NCRA • TIFR

MWA
MURCHISON
WIDEFIELD
ARRAY

Deciphering Faint Gyrosynchrotron Emission from CME using Spectro-polarimetric Radio Imaging

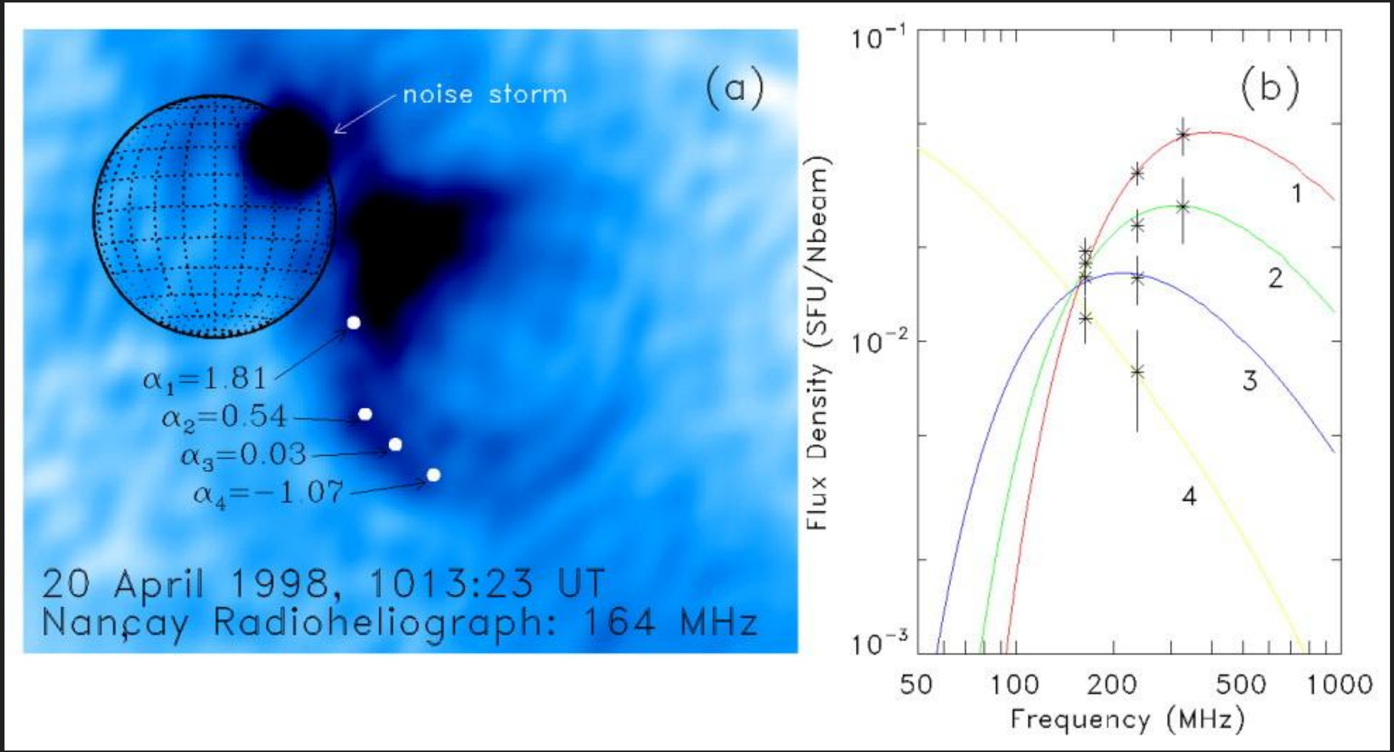
Devojyoti Kansabanik[1]
(Infosys Fellow)
[1] National Centre for Radio Astrophysics, TIFR, India
Email: dkansabanik@ncra.tifr.res.in, devojyoti96@gmail.com
Surajit Mondal[2], Divya Oberoi[1]
[1] National Centre for Radio Astrophysics, TIFR, India
[2] Centre for Solar-terrestrial Research, New Jersey Institute of Technology, USA

CESRA Workshop 2023

Methods at Radio Wavelengths

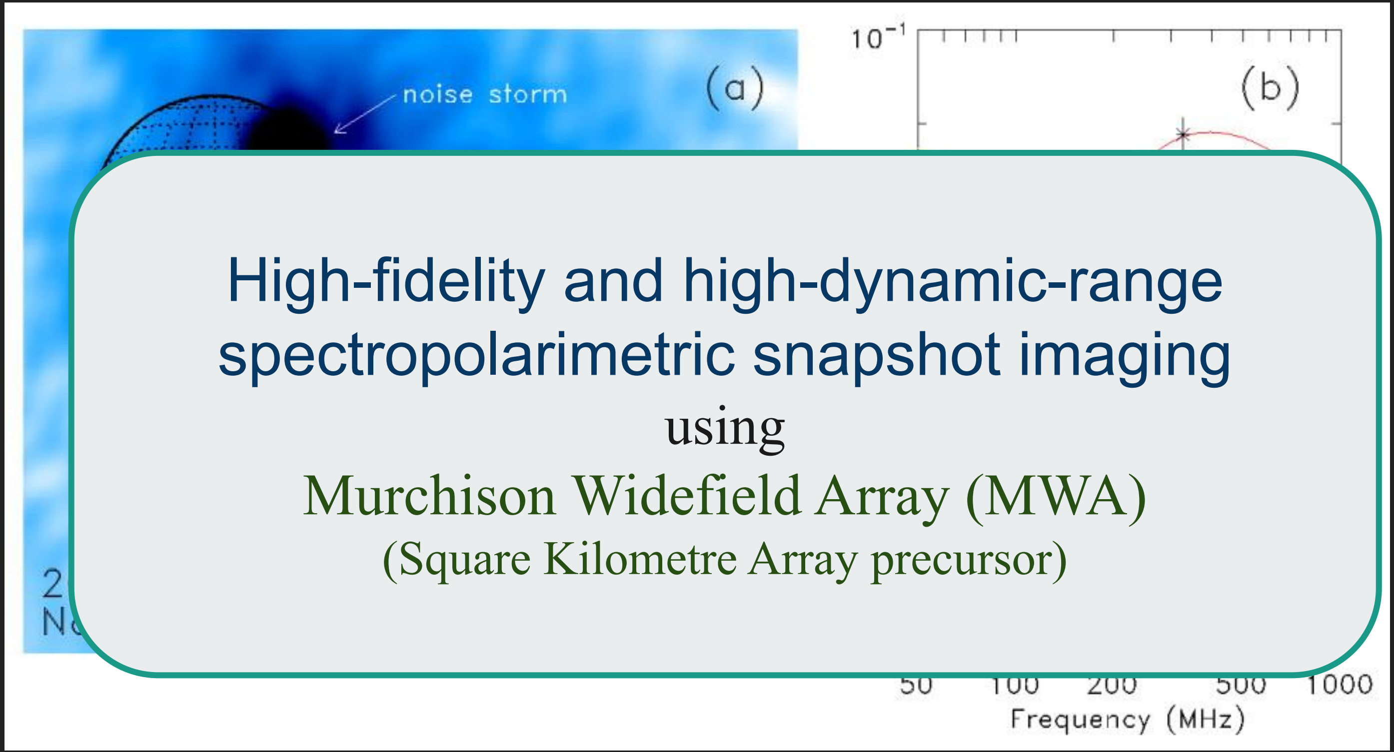
- Direct observables –
  - Radio bursts (upto ~2 $R_\odot$ using ground-based instruments)
    - From CME shocks and core
  - Radio emission from CME plasma (upto ~10 $R_\odot$)
    - Circular polarization of thermal emission (e.g., Gopalswamy & Kundu 1992, 1993, Ramesh et al. 2020, etc.)
    - Faint Gyrosynchrotron (GS) emission (e.g., Bastian et al. 2001, Mondal et al. 2020, etc.)
- In-direct observables –
  - Interplanetary Scintillation (IPS) (e.g. Manoharan 2010, Iwai et al. 2022, etc.)
  - Faraday rotation (FR) measurements (Kooi et al. 2022, for a review)
    - Background linearly polarized galactic/extra-galactic radio sources
    - Linearly polarized galactic diffuse emission

