EPFL

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Introduction to the Design of Space Mechanisms

Theme 2:

Environmental constrains

Part 2

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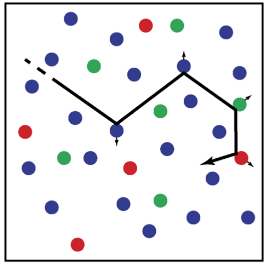
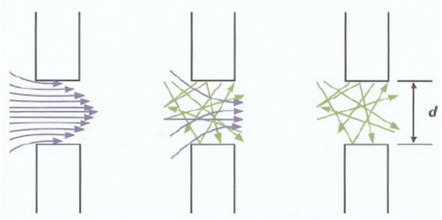
Gilles Feusier

Space Environment Constraints

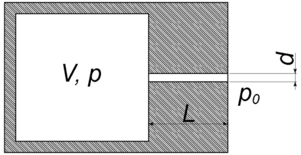
Main environmental constraints:

- **Vacuum**
  - Mean free path λ, molecular flow
  - Heat exchange: no convection
  - Outgassing of a cavity
  - Evaporation of materials
  - Breakdown Voltage
- **Radiations**
  - Electromagnetic and particles
  - ATOX: Atomic Oxygen (O, UV's)
- **Vibrations and Shocks**





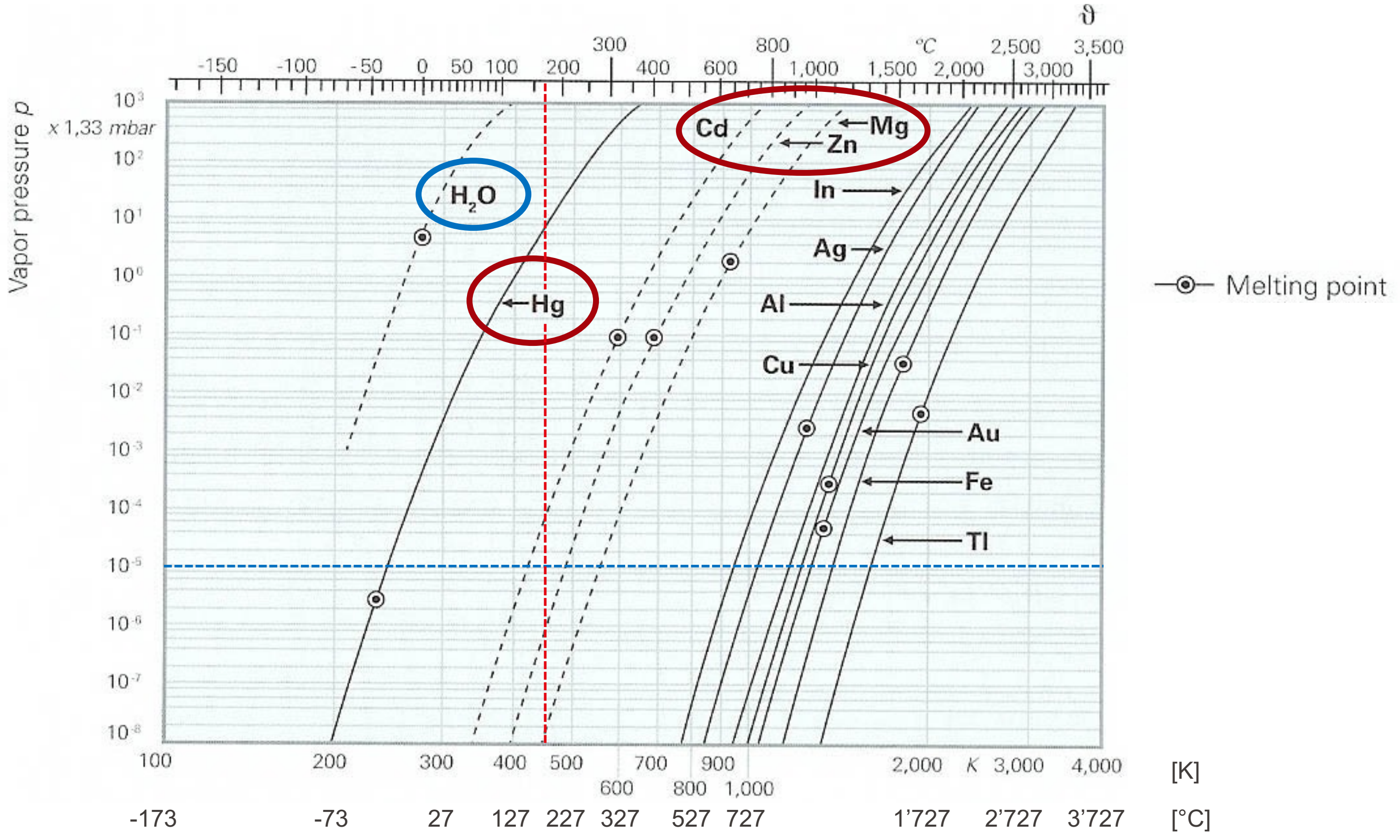
$K_n < 0.01$ $K_n > 0.5$



Conductance (C)

