Developing an Ultra-Thin UHMWPE Window for the Terahertz Intensity Mapper

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Terahertz Intensity Mapper (TIM)

- TIM is a NASA-funded balloon telescope that spectroscopically images the far-infrared (240–420 μm) sky using 7200 cryogenically cooled Kinetic Inductance Detectors (KIDs).
- TIM uses Line Intensity Mapping (LIM) to create 3D maps of [CII] 158 μm emission, a key tracer of dust-obscured star formation.
- TIM surveys cosmic time from z = 0.5–1.7 (~4.5 billion years), capturing the evolution of galaxy growth.
- The [CII] signal is analyzed to calculate the cosmic star formation rate density (SFRD).

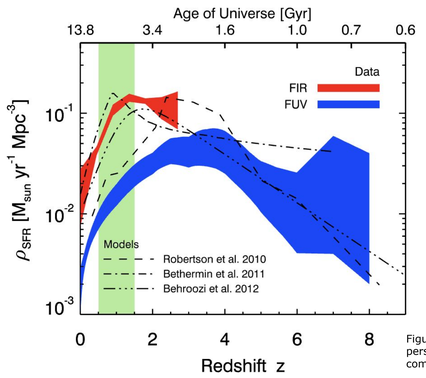
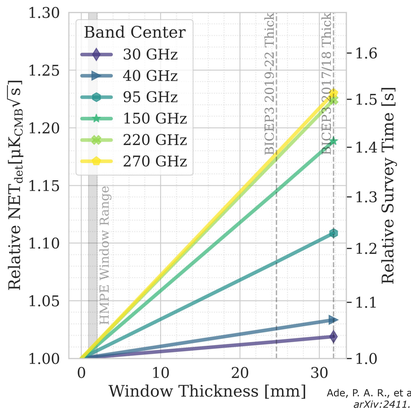


Figure from J. Vieira, personal communication

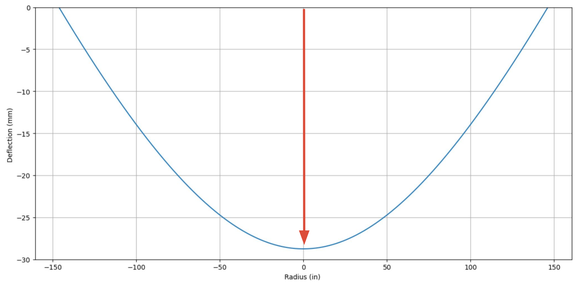
The UHMWPE Window for TIM



Ade, P. A. R., et al. *arXiv:2411.10428* (2024).

- TIM's detectors operate at <1 K in vacuum, requiring a low-loss window, transparent in FIR band
- Standard thick windows increase thermal emission (optical loading), reducing sensitivity.
- Thinner windows reduce photon noise, improving NET and survey speed, especially in the higher frequencies

Vacuum Tests



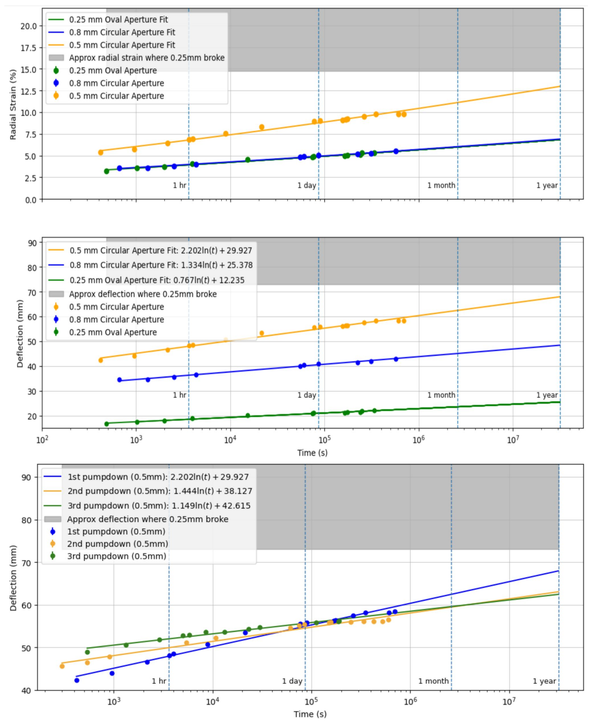
- Creep causes radial strain on the window, which is calculated using the equation below. These two variables are then plotted as a function of time.
- 3 pumpdowns were performed on the 0.5 mm window.
  - Each cycle showed a higher initial deflection
  - After ~3 days, deflection plateaued, and later cycles crept less than the 1st pumpdown.
- Repeated cycles suggest strain hardening due to the deformation.
- The 0.25 mm oval window reaches similar radial strain as the 0.8 mm in the circular aperture

