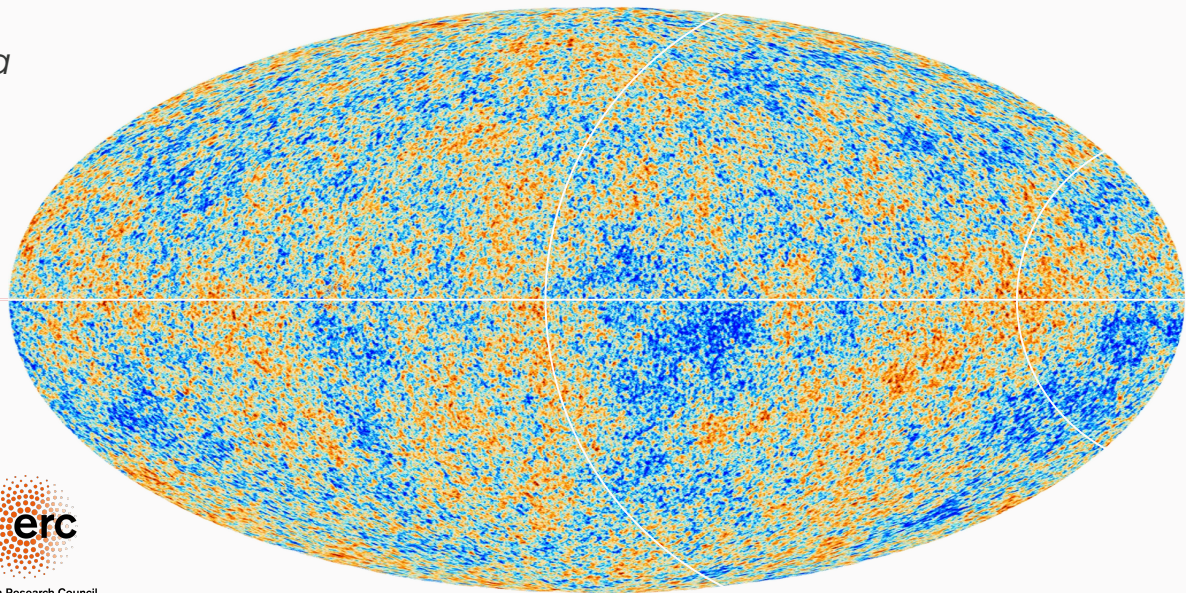


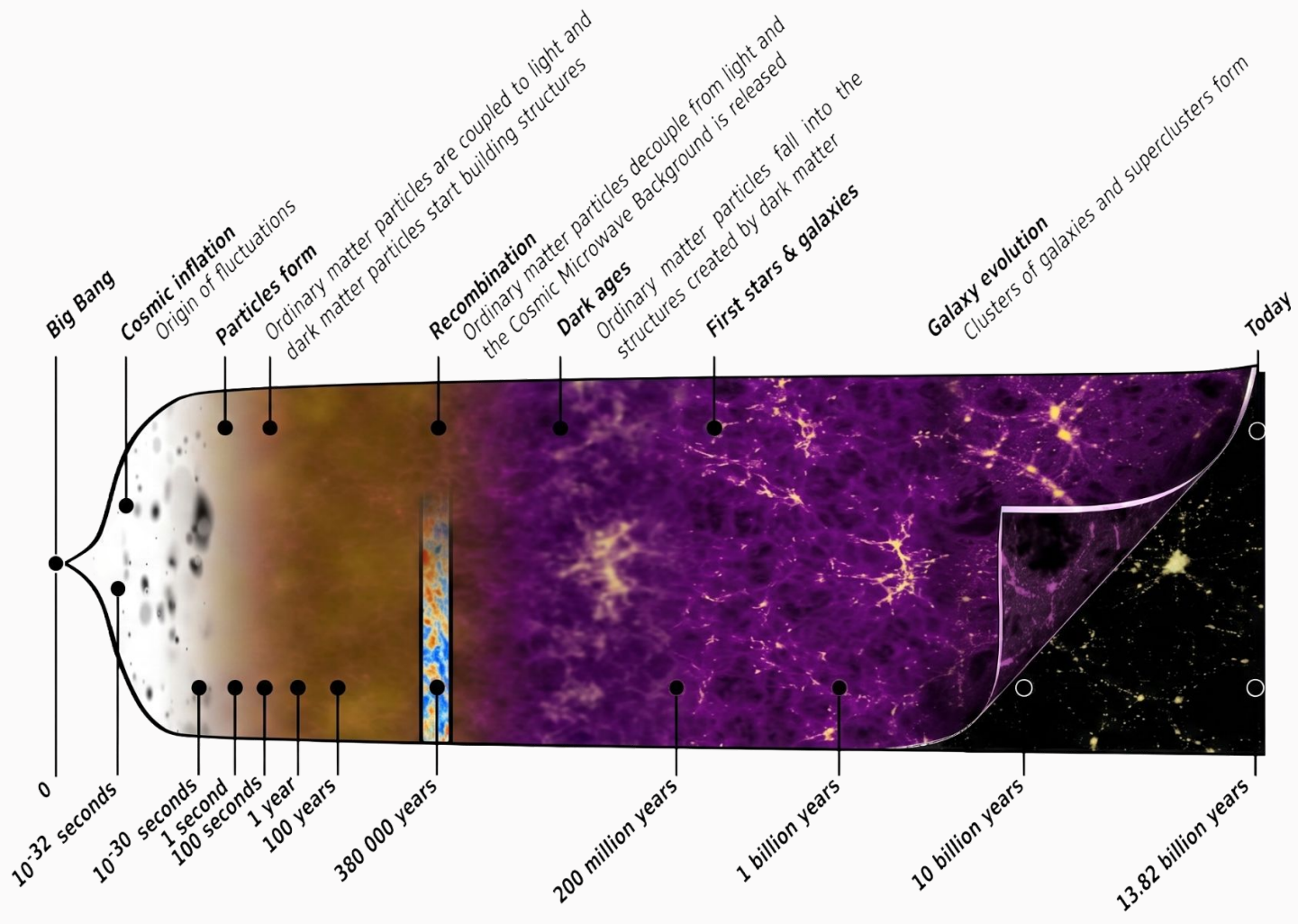
Calibration of Small-Aperture Telescopes for Cosmic Microwave Background with the POLOCALC drone-based artificial source