$$Q = C \cdot (p - p_0)$$

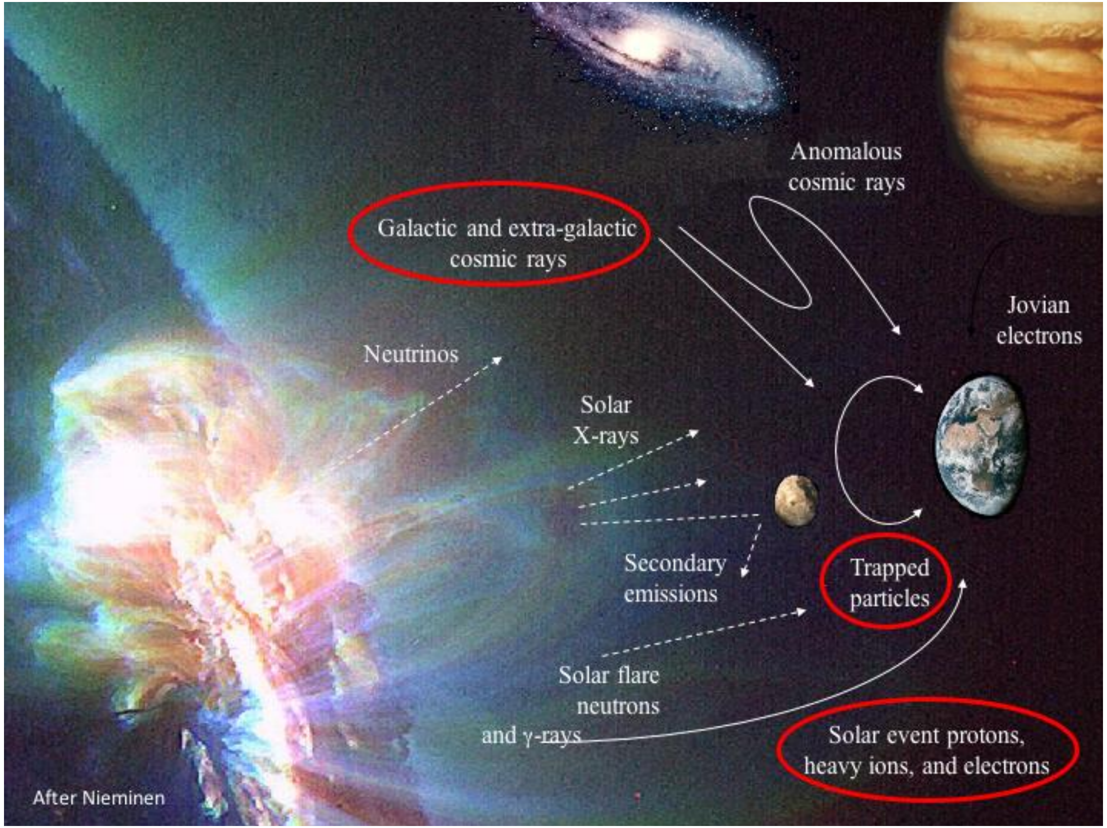
Vapor Pressure

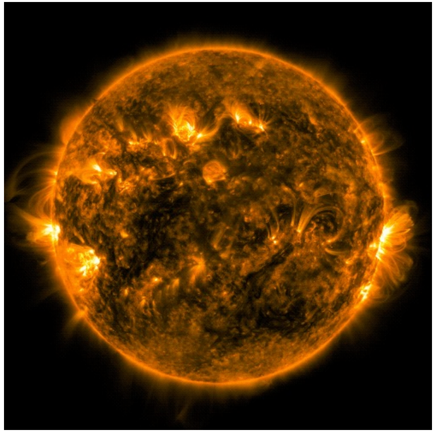


Source: Pfeiffer - The Vacuum Technology Book Volume II

Radiations

- Source of radiation in space





Source: NASA/SDO

Versoix, Switzerland, May 10th, 2024
G5 (Extreme) acc. to NOAA

Source: Lionel Peyraud / Meteosuisse

Source: C.Poivey, Radiation Effects in Space Electronics (ESA 2019),

Ionizing Radiations: Manned Space Flight

- Two types of radiation are particularly dangerous for humans:
  - **High energy Galactic Cosmic Rays** (GCR)
    - Various types of particles
  - Solar radiations: **Solar Particle Events** (SPE)
    - Mainly protons, lower energy than GCR, but much higher quantity

Reading: **[2.3]**

COMPUTER SIMULATIONS OF RADIATION SHIELDING IN SPACE BY POLYMERIC MATERIALS
Christopher A. O’Neill
College of William and Mary, Virginia (2006)
Advisor: Dr. Robert A. Orwoll, Ph.D

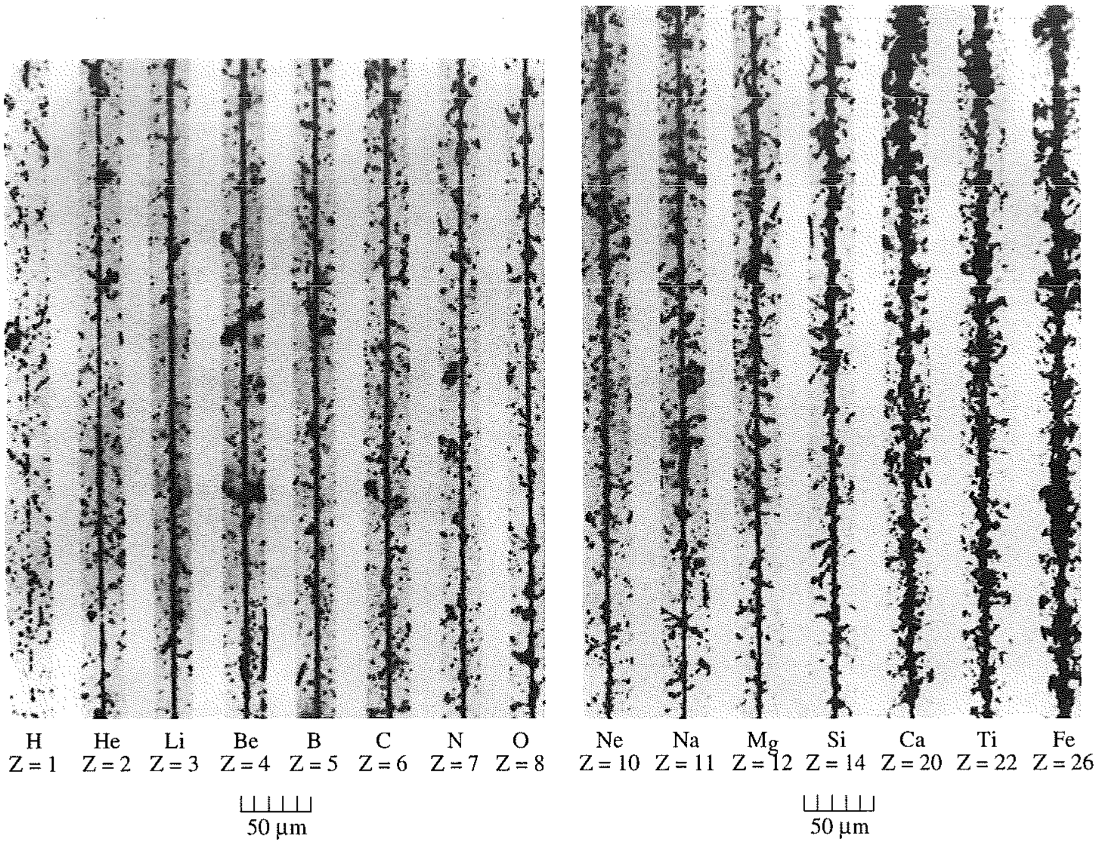
Ionizing Radiations: Manned Space Flight

Cosmic-ray ion tracks in nuclear emulsion

Effect of the interaction of charged particles with the mater.

Different Z materials, same energy of the incident beam.

