Meteoroid environment modeling: the Meteoroid Engineering Model and shower forecasting

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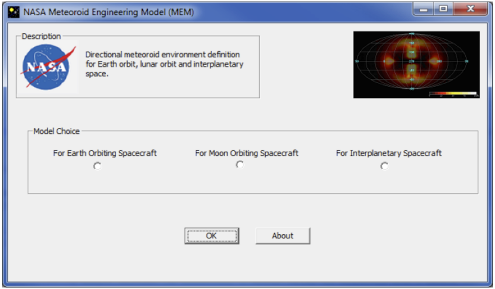
Outline

Meteoroid Engineering Model Release 2.0 (MEMR2)



- Stand-alone software
- Computes meteoroid environment relative to spacecraft
- Does not include temporal variations such as showers
- Most appropriate during design phase

MEM generates trajectory-specific environment

- MEM takes spacecraft trajectory into account
- Also accounts for influence of Earth or Moon in sub-models

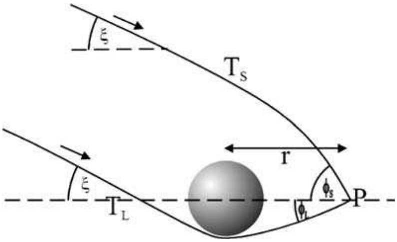
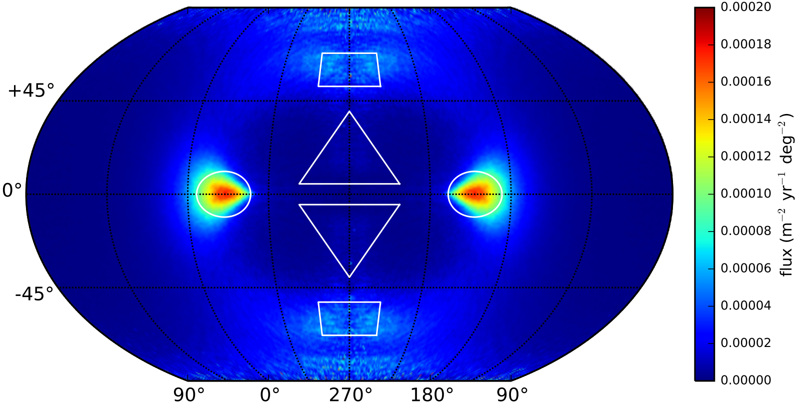


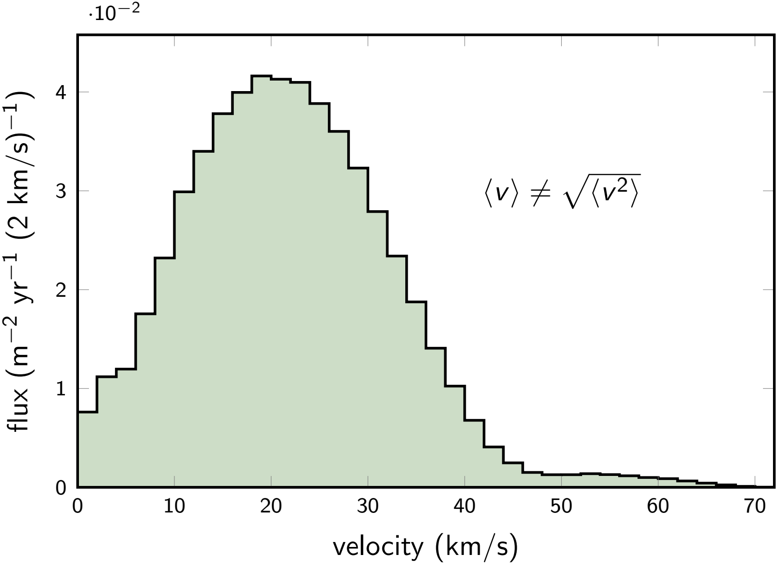
Diagram from Jones & Poole, 2007

- Earth's gravity enhances the meteoroid flux near Earth
- The Earth also physically blocks some meteoroids
- MEM computes both effects at the spacecraft's location

