Challenges for Components/Materials in the Space Environment

Dr. Christopher .O. A. Semprimoschnig

European Space Agency (ESA) / European Space Research and Technology Centre (ESTEC)

Materials Physics and Chemistry Section
Materials & Processes Division

Product Assurance and Safety Department
Keplerlaan 1, 2200 AG Noordwijk, The Netherlands

Email: **Christopher.Semprimoschnig@esa.int**
Tel: ++31-71-565-3990

Acknowledgements:
ESA: Staff of the Materials & Processes Division, Staff of the Components Division

Challenges On- Ground

Temperature

Humidity

Atmosphere

Biological

Transport loads

Testing
(Verification/Simulation)

Storage Issues
(Long term,
LOx, MMH, MOH, etc.)

Vibrations

Accelerations

Shocks

Thermal flux & Temperature

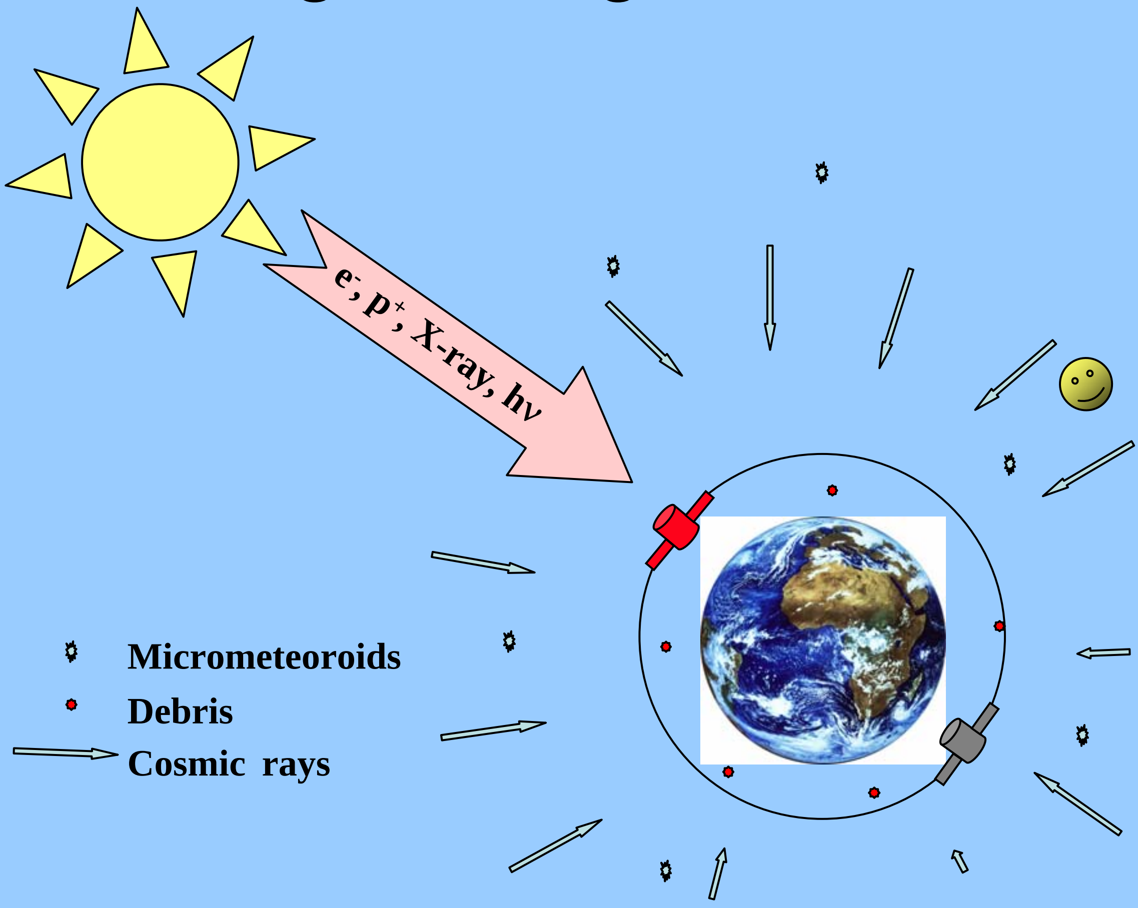
Lightening impact

Rain

Birds


Challenges from the Space Environment
Challenges from the specific Mission Environment

Challenges in flight for a successful mission



Vacuum

Temperature
(isothermal/cycling

Radiation

Space Debris

Micrometeoroids

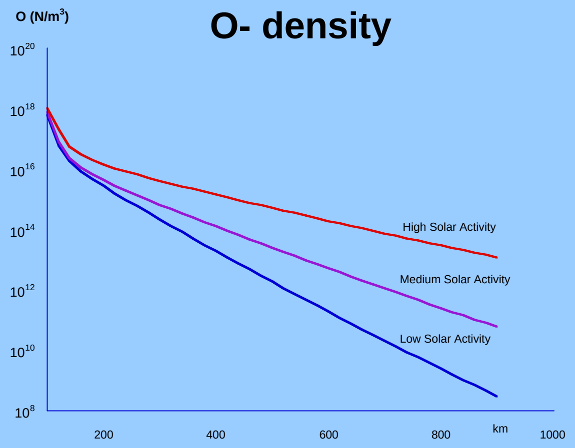
Atomic Oxygen

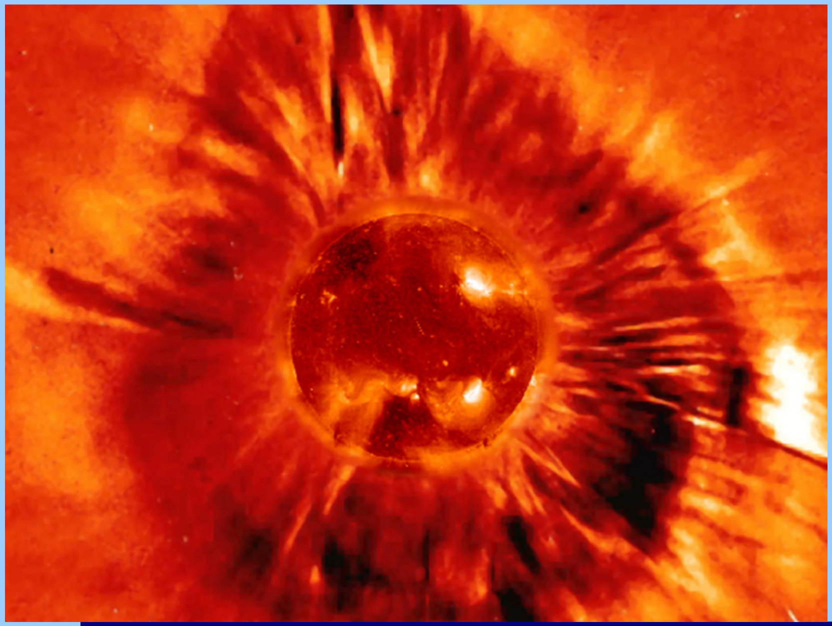
(Manned Volumes)

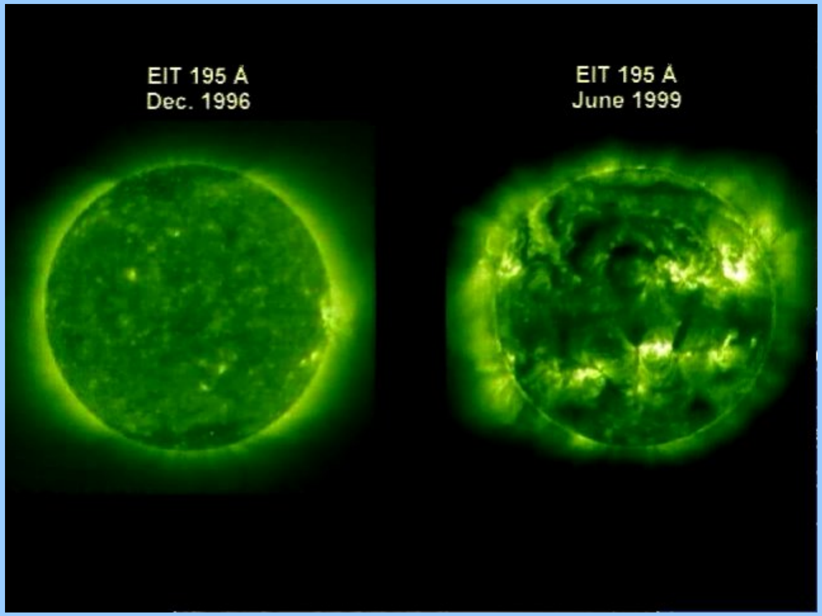
The SUN

- not steady
- Radiation
- Solar Wind
  Electromagnetic radiation

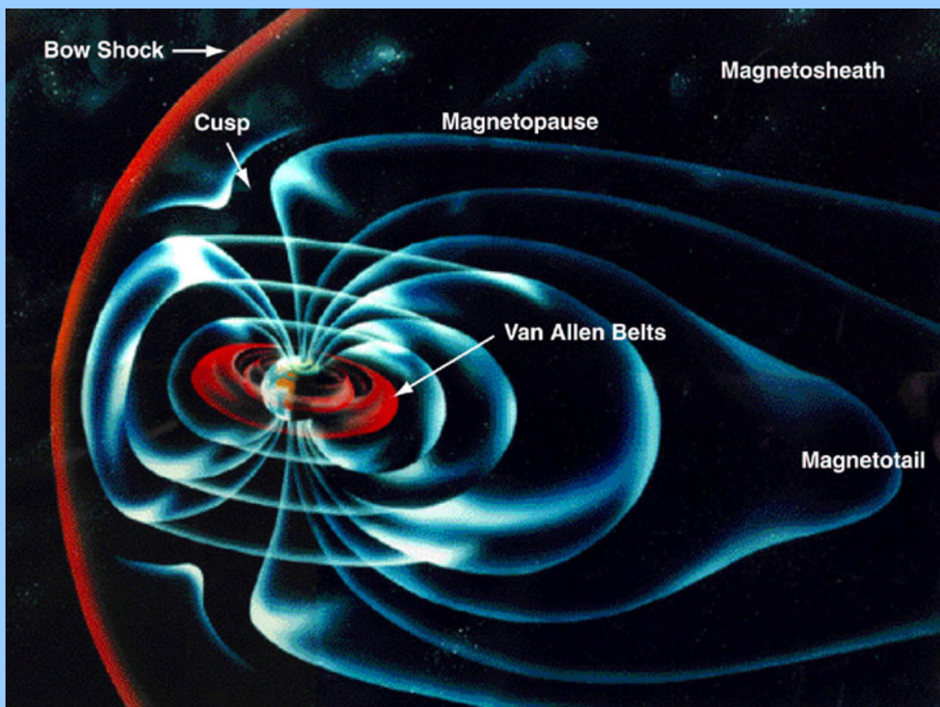
Type	Wavelength [nm]	Earth avg. [W/m2]	Earth w.c. [W/m2]
Near UV	180 – 400	118	177
VUV	< 180	2.3 E-2	4.6 E-2
EUV	10-100	7.5 E-3	1.5 E-2
X-rays	1.0-10	5 E-5	1 E-4
Flare X-rays	0.1 – 1	1 E-4	1 E-3

