Data Management & Characterization: Pipeline Approaches to Calibration/Reduction

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NRL
The LWA & the VLSS

- VLSS 74 MHz all sky survey will deliver initial calibration grid for LWA
  - Appropriate for LWA frequencies (< 100 MHz)
- Currently driving calibration algorithms to new levels of sophistication
  - 1\textsuperscript{st} step: imaging without self-calibration now possible
  - 2\textsuperscript{nd} step: “educate self-cal” to relax finite IP assumption
- Also driving pipelined reduction software – emerging ionospheric weather diagnostics
VLSS: Good science, Good for the LWA

• Deepest and largest long wavelength survey
  – N \sim 10^5 \text{ sources in } 10.3 \text{ sr} – 80\% \text{ of sky}
  – Statistically useful samples of rare sources
    • Large, unbiased samples of steep spectrum sources
  – Key radio galaxy sample immune from beaming effects
    • Dominated by isotropic emission
    • Unbiased view of parent populations for unification models
  – Exploitation of long wavelength absorption effects
  – Unique images of many resolved radio sources
• Key initial calibration grid for the LWA
Key LWA Calibration Hurdle:
Relaxing the finite Isoplanatic Patch assumption

• Current self-calibration assumes constant ionospheric solution across field of view
  – Assumption physically valid over much smaller region: \( \sim 1^\circ \) even for 74 MHz VLA (35 km)
  – Serious problems: differential refraction, image distortion, reduced sensitivity

• Zernike polynomial phase screen correction now available prior to self-calibration

• Next step is to introduce angular dependence of selfcal solutions based on a priori phase screen model:
  \( \varphi_i(t) \Rightarrow \varphi_i(t, \alpha, \delta) \)
Breakdown of Finite Isoplanatic Patch Assumption

Image Distortion

Differential Refraction

12 km Isoplanatic Patch

35 km Isoplanatic Patch

Sidelobe Confusion

Striping due to sidelobe confusion from a far-off source in a completely different IP

~15°
Field Based Calibration

- Non-selfcal reliant imaging code developed for VLSS
  - Visibility modeled as combination of instrumental, source, and time variable ionospheric terms
    - Determine instrumental complex gain – “filter out” ionospheric terms
    - Establishes WENSS/NVSS source grid around pointing position.
    - Determines offsets of apparent positions from their expected positions
    - Uses time series of fitted offsets to model ionospheric distortions using Zernike polynomials
    - Removes ionospheric distortions, images & CLEANs visibilities
- Self-cal – VLAFM comparisons
- Effectiveness measured by emerging “ionospheric seeing” diagnostics
  - Phase behavior as function of time
  - 1D, 2D Phase structure functions
Self-cal vs. Field Based Calibration
Comparisons (courtesy W. Tschager)

An unresolved source:

A resolved source:

Pure self-cal Pure CA “Hybrid”
Phase Delay Screen Modeling

1D – phase structure function

Before Zernike Model

After Zernike Model
Phase Delay Screen Model
(Zernike polynomial models – courtesy B. Cotton, J. Condon)

Fitted model ionospheric phase Delay screen rendered as a plane in 3-D viewed from different angles.
Cool Sky Movie
(courtesy B. Cotton)

Cool Sky Sources
A array 74 MHz

Cool Sky Zernike Model
A array 74 MHz
Emerging Ionospheric Weather Diagnostics

VLA Raw Phases (courtesy W. Tschager)

“Good day”

“Bad day”

Plot file version 7 created 24-MAR-2001 20:14:27
Gain phs vs IAT time for FIELD05.CLIP.1
SN 2 Rpol & Lpol IF 1

Plot file version 7 created 27-MAR-2001 12:19:15
Gain phs vs IAT time for FIELD12.TASAV.1
SN 12 Rpol & Lpol IF 1
Emerging Ionospheric Weather Diagnostics

VLBA Phases (courtesy G. Taylor)

“Good day”  “Bad day”
Emerging Ionospheric Weather Diagnostics

2D – phase structure function (courtesy W. Erickson)

“Good day”

“Bad day”

Looks promising, but unfortunately no “silver bullet” ionospheric weather diagnostic has yet been found.
VLSS Pipeline

- “Continuously” monitor Cygnus A and Virgo
- Determine BP and instrumental complex gain by filtering “out” time variable ionospheric terms
- Determine RFI excision grid
- Apply basic gain/BP calibration
- Filter RFI from the visibility data
- Average down spectral data base
- Establish grid of NVSS/WENSS sources around pointing positions
- Image and attempt to CLEAN NVSS/WENSS grid
- Determine offsets of the apparent positions from their expected positions
- Use time series of fitted offsets to model the ionospheric distortions using Zernike polynomials.
- Remove the modeled ionospheric distortions
- Image and CLEAN the resulting visibilities.
LWA Pipeline (continuum)

On a continuous basis, at modest bandwidth/temporal frequency:

* Determine Complex Gain & BP Response (Cyg, Cas, Vir)

Observe Basic Calibration Grid (VLSS/WENSS)

Determine Ionospheric Models/Weather

Determine RFI Excision Grid

Determine Frequencies of Observation

*Can we do this non-astronomically??
LWA Pipeline (continuum)

At full bandwidth apply the following pipeline procedure for imaging over a range of “good” frequencies

- Acquire full resolution data streams for range of “good” freq. ν1, ν2, ν3 ...
- For νx, science program y, apply basic calibration
- Remove RFI
- Store data at maximum bandwidth for future reference
- Deliver averaged uv data and image to observer with detailed “history” file
- Self-calibrate & image “through” a priori determined ionospheric model
- Average data to BW required by science program

5/23/2001 LWA Data Management
Summary

• VLSS survey/related 74 MHz Observations
  – delivering key initial calibration grid for LWA
  – driving pipeline reduction processes with lessons for LWA
• Emerging non-self-calibration reliant imaging algorithms
  – Developed for VLSS and related 74 MHz observations
  – Premium on determining instrumental complex gains
  – LWA should be designed so that it is capable of determining this independent of astronomical observations
• Emerging ionospheric weather diagnostics
  – Will greatly aid dynamic management of LWA data acquisition
  – Ionospheric turbulence: site & time dependent?
• Future
  – On verge of “educating self-calibration” by observing through a priori determined ionospheric model
  – Soon we can finally relax finite Isoplanatic Patch assumption
  – Fundamental breakthrough for the LWA