The Space Environment

- Lecture #05 - September 10, 2024
- Course schedule updates
- Planetary environments
- Gravitation
- Electromagnetic radiation
- Atmospheric particles
- Newtonian flow
- Solar wind particles
- Ionizing radiation
- Micrometeoroids/orbital debris
- Spacecraft charging

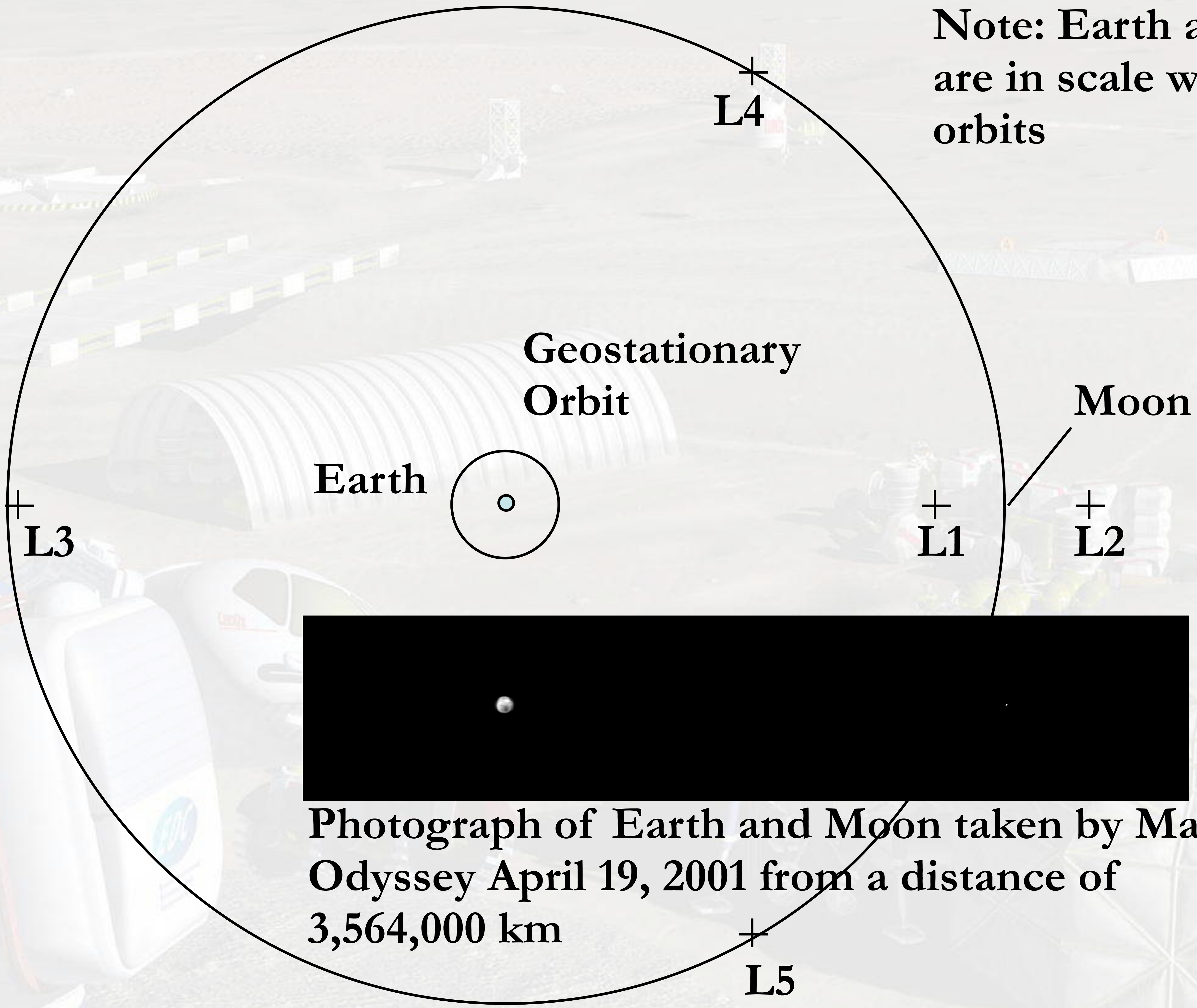
The Space Environment

"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

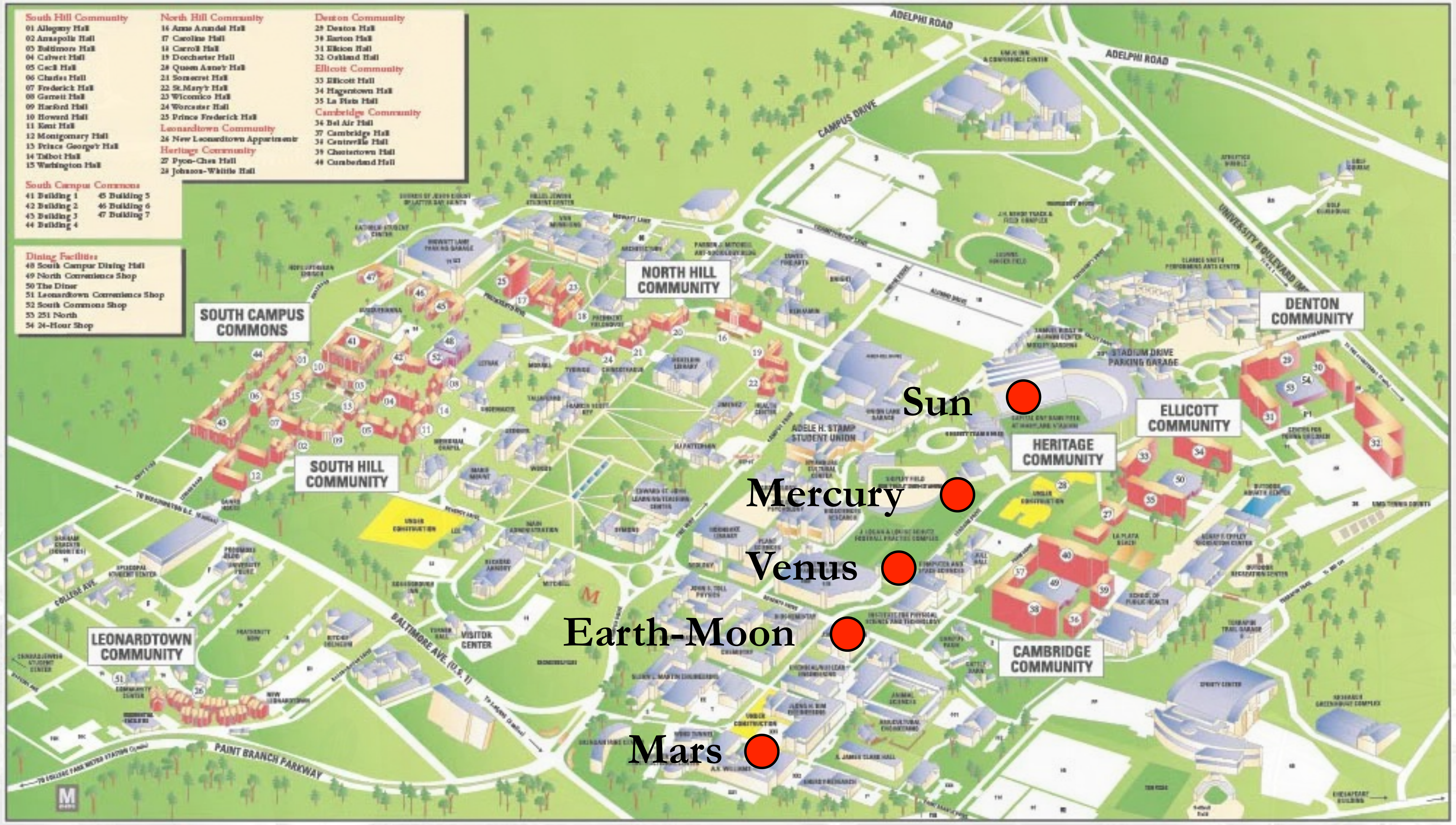
The Earth-Moon System

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

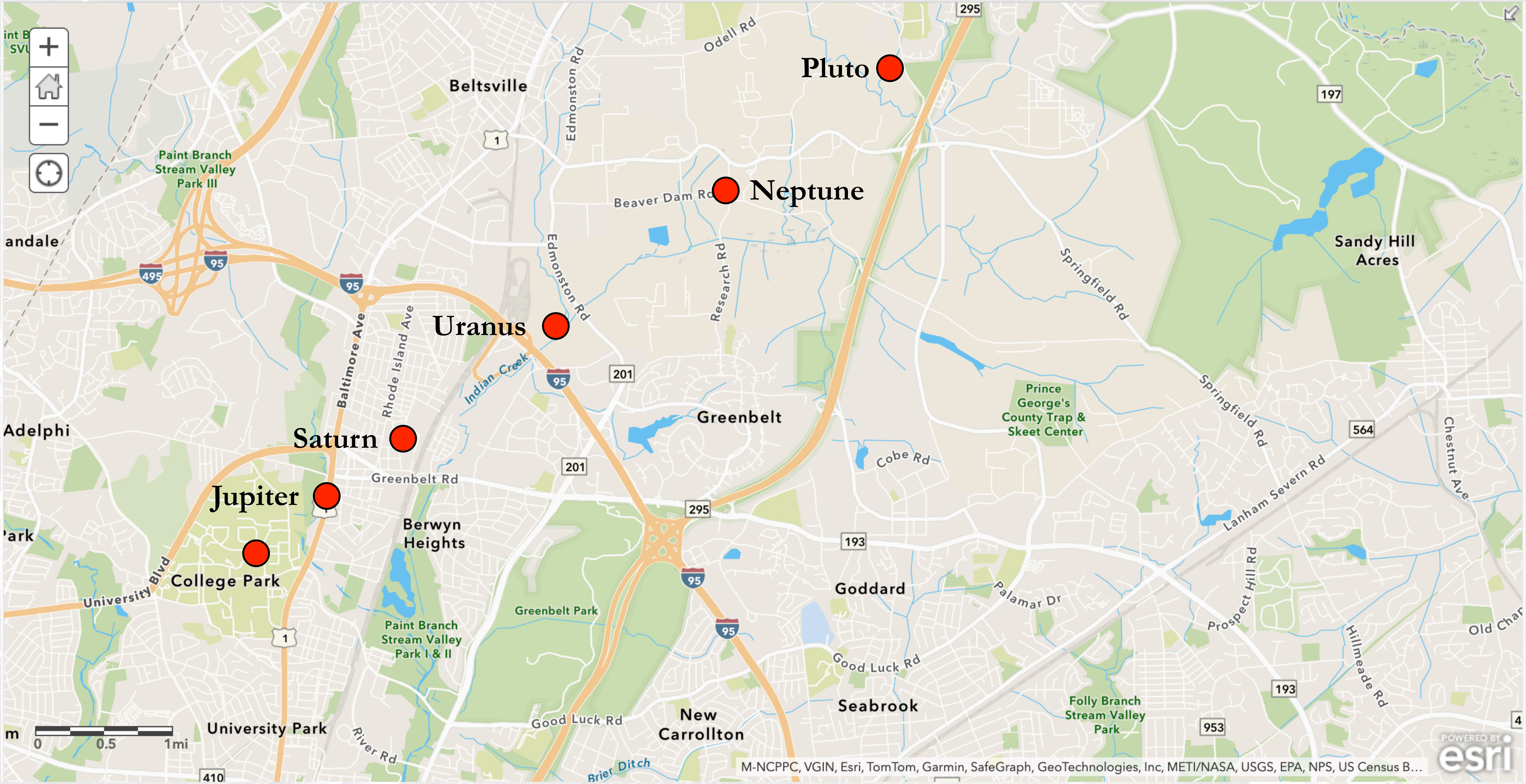


Photograph of Earth and Moon taken by Mars Odyssey April 19, 2001 from a distance of 3,564,000 km

In The Same Scale...



