National Aeronautics and Space Administration

Materials for Power Transmission in Extreme Environments

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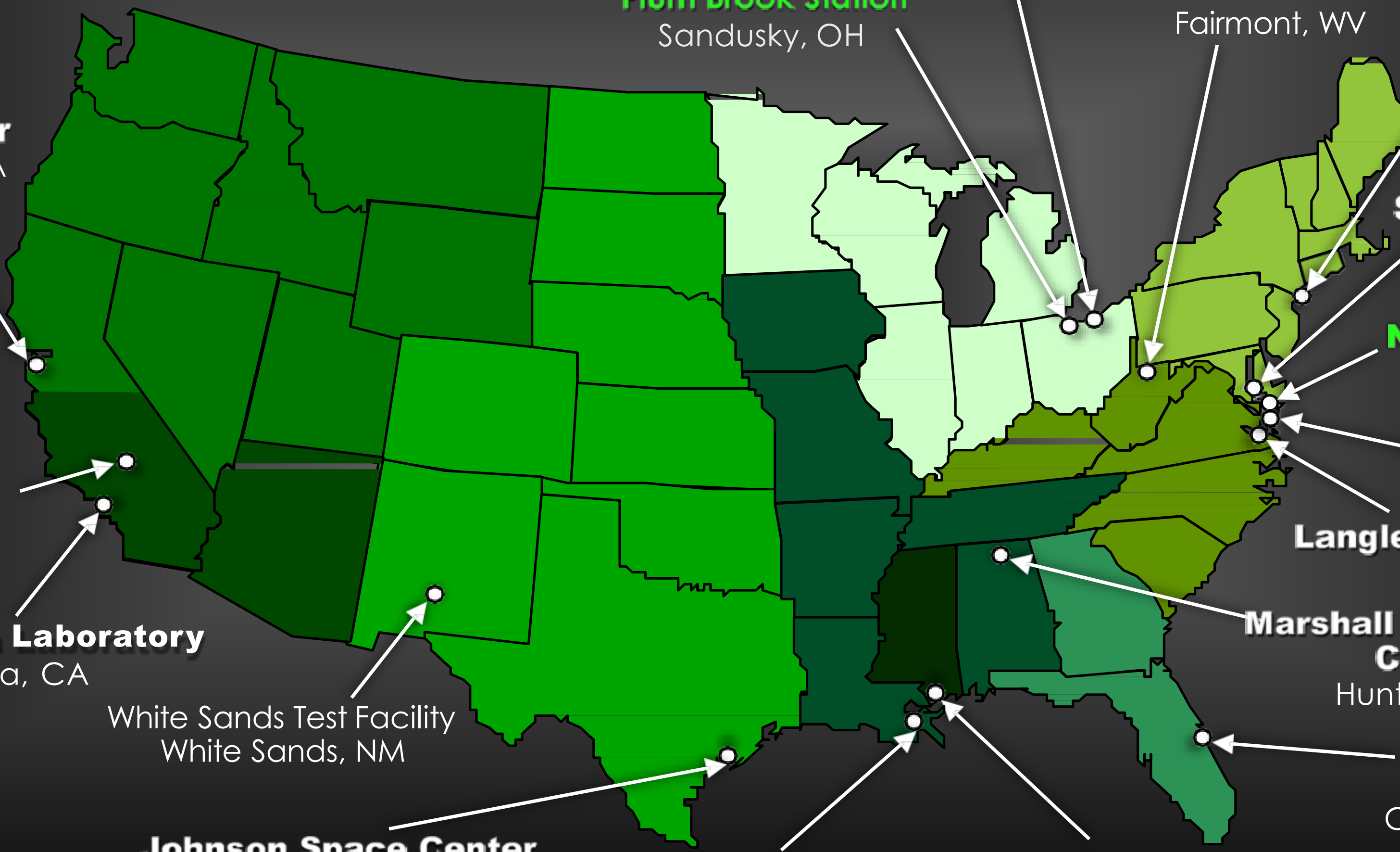
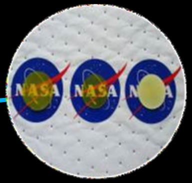
www.nasa.gov

NASA Centers and Installations

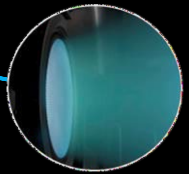
Deep Space Network Facilities:
- Goldstone, in California, Mojave Desert
- Near Madrid, Spain
- Near Canberra, Australia




