Beam mode

Simulating optical systematics for CMB experiments

Alexandre Adler, Stockholm University

The CMB, *B*-modes, inflation

The CMB constraints ΛCDM

Key tool: two-point correlation function/power spectrum

Partially polarised: E and B modes

Primordial gravitational waves from inflation create tensor perturbations

Largest as a fraction in the BB spectrum

Summary

- For CMB experiments, a detailed understanding of the optical response is becoming crucial.
- We need better beam models and a way to propagate the beam systematics to simulated TOD, maps, spectra...
- Using *beamconv*, we can simulate timestreams with complex beam models, non-ideal polarisation modulators, and ground pickup!

Repository:
https://github.com/AdriJD/beamconv

Papers:
1809.05034, 2012.10437, 2012.07613

The future of CMB experiments

Under construction

SIMONS OBSERVATORY

PARQUE ASTRONÓMICO ATACAMA, CHILE

ELEVATION: 5190m

22°57' S, 67°47' W

www.simonsobservatory.org

In development

CMB-S4

Next Generation CMB Experiment

In development

LiteBIRD

Noise and systematics

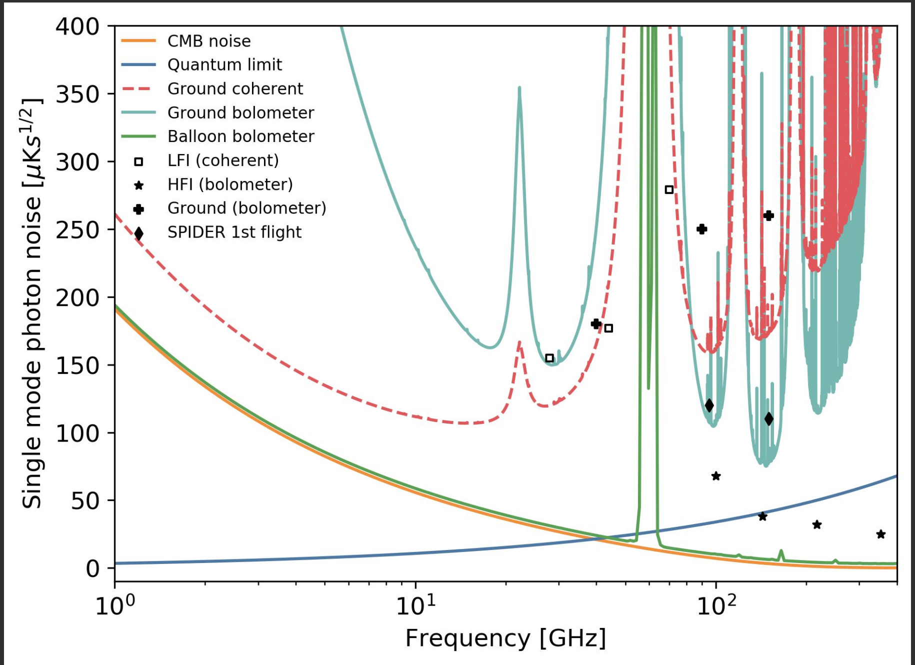
Noise can be lowered by increasing integration time and the number of detectors.

Systematics need to be modelled/controlled/subtracted.

E.g. Absolute calibration, detector thermal drift, pointing accuracy...

"Indeed, only toward the end of the *Planck* mission period did it become evident that the single most limiting factor for the overall analysis was neither instrumental systematics nor astrophysical foregrounds as such, but rather the interplay between the two."

-Beyond Planck I, 2020 (2011.05609)

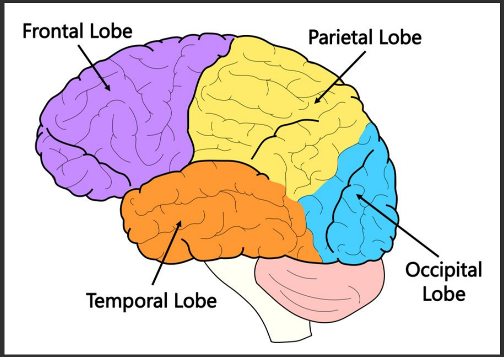


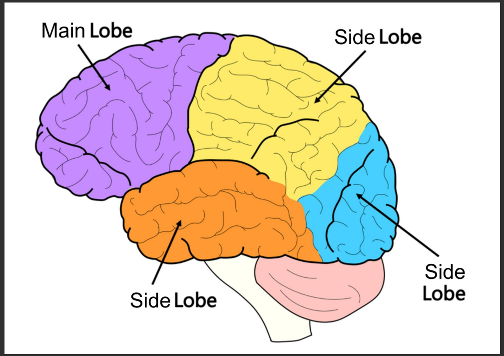
Gudmundsson, adapted from Hanany, Niemack and Page, 2012 (1206.2402)

Beams

Beam = PSF

Normal person:



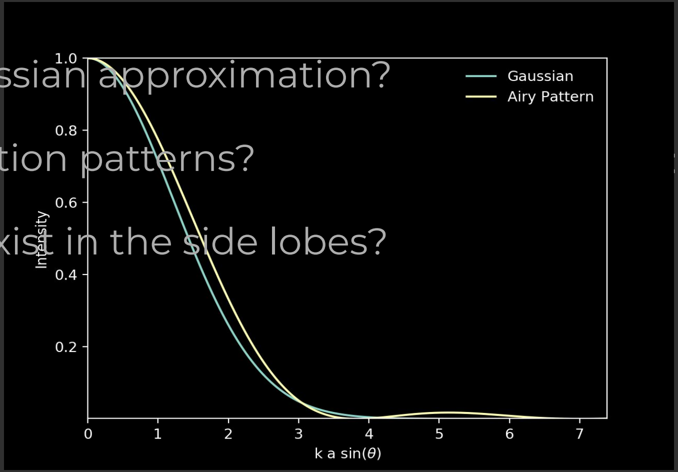


How appropriate is the Gaussian approximation?

