Space Debris from Spacecraft Degradation Products Final Presentation

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ONERA (Office National d'Etudes et de Recherches Aérospatiales)

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Will be presented:
Mon. 06 March 11:40 – 12:20

Activity – Index

Presentation contents:

- Motivation
- Space materials
    MLI; Paints; Fixation methods
- LEO Test campaign
    - Test Flow
    - Tested Samples
    - Some results
- GEO Test campaign
    - Test Flow
    - Tested Samples
    - Some results
- Master 2009 improvements
- Conclusions and further thinking's

Activity – Motivation

The project aim was to study the degradation and generation of debris of external spacecraft materials when exposed to long term space environment (for LEO and GEO conditions).

The study consisted in the following major tasks:

- Identification of the **most relevant space environment** conditions for GEO and for LEO most populated orbits.
- Survey on relevant (i.e. most representative; most used) **external spacecraft** materials.
- **LEO and GEO** space materials **environmental testing**, for 20 years of GEO and 9.7 years LEO (800 km ± 75 degrees) simulated space environment.
  - Measure relevant parameters to improve MASTER 2009
- **MASTER 2009 improvements** with the test results of the environmental testing.

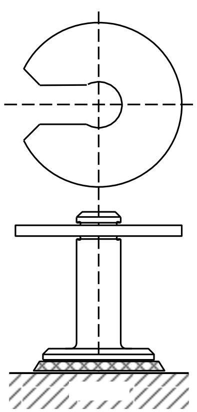
Activity – Space materials - Paints

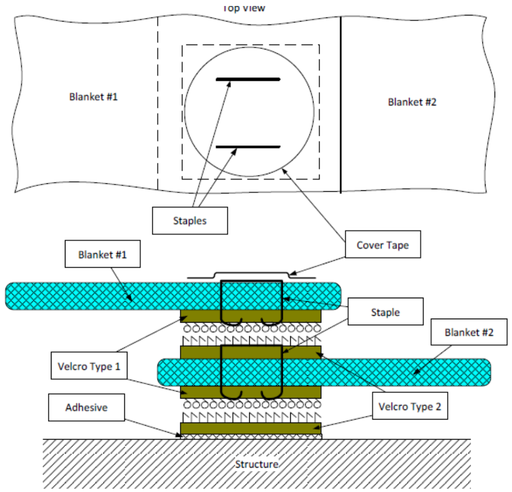
- MAP European space paints supplier
  - (used to protect equipment and change TO properties)
- Preferred Paints
  - Used outside satellite
  - Most used paints
  - Base composition
  - White/black
- GEO paints:
  - SG121FD; PSB; PNC
- LEO Paints:
  - SG121FD; PSB; PUK

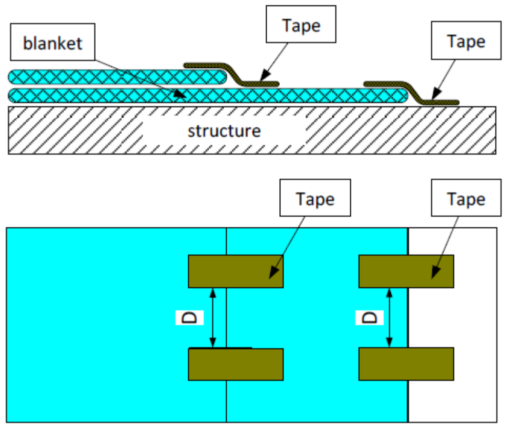
Paints	Number of missions	Paint colour	Base material	Substrates
PCBE	9	Matt-White	Silicone	Composites/light alloys
PSB	8	Matt-White	Potassium Silicate	AU4G/ composites
PSBN	2	Matt-White	Silicate	aluminium alloys
PNC	8	Matt-black	Silicone	Composites/light alloys
SG121FD	>37	silicone	Silicone	Composites/light alloys
SG122FD	2	Matt-White	Silicone	Composites/light alloys
PUK	27	Matt-black	Polyurethane	Composites/light alloys

Activity – Space materials - MLI

- Ultimate isolator, protect satellite from radiation and prevent heat loss.
  - External layer; bilayers of isolator/reflective)
    - VDA over polyester/ polyamide (Kapton)/ mylar/ other
    - Isolator Polyester/glassfiber/other
  - MLI blanket = external layer + bilayers(e.g. 12 to 40); Tailored for the satellite.
- External layers (1 mil polyimide / VDA; 1 mil ITO polyimide / VDA; 1 mil black Kapton / VDA; 1 mil Upilex / VDA; 2 mil Upilex / VDA; Betacloth / VDA; ….)



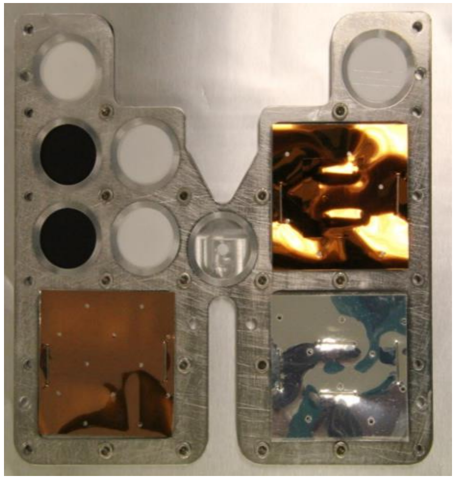


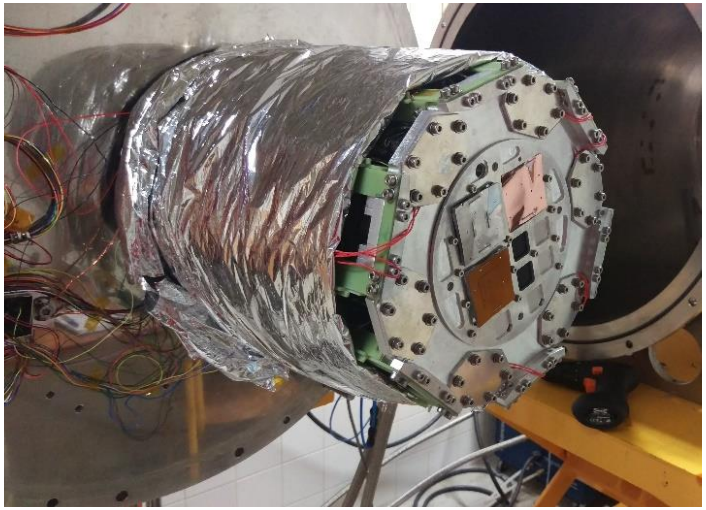


Activity – LEO test - Overview

- LEO Test flow

Initial sample characterization	Photos and mass
ATOX	Average Fluence 9.2E20 (~9.7 years in LEO; 800Km ± 75 degrees)
Intermediary Sample characterization	Photos and mass SEM and EDX
TVC + VUV	5140 ESH 500 TVC (+140 to -120)
Final sample characterization	Photos and mass Pelling test



