Constraining isotropic polarisation rotation with BICEP3

Clara Vergès, James Cornelison & the BICEP/*Keck* collaboration

CMB-S4 Collaboration Meeting - July 31, 2023

Motivation

Parity-violating field interacting with the electromagnetic field
Violation of Lorentz symmetry
Primordial magnetic fields
→ **polarisation rotation angle α**
aka "cosmic birefringence"

Effect integrates over the line-of-sight
→ **the CMB is the best place to look for the signal!**

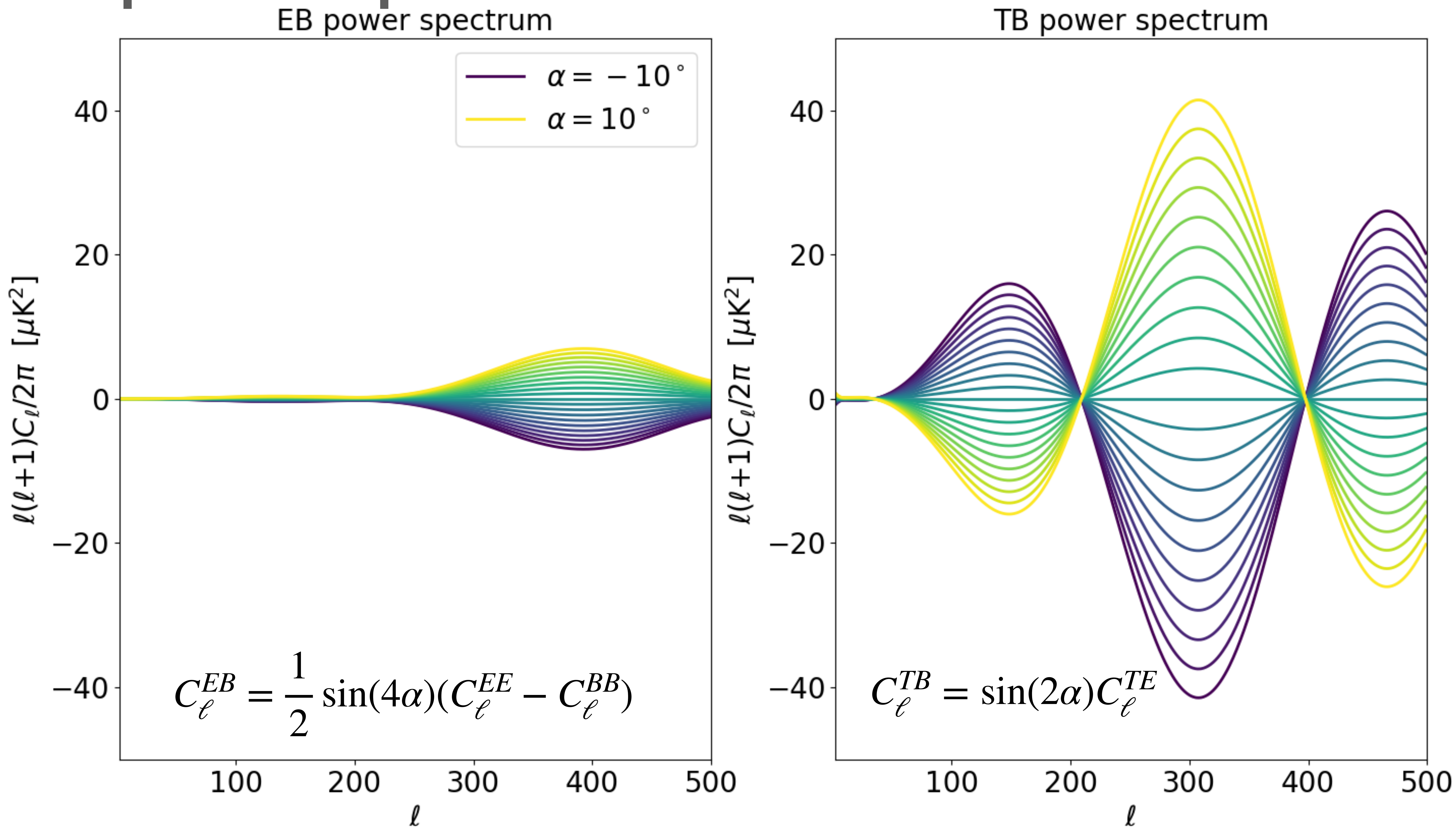
Impact on the CMB

E-modes

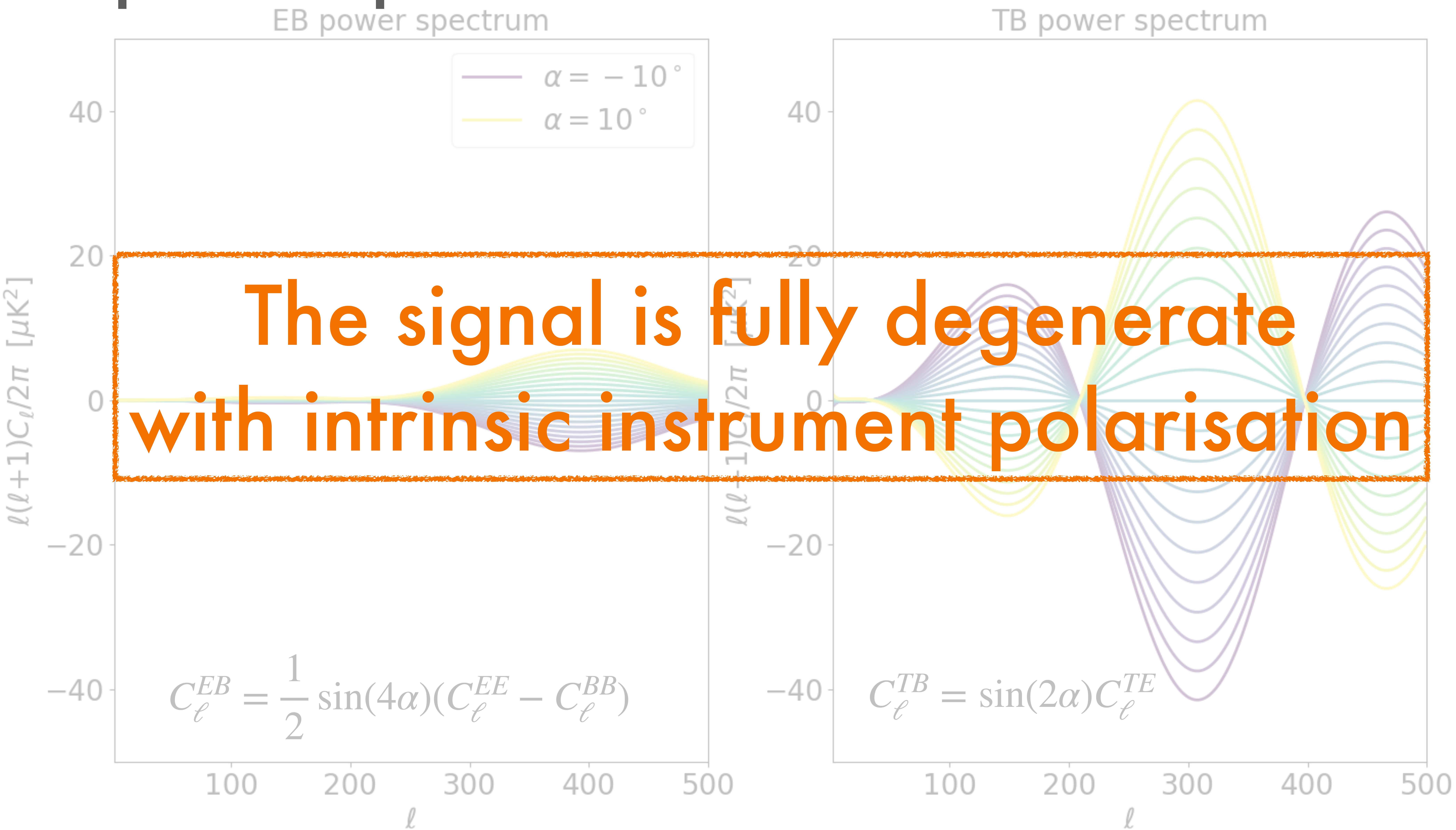
Angle α → **EB & TB signals**

B-modes

CMB power spectrum



CMB power spectrum



The signal is fully degenerate with intrinsic instrument polarisation

State of the art

ACTPol (2020): - 0.07° ± 0.09°
Celestial sources - no absolute reference

Planck/WMAP data (2021/2022): ~ 0.3° ± 0.1°
Assumes model for foreground emission