What are the diffraction patterns?

What significant features exist in the side lobes?

Source: Wikimedia Commons



Systematic example: diffraction by a ground screen

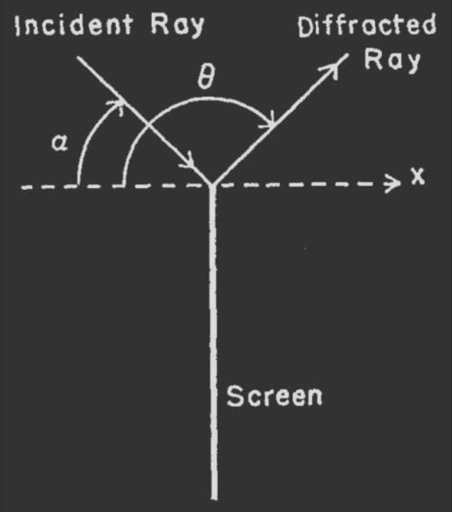
Alexandre
Adler (me)

Jon
Gudmundsson

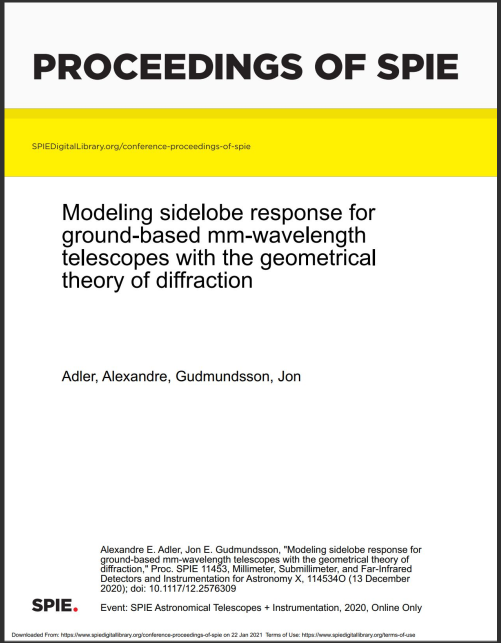
Credit: Bicep/Keck collaboration

Simulating diffraction by a ground screen

- Costly to model using physical optics (PO), un-modelable with geometrical optics (GO)
- Extend GO with rules for diffraction: the Geometrical Theory of Diffraction (GTD)!
- Create new rays at each diffraction, add up all rays going through a point in the far field.
- An old idea (Sommerfeld (1896); Keller (1962)), made more practical with more computing power.



Using GTD on an example telescope



PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Modeling sidelobe response for ground-based mm-wavelength telescopes with the geometrical theory of diffraction

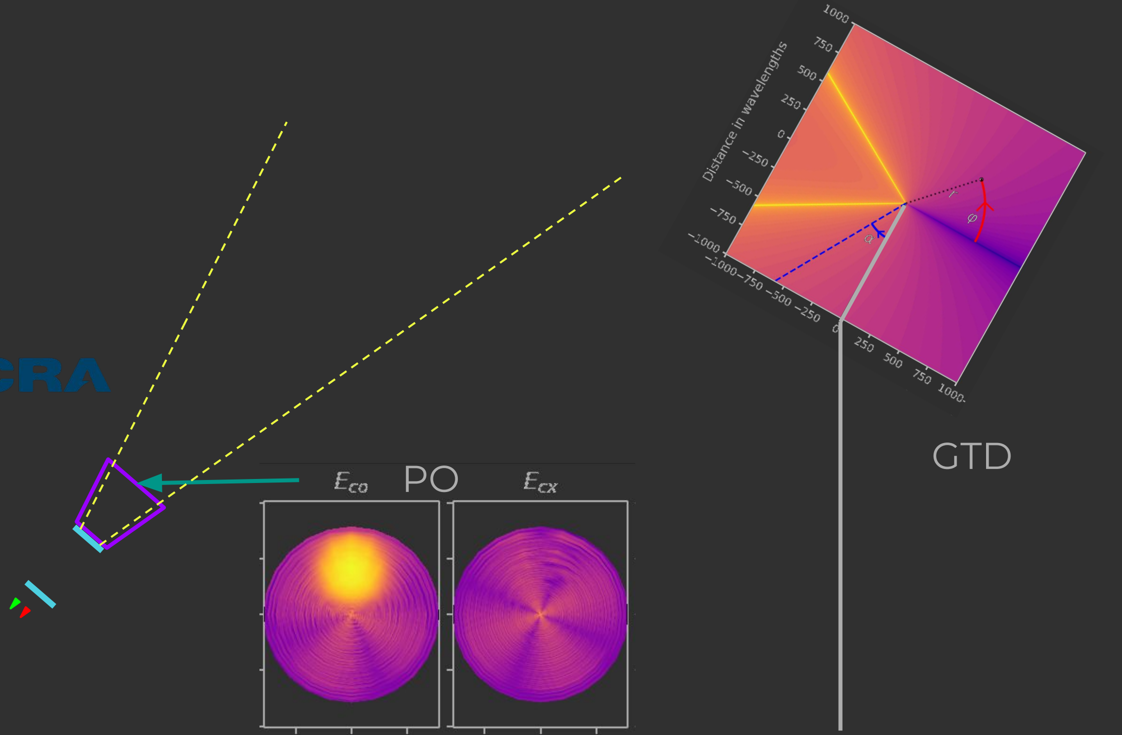
Adler, Alexandre, Gudmundsson, Jon

Alexandre E. Adler, Jon E. Gudmundsson, "Modeling sidelobe response for ground-based mm-wavelength telescopes with the geometrical theory of diffraction," Proc. SPIE 11453, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy X, 114534O (13 December 2020); doi: 10.1117/12.2576309