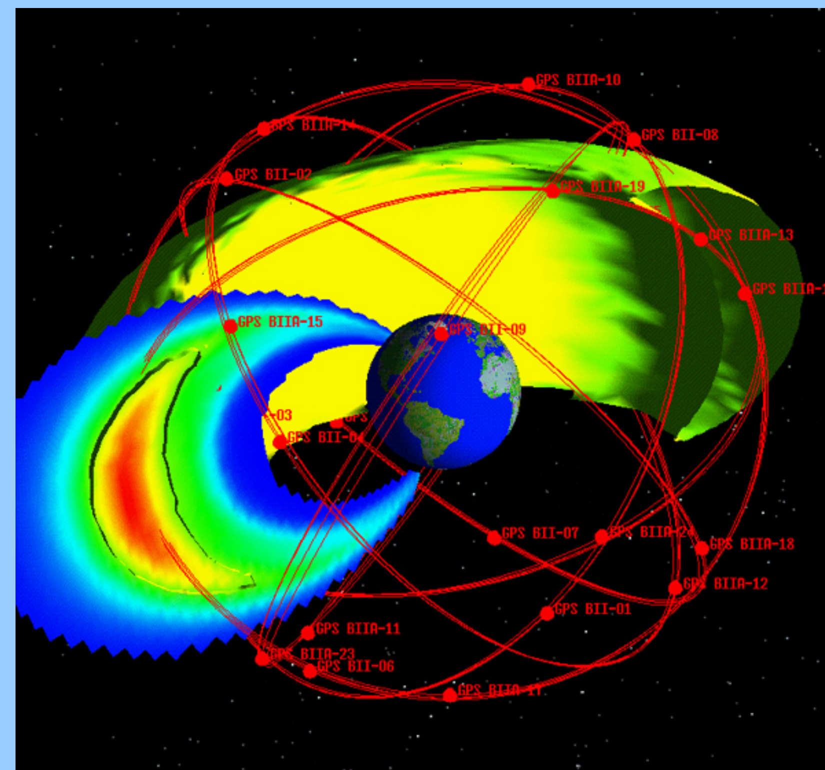






Radiation Fields around Earth

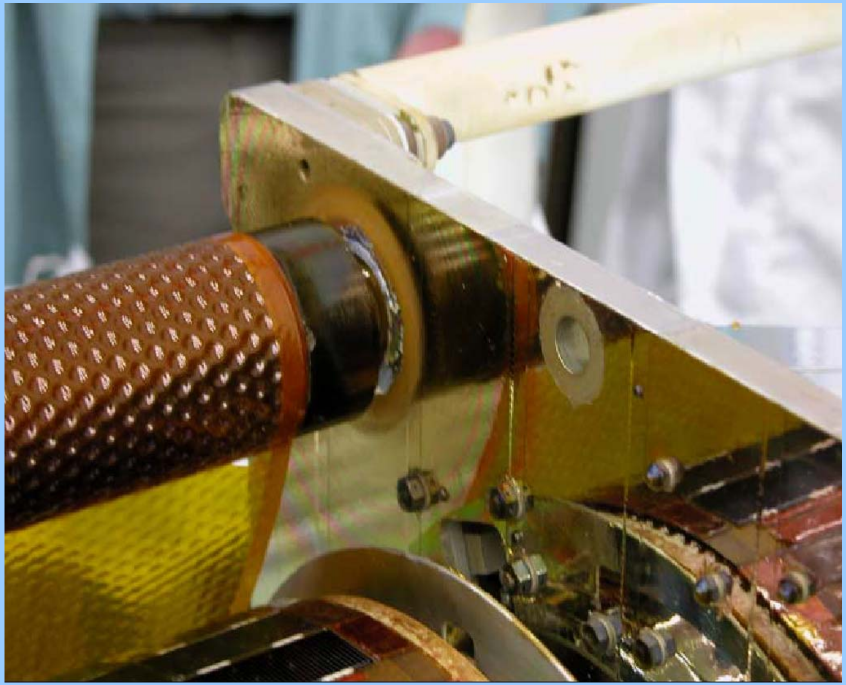


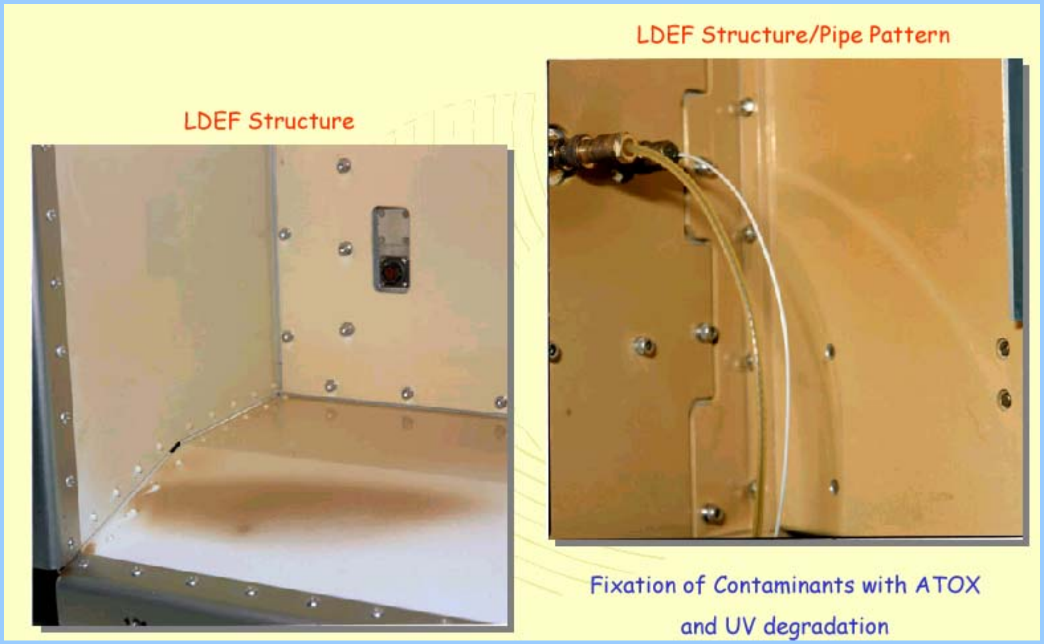


Orbits

	LEO (low earth orbit)	GEO (geostationary orbit)	Planetary missions and Deep Space
Orbit	200 tot 800 km	36000 km	n.a.
Temperature	-100°C to +100 °C; 16 cycles/day	-150 °C to +120 °C; 1 cycle /day	Outer:-180°C to–260°C Inner solar system very hot
Vacuum	10^{-4} to 10^{-9} mbar	10^{-9} till 10^{-10} mbar	till 10^{-14} mbar
Radiation	hν [X-ray (V)UV, Vis, IR] Particles (98 % e^-, 2% p^+, Van Allen Belts)	Van Allen belts (partial), Cosmic Rays, Sun activity	Cosmic Rays, trapped planetary radiation
Impacts	Micrometeoroids / Debris	Micrometeoroids/ Debris	Comets/Asteroids
Atmosphere	Atomic Oxygen	n.a.	Planets (reactive gases)