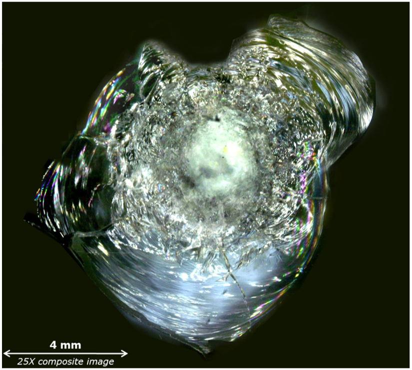
Meteoroid directionality is not isotropic



Meteoroid velocity is not uniform



Pillars of MEM

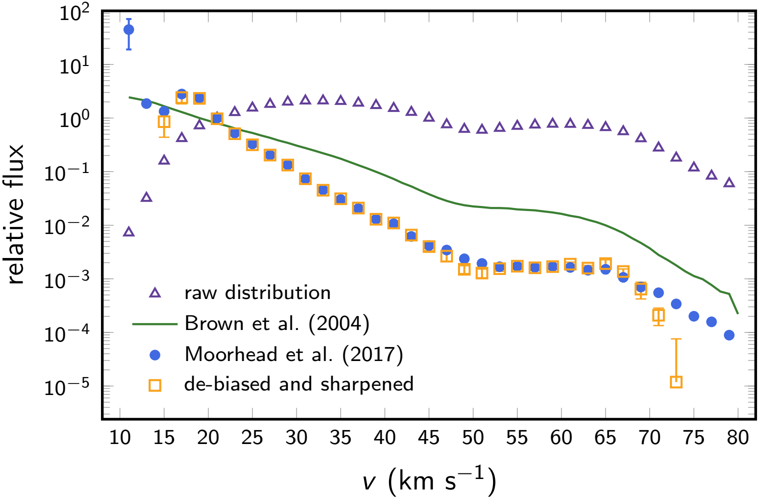


Meteoroid impact crater on shuttle window. Image provided by the NASA/JSC Hypervelocity Impact Technology (HVIT) Team.

- Damage done by a meteoroid impact depends on:
  - mass
  - velocity/impact angle
  - density (currently 1 g/cc)
- We are revisiting each of these components for the next version of our Meteoroid Engineering Model (MEM).

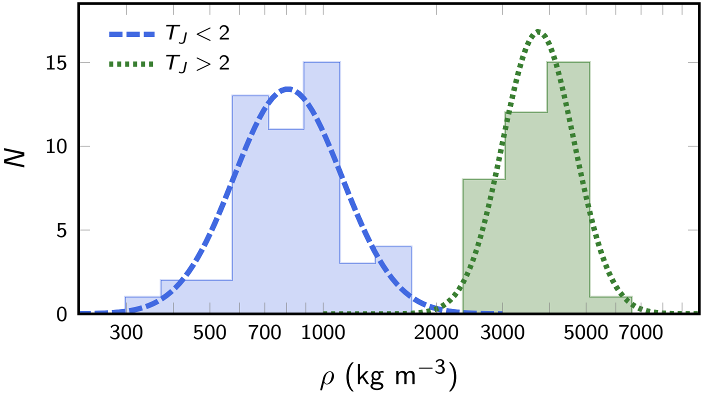
Velocity distribution improvements

Improved de-biasing and "sharpening"