Our goal: σ(α) < 0.1°
Absolute angle calibration, careful systematics mitigation

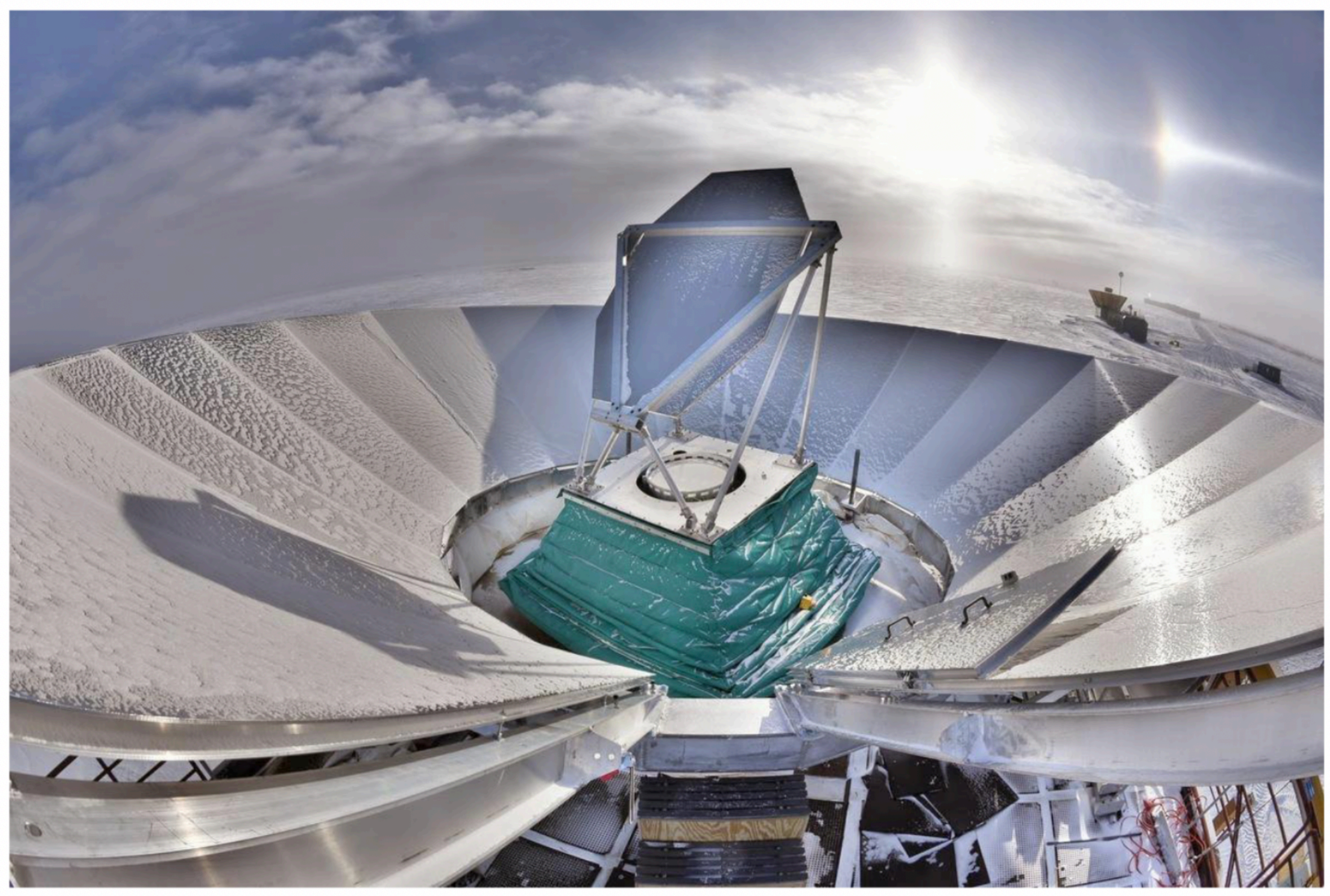
Overview

1. Measure **individual detector polarisation angles** of BICEP3
2. Use these angles in real data + sims to create **data products** that include information about the **telescope intrinsic polarisation**
3. **Fit an angle** to the real data and sims power spectra
4. Compare real data to sims given **error budget σ(α)**
   → Instrumental calibration (statistical and systematic uncertainties)
   → CMB data (noise, lensing, dust, instrumental systematics)

