Data Management & Characterization: Pipeline Approaches to Calibration/Reduction

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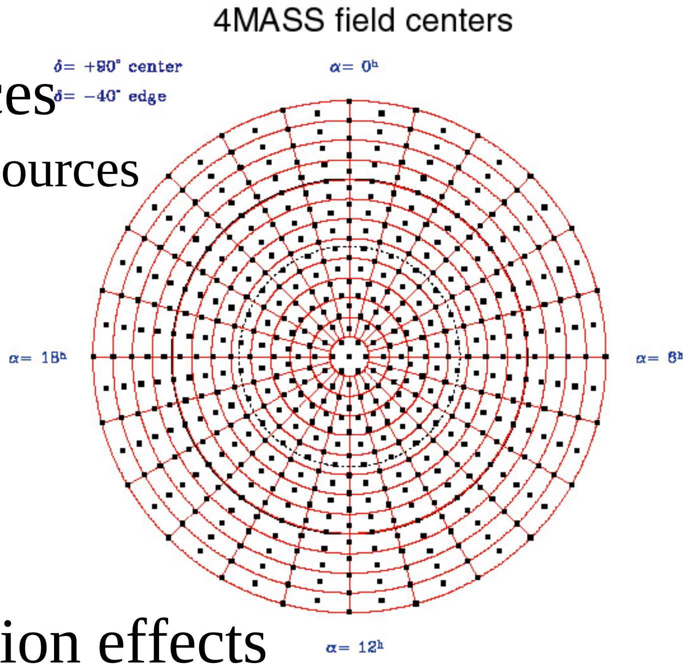
NRL

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^{st} step: imaging without self-calibration now possible
  - 2^{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 ~ 10^5 sources in 10.3 sr – 80% 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



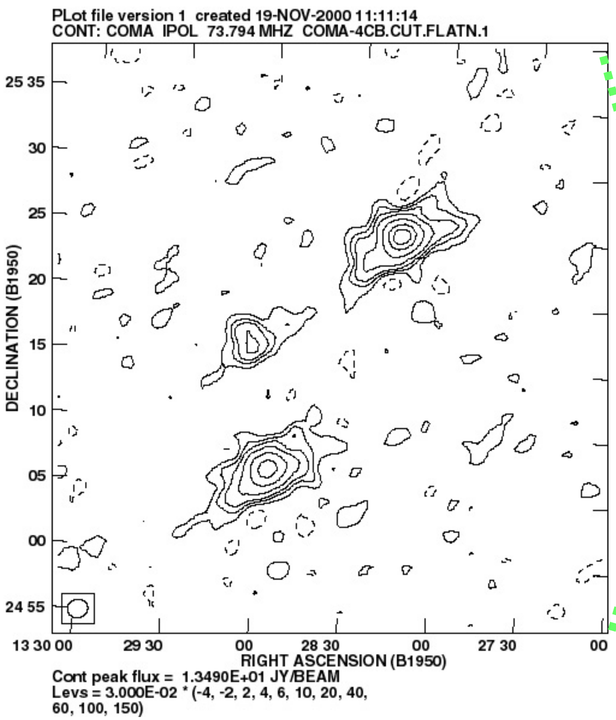
Key LWA Calibration Hurdle:
Relaxing the finite Isoplanatic Patch assumption

