The Space Environment

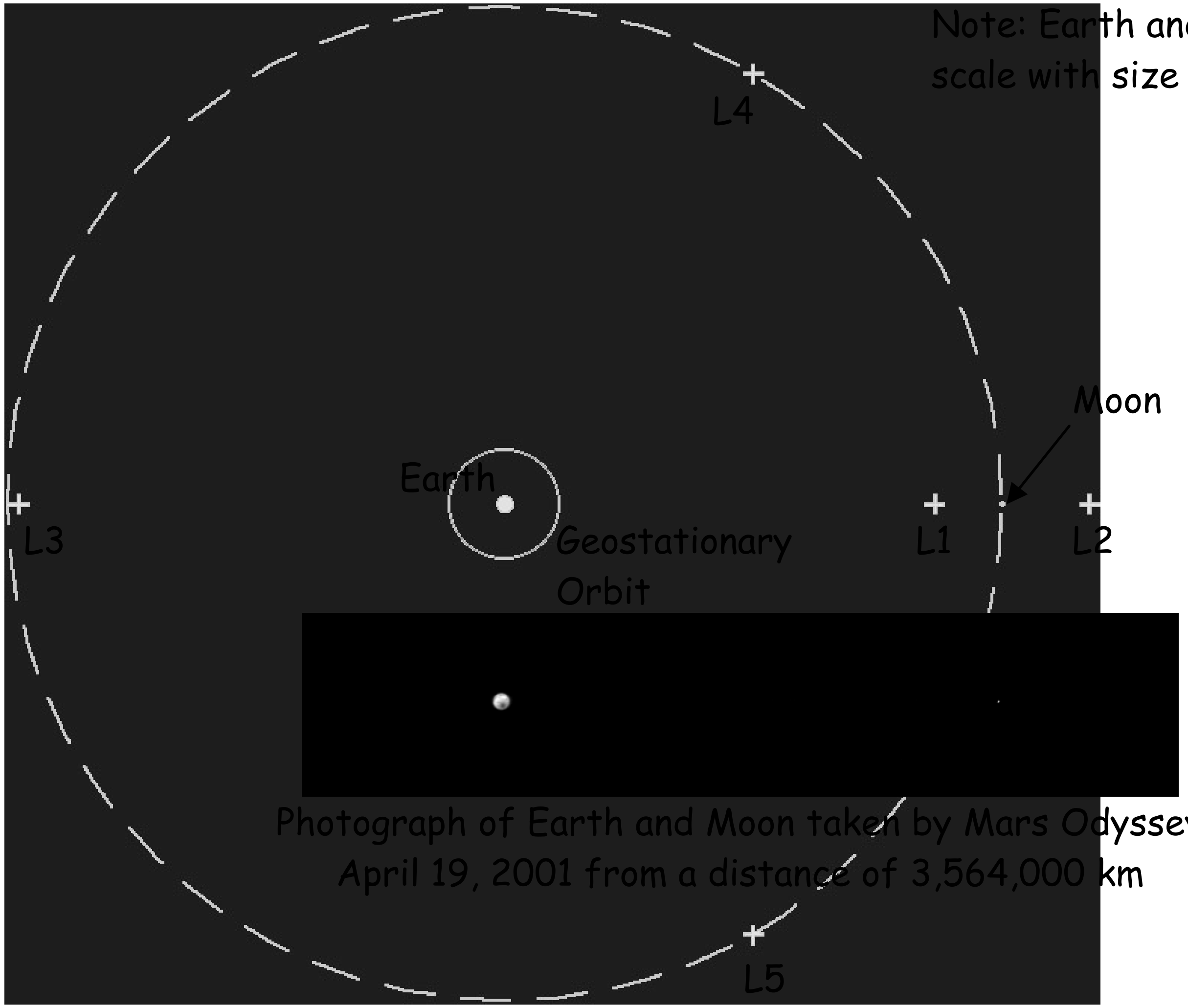
- Gravitation
- Electromagnetic Radiation
- Atmospheric Particles
- Solar Wind Particles
- Ionizing Radiation
- Micrometeoroids/Orbital Debris
- Spacecraft Charging
- Planetary Environments

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."

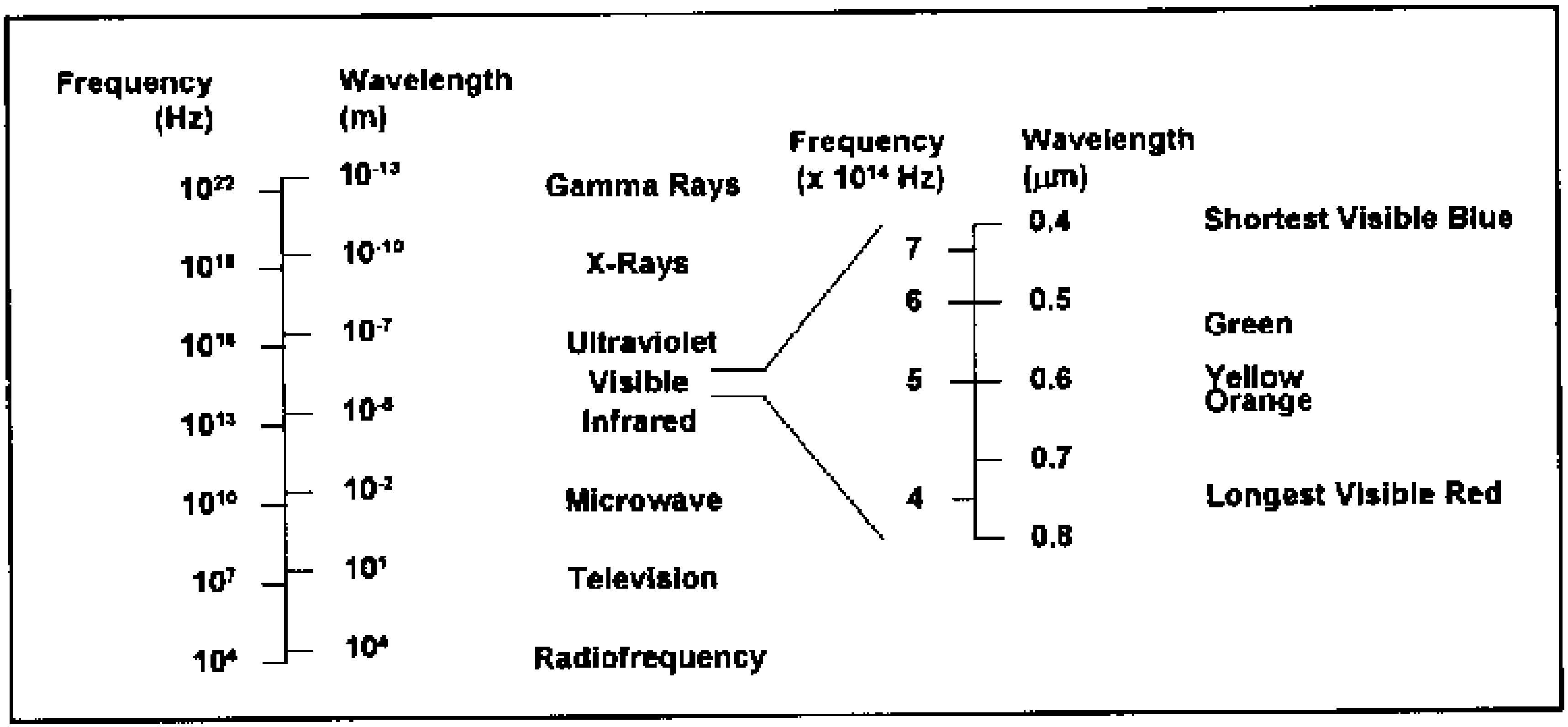
– Douglas Adams, *The Hitchhiker's Guide to the Galaxy*, 1979

The Earth-Moon System



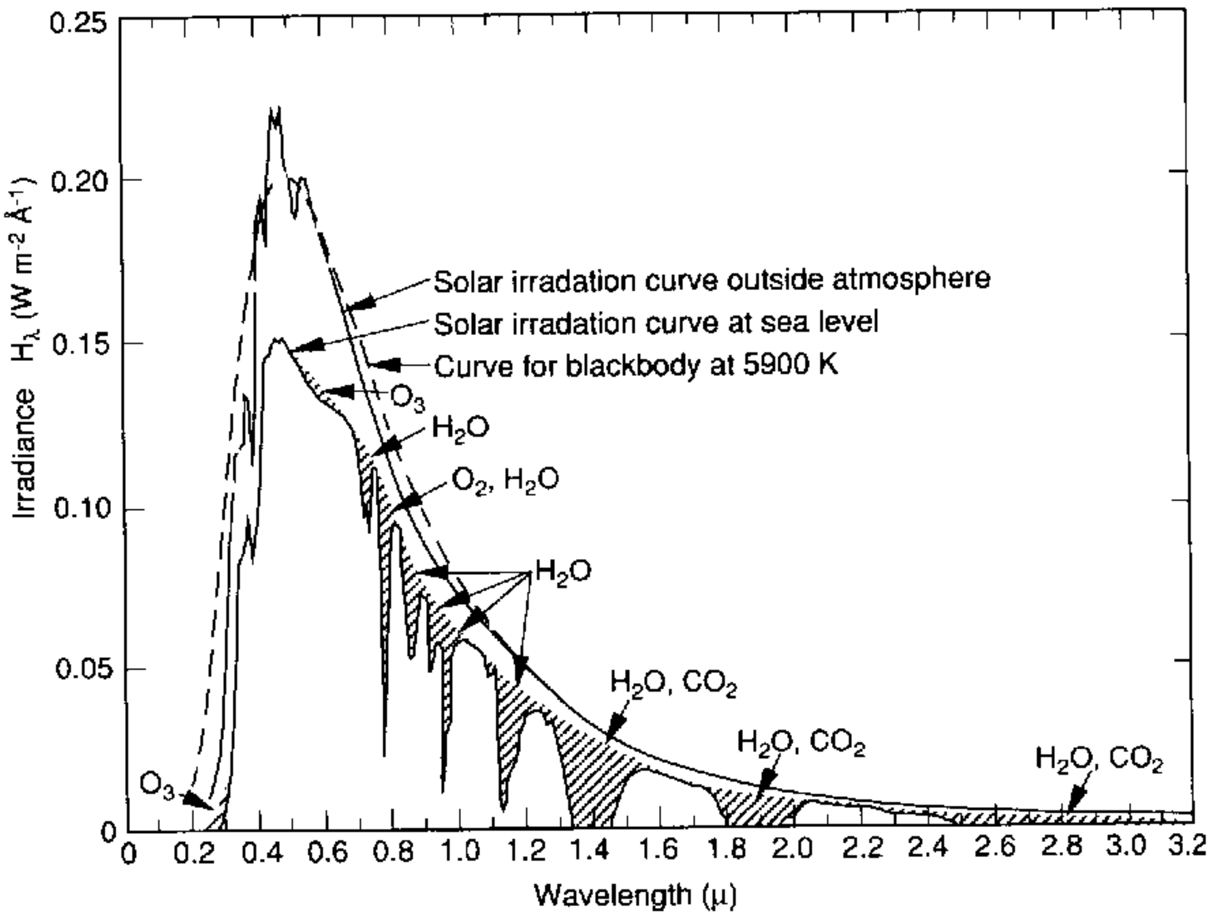
Photograph of Earth and Moon taken by Mars Odyssey April 19, 2001 from a distance of 3,564,000 km