We remain blinded to real data until we finalise the error budget

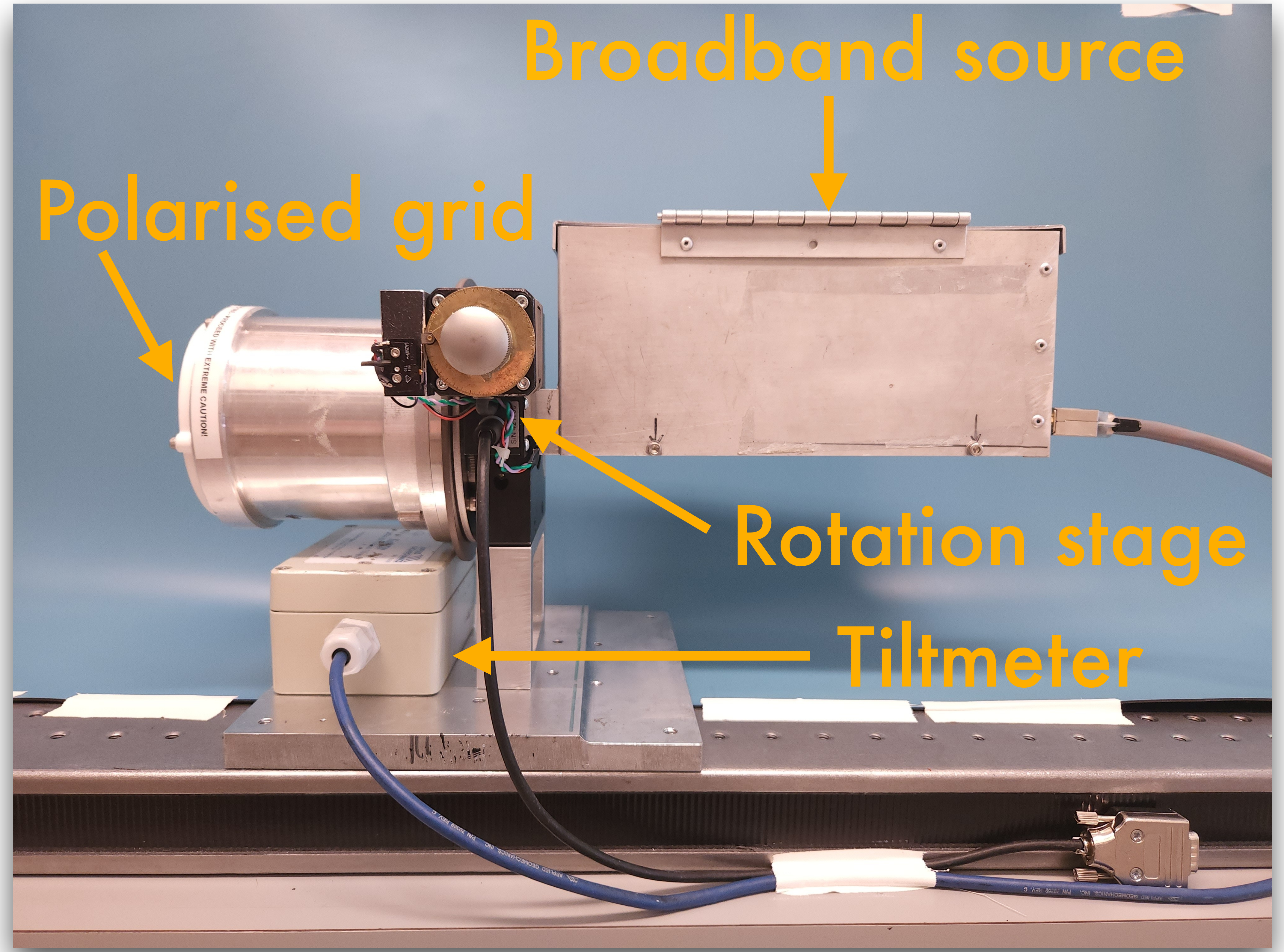
BICEP3

SAT @ South Pole
2400 detectors at 95 GHz
Small & deep sky patch



Calibrating BICEP3

Rotating Polarised Source (RPS)

