Polymer Aerogels for Lunar Applications and Beyond

Dr. Stephanie Vivod
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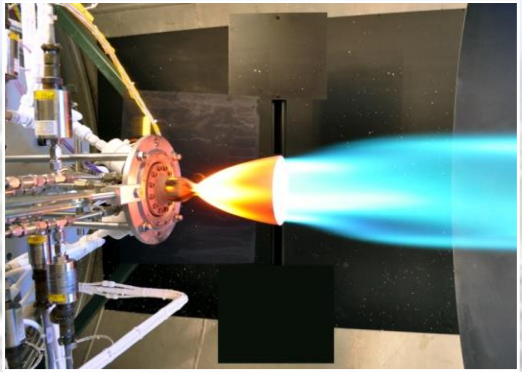
NASA Glenn Research Center

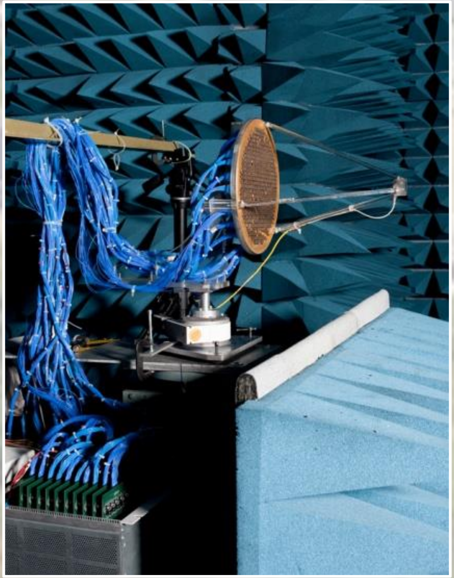
GRC Core Competencies

Air-Breathing Propulsion



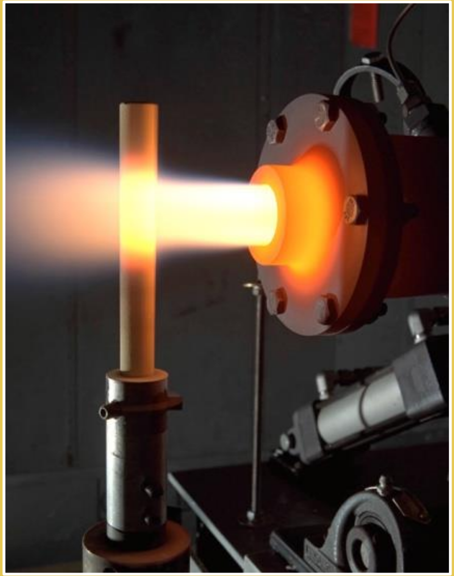
In-Space Propulsion and Cryogenic Fluids Management

Physical Sciences and Biomedical Technologies in Space



Communications Technology and Development

Power, Energy Storage and Conversion



Materials and Structures for Extreme Environments

WE’RE GOING BACK!

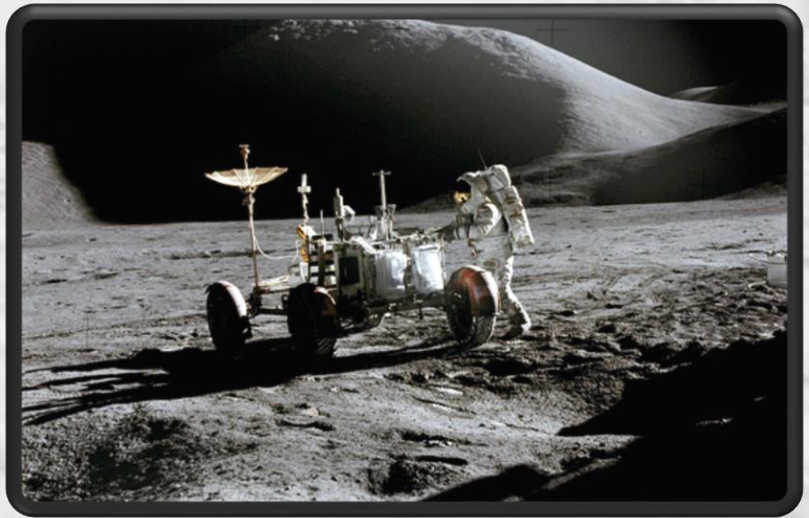
Artemis Program: Return to moon-2024

https://www.nasa.gov/specials/artemis/

Apollo Program ran from 1961 to 1972

Moon Landing Missions:

- **Apollo 11 (1969)** Neil Armstrong (Commander), Buzz Aldrin, Michael Collins
- **Apollo 12 (1969)** Charles “Pete” Conrad (Commander), Alan Bean, Richard Gordon
- ***Apollo 13 (1970)** James Lovell (Commander), Jack Swigert, Fred Haise
- **Apollo 14 (1971)** Alan Shepard (Commander), Edgar Mitchell, Stuart Rosa
- **Apollo 15 (1971)** David Scott (Commander), James Irwin, Alfred Worden
- **Apollo 16 (1972)** John Young (Commander), Charles Duke, Thomas Mattingly
- **Apollo 17 (1972)** Eugene Cernan (Commander), Harrison Schmitt, Ronald Evans



Apollo 15-Astronaut James B. Irwin, lunar module pilot, works on the Lunar Roving Vehicle

*mission aborted

Issues and Concerns with Spaceflight and Planetary Exploration

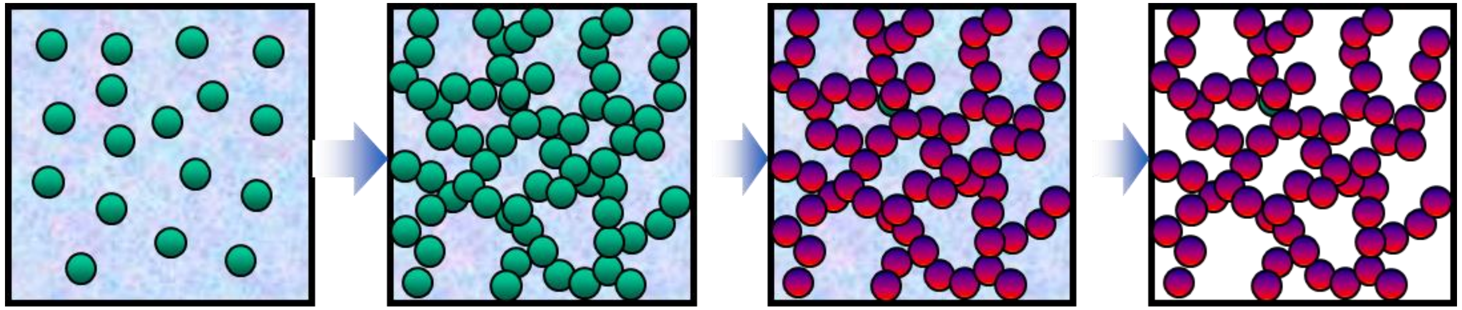
- Orbital debris
- Radiation
- Lunar dust
- Payload weight reduction
- In-situ resource utilization (ISRU)
- Crew health and safety

The Wonderful World of Polyimide Aerogels!

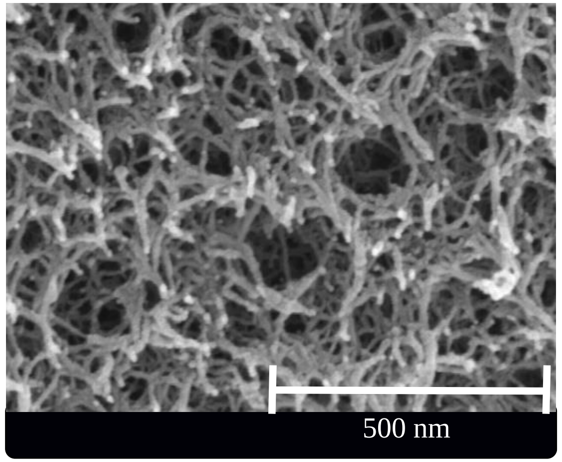
What is an aerogel?

