Beam Modeling in MeqTrees

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and

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MeqTrees

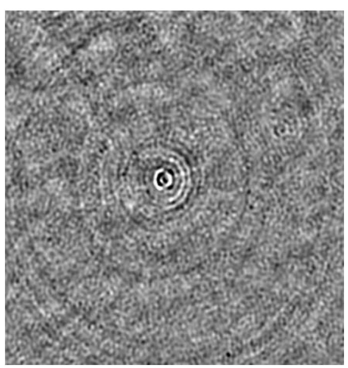
- MEQ: Measurement EQuation, Mathematical EQuation
- Any Equation defined as a tree (using python)
- Equation is solved/simulated using a server (C++)
- Easy to define equations, without sacrificing speed
- Example

$$a\sin(x) = bx^2 - c \;\rightarrow \hat{x} = \arg\min_{x} \|a\sin(x) - bx^2 - c\|^2$$

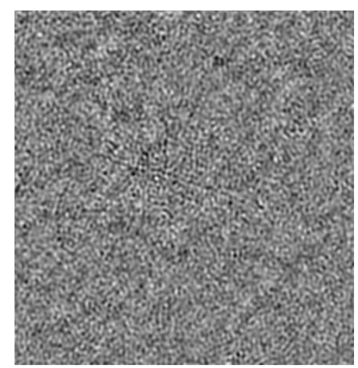
  solve for x given a, b, c
- Highly parallelized: threads, MPI
- Highly vectorized: BLAS, LAPACK
- Includes debugging, profiling facilities
- Extremely powerful visualization
- Opensource, GPL software
- http://www.astron.nl/meqwiki

MeqTrees for Astronomy

- Fully compliant with matrix measurement equation [Hamaker,Bregman,Sault 96]
- Supports AIPS++ Measurement sets
- Supports FITS files
- Supports AIPS++ measures, JPL ephemeris etc.
- Supports variety of sky models
- Extended sources: shapelets, Gaussians, images, disks etc.