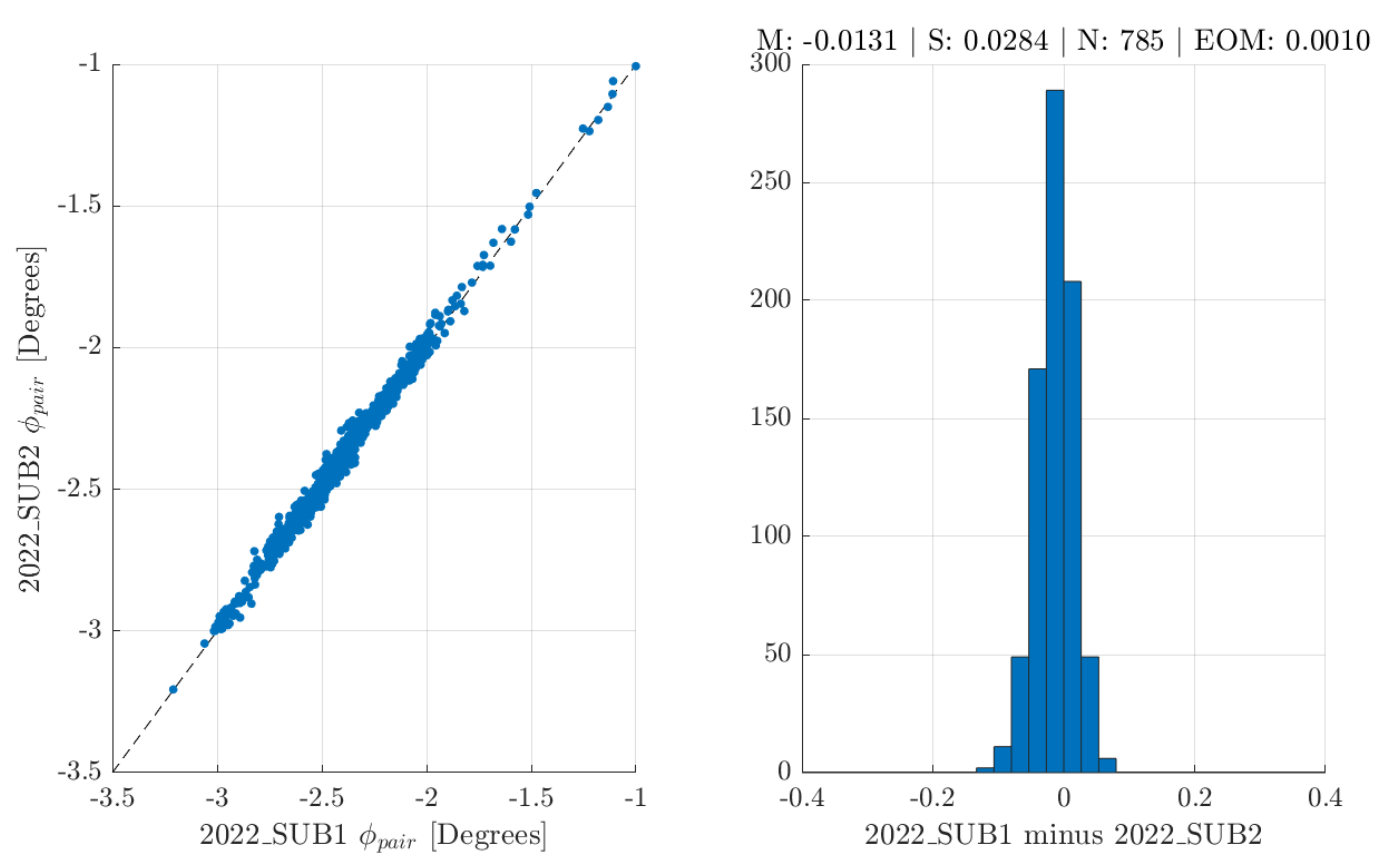


2022 RPS calibration campaign

1-month campaign
390hrs of calibration observation
+ 240hrs of cross-checks & Moon obs.
9 different telescope orientations

Polarisation angle measurements

Measurement statistical uncertainty - **σ(α) = 0.02°**



Measurements systematics

Errors on inputs to the model used to fit calibration data

→**RPS orientation - $\sigma(\alpha) \sim 0.062°$**

Dominated by rotation stage performance + tilt meter calibration

→**Pointing model of the telescope - $\sigma(\alpha) \sim 0.012°$**

Apparent orientation of the focal plane with respect to the RPS

Measurement uncertainties - still under investigation

Dominated by alignment error between the telescope and the RPS

Likely to be $> 0.05°$

Angle estimation

$$\chi^2 = (\hat{\mathscr{C}}_b^{XY} - \mathscr{C}_b^{XY})^t (\mathbf{C}^{XY})^{-1} (\hat{\mathscr{C}}_b^{XY} - \mathscr{C}_b^{XY})$$

Model

Measurement

Covariance matrix
(from simulations)

Signal type

TB does not bring more constraining power in addition to EB → **using EB only**

ℓ range

Using higher ℓ-bins better captures the typical shape of the EB signal
→ ℓ_{max} ~ **500** instead of ℓ_{max} ~ 300 as in other BK analysis

Constraining power of the BICEP3 data set

3.3 μK.arcmin map-depth in polarisation*

Sims that contain...
→ only noise: $\sigma(\alpha) = 0.061°$
→ only lensed-ΛCDM: $\sigma(\alpha) = 0.035°$ (vs unlensed-ΛCDM $\sigma(\alpha) = 0.004°$)
