My experiments in solar physics through PhD and postdoc

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The beginning

- Needed to write a PhD proposal with projects I intended to do during PhD
  - Polarimetric calibration for MWA solar observations
  - Determine quiet sun magnetic field with polarimetric observations
  - ---
  - Any other interesting project which catches my eye

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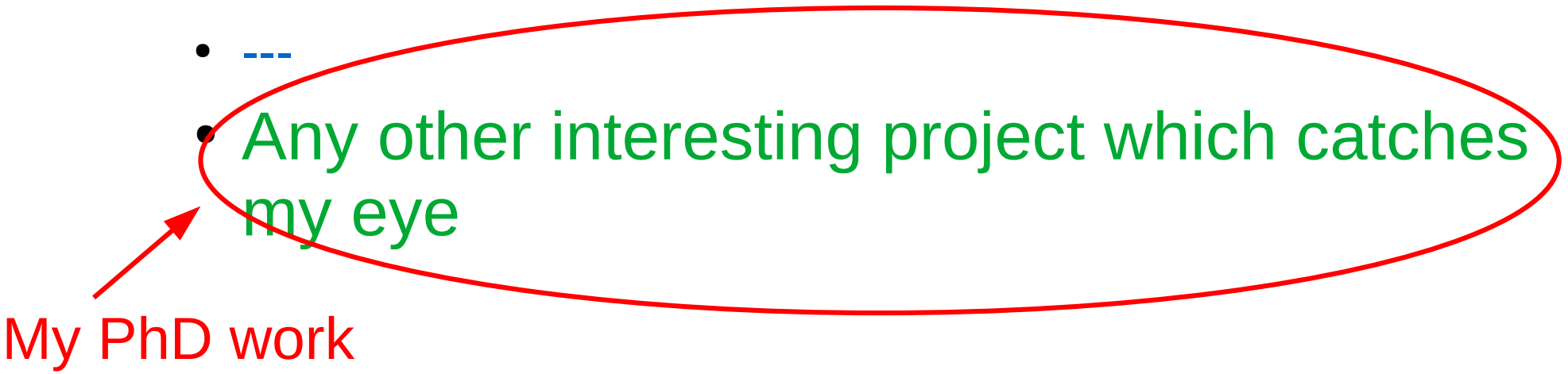


How it all started?

All started with my guide, Dr. Divya Oberoi, saying

“Surajit, can you please test this new algorithm developed at MIT Haystack and see how it improves the quiet sun images?”

Prior tests

- Acted well on a Type II radio burst (40 kHz and 0.5s) data.
- My job to image the quiet sun well at sufficient dynamic range failed miserably.
  - Very extended
  - Often no calibrator observation was taken
  - Self-calibration often failed because of poor prior calibration and hence poor starting model
  - Adhoc methods used earlier; varied from person to person.

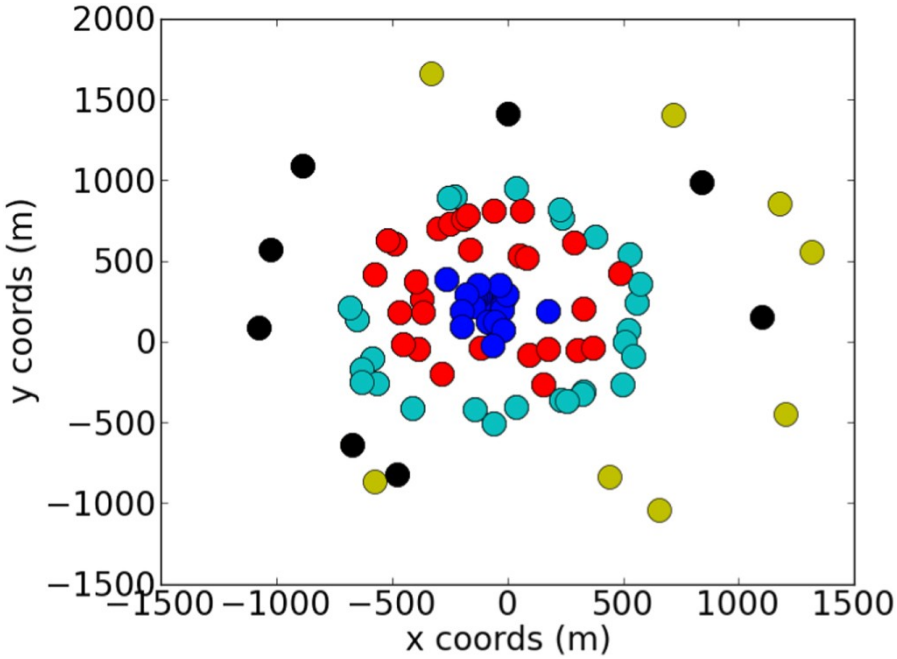
Breakthrough

One random evening after many trials, one ``random'' trial succeeded…

- Random????

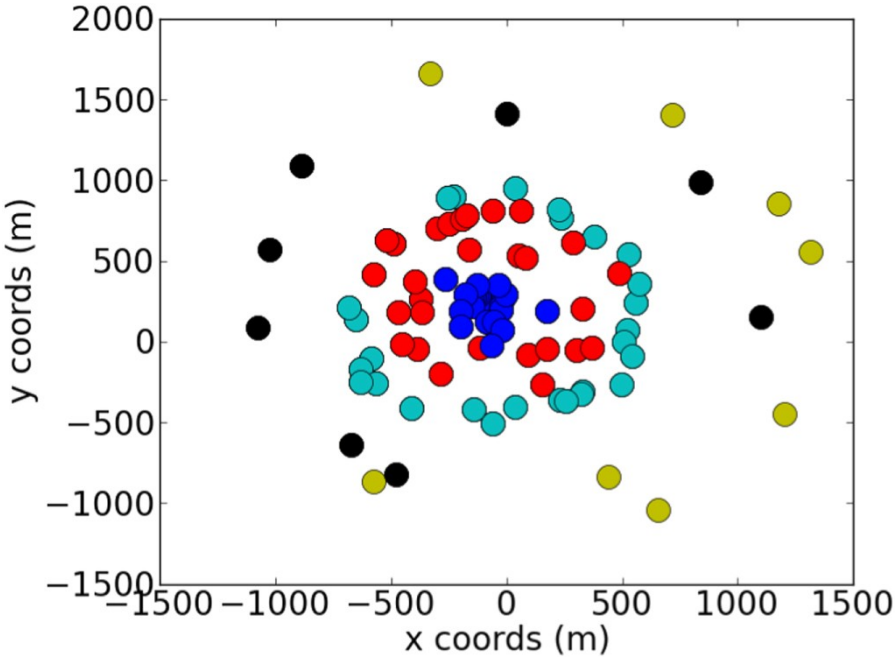
Basic algorithm

- Assume that all antennas are approximately identical.
- Core antennas look through the same ionosphere
    - Phase and amplitude coherency



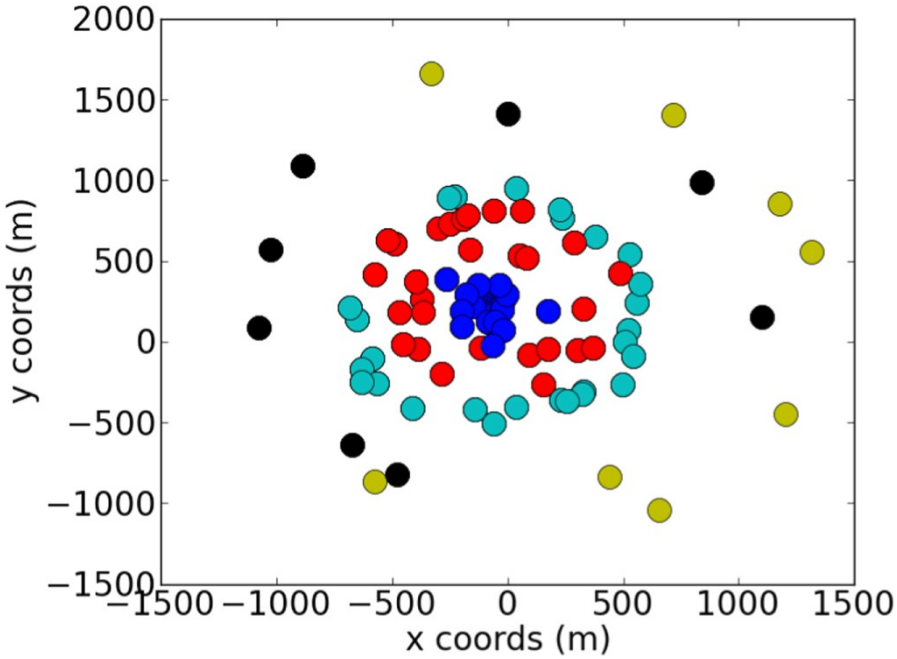
Basic algorithm

- Assume that all antennas are approximately identical.
- Core antennas look through the same ionosphere
    - Phase and amplitude coherency
- Maybe if you use only baselines which have at least one antenna from core, reasonable image can be made.
    - Selfcal, after adding other baselines in stages.



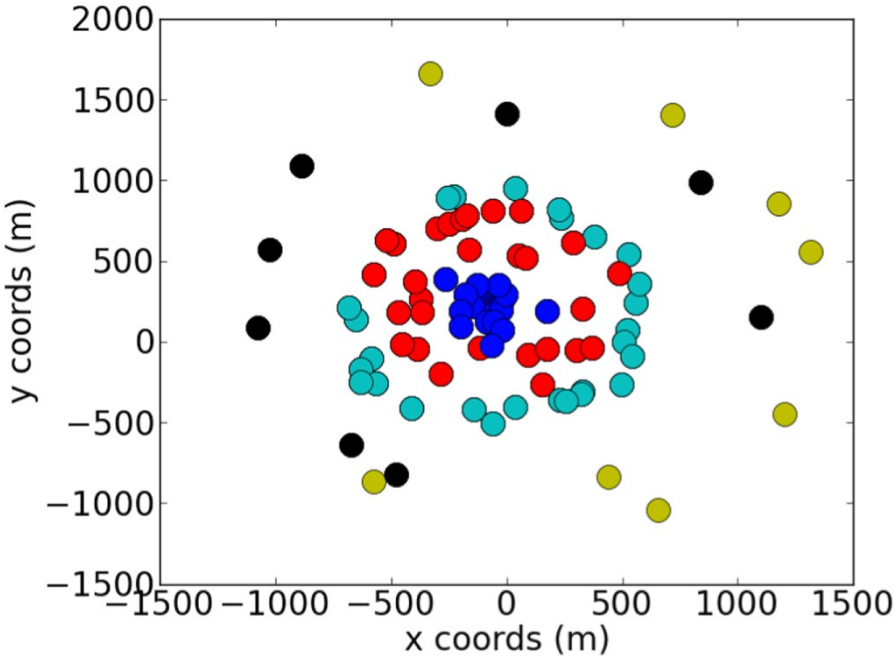
Basic algorithm

Self-calibration, turned out to be the magic pill



Basic algorithm

Self-calibration, with a twist, turned out to be the magic pill



Paper !!!

