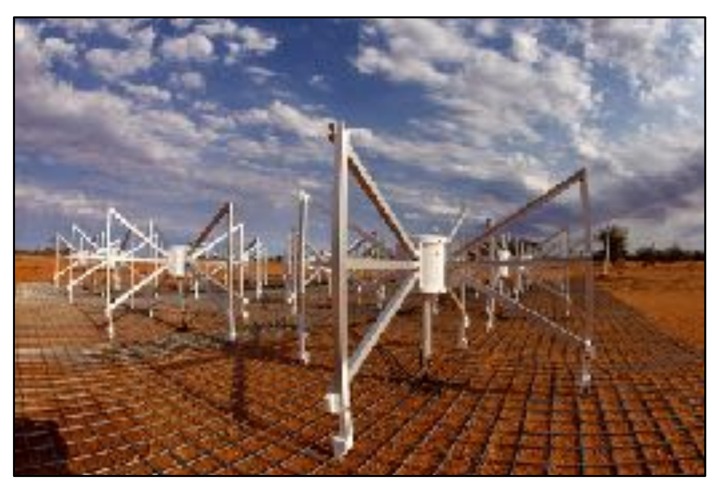
MWA Polarisation Studies

Emil Lenc

University of Sydney / CAASTRO
www.caastro.org

SPARCS VII (Perth)

20 July 2017



CSIRO; Swinburne

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THE UNIVERSITY OF SYDNEY

KEEP CALM
CARRY ON
WITH
POLARIMETRY

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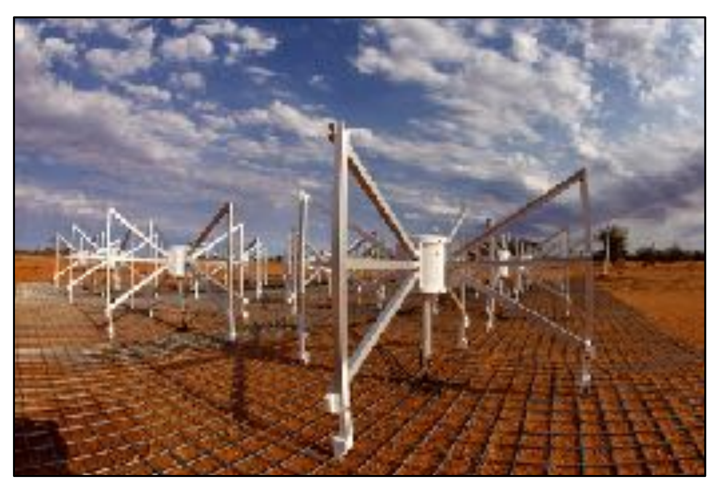
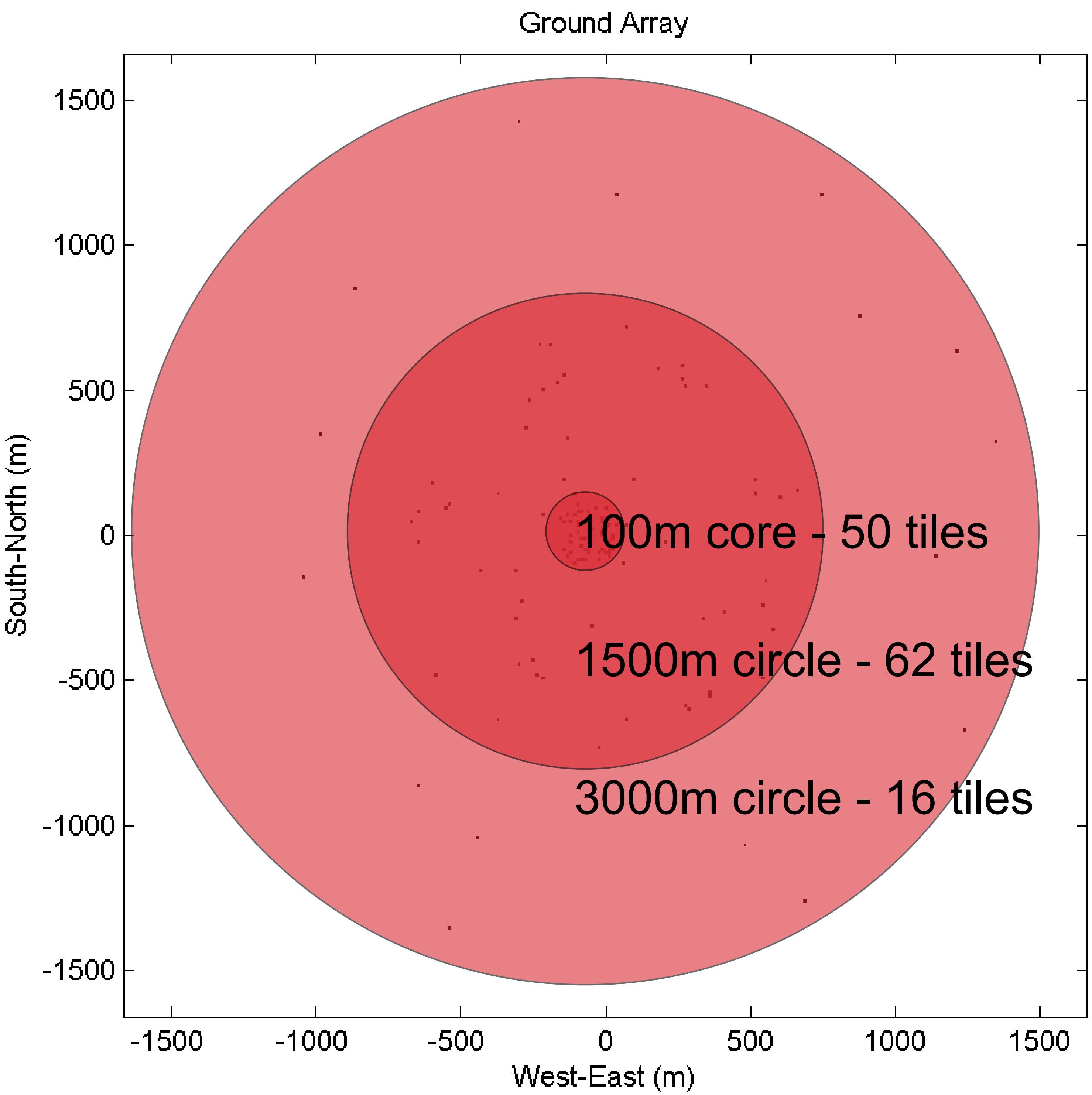



CSIRO; Swinburne

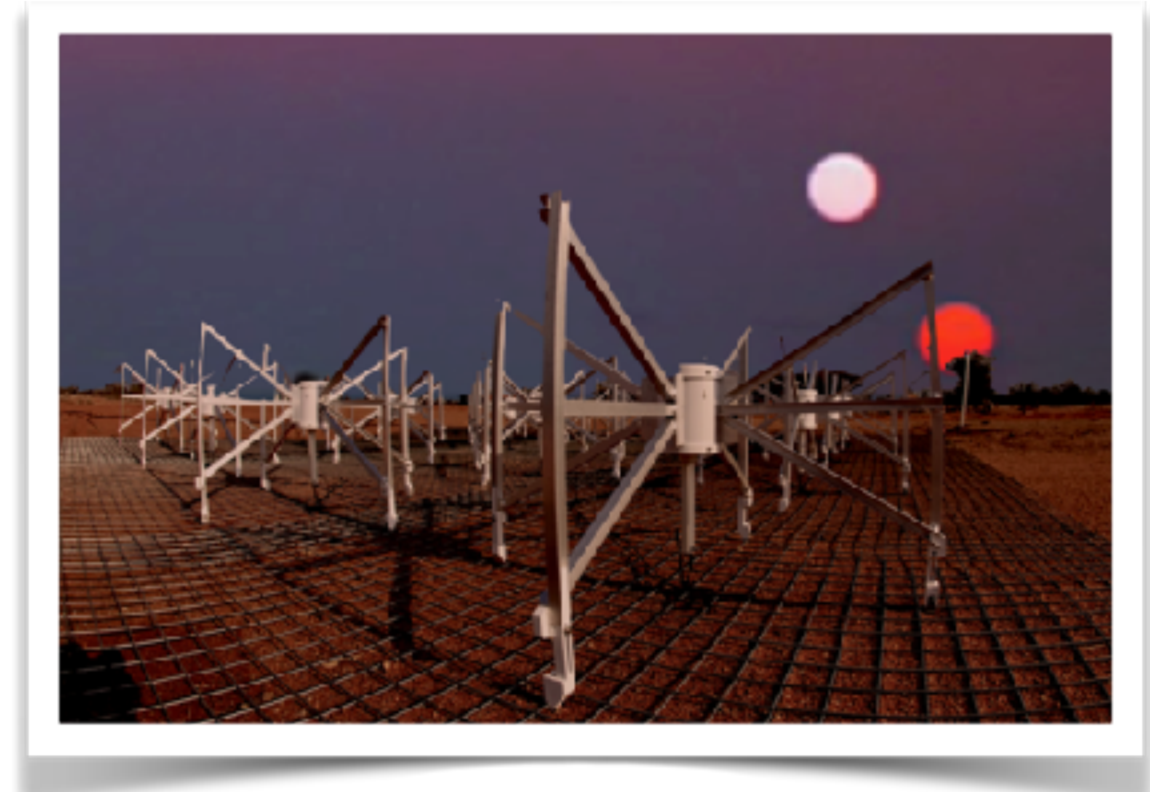
Overview

- What's the MWA?
- Why do long wavelength polarimetry?
- The challenges and opportunities
- How the MWA can save SKA-Low

The Murchison Widefield Array (Phase 1)



Full array = 128 tiles (128 T)

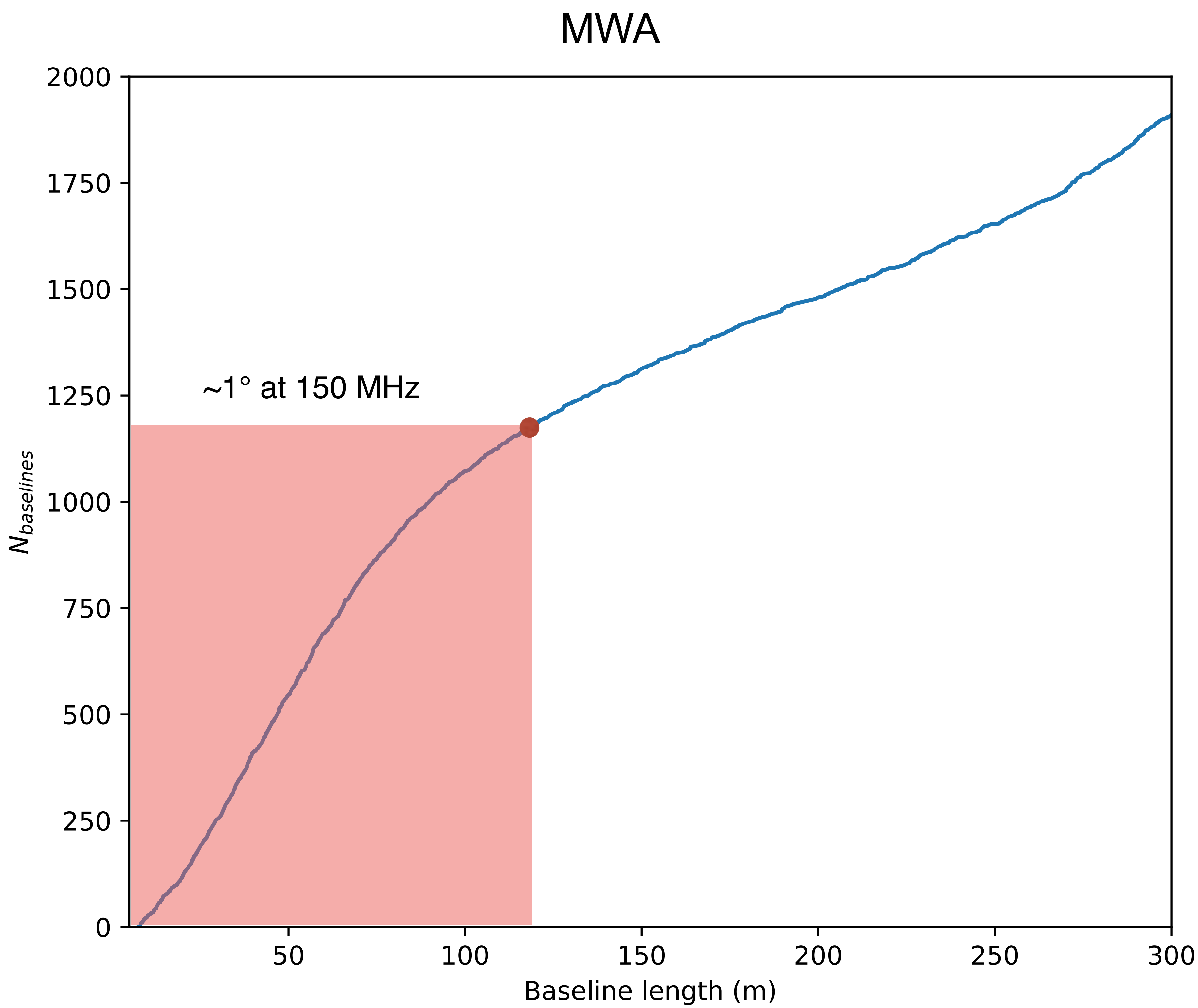


Murchison Widefield Array, Tatooine

- Electronically “steered”
- 16 dual-pol. dipoles
- Simple design
- 72-231 MHz range
- 15°-50° field-of-view
- Precursor to SKA Low
- ~Co-located with ASKAP

(Tingay et al. 2013)

Short baseline advantage



Why do long wavelength polarimetry?

$$\beta = RM\,\lambda^2$$

$$RM = \int n_e\, \mathbf{B}\, dl$$

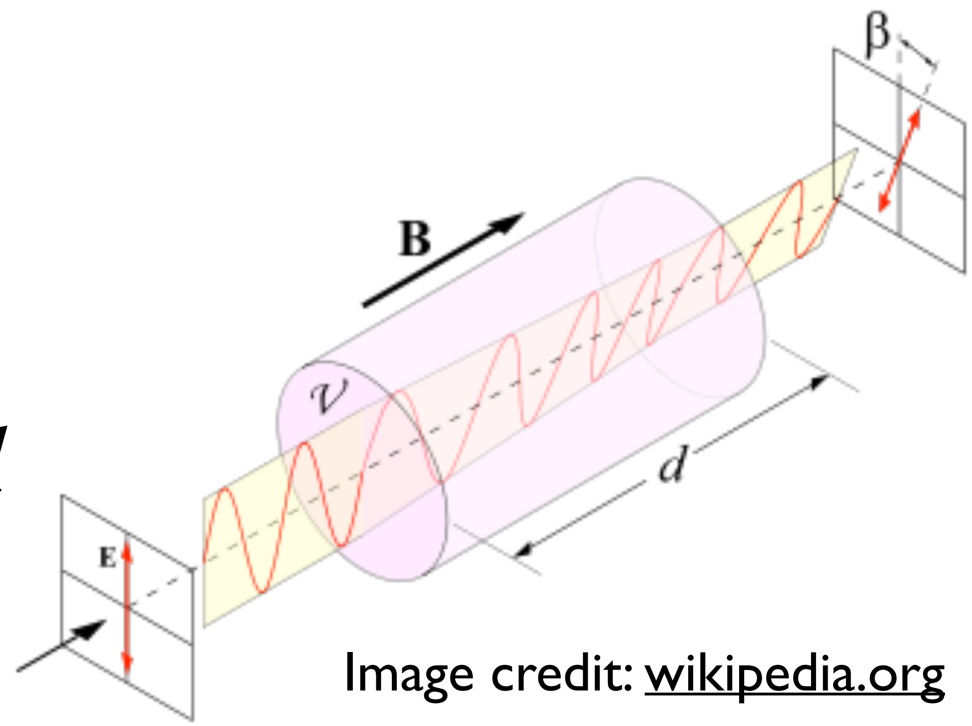


Image credit: wikipedia.org

Long wavelength observations exhibit higher rotation!
NB: MWA wavelength range is between 1.3 and 4 m.

Why do long wavelength polarimetry?

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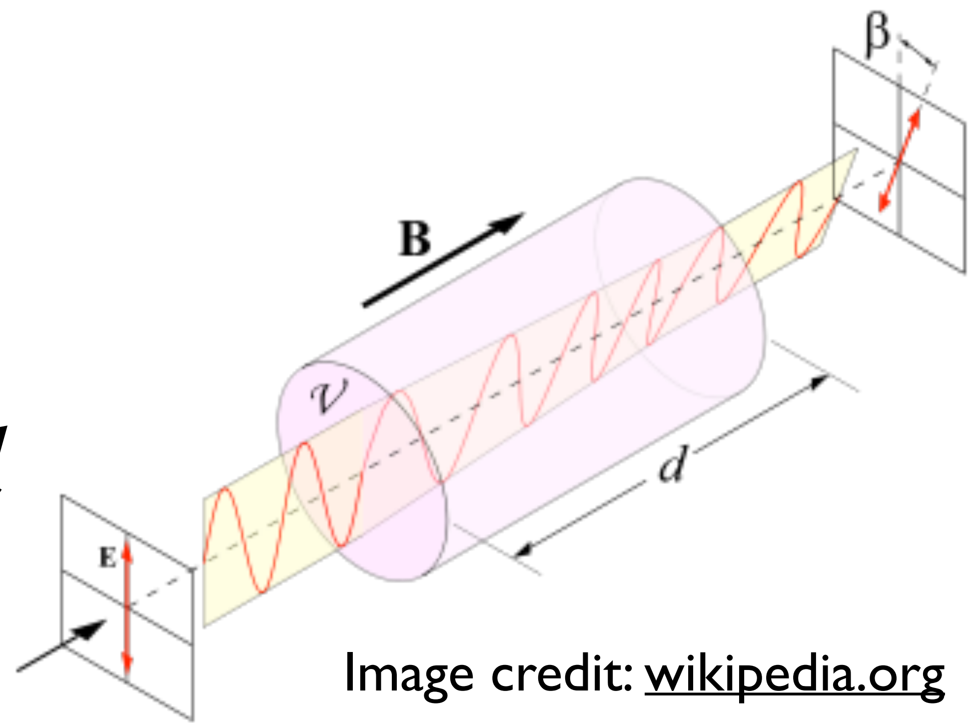

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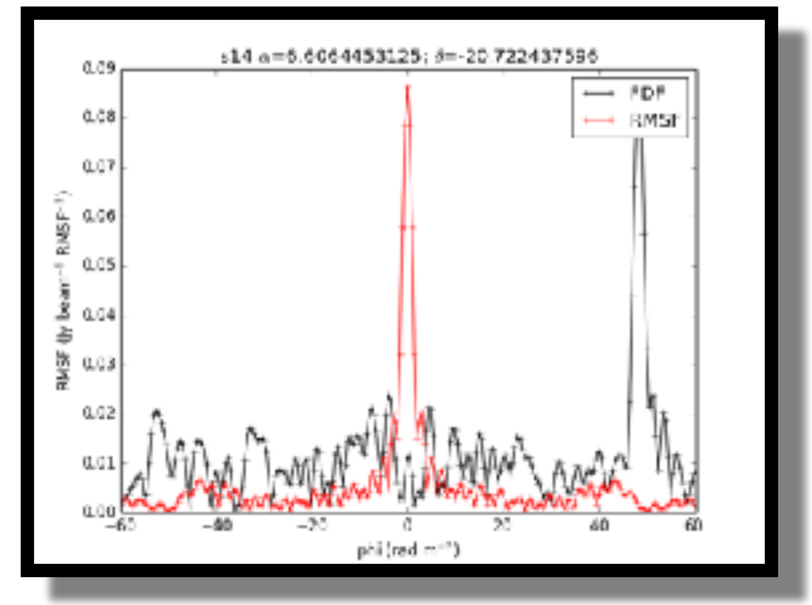
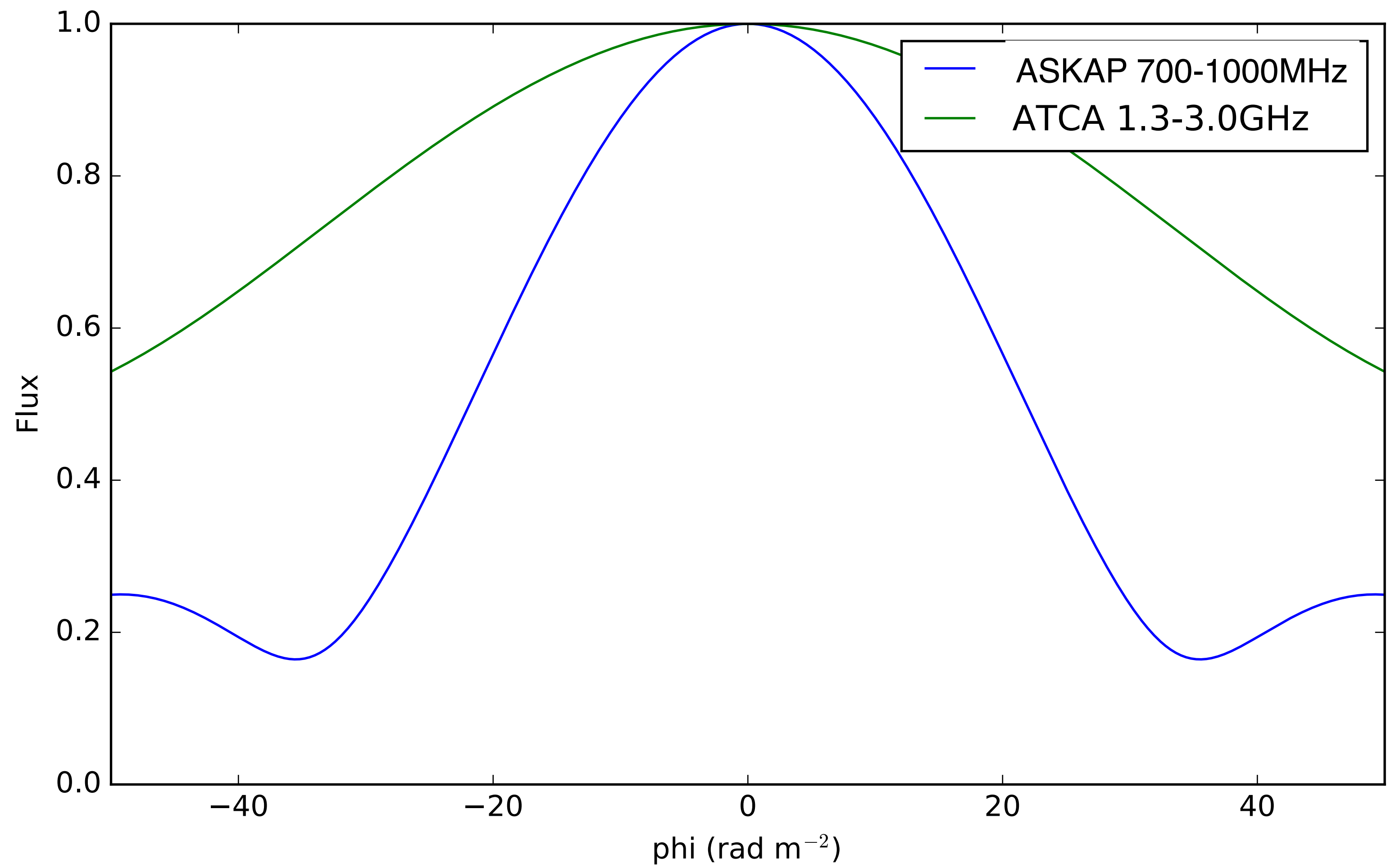


Rotation Measure (RM) Synthesis

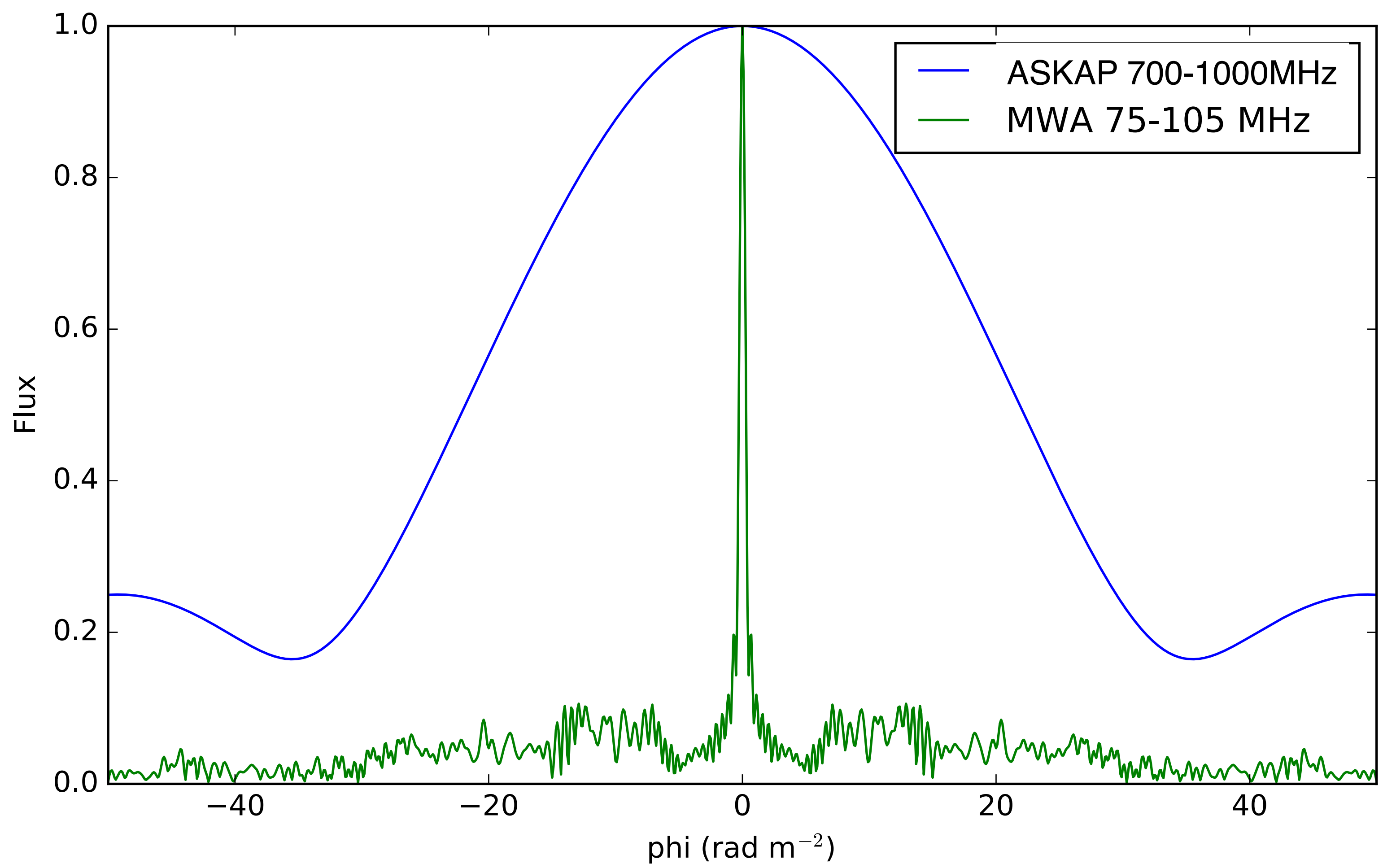
Long wavelength observations exhibit higher rotation!
NB: MWA wavelength range is between 1.3 and 4 m.