The Electromagnetic Spectrum



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

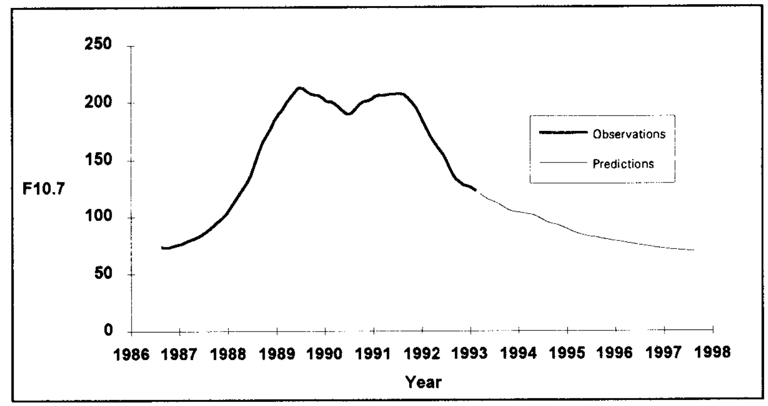
The Solar Spectrum



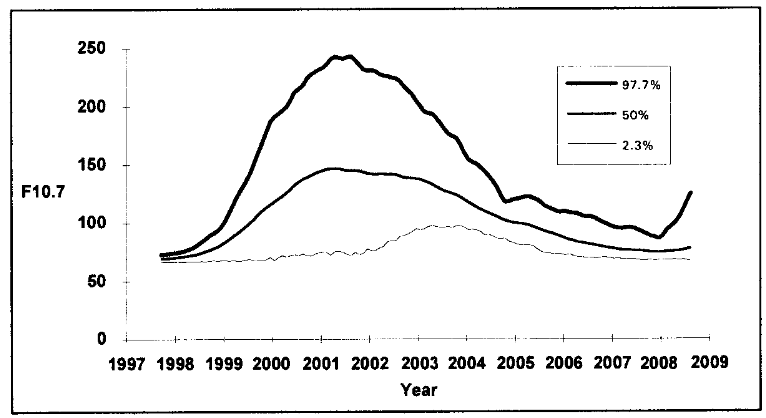
Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

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")



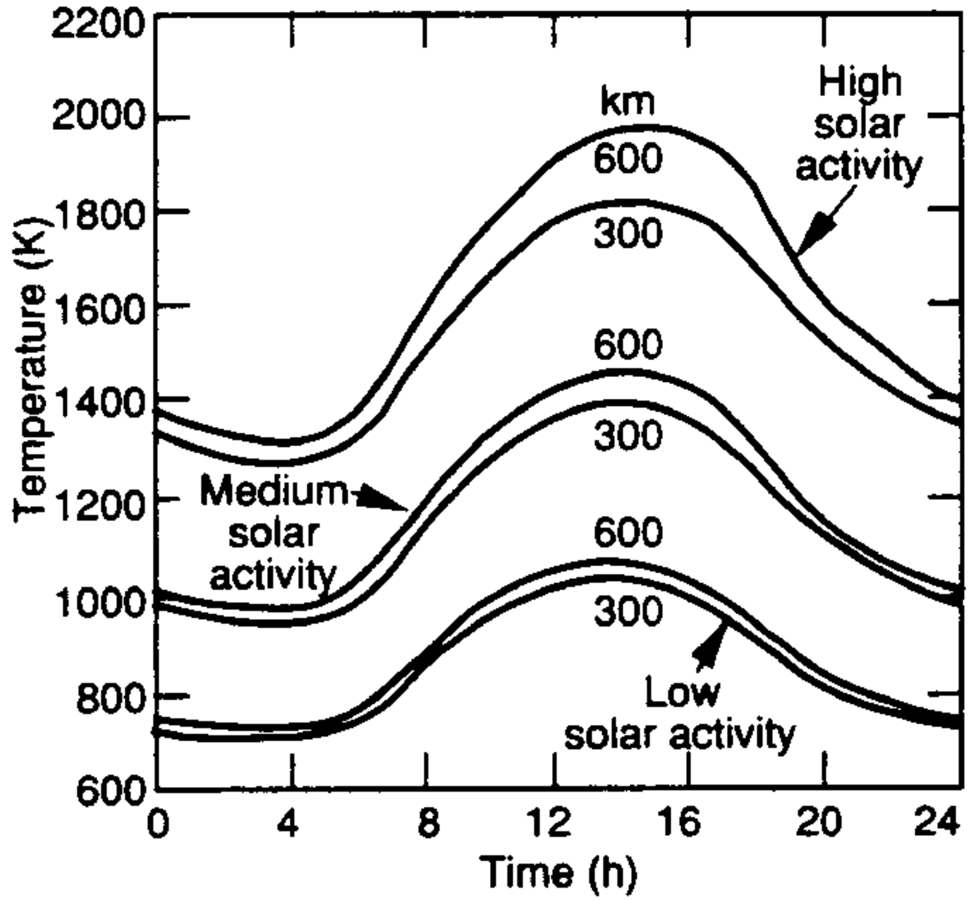
F10.7 values for solar cycle 22.



F10.7 values for solar cycle 23.

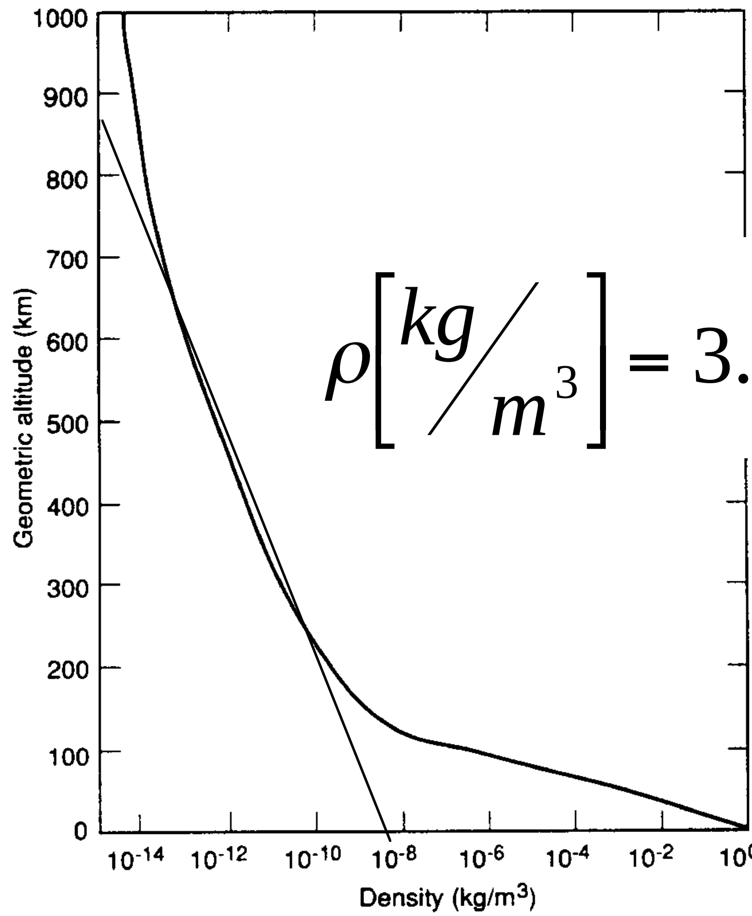
Ref: Alan C. Tribble, *The Space Environment*
Princeton University Press, 1995

Diurnal Variation of Atmosphere



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

Atmospheric Density with Altitude

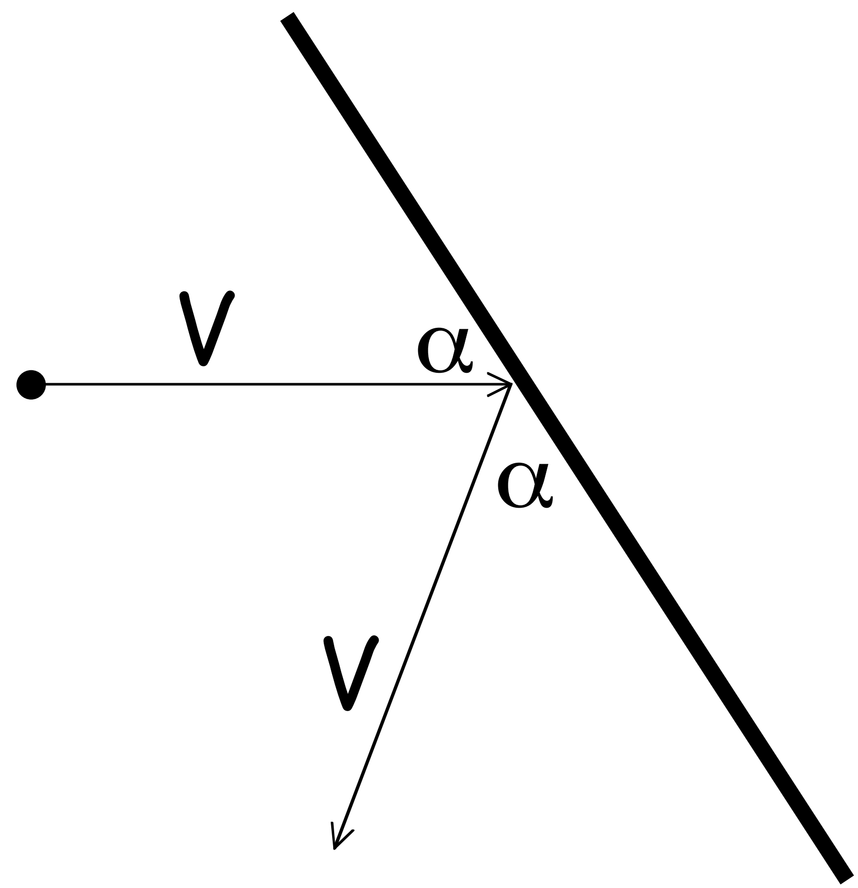


$$\rho\left[{}^{kg}\!/_{m^3}\right] = 3.875\times10^{-9} e^{-\frac{h[km]}{59.06}}$$

