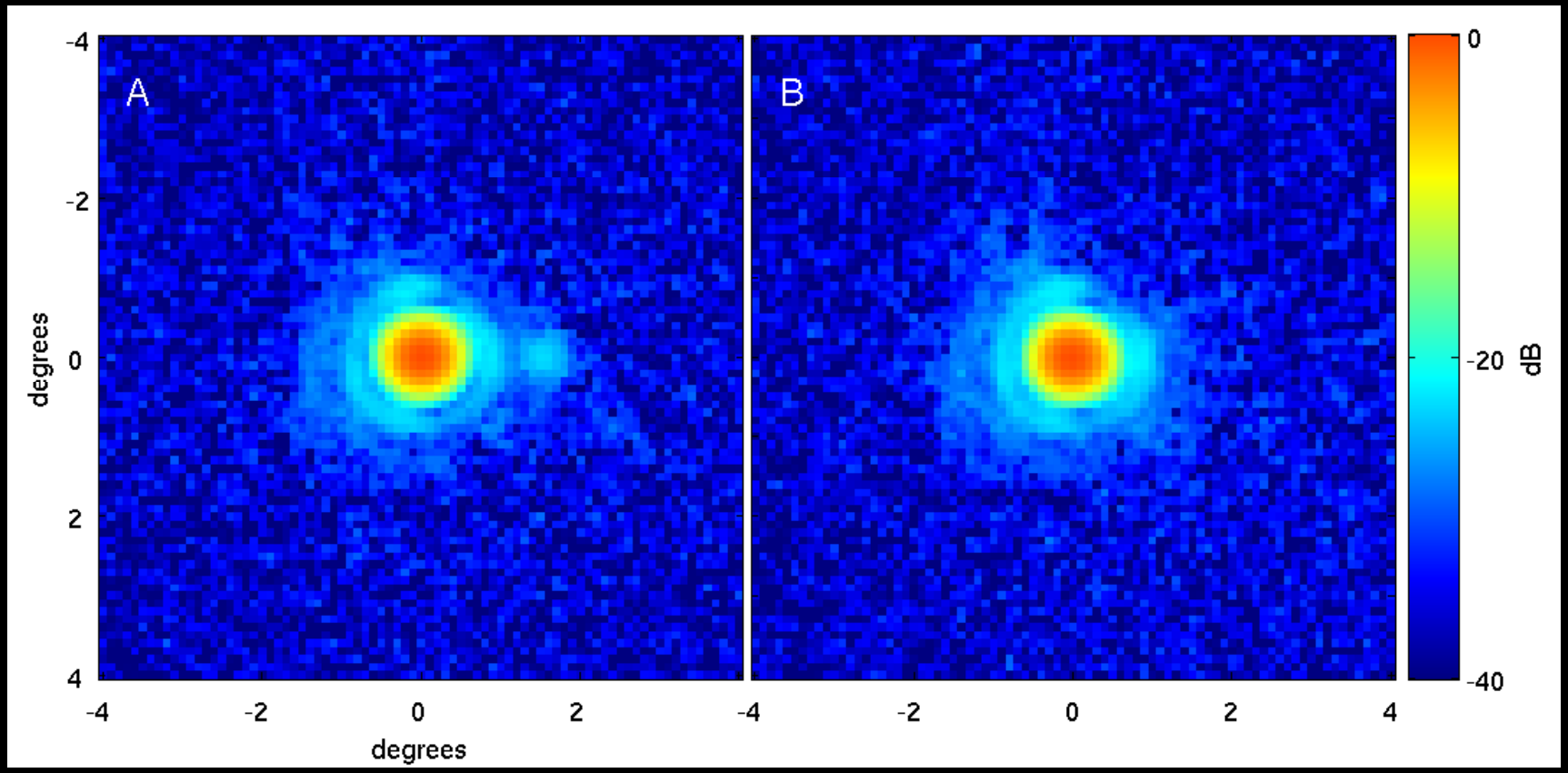
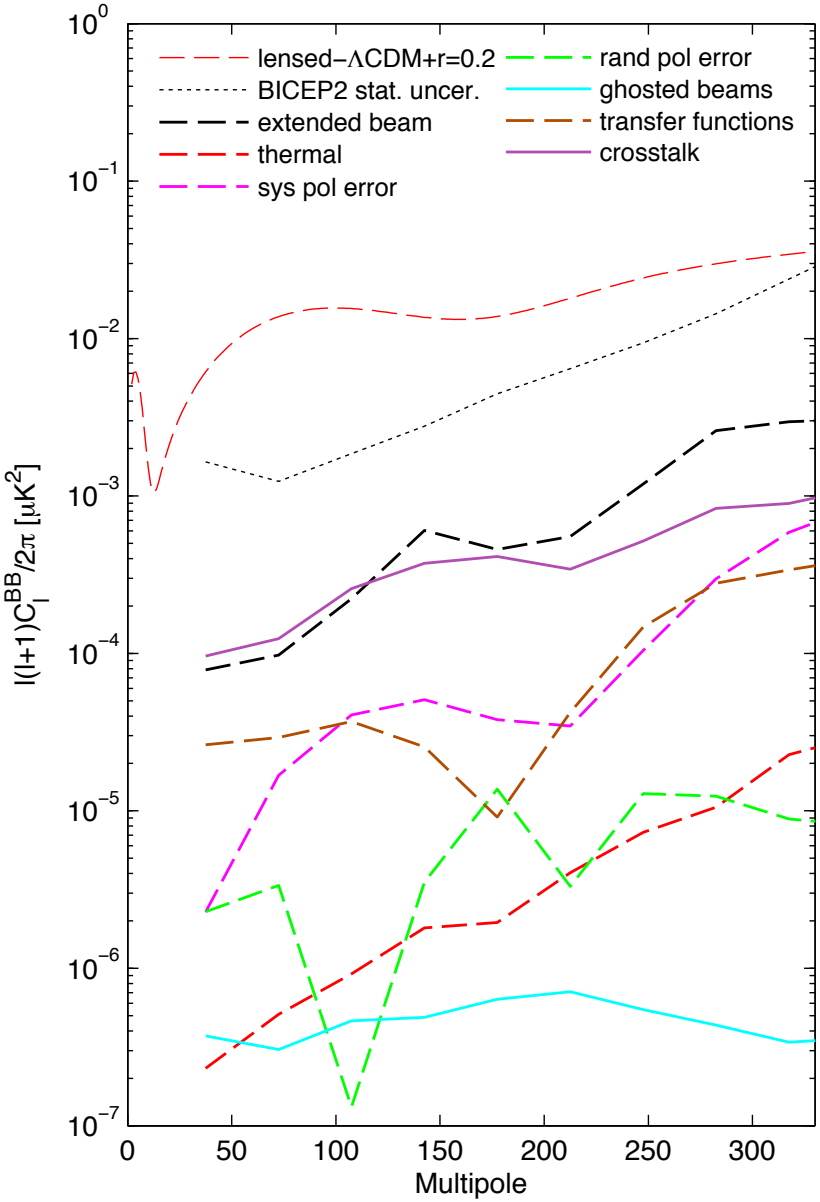
BICEP2 Instrumental Systematics



Christopher Sheehy for the BICEP2 collaboration
University of Chicago
Cosmo 2014, Chicago, IL
August 25, 2014

Instrumental Systematics



All systematic effects that we could imagine were investigated!

We find with high confidence that the apparent signal *cannot be explained* by instrumental systematics!

Christopher Sheehy for the Bicep2 Collaboration

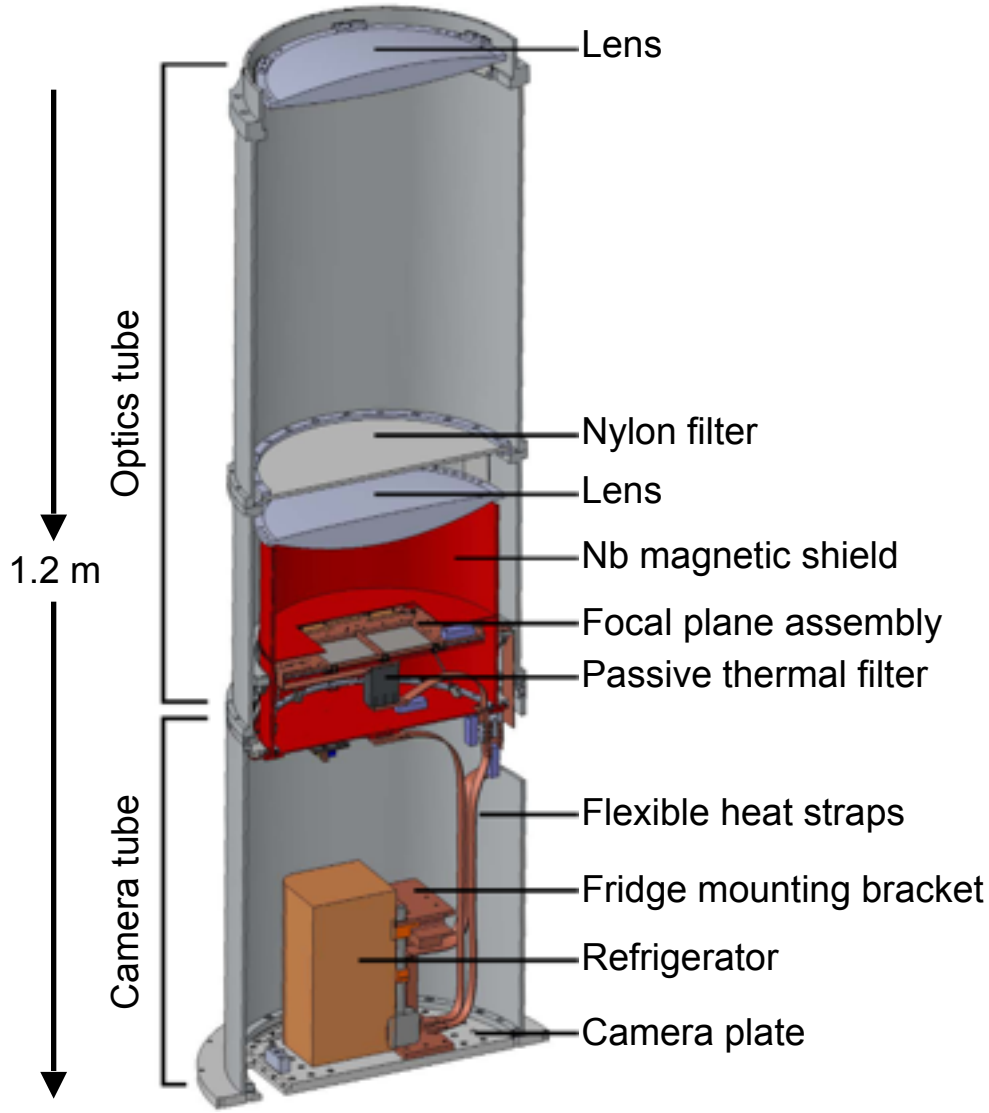
The BICEP2 Telescope

Telescope as compact as possible while still having the angular resolution to observe degree-scale features.

