Welcome to

EMERGING TECHNOLOGIES CONFERENCE

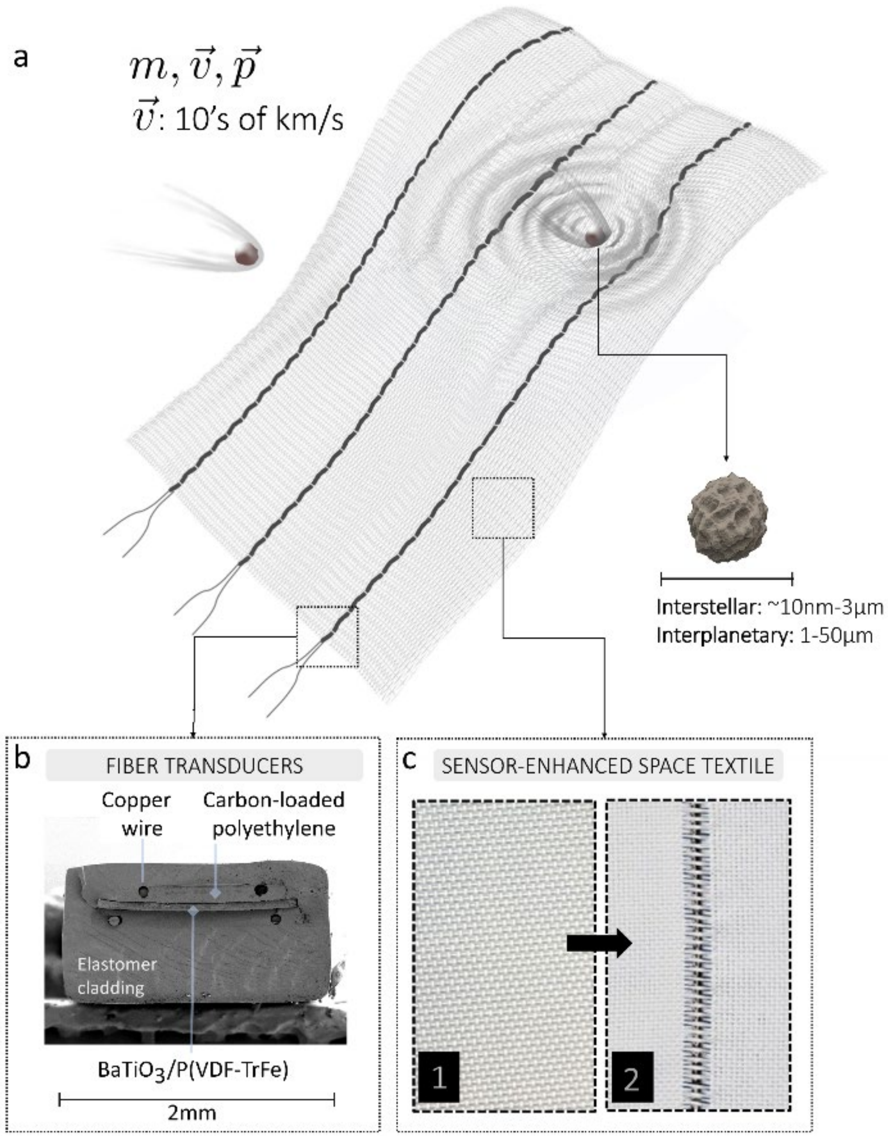
at Advanced Textiles EXPO®

The Well-Dressed Spacecraft

Academic partnerships for accelerating advanced textiles into the 'New Space' economy

Speaker:

Dr. Juliana Cherston
Emerging Technology Consultant
PhD, MIT Media Lab



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Part 1: Narrative - development and launch of the first electronic textile sensor to space

Addendum: ‘Behind the scenes’
– partnerships and financing to enable this work; learnings

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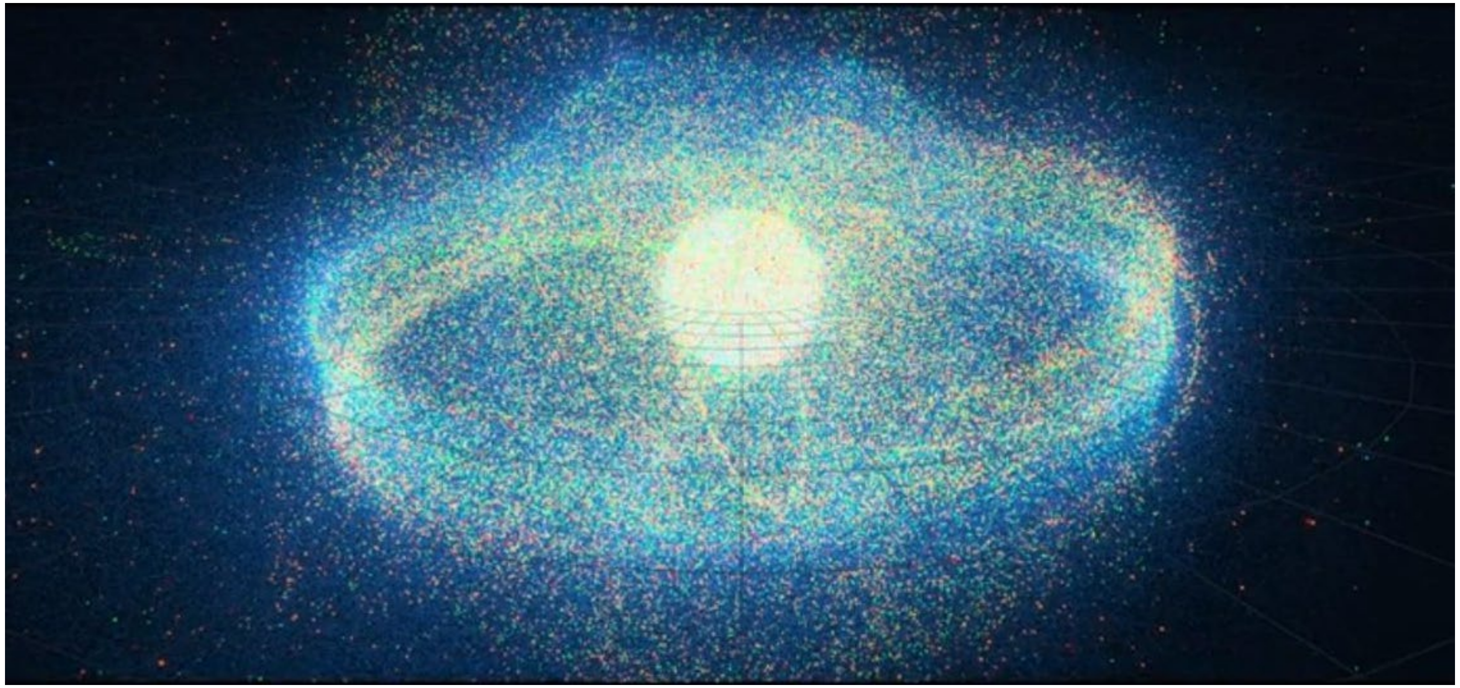
DUST IN LOW EARTH ORBIT

Manmade: paint flecks, solid rocket motor dust, aluminum…

Natural: iron/silicate micrometeoroids from interplanetary streams, asteroid/comet collisions…



ESA, 2021

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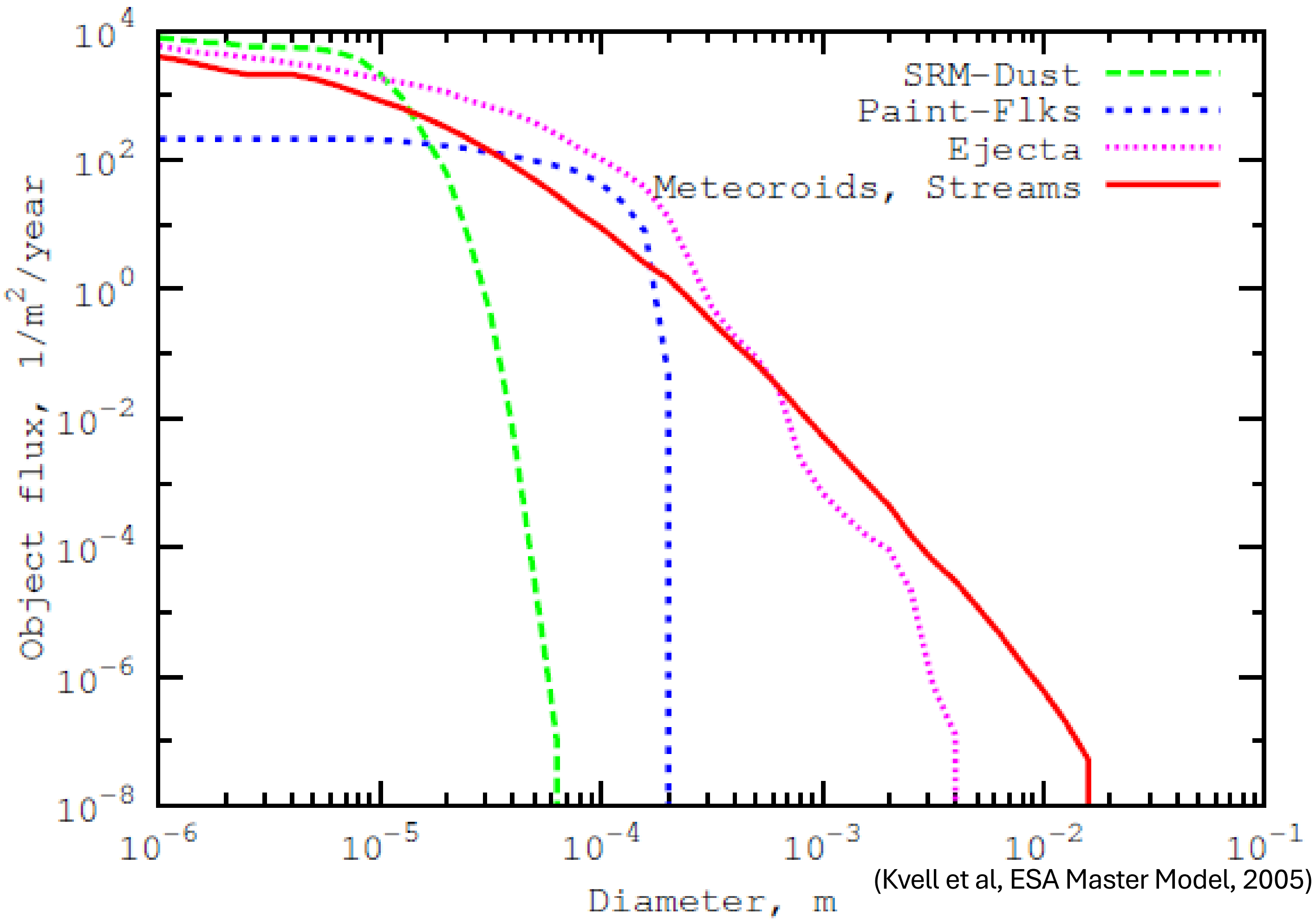
DUST IN LOW EARTH ORBIT

Manmade debris: 7-12 km/s

Cosmic dust: 11-72 km/s +

10,000+ collisions per m^2 area per year



(Kvell et al, ESA Master Model, 2005)

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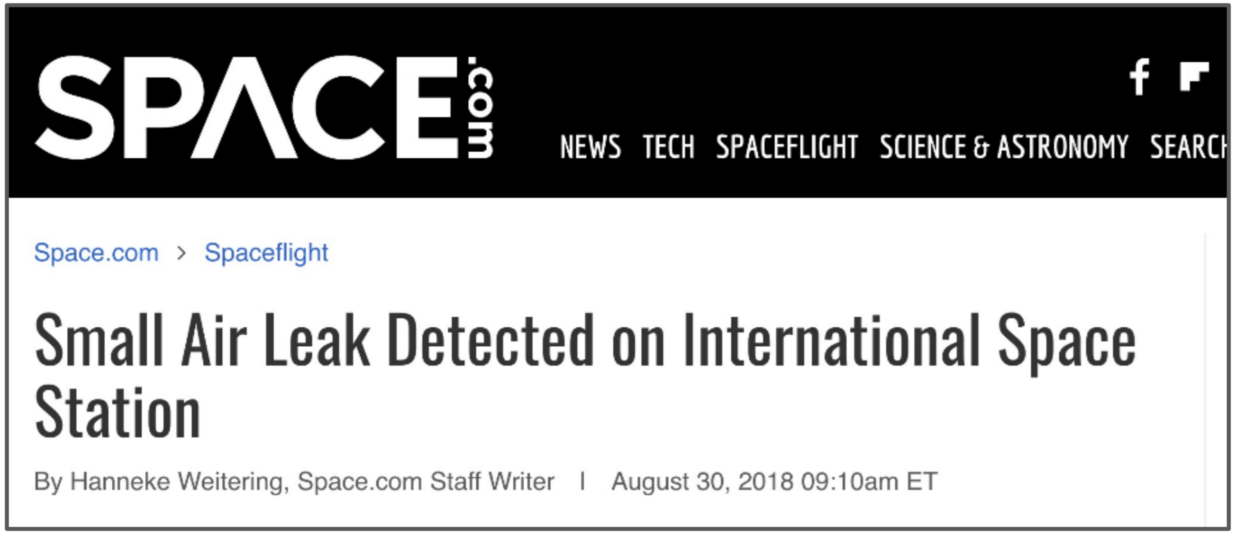
TALKING ABOUT ASTROPHYSICS TO INDUSTRY?

It’s more about damage detection.



=>How about ‘impact’ as standard telemetry data?

BRIDGE EMERGING ADVANCED TEXTILE AND AEROSPACE ENGINEERING MARKETS

‘Smart Fabrics’ projected **CAGR: 30.4%** (2019-2025) [1]

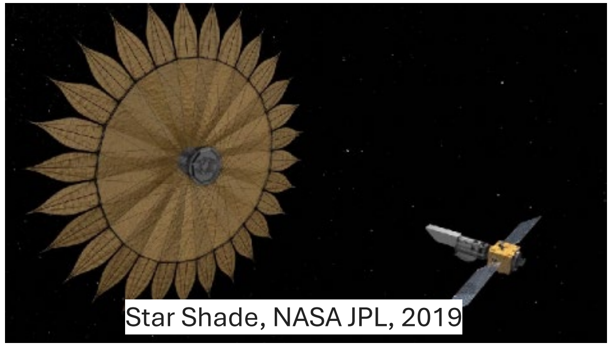
11000 satellites launching per year by 2025 [2]

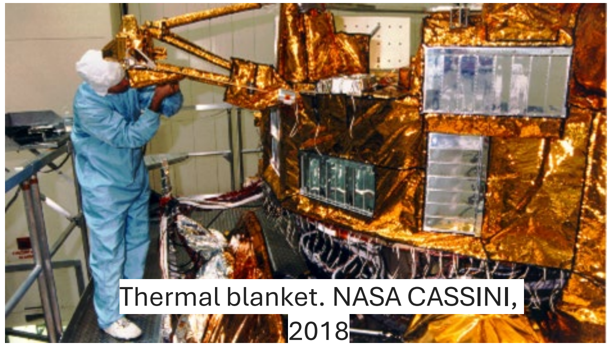
orbital object threats >10cm: [3]
2016: **18k**
2022: **25.5k**

[1] Smart Fabrics Market Size, Share & Trends Analysis Report, 2019 – 2025. Grand View Research Report. 2019. Accessed 07 April 2020.
[2] Ryan-Mosley T., et al. "The number of satellites orbiting Earth could quintuple in the next decade." MIT Technology Review (2019).
[3] National Aeronautics and Space Administration. The Orbital Debris Program Office. “LEGEND: 3D/OD Evolutionary Model,” Available at https://orbitaldebris.jsc.nasa.gov/modeling/legend.html, accessed 04 April 2020.

SKINS ARE AN ESSENTIAL ARCHITECTURE IN SPACE EXPLORATION


Solar Sail: Swartzlander, 2019


Star Shade, NASA JPL, 2019


Thermal blanket. NASA CASSINI, 2018


Spirit / Opportunity Airbag Landers

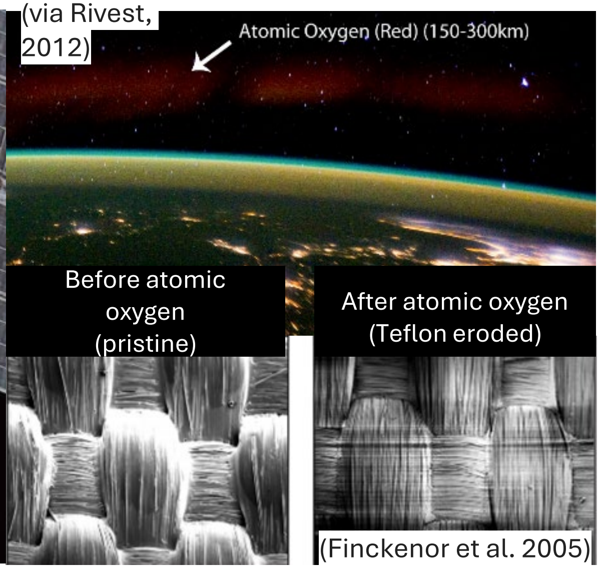

BEAM Habitat, NASA, 2017


Spacesuit, Armstrong, 1969

SPACE ENVIRONMENT IS HARSH TO STRUCTURES

Beta Cloth: Space Station's Protective Skin

Atomic Oxygen Erosion



+ **Extreme thermal cycling** [-184-149 C on orbit]

+ **UV exposure** [material degradation]

+ **Particulate radiation** [Bit flips]

+ **Micrometeoroid impact** [punctures, erosion]

