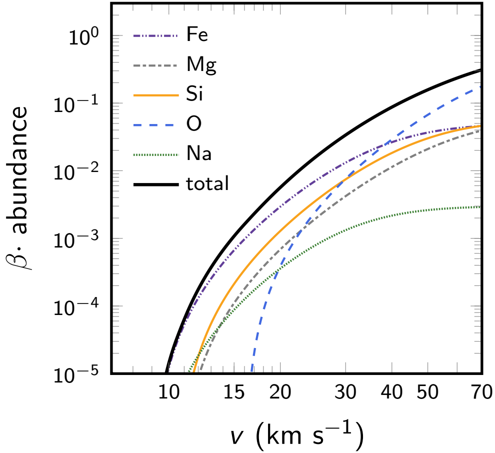
$$\cancel{q \propto m^a v^b}$$

$$q = -\frac{\beta(v)}{\mu v}\frac{dm}{dt}$$



Ionization efficiency

- We used Jones (1997) to debias CMOR's speed distribution in Moorhead et al. (2017)
- Corrected v_0 values and adjusted coefficients accordingly
- Added Na to the list, but didn't find it to be terribly significant (Janches et al. did the same thing in parallel)



Attenuation effects

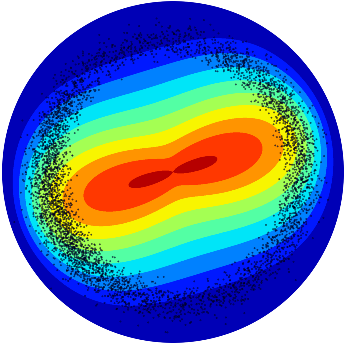
- Initial trail radius effect
  - Depends on meteor height and speed
  - Depends on radar wavelength
  - Correction: Ceplecha et al. (1998) with trail radius eq. derived by Jones & Campbell-Brown (2005) using dual-frequency CMOR observations
- Finite velocity effect
  - Depends on meteor height, speed, and range
  - Depends on radar wavelength
  - Correction: from Jones & Campbell-Brown (2005)
- Pulse repetition factor
  - Depends on meteor height
  - Depends on radar wavelength and pulse repetition frequency
- Faraday rotation
  - Not corrected for; day-night symmetry assumed

Gain pattern

The true limiting quantity is the received power, P_R:

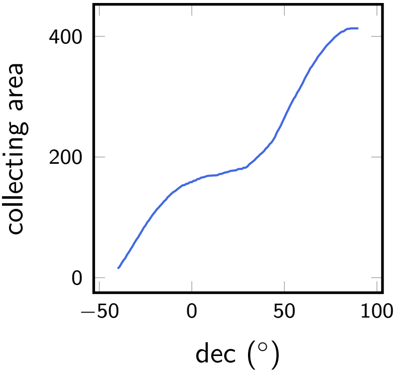
$$P_R \propto q^2 \alpha^2 \, (\lambda/R)^3 \, P_T \, G_T \cdot G_R(\theta, \phi)$$

- q - electron line density
- α - attenuation factor(s)
- λ - radar wavelength
- R - range
- $G_T \cdot G_R$ - gain pattern



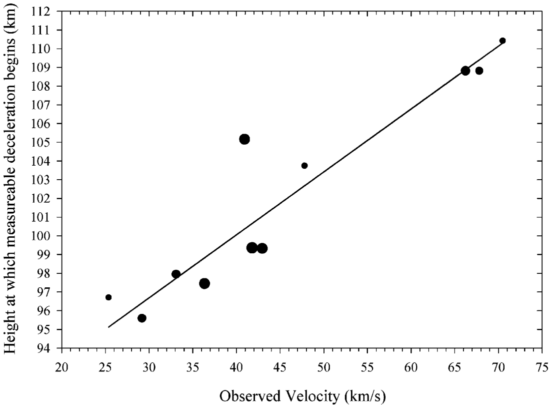
Collecting area

- CMOR's effective collecting area is a function of declination
- Characterized in Campbell-Brown & Jones (2006)
- (Correcting for this made very little difference in the speed distribution)

