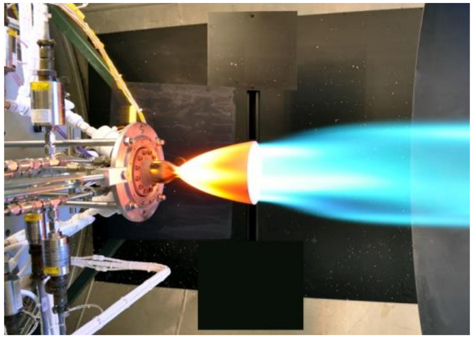
Polymer Aerogels for Lunar Applications and Beyond

Dr. Stephanie L Vivod

NASA Glenn Research Center, Cleveland OH 44135
Stephanie.L.Vivod@nasa.gov

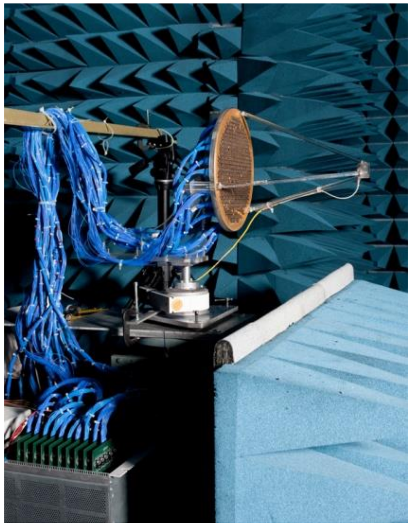
GRC Core Competencies

Air-Breathing Propulsion



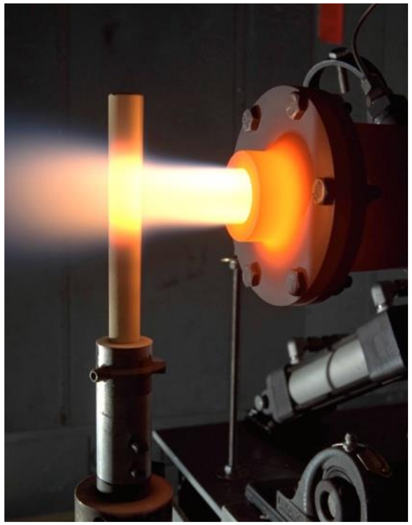
In-Space Propulsion and Cryogenic Fluids Management

Physical Sciences and Biomedical Technologies in Space



Communications Technology and Development

Power, Energy Storage and Conversion



Materials and Structures for Extreme Environments

Yes, we went to the moon…

Apollo Program ran from 1961 to 1972

Moon Landing Missions:

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

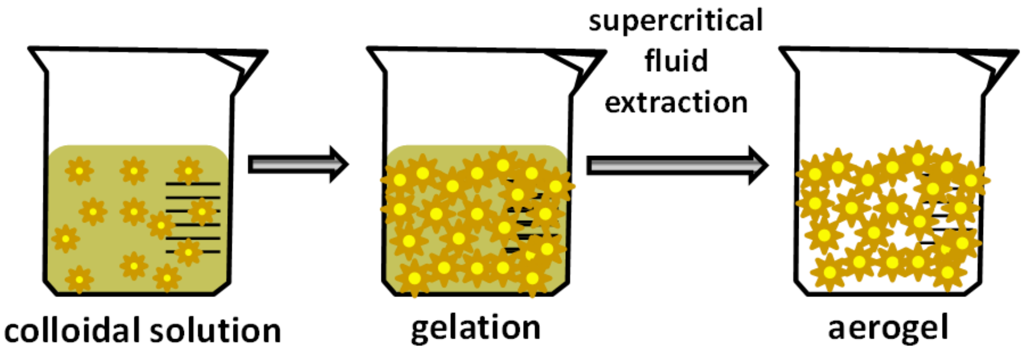
Apollo 15-Astronaut James B. Irwin, lunar module pilot, works on the Lunar Roving Vehicle

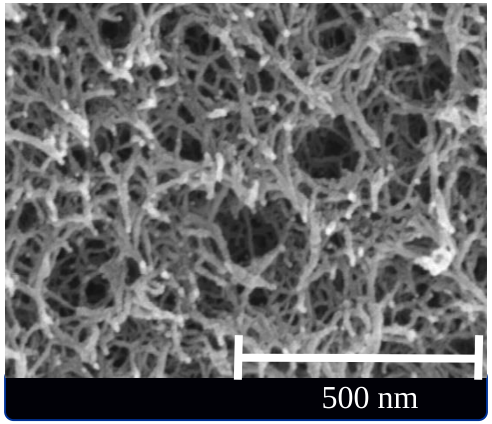
WE’RE GOING BACK!
Artemis Program:
Return to moon-2024

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

*mission aborted

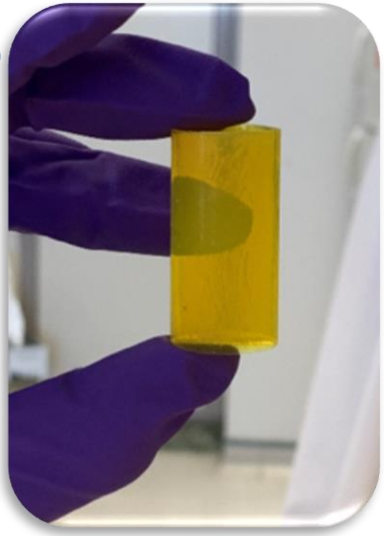
Wonderful World of Aerogels!!!

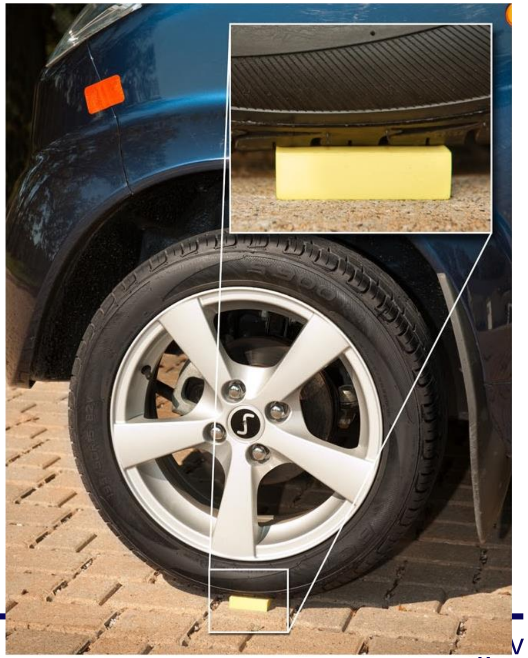




Scanning Electron Micrograph of polymer aerogel matrix

- Highly porous solid (>95%)
- Pore sizes (10-40 nm)
- Large surface areas (~850 m^2/g)
- Low density (0.15 g/cm^3)

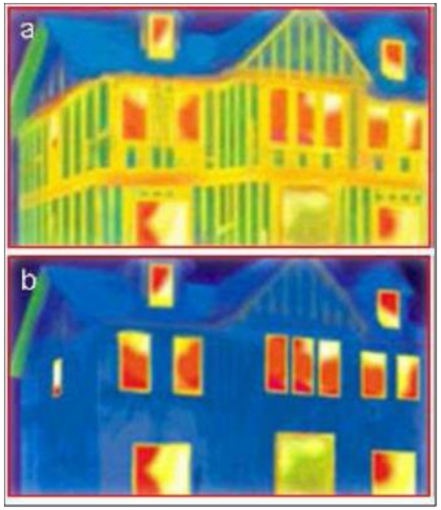




Current aerogel products and market

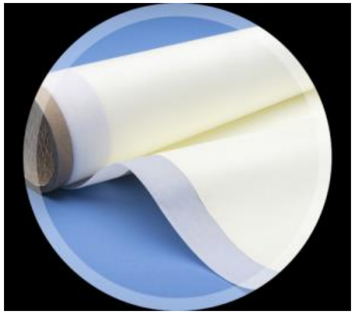
Cabot Lumira Aerogel in skylights Grand Rapids, Mi

Aerogel Technologies Airloy



Home insulation

Aspen Aerogels Pyrogel pipe insulation

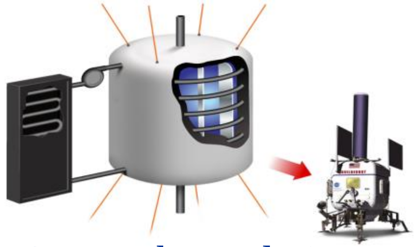


Blueshift AeroZero

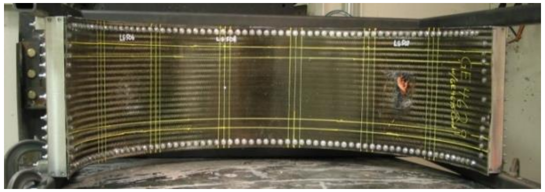
BASF Slentite panels

Outdoor gear/apparel

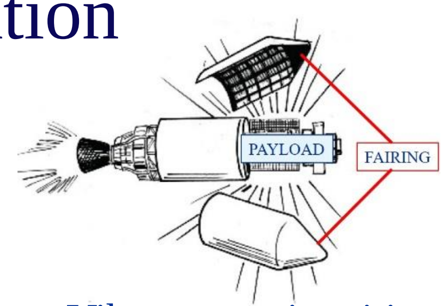
Potential applications for durable aerogels in aeronautics and space exploration



