Air Quality in the International Space Station

Marit E. Meyer, PhD

NASA Glenn Research Center, Cleveland, Ohio

Outline

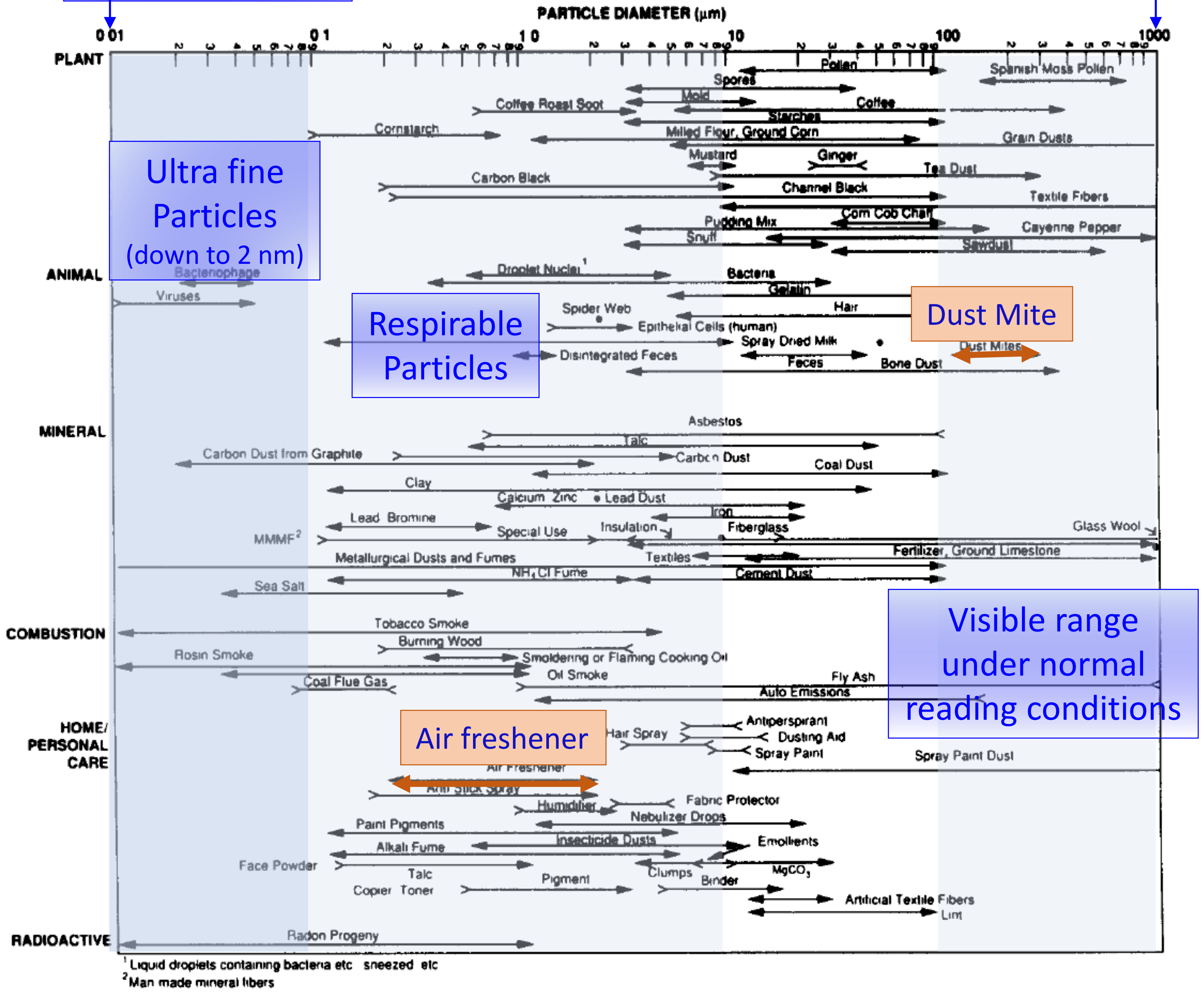
- Introduction and background
- ISS Aerosol Sampling Experiment
- Real-time instrument for ISS
- Lunar dust contamination in spacecraft
- Conclusions

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)*

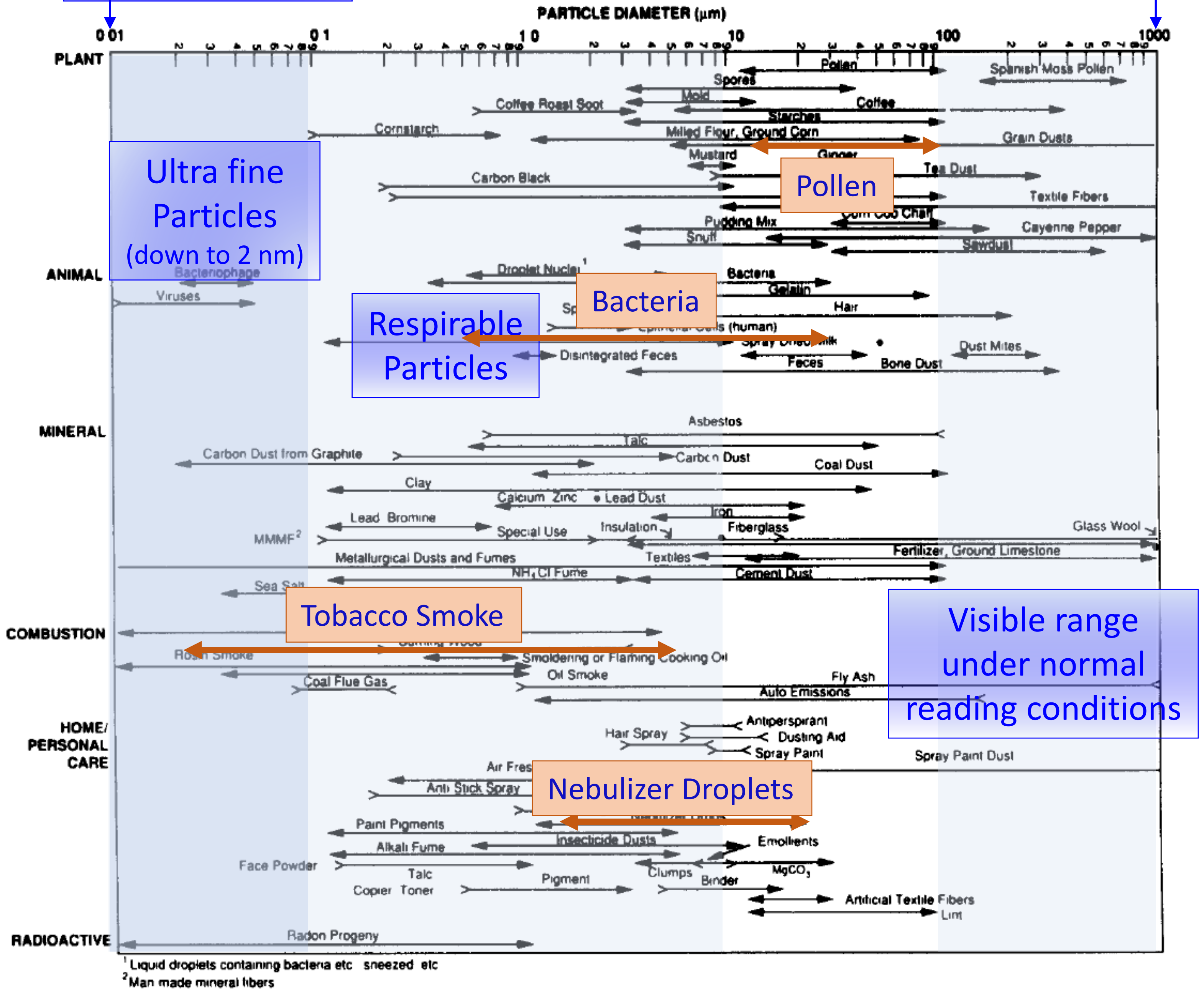


From Owen et al. 1992, Airborne particle sizes and sources found in indoor air, *Atmos. Env*. 26:12, 2149-2162 (also in ASHRAE Handbook: Fundamentals)

Sizes of Aerosols *(Log scale)*

10 nm = 1E-8 m

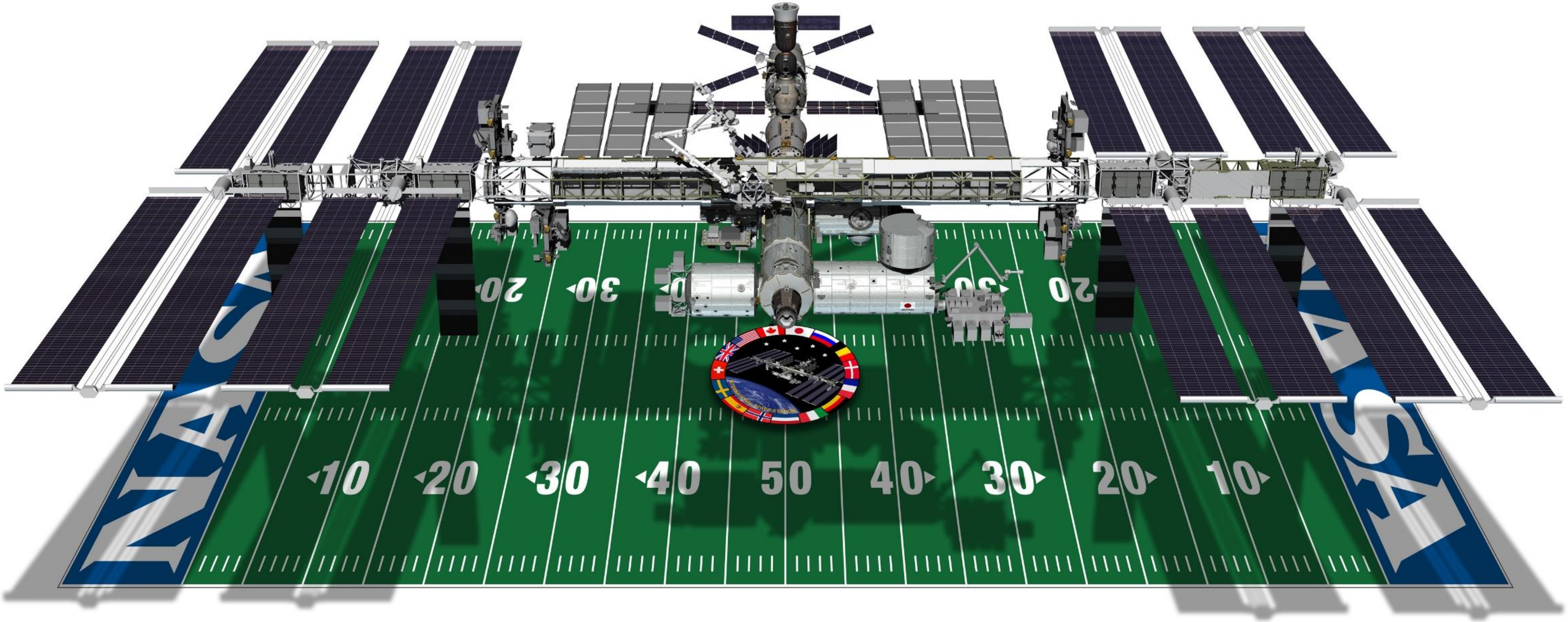
1000 µm = 1mm = 1E-3 m



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)

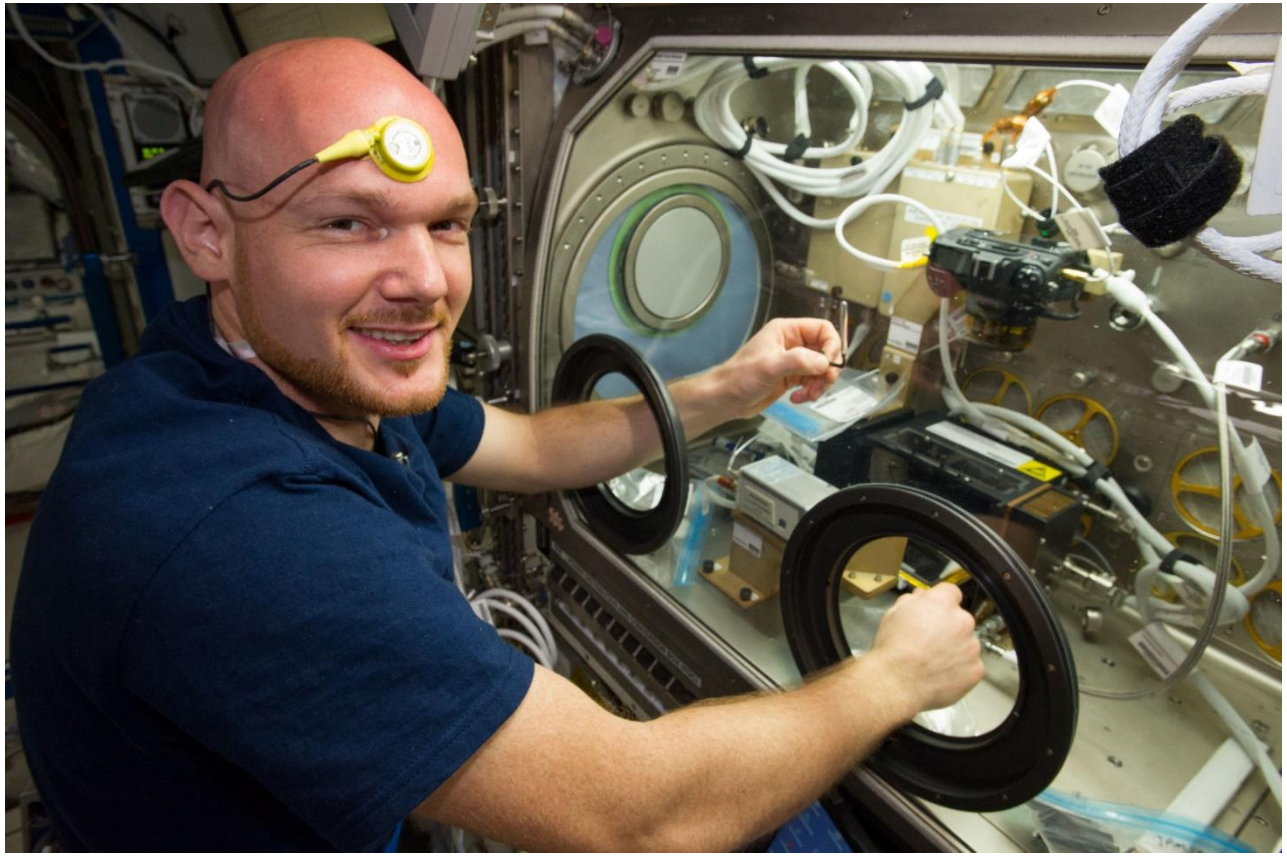
International Space Station (ISS)

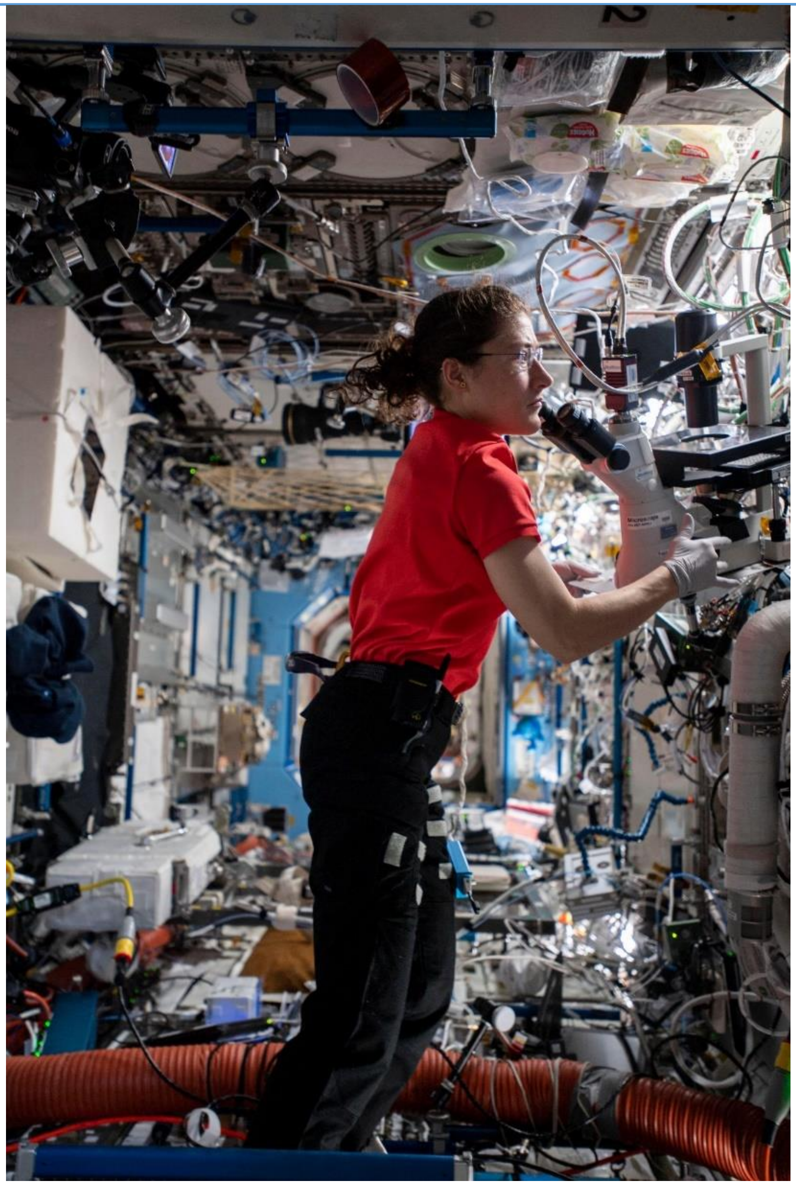
- 900 m^3 Habitable Volume
- Continuously occupied for over 20 years
  - Nearly 250 people



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

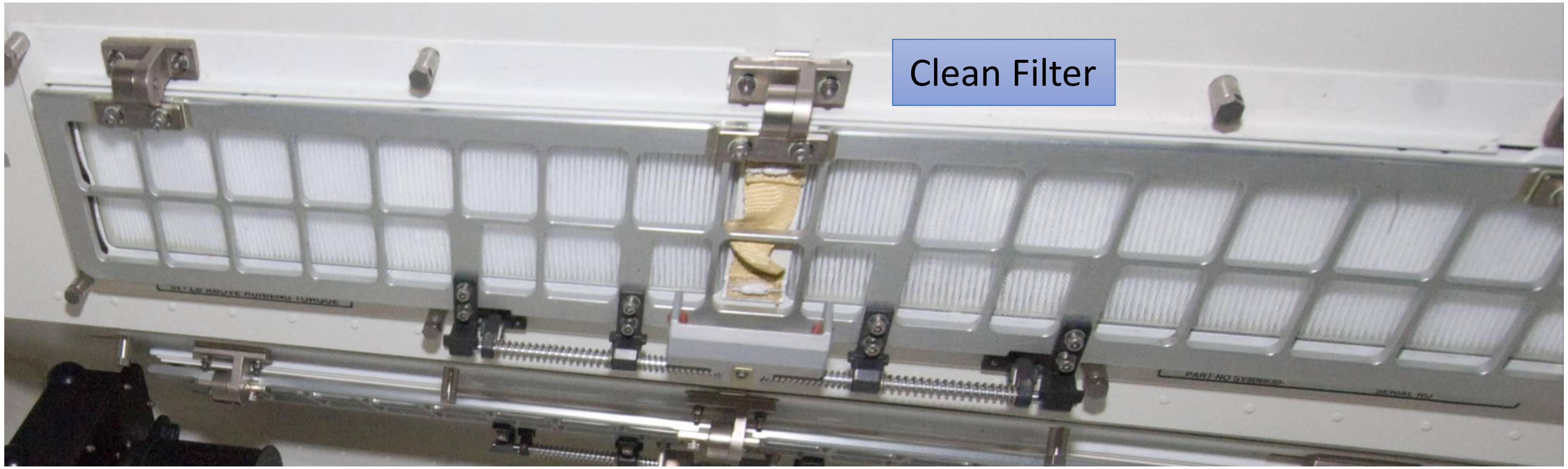
- Housekeeping
  - Vacuuming
    - Turn off smoke detectors
  - Disinfectant wipes for surfaces
  - No laundry yet
    - Wear clothes as long as possible, then throw away
- Personal hygiene
  - No shower, only wet wipes

