Robust Detection of Linearly Polarized Emission from Meterwave Solar Emission: Questioning the Conventional Assumptions

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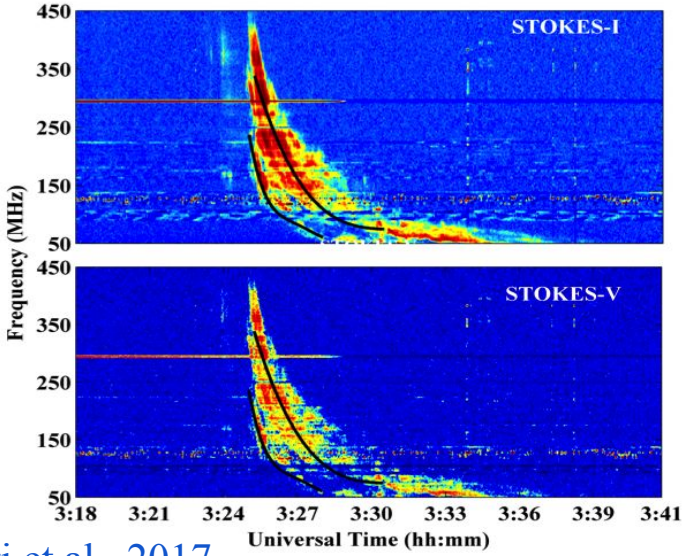
MWA MURCHISON WIDEFIELD ARRAY

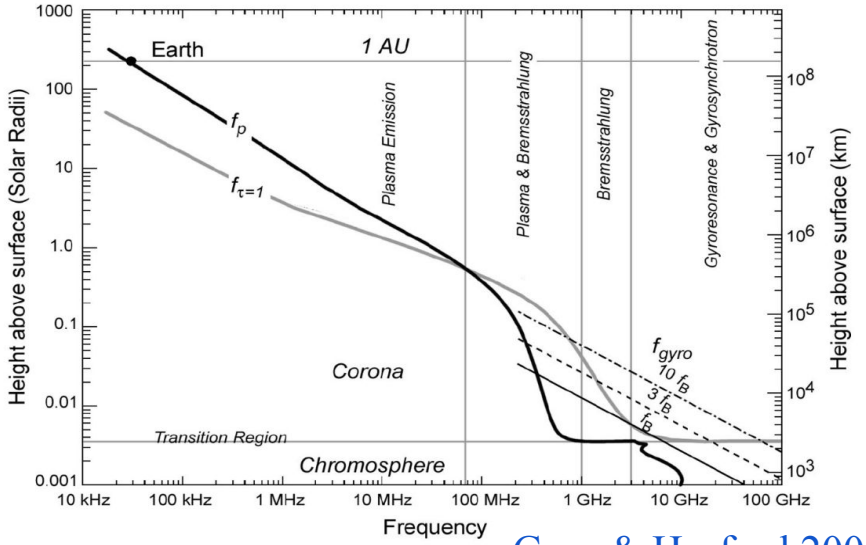
NCRA • TIFR

Active Solar Emission at Metrewavelengths

- Bright transient features mostly detected in solar dynamic spectrum.
- Classified as type I through V and many sub-categories.
- Mostly the plasma emission, sometimes gyrosynchrotron/ ECME emission.
- Flux density – ~ few hundreds to few thousands of SFU (1 SFU = 10^4 Jy).
- Produced by accelerated electrons by magnetic reconnection or shocks.