→ **lensed-ΛCDM + noise + Gaussian dust: $\sigma(\alpha) = 0.078°$**

*2-year data set with reduced coverage because we don't have angle measurements on all detectors

Dust

Dust models (Gaussian, MKD, Vansyngel, MHD)
→ no bias and no significant impact on statistical uncertainty

Maximally correlated dust toy model $\mathscr{C}_\ell^{EB} = \sqrt{\mathscr{C}_\ell^{EE} \times \mathscr{C}_\ell^{BB}}$

→ **maximum bias of 0.027°**

Dust B-modes x CMB E-modes
→ **maximum bias of 0.016°**

Additional σ(α) = 0.02° to account for dust contribution

Instrumental systematics

Temperature-to-polarisation leakage from main beam mismatch - $\sigma(\alpha) \sim 0.04°$

Due to T-to-B leakage correlating with TE in the CMB

Beam window function errors - 10% multiplicative error on α

Summary

	Calibration	CMB data
Statistical uncertainty	0.02°	**0.078°**
Systematic uncertainty	**> 0.08°**	0.045°

How to address the biggest contributions to the error budget?

1. Understand alignement error, improve hardware performance
2. Use more data, delens
   BICEP3 6-year data set ~1.9 μK.arcmin

Conclusion

→ Highest precision to date in measuring polarisation angles for a CMB experiment
→ Detailed breakdown of the uncertainty budget for BICEP3 2-year data set
→ All cross-checks and jackknives passed on real data splits

Future prospects
→Provide reference for cross-calibration of other CMB telescopes
→Extend the framework to include multi-frequency information