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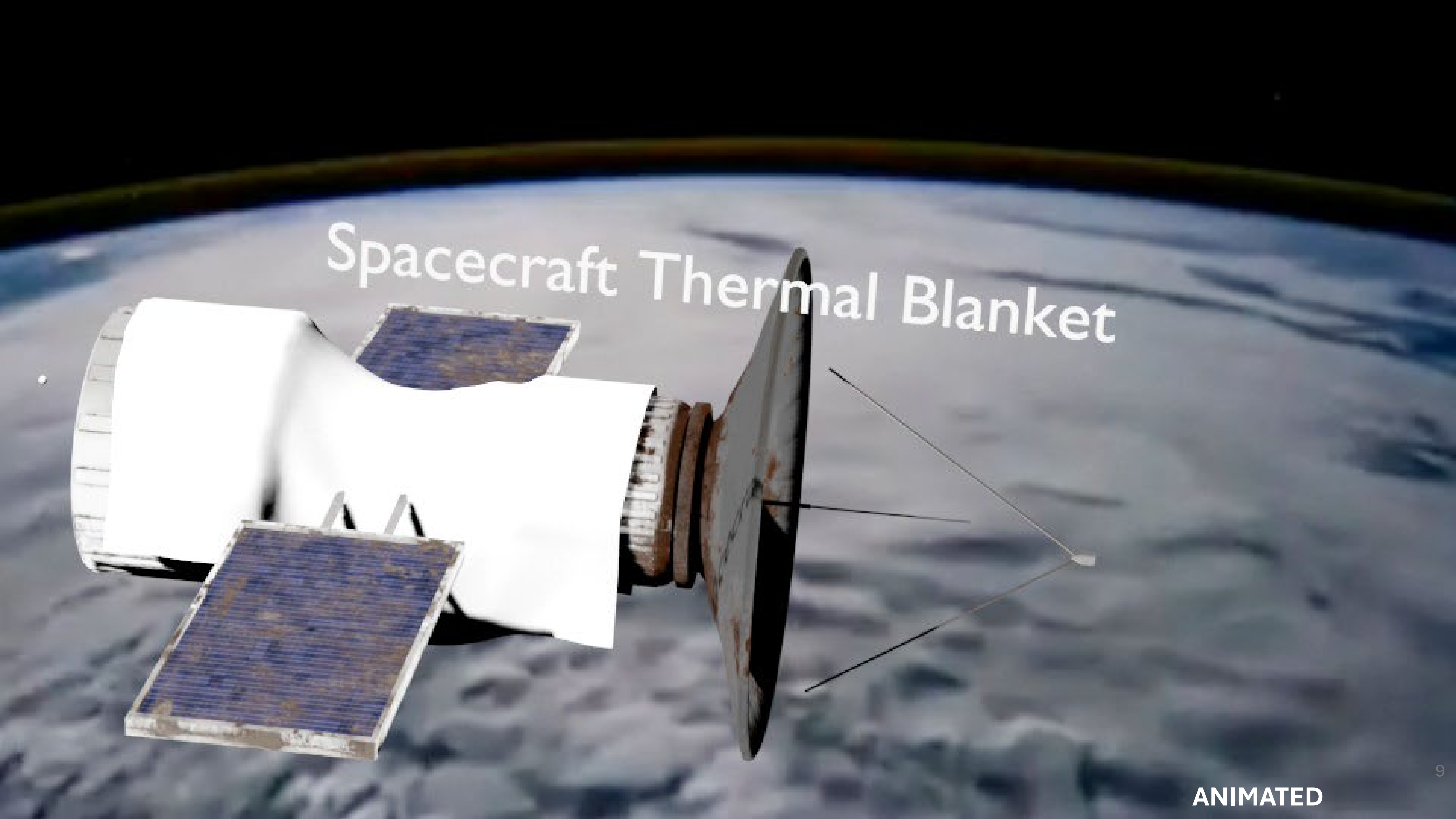
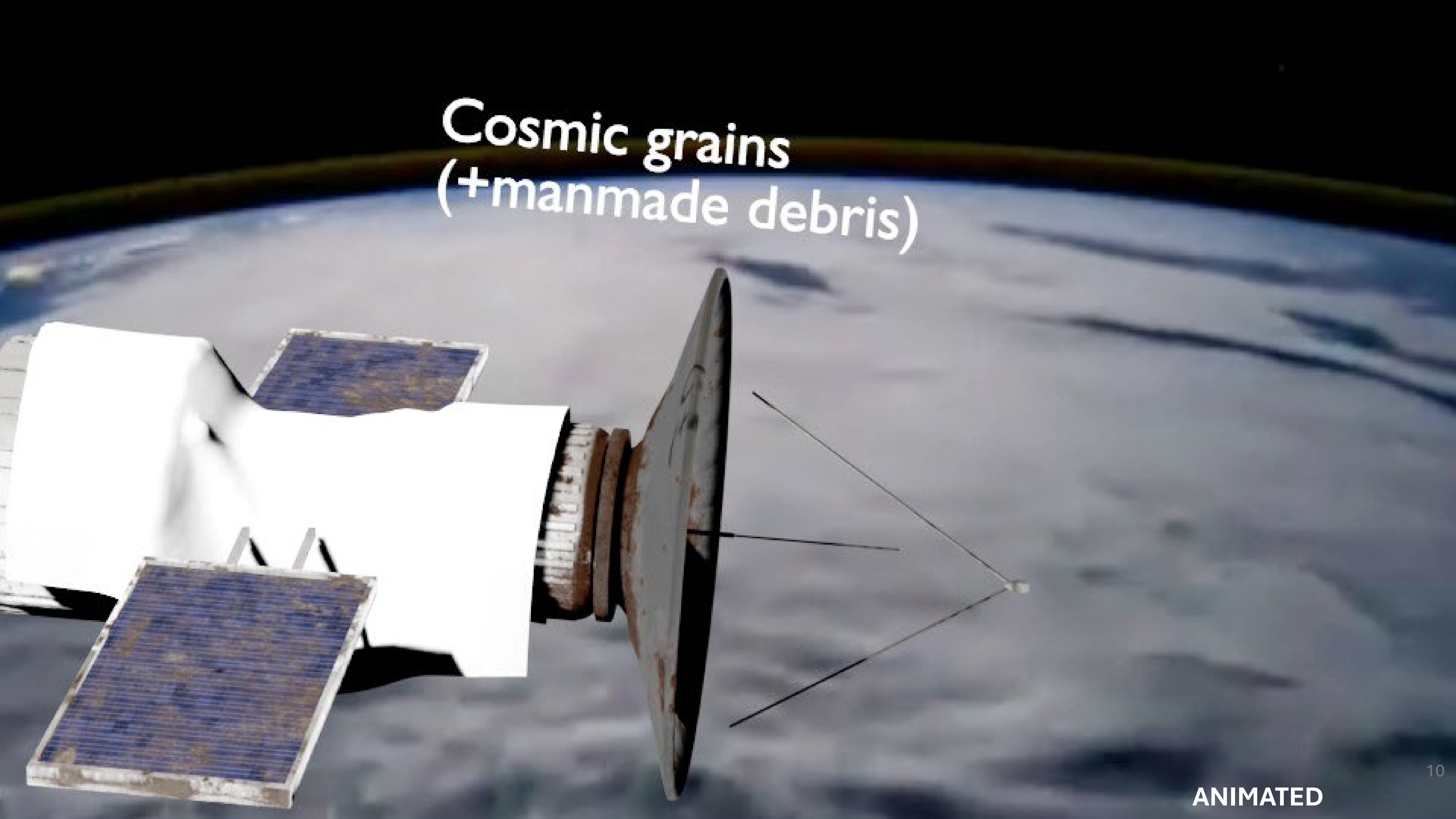
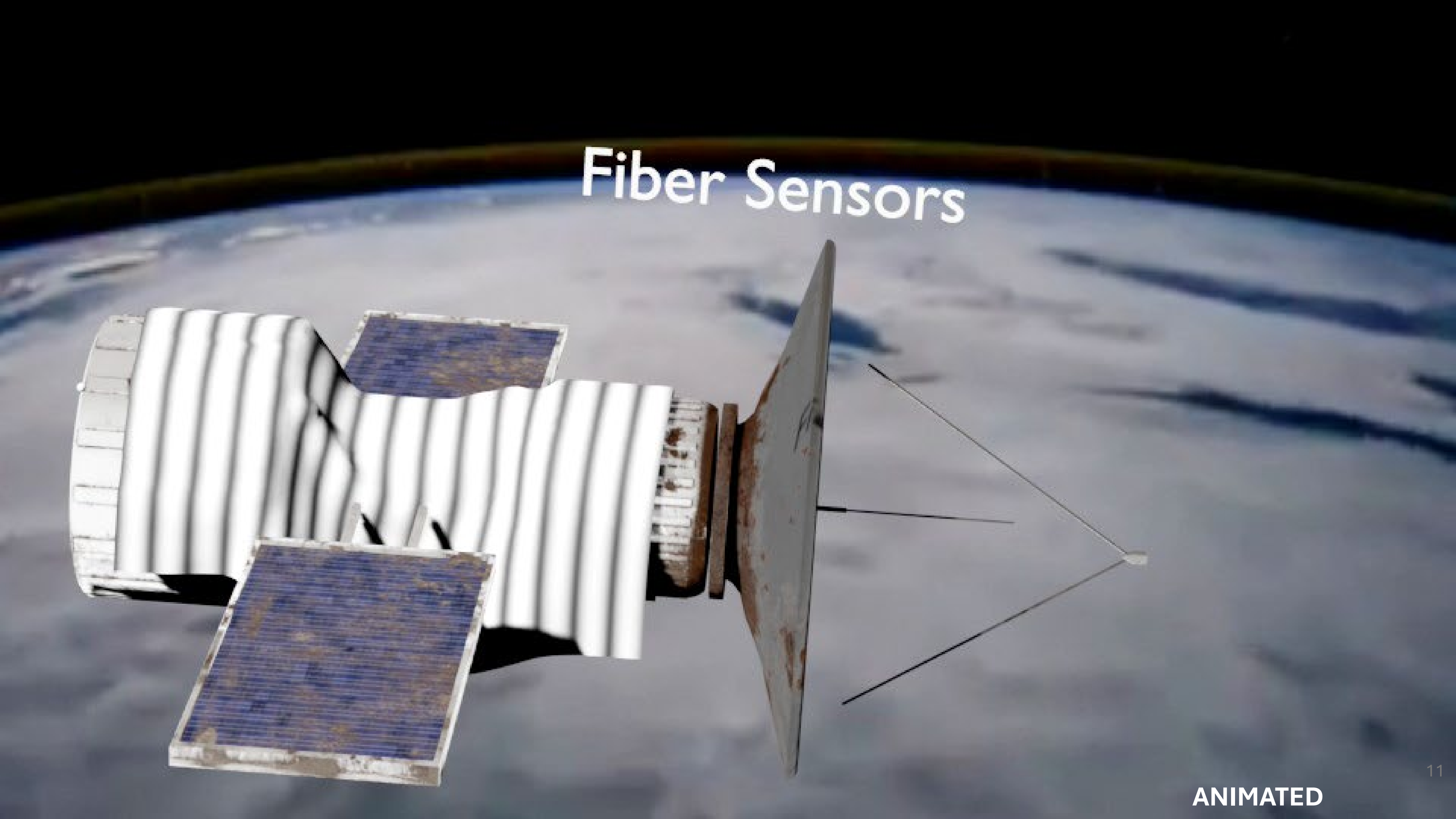
Spacecraft Thermal Blanket

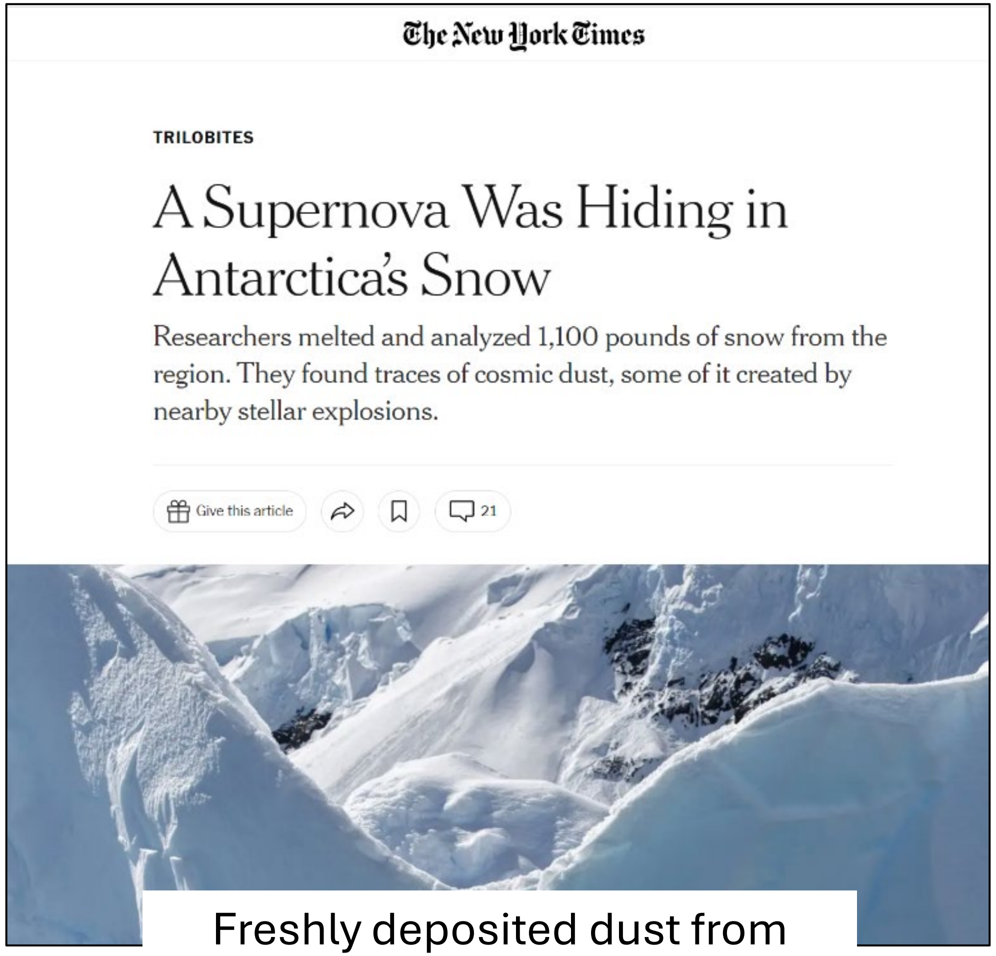


ANIMATED


Cosmic grains
(+manmade debris)
ANIMATED


Fiber Sensors
ANIMATED

SCIENTIFIC APPLICATIONS AS WELL
(E.G. INTERSTELLAR DUST CHARACTERIZATION)


The New York Times

TRILOBITES

A Supernova Was Hiding in Antarctica's Snow

Researchers melted and analyzed 1,100 pounds of snow from the region. They found traces of cosmic dust, some of it created by nearby stellar explosions.

Give this article

21

Freshly deposited dust from
Near-Earth Supernova

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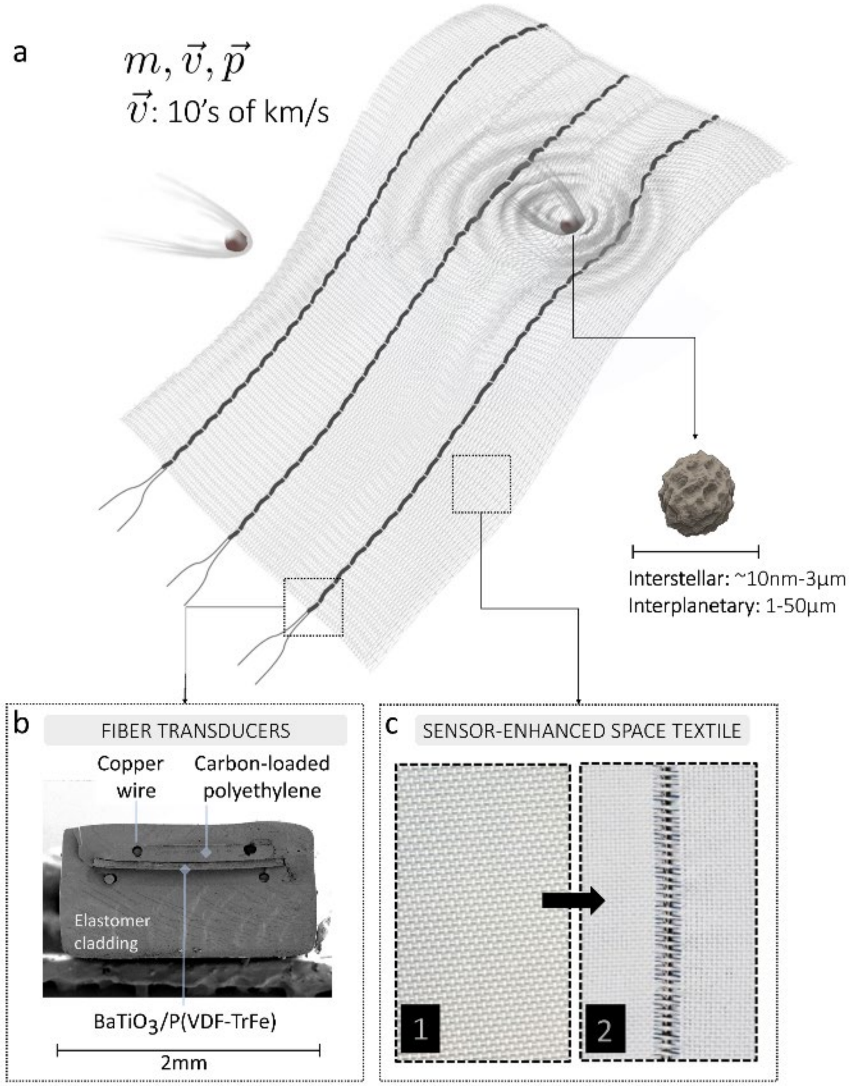
FABRIC ARCHITECTURE



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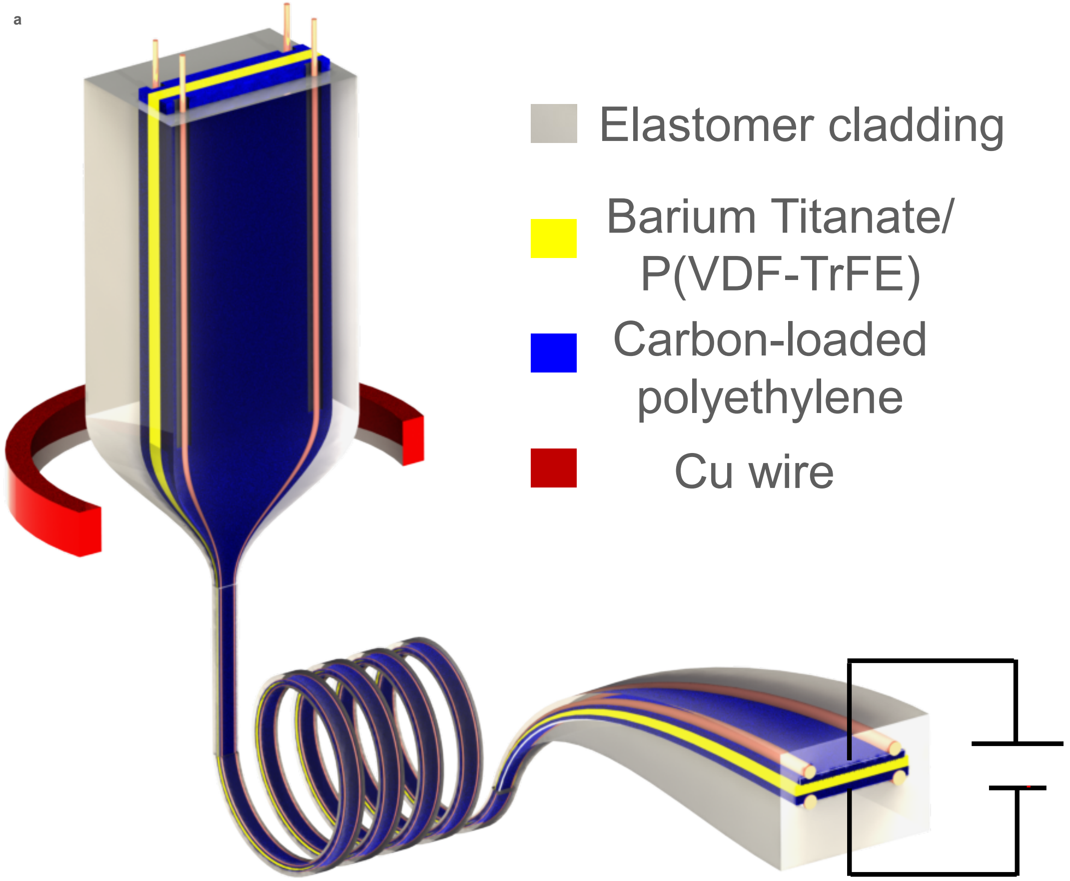
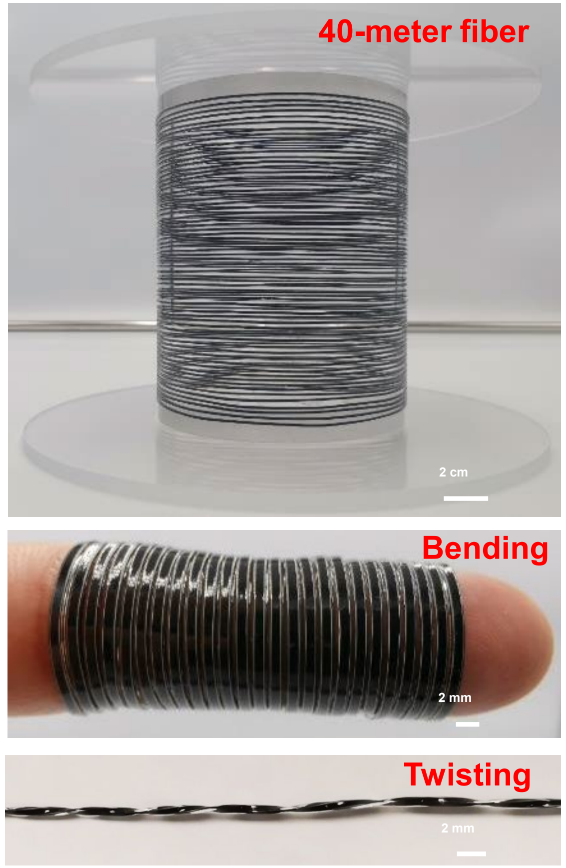
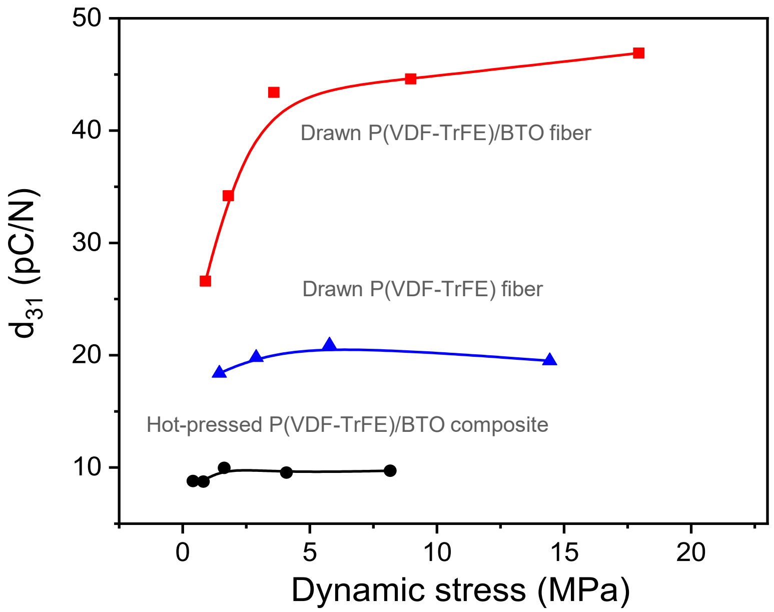
THERMALLY DRAWN FIBER

