Solar science with MWA: Status, Plans and Possibilities

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Status:

- Global leaders in metrewave solar imaging
  - Highest dynamic range images
    - >50,000 under favourable circumstances, ~1,000 under challenging ones
    - Previous best: ~300
  - Robust unsupervised snapshot spectroscopic imaging capability (AIRCARS, Mondal et al., 2019)
    - MWA can lead to up to ~0.1 Mimages/ minute
    - Previous best: Not sure of a suitable point of comparison
  - Weakest detection of nonthermal impulsive emissions
    - ~1mSFU (1 SFU = 10^4 Jy; Mondal et al., in prep.)
    - Previous best: ~1 SFU

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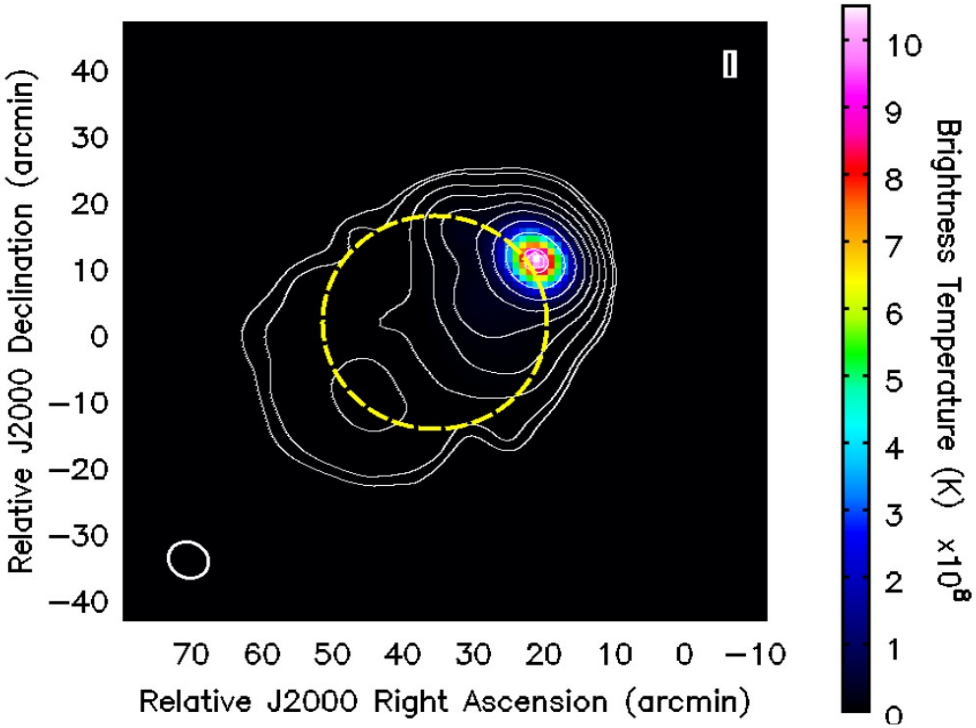
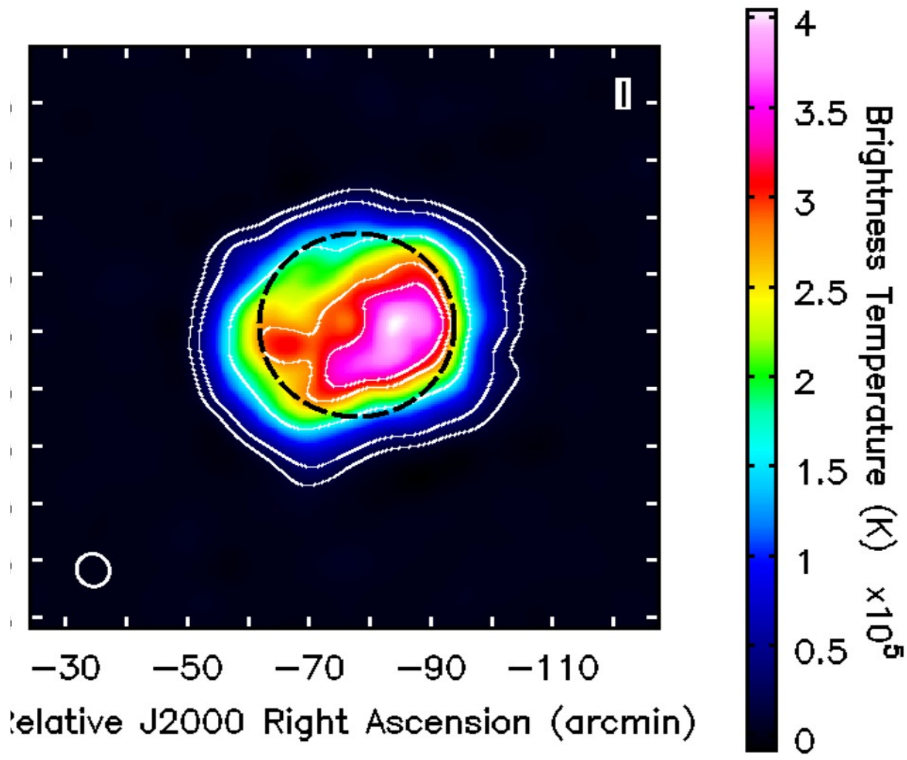
Automated Imaging Pipeline





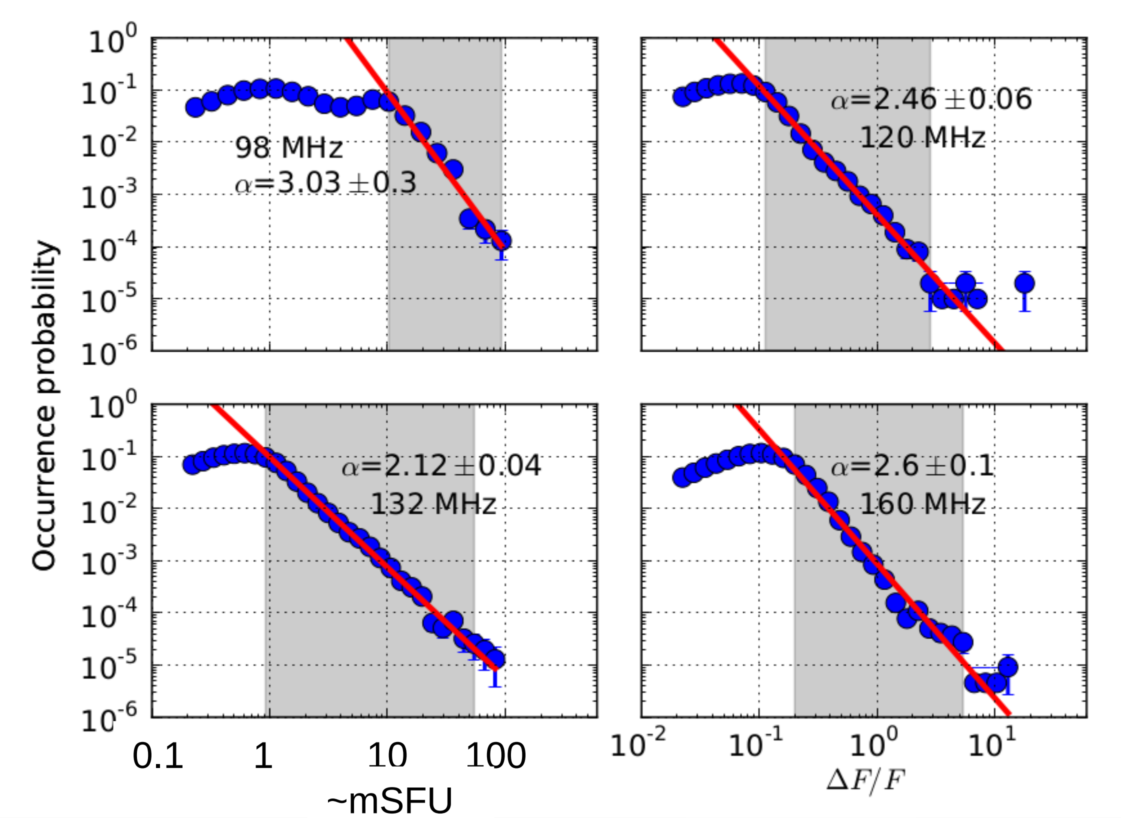
Contour levels: (0.0007, 0.002, 0.02, 0.2,0.4,0.8) X 10^9 K
144.32 MHz; 40 kHz; 0.5 s
Imaging dynamic range: >10^5

