Διαστημικό Περιβάλλον

Space Environment

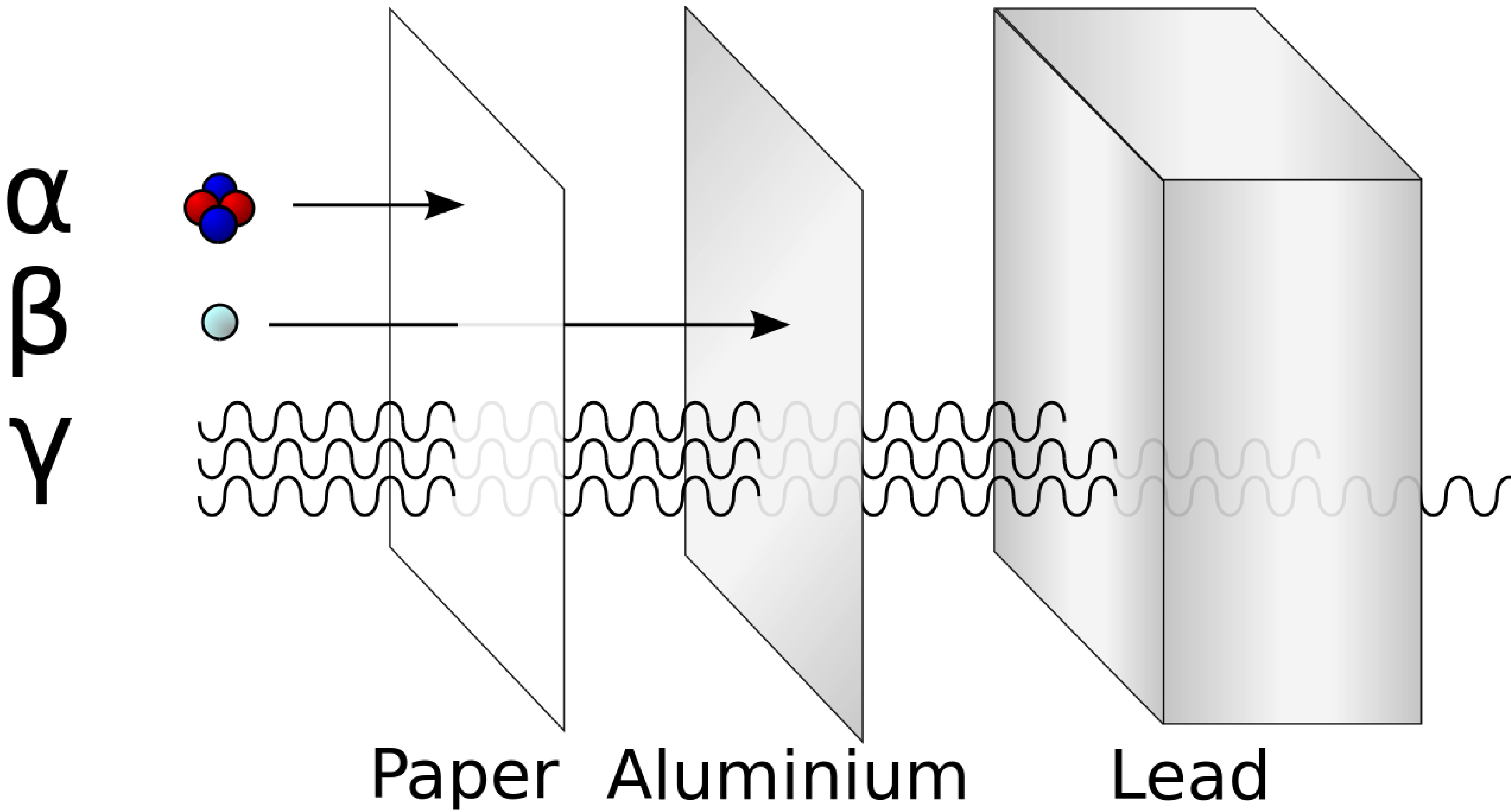
Space Environment
Lecture 11

Space weather

WHAT IS RADIATION?

- As an energetic particle passes through matter it will create atomic displacements and/or ionize atoms in the material.
- As a result the material properties will be altered.
- Radiation can be thought of as anything that deposits energy in a material.
  - Charged particles (electrons, protons)
  - Uncharged particles (neutrons)
  - Photons (gamma rays, x-rays)