- An open-celled, light weight, porous material derived from a gel in which the liquid is replaced by gas while maintaining the self-assembled three-dimensional structure

Can be formed into moldable shapes and thin films



Polyimide Aerogels made using sol-gel synthesis and supercritical fluid extraction



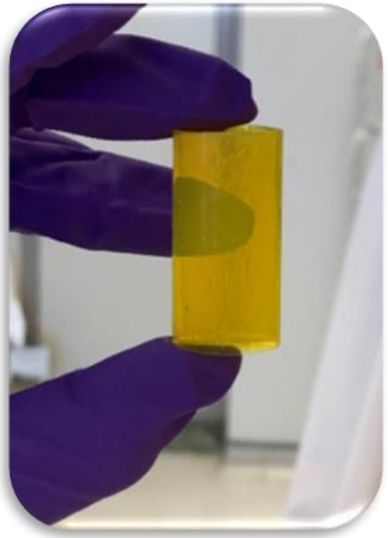
Scanning Electron Micrograph of polymer aerogel matrix

Polymer Aerogel Properties

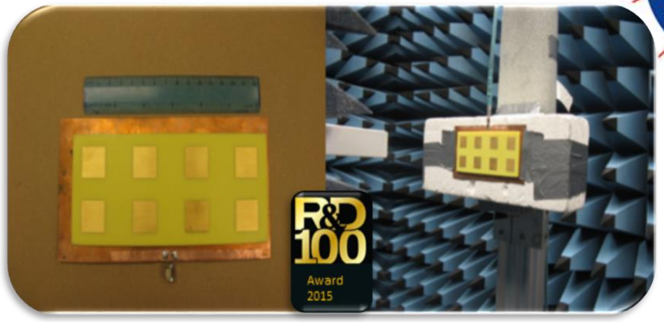
Many characteristics of aerogels are tailored by using various chemistries; however, all aerogels have these

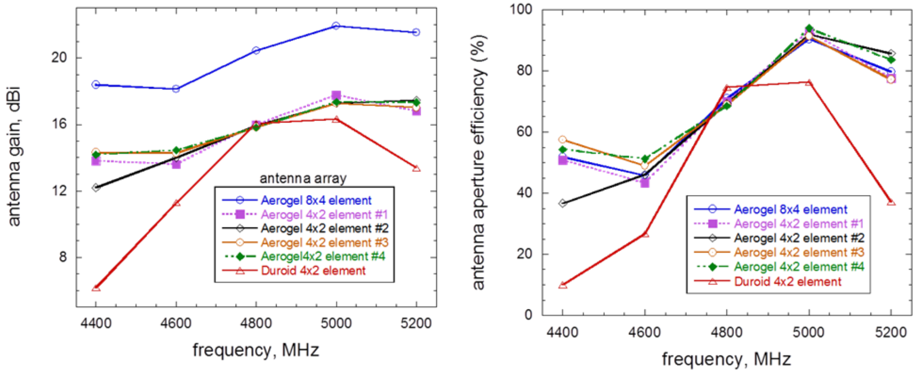
Typical Properties:

- High porosity (> 90 %)
- Nano-scale pore sizes (10-40 nm)
- Low density (0.05-0.2 g/cm^3)
- Large surface areas (400 – 850 m^2/g)
- Low thermal conductivity (~20mW/m·K)
- Low dielectric (1.1)
- Low refractive index (1.02-1.09)



polymer aerogel cylinder (1g)

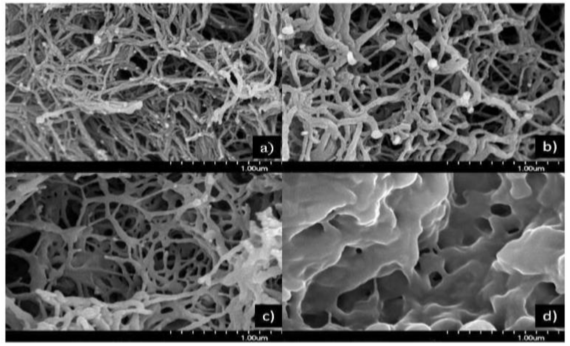




Low dielectric-Improved gain and efficiency over SOA Duroid antenna substrates

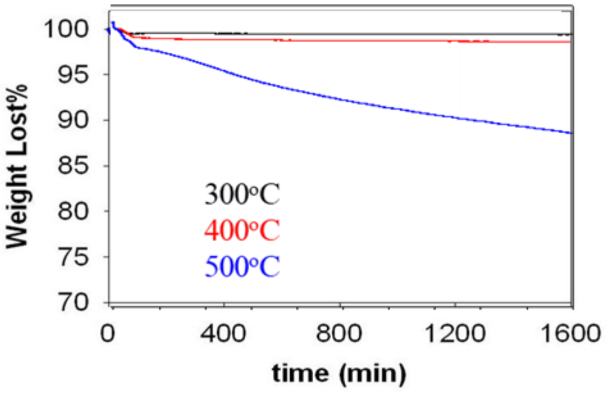
Before heating

After 300 °C

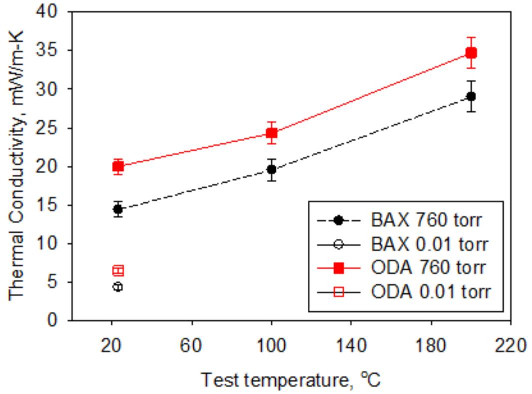


After 400 °C

After 500 °C



Polyimide aerogels-High Onset of decomposition (>550° C)



Low thermal conductivity

When were aerogels first discovered?

1. *1969*
2. *1930*
3. *1868*
4. *861*

When were aerogels first discovered?

1. 1969- First man on the moon

2. 1930- First Aerogel made by Samuel Kistler

3. 1868- Discovery of DNA

4. 861 AD- Vikings discover Iceland

Aerogel Timeline

SS Kistler
Chemistry professor for College of the Pacific (Stockton, CA)

1930s

First discovery of aerogels, first use of sfe for aerogels

1970s

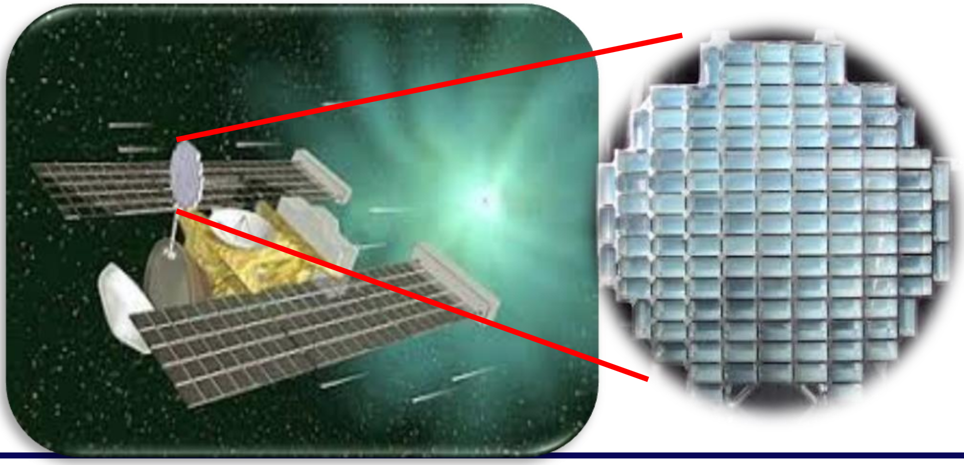
Resurgence of aerogel work- oxygen and rocket fuel storage

1980s

Use of supercritical CO_2 fluid extraction- increased safety and efficiency

1990s

NASA Space Missions use aerogel-Mars Rover battery and Stardust Mission



2000s

Polymer reinforced silica: x-aerogels, flexible aerogel blankets

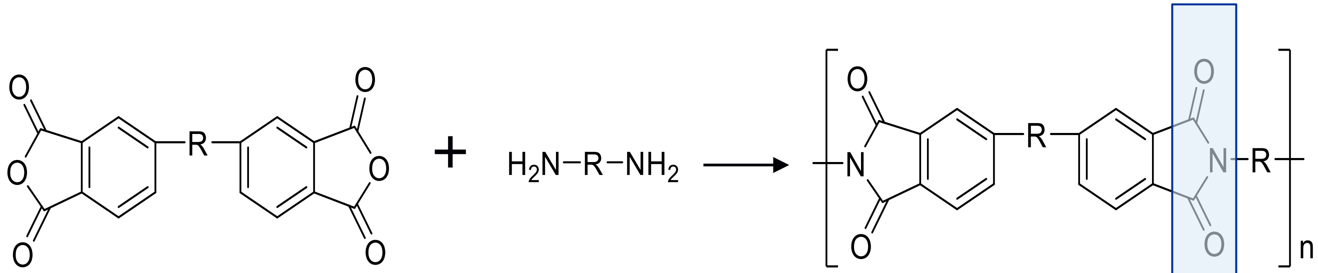
2010s

Flexible thin film polyimide

Current/ Future

3D printed polymer aerogels, Drug delivery, Sensors, Chemical Spills, filtration, tissue engineering

Why polyimide aerogels?



