ICRAR

International Centre for Radio Astronomy Research

LEAP: Parallel N-Directional Calibration Strategy & Ionospheric Studies

Maria J. Rioja (ICRAR-UWA, CSIRO)
Richard Dodson (ICRAR-UWA)
Thomas Franzen (ICRAR-Curtin)
George Heald (CSIRO)

CSIRO

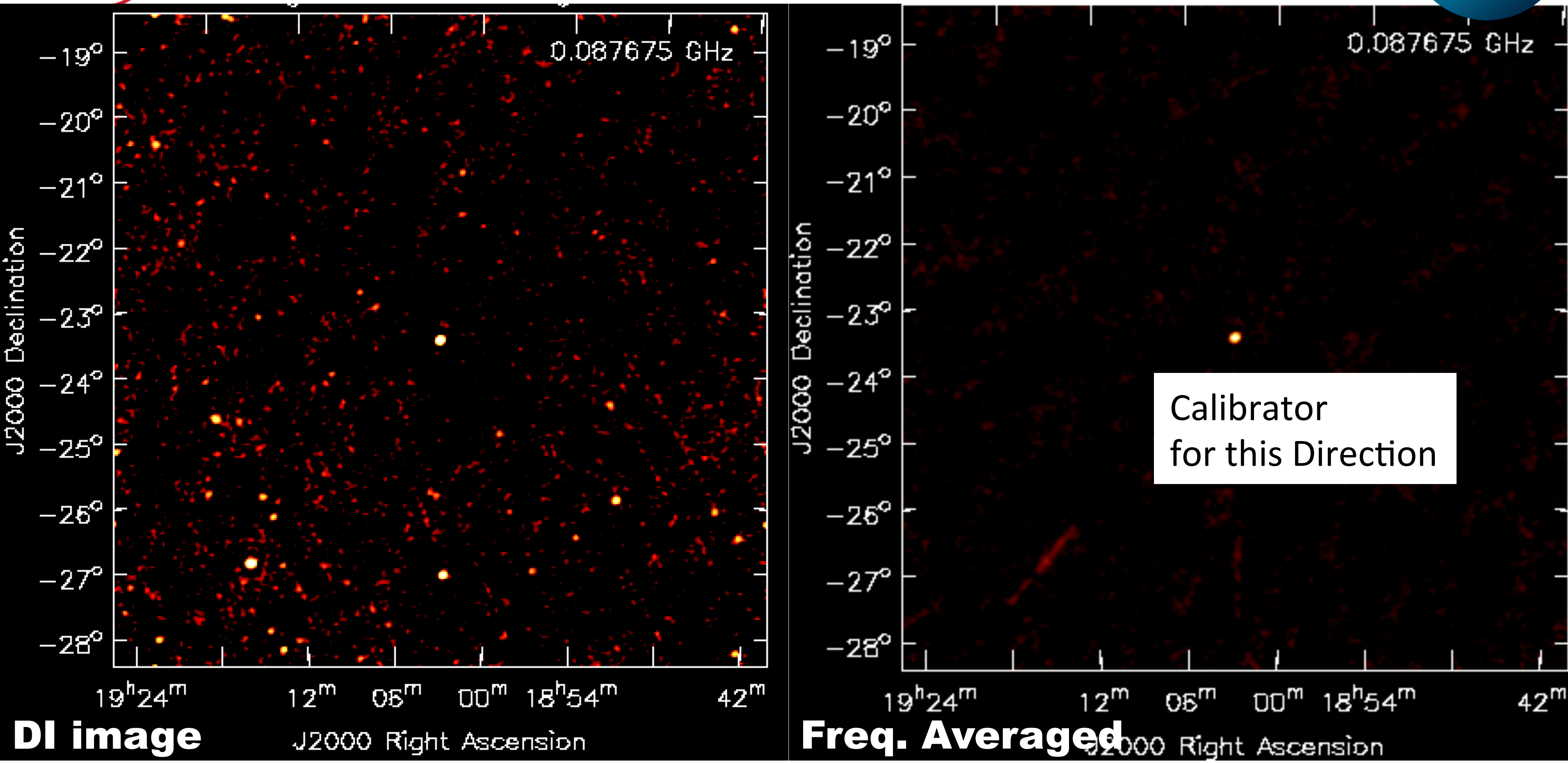
Curtin University

The University of Western Australia

OUTLINE

- Basis and Demonstration of LEAP (Phase 1) DDE ionospheric calibration strategy using MWA obs.
- Developments to include long baselines (LEAP-Phase 2) e.g. LOFAR
- Measurements of Fine Scale Ionospheric Spatial Structure
- Summary and on-going/future work

Frequency Smearing acts as an Efficient Filter…

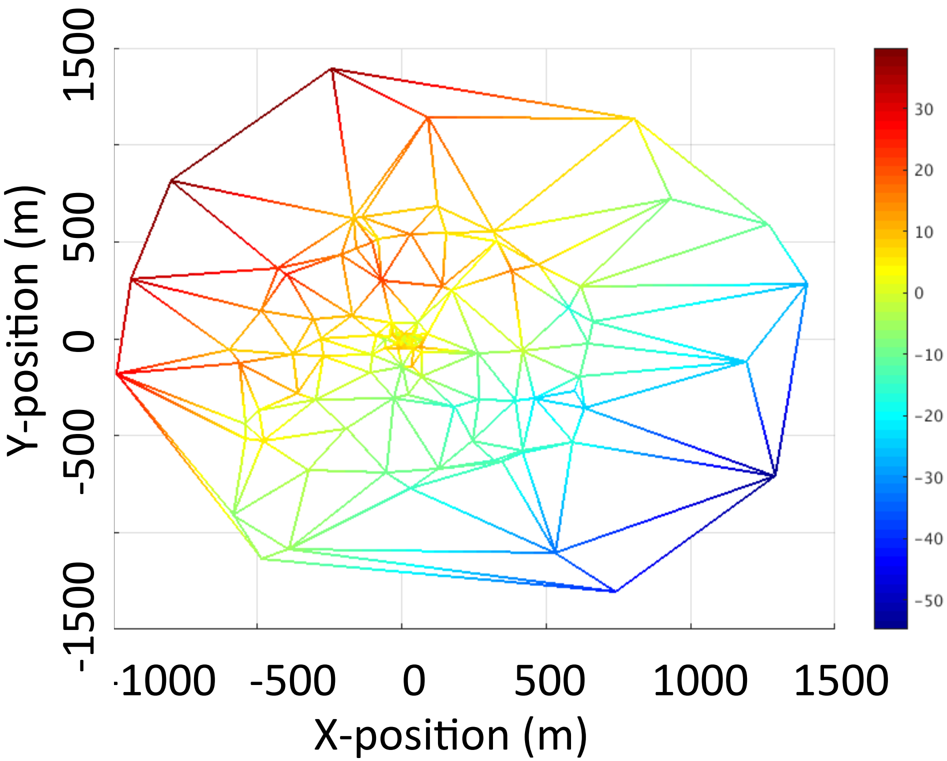


…. to separate directions within a large FoV

- Traditional self-cal (for phase) in a single direction (after DI cal)
- “Sky model” Free
- (Embarrasingly) Parallel – Parallel N-directional solving problem

Ionospheric Phase Distorsions
(above MWA array, along calibrator direction)

Antenna Phase solutions from SC vs. MWA antenna positions (X-Y plane)



(color coded in degrees)

