

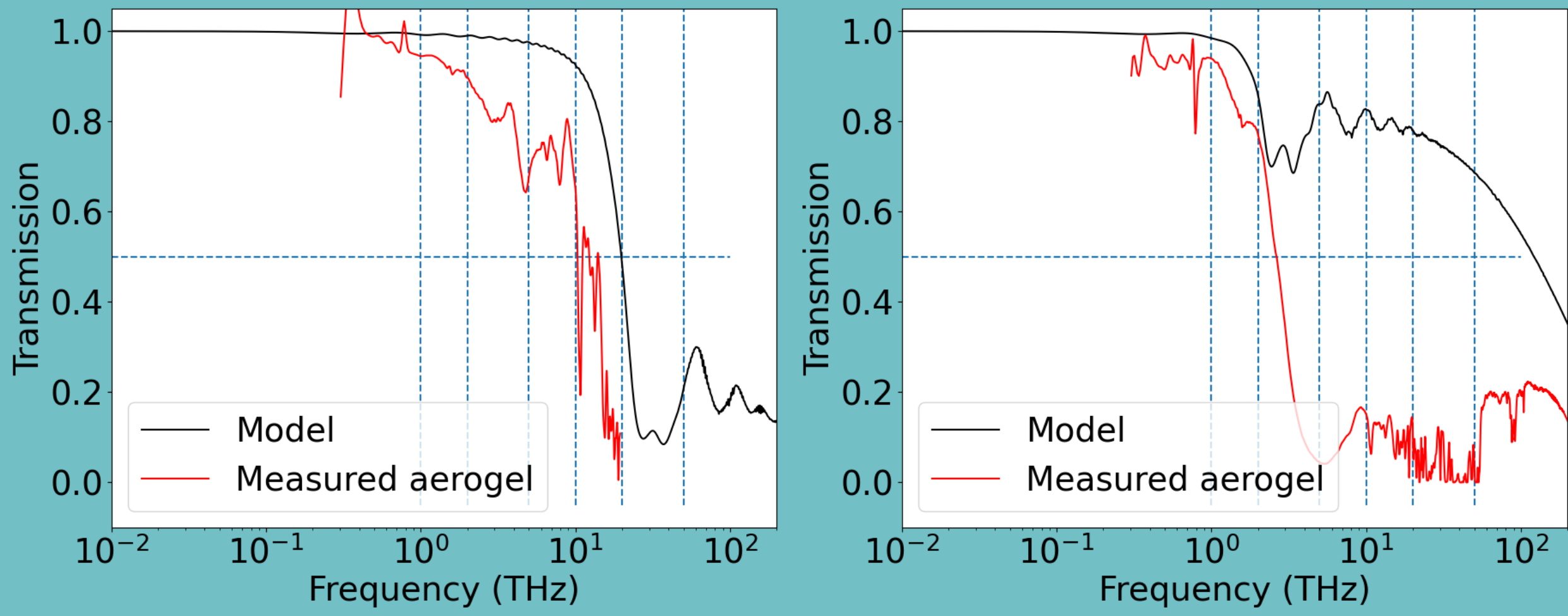
Novel infrared-blocking aerogel scattering filters and their applications in astrophysical and planetary science observations



