The Space Environment

- Lecture #07 - September 19, 2023
- Course schedule updates
- Planetary environments
- Gravitation
- Electromagnetic radiation
- Atmospheric particles
- Newtonian flow
- Solar wind particles
- Ionizing radiation
- Micrometeoroids/orbital debris
- Spacecraft charging

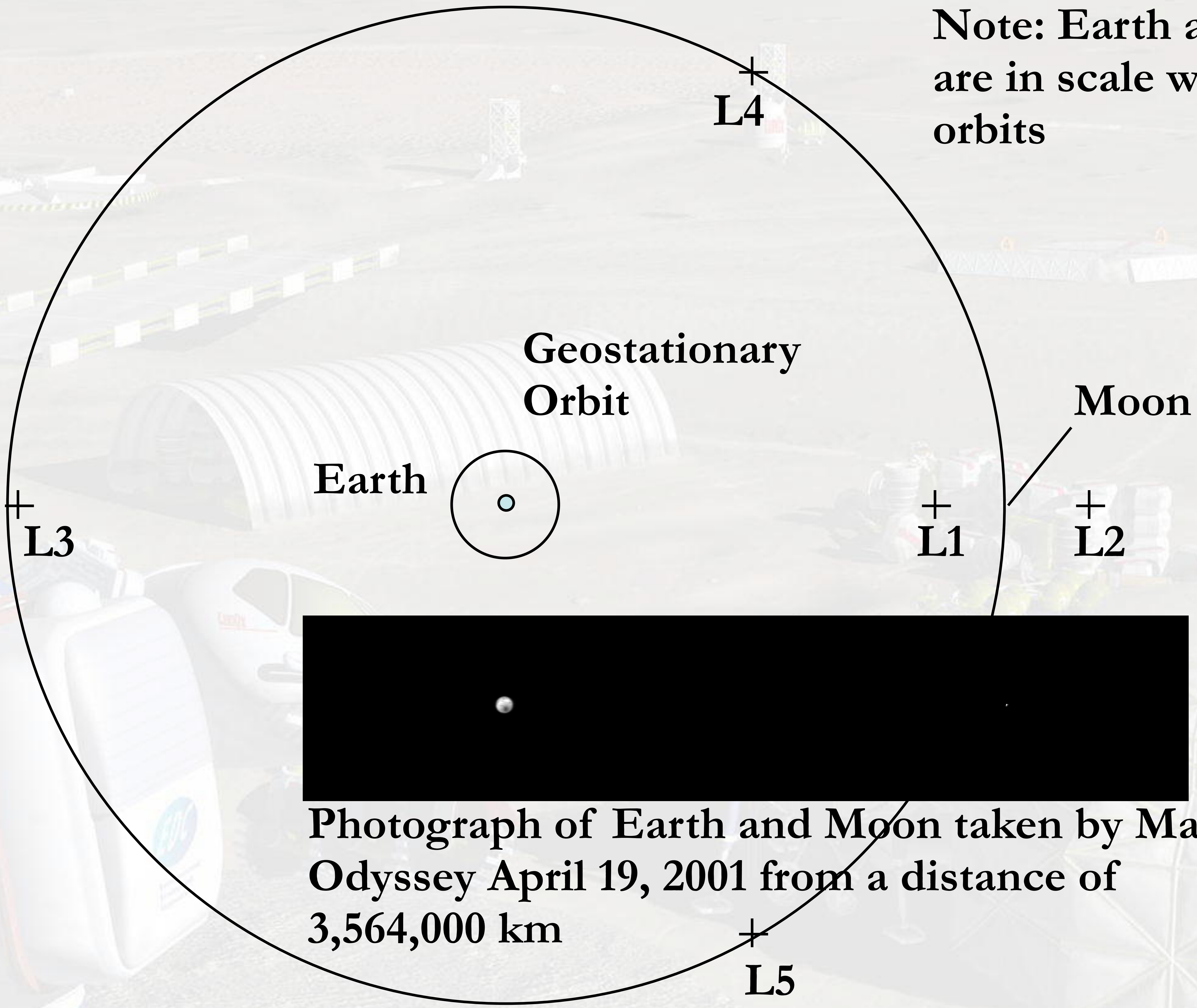
The Space Environment

"Space is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space."

Douglas Adams, *The Hitchhiker's Guide to the Galaxy*, 1979

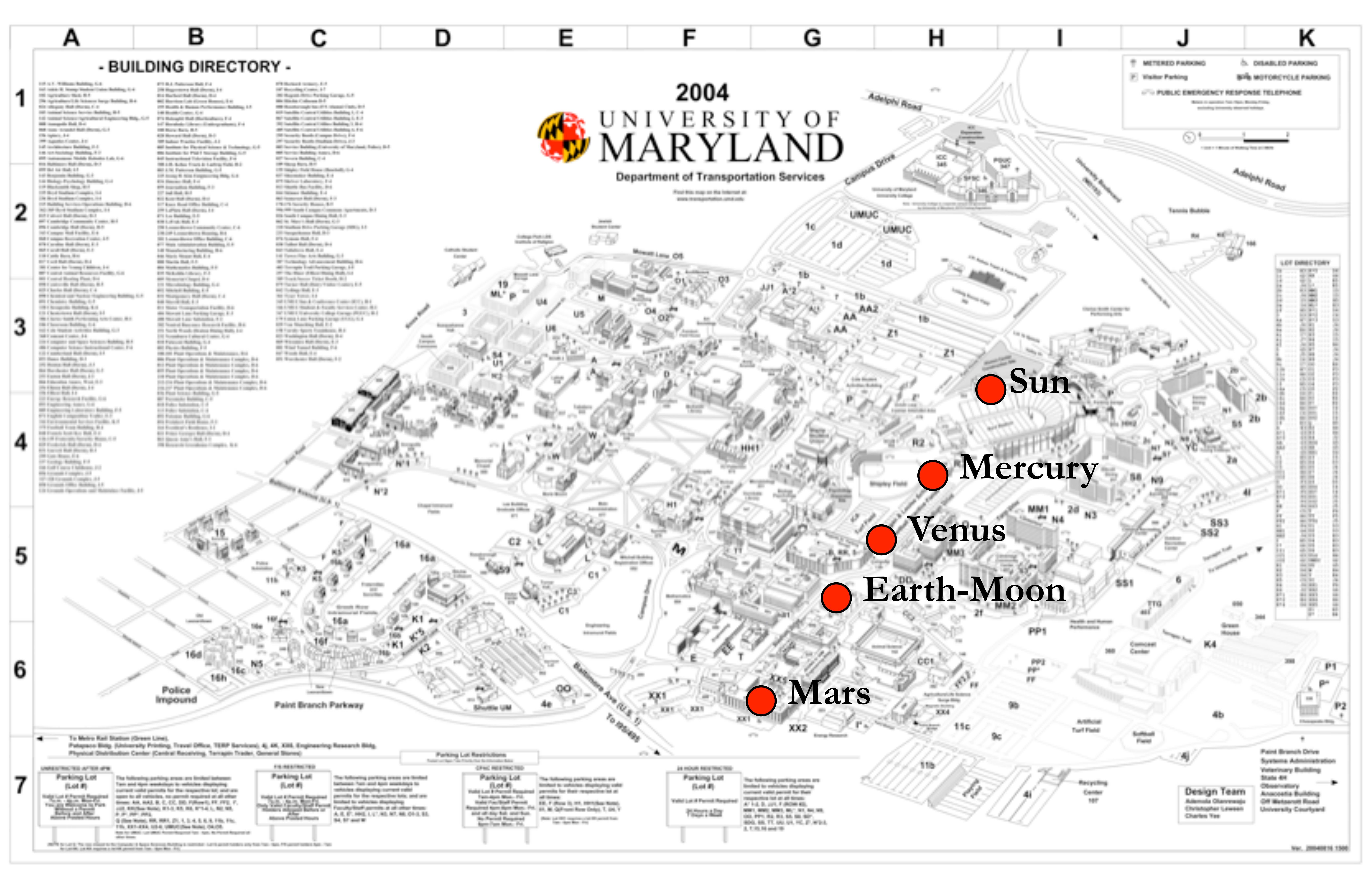
The Earth-Moon System

Note: Earth and Moon are in scale with size of orbits

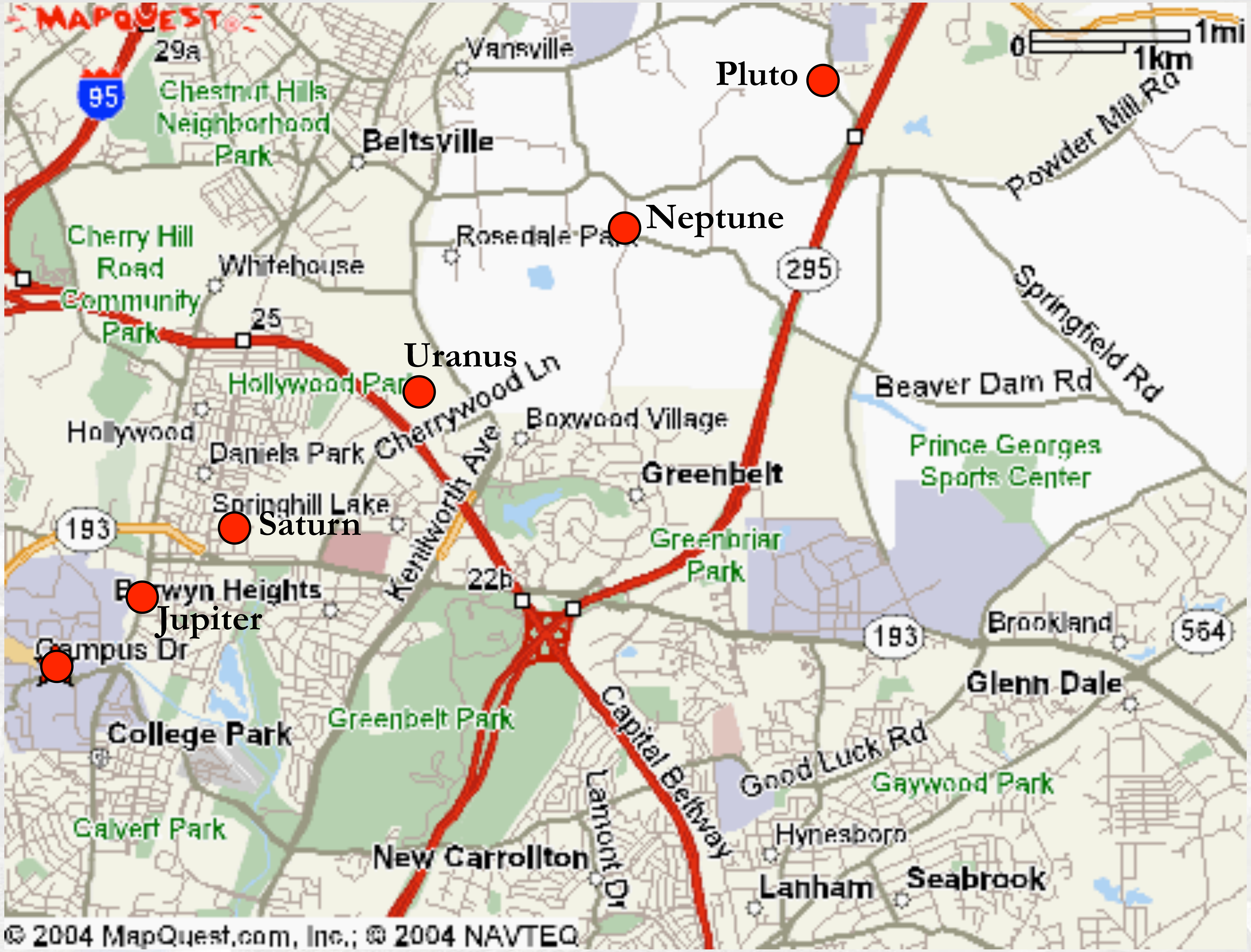


Photograph of Earth and Moon taken by Mars Odyssey April 19, 2001 from a distance of 3,564,000 km

In The Same Scale...