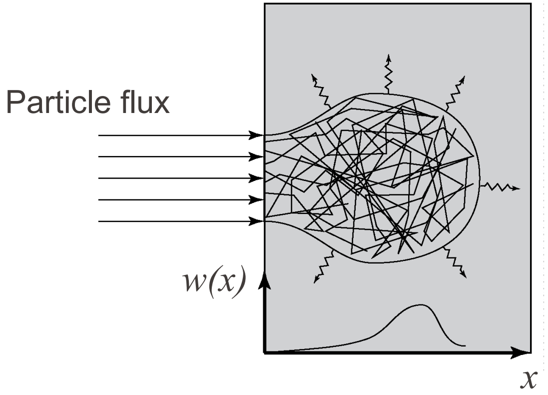
Source: J. W. Wilson et al., NASA Conference Publication 3360 (1997) p.13 /Taken from McDonald, NASA TM X-55245 (1965)



Ionizing Radiations: best absorbing materials

- most effective radiation shielding materials (i.e. producing less secondary electrons),
  - have the highest electron density,
  - the least electronic excitation energy,
  - the least tight binding corrections for the inner shell electrons

→ **Hydrogen**

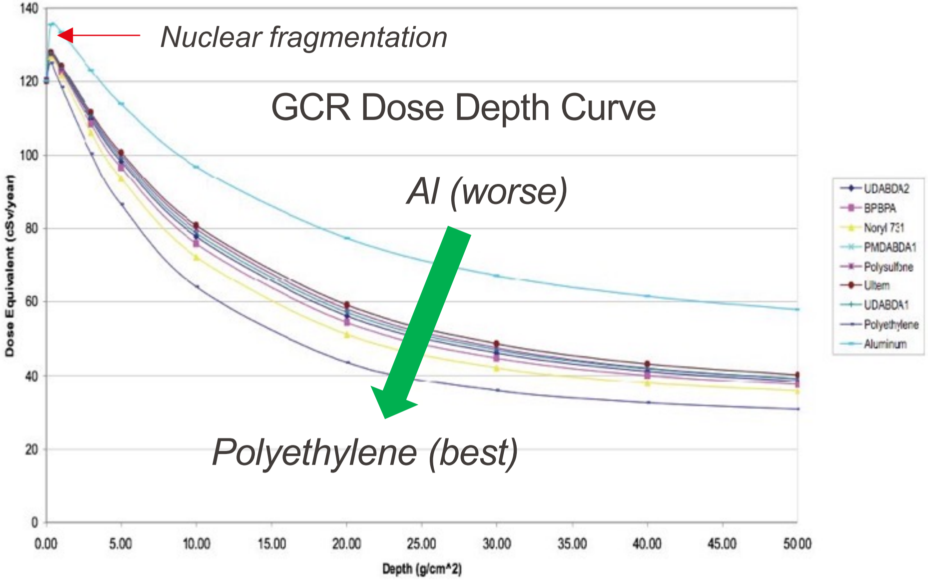


Shielding equivalence in water column heights:

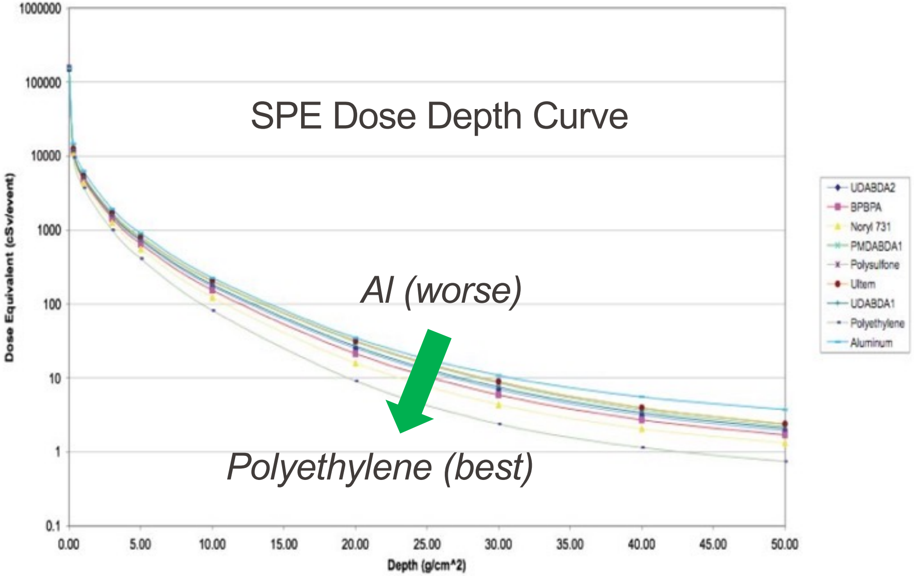
Atmosphere:	10 m
Typical spacecraft:	20 cm
Space suit:	1.5 cm

Source: T. Berger, "*Radiation dosimetry onboard the International Space Station ISS*", Z. Med. Phys. 18 (2008) 265–275

Ionizing Radiations: Manned Space Flight



Effect of shielding



GCR: Galactic Cosmic Rays
SPE: Solar Particle Events

Source: Christopher A. O'Neill "Computer Simulations of Radiation Shielding in Space by Polymeric Materials"

Ionizing Radiations: Manned Space Flight

- Radiation flux, fluence: $\phi = \frac{dN}{dA}$ [m^{-2}]

  Where where dN is the number of particles incident on a sphere of cross-sectional area dA

- Energy fluence: $\psi = \frac{dR}{dA}$ [J/m^2] or [eV/m^2]

  Where where dR is the radiant energy incident on a sphere of cross-sectional area dA

- Dose: $D = \frac{d\bar{\varepsilon}}{dm}$ [J/kg = Gy (Gray)]

  Mean energy $\bar{\varepsilon}$ absorbed by unit mass m

- Equivalent dose: $H_T = \sum w_R \cdot D_{T,R}$ [Sv (Sievert) = J/kg]

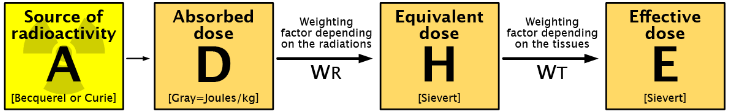
- Effective dose: $E = \sum w_T \cdot \sum w_R \cdot D_{T,R}$ [Sv]

  Dose in a tissue ($D_{T,R}$) weighted by a factor depending of the type of radiation and its energy (w_R) and a factor depending of the physiological effect on the tissue (w_T).

