The ability of NASA's Meteoroid Engineering Model (MEM) 3 to replicate *in situ* impact data

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Meteoroid environment models must describe the mass, directionality, velocity, and density distributions of meteoroids in order to correctly predict the rate at which meteoroids impact spacecraft. We present an updated version of NASA's Meteoroid Engineering Model (MEM) that better captures the correlation between directionality and velocity and incorporates a bulk density distribution. We compare the resulting model with the rate of large particle impacts seen on the Long Duration Exposure Facility (LDEF) and the Pegasus I and II satellites. Impact crater counts are modeled using two different ballistic limit equations (BLEs), one of which assumes a constant depth-to-diameter ratio and one of which yields depth-to-diameter ratios that depend on meteoroid speed and density. MEM agrees with the *in situ* crater record to within the range of values associated with different BLEs, but our preliminary analysis indicates that the level of agreement could be improved by reducing the strength of the toroidal meteoroid population and increasing the strength of the helion/antihelion and apex populations.

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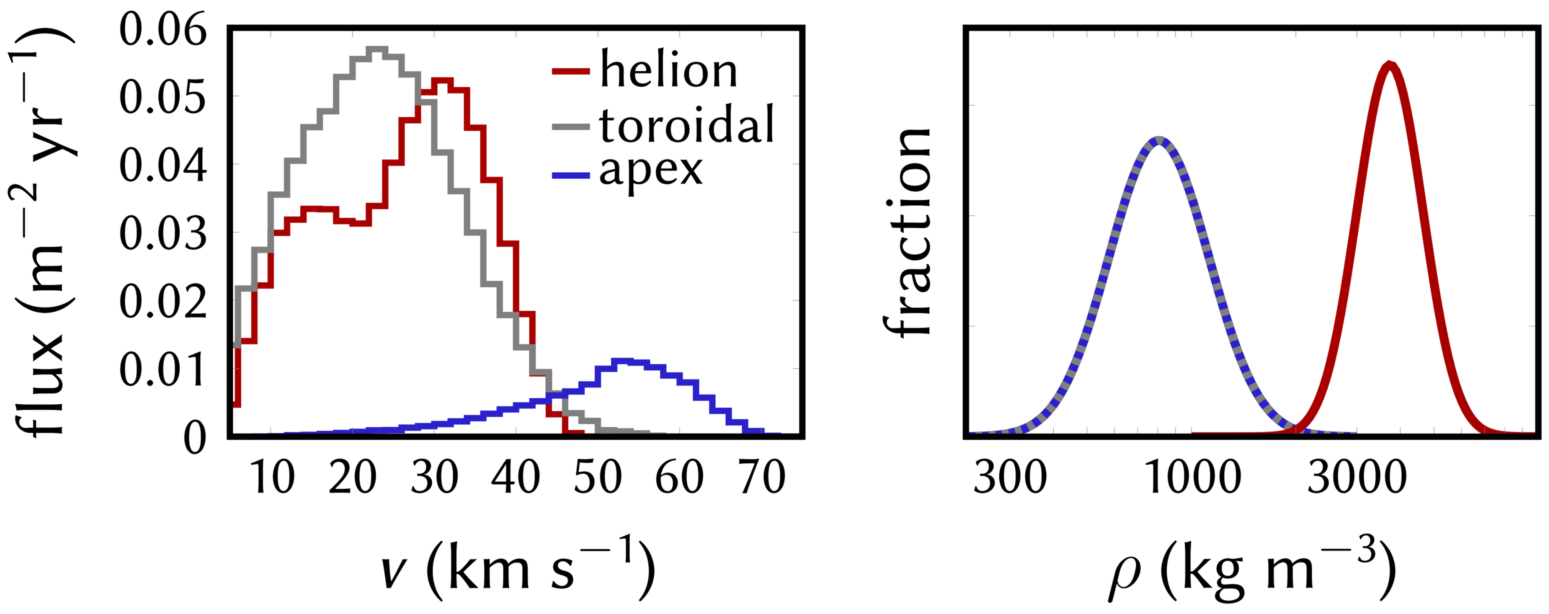
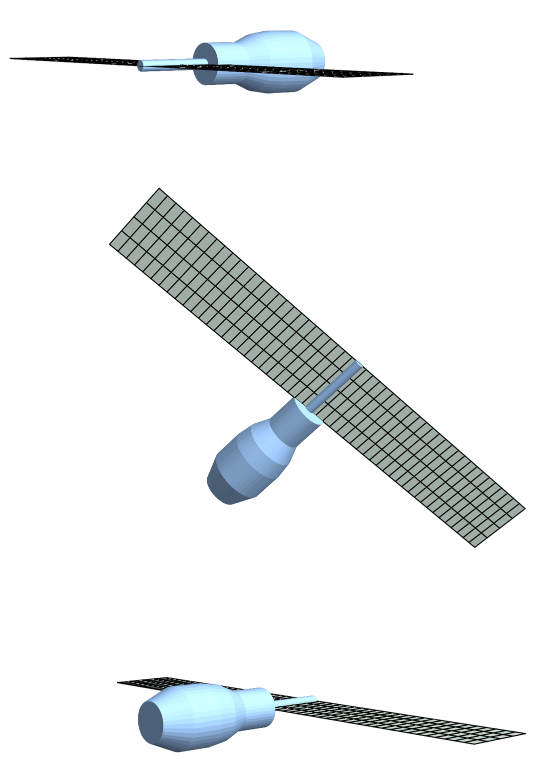
Meteoroid Engineering Model (MEM) 3

