Space Technology

The space environment

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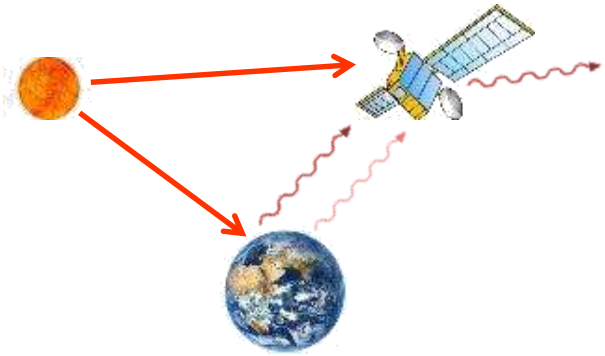
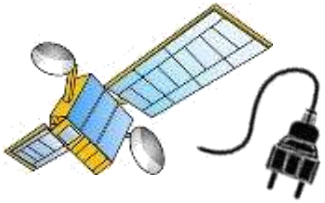
Environmental effects

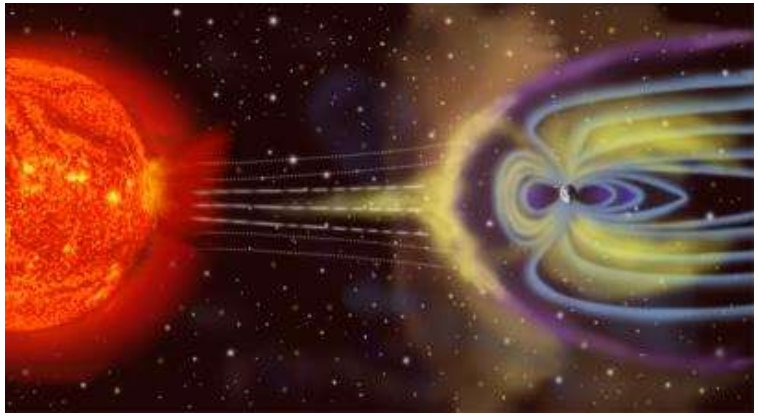


- Temperature



- Energy

- Vibration



- Radiation

- Vacuum

Environment conditions

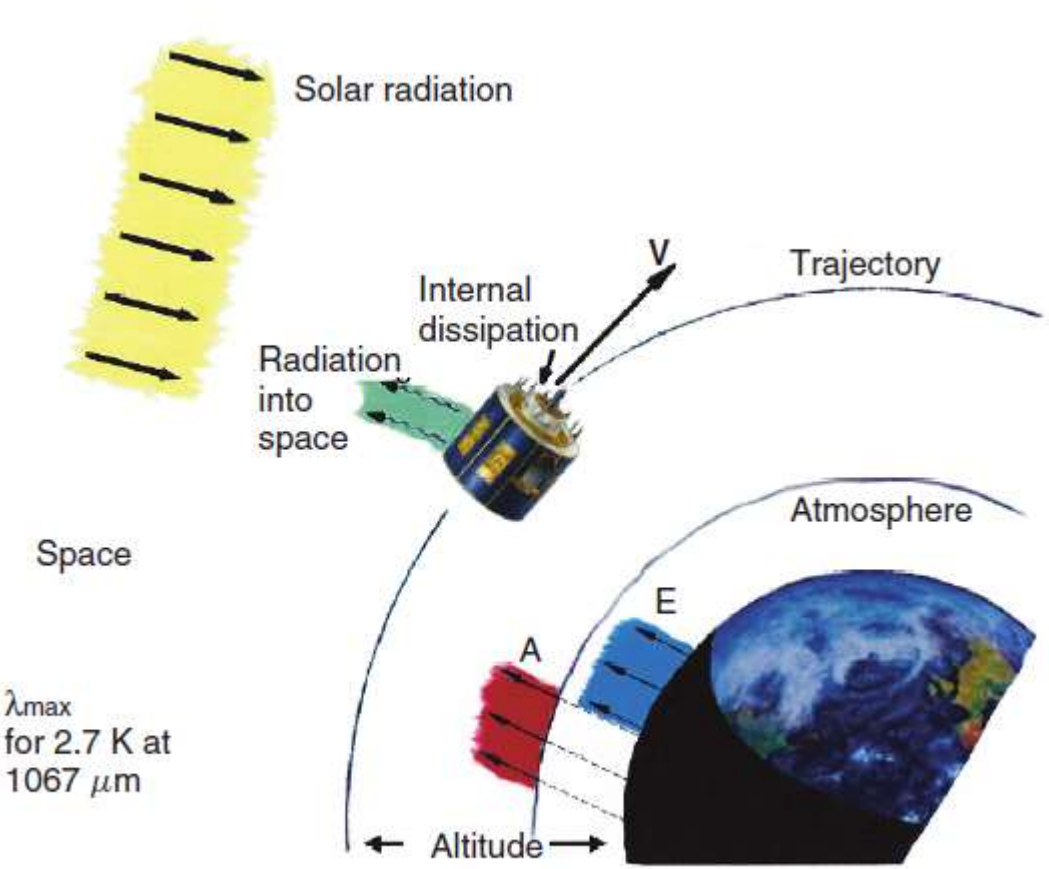
- Cold background of space
- High vacuum
- Microgravity/gravitational fields
- Aerodynamic drag of the atmosphere at low earth orbits
- Short-wave solar radiation (electromagnetic waves)
- Ultraviolet/X-rays
- Gamma radiation from the galactic background
- High-energy particles (electrons, protons, neutrons and alpha particles)
- The influence of atomic oxygen
- Rigid body interaction

