Beam Asymmetry Correction

A real space approach to estimating and correcting beam systematics

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Simulating for Beams
Timestream Simulation

- An simulation package developed at APC for the purpose of studying systematics.
- Optimised for a COre like scan strategy
- Uses optimised libraries and MPI parallelised and hence very fast
- Simulation capabilities
  - Realistic pointing for each data point
  - Polarisation angle on the local sky frame for each data point
  - Can add white noise
  - Convolve with a pixelised beam in real space
  - Capable of simulating pointing errors
Pixelised Beams

8′ symmetric beam

Realistic 5.79′ beam. Court. Mark Ashdown

8′, 10% elliptic beam
Convolving with the pixelised beams

- To optimise the simulation, it is important that the beam map resolution match exactly the co-scan scan resolution.
- The beam map is broken up into 1D rows and there is an independent timestream simulation for each row. So for a $N \times N$ beam map there will be $N$ timestreams generated.
- Each such timestream is convolved in Fourier space by its corresponding beam row.
- The convolved timestreams are then summed up to give the beam convolved timestream.
- This method scales as $\sim N$ for a $N \times N$ beam.
- Has the ability to convolve for any arbitrary beam shape.
- Belongs to the computationally intensive but more exact group of analysis techniques.
Beam Convolved timestream signal

- With our pixel space convolution we get a superior simulated signal as compared to scanning from pre-smoothed maps.
- We have better control over pixelisation issues and pointing at different points within the same Healpix pixel.
The data model for our scan is

\[ y_t = A_{tp}s_p + n_t \]

I implement a maximum likelihood map-maker that minimises the \( \chi^2 \)

\[ \chi^2 = (y - As)^T N^{-1}(y - As) \]

which gives

\[ \bar{s} = [A^T N^{-1} A]^{-1} A^T N^{-1} y \]

I implemented a PCG solver that solves for \( s \) from the system of linear equations

\[ [A^T N^{-1} A]s = A^T N^{-1} y \]
Leakage estimation pipeline: Summary

Input map → Convolved map → Deconvolve for circular beam in harmonic space → Estimated leakage map → Deconvolved map
Leakage due to asymmetric beams and correction
Input and Scan Parameters used

- High Resolution T,Q,U CMB only input maps
- $\text{NSIDE} = 4096$ for 4’ and 8’ beams High resolution required for first test of method.
  May be an overkill and possibility for reduction
- No Noise
- COrE like scanning
  - $\alpha = 45^0$
  - $\beta = 45^0$
  - For 8’ and 4’ beams
    - Spin period = 30s
    - Precession period = 190 hrs
    - Sampling rate = 750 Hz
  Such values used just to have no unseen pixels in the scan area
  - Scanned for 1 precession period $\rightarrow \sim 50\%$ of the sky
- 4 bolos in an optimal configuration i.e. at $45^0$ to each other. This makes the $3 \times 3$ covariance matrix diagonal and helps in singling out the systematics I am studying.
- 5% asymmetric beam map size of 4 FWHM
Input and Scan Parameters used

- High Resolution T,Q,U CMB only input maps
- NSIDE = 2048 for 30’ beam High resolution required for first test of method.
  May be an overkill and possibility for reduction
- No Noise
- COrE like scanning
  - $\alpha = 45^0$
  - $\beta = 45^0$
  - For 30’ beams
    - Spin period = 30s
    - Precession period = 110 hrs
    - Sampling rate = 400 Hz
  Such values used just to have no unseen pixels in the scan area
  - Scanned for 1 precession period $\rightarrow \sim 50\%$ of the sky
- 4 bolos in an optimal configuration i.e. at $45^0$ to each other. This makes the 3x3 covariance matrix diagonal and helps in singling out the systematics I am studying.
- 5% asymmetric beam map size of 4 FWHM
$8'$ fwhm beam, major-axis at $45^0$ to polarisation direction
8' fwhm beam, major-axis at $45^0$ to polarisation direction
8' fwhm beam, major-axis at 0° to polarisation direction

\[ \frac{l(l+1)C_l}{2\pi} [\mu K^2] \]

- EE
- BB

\[ r = 0.01 \]
\[ r = 0.001 \]

\( Q \)

\( U \)
$8'$ fwhm beam, major-axis at $0^0$ to polarisation direction
8’ fwhm beam, major-axis at random orientations
8' fwhm beam, major-axis at random orientations
4′ fwhm beam, major-axis at 45° to polarisation direction

\[ I(\lim, 0) / 2 \pi [\mu K^2] \]

Graph showing power spectra for different scenarios with labels EE and BB, and different values for r (0.01, 0.001).

Images showing polarisation maps with color scales indicating leakage in Q and U.
4′ fwhm beam, major-axis at 45° to polarisation direction
30' fwhm beam, major-axis at 45° to polarisation direction

**Q**

Leakage

1.3 gsp, 200,000 px

-2

-1.5

0

1.5

**U**

Leakage

1.3 gsp, 200,000 px

-2.24

2.07
30' fwhm beam, major-axis at 45° to polarisation direction
Leakage comparison, major-axis at $45^0$ to polarisation direction
Residue comparison, major-axis at $45^0$ to polarisation direction
• We see that the leakage due to beam asymmetries is significant, especially for the 30’ beam, given our target of $r = 0.001$.

• With our map level correction we have a noticeable improvement on the leakage and is promising as these results are very recent and has scope for maturing.

• This opens up the possibility of measuring many more $l$ modes of the lensing BB spectra and the ability for delensing.

• It also opens up the possibility to measure many more $l$ modes for unlensed BB.

• This is important for complementing similar work done on the harmonic and power spectrum space.
Future Work

- We are at an early stage of our analysis and hence large scope for improvement.
- Do analyses with
  - White Noise
  - 1/f Noise
  - Realistic T,Q,U beams
  - Include other systematics