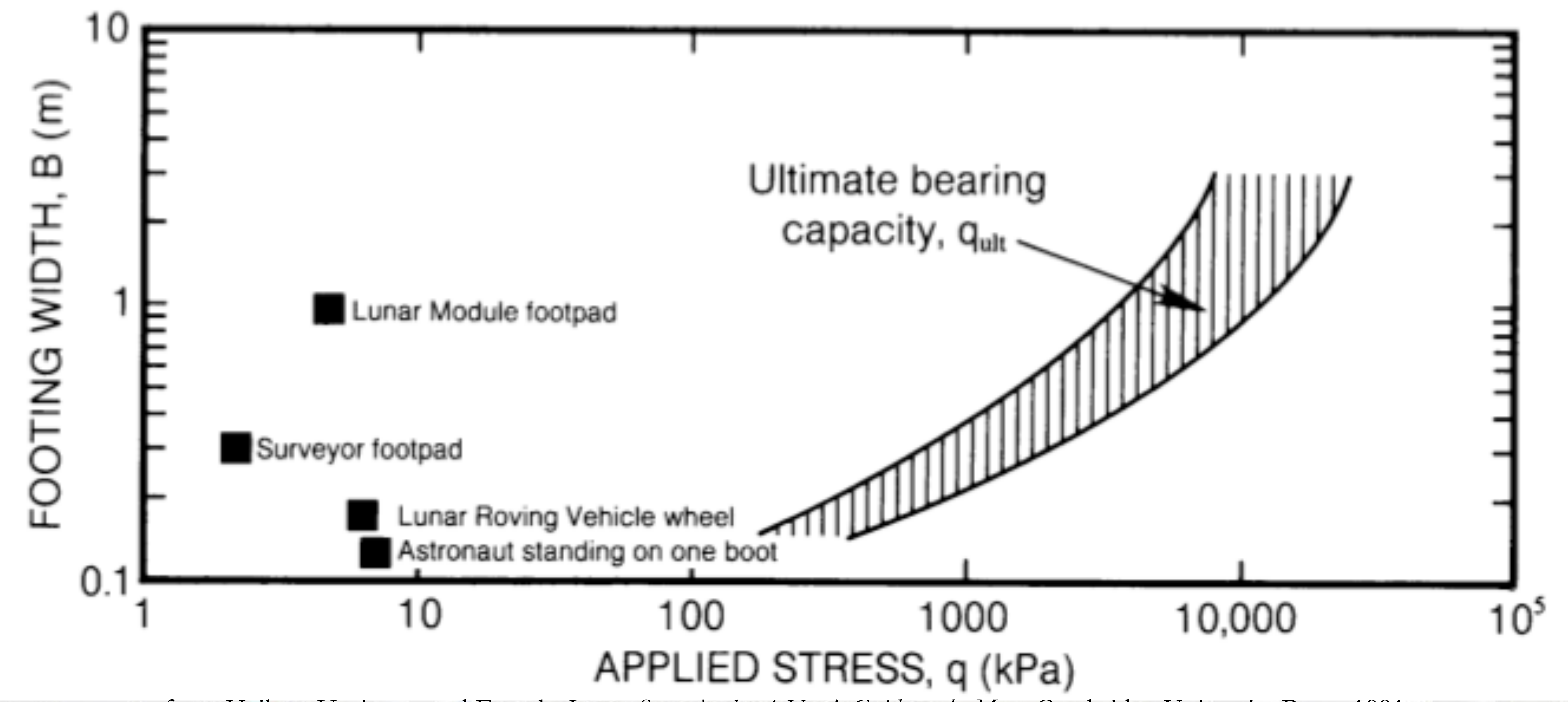
Still In The Same Scale



Comparison of Basic Characteristics

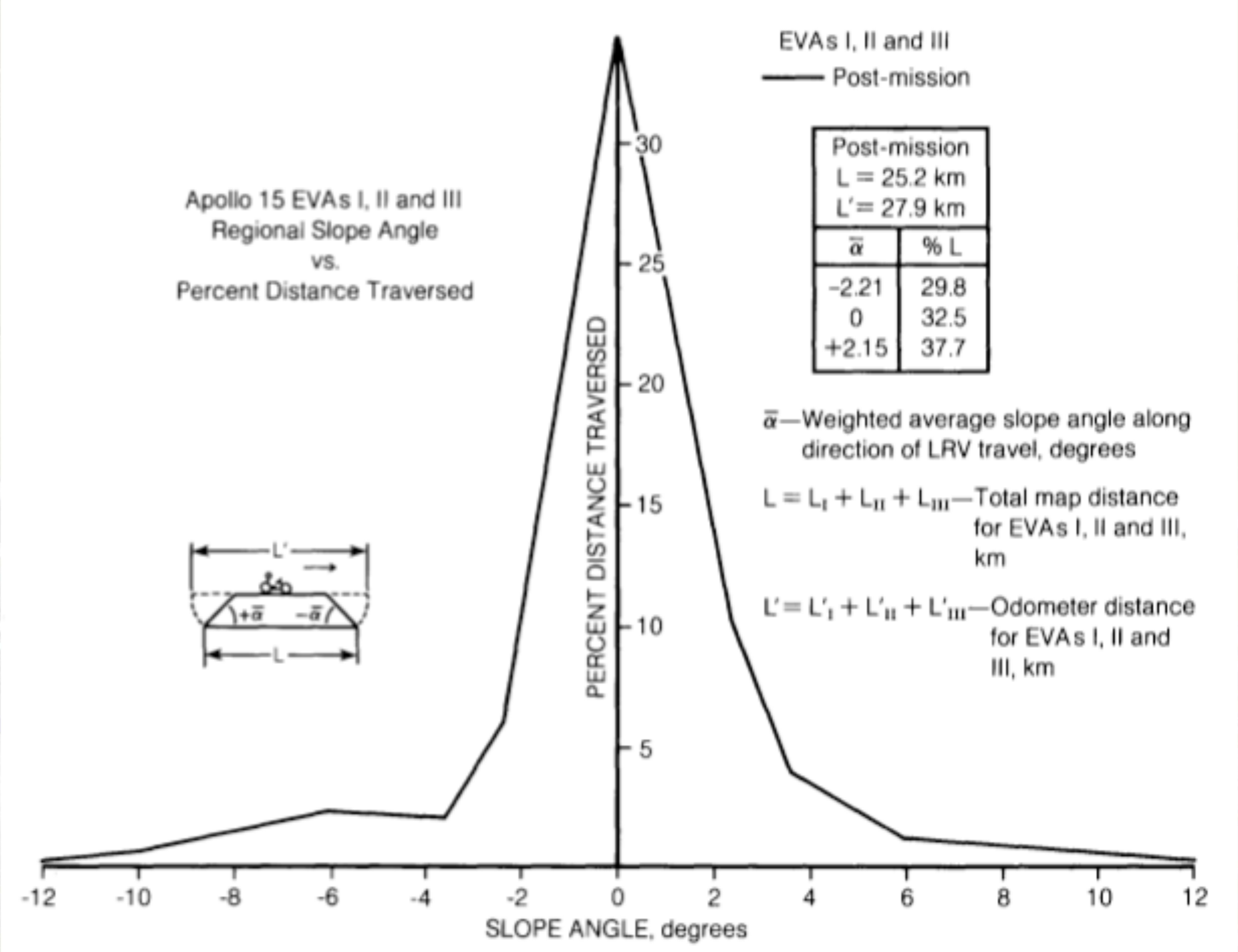
Quantity	Earth	Free Space	Moon	Mars
Gravitational Acceleration	9.8 m/s^2 (1 g)	–	1.545 m/s^2 (.16 g)	3.711 m/s^2 (.38 g)
Atmospheric Pressure	101,350 Pa (14.7 psi)	–	–	560 Pa (.081 psi)
Atmospheric Constituents	78% N_2 21% O_2	–	–	95% CO_2 3% N_2
Temperature Range	120°F -100°F	150°F -60°F	250°F -250°F	80°F -200°F
Length of Day	24 hr	90 min – Infinite	28 days	24h 37m 22.6s

Lunar Soil Bearing Limits



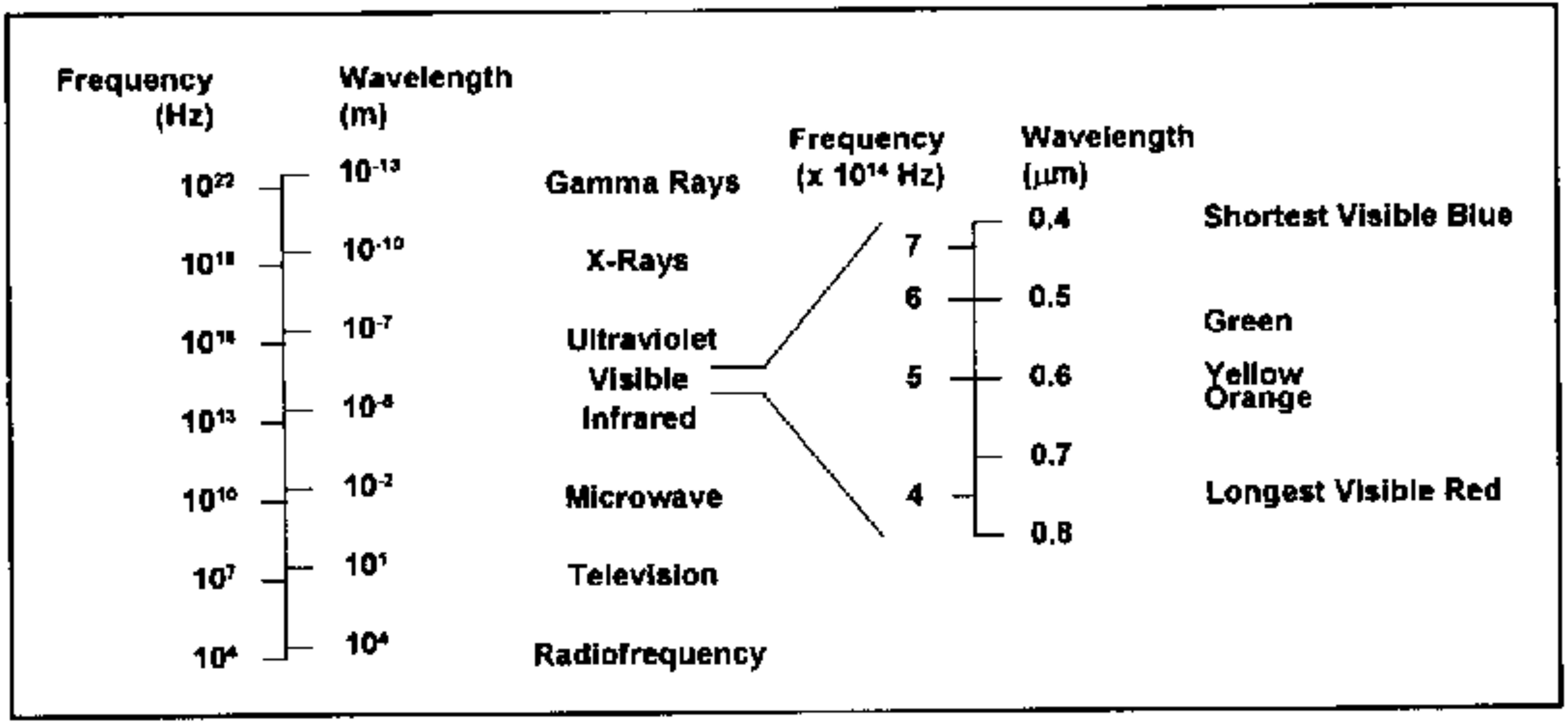
from Heiken, Vaniman, and French, *Lunar Sourcebook: A User's Guide to the Moon* Cambridge University Press, 1991

Lunar Slope Distribution (Apollo 15 data)



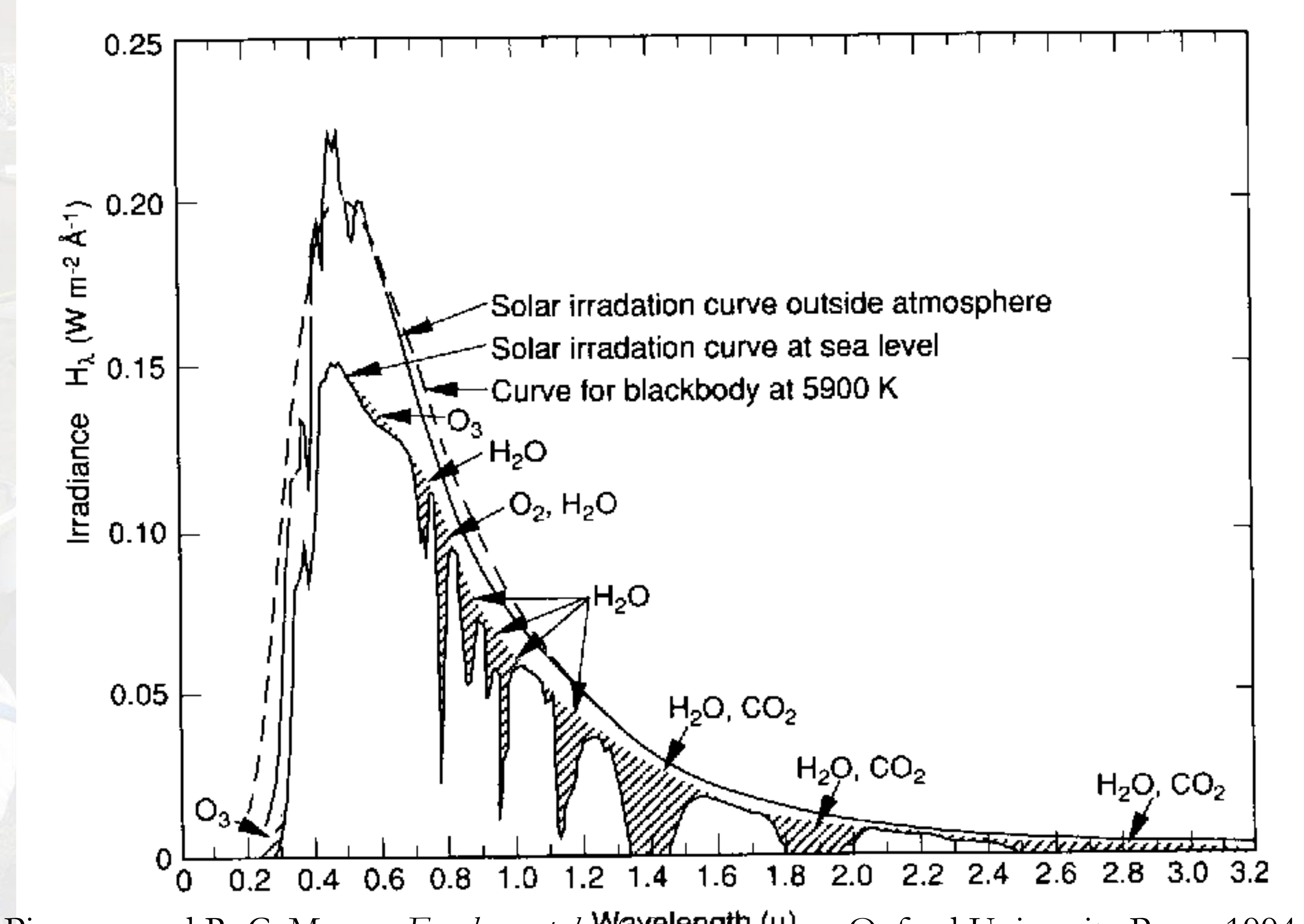
from Heiken, Vaniman, and French, *Lunar Sourcebook: A User's Guide to the Moon* Cambridge University Press, 1991

The Electromagnetic Spectrum



Ref: Alan C. Tribble, *The Space Environment* Princeton University Press, 1995

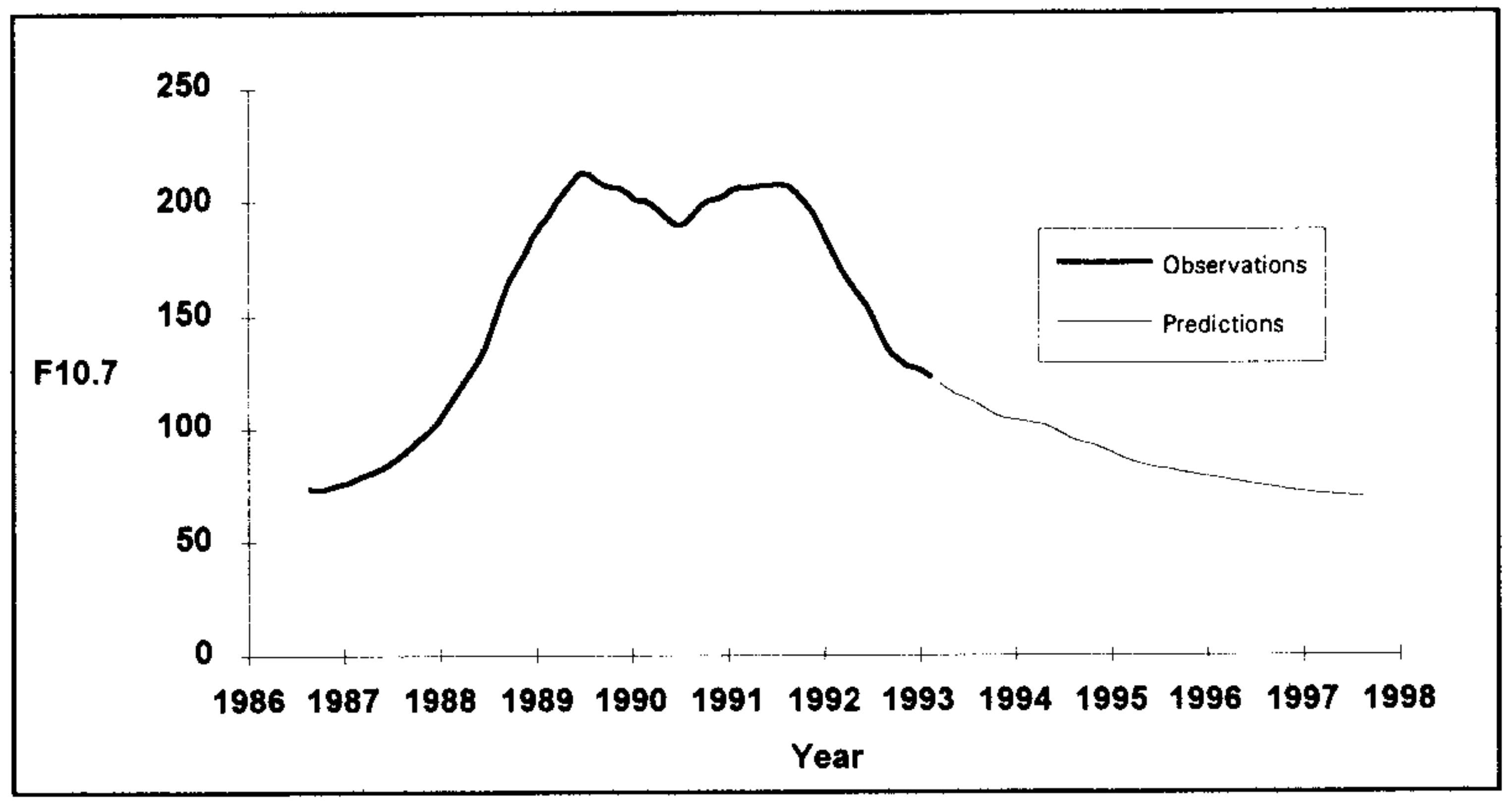
The Solar Spectrum



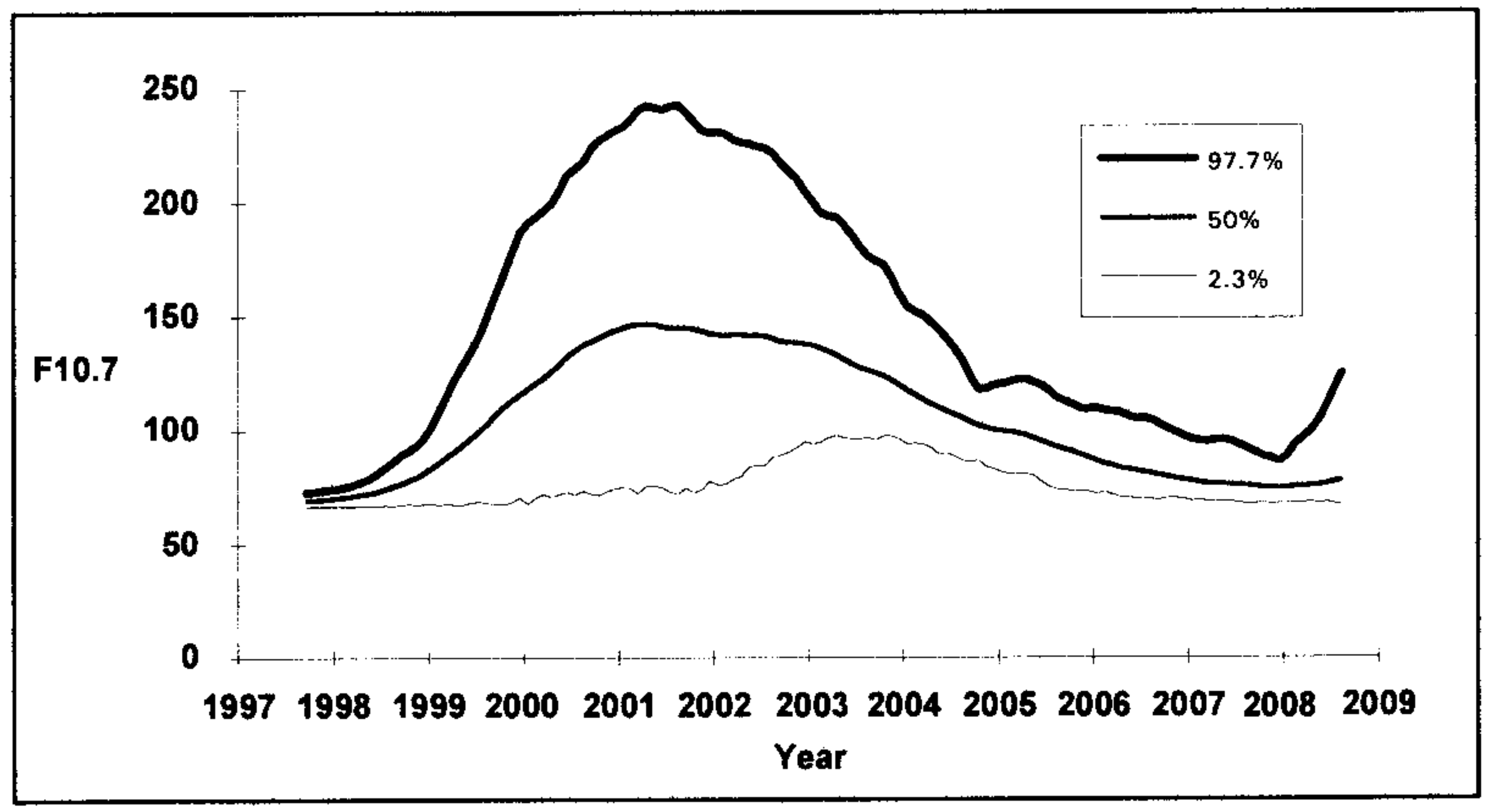
Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