Differential residual changes of TEC values above MWA along the calibrator direction.
Typical values ~ 0.01-0.02 TECU

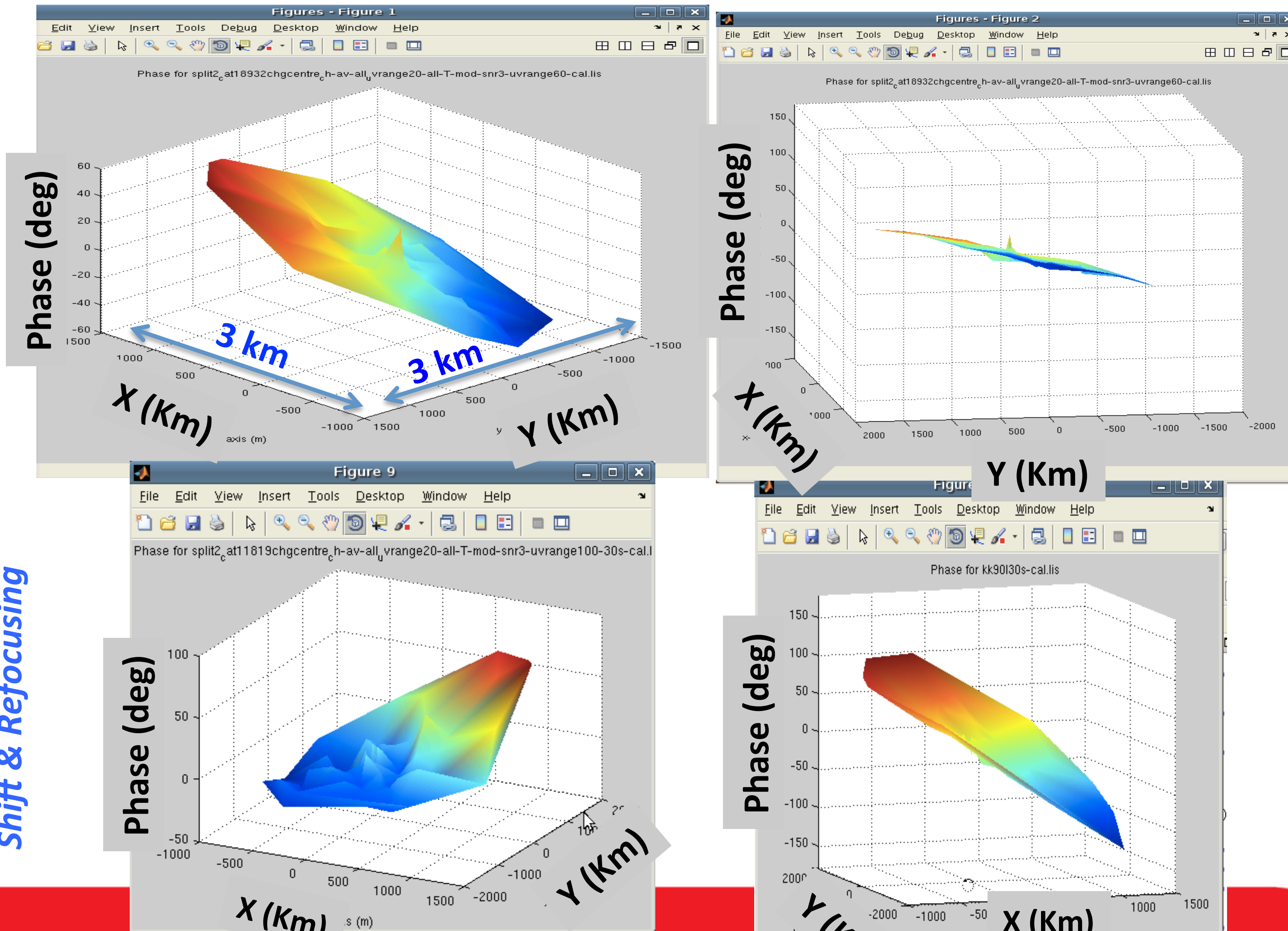
Antenna Phase Solutions (from SC)

IONOSPHERIC PHASE SCREENS

Plots: Antenna Phase solutions (Z-axis) vs. MWA antenna positions (X-Y plane)

“Average” & Fine Weather
Refractive Shift

Extreme Weather
(rare for MWA-type)
Shift & Refocusing



Empirical End-to-End Demonstration using MWA GLEAM obs. (LEAP-Phase 1)

Datasets:

7 (2-min) snapshots @ 150 MHz (~ 1 hour), Oct. 2014

7 interleaving (2-min) snapshots @ 80 MHz

Instantaneous BW ~ 30.72 MHz

Very wide FoV (up to 50°)

wsclean

DI calibrated .ms ➔ LEAP N-directional DDE calibration ➔ DDE calibrated .ms ("full")

-snapshots

-mosaic

-snapshots

-mosaic

wsclean, facets

Characterize performance of LEAP:

(As measured in DDE images vs. DI images)

➔ **Figure of Merit 1:**
Source position stability across the 7 snapshots (~1 hour)

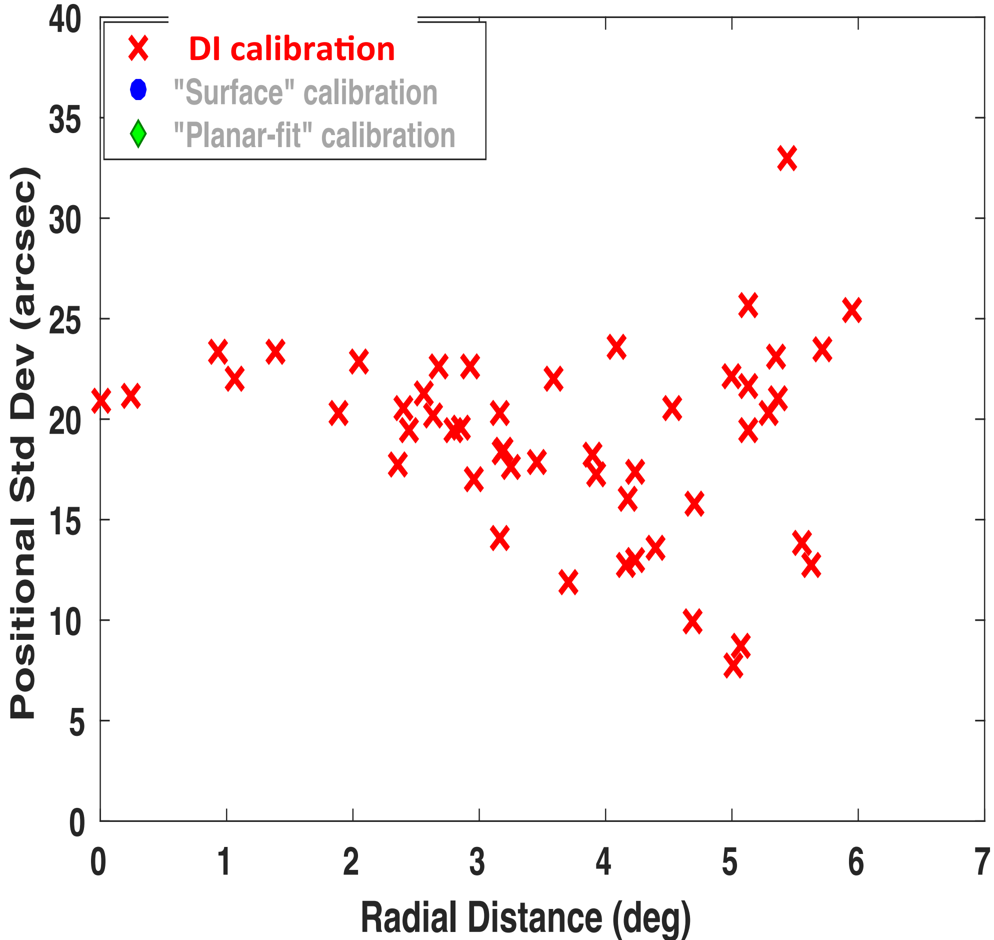
➔ **Figure of Merit 2:**
Source Peak Flux in mosaic image combining 7 snapshots