Power, Energy Storage and Conversion


Materials and Structures for Extreme Environments


Physical Sciences and Biomedical Technologies in Space

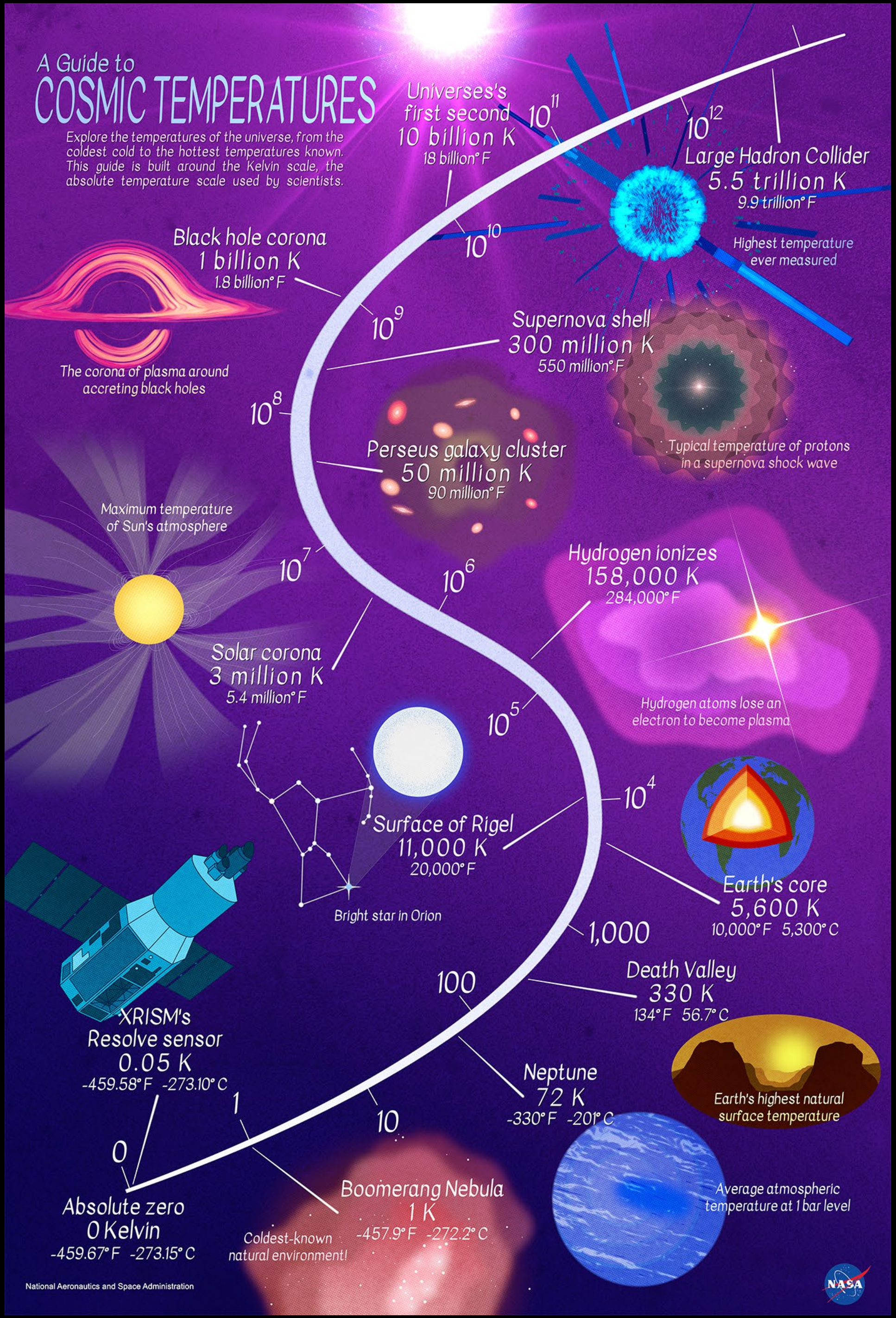

In-Space Propulsion and Cryogenic Fluids Management


Communications Technology and Development


Air-Breathing Propulsion

GRC Core Competencies

The Extreme Environment of Space



Extreme Temperatures

Deep Space
-459 °F/ -273 °C
to
Super Nova
550,000,000 °F

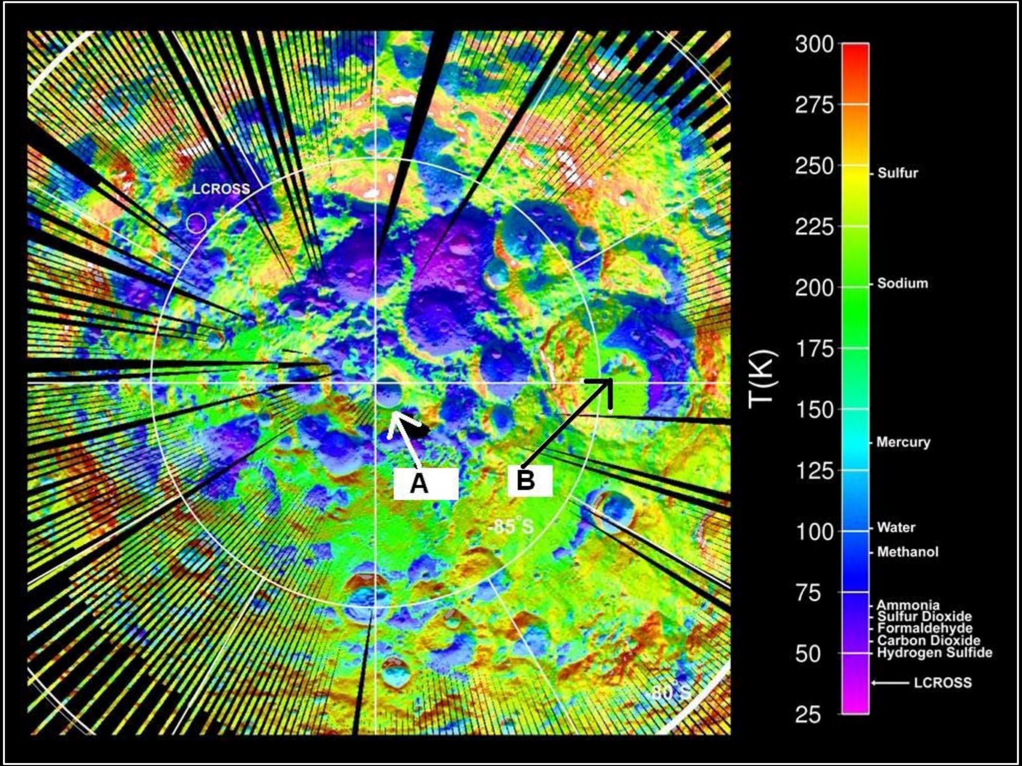
Big Bang
18 Billion °F

Man Made
Large Hadron Collider
9.9 Trillion °F

https://svs.gsfc.nasa.gov/vis/a010000/a014300/a014374/Cosmic_Temperatures_Horizontal_Scale_Full.jpg

Lunar Temperatures

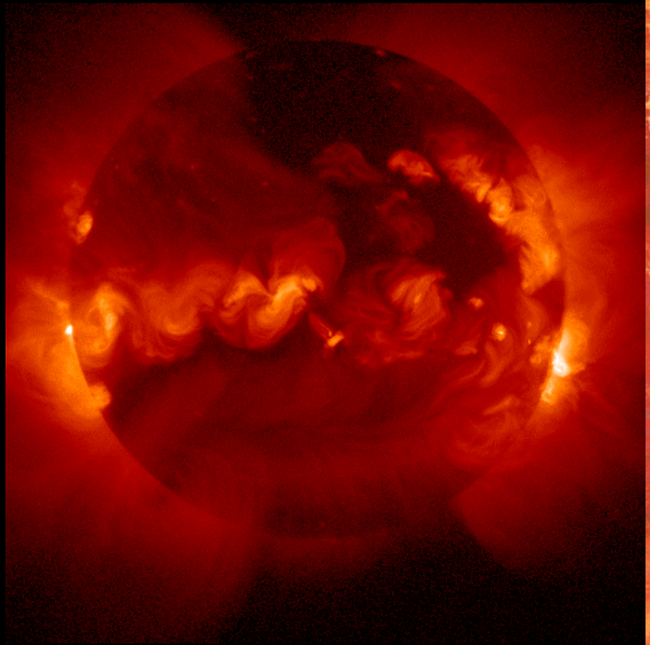
Lunar South Pole Temperature Mapping

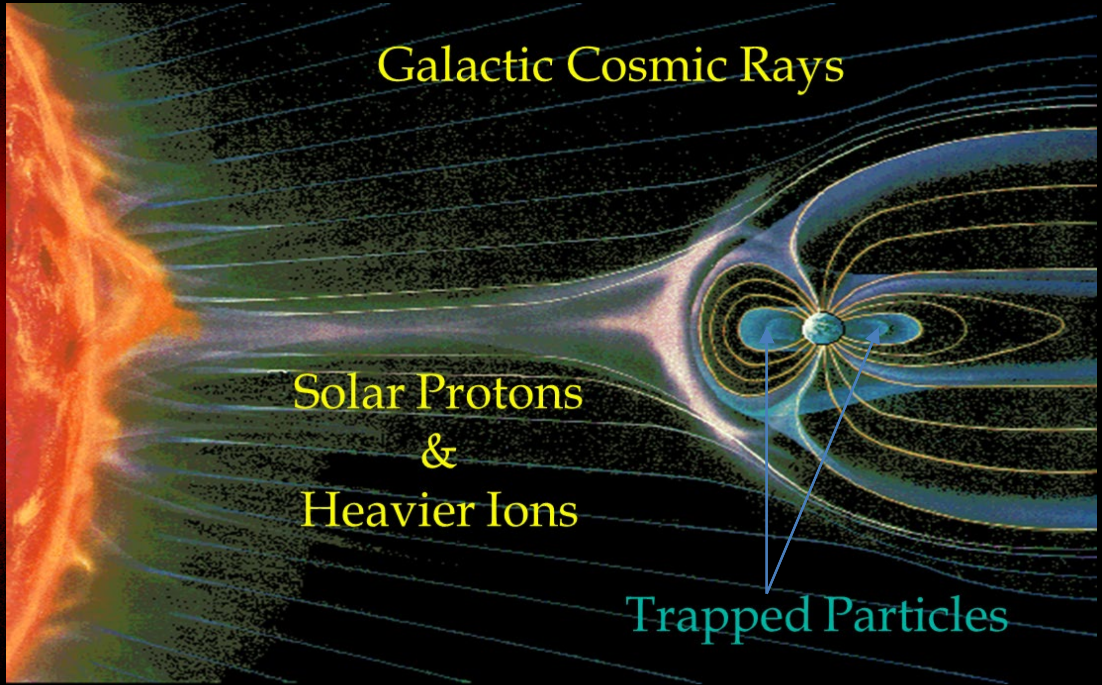


- Daylight temperatures near the Moon's equator ~ 208°F (-133°C) to 250°F (121°C)
- Nightfall at the equator drops to -208°F (-133°C).
- NASA's Lunar Reconnaissance Orbiter has measured temperatures lower than -410°F (-246°C).