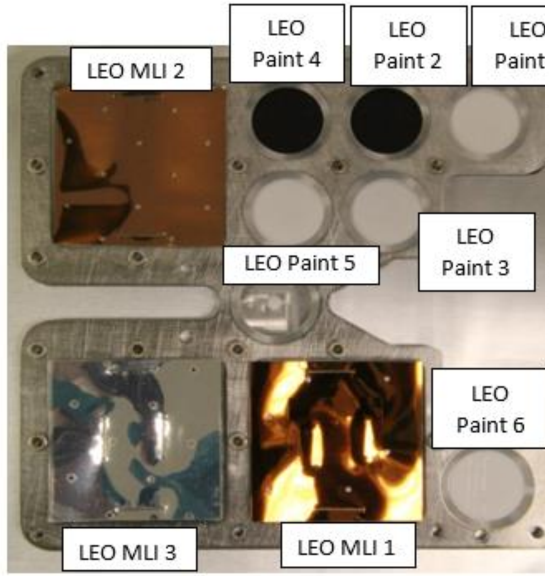


Activity – LEO test - Materials

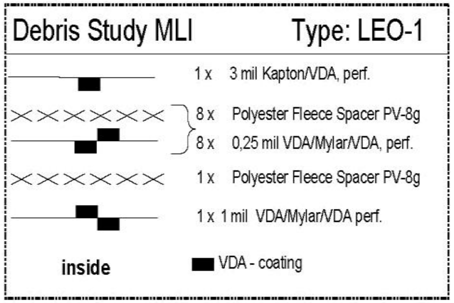
- Paints

Sample	Material/Substrate	dimensions
LEO Paint 1 PSB/CFRP	white silicate paint	Dimensions: 22x22x0.6 mm CFRP ref: M55J/RS3M
LEO Paint 2 PUK/CFRP	Black Polyurethane paint	
LEO Paint 3 SG121FD/ CFRP	white silicone pain	
LEO Paint 4 PUK/Alu	Black Polyurethane paint **3 slaches**	Aluminium: Au4G Dimensions: 21.9x21.9x4.1 mm
LEO Paint 5 SG121FD/ Alu	white silicone pain **3 slaches**	
LEO Paint 6 PSB/Alu	white silicate paint **3 slaches**	
LEO MLI 1	3 mil Kapton/VDA Velcro ref SJ3571 Nylon6.6	MLI size 46 mmx 46 mm Al Substrate 48.9x48.9mm
LEO MLI 2	2 mil ITO/SiOx/Kapton/VDA PSA	
LEO MLI 3	5 mil ITO/Teflon/Silver/Inconel Velcro ref SJ3571 Nylon6.6	

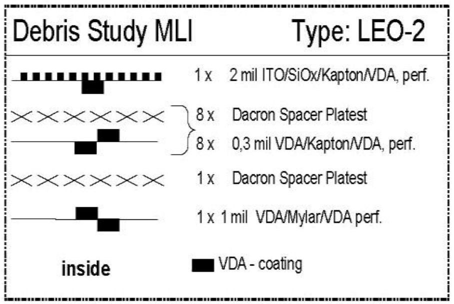
- MLIs



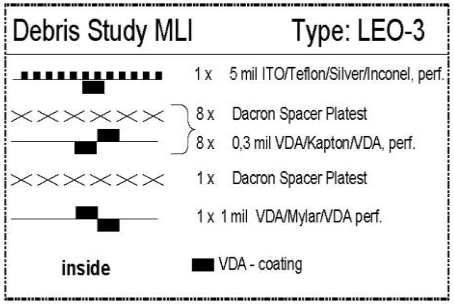
LEO MLI 1:



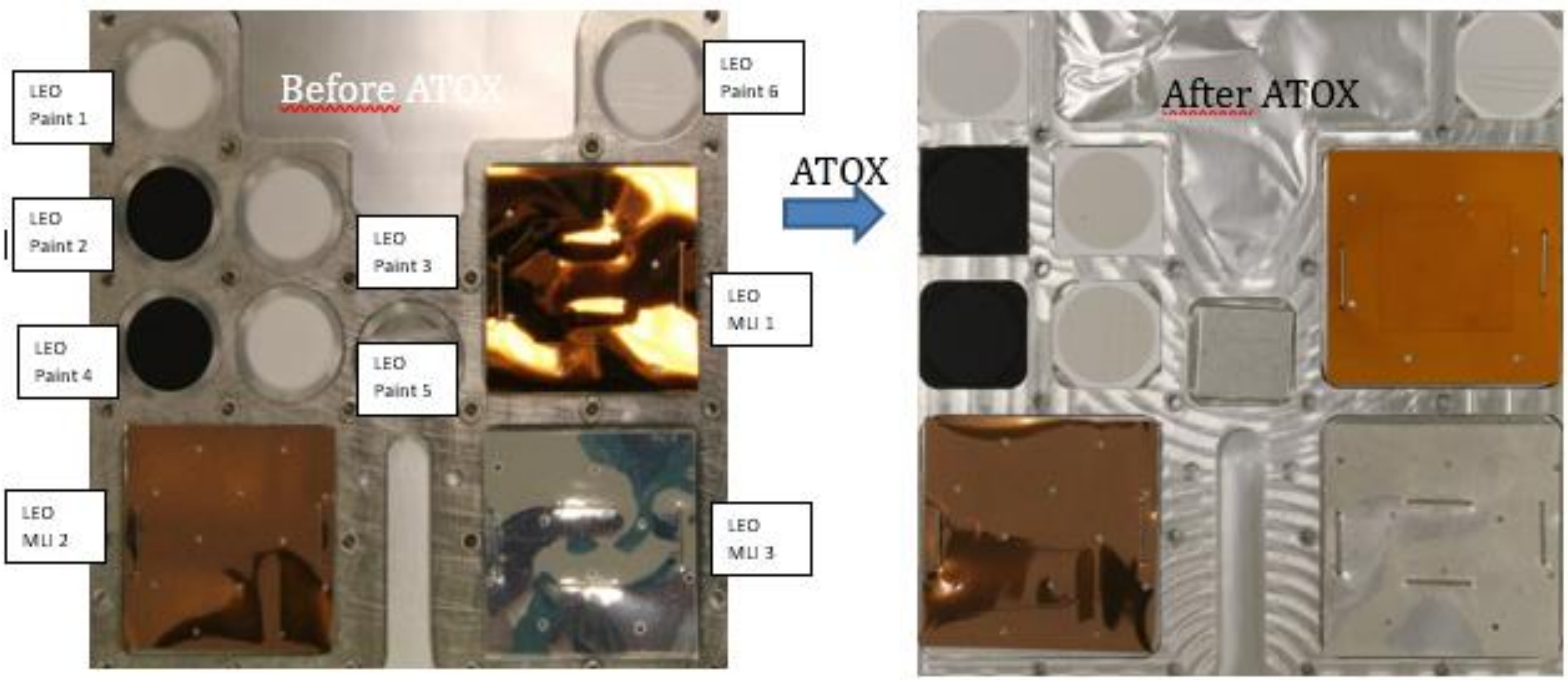
LEO MLI 2:



LEO MLI 3:



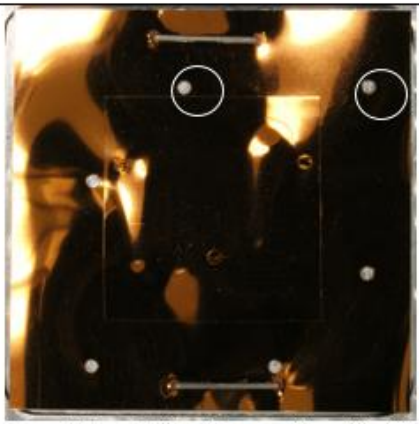
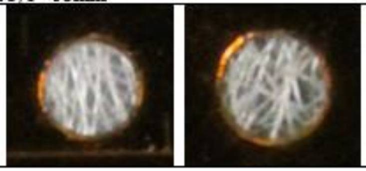
Activity – LEO test - ATOX



- Darkinng of white paints; whitening of black paints;
- Samples mass loss as function of ATOX fluence
- Kapton MLI and silver MLI degraded, loss of brightness.