Kumari et al., 2017

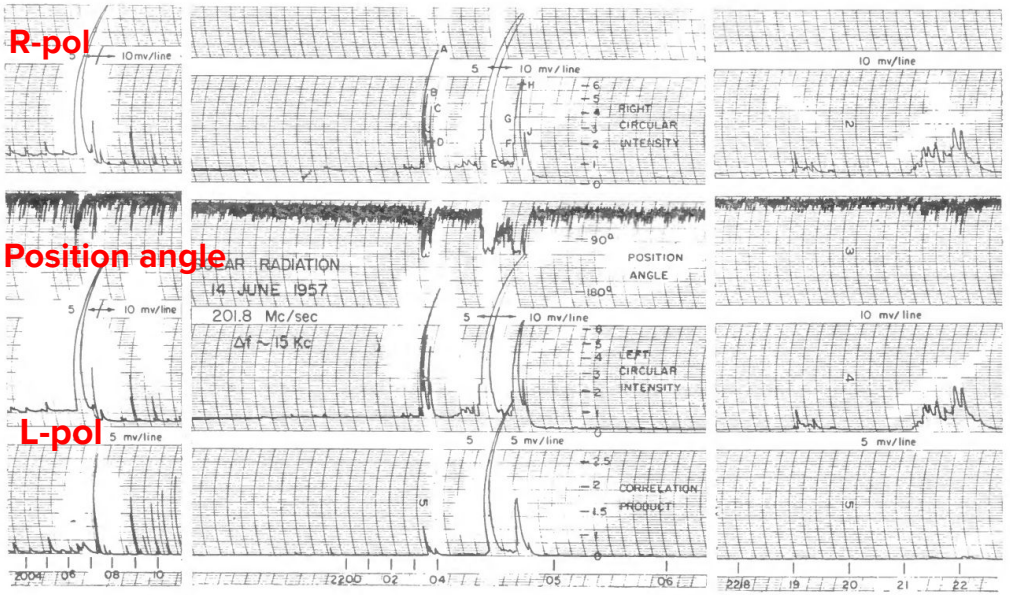


Gary & Hurford 2004

Background of a Decades Old Question

Polarization properties of Active Solar Emission : Circular, Linear or Elliptical?

- Started in 1960s, when first polarization observations of solar active emission started appearing
- Several claims about the detection of linearly polarized emission (Akabane and Cohen 1961, Bhonsle and McNarry 1964, Daene and Voigt 1964, Chin et al. 1971, etc.)
- Many studies reported non-detections as well (Dodge 1972, Grognard & McLean 1972; Boischot & Lecacheux 1975, etc.)



First claim of elliptically polarized emission from solar active emission (Akabane and Cohen 1961)

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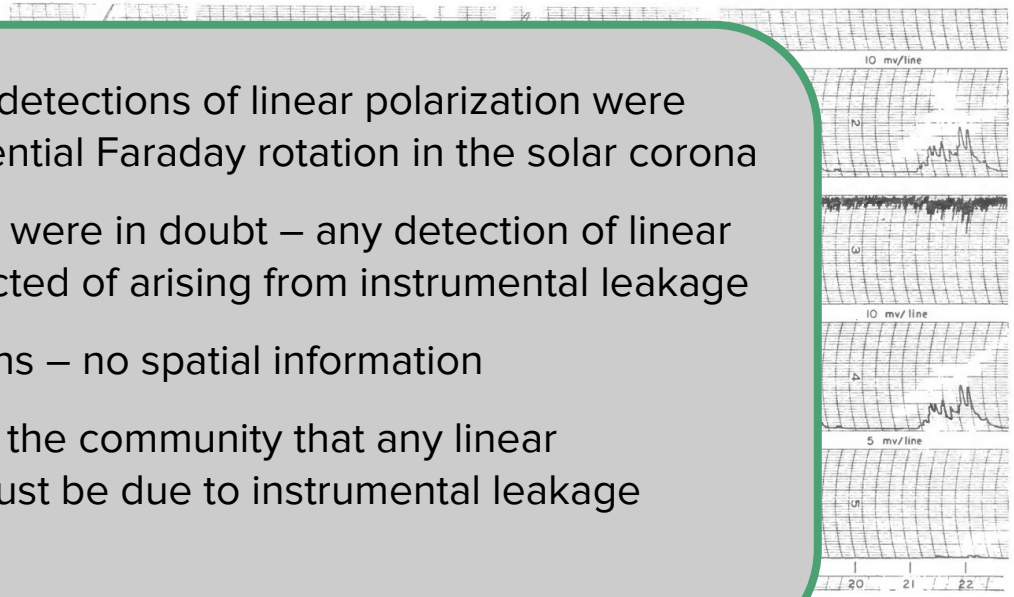
- A large numbers of non-detections of linear polarization were explained by high differential Faraday rotation in the solar corona
- Instrumental calibrations were in doubt – any detection of linear polarization were suspected of arising from instrumental leakage
- Non-imaging observations – no spatial information
- It was soon accepted by the community that any linear polarization detection must be due to instrumental leakage