Probing λ^2 Space
Where long wavelengths shine!



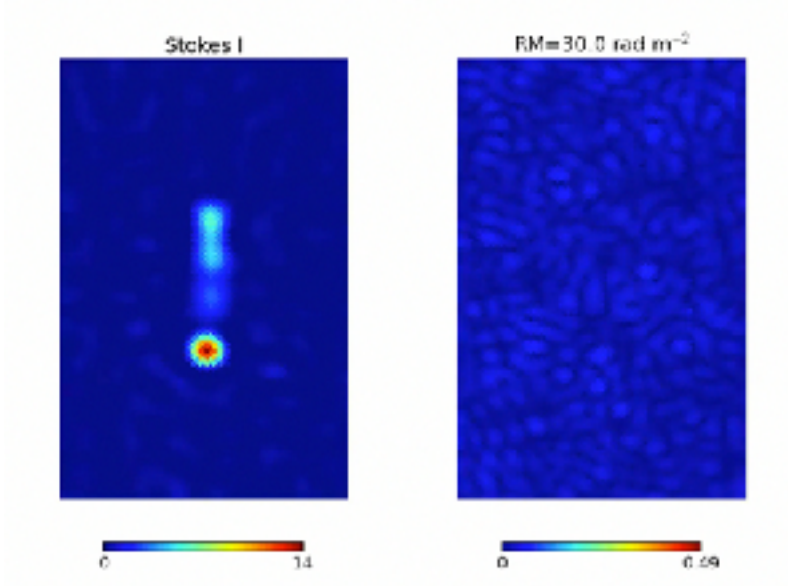
RMSF FWHM = 40 rad m^{-2} (c.f. ATCA RMSF FWHM = 78 rad m^{-2})

Probing λ^2 Space
Where long wavelengths shine!

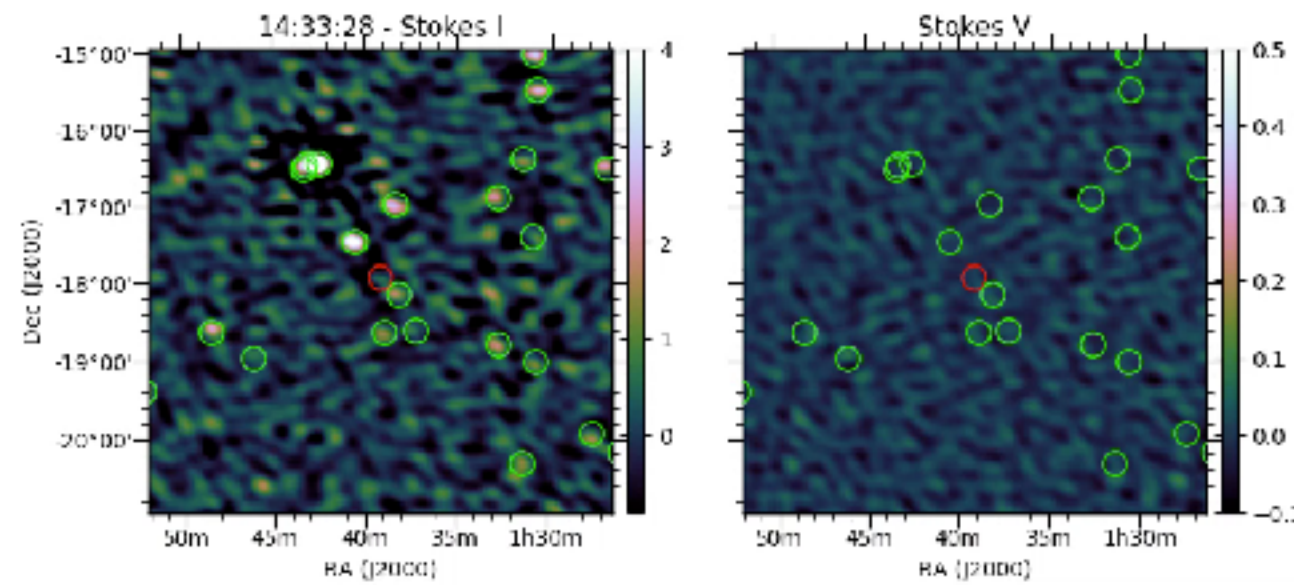


RMSF FWHM = 0.4 rad m^{-2}

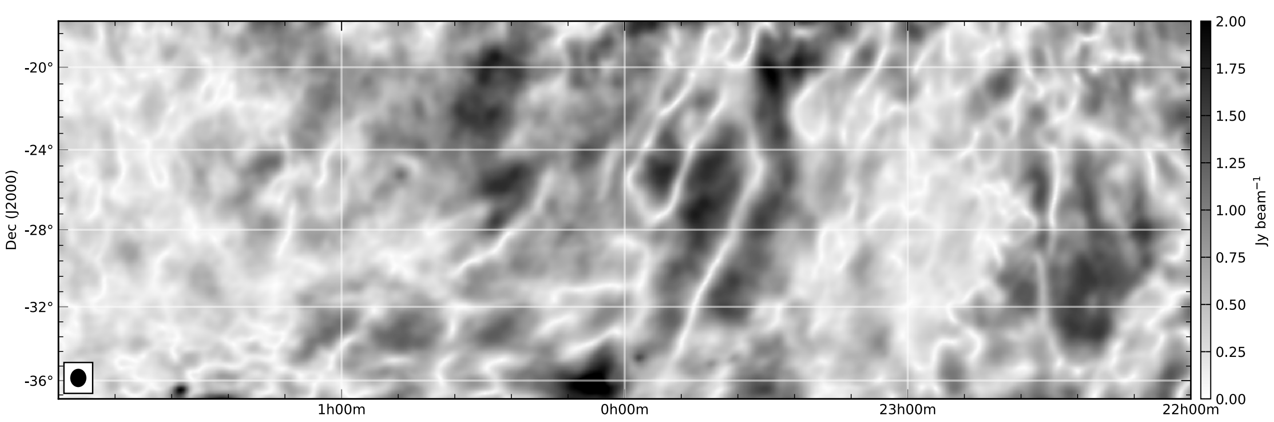
Why do long wavelength polarimetry?



Point source polarimetry
Lenc et al. (2016)
Lenc et al. (submitted)

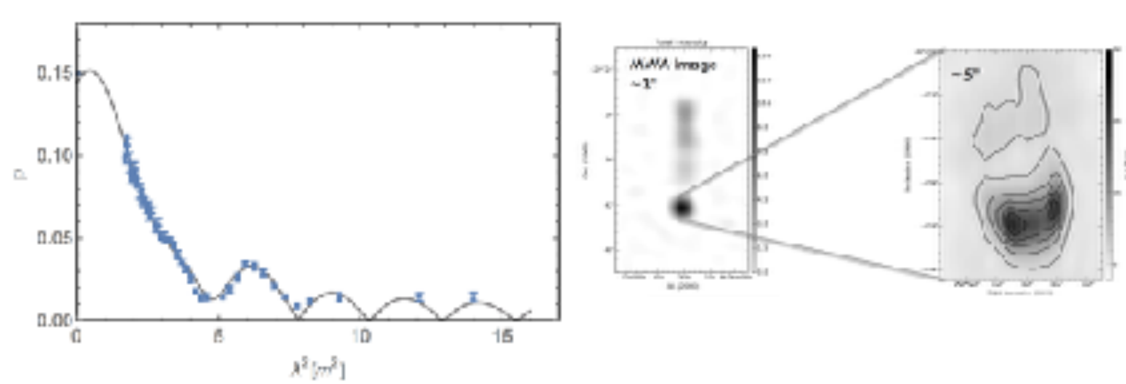


Flare stars
Lynch et al. (2017)
Lenc et al. (submitted)



Diffuse polarisation
Lenc et al. (2016)
Lenc et al. (submitted)

$$p_{01}\, e^{2i(\chi_{01}+\mathrm{RM}_1\lambda^2)} \frac{\sin \Delta\mathrm{RM}_1\lambda^2}{\Delta\mathrm{RM}_1\lambda^2} + p_{02}\, e^{2i(\chi_{02}+\mathrm{RM}_2\lambda^2)} e^{-2\sigma^2_{\mathrm{RM}_2}\lambda^4}$$



Source depolarisation
Lenc et al. (2016)
O'Sullivan et al. (submitted)
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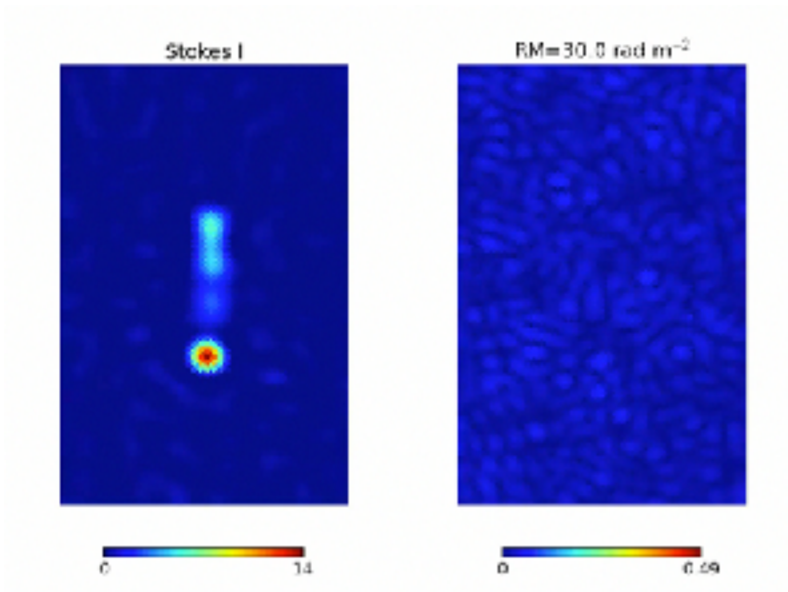
Why do long wavelength polarimetry?



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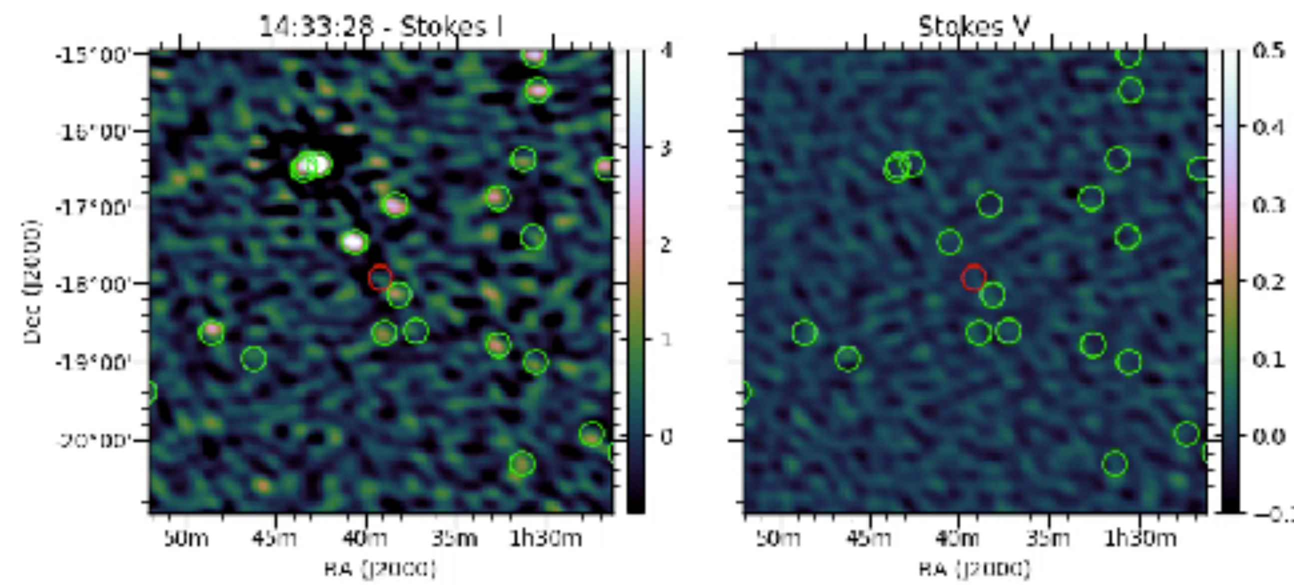

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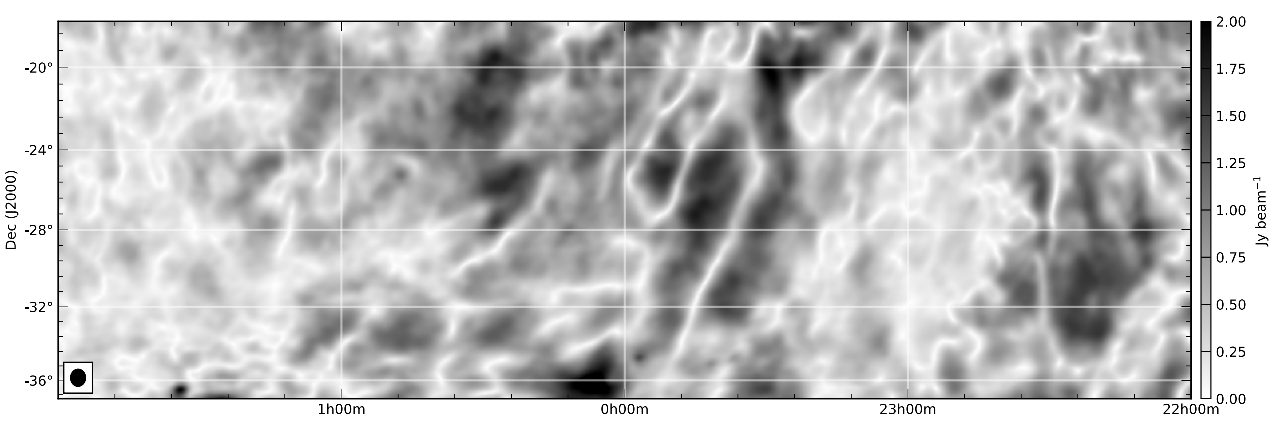

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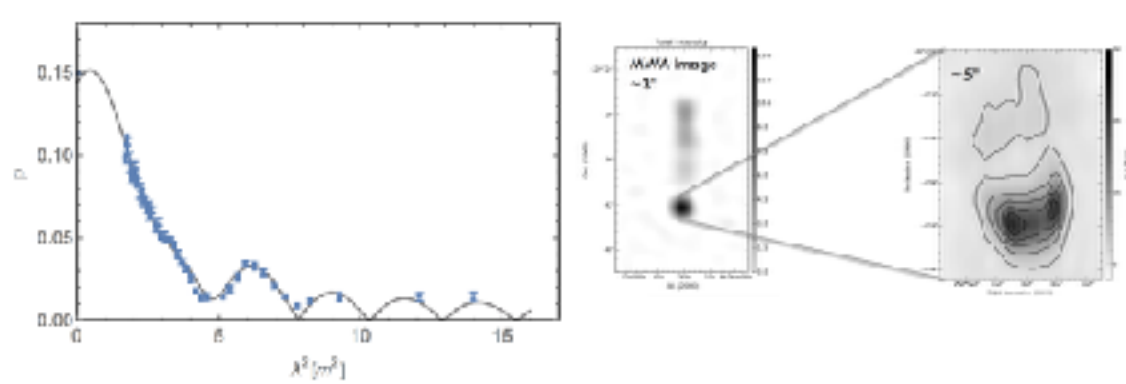

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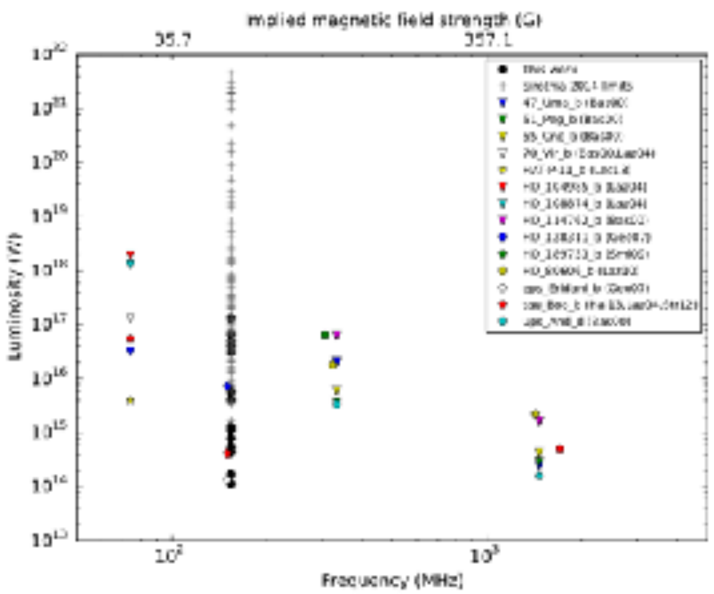
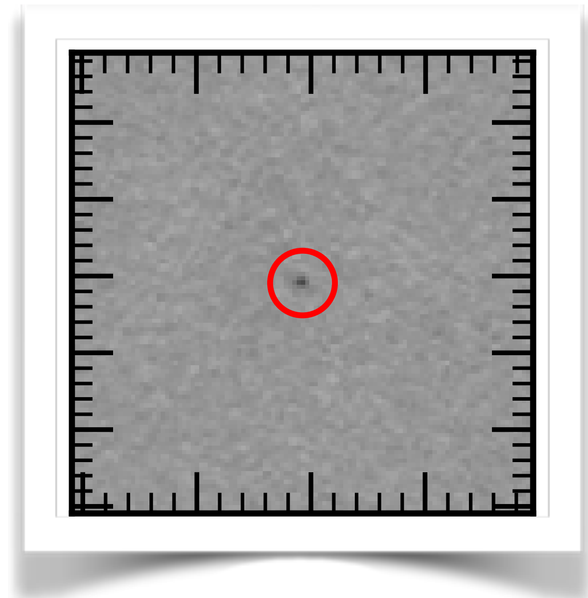
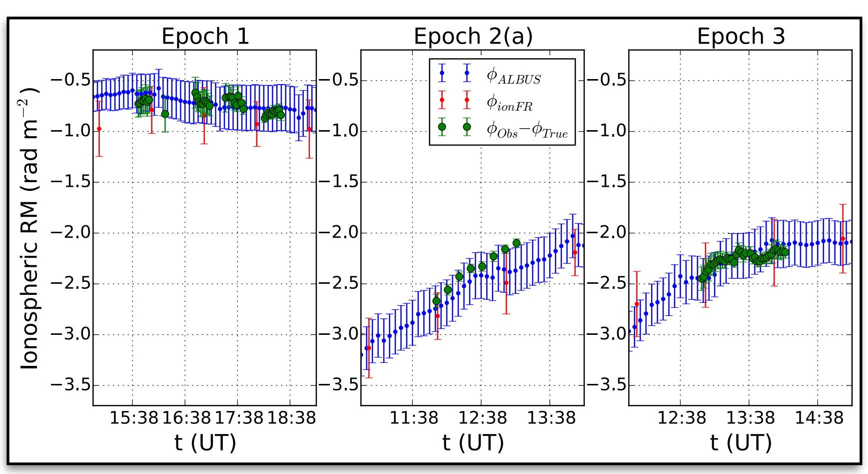


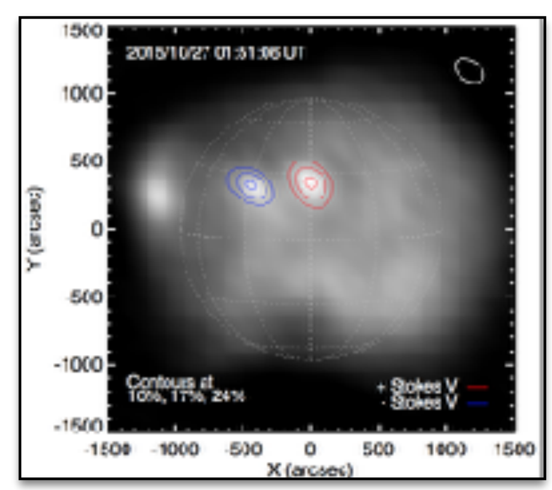
Exoplanets
Murphy et al. (2015)
Lenc et al. (submitted)



Pulsars
Lenc et al. (in prep)

