Beam Asymmetry Correction

A real space approach to estimating and correcting beam systematics

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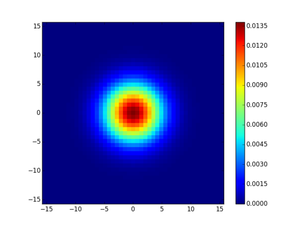
Simulating for Beams

Timestream Simulation

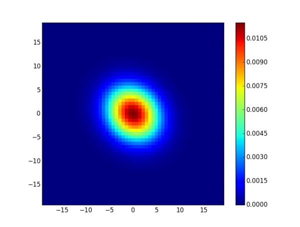
- An simulation package developed at APC for the purpose of studying systematics.
- Optimised for a COrE like scan strategy
- Uses optimised libraries and MPI parallelised and hence very fast
- Simulation capabilities
    - Realistic pointing for each data point
    - Polarisation angle on the local 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

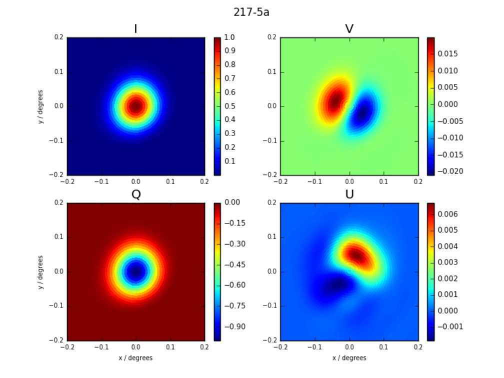
8′ symmetric beam



8′, 10% elliptic beam



Realistic 5.79′ beam. Court. Mark Ashdown

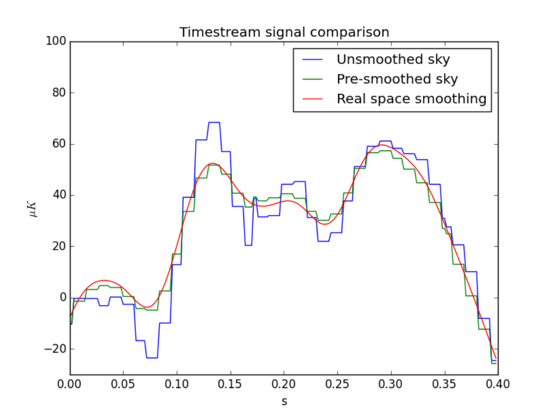


Convolving with the pixelised beams

- 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 *NxN* beam map there will be *N* timestreams generated.
- Each such timestream is convolved in Fourier space by it's corresponding beam row.
- The convolved timestreams are then summed up to give the beam convolved timestream.
- This method scales as $\sim N$ for a *NxN* 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 timestrem 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.



Data Model and Map making

- 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 χ^2

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

which gives

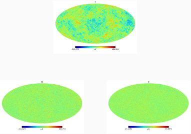
$$\bar{s} = [A^T N^{-1} A]^{-1} A^T N^{-1} y$$

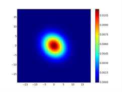
- I implemented a PCG solver that solves for s from the system of linear equations

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

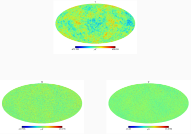
Leakage estimation pipeline : Summary

Input map



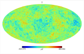


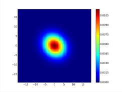
Convolved map



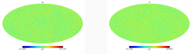
Deconvolve for circular beam in harmonic space

Deconvolved map





Estimated leakage map



Leakage due to asymmetric beams and correction

Input and Scan Parameters used

- High Resolution T,Q,U CMB only input maps
- 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 $3x3$ covariance matrix diagonal and helps in singling out the systematics I am studying.
- 5% asymmetric beam map size of 4 FWHM