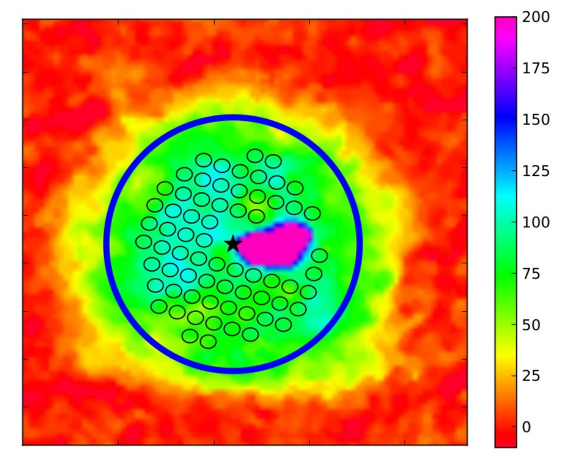
Contour levels: (0.03, 0.09, 0.4, 0.7, 0.8) x 4x10^5 K
239.10 MHz; 160 kHz; 0.5 s
Imaging dynamic range: ~1000

Mondal et al., 2019, ApJ, Vol. 875, 97

Quiet Sun

- *First* evidence for presence of impulsive nonthermal emissions



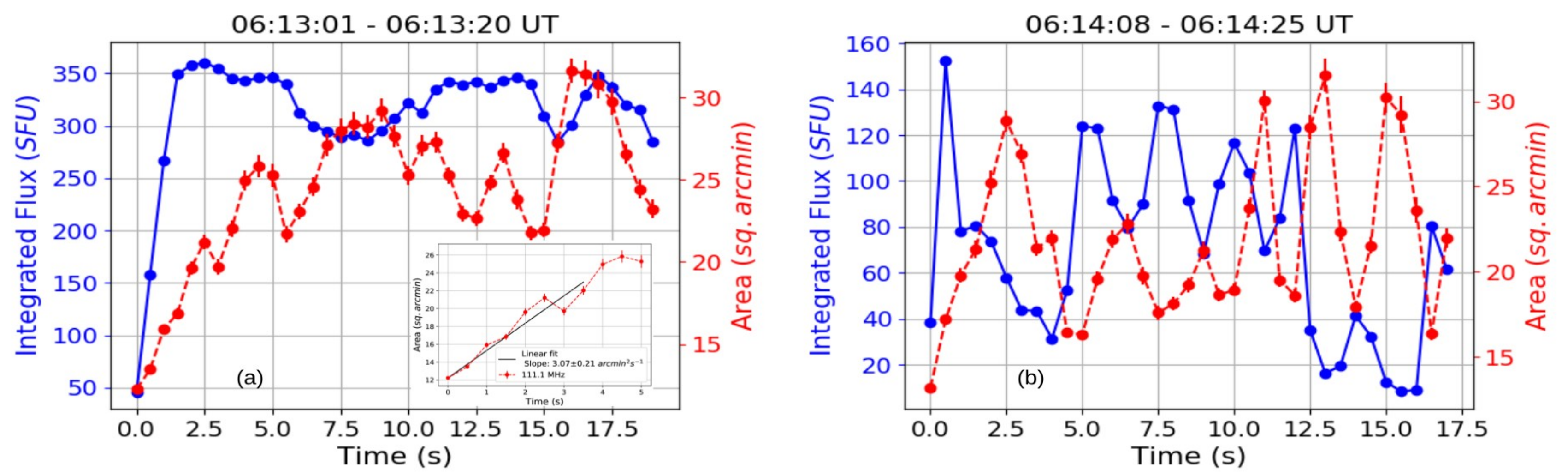


- 160 MHz (~2 MHz, 0.5s)