On-axis, refractive optics allow the entire telescope to rotate around boresight for polarization modulation.

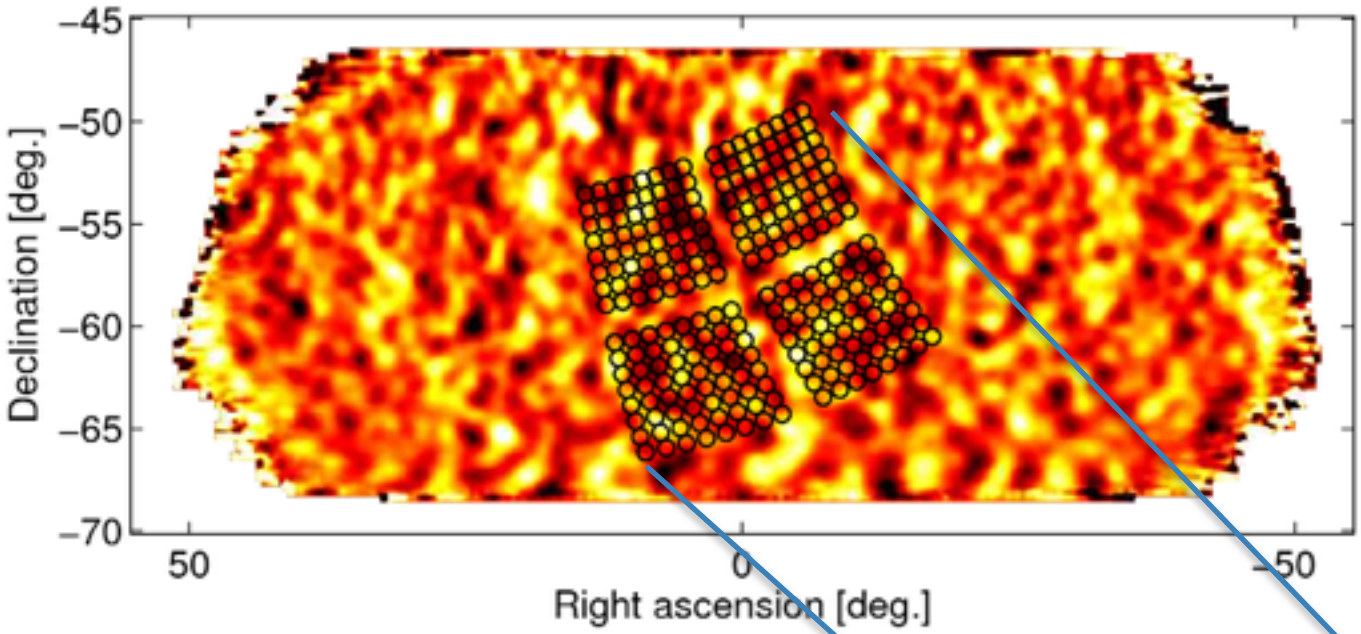
Liquid helium cools the optical elements to 4.2 K.

A 3-stage helium sorption refrigerator further cools the detectors to 0.27 K.



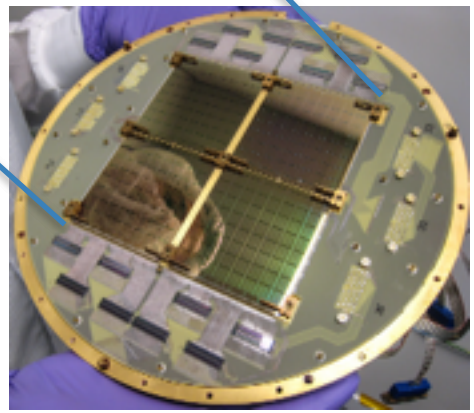
Christopher Sheehy for the Bicep2 Collaboration

BICEP2 on the Sky

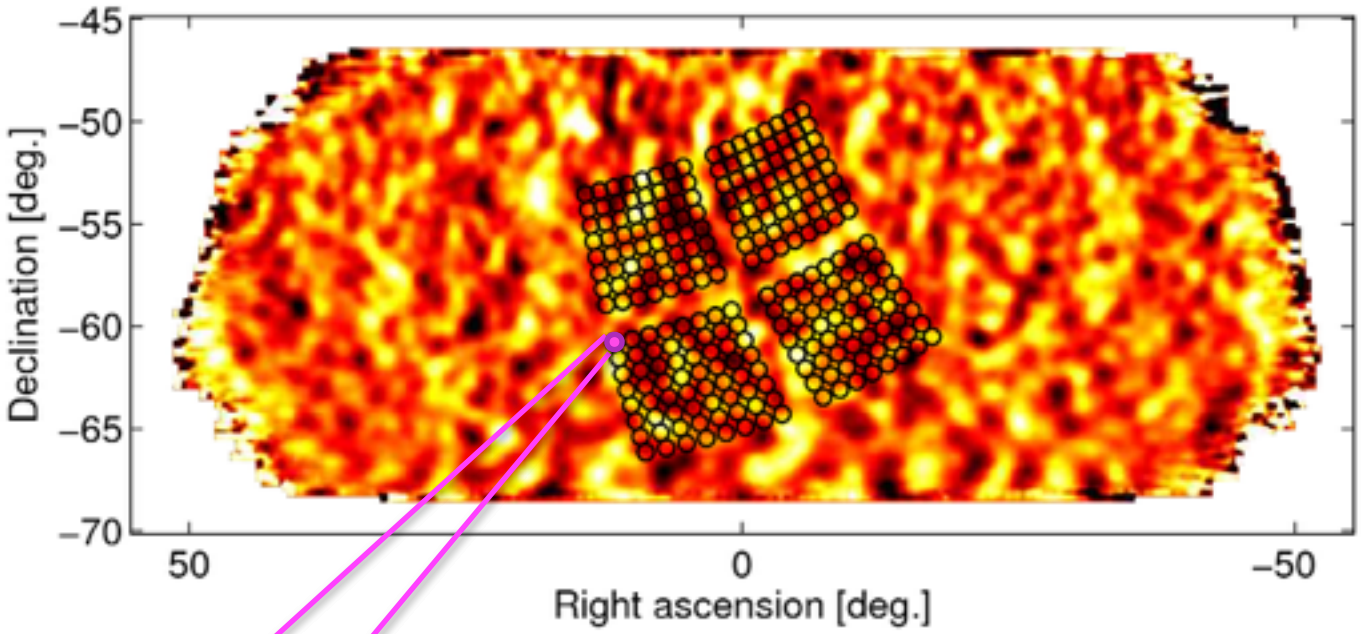


Projection of the BICEP2 focal plane on the sky!

(Background is the CMB temperature map as measured with BICEP2)



BICEP2 on the Sky



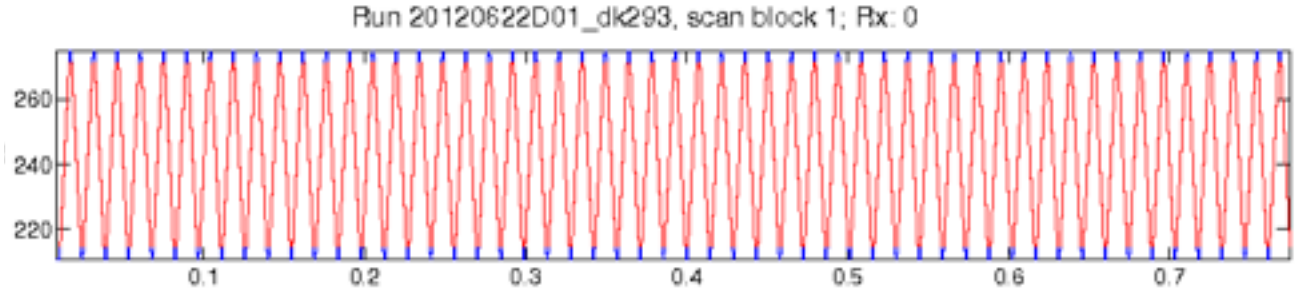
Each focal plane pixel is really *two* detectors — a horizontally polarized one and a vertically polarized one.

Measure CMB T by summing the signal from orthogonally polarized detector pairs.

Measure CMB polarization by differencing the signal.