Cryotank Insulation

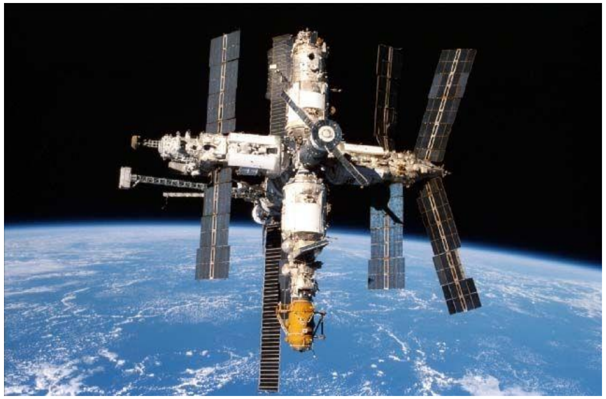


Fan engine containment (Ballistic protection)



Vibro-acoustic mitigation

Ultra-lightweight, multifunctional structures for habitats, rovers



Light weight satellite ODC

Propellant tanks

Heat shielding

Inflatable aerodynamic decelerators

Insulation for EVA suits and habitats

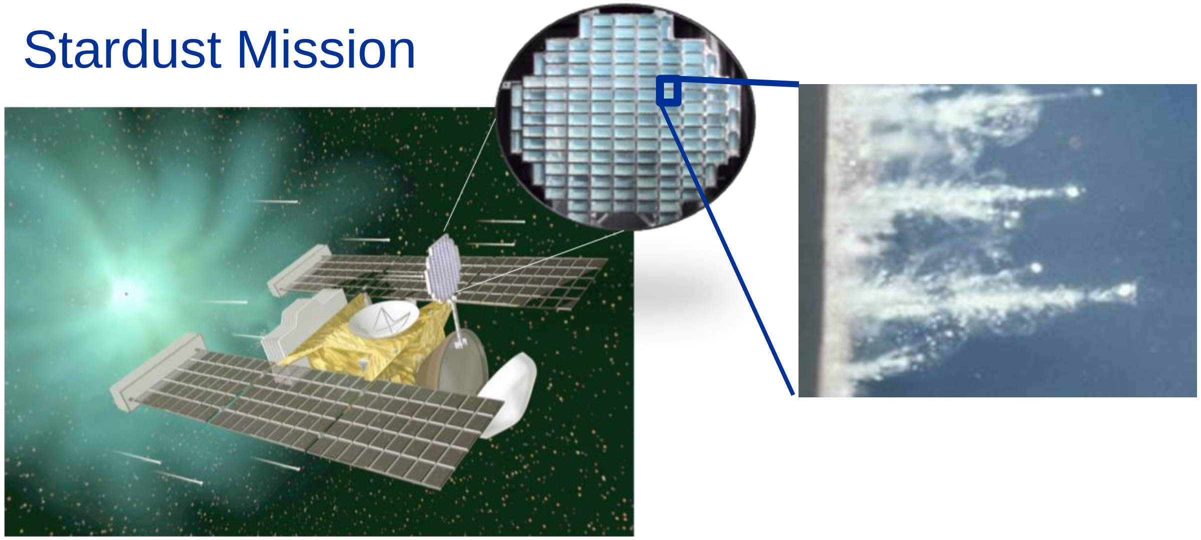
Improving on Previous Technology

Rover Battery Insulation

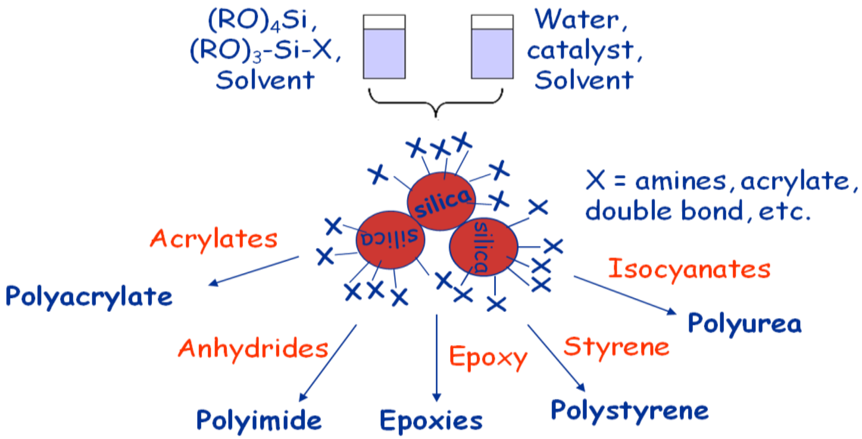
- Sensitive internal components must not exceed extreme temperatures of -40° Celsius to +40° Celsius (-40° Fahrenheit to 104° Fahrenheit)
- Night temperatures on Mars can drop to -96° Celsius (-140° Fahrenheit).
- The rover is kept warm by a special layer of silica aerogel

Stardust Mission

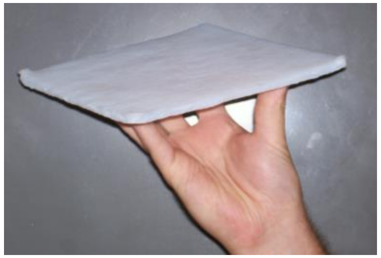
- NASA's Discovery Mission Stardust launched with the intention of performing a close (142 km) flyby of the comet Wild-2 in order to collect cometary samples embedded within an aerogel substrate.



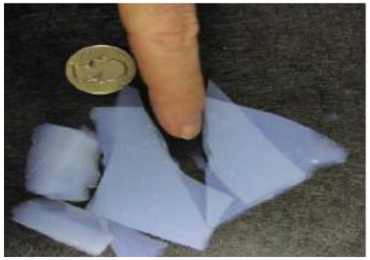
Durable aerogels by reinforcing silica aerogels with polymers



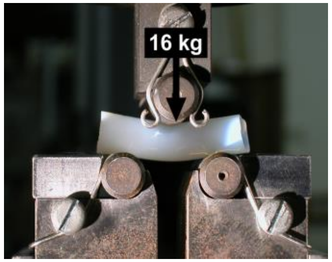
- Versatile: allows cross-linking with variety of polymers to tailor properties
- Collaboration with Aspen Aerogels to scale up streamlined process



Aspen fabricated polymer reinforced aerogels used to insulate cryotank--collaboration with MSFC

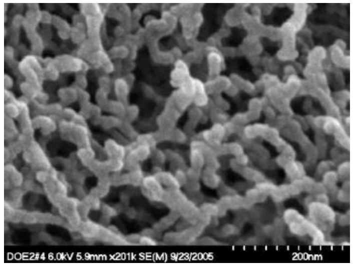


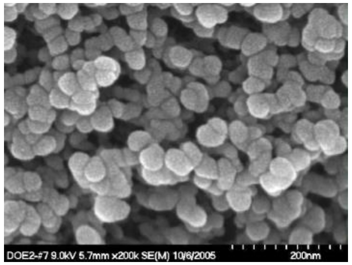
Native



Cross-linked

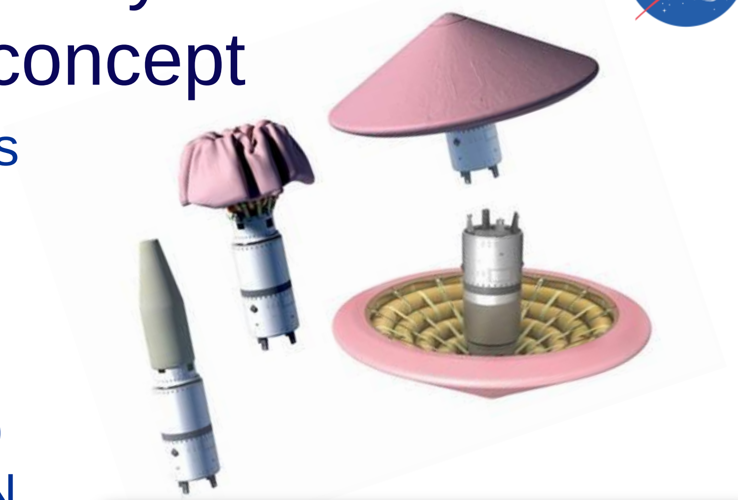
- Polymer reinforcement ***doubles*** the density
- Results in ***two order of magnitude*** increase in strength
- Does not change pore structure