$$\text{Radial strain} = \frac{R_{\text{arc}} - R}{R}$$

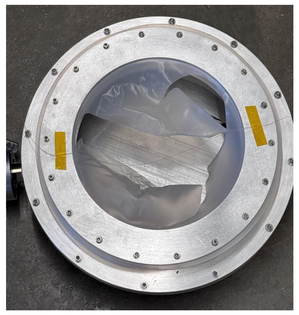
R-Radius of window aperture

$$R_{\text{arc}} = \frac{1}{2}\left[R^2 + 4\delta^2 + \left(\frac{R^2}{2\delta}\sinh^{-1}\left(\frac{2\delta}{R}\right)\right)\right]$$

δ-Deflection

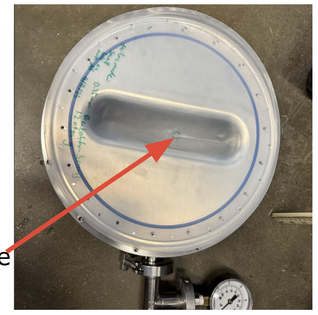


Vacuum Failure Modes

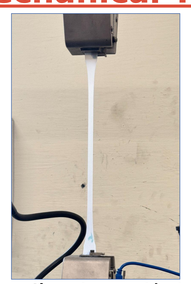


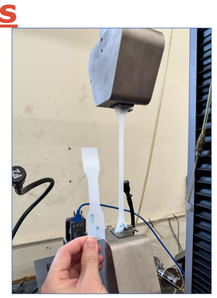
0.25 mm thick window under the oval aperture just undergone 2.2 atm pressure test with failure mode as a hole in the center.

0.25 mm thick window bursting under 1 atm with circular aperture. This failure mode only happened once.

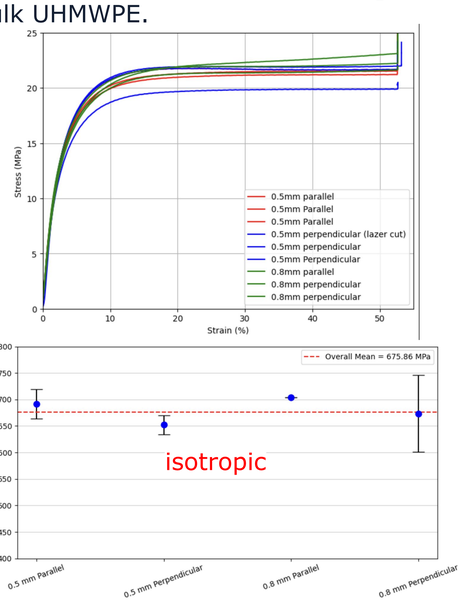


Mechanical Tests



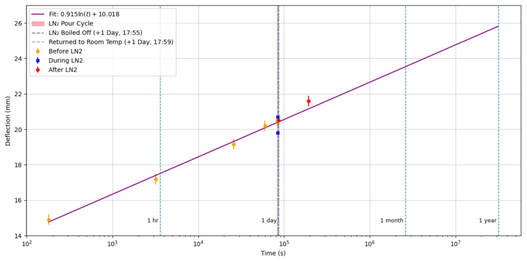


- Tensile strength tests were conducting using "dog bone" samples both in parallel and perpendicular direction to the skiving direction of bulk UHMWPE.

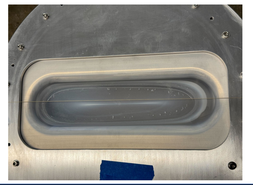


Freeze Test

To test the window's robustness at cold temperatures (-6°C) in Antarctica during December-January, we gently cooled down the window with cold nitrogen gas and liquid nitrogen from ~24°C to ~77K



the window survived 77K temperature for 25 minutes under 1 atm



Future Work

- Apply Anti Reflective (AR) coating and test whether that changes the deflection & radial strain
- Finalize the thickness for TIM at 0.5mm due to higher safety factor as revealed from high pressure tests, which is ~37% thinner than original baseline of 0.8mm

References

[1] Ade, P. A. R., et al. "BICEP/Keck XIX: Extremely Thin Composite Polymer Vacuum Windows for BICEP and Other High Throughput Millimeter Wave Telescopes." *arXiv preprint arXiv:2411.10428* (2024).

Acknowledgements

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