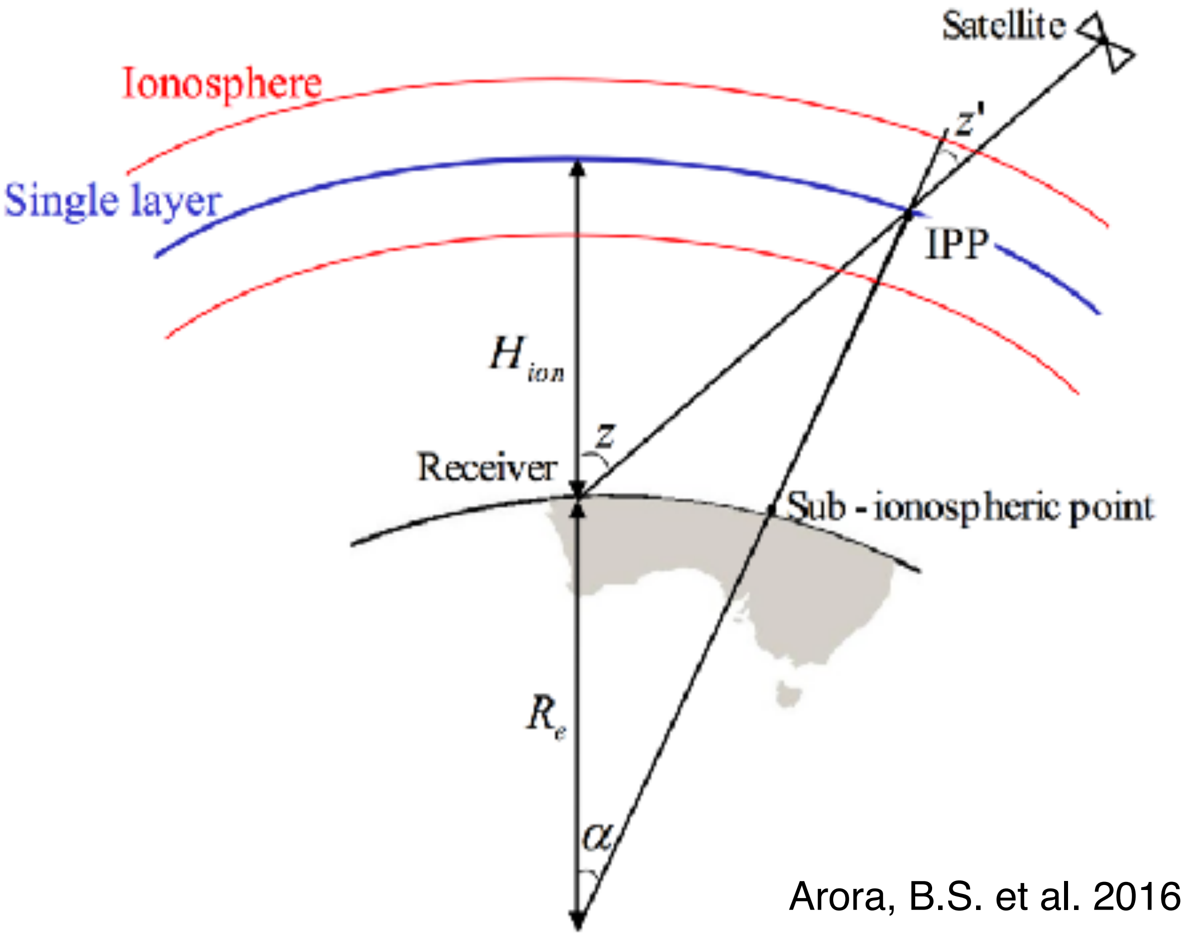


Ionosphere
Lenc et al. (2016)
Lenc et al. (submitted)



Solar
Lenc et al. (submitted)
McCauley et al. (in prep)

Challenge 1 -The Ionosphere Correcting with GPS data

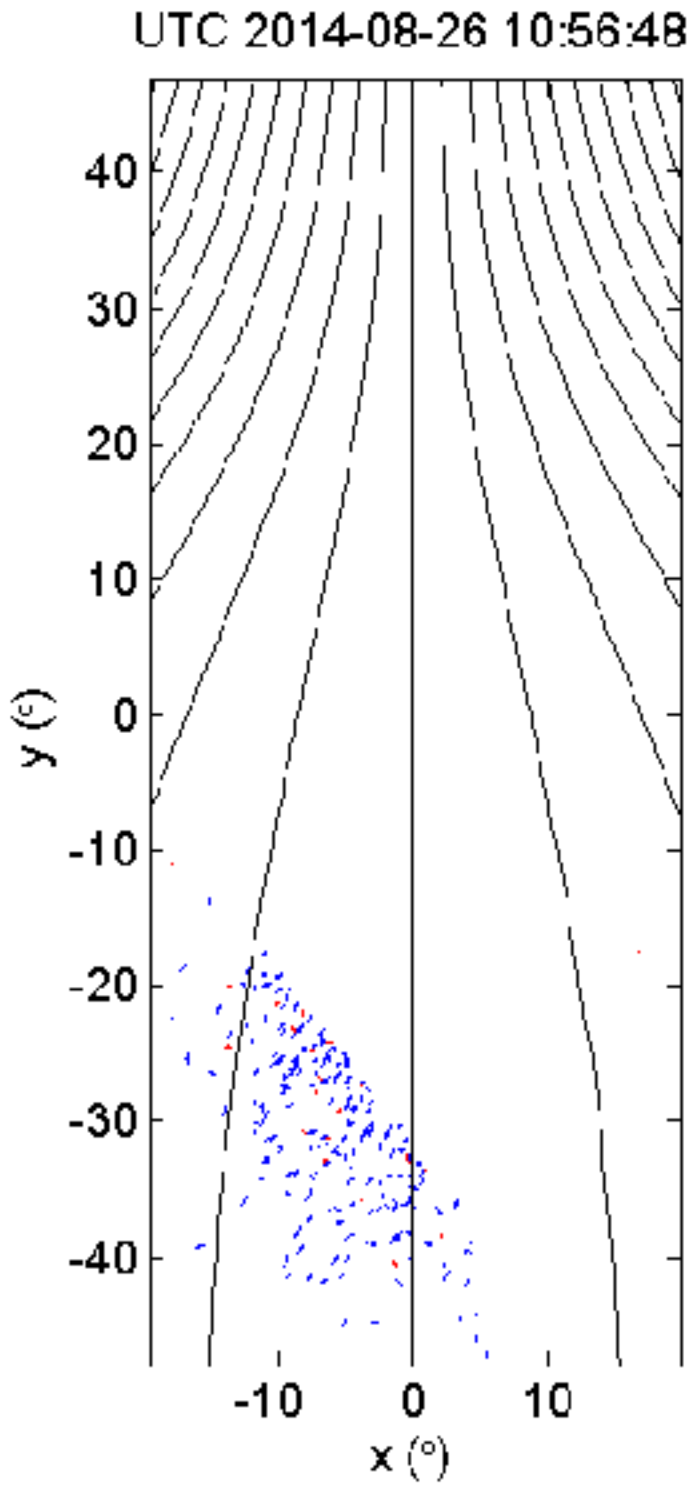


Arora, B.S. et al. 2016

Tools of the trade:
› ionFR (Sotomayor-Beltran, C. et al. 2013)
› RMextract (Mevius, M.)
› ALBUS (Willis, A.G., Anderson, J.M.)

- Accurate to line of sight to satellite.
- Simplistic models.
- Many receivers and satellites required to improve model.
- Data is coarse in time (2 h) and spatially (2.5-5 deg).
- Data not available in real-time.

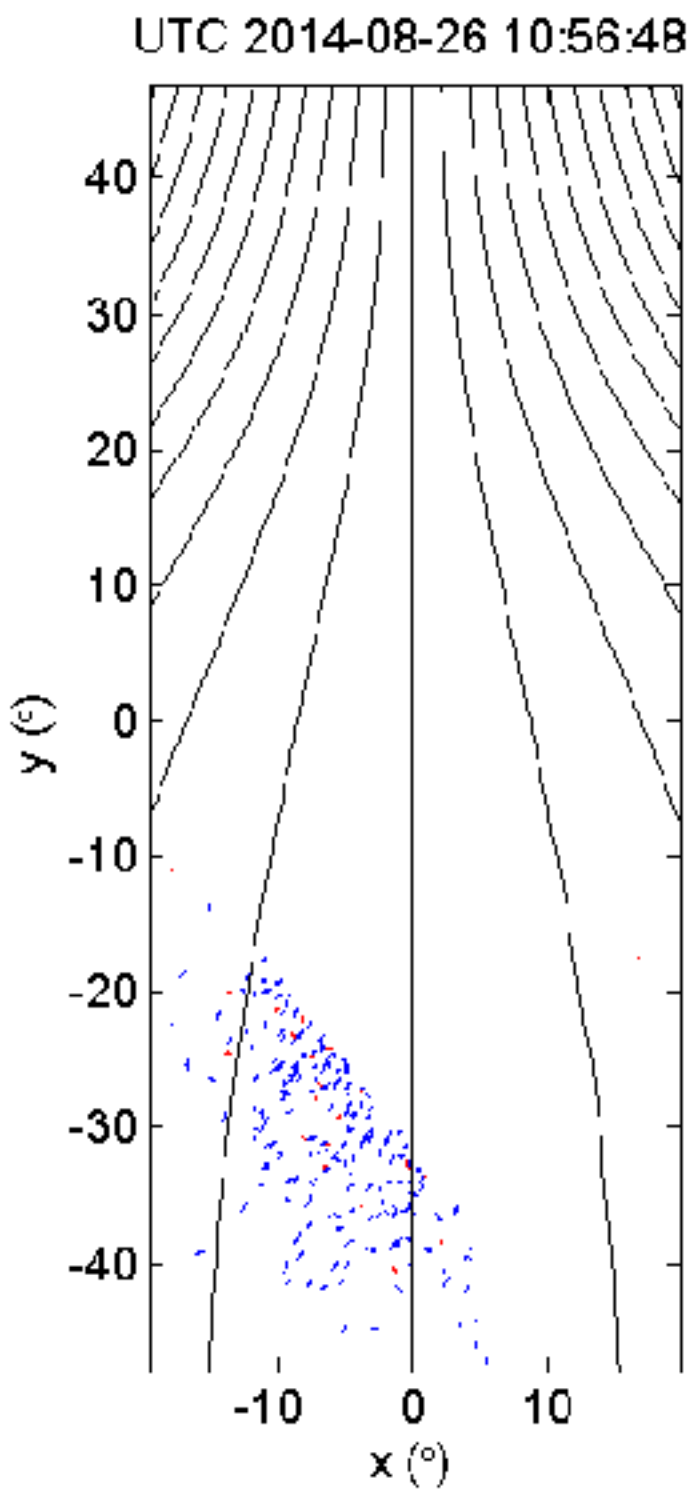
The Ionosphere is messy



Travelling Ionospheric Disturbance (Loi et al., 2016)

- Detected by measuring source displacements with the MWA.
- Time-scale = minutes!

The Ionosphere is messy



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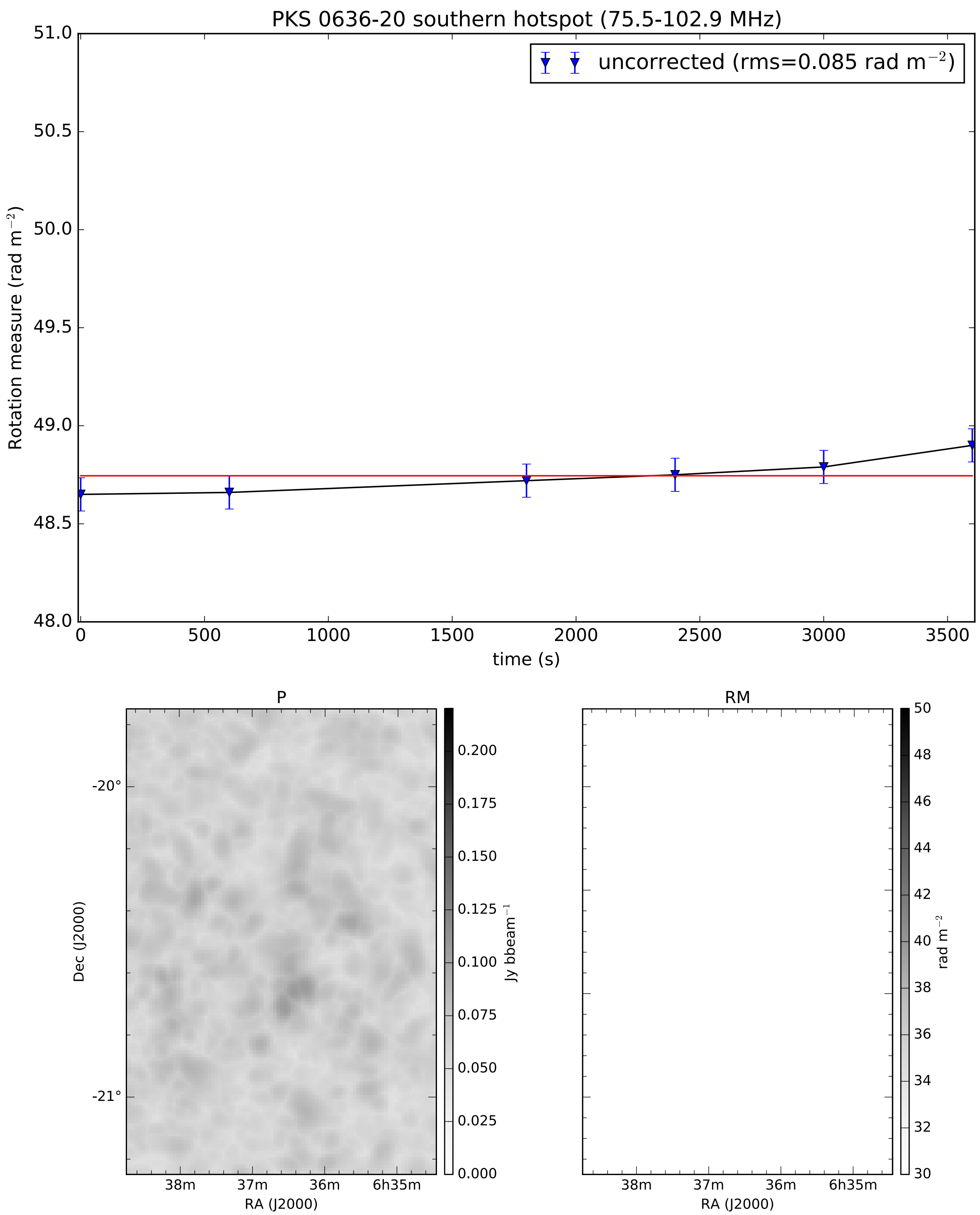
Measuring the ionosphere with point sources

Uncorrected



(Lenc et al. submitted, see also Offringa et al. 2016 and Moore et al. 2017)

Measuring the ionosphere with point sources

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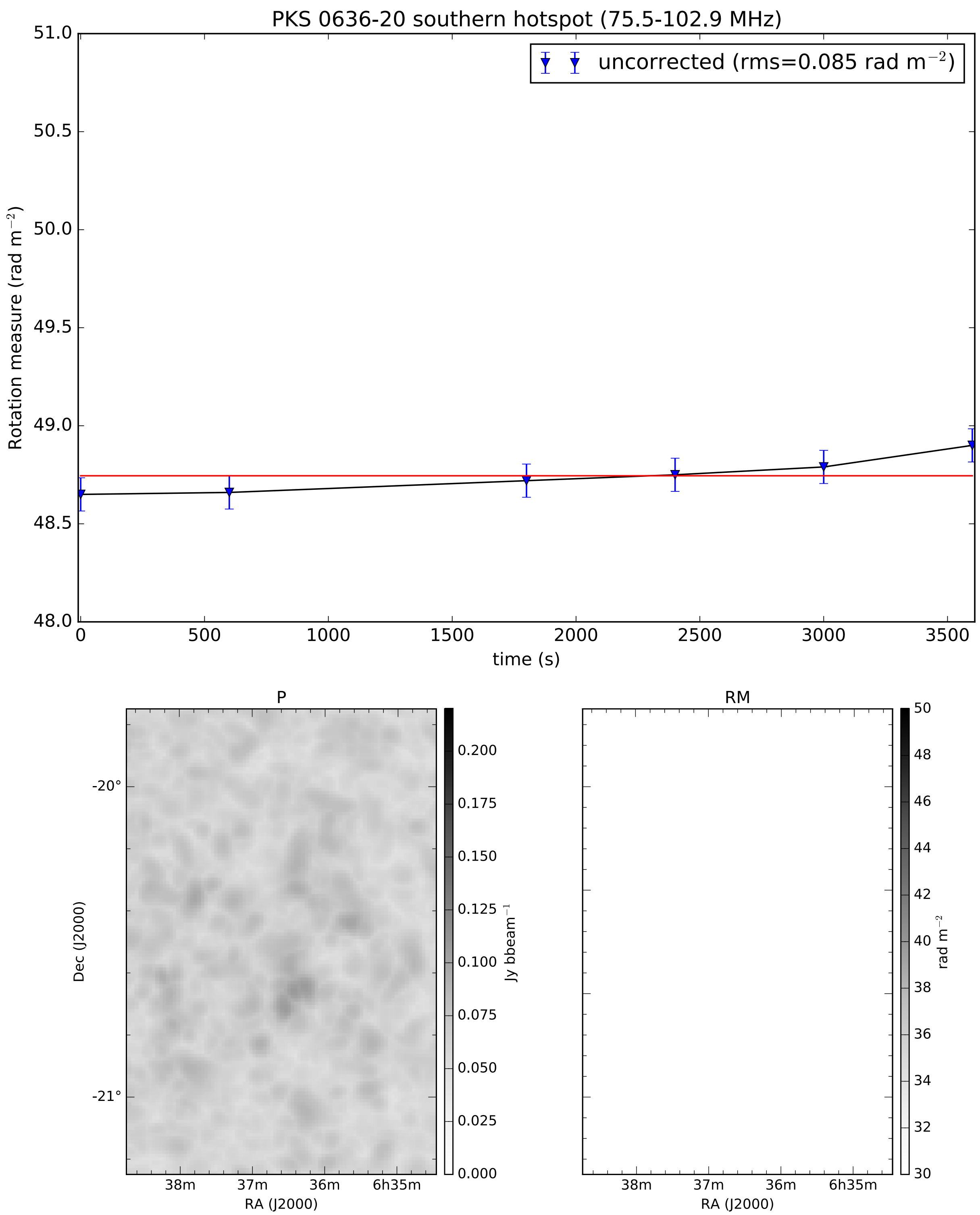
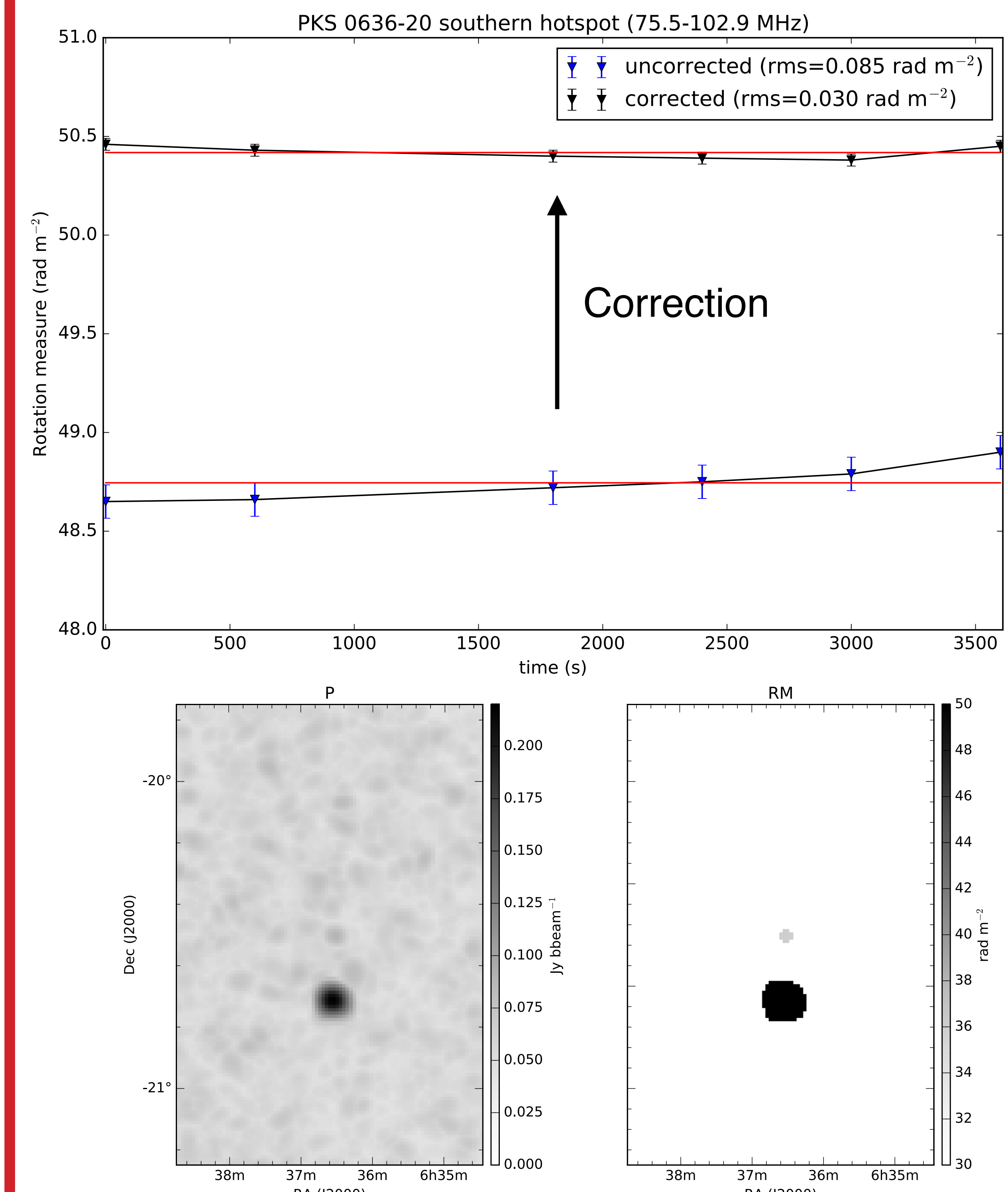
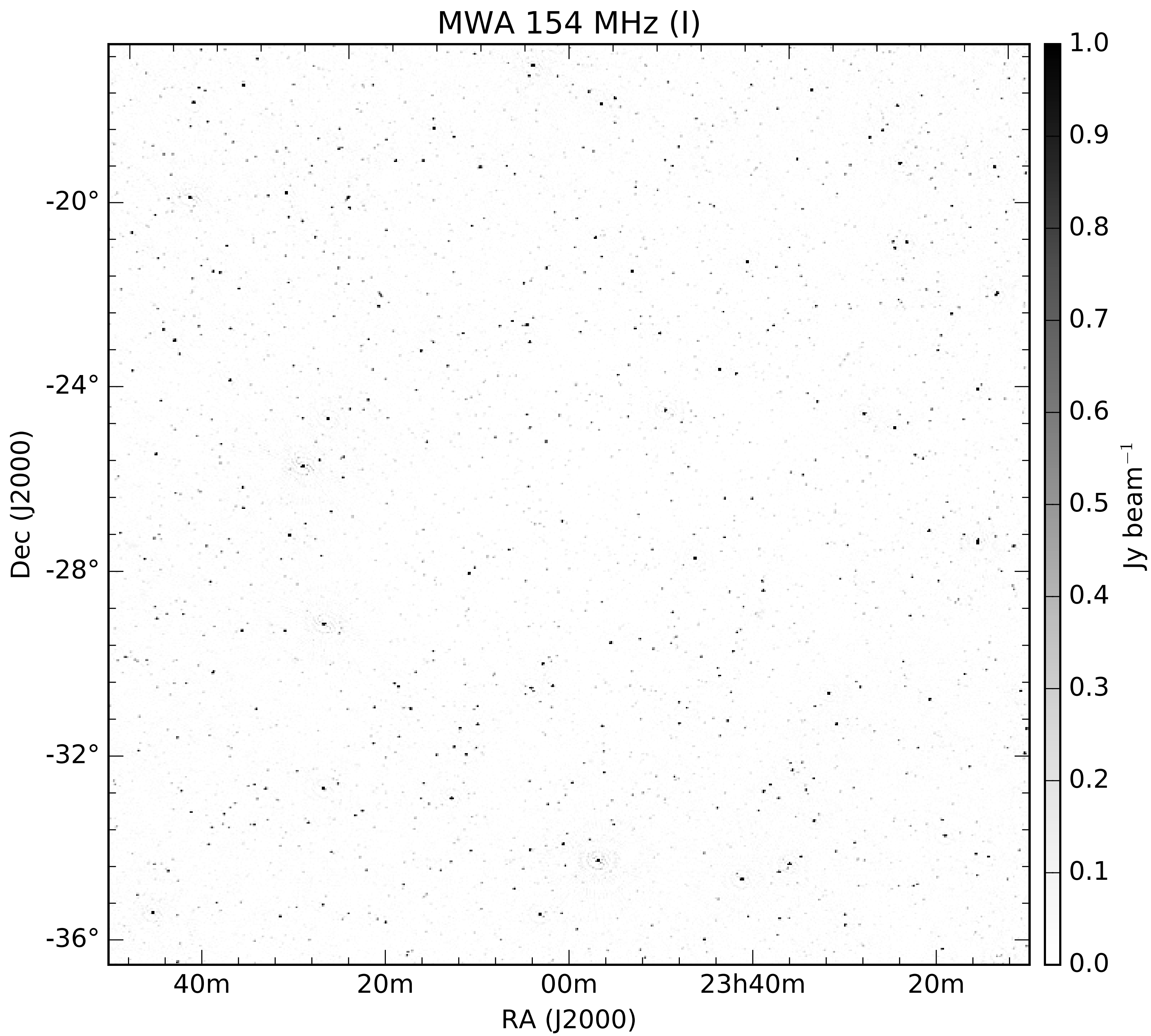


