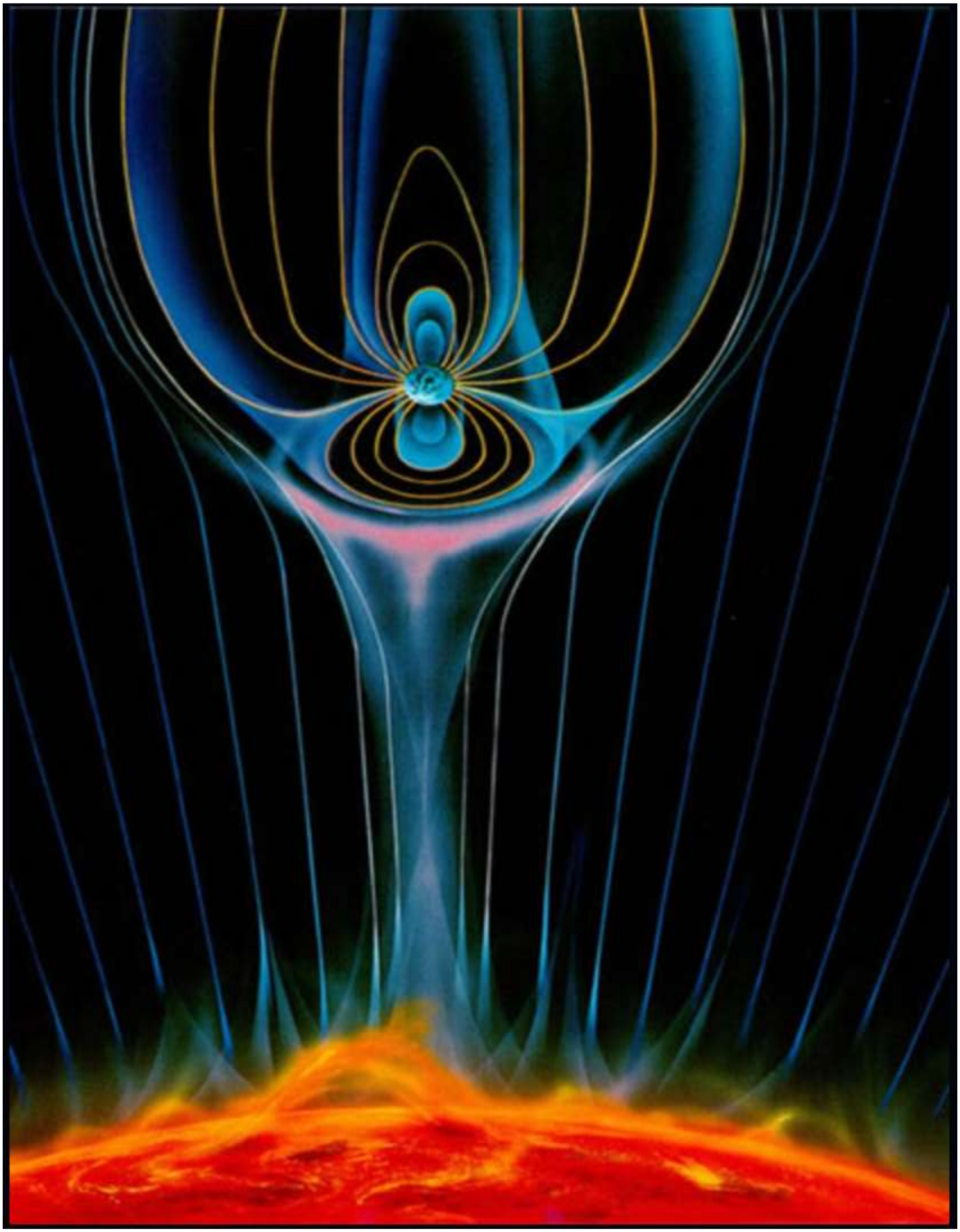
Spacecraft Environment

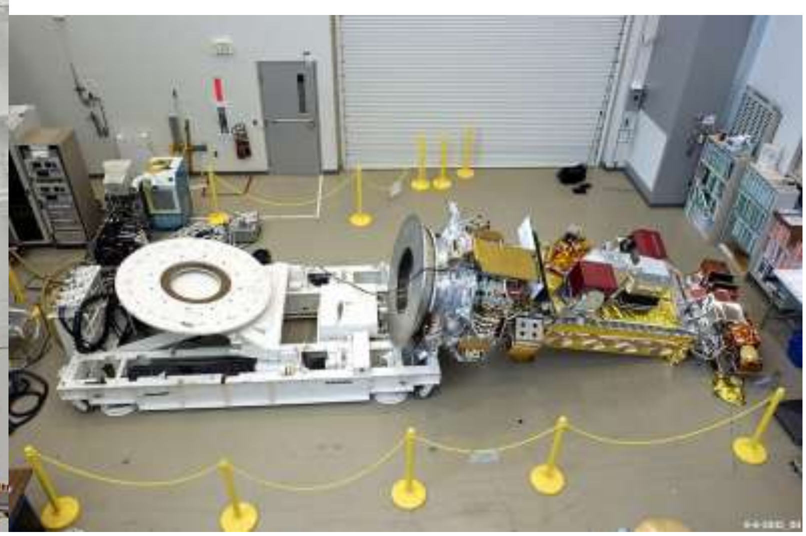


Spacecraft Environment

- Most of spacecraft's life in space, but must also survive manufacture, shipping, and launch
- Manufacturing & storage environment: cleanliness, humidity, movement care

- Example: NOAA-N Prime weather satellite 2003

  On September 6, 2003, the satellite was badly damaged while being worked on at the Lockheed Martin Space Systems factory in Sunnyvale, California. The satellite fell to the floor as a team was turning it into a horizontal position. A NASA inquiry into the mishap determined that it was caused by a lack of procedural discipline throughout the facility. While the turn-over cart used during the procedure was in storage, a technician removed twenty-four bolts securing an adapter plate to it without documenting the action. The team subsequently using the cart to turn the satellite failed to check the bolts, as specified in the procedure, before attempting to move the satellite. Repairs to the satellite cost $135 million.



Launch Environment

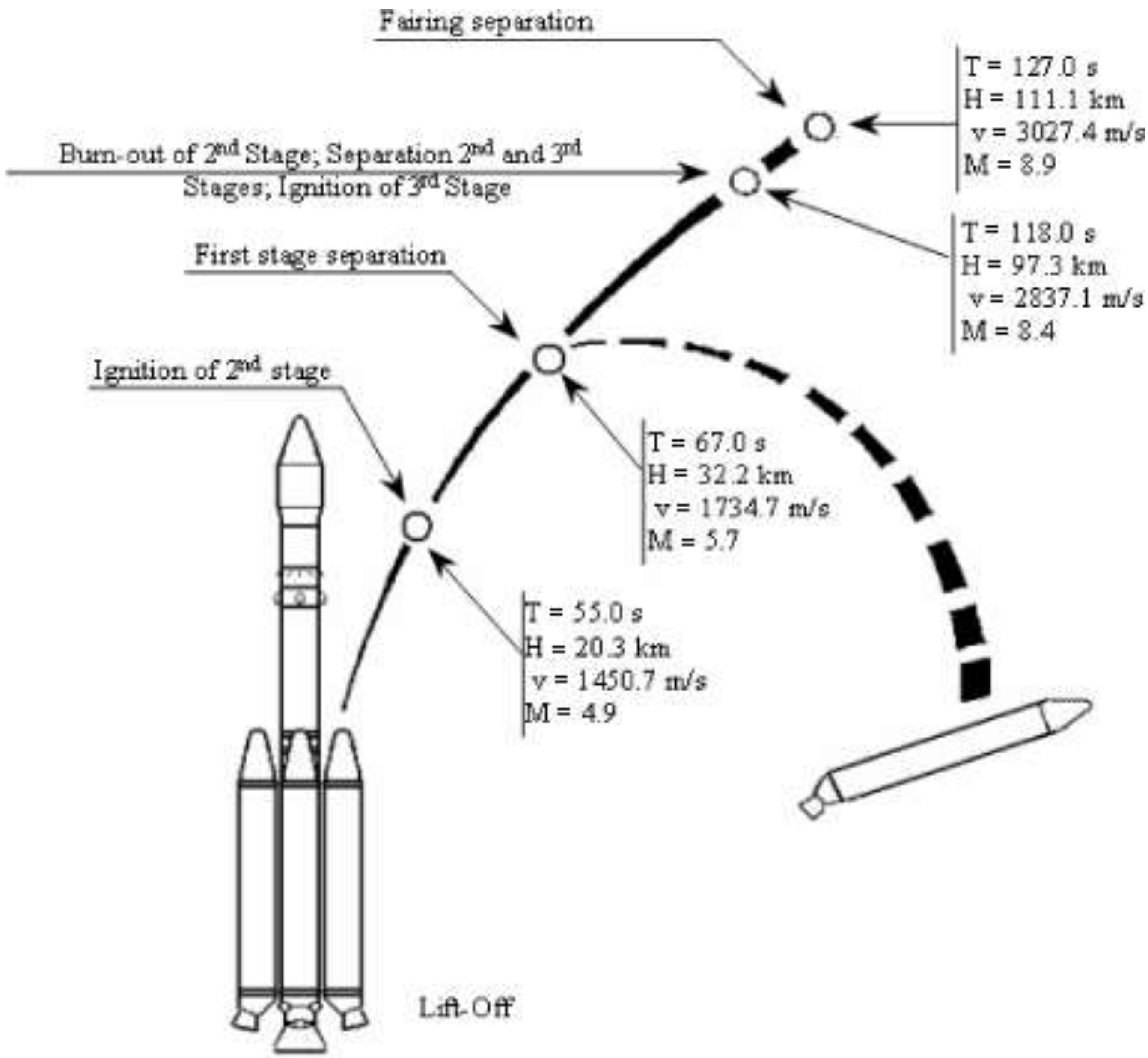


Figure 2. VLS trajectory during the atmospheric flight.

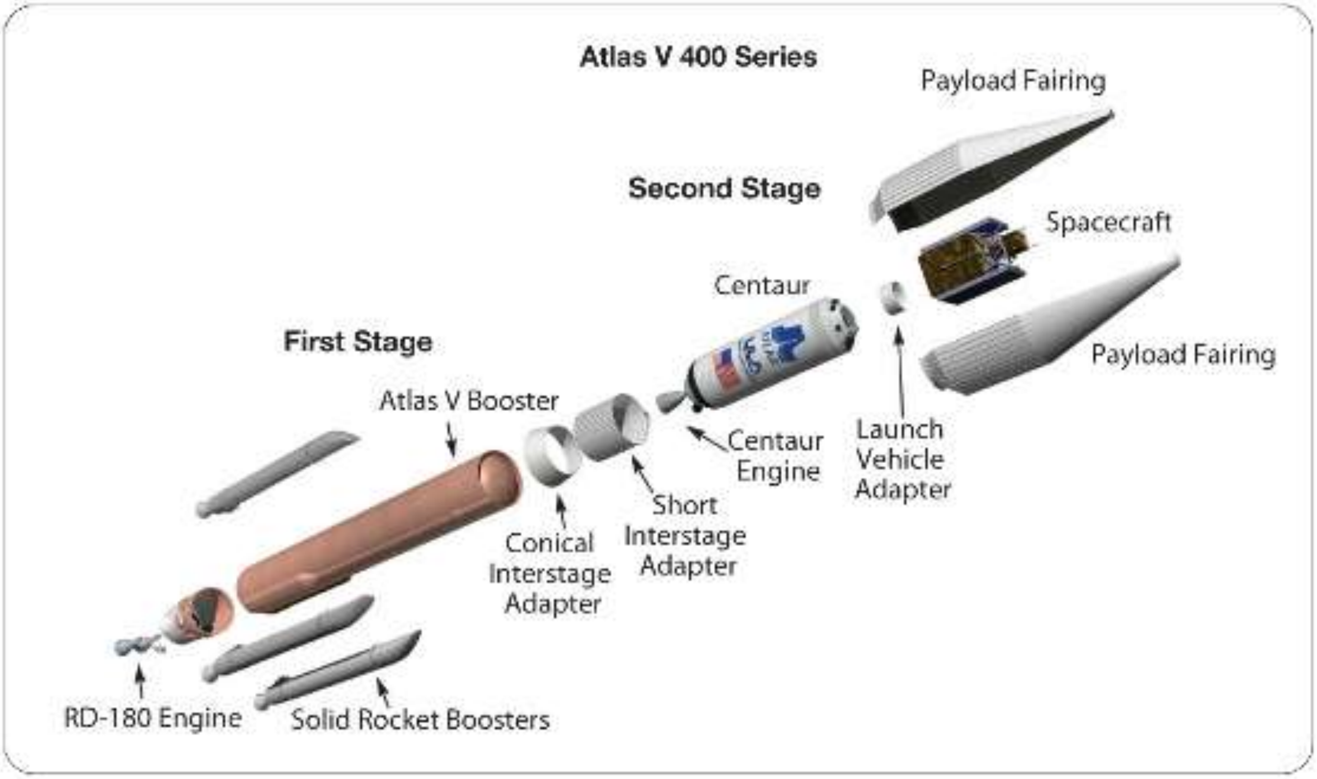
2.2 Launch Environment

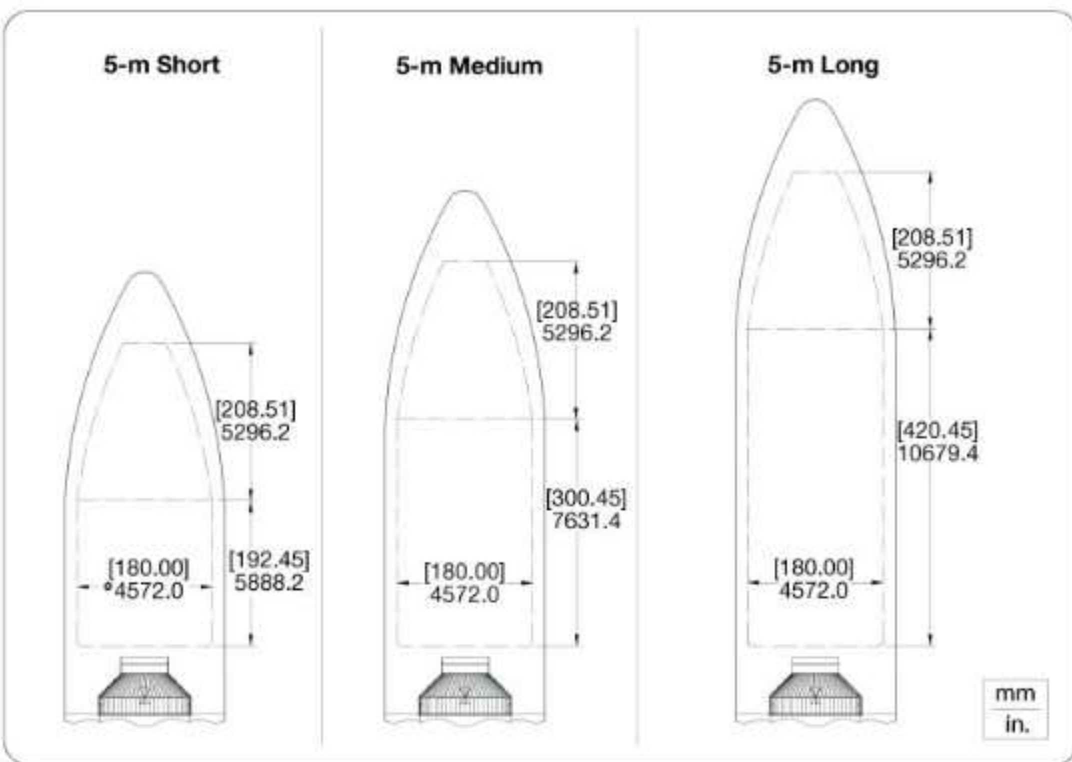
- **Payload vibration due to**
  - **Acoustic (fluctuation pressure field)**
  - **Structural Vibration**
- **Mean g-loads of launch, ascent**
- **Coupled loads: complex mass/spring system**
- **Mechanical shock: pyros**
- **Thermal dynamics**
- **Rapid –dp/dt during ascent**