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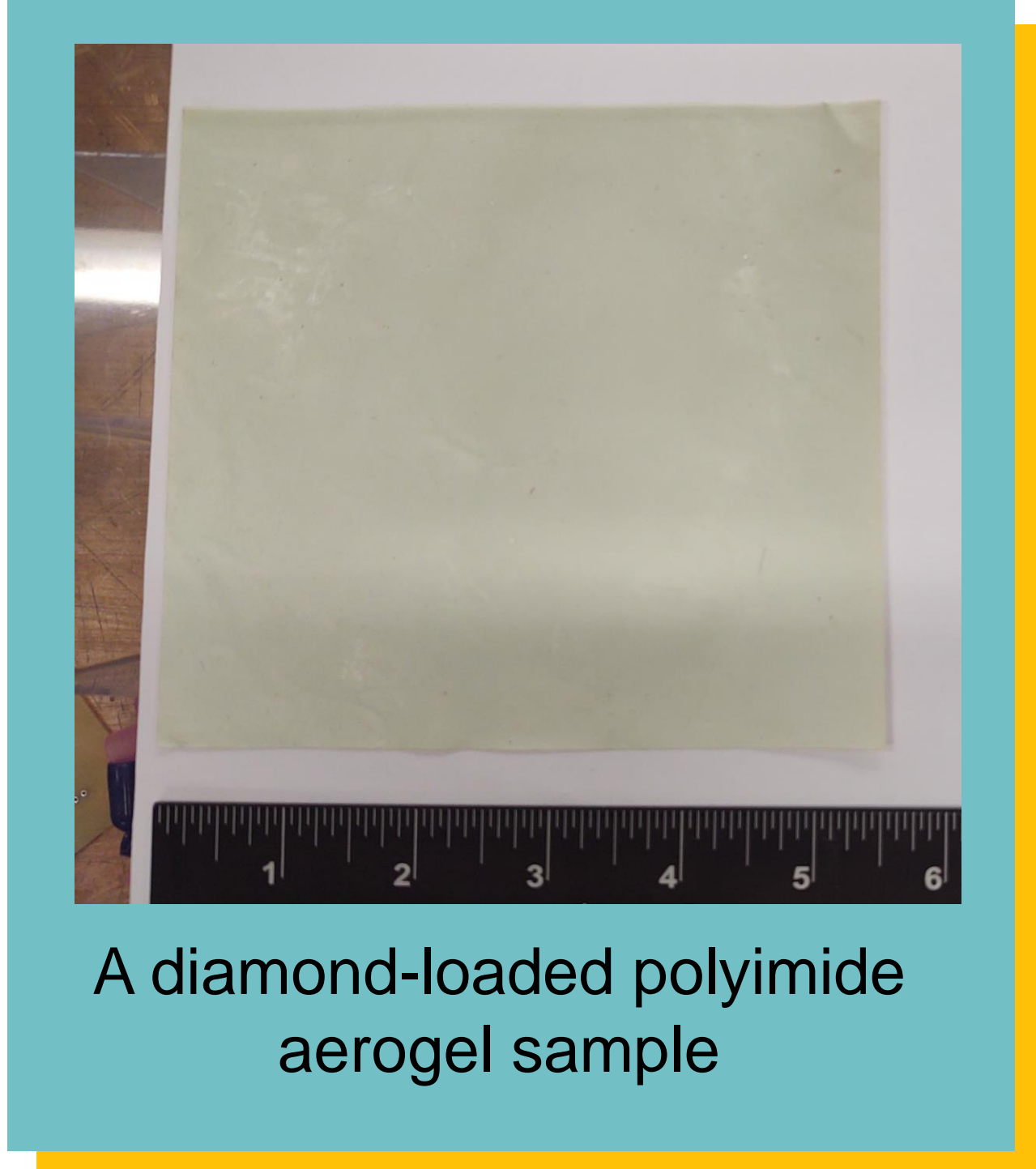
- Filtering out unwanted infrared light is an important design parameter of many missions in astrophysics, cosmology, and planetary science.
- Reduction of unwanted infrared light is especially important in cryogenic instruments
- We have successfully developed a series of polyimide aerogel scattering filters with a broad range of properties for use in the far infrared through microwave regimes [1].
- A polyimide aerogel matrix is embedded with diamond particles to scatter light
- Particle size and loading density can be modified to control desired cut-off frequency
- These scattering filters can be tuned to meet the needs of planetary science, astrophysics, and cosmology missions from ground, sub-orbital, and space-borne platforms.



Two different polyimide aerogel filters tuned to different cut-off frequencies and corresponding Mie scattering models