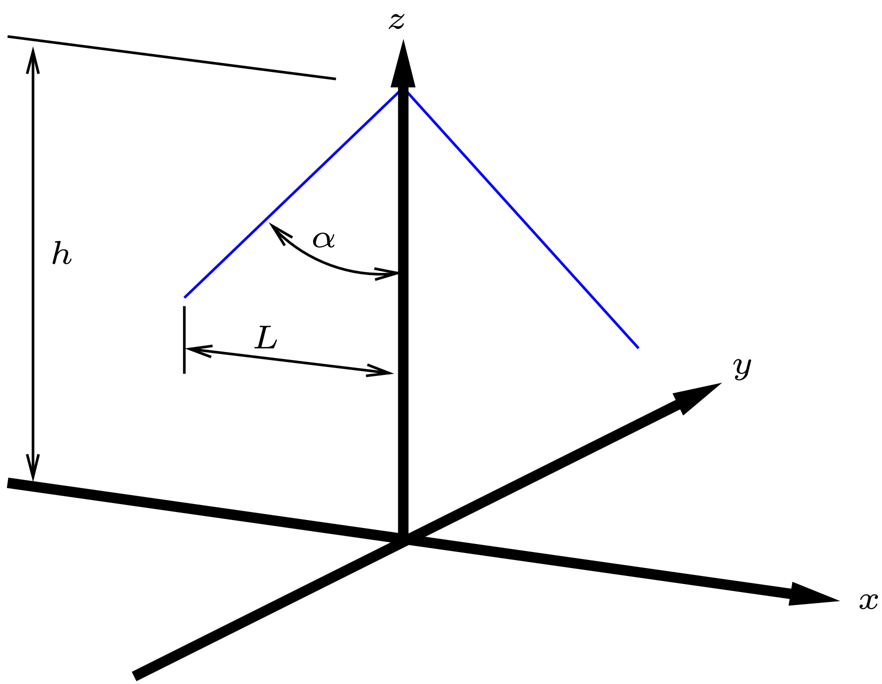


Before

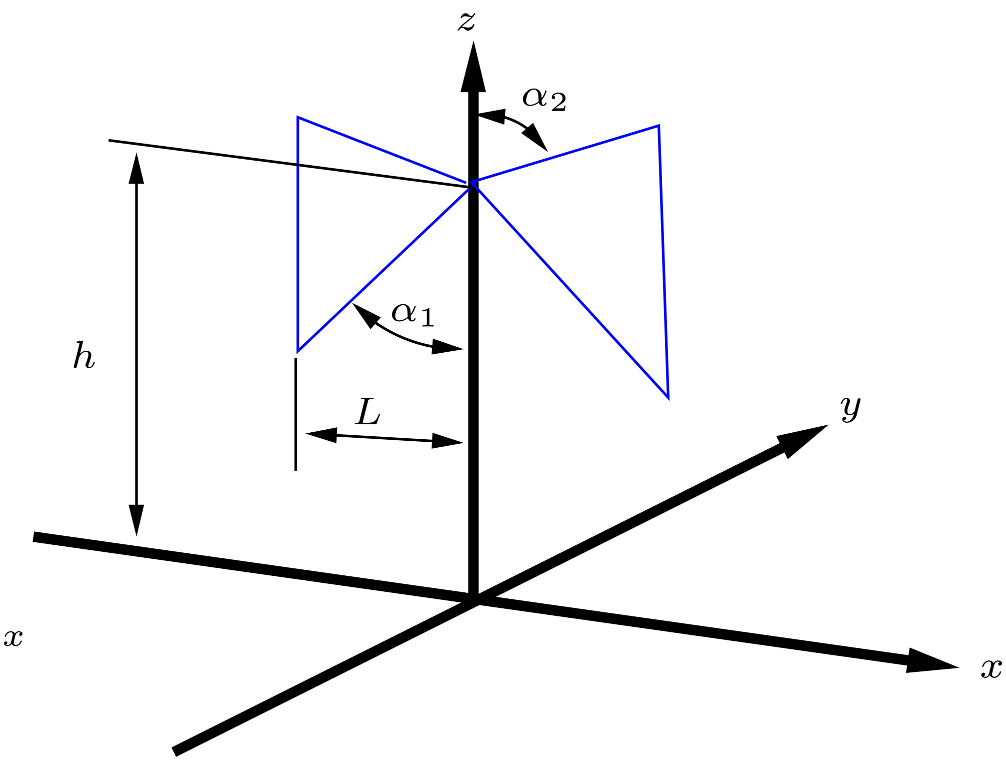


After

Dipoles

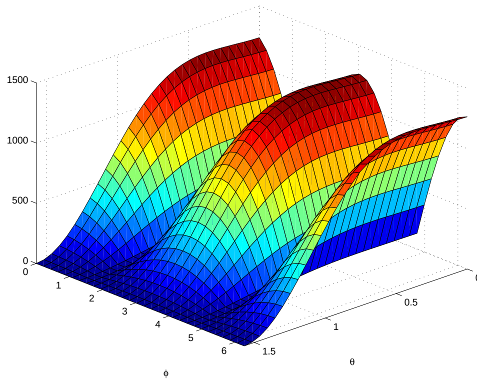


LBA X dipole geometry

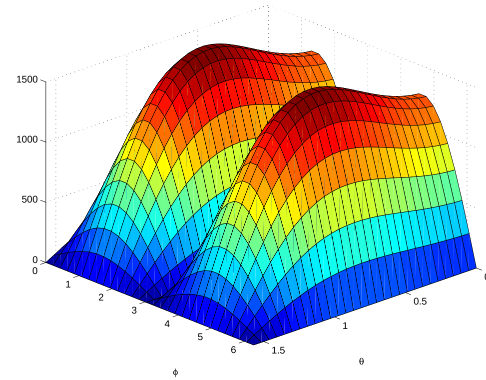


HBA X dipole geometry

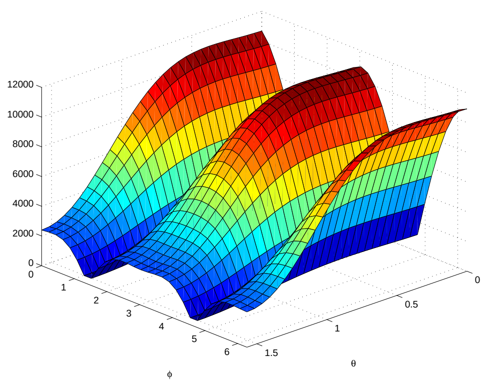
Dipole Beamshapes



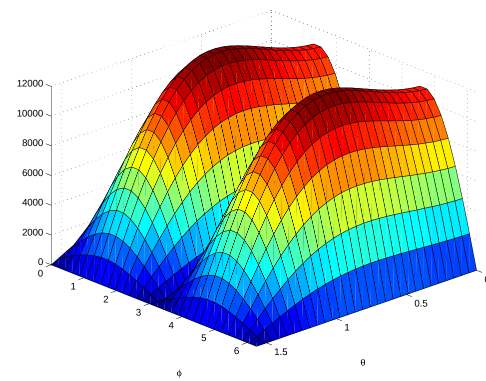
LBA $|E_\theta|$, 80 MHz



LBA $|E_\phi|$, 80 MHz



HBA $|E_\theta|$, 240 MHz

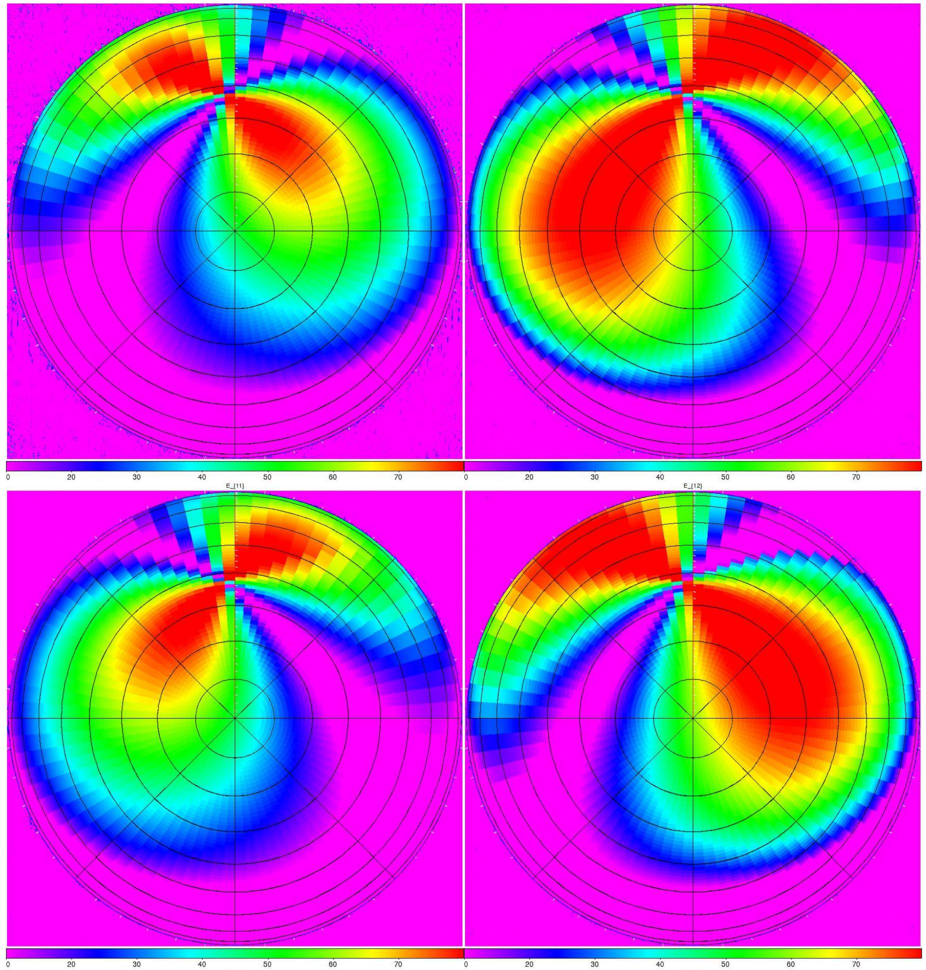


HBA $|E_\phi|$, 240 MHz

Beamshapes in MeqTrees

- Analytic beams: exact expression is implemented in C++
  - Dipoles: linear, thin wire dipoles on infinite ground plane
  - Narrowband station beamformer (with mutual coupling)
- Numerical beams: Electromagnetic simulations: FITS cubes
- Solving for true beamshapes
  - Use *a priori* knowledge: use a beam model
  - Solve for the error in beam model using an orthonormal basis (polar shapelets)

Dipole beam and the sky



Magnitude of $\mathbb{E}$ Jones matrix projected onto the sky, 10 min time, NCP image, zenith on top