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

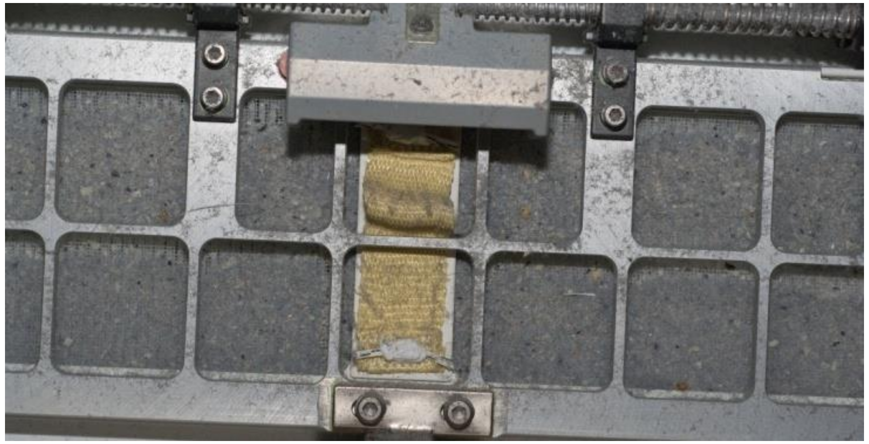
Dirty avionics intake fan

Aerosol Deposition on Filters



12 days accumulation

Node 3

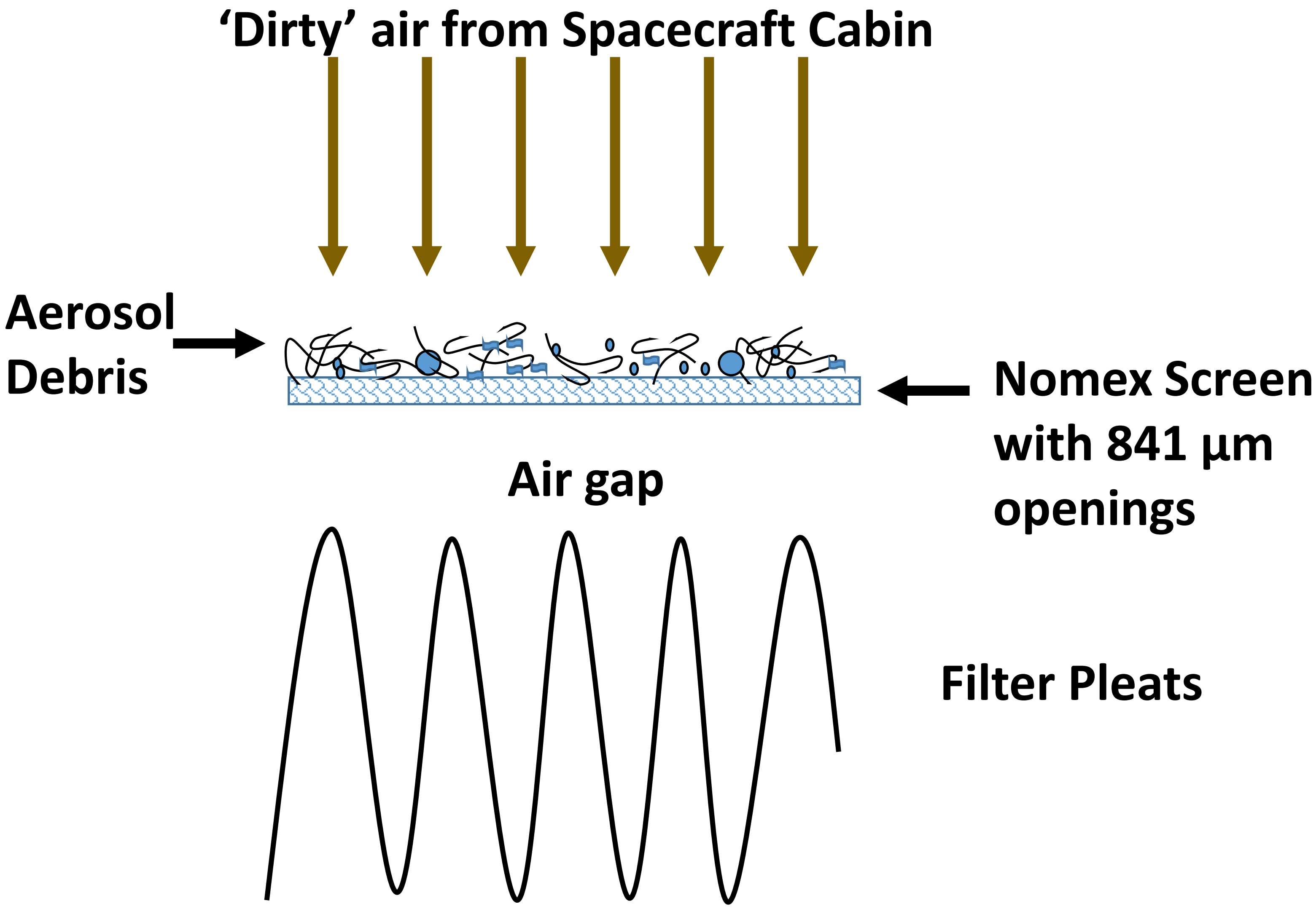


8 days accumulation

8 days accumulation

Node 1

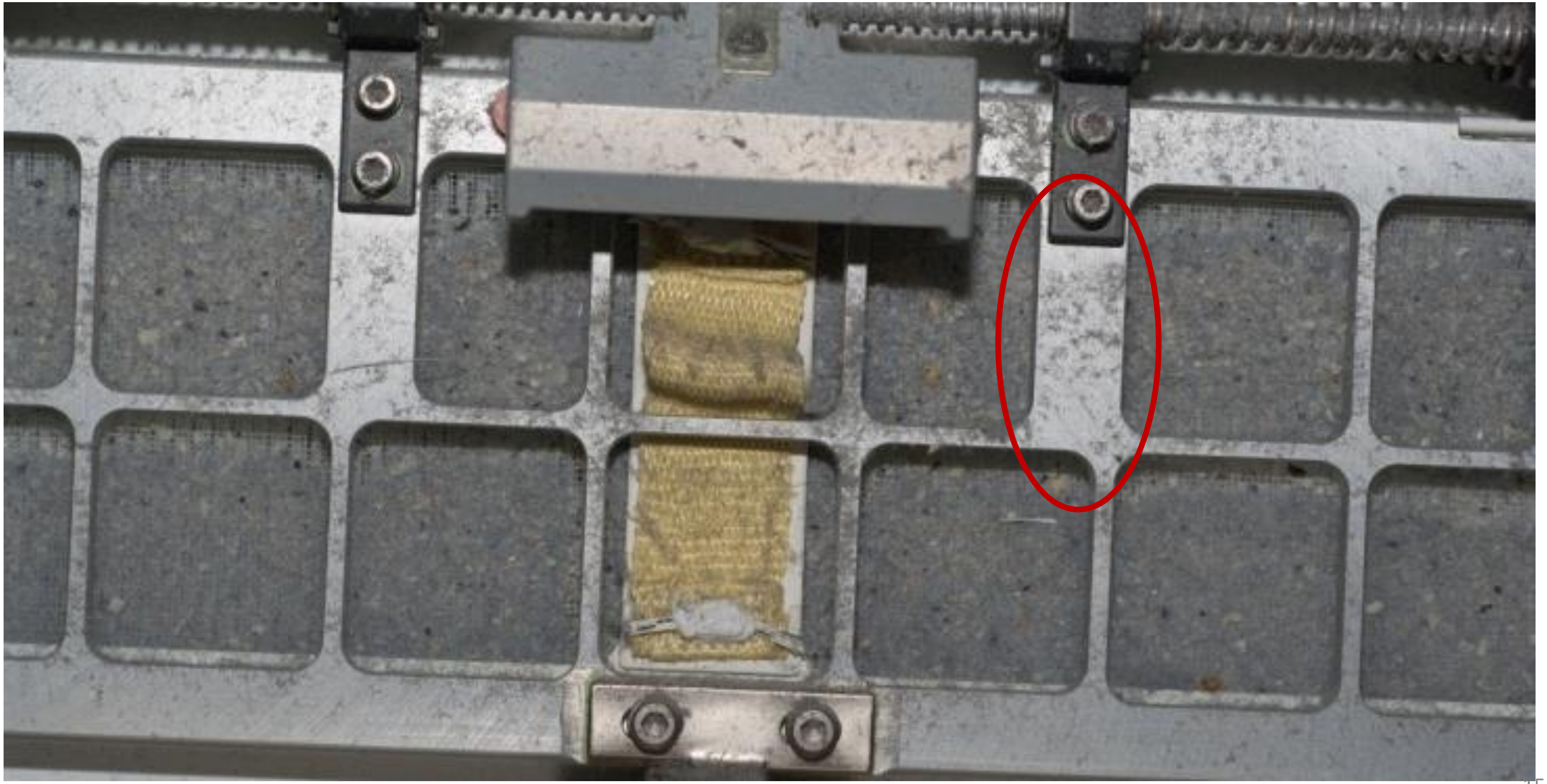
Aerosol Deposition on Filters



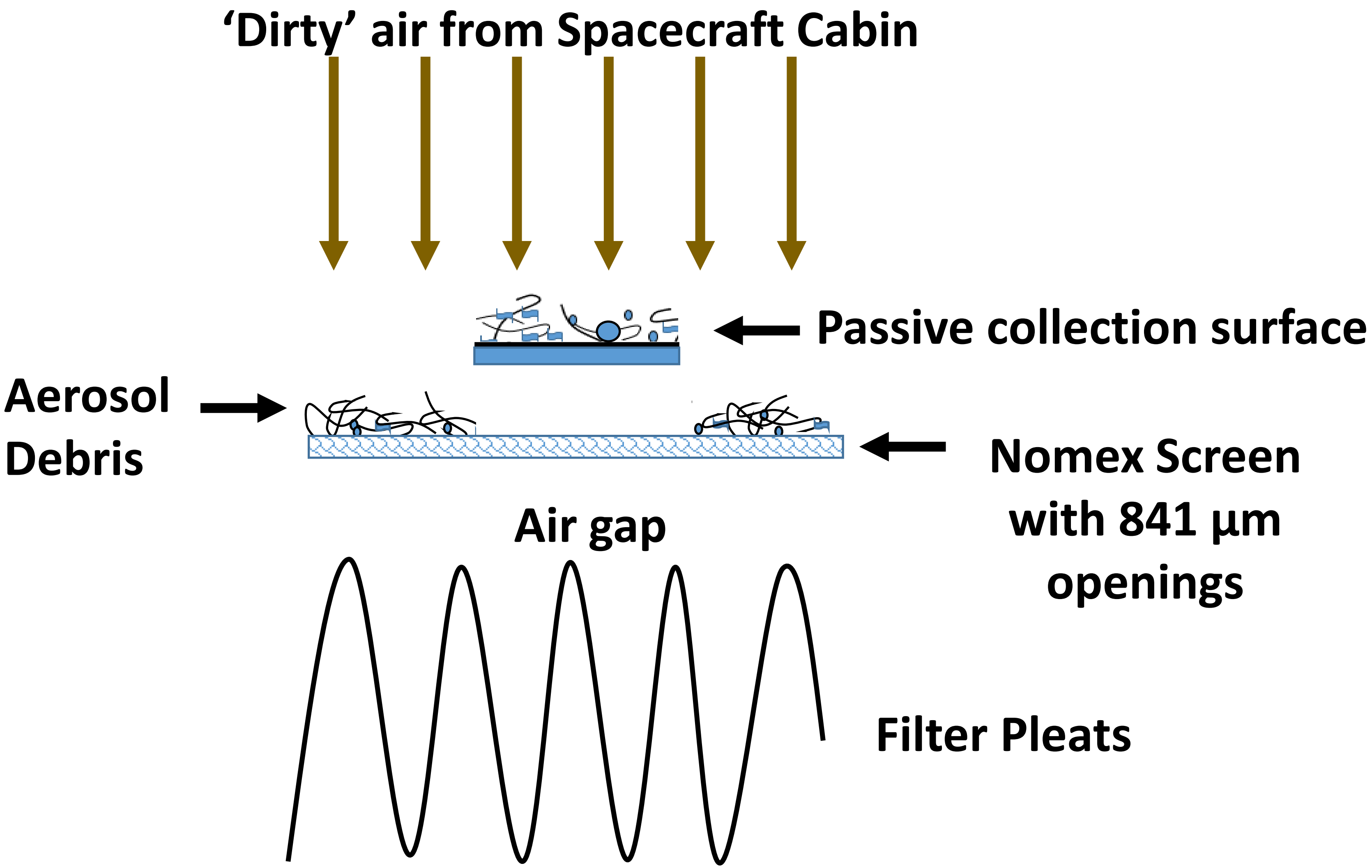
Aerosol Sampling Experiment

- 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

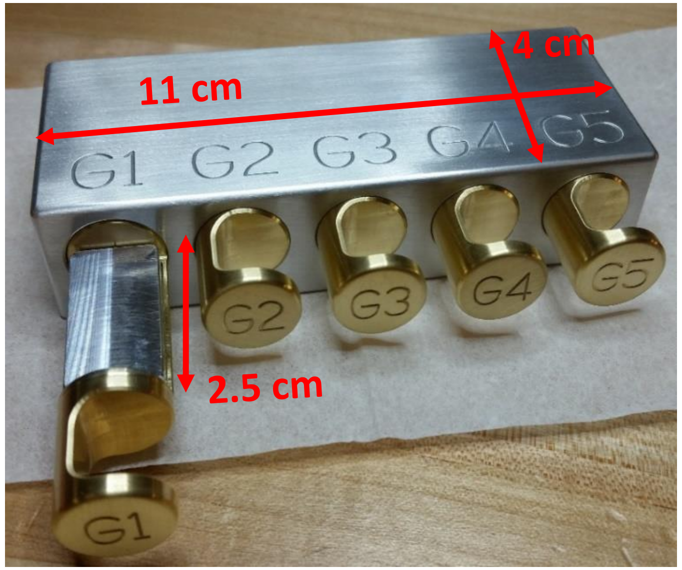


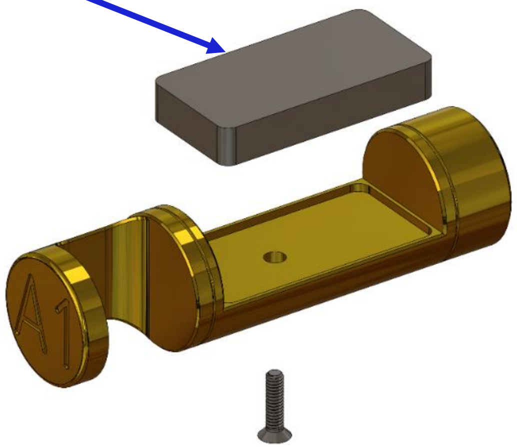
Aerosol Deposition on Filters



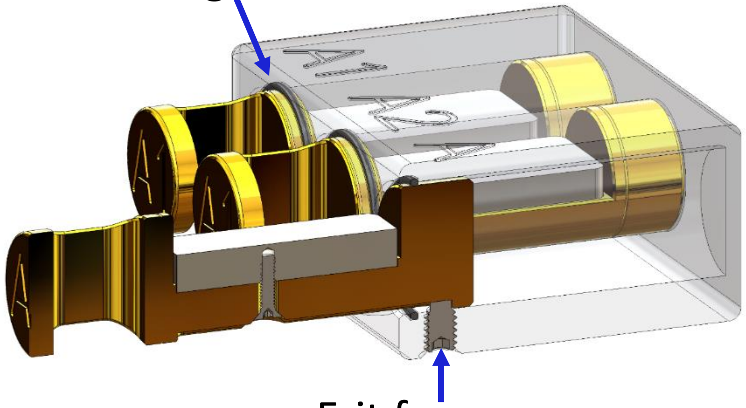
Passive Aerosol Sampler

- 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





O-ring seal

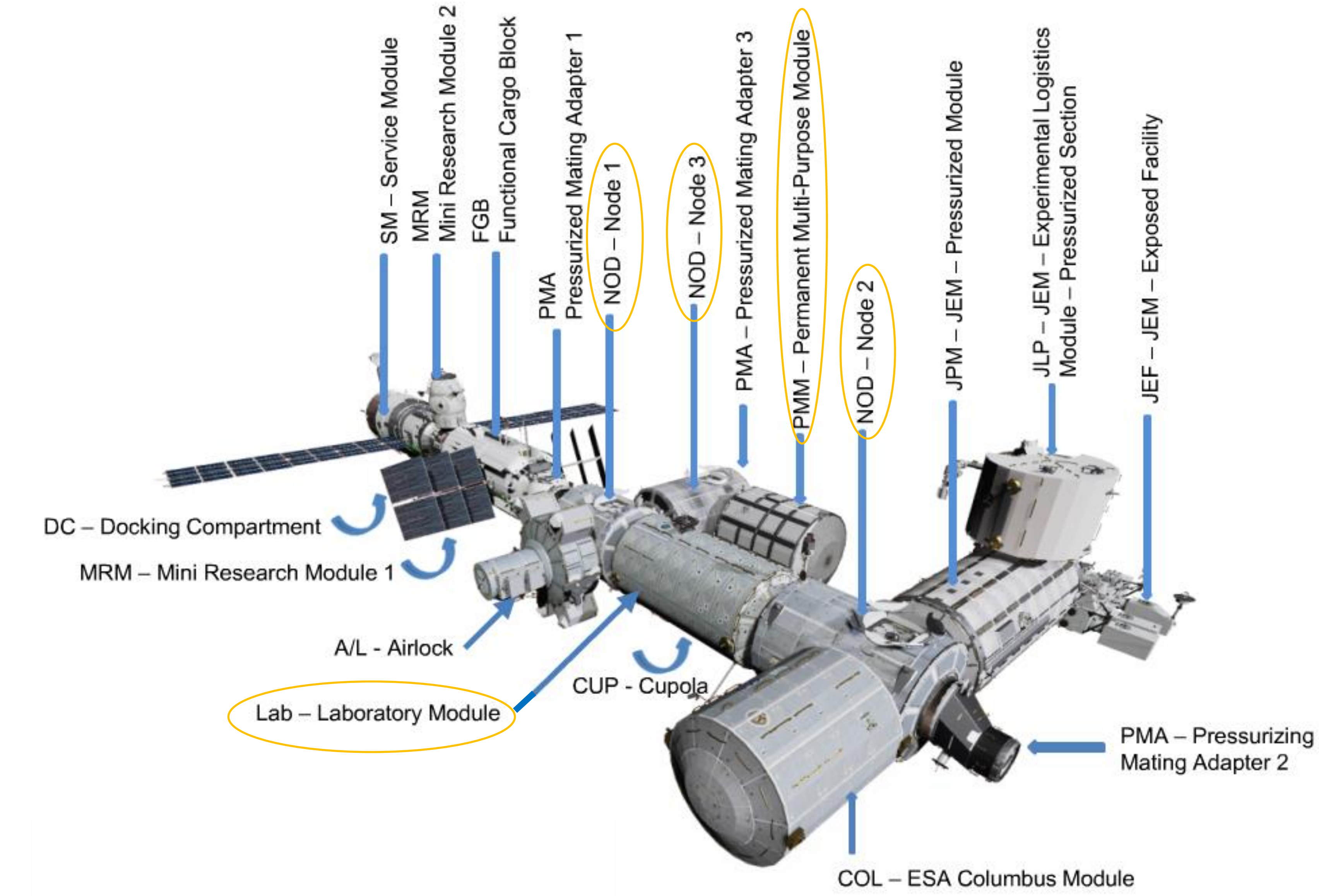


Frit for pressure equalization

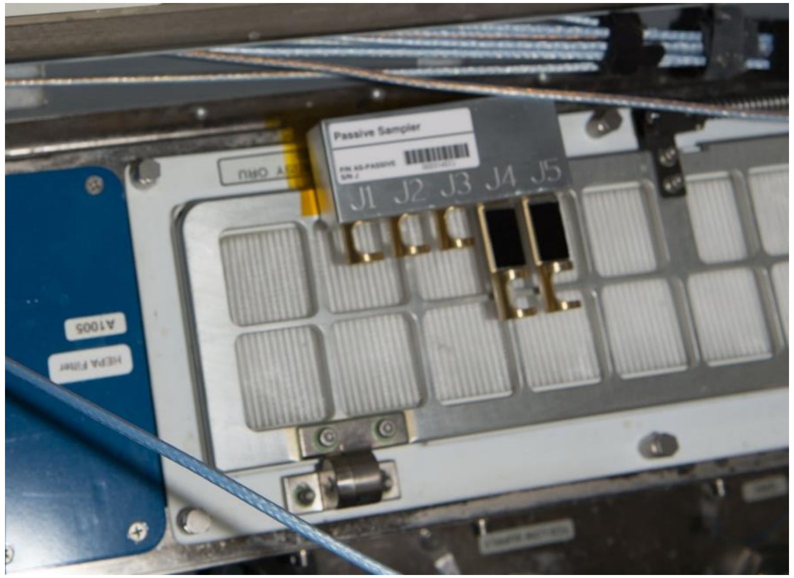
Aerosol Sampling Experiment

- 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**

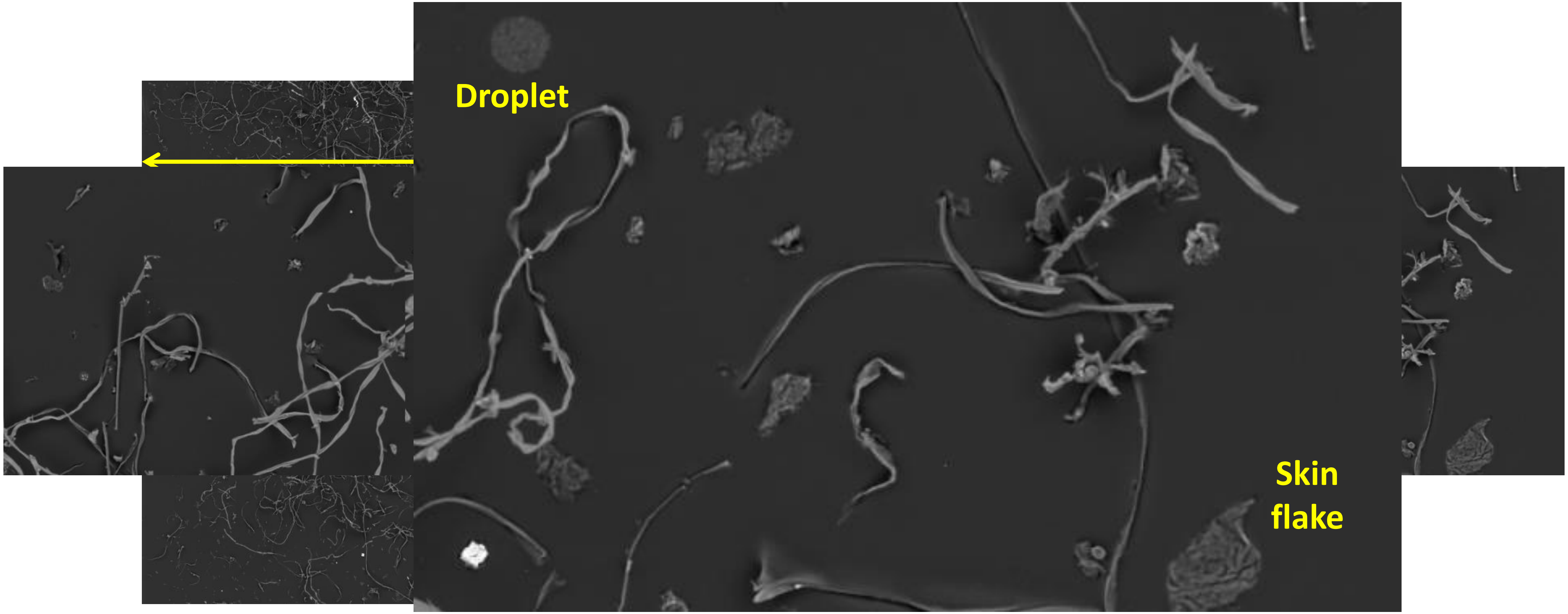
2018 LAB1PD3 US Lab Bay 3

2018 NOD2D3 Midbay
HEPA Return Register

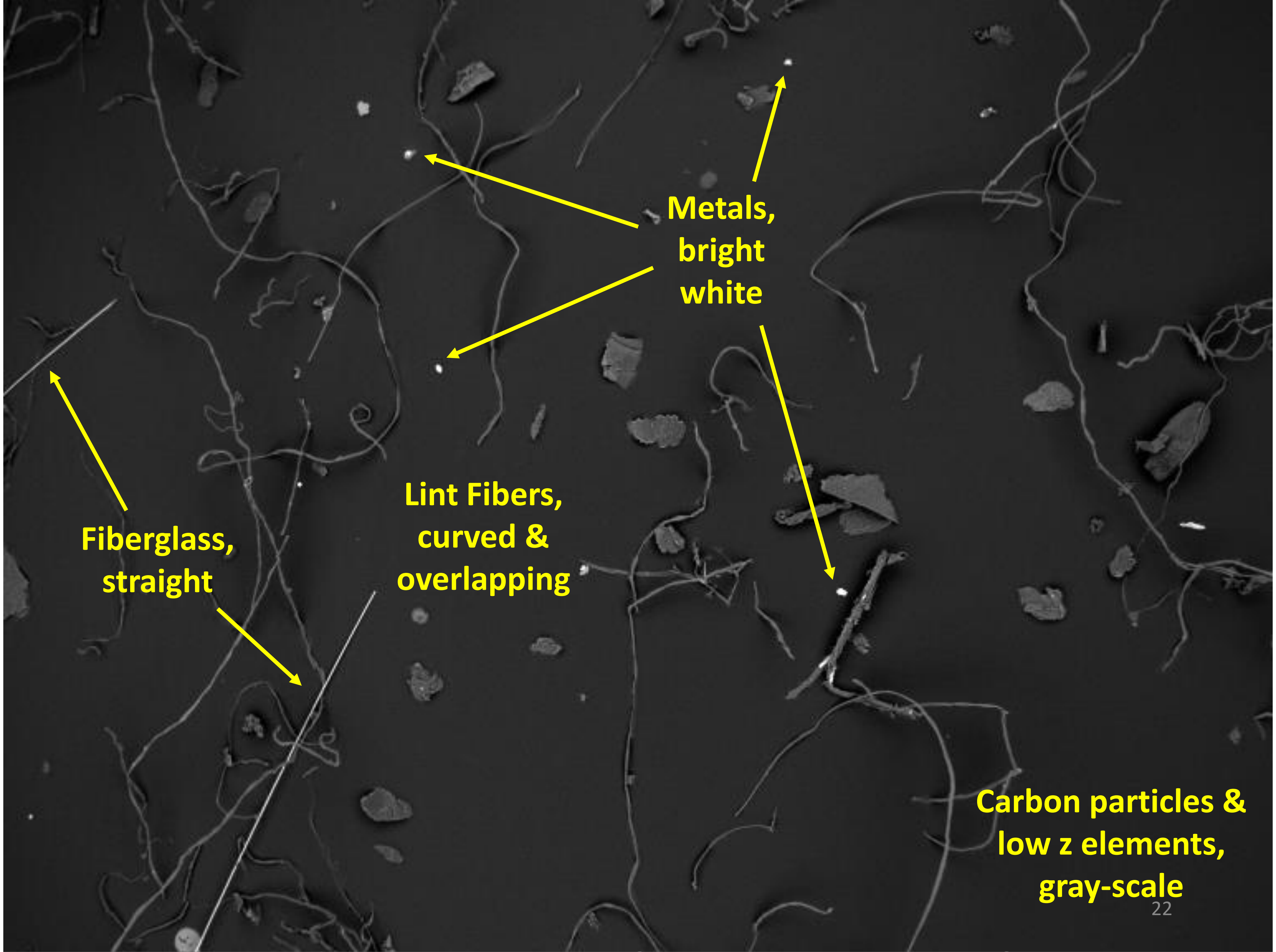
2018 NOD3F3
HEPA Register

Passive Sampler Microscopy