Solar Cycle

- Sun is a variable star with 11-year period
- UV output of sun increases thermal energy of upper atmosphere, accelerating atmospheric drag of LEO spacecraft
- Measured as solar flux at 10.7 cm wavelength (="F10.7")



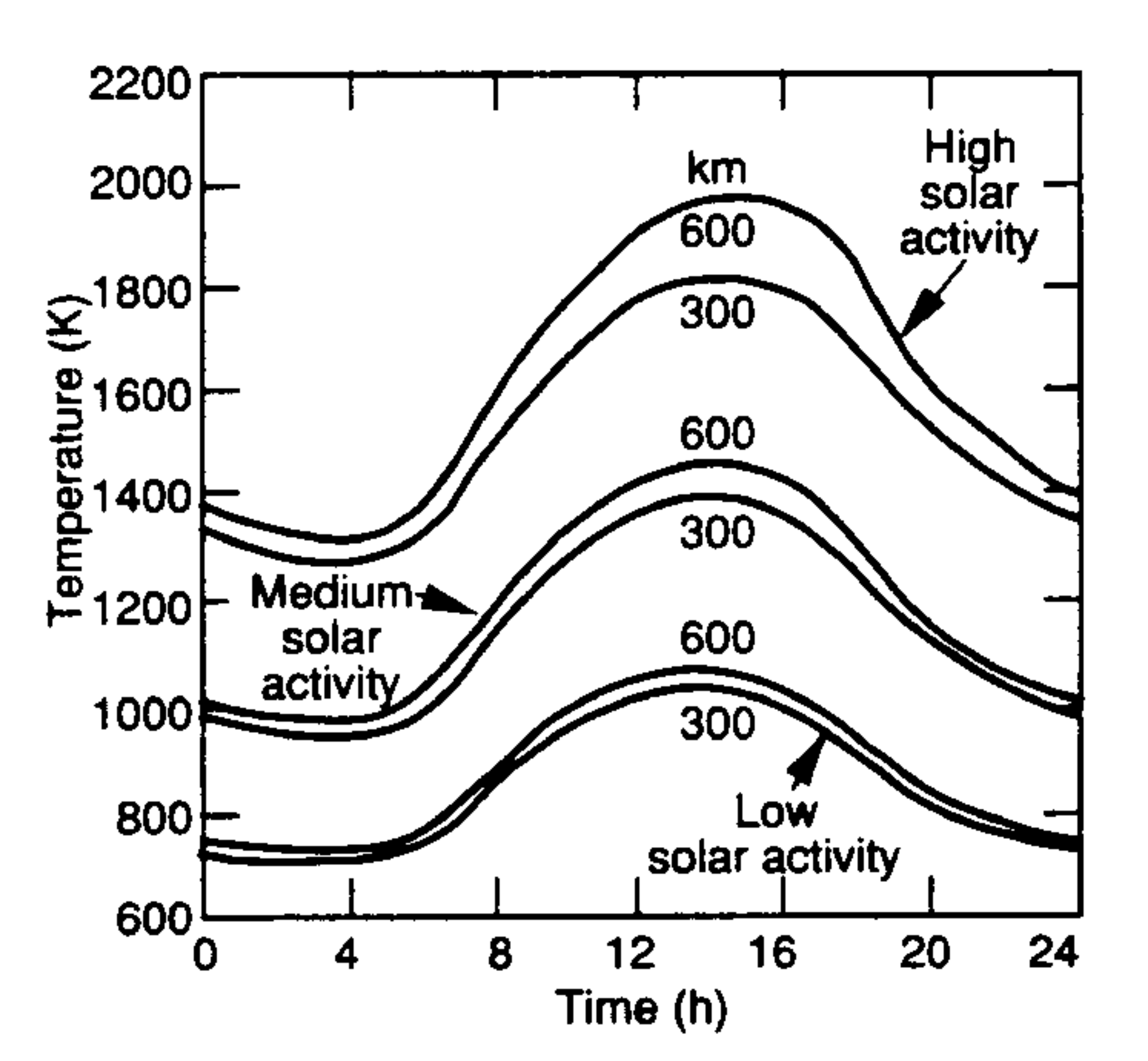
F10.7 values for solar cycle 22.



F10.7 values for solar cycle 23.

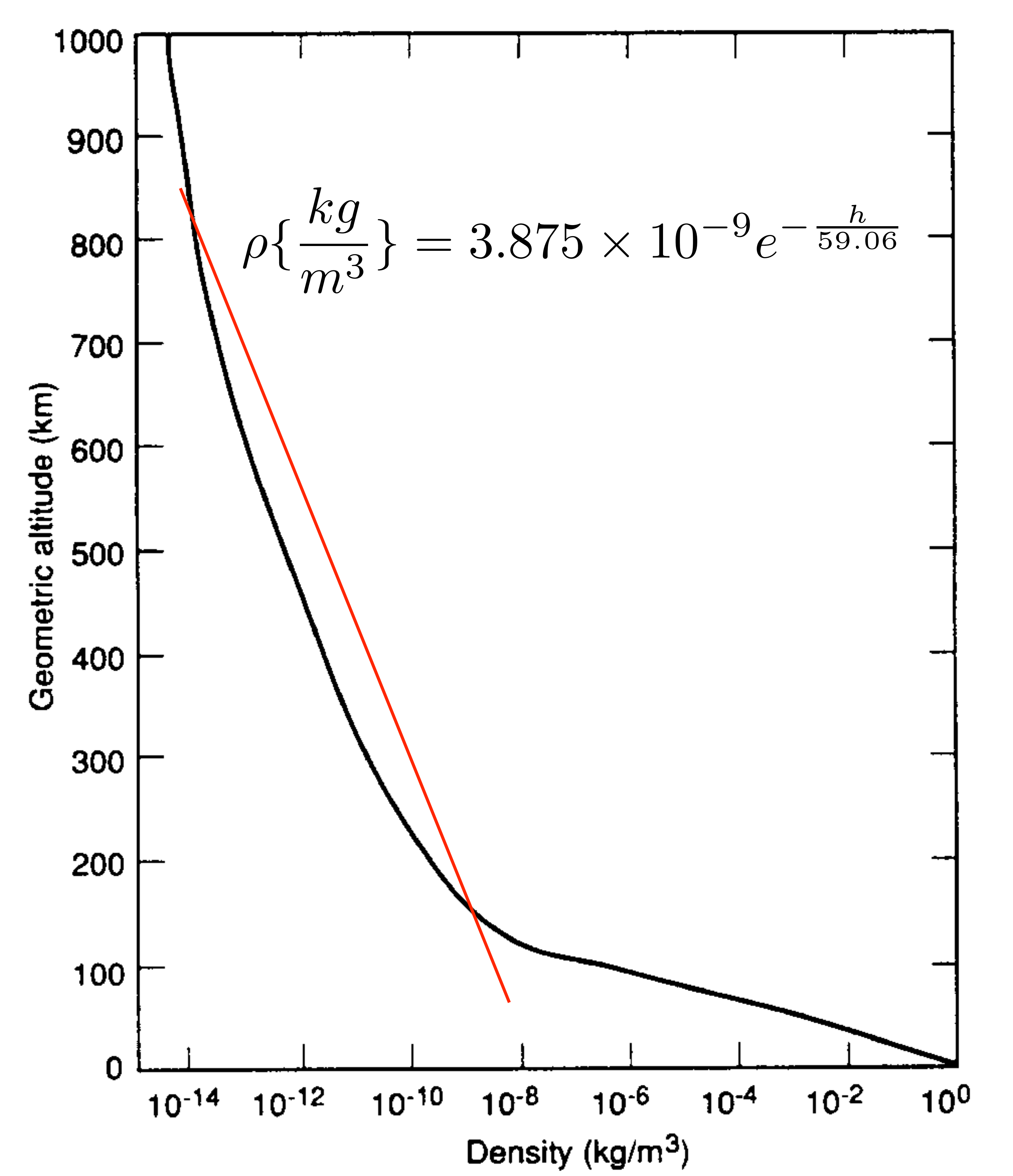
Ref: Alan C. Tribble, *The Space Environment*
Princeton University Press, 1995

Diurnal Variation of Atmosphere



Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

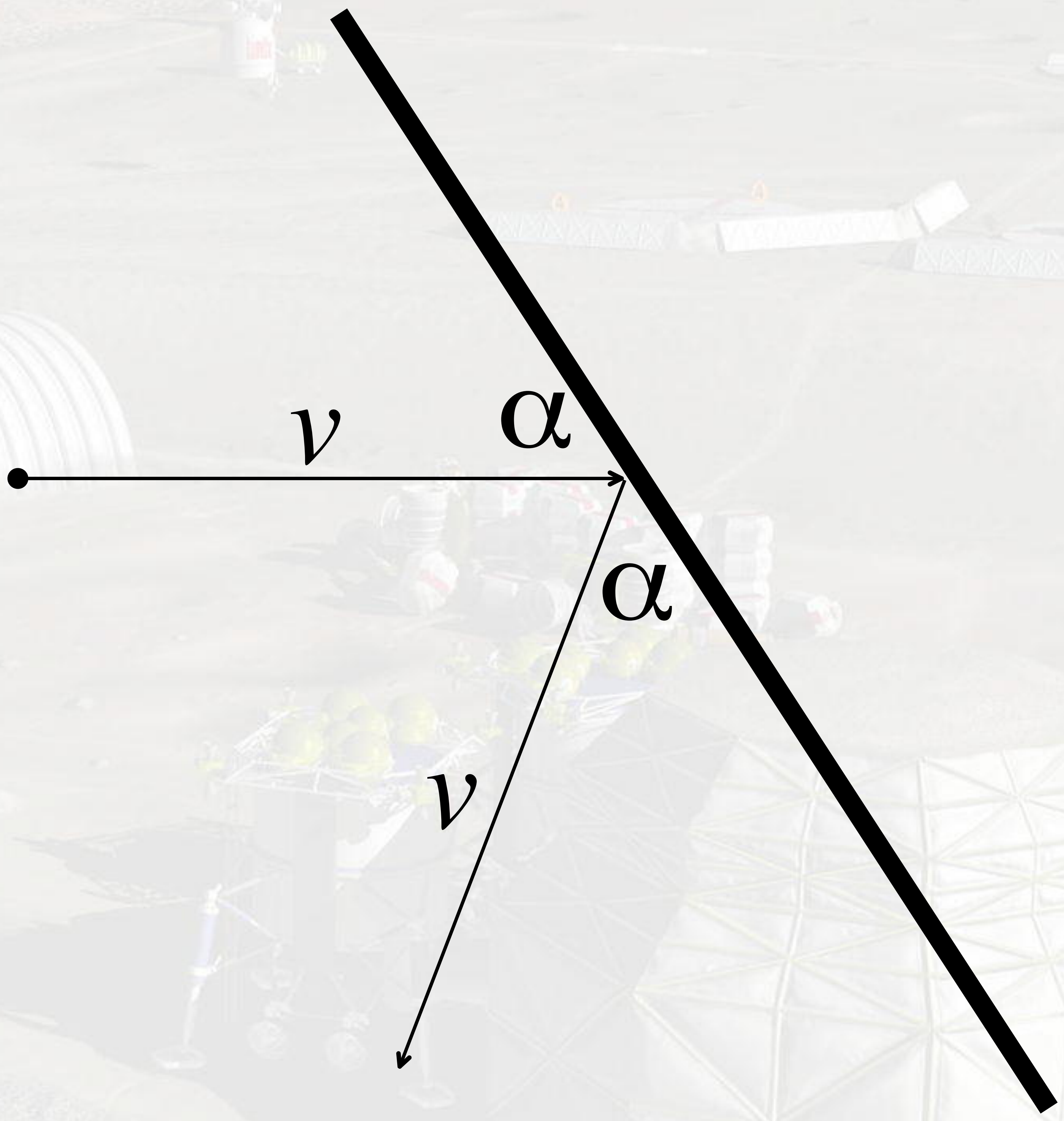
Atmospheric Density with Altitude



Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

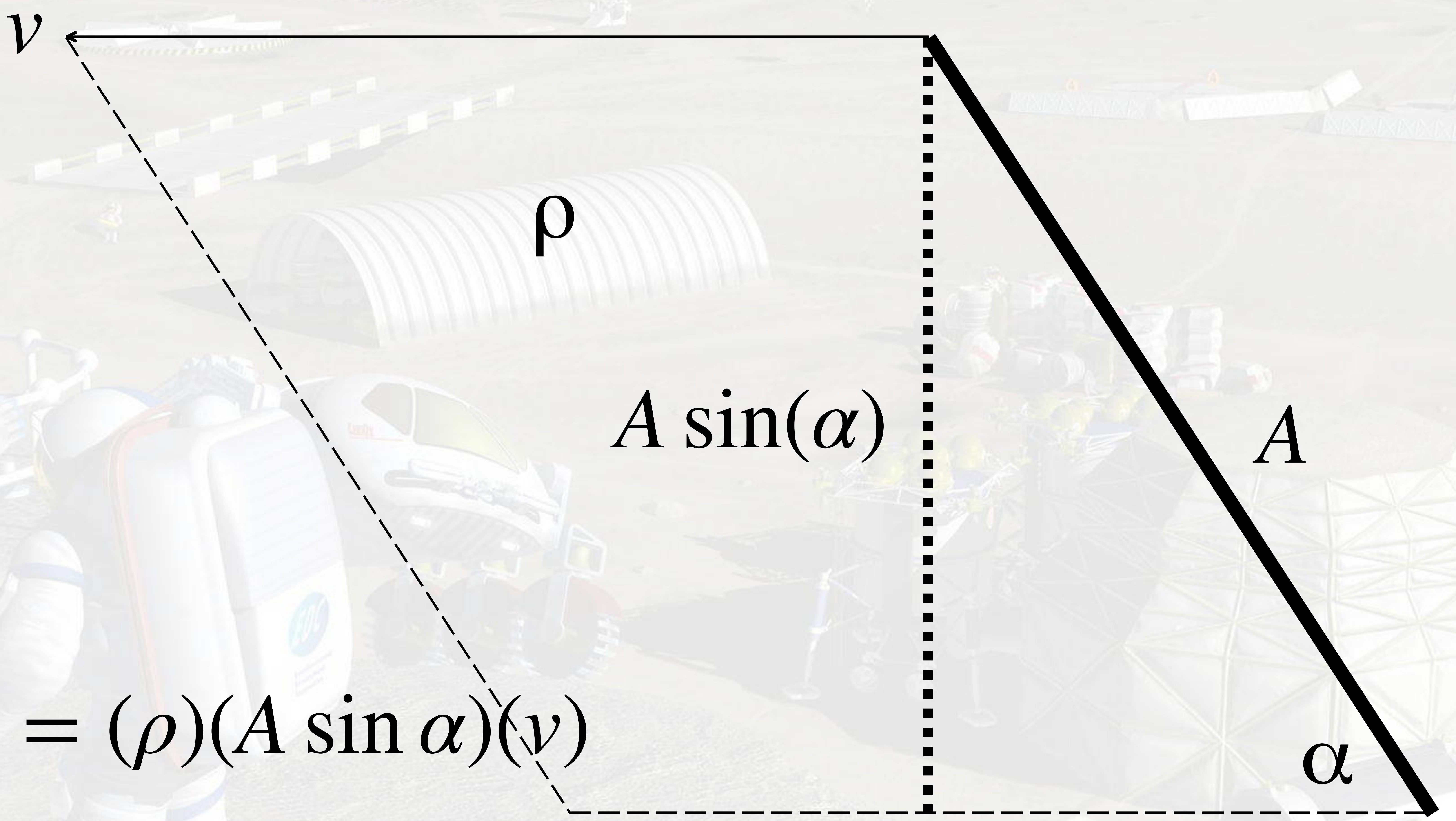
Newtonian Flow

- Mean free path of particles much larger than spacecraft --> no appreciable interaction of air molecules
- Model vehicle/ atmosphere interactions as independent perfectly elastic collisions