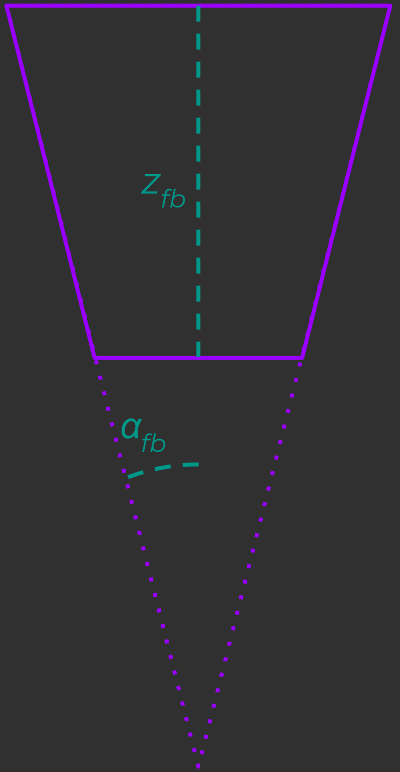
SPIE.

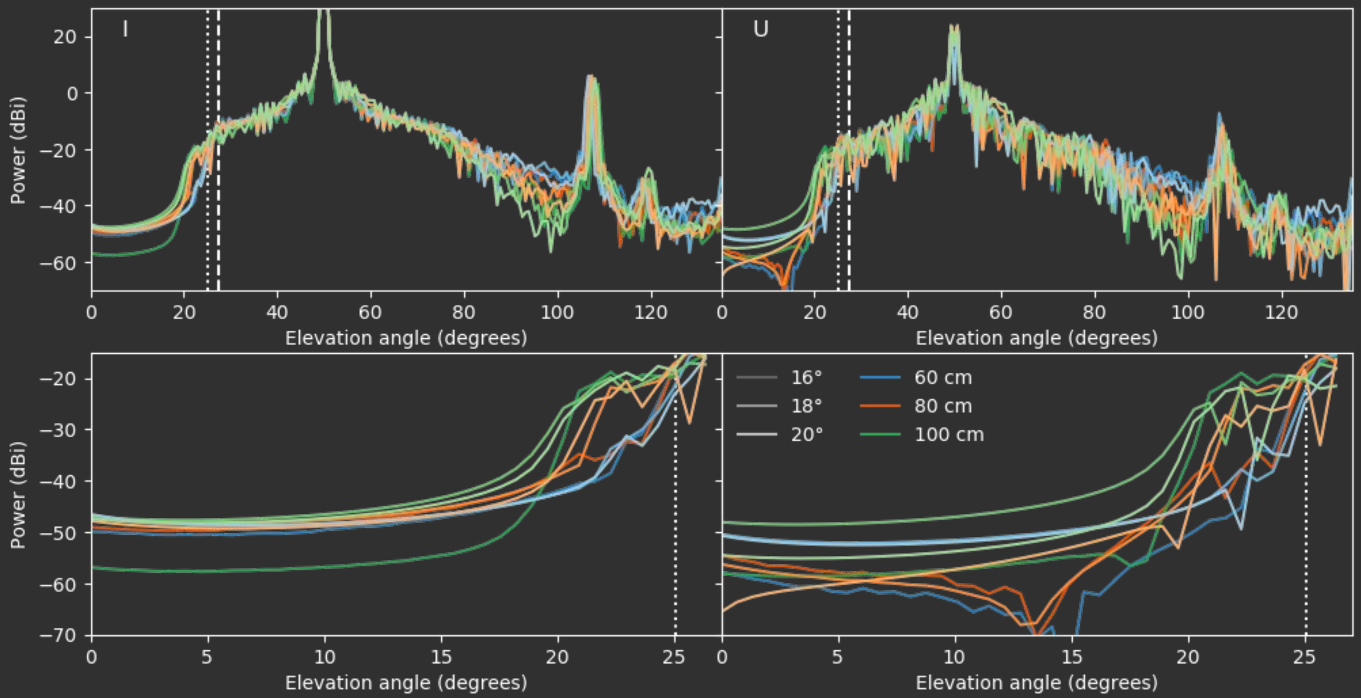
Event: SPIE Astronomical Telescopes + Instrumentation, 2020, Online Only

[2012.07613](https://arxiv.org/abs/2012.07613)



