

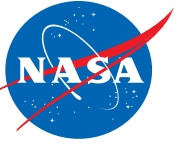
Air Quality in the International Space Station

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Ohio

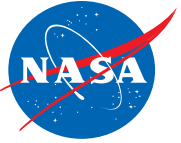
2 mm

Outline



- Introduction and background
- ISS Aerosol Sampling Experiment
- Real-time instrument for ISS
- Lunar dust contamination in spacecraft
- Conclusions

Aerosol Behavior in Low Gravity



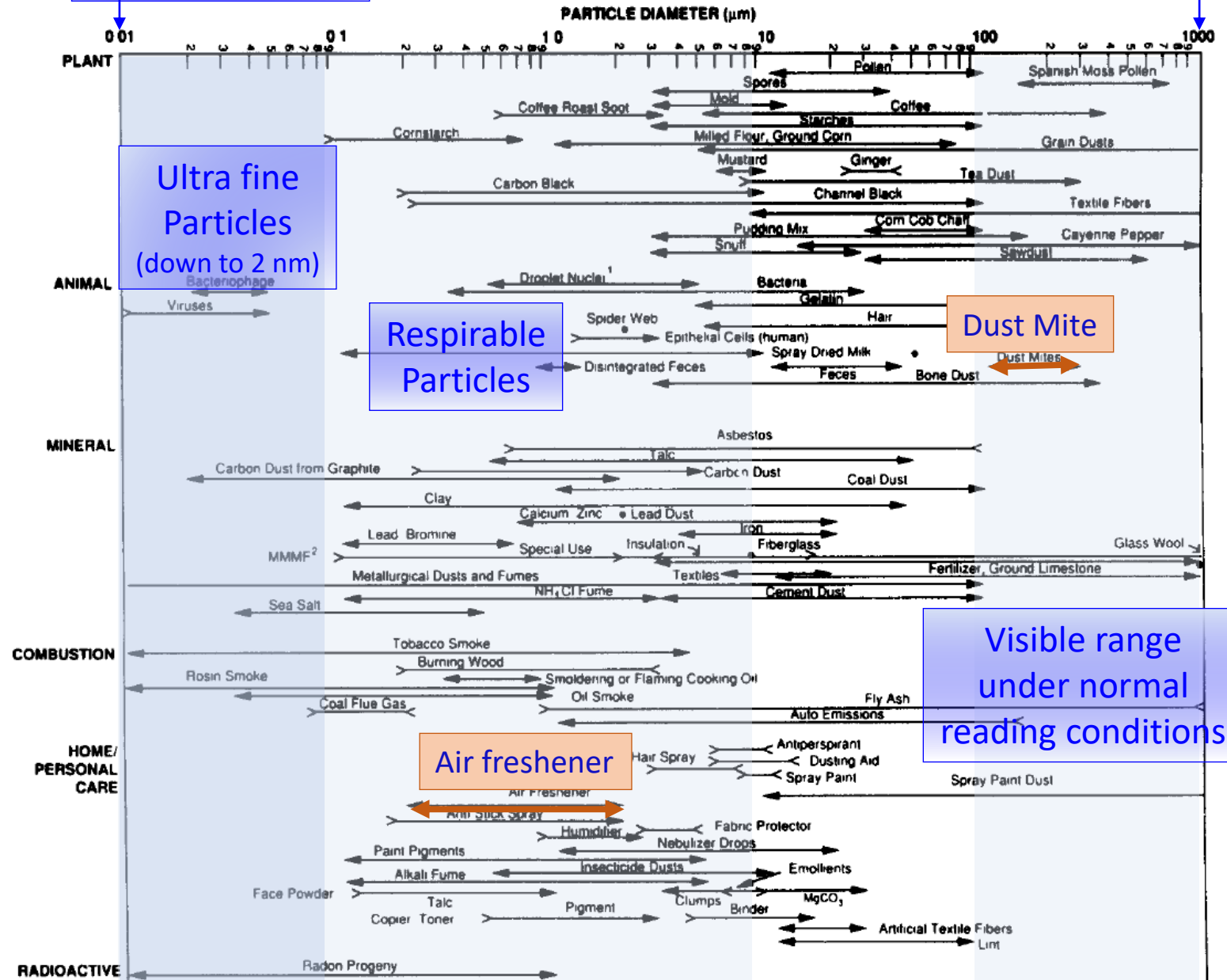
- Historic quote from Scott Carpenter
 - One of the Mercury 7
 - The second American to orbit the Earth in 1962
- "Every time I opened up the (food) bag, the crumbs would come crowding out like a swarm of bees"



Sizes of Aerosols (*Log scale*)

10 nm = 1E-8 m

1000 μm = 1mm = 1E-3 m



¹ Liquid droplets containing bacteria etc. sneezed etc

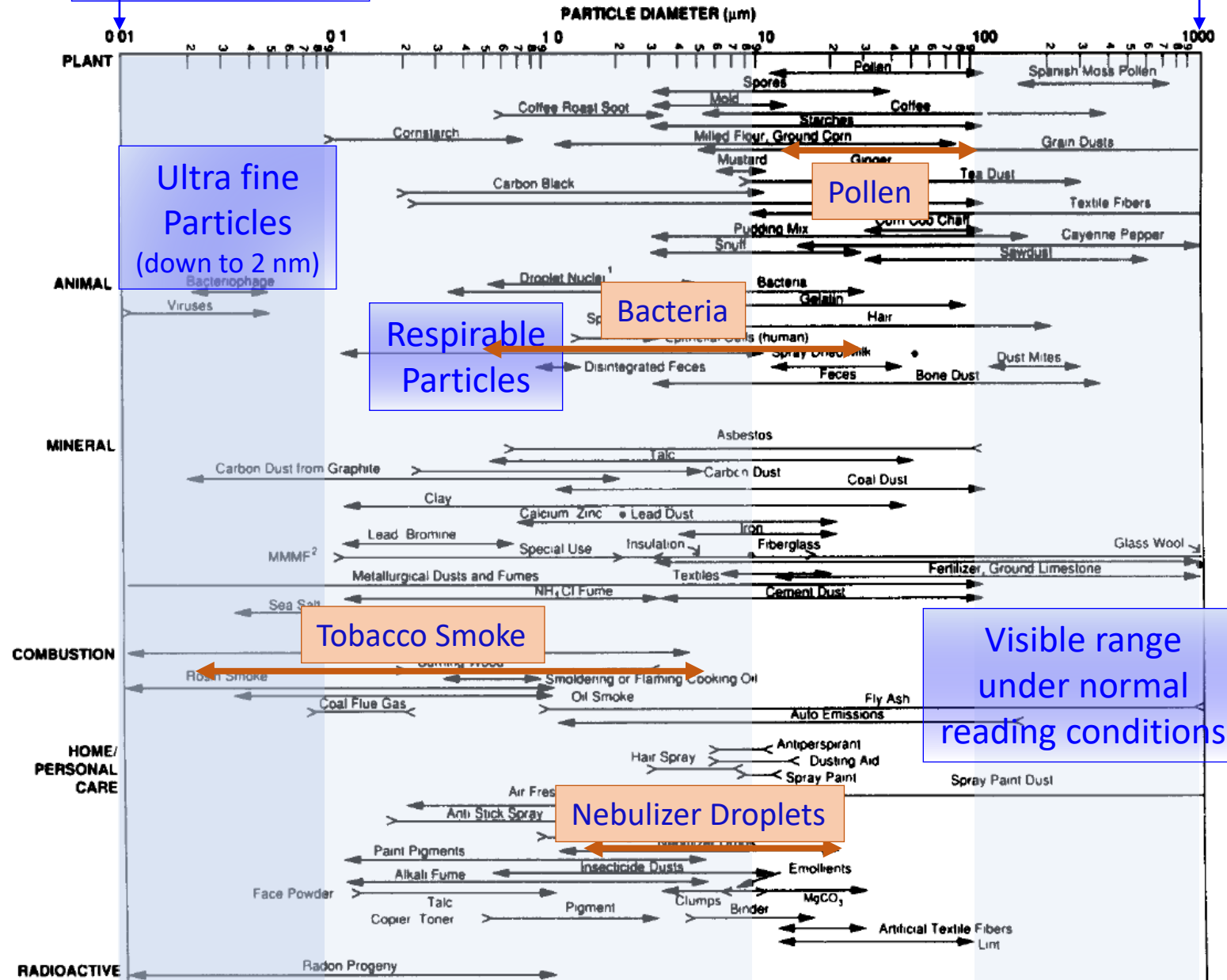
² Man made mineral fibers

From Owen et al. 1992, Airborne particle sizes and sources found in indoor air, *Atmos. Env.* 26:12, 2149-2162 (also in ASHRAE Handbook: Fundamentals)

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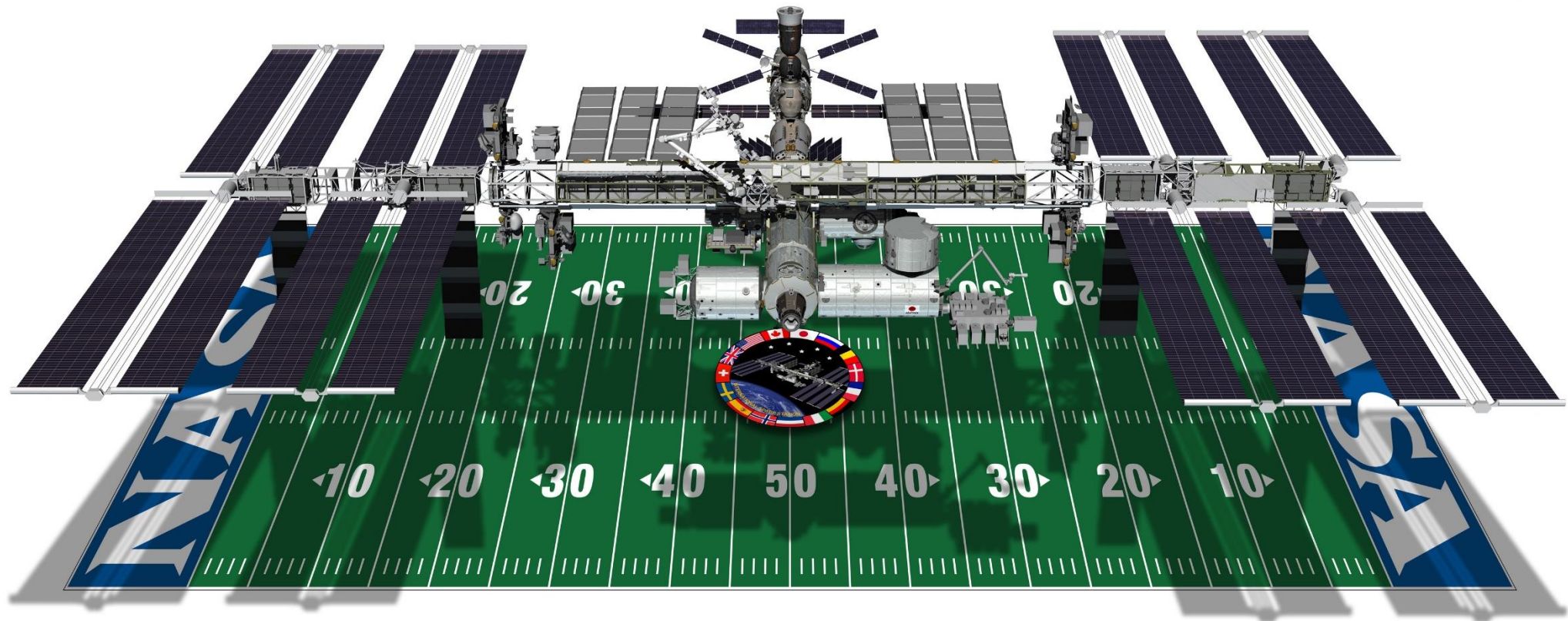
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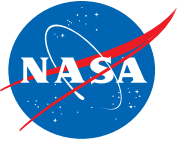
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International Space Station (ISS)

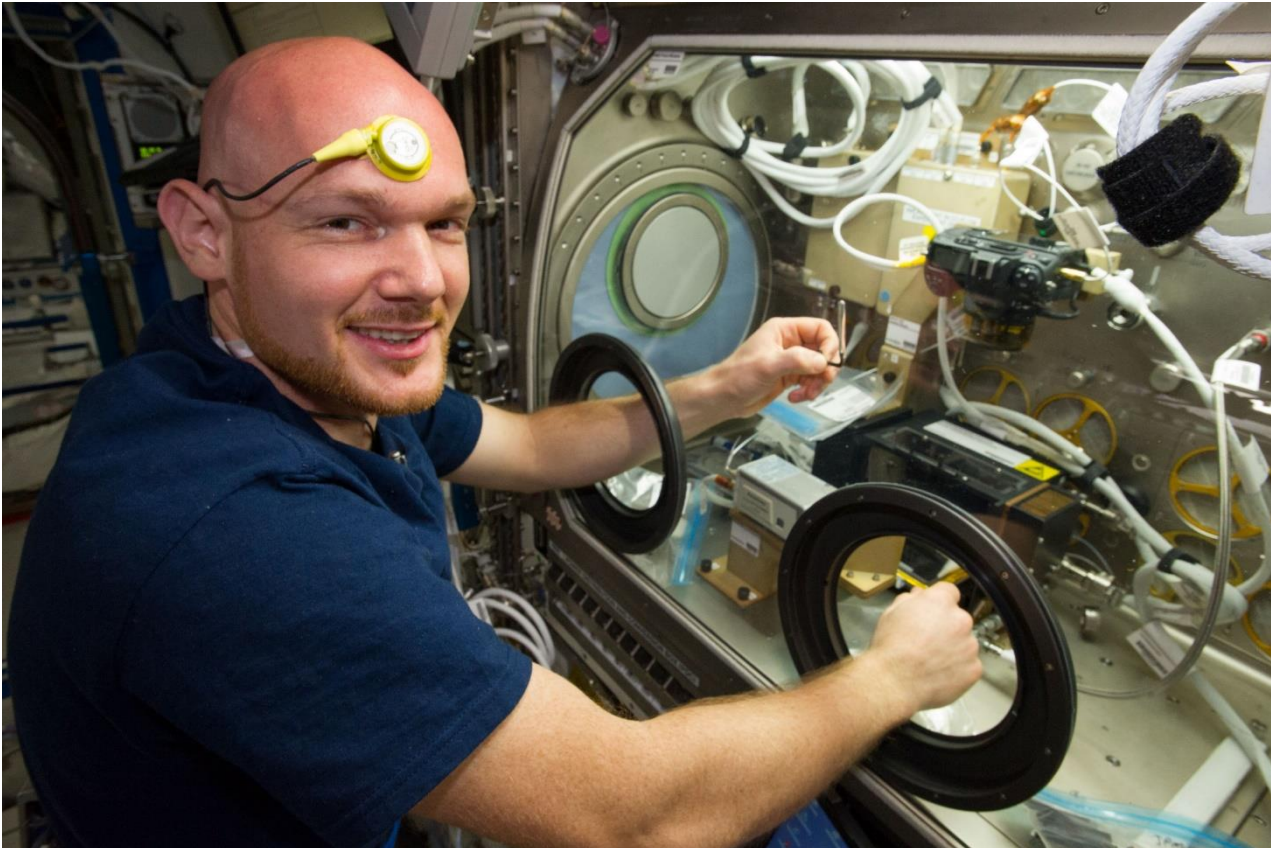
- 900 m³ Habitable Volume
- Continuously occupied for over 20 years
 - Nearly 250 people



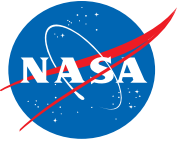
Activities on the ISS Create Aerosols



- Science Experiments
 - Unique materials



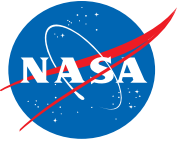
Activities on the ISS Create Aerosols



- Exercise
 - 2 hours/day, per crew member



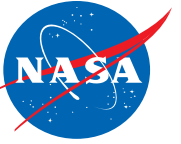
Activities on the ISS Create Aerosols



- Eating
 - No cooking, mostly heating pouches



Activities on the ISS Create Aerosols



- Housekeeping
 - Vacuuming
 - Turn off smoke detectors
 - Disinfectant wipes for surfaces
 - No laundry yet
 - Wear clothes as long as possible, then throw away
- Personal hygiene
 - No shower, only wet wipes



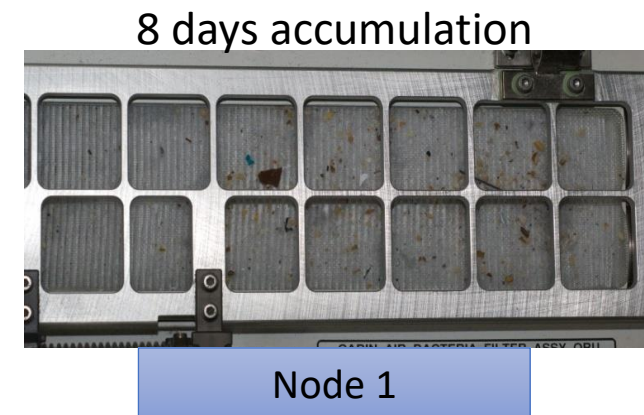
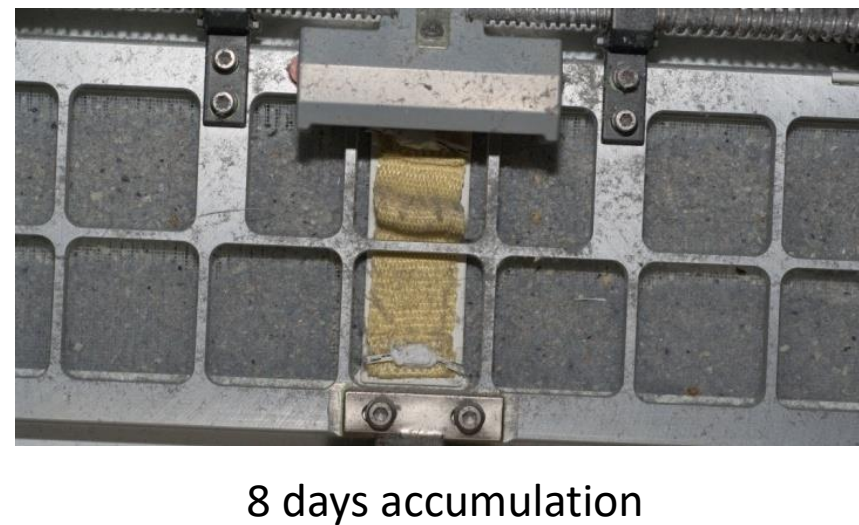
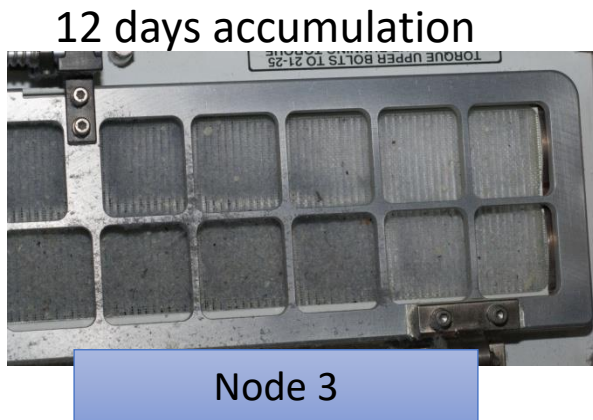
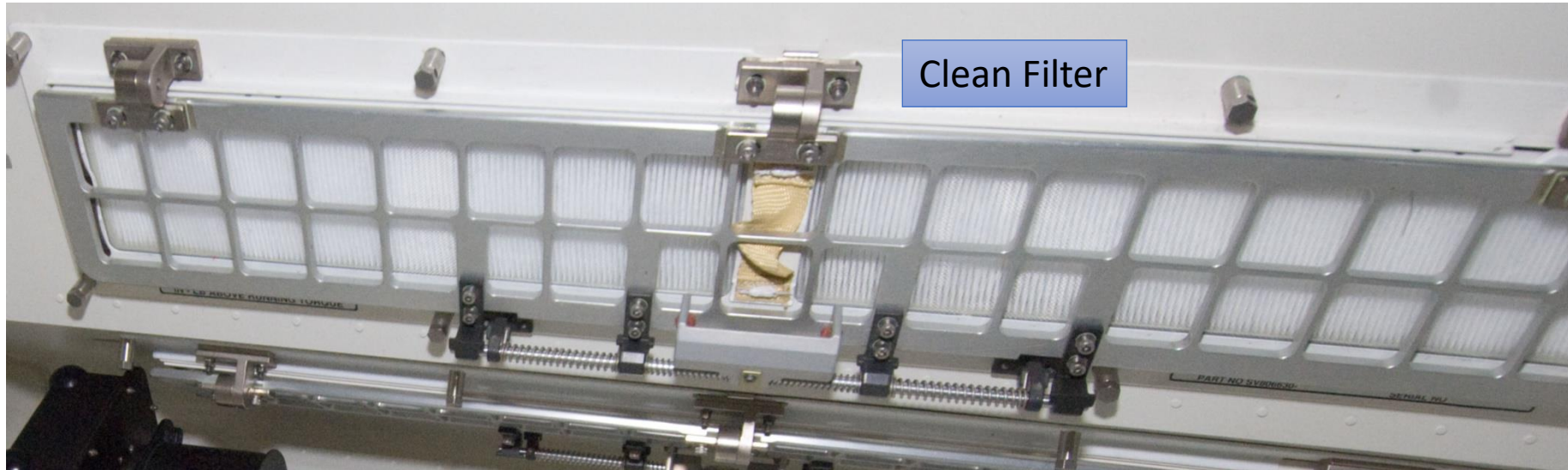
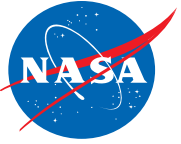
Aerosol Behavior in Low Gravity