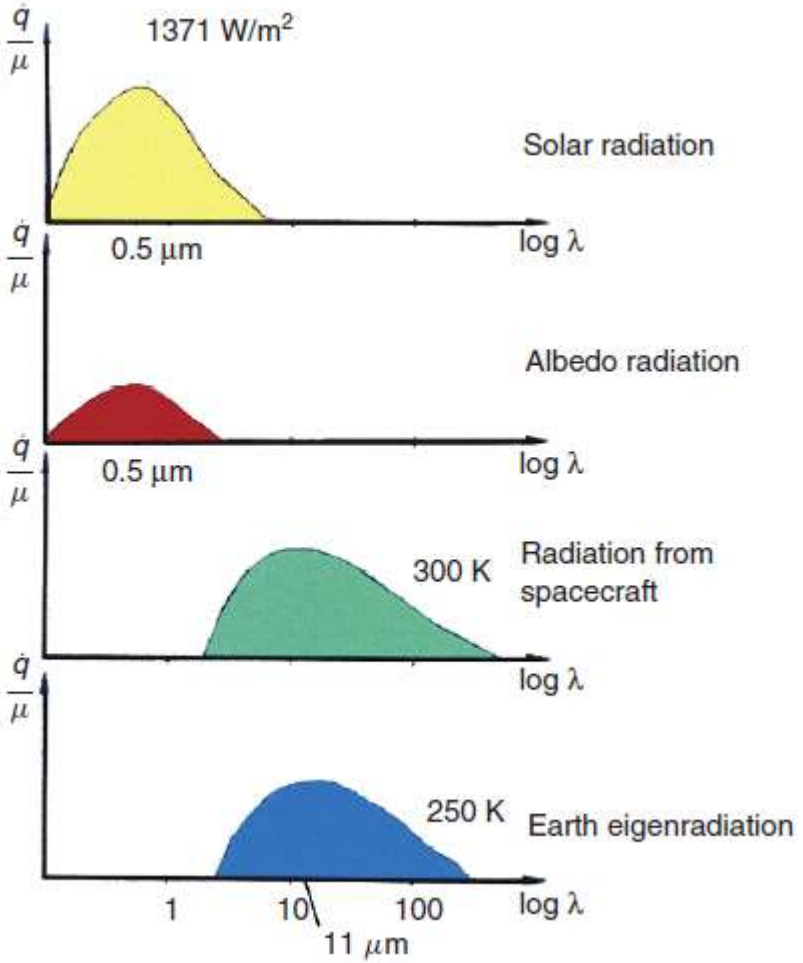
Mission orbit conditions

Orbit determines the circumstances

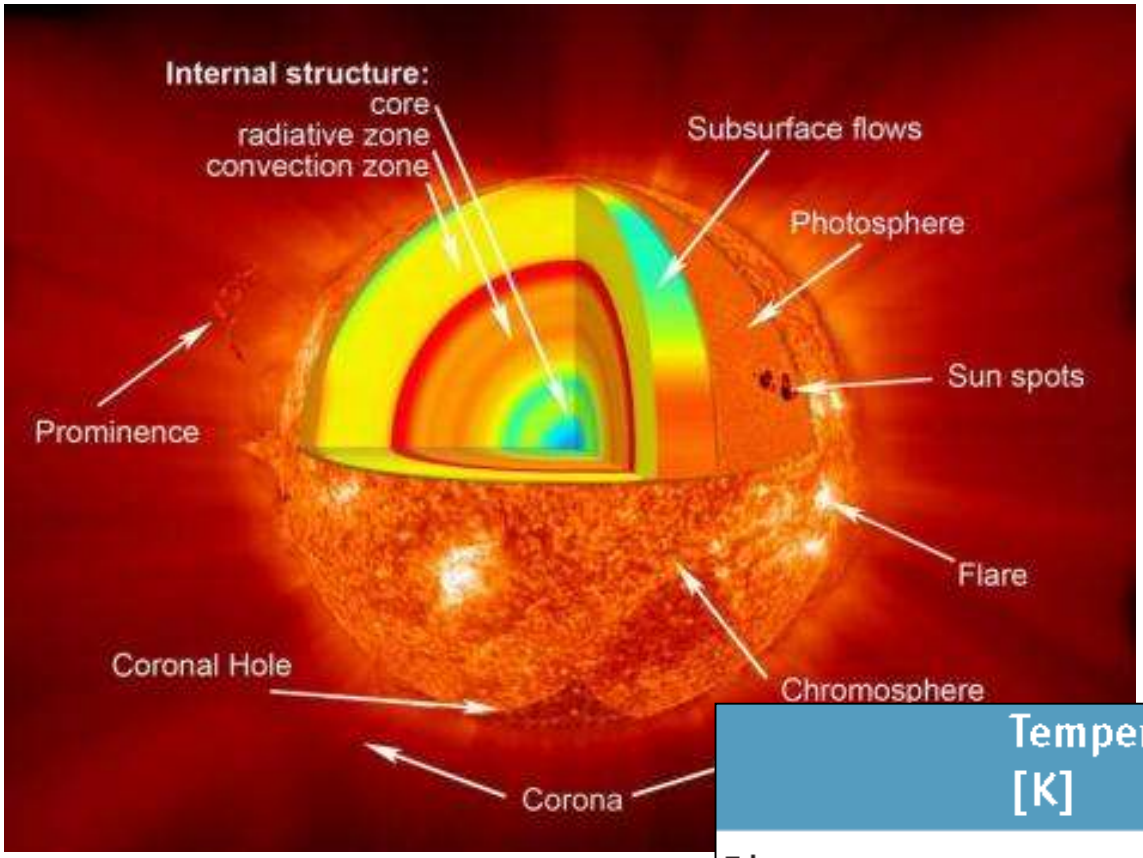
- Low Earth orbit (LEO)
- Medium Earth orbit (MEO)
- Geostationary orbit (GEO)
- Highly eccentric orbits (HEO, GTO)
- Polar orbits (e.g., Sun-synchronous, Molniya orbit)
- Orbits around the Lagrange points
- Interplanetary missions
- Planet orbits and landing, ascent and ground operations

Environmental conditions for a spacecraft in LEO





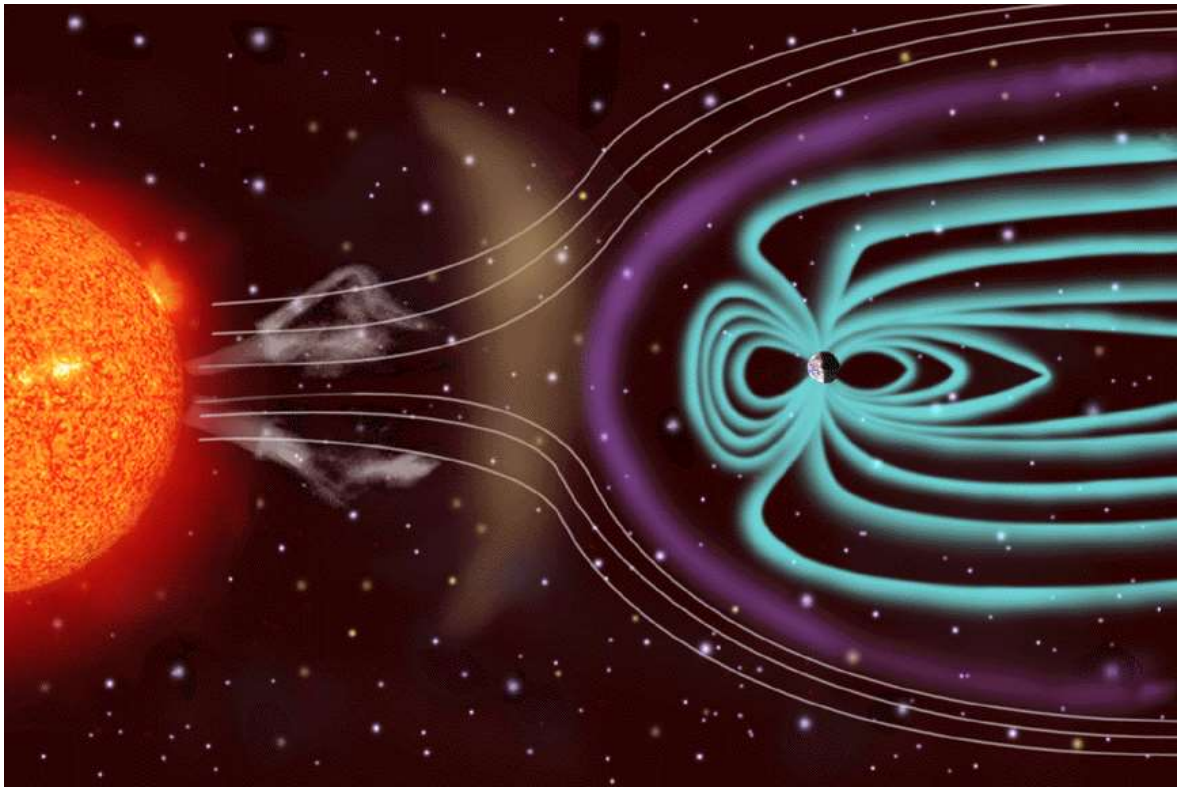
Influence of the Sun – solar radiation



	Temperature [K]	Height [km]	Emitted spectrum
Photo-sphere	3900–7160	0–200	UV, visible light, NIR
Chromo-sphere	42 000–10 000	200–2500	UV, Hα
Corona	$1 \cdot 10^6$–$2 \cdot 10^6$	2500–6R_S	EUV, X-ray, radio

