Using radio observations to constrain magnetic fields in the CME plasma

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Radio Stars in the Era of New Observatories
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Collaborators

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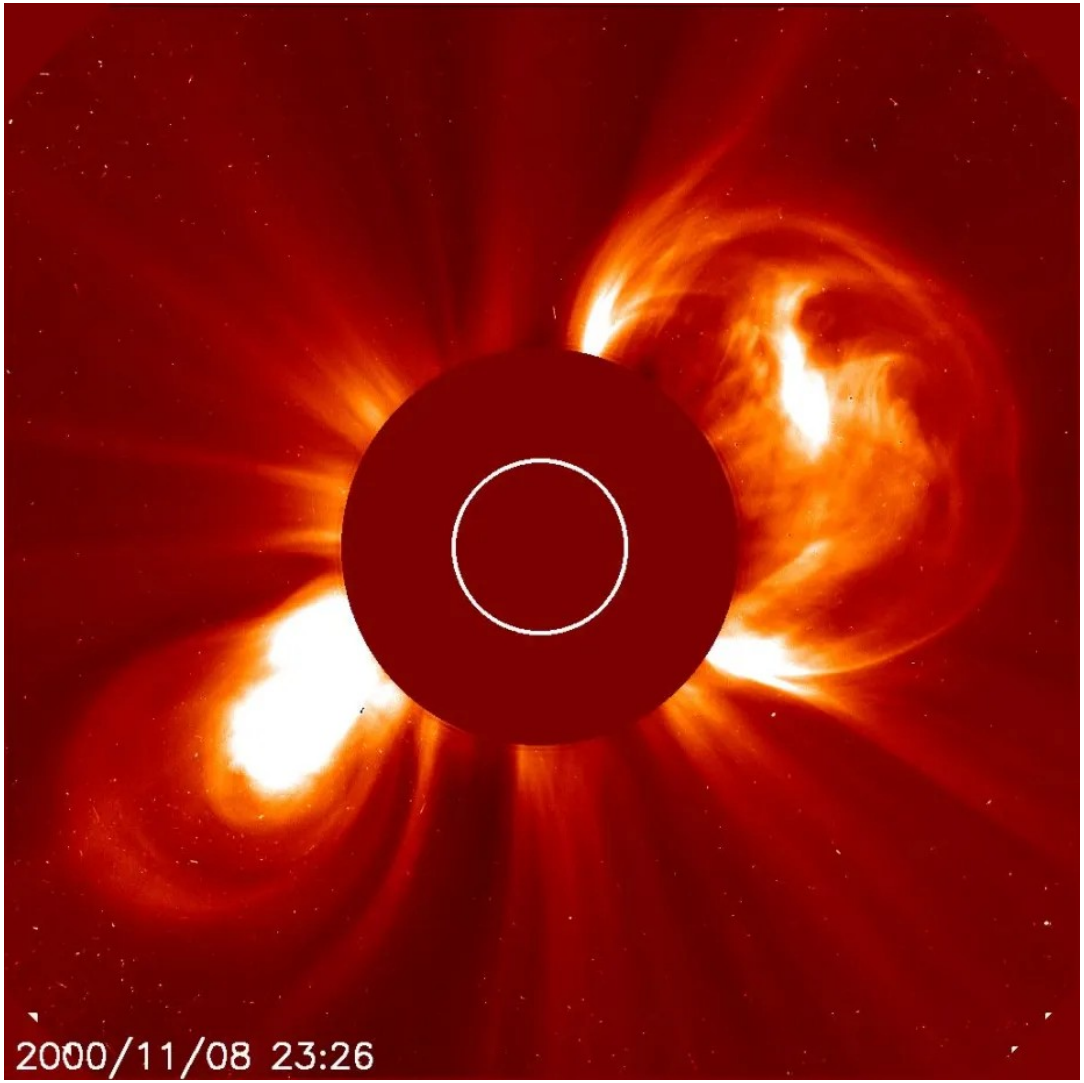
What are CMEs?



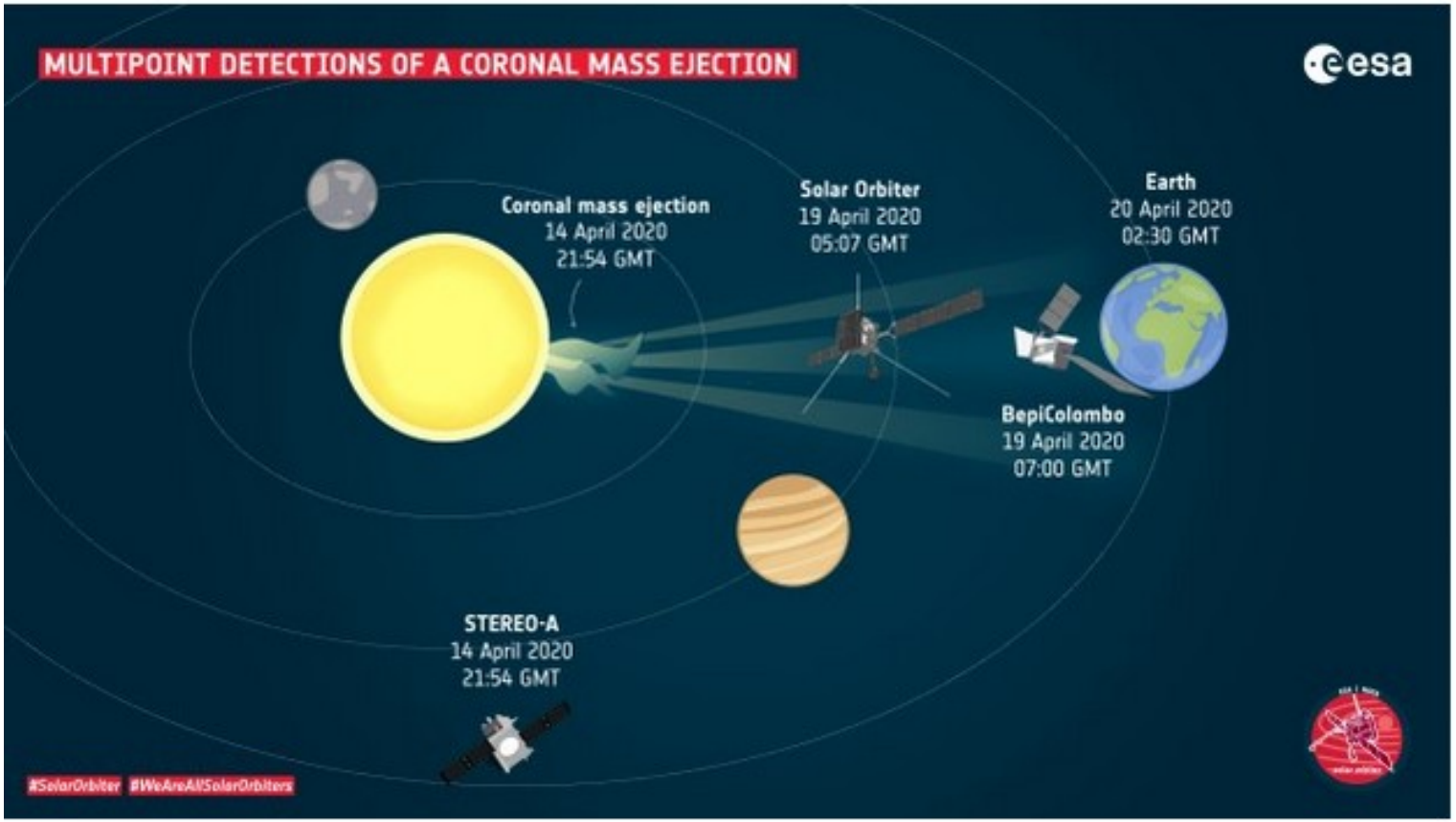
Credit: LASCO C2/ SOHO; ESA/NASA

Importance of magnetic fields

Major driver of space weather.