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



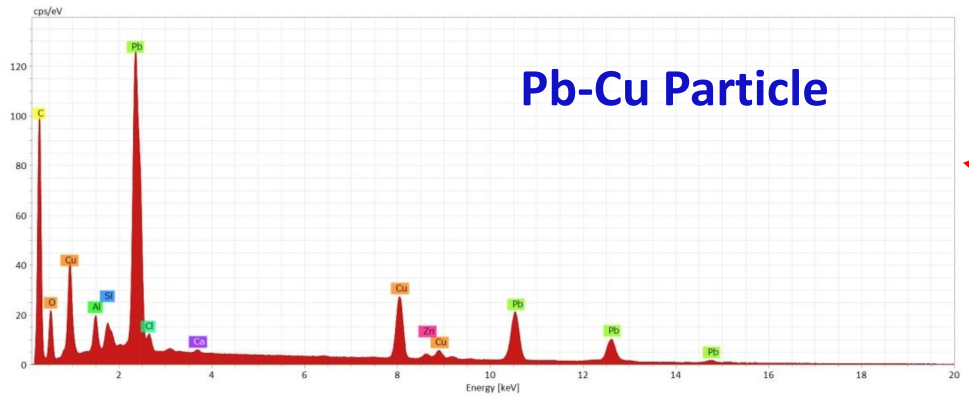
*Microscopy was performed through a subcontract with RJ Lee Group

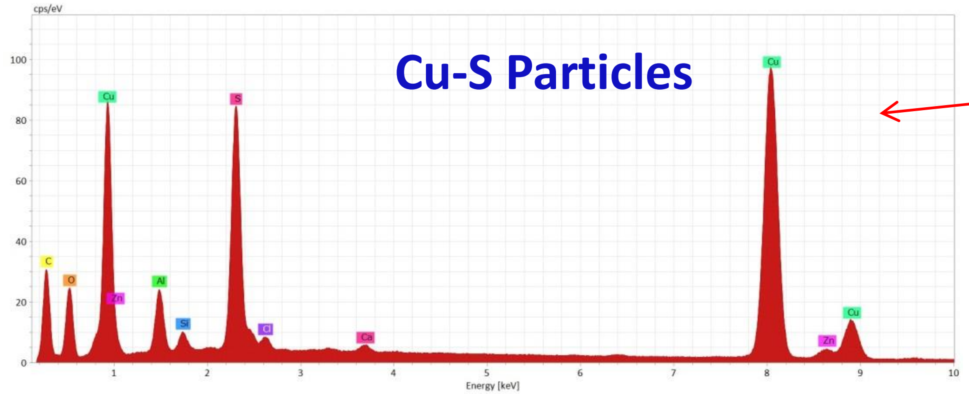

Metals,
bright
white
Fiberglass,
straight
Lint Fibers,
curved &
overlapping
Carbon particles &
low z elements,
gray-scale

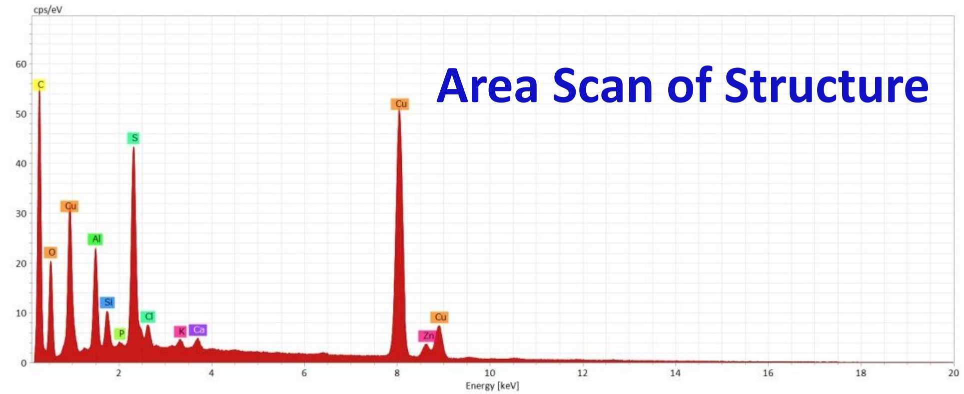
Unique Particle Morphology

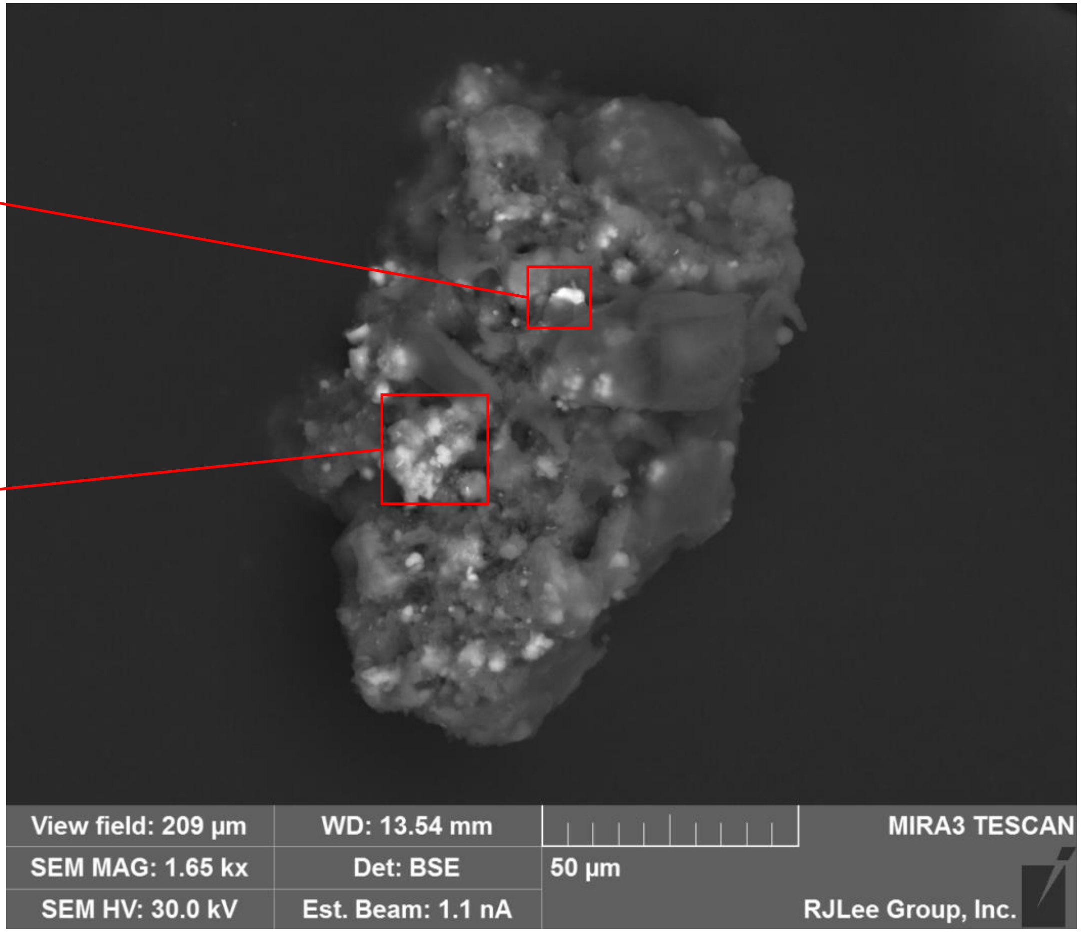
- ISS samples had many multi-component particles
  - Individual metal particles embedded in a carbonaceous matrix
- Presents challenges for counting particles by image analysis
  - Must distinguish edges to outline individual particles based on contrast thresholds
  - Fibers were a challenge as well

Multi-Component Particle









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

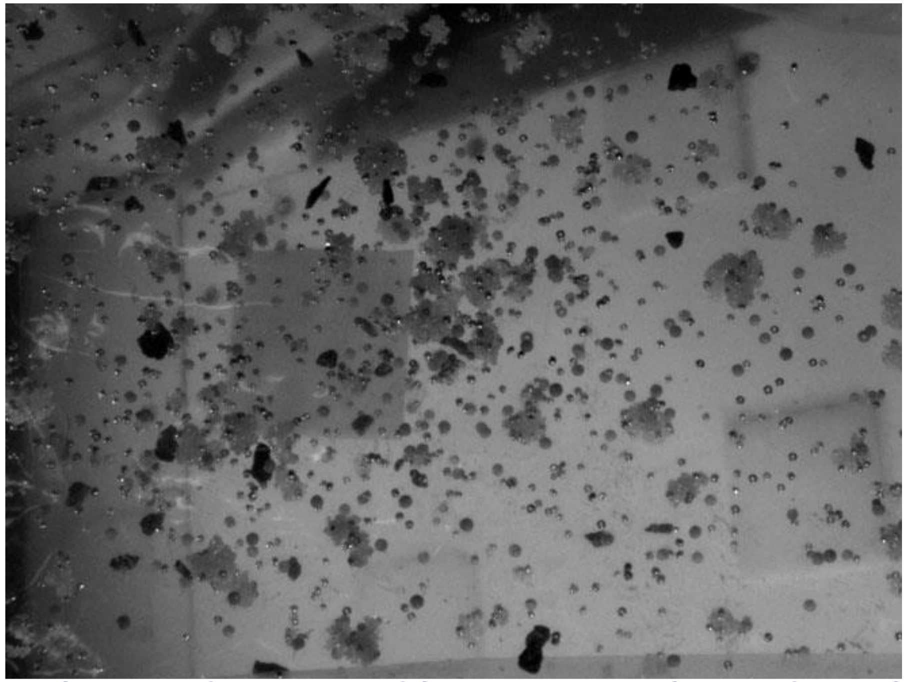
Formation Mechanism?

- 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*

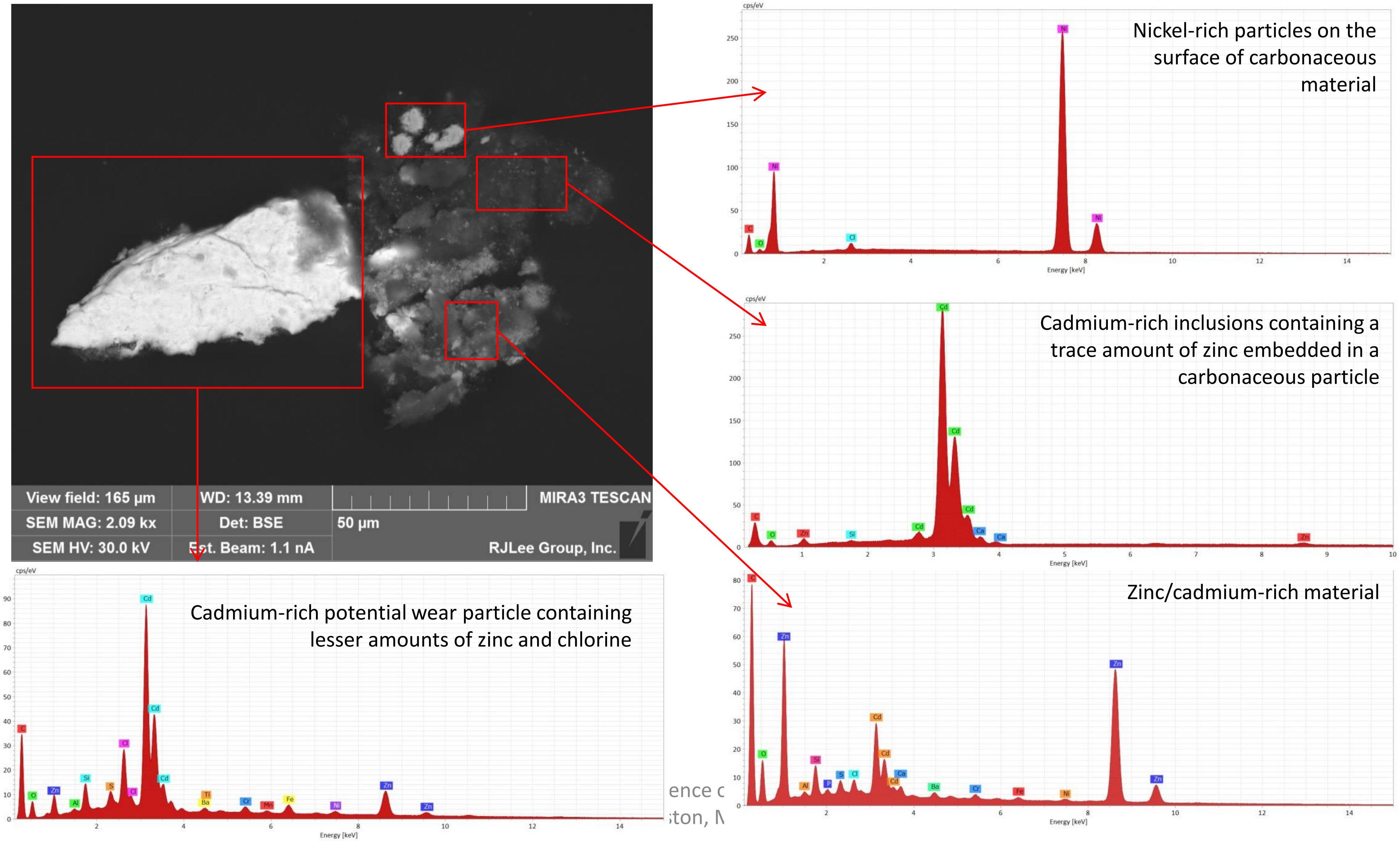


Clumps dominated by sugar, with incidental capture of acrylic spheres & meteorite particles

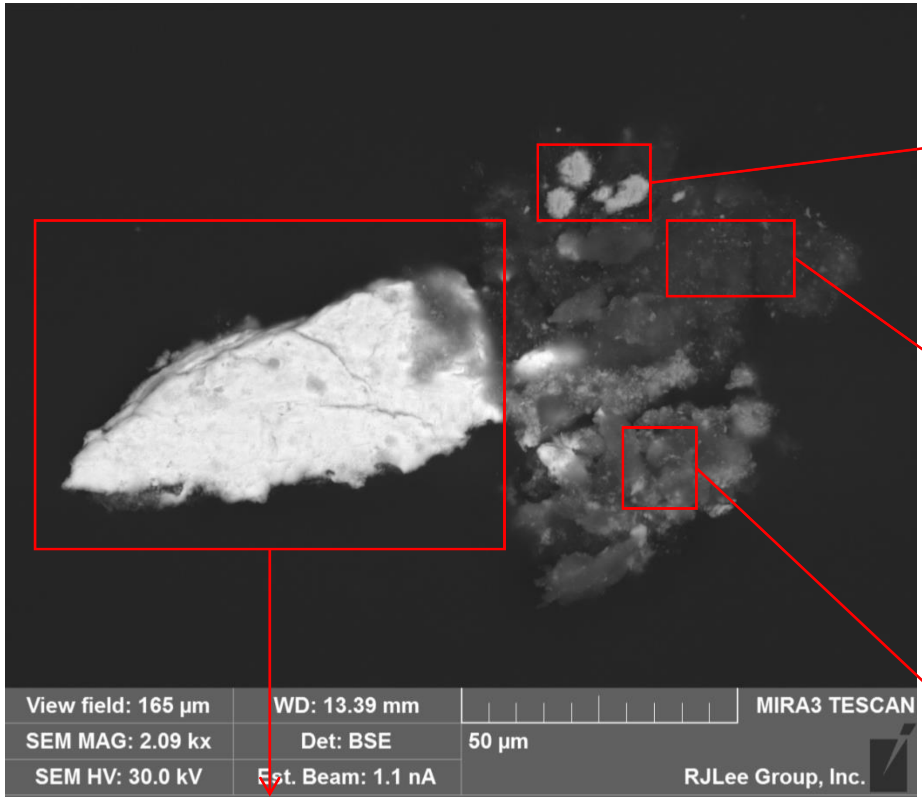
Possible Formation Mechanism of ISS Cabin Aerosols

