A Comparison of Damaging Meteoroid and Orbital Debris Fluxes in Earth Orbit

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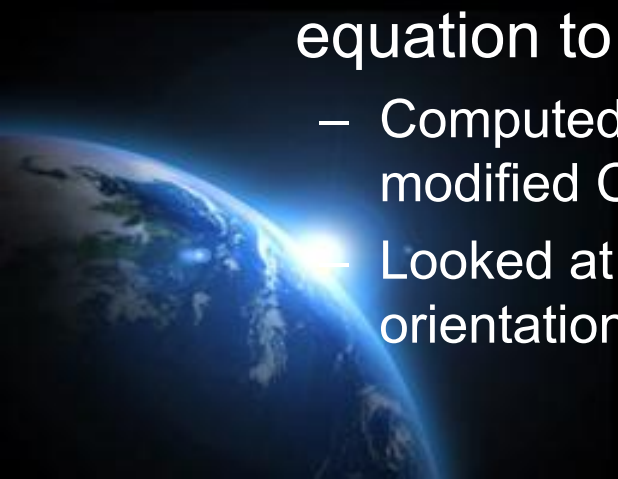
Why this work?

- A comparison of meteoroid/debris penetrating fluxes throughout Earth orbit has not been published.
- Past comparisons were for a specific altitude (e.g., 400 km for ISS) and involved flux as a function of mass (NASA TM-4527 or SSP-30425).
  - Ignored speed differences (12-72 km/s for meteoroids, 1-16 km/s for debris).
  - No density categories for orbital debris.
- We used latest NASA models – MEMR2 and ORDEM 3.0 – in conjunction with a simple single-wall damage equation to put both environments on the same footing.
  - Computed number of penetrations of 1mm thick Al plate using modified Cour-Palais single wall equation.
  - Looked at 16 altitudes, 3 orbital inclinations, and 6 surface orientations.



Modified Cour-Palais Damage Equation

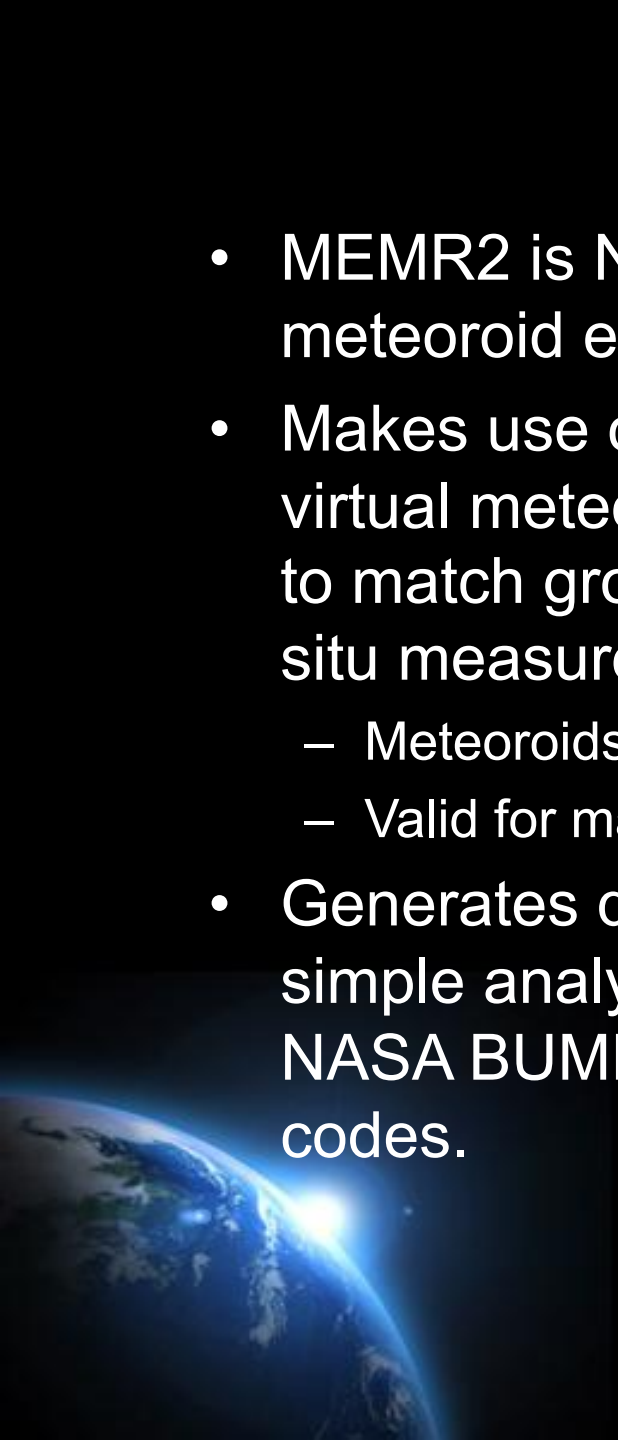
$$d = 5.24\, s^{19/18} B^{-1/4} (\rho/\rho_t)^{1/2} (v/c)^{2/3}$$

