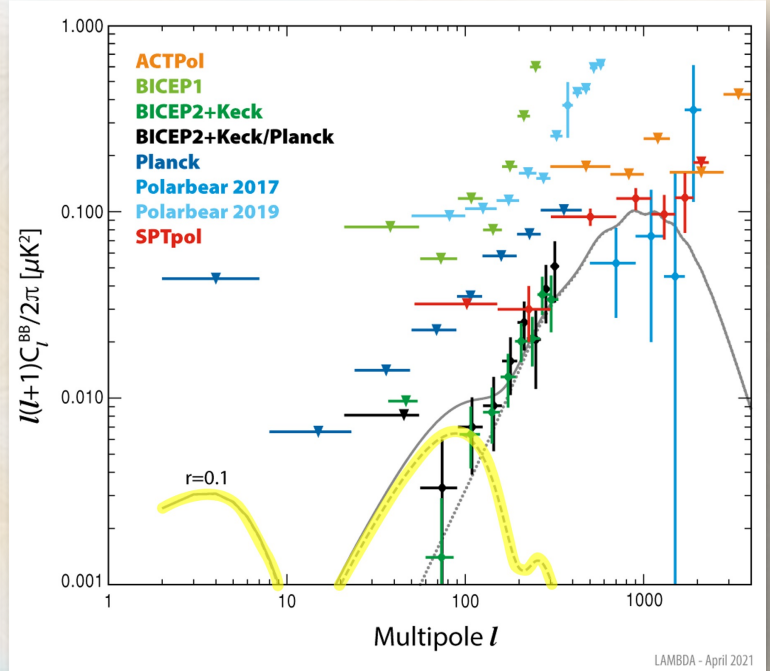
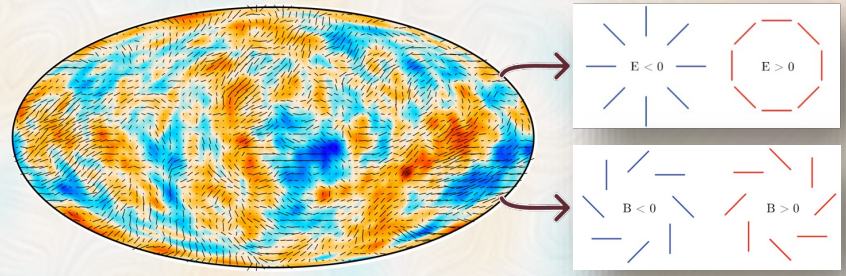




# POLARIZATION ANGLE CALIBRATION OF CMB TELESCOPES: STRATEGIES AND IMPLICATIONS FOR COSMOLOGICAL PROBES OF DARK MATTER AND DARK ENERGY

Noemi Mezzanzanica  
Dipartimento di Fisica "Giuseppe Occhialini"  
Università degli Studi di Milano-Bicocca

# CMB POLARIZATION AND B-MODES



GOAL: measure large-scale B-modes

- $30 \leq l \leq 200$
- Smoking gun evidence of IGW
- Multiple phenomena can originate spurious B-modes:
  - galactic foreground polarized emission
  - gravitational lensing
  - cosmic birefringence
  - **instrumental systematics**

Calibration of absolute polarization orientation  $\lesssim 0.1^\circ$

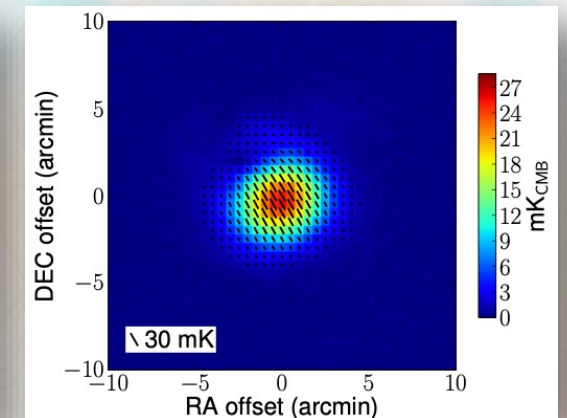
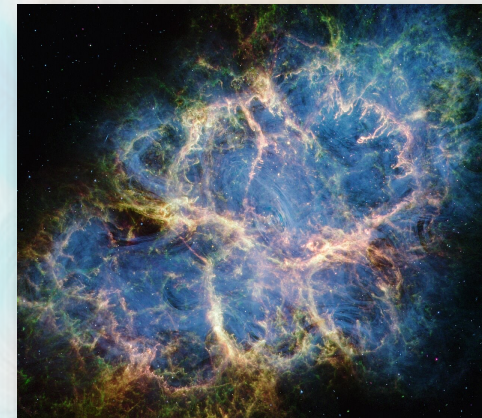
# CALIBRATION STRATEGIES

## SELF-CALIBRATION

- In standard  $\Lambda$ CDM the Universe is statistically invariant under parity  
 $\Rightarrow C_\ell^{TB} = 0 \wedge C_\ell^{EB} = 0$
- Miscalibration produces a distinct signature in TB and EB correlations