- 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



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

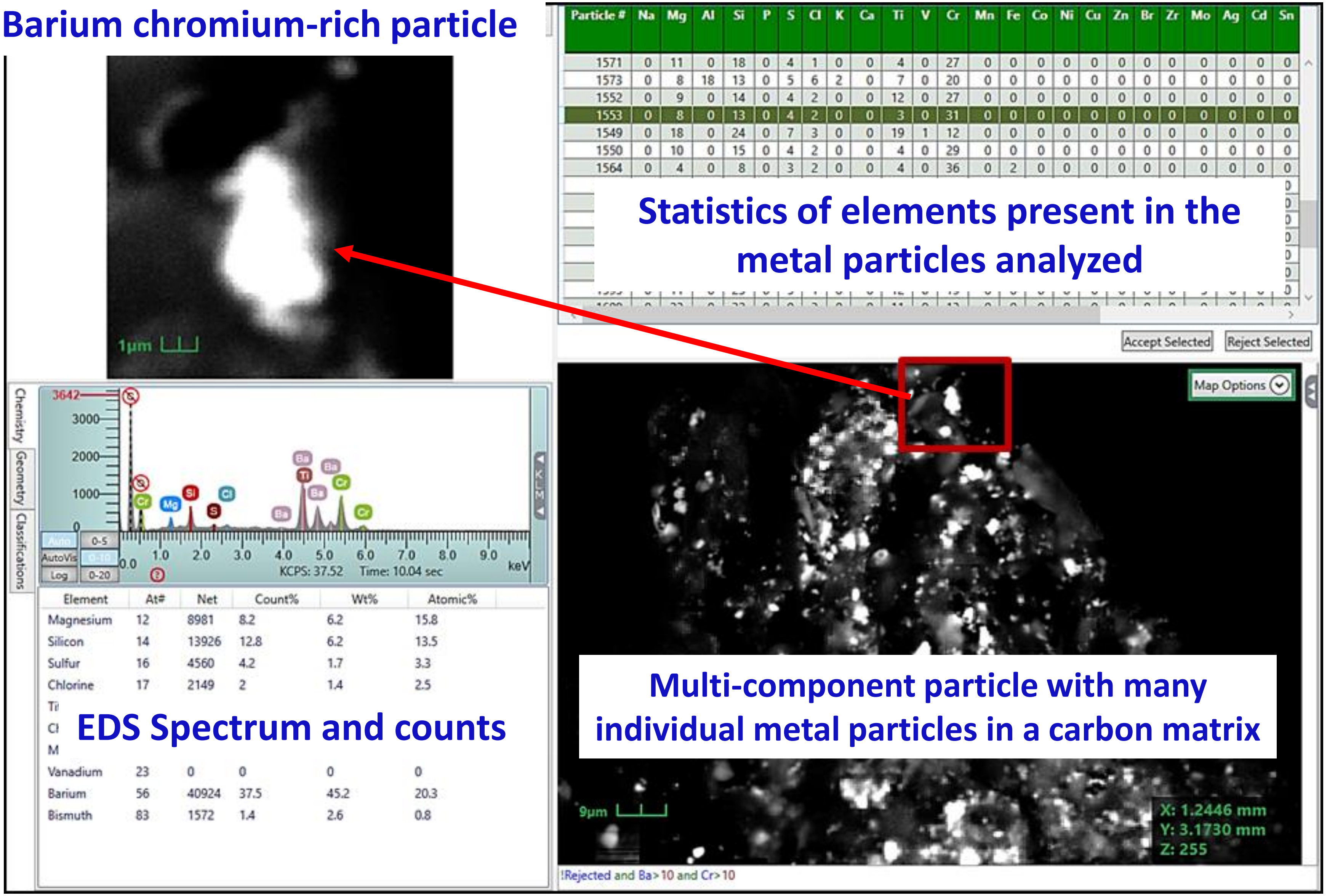
Sampled in Node 3

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

*IntelliSEM was performed through a subcontract with RJ Lee Group

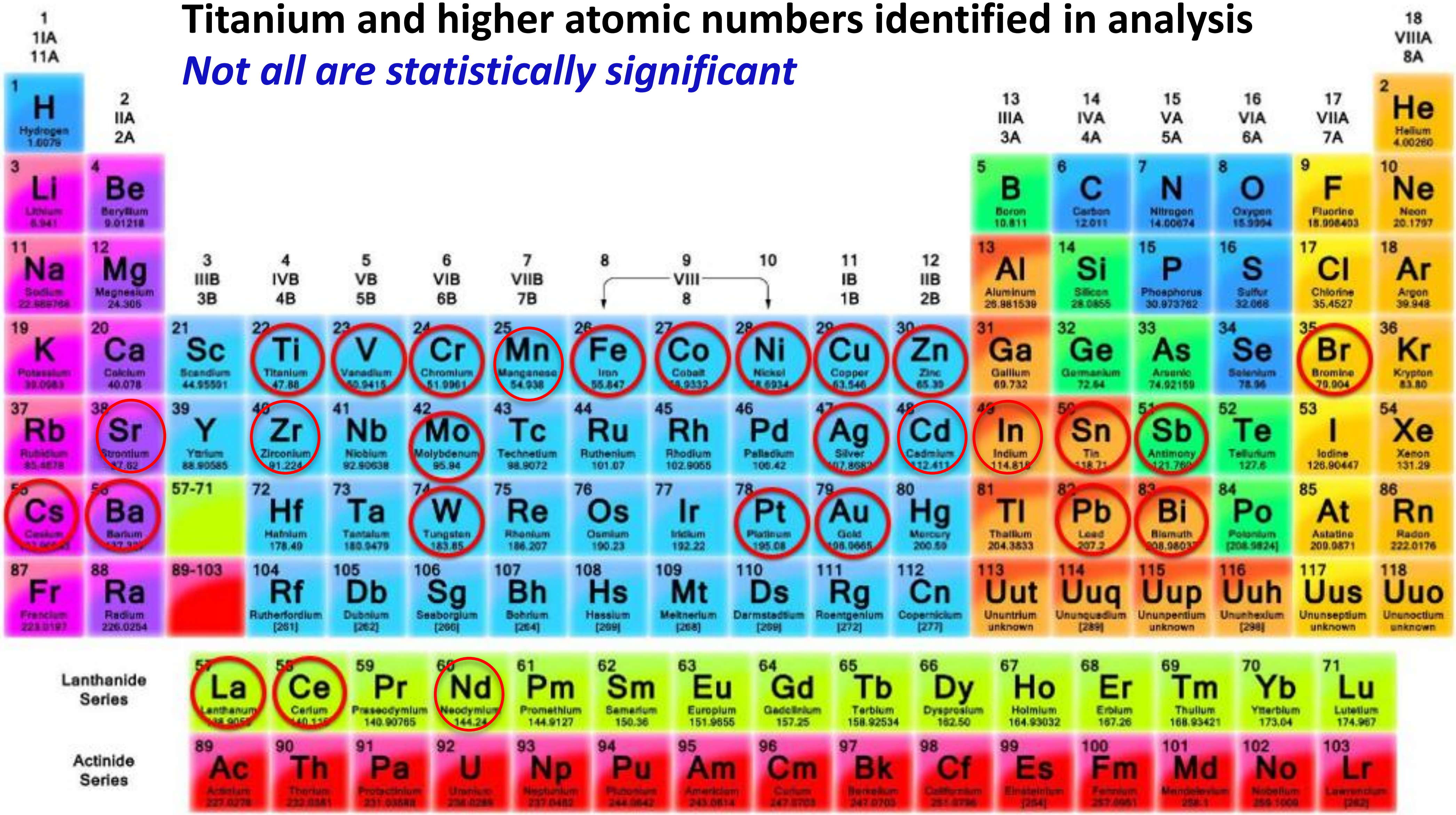
Data from IntelliSEM Workbench



27 Metals

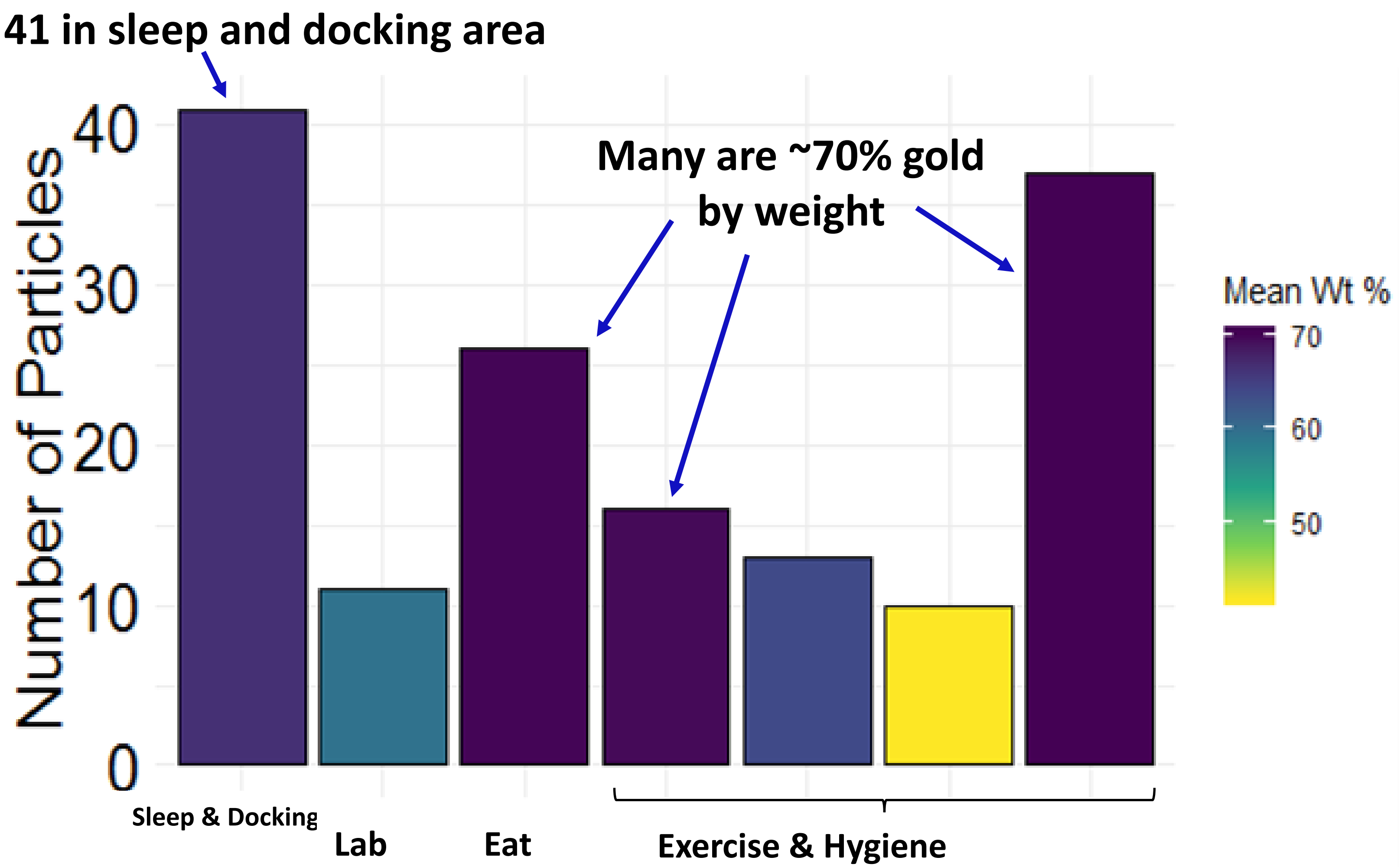
Titanium and higher atomic numbers identified in analysis

Not all are statistically significant



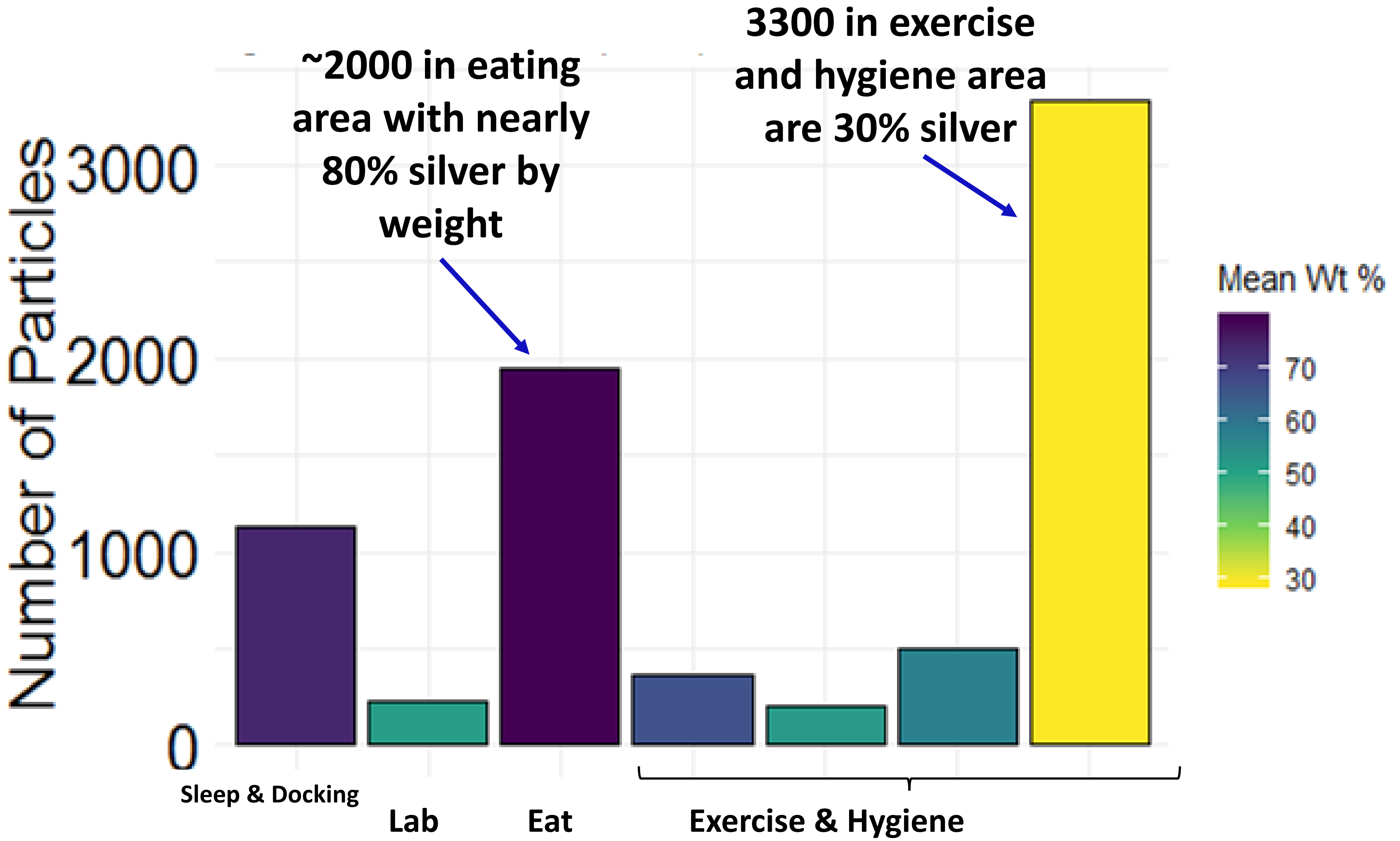
Gold on ISS - 2018

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



Silver on ISS - 2018

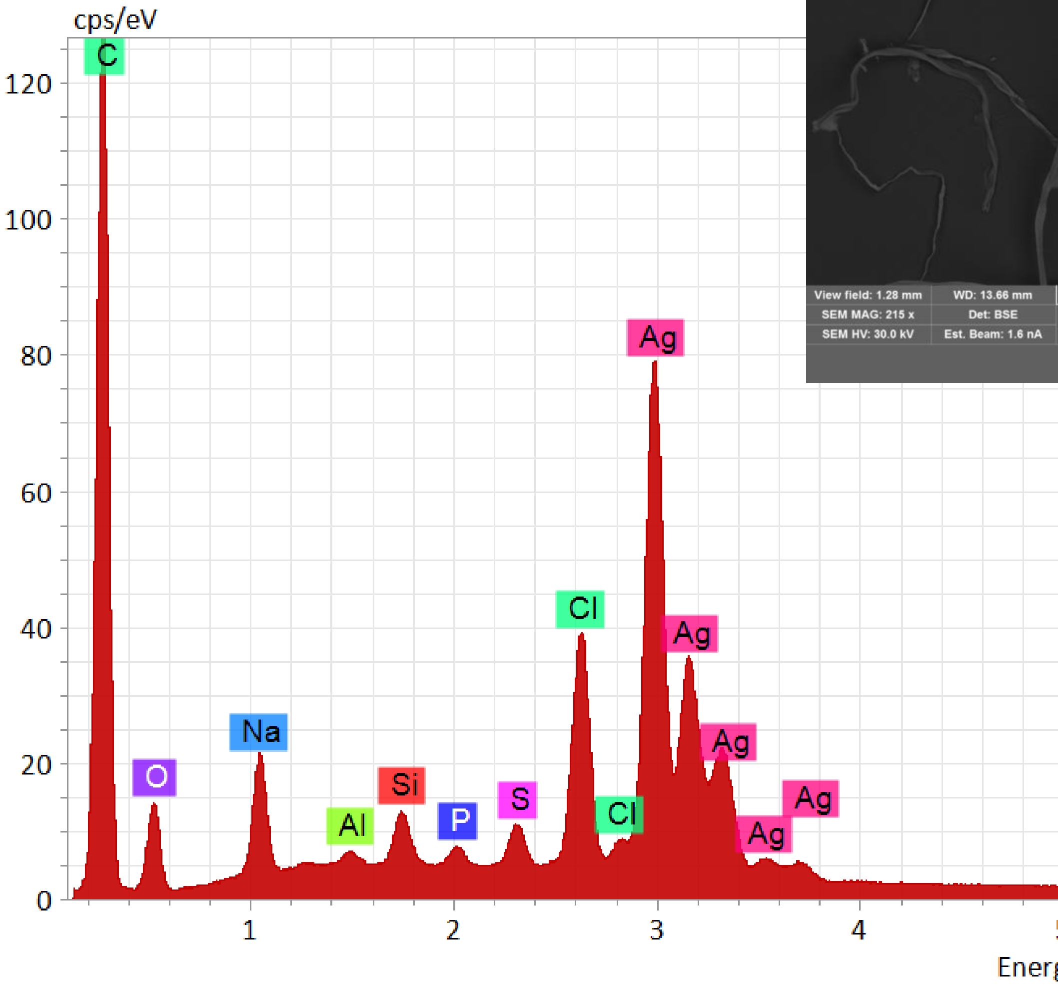
9.8 % of all metal inclusions/particles (by weight) contain some silver

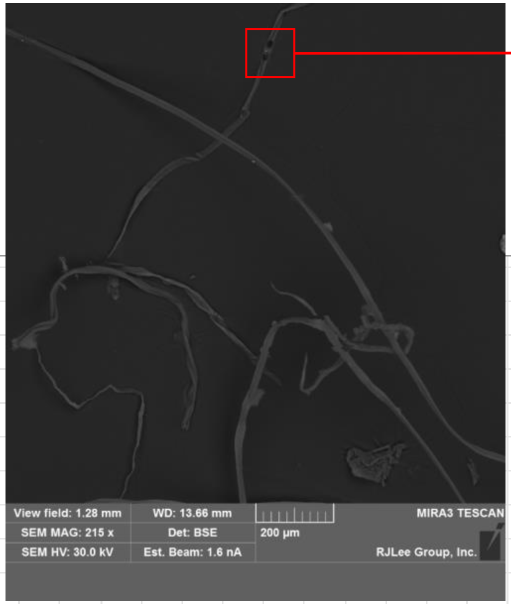


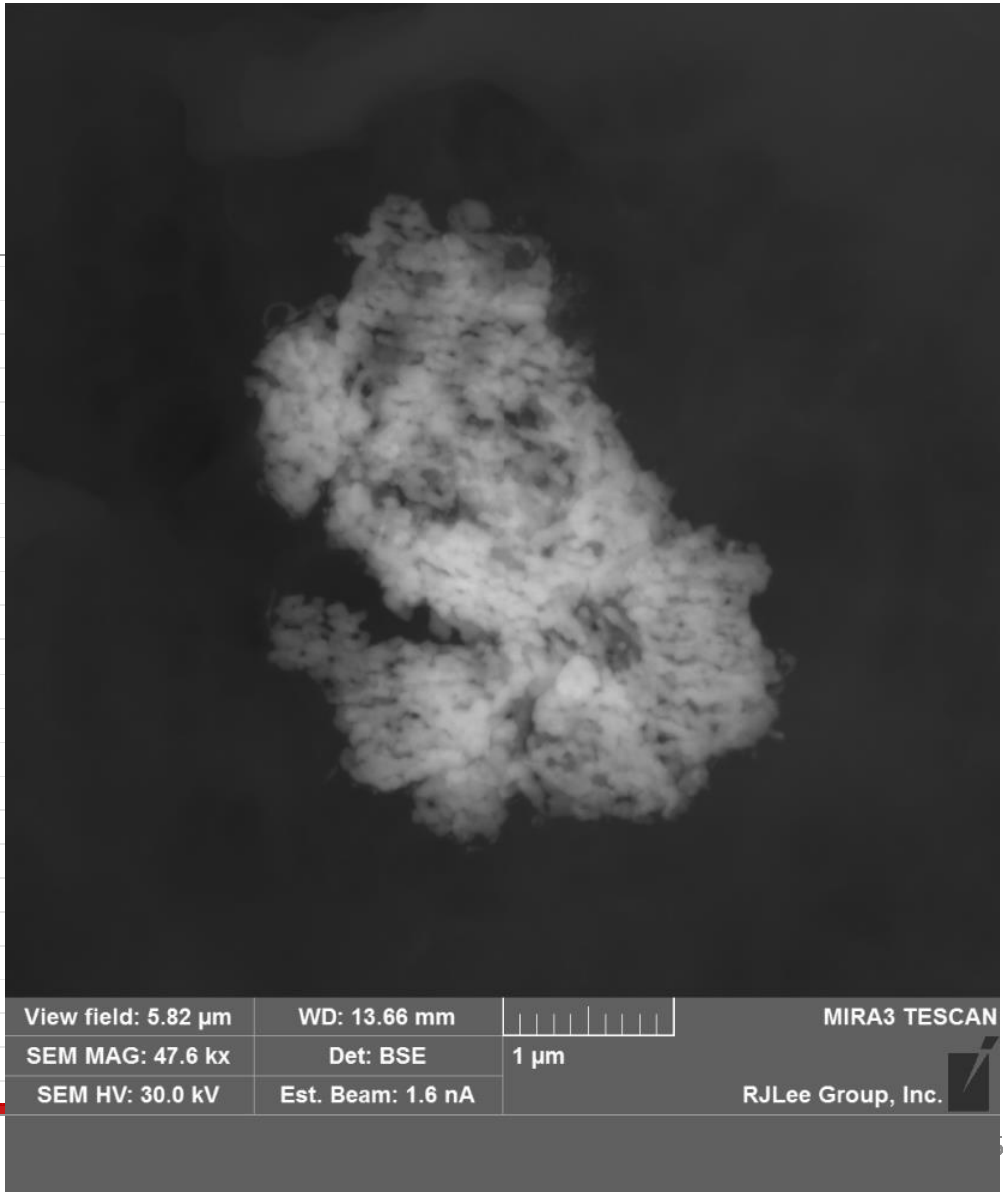
See also Ley, S.E., Li, W., Rodell, A.J., Calle, L.M, Meyer, M.E., Lersch, T., Bunker, K., Casuccio, G. (2021) Fate of Silver Biocide on the International Space Station Living Environment, 50th International Conference on Environmental Systems, July 12, 2021.