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Milano, 16/06/2026



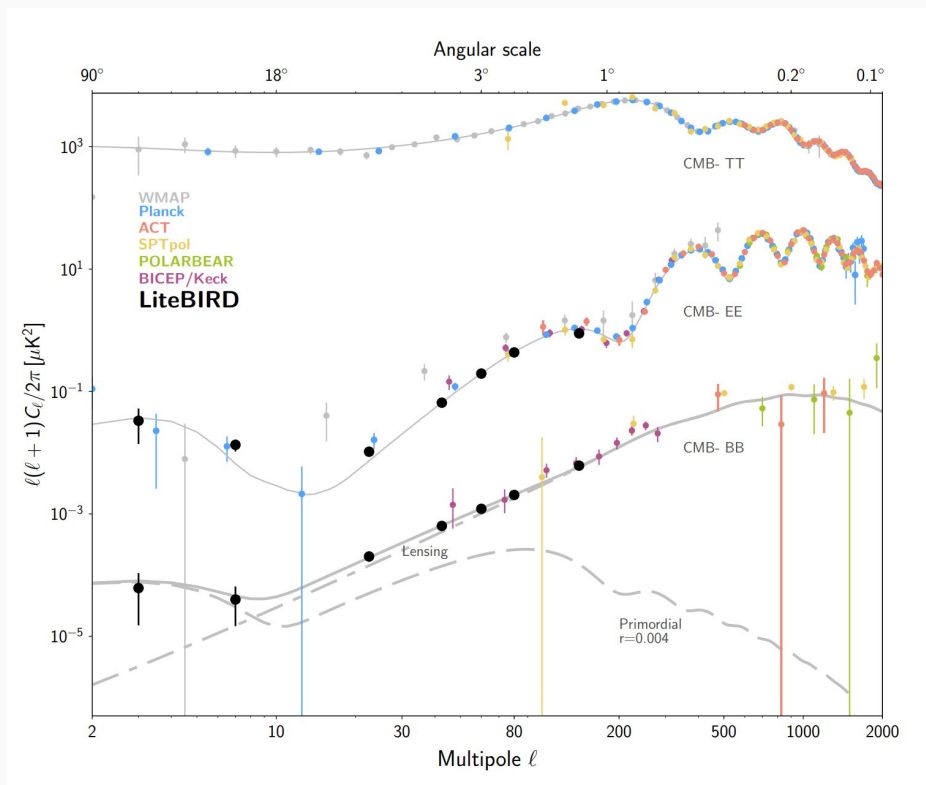




Outline

- 01 Introduction
- 02 Scientific Goals
- 03 Importance of Calibration
- 04 POLOCALC
- 05 POLOCALC Results
- 06 Conclusions