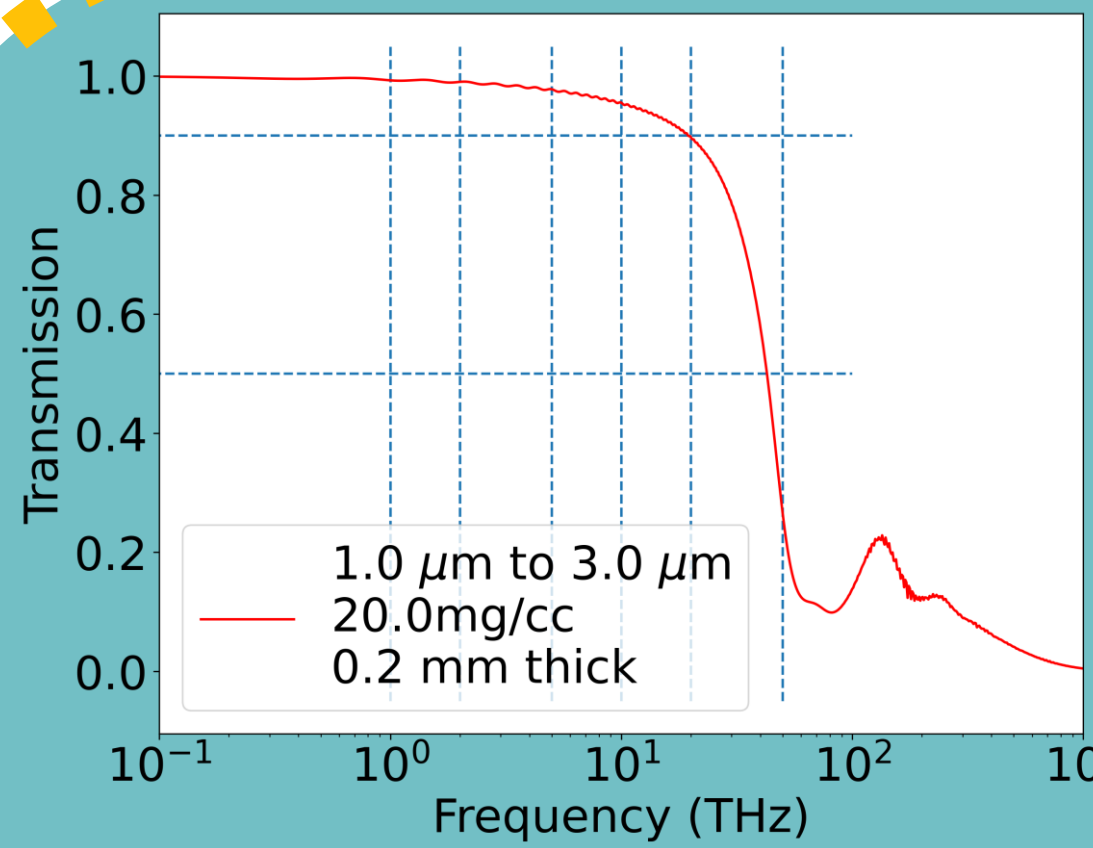
[1] Essinger-Hileman, et al., Aerogel scattering filters for cosmic microwave background observations, Applied Optics, Vol 59, Issue 18, pp5439-5446, 2020