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

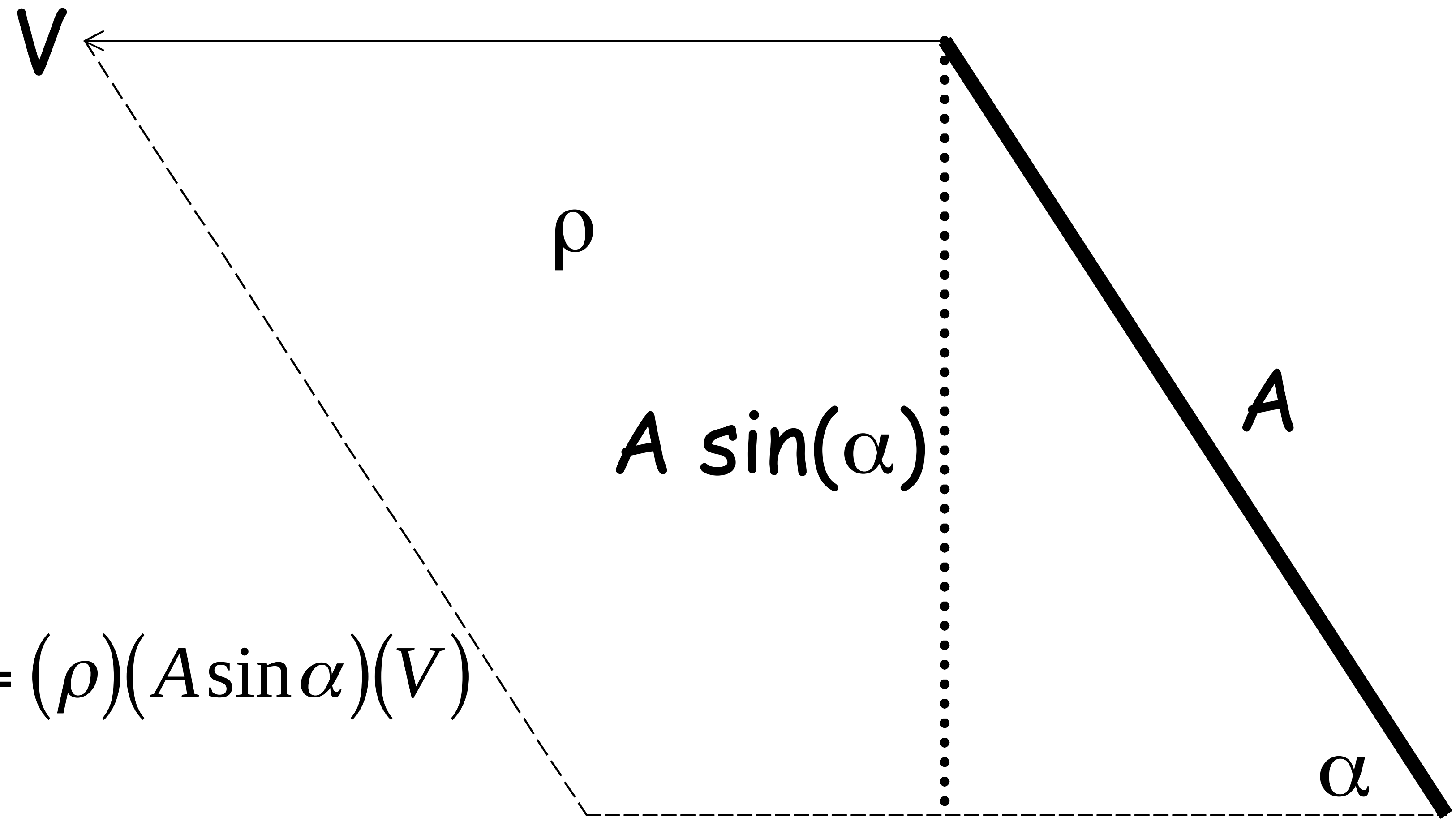
Newtonian Flow

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



Newtonian Analysis

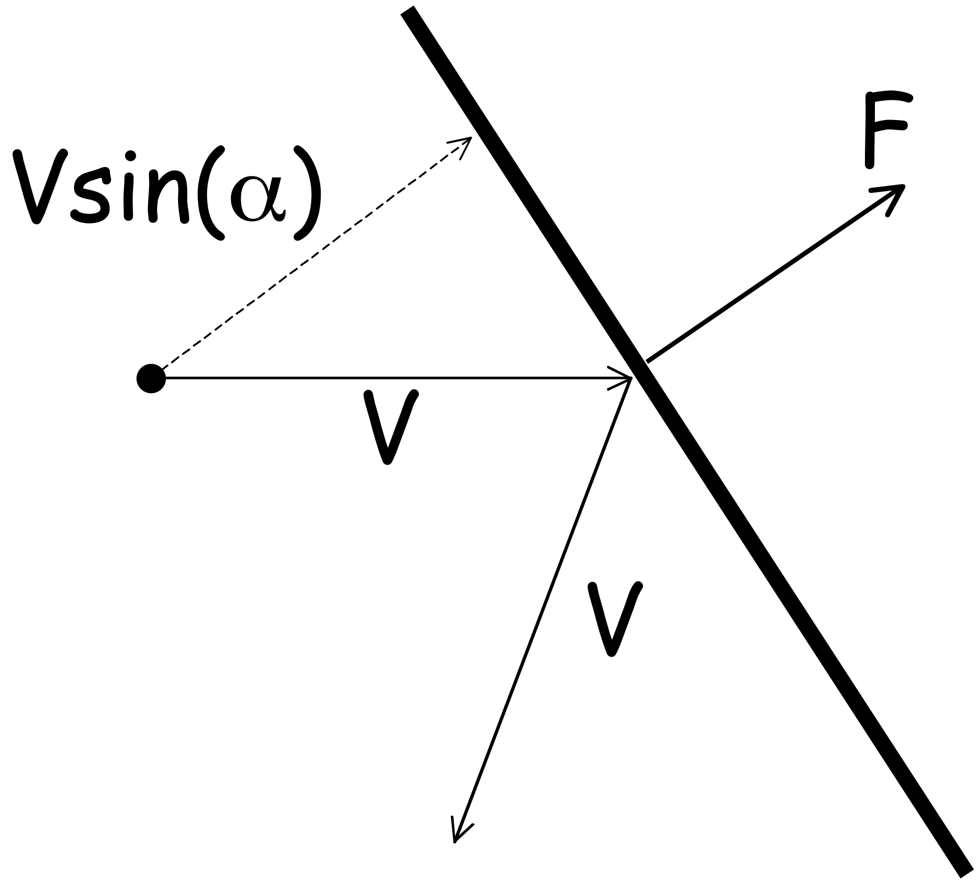
Mass flux = (density)(area swept)(velocity)



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

Momentum Transfer

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

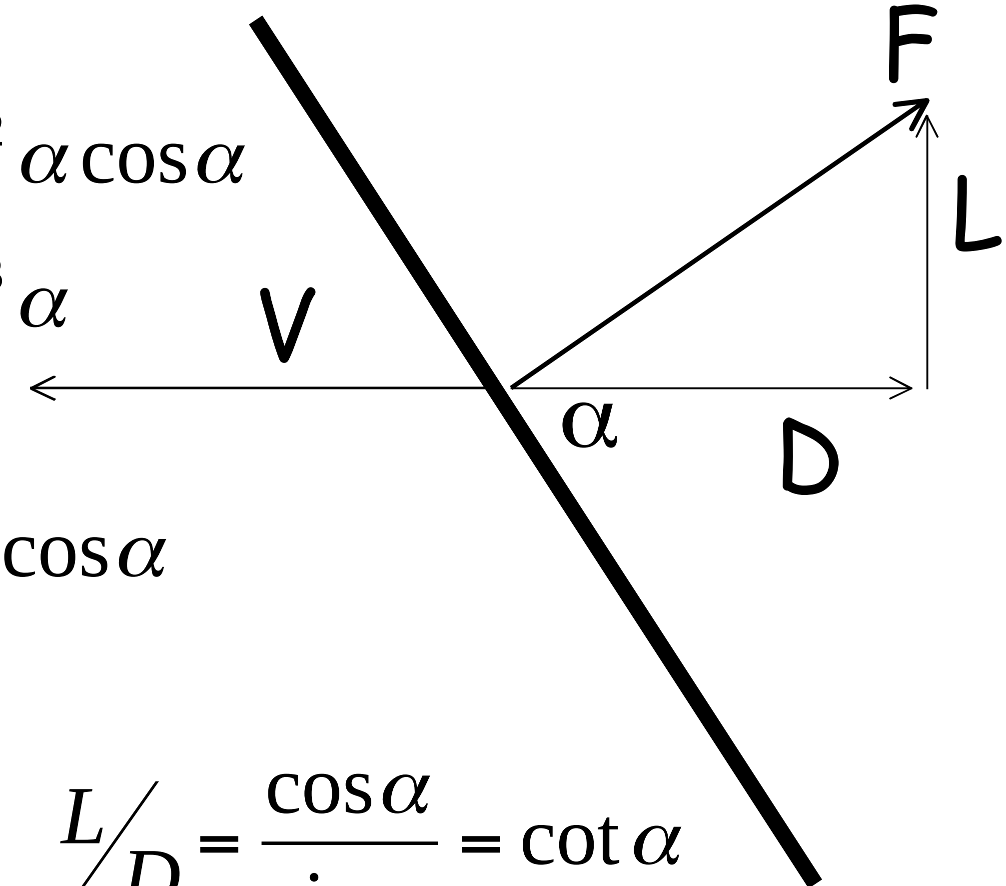


$$F = \frac{dm}{dt}\Delta V = \rho V A \sin\alpha \left(2V\sin\alpha\right) = 2\rho V^2 A \sin^2\alpha$$

