Estimating plasma parameters of solar coronal mass ejections at higher coronal heights using high fidelity low-frequency radio images

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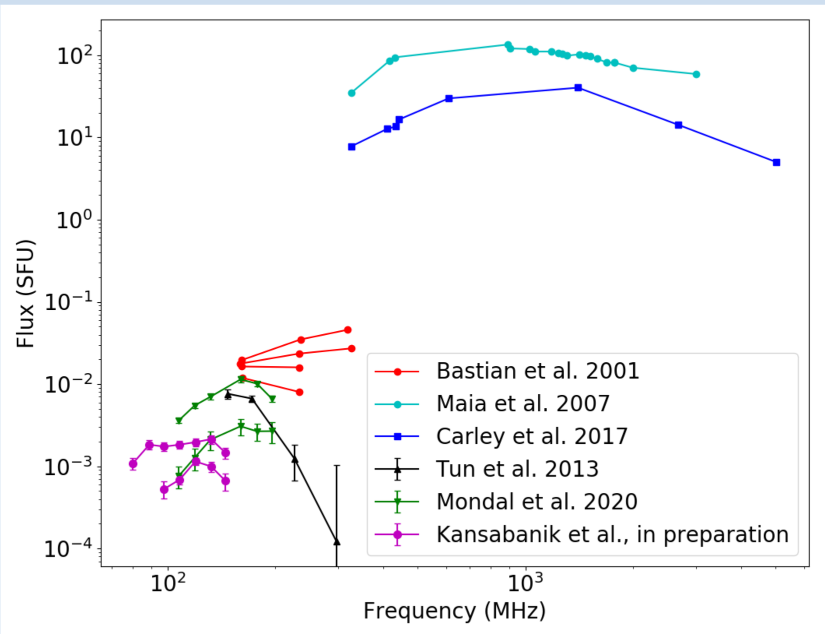
Introduction

- Coronal mass ejections (CMEs) are large scale eruptions of plasma and magnetic fields from the Sun and energised by coronal magnetic field.
- The dynamics and geo-effectiveness of the CME are governed by CME magnetic field, but magnetic field inside CME plasma remained hard to measure.
- Remote measurement of magnetic field inside CME plasma is possible through modelling the spectrum of the gyrosynchrotron emission generated by mildly relativistic electrons interacting with CME magnetic field.
- This gyrosynchrotron emissions are very faint compared to active emission usually present during CME time and even compared to quiet Sun.
- Using the recently available high dynamic range images using Murchison Widefield Array (MWA; Tinagay et al. 2013), it seems now routinely possible to detect this gyrosynchrotron emission for estimating CME plasma parameters.

Previous & Present work

A handful of studies have manager to detect these faint gyrosynchrotron emissions.We detected much fainter emissions at much higher coronal heights.



Previous works:

- Bastian et al. 2001 first detected the gyrosynchrotron emission from CME plasma upto 2.8 $R_\odot$ and demonstrated that it is possible to estimate the local magnetic field strength and energetic particle distribution inside CME plasma.

Present work:

- High fidelity and high dynamic range images from MWA allow us to detect faint gyrosynchrotron emission at all instances where we attempted.
- We detected radio emission from CME upto 4.73 $R_\odot$ in one event (Mondal et al. 2020) and upto 8.3 $R_\odot$ in another event (Kansabanik et al., in prep).
- Good spectral sampling provided by MWA has enabled more detailed modelling than has previously been possible.