Silver on ISS

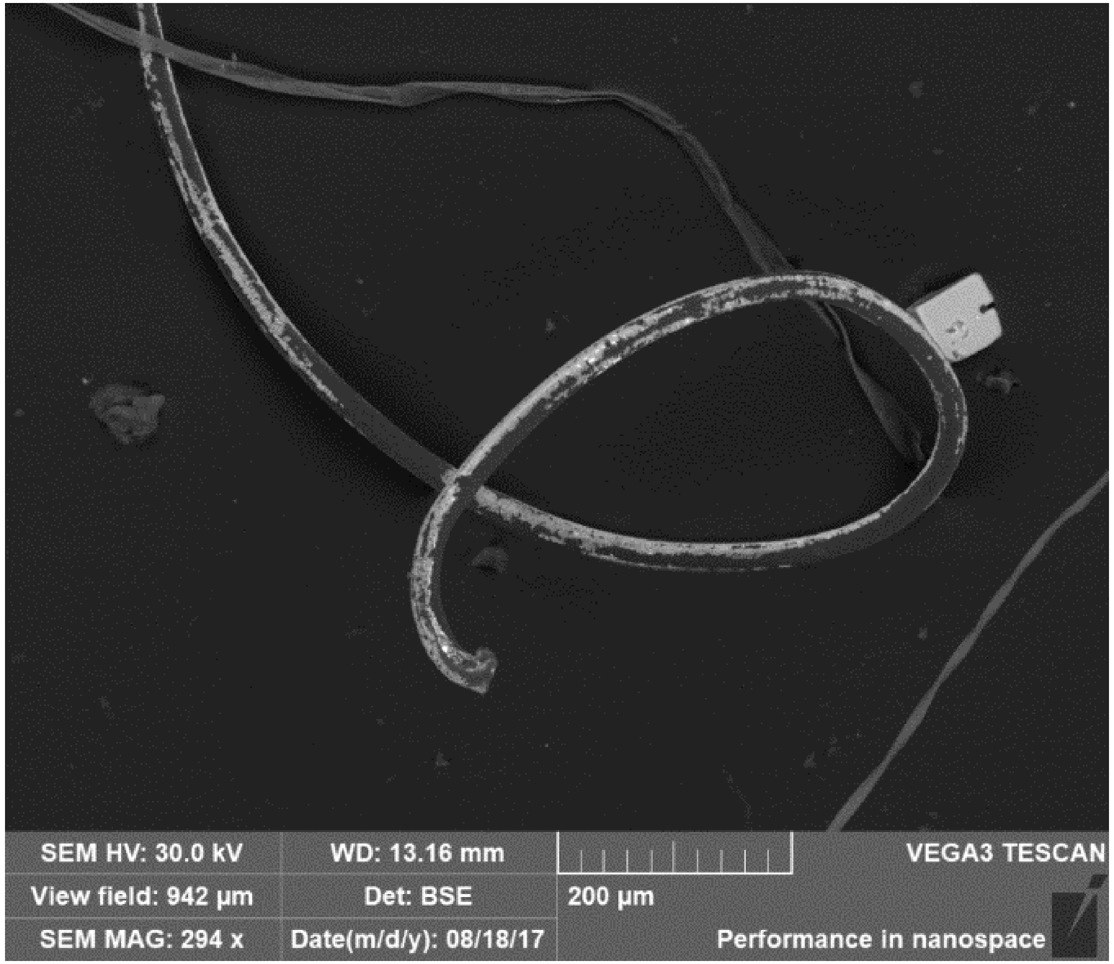
2018 LAB1PD3 - US Lab Bay 3 Port/Deck Standoff HEPA Return Register (PAS D-2)

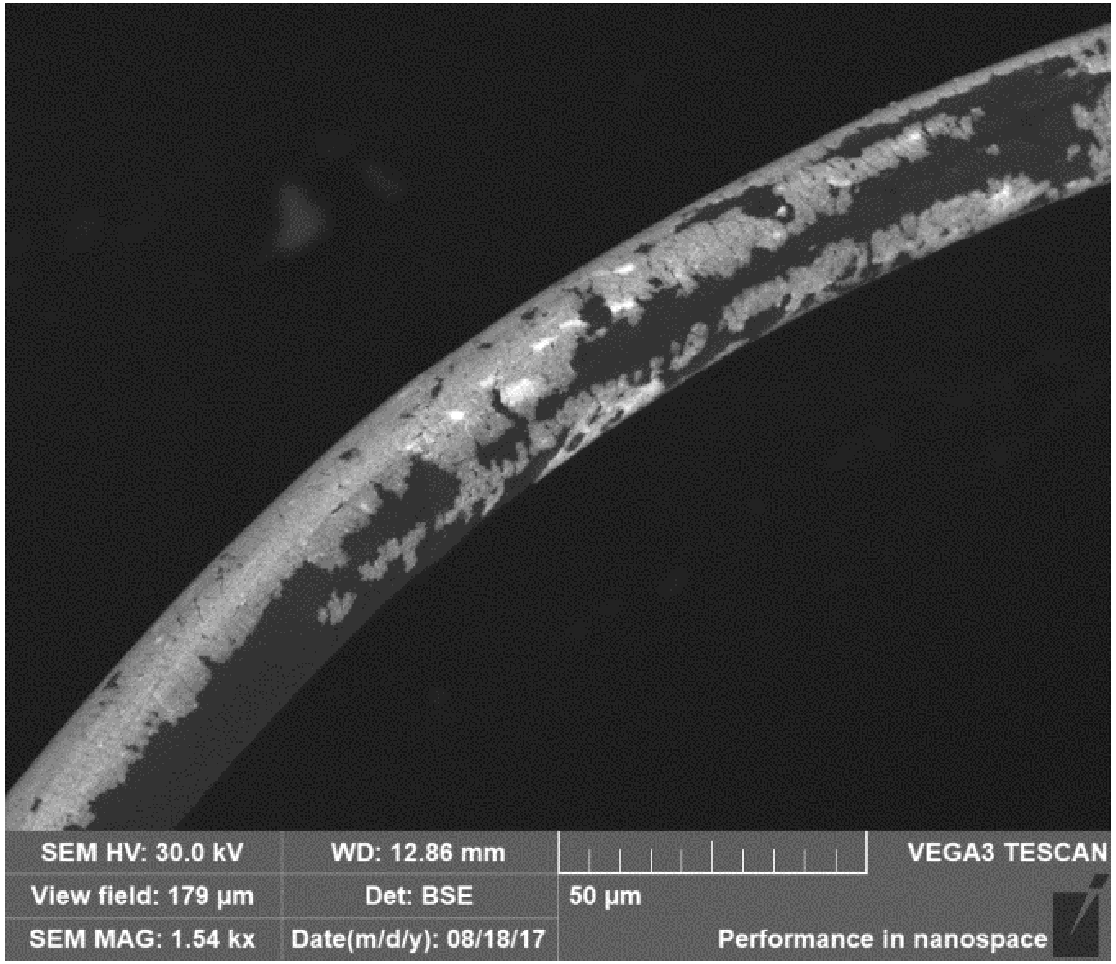






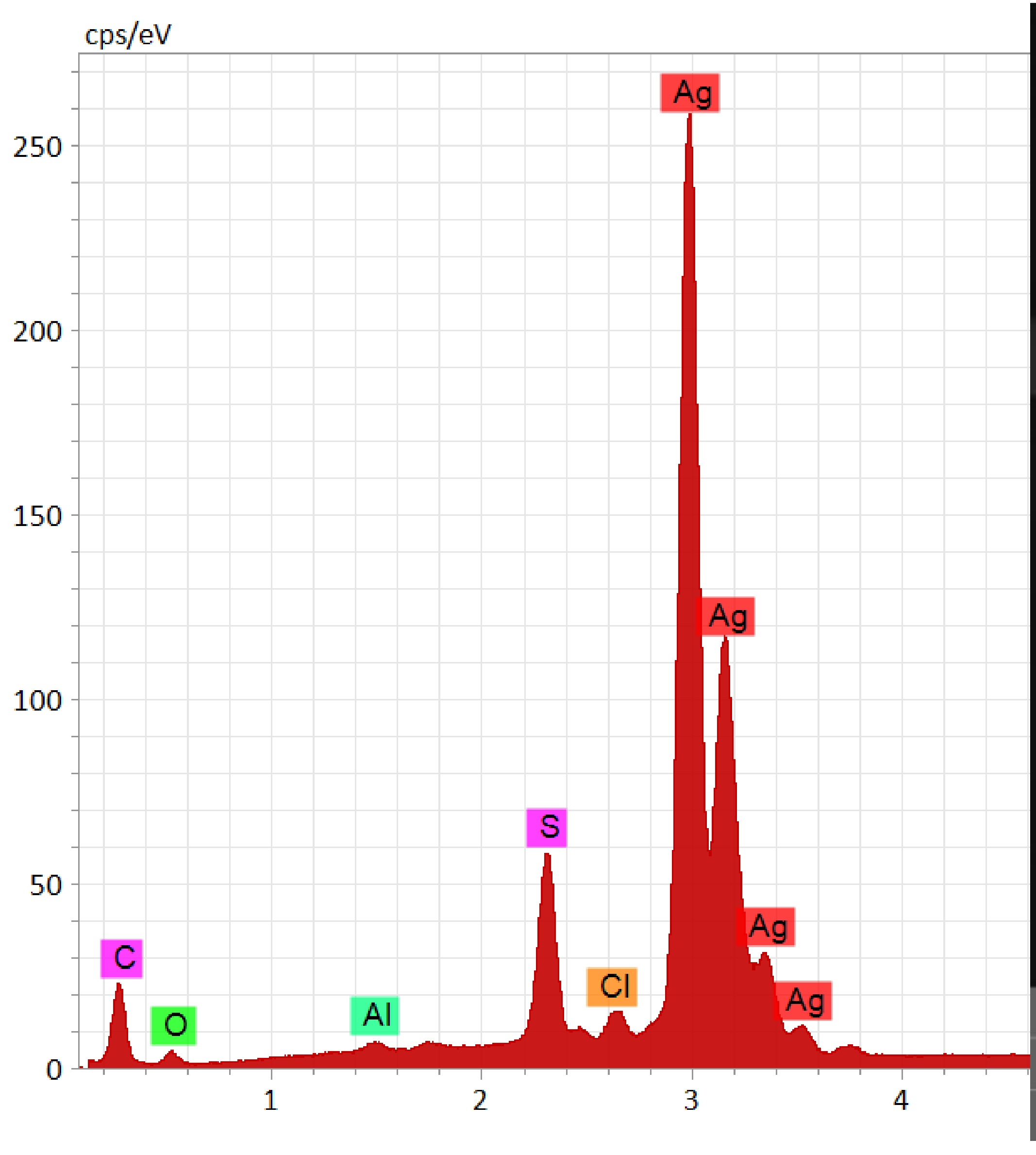
Silver on ISS – X-Static® Sock Fiber

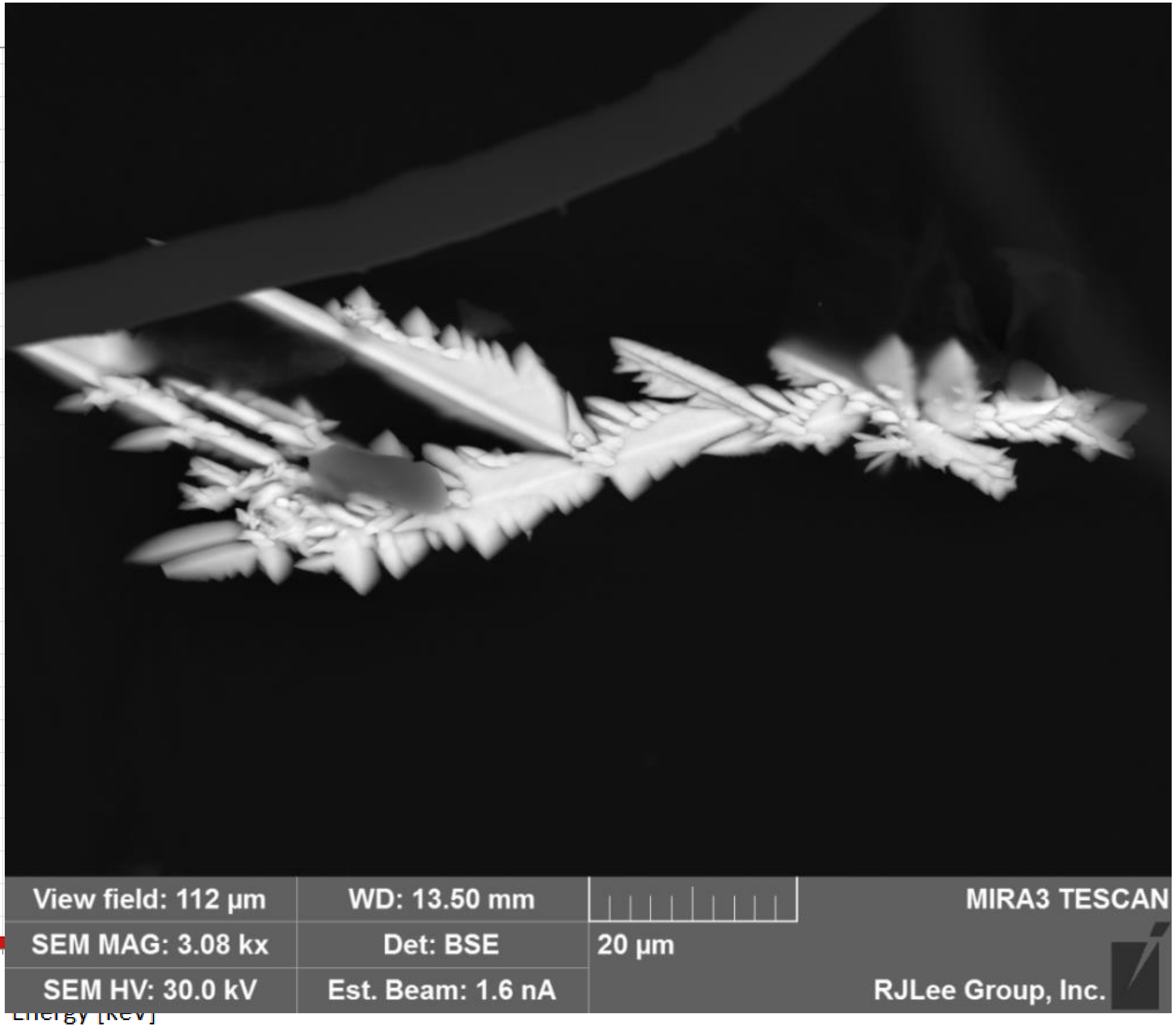




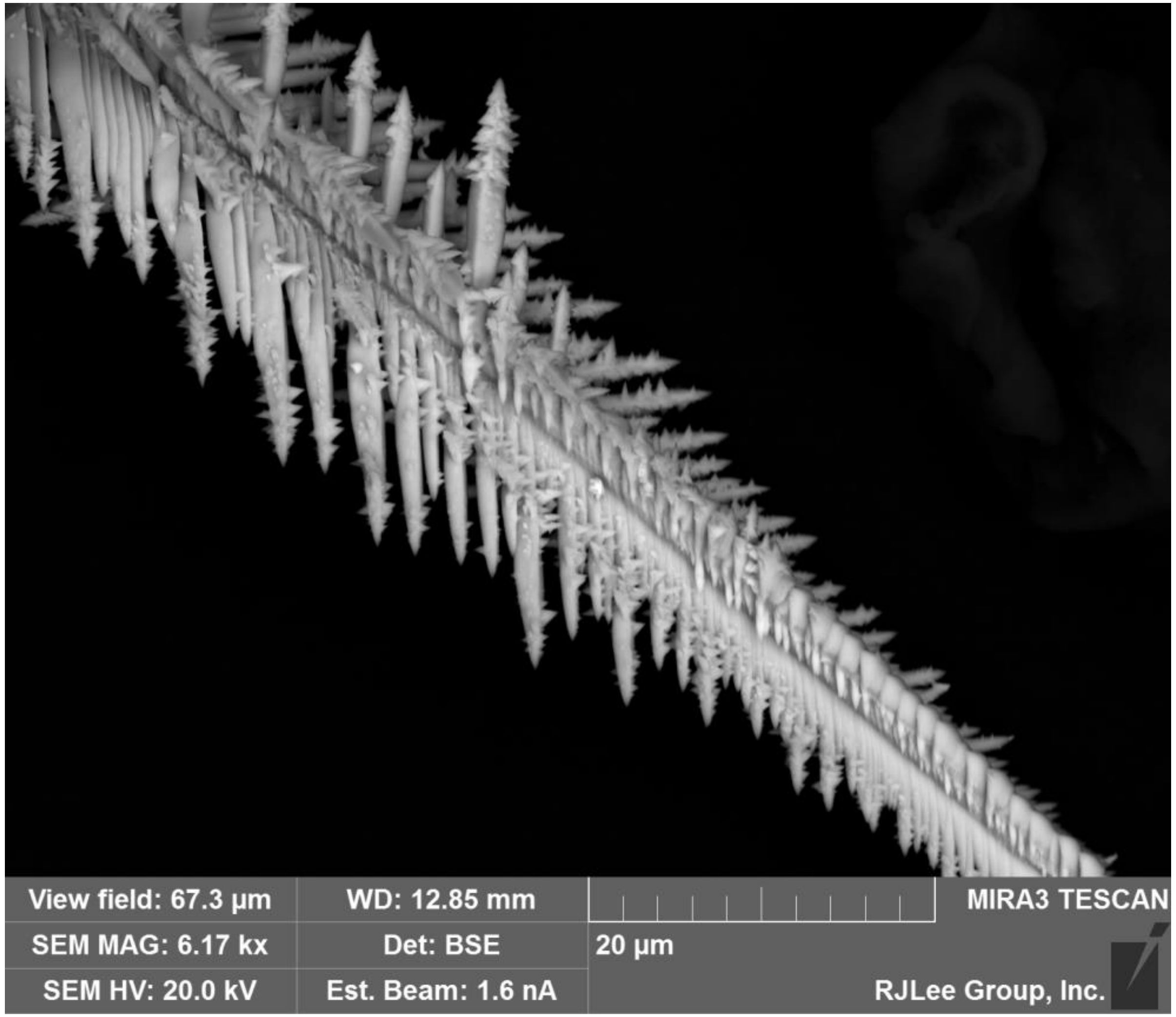
Silver on ISS

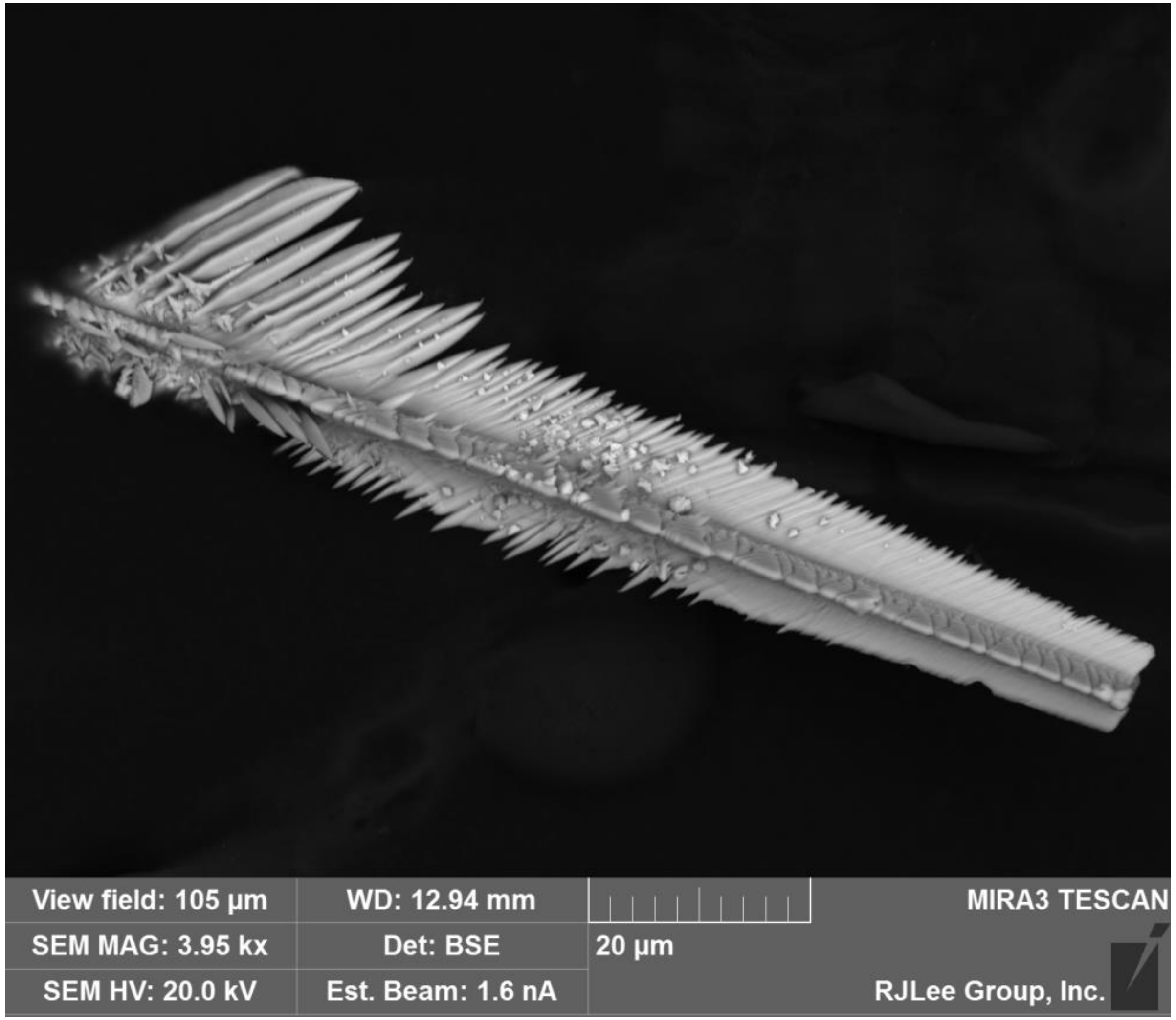
2018 NOD3OA3 - Overhead Supply Diffuser (PAS H-2)





