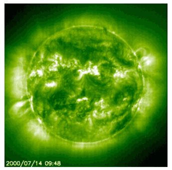
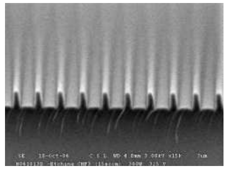
Space Environment

Pr. Jérôme Loicq





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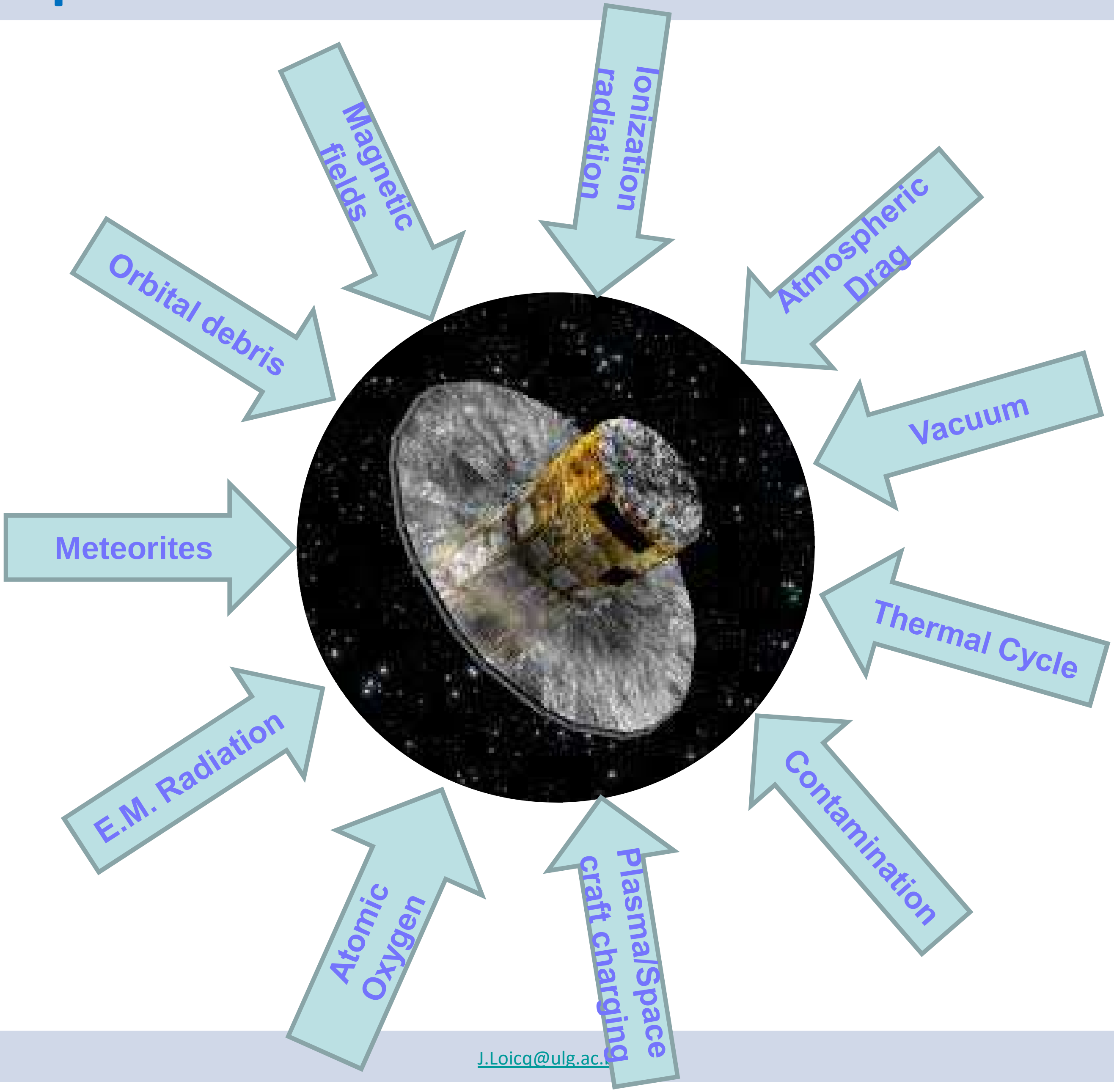
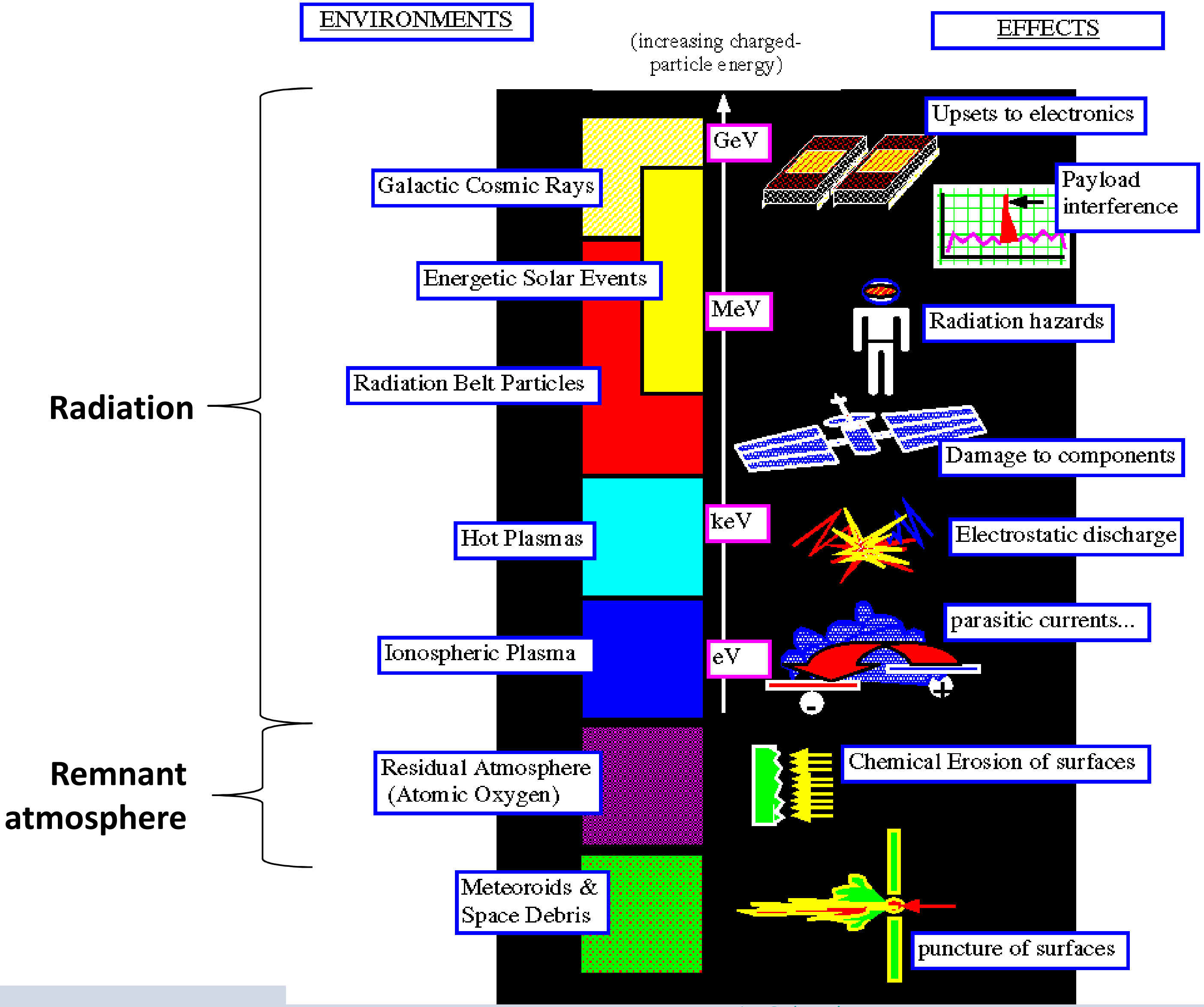
Learning goals

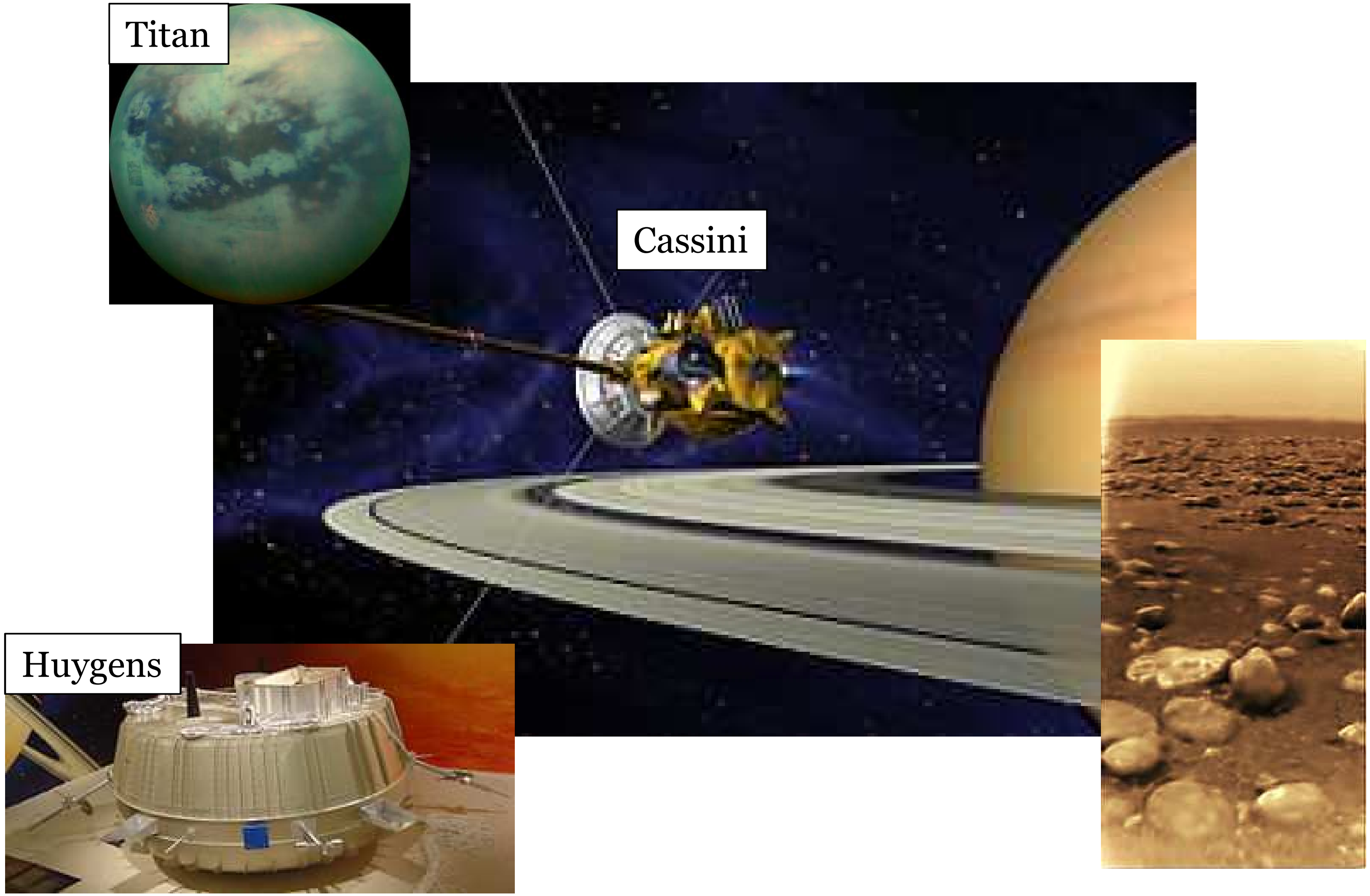
- **The students should be able to:**
  - Define the concept of reliability for Space
  - Describe the relevant elements of the Space environment
  - Describe and explain the relations between a spacecraft and its natural environment
  - Quantify the elements of the space environment as a function of the altitude
  - Quantify the impacts of the space environment on a mission design

Space Environment



Effect of the space environment



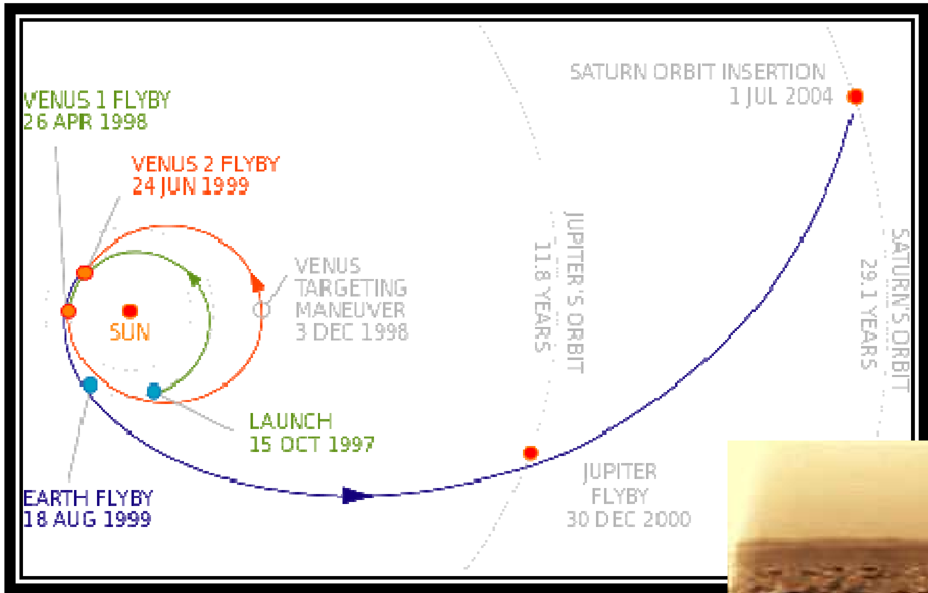

Titan
Cassini
Huygens

- **Huygens probe Landed on 2005 on Titan (Saturn's Moon)**

- **Camera 160x256 pixels (1990 technology)**

- **In the same time on Earth new cameras exist with 11 MegaPix**

- **Why a so huge difference between technology in space and on Earth?**
  - Mission time line
  - Reliability of the Mission
  - Data downlink



Goal of the space mission

Definition

Reliability : probability that an item will perform a **required function** **without failure** under **stated conditions** for a **stated period** of time.

[Practical Reliability Engineering, P. O'Connor (Wiley & Sons 2007)]

Space environment

Lifetime of the mission

A scientific Space Mission is

- **Scientific goals**
- A spacecraft with scientific instruments : the **payload** (with plenty of technology such as telescope, spectrometre, Electric/magnetic field detector, star tracker,…)
- **Data** to be sent to Earth and **analyzed** by scientific community

To achieve the goals of the mission every (sub/)system of the mission has to be reliable

Reliable for space = Space qualified

Space qualification

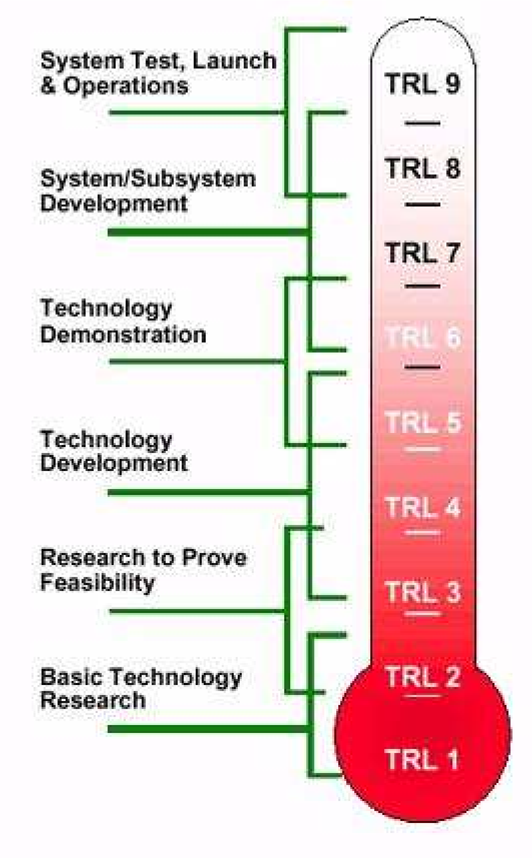
- **Processes defined by Space Agencies (NASA, ESA, CNES,…)**
- **Set of specific experiments on system and sub systems**
- **Test readiness Level (TRL) – Level of maturity for space**

  Scale from 1→9 (8= ready to flight)

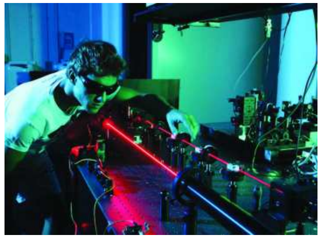
→ Driven by space environment

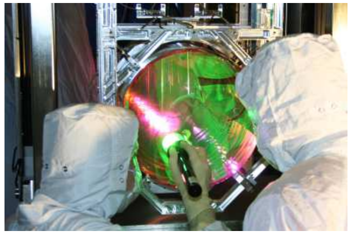
TRL

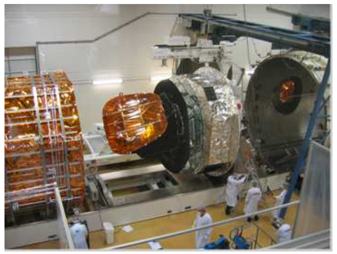
- **TRL = Technology Readiness Level**



TRL	Level Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard functional verification in laboratory environment
5	Component and/or breadboard critical function verification in relevant environment
6	Model demonstrating the critical functions of the element in a relevant environment
7	Model demonstrating the element performance for the operational environment
8	Actual system completed and accepted for flight ("flight qualified")
9	Actual system "flight proven" through successful mission operations

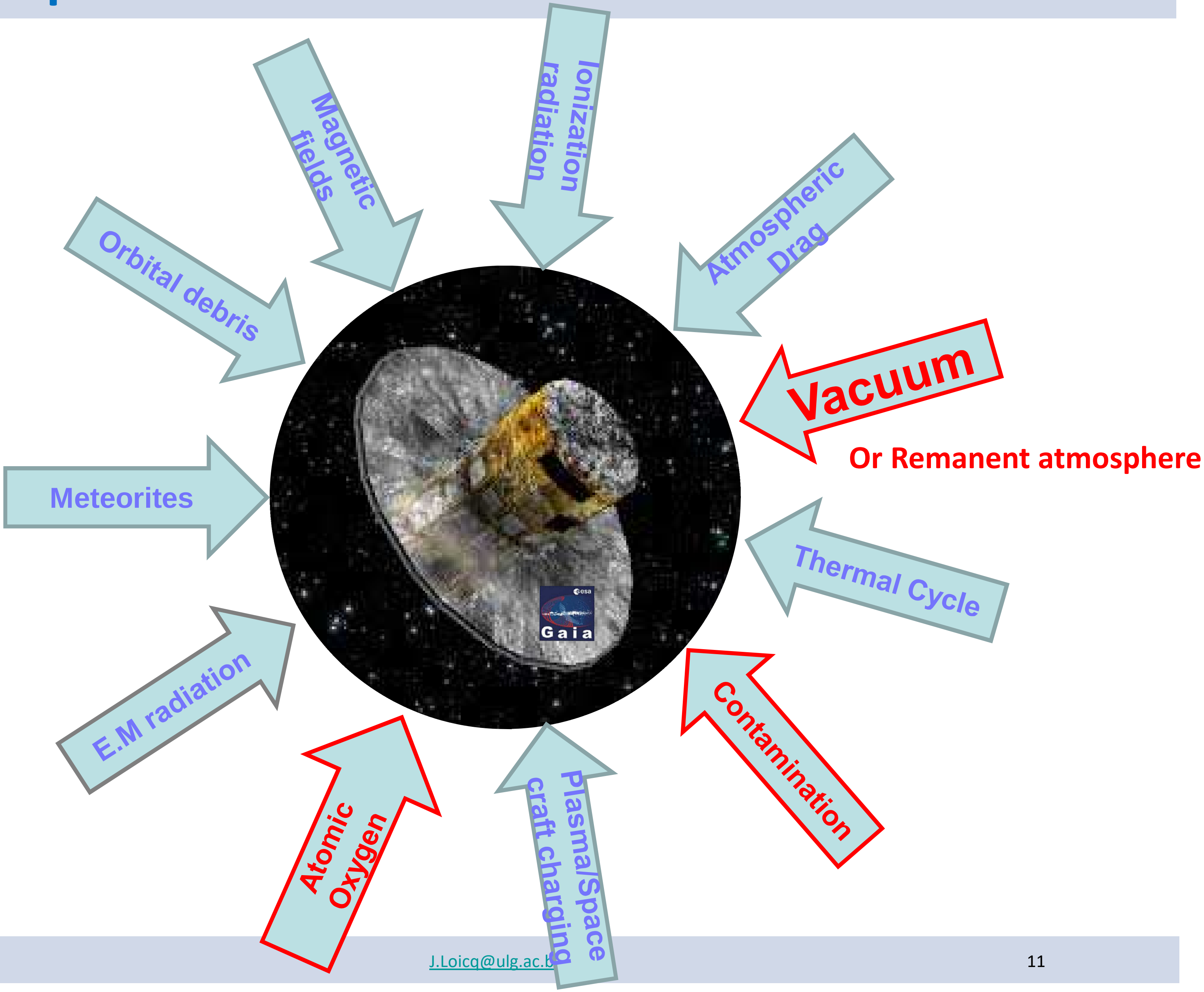




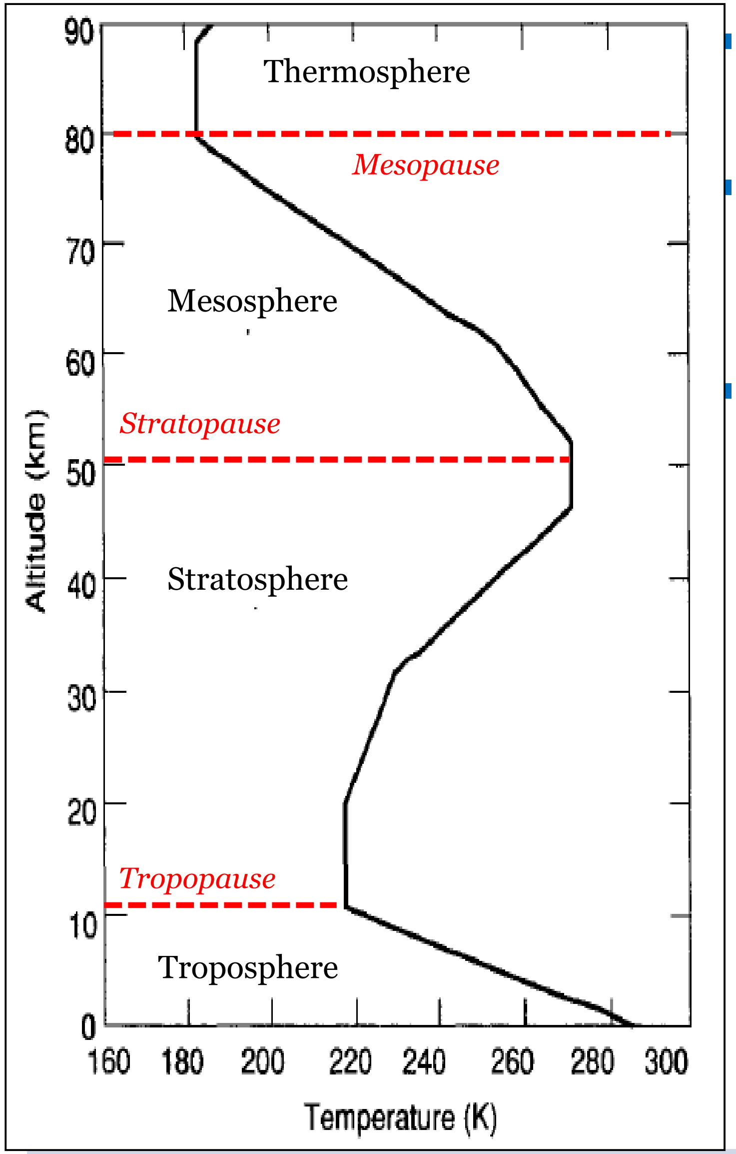


TRL	Definition	Explanation
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development.
2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented and R&D started. Applications are speculative and may be unproven.
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Active research and development is initiated, including analytical / laboratory studies to validate predictions regarding the technology.
4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together.
5	Component and/or breadboard validation in relevant environment	The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)	A representative model or prototype system is tested in a relevant environment.
7	System prototype demonstration in a space environment	A prototype system that is near, or at, the planned operational system.
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)	In an actual system, the technology has been proven to work in its final form and under expected conditions.
9	Actual system "flight proven" through successful mission operations	The system incorporating the new technology in its final form has been used under actual mission conditions.

Space environment effects – Overview



Atmosphere - Overview



Structure of the atmosphere

- dominated by Earth's gravity and Solar activity

Temperature

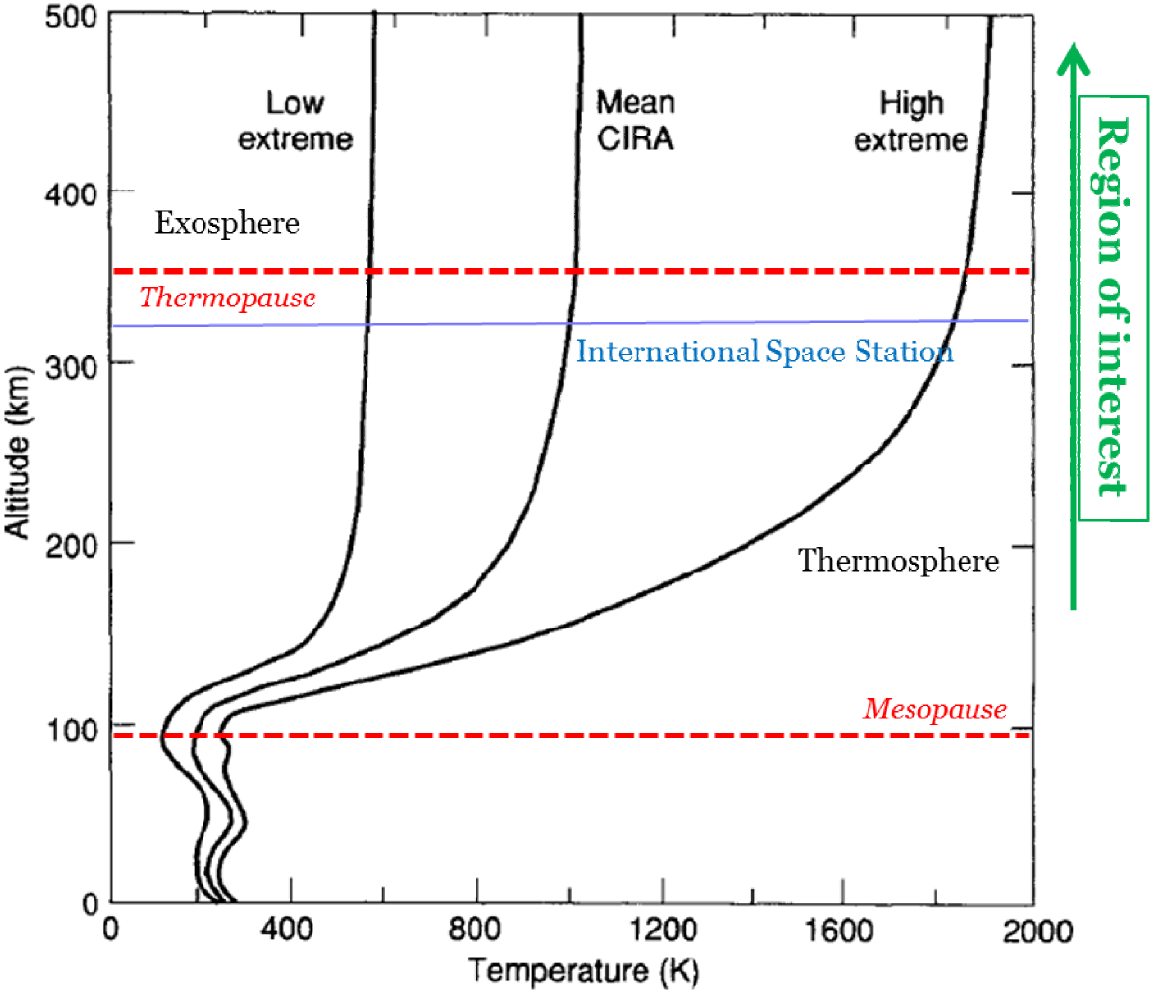
- not continuously decreasing with altitude → complex temperature profile

Atmosphere layers:

- Troposphere:
  - heated by Earth surface
  - Terrestrial weather occurs
- Stratosphere
  - Heated by EUV radiation → Ozone layer
  - Temperature rises
- Mesosphere
  - Large temperature variability during day and night
  - High CO_2 concentration → (Infrared radiator)