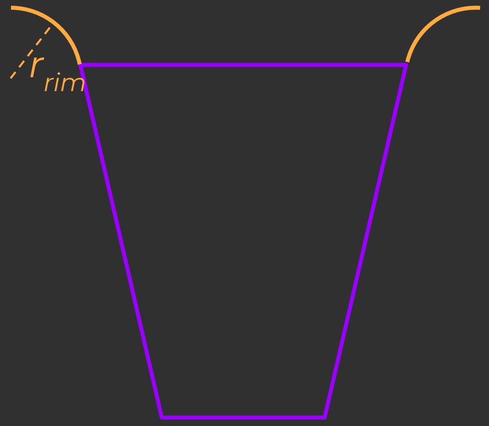
GTD beam systematics

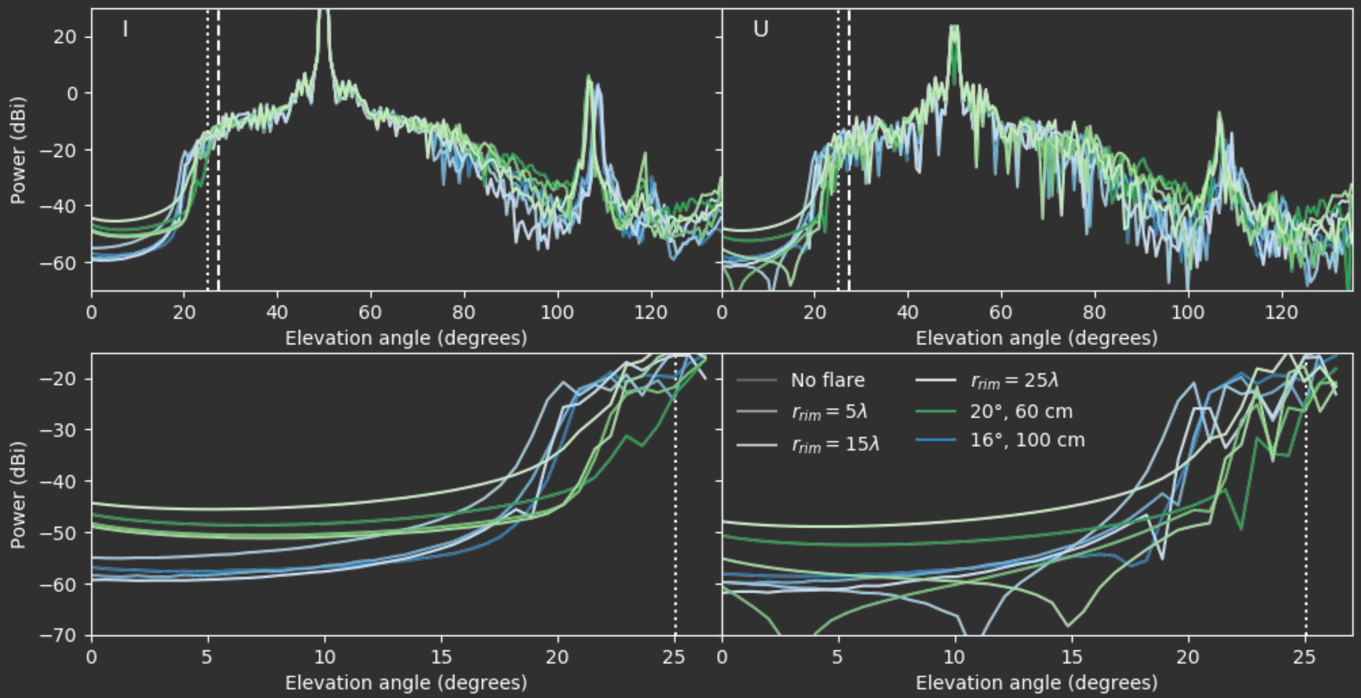




Forebaffle geometry Forebaffle flaring Dielectric properties Detector position

GTD beam systematics

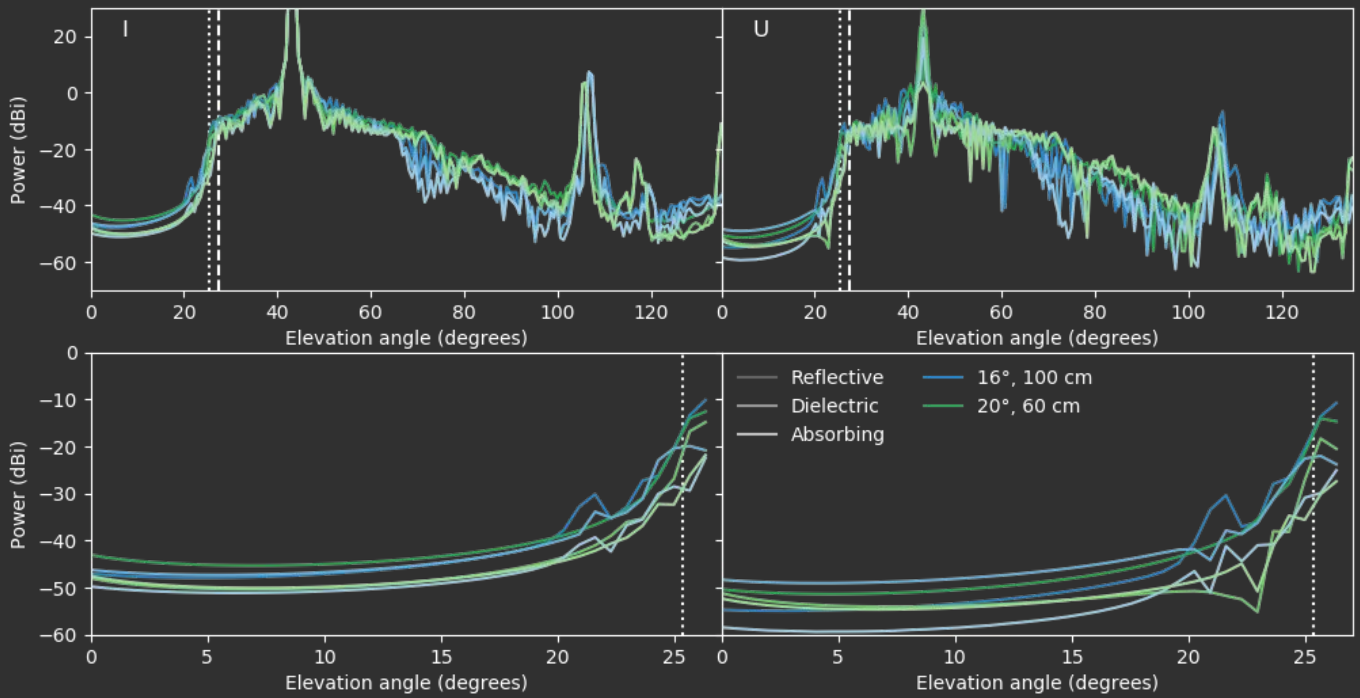




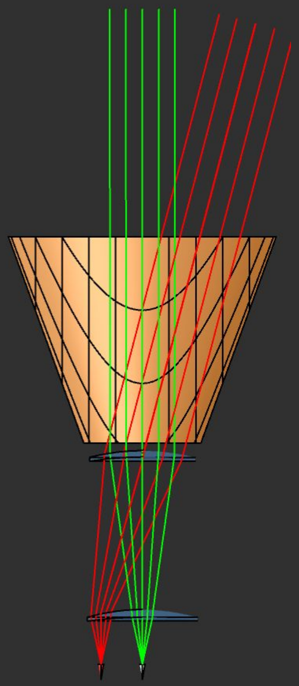
Forebaffle geometry Forebaffle flaring Dielectric properties Detector position