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

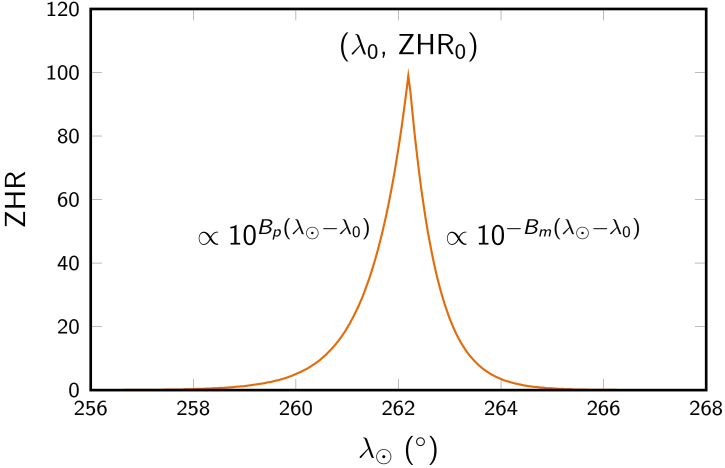


MEM Recap

- MEM: a stand-alone piece of software, describes meteoroid environment along user-supplied spacecraft trajectory.
- Currently working to revise model:
  - Velocity distribution is:
    - derived from radar (CMOR) observations,
    - de-biased using modern ionization efficiency, and
    - sharpened to remove uncertainty smoothing.
  - Density distribution is based on Kikwaya et al. (2011) and links density to dynamical class.
- Future work: revisit flux(mass) and characterize uncertainties.

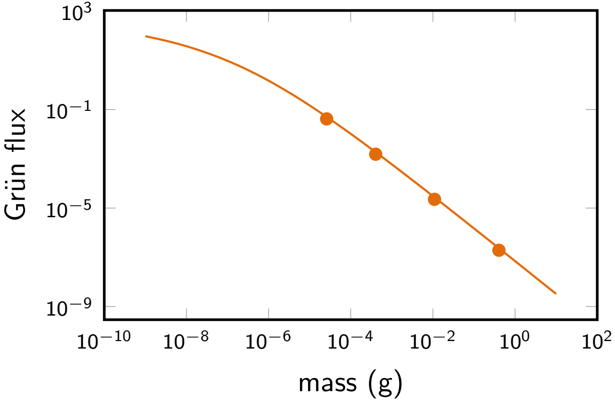
Shower forecasting

- MEM's environment is time-invariant
- MEO shower forecast provides time-dependent shower fluxes
- These are derived from hourly rates (ZHRs)

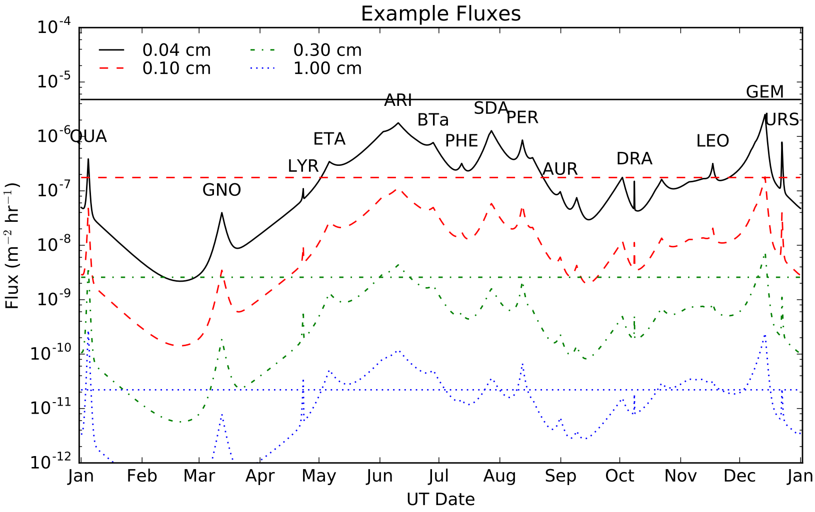


Baseline flux

- We use the Grün meteoroid flux as a point of comparison.
- Reference speed is 22.75 km s^{-1} at 400 km altitude (due to grav focusing).