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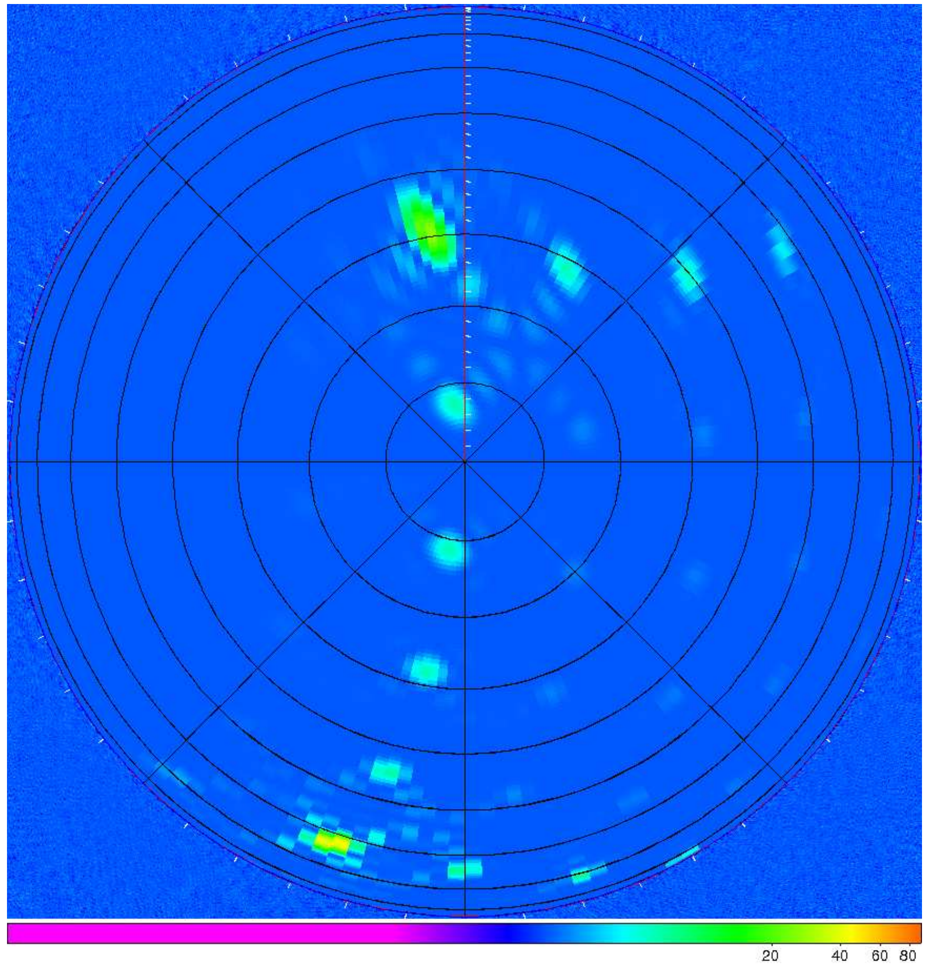
Station Beam

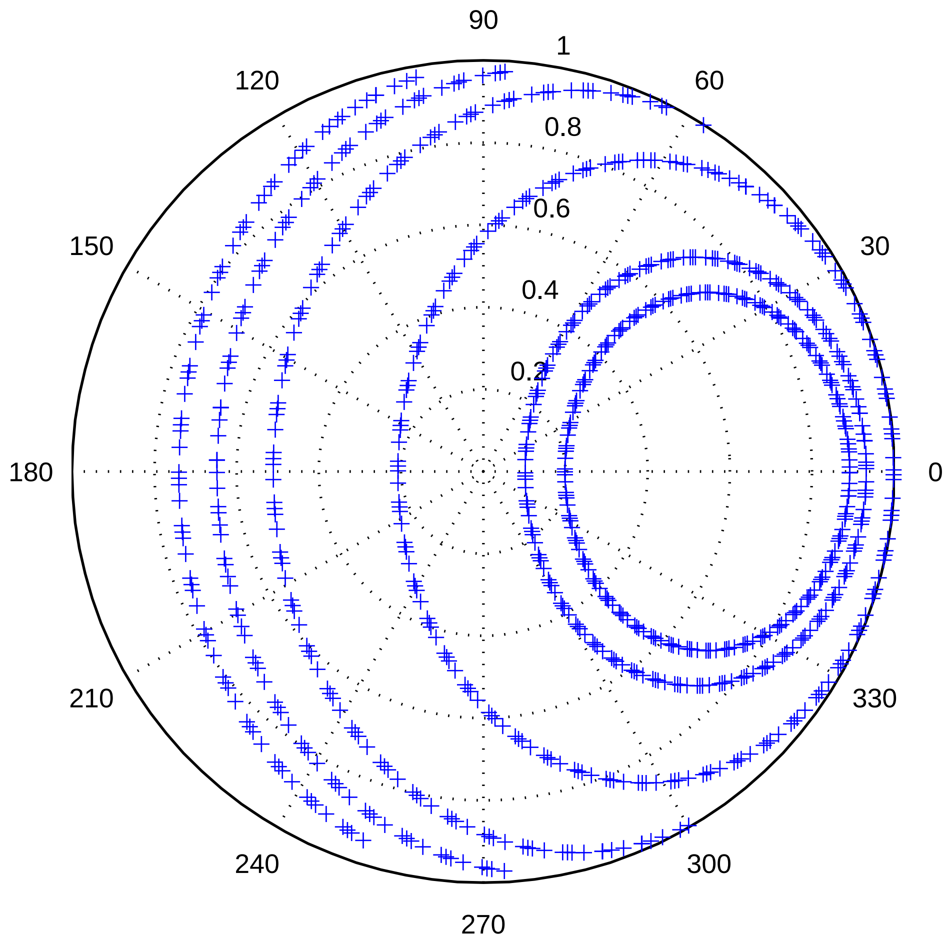


Magnitude of $\mathbb{E}$ Jones matrix projected onto the sky, 10 min time, NCP image, zenith on top