- Turned into a software with many checks and balances. Name:

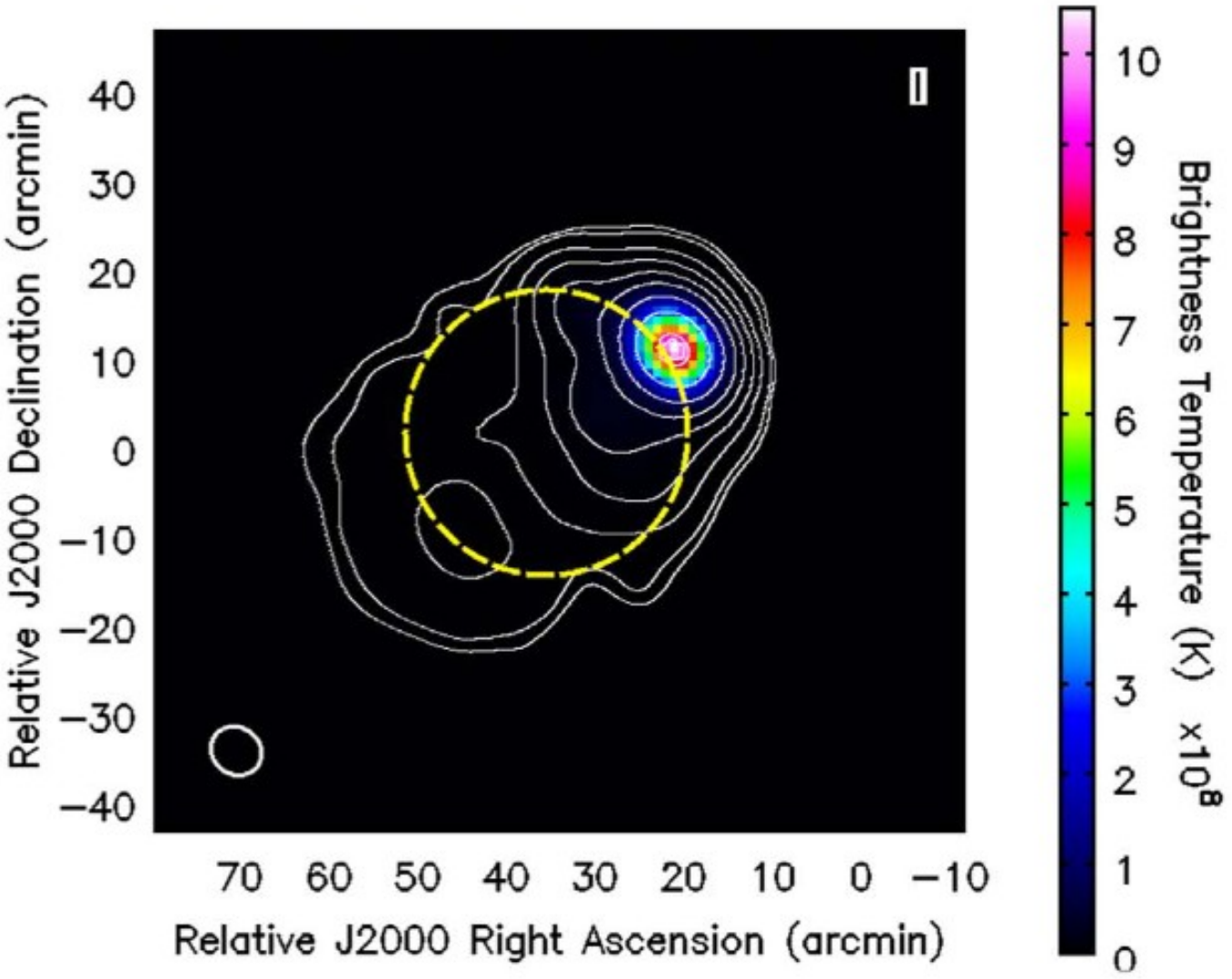
  Automated Imaging Routine for Compact Arrays for Radio Sun (AIRCARS)

Mondal et al. (2019)

Results

- Acted well on a Type II radio burst (40 kHz and 0.5s) data.
  - Earlier DR ~25000 or less, I do not remember those numbers
  - AIRCARS final DR~ 0.75-1 x 10^5
- Quiet Sun: Routinely imaged in an automated manner; DR at least factor of few for MWA data; for other instruments, about an order of magnitude.

AIRCARS highest DR image

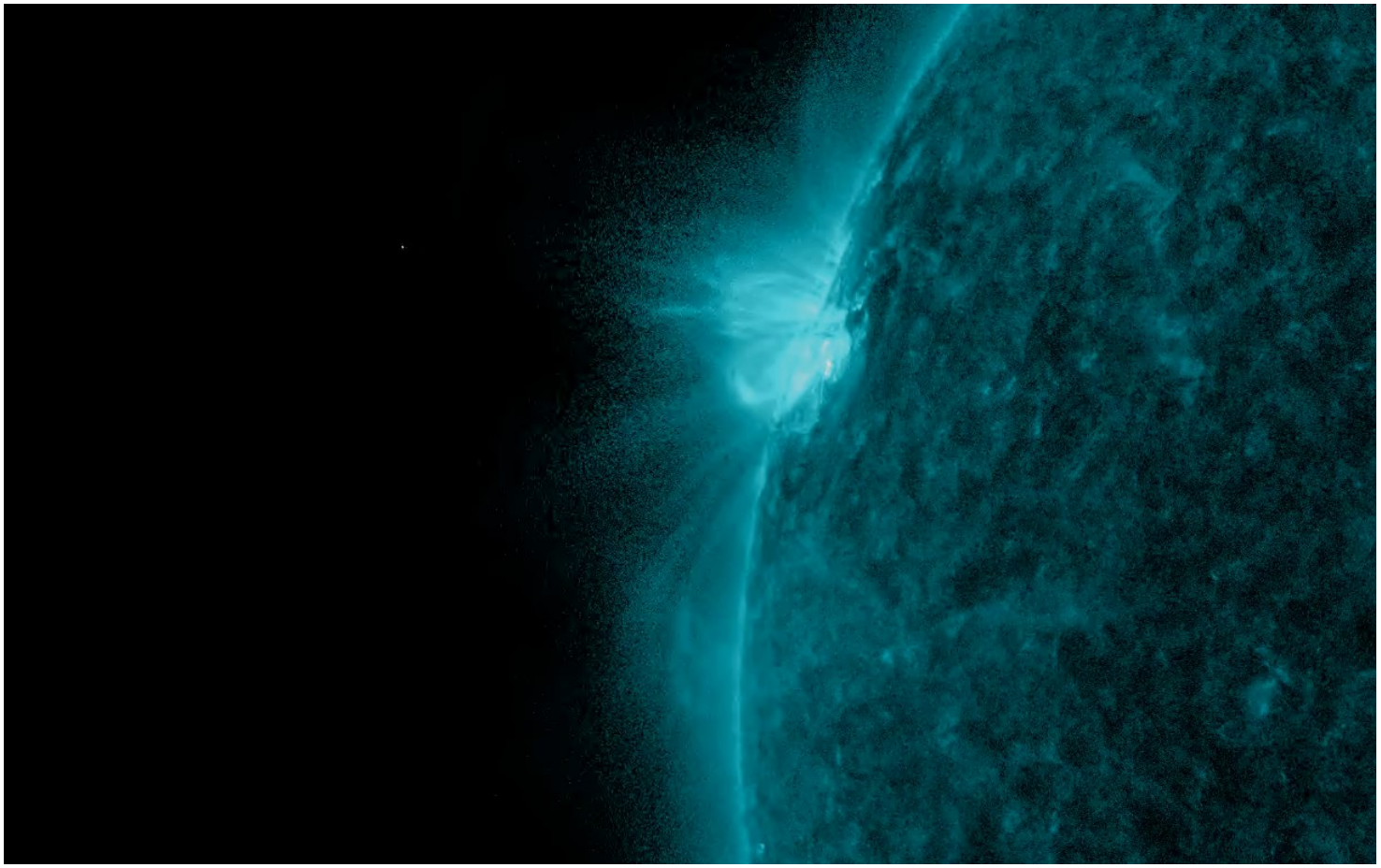


Lowest contour at 0.02% of the peak; no noise peak outside

My discoveries with AIRCARS

- Gyrosynchrotron emission from slow CME (Mondal et al. 2020a)
- Ubiquitous impulsive nonthermal emissions from the quiet sun (Mondal et al. 2020b, Mondal et al. 2023b,c)

Coronal Mass Ejections

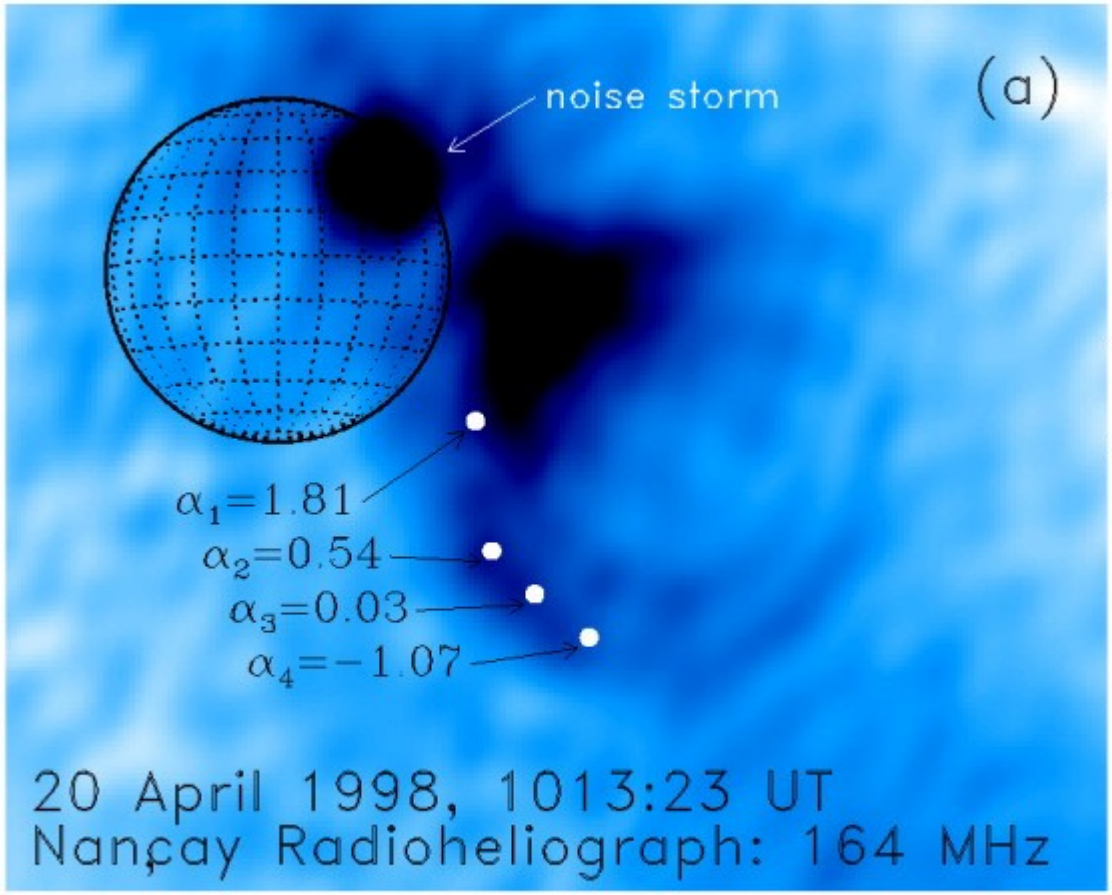


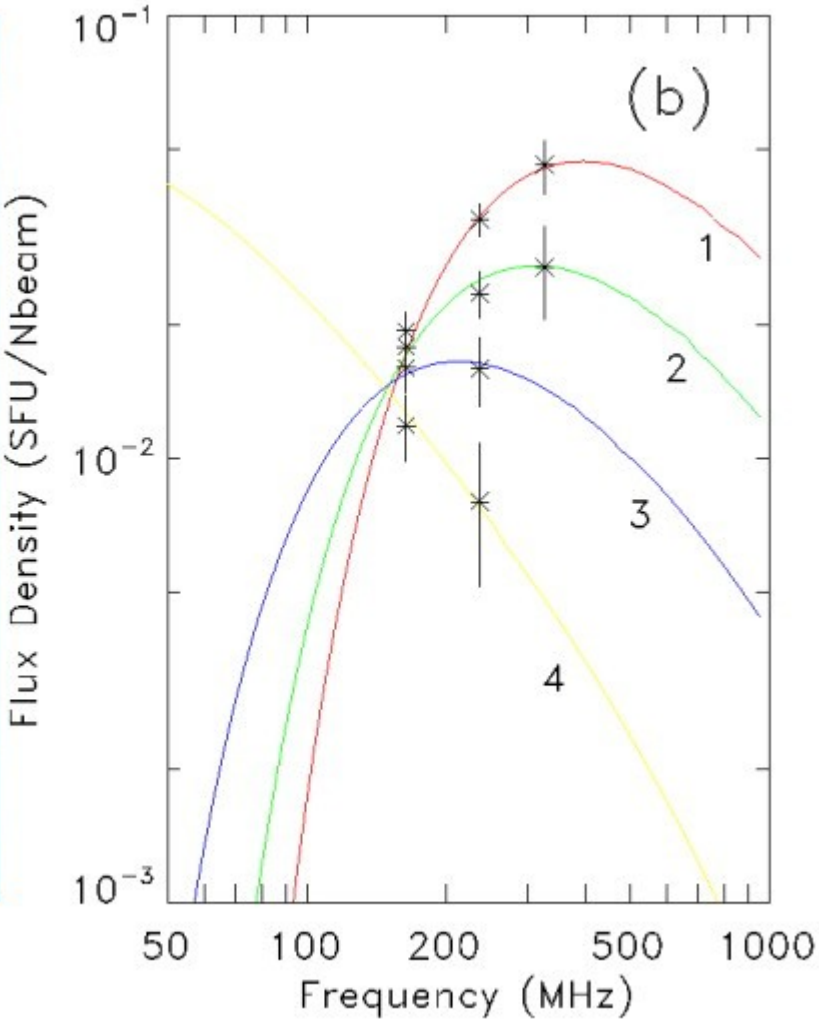
Space weather

CME magnetic field is a important determinant for its geoeffectiveness or its impact on Earth

How do we determine the magnetic field of the CME?