- MEM is a piece of software that models the meteoroid environment in the inner Solar System [1].
- Reports mass-limited flux, speed, directionality, and bulk density relative to spacecraft trajectories.
- Recently updated to add density distribution, correct bugs, and handle orbits near Mars, Mercury, and Venus.
- Largely based on radar meteor observations (plus zodiacal dust) [2]; includes three populations of meteoroid orbits called helion/antihelion, toroidal, and apex (see below plot).
- We compare MEM 3 to impact data from LDEF and Pegasus.



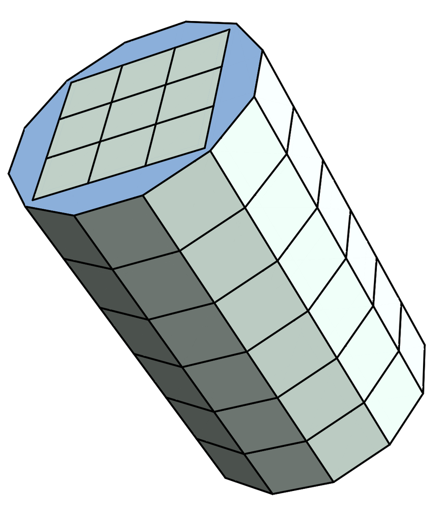
Pegasus mission

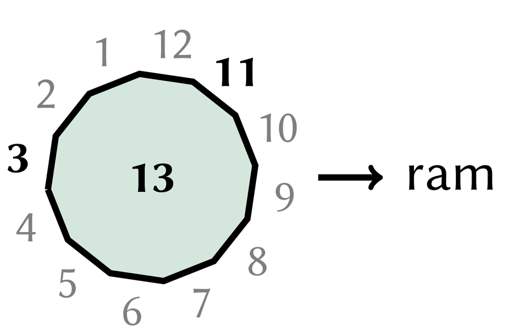


3 spacecraft dedicated to meteoroid detection [3]

- **Year(s) data collected:** 1965 (little orbital debris present)
- **Detection method:** penetration detectors with thicknesses of 0.038, 0.2, and 0.4 mm (we will use the latter)
- **Relevant area:** Over 200 m^2
- **Attitude:** Attitude information lost (treated as randomly tumbling)
- **Material:** 2024-T3 aluminum alloy

Long Duration Exposure Facility (LDEF)