Use of beamshapes

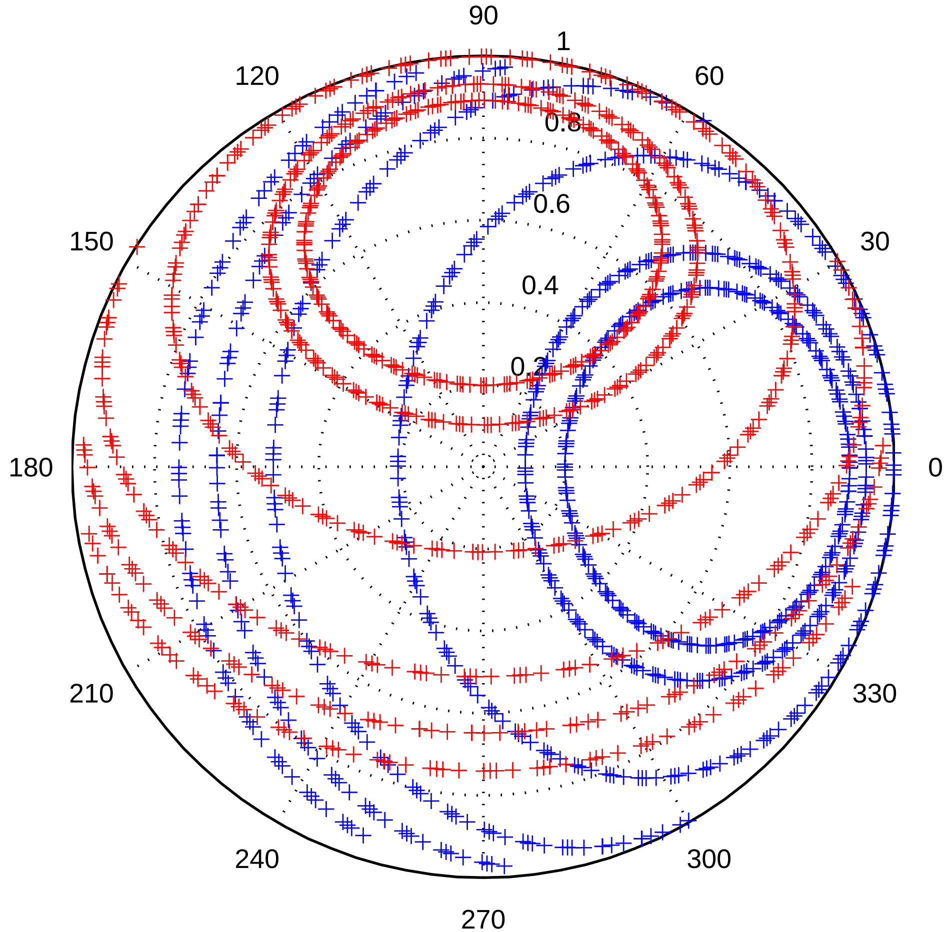
- Estimation of unknowns:
  - Clock delays (phase shifts) and electronic gains
  - Ionospheric effects
  - Source fluxes
- Removal of strongest sources Cas A, Cyg A, Tau A, Vir A ...
- Solving for true beamshapes
  - Use *a priori* knowledge: use a beam model
  - Solve for the error in beam model using an orthonormal basis (polar shapelets) [Massey and Refregier, 2005]
  - Accurate sky model required

Trajectories



24hr, 4days, X dipole

Trajectories



24hr, 4days, X,Y dipoles

Constraints

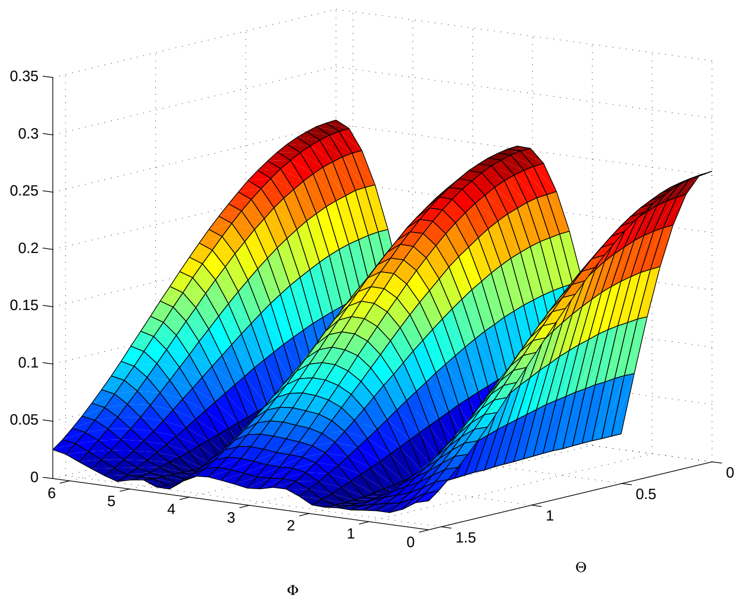
$$\|\widehat{\mathbf{C}} - \mathbf{E}(\boldsymbol{\theta})\mathbf{C}\mathbf{E}(\boldsymbol{\theta})^H\|^2$$

