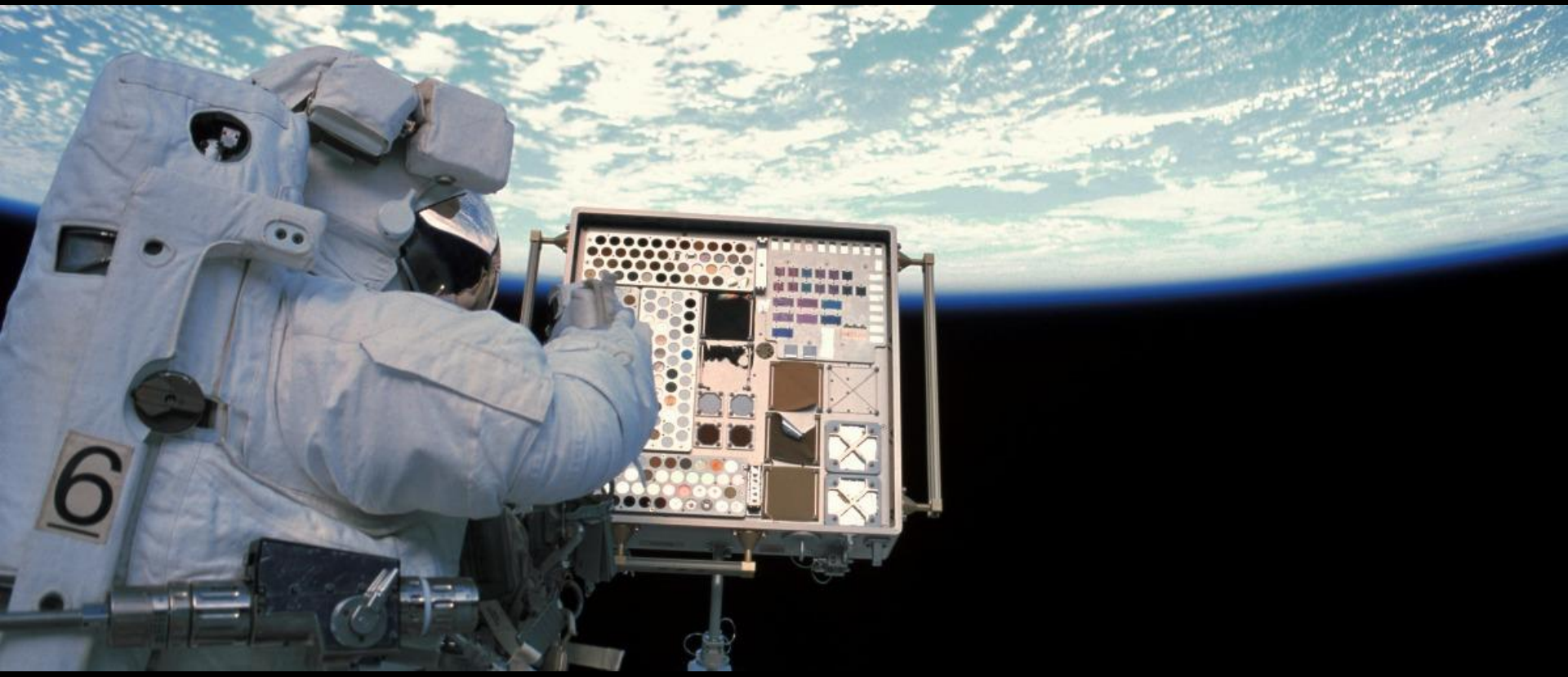
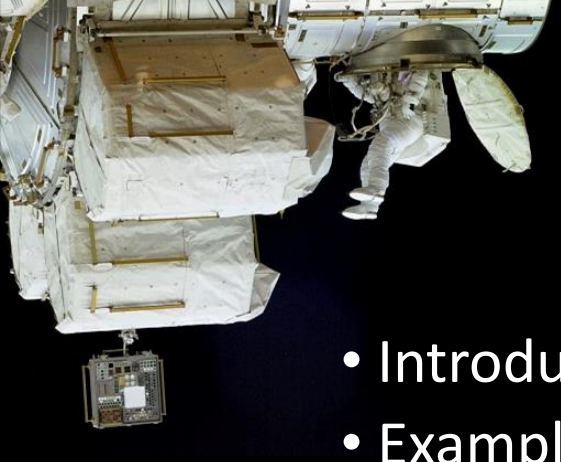
Materials International Space Station Experiment (MISSE): Overview, NASA Glenn's Experiments and Future Needs



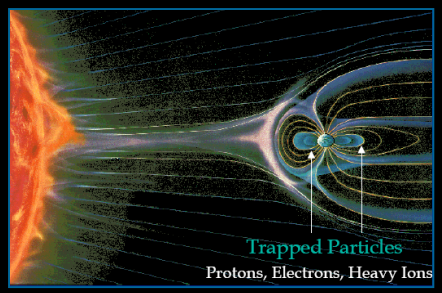
Kim K. de Groh
NASA Glenn Research Center

Materials in the Space Environment Workshop
May 17, 2016, Italian Space Agency (Rome, Italy)
Organized by the University of Rome "Tor Vergata"

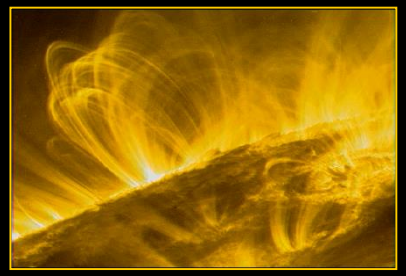


Presentation Outline

- Introduction to the space environment
- Examples of space environment induced degradation
  - Long Duration Exposure Facility (LDEF)
  - International Space Station (ISS)
  - Hubble Space Telescope (HST)
- Introduction to the Materials International Space Station Experiment (MISSE) project
- NASA Glenn Research Center's MISSE experiments
  - Introduce Glenn's MISSE 1-8 experiments
  - Overview & results from select experiments
- Future needs & MISSE-Flight Facility (MISSE-FF)
- MAPTIS MISSE Database



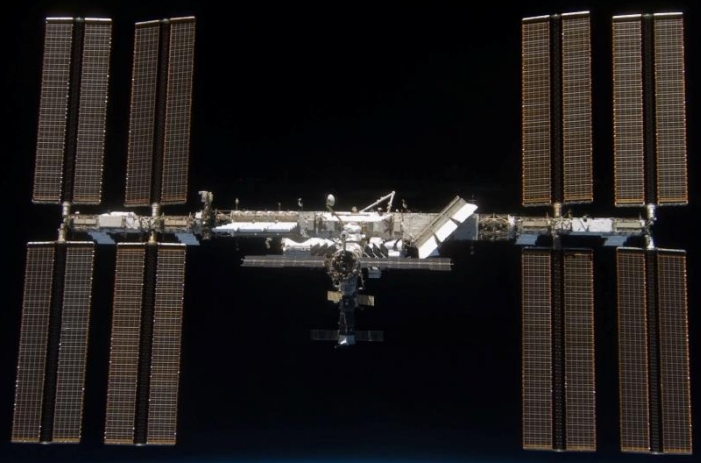
The Space Environment



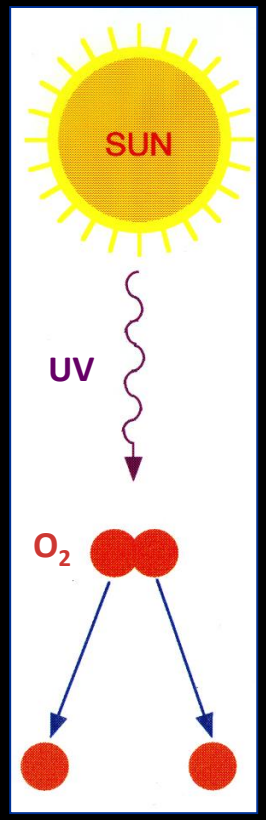
Spacecraft are exposed to many environmental threats, which can be harmful to spacecraft & their operation

In low Earth orbit (LEO) environmental threats include:

- Solar radiation (ultraviolet (UV), x-rays)
- Charged particle radiation (electrons, protons)
- Cosmic rays (energetic nuclei)
- Temperature extremes & thermal cycling
- Micrometeoroids & orbital debris (space particles)
- Atomic oxygen (reactive oxygen atoms)



Atomic Oxygen (AO)

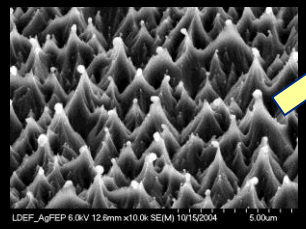


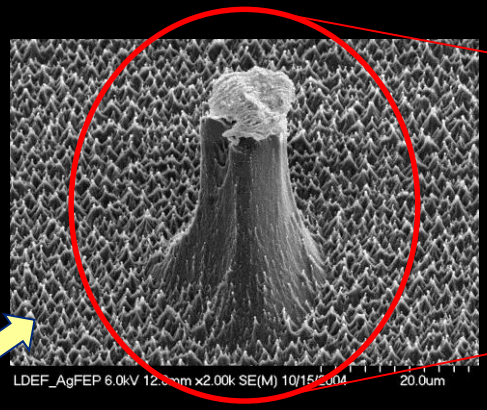
Atomic Oxygen

- AO is the predominant species in LEO (≈200-650 km)
- It is formed by photodissociation of molecular oxygen (O_2) by short wavelength energetic UV radiation
- At ram impact velocities (17,000 mph) the average impact energy is 4.5 eV
- AO oxidizes certain materials (such as polymers) with resulting gas formation - so *the material erodes away...*

⇒ *AO is a serious threat to spacecraft survivability*

Ram AO erosion causes "cone" formation





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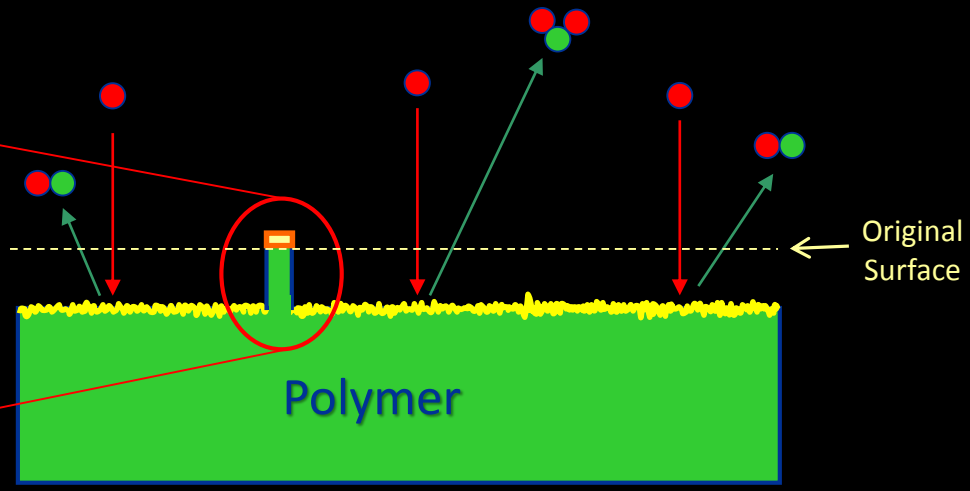
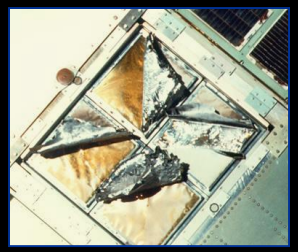


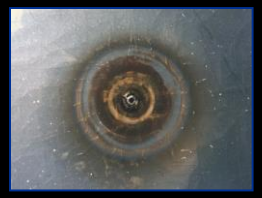
Space Environment Induced Degradation

Radiation induced darkening



Structural degradation

Long Duration Exposure Facility **(LDEF)**
5.8 yrs in space

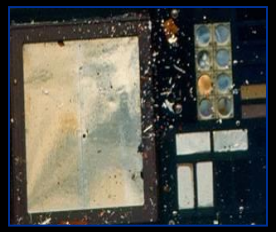


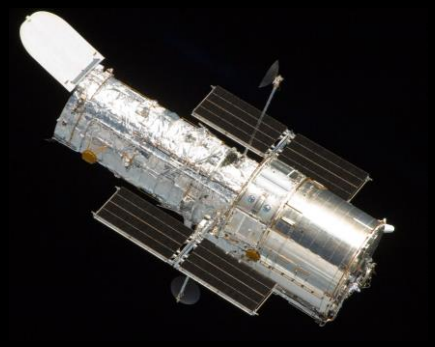
Impact site

Pre-flight **Post-flight**

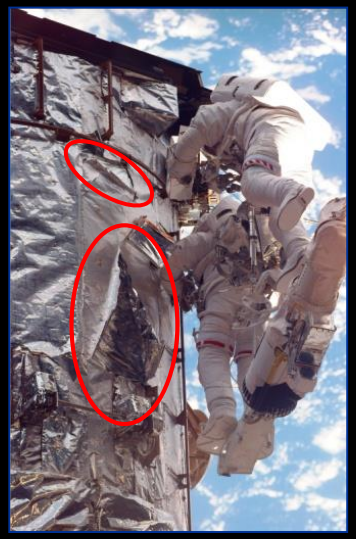
AO erosion of Kapton blanket

Debris generation

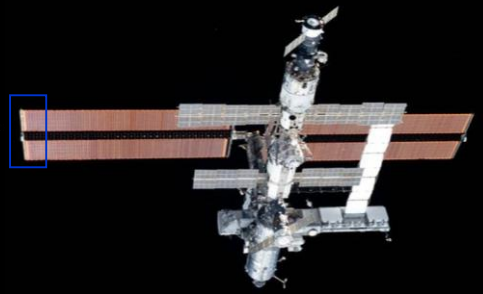




Hubble Space Telescope (HST)

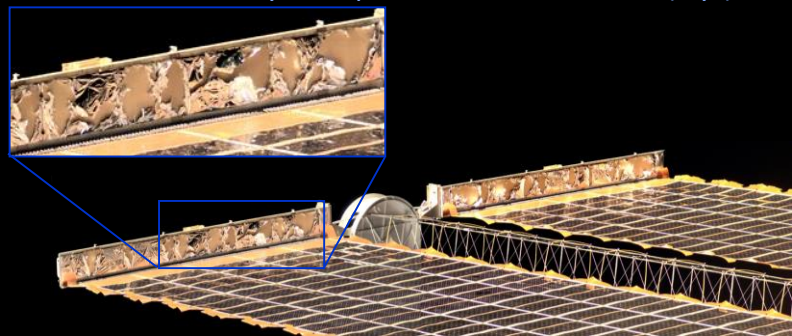


Radiation induced embrittlement & cracking of Teflon insulation (6.8 yrs)



International Space Station (ISS)
2001

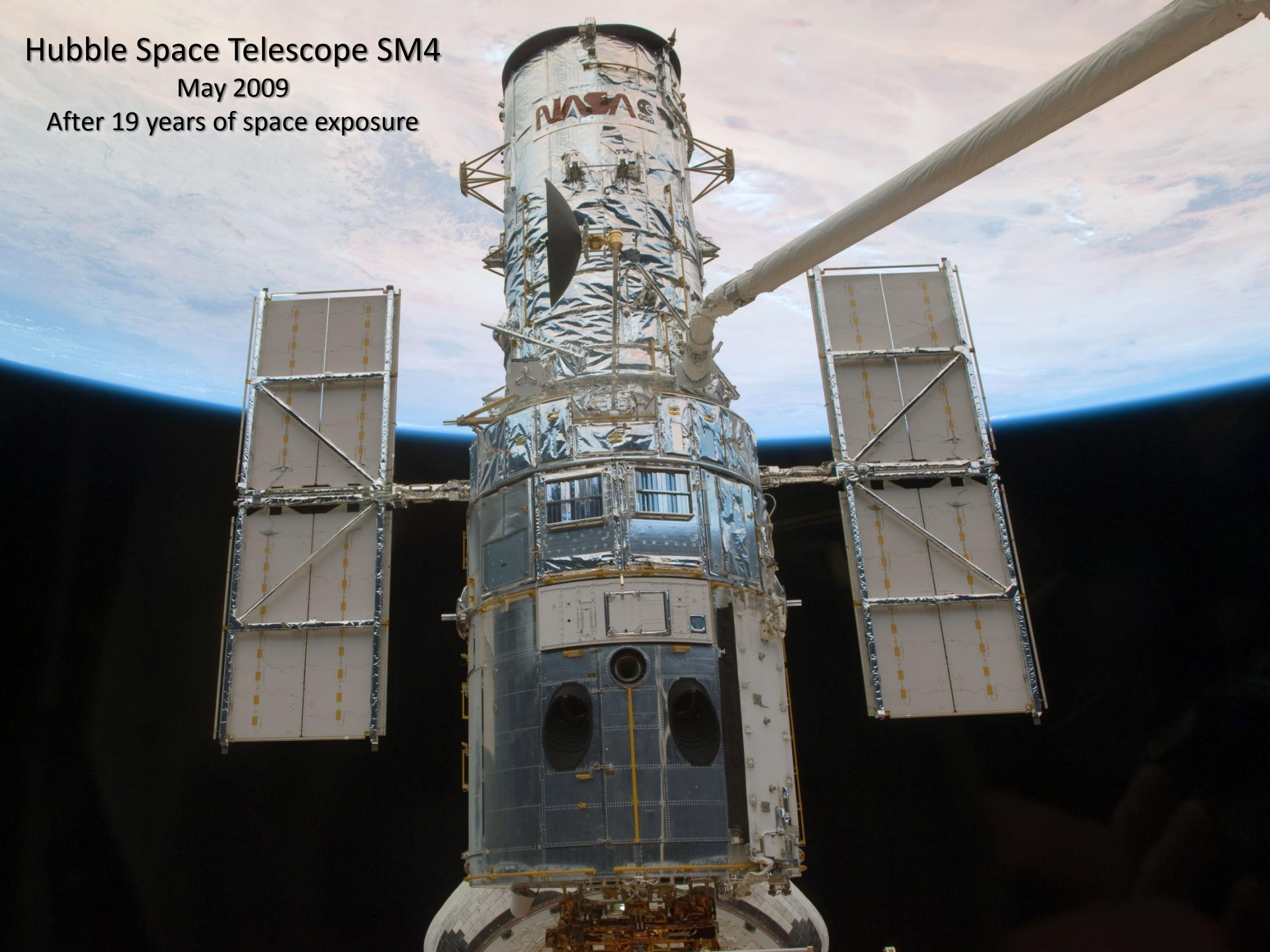
AO undercutting erosion of the P6 Port Solar Array Al-Kapton **blanket box cover** (1 yr)