Atmosphere - Overview

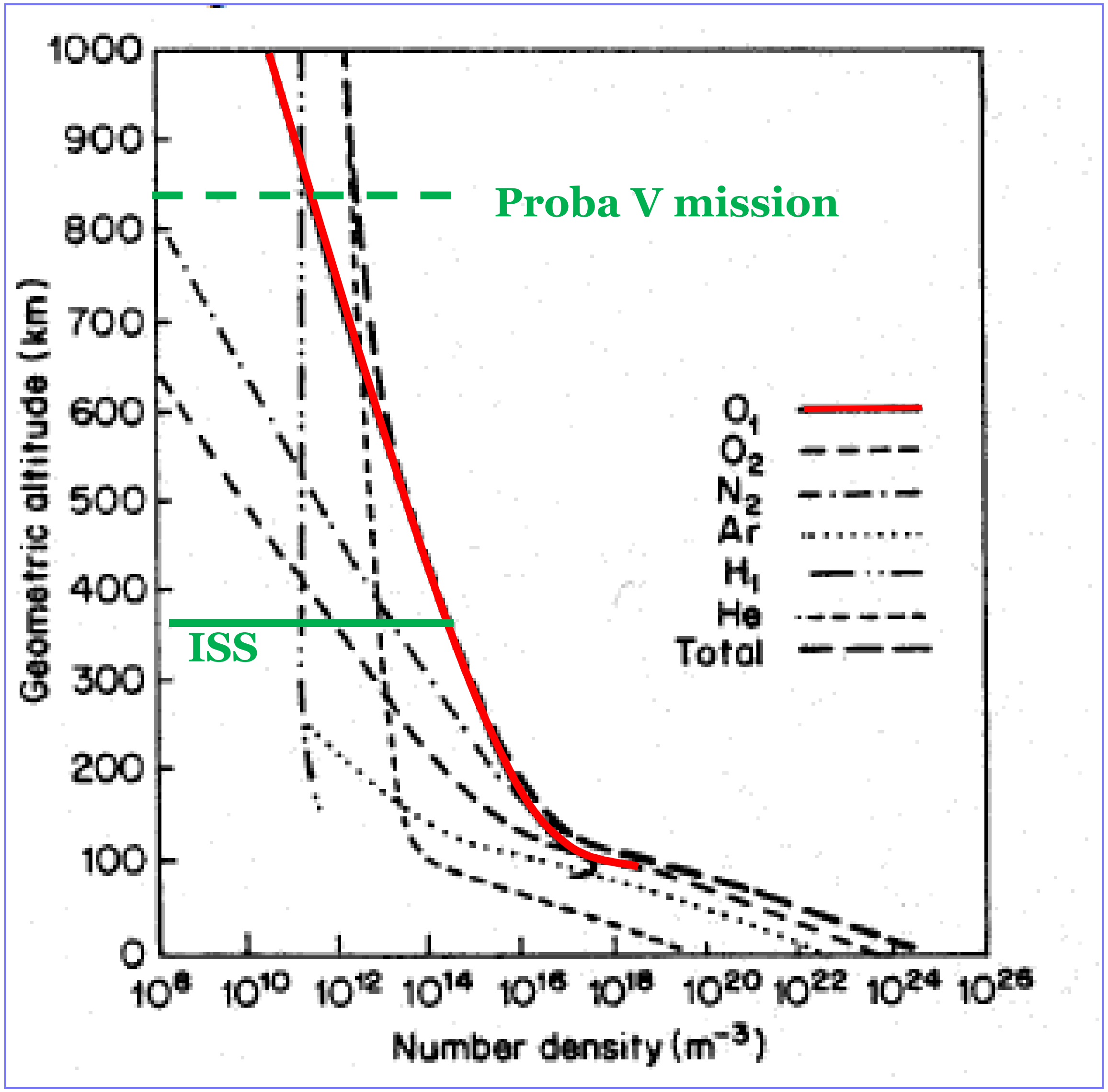
- **Thermosphere**
  - Heat dominated by EUV absorption .
  - T° dominated by solar activity.
  - Non homogeneous composition of the atmosphere.
  - Low concentration of triatomic molecule such as CO2 and H2O.
- **Exosphere**
  - Last remnant of the atmosphere.
  - Particle mean free path large --> Ballistic motion (>< Brownian motion).
  - T° dominated by solar activity.
  - T° cst with altitude



[Handbook of Geophysics and the space environment, 1985]

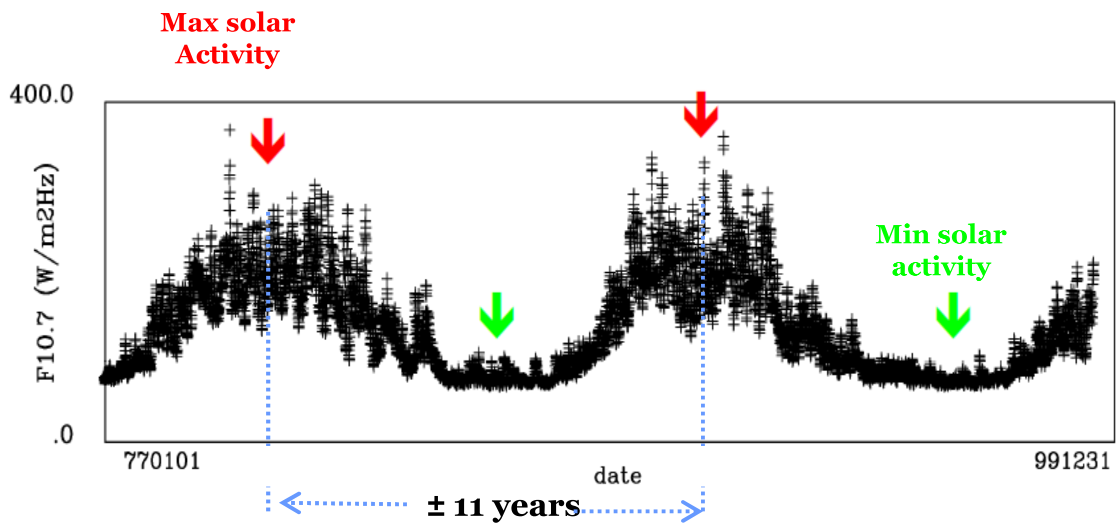
Atmosphere – Overview

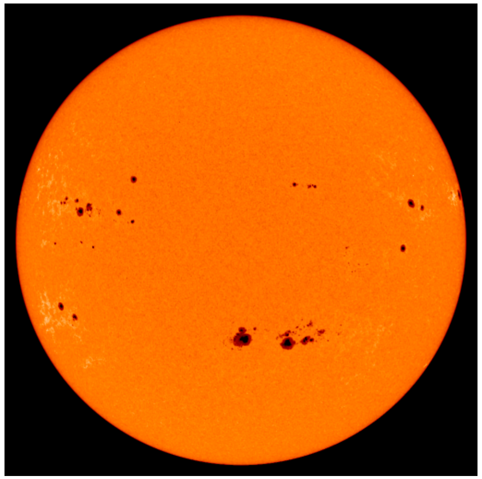
- **Compounds concentration decreases exponentially with altitude**
- $\rho(z) = \rho(z_o) exp\left[\frac{z_o - z}{H}\right]$
  - With ρ the mass density
  - z_o a reference altitude
  - $H = \frac{RT}{M_i g}$ (with R the natural gas constant, T, the temperature, M_i Molar mass, g gravitational acceleration)
  - H is called density scale height
- **Atomic oxygen (ATOX)**
  - Photo-dissociation of O2
  - Very corrosive with plastic/silicone,…
  - Need protection as gold, platinium, SiO2,…
  - Occurs in Low Earth Orbit



Atmosphere – Overview

- **The Earth's atmosphere (thermosphere and exosphere) responds mainly to 2 types of Solar Energy**
  - UV radiation ($\boldsymbol{F}_{\{10.7\}}$ index)
  - Highly energetic particles (Ap index)

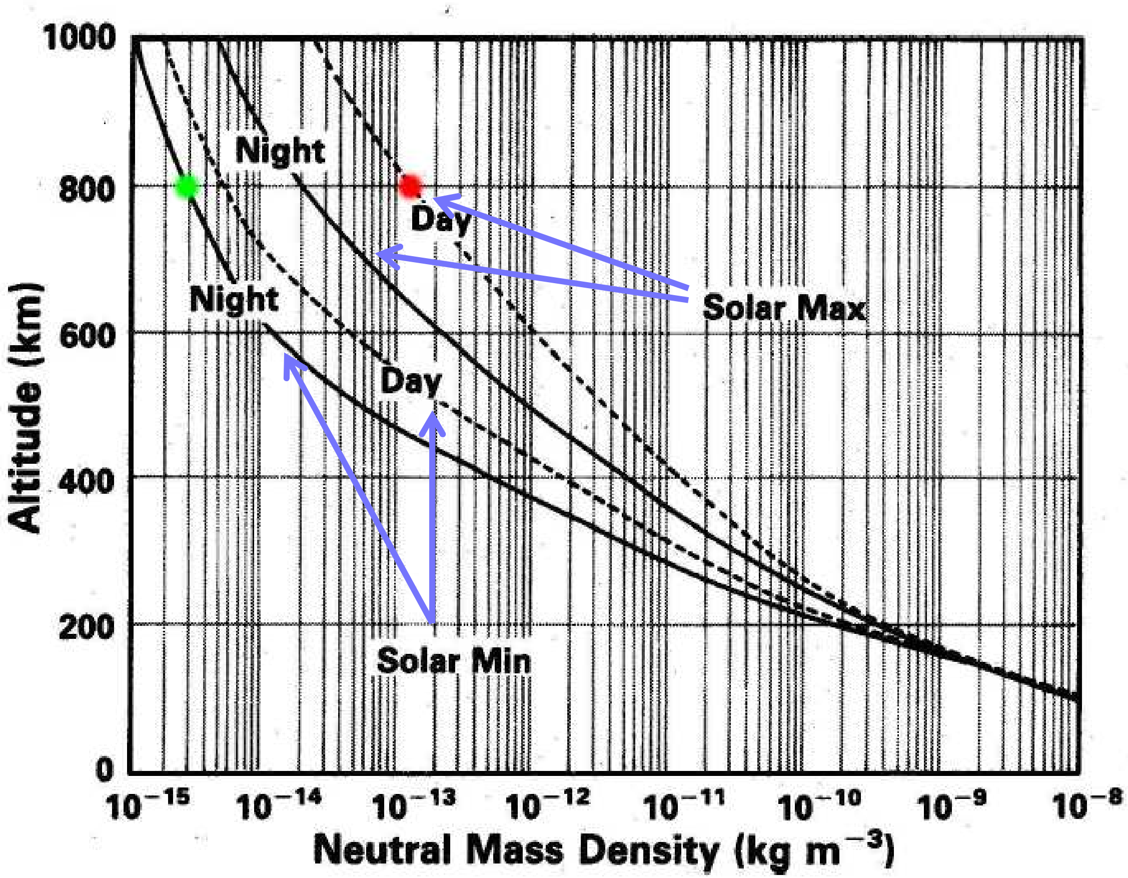




Atmosphere : Overview

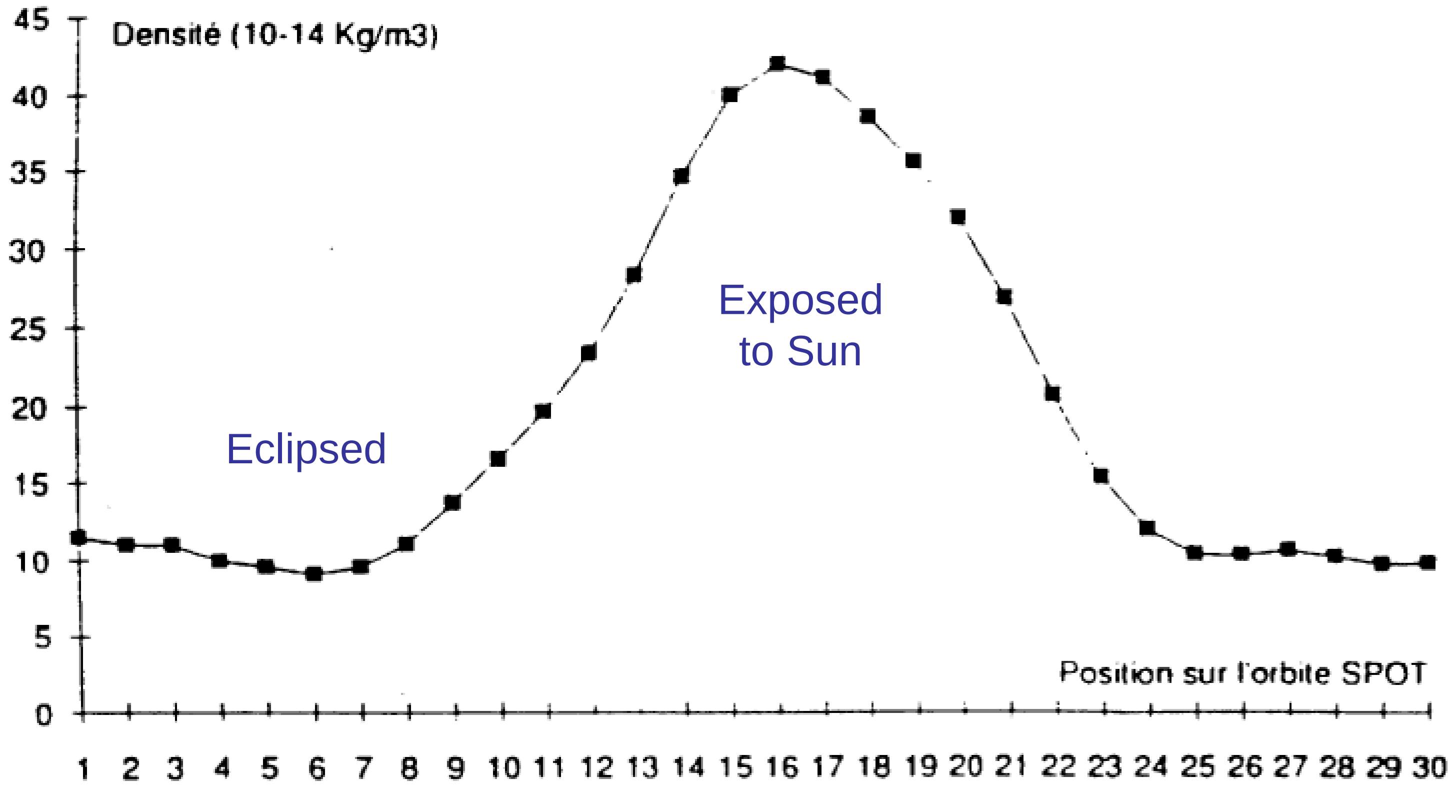
- **Density of the atmosphere depends on**
  - Altitude
  - Solar activity
  - Local time (night & day)

- **Density variability**
  - Influence on the Orbit deceleration
  - Concentration of atmospheric components vary with time (especially Atomic Oxygen)



[Wertz &Larson 1991]

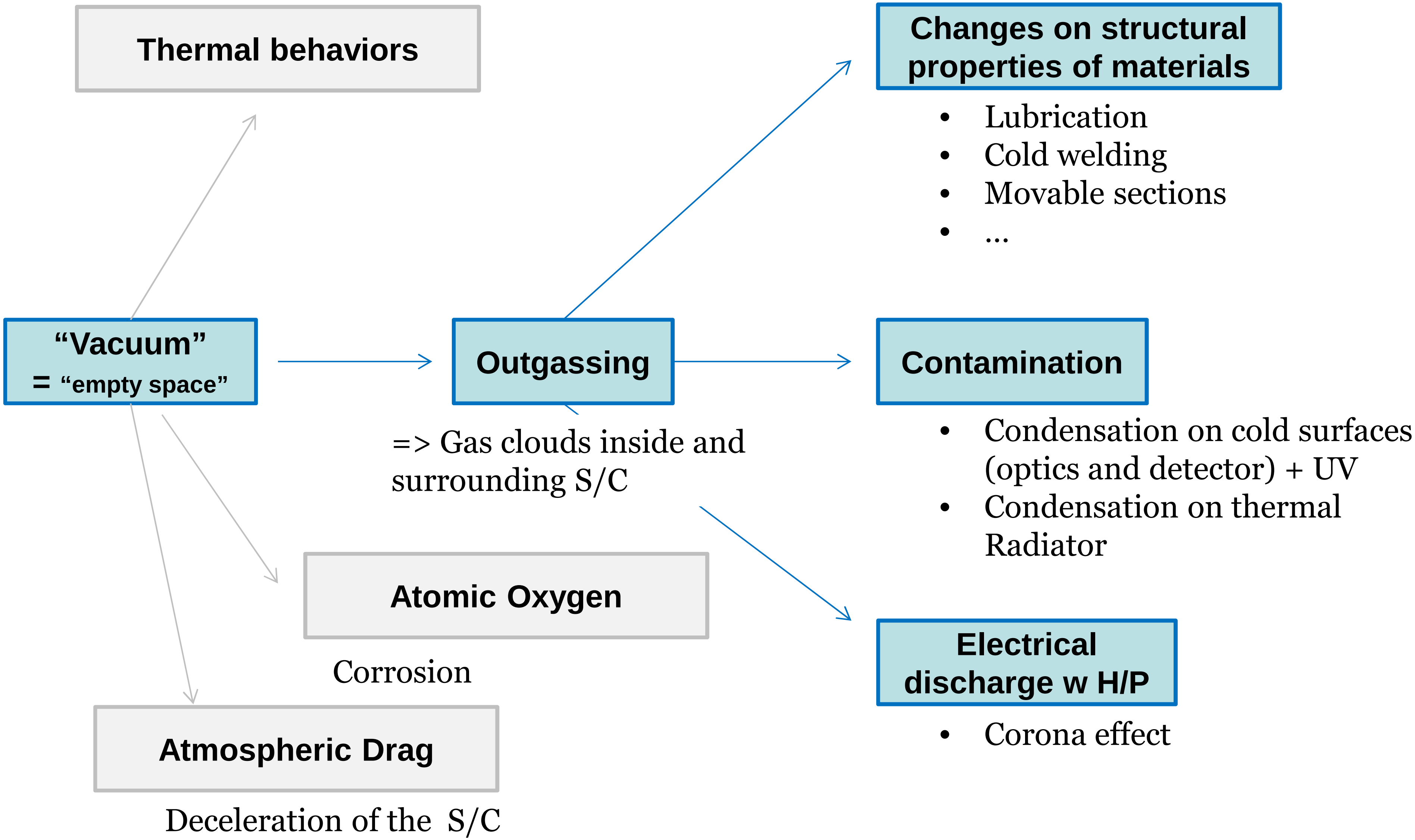
- **Mean density of the atmopshere on Spot orbit (822 km)**



	Altitude (km)	# particles [/m³]	Pressure [N/m2]
Earth ground	0	10^{25}	10^{5} (=10^{3} mbar)
LEO orbit*	300	10^{15}	10^{-5} (=10^{-7} mbar)
GEO orbit**	35800	10^{10}	10^{-10}(=10^{-12} mbar)

* LEO: Low Earth orbit
**GEO: Geostationary Earth Orbit

Effects of Vacuum on a Spacecraft (S/C)

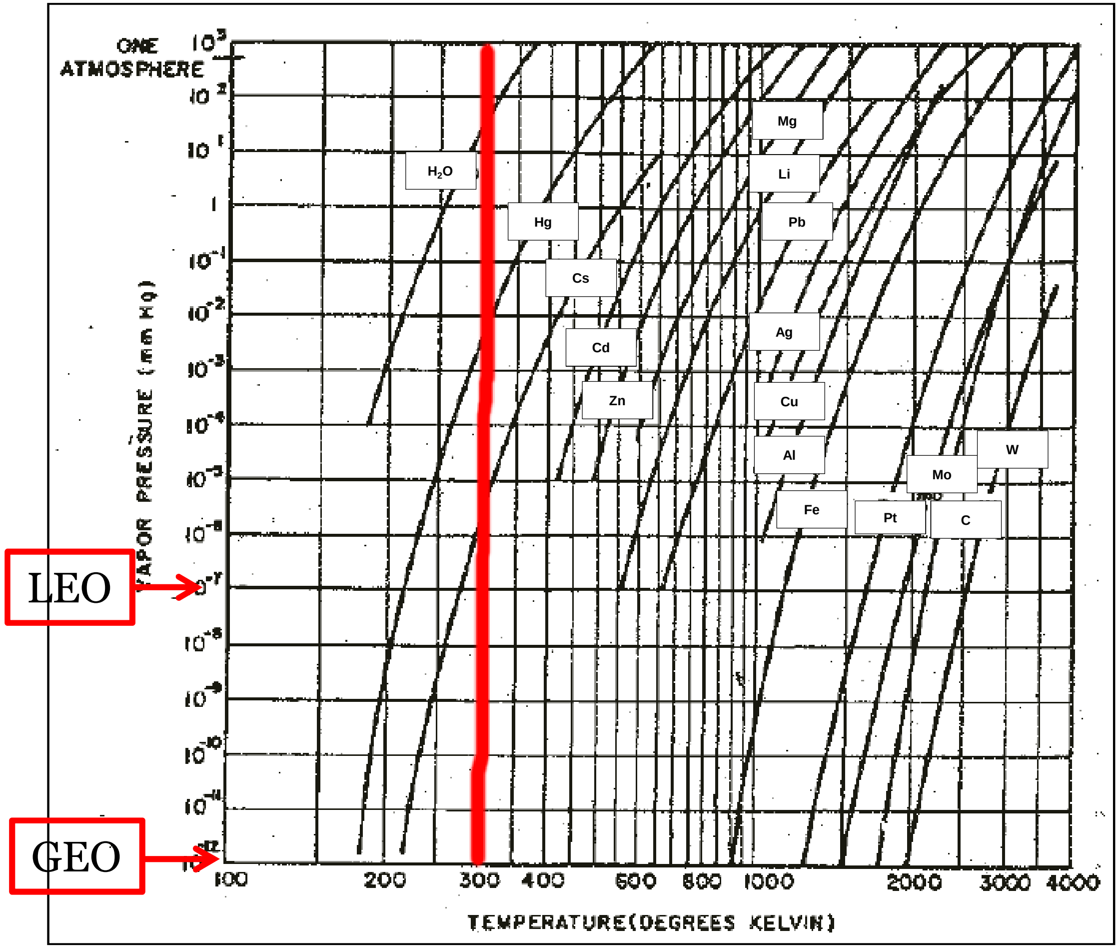


- **Vapor pressure in function of temperature for various material**
- **Gaseous phase**

  - Low ambient pressure → volatile material outgassing

  - Condensable fraction of material can be deposited on optics and cold surfaces (reducing optical transmittances)

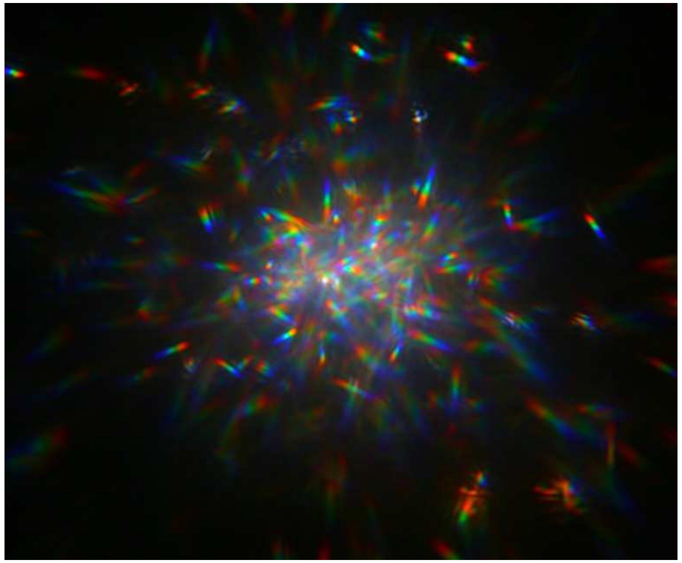
  - Loss of water vapor or waxes can decrease structural performances of material

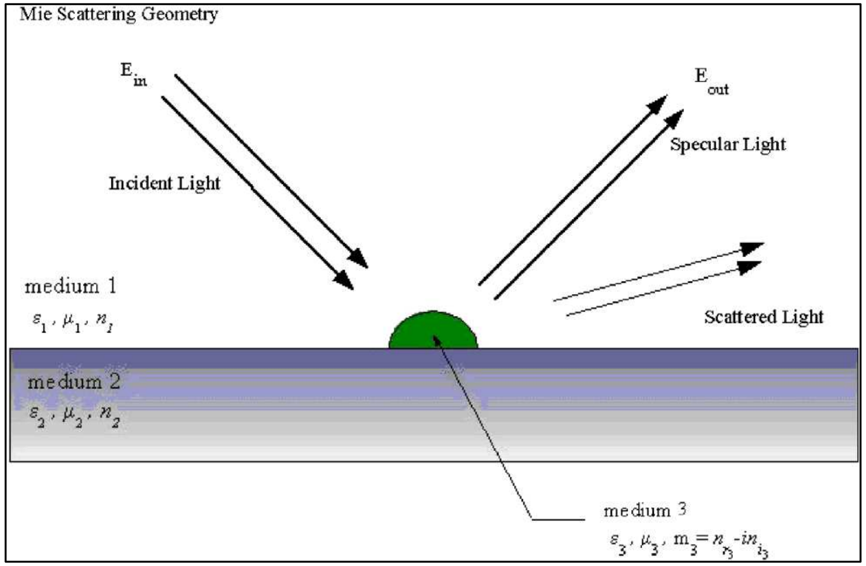


[Van der Laan, 1986]

Contamination

- **Definition**
  - = ***Induced*** molecular and particulate environment in the vicinity of and created by the presence of a spacecraft in space.
  - Type of contamination
    - **Molecular**
    - **Particulate**





Contamination: molecular

- **Primary sources:**
  - **Outgassing of organic materials**
    - = surface evaporation combined with a diffusion for bulk contaminant species.
    - These species can be either **initially present components** (water, solvents, additives, uncured monomeric material, lubricants, ground contamination species…), or **decomposition products** (due to exposure to thermal environment, solar radiation, atomic oxygen, charged particles, µ-meteroids/debris, charging,…).
  - **Plumes** resulting from
    - combustion, unburned propellant vapours, incomplete combustion products, sputtered material
    - It’s surroundings the S/C
    - leaks in systems or internal payloads… Return flux or back flow is possible due to ambient scattering, self scattering or diffusion processes.
  - **Pyrotechnics and release mechanisms**
- **Secondary sources :**
  - A surface can act as a **secondary source** if an incoming contaminant molecule reflects (not accommodate, stick or condense on the surface) or if it has a limited **residence time** on that surface. Secondary sources can for example be solar panels having a higher temperature than the surrounding surfaces.

Contamination: Particulate

- **Sources inherent to materials :**
  - Particles originating from **manufacturing** (machining, sawing), handling (e.g. for fragile materials such as certain paints)
  - Degradation of **chemical bonds** under different environments (e.g. AO, UV).
  - **Crack formation** and subsequent flaking as a result of thermal cycling.
  - Formation of particles due to **oxidation in an atomic oxygen** environment.

- **Sources external to materials :**
  - **Dust particles** can be caused by atmospheric fall-out (dust) during assembly, integration and storage or by human sources during such activities (e.g. hair, skin flakes, fibres from garments).
  - Particles can be produced during **spacecraft propulsion** or attitude control operations, the functioning of **moving parts** (such as shutters), and water dumps.
  - Particles can result from **micrometeoroid** or debris impacts on materials.

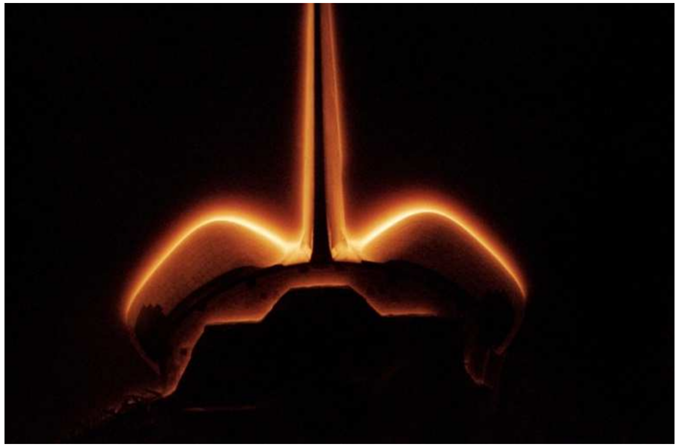
Contamination effect

- **Degradation of spacecraft performances due to the presence of:**
  - **Deposited species** onto a critical surface:
    - (thermo-)optical properties, such as transmission, reflection, absorption, scattering;
    - tribological properties, outgassing of lubricant, friction due to particles;
    - electrical properties, such as surface conductivity, secondary emission and photo-emission.
  - **Glow** or other surface/gas reactions.
  - **Free flying species** in the field of view of sensors:
    - light scattering (star trackers);
    - light absorption;
    - background increase (natural environment analysis).
- **The effect of a contamination can be altered by the exposure to other environmental parameters,**
  - UV can increase the absorption due to photo-degradation (darkening) of the deposited contaminant,
  - atomic oxygen can have a cleaning-up effect on hydrocarbon material, but can also form non-volatile SiOx that can further trap other contaminants.

Glow

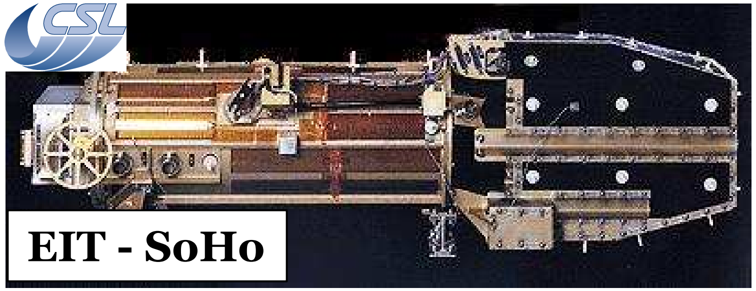
- **GLOW around exposed surfaces of the space shuttle facing the direction of orbital motion.**
  - This 'shuttle glow' extends about 10cm from the surfaces, is peaked in wavelength at 680 nm, and within a resolution of about 3.5 nm forms a continuum.
  - Similar anomalies were reported in rocket experiments as long ago as 1958.
  - Apart from its interest as an unusual physical phenomenon, shuttle glow may be a source of interference in space-based spectroscopy; anomalous airglow observations made by the Atmospheric Explorer spacecraft have been attributed to it.

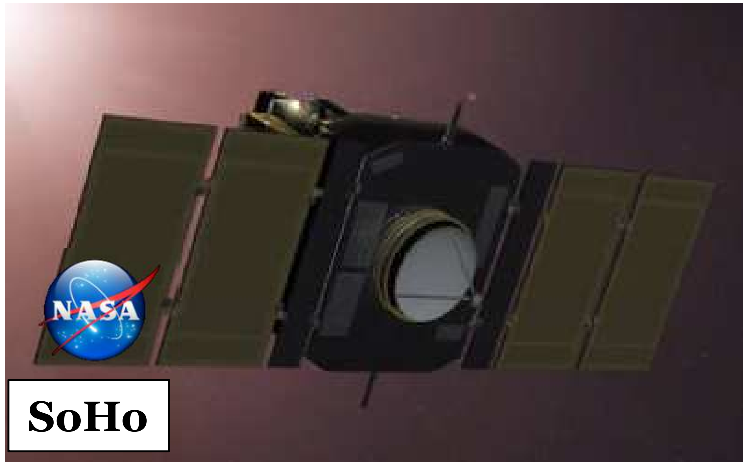
Glow



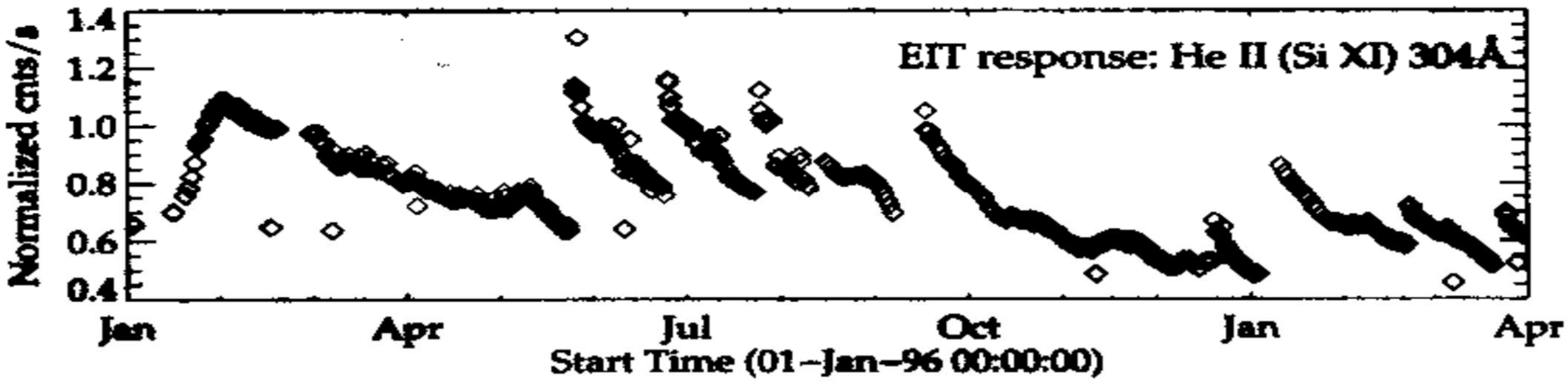
- **The most likely explanation seems to be**
  - the recombination of fast oxygen atoms in the upper atmosphere with NO adsorbed on the shuttle's surface.
  - This forms excited NO_2, which radiates light as it desorbs.
- **On a shuttle mission (STS-39)**
  - four gases, NO, CO_2, Xe and Ne were released for a plasma experiment.
  - Unintentionally, enough gas was scattered onto the surfaces of the shuttle tail that when NO was released a much more intense version of shuttle glow was observed.
  - The other gases did not affect the normal shuttle glow.