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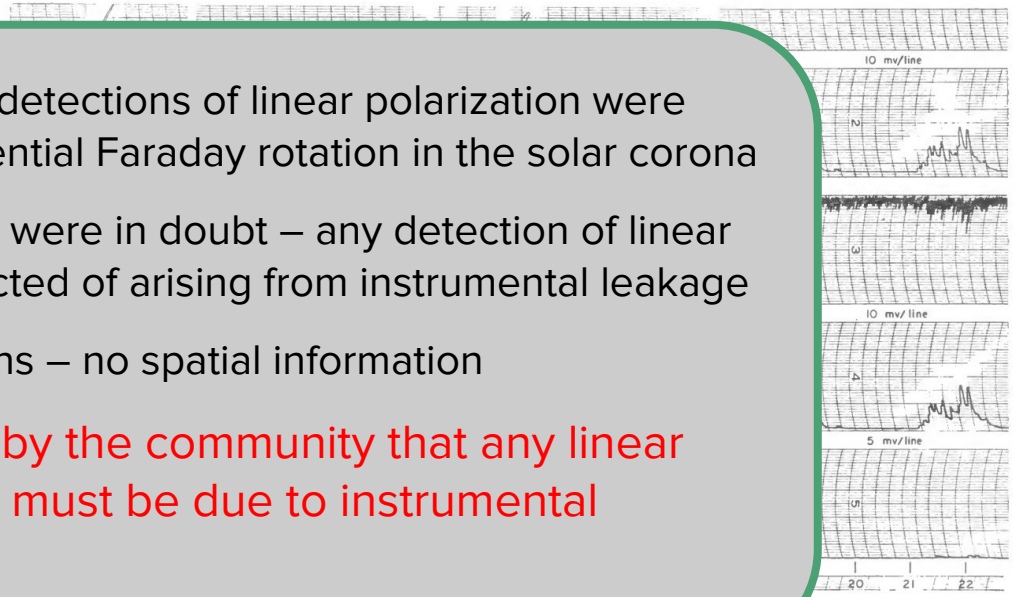

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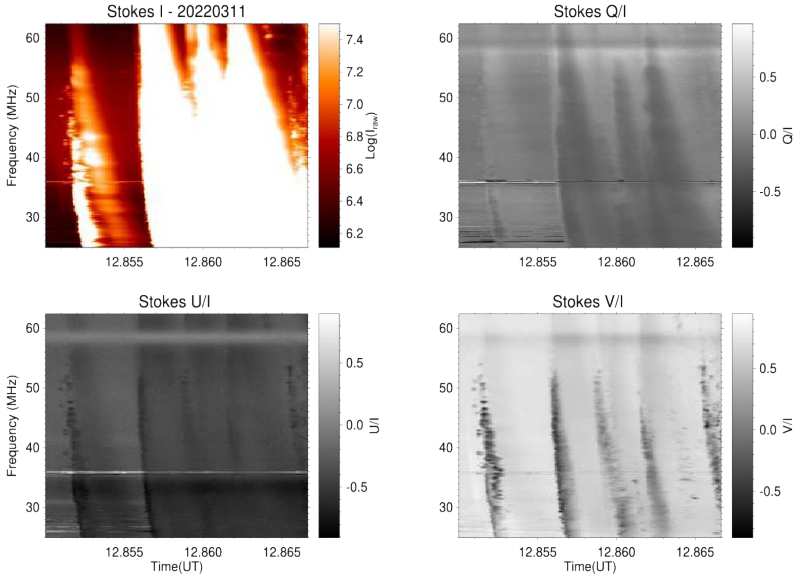
Assumed the Question is Answered – Bias in Calibration