Rioja+(in prep)

FOM1: Source Position stabilization & “facet” size

- Calibration for one direction, applied to a region around. Comparison of Images from 7 frames **@ 150 MHz** (~ 1 hour)

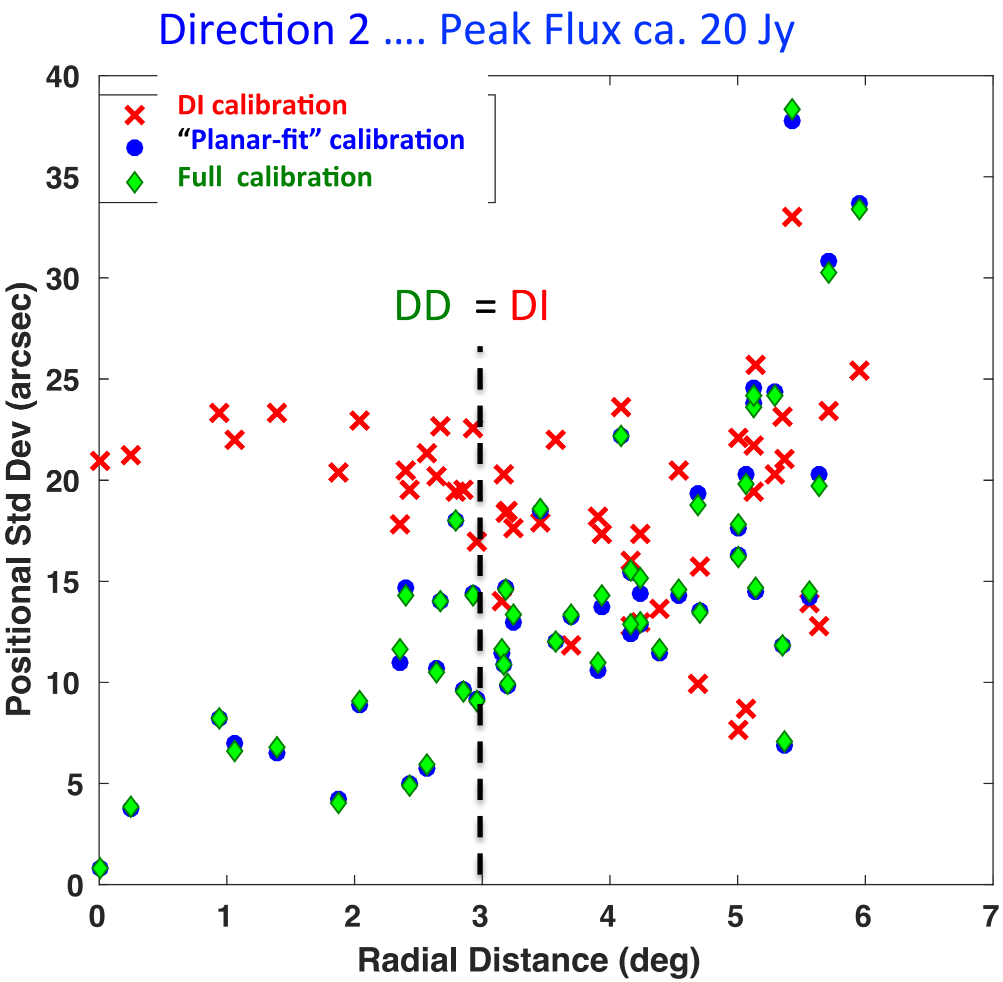
Direction 2 …. Peak Flux ca. 20 Jy



Rioja+(in prep)

FOM1: Source Position stabilization & “facet” size

- Calibration for one direction, applied to a region around. Comparison of Images from 7 frames @**150 MHz** (~1 hour)

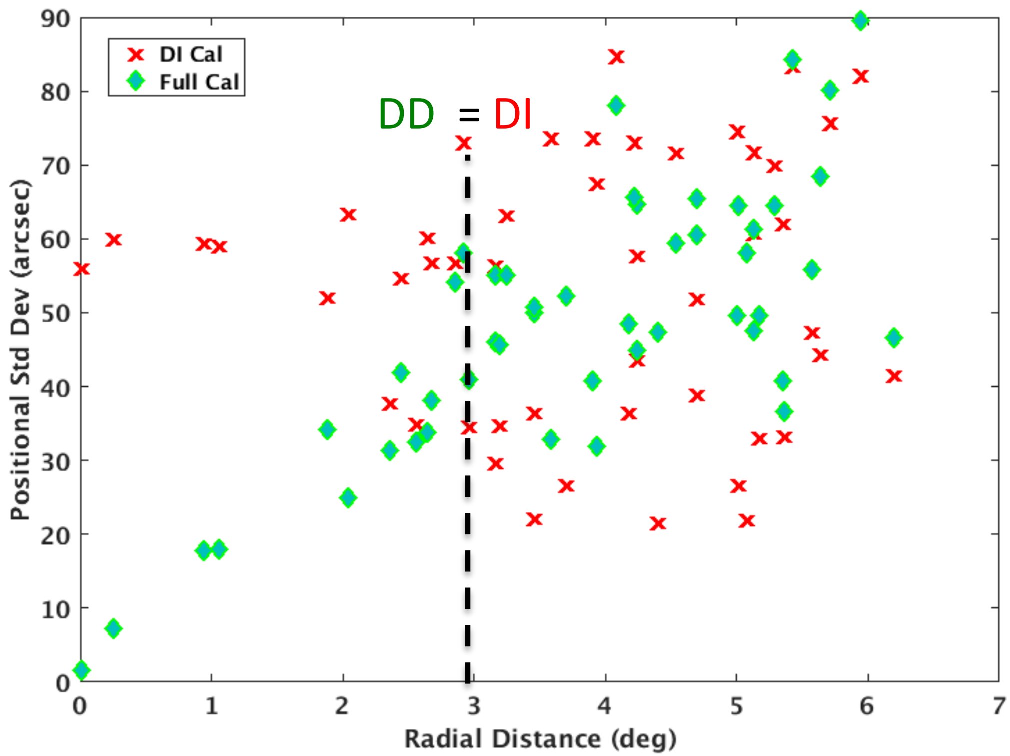


Rioja+(in prep)