Ionizing Radiations: Manned Space Flight

Type and energy range		Radiation weighting factor, w_R
Photons, all energies		1
Electrons and muons, all energies		1
Neutrons, energy	<10 keV	5
	10 keV to 100 keV	10
	100 keV to 2 MeV	20
	2 MeV to 20 MeV	10
	>20 MeV	5
Protons, other than recoil protons, energy >2 MeV		5
Alpha particles, fission fragments, heavy nuclei		20

Source: ECSS-E-ST-10-12C [2.2]



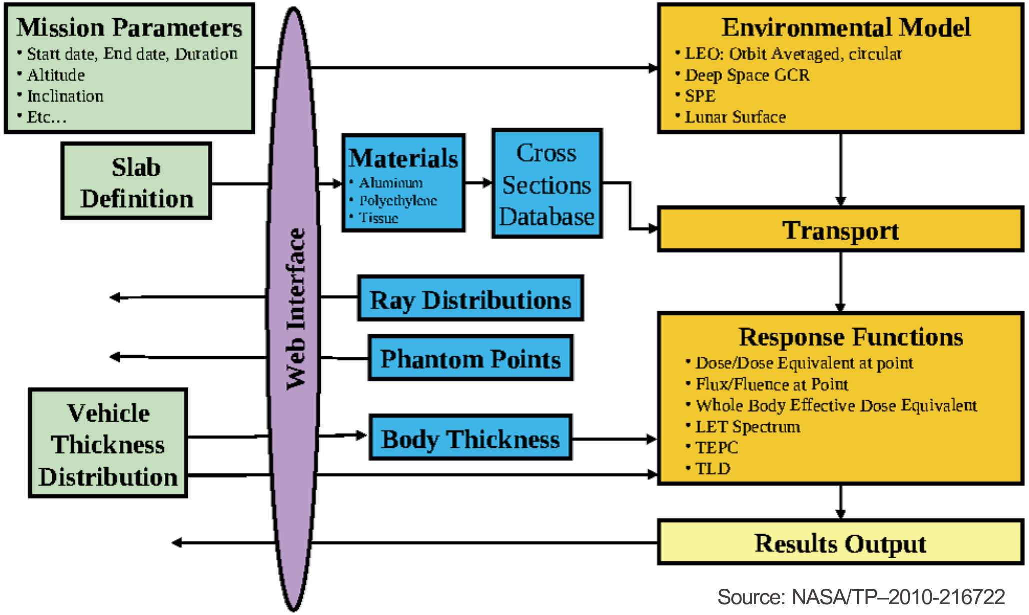
© Calmos, modified

Exercise 2.2: Radiations

Organ or tissue	Tissue weighting factor, w_T
Gonads	0,20
Bone marrow (red)	0,12
Colon	0,12
Lung	0,12
Stomach	0,12
Bladder	0,05
Breast	0,05
Liver	0,05
Oesophagus	0,05
Thyroid	0,05
Skin	0,01
Bone surface	0,01
Other tissues and organs	0,05

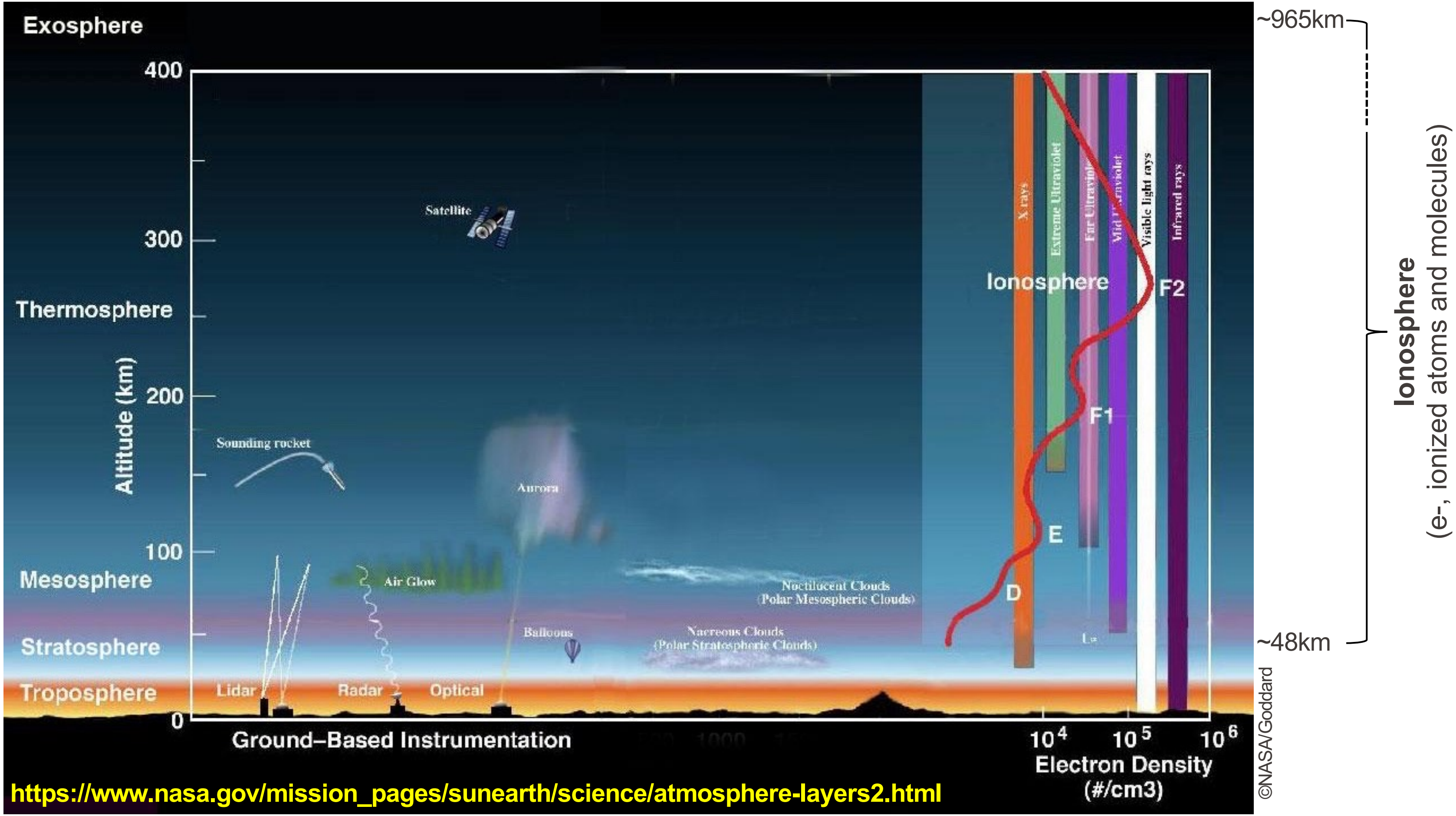
Ionizing Radiations: Tools

- ECSS-E-HB-10-12A - Calculation of radiation and its effects and margin policy handbook [2.7]
- ECSS-E-ST-10-12C - Methods for the calculation of radiation received and its effects, and a policy for design margins [2.2]
- …
- OLTARIS (On-Line Tool for the Assessment of Radiation in Space): https://oltaris.larc.nasa.gov