First Detection of GS Emission from CME-loops



Detected radio emission upto 2.8 $R_\odot$ (Bastian et al. 2001)

First Detection of GS Emission from CME-loops



High-fidelity and high-dynamic-range spectropolarimetric snapshot imaging

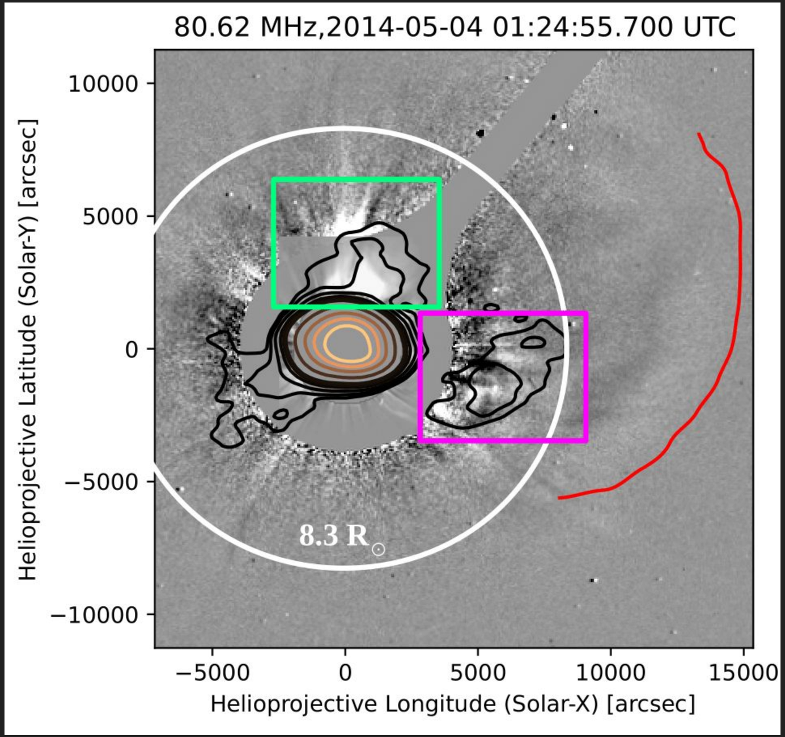
using

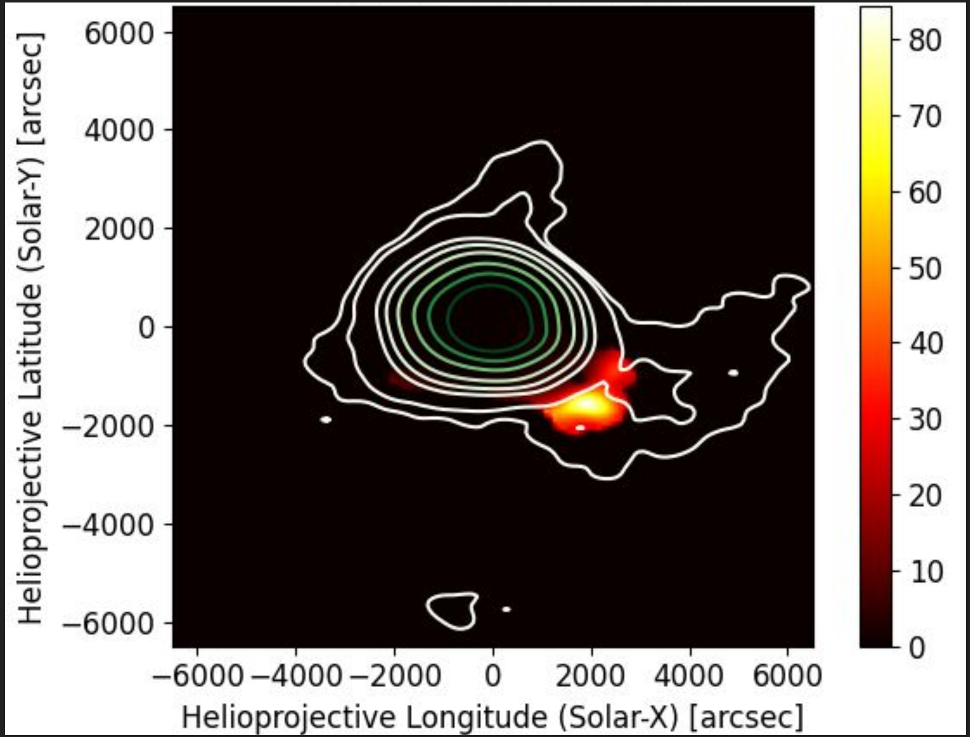
Murchison Widefield Array (MWA)

(Square Kilometre Array precursor)