Raw Data

Telescope Movement

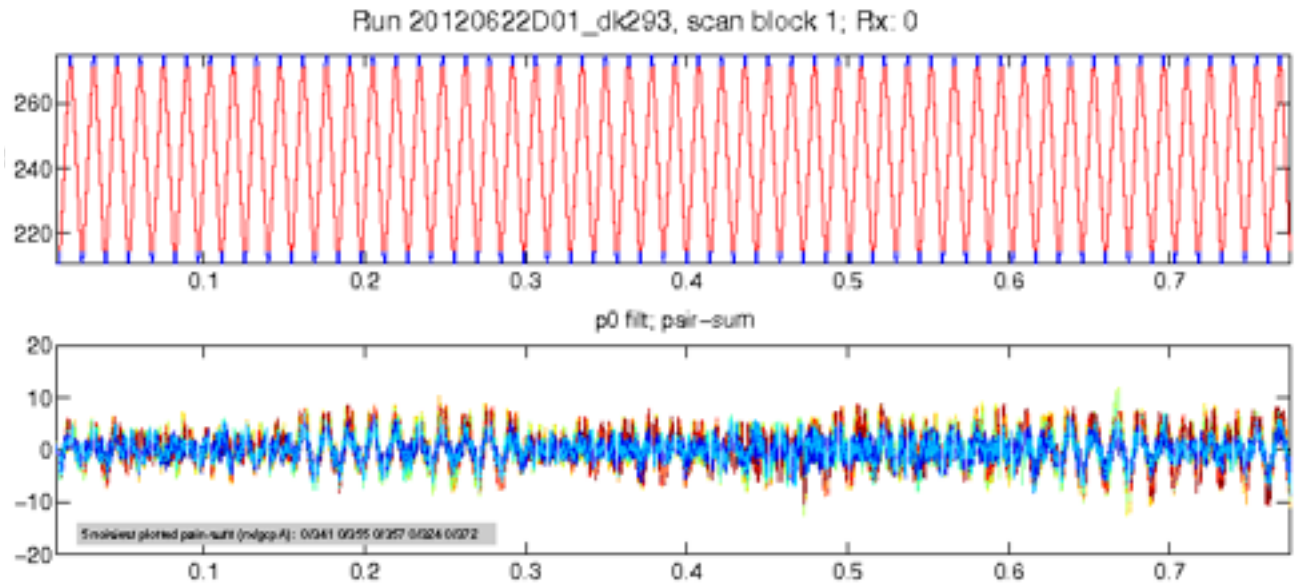


time (~1 hour)

Raw Data

Telescope Movement

Sum of detector pairs



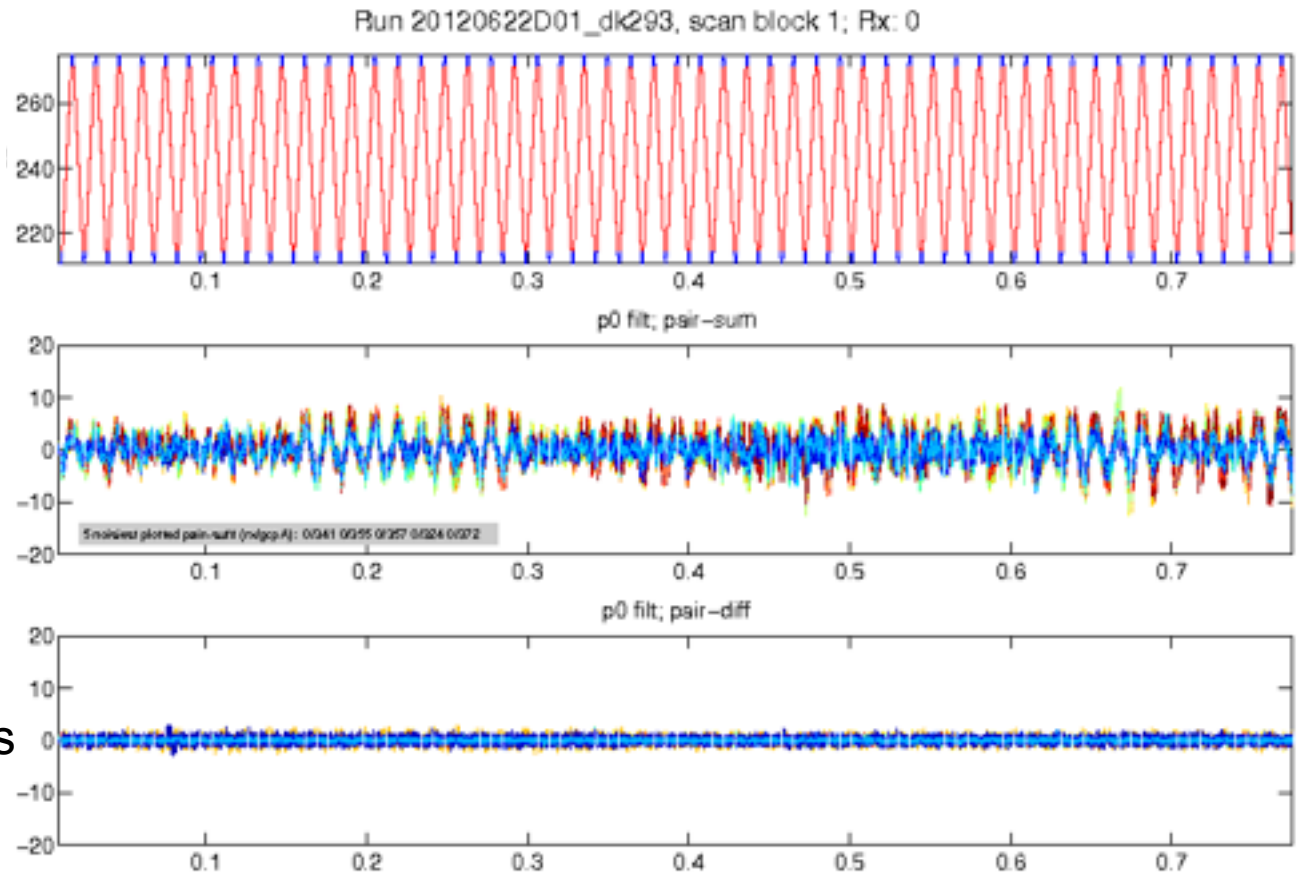
time (~1 hour)

Raw Data

Telescope Movement

Sum of detector pairs

Difference of detector pairs



time (~1 hour)

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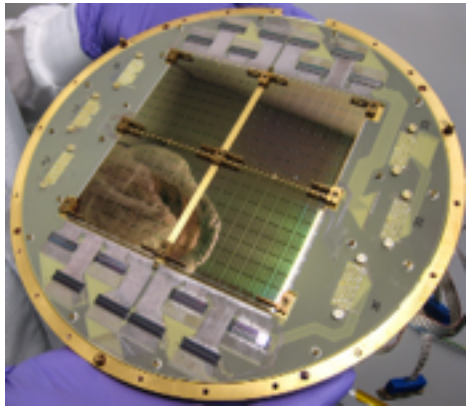
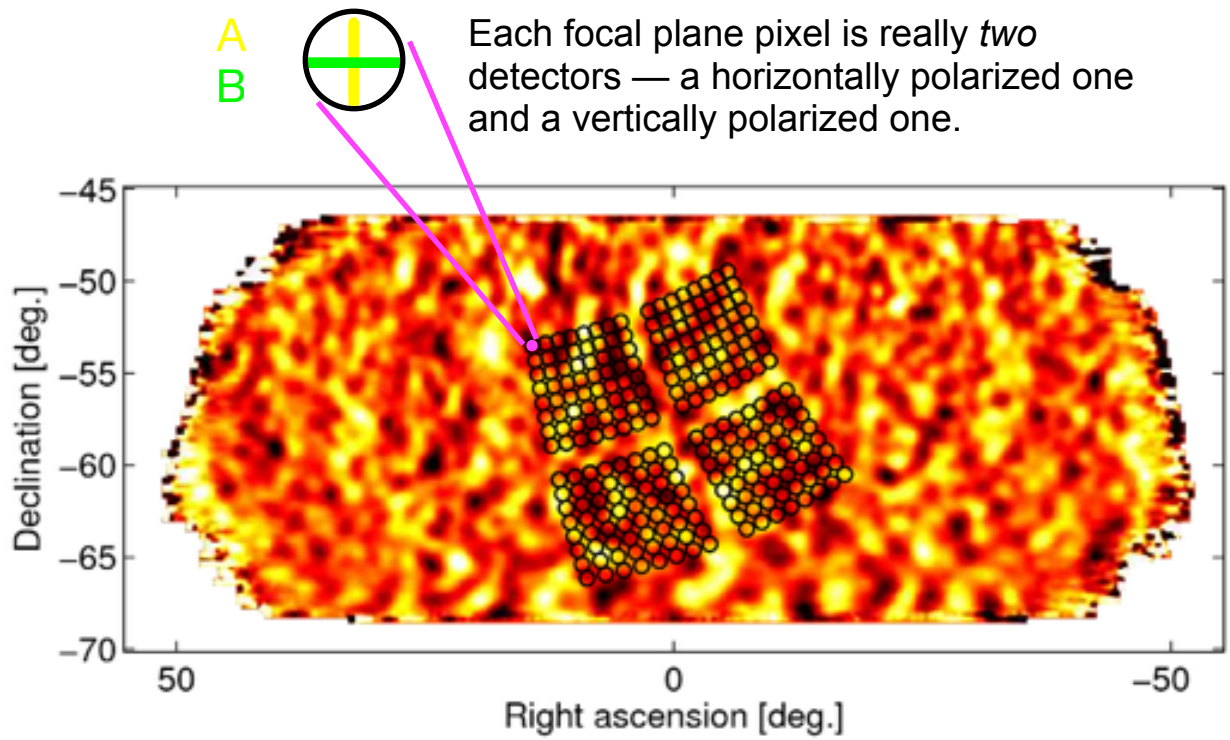
Beam Systematics

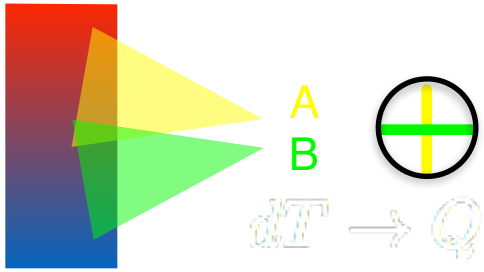
- Each focal plane pixel is really two orthogonally polarized detectors
- Call these detectors “A” and “B”. They nominally point to the same location on the sky and have identical response to the CMB, i.e. have the same “beam”.
- If the CMB is unpolarized, the “pair difference” should be zero
- If the response to the CMB is different for A and B, then even if the CMB is unpolarized, the pair difference is non-zero. This is contaminates polarization!