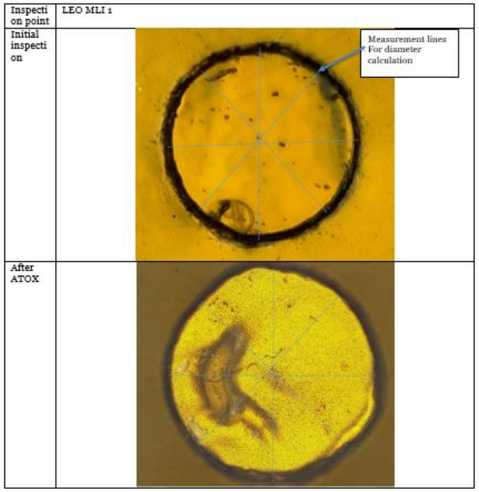
Activity – LEO test – ATOX - MLI

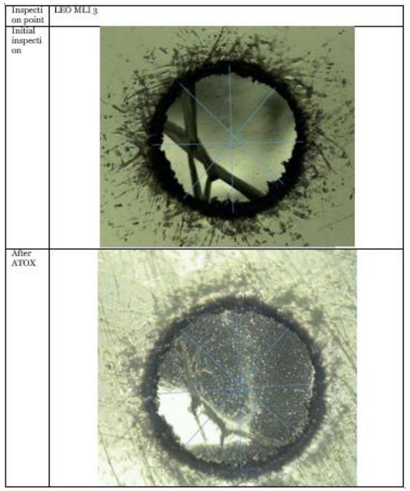
- MLI 1 After 8.1 Years (800Km orbit)

MLI ref.	Initial inspection	Intermediary inspection (i.e. After ATOX)
LEO MLI 1	 Canon EOS 550D; f/22; Exposure time 1/8 s; ISO-3200; F=60mm	 Canon EOS 550D; f/22; Exposure time 1/13 s; ISO-3200; F=60mm
LEO MLI 1 venting holes		

- Degradation of surfaces and isolating material

- MLI venting Holes

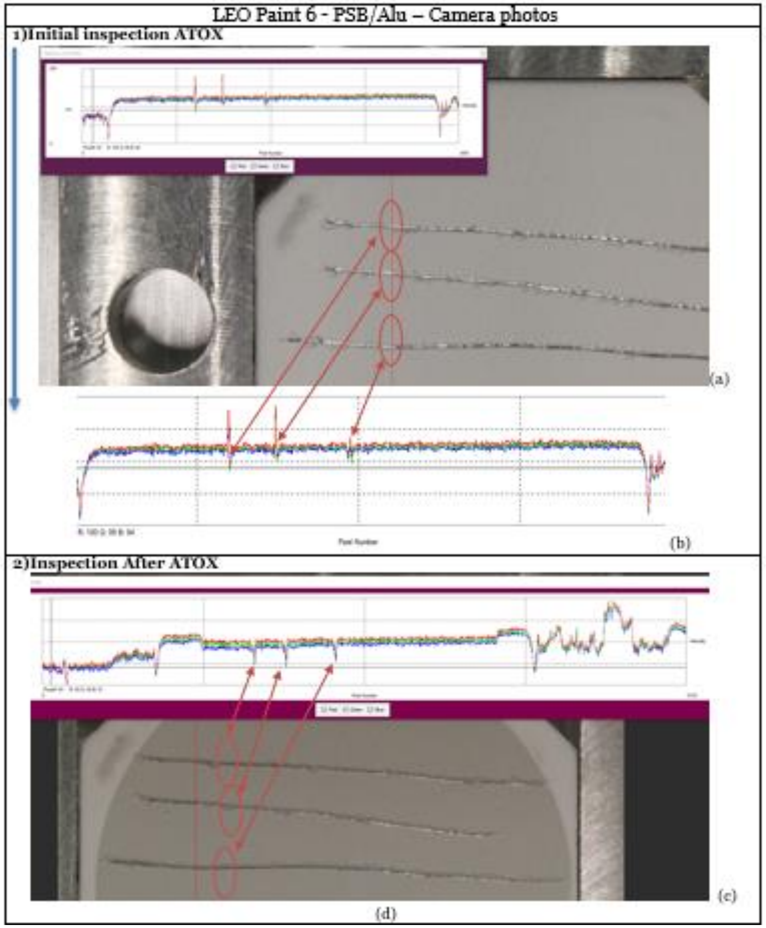


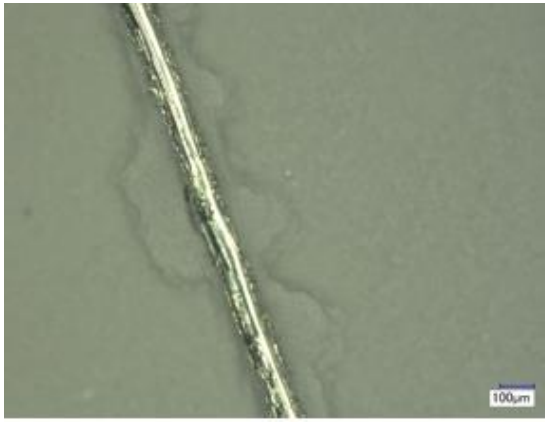


MLIs	Before ATOX [µm]	After ATOX [µm]	Scratch increase
MLI 1	1390	1488	7%
MLI 2	1217	1413	16%
MLI 3	1348	1360	0.8%

Activity – LEO test – ATOX - PAINTs

- PSB/Alu (white silicate)



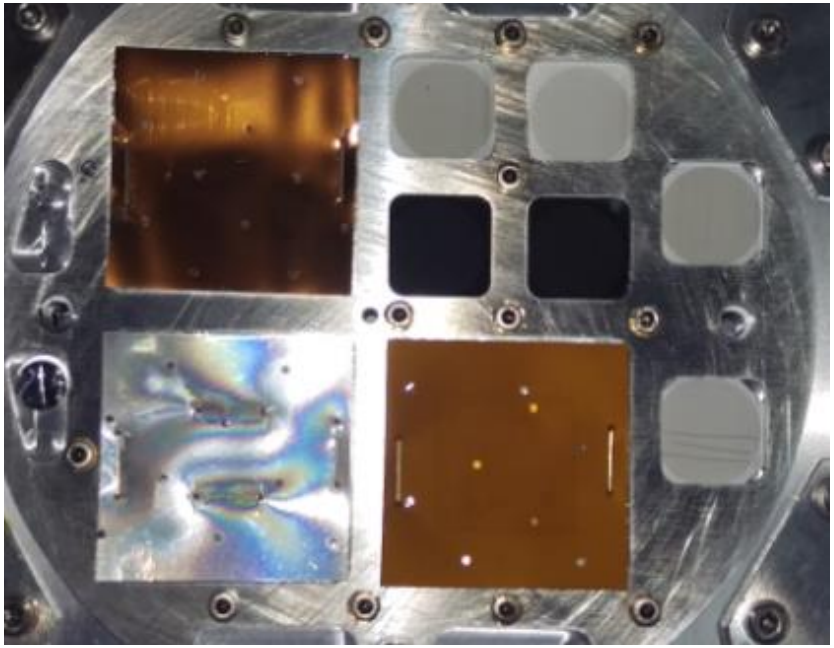


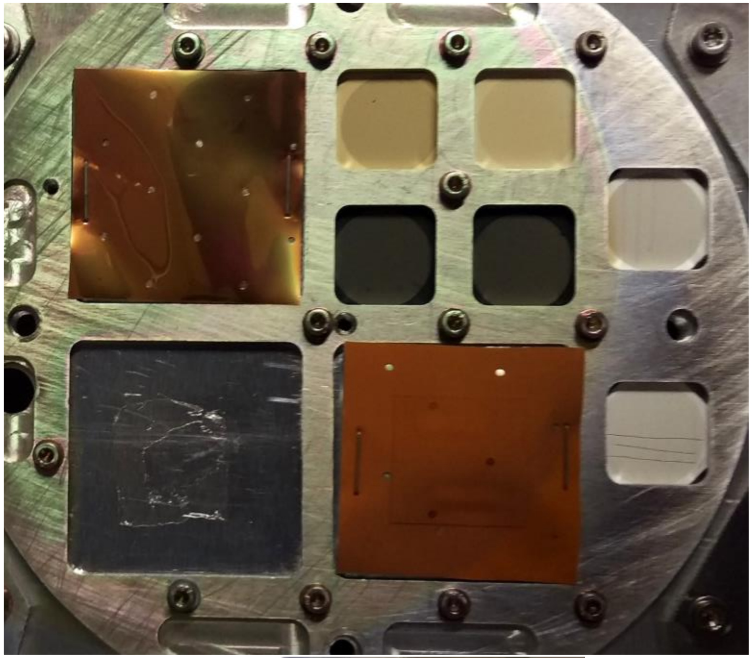
- Scratch increased observed in paint 6

Sample	Before ATOX			After ATOX			Scratch increase
Paint 6	scratch 1						
	92.9 [µm]	±	1.9	141.8[µm]	±	3.2	53%
	scratch 2						
	94.7 [µm]	±	2.4	132.2 [µm]	±	2.7	40%
	scratch 3						
	106.8 [µm]	±	2.8	185.1 [µm]	±	4.5	73%