Radio observations can do that, see Bastian et al. (2001)


noise storm
(a)
α_1=1.81
α_2=0.54
α_3=0.03
α_4=−1.07
20 April 1998, 1013:23 UT
Nançay Radioheliograph: 164 MHz


(b)
Flux Density (SFU/Nbeam)
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
50
100
200
500
1000
Frequency (MHz)

A non-radio solar expert hears it and says:

“Great to know you can do it.”

“Wait.. This is big news, why did I not hear about it earlier? For how many CMEs were you able to detect this emission?”

Solar radio person’s reply

Sad, by 2020, only in 4 CMEs such measurements were made.

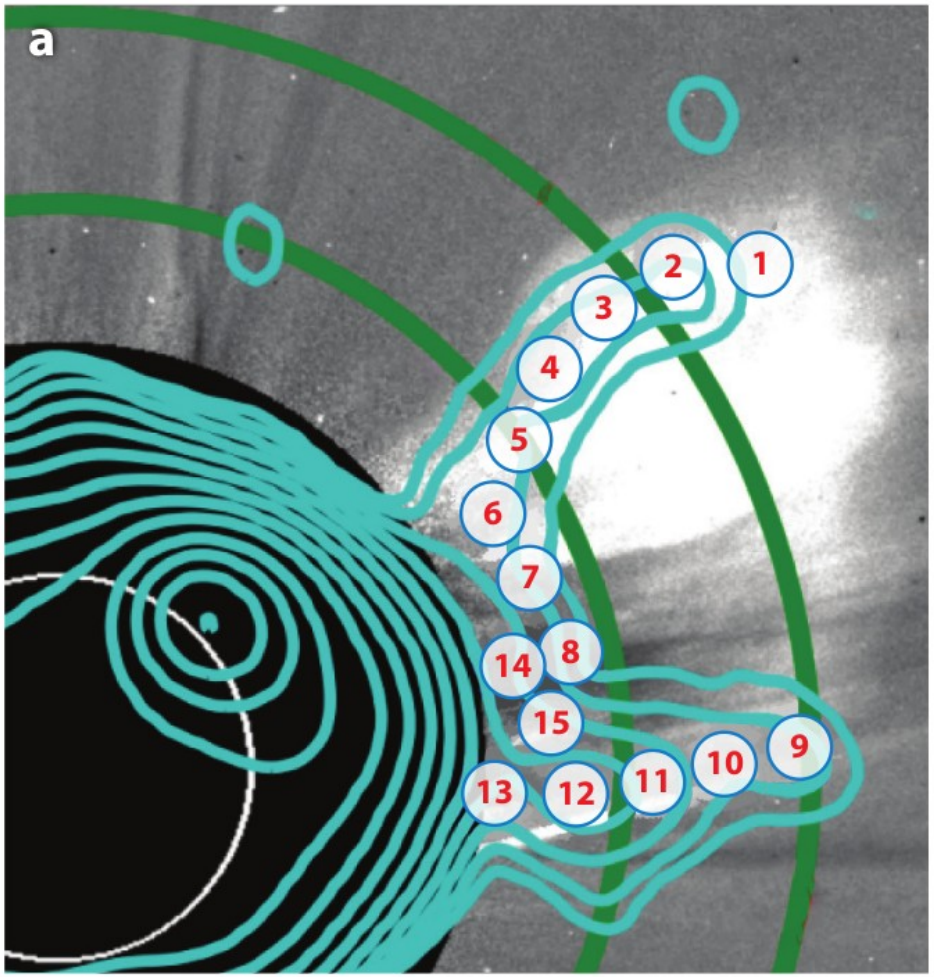
Big big problem

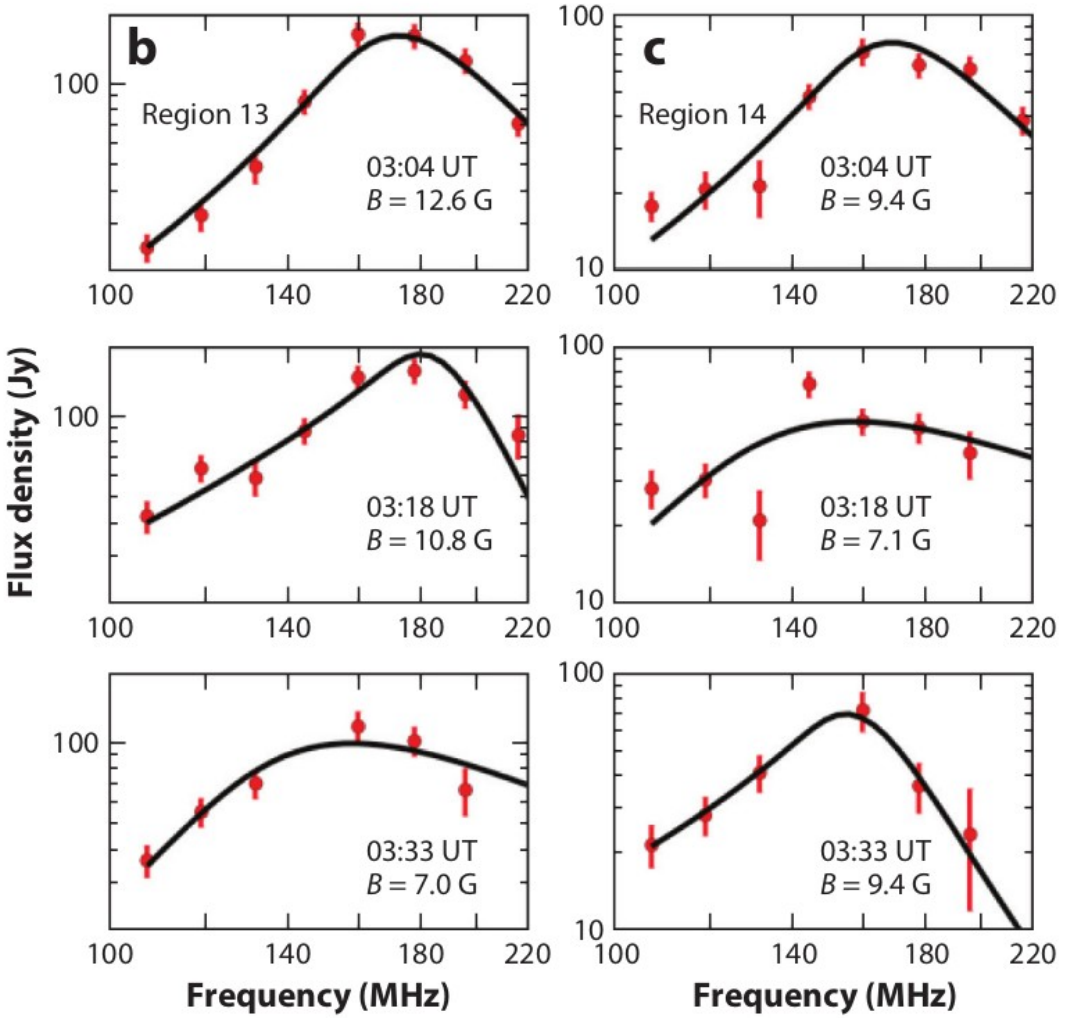
For any impact in space-weather science, we need to do these measurements routinely, not 4 out of hundreds.

Solution

Try AIRCARS

Success in first try





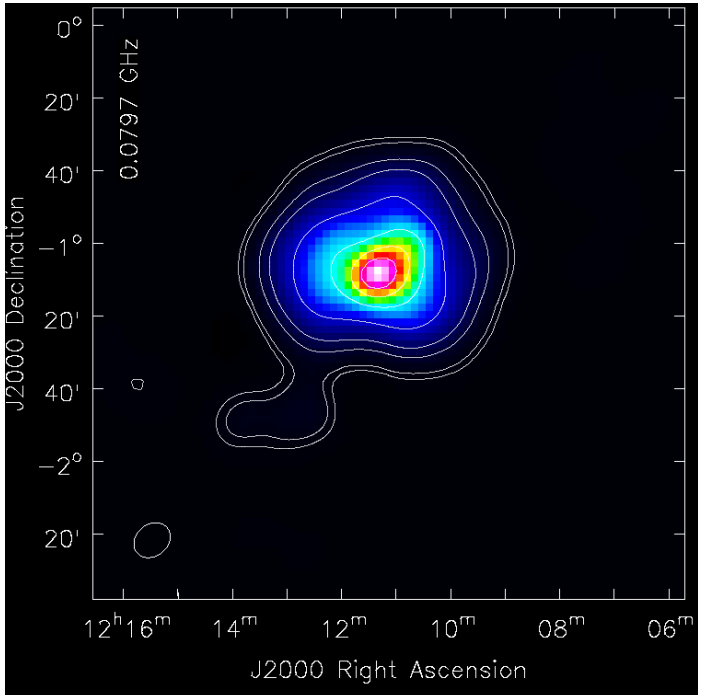
Mondal et al. 2020

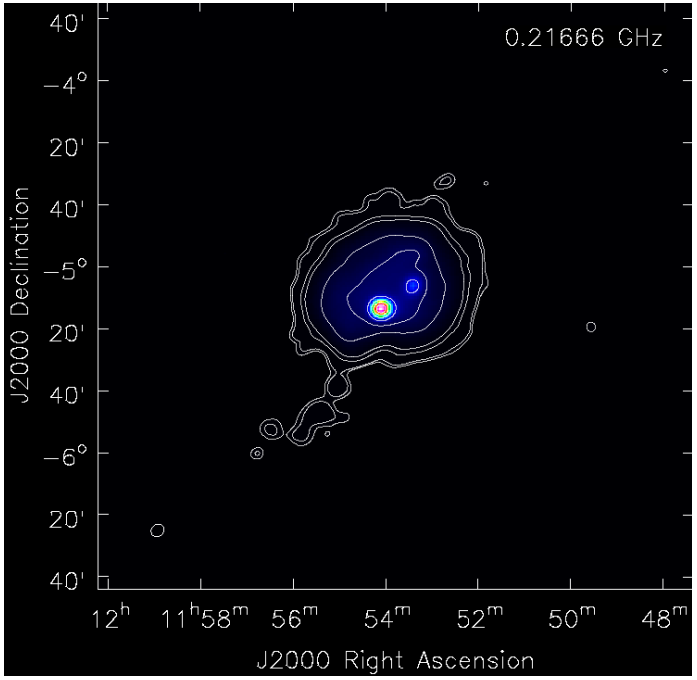
- Earlier CMEs were very energetic and fast; speed >700-800 km/s
- This CME was slow with speed ~400 km/s
- First such measurement from slow CME

Maybe it was just luck?

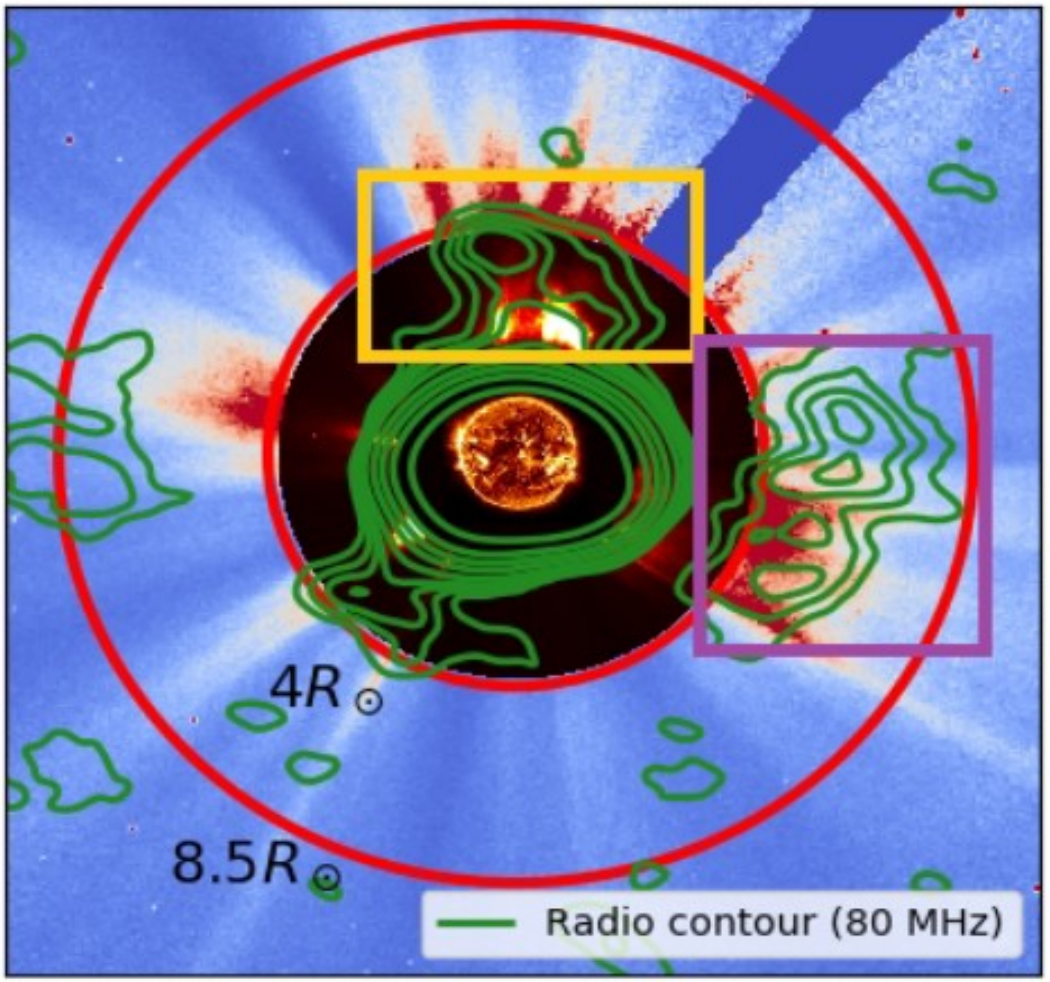
NO, IT WAS THE SOFTWARE AND MWA DATA

CME 1 example





CME 2



Using next generation named Polarization with AIRCARS, PAIRCARS (Kansabanik et al. 2023a,b)