Beam systematics
example: pointing center mismatch

“A” and “B” beams



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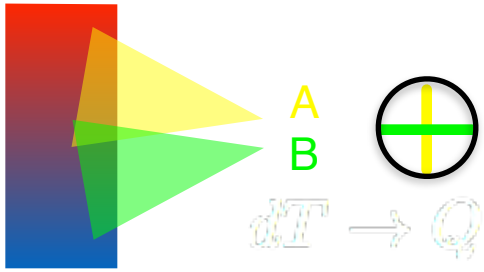
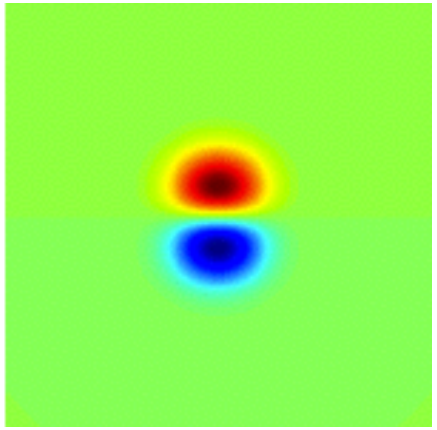


A-B difference beam



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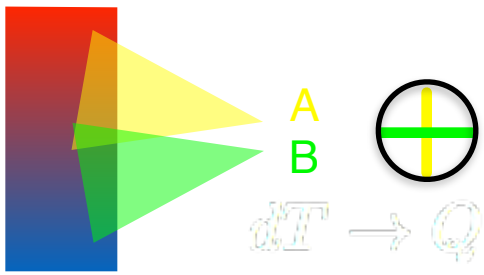

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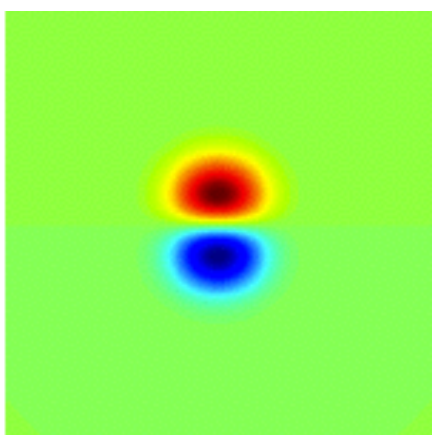

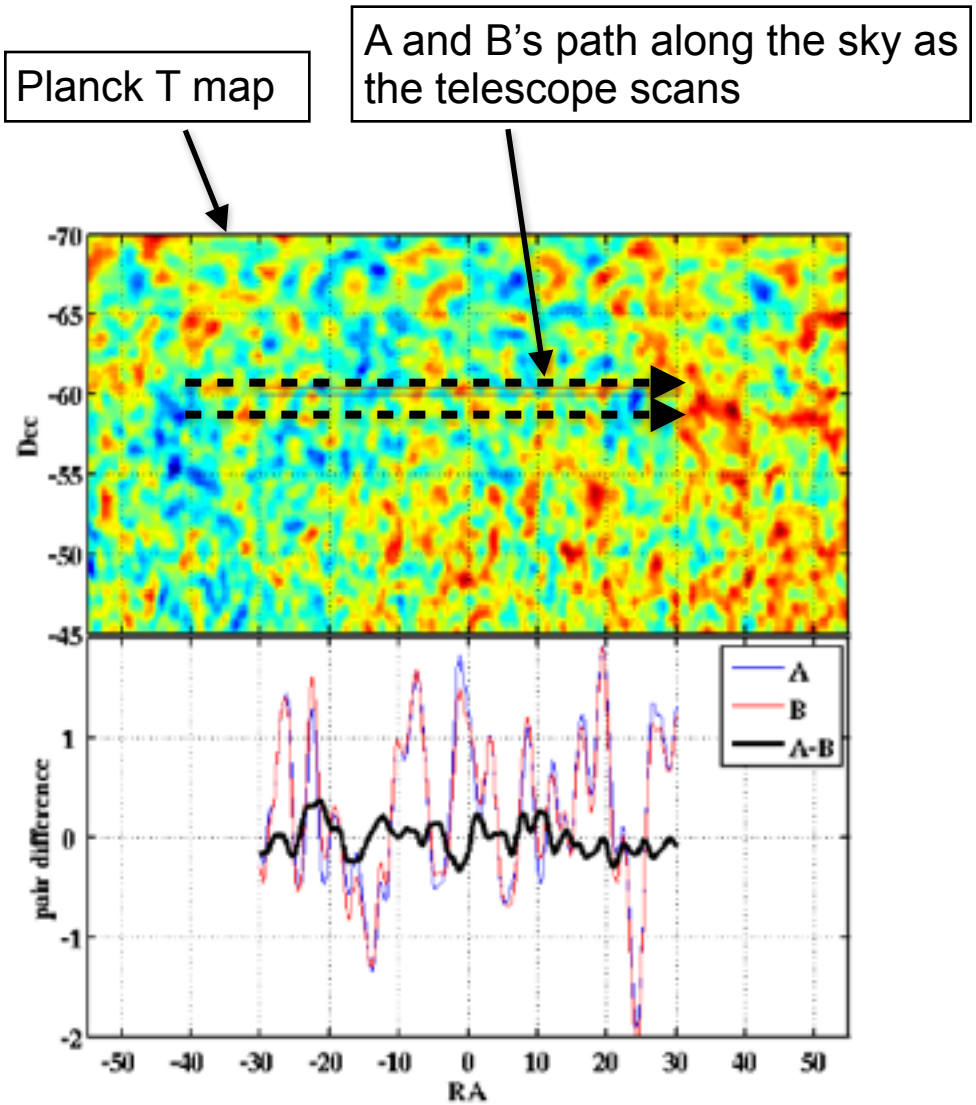

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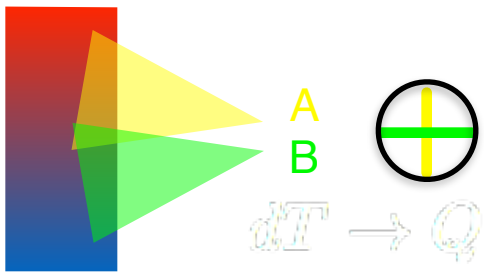
Systematics removal: deprojection
example: pointing center mismatch

"A" and "B" beams



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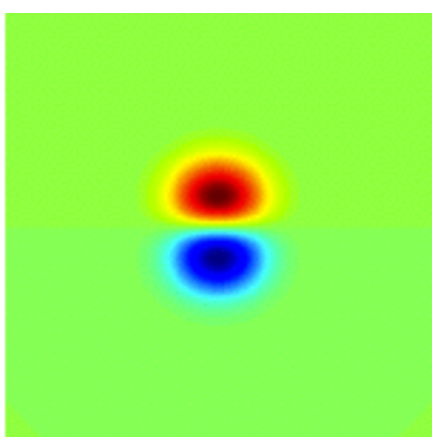
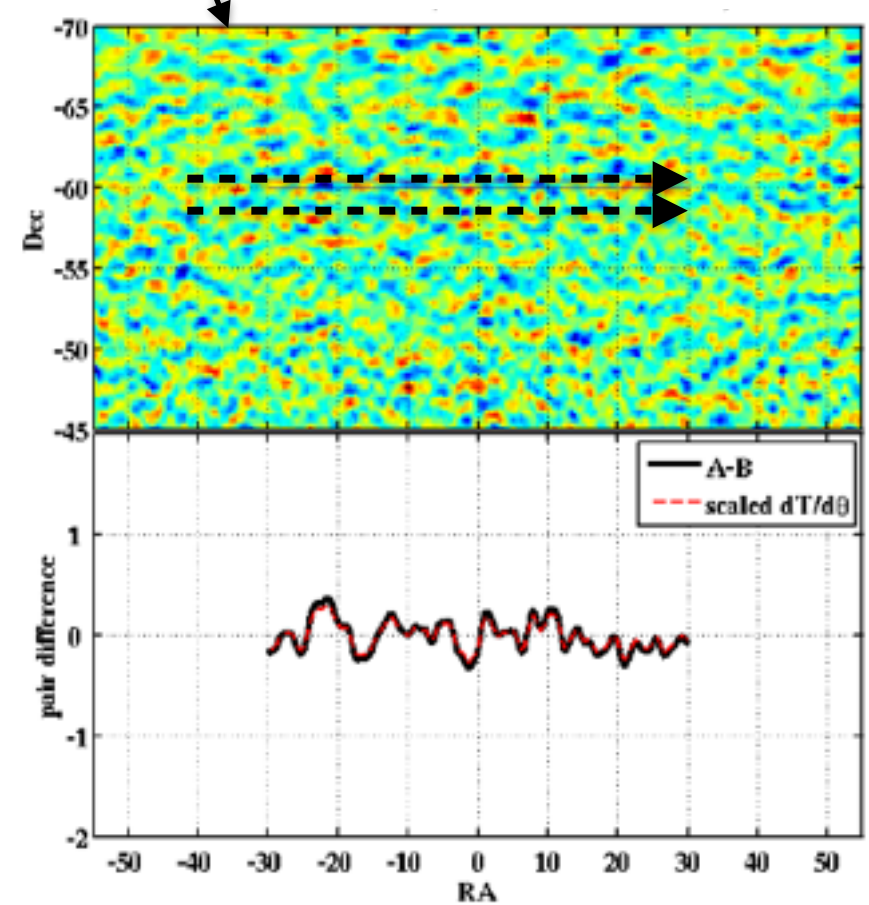
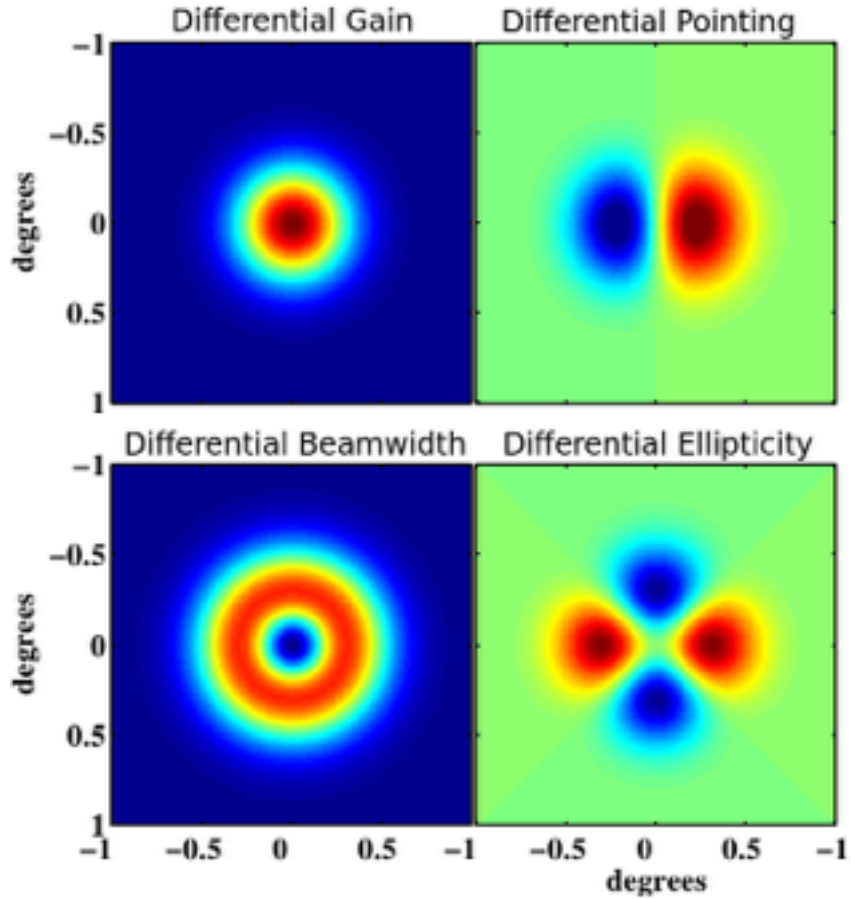


