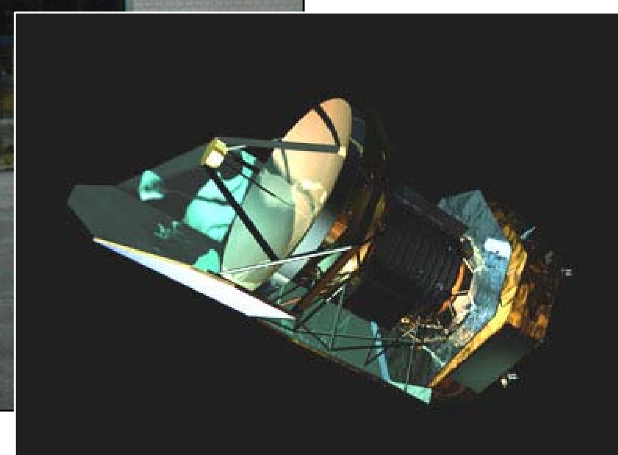
Micro-technology for Space Mission

Packaging M(o)ems Reliability



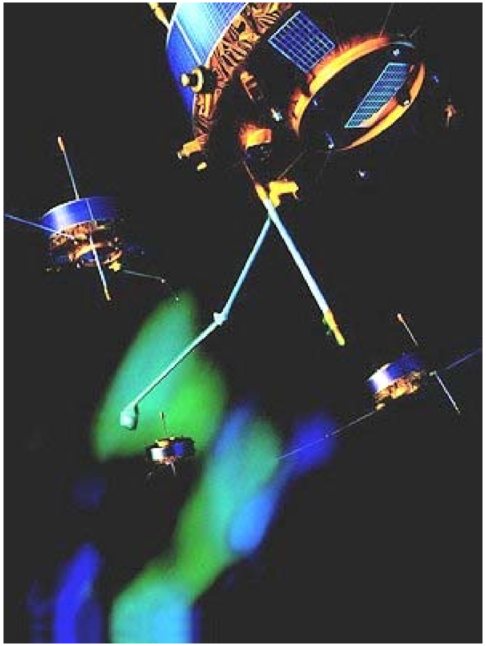
Plan

- **Introduction**
- **Space environment**
  - Definition
  - Problems evaluation
  - Reliable materials for space
  - Solution from space heritage
  - Space design guidelines
- **Space qualification for Micro technology**
  - Downscaling
  - James Webb Space Telescope
  - Test-sequences and CSL facilities
- **Conclusions**

Introduction

- Why space mission can be interested with micro-technology?

  - Size, mass, power consumption are constrained in S.M.
  - Launching (10 000 to 100 000$/kg)
  - Increase interest to “nano-satellite”
    - » Network of very small satellites



Space environment requirements

- **Thermal environment** (-150°C to 150°C)
- **Vacuum** conditions induce **outgassing** and **contamination**
- **Energetic charged particles** and **plasma**
- **Atomic oxygen**
- **Micrometeoroid** and Space debris
- **Vibration**

Failure mechanism induced in space environment

- Temperature cycling (between -150 to +150°C)
  - Fatigue
    - decreases the performance of lubricant
    - decreases the life-time of thermal control fluids
    - induces vibration of solar panel and destabilization of spacecraft
  - Internal stress
    - poor **Thermal Expansion** matching => internal stress
  - Metal packaging
    - CTE 10 times greater than silicon =>fracturing of the substrate
  - Semiconductors
    - modification of mechanical, charge transport properties

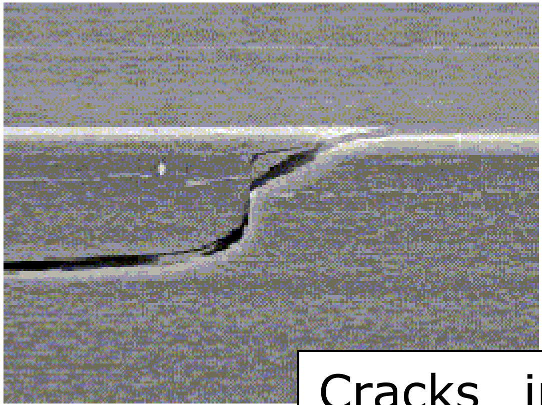
- Vacuum effects
  - mechanical trouble
    - especially for movable sections
    - cold welding: pieces manufactured in the same metal are joined together
  - contamination by outgassing (release of a gas trapped or frozen in some materials)
    - diminishing performance of optical elements
    - off-axis radiation scattering
    - increasing mirror scattering
  - contamination by sublimation or vaporization
    - loss of structural material