Acoustic/Vibration

- **Propulsion systems**
  - **Thrust -> struct vibration**
  - **Rotating machinery & plumbing (turbopumps)**
  - **Ground reflection of exhaust pressure field**
- **Aerodynamic buffeting**
  - **Separated flow on external surfaces**
  - **Transient shocks**
- **Two peak disturbance regimes:**
  - **Lift-off: acoustic reflection (indirect) & structurally-transmitted vibration (direct)**
  - **Transonic, maq q, shock-induced BL separation**

Spacecraft (payload) launched inside shroud:





Design Noise & Vibration Spectrum: examples

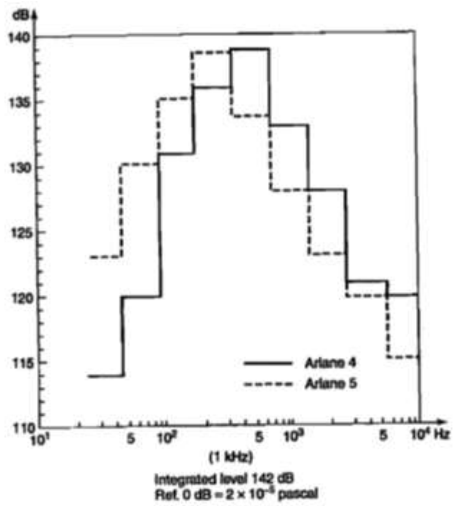


Figure 2.1 Ariane noise spectrum under SPELDA fairing, Ariane 4 [2] and SPELTRA, Ariane 5 [3]

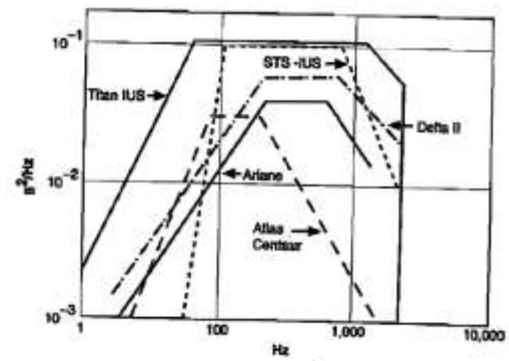
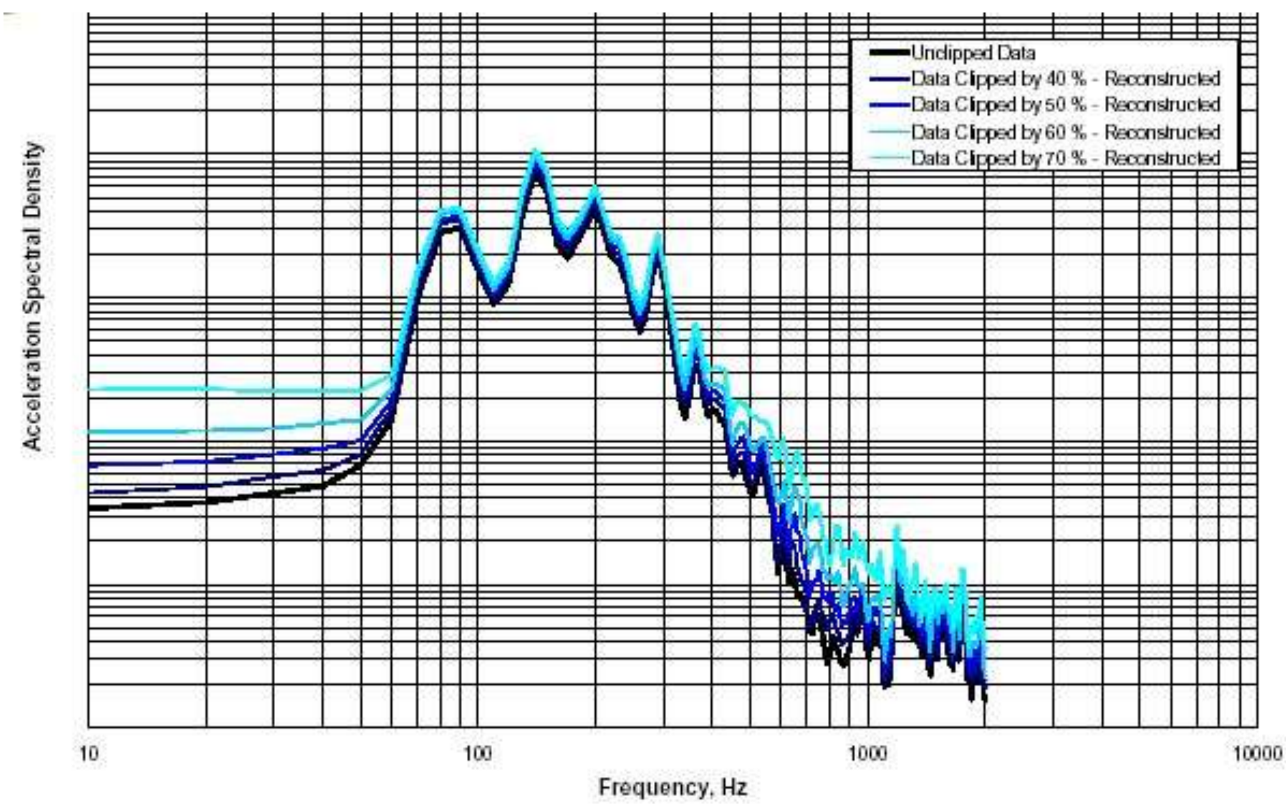


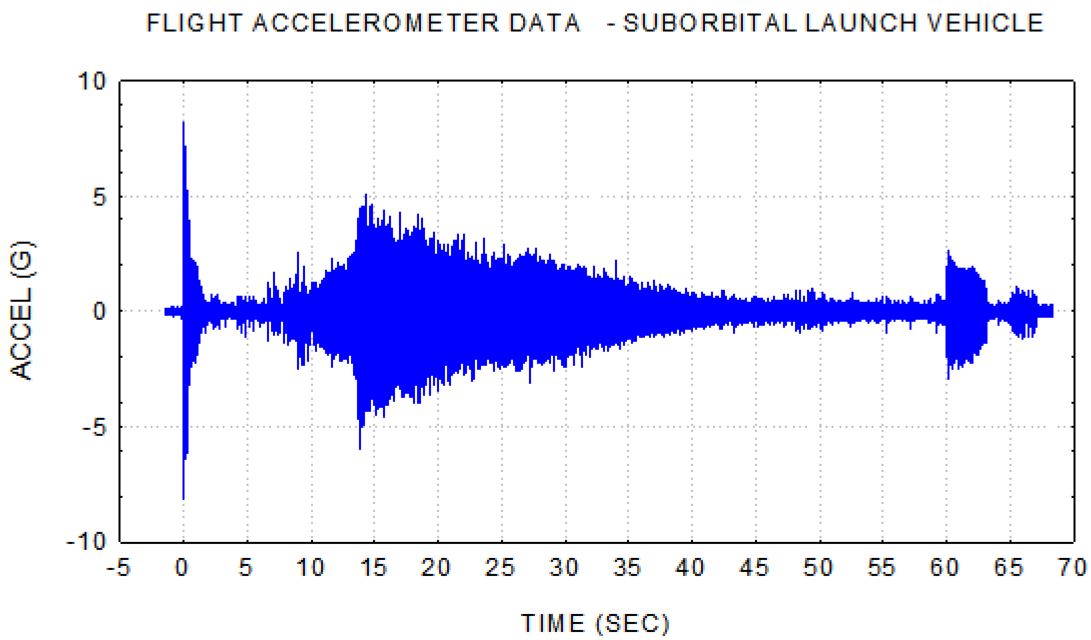
Fig. 18-10. Vibrational Environment for Launch Systems. The launch vehicle and fairing dictate the environment. The vertical axis is the power spectral density.



Spectrum of vibrational accelerations at the payload attachment for a Delta-II launch vehicle (Boeing).

Vibration Environment is temporally non-stationary:

- **Launch vehicle avionics components must be designed and tested to withstand random vibration environments. These environments are often derived from flight accelerometer data of previous vehicles. This data tends to be nonstationary as shown in the figure below:**



https://vibrationdata.wordpress.com/category/nasa/

http://www.vibrationdata.com/nonstationary.htm

http://www.vibrationdata.com/tutorials2/FDS_FDET_McNeill_with_corrections.pdf

Vibration Load Reduction:

- A spacecraft at launch is subjected to a harsh acoustic and vibration environment resulting from the passage of acoustic energy, created during the liftoff of a launch vehicle, through the vehicle's payload fairing. In order to ensure the mission success of the spacecraft it is often necessary to reduce the resulting internal acoustic sound pressure levels through the usage of acoustic attenuation systems. Melamine foam, lining the interior walls of the payload fairing, is often utilized as the main component of such a system.

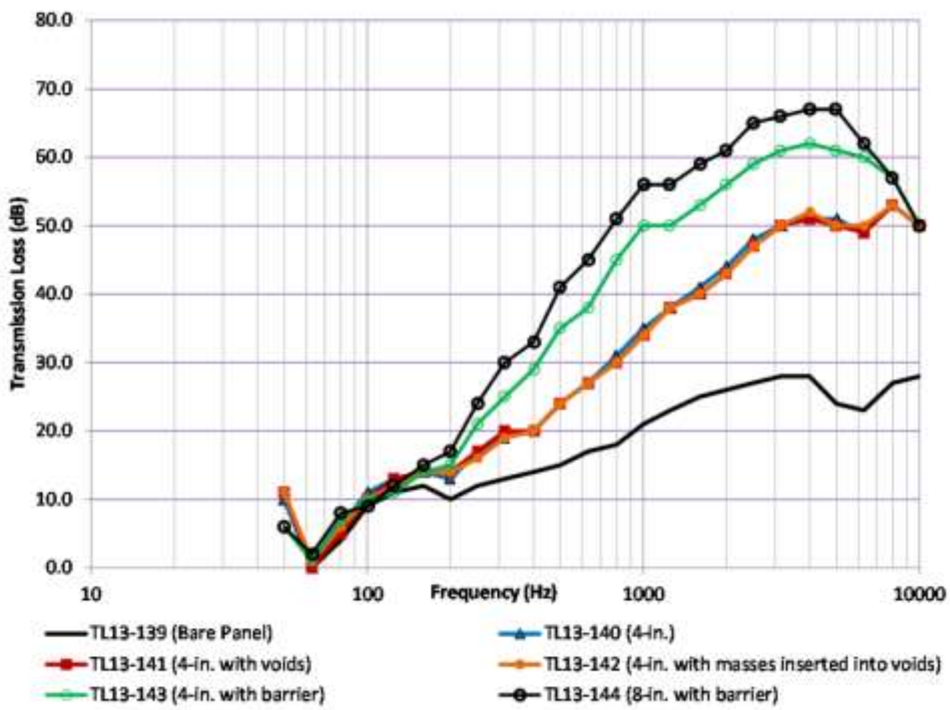


Figure 7.—NEMFAT TL test results.

29th_ATS_Absorption_Paper_23September2015_Final_as submitted to ATS

FINAL_29th_ATS_AMCNELIS_23Sept2015

TM-2014-218350 Noise Con 2014 on Melamine Foam Acoustic Testing

TM-2014-218127 ATS version of NEMFAT

(source: Tom Irvine)

DC Launch accel loads:

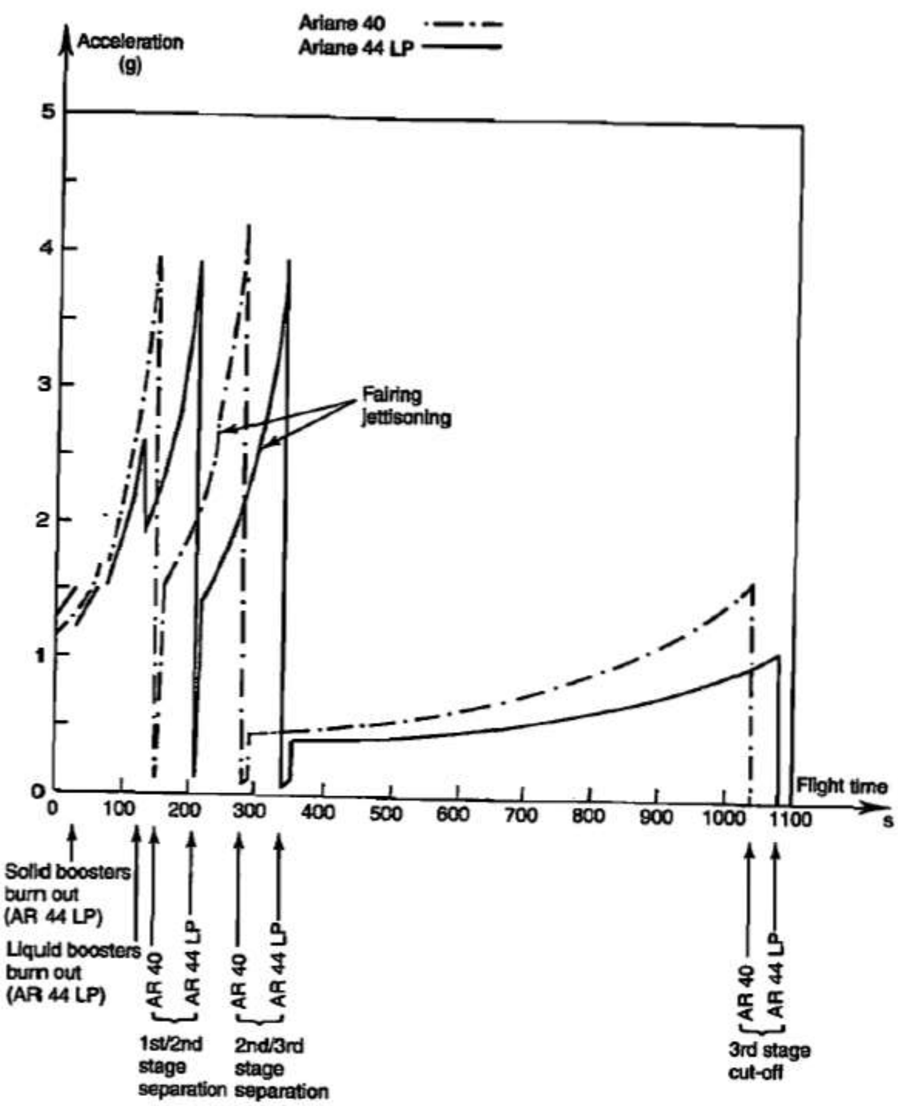
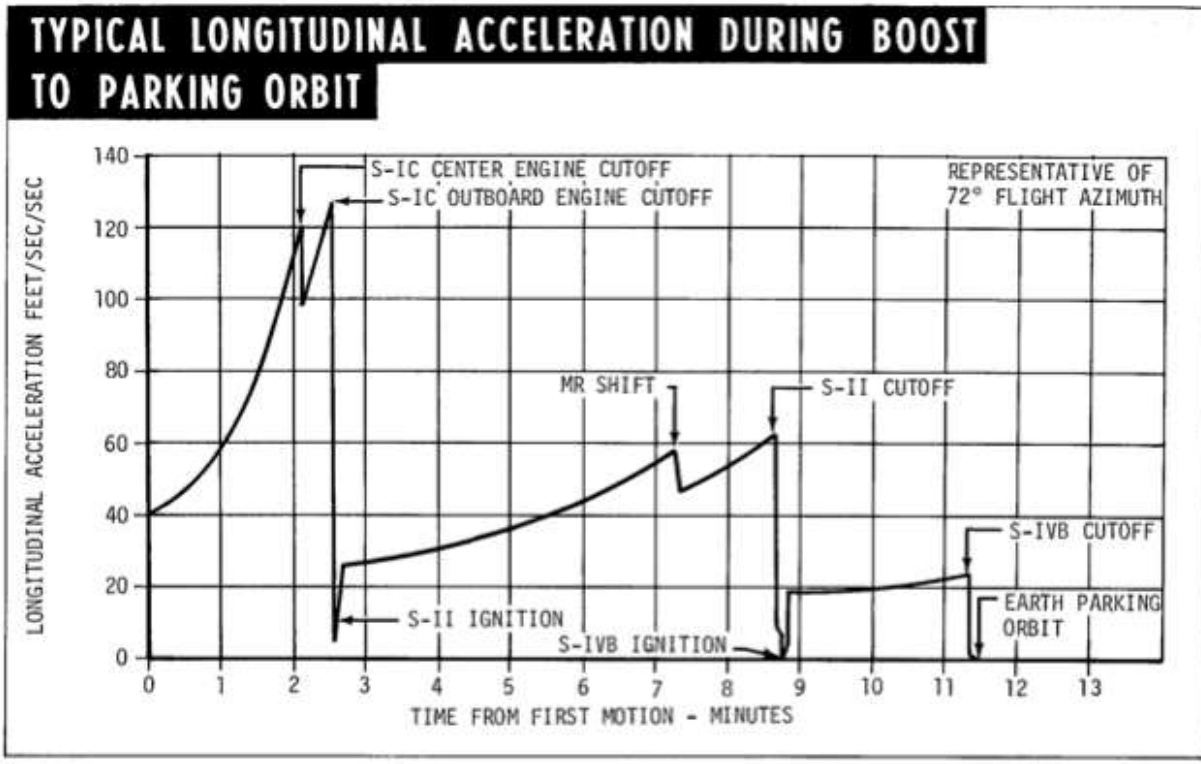