Contamination patterns from HST & LDEF

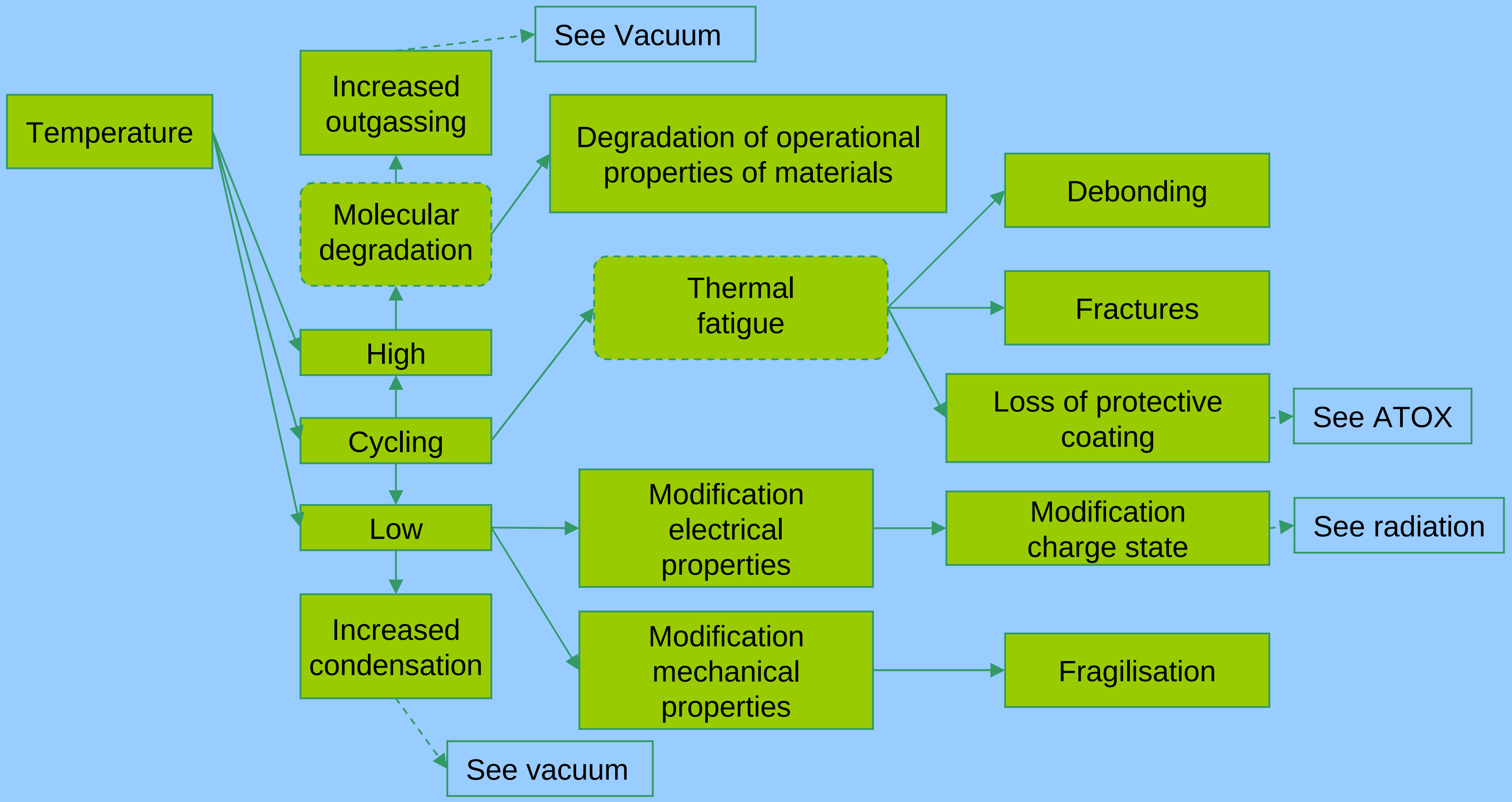




Contamination & Cleanliness Engineering is very important (especially for optical payloads)

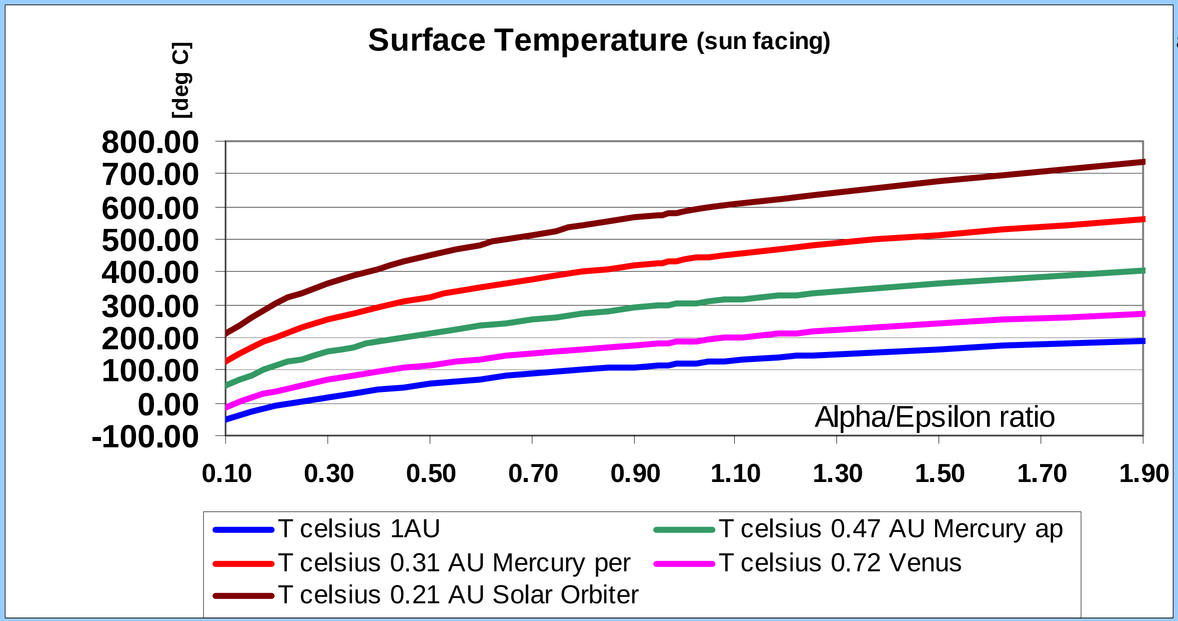
PREVENTION IS BETTER THAN CURE!

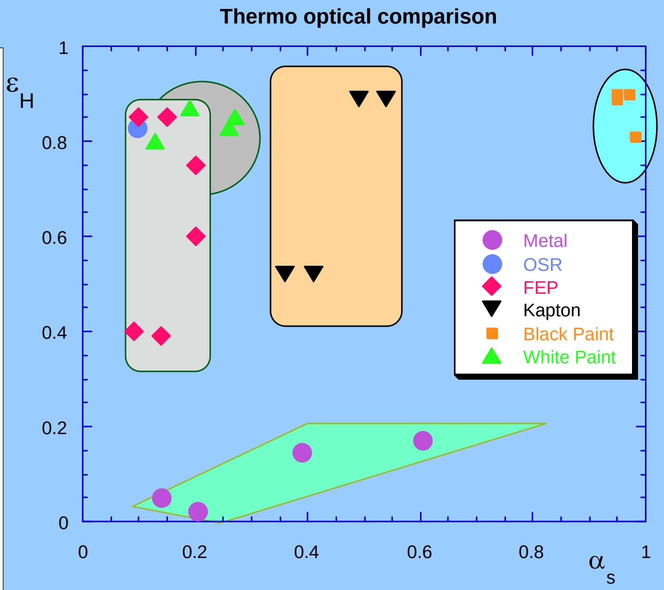
Example of complex interactions



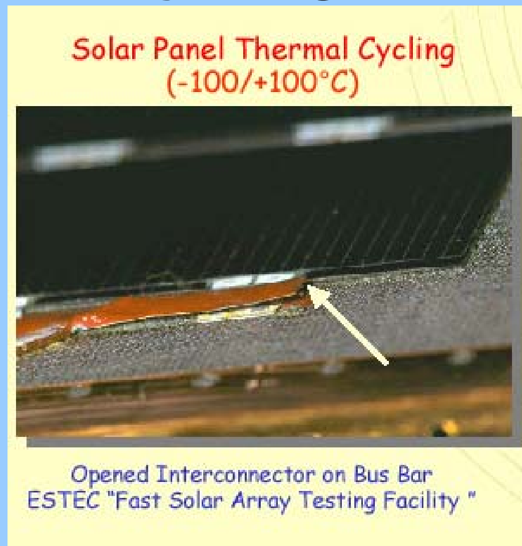
Equilibrium surface temperatures

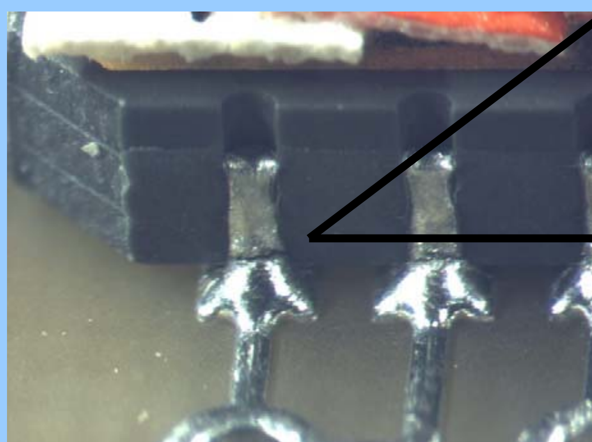
(sketch) as f (thermo-optical materials properties) and sun distance

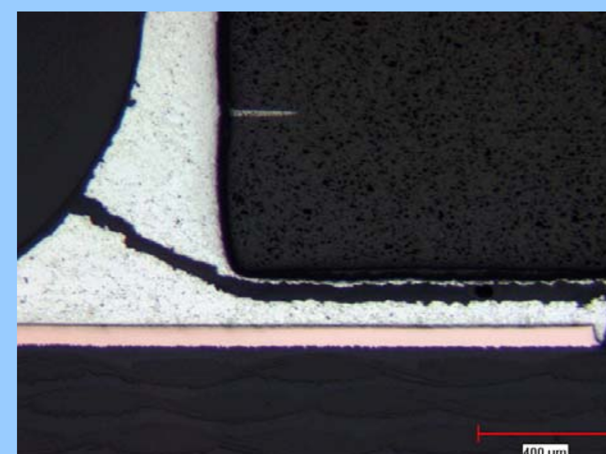




Thermal Cycling: Cracking of joints/connections





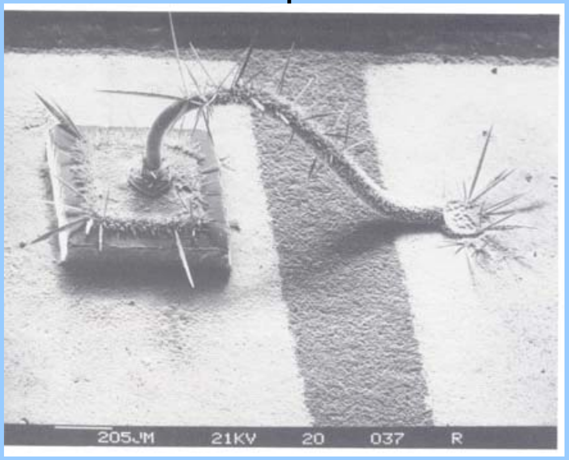


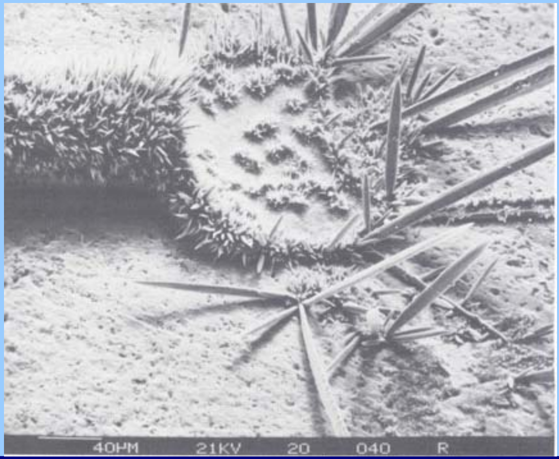
Routine PCB t/c programme: -55C to 100C

Credit: G. Corocher

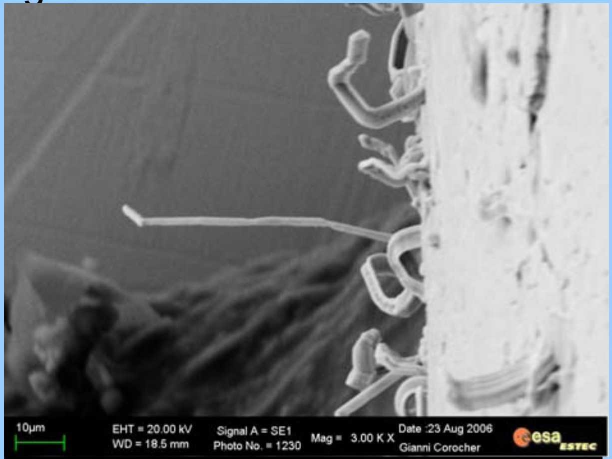
Whisker Growth on leads (components' connections)