- $\mathbf{C}$, source coherency, $\widehat{\mathbf{C}}$ estimate

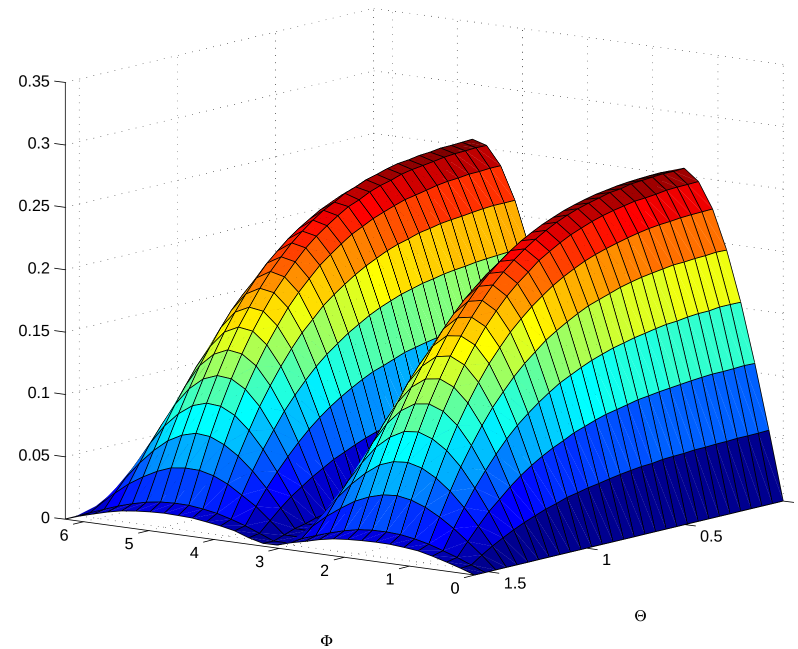
$$\mathbf{C} \triangleq \left[\begin{array}{cc} I+Q & U+jV \\ U-jV & I-Q \end{array} \right]$$

- $\boldsymbol{\theta}$, beam parameters (polar shapelet modes)
- Non linear least squares problem in $\boldsymbol{\theta}$
- Linear least squares problem in fluxes I, Q, U, V

