Simultaneous solar flares observations in X-rays and meter wavelengths using STIX and MWA

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FHNW, Windisch, Switzerland

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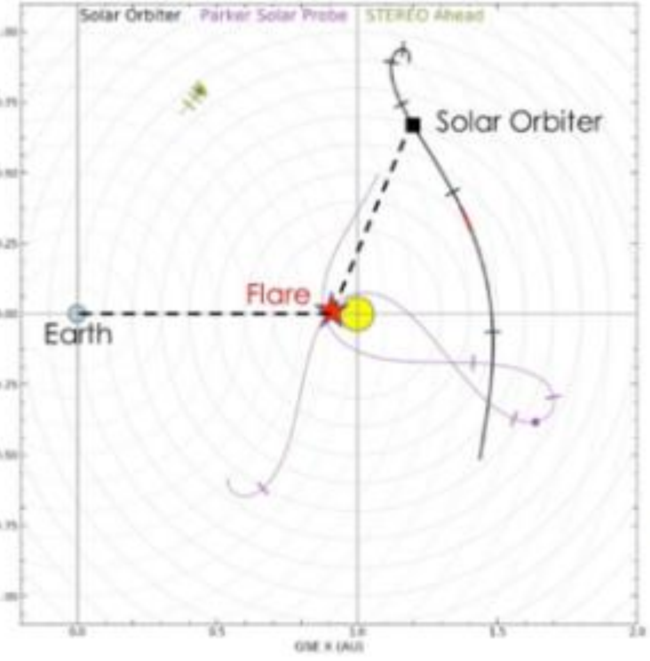
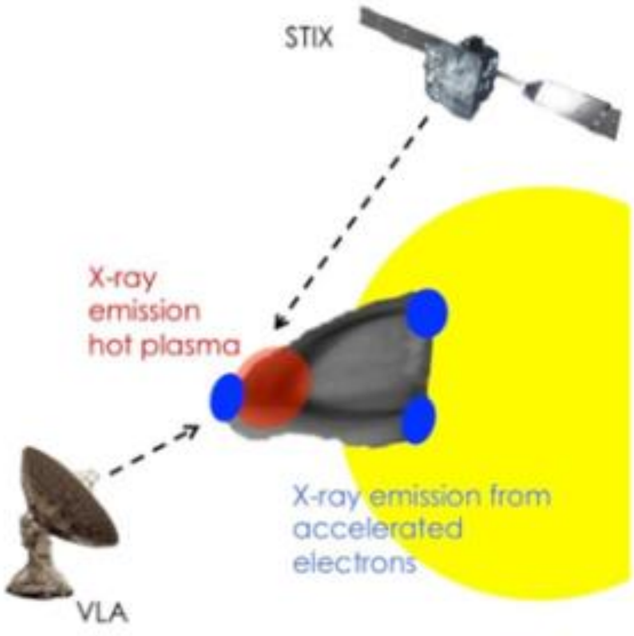
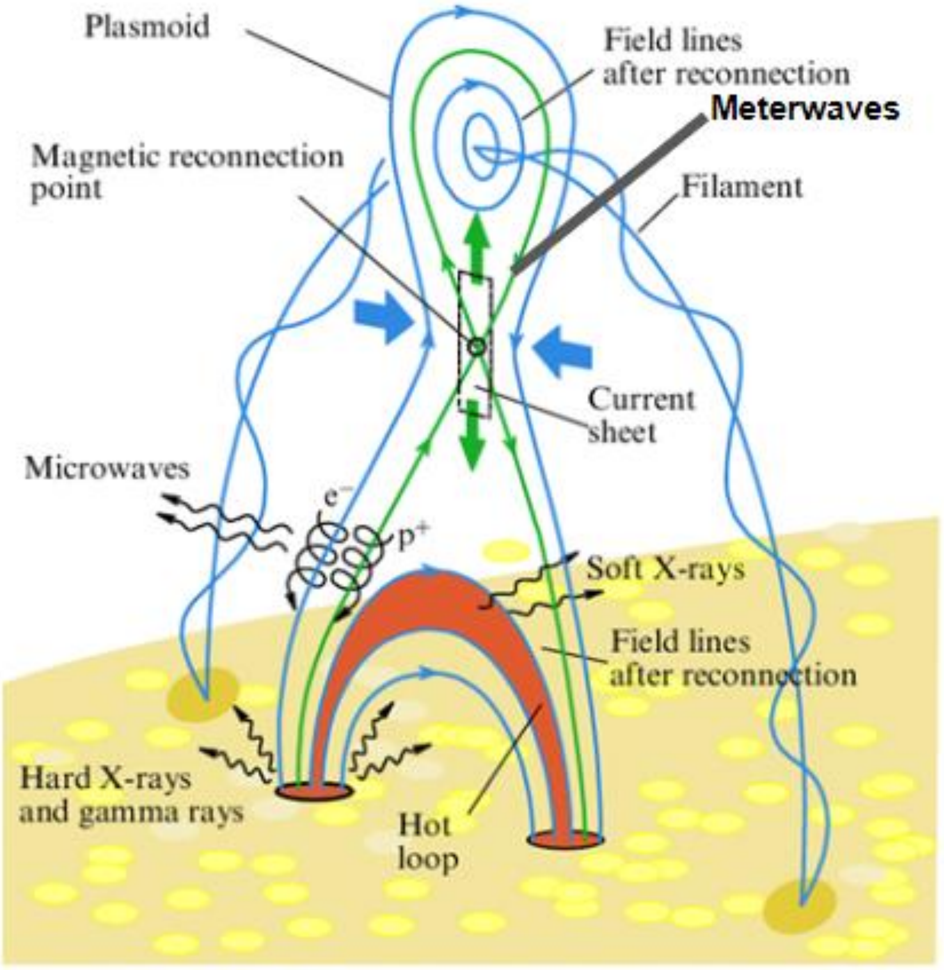
STIX Meeting 2023, Wrocław, Poland

Novelty in STIX-MWA Observations (3-D Picture)