- On Earth, our air quality is improved by gravitational settling
 - In μg , all particles remain airborne until deposited on surfaces, air inlet screens or ventilation system filters
- 'Dusty air' is an occasional complaint of astronauts
 - Indicates high concentrations of inhalable particles
- Filter inlets and fan intakes on equipment require regular vacuuming

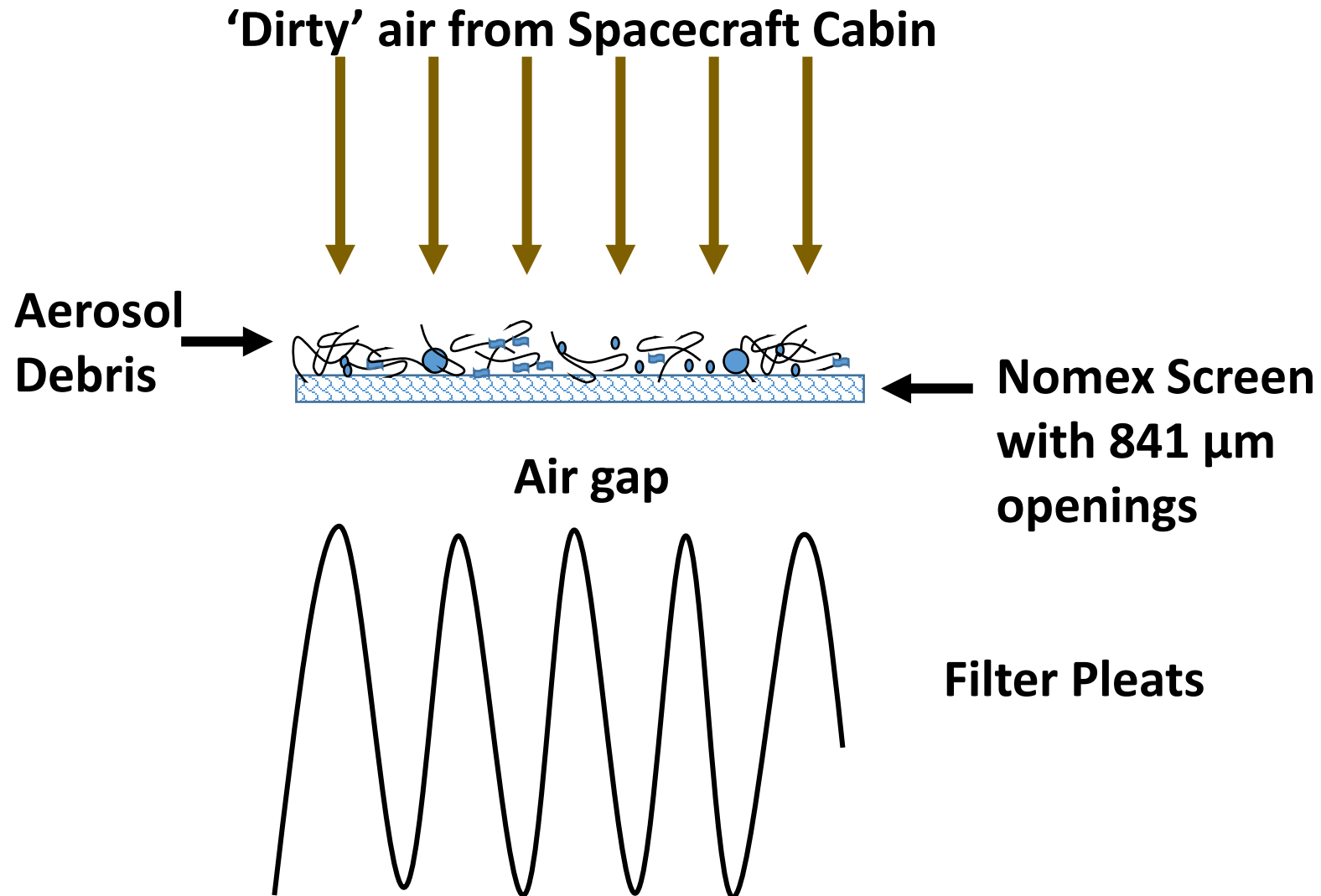
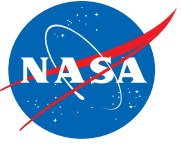


Dirty avionics intake fan

Aerosol Deposition on Filters



Aerosol Deposition on Filters

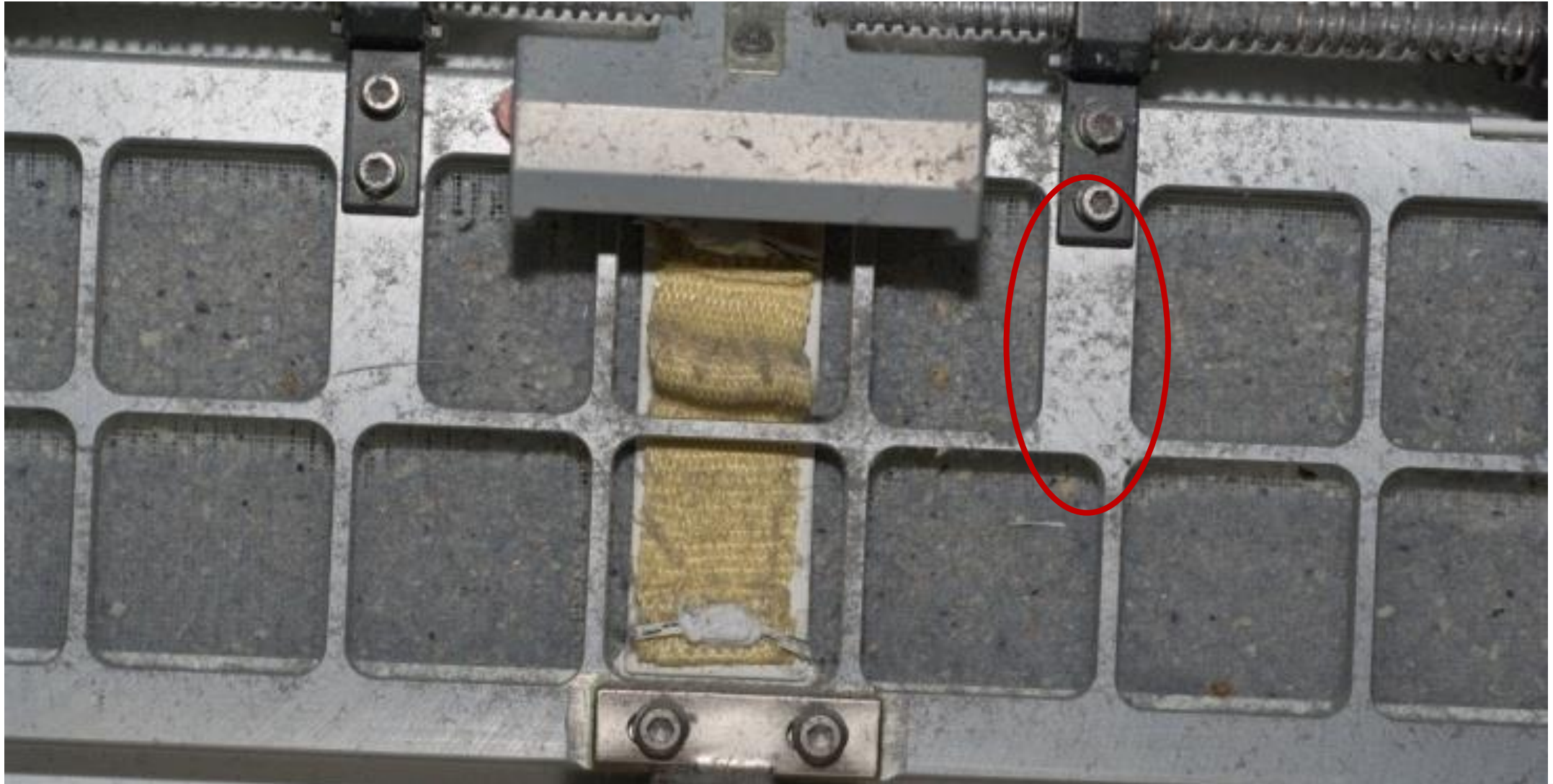
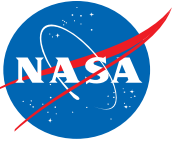




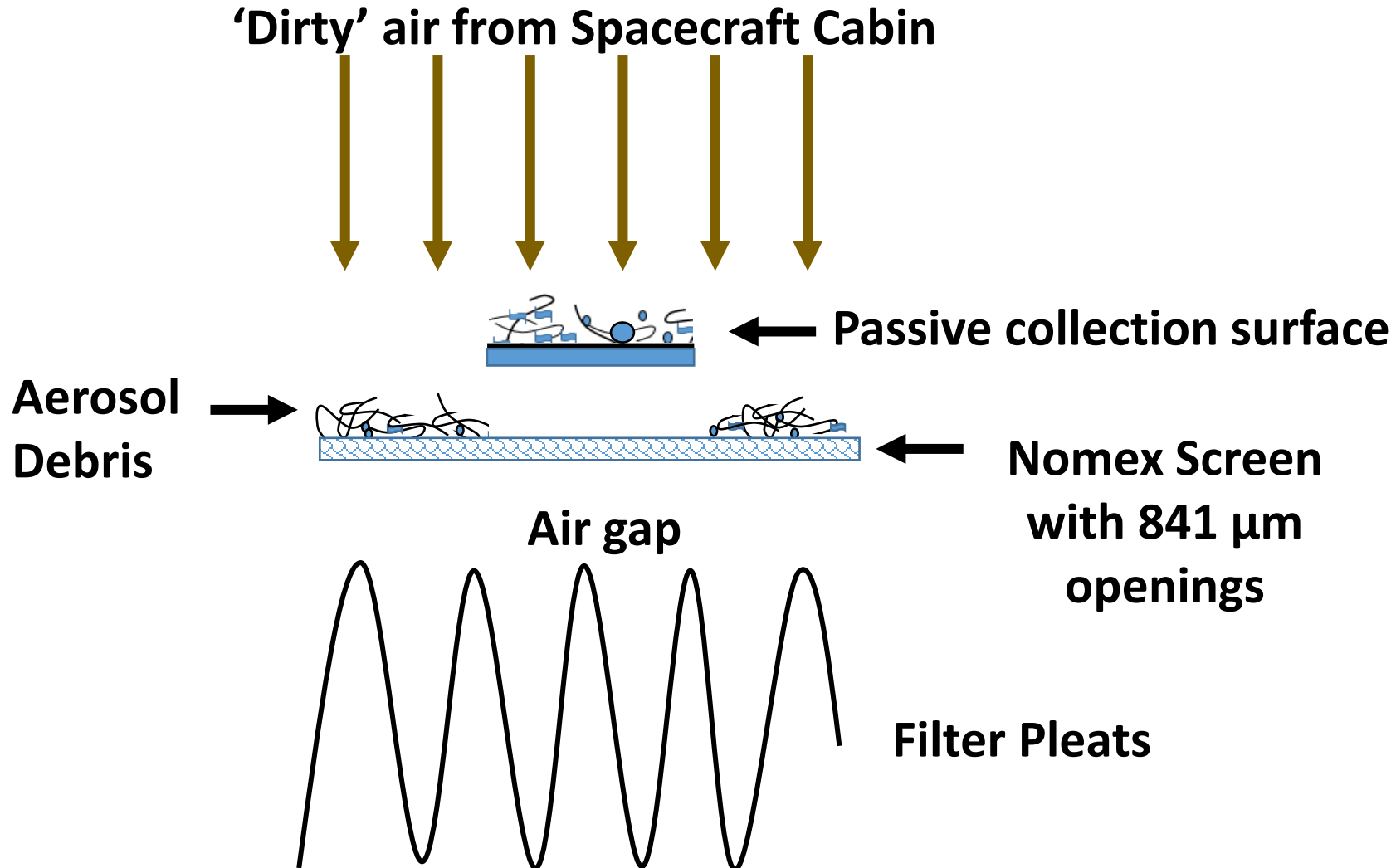
Aerosol Sampling Experiment

- Sampling is first step in characterizing ISS aerosols
 - Capture particles, bring samples back to Earth for analysis
- Aerosol Sampling Experiment funded by Life Support Systems Project
 - December 2016
 - July 2018

Passive Sampling without Gravity

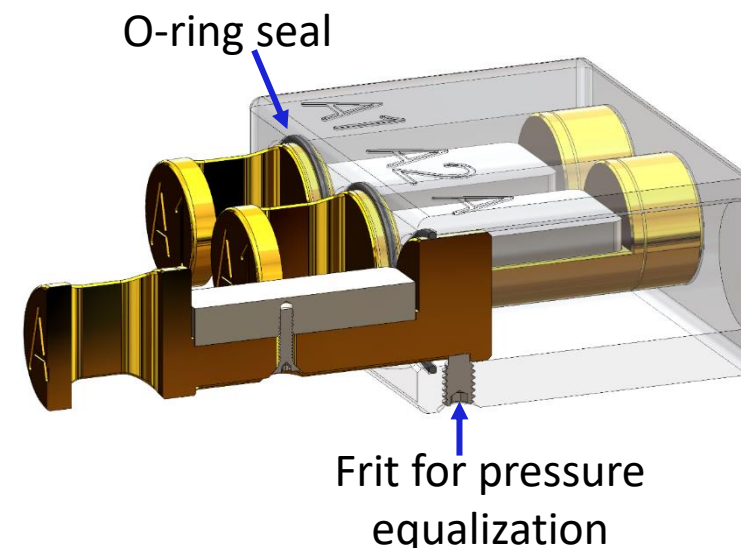
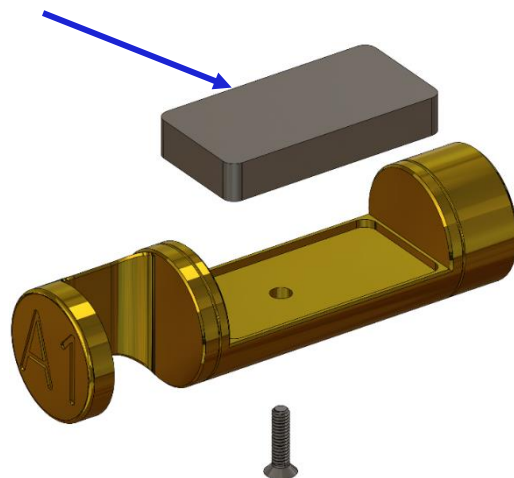


Aerosol Deposition on Filters



Passive Aerosol Sampler

- Five individually bored, separately sealed collection 'drawers'
- Drawers open, collect debris, and are closed to protect sample from contamination
- Aluminum block substrate with 2-way sticky carbon tape
 - Block fits in electron microscope

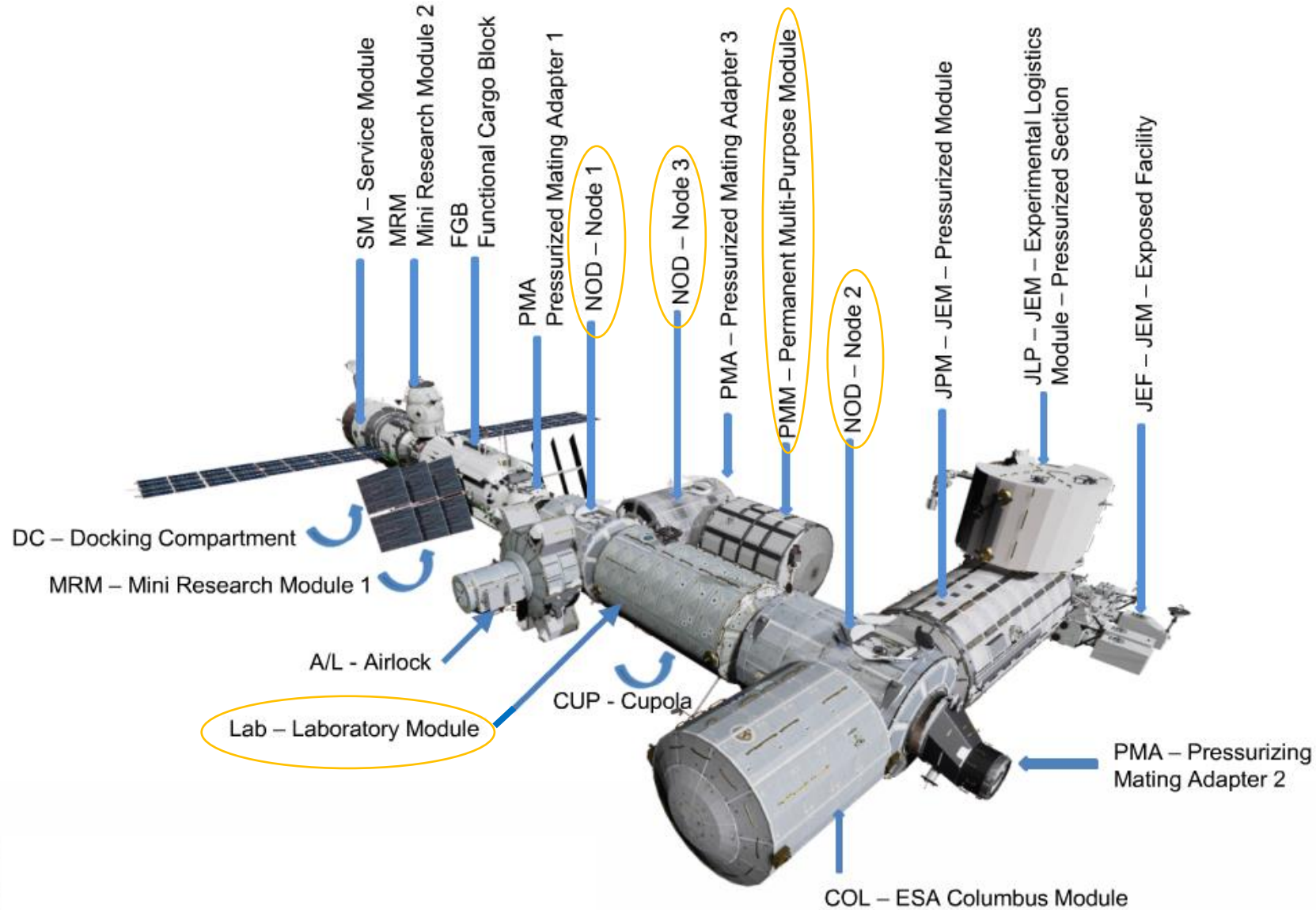
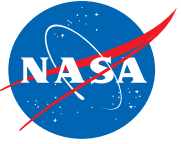


Aerosol Sampling Experiment

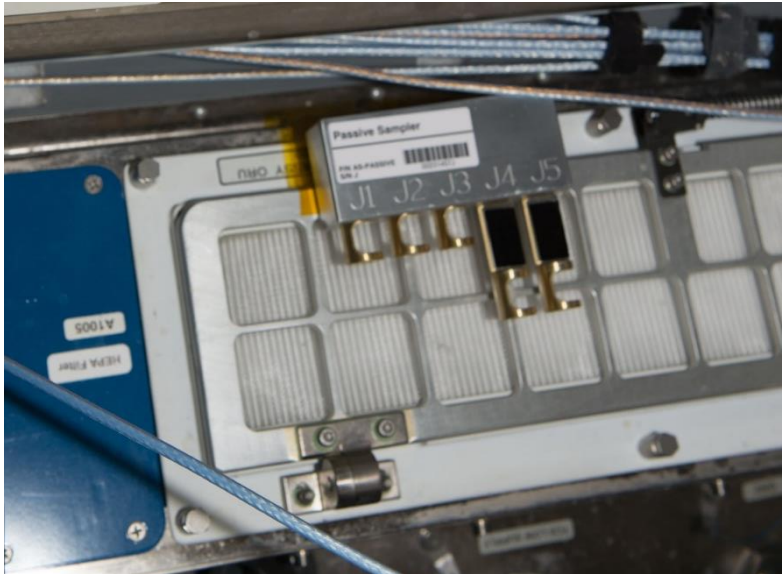
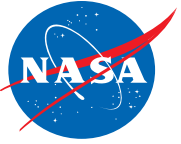
- The optimal sampling duration to get the best particle coverage for microscopic analysis varies by location
- Five substrates provided different particle loadings to choose from as well as redundancy to reduce risk
- The operations in 2016 collected particles for 2, 4, 8, 16 and 32 days
 - Ideal samples for microscopy were mostly in the 16 and 32-day durations
- Operations in 2018 collected particles for 26 days on all substrates
 - Better statistics
 - Less crew time