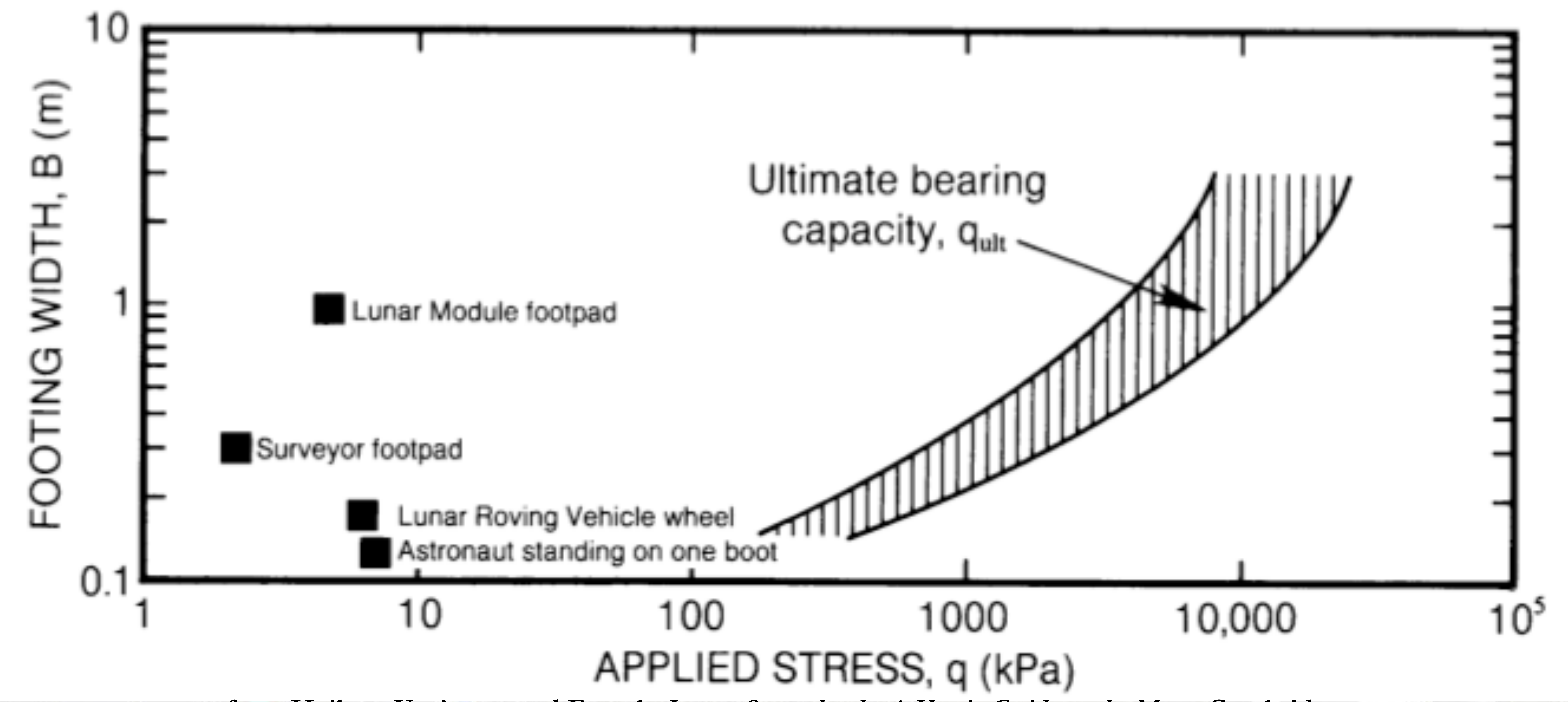
Still In The Same Scale



Comparison of Basic Characteristics

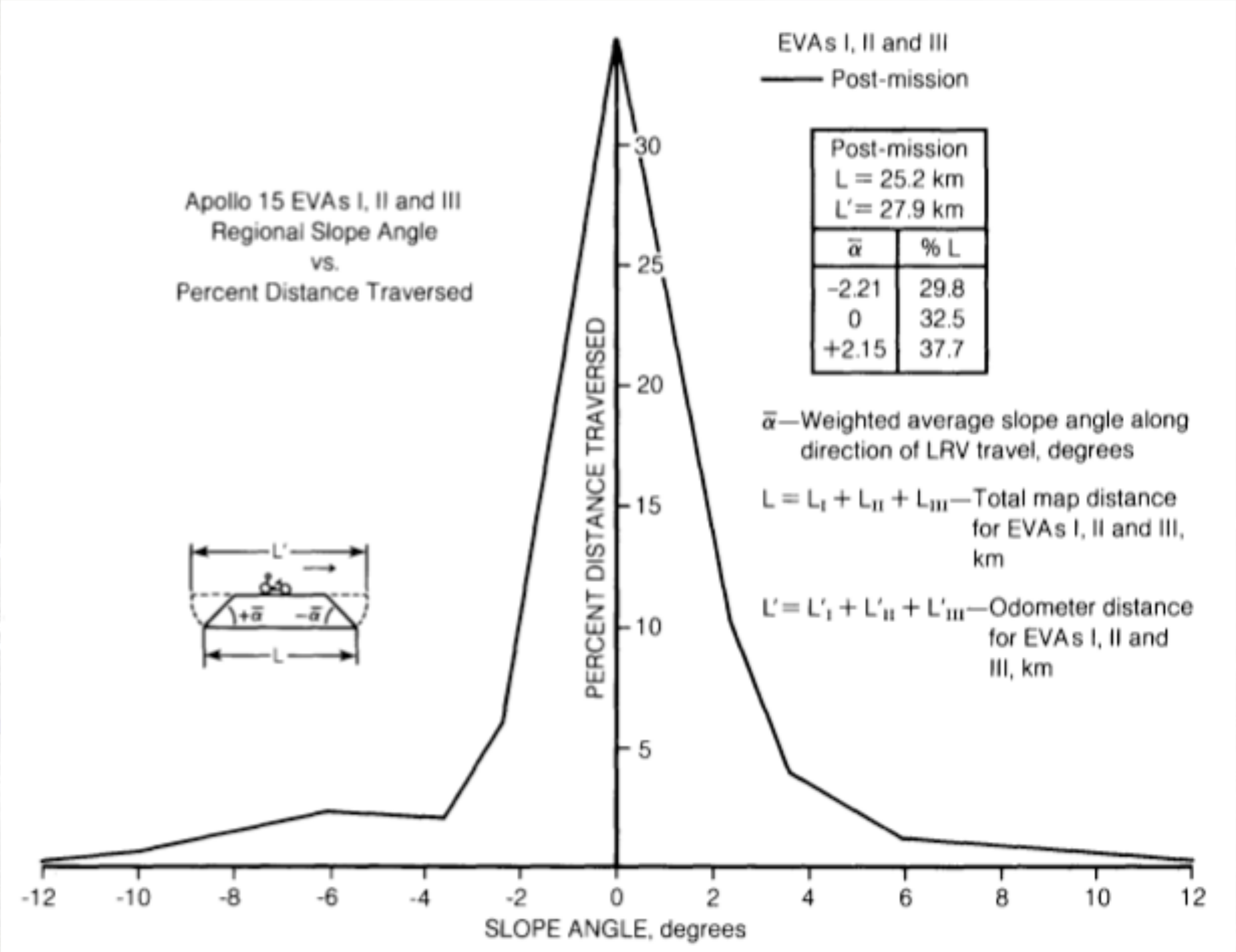
Quantity	Earth	Free Space	Moon	Mars
Gravitational Acceleration	9.8 m/s^2 (1 g)	–	1.545 m/s^2 (.16 g)	3.711 m/s^2 (.38 g)
Atmospheric Pressure	101,350 Pa (14.7 psi)	–	–	560 Pa (.081 psi)
Atmospheric Constituents	78% N_2 21% O_2	–	–	95% CO_2 3% N_2
Temperature Range	120°F -100°F	150°F -60°F	250°F -250°F	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

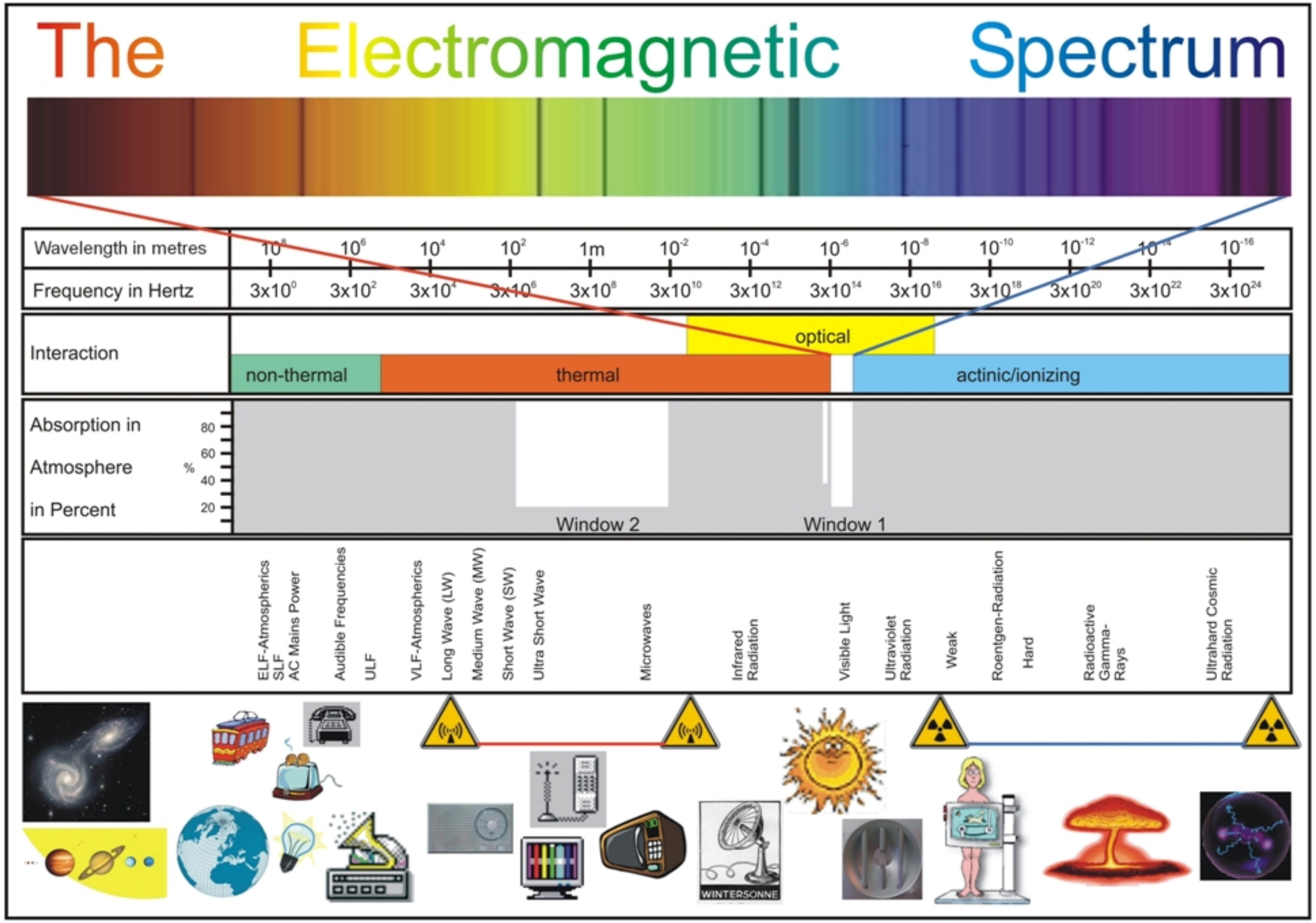
Lunar Slope Distribution (Apollo 15 data)



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

The Electromagnetic Spectrum

~750nm

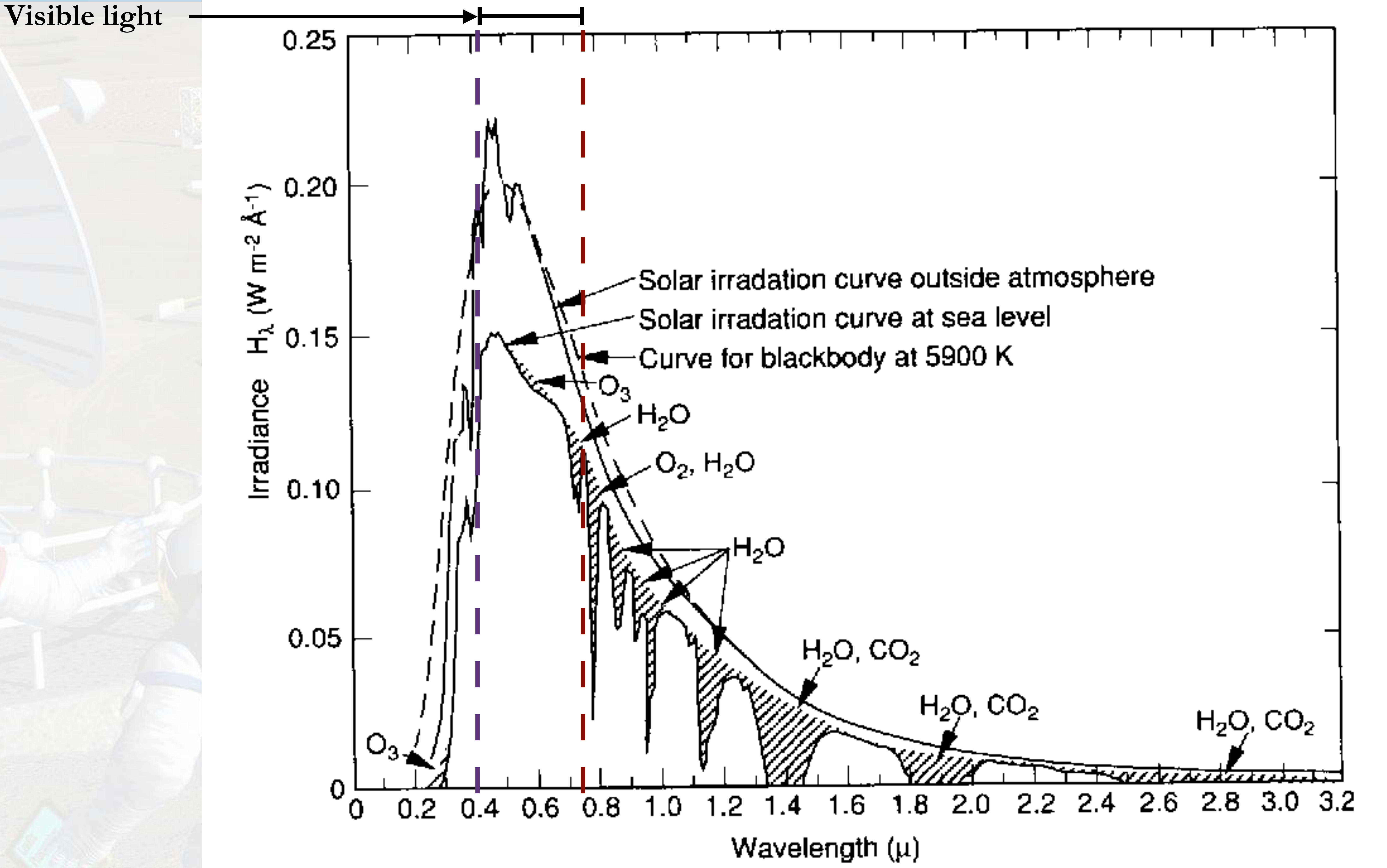


~400nm

This is for Earth ->

From ligo.org 2024

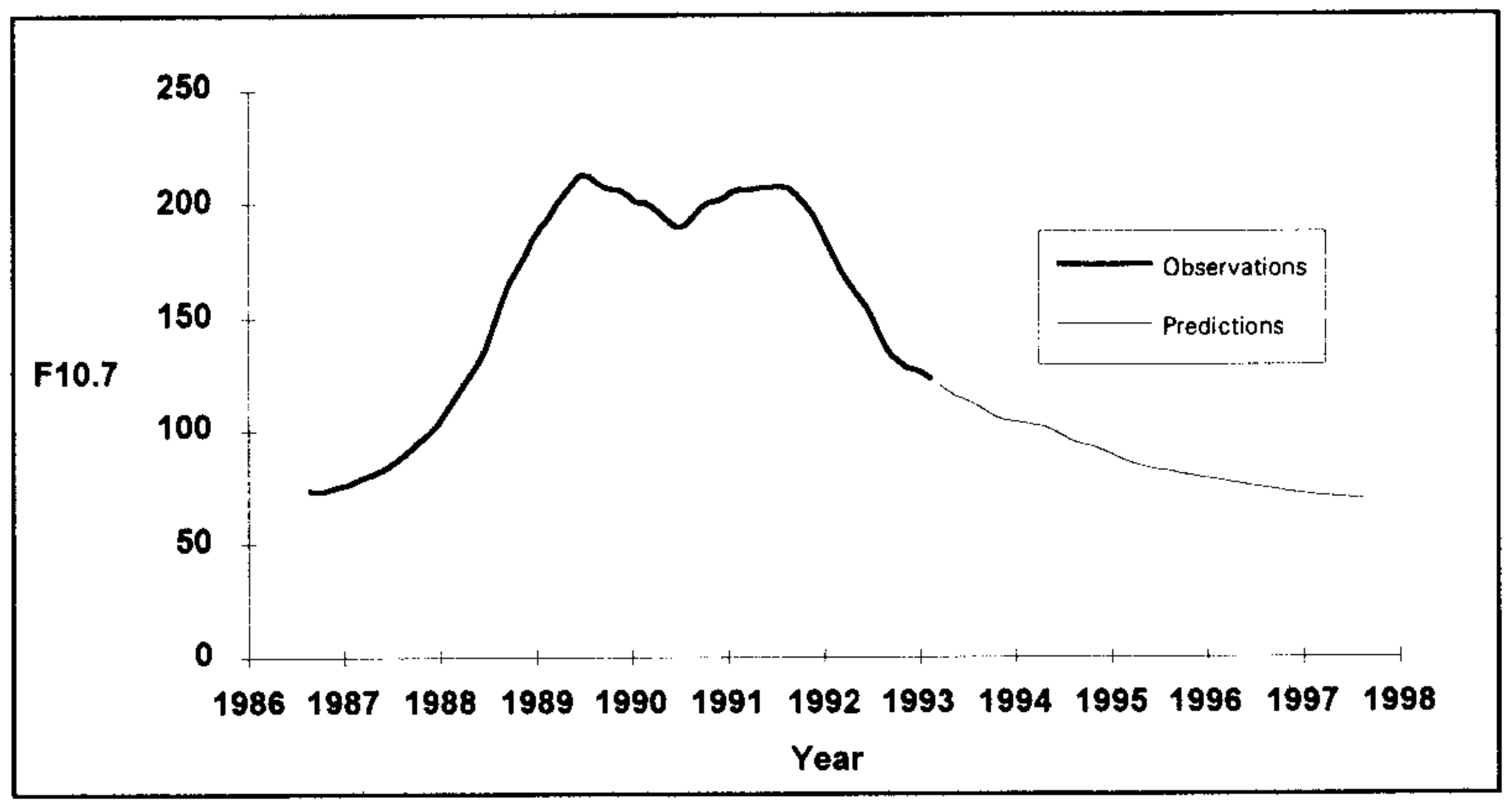
The Solar Spectrum



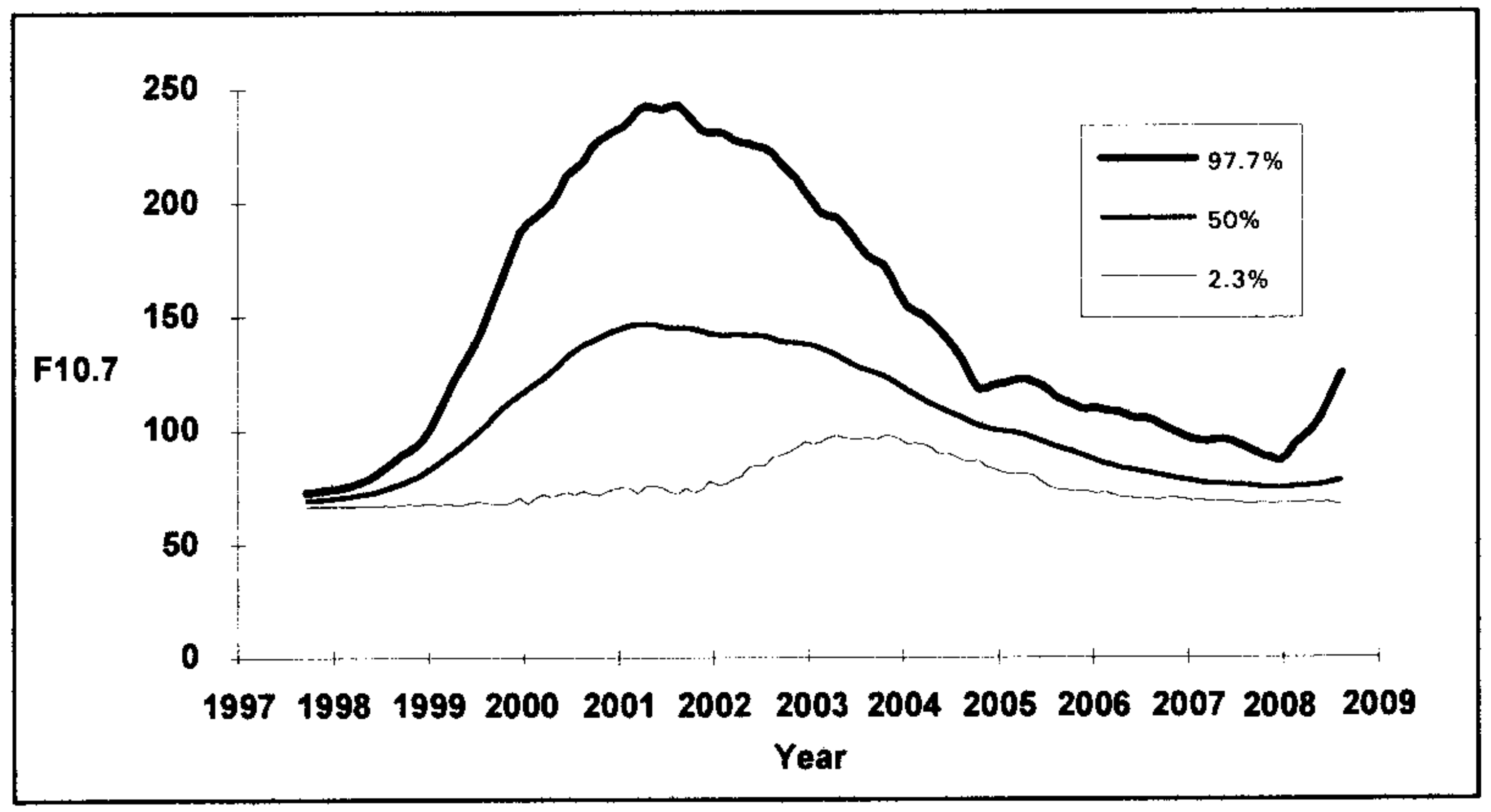
Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