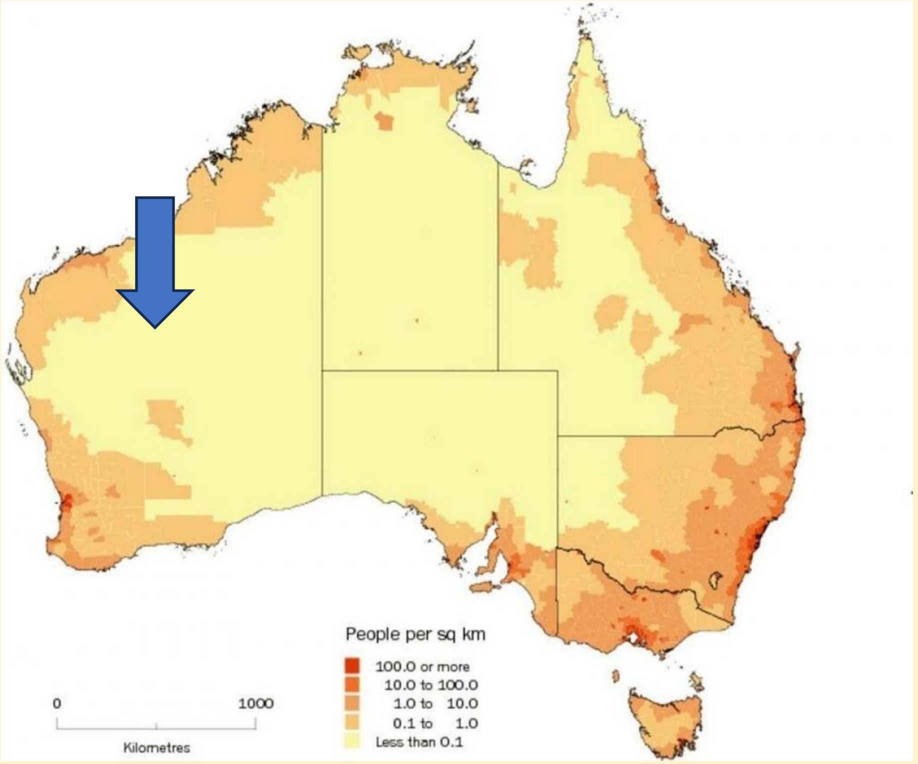
Murchison Widefield Array

Murchison Widefield Array

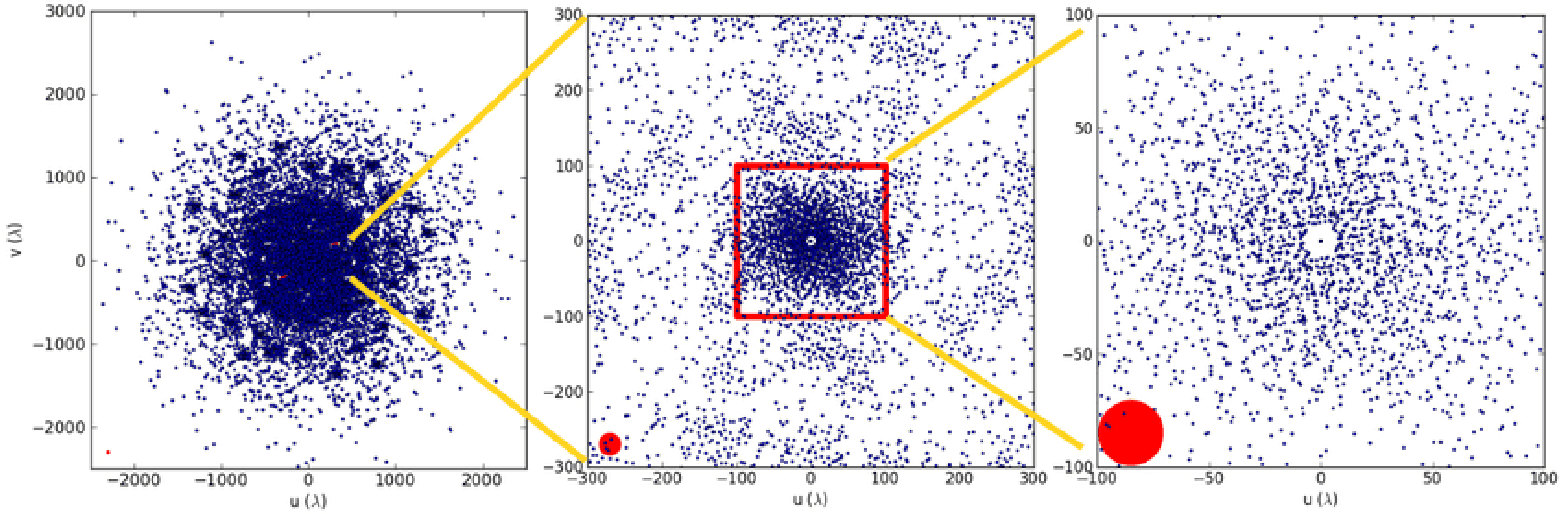
- MWA situated in Western Australia is a precursor of Square Kilometer Array (SKA). It operates in frequency range 80-300 MHz.

Parameters	150 MHz	200 MHz
Number of tiles	128	128
Area of one tile at zenith (m^2)	21.5	19.8
Total collecting area (m^2)	2752	2534
Receiver temperature (K)	50	25
Typical sky temperature (K)	350	170
Field of view (deg^2)	610	375
Instantaneous bandwidth (MHz)	30.72	30.72
Spectral resolution (MHz)	0.04	0.04
Temporal Resolution	0.5s	0.5s
Polarization	Full Stokes	Full Stokes
Minimum baseline (m)	7.7	7.7
Maximum baseline (m)	2864	2864
Angular resolution (1.5 km array)	$\sim 3'$	$\sim 2'$
Angular resolution (3 km array)	$\sim 2'$	$\sim 1'$

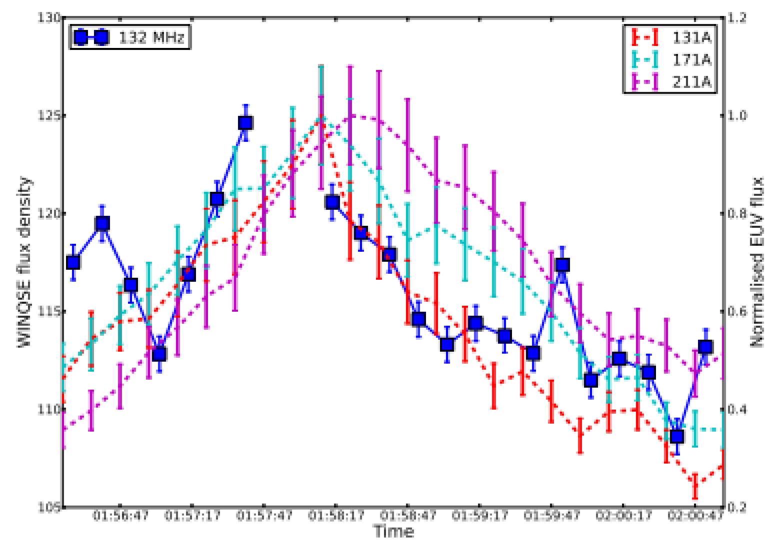
(Tingay et al. (2012)[4])

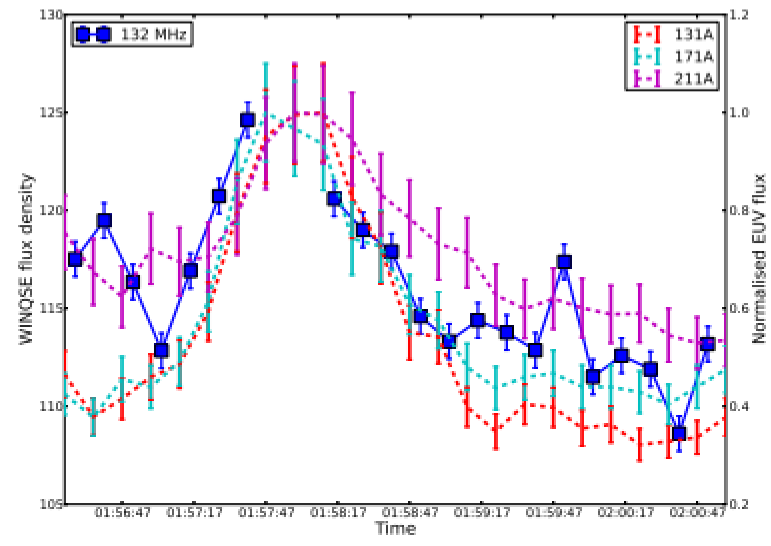


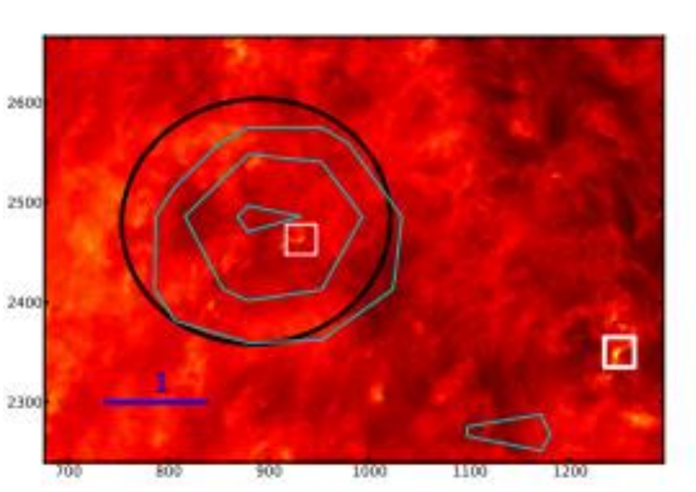
Instantaneous MWA UV Coverage



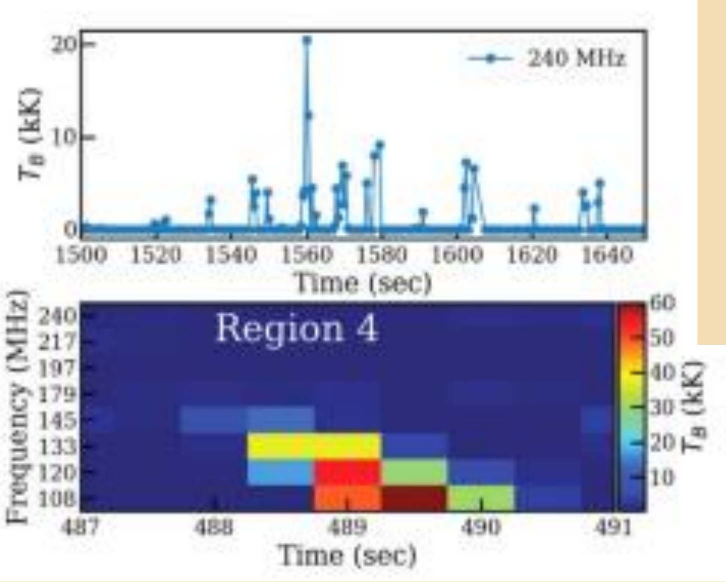
Weak and variable radio emission / bursts