Lift and Drag

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

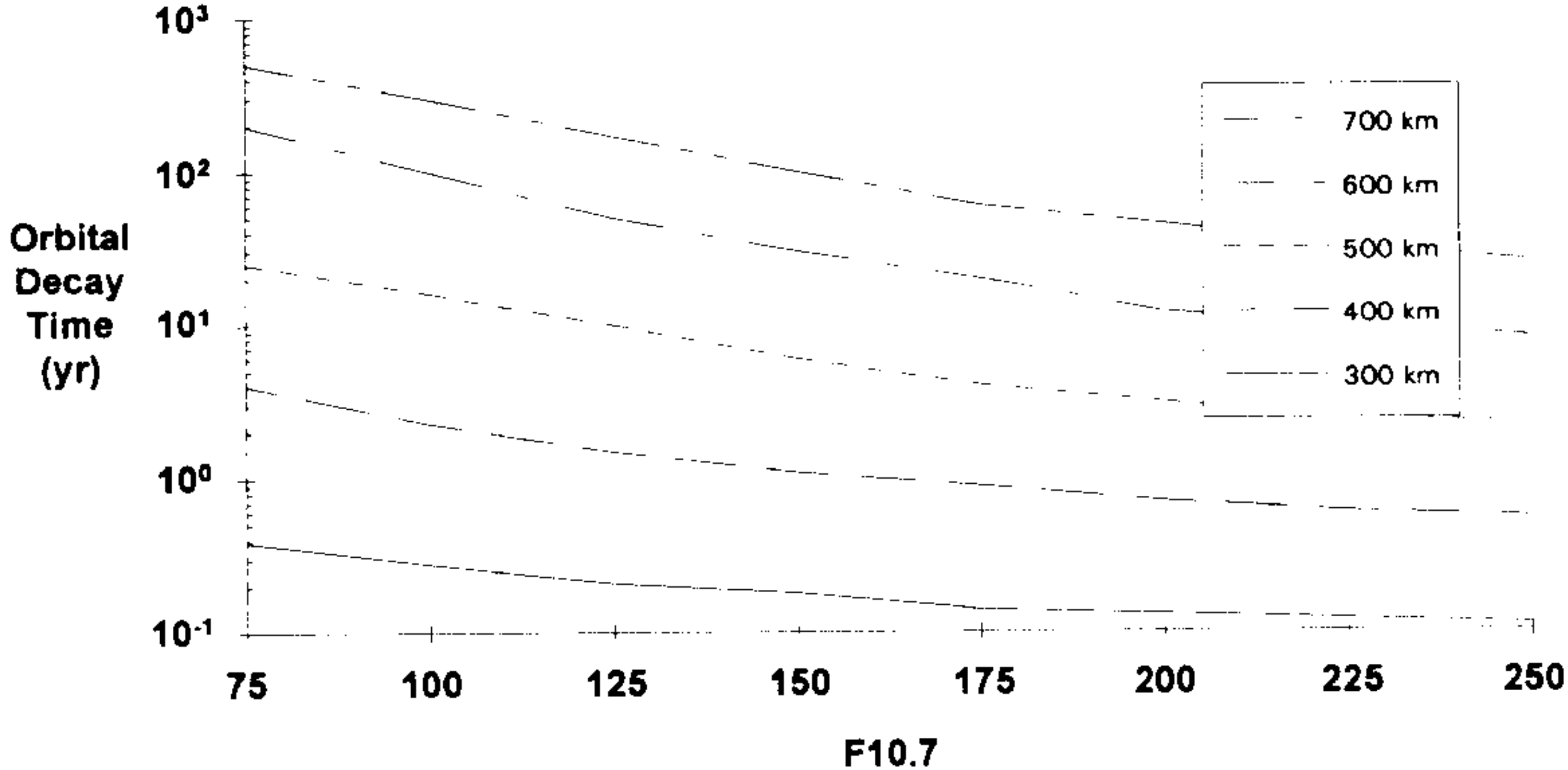
$$D = F\sin\alpha = 2\rho V^2 A\sin^3\alpha$$



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

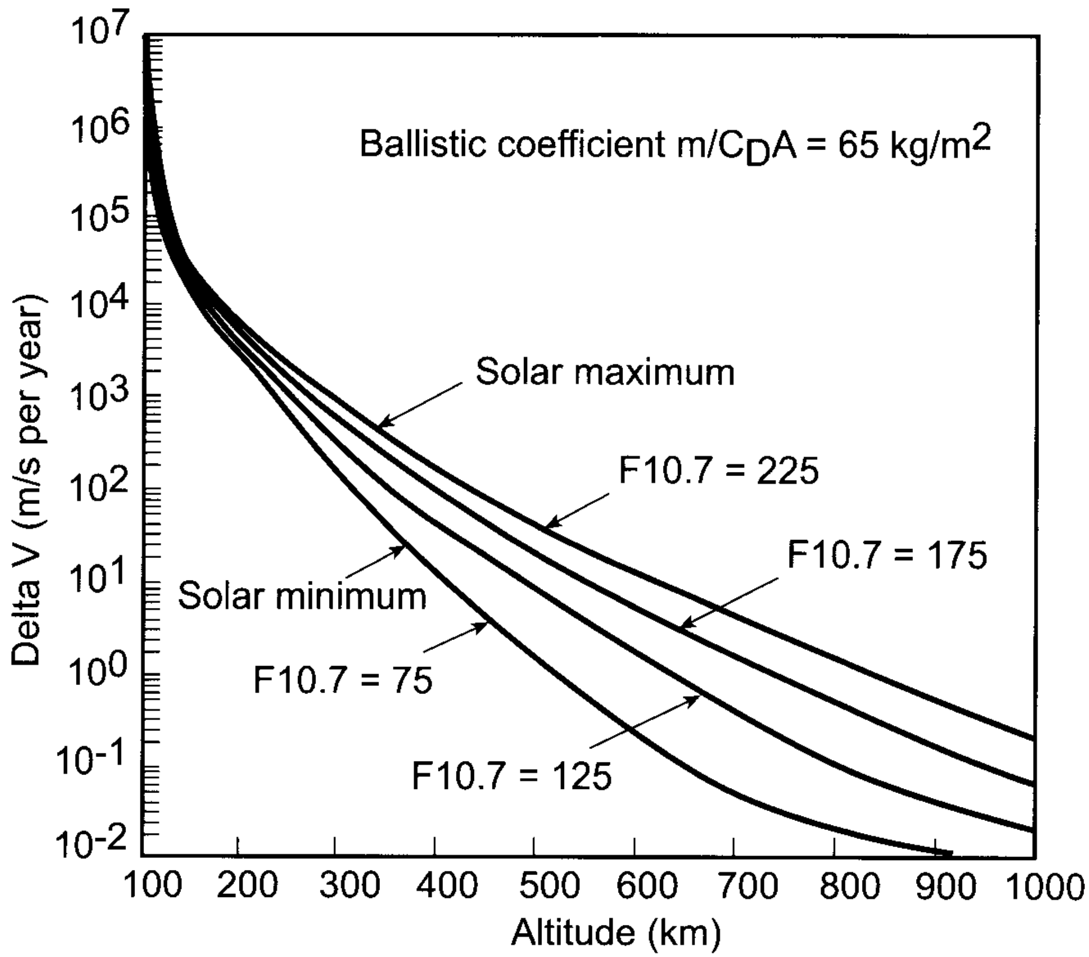
$$c_D = \frac{D}{\frac{1}{2}\rho V^2 A} = 4\sin^3\alpha \quad L/D = \frac{\cos\alpha}{\sin\alpha} = \cot\alpha$$

Orbit Decay from Atmospheric Drag



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

Makeup ΔV Due To Atmospheric Drag



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

Atmospheric Constituents at Altitude

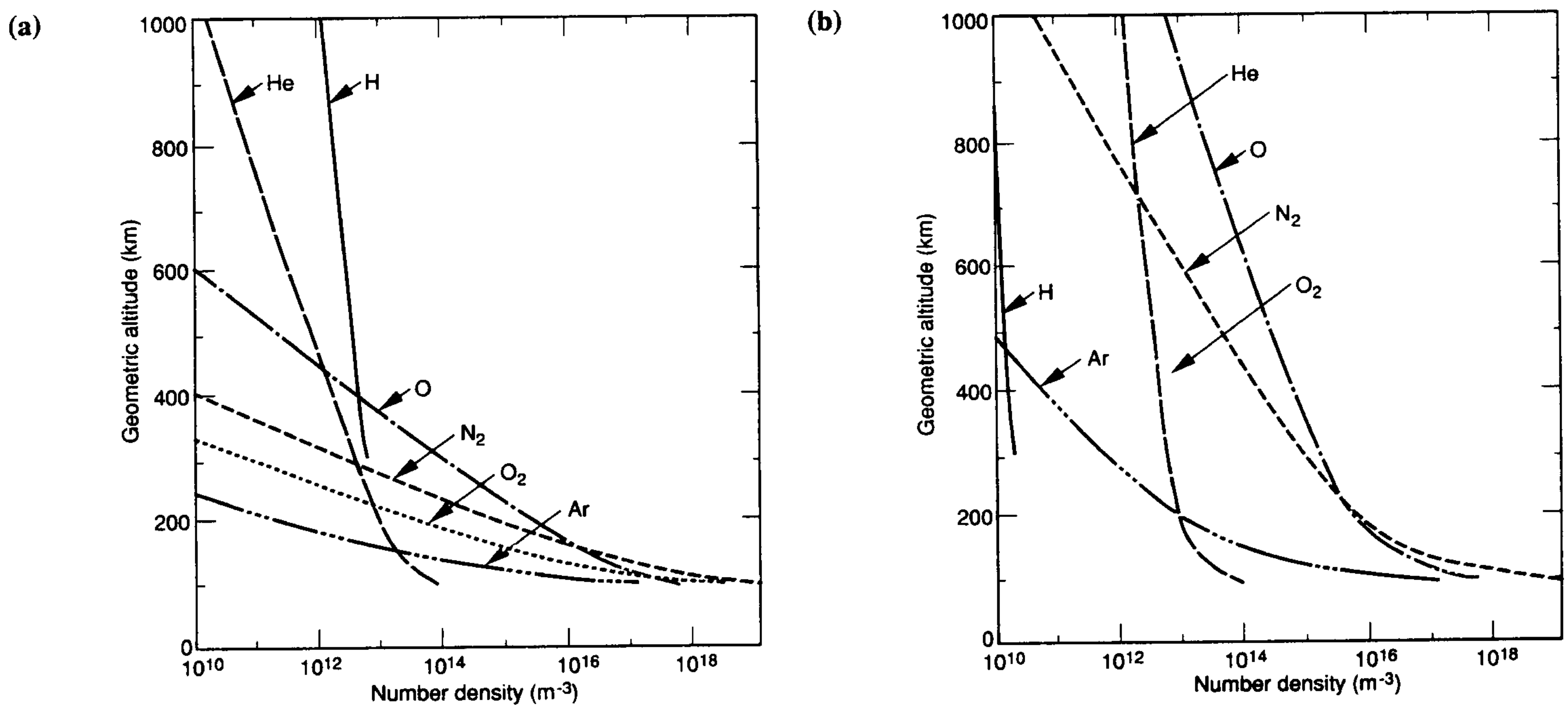


FIG. 2.3. **(a)** Relative concentrations of atmospheric constituents during periods of minimum solar activity. **(b)** Relative concentrations of atmospheric constituents during periods of maximum solar activity. (Adapted from *U.S. Standard Atmosphere*, 1976.)