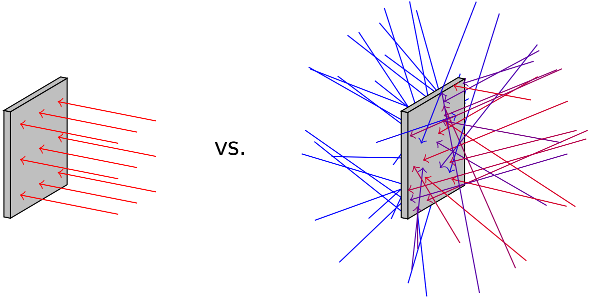


Flux comparison



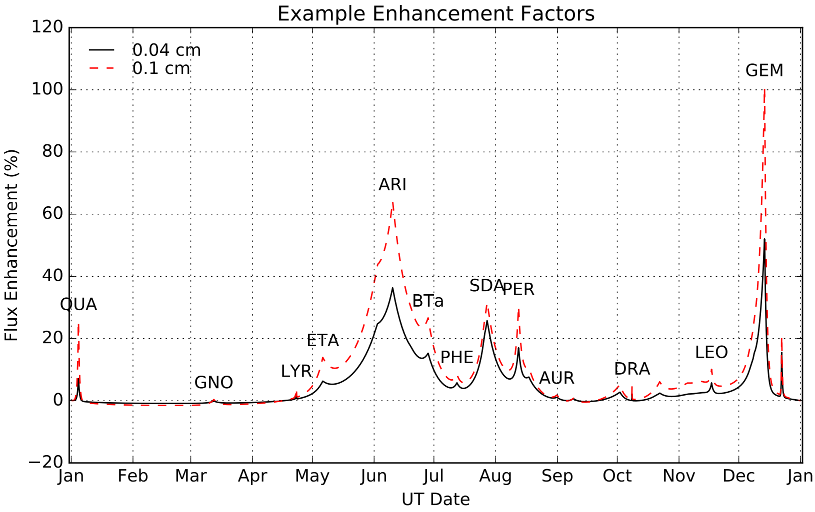
Enhancement factors

The forecast reports fluxes on a flat plate facing the shower radiant



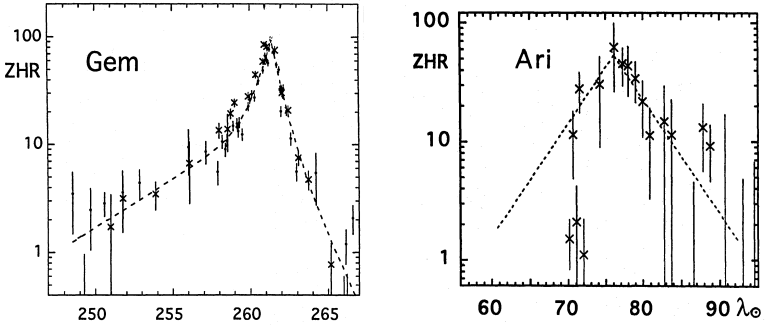
This is a “worst-case scenario” for shower exposure. Although typically showers are a small fraction (0.9% - 15%) of the baseline flux, the risk enhancement can be significant for a fully exposed element.

Enhancement factors



Activity profiles in the annual forecast

Original forecast parameters from Jenniskens (1994)

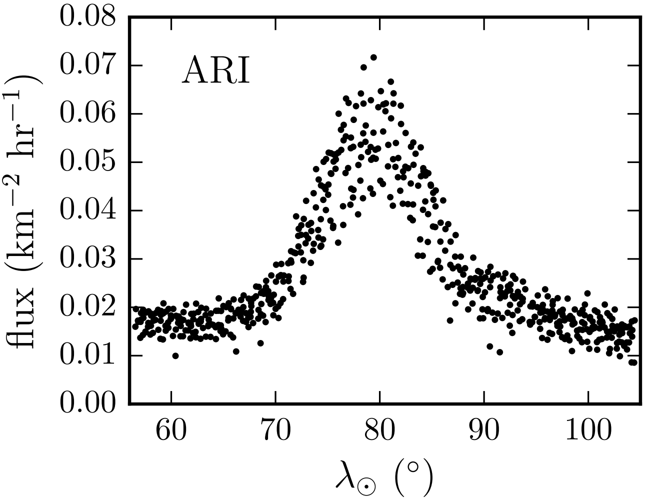


Plots from Jenniskens (1994)