Planck dT/dDec. map



Systematics removal: deprojection

Differences of elliptical Gaussians



Use the Planck 143 GHz map to form templates of leakage from mismatched elliptical Gaussian beams.

Fit these templates to the data and subtract.

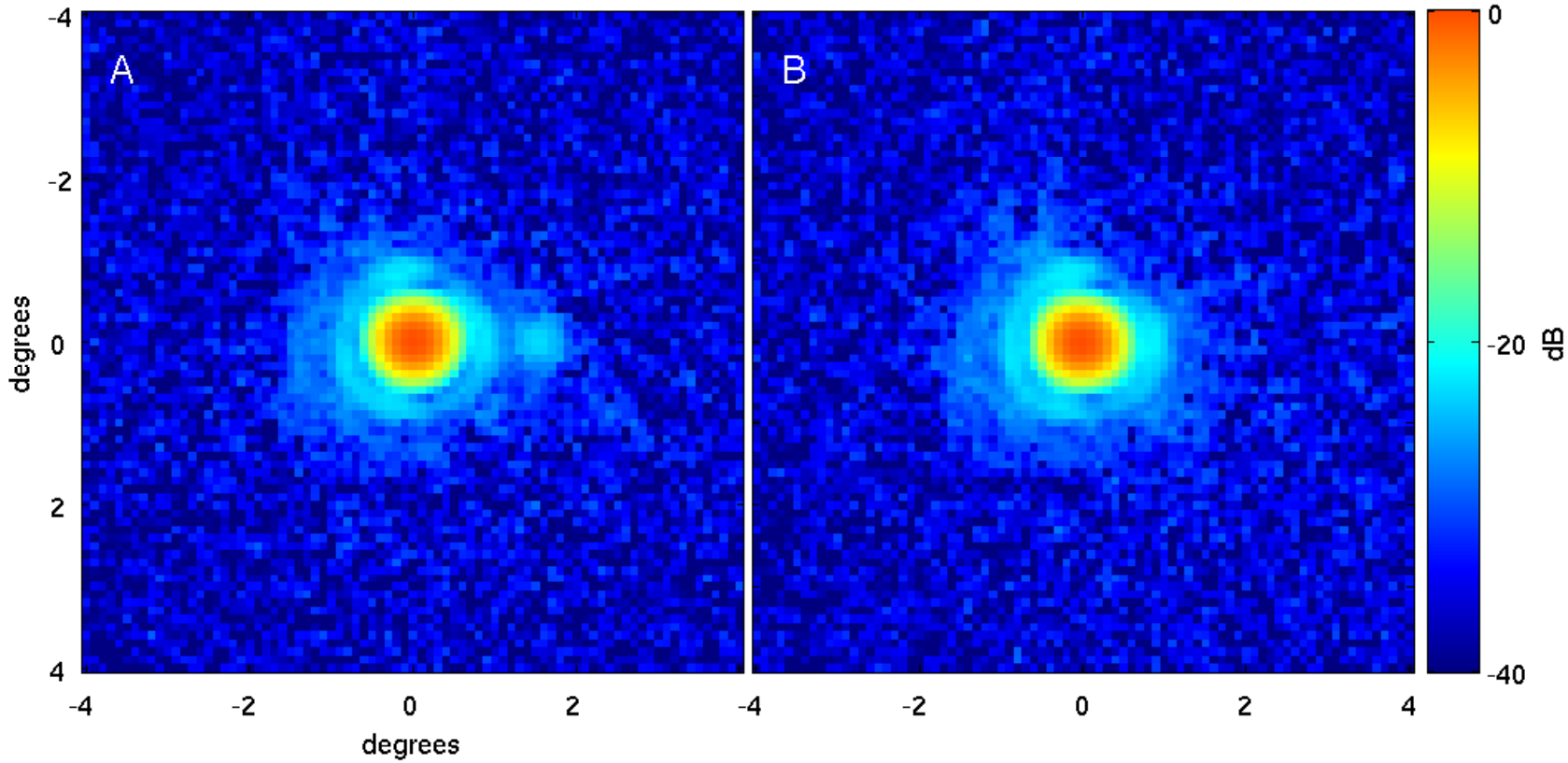
We know our beam shapes

Far field beam mapping:
microwave source mounted here

Detailed description in companion Instrument Paper

We know our beam shapes

High fidelity beam maps of individual detectors



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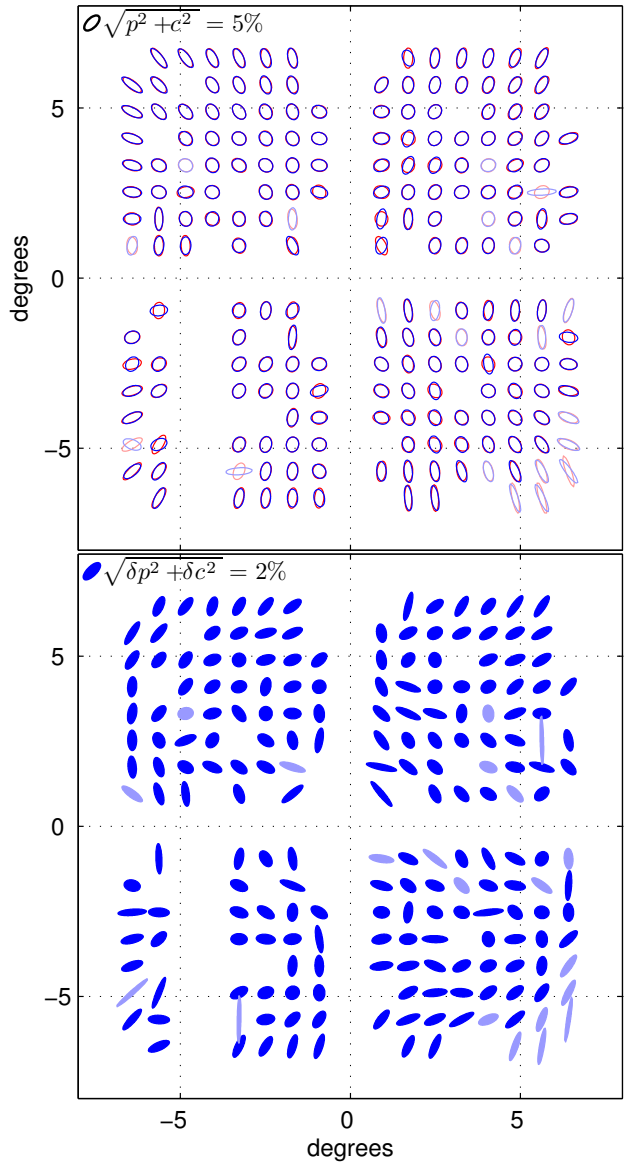
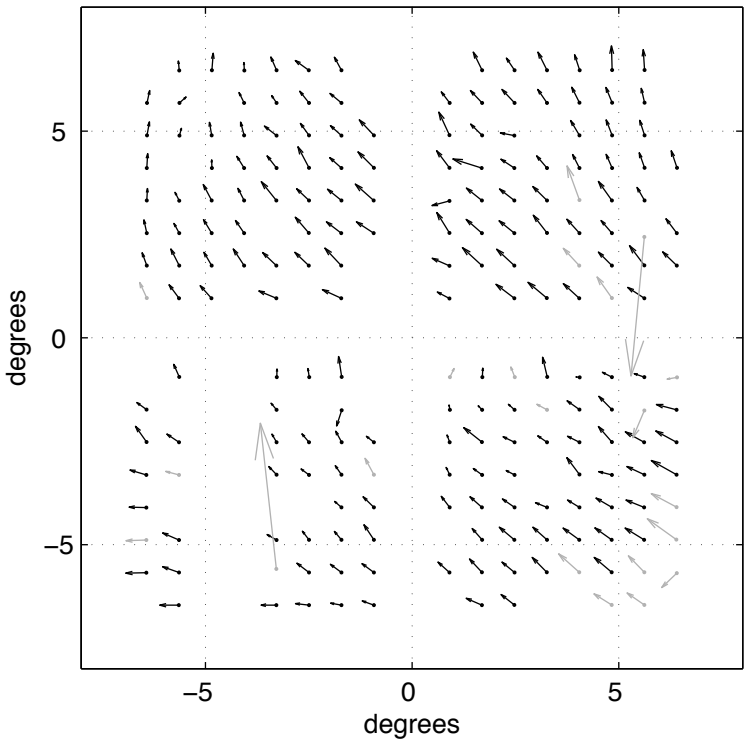
We know our beam shapes

beam ellipticity

differential ellipticity



differential beam centroids (x20)