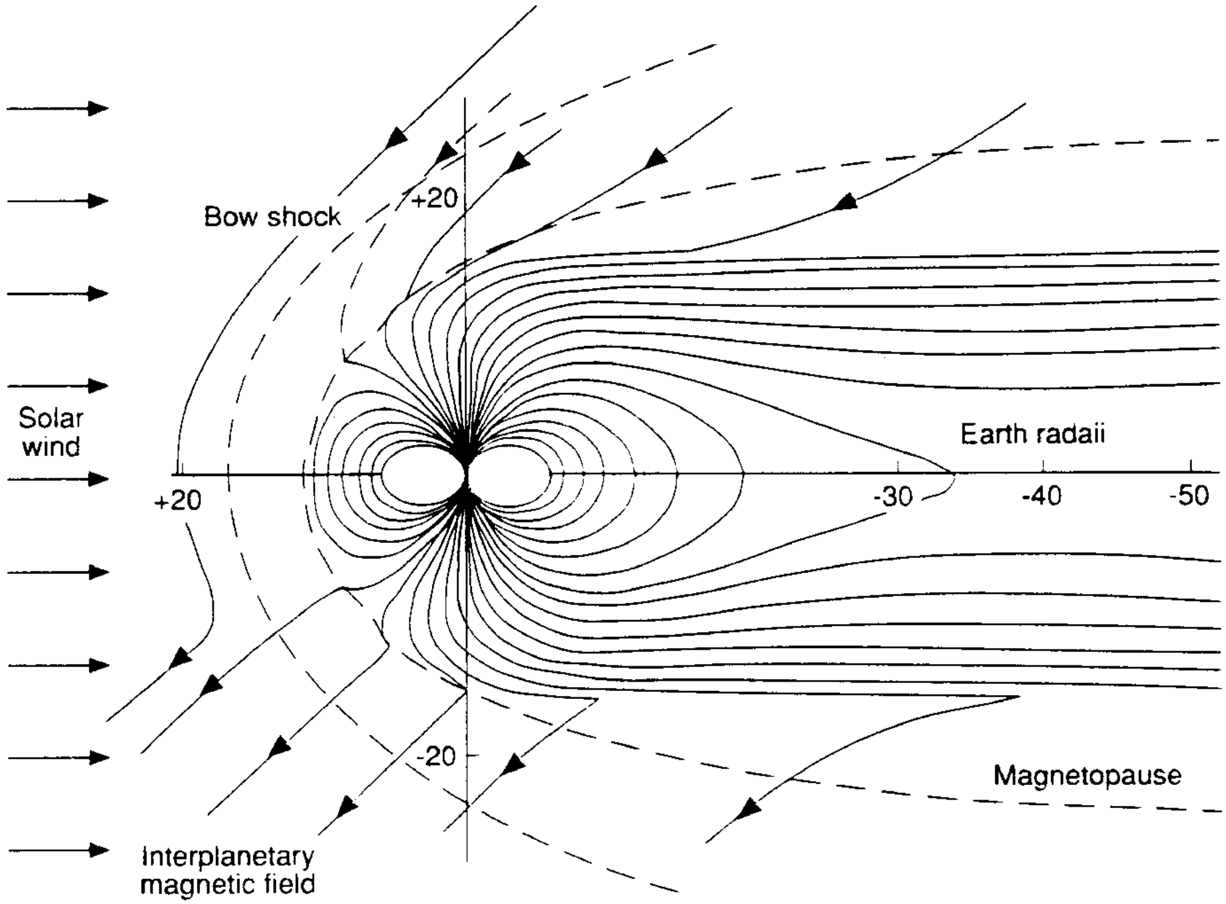
Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

Atomic Oxygen Erosion Rates

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

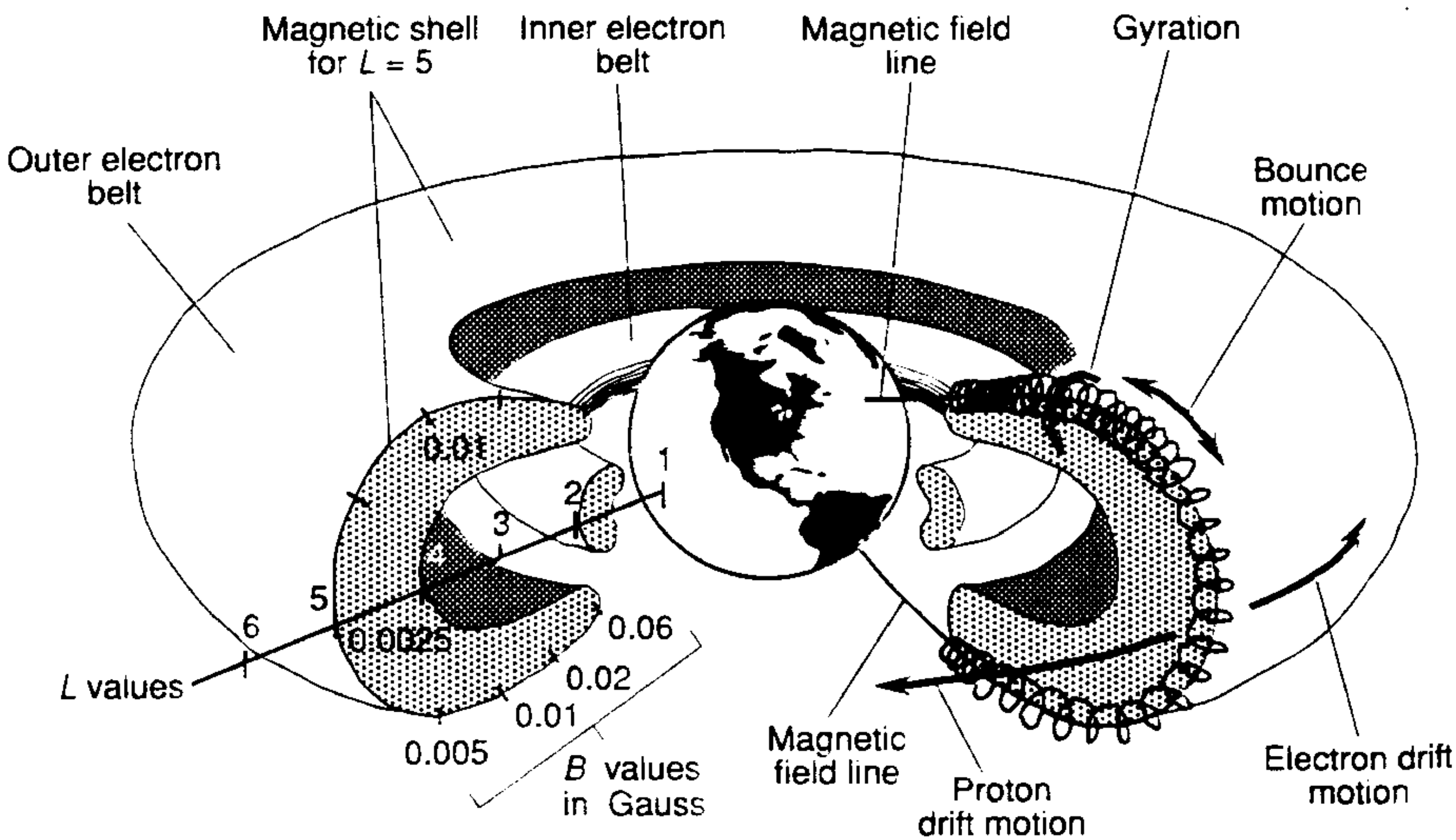
Material	Erosion Rate (mm/yr)
Silver	.22
Chemglaze Z302	.079
Mylar	.071
Kapton	.061
Epoxy	.048
Carbon	.020
Teflon	.00064
Aluminum	.0000076

The Earth's Magnetic Field



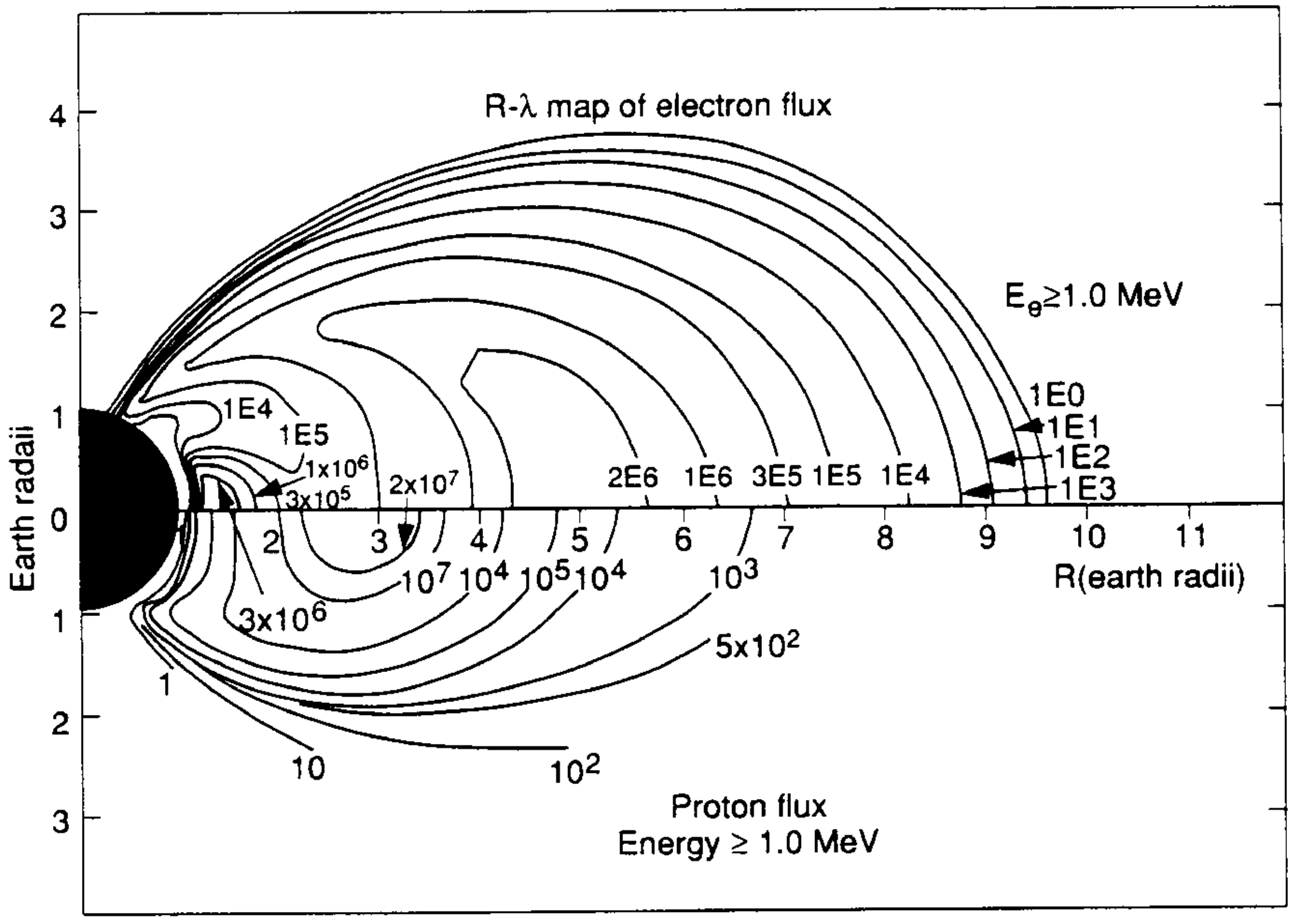
Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

