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SESA1015 Astronautics

Environment

Contents

Natural and Induced Environments

Possible Environments Include:

Fabrication, Assembly, Test, Terrestrial transportation, Launch. } *Induced*

Space Environment } *Natural*

Space Environment:

... hostile or friendly?

Our Solar System

What is the Space Environment?

Our Solar System

What is the Space Environment?

Temperature: 2.7° K

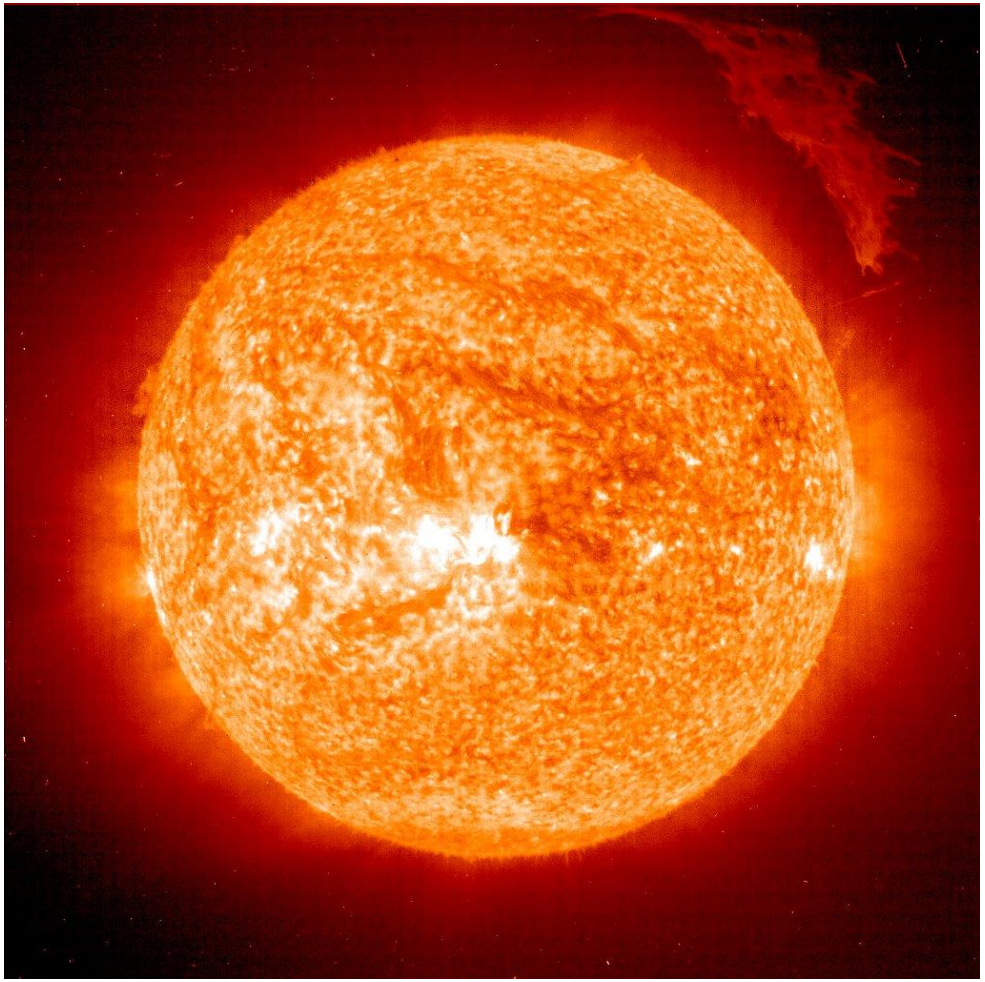
Vacuum

Microgravity

In our solar system, the main input to the space environment is… the sun.