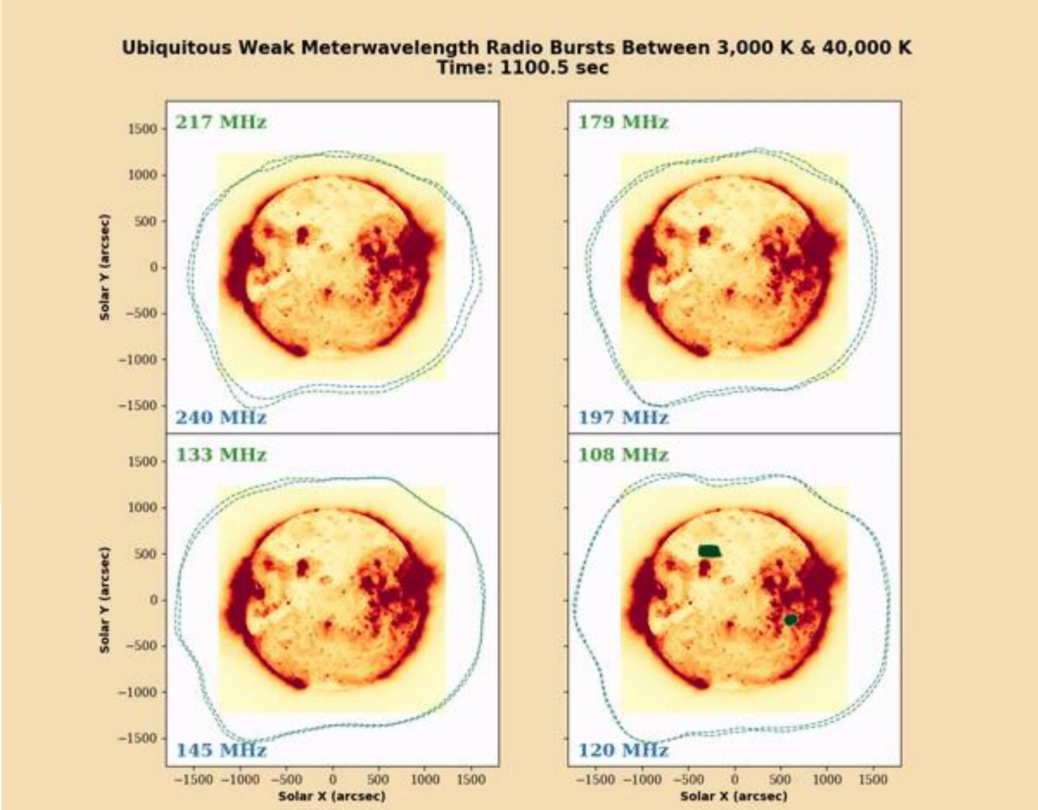






Mondal, S., 2021





Sharma, R., et al 2022

What is the origin of weak features?

- Electron beams
- Plasma flow / Waves
- Emission mechanisms

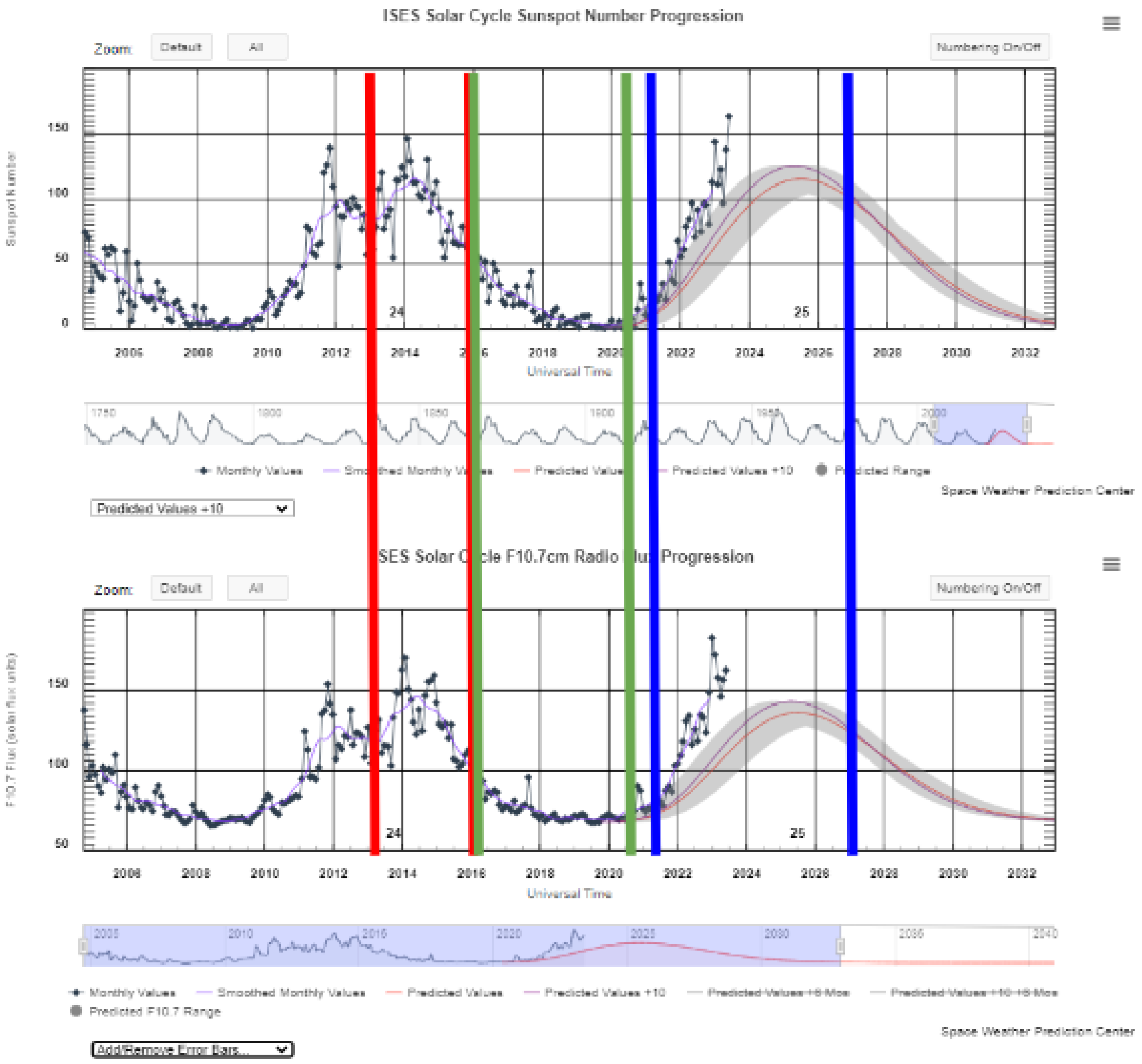
Solar Observation with MWA

+ <u>**Phase-I (mid-2013 - 2016)**</u>
- Particle Acceleration in the outer corona during strong solar flare
- Scattering of radio waves / Coronal turbulence
- Coronal Mass Ejections

+ <u>Phase-II (2016 - mid-2021)</u>
- Compact & **Extended**
- **Solar Flares (less frequent)**
- ***Mark the extended times***

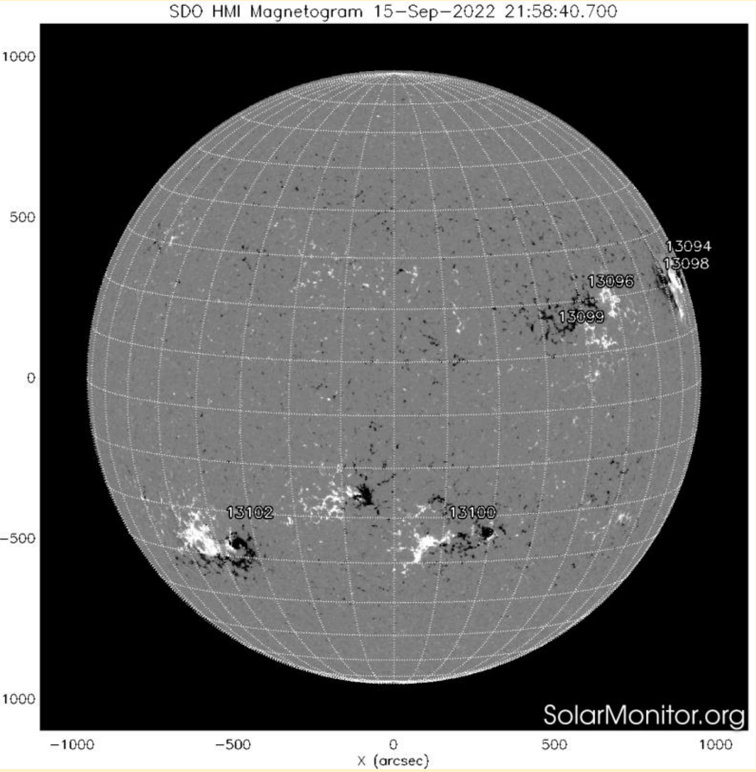
+ <u>Phase-III (2021-2026)</u>
- Suitable for all solar science cases with good spatial resolution and dense cores
- 25th Solar Maximum capture the rising phase of the cycle
- Not solar dedicated, solar maximum is ideal time
- 12 X-class flare per year
- Targeted / Trigger mode observation to catch a big flare

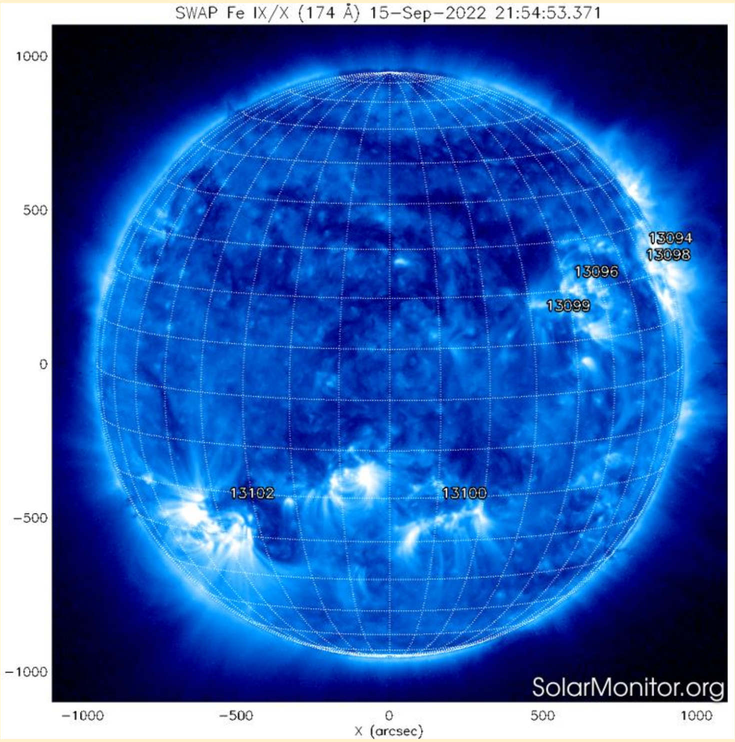
- **MWA Cycle 22 – 100 hours of observation between 1st May 2022 to 31st September 2022**
- **Best Observations in September month**