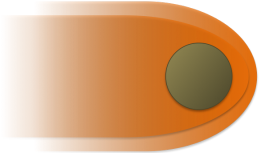


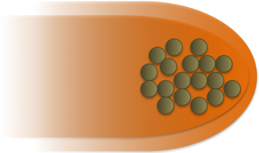
Deceleration

- Meteors decelerate between atmospheric entry and detection
- Brown et al. (2004) derived a deceleration correction using meteor showers
- Depends on meteor speed and height at detection



Fragmentation



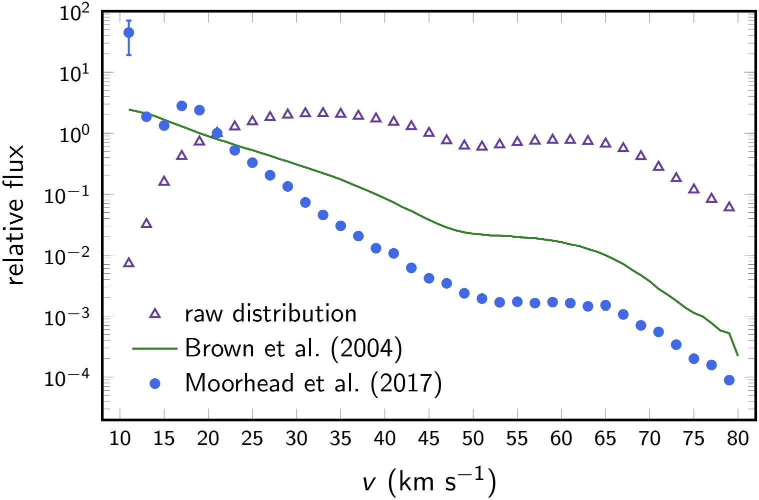


$$\frac{dm}{dt} \propto m^{2/3}$$

$$\frac{dm}{dt} \propto m$$

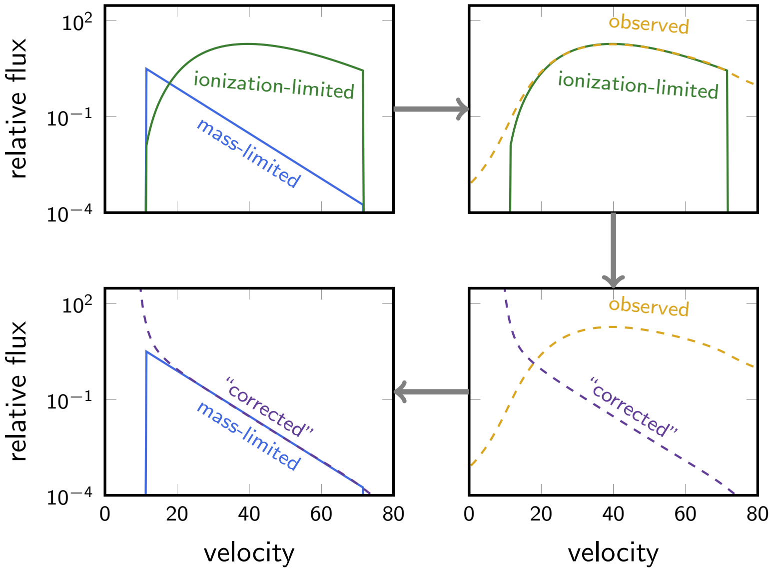
$$\frac{dm}{dt} = -\frac{\Lambda A}{2\xi}\left(\frac{m}{m_{frag}}\right)^{x}\left(\frac{m}{\rho_m}\right)^{2/3}\rho_a v_m^3$$