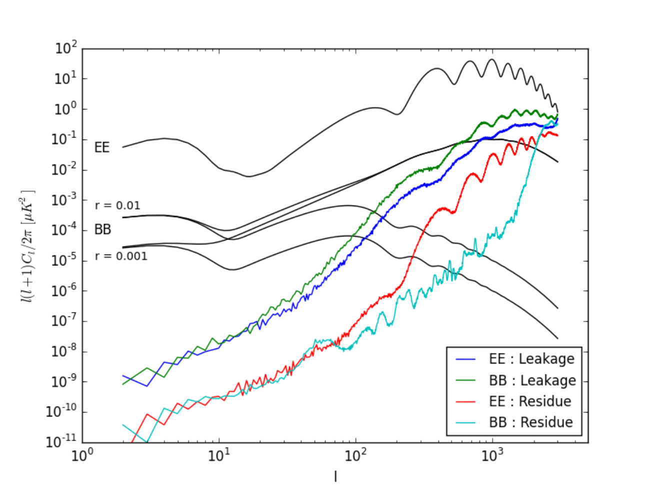
Input and Scan Parameters used

- 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



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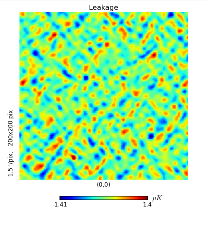

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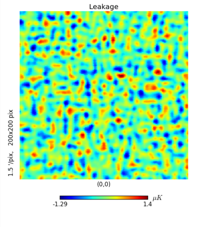
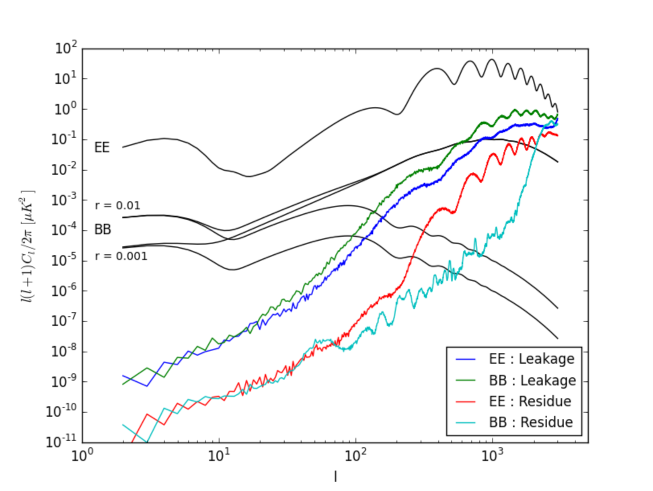


$8'$ fwhm beam, major-axis at 45^0 to polarisation direction



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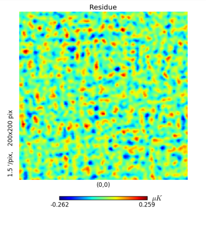

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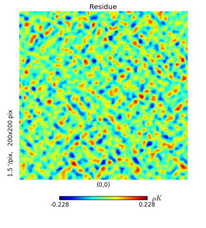
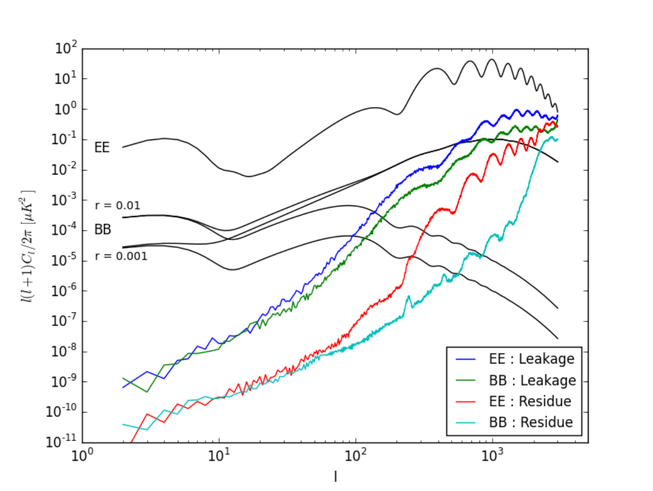


$8'$ fwhm beam, major-axis at 0^0 to polarisation direction



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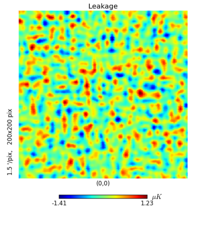

