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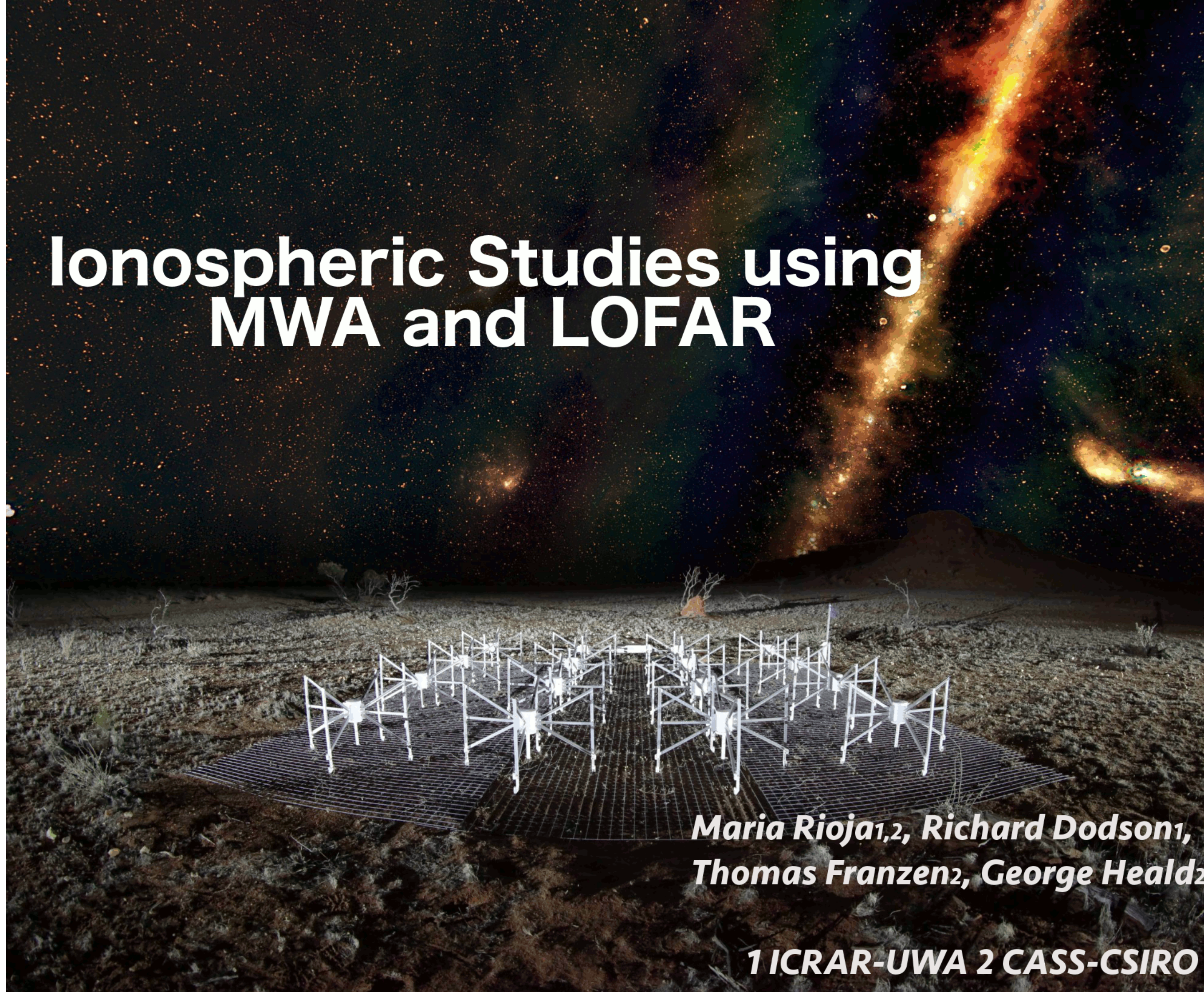

Ionospheric Studies using MWA and LOFAR

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THE GOVERNMENT OF WESTERN AUSTRALIA

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OUTLINE

Motivation: Improve ionospheric calibration methods for SKA
Addressing the direction dependent (DD) nature of the ionosphere

LEAP

Basis and Demonstration of LEAP (parallel multi-directional) calibration scheme using MWA obs. at m-wavelengths

Developments to include long baselines e.g. LOFAR

LEAP in SKA-era and Next Steps.