The Van Allen Radiation Belts



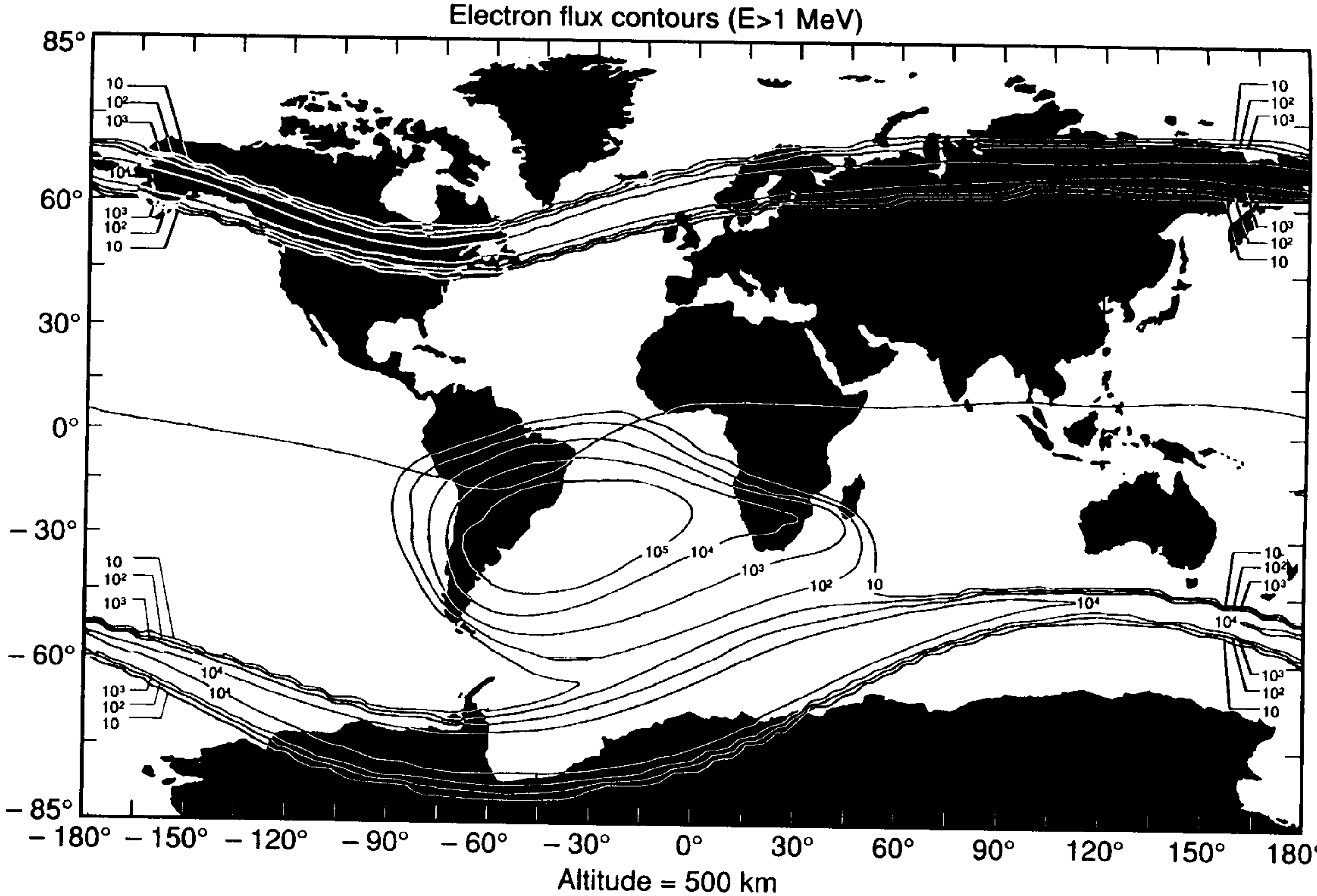
Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

Cross-section of Van Allen Radiation Belts



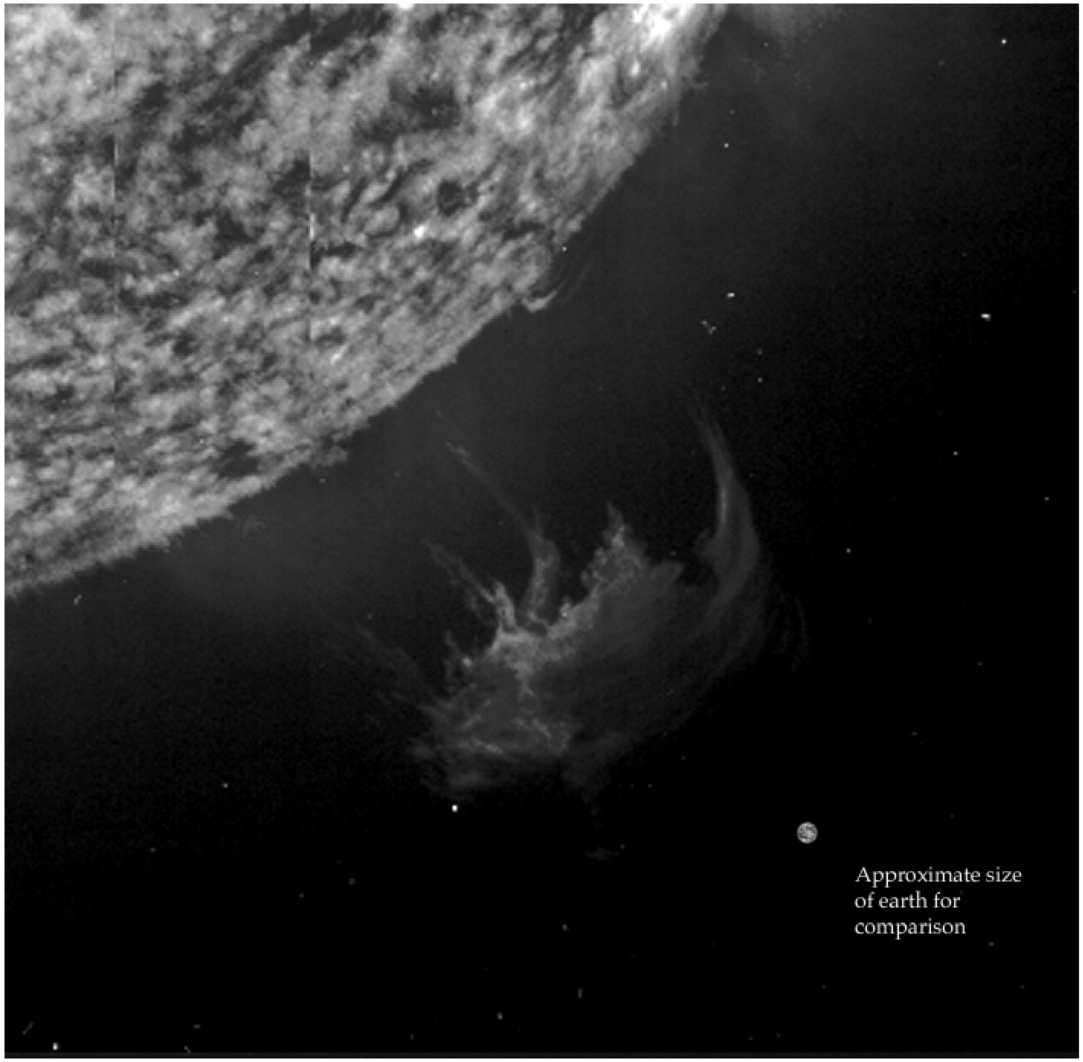
Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

Electron Flux in Low Earth Orbit

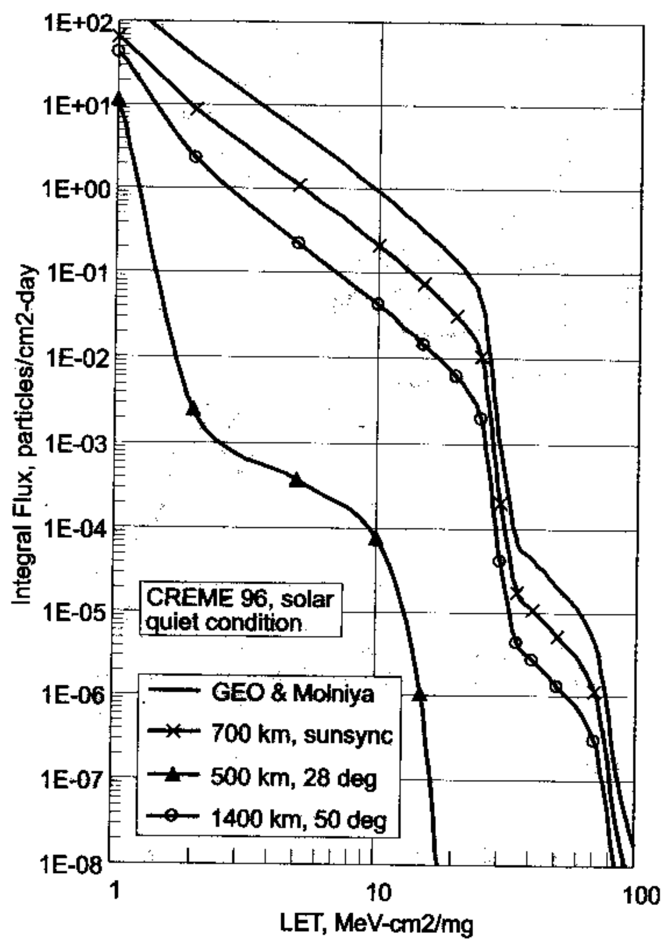


Ref: V. L. Pisacane and R. C. Moore, *Fundamentals of Space Systems* Oxford University Press, 1994