[LED BY FIBERS@MIT GROUP]







Yan, W., Noel, G., Loke, G., Meiklejohn, E., Khudiyev, T., Marion, J., Rui, G., Lin, **J., Cherston,** J., Sahasrabudhe, A. Wilbert, J., et al. *Nature*, *2022.*

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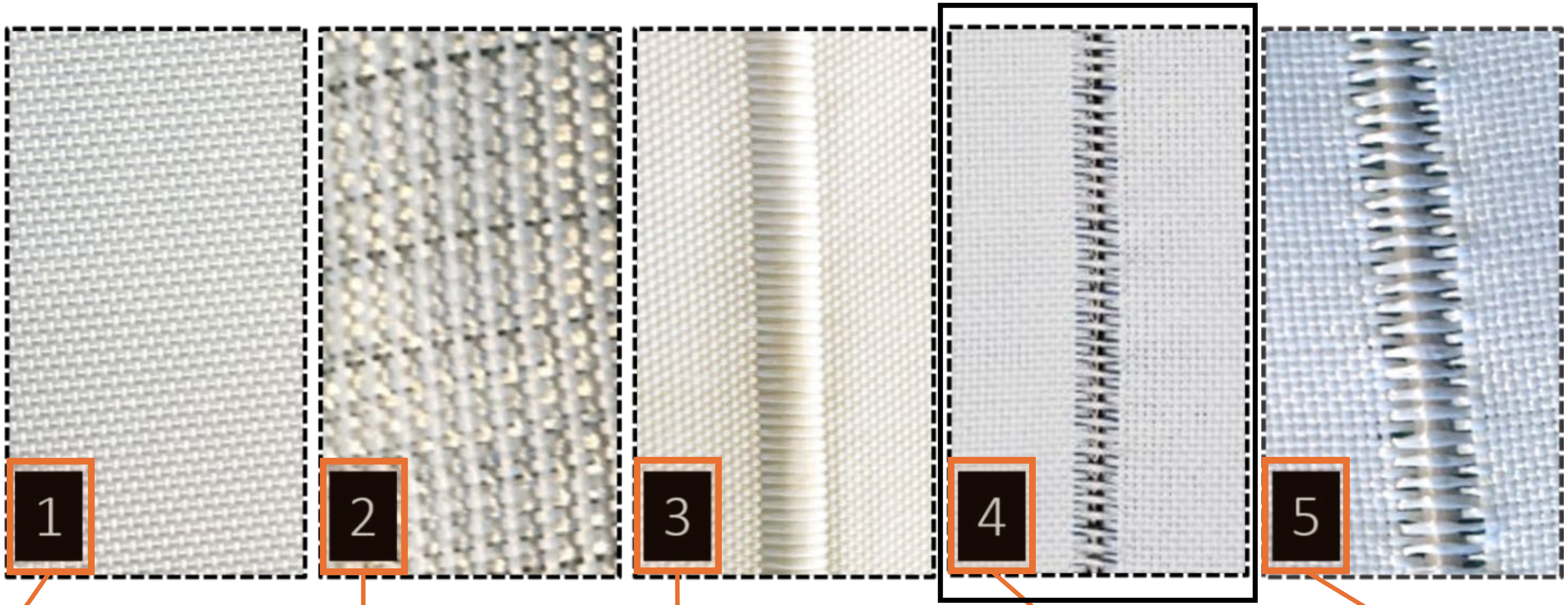
DEVELOPMENT OF FABRIC: COAT YARN TO AVOID HEAT TREAMENT



1. Commercial beta cloth: Teflon **impregnated** Heat treated fiberglass
2. Addition of conductive Vectran (sense charge)
3. Addition of spacer yarns
4. Teflon **coated** yarn + Thermally Drawn Fiber
5. Teflon **coated** yarn + Coated cable

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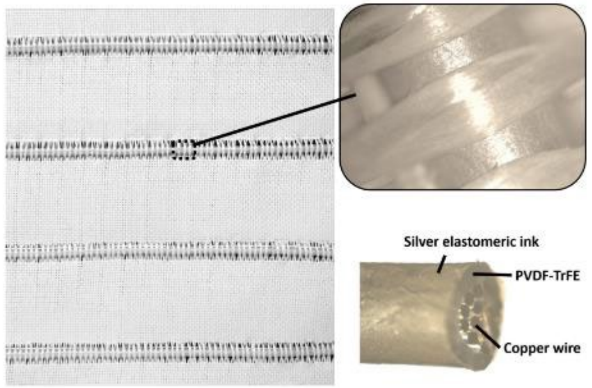
DEVELOPMENT OF FABRIC: COAT YARN TO AVOID HEAT TREAMENT

	Teflon process	Texture (yarns/in)	Thickness (in)	Weight (lb/yd2)	Filament (in)	Sensor weft insertion (cm)
(1) NASA Commercial Beta Cloth [Teflon impregnated BC Fiberglass yarn]	Impregnated fabric / heat treatment	85 x 60	.008	0.44	.00017	none
(4) Modified	Coated yarn (W.F. Lake)	42 x 35	.01	0.56	.0112	0.5, 1, 2



e.g. dense sensor spacing creates : **Greater impact sensitivity, higher channel count (↑power, ↓sampling frequency)**

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DEVELOPMENT OF FABRIC: GALLERY

With JPS Composites

PROTOTYPE GALLERY

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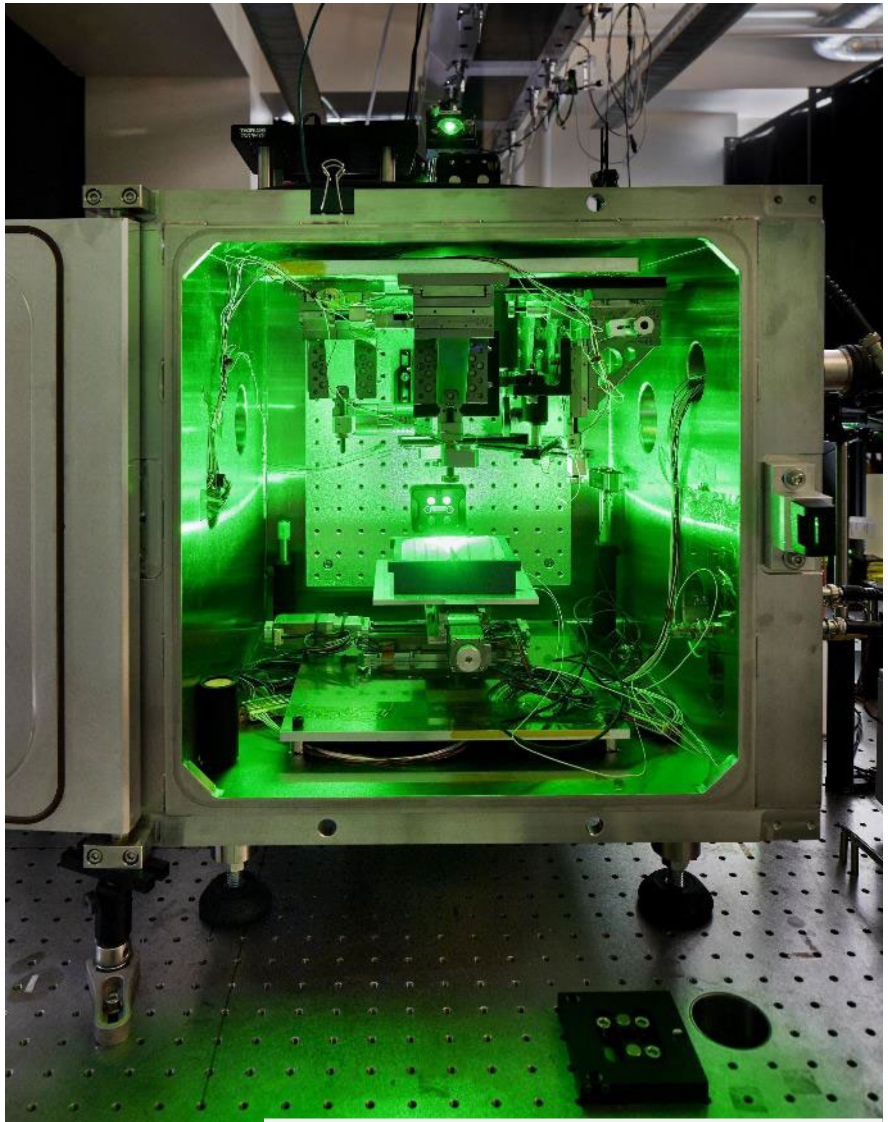
LIPIT TEST FACILITY
(MIT ISN / KEITH NELSON GROUP)

Laser ablation of gold film accelerates μm-scale particles to supersonic speeds



IEEE Spectrum Magazine, Dec 2021

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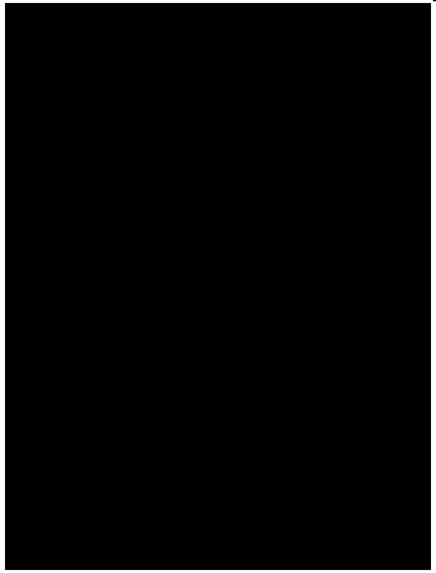
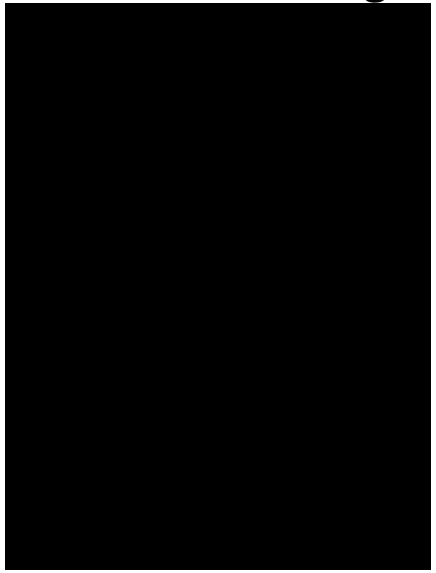
IDENTIFY SPEED REGIME THAT CAUSES MINIMUM DAMAGE

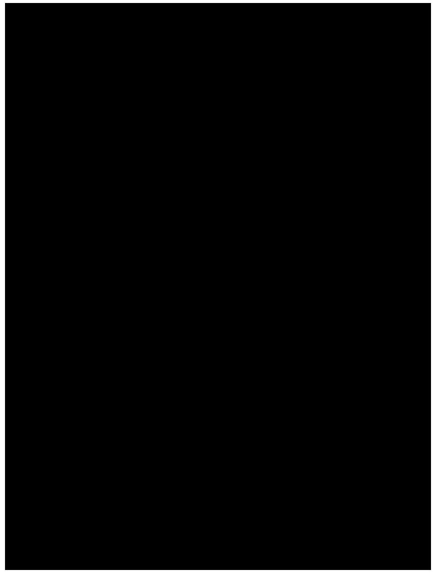
Like ripples on pond, we need to transfer transverse energy to the sparse fiber sensing elements



345 m/s



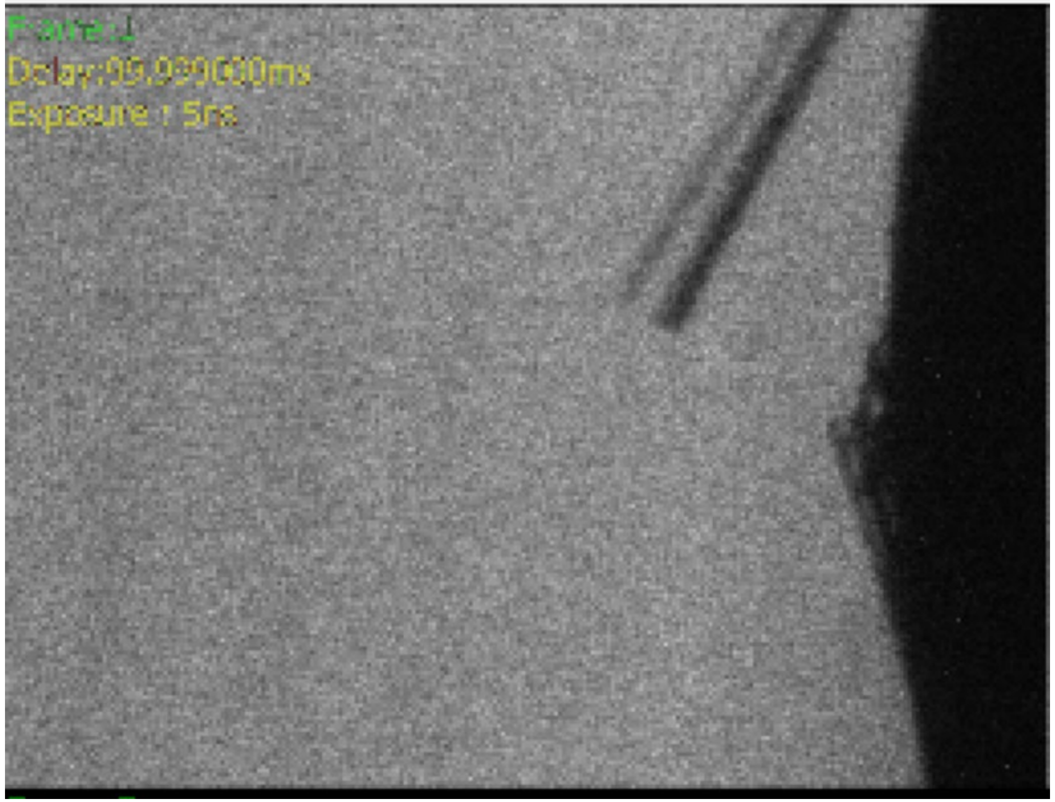
300 m/s



365 m/s

Transverse wave traveling at ~Vimpact carried by filaments

with Yuchen Sun



Damage Site: few broken filaments = minimum damage regime!

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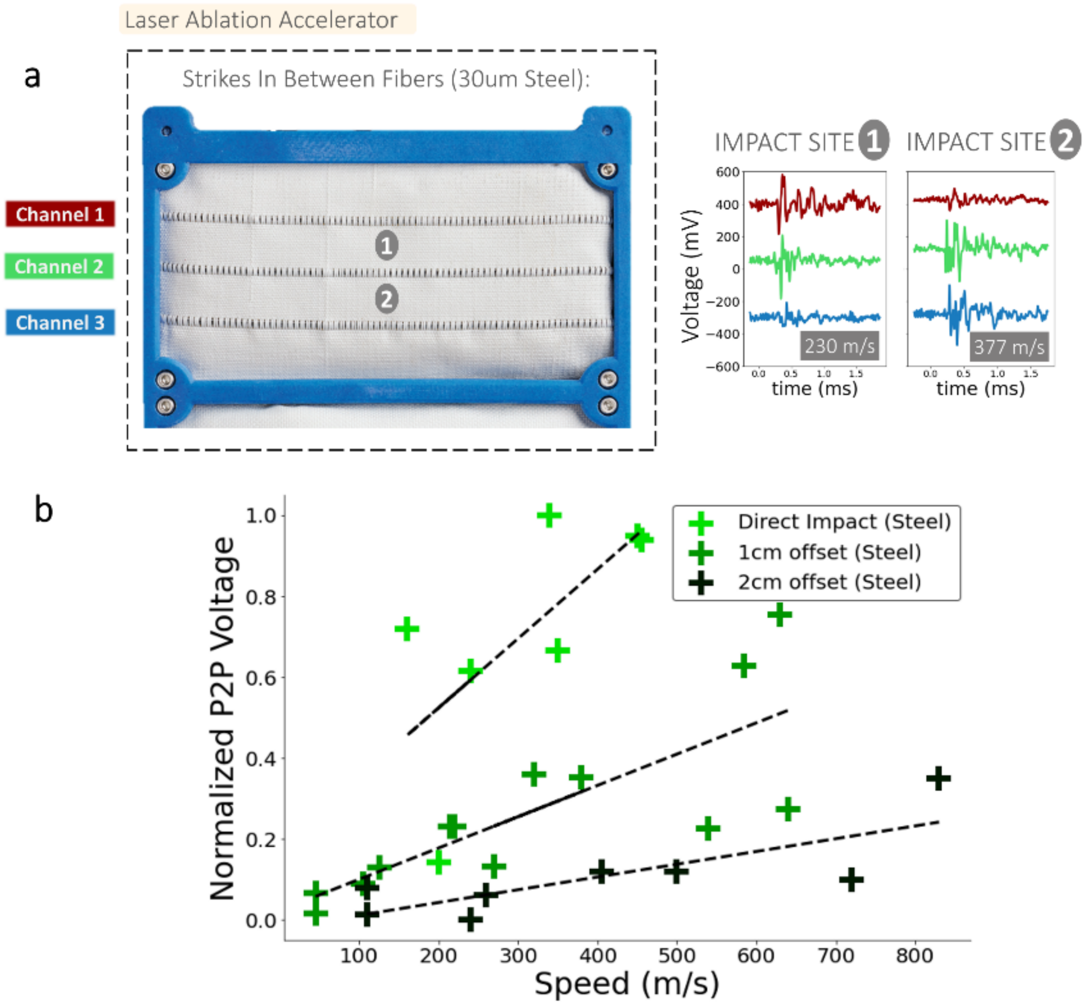
SENSITIVE TO IMPACTORS ON FABRIC, OFFSET FROM SENSOR