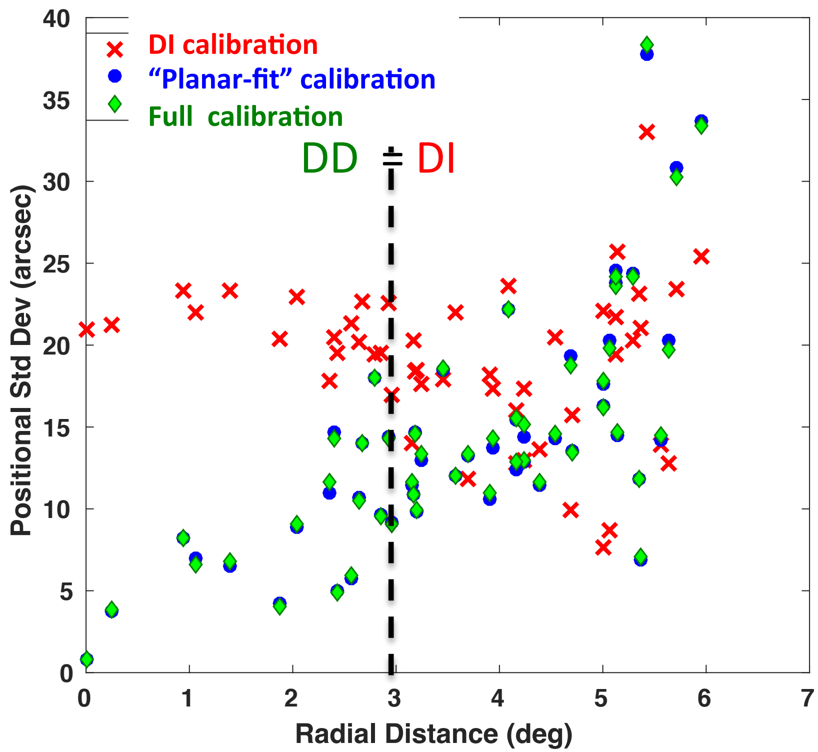
FOM1: Source Position stabilization & “facet” size

- Calibration for one direction, applied to a region around.
  Comparison of Images from 7 frames **@ 150 MHz** (~ 1 hour)
  Comparison of Images from 7 frames @ **80 MHz** (~1 hour)

