Overview of Importance of Materials in Space

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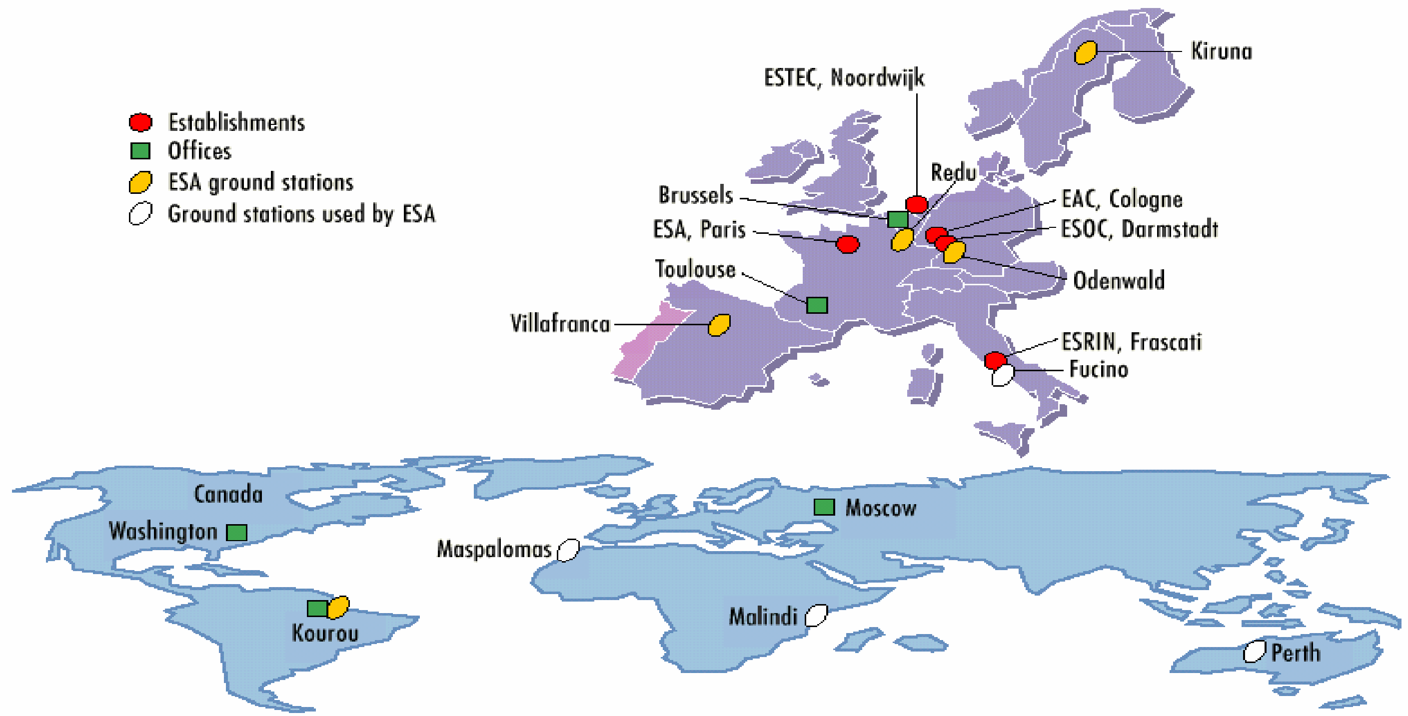
Presentation content

- Examples of spacecraft missions, achieved, planned and future;
- The enabling role of materials for missions, general overview:
  - Structures
  - Thermal;
  - Propulsion;
  - Optics;
  - Power;
  - Equipment, Components, MEMS & Mechanisms;
- Conclusions

ESA establishments;



ESA establishments, offices and ground stations

Overview of Importance of Materials in Space

- Most materials used in spacecraft are not different from those in terrestrial applications (metallic, organic, polymeric, semiconductor, and insulating materials)

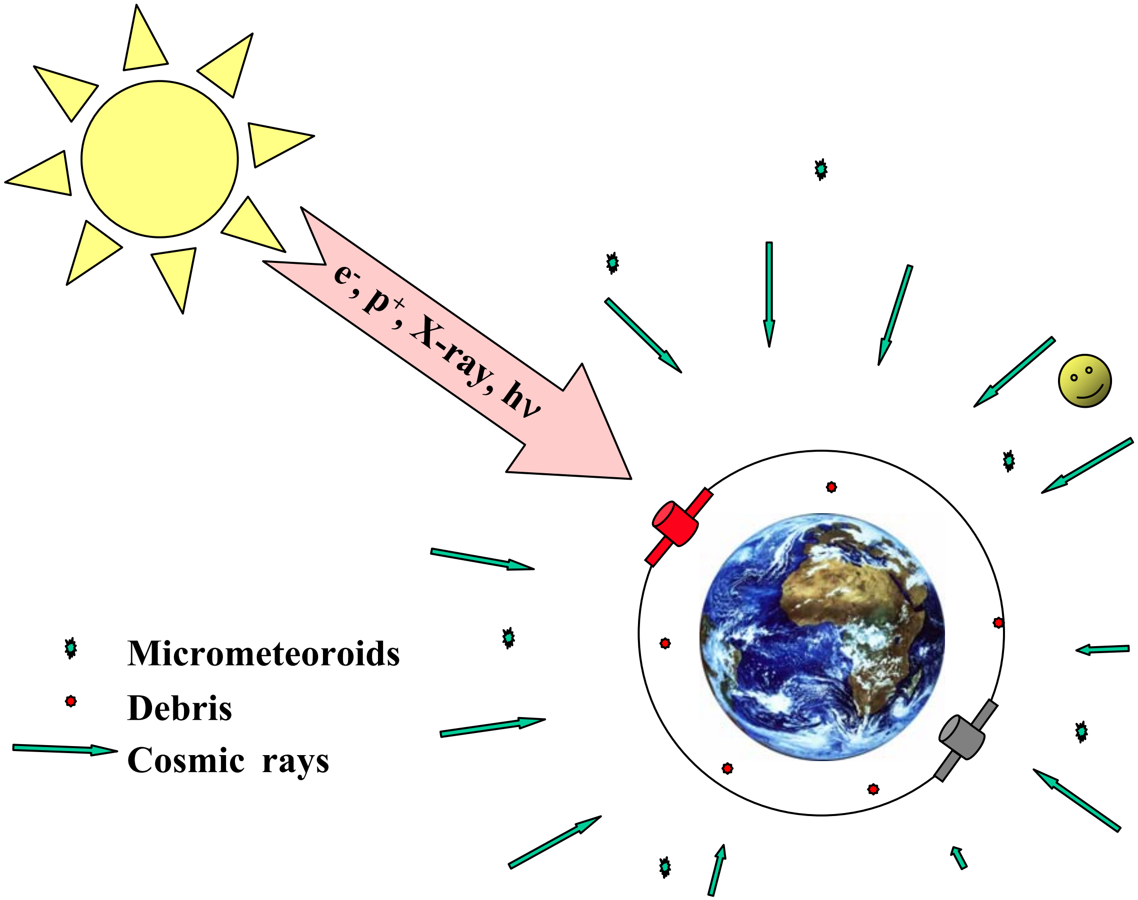
  → HOWEVER! The operational environment is!