- ✓ No additional observing time required
- ✗ Pixel rotation and cosmological birefringence are fully degenerate effects
- ✗ Bias on cosmological parameters
- ✗ Sensitive to foregrounds

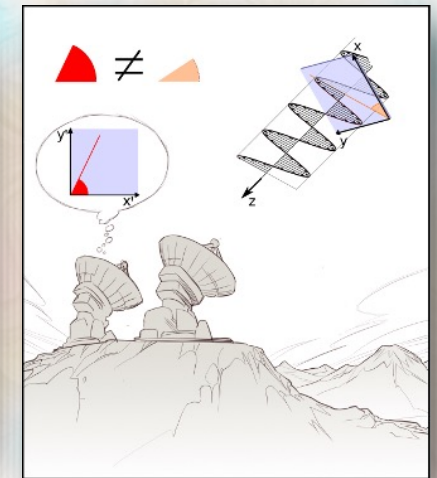
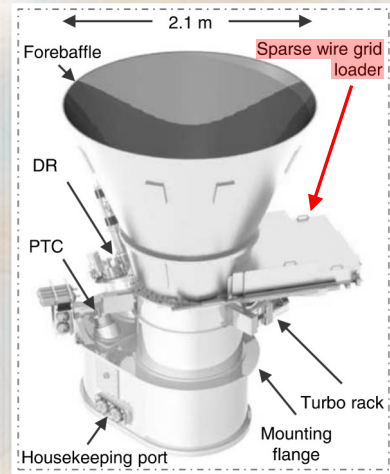
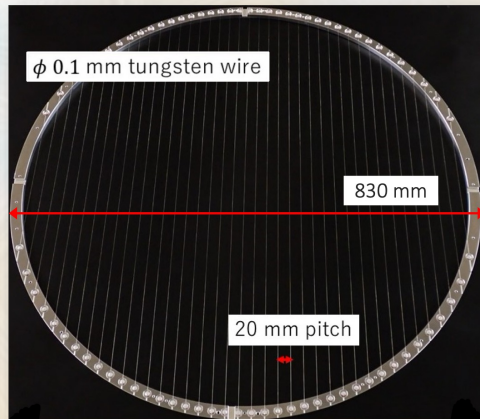
## CELESTIAL POLARIZED SOURCES



- ✓ In the far-field of the telescopes
- ✓ Cross-calibration between telescopes
- ✗ Time, frequency and spatial variability
- ✗ Limited sky-time availability, if visible at all
- ✗ Accuracy between  $0.5^\circ$  and  $1^\circ$

# CALIBRATION STRATEGIES

## ARTIFICIAL POLARIZED CALIBRATION SOURCES

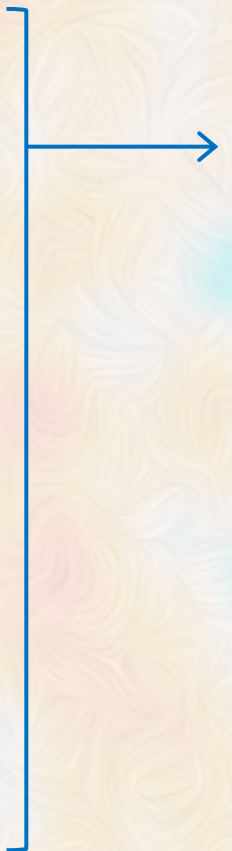
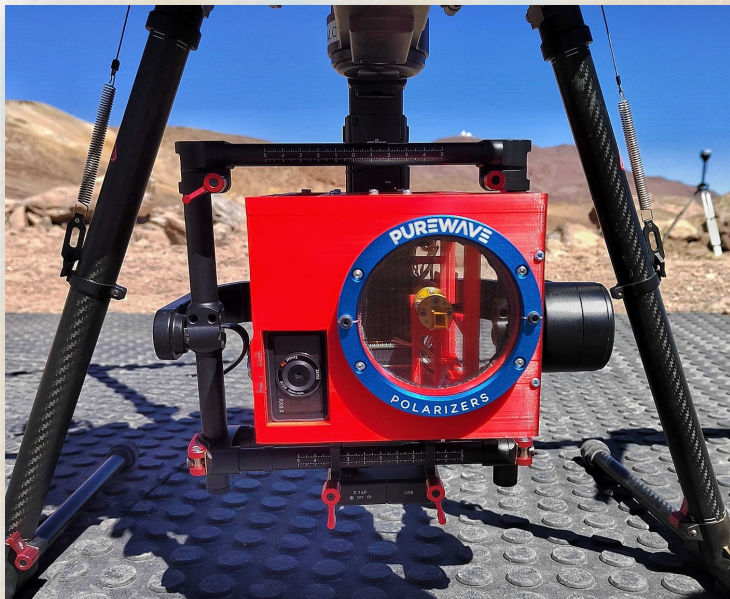


- ✓ Probes the full optical chain
- ✓ Calibrates all the detectors simultaneously
- ✗ In the near-field of the telescopes
- ✗ Must be removed before every science observation