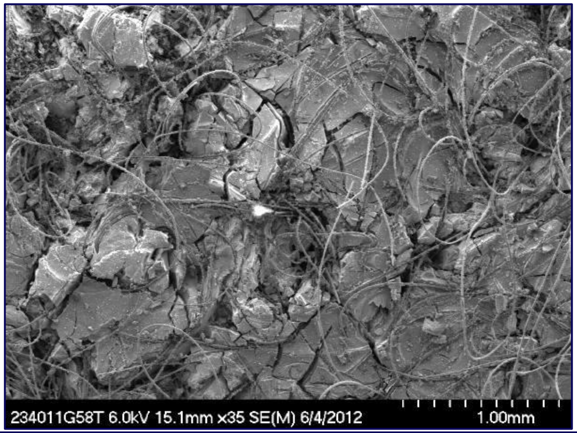


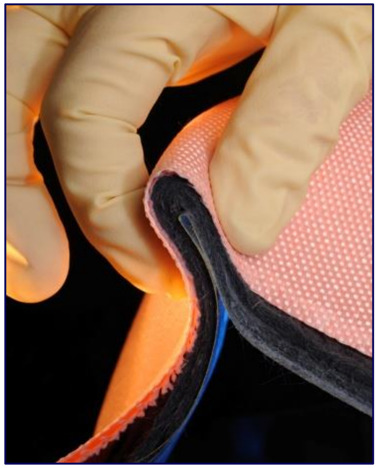
Low density... to higher density, same aerogel pore structure

Hypersonic inflatable aerodynamic decelerator (HIAD) concept

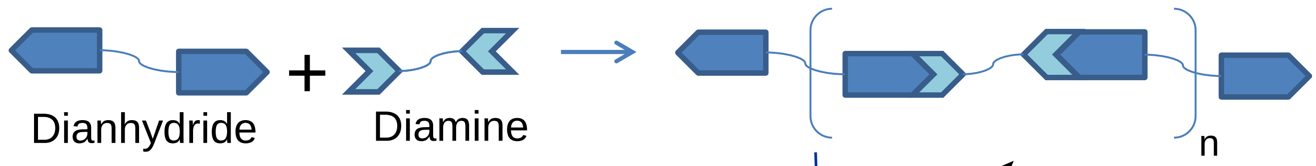


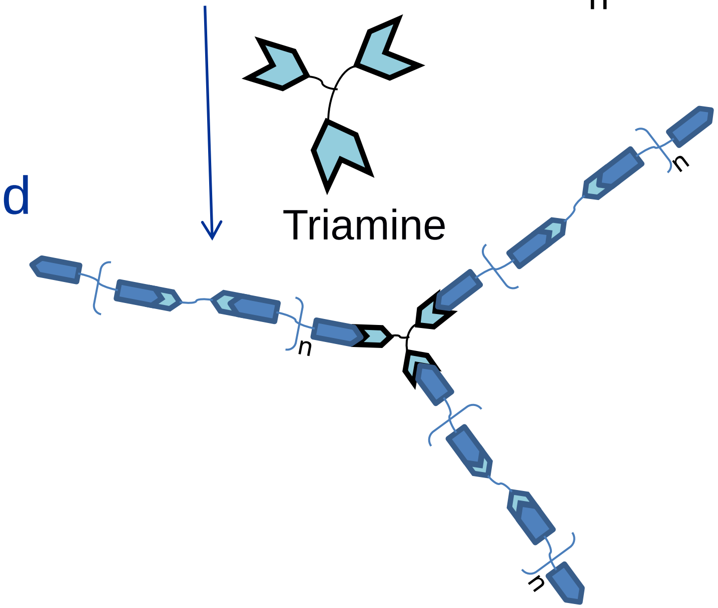
- Hard aeroshells used to land rovers on Mars limit size of payload
  - Inflatable structure overcomes this limitation
- Baseline insulation for HIAD (Pyrogel-2250) made up of silica aerogel particles in O-PAN batting
  - Flexible but sheds dust particles on handling
  - Begins to out gas at 380 °C



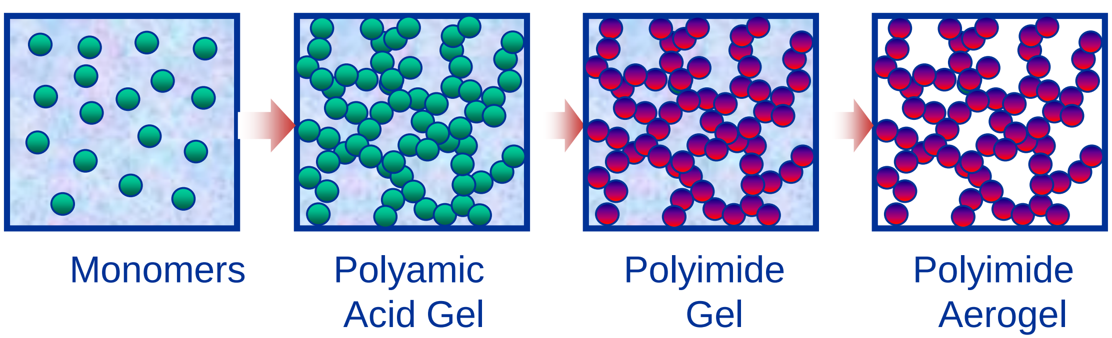


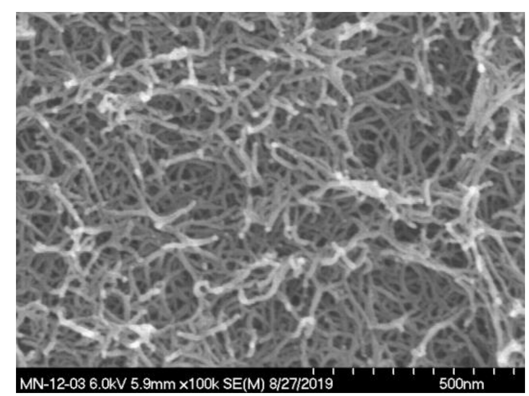
Cross-linked polyimide aerogels

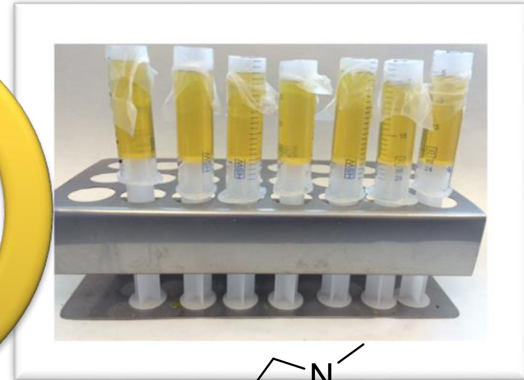


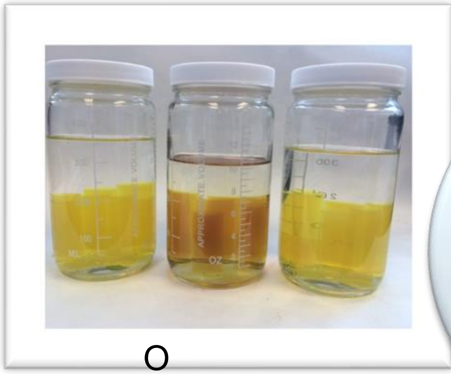


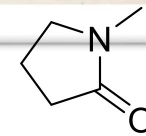
- Polyimide formed by reaction of diamine and dianhydride
- Use of triamines, or other multifunctional groups to form network structure
- Gelled polyamic acid network is imidized
- Solvent exchange to acetone then supercritical drying produces aerogel