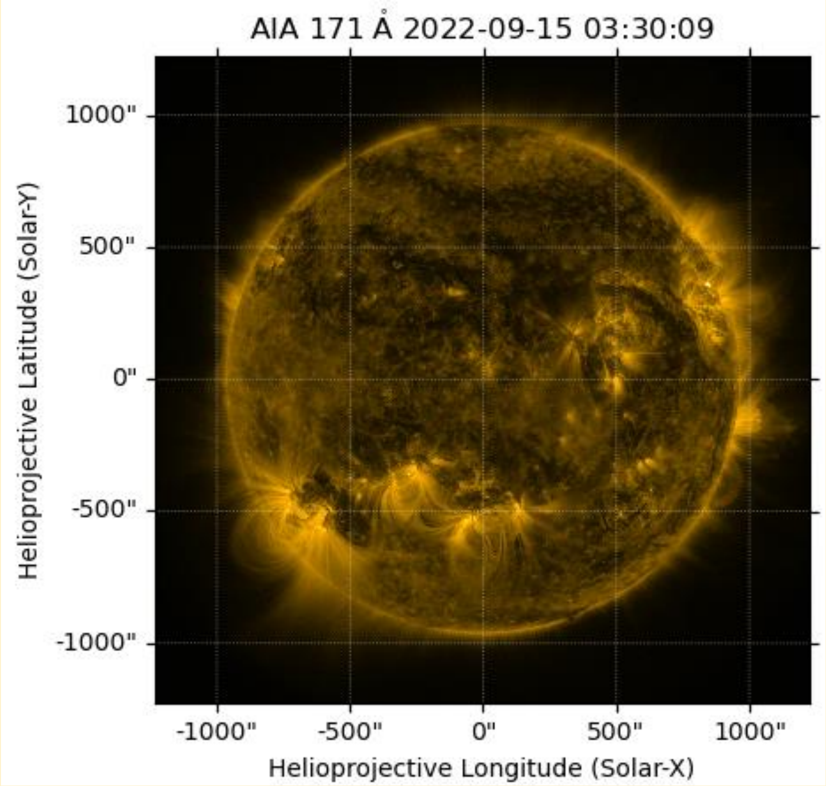


Phase-I Phase-II Phase-III

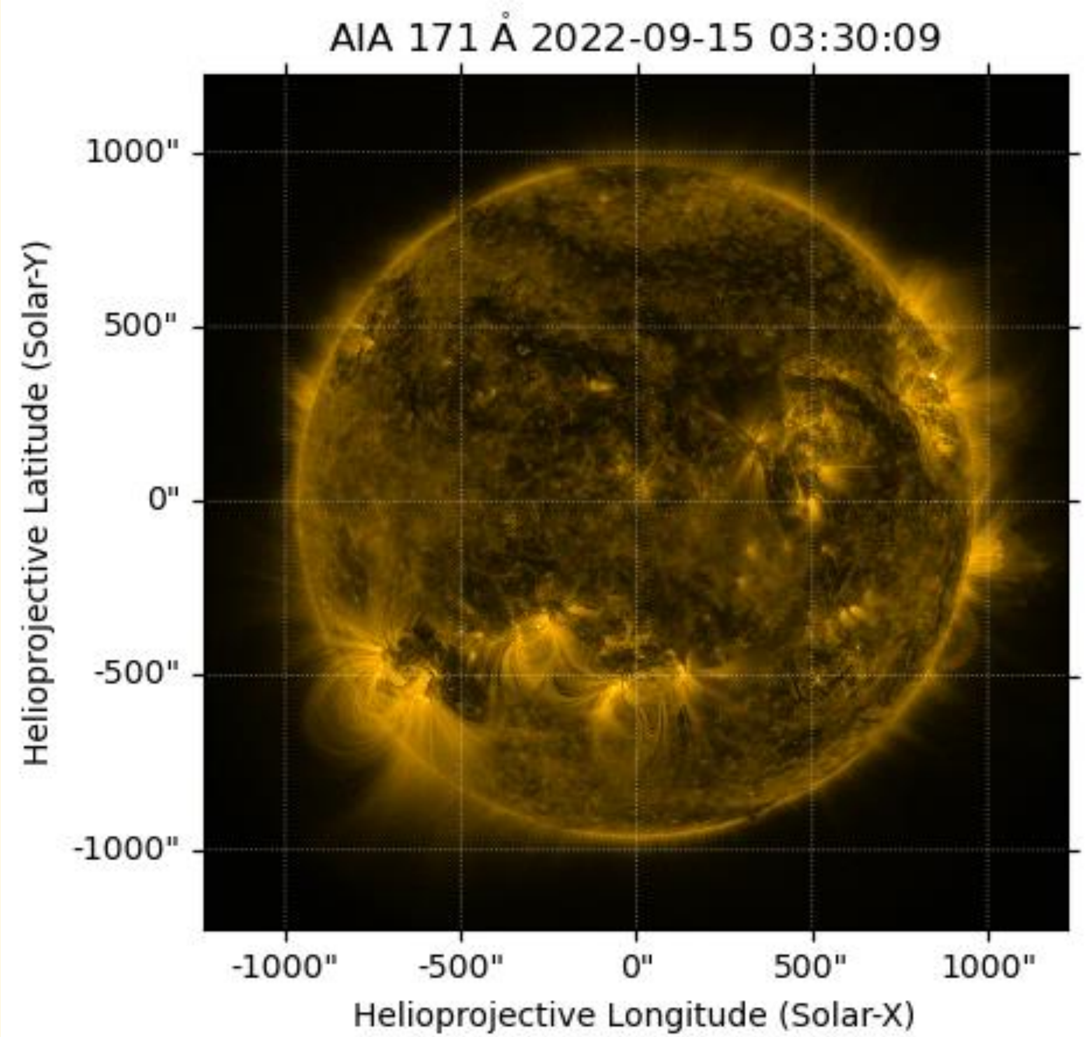
15th September 2022

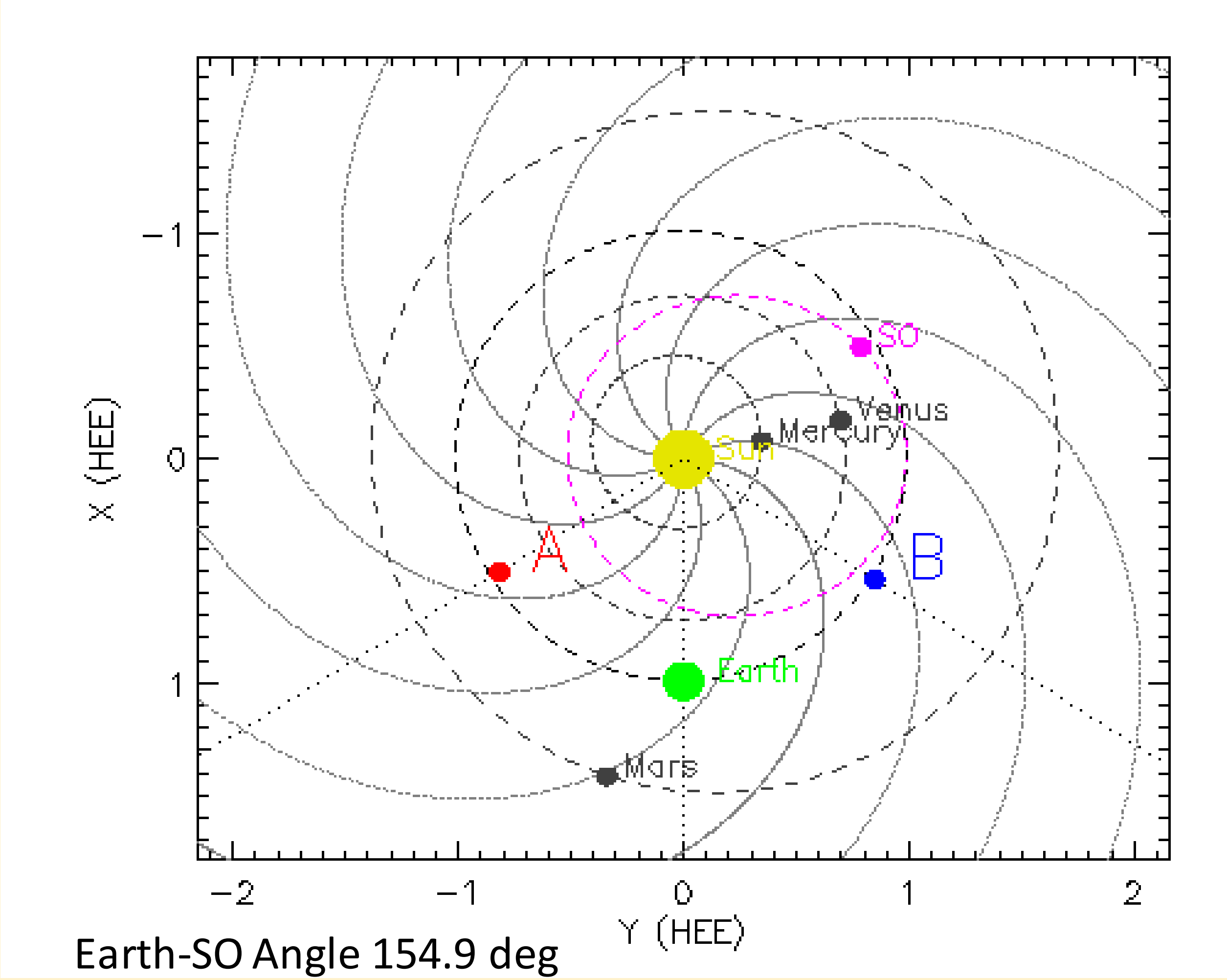