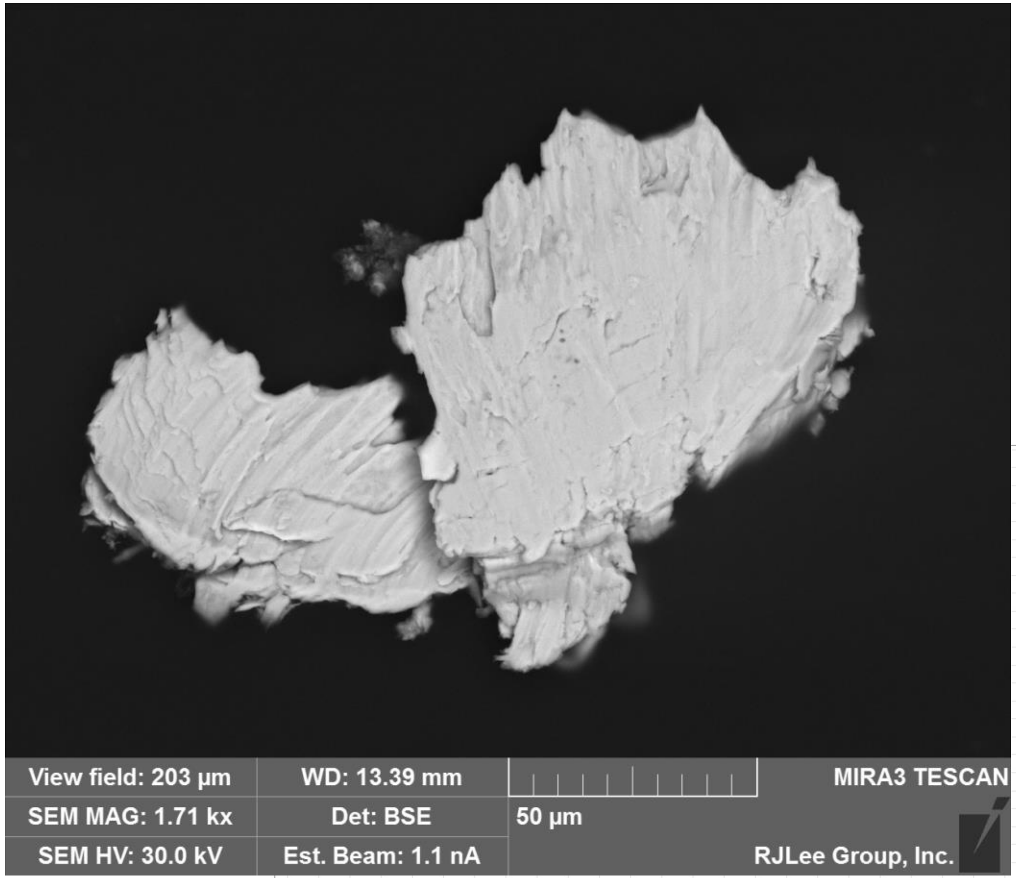
Silver on ISS - Dendrites

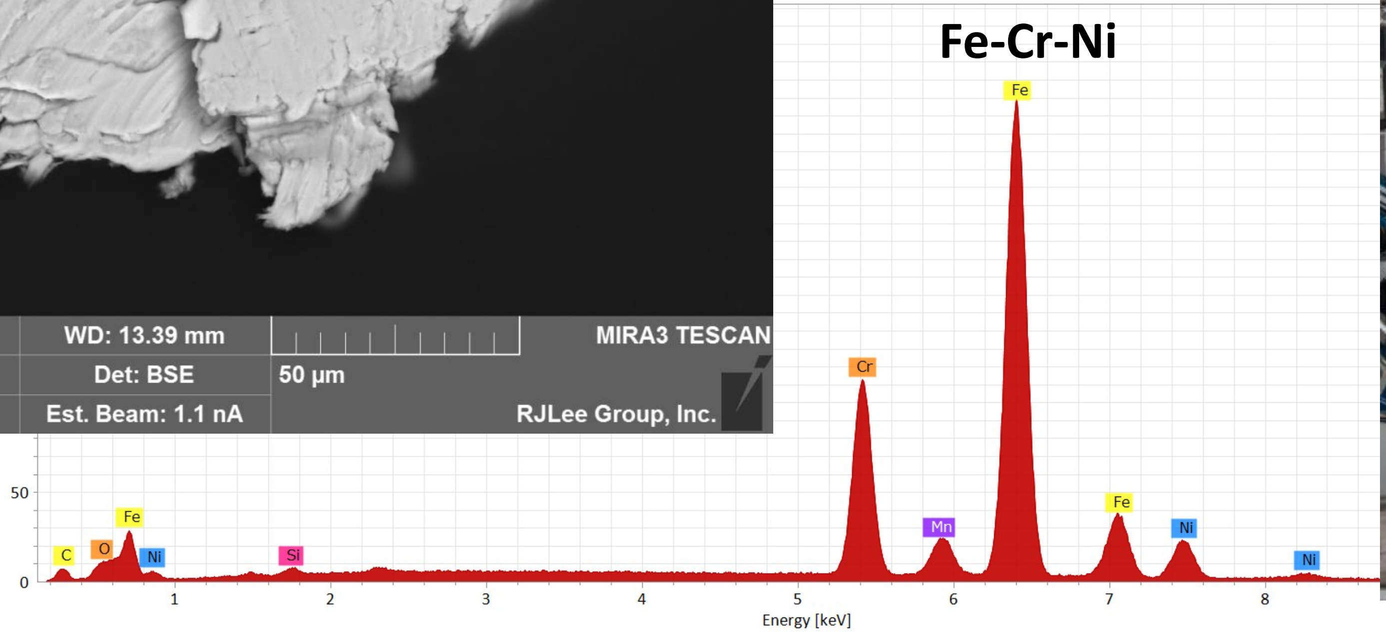




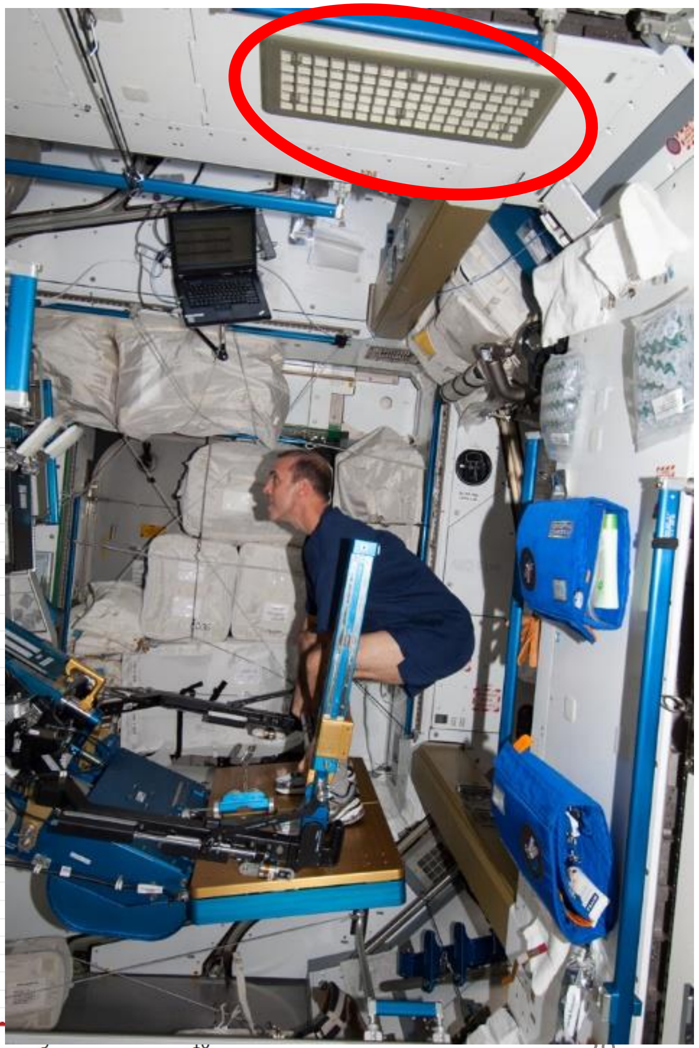
Stainless Steel Wear Particles

Sampler D near exercise machine, Node 3

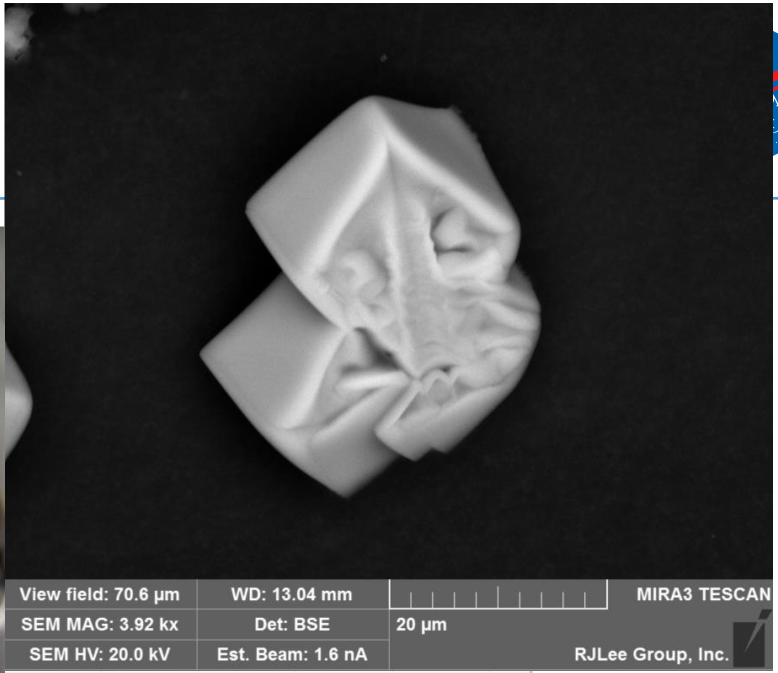


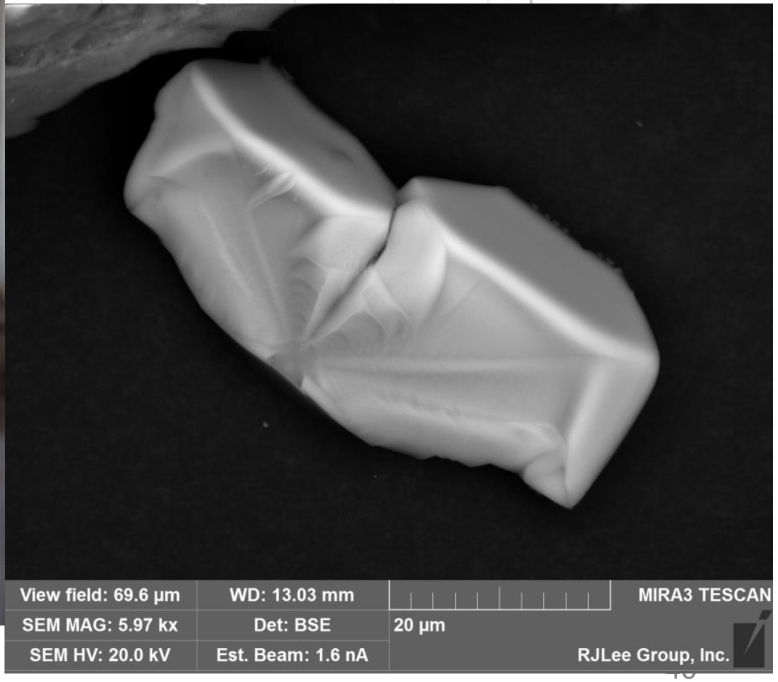


Advanced Resistive Exercise Device (ARED)



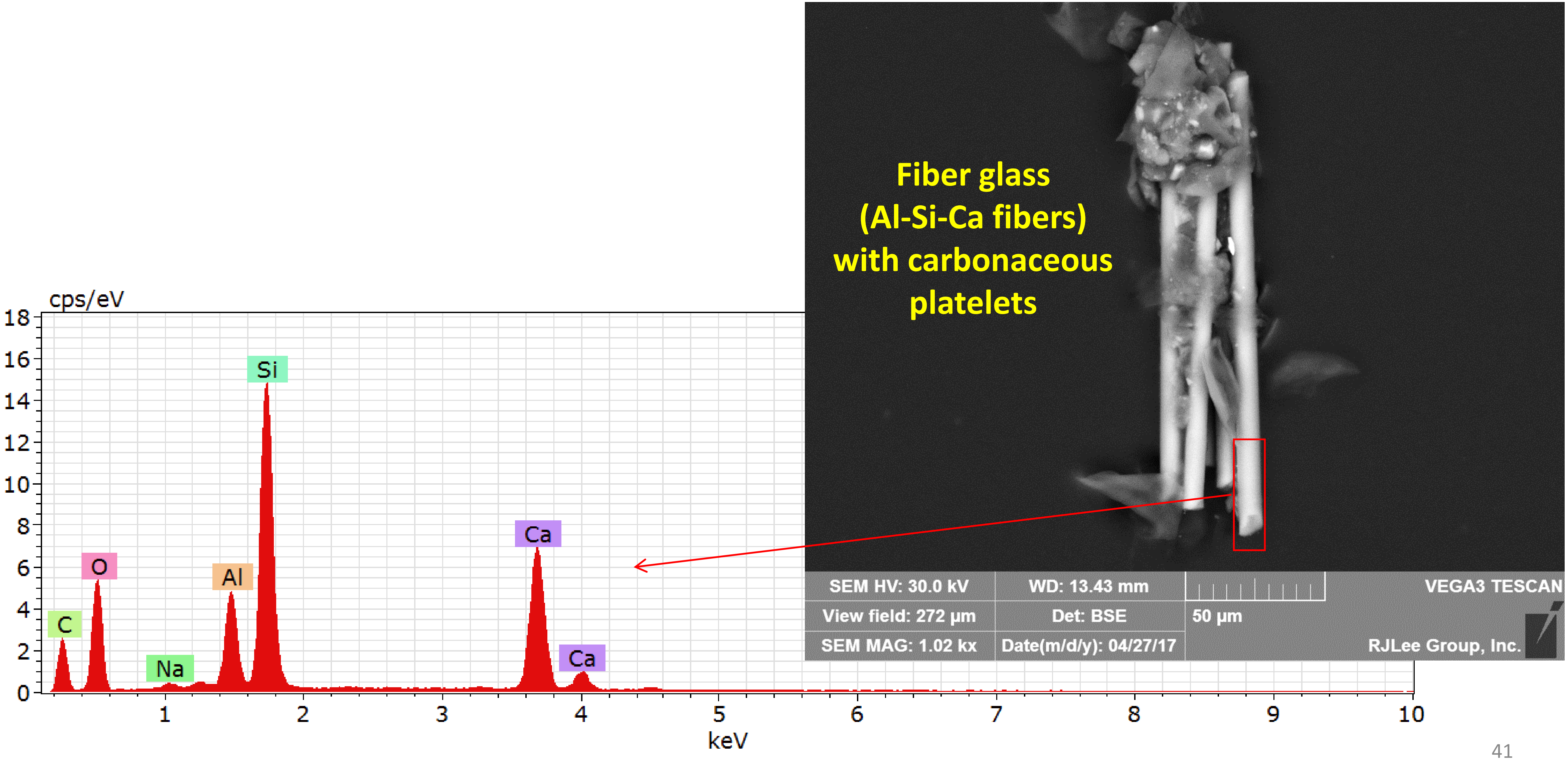
Particles in Node 1 (Eating Area)





Energy [keV]