Figure 2.3 Ariane static acceleration profile (Reproduced by permission of Arianespace [2])

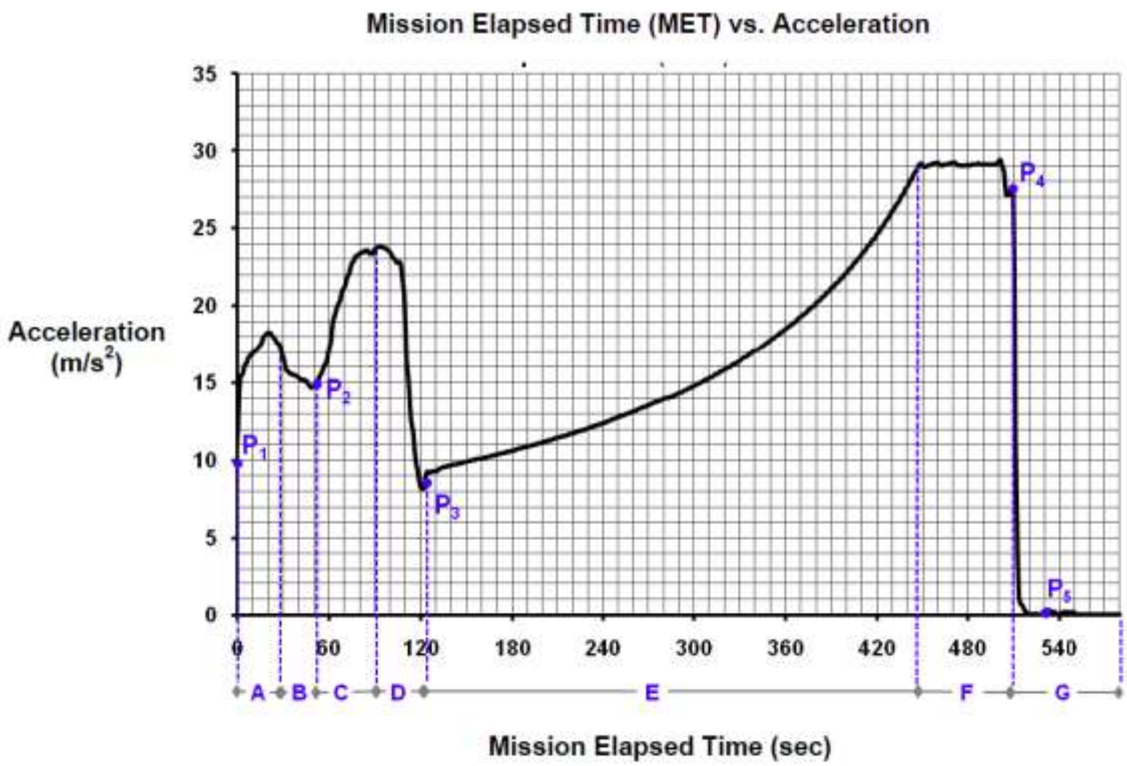
Table 2.1 Acceleration values for Ariane 5 launch vehicle [3]

Flight Event	Acceleration (g_0)		
	Longitudinal		Lateral
	Static	Dynamic	Static dynamic
Lift-off	−1.7	+/−1.5	+/−1.5
Maximum dynamic pressure	−2.7	+/−0.5	+/−2
P230 oscillations	−4.25	+/−1.75	+/−1
H155 thrust tail-off	−0.2	+/−1.4	+/−0.25

- **Saturn 5 (Apollo) Launch Loads:**



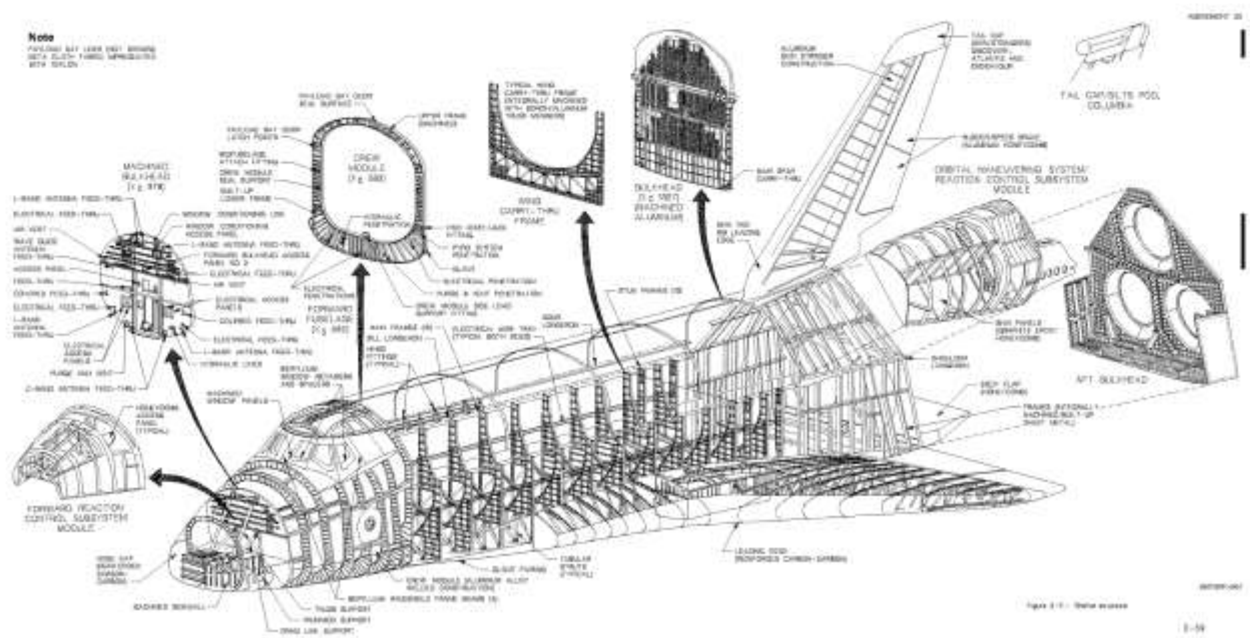
- **Shuttle:**



Graph 1: Acceleration profile of STS 121 during the ascent phase.

Coupled Loads:

- **Product of spacecraft-vehicle flexible body interactions – usually interested in freqs<60hz**
- **Difficult to predict - Iterative analysis + test**
- **Model system as collection of point-masses coupled together with a complex network of lightly-damped, massless springs of varying stiffness, all suspended without being fixed to Earth.**



Shock Loads

- **Intense, transient accelerations with broad frequency content and very short duration (< 20 ms)**
- **Staging, pyro, inflight vehicle config changes**
- **Shock isolation measures, if required**

Launch thermal environment:

- **Payload temp due to shroud temp, heating due to atmos frictional effects, M>5**
- **Friction heating of shroud balanced by radiative and convective losses**
- **Shroud on: payload via radiation & conduction from shroud and mounting structure**
- **Shroud off: minor aero heating**

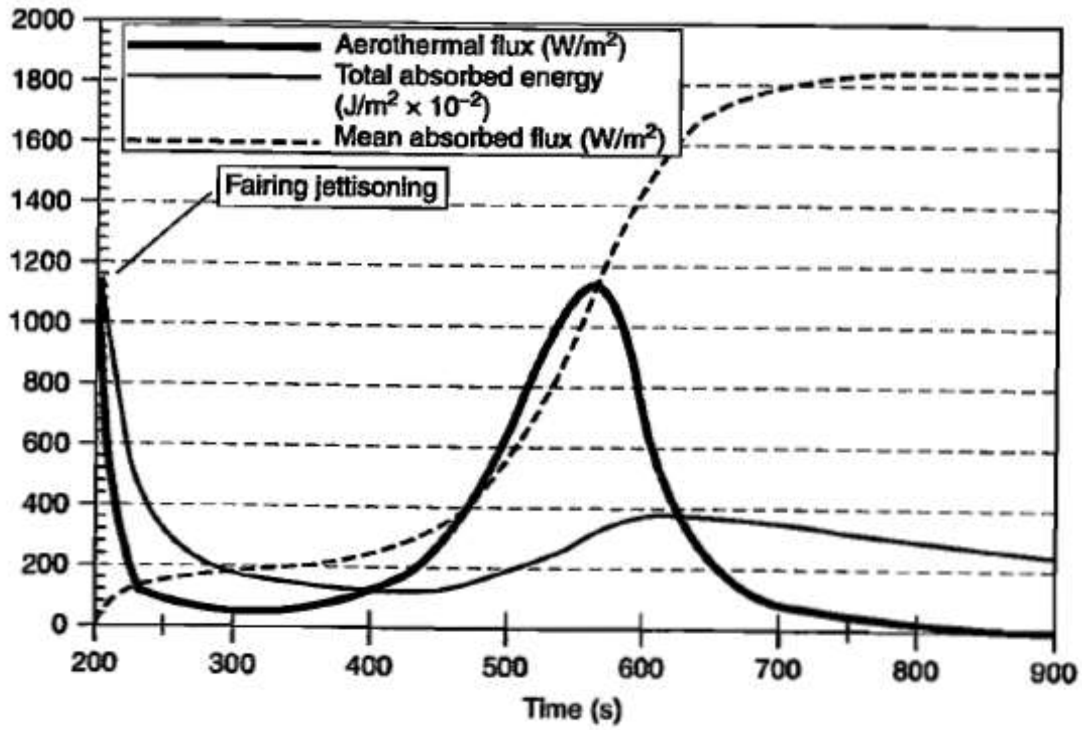


Figure 2.5 Aerothermal fluxes on a standard Ariane 5 trajectory. —— Aerothermal flux (W/m^2). —— Total absorbed energy ($J/m^2 \times 10^{-2}$). - - - - Mean absorbed flux (W/m^2). Fairing jettison and second flux peak constrained at 1135 W/m^2

Launch static pressure environment:

- **Must control shroud venting to minimize adverse static Δp loads on payload structures**
- **Electronic subsystems also vented**
- **Ariane ascent vent rate: 2.0-4.5 kPa/s**
- http://www.scielo.br/scielo.php?pid=S1678-58782005000400017&script=sci_arttext

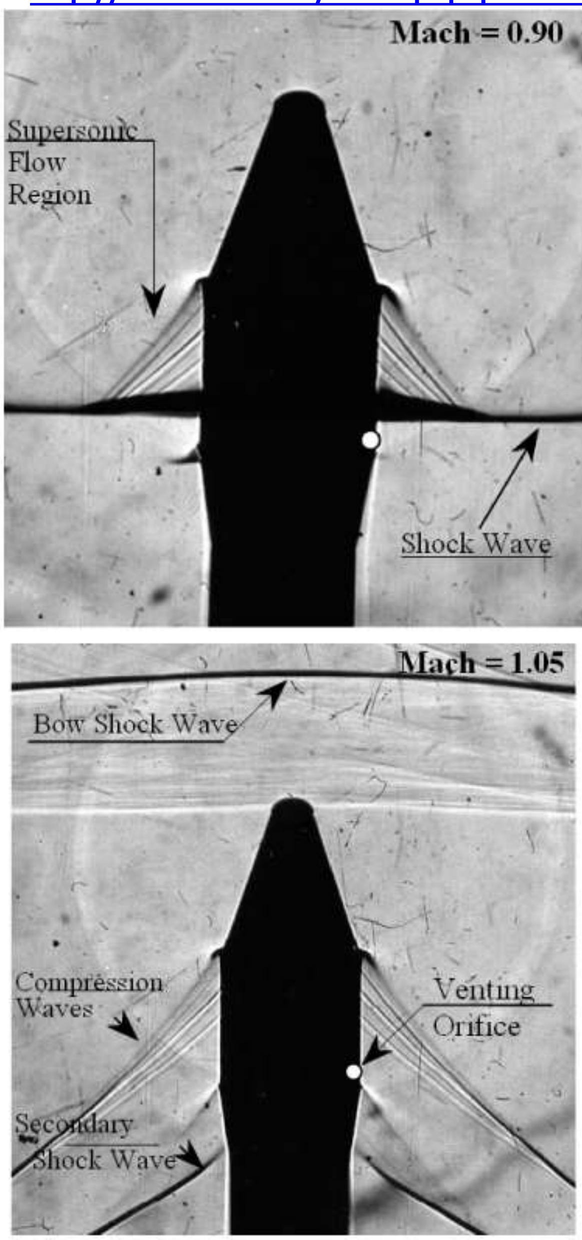


Figure 9. Schlieren pictures of the flow over the VLS fairing for Mach = 0.90 and Mach = 1.05.