Initial Beam

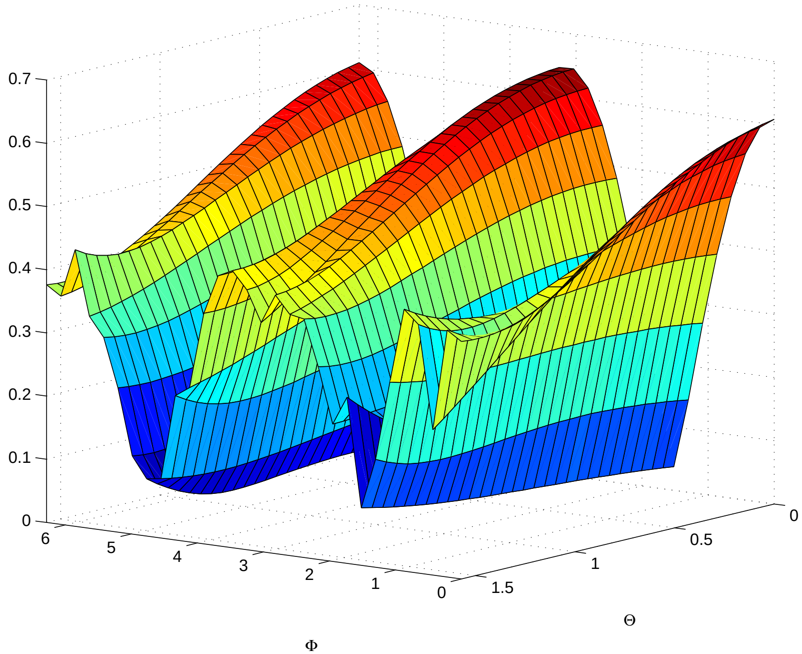


$$|\mathbf{E}_\theta(\boldsymbol{\theta})|$$

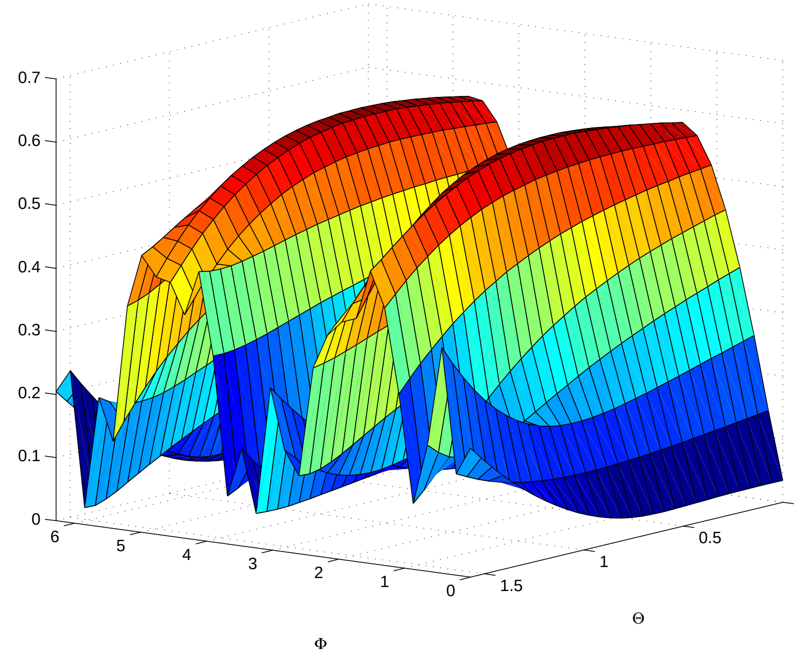


$$|\mathbf{E}_\phi(\boldsymbol{\theta})|$$

Solved Beam



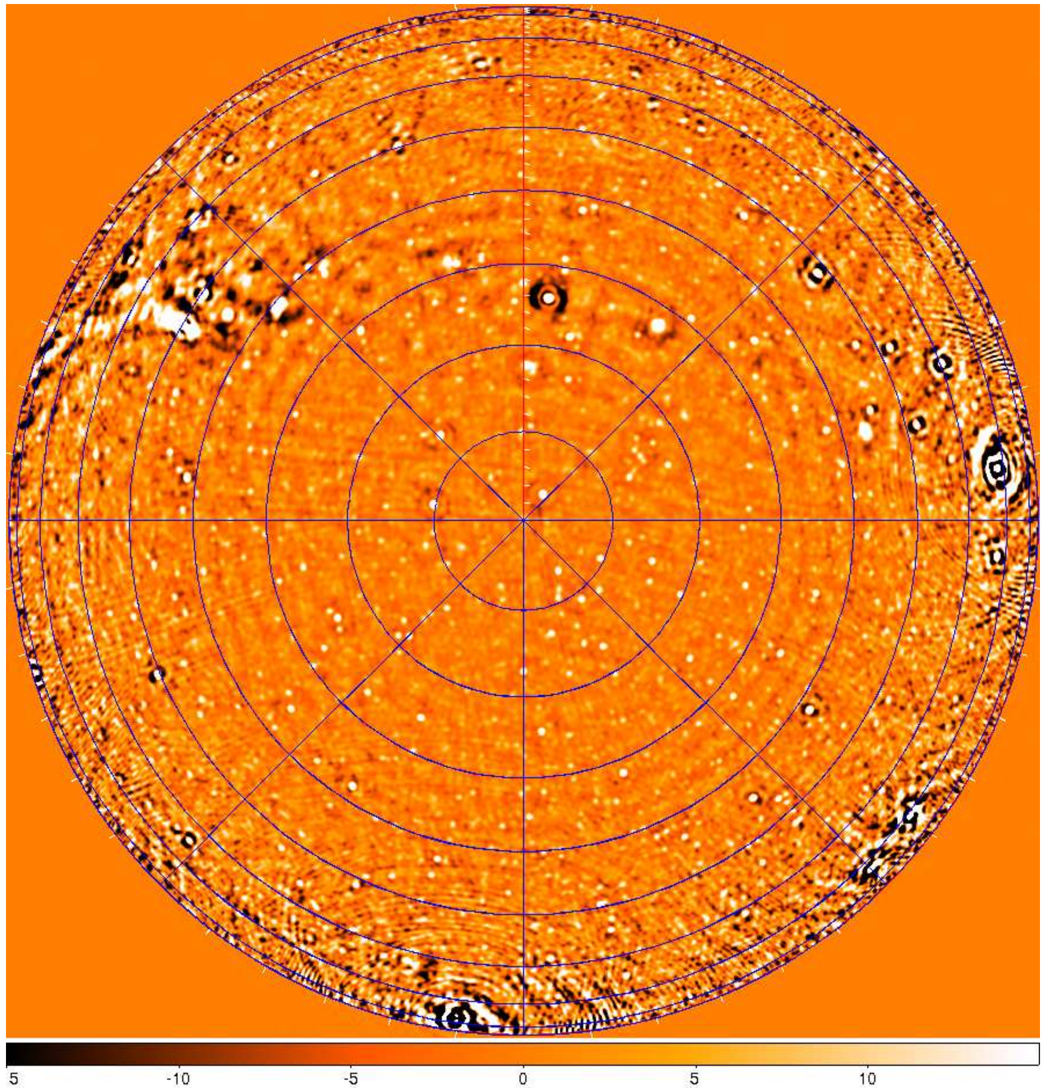
$|\mathbf{E}_\theta(\boldsymbol{\theta})|$