Flown with a variety of environment experiments, then retrieved

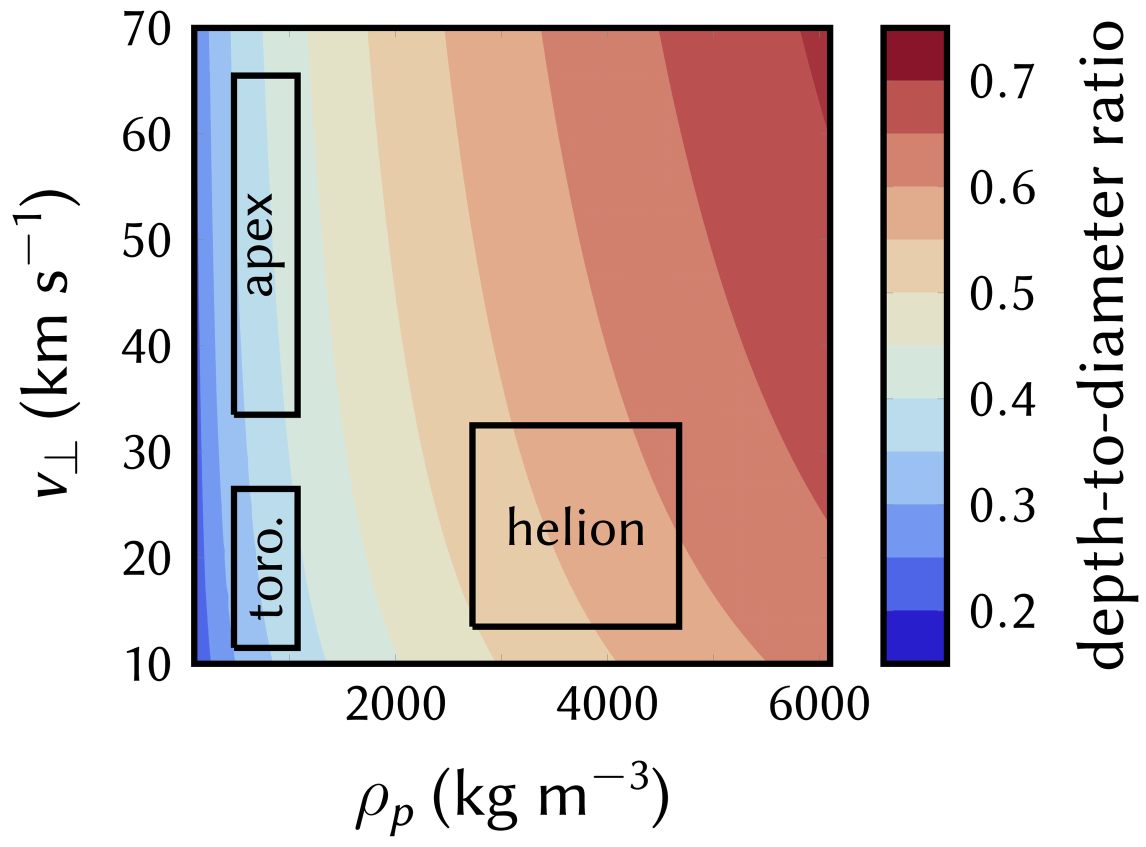
- **Year(s) data collected:** 1984 – 1990 (significant orbital debris present)
- **Detection method:** examination of panels
  - detection limited by crater diameter [4]
  - orbital debris estimates possible for sides 3, 11, and 13
- **Relevant area:** 10.8 m^2
- **Attitude:** Maintained constant orientation relative to orbit
- **Material:** 6061-T6 aluminum alloy

References

[1] McNamara, H. et al., 2004, *EM&P*, **95**, 123-139
[2] Jones, J., 2004, NASA/SEE CR 2004-400
[3] Clifton, S. and Naumann, R., 1966, NASA TM X-1316.
[4] Humes, D. H., 1995, *LDEF - 69 Months in Space*, **3**, 287-322
[5] Hayashida, K. B. and Robinson, J. H., 1991, NASA TM 103565.
[6] Watts, A. J. and Atkinson, D., 1995, *LDEF - 69 Months in Space*, **3**, 523-535

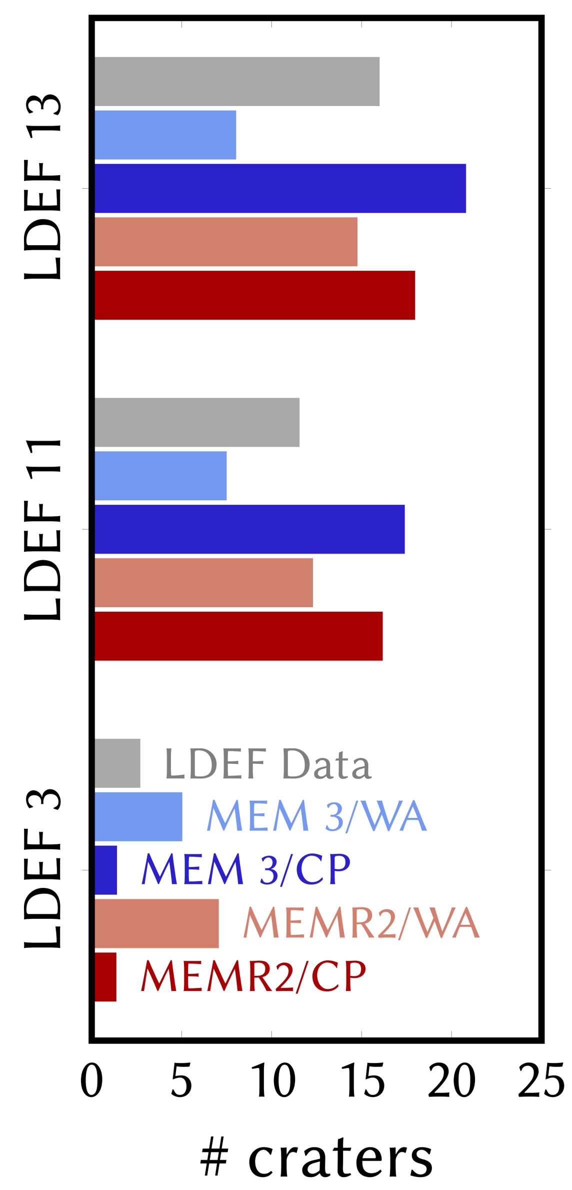
Ballistic limit equations (BLEs)