Effects of Vacuum on a Spacecraft





- **EIT (Extreme UV imager Telescope)**
  - Observation of reduced performances after a while
  - Deposition of contaminant on detector (supposed water)
  - Heating the detector surface → vaporized the containment
- **If contaminant is polymers/organic**
  - Can be permanently set on surface by UV → darkening (loss of optical transmission)

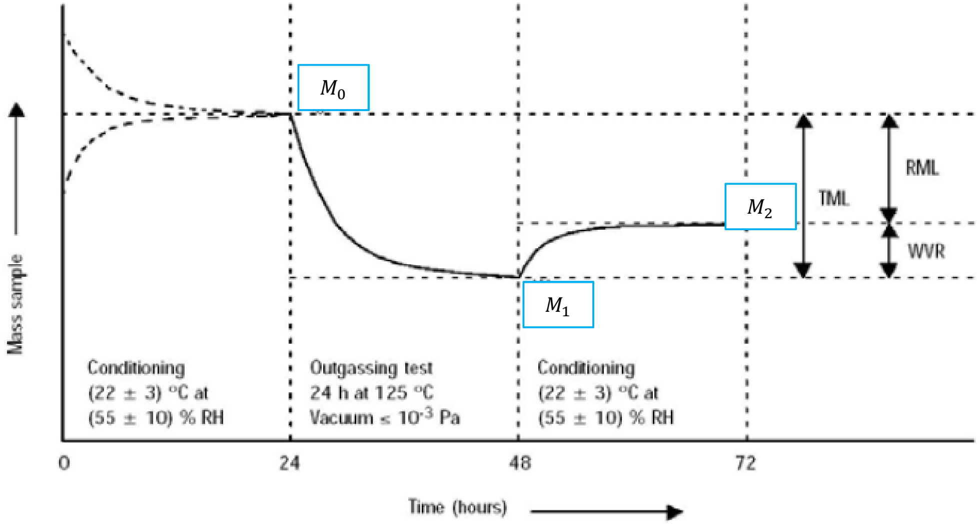


Space design guidelines: outgassing

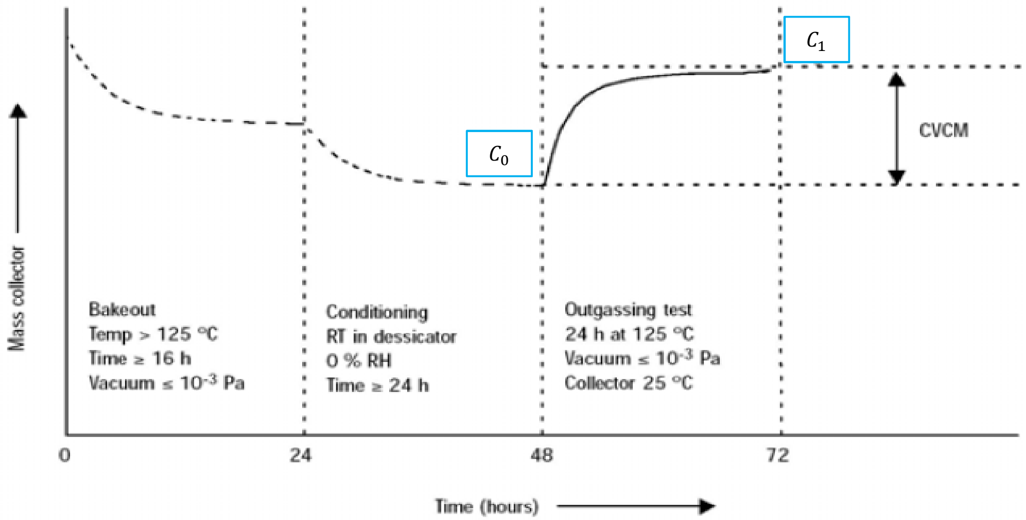
- **Material selection:**
  - Drastic rules driven by space agencies (Standard ESA: ECSS)
  - Outgassing test for new materials
- **Venting holes:**
  - the outgassing products are guided through venting holes.
- **Bake out prior launch:**
  - The outgassing is decreased by performing a prior bake out
  - and by flushing with dry nitrogen during storage & launch.
- **Cold traps & Chemical getters :**
  - collect contaminants
  - trap particular molecules, especially water; zeolith getter
- **Heaters:**
  - if contamination is not fixed to the surface (by UV), active heating may decontaminate

Vacuum material selection

- **Specific experiment on material**
  - "Micro-VCM" (micro vacuum condensable molecule deposition)
  - Place the sample to be analyzed on vacuum à 125°C during 24h
  - Hoven has an aperture placed in front of a surface maintained à 25°C → capture of the condensable vapors.
- $TML = \frac{M_0 - M_1}{M_0}$ **(total mass loss)**
- $RML = \frac{M_0 - M_2}{M_0}$ **(Rel. mass loss)**
- $VCM = \frac{C_1 - C_0}{C_0}$ **(volatile condensable materials)**
- **WVR Water vapour regained**
- **Criterions**
  - $TML < 1\%$
  - VCM <0.1%

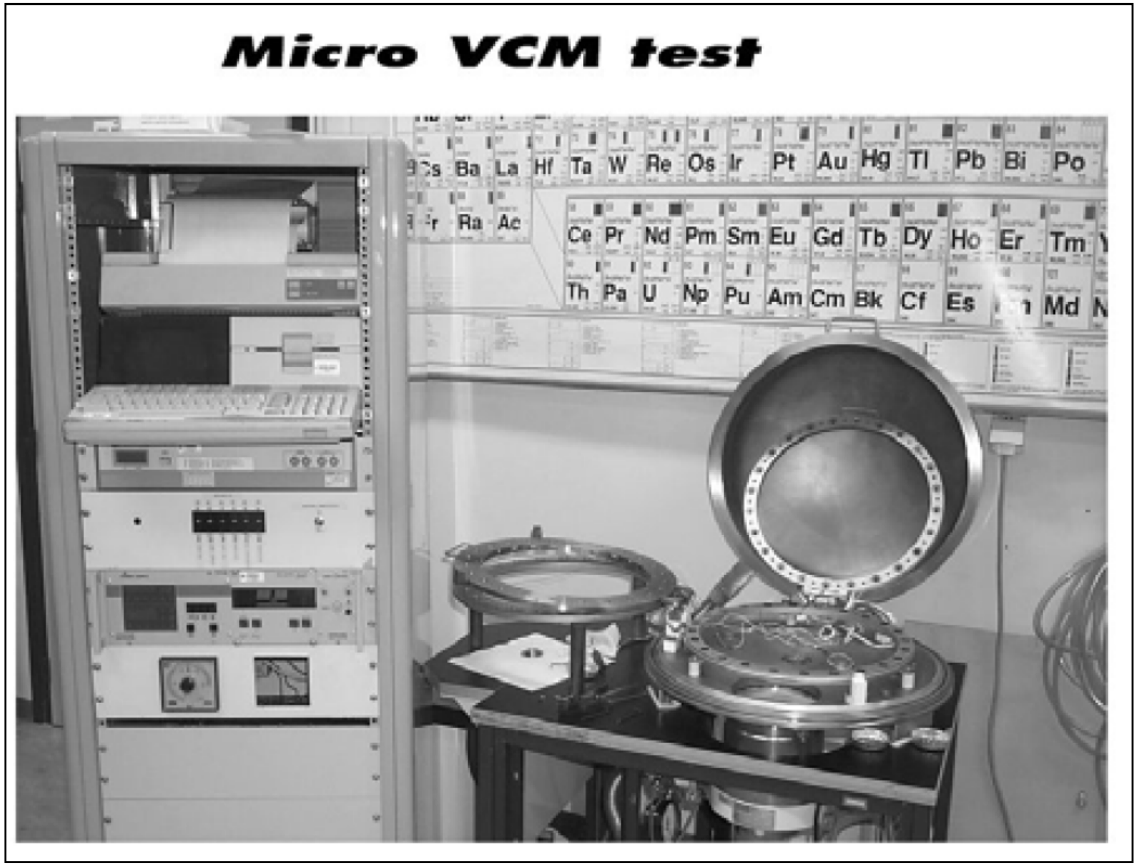


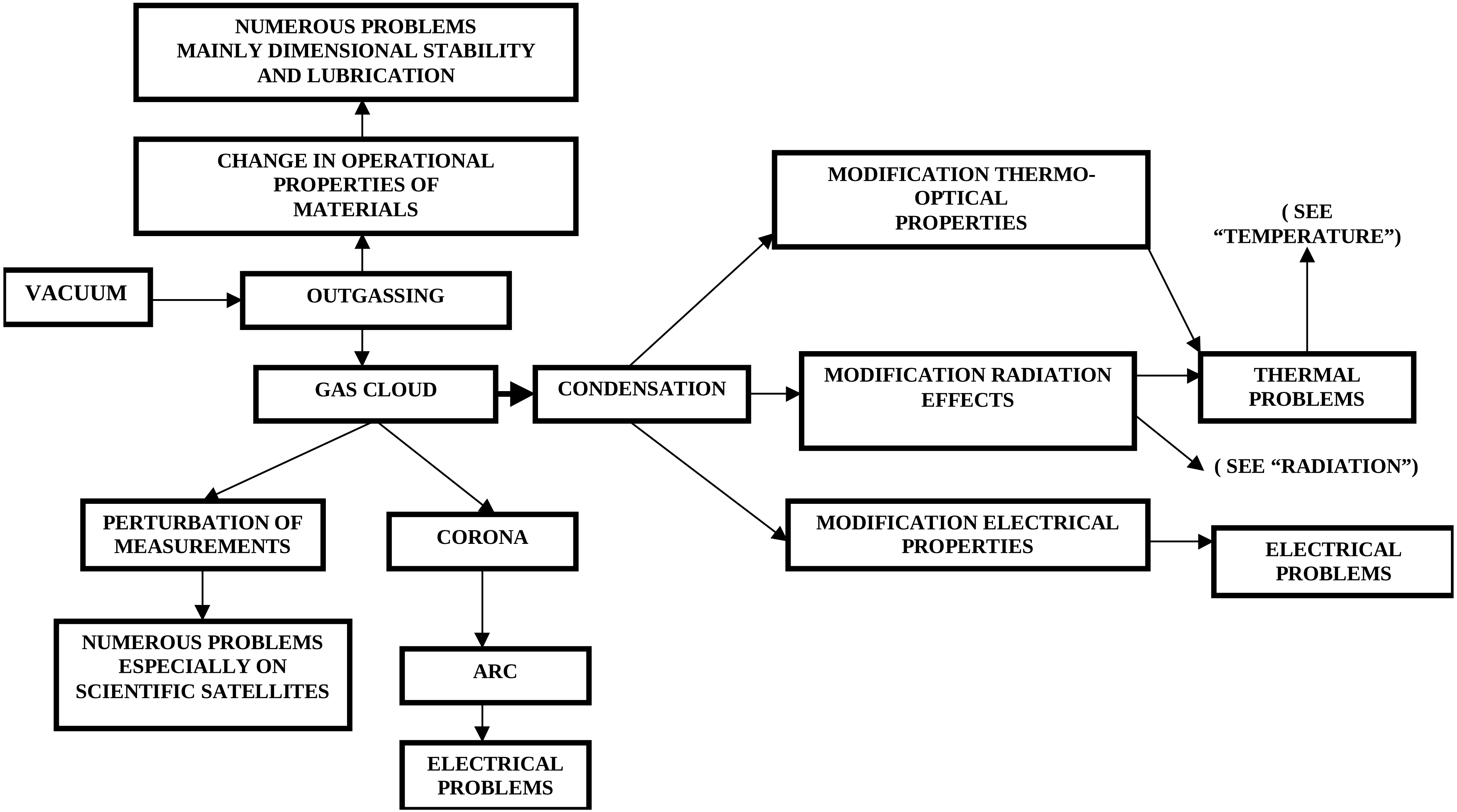
Parameters for sample

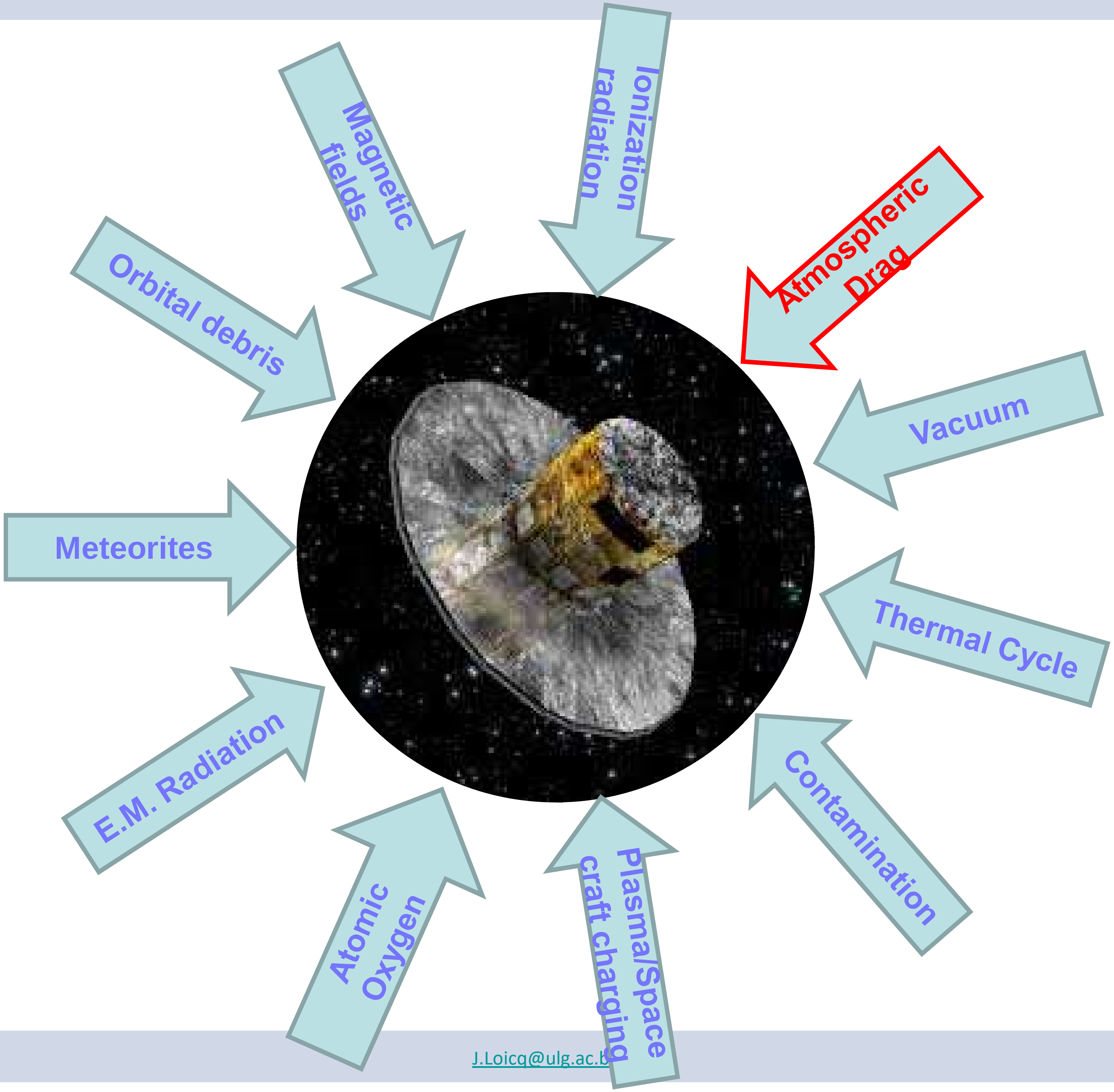


Parameters for collector plate

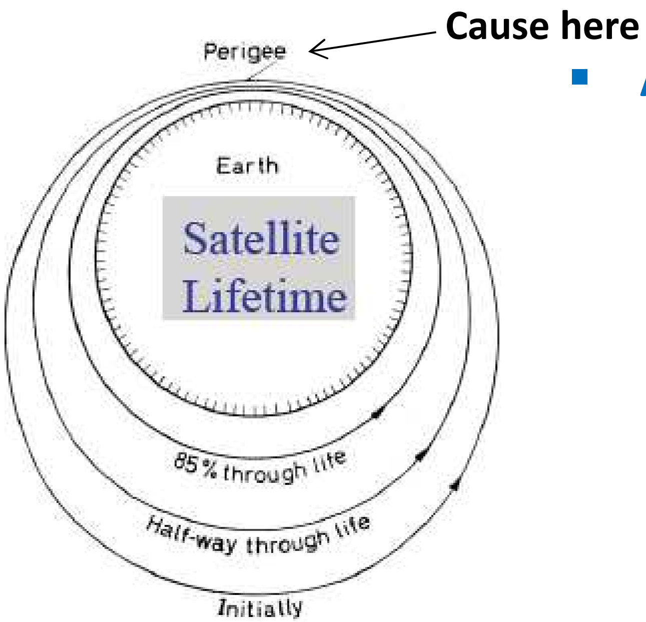
- **Order of magnitude**
- **Consider 1kg of material giving 0.1% of condensable material**
- **→ 1 gr potentially being condensable on a surface**
  - Optical surfaces
  - Detector
  - Thermal radiator




NUMEROUS PROBLEMS
MAINLY DIMENSIONAL STABILITY
AND LUBRICATION
CHANGE IN OPERATIONAL
PROPERTIES OF
MATERIALS
VACUUM
OUTGASSING
GAS CLOUD
CONDENSATION
MODIFICATION THERMO-
OPTICAL
PROPERTIES
(SEE
"TEMPERATURE")
MODIFICATION RADIATION
EFFECTS
THERMAL
PROBLEMS
(SEE "RADIATION")
MODIFICATION ELECTRICAL
PROPERTIES
ELECTRICAL
PROBLEMS
PERTURBATION OF
MEASUREMENTS
CORONA
NUMEROUS PROBLEMS
ESPECIALLY ON
SCIENTIFIC SATELLITES
ARC
ELECTRICAL
PROBLEMS


Magnetic fields
Ionization radiation
Atmospheric Drag
Orbital debris
Vacuum
Meteorites
Thermal Cycle
E.M. Radiation
Contamination
Atomic Oxygen
Plasma/Space craft charging

Effect of the atmosphere on sat

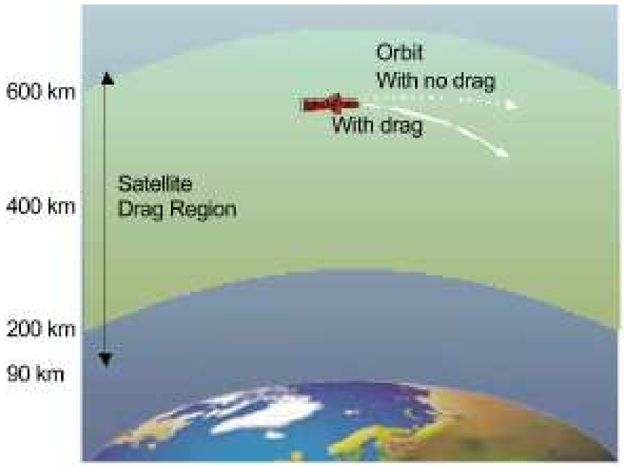


- **Atmospheric drag:**

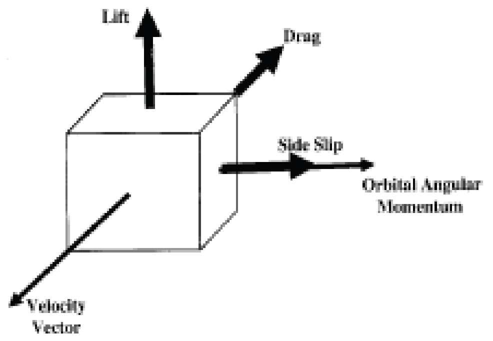
$$\mathbf{a} = \frac{\mathbf{C_D}}{\mathbf{2}}\frac{\boldsymbol{\rho}\mathbf{v}^2\mathbf{S}}{\mathbf{M_{sat}}}$$

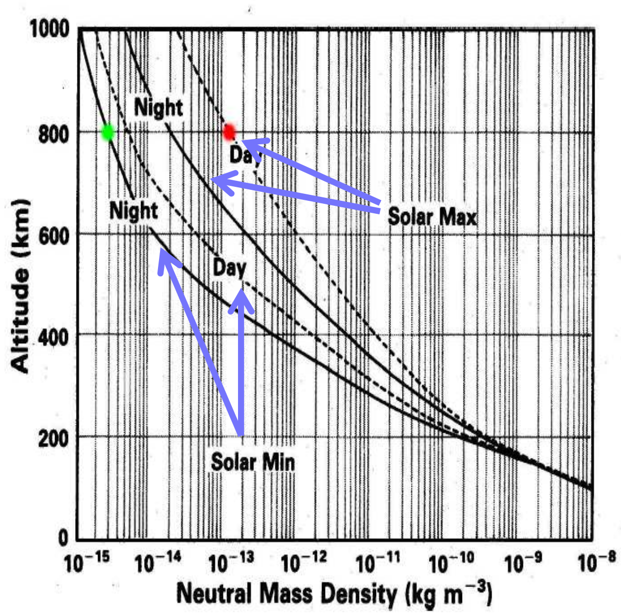
With

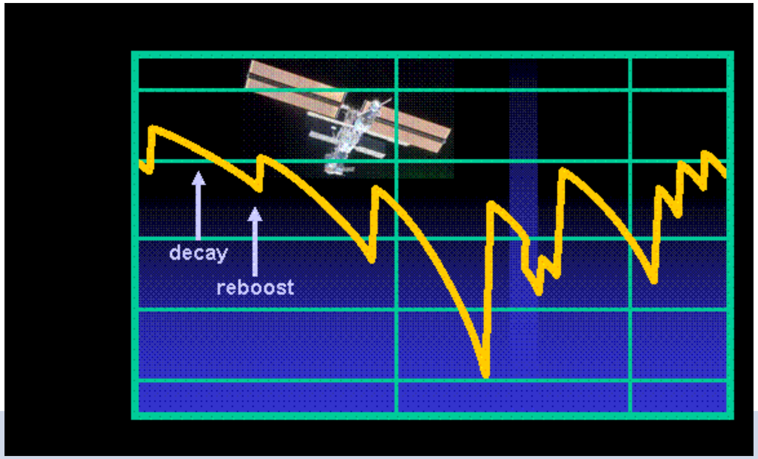
- $\mathbf{C_D}$ = Drag coefficient (≡ complex aerodynamic coef)
- $\boldsymbol{\rho}$ = Atmospheric density
- $\mathbf{v}$ = Satellite velocity w.r.t surrounding atmosphere
- $\boldsymbol{S}$ = cross section of satellite (area)
- $\frac{\boldsymbol{C_D S}}{\boldsymbol{M_{sat}}}$ = Ballistic coef.



- **The atmospheric density can vary with a factor of 100 or more**
  - Model uncertainty is around 15%-20%
  - The previous expression can also be written for lift and side force (as well as torques) BUT ➔ drag force is the largest
- **S/C drag induces lose of altitude, then speed-up and finally re-enter into the atmosphere**
- **S/C drag occurs in LEO**
- **Drag increase with solar U-V and atmospheric heating**