Square Kilometre Array Era

- At low frequencies (<150 MHz), i.e. SKA-Low, imaging fundamentally limited by ionospheric phase distortions.
  - Other challenges: wide field imaging, RFI, computational power…

The ambitious goals of SKA requires a precise correction of the ionospheric distortions

SKA-Low Pathfinders

Interferometric array of dipole antennas:

Murchison Widefield Array (MWA)

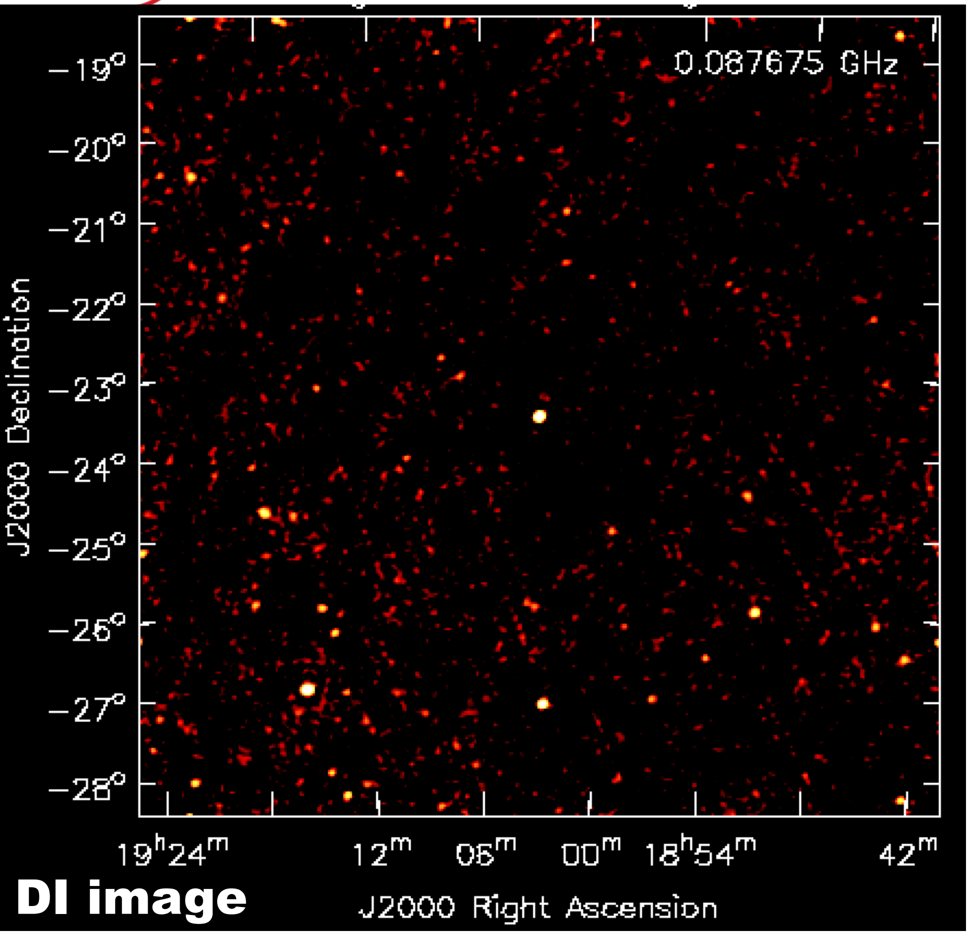
Low Frequency Array (LOFAR)

Location: Western Australia
Baseline: 3 km (6km)
Frequency: 72 ~ 300 MHz
Field of View: 15-50 deg

Location: The Netherlands + international
Baseline: ~50 km + international
Frequency: 10 ~ 240 MHz
Field of View: 2 – 40 deg

Our solution: independent multi-directional calibration ➔
Low frequency **E**xcision of **A**tmosphere in **P**ARALLEL (LEAP)