Dianhydride Diamine Polyimide

Two acyl groups bound to N creates imide

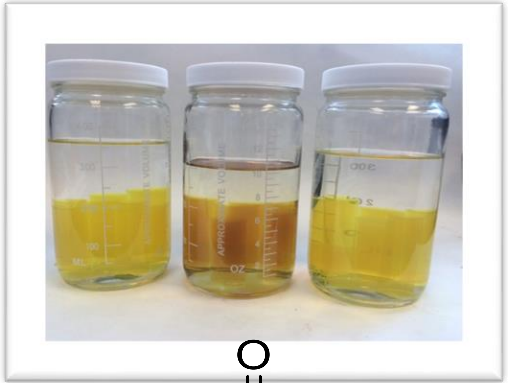
Polyimides

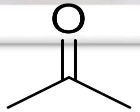
- DuPont-high temperature engineering polymers
- High glass transition (Tg) temp
- Thermal stability (>500 °C)
- Mechanical strength –toughness, flexibility, high tensile strength
- Chemical resistance
- Transparency
- Electrically insulating

Aerogels

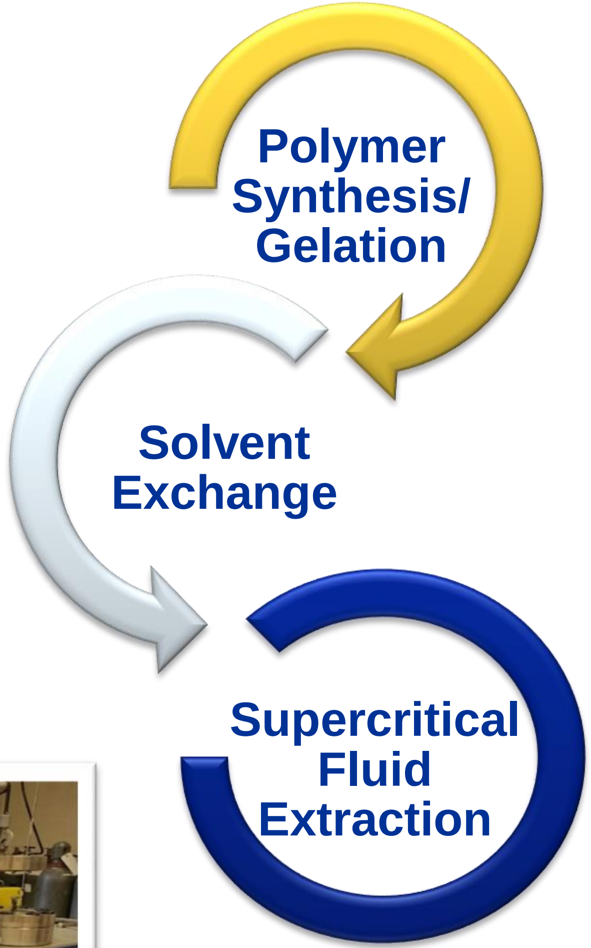
- Low density
- High porosity
- High surface area
- Low thermal conductivity

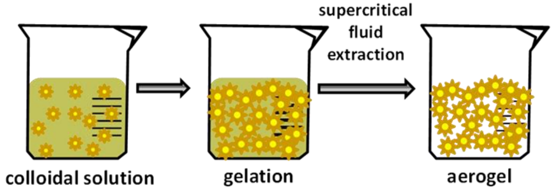
Aerogel fabrication process



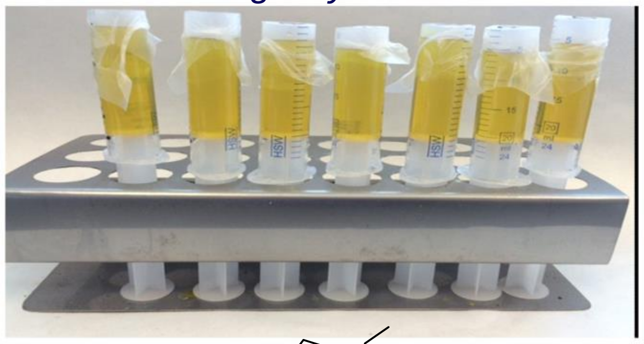


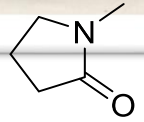
acetone



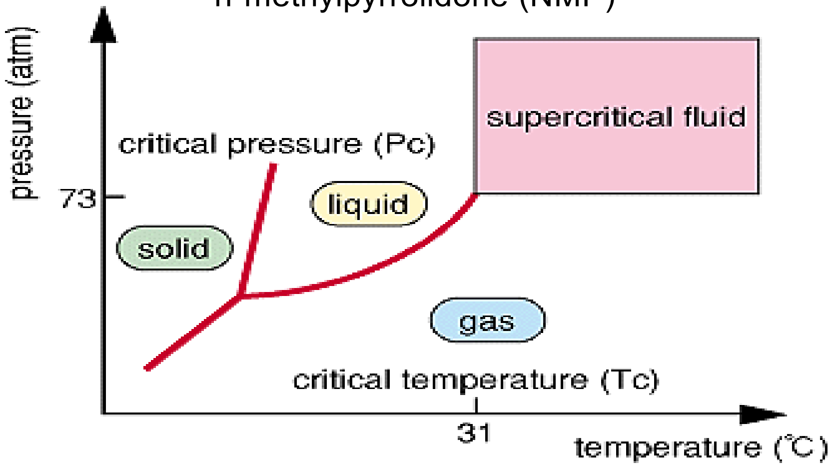


sol-gel synthesis

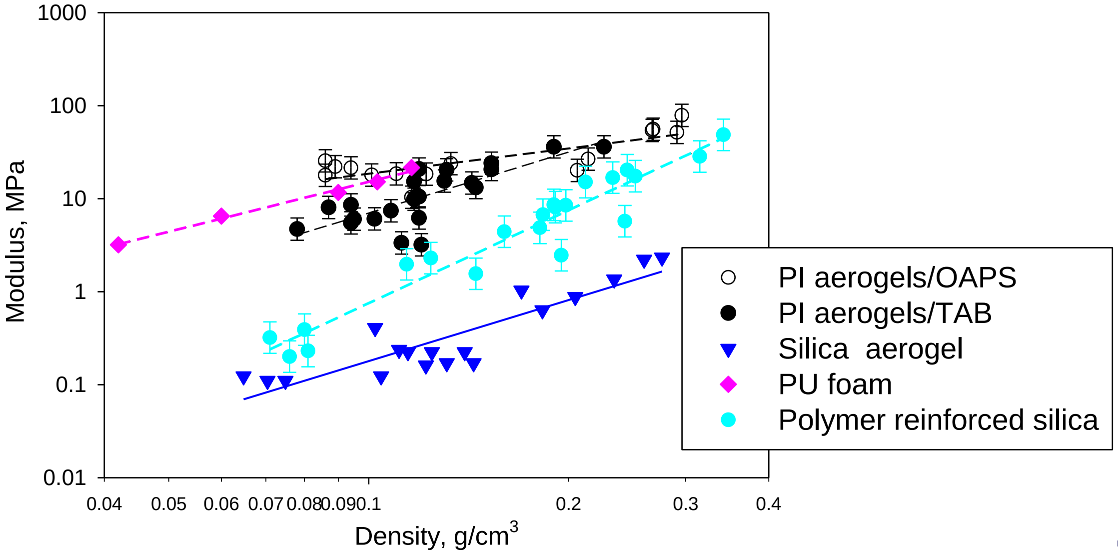




n-methylpyrrolidone (NMP)



Strong, flexible polyimide aerogels



Can be formed into moldable shapes and thin films with excellent mechanical properties and flexibility

What are potential applications for aerogels?

1. *Radiation mitigation*
2. *Acoustic Impedance*
3. *Thermal Insulation*
4. *IR Filtration*
5. *All of the Above*

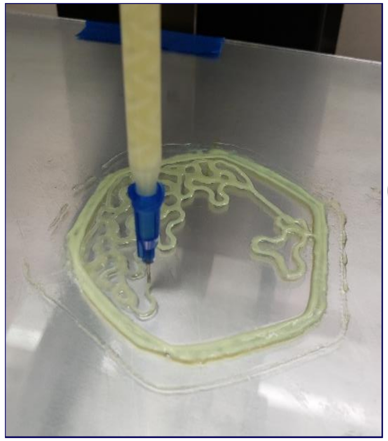
What are potential applications for aerogels?