Next Generation Scientific Goal

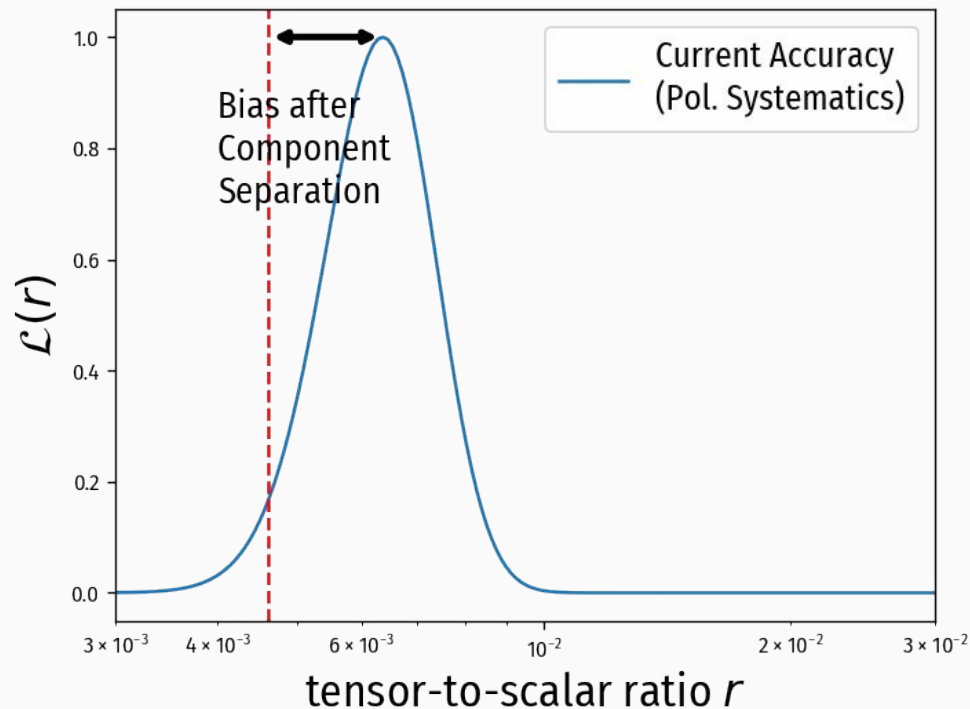


LiteBIRD 2022

CMB Science

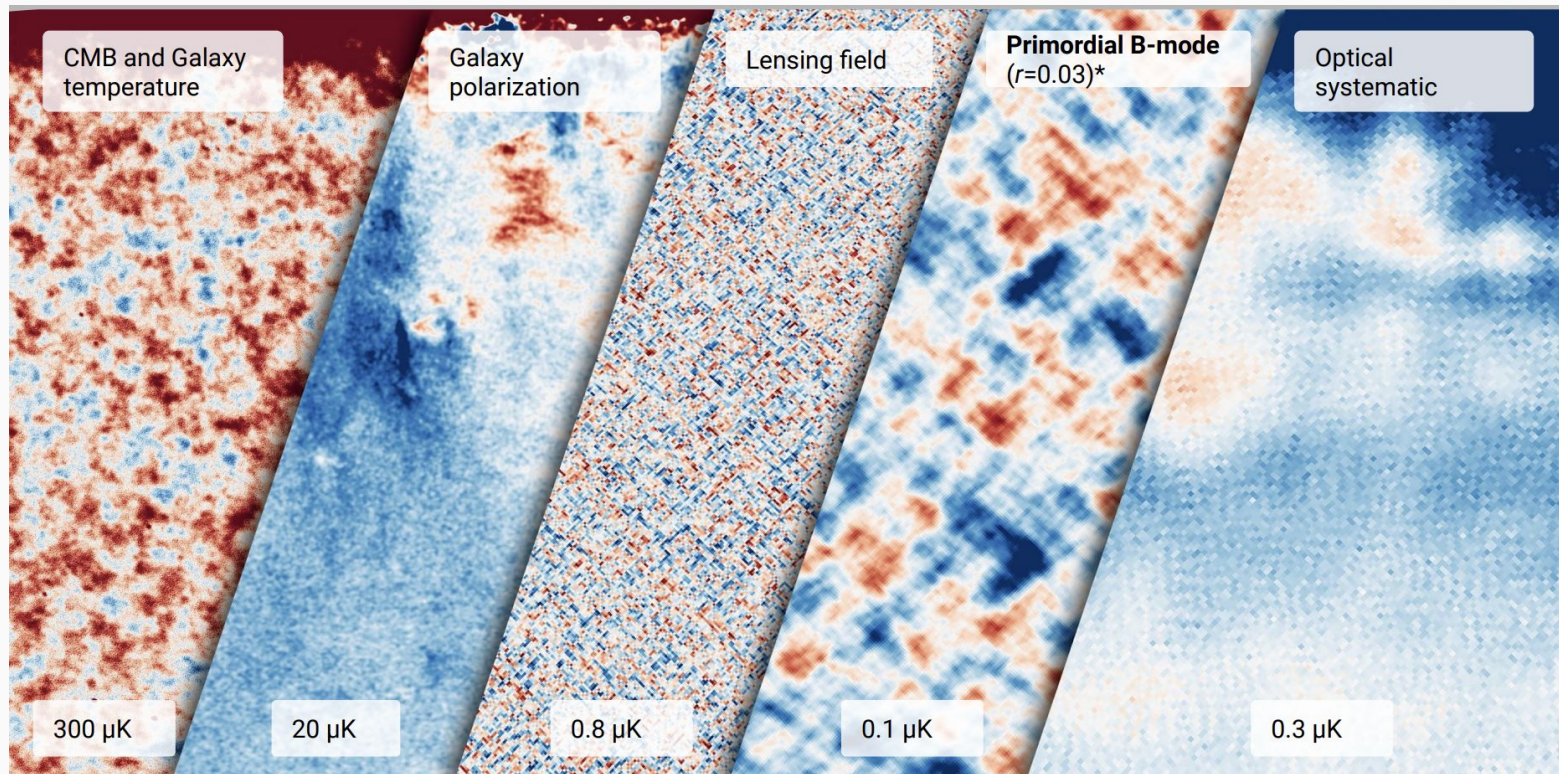
- Temperature: Done in the nineties
- Polarization:
 - E-modes: done in 2002 (DASI)
 - B-modes:
 - Lensing: Done in 2013 (SPT and PolarBEAR)
 - Primordial: **Missing**
- B-modes signal is significantly lower than any other CMB signal