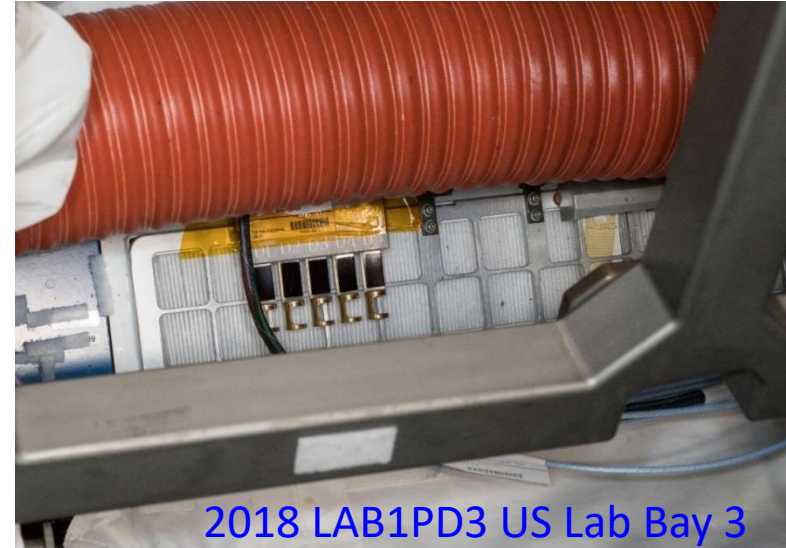
Sampling Locations



Passive Sampler Deployments



2016 deployment, **between day 8 and day 16**



2018 LAB1PD3 US Lab Bay 3



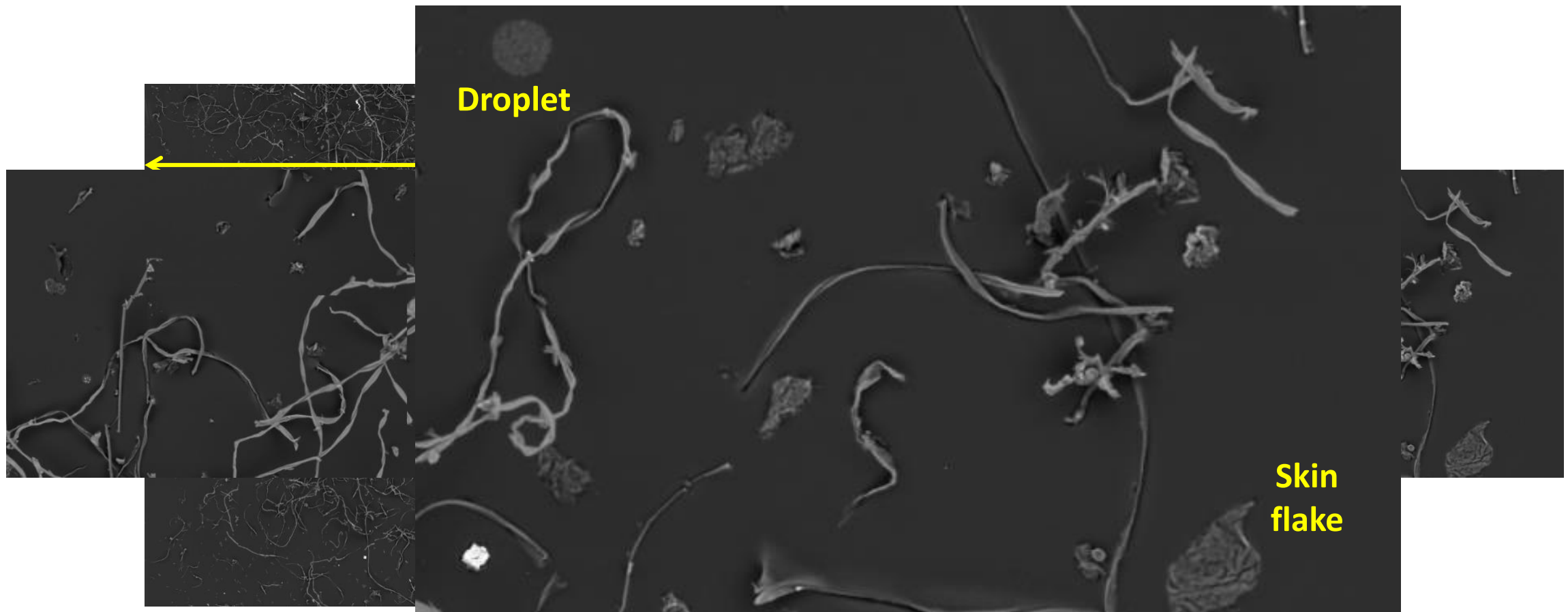
2018 NOD2D3 Midbay
HEPA Return Register

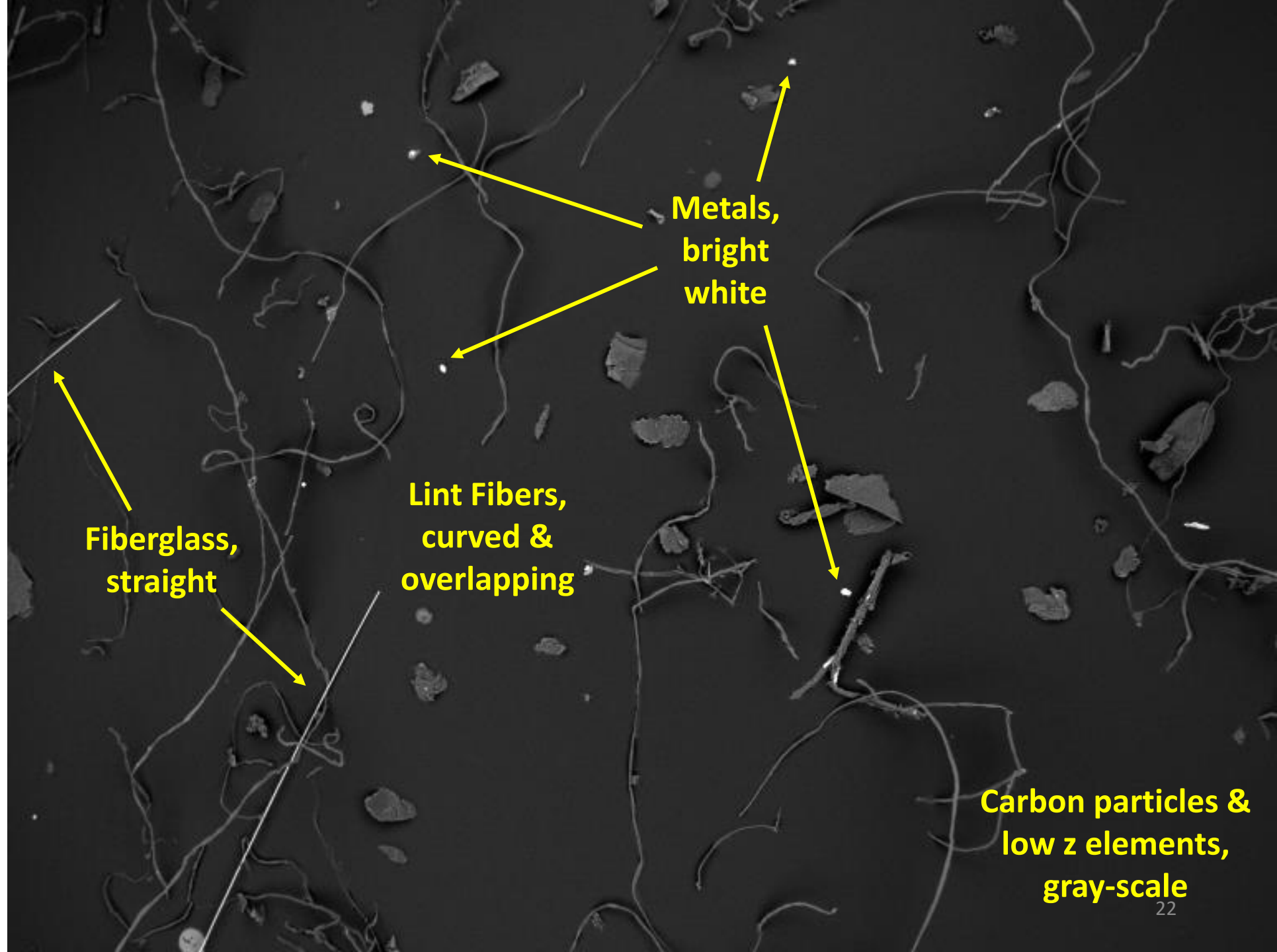


2018 NOD3F3
HEPA Register

Passive Sampler Microscopy

- A montage for each passive sample was created by combining fields of high-resolution SEM backscattered-electron images*





**Fiberglass,
straight**

**Lint Fibers,
curved &
overlapping**

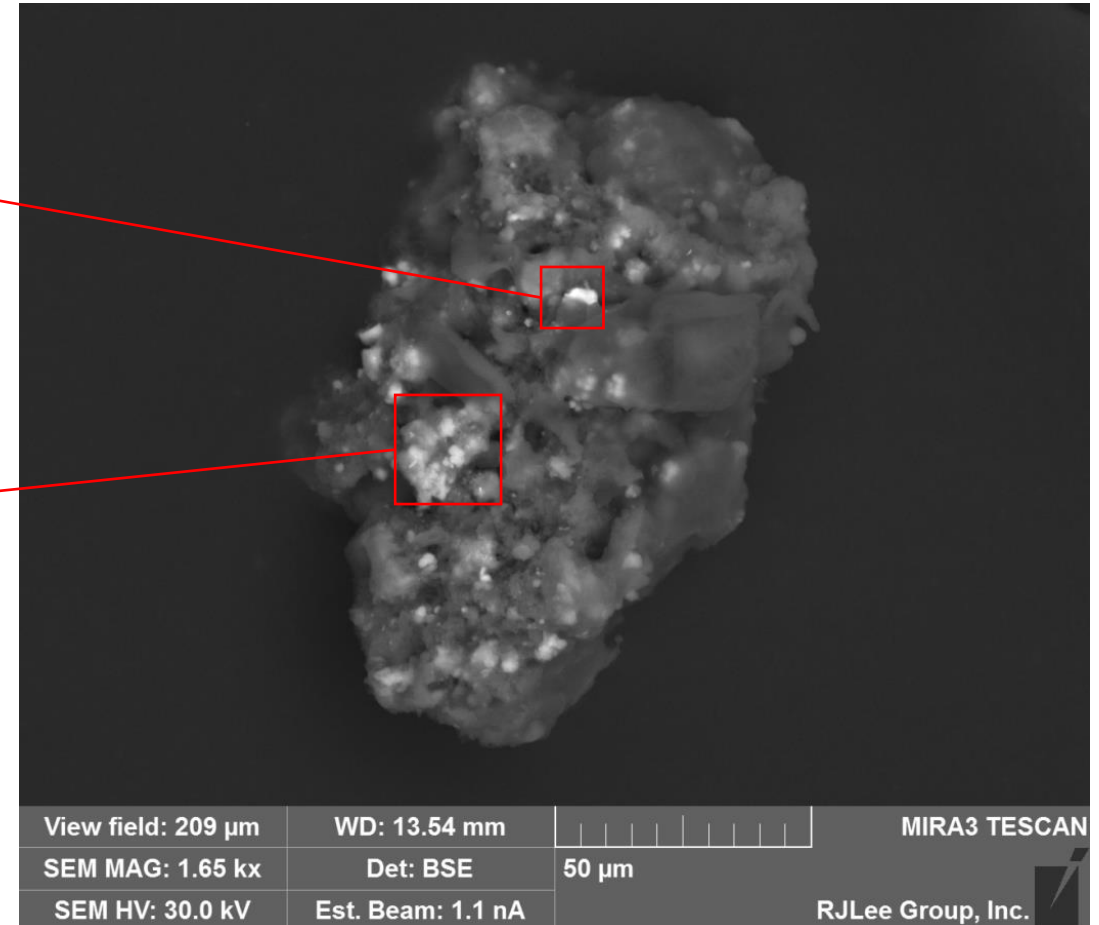
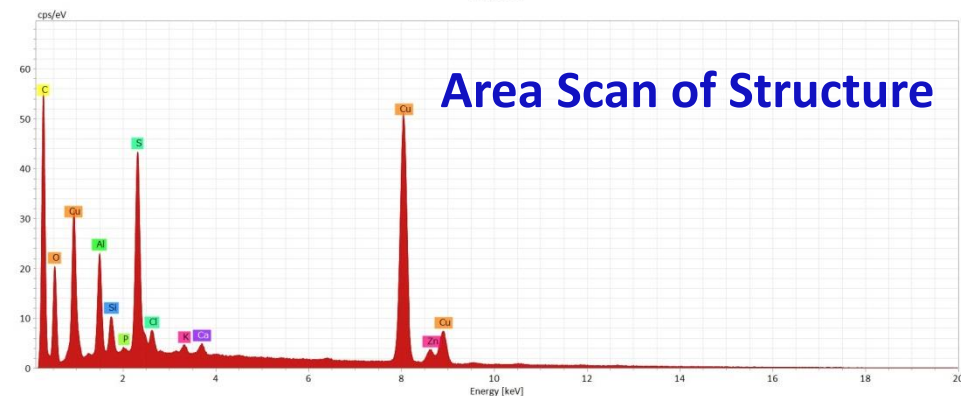
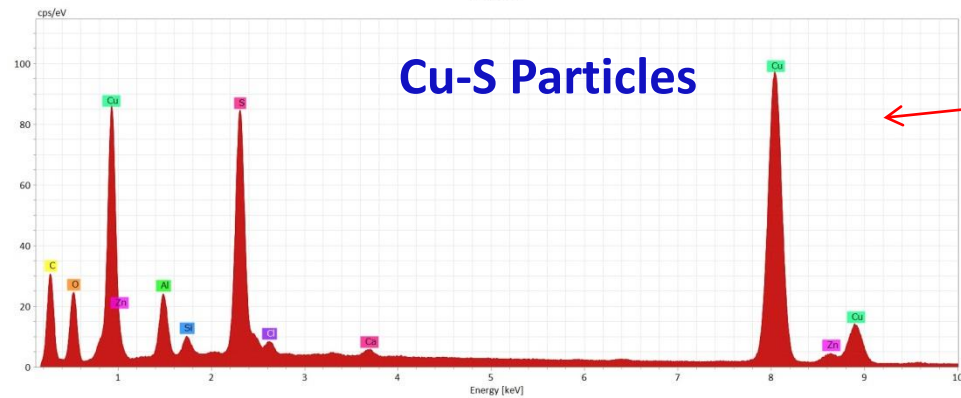
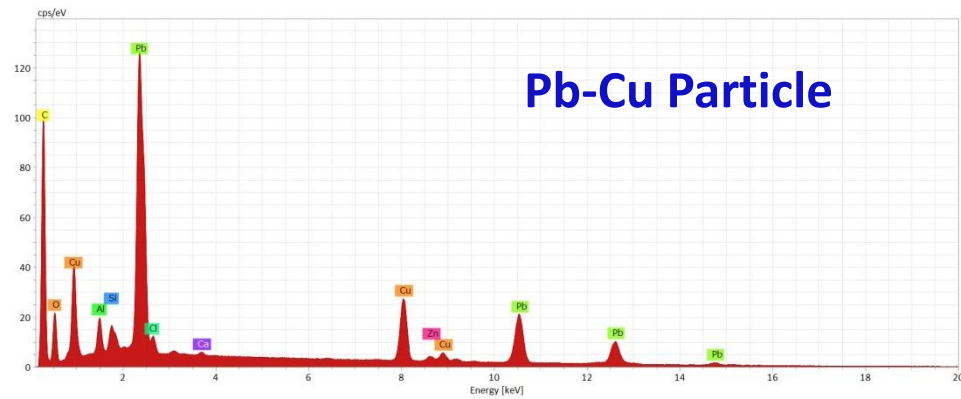
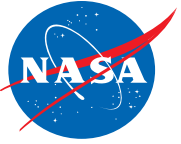
**Metals,
bright
white**

**Carbon particles &
low z elements,
gray-scale**

Unique Particle Morphology

- ISS samples had many multi-component particles
 - Individual metal particles embedded in a carbonaceous matrix
- Presents challenges for counting particles by image analysis
 - Must distinguish edges to outline individual particles based on contrast thresholds
 - Fibers were a challenge as well

Multi-Component Particle



**Copper/lead-rich particles and
copper/sulfur-rich particles associated
with carbonaceous material**

Formation Mechanism?

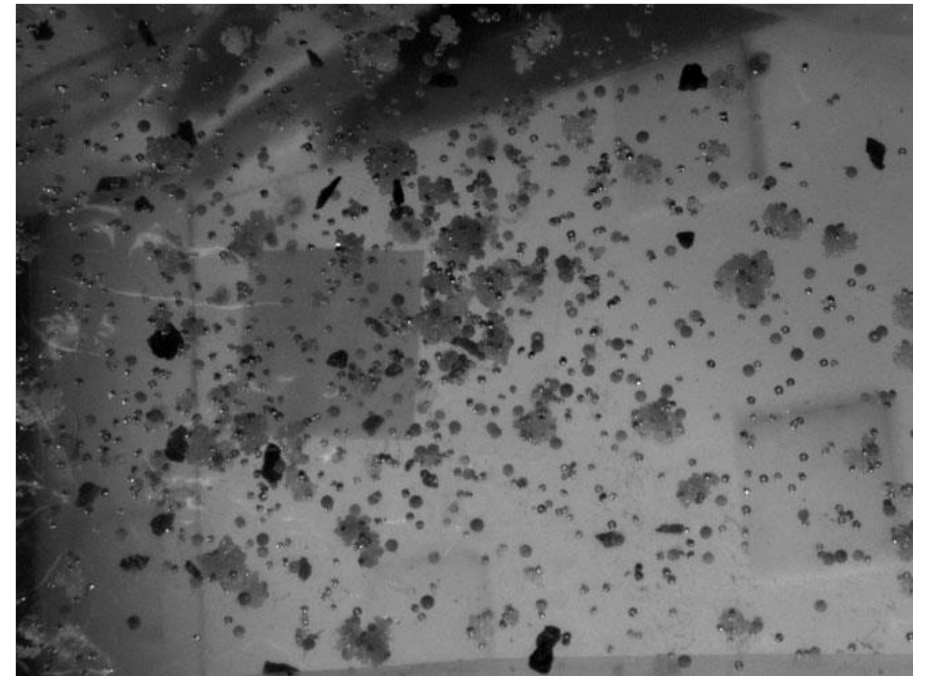
- Did many individual particles agglomerate after becoming airborne on ISS?
- Were the parent materials composites to begin with?
- Astronaut Don Pettit performed some “informal particle aggregation experiments” in plastic bags on ISS in 2003, 2008 and 2011*
 - CAPCOM/astronaut Stanley Love recognized these experiments could be representative of planetary accretion

*Love, S.G., Pettit, D.R., Messenger, S.R., (2014) Particle aggregation in microgravity: Informal experiments on the International Space Station, *Meteoritics & Planetary Science* 49, Nr 5, 732–739.