Our Solar System

The Sun

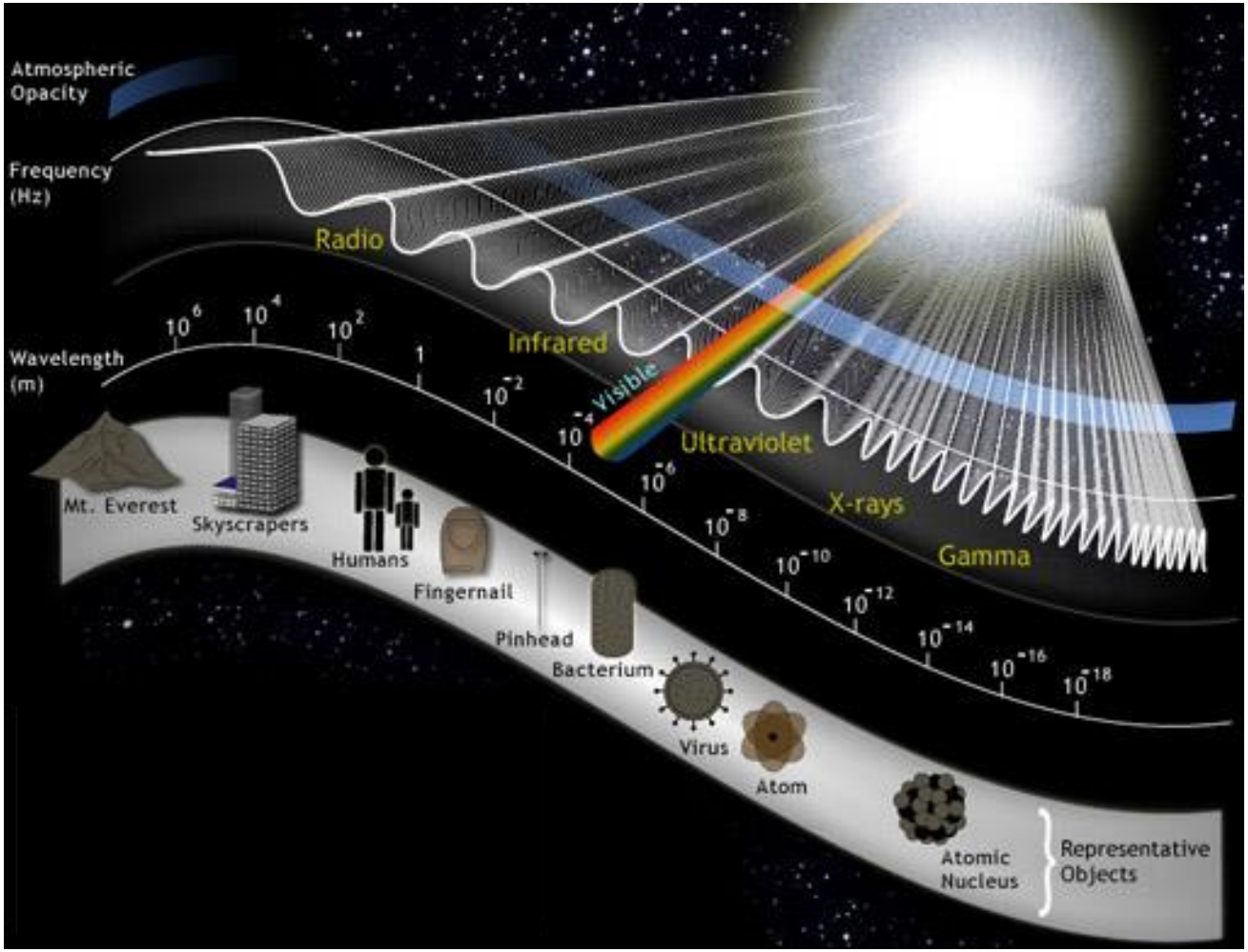


Diameter: 1,400,000 km
Source of energy:
Nuclear fusion

- Electromagnetic Radiation
- Particle Radiation

Our Solar System

The Sun – Electromagnetic Radiation – The Electromagnetic Spectrum

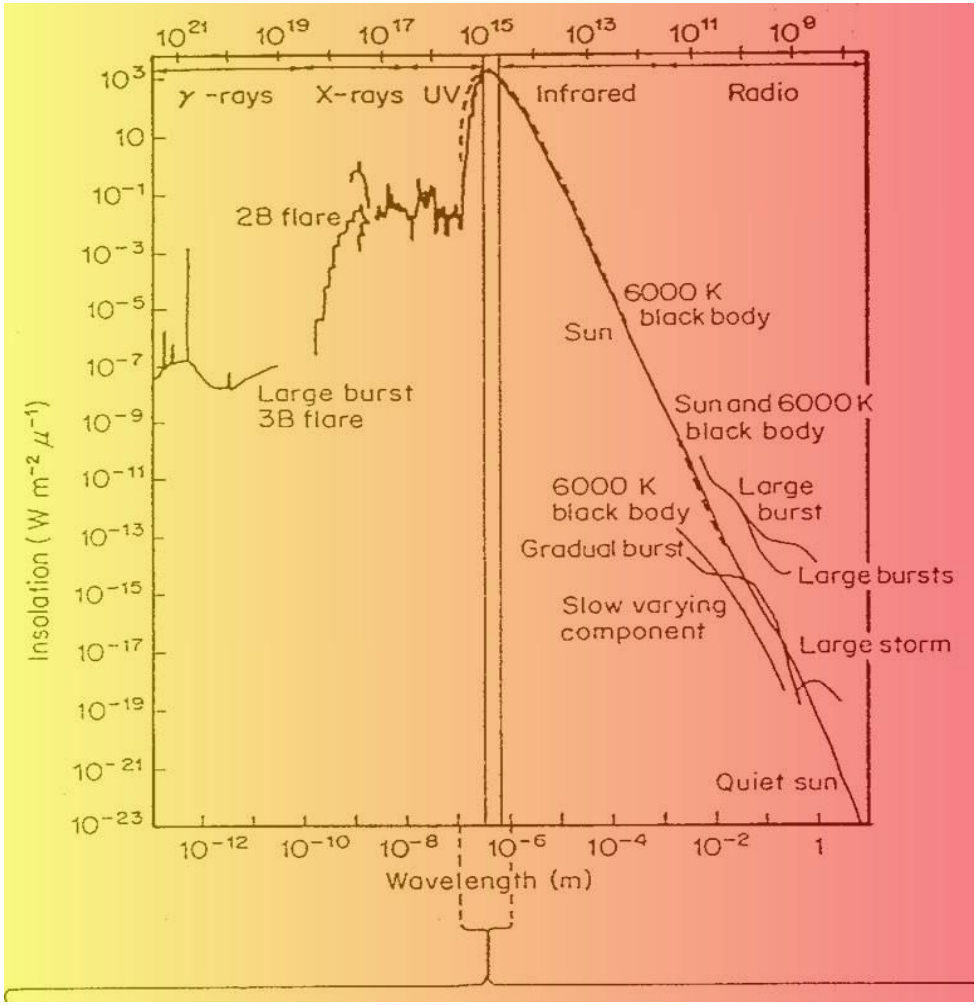


Average Energy output at 1 AU :
1370 W/m²

Solar Cycle – 11 year cycle

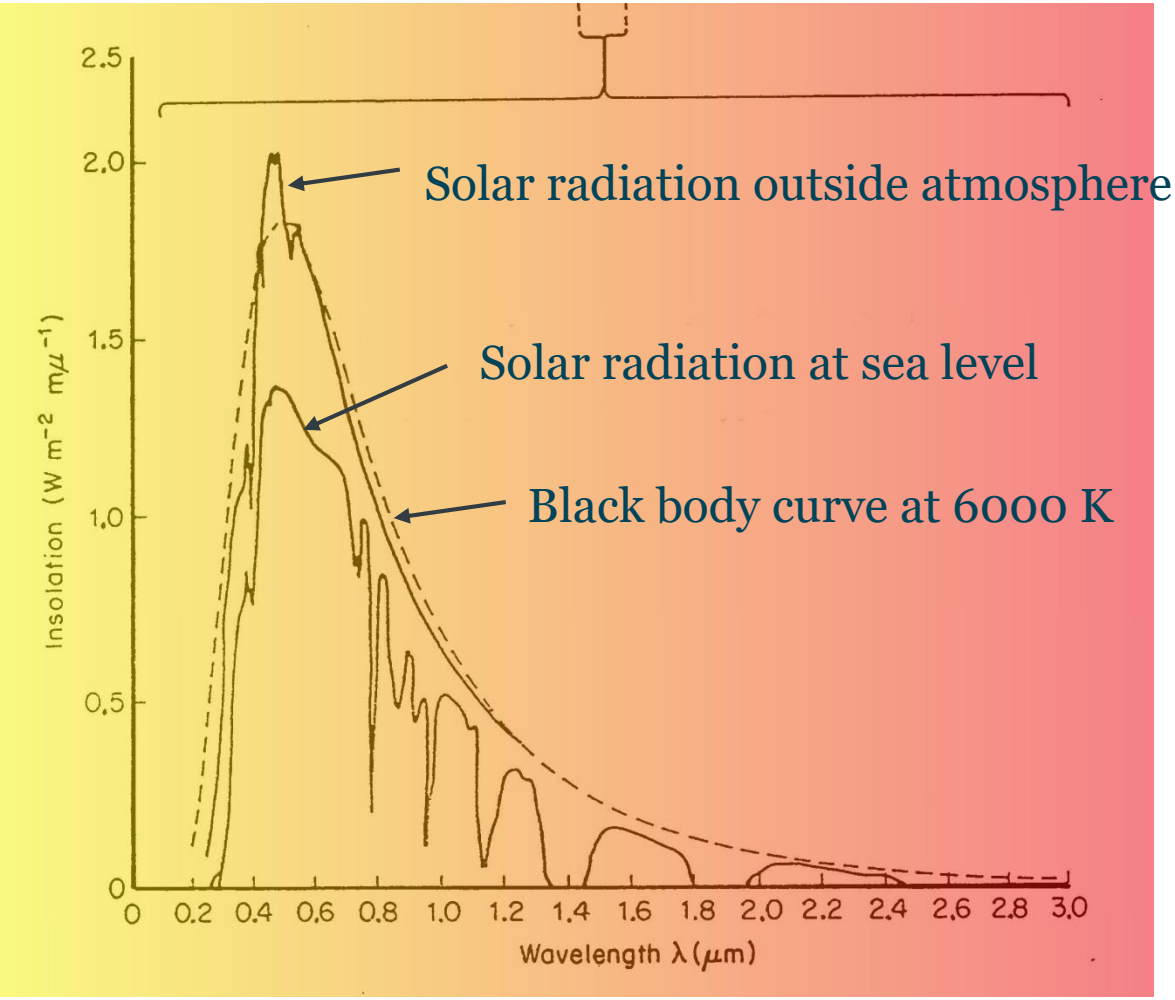
Our Solar System

The Sun – Electromagnetic Radiation



Our Solar System

The Sun – Electromagnetic Radiation – UV/visable wavelengths



Our Solar System

The Sun – Electromagnetic Radiation

- Solar spectrum approximates to a black body at ~6000K in UV, visible and IR.

- Peak output in visible at ~0.5 μm wavelength

- Solar Variability:

  Radio × 100;

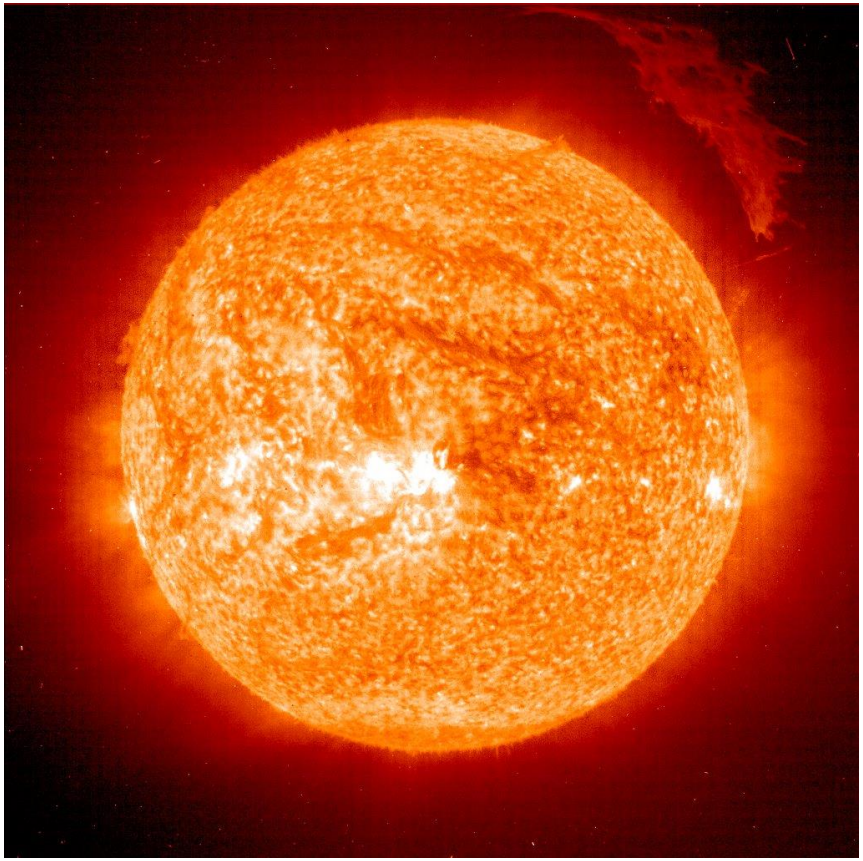
  IR small;

  Visible <1%;
  UV × few;

  X-ray × 100.

Our Solar System

The Sun – Particle Radiation



'stream of energetic (high speed) subatomic particles called the *solar wind*'

Source: violent eruptions that take place on the Sun's surface and in its atmosphere

Material is thrown into space as a result, consisting of *protons*, *electrons* and *ions* (the nuclei of atoms stripped of their electrons)

At Earth (depending on solar activity)

$n \sim 5 \times 10^6$ protons/m^3,

$v \sim 200$ - 800 km/s

Effects on spacecraft materials + systems

Our Solar System

The Sun – Solar Proton Events (SPE), '*Solar Storm*'

At times of a solar maximum the frequency and violence of the outburst's on the suns surface ('solar flares') increase. These events can discharge a cloud of energetic charged particles towards the Earth.

Increase in high energy protons (~ 1 MeV to 1 GeV) for a few hours to a few days.

Frequency – a few / year, peaking at solar max.

Other Particle Radiation – Galactic Cosmic Rays (GCR)

Extremely high energy particles emanating from outside the solar system (10^9 – 10^{12} eV).