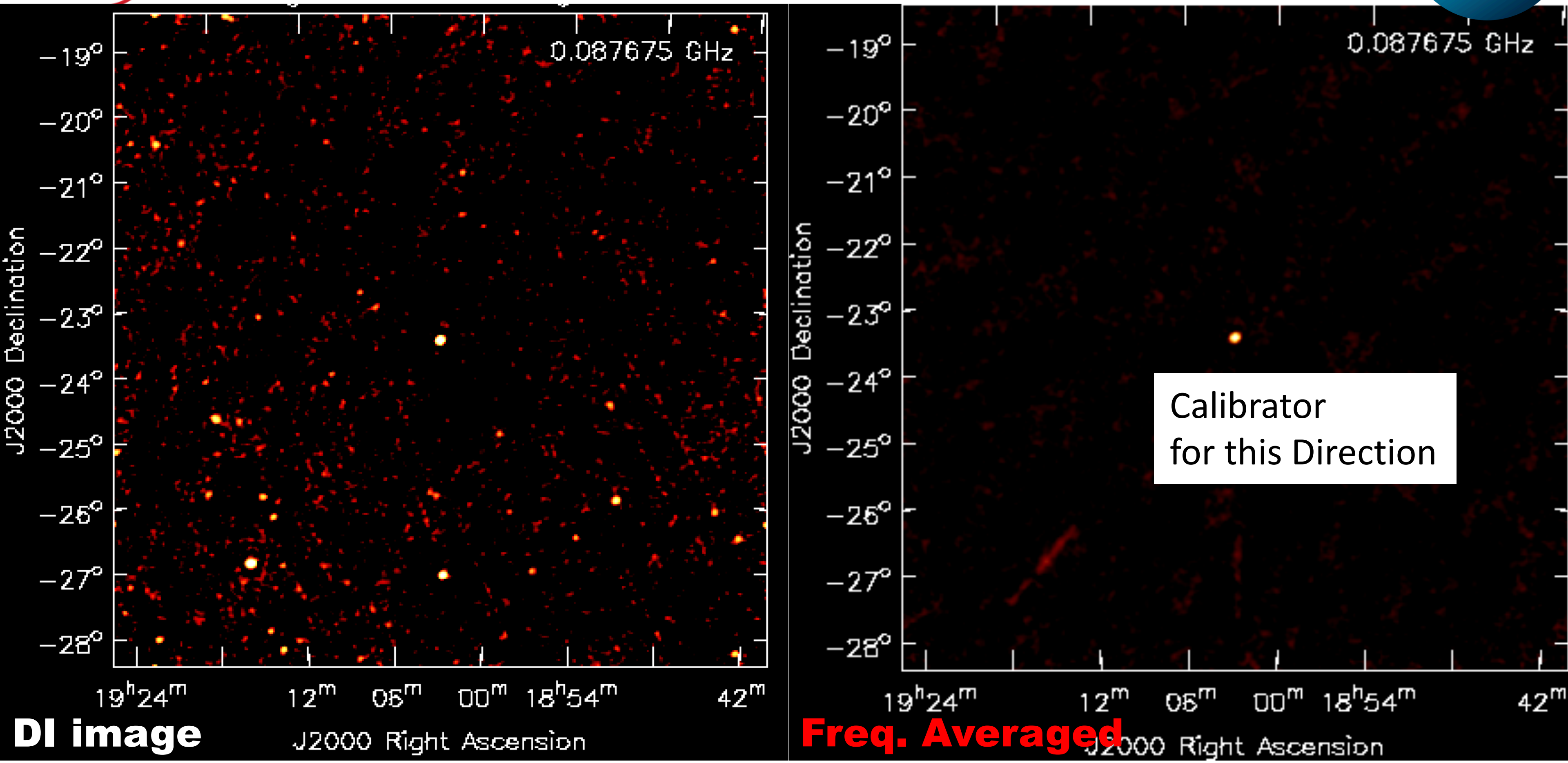
Basis of LEAP



MWA-1 (year-2) DI Image prepared by Tom Franzen

Basis of LEAP:

Frequency Smearing acts as an Efficient Filter…



…. to separate directions within a large FoV

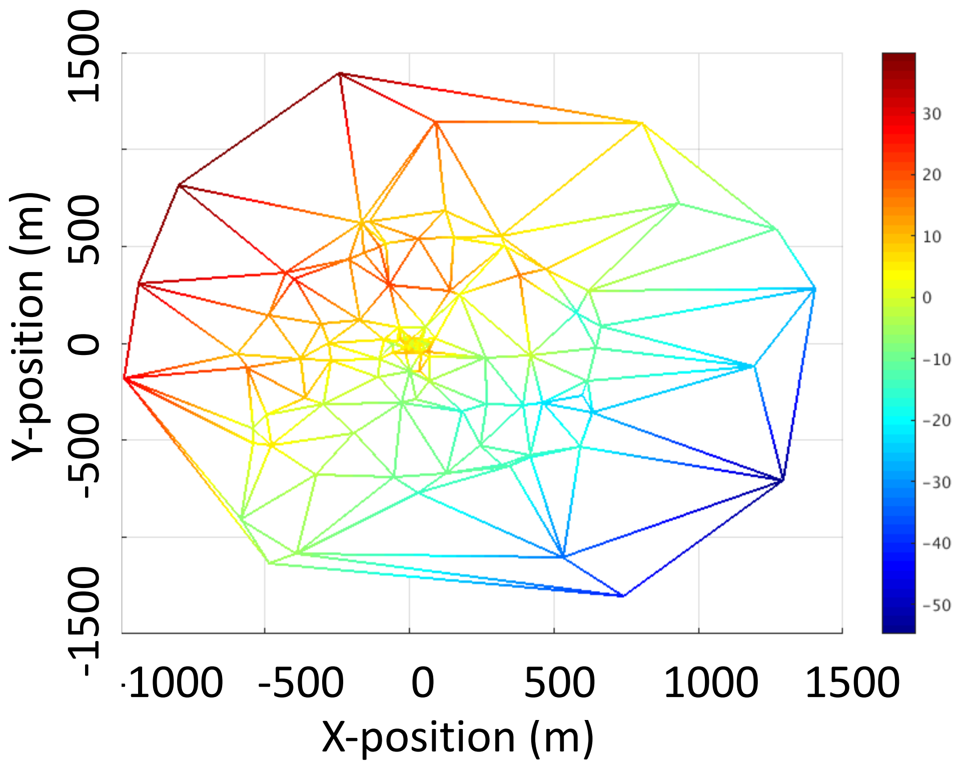
Equ

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 a calibrator direction)