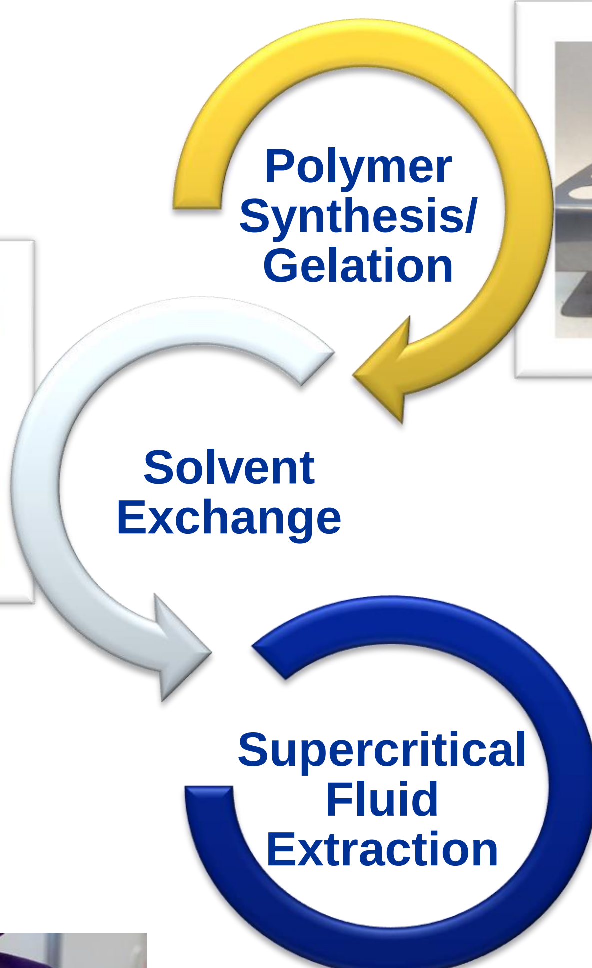


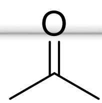




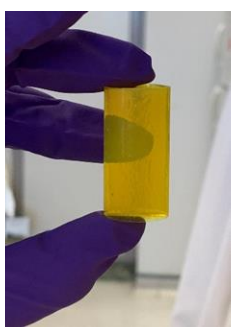


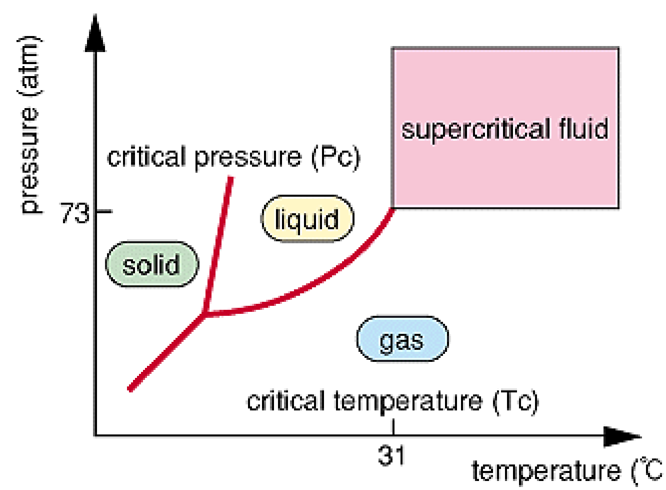
n-methylpyrrolidone (NMP)



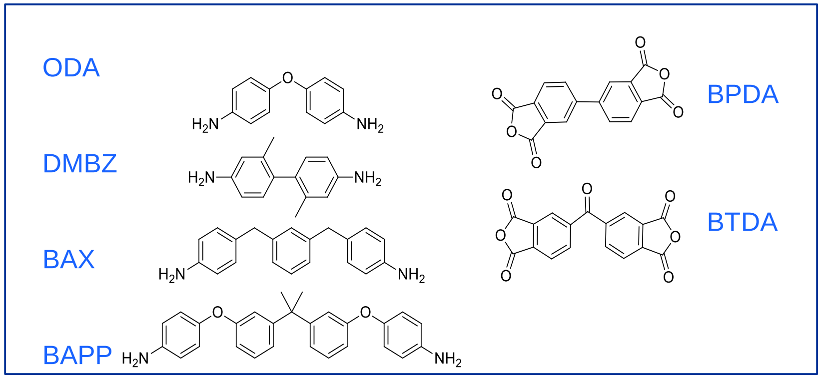


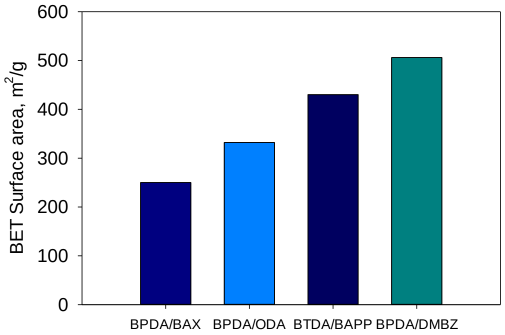
acetone

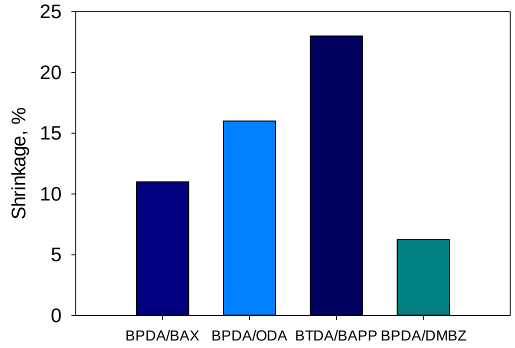


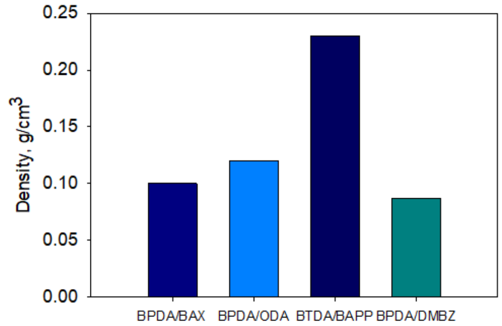


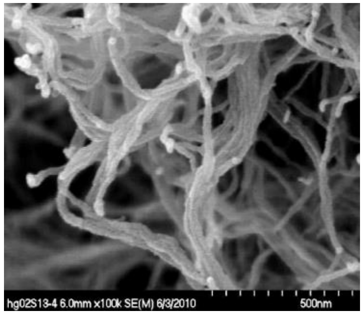
Formulation study various dianhydrides and diamines