1. Radiation mitigation
2. Acoustic Impedance
3. Thermal Insulation
4. IR Filtration
5. All of the Above

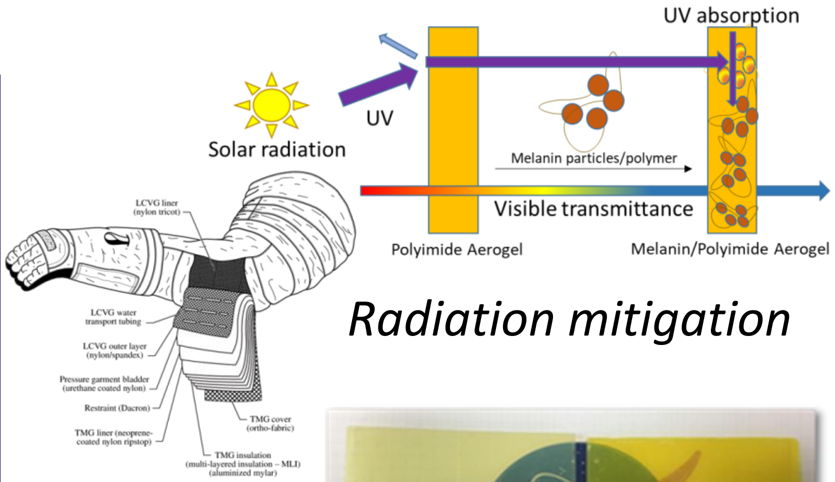
Aerogel applications with Industry, Academia, and OGA's

- **<u>Aerogel Technologies, LLC:</u>** Holds the highest number of licenses for NASA aerogel technology
- **<u>UT Austin/NSF:</u>** ultralight carbon aerogel electrodes to increase energy density of rechargeable batteries
- **<u>Scintilex,LLC/DoE:</u>** Highly transparent aerogel -high energy particle detection
- **<u>Aspen Aerogel-SBIR with NASA</u>**: Thin Aerogel as a Spacer in Multi-Layer Insulation. Fixed-Wing and Rotary-Wing Aircraft Thermal, Acoustic, IR & Fire Protection
- **<u>US DoD/ Lockheed Martin</u>**: Nanocellulose Aerogels for UAV applications
- **<u>Washington State University</u>**: 3D-printed LH2 Tank-Aerogel Insulation
- **<u>Bremont Watch Co(UK)/Boeing</u>**: Wristwatches and chronometers featuring Boeing aeroplane material (aerogel)
- **<u>Designer Claire Choisne</u>**: Boucheron's <u>Goutte de Ciel</u>, which translates as "taste of the sky."