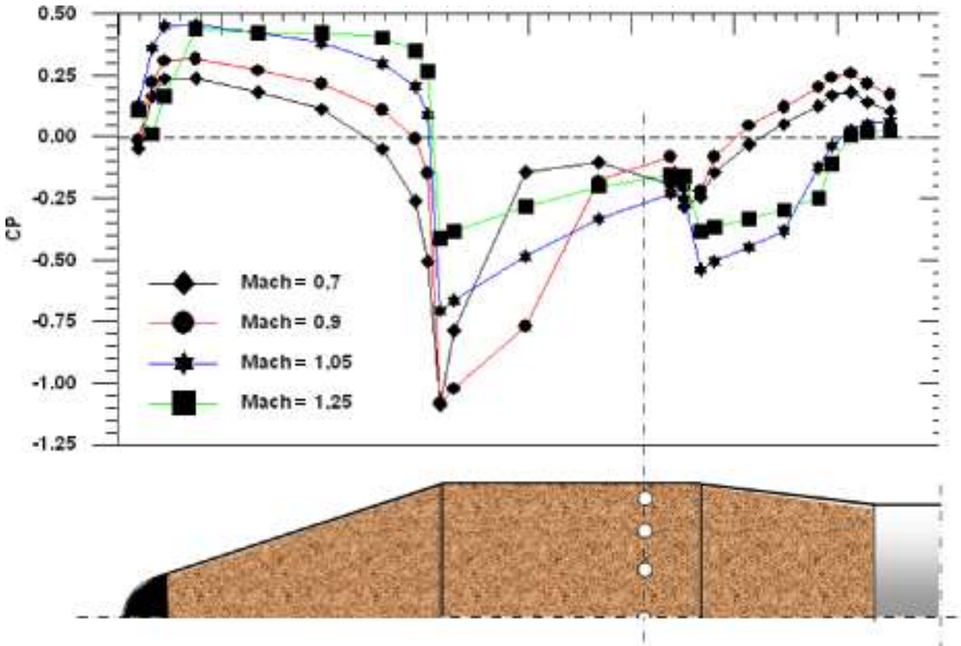


Figure 4. Pressure coefficient along the VLS fairing, 0.7 ≤ Mach ≤ 1.25.

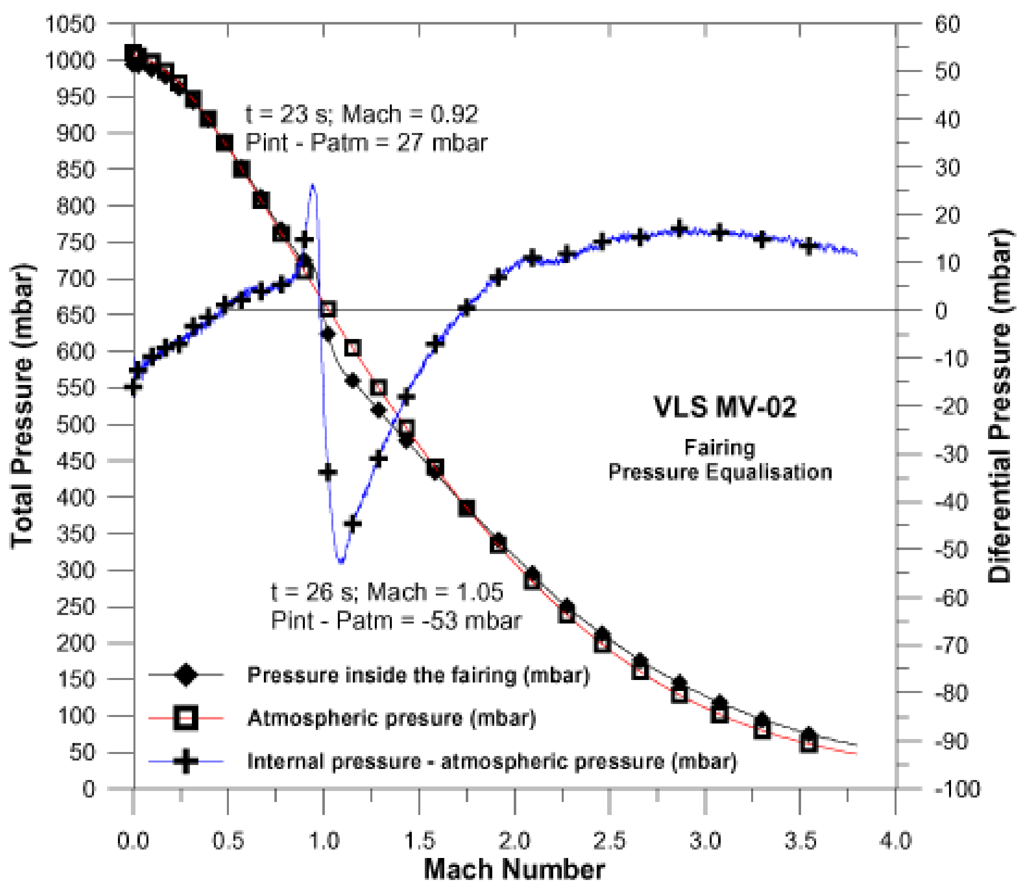
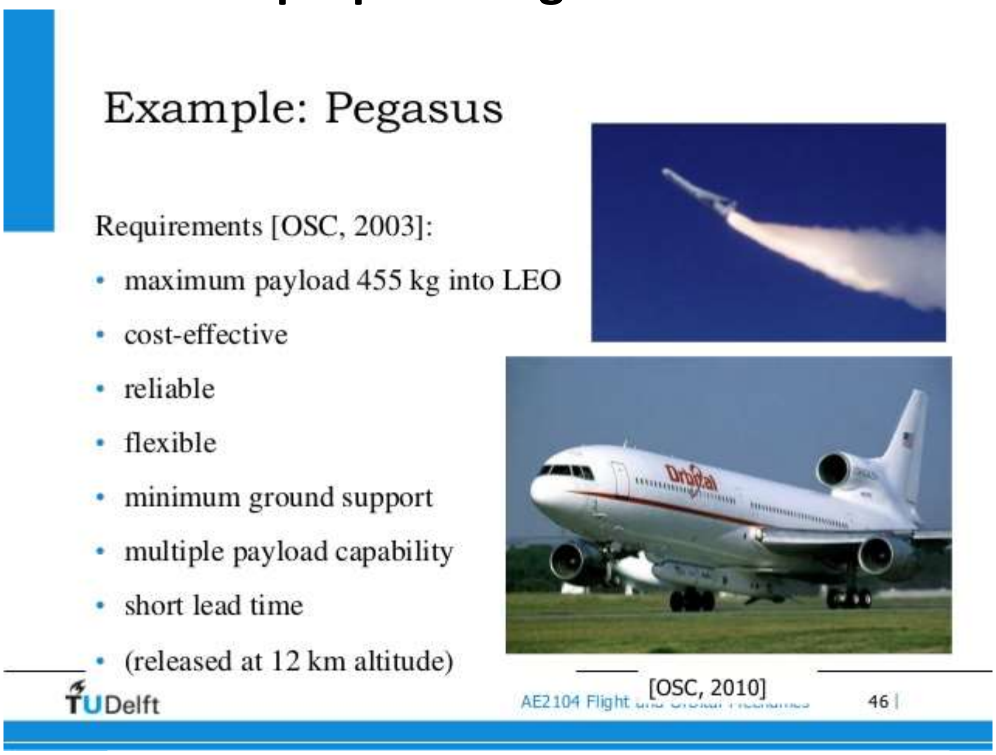


Figure 7. Pressure inside the fairing and atmospheric pressure as function of flight Mach number.

Electromagnetic interference (EMI) between components:

- **Essential to test**
- **Potential to damage: components, up to inadvertent propulsion ignition**



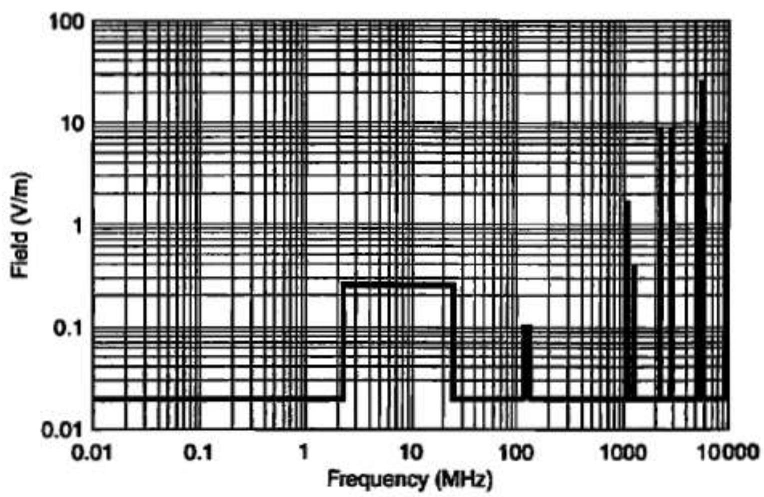
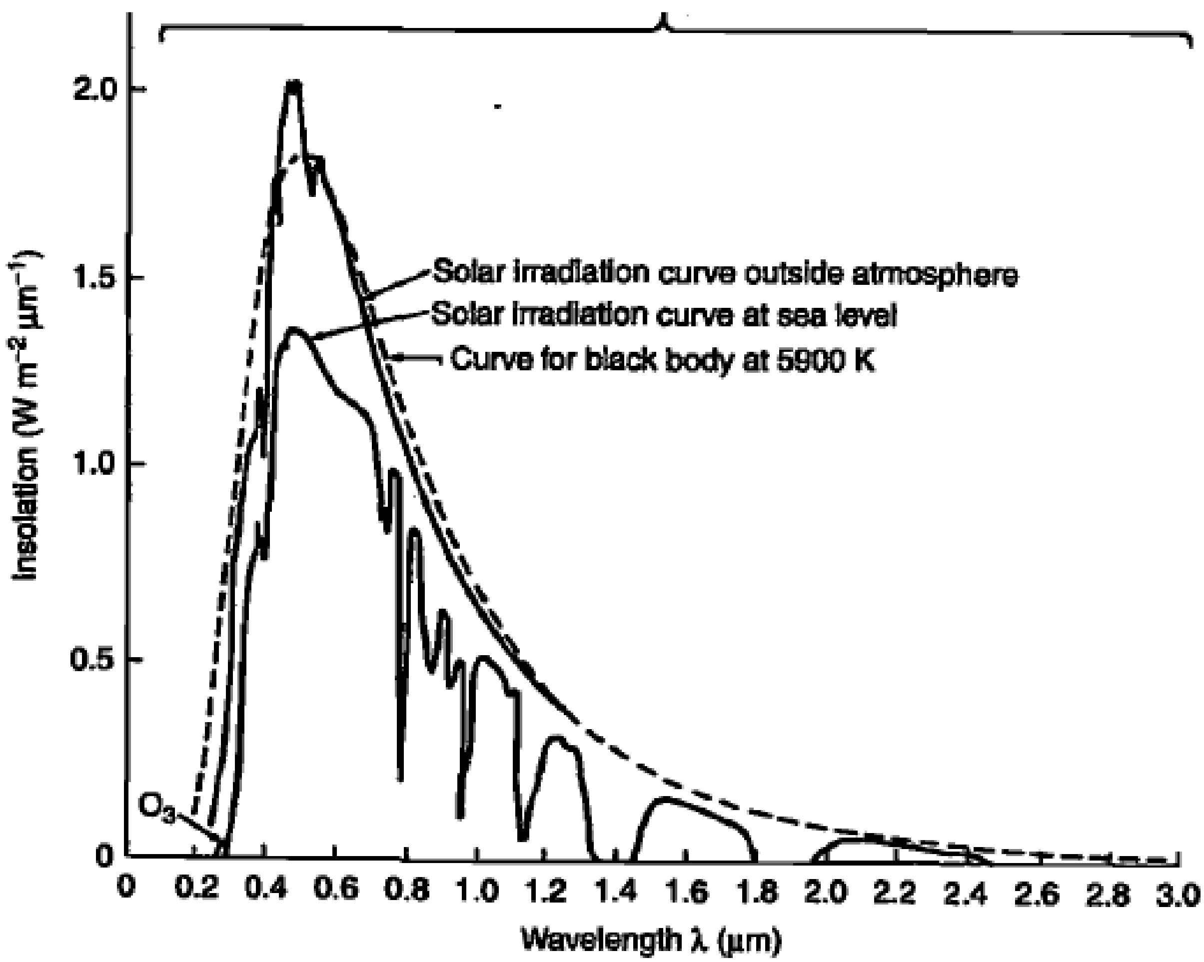


Figure 2.6 Electromagnetic interference for Pegasus vehicle at Western Test Range [4] Source: Orbital Sciences Corporation www.orbital.com

Spacecraft in Orbit

2.3 Operational Spacecraft Environments

Solar Radiation:



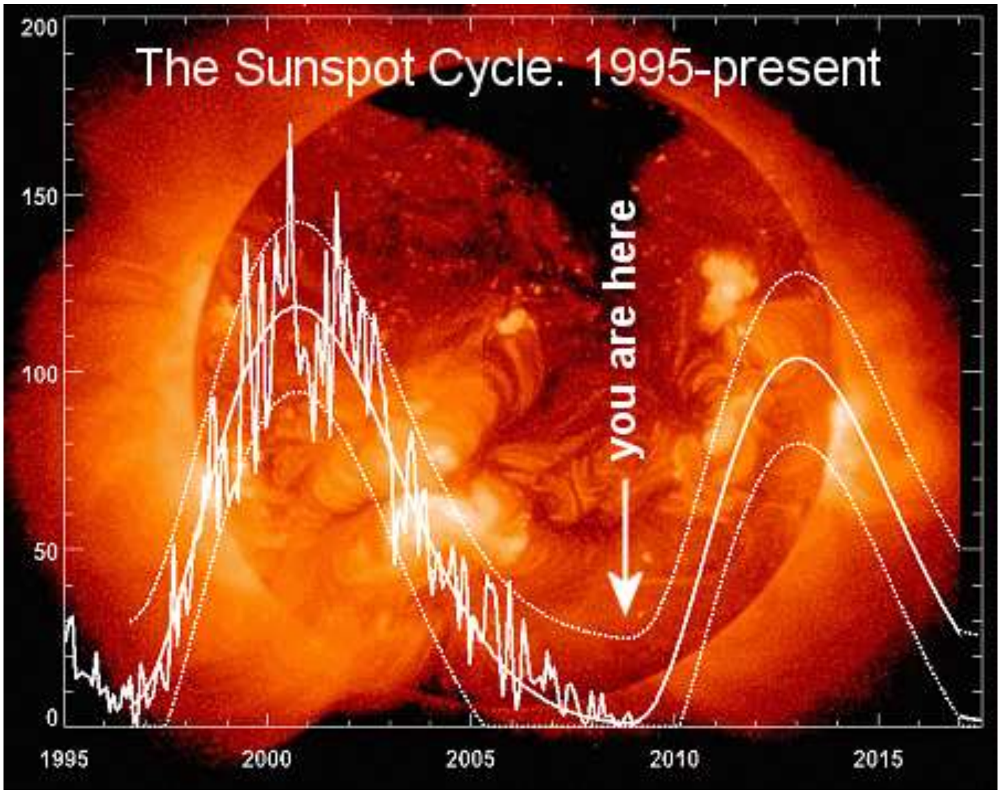
2.7 Solar spectrum (Reproduced by permission from Hynek, J. A. (1951)