https://www.jpl.nasa.gov/edu/images/news/apollo11_moonwork_collage.jpg

The Radiation Environment



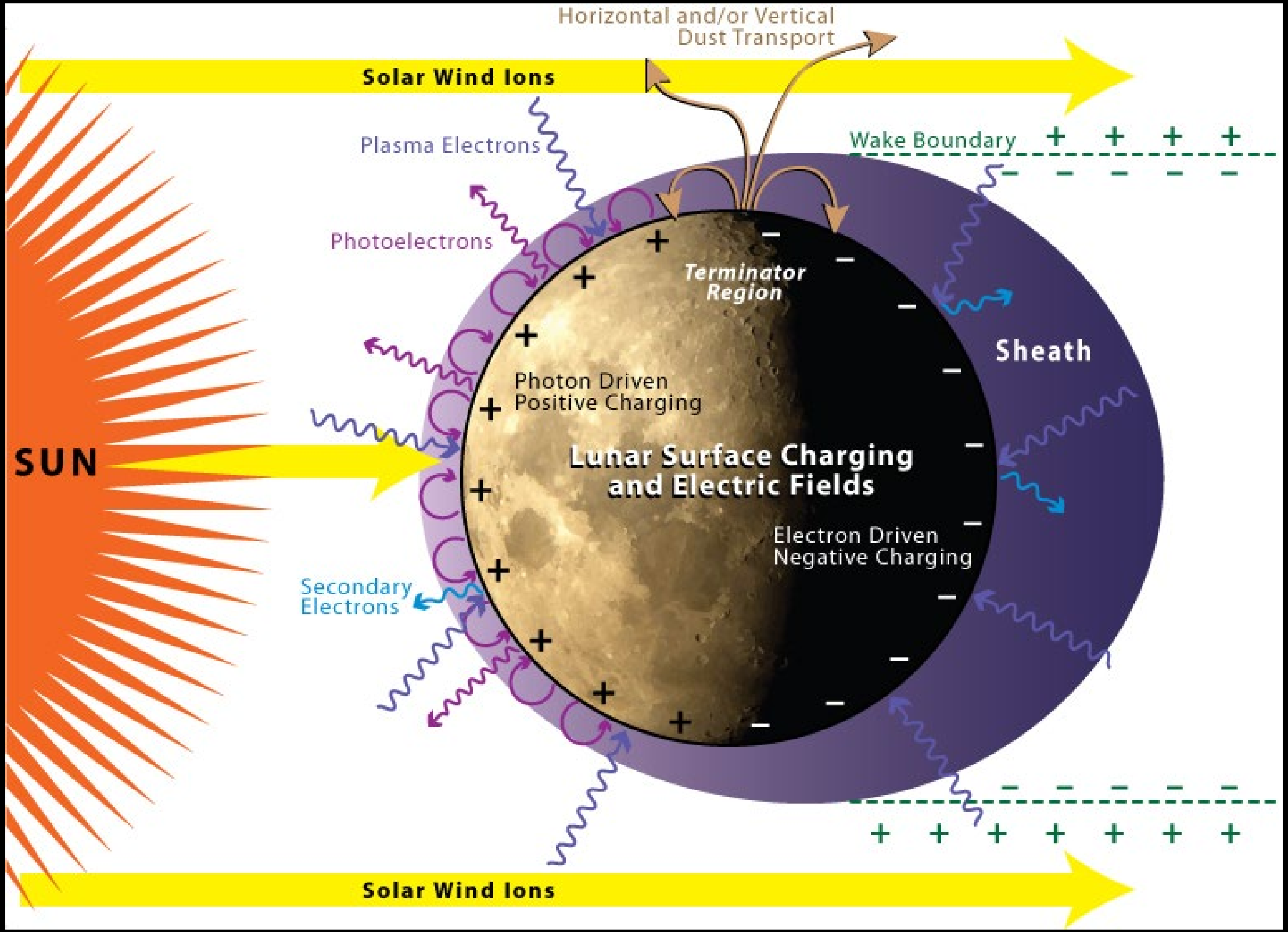


- Charged Particles: Protons, heavy ions, neutrons includes X – rays, UV rays
- Planetary asteroid debris as micrometeors.

https://radhome.gsfc.nasa.gov/radhome/RPO_slides.htm

The Moon is Like a Giant Capacitor

- The Moon is charged by all the charged particles in the heliosphere.
- UV light also deposit photoelectrons or creates ion and secondary electrons from striking regolith particles
- During Corona Mass Ejections while traveling the wake of the Earth's Magnetosphere, negative potentials of -4000 volts as well as dielectric breakdown have been observed.



CHARACTERIZING THE NEAR LUNAR PLASMA ENVIRONMENT. T. J. Stubbs, Goddard Earth Science and Technology Center, and NASA Goddard Space Flight Center, Mail Code 674, Greenbelt, MD 20771, (Timothy.J.Stubbs.1@gsfc.nasa.gov)

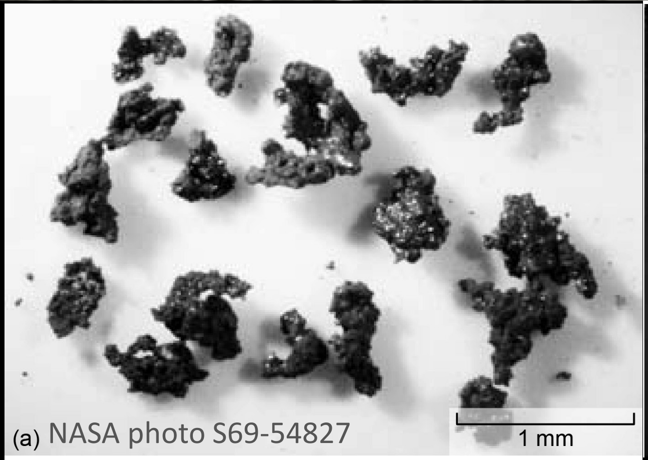
The Lunar Regolith

Regolith is unconsolidated rocky material (minerals, glasses, volcanic rock) that covers bedrock.

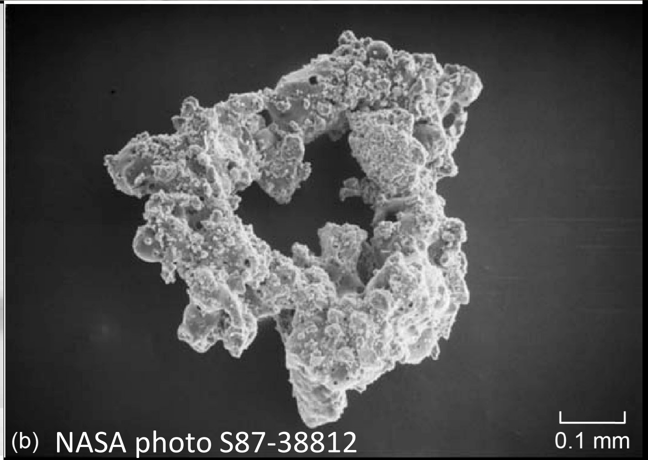
Lunar Regolith Dust :

- <20 microns to ~1 cm
- Electrostatic
- Abrasive with sharp edges

https://svs.gsfc.nasa.gov/vis/a010000/a014300/a014374/Cosmic_Temperatures_Horizontal_Scale_Full.jpg