Penetrating radiation



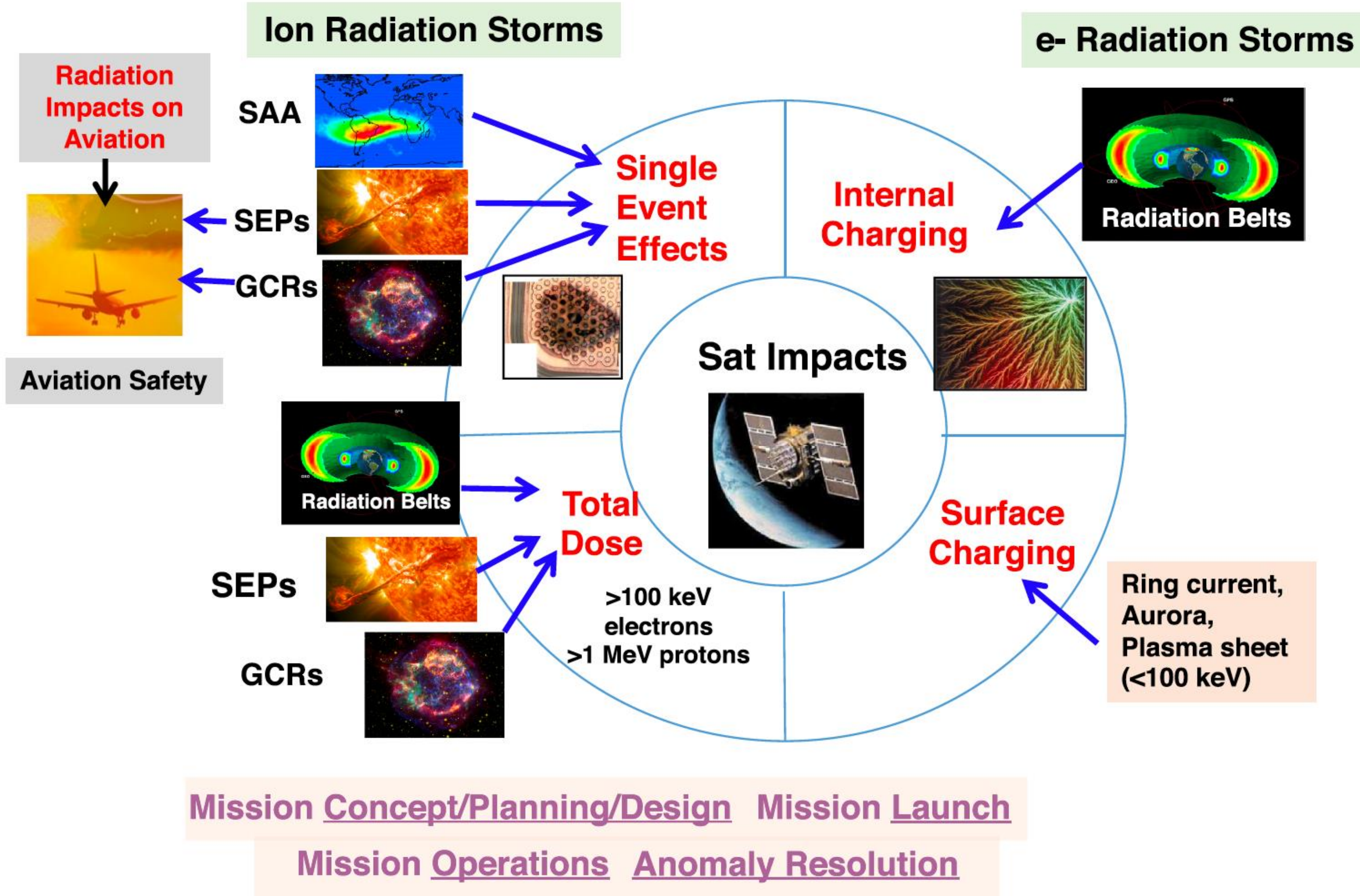
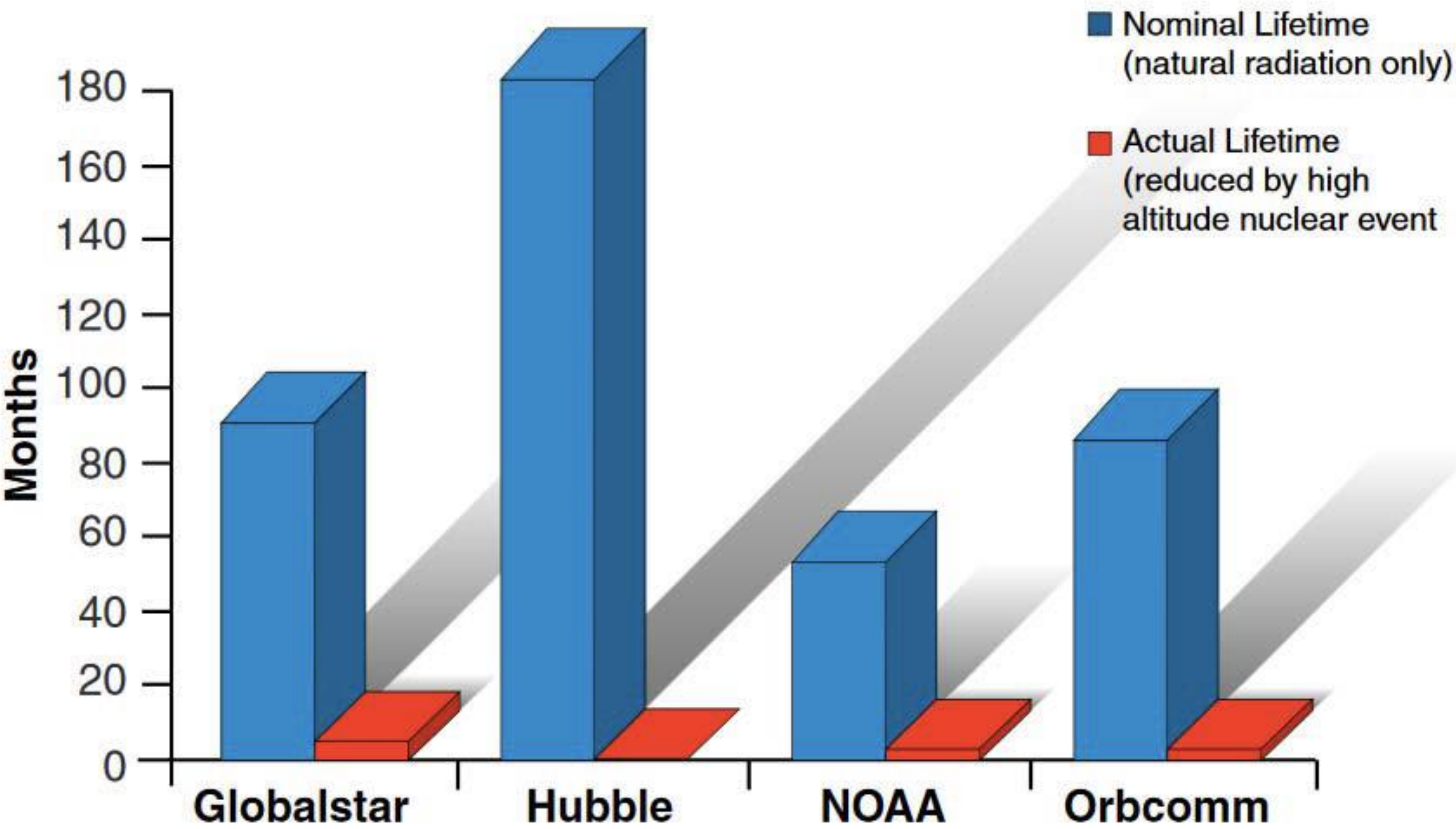
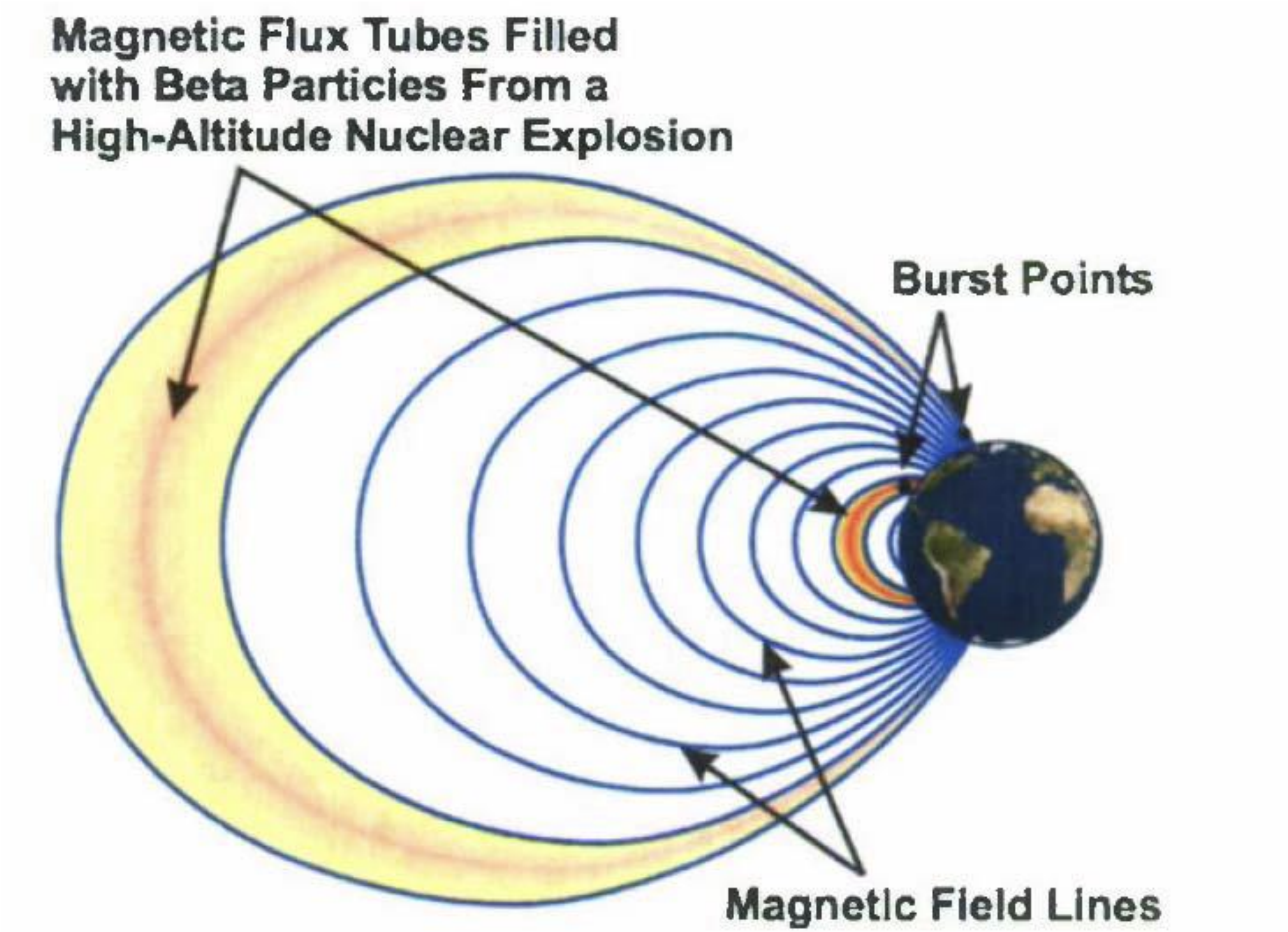