Activity – LEO test – TVC + VUV

- TVC (500 cycles; +140 to -120); - Average number of suns 2.4 (5145 ESH)





- MLI 2 Fall down during 433 cycles (cooldown)
- MLIs become stiffer/curved
- Darkening/whitening of paints of paints

Activity – LEO test – TVC + VUV

- MLI side view

- MLI becomes stiffer/curved
- Velcro shrinks
- PSA degrades

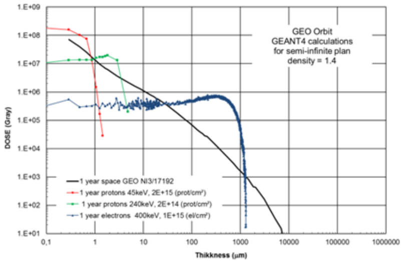
- Paint flaking observed in PUK and PSB paint

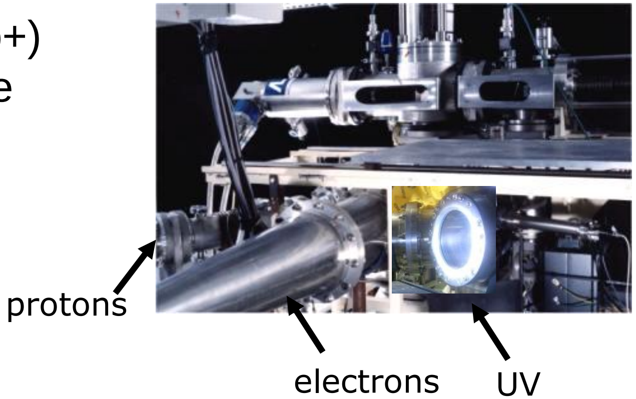
PUK flaking

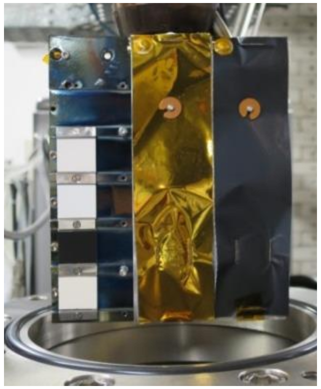
	Flaking Area (µm²)
1	15000
2	36000
3	18000

Activity – GEO - Test principle and Conditions

- Dose profile (UV -> e- >p+)
- Synergy with temperature



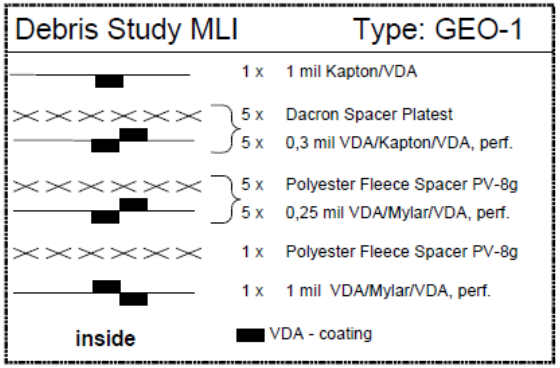




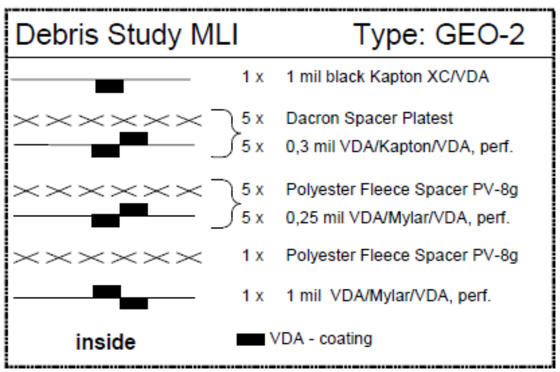
	MLIs	paintings
UV (200-380nm) (extreme surface)	5.2 – 6.6 suns, 8211esh UV (about 9-year dose)	
Particles (surface p+ -> bulk e-)	400keV electrons, 45 and 240keV protons. Flux: typically 1.5E11 #/cm².s 20-year GEO fluences: e400 = 2 10^{16}, p240 = 4 10^{15}, p45 = 4 10^{16}	
T° cycling -85°/+100° 1-2°C/min, 5-8min dwell	Hot conditions External foil ≥ 100°C Inner foils/velcros > T_v when above ~ 35°C	300 cycles
synergy	external foil, clip/washers: T°+ UV + electrons + protons inner foils and velcros : T° + electrons	T°+ UV + electrons + protons
sequence	steps at 5, 10 then every 2 years up to 20-year dose for visual inspection	

Activity – GEO test campaign: Samples

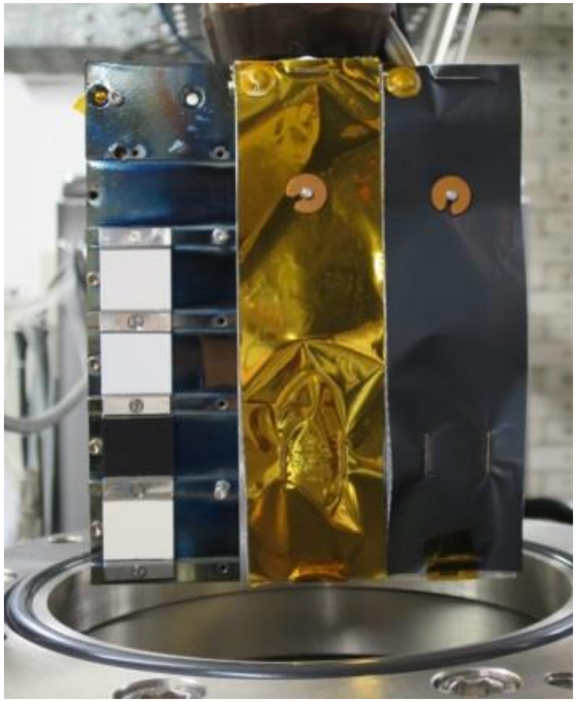
GEO MLI strip 1 and spare 1:



GEO MLI strip 2 and spare 2:

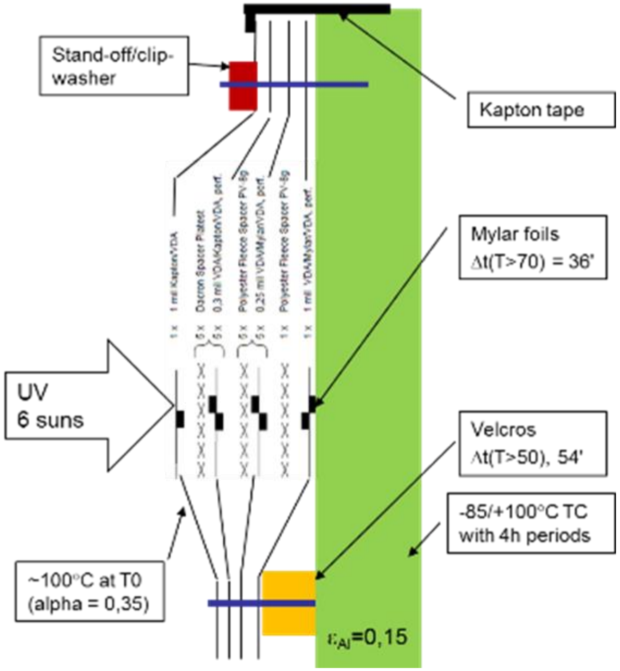


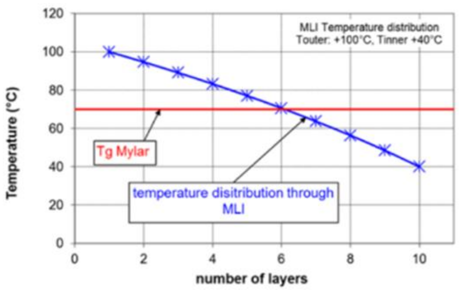
- 2 strips 4cmX14cm
- 2 fixations/ strips (velcros and clip/washers)



GEO	substrate
SG121FD (silicone white paint)	Au4G
PSB (silicate white paint)	Au4G
PSB (silicate white paint)	CFRP
PNC (silicone black)	Au4G