- ✓ In the far-field of the telescopes
- ✓ Sky-referenced polarized source
- ✓ Probes the full optical chain
- ✓ Accuracy better than  $0.01^\circ$
- ▷ MAIN CHALLENGE: characterize the source

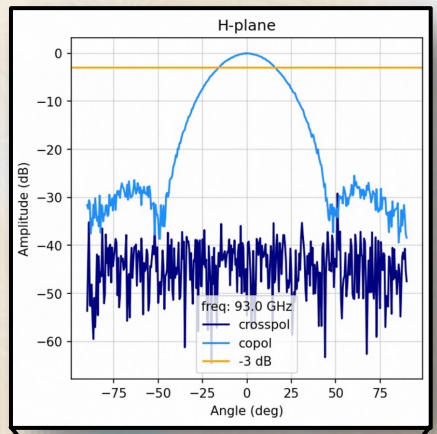
# SOURCE CHARACTERIZATION

Precisely measure the polarized emission of the millimetre-wave source



Beam pattern measurements in the anechoic chamber

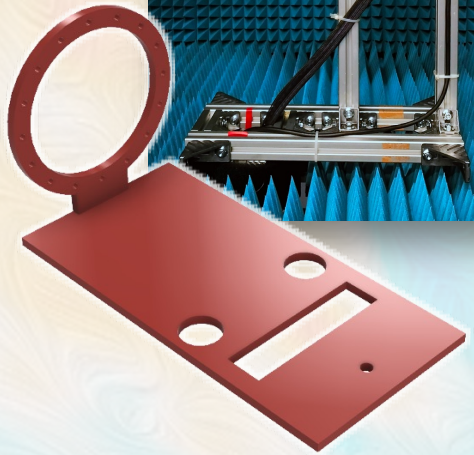
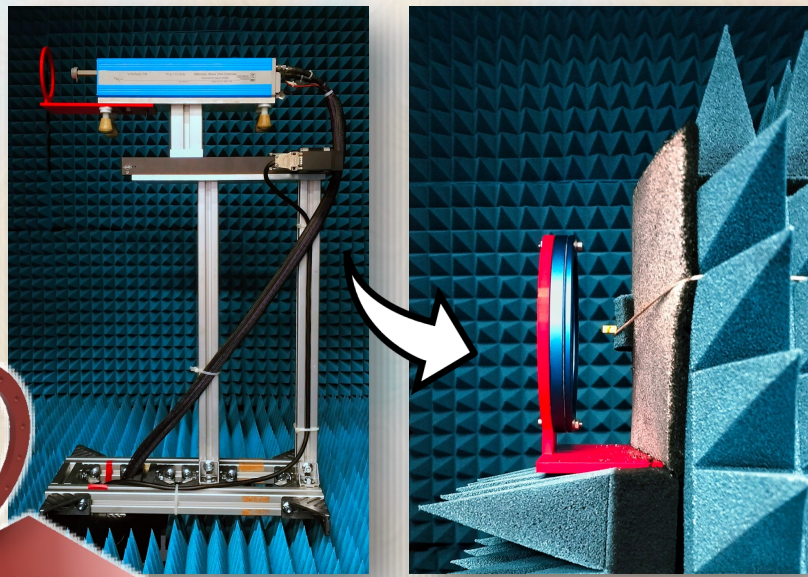
- emitted power
- polarization orientation



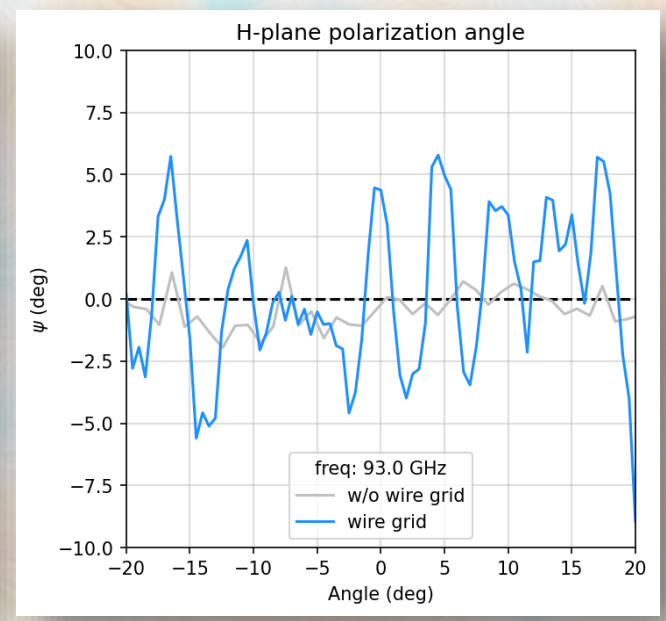
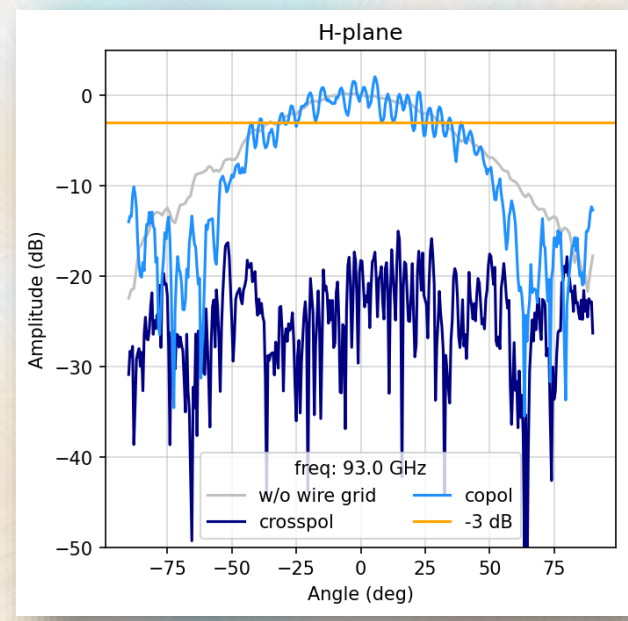
REQUIREMENTS: { stable power  
constant polarization direction