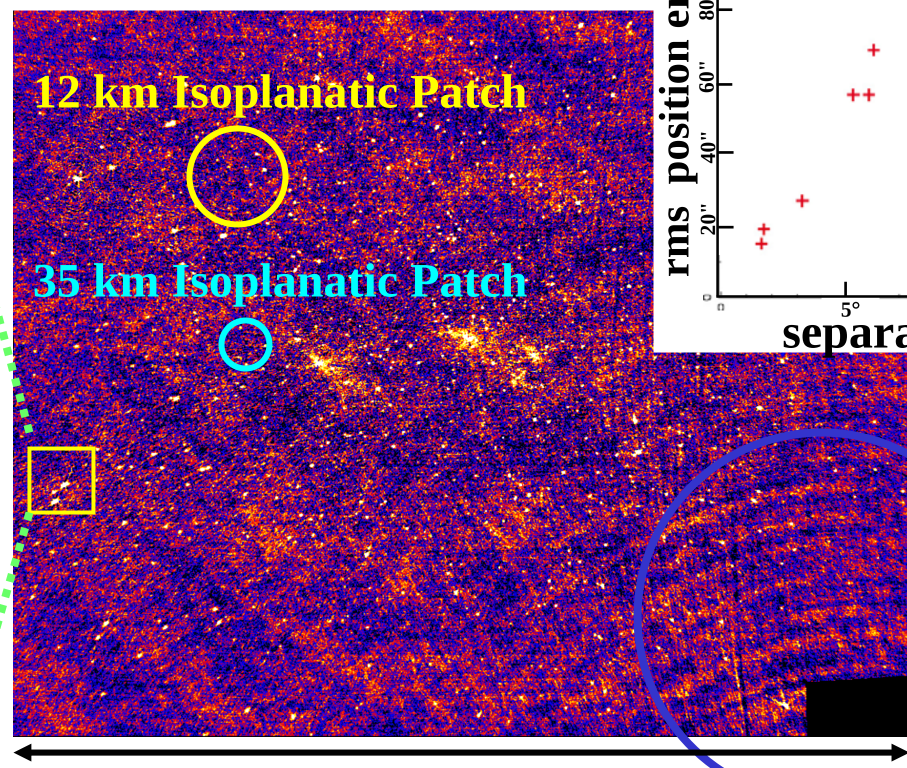
- Current self-calibration assumes constant ionospheric solution across field of view
  - Assumption physically valid over much smaller region: ~1° even for 74 MHz VLA (35 km)
  - Serious problems: differential refraction, image distortion, reduced sensitivity
- Zernike polyomial phase screen correction now available prior to self-calibration
- Next step is to introduce angular dependence of selfcal solutions based on a priori phase screen model:

$$\varphi_i(t) \Rightarrow \varphi_i(t, \alpha, \delta)$$

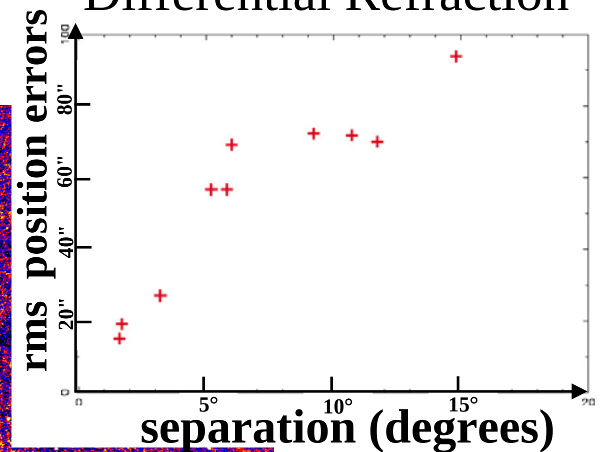
Breakdown of Finite Isoplanatic Patch Assumption