Importance of Calibration: Polarization



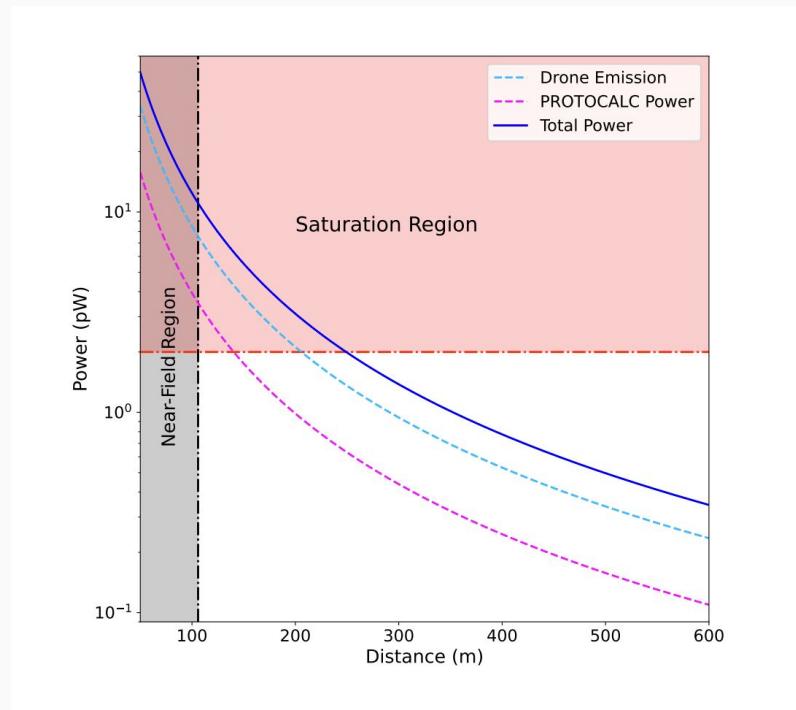
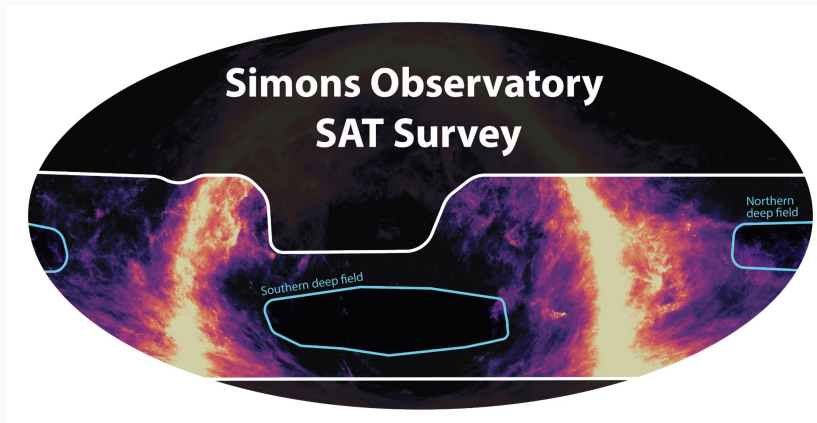
- For B-modes science, absolute polarization required is less than 0.1 deg
- Tau-A is known (sort-of) at a level of 0.27 deg
- Mis-calibration introduces biases