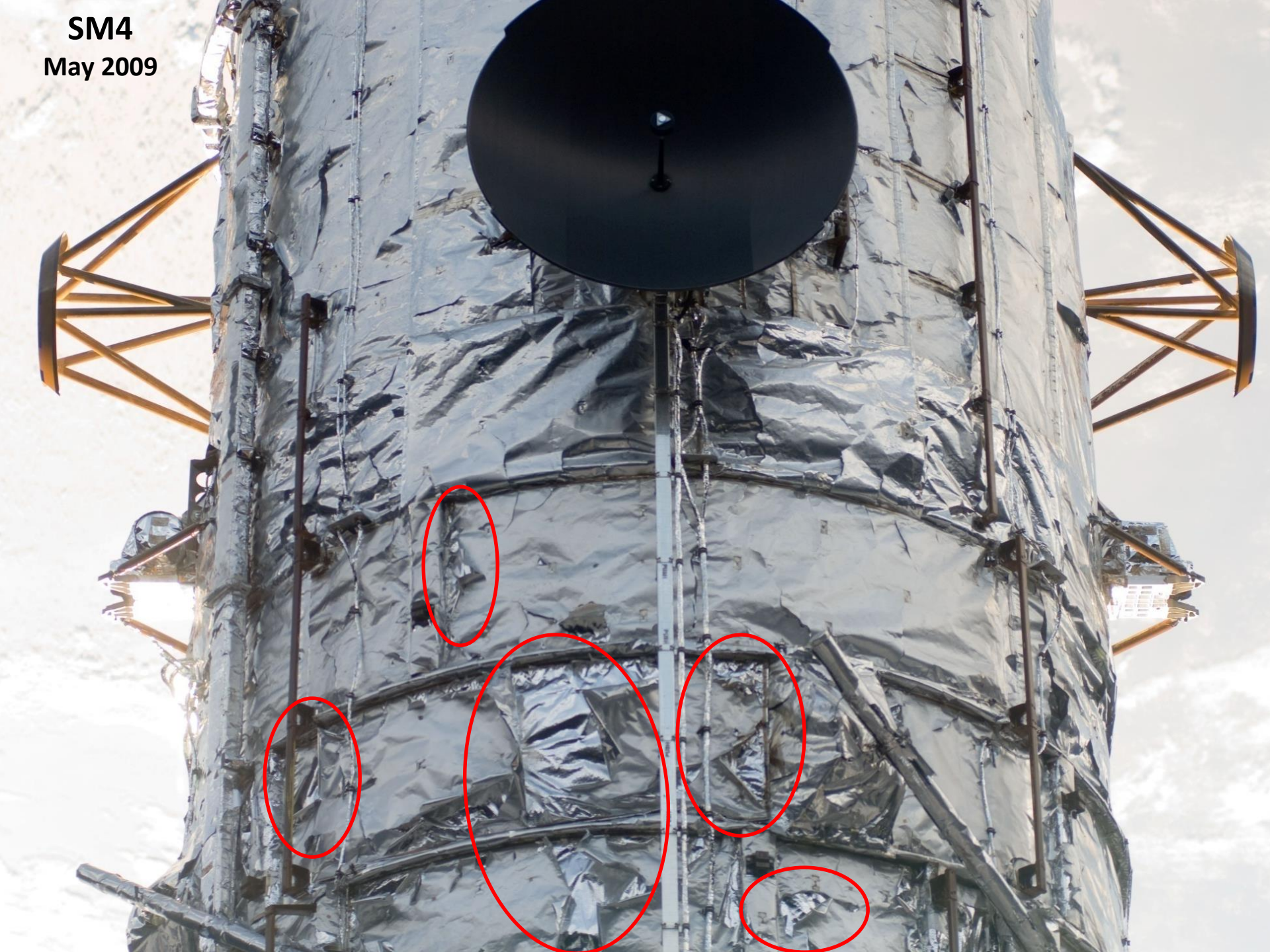


Hubble Space Telescope SM4

May 2009

After 19 years of space exposure




SM4
May 2009

Bay 8 New Outer Blanket Layer (NOBL) Installation

Equipment Bay 8 MLI
(Sun Facing)

MLI on Bays 5 & 8 were replaced with new insulation during SM4 to protect the underlying equipment from temperature extremes

To help understand and prevent materials degradation in space, researchers have flown spaceflight experiments as part of "MISSE"

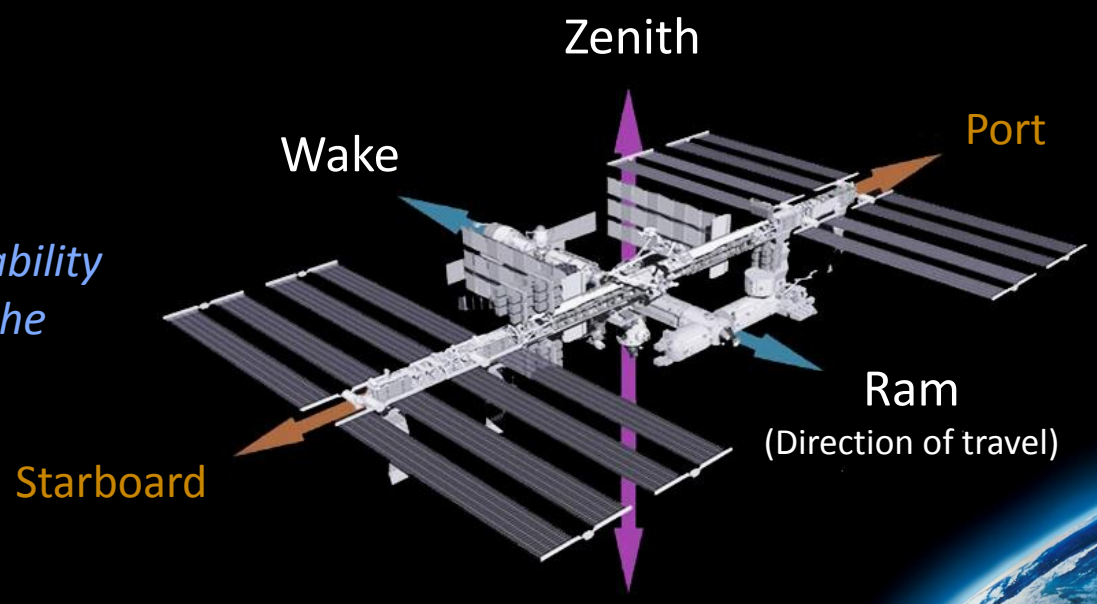
Materials International Space Station Experiment (MISSE)

MISSE is a series of materials flight experiments consisting of trays called Passive Experiment Containers (PECs), that were exposed to the space environment on the exterior of the International Space Station (ISS).

The PECs were positioned in either a *ram/wake orientation* or a *zenith/nadir orientation*.

Objective:

To test the stability and durability of materials and devices in the space environment



Flight Orientations & Environmental Exposures

Ram:

- *Facing the direction of travel (i.e. forward pointing or leading edge)*
- *<u>Highest AO</u> & moderate solar exposure*

Wake:

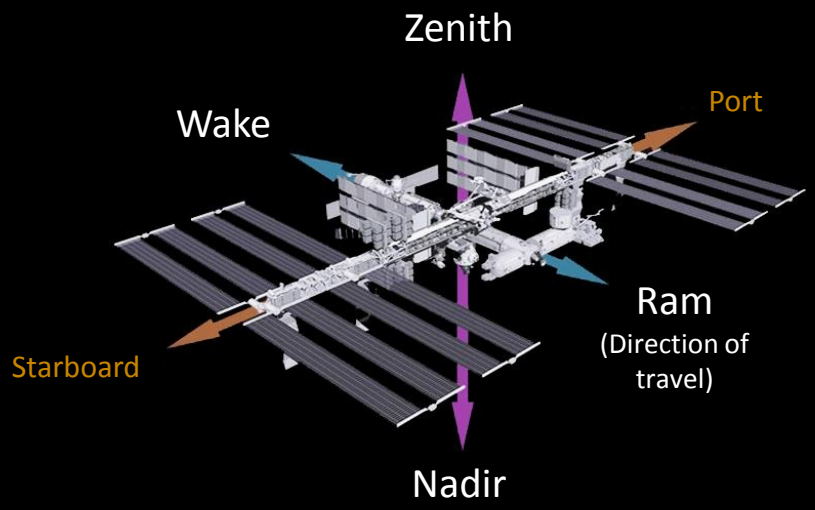
- *Facing away from the direction of travel (i.e. aft pointing or trailing edge)*
- *Very little AO & moderate solar exposure*

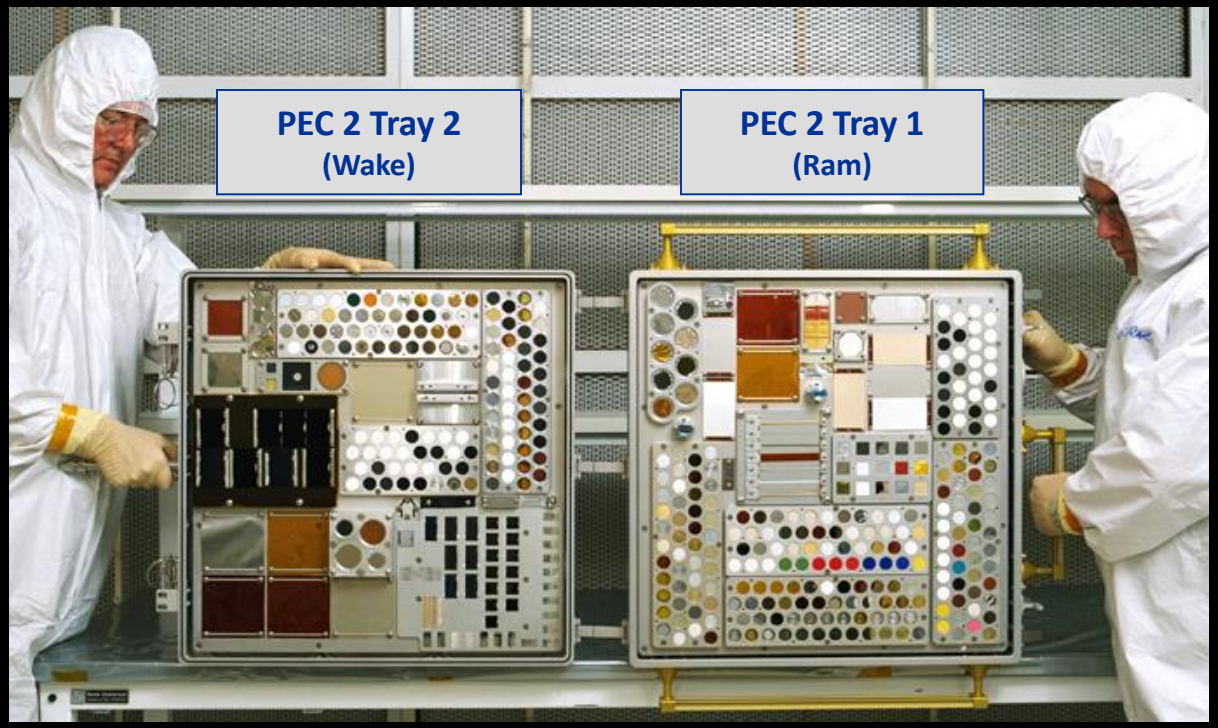
Zenith:

- *Direction facing away from Earth (i.e. directly above)*
- *Grazing AO & <u>highest solar exposure</u>*

Nadir:

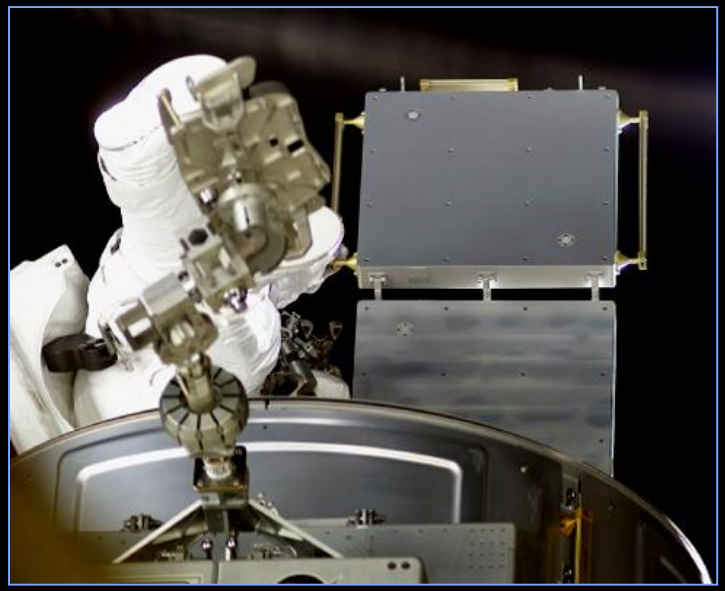
- *Direction facing towards Earth (i.e. straight down)*
- *Grazing AO & lowest solar exposure*





MISSE

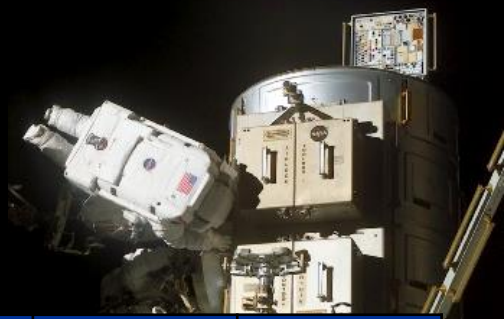
Experiment Integration, Shuttle launch & EVA Attachment



Patrick Forrester
& PEC 2

August 16, 2001

MISSE 1-8
Mission Summary



MISSE PEC	Launch Mission	Date Placed Outside ISS	Location on ISS	Tray Orientation	Retrieval Mission	Date Retrieved from Outside of ISS	LEO Exposure Duration (years)
1 & 2	STS-105	8/16/2001	PEC 1: High Pressure Gas Tank (HPGT) PEC 2: Quest Airlock	Ram & Wake	STS-114	7/30/2005	**3.95**
3 & 4	STS-121	8/3/2006*	PEC 3: HPGT PEC 4: Quest Airlock	Ram & Wake	STS-118	8/18/2007	**1.04**
5	STS-114	8/3/2005	Aft P6 Trunion Pin Handrail	Zenith & Nadir	STS-115	9/15/2006	**1.12**
6A & 6B	STS-123	3/22/2008	Columbus Laboratory	Ram & Wake	STS-128	9/1/2009	**1.45**
7A & 7B	STS-129	11/23/2009	EXPRESS Logistics Carrier 2 (ELC 2) on the S3 Truss	7A: Zenith & Nadir 7B: Ram & Wake	STS-134	5/20/2011	**1.49**
8 & ORMatE-III R/W	STS-134	8: 5/20/2011 ORMatE-III R/W: 7/12/2011**	EXPRESS Logistics Carrier 2 (ELC 2) on the S3 Truss	8: Zenith & Nadir ORMatE-III R/W: Ram & Wake	SpaceX-3 Dragon	7/9/2013	MISSE 8: **2.14** ORMatE-III: **2.00**

** Deployed during Expedition 13*

*** Deployed during STS-135*

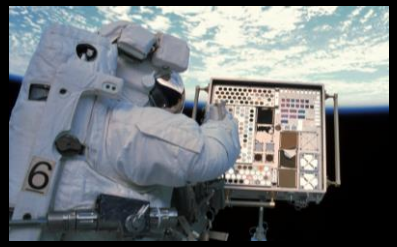
ORMatE-III R/W: Optical Reflector Materials Experiment III Ram/Wake

NASA Glenn's MISSE 1-8 Materials Experiments

MISSE	# Expts	Types of Experiments	Orientation	# Samples	Active/ Passive
1 & 2	7	Gossamer materials & thin film polymers, SiOx-coated Kapton, AO scattering chamber, spacecraft silicones	Ram Wake	80	P
3 & 4	8	Gossamer materials & thin film polymers, SiOx-coated Kapton, AO scattering chamber, spacecraft silicones, EMI shielding	Ram Wake	71	P
5	4*	Thin film polymers (tensile & erosion), silicones	Nadir	105	P
6A & 6B	11	Stressed polymers, thin film polymers, ITO coatings, solar cells, Cermet coatings, thermal control paints, AO scattering chamber, AO pinhole camera, AO fluence monitor	Ram Wake	177	A & P
7A & 7B	10*	Thin film polymers (tensile & erosion), spacesuit fabrics, seals, thermal control paints, AO scattering chamber, AO pinhole camera, AO fluence monitor	Ram Wake Zenith Nadir	157	A & P
8 & ORMatE-III	1	Thin film polymers (tensile & erosion)	Ram Wake Zenith	42	P