Image Distortion





Differential Refraction



Sidelobe Confusion

~15°

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

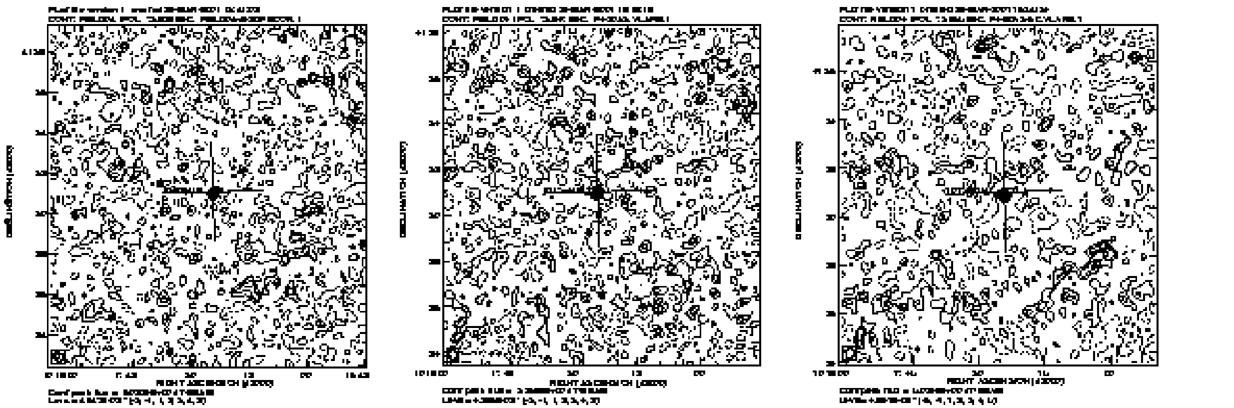
Field Based Calibration

- 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

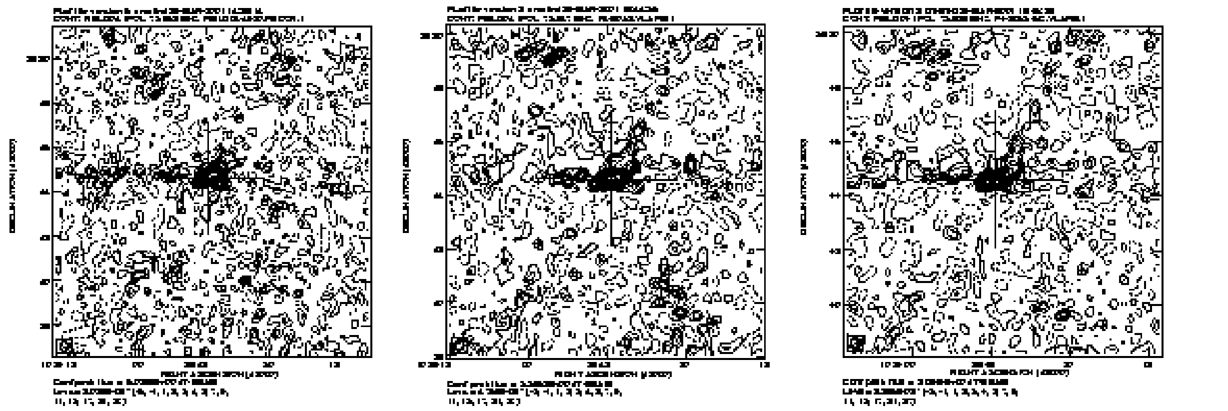
Comparisons (courtesy W. Tschager)

An unresolved source:



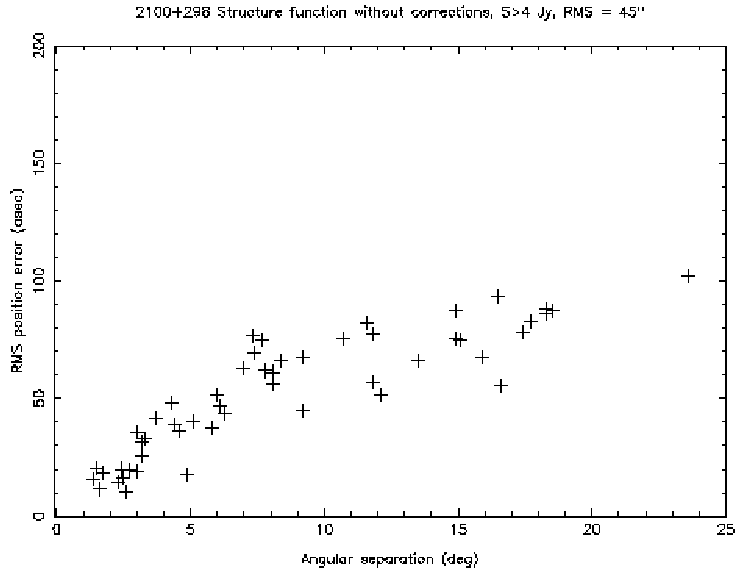
Pure self-cal | Pure CA | “Hybrid”

A resolved source:

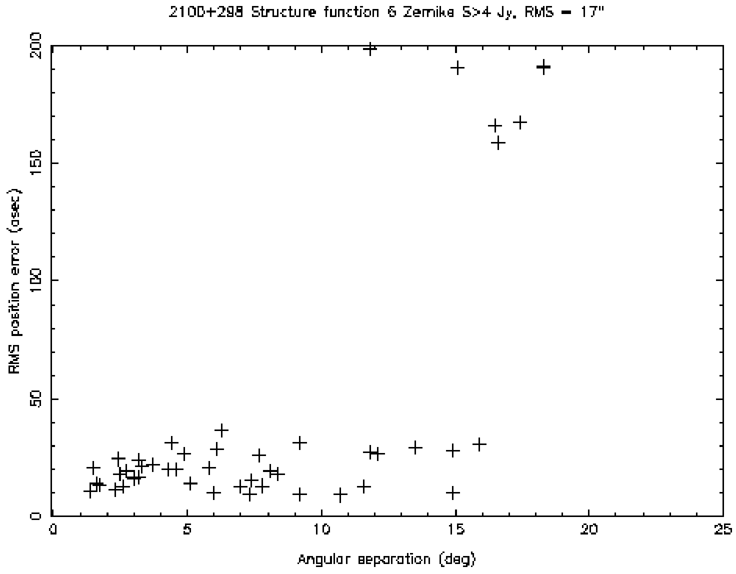


Phase Delay Screen Modeling
1D – phase structure function

Before Zernike Model

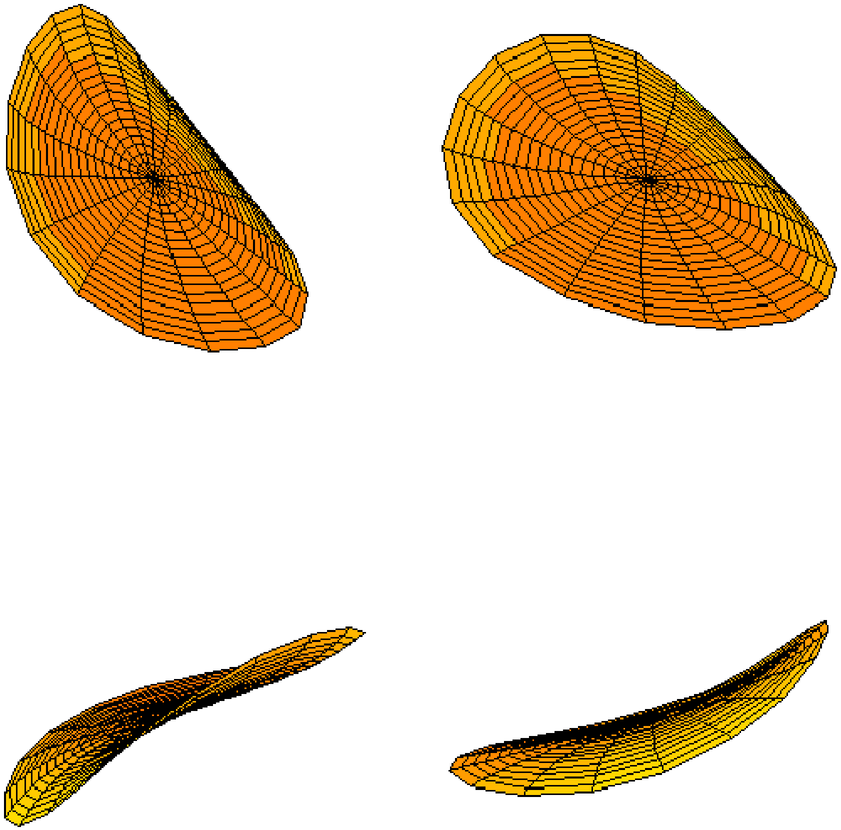


After Zernike Model



Phase Delay Screen Model

(Zernike polynomial models – courtesy B. Cotton, J. Condon)