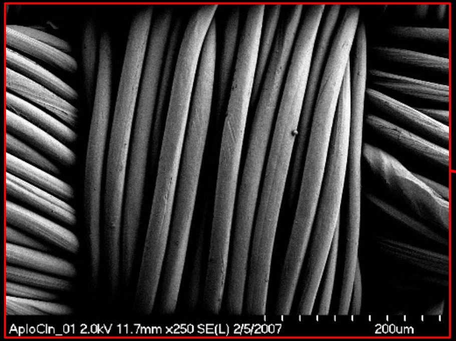
(a) NASA photo S69-54827

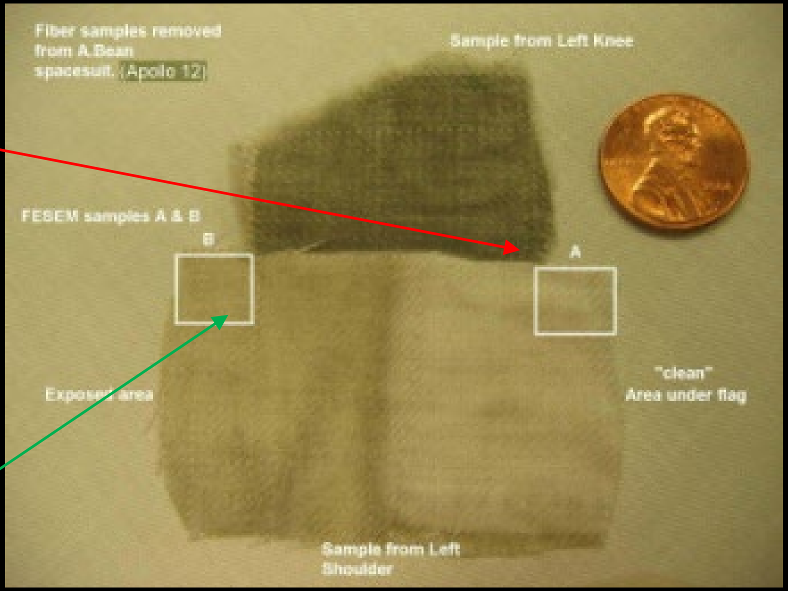


(b) NASA photo S87-38812

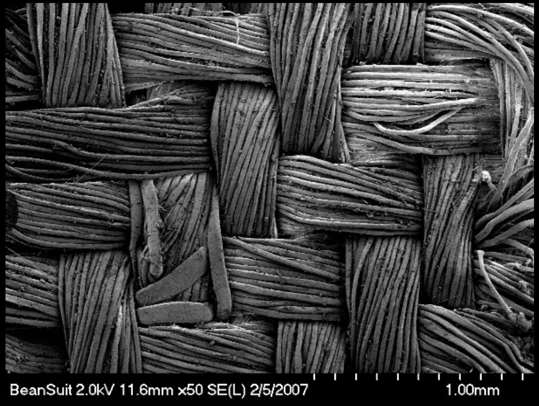
Apollo Era Space Suit and Lunar Dust

Spacesuit : Teflon coated fiber glass fibers Alan Bean Apollo 12 Mission

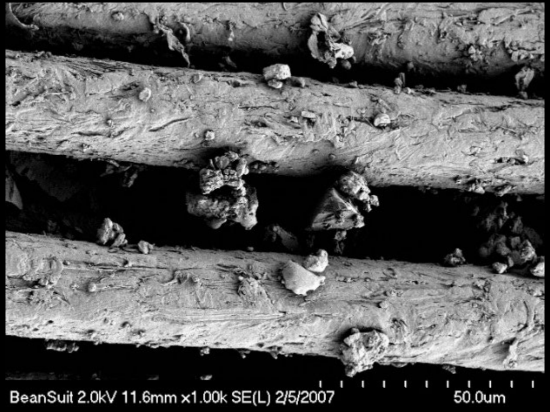




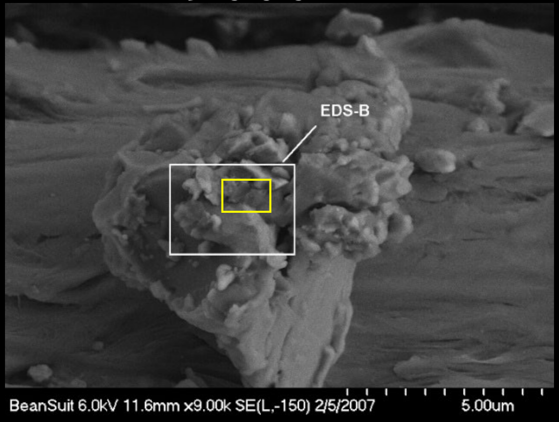
50X

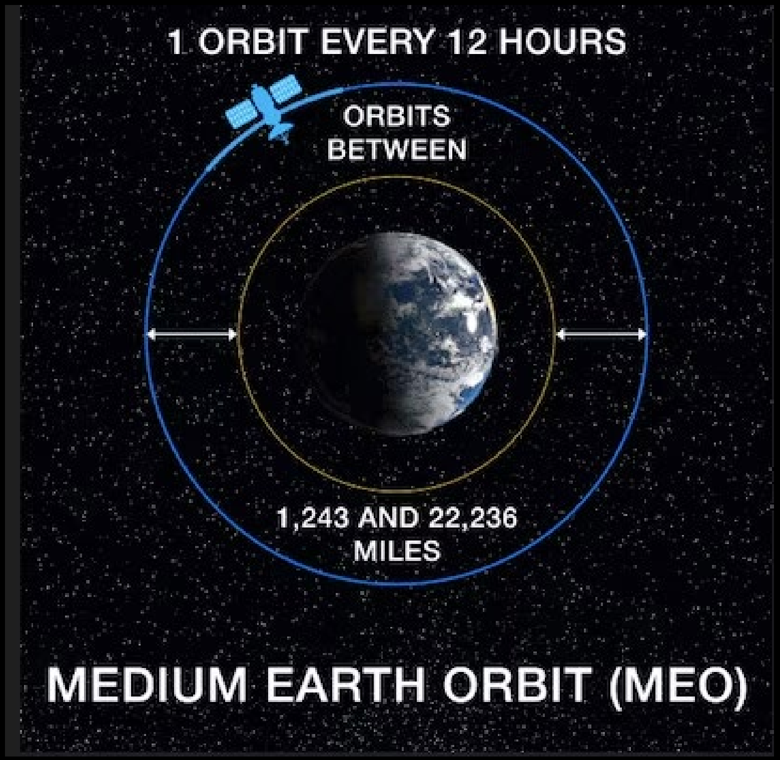


1000X



9000X





Challenges with High Power Transmission In Space

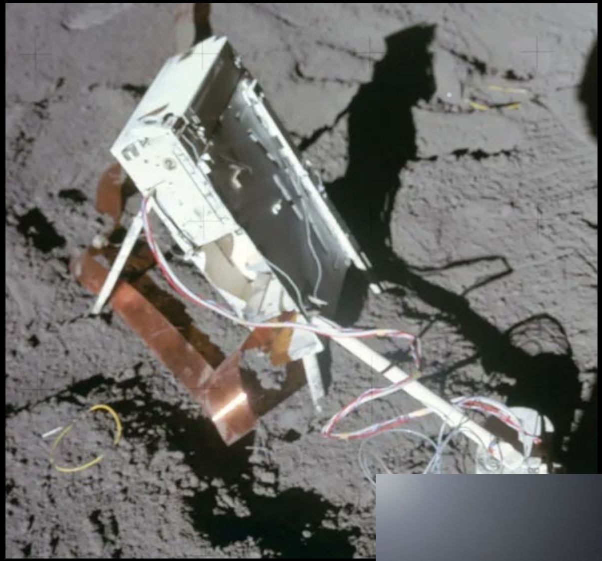
Powering Up The Future in Space

]Best Electrical Insulation Candidates
- Fluoropolymer (FP)
- Polyimides (PI)

Challenges for Reliable HV Power Transmission
- High electric fields (HEF)
- FP susceptible to radiation and creep effecting reliability
- Taped wrapped PI is not extrudable

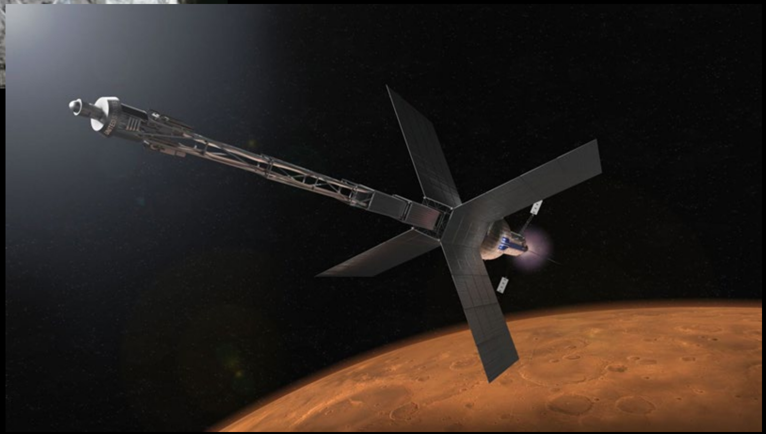
Historically Apollo ALSEP missions,
- PII, 70 W, 16V, 400 Hz (Apollo 17)

Future Lunar Economy
1 KV , 1 kHz PT or 60 kW, 2.5 kV_{AC} or 3 kV_{DC} at 1 kHz power grids,
Best SOA candidate materials are well known Earth, their HV stress, fields and aging rates are unknown in extreme environments



Apollo 15
Cold Cathode Ion Gauge (CCIG) Experiment

Photo AS15-86-11595



Concept of Nuclear Electric Propulsion spacecraft

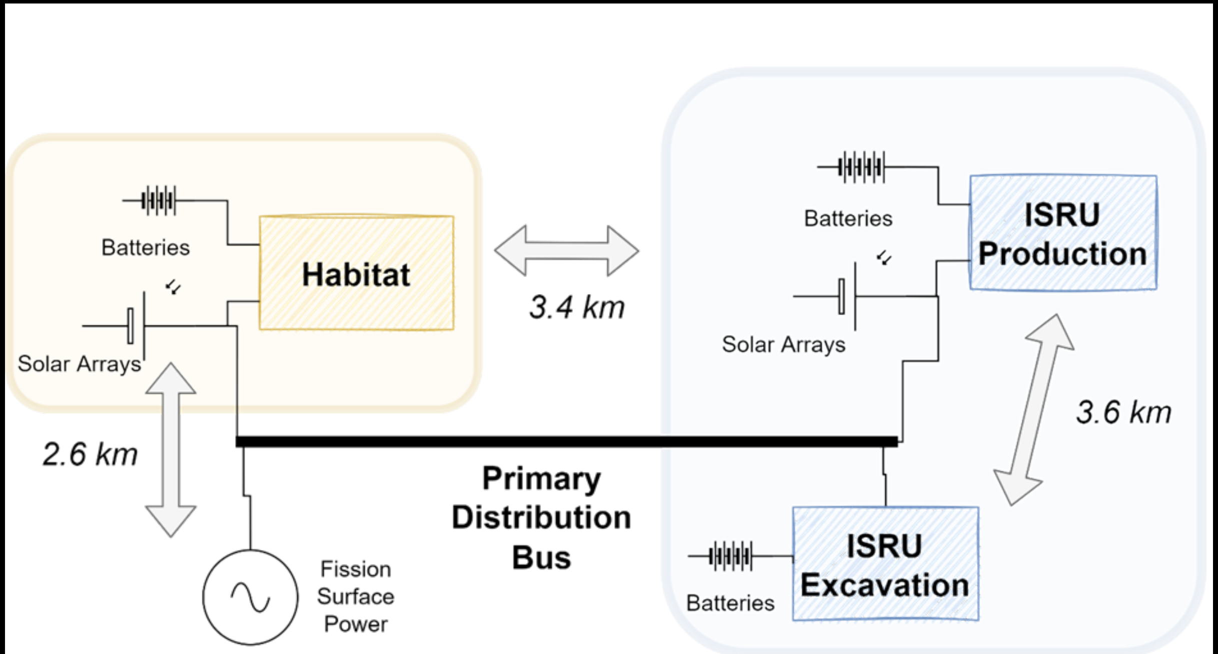
Concept of Artemis Base Camp Micro-grid

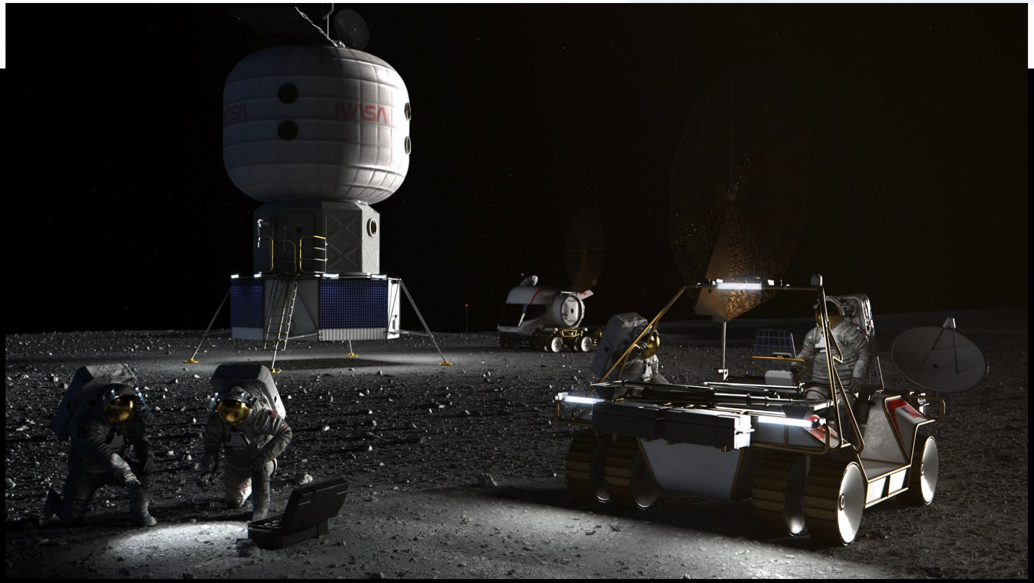
Trade studies focused on primary power distribution system