Image from Oberoi et al. (2023)

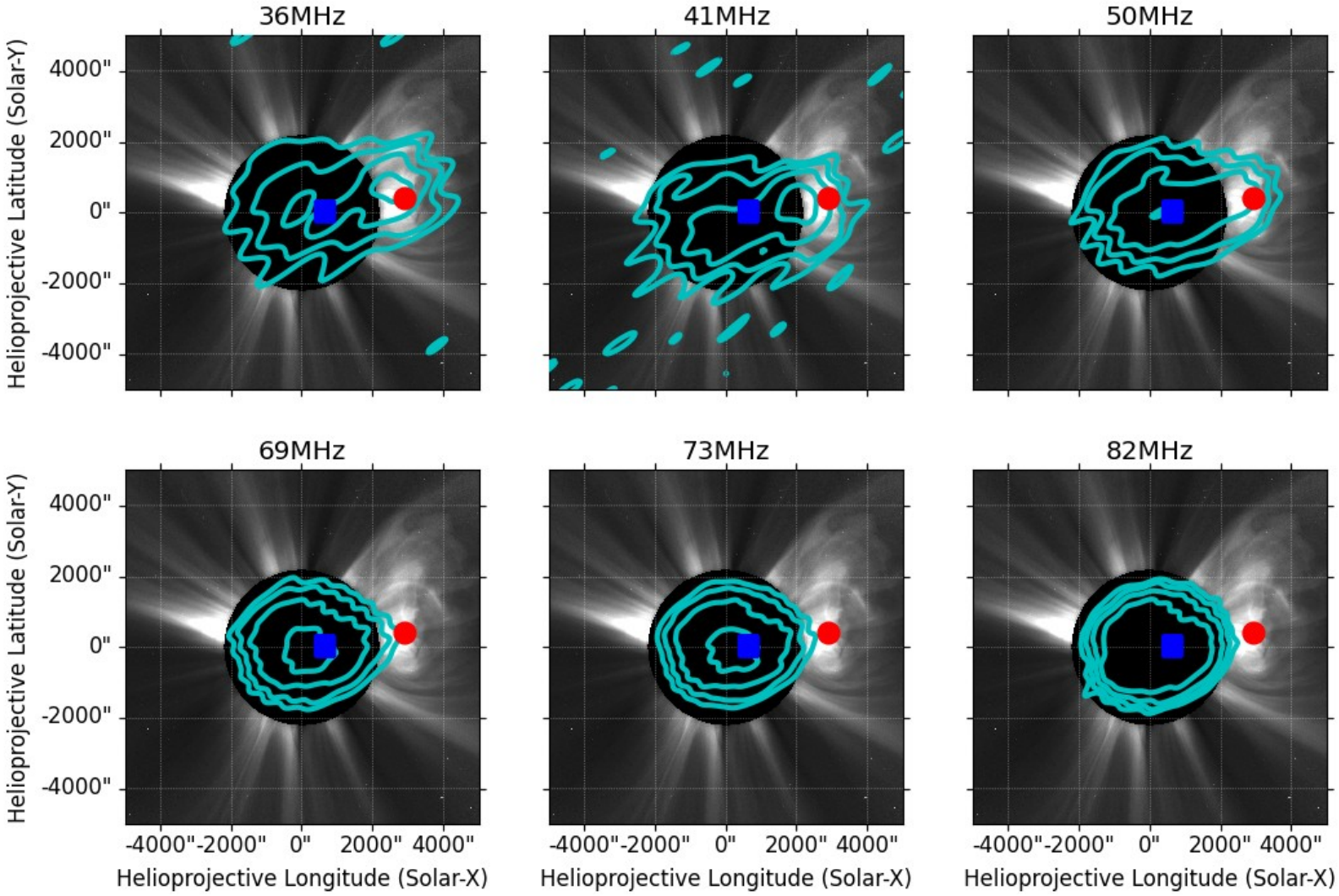
What’s next?

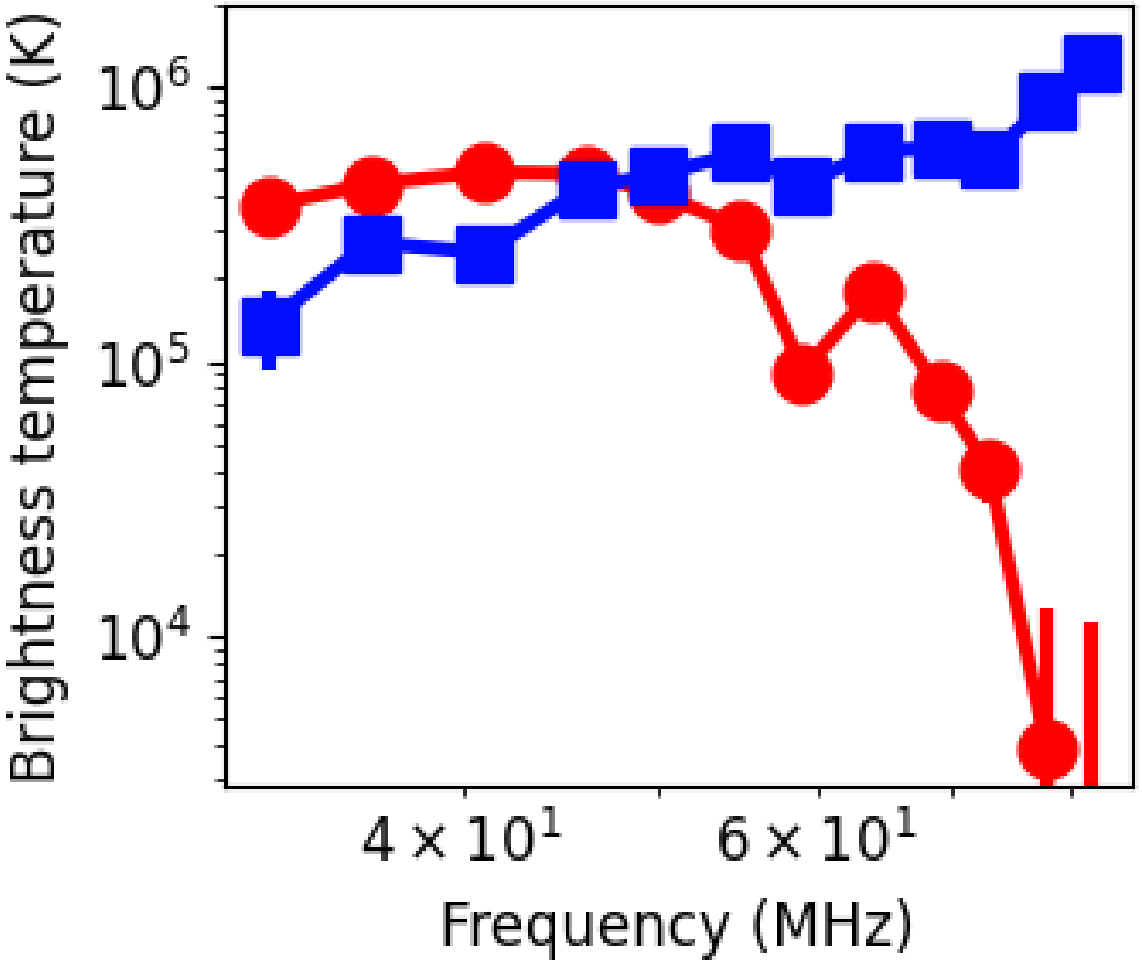
Let’s build a new array: Owens Valley Long Wavelength Array (OVRO-LWA)

OVRO-LWA

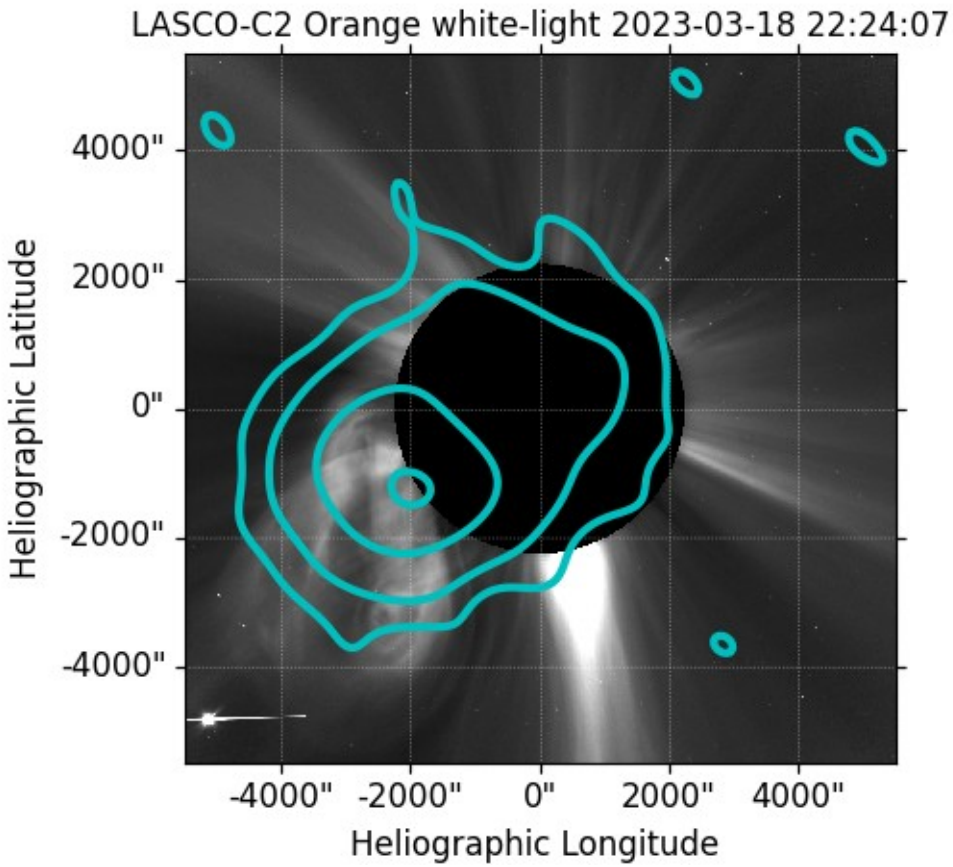
- 352 dipoles over ~2.6 km
- 15-85 MHz
- All-sky imager
- Solar-dedicated; so can do regular monitoring of CMEs
- Commissioning ongoing, but 4-5 CMEs detected already

Early results: CME1




Brightness temperature (K)
10^6
10^5
10^4
4×10^1
6×10^1
Frequency (MHz)

CME2


LASCO-C2 Orange white-light 2023-03-18 22:24:07
4000"
2000"
0"
-2000"
-4000"
Heliographic Latitude
-4000"
-2000"
0"
2000"
4000"
Heliographic Longitude