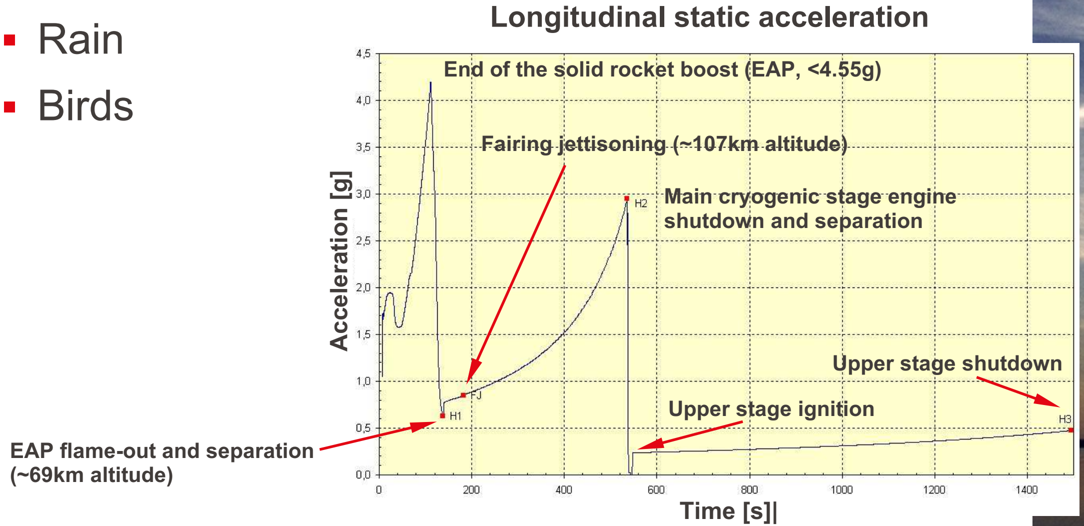
Source: NASA/TP–2010-216722

Ionizing Radiations: Absorption by atmosphere

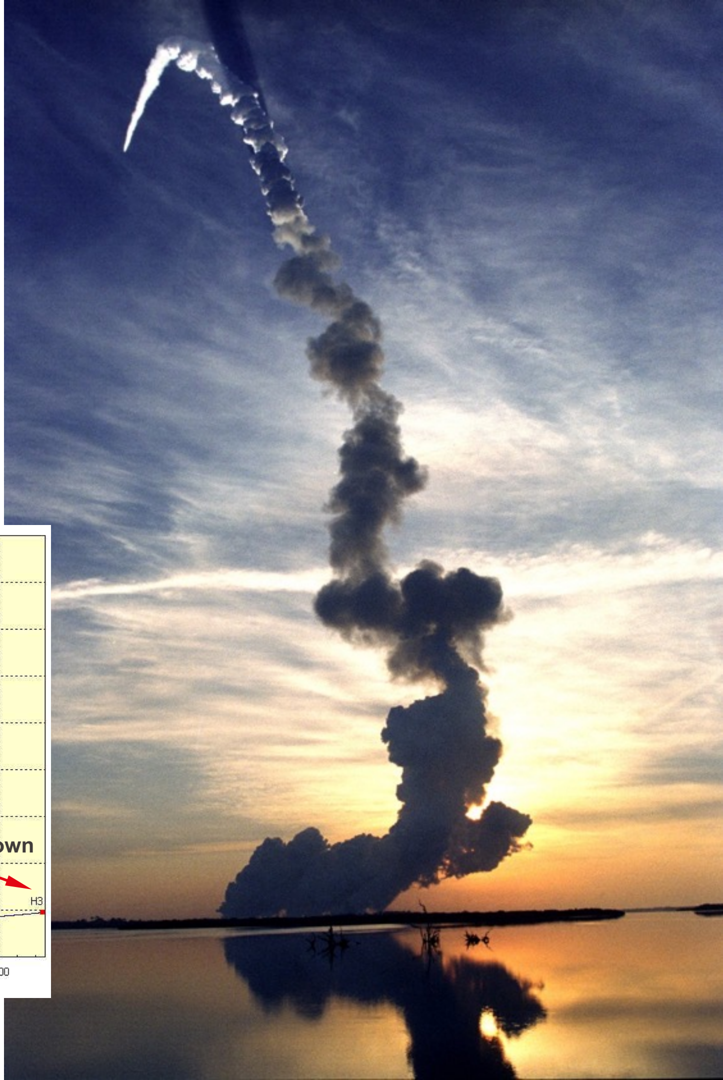


Launch and Ascent

- Vibrations (sine, random, acoustic)
- Accelerations
- Shocks
- Thermal Flux
- Lightening impact
- Rain
- Birds



Source: Ariane 5 User's Manual Issue 5 Revision 2



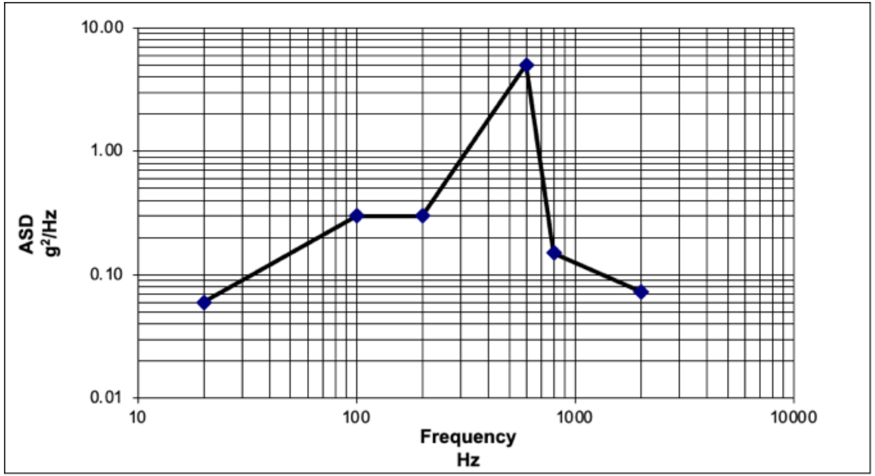
Source: NASA

Vibrations

- The vibration loads injected into a mechanism during the launch to orbit depend on:
  - the launcher (Ariane 5, Falcon 9, …)
  - the attachment point of the mechanism

- Typical vibration load levels for a mechanism mounted on a spacecraft launched by an Ariane 5 rocket (case of the ATV)
  - Overall Grms: 35 g_{rms}

Frequency [Hz]	ASD [g^2/Hz]	Slope [dB/Oct]
20 to 100	0.06 to 0.30	3.01
100 to 200	0.30	0.00
200 to 600	0.30 to 5.00	7.71
600 to 800	5.00 to 0.15	-36.69
800 to 2000	0.15 to 0.073	-2.37



ASD: Acceleration Spectral Density

Random Vibrations

- Given: **Acceleration Spectral Density** (ASD) in g^2/Hz

  *Note: We should speak of **Acceleration Spectral Density (ASD)** for the injected acceleration.*
  Power Spectral Density (PSD) refers formally to the measured plot (values of the accelerometers).

