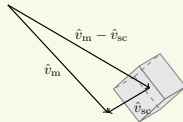
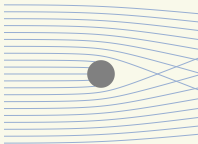
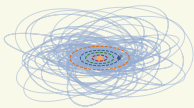


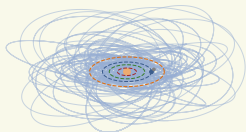
Meteoroid Engineering Model (MEM) 3: NASA's newest meteoroid model

Althea Moorhead
NASA Meteoroid Environment Office

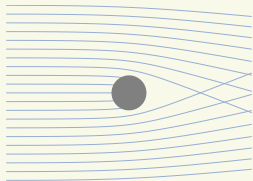
First International Orbital Debris Conference
10 December 2019



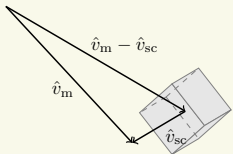
MEM does the following:



models meteoroid orbits
(and physical properties)



determines the local environment



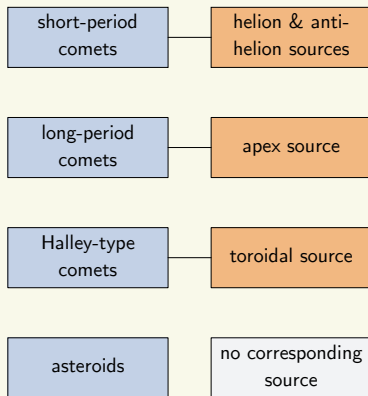
outputs the environment
relative to a spacecraft

MEM's orbital populations are derived from a physics-based model.

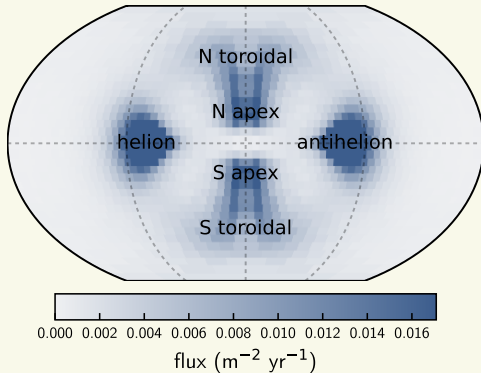
Jones (2004) simulated the release of meteoroids from comets and asteroids, taking radiative forces and collisions into account

The results were tuned to match **observed features of the environment at Earth**.

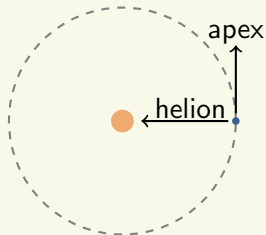
This physics-based approach allows us to extrapolate to other locations.



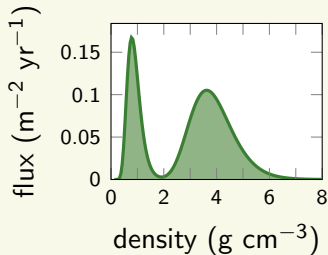
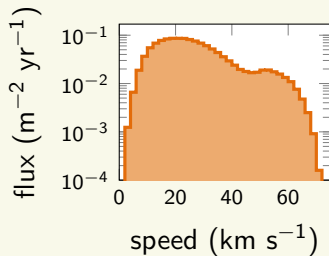
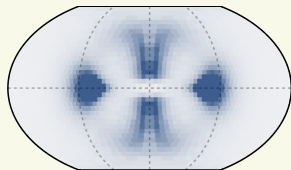
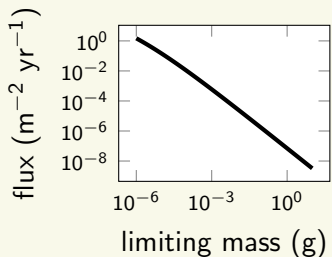
Meteoroid directionality is not random.



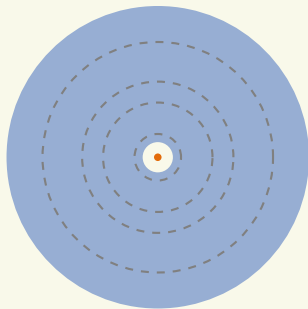
The three orbit populations appear as six concentrations (three pairs) of meteors in this directional map.



Damage depends on mass/size, angle, speed, and density.



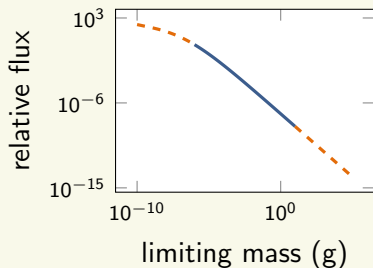
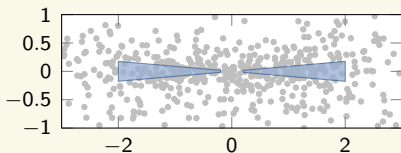
MEM has a few scope limitations.