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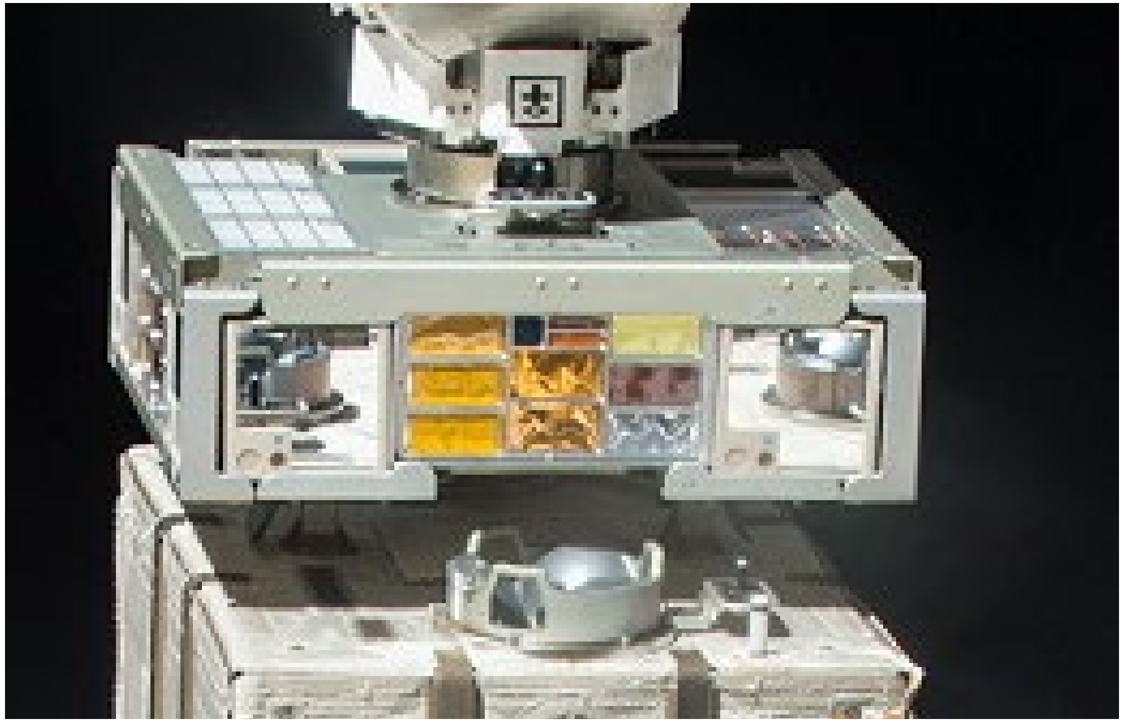
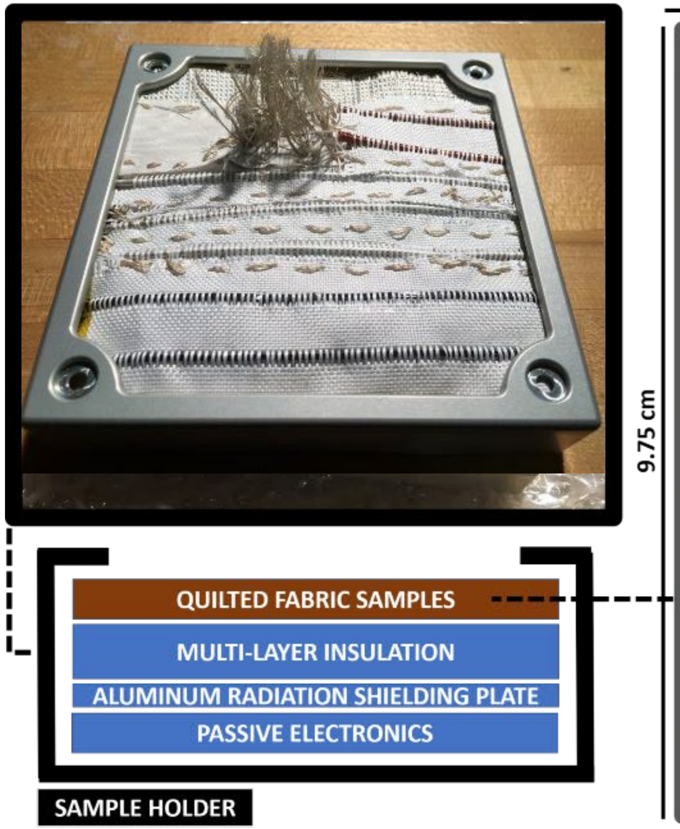
Japanese Experiment Module Exposure Facility (ExHAM)

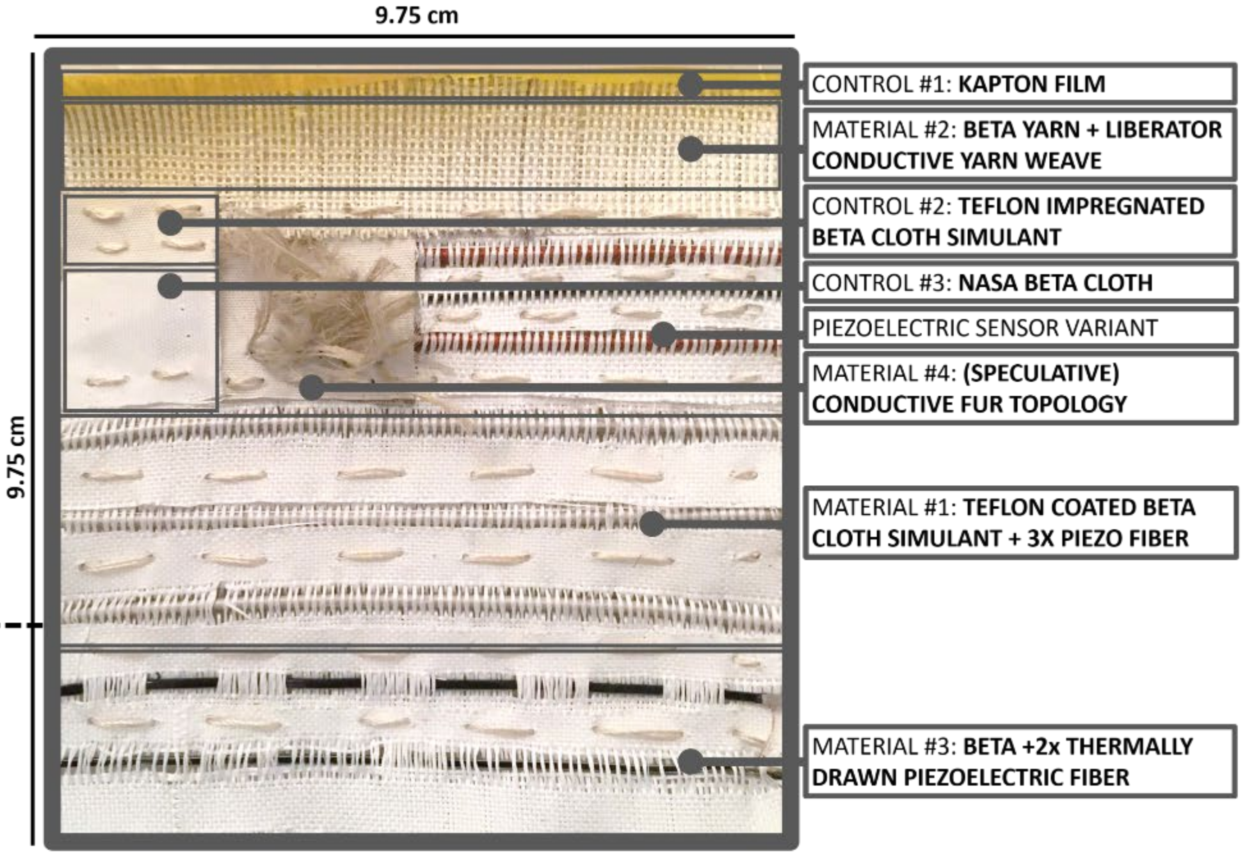
https://iss.jaxa.jp/en/kiboexp/ef/exham/



Exposure facilities are best method for evaluating robustness of new material assemblies to the space environment

'QUILT' OF FABRIC SWATCHES (UNPOWERED)





This testing was supported by Japanese company SpaceBD, JAXA, and the MIT Space Exploration Initiative

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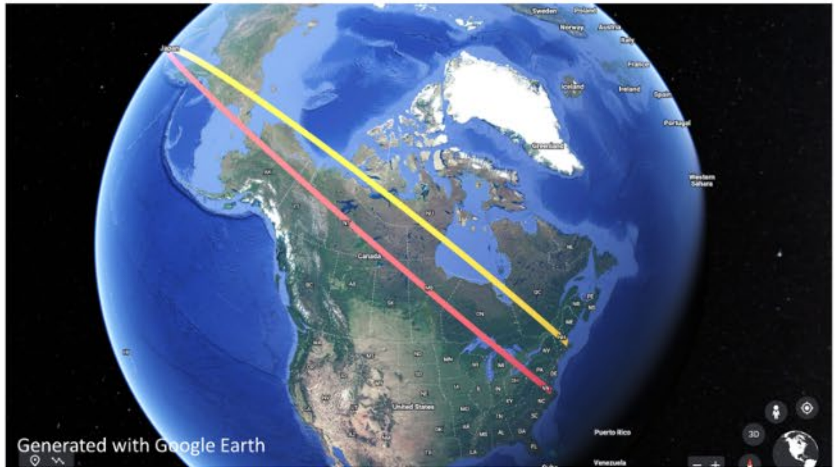
‘QUILT’ OF FABRIC SWATCHES TRAVELED MORE THAN MOST OF US IN 2020!

CAMBRIDGE, MA – TOKYO, JP – VIRGINIA [APR-OCT, 2020]



LAUNCH OF ANTARES, NASA WALLOPS, VA [OCT 3, 2020]

CYGNUS NG-14 ARRIVAL AT ISS [OCT 5, 2020]

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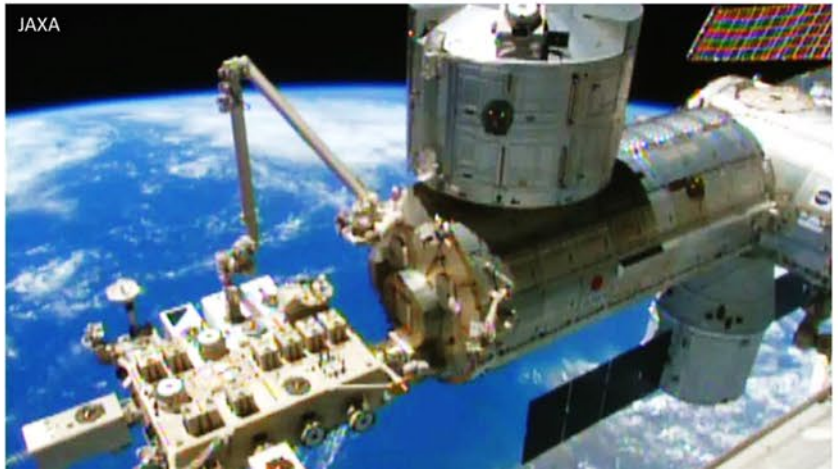
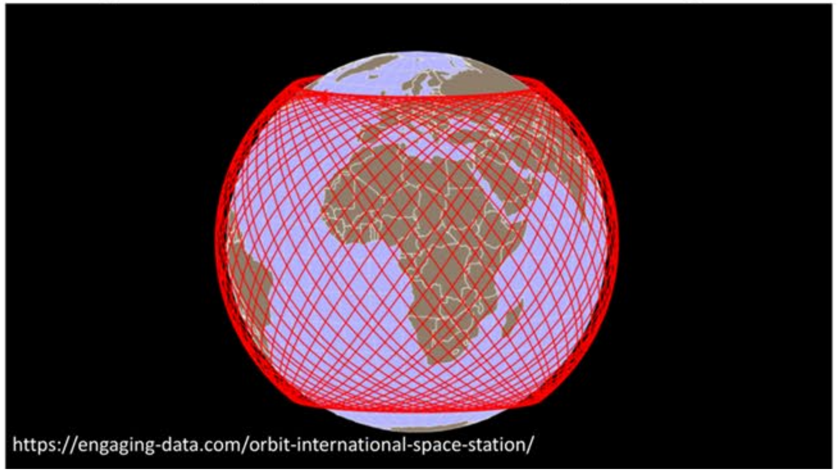
'QUILT' OF FABRIC SWATCHES TRAVELED MORE THAN MOST OF US IN 2020!

ROBOTIC ARM INSTALLATION
[OCT 28, 2020] (PHOTO IS GENERIC)



~7000 ORBITAL CYCLES AROUND EARTH
[OCT 28, 2020 – JAN 14, 2022]



ROBOTIC ARM OPS [JAN 14 2022]
PICKUP: SPX-24 DRAGON [JAN 23 2022]

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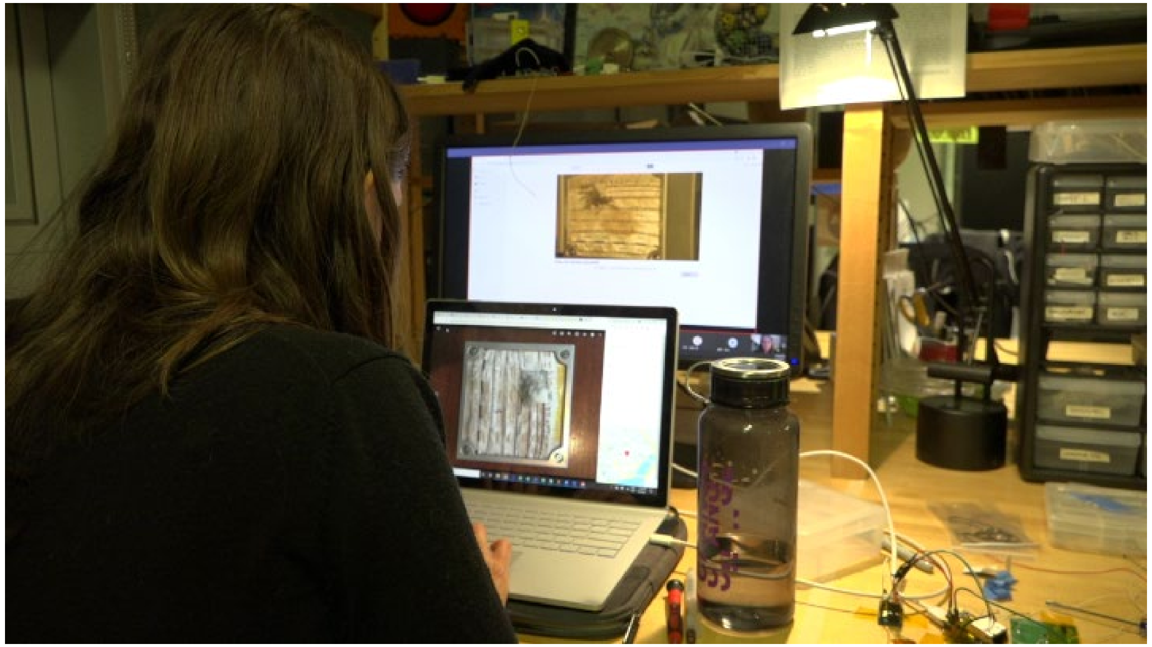
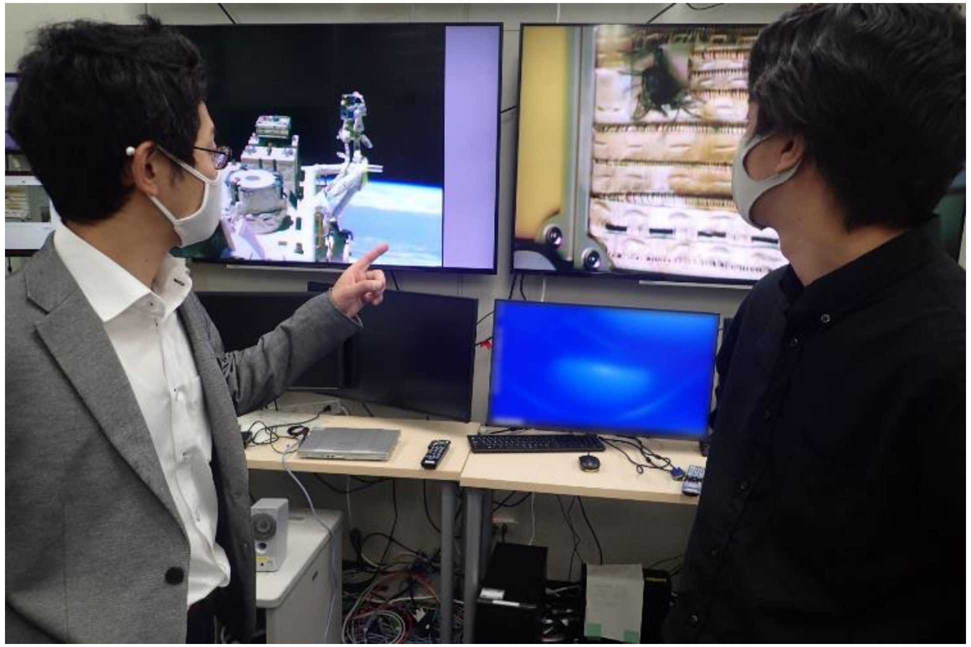
We Weren't Blind All Year: Real-Time Videography on ExHAM

MIT



Space BD / JAXA



SpaceSkin unpowered material samples
on Japanese ExHAM Exposure Facility
(Oct 2020)

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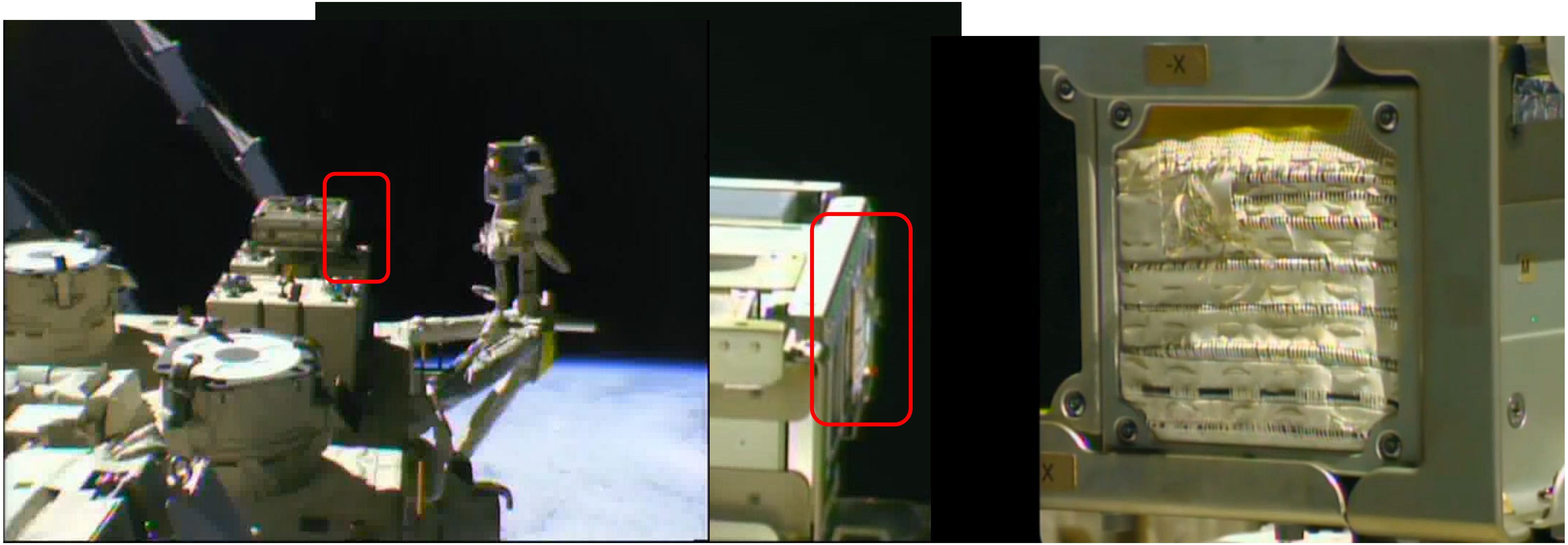