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")



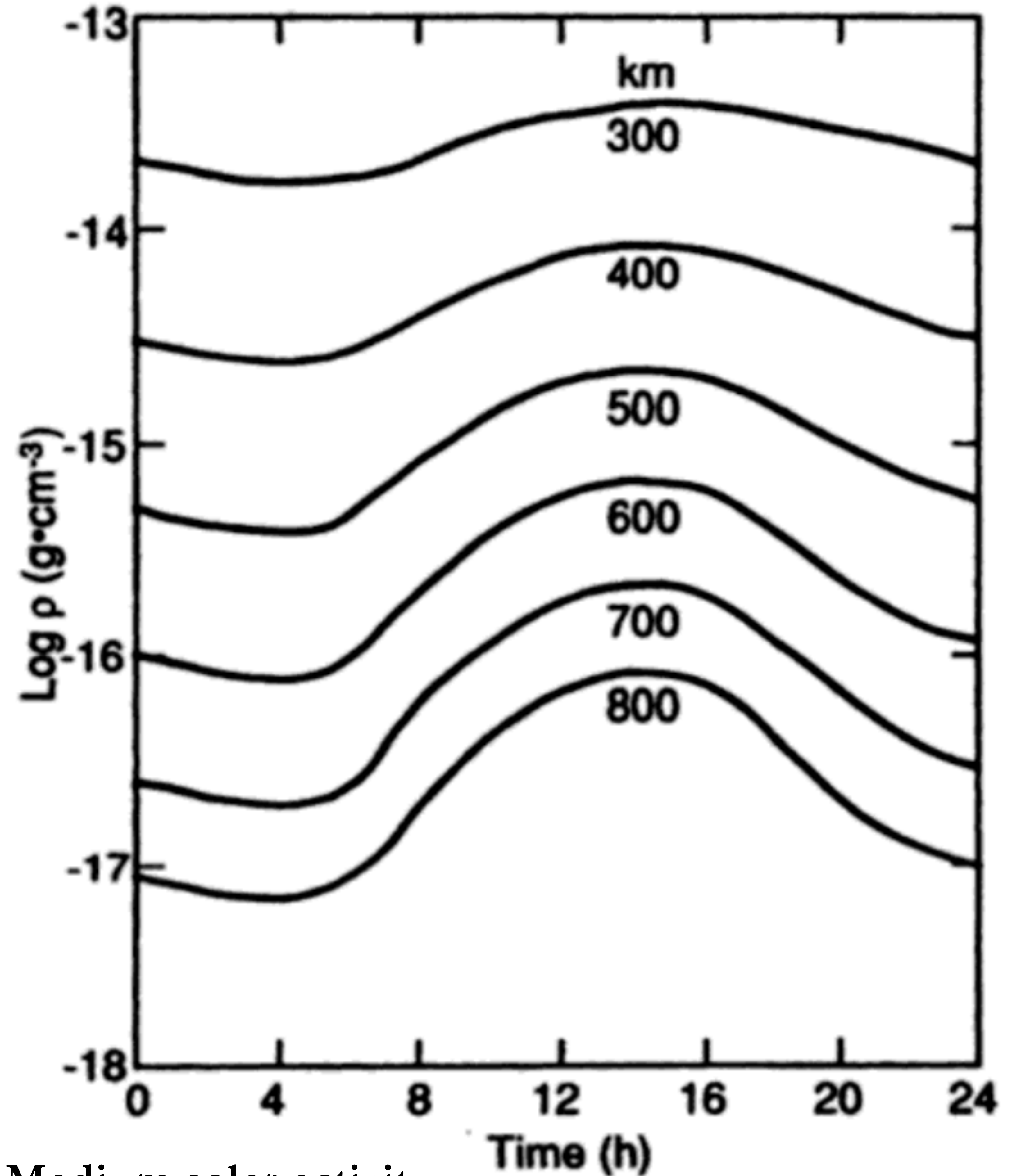
F10.7 values for solar cycle 22.



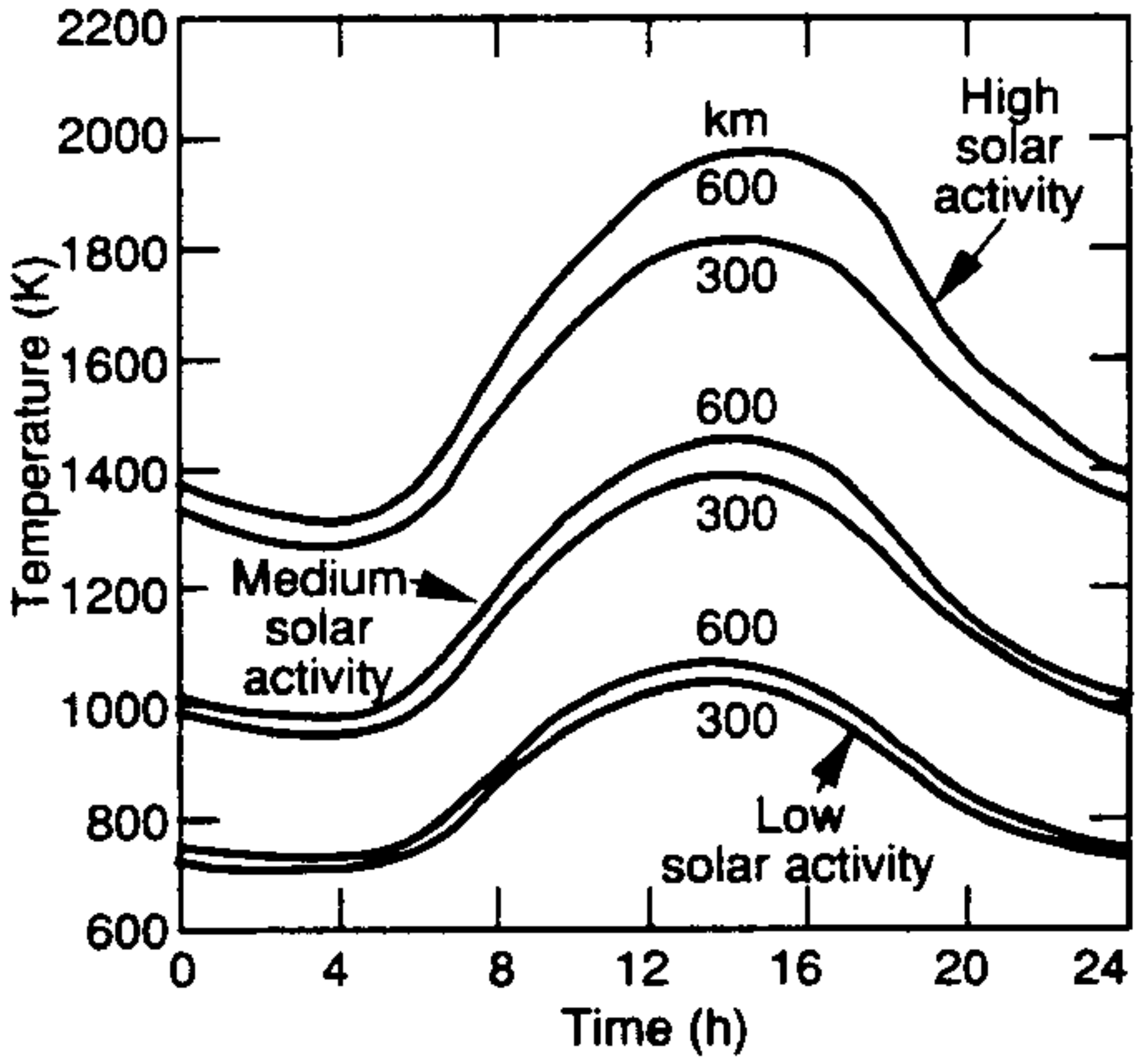
F10.7 values for solar cycle 23.