Contamination

- Contamination understanding:
  - Outgassing from warm surface
    - Condensation on colder surface
    - Contaminant layer is fixed with UV radiation
  - Otherwise, not permanently attached
    - Contaminant darkens with UV (optical loss is cumulating absorptivity and layer thickness increases)
    - Heating the surface vaporizes the contaminant (only when not permanently attached by UV)

Failure mechanism induced in space environment

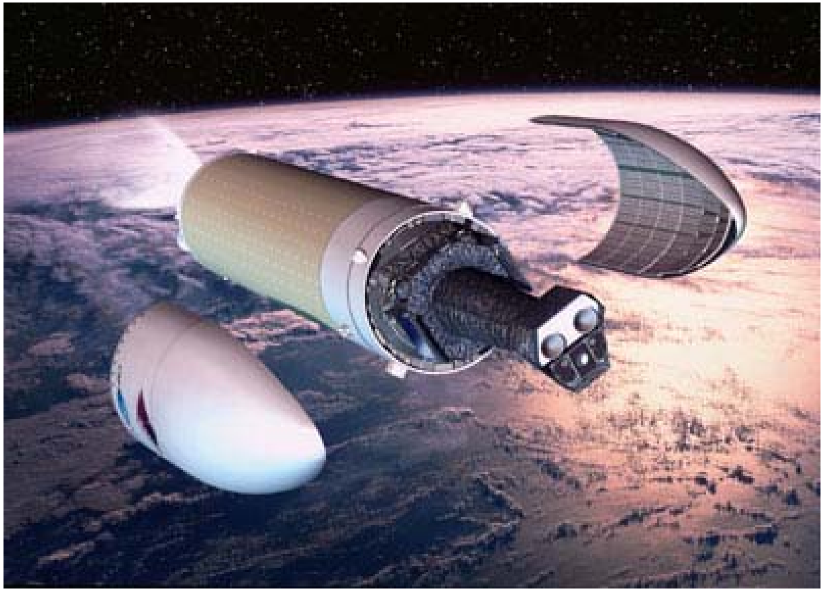
- Vibration (launch process)
  - surface adhesion
  - fracturing



Cracks in single crystal silicon support beams caused by vibrations induced by a launch simulation

Failure mechanism induced in space environment

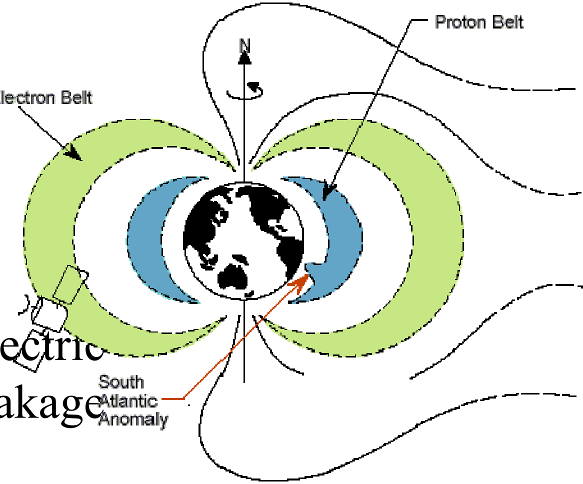
- Shock (during launch or transient mission phase)
  - high stress
    - buckling of long and slender structure
    - plastic deformation of structures
    - fracture in brittle components
  - high acceleration
    - vibration of relays
    - slip of the potentiometers
    - loss of bolts
  - excessive displacement
    - broken solder joints
    - cracked PC boards and wave guides
  - shock environment
    - electrical malfunctions in capacitors, crystal oscillators...



Failure mechanism induced in space environment

- Atomic oxygen
  - formation of insulation compound at surfaces =>increase of power loss
- Charged particles
  - electrostatic discharge with catastrophic effects on electronics circuits
- Space debris
  - the impact of fast moving particles can vaporize of fragments pieces

Failure mechanism induced in space environment



- Radiation
  - Ionization
    - creation of electron hole pairs within dielectric =>flatband threshold voltage shift, surface leakage current,...
  - Displacement
    - atom in crystal lattice are displaced by energetic particles => thermal dark current, loss in charge transfer efficiency, increased current in reverse biased junction...
  - Single event effect
    - interaction of single particle (p+, e-,…) with semi conductor => dark current generation centers

- Experience of **Space Solar cell**
  - The best semiconductors materials:SiC, GaAs, InP and combinations
    - » lowest reactivity with high energy radiation
  - Solar cell packaging
    - – **Borosilicate glass** with a nominal 5% of **cerium dioxide**. This ceria **stabilizes** the glass **preventing** the formation of **color centers** under electron and proton irradiation.