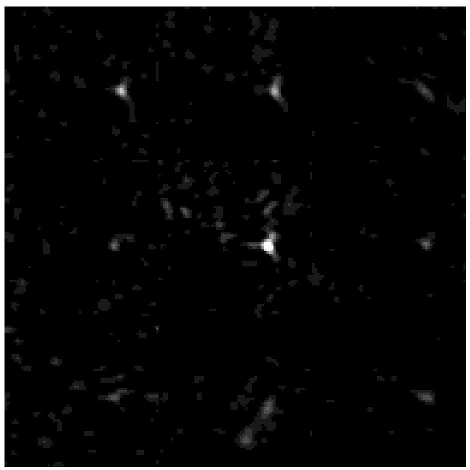
Fitted model ionospheric phase Delay screen rendered as a plane in 3-D viewed from different angles.

Cool Sky Movie

(courtesy B. Cotton)

Cool Sky Sources

A array 74 MHz



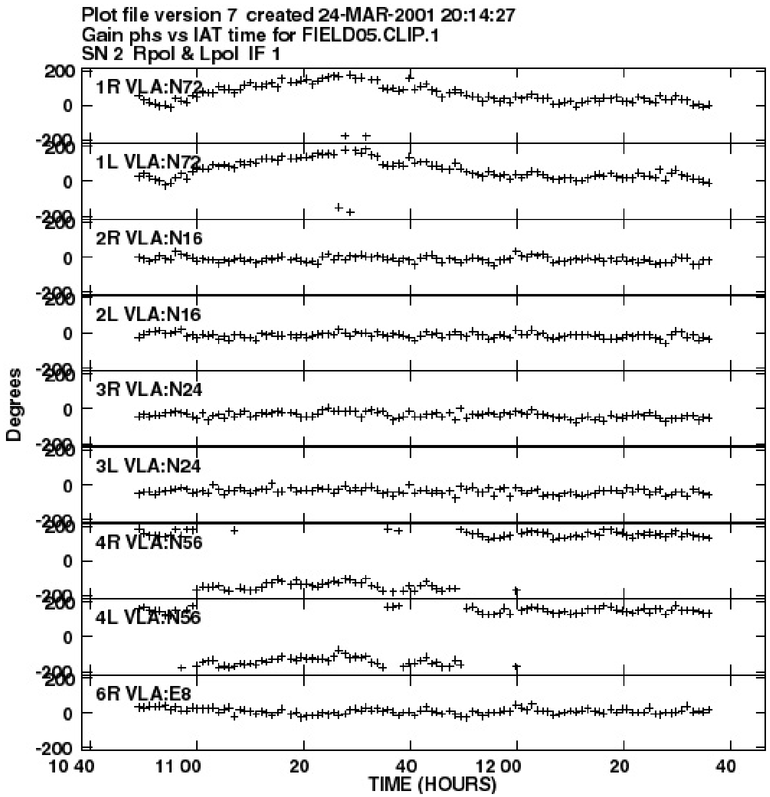
Cool Sky Zernike Model

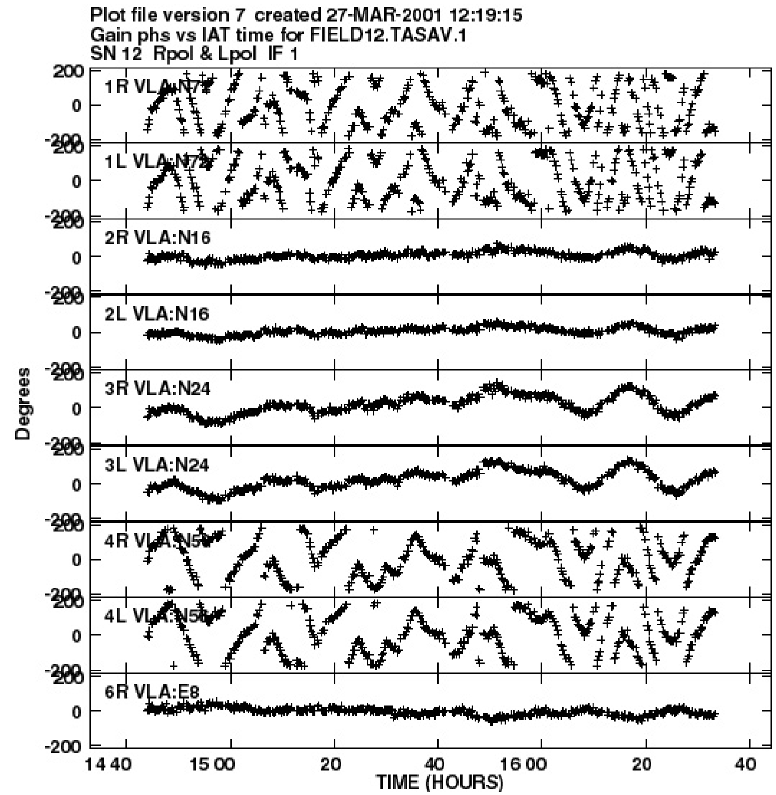
A array 74 MHz

Emerging Ionospheric Weather Diagnostics

VLA Raw Phases (courtesy W. Tschager)

"Good day" "Bad day"