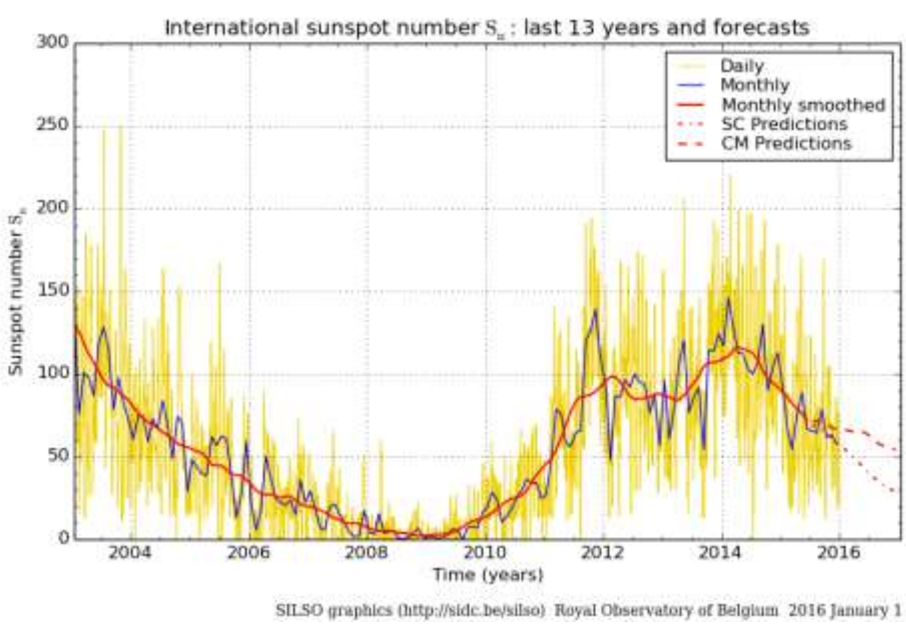
Solar wind: plasma efflux

velocity 450km/s,

density9 protons/cm^3

Sunspots: surface temp disturbances (dark = reduced radiation); high sunspot activity = increased overall radiation (http://sidc.oma.be/silso/)





Earth Orbit Environment:

- **Gravitationally-bound atmosphere**
- **Significant magnetic field**
- **Molecular species density depends on altitude above Earth surface and temperature (solar radiation)**

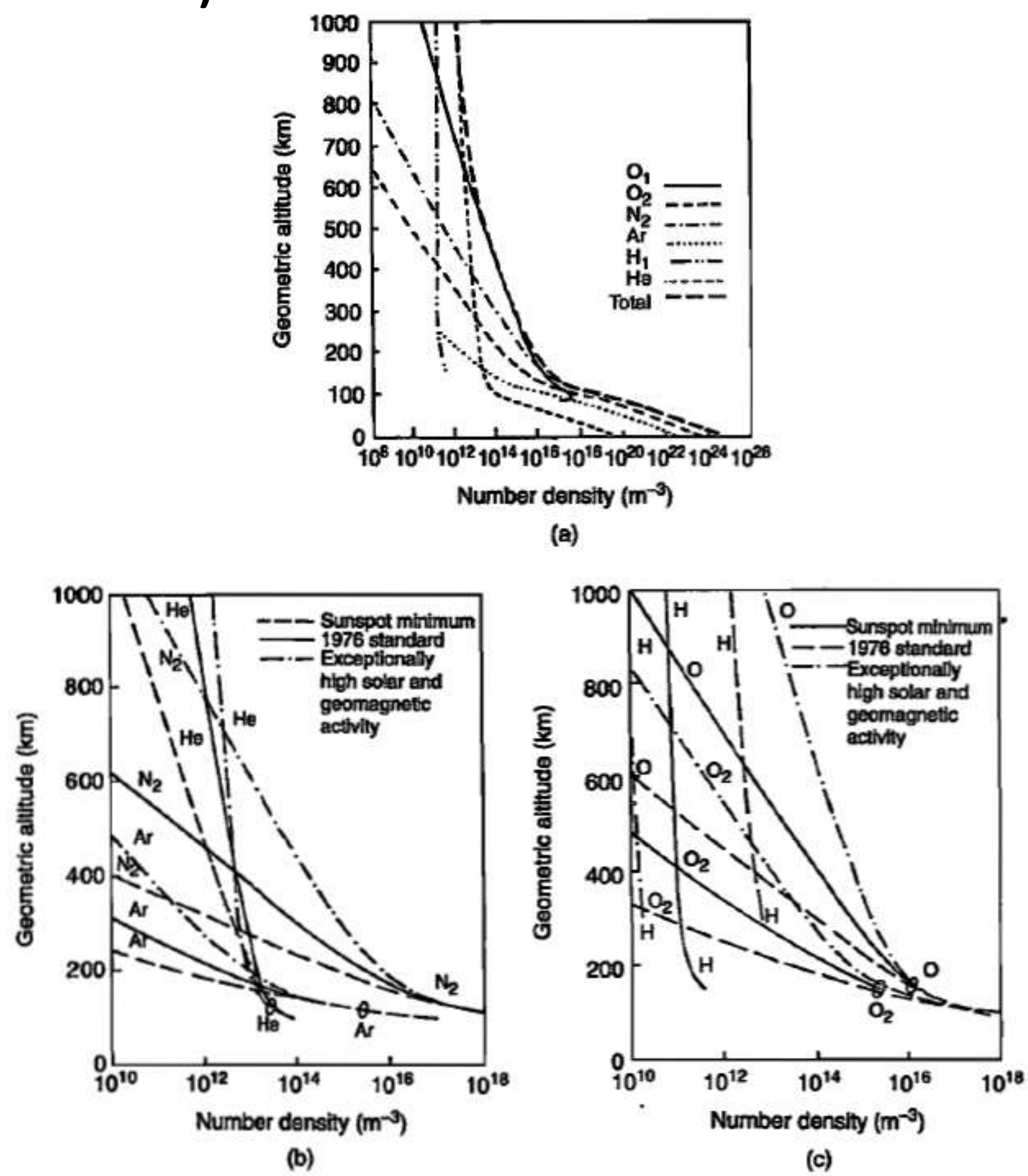
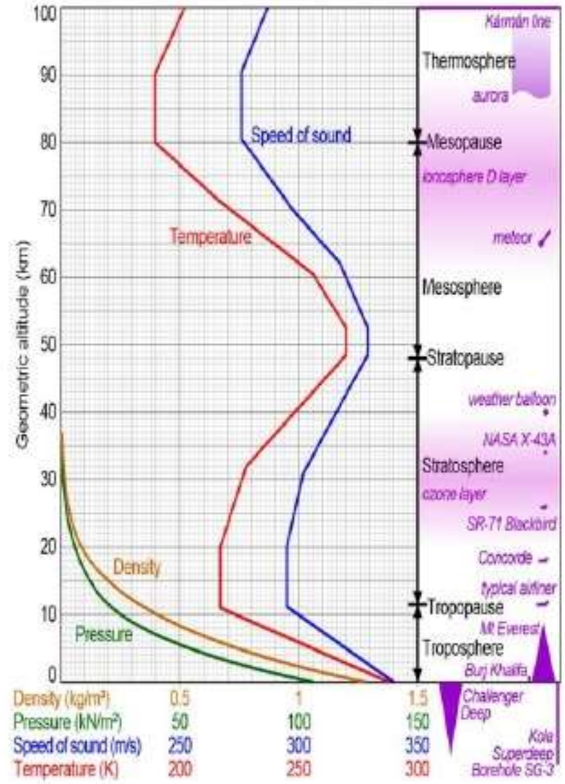


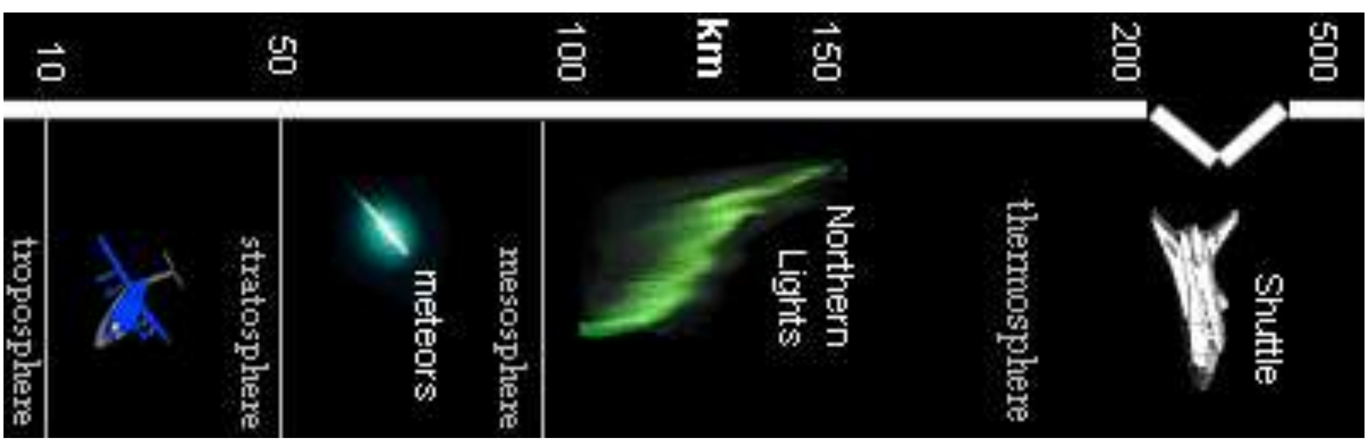
Figure 2.10 Species concentration (a) in US standard atmosphere and (b, c) under extreme conditions

EARTH ATMOSPHERE
Lower Atmosphere 2/2

- **Thermosphere**
  - Extends from mesopause to 200-300 km
  - Temperature increases to 1800 K
  - Small change in solar activity can cause large change in temperature
  - Upper boundary is **thermopause** or **exobase**
- **Exosphere**
  - Extends from thermopause/exobase upwards
  - Sometimes considered outer layer of thermosphere
  - Temperature is essentially constant
  - Density so low particles travel ballistic paths and may escape



http://en.wikipedia.org/wiki/Atmosphere_of_Earth



- **Solar activity affects temperature of atmosphere**

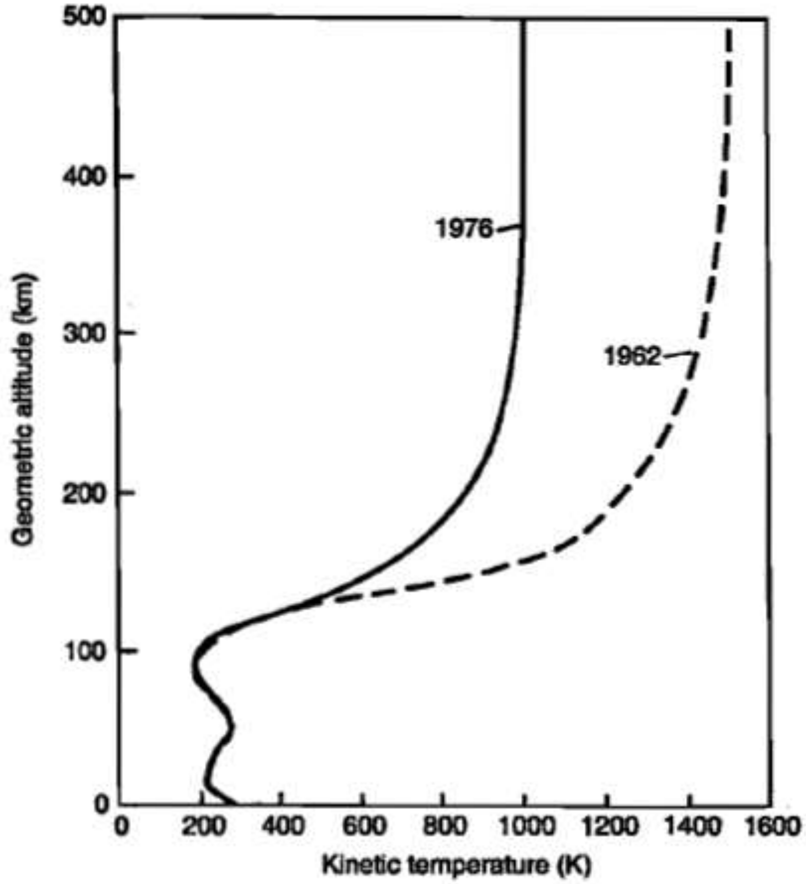


Figure 2.11 Temperature profile of atmosphere

$$\rho = \rho_{SL} \exp\left(\frac{-gM_i}{R^* T} Z\right)$$

Kinetic Temperature

The expression for gas pressure developed from kinetic theory relates pressure and volume to the average molecular kinetic energy. Comparison with the ideal gas law leads to an expression for temperature sometimes referred to as the kinetic temperature.

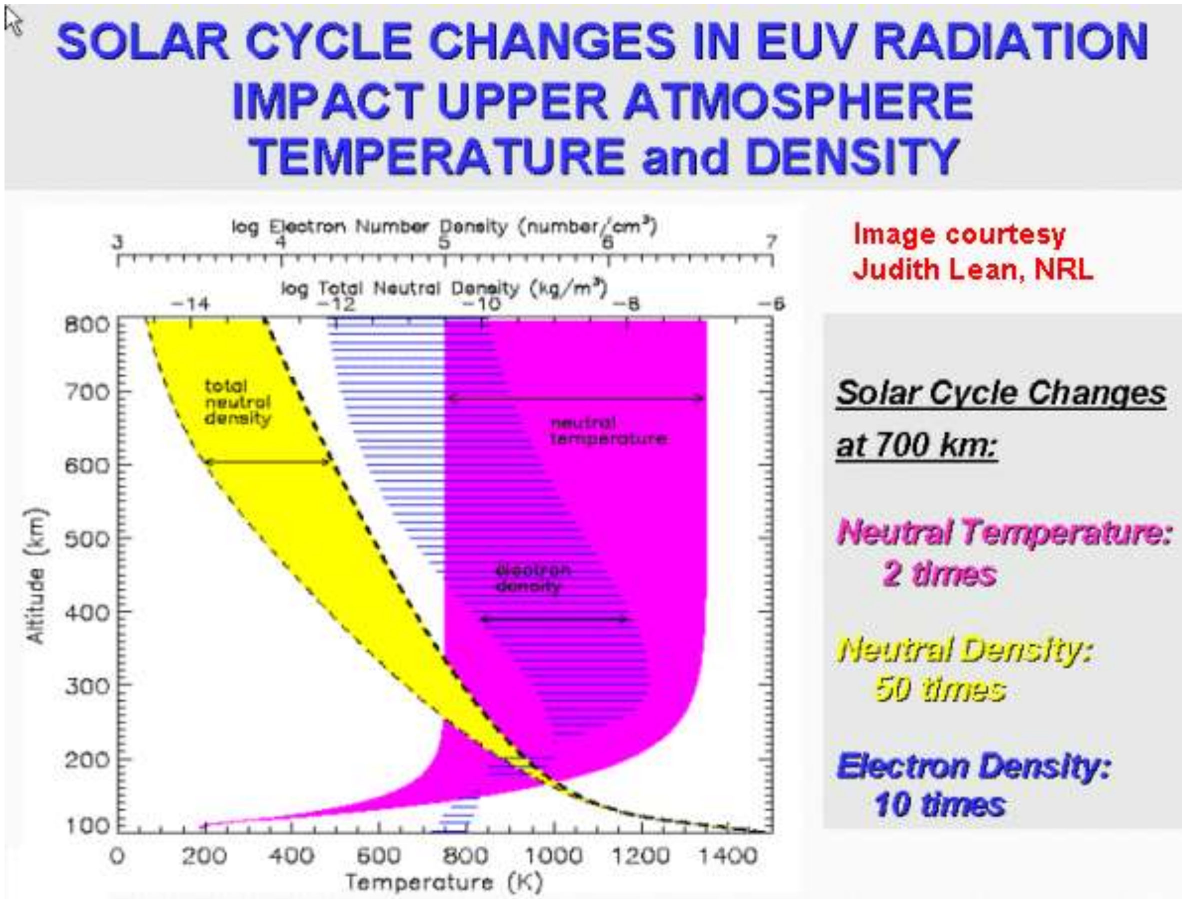
$$PV = nRT \Longleftrightarrow PV = \frac{2}{3} N \left[\overline{\frac{1}{2} m v^2} \right]$$