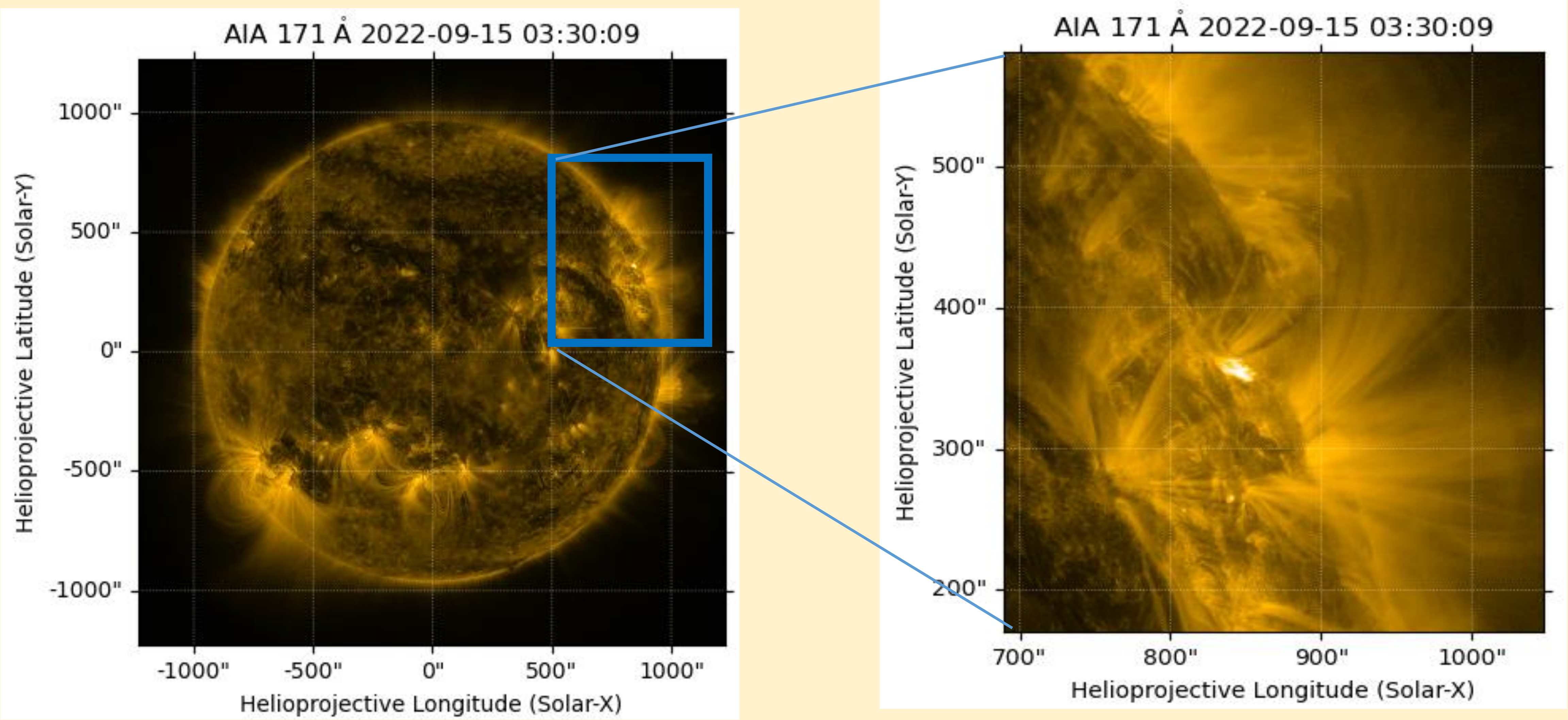
15th September 2022 – STIX Position



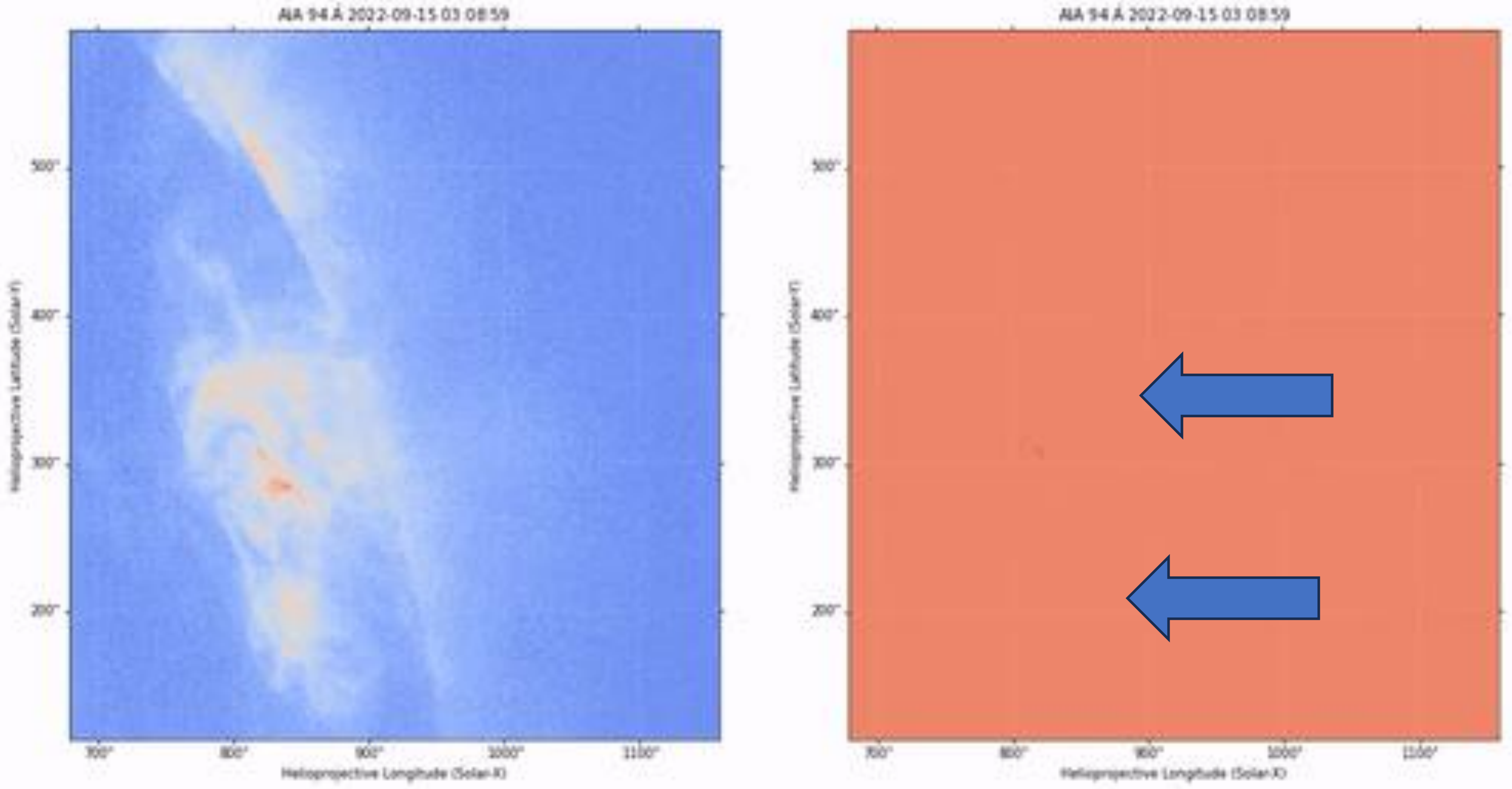


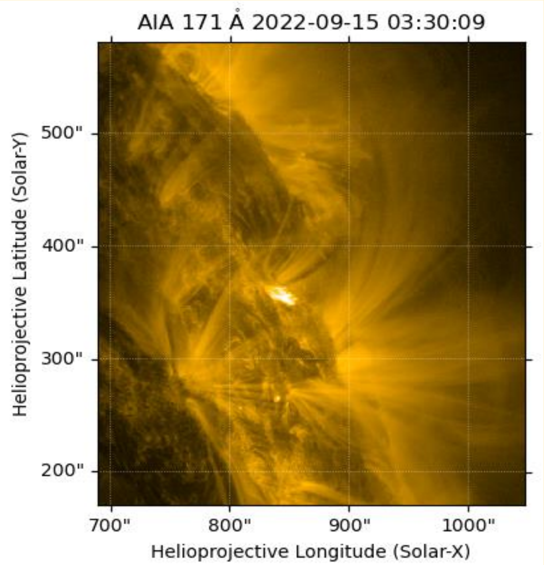
Earth-SO Angle 154.9 deg
Sun-SO distance 0.599 AU