Polyimide Aerogel Development

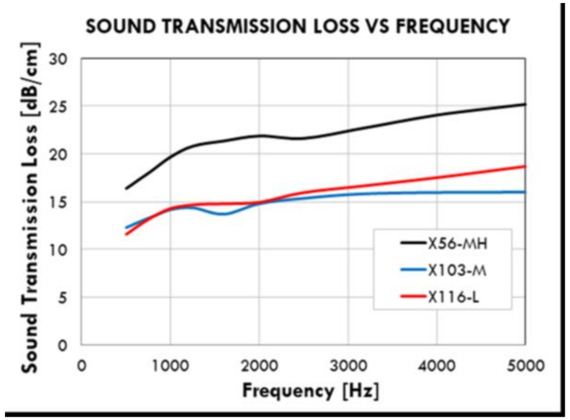


3D printing

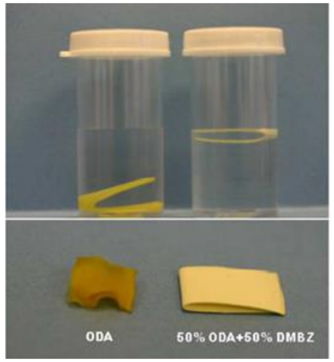


Radiation mitigation

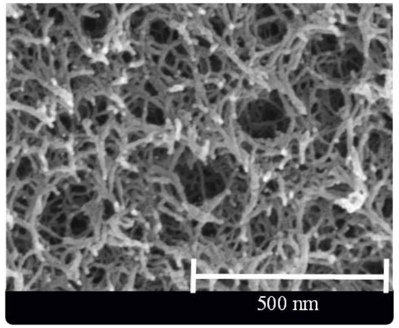
Tunable Transparency



Acoustic impedance

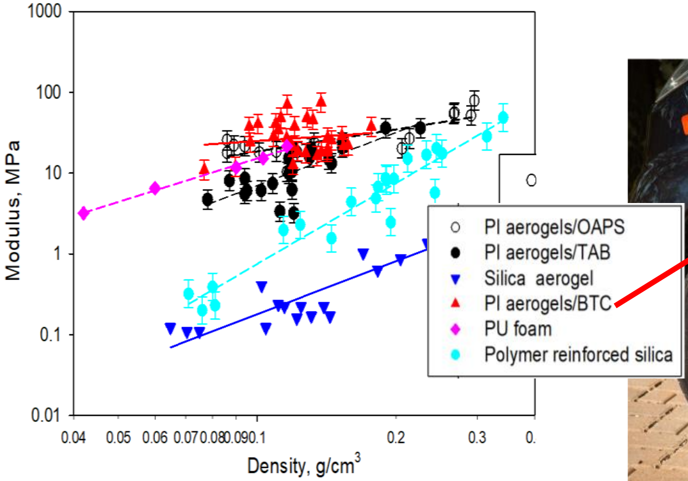


Tailored Hydrophobicity

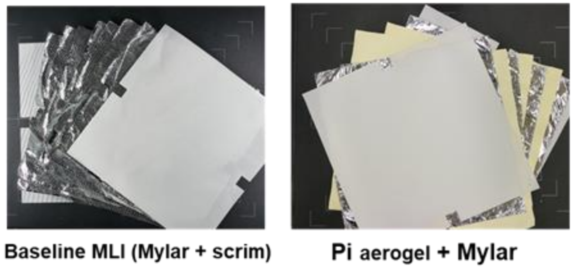


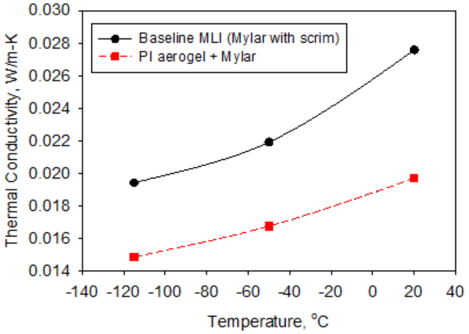
Tunable pore structure

Secondary debris containment

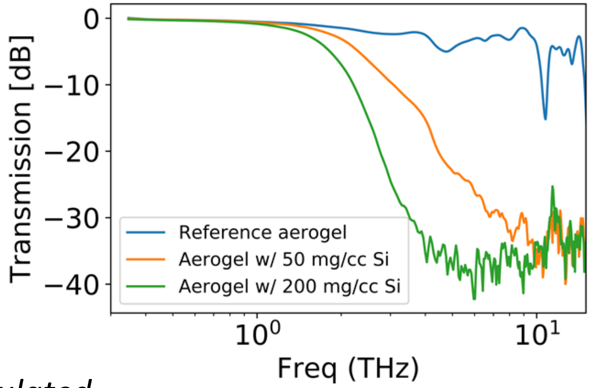


Improved mechanical properties



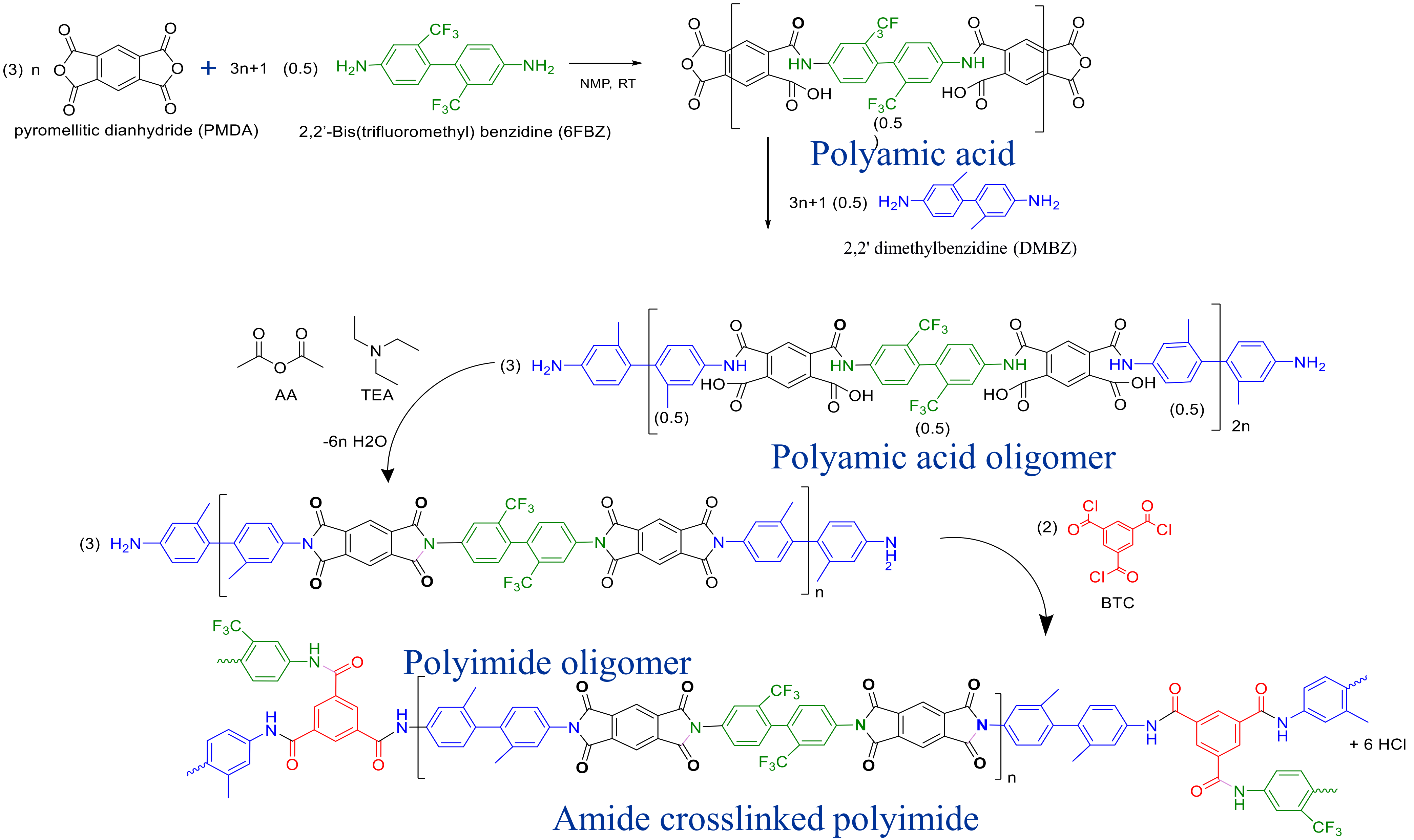


MLI with and without aerogel tested under simulated Mars atmosphere (8 Torr Argon, -120 to 20 ^oC)