- The CME magnetic field is a primary determinant of its geoeffectiveness

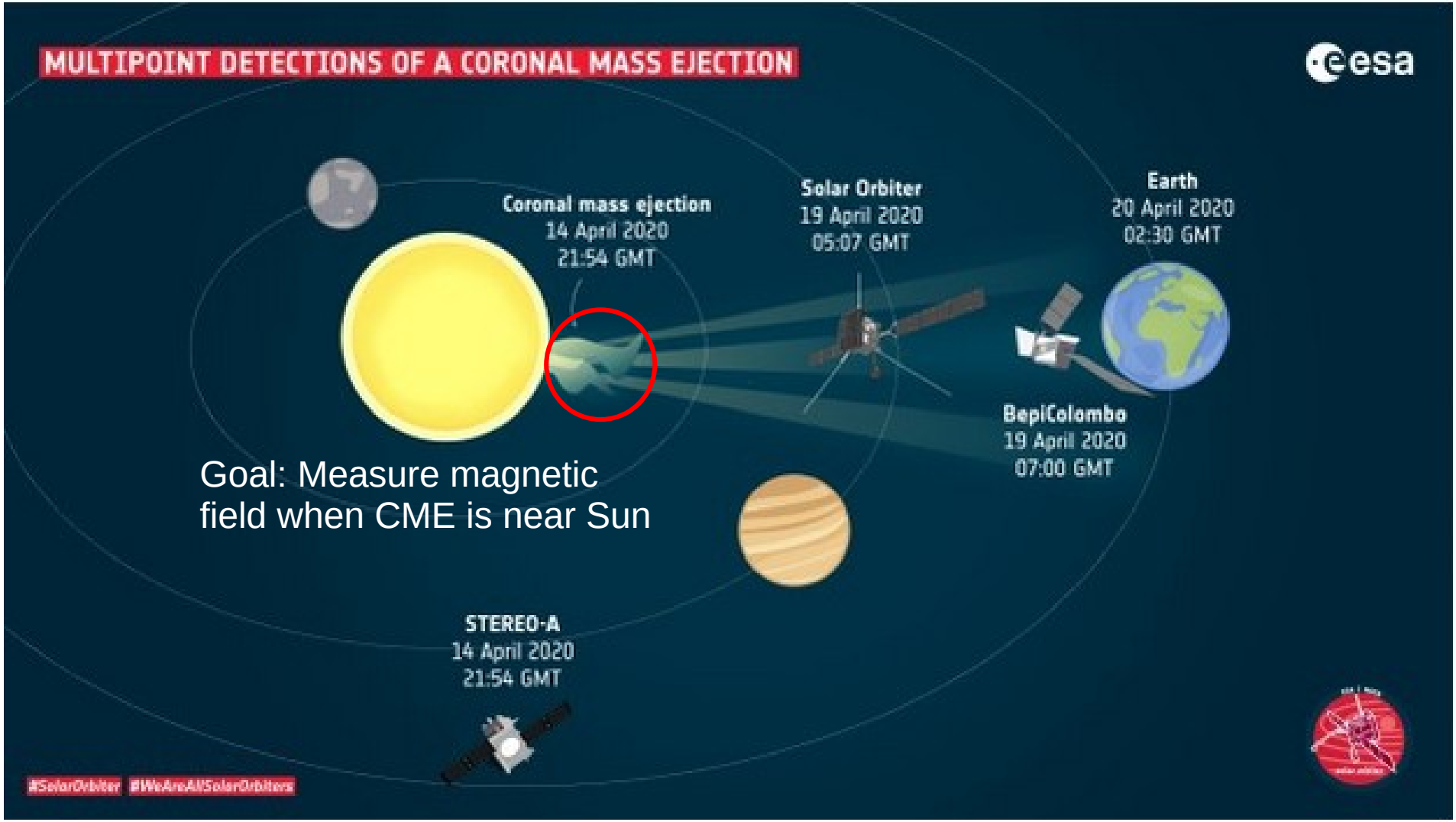
Current status



Can only be measured routinely when CME is close to Earth.

- Very little time for predicting the geo-effectiveness

Current status



Goal: Measure magnetic field when CME is near Sun

Measuring the CME magnetic field

- Remote sensing methods are essential to improve space weather predictions.
  - Radio techniques stand out due to their sensitivity to magnetic field and capability to provide spatially resolved maps of it.

Radio techniques

- Using Faraday Rotation of linearly polarised emission from background sources/artificial satellites.
- Gyrosynchrotron/gyroresonance emission from CMEs
- Split band Type II, circular polarisation from Type IVs etc.

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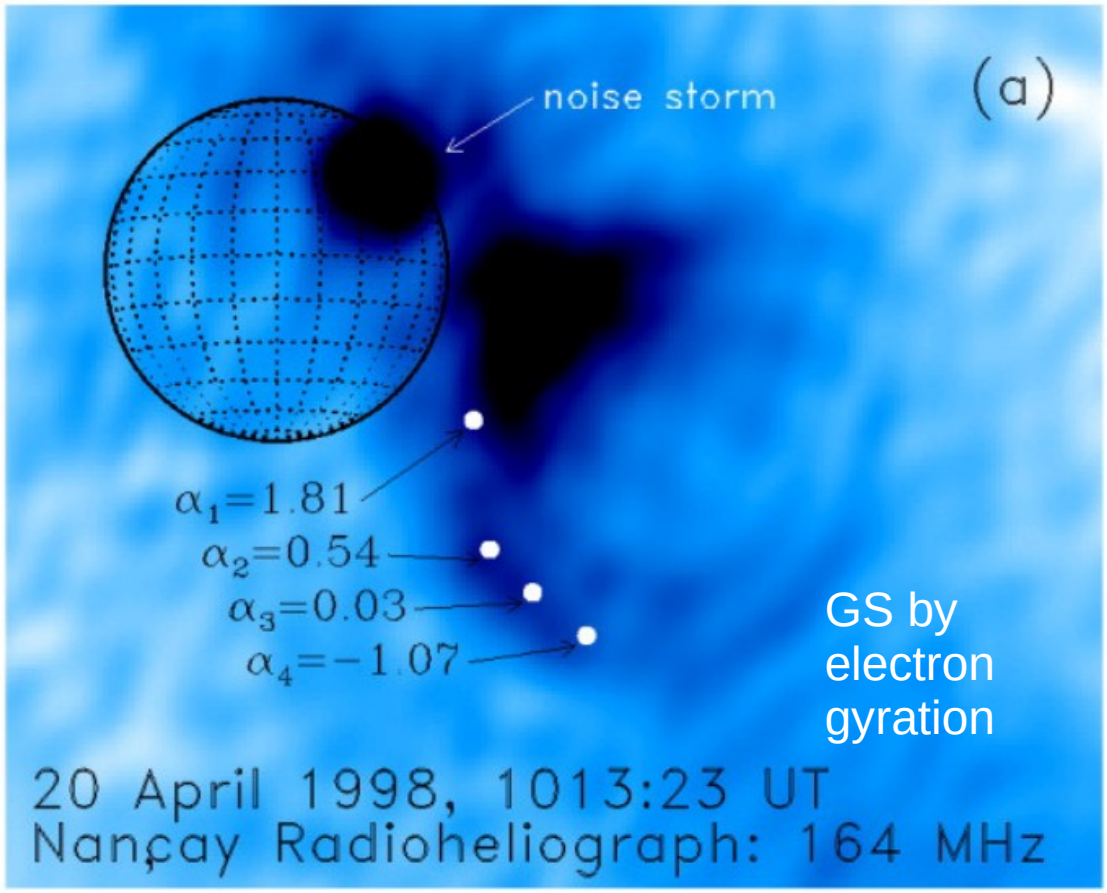
CME Gyrosynchrotron emission