Earth and the Earth Orbit Environment

The Earth has some degree of natural protection from the Sun's output…

- The atmosphere
- The Earths Magnetic field

Earth and the Earth Orbit Environment

Earths Atmosphere

Exosphere

Ionosphere

400 - 700km

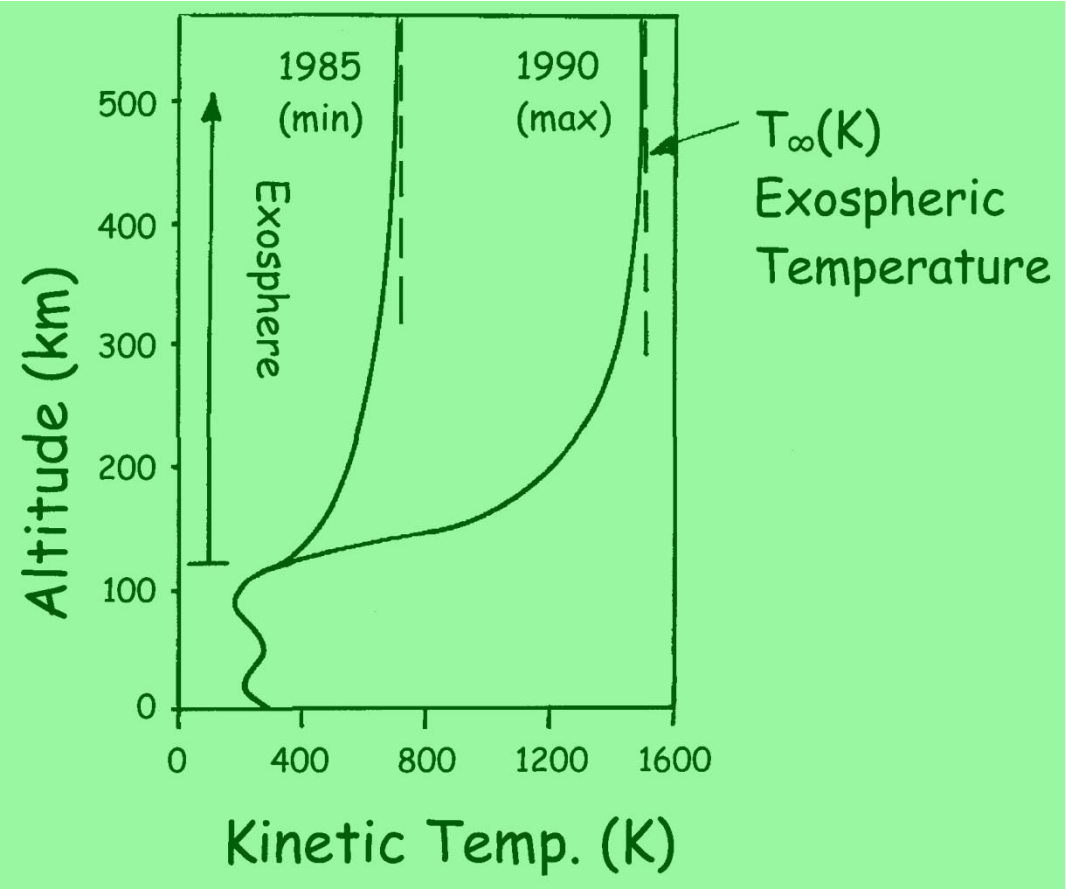
85 - 100km

50km

6 - 20km

Earth and the Earth Orbit Environment

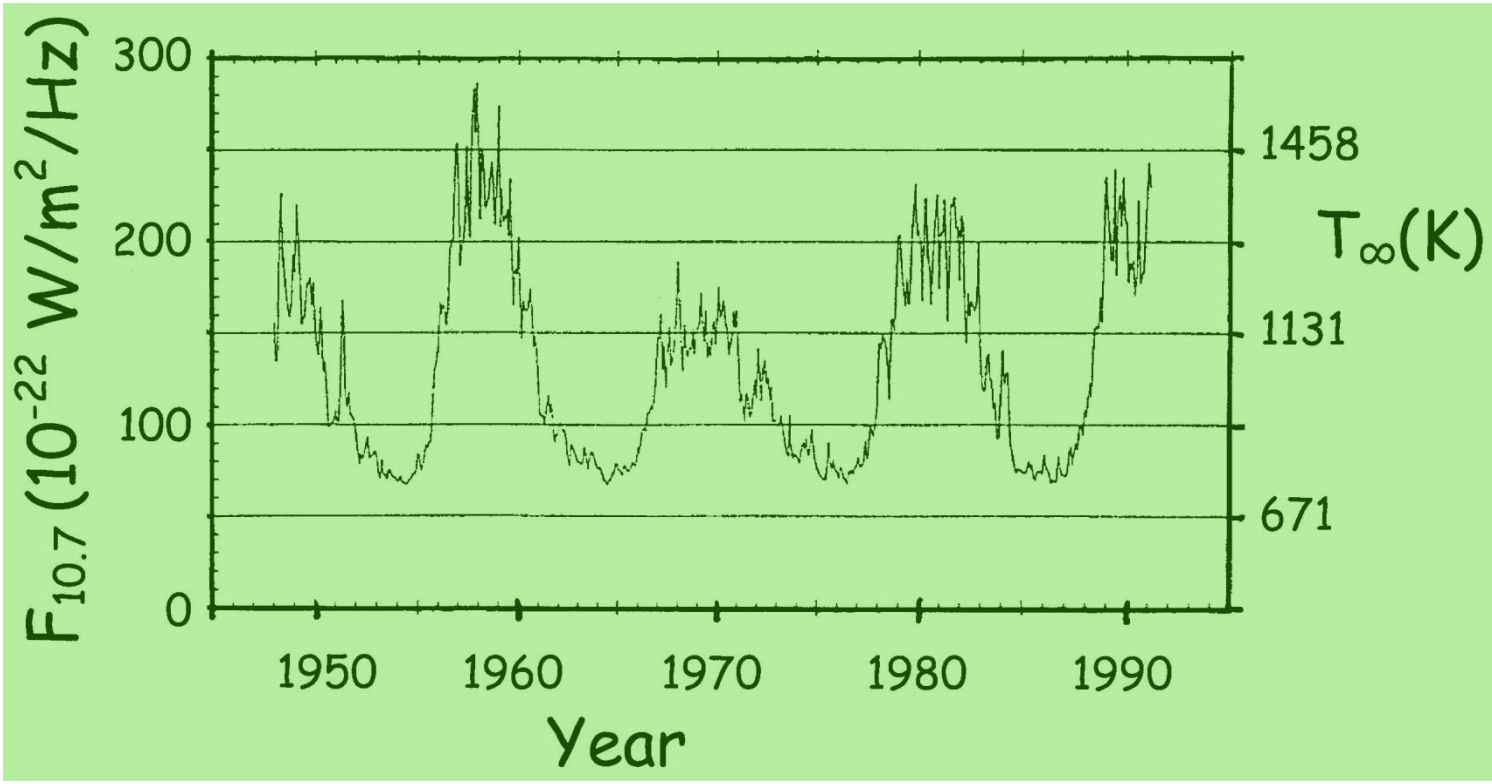
Earths Atmosphere – the atmosphere and the electromagnetic radiation



Earth and the Earth Orbit Environment

Earths Atmosphere – the atmosphere and the electromagnetic radiation

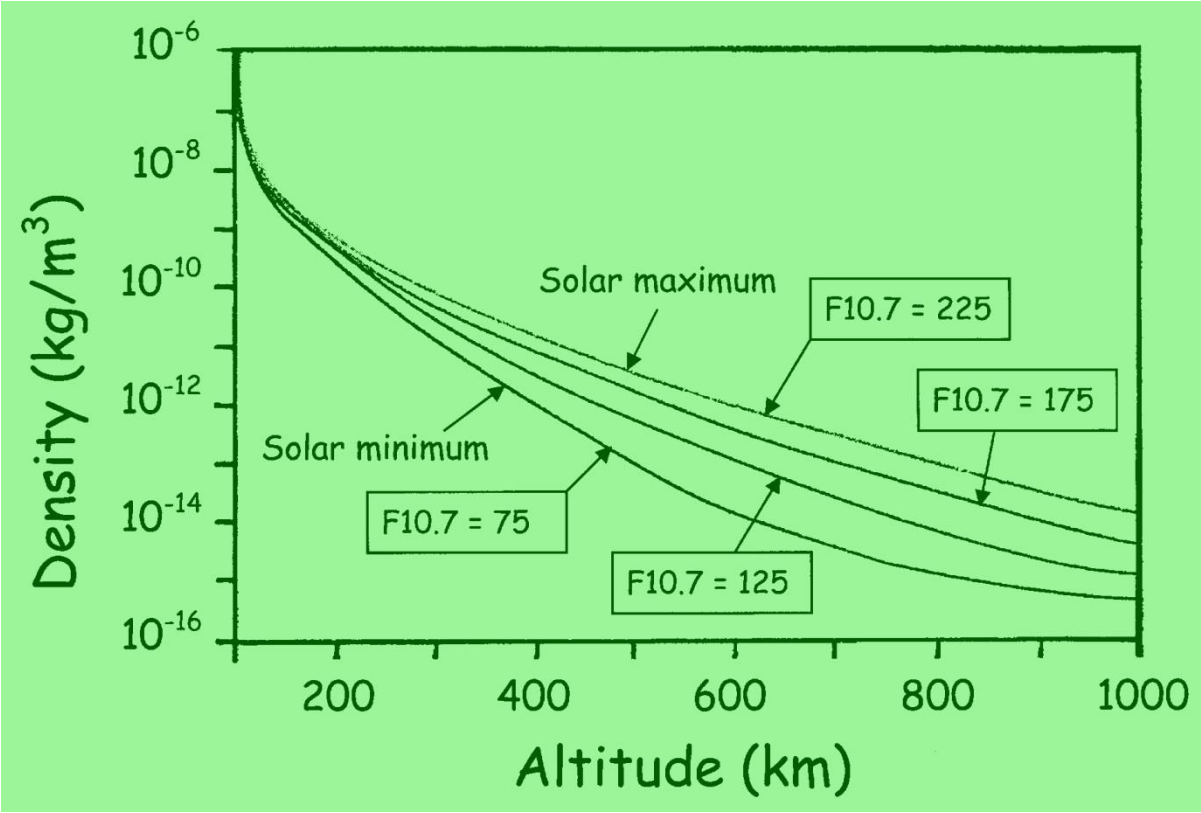
Exospheric Temperature with Solar Cycle



Earth and the Earth Orbit Environment

Earths Atmosphere – the atmosphere and the electromagnetic radiation

Atmospheric Density



Earth and the Earth Orbit Environment

Atmosphere – Density

Density above some reference altitude h_o is give by:

$$\rho_i = \rho_{i0} \exp\left\{\frac{-gM_i}{RT}(h - h_0)\right\}, \qquad (2.1)$$

where
ρ_i = density of species i
ρ_{io} = density of species i at height h_o
g = acceleration due to gravity
M_i = molecular weight of species i
R = Universal Gas Constant
T = atmospheric temperature

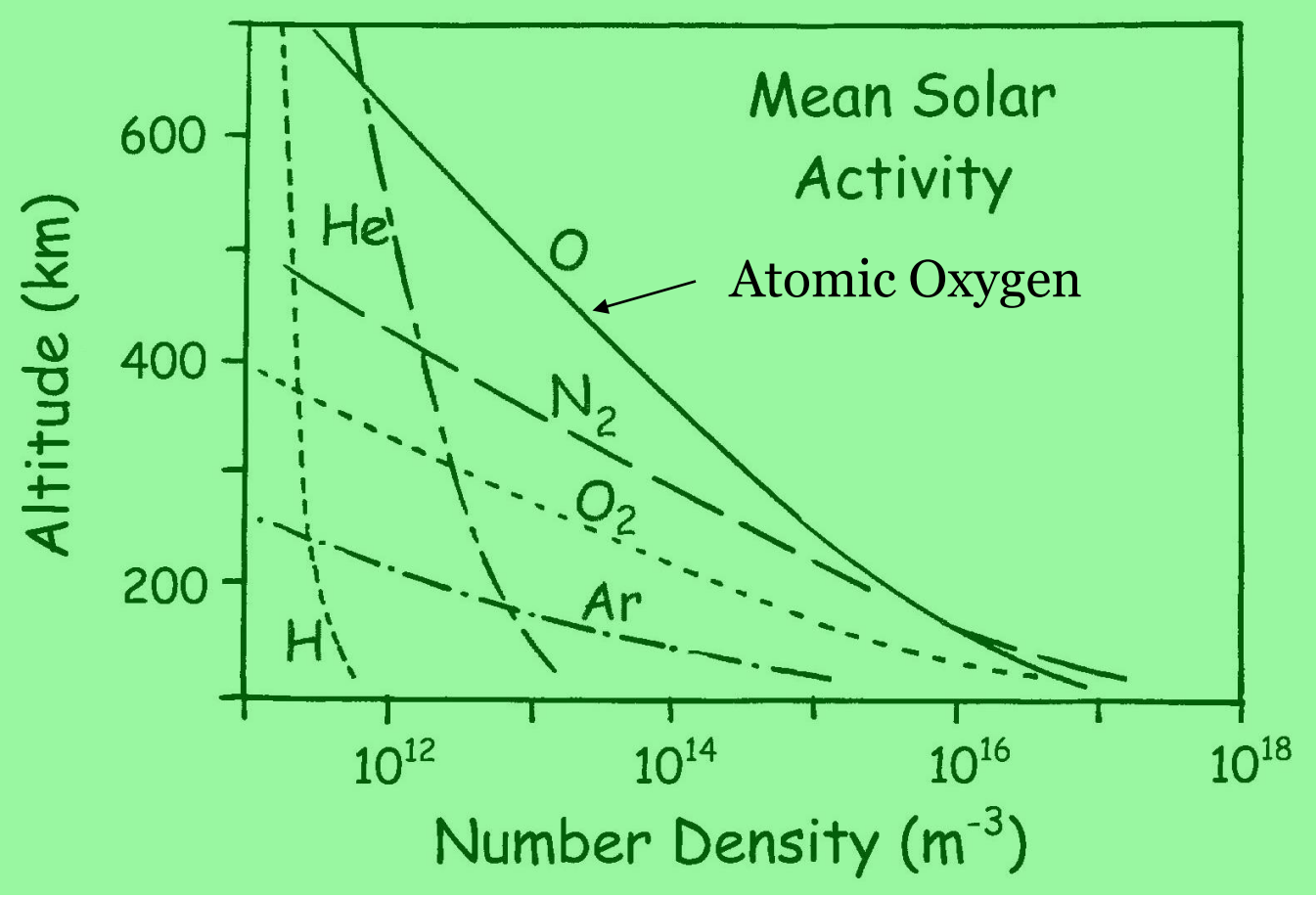
Total density is

$$\rho = \rho_0 \exp\left\{-\frac{(h - h_0)}{H}\right\}, \qquad (2.2)$$

where H = scale height ($\propto T/M_i$)