** Does not include the MISSE FTSCE experiments*

NASA Glenn has flown 41 experiments with 632 samples



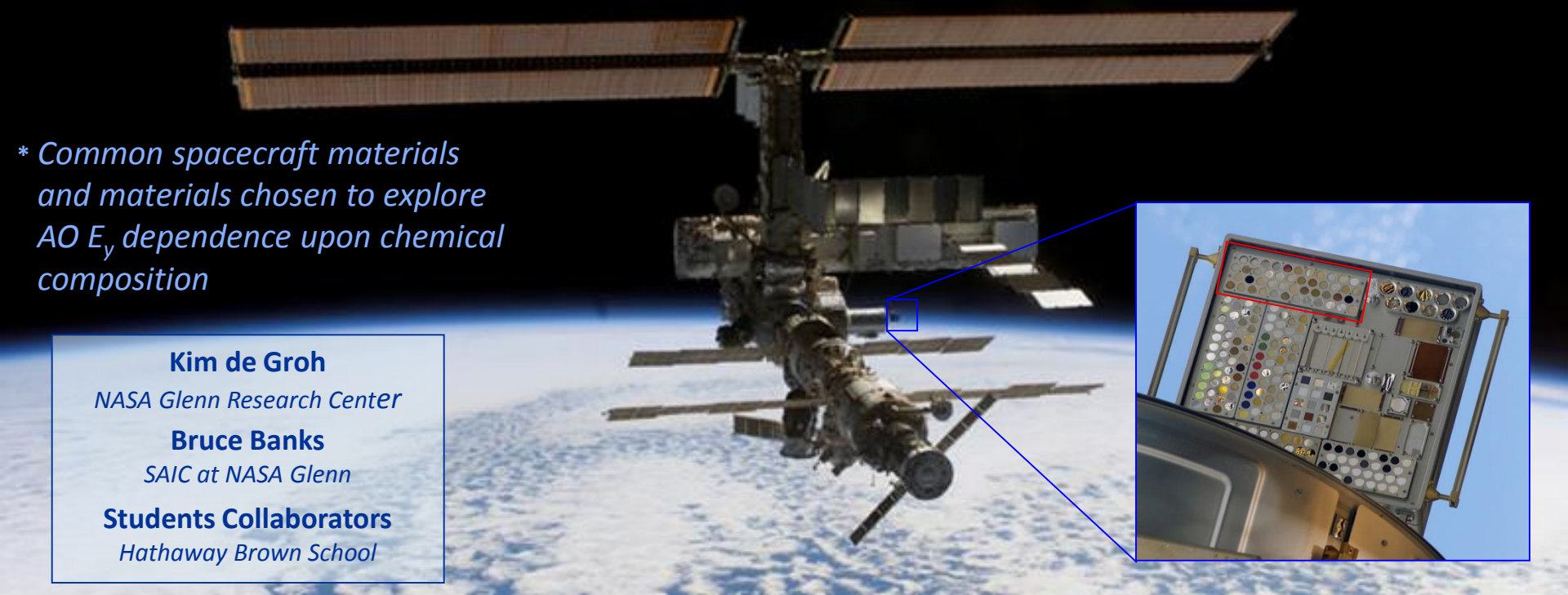
NASA Glenn Research Center's MISSE Polymer Experiments

Kim de Groh, PI

MISSE 2 PEACE Polymers Experiment

Polymers Erosion and Contamination Experiment (PEACE)

Objective:
To determine the atomic oxygen erosion yield (E_y, volume loss per incident oxygen atom) of a wide variety of polymers exposed for an extended period of time to the LEO space environment*



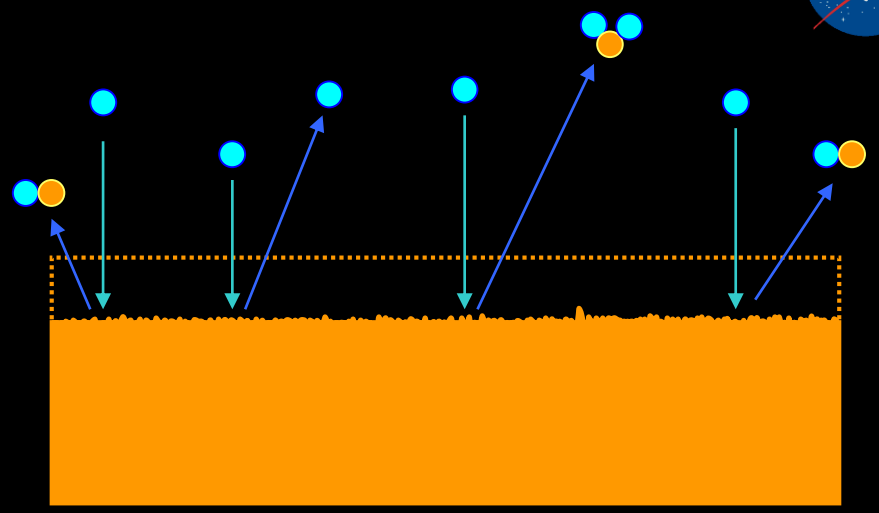
* *Common spacecraft materials and materials chosen to explore AO E_y dependence upon chemical composition*

Kim de Groh
NASA Glenn Research Center
Bruce Banks
SAIC at NASA Glenn
Students Collaborators
Hathaway Brown School

Atomic Oxygen Erosion Yield (E_y)

(Also called Reaction Efficiency or Recession Rate)

E_y is the **volume loss** per incident **oxygen atom** *(cm^3/atom)*



Ey based on Mass Loss Measurements

Erosion Yield (E_y) of Sample

$$E_y = \frac{\Delta M_s}{A_s \rho_s F_k}$$

where:
- ΔM_s = Mass loss of polymer sample (g)
- A_s = Area of polymer sample (cm^2)
- ρ_s = Density of sample (g/cm^3)
- F_k = AO fluence measured by Kapton H witness samples ($atom/cm^2$)

Atomic Oxygen Fluence

$$F_k = \frac{\Delta M_k}{A_k \rho_k E_k}$$

where:
- ΔM_k = Mass loss of Kapton H witness (g)
- A_k = Area of Kapton H witness (cm^2)
- ρ_k = Density of Kapton H sample (1.427 g/cm^3)
- E_k = Erosion yield of Kapton H (3.0×10^{-24} cm^3/atom)

MISSE 2 PEACE Polymers Experiment

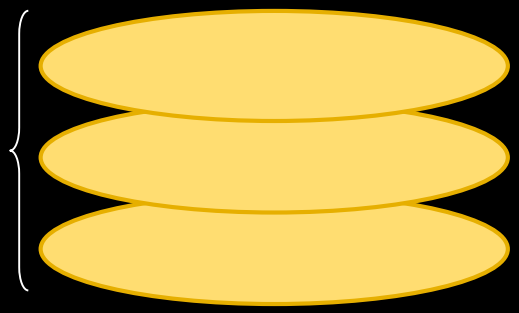
- 41 samples were exposed to LEO as part of MISSE 2 (38 polymers, pyrolytic graphite & 2 Kapton H fluence witness samples)

PEC 2 Tray 1: *Ram AO & solar exposure*

- The majority of polymers were in thin film form & enough layers were stacked to last a 3 year mission (3X the original planned duration)

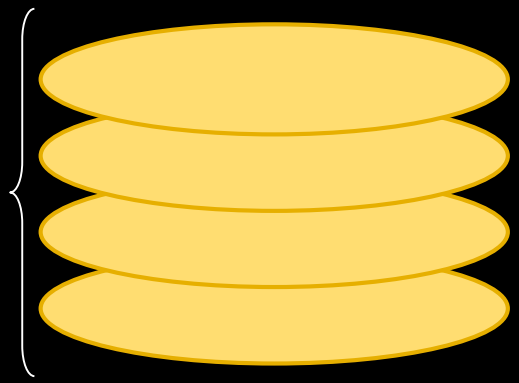
Part A

enough layers to survive 1.5 years

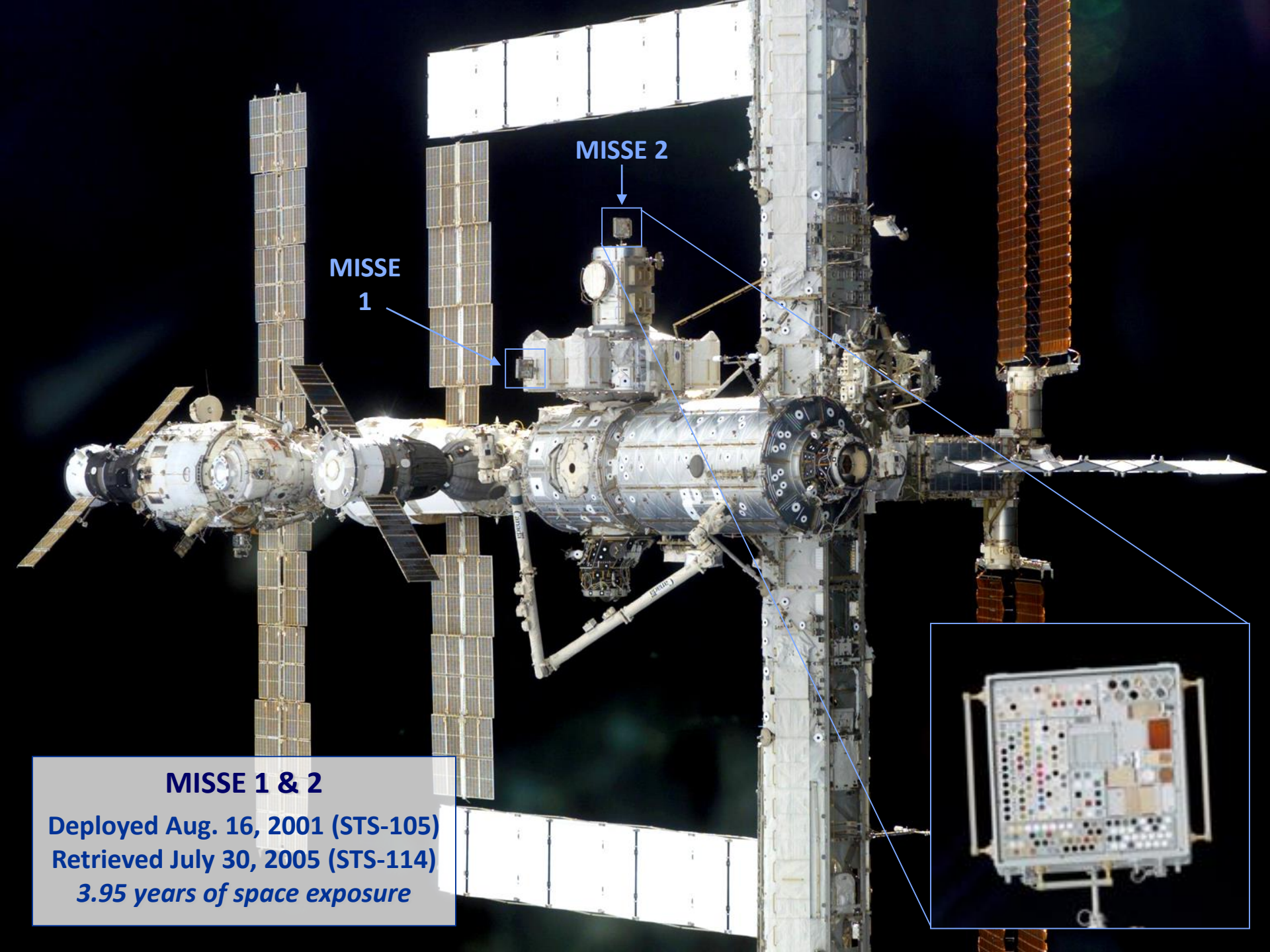


Part B

behind Part A; enough additional layers to survive 3 years



Collaborative experiment with students from Hathaway Brown School for girls



MISSE 1 & 2

Deployed Aug. 16, 2001 (STS-105)

Retrieved July 30, 2005 (STS-114)

3.95 years of space exposure

MISSE 2 PEACE Polymers Experiment

Pre-flight

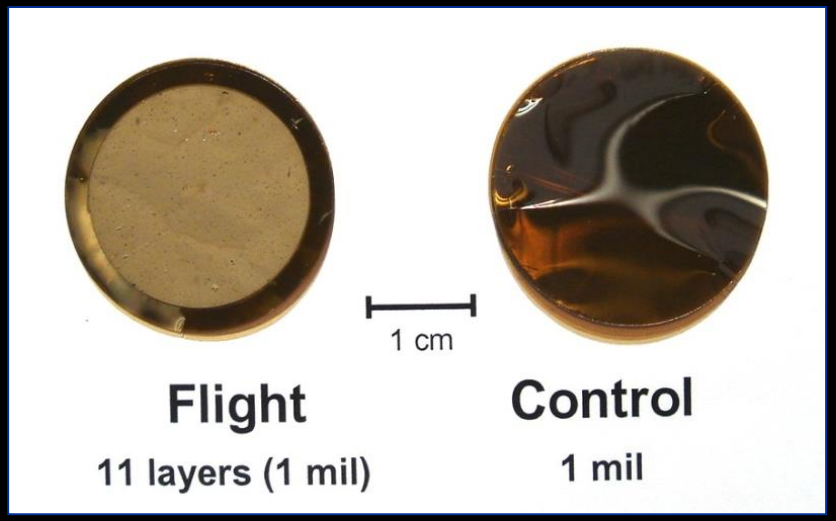
Post-flight

Polyimide (PMDA)
Upilex-S

2-E5-32

Post-flight photos

In flight tray

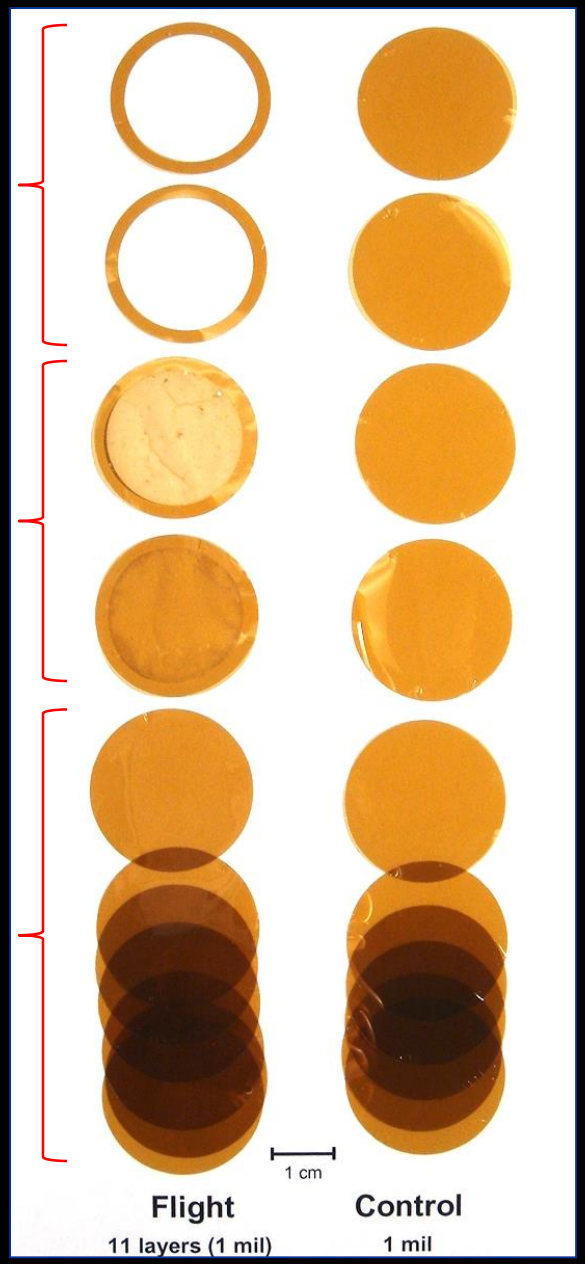


Out of tray

Complete erosion

Partial erosion

No erosion



MISSE 2 PEACE Polymers Erosion Yield Data

Polymer Abbrev.	E_y (cm^3/atom)	E_y Uncertainty (%)	Polymer Abbrev.	E_y (cm^3/atom)	E_y Uncertainty (%)
ABS	1.09E-24	2.7	PEI	*> 3.31E-24**	2.6
CA	5.05E-24	2.7	PA 6	3.51E-24	2.7
PPD-T (Kevlar)	6.28E-25	2.6	PA 66	1.80E-24	12.6
PE	*> 3.74E-24**	2.6	PI (CP1)	1.91E-24	2.8
PVF (Tedlar)	3.19E-24	2.6	PI (Kapton H)	3.00E-24	2.7
PVF (White Tedlar)	1.01E-25	4.1	PI (Kapton HN)	2.81E-24	2.6
POM (Delrin)	9.14E-24	3.1	PI (Upilex-S)	9.22E-25	3.0
PAN	1.41E-24	3.3	PI (PMR-15)	*> 3.02E-24**	2.6
ADC (CR-39)	*> 6.80E-24**	2.6	PBI	*> 2.21E-24**	2.6
PS	3.74E-24	2.7	PC	4.29E-24	2.7
PMMA	*> 5.60E-24**	2.6	PEEK	2.99E-24	4.5
PEO	1.93E-24	2.6	PET (Mylar)	3.01E-24	2.6
PBO (Zylon)	1.36E-24	6.0	CTFE (Kel-f)	8.31E-25	2.6
EP	4.21E-24	2.7	ECTFE (Halar)	1.79E-24	2.6
PP	2.68E-24	2.6	ETFE (Tefzel)	9.61E-25	2.6
PBT	9.11E-25	2.6	FEP	2.00E-25	2.7
PSU	2.94E-24	3.2	PTFE	1.42E-25	2.6
PU	1.56E-24	2.9	PFA	1.73E-25	2.7
PPPA (Nomex)	1.41E-24	2.9	AF	1.98E-25	2.6
PG	4.15E-25	10.7	PVDF (Kynar)	1.29E-24	2.7