Antenna Phase Solutions (from SC)
i.e. Ionospheric Phase Screen above MWA array in the direction of the calibrator

LEAP Calibration Phases (color coded) vs. MWA antenna positions (X-Y plane)



(color coded in degrees)

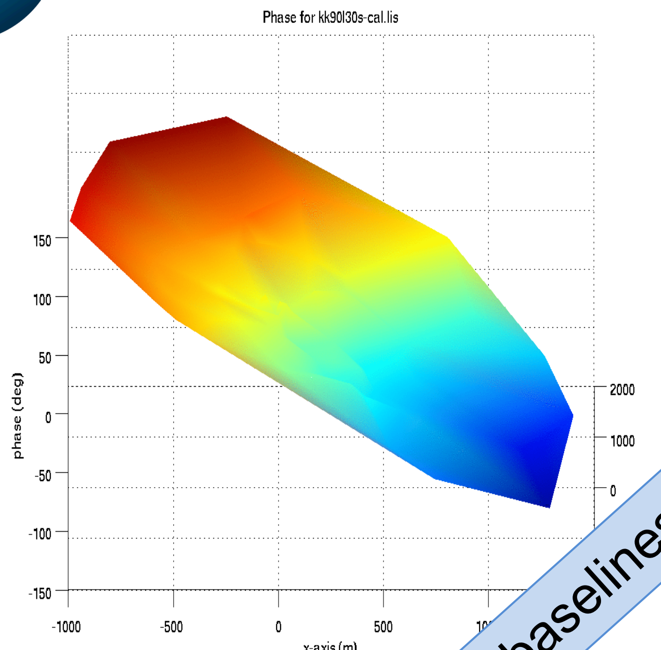
Differential residual TEC values above MWA along the calibrator direction.
Typical values ~ 0.01-0.02 TECU

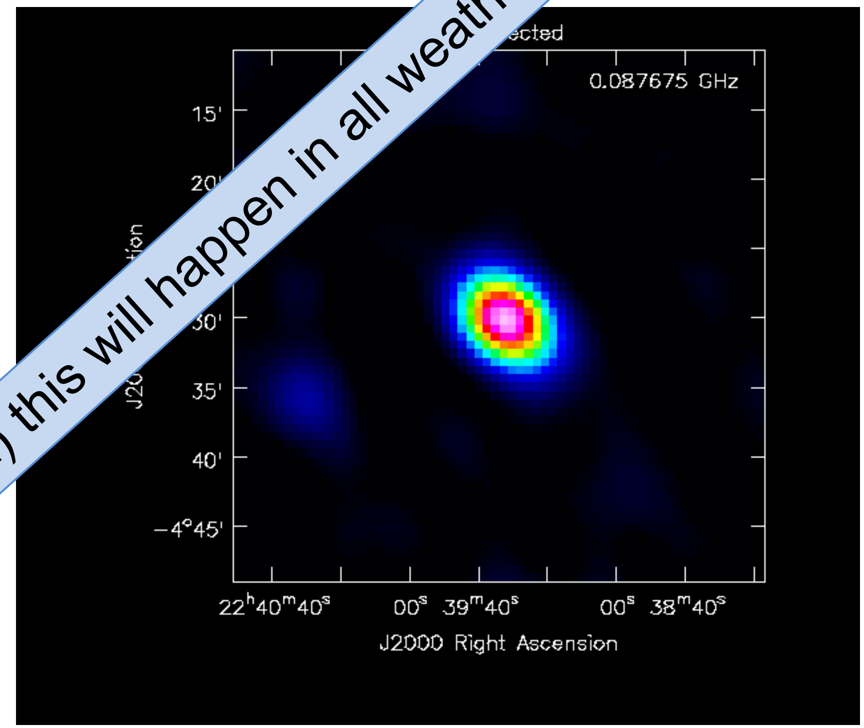
IONOSPHERIC SCREENS
(+ INSTRUMENTAL EFFECTS)

Probe ionospheric structures on fine scale ranges under size of array

(To be applied to original dataset)

Bad Weather (short baselines)





For longer baselines (>10km) this will happen in all weather

(~30 s d

- Image artifacts: position shift and defocusing
- Calibration in visibility domain is required

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

Verification Dataset:

Subset of GLEAM (GaLactic and Extragalactic All-sky MWA) Survey
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^{o})