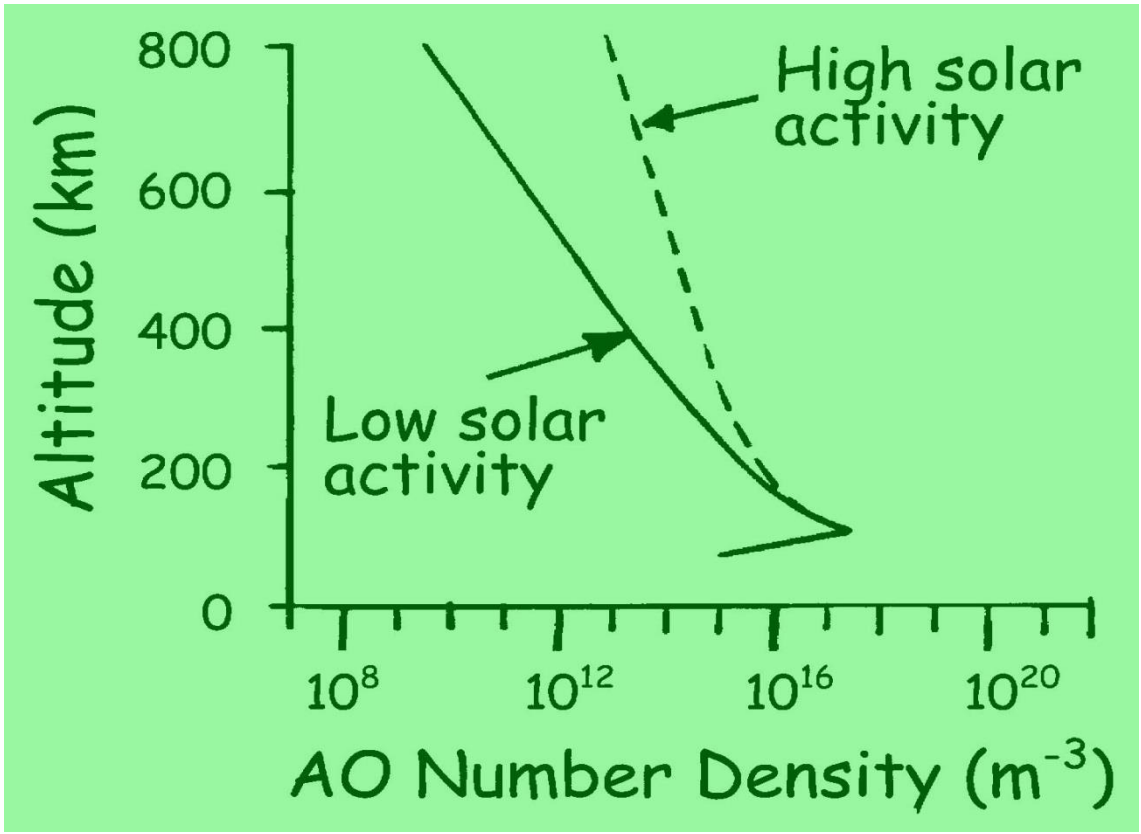
Earth and the Earth Orbit Environment

Earths Atmosphere – Constituents



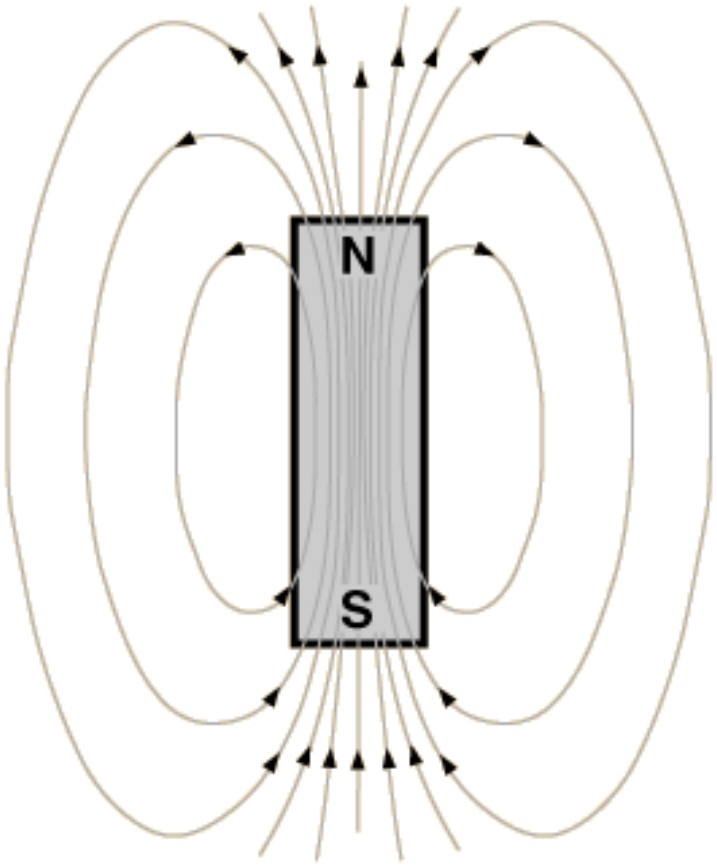
Earth and the Earth Orbit Environment

Earths Atmosphere – Atomic Oxygen (AO)