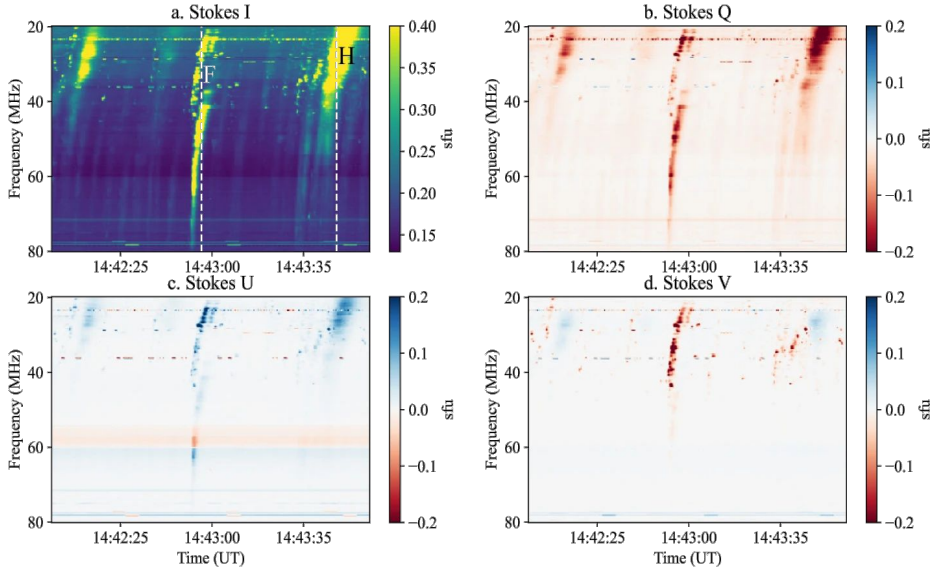
- Even very recent studies assume zero solar linear polarization.
- Became an accepted practise to calibrate polarization observations of solar radio observations (McCauley et al. 2019, Liu et al. 2022, Morosan et al. 2023).
- This leads to an implicit bias in all solar polarization studies so far.

NenuFAR dynamic spectrum



Credit: Carine Briand

LOFAR dynamic spectrum



Morosan et al. 2022

Need for Unbiased Full Polarimetric Calibration

Polarization mixing due to instrument –

- Polconversion – Stokes I to Stokes Q, U, V leakage (major contribution)
- Polrotation – Mixing between Stokes Q, U, and V.

Effects on solar observations —

- If calibrated based on assumption Stokes Q and U are zero, the measured Stokes V is also wrong.
- One needs to calibrate all instrumental effects causing the polrotation
- Even smaller effects of polrotation, which can be justifiably ignored for astronomical observations, may be important for bright solar observations and lead to spurious linear or circular polarization