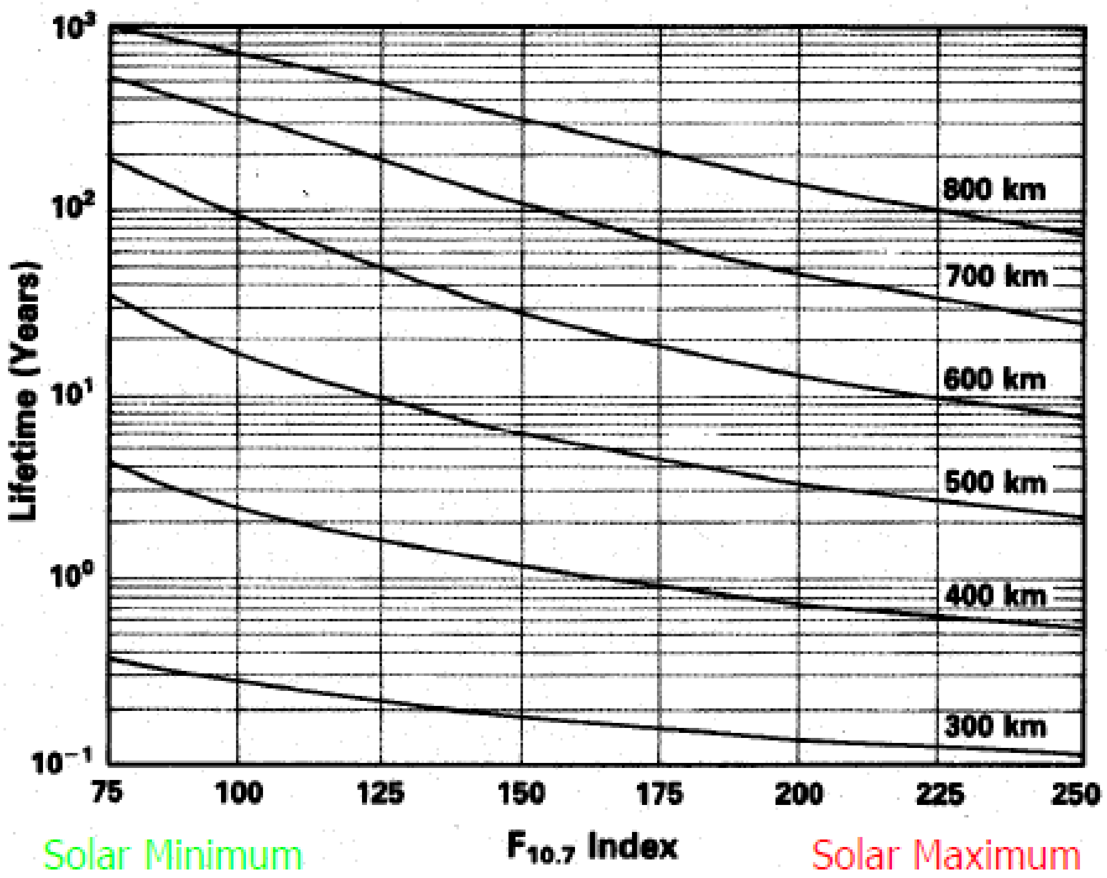


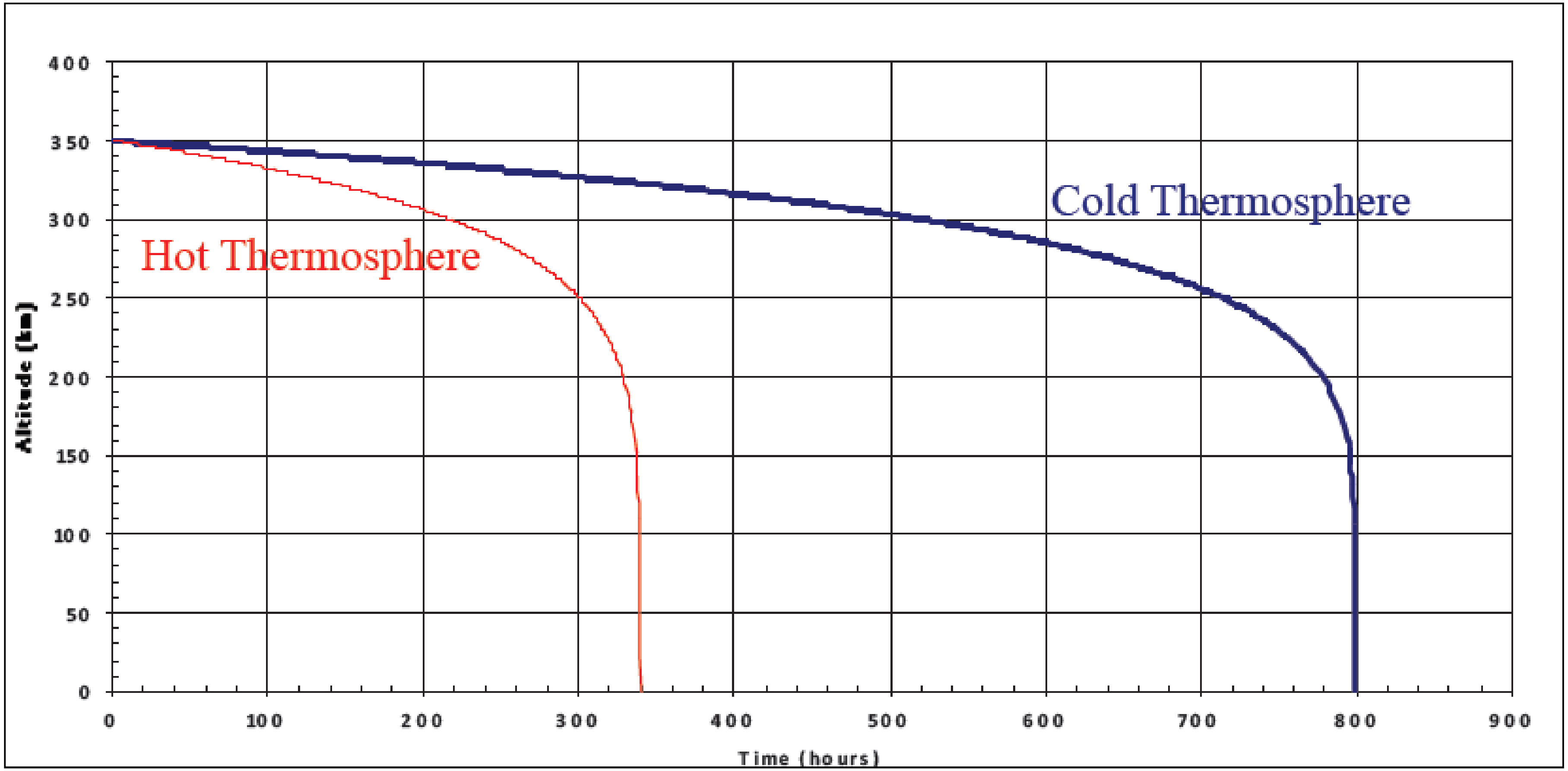


[Wertz &Larson

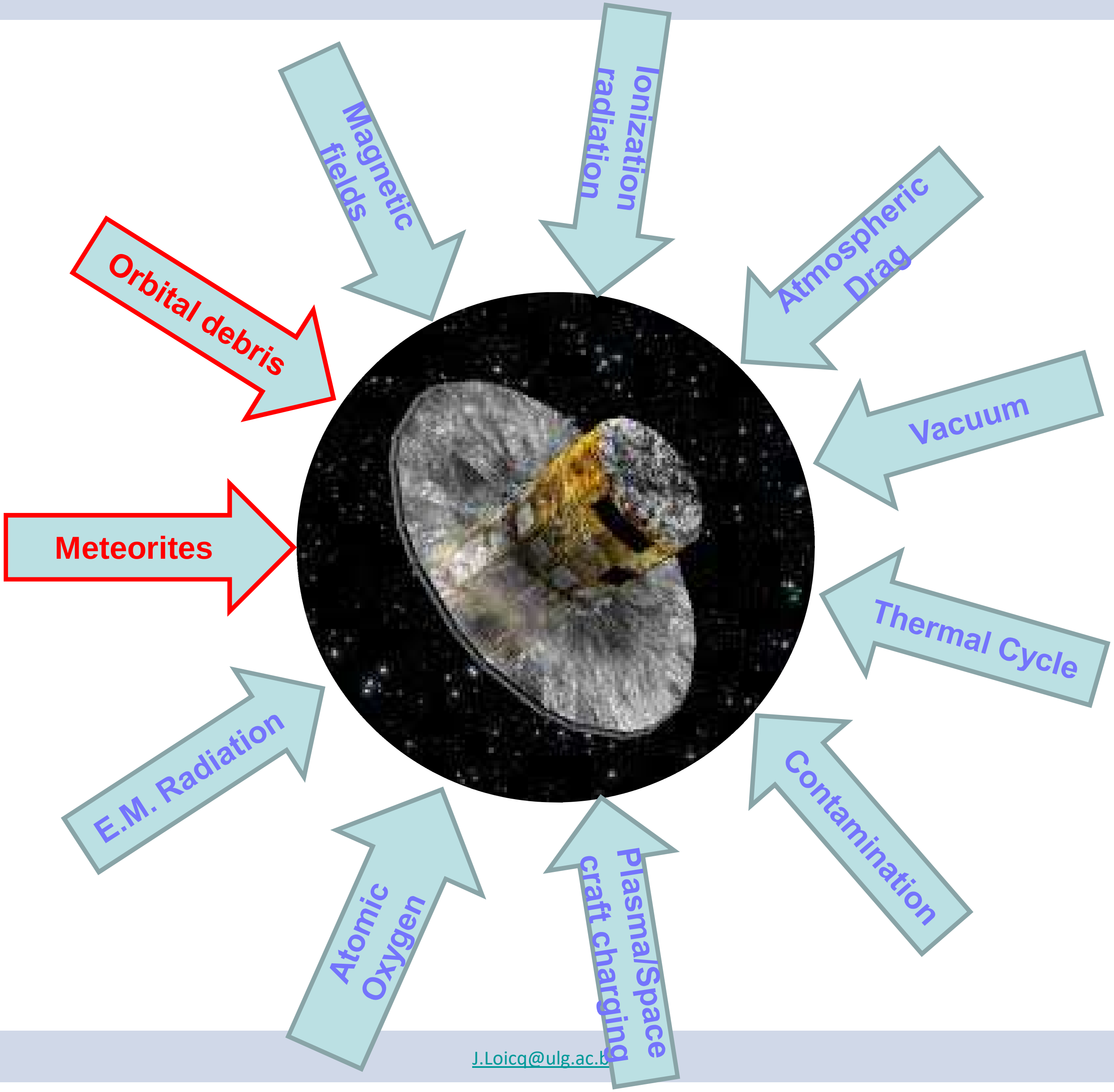
Example : MIR station

- **Lifetime Expectancy as a function of altitude and solar activity**
  - no orbital correction are made
  - Lifetime can varies by a factor of 10
  - 800km is one of the most popular altitude for earth observation
  - 300 km and below altitude give rise to a restricted lifetime around few days to weeks.



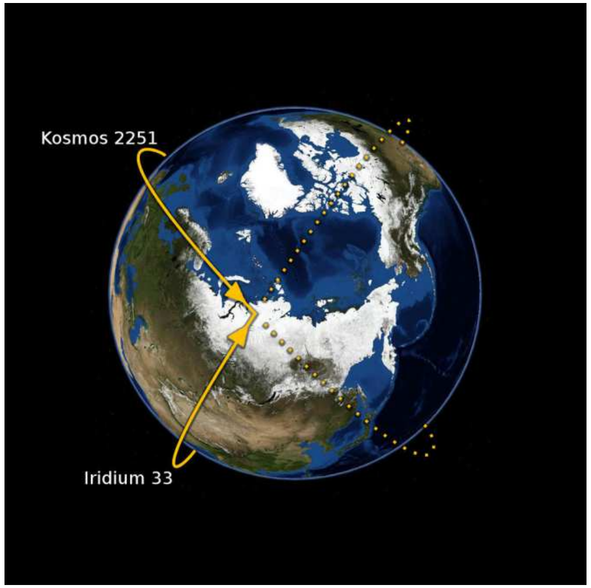


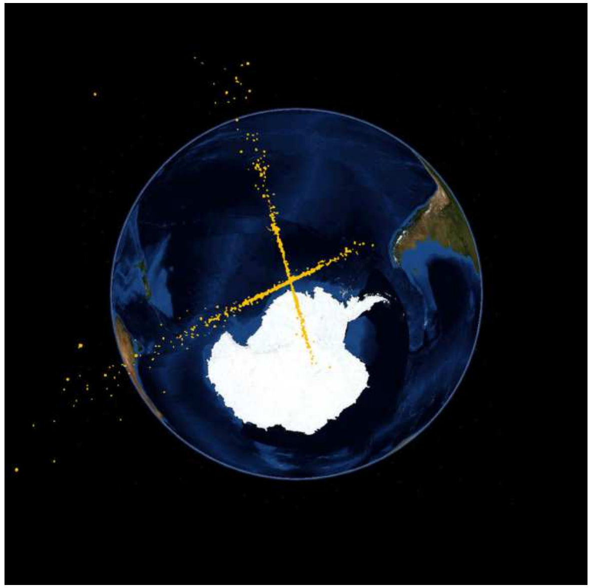
Cold Thermosphere
Hot Thermosphere
Altitude (km)
Time (hours)
0
100
200
300
400
500
600
700
800
900
50
150
250
350


Magnetic fields
Ionization radiation
Atmospheric Drag
Orbital debris
Vacuum
Meteorites
Thermal Cycle
E.M. Radiation
Contamination
Atomic Oxygen
Plasma/Space craft charging

Space debris

Iridium 33 & Kosmos 2251 collision
February 10 2009





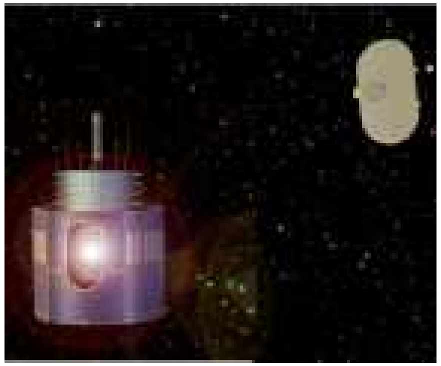
“Space debris are all non-functional man-made objects, as well as parts and fragments thereof, on Earth orbits or on atmospheric re-entry trajectories” (IADC Definition)

IADC= Inter-agency space debris coordination committee

Launches

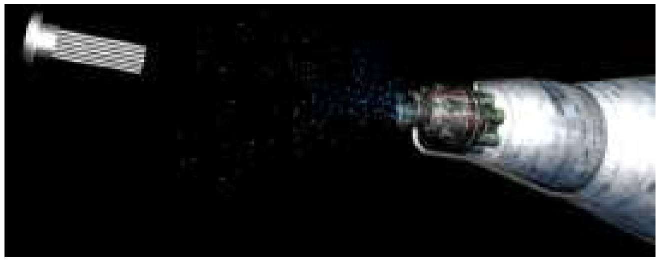
Satellites

Orbital rockets bodies
Expl: instrument doors

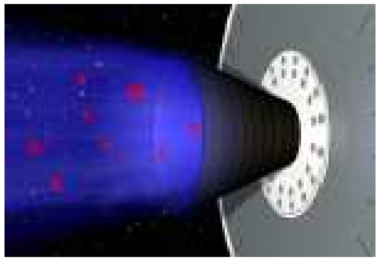


Explosion & collisions

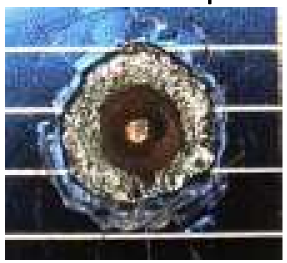
Reactor coolant



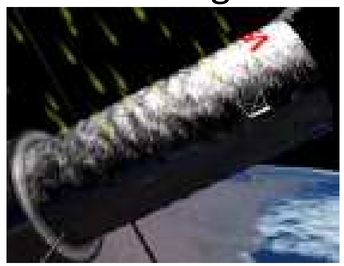
Combustion residues



Particles impacts



Surface degradation



Space debris detection and monitoring

Optical

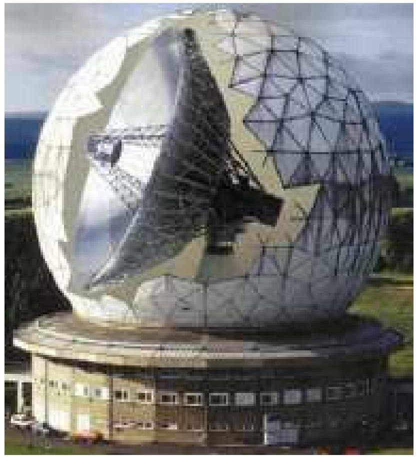
OGS (ESA)
detection limit :
≈ 15 cm at 36000 km

ESA telescope;
1 m aperture;
4k x 4k CCD;
mv ≈ 21

Radar

Cobra Dane (USA)
detection limit :
≈ 5 cm at 1000 km

US SSN network;
29 m antenna;
15 MW peak power;
1.2 GHz (L-Band)



TIRA/FHR (D)
detection limit :
≈ 2 cm at 1000 km

FHR/Fraunhofer;
34 m antenna;
1 MW peak power;
1.33 GHz (L-Band)

In-situ

HST (NASA/ESA)
max. impactor size :
≈ 1 mm at 10 km/s


© Supplied by LMK


Gravity

- **Orbit is drifting permanently**

  - Slow modification → earth reentry after a while

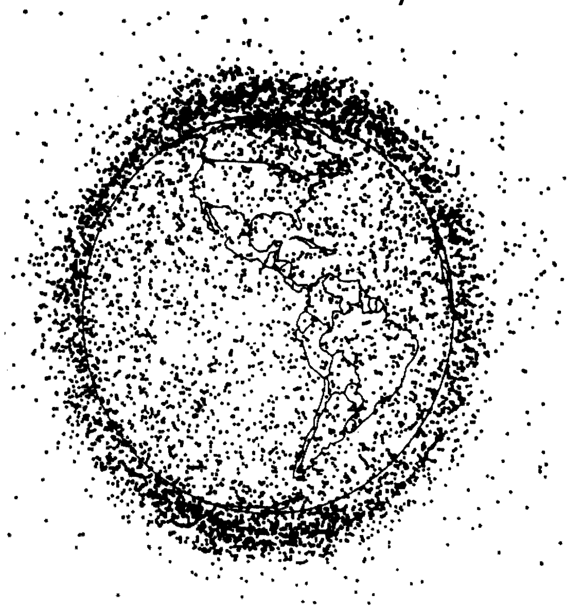
  - Depending the orbit

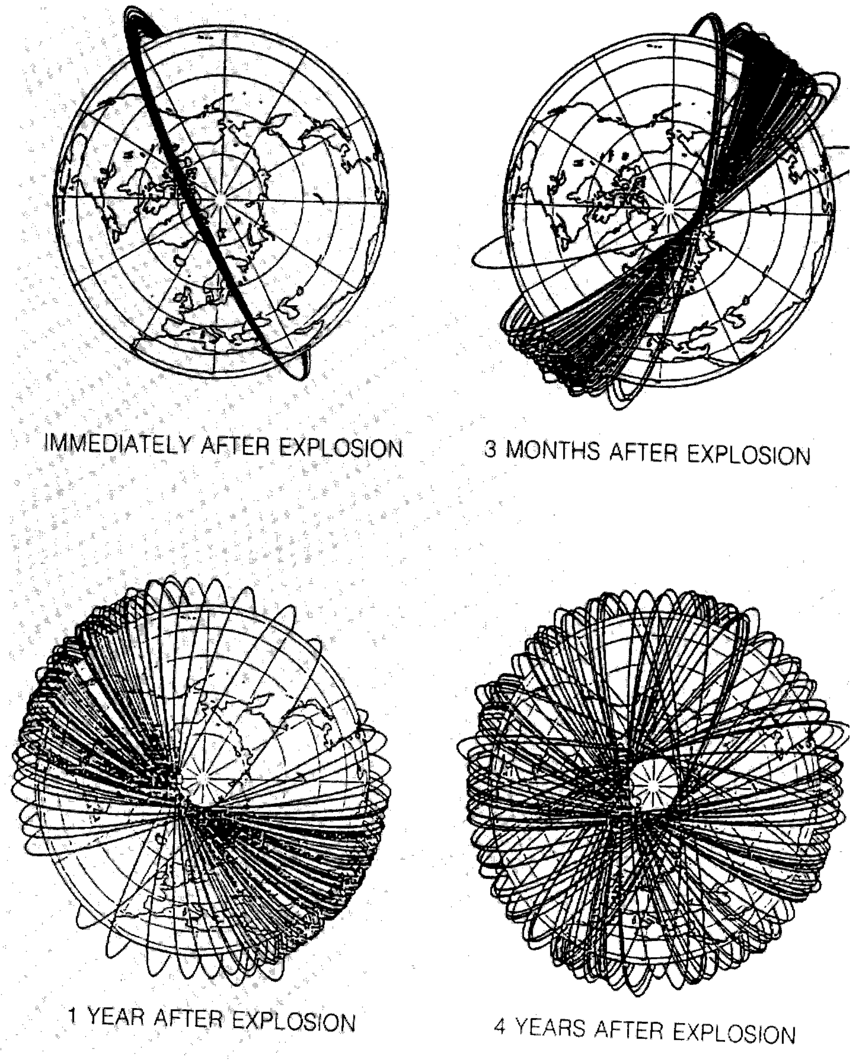
  300 km → some days/weeks

  600 km → 25/30 years

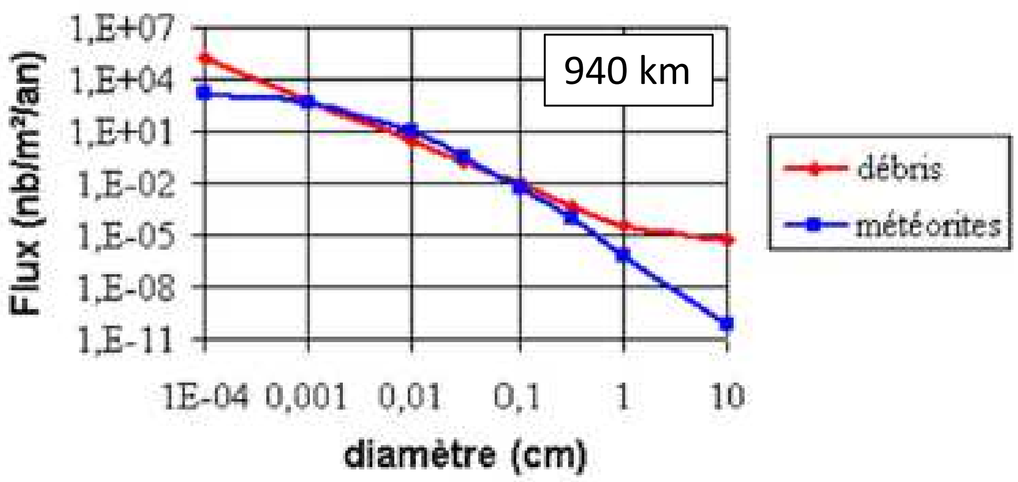
  800 km → 100/200 years

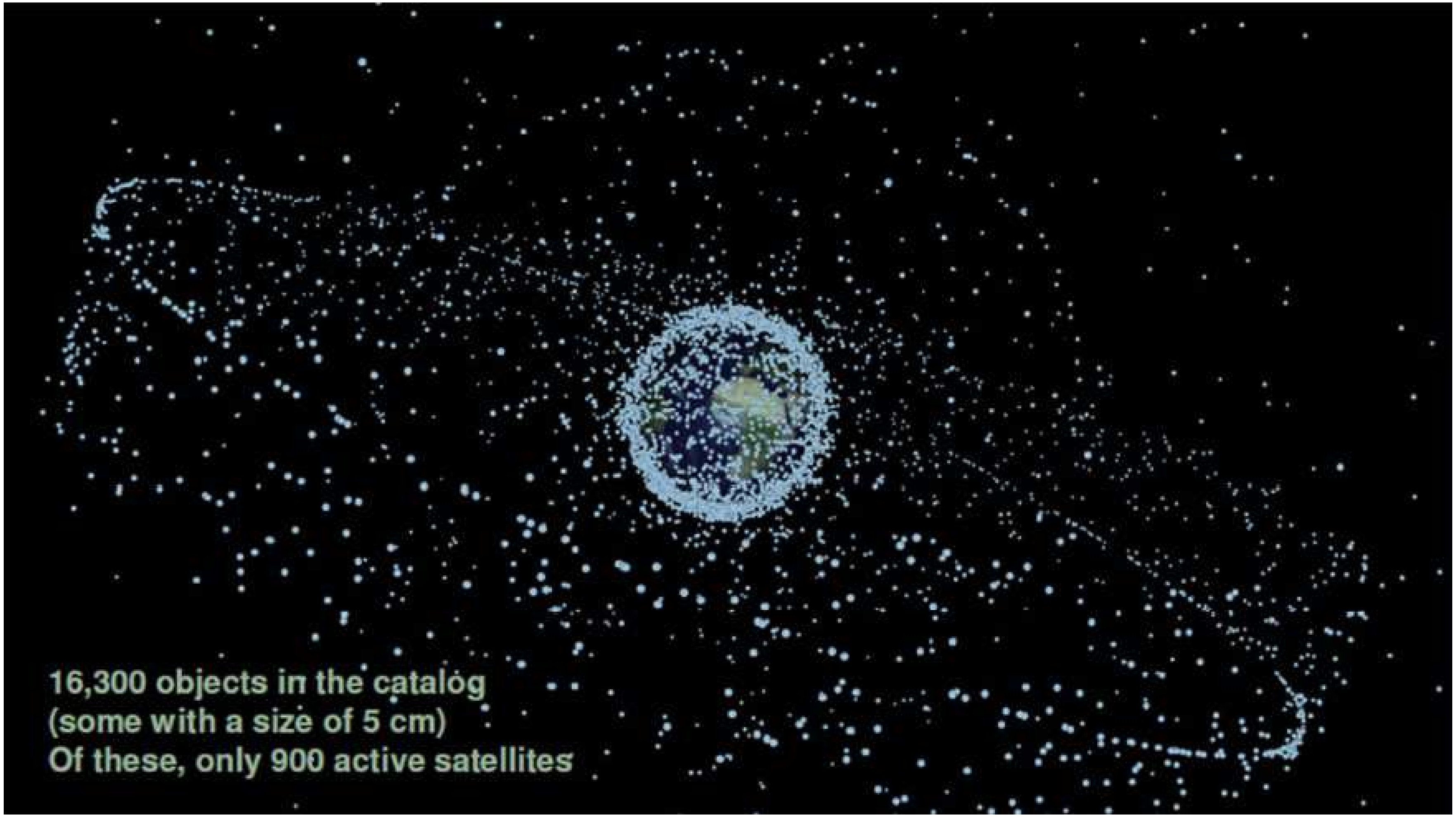
  1000 km → 2000 years

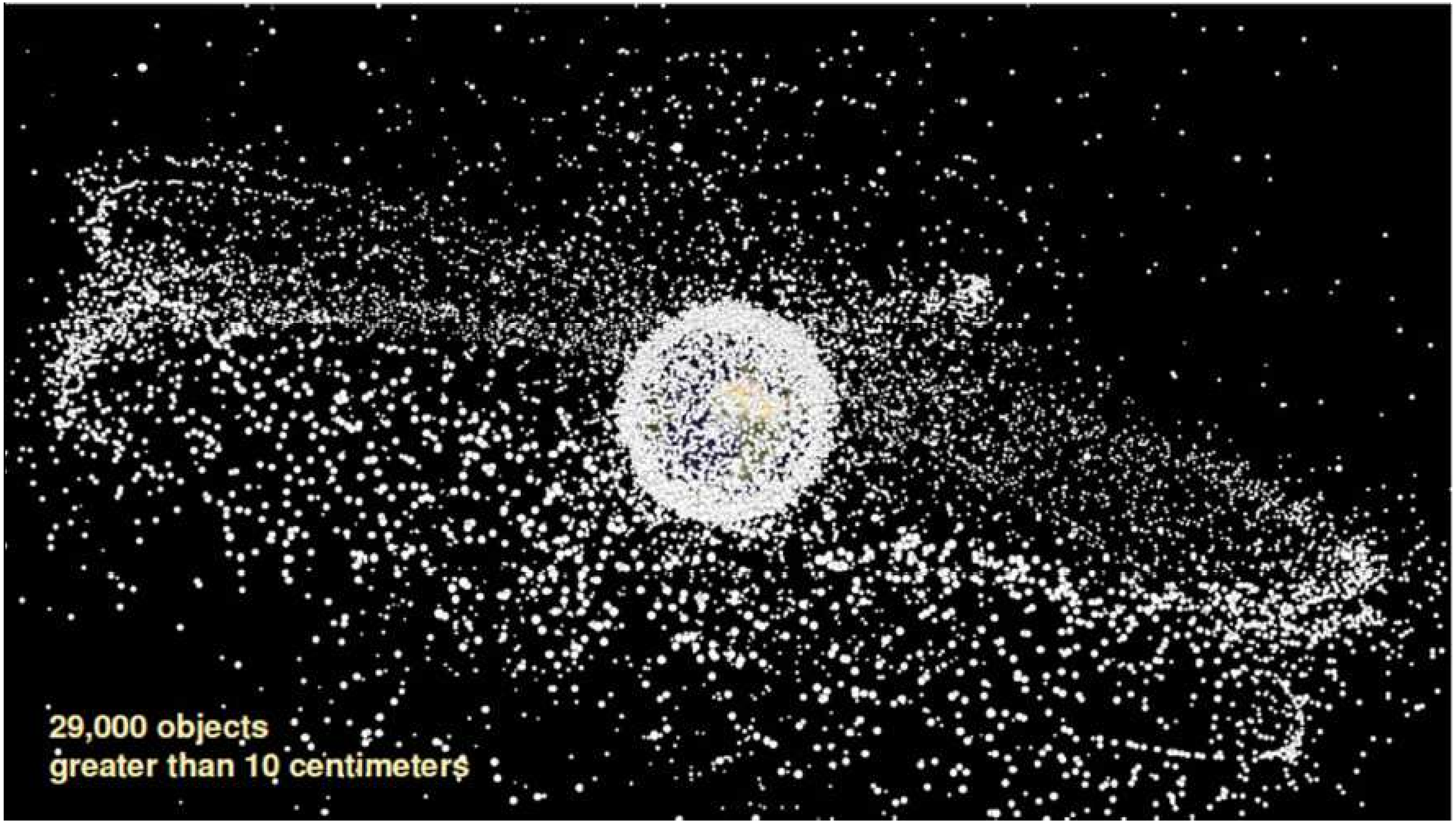


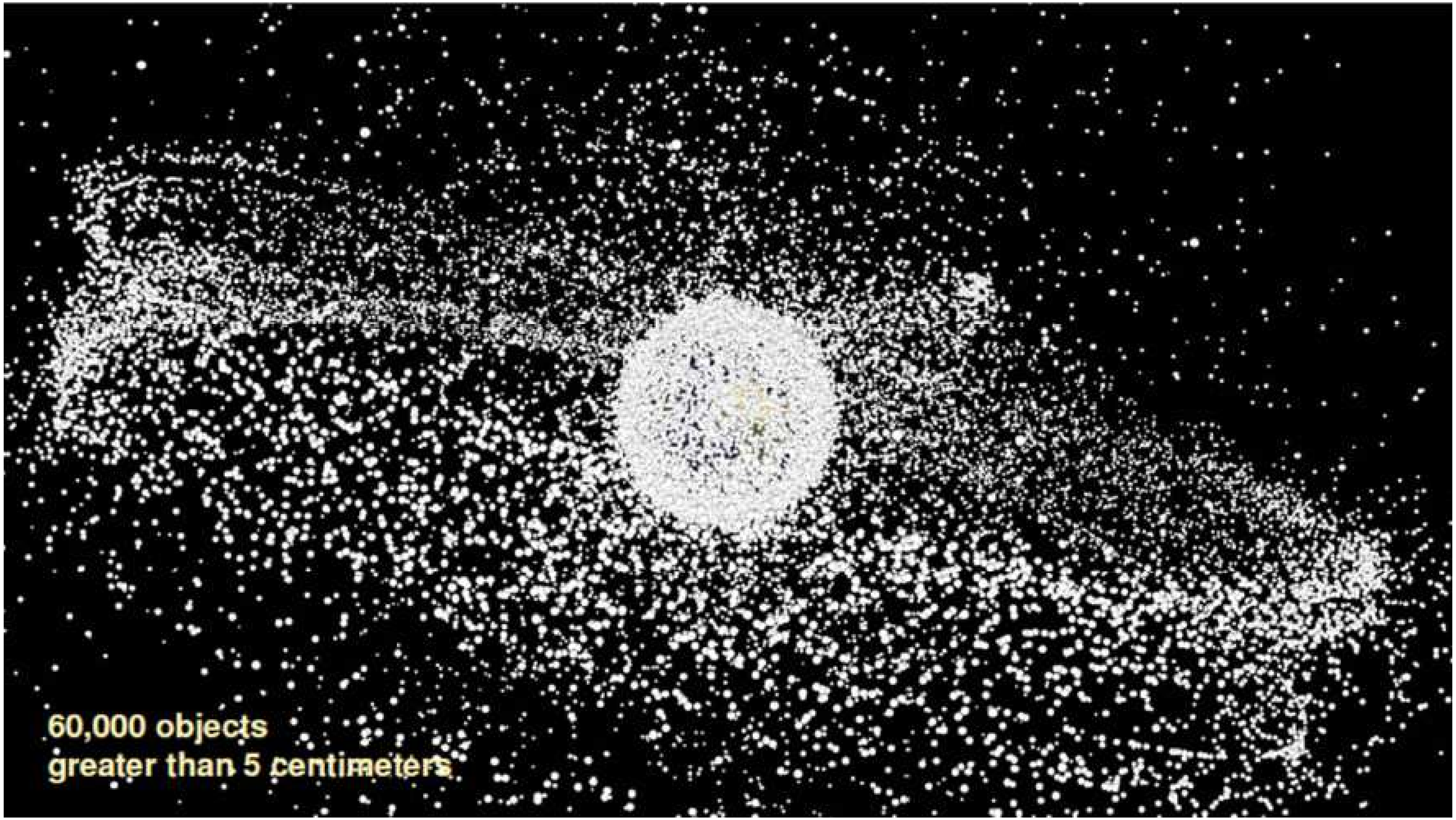


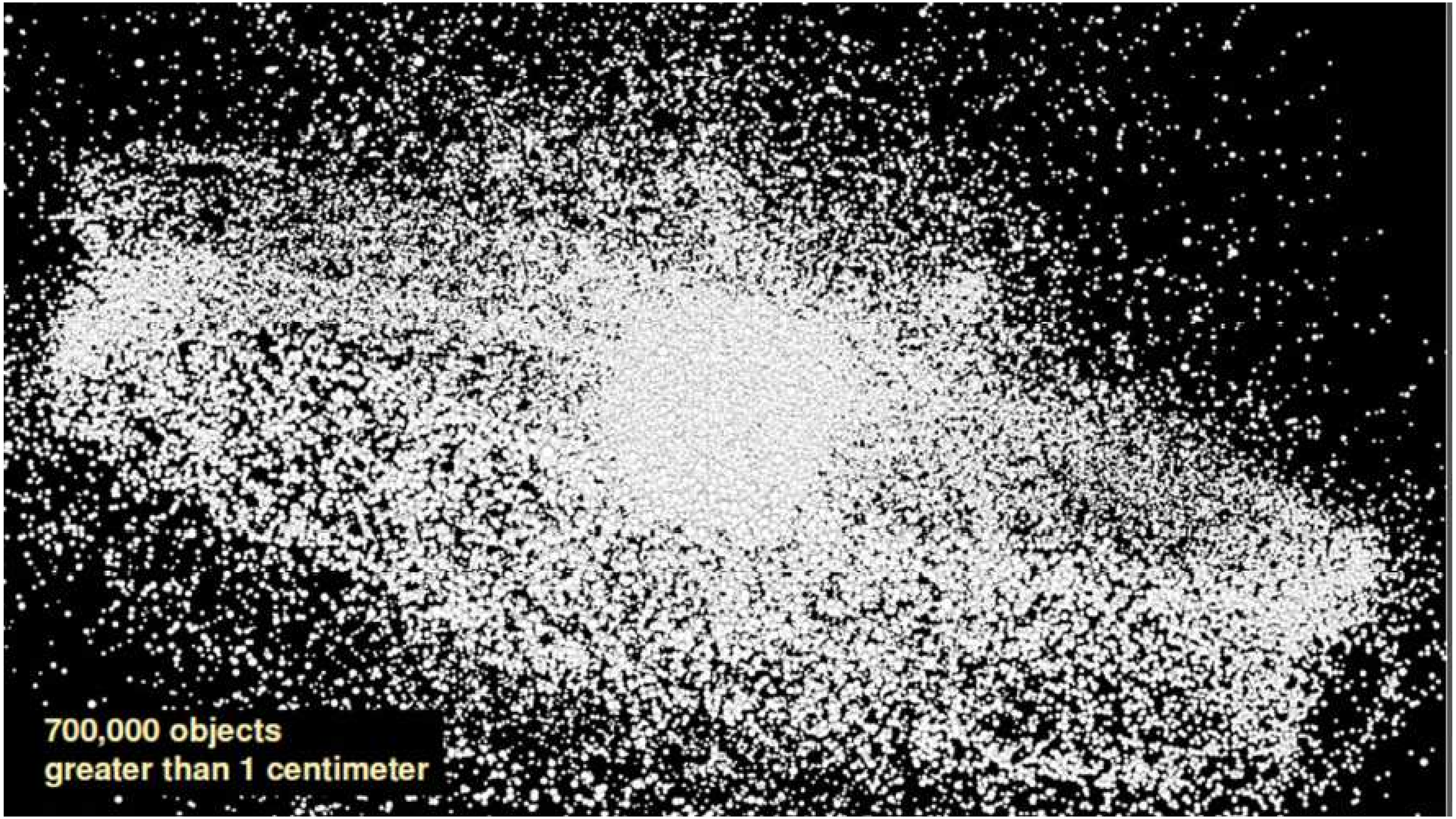
- **Since 1957:**
  - More than 4600 launches
  - ±170 spacecraft explosions
    - 9100 objects > 10 cm (identified objects)
    - 200 000 objects between 1 to 10 cm (non identified)
    - 35 000 000 objects between 0.1 to 1 cm