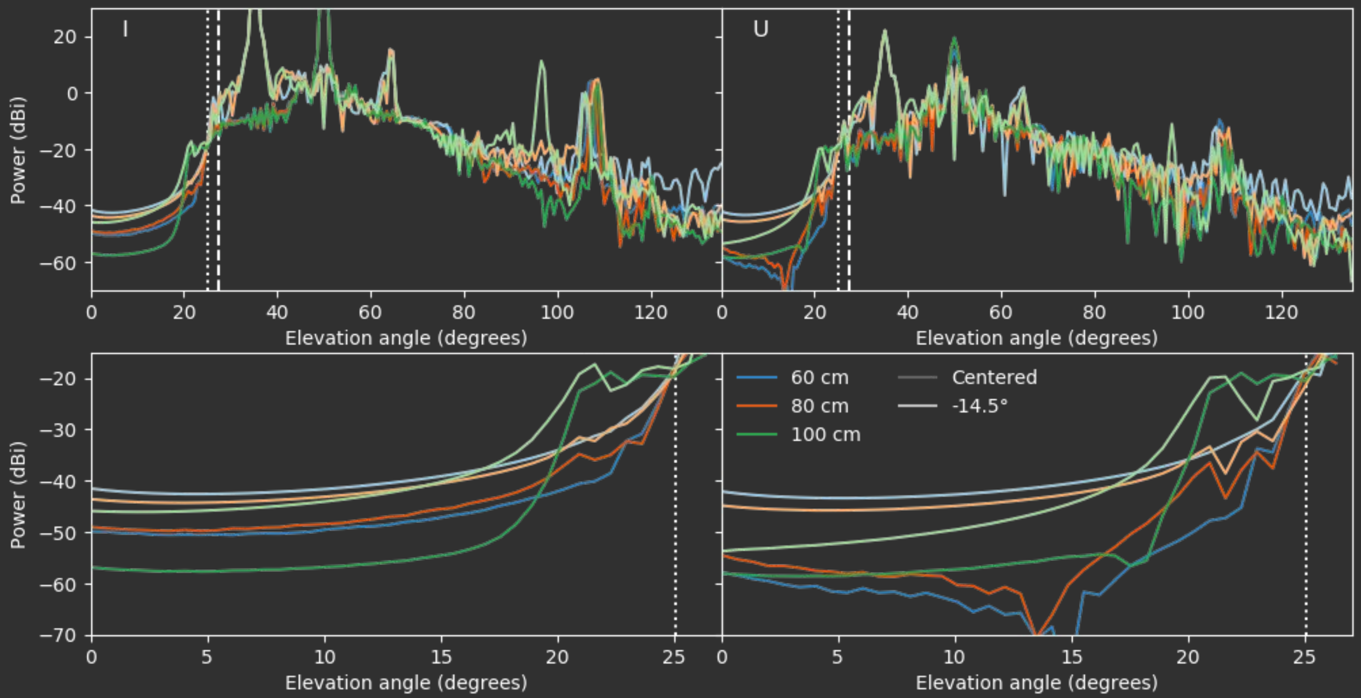
GTD beam systematics

A forebaffle of the BICEP Array being coated in absorbing foam (BICEP/KECK)



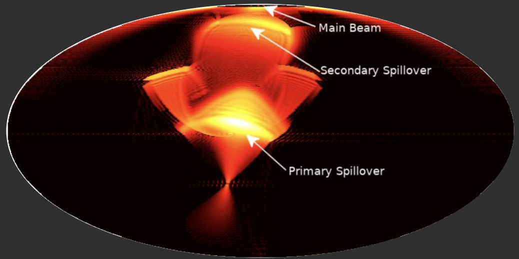
GTD beam systematics





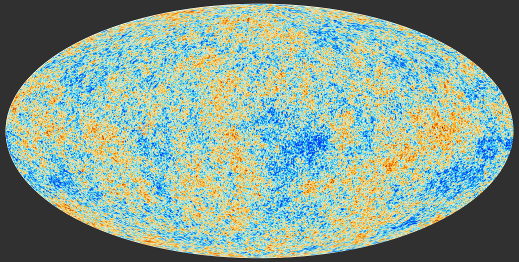
beamconv

Need: Full sky beam convolved with full sky map at each scan step



Beyond Planck I, 2020

*



Planck Release 3, 2018

Convolution in real space ↔ Multiplication in Fourier space

Led by

Adri Duivenvoorden
Princeton

+

beamconv

Jon Gudmundsson

+

Alexandra Rahlin
Chicago

+

beamconv HWP

Alexandre Adler

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Konstantina Dachlythra
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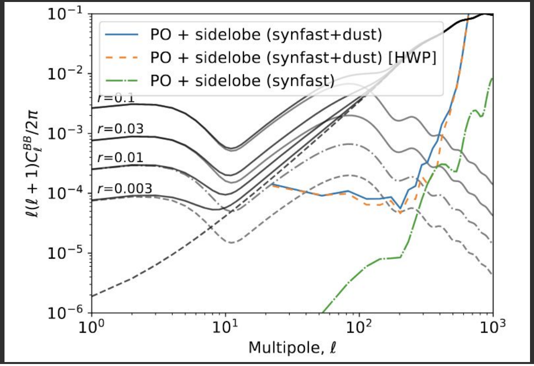
Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 486, 5448–5467 (2019) doi:10.1093/mnras/stz1143
Advance Access publication 2019 May 2