  - The physical and chemical environment in LEO and GEO is not benign, imposing a highly aggressive oxidation and degradation of materials;
  - It includes a rain of high energy particles and ionizing radiation from the Sun. This hot plasma (or solar wind) is trapped and concentrated in regions of the Earth's magnetic field.
  - Thermal waves and gradients exist in the upper atmosphere. For example the International Space Station (ISS) will undergo about 175,000 thermal cycles from +125°C to –125°C as it moves in and out of the Earth's shadow;
  - High velocity travelling meteoroids and debris particles form a constant threat to spacecraft.
  - Re-entry vehicles for Earth and planetary missions may encounter temperatures that exceed 1,600°C ;

- Often the material application is subject to conflicting requirements: (mass, stability/conductivity, strength, radiation …..)

- In many cases each satellite project has to address specific material issues.

Space Environment Requirements for Materials in flight



Vacuum

Temperature
(isothermal/cycling)

Radiation

Space Debris
Micrometeoroids
Atomic Oxygen

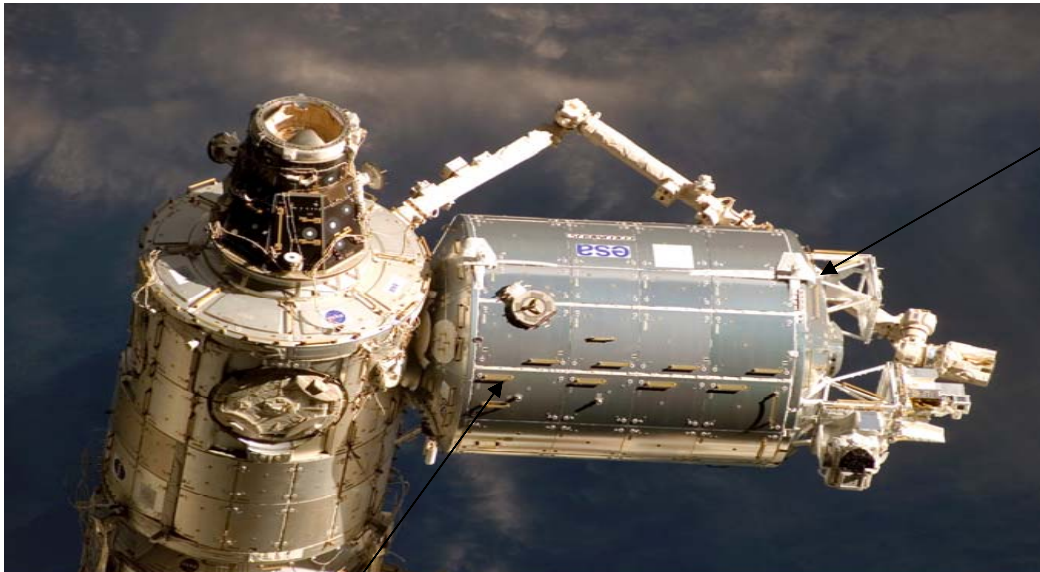
(Manned
Compartments)

Examples of spacecraft missions, achieved, planned and future;

Ariane 5, the European heavy-lift launcher!

VEGA

Examples of challenging materials applications for Manned Space missions COLUMBUS-ATV/ICC



Meteroid & Debris shield

-Material combination adequate to protect against high velocity impact: up to 18km/sec

-Nextel and Kevlar as secondary bumper.

-Nextel contributes to fragmenting further the projectile dispersed by the bumper.