Background

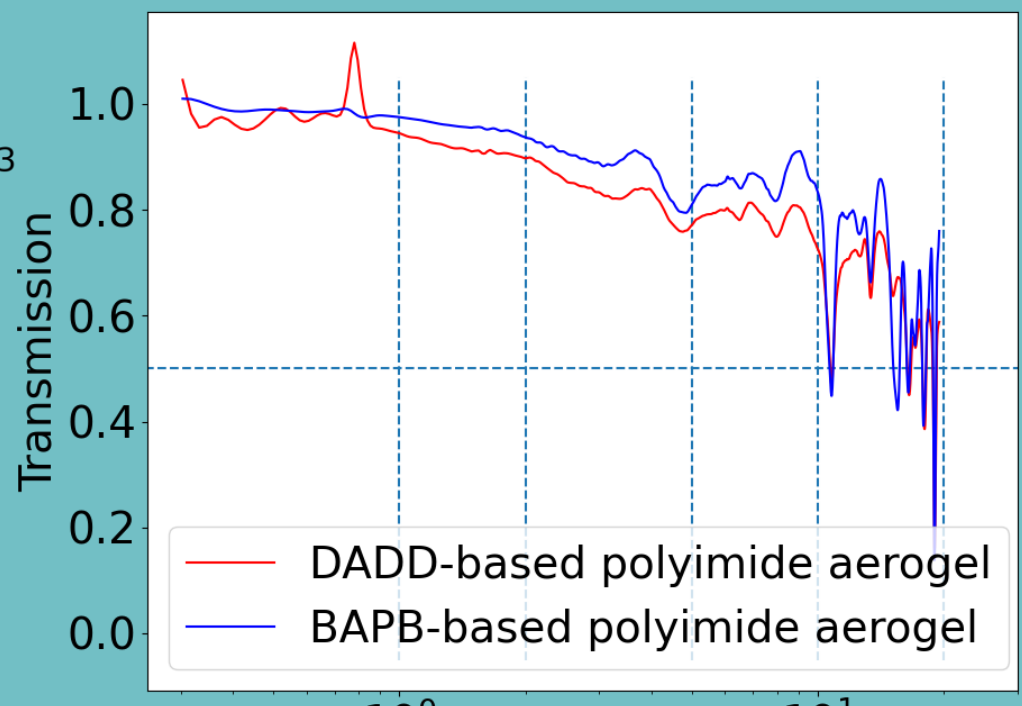


A diamond-loaded polyimide aerogel sample

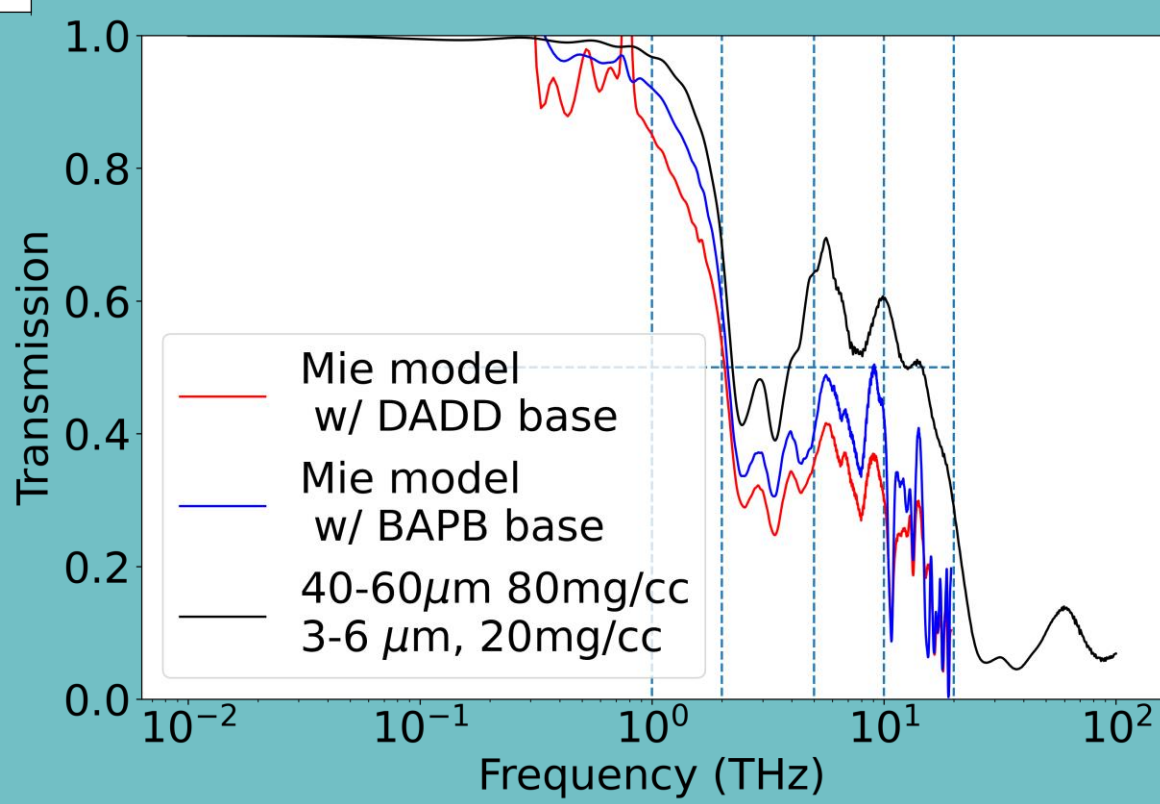
Modeling



- Mie Scattering models allowed successful prediction of filter cutoff behavior but did not incorporate the polymer behavior or the non-spherical nature of the particles
- Mie scattering treats the diamond particles like spheres of uniform size, which they are not, which leads to some high frequency disagreement between model and measured films.



- By measuring polyimide aerogel samples without diamond particles, we can determine the electromagnetic properties of the base matrix, which are not captured in Mie scattering models. (See Barlis, Poster 12190-158, July 21)
- Several different polyimide formulations have been tested, as well as other polymer aerogel matrices
 - 1,12-dodecylamine (DADD) and 4 4'-bis(4-aminophenoxy)biphenyl (BAPB) are two different diamines that can be used to form the polyimide polymer structure [2-3].