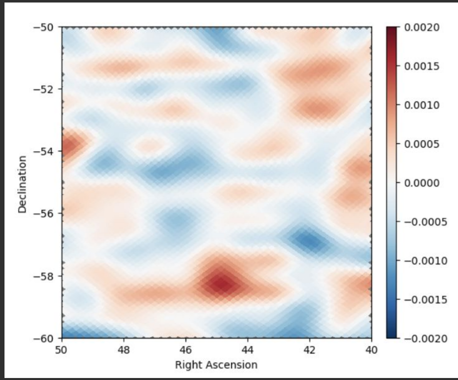
Full-sky beam convolution for cosmic microwave background applications

Adriaan J. Duivenvoorden[1★], Jon E. Gudmundsson[1] and Alexandra S. Rahlin[2,3]

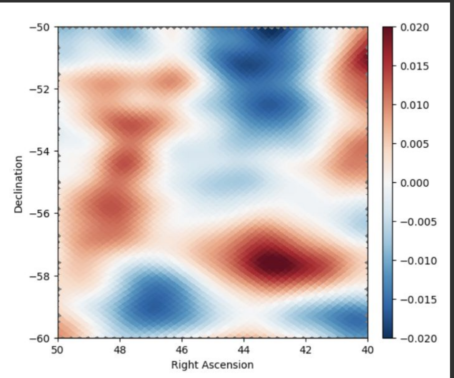
arxiv:[1809.05034]

Beamconv models of scans by a satellite show the effects of beams being non-Gaussian and of sidelobes

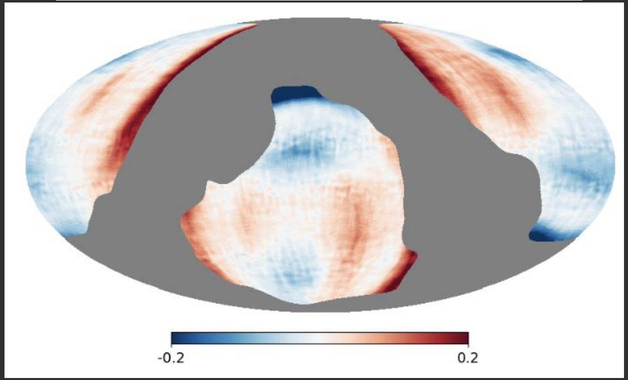




Gaussian - Elliptical Gaussian

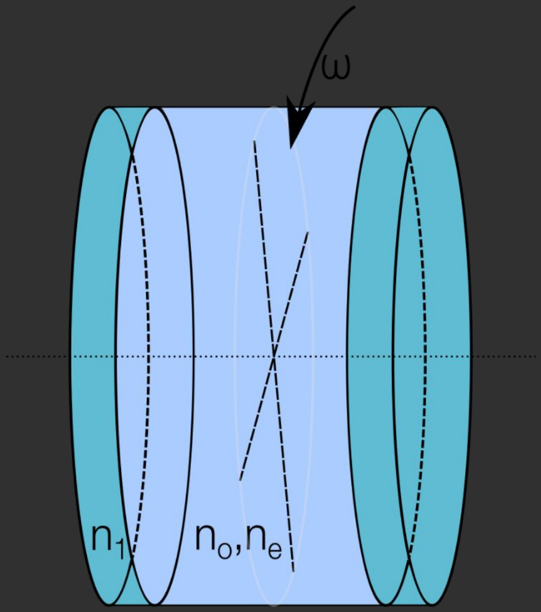


Gaussian - PO



Extended sidelobes pick up foregrounds

Half-wave plate

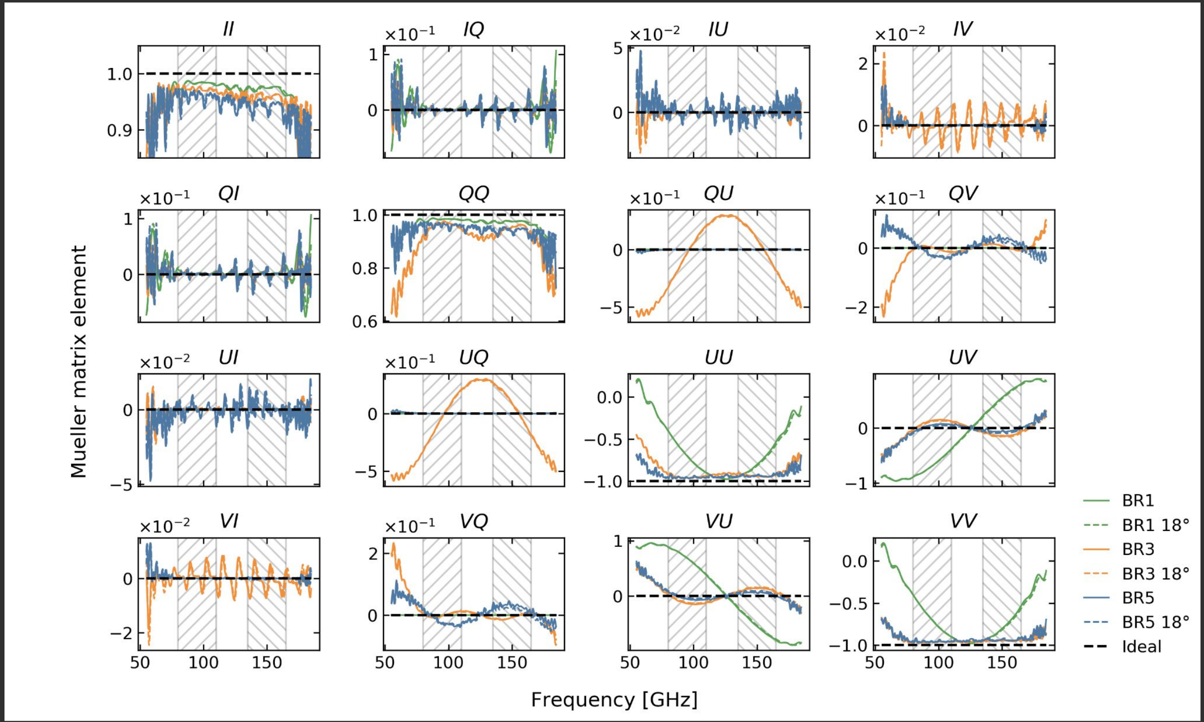


- The rotation of the plate modulates polarised light.
- Optimized for one frequency: by stacking rotated layers it is possible to create a broadband AHWP.

$$R_{-\omega t} M^{ideal}_{HWP} R_{\omega t} \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} I \\ Q\cos(4\omega t) + U\sin(4\omega t) \\ Q\sin(4\omega t) - U\cos(4\omega t) \\ -V \end{pmatrix}$$

The Mueller Matrix is frequency dependent

For a broadband AHWP: a frequency dependant rotation angle offset!



