Fermilab U.S. DEPARTMENT OF ENERGY Office of Science
FERMILAB-SLIDES-23-394-STUDENT

InfraBREAD: Characterization of Optically Smooth Reflector Parts

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Fall SULI Presentation

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Background

Dark Matter Mass Spectrum, Axions, and Dark Photons

The Dark Matter Mass Spectrum

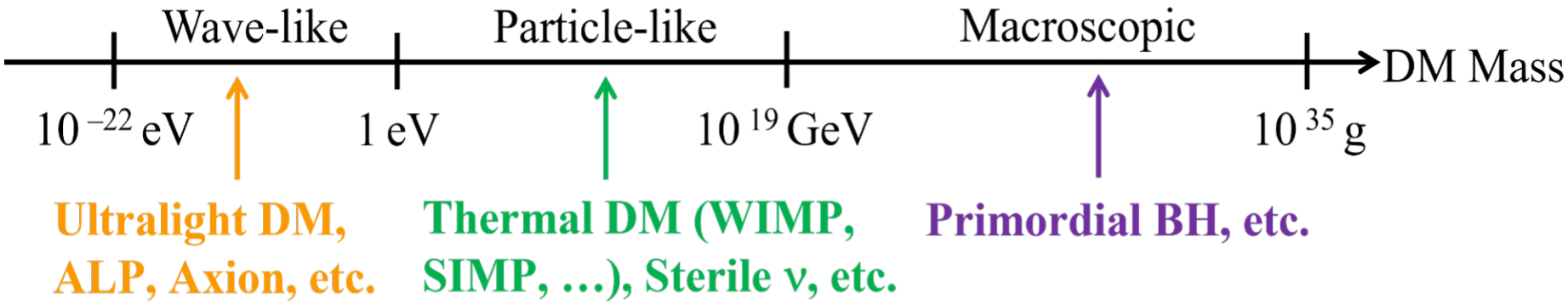
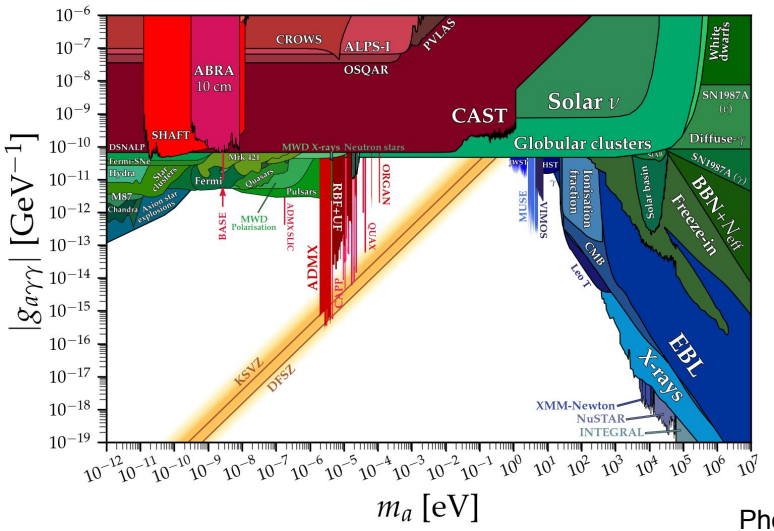


Photo Credit: Shigeki Matsumoto

Axions vs. Dark Photons

- Axions
  - Goal is to cover space between DFSZ and KSVZ lines.
    - Axions in that space solve the problem of CP violation.



- Dark Photons
  - Couple to SM particles through kinetic mixing with photon.
  - Massless to massive models are in existence.

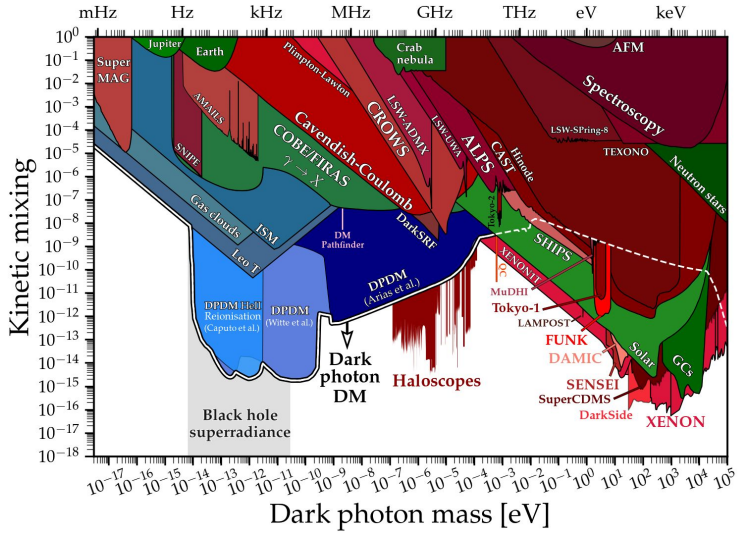


Photo Credits: [Axion Limits]

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BREAD (Broadband Reflector Experiment for Axion Detection)