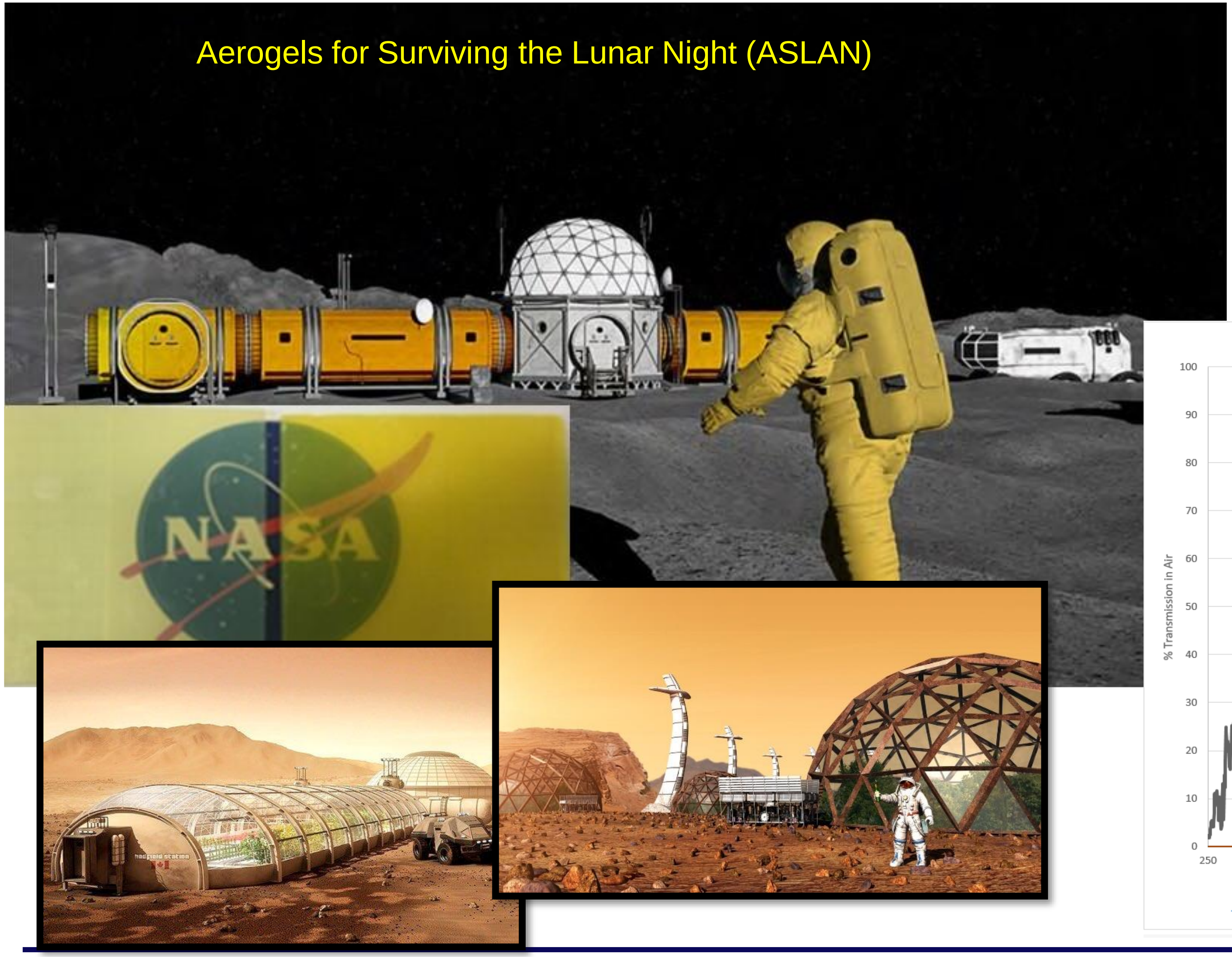


IR filtration

Polyimide Synthesis / Fluorinated Diamine

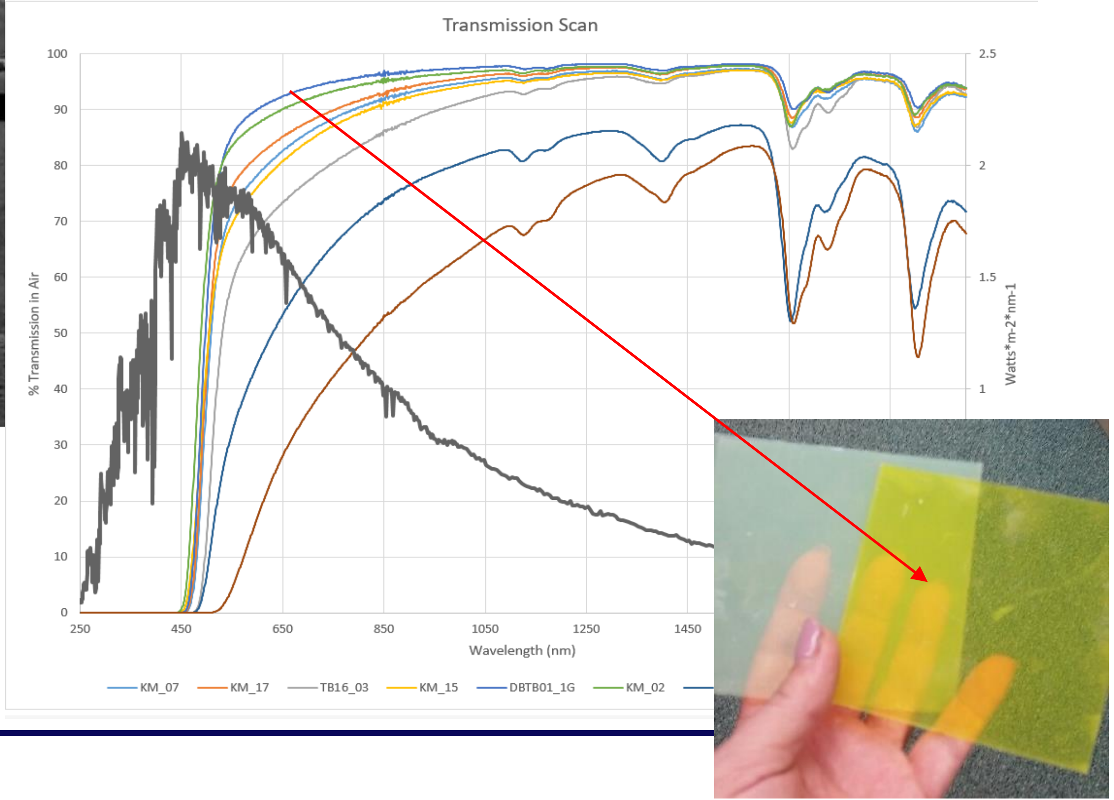


Polymer Aerogels for Passive Thermal Containment



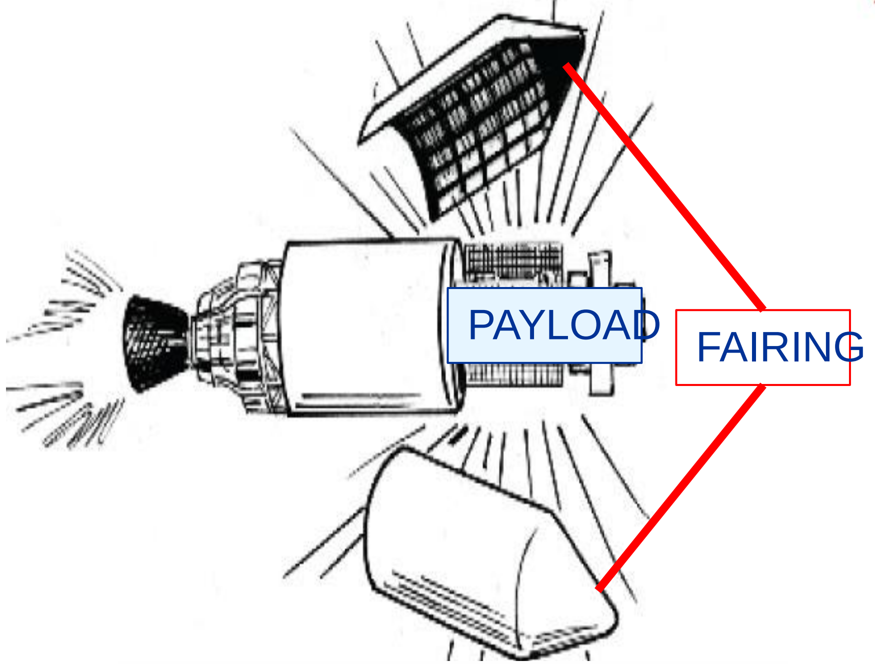
PTC for habitats, greenhouses, terraforming

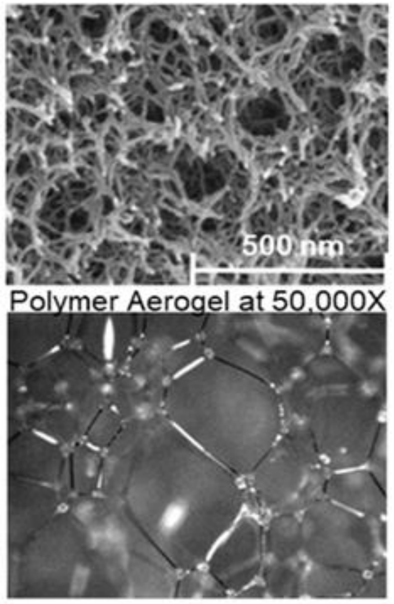
Tunable opacity



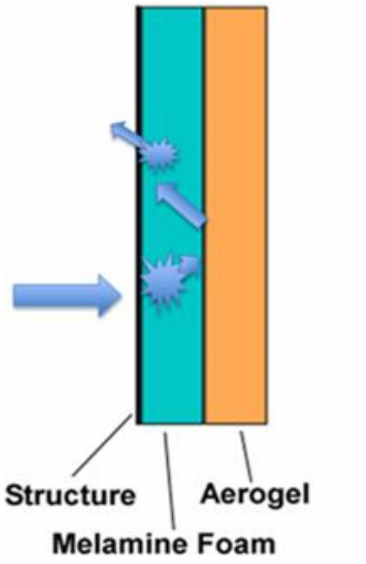
Advanced acoustic materials for noise mitigation

- Vibro-acoustic loads pose threat to payload launch survivability
- Aerogels will add damping to the structure, which reduces the amplitude of the vibration and noise transmission in addition to weight reduction

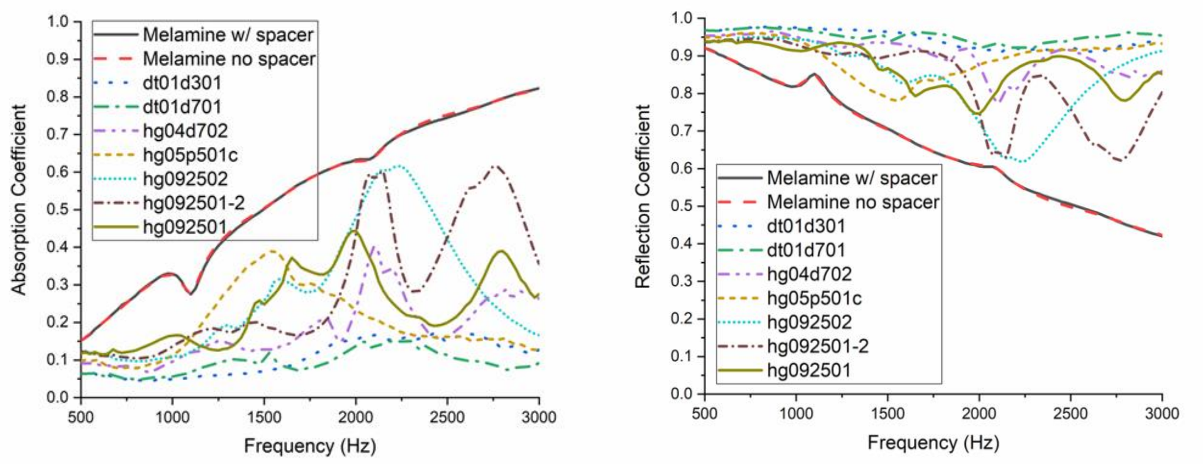




Melamine Foam at 80X

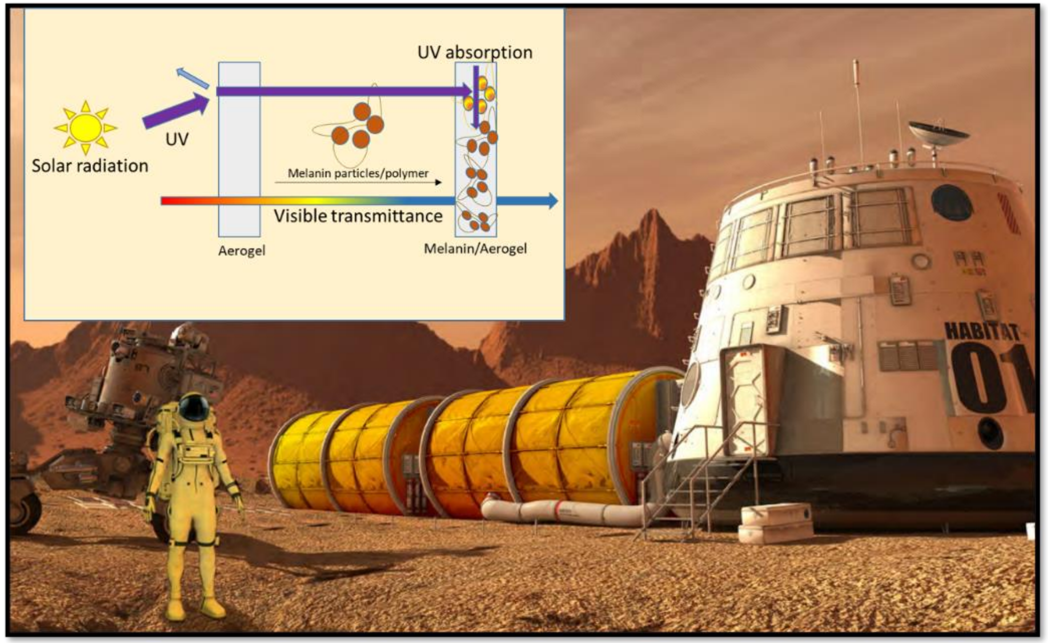


Absorbing material with aerogel as reflective backing

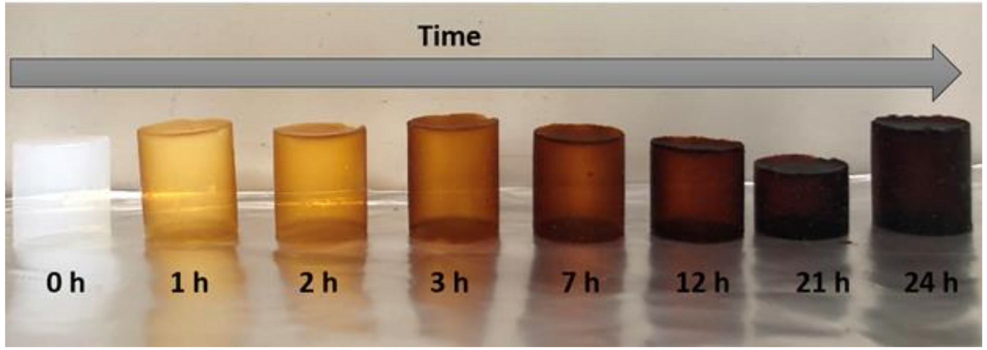


Absorption/Reflection coefficient of polyimide aerogels vs melamine foam

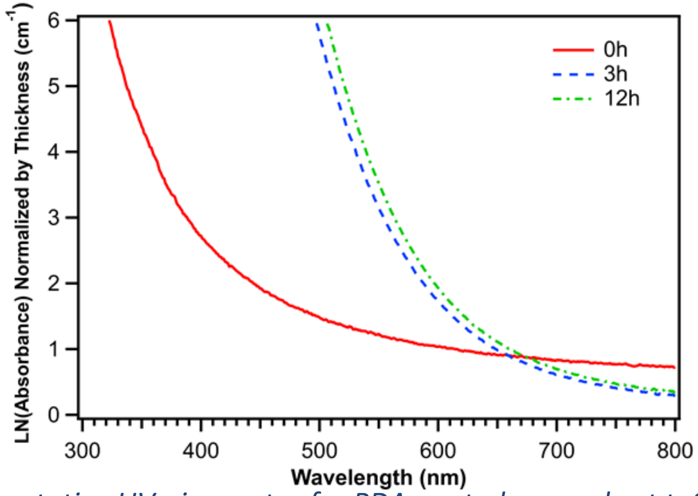
Melanized Aerogel for Radiation Mitigation