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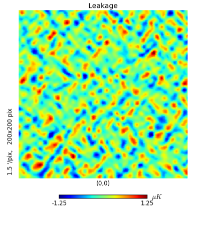
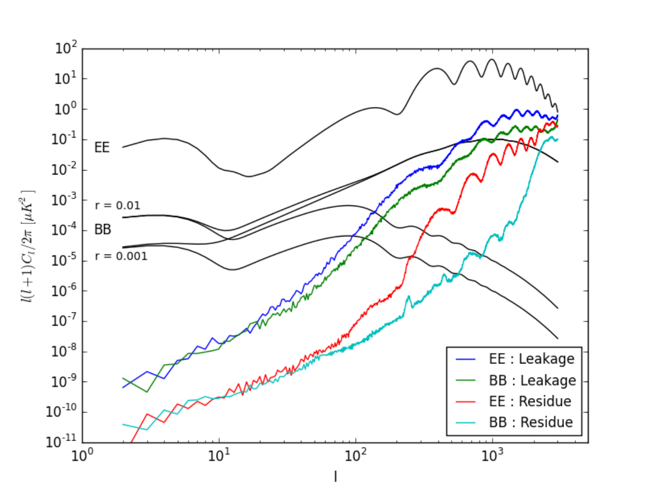
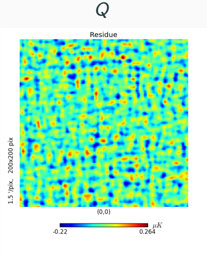
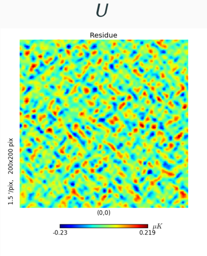


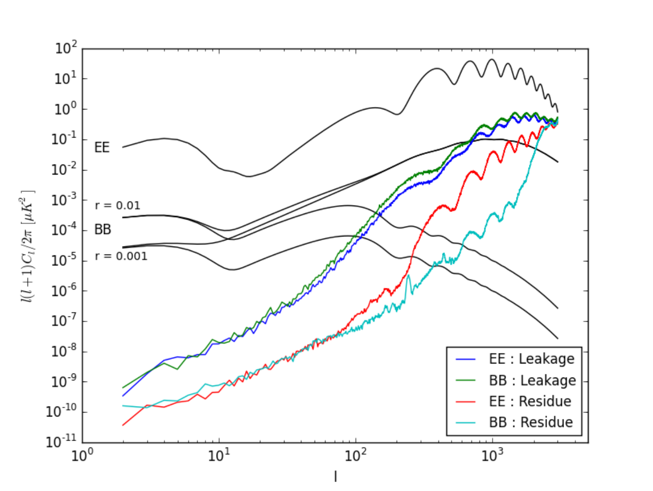
$8'$ fwhm beam, major-axis at 0^0 to polarisation direction







$8'$ fwhm beam, major-axis at random orientations



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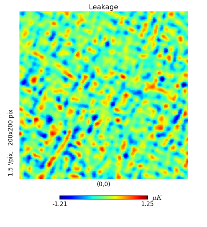

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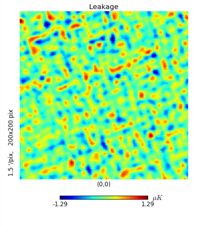
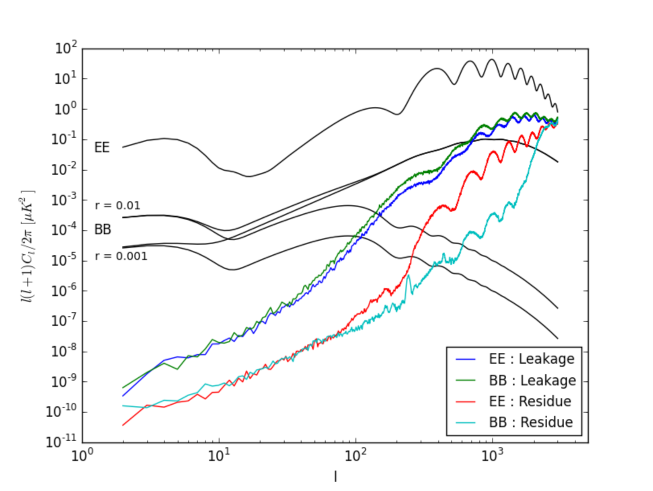


$8'$ fwhm beam, major-axis at random orientations



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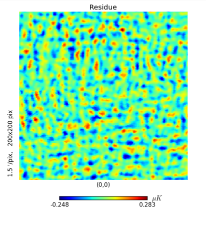