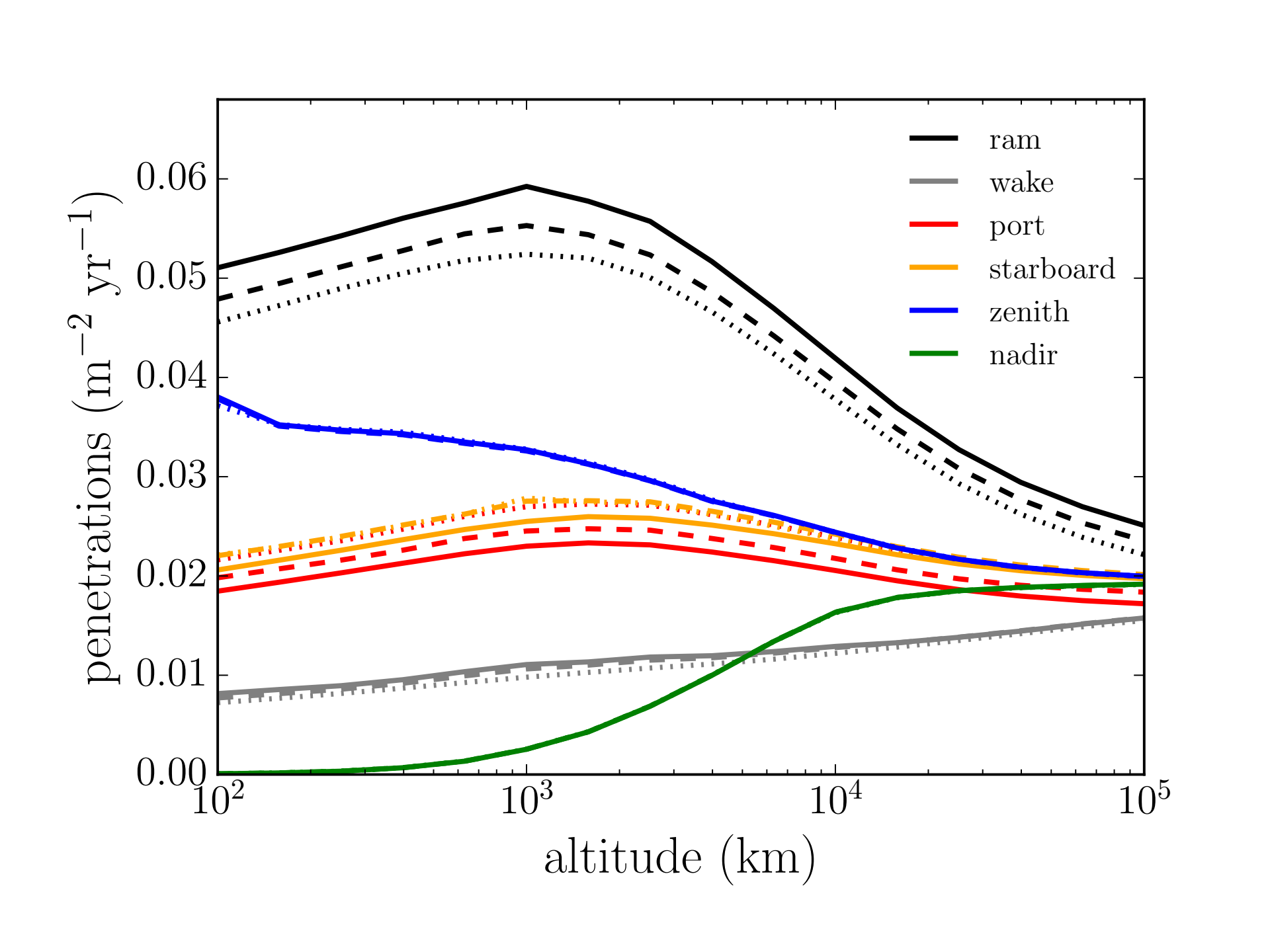
where d is the crater depth, s, ρ, v are the diameter, density, and speed of the impactor, and ρ_t, B, c are the density, Brinnell hardness, and speed of sound for the target (Hayashida and Robinson, 1991).

In the case of aluminum, ρ_t, B, and c have values of 2.7 g cm^{-3}, 90, and 6.1 km s^{-1}, respectively.

MEMR2

- MEMR2 is NASA's latest model of the sporadic meteoroid environment.
- Makes use of dynamically evolved distributions of virtual meteoroids from comets and asteroids, scaled to match ground-based radar observations and the in-situ measurements used in Grün (1985).
  - Meteoroids have same density of 1 gm/cc
  - Valid for masses $>10^{-6}$ g and from 0.2 – 2 au
- Generates quick look environment summary files for simple analyses and directional "threat igloo" for use in NASA BUMPER and ESA ESABASE risk assessment codes.

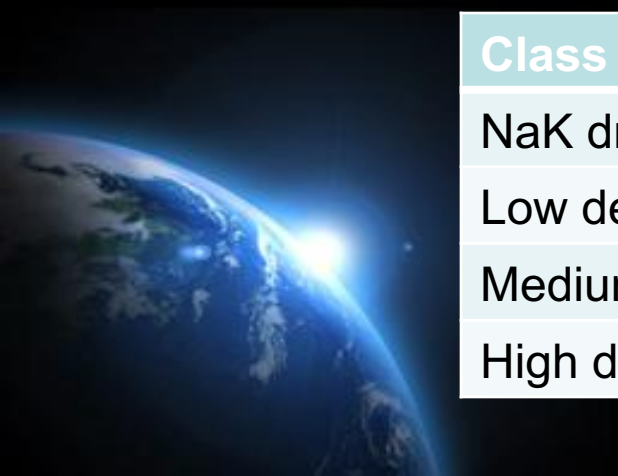



ram
wake
port
starboard
zenith
nadir
0.06
0.05
0.04
0.03
0.02
0.01
0.00
penetrations (m^{-2} yr^{-1})
10^2
10^3
10^4
10^5
altitude (km)

- Altitude variation of meteoroid flux is governed by two competing factors – Earth gravitational focussing and shielding.
  - Meteoroid flux is increased (focussed) at lower altitudes, but
  - Earth blocks more of the sky
  - Peak flux is around 1000 km altitude
  - Effect is strongest on ram-facing surface
  - Zenith (‘Space’) flux is only gravitationally focused
  - Nadir (‘Earth) flux is governed by Earth shielding – not a factor above 20,000 km
- Port and starboard penetrations less than/equal to those on zenith.
- Wake flux shows gentle increase with altitude.