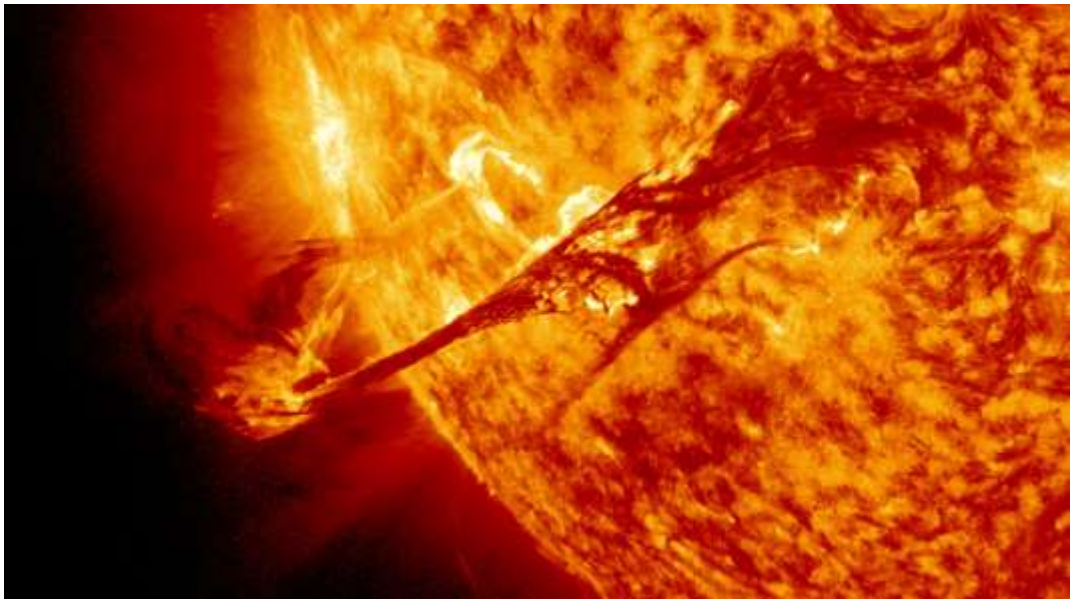
Influence of the Sun – solar wind

- The Sun emits material (it losts 10^6 tons hydrogen/sec)
- The solar wind consists of protons (96%), electrons and alpha particles (neutral plasma)
- Proton flux=$3*10^{12}$ $m^{-2}s^{-1}$
- Energy: 1-10keV
- The magnetosphere of the Earth deflects it
- Coronal mass ejections may occur

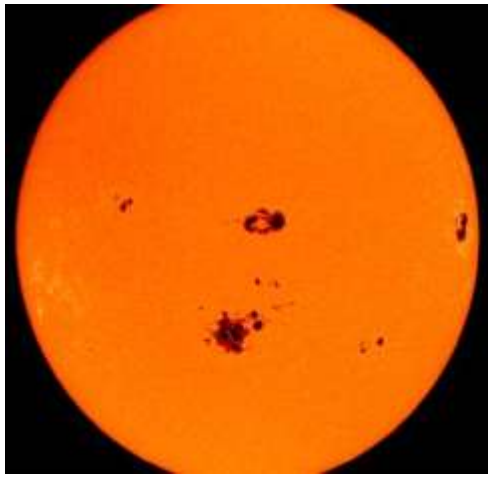


Sun eruption

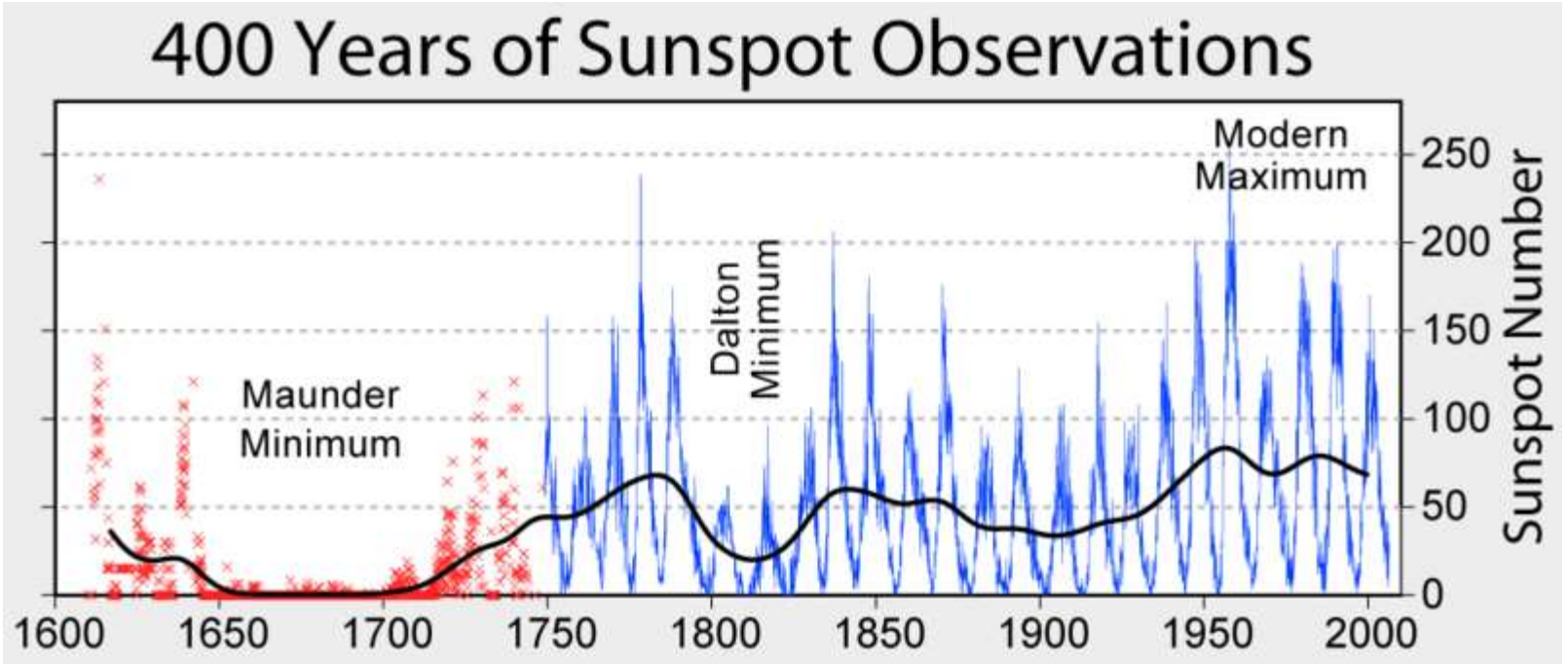
On August 31, 2012 a long filament of solar material that had been hovering in the sun's atmosphere, the corona, erupted out into space at 4:36 p.m. EDT. The coronal mass ejection, or CME, traveled away from the sun at over 900 miles per second. This movie shows the ejection from a variety of viewpoints as captured by NASA's Solar Dynamics Observatory (SDO), NASA's Solar Terrestrial Relations Observatory (STEREO), and the joint ESA/NASA Solar Heliospheric Observatory (SOHO).