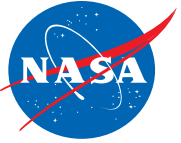
Agglomeration Experiment

- Several types of particle materials were mixed in different types of bags in microgravity
 - Particles between 100 and 7000 micrometers (7 mm)
 - Salt, sugar, coffee, meteorite particles, acrylic and glass beads
- Some particles aggregated with strong cohesion
 - Low number densities
 - On the order of seconds
- Smaller particles aggregated more quickly and with higher cohesive strength
- Angular particles aggregated readily whereas round smooth particles did not
- *Overall, electrostatic forces dominated the process*



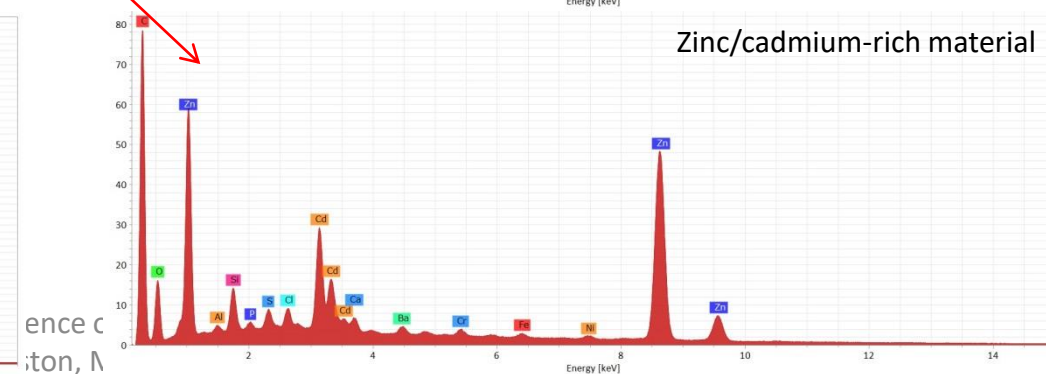
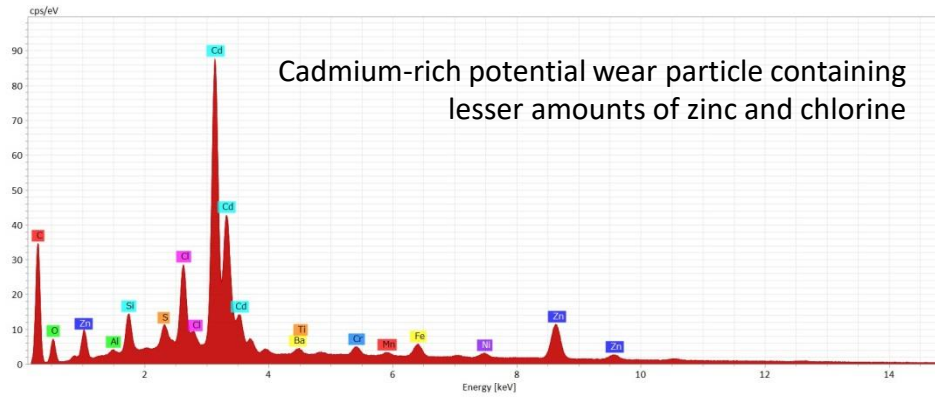
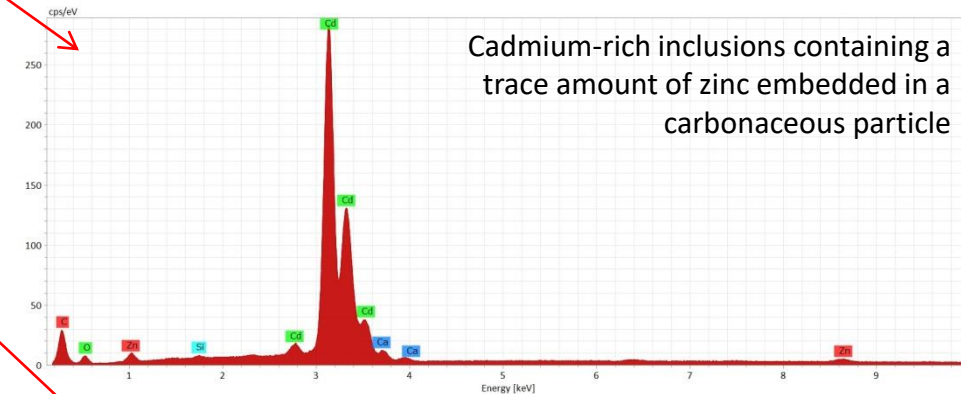
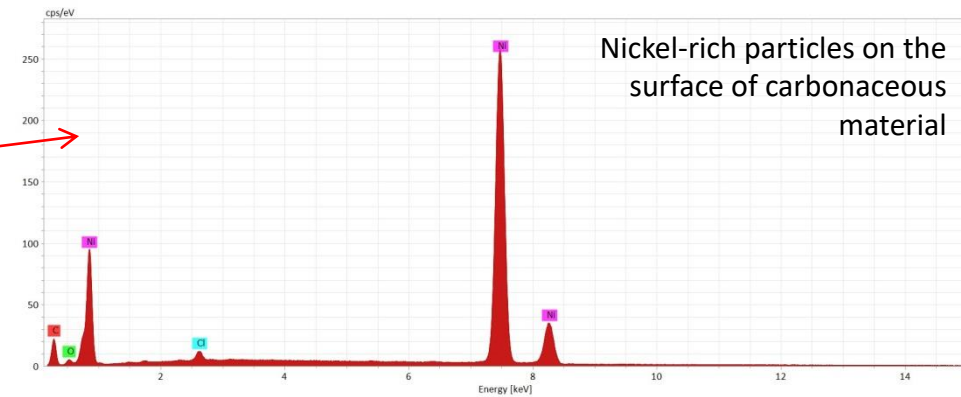
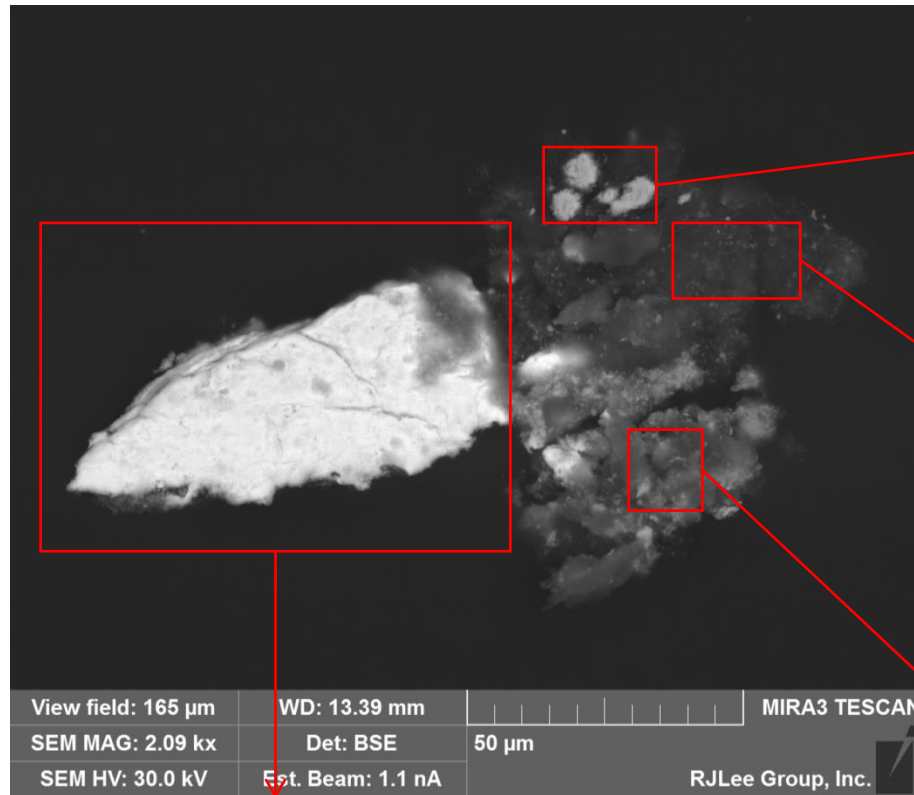
Clumps dominated by sugar, with incidental capture of acrylic spheres & meteorite particles

Possible Formation Mechanism of ISS Cabin Aerosols



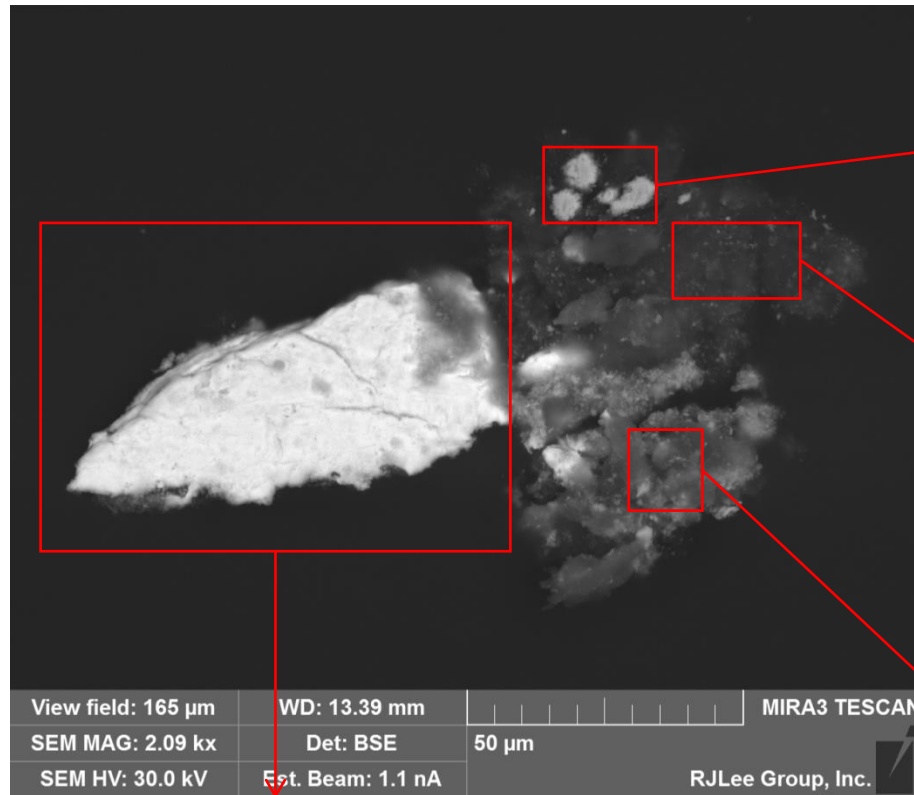
- The particle sizes in Don's experiments are similar to the passively sampled metal particles
- State of charge
 - Mechanically generated particles are more likely to have high levels of charge
 - Sodium chloride and polymeric aerosols are more likely to exist in a charged state than conducting materials
- These informal experiments indicate that **agglomeration is a plausible formation mechanism** of the multi-component particles on ISS

Unique Particle Morphology



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tion, N

Unique Particle Morphology



**Nickel-rich particles on the surface
of carbonaceous material**

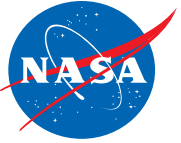
**Cadmium-rich inclusions
containing a trace amount of zinc
embedded in a carbon matrix**

Zinc/cadmium-rich material

**Mechanically generated wear
particle, rich in cadmium and
containing lesser amounts of zinc
and chlorine**

Sampled in Node 3

Sample Analysis Technique

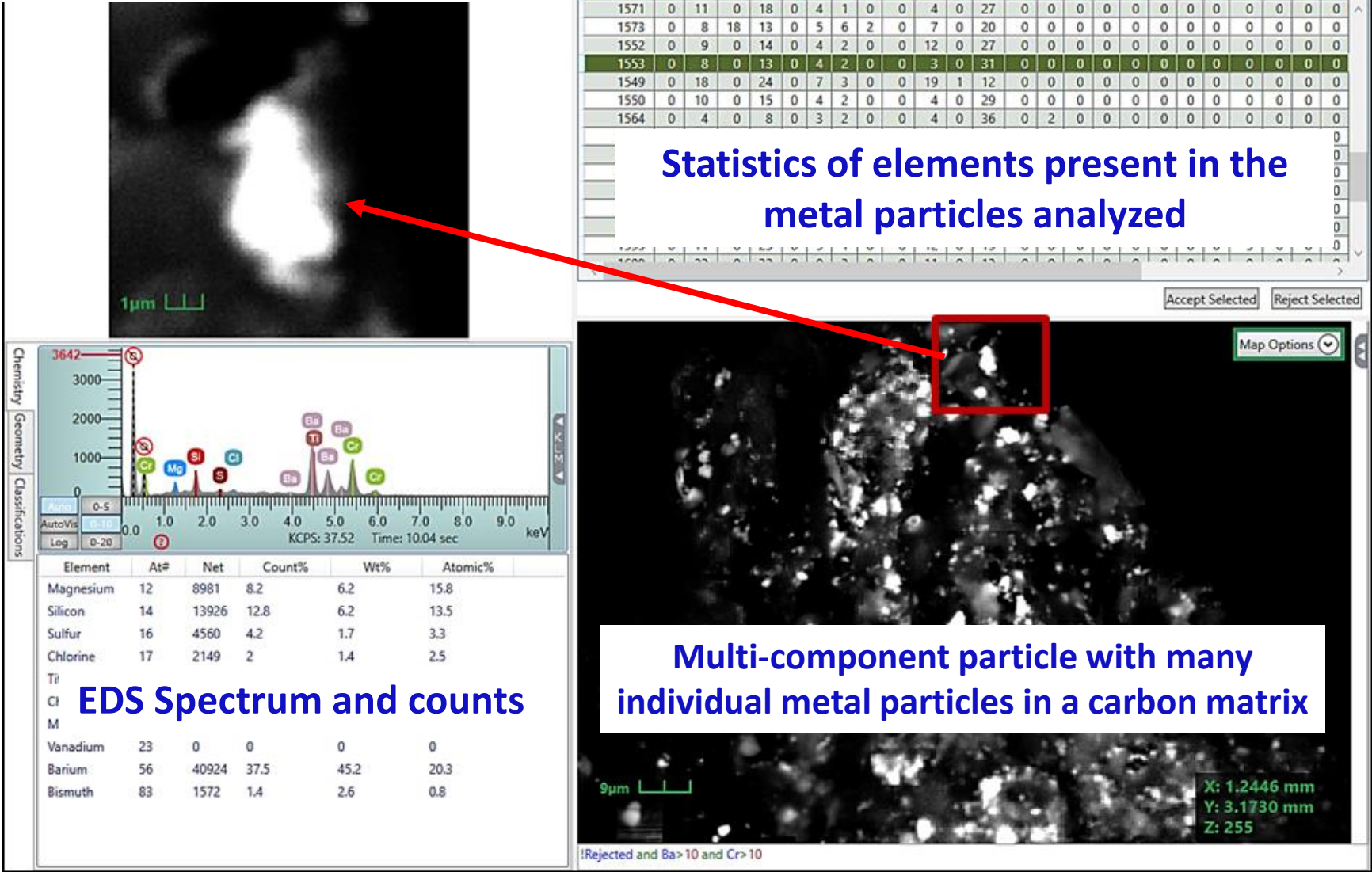


- Computer-Controlled SEM (CCSEM)
 - IntelliSEM* software
- Bright metal particles within complex structures were analyzed *individually*
 - Atomic number titanium and higher (bright enough for edge detection)
- The result was not total particle counts, but rather a characterization of metal inclusions in larger multi-component particles
- CCSEM metals analyses created a large dataset
 - Geometry and elemental composition

Data from IntelliSEM Workbench



Barium chromium-rich particle



27 Metals



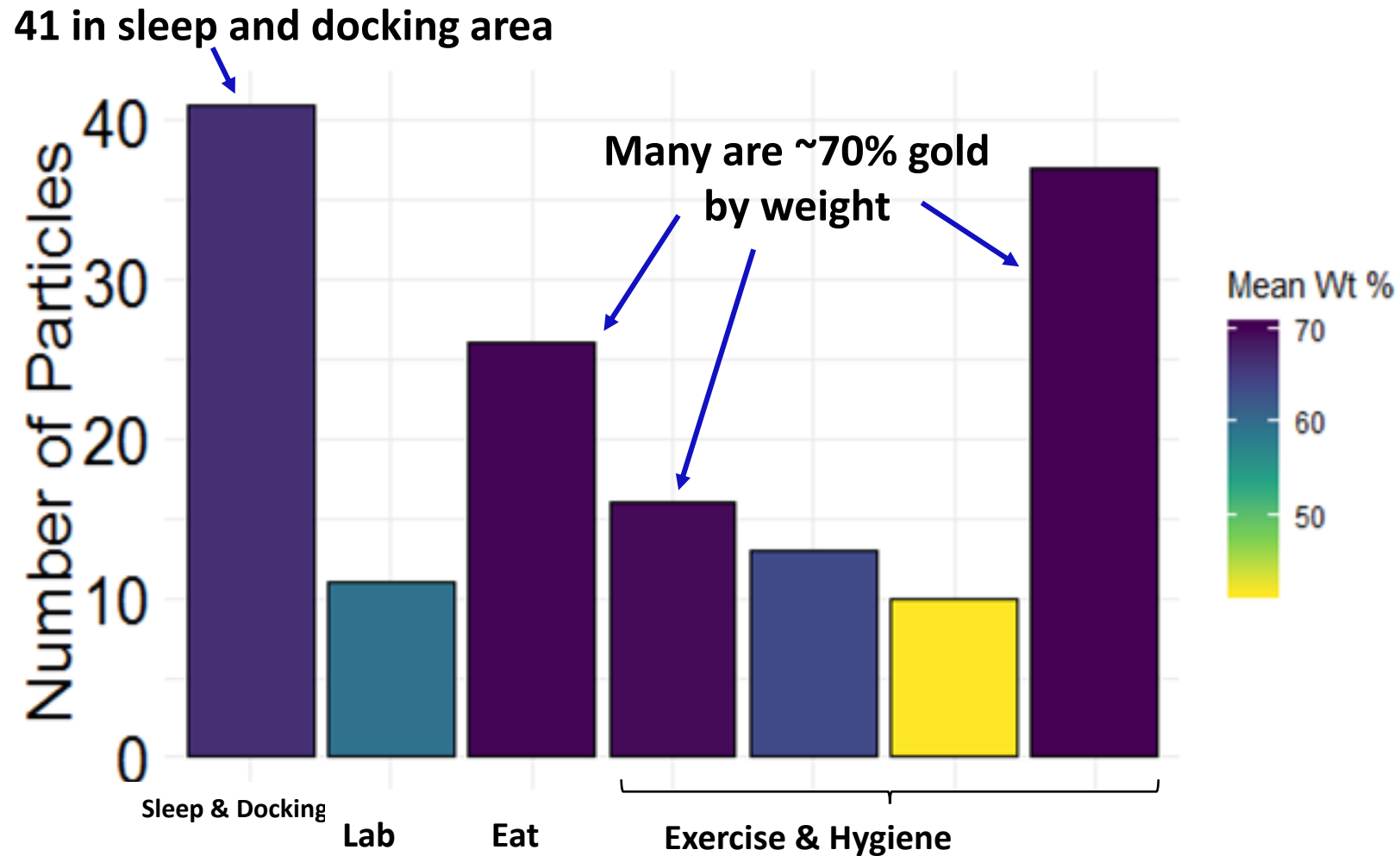
Titanium and higher atomic numbers identified in analysis
Not all are statistically significant

Titanium and higher atomic numbers identified in analysis																		18				
Not all are statistically significant																		VIIIA 8A				
1 1IA 11A																		2				
H Hydrogen 1.0079	2 IIA 2A																13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	He Helium 4.00260
3 Li Lithium 6.941	4 Be Beryllium 9.01218																5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.998403	10 Ne Neon 20.1797
11 Na Sodium 22.989769	12 Mg Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.981539	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948					
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.95591	22 Ti Titanium 47.88	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92159	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80					
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium 98.9072	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.90447	54 Xe Xenon 131.29					
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.9665	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98039	84 Po Polonium [209]	85 At Astatine 208.9804	86 Rn Radon 222.0176					
87 Fr Francium 223.0197	88 Ra Radium 226.0254	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Uuq Ununquadium [289]	115 Uup Ununpentium unknown	116 Uuh Ununhexium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown					
Lanthanide Series		57 La Lanthanum 138.90549	58 Ce Cerium 140.12	59 Pr Praseodymium 140.90768	60 Nd Neodymium 144.24	61 Pm Promethium 144.9127	62 Sm Samarium 150.36	63 Eu Europium 151.9655	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967						
Actinide Series		89 Ac Actinium 227.0278	90 Th Thorium 232.0381	91 Pa Protactinium 231.03688	92 U Uranium 238.02891	93 Np Neptunium 237.0482	94 Pu Plutonium 244.0642	95 Am Americium 243.0614	96 Cm Curium 247.0703	97 Bk Berkelium 247.0703	98 Cf Californium 251.0796	99 Es Einsteinium [254]	100 Fm Fermium 257.0951	101 Md Mendelevium 258.1	102 No Nobelium 259.1009	103 Lr Lawrencium [262]						