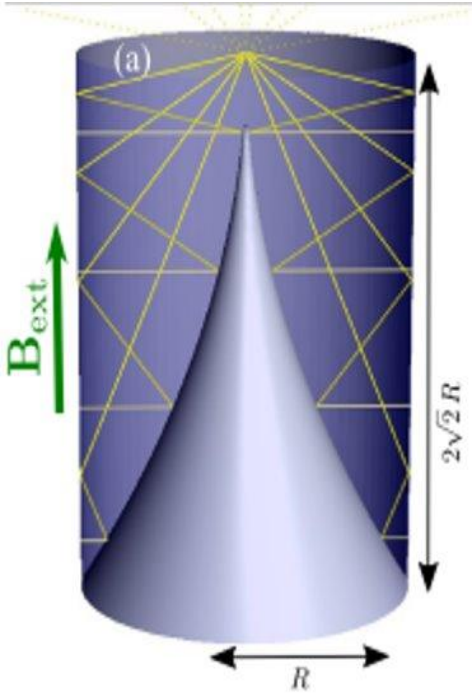

Photo Credit: BREAD Collaboration

- Dish Antenna
  - Spontaneous interactions will convert DM to photons.
  - Reflectors focus photons onto an SNSPD.
- External magnetic field needed for axion detection.
- InfraBREAD
  - Optically smooth inner reflector, inner cylinders.
  - Probes 20-200 THz frequency range.

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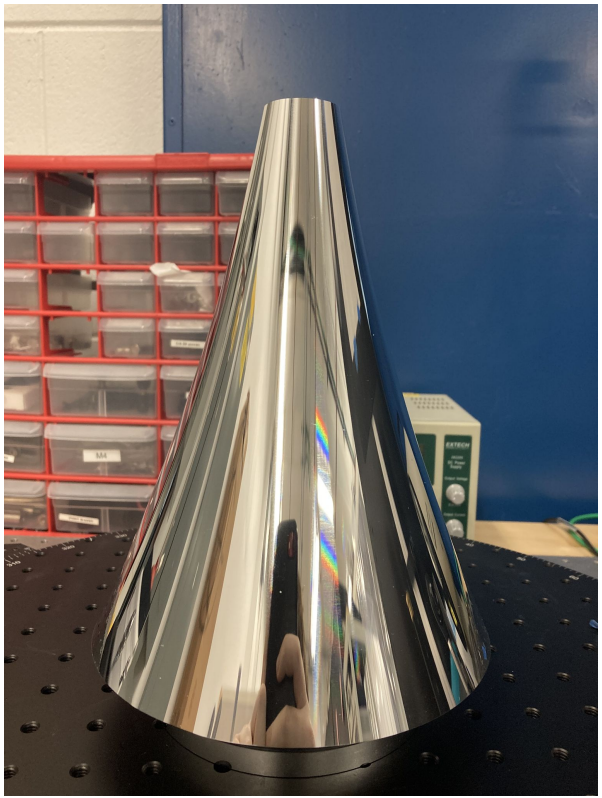
The Optics Setup

Reflectors, Lasers, Cameras, etc.

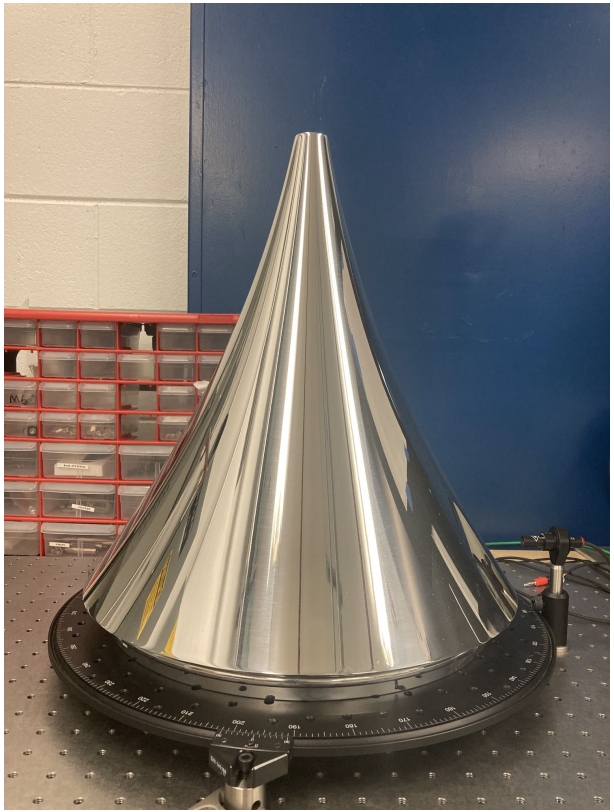
The Diamond-Turned Upper Reflector



Upper reflector half on the rotating table. Part is centered to the table through the central bore.

- Fabricated by Xometry.
  - Underwent diamond-turning process at Lawrence Livermore National Laboratory.
  - Part of a two-part design, where it will fit into a lower reflector half.