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2022: RETURN OF 'QUILT' OF FABRIC SWATCHES TO EARTH

SPLASHDOWN OFF PANAMA COAST
[JAN 24, 2022] (GENERIC DRAGON)

PANAMA CITY, FL – CAMBRIDGE, MA
[EARLY FEB, 2022]

ARRIVAL AT MIT!
FEBRUARY, 2022

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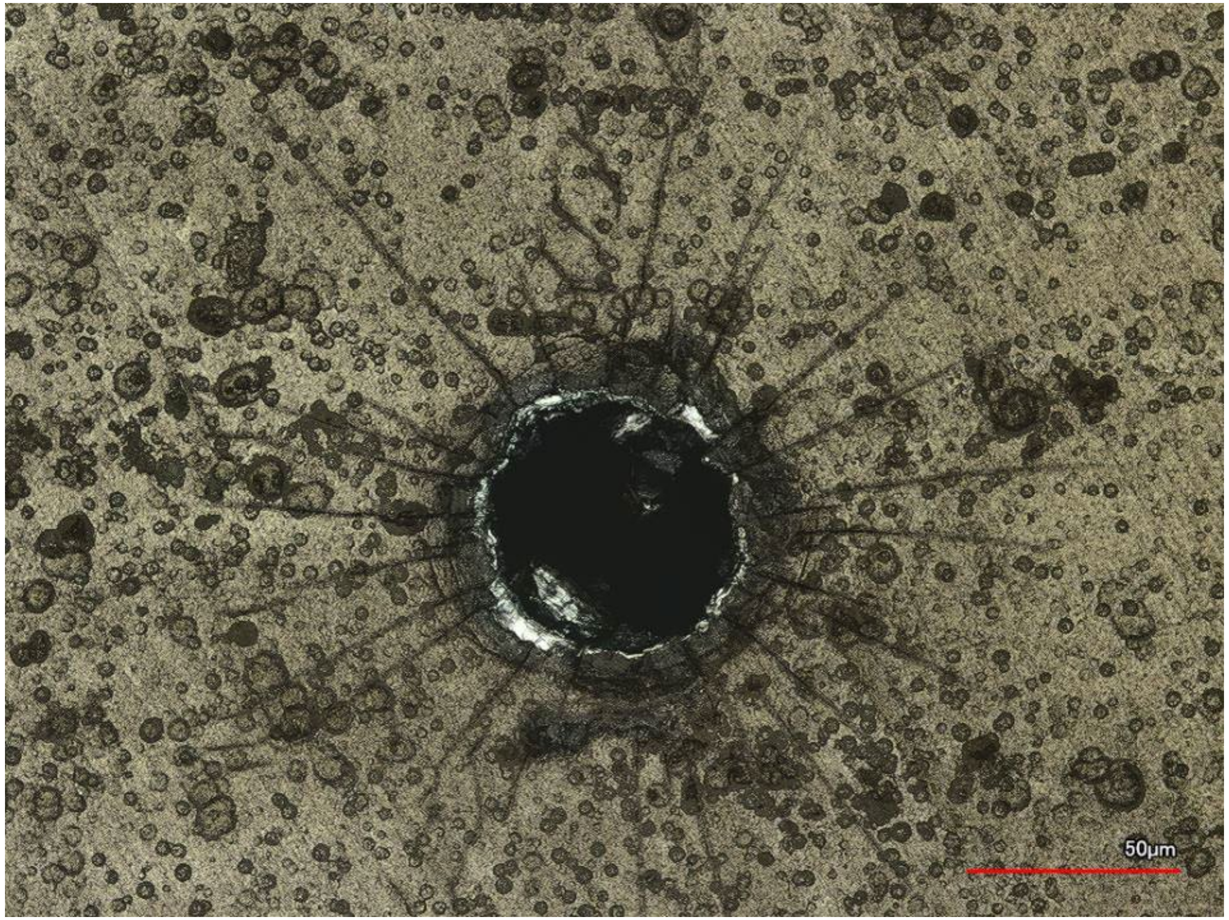
ALUMINUM FRAME IMPACT



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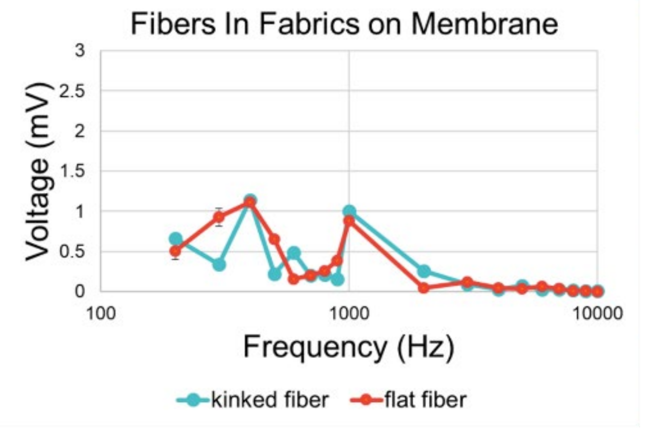
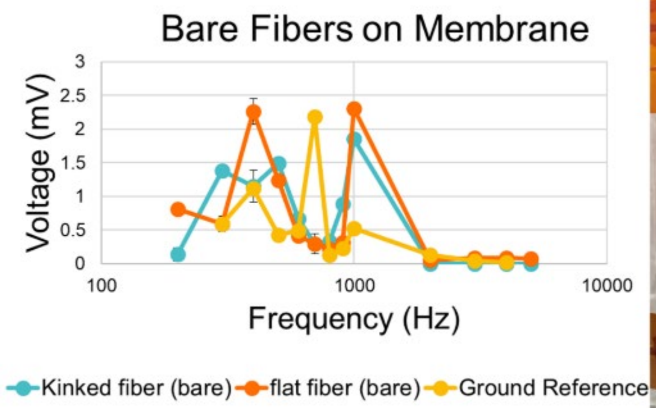
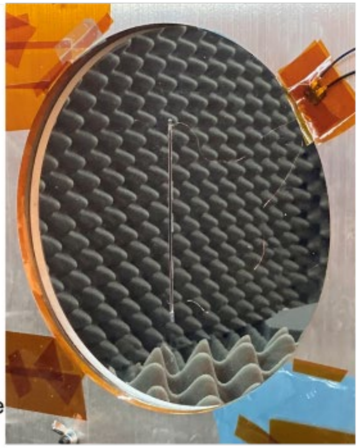
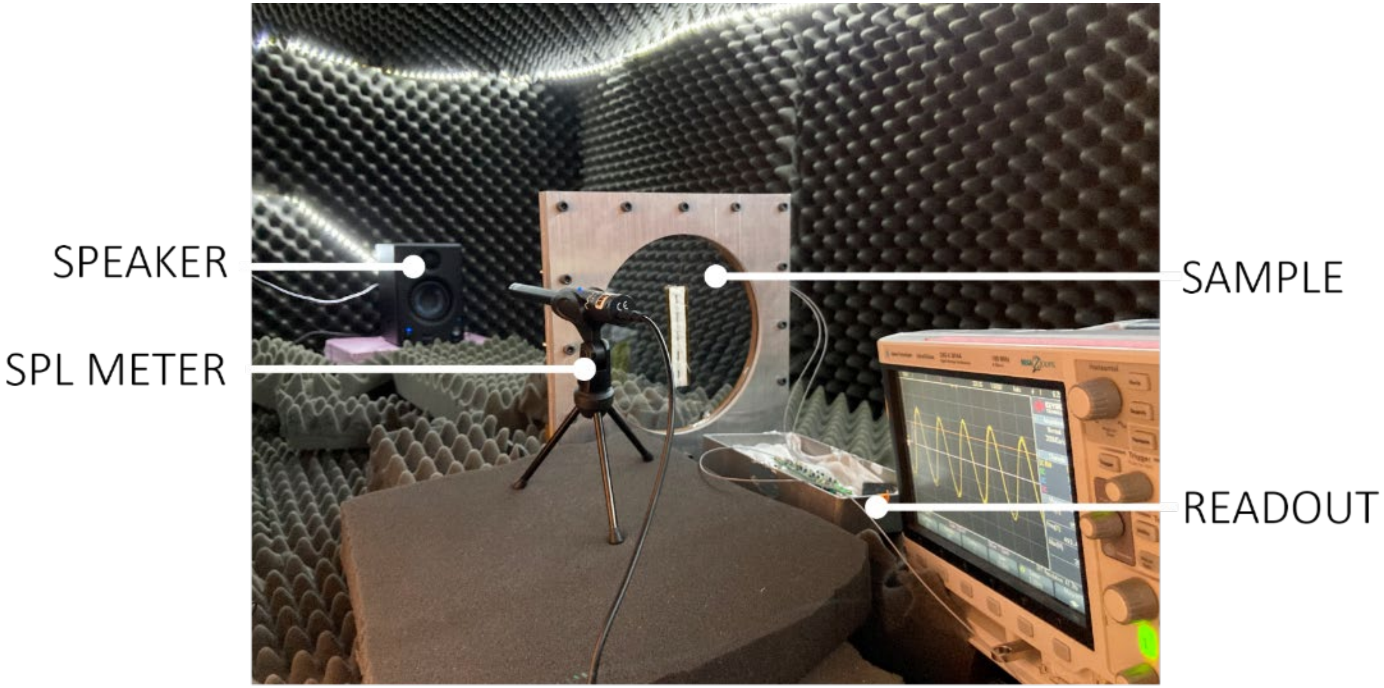
Key Result: Sensitivity of Thermally Drawn Fiber Preserved after 14.5 Months of Spaceflight









With Grace Noel (Fibers@MIT)

- Kinked fiber's performance equivalent to flat fiber
- Potentially some frequency shifting (vs. ground reference)

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MISSE Facility: Now we’ve got power/data in space!

Our gratitude to **the ISS US National Lab**
for providing the grant that is funding this deployment

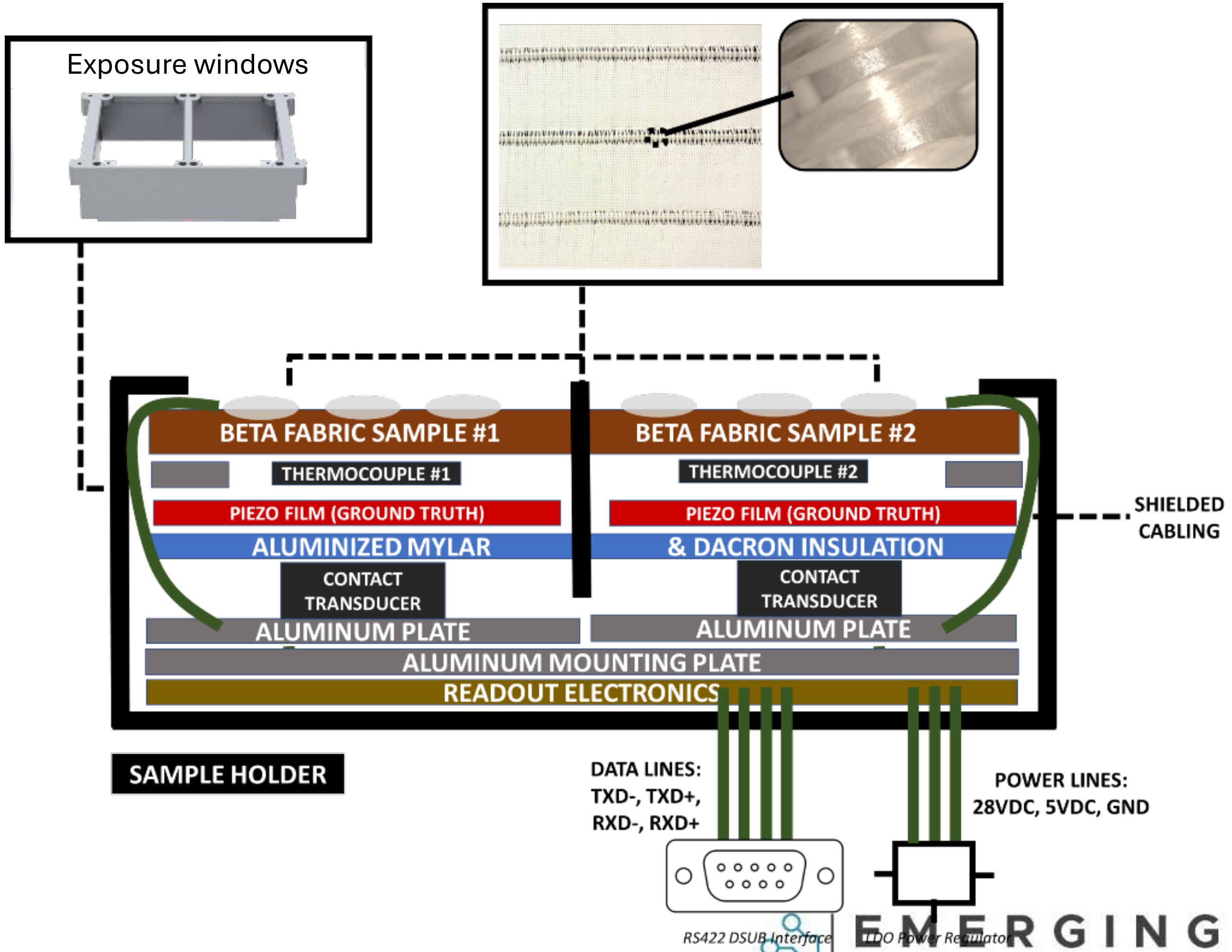
And **Accenture** for supporting my year of preparation

IN-SPACE TECHNOLOGY ASSESSMENT DESIGN

(1) Use contact transducers to activate fiber sensor with known vibration profile.

(2) Assess environmental effects on fiber sensor performance over time

(Stretch goal: impact sensing)



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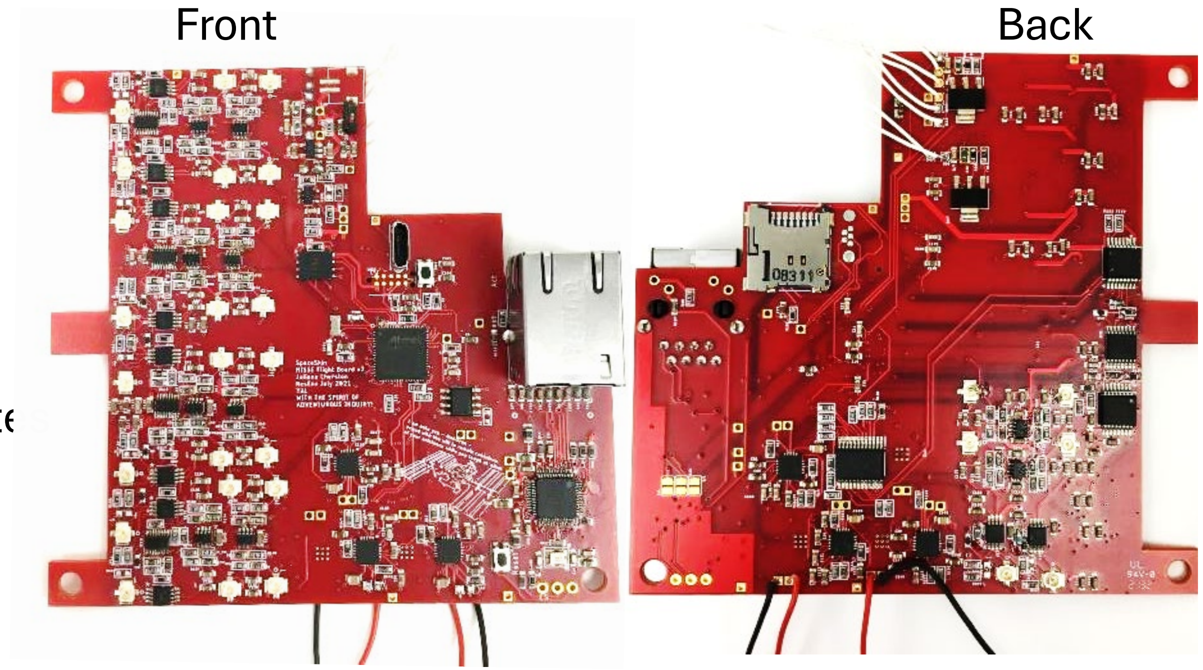
IN-SPACE ELECTRONICS

ELECTRONICS

KEY PARTS / FEATURES

- SAMD51 MCU (flight heritage, improved dev tools)
- Multichan Direct Memory Access (DMA)
- Wiznet 5500 Ethernet Driver
- UDP protocol (optimized to 480 packets/second, 1248 byte / packet, 8 bit)
- Ground sampling to eliminate channel crosstalk



Thanks Patrick Chwalek for firmware tips!