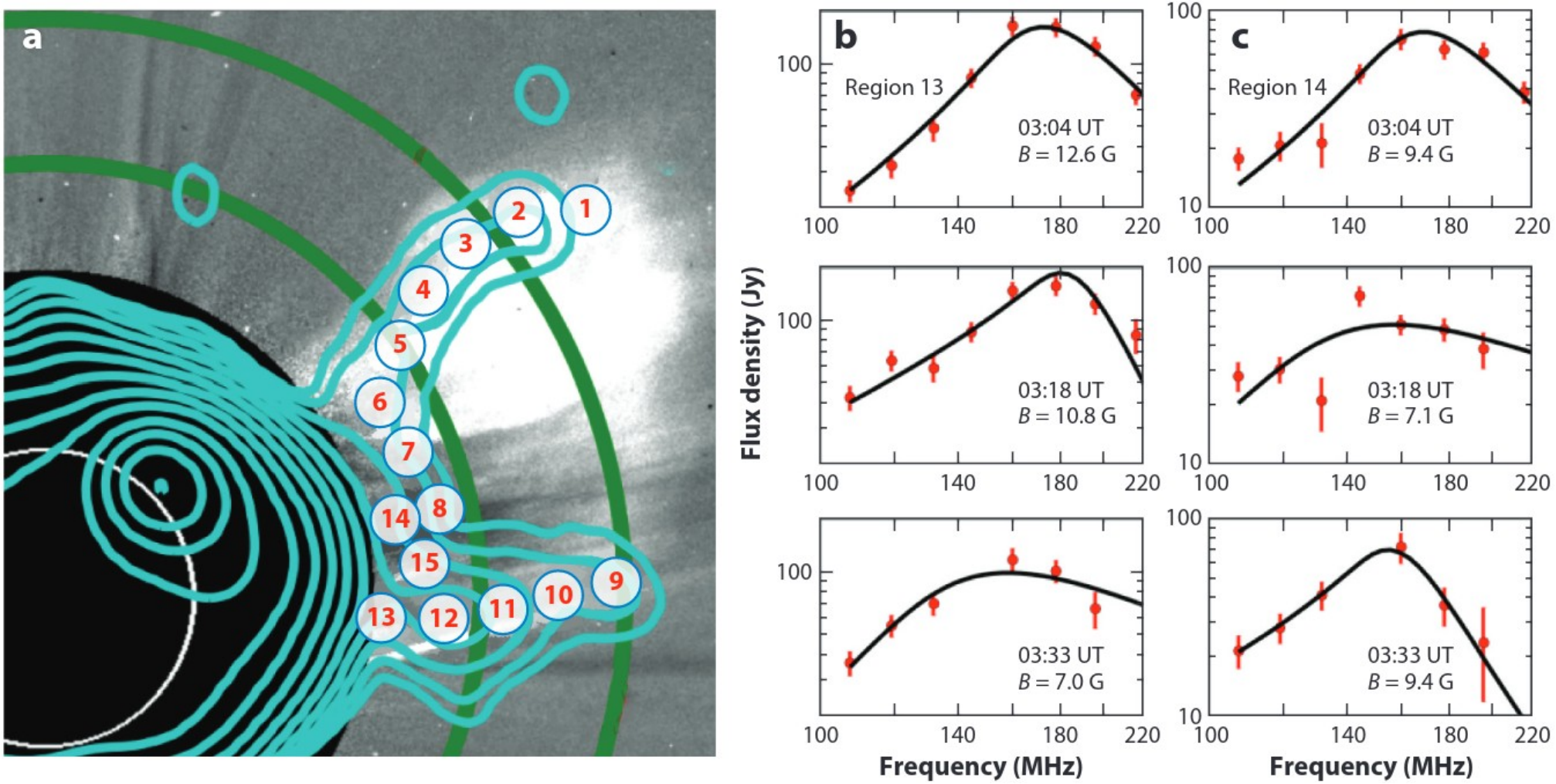
- Electrons get accelerated at the flare-site or by the shocks produced by the CME.
- Gyrate in the CME magnetic field and emit gyrosynchrotron emission.

Fig. 2. from The Coronal Mass Ejection of 1998 April 20: Direct Imaging at Radio Wavelengths
Bastian et al. 2001 ApJL 558 L65 doi:10.1086/323421
https://dx.doi.org/10.1086/323421



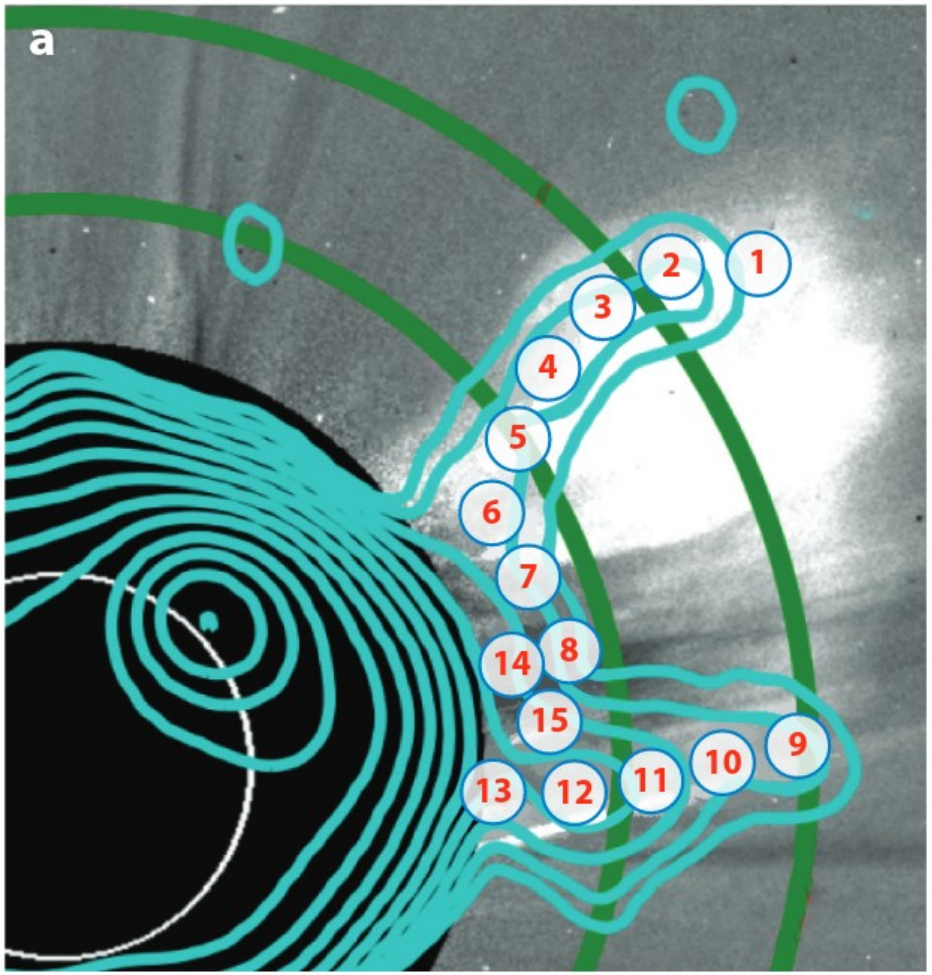
- Emission was reported from a total of 3 CMEs between 2001-2020.
- All of them were highly energetic CMEs, with speeds exceeding 1000 km/s.
    - Rare
    - can we really say that we can use gyrosynchrotron emission to measure the CME magnetic field regularly?

- The scenario changed after 2020.
  - High surface brightness sensitivity and excellent spectroscopic snapshot PSF of MWA
  - Innovative calibration strategies developed to bring out the faintest of emissions (Mondal et al. 2019, Kansabanik et al. 2022, 2023)