Corrected



(Lenc et al. submitted, see also Offringa et al. 2016 and Moore et al. 2017)

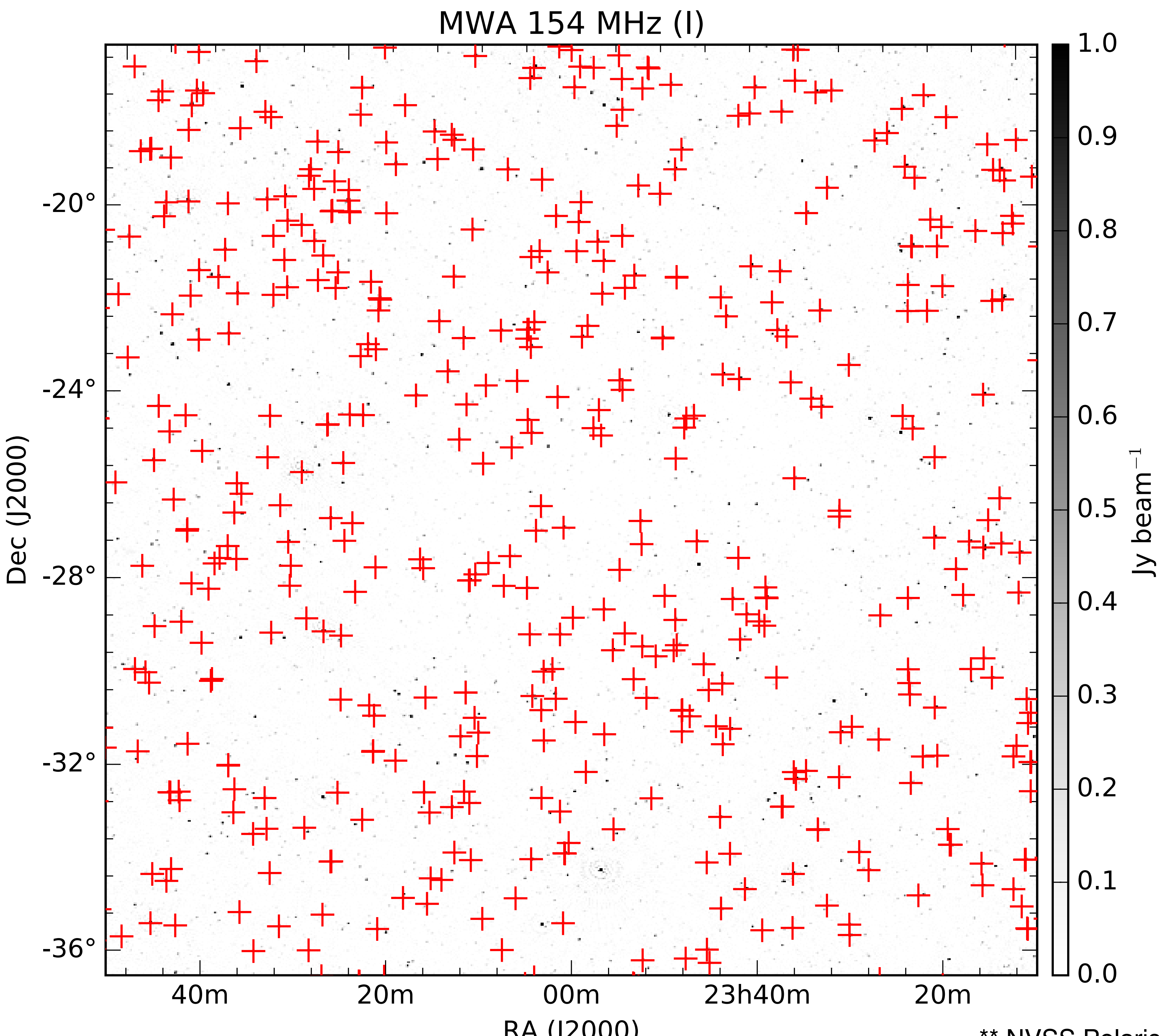
Reality Test
MWA Observation of South Galactic Pole



600 sq. degree 2-minute MWA snapshot (dirty image).

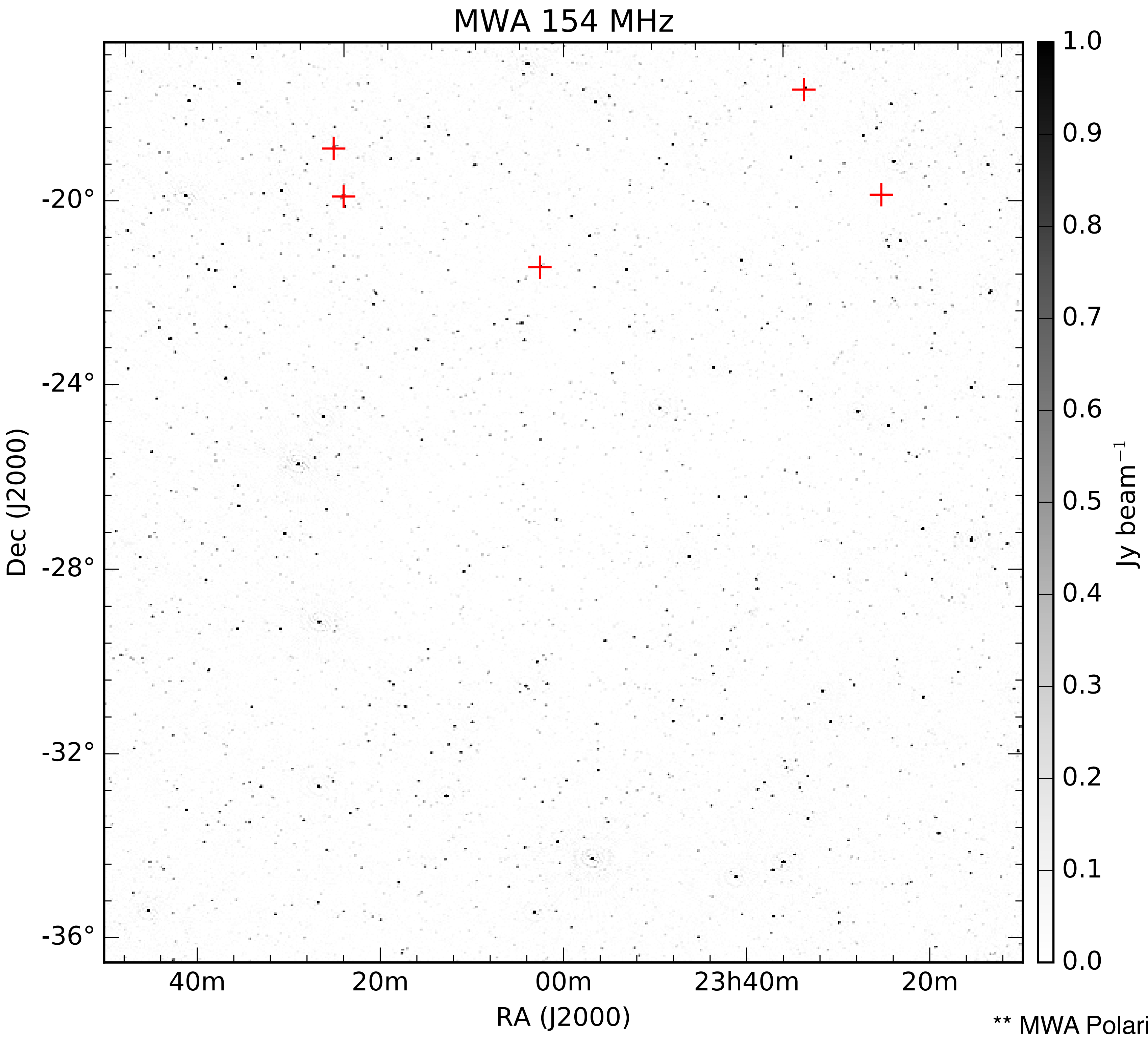
Centred just off the South Galactic Pole (SGP).

Reality Test
MWA Observation of South Galactic Pole



** NVSS Polarised Sources Highlighted

Reality Bites
MWA Observation of South Galactic Pole



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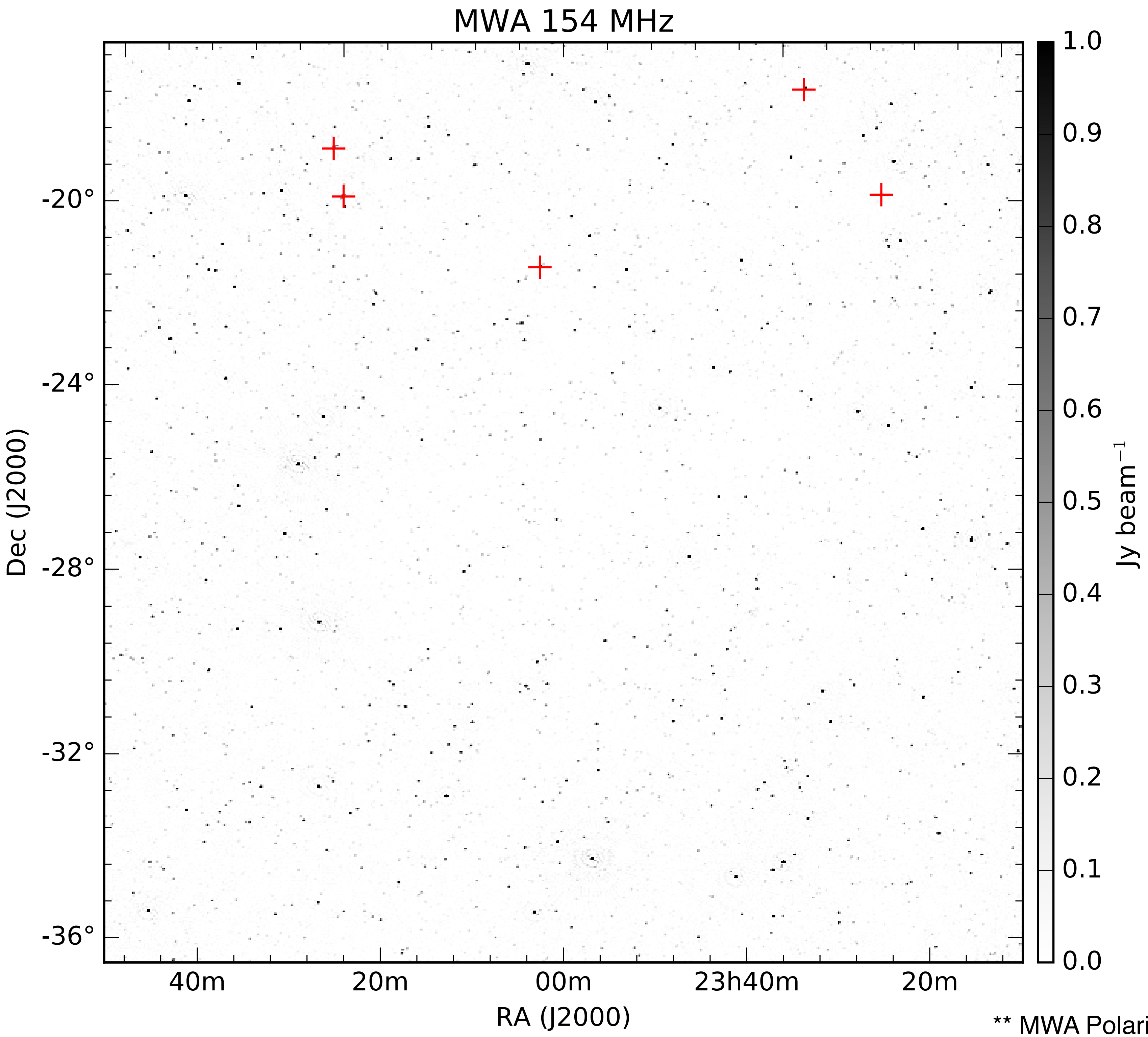
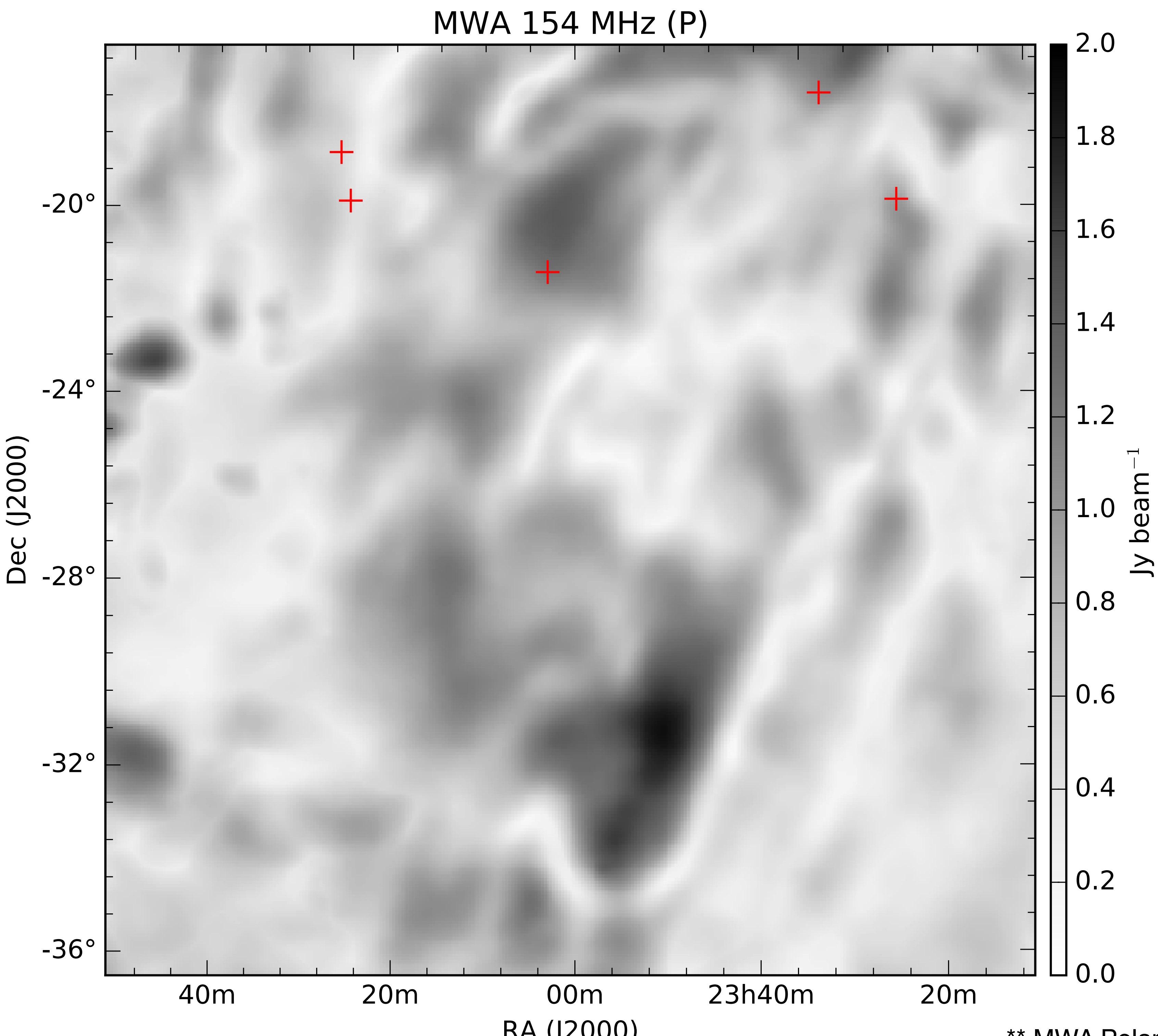
Reality Bites
MWA Observation of South Galactic Pole



** MWA Polarised Sources Highlighted (Lenc et al., 2016)

What about diffuse polarisation?



2-minute MWA snapshot!

Structures are local (~50 pc)

** MWA Polarised Sources Highlighted (Lenc et al., 2016)

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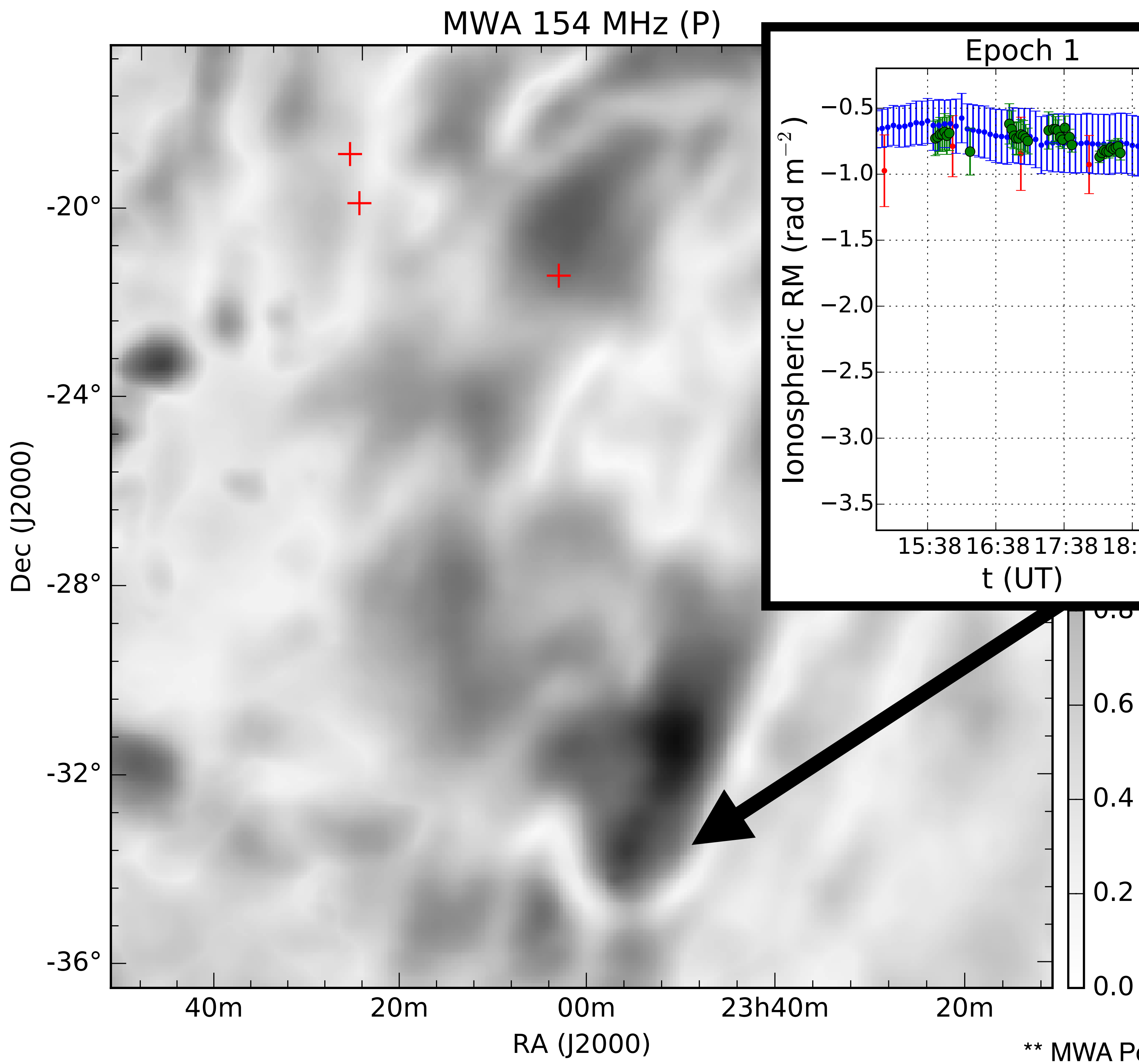
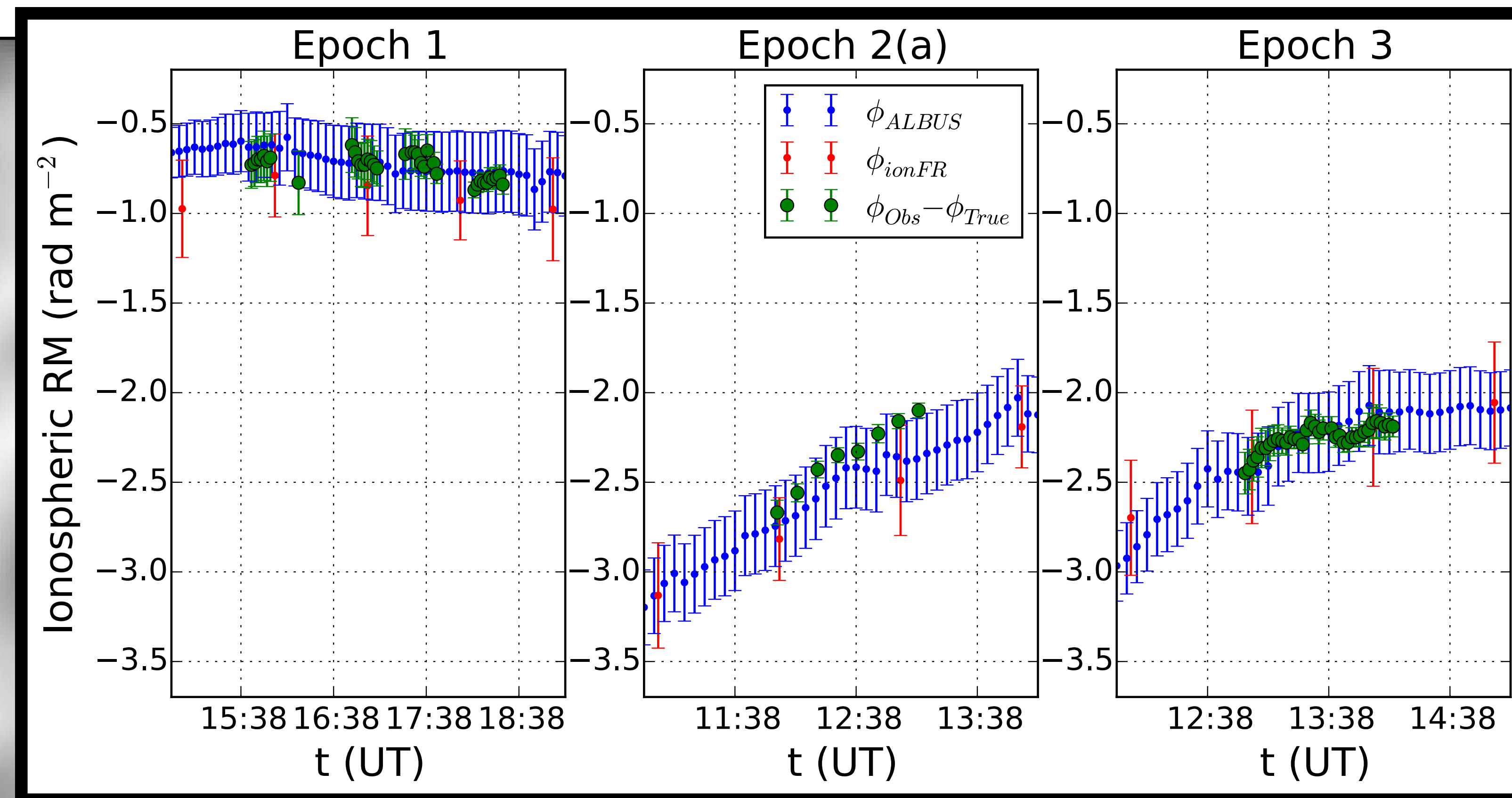
Diffuse polarisation FTW!