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

Diurnal Variation of Atmospheric Temperature

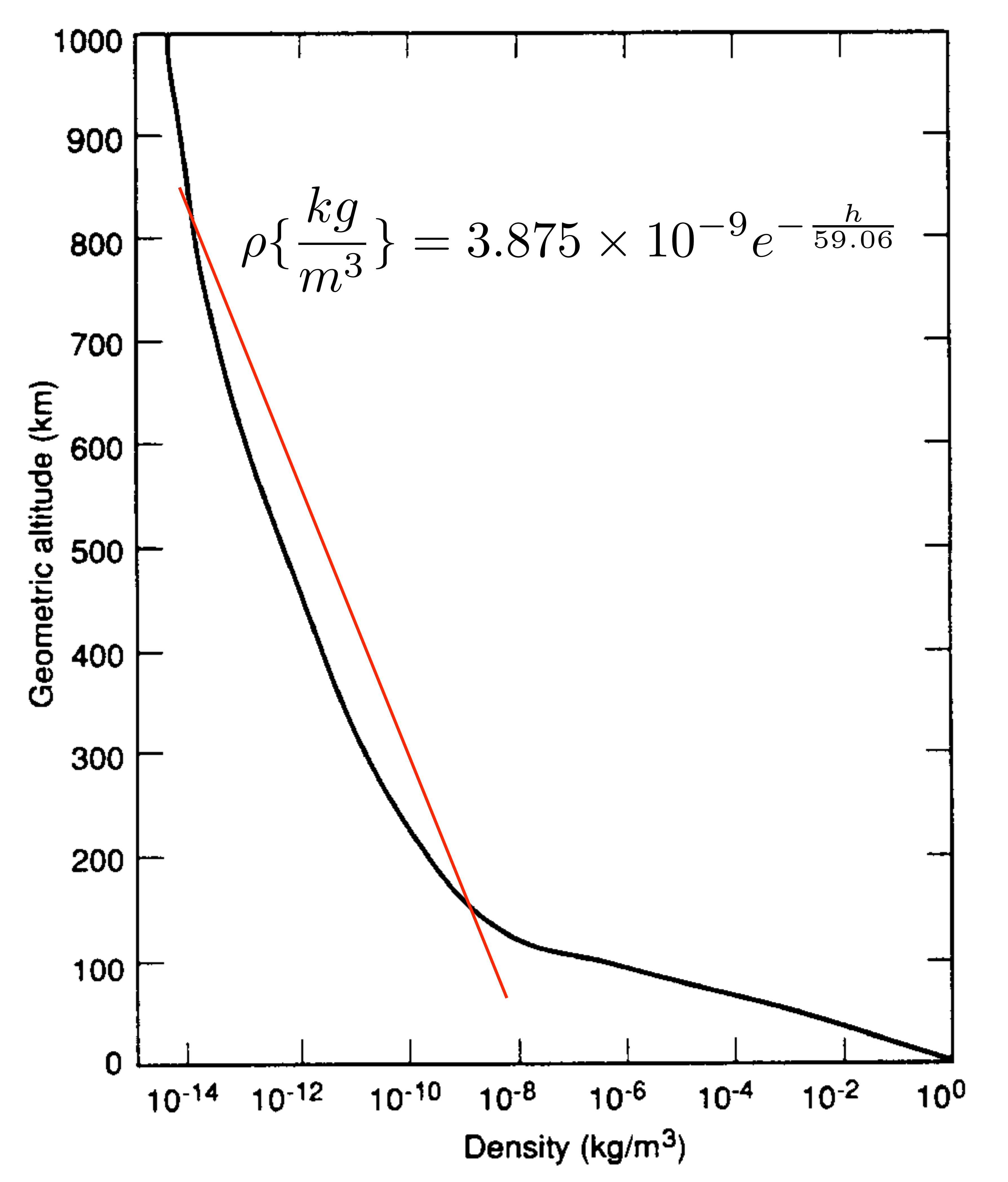


Medium solar activity



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

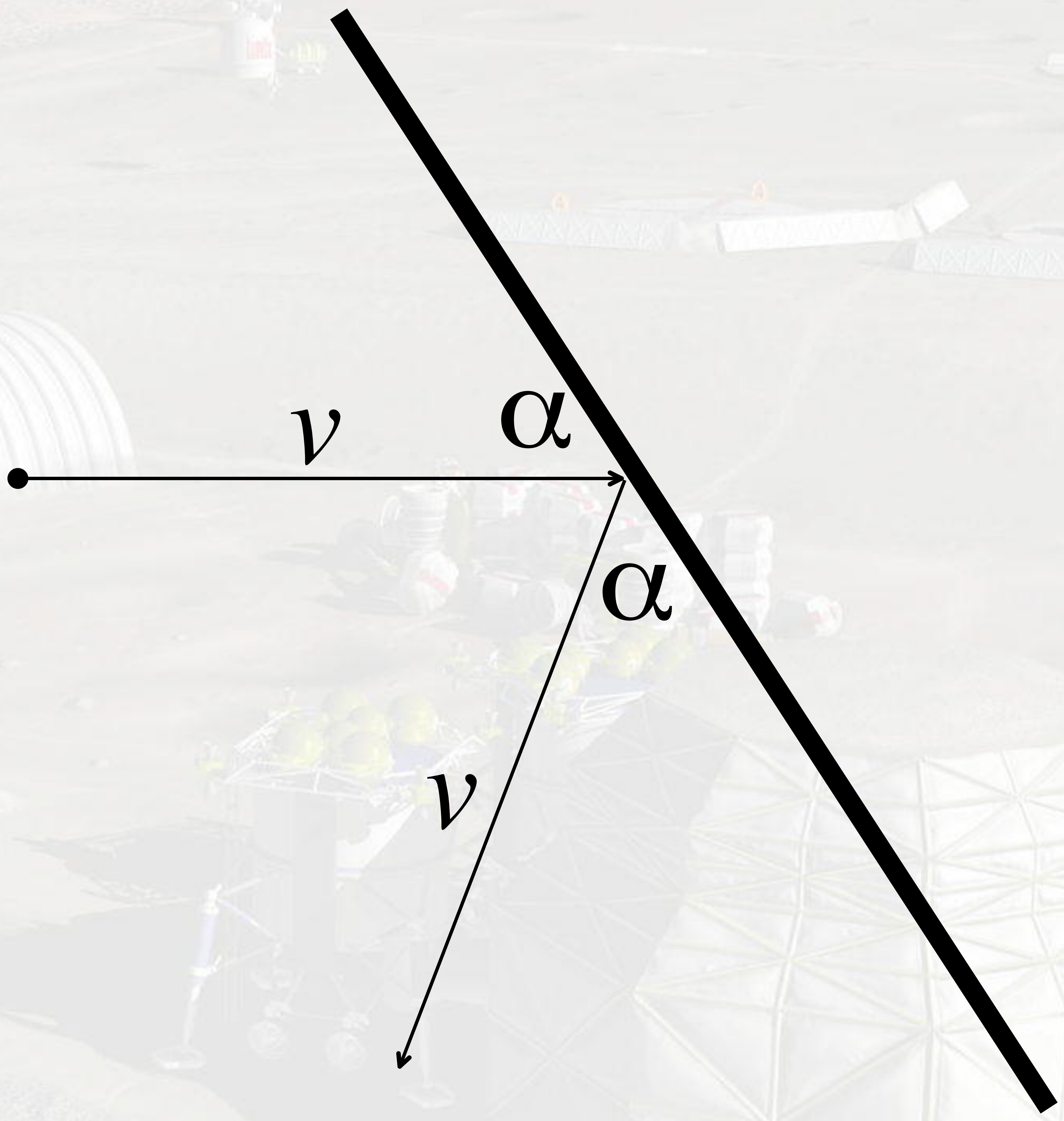
Atmospheric Density with Altitude



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

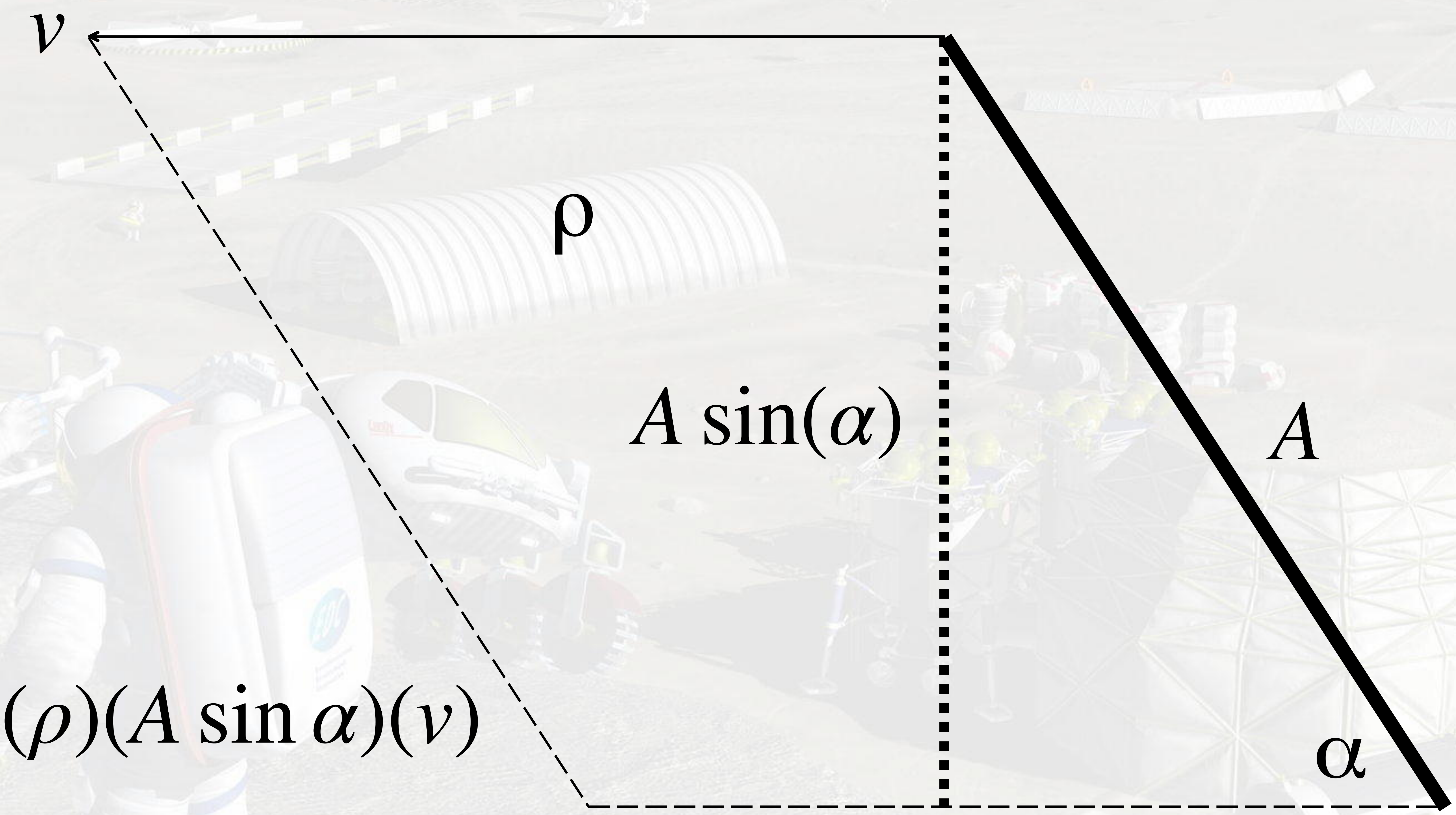
Newtonian Flow

- 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

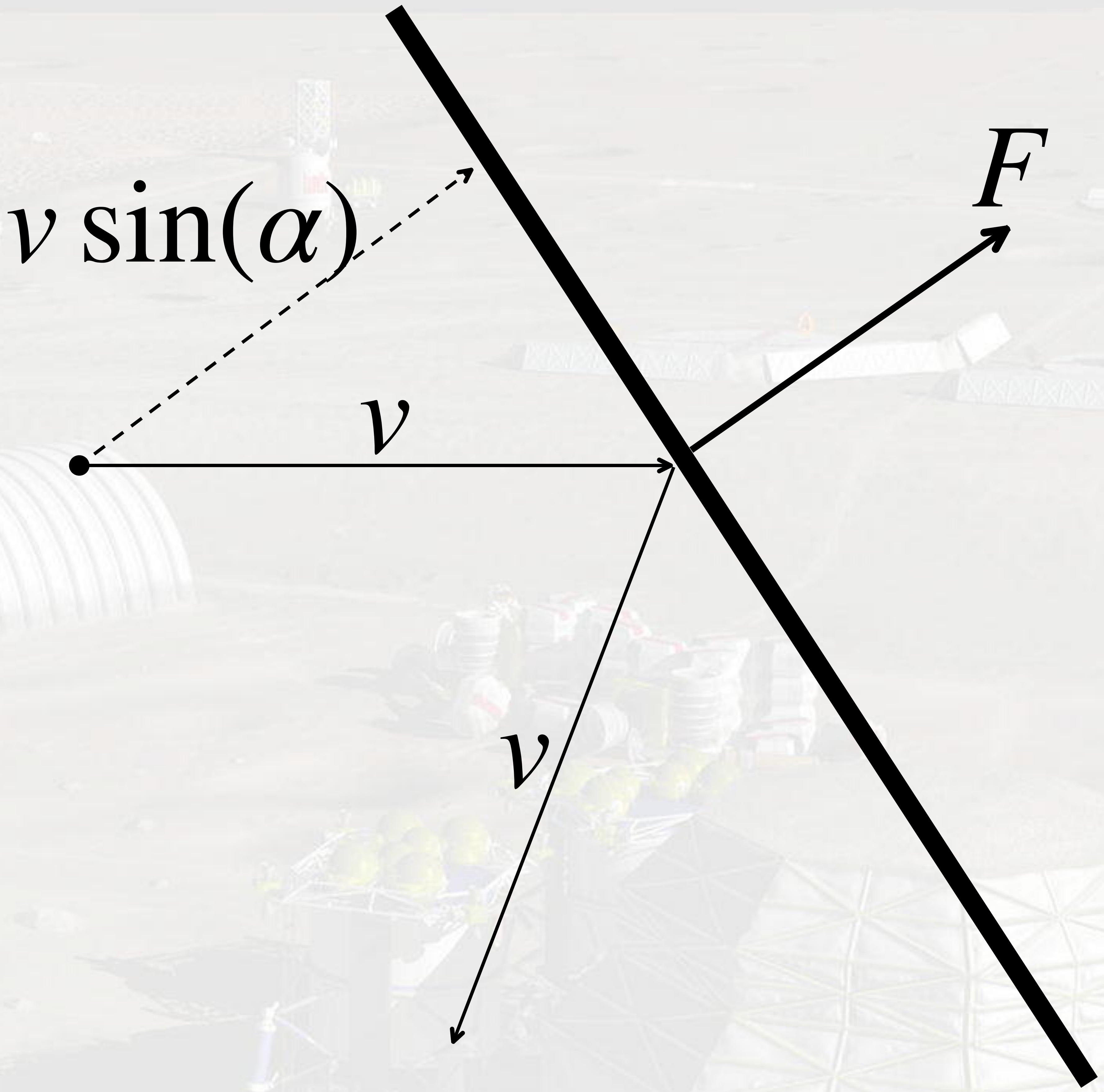
$$\text{mass flux} = (\text{density})(\text{swept area})(\text{velocity})$$



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

Momentum Transfer

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

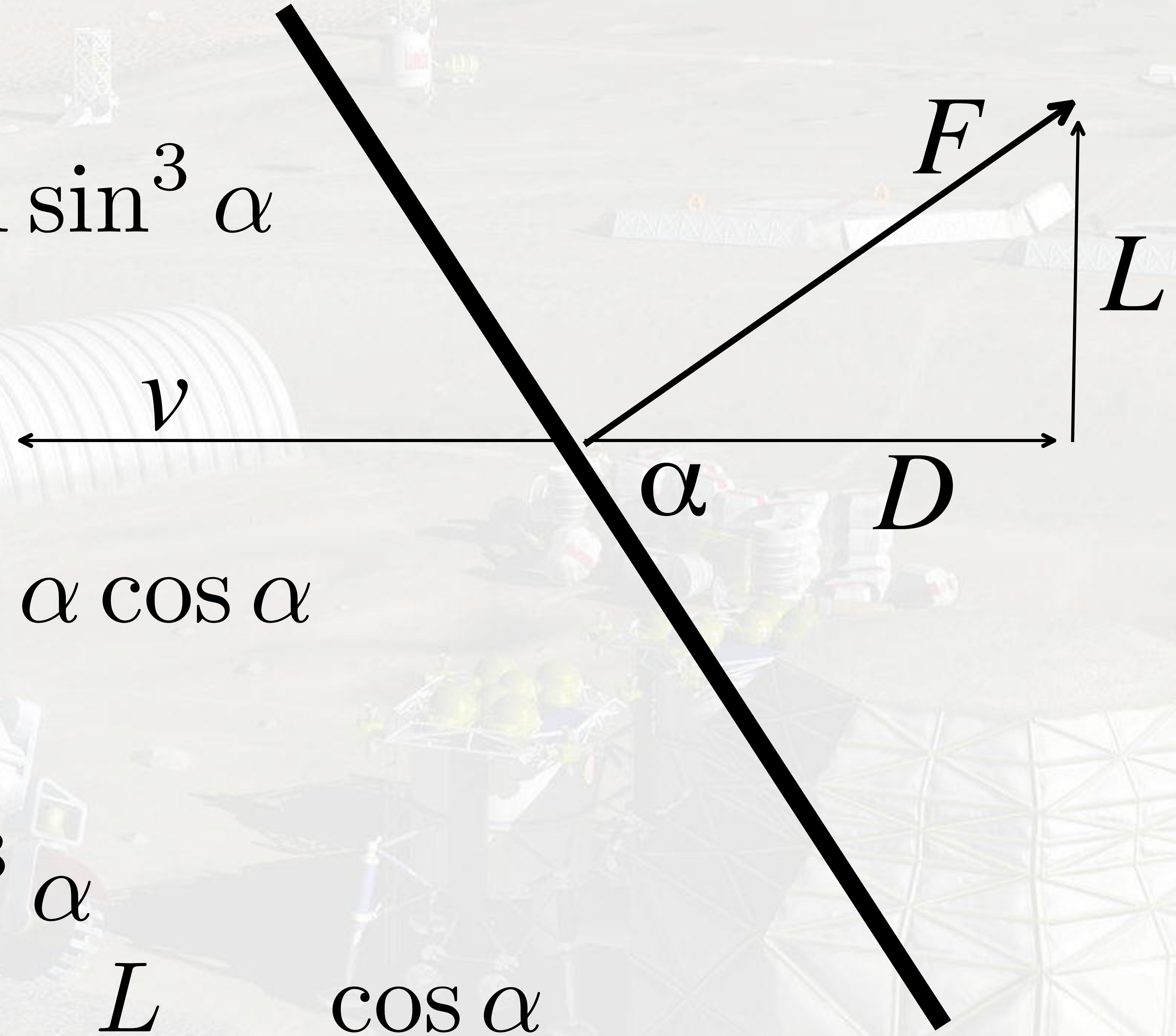


$$F = \frac{dm}{dt}\Delta v = \rho v A \sin\alpha(2v\sin\alpha) = 2\rho v^2 A \sin^2\alpha$$