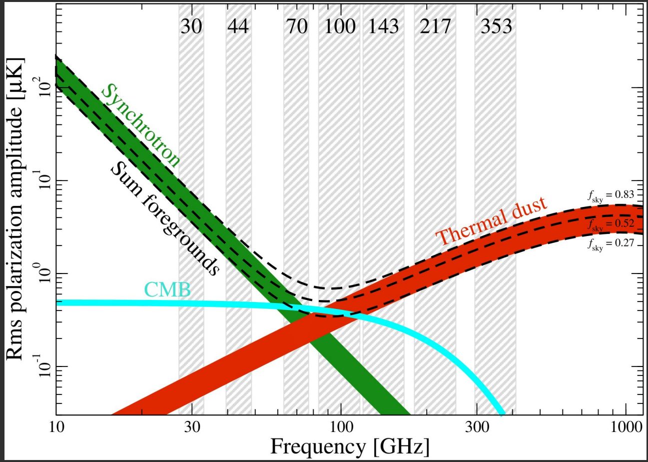
Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 502, 4526–4539 (2021) doi:10.1093/mnras/stab317
Advance Access publication 2021 February 6

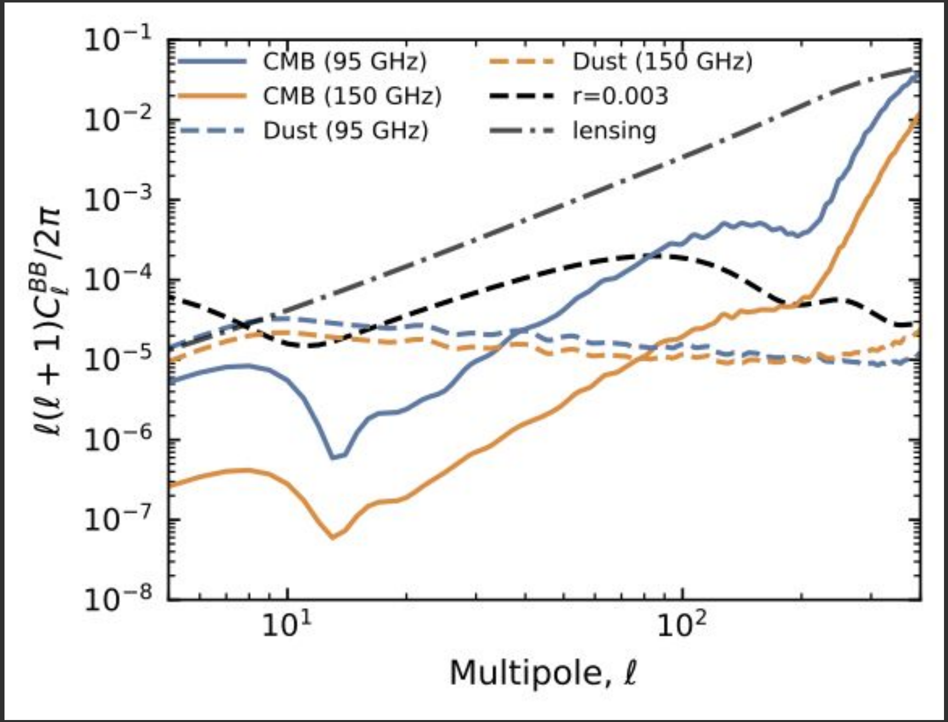
Probing frequency-dependent half-wave plate systematics for CMB experiments with full-sky beam convolution simulations

Adriaan J. Duivenvoorden,[1★] Alexandre E. Adler,[2] Matteo Billi,[3,4,5] Nadia Dachlythra[2] and Jon E. Gudmundsson[2]

arxiv:[2012.10437]

