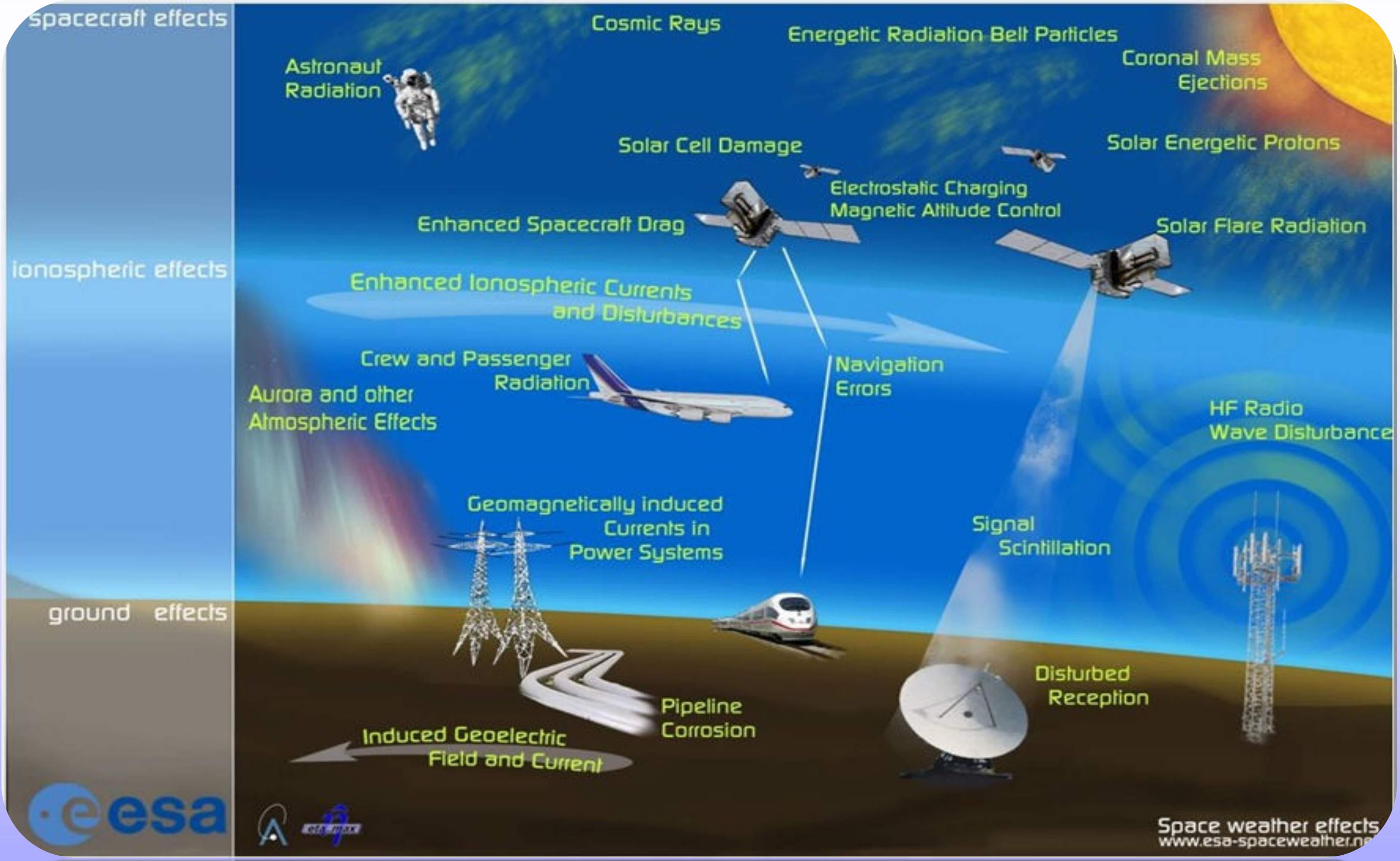
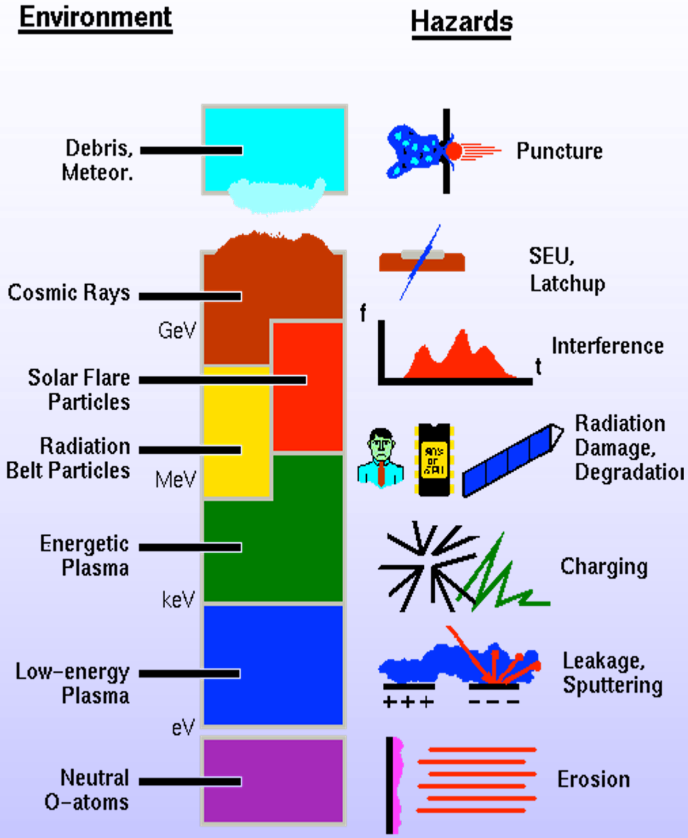
Effects on Spacecraft