Lift and Drag

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

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

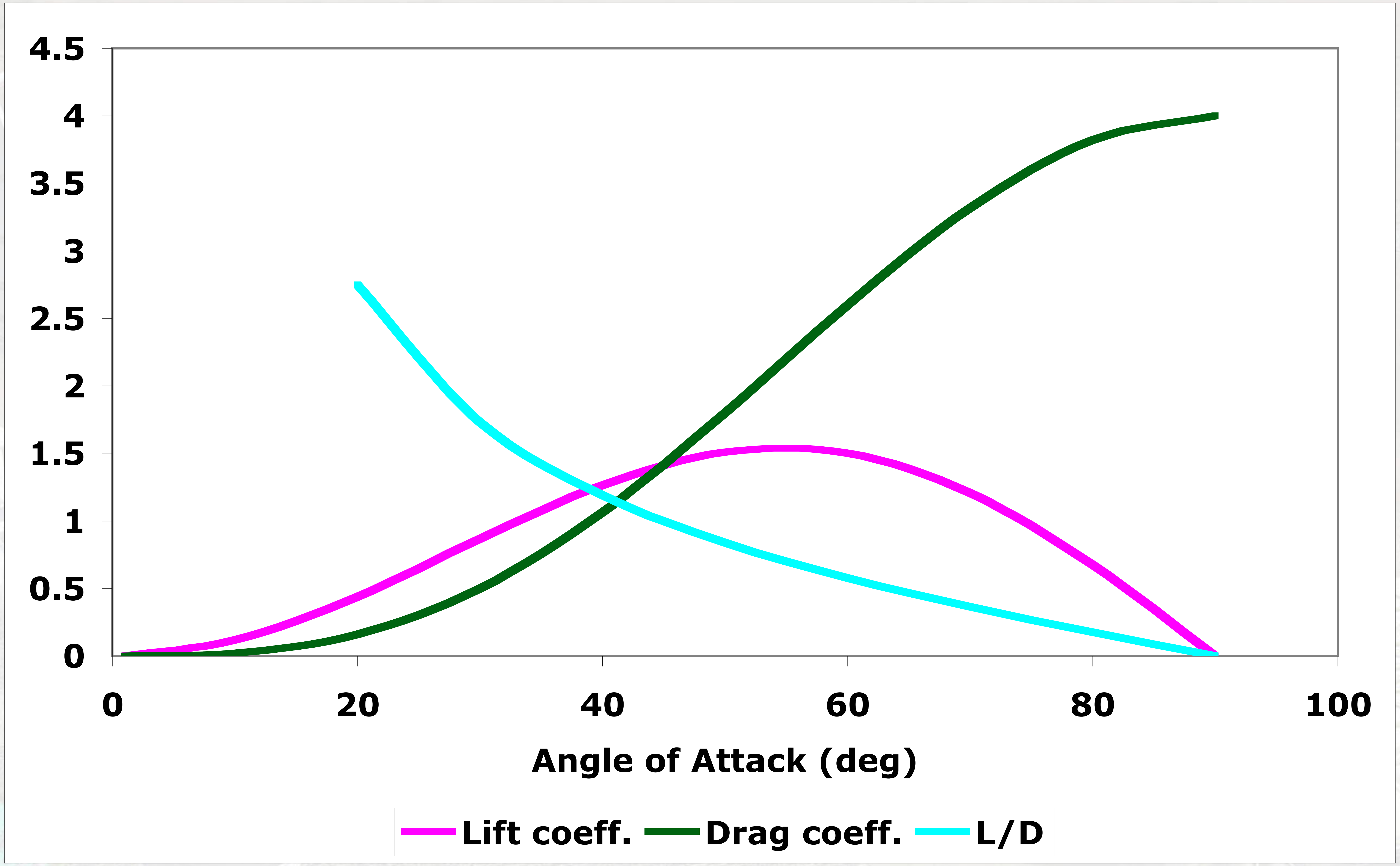


$$c_L = \frac{L}{\frac{1}{2}\rho V^2 A} = 4\sin^2\alpha\cos\alpha$$

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

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

Flat Plate Newtonian Aerodynamics

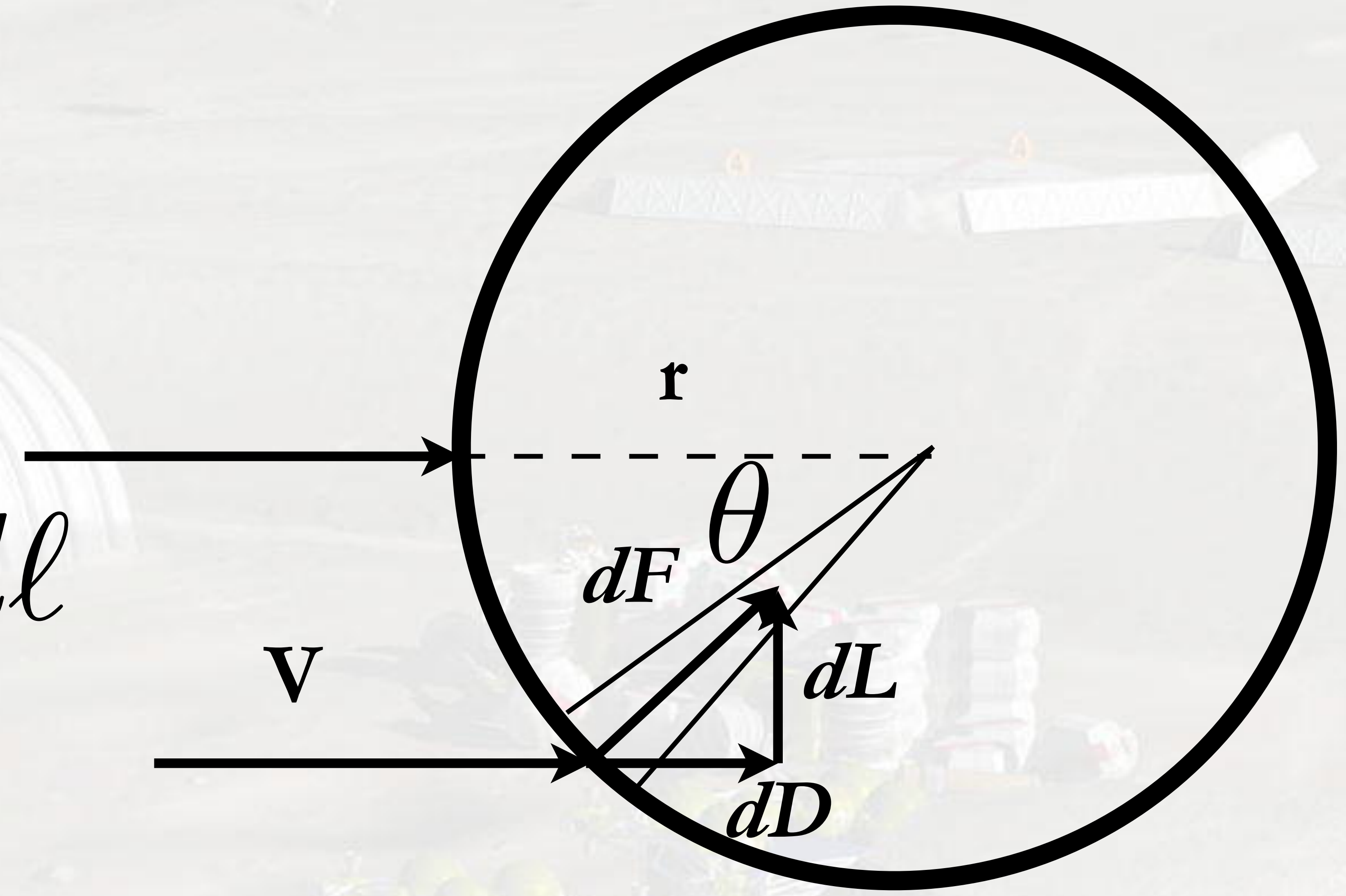


Example of Newtonian Flow Calcs

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 $\theta = -\frac{\pi}{2} \rightarrow \frac{\pi}{2}$

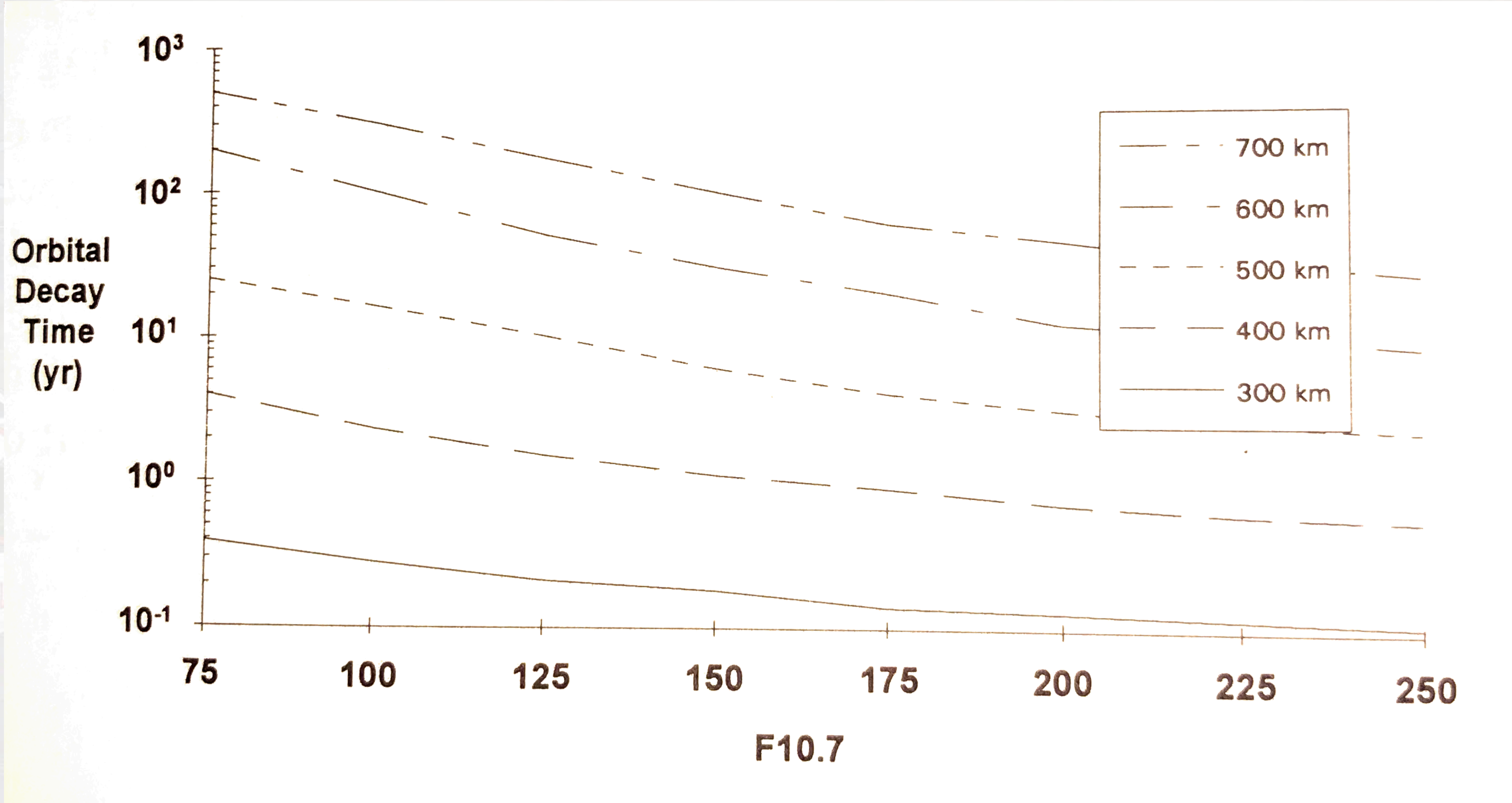
$$D = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \int_0^{\ell} dD = 2\rho V^2 r \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \int_0^{\ell} \cos^3\theta d\theta d\ell$$

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

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

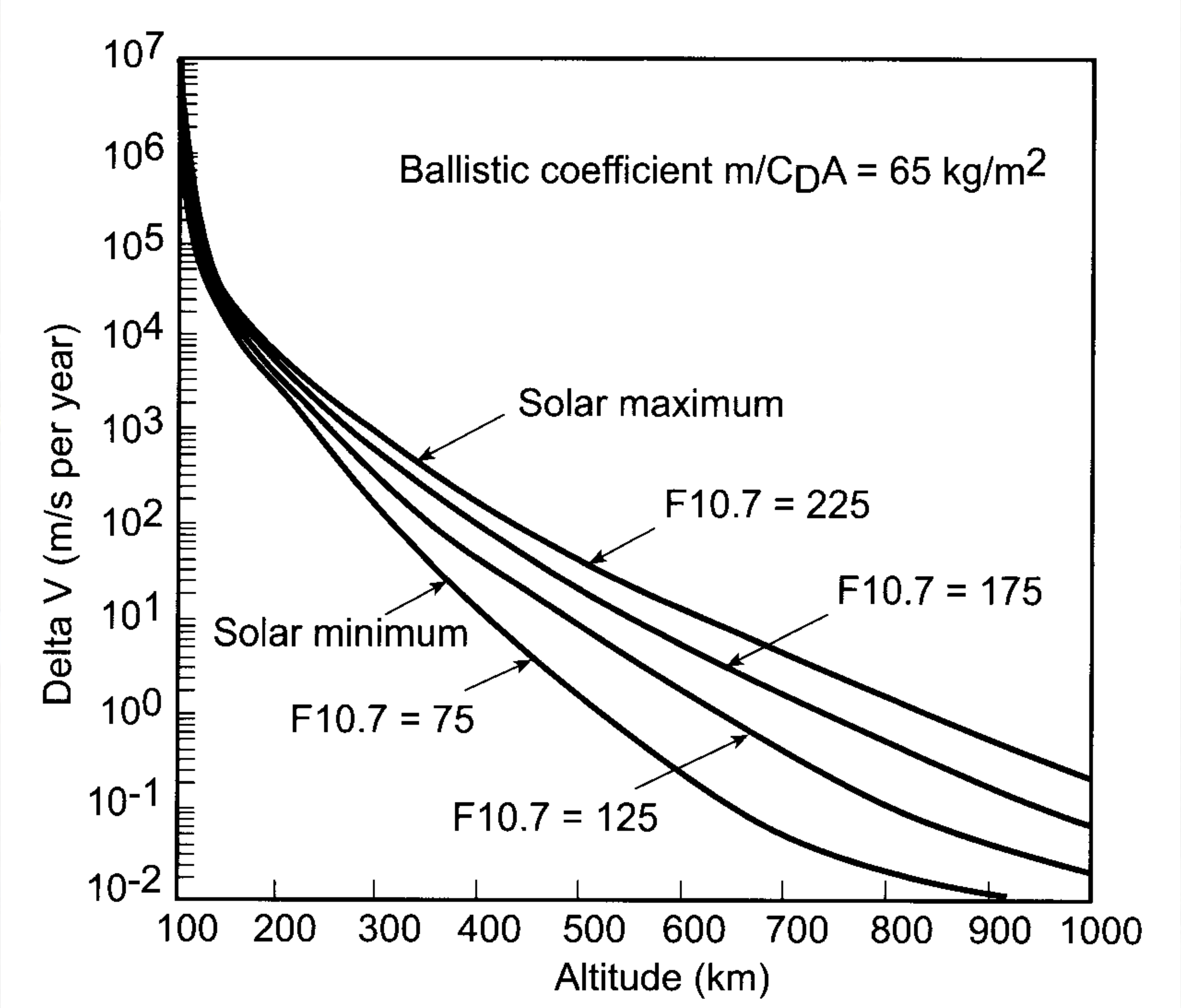
$$\rho V^2 r\ell c_D = \frac{8}{3}\rho V^2 r\ell \implies \boxed{c_D = \frac{8}{3}}$$

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

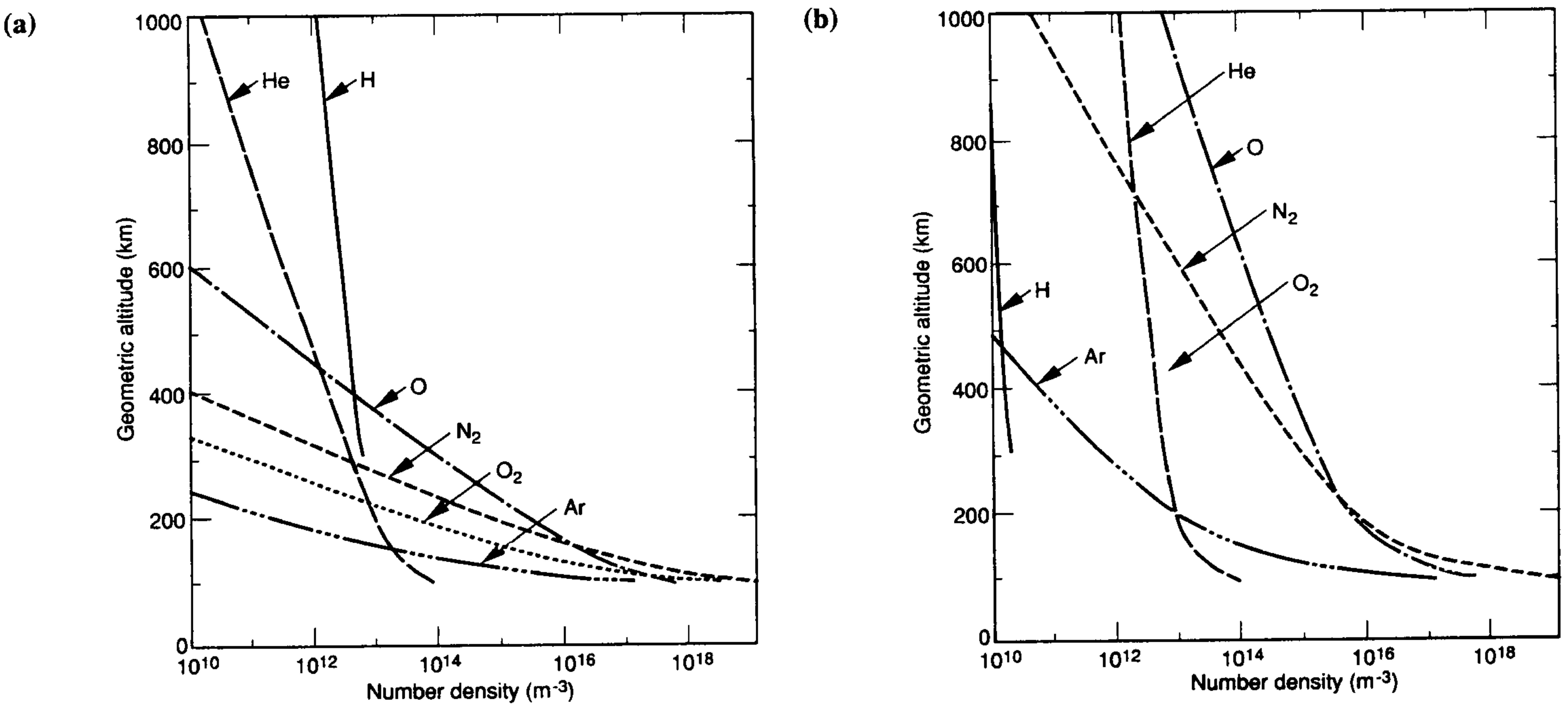


Fig. 2.3. (a) Relative concentrations of atmospheric constituents during periods of minimum solar activity. (b) Relative concentrations of atmospheric constituents during periods of maximum solar activity. (Adapted from *U.S. Standard Atmosphere*, 1976.)