80 MHz

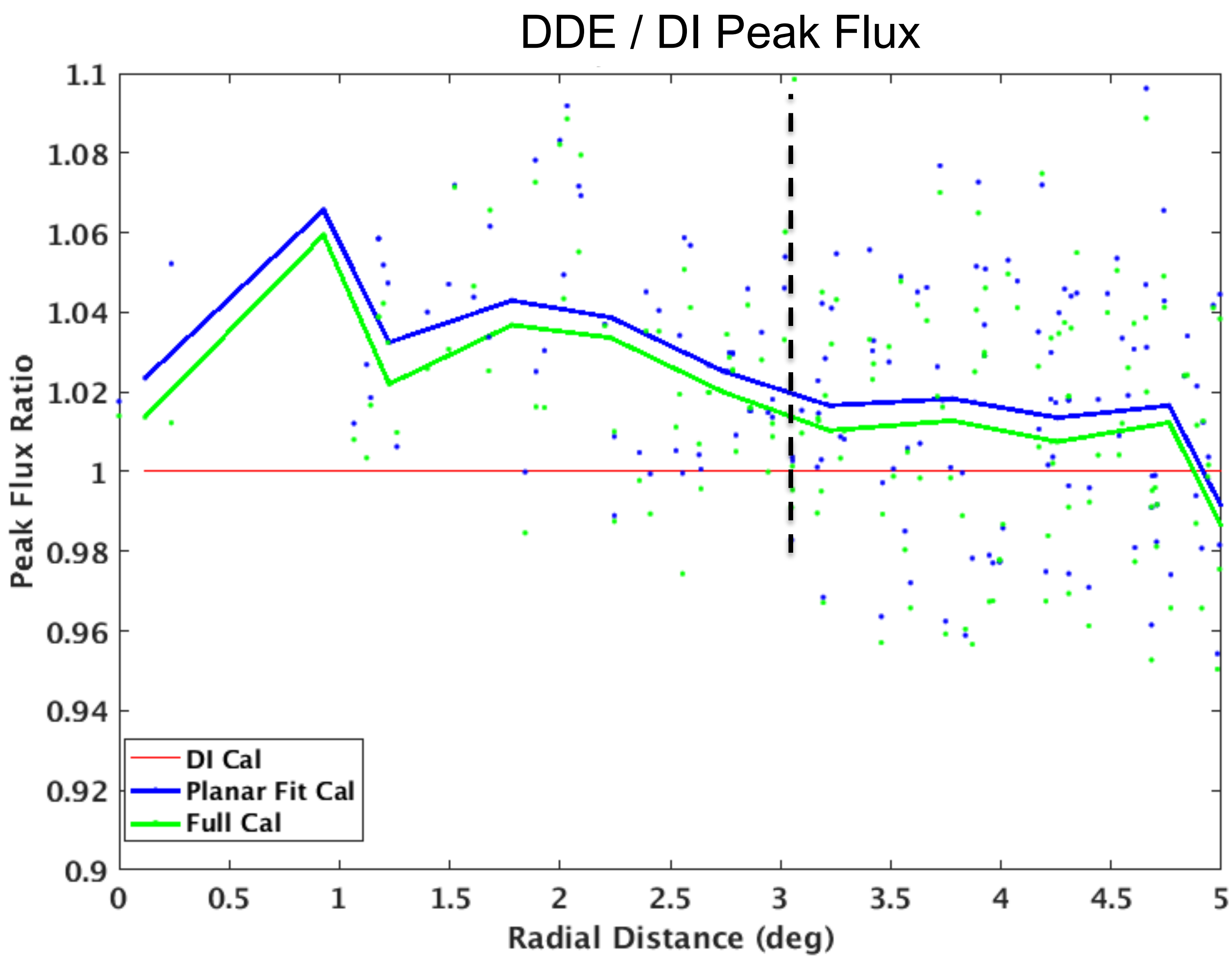


150 MHz



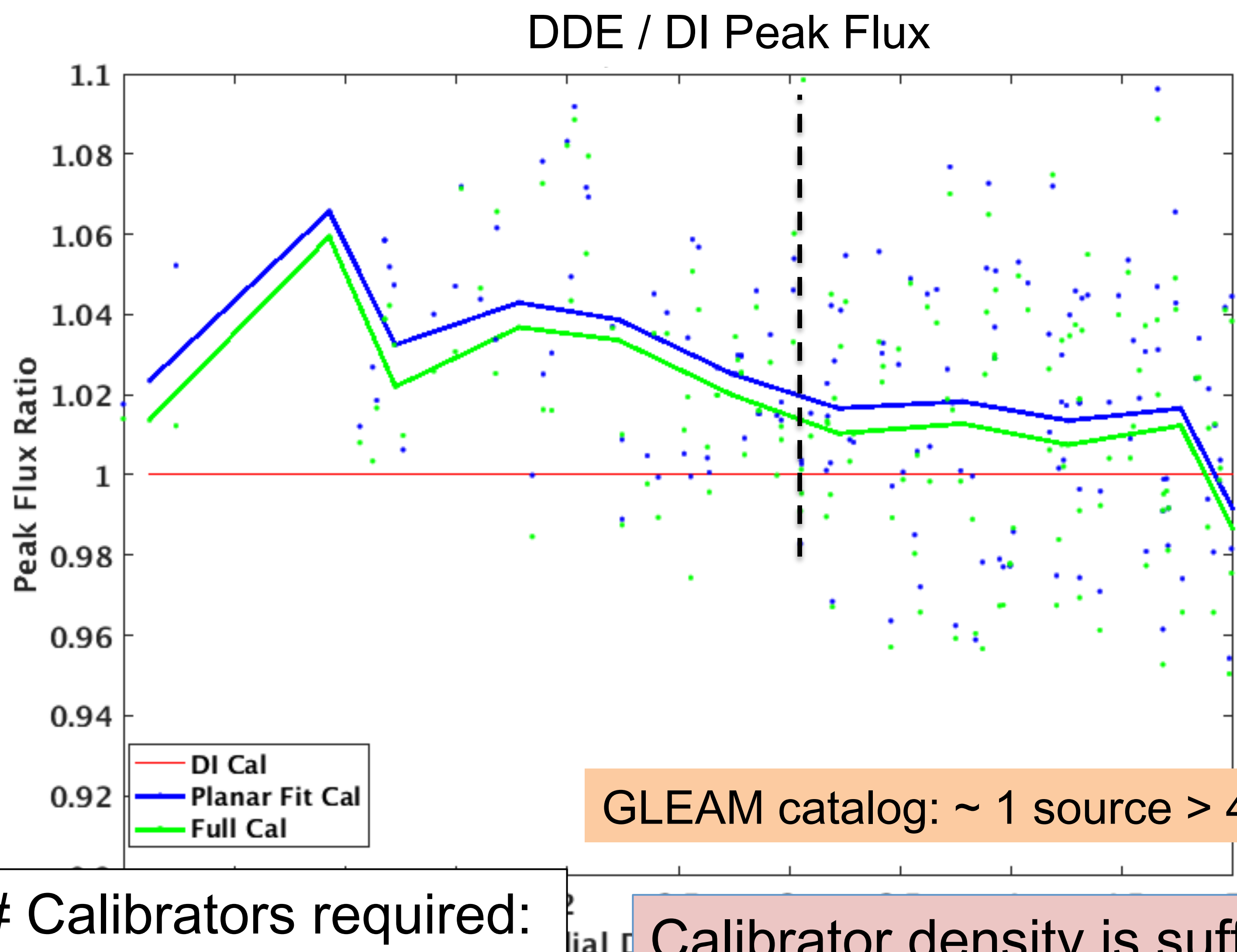
Rioja+(in prep)

FOM2: Comparison of Peak Fluxes in mosaic images



150 MHz

FOM2: Comparison of Peak Fluxes in mosaic images



GLEAM catalog: ~ 1 source > 4 Jy every 2º

Min. # Calibrators required:
~ 16 calibrators at 150 MHz
~ 64 calibrators at 80 MHz

Calibrator density is sufficient to calibrate the whole MWA FoV

Low frequency Excision of Atmosphere in PARALLEL (LEAP)

Processing Time

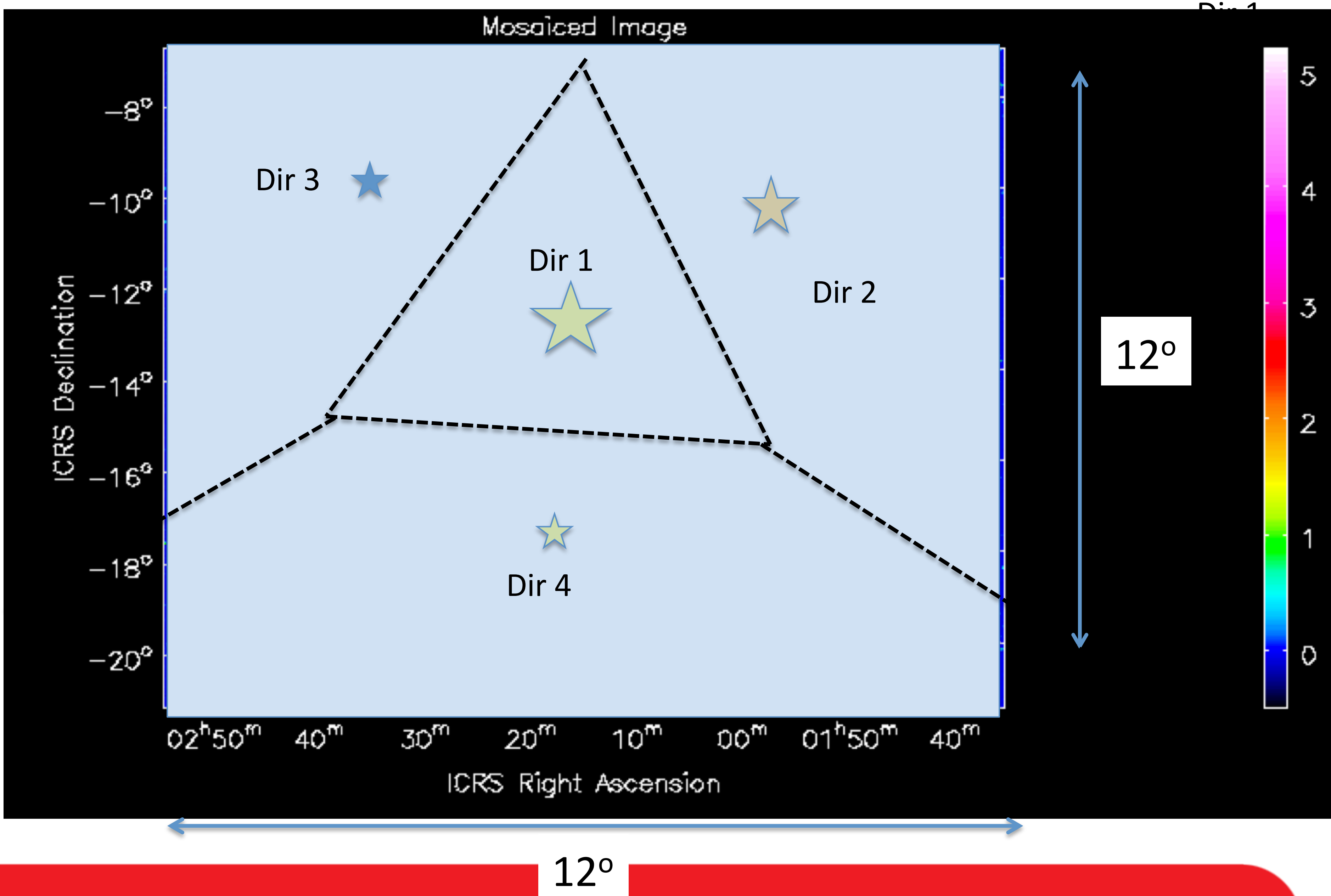
LEAP is embarrasingly parallel.
Because the FoV is reduced to a direction of interest there is no need for
sequencial calibration, nor
simultaneous calibration
Every direction is independent, and therefore can be derived in **parallel.**

In our test runs on Pleiades, a small version of Pawsey, LEAP DDE calibration Measurements takes **~ 200-300 sec** for a single direction.