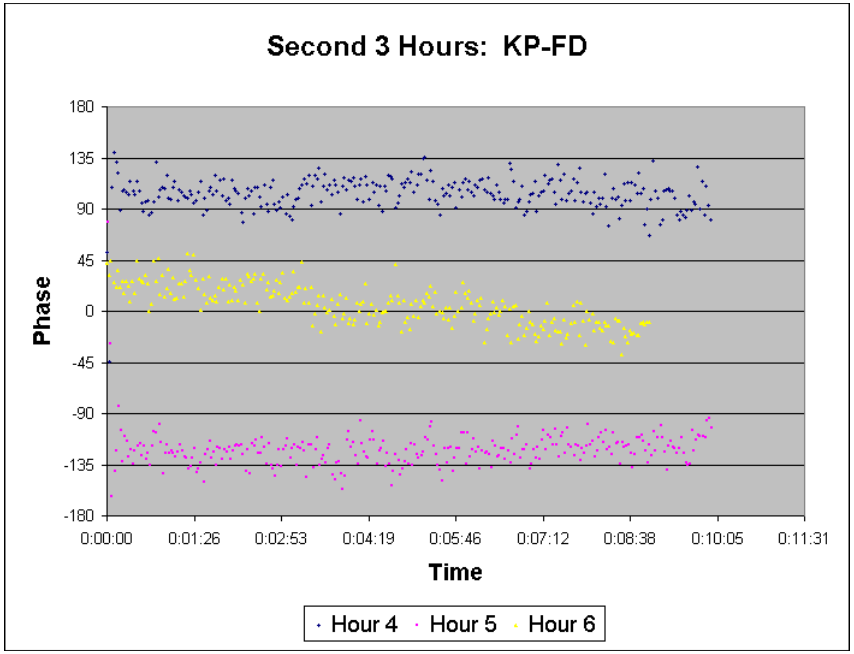


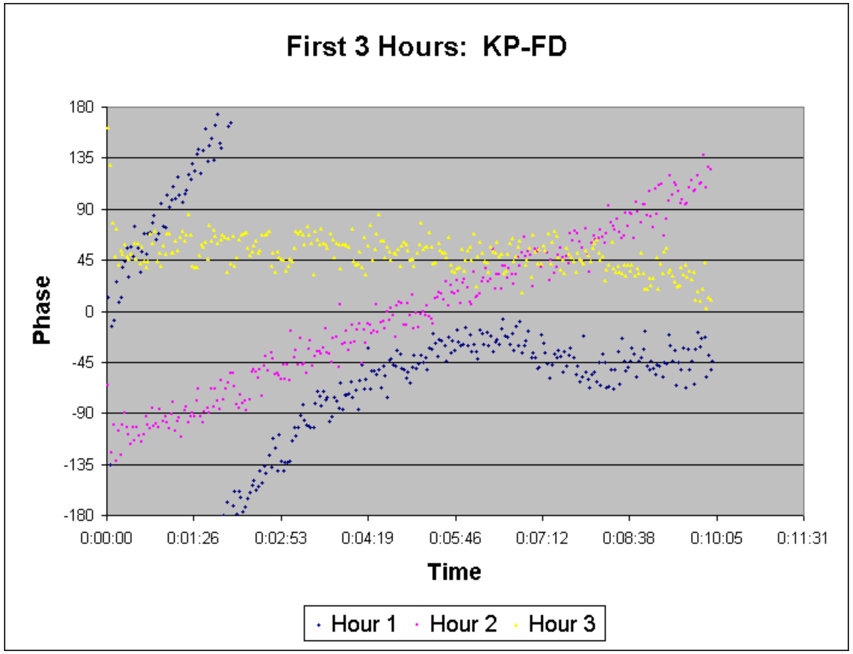


Emerging Ionospheric Weather Diagnostics

VLBA Phases (courtesy G. Taylor)

“Good day” “Bad day”