Future plans with MWA

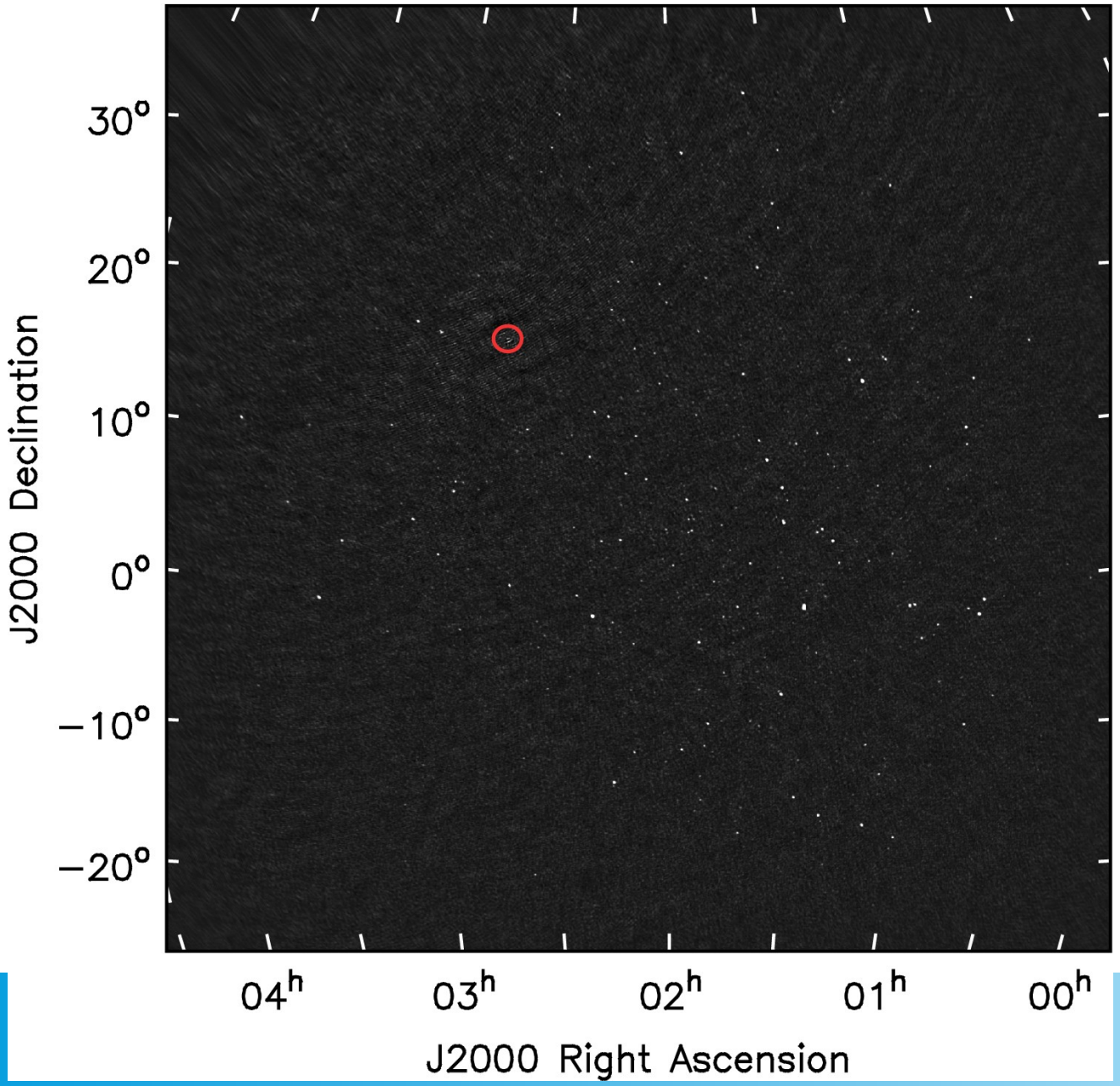
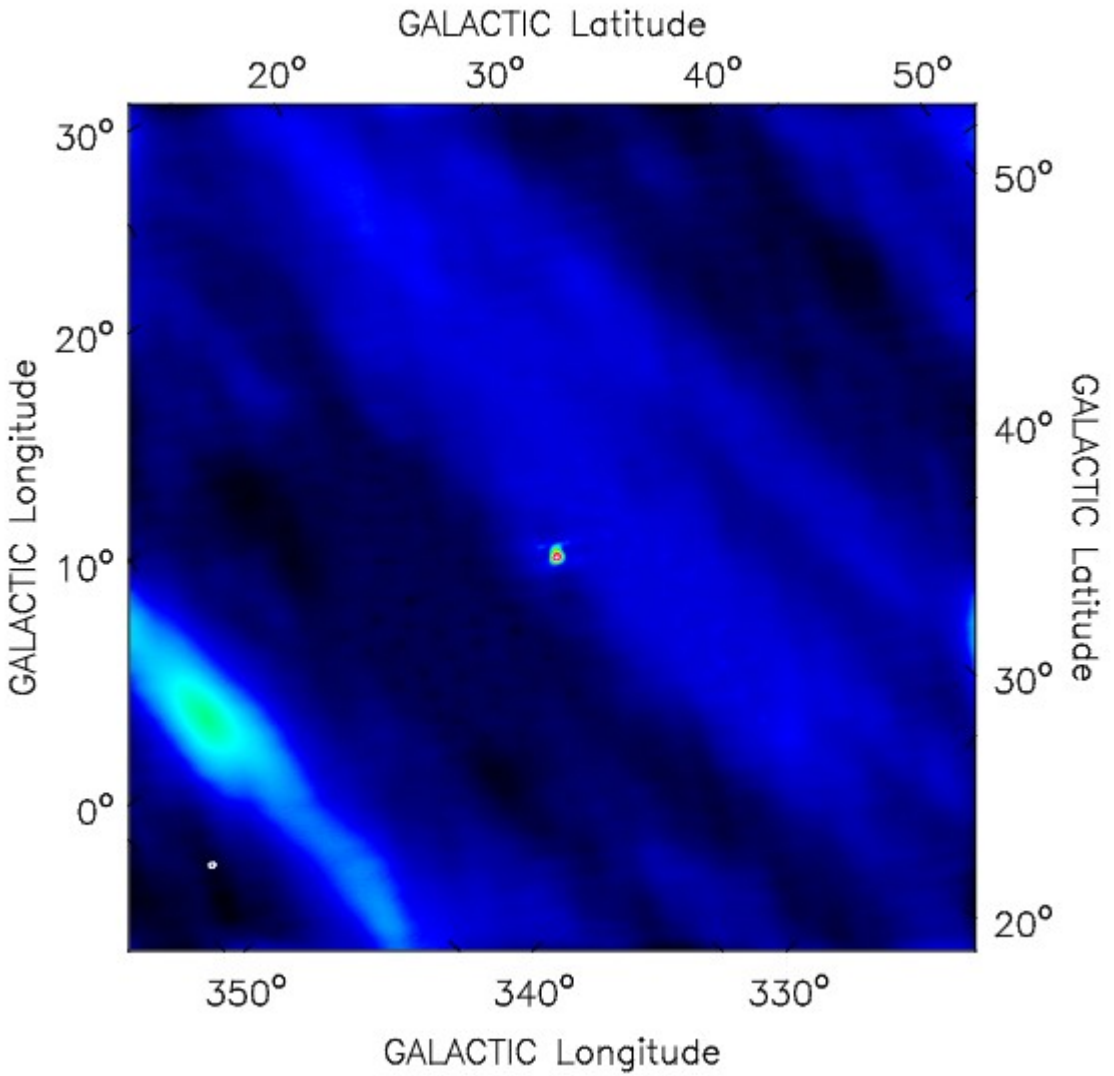
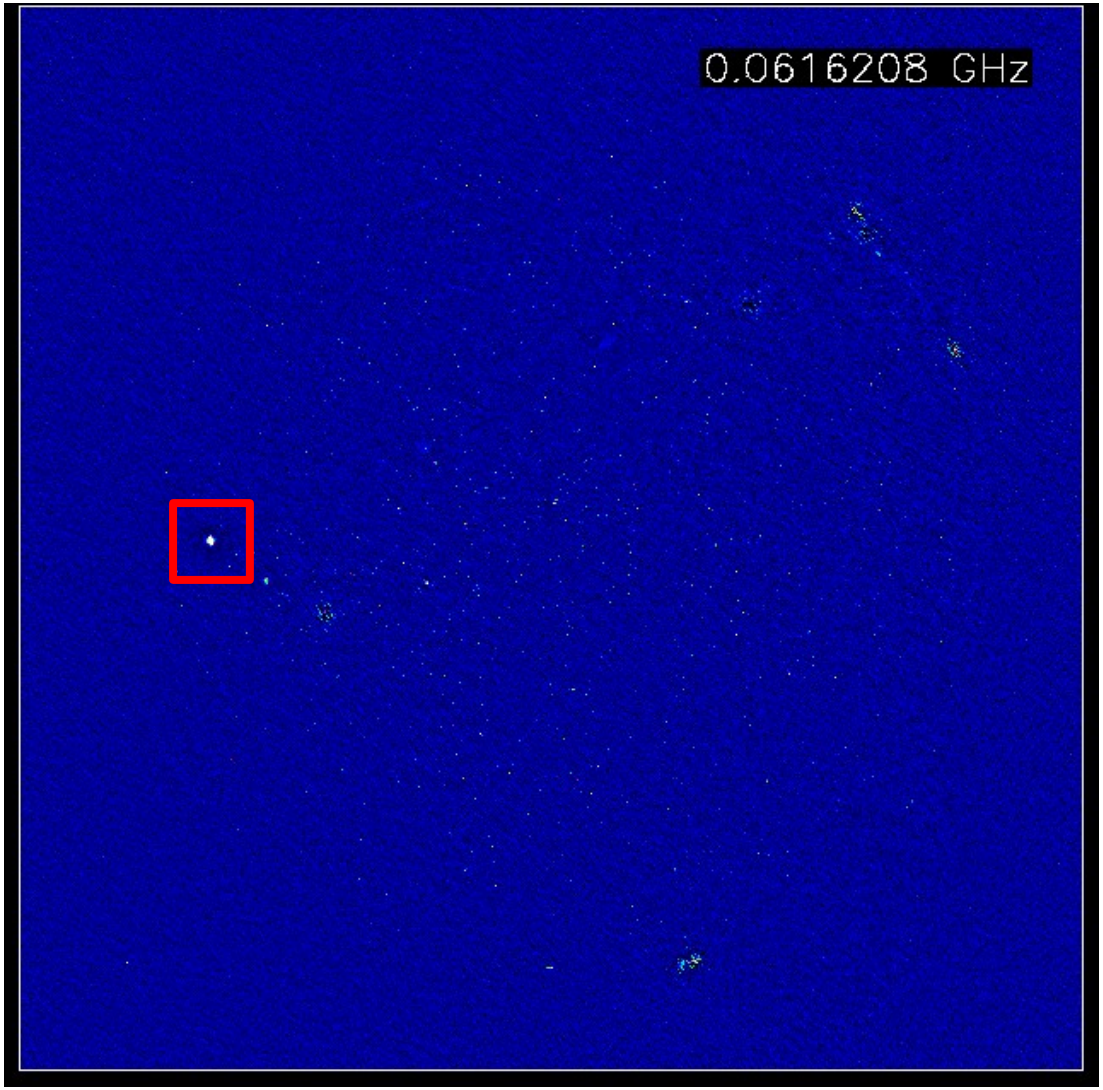