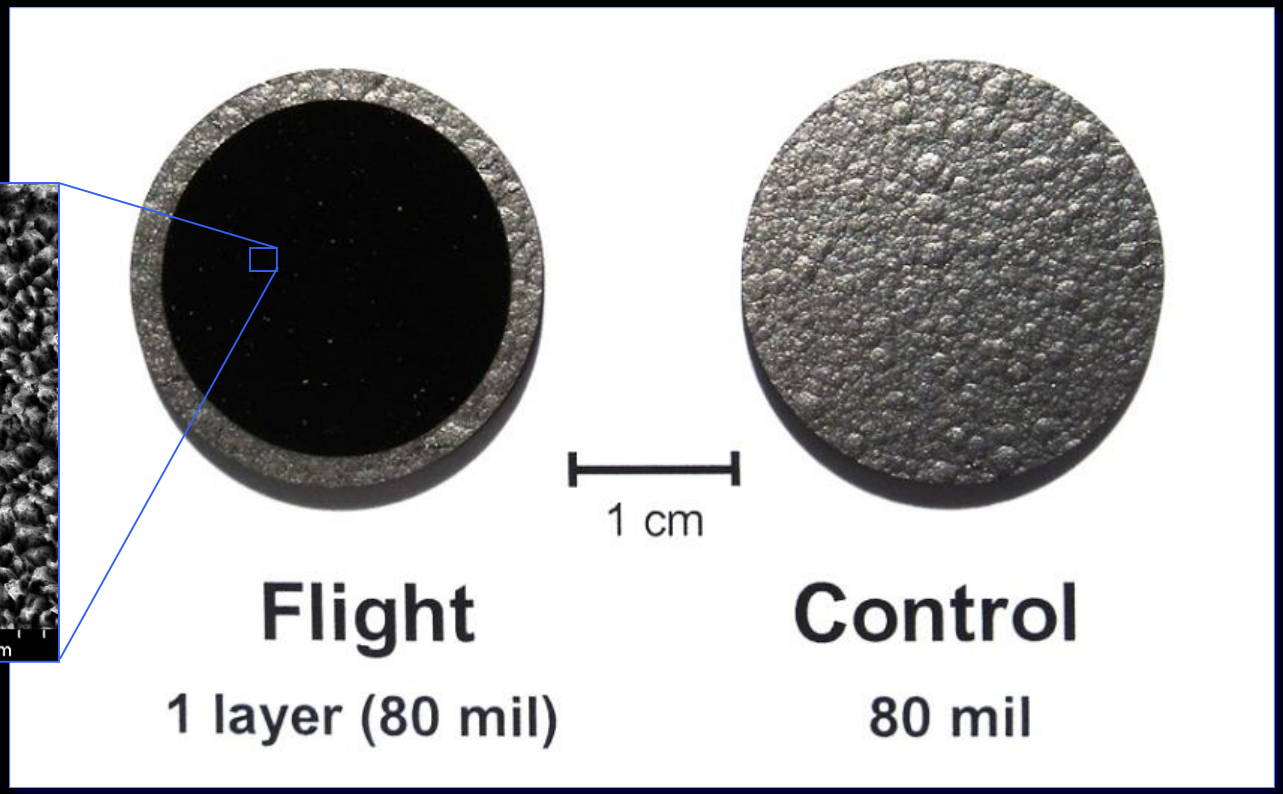
*E_y > this value because sample stack was partially, or fully, eroded through

Average error: 3.30%

Pyrolytic Graphite (PG)

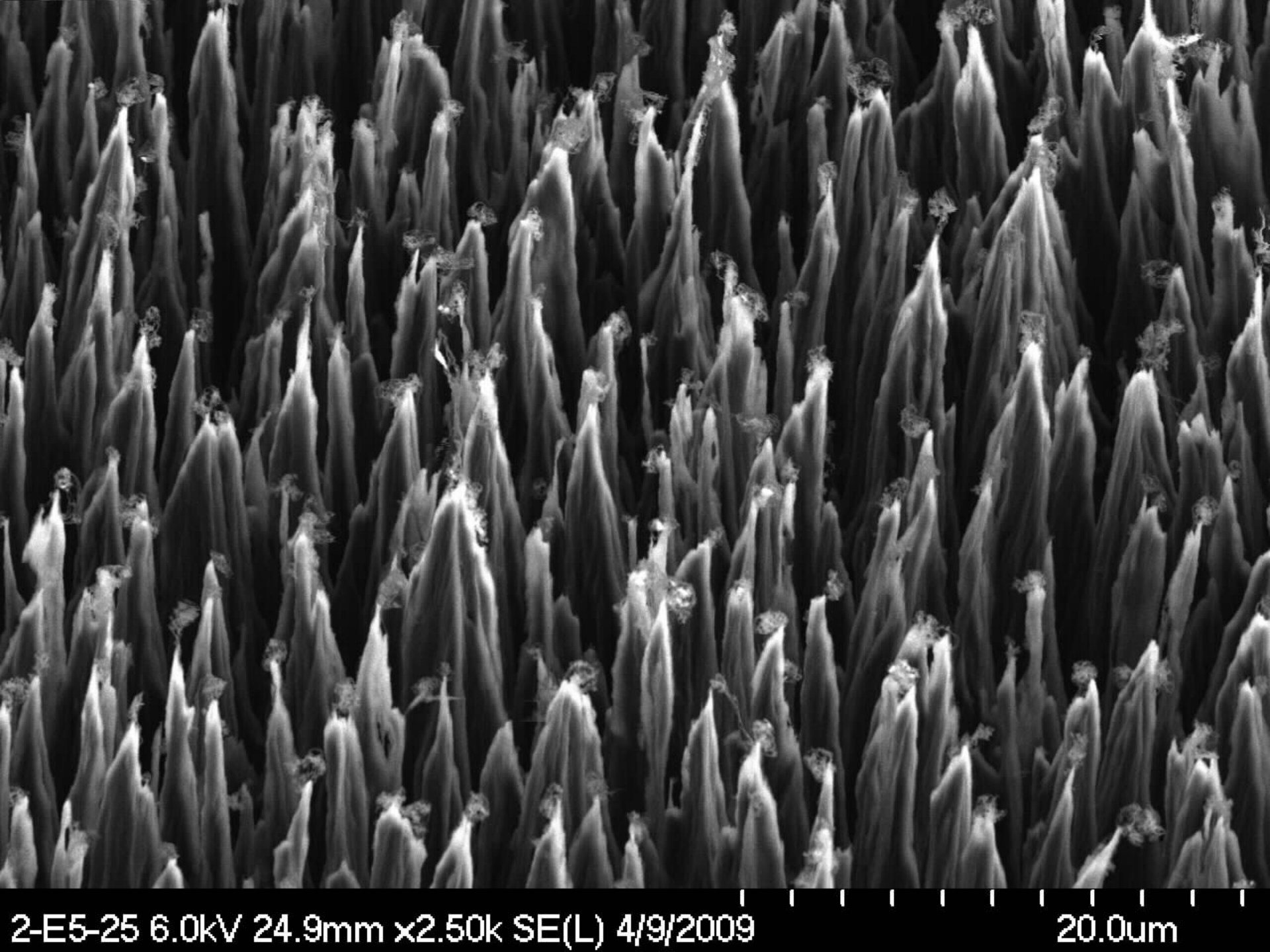
2-E5-25

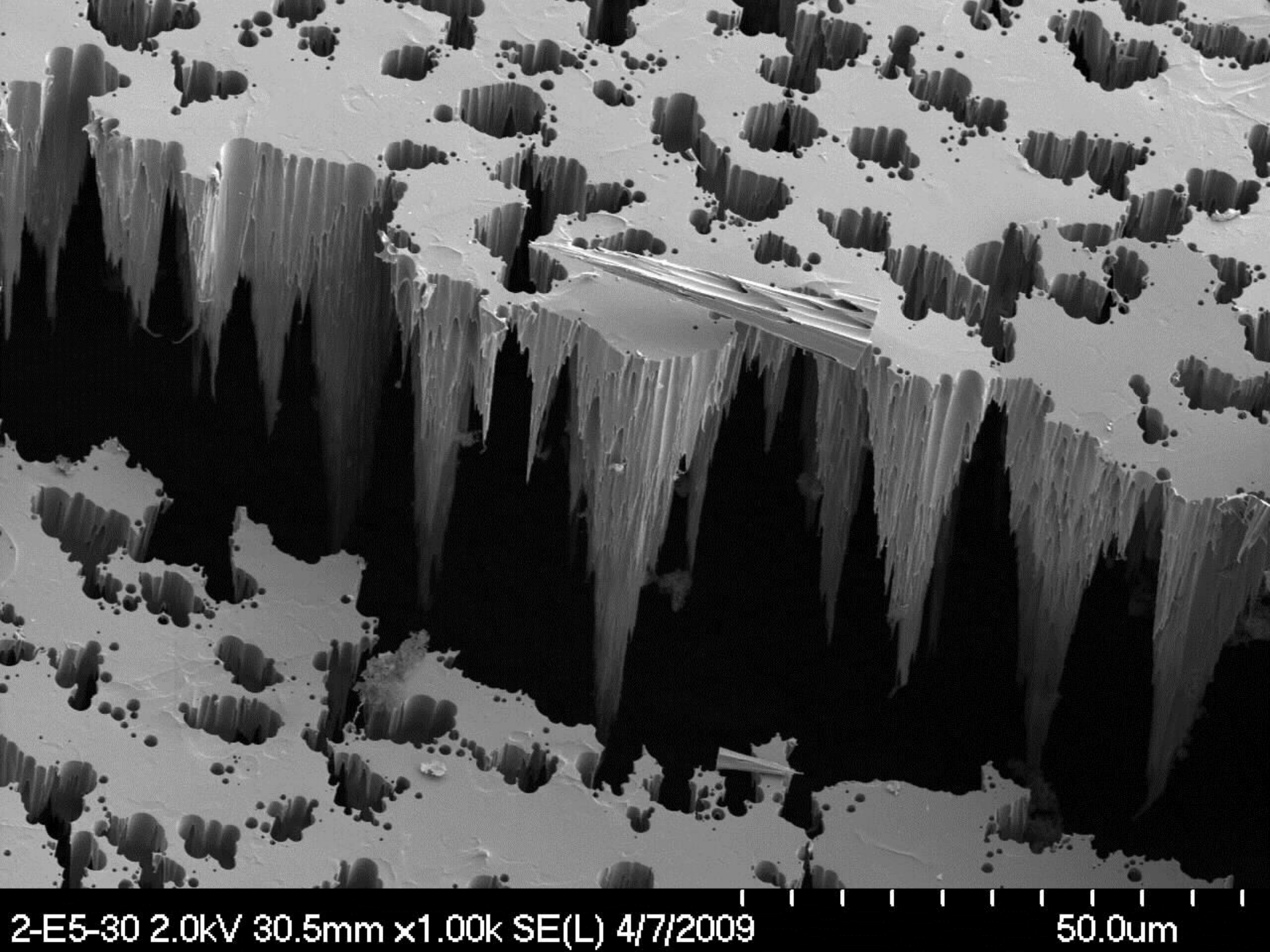
The directed ram LEO atomic oxygen exposure resulted in the development of *a black velvet-looking texture*



The MISSE 2 LEO Ey:

4.15×10^{-25} cm^3/atom

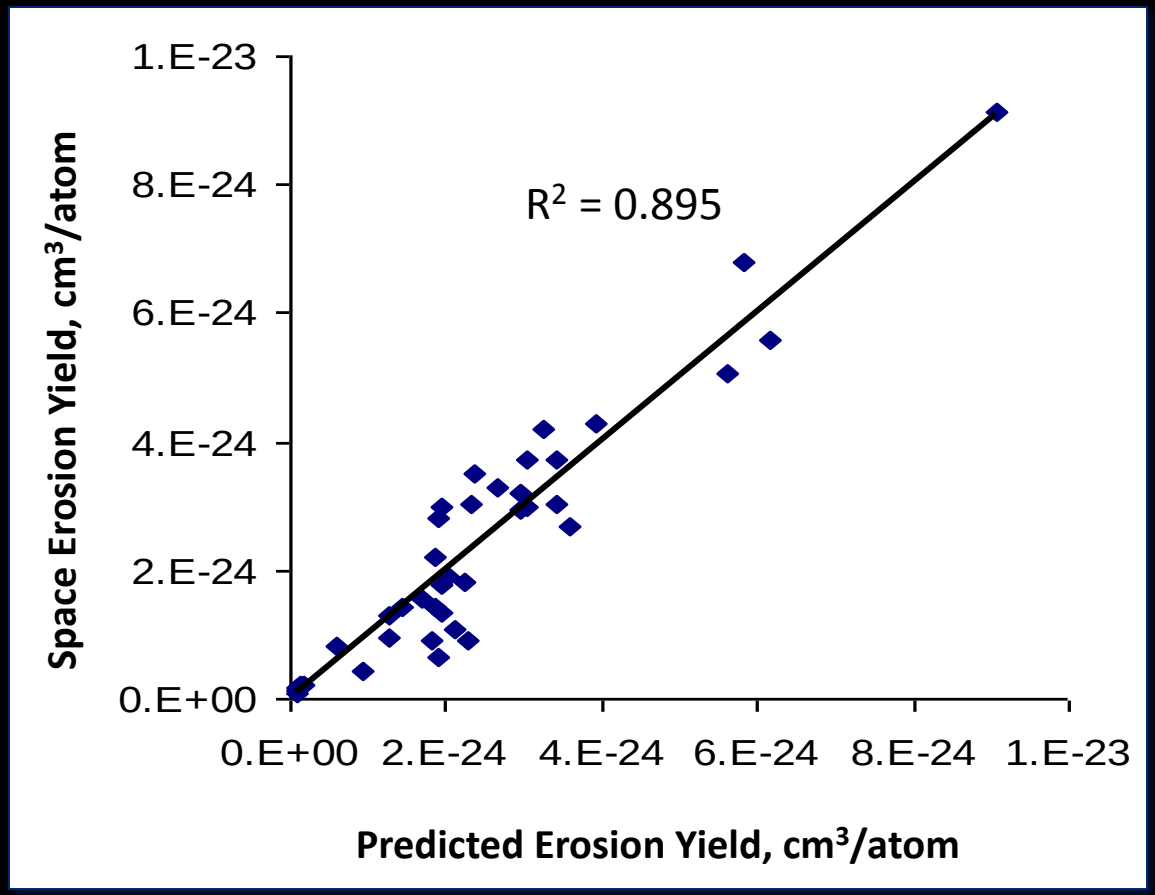

2-E5-25 6.0kV 24.9mm x2.50k SE(L) 4/9/2009
20.0um


2-E5-30 2.0kV 30.5mm x1.00k SE(L) 4/7/2009
50.0um

Atomic Oxygen Erosion Predictive Tool
(based on the MISSE 2 PEACE Polymers data)

Bruce A. Banks (PI)

Predictive tool enables Ey determination of non-flown and new polymers without requiring flight testing



Factors:

Chemistry:

- No. & type of atoms
- No. & types of oxygen bonds
- Chemical structure

Physical Properties:

- Density
- How closely packed the atoms are
- Ash content

Mission Characteristics

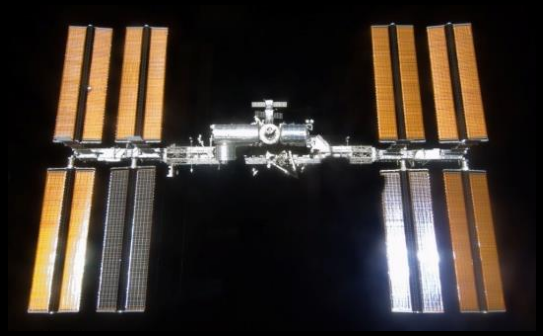
- Mission fluence

Ref: B. A. Banks, et al. "Atomic Oxygen Erosion Yield Prediction for Spacecraft Polymers in Low Earth Orbit," Proceedings of the ISMSE-11, September 15-18, 2009, Aix-en-Provence, France, 2009; also NASA TM-2009-215812, September 2009

Ground-Laboratory to In-Space Correlation

Differences between LEO and Plasma Asher

- Arrival directions are different between LEO and asher:
  - MISSE 2 samples received ram AO
  - Asher atomic oxygen (AO) arrival is isotropic
- AO fluxes vary:
  - AO flux at ISS altitudes: $\approx 1.0 \times 10^{14}$ atoms/cm^2
  - AO flux in plasma asher: $\approx 3.6 \times 10^{15}$ atoms/cm^2
- Energy varies:
  - LEO: AO energy $\approx$4.5 eV
  - Asher: AO energy $\approx$0.01-0.04 eV
- Radiation varies:
  - LEO: UV, x-rays, electron & proton radiation etc.
  - Asher: Strong UV line (143 nm)
- Species vary:
  - LEO: AO most predominant-in ground energy state
  - Plasma asher: N2, O2, N, O-in excited & ground states



Objective: ***To compute the ratio between the Ey in space with the Ey in a plasma asher for the MISSE 2 PEACE Polymers***

Asher to In-Space Erosion Yield Ratios

MISSE Serial #	Material	Abbrev.	MISSE 2 Ey (cm^3/atom)	Asher Ey (cm^3/atom)	Asher to In-Space Ey Ratio
2-E5-6	Acrylonitrile butadiene styrene	ABS	1.09E-24	6.76E-24	6.2
2-E5-7	Cellulose acetate	CA	5.05E-24	1.05E-23	2.1
2-E5-8	Poly-(p-phenylene terephthalamide)	PPD-T (Kevlar)	6.28E-25	1.51E-23	24.0
2-E5-9	Polyethylene	PE	3.74E-24	6.84E-24	1.8
2-E5-10	Polyvinyl fluoride	PVF (Tedlar)	3.19E-24	5.15E-24	1.6
2-E5-11	Crystalline polyvinylfluoride w/white pigment	PVF (White Tedlar)	1.01E-25	3.73E-24	37.1
2-E5-12	Polyoxymethylene; acetal; polyformaldehyde	POM (Delrin)	9.14E-24	2.55E-23	2.8
2-E5-13	Polyacrylonitrile	PAN	1.41E-24	5.04E-24	3.6
2-E5-14	Allyl diglycol carbonate	ADC (CR-39)	6.80E-24	1.52E-23	2.2
2-E5-15	Polystyrene	PS	3.74E-24	4.39E-24	1.2
2-E5-16	Polymethyl methacrylate	PMMA	5.60E-24	1.08E-23	1.9
2-E5-17	Polyethylene oxide	PEO	1.93E-24	1.79E-23	9.3
2-E5-18	Poly(p-phenylene-2 6-benzobisoxazole)	PBO (Zylon)	1.36E-24	3.73E-24	2.8
2-E5-19	Epoxide or epoxy	EP	4.21E-24	1.01E-23	2.4
2-E5-20	Polypropylene	PP	2.68E-24	1.22E-23	4.6
2-E5-21	Polybutylene terephthalate	PBT	9.11E-25	5.67E-24	6.2
2-E5-22	Polysulfone	PSU	2.94E-24	3.95E-24	1.3
2-E5-23	Polyurethane	PU	1.56E-24	1.45E-23	9.3
2-E5-24	Polyphenylene isophthalate	PPPA (Nomex)	1.41E-24	8.29E-24	5.9
2-E5-25	Graphite	PG	4.15E-25	5.08E-25	1.2