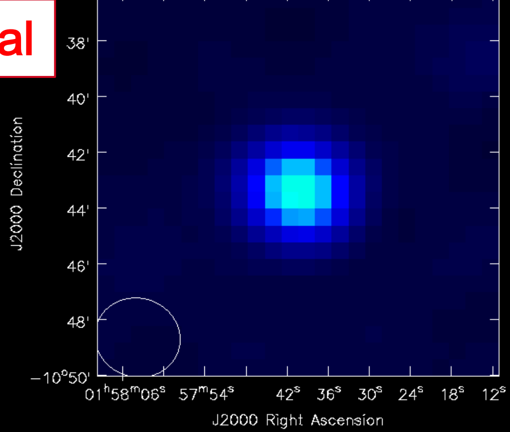
FOM imply DD corrections better than DI out to 3deg radius

Rioja+submitted

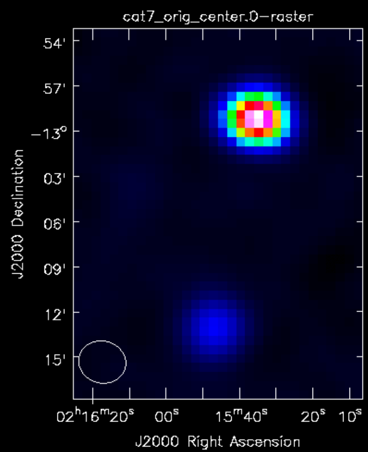
DI cal

Dir 1 cal

150 MHz

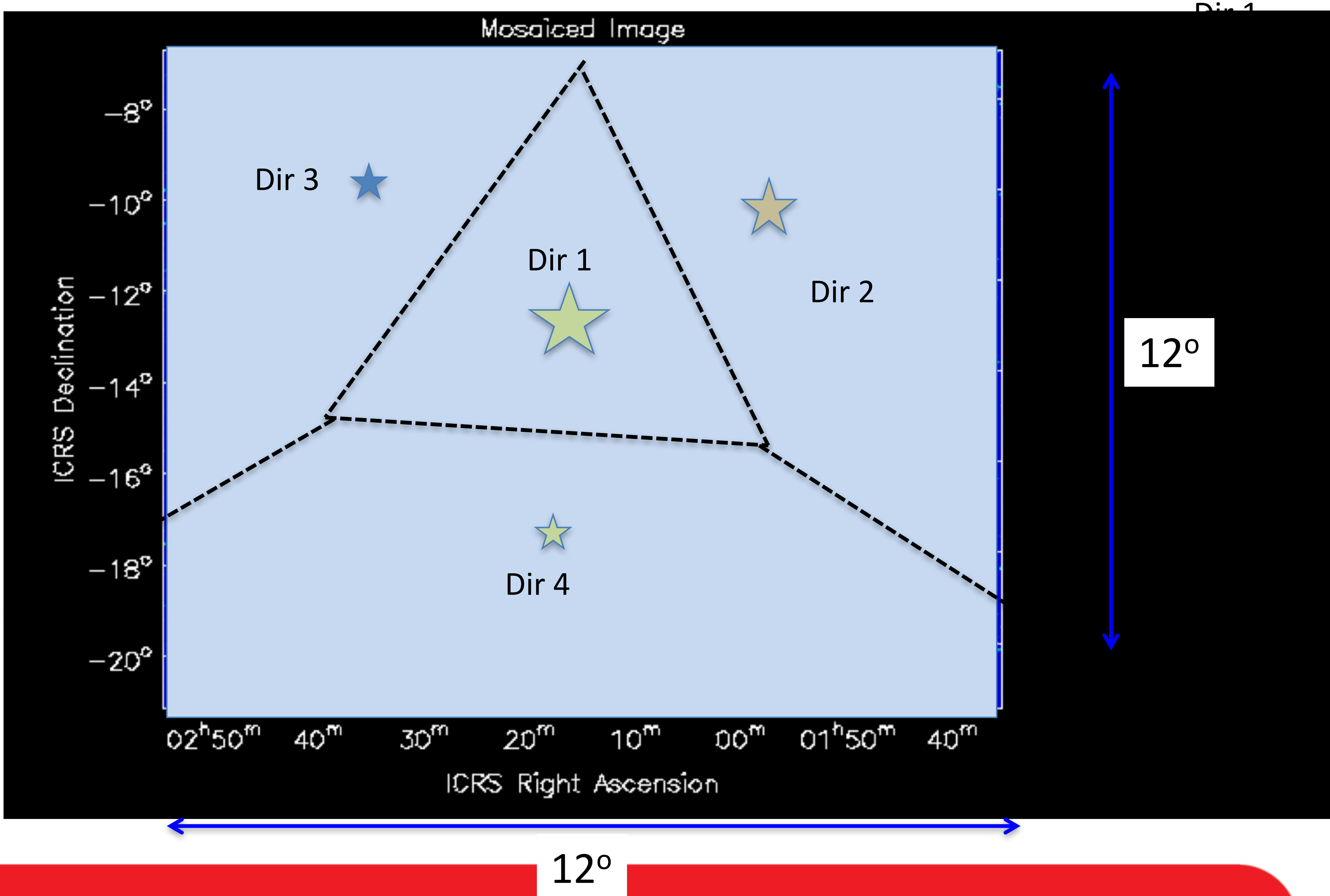


Dir 2 cal

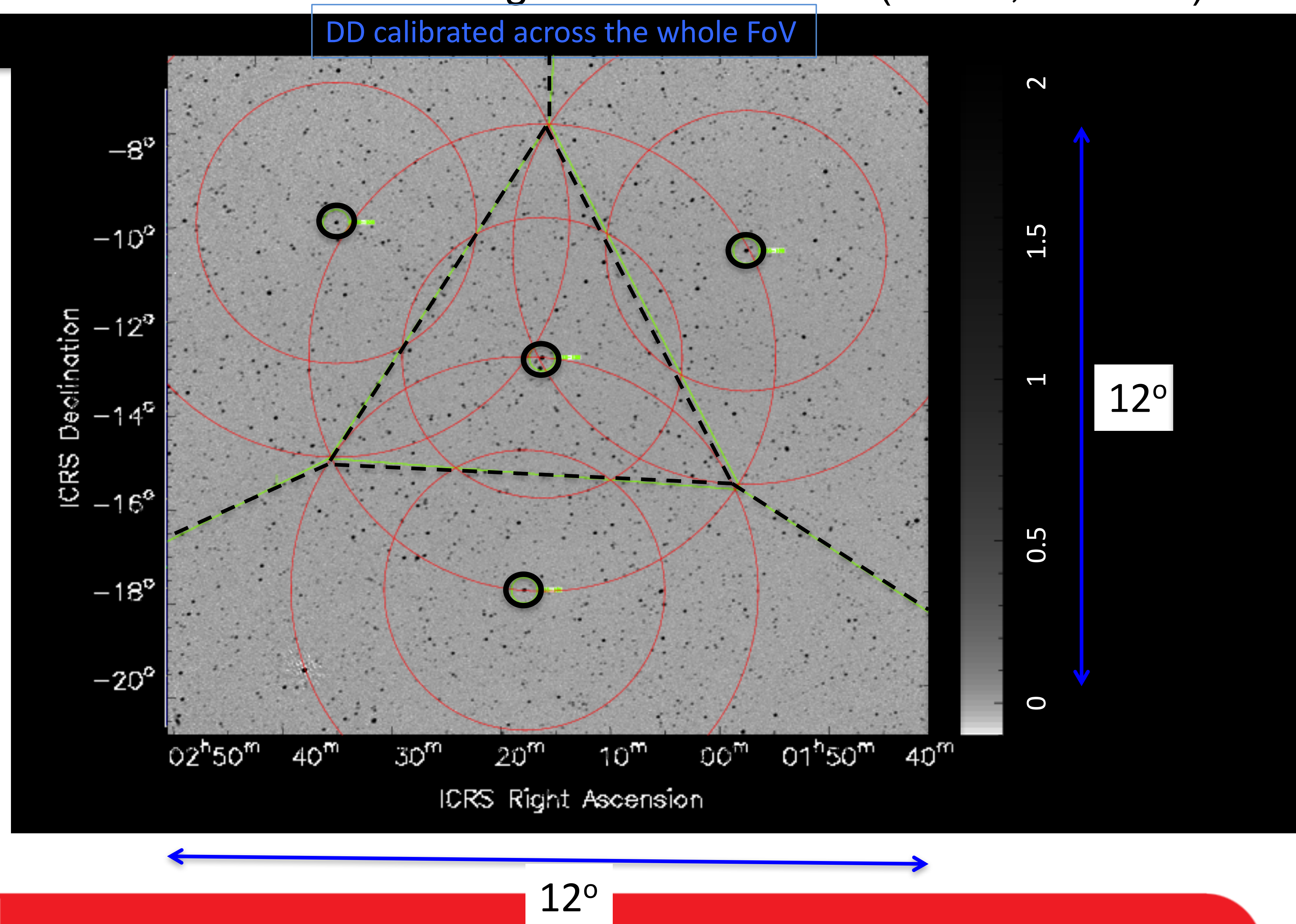


Multi Frames

MOSAIC DD IMAGE of VERIFICATION FIELD



MOSAIC DD IMAGE using LEAP calibration (facets, wsclean)



DEVELOPMENTS TOWARDS LONGER BASELINES
(=larger ionospheric effects)

Phase 1

Full Band Frequency Averaging
Phase only recovered (not delay)
Simulation studies for error analysis @80 MHz:
Astrometric errors < 2”, amplitude loss < 1%, no change in image noise
Suitable for MWA size
Imaging with WSClean