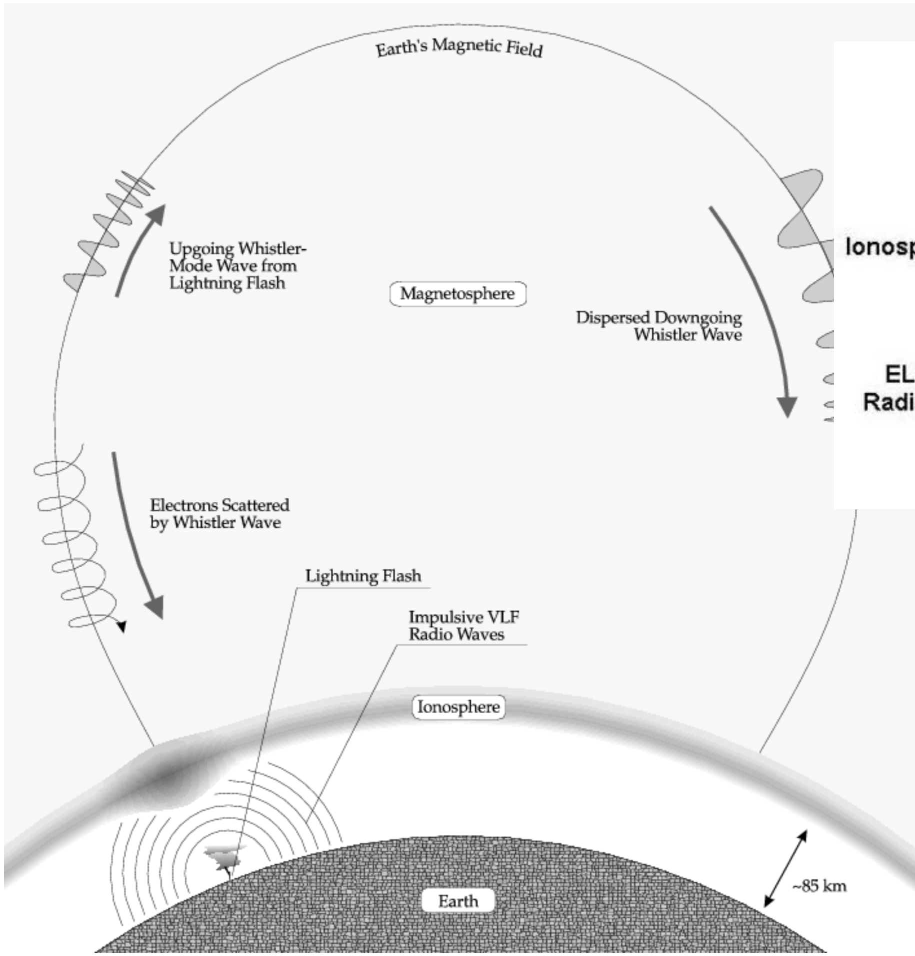
Figure 2. Space radiation and plasma impacts and their sources.

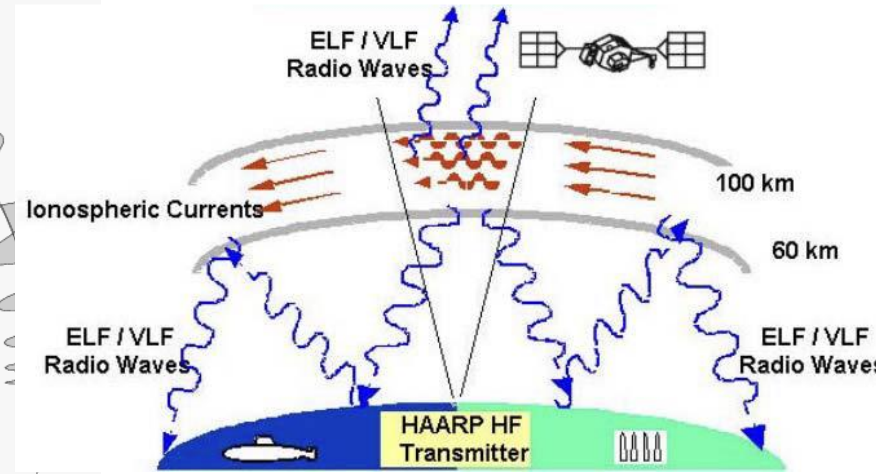


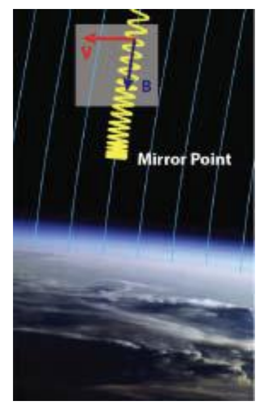
Source: Defense Threat Reduction Agency

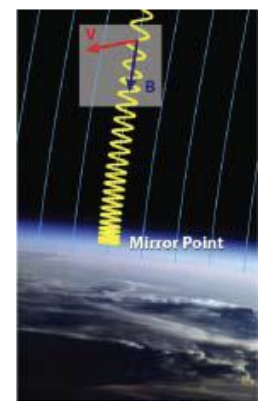
Detonation closer to a pole will fill a larger L-shell, whereas a detonation closer to the equator will fill a lower L-shell




Earth's Magnetic Field
Upgoing Whistler-Mode Wave from Lightning Flash
Magnetosphere
Dispersed Downgoing Whistler Wave
Electrons Scattered by Whistler Wave
Lightning Flash
Impulsive VLF Radio Waves
Ionosphere
Earth
~85 km


ELF / VLF Radio Waves
100 km
Ionospheric Currents
60 km
ELF / VLF Radio Waves
ELF / VLF Radio Waves
HAARP HF Transmitter


V
B
Mirror Point


V
B
Mirror Point

Locations of Operational Space Environment Hazards

Single Event Effects (SEEs)

- inner (proton) belt and higher L shells with solar particle event
- quiet-times from galactic cosmic rays

Internal charging and resulting **electrostatic discharges (ESD)**

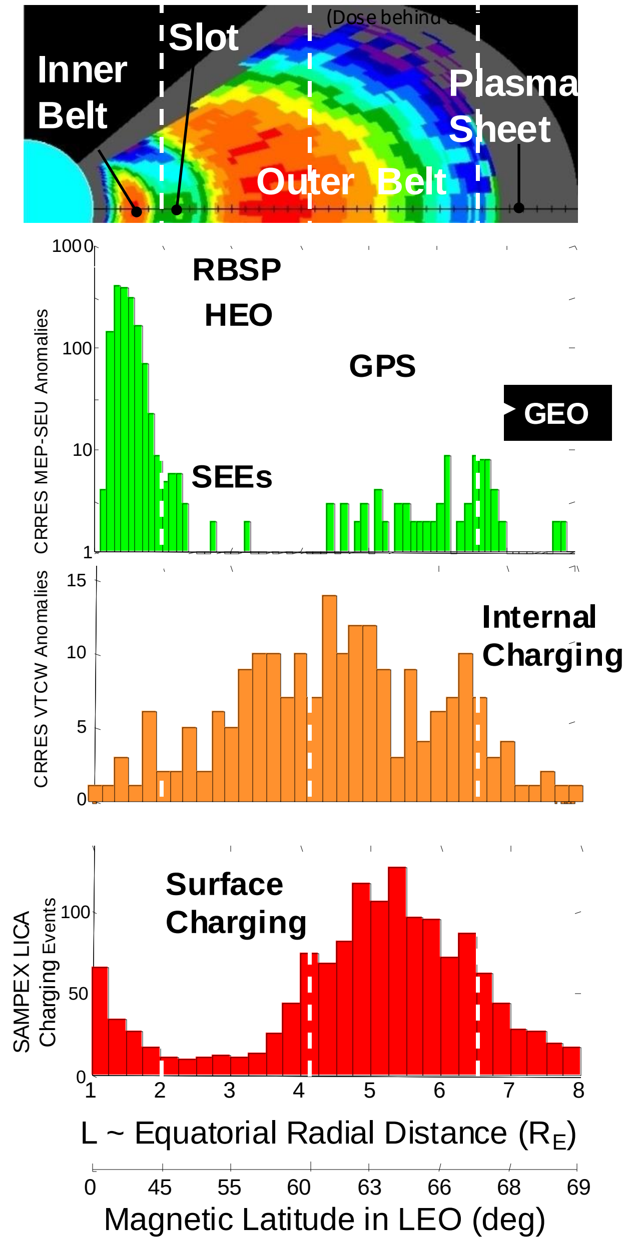
- broad range of L values
- corresponding to the outer belt
- where penetrating electron fluxes are high