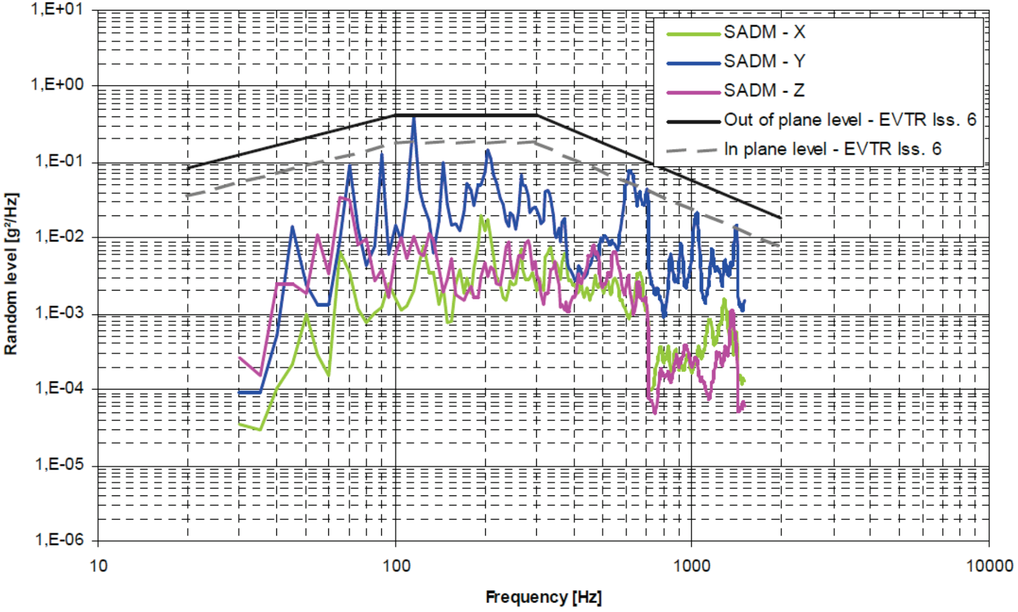
- Root-Mean-Square Acceleration $$\bar{A} = \sqrt{\int_{\nu_L}^{\nu_H} ASD(\nu) \cdot d\nu} \qquad [g_{rms}]$$

  - It is the average acceleration load injected into the mechanism.
  - The mechanism may have eigenfrequencies leading to much higher effective amplitude for some of its components.
  - The concept of “overstress” will be introduced later on.

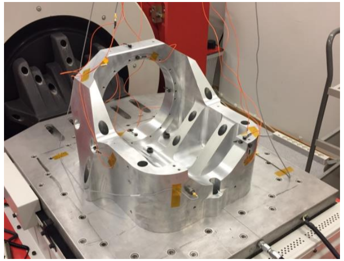
- *Reminder: an octave is a doubling of* ν: $$\#\,Octave = \frac{\log\left(\nu_H/\nu_L\right)}{\log(2)}$$

Random Vibrations

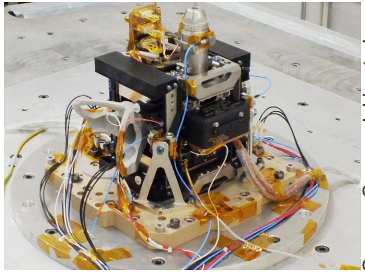
- Vibroacoustic analysis of random vibration levels for Sentinel 3 SADM



Source: ECSS-E-HB-32-26A Space engineering - Spacecraft mechanical loads analysis handbook [2.5]



Source: Elkjaer et al. ESMATS 2019



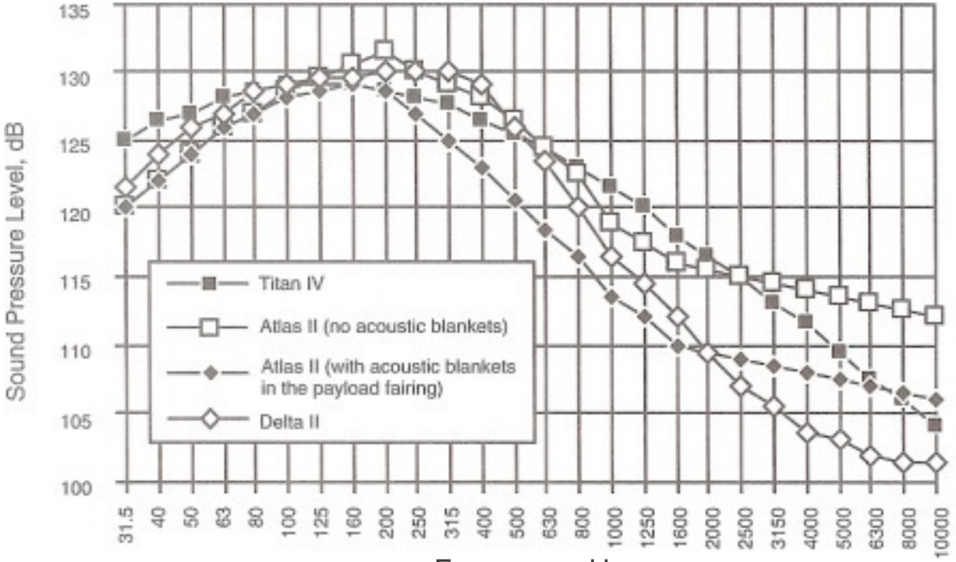
Source: Spanoudakis et al., ESMATS 2019

Launch Acoustic Noise

- $SPL(\nu)$: Sound Pressure Level as a function of the frequency ν.

$$SPL(\nu) = 20 \cdot \mathrm{Log}_{10} \frac{P(\nu)}{P_{ref}} \qquad [\mathrm{dB}]$$

$$P_{ref} = 2 \cdot 10^{-5}\ \mathrm{Pa} \qquad \textit{(threshold of hearing)}$$