- 70 min of quiet time data
- 33,000+ images

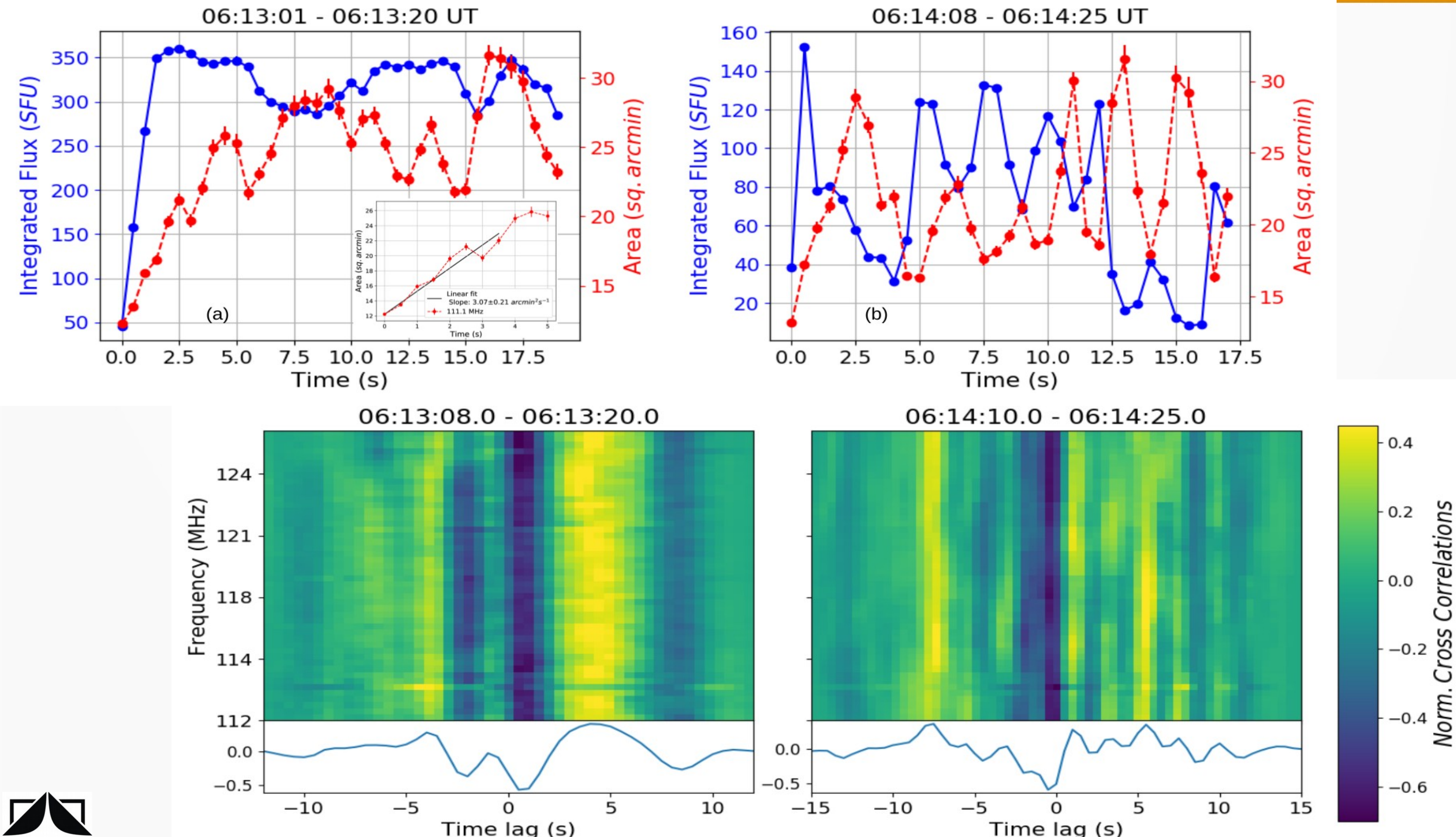
Mondal et al., 2019, in preparation

Discovery of anti-phased QPOs in flux density and area of a type III burst



Mohan, Mondal, Oberoi+, 2019, ApJ, 875, 98

Discovery of anti-phased QPOs in flux density and area of a type III burst



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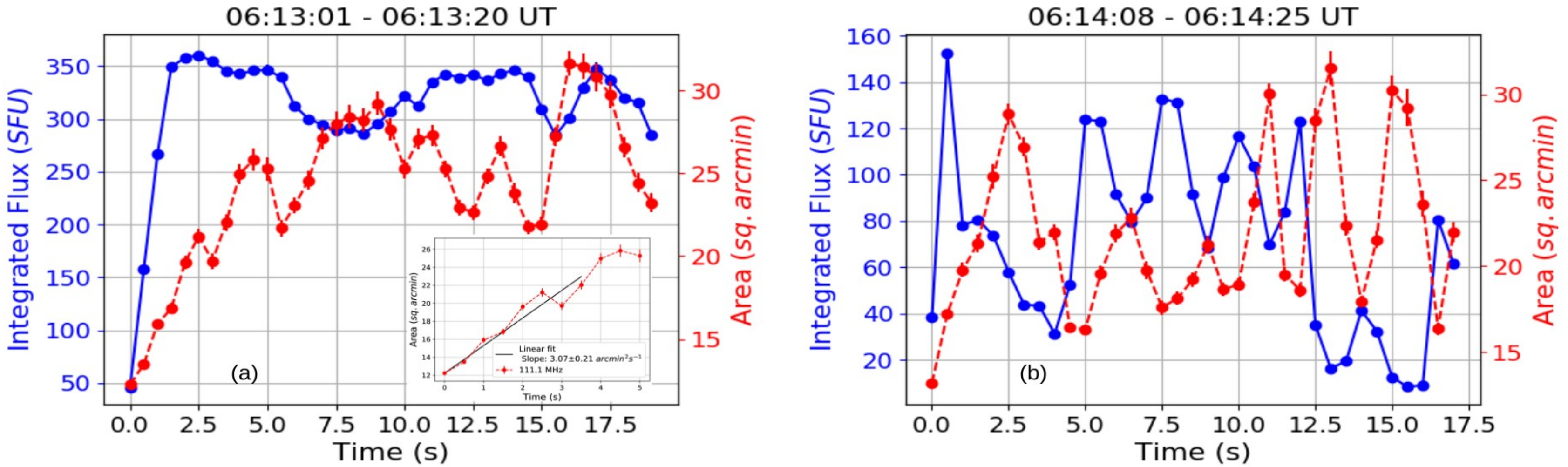
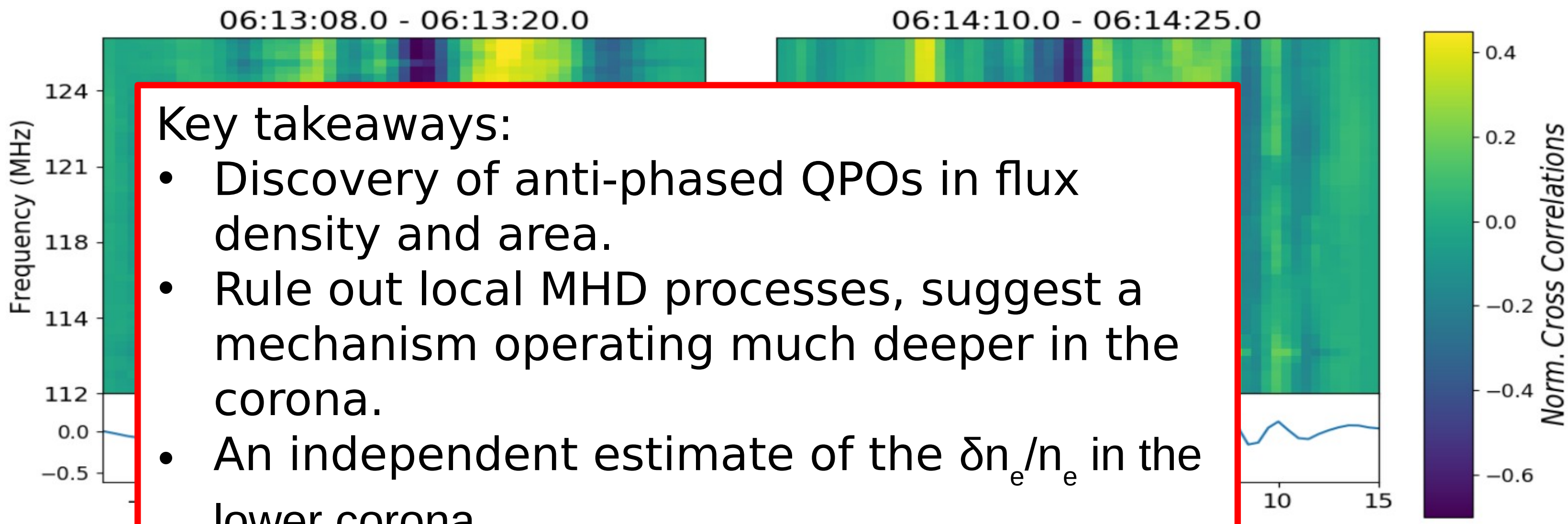
Discovery of anti-phased QPOs in flux density and area of a type III burst