Limited to inner Solar System:
0.2 – 2 au

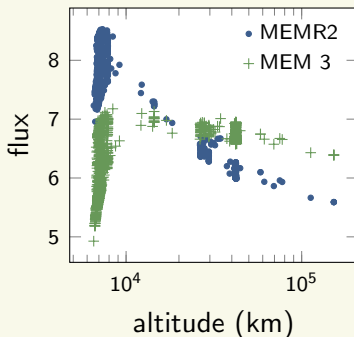
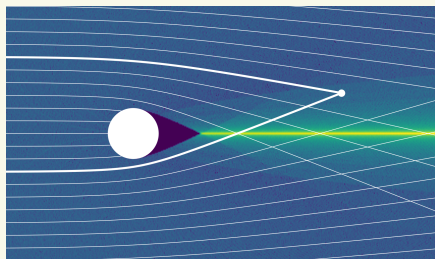
Limited to ecliptic plane:
within $\sim 5^\circ$ of the ecliptic

Limited to $> 10^{-6} \mu\text{g}$



MEM 3 correctly handles planetary gravity.

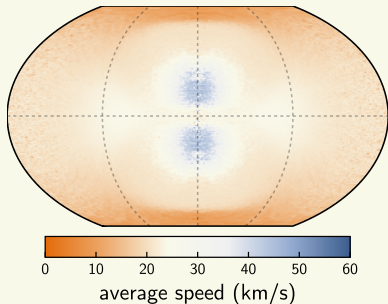
Planets (and moons) bend and block the paths of meteoroids



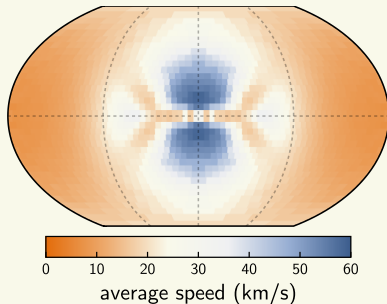
This effect was erroneously large in MEMR2, and has been corrected in MEM 3. The flux is now lower at low altitudes and higher at high altitudes.

MEM 3 preserves correlations between direction and speed.

MEMR2:

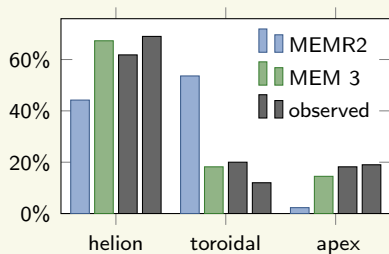


MEM 3:

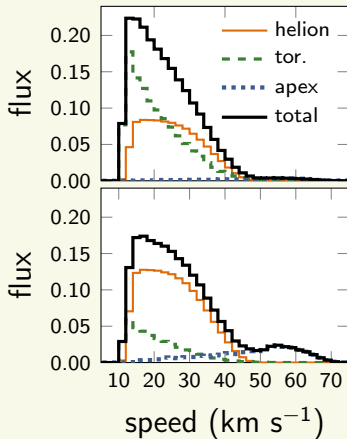


Accurate descriptions of the flux and speed of meteoroids onto each side of a spacecraft allow optimal placement of shielding.

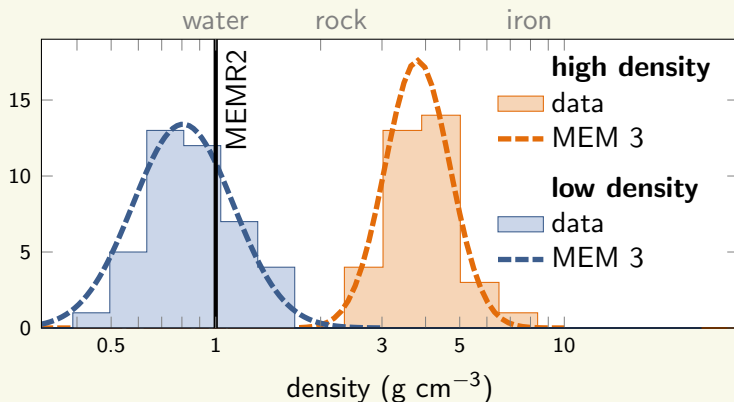
MEM 3's orbital populations match their observed strength at Earth.



This re-weighting of the orbital populations also changes the speed distribution.