Sunspots



- Darker areas in the photosphere
- Size: 1.5-100 Mm
- Temperature: 200°C less
  (relating to the 5700°C average surface temperature)
- Strong magnetic field

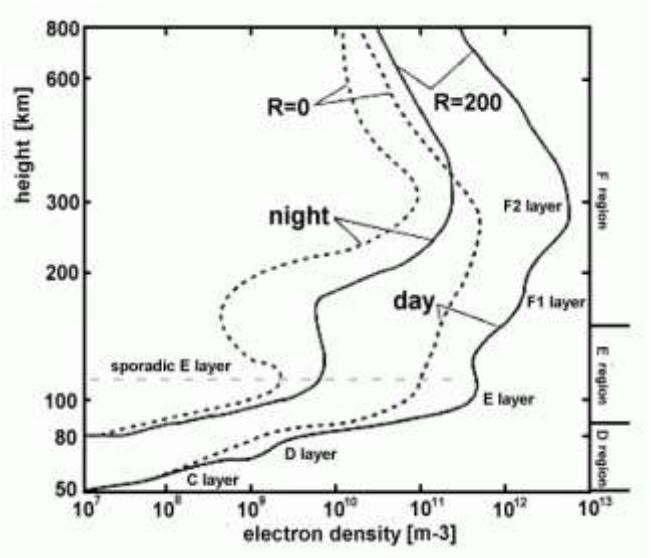


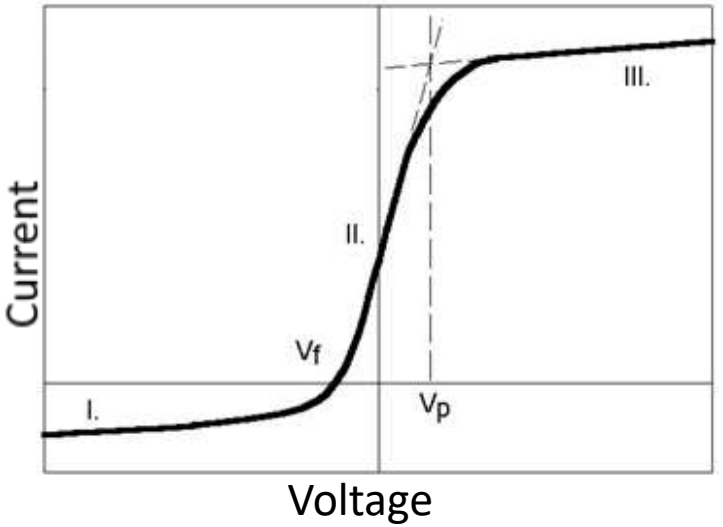
The atmosphere of the Earth

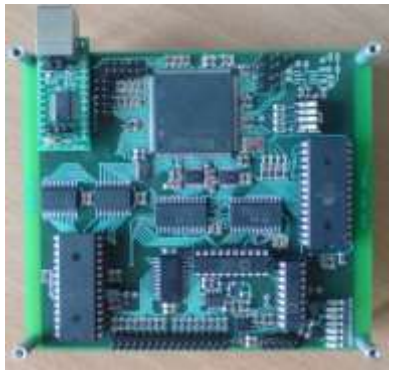
>500km	Exosphere	
80-500km	Thermosphere	temperature increase with altitude
50-80km	Mesosphere	temperature decrease with height
10-50km	Stratosphere	dry, ozone layer
<10km	Troposphere	meteorological weather

- Gases
- Ionized particles
- Charged particles
- Electrons

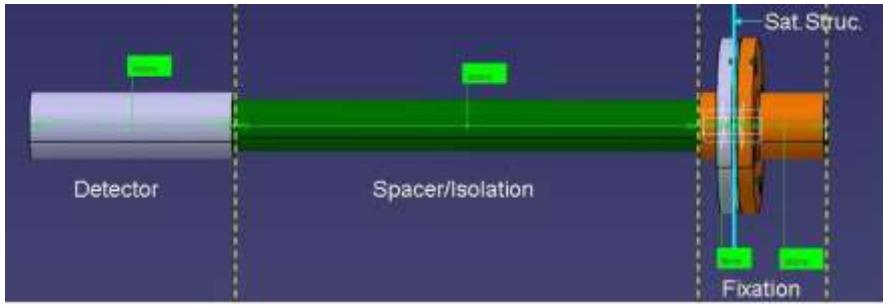
- Ionization layers







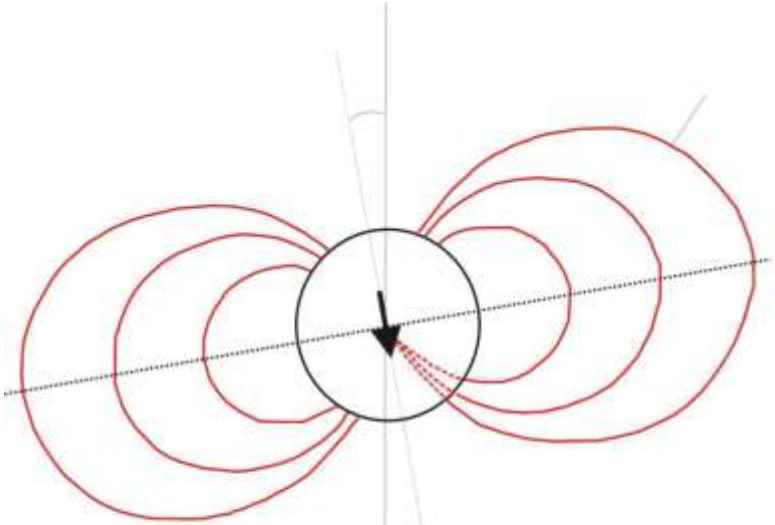
The ESEO LMP experiment (Langmuir probe)



Atmospheric influences

- Significant only if the spacecraft is close to a planet
- Earth: LEO orbits (300-1500km)
- Atmospheric drag; e.g. ISS loses 100-200 m height/day
- Atomic oxygen: aggressive environment; high particle velocity 8km/s, erosion
- Short-wave radiation of the Sun: ionization of parts of the upper atmospheric layer; radio wave reflections