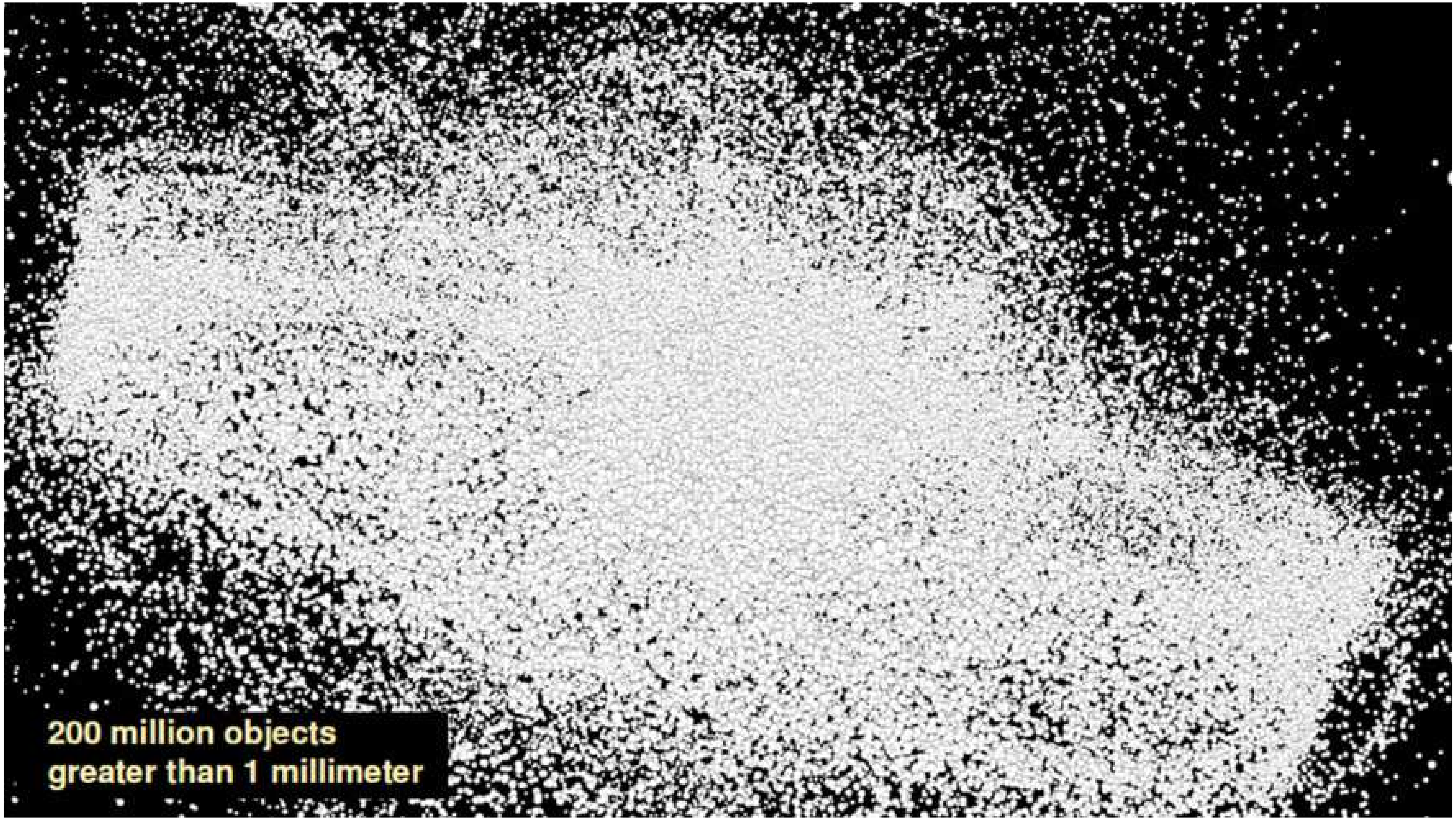


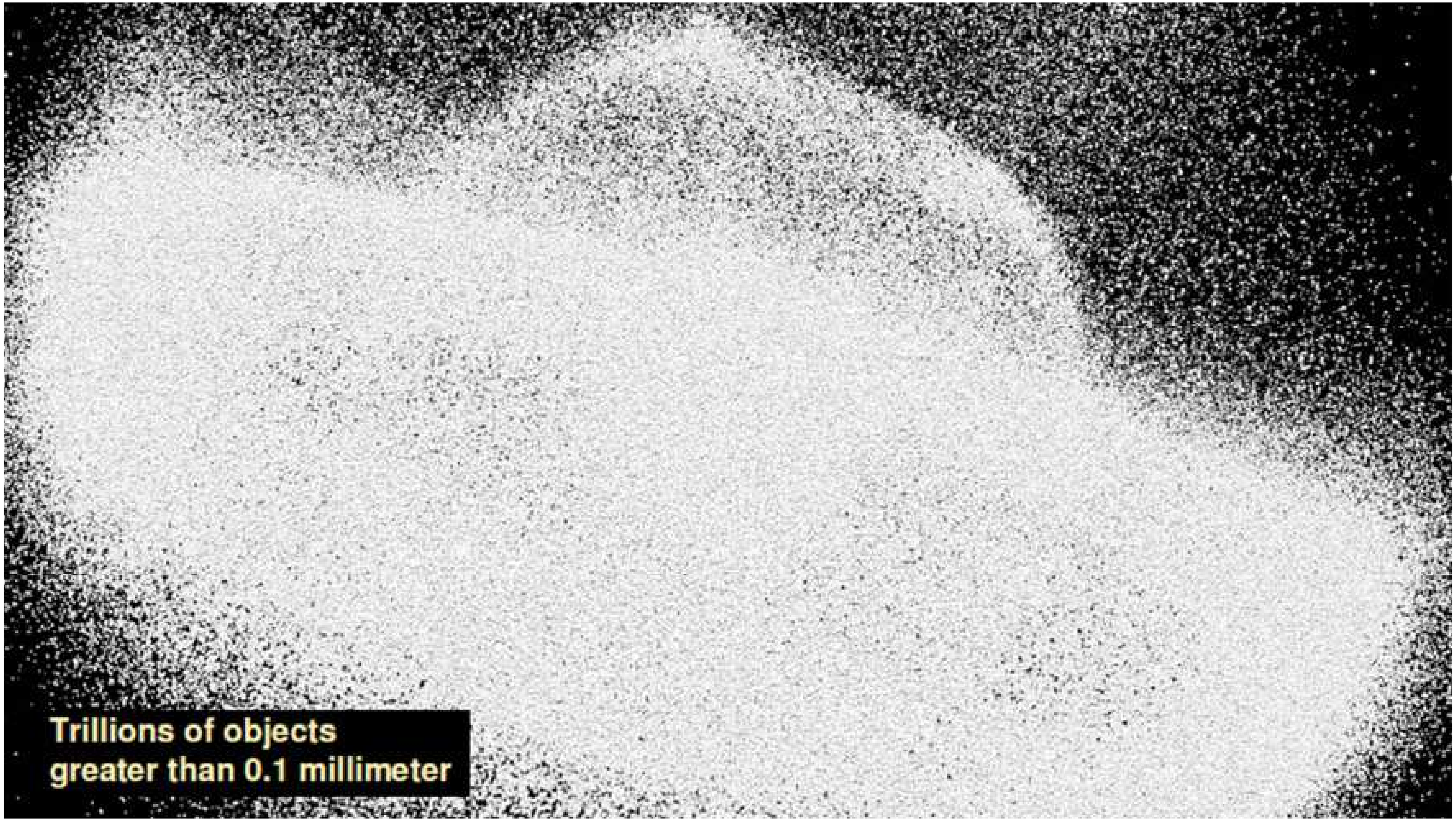

16,300 objects in the catalog
(some with a size of 5 cm)
Of these, only 900 active satellites

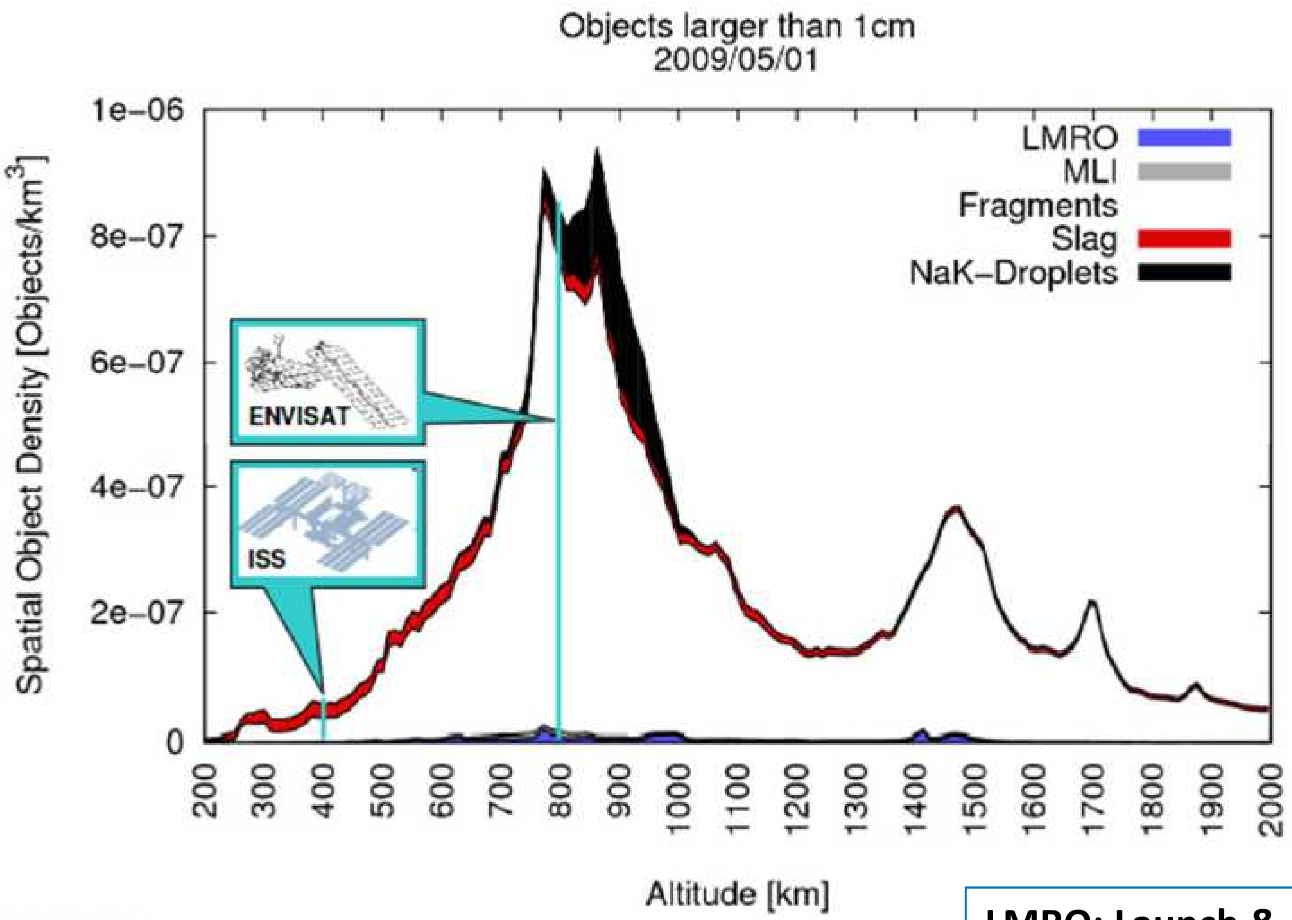

29,000 objects
greater than 10 centimeters


60,000 objects
greater than 5 centimeters


700,000 objects
greater than 1 centimeter


200 million objects
greater than 1 millimeter


Trillions of objects
greater than 0.1 millimeter



LMRO: Launch & Mission Object Related
MLI: multi-layer insulation
Fragment/SLAG = debris
NaK : Sodium-potassium alloy (used as coolant liquid in thermonuclear)

- **Which satellites are most likely to collide?**

- **Collision will mainly occurs between sun-synchronous satellites (between 98° and 82°)**

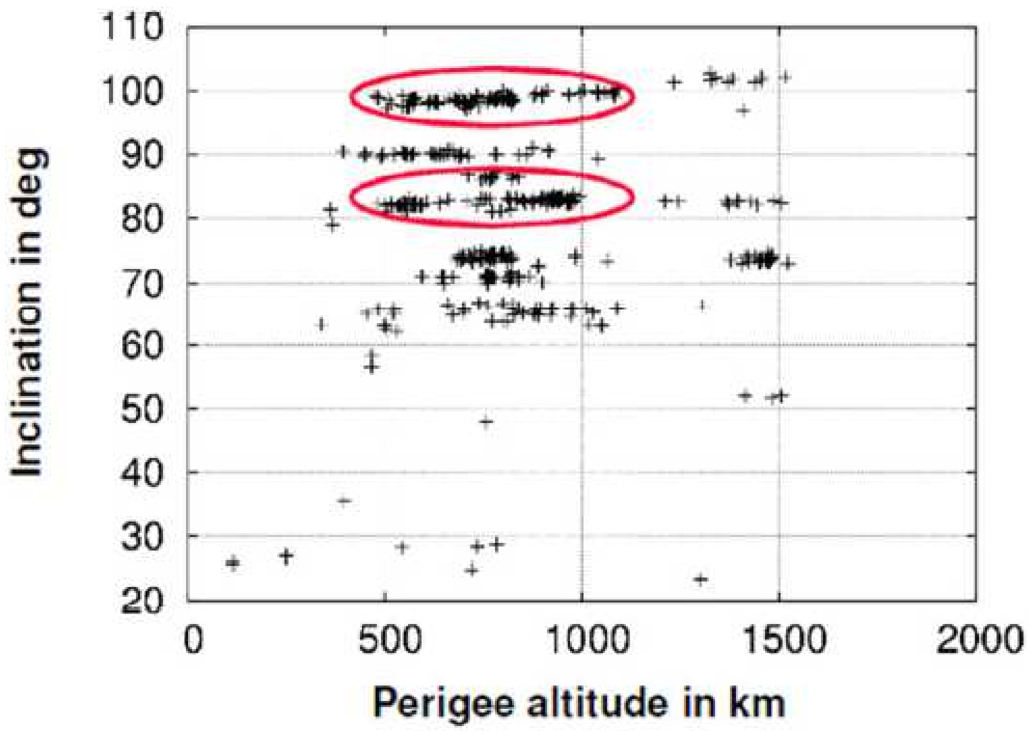
  SSO will scan every inertial direction/plan over a years then the probability to meet a foreign body is higher

- **Orbital structure of foreign objects:**

  Semi-major axis

  Eccentricity

  Inclination

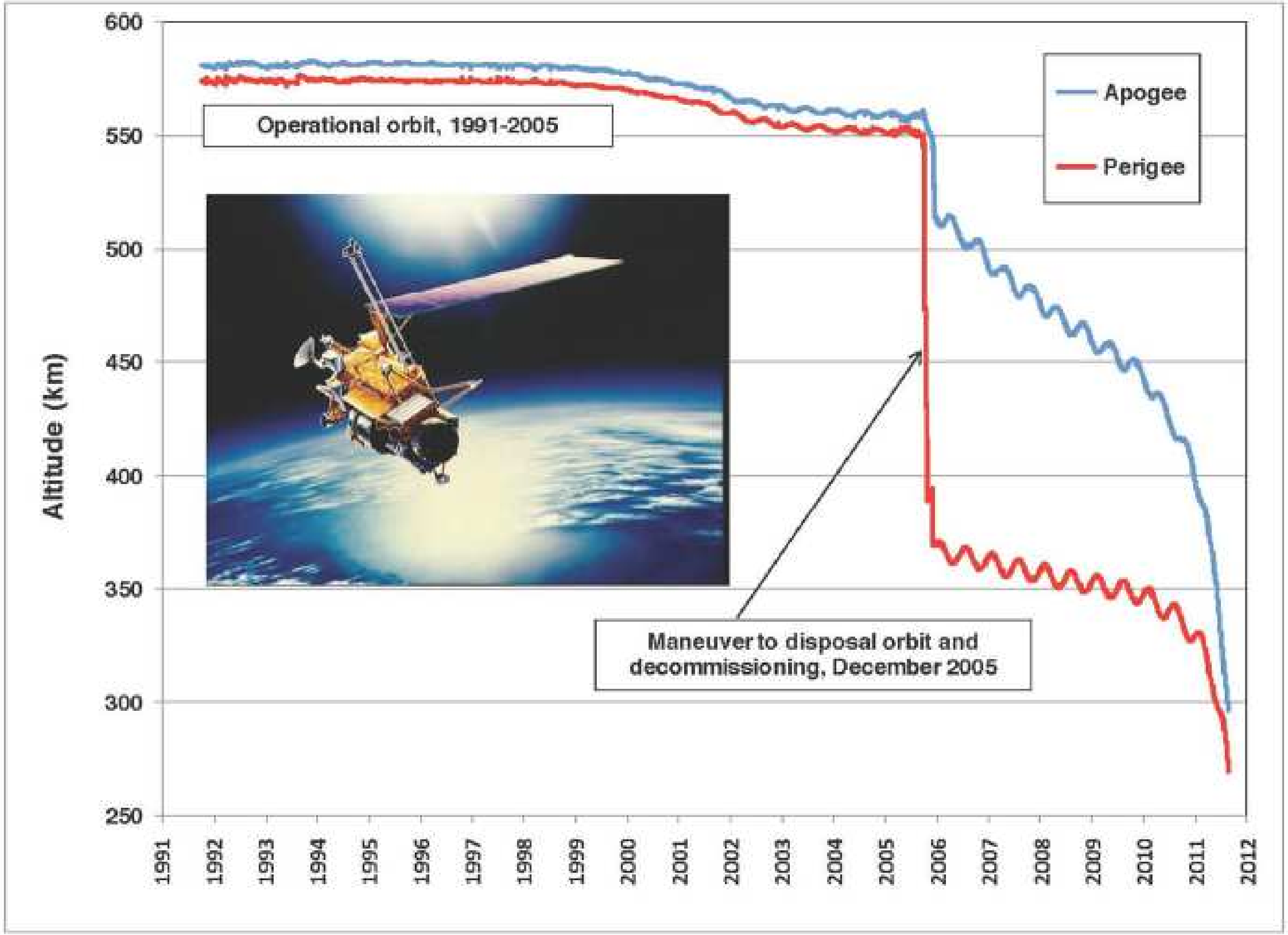


- **Orbital region of special interest → 800 km altitude**
  - High number of debris
  - High collision velocity
  - High probability of catastrophic collisions → Collisional cascading

- **Scientific and technical challenges**
  - Identification of long living risk objects
  - Active removal (need prioritization/ de-orbiting)

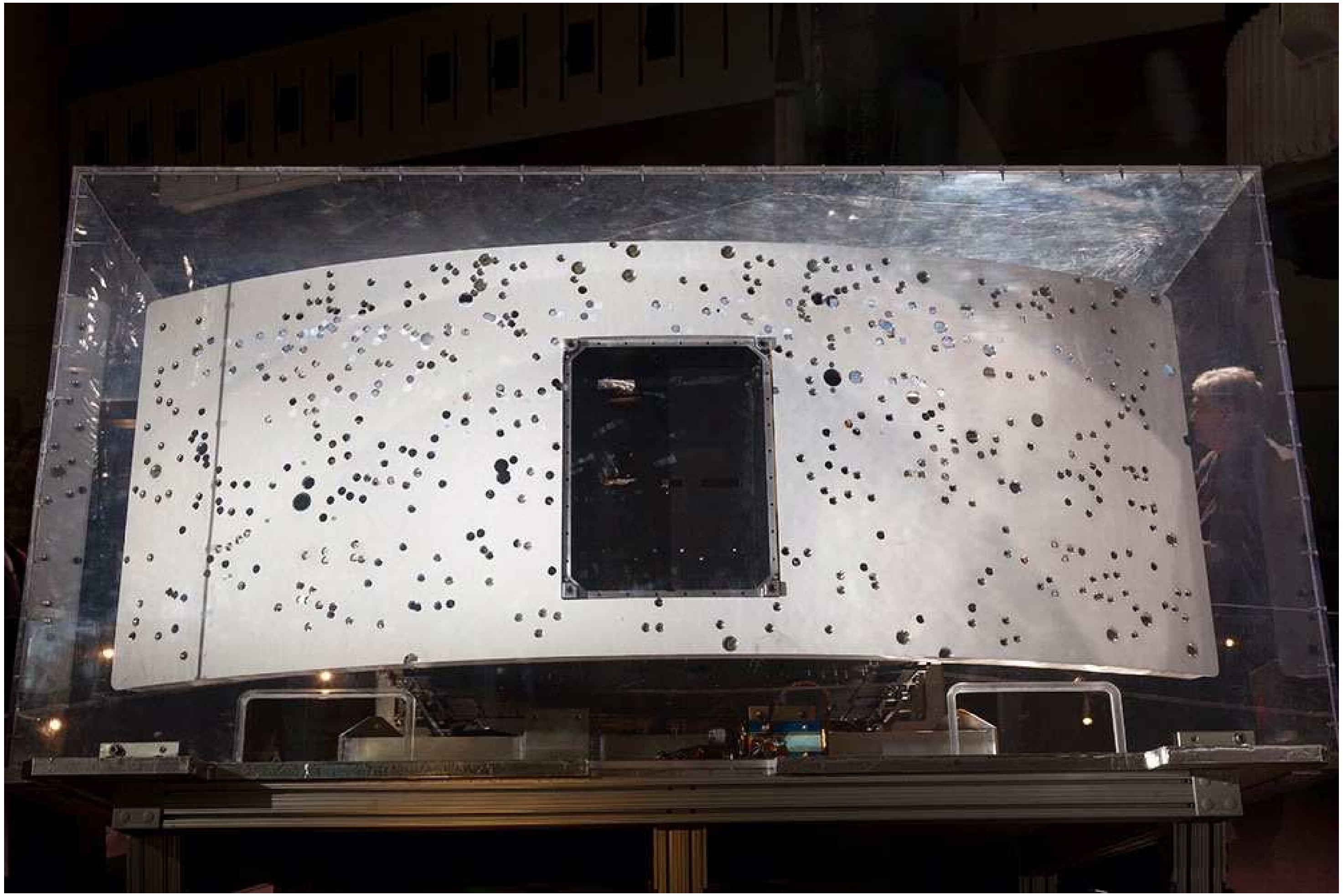
- **Legal challenges**
  - New satellites and rocket stages → implementation of an obligationof de-orbiting at EOL (End Of Life)
  - Need to define a deorbiting maneuver at the end (need propellant,…)

Deorbiting



Altitude (km)
600
550
500
450
400
350
300
250
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Apogee
Perigee
Operational orbit, 1991-2005
Maneuver to disposal orbit and decommissioning, December 2005

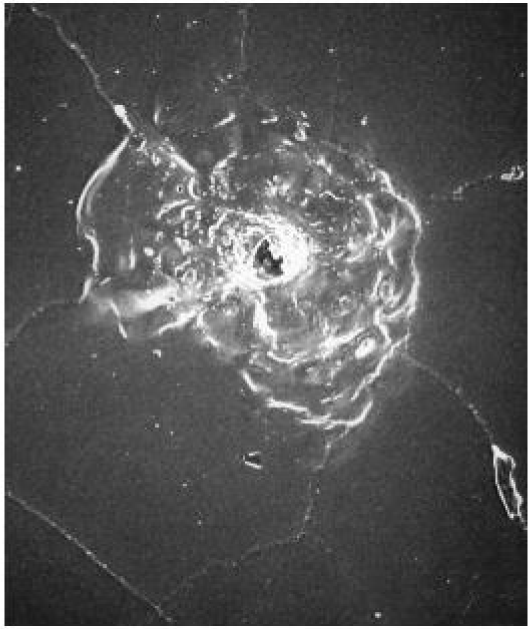
Effect of debris



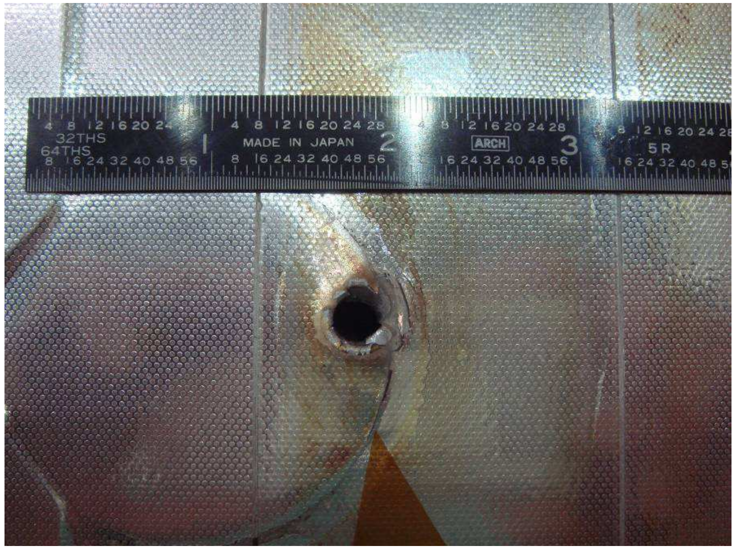
Hubble radiator

Effect of debris

Challenger window
(STS-7, June 1983)



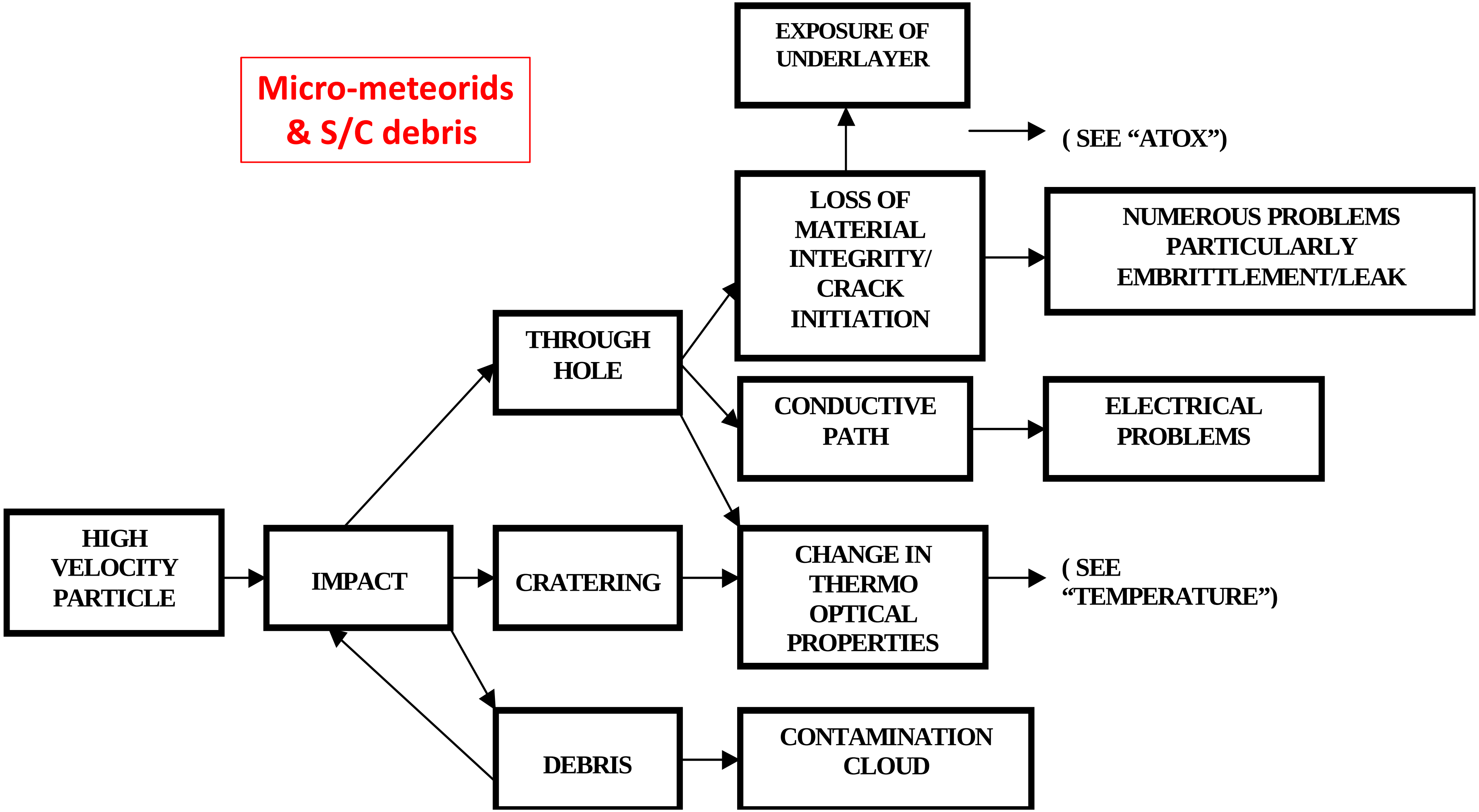
Endeavour window
(STS-97, December 2000)