MISSE 2 PEACE Polymers Experiment
Results and Benefits

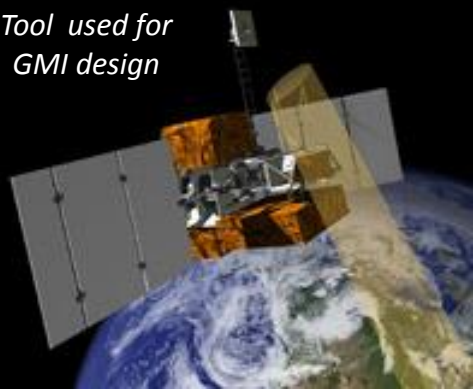
- Results:
  - LEO AO Ey of 38 polymers & pyrolytic graphite have been obtained
  - Flight data was used for determining ground-to-space correlations for AO plasma ashers and energetic beam systems
  - An AO Erosion Yield Predictive Tool was developed using the flight data

MISSE 2 PEACE experiment post-flight

- Benefits:
  - *Ground-to-space correlations enables more accurate ground-laboratory testing*
  - *Predictive Tool enables Ey prediction for new or non-flown polymers*
  - *Flight, or Predictive Tool, Ey data has been highly requested (65+ requests) and the data has directly impacted spacecraft materials design, including:*
    - *ISS (external debris shielding components)*
    - *Global Precipitation Measurement-Microwave Imager (GMI)*
    - *Space Test Program's Standard Interface Vehicle (STP-SIV)*
    - *Operational Land Imager (OLI)*
    - *WorldView-2 & Worldview-3*
  - *NASA Standards Handbook <u>Spacecraft Polymers Atomic Oxygen Durability Handbook</u> (NASA-HDBK-6024) has been written based on the flight data enabling spacecraft engineers to design more durable spacecraft*

More accurate ground testing

GRC Predictive Tool used for GMI design



MISSE 5

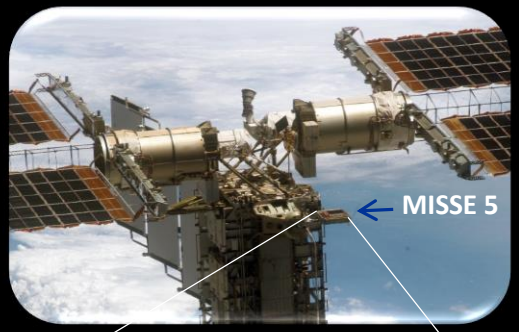
Launched: July 2005
Retrieved: Sept. 2006
(13 months space exposure)

Photo credit: Naval Research Laboratory

Self- powered with on-board two-way comms (PCSat2 amateur radio system)

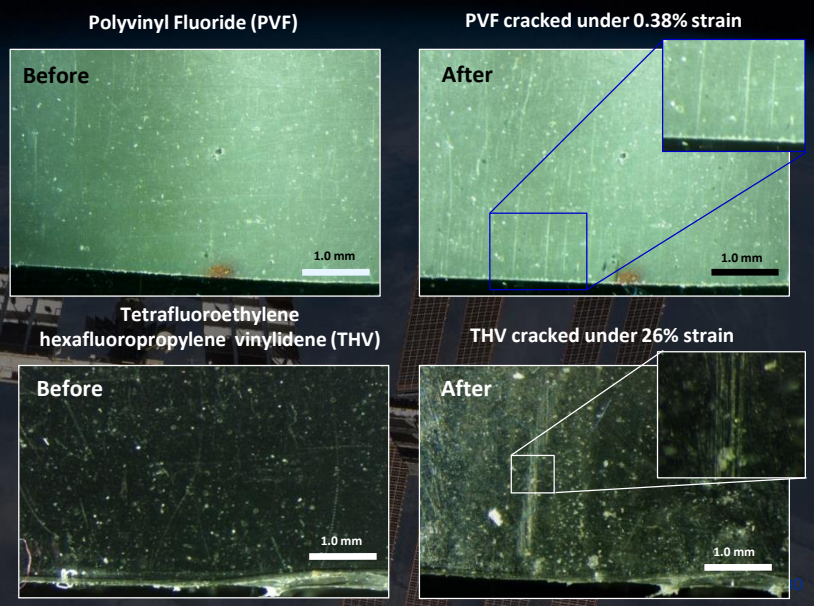
MISSE 5 PEACE Polymers Experiment

Kim de Groh, NASA Glenn Research Center

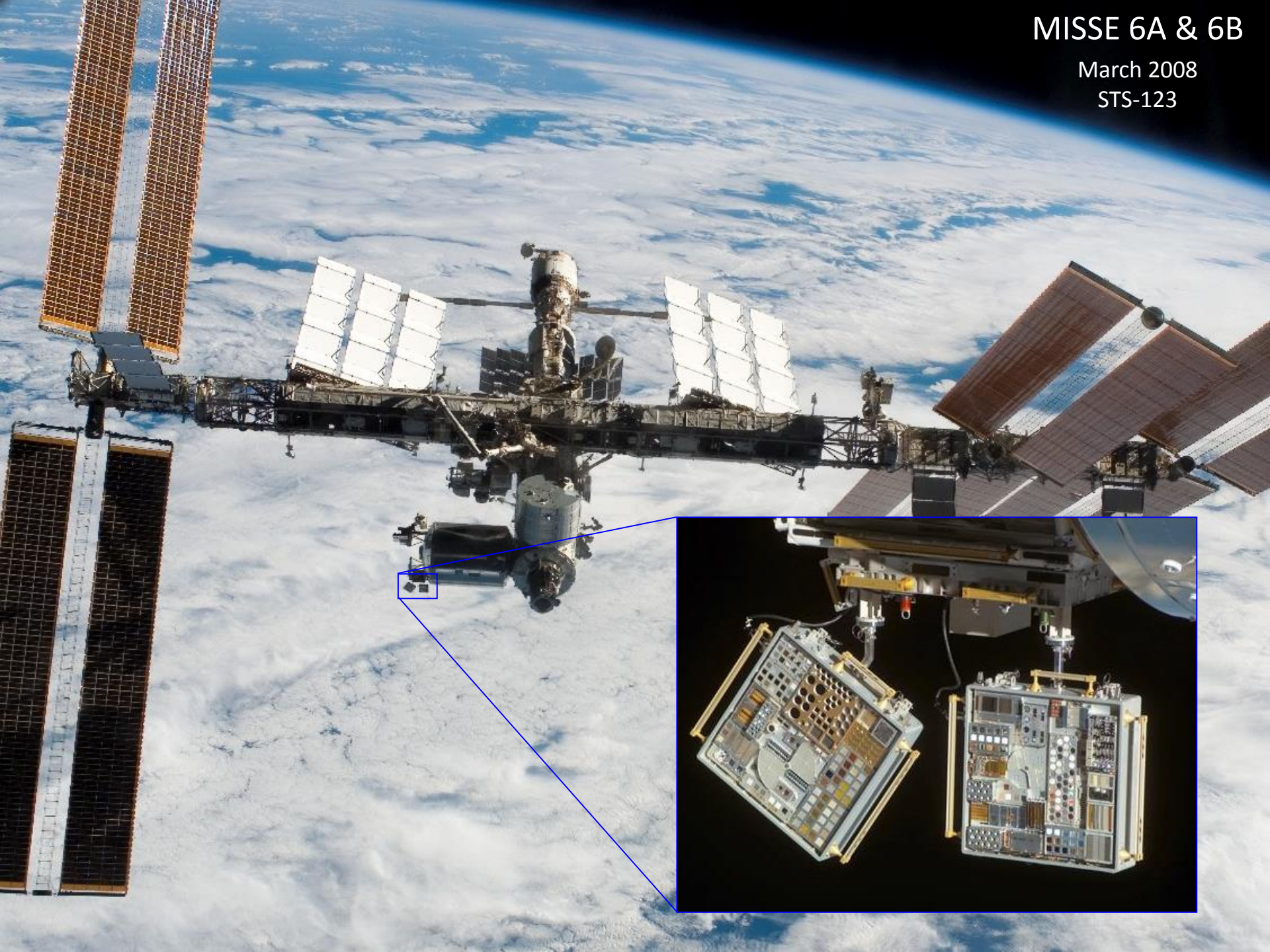


MISSE 5 Thermal Blanket Materials Experiment (pre-flight)

- MISSE 5 PEACE Polymers Experiment:
  - *Experiment objective:* To determine the embrittlement of 37 thin film polymers exposed to the LEO nadir space environment
  - Passive experiment flown in the nadir direction for 13 months as part of the **MISSE 5 Thermal Blanket Materials Experiment**
  - Samples were analyzed for space-induced embrittlement using a bend-test procedure in which the strain to induce surface cracking was determined
- Experiment Results:
  - No pristine materials cracked, even under high strain
  - 18 of the 37 flight samples (49%) experienced embrittlement as shown by surface tensile-induced cracking after just 13 months of exposure in LEO
- Experiments Benefits:
  - ➢ *Results indicate that many thin film polymers are susceptible to embrittlement in LEO, even with low dose solar and particle radiation exposure*
  - ➢ *Even "minimal" levels of radiation exposure should not be overlooked when designing spacecraft*



Examples of before & after bend-testing

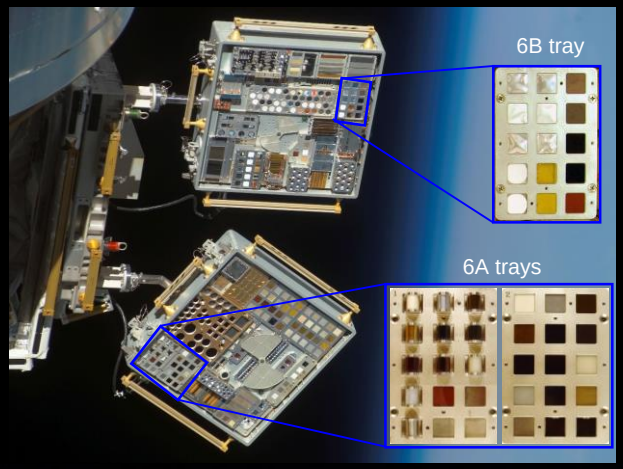

MISSE 6A & 6B
March 2008
STS-123

MISSE 6 Stressed Polymers Experiment

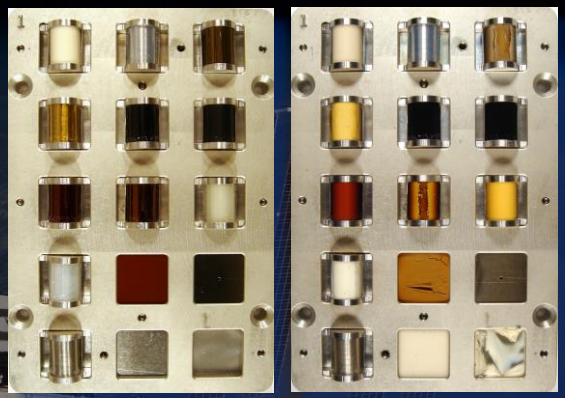
Kim de Groh, NASA Glenn Research Center

- MISSE 6 Stressed Polymers Experiment:
  - *Experiment objective:* To compare the AO erosion yields (Ey) of stressed and non-stressed polymers to determine if AO erosion is dependent upon stress while in LEO
  - Passive experiment flown in the ram direction for 1.5 years
    - *11 stressed/non-stressed polymer pairs*
    - *14 additional non-stressed samples (36 total samples)*
- Results:
  - Ey was determined for 34 samples
  - Only 1 material (CP1) had a stressed/non-stressed Ey >1 (1.11)
    - *Ratios ≈1.0: Upilex-S, Kapton (CB, XC, E & H), Mylar A, PE*
    - *Ratios <1.0: PTFE (0.76) & FEP (0.83)*
  - May be attributed to the differences in exposures, such as the stressed sample's geometry resulting in lower equivalent sun hours (ESH)
- Benefits:
  - ➢ *Simplified geometry experiment with flat tensile loaded samples is needed, and has being designed for a future MISSE mission*

Stressed Polymers Experiment on MISSE 6



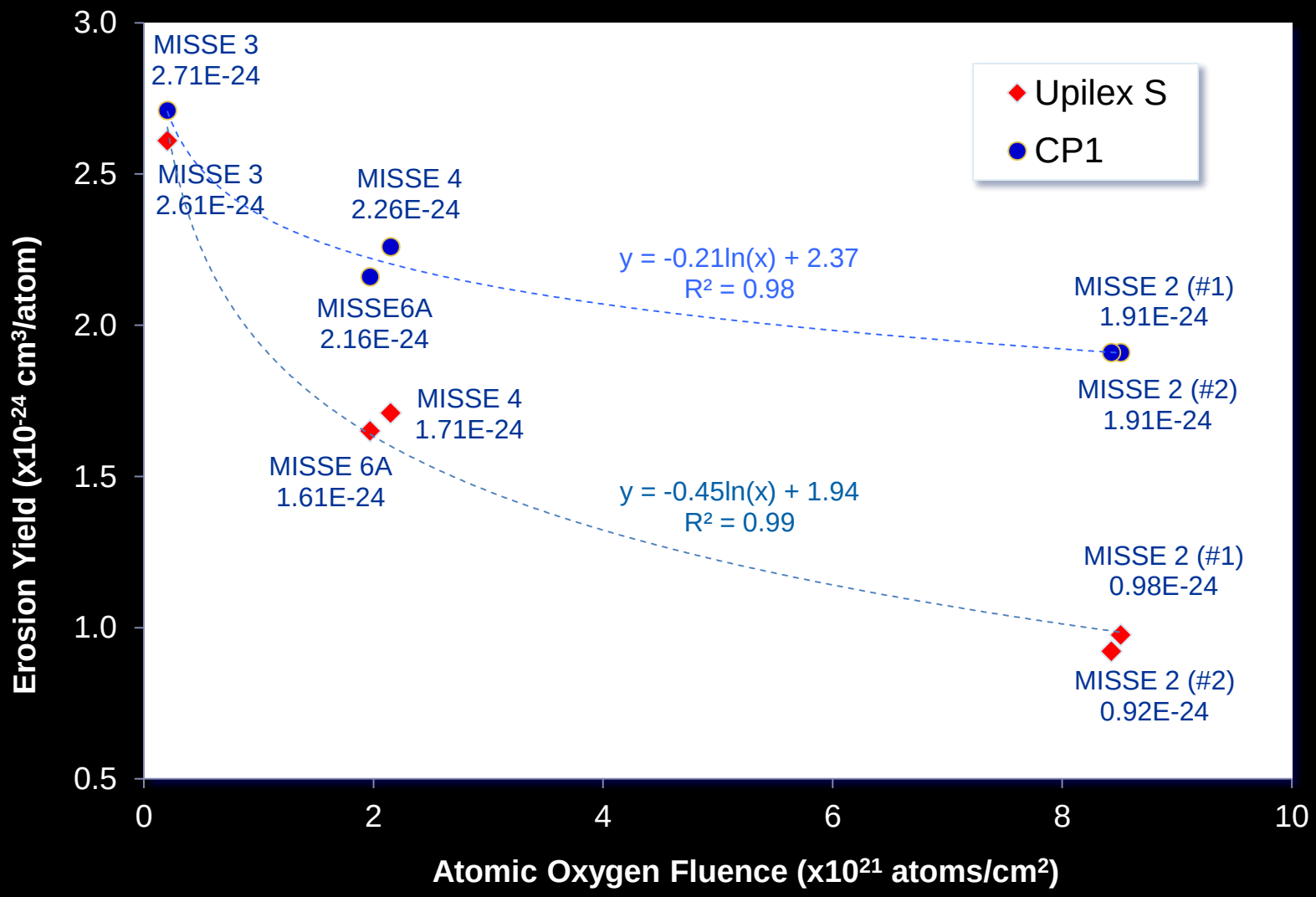
Pre-flight *Post-flight*



Post-flight stressed Kapton E

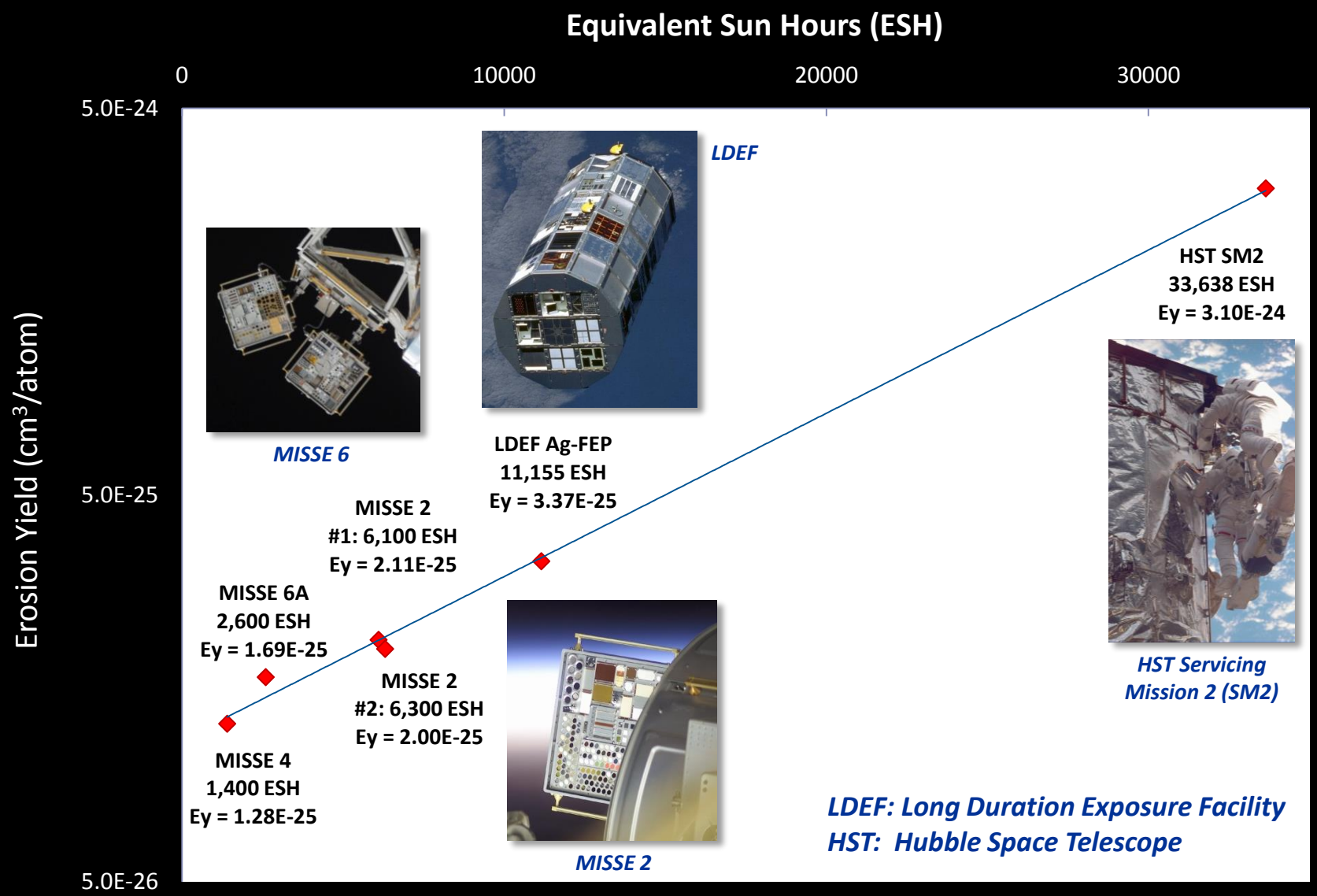
Upilex-S and CP1 (Clear Polyimide)