Fiberglass



cps/eV
18
16
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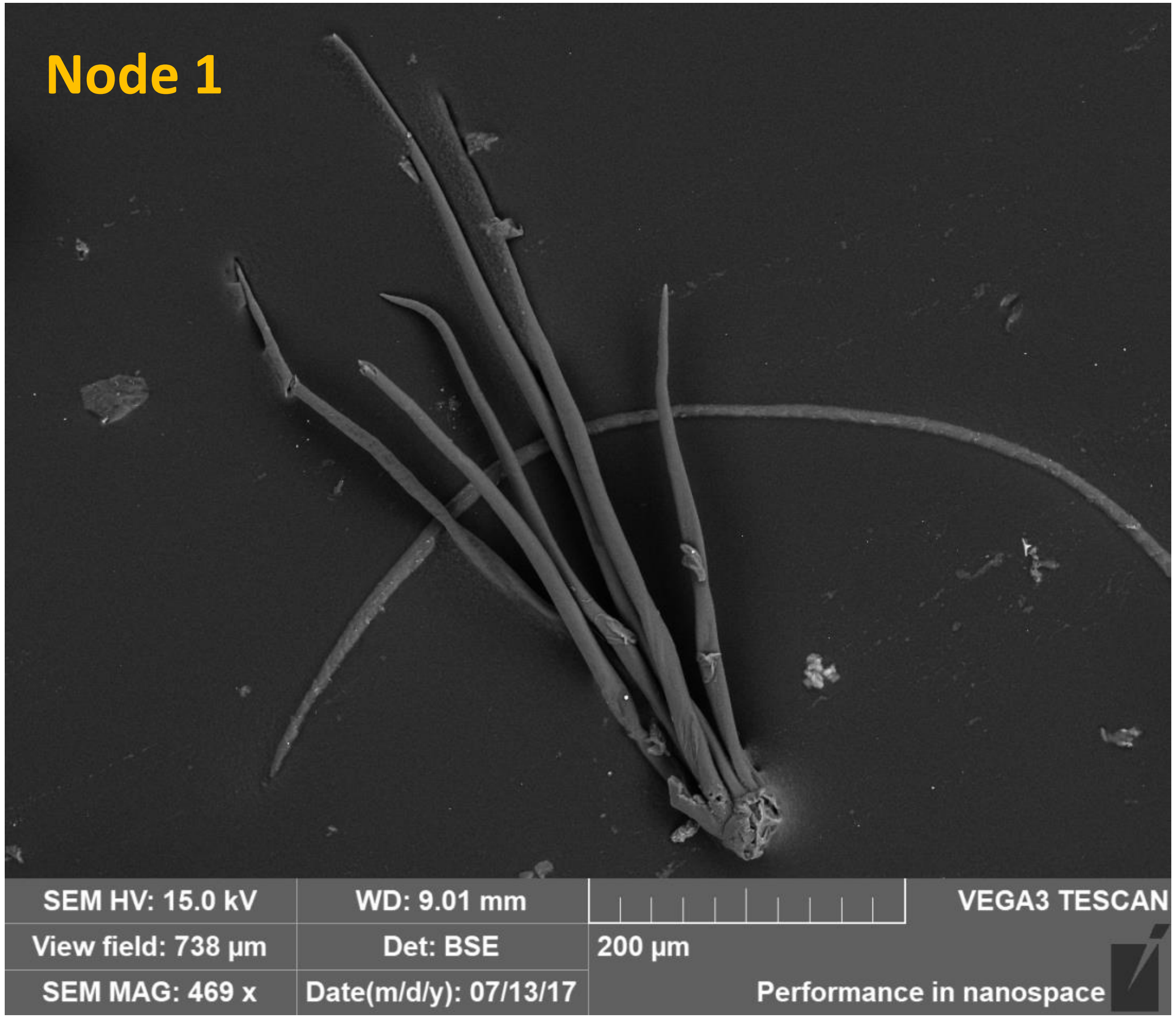
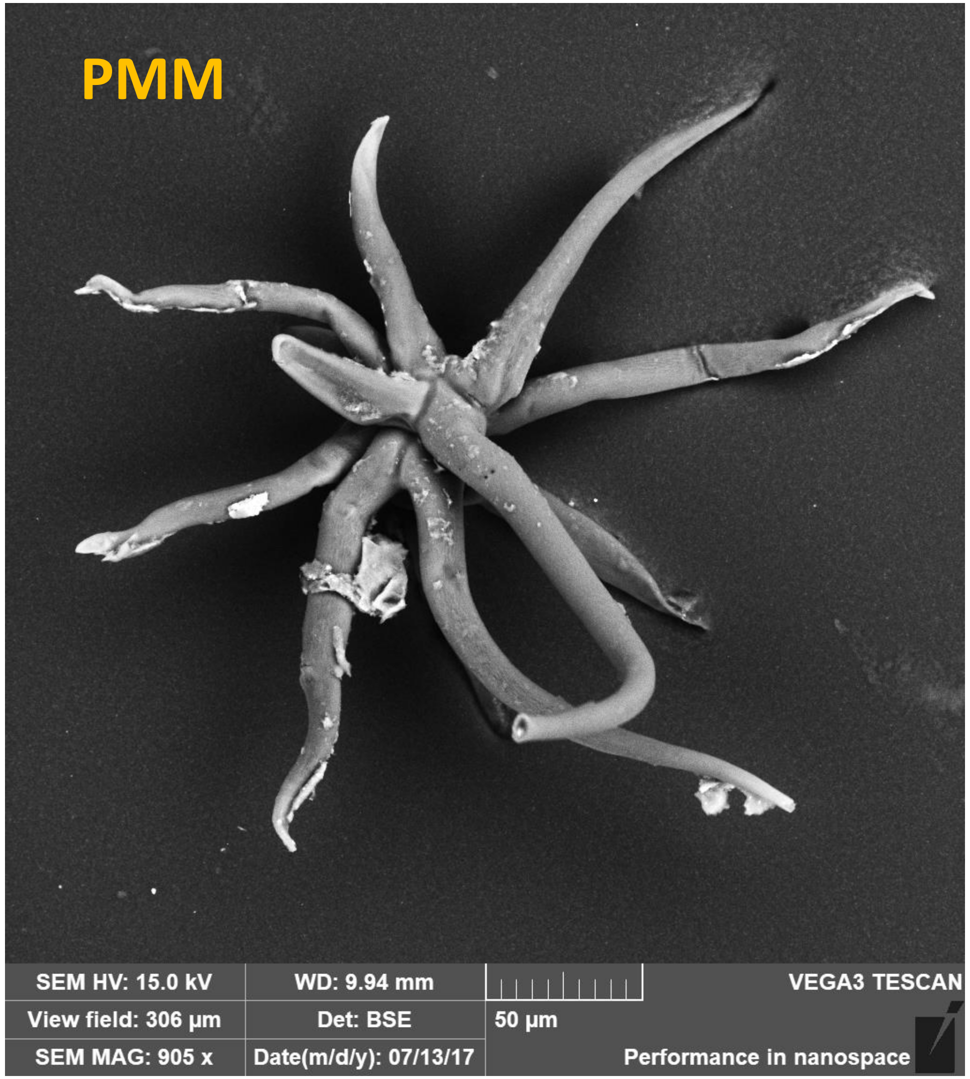
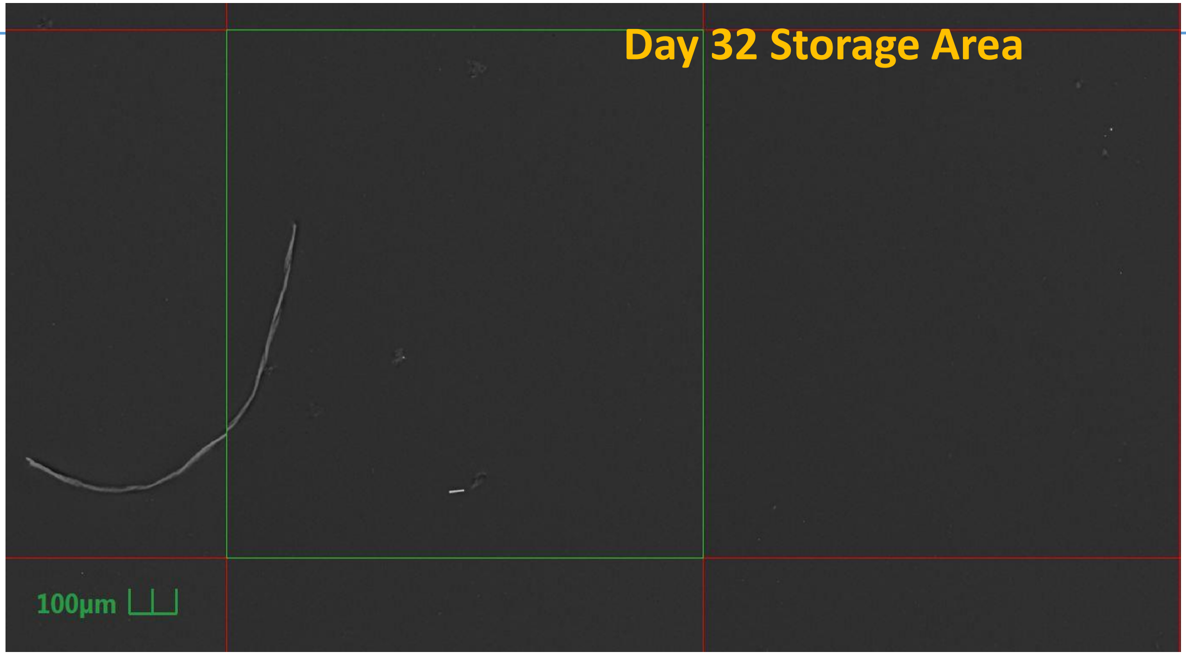
keV
Fiber glass
(Al-Si-Ca fibers)
with carbonaceous
platelets
SEM HV: 30.0 kV
WD: 13.43 mm
VEGA3 TESCAN
View field: 272 μm
Det: BSE
50 μm
SEM MAG: 1.02 kx
Date(m/d/y): 04/27/17
RJLee Group, Inc.

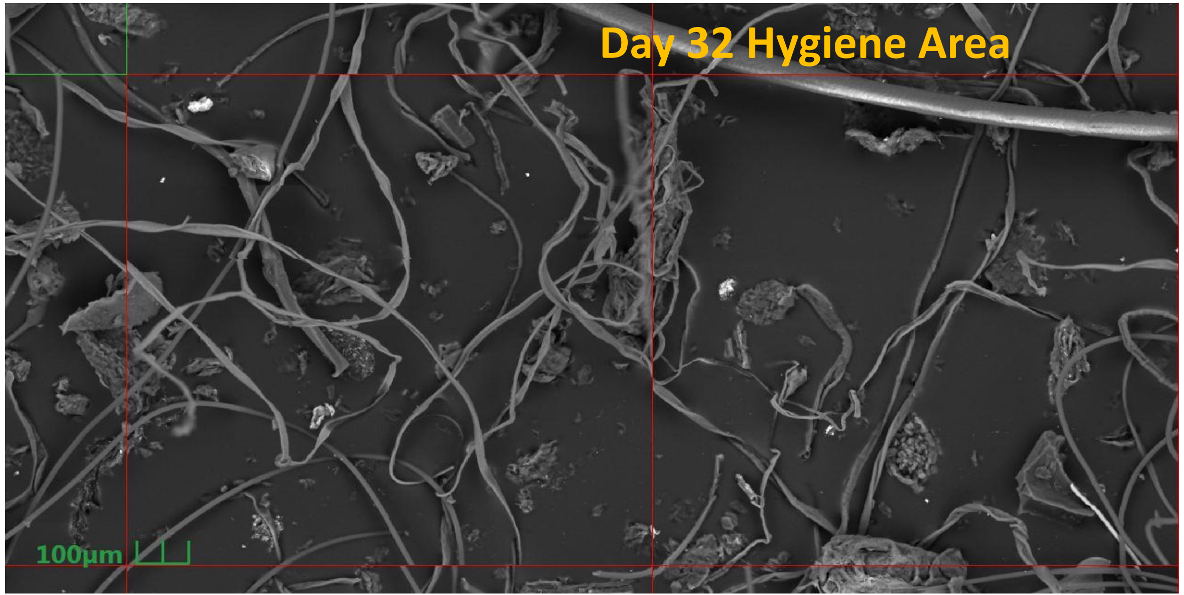
Plant Trichomes

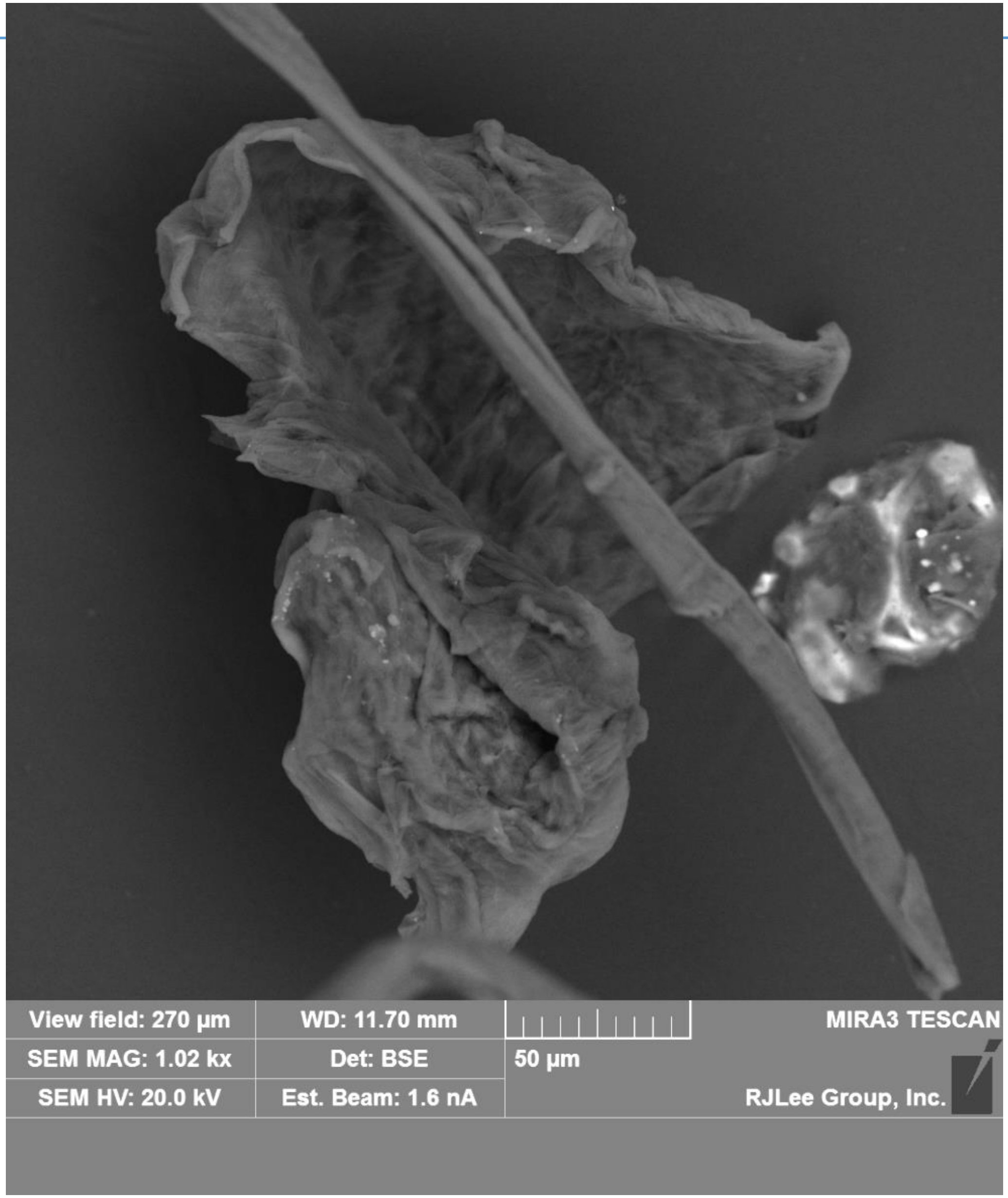




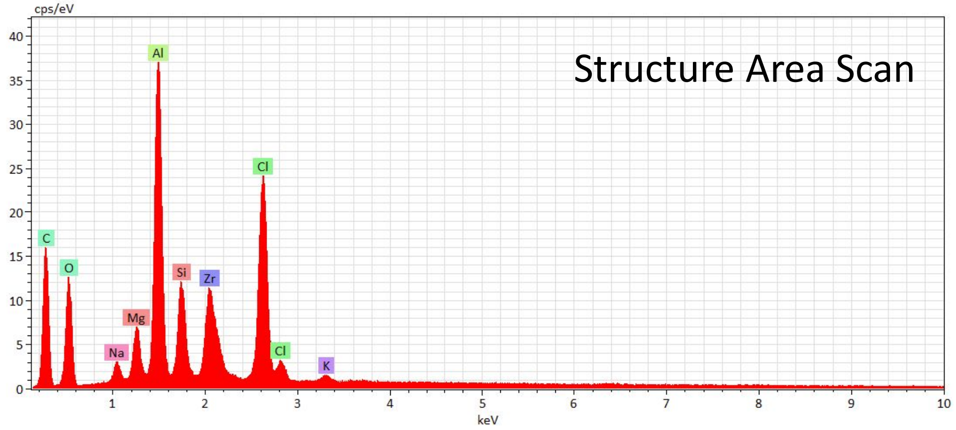
Human-generated particles

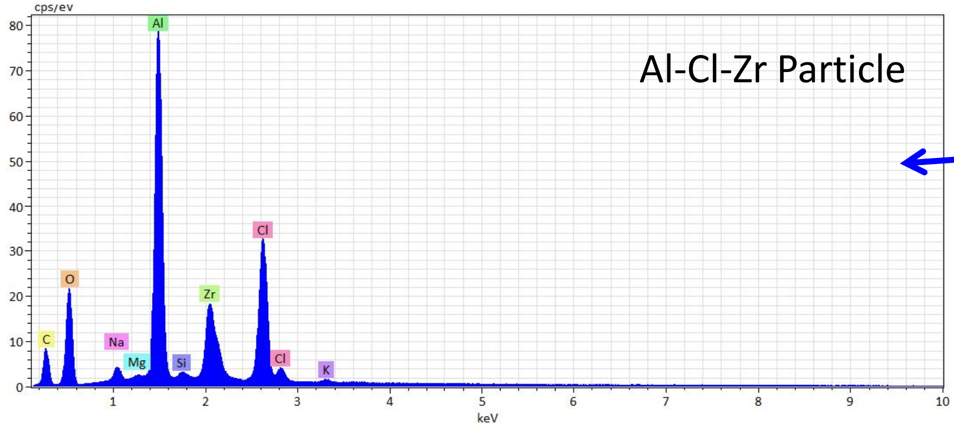


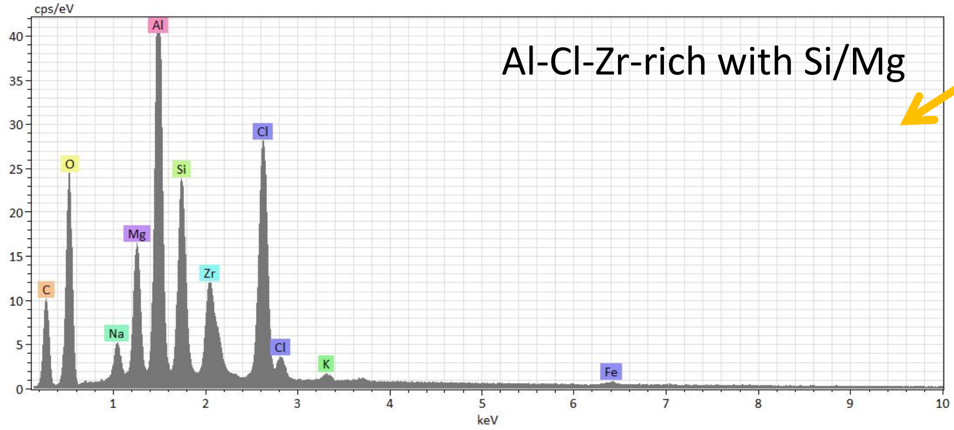


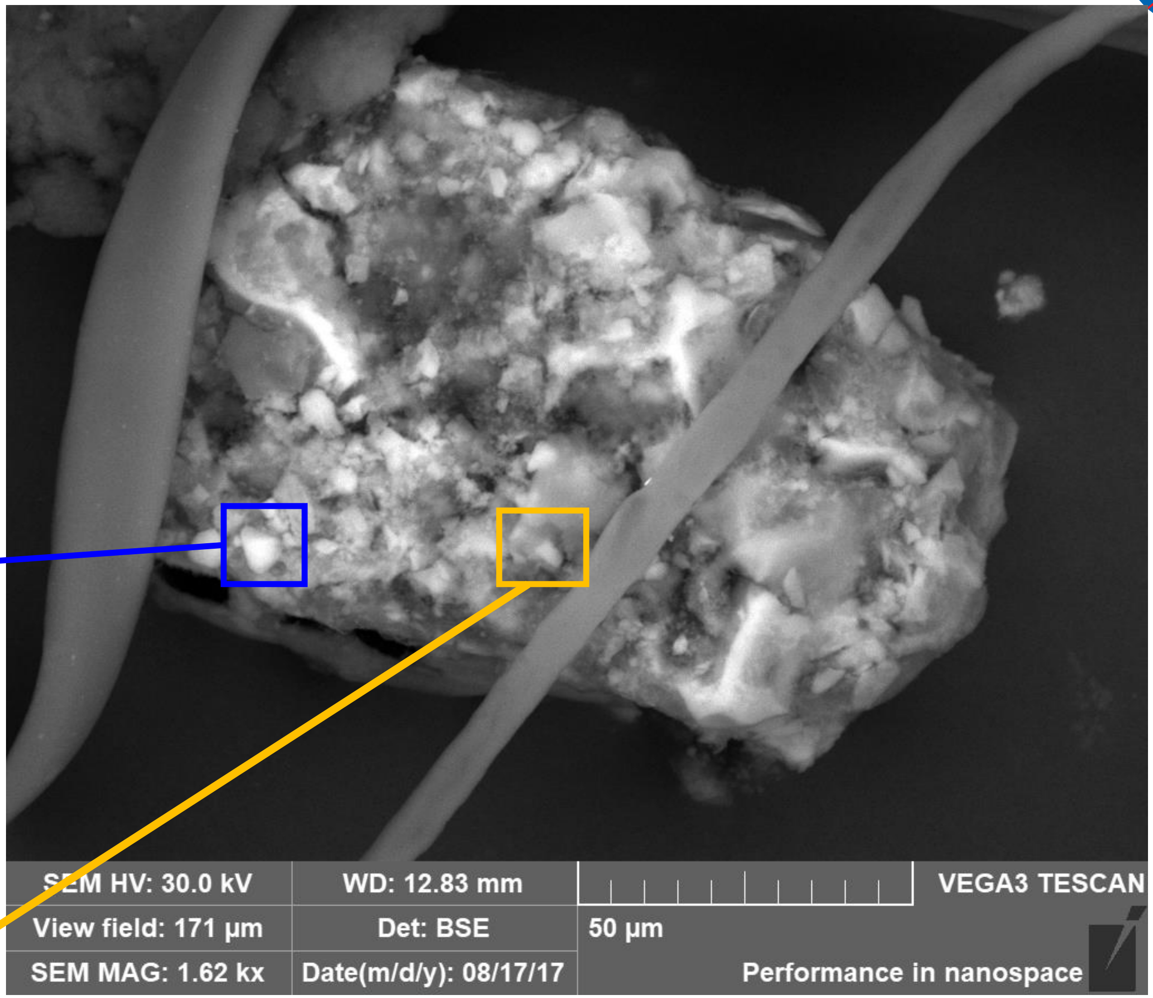


Antiperspirant Particle from Node 2







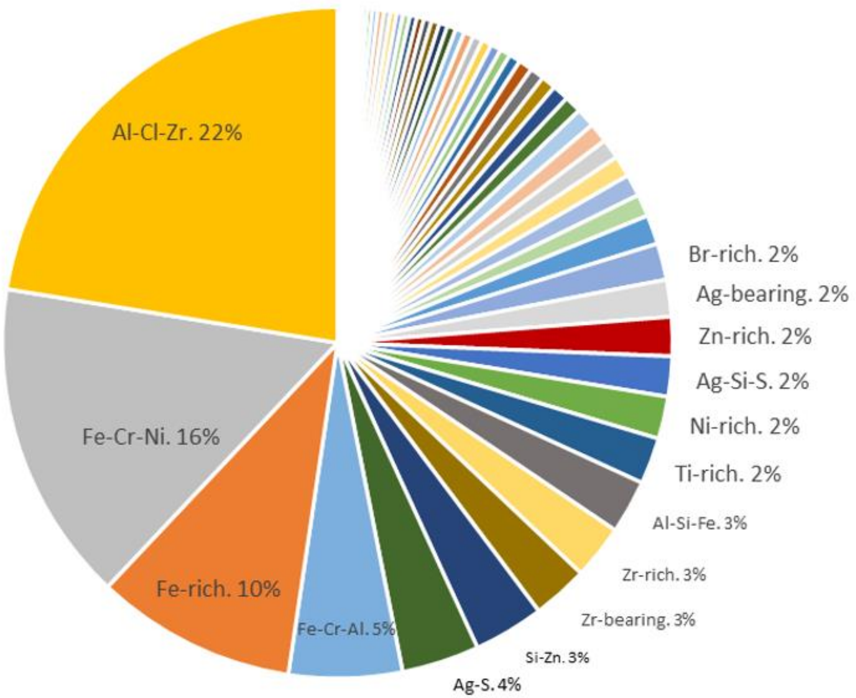


Aluminum-chlorine-zirconium and silicon-magnesium (talc) agglomerated particles

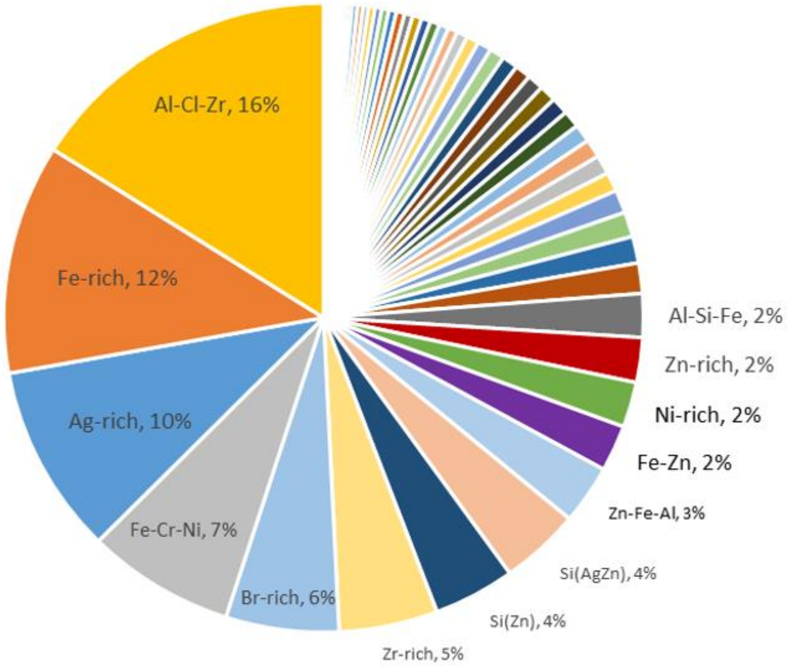
Aluminum zirconium tetrachlorohydrex glycine