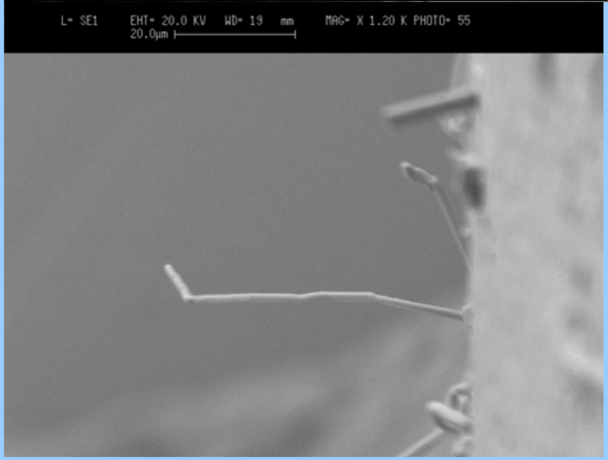
- Whisker growth can be classified into two categories:
- 1) Growth by condensation from the vapour phase – tip is growing
- 2) Growth in the solid phase - bottom/base is growing





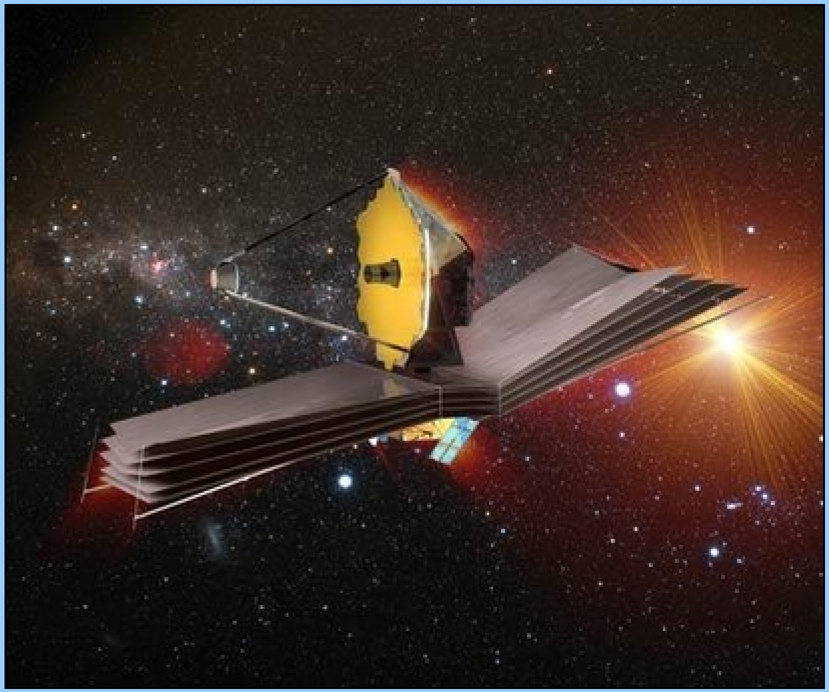
Source: B. Dunn





Credit: G. Corocher

Ultra-stable S/C at ultra-low temperatures



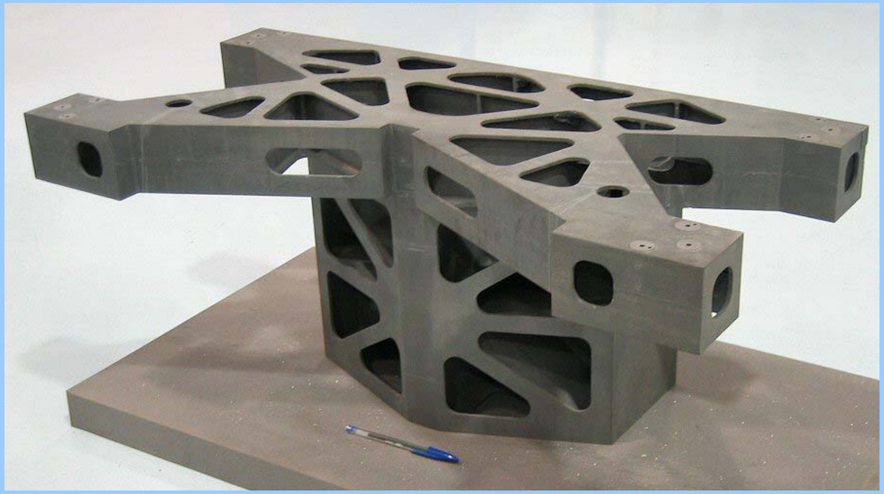
- 3.5m Herschel Telescope
- Operates at 70K

Near Infra-Red Spectrometer for JWST
Operates at 30K

Understanding materials properties at ultra low temperature & processing issues of candidate materials is important

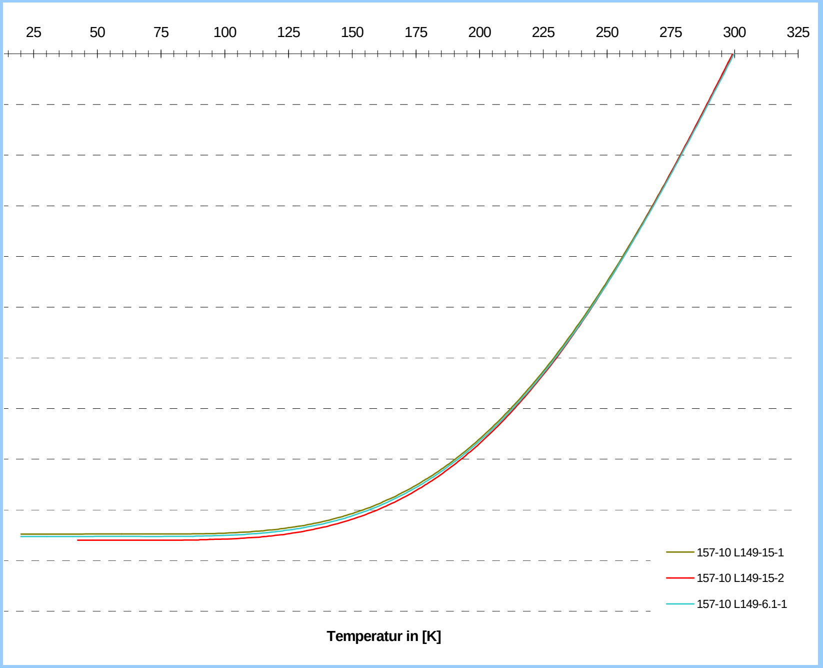
Material characterisation for extreme environments

- Isotropic and reliable CTE (independent of batches, runs and directions)
- Low CTE at ambient : 2,1x10-6m/mK
- Zero CTE between 20K and 100K

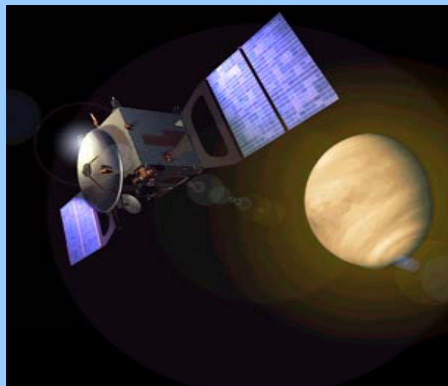


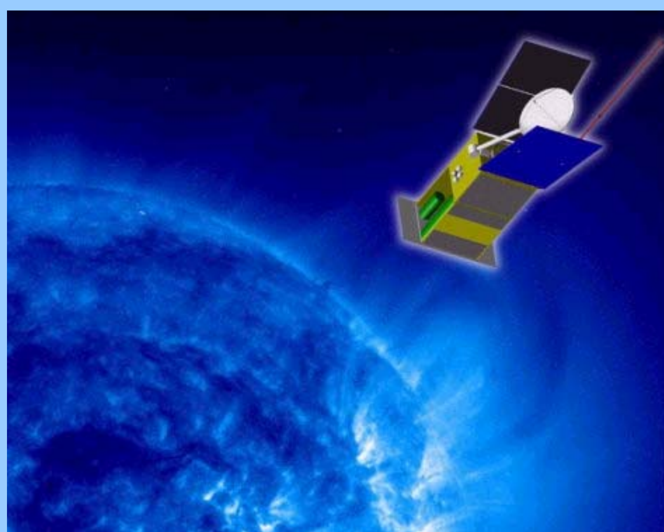
GAIA LOS beam support demonstrator from CeSiC
820 x 395 x 360 mm ; 16,3 kg