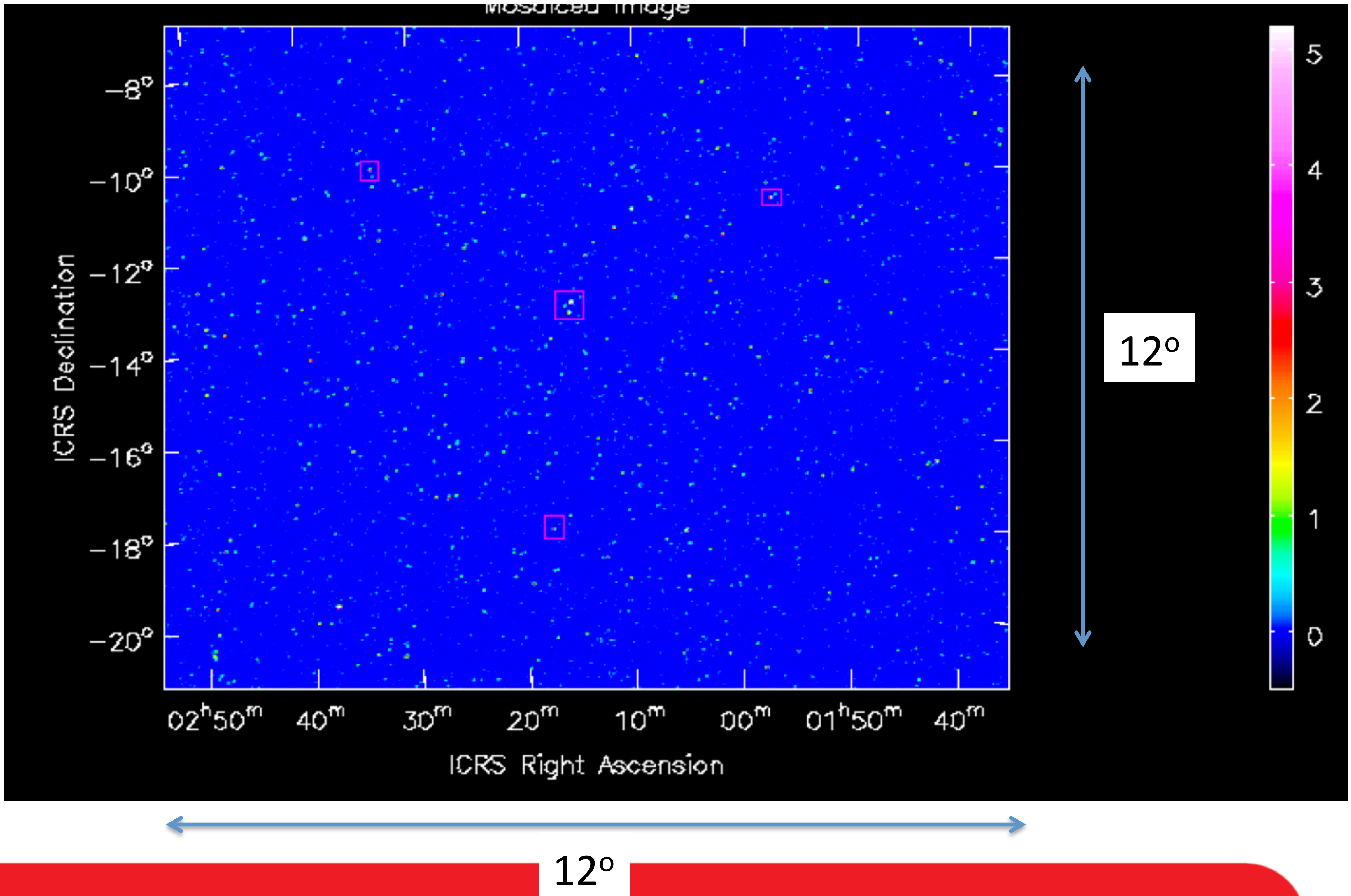
For **N-directions**, with N-nodes, LEAP DDE calibration takes ~ **200-300 sec**

This confirms that LEAP is truly **embarrasingly parallel.**

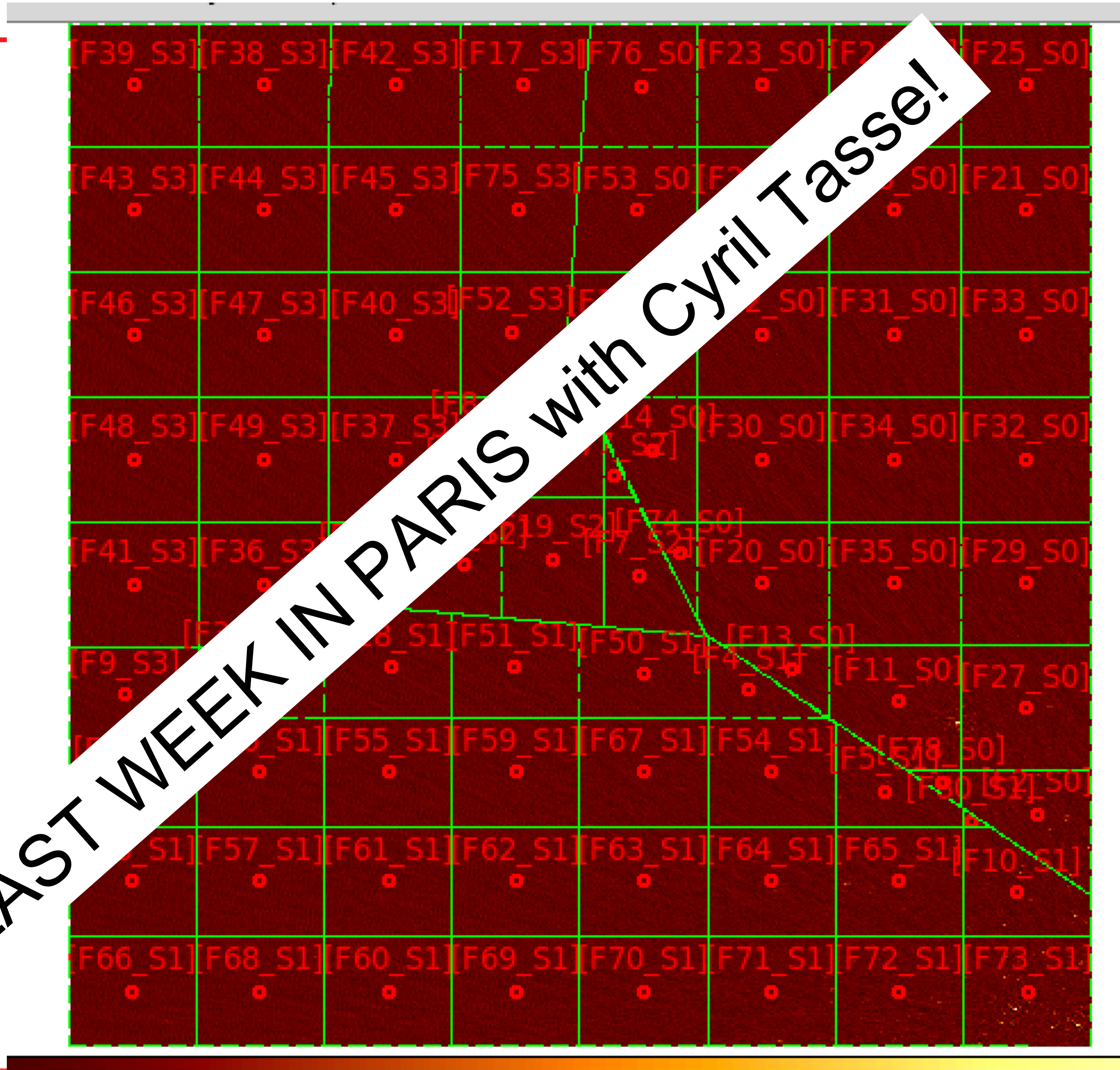
MOSAIC DDE IMAGE using LEAP calibration (facets, wsclean)