- Architecture (radial, ring, mesh)
- Power type (AC vs DC)
- Voltage: (600V – 6 kV)
- Data contains estimated mass of converters + cables

Results

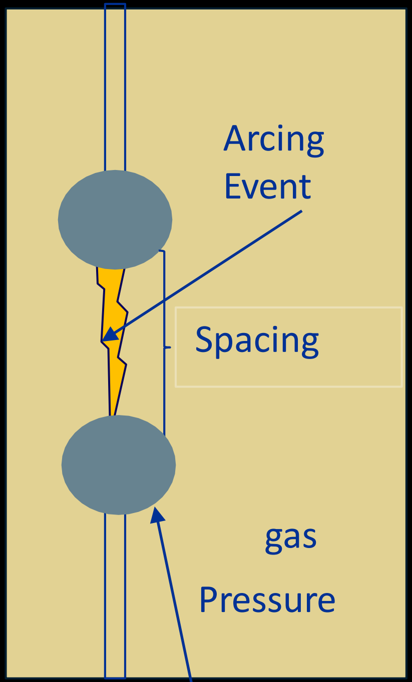
- Voltage 3 kV has mass advantages
- AC vs DC is marginal
- Technology limitations need to be considered

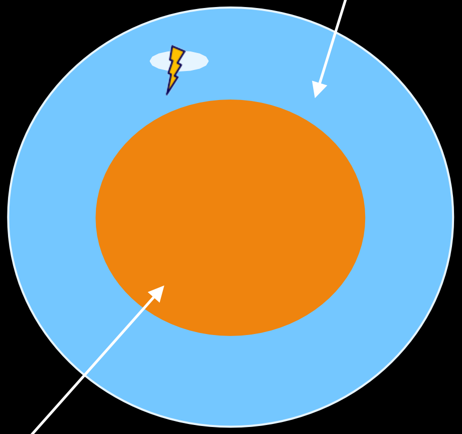


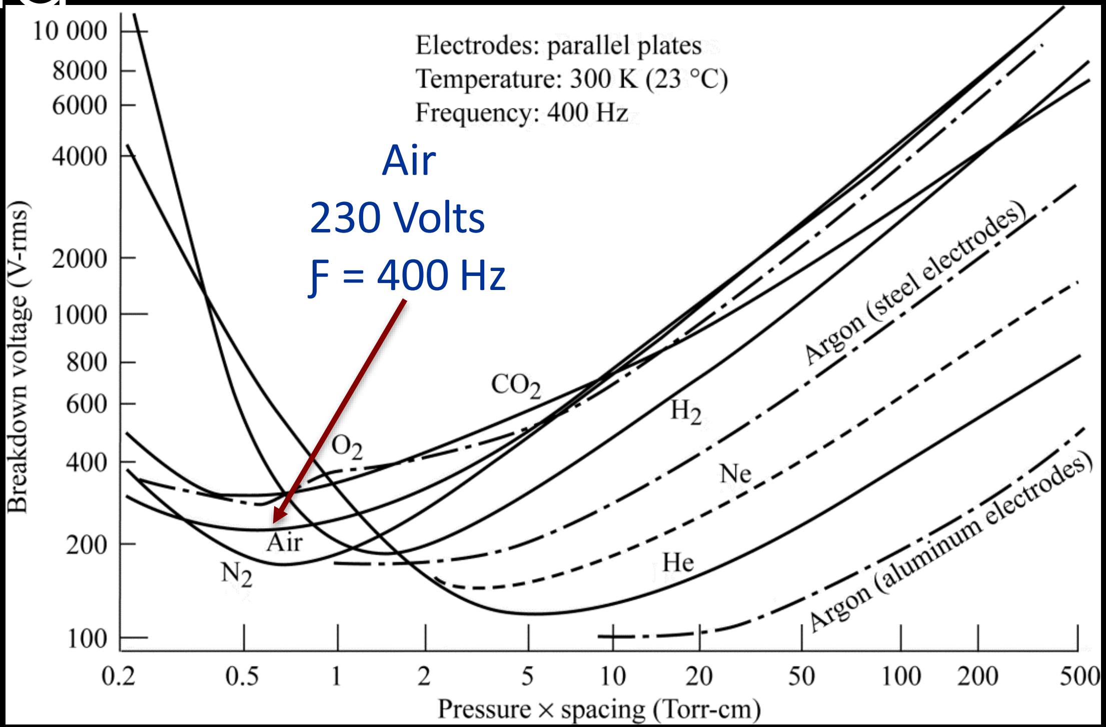


J. Csank, J. H. Scott, Advanced Research Projects Agency Energy, April 29, 2022

Technical Challenges: Partial Discharge and Corona







Breakdown Voltage of Several Gases as a Function of *pd* at Room Temperature

The minimum voltage for electrical discharge between two metal conductors at ***high altitude*** will occur at ~ 327 V. ***At 400 Hz the minimum voltage drops to 230 V for arcing to occur***. Additionally, voids, defects and contaminants in electrical insulation can experience intensified local discharge called partial discharge.

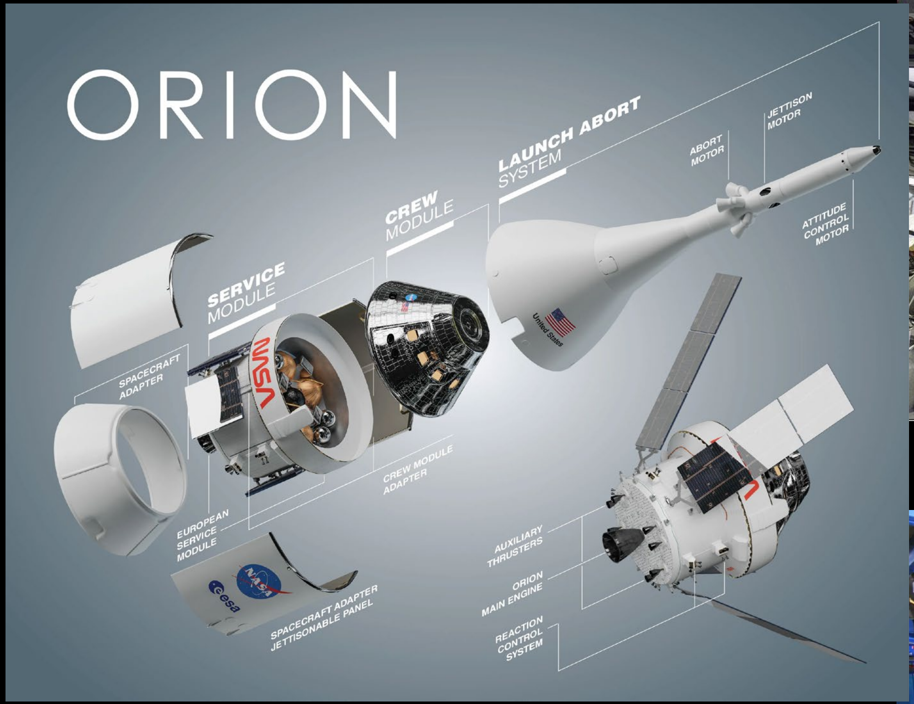
Chart Reference: NASA-HDBK-4007 W/CHANGE 3

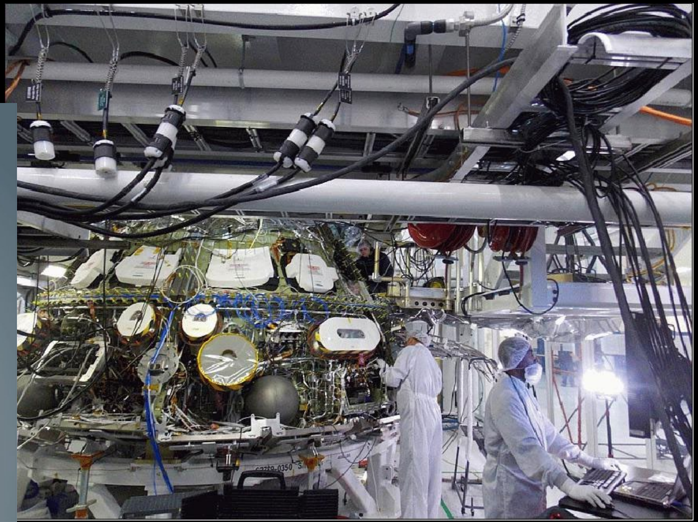
Thermal, Electrical, Mechanical and Environmental Challenges

- Temperature Swings
- Electrical Stress and High Electric Fields
- Mechanical Stress from manufacturing, transport, handling onto spools, loading or installing in spacecraft and deployment
- Environments from sitting on launch site, lift-off conditions, time of flight in standard atmospheric pressures to vacuum.