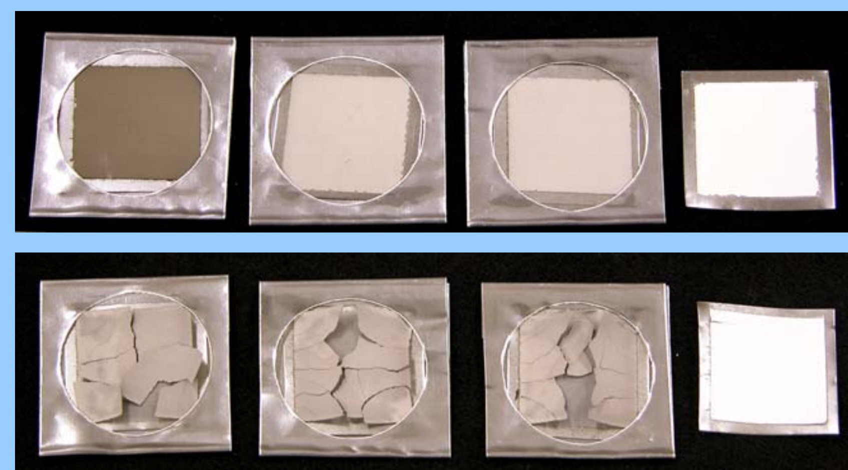
Credit: M. Krödel**, ECM**



Materials for extreme environments



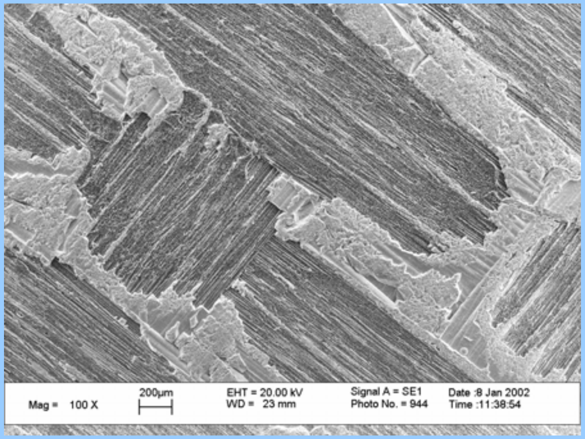


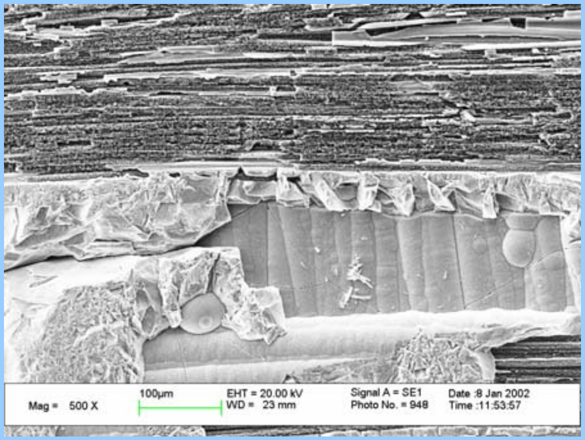


Source: Heltzel, Semprimoschnig, van Eesbeek 10th ISMSE & submitted to AIAA

Re-entry

Challenges with coatings on CMC materials





Inflatable Re-entry Ideas

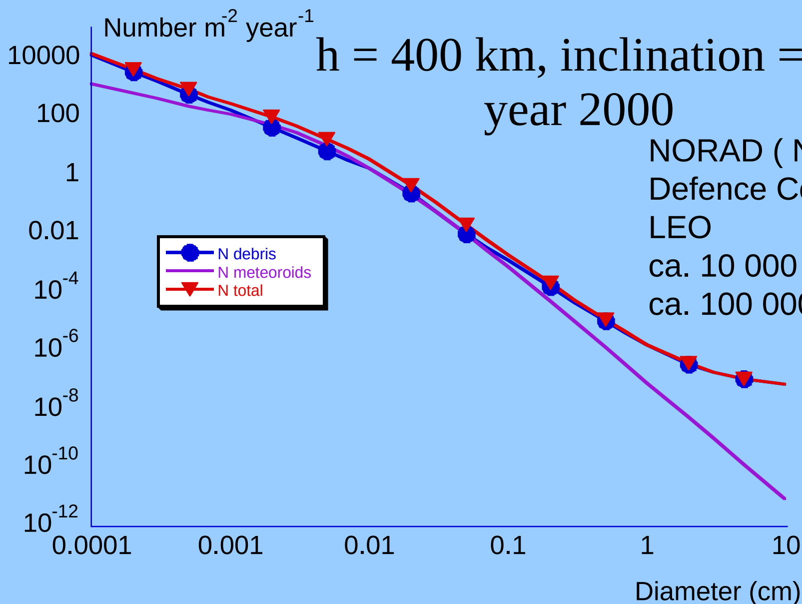
- Thermo-oxidative resistance of materials
- Ablative Materials

1st inflatable deceleration unit

2nd inflatable deceleration unit

Ablative shield

Cumulative number of impacts in ISS Orbit

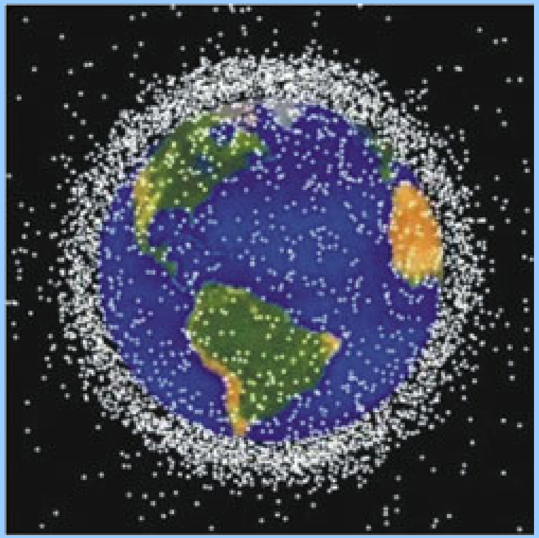


h = 400 km, inclination = 51.6º, year 2000

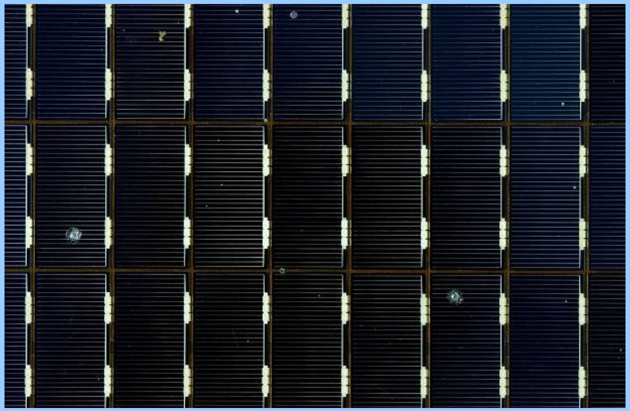
NORAD (North American Aerospace Defence Command) : Ground Tracking: LEO

ca. 10 000 objects > 10 cm

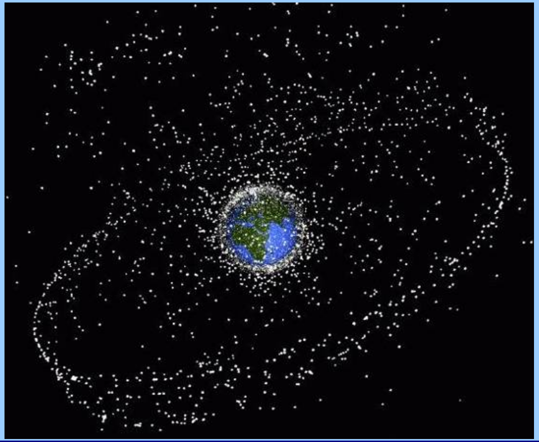
ca. 100 000 objects > 1cm < 10cm



LEO



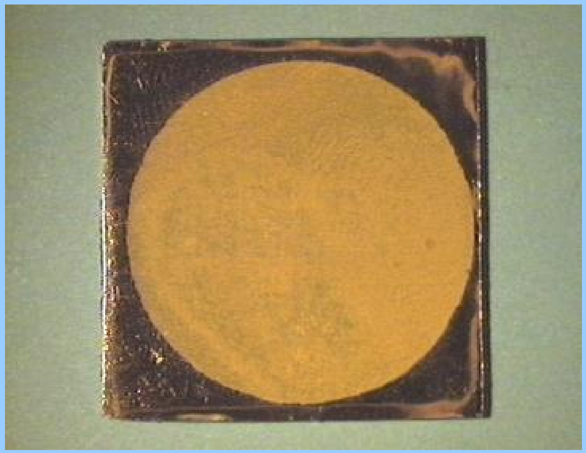
Credit: G. Drolshagen

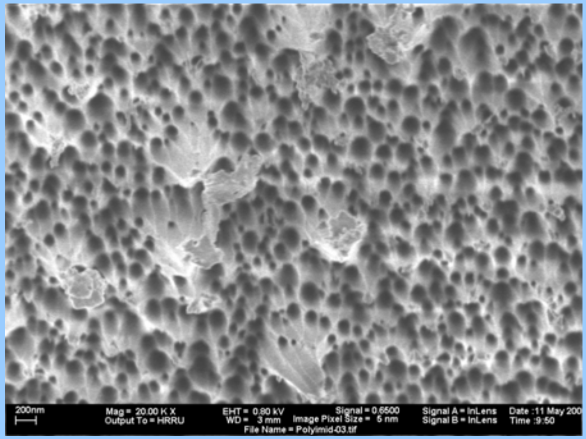


GEO

Challenge: Atomic Oxygen

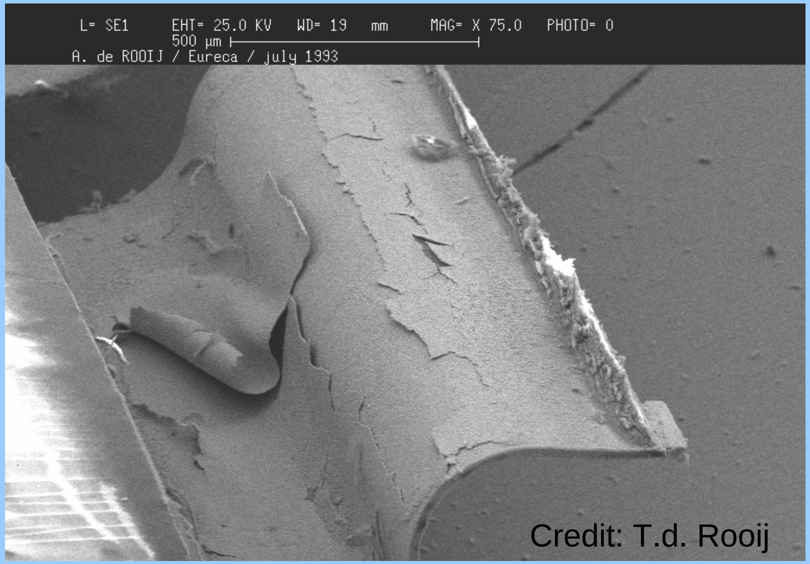
Examples of attack on polymers (left) and metals