MOSAIC DDE IMAGE using LEAP calibration (facets, wsclean)



DDE IMAGE using LEAP calibration and DDFACET imager



DEVELOPMENTS TOWARDS LONGER BASELINES
(=larger ionospheric effects)

Phase 1

Full Band Frequency Averaging
Simulation studies for error analysis @80 MHz:
Astrometric errors < 2”, amplitude loss < 1%, no change in image noise
Suitable for MWA size

Phase 2

Baseline Dependent Filter (smoothing)
(i.e. small FoV whilst keeping spectral signature across BW)
Clustering sources
On going developments at UWA
Suitable for LOFAR / MWA-2 / SKA-Low

Probing Fine Scale (< 3 km) Ionospheric Spatial Structure

(unique to visibility domain & <u>unconstrained</u> antenna phase gains)

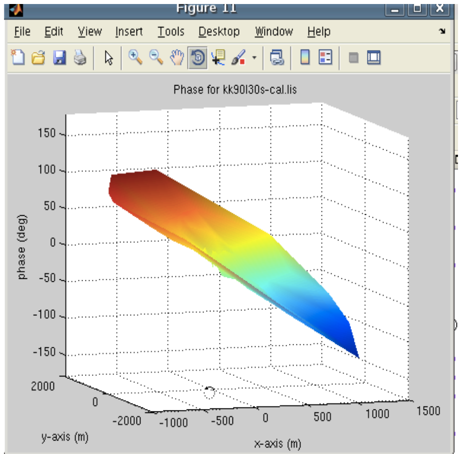
- Understand this source of stochastic errors
- For SKA-Low sensitivities anticipated to be significant

  (Sensitivity is key detect non-linear distortions)

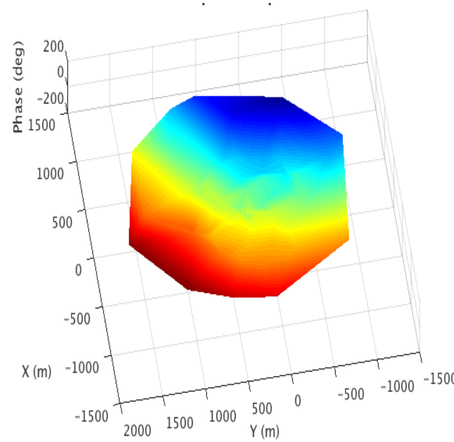
Probing Fine Scale (< 3 km) Ionospheric Structure @ 80 MHz

(MWA)

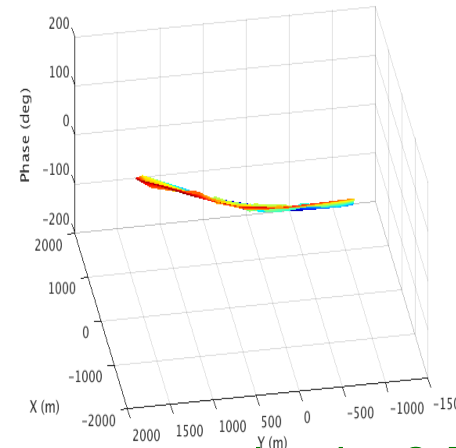
Measured Ionospheric Distortions @ 80 MHz



Top View

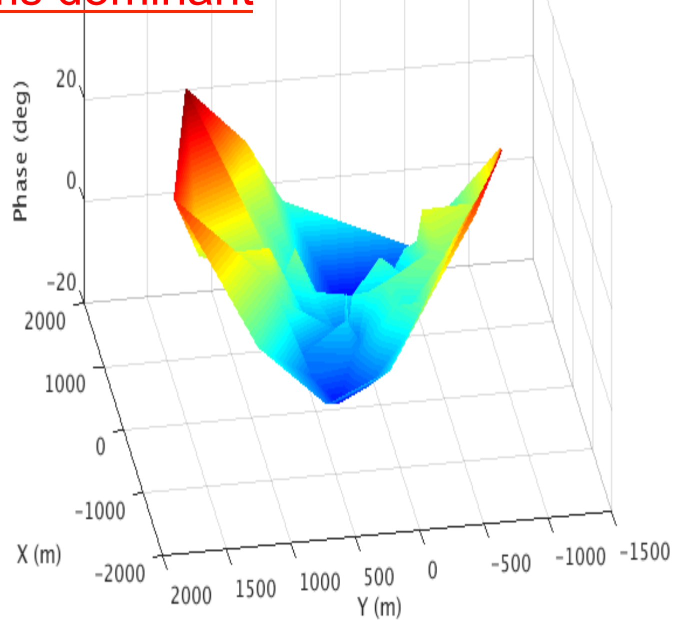


Edge-on View

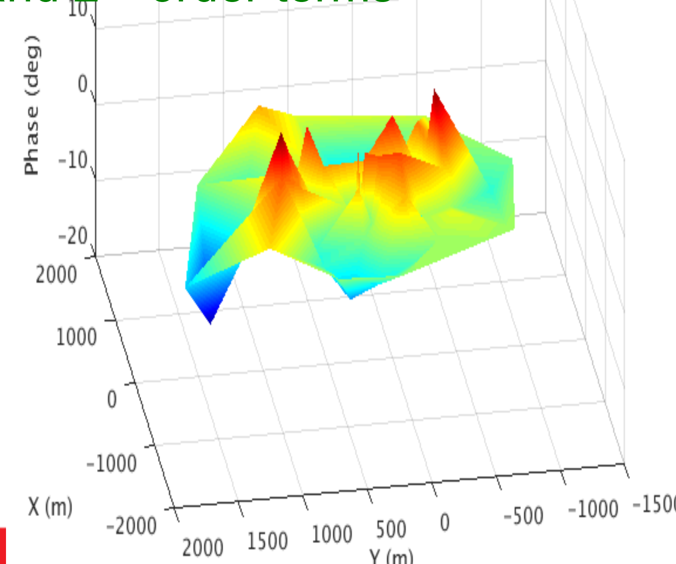


Deviations from a planar surface (rms=10°)

2nd order terms dominant



Deviations from a second order 2-D surface (rms=5°) "Ripples" align with major axis of 1st and 2nd order terms