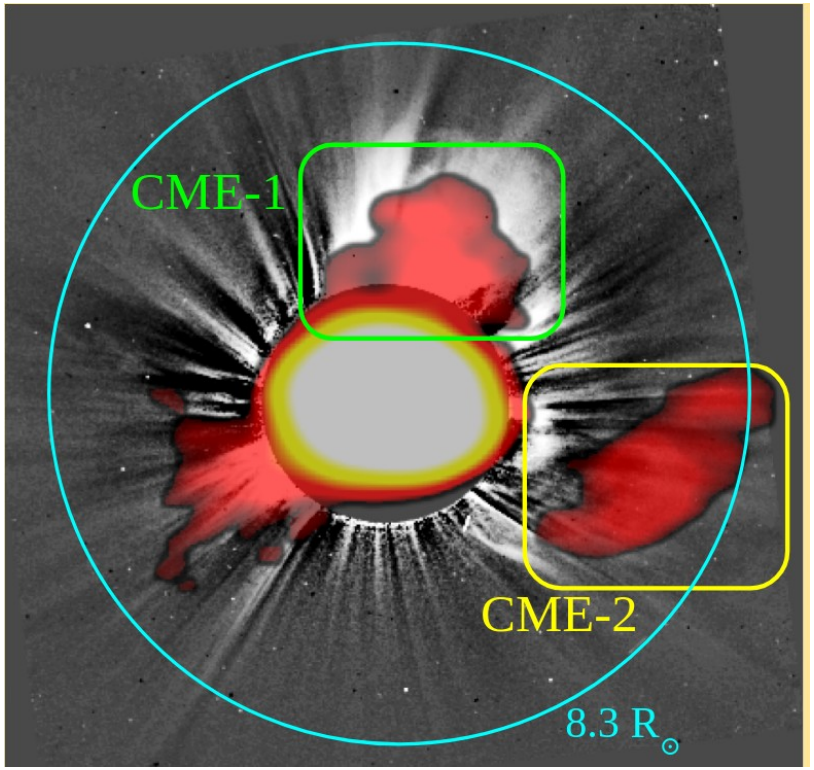


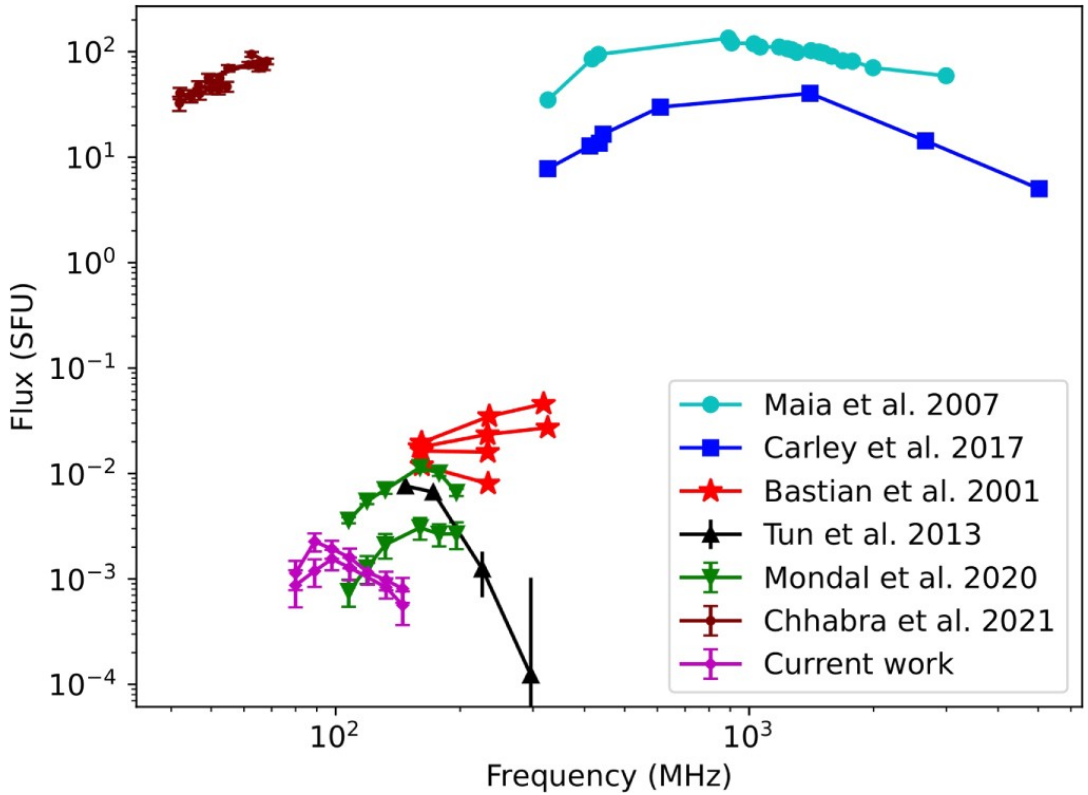
Mondal et al. 2020

- First detection from a weak and rather regular CME.
- Speed ~400 km/s



2023-2024





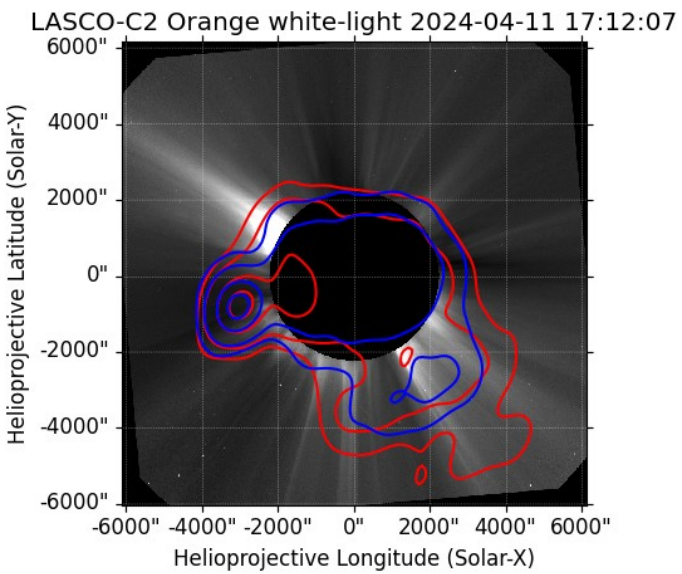
Kansabanik et al. 2023

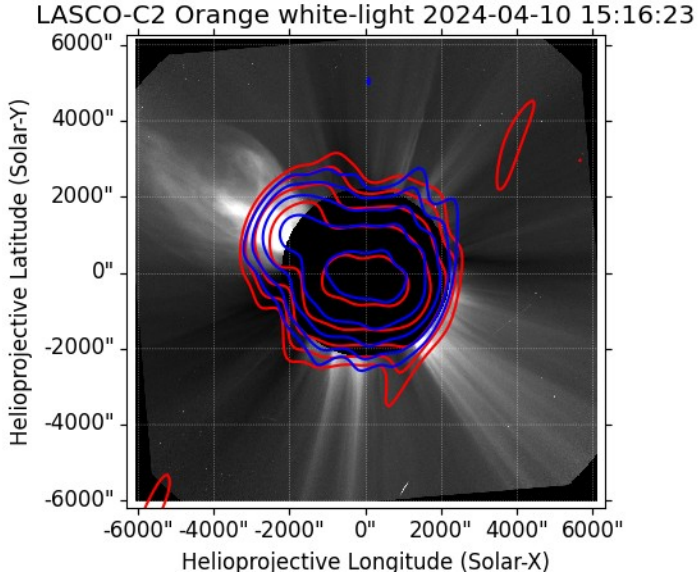
OVRO-LWA

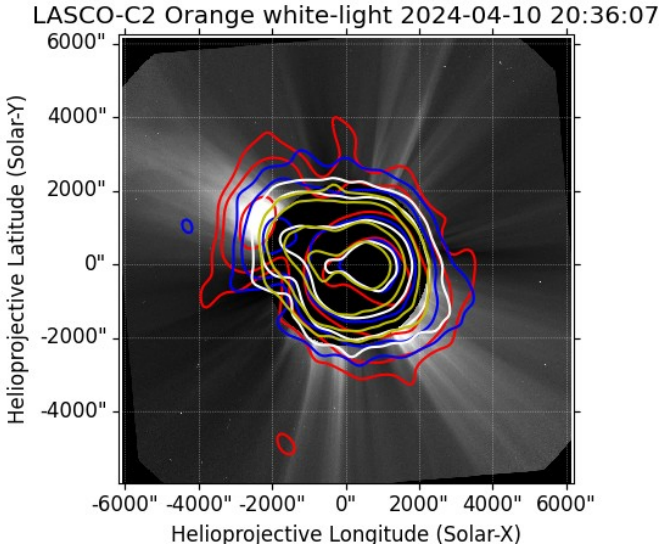
- Owens Valley Radio Observatory Long Wavelength Array
- All sky imager operating in the 12-85 MHz range
- 352 dipoles spread over an area of 2.5 km.

- Solar-dedicated observing modes.
  - Pipeline producing multi-frequency images with low latency
- Can now detect incoherent emission from CMEs regularly