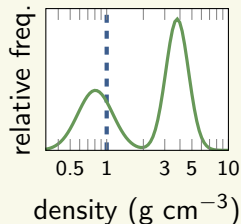
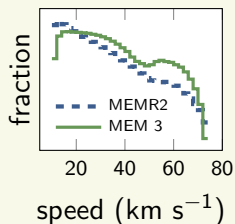
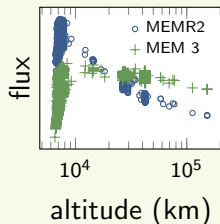


MEM 3 introduces new density distributions.



This bimodal density distribution is based on constraints from a detailed modeling of meteors in the atmosphere.

MEM 3 predicts higher risk at NRHO

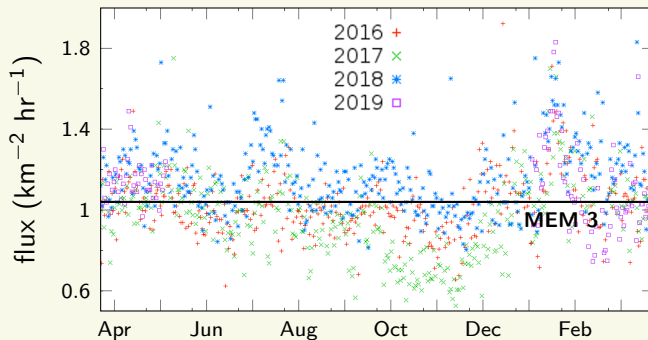


MEM 3 has a higher flux (at some altitudes), a faster speed distribution, and new high densities. All of these factors will increase the risk.

How do we know that's justified?

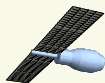
MEM 3 matches the observed meteor flux at Earth.

The Canadian Meteor Orbit Radar (CMOR) has been measuring the meteoroid flux at the top of the atmosphere for ~ 15 years



We also compared MEM 3 to two *in situ* missions.

Pegasus



Year(s) data collected:

1965 (little orbital debris)

Purpose:

measure meteoroid flux
before the Apollo missions

Detection method:

penetration detectors

Relevant area: over 200 m²

Attitude: info lost

(assume randomly tumbling)

Altitude: 441 – 740 km

LDEF



Year(s) data collected:

1984 – 1990 (debris present)

Purpose:

measure long-term space
environment effects

Detection method:

examination of panels

Relevant area: 10.8 m²

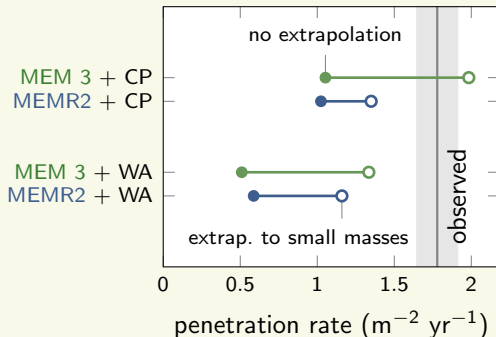
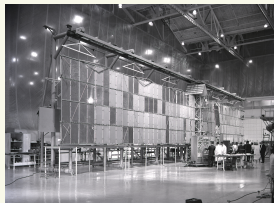
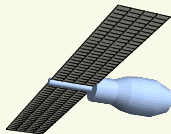
Attitude:

constant relative to orbit

Altitude: 500 km

MEM 3 tends to underpredict the penetration rate measured by Pegasus.

We used two damage equations (CP, WA) and mass extrapolation methods

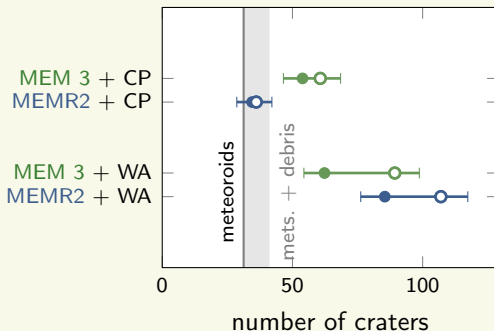


MEM 3 underpredicts rate in 3/4 cases.

MEM 3 overpredicts the number of craters on LDEF.

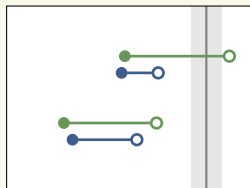


Same two damage equations (CP, WA)
and mass extrapolation methods

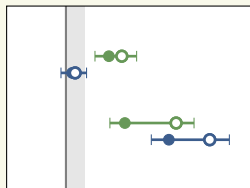


MEM 3 overpredicts the number of craters
in both cases.

MEM 3 matches the combination of data that is available.



penetration rate



number of craters

MEM is a physics-based meteoroid environment model that is designed to support spacecraft risk assessments.

The changes made in MEM 3 will result in higher risk predictions in most cases.

MEM 3 lies between the two best sets of *in situ* data we have in the threat regime ($1 \mu\text{g}$ - 1 g).