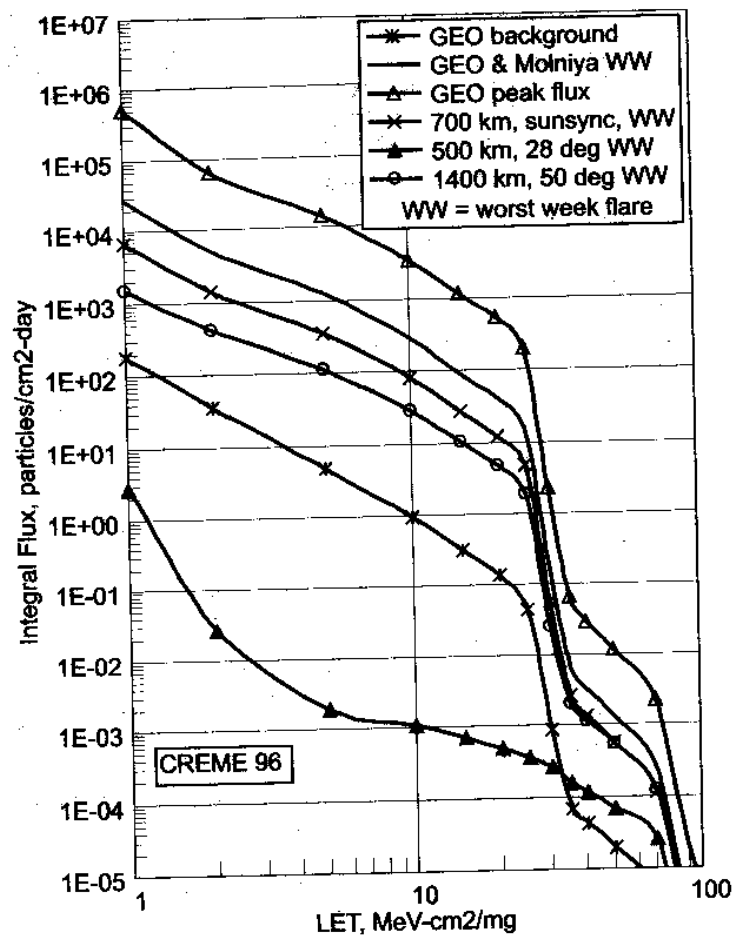
The Origin of a Class X1 Solar Flare



Heavy Ion Flux



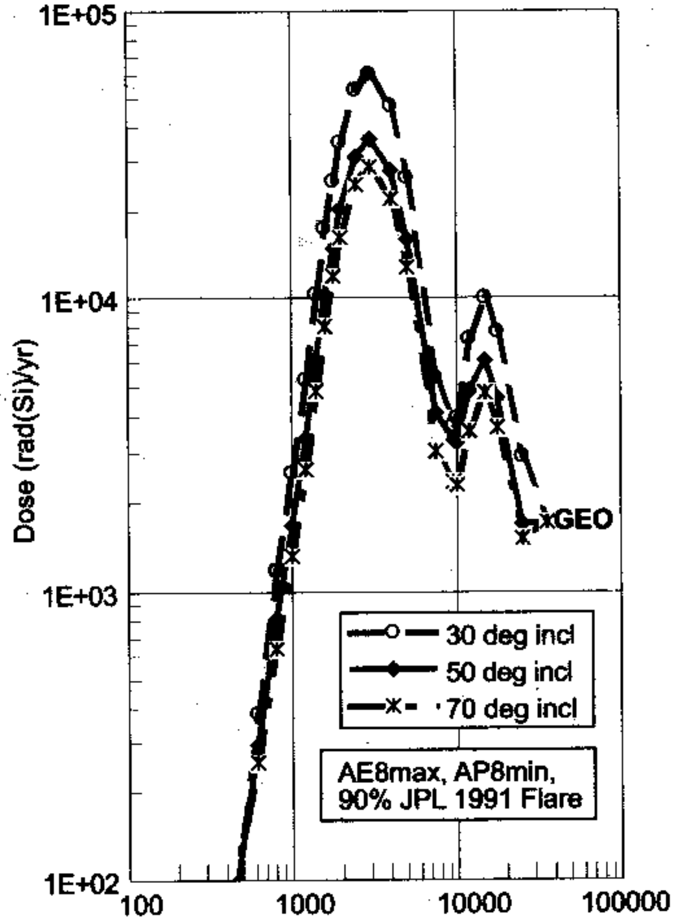
Background



Solar Flare

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

Radiation Dose vs. Orbital Altitude

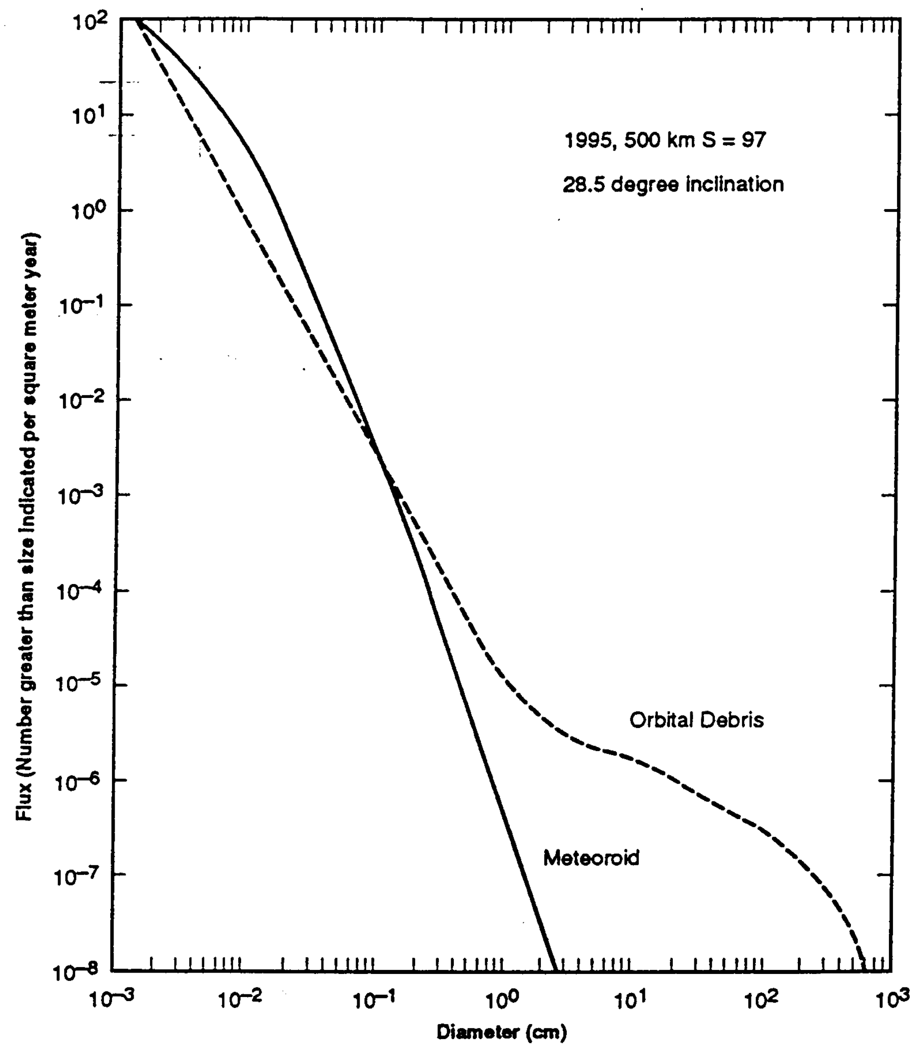


300 mil (7.6 mm) Al shielding

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

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

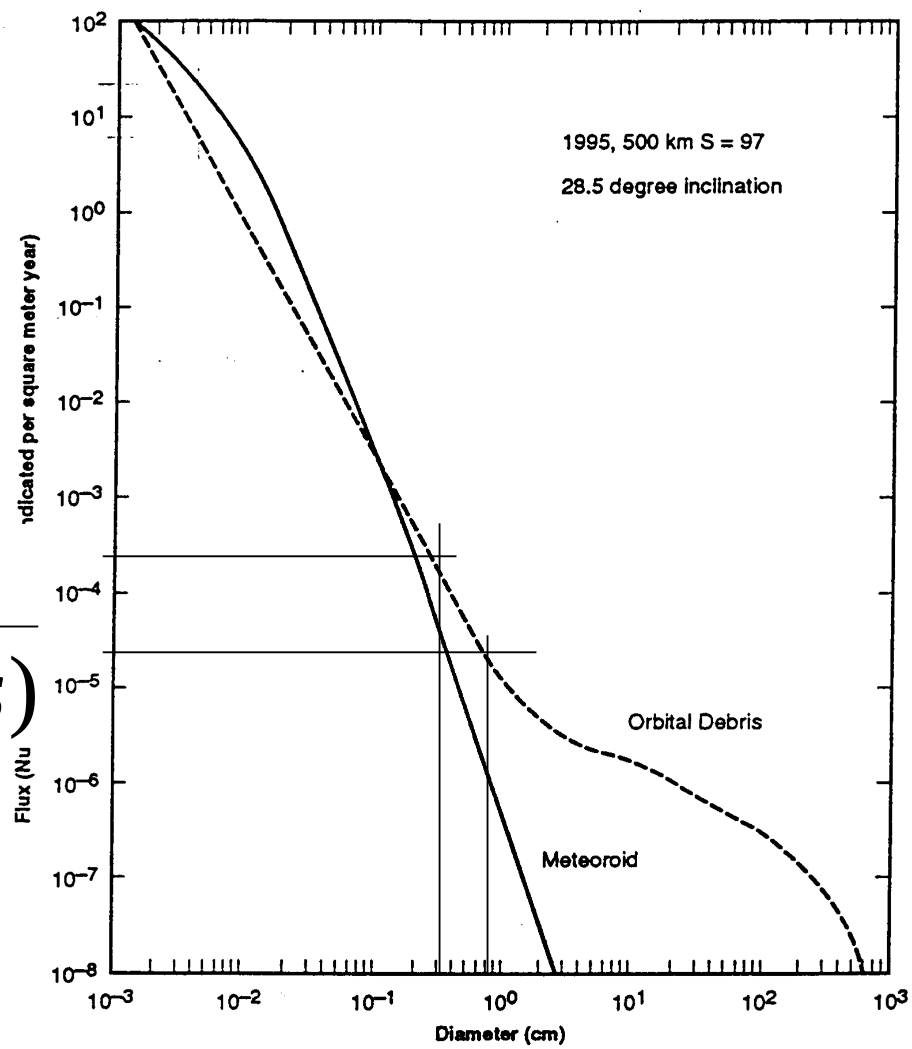
Surface area=221 m^2

Flux value for one hit in 20 years

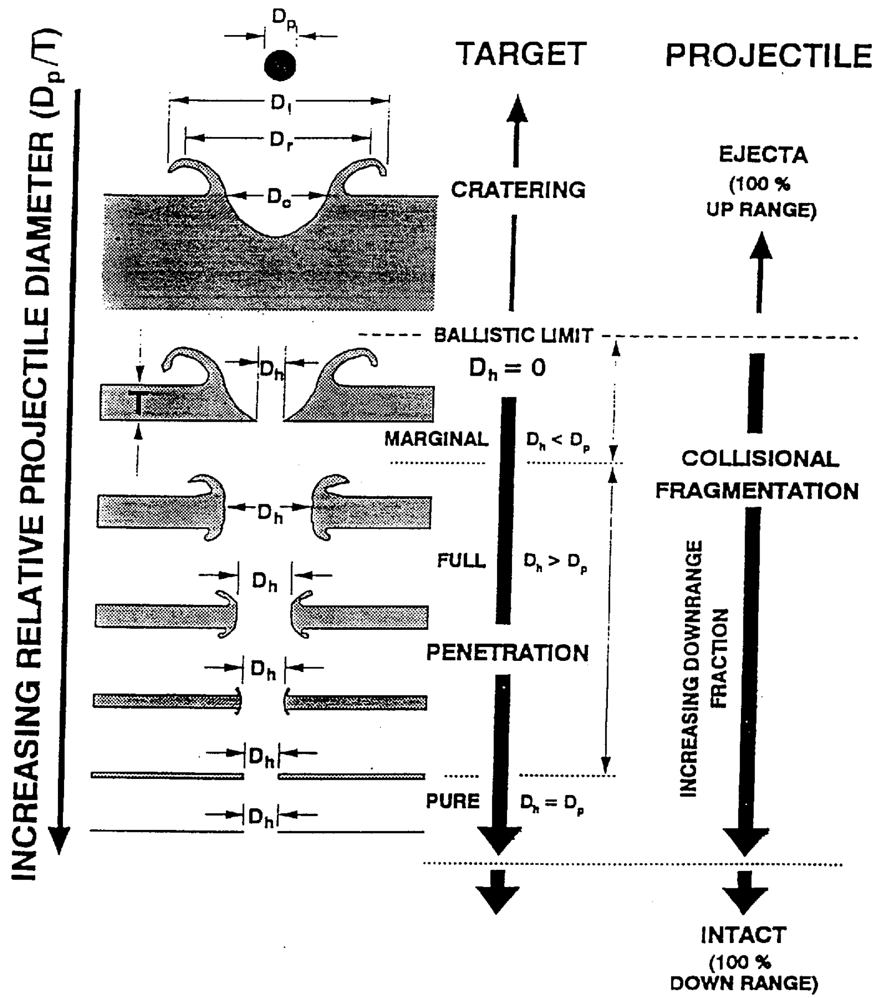