- Optical material
  - Radiation induce Color center ⇒ Reduction of optical transmission properties

Space design guidelines

Material selection: CTE mismatch should be avoid, radiation shielding foreseen and contamination understanding

Venting holes: the outgassing products are guided through venting holes (ie Multi Layer Insulator). The outgassing is decreased by performing a prior bake out of by flushing with dry nitrogen during storage.

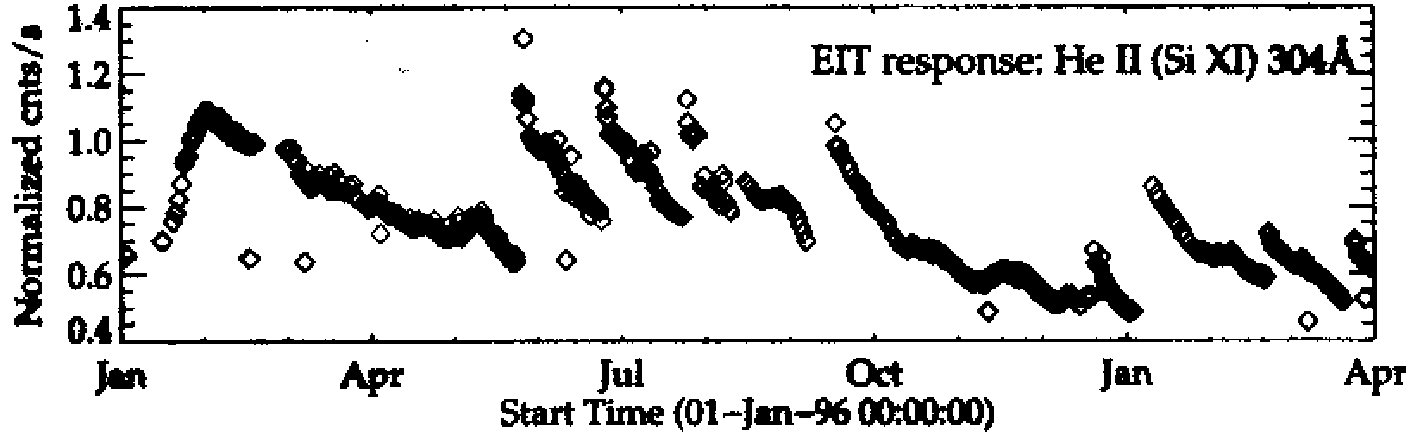
Cold traps: collect contaminants and depend on the sticking coefficient (ie at 120K 100% of water molecules stick

Chemical getters: trap particular molecules, especially water; zeolith getter are also successfully used

Heaters: if contamination is not fixed to the surface (by UV cross-linking), active heating may decontaminate (but require hit level of power consumption)

Example of contamination

- Space Heritage: EIT (SOHO)