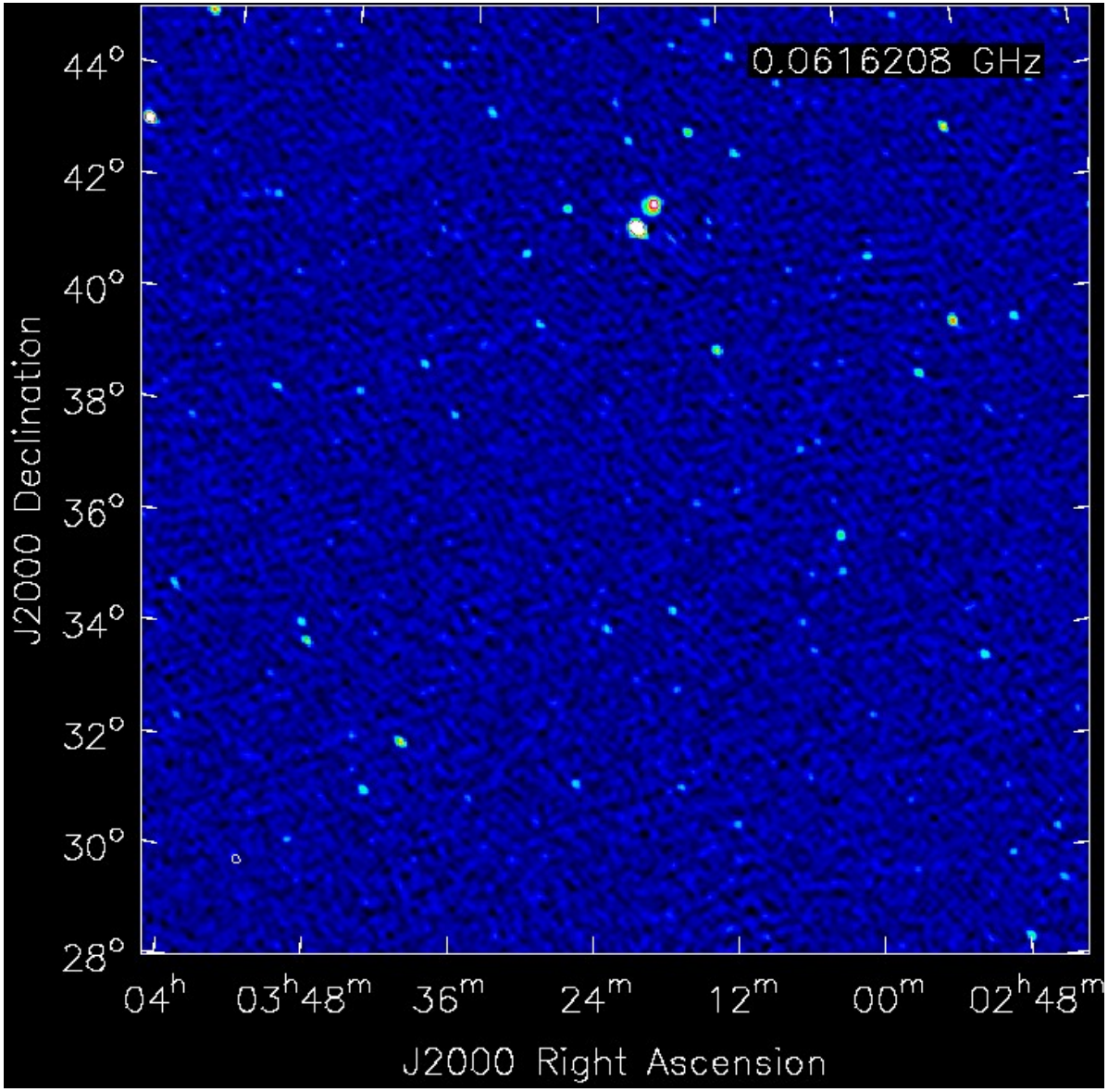
Image with P-AIRCARS
(Kansabanik et al. 2023d)

Image with AIRCARS (Oberoi et al. 2023)

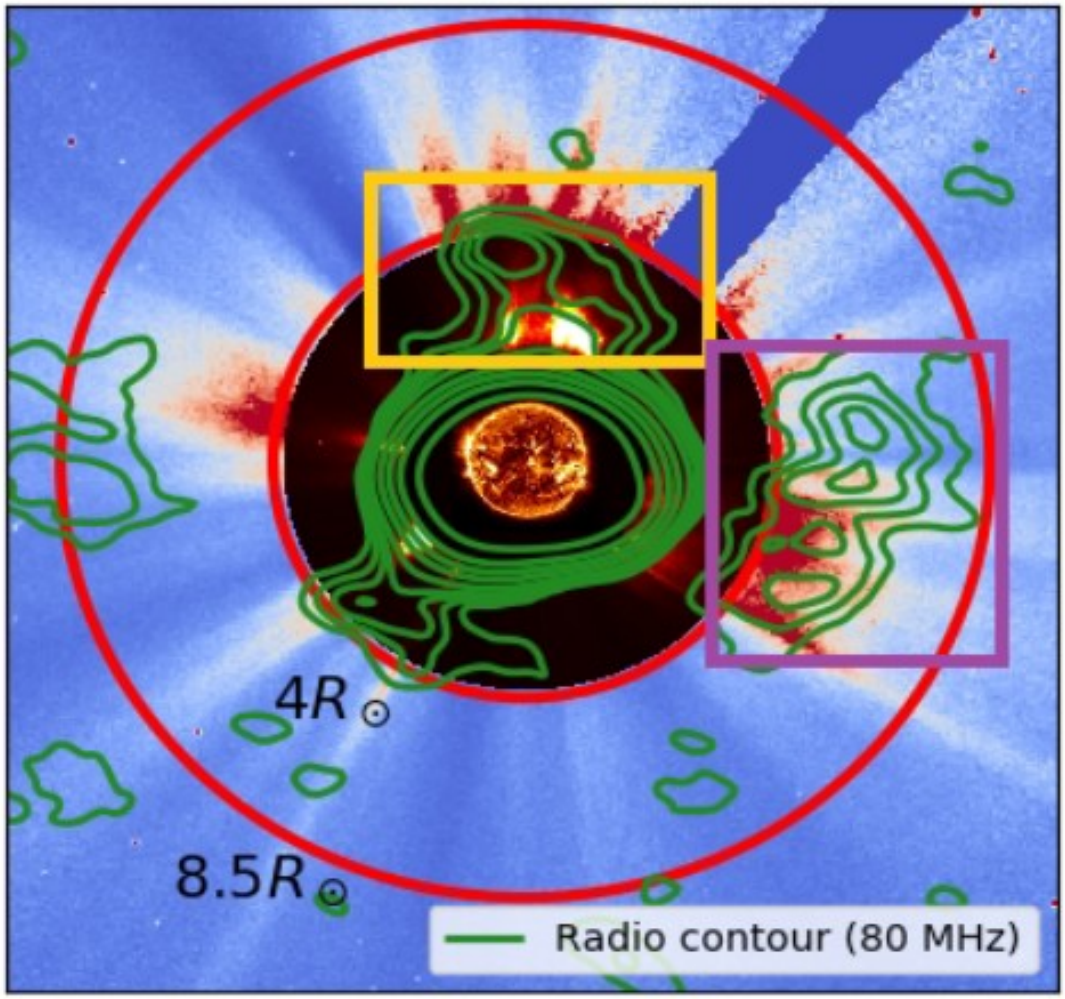


Example image with OVRO-LWA

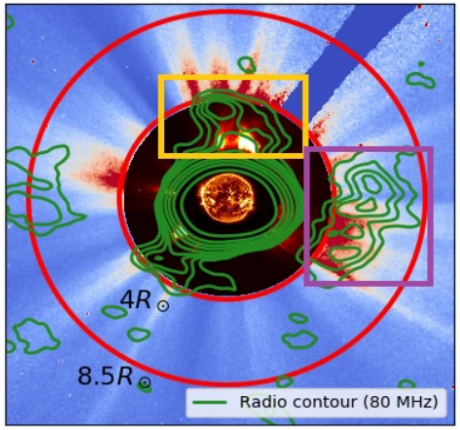


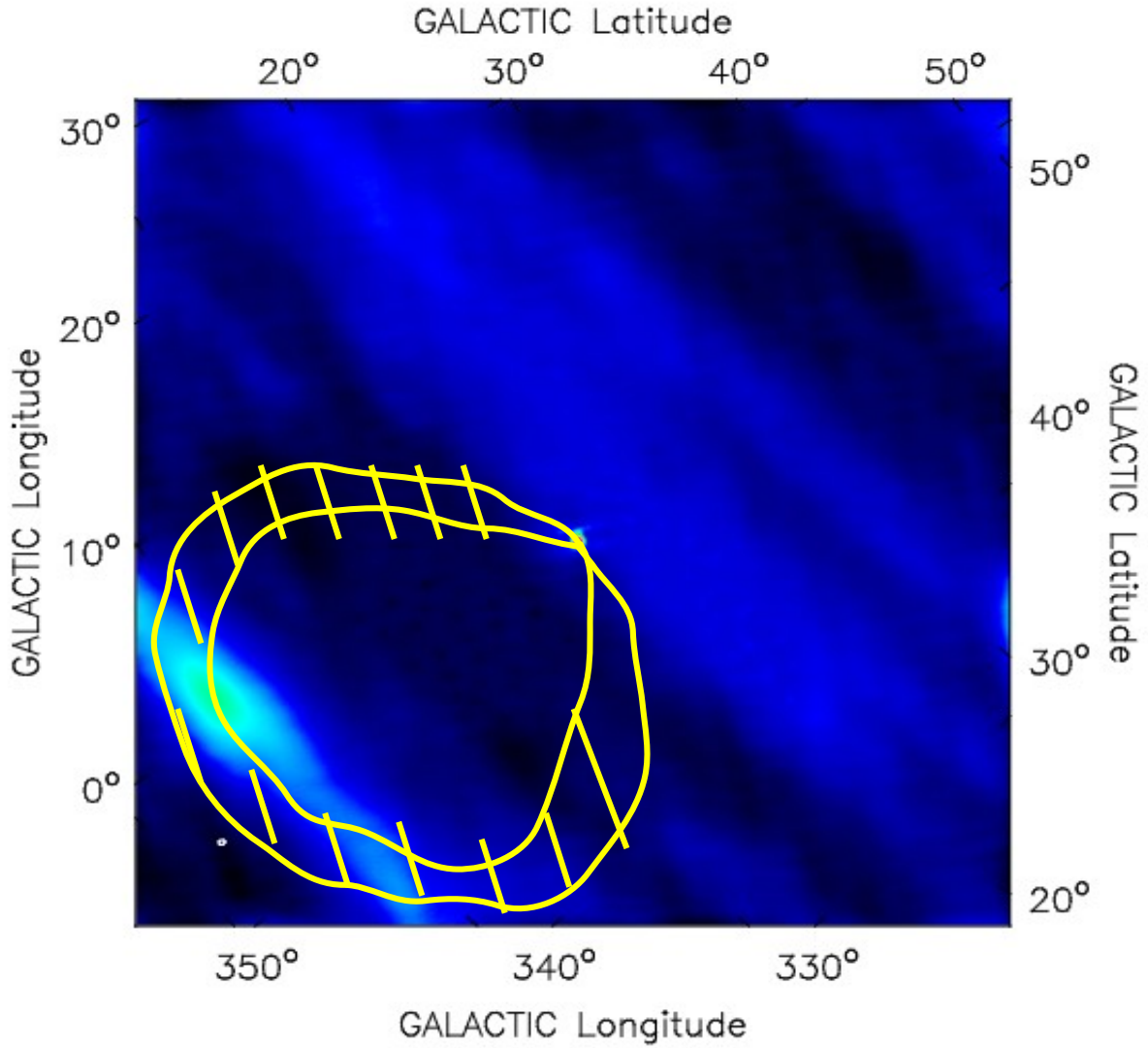

0.0616208 GHz
44°
42°
40°
38°
36°
34°
32°
30°
28°
J2000 Declination
04h
03h48m
36m
24m
12m
00m
02h48m
J2000 Right Ascension

Long-term goal (Combine)

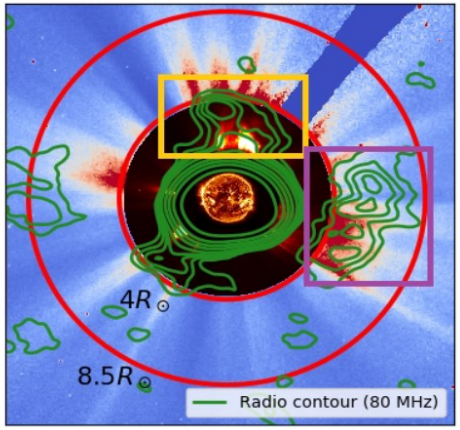


Long-term goal (Combine)