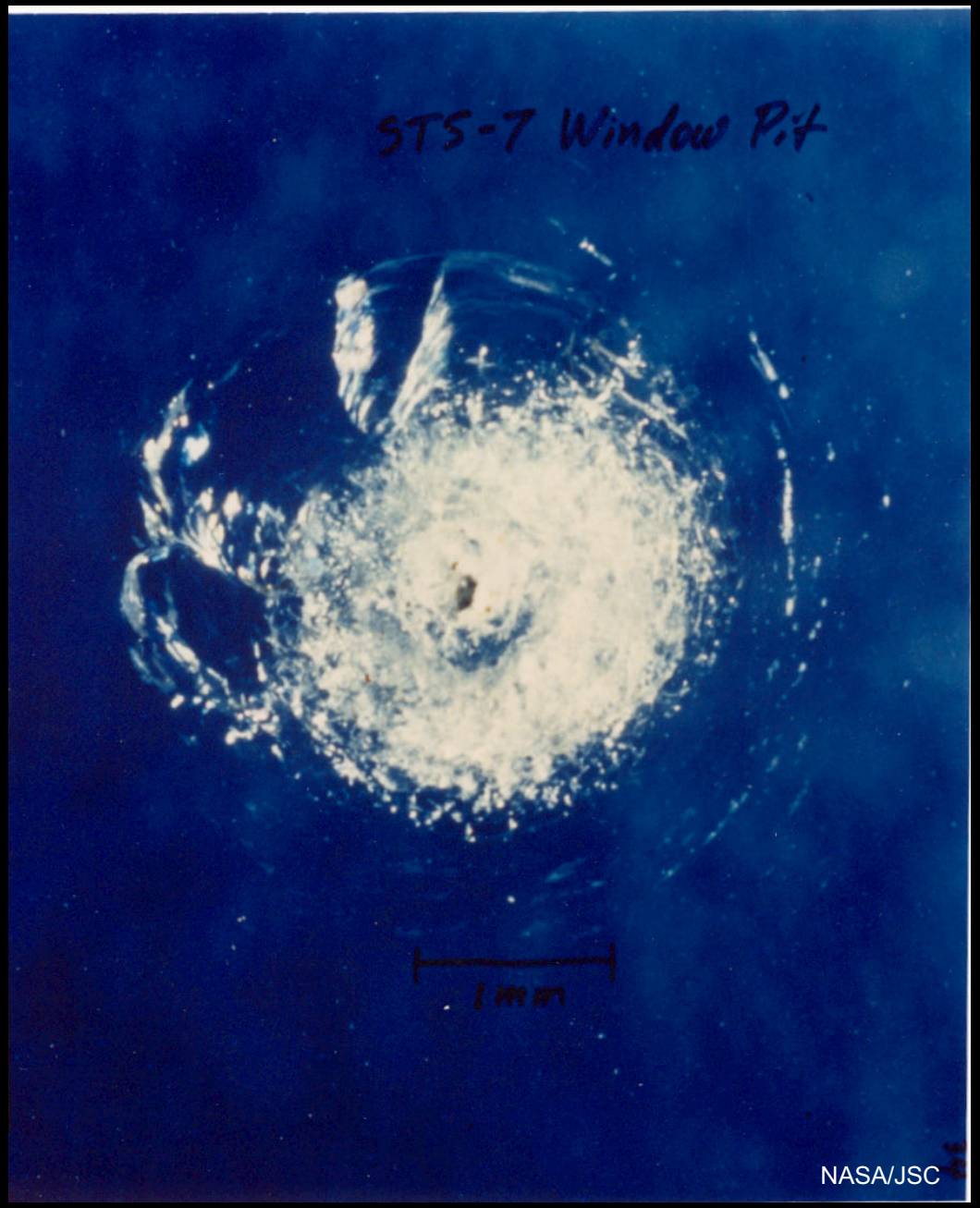
ORDEM 3.0

- ORDEM 3.0 is NASA's latest model of the orbital debris environment.
- It differs from the previous model (ORDEM 2000) in several ways:
  - Uncertainties in the flux estimates
  - Characterizes debris environment from 100 to 40,000 km altitude
  - Can handle highly elliptical spacecraft orbits
  - Divides the debris population into 4 density classes