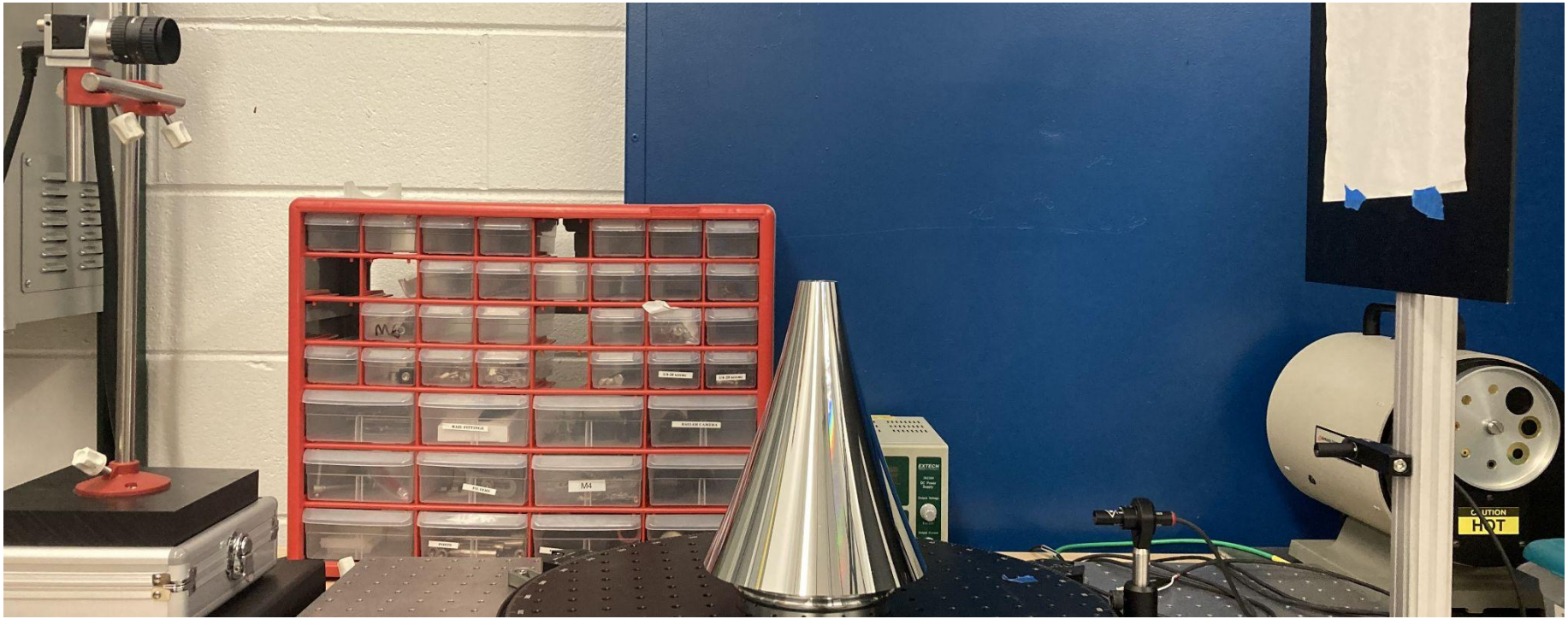
The GigaBREAD Reflector



GigaBREAD reflector on the rotating table. Centered through central bore.

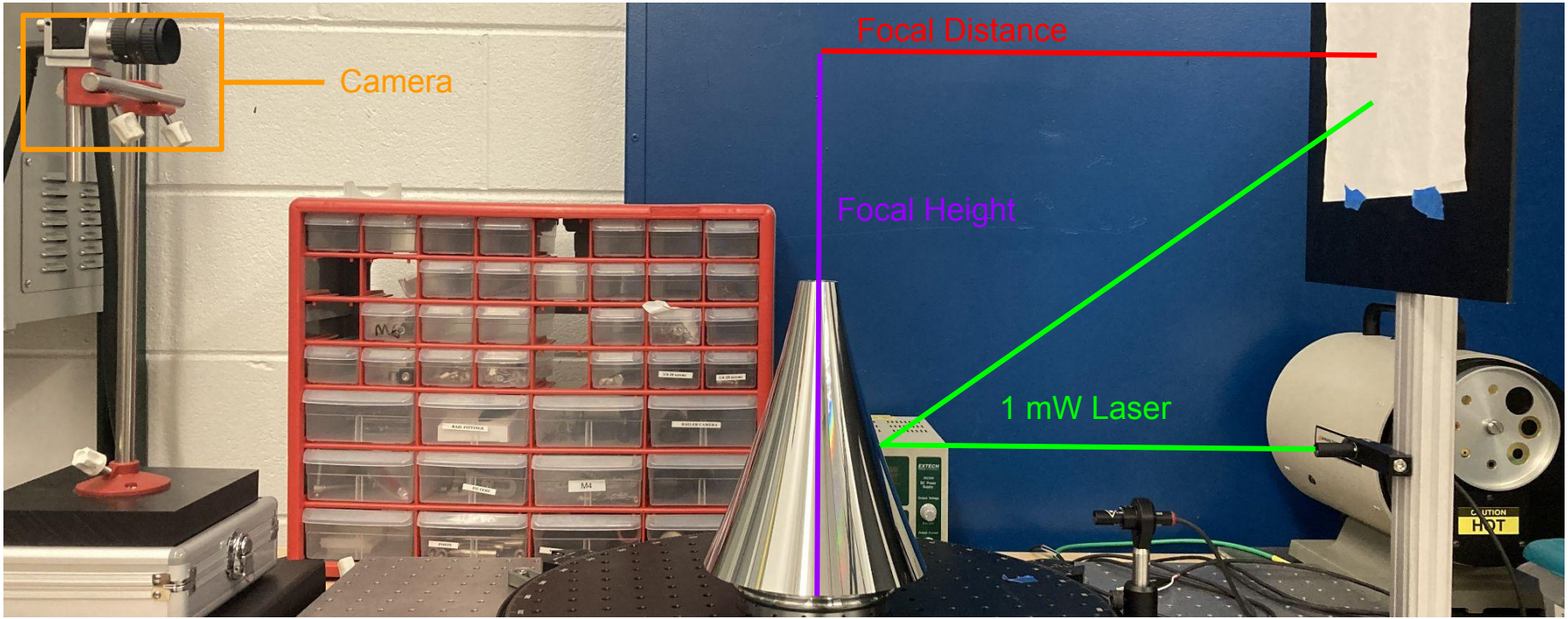
- Fabricated by WPAWorks.
  - Made in one full-sized piece compared to previous.
  - Part will not undergo diamond turning process.