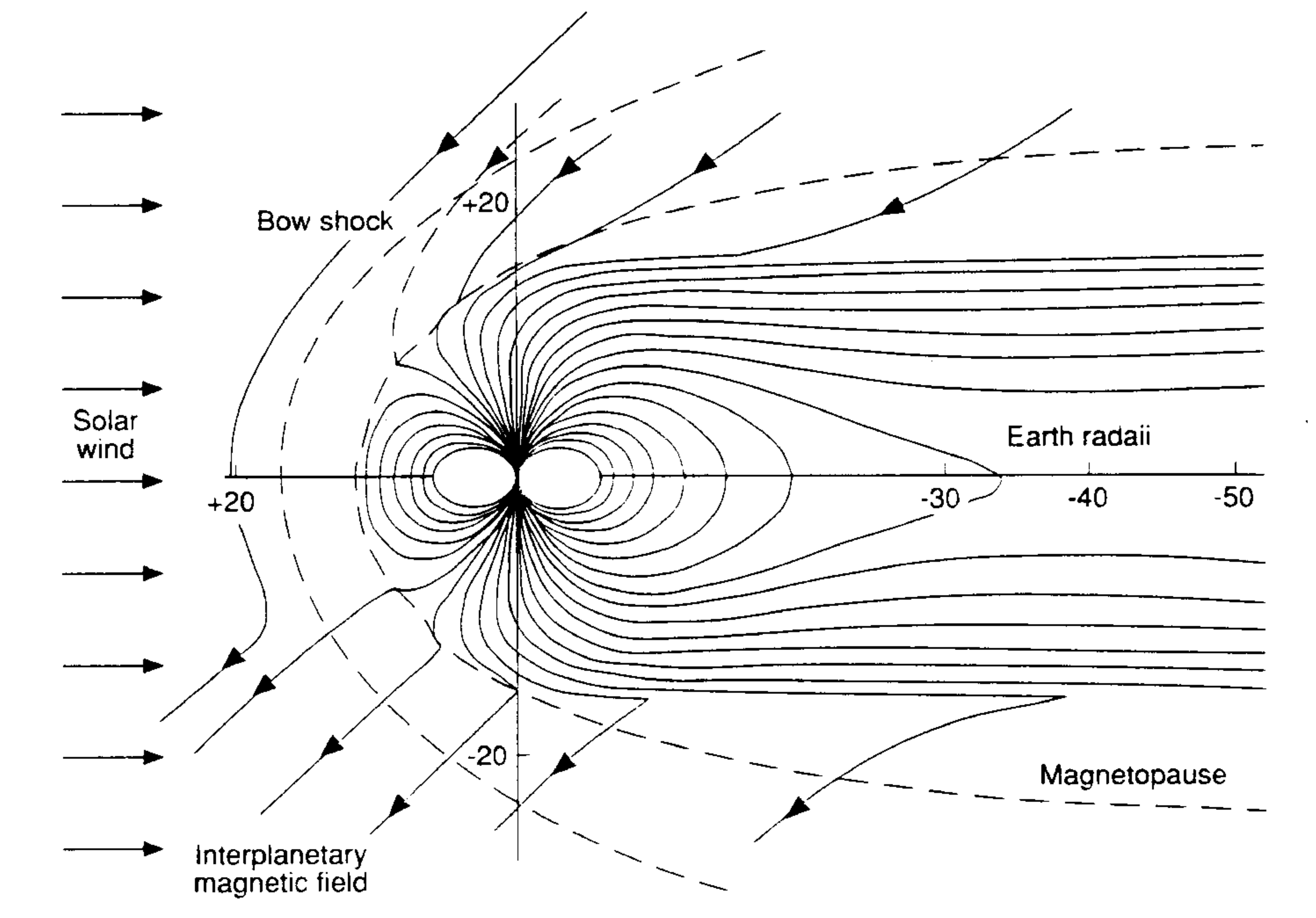
Ref: V. L. Pisacane and R. C. Moore, Fundamentals of Space Systems Oxford University Press, 1994

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



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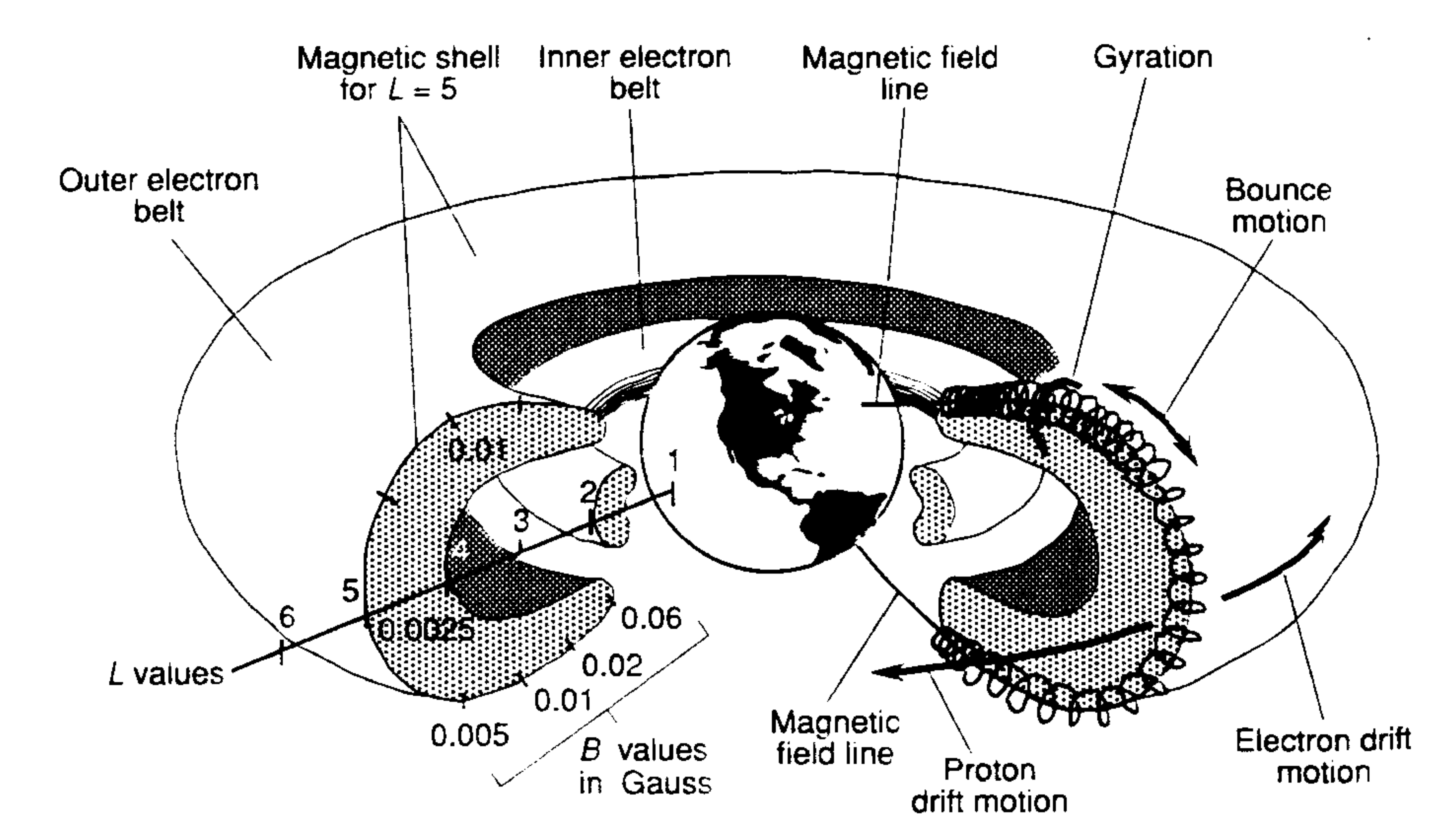
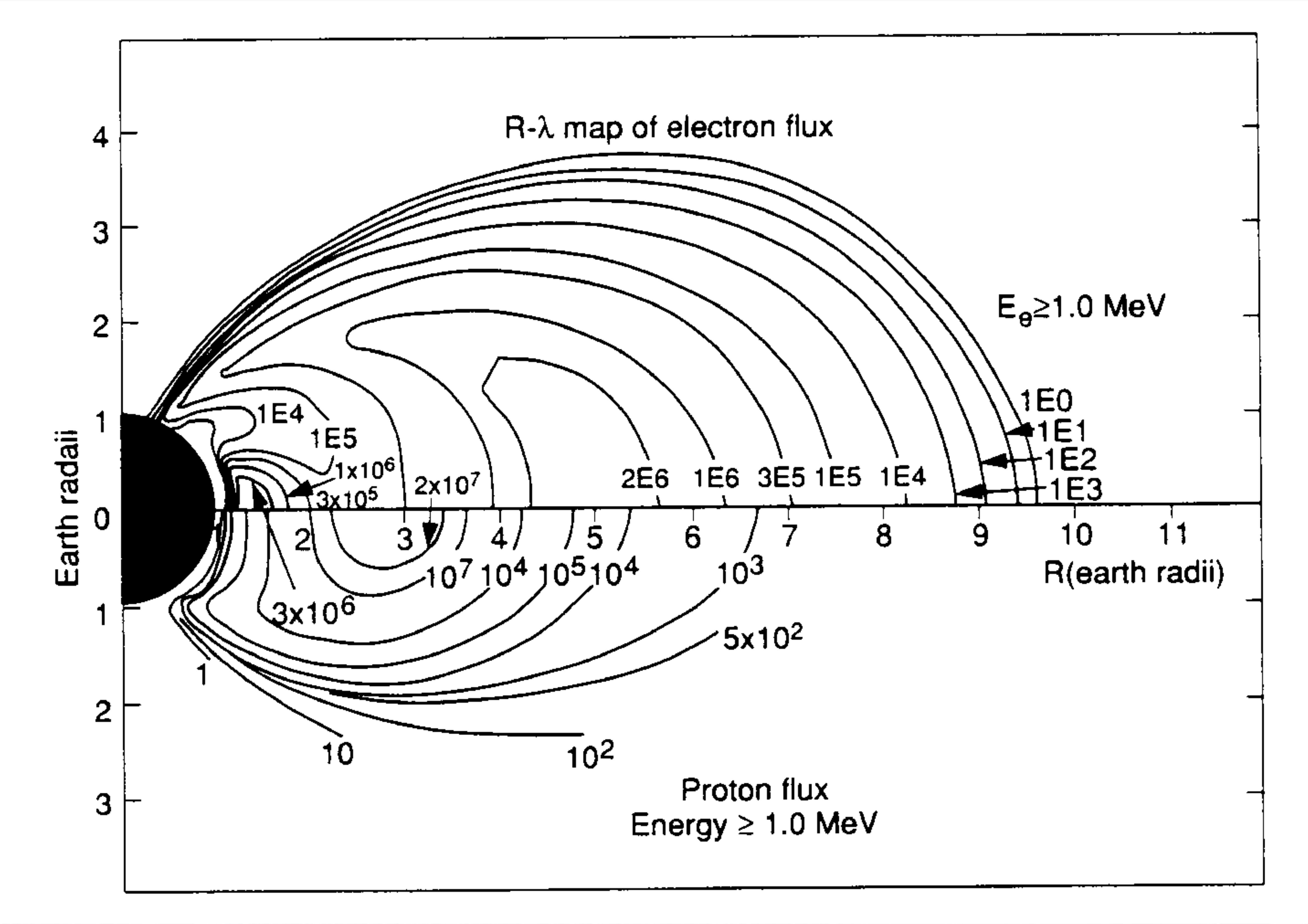
The Van Allen Radiation Belts



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

Cross-section of Van Allen Radiation Belts



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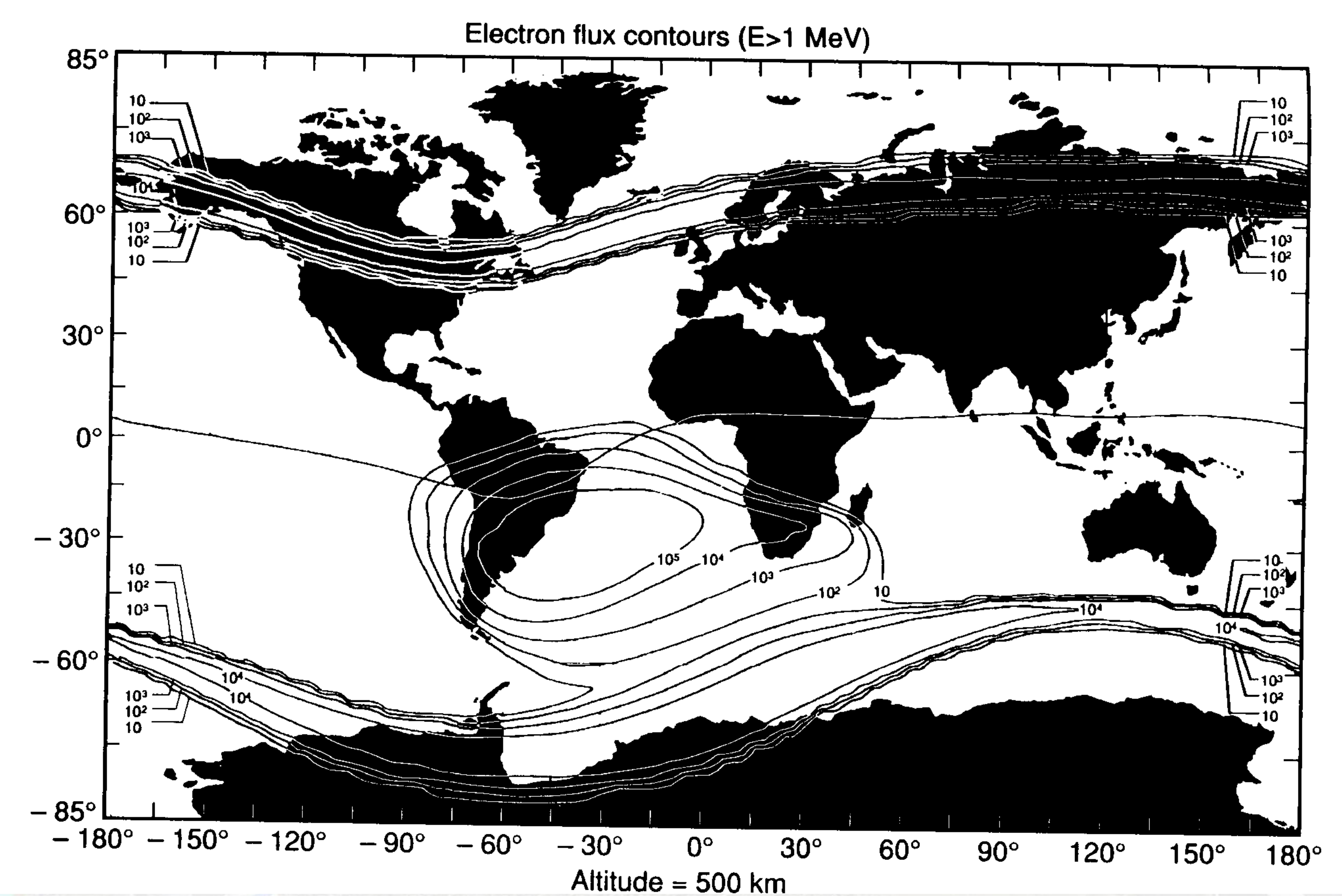
Electron Flux in Low Earth Orbit