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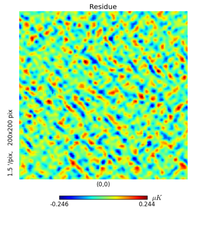
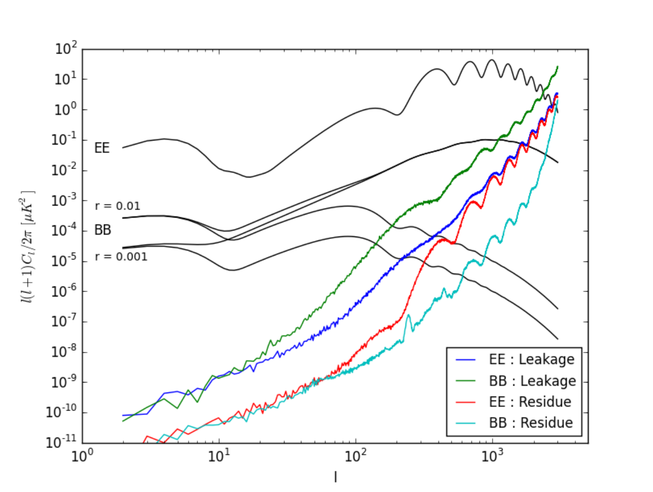


$4'$ fwhm beam, major-axis at 45^0 to polarisation direction



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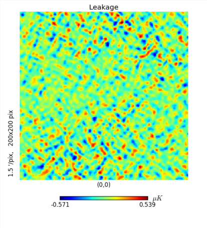

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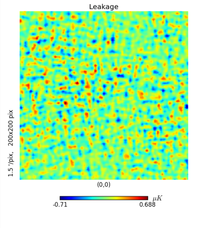
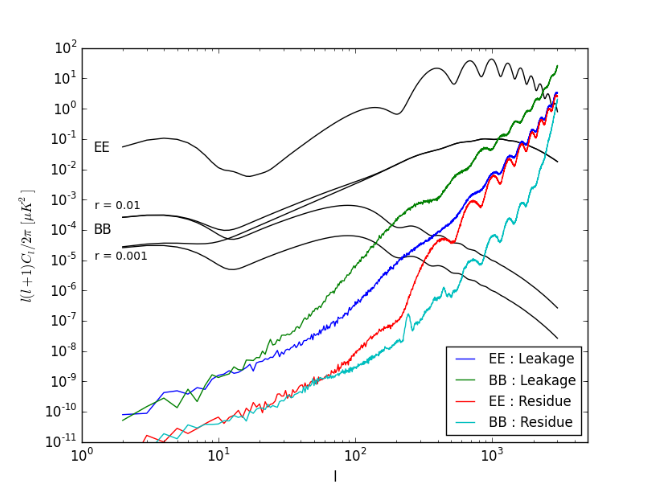


$4'$ fwhm beam, major-axis at 45^0 to polarisation direction



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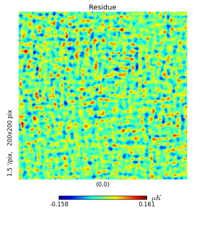

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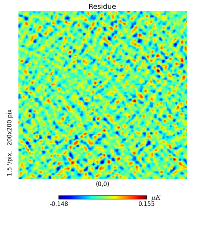
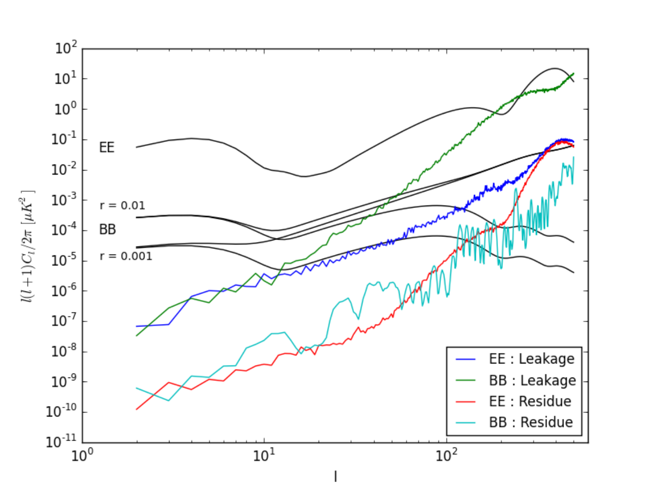


$30'$ fwhm beam, major-axis at 45^0 to polarisation direction



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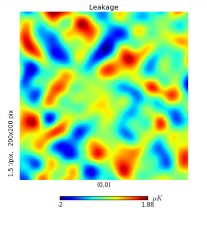