- 4 paints 2cmX2cm





!!! MLI temperature: oscillating upper/low Tv (Mylar - inner foils / nylon – velcro)

Activity – GEO test campaign: results

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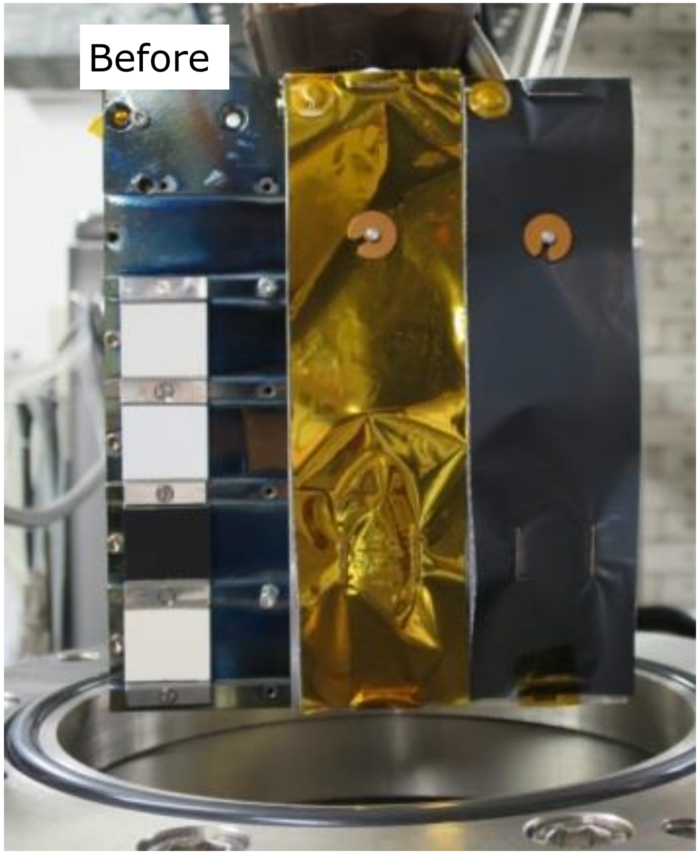
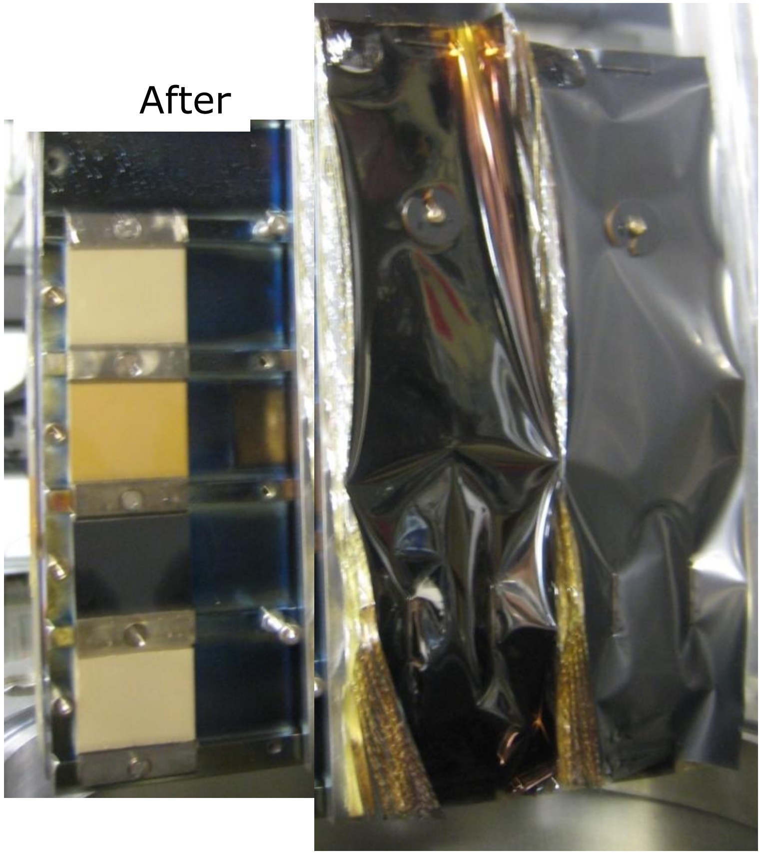
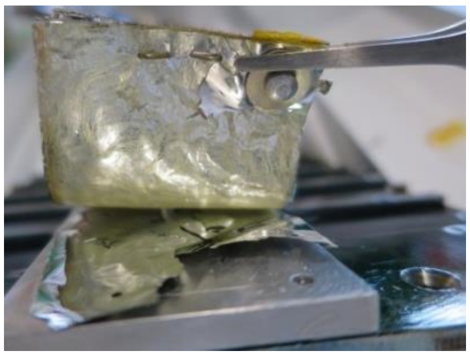




- MLIs: Strong darkening of external kapton layer (solar absorptance almost doubled 0,35>0,68), very slight whitening of black kapton (less degraded), no in situ evidence of mechanical damage (only curling),
- Paintings: discolouring of white paints (solar absorptance x3-5), no-self flaking (no sample fracture even after peeling test)

Activity – GEO campaign: inner foils

ex situ visual inspection shows strong degradati



Dismounting the strips from the plate …

- mylar foils appeared brittle and falling apart (debris generated from handling)
- velcros is discoloured/bended (local mechanical stress at mylar foils) and brittle loops
- Polyester fleece spacers and dacron are OK

Layer 1 (numbering from the back)

electrons dose effect

influence of T° (≥ T_v)

DSC shows strong degradation with partial-to-complete vanishing of crystalline content in both materials