Erosion Yield Vs. AO Fluence



⇒ *Flying the same polymer on various MISSE missions provides important information on erosion dependence on environmental exposures.*

Teflon Fluorinated Ethylene Propylene (FEP)
Erosion Yield Vs. Equivalent Sun Hours (ESH)



MISSE 7A & 7B

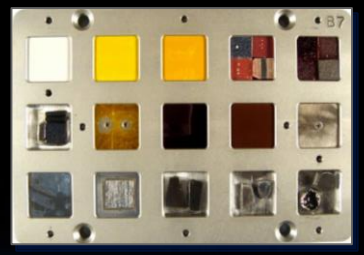
Deployed Nov. 23, 2009
Retrieved May 20, 2011

1.49 years of space exposure

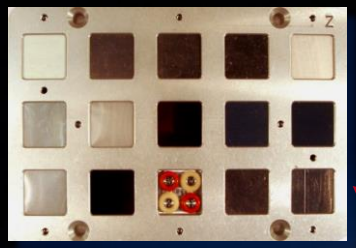
MISSE 7 Polymers & Zenith Polymers Experiments

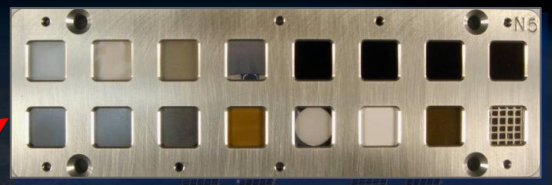
Kim de Groh, NASA Glenn Research Center

- MISSE 7 Polymers & Zenith Polymers Experiments:
  - *Experiment objectives:*
    - Determine the LEO AO erosion yield (Ey) of polymers in ram, wake & zenith orientations, and evaluate effects of solar exposure on Ey of fluoropolymers
    - Determine the effect of space exposure on the mechanical properties of fluorinated polymers
    - Determine the effect of space exposure on the optical properties of polymers
  - Passive experiments (75 samples) exposed to space for 1.5 years
    - *37 samples: **ram** orientation*
    - *25 samples: zenith orientation*
    - *7 samples: wake orientation*
    - *6 tensile samples: nadir orientation*



Zenith *samples*





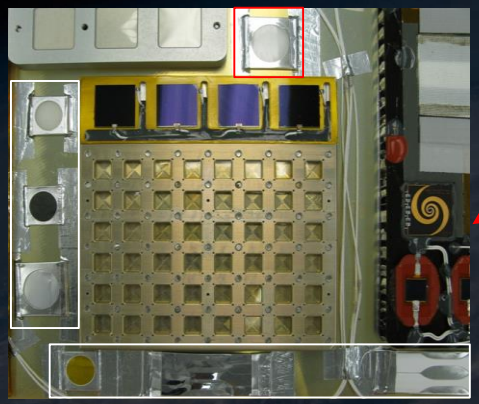
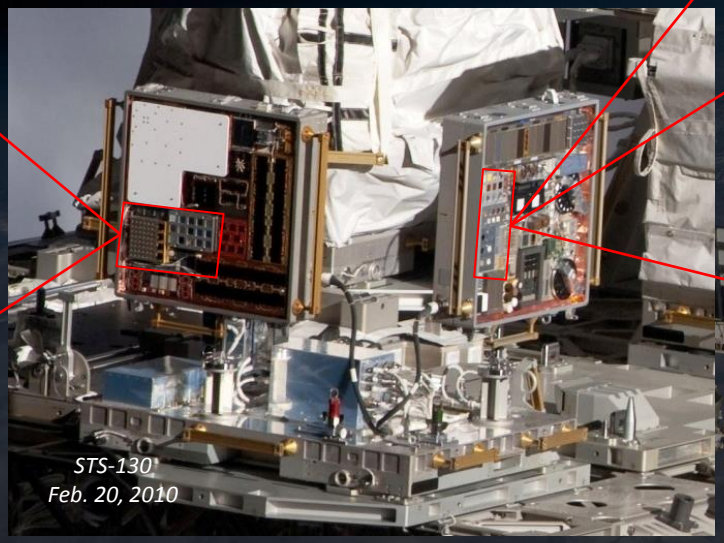
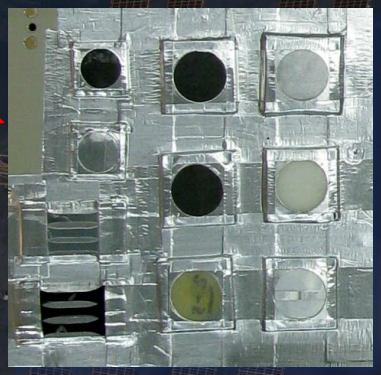


Photo credit: Naval Research Laboratory



MISSE 7A (left) and MISSE 7B (right)



Ram *samples*

MISSE 7A & 7B

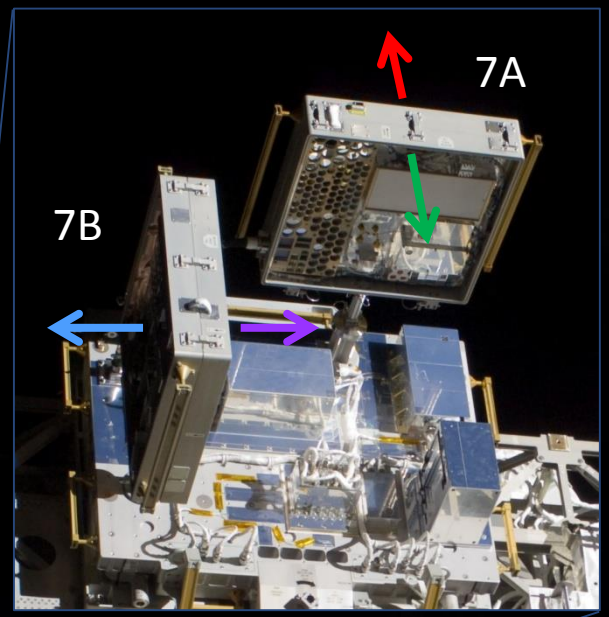
Environmental Exposures

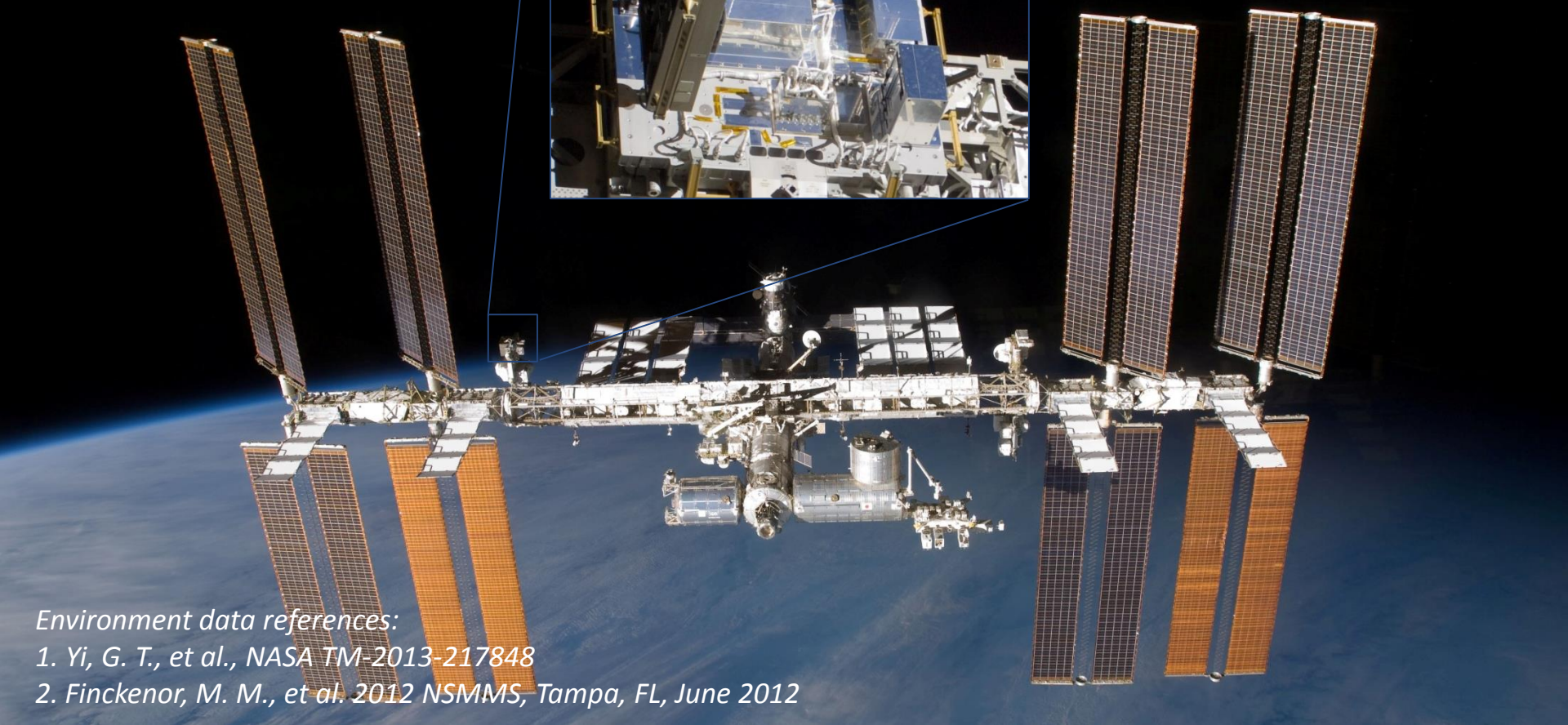
Zenith
4,300 ESH
AO F= 1.6×10^{20} atoms/cm^2

Nadir
<<2,000ESH
AO F= ~1.6×10^{20} atoms/cm^2

Ram
2,400 ESH
AO F= 4.2×10^{21} atoms/cm^2

Wake
2,000 ESH
AO F= 2.9×10^{20} atoms/cm^2





Environment data references:

1. Yi, G. T., et al., NASA TM-2013-217848

2. Finckenor, M. M., et al. 2012 NSMMS, Tampa, FL, June 2012

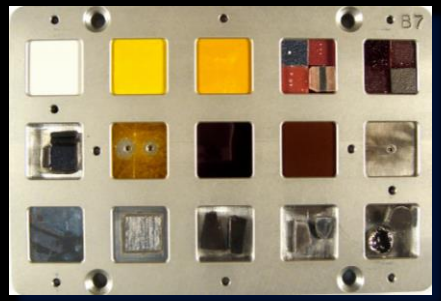
MISSE 7 Polymers & Zenith Polymers Experiments

Atomic Oxygen Erosion Yield Results

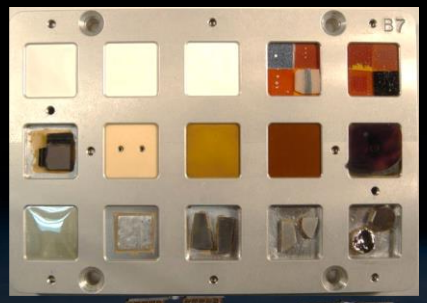
- MISSE 7 Polymers & Zenith Polymers Experiments:
  - *Experiment objectives:* Determine the LEO AO erosion yield (Ey) of polymers in ram, wake & zenith orientations, and evaluate effects of solar exposure on Ey of fluoropolymers
  - 55 samples exposed for 1.5 years for AO Ey:
    - *30 samples: **ram** orientation (3 for recession depth)*
    - *5 samples: wake orientation*
    - *18 samples: zenith orientation*
    - *2 Kapton H AO fluence witness samples (ram & zenith)*

- Results & Benefits:
  - AO Ey of 49 samples have been obtained based on mass loss
  - High Ey samples include: polyvinyl alcohol, cellulose nitrate, polyethylene and polyethylene oxide
  - Low Ey samples include: samples with protective coatings, ram-facing fluorinated polymers, white Tedlar & CORIN
  - *Fluoropolymers exhibit much higher Ey values with zenith exposure than ram exposure showing the effect of solar radiation and/or heating due to solar exposure on erosion*

Ram B7-R tray pre-flight

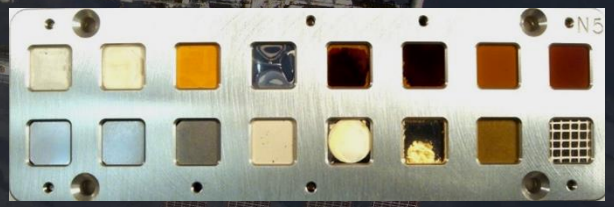


Ram B7-R tray post-flight



Ram N5-R tray pre-flight

Ram N5-R tray post-flight



FEP: Fluorinated ethylene propylene

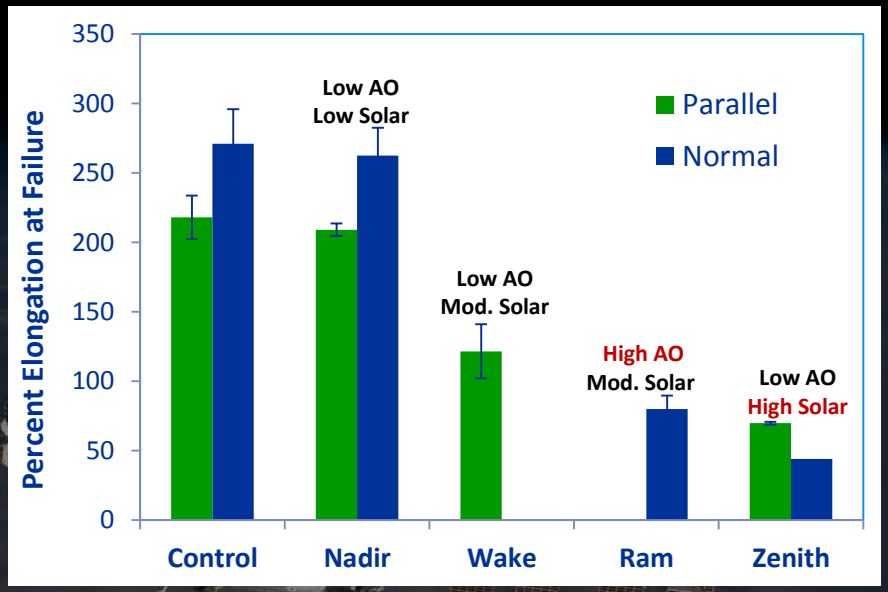
MISSE 7 Polymers & Zenith Polymers Experiments

Tensile Properties Results

- MISSE 7 Polymers & Zenith Polymers Experiments:
  - *Experiment objectives:* Determine the effect of space exposure on the mechanical properties of fluorinated polymers
  - 19 passive tensile samples exposed to space for 1.5 years
    - *6 Al-FEP samples: nadir orientation*
    - *2 Al-FEP samples: wake orientation*
    - *3 Al-FEP & 3 C-FEP samples: **ram** orientation*
    - *3 Al-FEP & 2 ePTFE samples: zenith orientation*

Cracked C-FEP tensile samples (post-flight)

- Results & Benefits:
  - Prolonged exposure to space can cause catastrophic degradation of 2-mil Al-FEP
  - Extent of degradation is dependent on exposure:
    - *Nadir (low AO & low radiation): minimal damage*
    - *Wake (low AO & mod. solar): some embrittlement*
    - ***Ram** (high AO & mod. solar): large thickness loss & significant embrittlement*
    - *Zenith (high solar & mod. AO): extensive embrittlement*
  - The C-FEP samples cracked while on-orbit
    - *On-orbit heating has a significant impact on radiation-induced degradation of FEP*