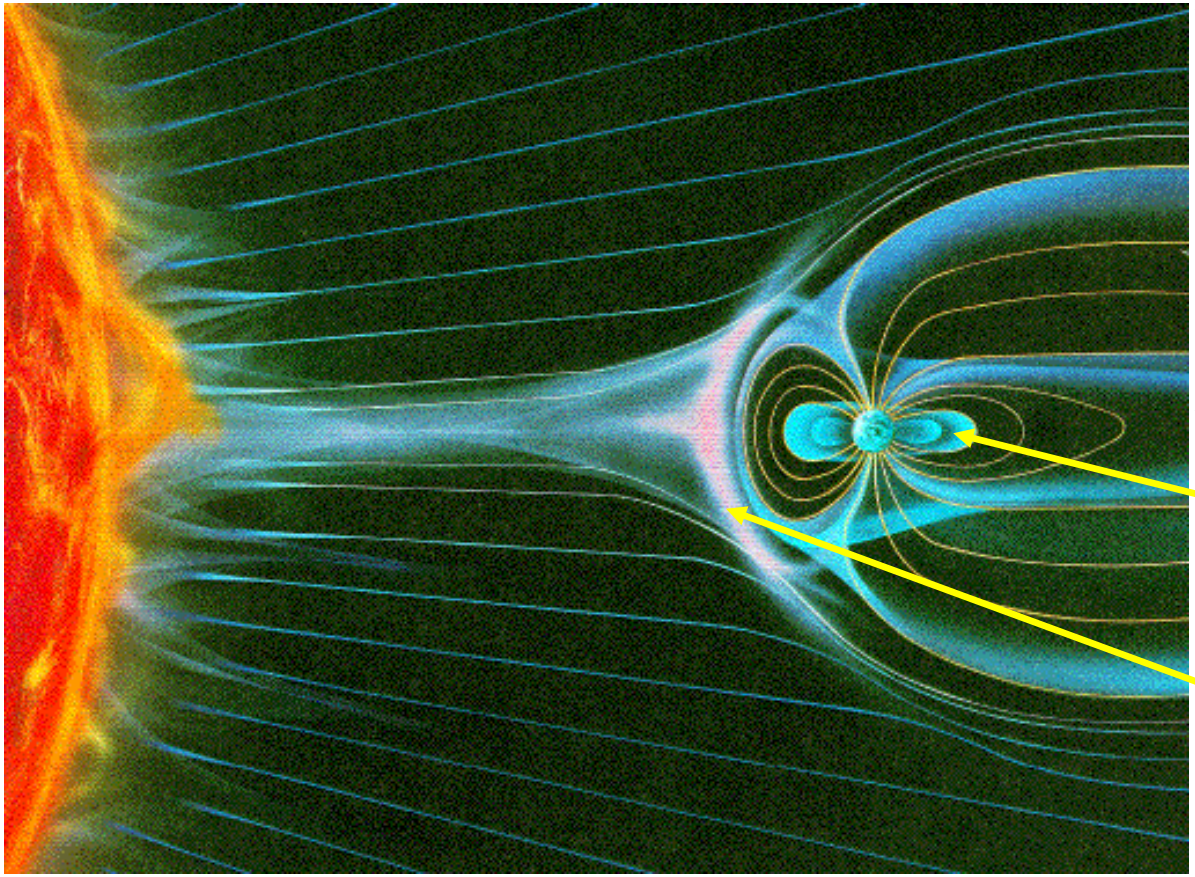
Earth and the Earth Orbit Environment

Earths Magnetic Field



Earth and the Earth Orbit Environment

Earths Magnetic Field – The Magnetosphere



Earth and the Earth Orbit Environment

Earths Magnetosphere and Ionizing Particle Radiation

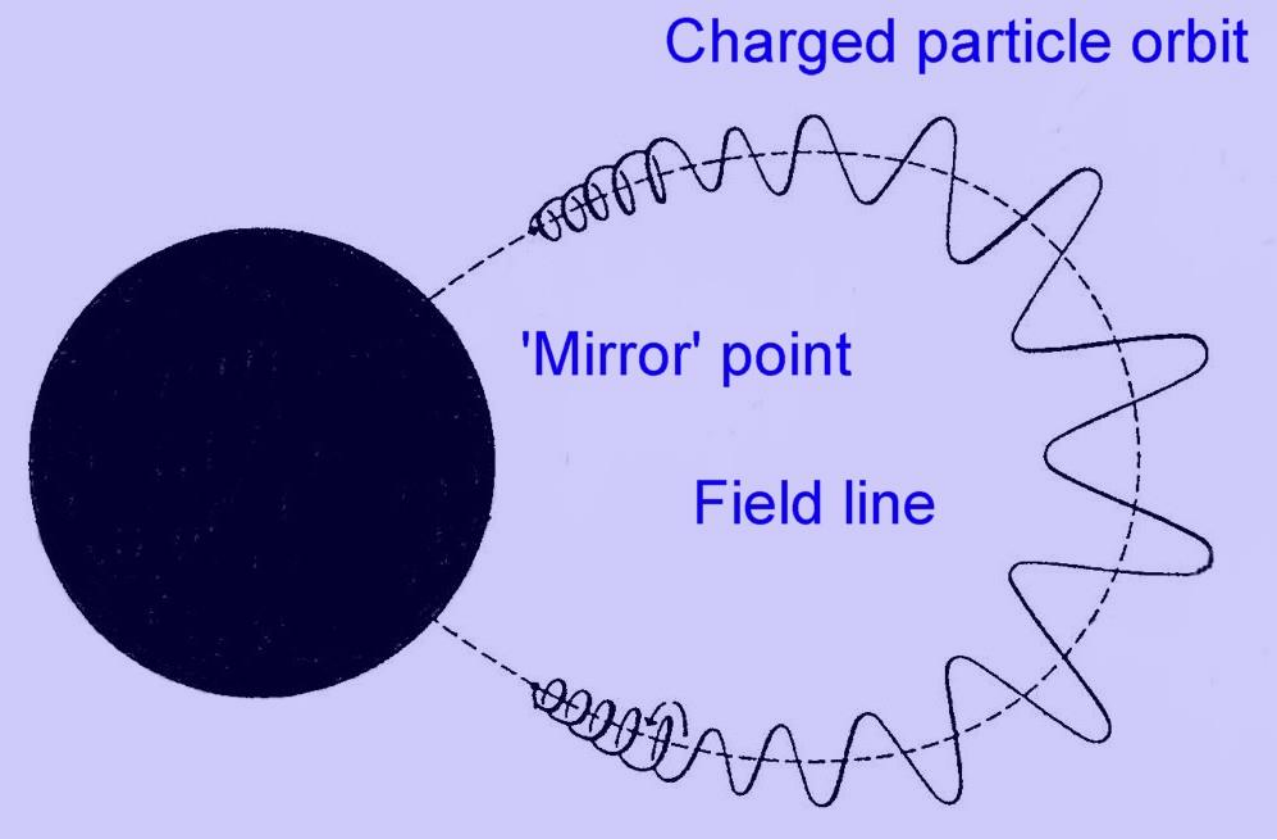
- Structure of magnetosphere formed by interaction of solar wind and Earth's (approximately) dipole field

- Particles penetrate magnetosphere at North and South magnetic poles, and become trapped (Van Allen trapped radiation belts)

- Magnetosphere boundary is dynamic and variable, depending on intensity of the solar wind ('magnetic storms')

Earth and the Earth Orbit Environment

Ionizing Particle Radiation – Trapped Radiation

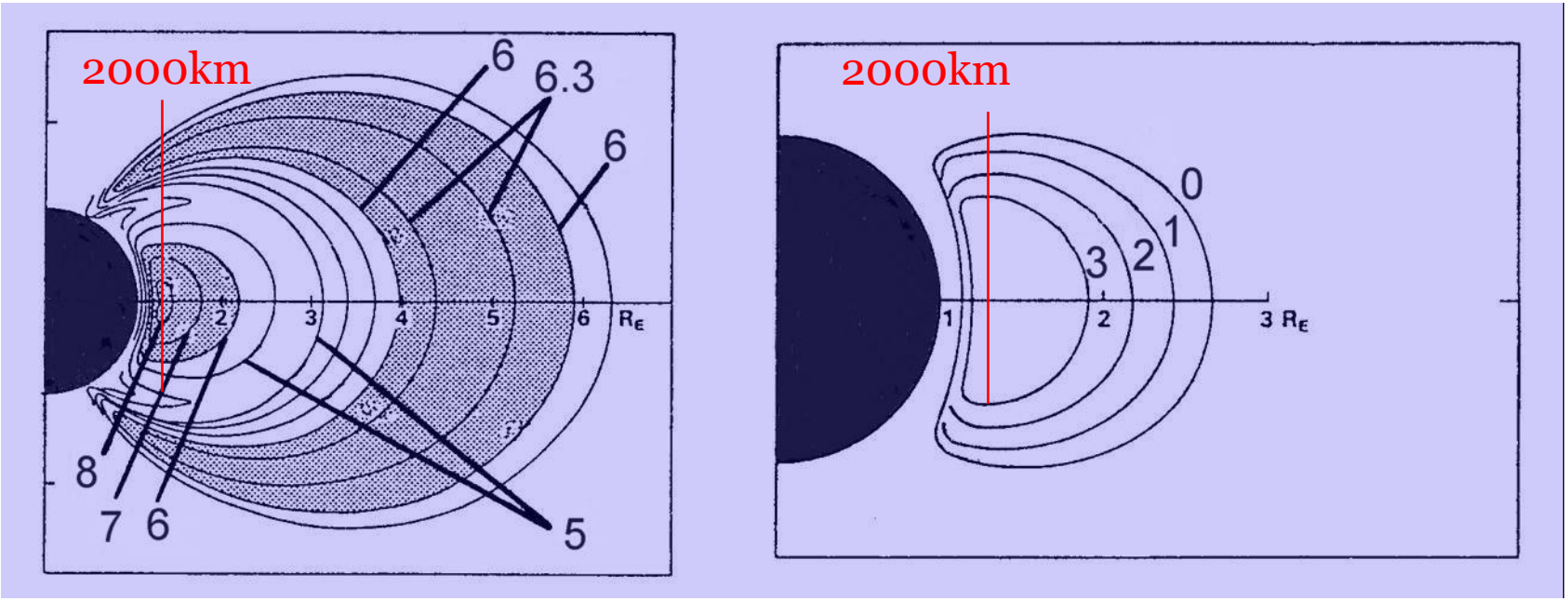


Earth and the Earth Orbit Environment

Ionizing Particle Radiation – Trapped Radiation

Structure of the Van Allen radiation belts.

Numerical values are x, where flux is 10^x cm^{-2} s^{-1}.



Electrons, E > 0.5 MeV

High energy protons, E ≥100 MeV

Earth and the Earth Orbit Environment

Debris

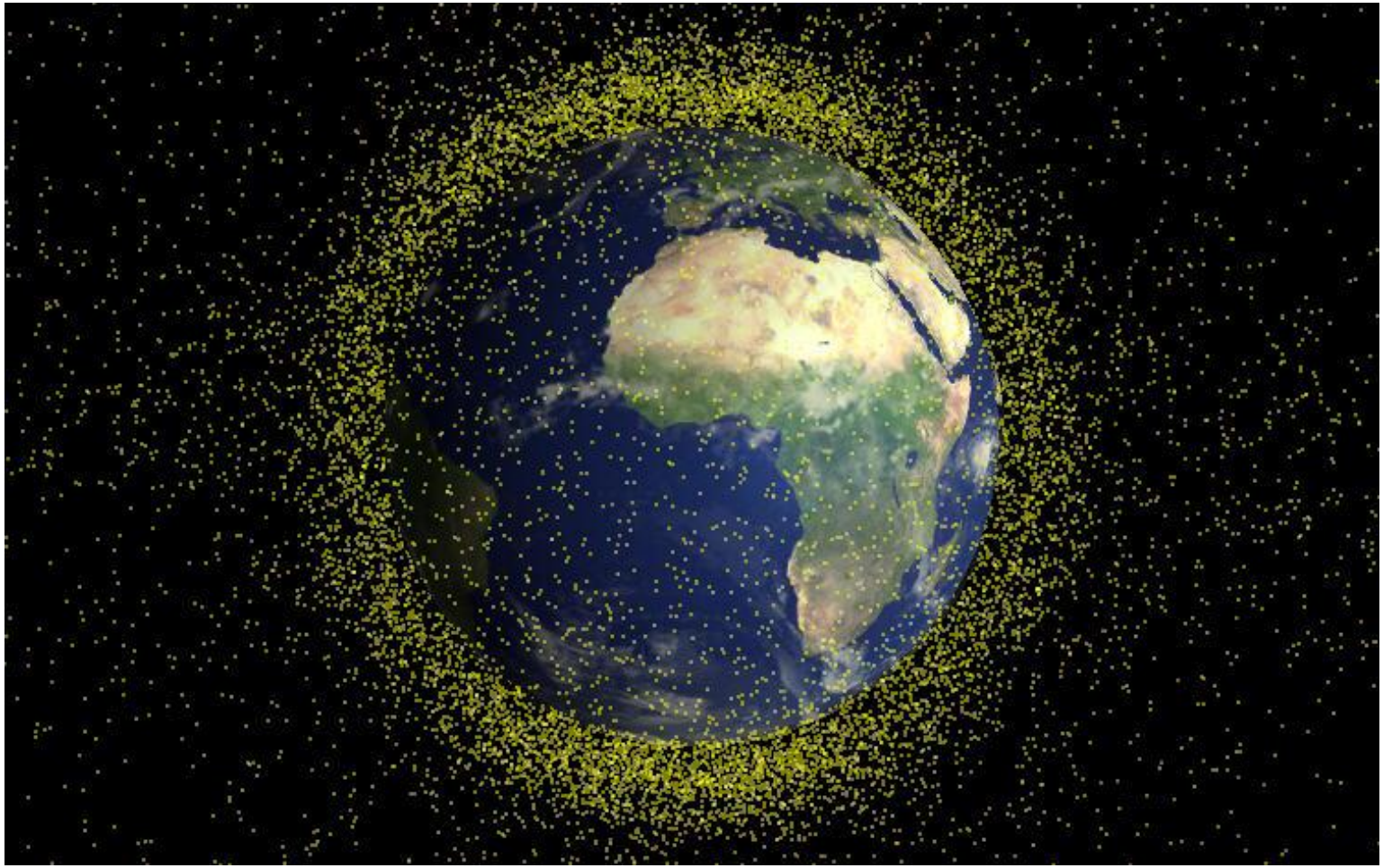
Divided into:

- *Natural Space Debris* – meteroids that the earth encounters through its orbit (estimated that ~100 metric tonnes of this material rains down into the Earth atmosphere each day)