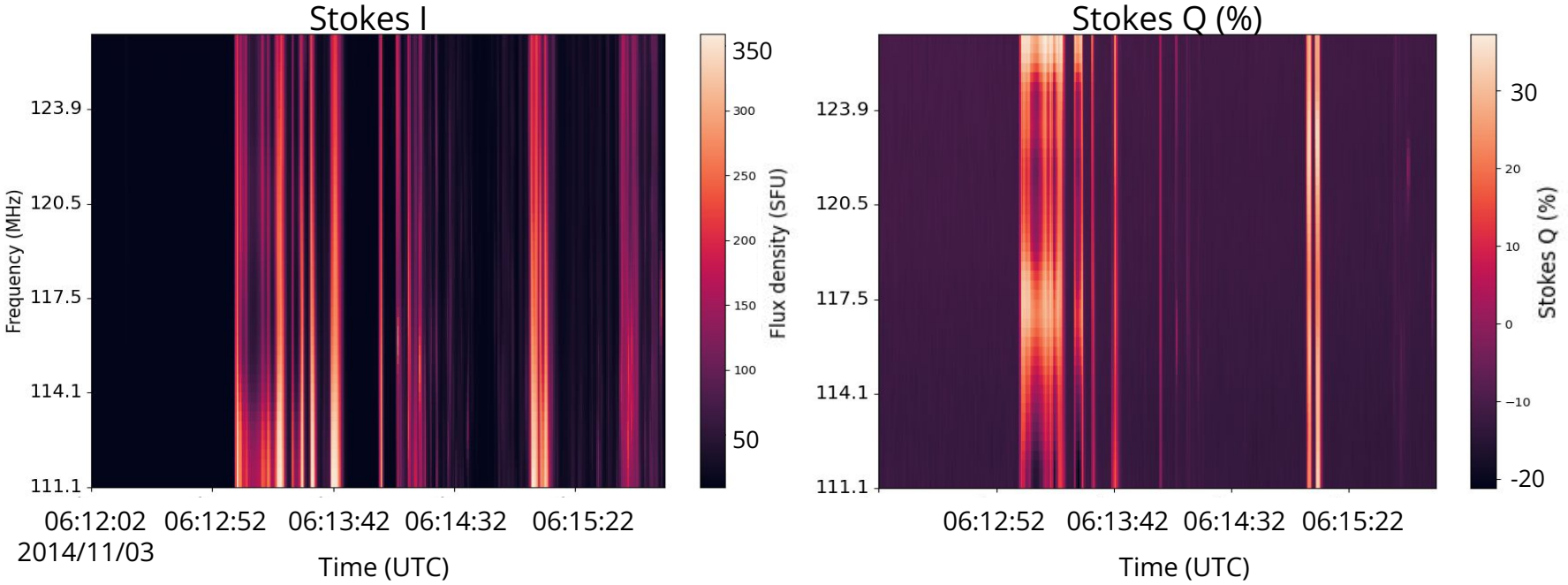
Developed a robust polarization calibration pipeline for MWA solar observations –

P-AIRCARS (Polarimetry using Automated Imaging Routine for Compact Arrays for the Radio Sun)

(Kansabanik et al, 2022, 2023)

Reason for Revisiting the Problem

- Uncalibrated dynamic spectrum of a type-III solar radio burst observed with the Murchison Widefield Array (MWA)
- Variable Stokes Q fraction over small timescales, which is not expected to come from instrumental polarization



Expected Characteristics of Instrumental and True Polarization

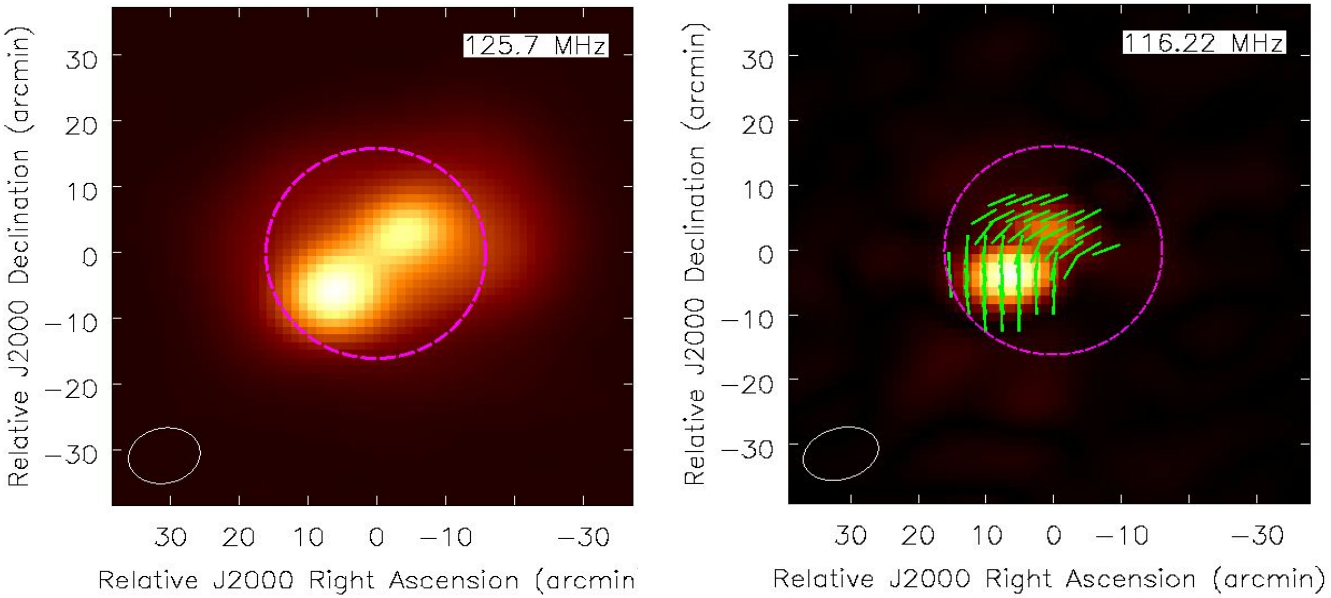
Properties of instrumental leakage for the MWA –