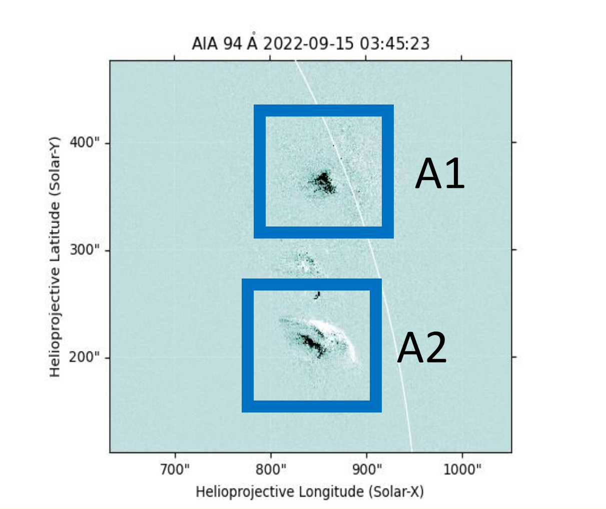
Event – AIA flare site



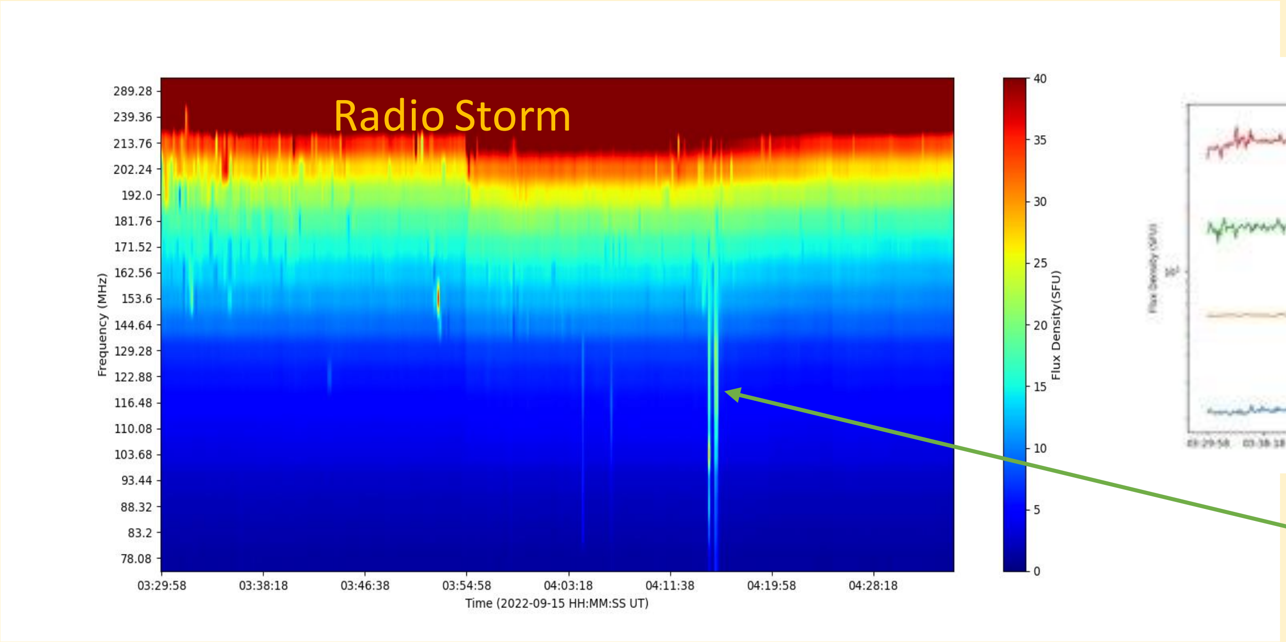
Event – AIA Movie

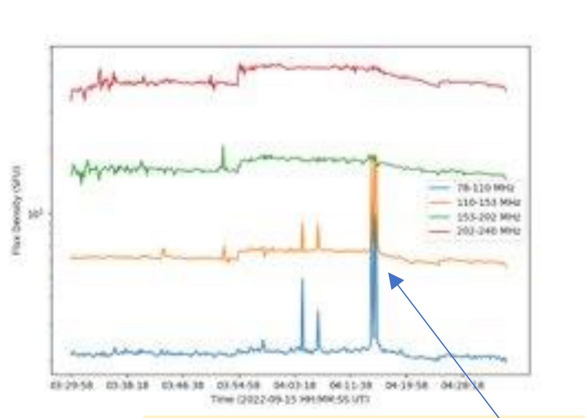


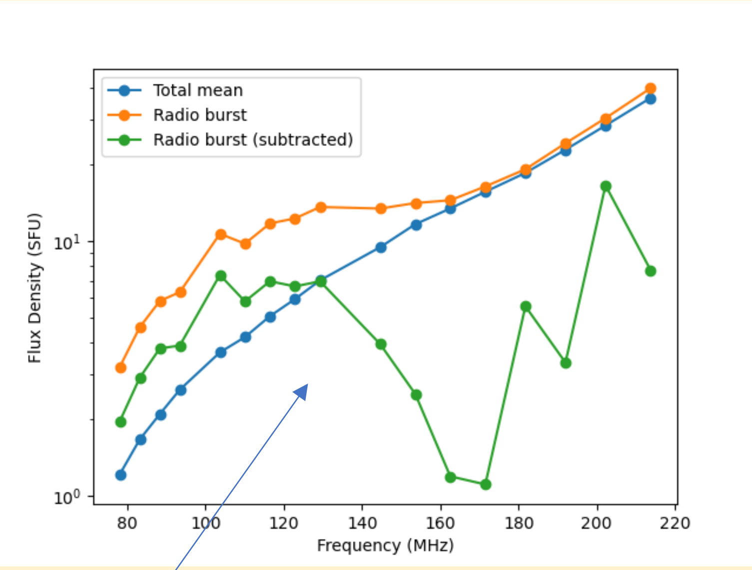




Event – Overall Radio Observations





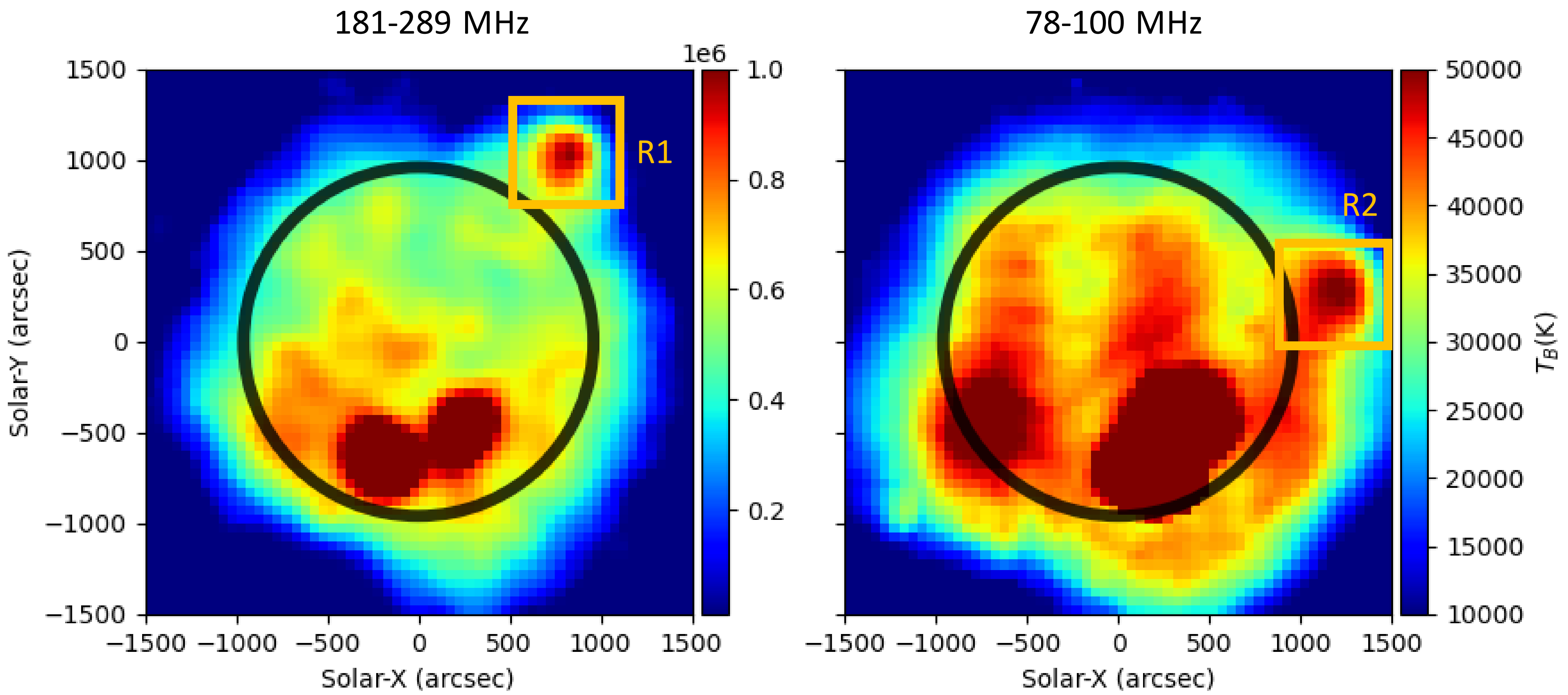


Radio burst

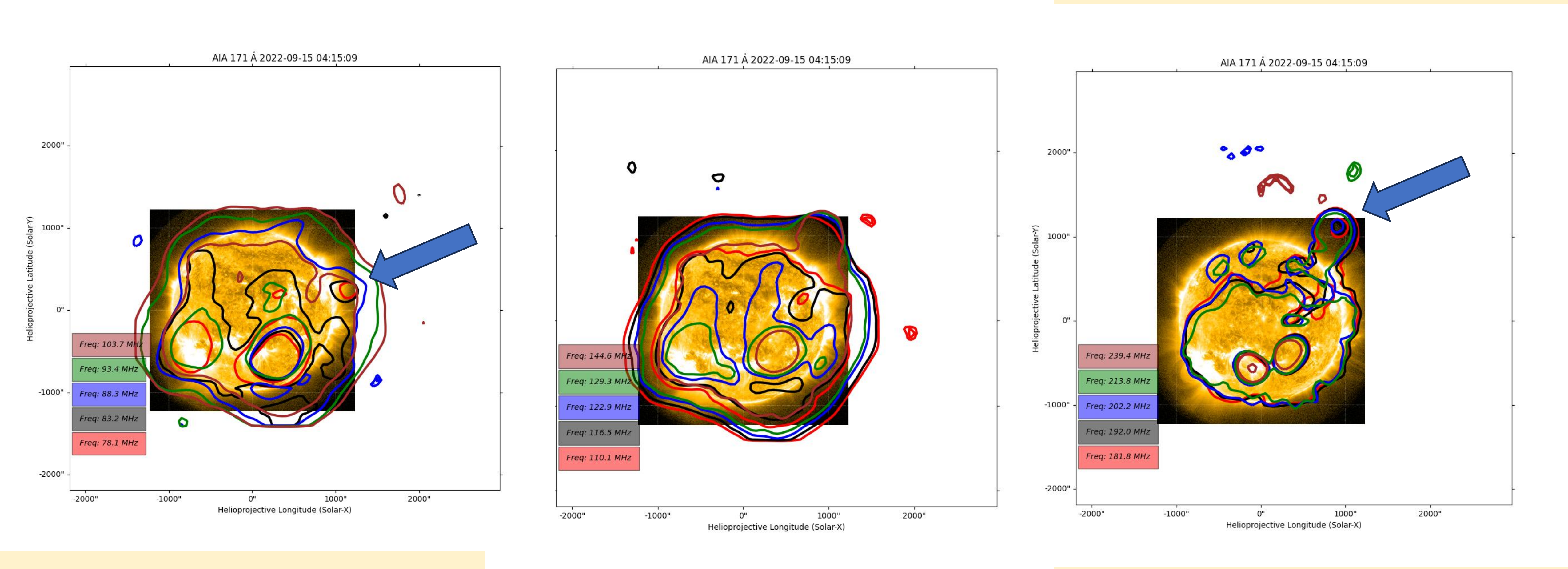
Initial analysis with 10 s time integration

Nothing from the flare here!