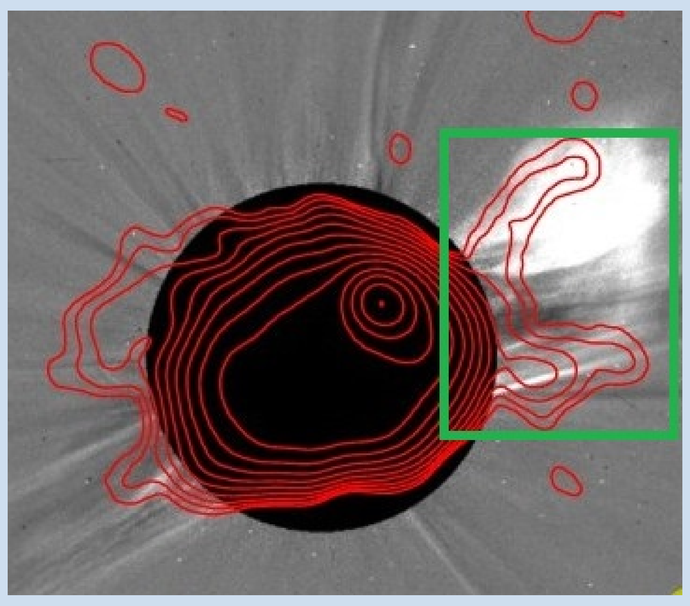
Summary & Future work

- Using the new generation instrument along with novel calibration and imaging allow us to detect the faint gyrosynchrotron radio emission from the CME plasma where we have attempted so far.
- Spatially resolved spectra with good spectral coverage allow us to estimate CME plasma parameters at different spatial locations.
- We are currently working on polarimetric calibration and imaging, which will significantly improve the robustness of the gyrosynchrotron modelling.
- Together this implies that, this method is very promising to estimate CME plasma parameters and magnetic fields with remote observations routinely, which will significantly improve space-weather prediction.

Brief overview of the observation and data analysis

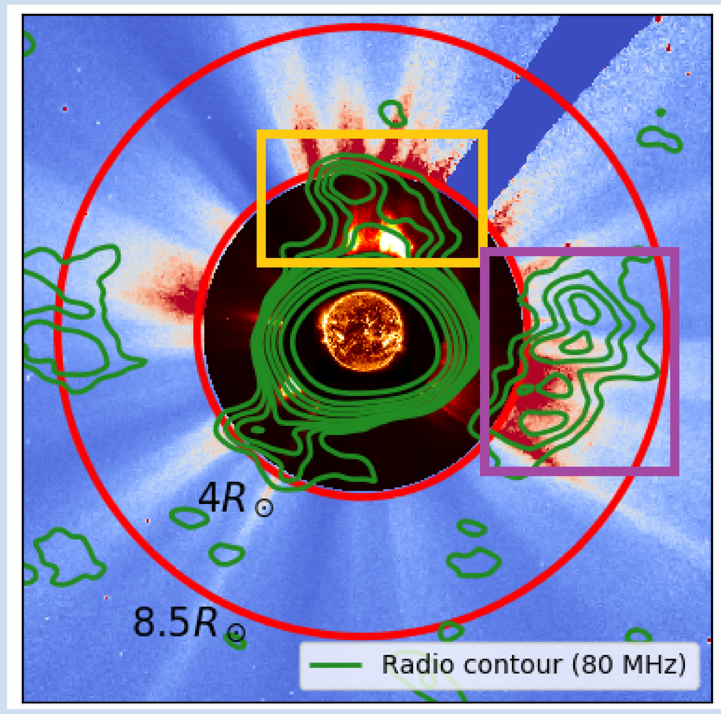
- MWA is a new generation radio interferometric array consists of 128 antenna elements operating at 80−300 MHz.
- It has a dense core which provide good sensitivity and fidelity at large scale emissions at highest time and frequency resolution.
- Novel interferometric calibration and imaging algorithm (AIRCARS; Mondal et al. 2019) allow to routinely produce high dynamic range and high fidelity radio images.
- Typical dynamic range of the images used in these study is $\sim 4000 - 13000$, which allow to detect faint gyrosynchrotron emission from the CME plasma.
- We have analysed two CME events:
  1. 2015 November 04, 03:00-03:35 UTC, 2. 2014 April 05, 01:23-01:27 UTC

Radio emission :Event 1



- Radio emission averaged over 108−145 MHz is shown by red contours overlaid on LASCO C2 base difference image.
- Lowest contour level is 0.02% of the peak and subsequent contours are multiple of 2.
- The extended radio emission upto 4.73 $R_\odot$ inside the green box corresponds to the radio emission from the CME plasma spatially coincide with white-light CME.