# INVESTIGATING WIRE GRID TRANSMISSION

I need to include the wire grid polarizer in the measurements



the amplitude shows ripples of up to 5dB, on top of the gaussian beam

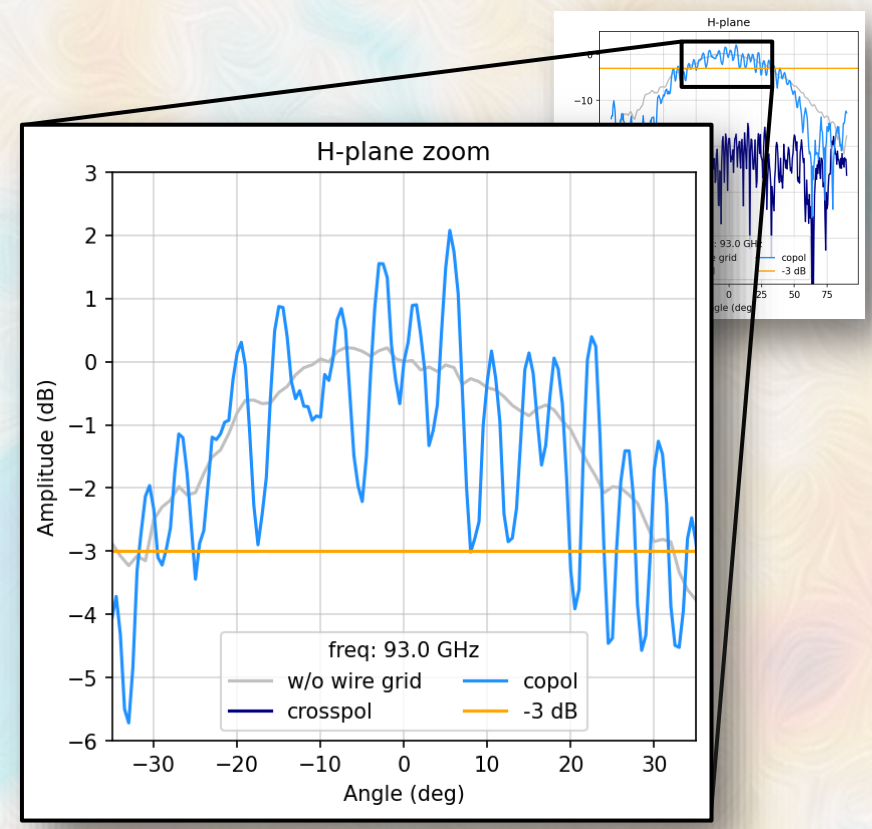
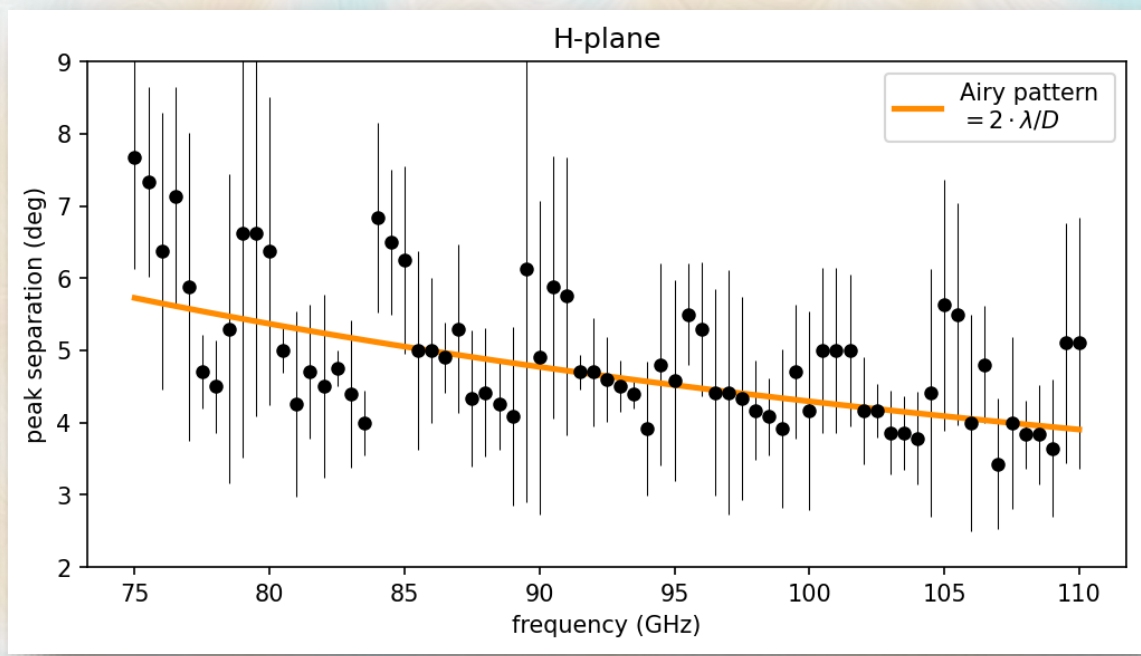