$$Flux = \frac{1\,hit}{(221\,m^2)(20\,yrs)}$$

Flux=2.26x10^{-4} hits/m^2-yr (3mm)

For 0.1 hits/20 years, allowable
flux= 2.26x10^{-5} hits/m^2-yr (9 mm)



Damage from MMOD Impacts



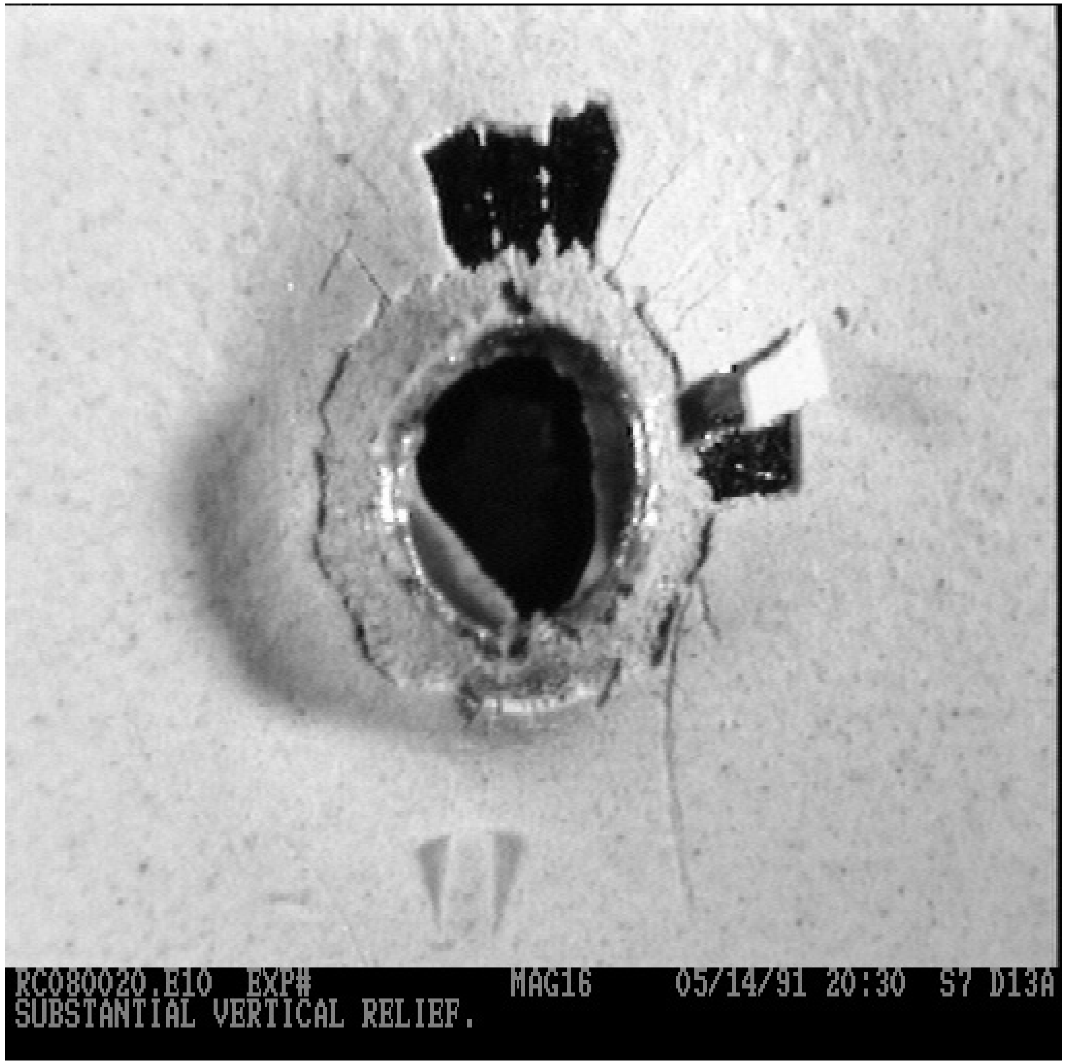
Long Duration Exposure Facility (LDEF)

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

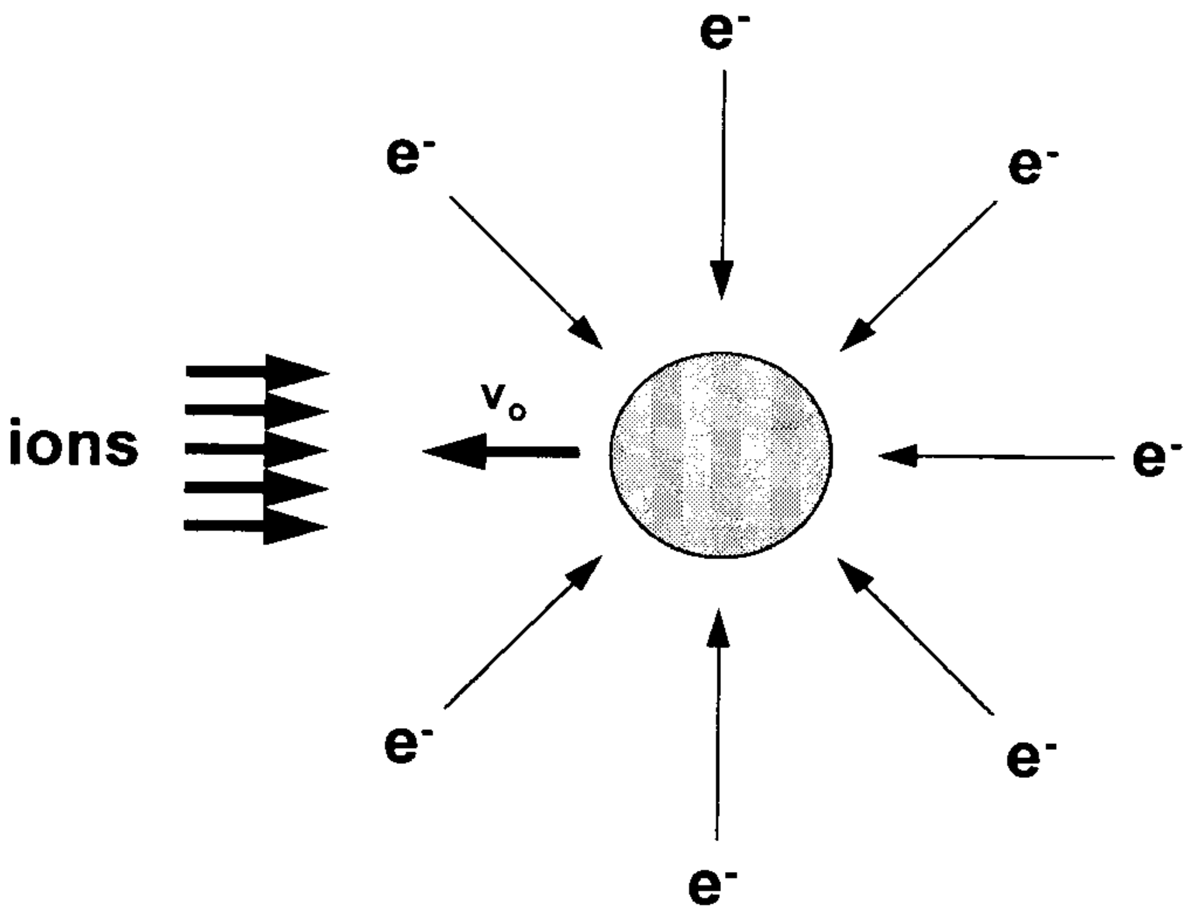
Surprising Results from LDEF

- 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

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 Density	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

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