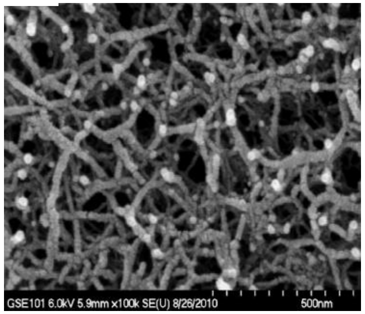




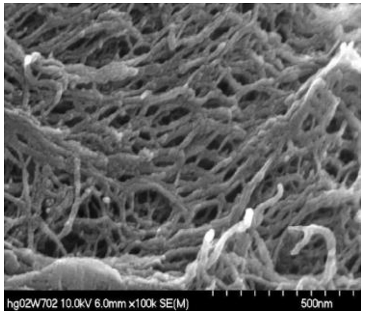




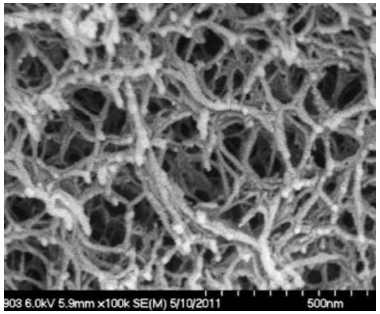
BPDA/BAX



BPDA/ODA

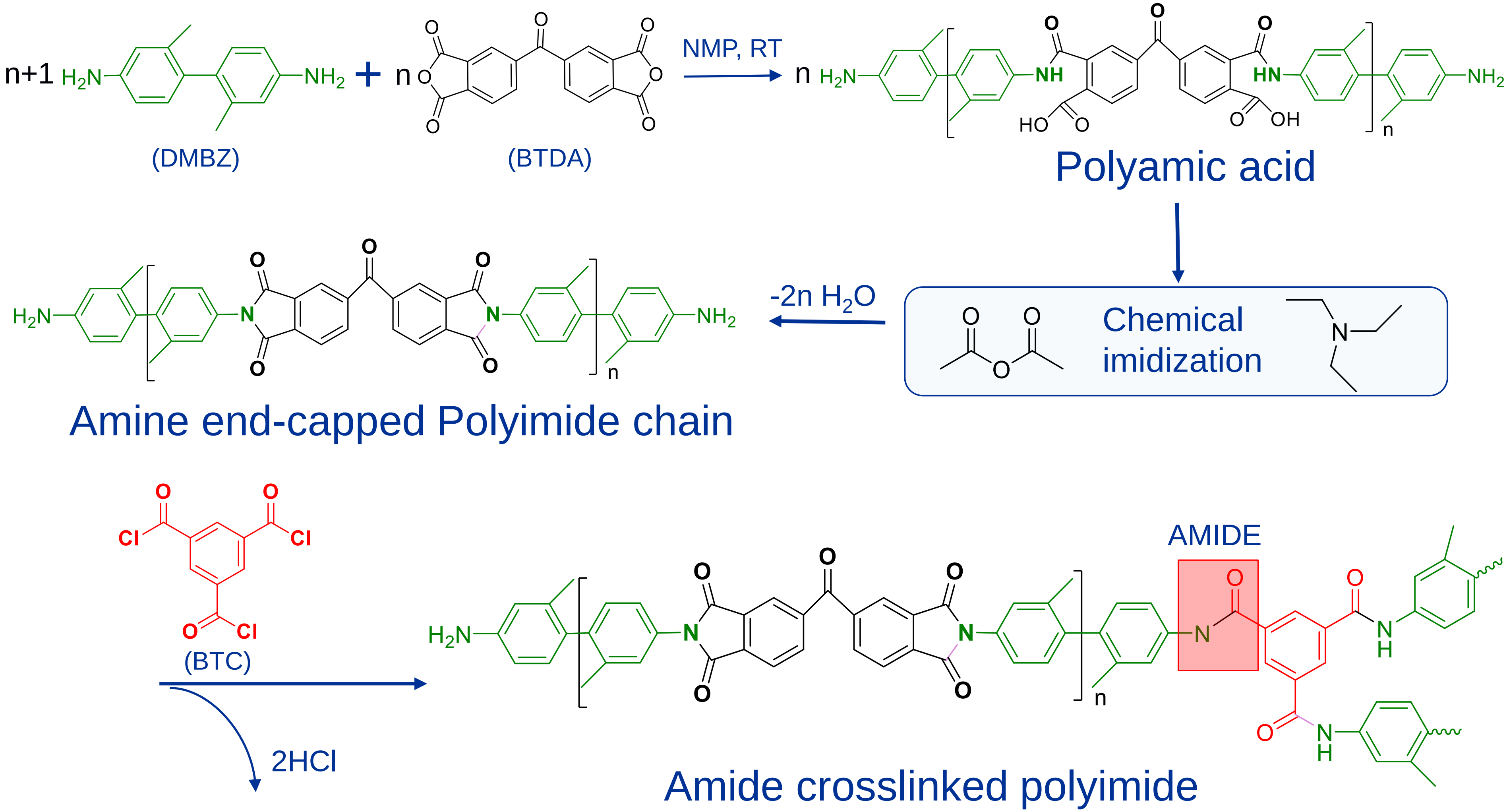


BTDA/BAPP



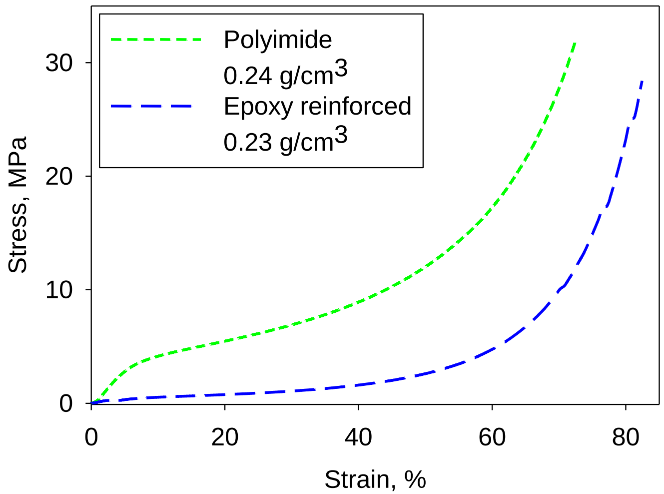
BPDA/DMBZ

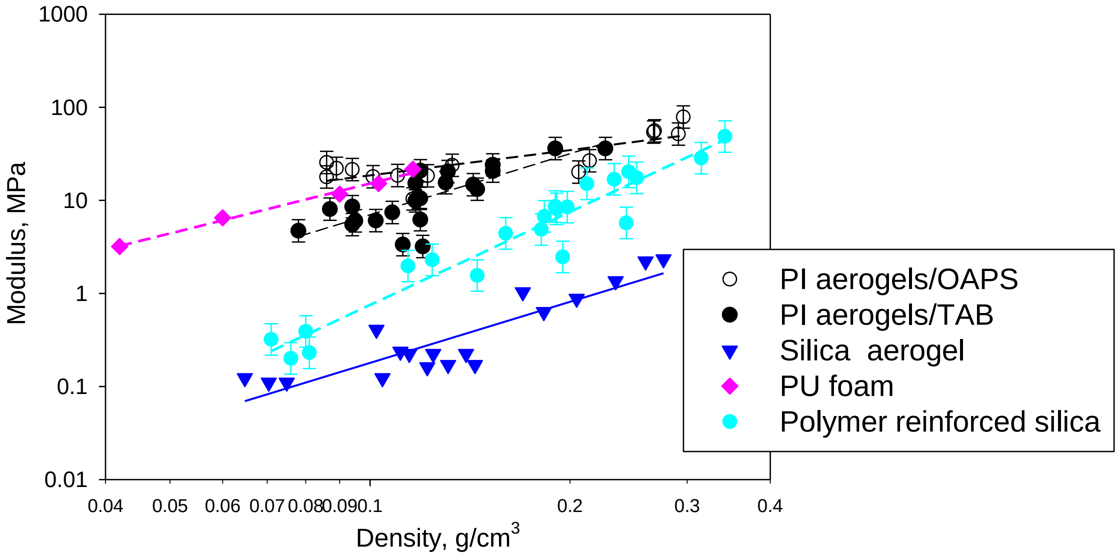
Polyimide chain formation with amide crosslink

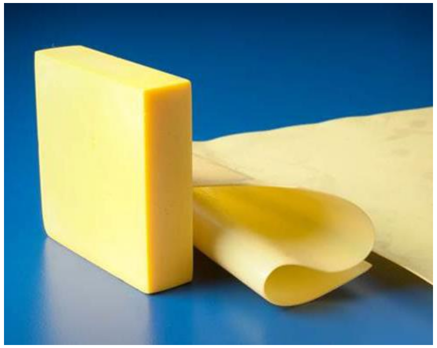


Strong, flexible polyimide aerogels

2 to 5 times stronger than epoxy reinforced aerogels at similar density





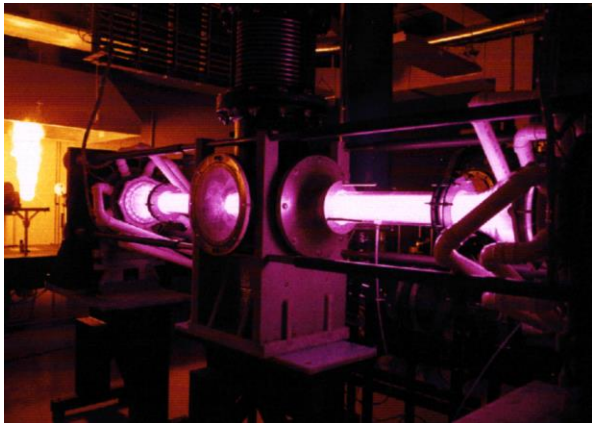


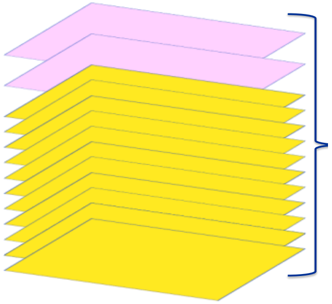
Can be manufactured in a flexible form with excellent mechanical properties

High temperature testing of PI aerogel thin films

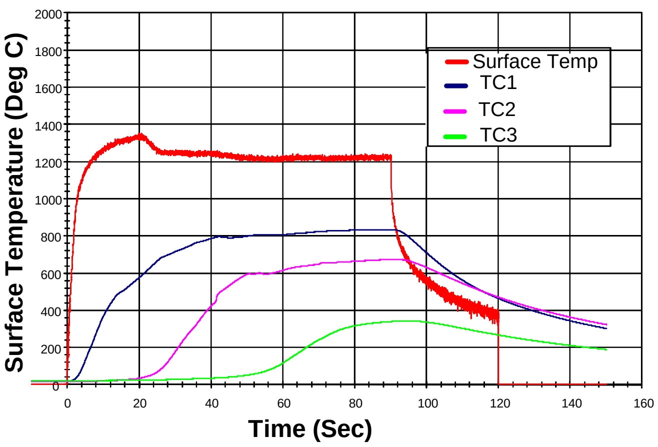
High heat flux testing at **Laser Hardened Materials Experimental Lab (LHEML)**, Wright Patterson Air Force Base

- Heat flux 20 W/cm^2, 8 torr N_2
- 90 sec duration
- Bottom layer only darkened, no hole, no cracks





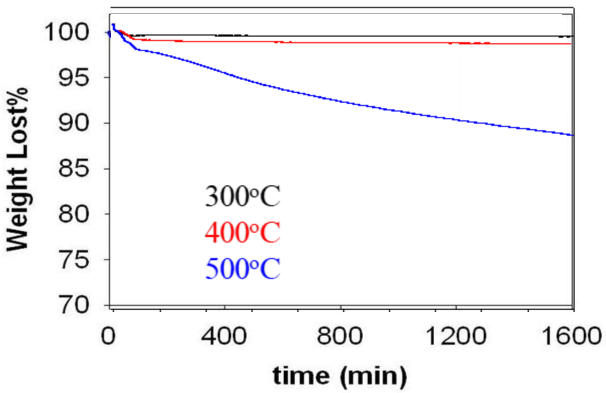
Two layers ceramic fabric, 11 layers PI aerogel film



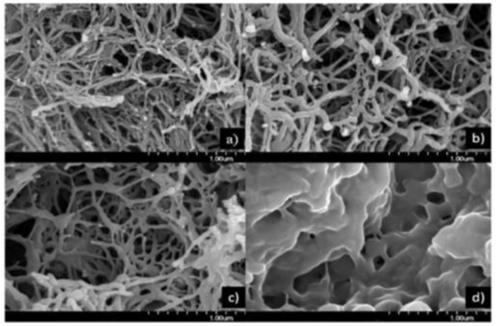
Test specimen with thermocouples

Isothermal aging 24 hours

- Very little weight loss up to 400 °C
- Collapse of pore structure and weight loss at 500 °C