Detected radio emission upto 2.8 $R_{\odot}$ (Bastian et al. 2001)

Faint GS Emission from Two Slow CMEs

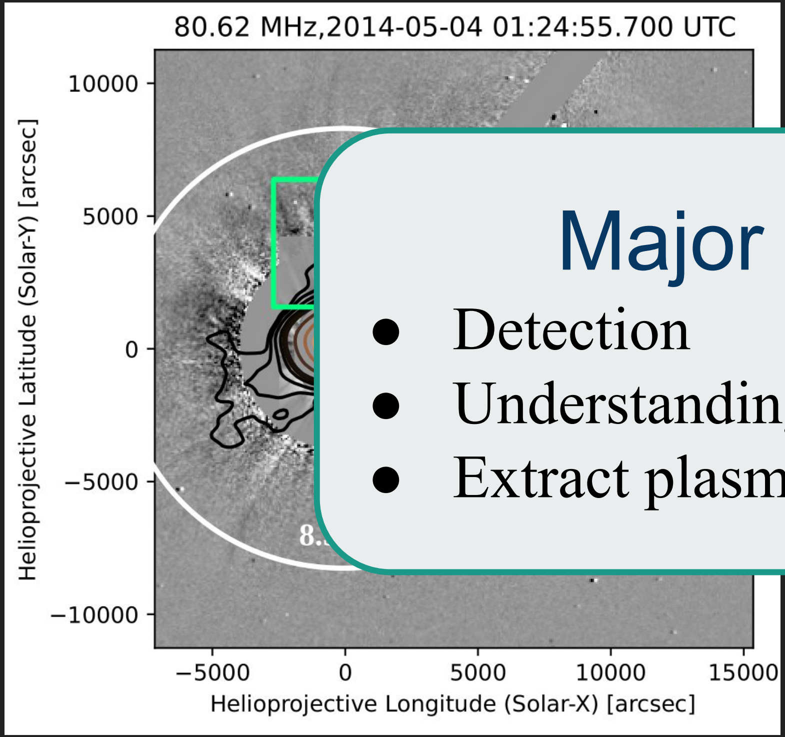


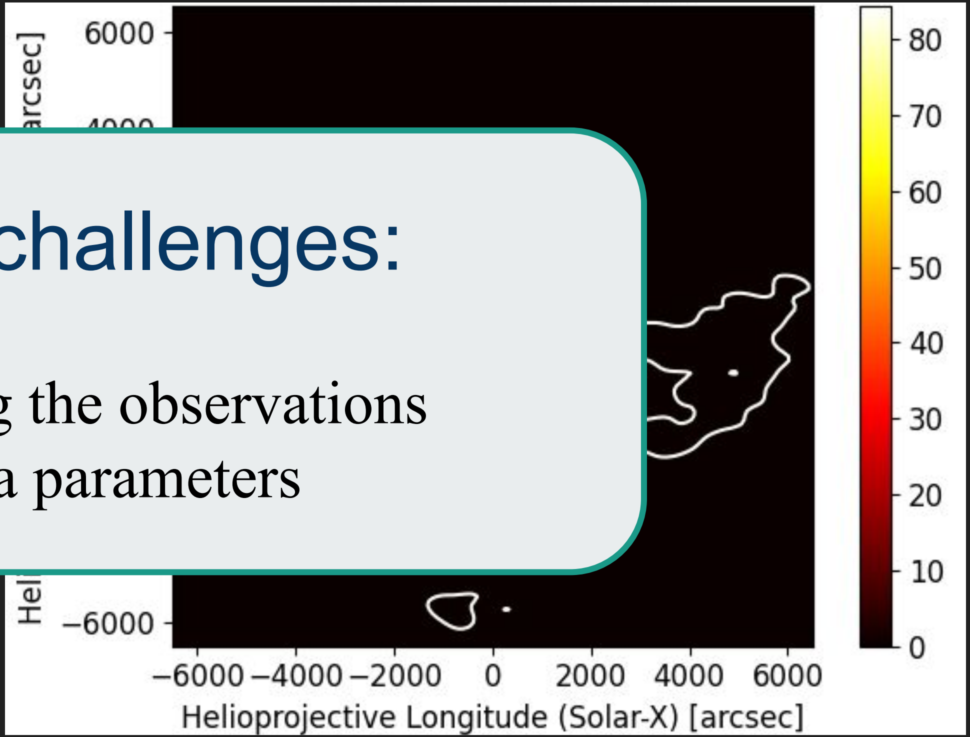


Detection of the faintest GS emission at the highest heliocentric distance (8.3 $R_{\odot}$)

Kansabanik et al. 2023, ApJ 950 164

Faint GS Emission from Two Slow CMEs





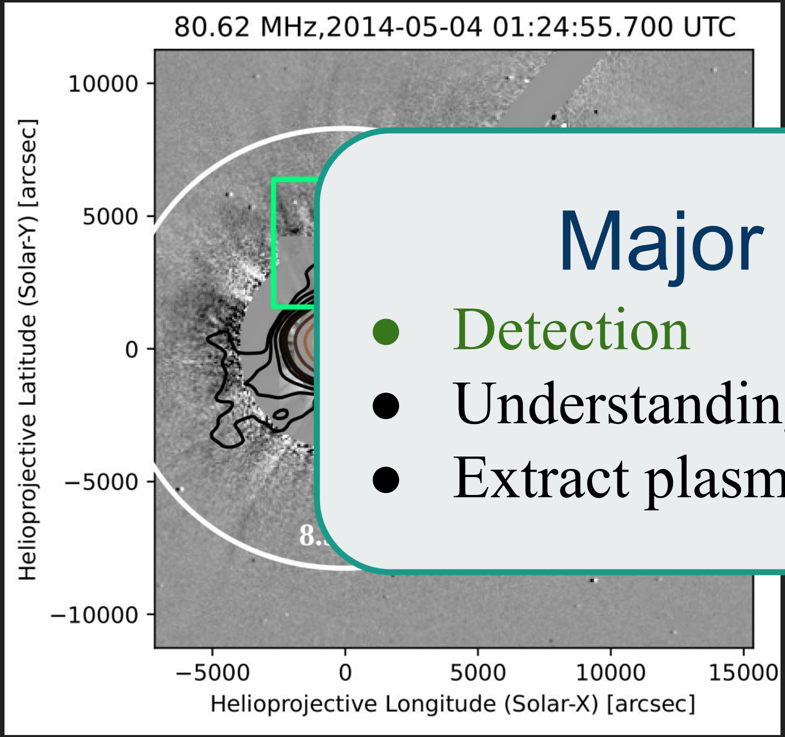
Major challenges:

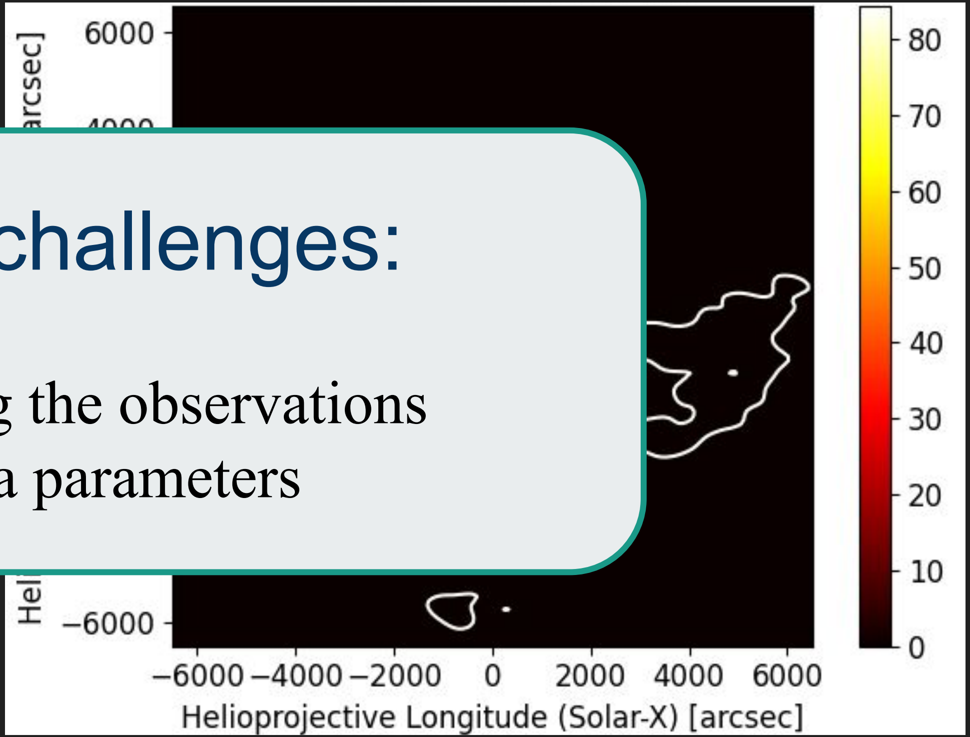
- Detection
- Understanding the observations
- Extract plasma parameters

Detection of the faintest GS emission at the highest heliocentric distance (8.3 $R_\odot$)

Kansabanik et al. 2023, ApJ 950 164

Faint GS Emission from Two Slow CMEs





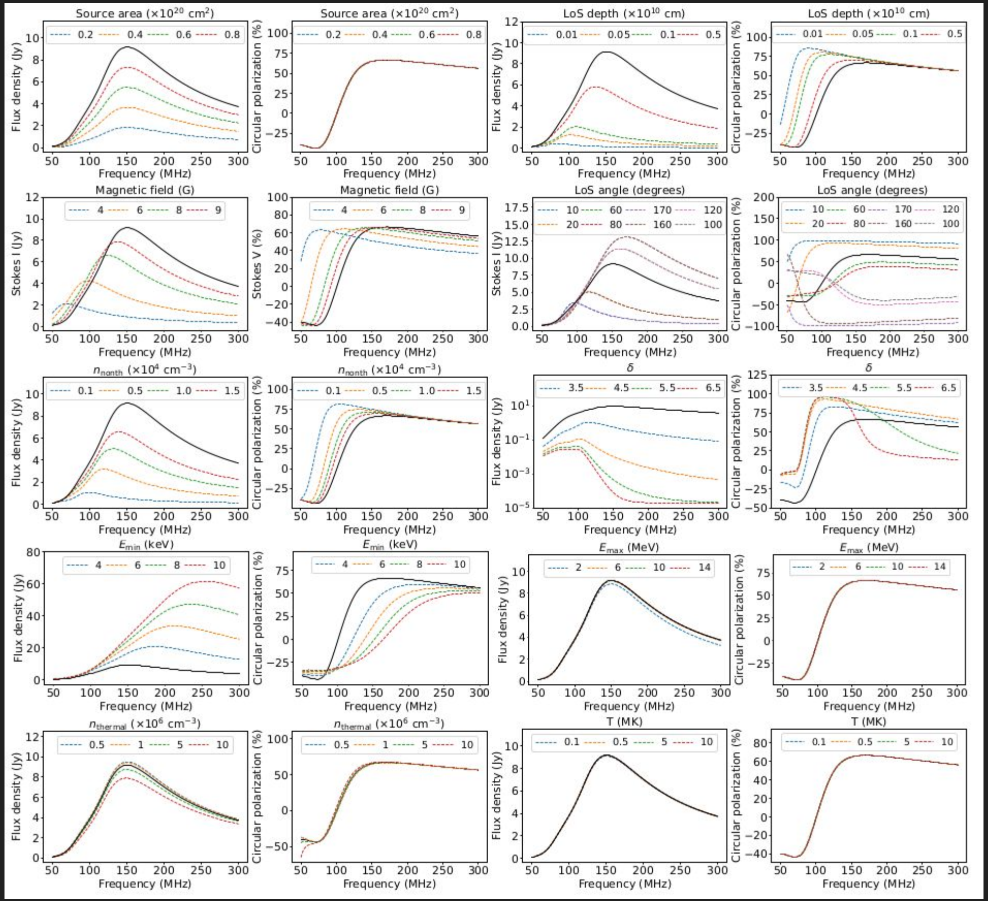
Major challenges:

- Detection
- Understanding the observations
- Extract plasma parameters

Detection of the faintest GS emission at the highest heliocentric distance (8.3 $R_\odot$)

Kansabanik et al. 2023, ApJ 950 164

GS Model Parameters — too many



- We used ultimate fast GS code developed by

  Kuznetsov & Fleishman 2021.