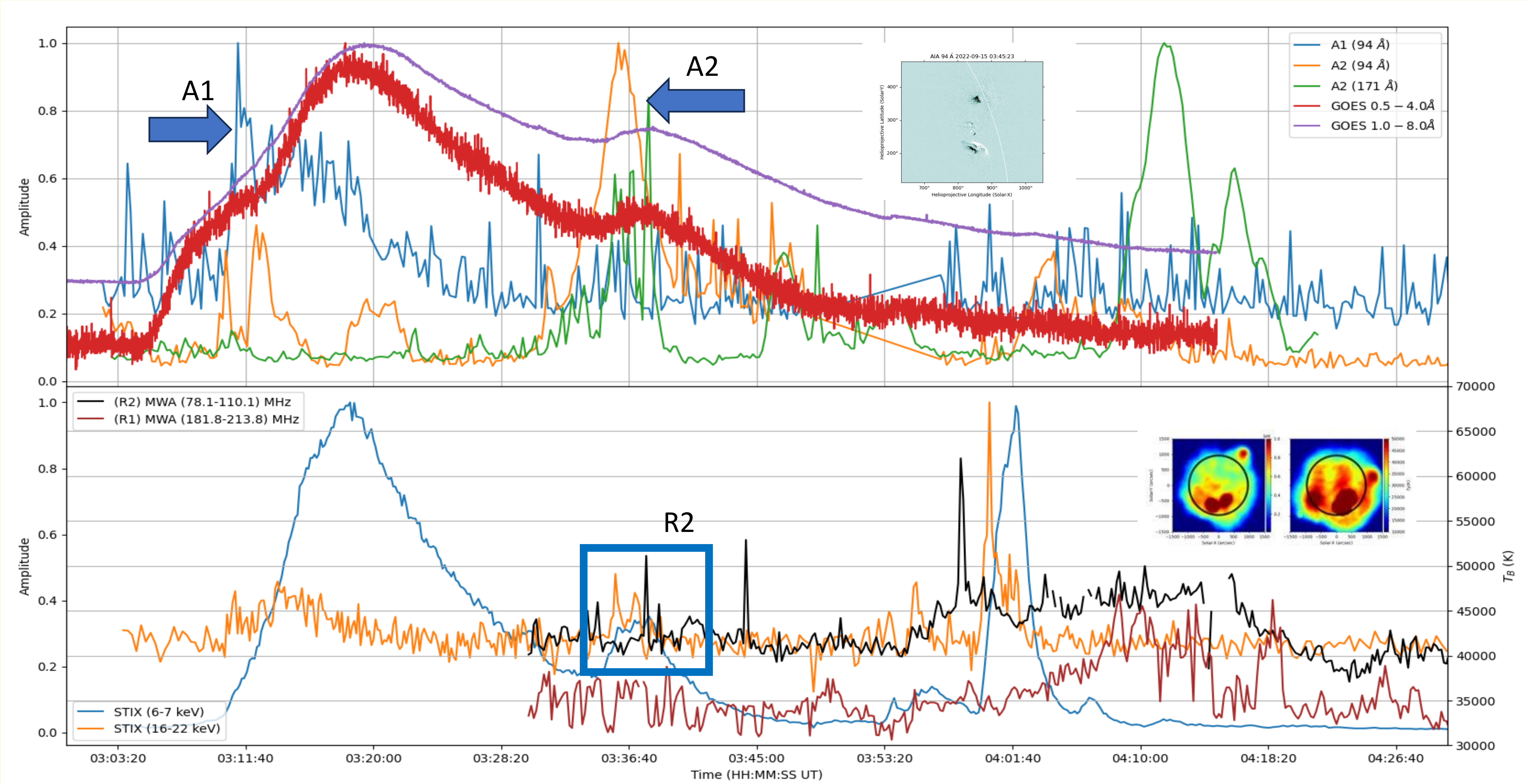
Event – Radio Images

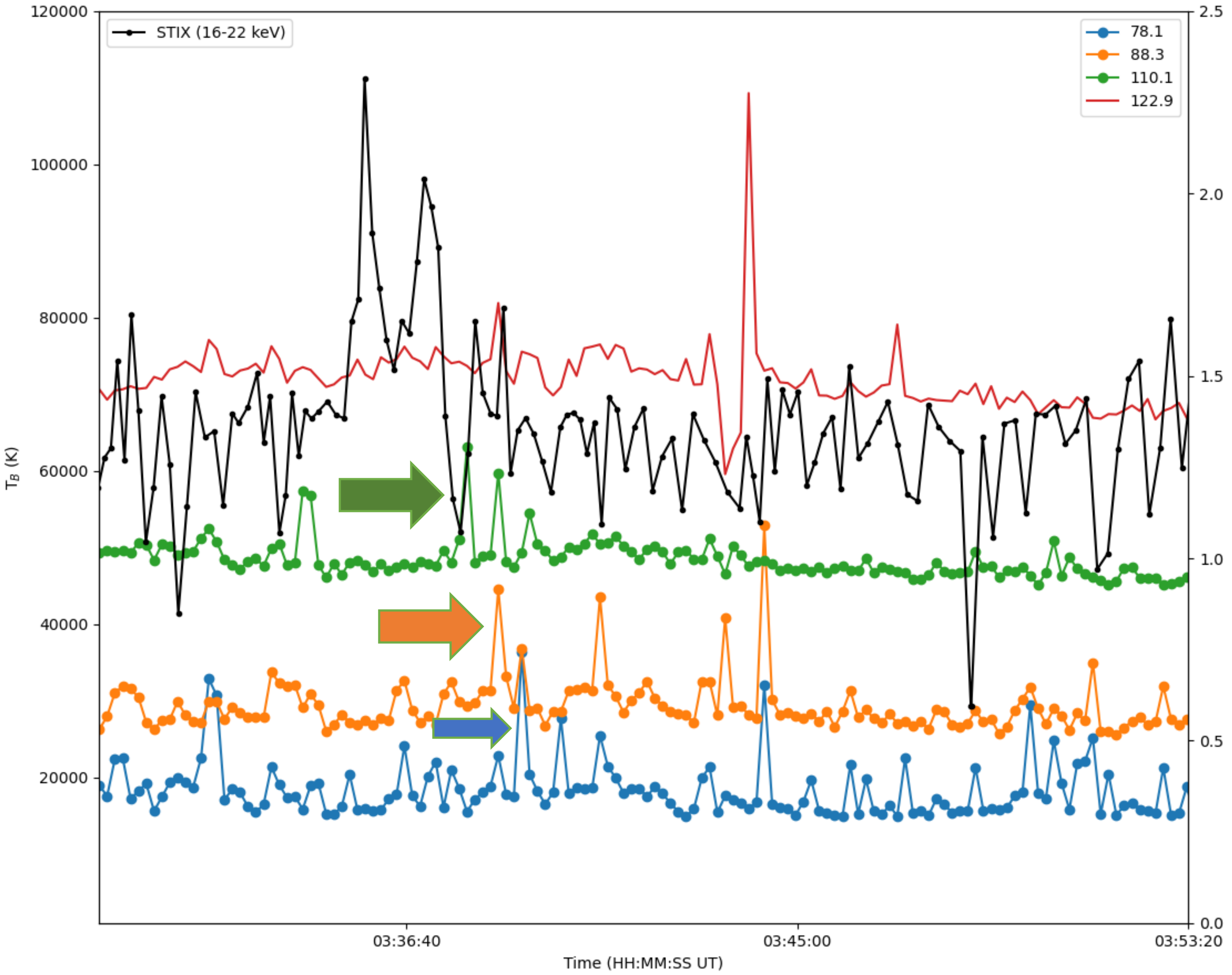


Combined Radio Contours and EUV

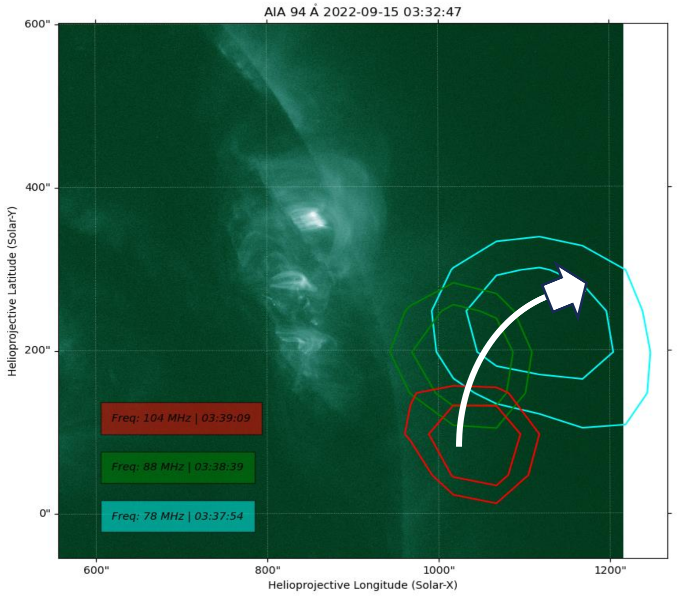


Temporal Evolution and Complexities

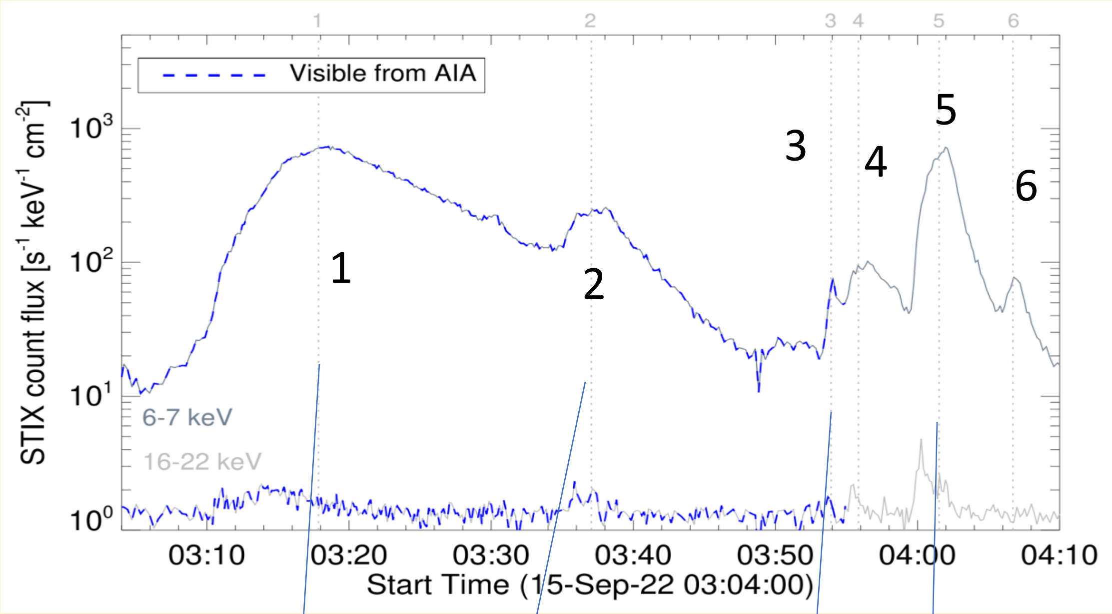