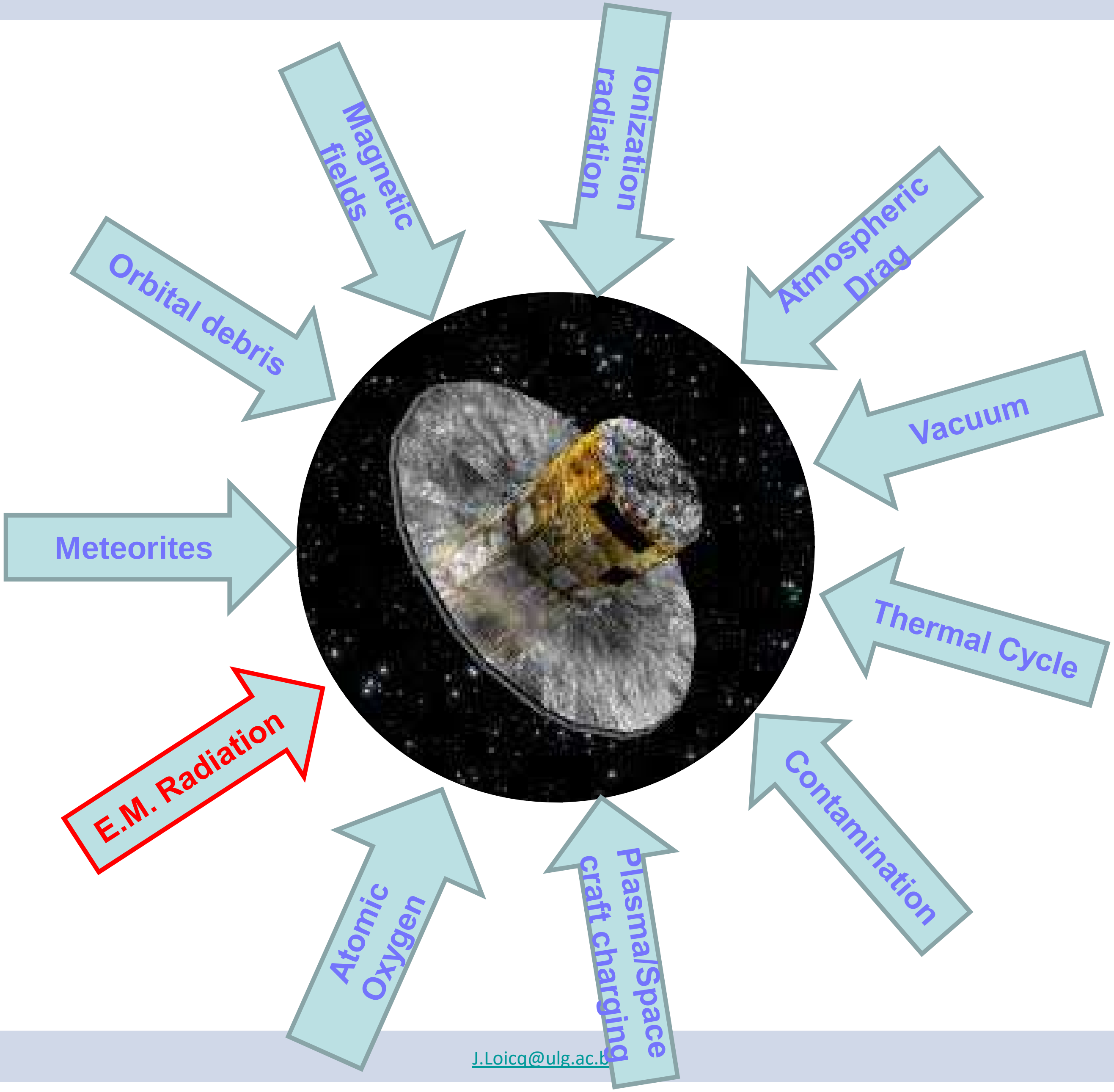
Endeavour radiator
(STS-118, August 2007)

Effect of the space environment: summary

Micro-meteorids & S/C debris



[Barrie Dunn, Metallurgical Assessment of Spacecraft Parts Materials & Processes, Praxis Publishing, 1997]


Magnetic fields
Ionization radiation
Orbital debris
Atmospheric Drag
Vacuum
Meteorites
Thermal Cycle
E.M. Radiation
Contamination
Atomic Oxygen
Plasma/Space craft charging

Solar irradiation

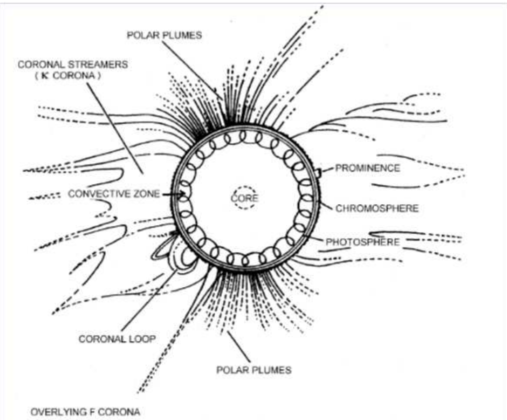
- **Origins of the solar E.M. radiation**

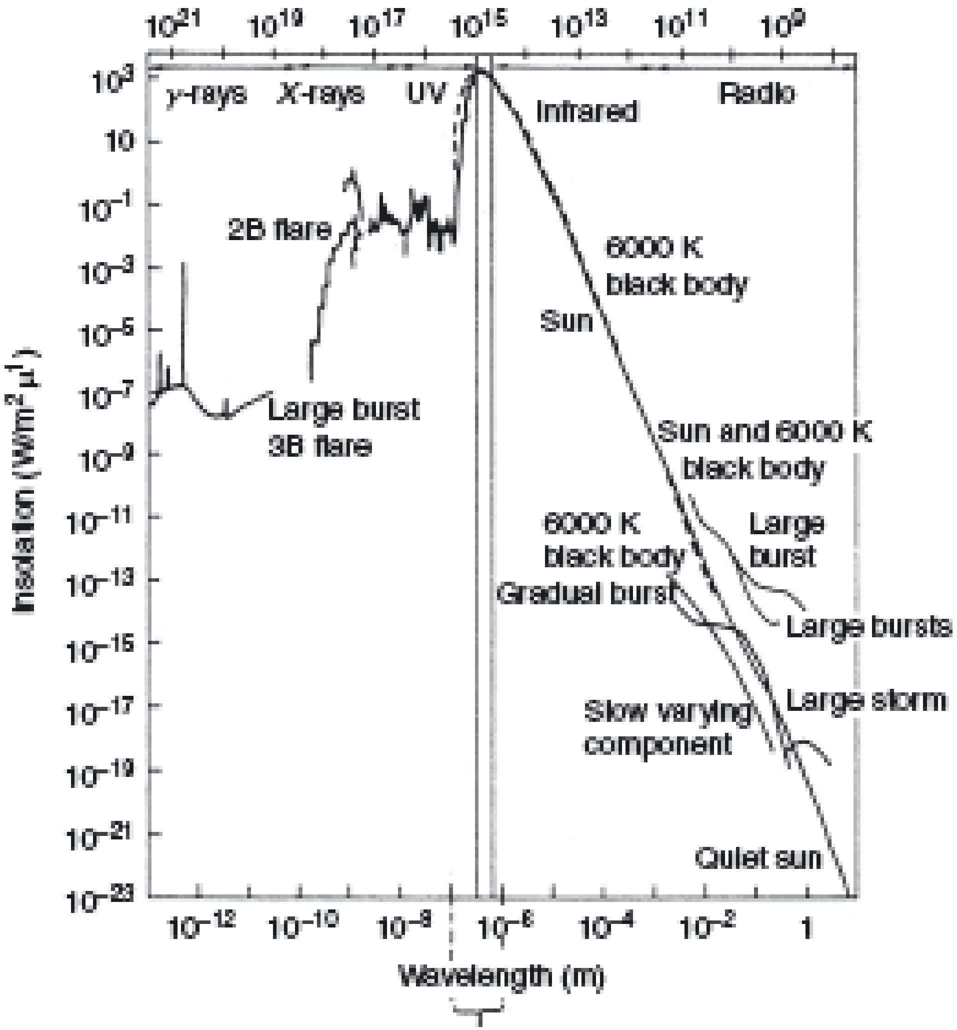
  Black body : from the photosphere (Sun « surface ») @ 5800 K

- **Departures from black body :**

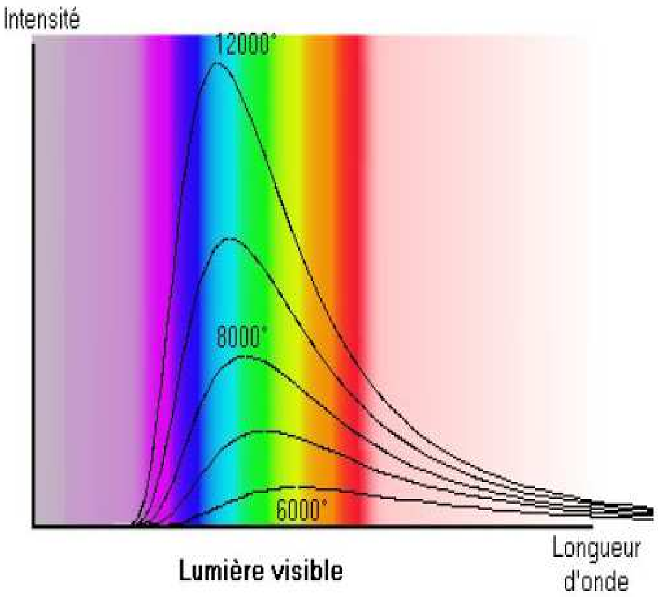
  - **Chromosphere :** up to several thousands km above the photosphere, temperature increases up to 10000 K, enhanced UV emission

  - **Corona** : upper solar atmosphere, up to several solar radii, temperatures up to 2 MK, substantial X-ray emission





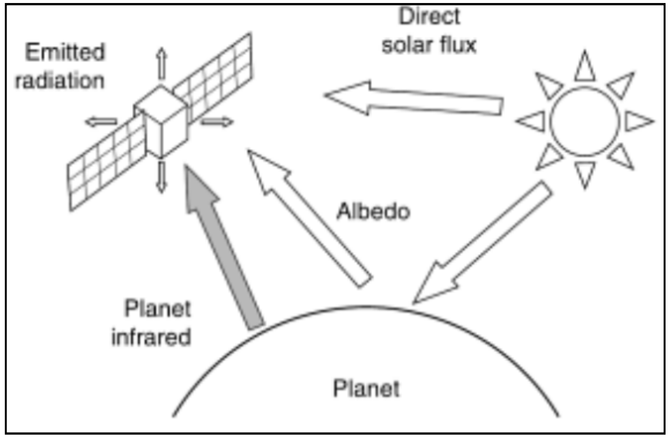
Solar radiation



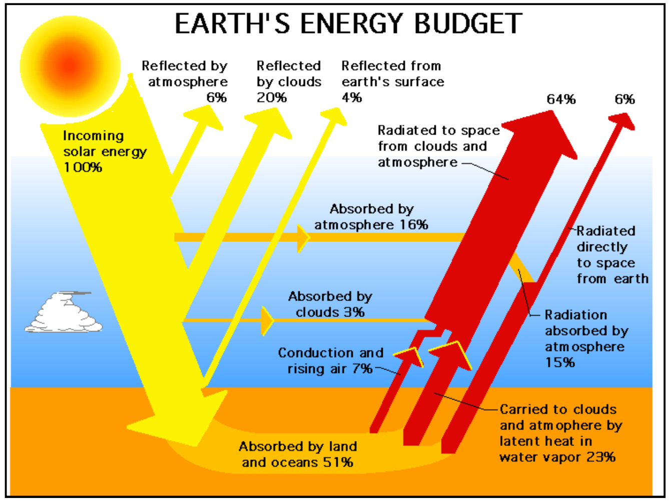
- **Energy equation for black body (per unit surface area, per second, per meter) (Planck's Equation):**
  - $E(\lambda) = \frac{2\pi\, h\, c^2}{\lambda^5} \frac{1}{\exp\left(\frac{ch}{kT\lambda}\right)-1}$
- **Total energy radiated by black body (integrated value, per unit surface area, per second)**
  - $E_{tot} = \sigma T^4$
- **Wien law**

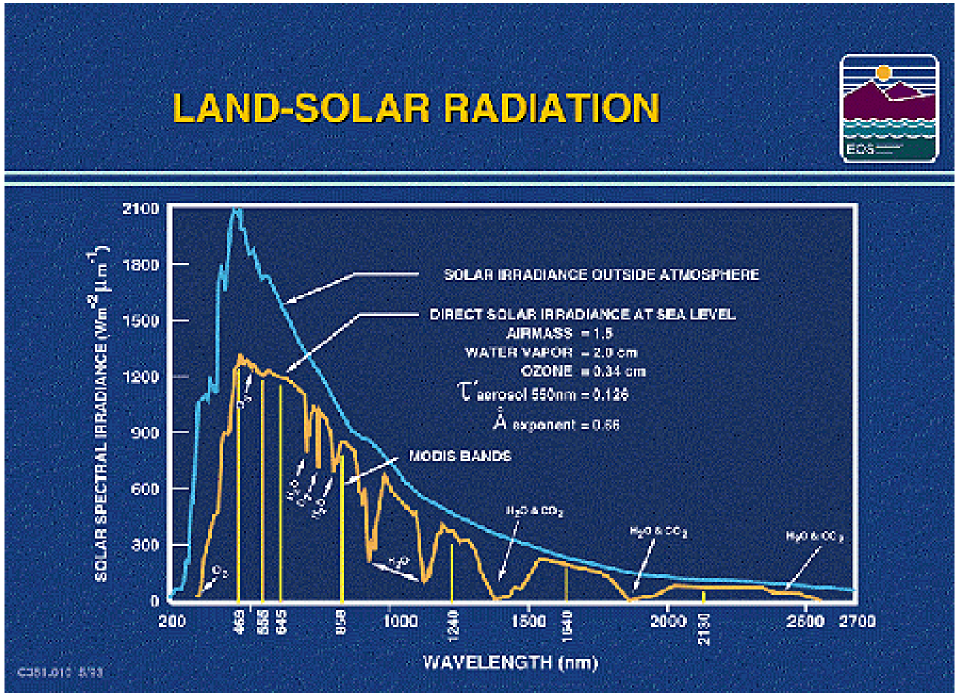
$$h\nu_{\max} = 2.82\, kT$$

A **black body** is a hypothetical object, which emits the **maximum amount of energy** on any given wavelength; this is **fully determined** by the **temperature of the object**. It serves as a **reference** to express radiation and reflectance characteristics of actual objects.



- **Spacecraft mainly encounter**
  - (1) Direct solar radiation,
  - (2) Albedo radiation
  - (3) Earth infra-red radiation.





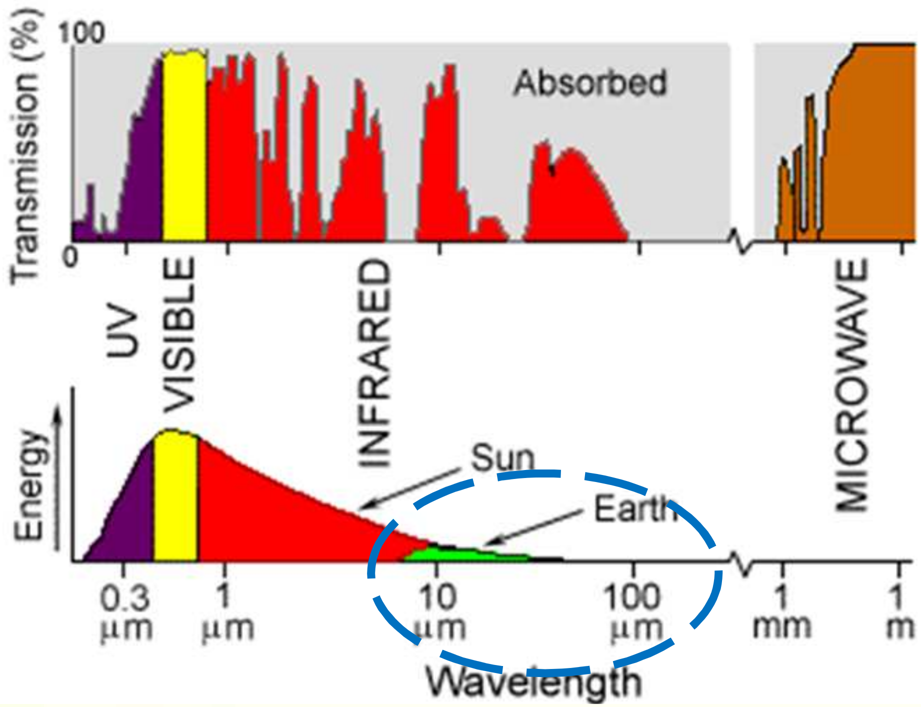
Earth Electromagnetic radiation

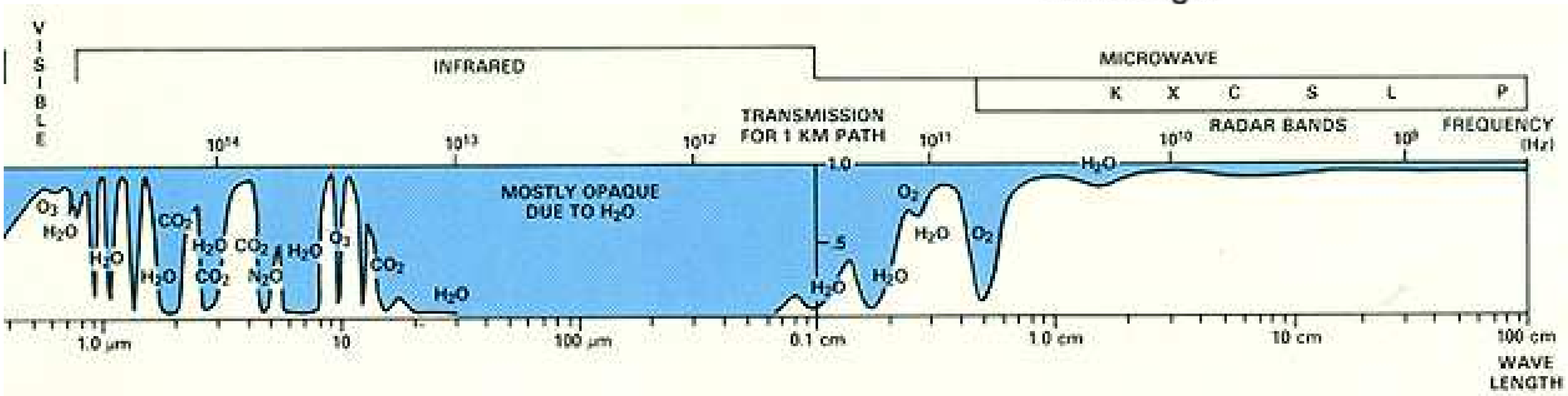
- **VIS/NIR**

  reflected solar radiation

- **TIR (thermal infrared) :**

  Earth thermal emission @ 10µm (300K BB radiation)





Earth Electromagnetic radiation

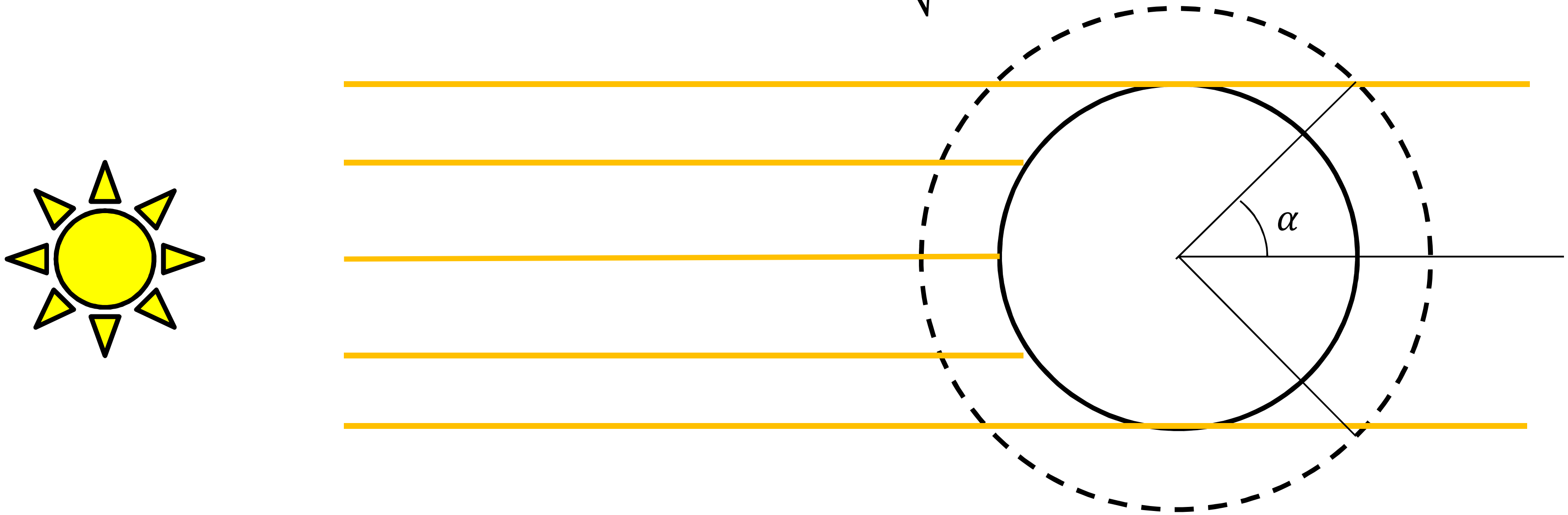
- **Albedo:**
  - = fraction of sunlight reflected by a plane
  - Albedo spectrum can change, depending on surface properties and on the atmosphere
  - Ground vegetation, water and dust in certain wavelengths can lead to absorption in certain spectral bands
  - Standard value for Earth : 0.3, but highly variable and ranges from about 0.05 to 0.6.

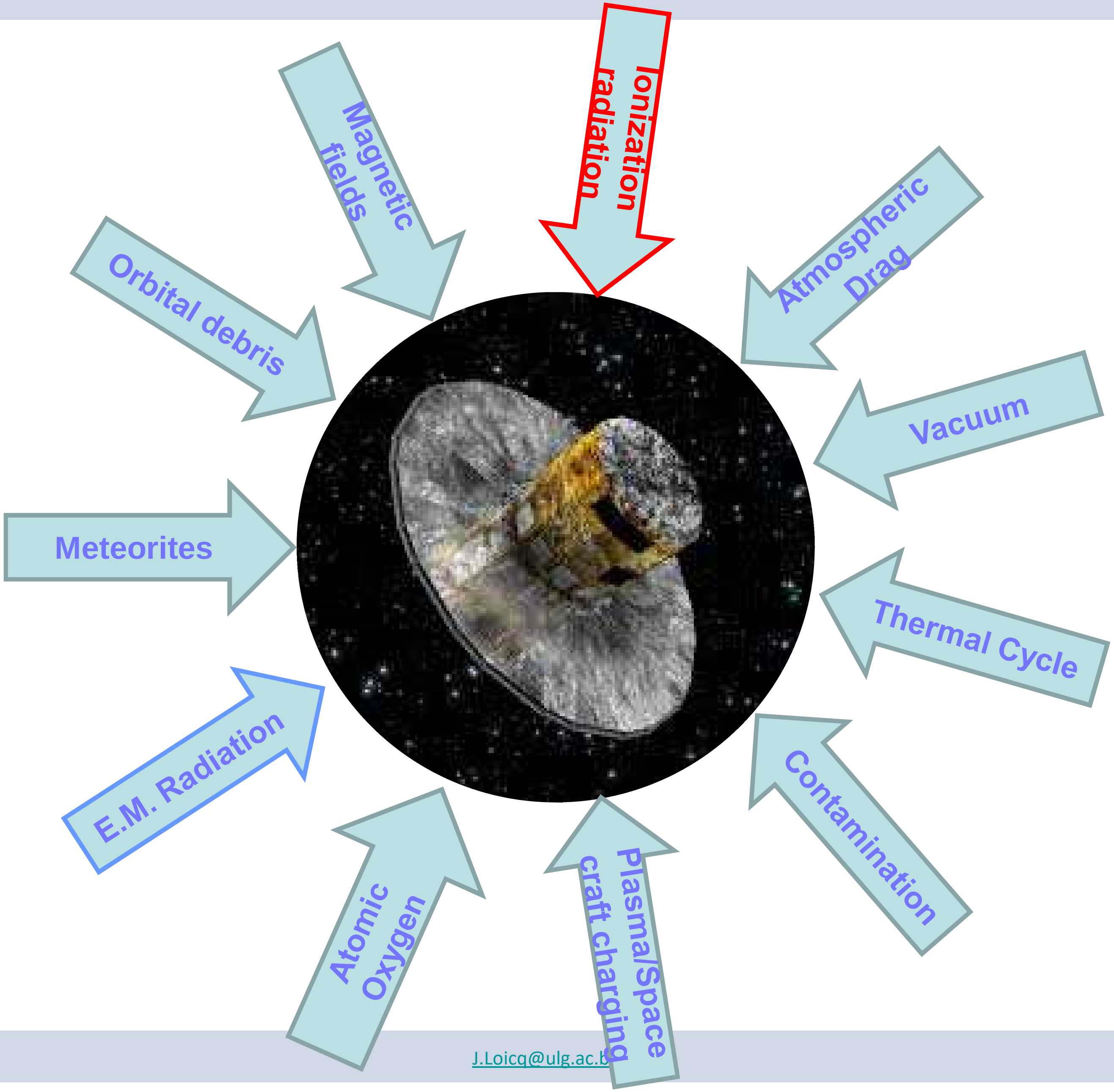
E.M. Radiation effect on Satellite

- **Attitude control**
  - Sun sensor
  - Earth sensor
  - Star sensor
- **Energy supply**
  - solar panels
- **Thermal control**
- **Damage**
  - Degradation of detectors
  - thermal effects
  - electrical damage (Single Event Upsets, SEUs)
- **Orbit perturbations**
- **Communication**
- **Astronaut health**

E.M. Radiation effect on Satellite

- **Eclipse calculation (2D computation)**
  - Earth half angle α: $\sin(\alpha) = \frac{R_{earth}}{R_{earth}+h}$ with h the altitude
  - Eclipse fraction : $F_{eclipse} = \frac{2\alpha}{360}\, 100$ [%]
  - Eclipse duration: $T_{eclipse} = \frac{2\alpha}{360}\, T_{orbit} = \frac{2\alpha}{360} 2\pi \sqrt{\frac{\left(R_{Earth}+h\right)^3}{\mu}}$ [s]

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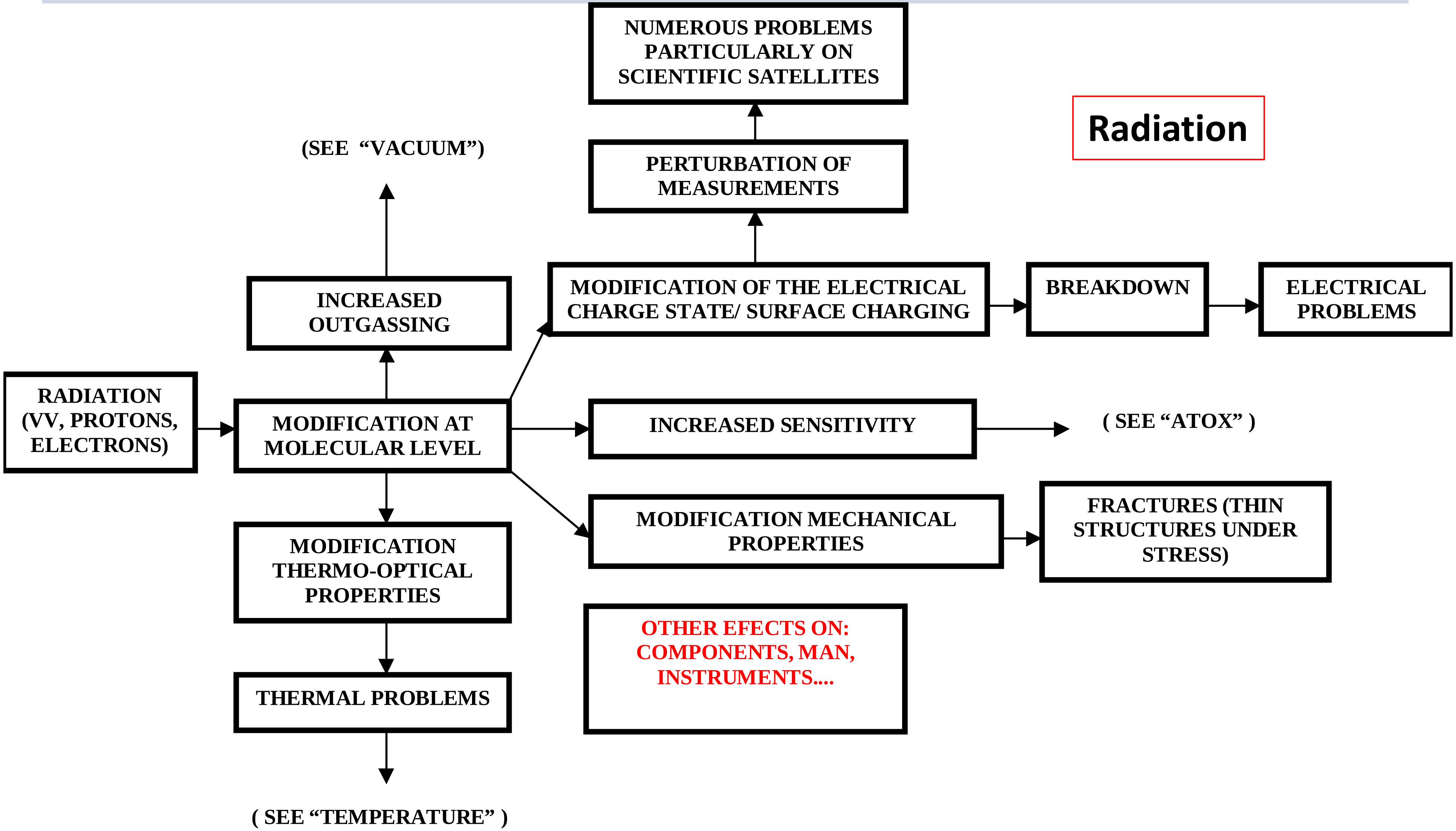
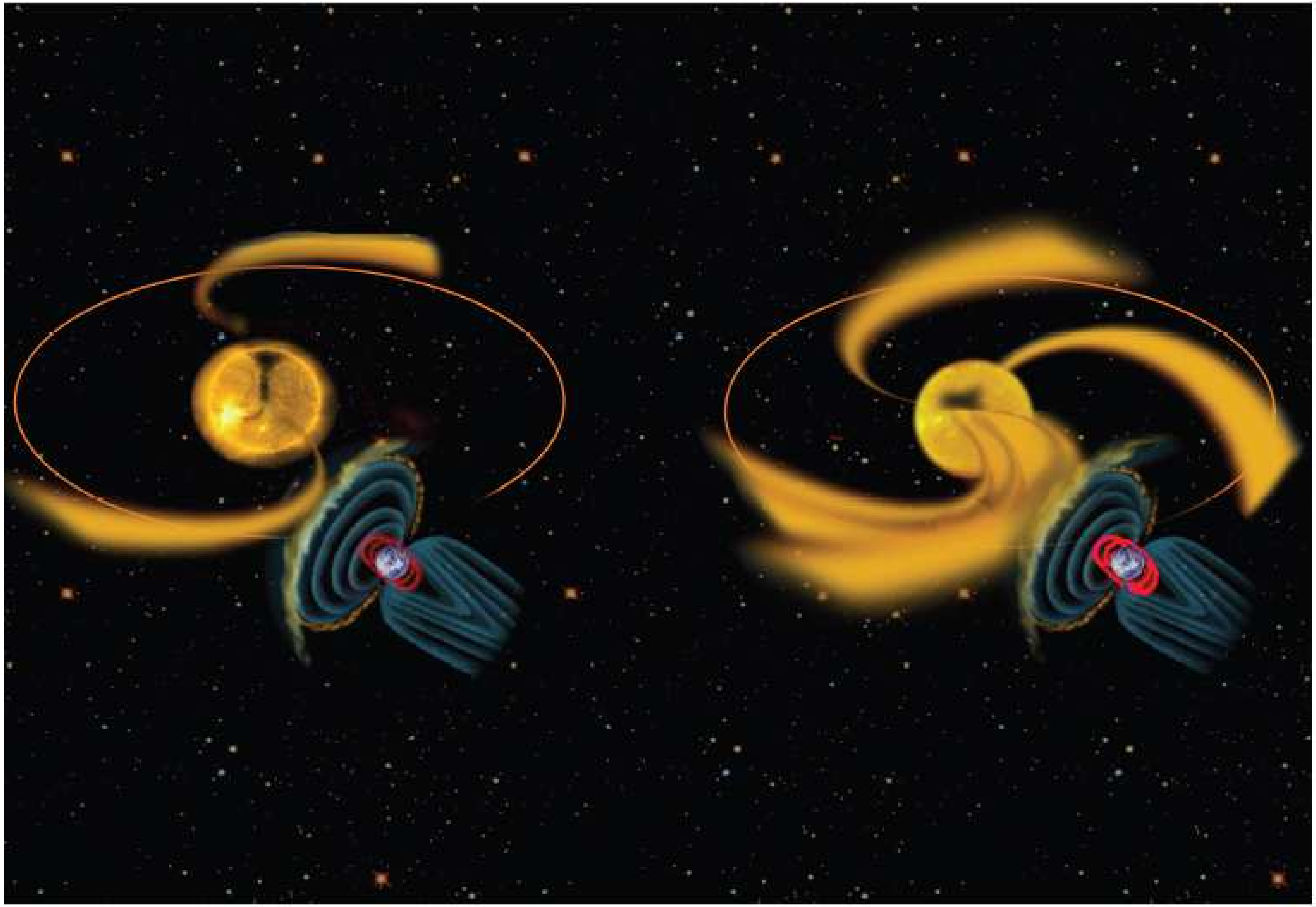
Effect of the space environment: summary