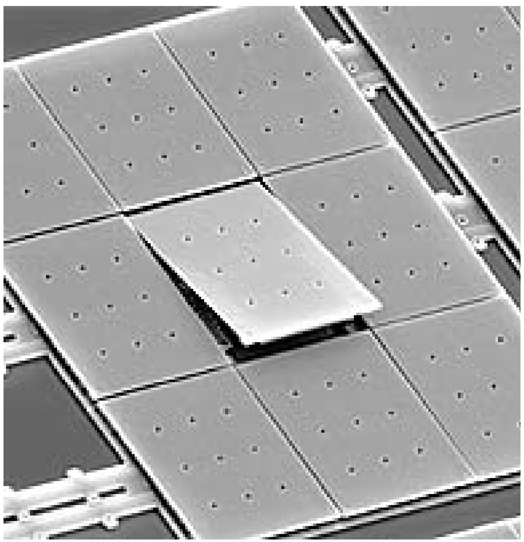


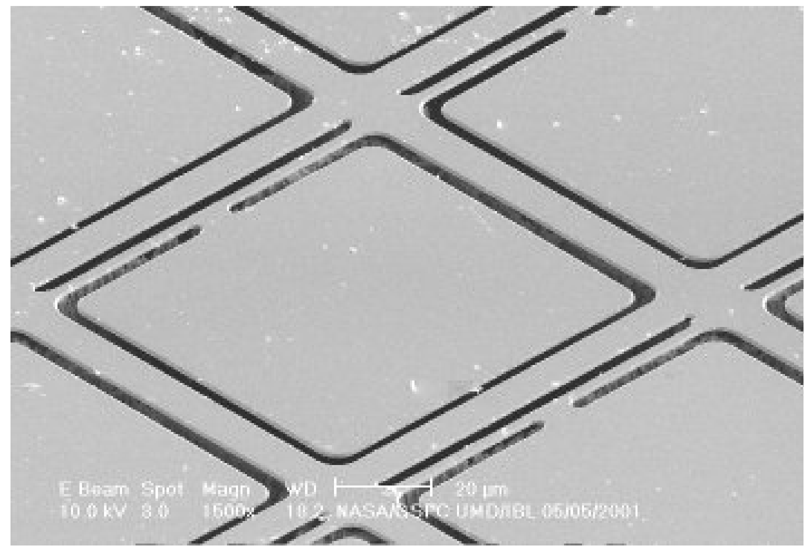
  - Loss related to ice contamination on CCD surface
  - Heating (~1 day) retrieves the sensitivity by sublimation
  - No venting holes in the vicinity: ice re-condensing
  - Periodic cleaning
  - Partial recovering only (other aging effects)

- Package sealing: Hermetic or not hermetic?
  - Sealing protects from contamination and moisture from the outside world
    - During space mission, hermetic is not required (vacuum)
    - During AIT: hermetic is the best but flushing with dry nitrogen is a alternativ solution
  - Sealing confines potential contamination inside the MOEMS
    - Venting holes in the vicinity of outgassing surface reduces the inner contamination vapor
    - Heaters could help vaporization on contaminant (see EIT)

Downscaling

- Example: James Webb Space Telescope (JWST)
  - NIRSpec: IR spectrograph with MOEMMicro Mirro Array (MMA) ⟺ Micro Shutter Array(MSA





MSA is finally selected for maturity reason...

- MMA Improvement exercise:
  - Mirror potential optical degradation:
    - Coating reflectivity loss (contamination)
    - scattering increase (contamination)
    - flatness degradation (thermo-mechanics)
  - Potential design solutions
    - Without protective window
      - » UV rejection forward in the light path
      - » Heater attached to the rear side of MMA
      - » Radiation shielding: no improvement
    - With Protective window (radiation resistant glass)
      - » UV rejection filter + AR
      - » Additional radiation shielding
      - » Contamination issue more complex but solutions

Space qualification Test

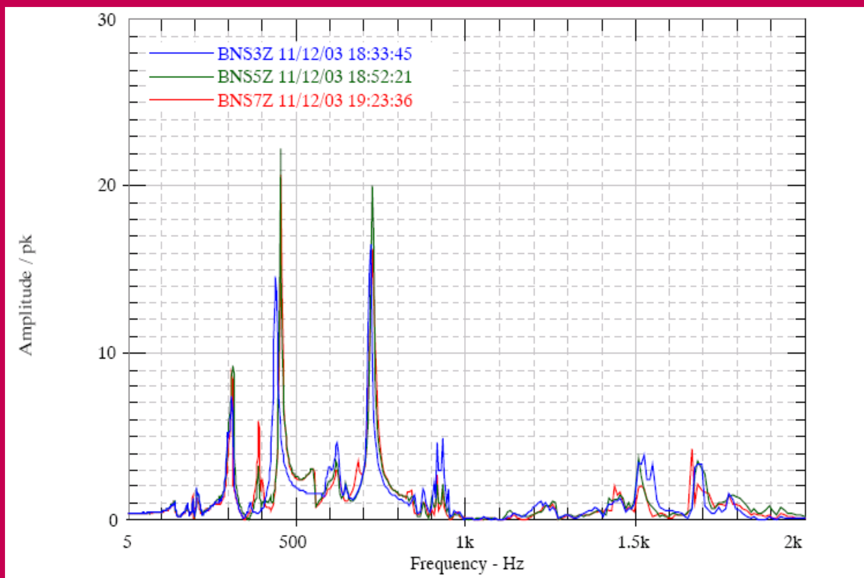
Space qualification stress the equipment to get confidence that it will survive the rigorous launch and will operate correctly in severe space environment