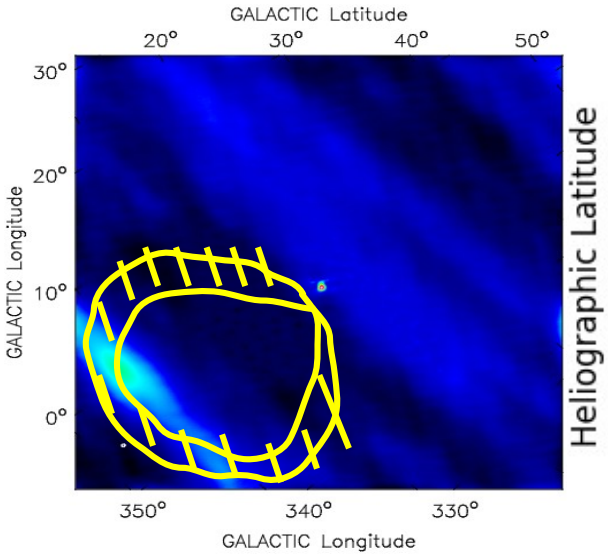




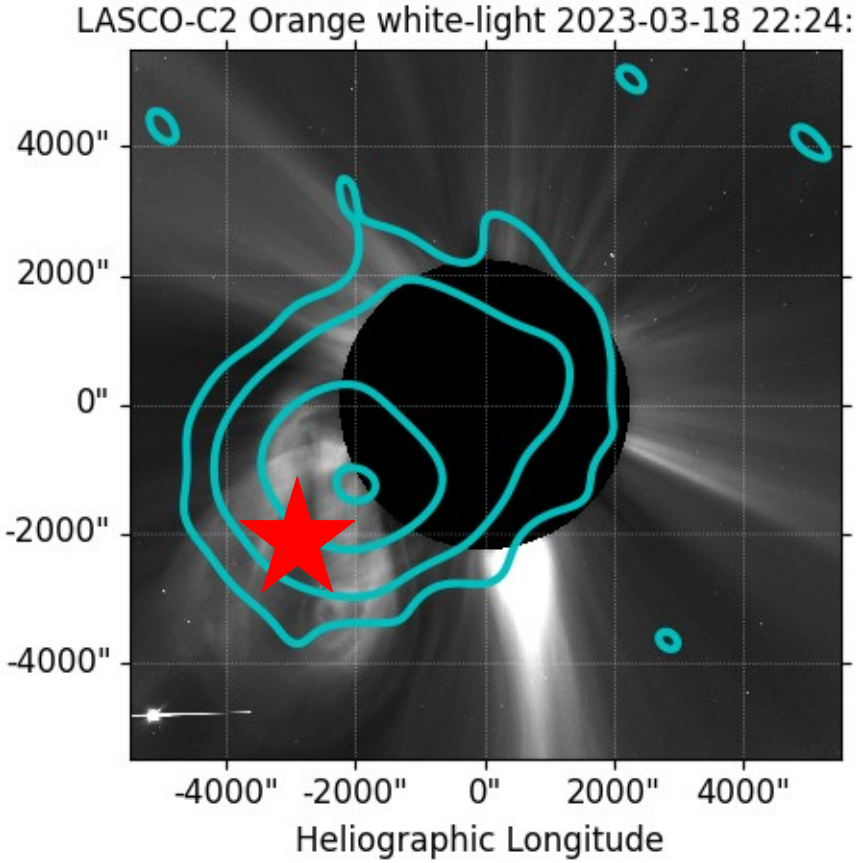
Long-term goal (Combine)



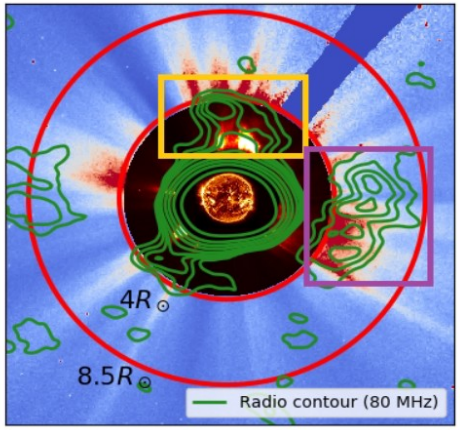
Known method



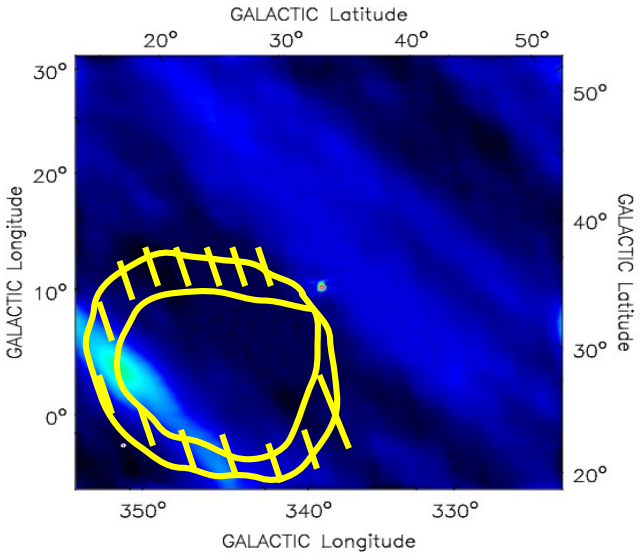
unknown method



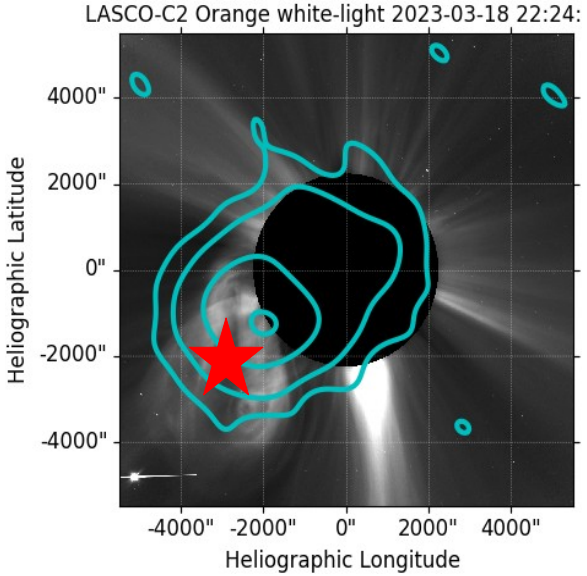
Long-term goal (Combine)



Known method

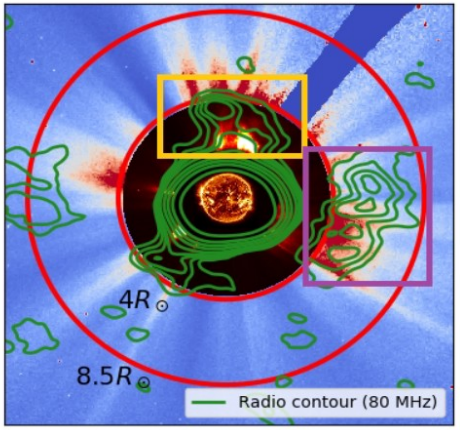


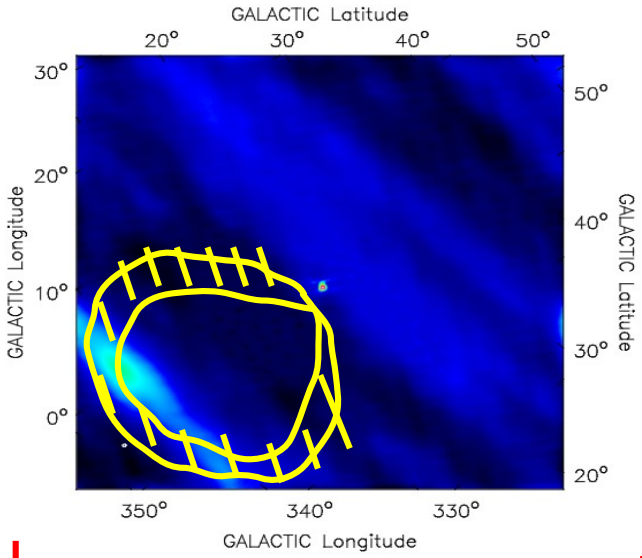
unknown method

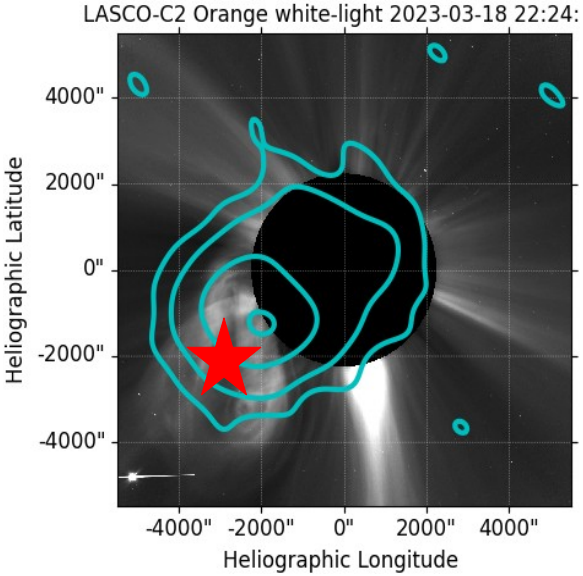


Known method

Long-term goal (Combine)