Newtonian Analysis

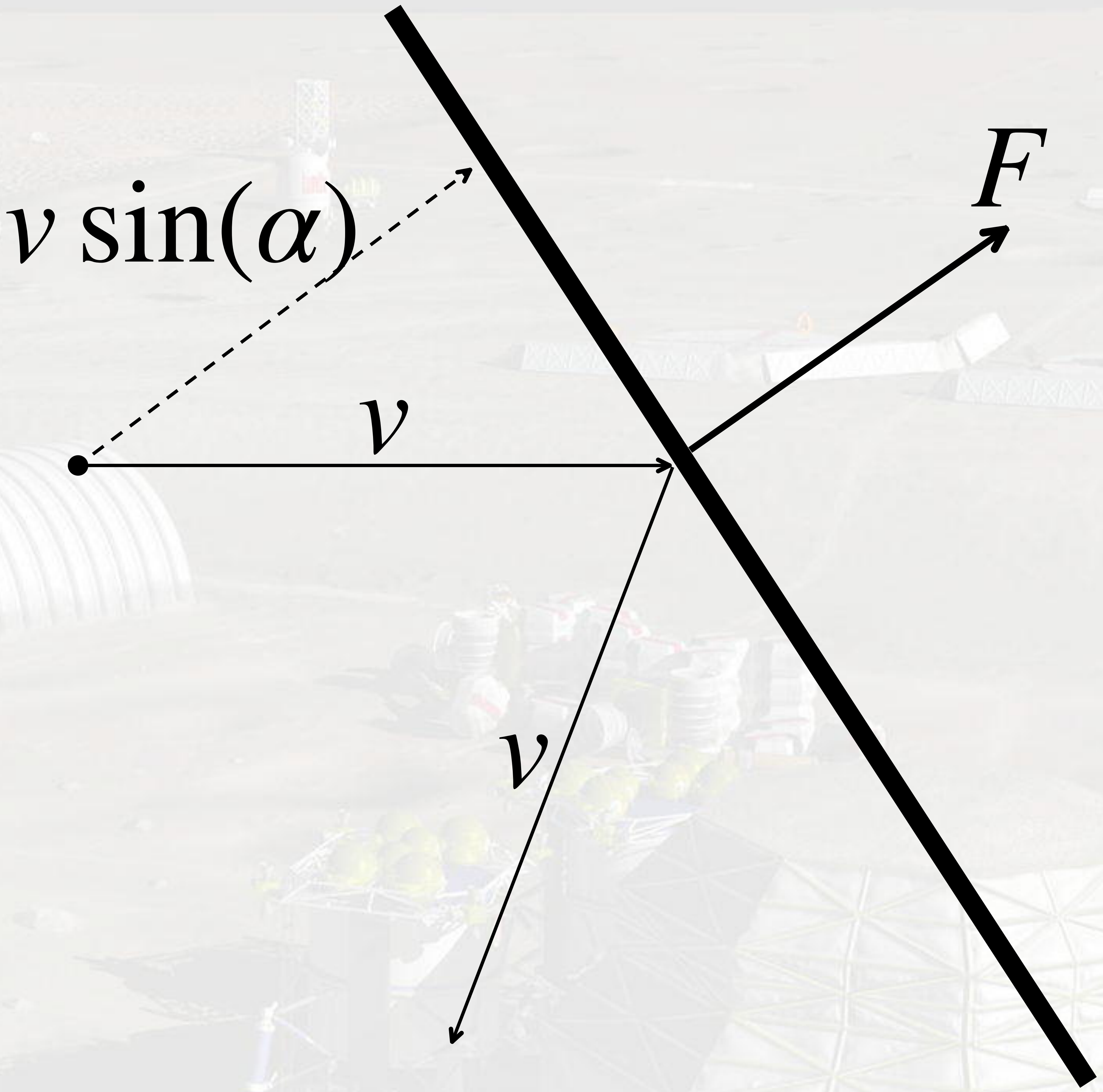
$$\text{mass flux} = (\text{density})(\text{swept area})(\text{velocity})$$



$$\frac{dm}{dt} = (\rho)(A \sin\alpha)(v)$$

Momentum Transfer

- Momentum perpendicular to wall is reversed at impact
- "Bounce" momentum is transferred to vehicle
- Momentum parallel to wall is unchanged

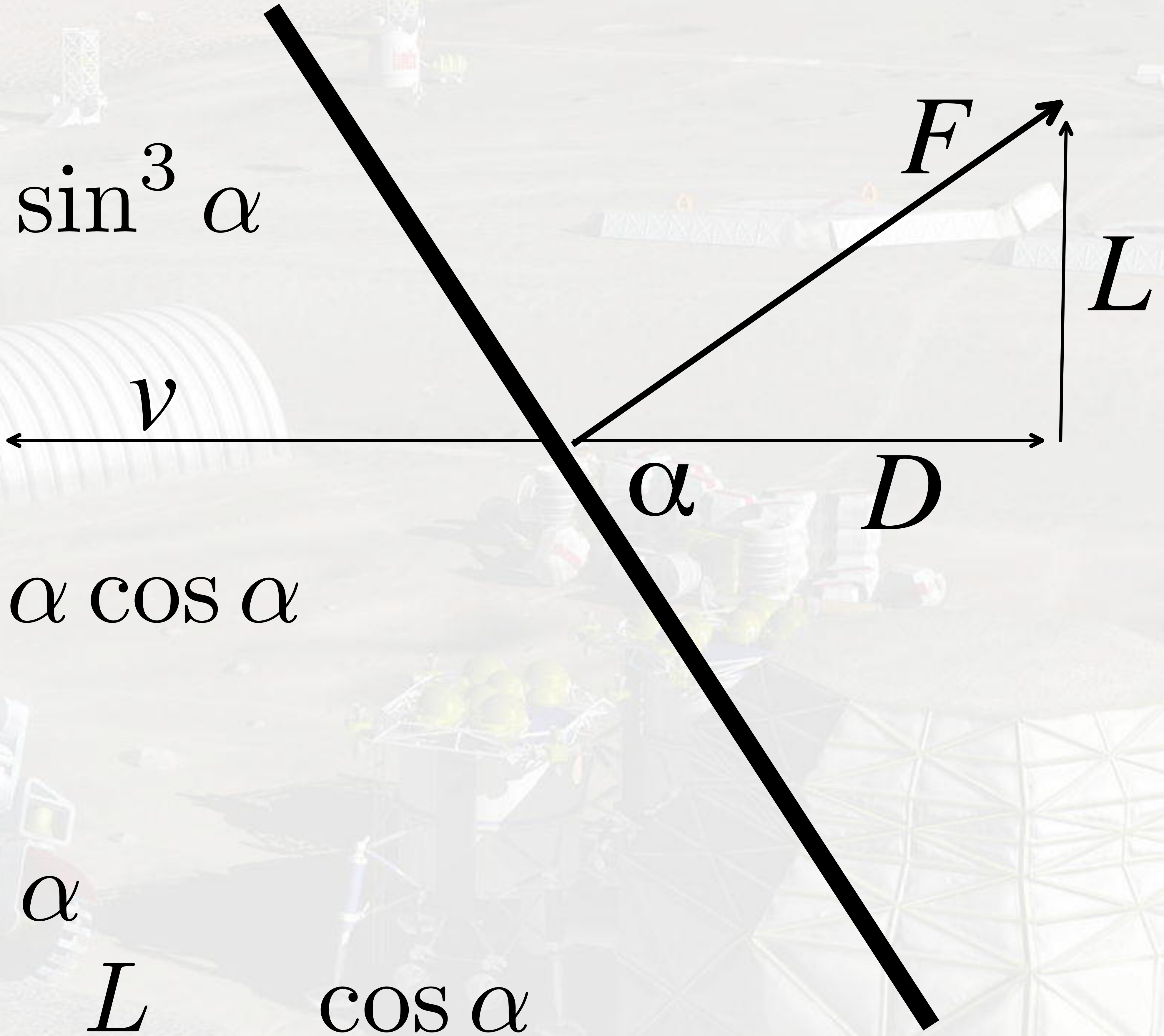


$$F = \frac{dm}{dt}\Delta v = \rho v A \sin\alpha(2v\sin\alpha) = 2\rho v^2 A \sin^2\alpha$$

Lift and Drag

$$L = F\cos\alpha = 2\rho V^2 A \sin^2\alpha\cos\alpha$$

$$D = F\sin\alpha = 2\rho V^2 A \sin^3\alpha$$

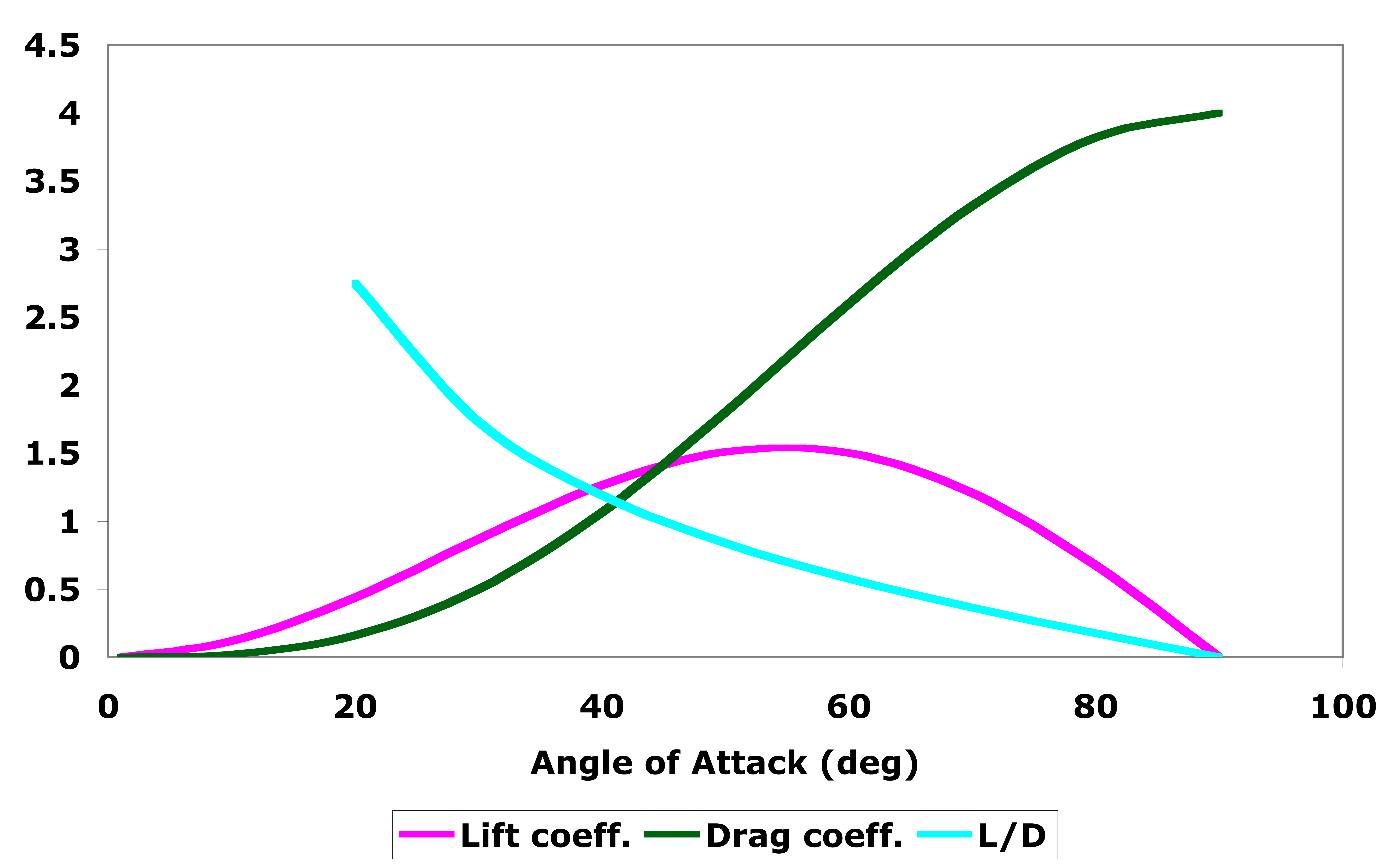


$$c_L = \frac{L}{\frac{1}{2}\rho V^2 A} = 4\sin^2\alpha\cos\alpha$$

$$c_D = \frac{D}{\frac{1}{2}\rho V^2 A} = 4\sin^3\alpha$$

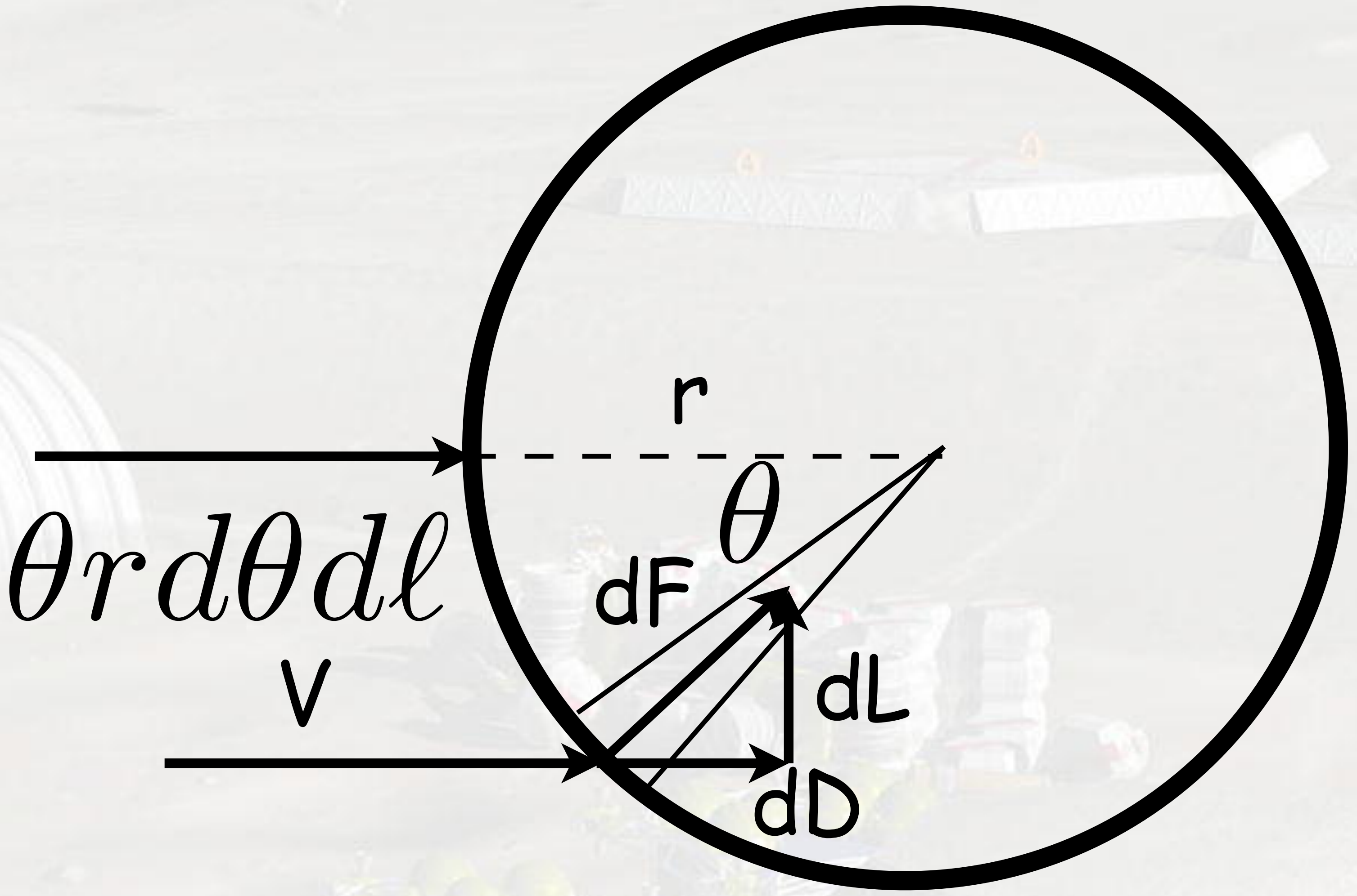
$$\frac{L}{D} = \frac{\cos\alpha}{\sin\alpha} = \cot\alpha$$