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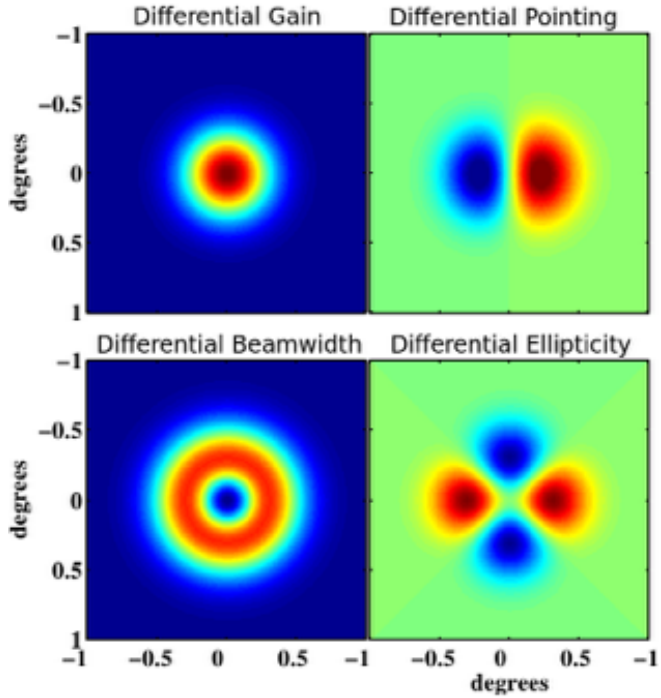
Systematics removal: deprojection

Differences of elliptical Gaussians



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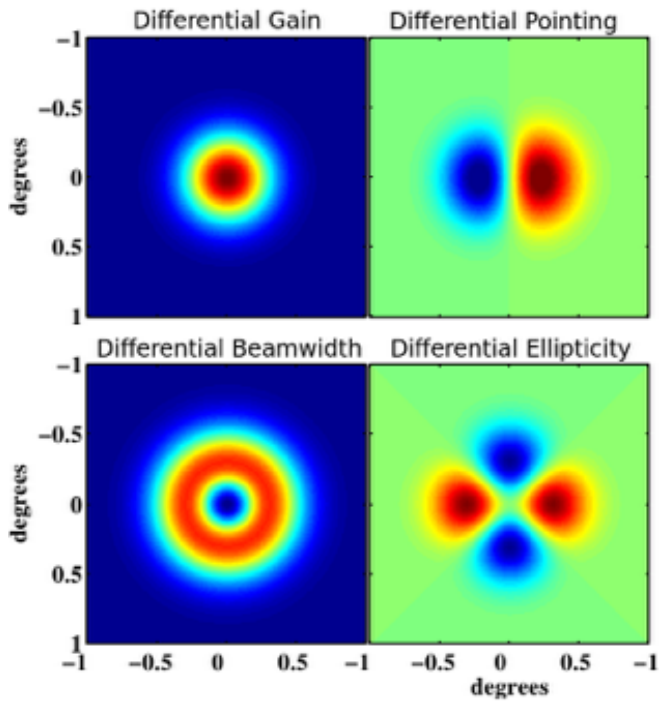

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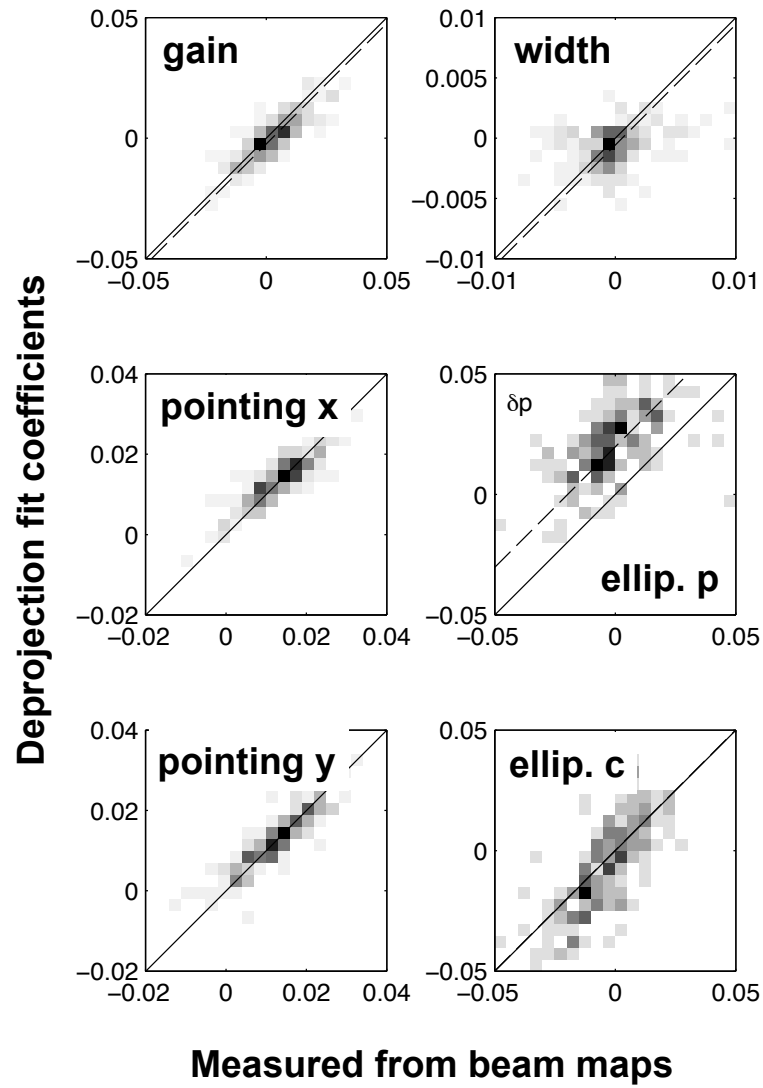

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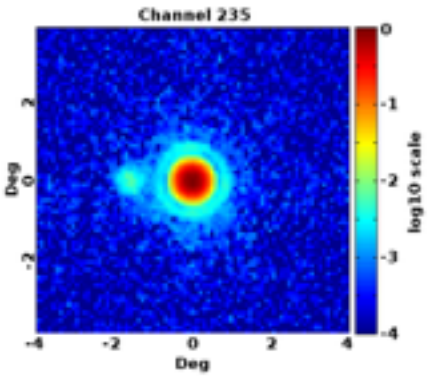
Because contamination from beam shape mismatch is entirely deterministic, we can both remove it (deprojection) **and** predict it in simulation using calibration data as input.

Calibration data
for each detector



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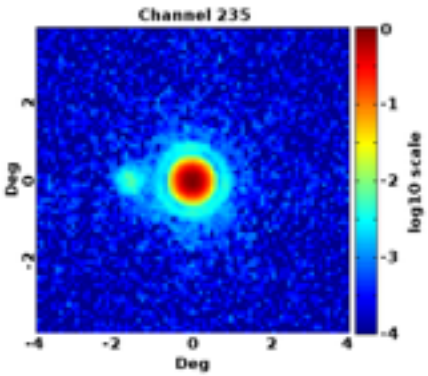
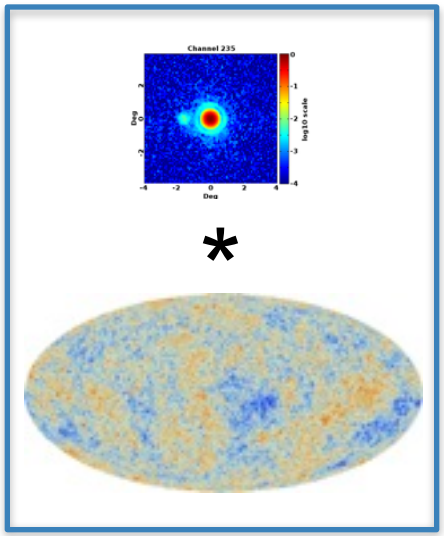


Simulation
(explicit convolution with Planck T map)



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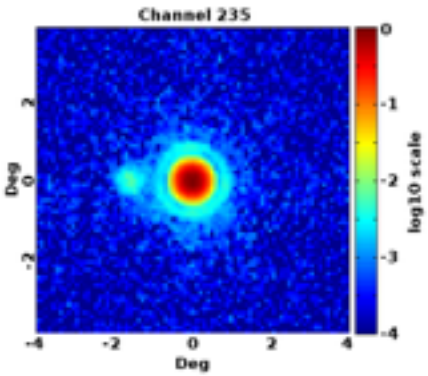