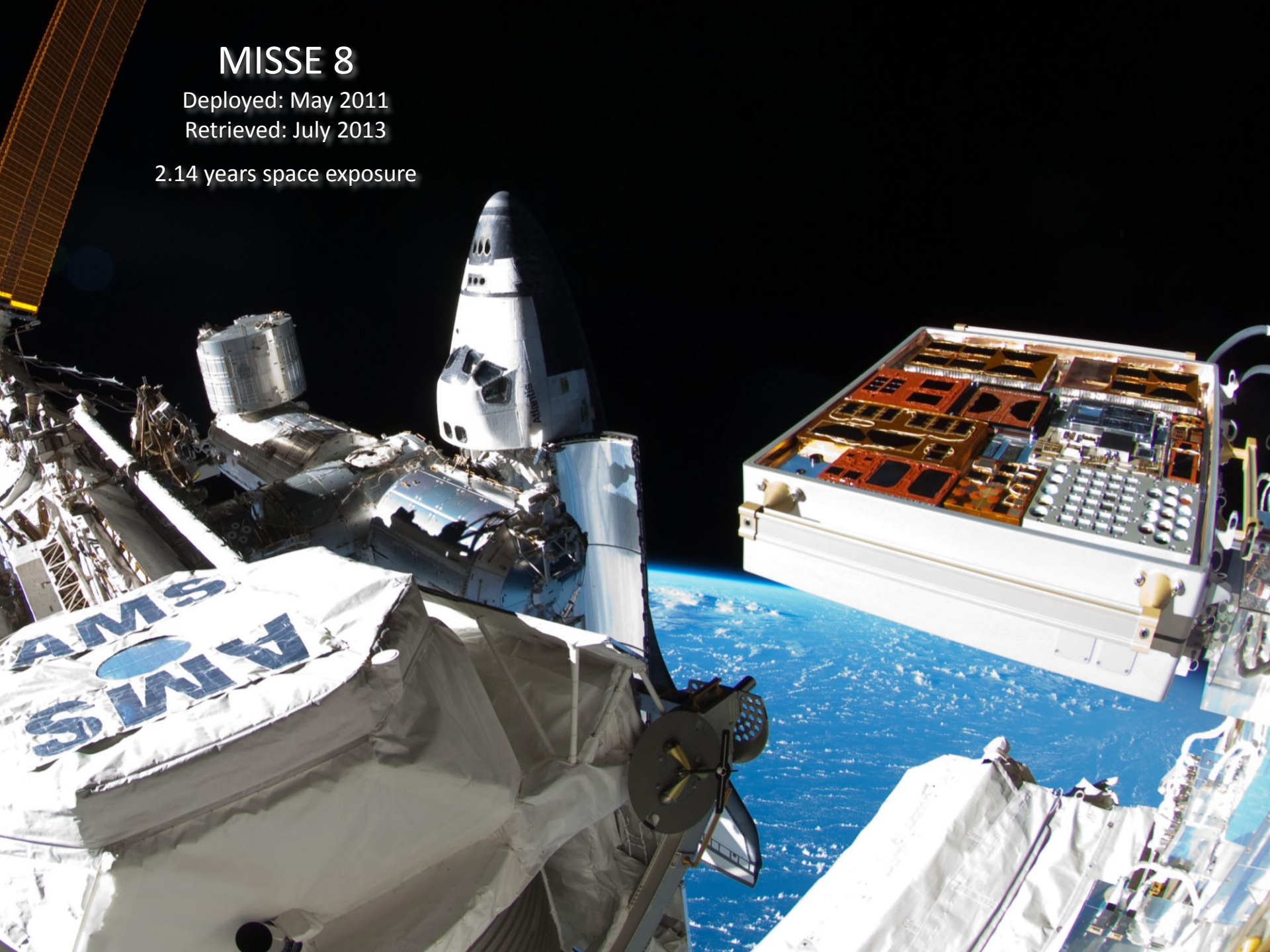


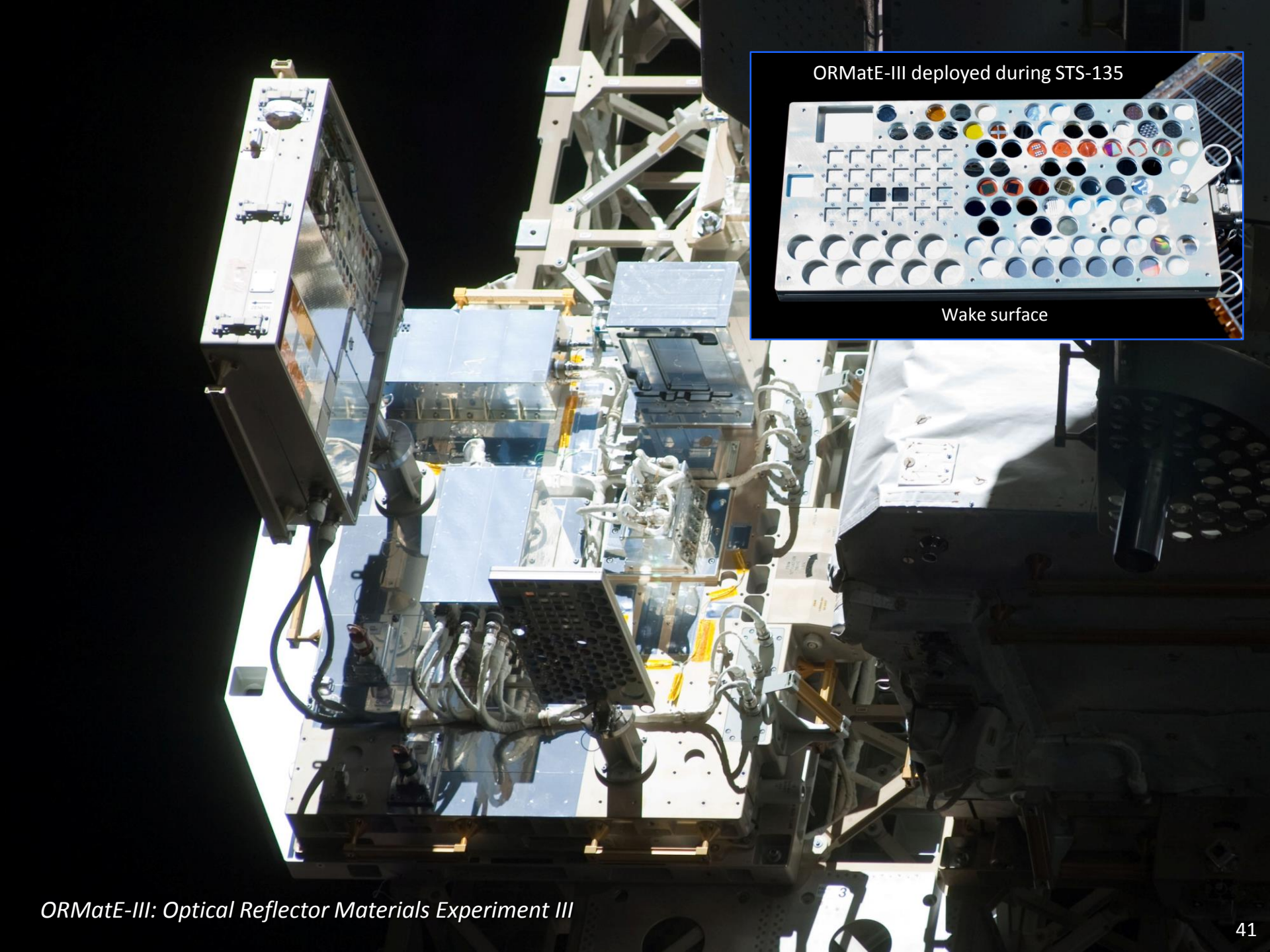
Al-FEP: *Back surface aluminized-fluorinated ethylene propylene*
C-FEP: *Carbon paint back-surface coated FEP*
ePTFE: *Expanded-polytetrafluoroethylene*

MISSE 8

Deployed: May 2011
Retrieved: July 2013

2.14 years space exposure





ORMatE-III: Optical Reflector Materials Experiment III

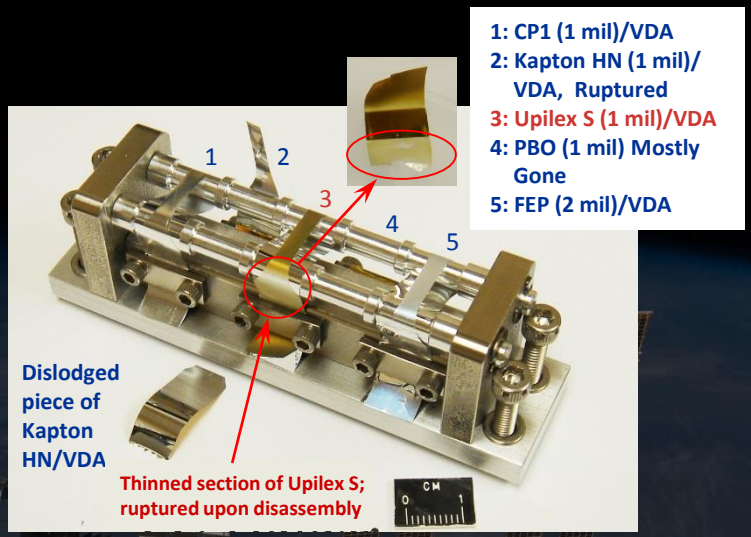
Examples of other NASA Glenn Research Center MISSE Experiments and Benefits

MISSE 1 & 2 Polymer Film Thermal Control and Gossamer Materials Experiments

Joyce Dever, NASA Glenn Research Center

- MISSE 1 & 2 Polymer Film Thermal Control and Gossamer Materials Experiments:
  - *Experiment objectives:* To examine changes in optical and mechanical properties of polymer films typically used for spacecraft thermal control applications, and to correlate property changes with environment exposure conditions
    - *10 tensile samples (5 ram & 5 wake)*
    - *21 optical samples (15 ram & 6 wake)*
- Results:
  - 5 of 10 tensile samples broke, or eroded away on-orbit
    - *Most tensile specimens had significant degradation in mechanical properties (Teflon FEP, Kapton HN and Upilex-S)*
    - *Mechanical degradation was affected by AO erosion*
  - Solar absorptance changes ranged from -0.010 (SiOx-8% PTFE/5 mil FEP/VDA) to 0.151 (TOR LM)
  - Uncoated samples decreased in thermal emittance, consistent with reduced thickness from AO erosion
- Benefits:
  - ➢ *Optical properties data will facilitate more accurate prediction of in-space performance of thermal control materials*

Pre-flight photo of ram optical samples



MISSE 1 Wake Holder 2-Q2

Flight (left) & control (right)

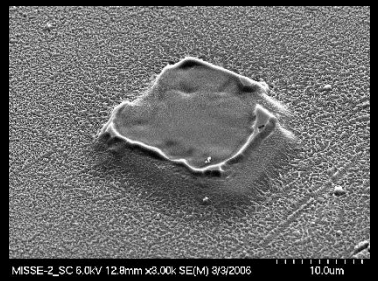
SiOx-8% PTFE/1 mil Kapton HN/VDA

1.5 mil TOR LM

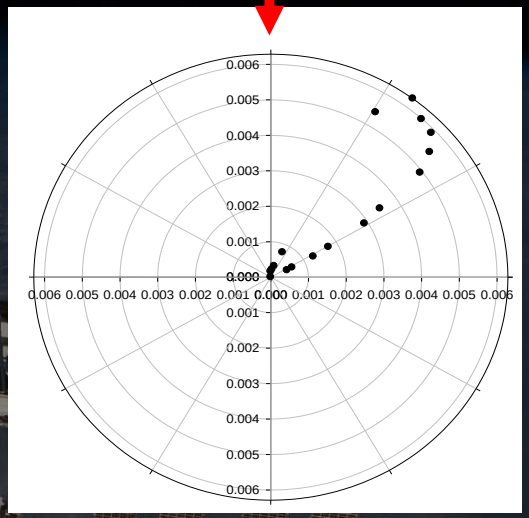
MISSE 2 Atomic Oxygen (AO) Scattering Chamber Experiment

Bruce A. Banks, SAIC at NASA Glenn Research Center

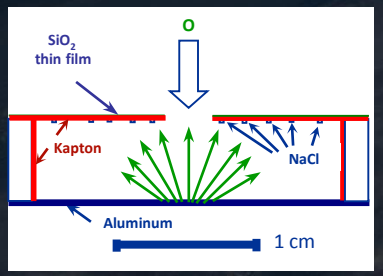
- MISSE 2 Atomic Oxygen (AO) Scattering Chamber Experiment:
  - *Experiment objective:* To measure the AO erosion characteristics of scattered AO including angular distribution and scattered AO erosion yield (Ey)
- Results:
  - The peak flux of scattered AO was determined to be 45° from normal incidence, not the model predicted cosine dependence
  - The Ey of Kapton H for AO scattered off oxidized aluminum is 6.54×10^{-25} cm^3/atom; 0.218 the Ey of direct AO impingement
- Benefits:
  - ➢ *Results were used to help understand degradation of the Hubble Space Telescope Cosmic Origins Spectrograph Experiment*
  - ➢ *Results provide understanding of AO damage in telescope cavities*



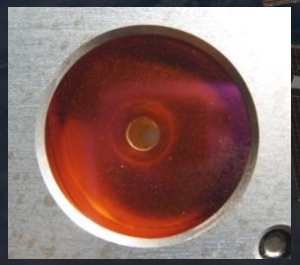
SEM image of a salt-protected butte on the inside surface of the flight aperture lid



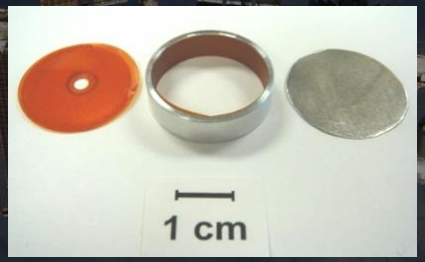
Angular distribution of scattered atomic oxygen erosion rate relative to incident (arrow) atomic oxygen erosion rate



Section view drawing



Post-flight photograph of scattering chamber

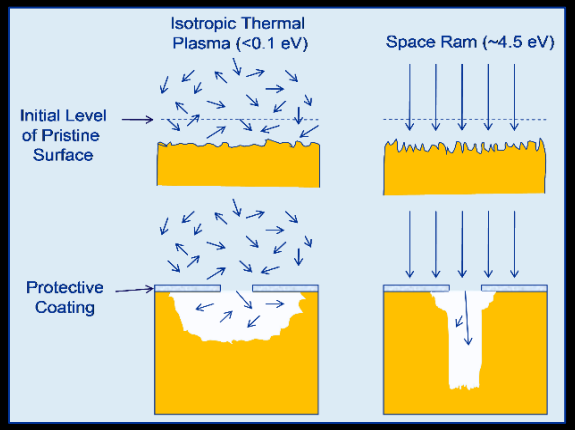


Post-flight photograph of component parts

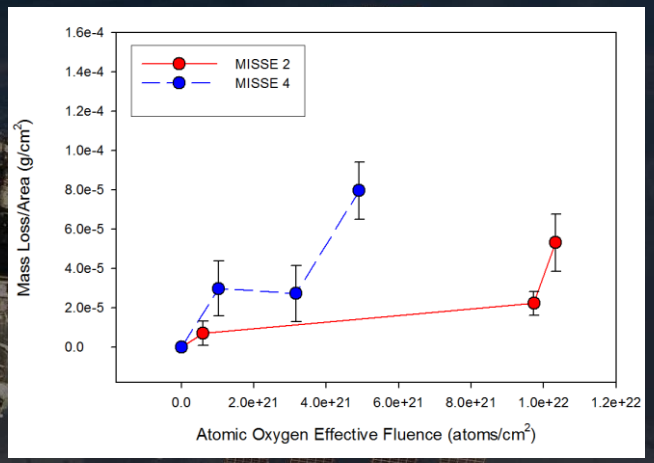
MISSE 2 & 4 Double SiOx-Coated Kapton (Mass Loss) Experiment

Sharon K. R. Miller, NASA Glenn Research Center

- MISSE 2 & 4 Double SiOx-Coated Kapton Experiment:
  - *Experiment objective:* To determine atomic oxygen (AO) undercutting rate dependence in space as compared to ground-facility (mass loss)
- Results:
  - Data showed that the erosion in a ground-based isotropic atomic oxygen plasma system is about 18 times more reactive for coated Kapton than in LEO
- Benefits:
  - *Ground-to-space correlations will facilitate more accurate ground testing and improve predictive modeling of AO erosion of polymers with protective coatings*
  - *Data used to predict the condition of aluminized-Kapton multi-layer insulation for Hubble Space Telescope Servicing Mission 4*



Example of how the difference in atom energy between the ground-based isotropic AO plasma and LEO can lead to over testing of protective coated polymers



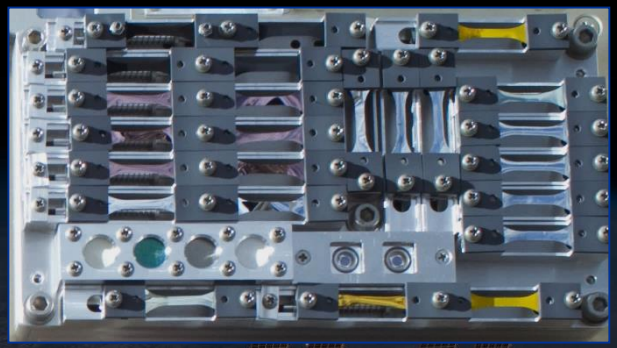
Coated Kapton samples exposed to ground-based isotropic AO prior to, and after, flight. Central slope region represents loss during MISSE flight

MISSE 6 Polymer Film Tensile Experiment (PFTE)

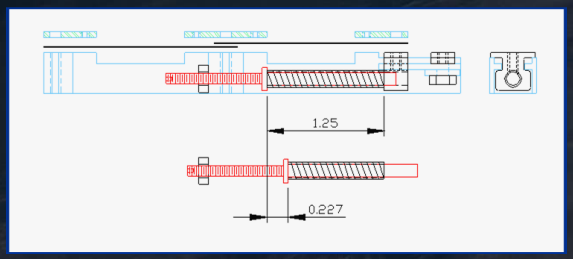
Sharon K. R. Miller, NASA Glenn Research Center

- MISSE 6 Polymer Film Tensile Experiment (PFTE):
  - *Experiment objective:* To expose a variety of polymer films to the low Earth orbital environment under both relaxed and tension conditions
- AO Erosion Results:
  - Data showed that the erosion rate of some polymers increases if the material is under tensile loading, which impacts missions flying in LEO with polymers under tensile loading such as solar array blankets
- Benefits:
  - ➢ *Data used to provide information on changes that could be expected for polymers under tension for James Webb Space Telescope enabling better material selection*

On-orbit photo of MISSE 6 PFTE ram tray

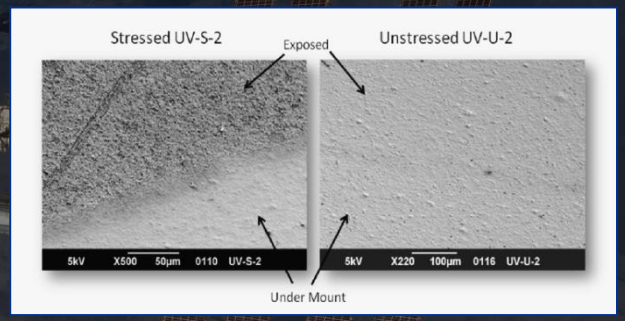


On-orbit photo of MISSE 6 PFTE wake tray



Side view drawing of a stressed sample holder

Stressed (left) and unstressed (right) samples



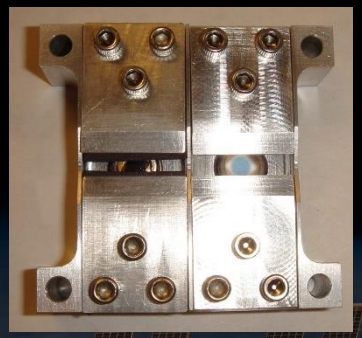
SEM images of stressed (left) & unstressed (right) Kapton XC