- We consider a single power-law distribution for non-thermal electrons

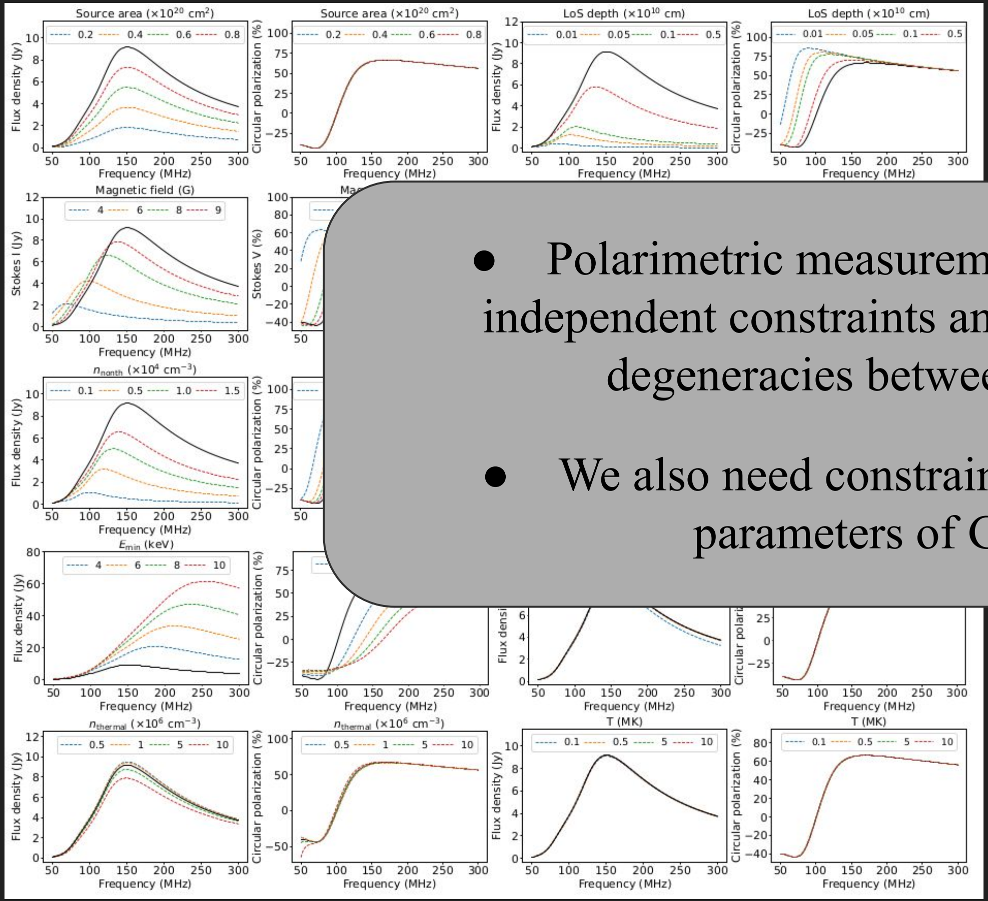
$$u(E) = N\,E^{-\delta}\ (E_{min} < E < E_{max})$$

Main assumption:

- Homogeneous medium
- Isotropic pitch-angle distribution

Kansabanik et al. 2023, ApJ 950 164

GS Model Parameters — too many

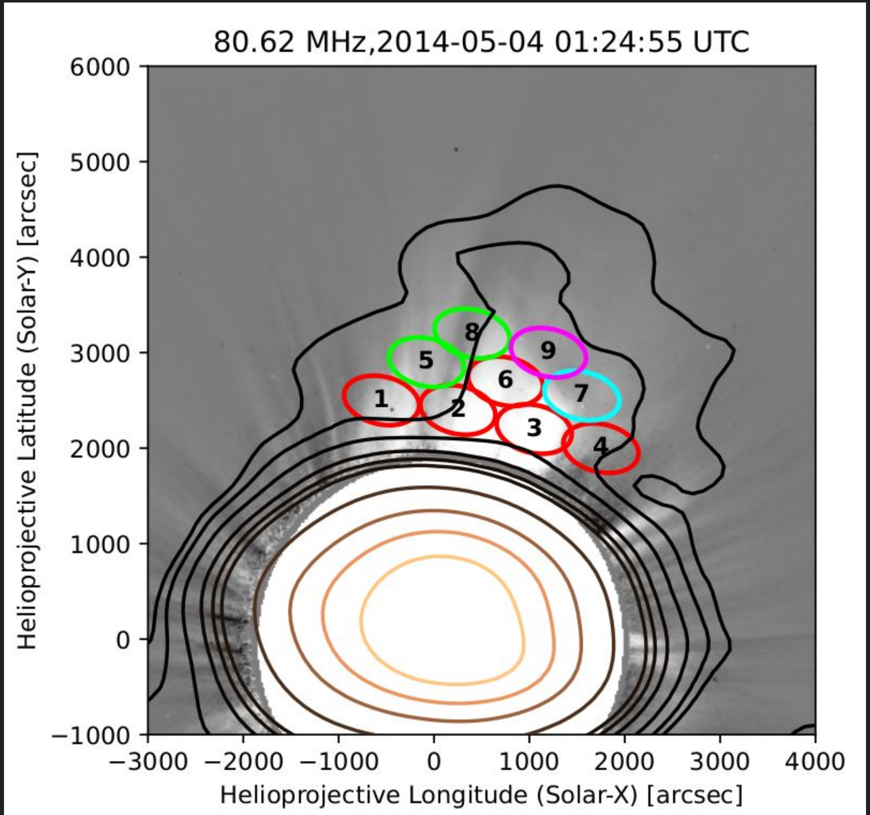


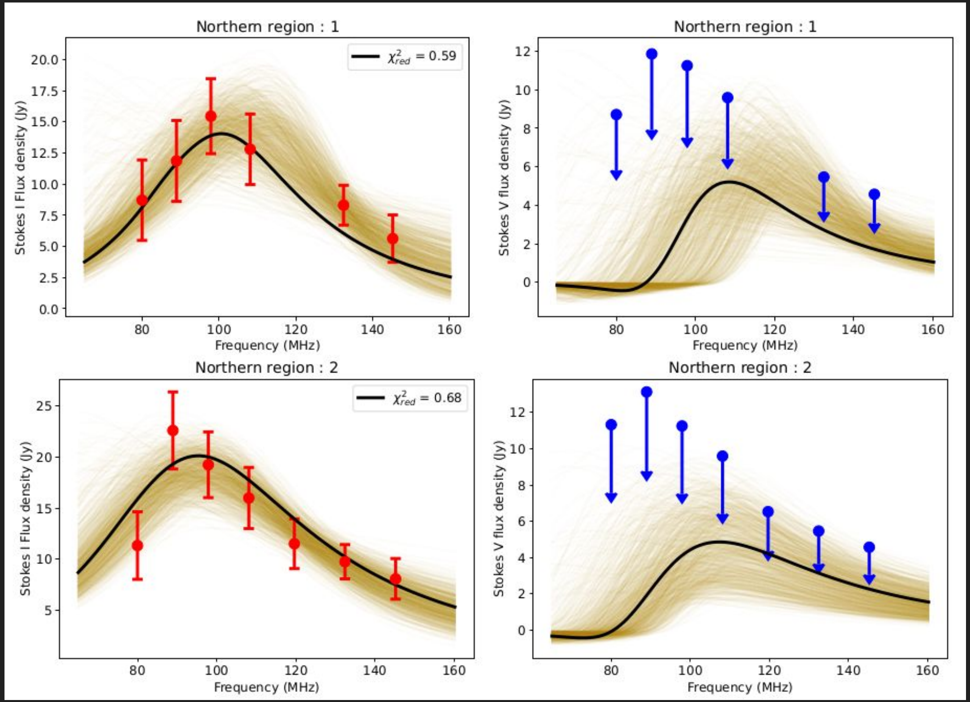
- Polarimetric measurements can provide independent constraints and break some of the degeneracies between parameters
- We also need constraints on geometric parameters of GS model

- We used fast numerical GS code developed by
  ...an 2021.
- ...ngle power-law ...non-thermal
- ...$E_{min} < E < E_{max}$)
- Homogeneous medium
- Isotropic pitch-angle distribution

Kansabanik et al. 2023, ApJ 950 164

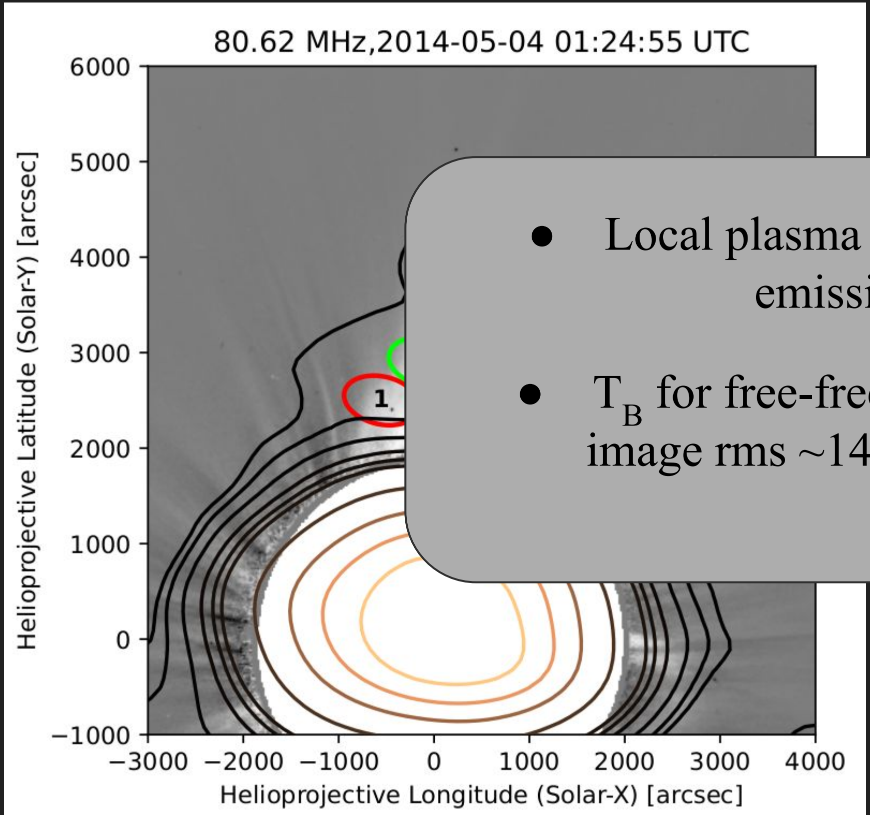
Spatially Resolved Modeling of Observed Spectra