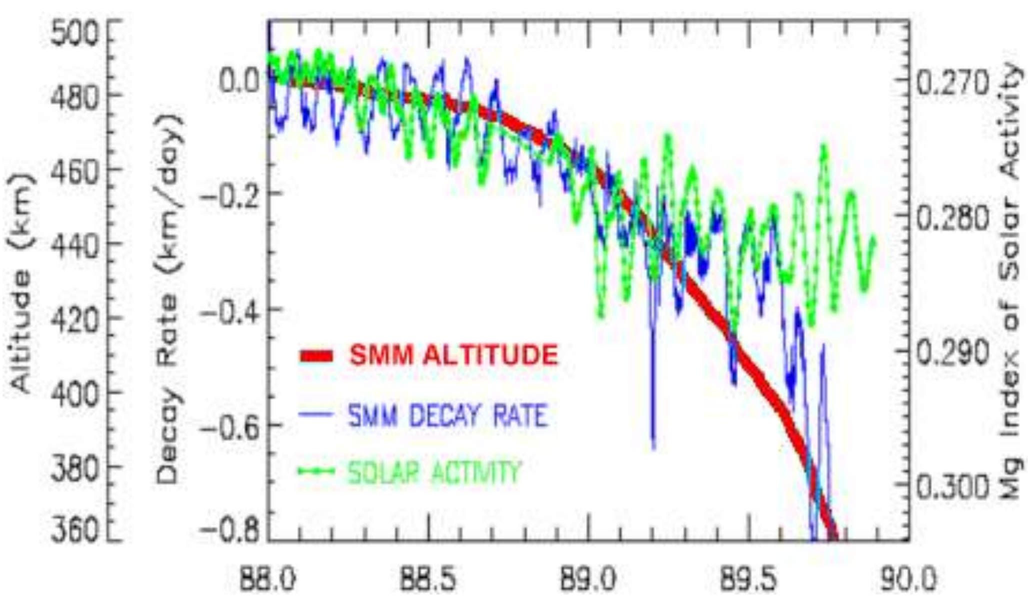
This leads to the expression

$$T = \frac{2}{3} \frac{N}{nR} \left[\overline{\frac{1}{2} m v^2} \right] = \frac{2}{3} \frac{1}{k} \left[\overline{\frac{1}{2} m v^2} \right]$$

where N is the number of molecules, n the number of moles, R the gas constant, and k the Boltzmann constant. The more familiar form expresses the average molecular kinetic energ

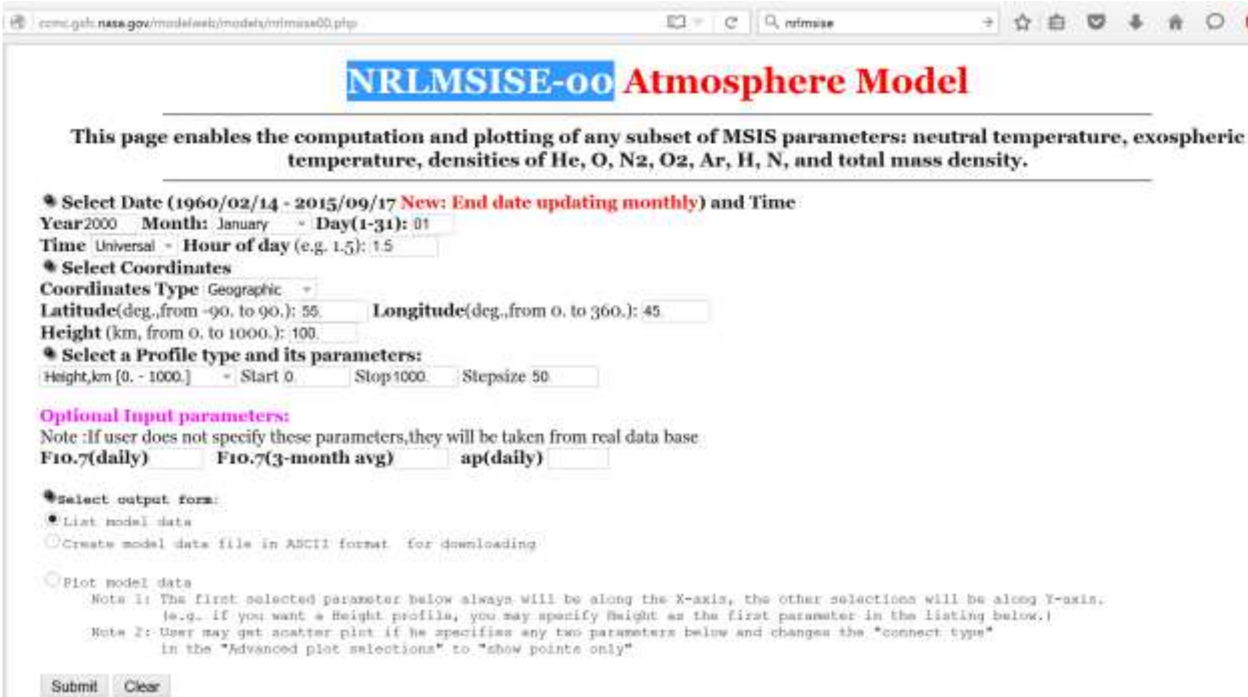
- **Solar activity affects drag of LEO satellites**

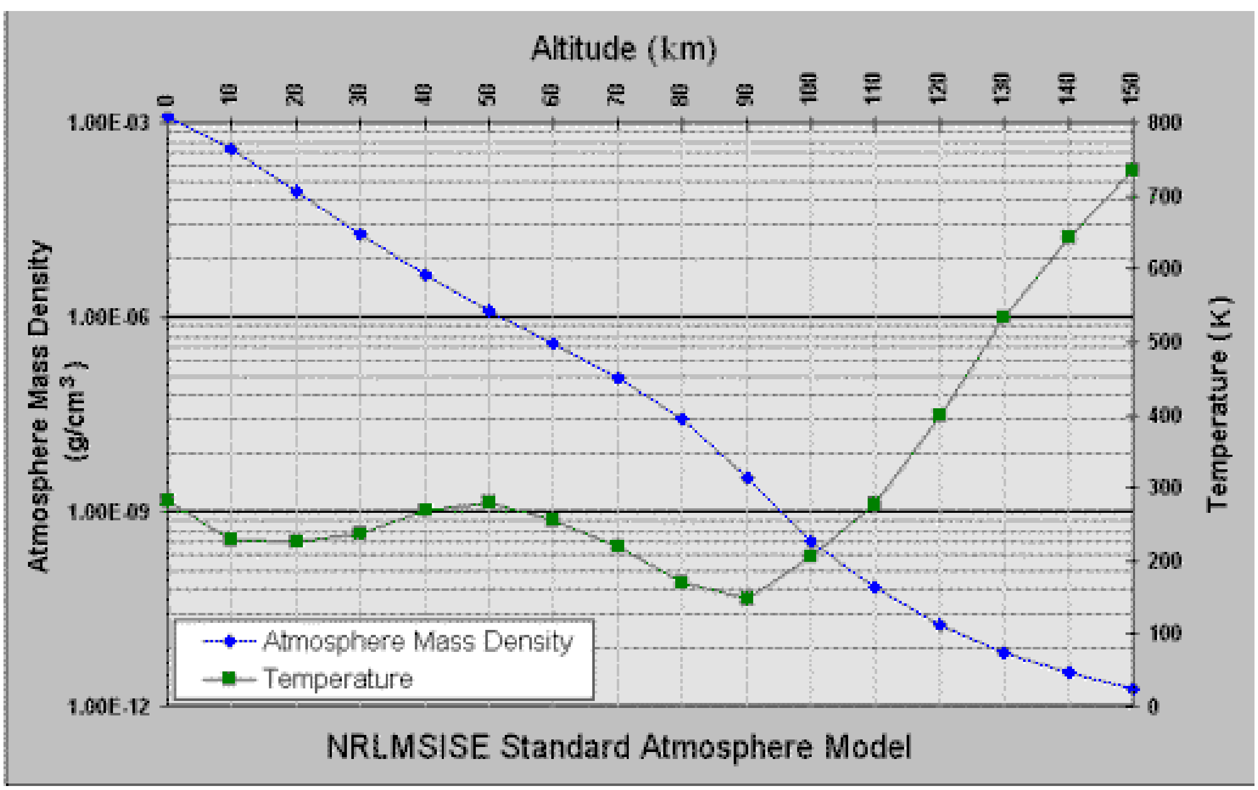


- 

The decay rate of the Solar Maximum Mission, which deorbited in December 1989, varied with the Sun's 27--day rotation and the solar cycle.

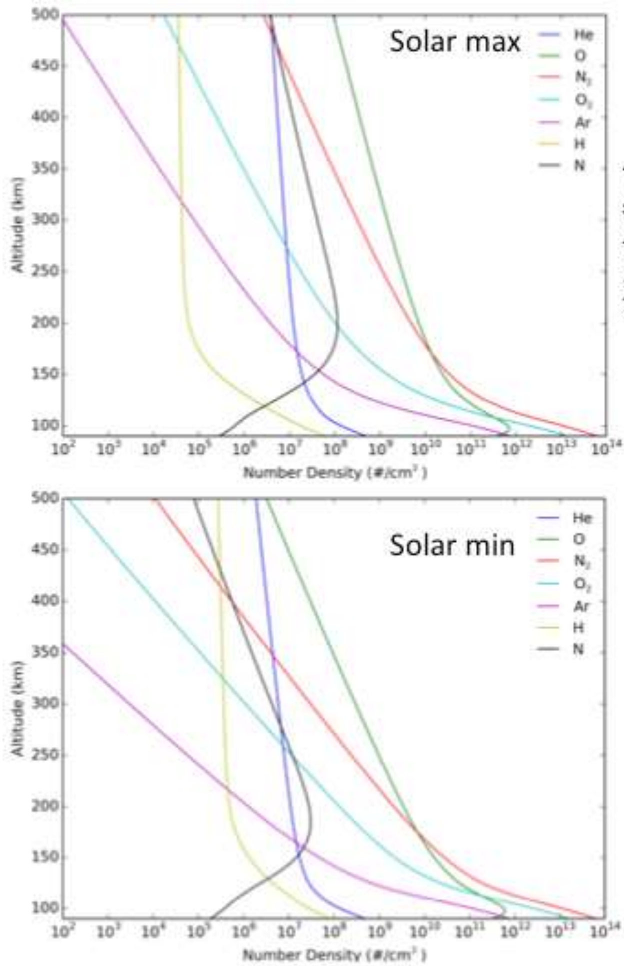
- **NASA Atmospheric model: NRLMSISE-00**
  http://ccmc.gsfc.nasa.gov/modelweb/models/nrlmsise00.php

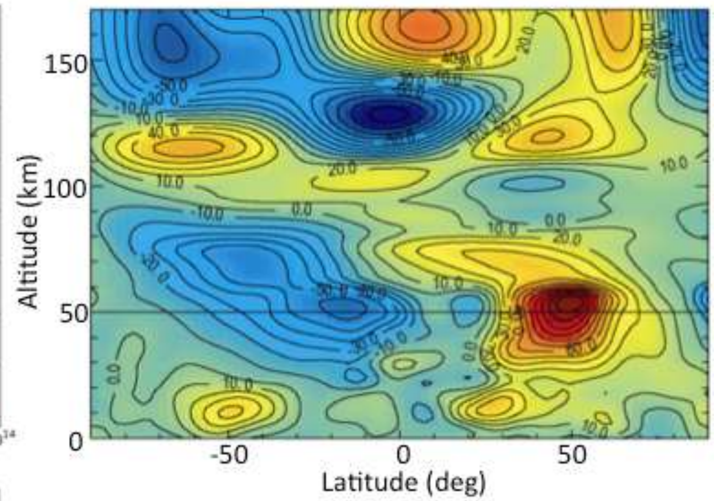




Empirical Modeling of the Upper Atmosphere: NRLMSISE-00, HWM07, and G2S models

Varies with altitude, latitude, and solar activity





Left: Major species concentrations of the thermosphere from 90 to 500 km at (a) solar maximum and (b) solar minimum. **Above:** Global zonal winds from 0 to 180 km from HWM07 merged with operational numerical weather prediction analysis fields below 50 km (G2S).

http://www.nrl.navy.mil/ssd/branches/7630/modeling-upper-atmosphere

Effect of Mean Free Path:

- **Above 150km, MFP larger than spacecraft dimensions**

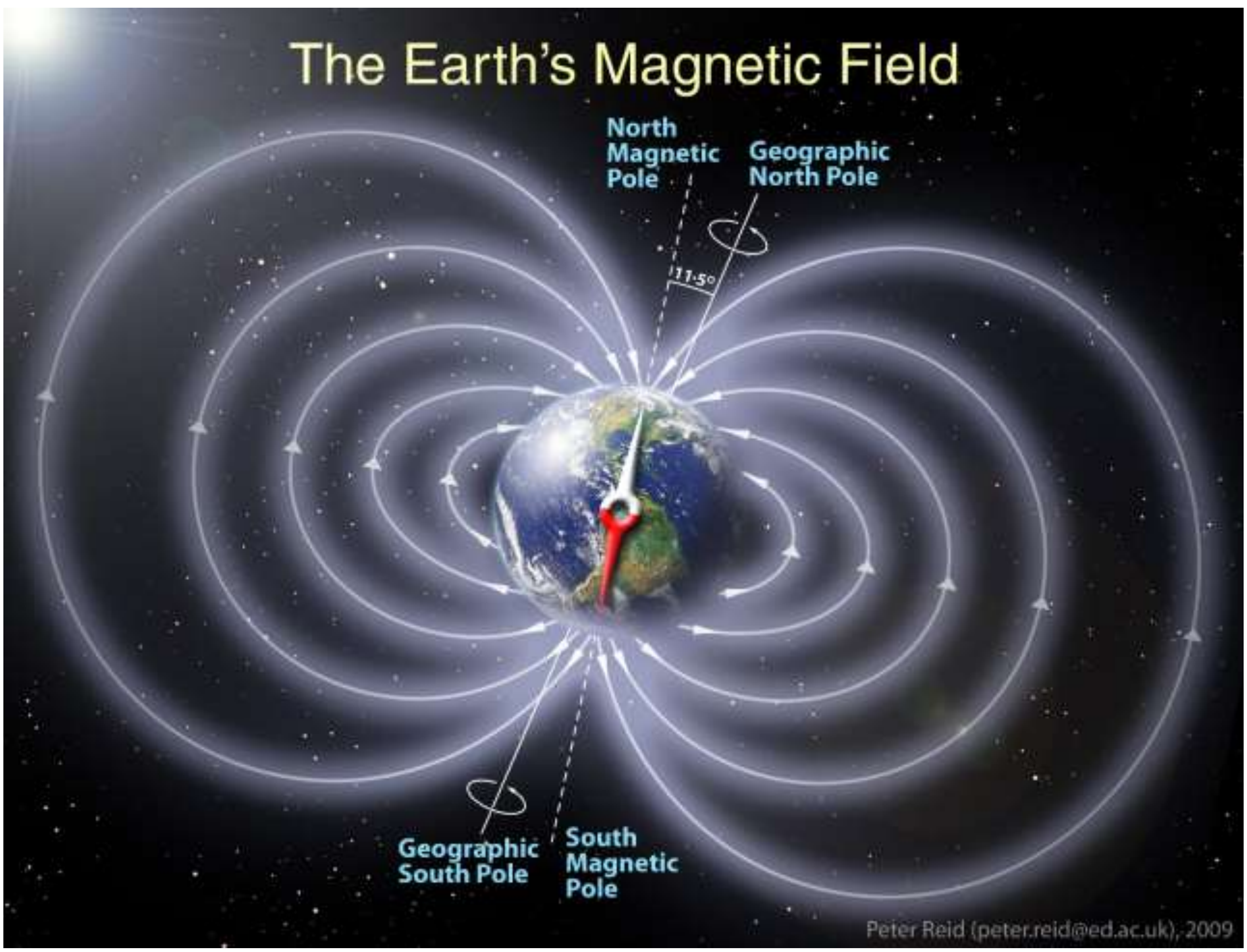
Table 2.3 Mean free path λ_0 as a function of altitude