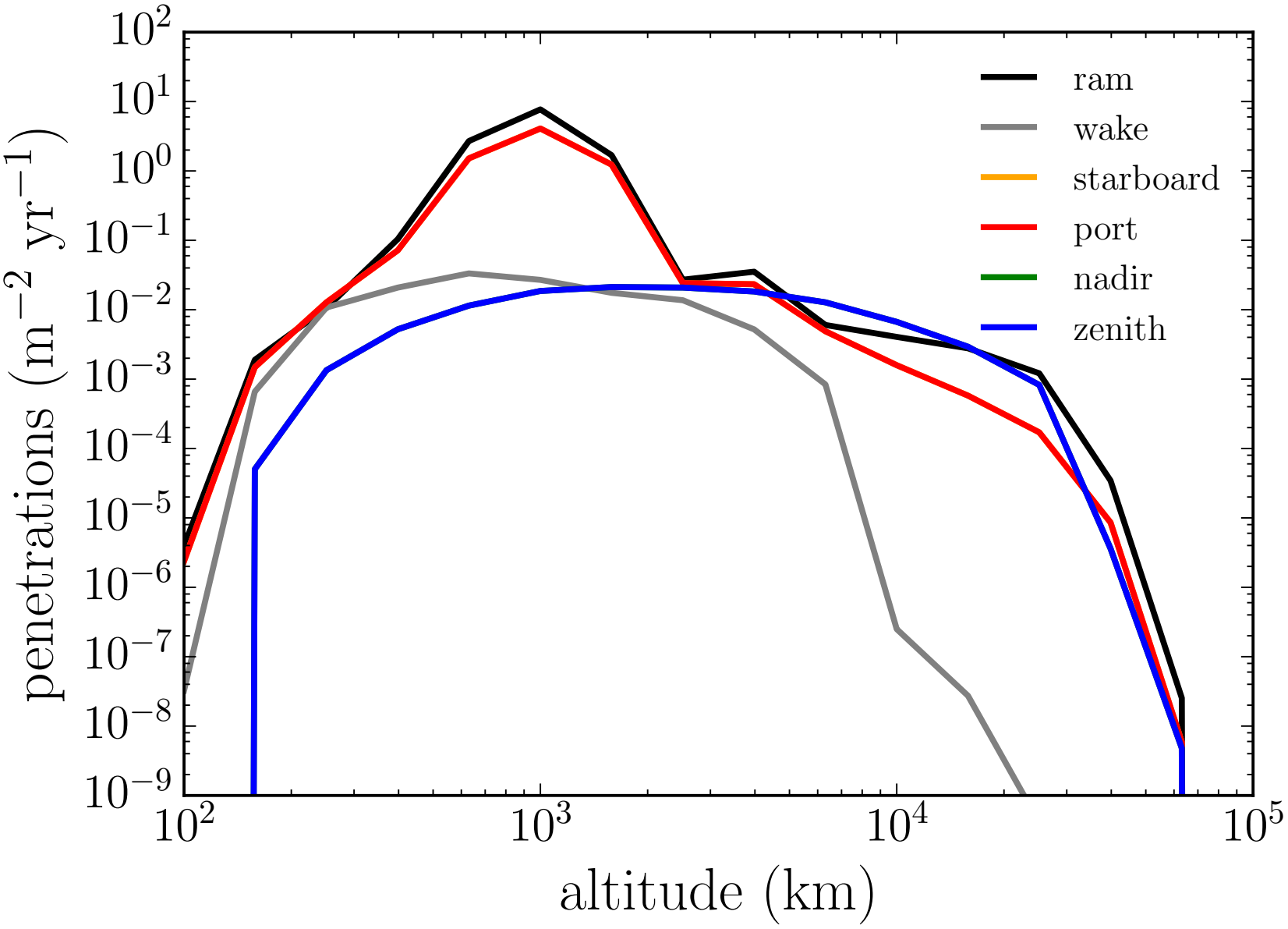


Class	Density (g/cc)
NaK droplets	0.9
Low density	1.4
Medium density/Intacts	2.8
High density	7.9

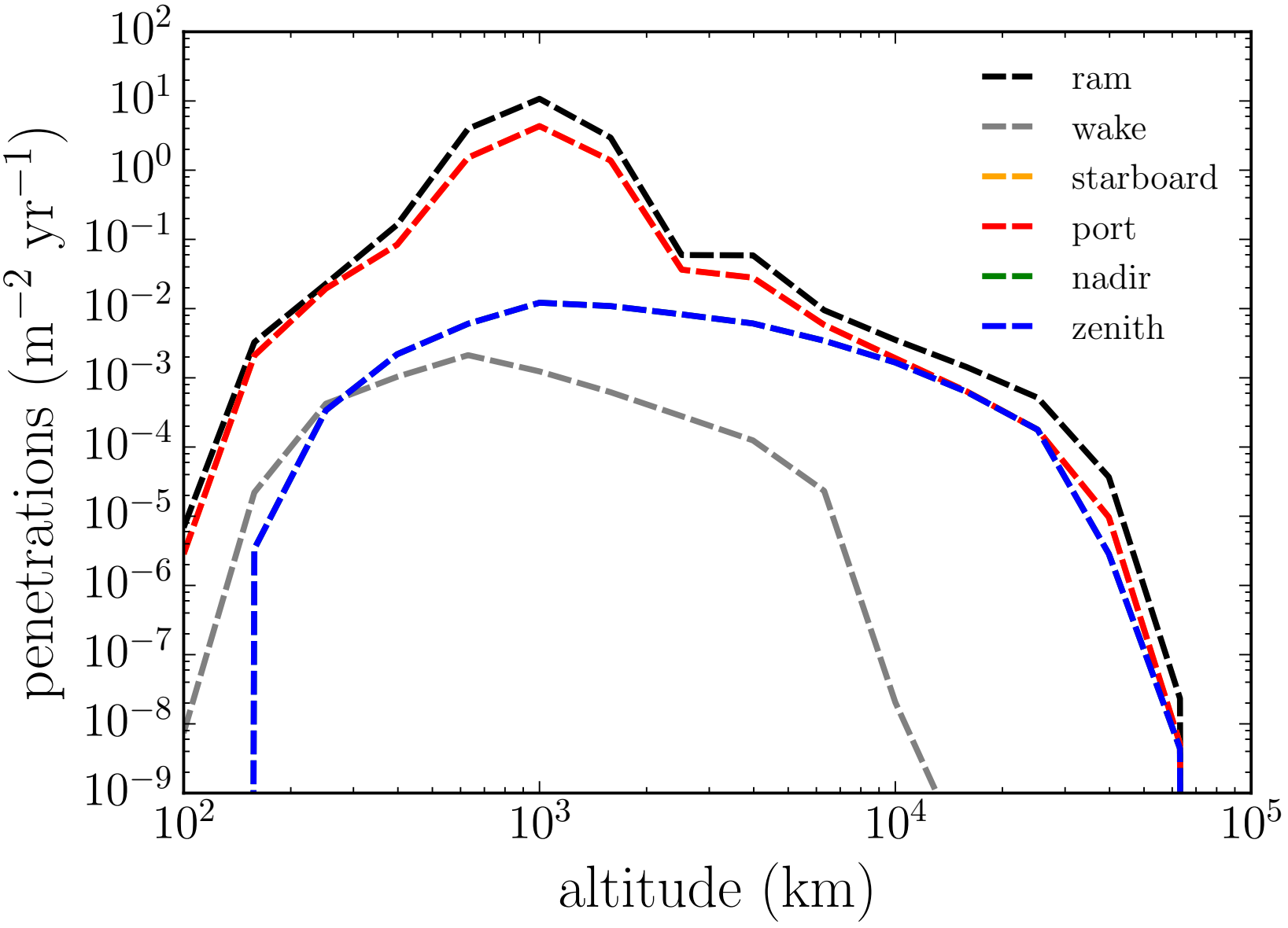
- ORDEM 3.0 also includes the cratering data obtained from inspection of Shuttle windows and radiators after mission completion (>600 features, most analyzed by SEM).
- In addition to generating a threat igloo, the model can also output debris fluxes by range bins for ground-based sensors.