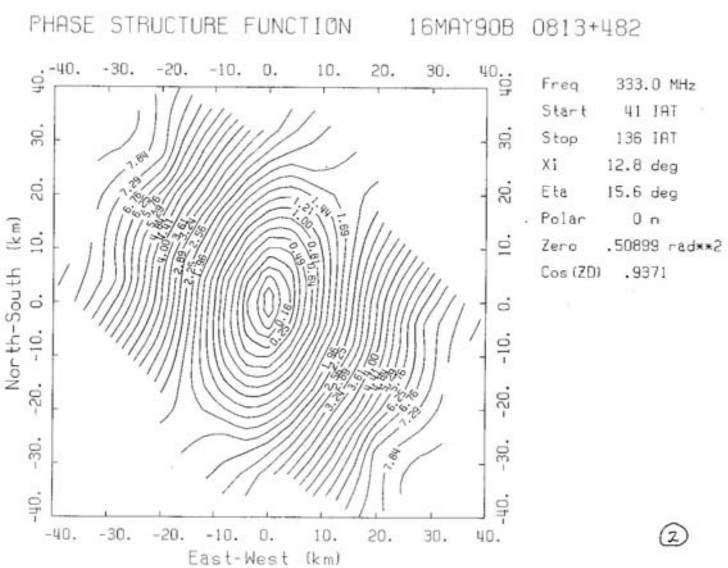




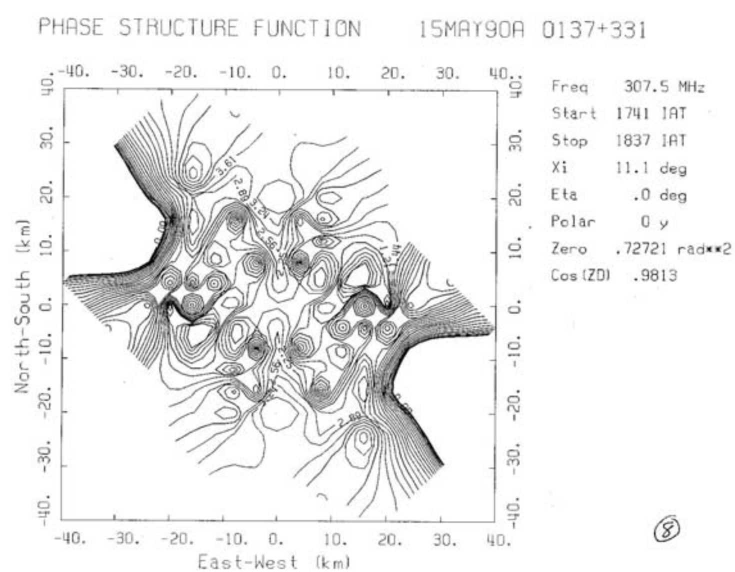
Emerging Ionospheric Weather Diagnostics

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

“Good day”



“Bad day”