Flat Plate Newtonian Aerodynamics



Example of Newtonian Flow Calcs

Consider a cylinder of length l, entering atmosphere transverse to flow



$$dA = r d\theta dl$$

$$d\dot{m} = \rho dA \cos\theta V = \rho V \cos\theta r d\theta d\ell$$

$$dF = d\dot{m}\Delta V = 2\rho V^2 \cos^2\theta r d\theta d\ell$$

$$dD = dF\cos\theta = 2\rho V^2 \cos^3\theta r d\theta d\ell$$

$$dL = dF\sin\theta = 2\rho V^2 \cos\theta \sin\theta r d\theta d\ell$$

Integration to Find Drag Coefficient

Integrate from $\theta = -\frac{\pi}{2} \to \frac{\pi}{2}$

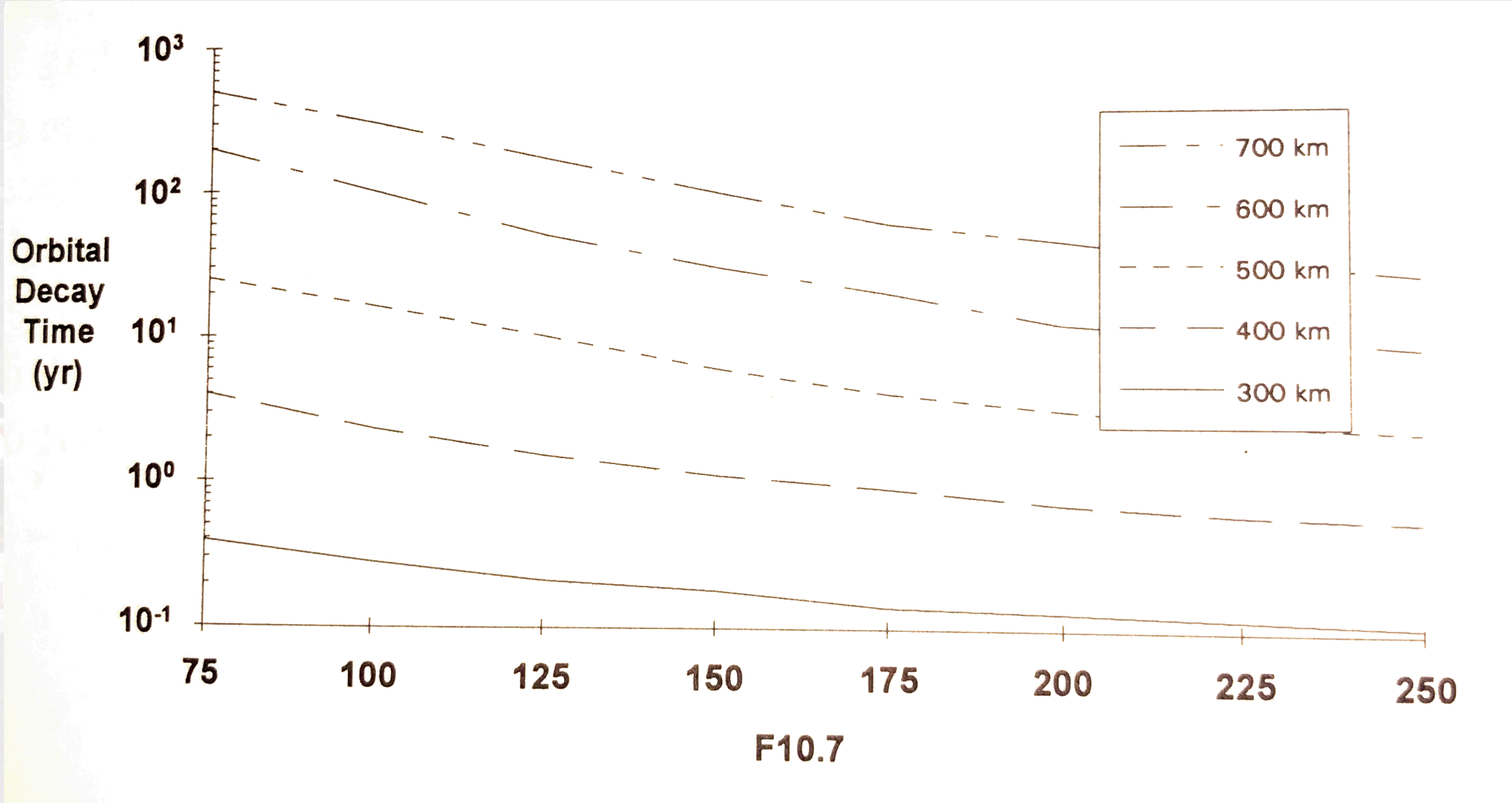
$$D = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \int_0^{\ell} dD = 2\rho V^2 r \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \int_0^{\ell} \cos^3\theta d\theta d\ell$$

$$= 2\rho V^2 r\ell \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \cos^3\theta d\theta = \boxed{\frac{8}{3}\rho V^2 r\ell}$$

By definition, $D = \frac{1}{2}\rho V^2 A c_D$ and, for a cylinder $A = 2r\ell$

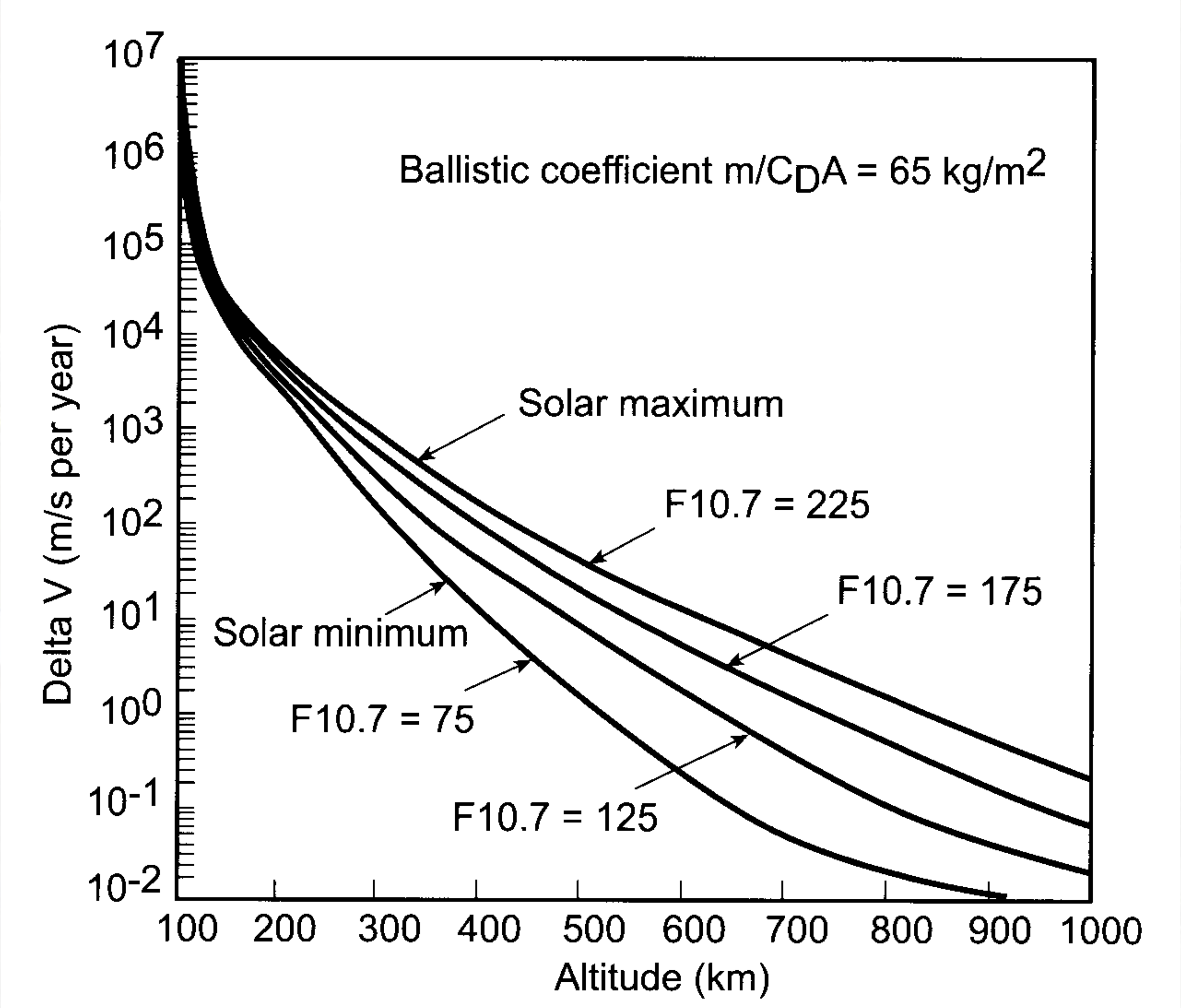
$$\rho V^2 r\ell c_D = \frac{8}{3}\rho V^2 r\ell \Longrightarrow \boxed{c_D = \frac{8}{3}}$$

Orbit Decay from Atmospheric Drag



Ref: Alan C. Tribble, *The Space Environment* Princeton University Press, 1995

Makeup ΔV Due To Atmospheric Drag



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Atmospheric Constituents at Altitude

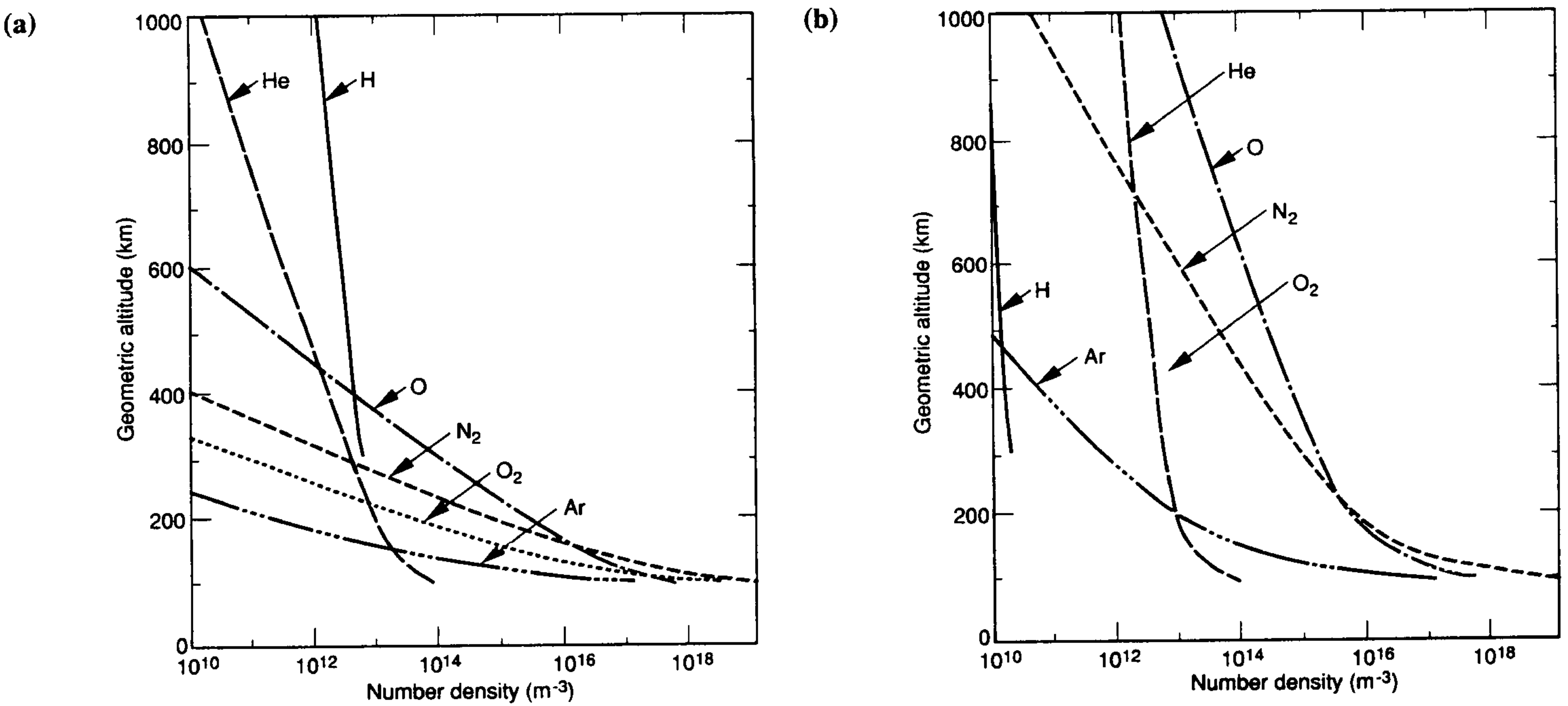


Fig. 2.3. **(a)** Relative concentrations of atmospheric constituents during periods of minimum solar activity. **(b)** Relative concentrations of atmospheric constituents during periods of maximum solar activity. (Adapted from *U.S. Standard Atmosphere,* 1976.)

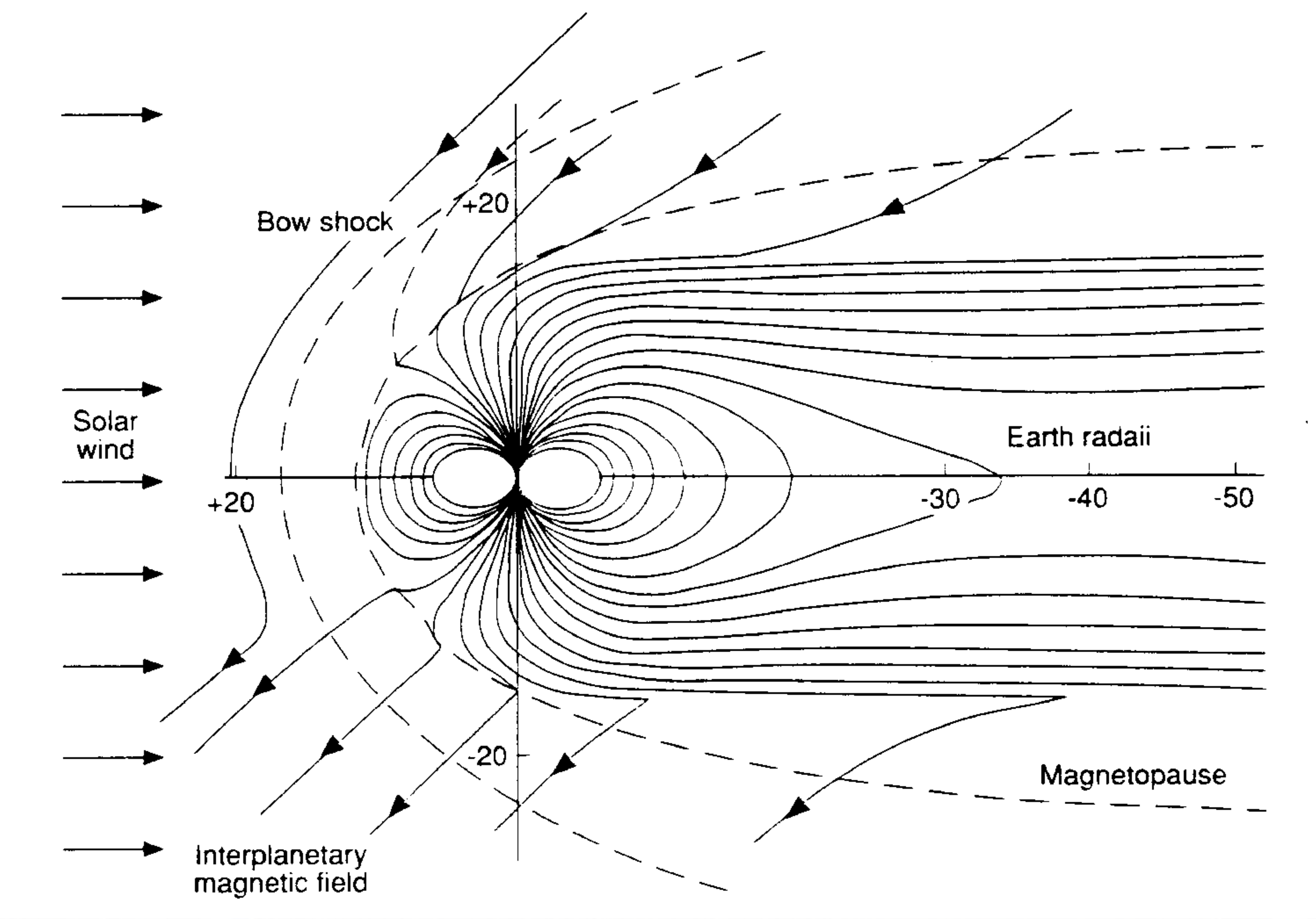
Ref: V. L. Pisacane and R. C. Moore, Fundamentals of Space Systems Oxford University Press, 1994