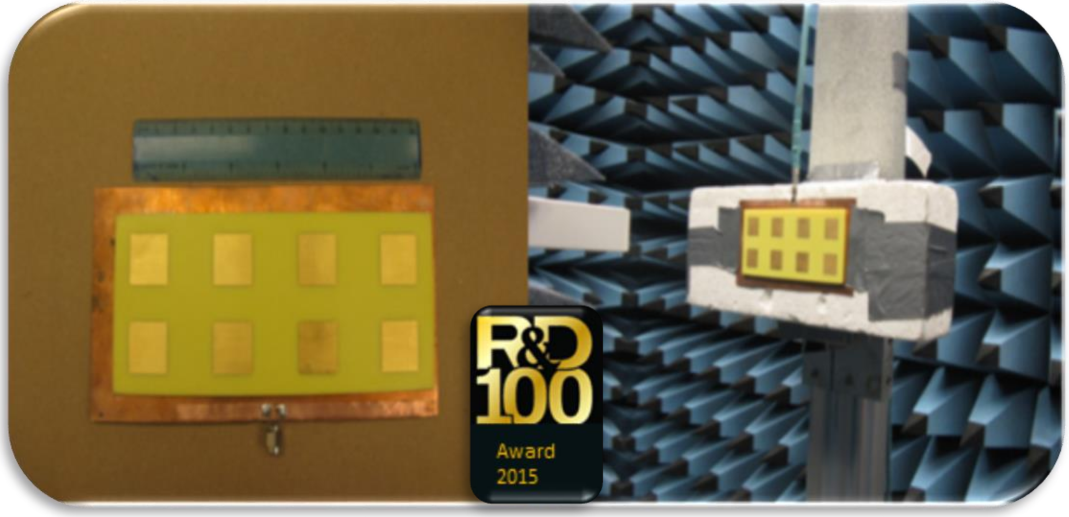
Before heating | After 300 °C

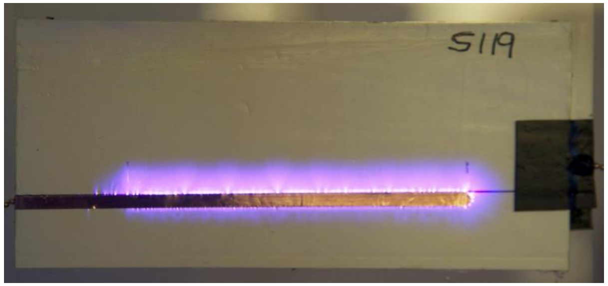


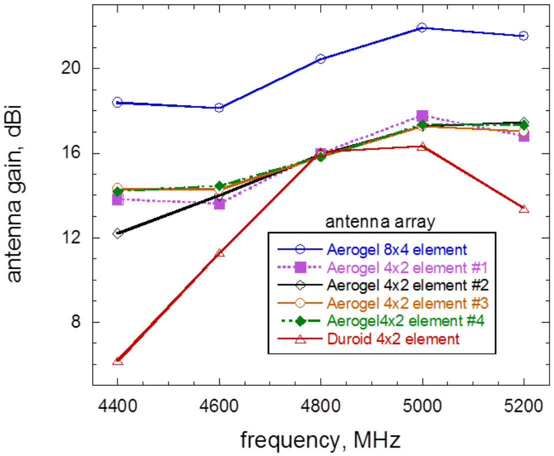
After 400 °C | After 500 °C

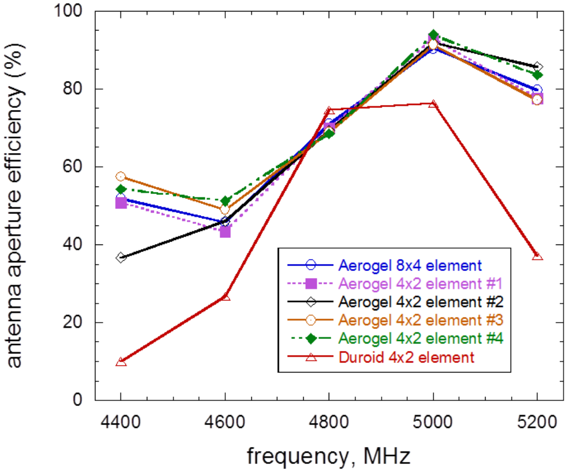
Low dielectric properties of PI aerogel lead to higher performance, lighter weight antennas

- Improved gain and efficiency over Duroid substrates
- Dielectric constant of 1.16 for aerogel, 2.1 for Duroid
- 77 % lighter in weight
- Also, can be used as substrate in dielectric barrier discharge (DBD) devices





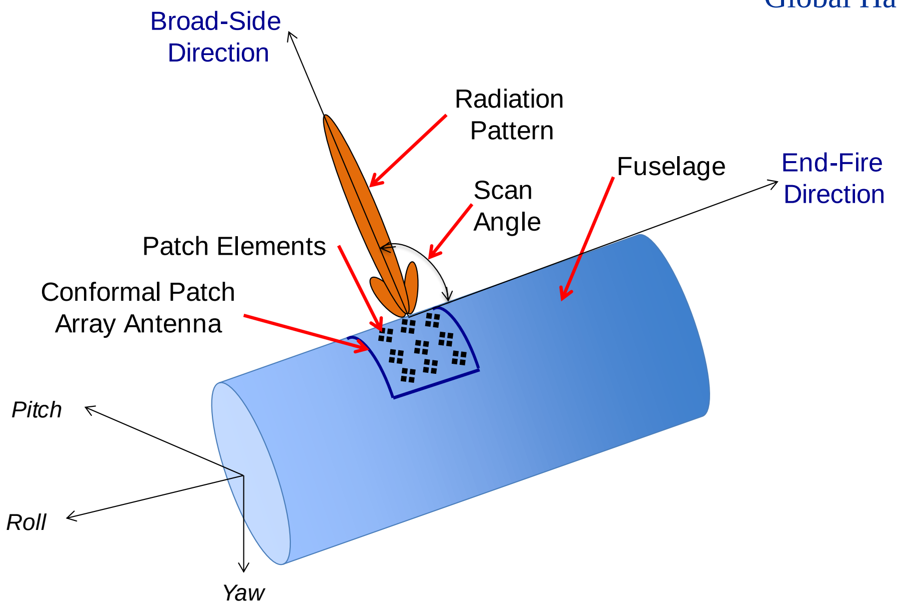




Beyond line of sight (BLOS) coverage for UAS

- Currently only large UAS platforms can accommodate dish antennas
- Solution: Conformal, Phased Array Antenna

Global Hawk/Northrop Grumman

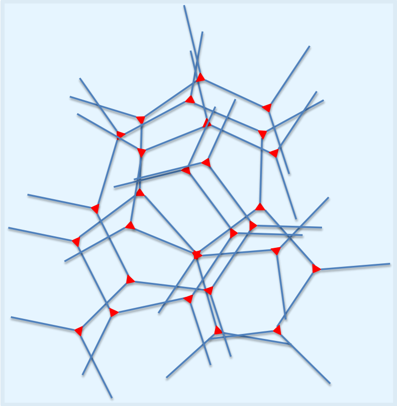


- Electronically attenuated ultra low side lobes to avoid interference with ground
  - Will enable BLOS for UAV operating in Ku provisional bands
- Build out of ultra-lightweight, low dielectric polymer aerogels
  - Up to 80% weight savings by using unconventional materials
- Reduced drag through use of conformal designs

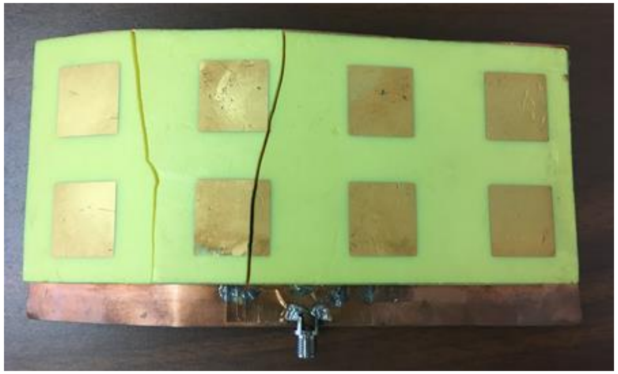
For conformable antennas, need more conformable aerogels