Optical Bench Setup



Rotating Table, Lasers, and Screen Setup were all procured through ThorLabs. The camera is a Basler acA4024.

Optical Bench Setup



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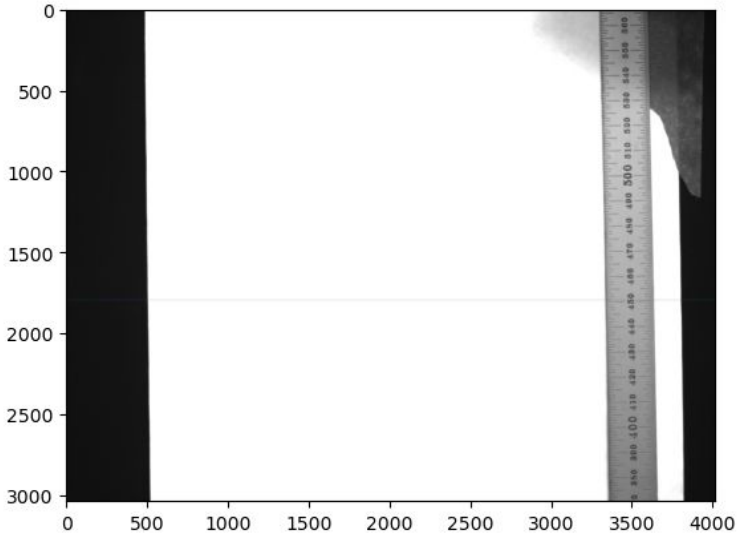
Measurements and Results

Focal Point, Total Integrated Scatter, and Surface Wave Characteristics

Focal Point

- Ruler used to measure the focal distance, focal height of reflected beam.
  - Goal: Constrain distance measurement uncertainty to below 500 microns, height uncertainty to ~10's of microns.



A measurement standard for the vertical height with the ruler held at a congruent angle from the reflection as the screen.

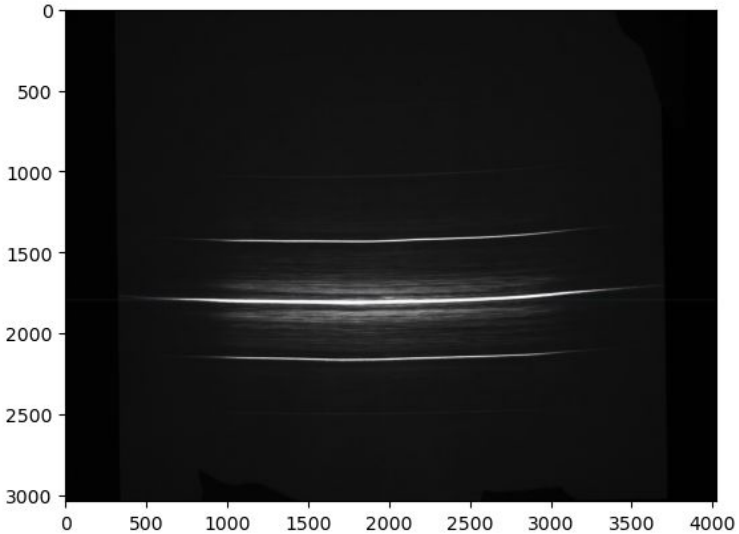


Photo of the laser reflection as it hits the screen. Taken at 75000 microsecond exposure time.