Current (terrestrial) tests:
- physical measurements
- electromagnetic compatibility
- visual inspection

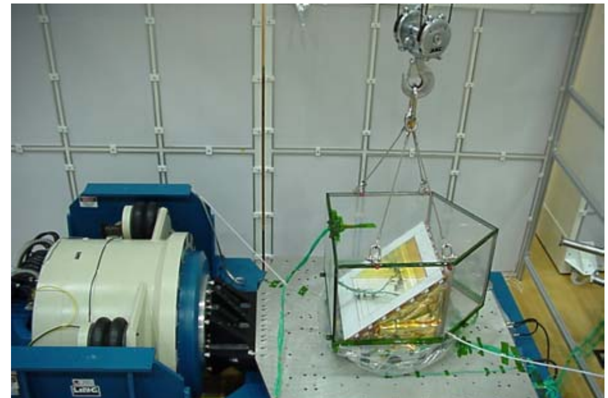
Space qualification additional tests
- structural tests (vibration-launch simulation)
- thermal cycling vacuum test
- radiation test

CSL facilities

Vibration (Exp. launch simulation)



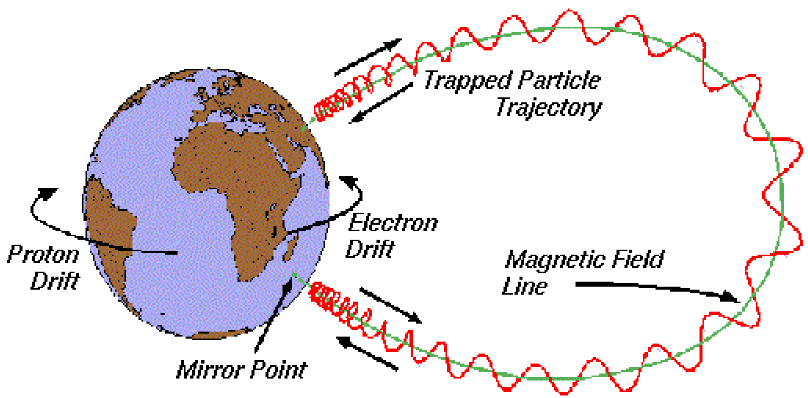
- Thermal cycling under Vacuum and outgassing qualification

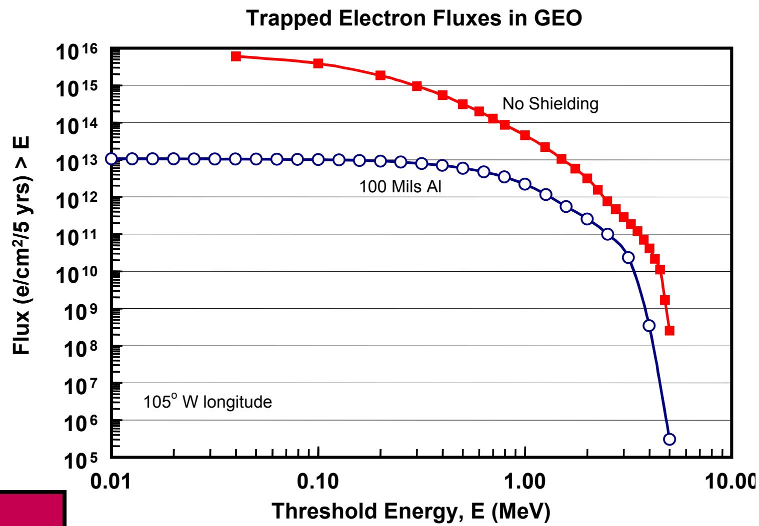


Thermal vacuum testing

CSL facilities

Simulation of radiation reaching spacecraft during the mission





Irradiation and interpretation with partners:

Csl partners	Radiation-particles	Energy
ULG-IPNAS	Protons-Deuterons	100keV-15MeV
UCL	Protons-Neutrons-heavy ions	10-68MeV
SCK-CEN Mol	Gamma-Slow neutron	7-40 MeV
SCK-CEN VUB	Protons-gamma	8-40 MeV
	Deuterons	10-22 MeV
	alpha	22-42 MeV
TU Delft	Electrons	1 MeV