Surface charging and resulting **ESD**

- spacecraft or surface potential elevated
- 2000-0800 local time in the plasma sheet
- regions of intense field-aligned currents
- observed, but not explained, at very low L

Total ionizing dose

- electronics and solar panels degrade over time



NOAA Space Weather Scale Summary

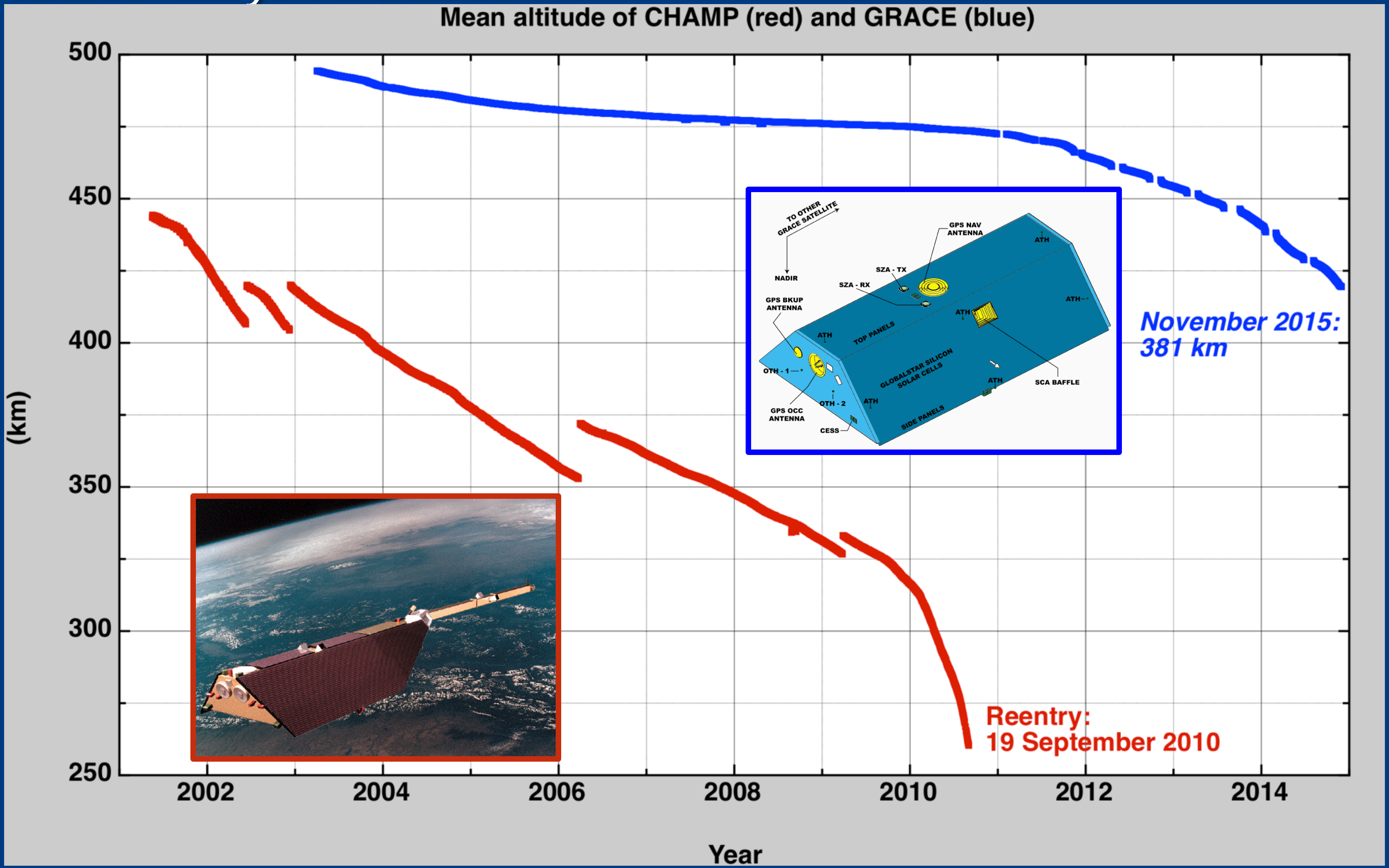
		Geomagnetic Storms	Solar Radiation Storms	Radio Blackouts
Extreme	5		High Radiation Hazard	
Severe	4	Power Grid Instability		
Strong	3			HF Blackout for an Hour
Moderate	2		Infrequent SEU	
Minor	1	Minor Impact on Satellites		
Measures		**Kp Geomagnetic Index**	**GOES >10 MeV p**	**GOES X-Rays**

Atmospheric drag

A satellite/object in Low Earth Orbit loses altitude due to interaction with the neutral air particles (the thermosphere).

Ultimately, it reenters and burns up in the atmosphere.

GRACE re-entry: 10/3/2018



Atmospheric drag

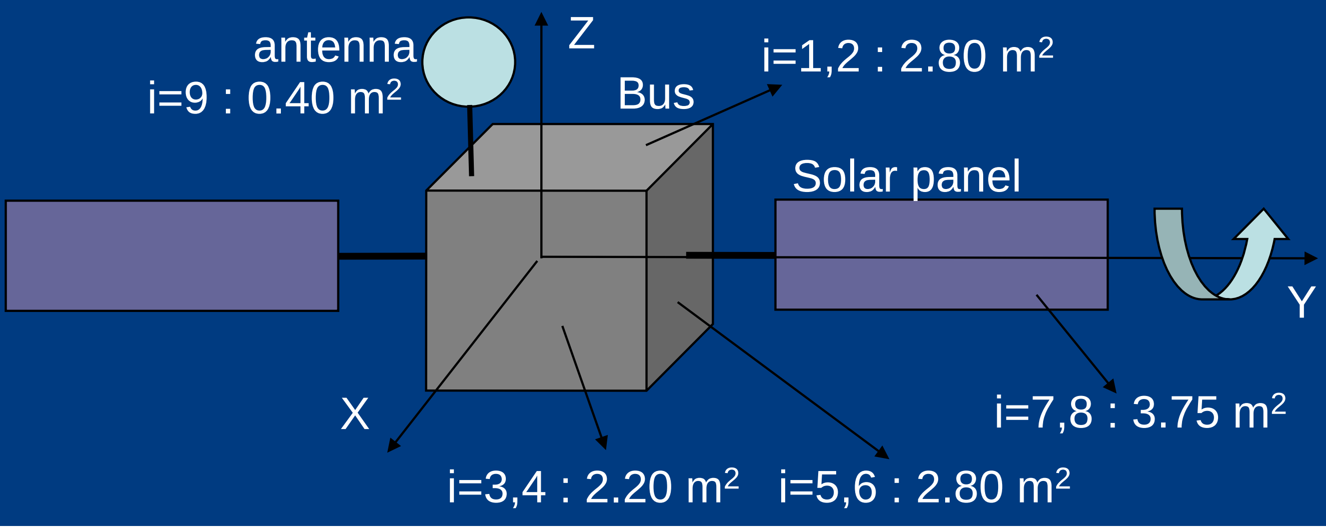
Satellite drag deceleration:

$$a_{drag} = -\tfrac{1}{2} C_D \frac{A}{m} \rho v^2$$

- *v* = satellite speed with respect to co-rotating atmosphere (*orbit*)
- *A* = satellite surface perpendicular to speed, or ram area
- *m* = satellite mass
- C_D = aerodynamic coefficient (*model*)
- ρ = thermosphere density (*model*)