- *Artificial Debris* – man made objects
(in 2009 Earths orbital environment contained 3,371 operational satellites and 11,492 debris objects ≥ 10cm, NASA)

Earth and the Earth Orbit Environment

Debris



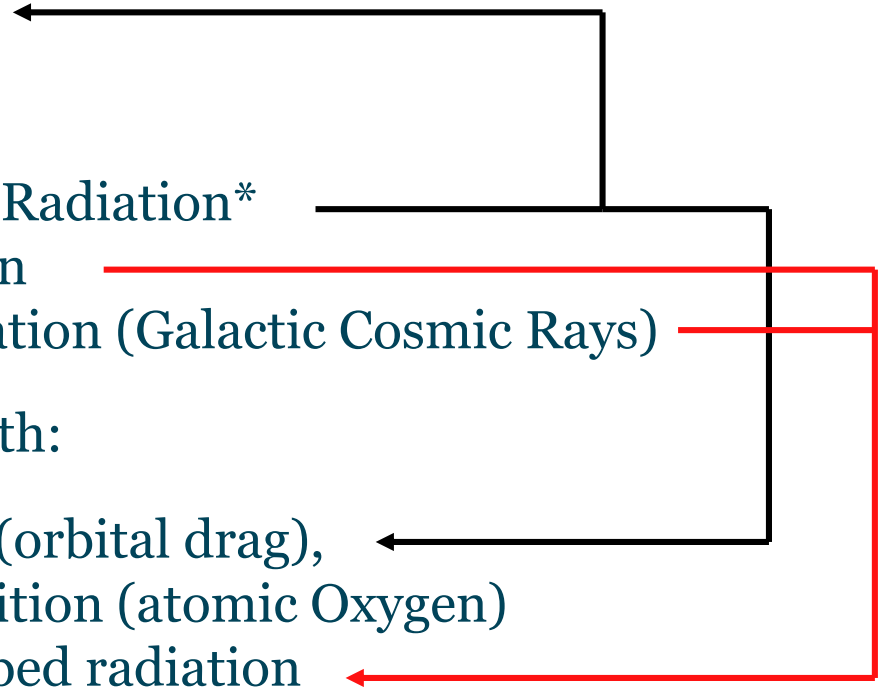
Summary of Space Environment

In the Solar System:

- Low Temperatures*
- Vacuum
- Microgravity
- Sun's Electromagnetic Radiation*
- Sun's Particle Radiation
- External Particle Radiation (Galactic Cosmic Rays)

Environment Around the Earth:

- Atmosphere – density (orbital drag), composition (atomic Oxygen)
- Magnetic Field – Trapped radiation
- Debris



Environmental Effects on Design/Humans

Is the environment hostile or friendly?

- Hostile
  - High vacuum
  - Particle radiation
  - High energy Electromagnetic radiation
  - Atomic oxygen (Earths Atmosphere)
  - Debris
- Friendly
  - No water vapour/rain
  - No wind
  - Clean environment
  - Zero effective gravity

Environmental Effects on Design/Humans

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Vacuum

Some materials evaporate in hard vacuum (known as 'outgassing')

- resins
- adhesives
- lubricants
- some metals

Temperature for given outgassing rate

Material	0.1 μm/yr	1 mm/yr
Cadmium	38°C	122°C
Magnesium	110°C	233°C
Gold	660°C	950°C
Titanium	920°C	1250°C

Generally not an issue of structural integrity, but one of contamination.

Environmental Effects on Design/Humans

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Micro gravity

- Structural design
- Difficulty in mechanism deployment testing on the ground
- No convective heat transport
- Propellant management problems
- (Physiological effects on humans)

Environmental Effects on Design/Humans

Solar Radiation – Electromagnetic Output

Effects of solar e.m. radiation (UV):

- Changes in optical and electrical properties
- Embrittlement in polymers
- Darkening of solar array cover-glass and adhesives

Environmental Effects on Design/Humans

Ionizing Particle Radiation – Effects on materials and systems

- Degradation of semi-conductor devices (solar arrays)
- On-board software errors by single particle event (Single Event Upsets, SEU)
- Spacecraft charging
- (Physiological effects on humans)

Environmental Effects on Design/Humans

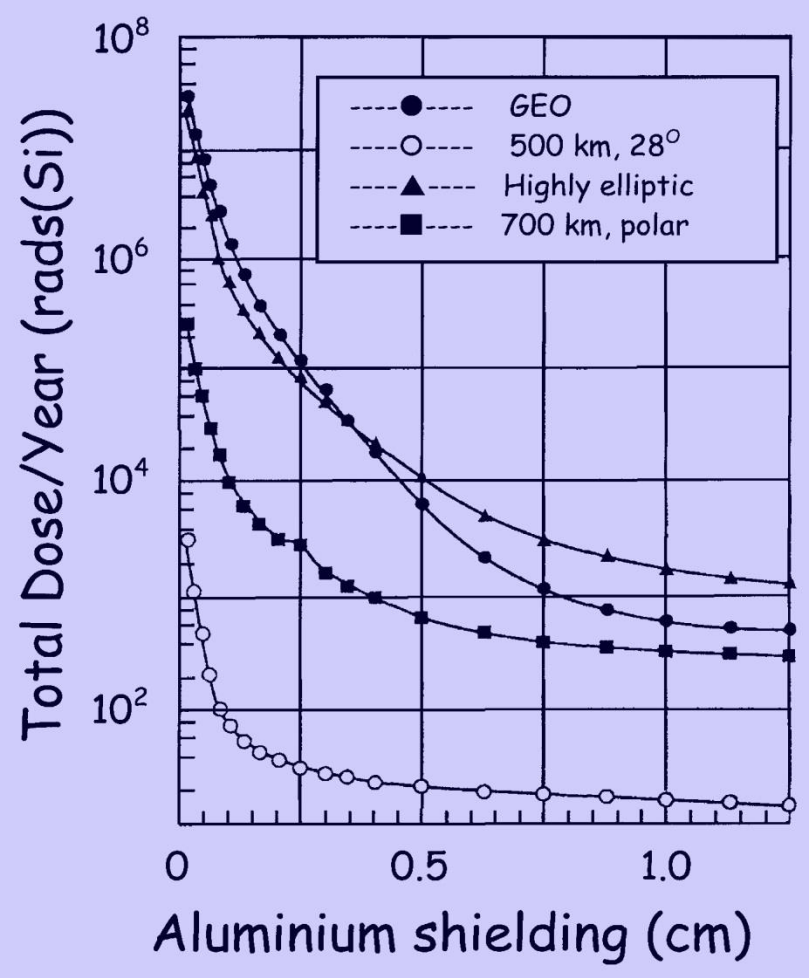
Ionizing Particle Radiation – Total Dose as a Function of Orbit

Standard Unit:

A rad (Si) (Radiation Absorbed Dose) is that amount of radiation which deposits 100 ergs of energy per gram of silicon semi-conducting material.

(1 erg = 10^{-7} J,

→ 100 rads = 1 J/kg)



Environmental Effects on Design/Humans

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Earth Atmosphere - Effects

- aerodynamic drag, lift and heating (re-entry)
- erosion (AO)

Atomic Oxygen (AO) Erosion Example

Estimate the depth of erosion of kapton for a typical space shuttle mission of 10 days duration during solar maximum.

Kapton:

- material commonly used in spacecraft insulation blankets.
- erosion rate ~2.8 μm for every 10^{24} atoms/m² of AO fluence

Environmental Effects on Design/Humans

Earth Atmosphere – Atomic Oxygen (AO) Erosion Example

AO fluence over time t is $$\boxed{F_0 = n_{AO} V t \quad (\mathrm{m}^{-2})} \qquad (2.3)$$

where n_{AO} = number density of AO (m^{-3})
V = spacecraft velocity (m s^{-1})

Typical shuttle altitude ~300 km, so

$$F_o = (10^{15} / \mathrm{m}^3)\,(7.7 \times 10^3\ \mathrm{m/s})\,(8.64 \times 10^5\ \mathrm{s})$$
$$\sim 6.7 \times 10^{24}\ \text{atoms} / \mathrm{m}^2$$

$\therefore$ Depth of erosion $\sim 2.8\ \mu\mathrm{m}\ (6.7 \times 10^{24}) / 10^{24}$
$\sim 19\ \mu\mathrm{m}$

Environmental Effects on Design/Man

Earth Atmosphere – Atomic Oxygen (AO) Erosion rates

Material	Surface Recession* (μm)
Kapton	2.8
Teflon	0.029
Aluminium	0.00035
Silver	9.8

* Surface recession for every 10^{24} atoms / m^2 of AO fluence.

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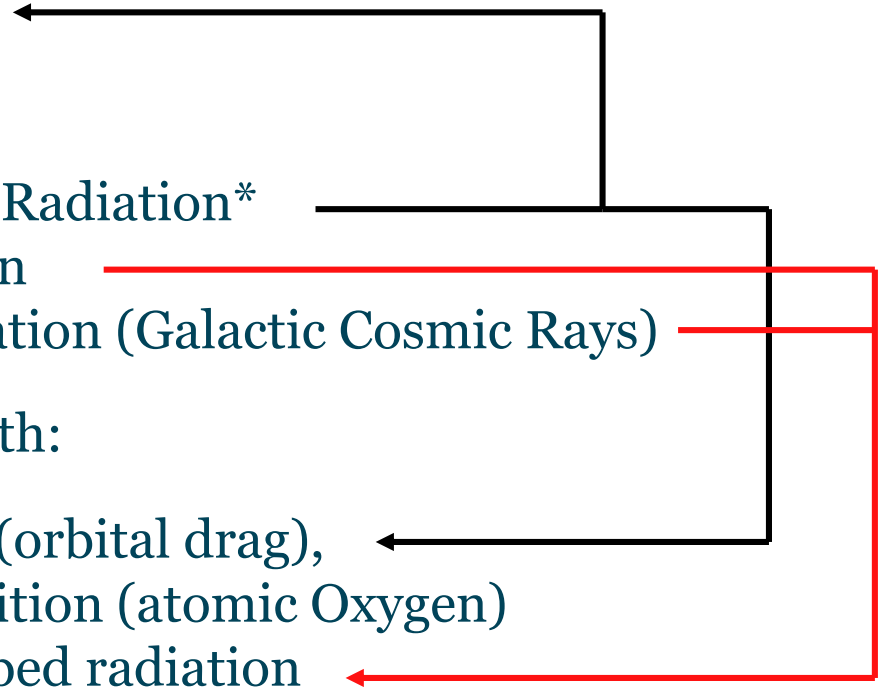