Gold on ISS - 2018



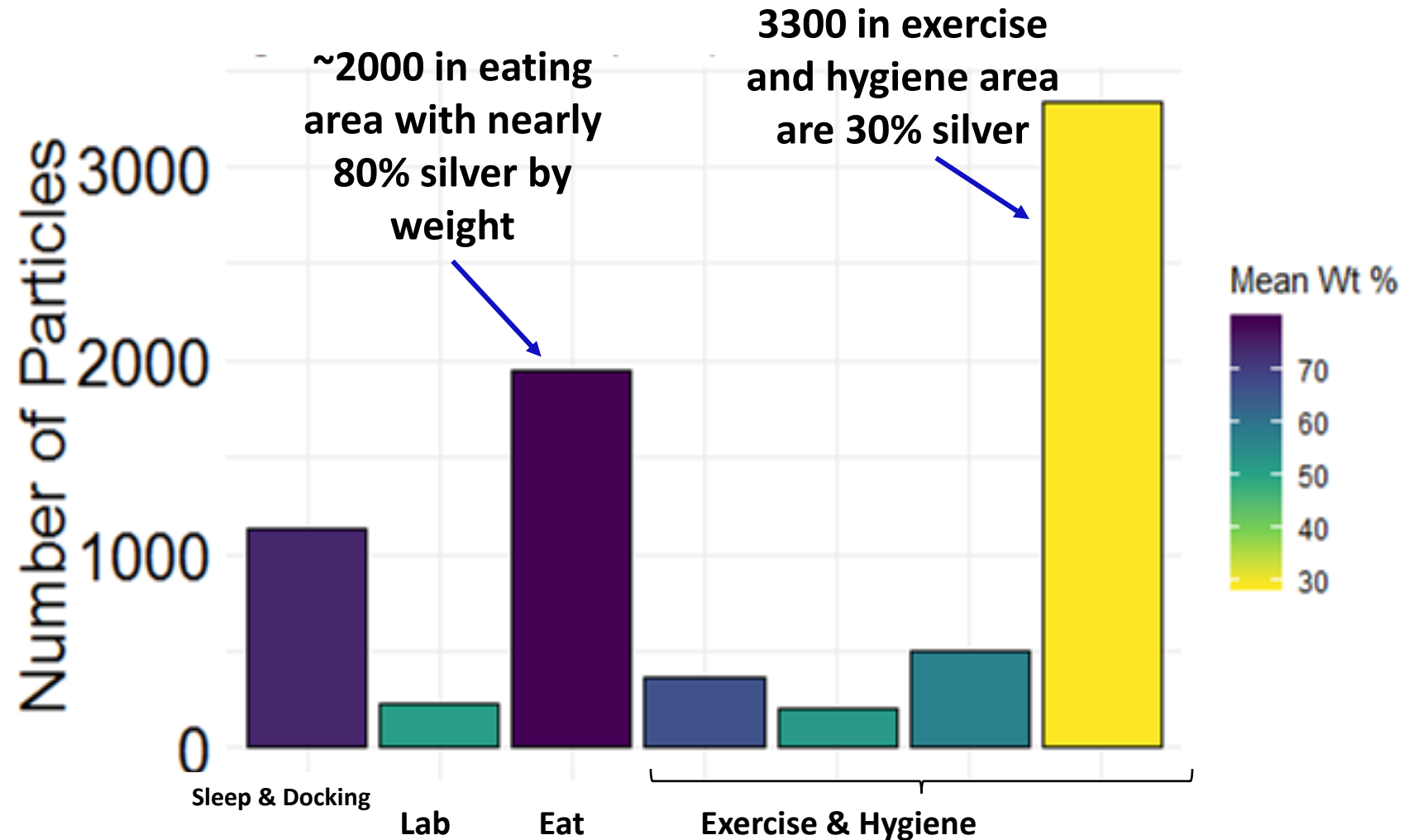
0.2 % of all metal inclusions/particles (by weight) contain some gold



Silver on ISS - 2018

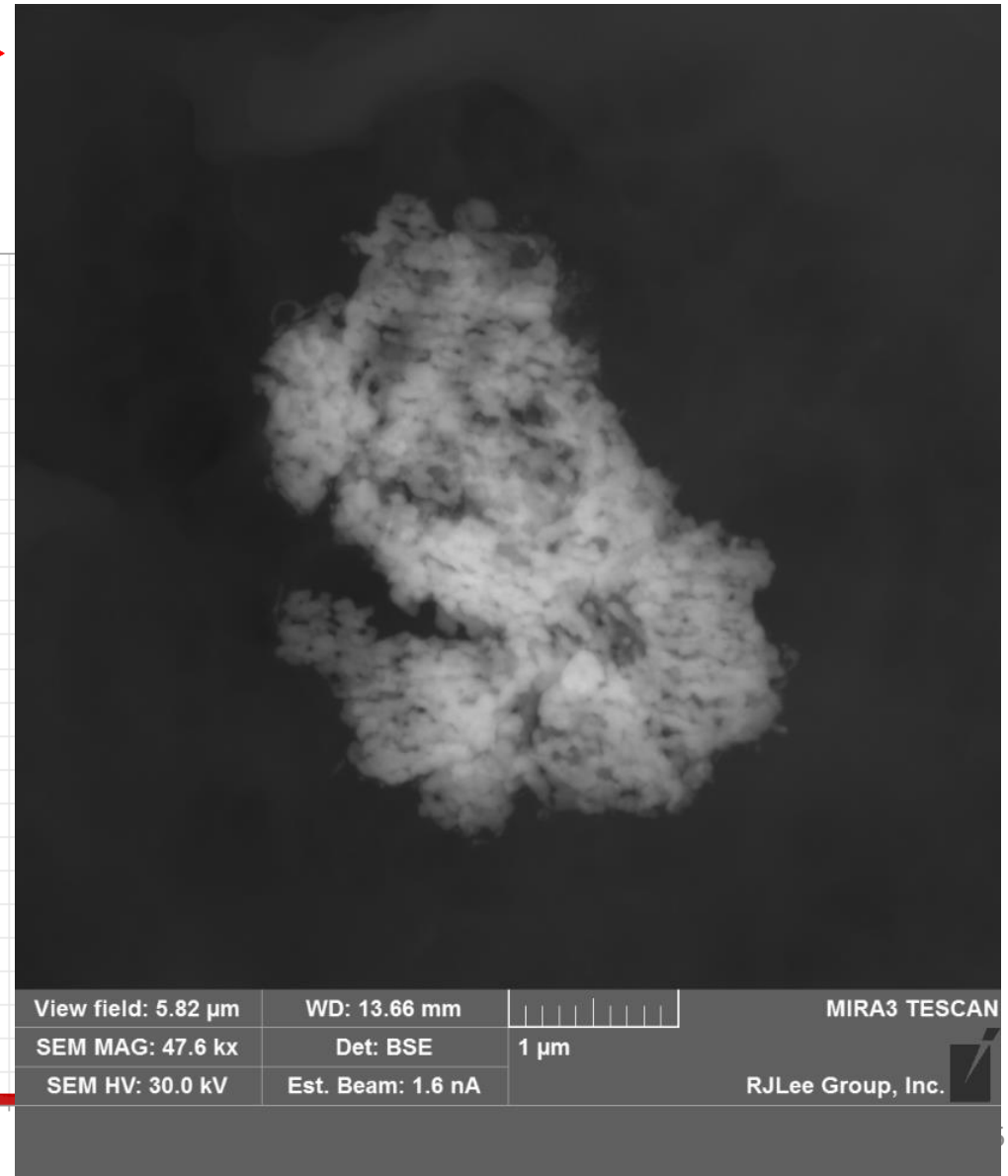
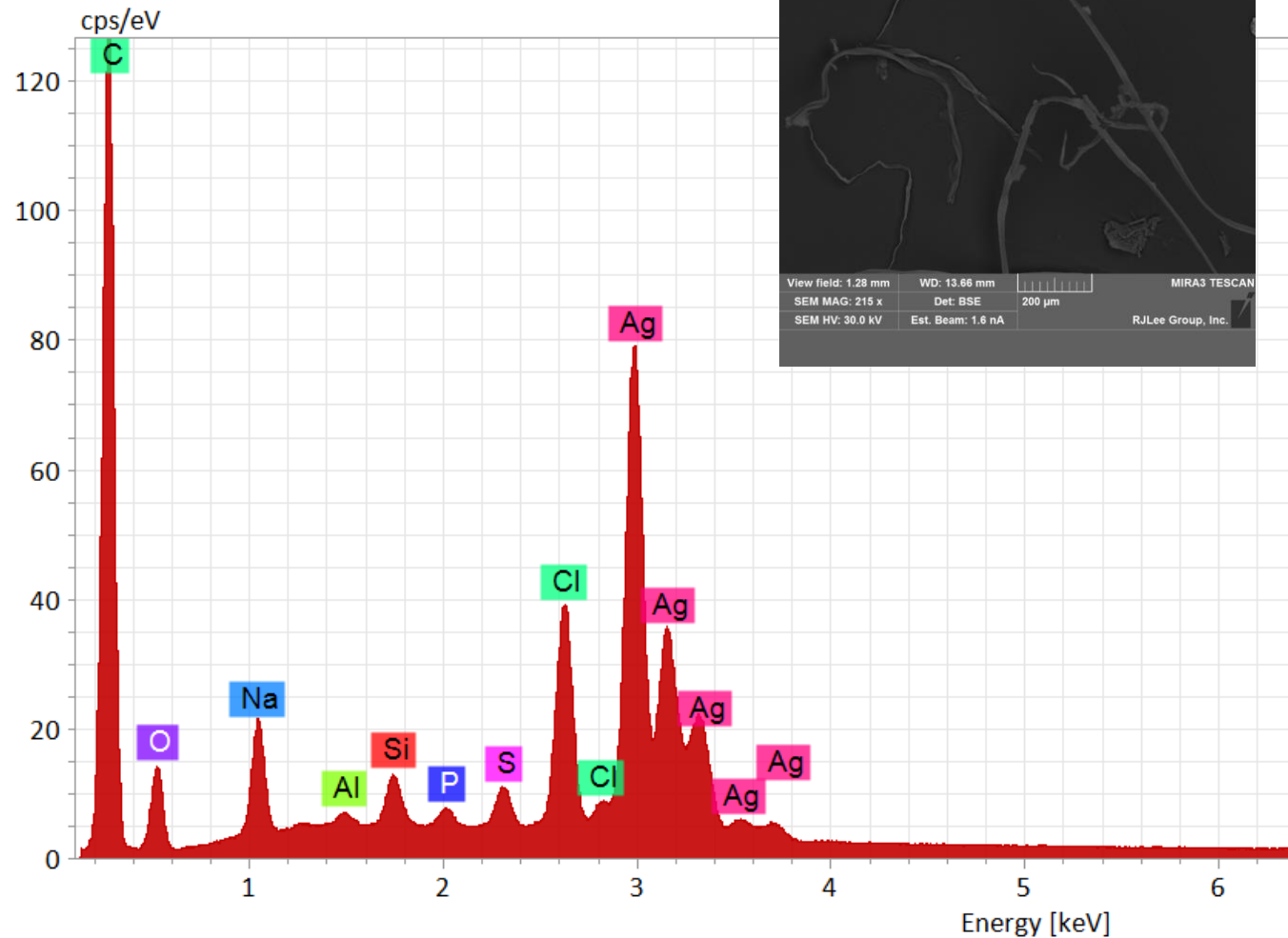


9.8 % of all metal inclusions/particles (by weight) contain some silver

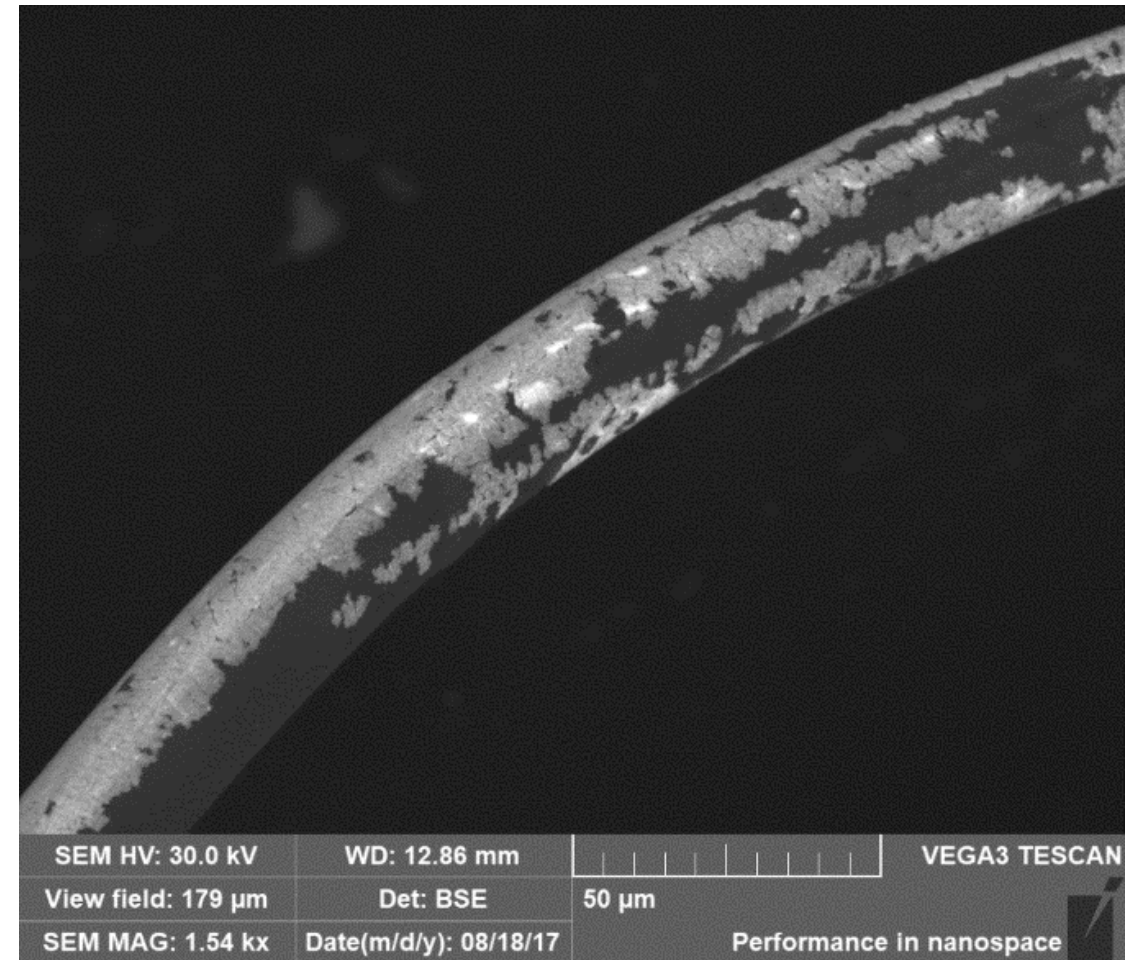
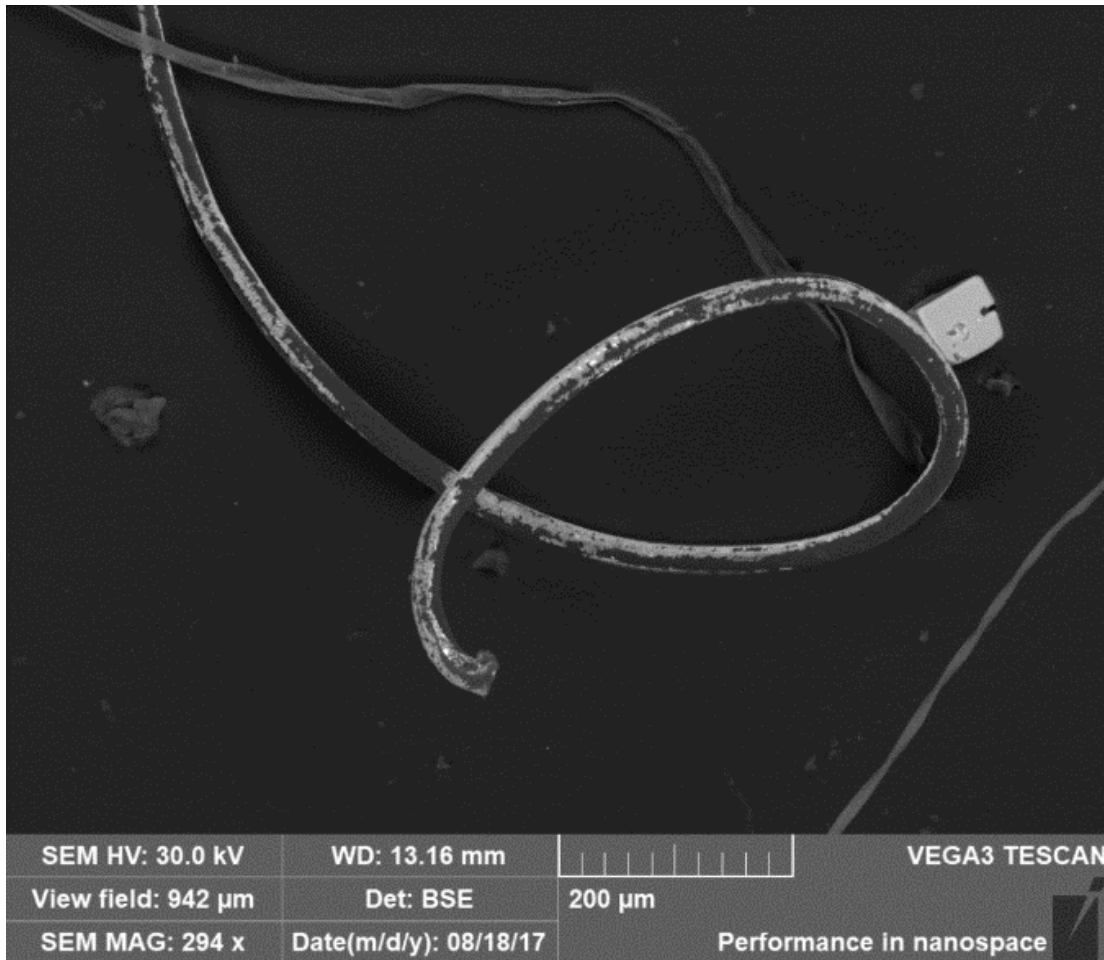