MISSE 6 & 7 Atomic Oxygen (AO) Fluence Monitors

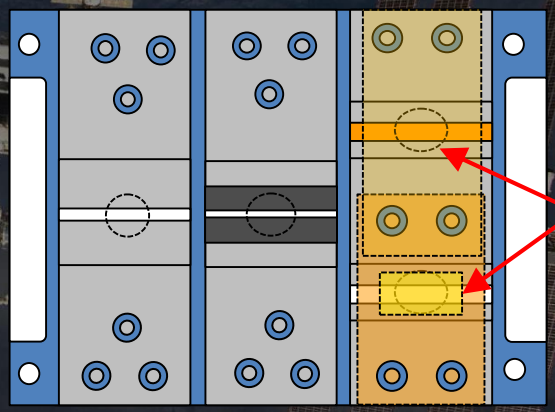
Bruce A. Banks, SAIC at NASA Glenn

- MISSE 6 & 7 Atomic Oxygen (AO) Fluence Monitors:
  - *Experiment objective:* To measure the cumulative atomic oxygen fluence as a function of time in space
- Results:
  - Active data:
    - *The electronics failed on the MISSE 6 AO monitor*
    - *The duration of active data accumulation for the MISSE 7 monitors (88 days) was not sufficient to provide meaningful fluence measurements*
  - Post-flight passive data was obtained for both experiments
  - The results from both experiments indicated that the graphite wedge erosion process worked as expected
- Experiment Benefits:
  - *Results have been used to design self-calibrating AO fluence monitors, which utilize the erosion yield of Kapton to provide calibrated AO fluence over time for electrically active experiments*
  - *New AO fluence monitor designs allow for high fluence (>10^{23} atoms/cm^2) mission data*

MISSE 6 AO Fluence Monitor (flown in the ram direction)

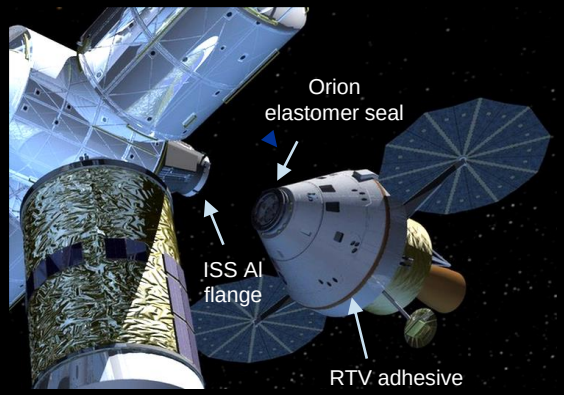


MISSE 7 AO Fluence Monitor (4 total) (flown in ram, wake, zenith & nadir directions)



MISSE 7 Low Impact Docking System (LIDS) Seal Experiment

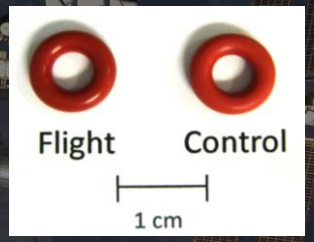
Henry C. de Groh III, NASA Glenn Research Center



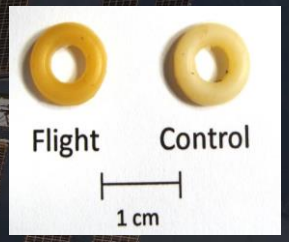
- MISSE 7 LIDS Seal Experiment:
  - *Experiment objective:* To characterize the performance of rubber seal materials subjected to the combined effects in low Earth orbit
  - Samples flown for 543 days in ram, wake and zenith directions
- Experiment Results:
  - LEO exposure did not considerably damage ELA-SA-401 silicone
  - S0383-70 silicone flight samples leaked ~10 times more than ELA-SA-401
  - Atomic oxygen caused more damage than UV radiation
  - Anodized aluminum exposed to LEO was not damaged, though damage to S0383-70 was exacerbated when paired with exposed Al
- Benefits/Next Steps:
  - ➢ *Development of seal coatings to provide UV and AO protection for longer duration missions*

Zenith flight assembly

Pre-flight ram and wake assembly



S0383-70
Parker Hannifin peroxide cured silicone elastomer

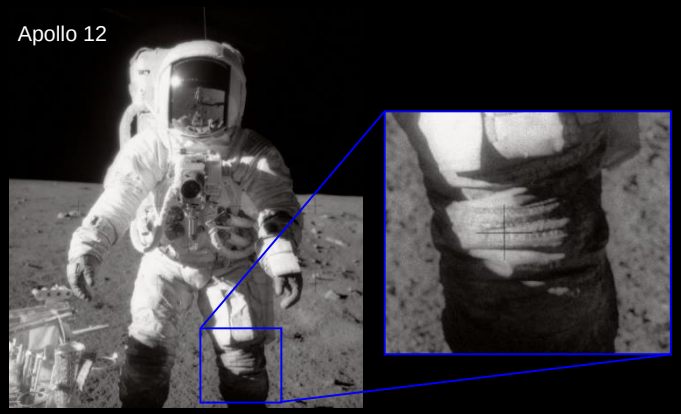


XELA-SA-401
Esterline peroxide cured silicone elastomer

MISSE 7 Spacesuit Fabrics Exposure Experiment

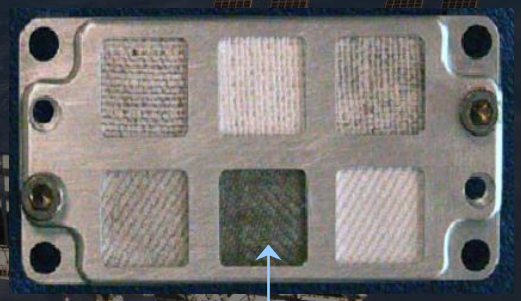
James R. Gaier, NASA Glenn Research Center

- MISSE 7 Spacesuit Fabrics Experiment:
  - *Experiment objective:* To identify and evaluate the effect of long term ultraviolet (UV) radiation upon pristine and dust-damaged spacesuit fabric
  - Experiment flown in the wake direction
- Experiment Results:
  - Apollo-like FEP fabric degraded by space radiation
    - Darkened (α increased 27%) so less efficient cooling
    - Weakened (UTS decreased 4×)
    - Stiffened (modulus increased 2×)
  - ISS/Shuttle fabric (Orthofabric)
    - Darkened even more (α increased 38%)
  - No synergistic effects seen with dust
- Benefits:
  - ➢ *Data provides information on changes expected for spacesuit outer fabric properties during extended exploration missions such as the Asteroid Redirect Mission and lunar missions*



Apollo 12 photo showing the extent of lunar dust on Alan Bean's spacesuit; with a close-up of his left knee

Spacesuit Fabrics Exposure Experiment
Top row: contains modern orthofabrics
Bottom row: contains Apollo era β-cloth



Alan Bean's Apollo 12 spacesuit left knee

MISSE Overview & Benefits

- MISSE is a multi-organization technology development and materials testing project that provided space environment exposure on ISS for 12 years
- 1000's samples & devices were exposed to space since 2001
- Provided long-duration space environmental performance & durability data:
  - Material selection, validation & space qualification
  - Improved predictions of material, component and device lifetimes in space
  - Model verification and development
  - Correlation factors between space-exposure and ground-facilities:
    - ⇒ *Enabling more accurate in-space performance predictions based on ground testing*
  - NASA Technical Standards Handbook "Spacecraft Polymers Atomic Oxygen Durability Handbook"

⇒ Benefits have impacted a wide variety of aerospace programs

- *MISSE operations need to change in the post-Shuttle era*

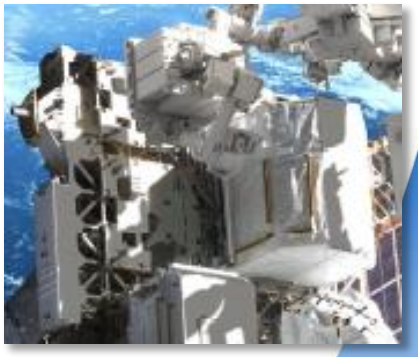
MISSE-X – Future Needs

Because MISSE operations need to change significantly in the post-Shuttle era, NASA invested in the next generation MISSE concept called MISSE-X:

- Space Technology Mission Directorate (STMD) Technology Demonstration Missions (TDM) Project, funded from 2011 to 2013

Future MISSE Facility:

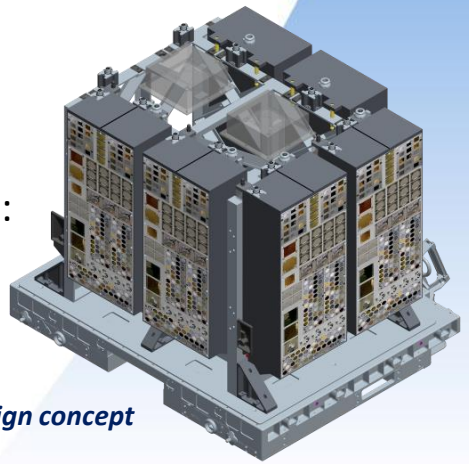
- Needs to host small, modular experiments for testing and demonstrating performance, reliability and durability
- Needs to accommodate aerospace technology customers from industry, government and academia
- Needs to be a *robotically serviceable ISS external facility*



Robotically serviceable

Key Products from the MISSE-X Project:

- Surveyed the space community for future external flight experiment demands & needs
- Developed Facility Requirements (FRs), supported by survey results
- Developed a design concept (passed the System Requirements Review):
  - *Robotic plug & play capability*
  - *Ram, wake, zenith & nadir exposures*
  - *Supports active & passive experiments*
  - *Environmental exposure monitoring*



Design concept

NASA Research Announcement (NRA) Solicitation

- **ISS NRA "Soliciting Proposals for Exploration Technology Demonstration and National Lab Utilization Enhancements" (2013)**
  - *"NASA is soliciting proposals (follow-on activity associated with RFI-LARC-MIS-3) that suggest either a full commercial business model, or a partial commercial business model for developing and maintaining an ISS external facility for testing and demonstrating performance, reliability, and durability of spacecraft materials, devices and subsystems."*
    - **Full commercial model:** proposer would fund the development and ongoing operations of the facility privately, and develop a menu of fee-based services for users of the platform based on market forces.
    - **Partial commercial model:** proposer could suggest some level of government funding to augment private financing, with user fees adjusted accordingly.

- **An ISS external facility will enhance ISS utilization and provide long duration space environmental performance and durability data, and will:**
  - Become a new ISS facility for the life of ISS
  - Accelerate technology insertion through TRL maturation of new space materials and devices
  - Continue the long rich heritage of the MISSE missions in the post-Shuttle era

NRA Website: http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7b21E0270C-BC1F-EFC4-3D87-30713B5FF373%7d&path=open

Materials International Space Station Experiment Flight Facility (MISSE-FF)

AlphaSpace
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MISSE-FF

Material International Space Station Flight Facility

Send Your Payload to the International Space Station for Accelerated and Accurate Testing Results

Materials International Space Station Experiment (MISSE-FF) Flight Facility gives researchers unprecedented insight to experiments that benefit space programs and on-earth applications alike. These benefits include technological advancements to improve our nation's defense and enhance our standard of living.

MISSE-FF is fixed to the exterior of the ISS where experiments endure extreme levels of solar- and charged-particle radiation, atomic oxygen, hard vacuum, and temperature extremes with little-to-no contamination. MISSE yields accelerated and accurate testing results for experiments varying from space suits and flight hardware to car paint and electronics.

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Materials and Processing Technical Information System (MAPTIS) MISSE Database

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MAPTIS

MATERIALS AND PROCESSES TECHNICAL INFORMATION SYSTEM

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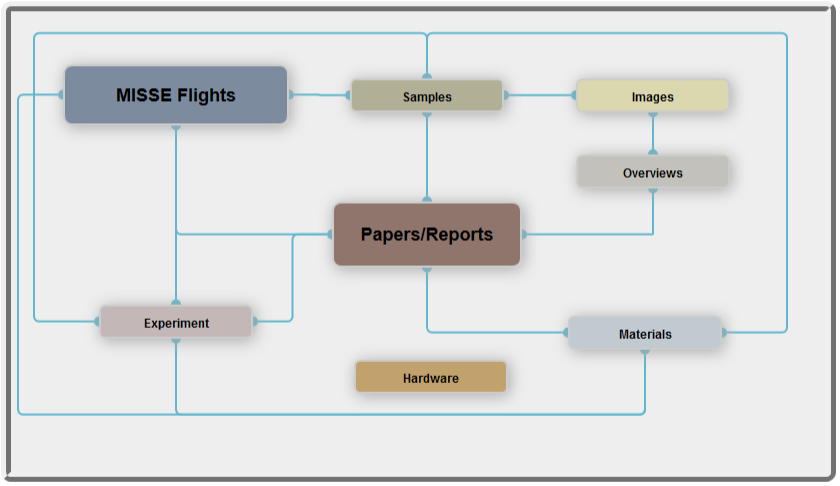

back to MAPTIS

Please note:

The data for this database is still being collected, organized and uploaded. If you cannot find some information please check back as data is continually being updated. If you have MISSE data please contact us so that your data can be included in this project.

Materials International Space Station Experiment (MISSE)

MISSE is a series of experiments mounted externally on the International Space Station (ISS) that investigates the effects of long-term exposure of materials to the harsh space environment.

The MISSE project evaluates the performance, stability, and long-term survivability of materials and components planned for use by NASA, commercial companies and the Department of Defense (DOD) on future low Earth orbit (LEO), synchronous orbit and interplanetary space missions. The Long Duration Exposure Facility (LDEF), which was retrieved in 1990 after spending 68 months in LEO, revealed that space environments are very hostile to many spacecraft materials and components. Atomic oxygen, which is the most prevalent atomic species encountered in low earth orbit, is highly reactive with plastics and some metals, causing severe erosion.

There is also extreme ultraviolet radiation due to the lack of an atmospheric filter. This radiation deteriorates and darkens many plastics and coatings. The vacuum in space also alters the physical properties of many materials. Impacts of meteoroids and orbiting man-made debris can damage all materials exposed in space. The combined effects of all of these environments on spacecraft can only be investigated in space. MISSE evaluates materials currently being used and those planned for use in future space missions.

MISSE is a direct successor of the Mir Environmental Effects Payloads (MEEP) that were attached for over a year to the Mir Docking Module of the space station Mir between shuttle flights STS-76 and STS-86; and is a descendant of the Long Duration Exposure Facility.

The MISSE Project is a cooperative endeavor managed by NASA Langley Research Center. Participants include: Johnson Space Center, Marshall Space Flight Center, Glenn Research Center, the Materials Laboratory at the Air Force Research Laboratory, Infosight Corporation, the Boeing Phantom Works and others.

NASA Official: **Teresa Miller**

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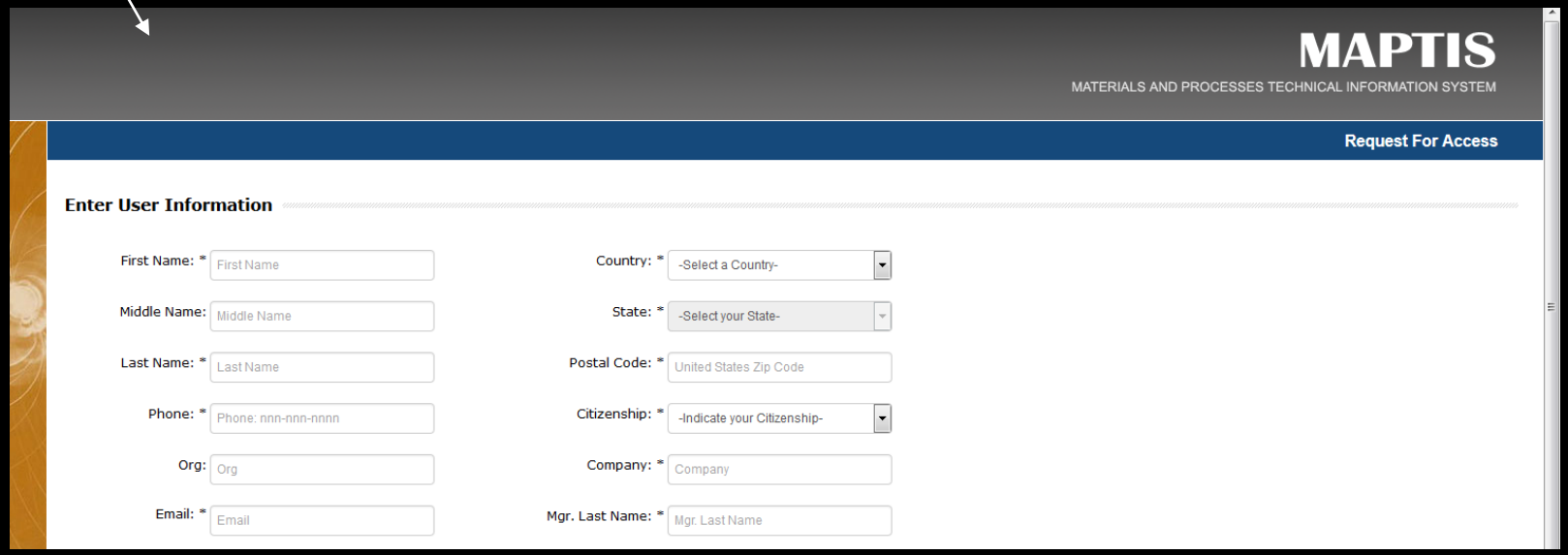

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The Glenn MISSE PIs and I would like to express our sincere appreciation to Gary Pippin (retired, Boeing) and Phil Jenkins (NRL) for providing the opportunity to fly these experiments as part of the MISSE missions

This research has been supported by various projects over the past 15 years including the ISS Research Program, the MISSE-X Project and the MISSE Informatics Project