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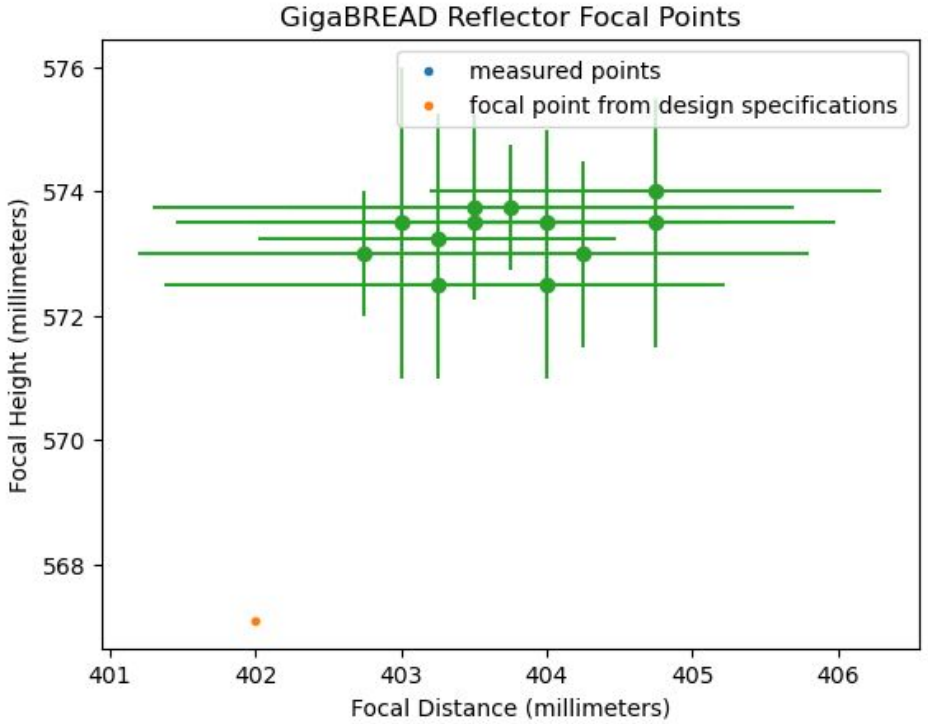
GigaBREAD Reflector Focal Point Results



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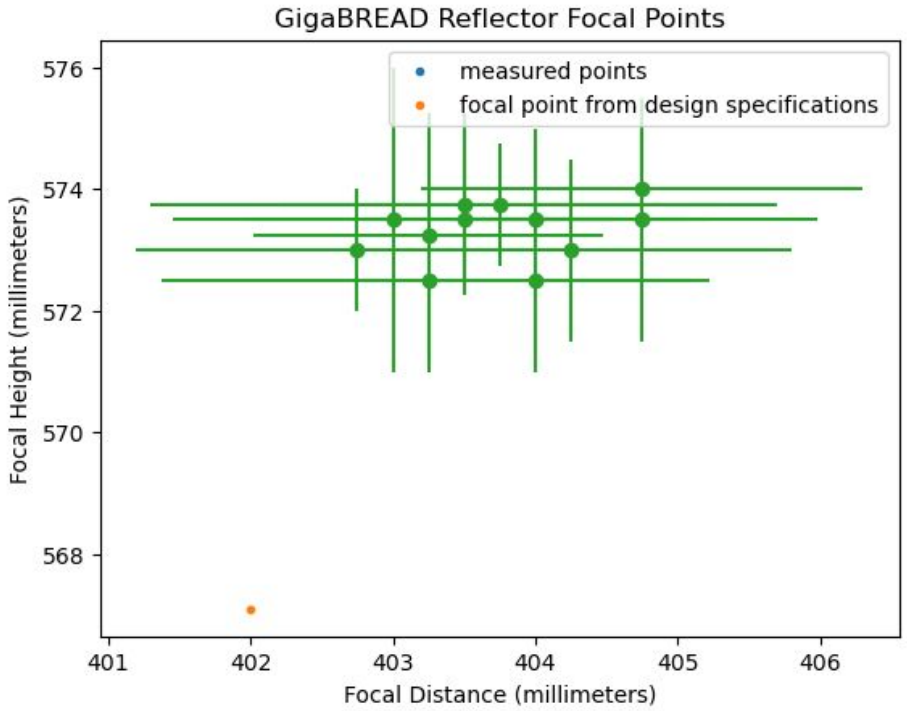
GigaBREAD Reflector Focal Point Results



TAKEN WITHOUT USE OF THE CAMERA

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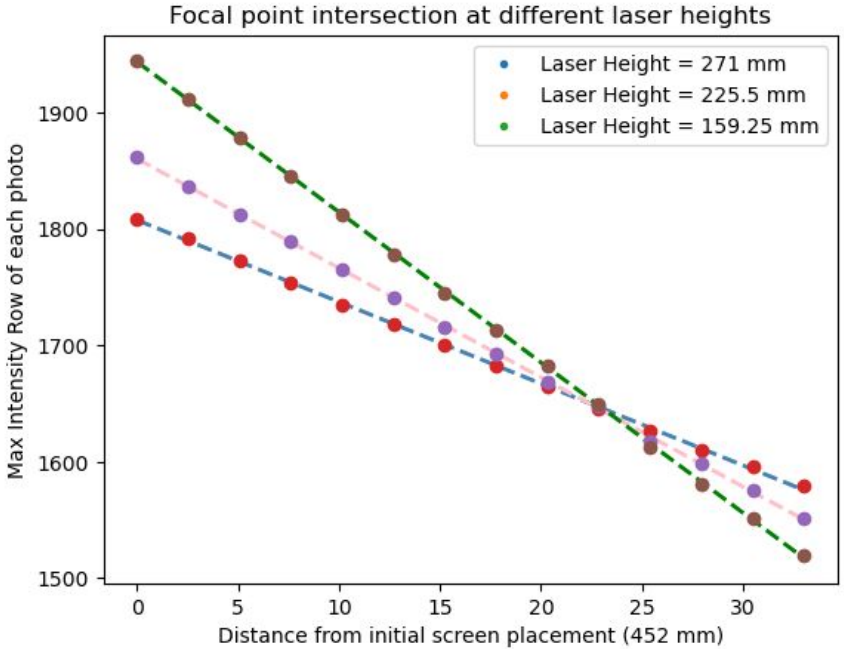
InfraBREAD Reflector Focal Point Results

- The rows are translated to a focal height by the previous measurement standard.
- The screen can be moved in .635 mm increments.
- Focal distance = 388.50 +/- .78 mm , Focal Height = 369.05 +/- .04 mm



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Total Integrated Scatter/Reflector Surface Roughness

- Total integrated scatter (TIS) = diffuse reflection/ (specular reflection + diffuse).
  - Diffuse intensity is obtained through removing the specular intensity from high exposure photos.