Simple satellite model (macromodel). Example below: « box-and-wing »

Attitude must be known

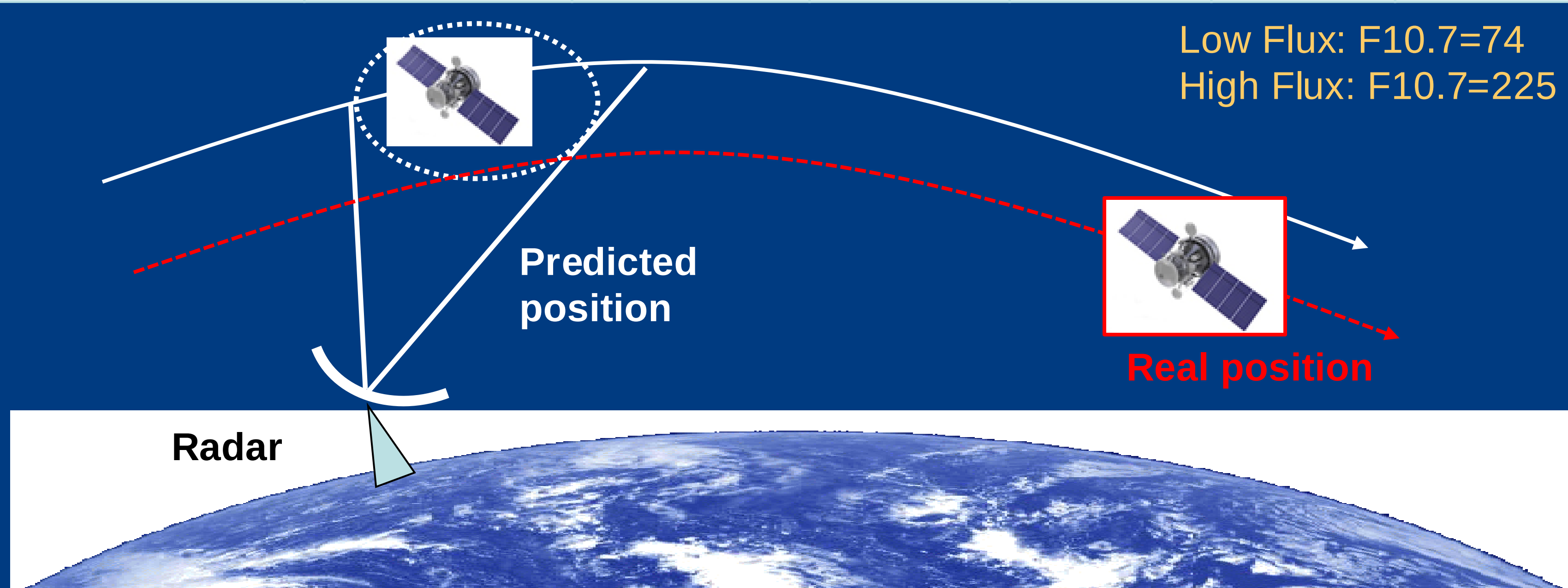


Atmospheric drag – orbit perturbation

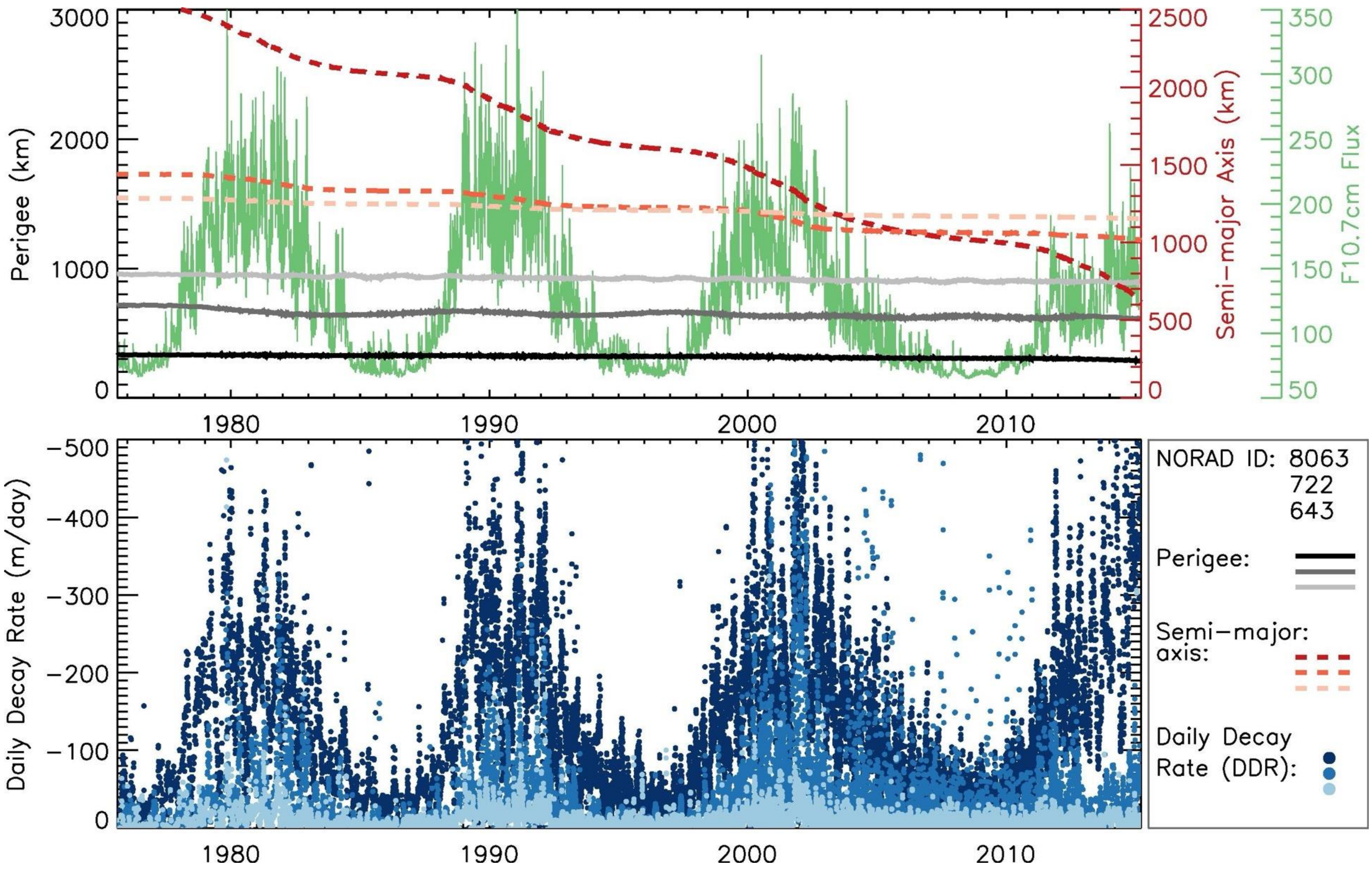
Atmospheric drag computation is not accurate because of:

- Thermosphere model (1-σ) precision of 10-25%
- Aerodynamic coefficient, mass, attitude and macromodel error (5-??%)