[Barrie Dunn, Metallurgical Assessment of Spacecraft Parts Materials & Processes, Praxis Publishing, 1997]

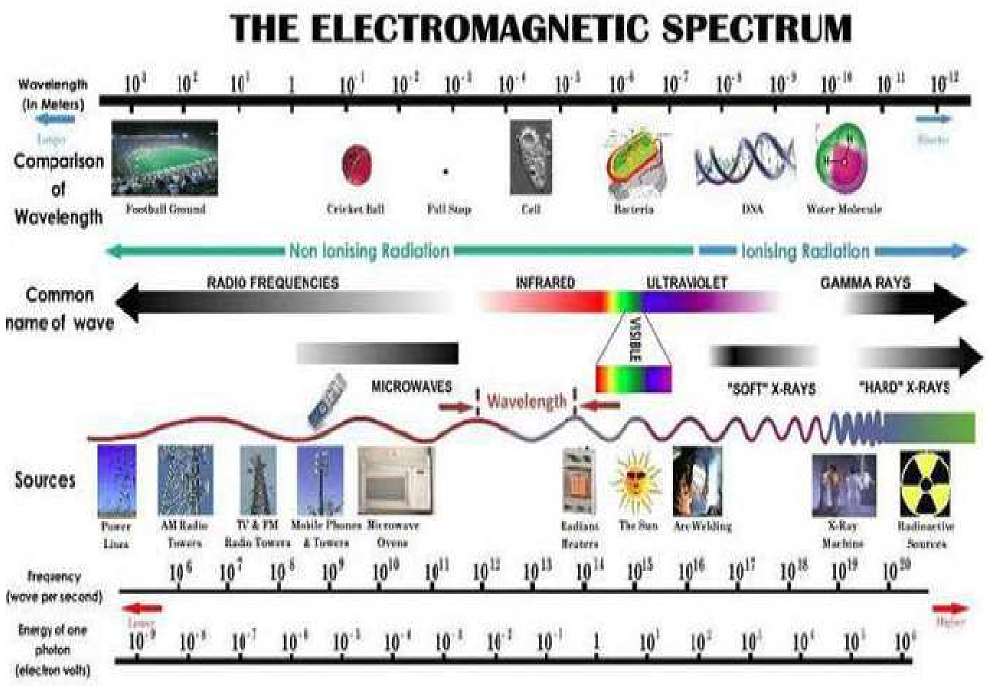
Solar Wind and ionizing particles

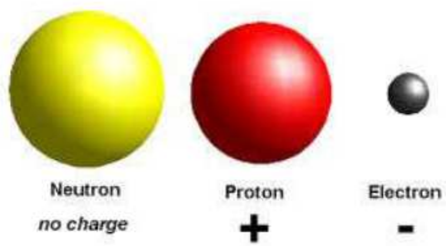


Gibson et al., 2009

Radiation type

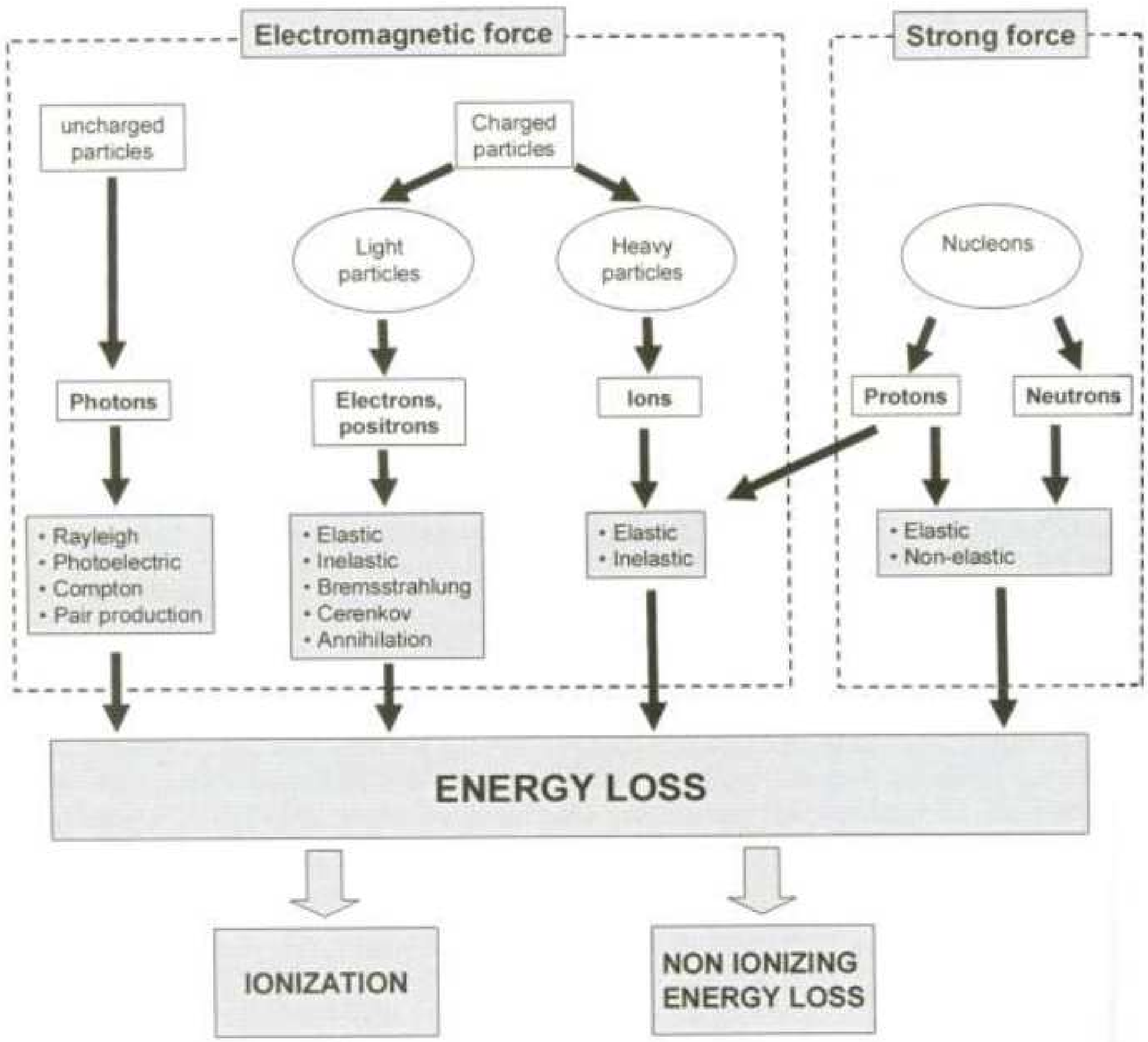
- γ**- rays**: Photons with energy higher than X-rays
- β: electrons (e^-) or positrons (e^+)
- p^+: protons
- α : He nuclei
- $Ions$: He or heavier
- $Neutrons$





Mass (in term of mc²):
Neutron = 939.56563 MeV
Proton = 938.27231 MeV
Electron = 0.51099906 MeV

Radiation: Physical process

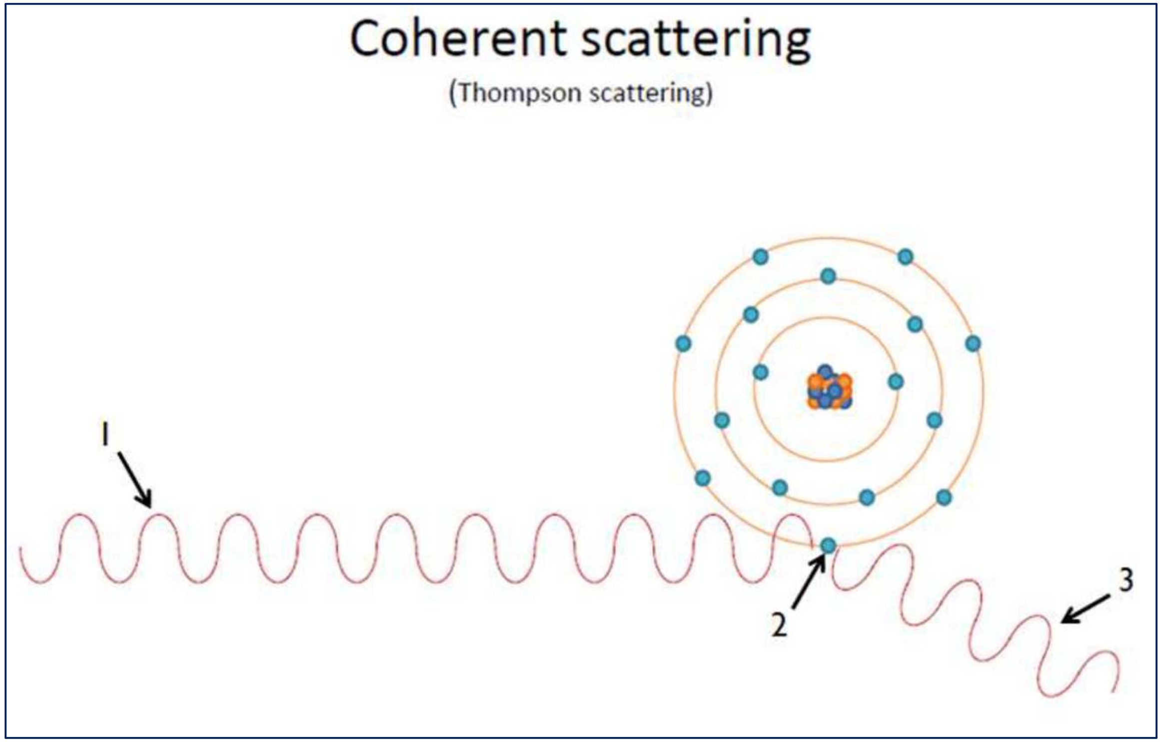


Radiation: photon

- **Rayleigh scattering**
  (elastic scattering, coherent scattering)

- Photons are scattered by bound electrons **without excitation** of the target atom.

- **Energies of incident** and **scattered photon** are identical



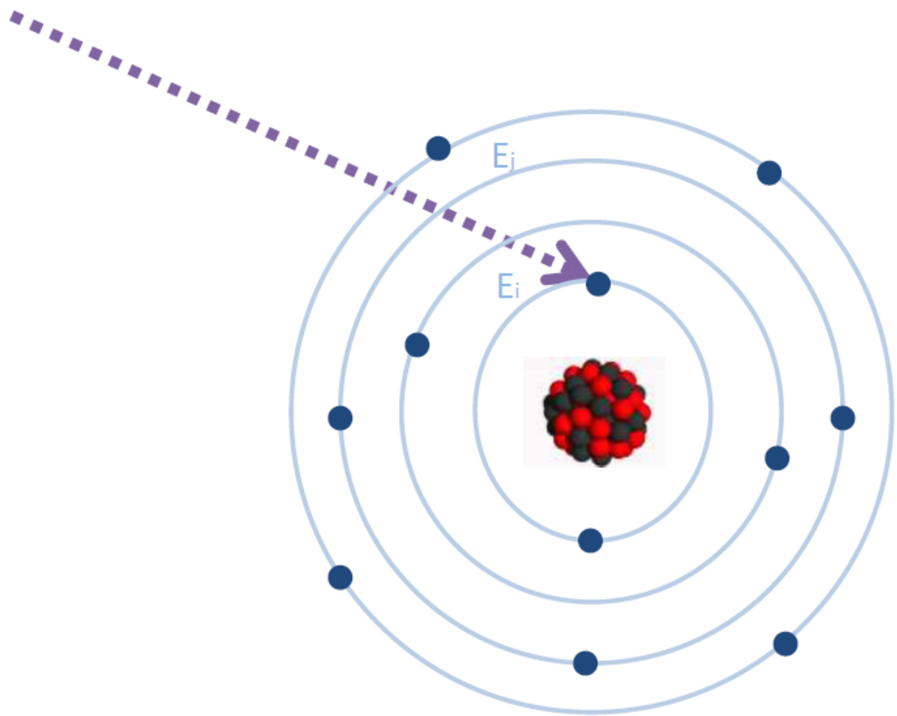
$$\sigma_{Rayl} = \frac{8}{3}\pi r_e^2 Z^2$$

Radiation: photon

- **Photo-electric effect:**

  emission of electrons or when light is shone onto a material.

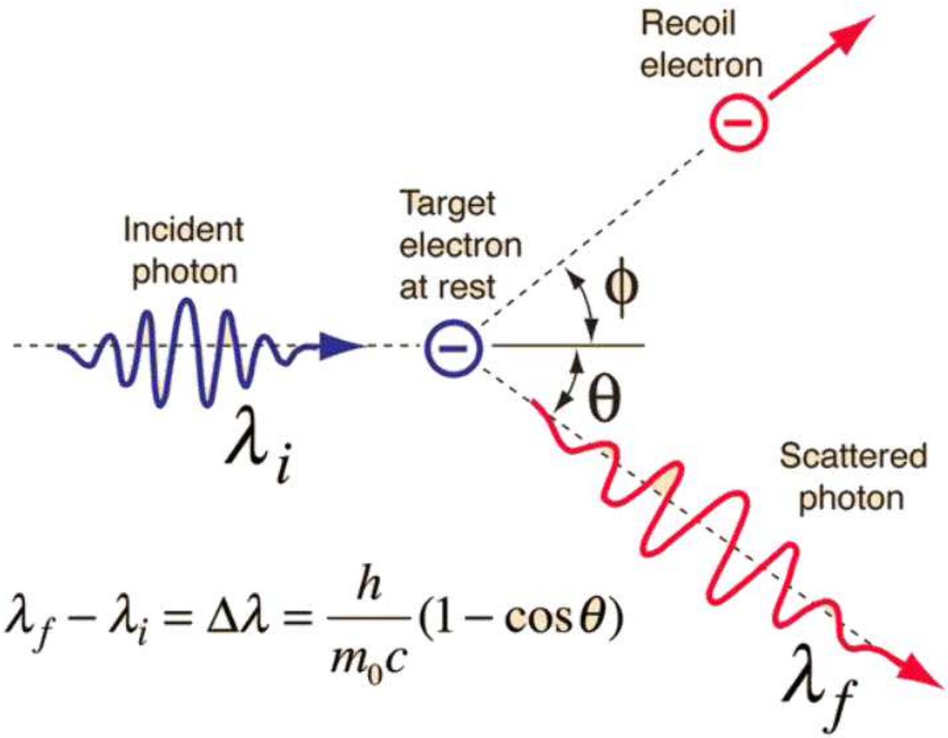
- **Quantum process**



Radiation: photon

- **Compton scattering**

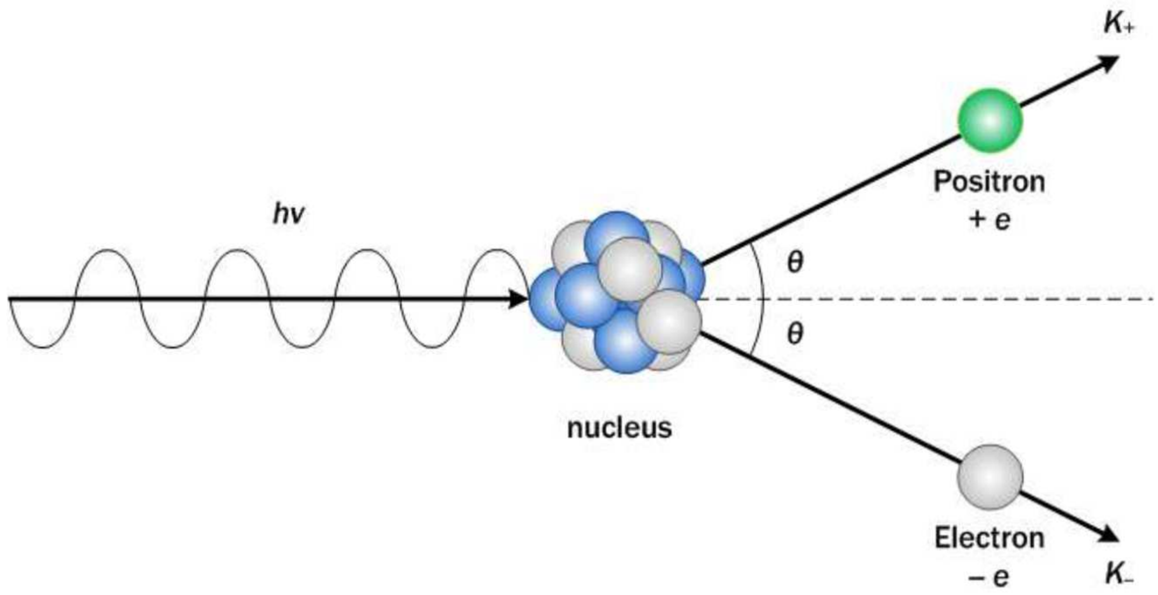
- **Incident photon ejects** an electron from an atom and a **photon of lower energy is scattered**



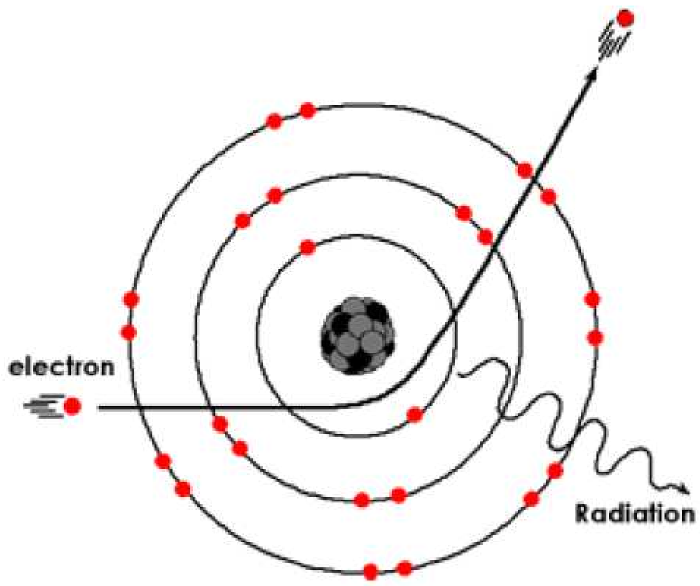
$$\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$$

Particles and photon interaction

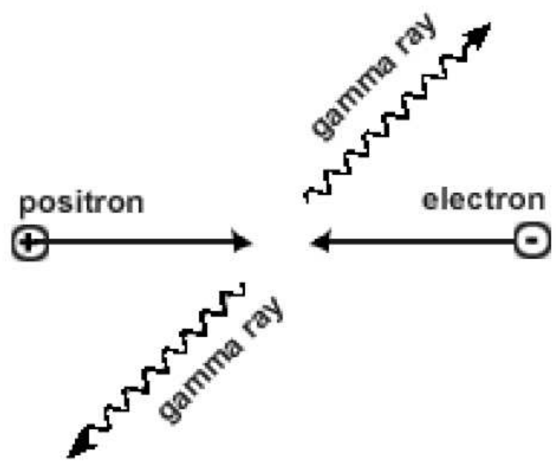
- Electron-positron pair production



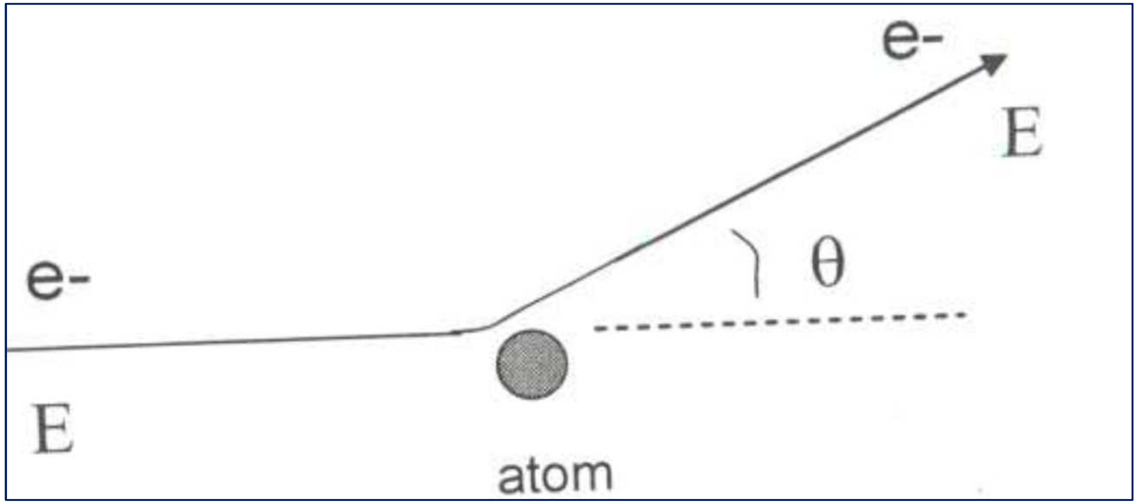
- **Bremsstrahlung**
- Charged particles (light):
  (electrons and positrions)



- **Positron annihilation:**
- $e^{+} + e^{-} \rightarrow 2\gamma$



- **Elastic collision**



- **Inelastic collision**

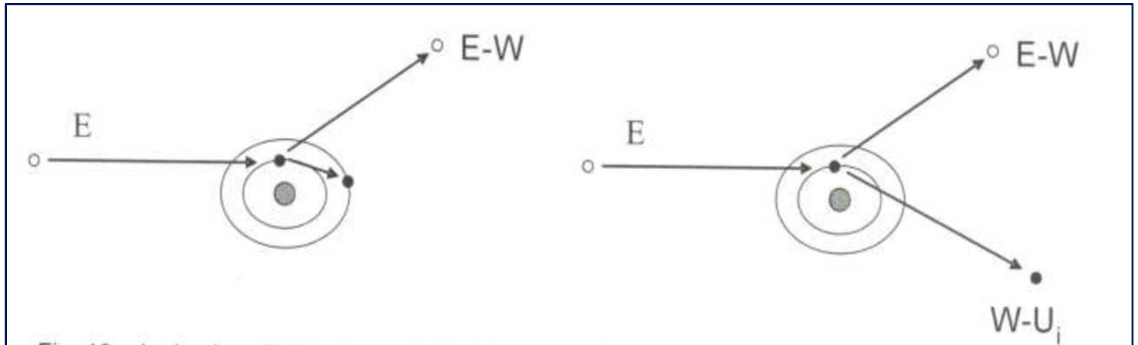
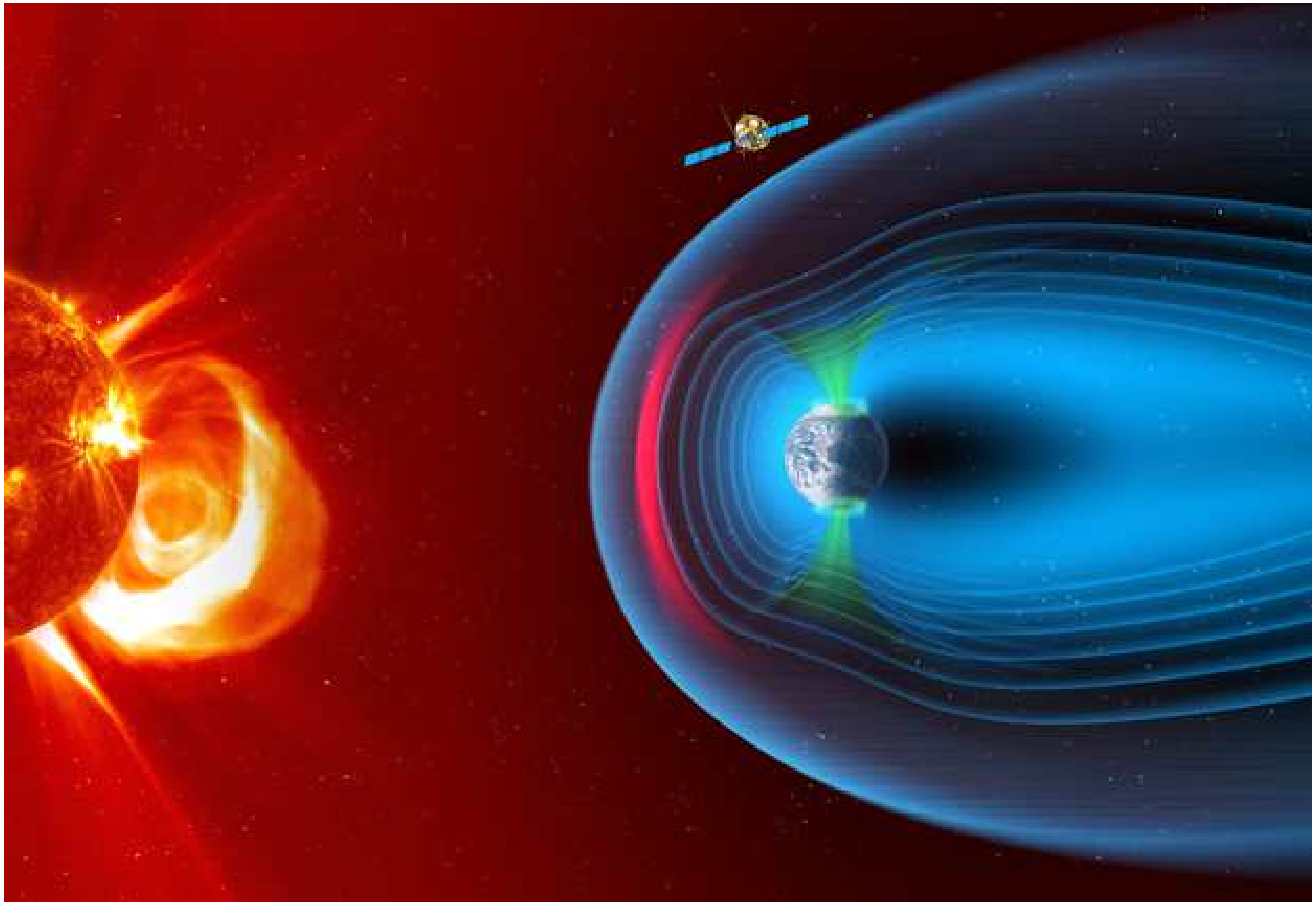
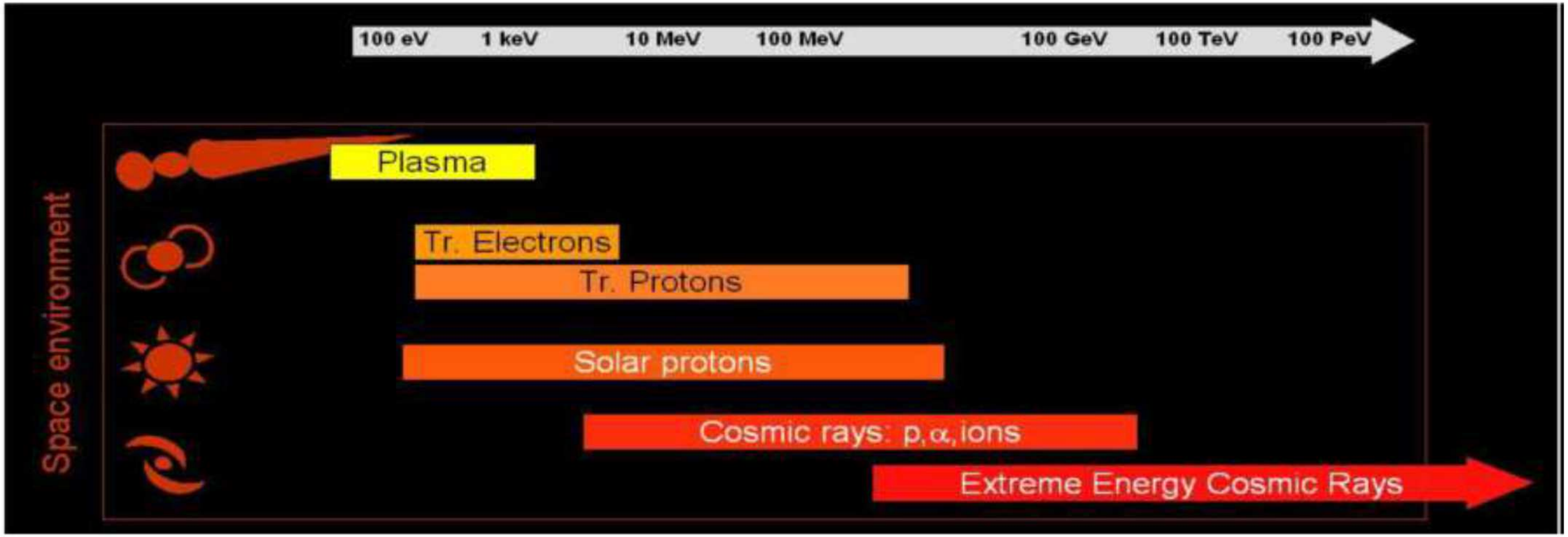


Fig. 13 – Inelastic collision of an electron (or positron) leading to excitation

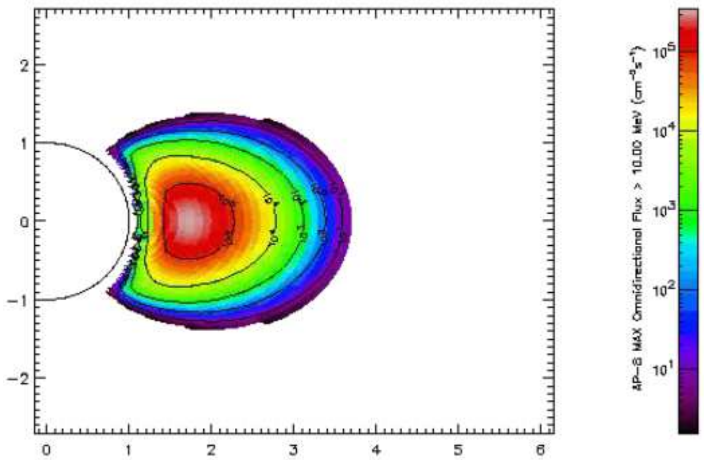
Fig. 14 – Inelastic collision of an electron (or positron) leading to ionization. U_i represents the binding energy.