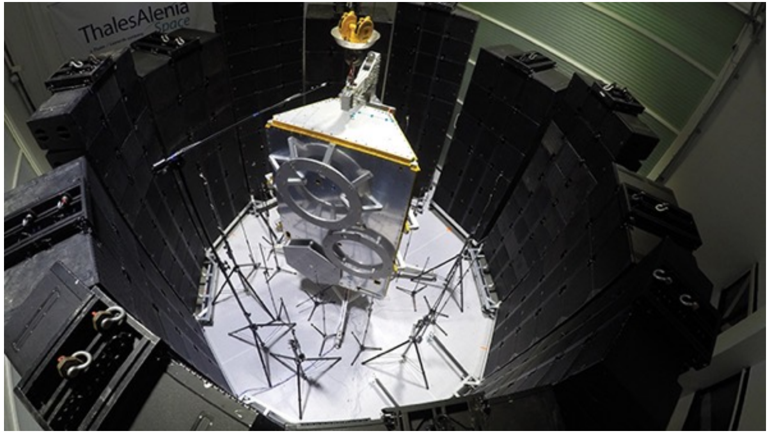


Source: ESA–G. Porter

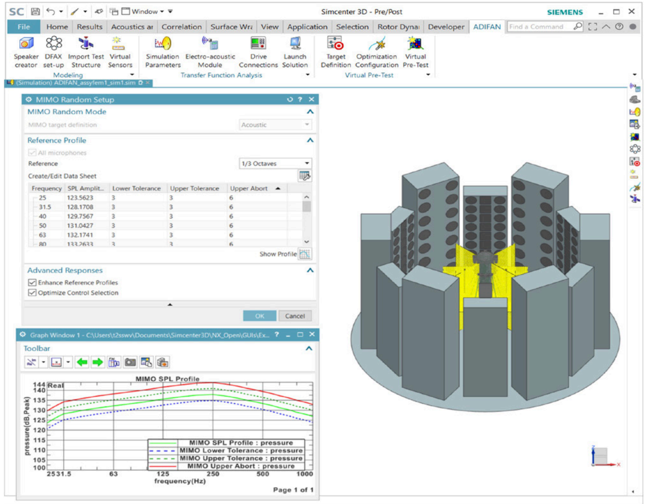
Source: Th. P. Sarafin (ed.), Spacecraft, Structures and Mechanisms, Wiley J. Larson, Managing ed., 2003, fig.3.7, p. 45 [2.4]

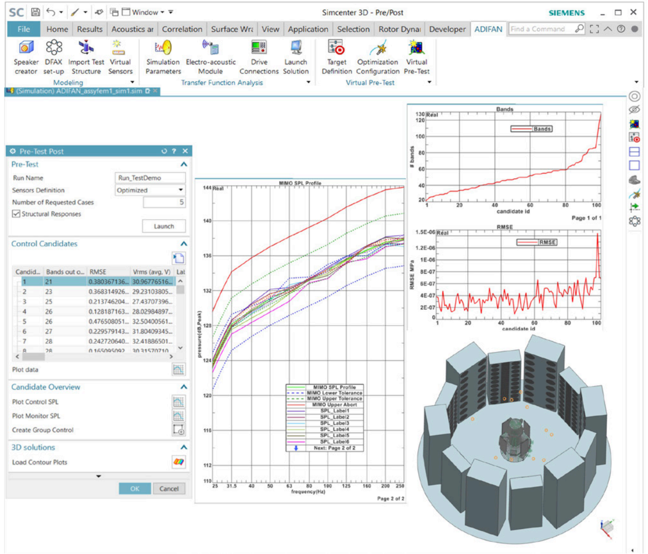
Launch Acoustic Noise

- Digital Twins
  - First: NASA 2010
  - Industry 4.0
  - Artificial Intelligence, Machine Learning, IOT …



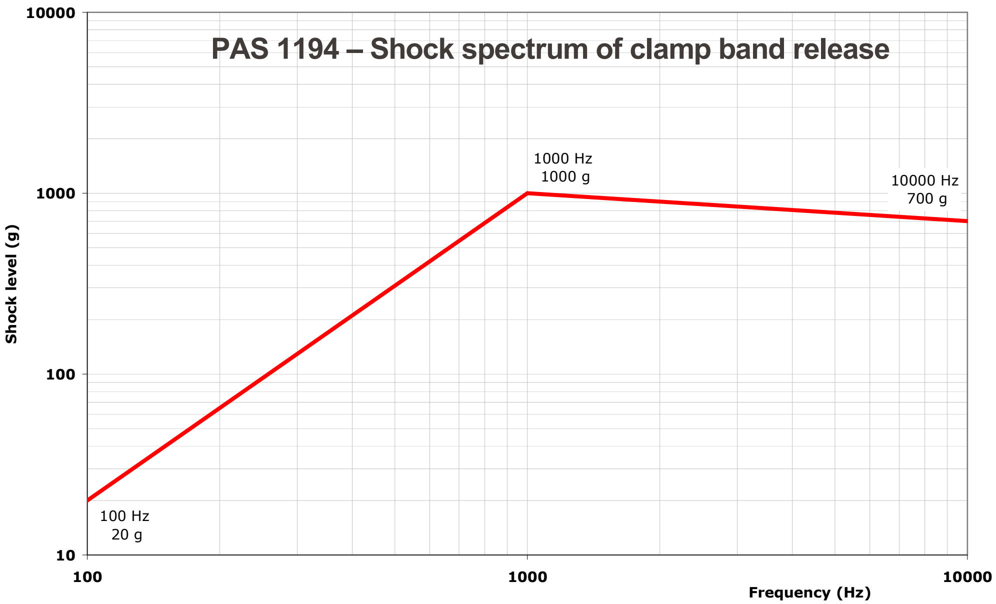
Source: Siemens/Thales Alenia Space

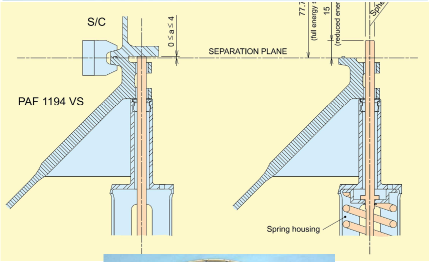




Shocks

- Main events producing noticeable shocks:
  - the launch vehicle upper stage separation from the main cryogenic stage
  - the fairing jettisoning
  - the spacecraft separation
  - sub-system release and deployment