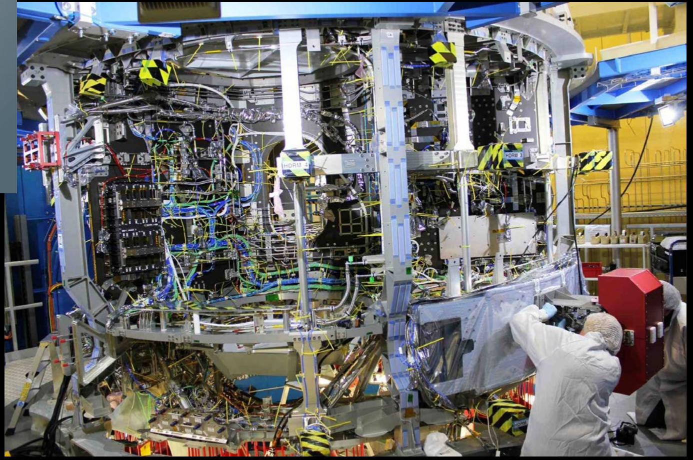
Other Considerations

- Wires and Cables for Mega Watts of power in a future Lunar Economy or Nuclear propulsion vehicles must be safe and reliable.
- Wiring can contribute 50% or more of the Payload increasing costs.
- We need lightweight, safe and reliable solutions.





Orion Crew Capsule

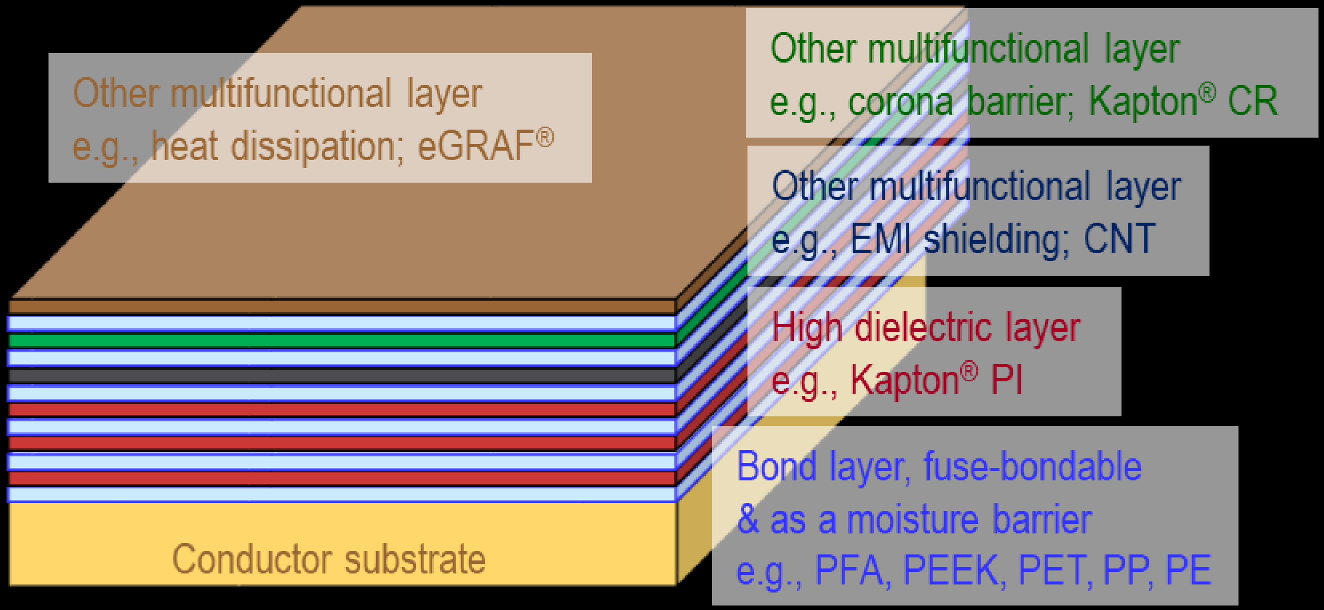


Orion Service Module

credits: NASA

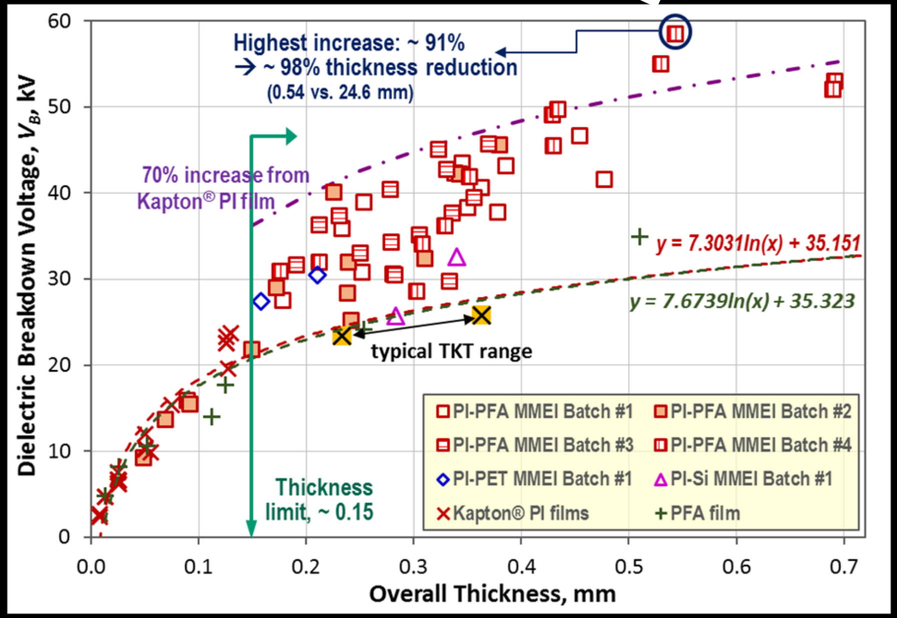
MASA Materials R&D for High Power High Voltage Transmission

NASA developed a Micro-Multilayered-Multifunctional Electrical Insulation (MMEI)

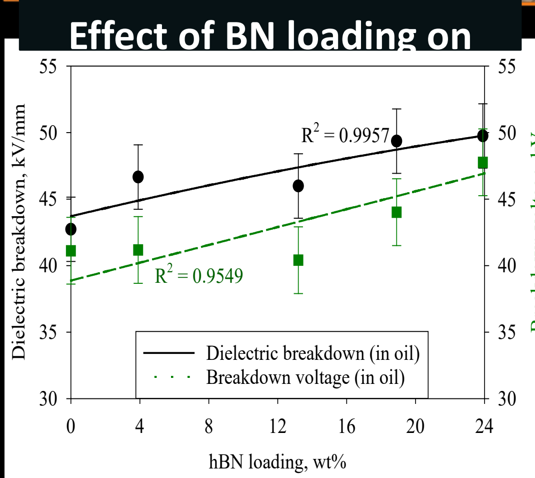


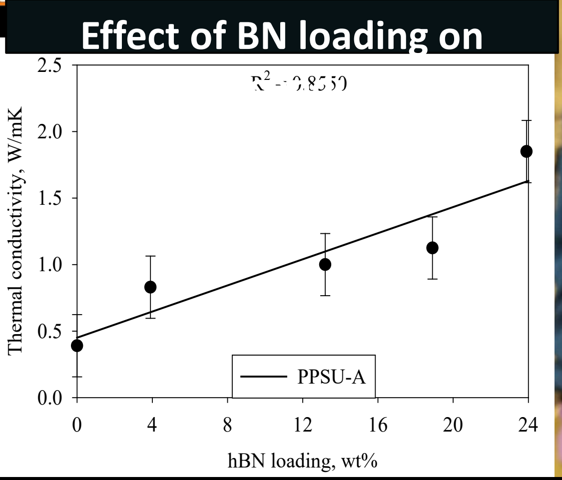
Compared to SOA Teflon-Kapton-Teflon (TKT)

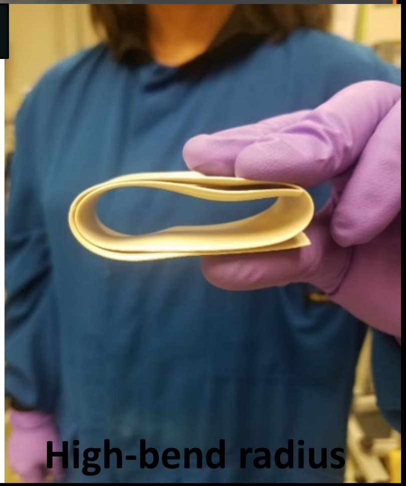
- 91 % increase in dielectric break-down Voltage
- 99% decrease in insulation thickness



Improved Properties of Polymer with Fillers







Demonstrated better Thermal and Electrical Performance with ceramic fillers.