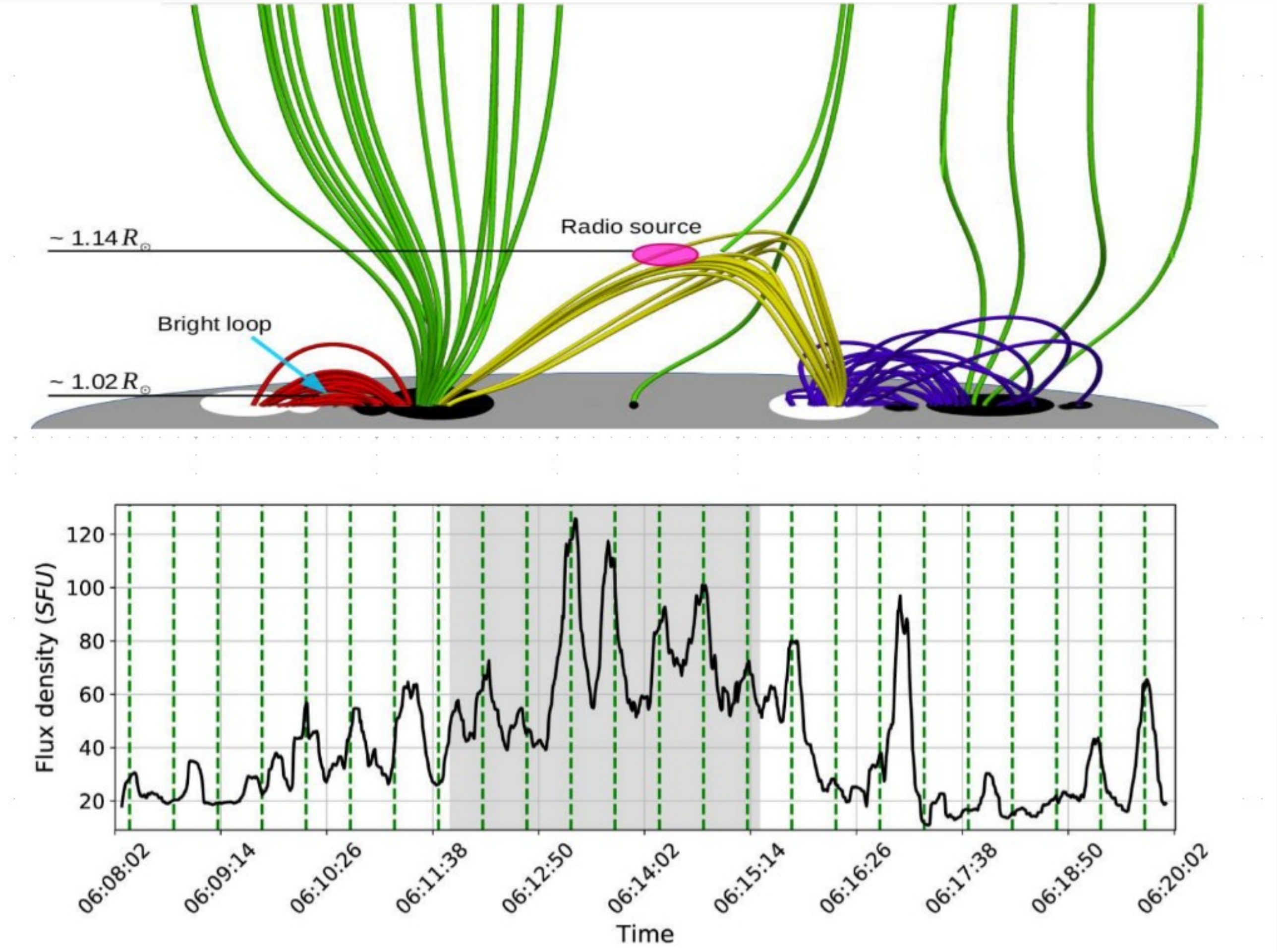


Key takeaways:

- Discovery of anti-phased QPOs in flux density and area.
- Rule out local MHD processes, suggest a mechanism operating much deeper in the corona.
- An independent estimate of the $\delta n_e/n_e$ in the lower corona.

Mohan, Mondal, Oberoi+, 2019, ApJ, 875, 98

First SS study of a type I



- First detailed study of an Active Region Transient Brightening associated with a type-I radio noise storm.
- Established spatio-temporal correlation between emissions in the radio, EUV and X-ray bands
- Discover of a 30s periodicity, interesting physical interpretation

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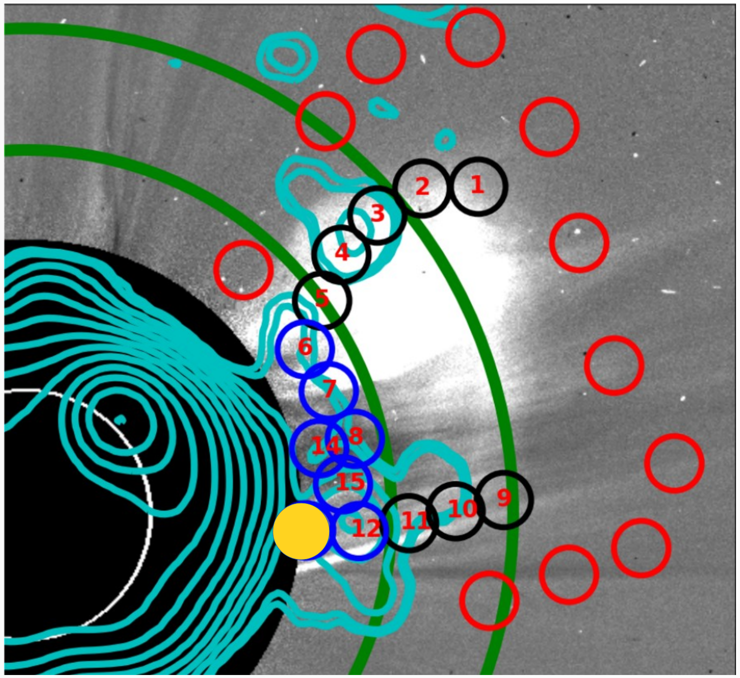
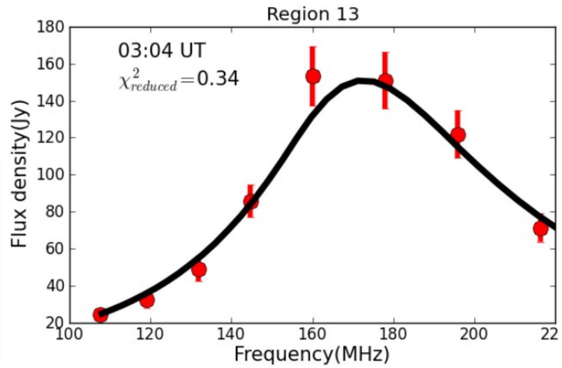
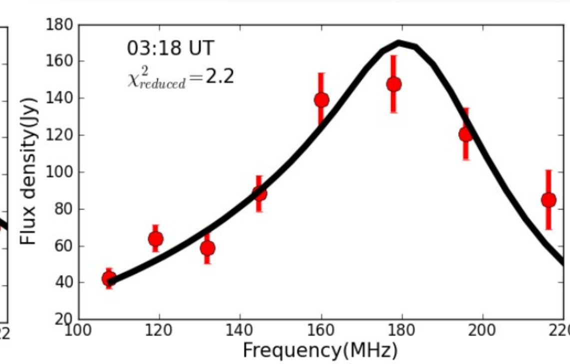
Mohan, McCauley, Oberoi+, 2019 ApJ, 883, 45