Launch Environment

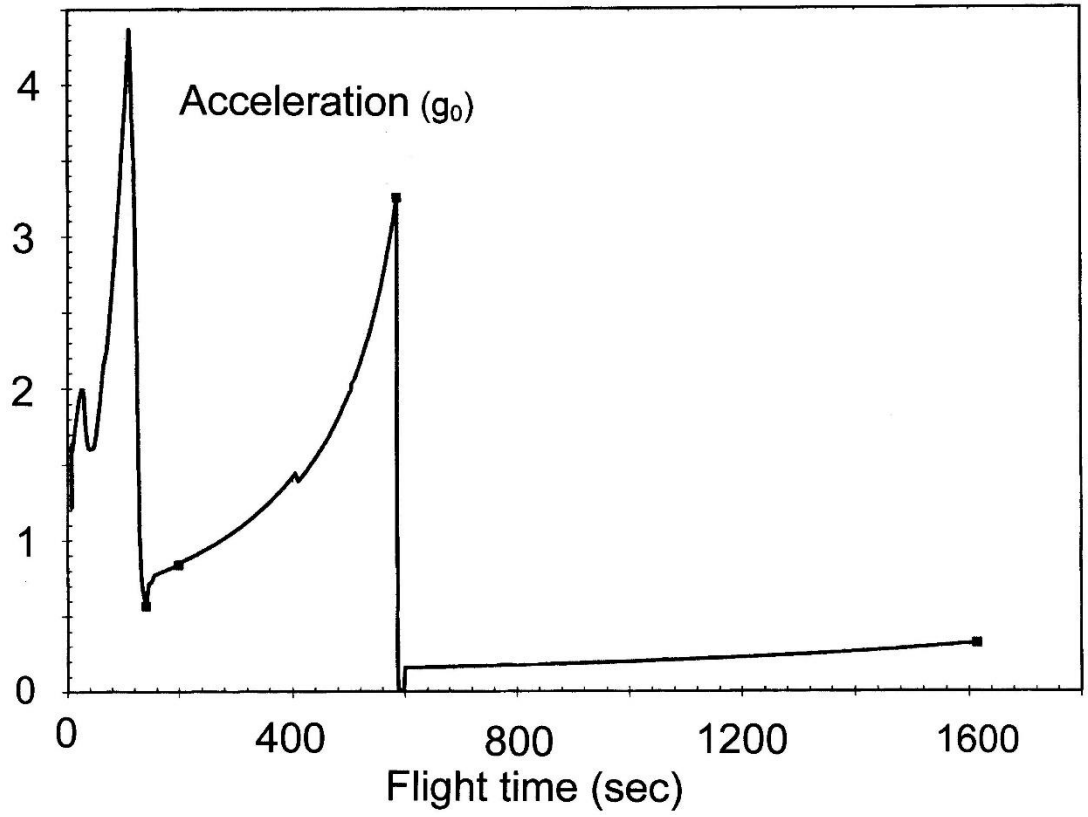
- Most Severe Environment (usually):
  - main driver for structural design of spacecraft

- 'Static' Acceleration:
  - launch vehicle dependent
    Ariane 5 $\leq 4g_0$
    Shuttle $\leq 3g_0$
    Saturn $\leq 8g_0$
  - peak occurs at stage burnout

Launch Environment

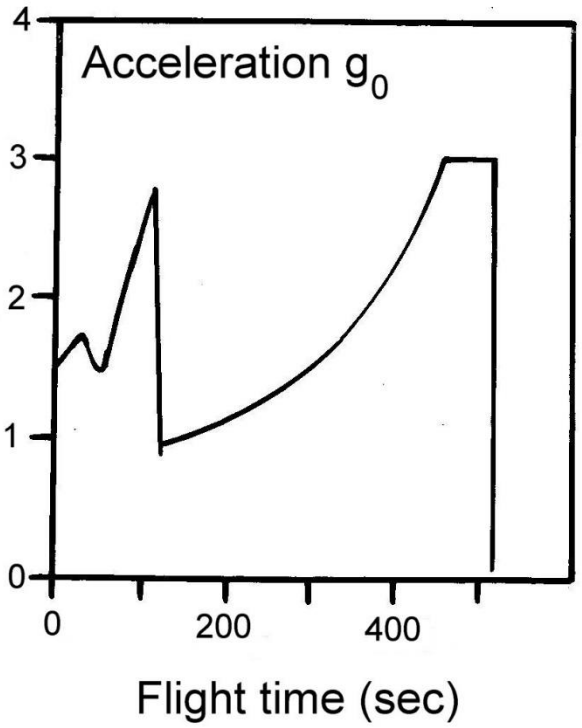
Static Acceleration

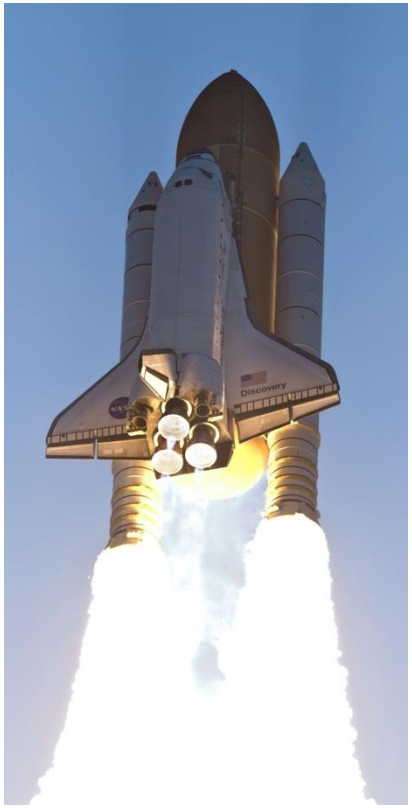
Ariane 5 static acceleration on launch



Launch Environment

Static Acceleration





Space shuttle static acceleration

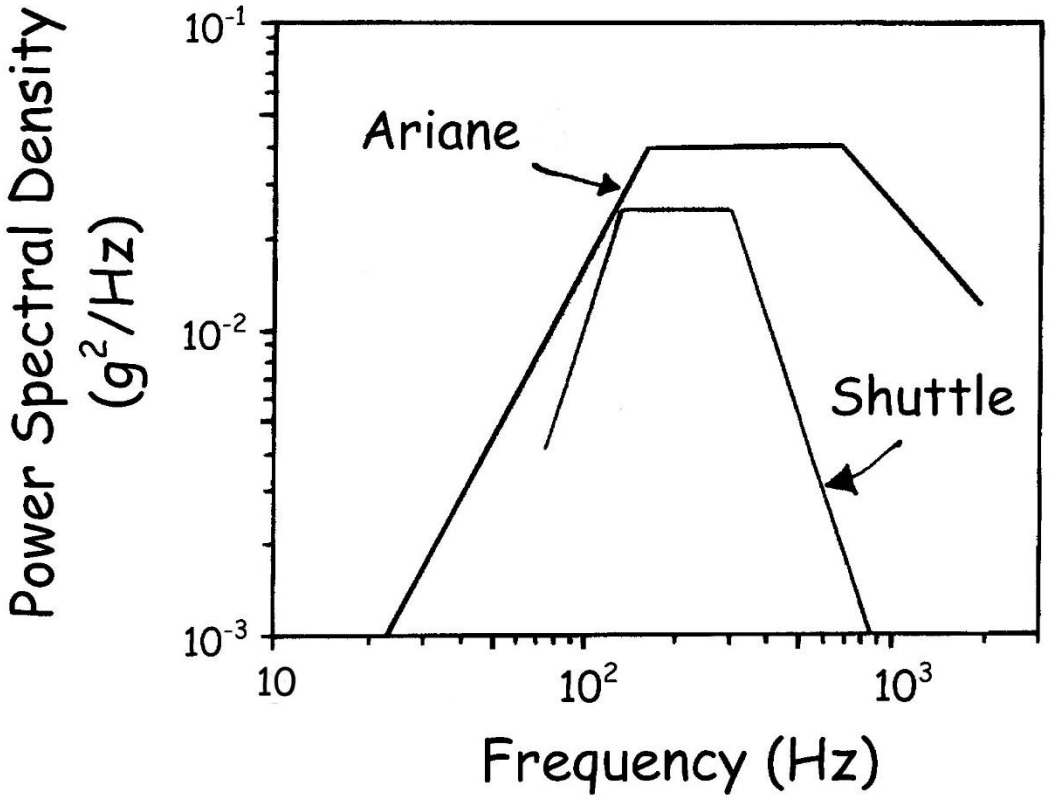
Launch Environment

Dynamic Acceleration

(or “oscillatory acceln.” or “random vibration”)

Generated by:

- Functioning machinery
- Combustion phenomena
- Structural excitation in acoustic field