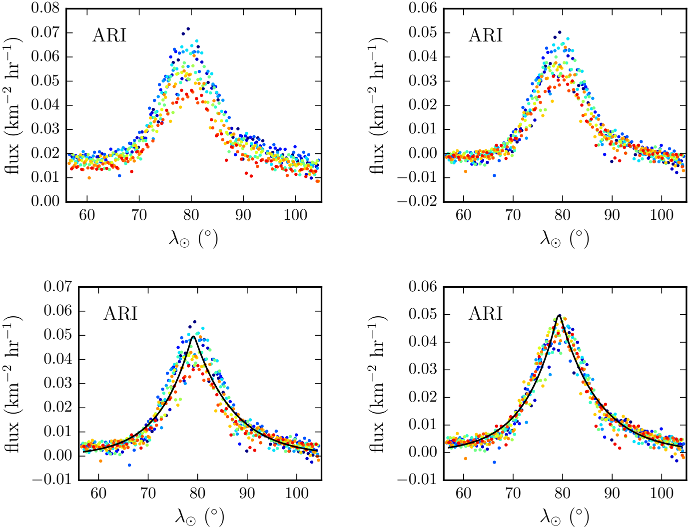
Visual observations in both the northern and southern hemispheres.

14 years of CMOR data

Arietids

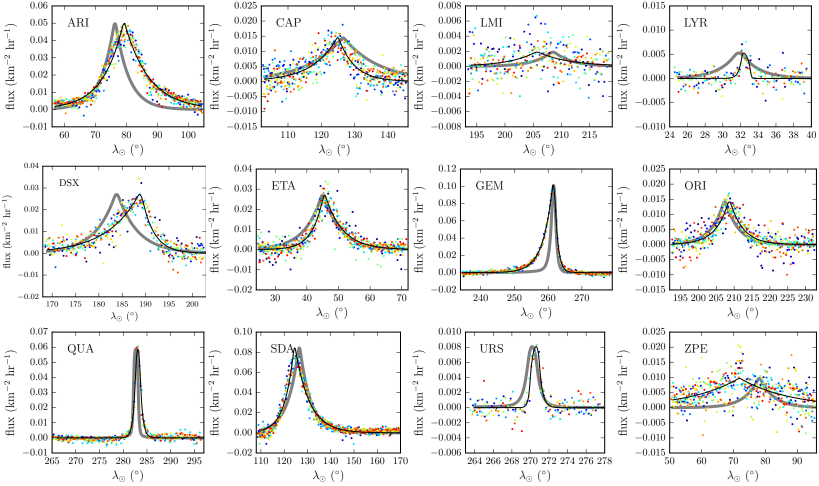


Arietids


ARI
ARI
ARI
ARI
flux (km^{-2} hr^{-1})
$\lambda_\odot$ (°)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
−0.01
−0.02
60
70
80
90
100

Improved showers

In the end, we were able to improve the activity profiles for 12 showers:



Shower forecast recap

- The MEO generates annual meteor shower forecasts that report:
  - Shower fluxes (based on ZHR and other shower parameters)
  - Baseline fluxes
  - Enhancement factors (to support risk assessments)
- More recent, we revised many shower activity profiles.
  - We used 14 years of fluxes from CMOR (advantageous for daytime showers in particular)
  - We were able to improve the profiles of 12 major meteor showers.
- We plan to expand this in the future to include additional data and constrain mass indices.