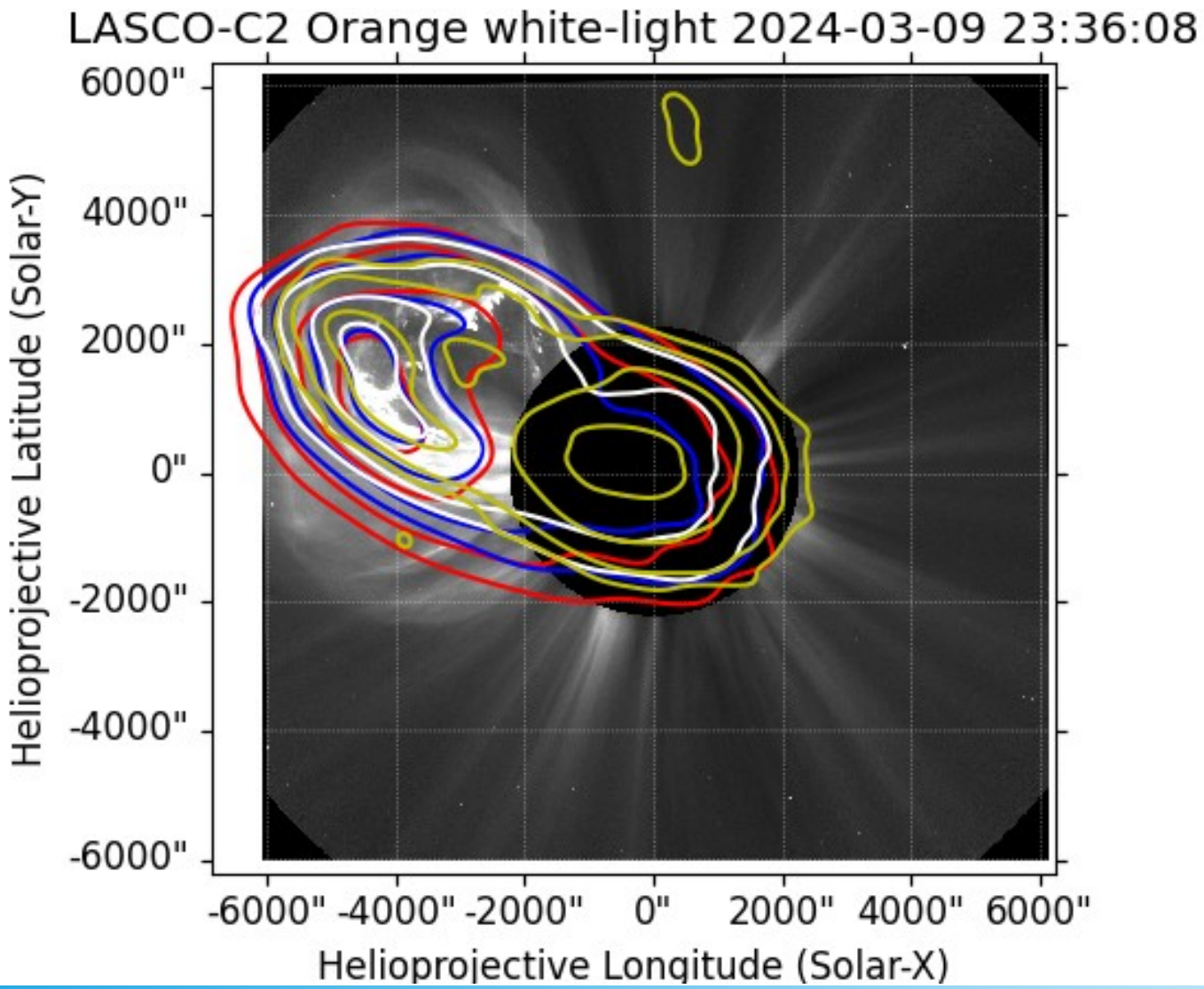
CMEs detected last week

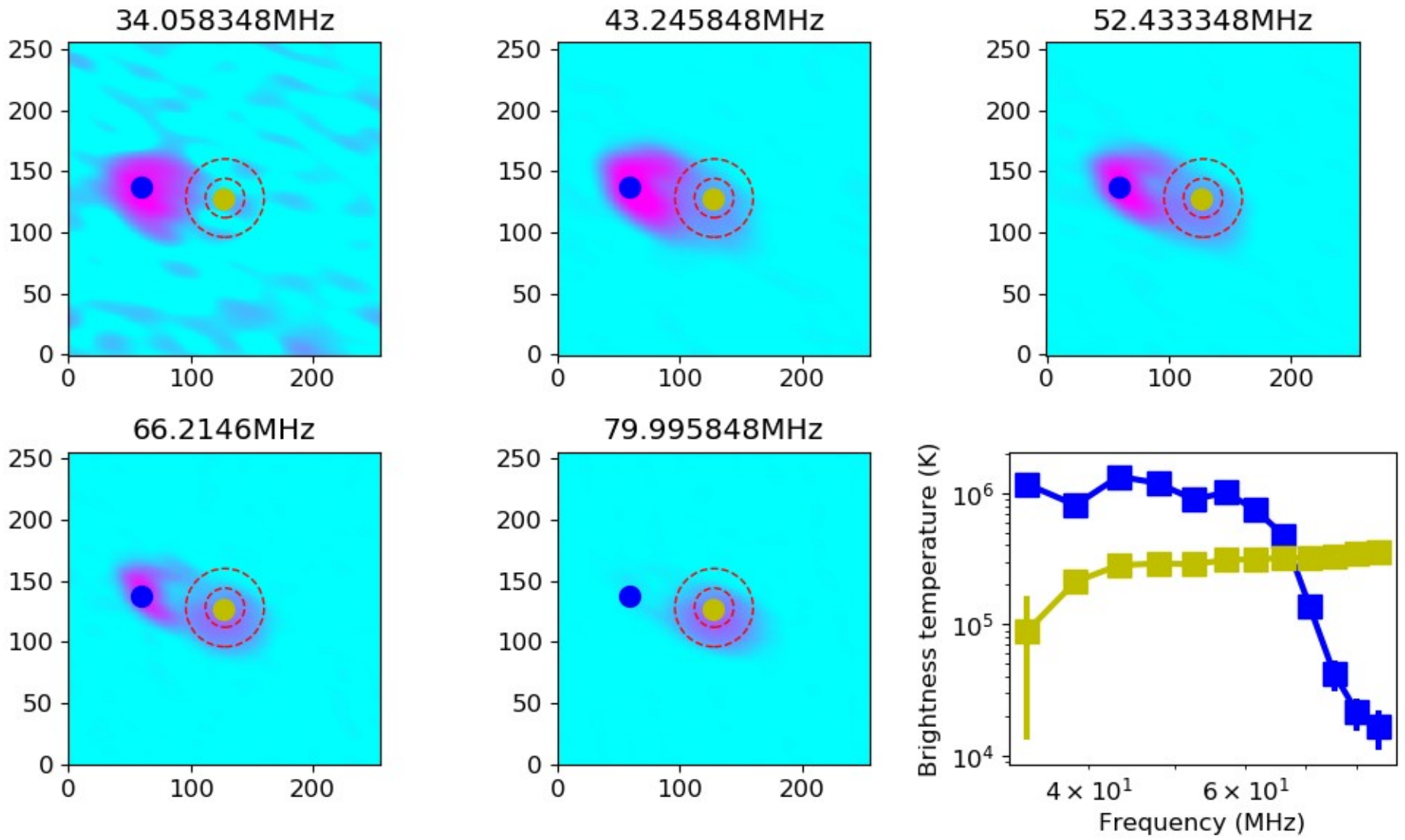






Discovery by OVRO-LWA




34.058348MHz
43.245848MHz
52.433348MHz
66.2146MHz
79.995848MHz
250
200
150
100
50
0
0
100
200
Brightness temperature (K)
10^6
10^5
10^4
4×10^1
6×10^1
Frequency (MHz)

What’s in the future?

- Low latency CME diagnostics using radio data
- Tracking the magnetic field energy from the low corona to the interplanetary space

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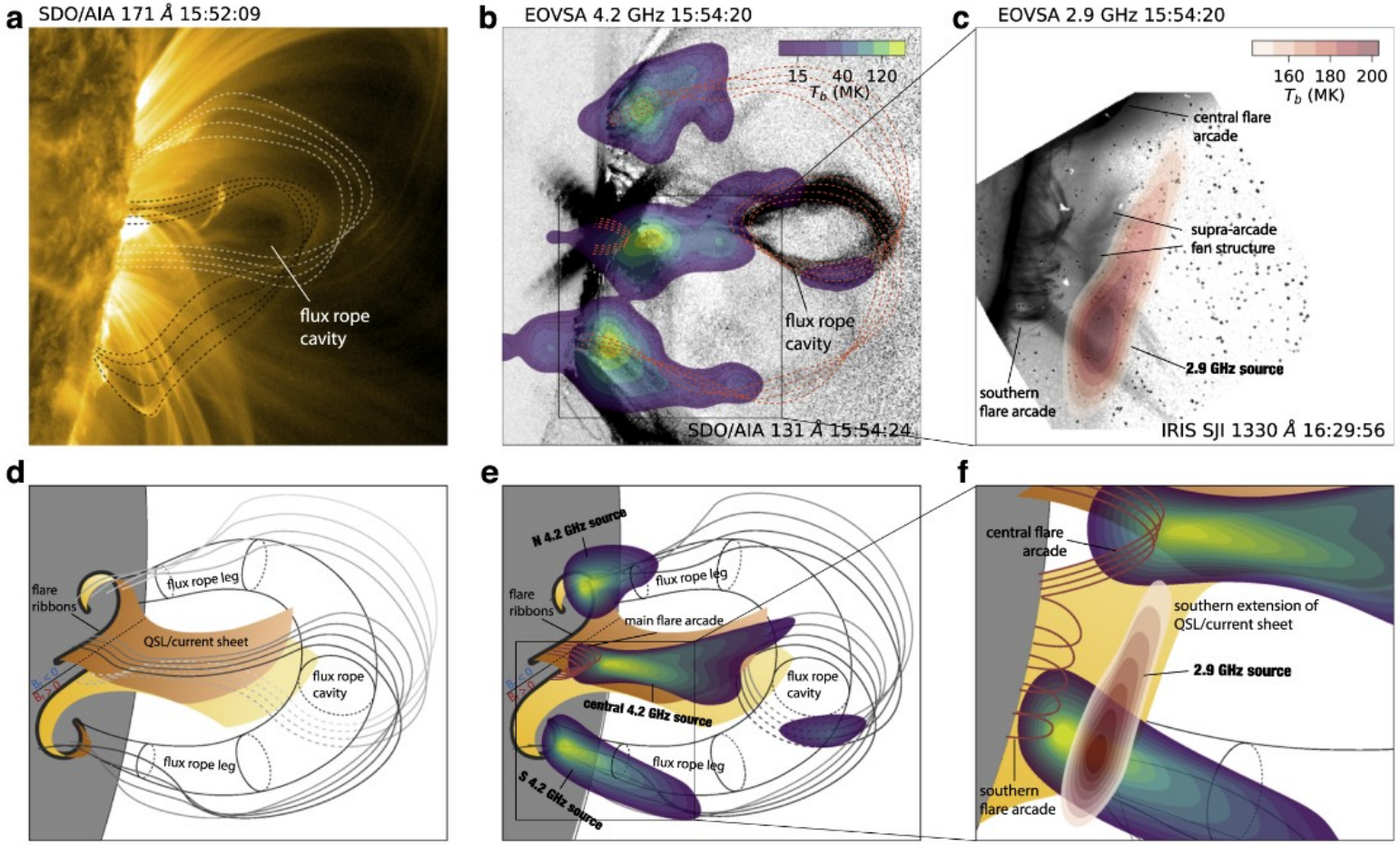
Magnetic field in low corona