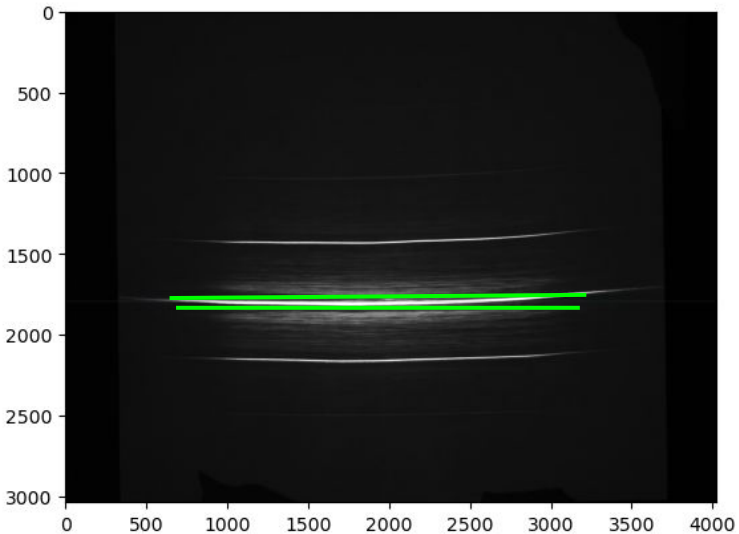
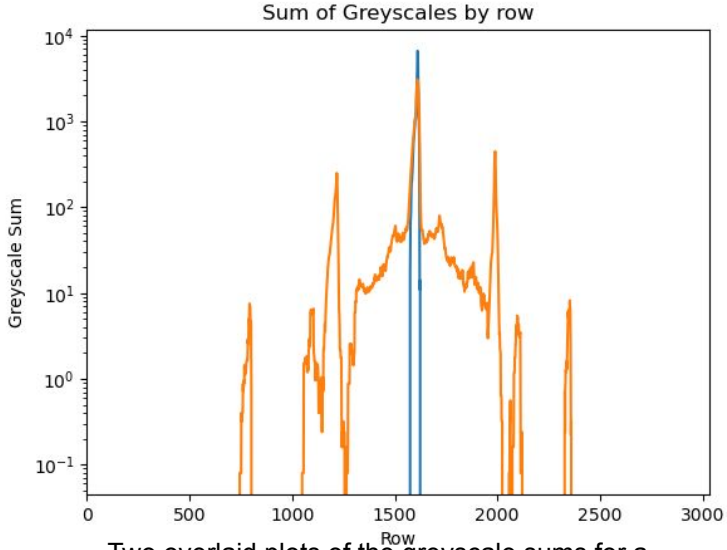


Photo of the laser reflection as it hits the screen. The area inside the green lines is a rough representation of the specular reflection area.



Two overlaid plots of the greyscale sums for a reflection. The blue represents the reflection at a 48 microsecond exposure, while the orange is the same reflection at 4800 microseconds.

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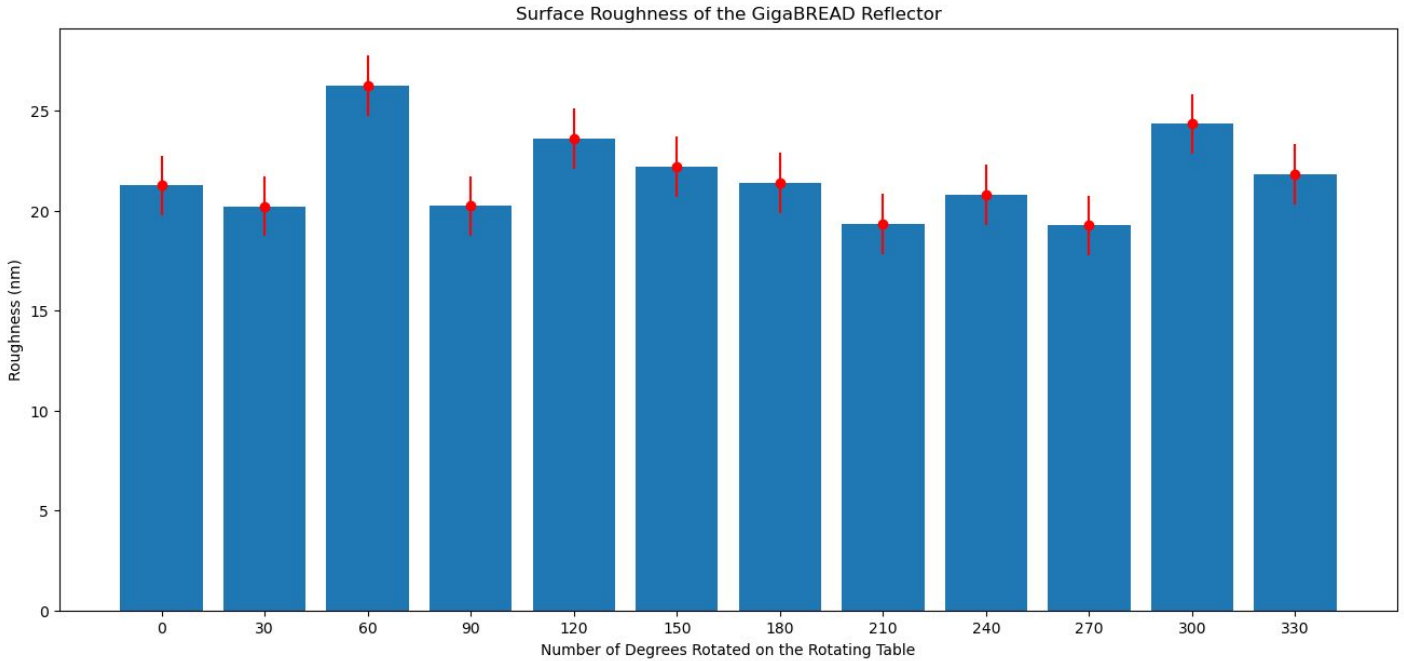
Results for the GigaBREAD Reflector