Effetti su Spacecraft

The space environment consists of many hazards. Most of these hazards have specific effects on spacecraft and their components

- Radiation: Van Allen belts, source of energetic charged particles, surround the Earth. Sun activity create additional energetic particles in sudden bursts. High energy heavy charged particles reach the Earth vicinity from outside the solar system
- Plasma, ionised gases around Earth: electrostatic charging of surfaces when energetic plasma is injected near the busy GEO (magnetospheric storms/substorms). Discharges can severely disturb operations. The cold ionospheric plasma is a problem for operating high power systems because of its conductivity
- Micro-meteoroids and space debris can seriously damage satellites (manned missions). Increasing space activities add to the space debris problem in popular orbits while the meteoroid environment is an ever-present sporadic feature
- Others environments include the residue of the atmosphere at low orbital altitudes including highly-reactive atomic oxygen, contamination, dust …



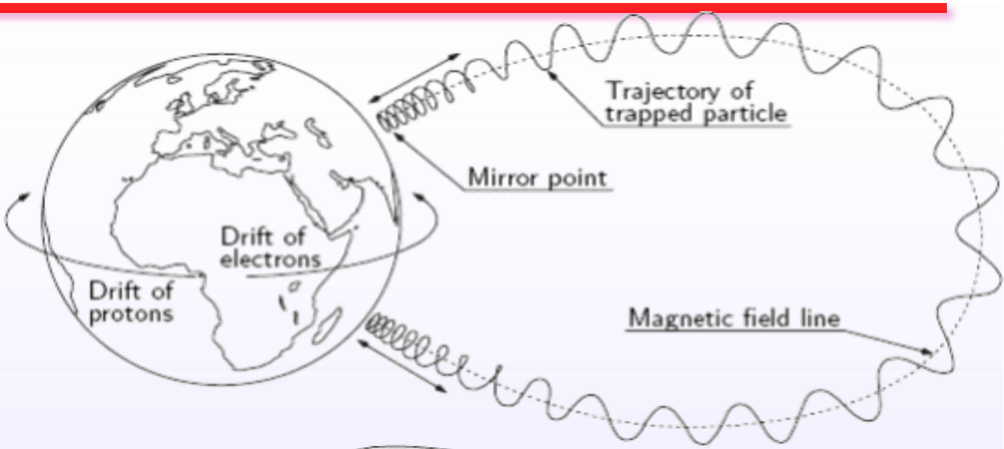
© ESA/ESTEC/TEC-EES

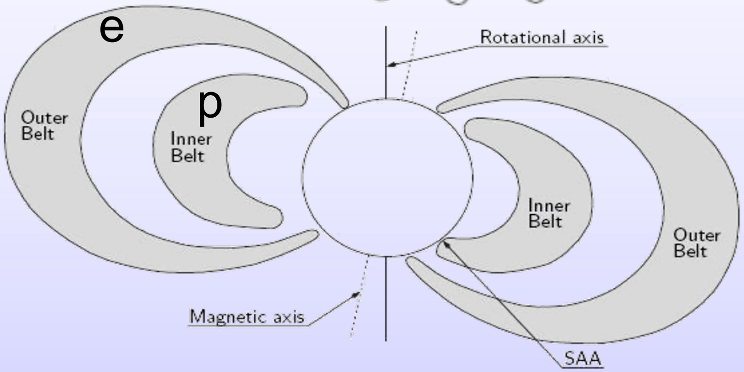
Space Environment

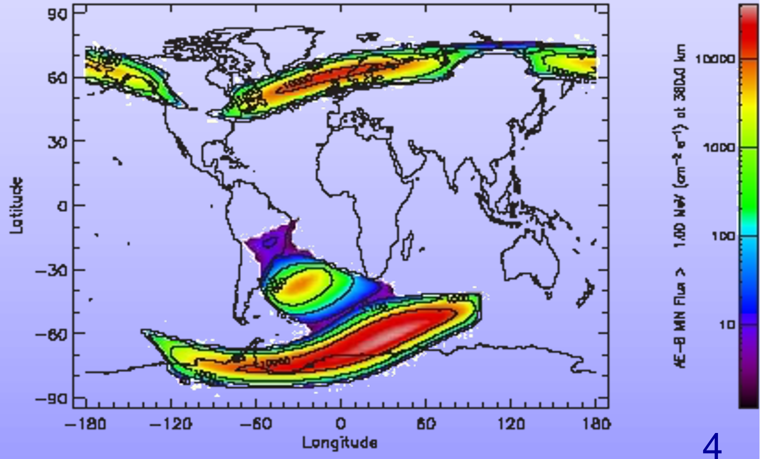
- Radiation
- Plasma
- Geomagnetic field
- Space debris
- Micro-particles & Meteorids
- Atomic Oxigen
- Contamination

Radiation Environment

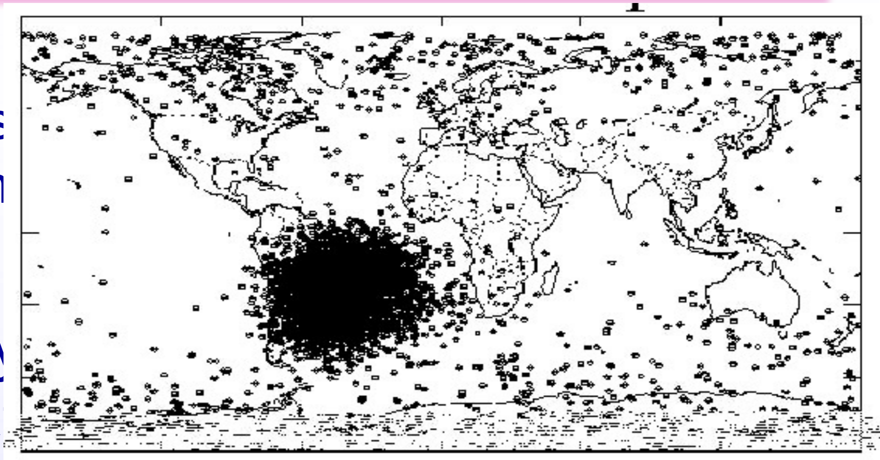
- Trapped particle belts
  - electrons of up to a few MeV
  - protons of up to several 100 MeV
  - low altitude (LEO)
- Solar particle events
  - large fluxes of energetic protons, peak flux in excess of ~10^6 p/cm^2/s, ≥10 MeV
  - Geomagnetic shielding but reach polar regions and high altitudes (GEO)
- Cosmic rays
  - originated outside the solar system, low fluxes but heavy-energetic ions (iron)
  - intense ionisation passing through matter, significant hazard (difficult to shield) for integrated electronic components, solar cells, interference and radiobiological effect