Importance of Calibration

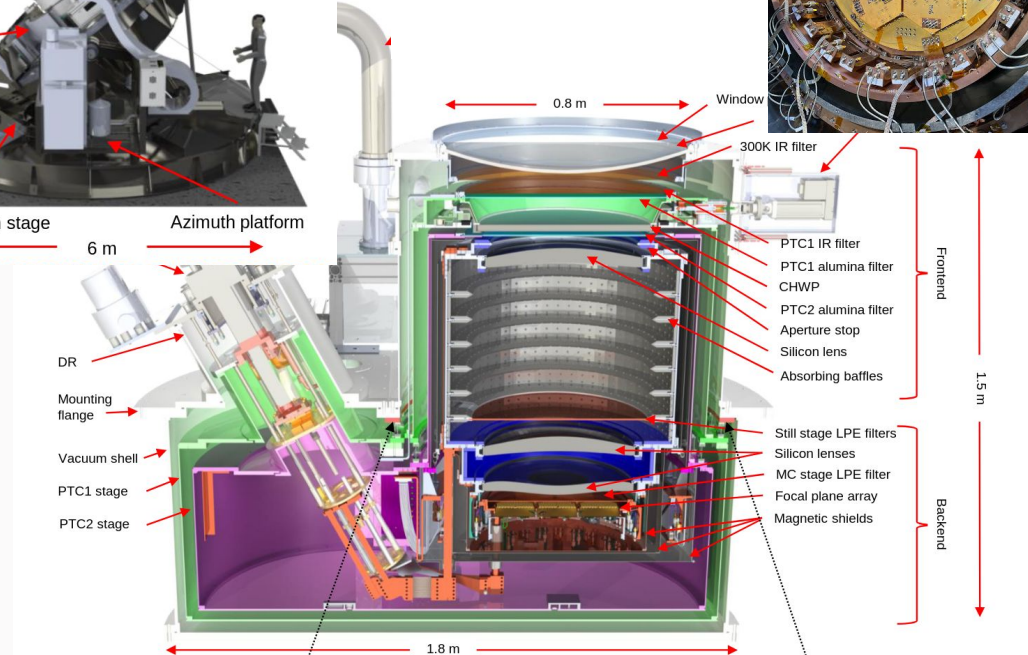
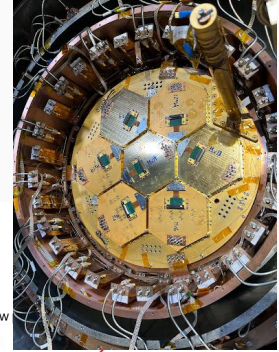
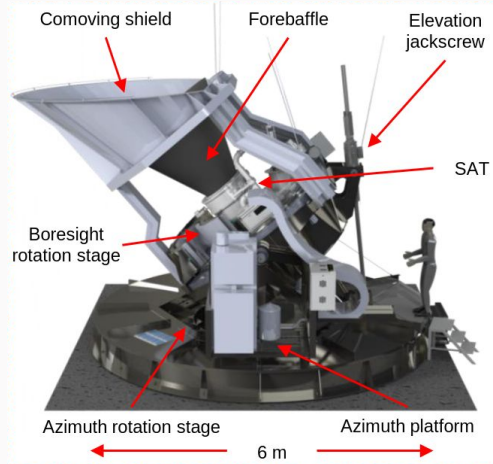
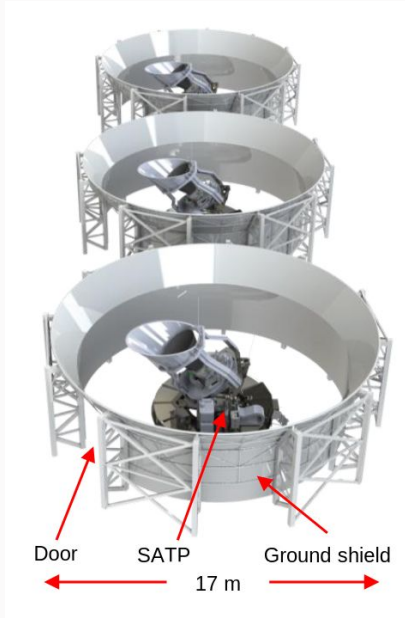


Why Small Aperture? And what is a small aperture?

- Small aperture Telescopes are ~50 cm aperture telescopes
- Optimized for angular scales of the B-modes signal
- Convenient for calibration (far-field is close)



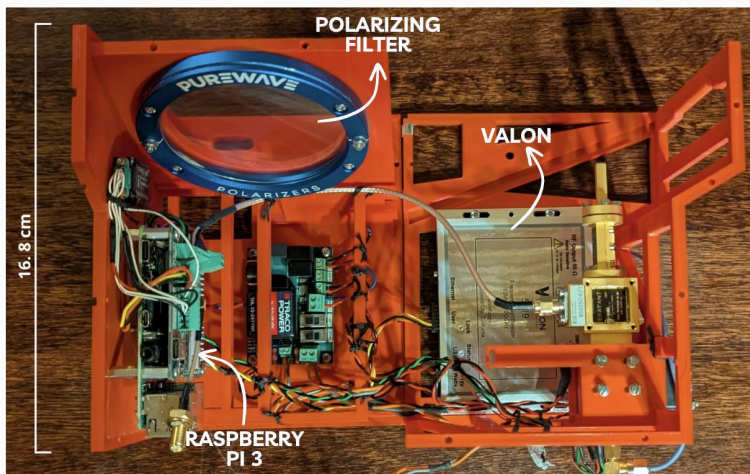
Small Aperture Telescopes



- 45cm Refractor Telescopes
- 100mK Camera
- 7 separate Focal Plane Modules
- Co-added P depth 1.3 $\mu\text{K-arcmin}$ (0.9 $\mu\text{K-arcmin}$ goal)