- TIS is directly proportional to the surface roughness of the reflector.
  - Related by the formula: $TIS \equiv \frac{P_s}{P_0 + P_s} = 1 - \exp\left[-\left(\frac{4\pi\sigma\cos\theta_i}{\lambda}\right)^2\right] \cong \frac{P_s}{P_0} \cong \left(\frac{4\pi\sigma\cos\theta_i}{\lambda}\right)^2$



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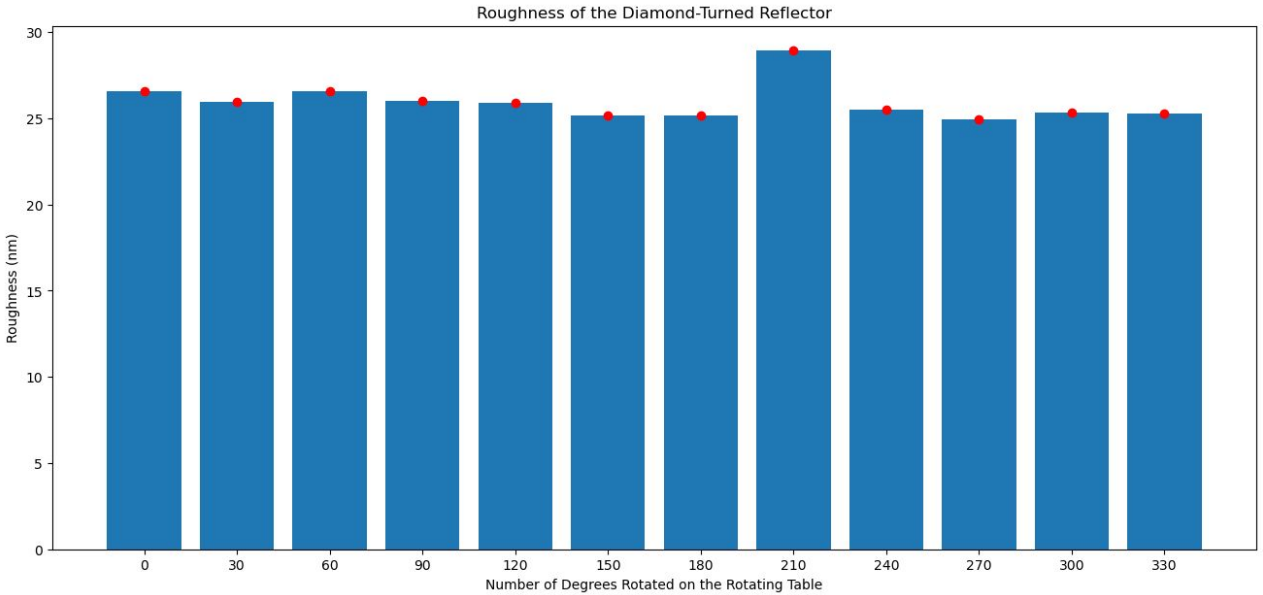
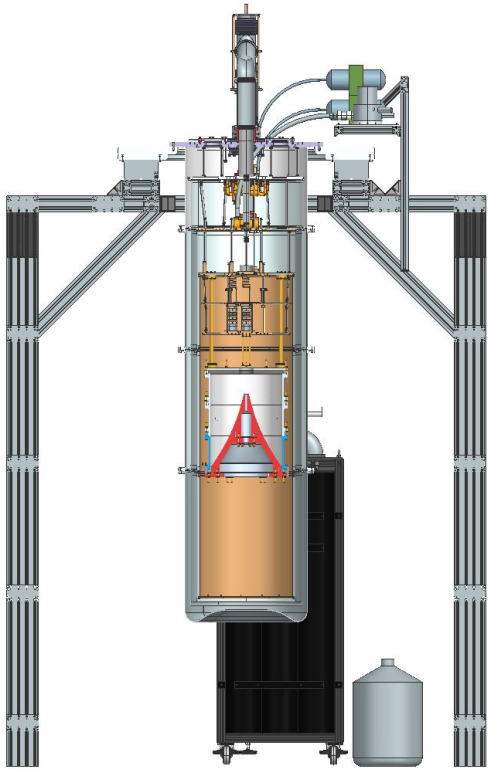
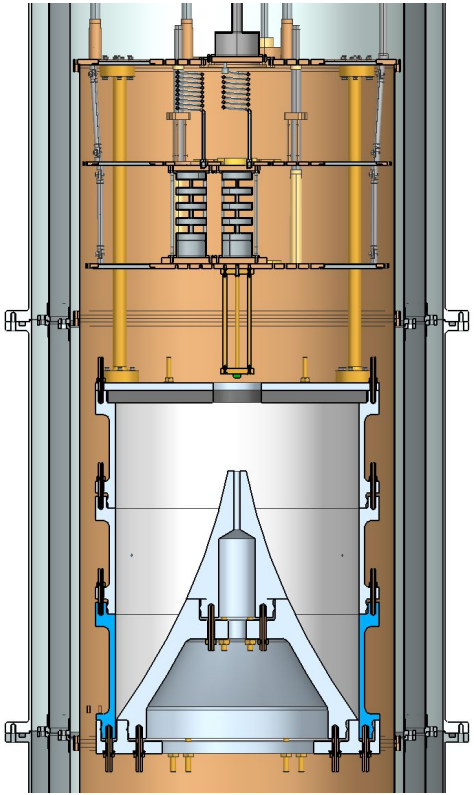
InfraBREAD Reflector Results