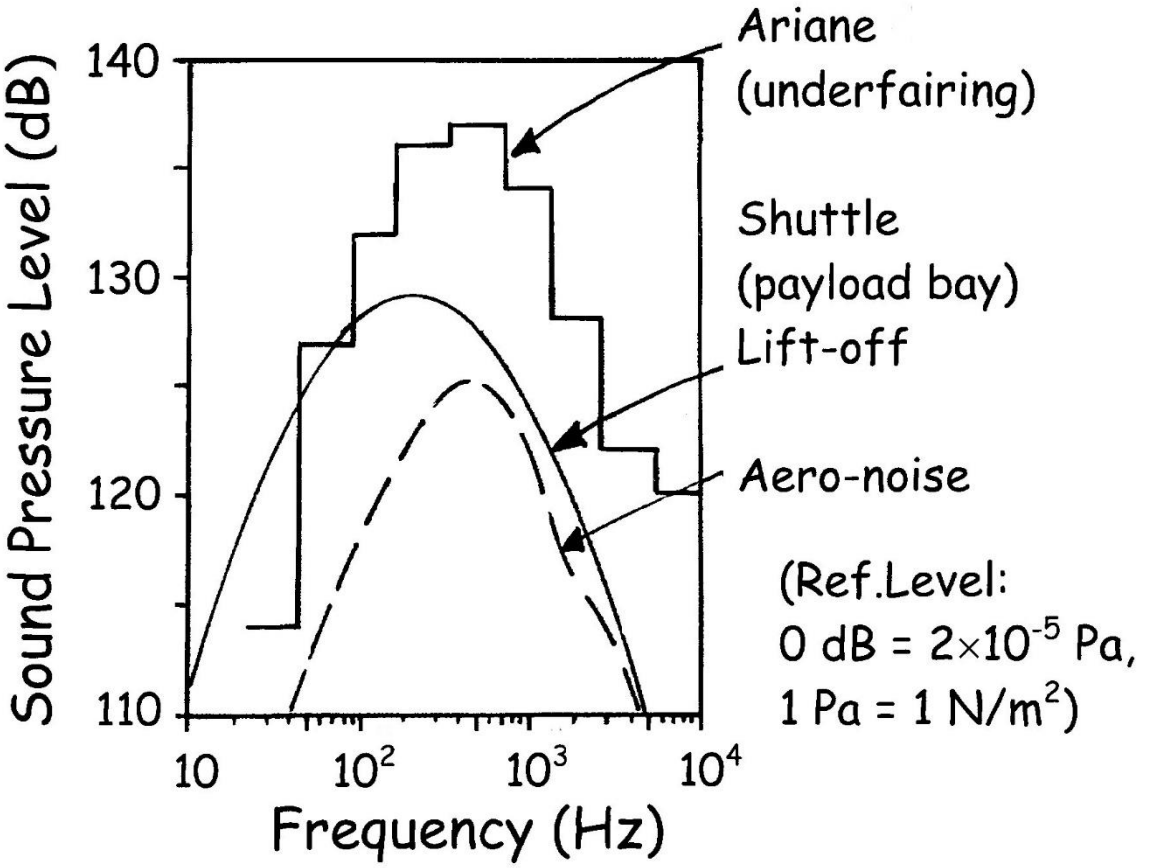
PSD Envelopes

Launch Environment

Acoustic Environment

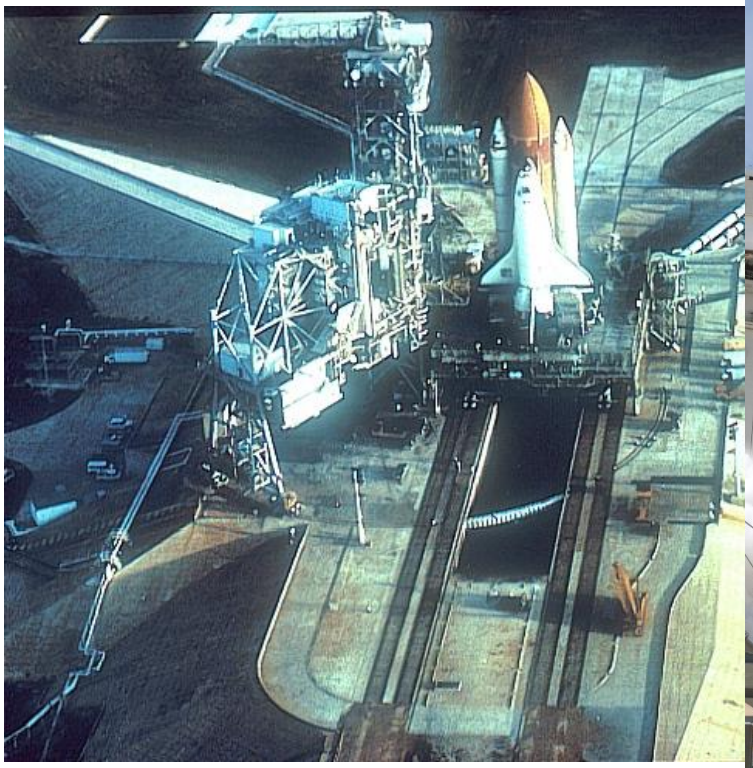
Intense acoustic field generated by:
- engine noise
- aerodynamic noise

Greatest intensity at:
- launcher release
- transonic speed



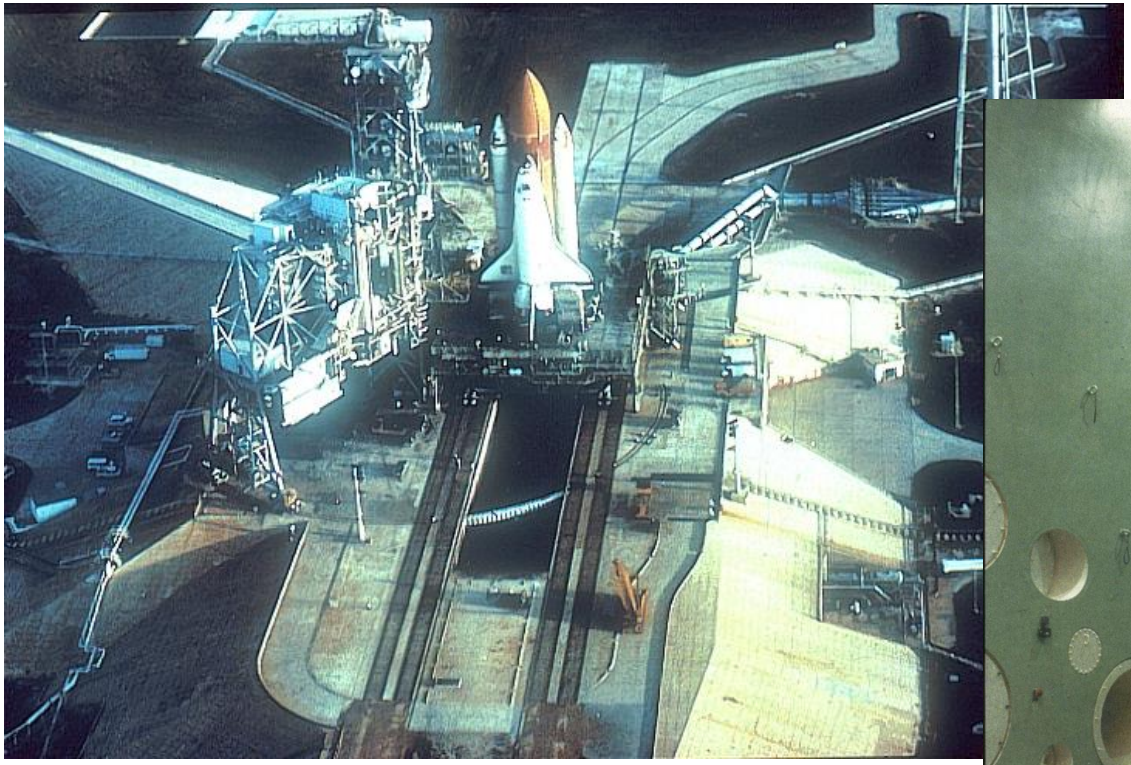
Launch Environment

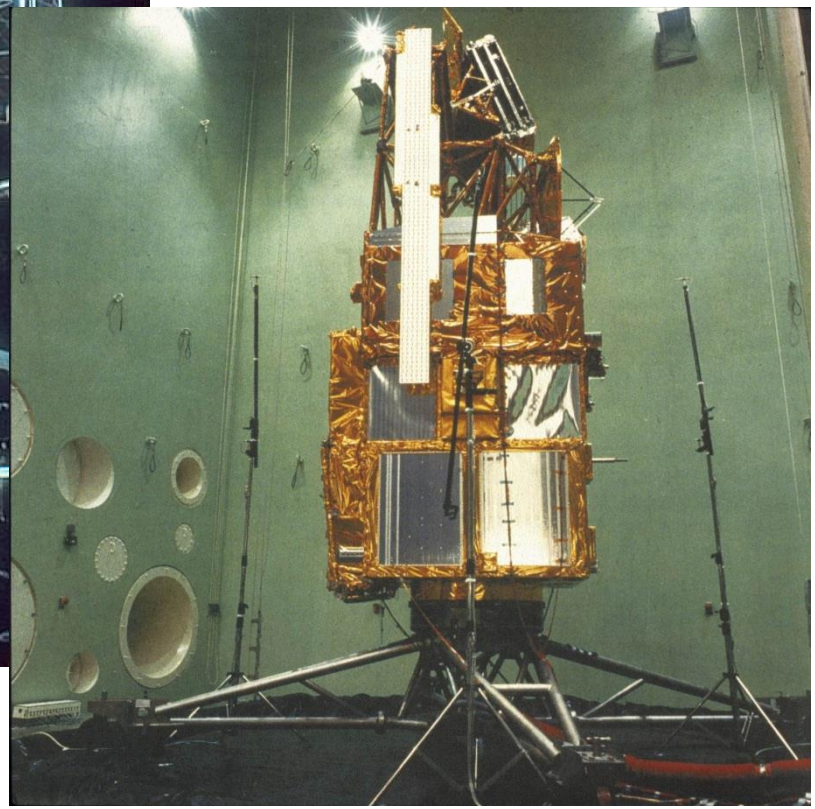
Acoustic Environment



Launch Environment

Acoustic Environment





Launch Environment

Effects on Spacecraft

- Main input to structural design

- Ground testing to ensure spacecraft survival on launch

Environment Summary

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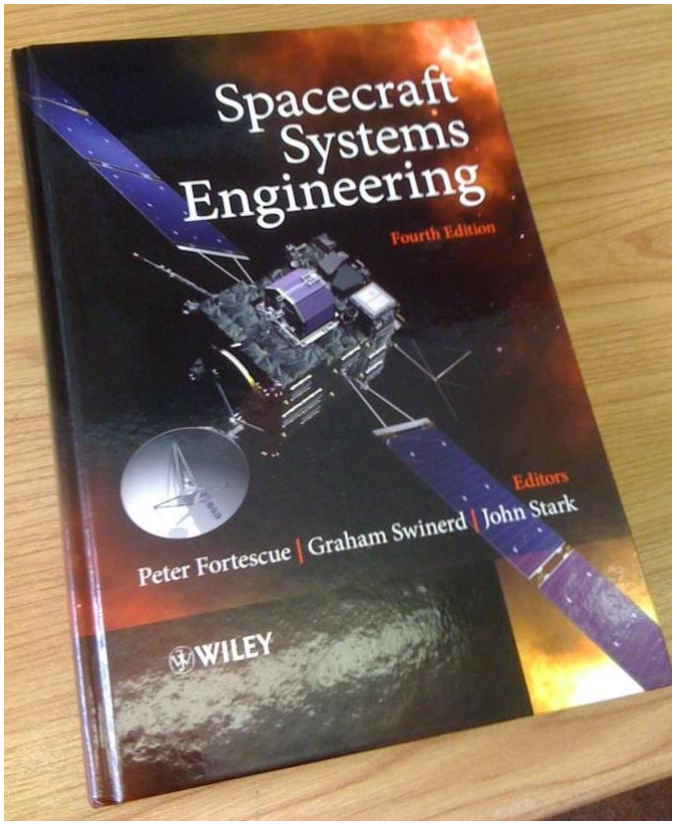
Key points:

Natural and Induced Environments	• Categories and types of environments that the satellite will have to survive
Our Solar System	• The important environmental inputs to our Solar system and their basic properties
Earth and the Earth Orbit Environment	• The important properties of the space environment around the Earth • How these properties interact with the inputs from the Solar system and • How these properties generally vary proportional to orbital altitude/location
Environmental Effects on Design/Man	• How the space environmental properties, both in the Solar system and around the Earth, most significantly affect the design of spacecraft
Launch Environment	• The important environmental inputs from launch • How these environments are quantified • How they affect the design of spacecraft

Environment Summary



Read Chapter 2 of Fortescue, Stark & Swinerd

Read Chapter 6 of 'How S/C Fly'