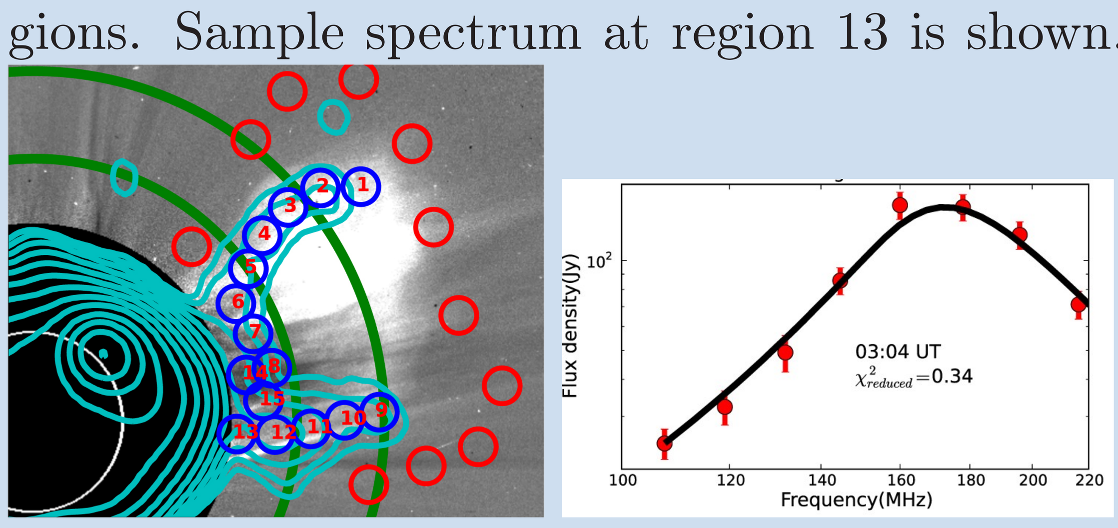
Radio emission :Event 2



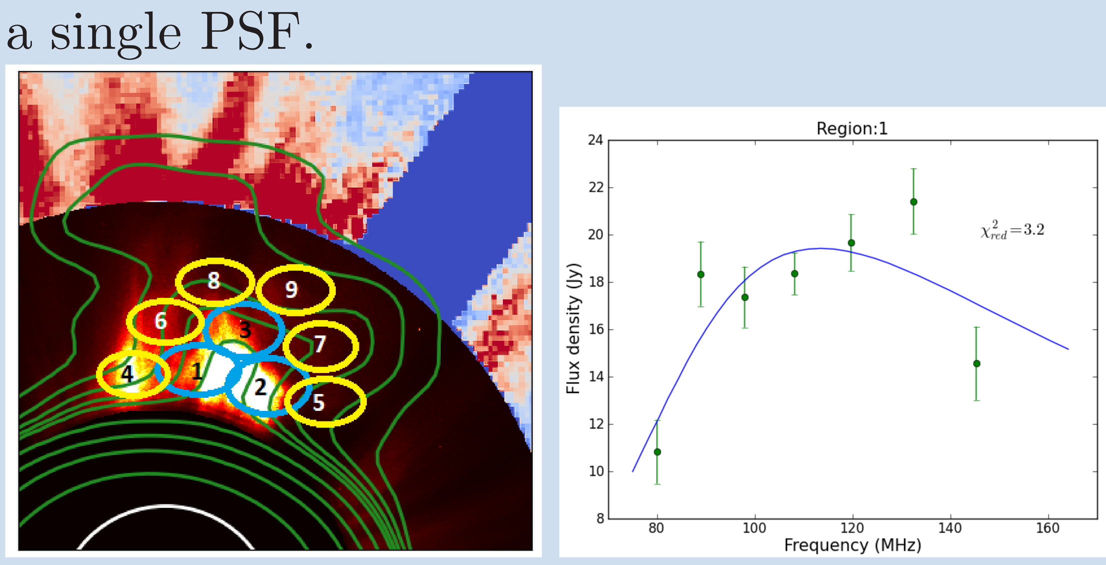
- Radio emissions at 80 MHz is shown by green contours. Lowest contour is at 0.2% of the peak and increases in multiple of 2.
- Radio emissions from two CMEs are detected; one in northern part (inside yellow box) and another at south-western part upto 8.3 $R_\odot$ (inside purple box).

Observed & modelled spectra

Event 1 : Spectra are extracted in spatially resolved manner in blue PSF sized regions. Sample spectrum at region 13 is shown.



Event 2: Spectrum of region 1 of the northern CME is shown. Observed spectra have multiple peak suggesting multiple emitting region inside a single PSF.



Gyrosynchrotron modelling

- Gyrosynchrotron model has 9 independent parameters, some of them are independently estimated or fixed at some physically motivated values.
- E.g, thermal electron density estimated from white-light coronagraph images and line of sight depth fixed at $\sim 10^{10}$ cm which is close to size of the PSF.
- We fit the magnetic field strength (B), non-thermal electron power-law index (p) and area of emission (A) using numerical code by Fleishman Kuznetsov 2010.

Estimated parameters

- **Event 1:** $B = 12.6 \pm 0.4$G (2.2 $R_\odot$); $p = 4.4 \pm 0.4$; $A = 193 \pm 44\ Mm^2$
- **Event 2:** $B = 5.1 \pm 1.1$G (2.2 $R_\odot$); $p = 2.5 \pm 0.2$; $A = 3 \pm 1\ Mm^2$
- Smaller emission area suggests either smaller filling factor of non-thermal electrons or presence of magnetic knots (Karpen et al. 2012).