Radiation effects & analysis



- Degradation - radiation damage
  - induced by the ionisation that radiation caus
    the molecular structure of a material and sin
- Single Event Upset (SEU)
  - from ionisation produced by energetic heavy
    semiconductor chip, the free charge genera
    of the bit
  - from energetic protons/ions hitting a nucleus in a sensitive component location. The nuclear interaction produces spallation splitting the nucleus, the spallation products generate the ionisation flipping the bit state
- Radiation Background
  - interference with detectors (astronomy missions) increasing background
  - Interference from secondary radiation (γ-rays, $e^{\pm}$, ions) by interactions of primaries (bremsstrahlung, nuclear interactions). In optical components: energetic particles cause scintillation (fluorescence) and Cerenkov

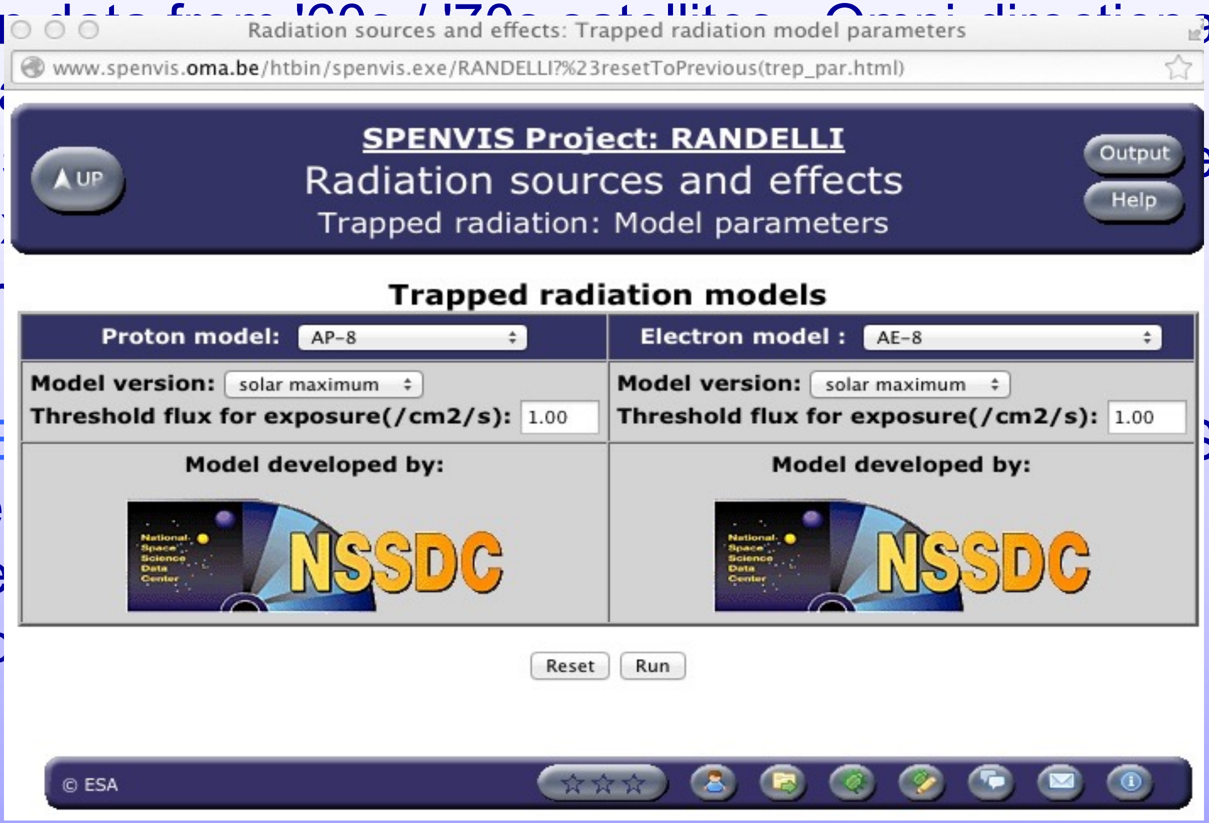
Radiation effects & analysis

- Radiation is a concern for manned missions (low altitude, ISS)
  - The radiation risk due to highly ionising cosmic ray nuclei is of particular concern for astronauts especially for long flights such as those for the space station and for future inter-planetary missions. The radiation risk can be estimated base on the flux of particles as a function of their energy loss, LET (Linear Energy Transfer)