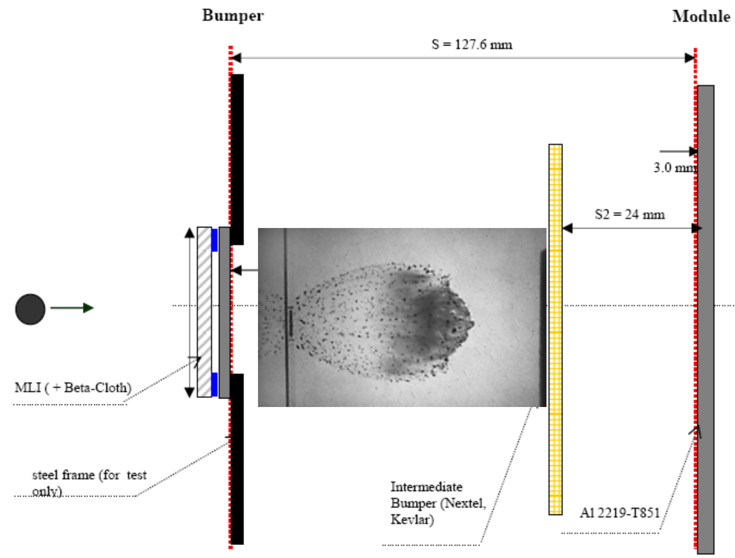
-Kevlar contributes to retain and to

Shell structure

Welded Alu 2219

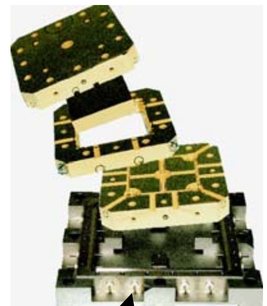
Thickness driven by unzipping- and radiation protection requirements (4.8mm) => mass penalty!

Future Alternatives:
Composite materials?
Inflatable structures?

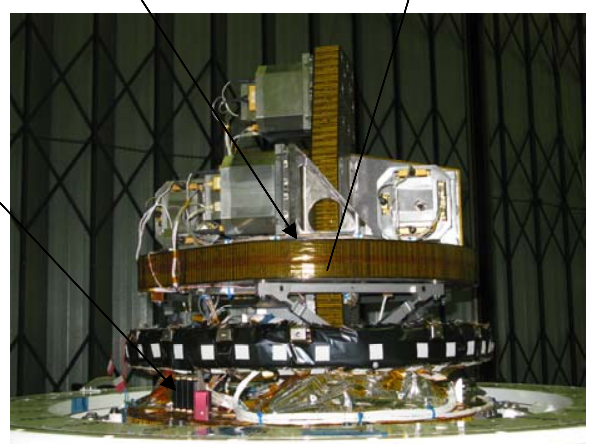


Example of bumper test setup

Examples of challenging materials applications for Earth Observation missions



Carbon-Carbon stable platform



Three-Axis Gradiometer

Material needed:

-appropriate dielectric properties (surfaces are electrodes of capacitor, with moving mass inside)
-thermally stable (low CTE, matching with adjacent parts)

Selected material: ULE (glass-material) cage, gold coated, assembled with titanium fasteners, interfacing with invar metallic parts

Challenge:

Brittle materials are susceptible to flaw growth under constant load, and hardware development requires:

- -Detailed stress analysis, accounting for all notches
- -Careful inspection for cracks
- -Careful control of fastener preload and load introduction
- -Accounting for initial surface crack probabilistic distribution ('Weibull')
- -Crack growth analysis to determine critical initial crack size, as risk assessment
- -Some failures seen during the development!

Examples of challenging materials applications for Science missions

Herschel Telescope – 3.5m diameter SiC mirror

Photo: ESA

- Cassegrain telescope; 3.5m primary mirror operating at 80-670µm wavelengths, operational temperature 70°K (design and developed by Astrium France and Boostec);
- Primary mirror; 12 SiC (sintered high purity silicon carbide) segments (brazed joints);
- Secondary mirror & structure; SiC, plus Invar joints;
- SiC and Invar selected for similar and very low CTE (1.5 ppm/°K ambient to 70°K).
  - **Predicted focus shift; ambient - 70°K; -1.6mm**
  - **Measured(1) focus shift on ground; -11.7mm**

WHY?

- Difference measured (best fit) vs. apparent CTE's;

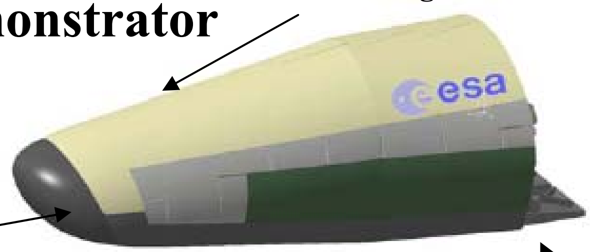
	Coupon Measured, used for design	Apparent(2)
SiC	1.21 ppm/°K	1.00 ppm/°K
Invar	1.36 ppm/°K	1.97 ppm/°K

- Difficulty to accurately measure small strains at cryogenic temperatures. Actual values within scatter of measured values.
- Telescope is very sensitive to distortion.

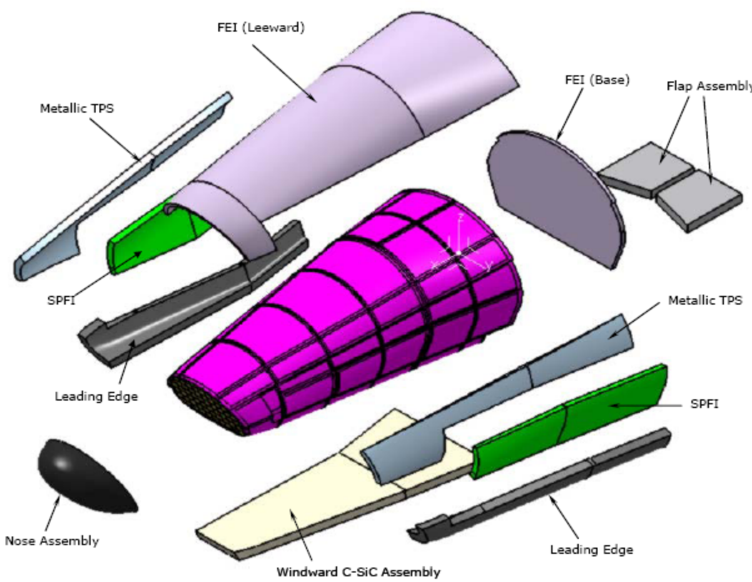
NOTE (1); Ground test in TV chamber at 100°K and extrapolation to 70°K
(2); CTE values which best fit to measured telescope performance by stochastic analysis