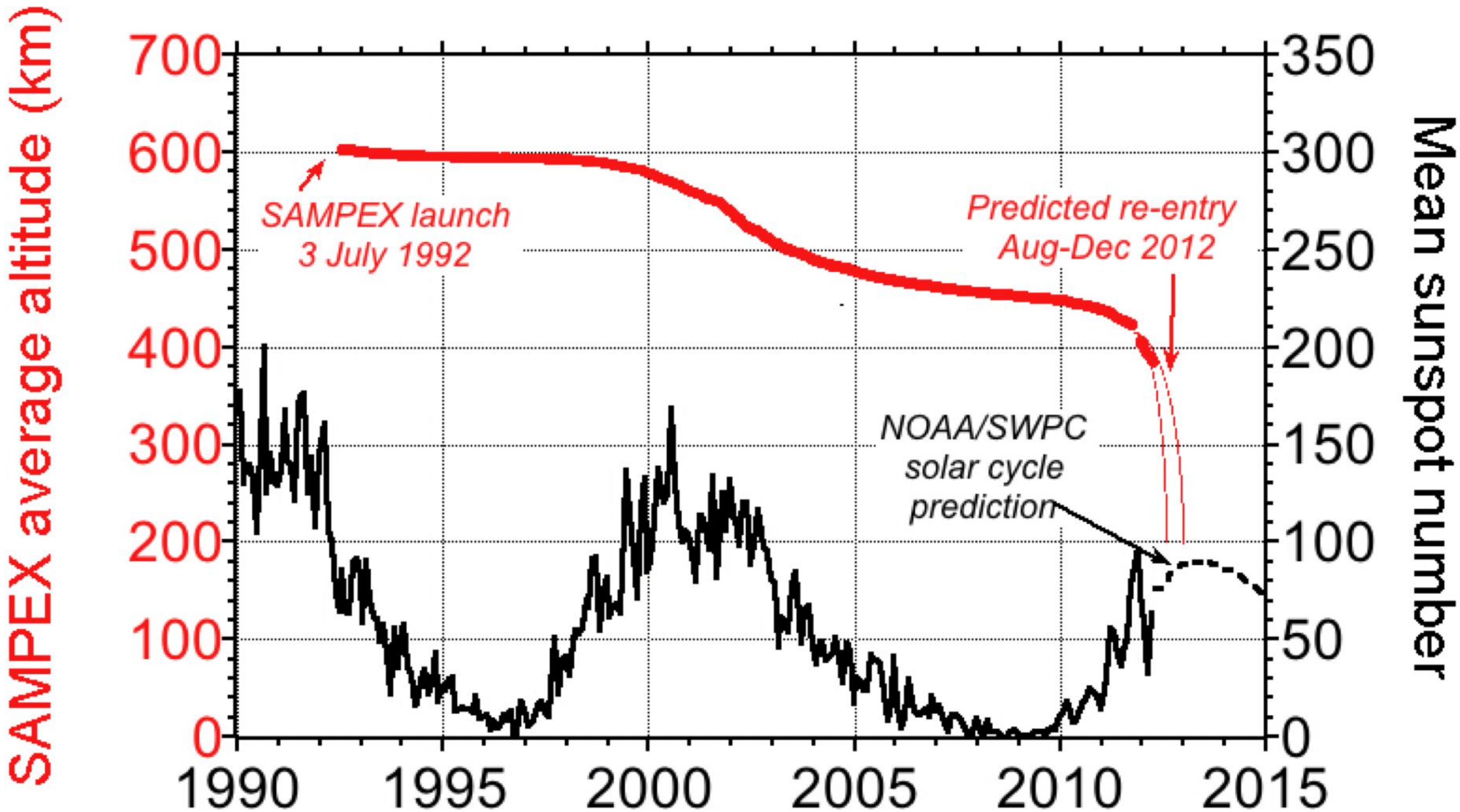
	250 km		550 km		850 km	
	LF	HF	LF	HF	LF	HF
Total effect	89.8 km	414.0 km	146.3 m	4.2 km	15.8 m	195.6 m
* 0.5	45.0 km	209.4 km	73.4 m	2.1 km	7.9 m	98.1 m
Δ models	5.7 km	12.2 km	42.1 m	0.8 km	5.6 m	60.7 m



Orbital decay



8063: 1975-072B, 9/8/1975-20/5/2017. 722=1963-053C: 19/12/1963-18/4/2018. 643=1961-015GU: 29/6/1961- (debris)



Baker, Mazur, & Mason [*Space Weather*, 2012]

Διαστημικό περιβάλλον και επιπτώσεις

Table 12.1. The effects of the space environment on space systems.

Environment	Main effect on space systems
Cosmic rays (~ 100 MeV to ~1 GeV) High energy solar particles (~100 keV to ~300 MeV (sometimes GeV))	Ionizing and non ionizing dose effects (components and material degradation, living cell damage) Single event effects
Radiation belt particles (electrons: ~100 keV to ~10 MeV; protons: ~1 MeV to ~1 GeV)	Ionizing and non ionizing dose effects (components and material degradation, living cell damage) Single event effects Deep dielectric charging
Ionospheric plasma (~0.1 eV) Plasmasphere (~1 eV) Solar wind plasma (electron: ~1 eV; proton: ~0.1 to 1 keV)	Particle flux effect (electrical current noise, erosion, sputtering) Small electrostatic potential
Auroral filament plasma (~100 10 keV) Plasmasheet plasma (~1 to 10 keV)	Particle flux effect (electrical current noise, erosion, sputtering) Strong electrostatic potential
Visible and IR photons	Thermal
UV, X and γ photons	Ionizing effects
Radio waves	EM noise
Geomagnetic field	Magnetic torque on current loop Induced electric field in conductors
Interplanetary magnetic field	Torque Induced electric field
Neutral atoms	Spacecraft drag Chemical reactions on surfaces, and associated degradation
Microparticles	Puncture Transient dusty plasma cloud

Επιπτώσεις και σχέση τους με το περιβάλλον

Space weather effect	Space weather parameters	Material/object parameters
Drag	Total density Temperature Fluid velocity	Cross-sectional frontal area Mass Relative velocity Shape
Atom displacement	Particle flux	Shielding, material, geometry
Dark current increase	Particle flux Photon flux (UV, X, γ)	Shielding Absorption
Surface charging	Electron flux (< 300 keV) Proton flux (< 8 MeV) UV flux	Secondary emission Photoelectric emission Geometry
Internal charging	Electron flux (> 300 keV)	Shielding, material, geometry
SEEs	Ion flux (> 100 MeV) Proton flux (> 10 MeV)	Technology (CMOS,…)
Human effects	Ion flux (> 100MeV) Proton flux (> 10 MeV)	Cell nature (eyes, gonads, bone marrow)
Orbital elements	Atmospheric scale height	Cross-sectional area, optical properties, shape
Electrostatic discharges	Meteoroids and debris UV radiation, plasma	Relative velocity, size, type of surface
Collision	Meteoroids and debris	Technology, type of materials

«Ζωντανά» δεδομένα

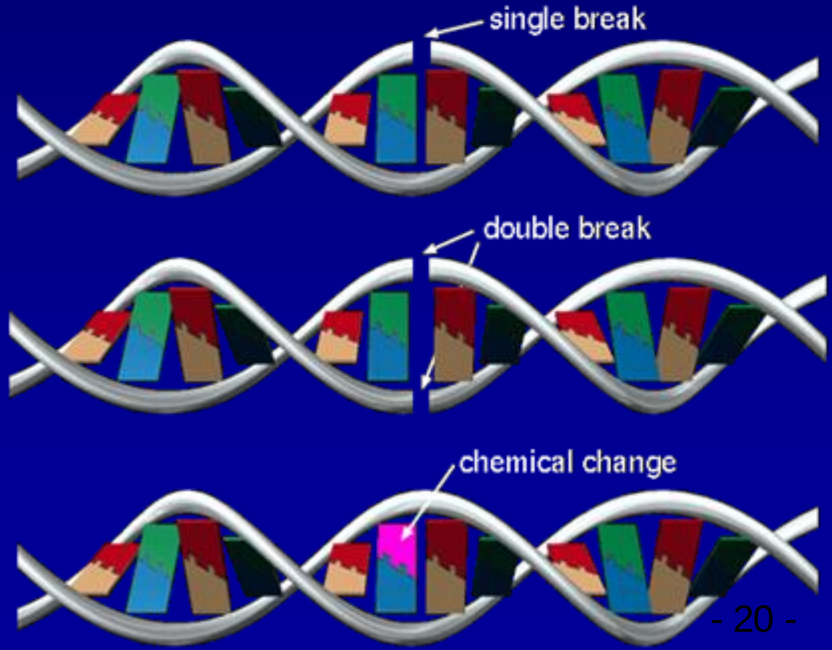
Table 12.3. Relevant near real time data source for space environment effects.