- Polarization leakage fraction is constant/smoothly varying over time for a single pointing
- Smoothly varying over frequency
- Due to large primary beam, residual leakage fraction after correction model beam is essentially constant over the solar disc, a small fraction of the overall beam

Expected properties of polarization of active solar emissions –

- Show variation across time and frequency
- Linear polarization fraction can vary across the sources

First Image Based Detection of Linearly Polarised Emission

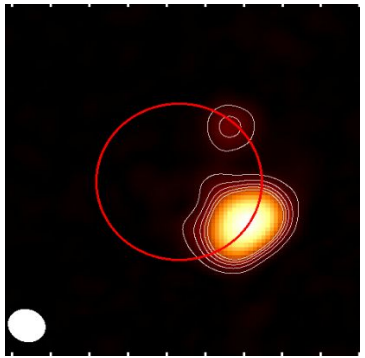


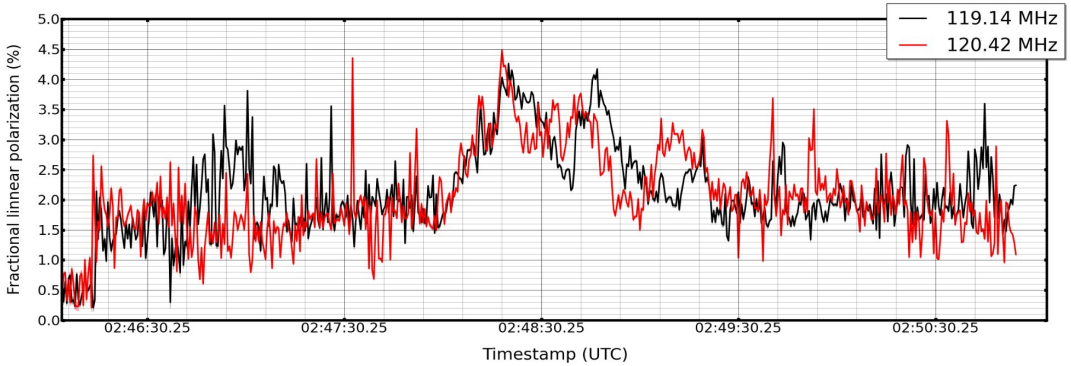
- Type-I noise storm from an active region
- Polarisation fraction is about 20-25%, residual Stokes I leakage is <3%.
- Polarisation fraction is highly variable with time and frequency, and also spatially.
- Polarization angle is varying over the source.