Atomic Oxygen Erosion Rates

- Annual surface erosion at solar max
- Orbital altitude 500 km

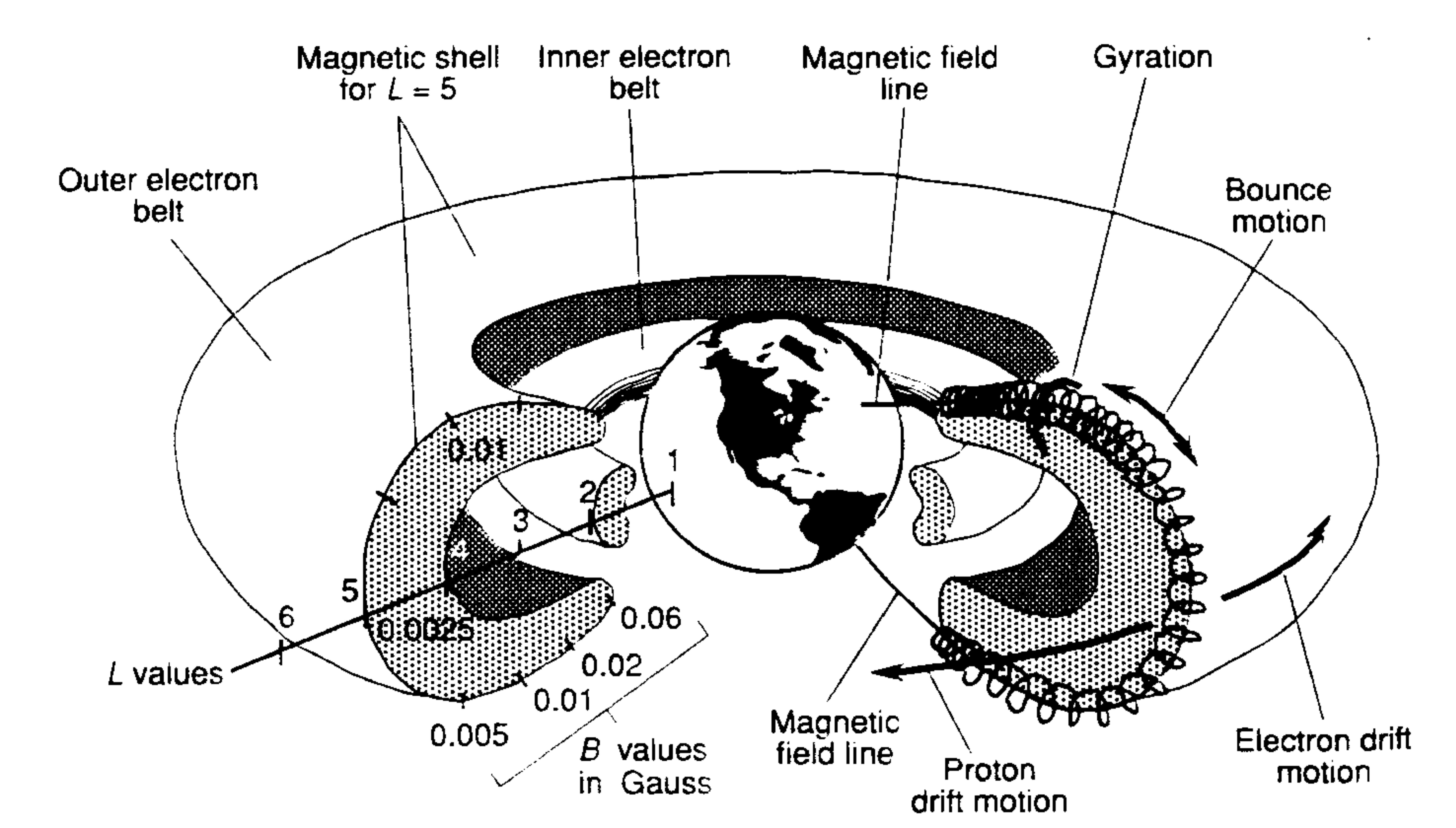
Material	Erosion Rate (mm/yr)
Silver	.22
Chemglaze Z302	.079
Mylar	.071
Kapton	.061
Epoxy	.048
Carbon	.020
Teflon	.00064
Aluminum	.0000076

The Earth’s Magnetic Field



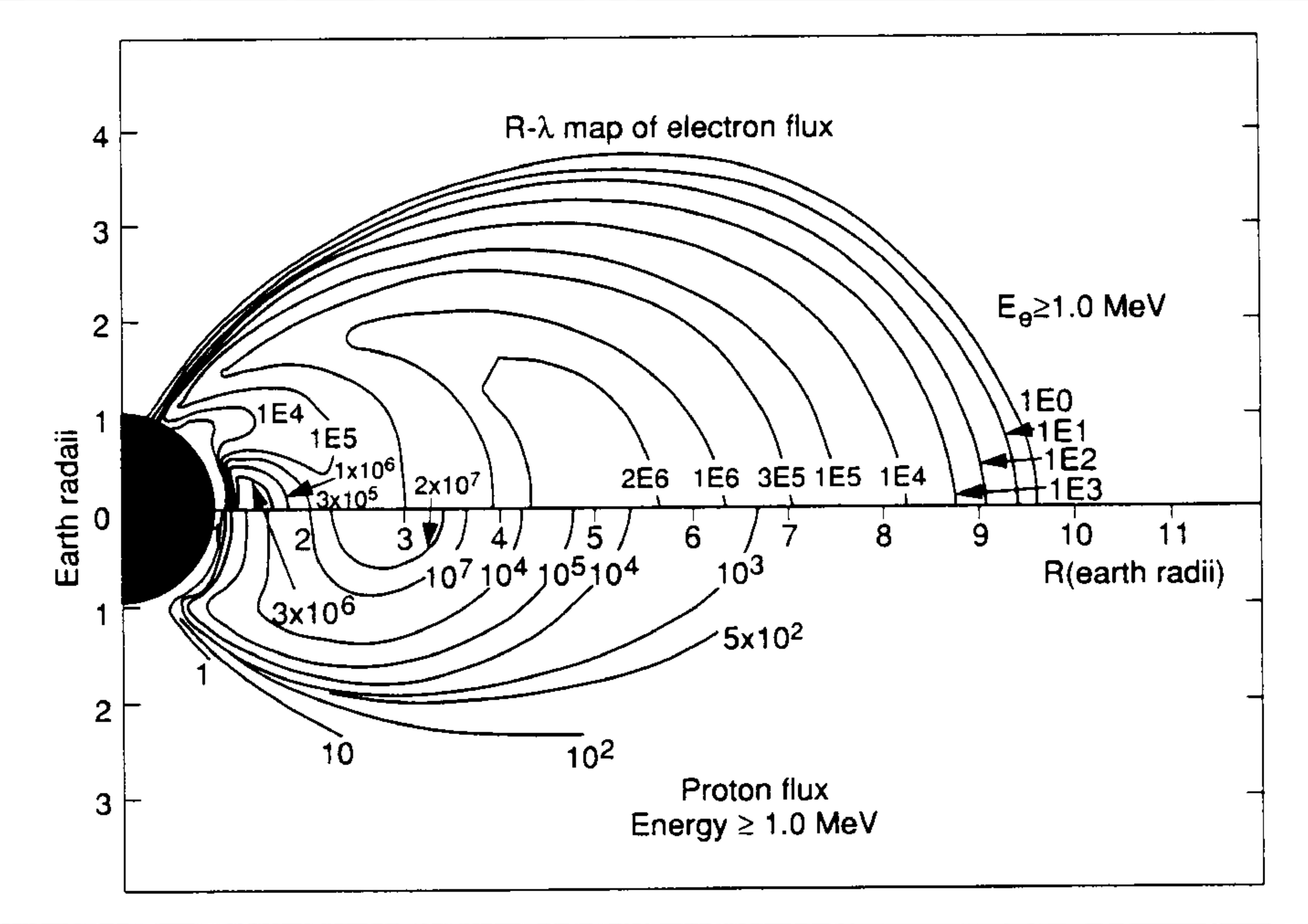
Ref: V. L. Pisacane and R. C. Moore, Fundamentals of Space Systems Oxford University Press, 1994

The Van Allen Radiation Belts



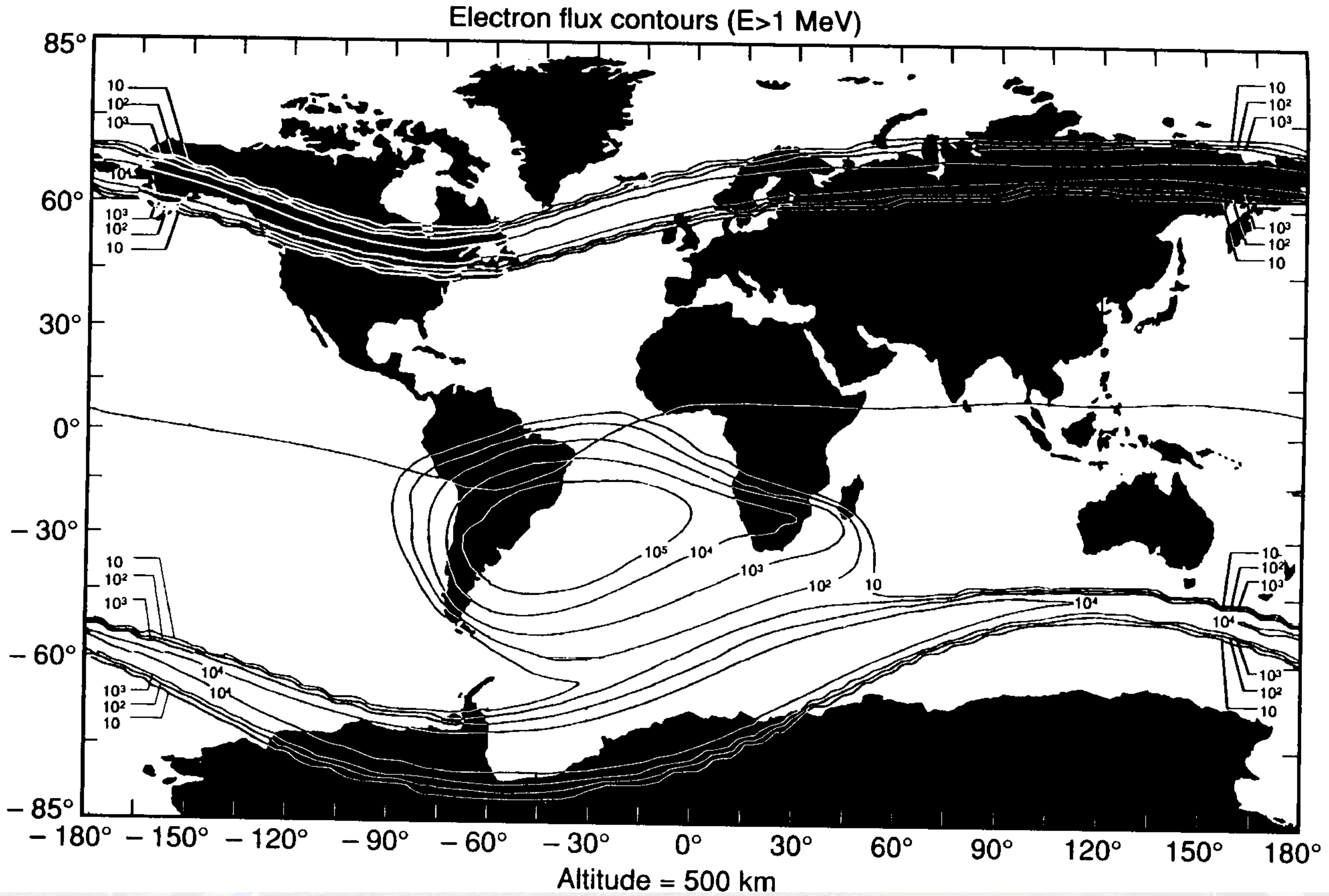
Ref: V. L. Pisacane and R. C. Moore, Fundamentals of Space Systems   Oxford University Press, 1994

Cross-section of Van Allen Radiation Belts



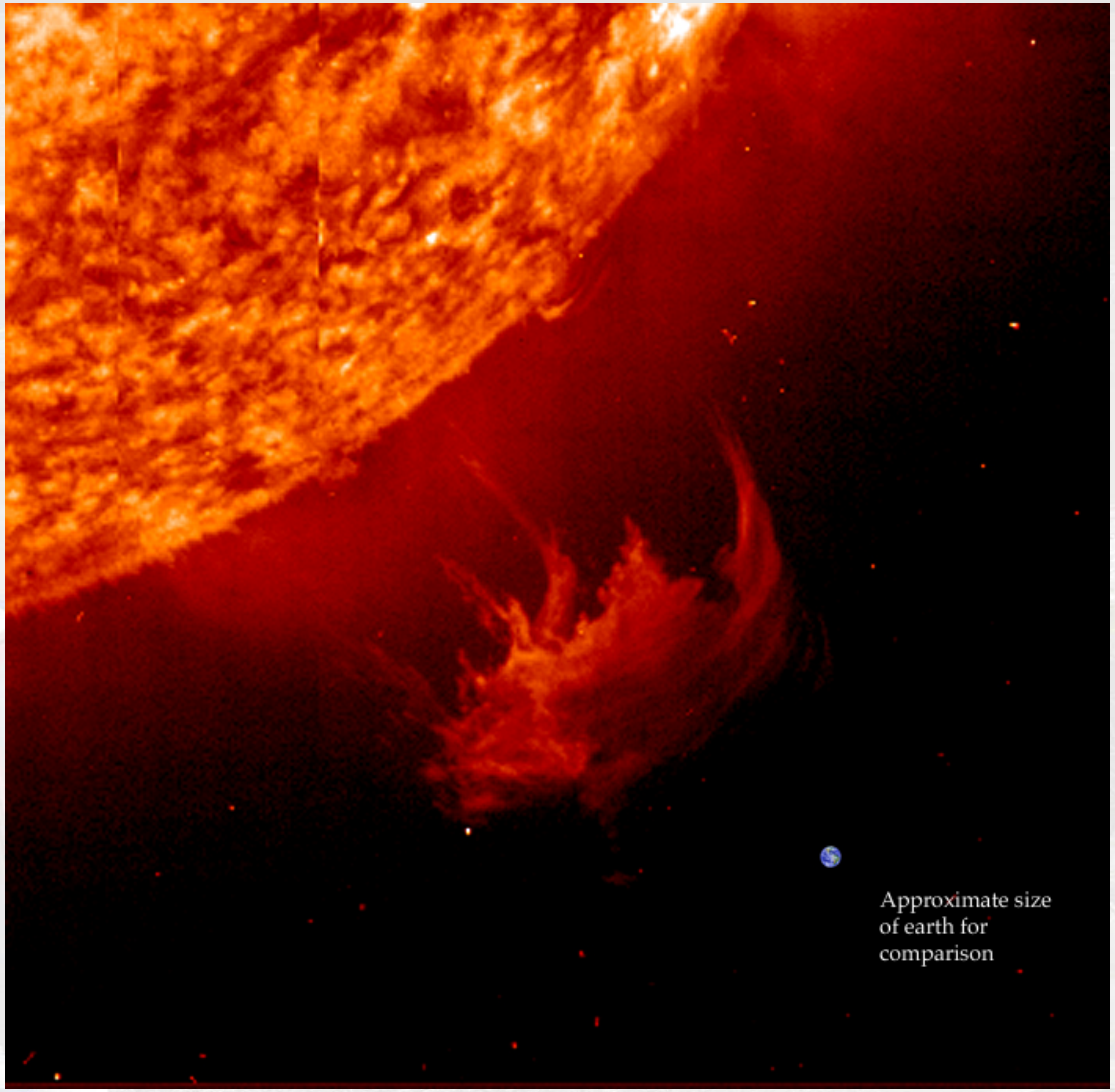
Ref: V. L. Pisacane and R. C. Moore, Fundamentals of Space Systems   Oxford University Press, 1994