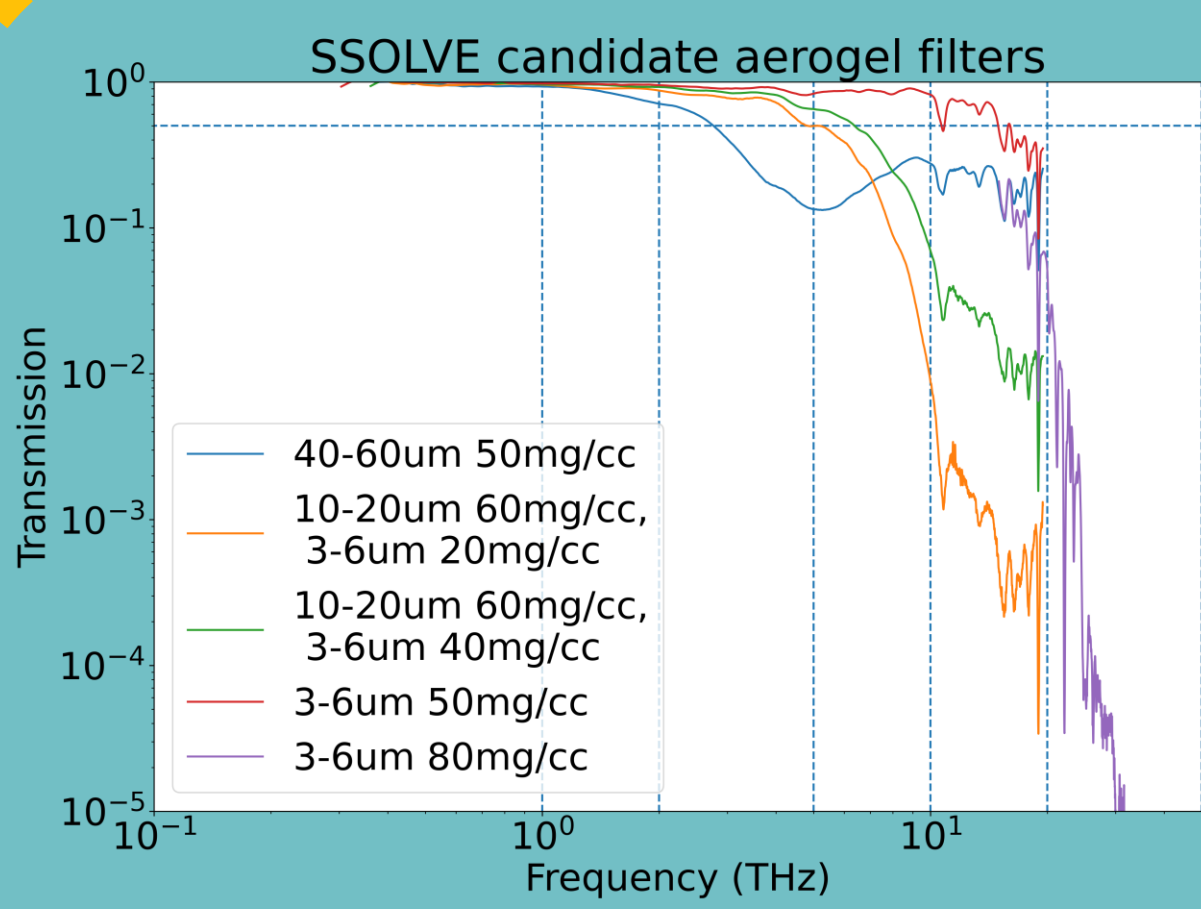


- The model can then incorporate the electromagnetic properties of the aerogel matrix with the Mie scattering calculations to create more realistic models

[2] Meador, et. al., Polyimide Aerogels with Amide Cross-Links: A Low Cost Alternative for Mechanically Strong Polymer Aerogels ACS Applied Materials & Interfaces 2015 7 (2), 1240-1249, DOI: 10.1021/am507268c
[3] Guo, et. al., Flexible Polyimide Aerogels with Dodecane Links in the Backbone Structure, ACS Applied Materials & Interfaces 2020 12 (29), 33288-33296, DOI: 10.1021/acsami.0c09321



The CLASS telescopes in the Atacama Desert in Chile, image from Dr Sarah Marie Bruno