Altitude (km)	λ_0 (m)	Altitude (km)	λ_0 (m)
100	0.142	300	2.6×10^3
120	3.31	400	16×10^3
140	18	500	77×10^3
160	53	600	280×10^3
180	120	700	730×10^3
200	240	800	1400×10^3

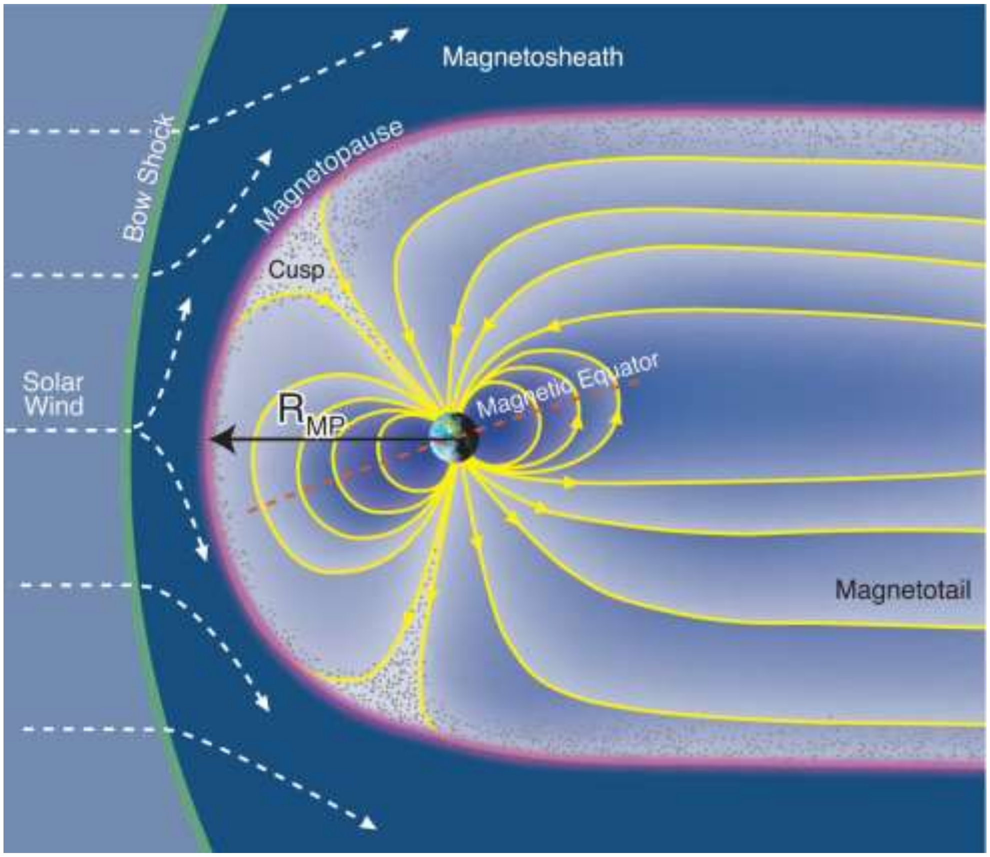
- **Result 1: heat exchange between spacecraft and environment due to radiation:**
  - **Sun: 1370 W/m^2**
  - **Earth albedo (reflection of solar radiation from outer edges of atmosphere + reflection from Earth): 200 W/m^2**
  - **Solar wind: negligible heating**

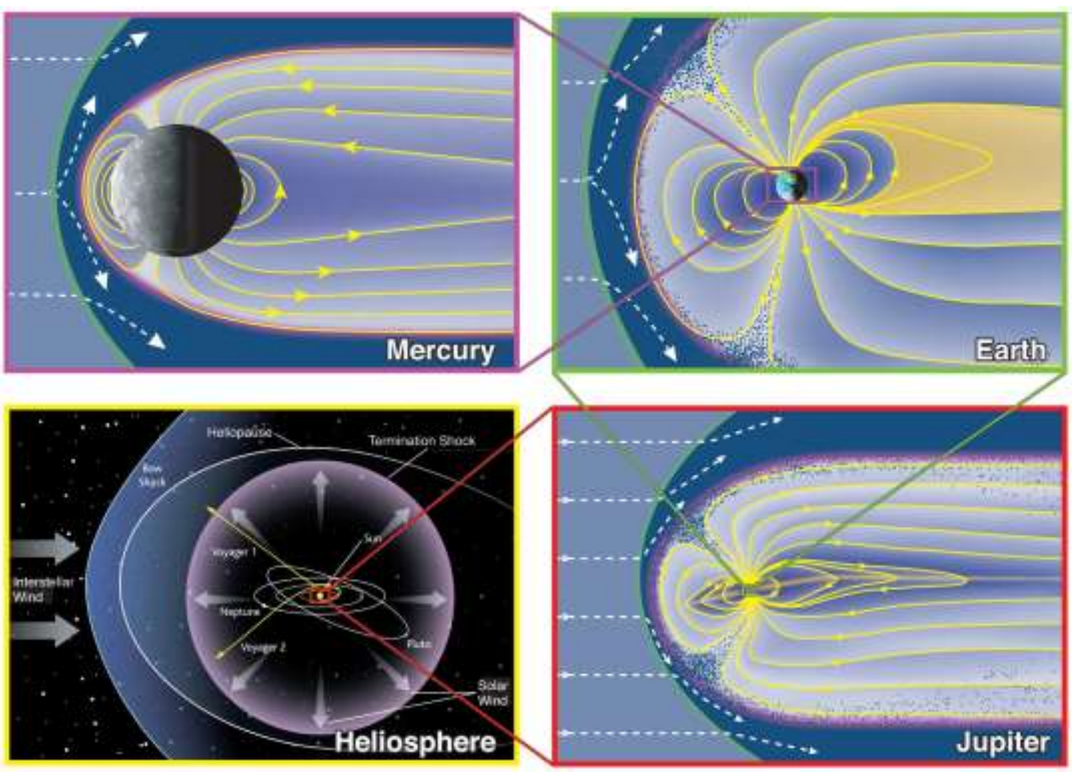
- **Result 2: aerodynamic drag not based on continuum fluid theory. Frictional heating negligable**

- **Earth's magnetic field:**
  - **At surface: elec currents within molten Fe core**
  - **Above surface:**
    - **Differential motion of electrons and ions in magnetosphere**
    - **Solar wind plasma carries its own magnetic field which significantly distorts Earth's simple dipole field**



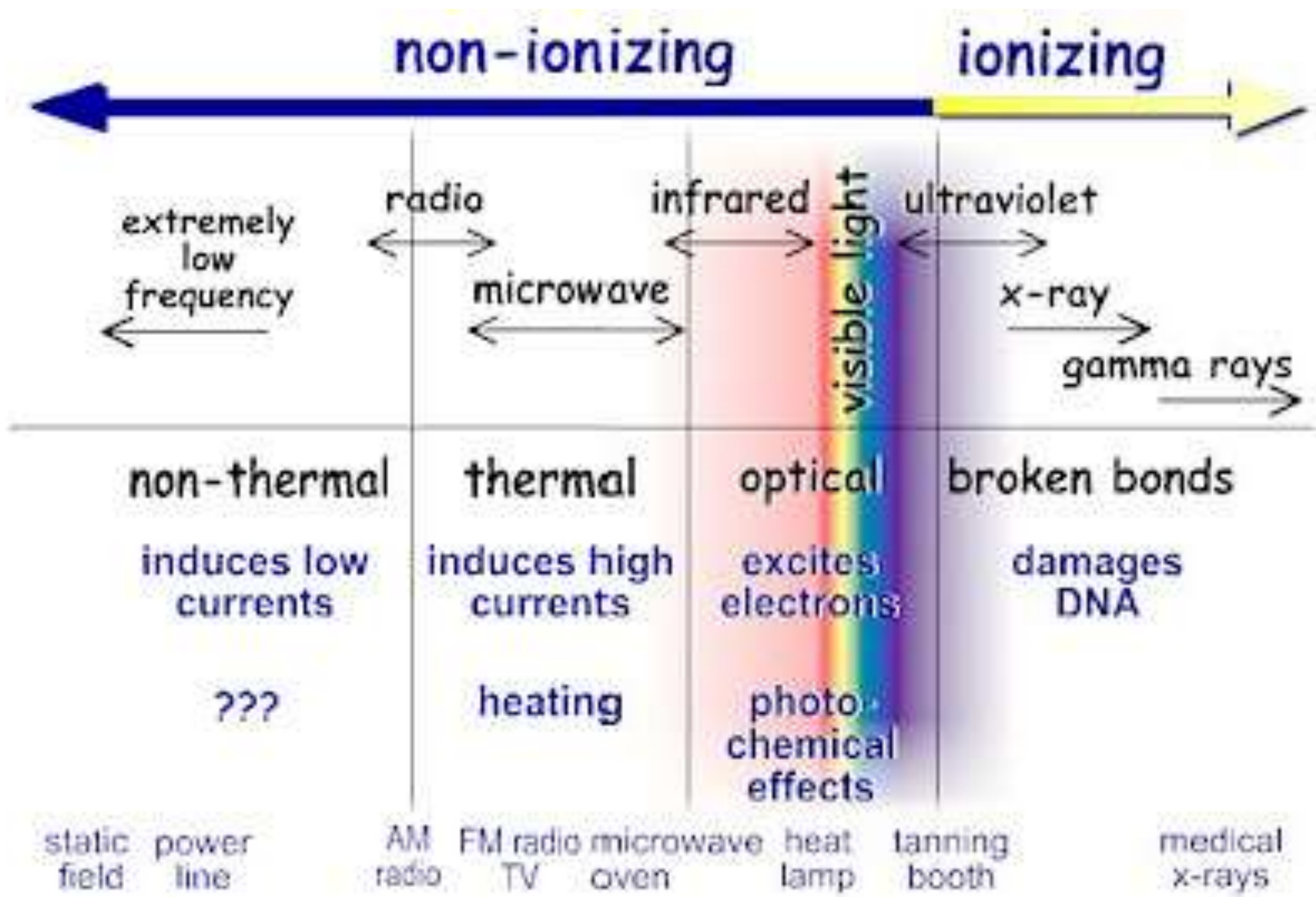
http://lasp.colorado.edu/home/mop/graphics/graphics/Š

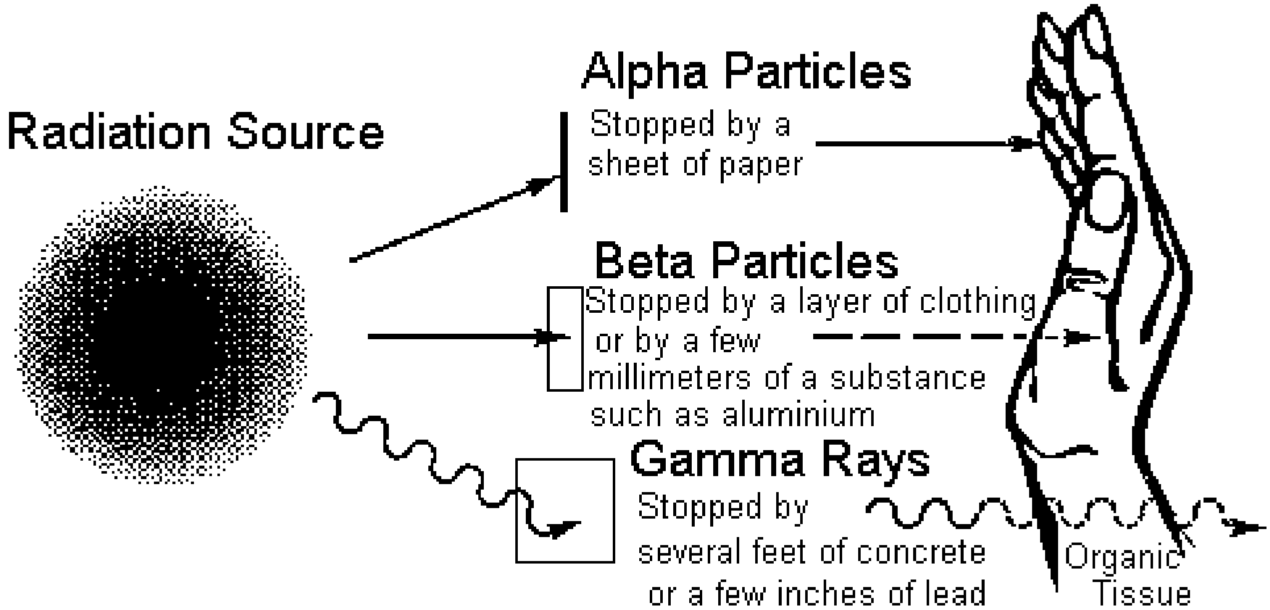


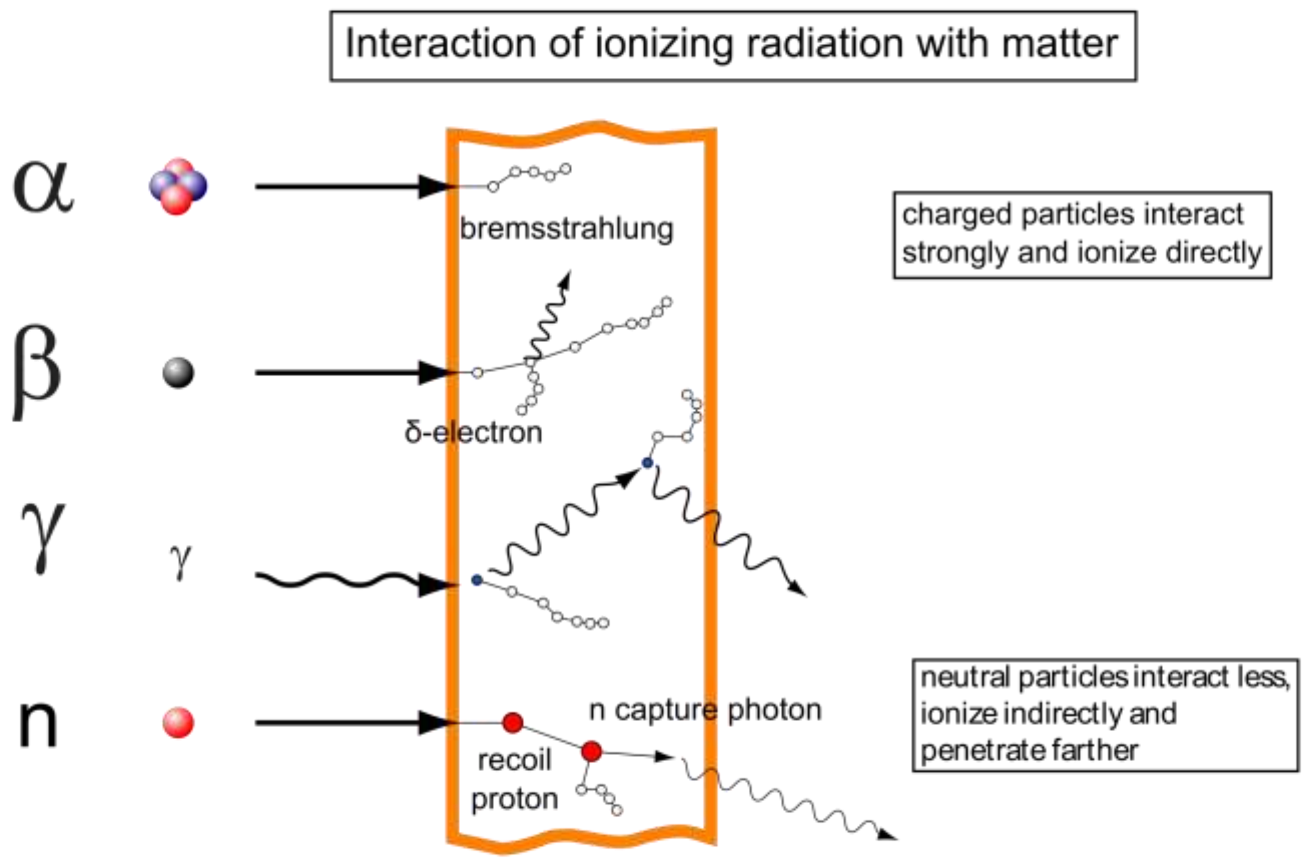


Ionizing Radiation:

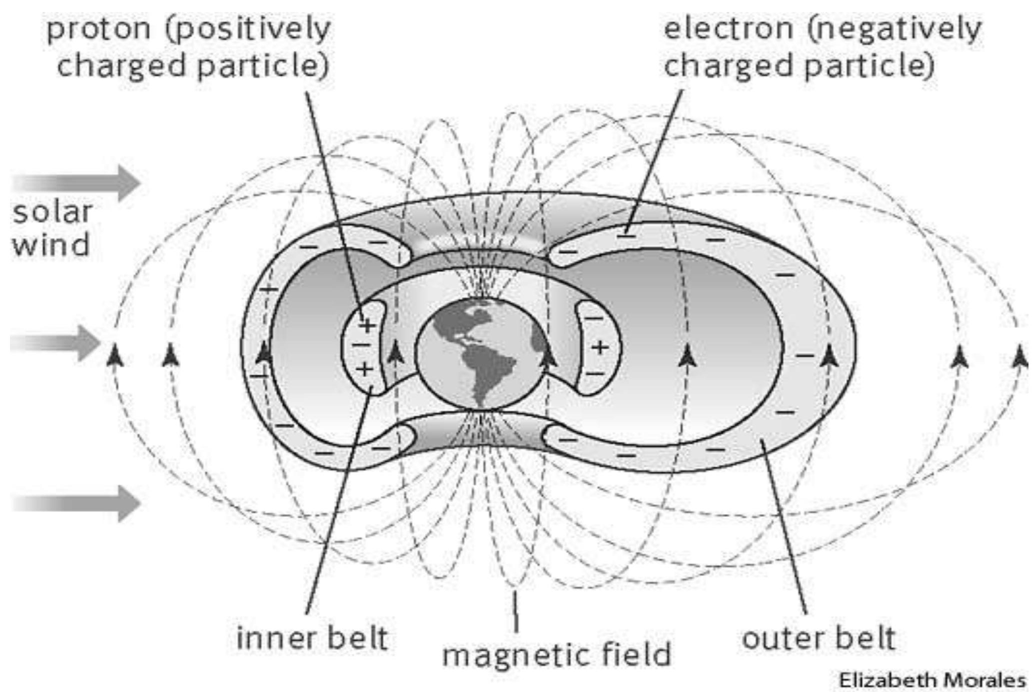
- **Ionizing radiation is any type of particle or electromagnetic wave that carries enough energy to ionize or remove electrons from an atom. There are two types of electromagnetic waves that can ionize atoms: X-rays and gamma-rays, and sometimes they have the same energy.**




Radiation Source
Alpha Particles
Stopped by a sheet of paper
Beta Particles
Stopped by a layer of clothing or by a few millimeters of a substance such as aluminium
Gamma Rays
Stopped by several feet of concrete or a few inches of lead
Organic Tissue


Interaction of ionizing radiation with matter
α
bremsstrahlung
β
δ-electron
γ
γ
n
n capture photon
recoil proton
charged particles interact strongly and ionize directly
neutral particles interact less, ionize indirectly and penetrate farther

Van Allen Belts: **Van Allen radiation belts (cross section) A radiation belt is a layer of energetic charged particles that is held in place around a magnetized planet, such as the Earth, by the planet's magnetic field. The Earth has two such belts and sometimes others may be temporarily created.**



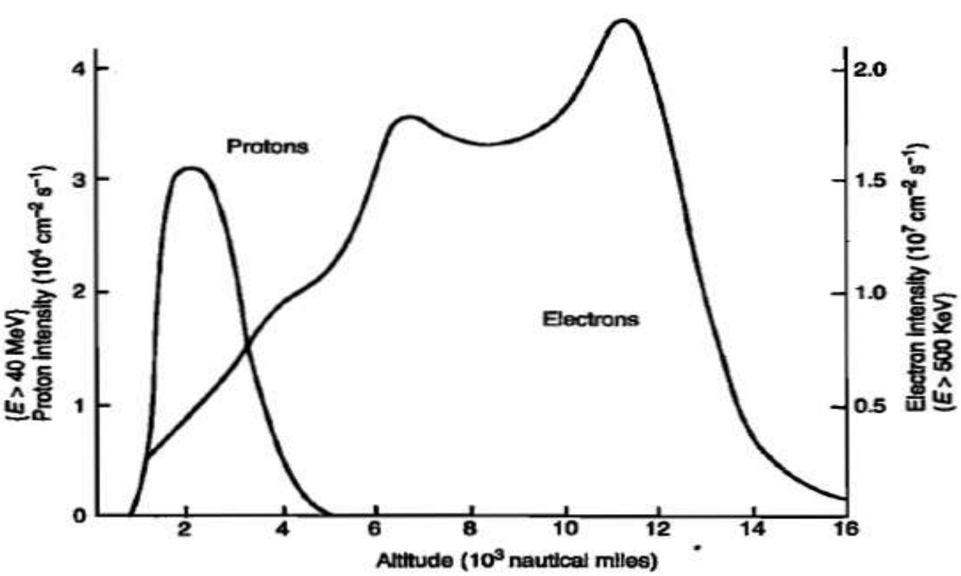


Figure 2.14 Van Allen radiation belts (idealized)

Particles in Van Allen Belts are trapped at low altitudes by Earth's magnetic field

- **High-Energy Particle Impacts on Spacecraft Components**
- **Significant effect on semiconductors (solar array cells, computer components)**
- **Impacts can damage both energy structure and molecular lattice structure -> Single Event Upsets can change a bit**
- **Protons can do more damage than electrons (more mass)**
- **Model trapped electron and proton fluxes with NASA AE8 and AP8 models: http://radhome.gsfc.nasa.gov/radhome/papers/nsrec05_w16.pdf**

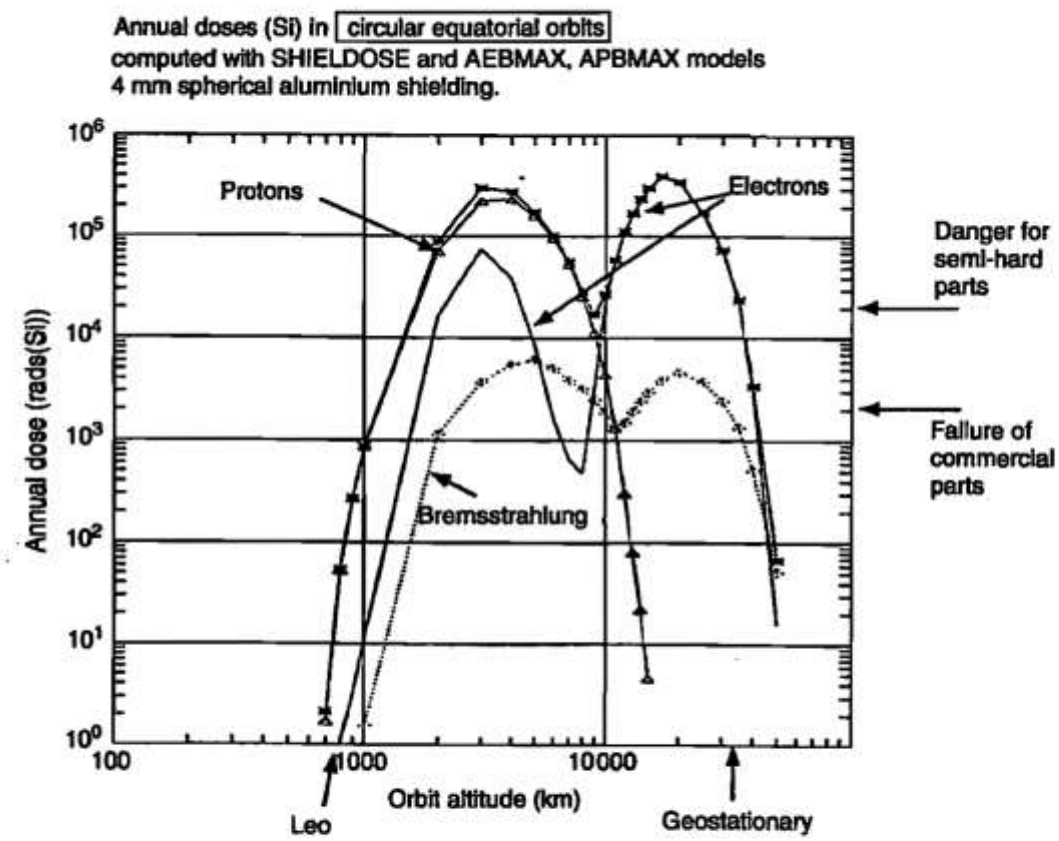
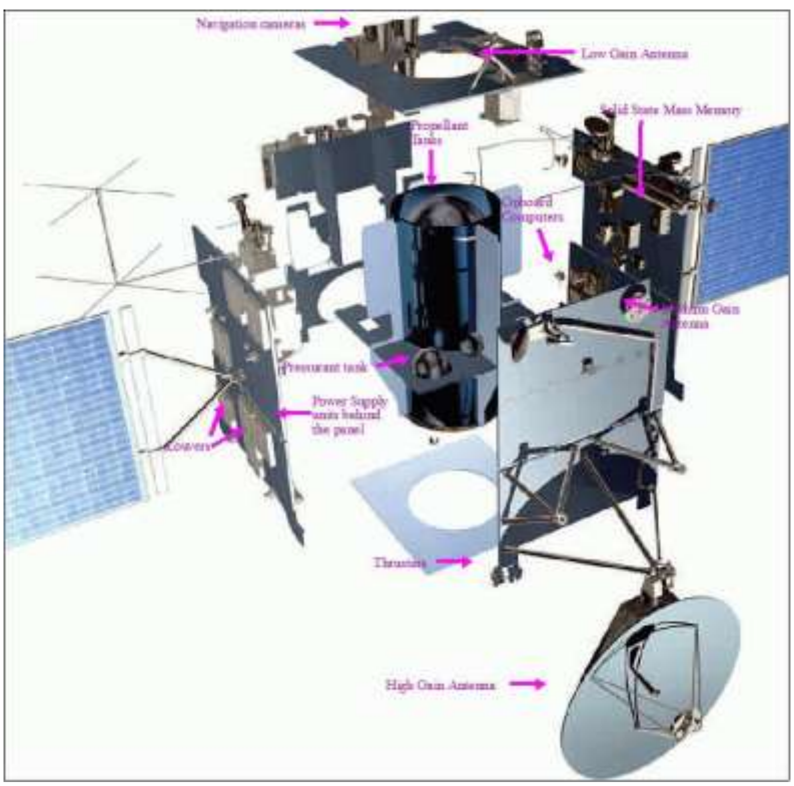


Figure 2.17 Variation of computed annual dose on circular orbits as a function of altitude. Computed with AE8 and AP8 models and SHIELDOSE [13]. (Reproduced by permission of the International Astronautical Federation)

2.4 Environmental Effects on Spacecraft Design

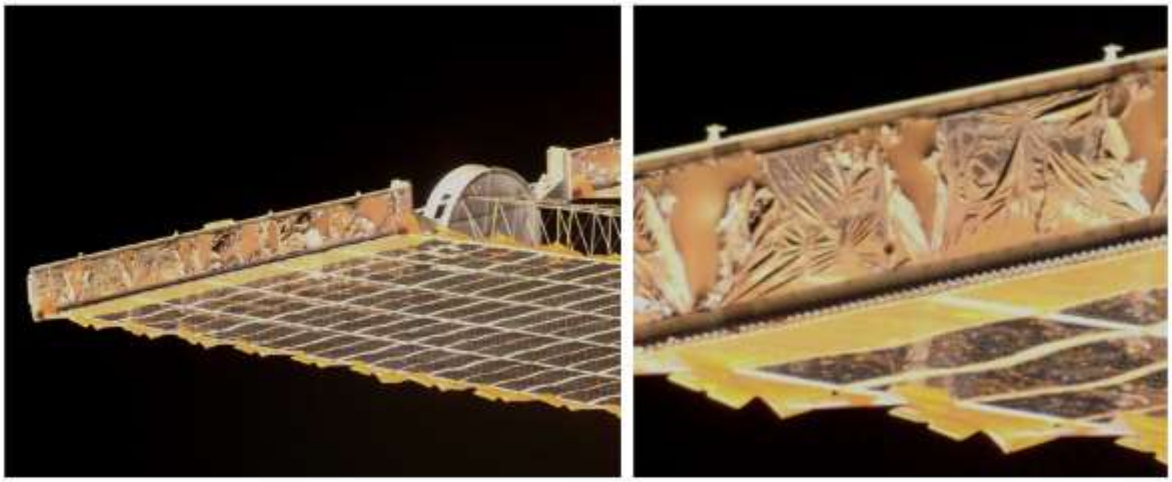
Outgassing/sublimation

- **Vaporization of surface atoms when pressure near material vapor pressure**
- **Outgassing products can condense onto optical elements, thermal radiators, or solar cells and obscure them**
- **Lubricants must generally be solid-based (MoS_2)**
- **Plastics can be problem**
- **NASA and ESA resources for choosing matl's:**
- https://outgassing.nasa.gov/
- http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20030053424.pdf
- http://esmat.esa.int/services/outgassing_data/outgassing_data.html



Atomic Oxygen Erosion

- **O is major species in LEO (Fig 2.10)**
- **Both chemical reaction and mechanical impact/momentum transfer (8km/s) can damage mat'ls**
- **Irreversible degradation of material properties:**
  - **Optical**
  - **Thermal**
  - **Mechanical**
  - **Electrical**
- **NASA Long-Duration Exposure Facility (satellite)**
  - **5.8 years in LEO**
  - **Huge assortment of materials on outside of spacecraft**



a. ISS solar array blanket box. b. Close-up of damage.

Figure 10. International Space Station solar array blanket box after one year in LEO showing only the vacuum deposited aluminum coatings are present after complete oxidation of the underlying Kapton [10].

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040191331.pdf

https://www.quora.com/How-do-things-age-in-outer-space#!n=12

Single Event Effects

- **Single Event Upset: high-energy particle impacts semiconductor-based integrated circuit**
- **Changes local logic state of device – unpredictable results**
- **Heavy ions, protons, neutrons**
- **Positive Ion - Occurs when an atom loses an electron (negative charge) it has more protons than electrons.**
- **Negative Ion - Occurs when an atom gains an electron (negative charge) it will have more electrons than protons.**

Properties of Protons, Neutrons, and Electrons

	Electron	Proton	Neutron
Symbol	e–	p	n
Charge	1–	1+	0
Location	electron cloud around the nucleus	nucleus	nucleus
Relative mass	1/1,840	1	1