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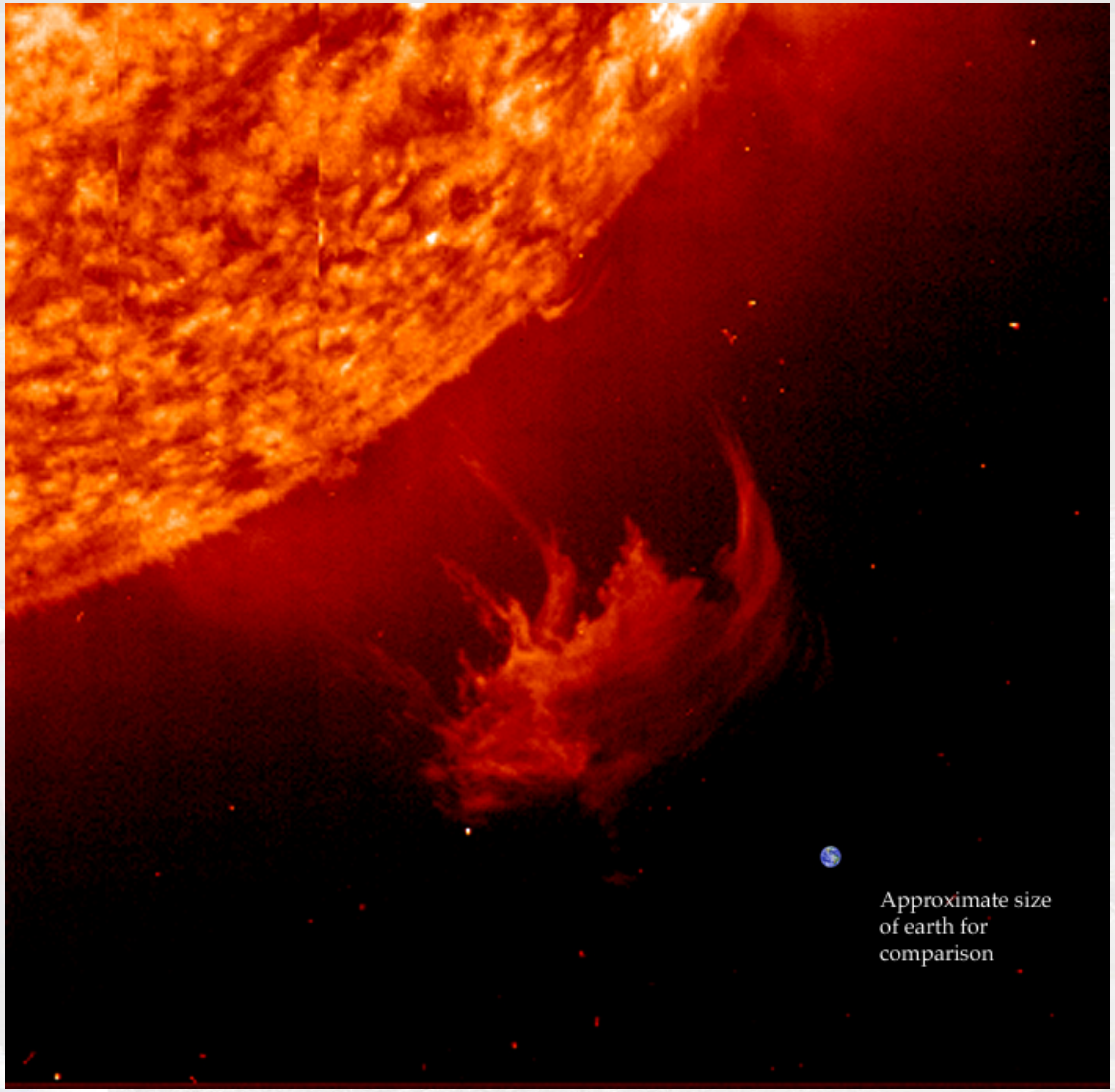
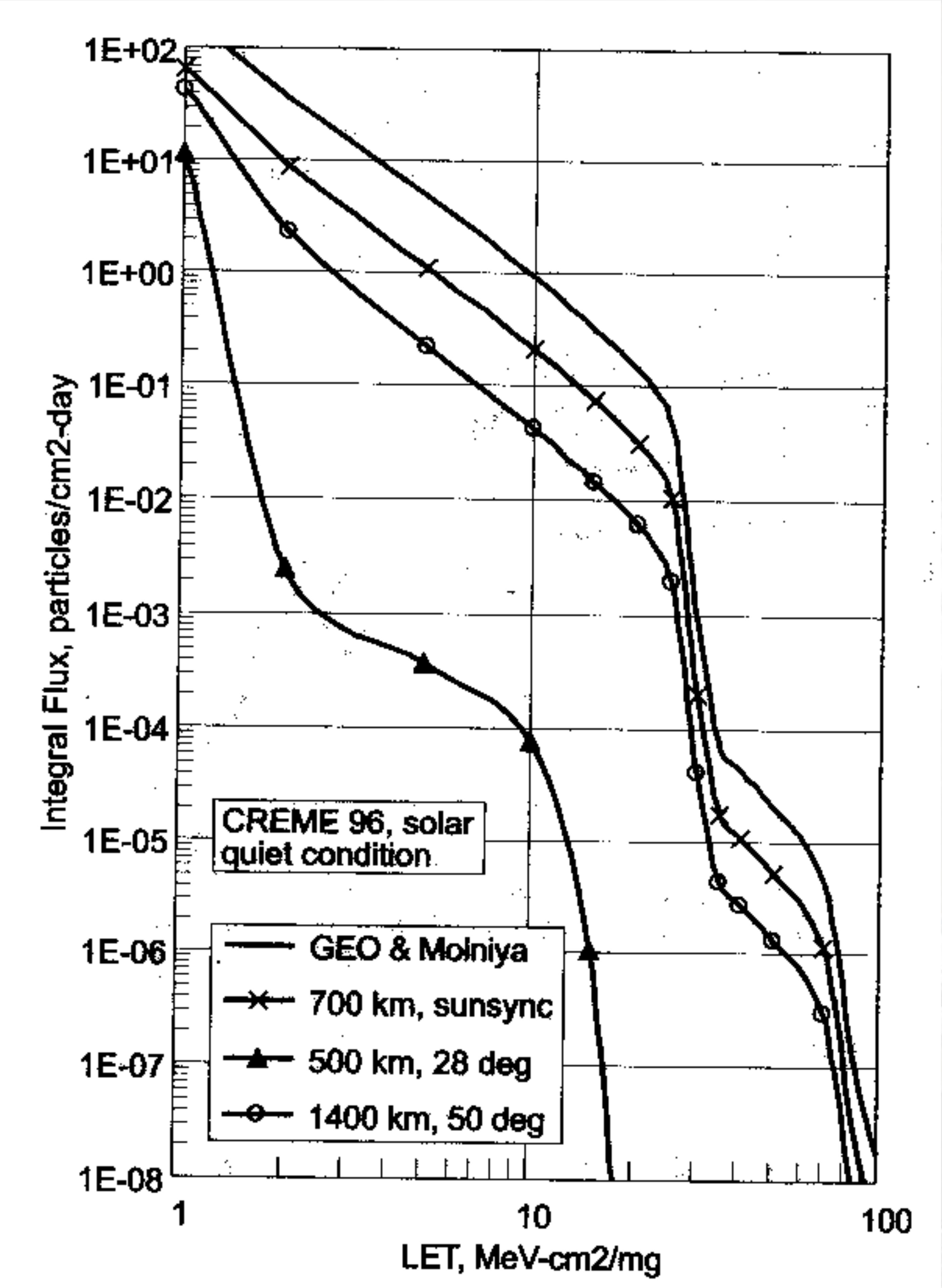
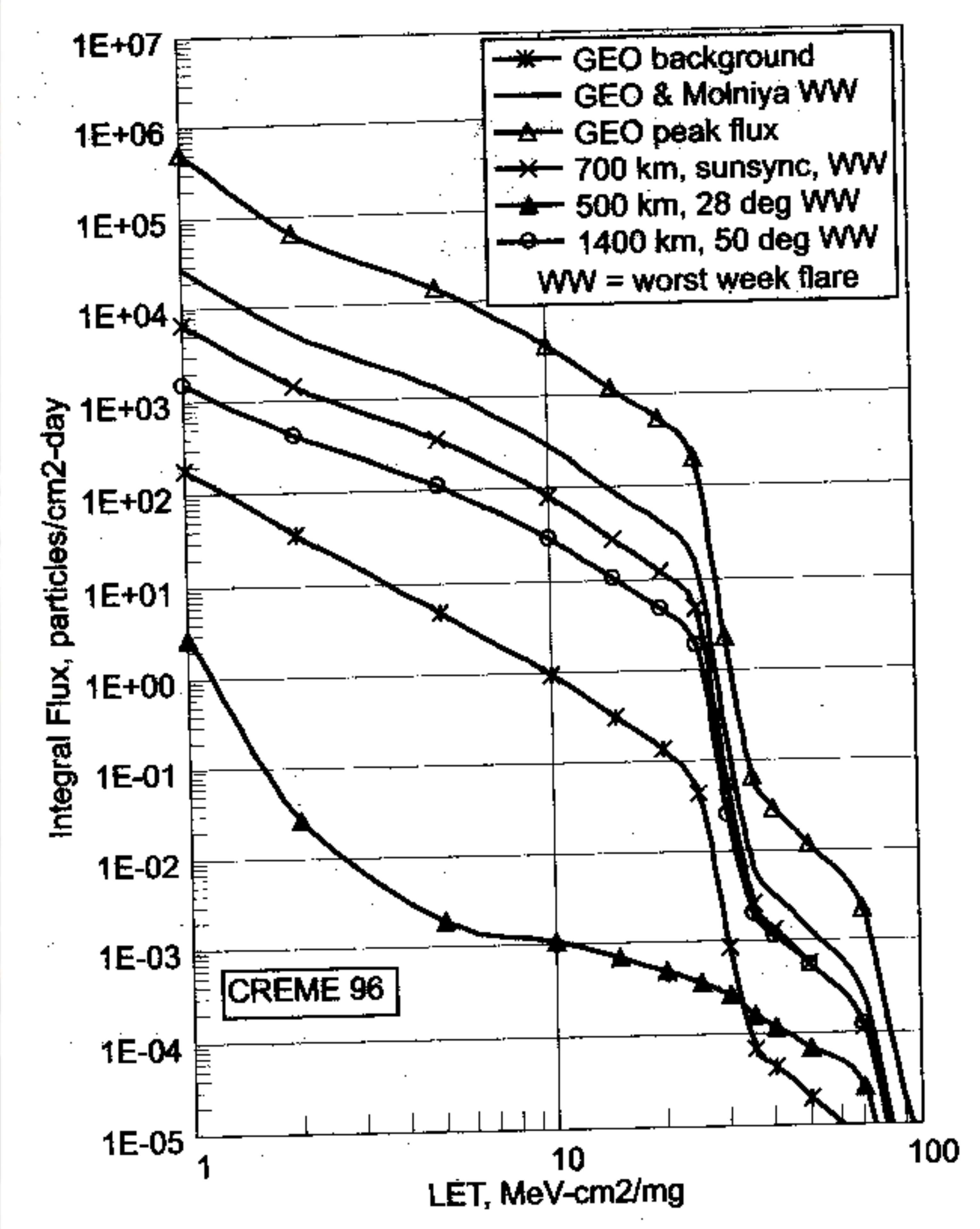
The Origin of a Class X1 Solar Flare