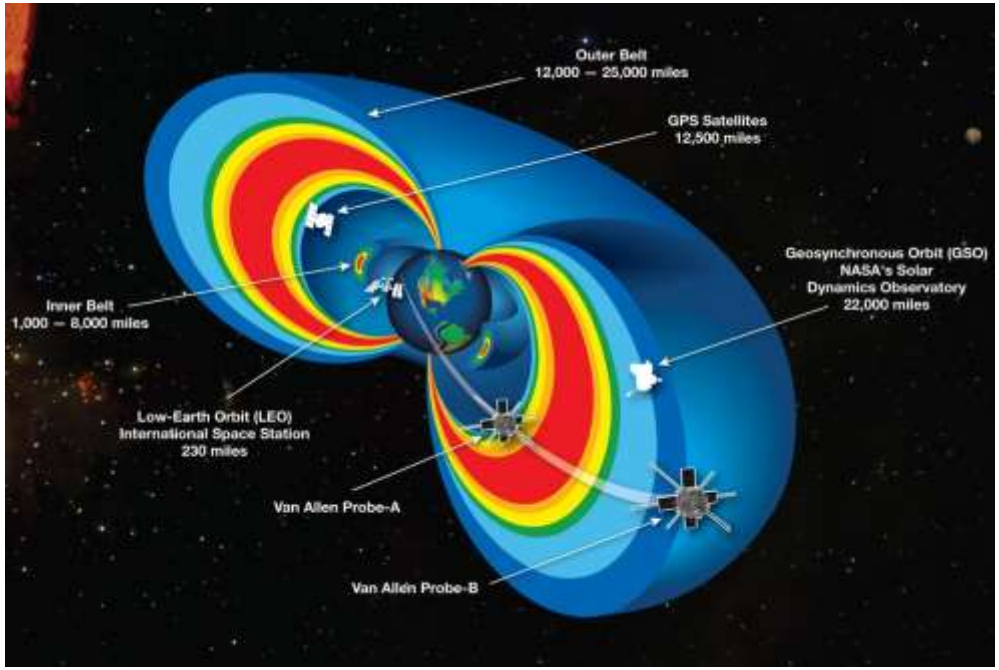
The Earth's magnetosphere and magnetism



Radiation belt (Van Allen Belt):

- Highly energetic particle population
- Protons >1MeV
- Electrons >50keV

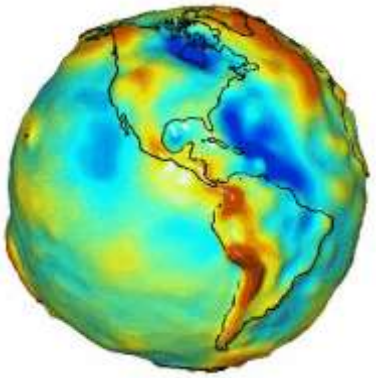
- Spacecraft moving in magnetic field:
  - induced electromagnetic forces
  - might be used to generate electrical power
  - magnetic attitude control possible



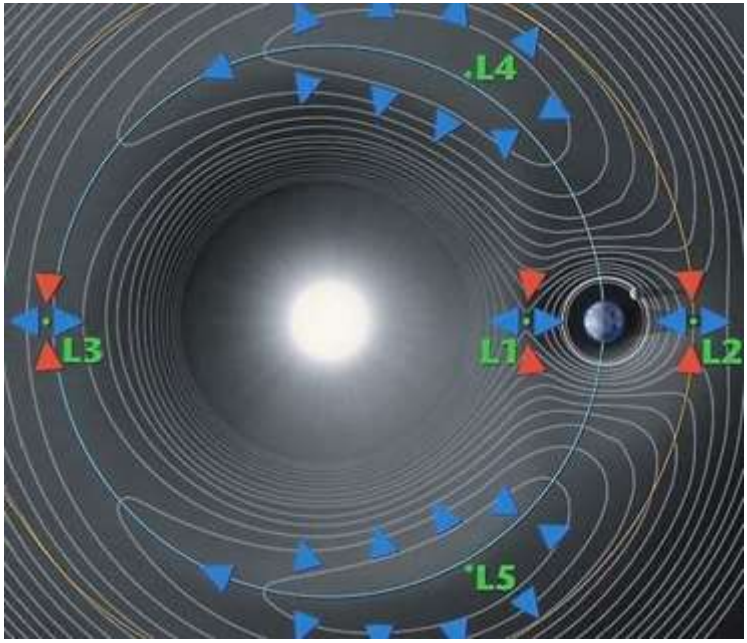
Radiation Belt Storm Probes (RBSP) mission (2012)

Gravity

- Newton's law is valid for:
  - Spherical bodies
  - Absence of atmosphere
  - Nonrelativistic conditions
  - Central body exists; other celestial bodies are negligible
- Multibody system: more complex (n≥3)
- Numerical models are existing for the Earth's gravitational field



- Gravitational fields may help in fly-by manoeuvres (e.g. Rosetta)
- Lagrange points



- Absence of gravity: small static and dynamic load
- Liquids (propellants) problems