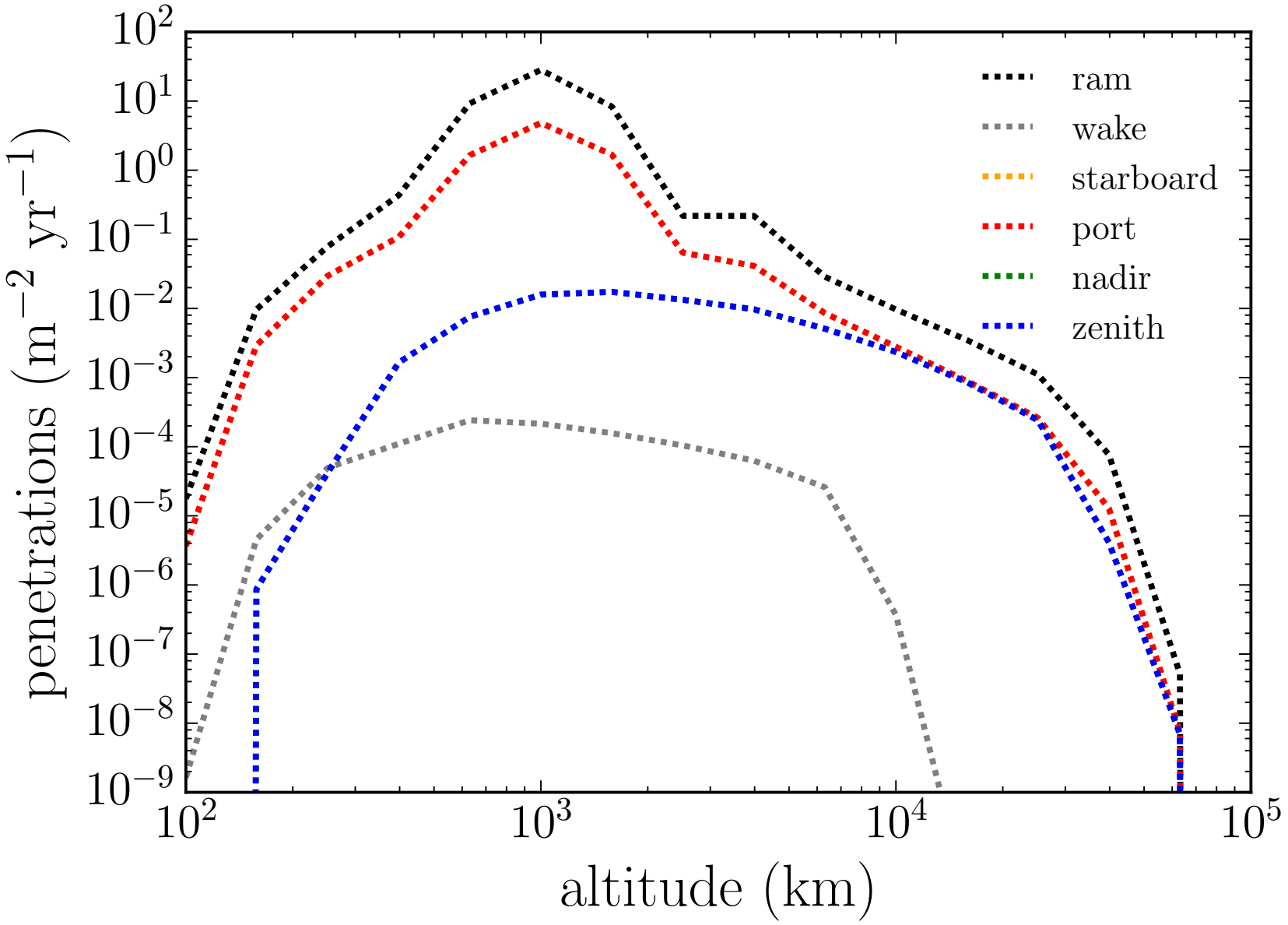
0° inclination



45° inclination

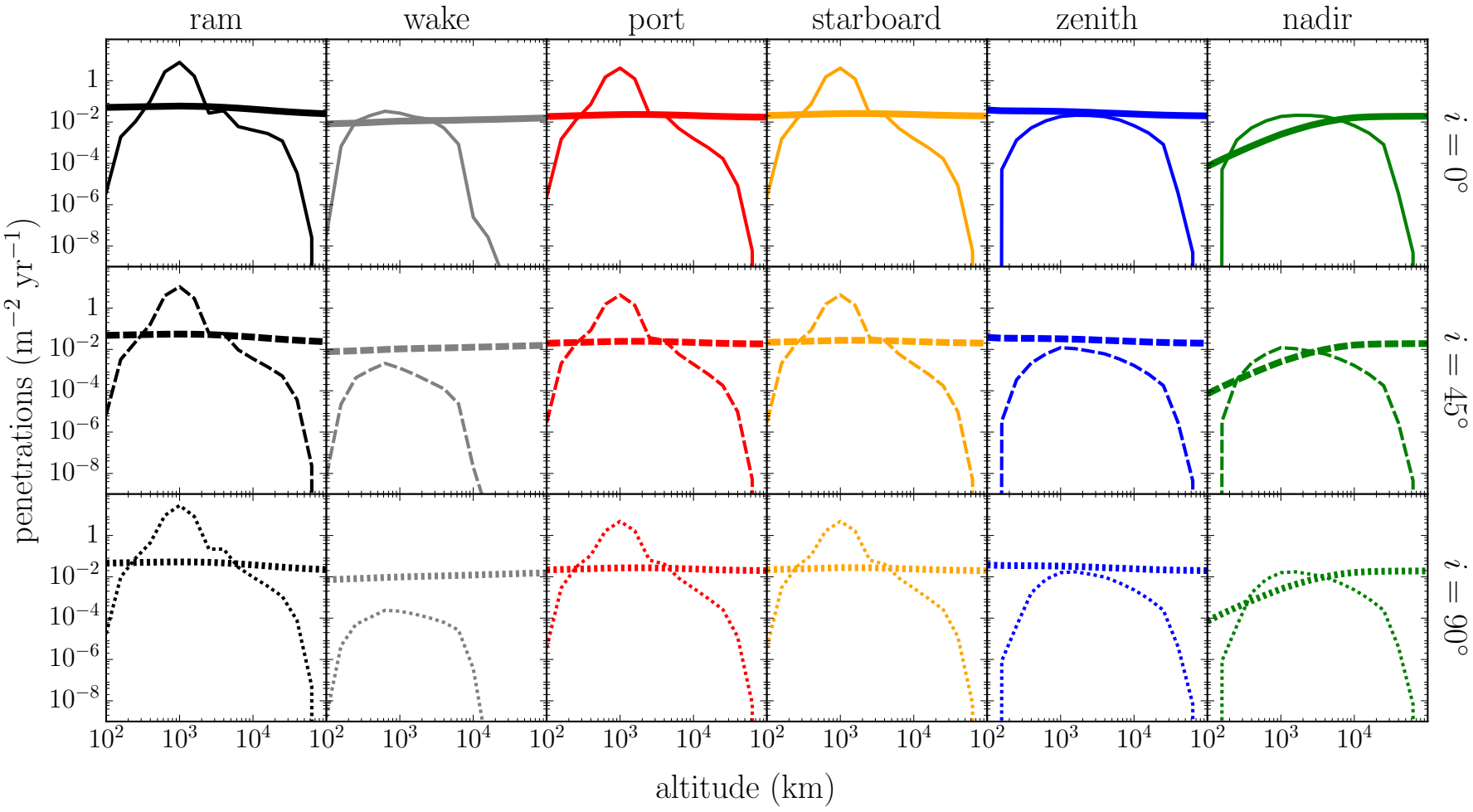


90° inclination

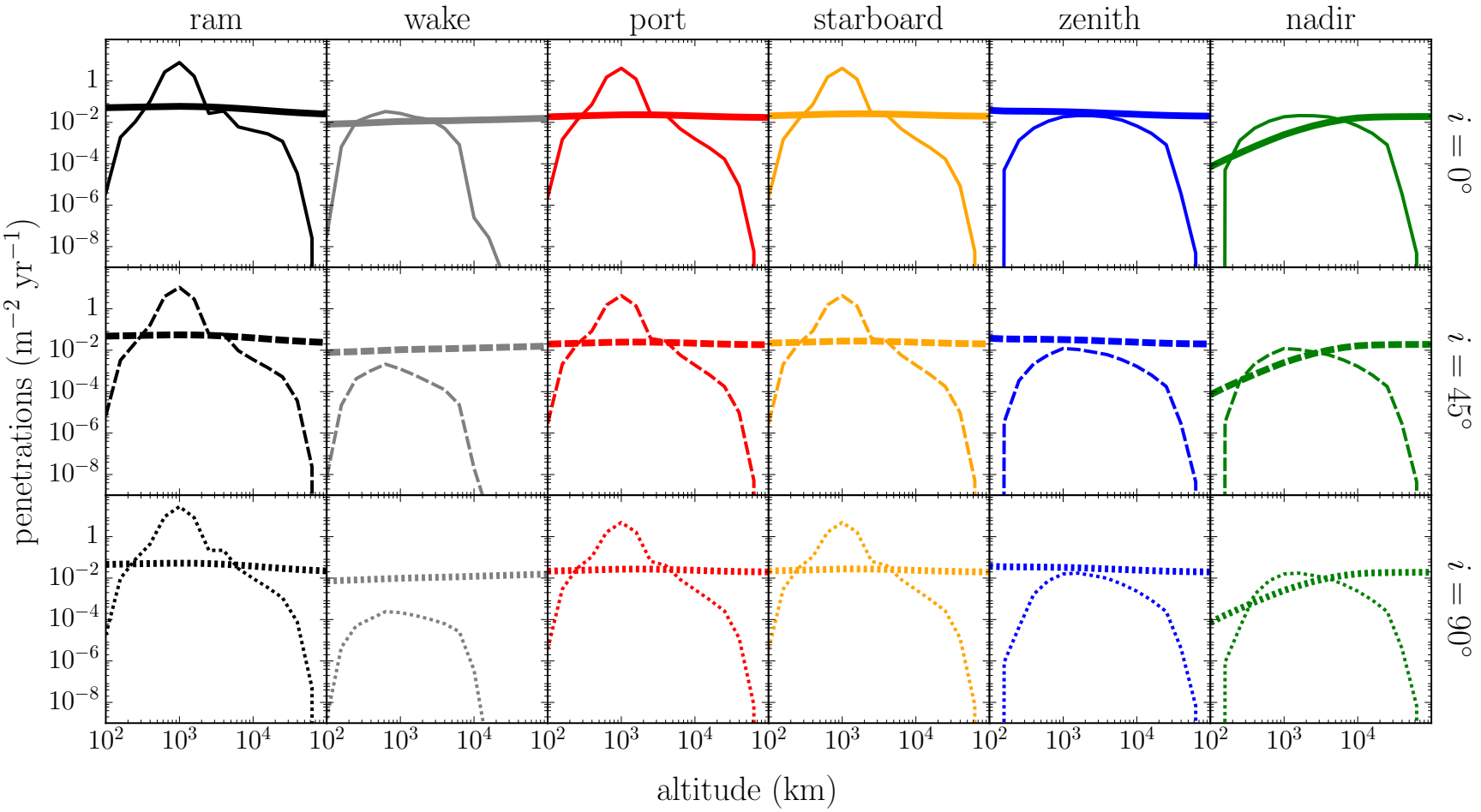


- Orbital debris penetrating fluxes strong function of speed – ram and wake can differ by many orders of magnitude.