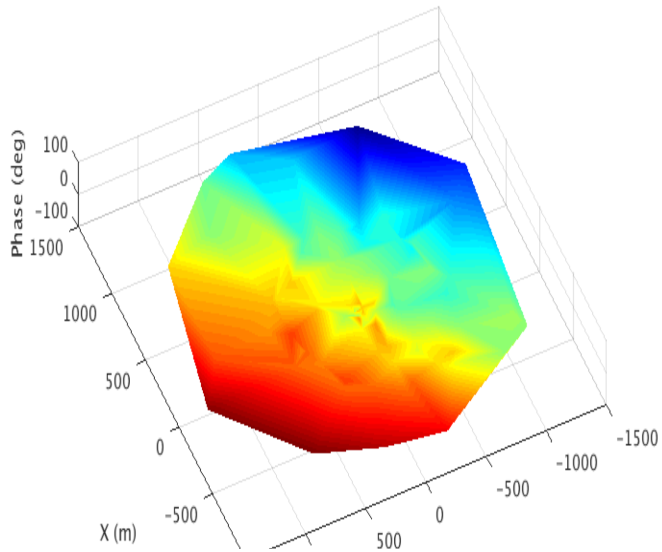


Probing Fine Scale (< 3 km) Ionospheric Structure @ 150MHz

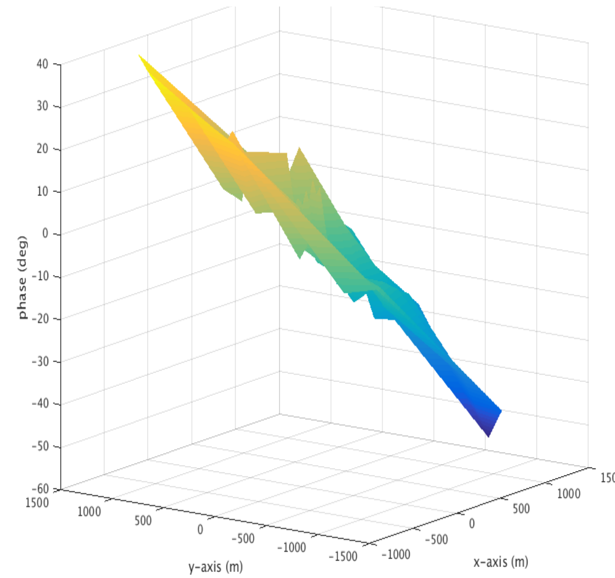
(MWA)

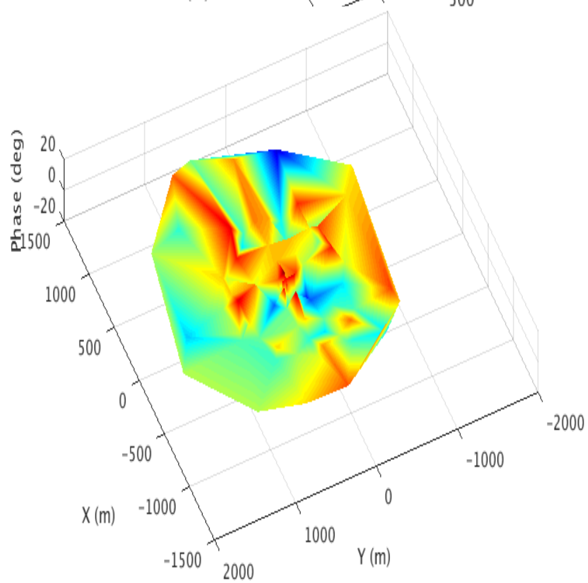
Measured Ionospheric Distortions @ 150 MHz

Top View



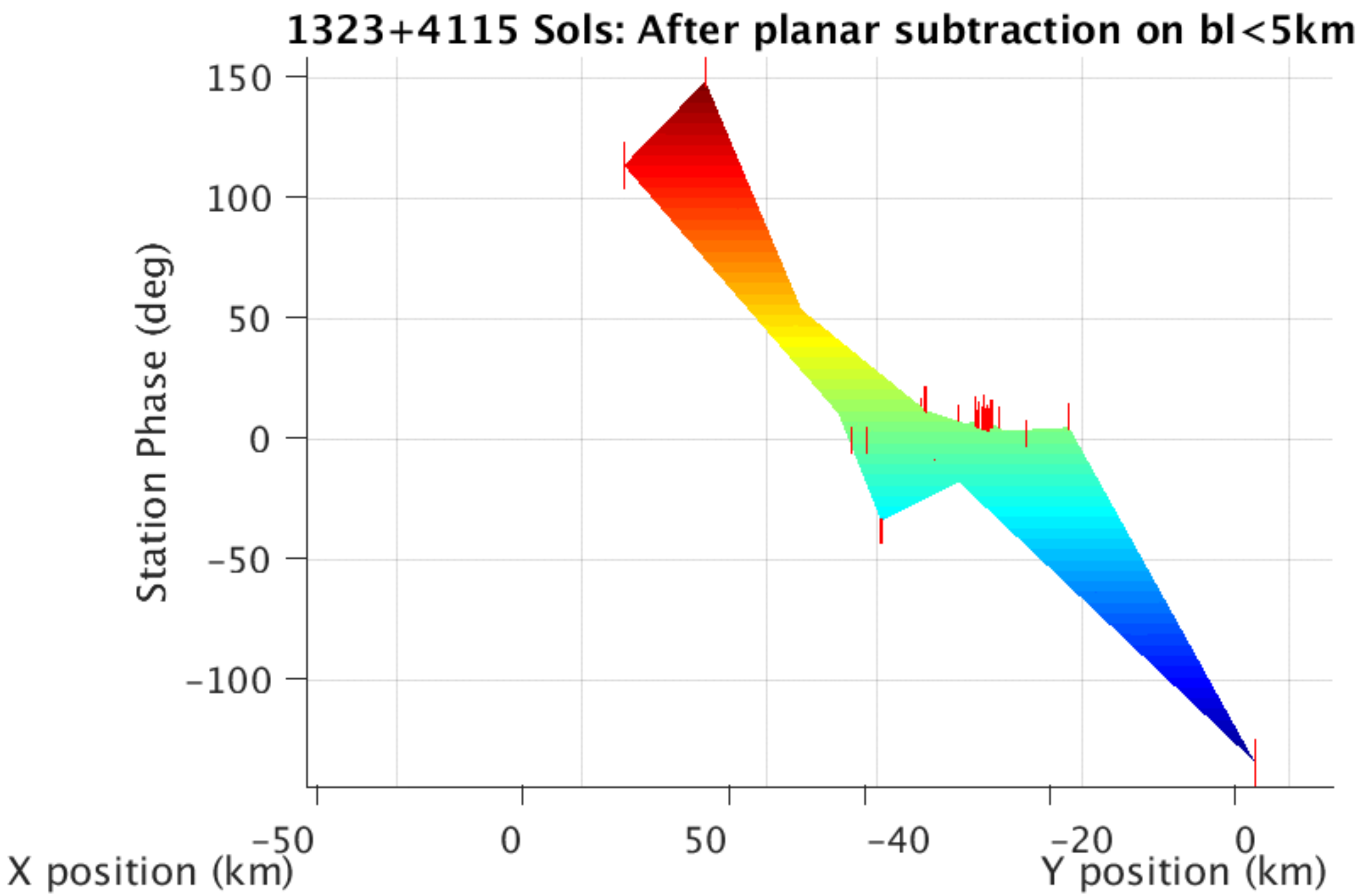
Edge-on View





Deviations from a planar surface: "Ripples" detected similar in scale and strength to those at 80 MHz.
No signature of 2^{nd} order term and
No alignment.

Preliminary: LOFAR small scale Ionospheric Structure @ 150 MHz



SUMMARY and on-going/future steps

End-to-end demonstration of LEAP-Phase 1 feasibility for ionospheric DDE mitigation for MWA obs:

PARALLEL N-directional calibration (embarrasingly parallel), Rapid (~ 300 seconds)
Full Sky model not required
Astrometrically valid
Calibrator density is more than sufficient.

Probes Small scale (< 3km) higher order ionospheric structure
(therefore can be corrected for, at lowest frequency and extreme weather).

For SKA_Low sensitivities this is anticipated to be significant, and such higher-order effects should be addressed.

On going and future work towards SKA-Low:
Development of Baseline Dependent Filters (Phase 2) using SKA simulations
Demonstration using LOFAR obs. (Phase 1+; Phase 2)
Demonstration using MWA-2 obs.

Images with LEAP solutions and DDFacet