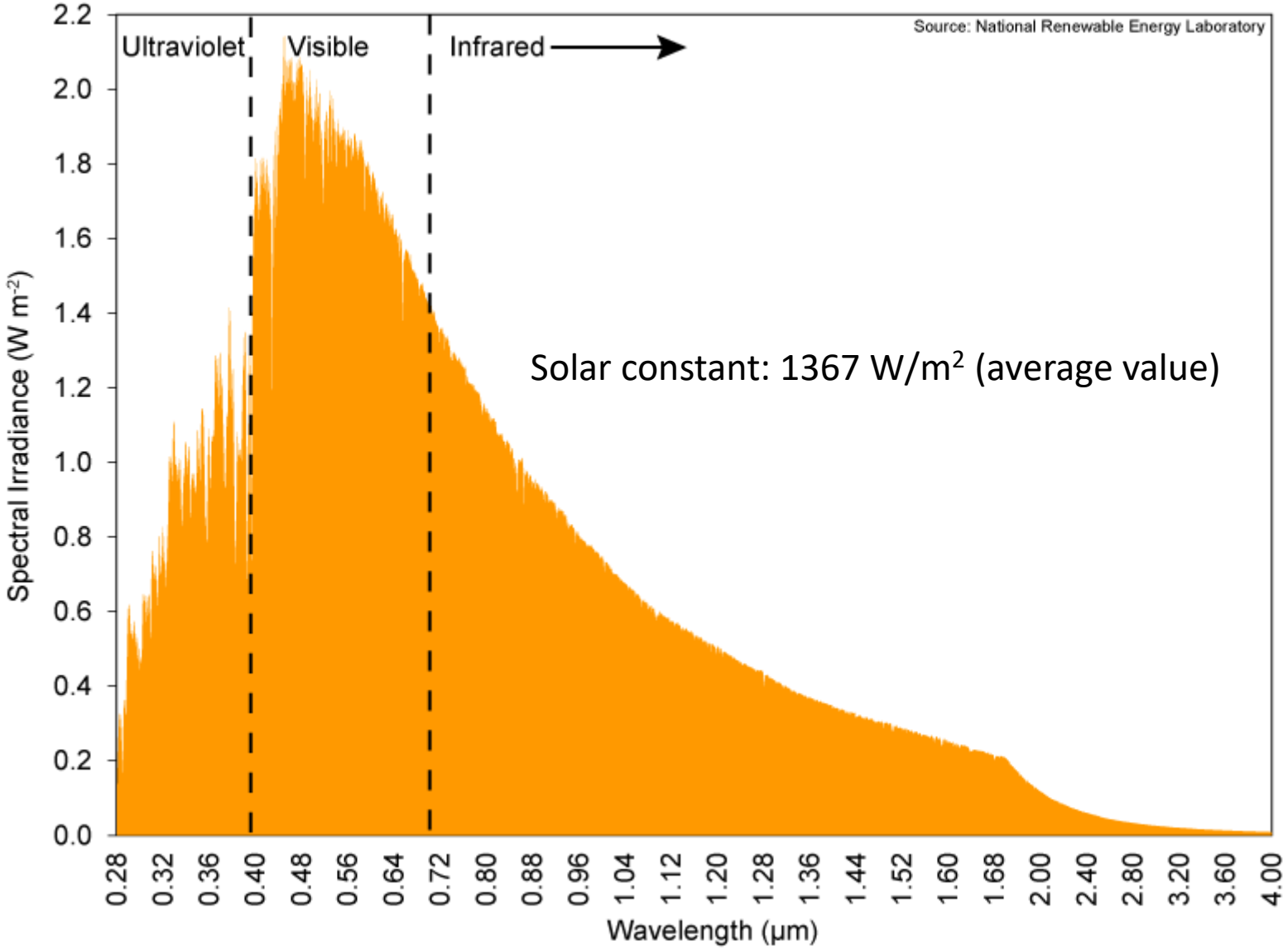
- Attitude control system tasks

Radiation type 1: Electromagnetic radiation

Radiation emitted by the Sun is dominant

- Thermal energy: challenge for the Thermal Control System
  - cosmic background radiation (T = 2.7 K)
- Chemical influence: UV, X-ray may change atomic structures
- Solar arrays: photovoltaic effect to create power
- Electrostatic charging: removal of electrons from their atomic structure at the spacecraft's surface
  - Currents may flow on the spacecraft's surface
  - Degradation of solar cells, optical sensors, surface coatings
  - Conductive surface may prevent these effects
- Change of electrical resistance due to UV radiation (removal of electrons from their atomic structure)

Solar radiation at the top of the atmosphere



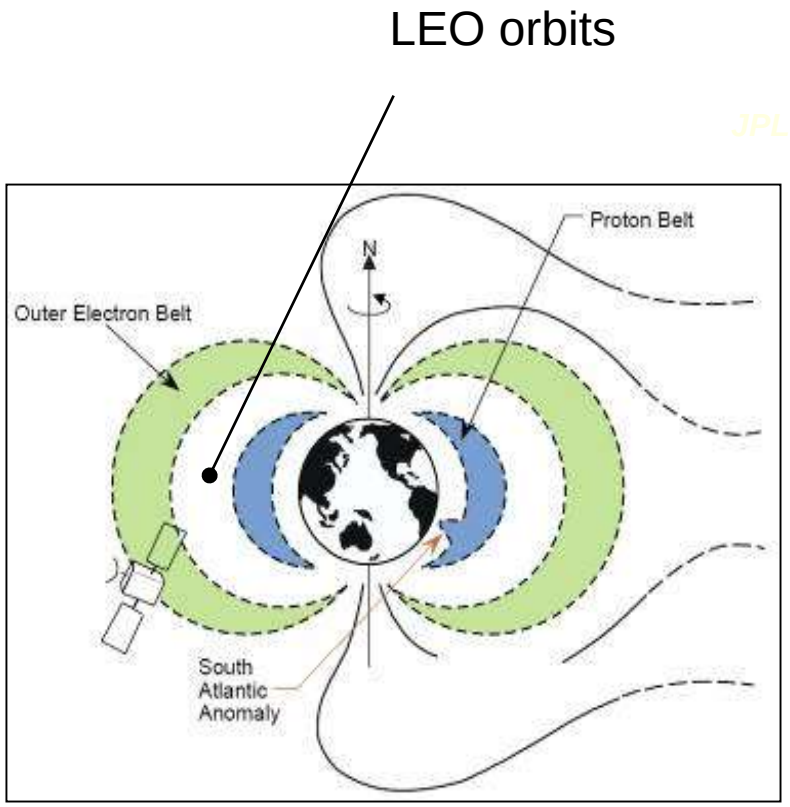
Radiation type 2: Particle radiation

❑ Base types:

- Galactic cosmic rays; particles from all directions
  - They come from outside of the Solar System
  - Mostly protons, α particles= He^{2+}, heavy ions
  - High energy (100MeV-10GeV) → cannot be shielded

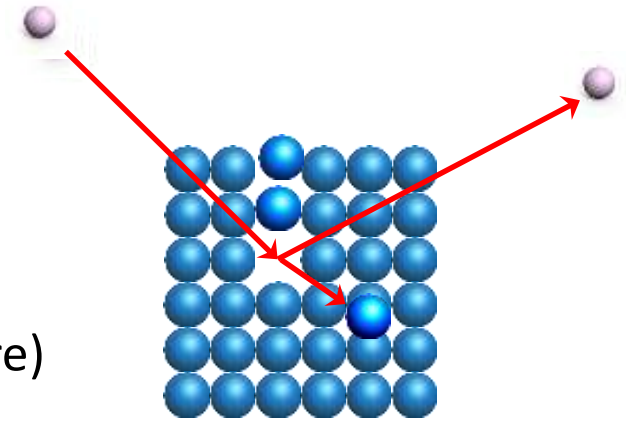
- Solar flares
  - charged particles (proton, α)
  - medium energy → shieldeable

- Earth's specialty: the Van-Allen belt
  - Charged particles (proton, electron)
  - Concentrated by the Earth magnetic field



Particle radiation: cumulating

- **Dose and dose equivalent**
  - rad/gray (1 rad = 10^{-5} Joule/g absorbed energy)
  - rem/sievert
- **Cumulation of the radiation effects**
  - total ionizing dose / dose rate
  - displacement error (changing the crystal structure)