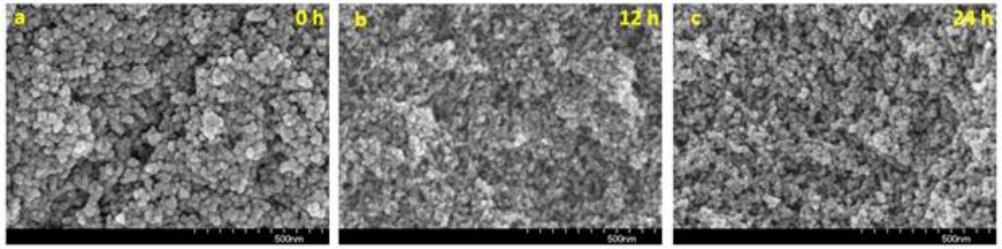
Melanized aerogels exhibit higher absorption over native aerogel with little to no effect on surface area, density, shrinkage, and porosity.



Images of the PDA-coated silica aerogels at coating time (t) t=0, 1, 2, 3, 7, 12, 21, 24 h.



Representative UV-vis spectra for PDA-coated aerogels at t=0, 3,12 h where absorbance is plotted as a function of wavelength.



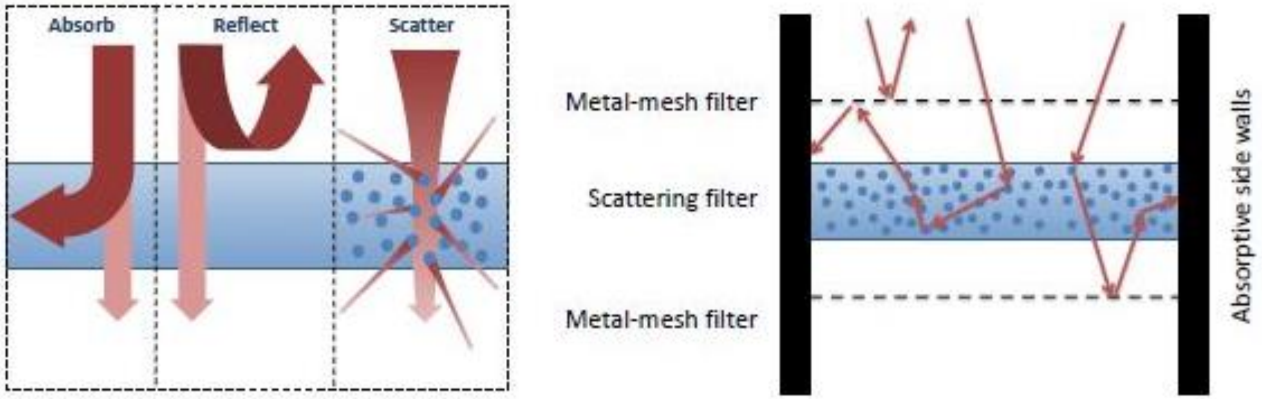
SEM images of the surface morphology of the native aerogel (a) and PDA coated aerogel at t=12 h (b) and t=24 h (c)

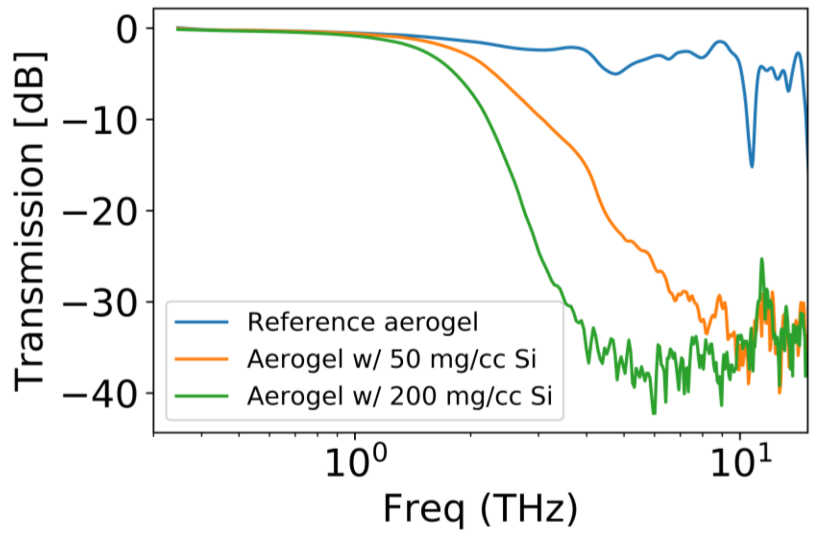
Sample	Porosity	BET Surface Area	Shrinkage	Bulk Density
	(%)	(m^2/g)	(%)	(g/cm^3)
0 h	92.8±0.8	642±45	7±1	0.14±0.02
12 h	92.6±0.9	614±35	7±2	0.13±0.01
24 h	92.4±0.7	658±15	8±1	0.13±0.01

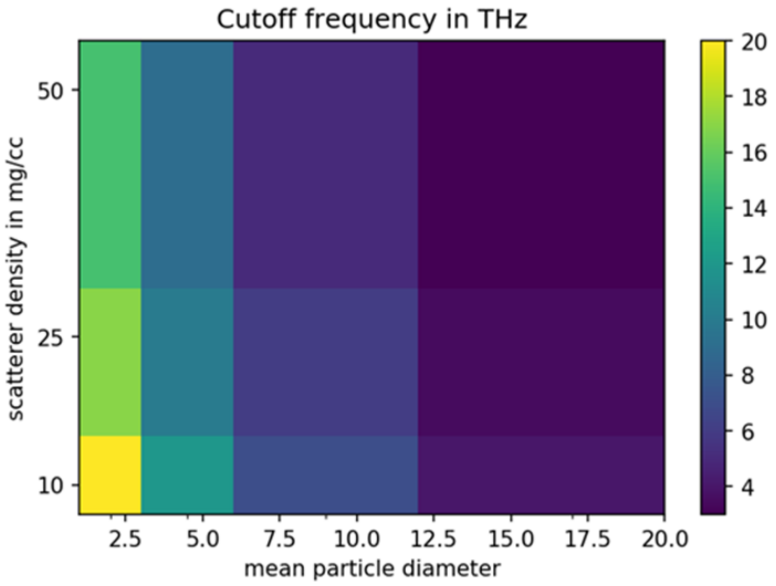
**Collaboration with Dr. Ali Dhinojwala- The University of Akron*

Aerogel IR Scattering Filters for mm and Sub-mm Astrophysics (Origin of Life Studies)

- IR blocking filters made by embedding scattering particles in an aerogel substrate
- Maximizing the sensitivity of millimeter and sub-millimeter instruments requires rejection of infrared (IR) light.