the polarization angle exhibits fluctuations exceeding 10°

# INVESTIGATING WIRE GRID TRANSMISSION

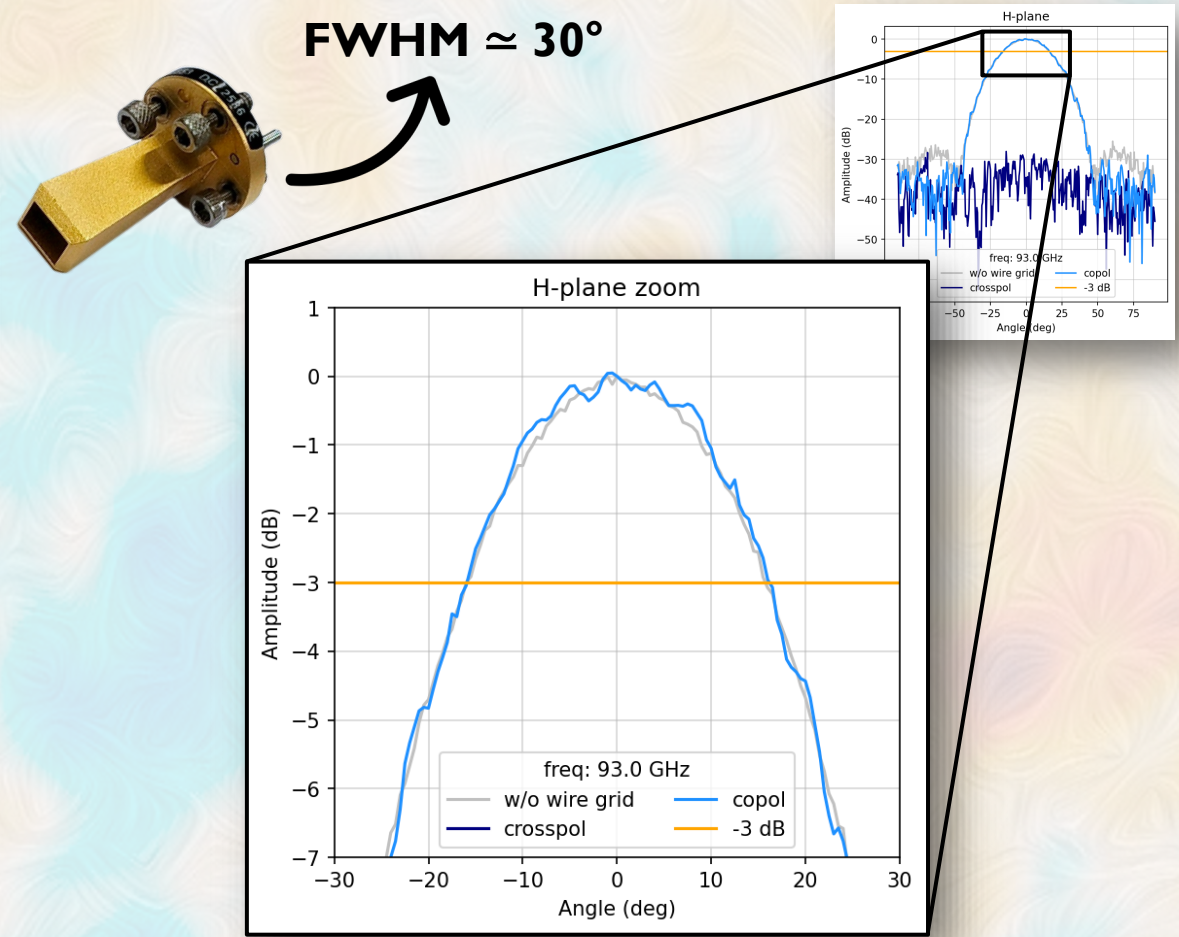
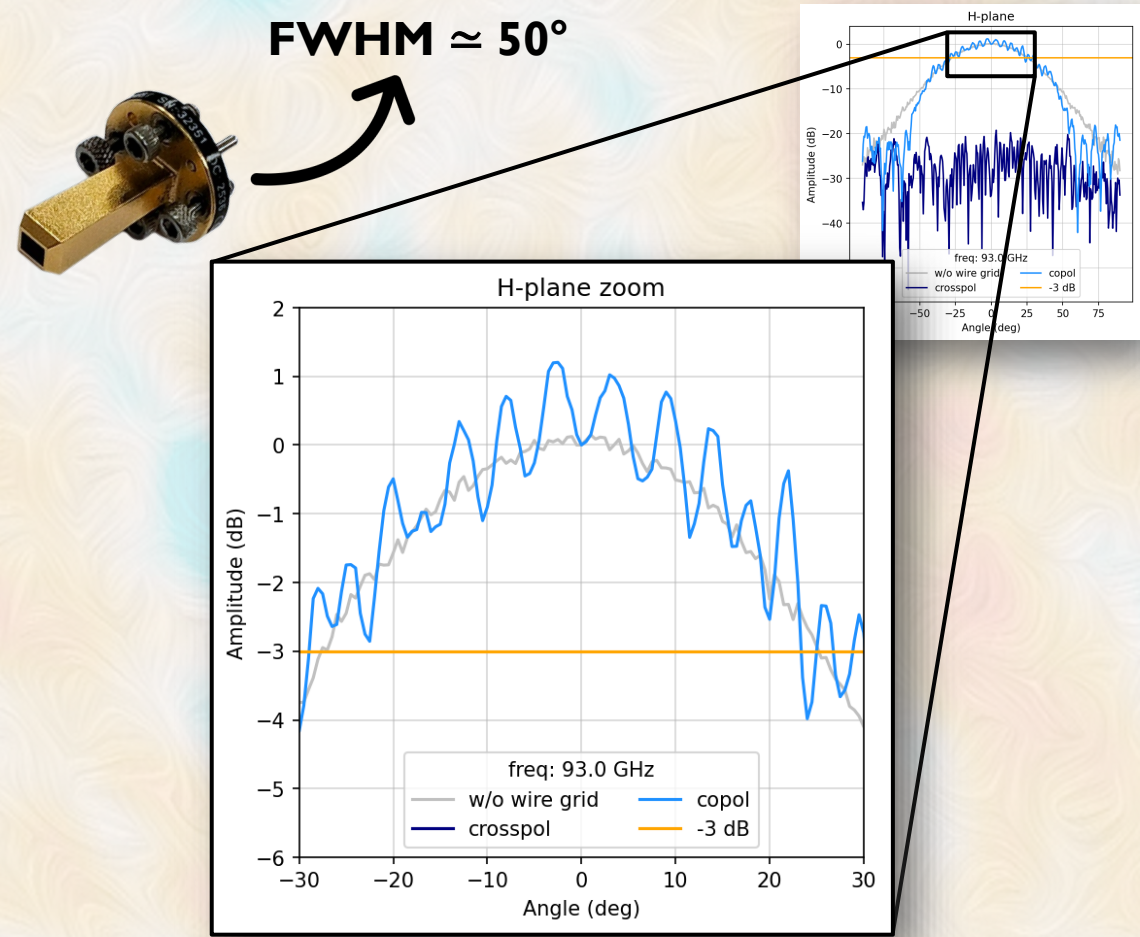
## Diffraction through a circular aperture