Gratitude to Brian Mayton, Mark Feldmeier, Gavin Lund, and David Bono for sustained mentorship in PCB development

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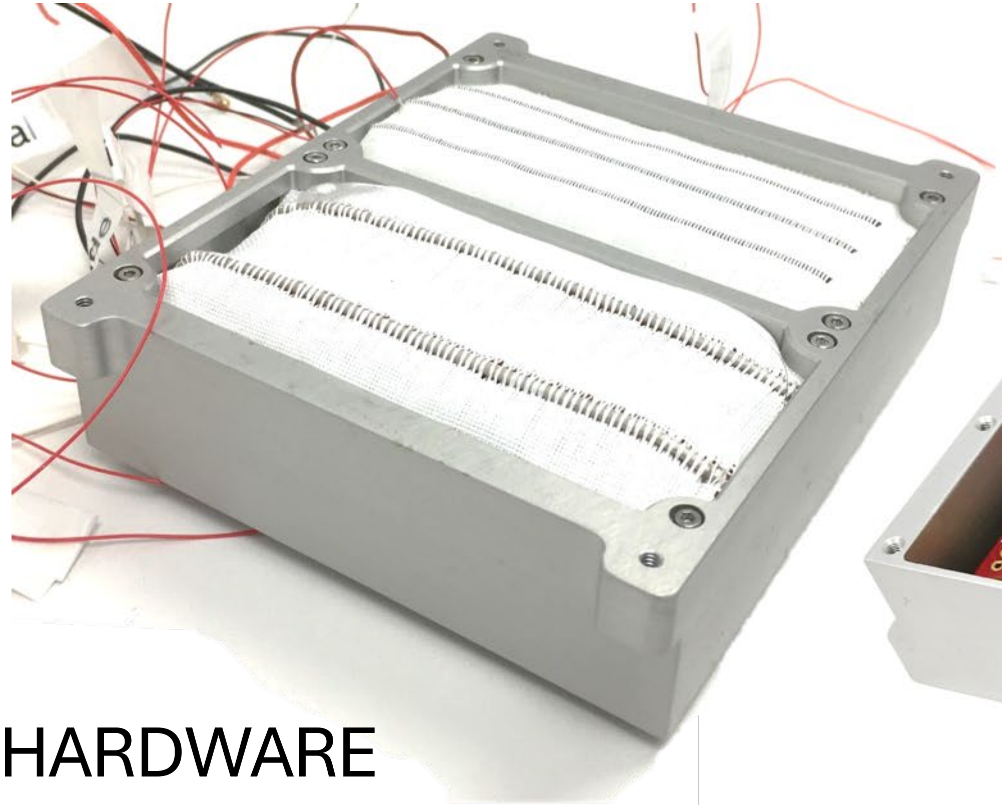

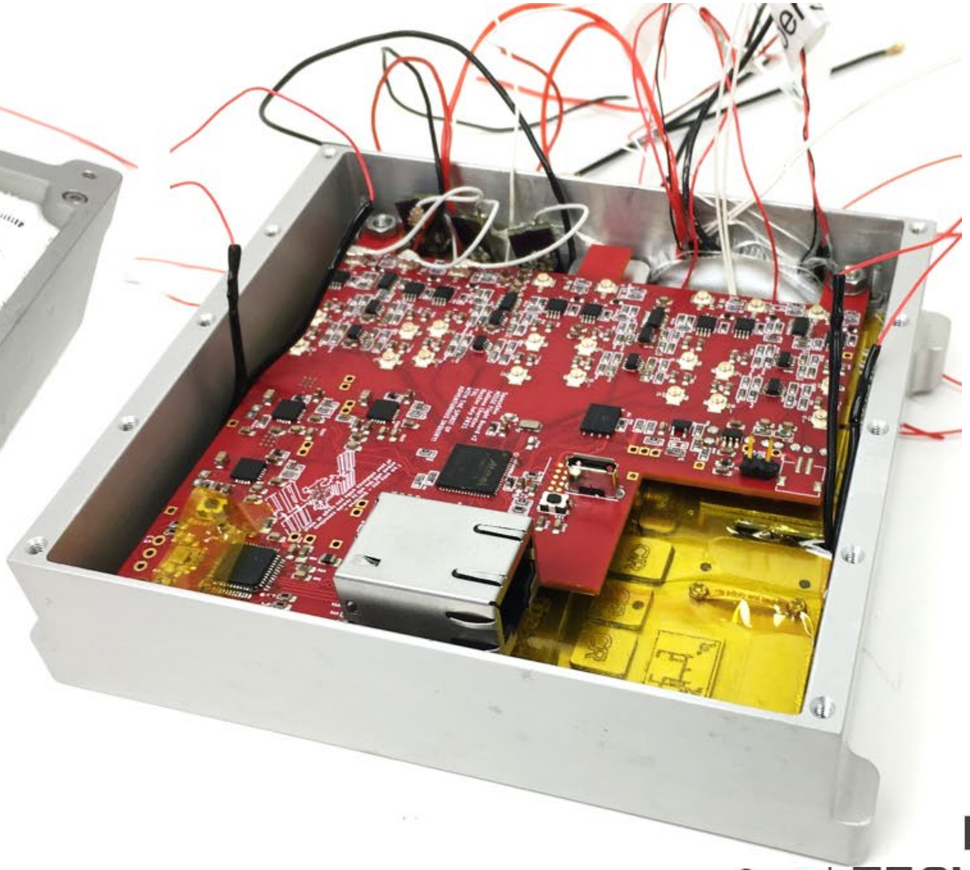

FLIGHT HARDWARE

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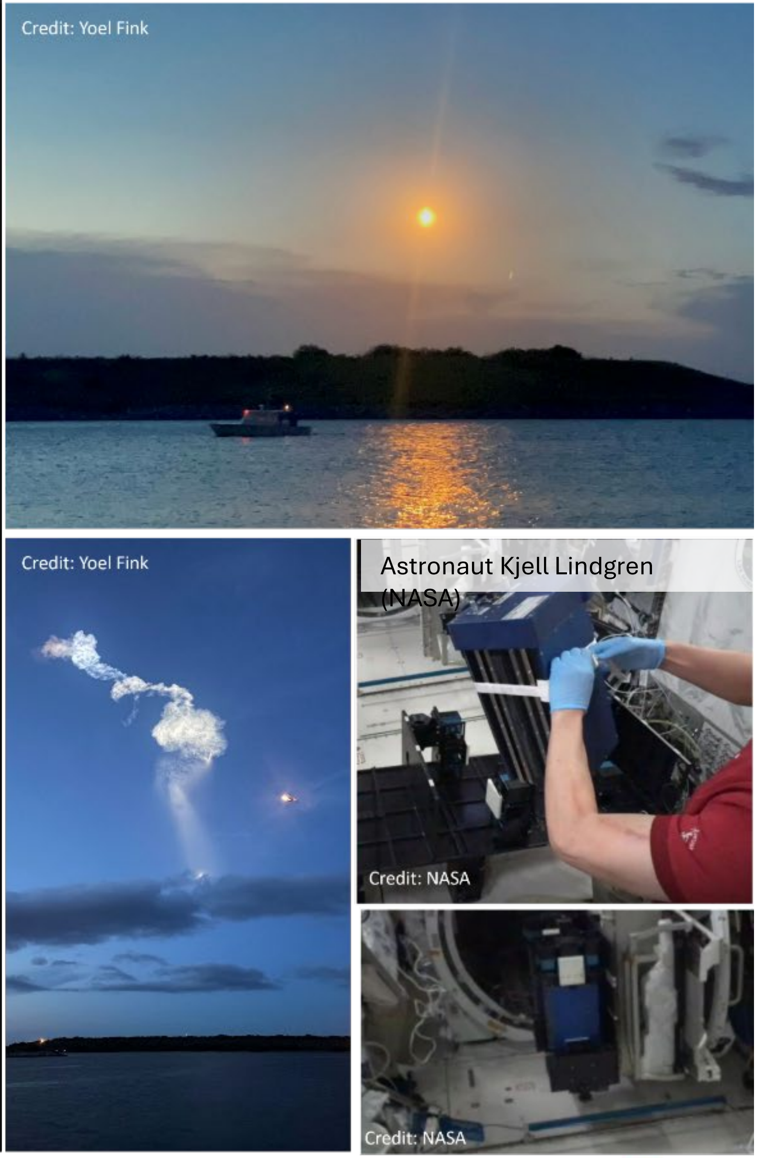
Installation & Delivery September, 2021

Thanks to Allison Goode, JC, Jeff Buell , Mark Shumbera, and team at Aegis



Launched July 14, Exterior Mount Aug 2nd!

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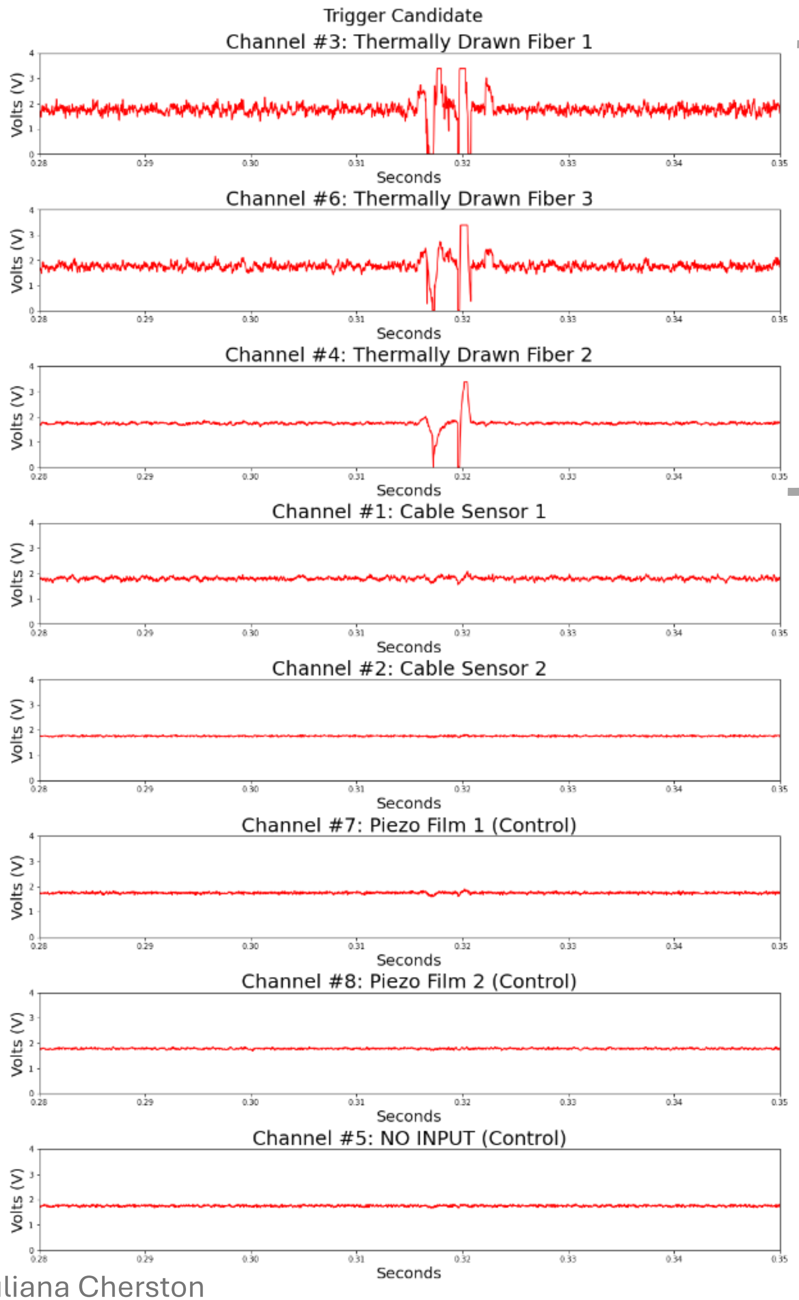
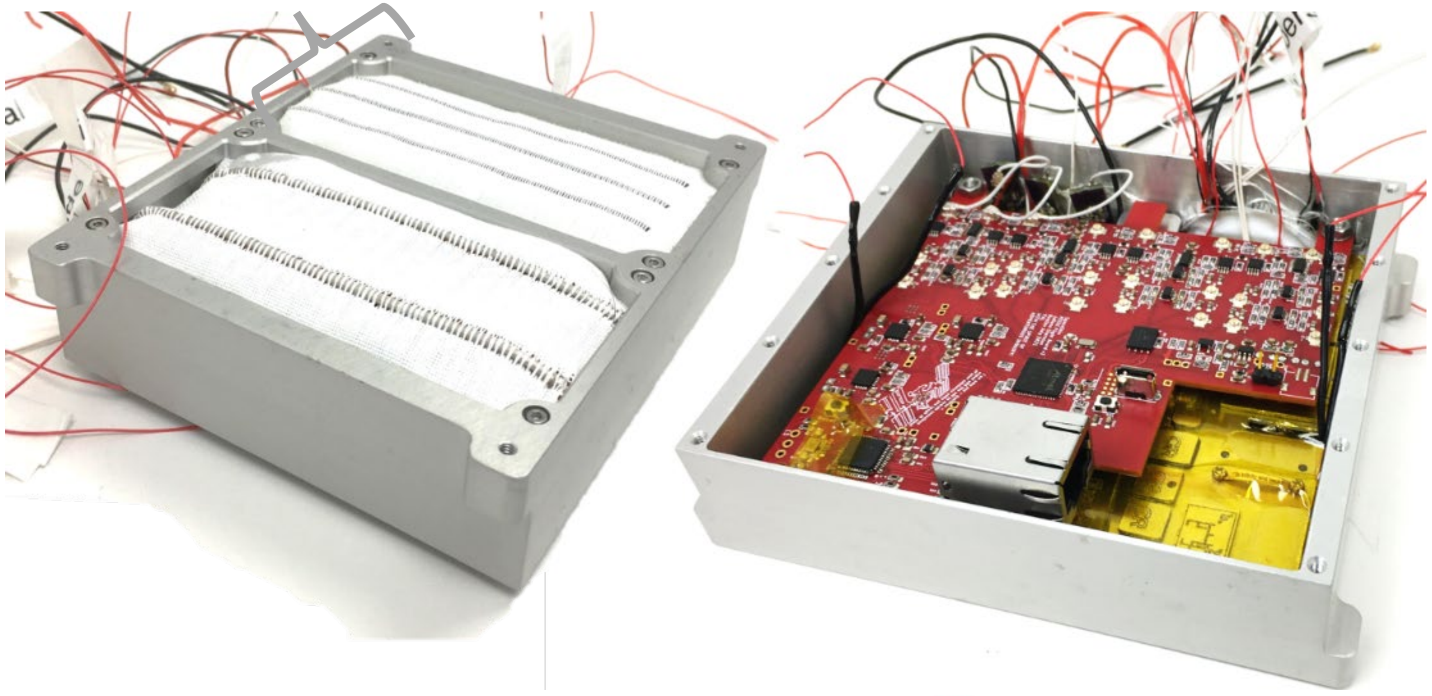
EXAMPLE PULSES FROM SPACE





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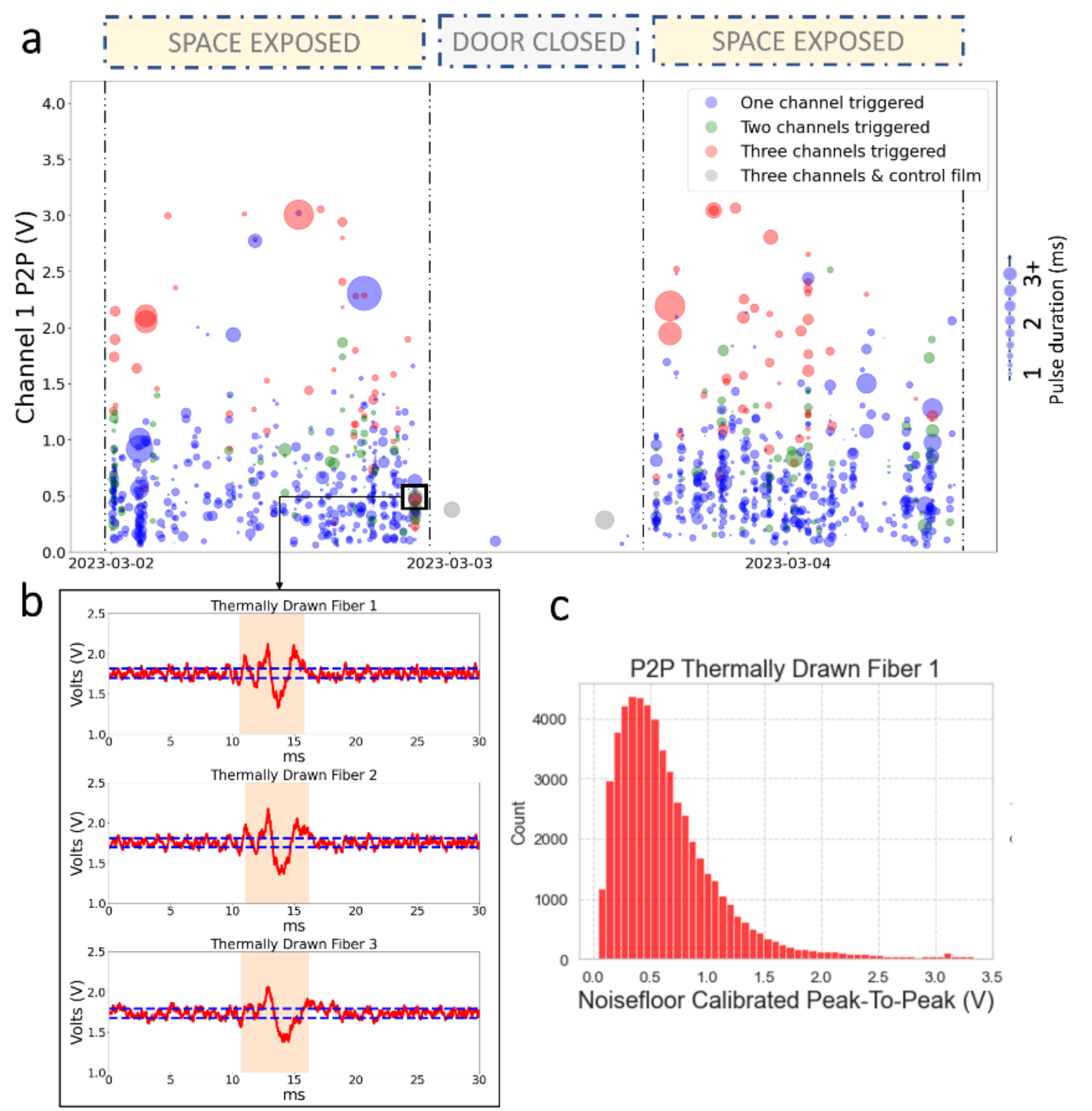
PULSES ORIGINATE FROM SPACE EXPOSURE



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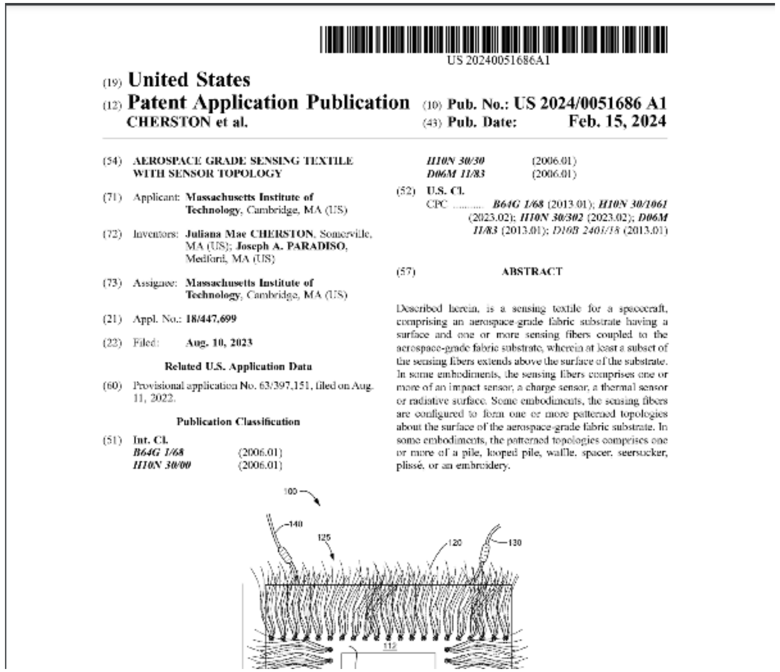
OUTPUT

1 CONTEST WIN (TECH BRIEFS)

1 PATENT APPLICATION



US 20240051686A1

(19) United States
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(54) AEROSPACE GRADE SENSING TEXTILE WITH SENSOR TOPOLOGY

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(57) ABSTRACT

Described herein, is a sensing textile for a spacecraft, comprising an aerospace-grade fabric substrate having a surface and one or more sensing fibers coupled to the aerospace-grade fabric substrate, wherein at least a subset of the sensing fibers extends above the surface of the substrate. In some embodiments, the sensing fibers comprises one or more of an impact sensor, a charge sensor, a thermal sensor or radiative surface. Some embodiments, the sensing fibers are configured to form one or more patterned topologies about the surface of the aerospace-grade fabric substrate. In some embodiments, the patterned topologies comprises one or more of a pile, looped pile, waffle, spacer, seersucker, plissé, or an embroidery.

2 CONFERENCE PUBLICATIONS
3 PENDING JOURNAL PUBLICATIONS

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Part 1: Narrative - development and launch of the first electronic textile sensor to space

Addendum: ‘Behind the scenes’
– partnerships and financing to enable this work; learnings / recommendations

Funding Sources

Industry-Funded Grants
- Accenture – “Advancing Industry Convergence Through Technology and Innovation”
- Hayashi-ULVAC MISTI Seed Fund (for collaboration with Japanese entities)

Government Grants
- ISS US National Lab
- NASA TRISH

Internal
- MIT Media Lab Consortium
- MIT Media Lab Space Exploration Initiative

Project Dynamics

- Project funded by various grants originating from both government and industry
- Industry resources then purchased by academic lab
- Not a formal public-private partnership
- Some in-kind support provided (e.g. access to space qualification facilities)

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Textile Manufacturing - Started off amateur!