Electron Flux in Low Earth Orbit

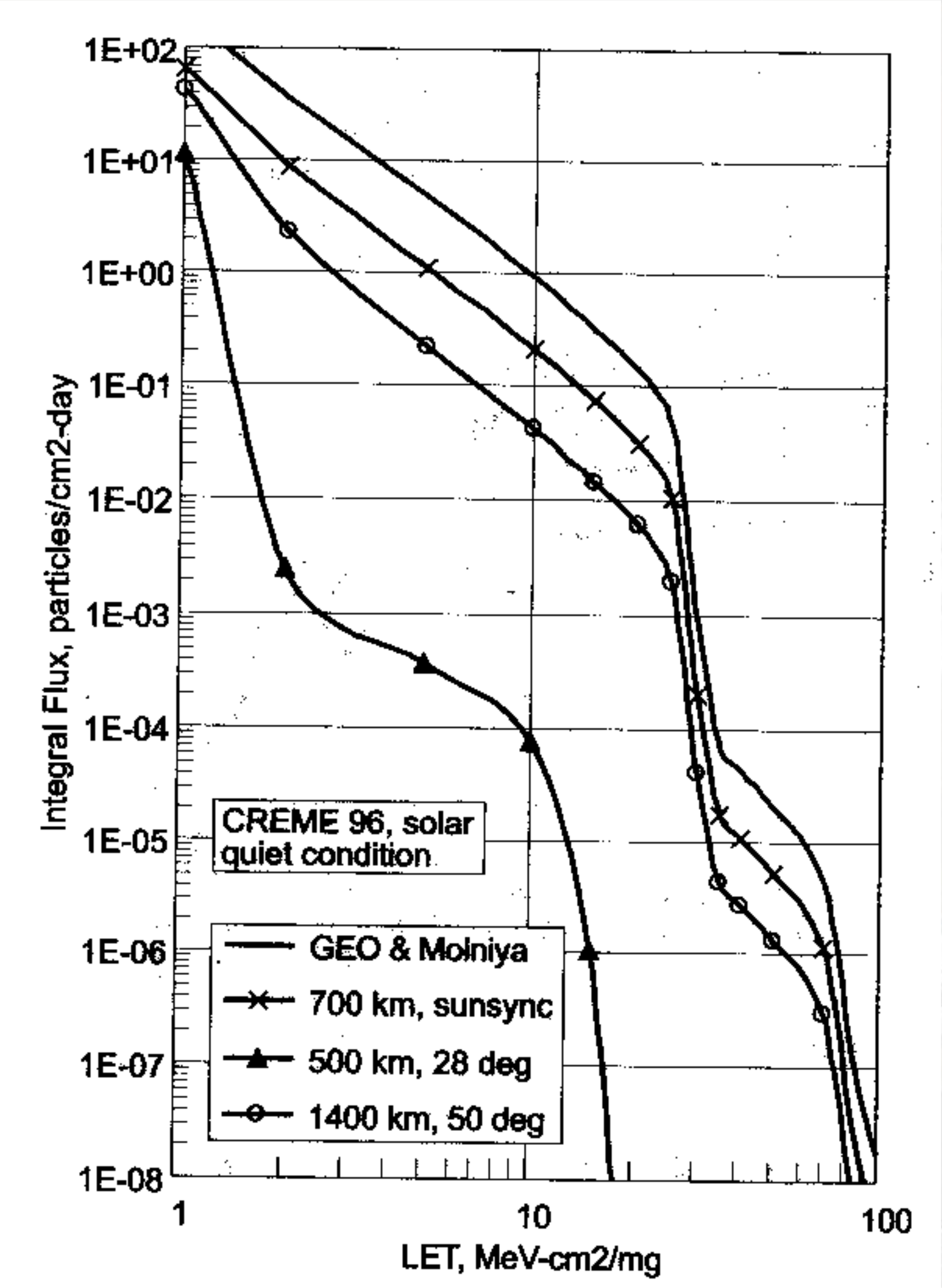


Ref: V. L. Pisacane and R. C. Moore, Fundamentals of Space Systems Oxford University Press, 1994

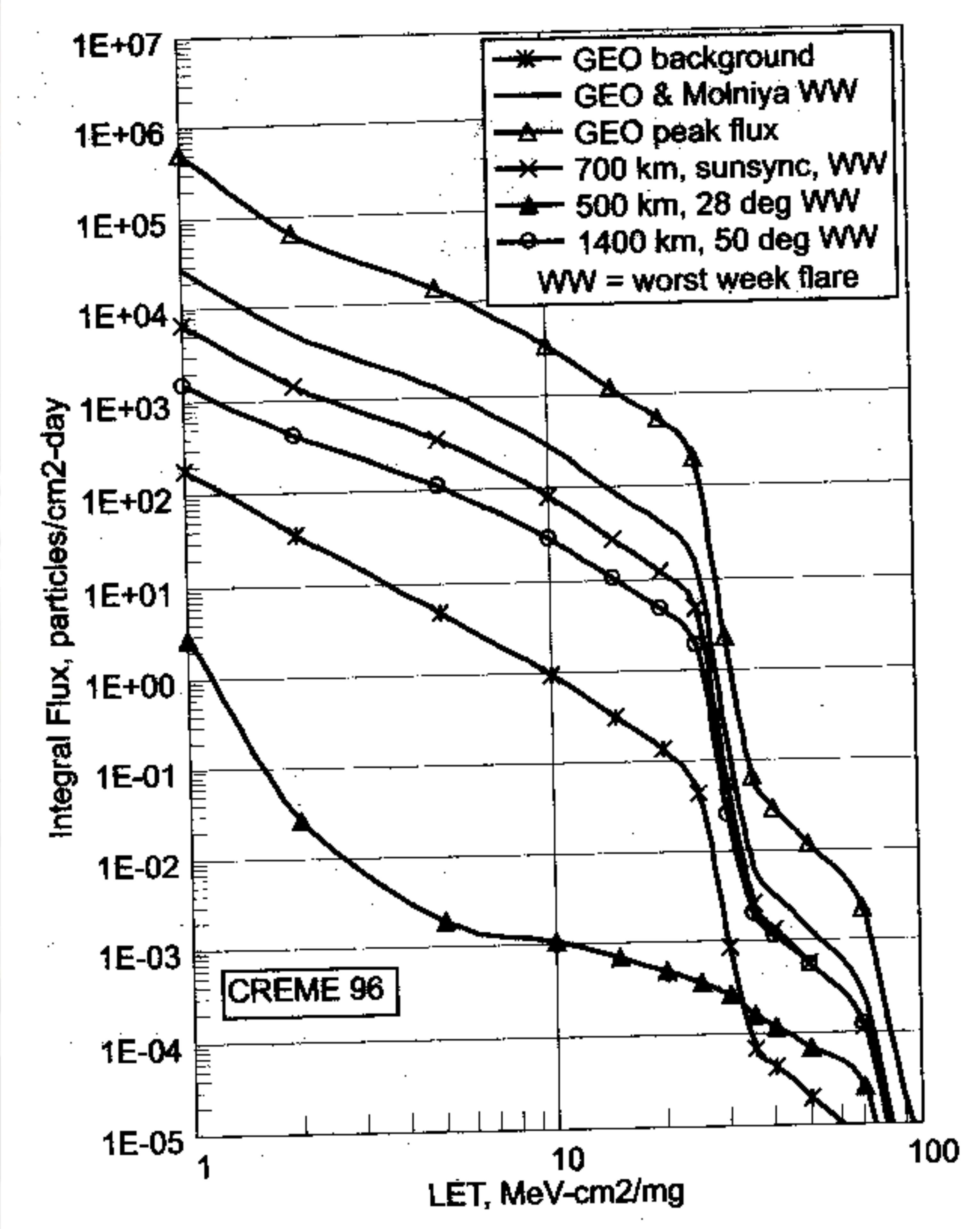
The Origin of a Class X1 Solar Flare



Heavy Ion Flux



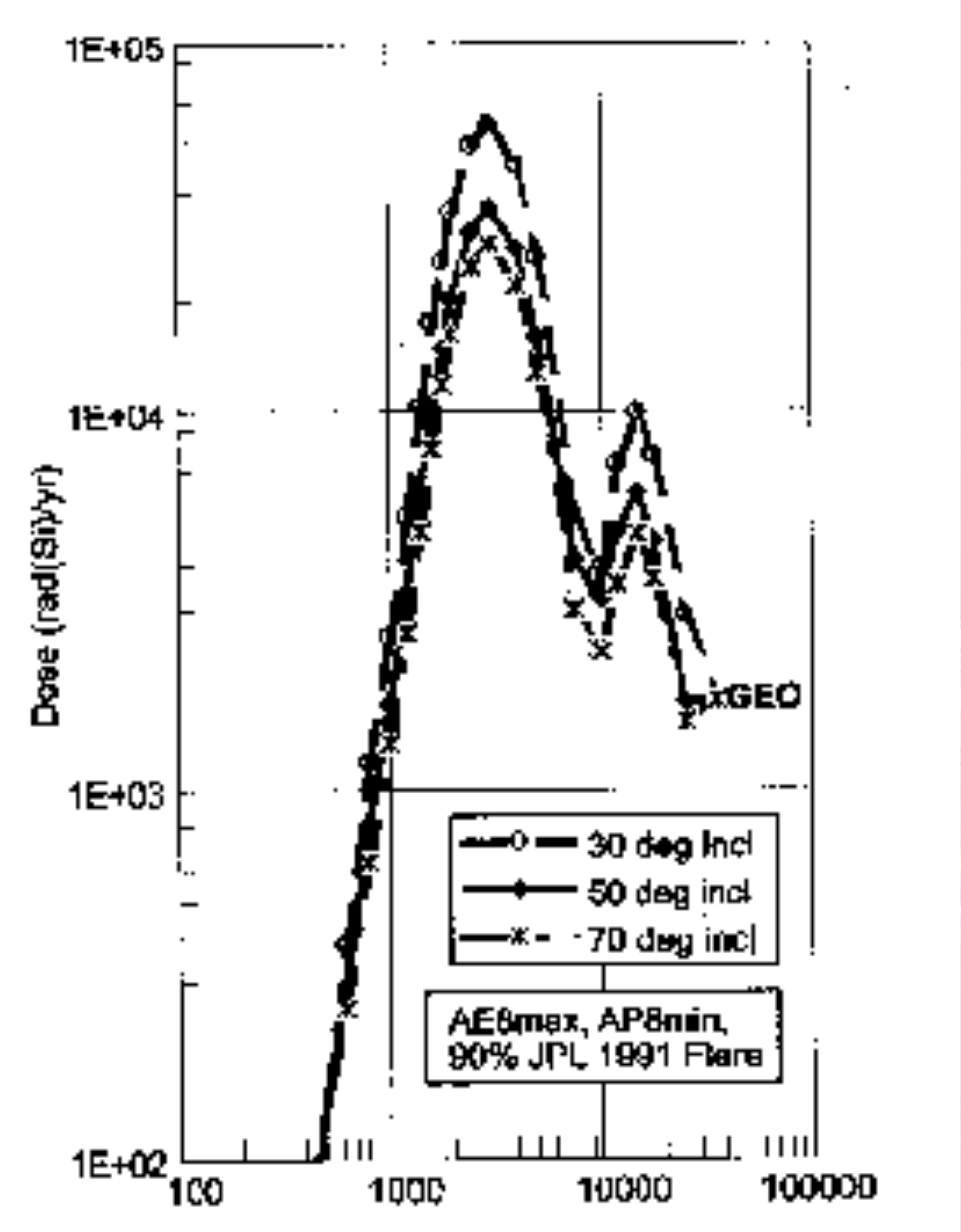
Background



Solar Flare

Ref: Neville J. Barter, ed., TRW Space Data, TRW Space and Electronics Group, 1999

Radiation Dose vs. Orbital Altitude

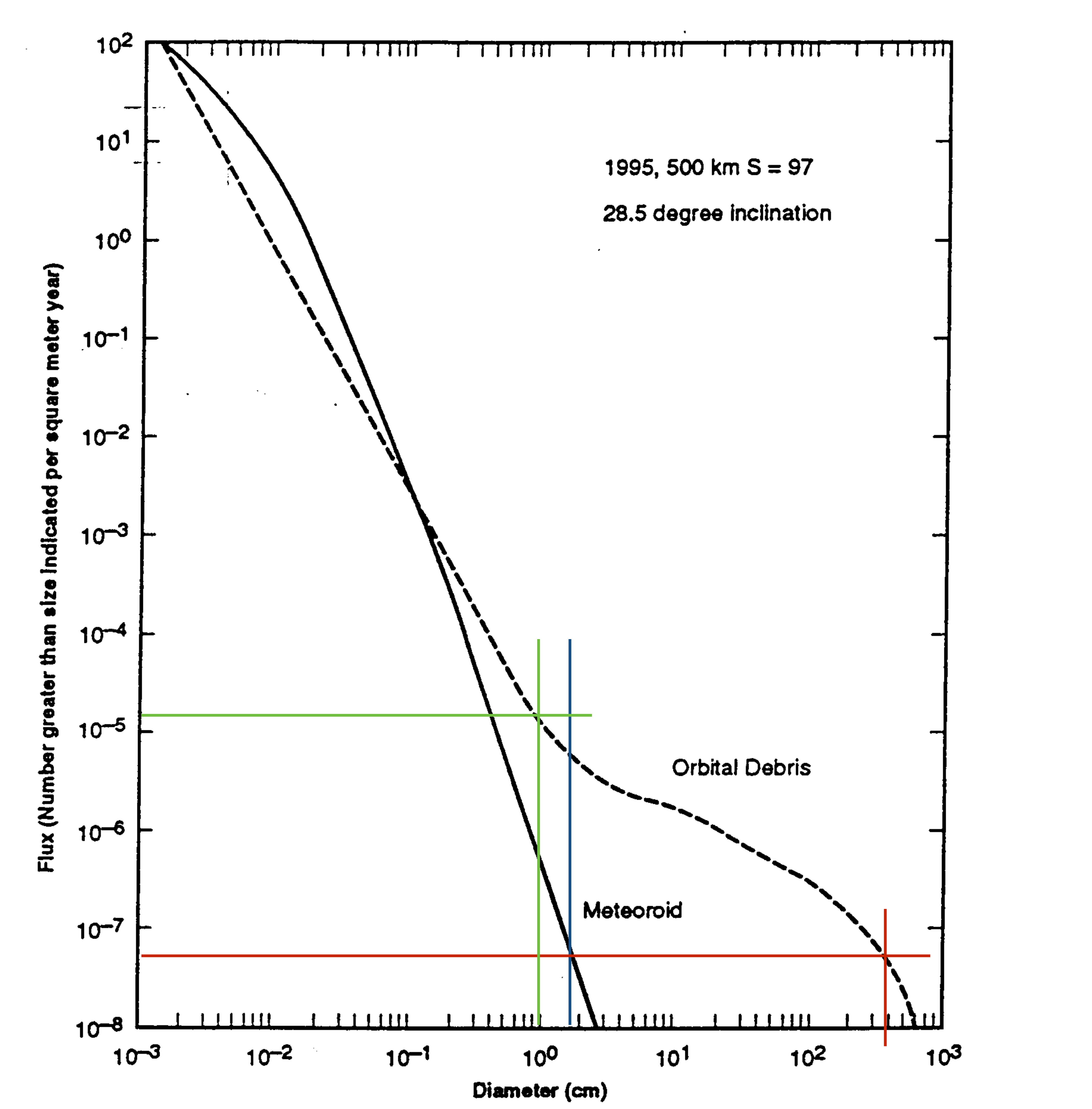


300 mil (7.6 mm) Al shielding

Ref: Neville J. Barter, ed., TRW Space Data, TRW Space and Electronics Group, 1999