Estimating CME magnetic fields



Background image: LASCO C2/ SOHO Coronagraph
Contours: MWA 132.48 MHz
Contour levels: 0.02% onwards, increasing in factors of 2





B = 12.6 ± 0.4 G

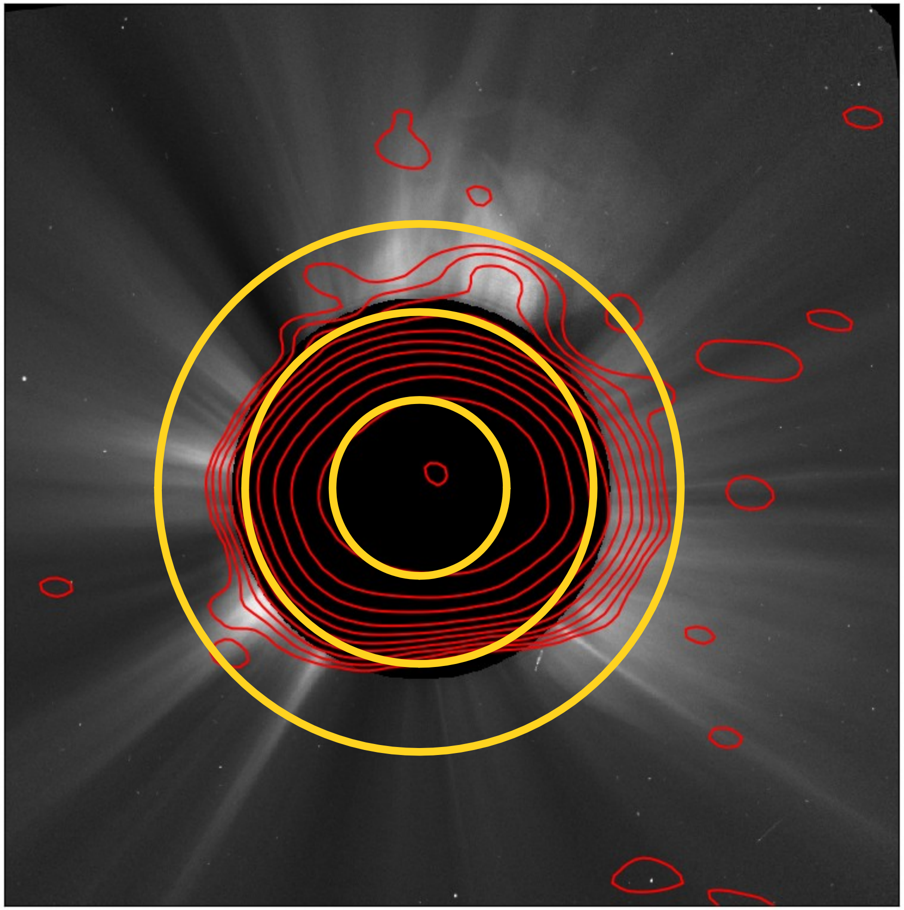
B = 10.8 ± 0.4 G

- Only 3 published instances of direct radio imaging of CME plasma
- This was a slow (442 km/s) and unremarkable CME, still able to image it out to 4.73 R_sun

- Expect to routinely model the observed spectra to estimate the CME magnetic fields
- Crucial step forward for understanding CMEs and their evolution

Mondal et al., 2019, arXiv:1902.08748

Gyrosynchrotron imaging of CMEs



- Detected emission from CME in all 3 instances where we have tried
- Detailed modeling of 2nd CME just started
- Able to detect the CME out to ~7 R_sun!
- Attempting to detect emission from the front/leading edge (relevant for Space Weather)

Background image: LASCO C2
Contours: MWA 108.3 MHz (10s, 1.2 MHz)
Contour levels – 0.08% onwards increasing in factors of 2

Kansabanik et al., in preparation

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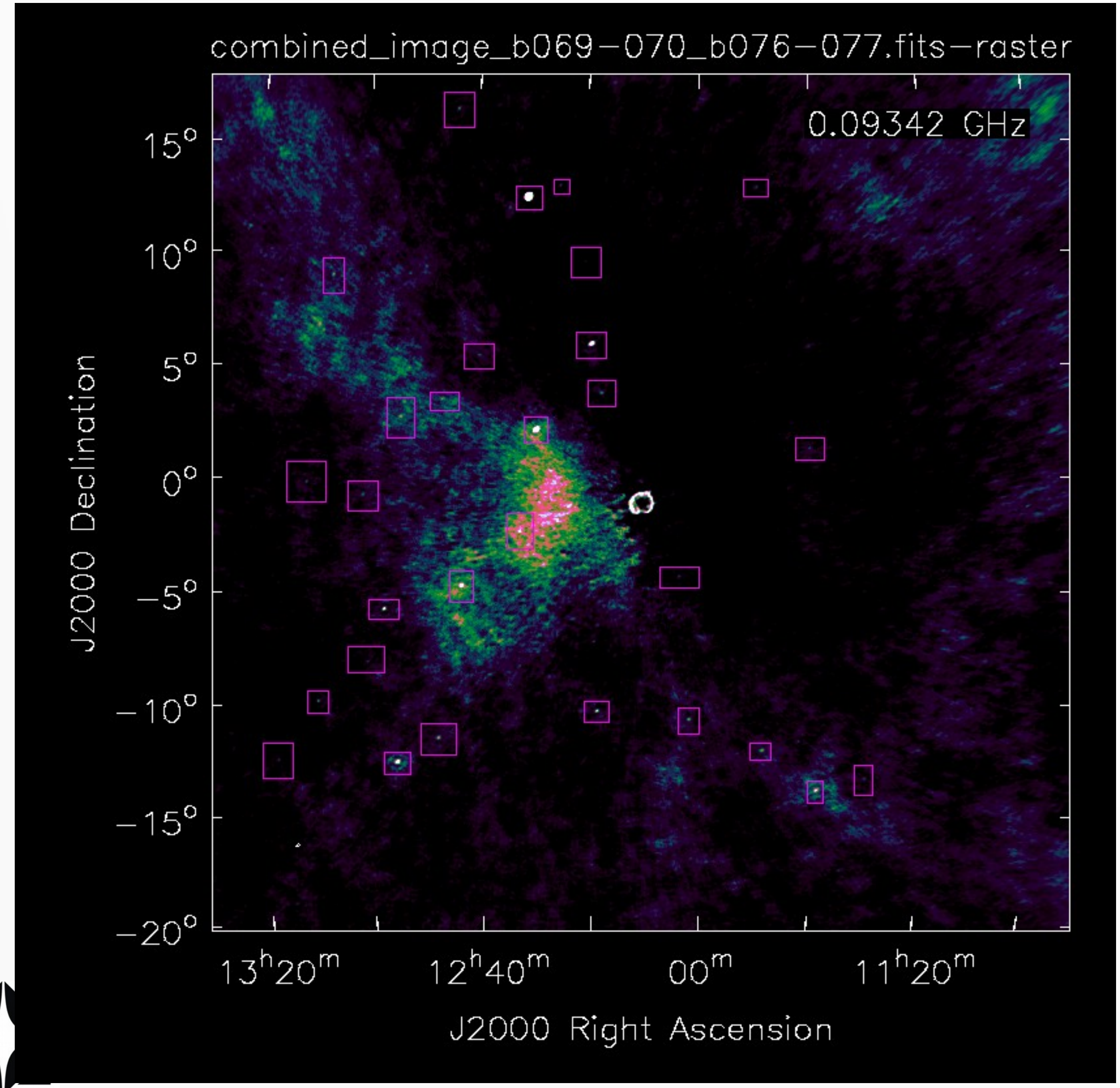
Stars in daytime!