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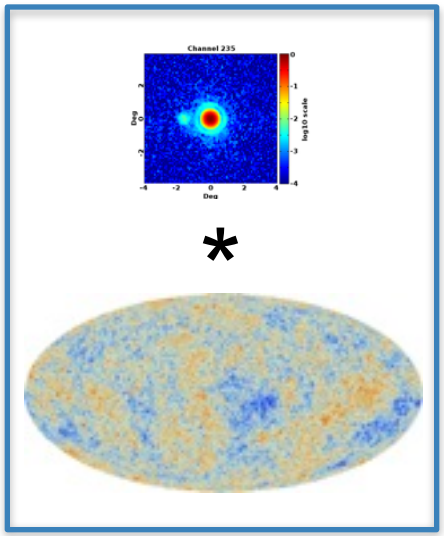
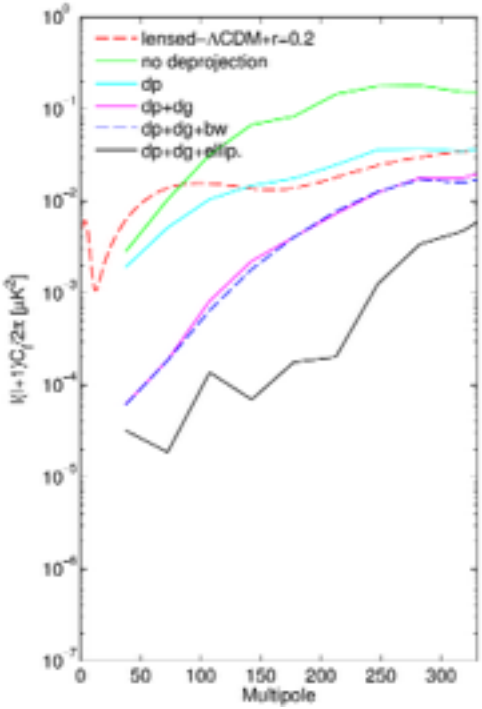
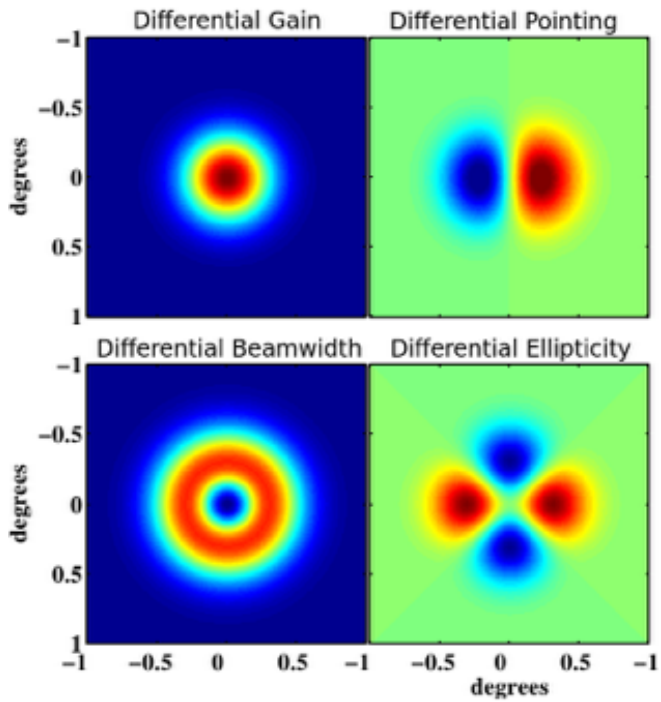


Predictions of contamination



Systematics removal: deprojection

Differences of elliptical Gaussians



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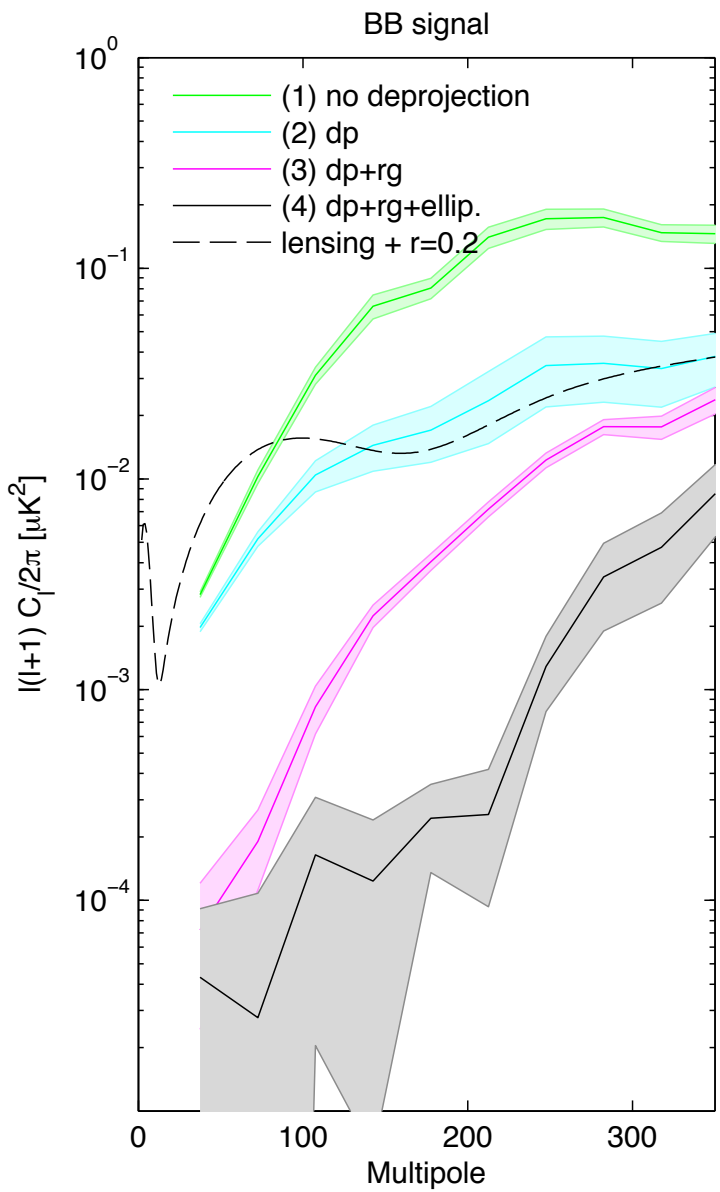
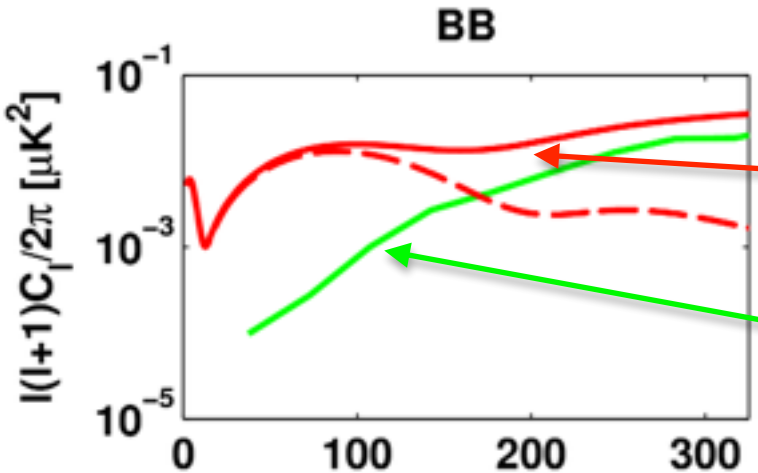


We know our beam shapes

example: slightly elliptical beams



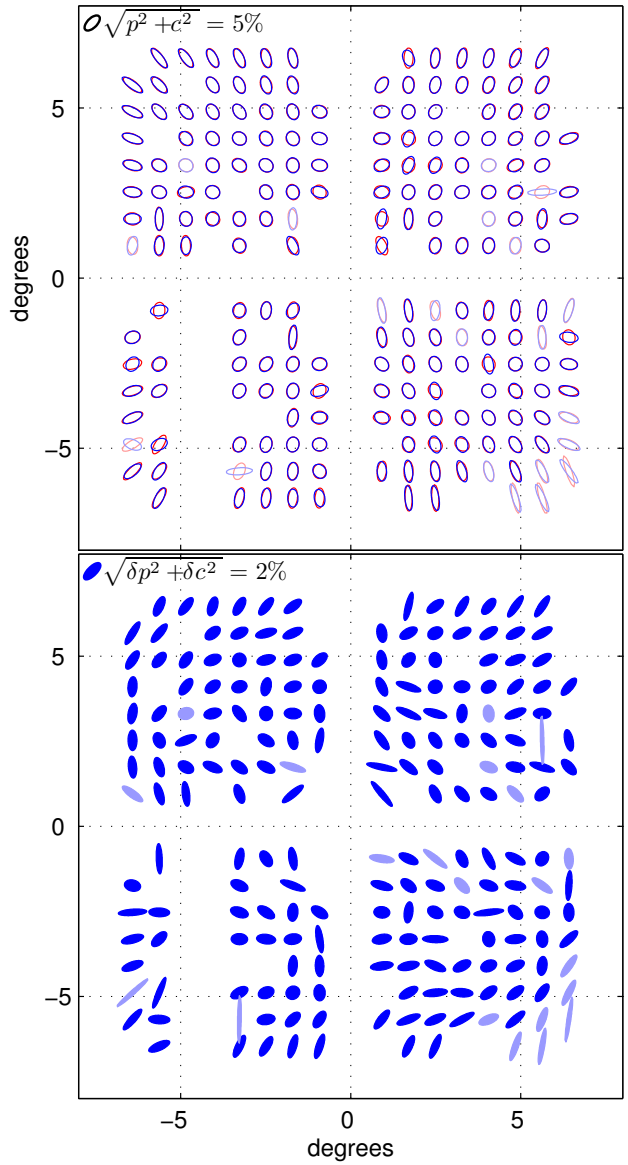
r=0.2 + lensing

Without ellipticity deprojection, predicted contamination in BB is negligible compared to noise level