Multiple Instances of Snapshot Image Based Detection

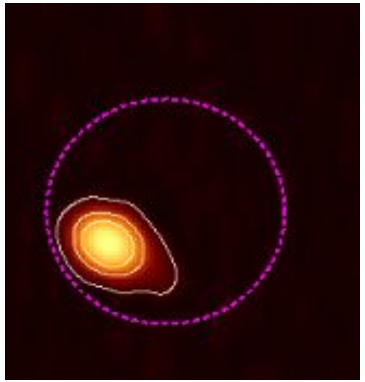
Two instances of type-II radio bursts showing linear polarization

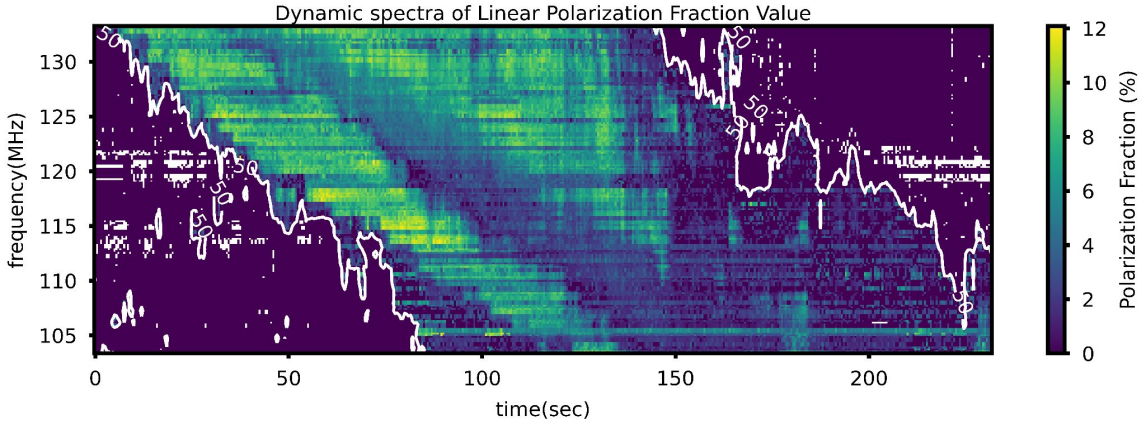
1. Linear polarization intensity map of a type-II solar radio burst on 2014/09/28





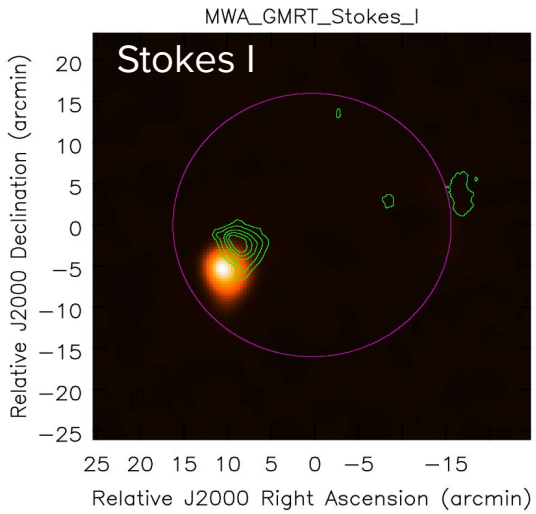
2. Linear polarization intensity map of a type-II solar radio burst on 2014/09/07