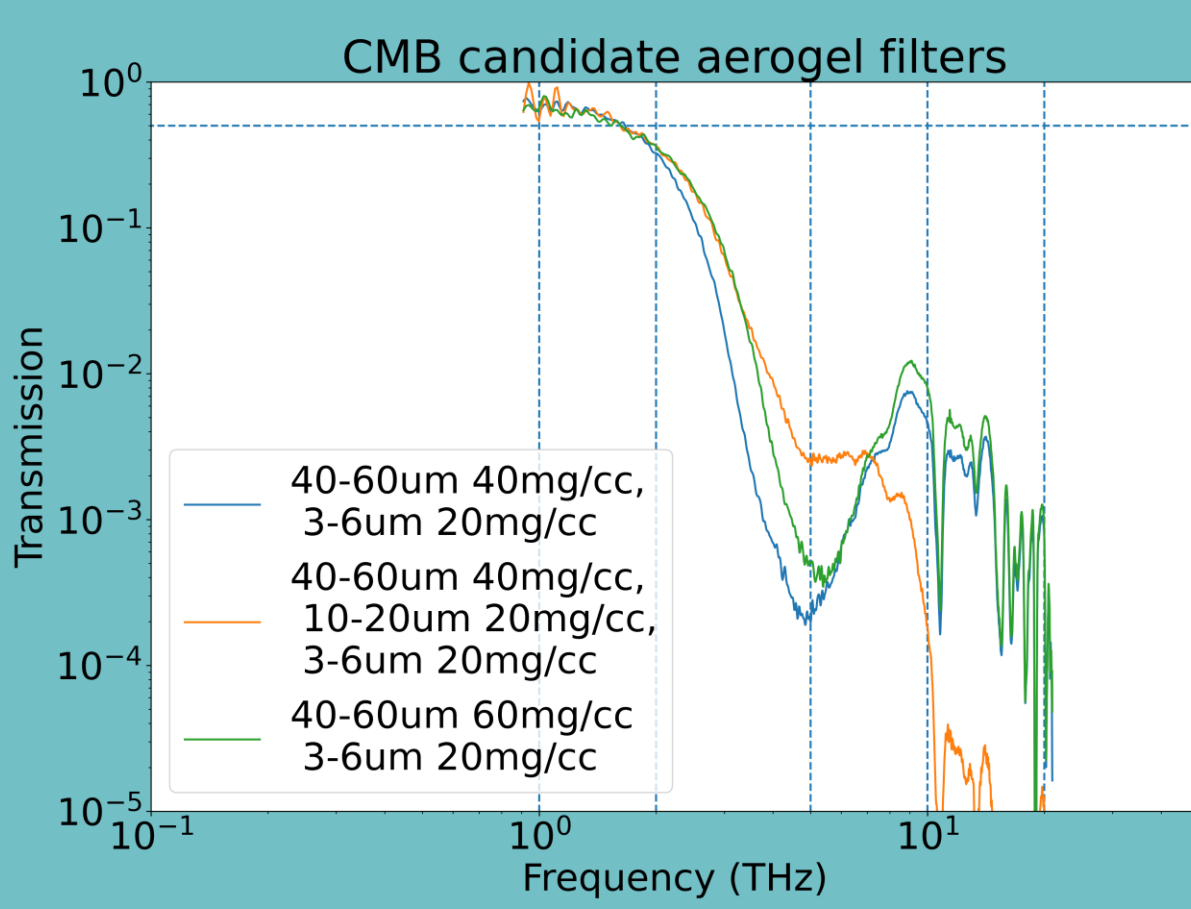


- Film cutoff frequencies have been designed to meet the needs of the **Submillimeter Solar Observation Lunar Volatiles Experiment (SSOLVE)** mission, which will observe the H₂O, OH, and HDO molecules in the lunar atmosphere, from ~500 GHz to ~2 THz [4].
- Film cutoff frequencies have also been designed to meet the needs of the cosmic microwave background experiments, like the **Cosmology Angular Scale Surveyor (CLASS)**, which commonly observe in the 40-500 GHz range [5].
- Such filters are also being designed and prototyped for the upcoming **Experiment for Cryogenic Large-Aperture Intensity Mapping (EXCLAIM)** telescope, which observes from approximately 400-500 GHz [6].

[4] B. Bulcha et al., "Submillimeter Solar Observation Lunar Volatiles Experiment (SSOLVE) Optics and Front-end Spectrometer," 2021 46th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), 2021, pp. 1-1, doi: 10.1109/IRMMW-THz50926.2021.9566908.