$$\text{Airy pattern: } \sin(\alpha) = n_m \frac{\lambda}{D}$$



Ripples prevent precise knowledge of both the illumination power and the polarization angle at the telescope

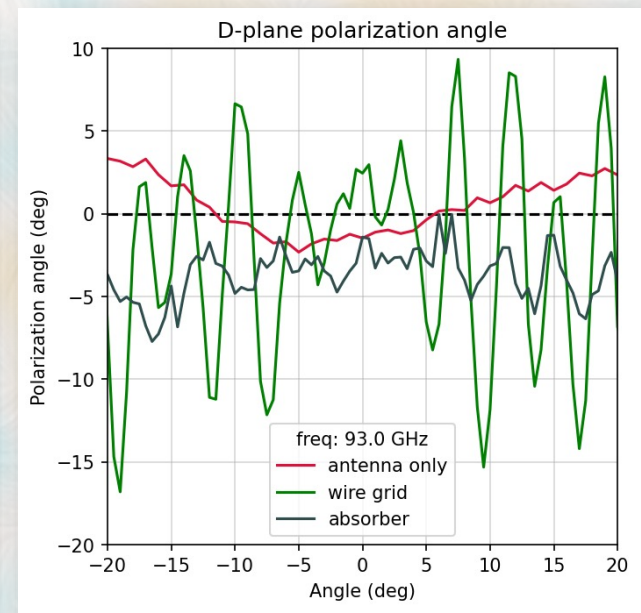
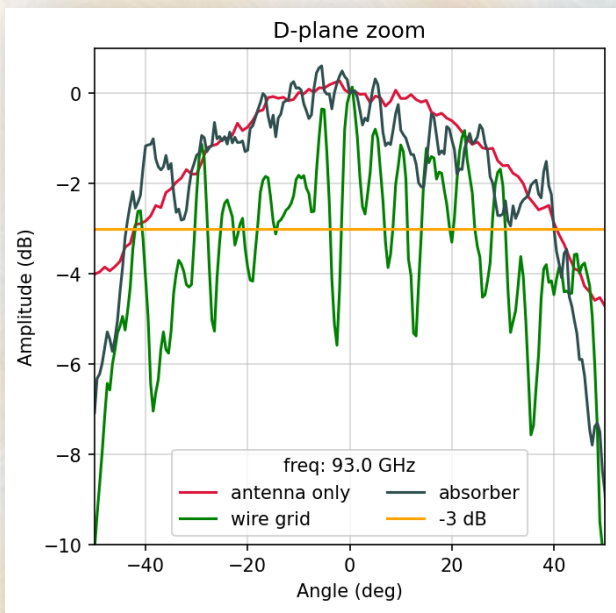
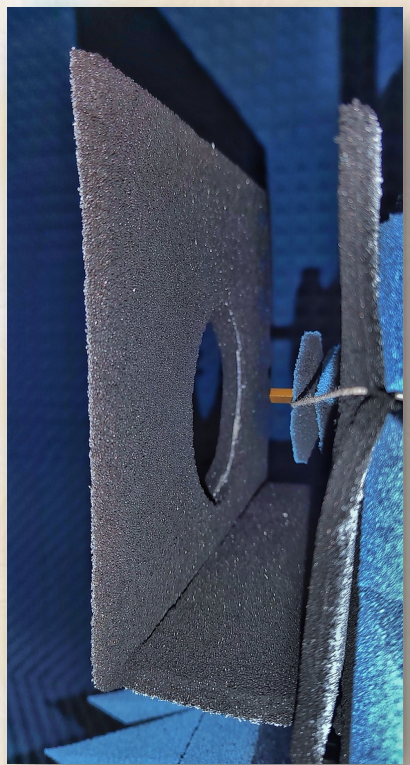
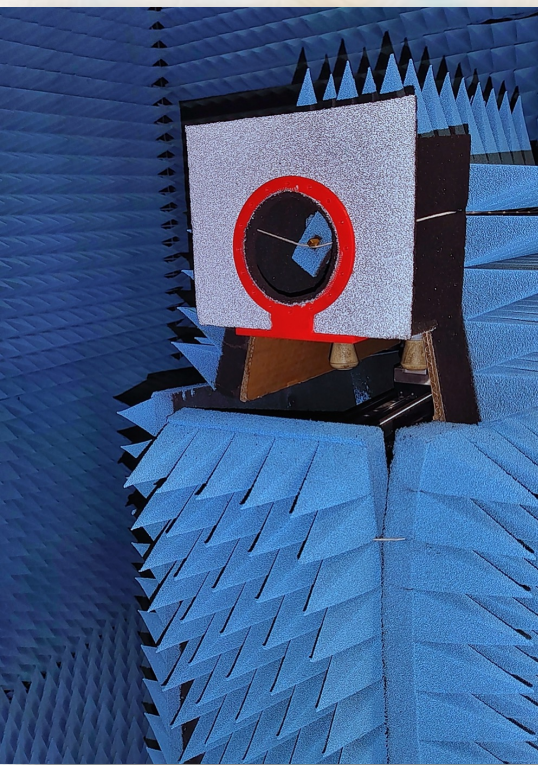
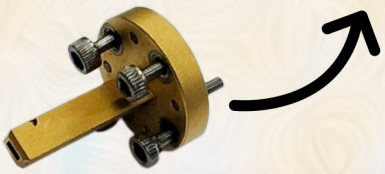
# NARROWER BEAM ANTENNAS



narrower antenna main beam  $\Rightarrow$  lower power illuminating the aperture edge  $\Rightarrow$  smaller ripple amplitude

# ABSORBING MATERIAL SHIELDING

FWHM  $\in$  [60°; 100°]