Layer2

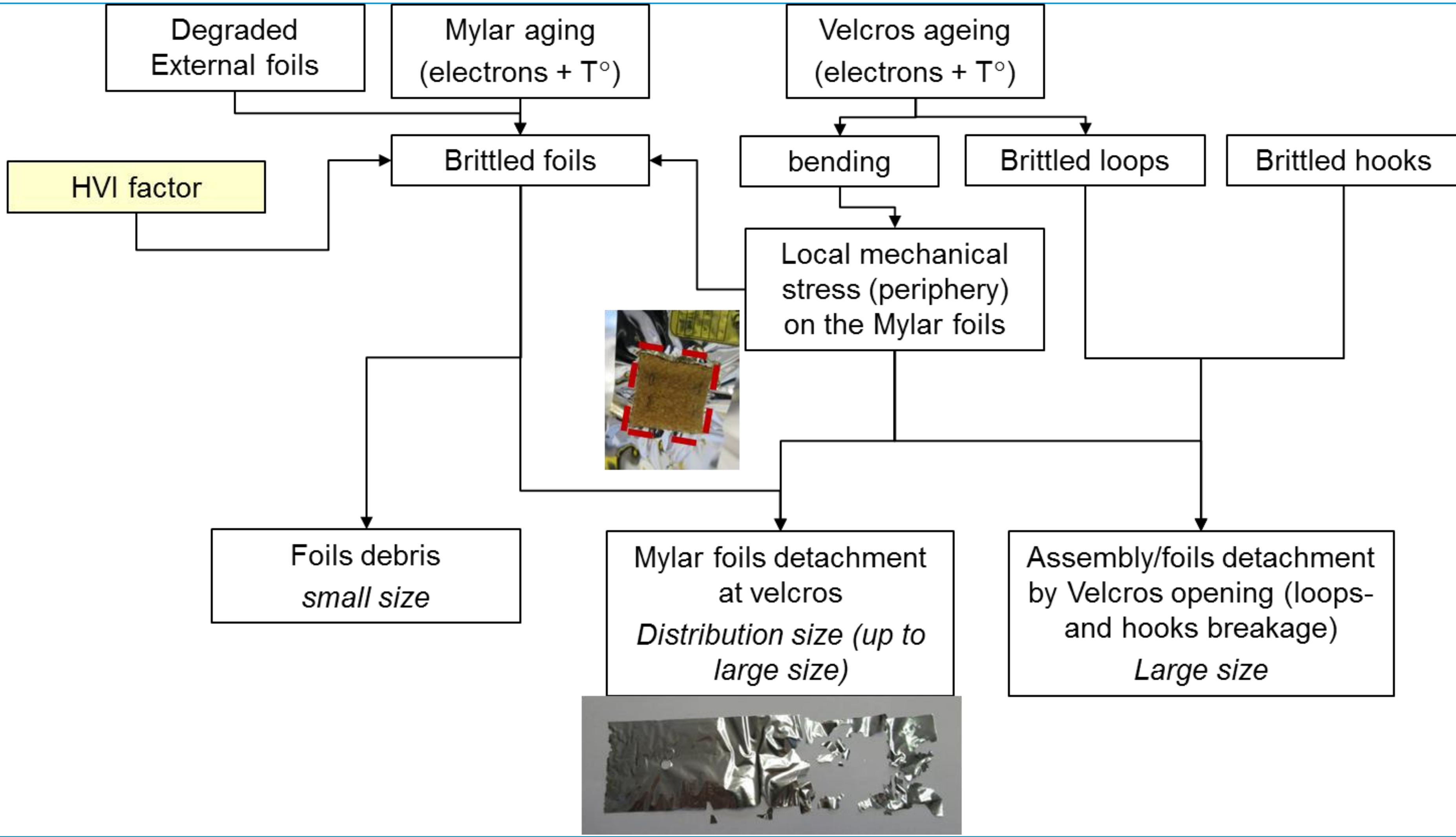
Layer3

Layer4

Layer5

Layer6 (front)

Activity – Debris investigation : Scenario for MLI debris generation



Activity – Debris investigation: MLI debris characteristics (Mylar foils)

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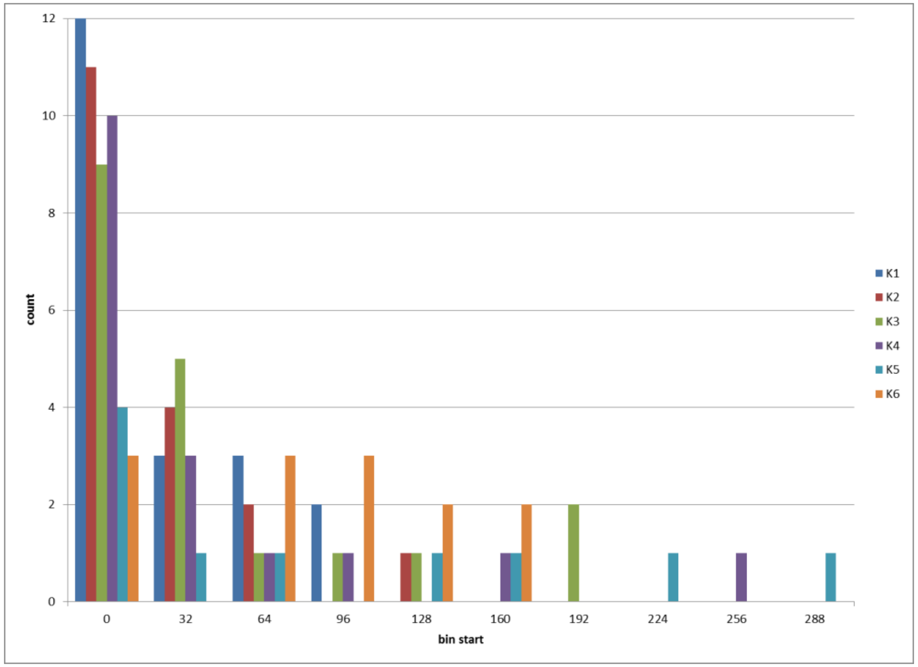
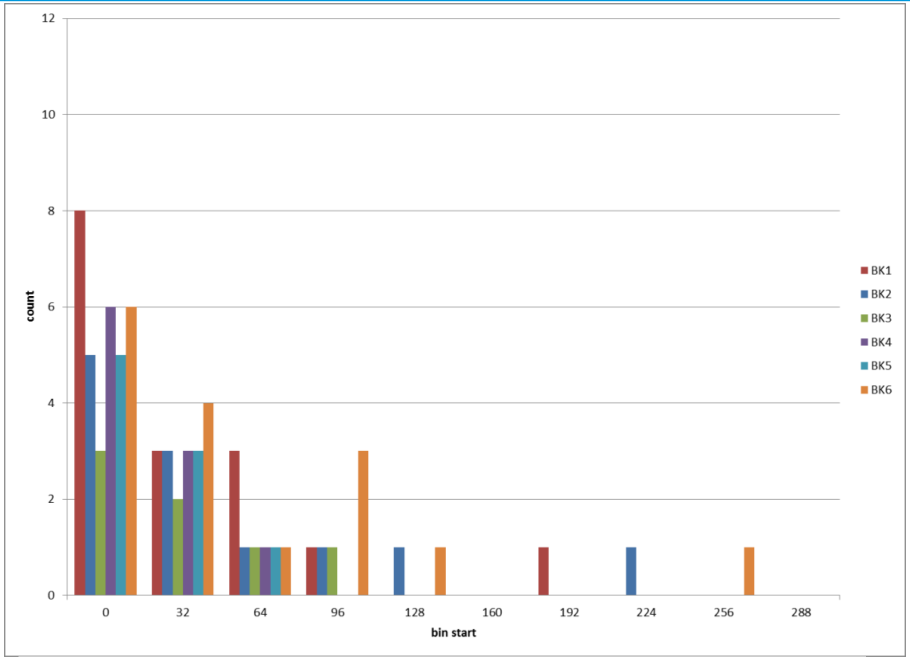


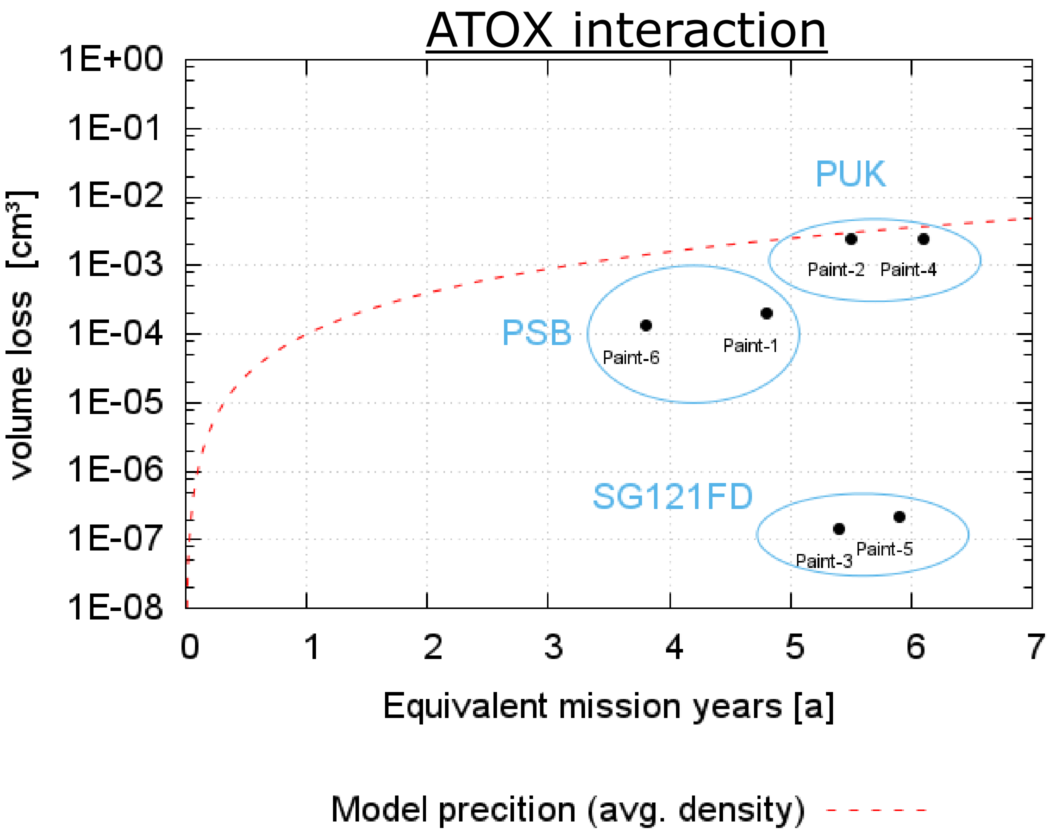


Bins in mm²

Distribution shapes are similar for each layer and for both K and BK MLIs

Conical, triangle …. angular shapes

Comparison: experimental observations and current calibration



Paint	Description
PUK	Polyurethane black
PSB	silicate white paint
SG121FD	silicone white paint