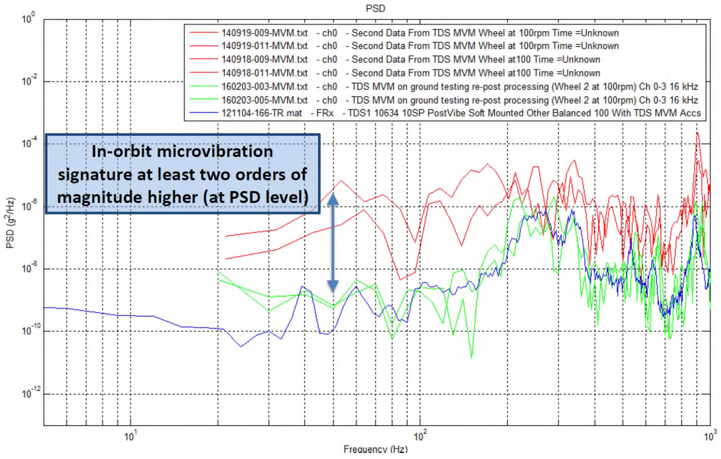




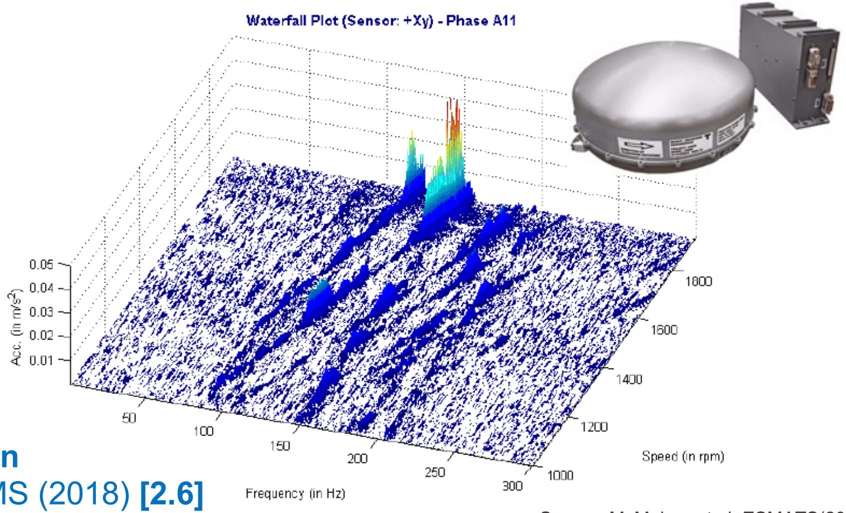
Source: Ariane 5 User's Manual Issue 5 Revision 2

Micro-vibrations

- Has effects on:
  - Micro-g space laboratory experiments
  - Attitude control of spacecraft
  - Quality of images for Earth Observation (EO) spacecrafts or space telescopes
  - …
- Can be produced by operating mechanisms and human induced vibrations:
  - Reaction wheels, momentum wheels,
  - Pumps, valves, cryocoolers …,
  - Heating, ventilation, air conditioning (HVAC) systems,
  - …
- Due to:
  - Imbalance
  - Parts irregularity and imperfections (bearings, gears)
  - Motors (cogging, stepper motors, …)
  - Control
  - Wear, including lubricants (cf. Rosetta)
  - …



Source: Smet et al., AMS(2018)



Source: Bradford Space

Source: McMahon et al. ESMATS(2017)

- Reading: G. Smet and S. Patti, "**A Mechanisms Perspective on Microvibration – Good Practices and Lessons Learned**", AMS (2018) **[2.6]**

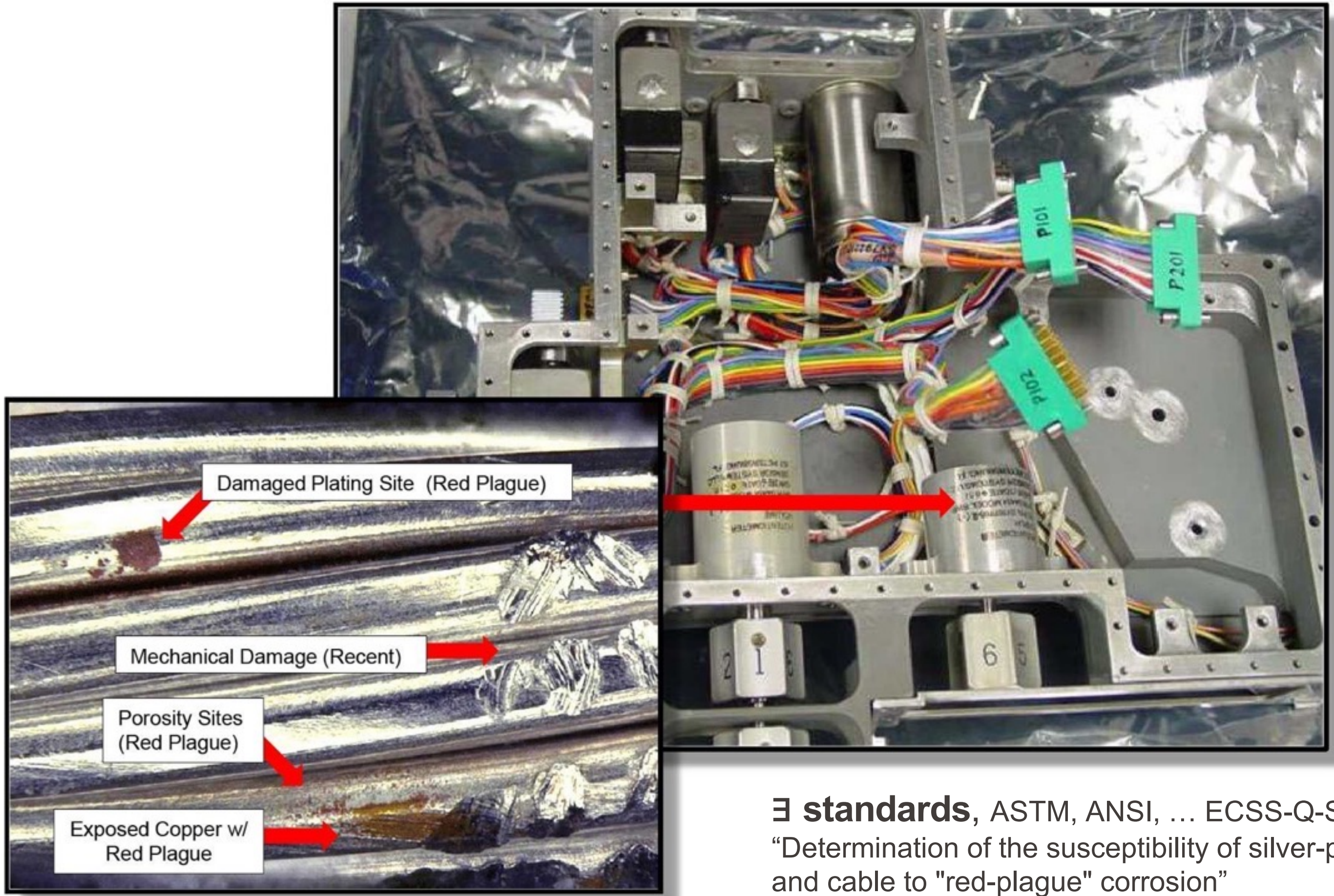
… and on Ground

- Temperature
- Humidity
- Atmosphere
- Biological
- Transport loads
- Test

Source: ESA

Source: Arianeespace

Red Plague - Corrosion of copper when plated with silver



Source: NASA

∃ **standards**, ASTM, ANSI, … ECSS-Q-ST-70-20C
“Determination of the susceptibility of silver-plated copper wire and cable to "red-plague" corrosion”

Theme 2 Summary

- Space environment constrains:
  - Vacuum
    - Properties of vacuum
    - Material selection
    - Effects on design
  - Radiations
    - Ionizing, non-ionizing
    - Dependent on the mission (orbits, duration)
    - Effects on materials, components, life (material selection, shielding)
  - Vibrations and shocks
    - Sinus and random vibrations as well as shocks spectra: launch, ascent, separation, deployment (but also on ground!)
    - Micro-vibrations
- Ground environment constrains
  - Material selection and design shall also be done for MAIT