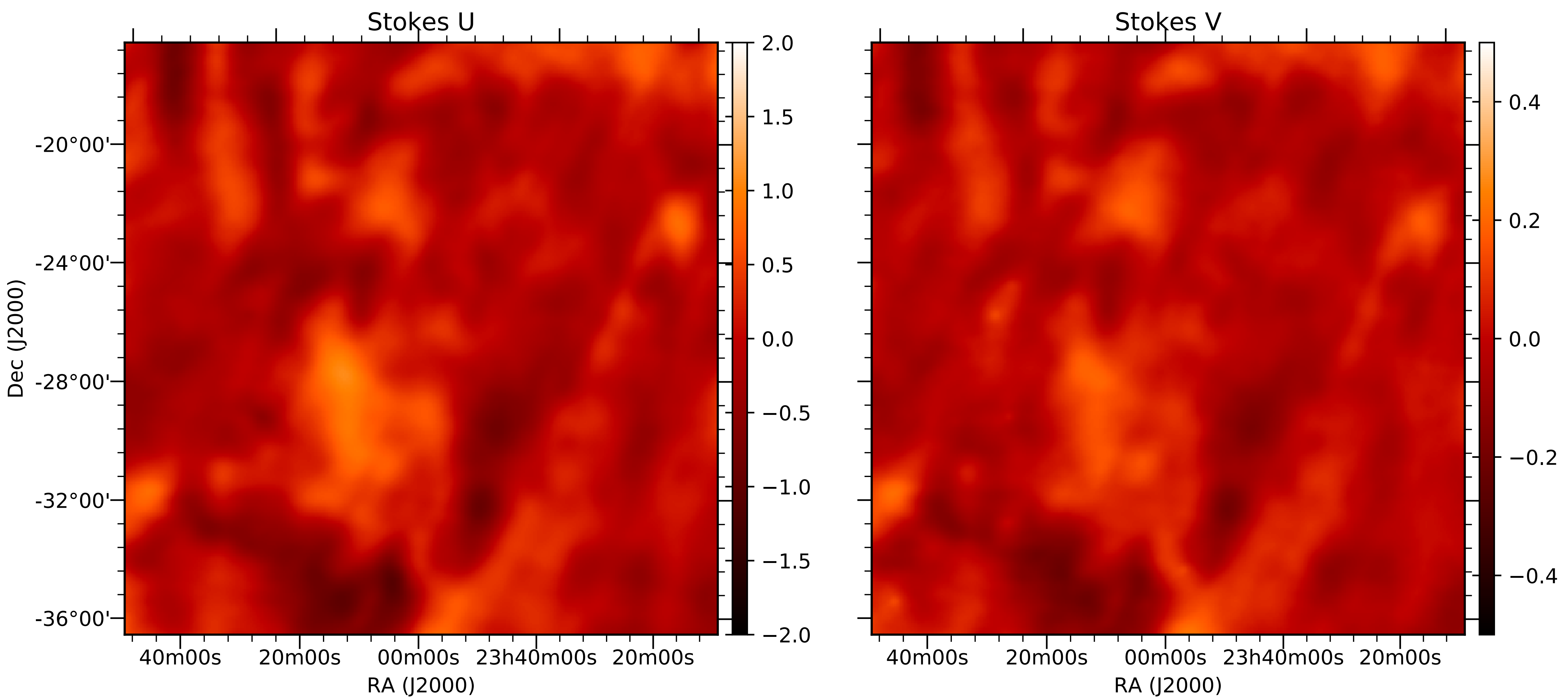


Data from just a **single** pixel of a **single** 2-minute snapshot taken from the MWA diffuse polarisation RM cube!

** MWA Polarised Sources Highlighted (Lenc et al., 2016)

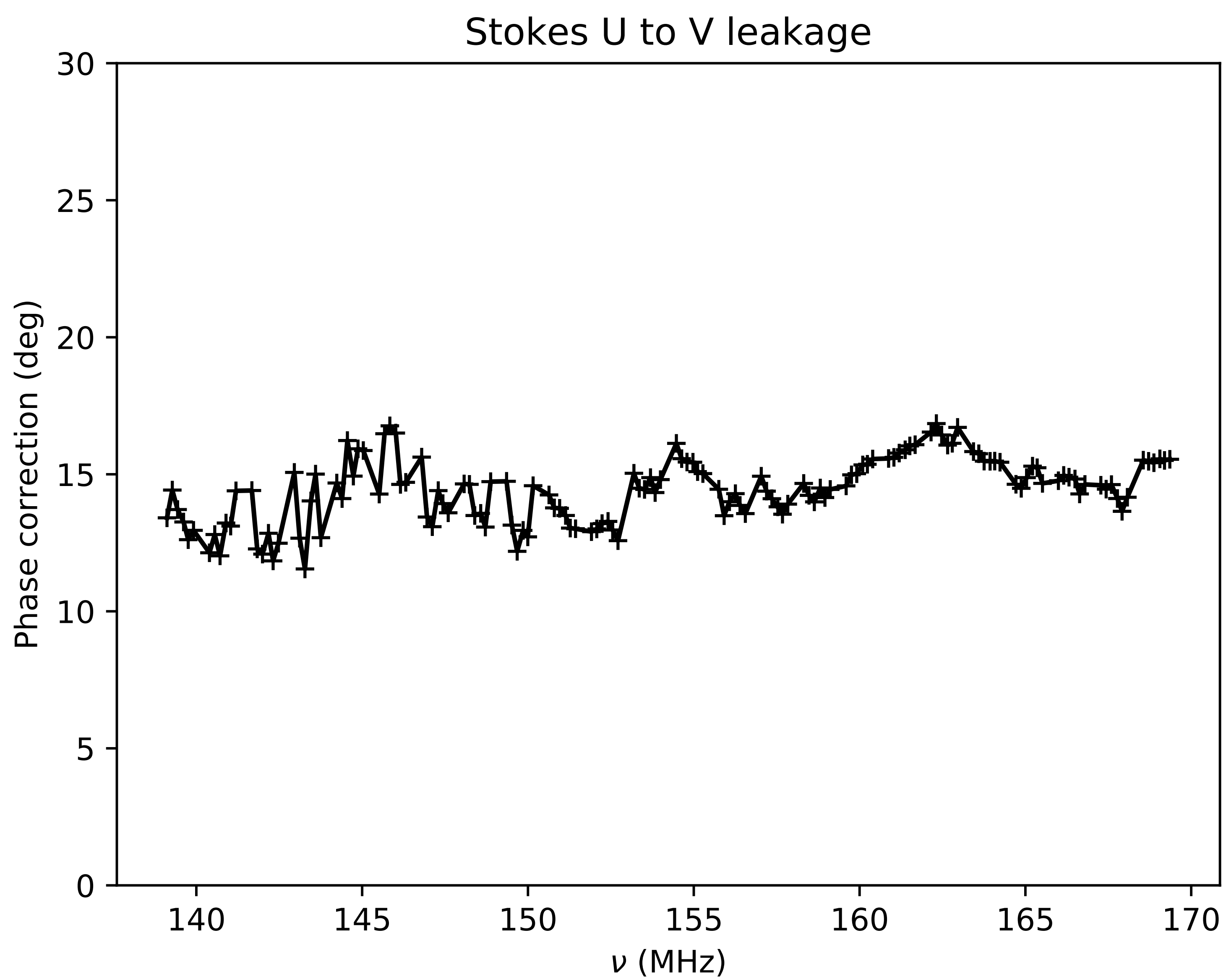
Challenge II: XY-Phase correction

An XY Phase causes Stokes U to leak into Stokes V
(see Lenc et al. 2016)



XY-Phase correction

Assume sky not circularly polarised (Similar to Carozzi, T.D., 2016)

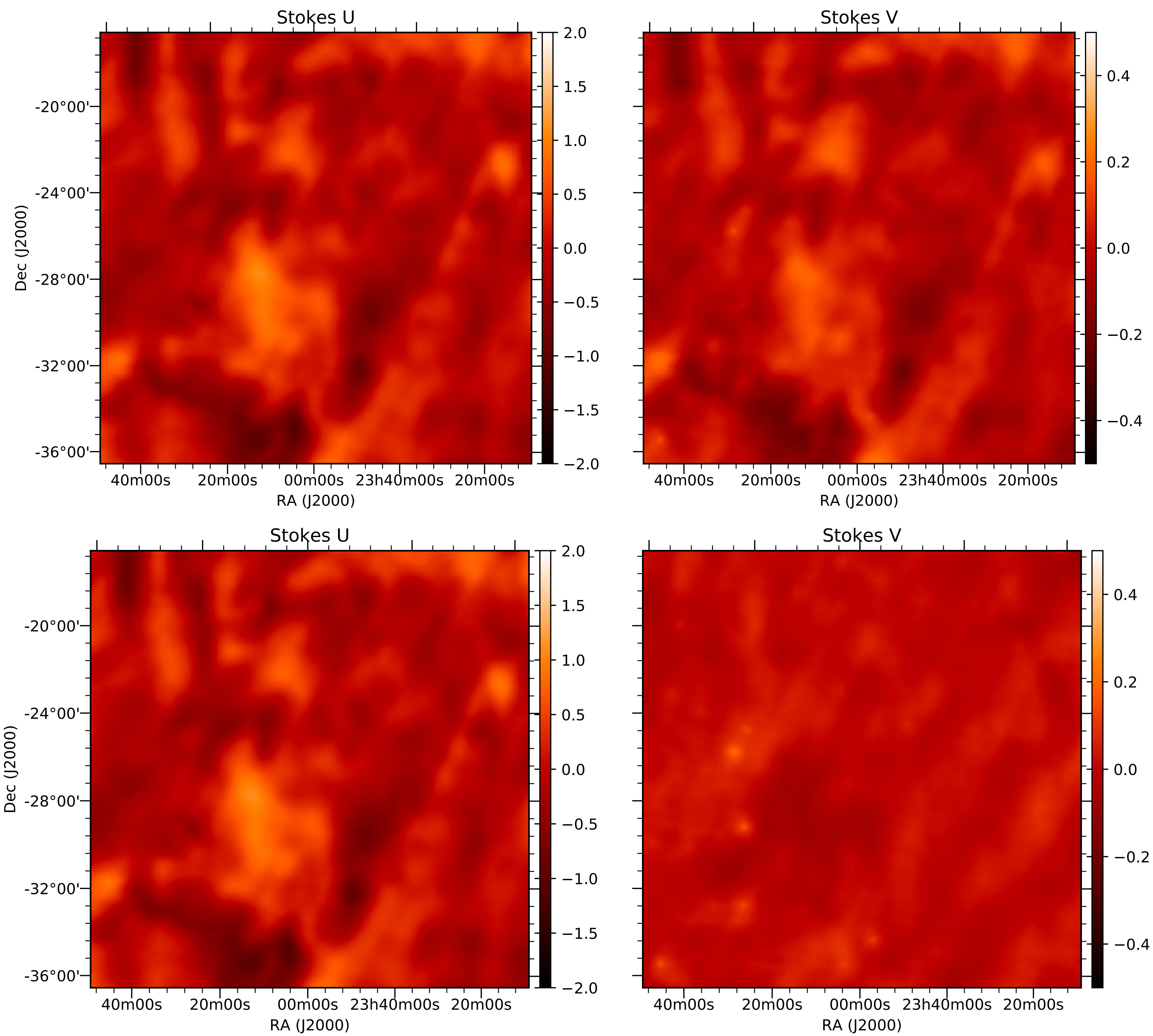


(Lenc et al. in prep.)

XY-Phase correction

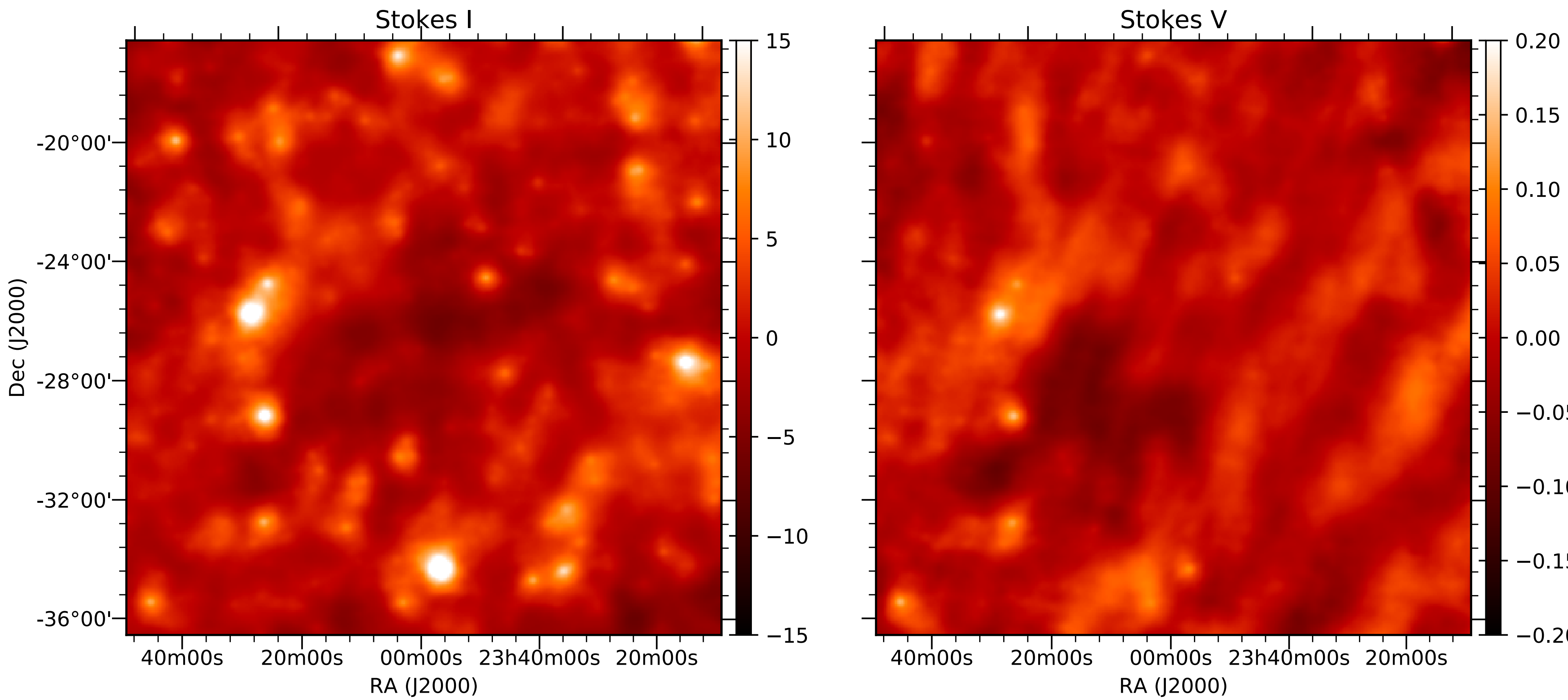
Uncorrected

Corrected

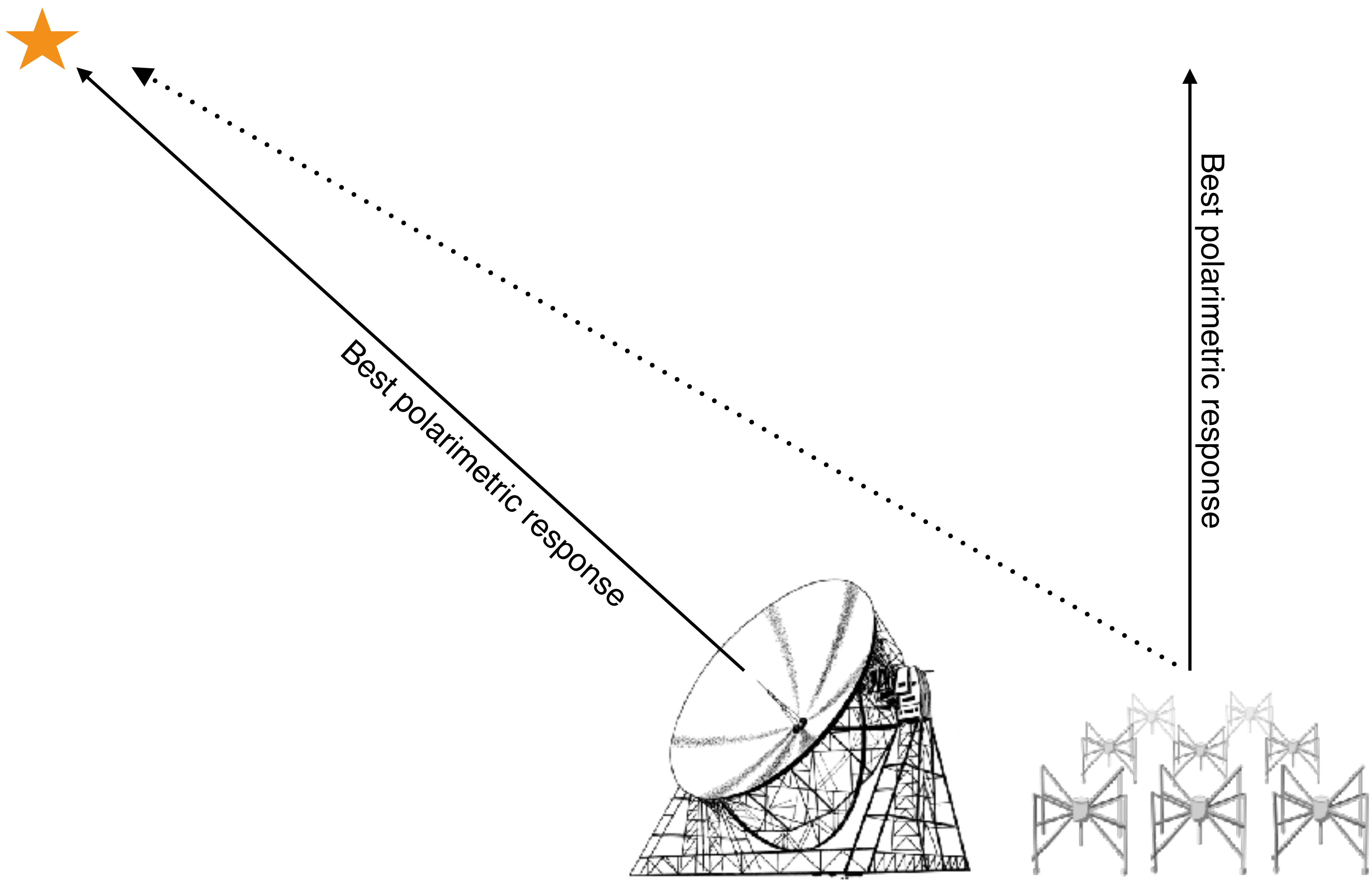


XY-Phase correction

Now dominated by leakage from Stokes I at ~1% level
Not position independent!

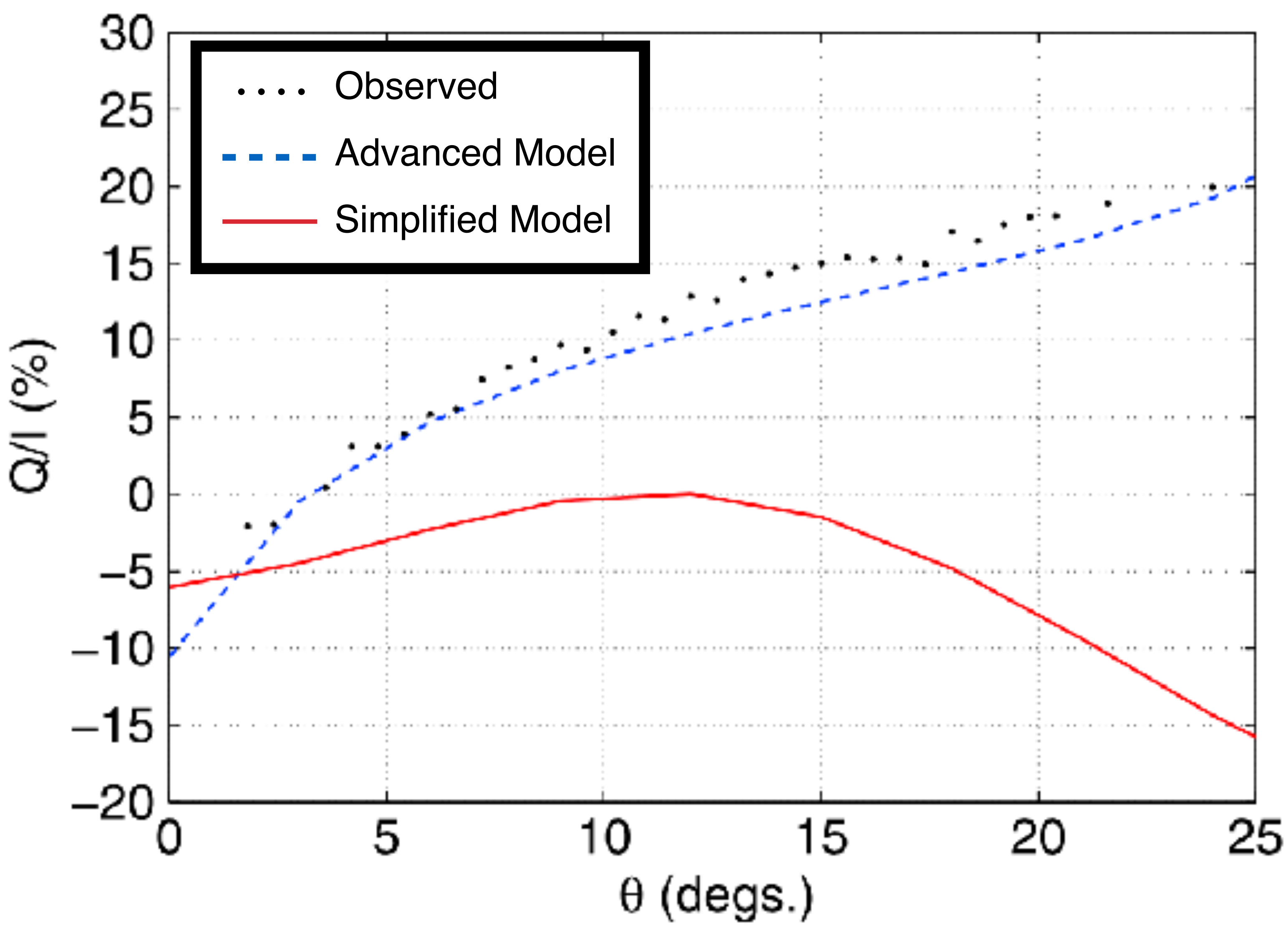


Challenge III: The Beam
The downside of no moving parts



Reducing effects of Leakage

Building a better beam



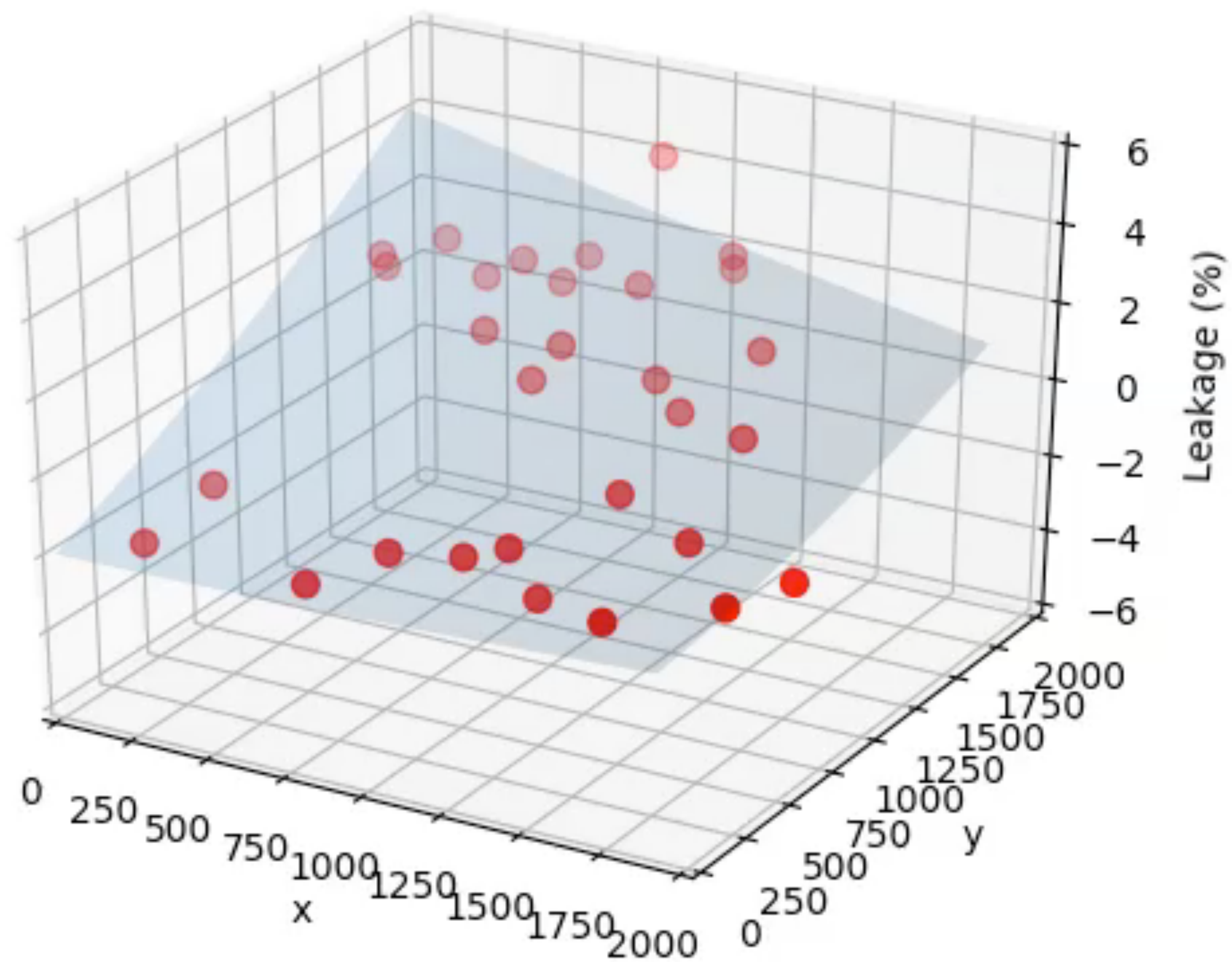
(Sutinjo et al. 2014, Sokolowski et al. submitted)

Simple beam models
- very large amounts of leakage observed
- computationally simple

Advanced beam models
- reduce observed leakage
- more computationally intensive
- great for meridian scans where limited number of beams need to be generated.
- still imperfect and leakage apparent at extremes of frequency and elevation.