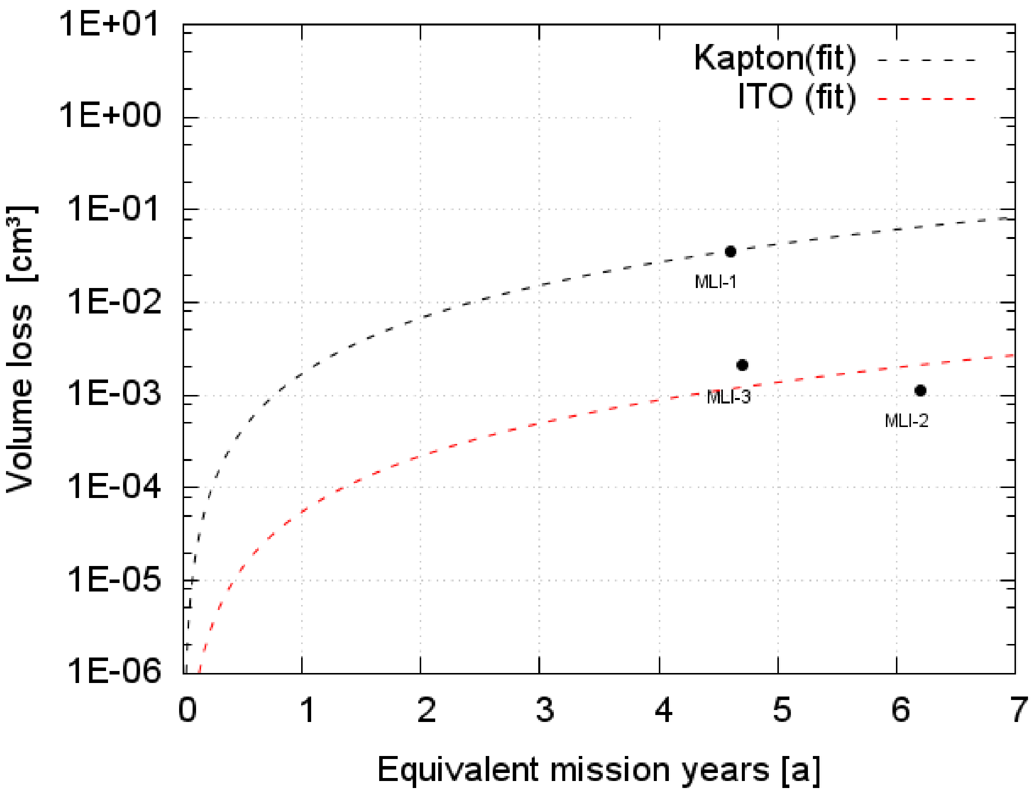
current calibration

$$y(t_{age}) = y_0 \cdot \left(\frac{t_{age}}{1a}\right)^2$$

$$y_0 = 6 \cdot 10^{-25} \frac{cm^3}{atox}$$

Activity – MASTER 2009
MLI LEO ATOX interaction

Fundamentals for new MLI degradation approach



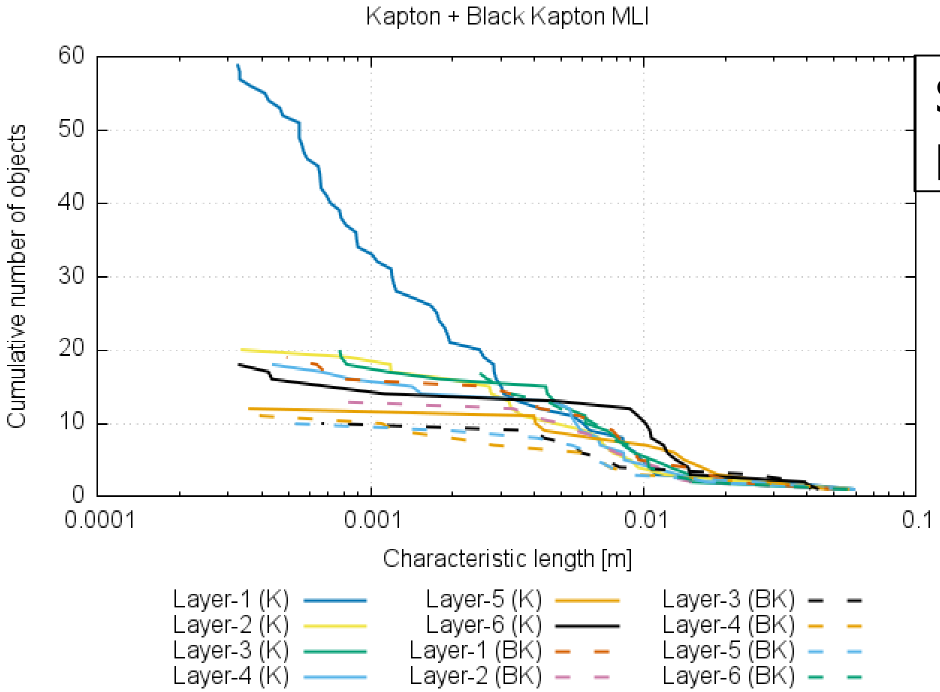
MLI susceptibility to ATOX → Volume loss F (derived from mass measurements)

Based on *paint-atox-interaction*-approach

$$F_{Kapton}(t_{age}) = 1.7 \cdot 10^{-3}\ cm^3 \cdot \left(\frac{t_{age}}{a}\right)^2$$

$$F_{ITO}(t_{age}) = 5.5 \cdot 10^{-5}\ cm^3 \cdot \left(\frac{t_{age}}{a}\right)^2$$

Activity – Conclusions
MLI GEO interaction



Same magnitude for numbers of particles (except Kapton layer 6)

- <u>Fundamental new approach</u>
  - Radiation contribution
  - Small particle release

Activity – Conclusions

- Critical issues detected during the project:
  - Extreme Velcro degradation
    - In GEO, the Velcro become brittle and any mechanical action may release it.
  - For GEO MLI internal layers total degradation
  - Paint flaking in LEO conditions and PSA failure
  - A critical radiation dose threshold could explain an increased number of MLI in GEO and give new insights into mission safety.
- Future activities
  - Further investigation with measurement of onset dose for Velcro failure and Mylar embrittlement
  - Investigation of Germanium foils and different new paintings
  - Synergy studies of long term space exposure (e.g. radiation + ATOX + TVC) with Hypervelocity impact.
  - PSA testing. It was observed that at low temperatures the PSA fails.

Activity – Conclusions

Specificity of degradation-induced-debris investigation

- Limited Sample size
    - Distribution extrapolation (depends on scenario)
- Limited in situ « testing » capabilities (visual inspection and debris collection)
    - Onset dose not accessible

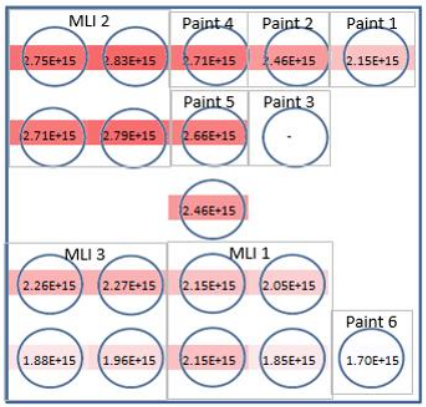
Validation of scenario (mechanisms) and complementary data (onset dose)