Component	Available measurement	Caveat	Delay before availability
Galactic cosmic rays: 100 MeV to 1 GeV	Neutron monitor	Proxy	1 hour
Flare protons: 10 MeV to ~300 MeV	GOES	Require model for low altitude correction	5 min
	Neutron monitors	Proxy Only above ~400 MeV	1 hour
SPE particles: 100 keV to ~100 MeV	GOES ACE	Require model at low altitude	5 min
X, EUV, UV photons	GOES SOHO		5 min
Magnetopause boundary location	GOES ACE	Only 2 points at GEO Input to model	5 min 5 min
Plasma: 0.1 to 100 eV	TEC NPOES	Integrated value Only at 830 km altitude	1 hour 1 hour
Plasmasheet and auroral Electron energy spectrum (100 eV to 20 keV)	LANL NPOES Kp A	Only at GEO Only at 830 km Proxy Proxy	1 day 1 hour 1 day 1 day
Radiation belts proton energy spectrum 1 MeV to 1 GeV	GOES	Only at GEO Reduced energy range	5 min
	NPOES	Only at 830 km	1 hour
Radiation belts electrons energy spectrum 100 keV to 10 MeV	GOES LANL NPOES Kp A	Only at GEO Only at GEO Only at 830 km Proxy Proxy	5 min 24 hours 1 hour 1 day 1 day
Thermospheric flux	F10.7 Kp	Input to model	Once a day 1 day

Consequences of Space Weather

- Outside the magnetosphere, the most relevant Space Weather Effect are the **Solar Radiation Storms** (elevated levels of radiation that occur when the numbers of energetic particles increase)
- Biological effects (ICRP, 1991)
  - Acute effects (Malfunctions of organs, eye cataracts, etc). Deterministic, threshold doses
  - Late effects (DNA damage, mutations, cancer) Stochastic, no threshold doses

Accumulated dose from GCR is a serious problem for long voyage scenarios (Mars), even at solar maximum



RADIATION DOSE UNITS

- Roentgen (R)
  - The amount of radiation that will produce one electrostatic unit (ESU) of charge of either sign in one cubic cm (0.001293 g) of air
- Radiation Absorbed Dose (RAD)
  - The amount of any kind of radiation that deposits 100 ergs per gram of material
    - 0.01 J/kg
- Gray
  - The amount of any kind of radiation that deposits 1 J/kg of material
    - 1 gray = 100 RADS

RADIATION DAMAGE THRESHOLDS

- In many materials, the total dose of radiation is the critical issue in determining useful lifetime

Material	Damage Threshold (Gray)
Biological Matter	10^{-1} - 10^{0}
Electronics	10^{0} - 10^{2}
Lubricants, Hydraulic Fluid	10^{3} - 10^{5}
Ceramics, Glasses	10^{4} - 10^{6}
Polymeric Materials	10^{5} - 10^{7}
Structural Metals	10^{7} - 10^{9}

0-50 rads (0.5 Gray) - No obvious short-term effects
80-120 rads (0.8-1.2 Gray) - You have a 10% chance of vomiting and experiencing nausia for a few days
130 -170 rads (1.3-1.7 Gray) - You have a 25% chance of vomiting and contracting other symptoms
180-220 rads (1.8-2.2 Gray) - You have a 50% chance of vomiting and having other severe physical effects
270-330 rads (2.7-3.3 Gray) - 20% chance of death in 6 weeks, or you will recover in a few months.
400-500 rads (4-5 Gray) - 50% chance of death
550-750 rads (5.5-7.5 Gray) - No survivors
> 1000 rads (>10 Gray) - Immediate incapacitation and death within a week or less

Πόσο επικίνδυνη είναι η ακτινοβολία;

Πιθανότητα Θανάτου 1 : 1.000.000 (10^{-6})

- ✓ 0.5 mSv δόσης από ακτινοβολία
- ✓ 40 κουταλιές Φυστικοβούτυρο
- ✓ 100 ψητές μπριζόλες
- ✓ 2 ημέρες στη Νέα Υόρκη
- ✓ 1.5 τσιγάρο
- ✓ 500 χλμ με αυτοκίνητο
- ✓ 1500 χλμ με αεροπλάνο

Ακτινοβολία
Φυσικά μεγέθη

Παλιές μονάδες	**Μονάδες SI**
1 rad = 10 mJ/kg	1 gray (Gy) = 100 rad = 1 J/kg

- **Kerma (K)**: **K**inetic **E**nergy **R**eleased per unit **M**ass
- **Absorbed Dose (D)**

Kerma ≥ Absorbed Dose

Διότι μέρος της ενέργειας που εκλύεται,

ΔΕΝ απορροφάται

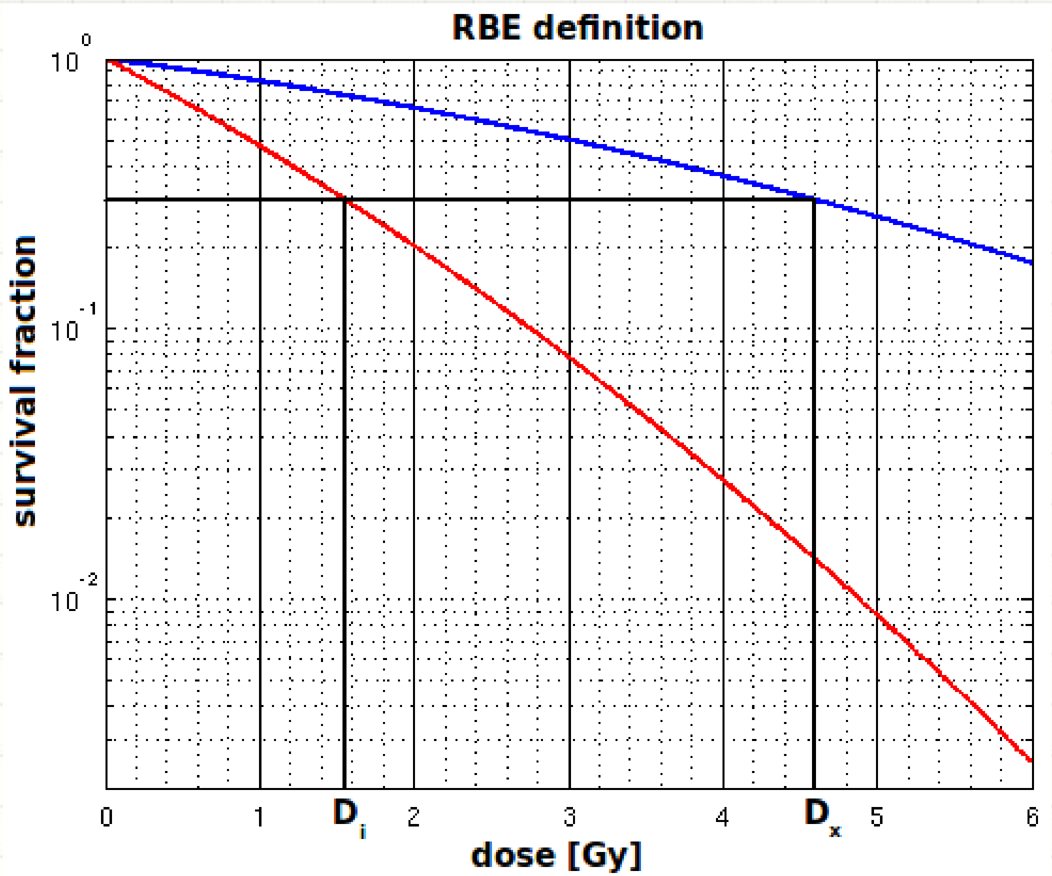
Επιπλέον:

Kerma (a) = Kerma (b)

δεν σημαίνει ίδιο αποτέλεσμα

πχ σωματίδια α και ακτίνες γ

(relative biological effectiveness - RBE)



Μπλε: φωτόνια

Κόκκινο: ιόντα άνθρακα

Kerma ≥ Absorbed Dose

While kerma approximately equals absorbed dose at low energies, kerma is much higher than absorbed dose at higher energies, because some energy escapes from the absorbing volume in the form of bremsstrahlung (X-rays) or fast-moving electrons, and is not counted as absorbed dose.