Phase 2

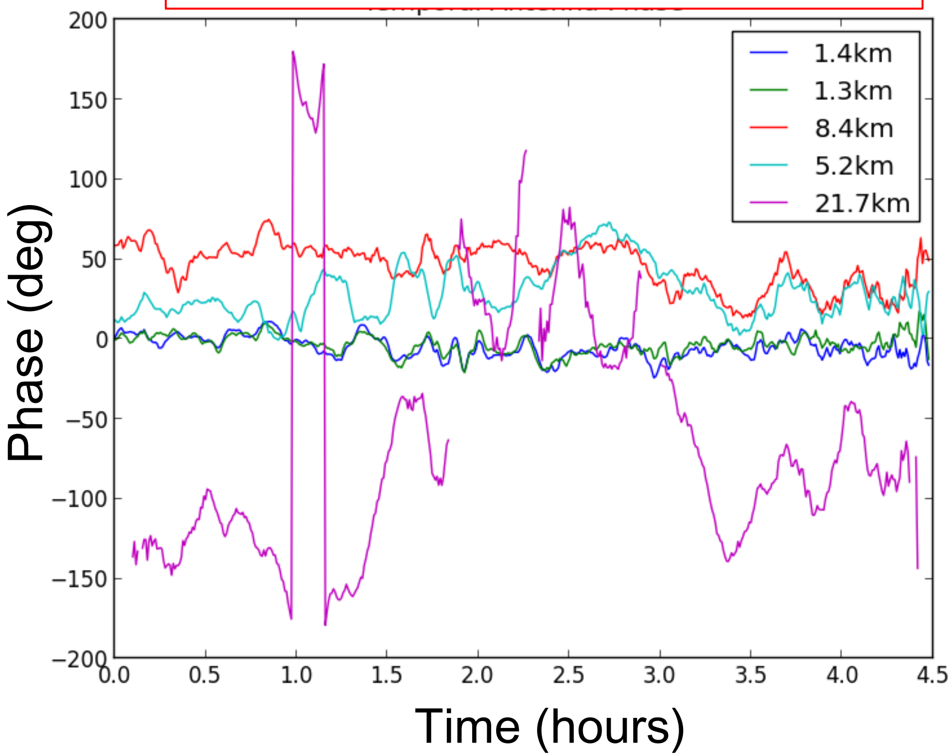
Baseline Dependent Filter (smoothing)
(i.e. small FoV whilst keeping spectral signature across BW)
ΔTEC recovered – phase ambiguities solved
Clustering sources
On going developments
Suitable for LOFAR / MWA Phase 2 / SKA-Low
Imaging with DDFacet

LOFAR at 150 MHz

(longer baselines, larger distortions)