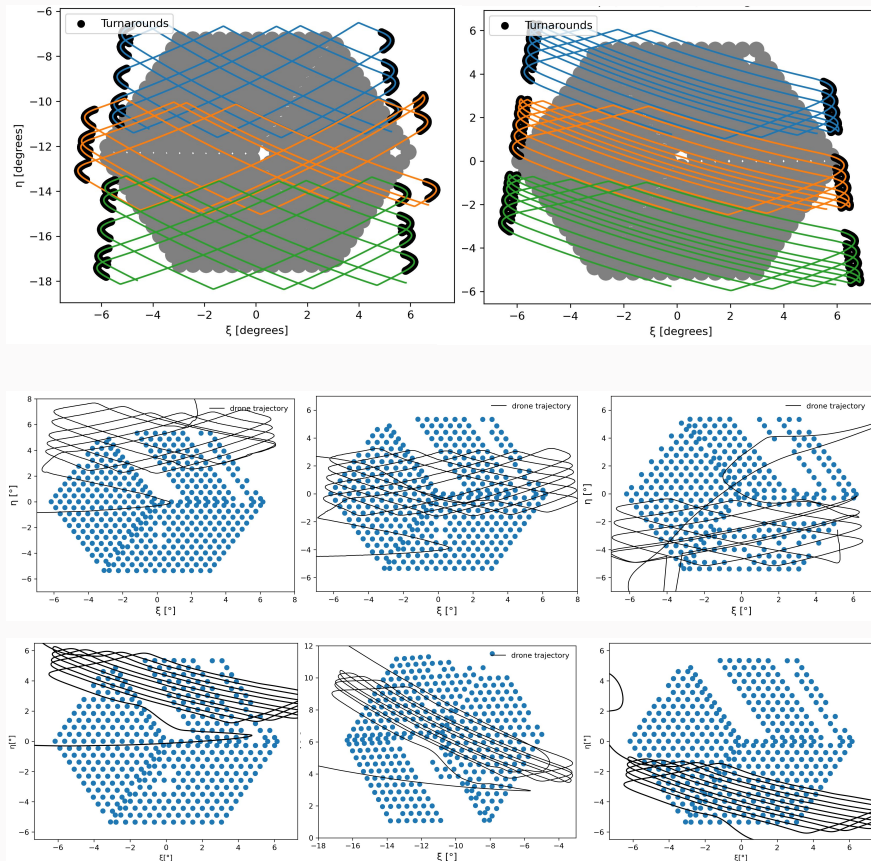
Drone Calibration: POLOCALC

- Monochromatic Artificial Calibrator
 - Cover all the SO calibration bands
- Target Accuracy < 0.1 deg
- Developed with a Marie-Curie and then an ERC

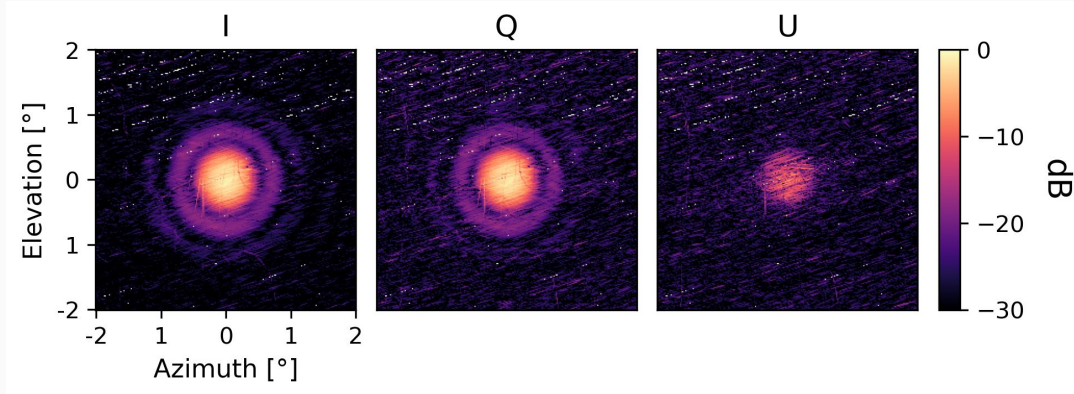


POLOCALC Campaigns

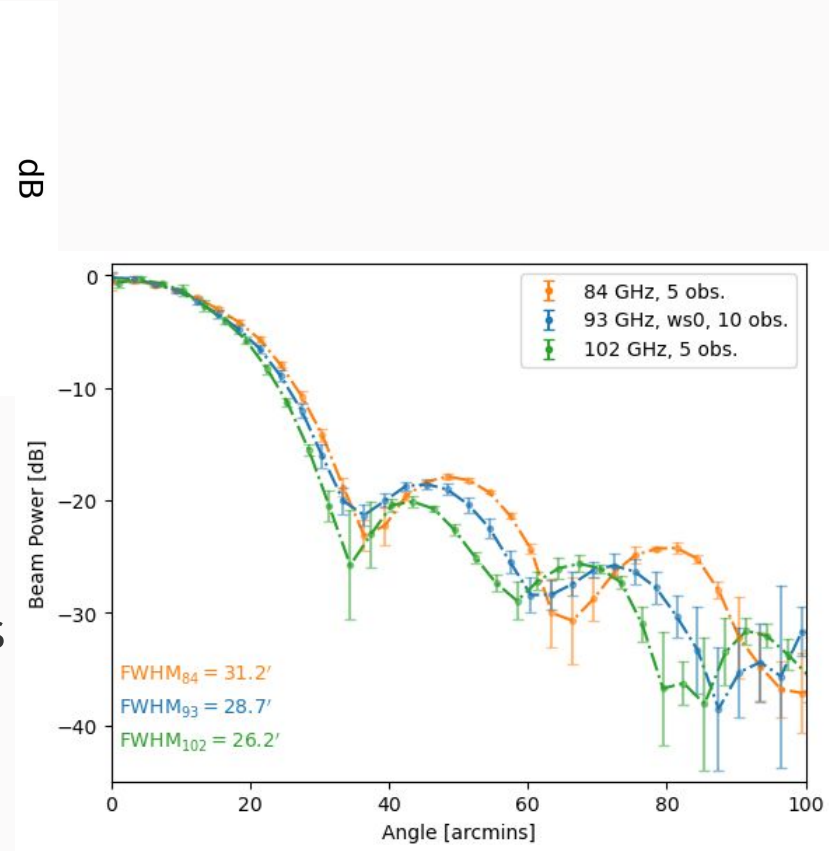
- 6 Calibration campaigns (starting in 2022 and looking at CLASS also)
- Typical flight is ~12 min (7min on target)
- Focus on focal plane subsets
- 350m from the ground
- Contemporary observations of multiple SATs and CLASS
- Specific flight for sidelobe measurements.