Examples of challenging materials applications for re-entry vehicle missions

Intermediate eXperimental Vehicle (IXV)
Re-entry system and technology demonstrator



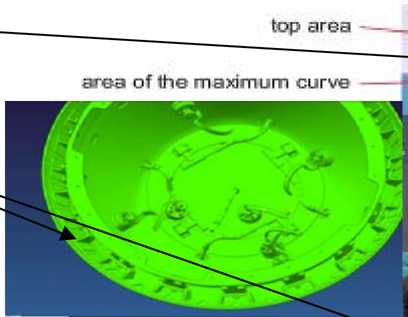
- Materials for Thermal Protection Systems (TPS):
  - Ceramic **(up to 1900 deg C)**
  - Flexible External Insulation **(700-800 deg C)**
  - Surface-Protected Flexible Insulation **(700-800 deg C)**
  - Metallic **(max 1140 deg C)**
- High temperature CFRP (175 deg C):
  - Cyanate ester or bismaleimide resin
  - Cocuring prepreg/honeycomb
- Material behaviour in re-entry environment:
  - Catalycity
  - Oxidation

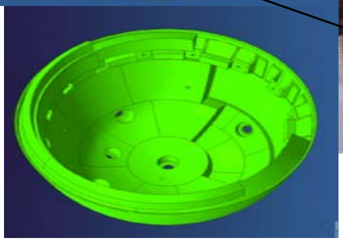


Launch scheduled for 2012 with VEGA

Examples of challenging materials applications for re-entry vehicle missions

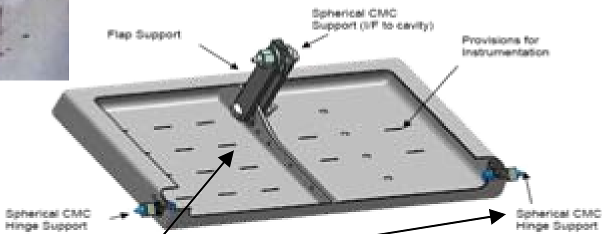
EXPERT: Hot Structures and TPS to resist re-entry environment!

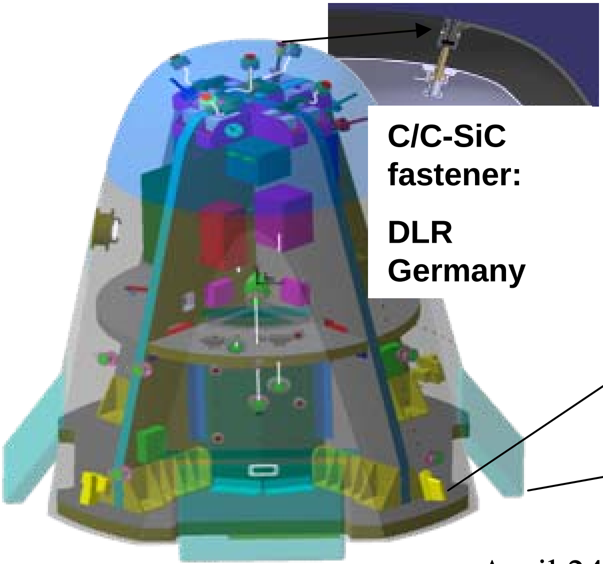




Nose, hot structure (C/C-SiC), TPS
$T_{RE-ENTRY}$= 2000 C

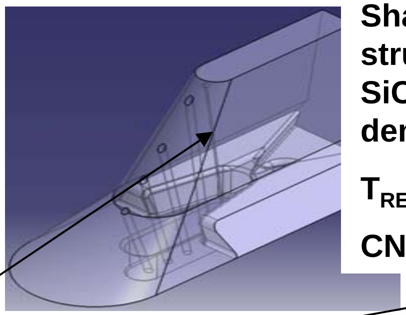
DLR Germany





C/C-SiC fastener:

DLR Germany



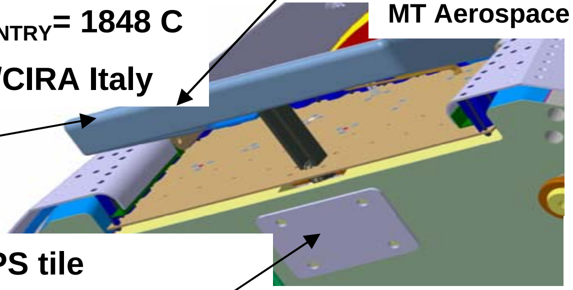
Sharp Hot structure ($ZrBr_2$-SiC), TPS demonstrator

$T_{RE-ENTRY}$= 1848 C

CNR/CIRA Italy

Flap, hot structure and hinges (C/SiC Keraman ®)