Figure 5. from Microwave Spectral Imaging of an Erupting Magnetic Flux Rope: Implications for the Standard Solar Flare Model in Three Dimensions

null 2020 APJL 895 L50 doi:10.3847/2041-8213/ab901a
https://dx.doi.org/10.3847/2041-8213/ab901a



EOVSA can measure the magnetic field in the low-corona.

Severely dynamic range limited.

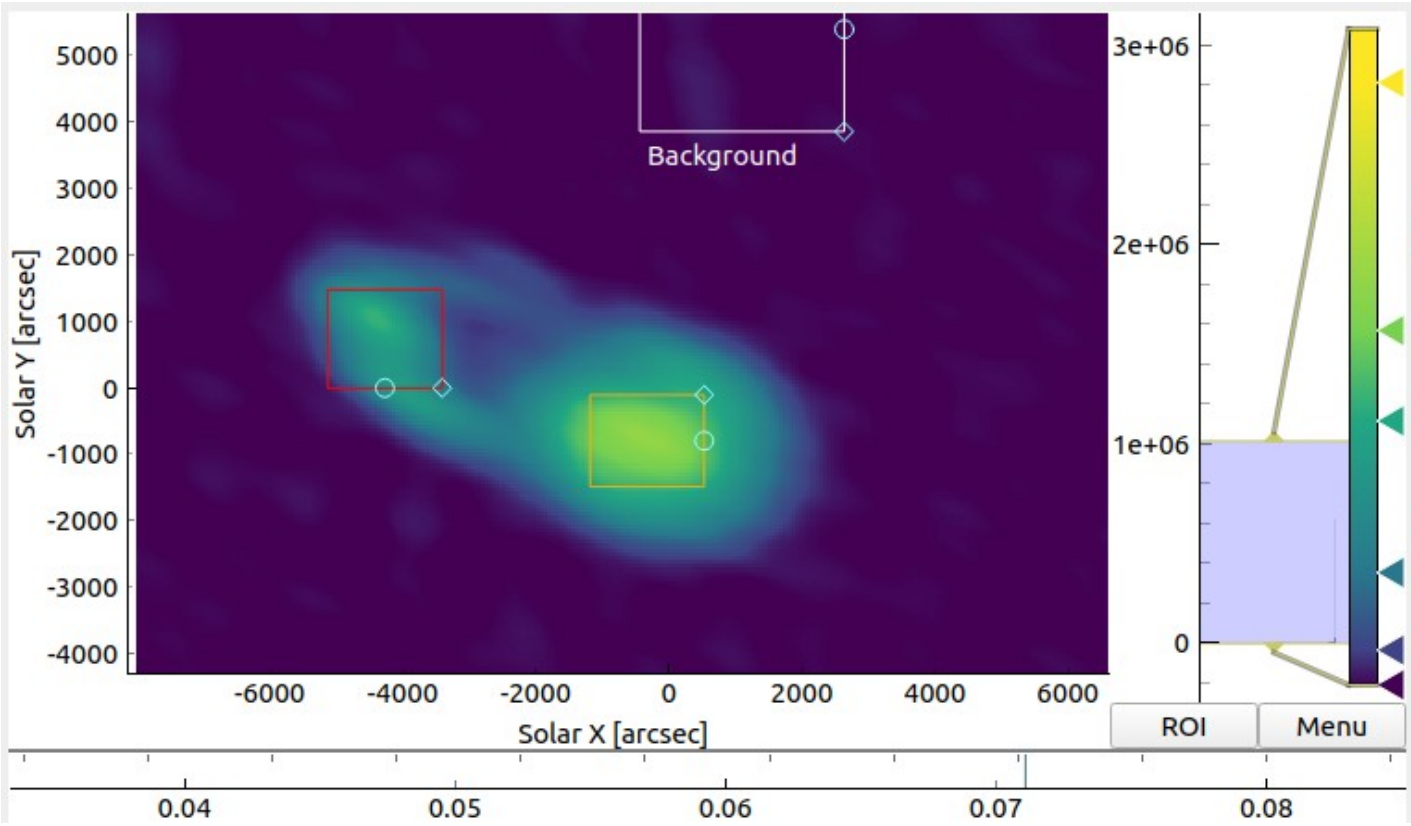
Much better image fidelity and robust magnetic field measurements with EOVSA-15.