- Average roughness ~25 nm.
  - Matches what was expected from diamond-turning process at LLNL.
  - Across the same height machining is consistent, further tests could be run at different heights.

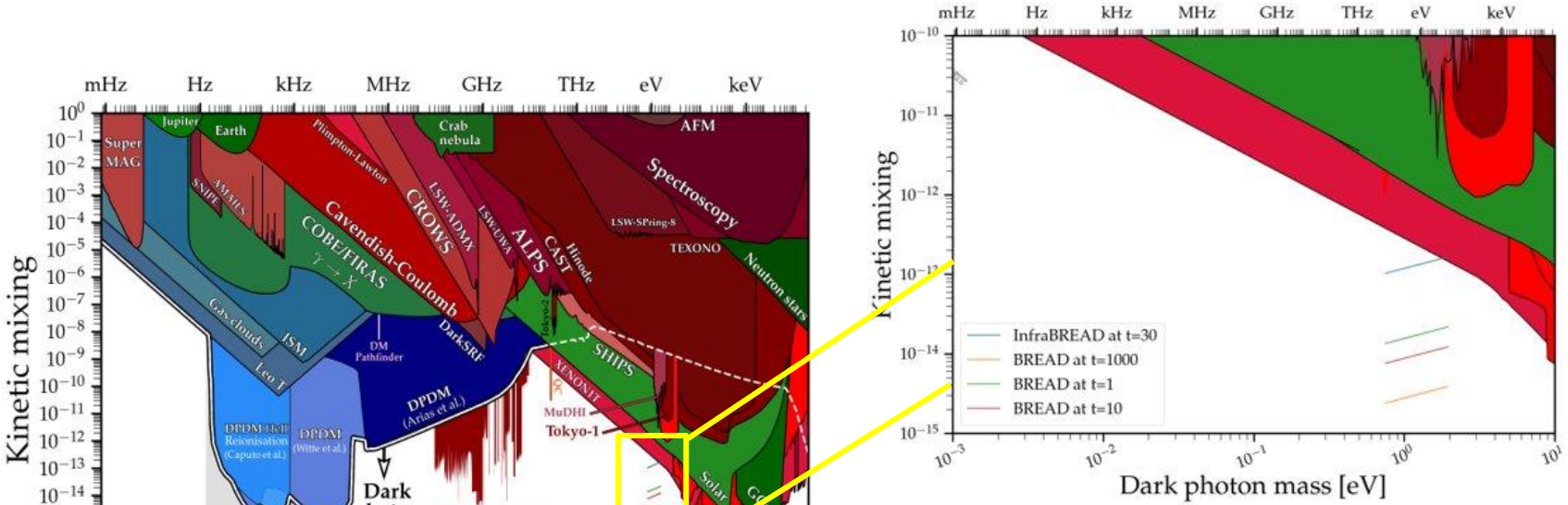


Why?





Dark Photon Sensitivity for InfraBREAD



A zoomed in image of the phase space diagram. The top line in blue describes the current setup with a one square meter dish, .05 detection efficiency, and a Dark Count Rate ~ 10^-3 Hz. The other BREAD lines are at the optimal design setup (ie. 10 square meter dish, .5 detection efficiency, and DCR ~ 10^-4 Hz.

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Collaborations/ Acknowledgments

Dr. Andrew Sonnenschein, Dr. Stefan Knirck, Aiman Imran, Gary Teafoe, Don Mitchell, Mark Ruschman, and the rest of the BREAD Collaboration