Heavy Ion Flux



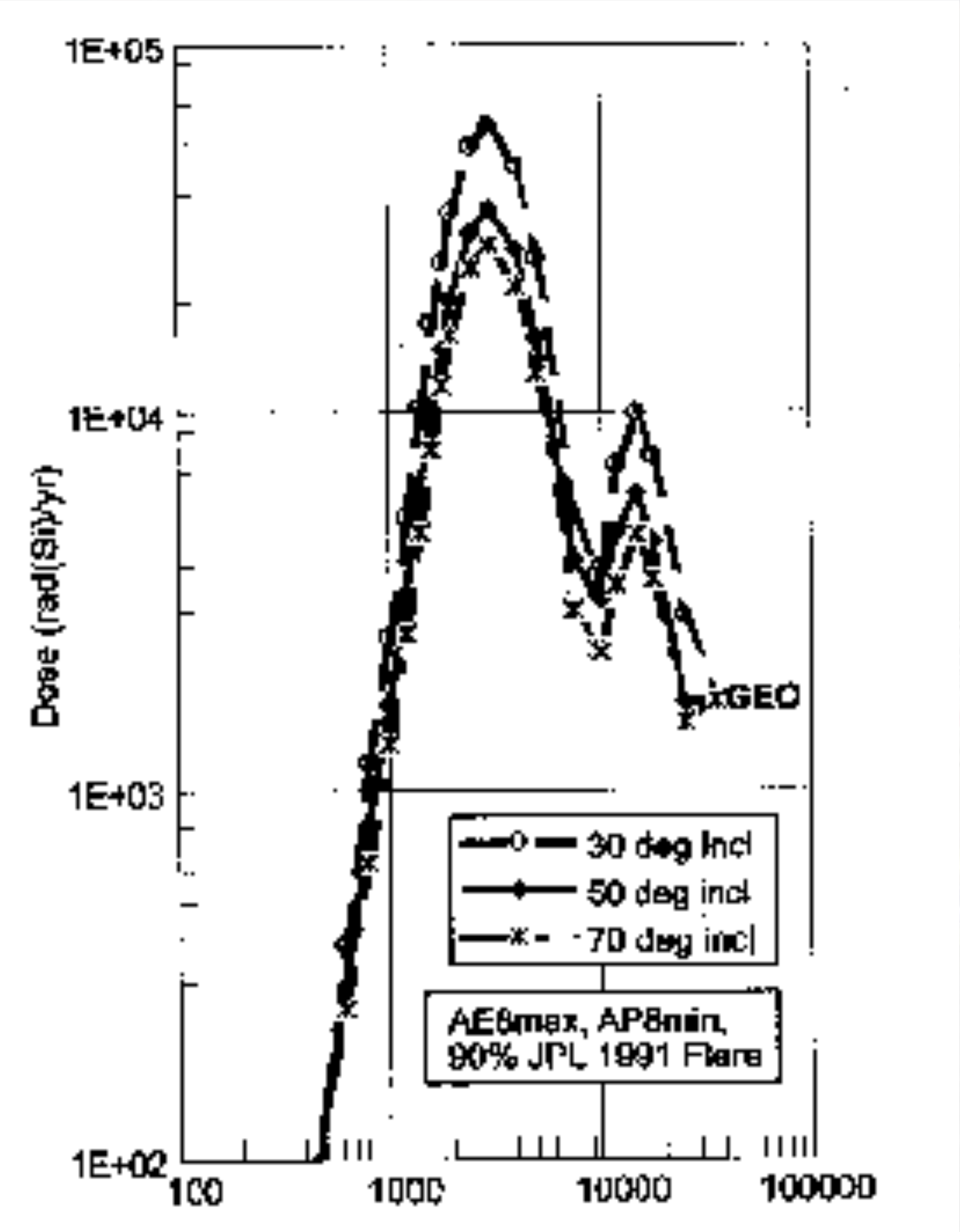
Background



Solar Flare

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

Radiation Dose vs. Orbital Altitude

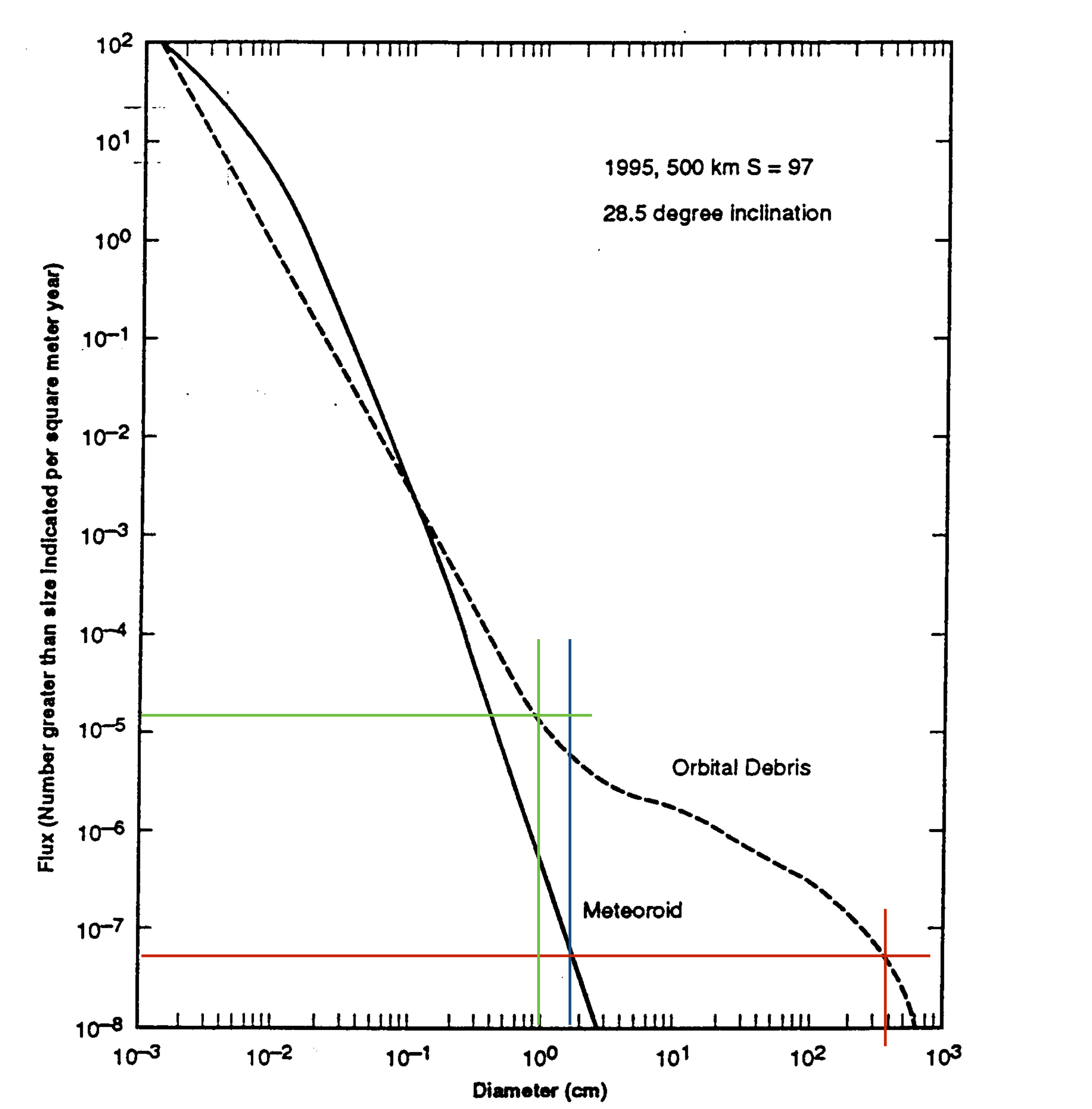


300 mil (7.6 mm) Al shielding

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

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

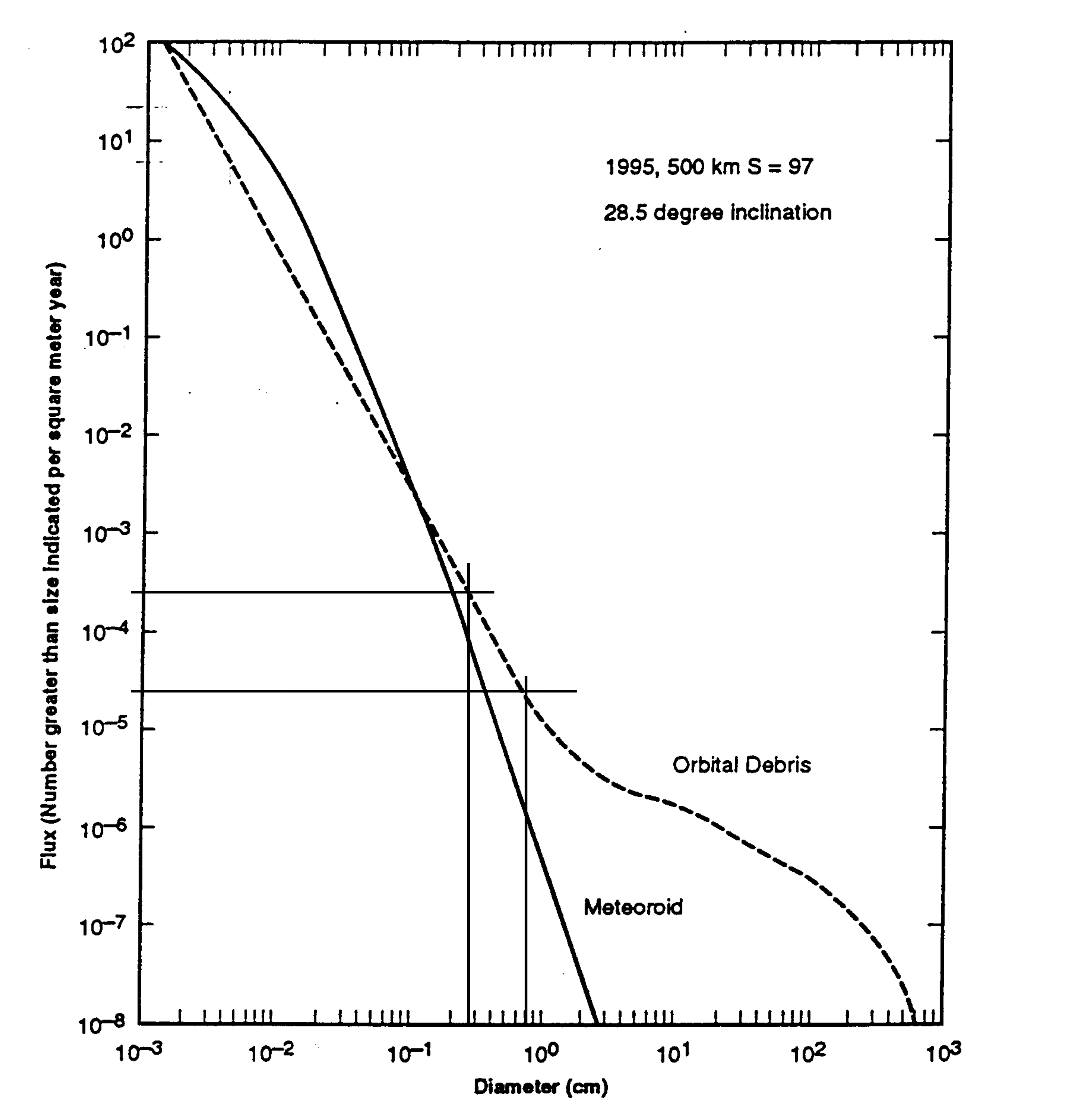
Surface area=221 m2

Flux value for one hit in 20 years

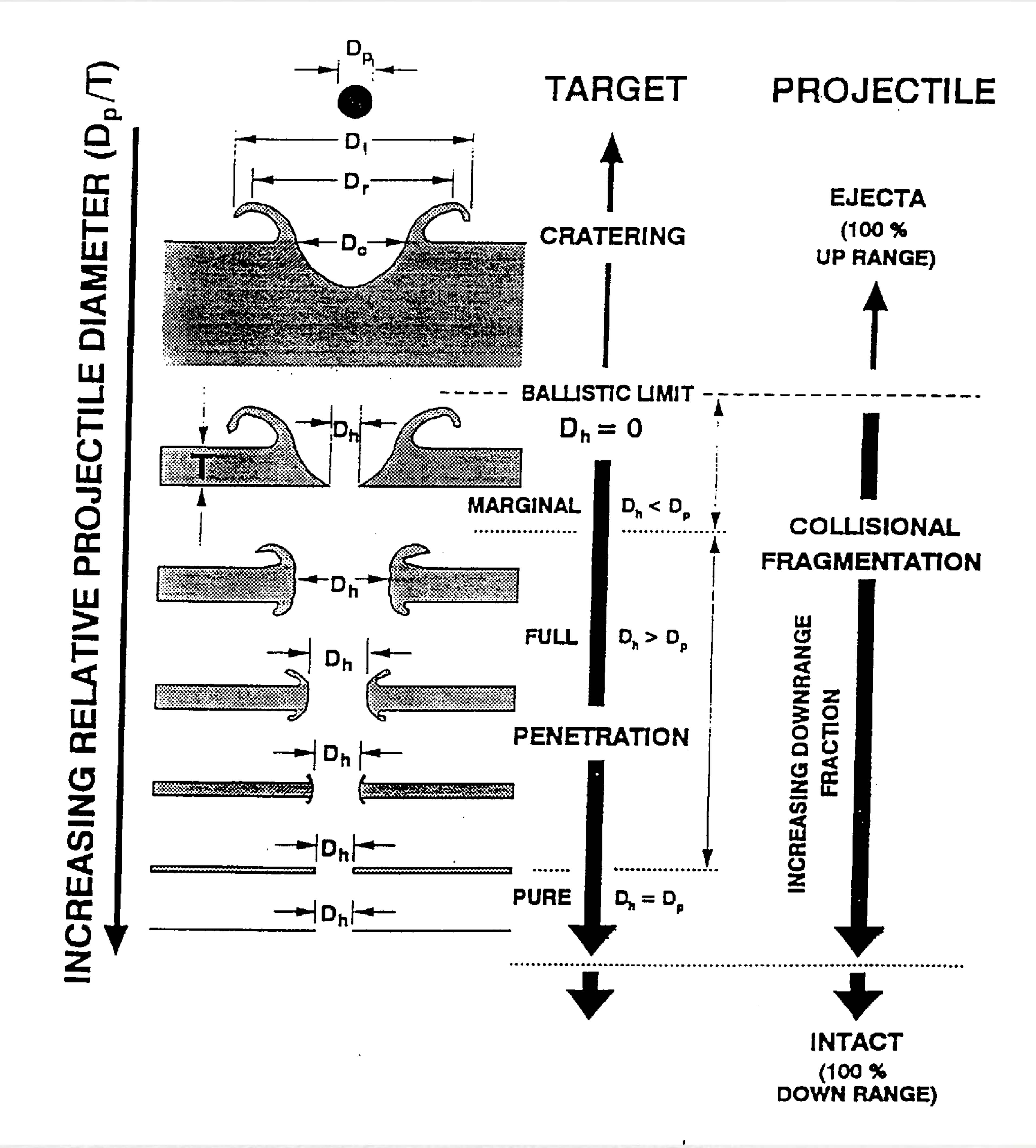
$$Flux = \frac{1 \text{ hit}}{(221 \text{ m}^2)(20 \text{ yrs})}$$

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



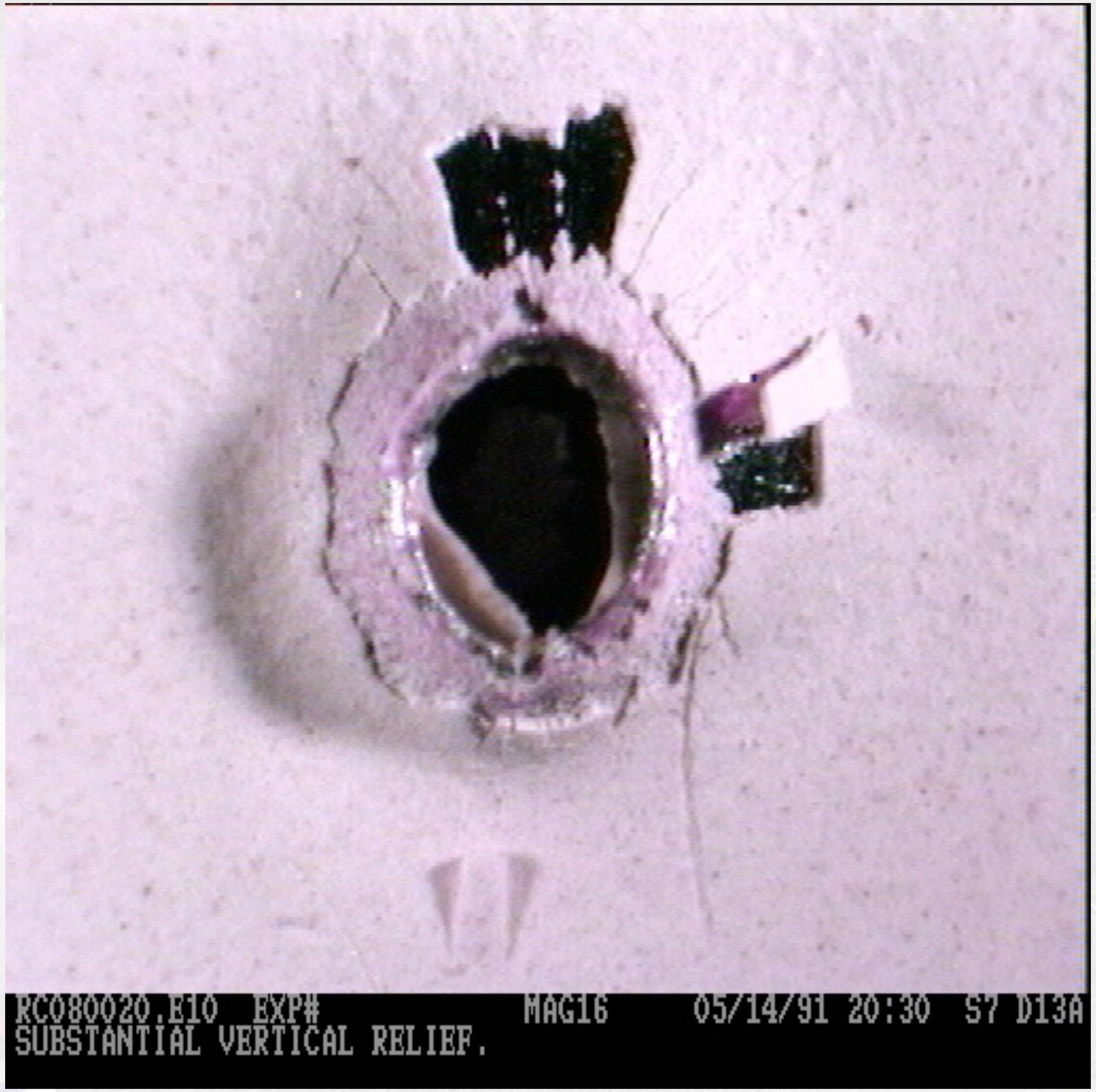
Long Duration Exposure Facility (LDEF)

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

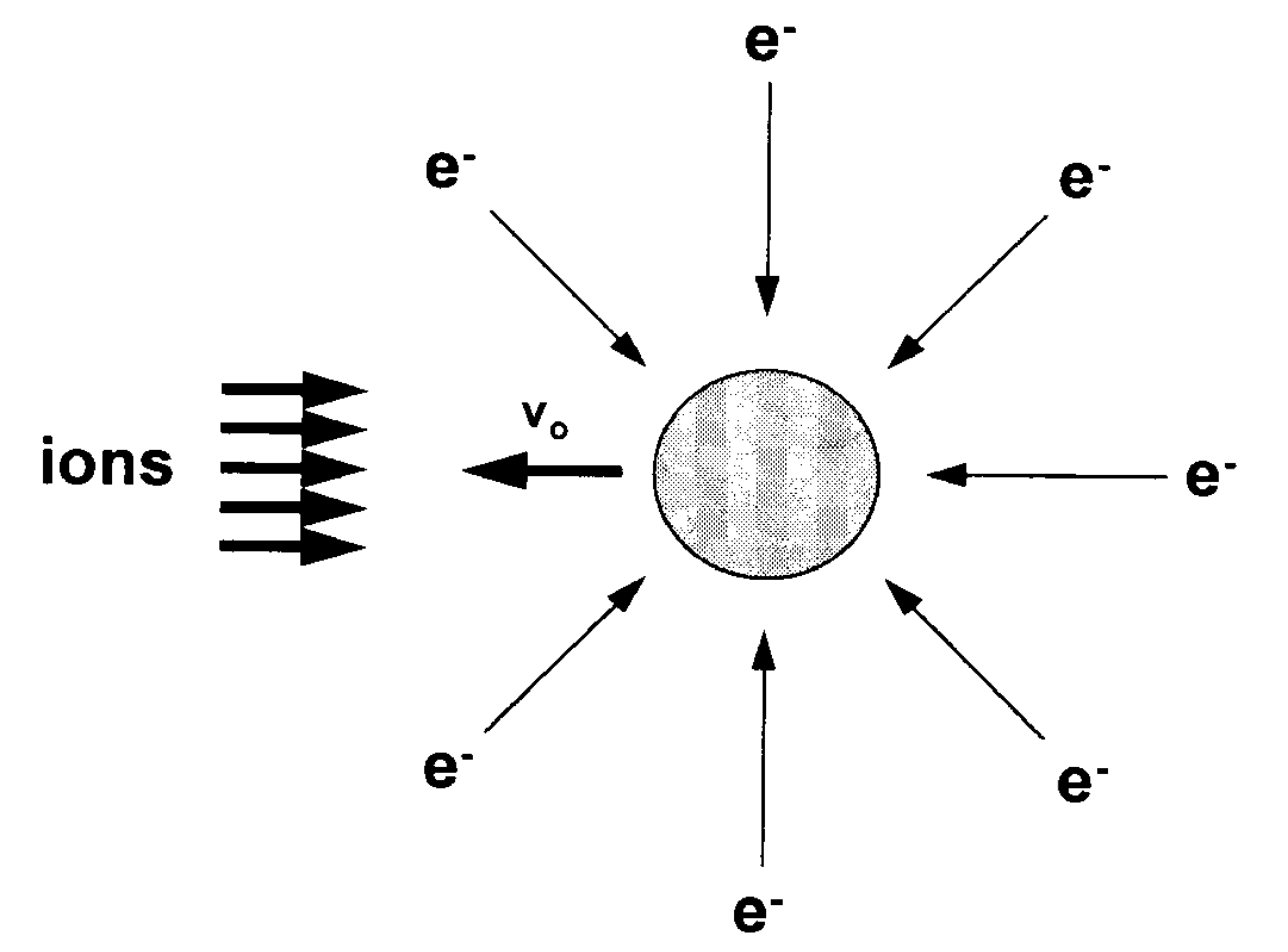
Surprising Results from LDEF

- 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



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

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