Reducing effects of Leakage

Stokes V Leakage in "Drift and Shift" Scan
(~5 h, 11 beam pointings)



(Lynch et al. 2017, Lenc et al. submitted)

Reducing effects of Leakage

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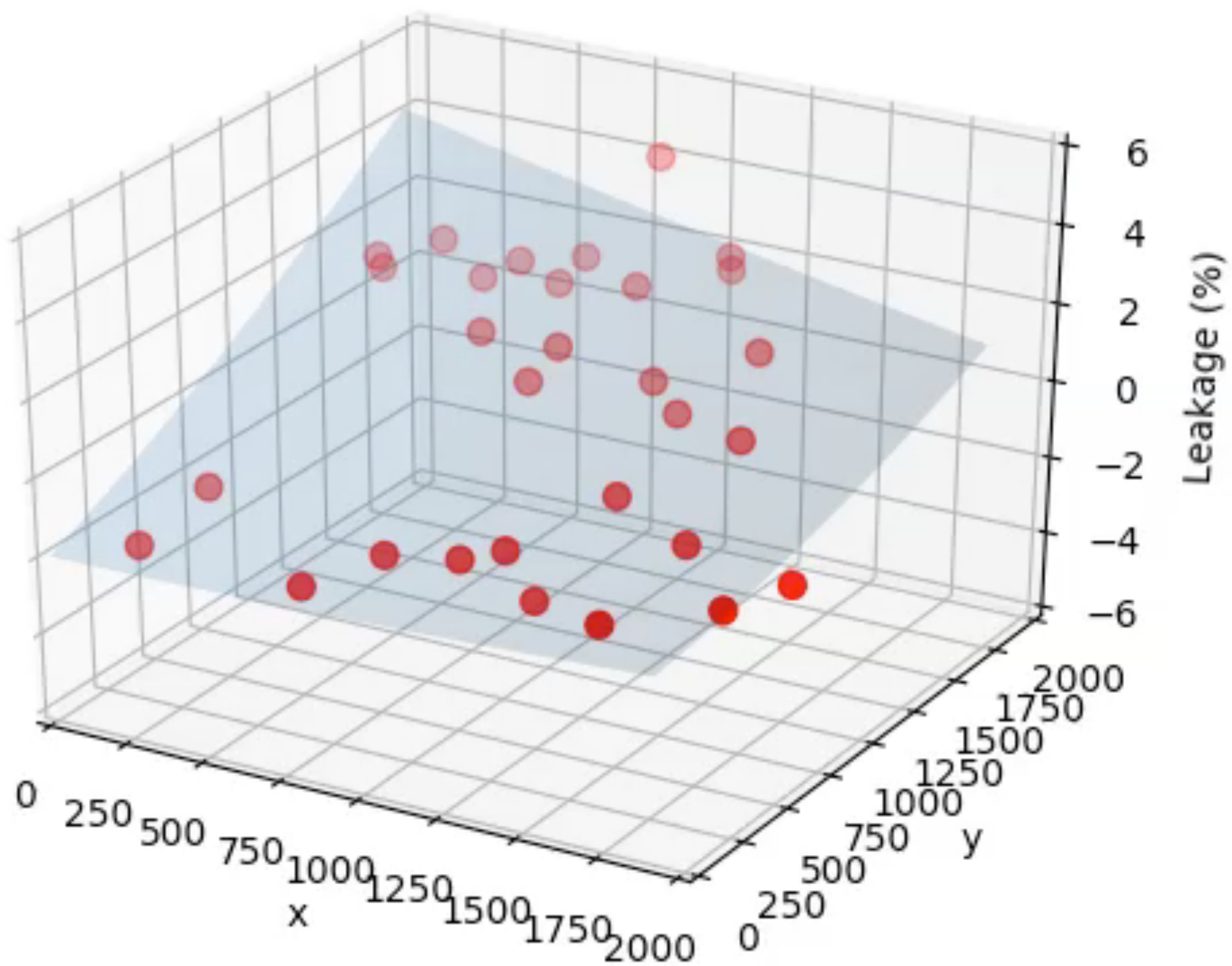
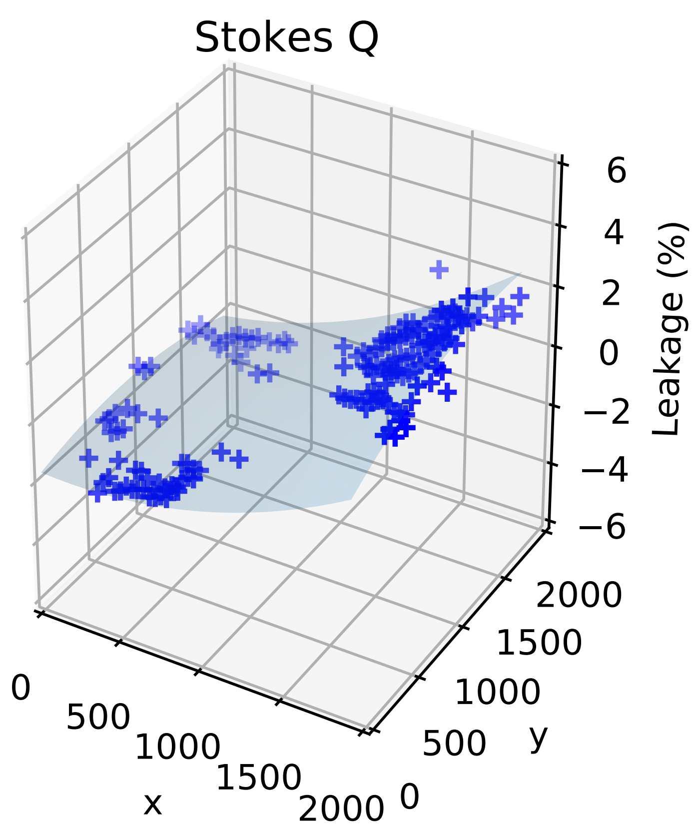


(Lynch et al. 2017, Lenc et al. submitted)

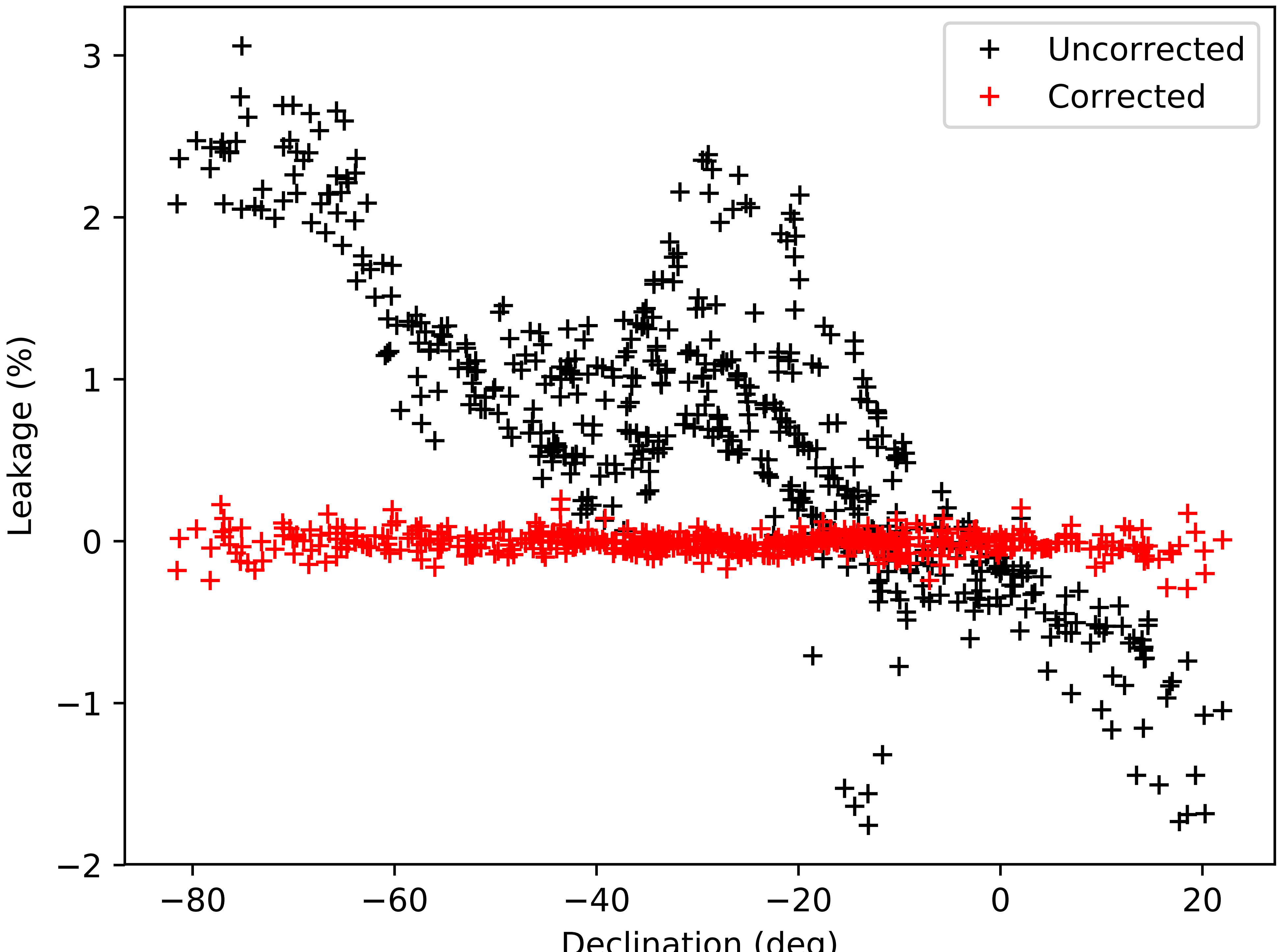
Reducing effects of Leakage

Different Stokes have different behaviour.
Behaviour is also frequency dependent.



(Lynch et al. 2017, Lenc et al. submitted)

Removing Leakage
All-sky circular polarisation survey



Lenc et al. (in prep)

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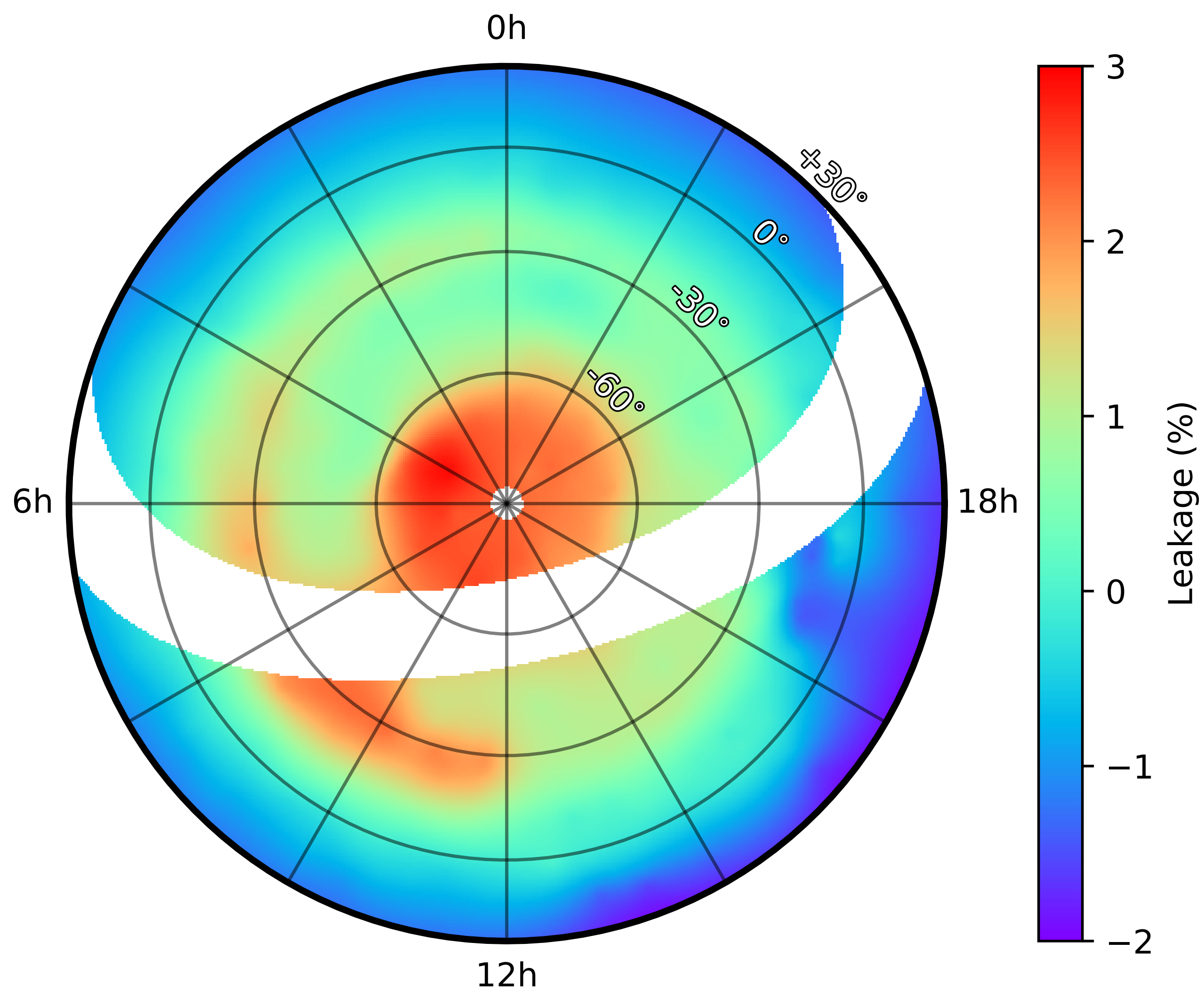
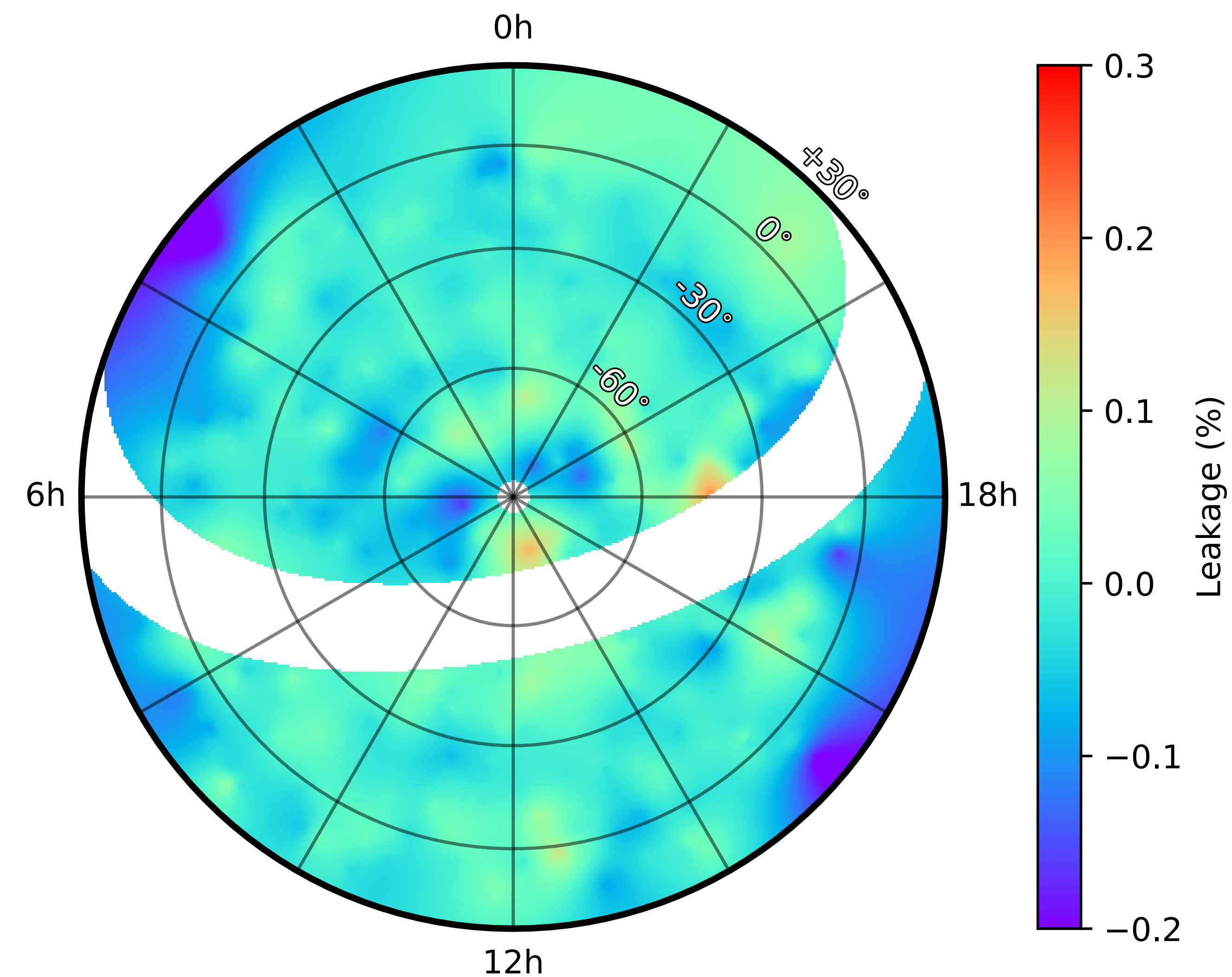


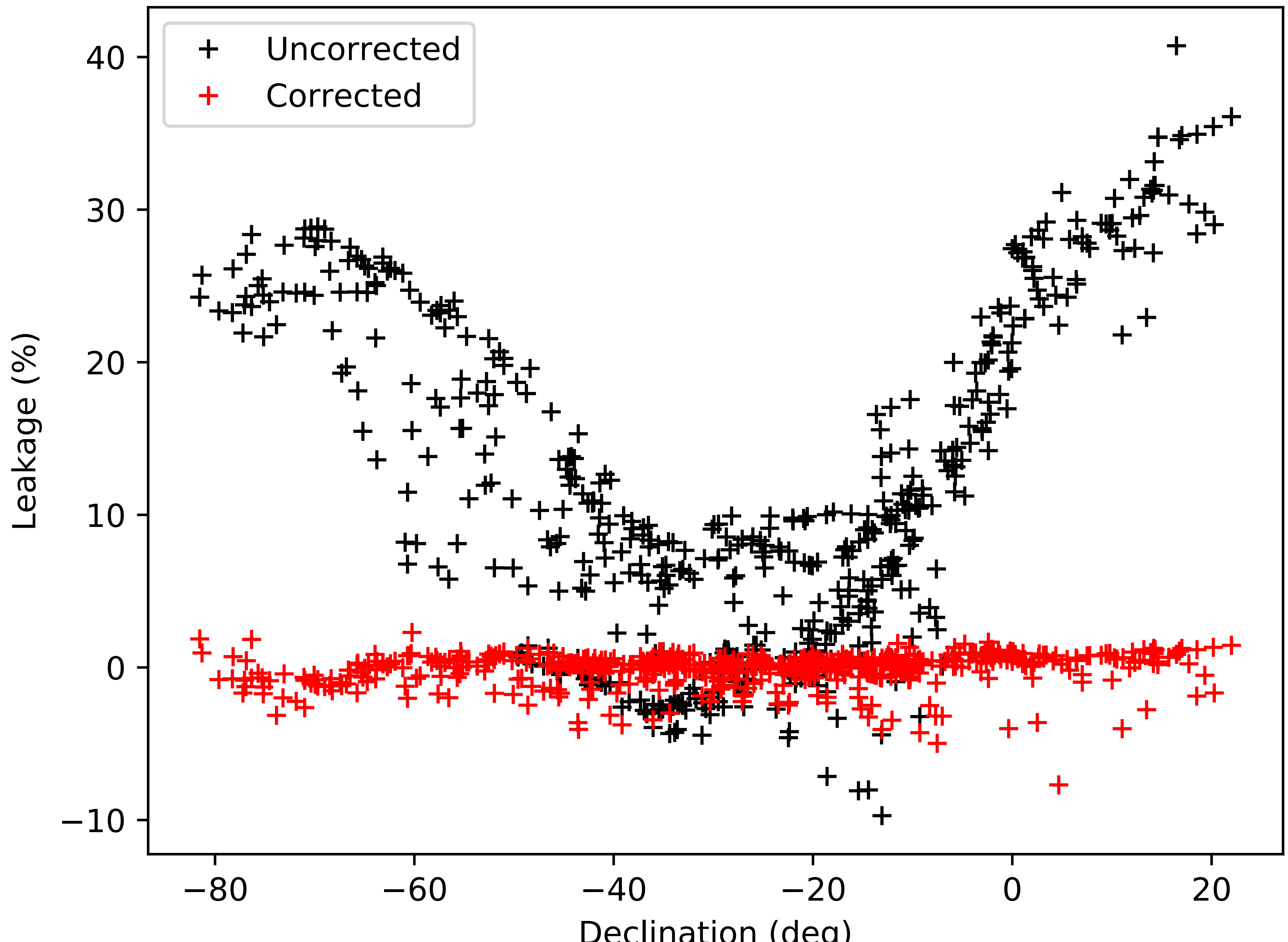
Stokes V Leakage
Before Correction



Stokes V Leakage
After Correction

Lenc et al. (in prep)

Removing Leakage
All-sky Q polarisation leakage



Lenc et al. (in prep)