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Large Ecosystem of Prototyping/Manufacturing Facilities In Boston

Visited Fabric Discovery Centers
- UMass Lowell
- MIT Lincoln Lab
- AFFOA

Challenges around: tool training, facility access, funding, facility priorities

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Improved our Lab's Internal Facilities When Possible

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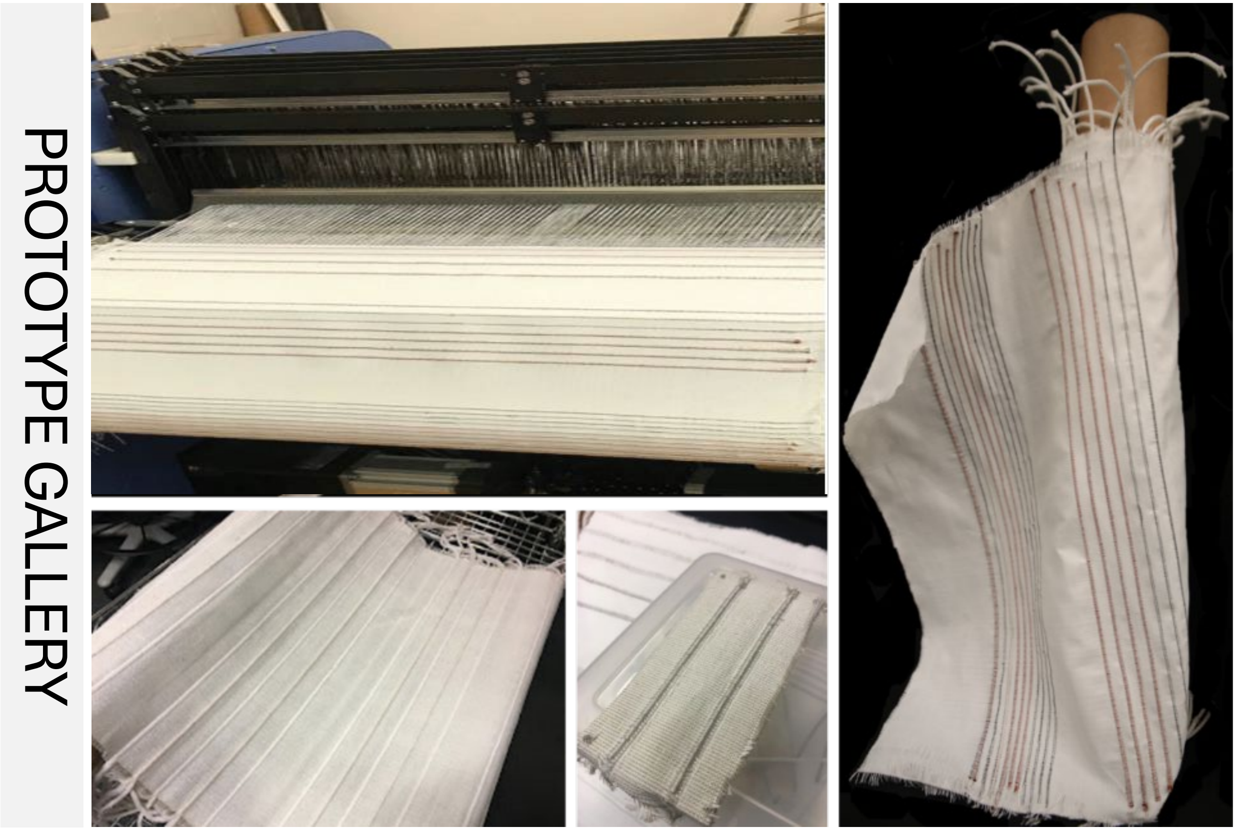
Commentary On Textile Manufacturing

- Contacted many aerospace textile companies
- Worked under contract with JPS Composite Materials R&D team
  - Academic projects can be exciting for industry teams
  - Space launch aspect added to excitement
  - Small batch runs purchased in order to imitate NASA heritage material
  - Mailed in fiber sensors for manual weft insertion
- Yarn sourced from WF Lake
- Expensive
- Challenging to iterate as project evolved
- Initiated collaboration with RISD textile department
- Final fabric sample produced by RISD



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SUMMARY

- Presented case study on deployment of first e-textile to space
- Partially industry-funded for potential commercial applications
- Partially supported by a commercial textile manufacturing entity
- Patent application submitted

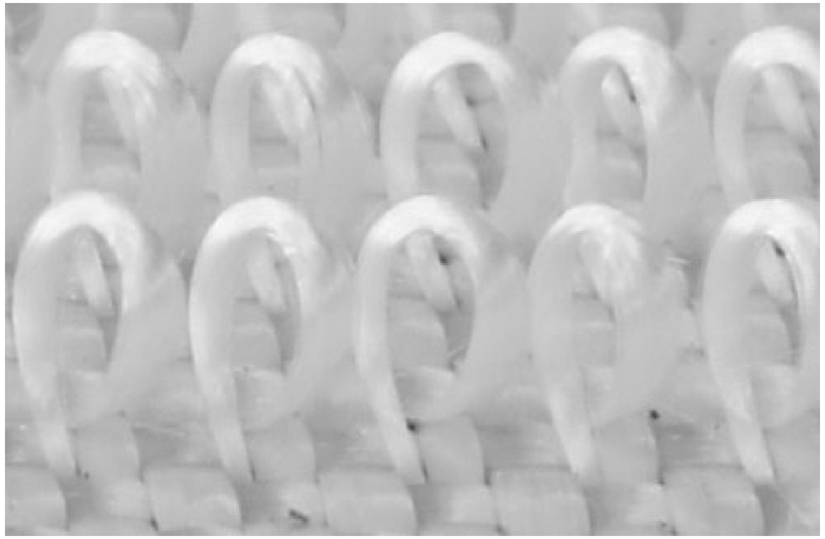
QUESTION

What would it take to inspire companies to formalize pipelines for small-run academic collaborations?

END / APPENDIX

WHERE THIS WORK POINTS:

Broad challenge is to mate form to scientific function



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How Might We Enhance Charge Sensitivity? Increase Charge Production!

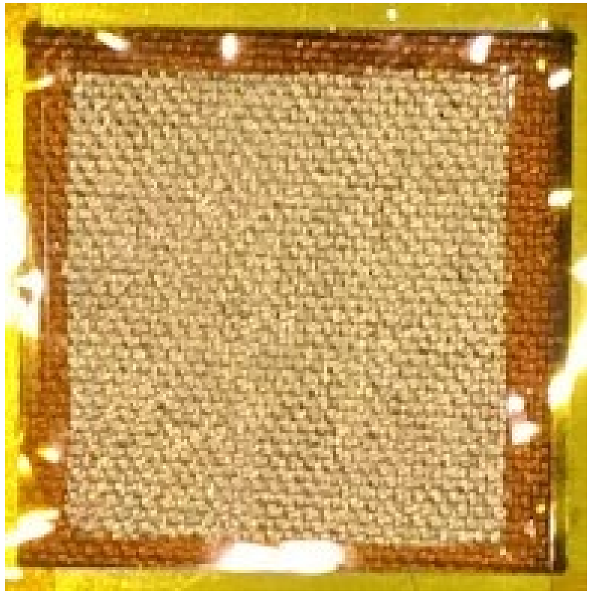
Gold produces 1-3 orders of magnitude more charge in impact plasma vs. other common targets

Table 1. Impact Charge Yield Relations From the Literature, After *Auer* [2001][a]

Target Material	Scaling Relation	Range (km/s)	10 km/s	50 km/s	Reference
Al	$7.0 \times 10^{-1}\ m^{1.02} v^{3.48}$	2–40	1,060	287,000	*McBride and McDonnell* [1999]
W	$5.1 \times 10^{-1}\ mv^{3.5}$	2–40	1,610	451,000	*Dietzel et al.* [1973]
Al	$1.4 \times 10^{-3}\ mv^{4.8}$	8–46	88	200,000	*Grün* [1984]
Au	$6.3 \times 10^{-4}\ mv^{5.6}$	9–51	2,508	20,600,000	*Grün* [1984]
PCB-Z Paint	$4.7 \times 10^{-3}\ mv^{4.1}$	3–36	59	43,400	*Grün* [1984]
Antenna (Ag/BeCu)	$5.0 \times 10^{-2}\ mv^{3.9}$	3–40	397	211,000	*Grün et al.* [2007]
Kapton (Al coated)	$1.0 \times 10^{-2}\ mv^{4.6}$	3–40	398	654,000	*Grün et al.* [2007]
Polyimide	$1.2 \times 10^{-1}\ mv^{3.3}$	3–45	239	48,500	*Grün et al.* [2007]
Ag	$8.9 \times 10^{-3}\ mv^{3.9}$	2–40	71	37,600	This work
BeCu	$1.2 \times 10^{-2}\ mv^{3.8}$	2–30	76	34,300	This work
Kapton (Ge coated)	$2.5 \times 10^{-3}\ mv^{4.5}$	2–40	79	110,000	This work
Solar cell	$4.7 \times 10^{-3}\ mv^{4.2}$	2–40	74	64,200	This work
MLI[b]	$1.7 \times 10^{-3}\ mv^{4.7}$	2–40	85	164,000	This work

[a] Scaling relation mass in kg, speed in km/s, example yields are in fC for a 1 pg projectile at the indicated speeds.
[b] MLI, multilayer thermal insulation.

Collette, A., et al. *Space Physics* 119.8 (2014): 6019-6026.



Answer: **Goldized Beta Cloth** [Bonus: space legacy!]

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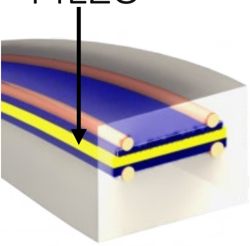
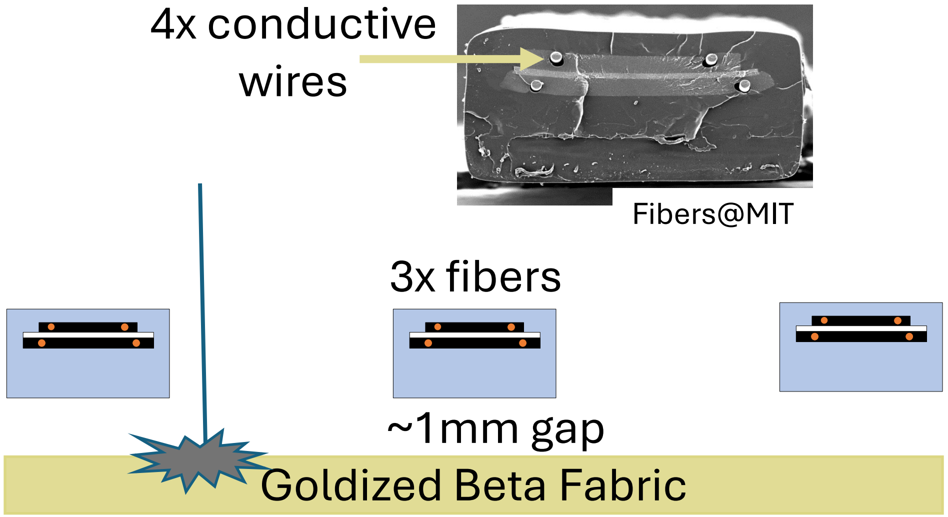
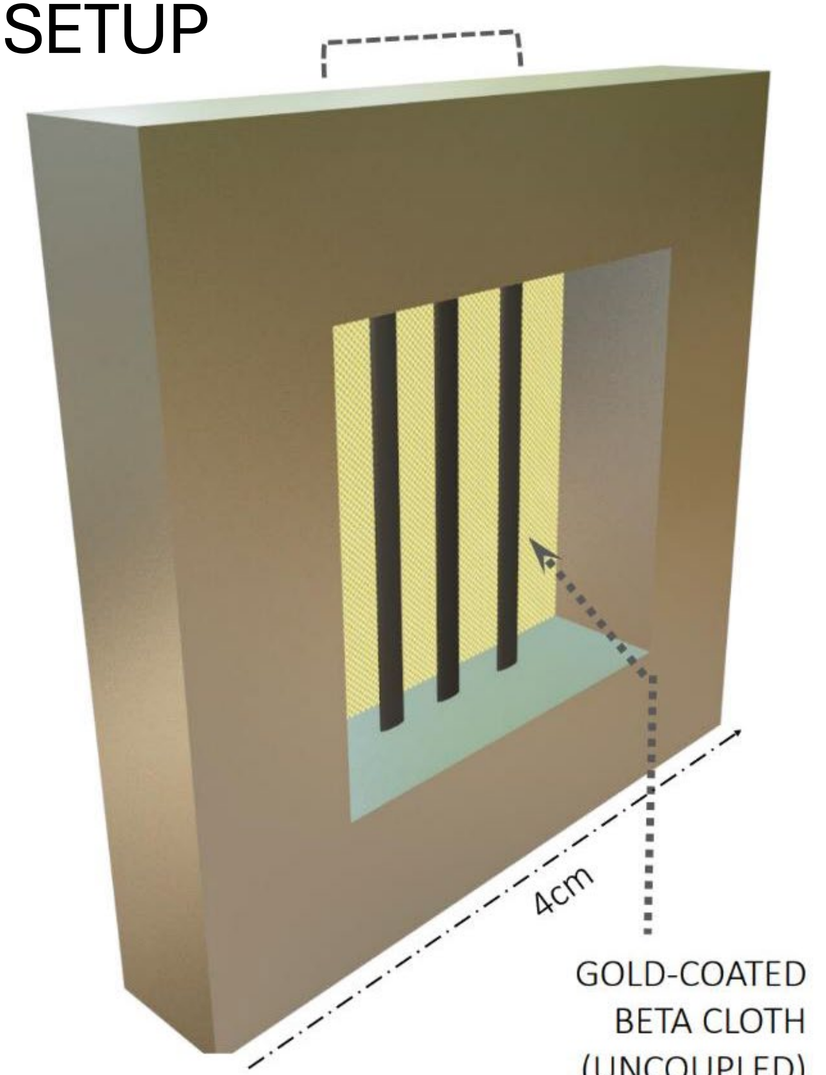


GOLDIZED BETA FABRIC: EXPERIMENT SETUP



Wires internal to fiber are suspended ~1mm above electron plasma plume

(In practice, would need to get creative to suspend piezoelectric fibers above fabric with gap)



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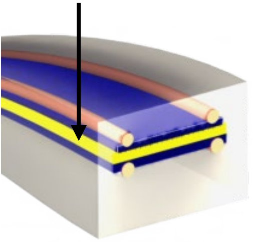
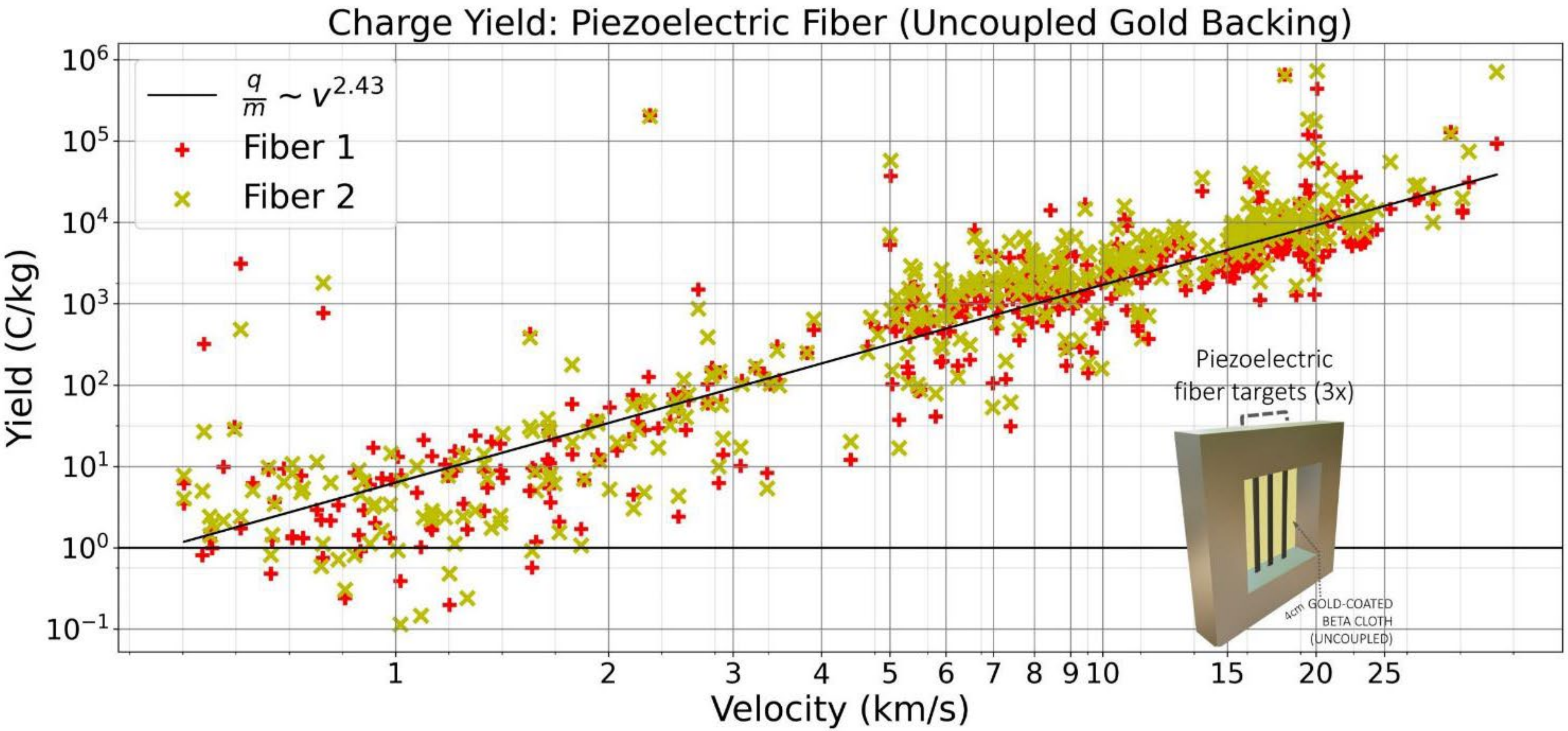


PIEZOELECTRIC FIBER + GOLDIZED BETA CALIBRATION CURVE



$$\frac{q}{m} \quad \frac{\text{Detected charge}}{\text{Mass of impactor}}$$

$$\left(\frac{m}{Q}\right)\mathbf{a} = \mathbf{E} + \mathbf{v} \times \mathbf{B}.$$

[Two particles with the same mass-to-charge ratio move in the same path in vacuum when subject to same electric and magnetic fields]

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How Might We Enhance Charge Sensitivity EVEN FURTHER?
Increasing charge collection area....

How About Fur.

(Conductive pile fabric)

- 2.5D geometry may enhance direct charge capture

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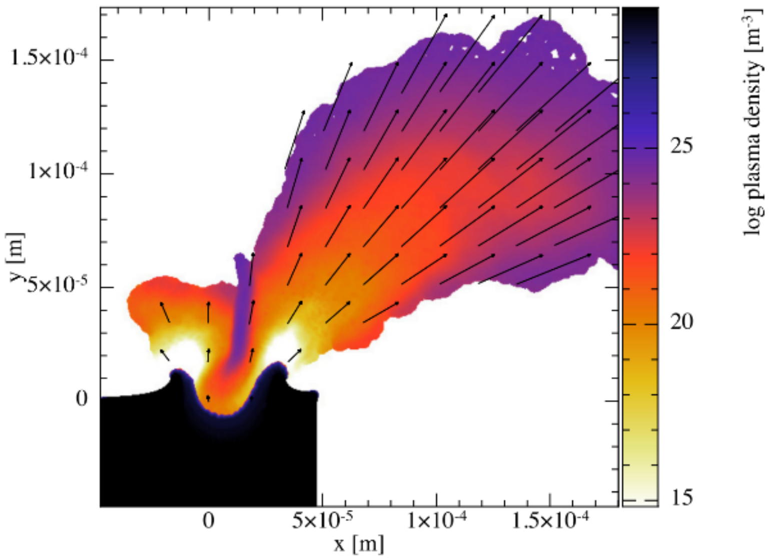
How Might We Enhance Charge Sensitivity EVEN FURTHER?
Increasing collection area....