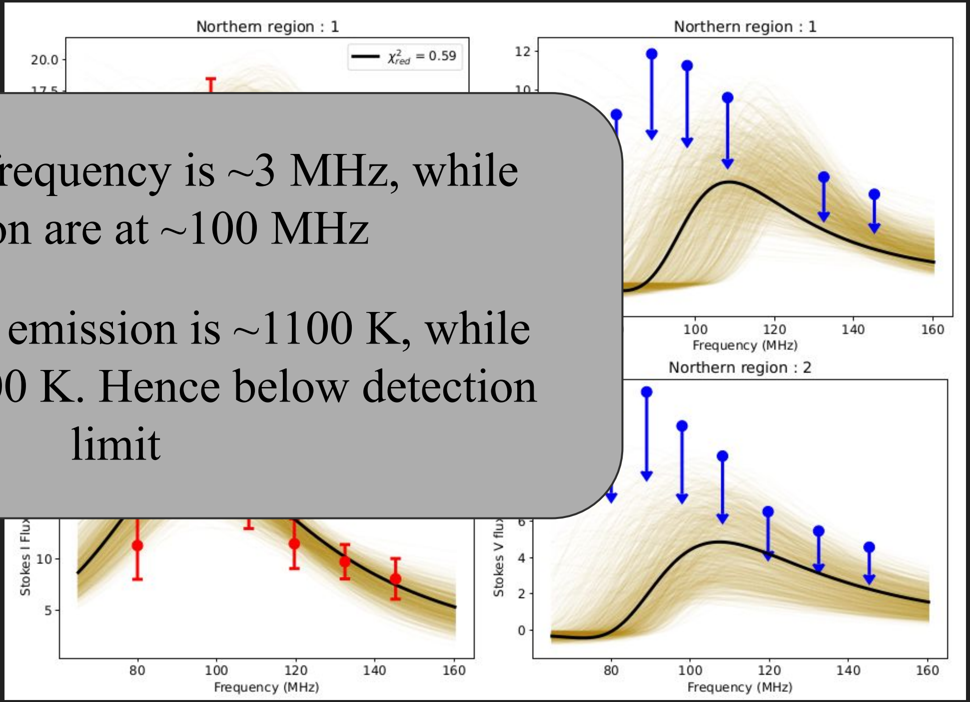




Kansabanik et al. 2023, ApJ 950 164

Spatially Resolved Modeling of Observed Spectra

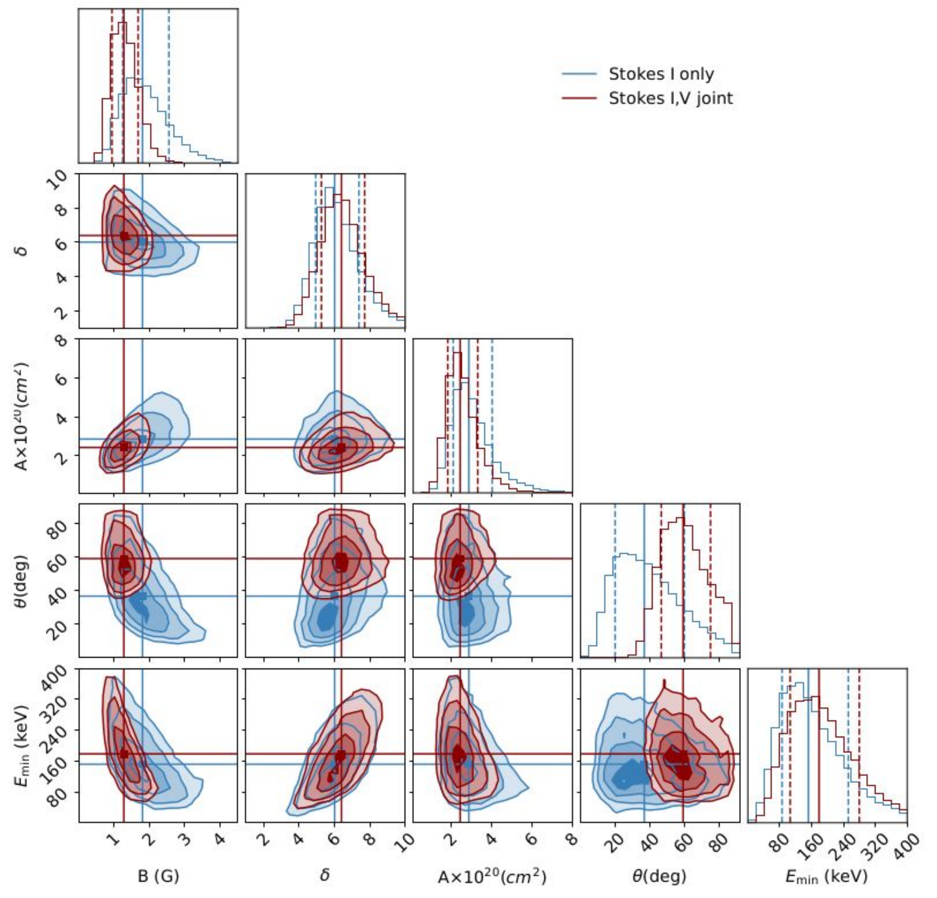




- Local plasma frequency is ~3 MHz, while emission are at ~100 MHz
- T_B for free-free emission is ~1100 K, while image rms ~1400 K. Hence below detection limit

Kansabanik et al. 2023, ApJ 950 164

Improved Robustness using Joint Stokes I and V Modeling



❖ Even upper limits on absolute Stokes V lead to tighter constraints on model parameters (upto 40% improvements).

❖ Joint Stokes I and V modeling allows us to fit more parameters

❖ Estimated GS model parameters

- Magnetic field strength (B)
- Area of emission (A)
- Non-thermal electron power-law index (δ)
- LoS angle with the magnetic field
- E_{min}
- LoS depth

Kansabanik et al. 2023, ApJ 950 164

Current Status

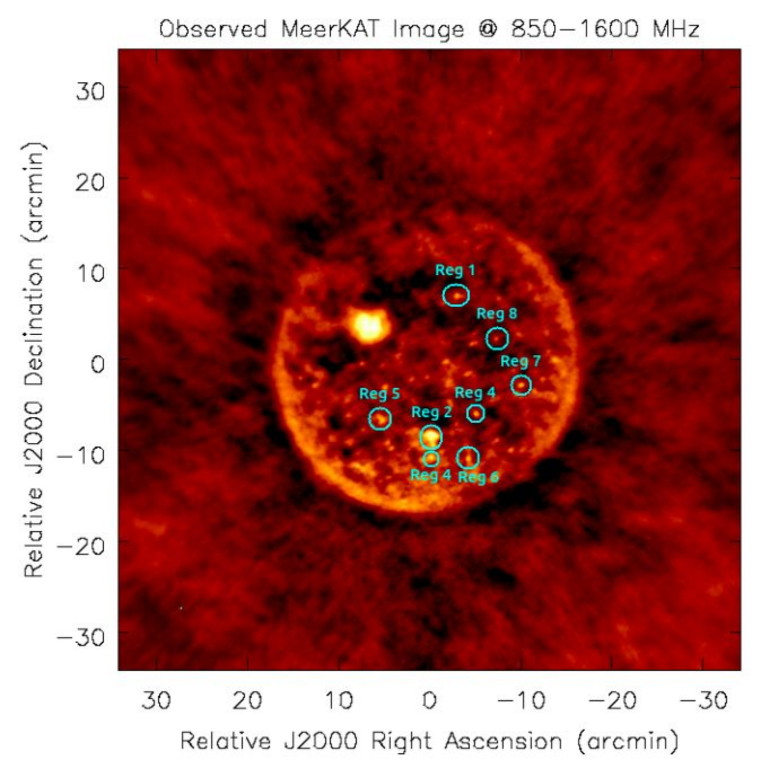
- Routine observations of GS emission from CME plasma are now possible.
  - Spectropolarimetric observations with the MWA (~100 CMEs observed with MWA in between 2014 to 2015 are currently being studied).
  - Future SKA observations.
- Focus now shifted towards the modeling of the observed spectrum.
  - Stokes V provides important constraints.
  - Multi-vantage point white light observations are necessary as well.

Future Works

- Individual regions are considered independent.
- No attempt has been made to model the GS emission of the CME as a single large-scale structure.
- Forward modeling based approach can be explored.
- High-dynamic-range spectroscopic snapshot imaging at higher frequencies (>300 MHz) is required to study CME GS emission at lower coronal heights.