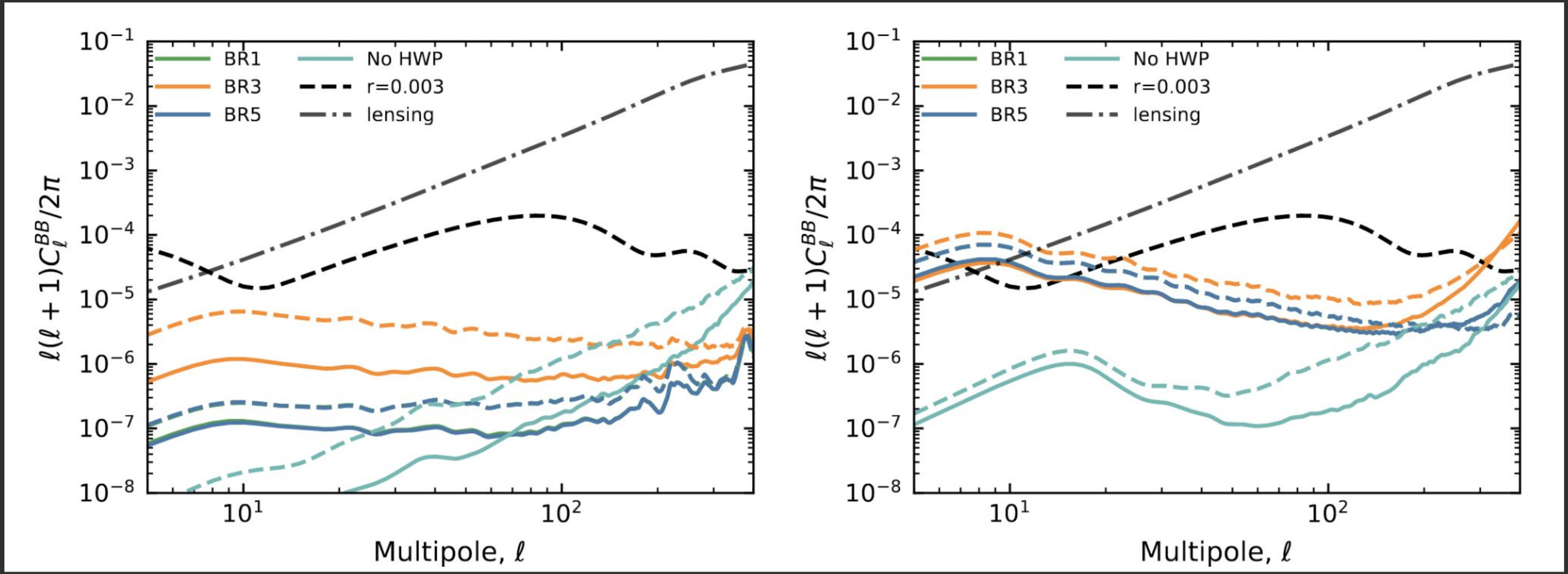
Consequence: critically important to do component separation properly/know the SED.



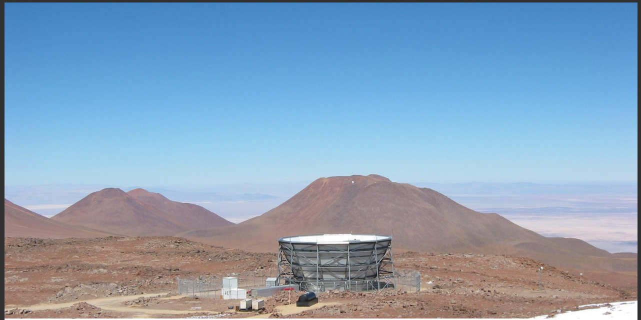


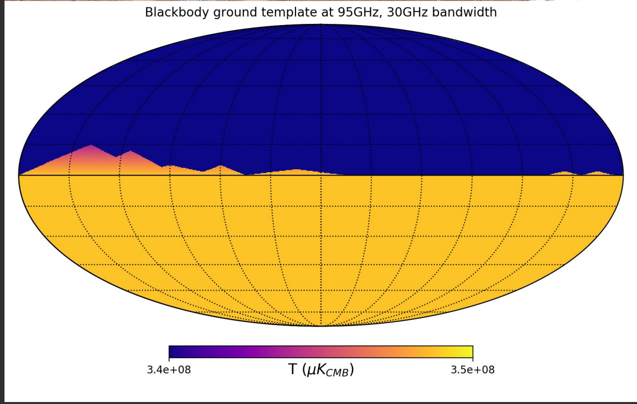
Simulating HWP+beam systematics with *beamconv*

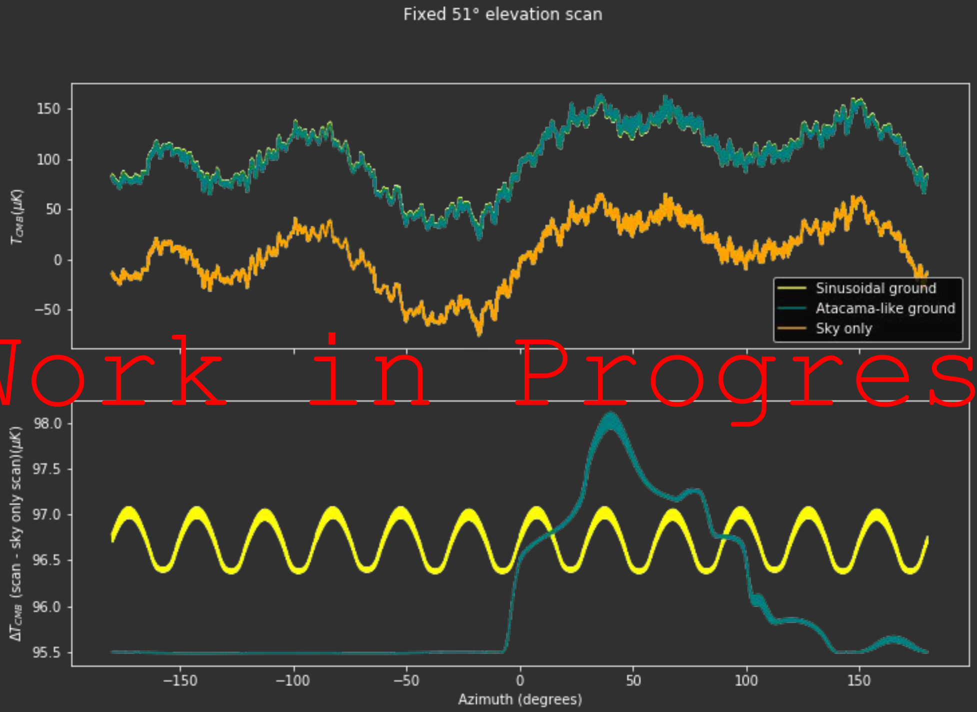
Sidelobes+HWP non-idealities also impact BB systematics



Scan-synchronous noise







Work in Progress

Conclusion:

- For the B-mode search, we need to understand the optical response.
- Using GTD and other new optical simulation methods, we can generate complex beams.
- Using *beamconv*, we can then see the effect of those beams on timestreams, including HWP non-idealities and ground pickup.

Repository:
https://github.com/AdriJD/beamconv

Papers:
1809.05034, 2012.10437, 2012.07613