- Formulations of aerogel had rigid polymer backbone

Rigid aerogel

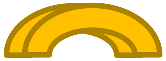


Rigid polymer backbone

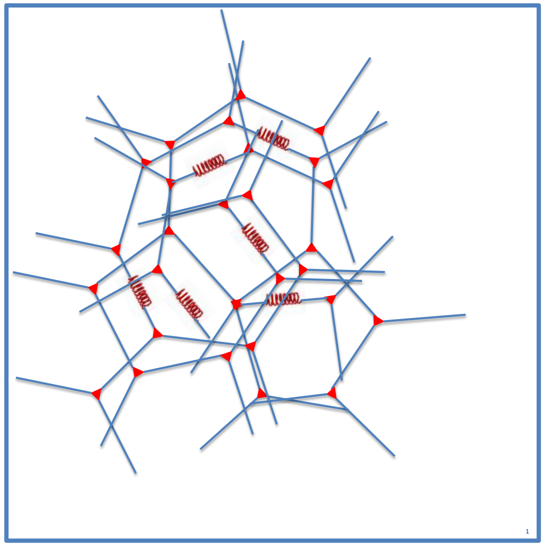


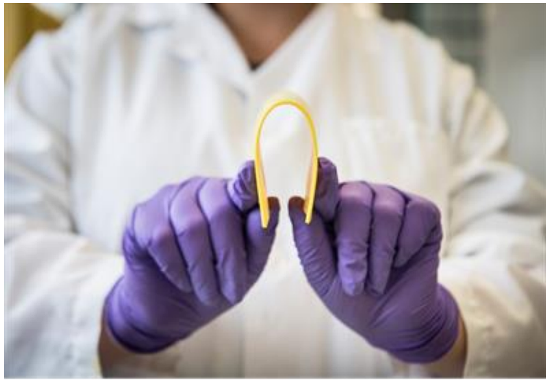
Broken antenna

- Rod-coil approach to more flexible aerogels
  - Blocks covalently bonded together
  - Rods provide reinforcement, coils provide flexibility
  - Nano-phase separation of blocks allows separate functionality to be exhibited



Conformal aerogel

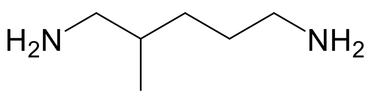




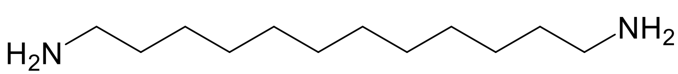
Improved antenna performance with 77% lower mass

Approach to more flexible aerogels

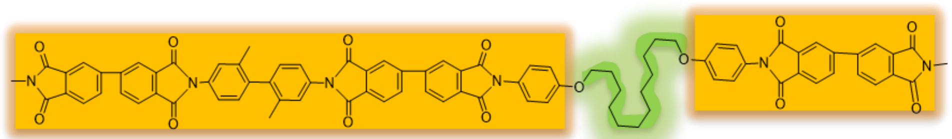
- Utilize aliphatic diamines to replace up to 75 % of aromatic diamine



1,5-diamino-2-methylpentane (DAMP)

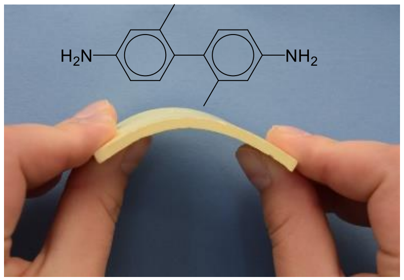


1,12-diaminododecane (DADD)

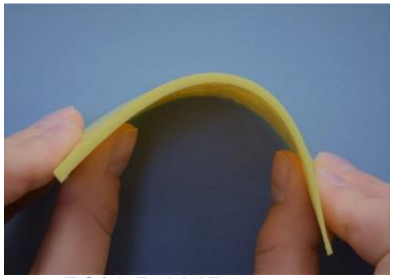


Rigid polymer backbone

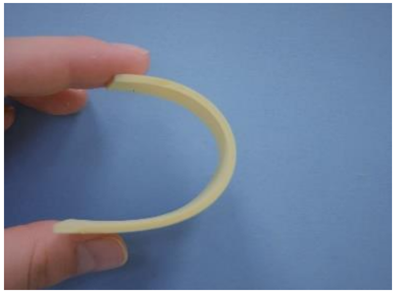
Flexible link



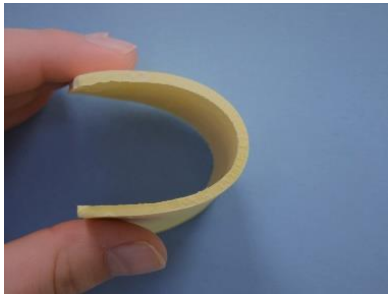
DMBZ+ODA



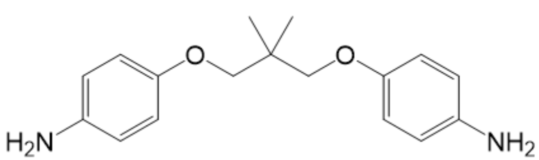
50% DAMP



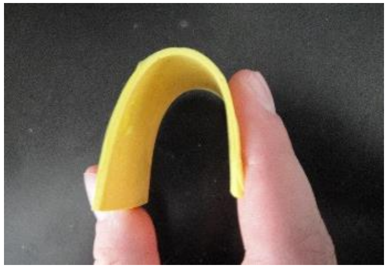
75% DAMP



75% DADD

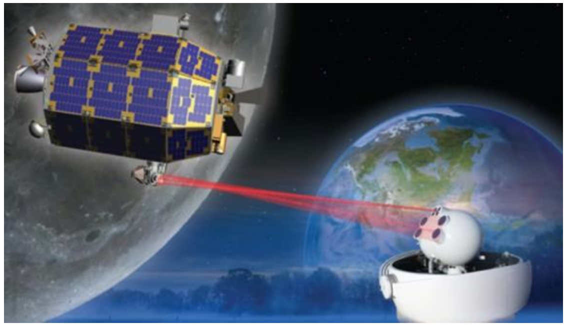


1,3-Bis(4-aminophenoxy)neopentane (BAPN)

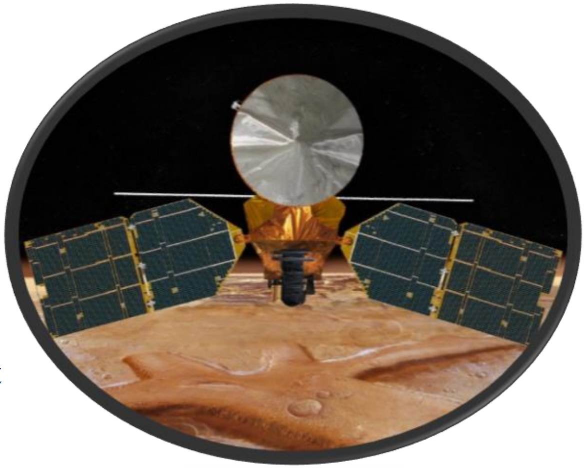


50% BAPN

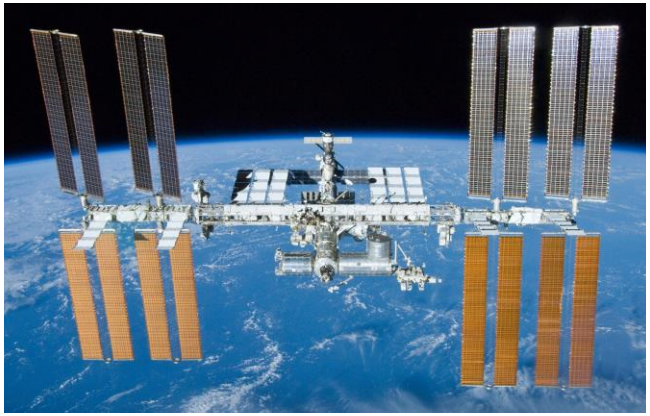
BLOS Communication for Space Applications