Solar Wind

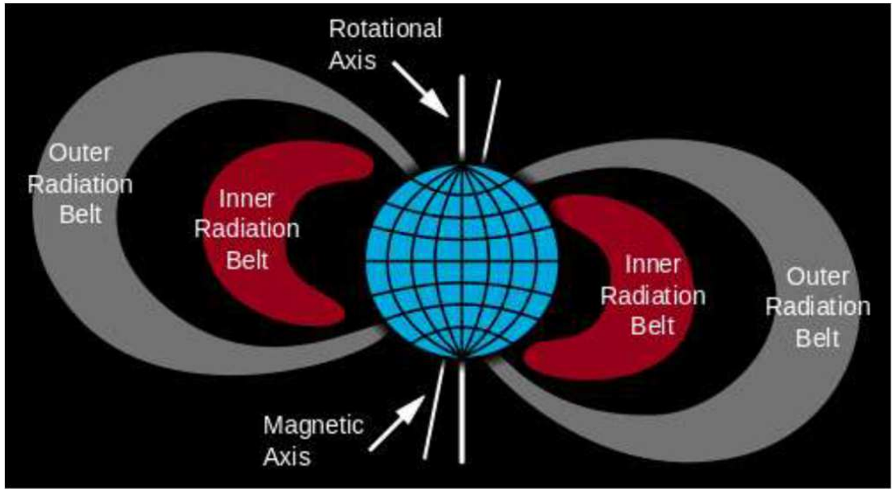


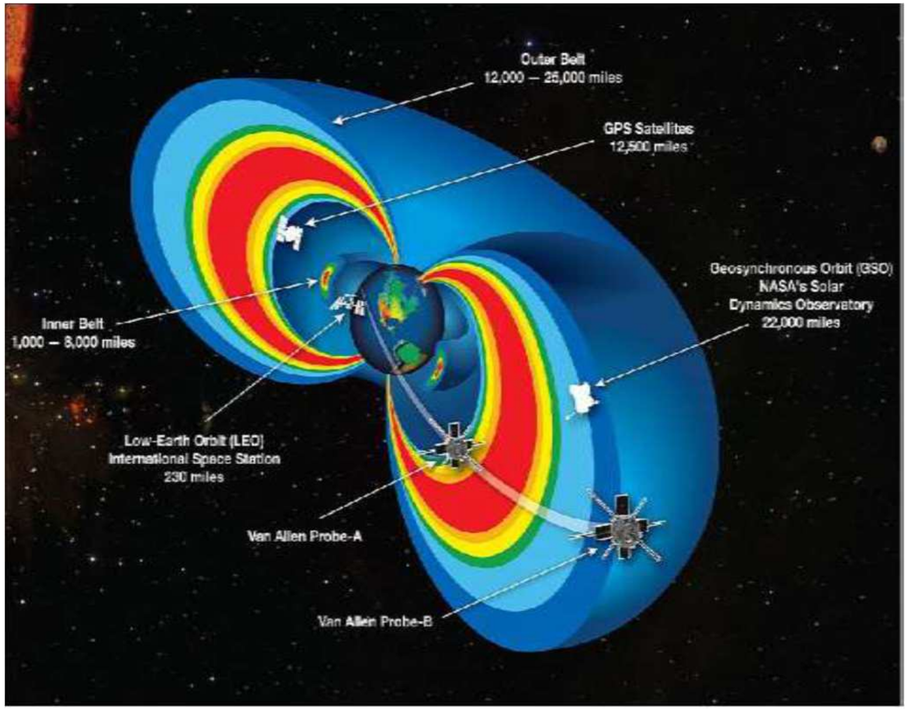

100 eV
1 keV
10 MeV
100 MeV
100 GeV
100 TeV
100 PeV
Space environment
Plasma
Tr. Electrons
Tr. Protons
Solar protons
Cosmic rays: p, α, ions
Extreme Energy Cosmic Rays

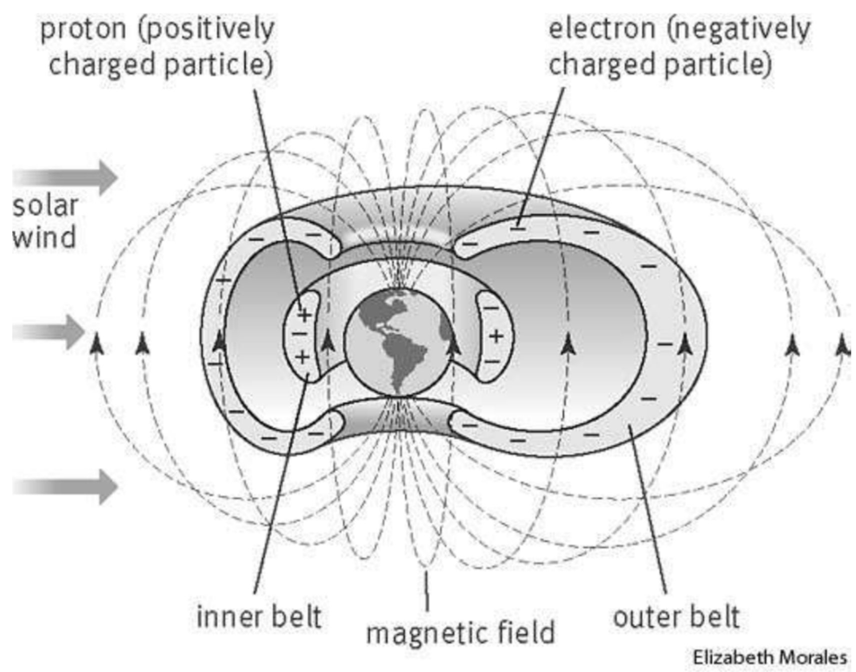
- First US satellite (Explorer 1, 1958) had a Geiger counter onboard
- Trapped electrons and protons (Van Allen belt)



AP-8 MAX integral proton flux >10 MeV. The semi-circle represents the surface of the Earth, distances are expressed in Earth radii





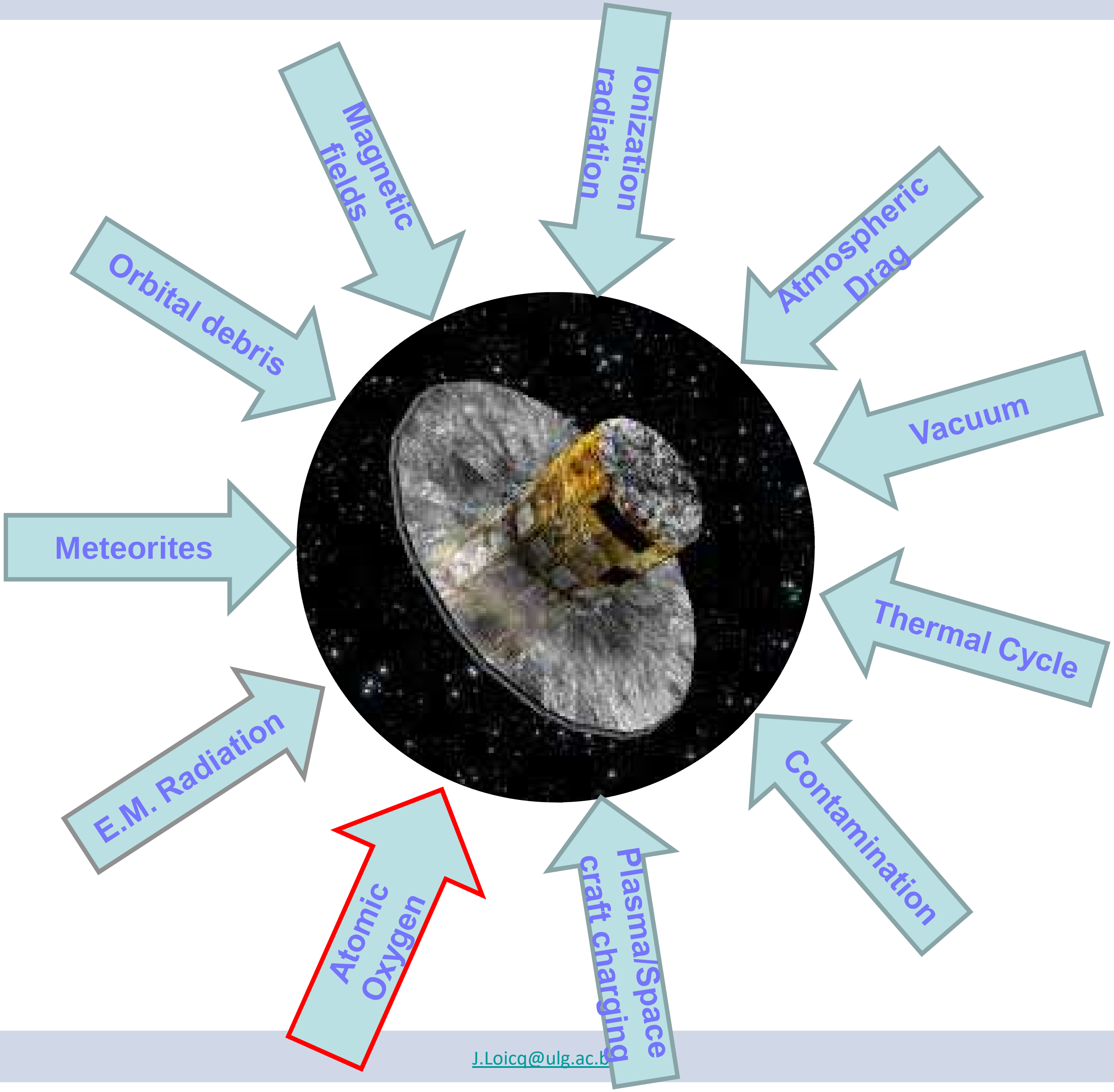


- **1rst belt → Protons**

  700 → 10000 km
- **2d belt → Electrons**

  13000 → 65000 km

- **High velocity moving particles**
  - (electron and proton)


Magnetic fields
Ionization radiation
Atmospheric Drag
Orbital debris
Vacuum
Meteorites
Thermal Cycle
E.M. Radiation
Contamination
Atomic Oxygen
Plasma/Space craft charging

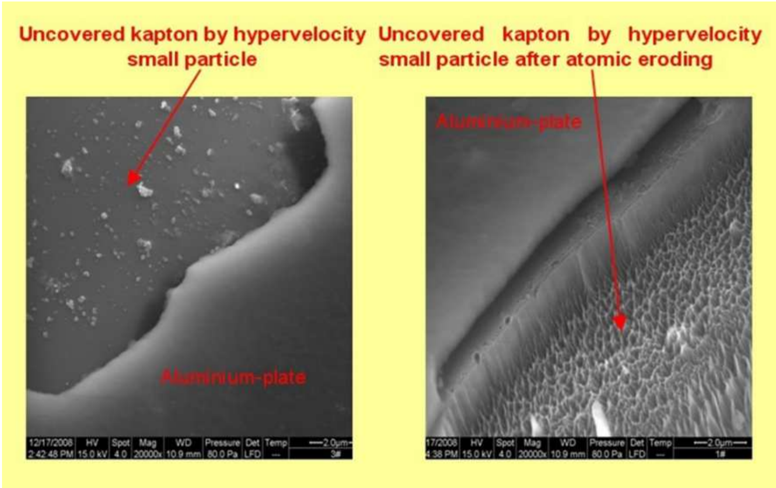
Atomic Oxygen

Kapton

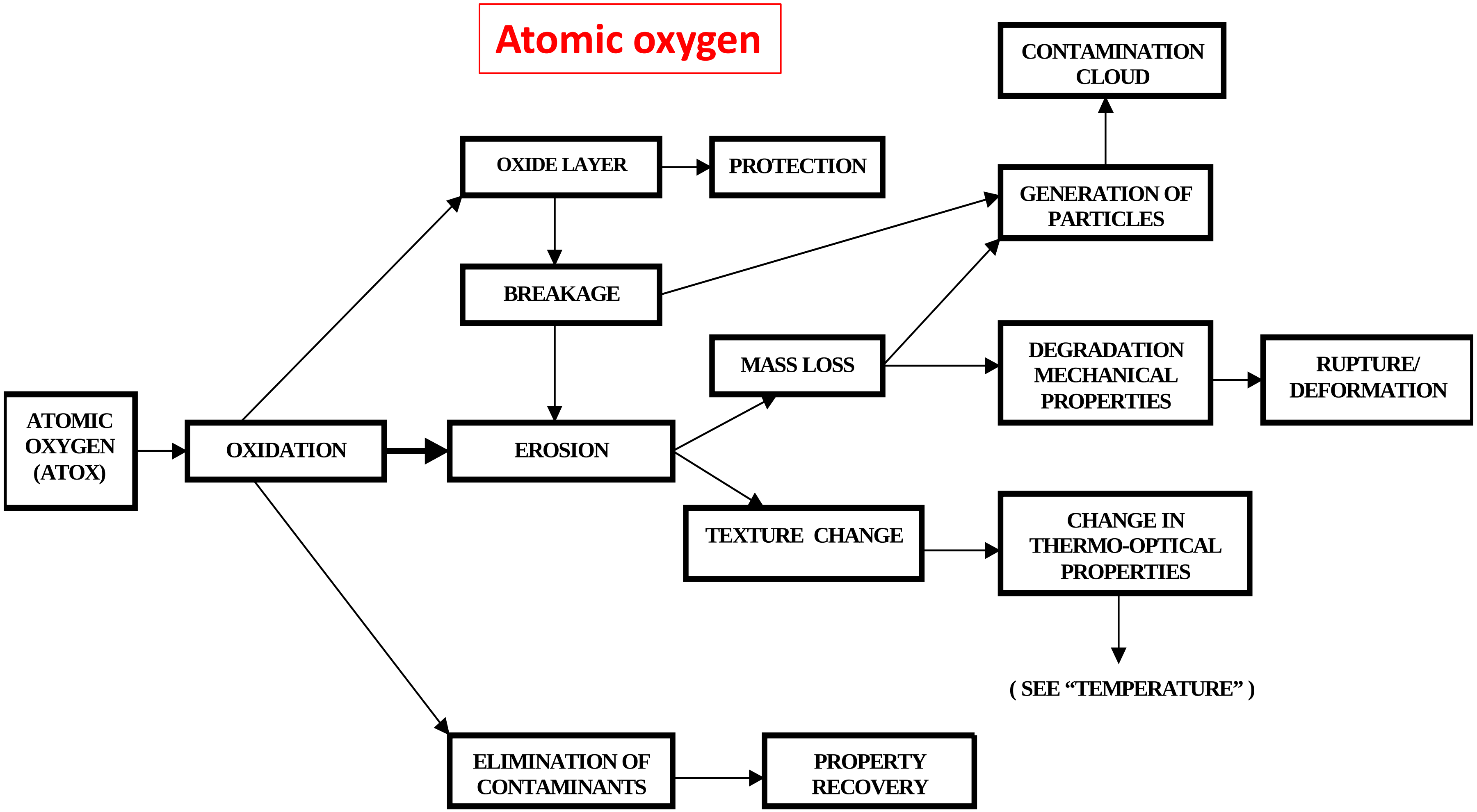
Silver

Atomic Oxygen

- **Atomic oxygen:**
  - Photo-dissociation of molecular oxygen in the upper atmosphere (200 → 700 km)
  - Density of 10^7 to 10^8 atom/cm^3 at ISS altitude
  - Small molar mass, so present at high altitudes
  - Aggressive: organics, metals and composites
  - Malfunctioning of sensors
- **The flux of atomic oxygen interacting with the S/C depends**
  - on the atomic oxygen density,
  - the relative spacecraft velocity
  - the orientation of spacecraft surfaces.

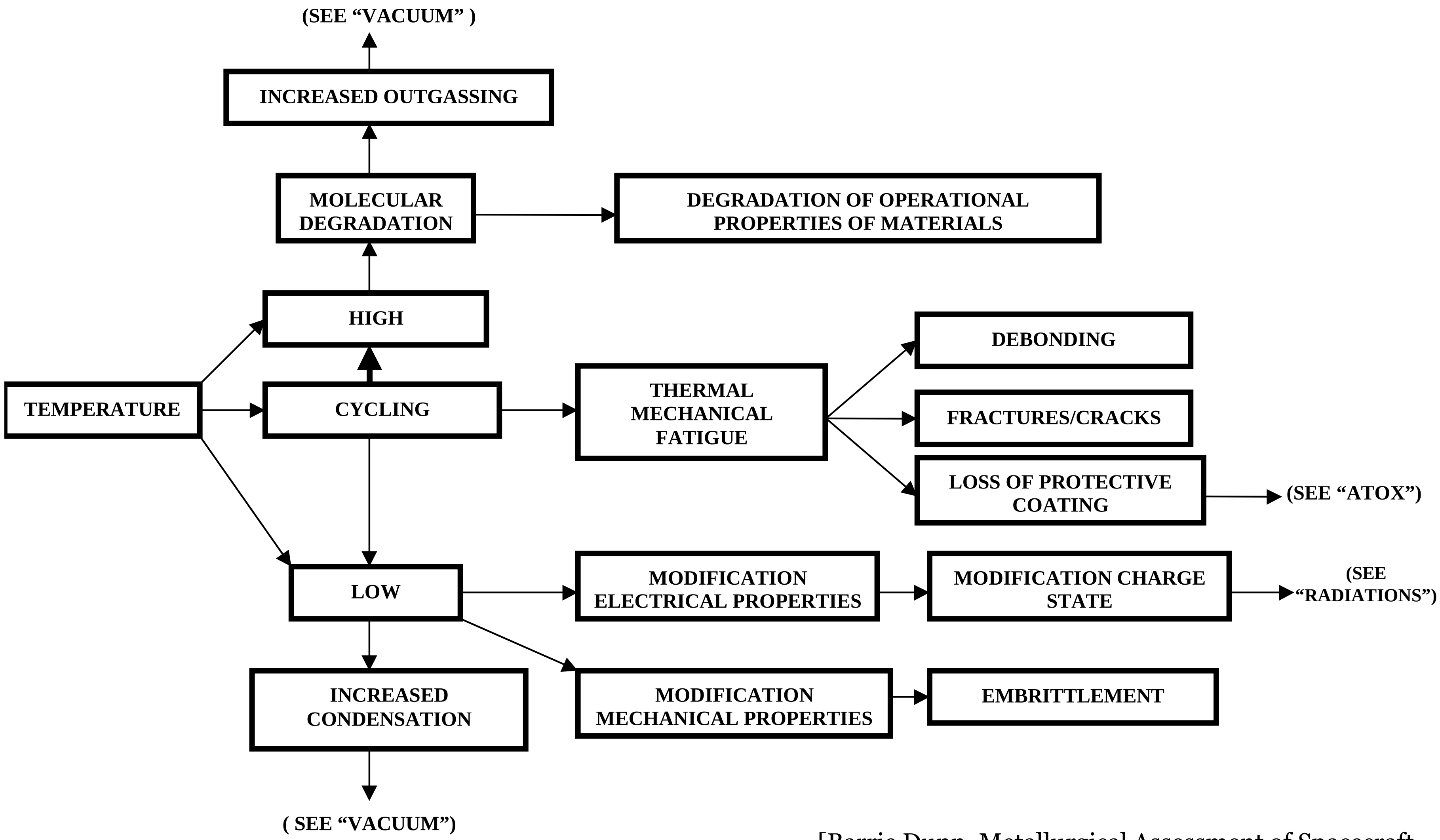


Effect of the space environment: summary

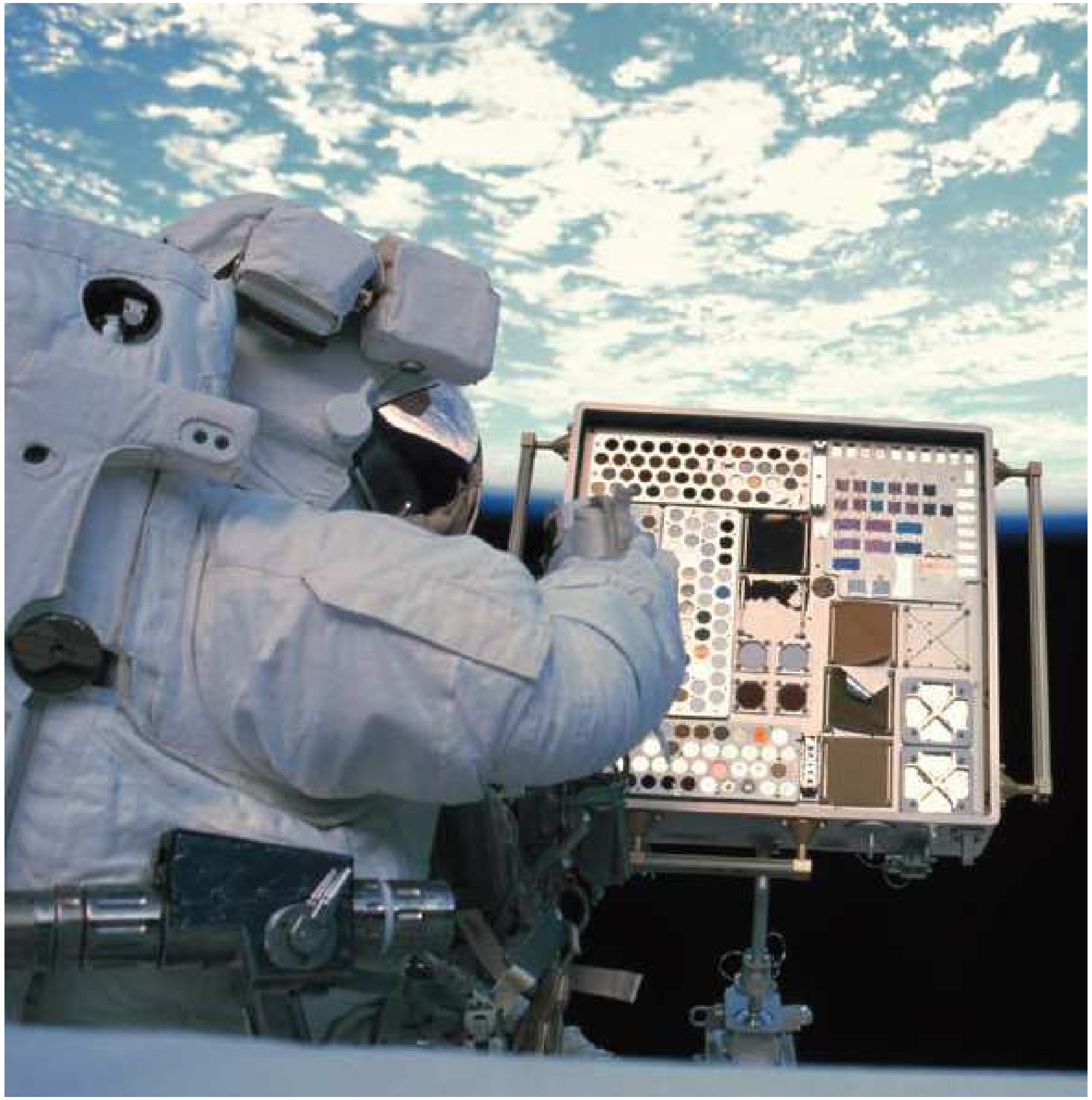


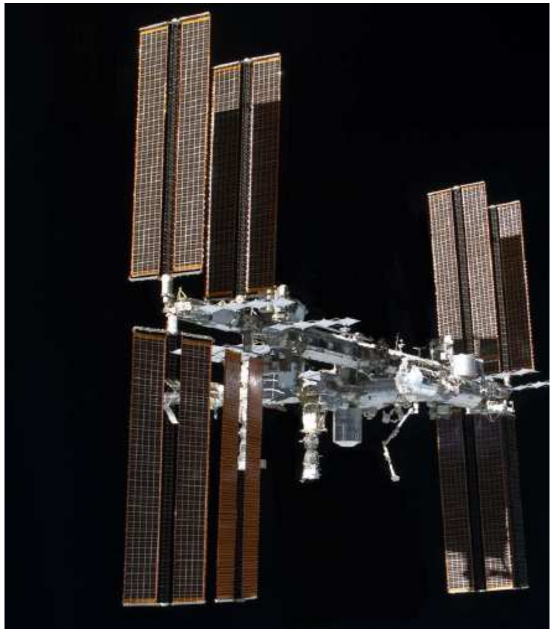
[Barrie Dunn, Metallurgical Assessment of Spacecraft Parts Materials & Processes, Praxis Publishing, 1997]

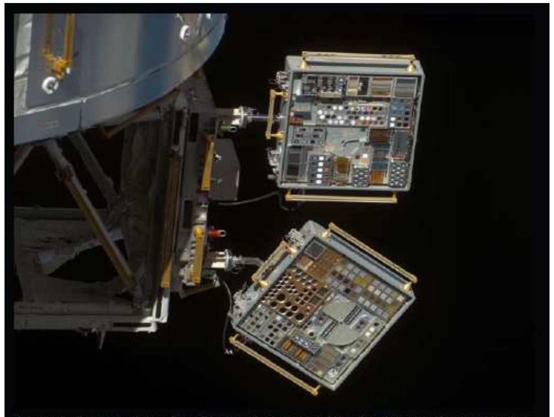
Effect of the space environment: summary



[Barrie Dunn, Metallurgical Assessment of Spacecraft Parts Materials & Processes, Praxis Publishing, 1997]

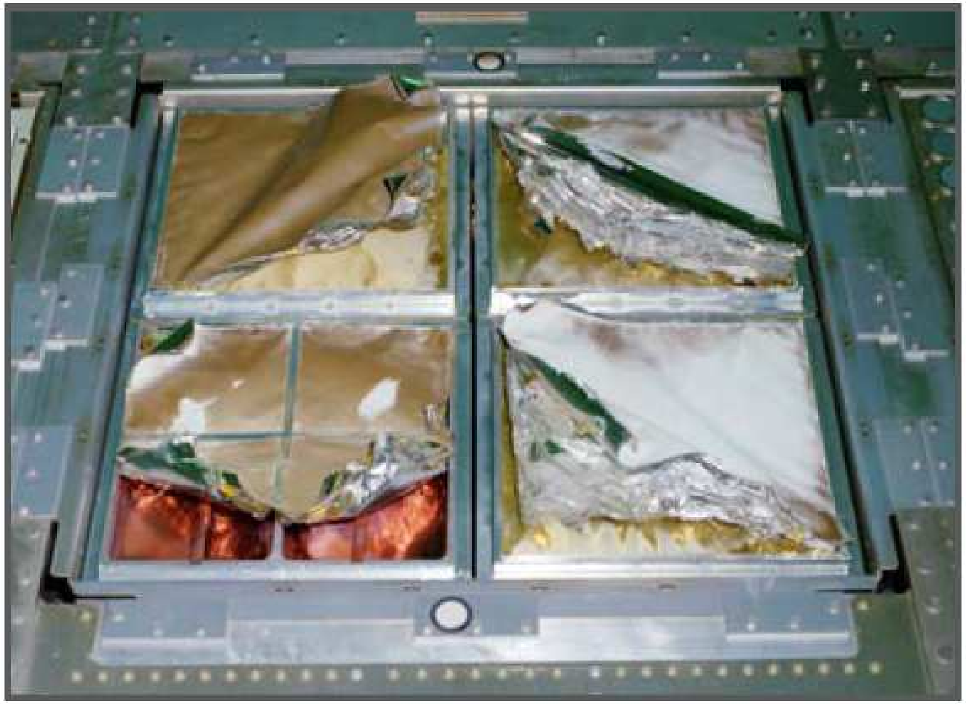






Close-up view of the Materials International Space Station Experiment (MISSE) 6A and 6B Passive Experiment Containers (PECs) on the European Laboratory/Columbus. Photo was taken during a flyaround of STS-123 Space Shuttle Endeavor.

Preflight



Postflight

Figure 1. Preflight and postflight Long Duration Exposure Facility M0001 Heavy Ions in Space experiment, indicating atomic oxygen erosion and ultraviolet degradation.

Large radiation-induced cracks in the outer layer of multilayer insulation after 6.8 years of space exposure (Townsend et al., 1999).

Severe degradation to the aluminized-Teflon® outer layer of multilayer insulation after 19 years of space exposure (Yang and de Groh, 2010).

Figure 2. Space-exposure damage to Hubble Space Telescope multilayer insulation.

Figure 9. Postflight photograph shows an room temperature vulcanization sample from the Long Duration Exposure Facility A0171 experiment with deposited silicone contaminant on baseplate and sample. Also note oxidized silver fastener.


Thank you for your attention