- Ram, port, and starboard most affected by debris – numbers of penetrations increase around 400 km altitude, peak around 1000 km, and decline significantly after 2500 km altitude. Flux on these surfaces increases with increasing orbital inclination.
- For sun-synchronous orbits,1 mm thick Al surfaces facing ram could receive as many as 20 penetrations per year, due to high fluxes and presence of sub-mm steel (high density) population.
- Flux trails off to 0 just beyond GEO altitude.

Meteoroid/Orbital Debris Comparison

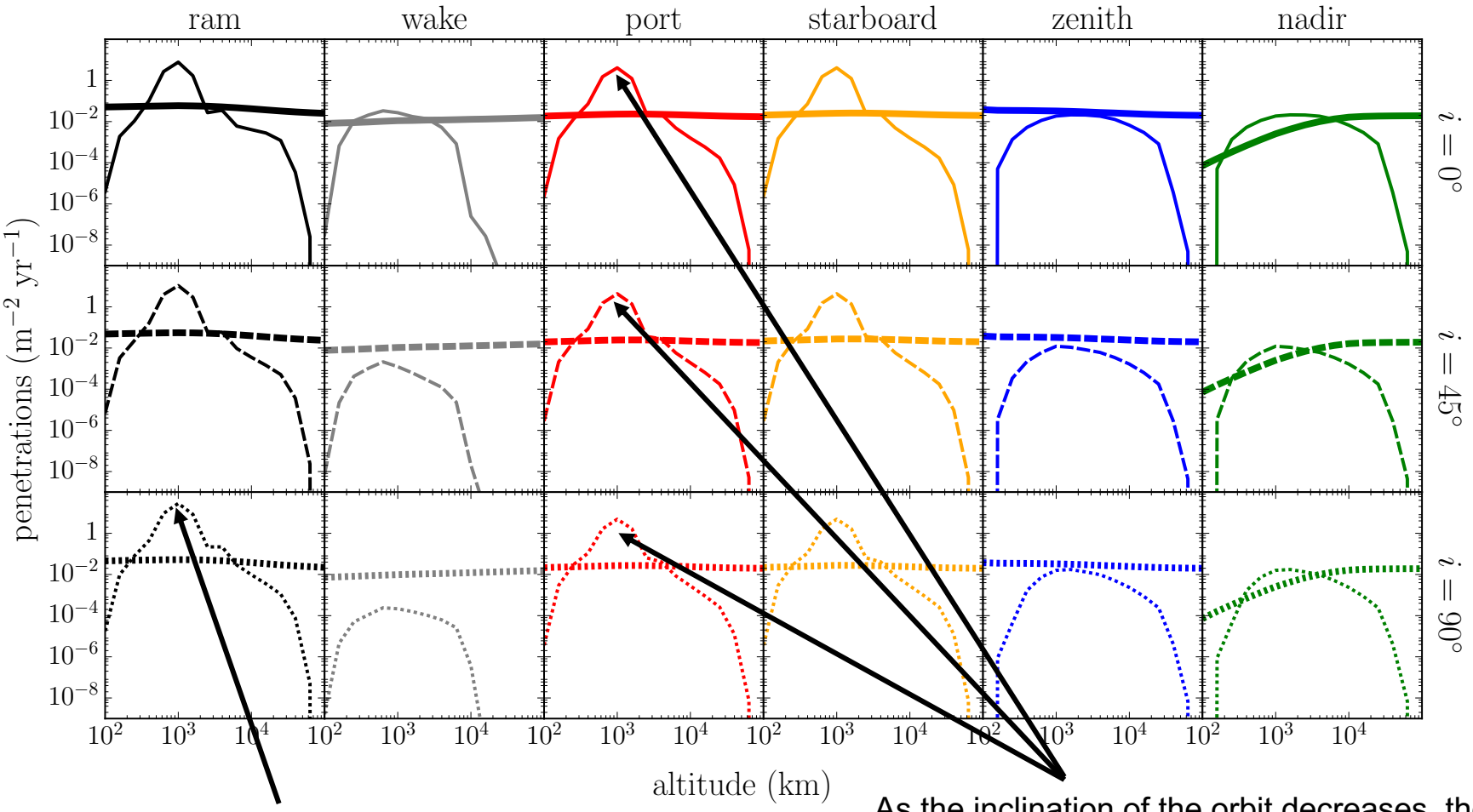


Meteoroid penetrating flux varies by only a factor of a few over all surfaces and altitudes; that of orbital debris spans several orders of magnitude.