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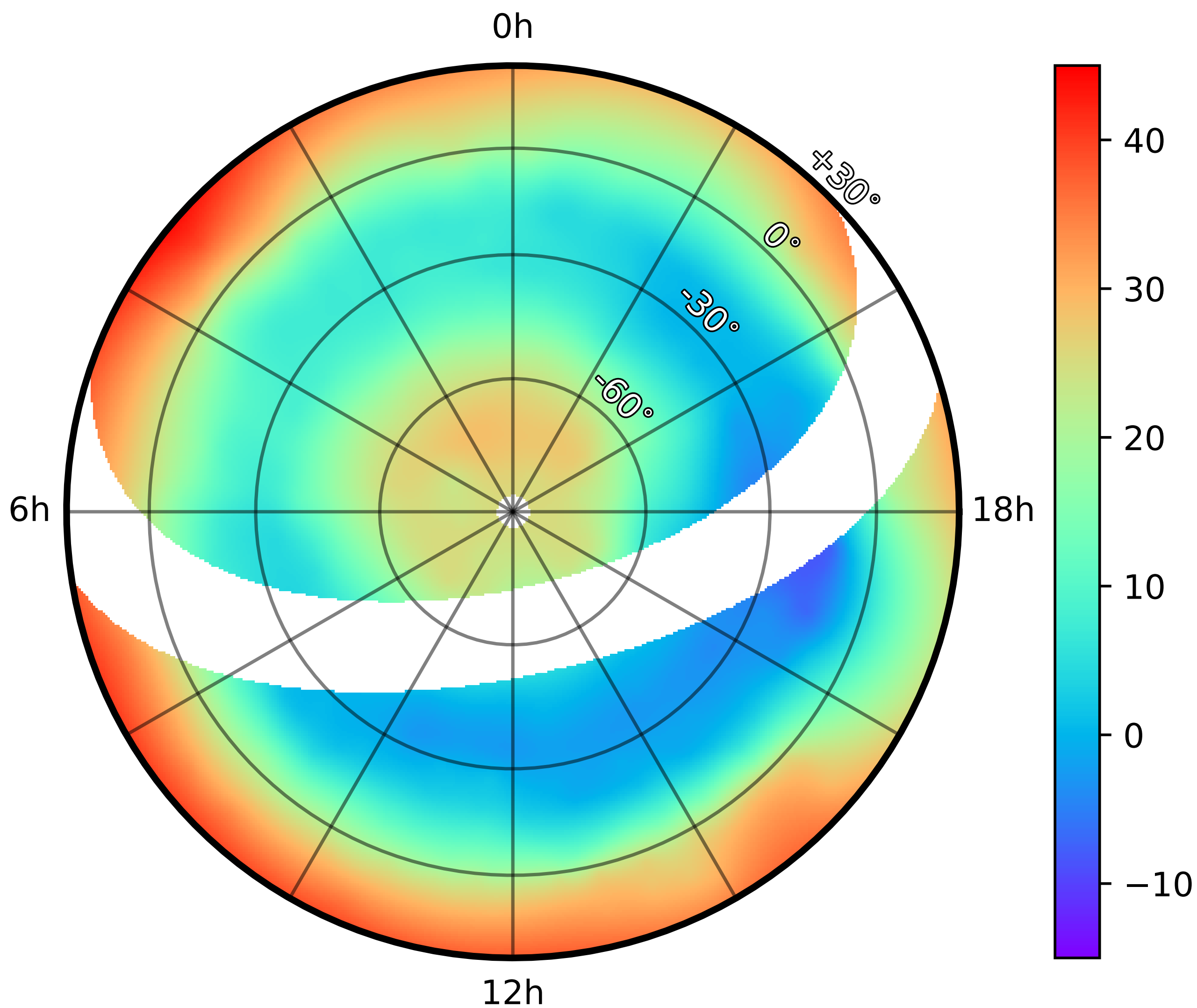
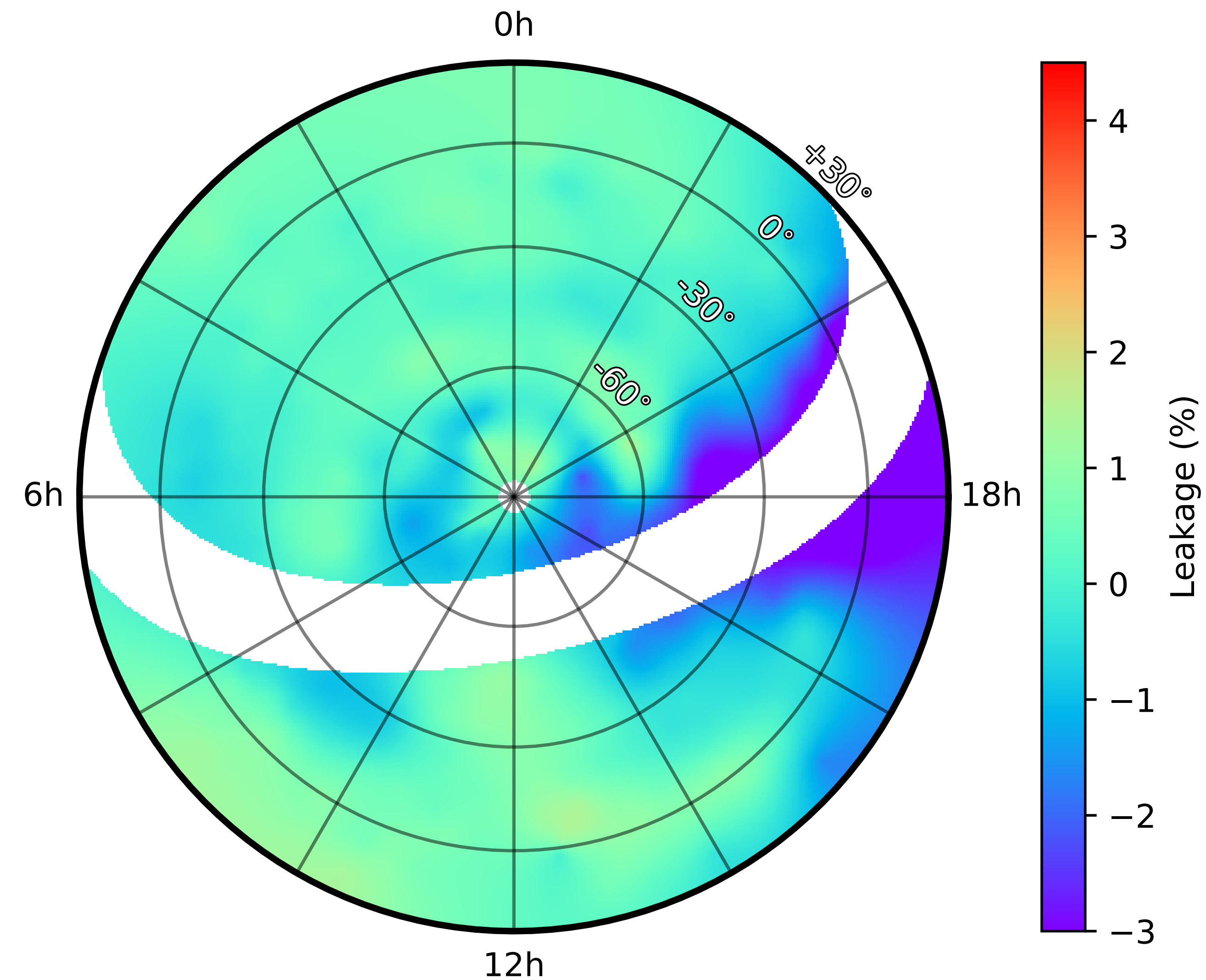


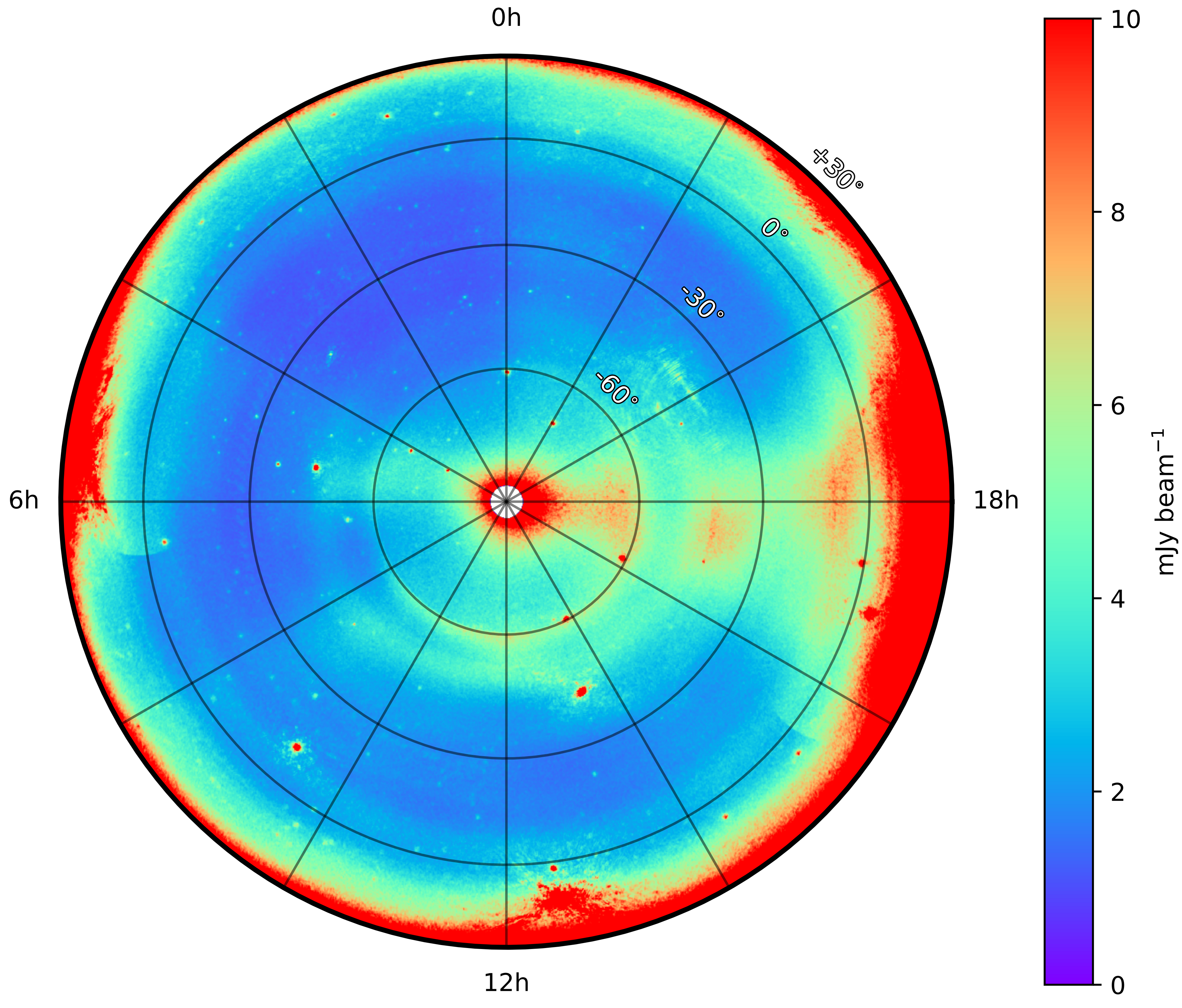
Stokes Q Leakage
Before Correction



Stokes Q Leakage
After Correction

Lenc et al. (in prep)

Removing Leakage
All-sky CP Survey



Lenc et al. (in prep)

Removing Leakage
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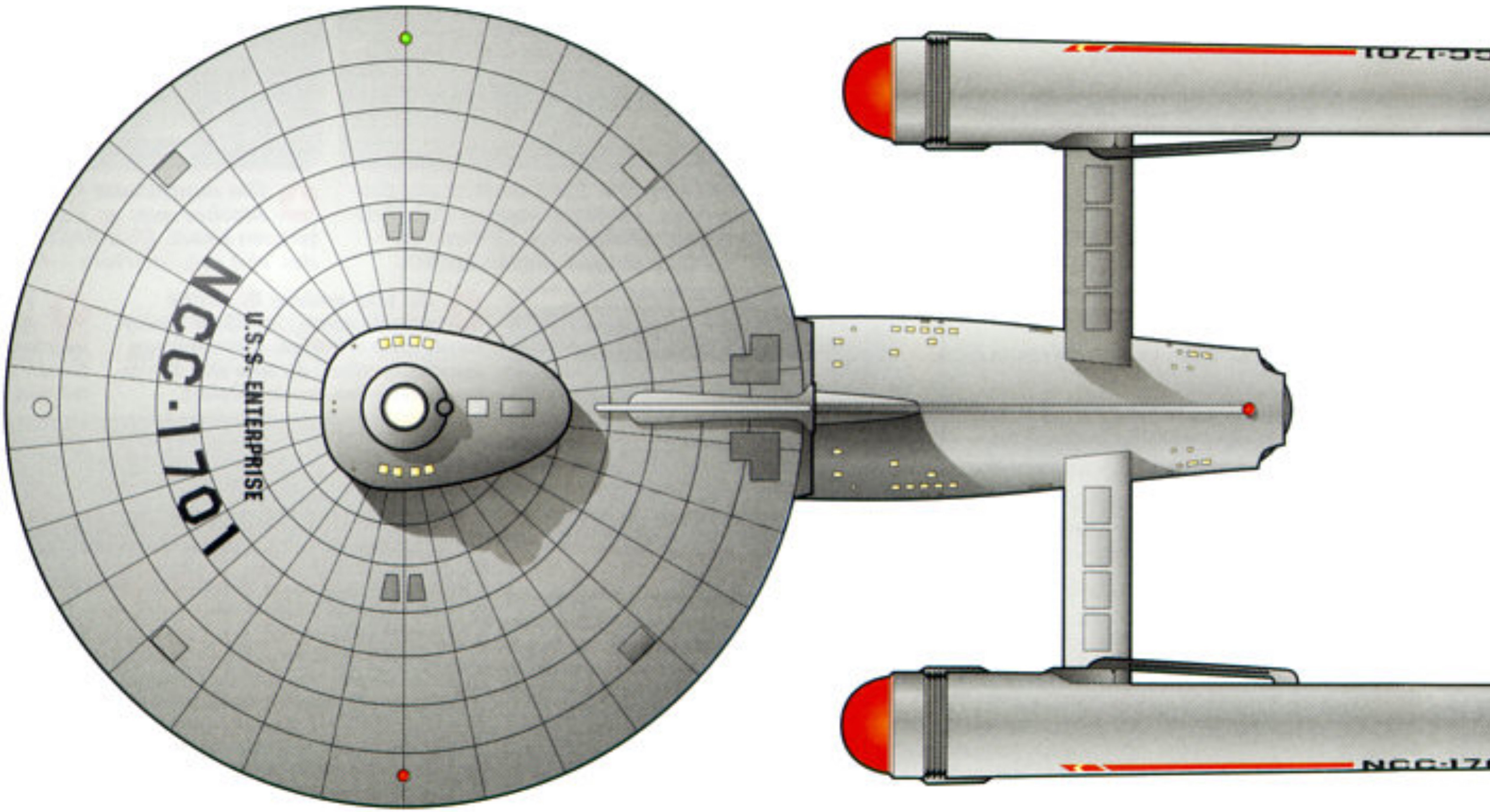

Lenc et al. (in prep)

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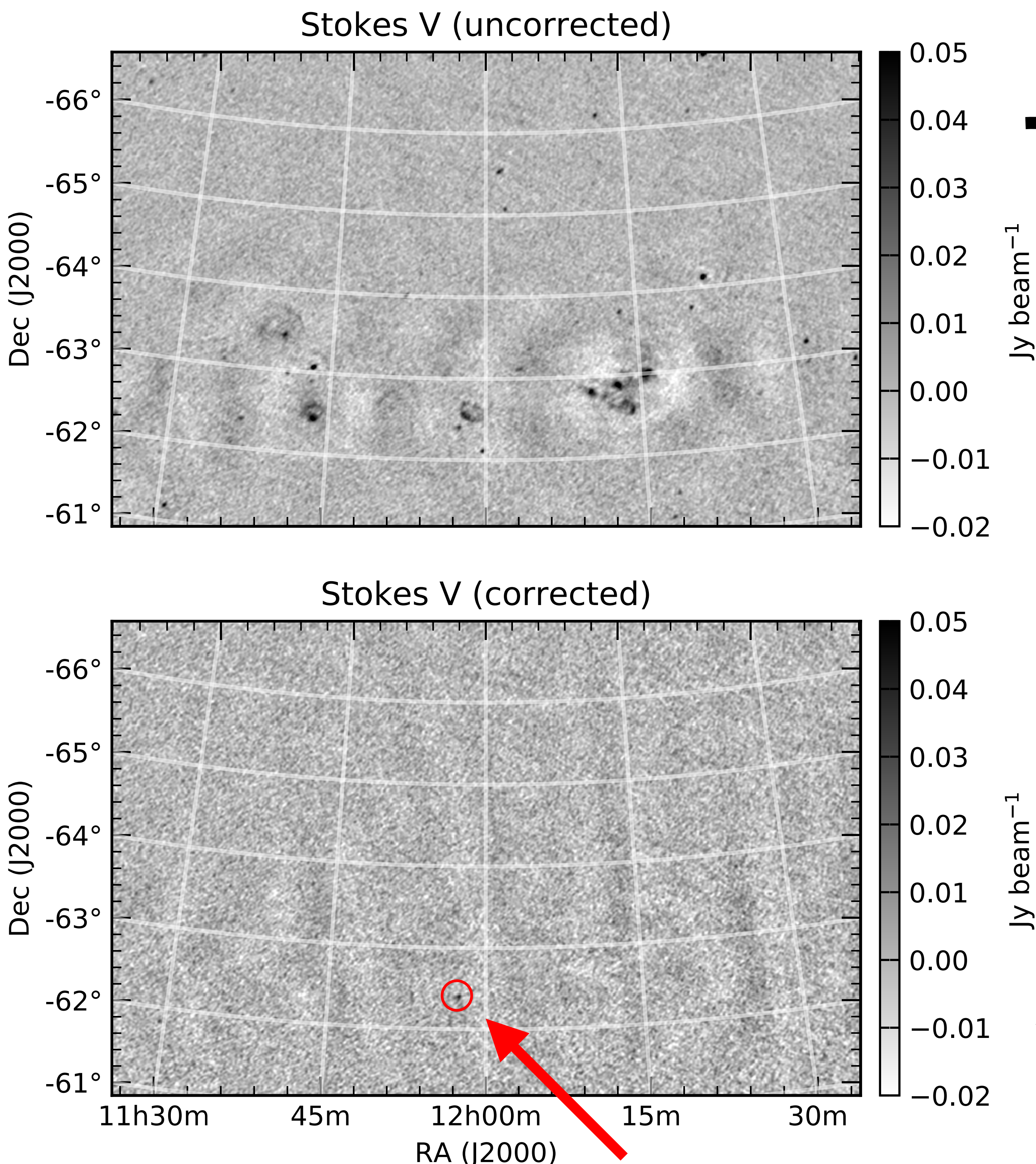
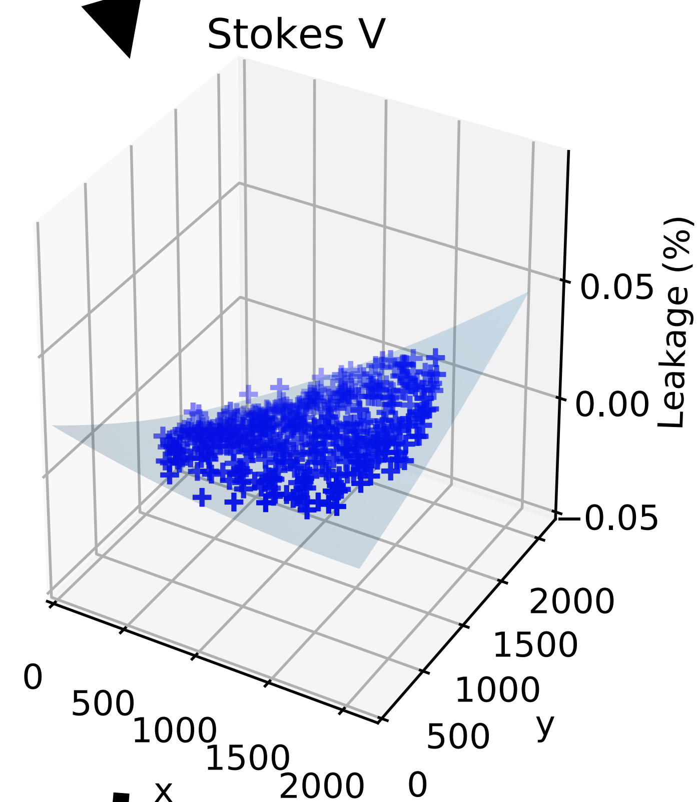
Lenc et al. (in prep)

All-sky CP survey (Lenc et al. in prep.)



Model Stokes I to Stokes V leakage for each beam-former setting

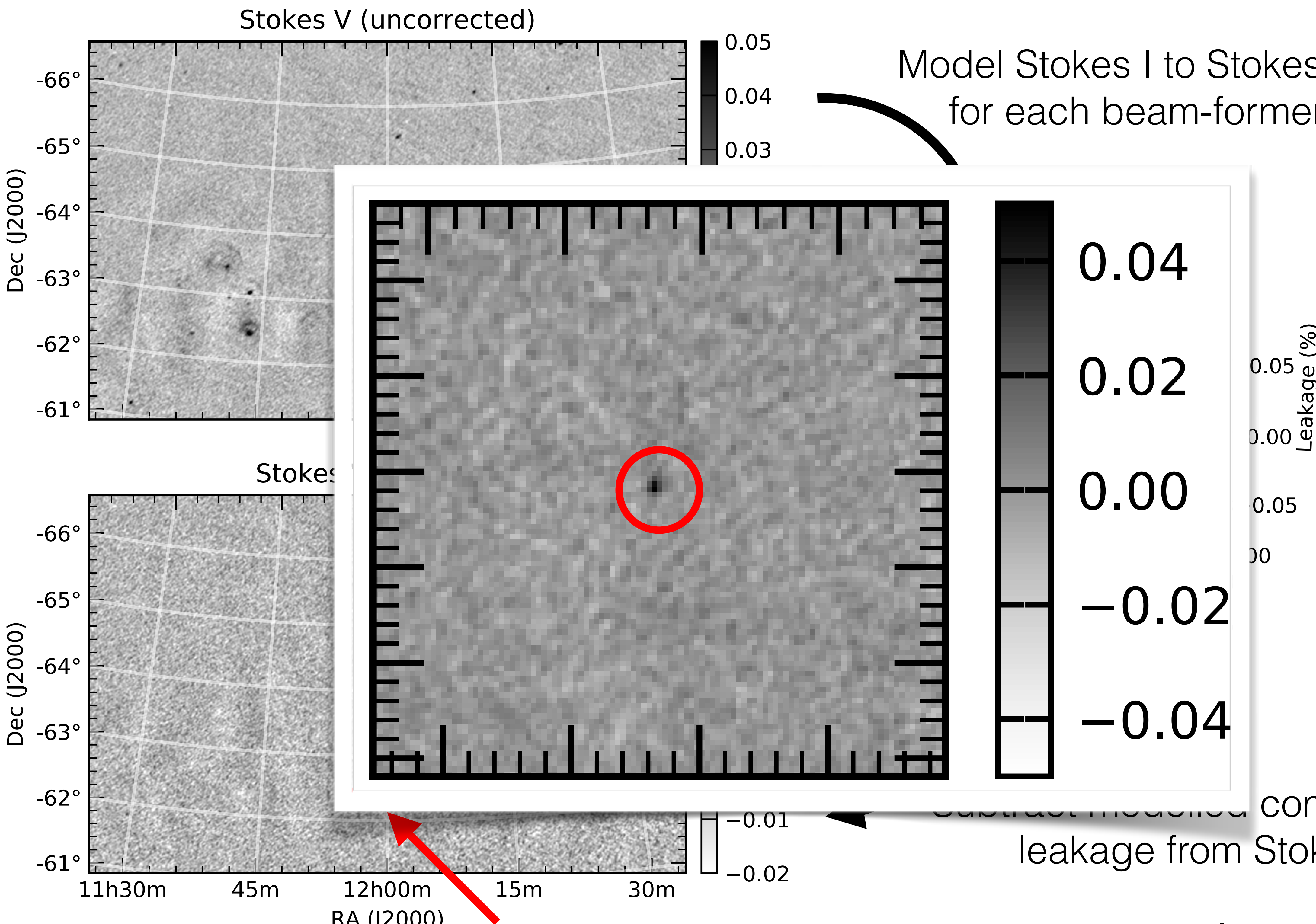


Subtract modelled component of leakage from Stokes V.

PSR J1157-6224

Lenc et al. (in prep)

All-sky CP survey
(Lenc et al. in prep.)