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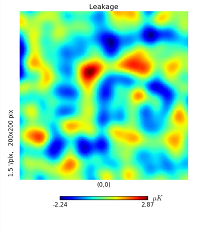
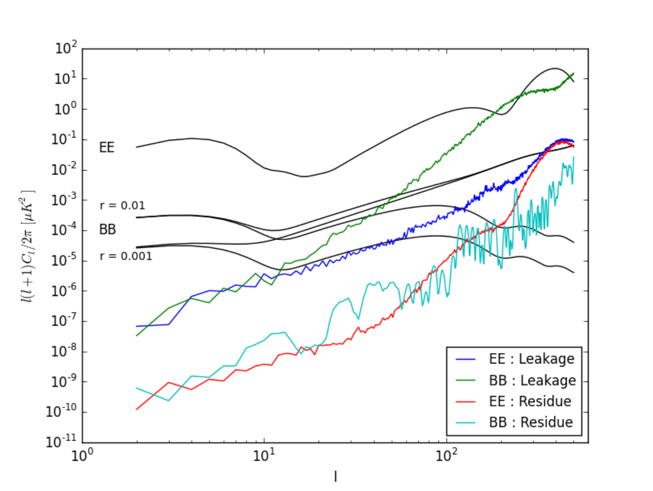


$30'$ fwhm beam, major-axis at 45^0 to polarisation direction



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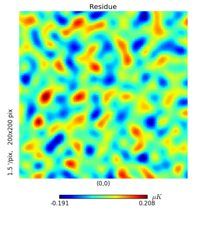

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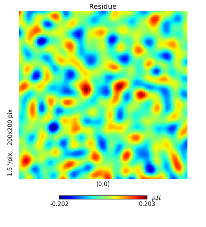
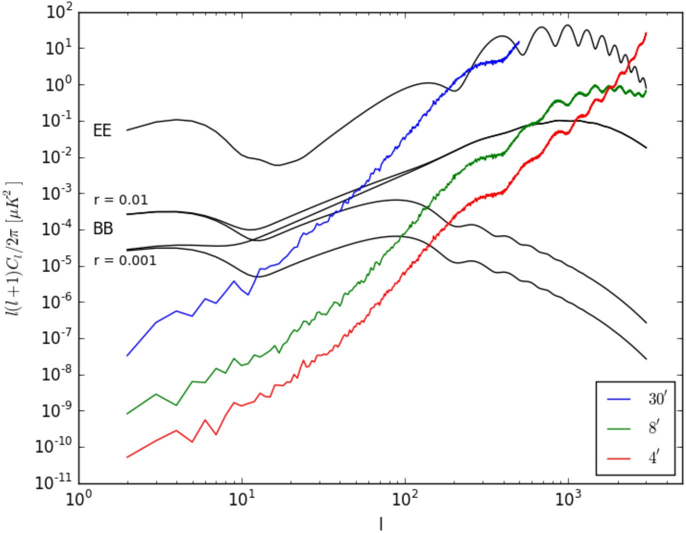
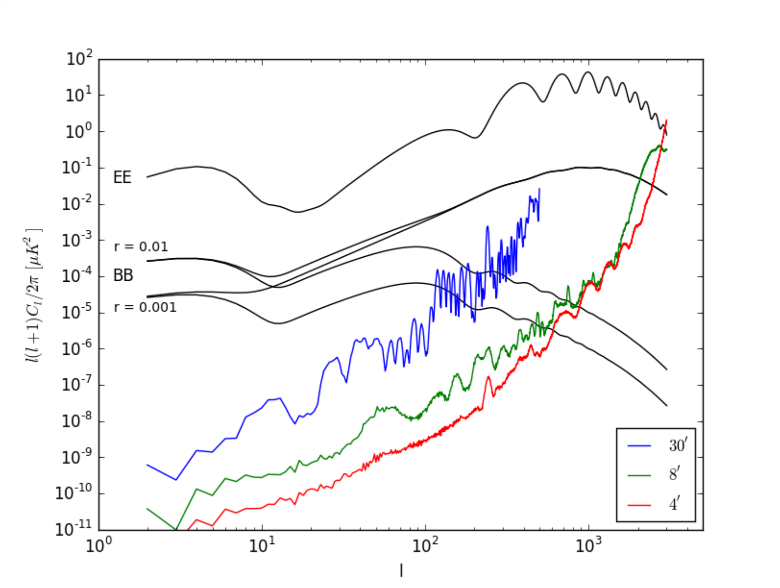


Leakage comparison, major-axis at 45^0 to polarisation direction



Residue comparison, major-axis at 45^0 to polarisation direction



Outlook

- 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