Radiation Analysis

Radiation can penetrate S/C walls and deposit 100s krads in certain orbits. Shielding: mass & cost (+showering)

- Trapped particle belts
  - AE8 and AP8 models for e± / protons, developed by Vette et al. (NSSDC
    @NASA/GSFC) based o… al
    fluxes as functions of ide…
    (spenvis). Apart from for … e
    temporal behaviour of flu…
    orders of magnitude over
    variations
  - New Trapped Radiation E… S
    and ISEE have been use…
    anisotropy models of ene…
    characteristics taking into
    atmospheric density


Radiation sources and effects: Trapped radiation model parameters

www.spenvis.oma.be/htbin/spenvis.exe/RANDELLI?%23resetToPrevious(trep_par.html)

SPENVIS Project: RANDELLI

Radiation sources and effects

Trapped radiation: Model parameters

Trapped radiation models

Proton model: AP-8	**Electron model :** AE-8
Model version: solar maximum	**Model version:** solar maximum
Threshold flux for exposure(/cm2/s): 1.00	**Threshold flux for exposure(/cm2/s):** 1.00
Model developed by: NSSDC	**Model developed by:** NSSDC

© ESA

Radiation Analysis

- Solar particle events (SPE)
  - It is not possible to predict the exact occurrence, intensity or duration of SPE: mission planning can be problematic
  - Short-term forecasts are necessary for any tasks requiring extra-vehicular activity (EVA) and the operation of radiation-sensitive detectors
    - Sun real-time observation can provide useful warning of solar activity, as large proton events are usually associated with the strong emission of electromagnetic radiation (visible light, radio waves, soft X-rays)
  - Long-term predictions of the radiation levels resulting from events are derived from statistical models based on past observations
    - King model: standard model used to predict mission-integrated solar proton fluences
    - JPL (Feynman) model: recently recommended for use for future mission planning

Radiation Analysis

- Cosmic rays
  - CRÈME, Cosmic-Ray environment and effects models by Adams et al. @NRL: a comprehensive set of cosmic-ray and event ion LET and energy spectra, including treatment of geomagnetic shielding and material shielding
  - CREME also includes upset/hit rate computation based on the path length distribution in a sensitive volume and can also treat in a simple manner trapped proton-induced SEUs

Plasma Analysis

- Charging (large amount of input data and careful use)
  - Simple non-geometrical methods (MATCHG) can be used to predict a given material tendency to charge by solving the balance equation, also as a useful aid to interpretation of testing results
  - 3-dim models (NASCAP) include shadowing producing photo-emission differences, electric fields around the S/C affecting the currents striking or leaving a surface and inter-material currents which will affect their potentials
  - Spacecraft Plasma Interaction System (SPIS), used in parallel
- Plasma (close link of numerical simulation and experiments on S/C-plasma interactions)
  - POLAR & NASCAP/LEO: for assessing the problems of plasma interaction at low altitude. Same as NASCAP, same material properties but are applicable to short-Debye-length regimes (i.e. cold dense plasmas). POLAR: to evaluate charging expected in auroral oval while LEO to evaluate anomalous current collection – snapover

Space Debris

Space debris is man-made, growing in numbers. Long lifetime due to the small amount of the perturbing forces (atmospheric drag, gravitational attraction of Earth, Moon, Sun). Four parts:

- Fragmentation debris
  - Breakups are destructive events that generate numerous smaller objects with a wide range of orbital parameters. Products of deterioration can be large enough to be detected from Earth. Parts of the S/C are detaching and become space debris (thermal blankets, protective shields, parts of solar panels). Deterioration is the result of the harsh space environment (thermal cycling, atomic oxygen). Fragmentation material is the single largest component of the tracked space debris population, accountable for over 40% of space debris
- Non-functional spacecraft
  - S/C that are intact structures having completed their mission, or satellites which had a non-destructive malfunction that shortened their lifetime. This group is accountable for 25% of space debris

Space Debris

- Rocket bodies
  - Rocket bodies are of particular importance for the future evolution of the space debris population, due to their large dimension and the potentially explosive residual propellant. With the deployment of a satellite mission, many parts of the launcher become space debris
- Mission related debris
  - Items related to the functional operation of the satellite itself: explosive bolts, vehicle shrouds and lids covering telescopes and other fragile equipment. This comprises all man-made items of space flight: exhaust products from Solid Rocket Motors (SRM), paint flakes, Radar Ocean Reconnaissance SATellite (RORSAT) droplets, Westford needles:
    - SRM can release droplets, such as Al_2O_3, particles are generally small (diameters from 0.1 μm to 3 cm) but flux rate is high
    - Paint flakes, de-attached from S/C, are the result of the harsh space temperature environment
    - The RORSAT droplets are coolant droplets from the Russian RORSAT satellites. These inactive satellites released coolant droplets (NaK, liquid metal) from the nuclear reactor when it was separated from the S/C

Space Debris

- Mission related debris
  - Westford needles was a project of DoD, 1962. A large number of copper needles were intentionally released in an attempt to lay a radio-reflective ring around the Earth, like dipoles as an artificial scattering medium for radio signals in the cm band. The experiment was greatly criticized by astronomers who feared optical and radio pollution. The 1st experiment did not work as a radio reflector, the 2nd one was successful, new needle populations are discovered by radar and optical measurements
  - Mission related debris is generally small in diameter. Therefore they are hard to detect with the current observation methods, which can trace space debris from a diameter of 10 cm and larger, depending on the debris altitude. The amount of released debris can be quite large. For example, 200 pieces of mission related space debris were linked to the Russian space station Mir during its first 8 years of operation. Most of the mission related debris was dumped intentionally, but there are also examples of astronauts who lost items during Extra-Vehicular Activity
  - “Mission related debris” is accountable for over 14% of space debris
- The remaining 2% of space debris has an unknown source

Micro-Meteoroids Environment

- LEO: micro-meteoroids are a minor part of th
- GEO: micro-meteoroids are more likely to be r interplanetary missions, natural particles are particles
- Special attention must be paid to meteoroid s Leonids. These showers, which occur annua S/C by an increased meteoroid impact flux. S e taken to minimize the impact risk

Name	Event maximum
Quadrantids	3 and 4 January
April Lyrids	21 and 22 April
Eta aquarids	3 and 4 May
Delta Aquarids	28 and 29 July
Alpha capricornians	29 and 30 July
Perseids	12 and 13 August
Orionids	21 and 22 October
Taurids	3 and 4 November
Leonids	16 and 17 November
Geminids	13 and 14 December
Ursids	21 and 22 December

- Meteoroid showers occur when the Earth and an asteroid (or comet) orbit intersect. The Earth will enter the stream of the comet for a few days, and will be confronted with the individual particles
- Showers vary in strength, depending upon factors such as age, body composition, shower particle density and distribution and how close Earth approaches the shower core
- Meteoroid showers are named after a fixed point in the bkg star constellation. When a shower becomes visible due to burn-up in Earth atmosphere, the trails seem to originate from one fixed point, the radiant

Micro-Particle Effect

- The micro-meteoroid and space debris environment are considered together: fast moving pieces of matter. Behaving like projectiles, they can penetrate material. Their energy is very high and the impact can vaporise the primary particle, generate fragments and leaving craters or holes on surfaces
- The amount of damage depends on the mass of the particle and the relative velocity of the impact. Many small impacts are observed on the surfaces returned from LDEF (Long Duration Exposure Facility), EURECA, HST Solar Array
- Man-made space debris and natural micro-meteoroid particles can damage satellites and constitute a serious hazard to manned spaceflight. The ISS, with its large surface area and long planned lifetime, has multi-wall design to protect it
- Environment models for impact risk assessment: Kessler NASA/JSC for space debris, Gruen for micro-meteoroids. Sophisticated micro-particle prediction models: NASA orbital debris engineering model ORDEM2000, ESA Meteoroid and Space Debris Terrestrial Reference MASTER-2005