Silver on ISS

2018 LAB1PD3 - US Lab Bay 3 Port/Deck Standoff HEPA Return Register (PAS D-2)

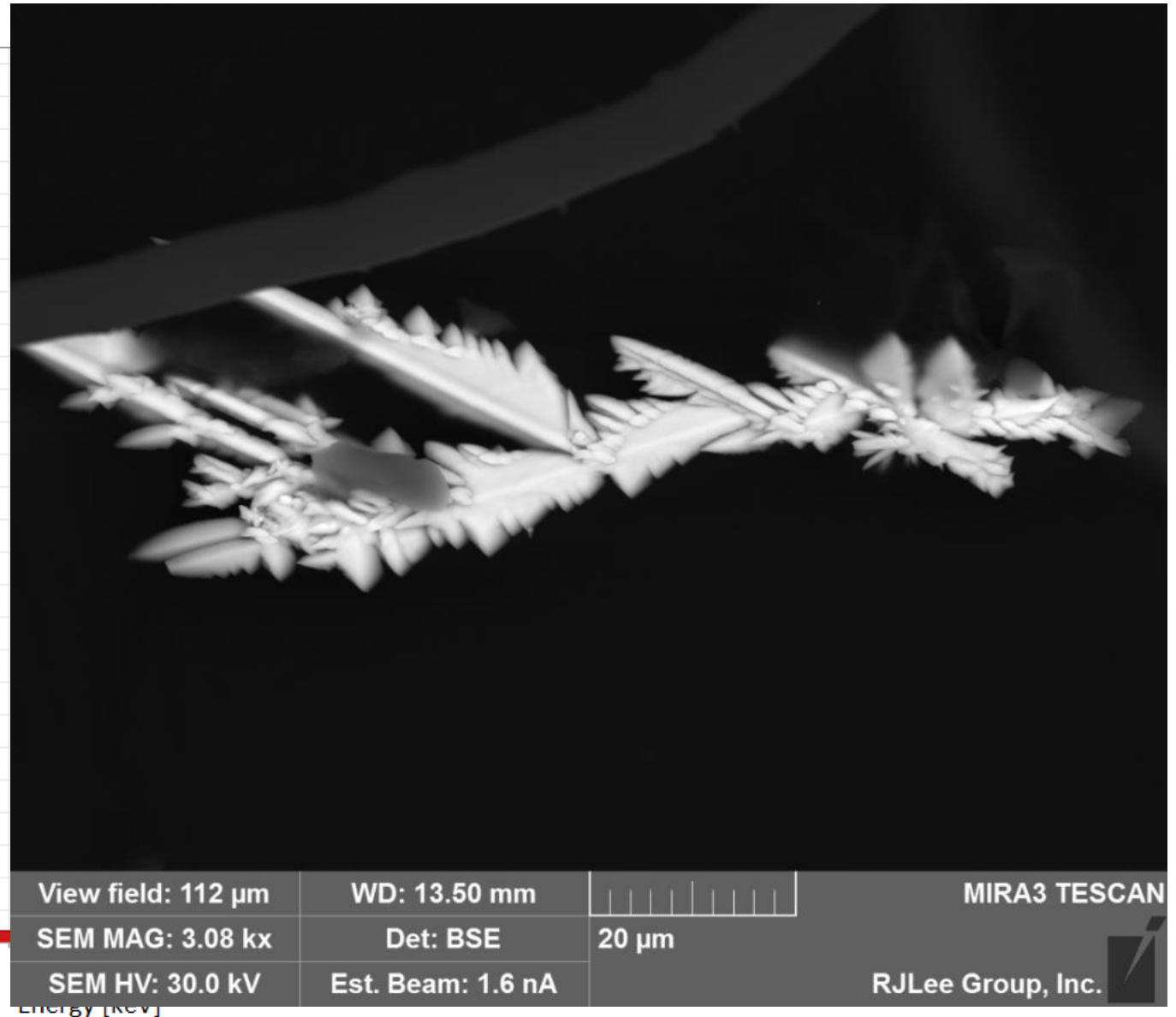
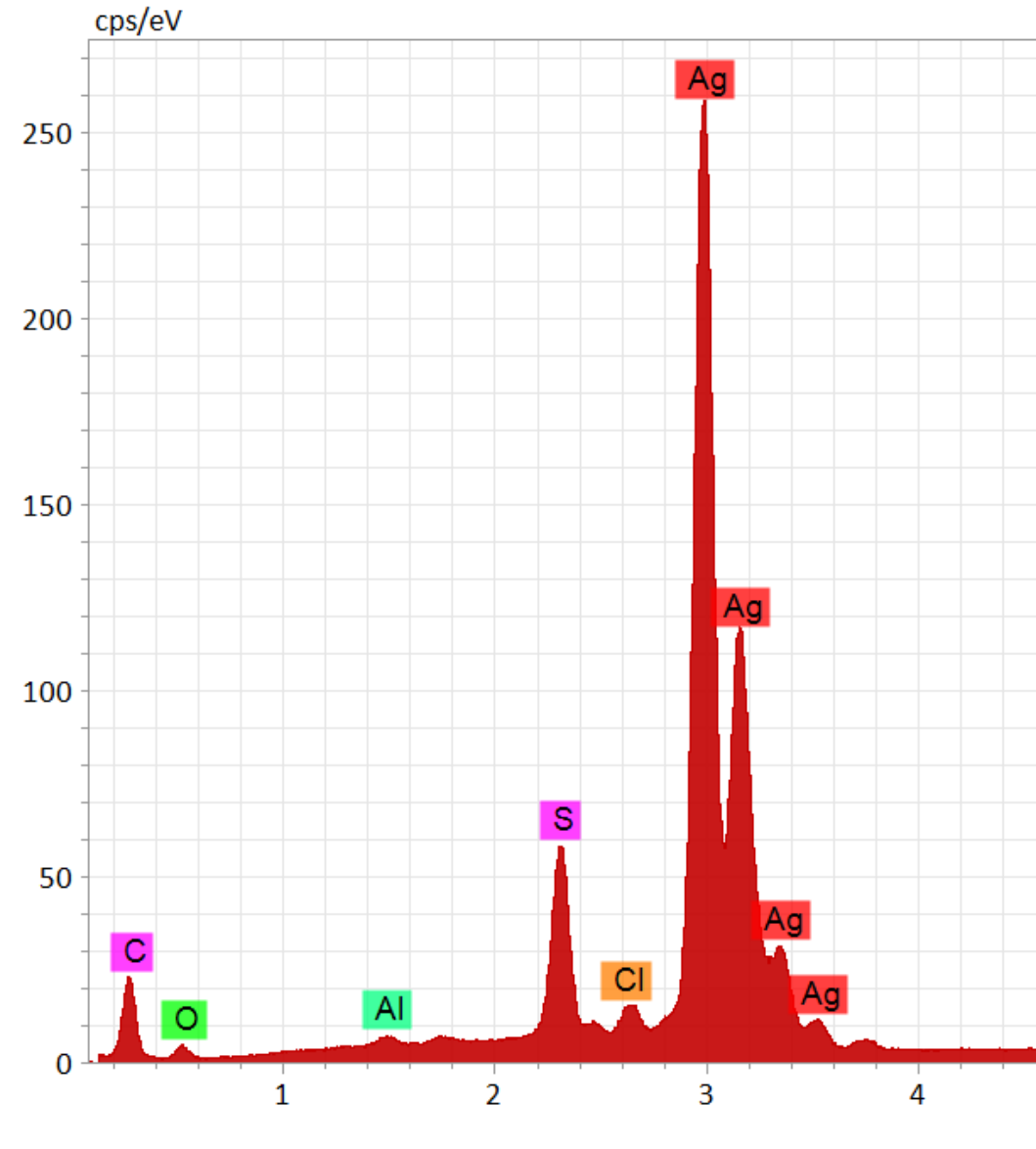


Silver on ISS – X-Static® Sock Fiber

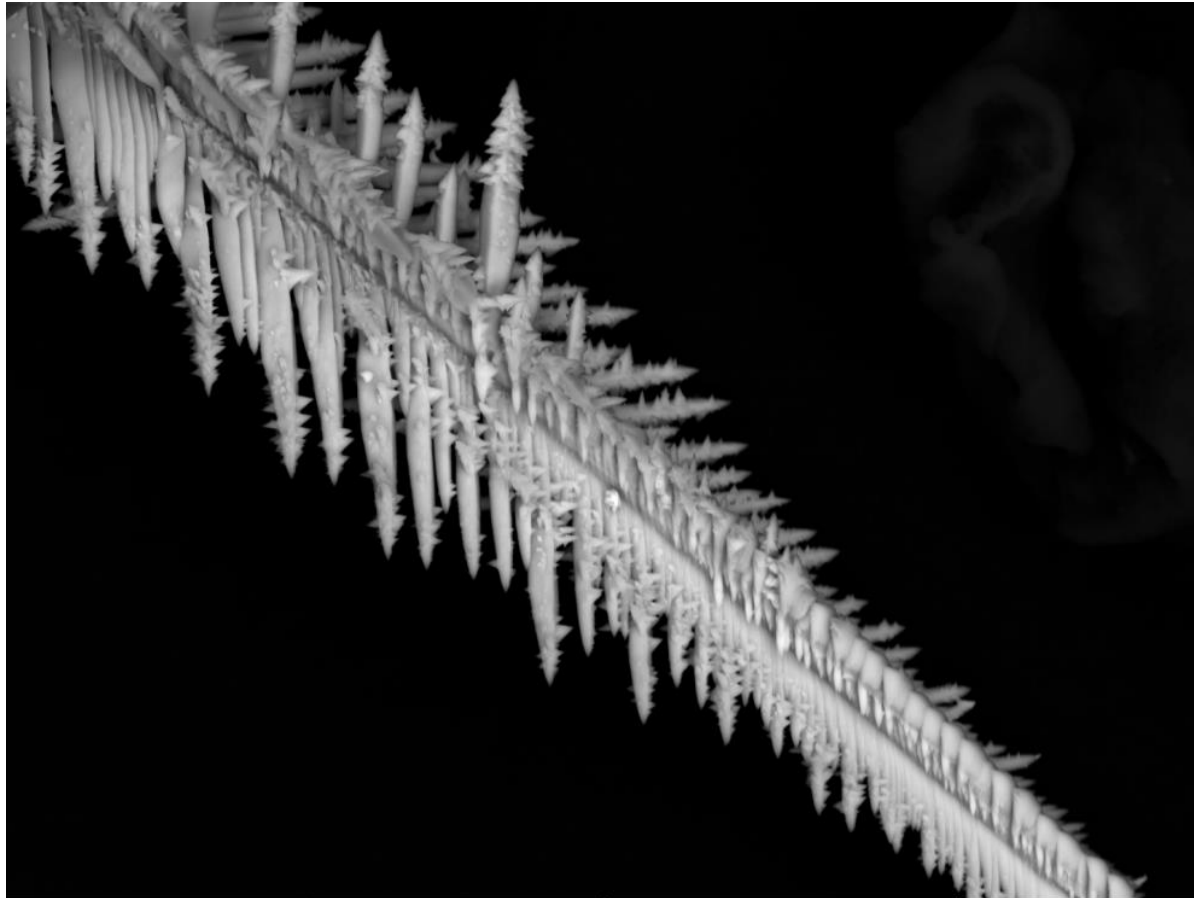
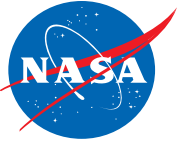


Silver on ISS

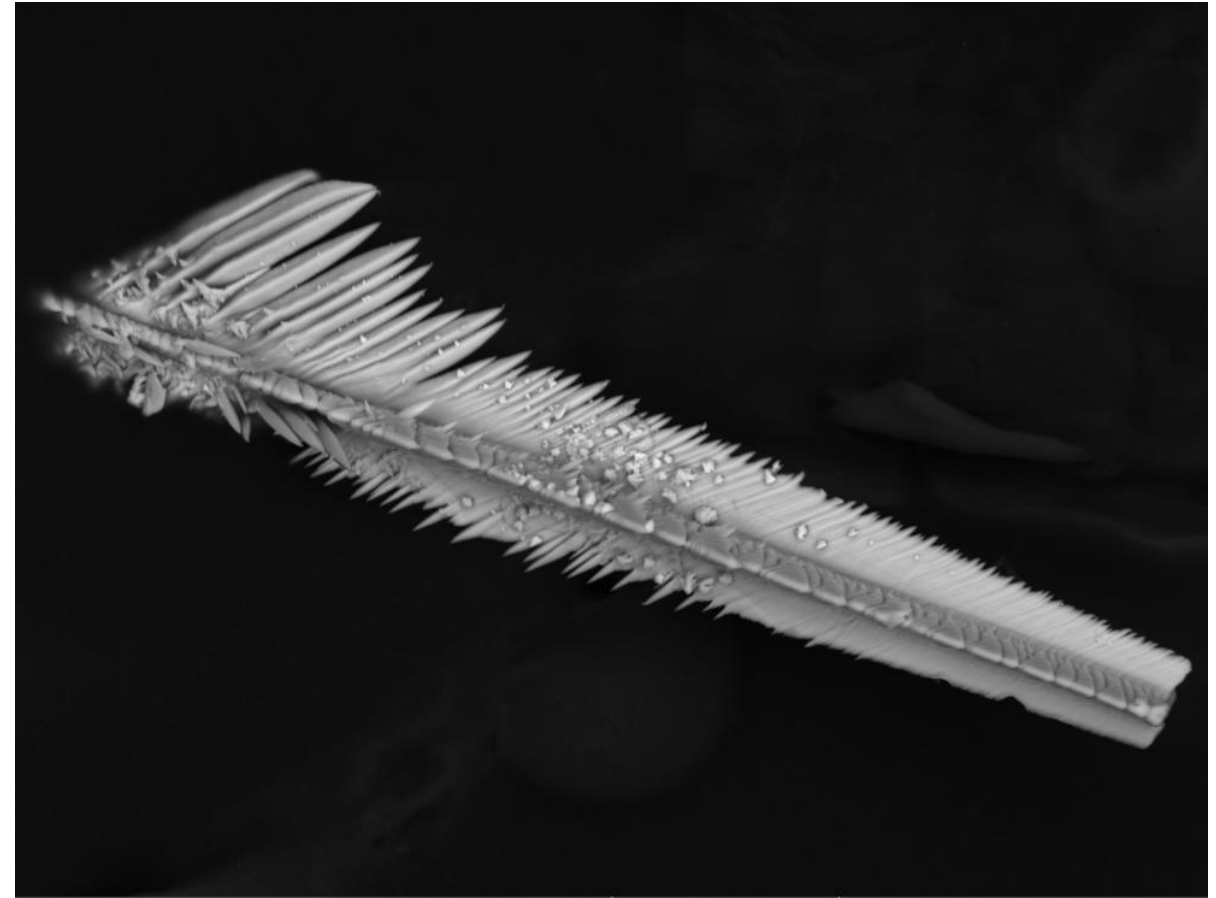
2018 NOD3OA3 - Overhead Supply Diffuser (PAS H-2)



Silver on ISS - Dendrites



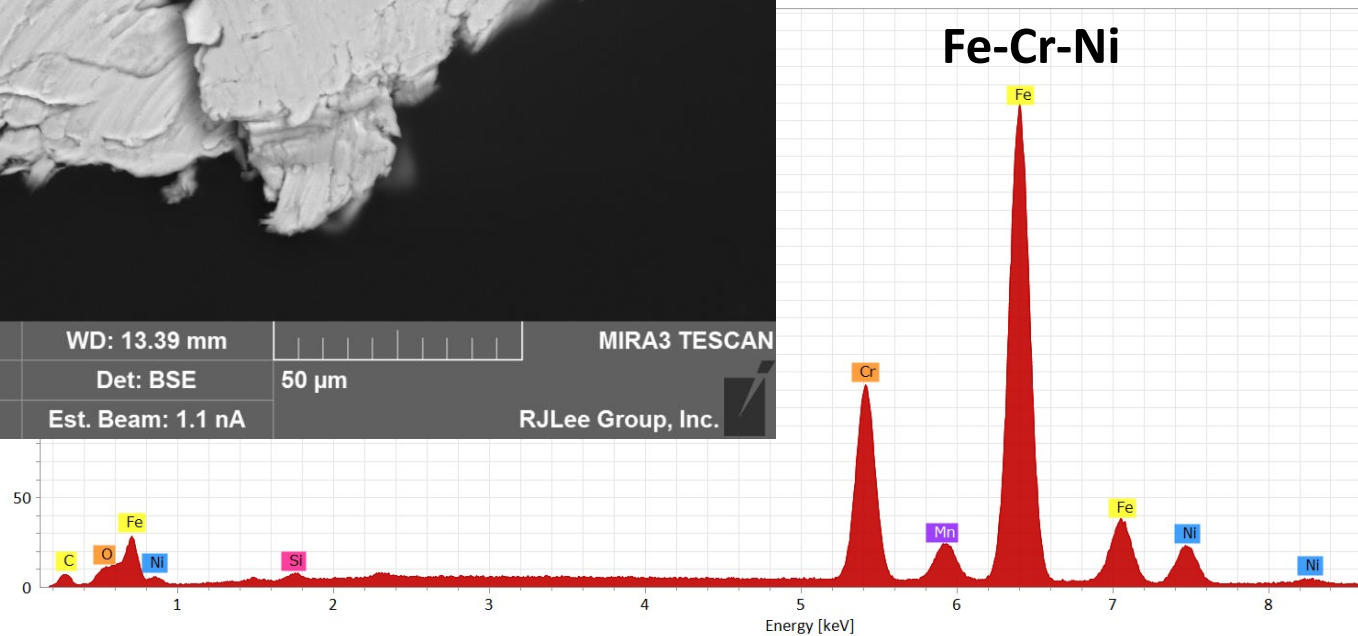
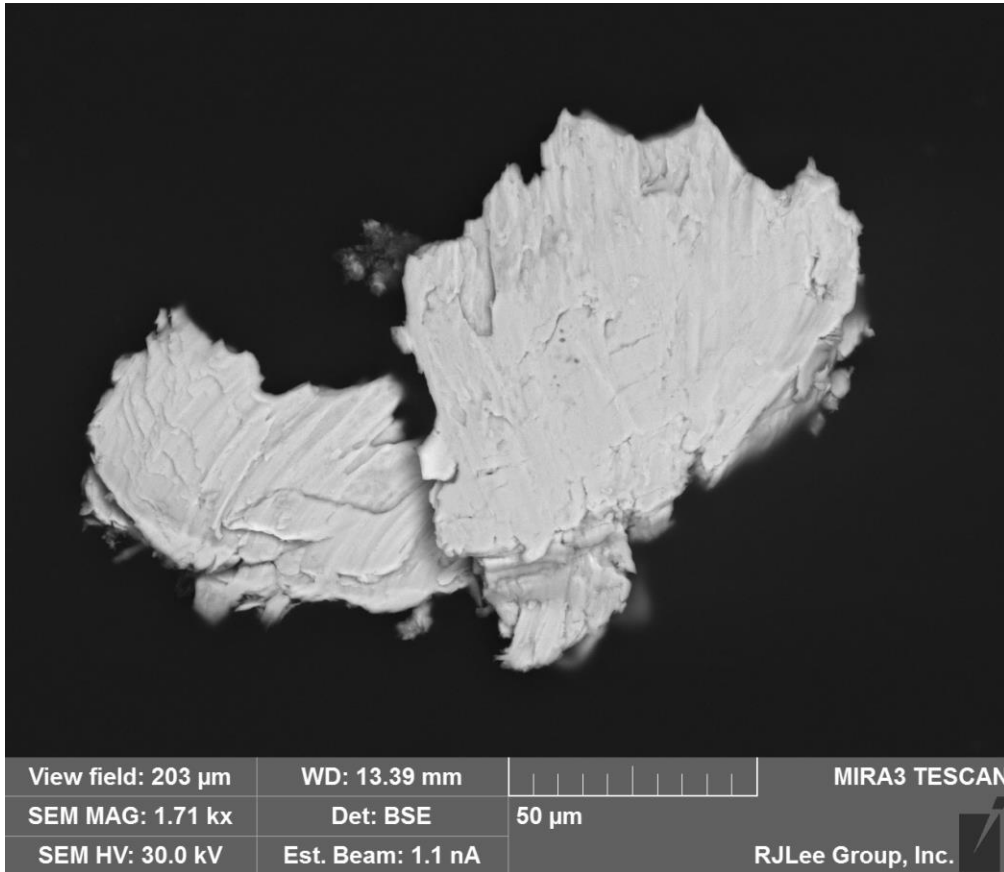
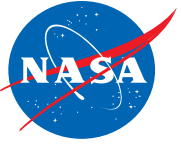
View field: 67.3 μm	WD: 12.85 mm	MIRA3 TESCAN
SEM MAG: 6.17 kx	Det: BSE	20 μm
SEM HV: 20.0 kV	Est. Beam: 1.6 nA	RJLee Group, Inc.



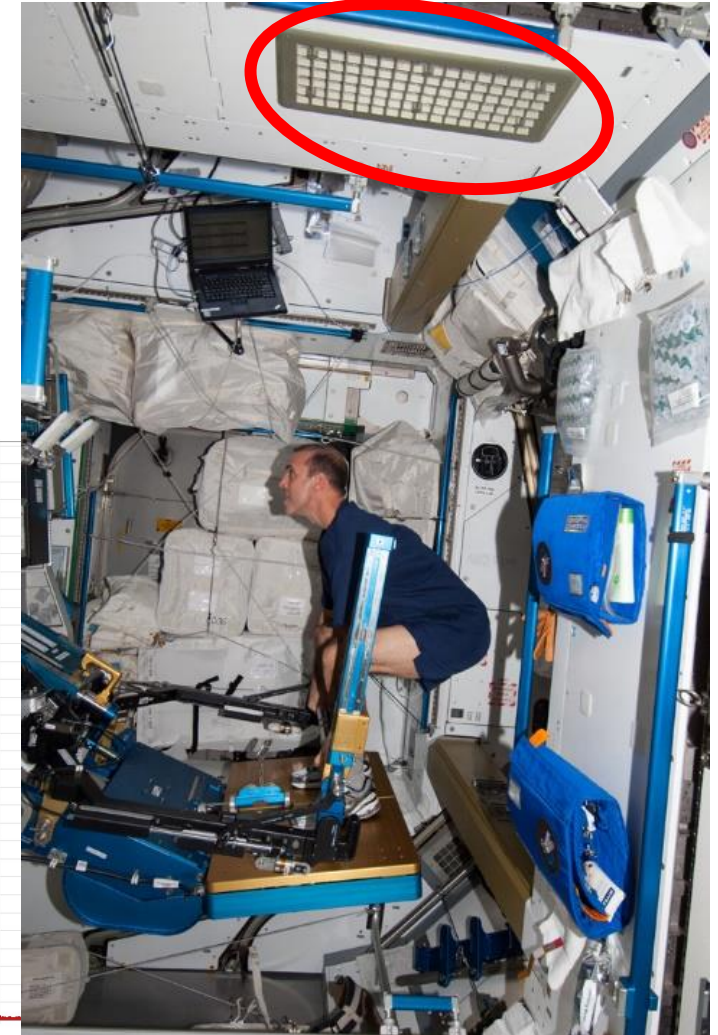
View field: 105 μm	WD: 12.94 mm	MIRA3 TESCAN
SEM MAG: 3.95 kx	Det: BSE	20 μm
SEM HV: 20.0 kV	Est. Beam: 1.6 nA	RJLee Group, Inc.