Trackable Objects On-orbit

Micrometeoroids and Orbital Debris



MMOD Sample Calculation

Space Station module - cylindrical, 15' diam. X 43' long

$$Area = \pi l d + 2\frac{\pi d^2}{4}$$

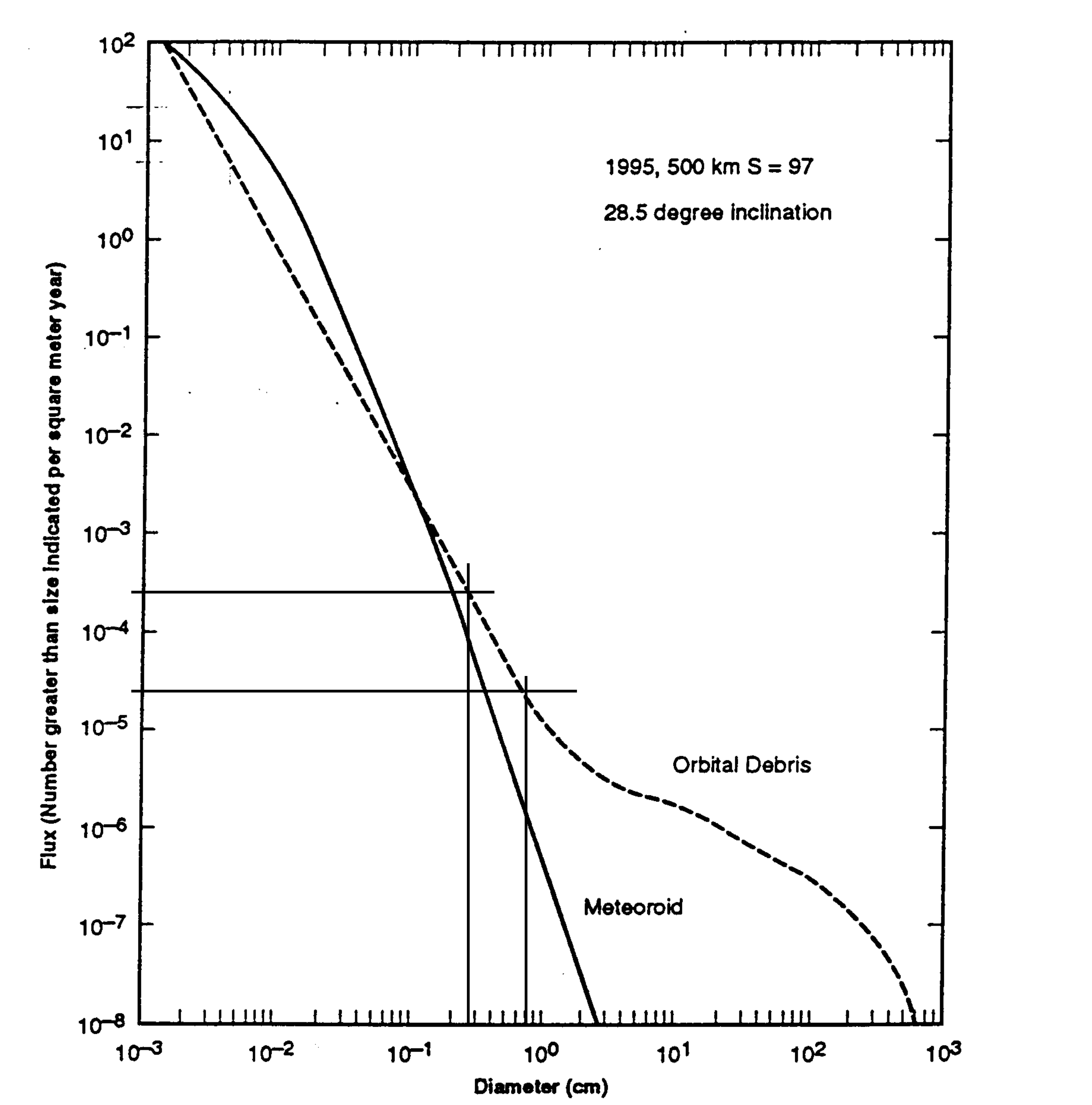
Surface area=221 m2

Flux value for one hit in 20 years

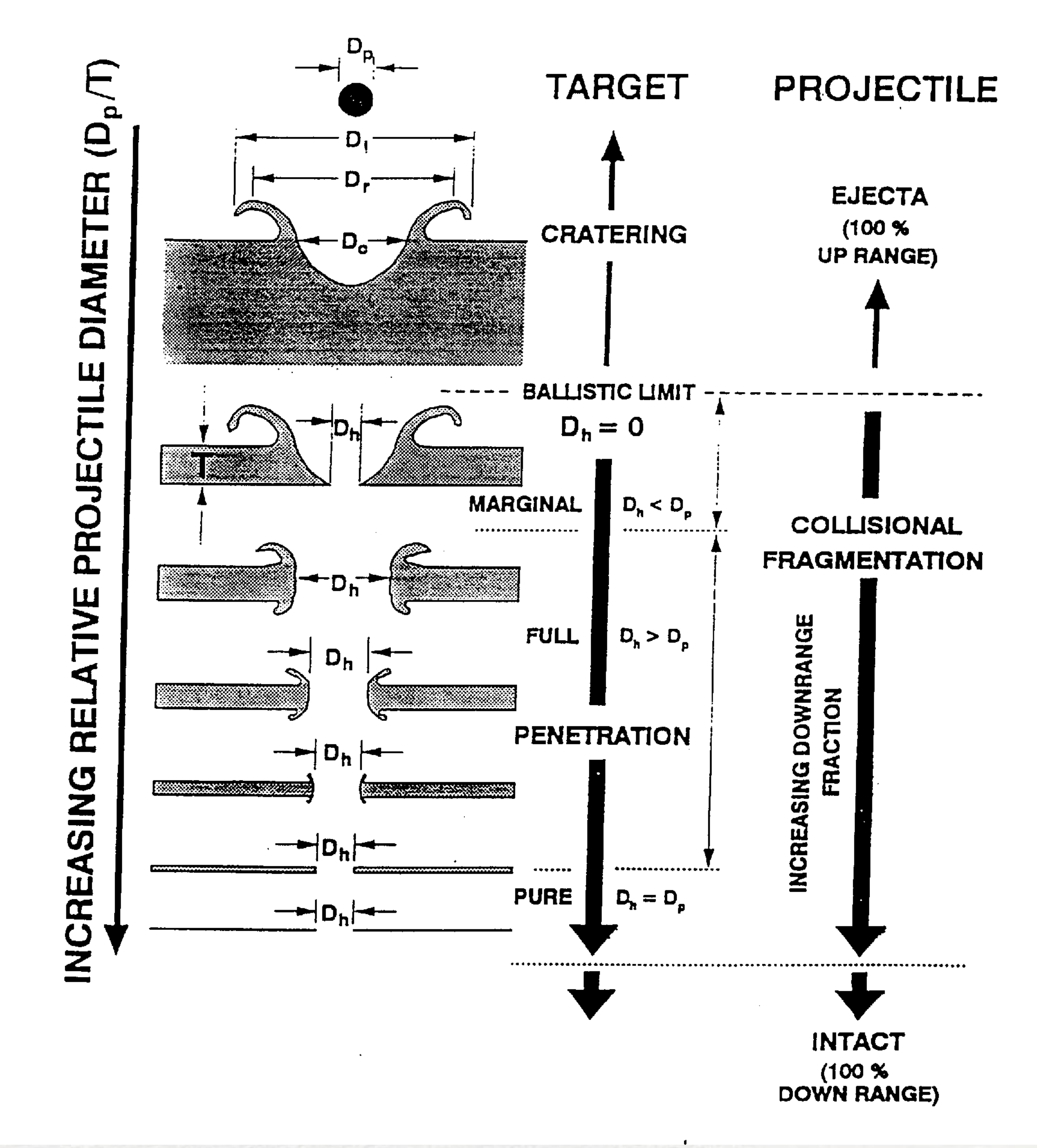
$$Flux = \frac{1 \text{ hit}}{(221 \text{ m}^2)(20 \text{ yrs})}$$

Flux=2.26x10-4 hits/m2-yr (3mm)

For 0.1 hits/20 years, allowable flux= 2.26x10-5 hits/m2-yr (9 mm)



Damage from MMOD Impacts



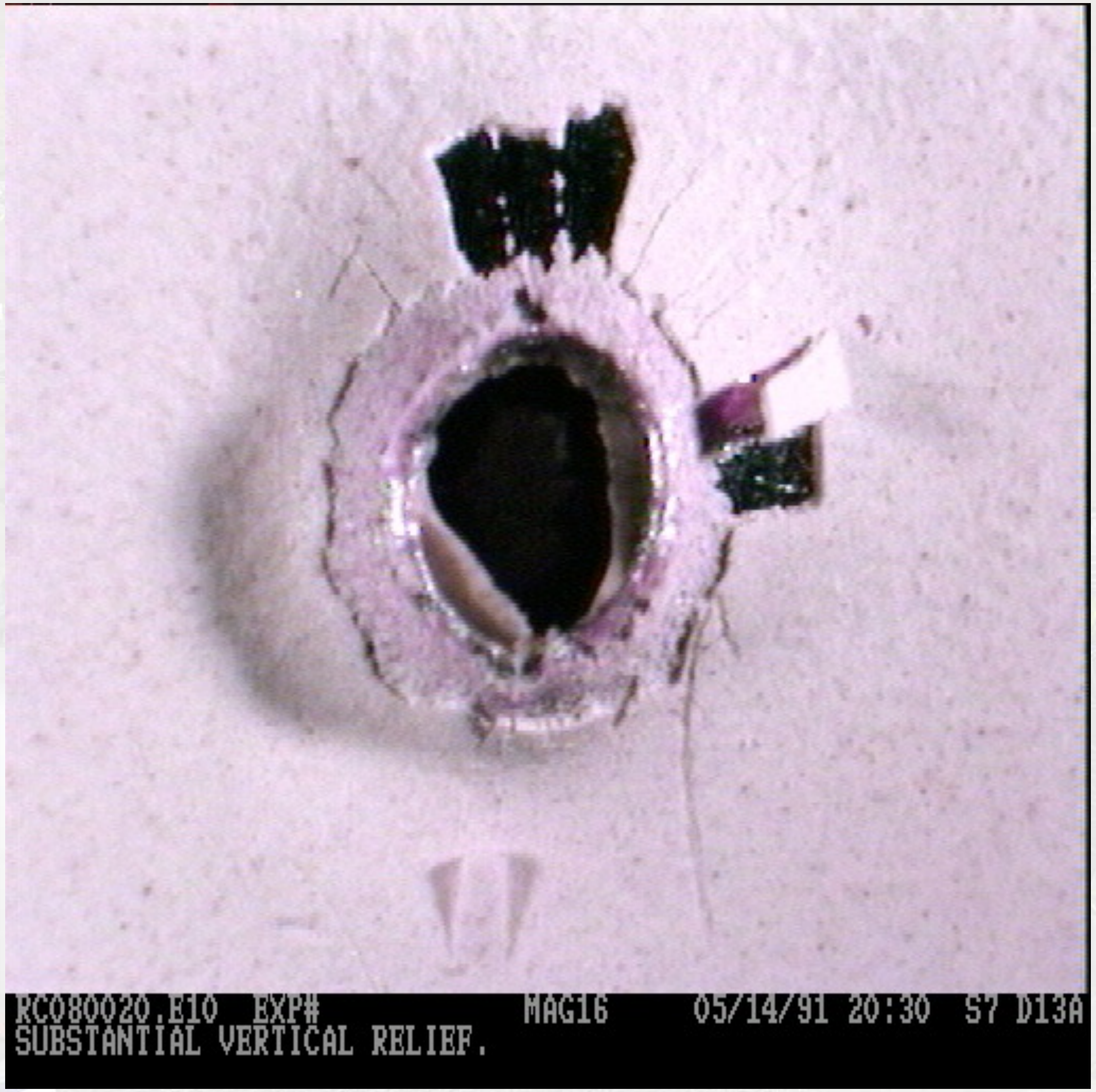
Long Duration Exposure Facility (LDEF)

- Passive experiment to test long-term effects of space exposure
- 57 experiments in 86 trays
- Deployed April, 1984
- Retrieved January, 1990

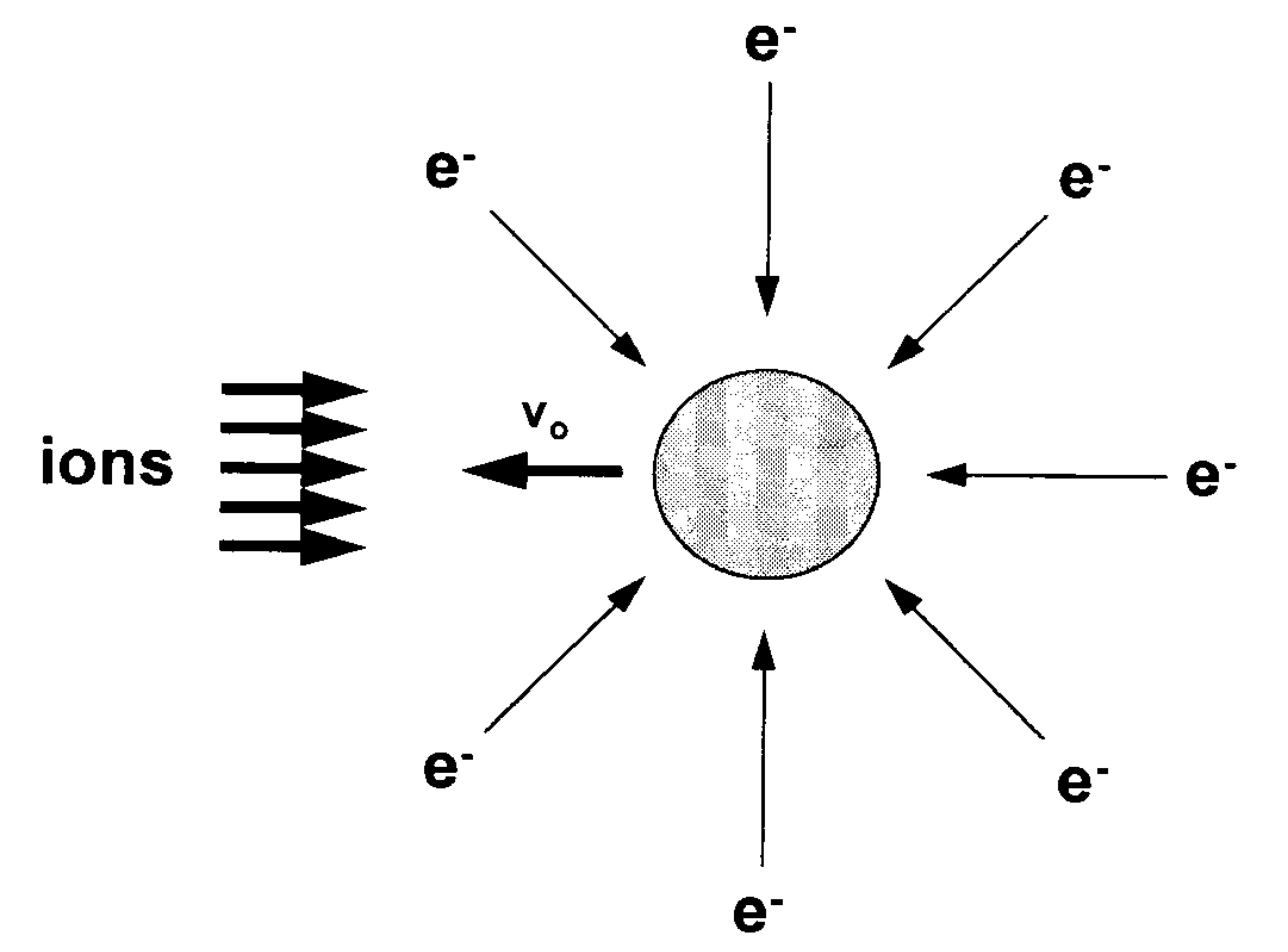
Surprising Results from LDEF

- Presence of C-60 (“buckeyballs”) on impact site
- Much higher incidence of MMOD impacts on trailing surfaces than expected
- Local thermal hot spots did surprising levels of damage to blankets and coatings
- Thermal blankets are effective barriers to smaller high velocity impacting particles
- Anomalies are typically due to design and workmanship, rather than materials effects

Typical MMOD Penetration from LDEF



Spacecraft Charging



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References

- Alan C. Tribble, The Space Environment: Implications for Spacecraft Design Princeton University Press, 1995
- Vincent L. Pisacane and Robert C. Moore, Fundamentals of Space Systems Oxford University Press, 1994 (Chapter 2)
- Neville J. Barter, ed., TRW Space Data TRW Space and Electronics Group, 1999
- Francis S. Johnson, Satellite Environment Handbook Stanford University Press, 1961