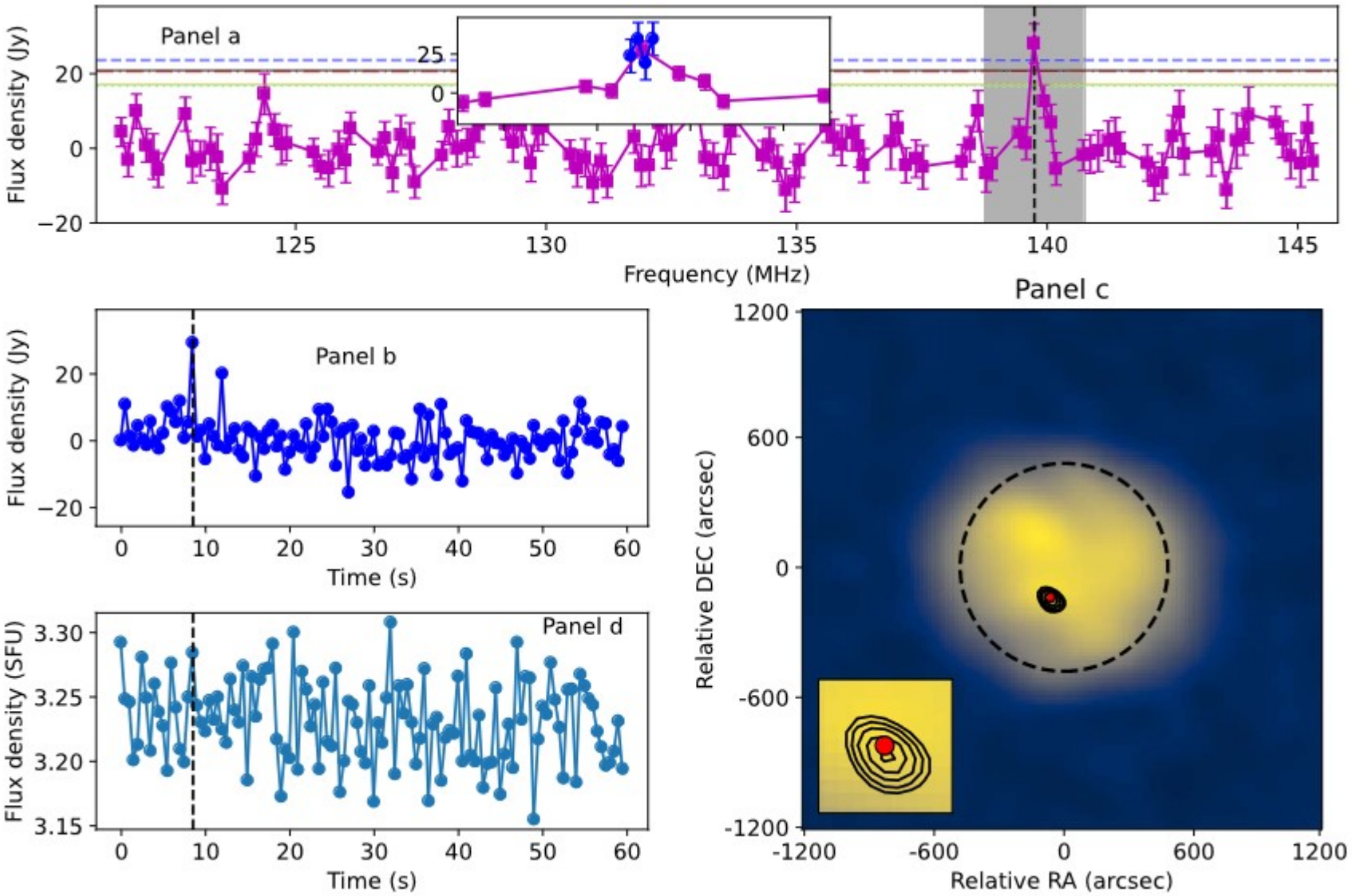


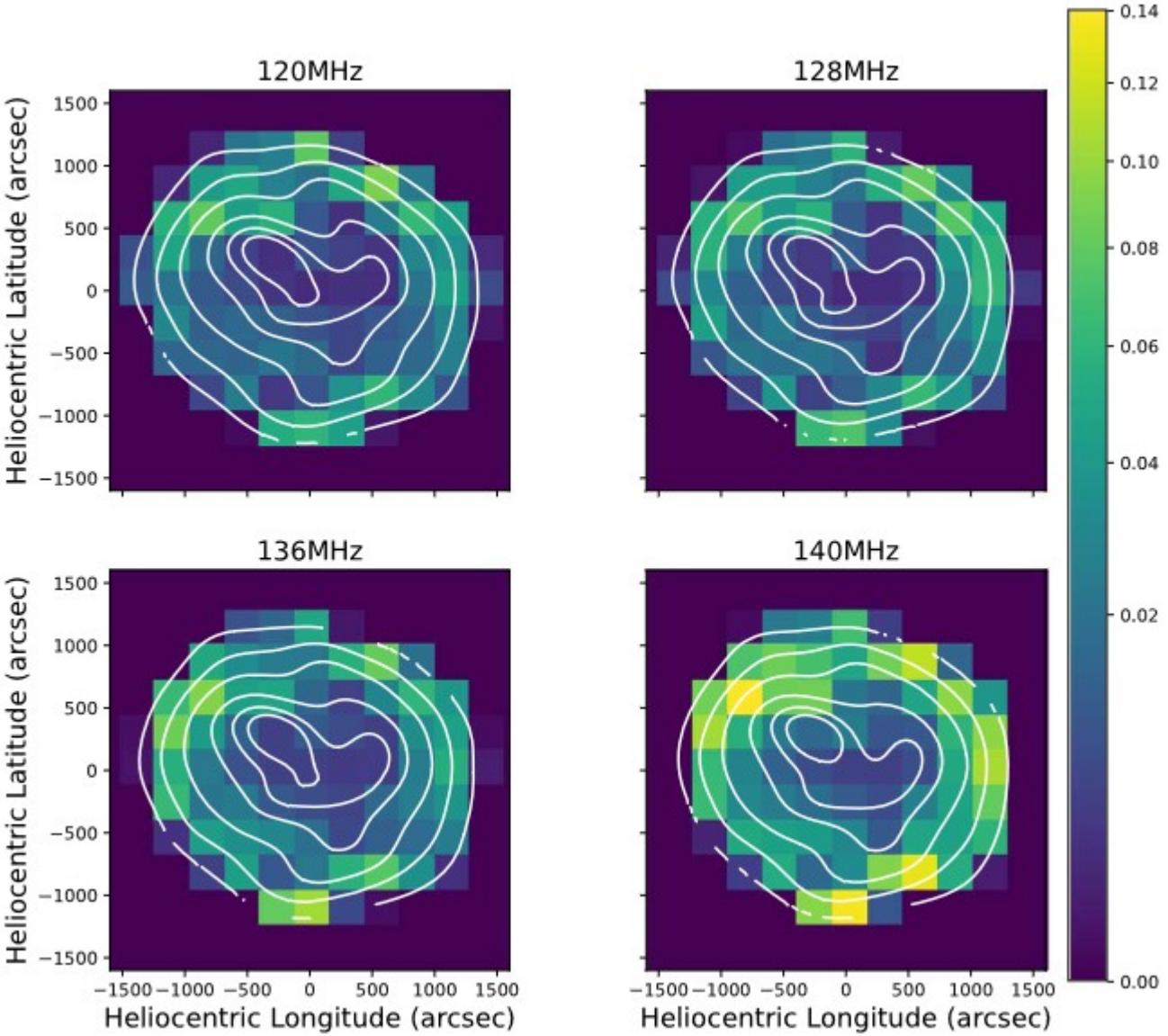


Known method + unknown method + Known method

= Track the vector magnetic field of CME

Extra slides




120MHz
128MHz
136MHz
140MHz
Heliocentric Latitude (arcsec)
Heliocentric Longitude (arcsec)
1500
1000
500
0
−500
−1000
−1500
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00

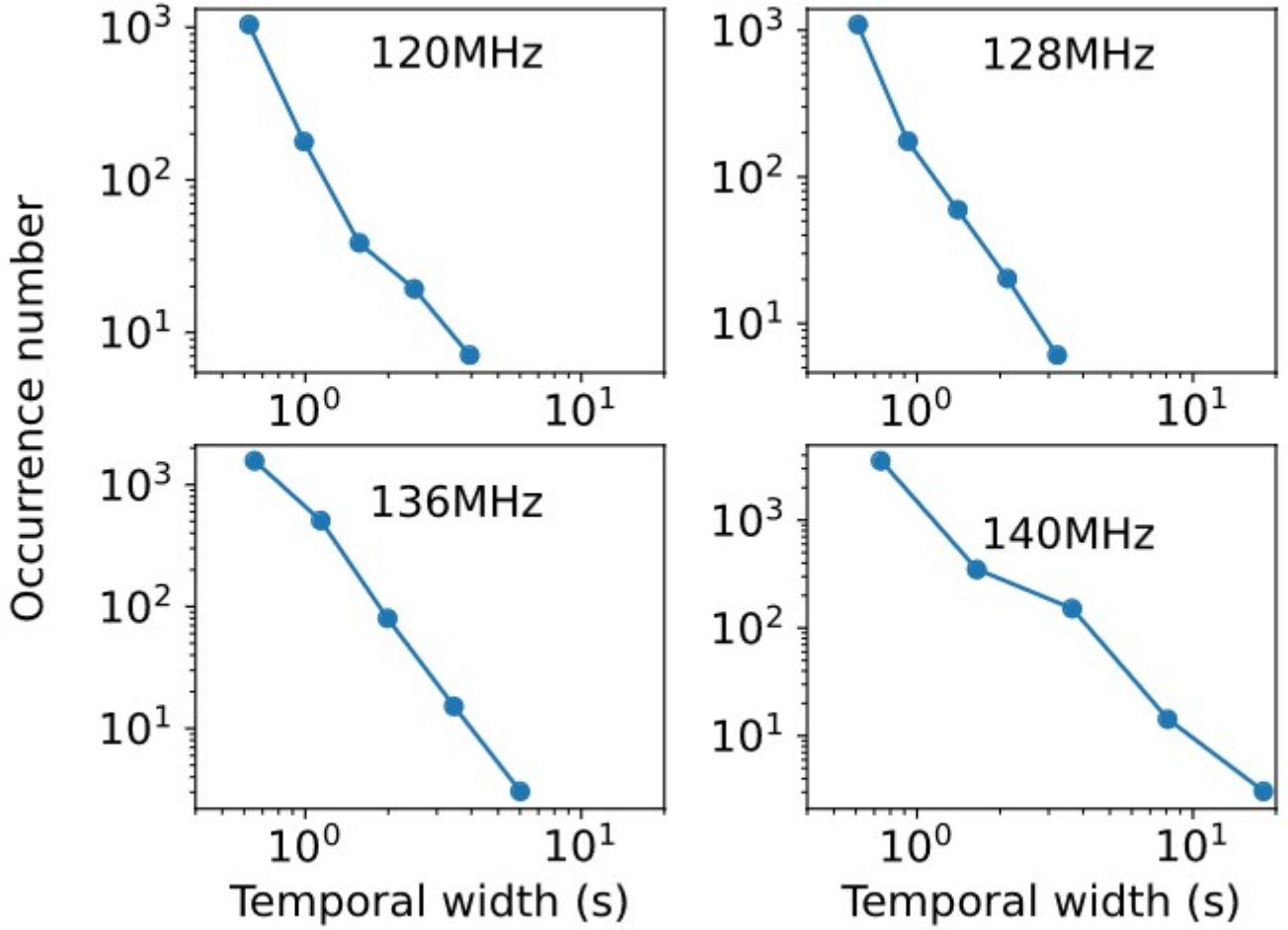
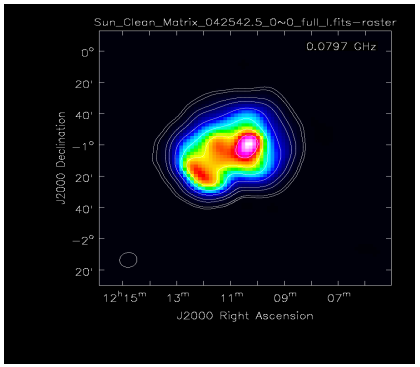
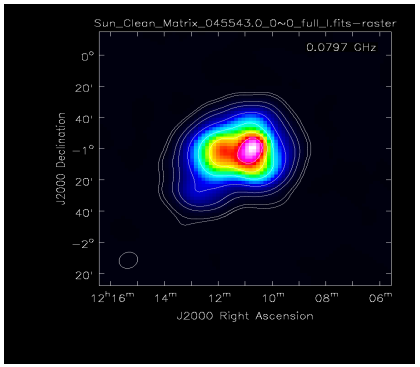


Figure 4. Temporal width distribution of the detected WINQSEs.


Sun_Clean_Matrix_042542.5_0~0_full_I.fits-raster
0.0797 GHz
J2000 Declination
J2000 Right Ascension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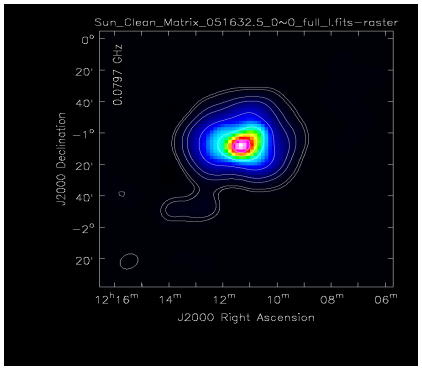
0.0797 GHz
J2000 Declination
J2000 Right Ascension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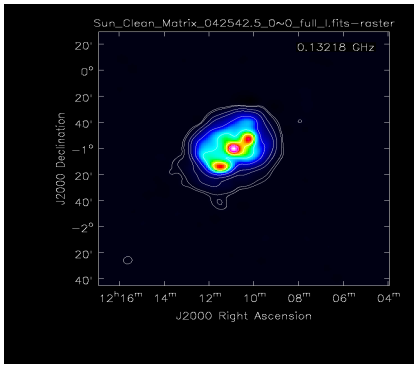
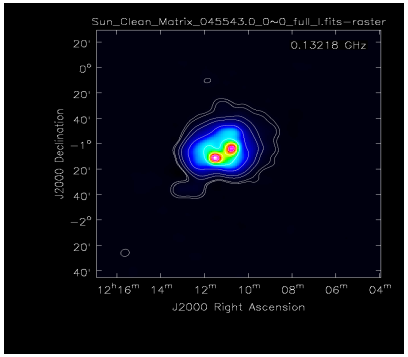
0.0797 GHz
J2000 Declination
J2000 Right Ascension


Sun_Clean_Matrix_042542.5_0~0_full_I.fits-raster
0.13218 GHz
J2000 Declination
J2000 Right Ascension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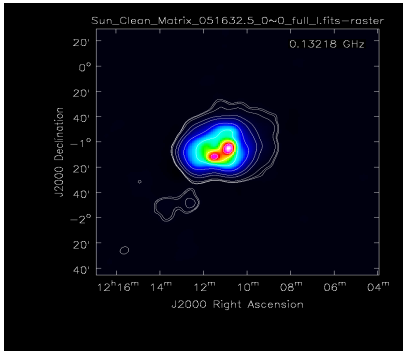
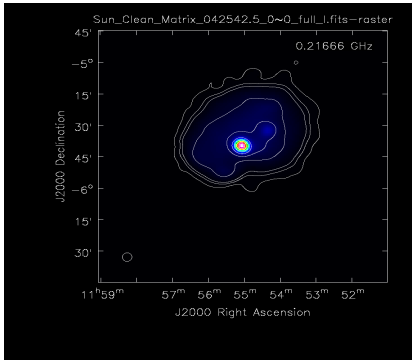
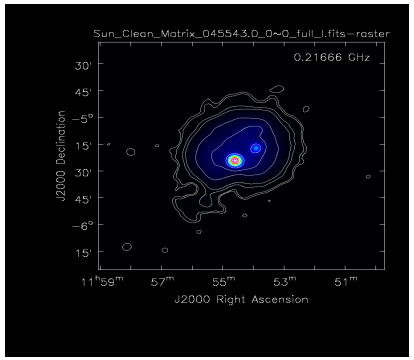
0.13218 GHz
J2000 Declination
J2000 Right Ascension


Sun_Clean_Matrix_051632.5_0~0_full_I.fits-raster
0.13218 GHz
J2000 Declination
J2000 Right Ascension


Sun_Clean_Matrix_042542.5_0~0_full_I.fits-raster
0.21666 GHz
J2000 Declination
J2000 Right Ascension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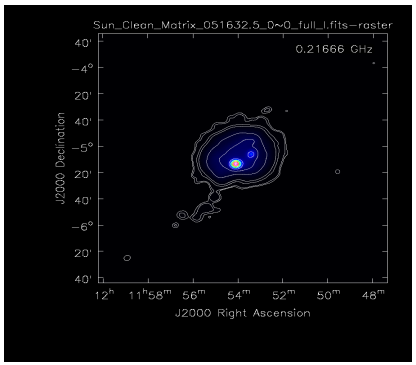
0.21666 GHz
J2000 Declination
J2000 Right Ascension


Sun_Clean_Matrix_0516.32.5_0~0_full_I.fits-raster
0.21666 GHz
J2000 Declination
J2000 Right Ascension