Ακτινοβολία
Λειτουργικά μεγέθη
Βιολογική δόση ή ισοδύναμη δόση H (equivalent dose)

Παλιές μονάδες	Μονάδες SI
1 rem (**r**ad **e**quivalent **m**an) = RBE x rad	1 sievert (Sv) = quality factor (QF) x gray

1 gray = 100 rad, άρα 1 Sv ≈ 100 rem

Όχι «=» επειδή RBE ≠ QF

Παραδείγματα:

1 ακτινογραφία θώρακα = 50 μSv

Airport scan = 0.10 μSv

Μέγιστη ετήσια δόση για πολίτες: 5 mSv

- για αστροναύτες: 50 mSv

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Στο ηλιακό ελάχιστο λόγω GCR: 600 mSv/yr

Ταξίδι στον Άρη (6 μήνες): > 300 mSv

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Όριο θεραπεύσιμων επιδράσεων: 4 Sv (♀ : 3)

Point of no return: 8 Sv

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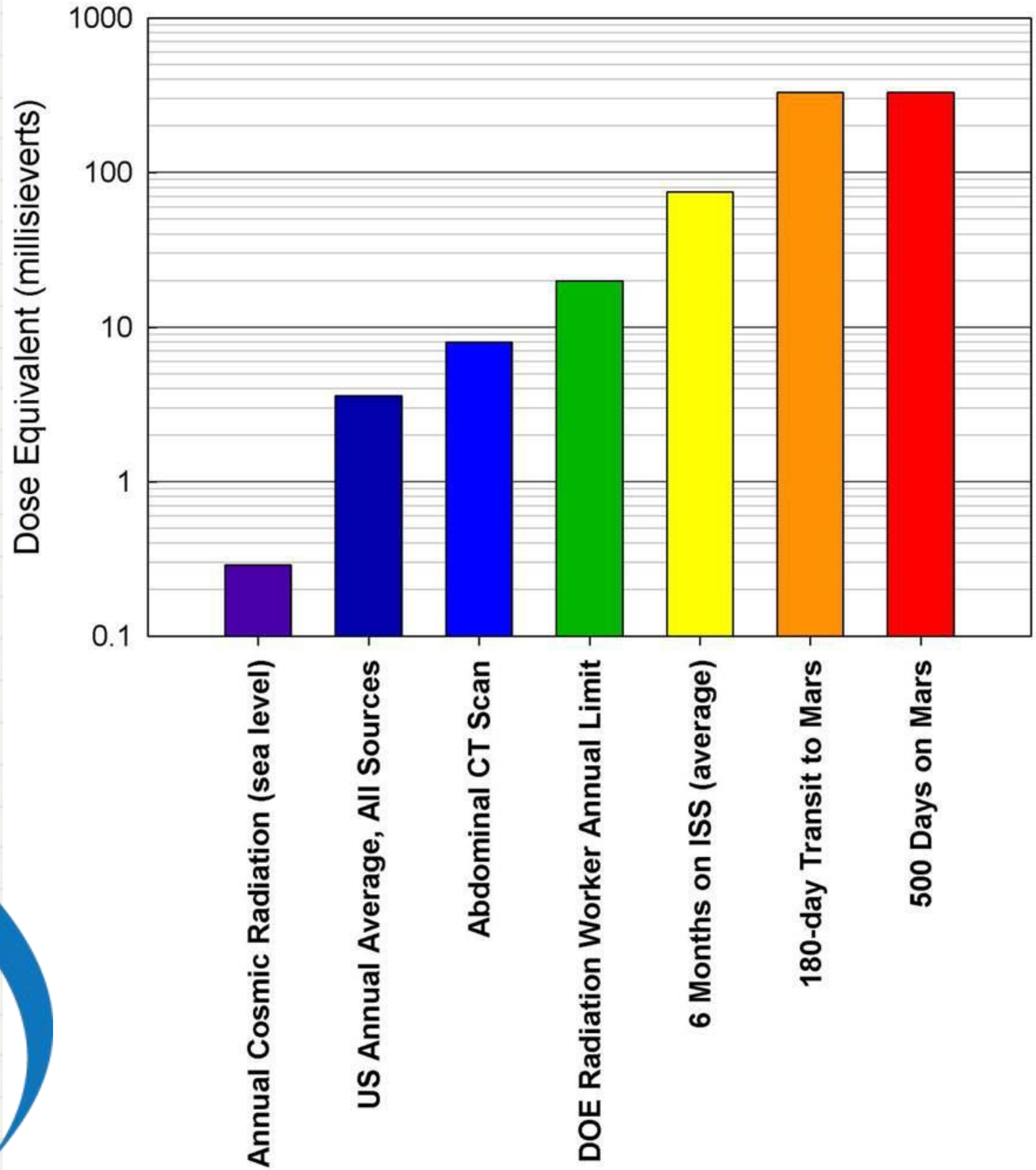
Point of no return: 8 Sv

10 λεπτά Τσερνομπίλ: 50 Sv

1 μπανάνα: 0.1 μSv (BED)

Environmental - the ground around your feet, the cement and brick in your homes, emit radiation from their infinitesimal loads of trapped radioactive debris to the tune of about 60 millirem per year, but this changes quite a bit depending on where you live. For example, in states like Georgia, California, Florida and Maryland the terrestrial background radiation level is between 500-700 microsievert per year, in Louisiana it is as low as 300 μSv, and in Colorado and South Dakota it can be as high as 1150 μSv. **The difference between living in Louisiana and Colorado is equal to an additional four chest X-rays per year added to your lifetime total**. **If you really want to live on the edge, you have to visit places like Kerala, India, where the thorium-rich sands give you a dose of 3.8 mSv every year, and in Guarapari, Brazil where you get a sizzling 175-1100 mSv** per year. In comparison to the natural background sources and their variations, one wonders why so many people worry about one versus two extra chest X-rays per year. If you want a big savings in exposure, just move to a seacoast town, **forget about prolonged vacations in Denver, Brazil or India, and**



Dose Equivalent (millisieverts)
1000
100
10
1
0.1
Annual Cosmic Radiation (sea level)
US Annual Average, All Sources
Abdominal CT Scan
DOE Radiation Worker Annual Limit
6 Months on ISS (average)
180-day Transit to Mars
500 Days on Mars

Επιπτώσεις ακτινοβολίας στους αστροναύτες

Συνέργεια

ακτινοβολίας και έλλειψης βαρύτητας

Humans in space can get even lethal radiation doses in solar particle events

- Astronauts have 20 min to get inside after a large particle event on the Sun
- Total doses increase even inside space station

Shielding capacity (mass per area)

- Space suit: 0.25 g/cm^2
- Apollo Command Module: 8 g/cm^2
- Space shuttle: 11 g/cm^2
- ISS: 15 g/cm^2
- Future moon bases: >20 g/cm^2

Storm on the moon

Out on the Moon: 4000 mSv

In Apollo Command Module: <350 mSv

Bone marrow transplant or oral medication …