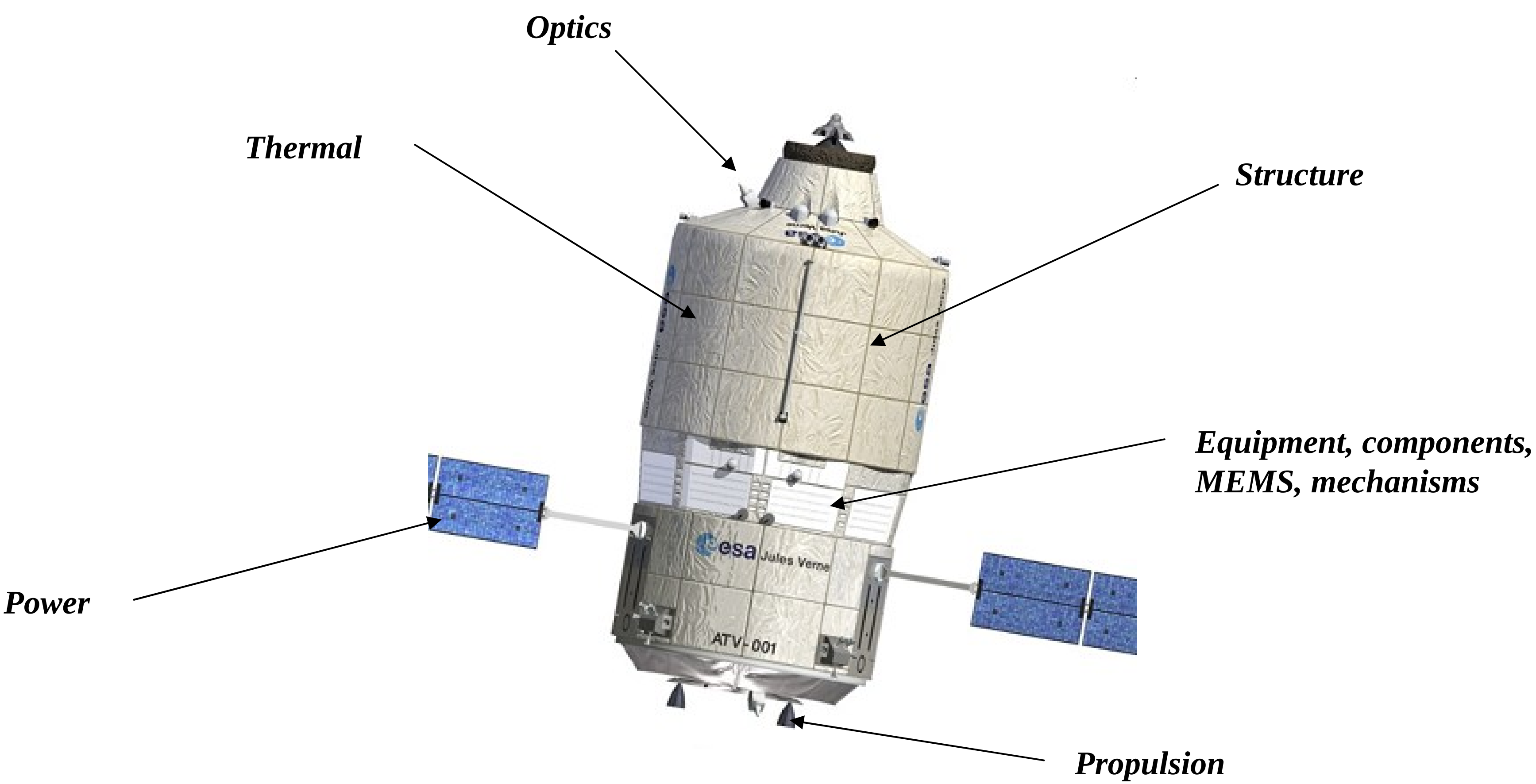
$T_{RE-ENTRY}$= 1727 C
MT Aerospace



(Ti_2AlNb), TPS tile demonstrator. INASMET Spain $T_{RE-ENTRY}$=800C

Launch scheduled for 2010 with Volna

Materials are important for all subsystems!



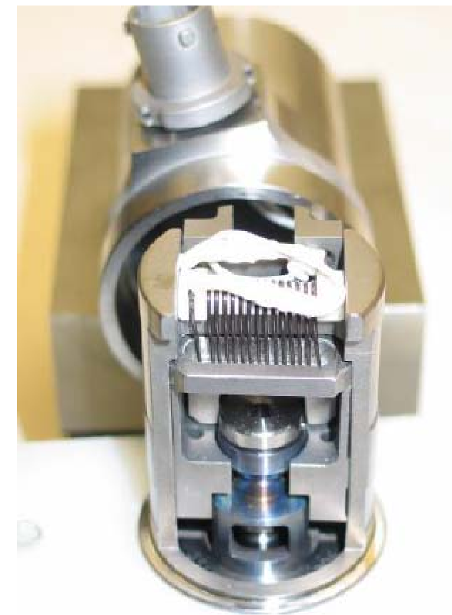
Important of Materials for MEMS:

- Prominent current issues
  - Microsystem integration materials: slim packages in harsh environment, radiation shielding, thermal, electrical, and structural pathway improvement.
  - Functional materials compatibility in complex microsystems operation and manufacture.
  - Microsystem materials in harsh (space and planetary) environment. Space flight heritage.

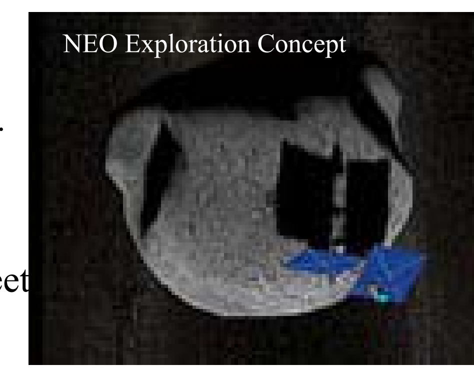
- Required material development for MEMS in space
  - Near term:
    - Improved valve actuator materials: fast response, low voltage, large stroke, high force.
    - Silicon and glass remain the main material for new MEMS. Spin-in MEMS may use other materials, but need to pass space qualification.
    - Coatings with high elasticity for high mechanical loads and reliability
  - Long term:
    - Ubiquitous integration of smart materials for sensing and control purposes.
    - High temperature micromachined materials (e.g. in microrocket engines)
    - New substrates – advanced polymers, extreme light-weight materials, wavelength-attuned materials for optical instrument microsystems.
    - Superconductive coatings and substrates for efficient actuators/sensors