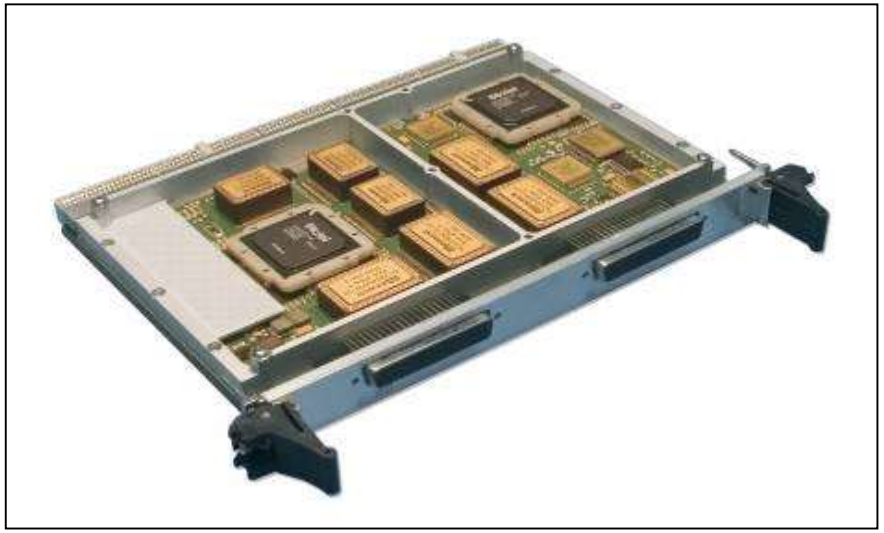


- LEO 300-1400km ~ 2-4krad/year (between the atmosphere and the inner Van Allen belt)
- MEO 1400-4000km ~ 100krad/year
- GEO 36000km ~ 10krad/year
- Mars ~ 5krad/year (proton)
- Giant planets ~ 0,1-100Mrad/year (proton, electron)

- Human effects: >550 rad deadly

Cumulation: semiconductors

- The effect of charged particles in semiconductors
  - ionization, changing the crystal-lattice , heating
- Diodes: increase of back current and breakdown voltage
- Transistors: decrease of amplification, change of characteristics
  - FET / MOS : sensible to ionizing radiation
- Integrated circuits: according to the base components
- Rosetta: >15 krad component tolerance / with 2mm Al shielding

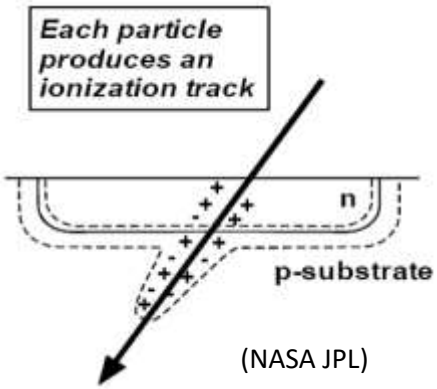


Particle radiation: transient effects

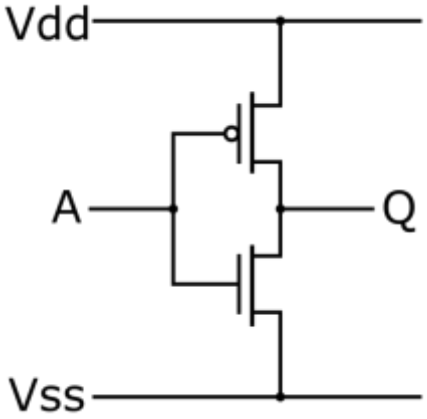
❑ Single effects:

- single event effects (SEE), cause by a single particle:

  • SEL latch-up: soft / hard error (burnout)
  • Linear Energy Transfer Rate: 10-100 MeV/mg/cm^2)



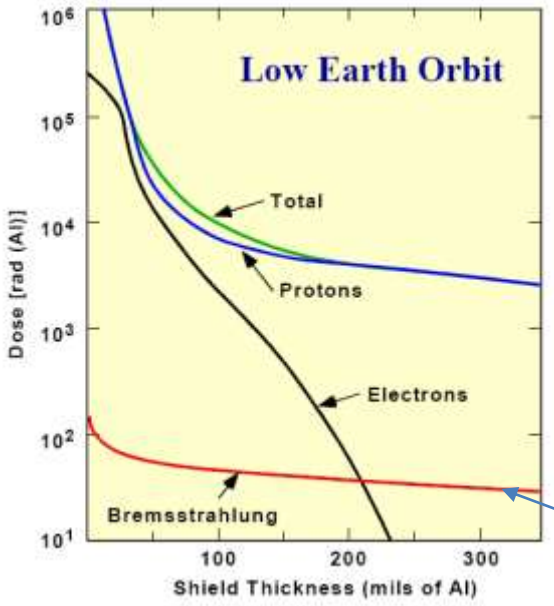
(NASA JPL)



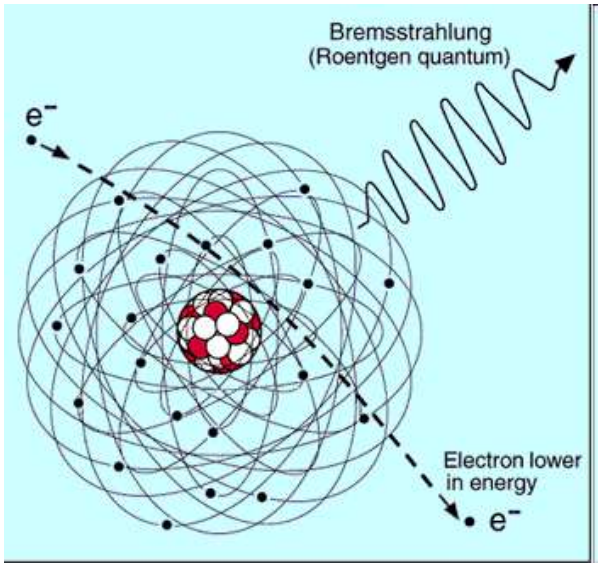
  • SEU upset: soft error e.g. in memory cells

Particle radiation: shielding

- **Shielding**
  - alpha particle (He nucleus): a sheet of paper
  - proton/beta particle (electron) <30MeV: aluminum 1-3 mm, polyethylene
  - Ta: proton, Roentgen, gamma
  - using high atomic number materials (protons)
  - secondary radiation may arise (gamma/Roentgen rays, neutrons)
  - active protection: electrostatic or electromagnetic shielding
  - shielding of electrons is easier, problem: shielding protons (ionizing radiation)
  - neutron: no charge carried->penetrating; spacecraft wall shields