Composite insulation showed **improvement in dielectric strength** and **increase in thermal conductivity** relative to the neat polymer

T. Williams, B. Nguyen and W. Fuchs, 2020 IEEE 3rd International Conference on Dielectrics (ICD), 2020, pp. 541-545, doi: 10.1109/ICD46958.2020.9341910

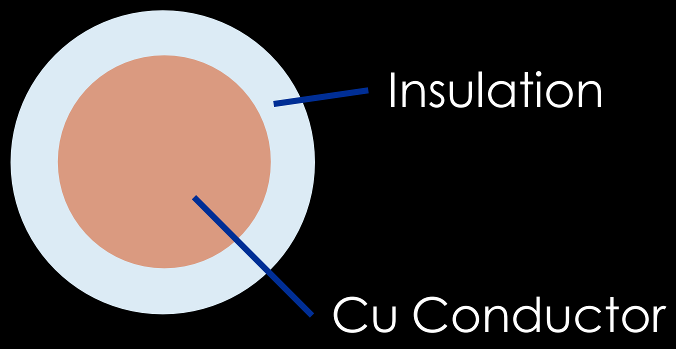
Tiffany Williams, Baochau Nguyen, Witold Fuchs

Lightweighting Conductor

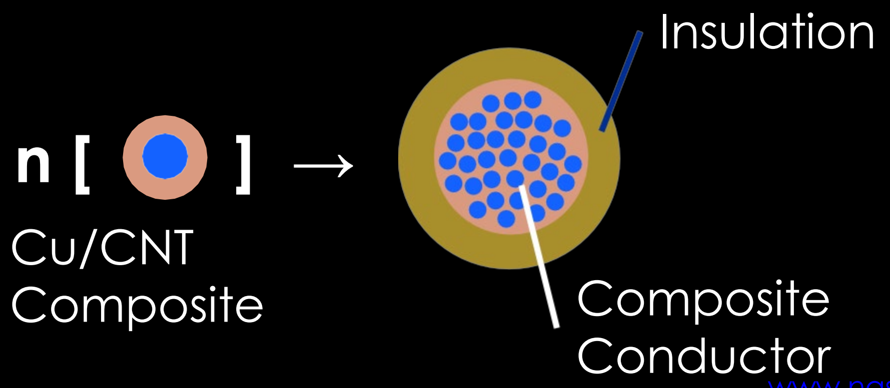
	Copper	Carbon Nanotube (CNT) Yarn
Electrical Conductivity (κ, S/m)	5.8×10^7	*1.3×10^6
Tensile Strength (σ, MPa)	2 00	1500

Key Feature	(σ_{TS}, MPa)	Electrical Conductivity (κ)
Electroless plating [2]	-	90% IACS
Self-fueled electrodeposition [3]	500-650	51% IACS
Super-aligned CNTs [4]	287	46.8 MS/m
Cu-Ti alloy matrix [5]	362 *σ_{YS}	93% IACS
SPS composites, not aligned [6]	275	93% IACS
Higher ampacity [4,7]	-	46-47 MS/m

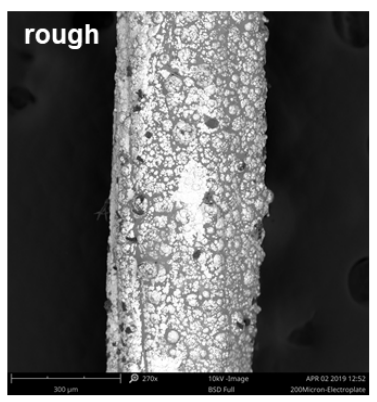
Now

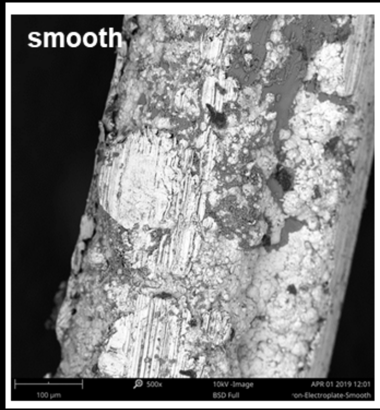


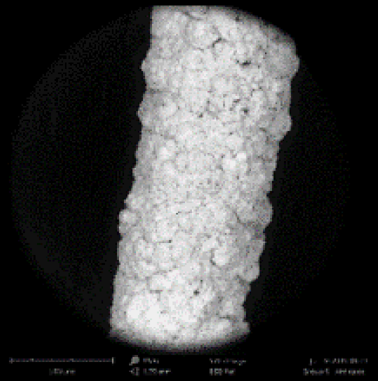
Future



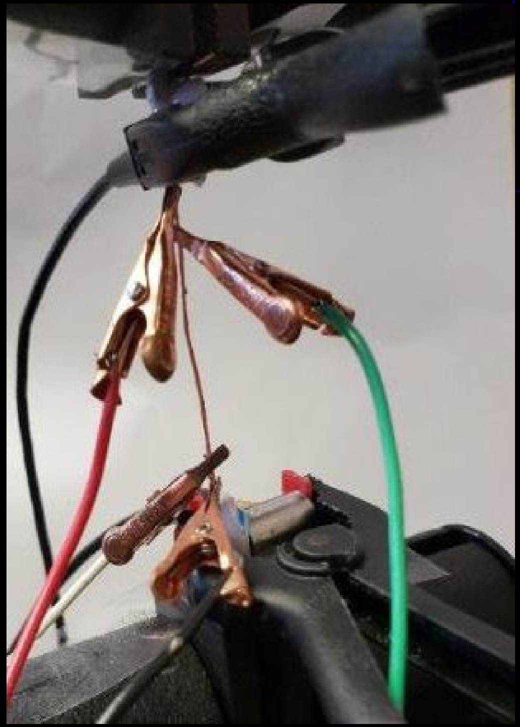
Lighter weight Cu/CNT Conductor



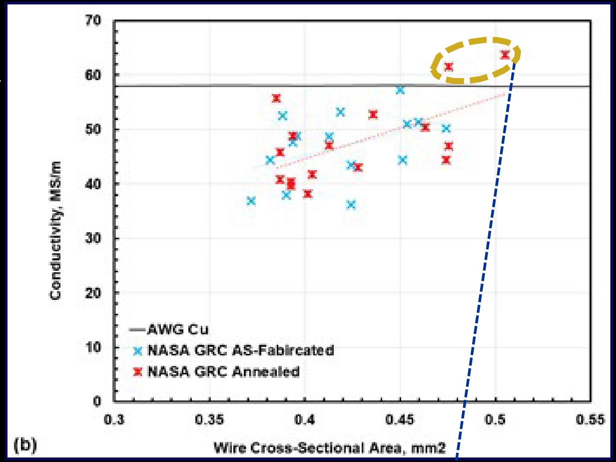




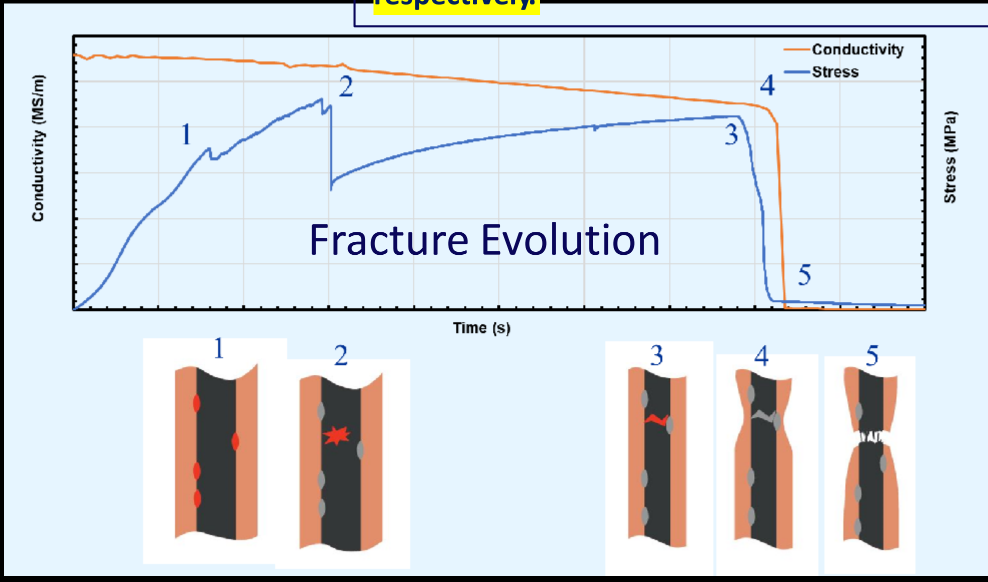
Correlate electrical and mechanical behaviors via 4-probe electrical resistance (ER) and acoustic emission (AE) monitoring



Cu/ CNT composite provides opportunity to further reduce wire/cable weight while maintain most of the electrical conductivity of the conductor and increase strength.



Batch 5 conductivities were greater than both theoretical predictions and pure annealed Cu by 9.8 and 4.8 percent, respectively.