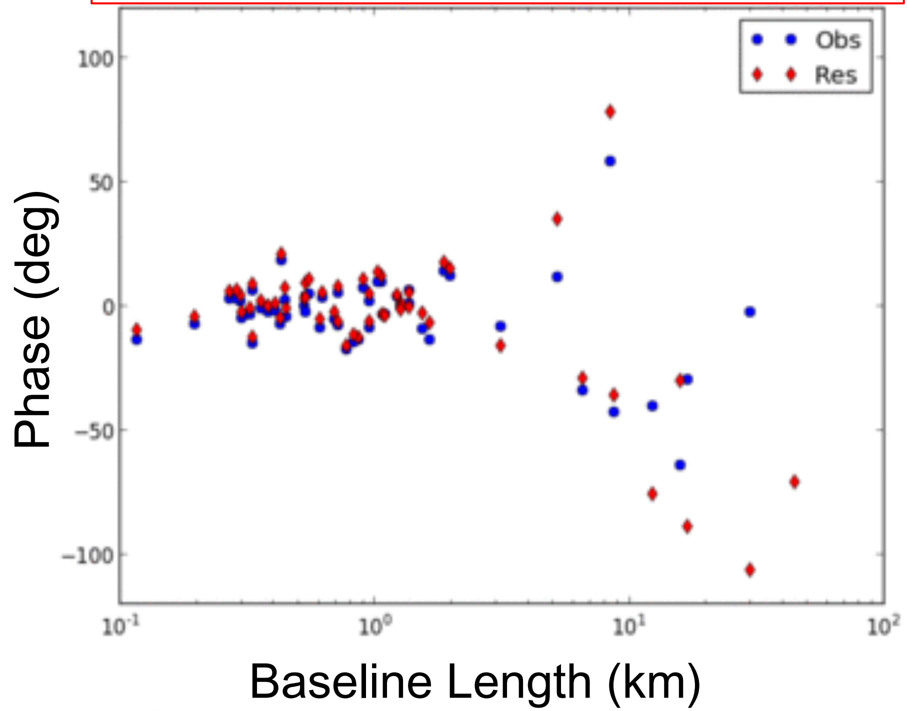
Preliminary

Calibration Phases vs. Time, for DIR1



4 hours

Temporal sequence (30s) of Calibration Phases vs. Baseline Length

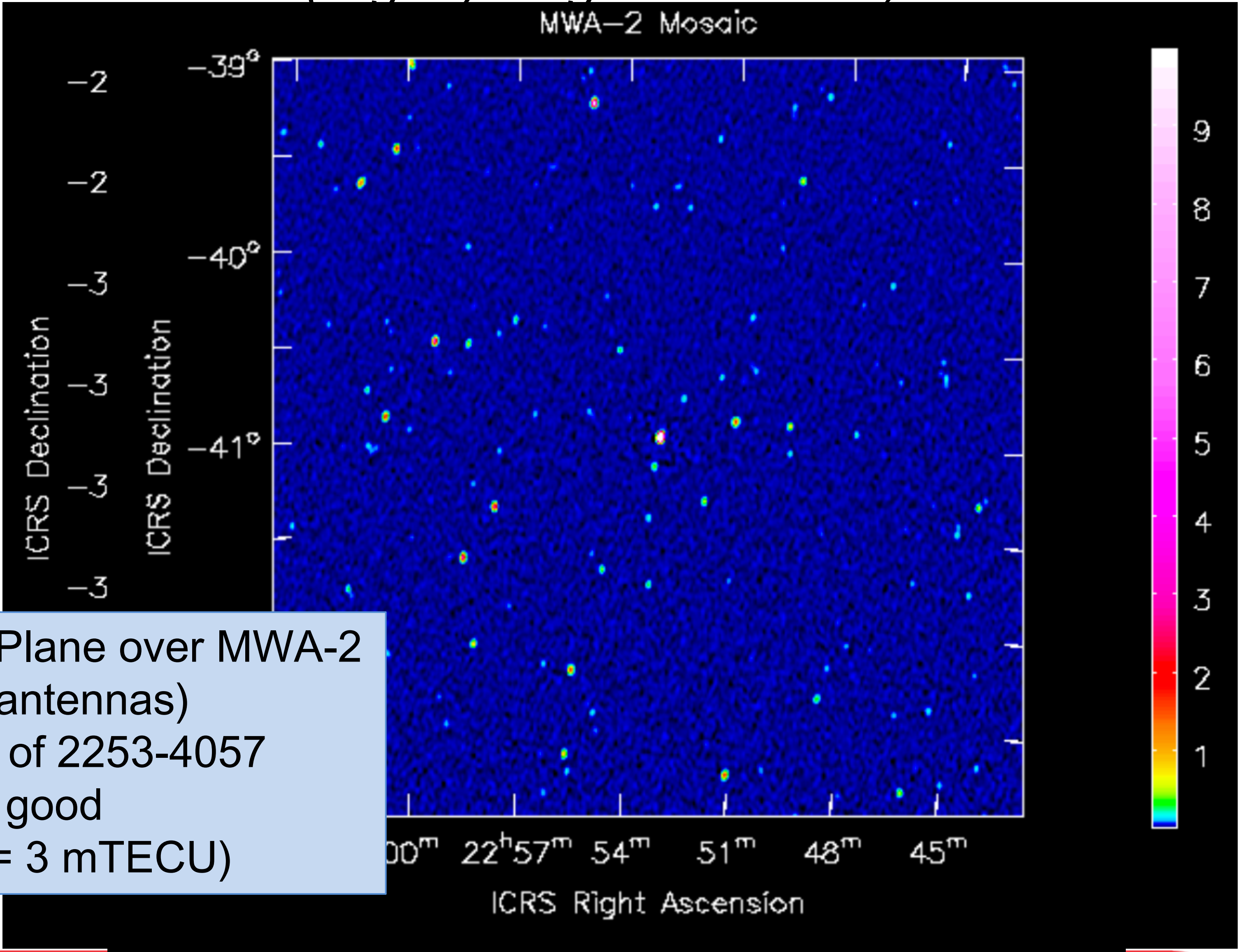


100 km

The planar aproximation breaks down beyond a few kilometers.

MWA-2 at 150 MHz

(slightly longer baselines)



DD Phase Plane over MWA-2 array (~60 antennas)
In direction of 2253-4057
Weather v. good
(~5arcsec = 3 mTECU)

DI Image from Tom Franzen – as seen in George H's talk

LEAP SUMMARY

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

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

Probes Small scale (< 3km) higher order ionospheric structure, for MWA and for LOFAR on scale ranges from 100m to tens of Km.
Causes shift and defocusing, as shown. Can be corrected for, as demonstrated.

For SKA_Low sensitivities these will be even more significant. Such effects must be addressed, either by our, or other, techniques.