We know our beam shapes

beam ellipticity

differential ellipticity



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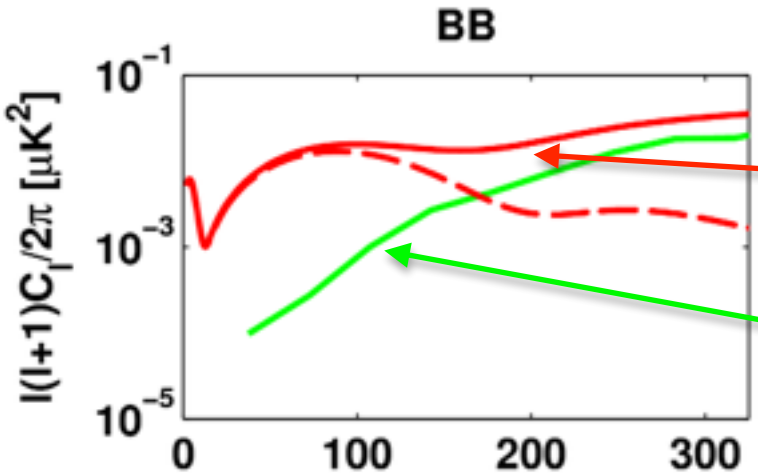

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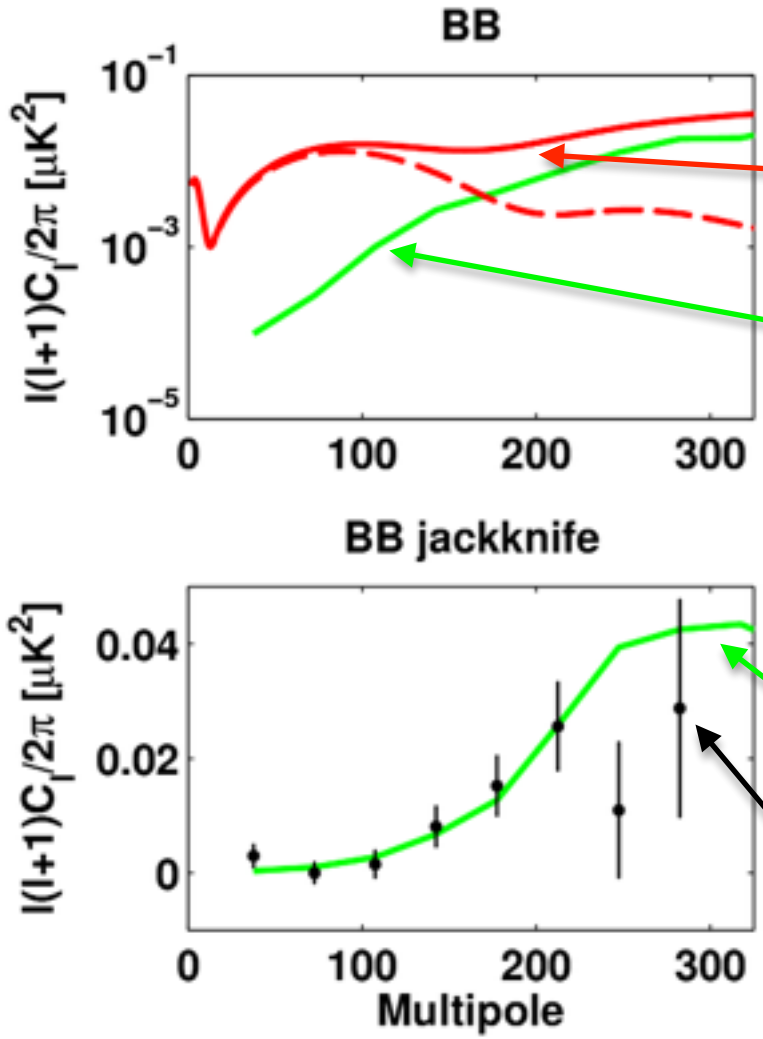

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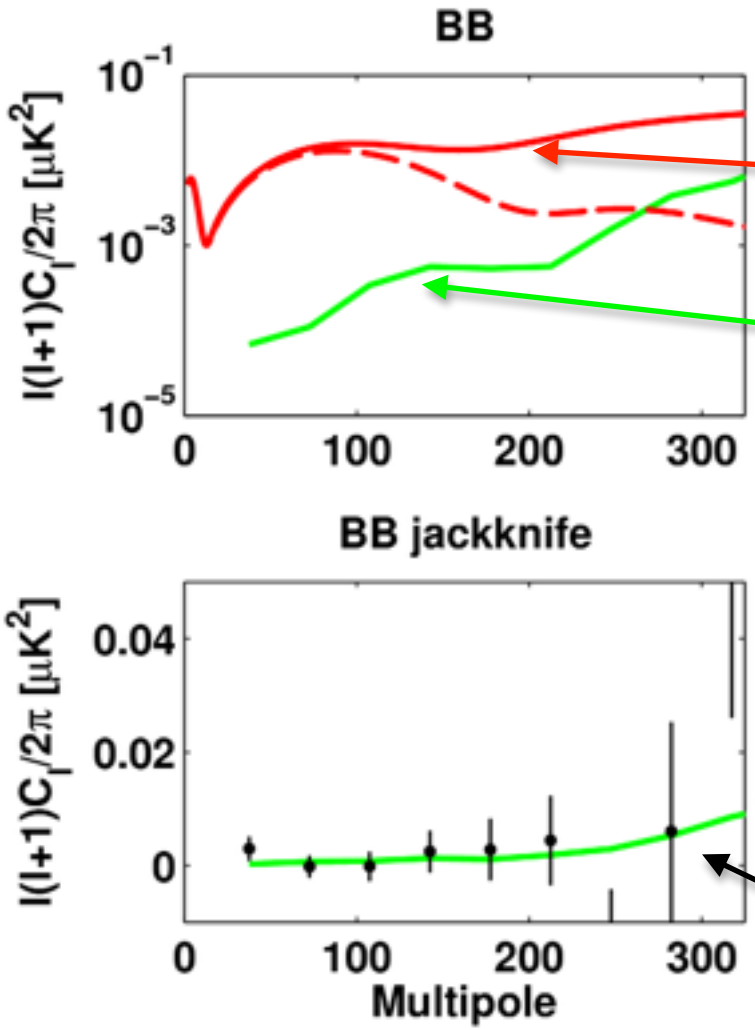
…but the focal plane inner/outer jackknife is still sensitive to it

real data

We know our beam shapes

example: slightly elliptical beams



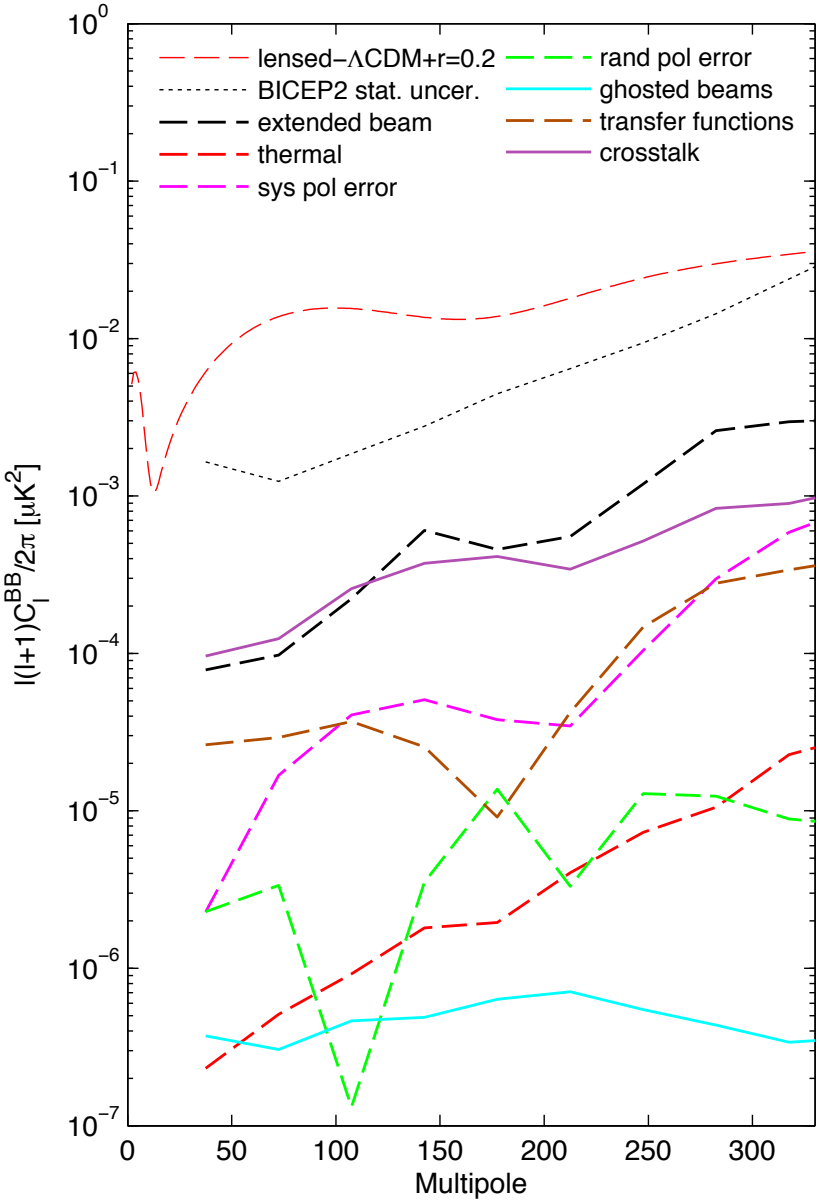
r=0.2 + lensing

With ellipticity deprojection, predicted contamination in BB is still negligible

…and the jackknife cleans up exactly as simulations predict

real data

Instrumental Systematics



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Thanks