Future Works

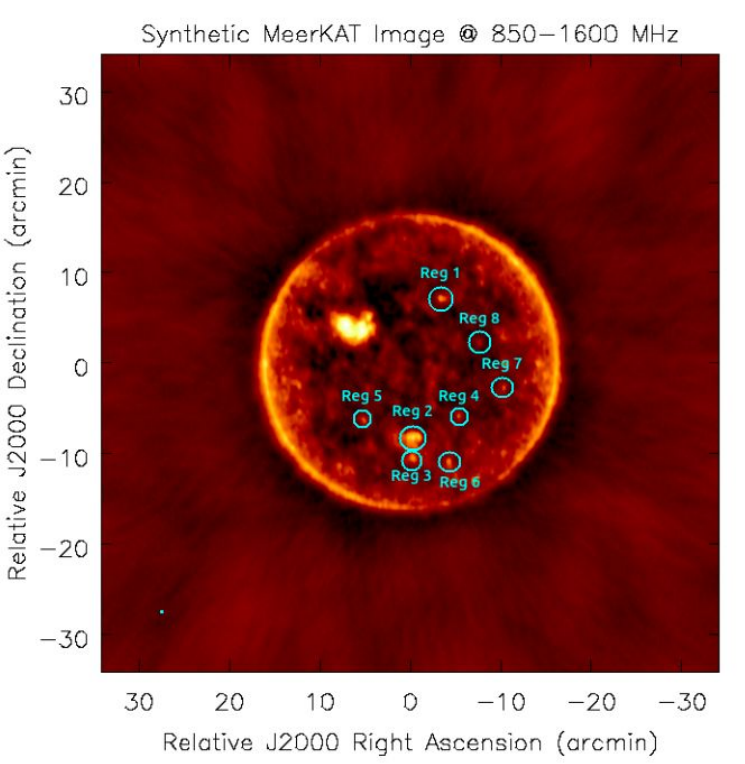
- Individual regions are considered independent.
- No attempt has been made to model the GS emission of the CME as a single large-scale structure.
- Forward modeling based approach can be explored.
- High-dynamic-range spectroscopic snapshot imaging at higher frequencies (>300 MHz) is required to study CME GS emission at lower coronal heights.

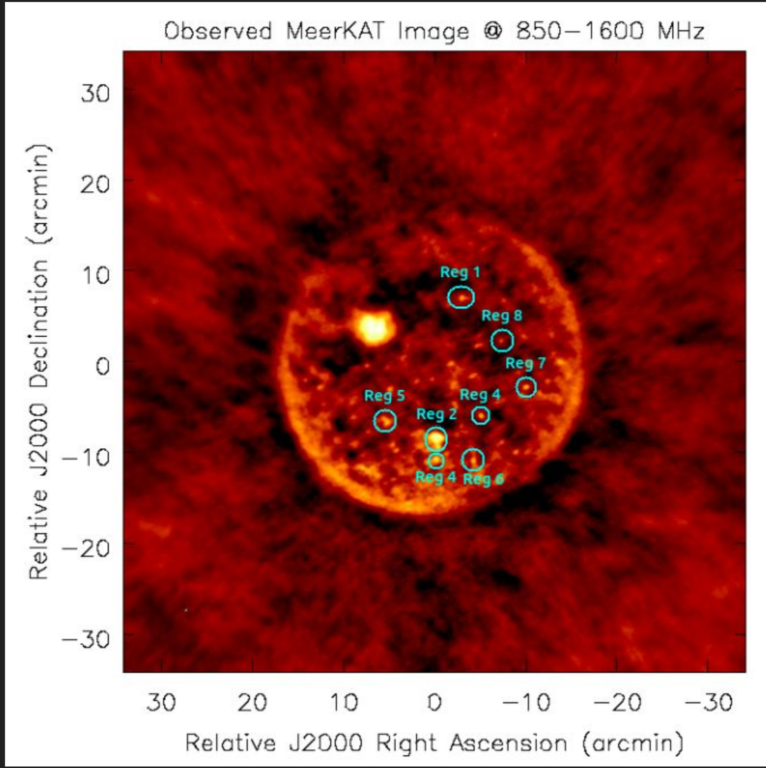


MeerKAT (550 MHz - 3.5 GHz) is the ideal instrument for this purpose

Kansabanik et al. 2023, Submitted in arXiv, will appear tomorrow

Future Works



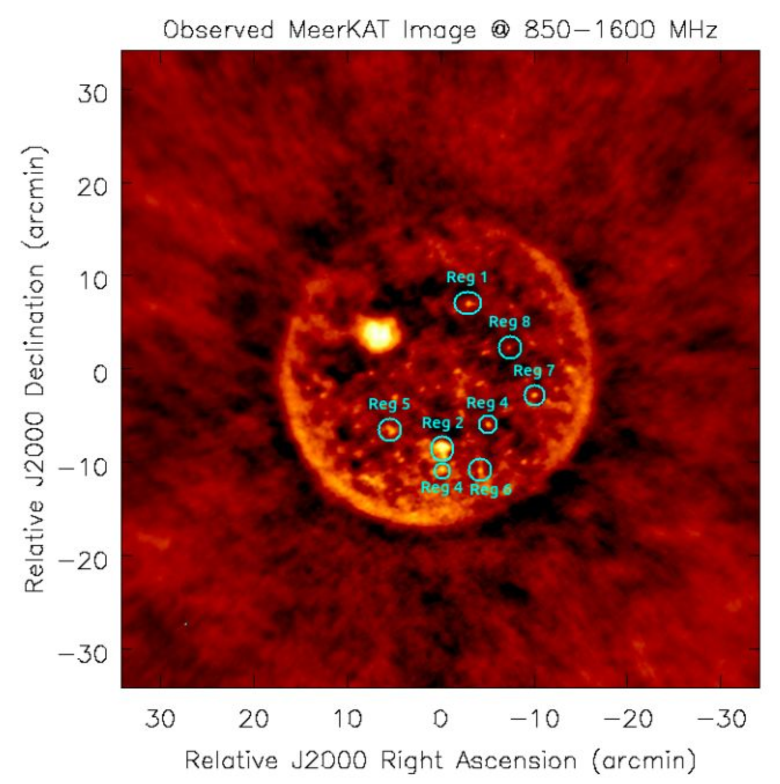


MeerKAT (550 MHz - 3.5 GHz) is the ideal instrument for this purpose

Kansabanik et al. 2023, Submitted in arXiv, will appear tomorrow

Future Works

- Individual regions are considered independent.
- No attempt has been made to model the GS emission of the CME as a single large-scale structure.
- Forward modeling based approach can be explored.
- High-dynamic-range spectroscopic snapshot imaging at higher frequencies (>300 MHz) is required to study CME GS emission at lower coronal heights.



MeerKAT is the ideal instrument for this purpose