Stainless Steel Wear Particles

Sampler D near exercise machine, Node 3



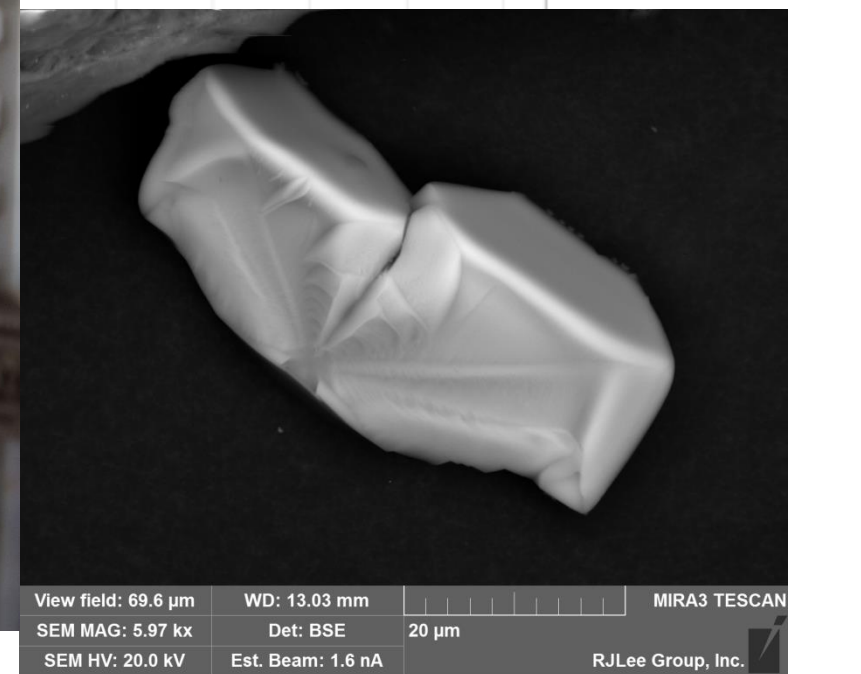
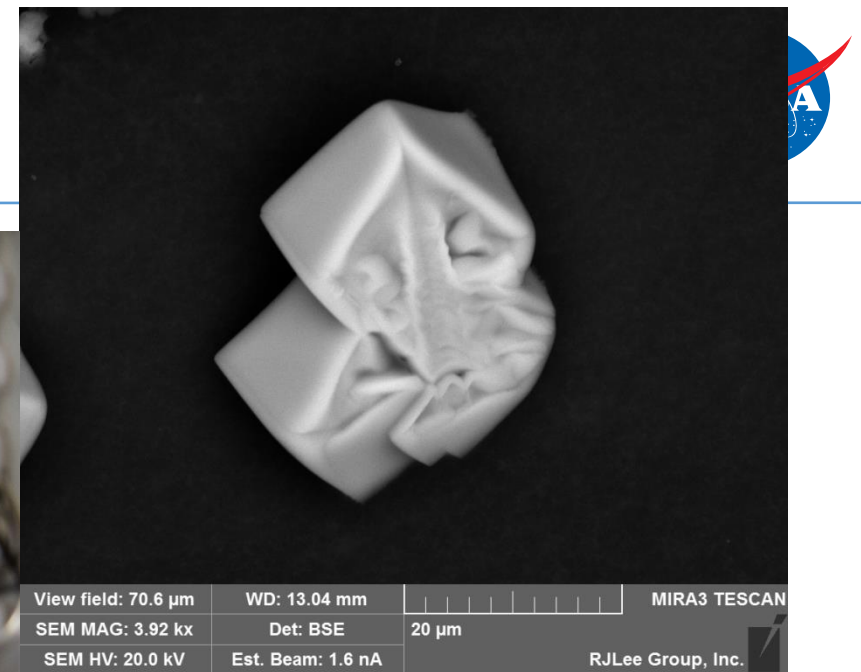
Advanced Resistive Exercise Device (ARED)



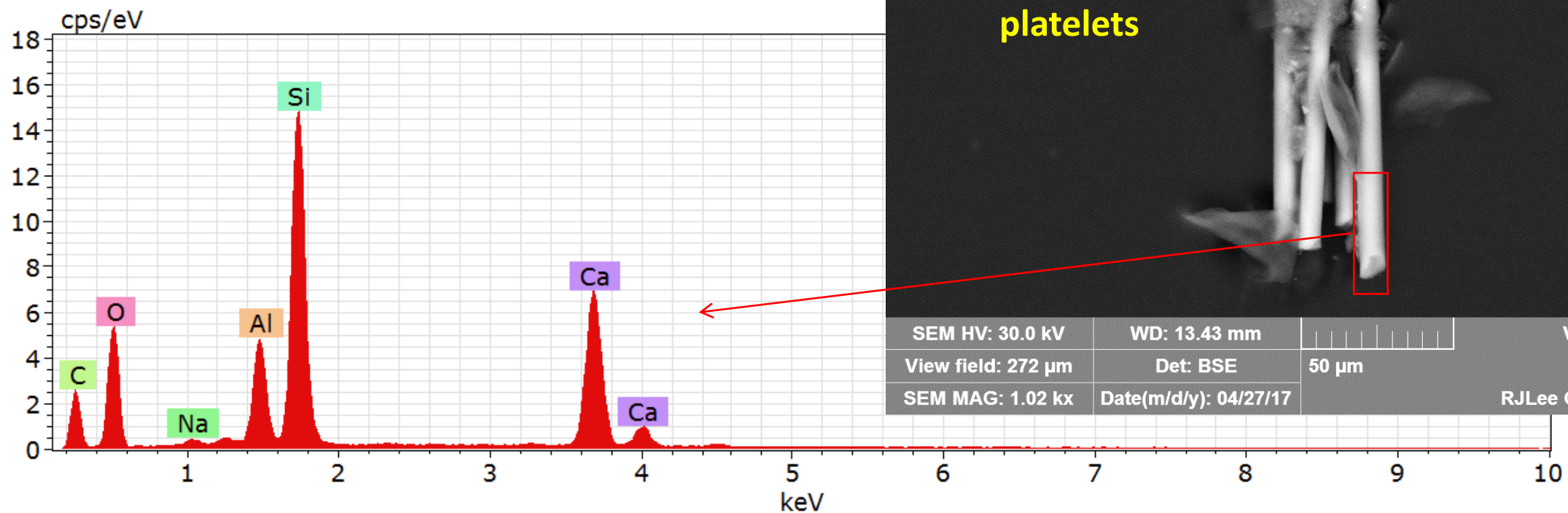
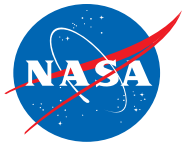
Particles in Node 1 (Eating Area)



Energy [keV]



Fiberglass



**Fiber glass
(Al-Si-Ca fibers)
with carbonaceous
platelets**

SEM HV: 30.0 kV	WD: 13.43 mm	VEGA3 TESCAN
View field: 272 µm	Det: BSE	50 µm
SEM MAG: 1.02 kx	Date(m/d/y): 04/27/17	RJLee Group, Inc.

Plant Trichomes

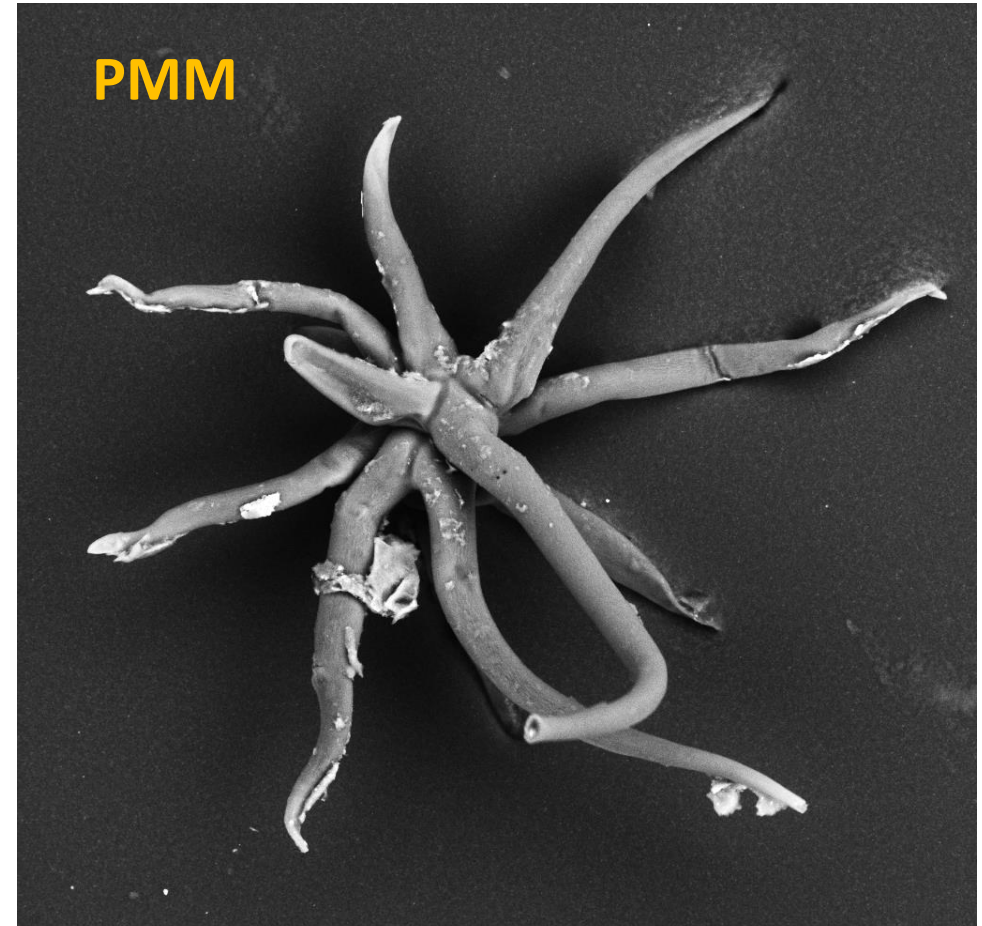


Node 1



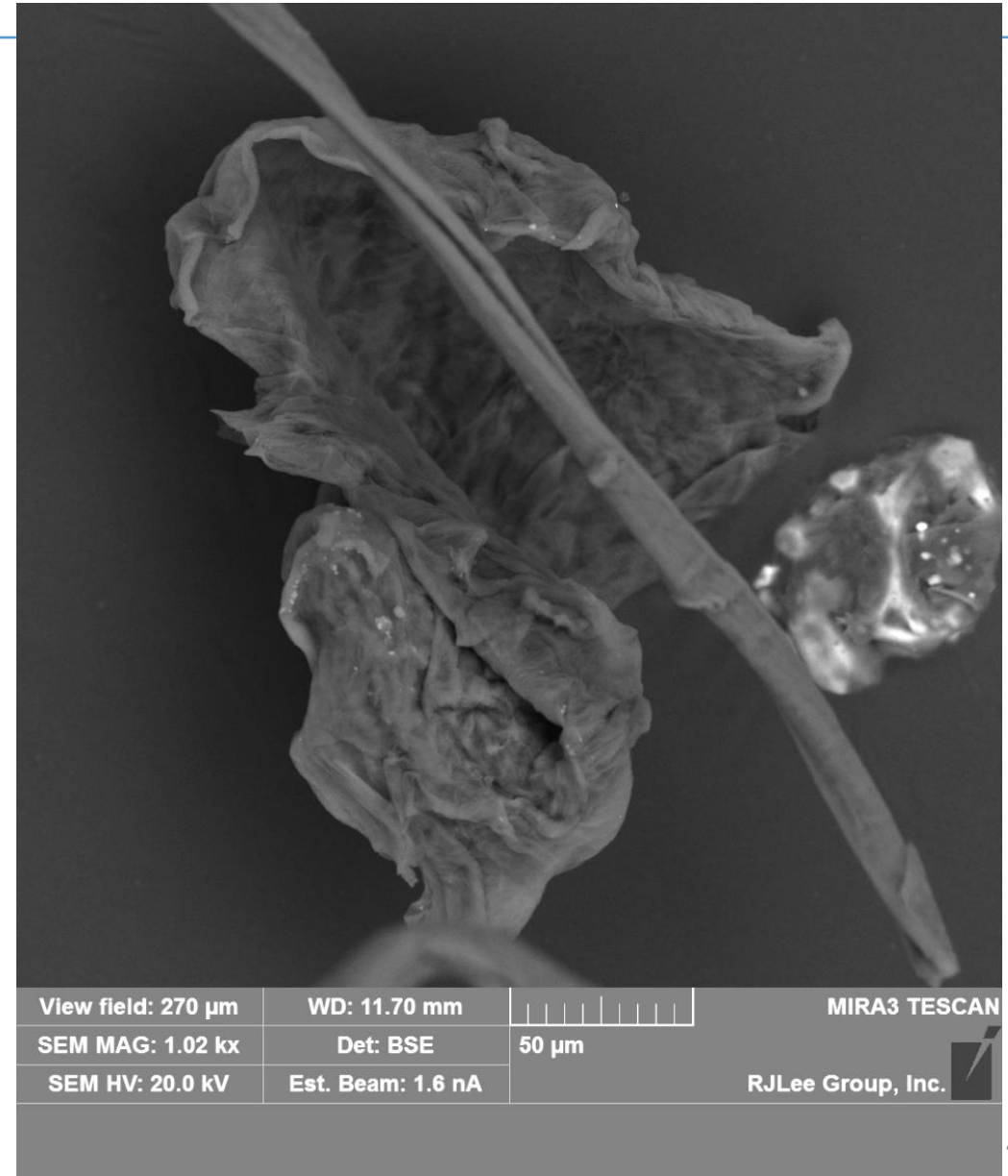
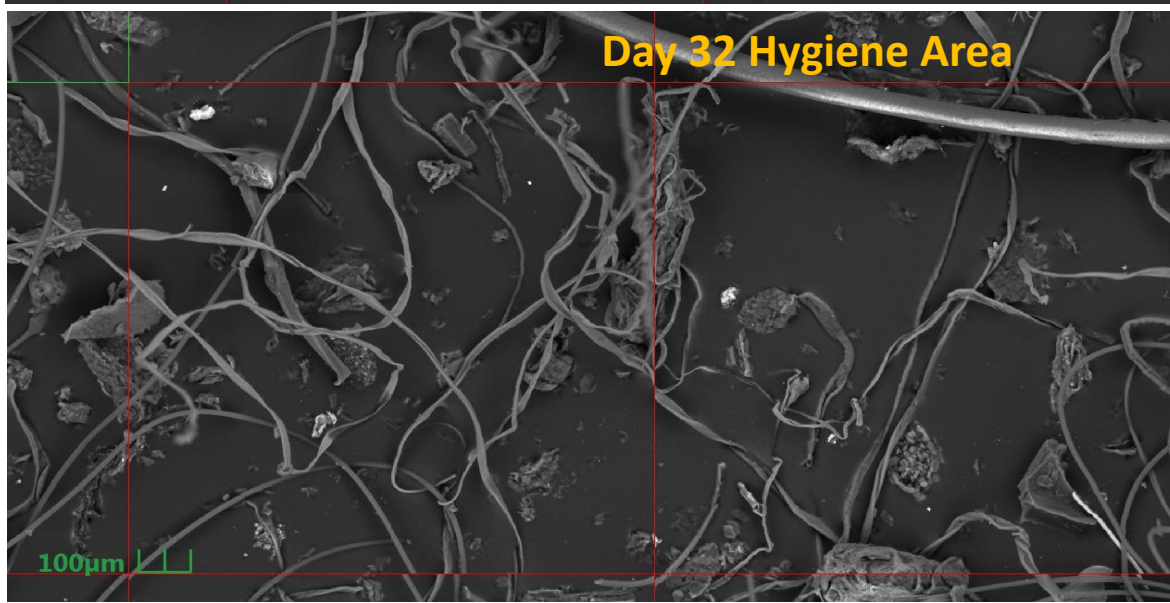
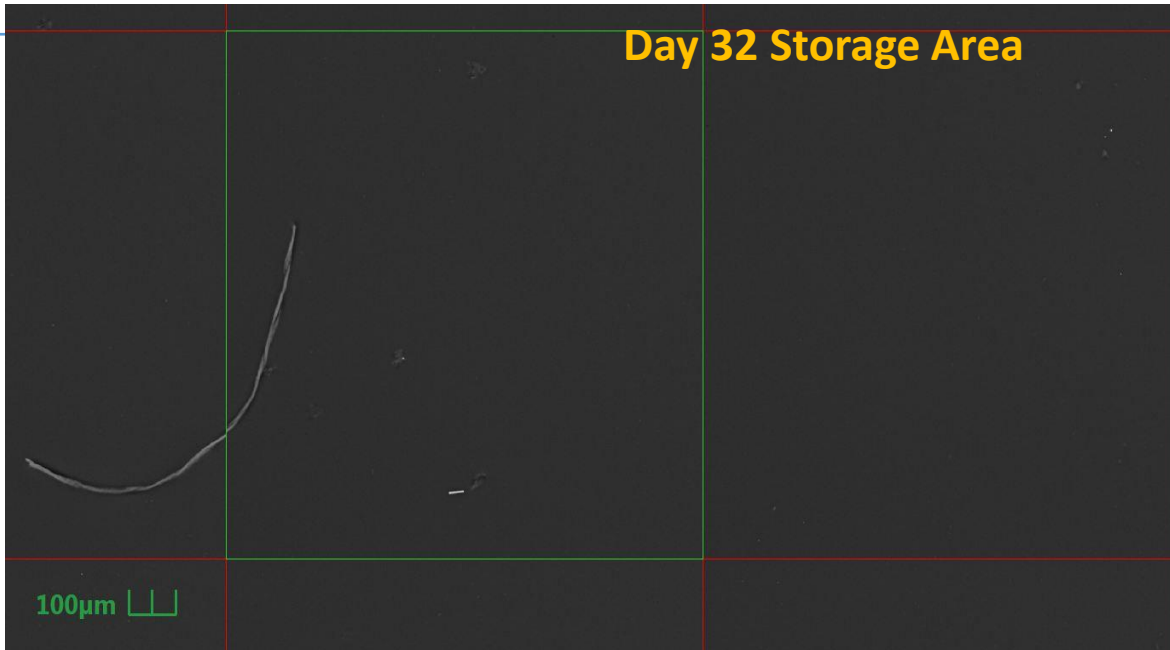
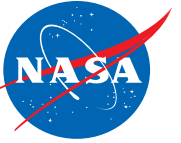
SEM HV: 15.0 kV	WD: 9.01 mm	VEGA3 TESCAN	
View field: 738 μ m	Det: BSE	200 μ m	
SEM MAG: 469 x	Date(m/d/y): 07/13/17	Performance in nanospace	