Al shielding

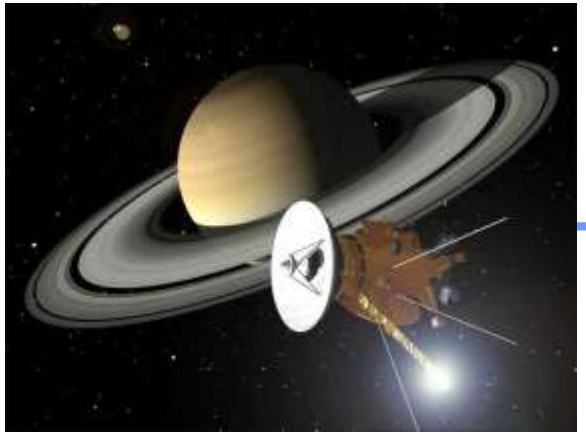


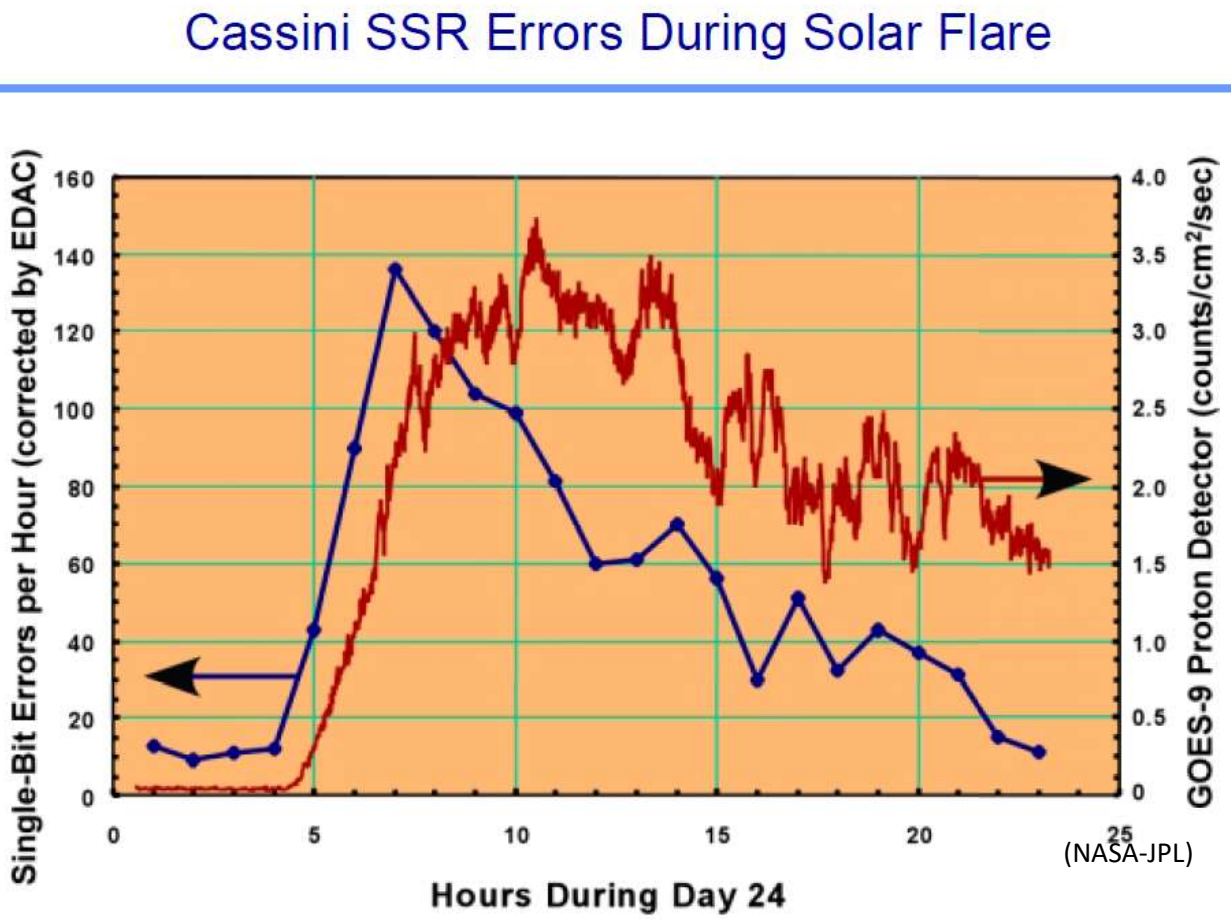
Secondary radiation

High-Energy Particle Radiation: summary

- Particles in the MeV range may cause disturbances or danger
- The design phase of the orbit is important
  - Radiation belts (Van Allen)
  - Solar flares
  - Cosmic particle radiation
  - Secondary particle radiation
  - Other radiation sources
- Radiation dose: astronauts and electronic components (degradation) are affected
- Single event effects: depends on the linear energy transfer (LET)
  - SEU, SEL, burnout
- Activation: collision with highly energetic particles
- Electrostatic charging of the spacecraft

Cassini measurements (Saturn exploration 2004-)





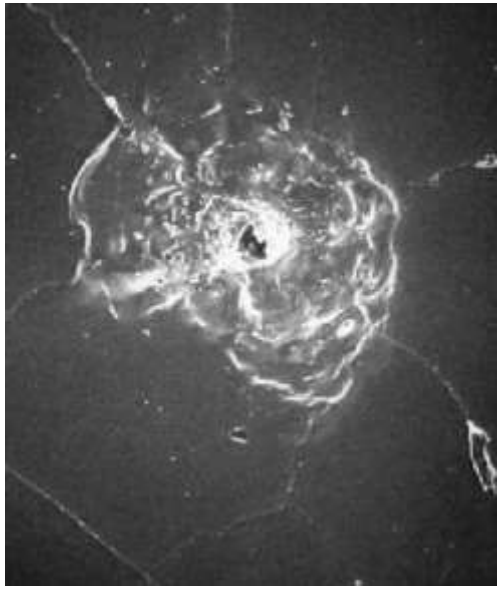
SSR=Solid State Recorder

High vacuum

- Altitude >100km
- 500km: 10^{-7} Pa, geostationary orbit: 10^{-15} Pa
- The effects:
  - Outgassing/sublimation
  - Missing natural convection (heat transfer problem)
  - Change of material properties
  - Cold welding

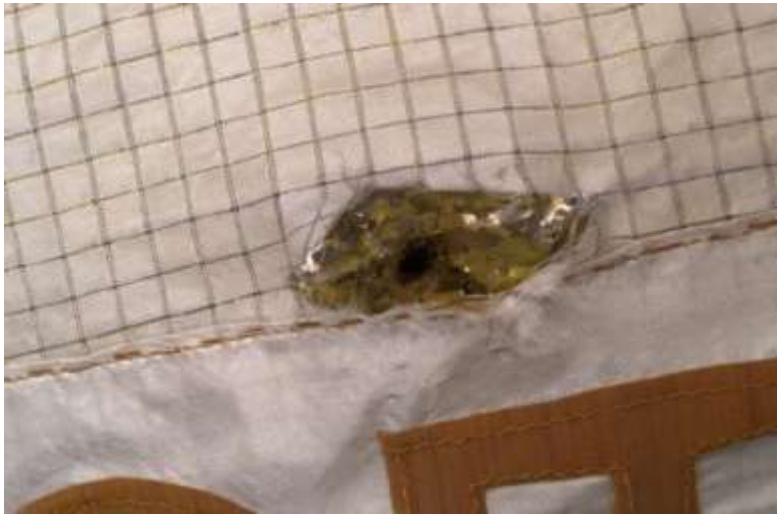
Contamination

- Sources of contamination:
  - Degassing, including decay products
  - Particle plumes from the propulsion systems
  - Particle populations in plasma
  - Micrometeorites and space debris
  - Pyrotechnic units or release mechanisms



Space Shuttle
window damage

ISS
MLI damage



Sources:

- Gary D. Gordon, Walter L. Morgan:
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  Wiley, ISBN: 978-0-471-55796-8
- Wilfried Ley, Klaus Wittmann and Willi Hallmann (ed):
  Handbook of Space Technology
  Wiley, ISBN: 978-0-470-69739-9

Main topics / questions

- Special environmental conditions in space
- The main influences of the Sun
- Impact of Earth’s atmosphere to satellites
- The magnetic field of the Earth; Van Allen belts
- Gravity in space
- The impact of high vacuum
- Particle radiation; single event effects and cumulation