Imaging and Ionospheric Calibration

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Making Real-Time Images

• The Mapper and Iono-Cal workpackages produce calibrated images in RA/Dec: in real-time C.
• Inputs:
  – visibilities rotated to relevant sky position and binned to appropriate FOV.
  – true positions of ionospheric calibrator sources.
  – Small maps of out-of-beam ionospheric calibrators.
• Outputs:
  – Full Tile Maps: ASM, Survey/GSM
  – 2deg Solar Map: Solar Imaging
  – ~100 small maps: Ionospheric Calibration
  – 2-D Ionospheric calibration for correcting images and subtracting out-of-beam sources: parameterized func.
Imaging Data Flow

- **BINNER**
  - (u,v,f,p) data Rotated to FOV 32kHz channels
  - FFT
  - In relative coordinates

- **BUFFER**
  - Oversampled ‘Dirty’ Cube 4 pol, 32kHz Every 8 sec
  - To Hold for Ionospheric Cal
  - Coord xform to RA/DEC

- At last apparent position of sources
  - Postage Stamp Maps of 100 Cal’s 4 pol, 8 sec
  - Iono Cal
    - Iono cal De-distortion.

- **GSM**, **SURVEY**, **ASM**
  - Map in RA/DEC 32kHz, 4 pol Average to 100s
  - Map in RA/DEC 96kHz, I pol Every 8 sec
Widefield Imaging

• Breakdown of 2-D Fourier (uv, sky) xform:

\[ \varphi = 2\pi w(\sqrt{1 - l^2 - m^2} - 1) \geq 1 \]

• If co-planar array then coord transform allows application of 2-D Fourier Transform again.

• If not, how many w-planes necessary:

\[ \# w-planes : 2\pi \Delta w \]

- \( \sim \) of order a few w-planes (10).

• Then 2-D FFT and a few DFT’s to account for w-planes: 3-D deconvolution required for later image processing.
Widefield Imaging cont’d

- Can create widefield image by facets, each imaged and deconvolved separately and combined later.
- Use w-projection algorithm to project and grid $V(u,v,w)$ points to $V(u,v,w=0)$ and then use 2-D FT to obtain image: about an order of magnitude faster than faceting.
- Issue: where is widefield computation done
  - binner (w-projection, facets)
  - mapper (3-D solution, facets).
Subtracting the GSM

• Despite binning to tile (or solar) FOV, out-of-beam sources will contribute to image noise level via PSF sidelobes.

• Use instrumental and ionospheric cal to accurately subtract these sources:
  – From \((u,v)\) data in binner
  – Or, from images in mapper.

• Image deconvolution via GSM subtraction within FOV.
Ionospheric Calibration for the LFD

- Over the LFD, the ionosphere has a position dependent refraction effect.
- Ionospheric calibration involves fitting the image plane distortions by using the observed offsets of known calibrators.
- Sources in the Global Sky Model can then be subtracted from the UV data and position dependent ionospheric shifts can be removed from images.
- Simulation results of this algorithm show promise.
Modeling the Ionosphere

- Kolmogorov Turbulence (2km to 100km)
- Chapman density profile
- 3-D ionosphere placed above array.
- Line integrals through ionosphere above each element provide ionospheric phase across field of view
MAPS

• For each baseline, the position dependent differential phase is fourier transformed and convolved with (u,v) data.
• Convolved (u,v) data are numerically integrated to give ionospherically corrupted visibility.
• Imaging shows distorted sky.
Refractory Offsets of Calibrators
Offsets of all sources
Finding best fit polynomial

- Cotton uses Zernike polynomials: 74MHz VLA has \(~10\) calibrators in 10deg sq field.
- MWA will have \(\sim200\) calibrators in same field.
- Sean Ting (REU) implemented algorithm to generate orthogonal polynomials over basis of calibrator positions.
- Makes estimation of most likely solution straightforward.
9th Degree Poly fit to calibrator offsets
Residuals to 9th degree Offset model
Simulations

- 8x8 sq degree field
- 200MHz, MWA beam ~210 arcsec
- ~330 sources, some number of them calibrators (variable).

• Questions:
  - What degree of poly is best given a fixed number of calibrators?
  - How well can method perform?
RMS residuals vs degree poly fit
Results

- RMS residuals with 9 degree poly gets down to ~2-3% of beam offset.
- Sidelobe noise (after GSM subtraction) ~ \( \frac{1}{N_{\text{stat}}} \) * (beam fraction offset) * (integrated flux density of sources) ~ 10 uJy
- Compares to thermal noise of MWA in ~1000 hours.
- Need to put real sky into simulations and verify sidelobe noise.
Outlook

• Outstanding Issues:
  – Widefield approach and implementation (location).
  – GSM subtraction and implementation (location).
  – Establish standard interface for image x-fer.

• No major risks, all algorithms exist, but must be tailored and tested for LFD implementation
  – will require effort.

• Advantage: Mapper and Iono-cal amenable to rigorous testing with simulated data and applicable to some existing data sets (VLA).

• Skills: Interferometric imaging, fitting software, algorithm implementation, testing.

• Reliant only on binner.