- Boxes - detected sources with a counterpart in the TGSS and GLEAM 150 MHz survey.
- Sun imaged at 0.5 s, 160 kHz resolution.
- The model for Sun was then subtracted from the data and the residual data from ~350 such frames were combined.
- Complete till 15 Jy (> 5σ)

- The bright annular region at the center of the image is the unmodeled contribution from the Sun.

Figure credit: Surajit Mondal (NCRA)

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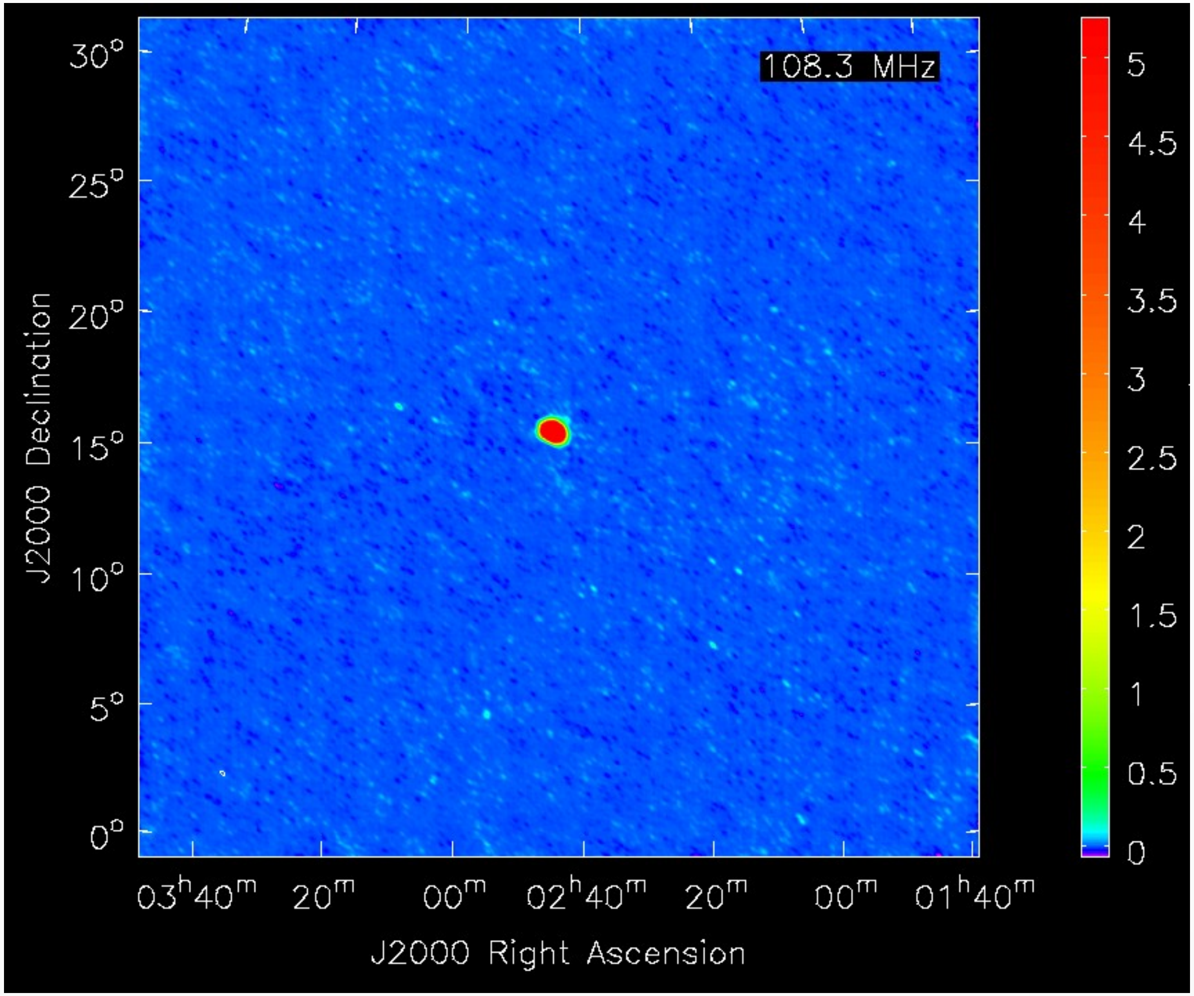
An improved attempt



- Preliminary results
- 10s, 1.2 MHz
- Can see sources down to ~5 Jy!

- Provides a robust and independent flux calibration

Image credit: Kansabanik, D. (NCRA)