Model Stokes I to Stokes V leakage for each beam-former setting

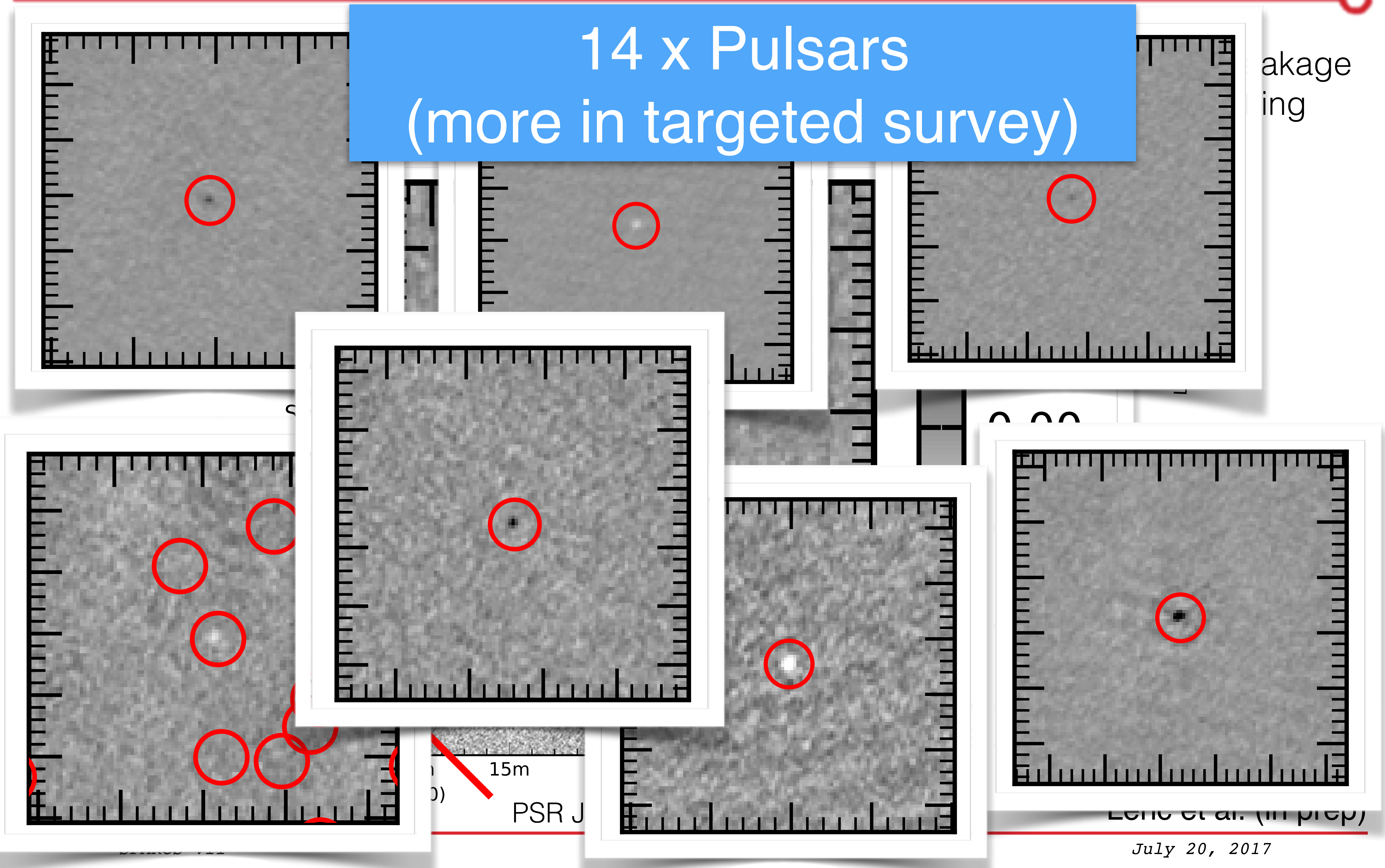
component of leakage from Stokes V.

PSR J1157-6224

Lenc et al. (in prep)

All-sky CP survey
(Lenc et al. in prep.)

14 x Pulsars
(more in targeted survey)



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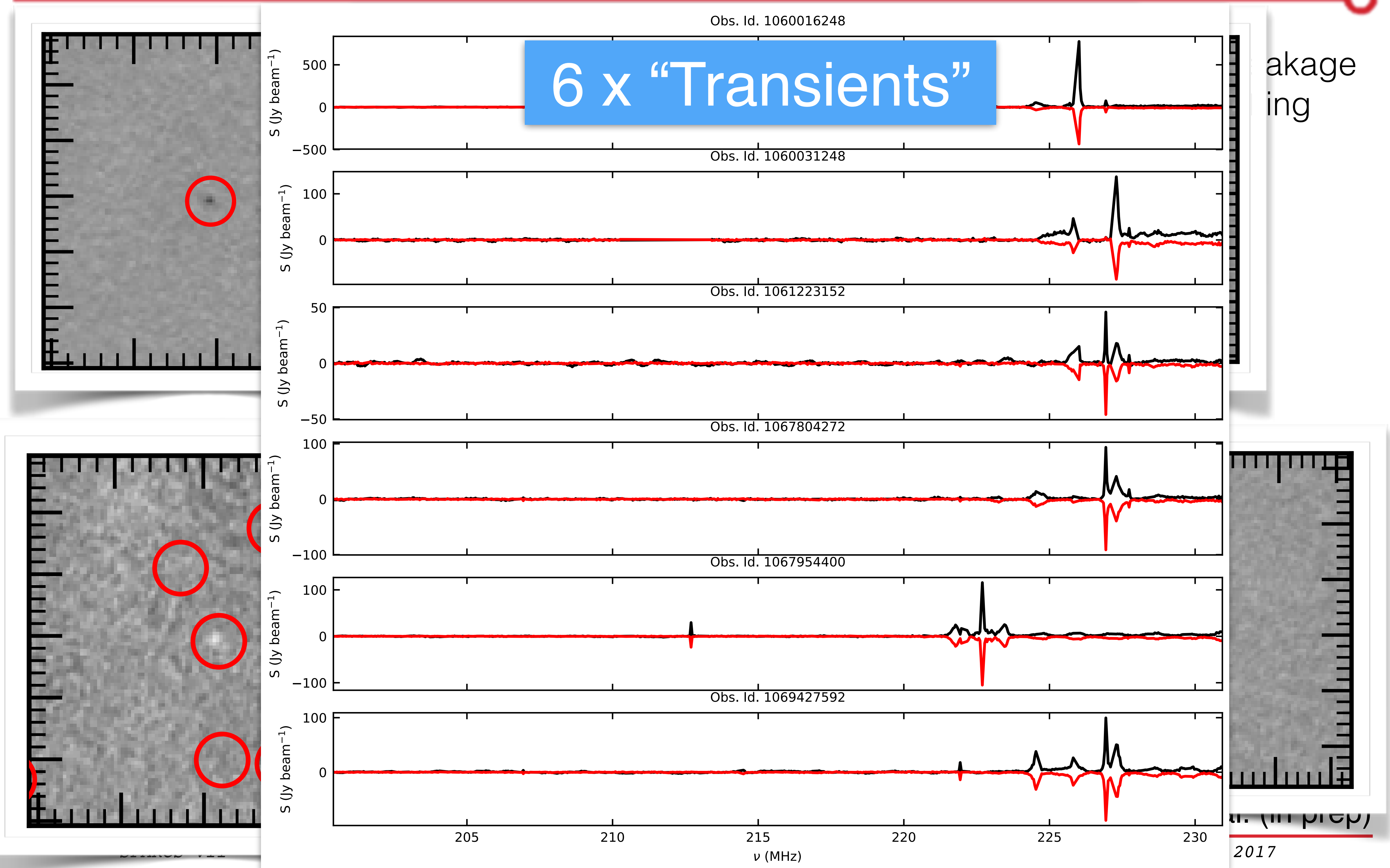
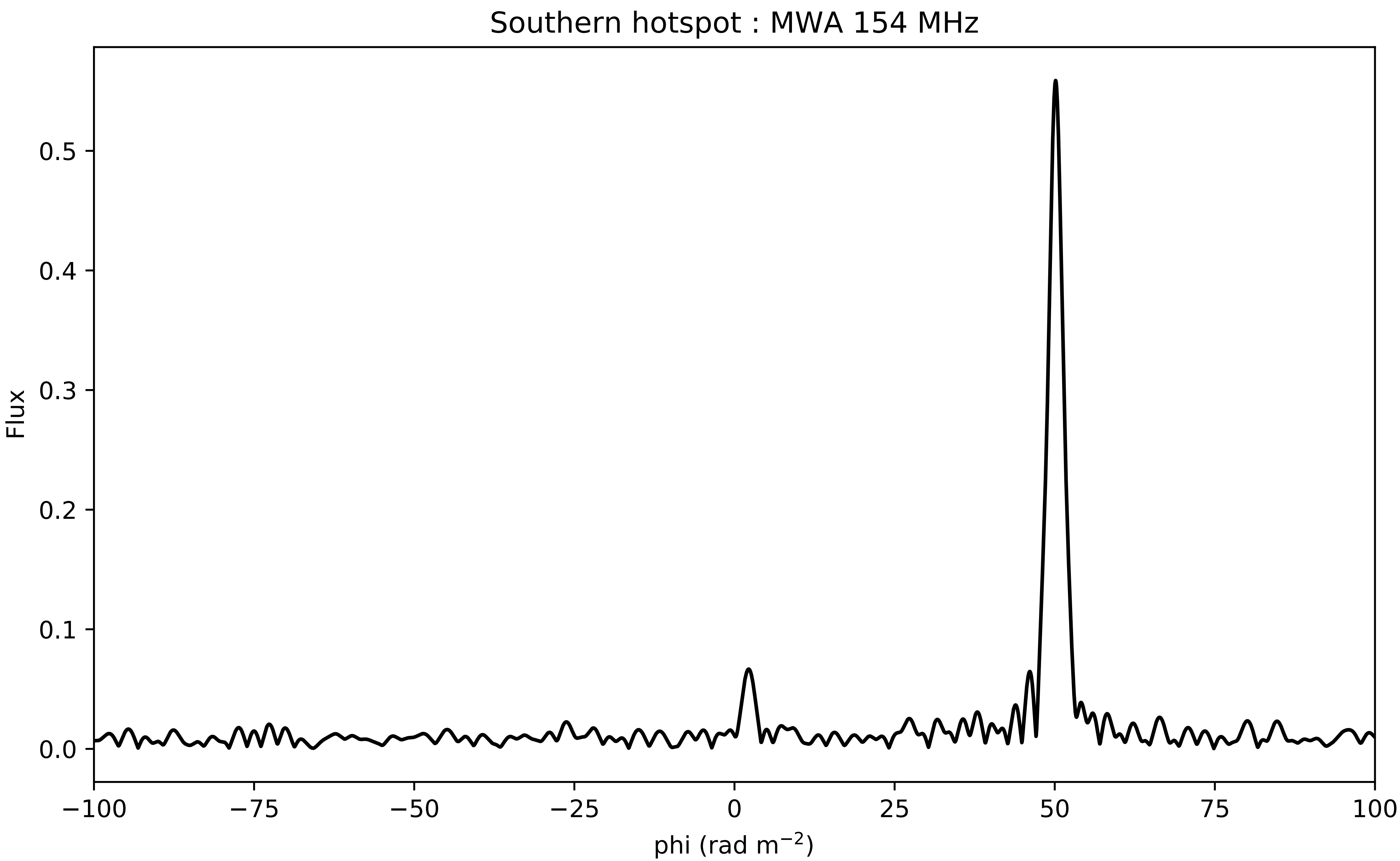
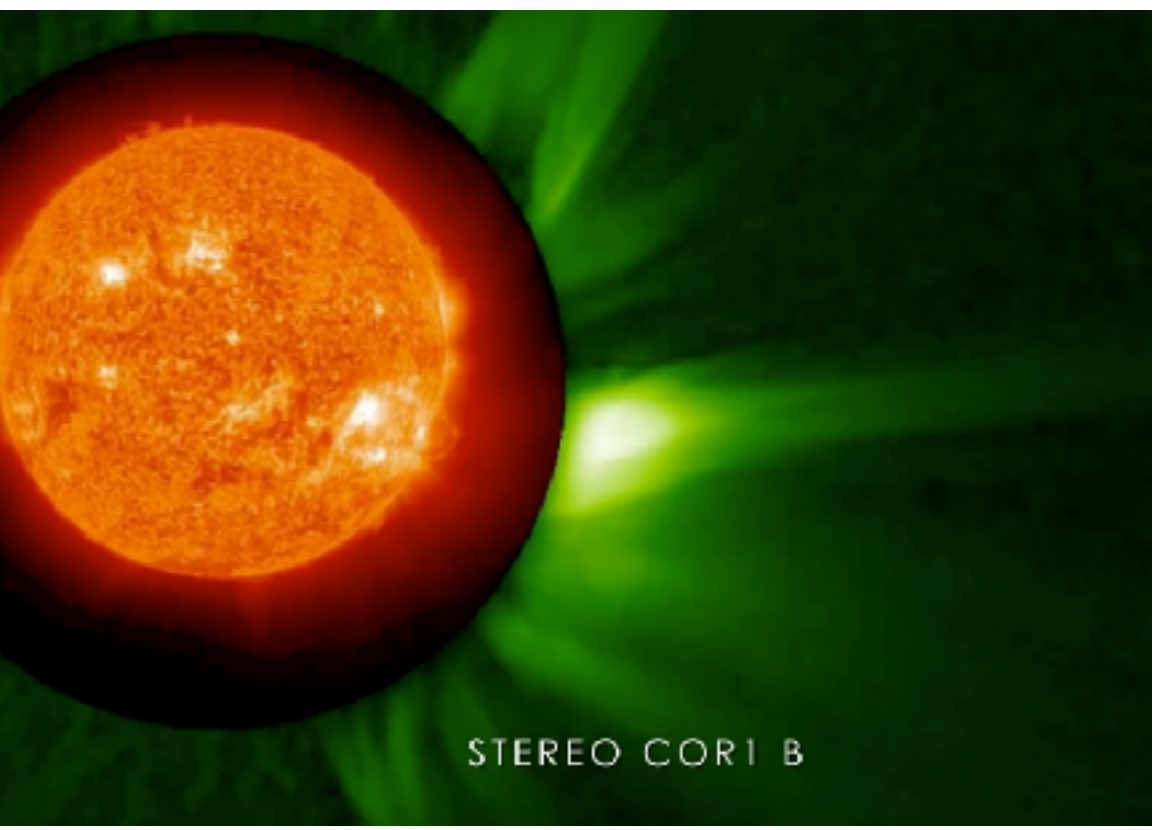


CAASTRO ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

Opportunities: Finding Hidden Signals

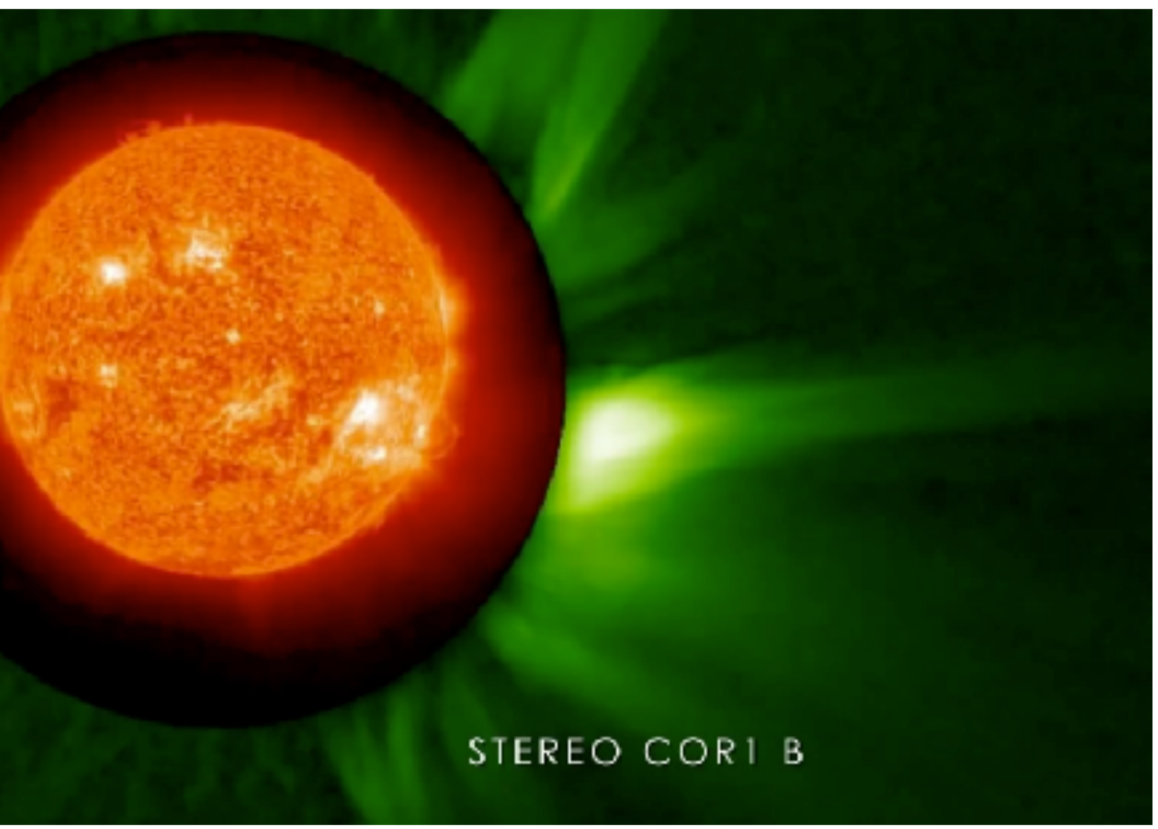


Ionosphere to the rescue?



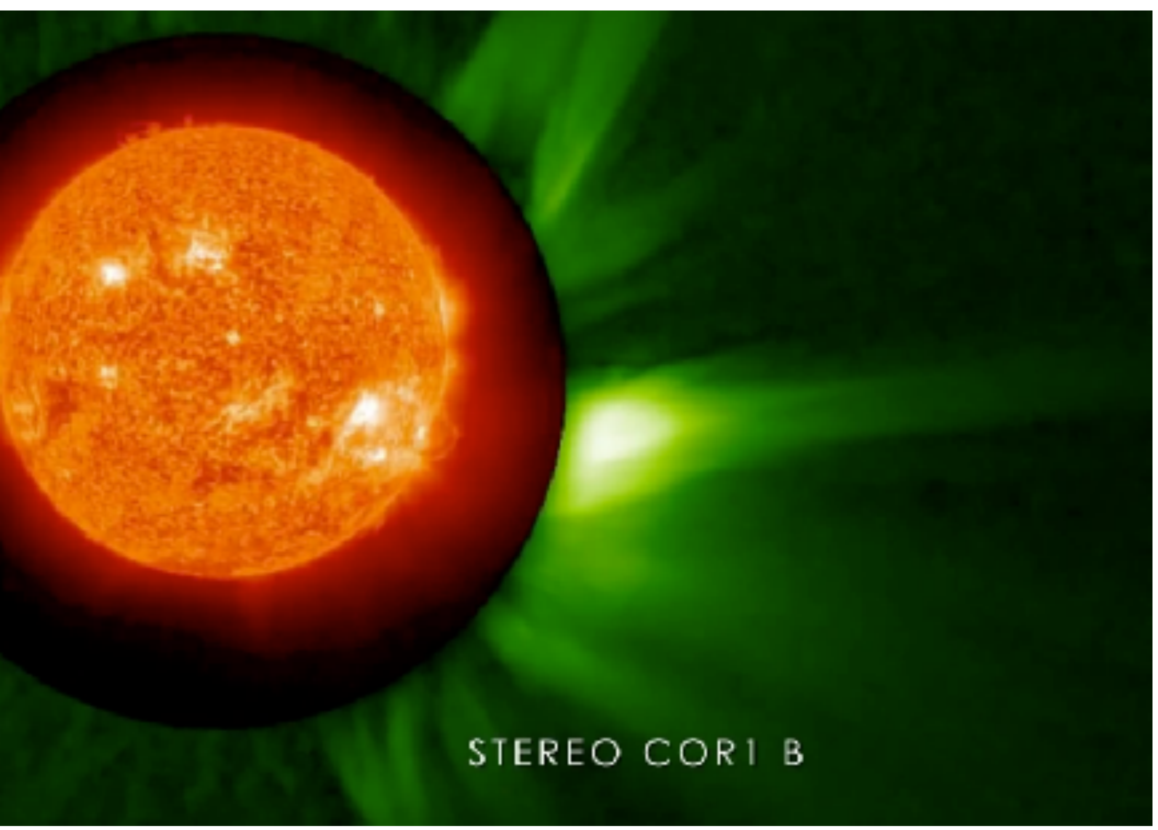
RM

Ionosphere to the rescue?

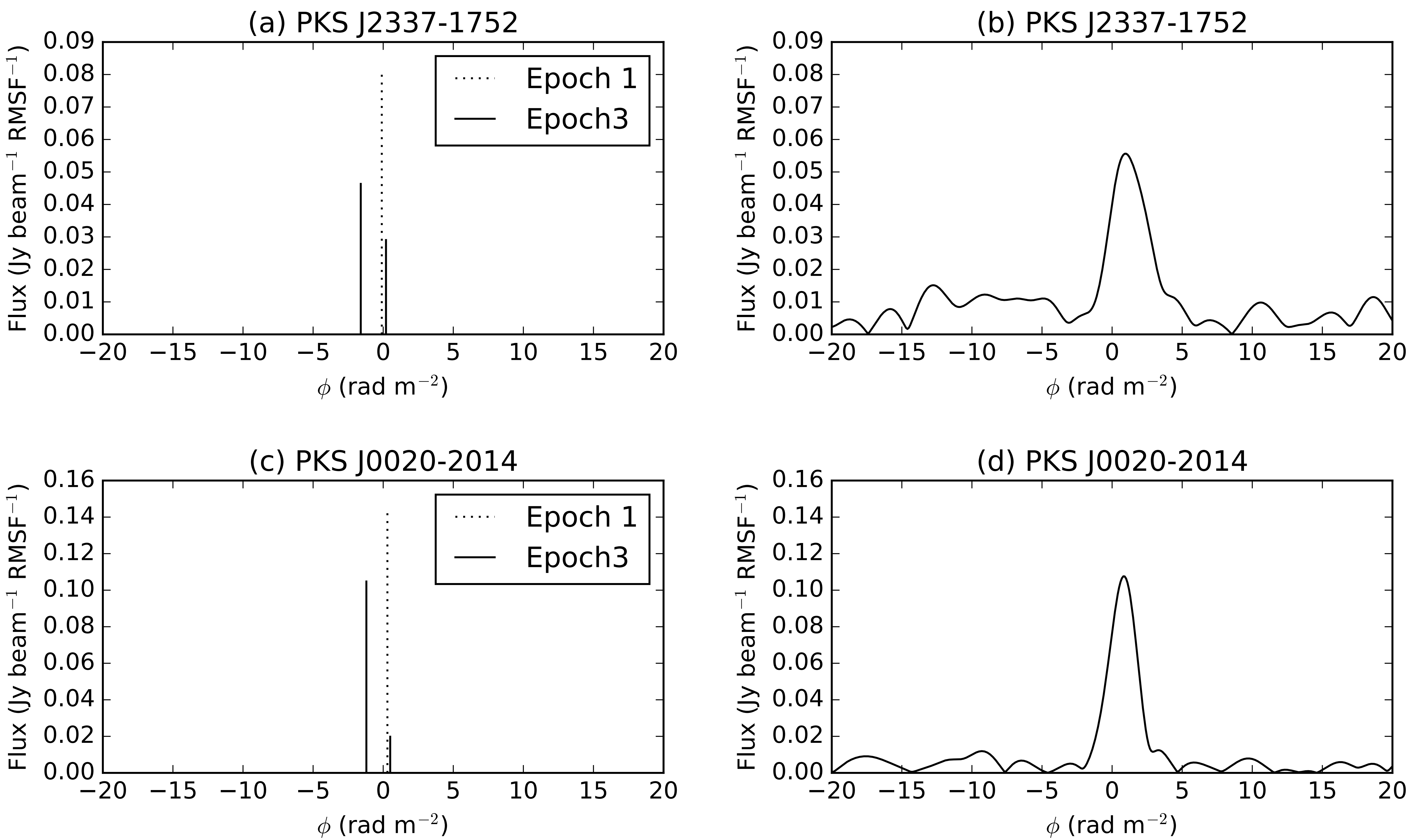


RM

Ionosphere to the rescue?



Ionosphere to the rescue?



Summary

- The MWA provides for a HUGE lever arm in λ^2 space resulting in excellent RM resolution.
- The MWA is excellent for diffuse polarisation studies over a large field of view (600+ sq. deg) but not so great for polarised point source surveys
- Can use diffuse polarised emission detected with compact baselines to correct for ionosphere and XY-phase.
- Can model and subtract out leakage on a per-beam basis by mapping leakage in diffuse emission and/or unpolarised sources.
- Can use the ionosphere to reveal "hidden" polarised sources.

MWA Key Learnings

- Short-baselines have turned out to be surprisingly useful for polarimetry and calibration.
- Wide fields-of-view are fantastic for survey work, unique science and characterising the instrument (e.g. Loi et al).
- Excellent instantaneous uv-coverage is brilliant for snapshot imaging (for characterising instrument and transient searches).

Thank-you!