Lunar Atmosphere and Dust Environment Explorer (LADEE) satellite in lunar orbit



Mars Reconnaissance Orbiter Mission

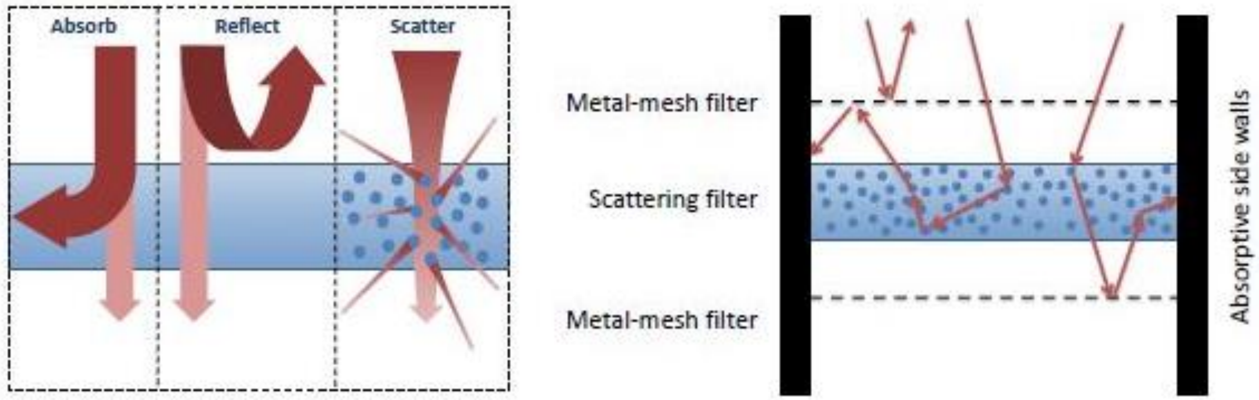


International Space Station

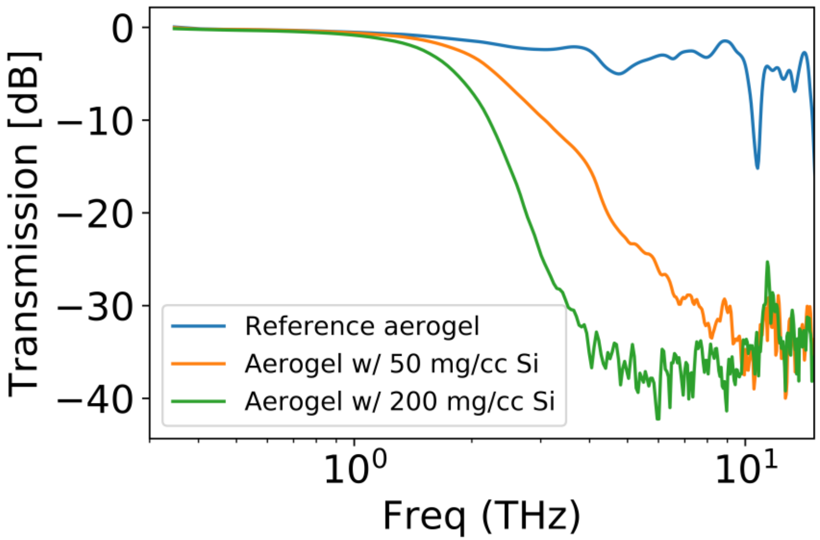
https://www.nasa.gov/sites/default/files/atoms/audio/ep157_gateway.mp3

The Deep Space Network (DSN): NASA's international array of giant radio antennas that support interplanetary spacecraft missions

Aerogel IR Scattering Filters for mm and Sub-mm Astrophysics

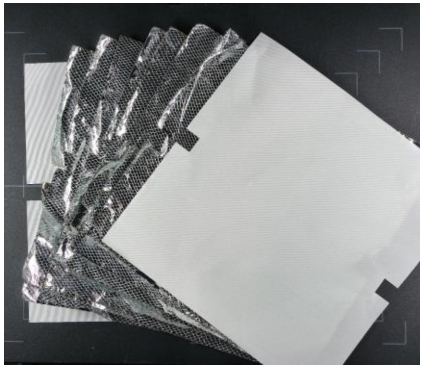


- IR blocking filters made by embedding scattering particles in an aerogel substrate
- Maximizing the sensitivity of millimeter and sub-millimeter instruments requires rejection of infrared (IR) light.



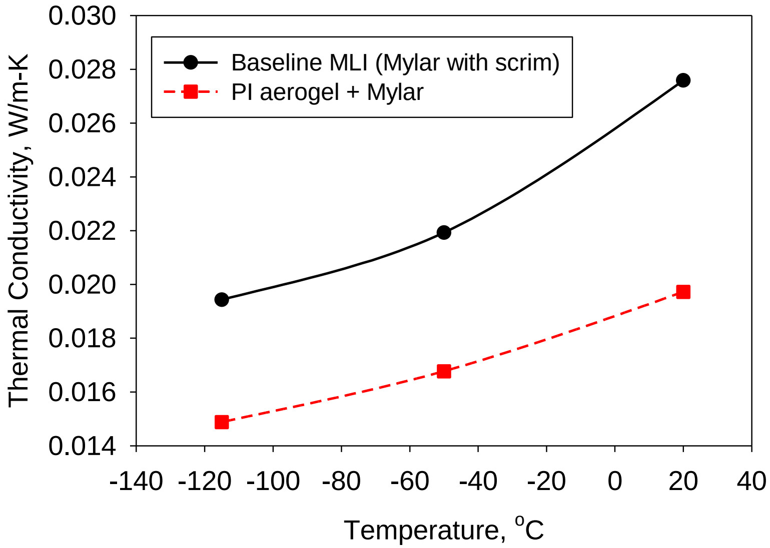
Multifunctional, Universal Thermal Insulation System

- Current multilayer insulation (MLI) only functions in vacuum
  - Layers of Mylar separated by scrim layers
- Aerogel is best insulation in gaseous environment
- MLI incorporating aerogel in place of scrim reduces TC by 23-37%



Baseline MLI (Mylar + scrim)

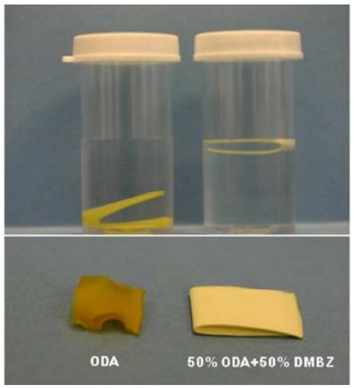
Pi aerogel + Mylar



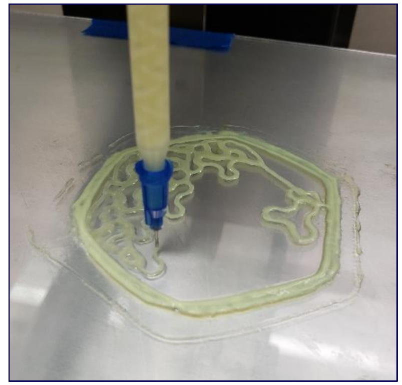
MLI with and without aerogel tested under simulated Mars atmosphere (8 Torr Argon, -120 to 20 ºC)

Polyimide Aerogel Development

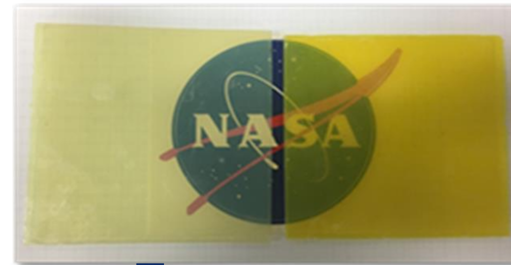
- Multiple cross-linkers evaluated
- Over 100 different combinations of backbone chemistry studied



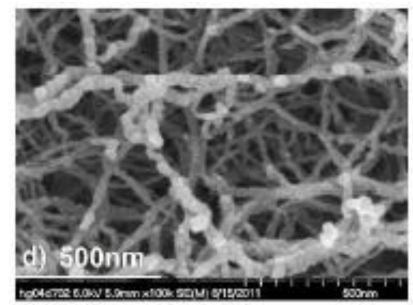
Hydrophilic to hydrophobic



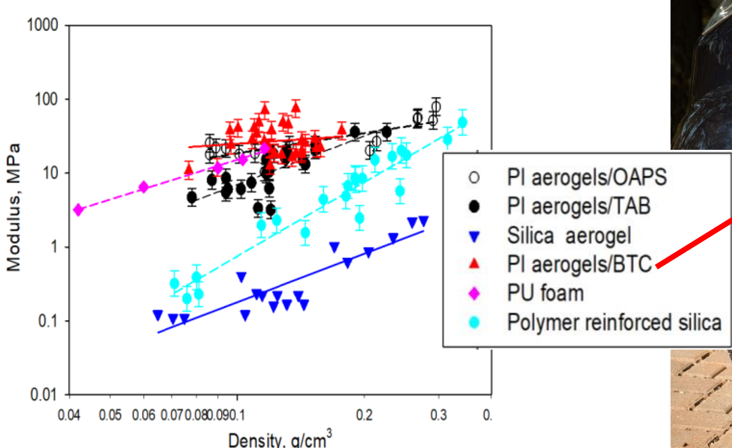
3D printing



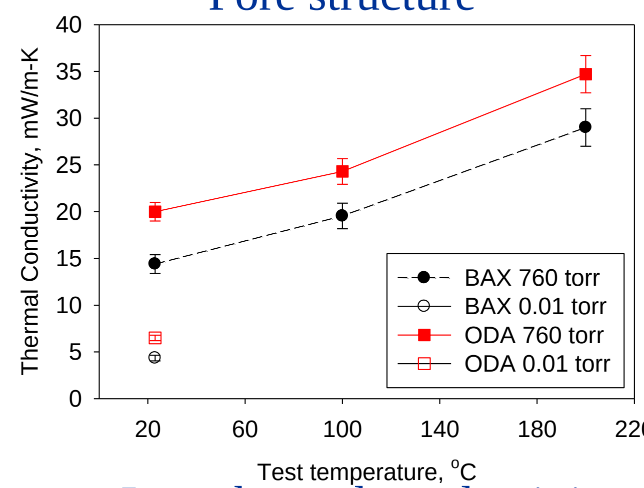
Transparency



Pore structure



Mechanical properties



Low thermal conductivity

Acknowledgments

Polymer aerogel fabrication and characterization

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