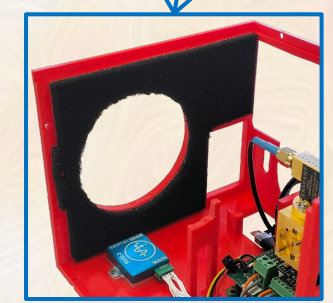
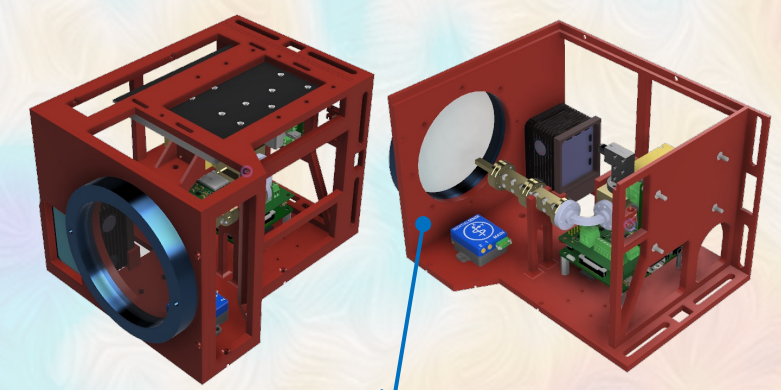
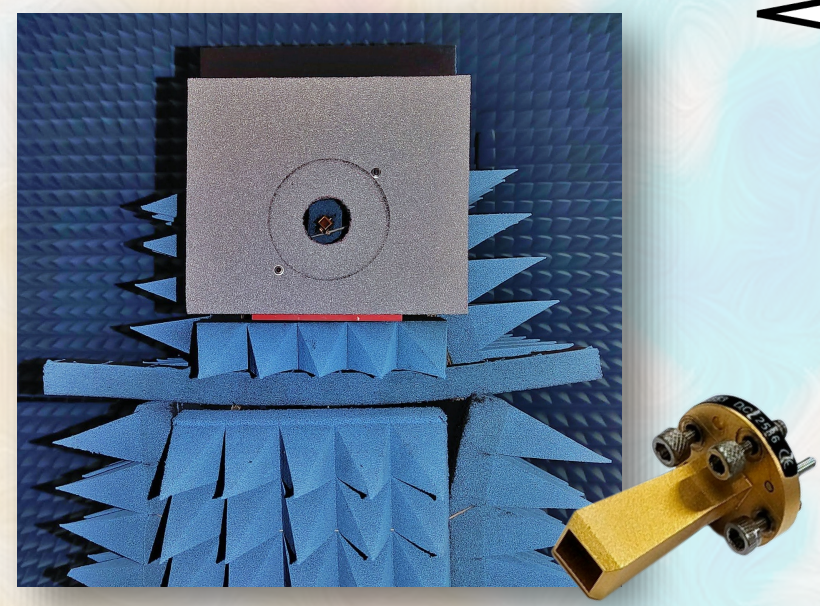
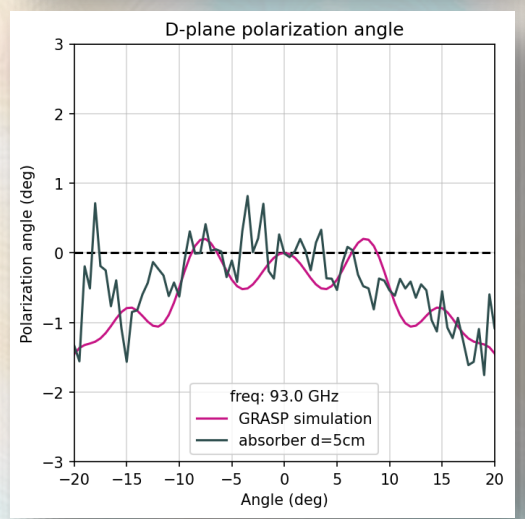
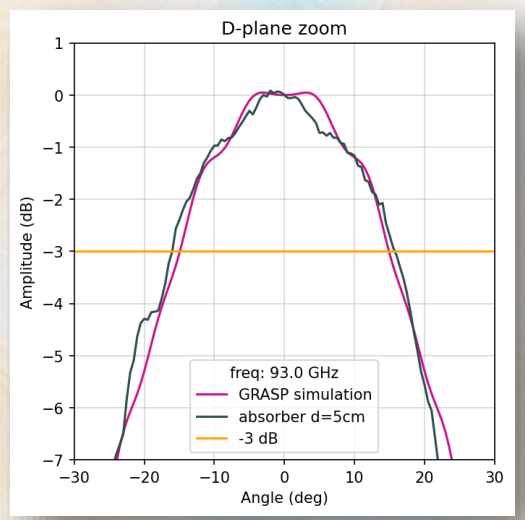
ripple amplitude: ~5dB  $\rightarrow$  < 1dB  
 polarization angle variation: 15°  $\rightarrow$  5°

Shielding with absorbing material is an effective strategy

# POLOCALC IMPROVEMENTS

**Optimal strategy:**  
combine a narrow-beam  
antenna with absorbing  
material shielding

Informed improvements in  
the POLOCALC payload



# CONCLUSIONS

- **Polarization angle calibration** is the **dominant systematic** on the path to primordial B-mode detection
- No single calibration strategy is self-sufficient: self-calibration, celestial sources, and hardware solutions each present distinct advantages and limitations that make them complementary rather than interchangeable
- **Drone-borne polarized sources** represent the most promising emerging technique, but a thorough characterization of their systematics is required before they can serve as reliable calibrators
- The characterization of POLOCALC - identifying **diffraction** at the polarizer aperture and **wide-beam illumination** as the dominant systematics sources - led to **targeted mitigation strategies** that significantly reduced beam distortions, advancing the system toward a robust, high-precision calibration tool for next-generation CMB polarization experiments



**THANK YOU FOR YOUR ATTENTION!**