Velocity distribution debiasing



Velocity distribution sharpening

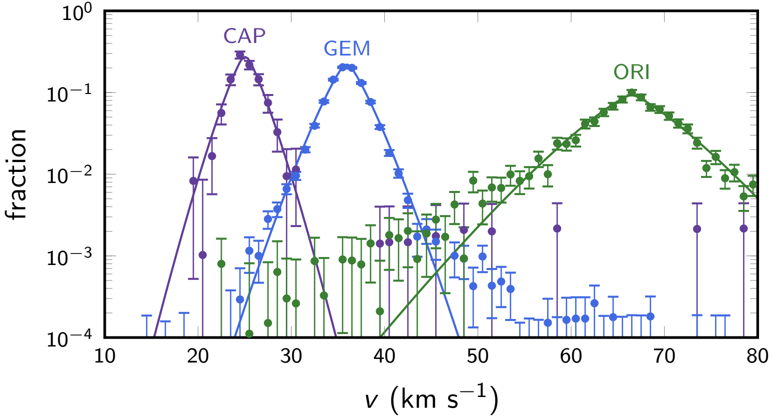
Measurement uncertainty has a blurring effect



Velocity distribution sharpening

Constructing a filter

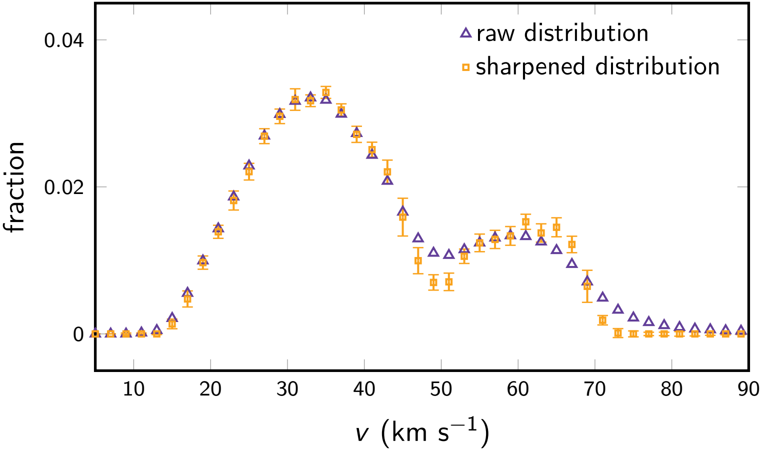
- We use meteor showers to characterize our observation "filter" ...



Velocity distribution sharpening

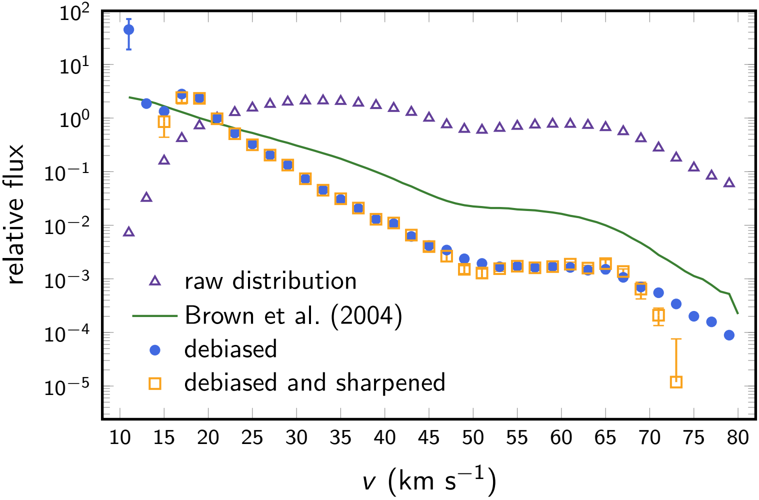
Sharpening the raw distribution

- 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 debiased distribution



Can this be applied to MAARSY?

It would be great to compare MAARSY's speed distribution with CMOR's using the same approach.

- Ionization efficiency: same
- Initial trail radius: substitute MAARSY's wavelength
- Finite velocity effect: substitute MAARSY's wavelength
- Pulse repetition factor: substitute MAARSY's wavelength and pulse repetition frequency
- Faraday rotation: Continue to ignore?
- Gain pattern: Substitute MAARSY's?
- Collecting area: Characterize for MAARSY?
- Deceleration: Characterize for MAARSY?
- Distribution sharpening: Characterize for MAARSY?
- Observation limit: Characterize for MAARSY?