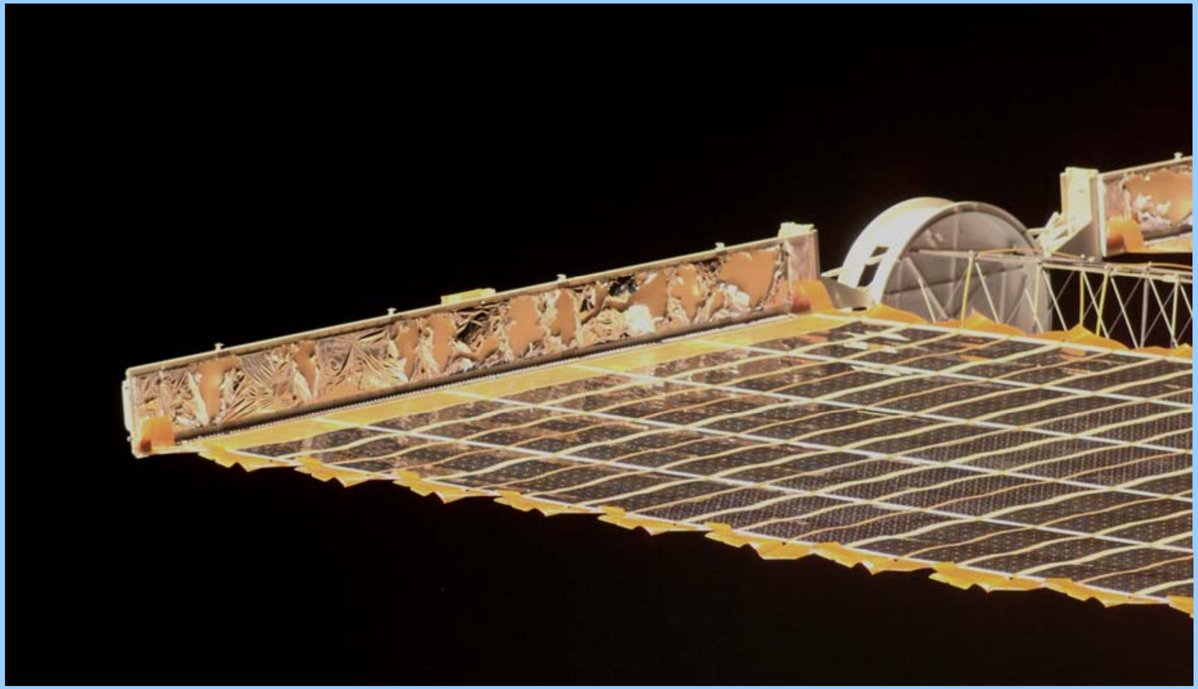


Left, Kapton, exposed in ESTEC atomic oxygen facility. Circular area is exposed, outside region still shiny. Mass loss : 3 micron per 10^{20} atoms

Bottom, Silver interconnector flown on Eureca. The silver is oxidised. Silver loss: 11 micron per 10^{20} atoms



International Space Station Solar Array



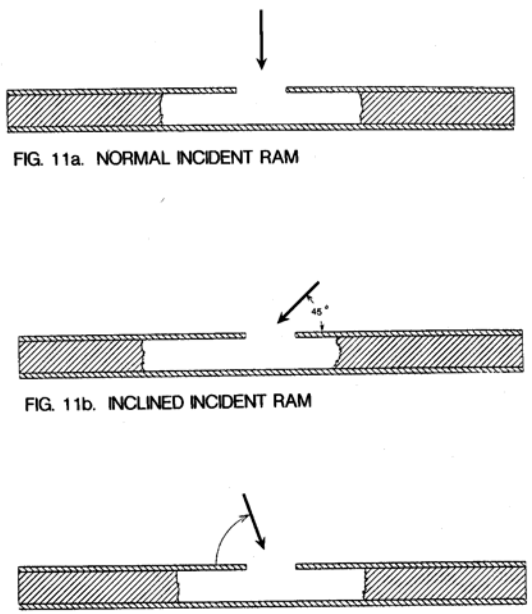


FIG. 11a. NORMAL INCIDENT RAM

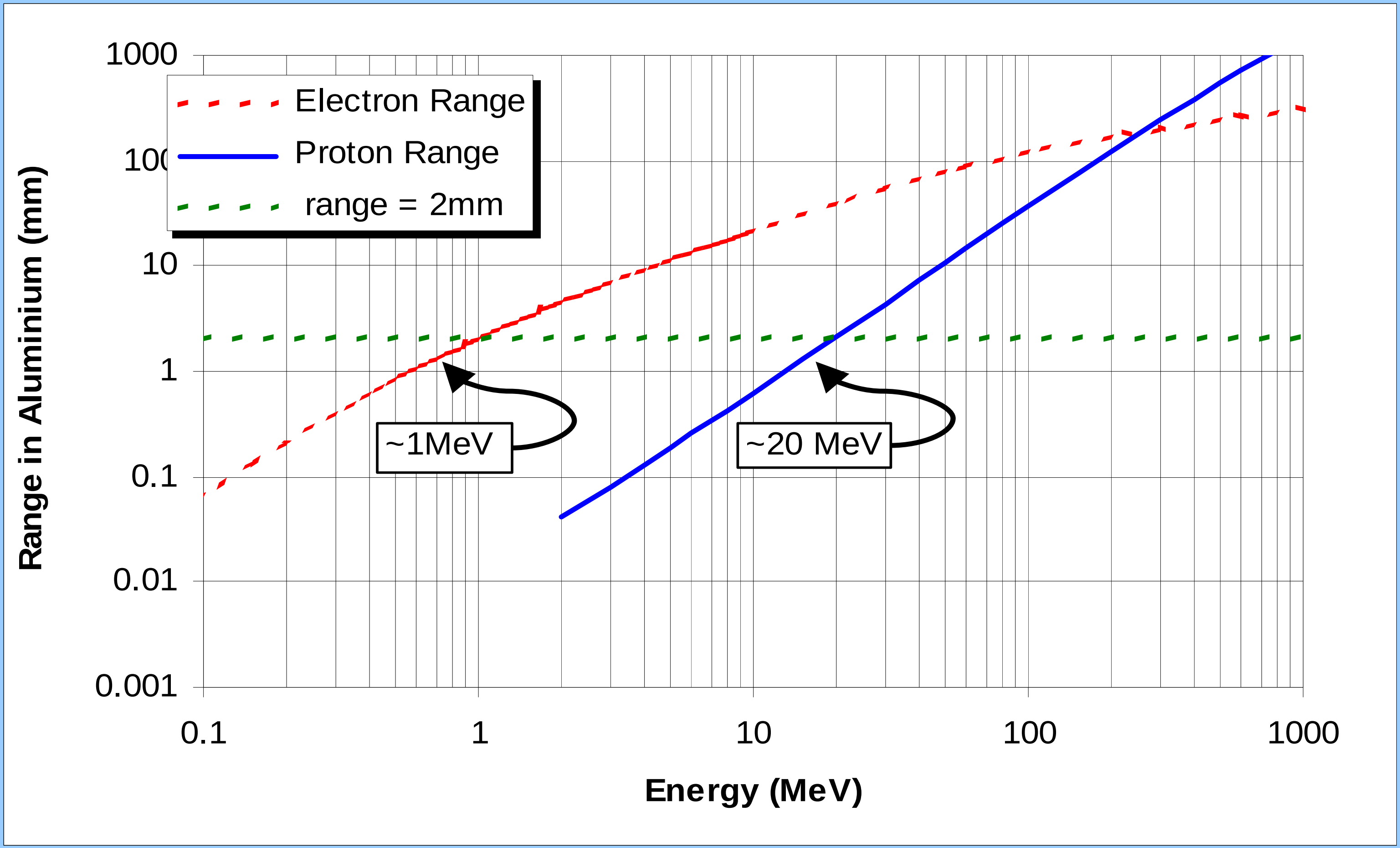
FIG. 11b. INCLINED INCIDENT RAM

FIG. 11c. SWEEPING INCIDENT RAM

Credit: B. Banks NASA/GRC

Materials developments are on-going/needed for intrinsically ATOX resistant materials or ATOX self healing materials

Radiation Damage



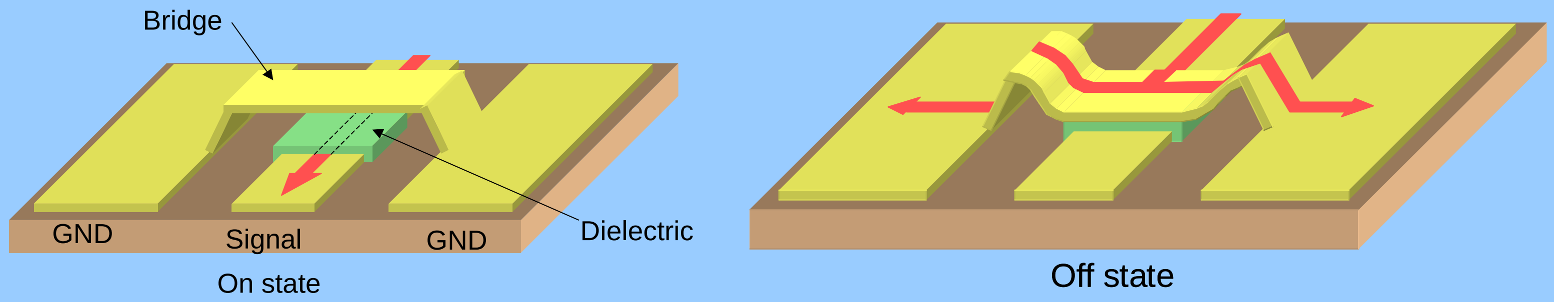
Radiation Damage Issues

Radiation effect	Parameter
Electronic component degradation	Total ionizing dose
Material degradation	Total ionizing dose
Material degradation (bulk damage)	Non-ionizing dose (NIEL)
CCD and sensor degradation	NIEL
Solar cell degradation	NIEL and equivalent fluence
SEU and latch-up	LET spectra (ions); proton energy spectra: explicit SEU/SEL rate of devices
Sensor interference (background signals)	Flux above energy threshold or flux threshold; explicit background rate
Internal electrostatic charging	Electron flux and fluence; dielectric E-field

Example: Internal Charging (Dielectric charge trapping)

Limits lifetime in several types of MEMS

- Primarely in electrostatic RF MEMS, gyro, and other and other capacitive MEMS sensors.
- Actuation-voltage shift & Stiction
- Despite some improvements recent activities have shown that a drift in performance is still observed:



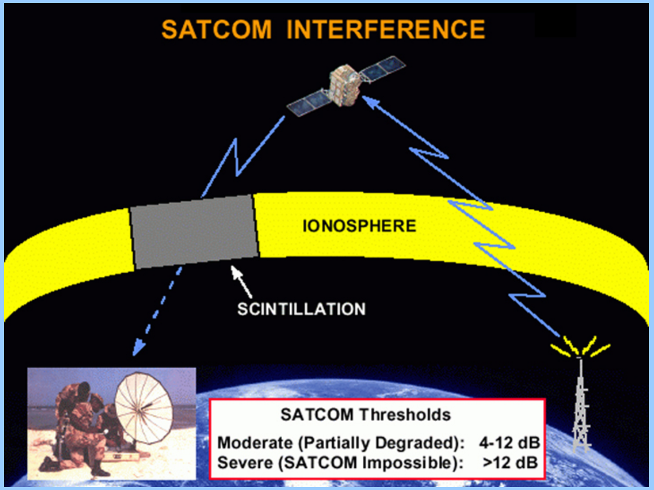
Principle of the electrostatic capacitive bridge

Credit: L. Marchand

Examples Plasma Effects

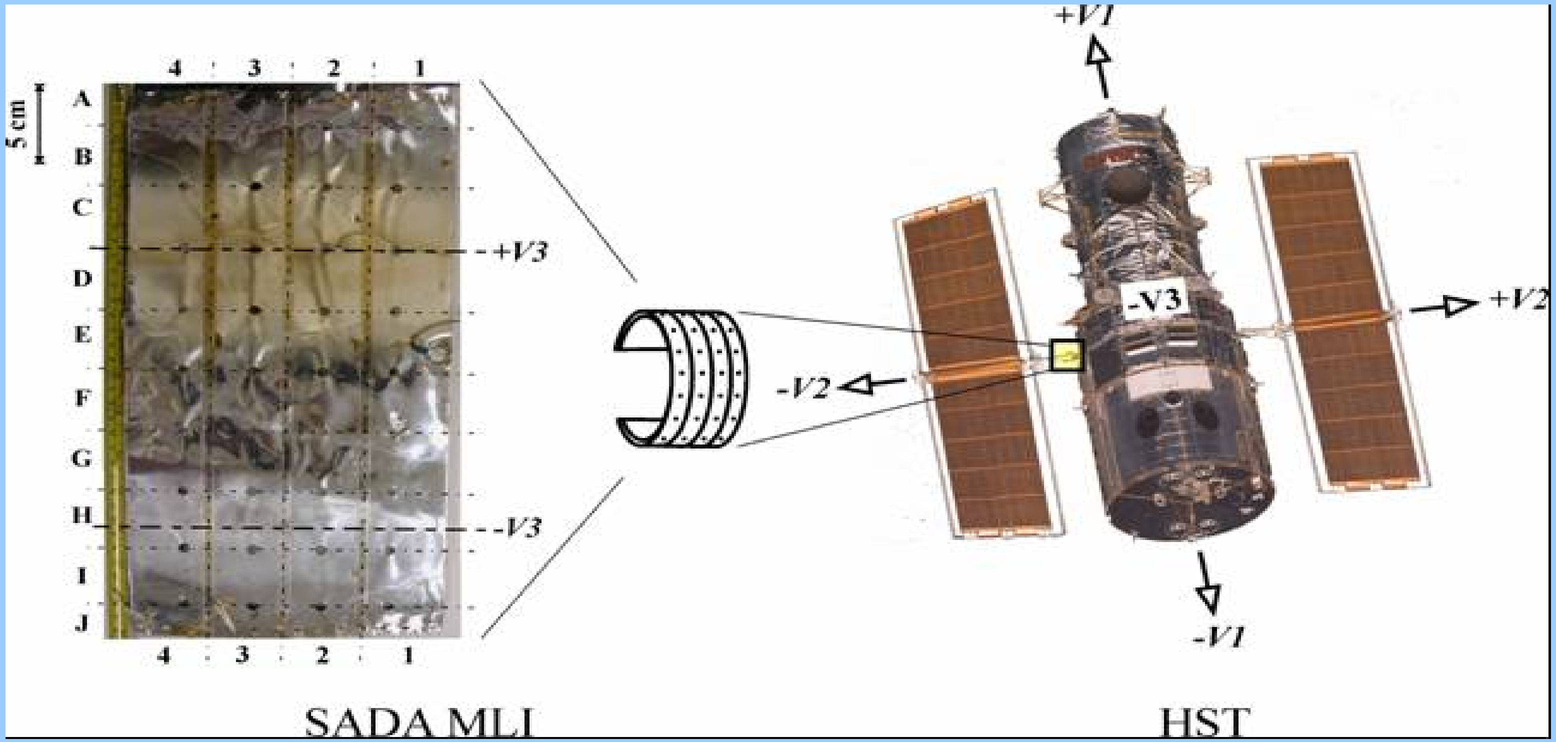
- Aurora
- Arcing
- Navigation Problems

Sustained Arc on EOS-AM1 (Terra) Q-Board (Ferguson, NASA Glenn)



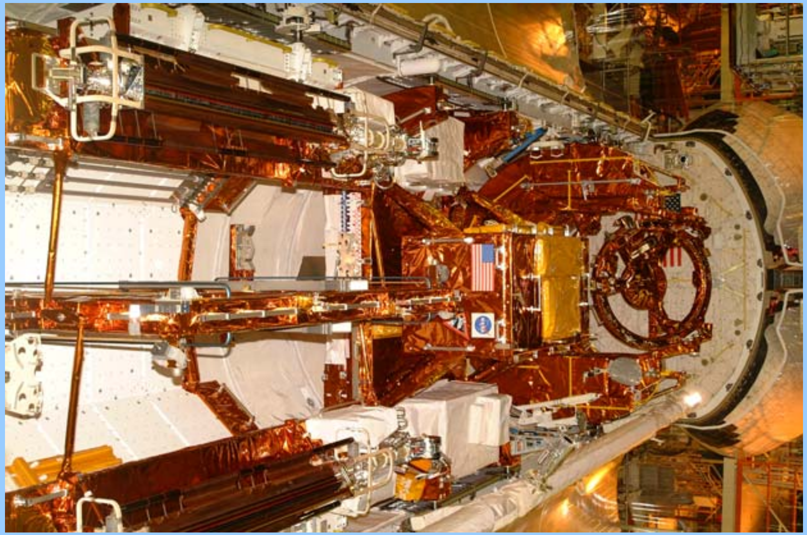
Materials Research on-going to mitigate plasma induced effects

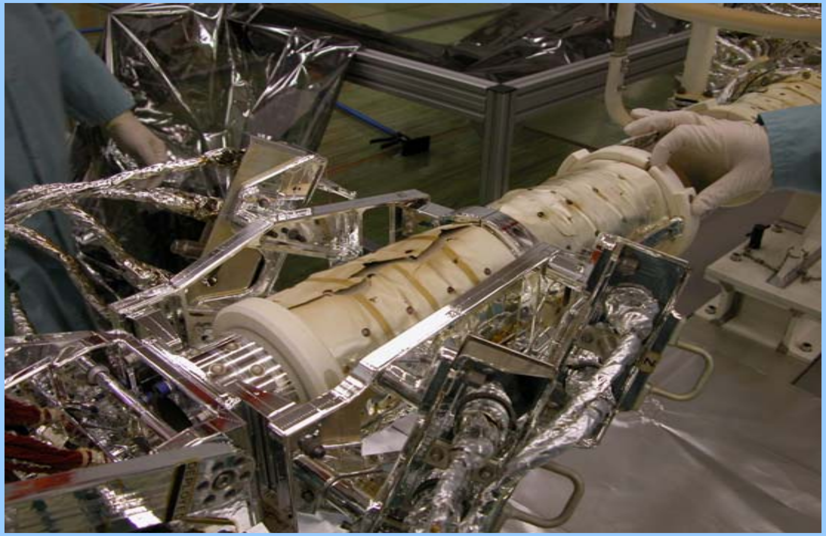
HST SA SM 3B (2002)



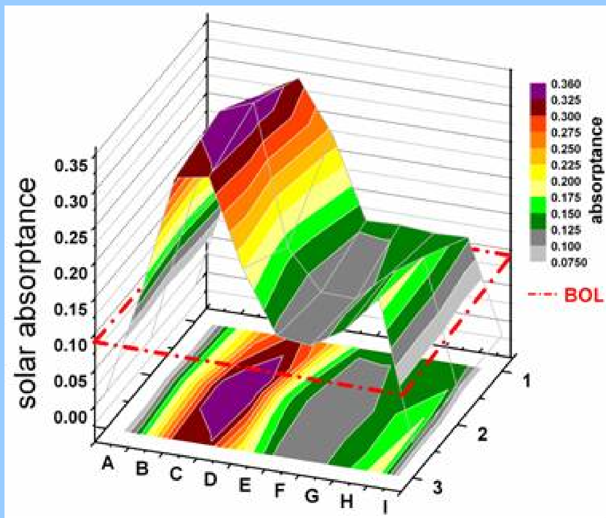
Source: Moser, Semprimoschnig, van Eesbeek, R. Pippan ,10th ISMSE & submitted to HPP 2007