POLOCALC Results: Beams



- Higher SNR than Planets
- First calibrator to:
 - Polarized beams measurements
 - Chromatic beams



Impact of Chromaticity

Gaussian Foreground

Parameter	Input	Achromatic (A)	Chromatic (C)	$(C - A)/\sigma(A)$
A_{lens}	1	0.94 ± 0.04	0.93 ± 0.04	0.18
r (10^{-3})	0	1.320 ± 2.282	1.369 ± 2.305	0.02
β_d	1.54	1.540 ± 0.009	1.538 ± 0.008	0.17
ε_{ds} (10^{-3})	0	-3.375 ± 34.65	-0.35 ± 32.33	0.09
α_d	-0.16	-0.229 ± 0.035	-0.239 ± 0.031	0.27
A_d	28	27.8 ± 0.9	27.1 ± 0.7	0.77
β_s	-3.0	-2.992 ± 0.051	-2.979 ± 0.051	0.24
α_s	-0.93	-0.918 ± 0.197	-0.920 ± 0.194	0.01
A_s	1.6	1.57 ± 0.14	1.56 ± 0.14	0.06

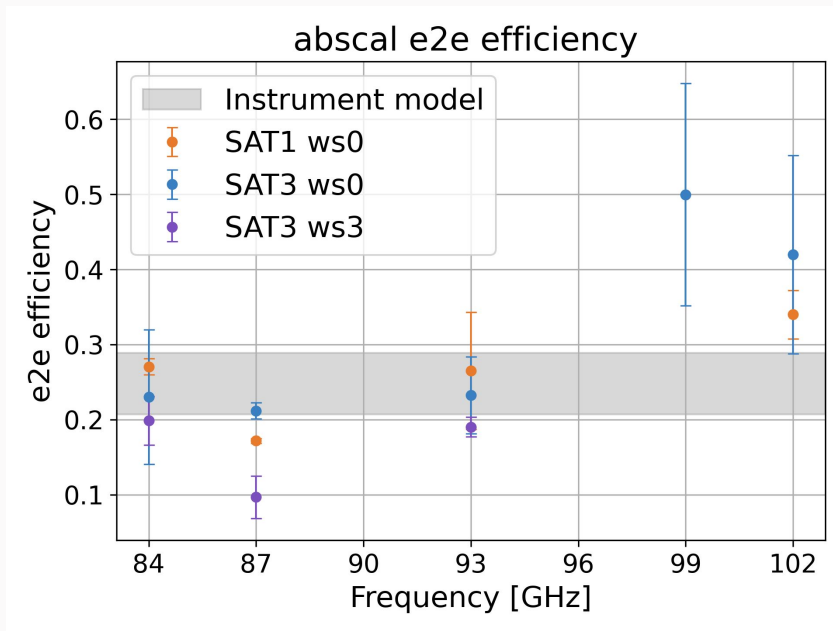
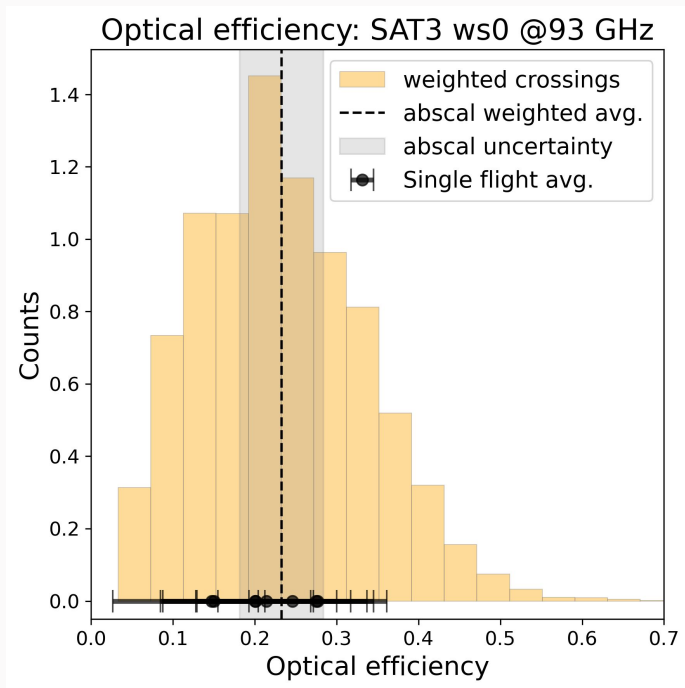
Results from simulations