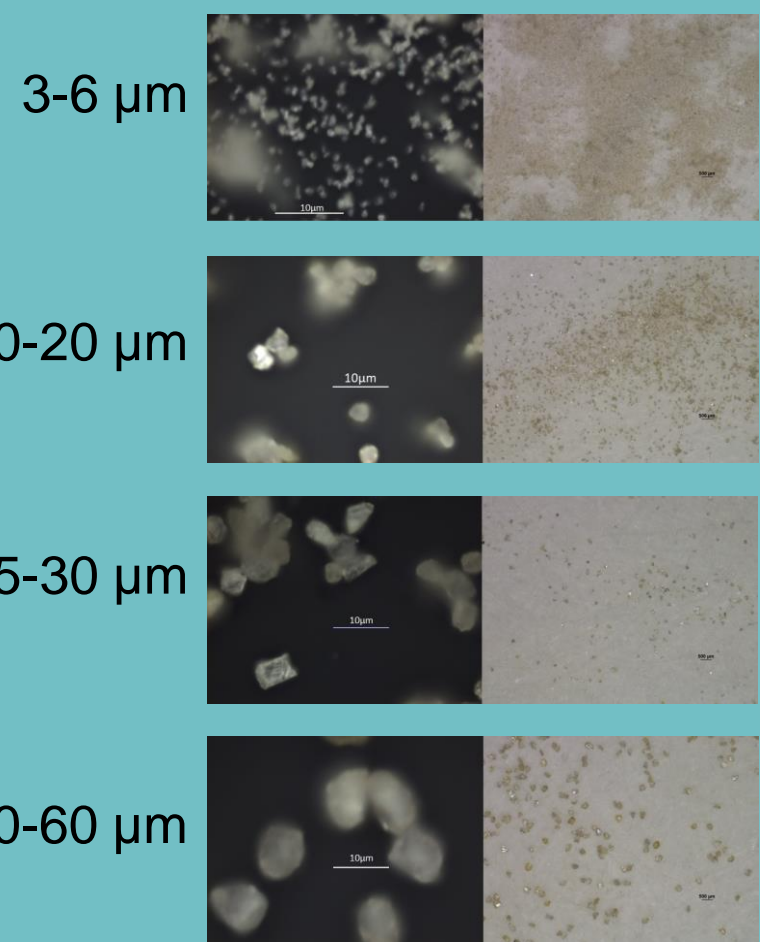
[5] Harrington, et. al., "The Cosmology Large Angular Scale Surveyor," Proc. SPIE 9914, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VIII, 99141K (19 July 2016); https://doi.org/10.1117/12.2233125

[6] Ade, P.A.R., et al. The Experiment for Cryogenic Large-Aperture Intensity Mapping (EXCLAIM). J Low Temp Phys 199, 1027–1037 (2020). https://doi.org/10.1007/s10909-019-02320-5

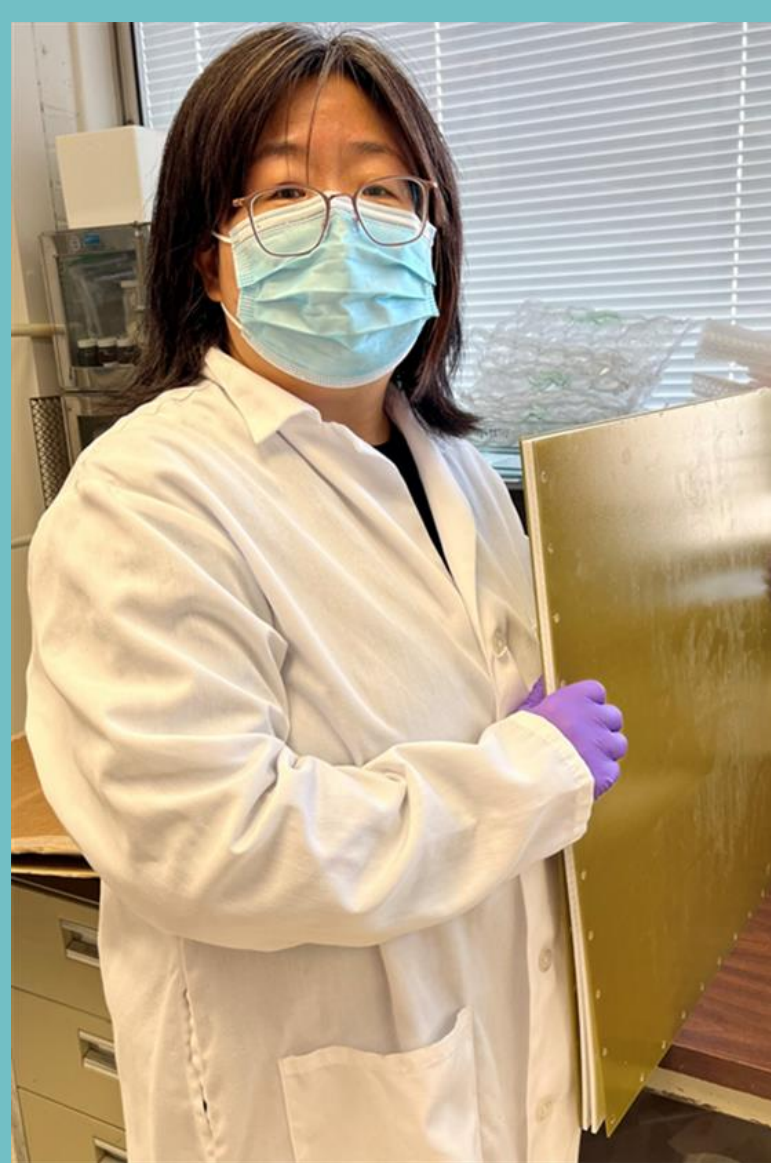


Filter Tuning

- Optical microscope images of sample diamond particles.