- A Selection of current and upcoming activities
  - Nanotechnology and nanomaterials survey
  - Most microsystem activities involve functional materials, e.g. a variety of thin-film coatings.
  - Shape Memory Alloy materials show promising results.
  - NEOMEx microsystem-based nanospacecraft technology research activities

MEMS rate sensor, BAE Systems, UK



SMA valve, Technodpace Aero, BE



Importance of Materials for Structures

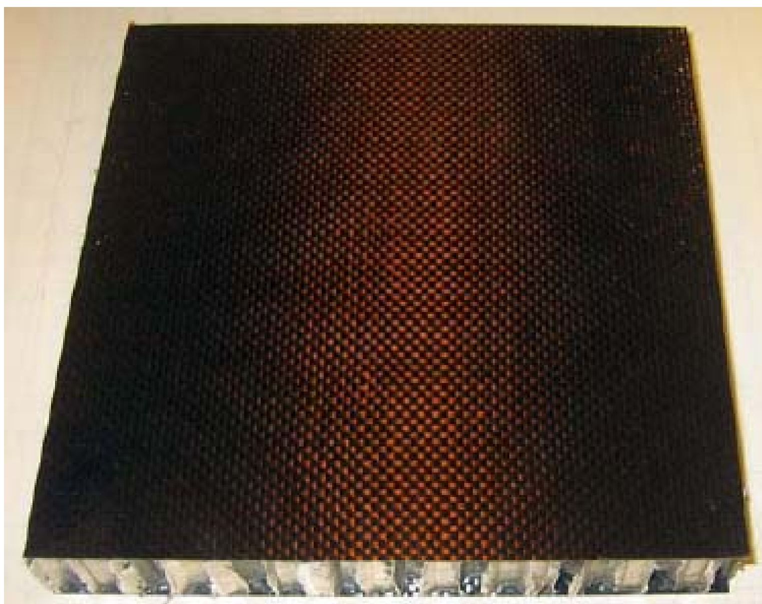
GOCE

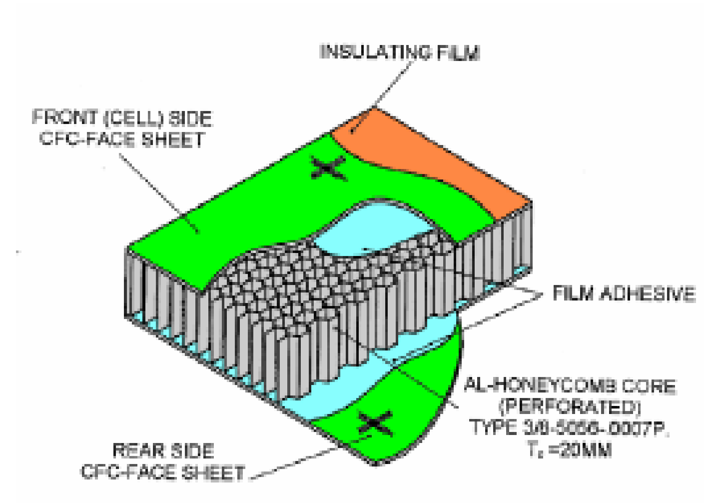
- Material selection mostly driven by stiffness, mass and stability
- App 10-20% of total system mass => ***mass does matter!***
- Increased use of composite structures, mainly using high stiffness and high strength fiber materials and cyanate ester resins.
- Thermo-elastic stability requirements dictates the need for low CTE materials such as SIC (Silicon carbide, Boostec France), CeSIC (ECM Germany), Zerodur (Schott Germany)
- Future trends:
  - Increased use of pitch fibers (stiffness and conductivity)
  - Increased use of ceramics for optical benches and load carrying structures;
  - Carbon Nano Tubes (CNT) doping of existing materials for performance improvements;
  - Improvements in manufacturing processes, e.g. curing process improvements;
  - Increased use of braided and woven materials.

Importance of Materials for Solar Generators

Solar Array Substrate Construction

- Sandwich Panel: typically CFRP face-sheets/Al honeycomb core
- Insulating Film: typically kapton bonded to cell-side face-sheet

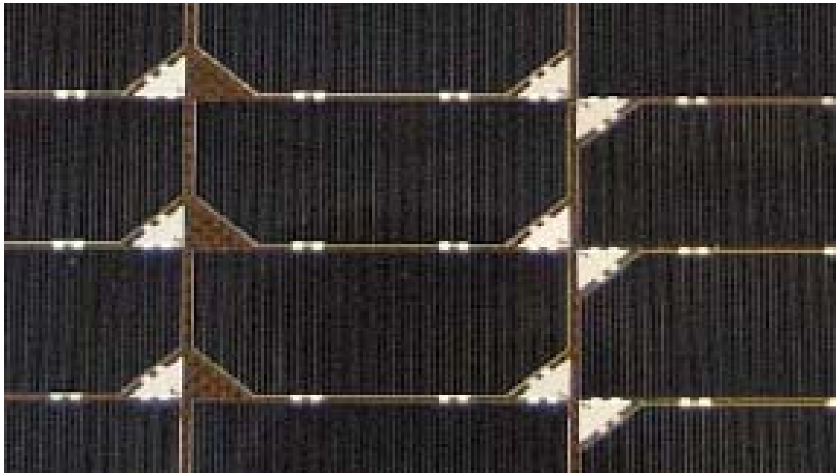




Importance of Materials for Solar Generators

Hardware Construction

- Rigid panels supporting delicate PVA components
- Stringent flatness requirements: <0.07 mm variation within 100 mm x 100 mm



Solar cells, bi-pass diodes bonded to substrate

- High performance composites often subjected to ITAR restrictions.