Micro-Particle Analysis

- Evaluating space debris and micro-meteoroid effects:
  - Knowledge of size, velocity of particle penetrating a given shield design. The shield may comprise a single aluminium wall or multiple walls with spacing
  - Design equations give the particle size which just penetrates (or causes some defined damage) as a function of particle velocity for a given shield. The design equation can be used together with the environment model, providing particle fluxes as a function of size and velocity, to predict penetration or damage probability over a certain time
  - Good test results as a prerequisite to a reliable analysis
  - Since current technology impact tests cannot reach the extreme velocities of the debris population, hydrodynamic computer codes need to be used to augment the test data in establishing design equations
  - S/C geometry and orientation need to be taken into account because of the relative velocity of the S/C through the environment: new impact risk assessment tool (ESABASE2/Debris). It computes the number of impacts over time and failures for user-defined mission parameters, geometry, attitude and shield design
  - The environment remains uncertain, especially for particle sizes just below the trackability limit. More flight data are required

Atomic Oxygen

- In low Earth orbits, satellites encounter the very low density residual atmosphere composed primarily of oxygen in an atomic state. Although oxigen density is low, the flux is high
- Effects
  - The large flux of atomic oxygen, in a highly reactive state, can produce serious erosion of surfaces through oxidation. Thermal cycling of surfaces can remove the oxidised layer from the surface. Some surfaces respond differently by changing dramatically their surface structure and therefore properties, which are important for S/C thermal control
- Analysis
  - The flux of atomic oxygen depends on its density, the relative S/C velocity and the orientation of surfaces. The recession rate is proportional to the fluence (time-integrated flux) and is material dependent. Kapton recedes at about 3 μm per 10^{20} atoms/cm^2: a surface in LEO can accumulate 10^{21} atoms/cm^2 in a months. Preliminary predictions for the ISS indicated that Kapton exposed on ram surfaces could recede at 360 μm / solar cycle

Atomic Oxygen Analysis

- Atomic oxygen fluence analysis (ESABASE/Atomox)
  - Orbit (position, velocity), an orbit generator and mission evolution
  - Surface orientation with respect to velocity vector
  - Atomic oxygen density: MSIS-86 (known as CIRA-86) atmospheric model of Hedin et al. used to derive density as a function of altitude, time, solar and geomagnetic activity, latitude and longitude
  - Solar activity prediction (or observation)
- The worst-case fluence is to a ram surface and is greatest at solar maximum when the atmosphere expands
- Since atomic oxygen density varies strongly with altitude, strong variations are also expected in its effects. In a decaying satellite orbit most of the damage is caused towards the end of the mission
- Anti-sun-pointing surfaces in circular, low-inclination, low Earth orbits accumulate more atomic oxygen than sun-pointing ones (peak atomic oxygen density is after noon)
- Ground-test facilities are needed to be compared with model predictions. There is also a need for more flight data to evaluate long-term effects (LDEF)

Contamination

- Contamination from outgassing, venting, leaks and thruster firing can degrade surfaces on which contaminants deposit. The contaminant cloud can also disrupt payload operations (e.g telescopes). On-orbit contamination may modify surfaces and invalidate ground-based characterisation (charging properties measurements). High contaminant levels may also contribute to the onset of electrostatic discharge
- Analysis
  - ESABASE/Outgassing has been developed to compute deposition on surfaces of a 3-dim model of a S/C resulting from the outgassing of other surfaces
  - Direct flux, flux reflected by other surfaces, reflections from other contaminant molecules (using a simplified cloud model), and ambient gas scattering are taken into account
  - A temperature-dependent residence-time model is used for the outgassing

Bibliography

ilwsonline.org

spaceweathermonitor.com

helioviewer.org

www.esa.int/TEC/Space_Environment/index.html