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Imaging Galactic Emission

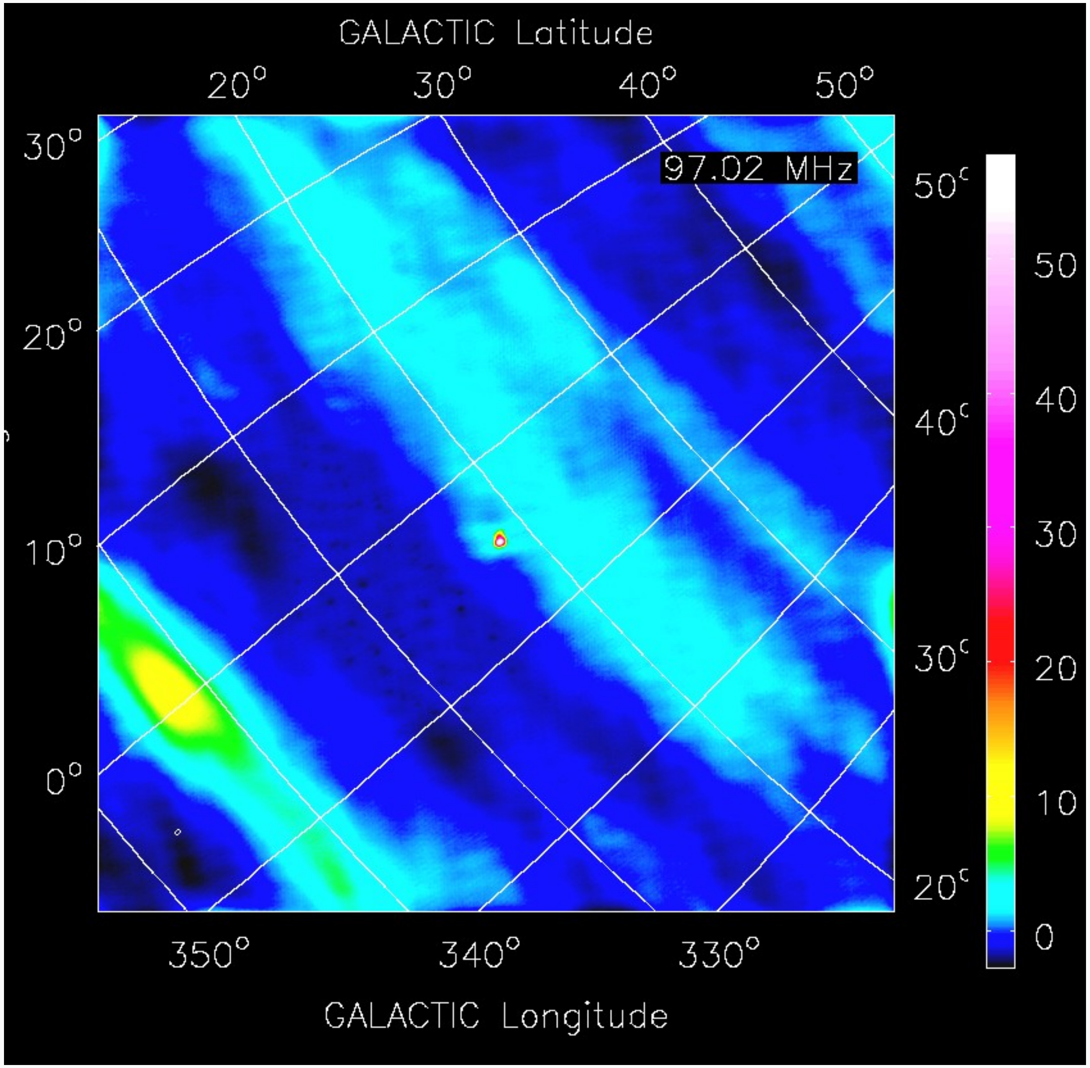

Figure credit: Mondal, S. (NCRA)

Measuring Geo-effectiveness of CMEs

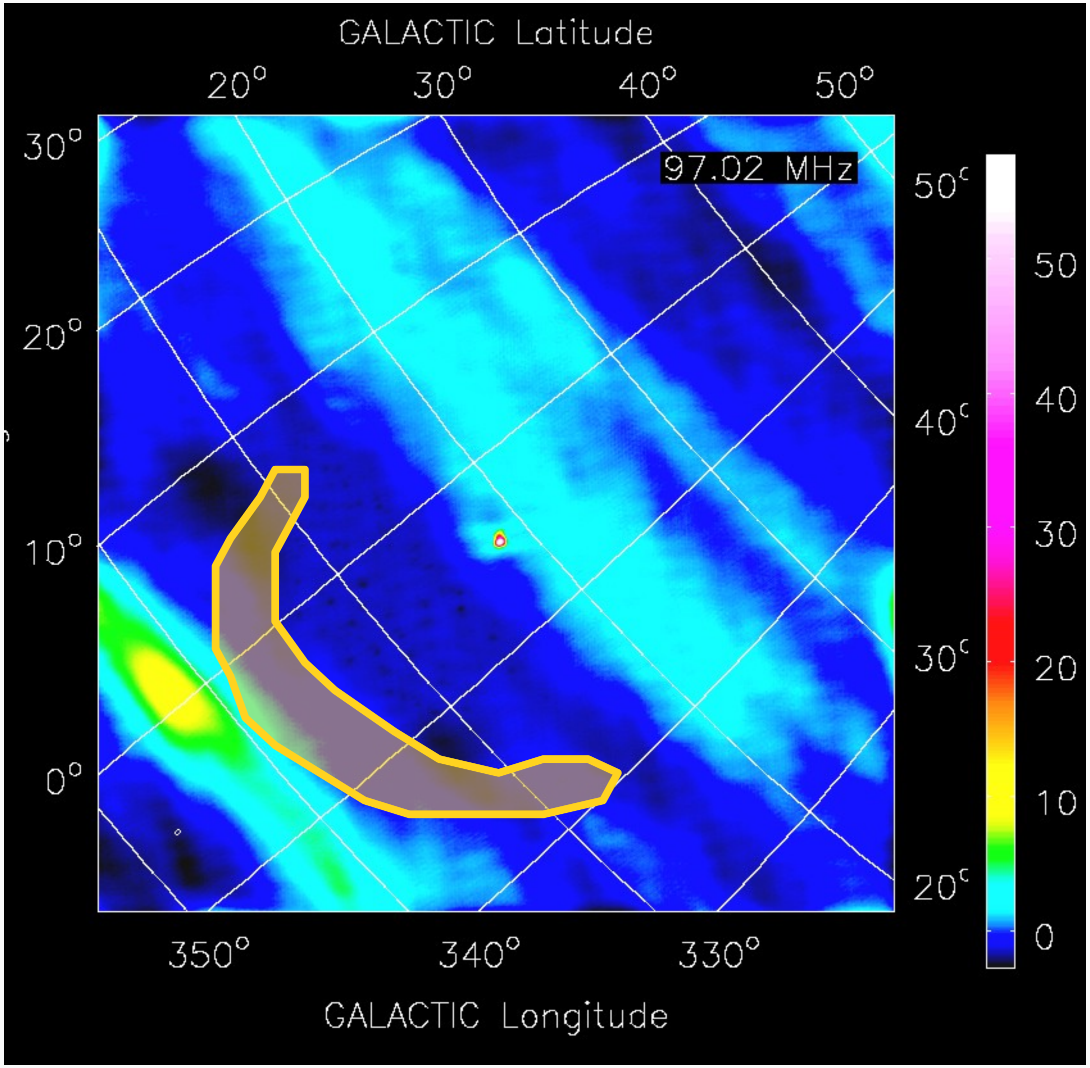

Figure credit: Mondal, S. (NCRA)

- The geo-effectiveness of CMEs is crucially dependent on its vector magnetic field topology
- Radio observations provide the only known technique to measure it remotely – by measuring the Faraday rotation of the linearly polarised radiation from the background radio sources.
- It is a very challenging problem requiring >10^6 dynamic range and exquisite calibration of ionspheric propagatioin effects

Opens up vast new phase space

- Propagation effects
- Ionospheric science

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The next steps: Technical

- Polarisation calibration
  - Part of the next thesis project
- Ionospheric calibration
  - Ionospheric phase across the ~45’ solar disc
    - Collaboration with ARDG, NRAO
  - Ionospheric phase across the MWA FoV
    - Will benefit from working with the MWA Polarimetry team
- AIRCARS V2
  - Improved design and built on CASA 6
  - Computational efficiency and flexibility

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The next steps: MWA hardware/ upgrade

- Characterization of the MWA signal chain
  - Attenuator response
- Provide Solar-Heliospheric perspective for the next phase of MWA
  - Array configuration
  - Processed bandwidth and flexibility in spectral sampling
  - Flexible correlator – e.g. tradeoff(s) between processed bandwidth *and* time resolution
  - van Vleck correction?