=> Need identification of potential new European sources of high performance composite materials;

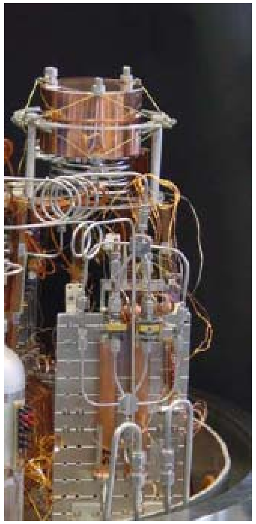
- Insulating film liable to delaminate/degrade under extreme temperature (200 °C) or thermal cycling (-160 °C ↔ +160 °C).

=> Development of improved insulating films, to extend lifetime of solar generators needed.

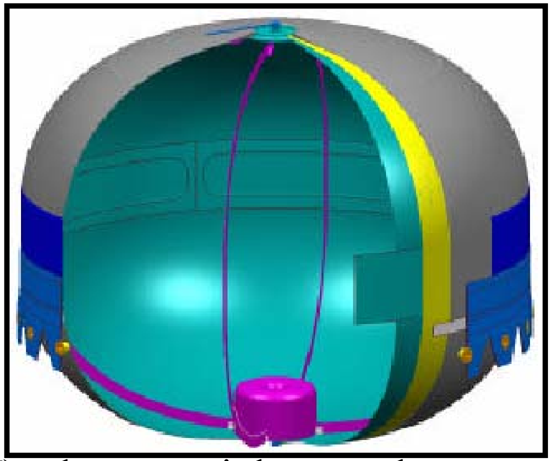
Importance of Material for Thermal subsystems

Some of the current material development needs:

Sorption Compressor with Joule-Thomson Cooler



- Coatings with low solar absorptivity and high infrared emissivity having a low degradation of thermo-optical properties over life;
- Tuneable emittance surfaces (adaptation of emissivity - actively or passively controlled for radiators) with low solar absorptivity and large range of emissivity => Ongoing ESA R&D activity on passive system;
- Polymeric, flexible materials with PTC (positive thermal coefficient) electrical resistance for self-regulating heaters
- Insulation materials for low atmospheric pressure environments (e.g. Mars)
- Composite materials for cryogenic tanks and lines with very low thermal conductivity and negligible permeability for gases at cryogenic temperatures => ongoing ESA R&D activity
- Materials with very high absorptivity for gases at cryogenic temperatures for high efficient getters or compressors (for e.g. use with Joule-Thomson coolers)
- Low-mass European ablative materials for missions involving high speed atmospheric entries => ESA R&D program in preparation
- High temperature thermal control materials (coatings, Optical Solar Reflectors's, MLI, etc.) => currently under development in frame of BepiColombo; potential re-use for Solar Orbiter
- Advanced (high ZT) materials for thermoelectric generators and Peltier elements => two PhD activities ongoing sponsored by ESA

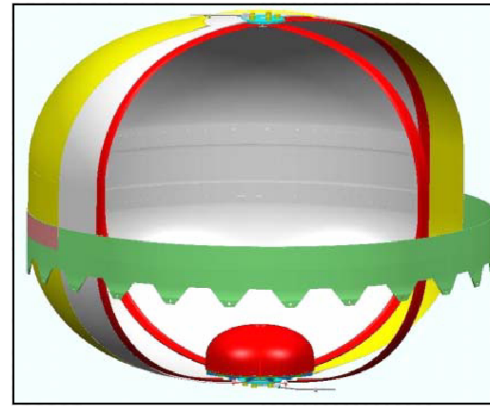


Importance of Materials for Propulsion
Spacecraft Chemical Propulsion

- **Transition Tube**
  - Used for welding titanium alloy (Ti 3Al 2.5V or Ti 6Al 4V) tubes to stainless steel (304L or 316L) component stub pipes.
  - Needs to be compatible with Propellants (e.g.. Hydrazines, N_2O_4), Cleaning fluids (e.g.. Propan-2-ol/IPA), simulant fluids (e.g.. Water, HFE 7100)
  - Development activity for both suitable manufacturing and inspection processes in progress.

- **Simulant Compatibility**
  - Research conducted into the suitability of proposed Freon-113 (1,1,2-trichlorotrifluoroethane) replacement fluids such as HFE 7100, for use as propellant mass simulants, and cleaning solvents.
  - Long term compatibility testing with Titanium (incl. Stress corrosion cracking susceptibility) is ongoing at ESTEC.

Importance of Materials for Propulsion
Spacecraft Chemical Propulsion



- **Elastomeric Diaphragms**
  - No European Formulations compatible with mono-propellant grade hydrazine or bi-propellants.
  - Silica free requirement for Diaphragms (Silica has been used as a filler in the material formulation, however leaching out of the material is incompatible with thruster catalyst beds for long term missions employing monopropellants)
  - Europe also requires formulations compatible with common bi-propellants (Mono-methyl hydrazine, Mixed Oxides of Nitrogen – MON)
  - New development activity in progress for mono-propellant grade compatible diaphragm material.
  - However more development may be required in the future to ensure compatibility with the common bi-propellants as well.

- **Shaped Memory Alloys for Valve Actuator Replacement.**
  - Need to replace Pyro-valve Actuators (one-shot, explosive initiator)
  - However need to maintain leak tightness requirements (1×10^{-4} scc/s (He) over 15 years)
  - A re-settable shaped memory alloy based actuator has the potential to meet high requirements of pyrovalves whilst being multi-use (resettable actuator)
  - ESA has two current contracts looking at the potential of these materials.