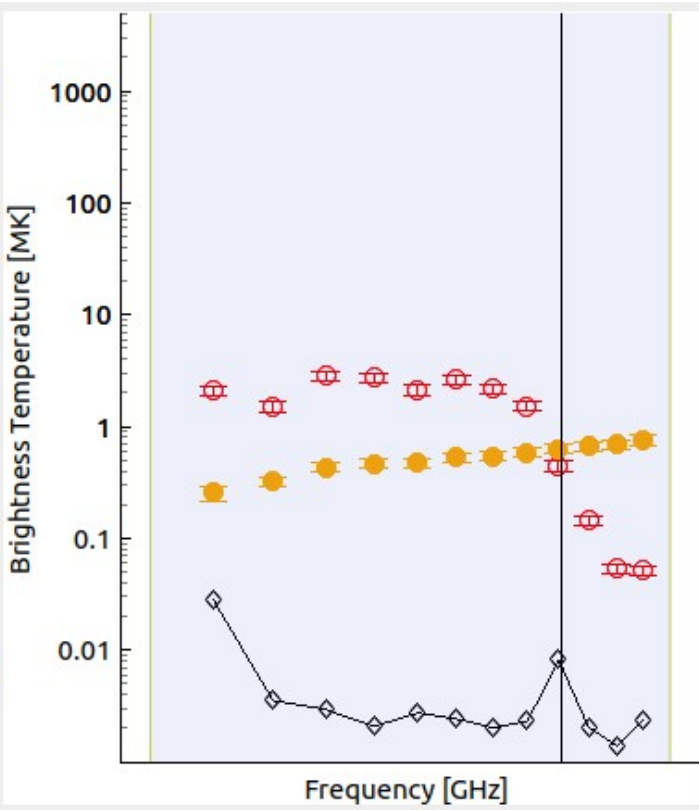
Magnetic field in the high corona

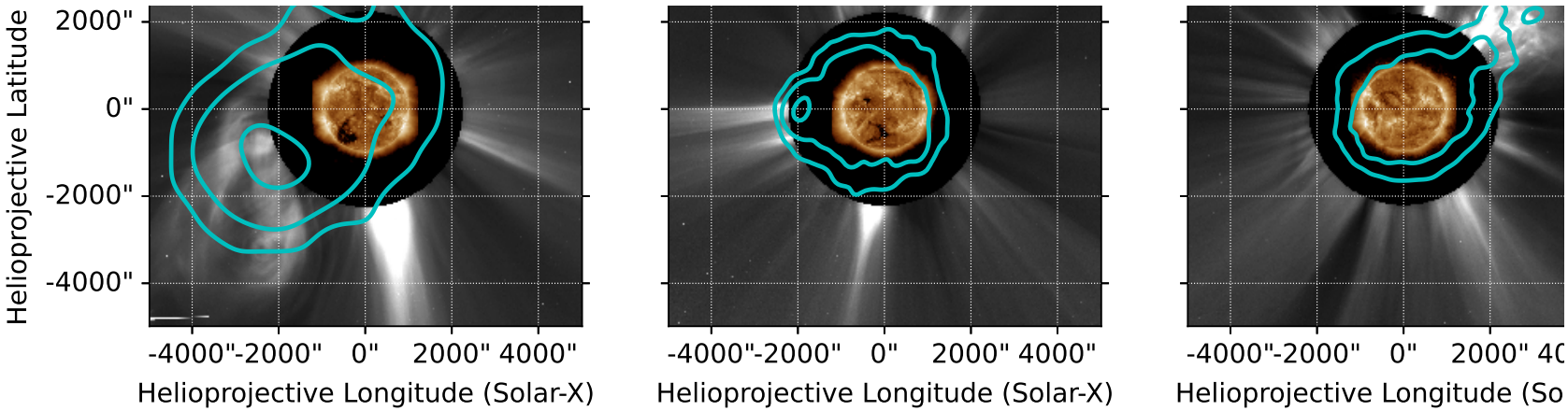
- Faraday rotation measurements using the VLA has been done to measure the CME magnetic field at radii about 5-20 solar radii (Kooi et al. 2017, 2021)
  - Complementary to the measurements made by OVRO-LWA at radii smaller than 5 solar radii

Summary

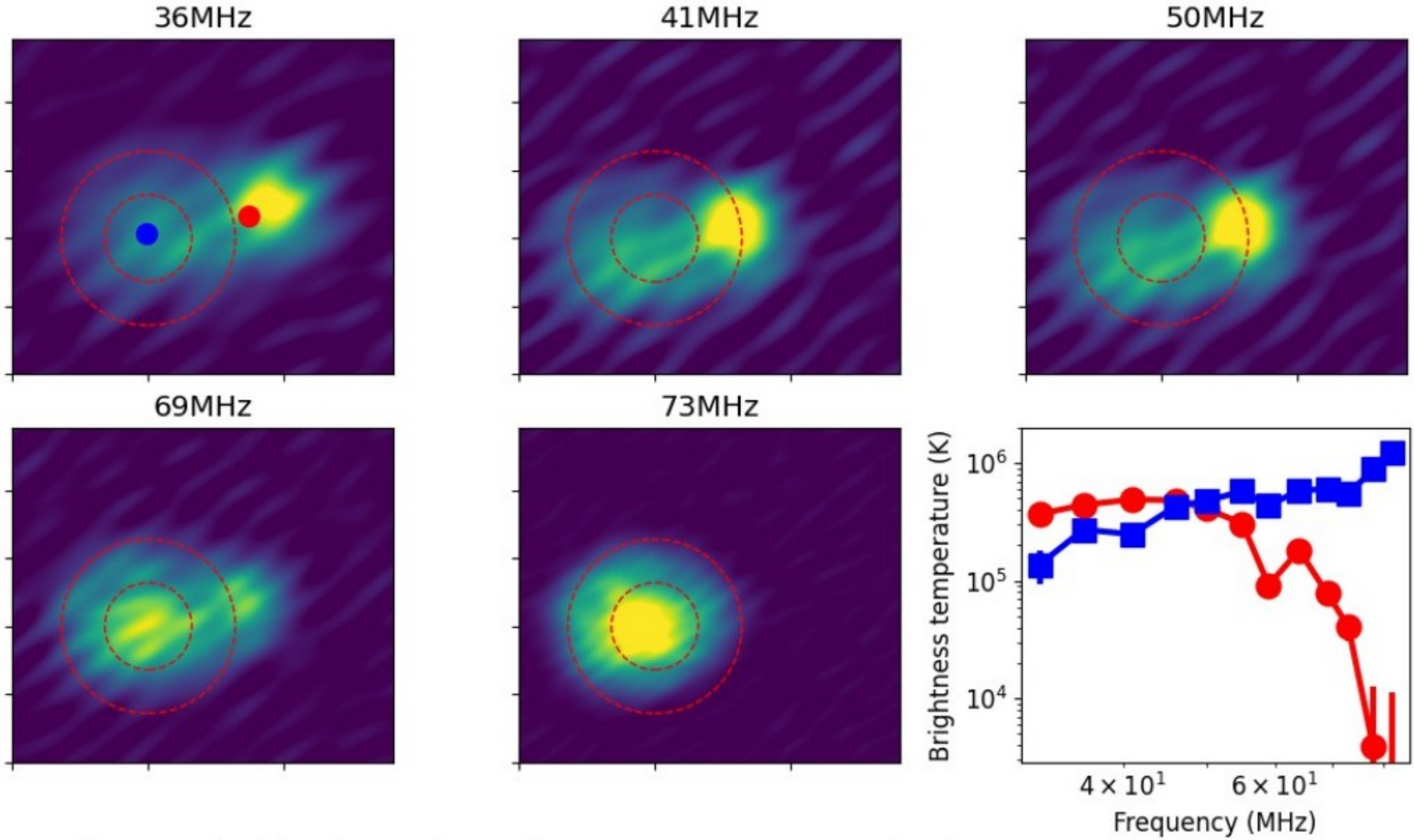
- Low frequency radio instruments and data analysis pipelines are now mature enough to regularly detect incoherent emission from CMEs.
    - Spectrum can be modelled to regularly provide magnetic field measurements close to the Sun.
- Efforts ongoing to track the evolution of the magnetic field energy from close to the Sun into the heliosphere.


Background
Solar Y [arcsec]
Solar X [arcsec]
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-6000
-4000
-2000
0
2000
4000
6000
3e+06
2e+06
1e+06
0
ROI
Menu
0.04
0.05
0.06
0.07
0.08