$|\mathbf{E}_\phi(\boldsymbol{\theta})|$

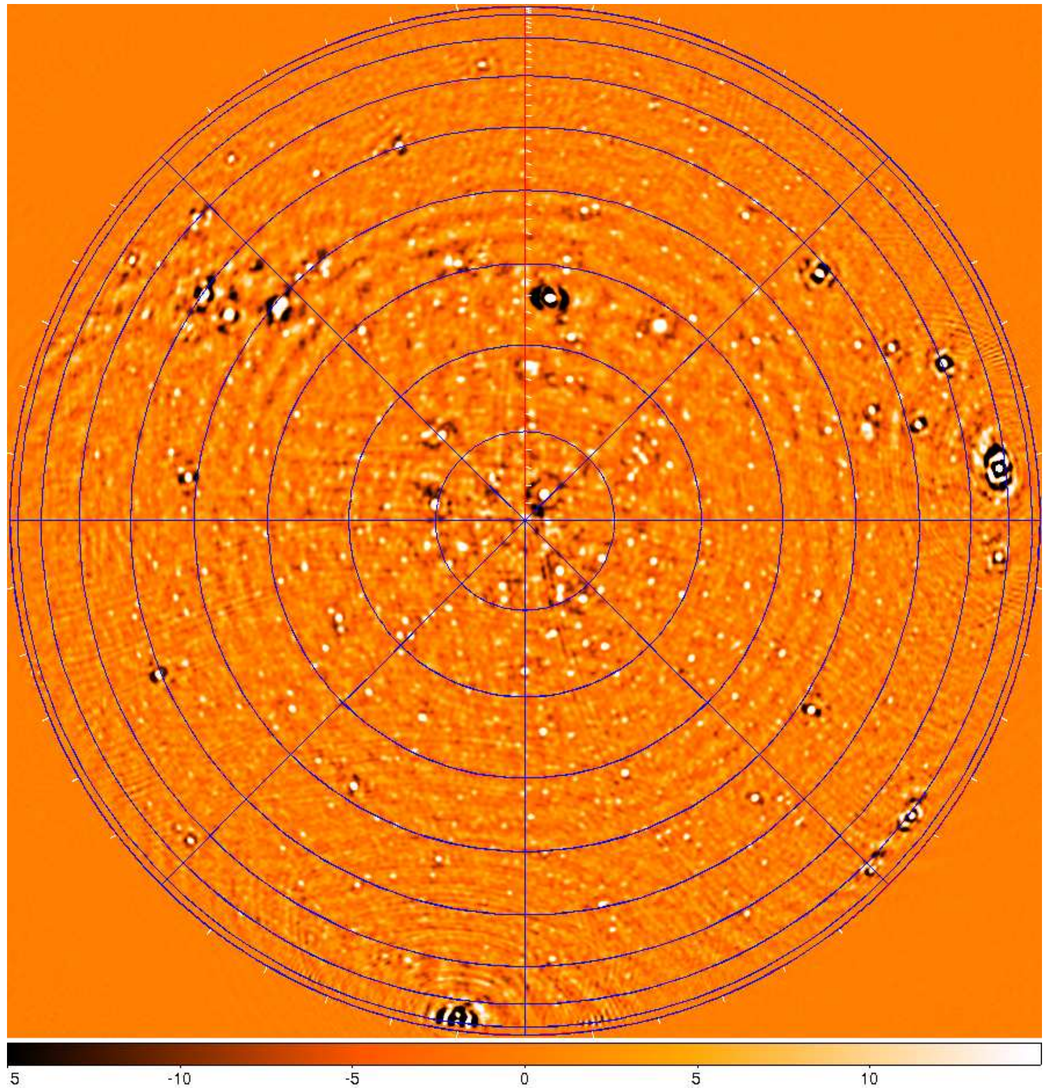
solution not good below 10 deg elevation (yet!)

Beam correction: method 1



LBA image, NCP, correction for average beam

Beam correction: method 2



LBA image, NCP, correction for snapshots

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