Non-Gaussian Foreground

Parameter	Input	Achromatic (A)	Chromatic (C)	$(C - A)/\sigma(A)$
A_{lens}	1	0.94 ± 0.04	0.93 ± 0.04	0.14
r (10^{-3})	0	0.916 ± 2.273	0.930 ± 2.283	0.01
β_d	1.54	1.539 ± 0.007	1.539 ± 0.007	0.01
ε_{ds} (10^{-3})	-	35.7 ± 49.5	46.7 ± 46.2	0.22
α_d	-	-0.318 ± 0.036	-0.335 ± 0.033	0.47
A_d	-	34.1 ± 1.1	33.4 ± 1.0	0.53
β_s	-3.0	-3.05 ± 0.09	-3.05 ± 0.09	0.15
α_s	-	-1.579 ± 0.303	-1.597 ± 0.293	0.06
A_s	-	0.63 ± 0.14	0.63 ± 0.14	0.02

POLOCALC Results: Optical Efficiency

- Not only Beams (and future polarization angle)
- Polarization Efficiency at Planet Level

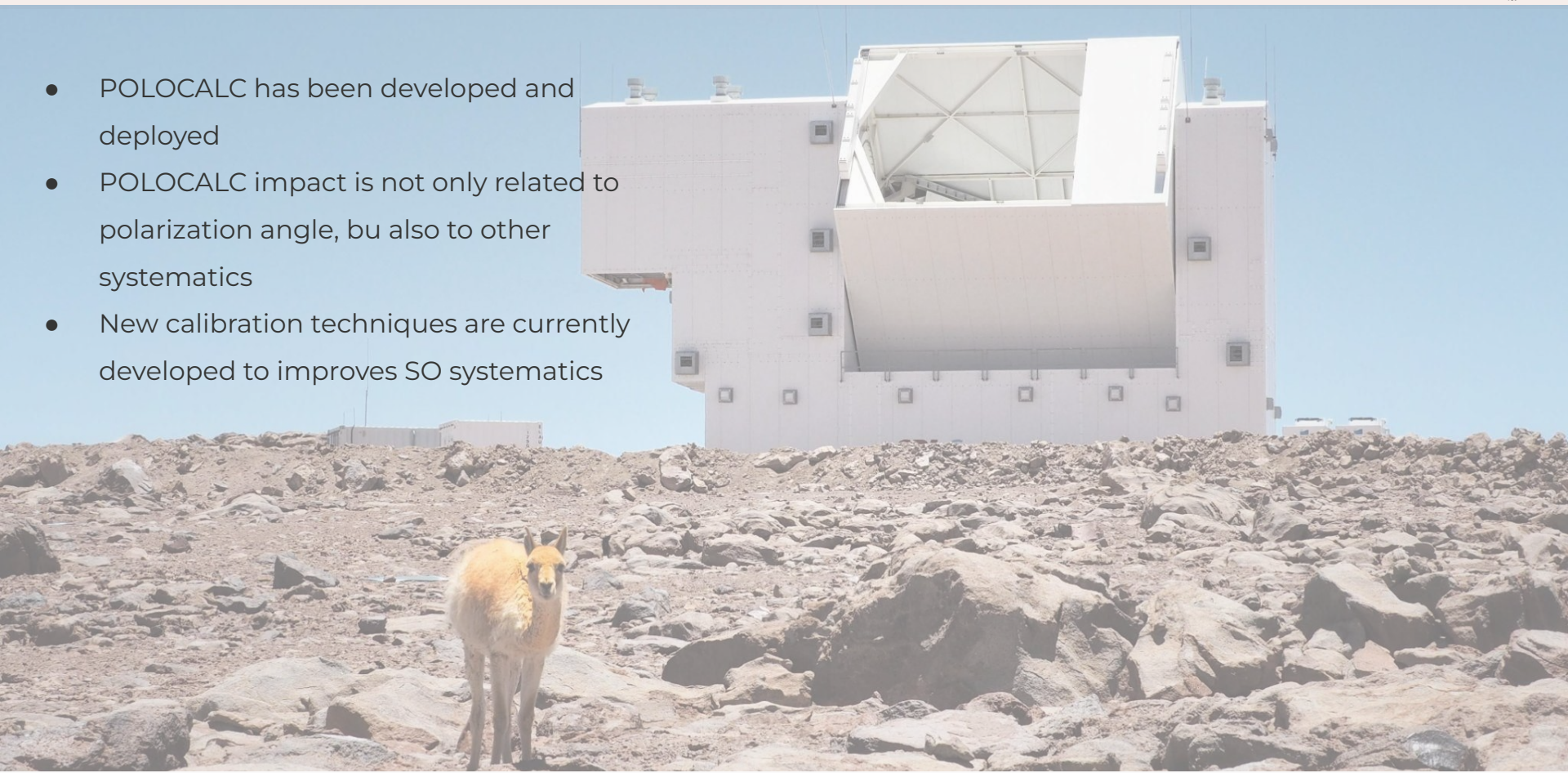


Credits: Ludovico Bizzarri

Conclusions



- POLOCALC has been developed and deployed
- POLOCALC impact is not only related to polarization angle, but also to other systematics
- New calibration techniques are currently developed to improve SO systematics



Thank you!