- BLEs predict impact crater size; depend on meteoroid diameter (d_p), density (ρ_p), speed, and impact angle ($v_\perp = v\cos\theta$). We apply two BLEs:
  - The modified Cour-Palais (CP) BLE [5] plus a constant depth-to-diameter ratio of 0.5.
  - The Watts & Atkinson (WA) BLEs [6], which predict a *varying* depth-to-diameter ratio ...



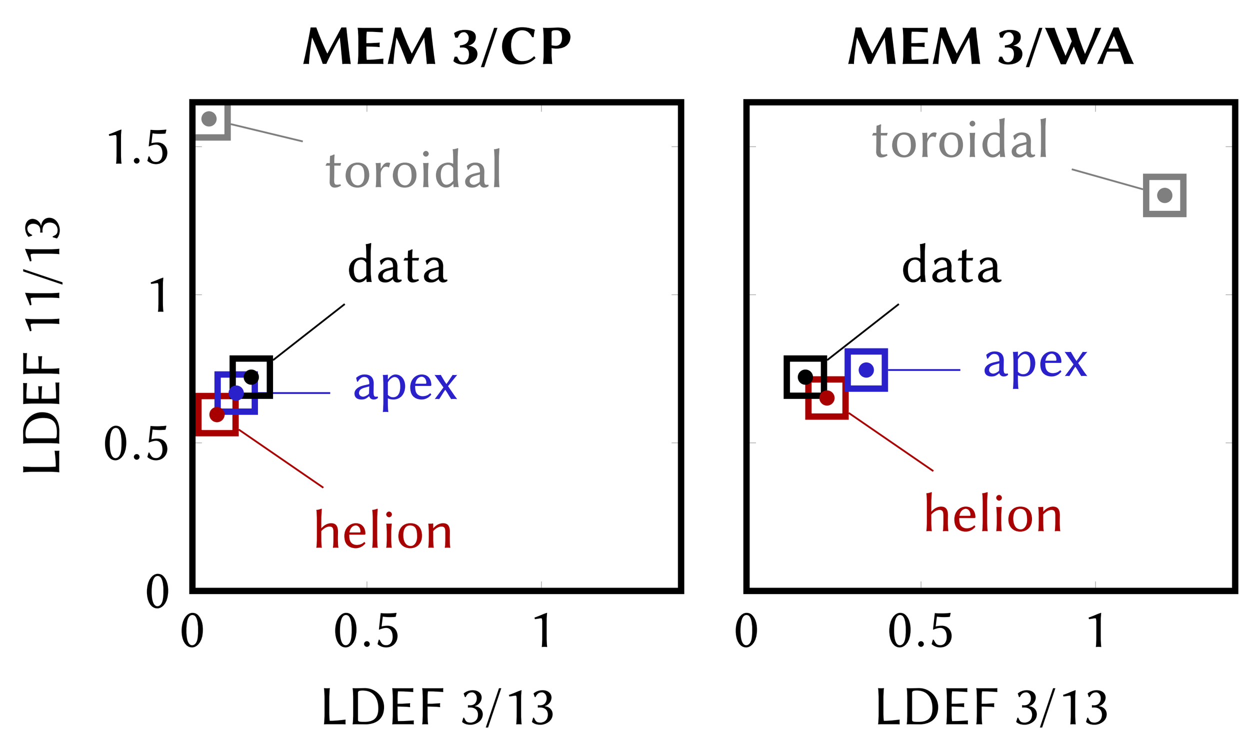
- Low-density, slow meteoroids will be heavily represented in the LDEF data because their depth-to-diameter ratio is so small.

Comparison with MEM



- Number of craters predicted depends on MEM version and BLE (bar chart).
- The WA BLE yields more craters on wake than the CP BLE and fewer on ram and space-facing surfaces. This trend is more extreme for MEM 3 due to the introduction of densities.
- MEM 3 and the CP BLE *underpredict* craters on Pegasus (see table).
- Toroidal meteoroids have the poorest fit to the ratio of craters on different sides of LDEF (below plots).

	MEM 3/CP	Pegasus
apex	0.031	
toroidal	0.629	
helion	0.577	
total	1.237	1.779



Better agreement between MEM and *in situ* data could be obtained by reducing the strength of the toroidal source and increasing the strength of the helion/antihelion and apex sources.