Meteoroids dominate the one millimeter penetrating flux at altitudes below 250 km and above 4000 km.

The number of one millimeter aluminum plate penetrations caused by orbital debris greatly exceeds that of meteoroids for ram, port, and starboard facing surfaces in the 250 to 2500 km altitude regime

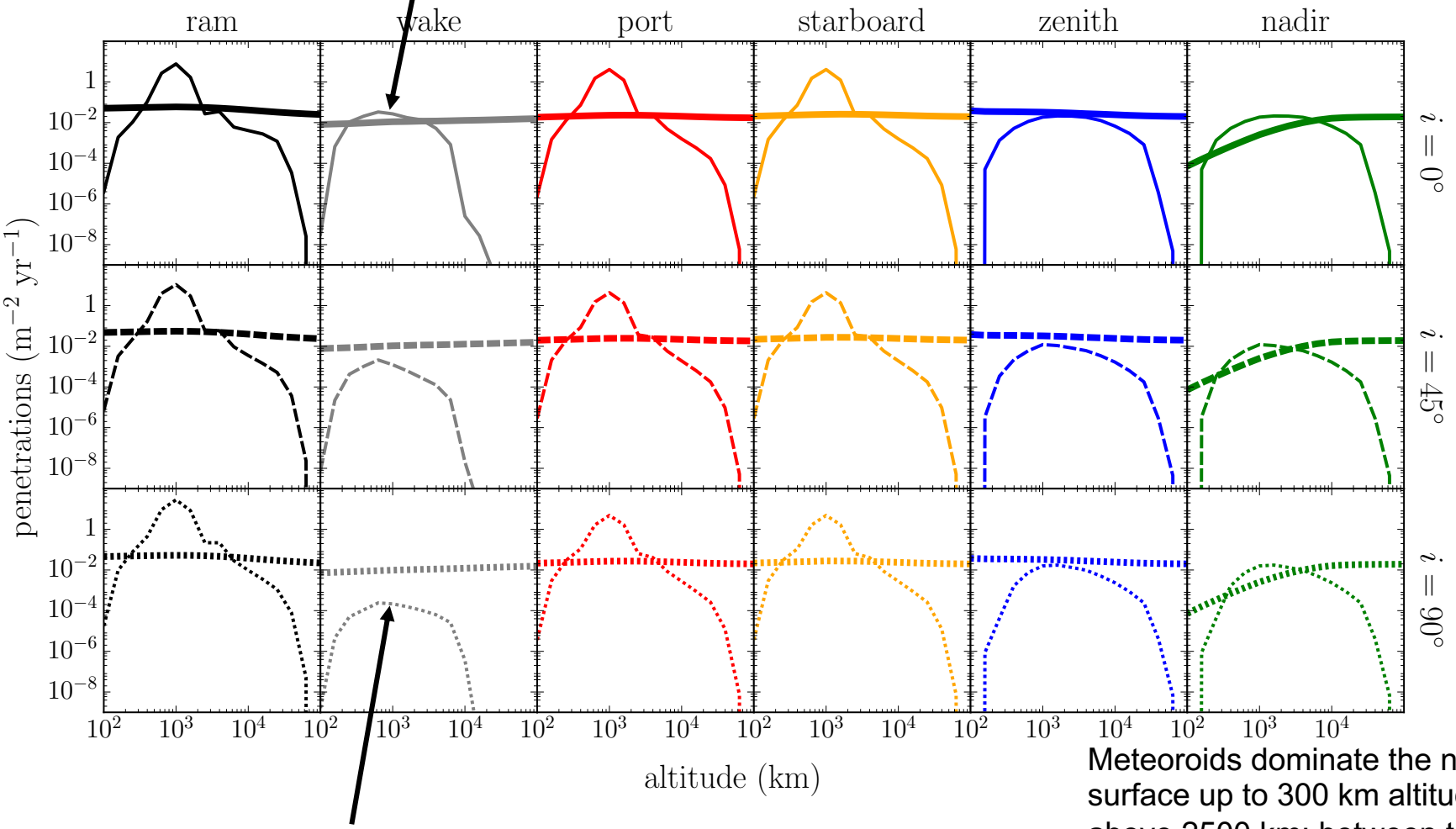


At 1000 km and 90° inclination, the number of debris penetrations is almost 500x that of meteoroids.

As the inclination of the orbit decreases, the number of debris penetrations on ram, port, and starboard decrease, reaching one half the 90° values at 0° inclination.

Orbital debris penetrations on wake increase with decreasing orbital inclination. At 0° inclination, the debris penetrating flux on wake equals or exceeds that of meteoroids from 250 to 2500 km altitude.

Only surfaces facing orbital zenith ('space') are dominated by meteoroids for all considered altitudes and inclinations.



The wake surface may also be a good place for meteoroid detector if the vehicle is in an orbit with inclination near 90°

Meteoroids dominate the nadir surface up to 300 km altitude and above 2500 km; between these limits, the debris penetrating flux equals or exceeds that of meteoroids up to a factor of 3.