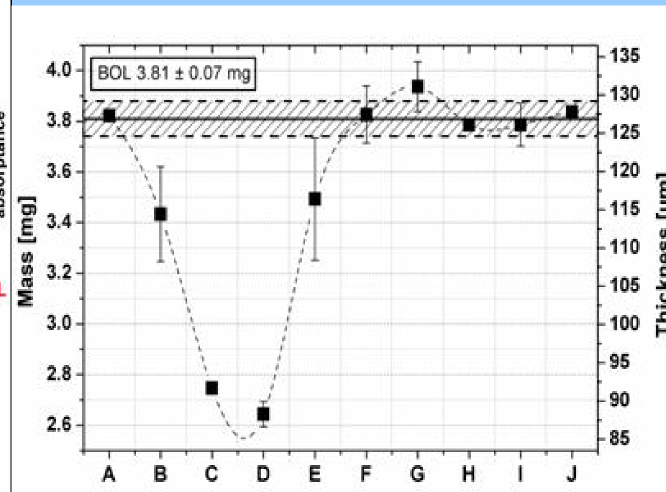
HST SA 2002

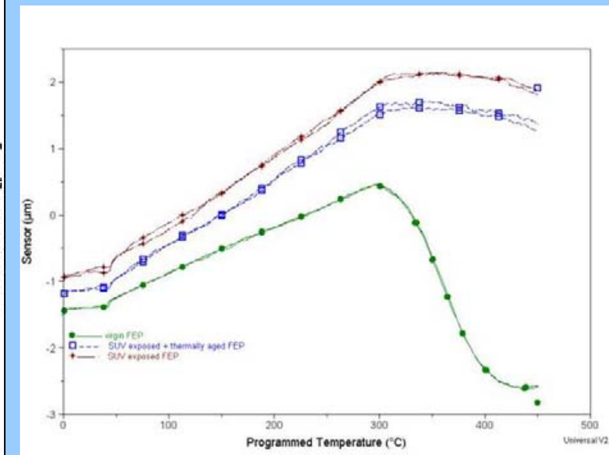


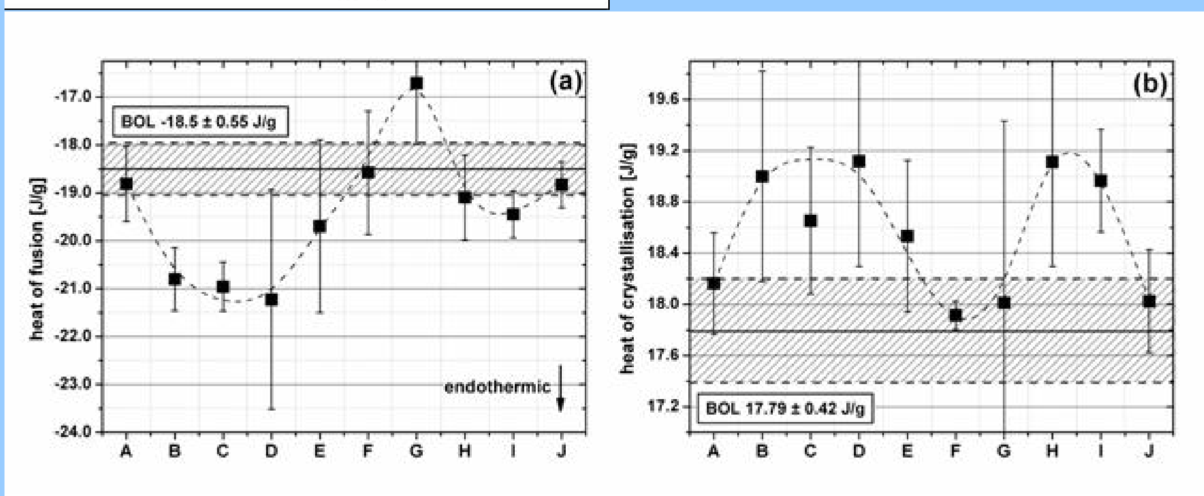


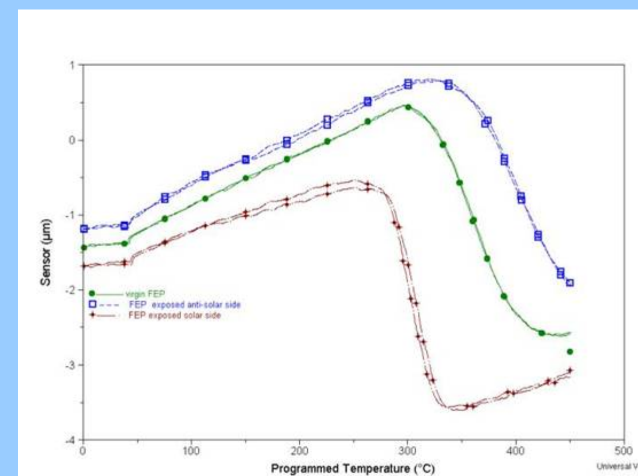

HST SA Post Flight Analysis





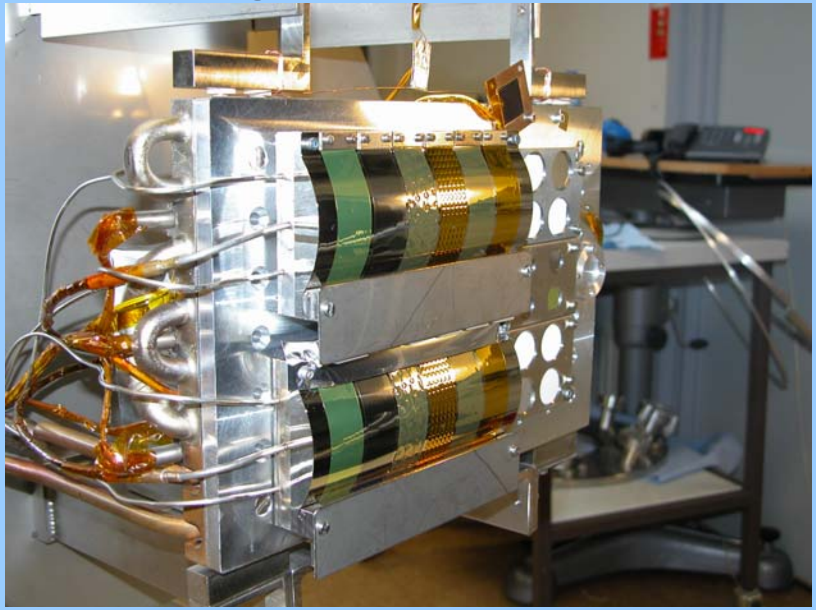


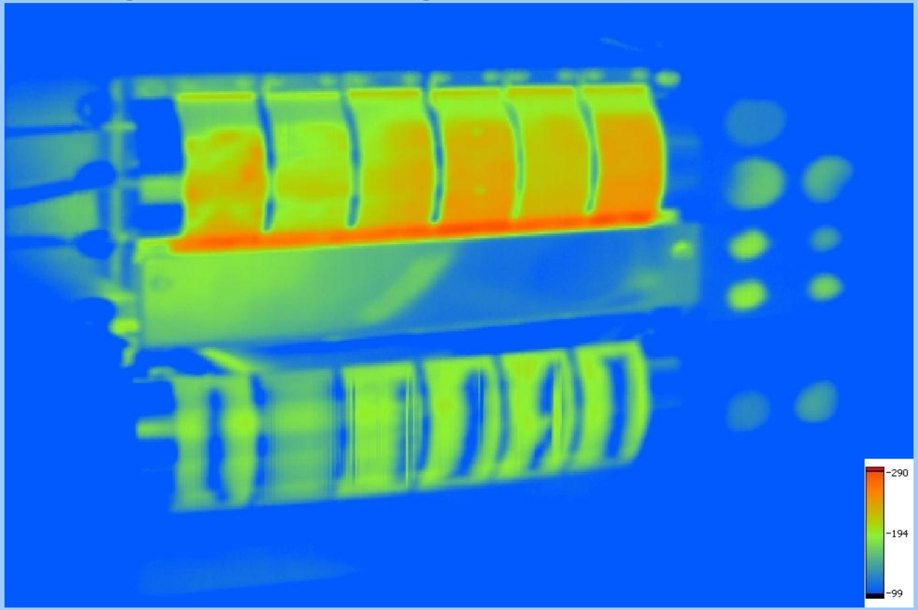


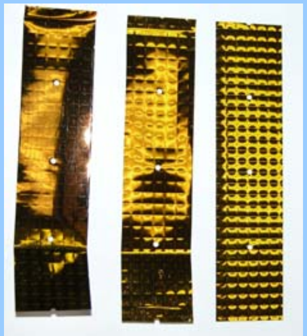


Sources: Moser, Semprimoschnig, van Eesbeek, R. Pippan ,10th ISMSE & submitted to HPP 2007
Fischer & Semprimoschnig, 10th ISMSE & submitted to AIAA 2007

Synergistic Irradiation Testing (UV + high temperature)







Testing for Venus Express launched in 2005

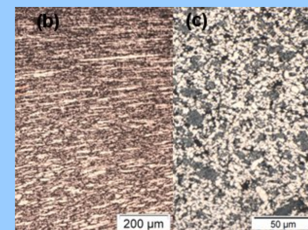
19 000 e.s.h. duration
Sample Temperatures 100 °C to 300 °C

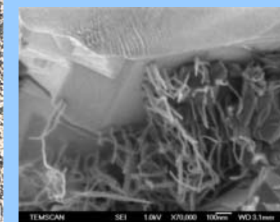
Source: Semprimoschnig, Heltzel, v. Eesbeek, Tighe, Polsak, 10th ISMSE & submitted to AIAA

Examples of Materials Research Areas

- Ultra-light materials like Aerogels
- Radiation resistant Adhesives/Materials
- Flexible Sol/Gel Coatings
- Carbon nano-tube re-inforced materials
- Space stable ceramic coatings & materials
- Contamination trapping materials
- Laser damage resistant materials
- Ultra-thin materials (Gossamer/ inflatable etc.)
- Self healing materials/composites
- HT composites / Thermo-plastic composites
- Laser/Electro beam Sintering for 3D parts
- Out of Autoclave Composite Manufacturing
- Gecko mimetic Tape as new joining technology
- CTE variation of thermally stable materials
- Sterilisation / Ultra-Cleaning of Materials/Payloads
- Flight Experiments of novel Materials
- Friction Stir Welding Process
- ITAR free materials supply for Europe

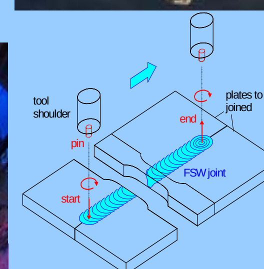


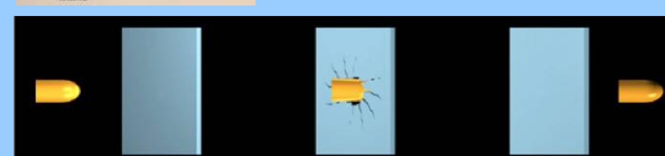













Conclusion

- Space is a unique and challenging environment

- Materials Engineering plays a fundamental part in the success of space mission,
  - use the functional properties of materials!
  - Materials & Process Selection requires to understand the interaction posed on materials and components going through their respective life cycles

- Several R&D possibilities exist with ESA and with the Materials & Processes Division.