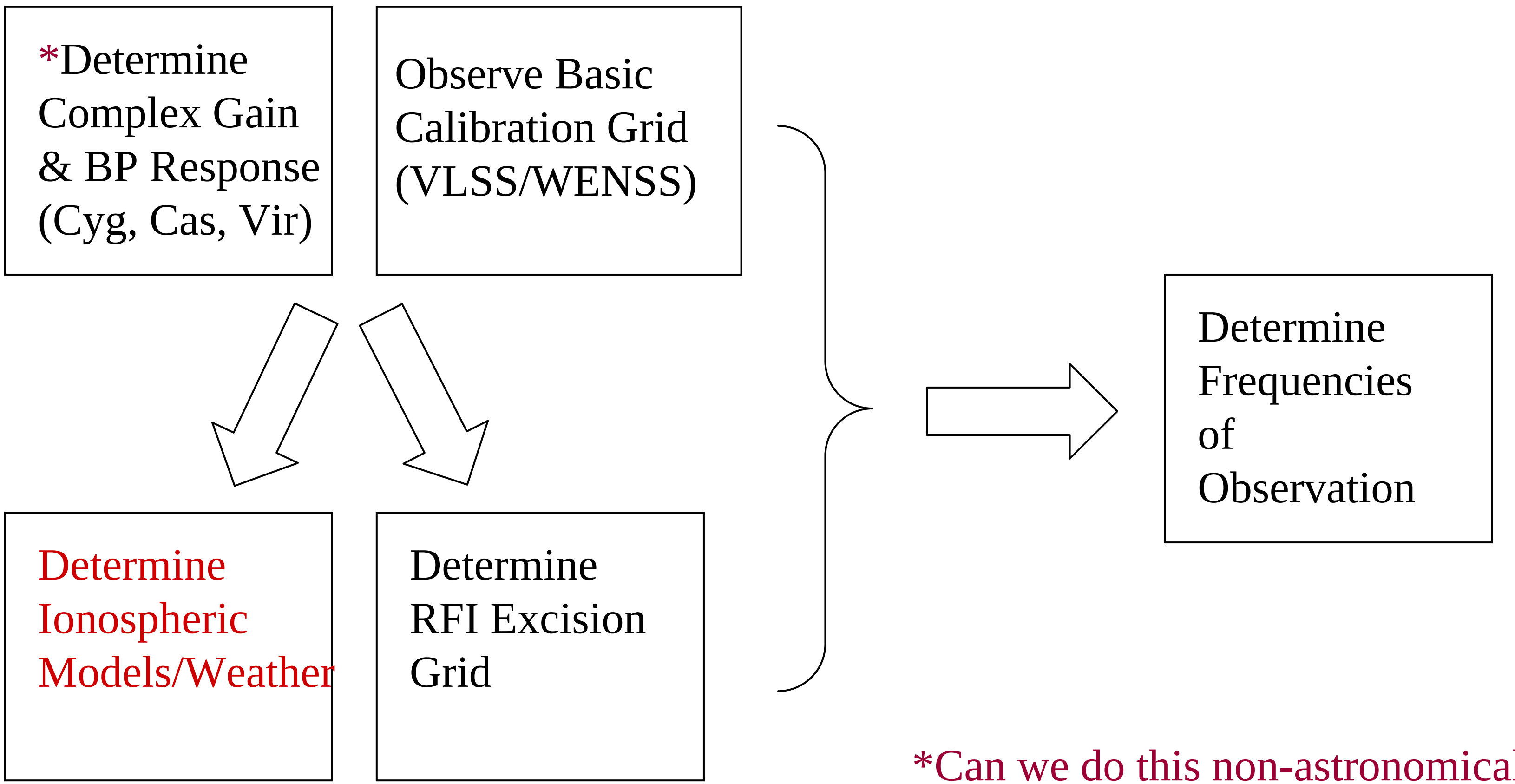
Looks promising, but unfortunately no “silver bullet” ionospheric weather diagnostic has yet been found.

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:



*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 ν x, science program y, apply basic → calibration

Remove RFI →

Store data at maximum bandwidth for future reference

↓

Average data to BW required by science program

← Self-calibrate & image “through” a priori determined ionospheric model

← Deliver averaged uv data and image to observer with detailed “history” file

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