PMM

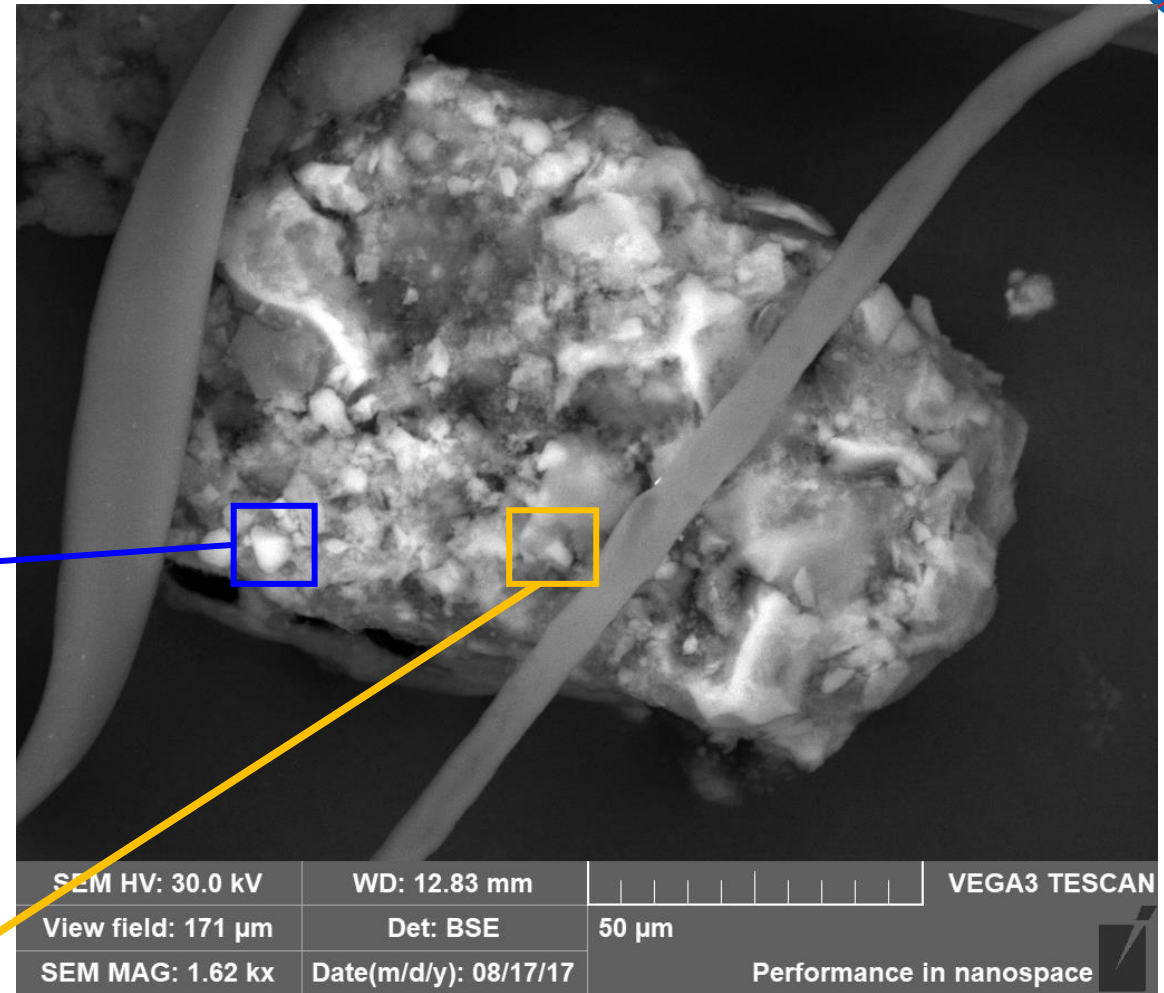
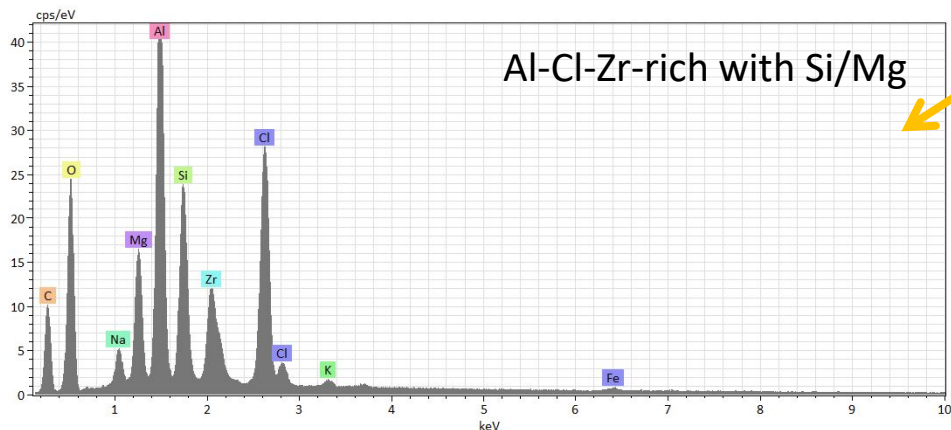
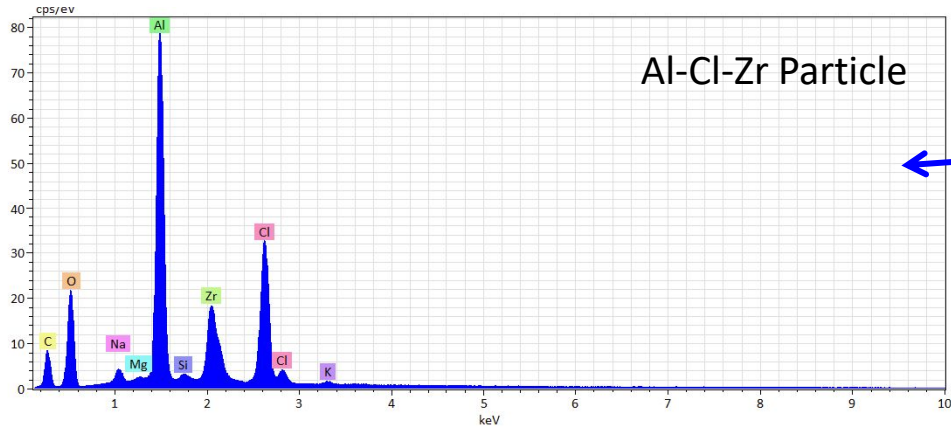
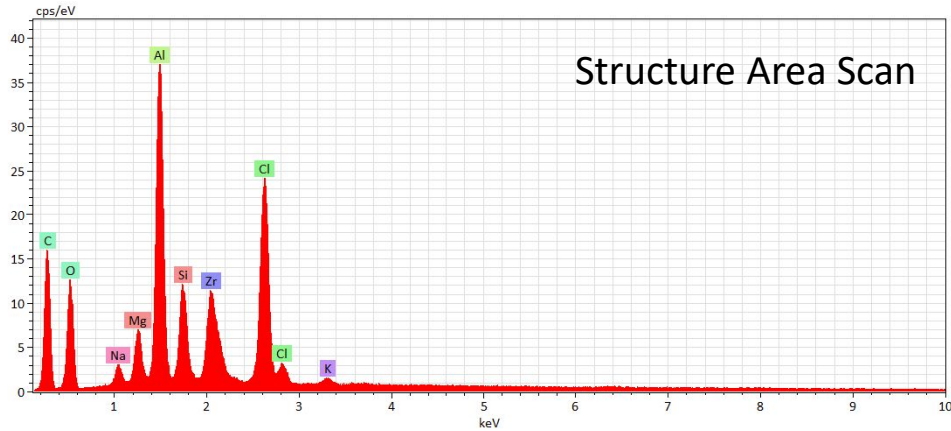
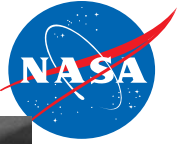


SEM HV: 15.0 kV	WD: 9.94 mm	VEGA3 TESCAN	
View field: 306 μ m	Det: BSE	50 μ m	
SEM MAG: 905 x	Date(m/d/y): 07/13/17	Performance in nanospace	

Human-generated particles



Antiperspirant Particle from Node 2



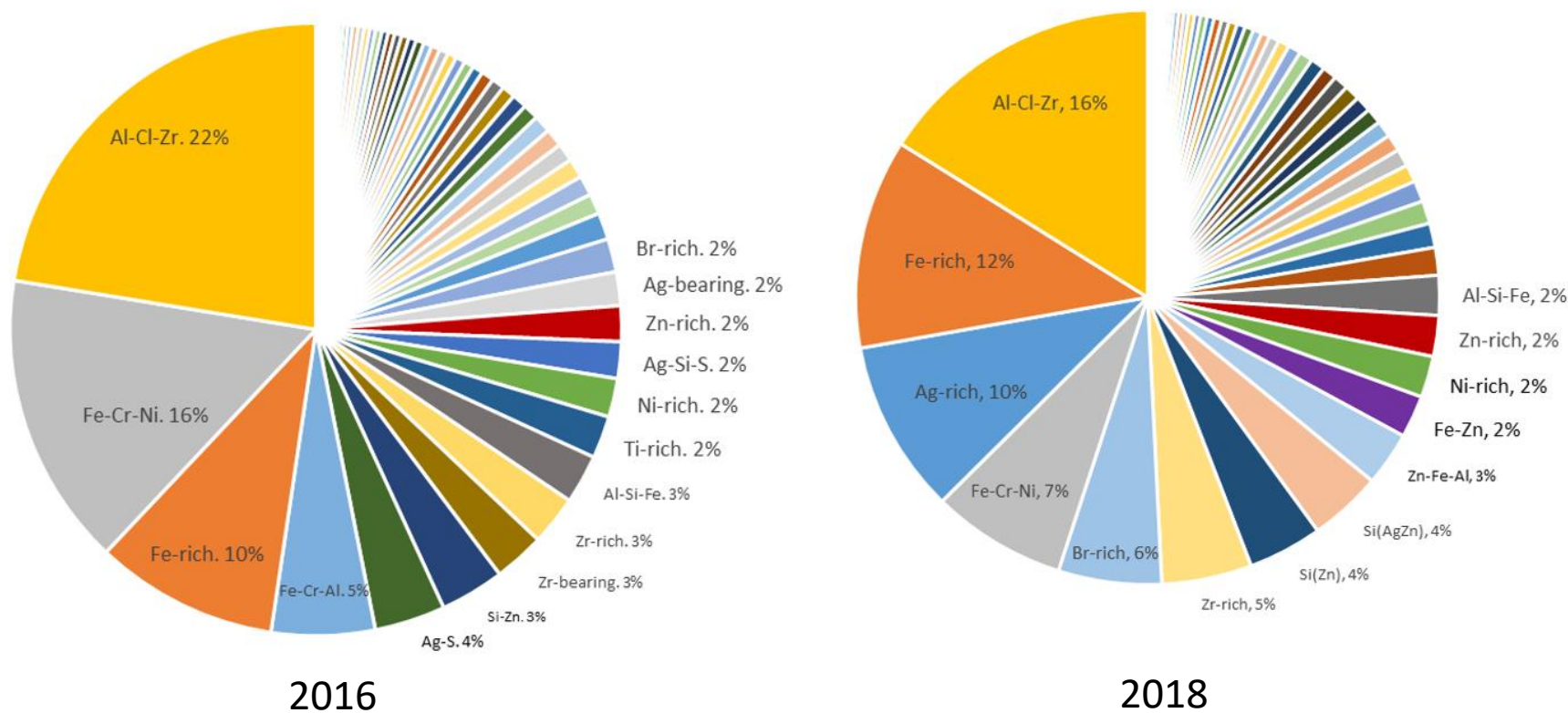
Aluminum-chlorine-zirconium and silicon-magnesium (talc) agglomerated particles

Aluminum zirconium tetrachlorohydrate glycine

2018 and 2016 Metal Results of Aerosol Sampling Experiment



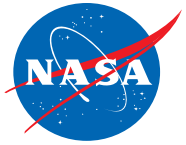
Particle material classes, by weight % of all particles collected



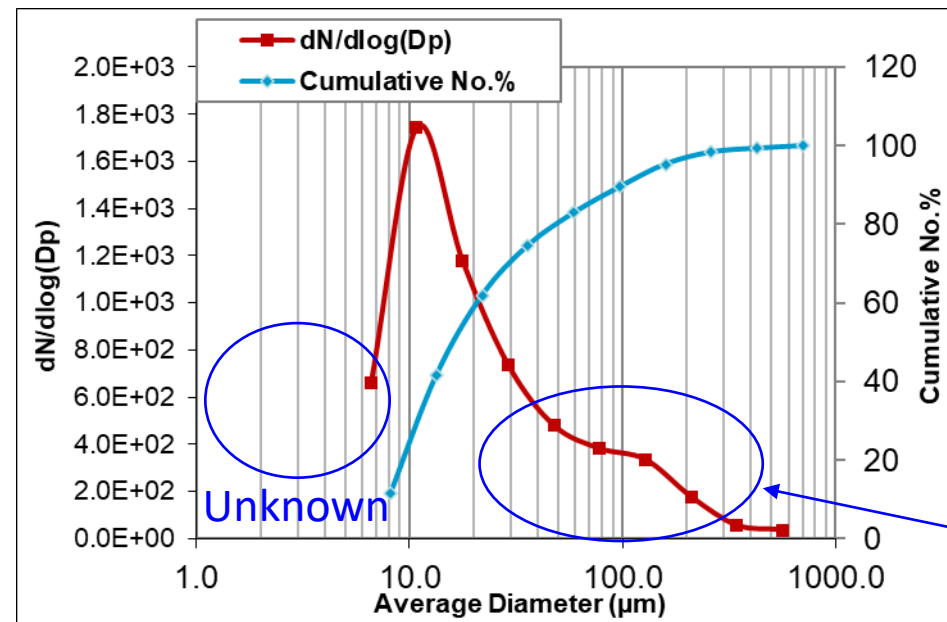
- Al-Cl-Zr are antiperspirant particles, which make up 22% and 16% of the weight of all particles collected in the two experiments***

You can interact with this data with the ISS particle database web tool: <https://iss-particle-db.arc.nasa.gov/>

Sample Particle Sizes → Instrument Design



LAB1PD3, PAS D-2: Computer-Controlled SEM Results for Particles $>5\mu\text{m}$
Particle Size Distribution by Number

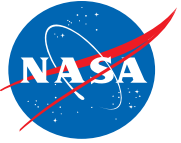


No. of Particles Detected	Minimum Diameter (μm)	Maximum Diameter (μm)	Average Diameter (μm)	Median Diameter (μm)	Standard Deviation (μm)
1243	5.3	683.8	39.5	16.3	64.9

Smallest particle in analysis
(by microscopy)

Instrument should go up to 20 μm

First Aerosol Measurements

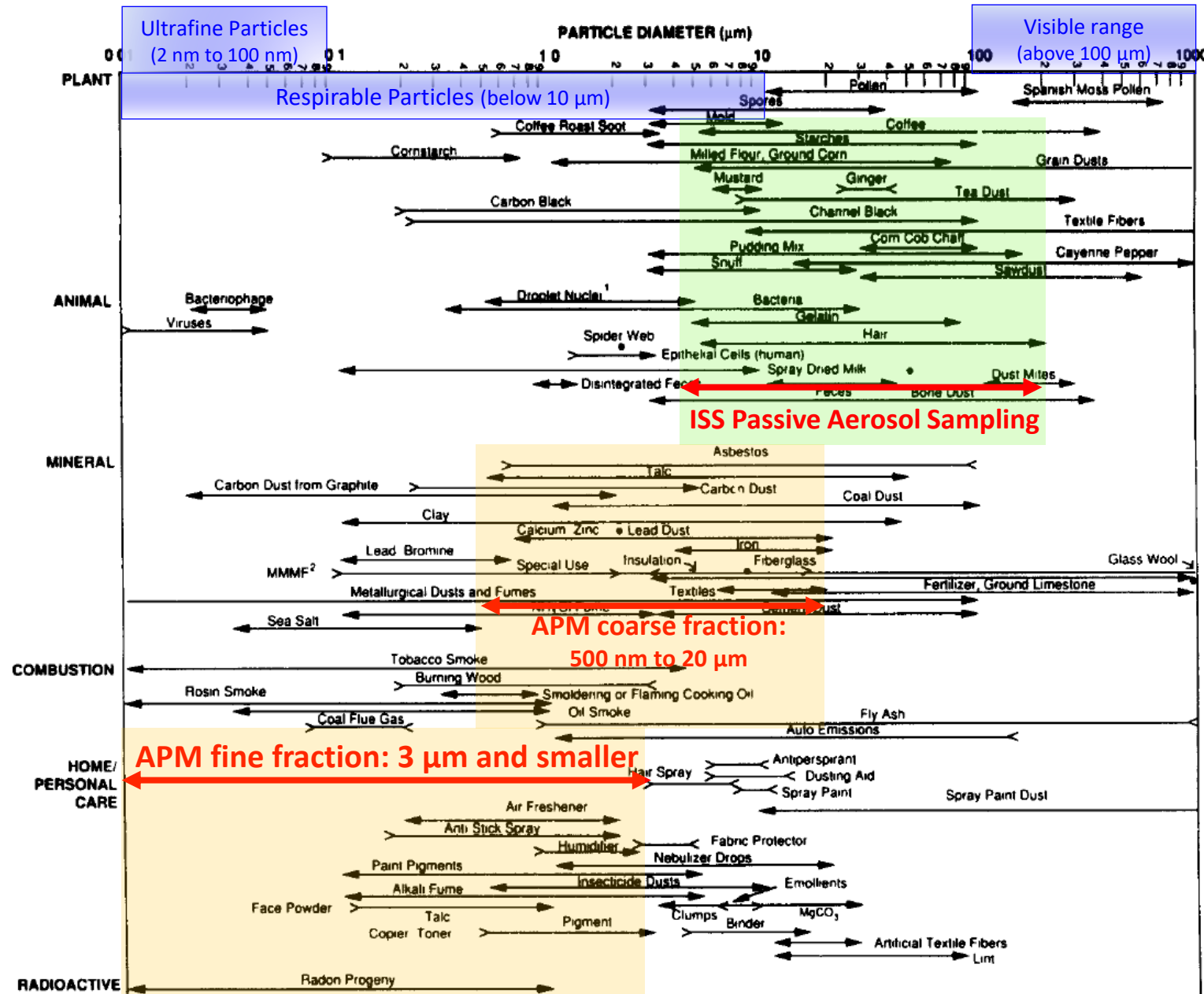


- Airborne Particulate Monitor (APM)
- Launched November 2020
- Ran 24/7 in sampling locations
- Reference-quality instrument
 - MAGIC* water condensation particle counter
 - Aerosol Dynamics, Inc.
 - Measures particle concentrations from 5 nm to 3 μm
 - Portable Optical Particle Spectrometer (POPS)
 - Handix Corp.
 - Measures particle size distribution from 500 nm to 20 μm



* "Moderated Aerosol Growth with Internal water Cycling"

Sizes of Aerosols (*Log scale*)

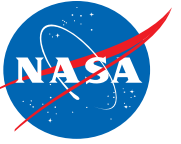


¹ Liquid droplets containing bacteria etc. sneezed etc

² Man made mineral fibers

From Owen et al. 1992, Airborne particle sizes and sources found in indoor air, *Atmos. Env.* 26:12, 2149-2162 (also in ASHRAE Handbook: Fundamentals)

APM in Node 3, Increment 64





MAGIC CPC Data from Node 3, counting sizes from 10 nm to 3 μm

Diurnal pattern with spikes of 500 to 3000 particles/ cm^3

Drops to near zero in-between and at night

Fine Fraction Particle
Concentration ($\#/\text{cm}^3$)

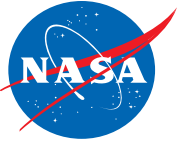
vacuuming

vacuuming

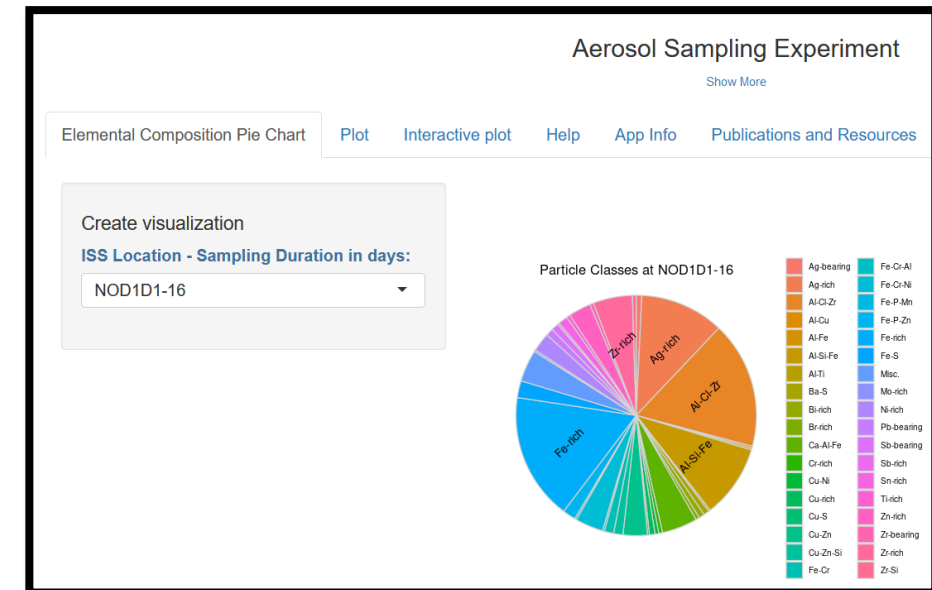
APM wick
priming
before
measuring

11/20 11/21 11/22 11/23 11/24 11/25 11/26 11/27 11/28 11/29 11/30
noon noon noon noon noon noon noon noon noon noon
Fri Sat Sun Mon Tue Wed Thu Fri Sat Sun Mon

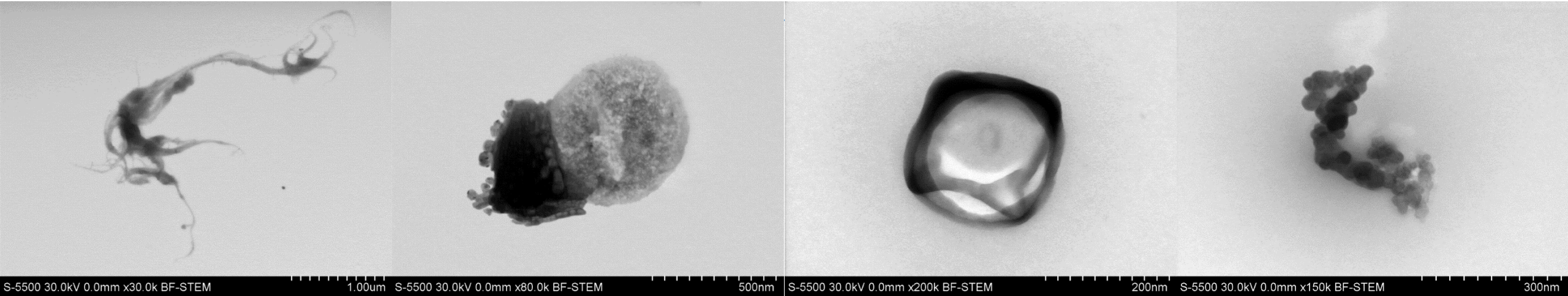
Conclusions



- Sampling Experiment characterized ISS aerosols
- First real-time particle measurements
 - Airborne Particulate Monitor
- You can access and use the data!
- Public-facing interactive website:
 - <https://iss-particle-db.arc.nasa.gov/>
- Coming soon: Physical Sciences Informatics
 - <https://www.nasa.gov/PSI>
 - Database of open-access results from microgravity experiments
 - There may be opportunities to apply for grant money to work with this data



Particles from Node 3



Thank you for your attention!