*Collaboration with NASA GSFC

M16 ▪ Eagle Nebula

Hubble Space Telescope ▪ WFC3/UVIS/IR

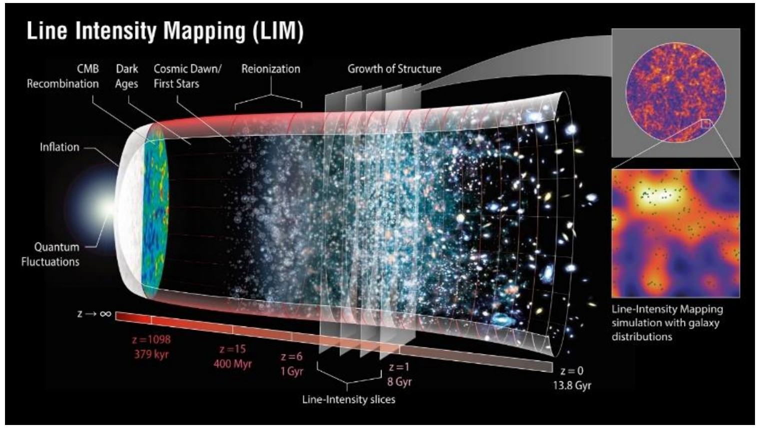
NASA and ESA

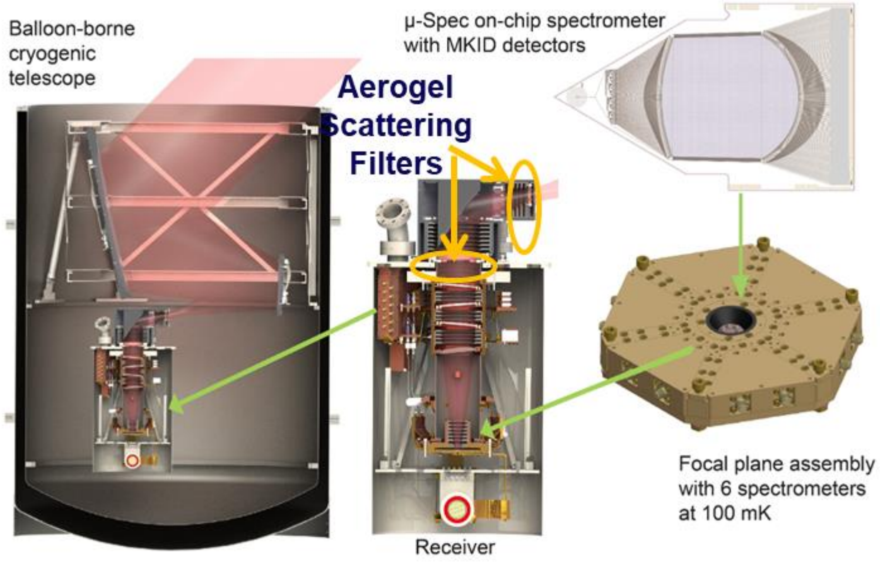
STScI-PRC15-01c

EXCLAIM:

The EXperiment for Cryogenic Large-Aperture Intensity Mapping

EXCLAIM will try to map CO and ionized carbon [CII] at redshifts of 0 < z < 3.5 (depending on the line) to try to understand star formation over cosmic time





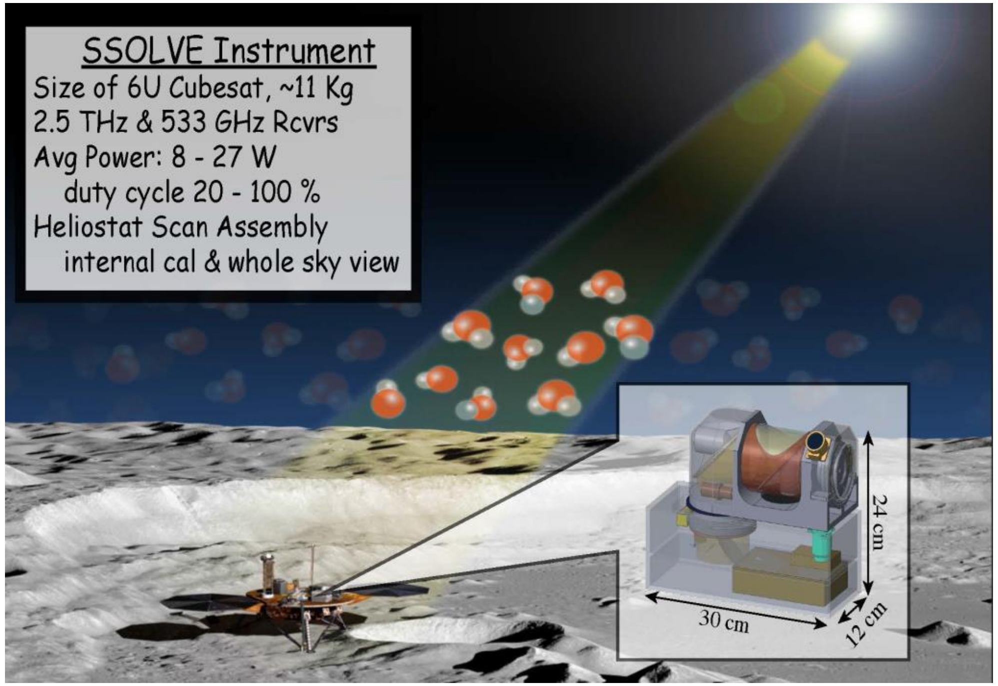
Aerogel scattering filters are the baseline infrared-blocking filter for EXCLAIM

The EXCLAIM band is 420-540 GHz and the filters should effectively block radiation above 1 THz

PI: Eric Switzer (GSFC)

SSOLVE:

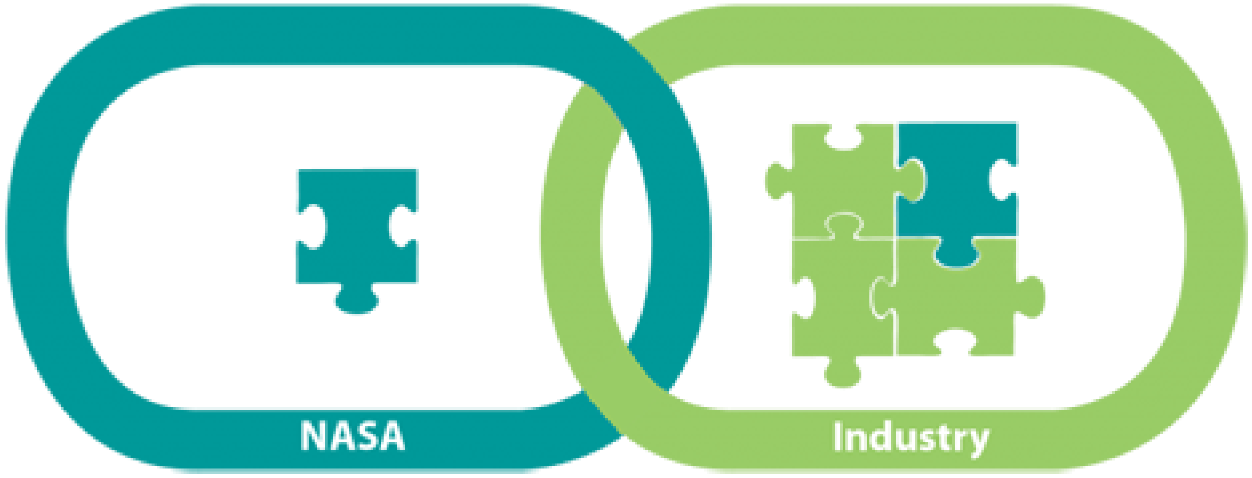
Submillimeter Solar Observation Lunar Volatiles Experiment



- SSOLVE will measure water vapor to learn which source(s) of water dominates the lunar atmosphere.
- Operate submillimeter spectrometers from a lander, using a heliostat to target the Sun and to measure the column abundance of H_2O, OH, and HDO in the lunar atmosphere

PI: Tim Levingood (GSFC)

Glenn Research Center | NASA TECHNOLOGY TRANSFER PROGRAM



Leverage the outstanding capabilities and accomplishments of NASA's Glenn Research Center for the benefit of both NASA and U.S. taxpayers

COLLABORATIVE EFFORTS TO UTILIZE NASA TECHNOLOGY

- Licensing- NASA's patent portfolio
- Innovative Research Grants
- Cooperative Agreement
- Interagency Transfer

A Universe of NASA Opportunities

https://intern.nasa.gov/

Acknowledgments

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–Linda McCorkle, Dan Scheiman Frank Bremenour, Spyro Efpraxias (NASA)

–Dr. Ali Dhinojwala, Gabrielle Rey, Saranshu Singla (University of Akron)

–Dr. Stephen Steiner, Justin Griffin, Ryan Moriah Buckwalter (Aerogel Technologies)

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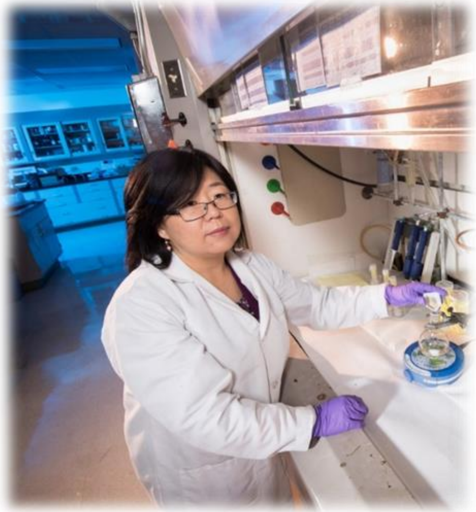
STMD Game Changing Development Program (GCDP) ACO
NASA Center Innovation Fund (CIF)
NASA Independent Research and Development (IRAD) Program

Dr. Stephanie Vivod

Dr. Sadeq Malakooti



Dr. Haiquan Guo

Ariel Tokarz

Questions – Comments - Ideas