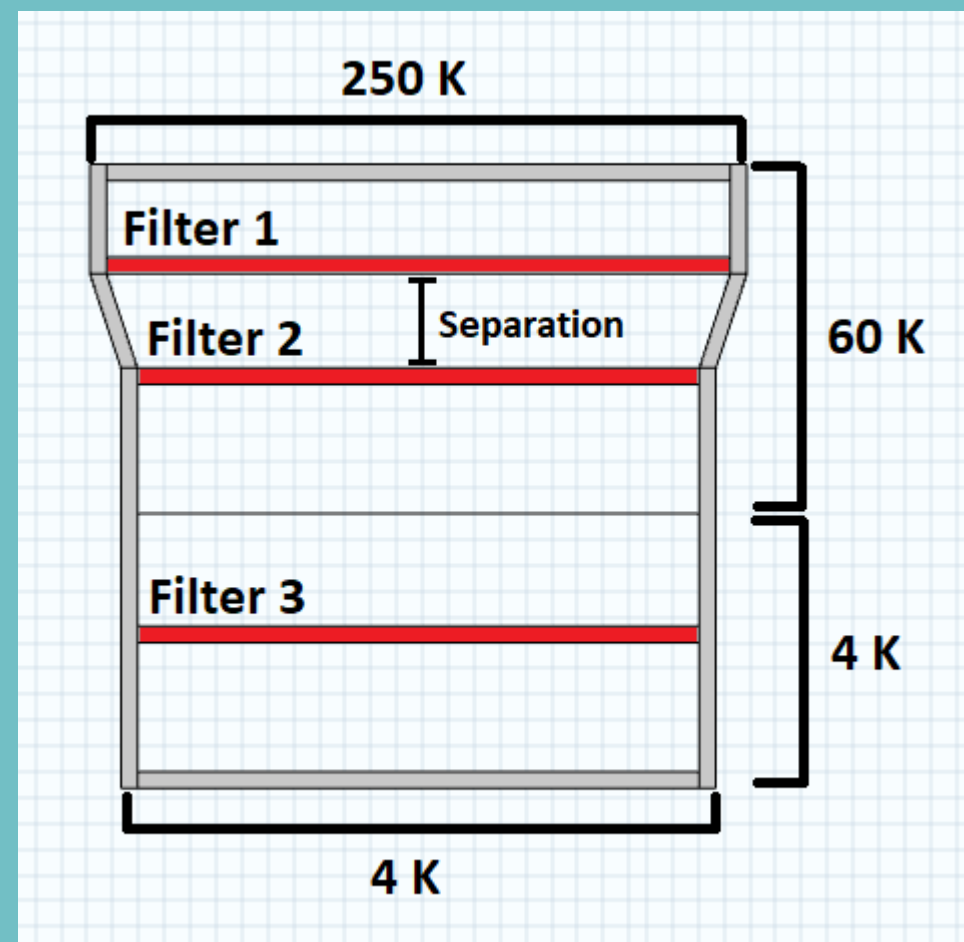
- Size ranges represent three standard deviations of size as specified by the manufacturer



Dr. Guo holds a large vertical film casting mold.

Cryogenic Testing

- Using the existing CLASS receiver as an example of a realistic deployment scheme, a COMSOL model of a cryogenic stack of three aerogel scattering filters was compared to existing state-of-the-art PTFE and alumina filters
 - The simulation estimates the total amount of infrared power that passes through the filters and reaches the 4 K stage.
- Three aerogel scattering filters (arranged as shown in the figure at right) are predicted to cut excess IR loading to the 4K stage of the receiver below the required 0.1 W, provided the net emissivity is below 50%
 - Three alumina filters similarly arranged provide greater rejection of IR power, but at the cost of lower in-band transmission and greater cost and complexity
 - The simulation results depend strongly on the emissivity of the aerogel filters
- Cryogenic tests of large, ~30 cm diameter, aerogel filters are underway. By measuring their performance in a cryogenic receiver, the emissivity can be inferred by measuring the equilibrium temperature.
 - This also provides an opportunity to refine the manufacturing techniques of very large films.



A schematic showing the location of the aerogel scattering filters in a CLASS telescope receiver