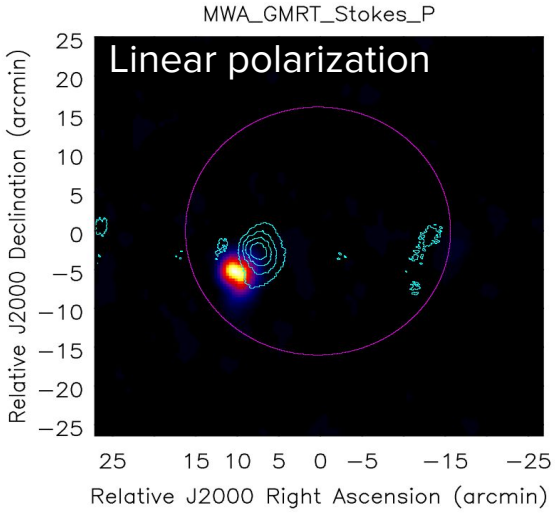




Next Step of Verification : Coordinated Observations

Simultaneous observations with the upgraded GMRT and the MWA



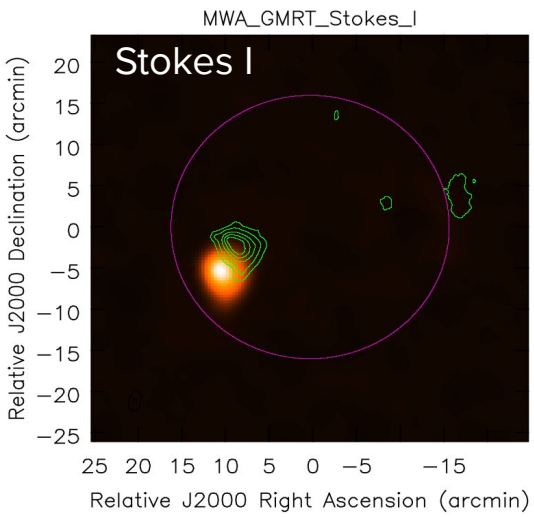


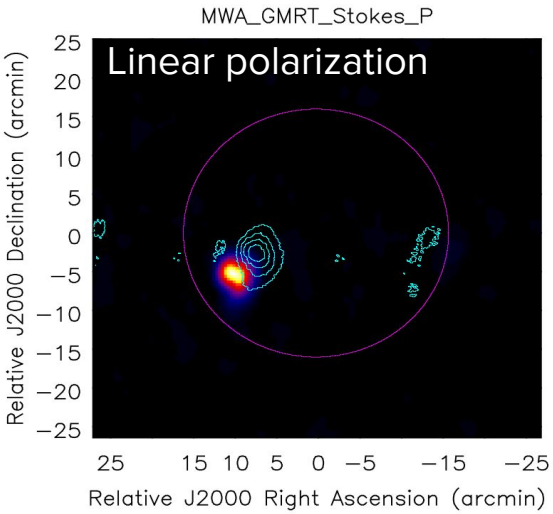
- Simultaneous observations are done at the same frequency
- Two different instruments at different locations, different electronics, different instrumental polarization properties
- Incident emission must be linearly polarized if both instruments show the same thing

Next Step of Verification : Coordinated Observations

Simultaneous observations with the upgraded GMRT and the MWA

- Background colormaps are the MWA images at 212 MHz.
- Contours show the uGMRT images at 217 MHz.
- Both shows similar linear polarization fractions –
  - uGMRT ~ 5.7%
  - MWA ~ 3.7 %
- Compact and similar sizes





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Where do We Stand Now About Our Understanding?

- Arguments why these emissions are not of instrumental origin –
  - Temporal, spectral and spatial variability
  - Simultaneous detection with the MWA and uGMRT
- Multiple instances of detection with varying linear polarization fractions ranging from a few percent to few tens of percent
- Observed linear polarization fraction indicates toward lower rotation measure (RM) than proposed very high RM
- Probably the linear polarization is produced at much higher coronal heights during propagation through the corona due to reflection from high density structures

Conclusion and Looking Ahead

- Revived a decade old question, which was assumed solved and routinely used for calibrating the instruments
- Our claim is stronger than any of the earlier works using older generation narrow-band non-imaging instruments –
  - Robust instrumental calibration
  - High instrumental stability of the MWA
  - High-fidelity spectroscopic snapshot imaging
  - Simultaneous observation with the uGMRT
- Questioning our understanding of polarization properties of active solar emissions –
  - Emission mechanism ?
  - Propagation effect? Full Stokes propagation effect has not been explored
- Solar community should look examine this issue with other instruments with good polarization capabilities (e.g. LOFAR) and without an inherent bias in calibration

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