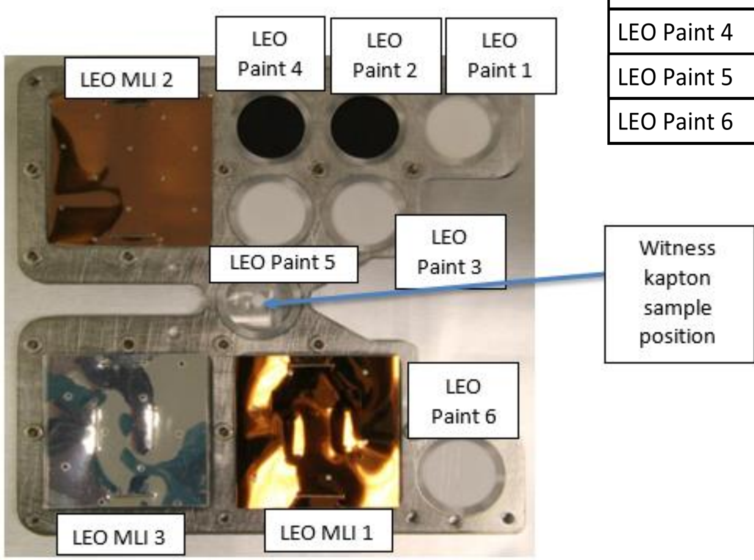
- Test conditions adapted to objective
    - electron testing of velcros* and mylar foil
    - Importance of temperature (representativeness)
    - HVI test on aged assembly and/or external foils
- Risk assessement for various MLI mounting principles
    - Attachement types
    - Patch size: worst case distribution

BACKUP SLIDES

Activity – LEO test - ATOX

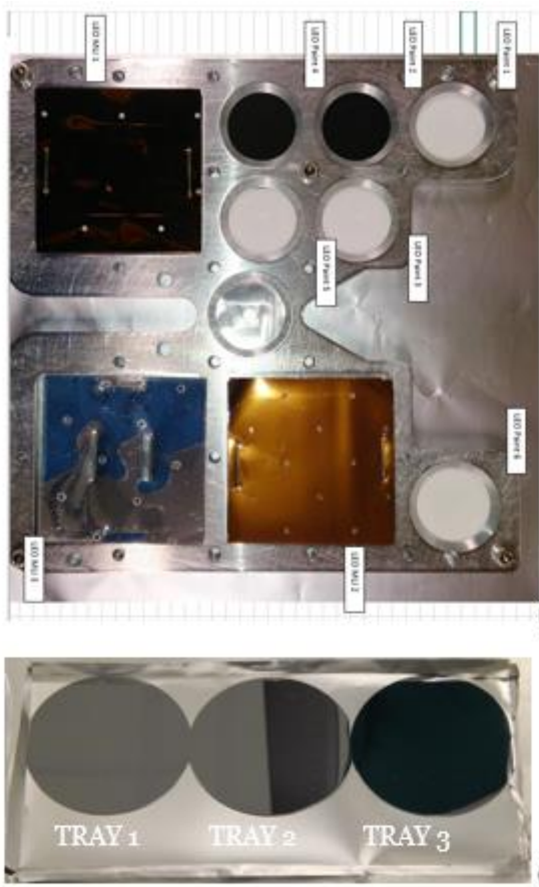
- ATOX fluence and mission years





Sample reference	Description	Fluence	Equivalent mission years			
			(745 Km, ± 75 degrees)	(800 Km, ± 75 degrees)	(900 Km, ± 75 degrees)	(1000 Km, ± 75 degrees)
LEO MLI1	3 mil Kapton/VDA	7.62E+20	4.6	8.1	21.1	54.4
LEO MLI2	2 mil ITO/SiOx/Kapton/VDA	1.00E+21	6.2	10.6	27.7	71.4
LEO MLI3	5 mil ITO/Teflon/Silver/Inconel	7.78E+20	4.7	8.3	21.5	55.5
LEO Paint 1	PSB/CFRP	8.00E+20	4.8	8.5	22.2	57.1
LEO Paint 2	PUK/CFRP	9.13E+20	5.5	9.7	25.3	65.2
LEO Paint 3	SG121FD/CFRP	8.96E+20	5.4	9.5	24.8	64.0
LEO Paint 4	PUK/Alu	1.01E+21	6.1	10.7	28.0	72.1
LEO Paint 5	SG121FD /Alu	9.89E+20	5.9	10.5	27.4	70.6
LEO Paint 6	PSB/Alu	6.33E+20	3.8	6.7	17.5	45.2

Activity – LEO test - EDX and SEM



(a)
(b)

Samples	substances	elements
PUK	Black Polyurethane paint	C and N
PSB	white silicate paint; Binder is potassium metasilicate; Pigment is zinc orthotitanate.	Si; Zn; O; Ti
SG121FD	white silicone paint. Binder is polydimethylsiloxane resins; pigments: zinc oxide calcined at 600°C sodium perborate coated	C; O; Si; Zn; Na; B
MLI LEO -1	Kapton, VDA, Polyester, Mylar	C, N; O; Al;
MLI LEO - 2	ITO/SiOx/Kapton/VDA; Dacron; Mylar; VDA	I Sn O Si C O
MLI LEO - 3	ITO/Teflon/Silver/**Inconel**; Dacron; Kapton; VDA; Mylar	I Sn O Si C O Inconel may include: (Ni Cr Fe Mn Cu Al Si C S)

Case study #	Probable origin of debris	Particle size
1	PSB	10 µm square
2	PSB	6.25 µm square
16	PSB	4 µm square
21	PSB	6.7 µm square
21	PSB	4.4 µm square
24	PSB	5.4 µm
24	PSB	3.4 µm
24	PSB	2.9 µm
26	PSB	24 µm

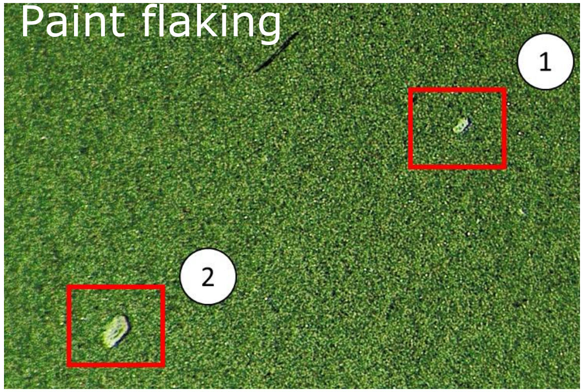
Space Debris from Spacecraft Degradation Products

MS2 TRB

- **Microscope inspection -** LEO Paint 1 PSB/CFRP–

Activity – Summary of Results

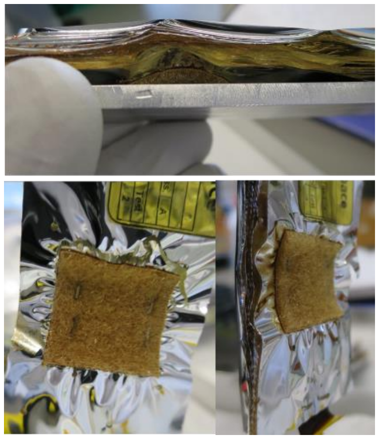
Observed in LEO material tests:



Observed in GEO material test:

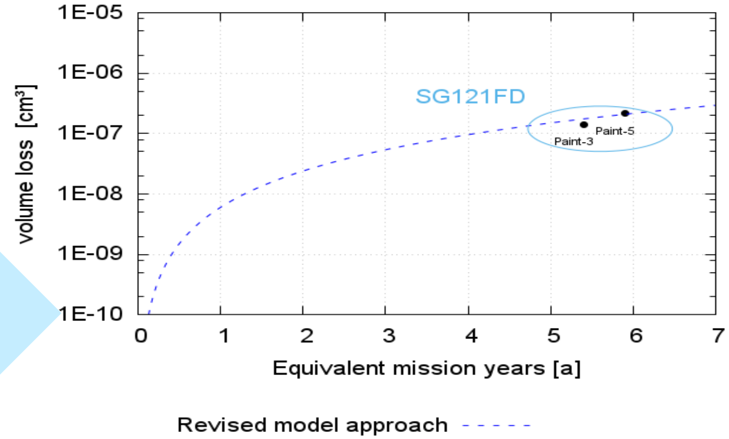
Debris of MLI internal layers

Velcro degradation



Master 2009 improvements

- Revision of mass loss calibration (LEO paints)



- Debris MLI size distribution revision (GEO)

Other observations:

- Discover that Velcro's severe degradation