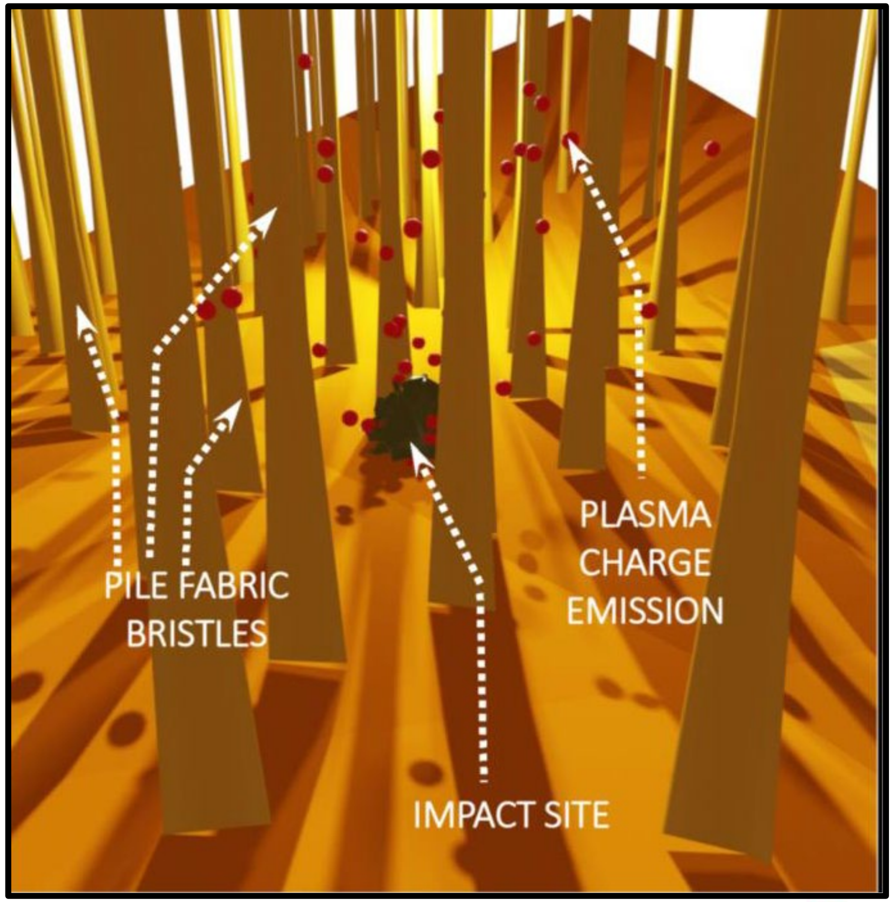
Prior Art:



Impact plasma ejected at an angle relative to spacecraft surface

(Fletcher, 2015)

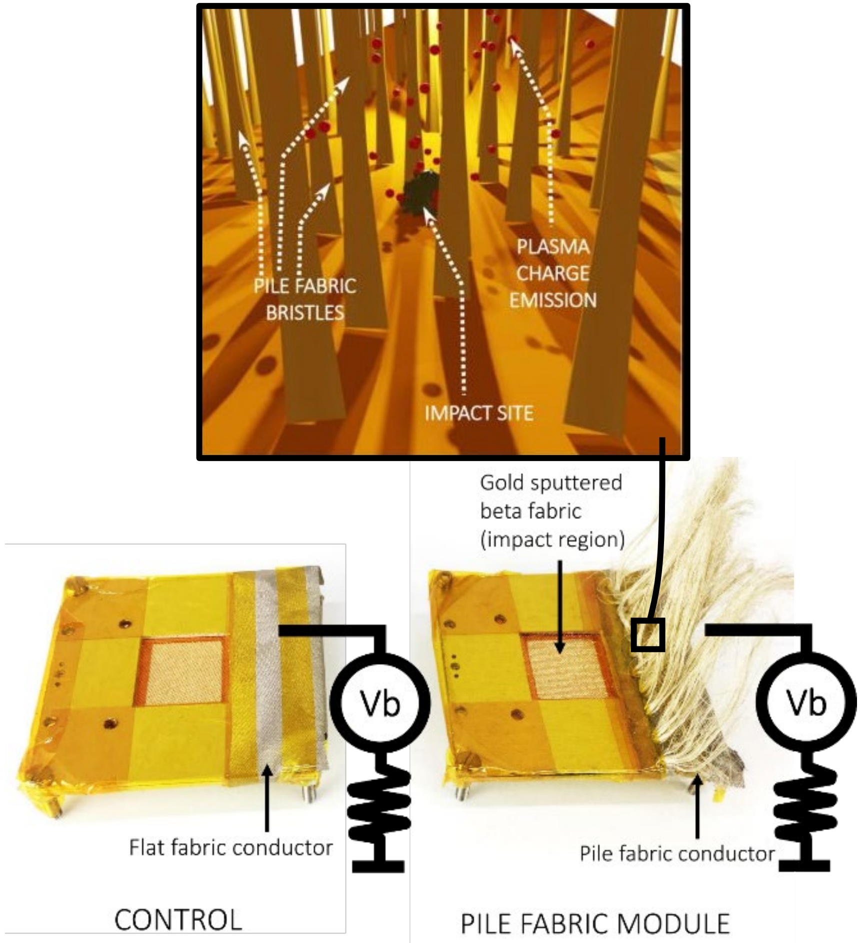
Cartoon: impact plasma electrons on fur



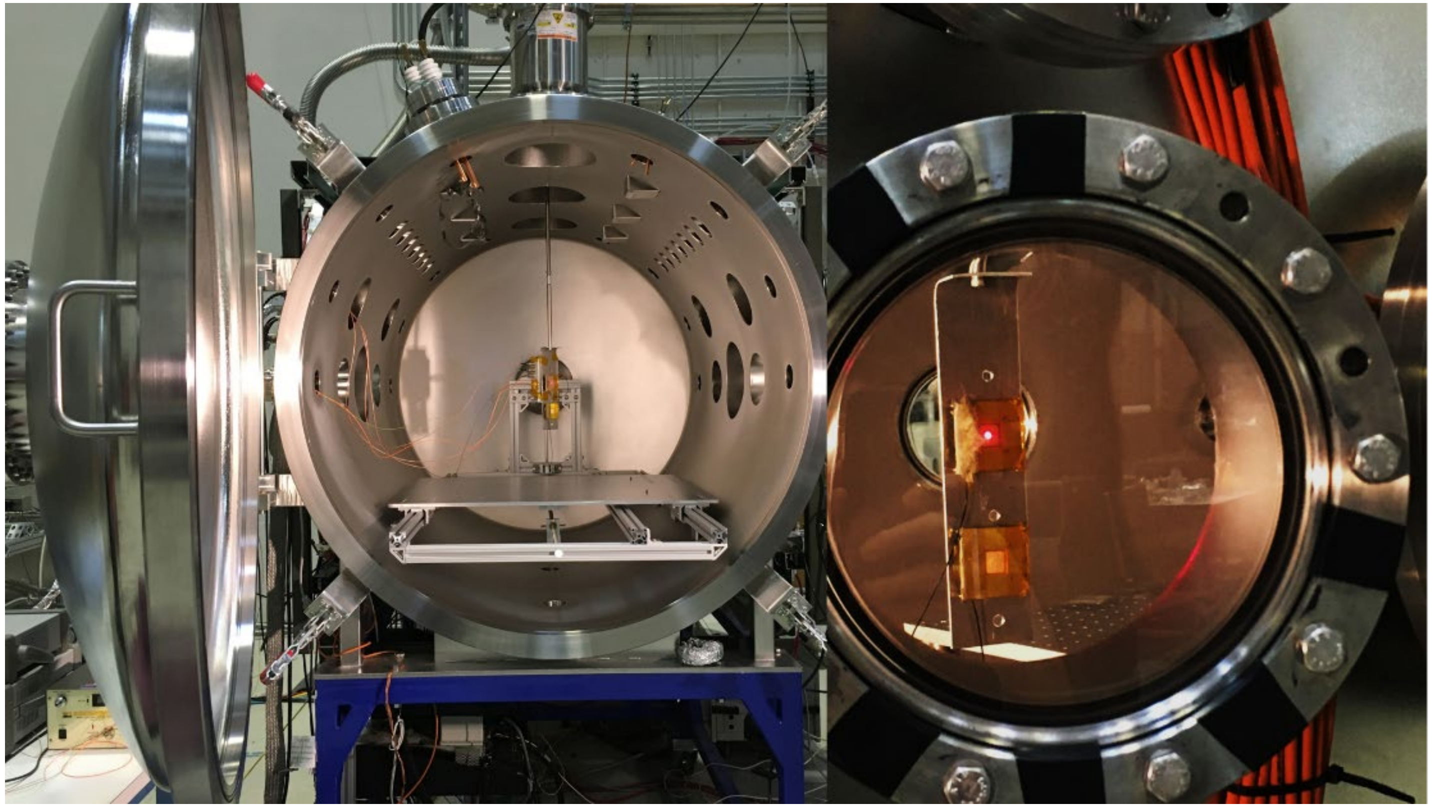
(Future work: tune bristle length, sparsity...)

Pile Fabric Experiment Modules

Experiment Modules



Dedicated charge sensor samples installed in UHV chamber at LASP



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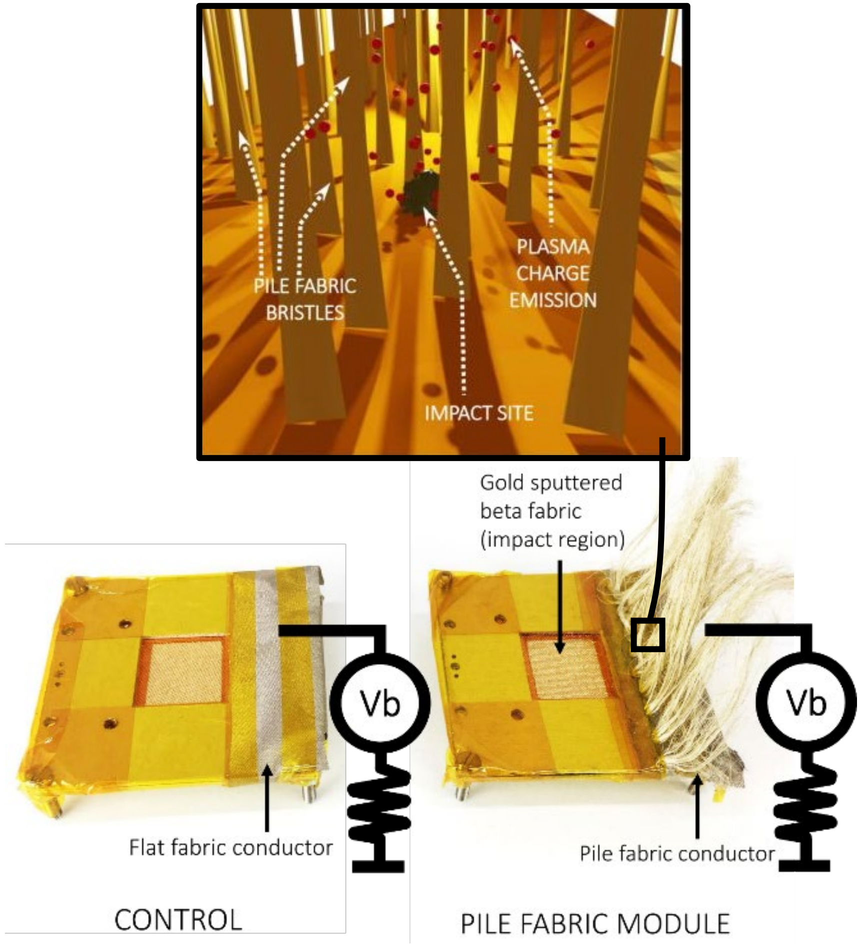
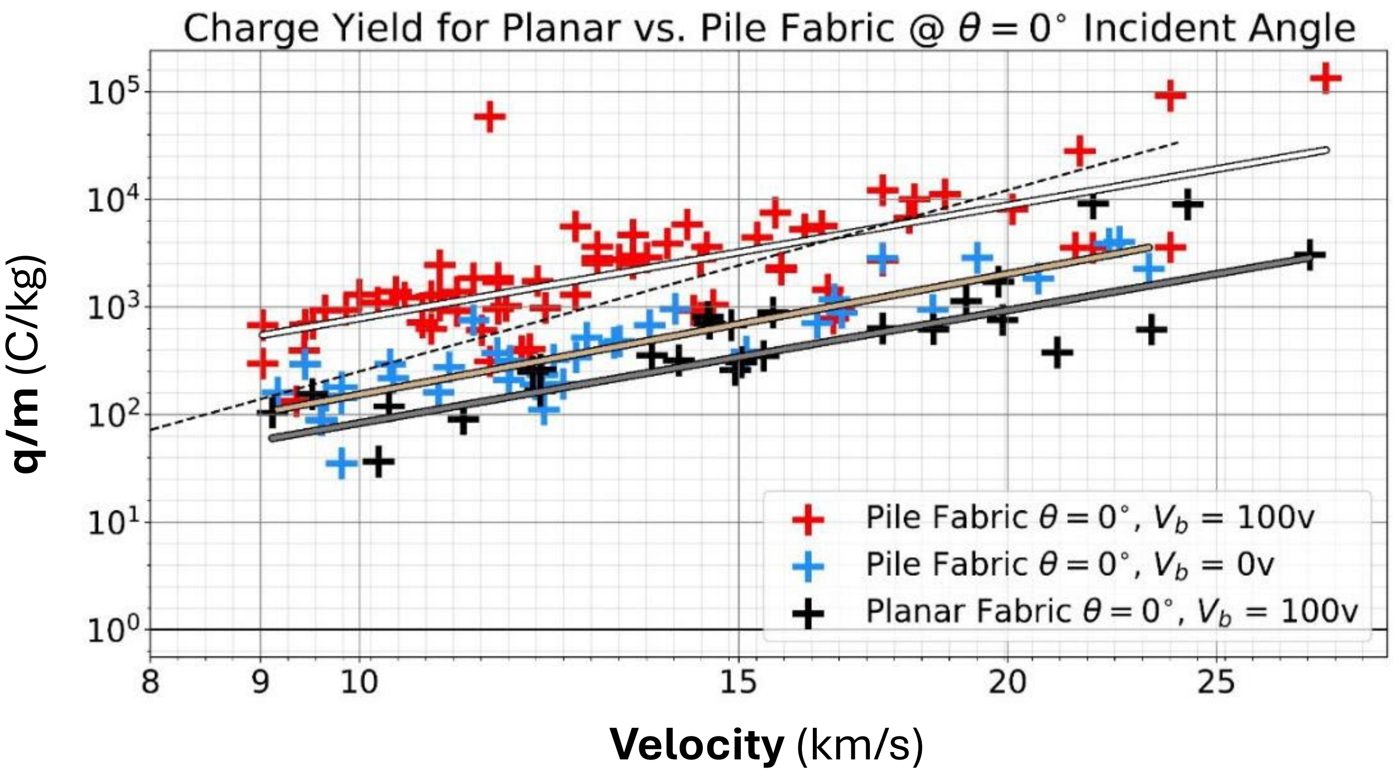
FURTHER INCREASE CHARGE SENSITIVITY VIA CONDUCTIVE PILE FABRIC

Experiment Modules





Biased fur (+100v) **outperforms** unbiased fur & biased planar conductor in charge sensitivity by ~1 order of magnitude

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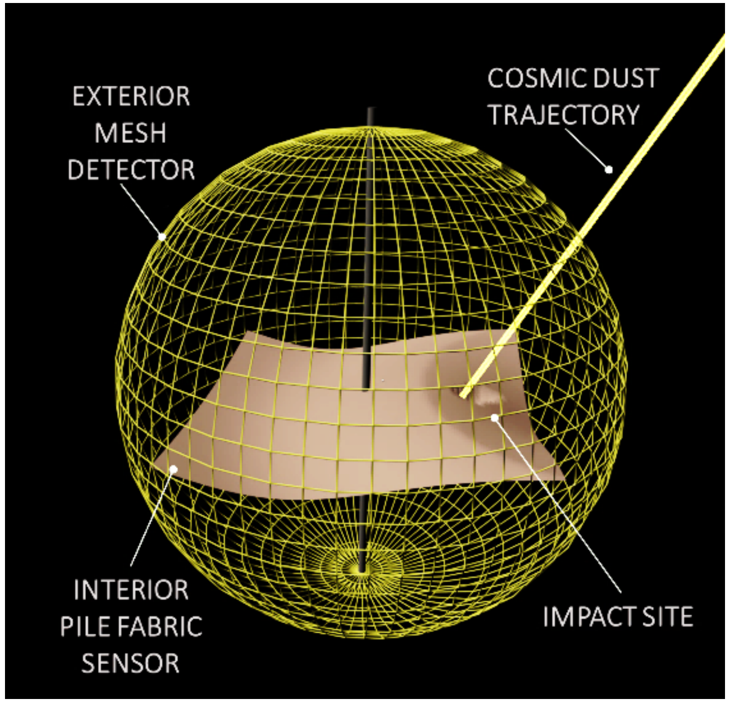
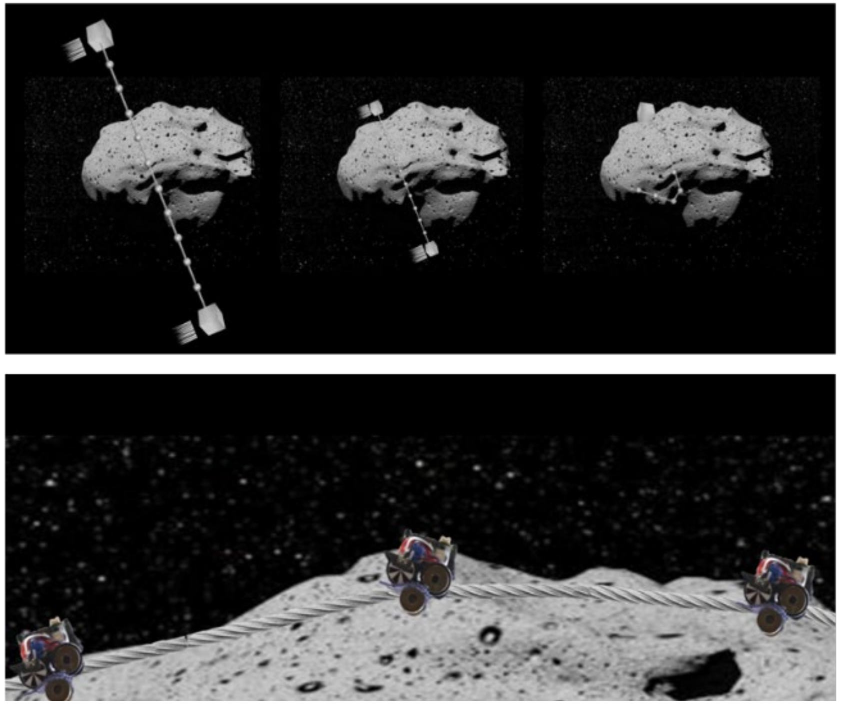
WHERE THIS WORK POINTS: RICH FUTURE FOR ADVANCED FIBERS IN SPACE

TEXTILE TELESCOPES



ROBOTIC ASTEROID INFRASTRUCTURE



HAPTICS ON SPACESUITS

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