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The next steps: Resourcing/Infra

- Prototype SKA India data center
  - High bandwidth data transport from Pawsey
  - Local compute and storage infrastructure
- Support from MWA Project to access funding opportunities with the NSF
- Access computational resources in Australia, via Australian PIs
- Adapting AIRCARS to run on Pawsey infrastructure

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The next steps: Interpretation

- Theoretical and modeling work to relate observations to physics
  - Space weather and CMEs
    - Detailed 3D models for CMEs and their propagation
  - Relating radio observables to coronal heating scenarios
    - MHD both analytic and computational

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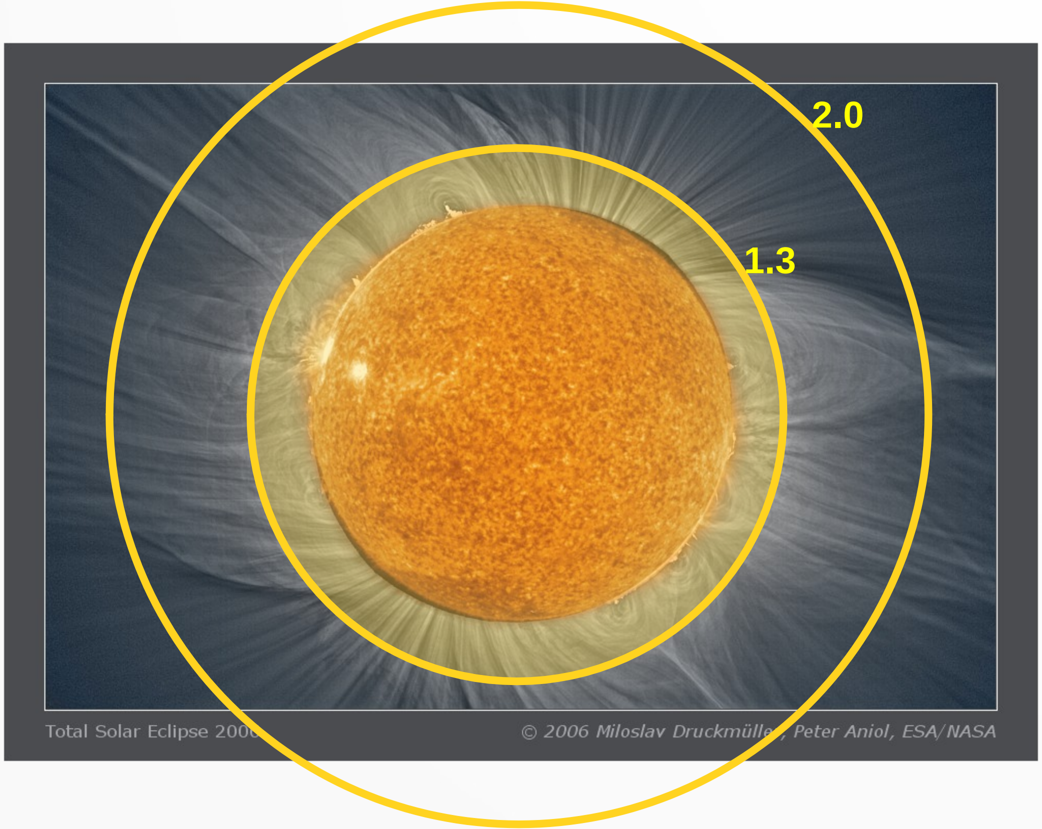
The radio advantage



- The inner most yellow disc shows the field-of-view (FoV) of typical present generation EUV and X-ray instruments of ~1.3 R_{Sun}
- The FoV of the most successful of the present generation coronaraph can starts at ~2 R_{Sun} and extends outwards
- Radio observations can probe the full unobscured disc of the Sun and the surrounding region - overlapping with the EUV and X-ray FoVs and extending well into the coronagraph FoV

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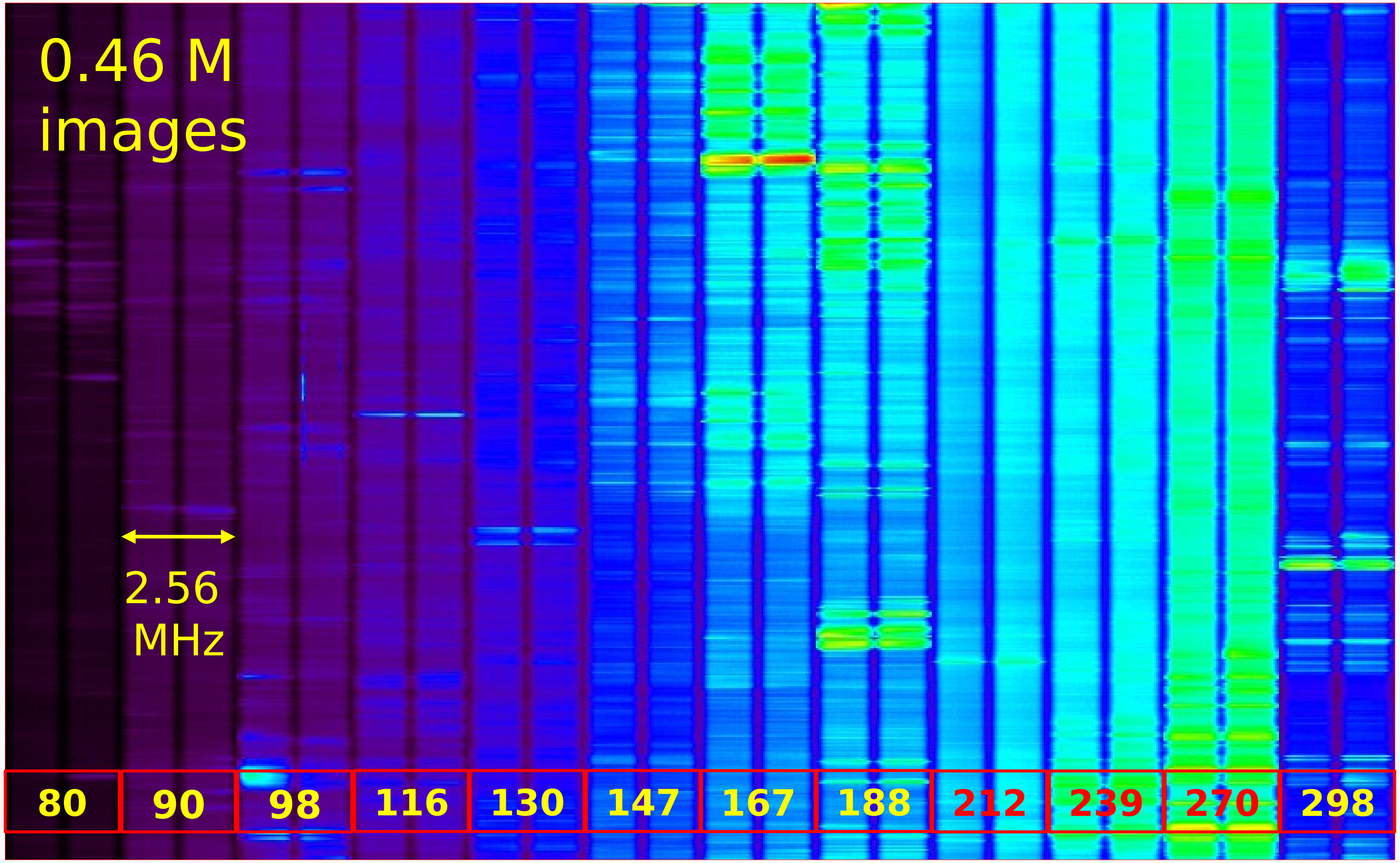
Sample MWA Dynamic Spectrum

Time
(5 min)



Frequency (MHz)

(12 log-spaced groups of 2.56 MHz spanning 80 – 300 MHz)

Figure credit: Divya Oberoi

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Gyrosynchrotron: Another example