Importance of Materials for Optics

Material issues for telescopes:

- Regardless of the operating wavelength, the greatest technical challenge for space optical systems is the ability to make large aperture mirrors of low area density, high mechanical stiffness, low CTE but high thermal stability, high surface finish and accurately maintained figure precision.
- A further important requirement is to use materials that allow for a reduction in current manufacturing costs and lead times, which leads to the need for materials that can be net or near-net shapeformed as much as possible and that are scalable.

Today following materials are used for low-mass monolithic mirrors and/or complex-shape optical benches:

- silicon carbide (SiC)
- carbon reinforced silicon carbide (C/SiC, Cesic)
- Carbon Fiber Reinforced Polymere (CFRP)
- Zerodur glass-ceramic (lightweighted)
- Beryllium

Importance of Materials for Optics

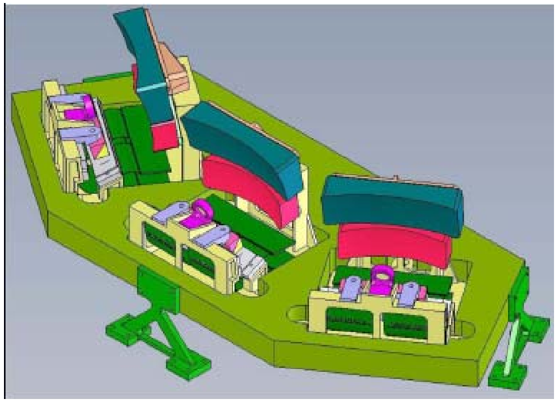
	Density	Young's modulus	Poisson ratio	Max Stress	CTE @ 270 K	CTE @ 40 K	Thermal conductivity	Specific heat capacity
	ρ (g/cm^3)	E (GPa)	ν	MPa	10^{-6}/K	10^{-6}/K	κ (W/m K)	c_p (J/Kg K)
Borosilicate	2.2	63	0.2	78	3.3	-3.2	1.2	800
Zerodur	2.5	91	0.24	57	0.05	-0.7	1.5	820
ULE	2.2	68	0.18	50	0.03	-0.9	1.3	760
Al	2.7	70	0.33	310	23	2.5	170	890
Be	1.85	300	0.08	240	11	0.05	210	1900
SiC (CVD)	3.2	466	0.21	440	2.2	0.05	190	730

Ceramic Materials like SiC and C/SiC have a high specific stiffness (ratio of Young modulus to density) allowing unprecedented surface/mass ratio: 24 Kg/m² (60-cm diameter mirror demonstrator in HB Cesic (representative of a 3-m diameter DARWIN mirror) with active astigmatism compensation at 100K, running TRP contract)

Low-cost metallic mirrors:

Pure Aluminium made with new processes like rapid solidification allow to push mirror manufacturing beyond current state-of-art. With Single Point Diamond (SPD) turning a surface roughness down to 5 nm is now achievable. Free form mirror manufacturing without the need for polishing opens the door to new optical design concept, until now unthinkable:

- High aspherical mirrors with very low f-number (< 0.5)
- Multiple monolithic mirrors

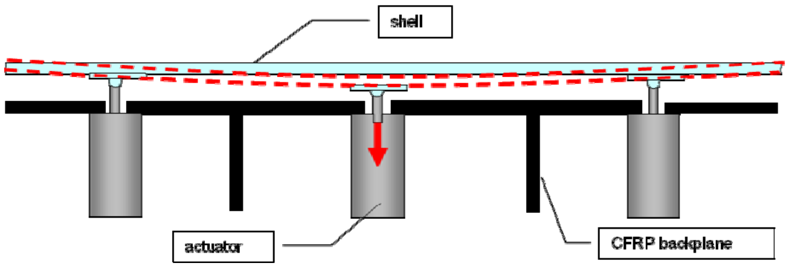


Wide FoV TMA for Land Observation

Importance of Materials for Optics

Apertures exceeding the launcher fairing diameter (> 4 m) can be realised with deployable/segmented telescopes based on **thin film mirror facesheets** (polymer materials, thin metal films, as well as possibly metal films reinforced with polymer layers). The key to achieving a high quality mirror is a stiff backplane structure to which the facesheet is rigidly attached.

The correct figure shape and the surface quality (WFE) are **actively controlled via actuators**. The backing structure, optimized for stiffness and mass, can be made from thin sheets of carbon fibre reinforced plastic.



Materials development trends:

- Mission-customised Zerodur and ULE glass for monolithic mirrors
- Thin film (~1 mm) Zerodur or ULE glass facesheets for segmented mirrors
- Mirror blanks made of ceramic facesheets (e.g. Silicon Carbide) with thin ribs stiffeners or honeycomb backplane structures instead of glass
- Carbon fibre stiffened composite or hybrid materials for segmented mirrors
- Extremely light, metal coated, carbon foam mirrors (with application-tailored cell size), produced to required shape with ribbed or honeycomb backplane
- Polymer-based membranes (e.g. Aluminised Mylar)
- Controllable multilayer coatings able to control the mirror shape
- Material characterisation (nano-scale-modelling): **CTE, moisture release, crack propagation**

Conclusions

- Material developments are essential for all spacecraft subsystems –
  => Mission enabling!
- Not all developments are space specific –
  => spin-in to be adapted where possible!
- Improved interaction with academia – research programmes, PhD and post doc programmes to be pursued further;

  - Partners with ESA and industry in R&D projects;
  - Jointly defined and funded PhD programmes;