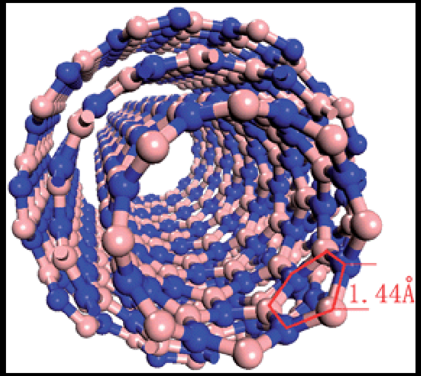
Hexagonal Boron Nitride Nanomaterials

NASA Glenn Research Center (GRC) has 2 decades of expertise synthetizing BNNTs and other BN nanomaterials for different Aerospace applications due to their multifunctionality

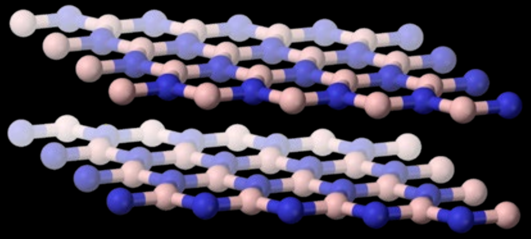
BN Applications:

- ✓ Aerospace structures and components
- ✓ Radiation Shielding
- ✓ Electric propulsion components
- ✓ Energy Storage
- ✓ Tribology
- ✓ Thermoelectric
- ✓ Ballistic Armor
- ✓ Cosmetics

- **Good Insulation Properties**
  - ✓ Constant wide band gap above 5.2 eV
- **Good Mechanical Strength**
- **High Thermal Conductivity**
  - ✓ Thermal Conductivity (W/(m·K)):
    - ✓ BNNT > 600, W/m·K
    - ✓ h-BN in plane > 100, W/m·K
    - ✓ h-BN through plane ~ 30 W/m·K
  - ✓ Ability to dissipate heat in nano electrics
  - Promising results in thermal shock experiments
- **Chemically and Thermally Stable**
  - ✓ Hydrophobic
  - ✓ Chemical stability
  - ✓ Oxidation in air above 1100 °C

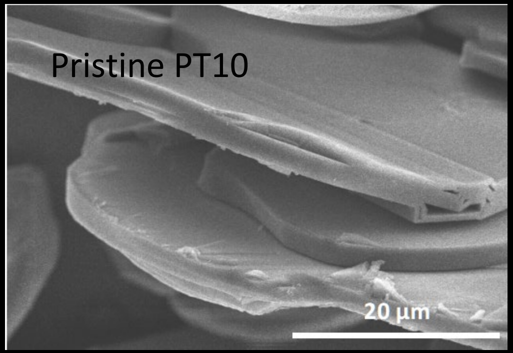


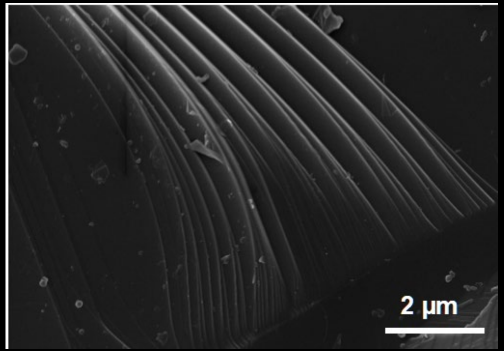
BNNT

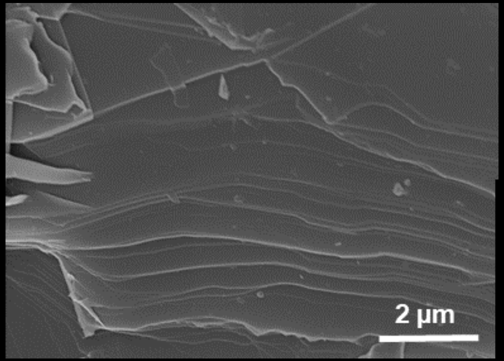


h-BN

What Can We Do With h-BN ?



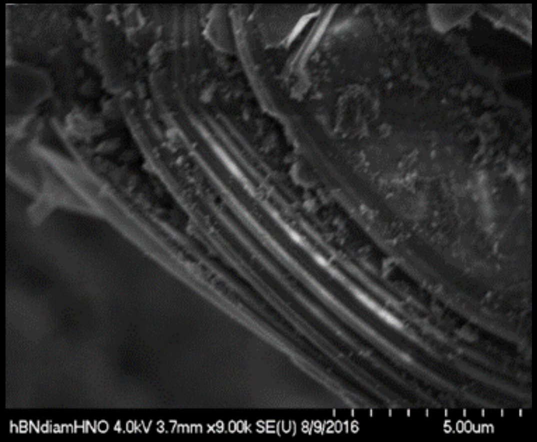


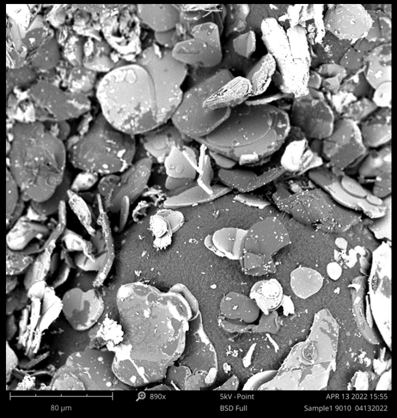


Make them into nanosheets to increase surface area

We can fill them or coat them with other materials. To change properties

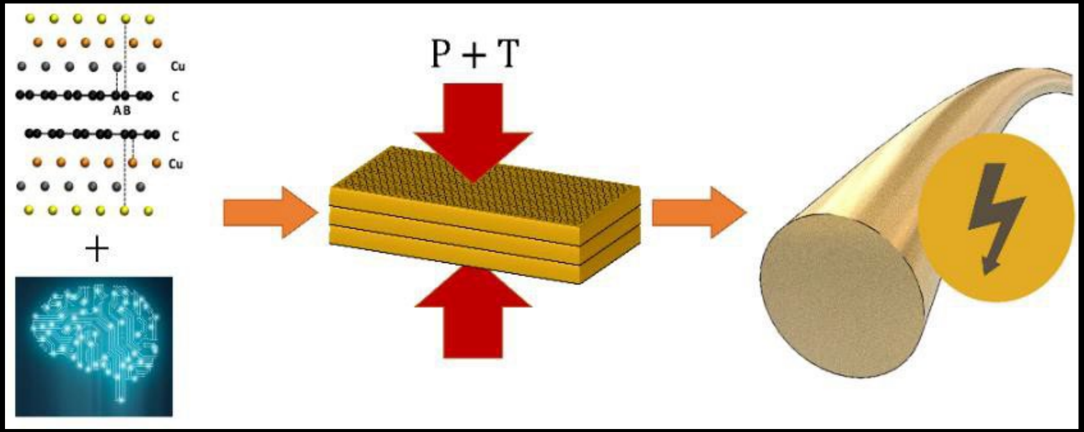
And make composites.





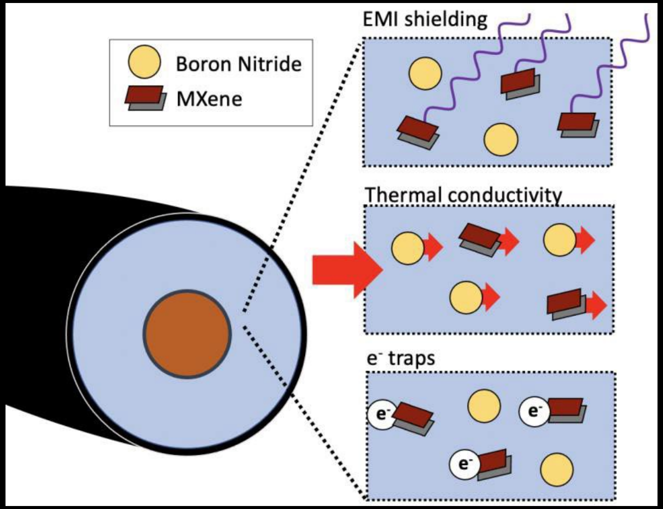
ESI 21 Topic 1: Materials For High Voltage Power Transmission on the Moon

PI: Mehran Tehrani and Co-PI: Michael Cullinan, University of Texas at Austin



Objectives: Design, manufacture, and characterize ultra-conducting graphene-copper wires for high voltage applications.

Dr. Zhiting Tian, Cornell University



Objectives Create multifunctional nano composites with improved thermal , electric & shielding properties.

The Pale Blue Dot
This is our Earth, our HOME

The Pale Blue Dot is a photograph of Earth taken Feb. 14, 1990, by NASA's Voyager 1 at a distance of 3.7 billion miles from the Sun. The image inspired the title of scientist Carl Sagan's book, "Pale Blue Dot: A Vision of the Human Future in Space," in which he wrote: "Look again at that dot. That's here. That's home. That's us."

https://science.nasa.gov/resource/voyager-1s-pale-blue-dot/

Thank you!

NASA Fellowships:
https://www.nasa.gov/stem/fellowships-scholarships/index.html

NASA Internships:
https://intern.nasa.gov/

NASA Careers:
https://www.usajobs.gov/.

Acknowledgements:
NASA STMD ESI Program
NASA TACP TTT Project
NASA AAVP AATT