2018 and 2016 Metal Results of Aerosol Sampling Experiment

Particle material classes, by weight % of all particles collected



2016



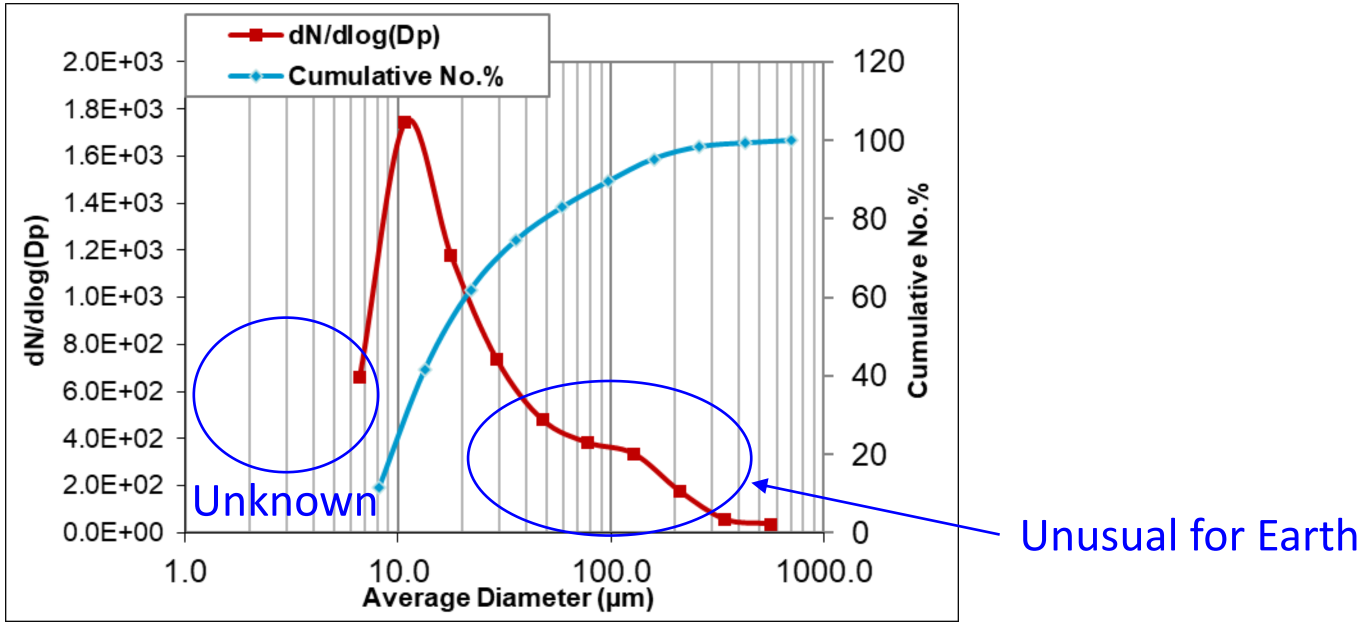
2018

- ***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 >5µm
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)

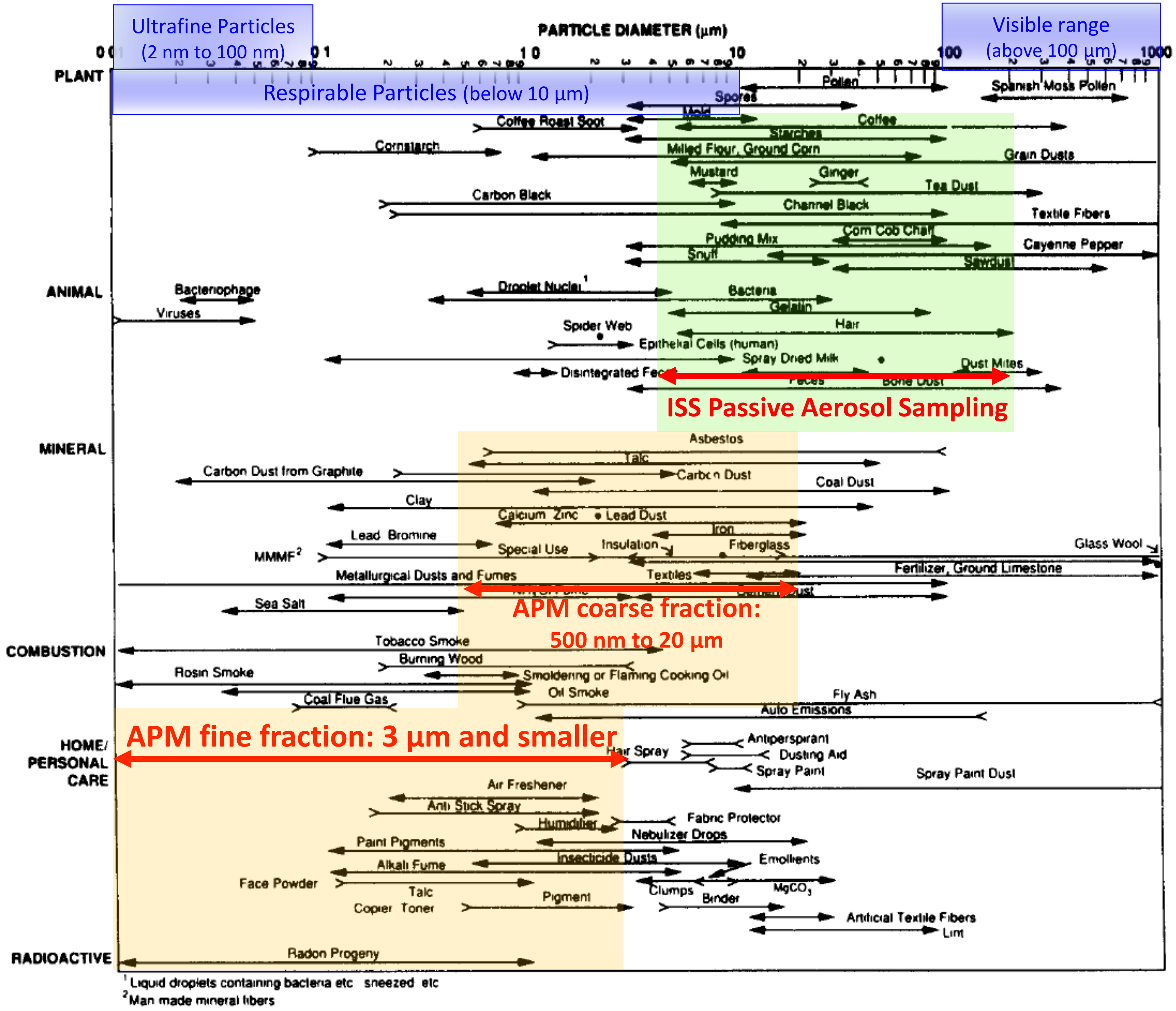
Instrument should go up to 20 µm

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

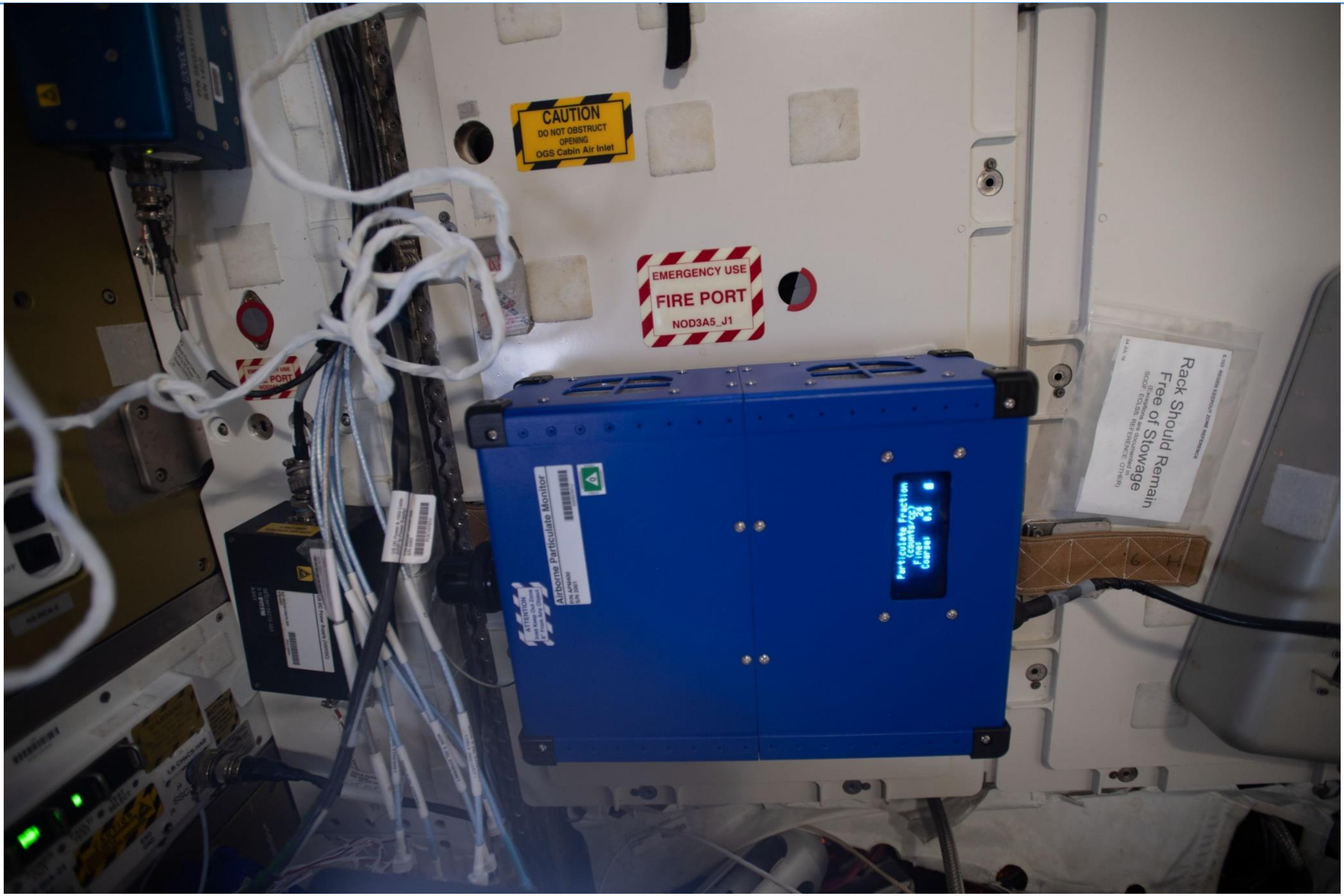
* ”Moderated Aerosol Growth with Internal water Cycling”

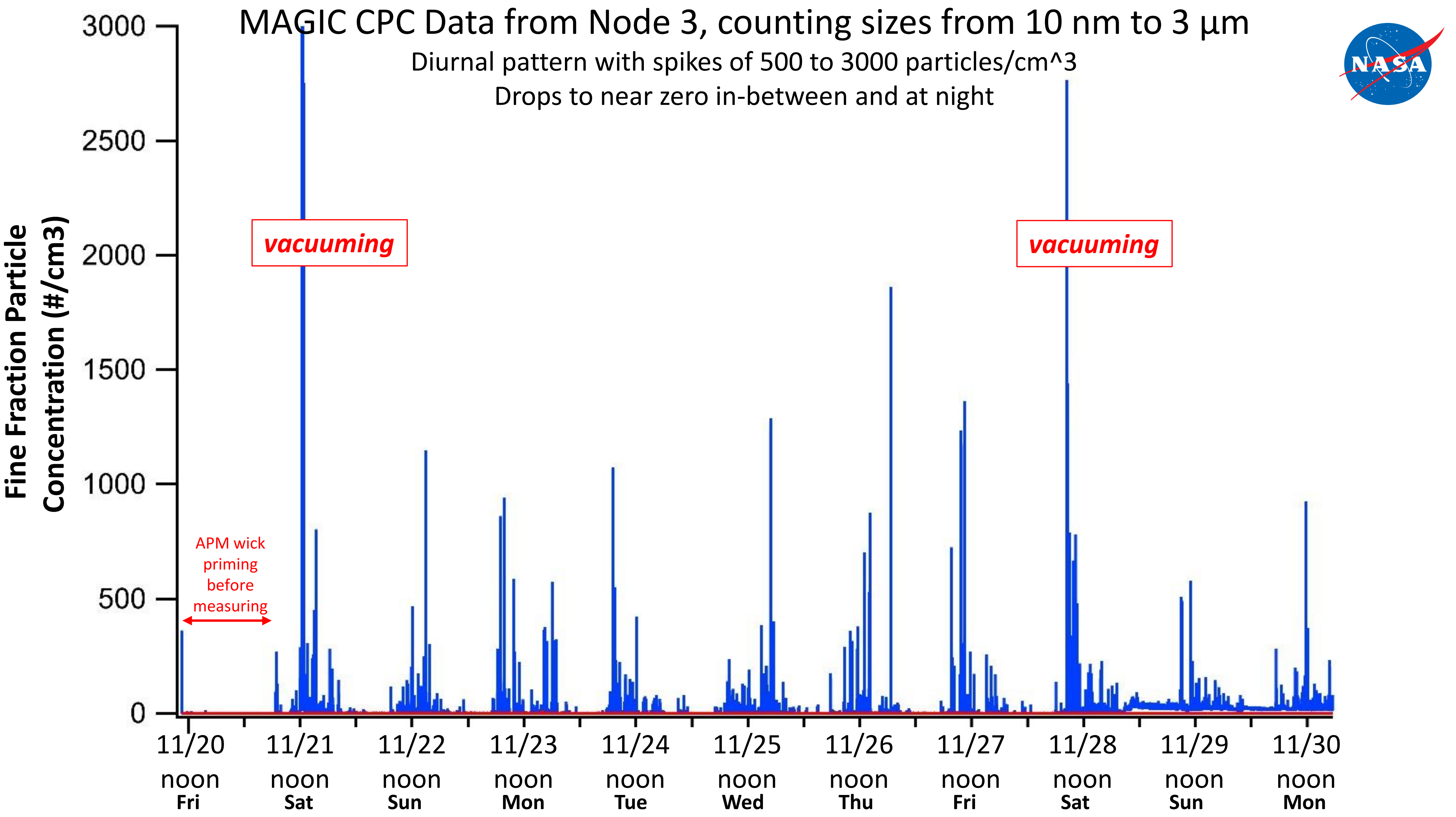
Sizes of Aerosols *(Log scale)*



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

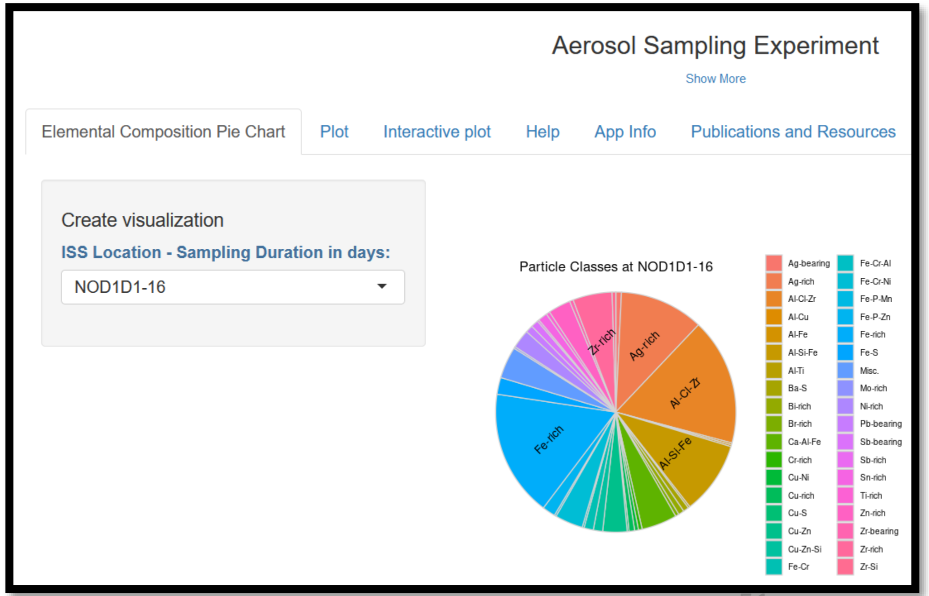




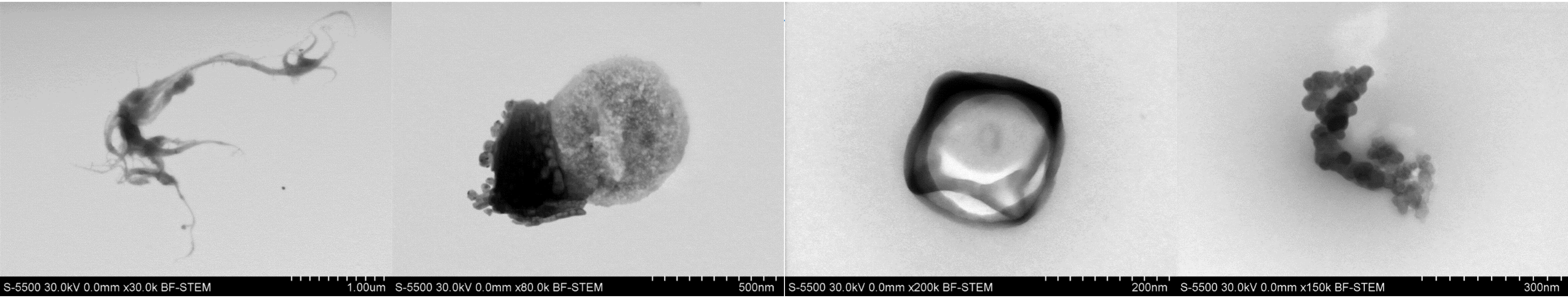
MAGIC CPC Data from Node 3, counting sizes from 10 nm to 3 µm
Diurnal pattern with spikes of 500 to 3000 particles/cm^3
Drops to near zero in-between and at night
Fine Fraction Particle Concentration (#/cm3)
3000
2500
2000
1500
1000
500
0
vacuuming
vacuuming
APM wick priming before measuring
11/20 noon Fri
11/21 noon Sat
11/22 noon Sun
11/23 noon Mon
11/24 noon Tue
11/25 noon Wed
11/26 noon Thu
11/27 noon Fri
11/28 noon Sat
11/29 noon Sun
11/30 noon 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!