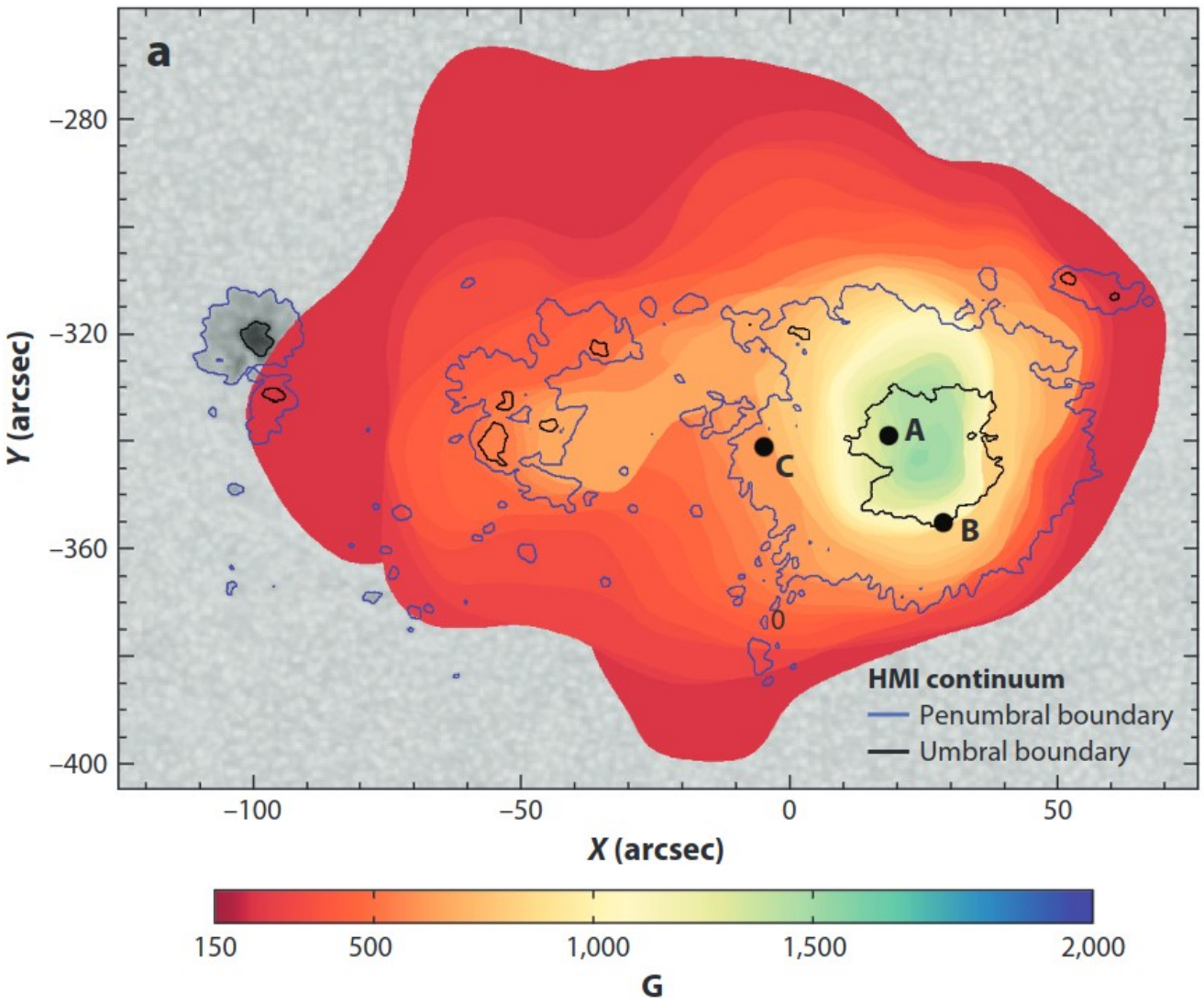

Brightness Temperature [MK]
1000
100
10
1
0.1
0.01
Frequency [GHz]

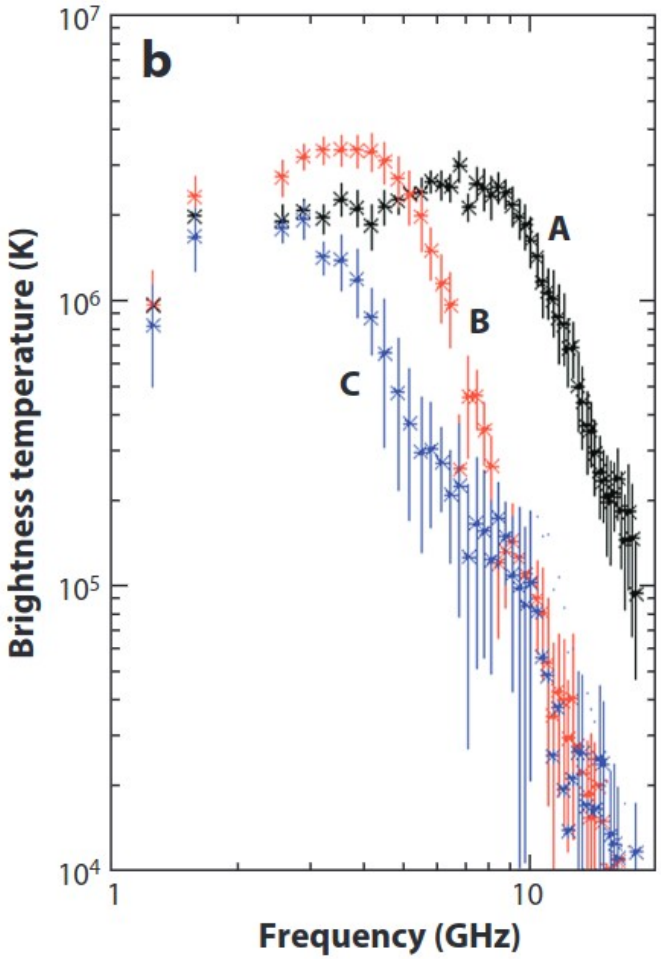

Helioprojective Latitude
2000"
0"
-2000"
-4000"
-4000"-2000" 0" 2000" 4000"
Helioprojective Longitude (Solar-X)
-4000"-2000" 0" 2000" 4000"
Helioprojective Longitude (Solar-X)
-4000"-2000" 0" 2000" 4(
Helioprojective Longitude (So

Surprises revealed by OVRO-LWA



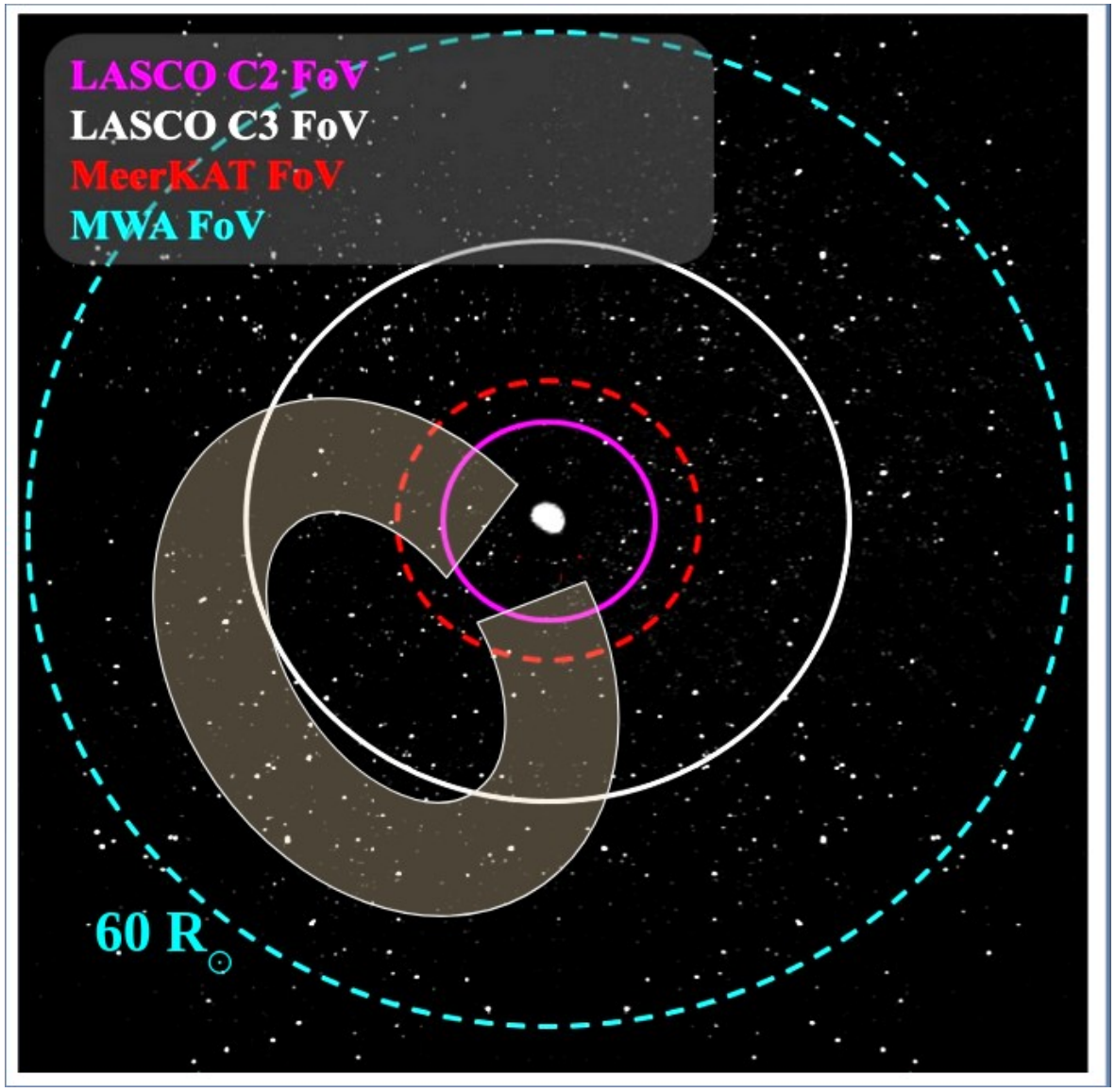
First probable detection of gyroresonance emission from CMEs. Estimated magnetic field ~9G


a
−280
−320
−360
−400
Y (arcsec)
−100
−50
0
50
X (arcsec)
A
B
C
HMI continuum
Penumbral boundary
Umbral boundary
150
500
1,000
1,500
2,000
G


b
10^7
10^6
10^5
10^4
Brightness temperature (K)
1
10
Frequency (GHz)
A
B
C

Gary 2023

Magnetic field: interplanetary space



- Polarimetry with OVRO-LWA is still in progress
- But in principle, we should be able to measure the FR far into the heliosphere.

Figure credit: Devojyoti Kansabanik