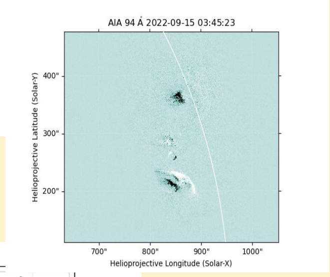


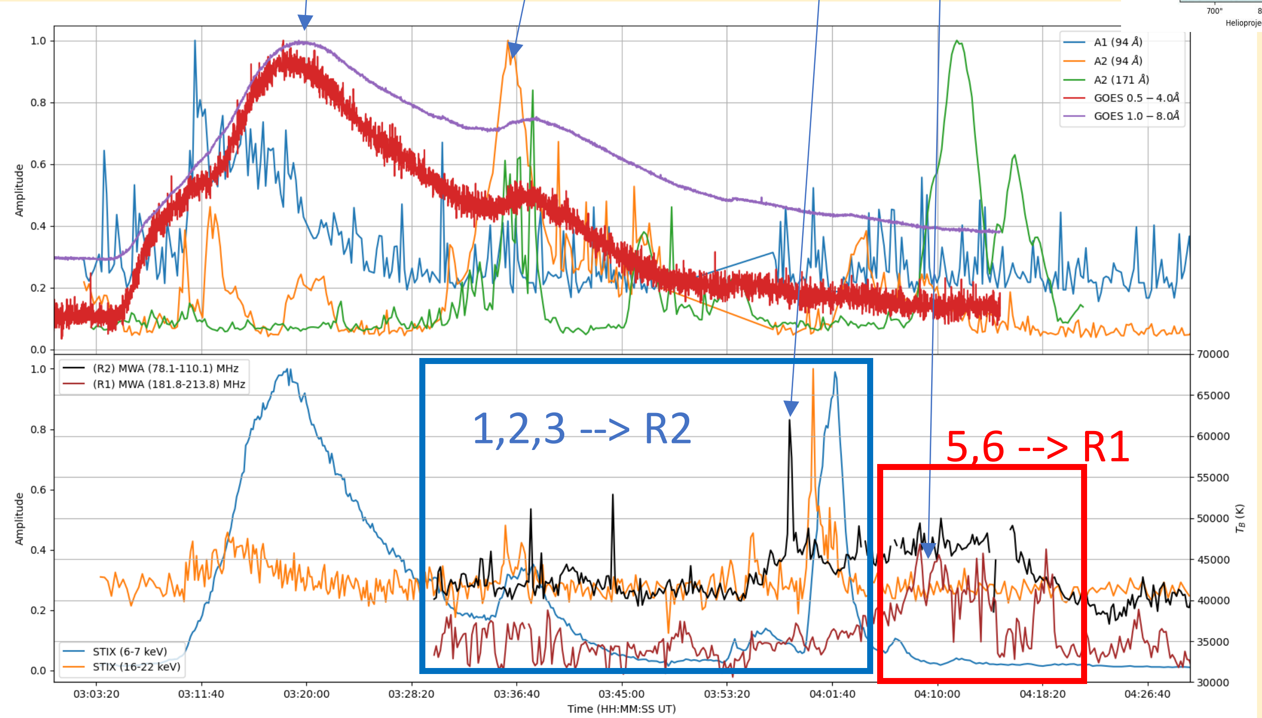
+ Radio Drift frequency: 110 MHz to 78 MHz
+ Time difference: 60 seconds
+ Radio Drift Rate: 0.45 MHz/s
+ Drift speed for electron: 0.62 Mm/s ~ 620 km/s
+ HXR & 110 MHz peak time difference: 60 sec / rate

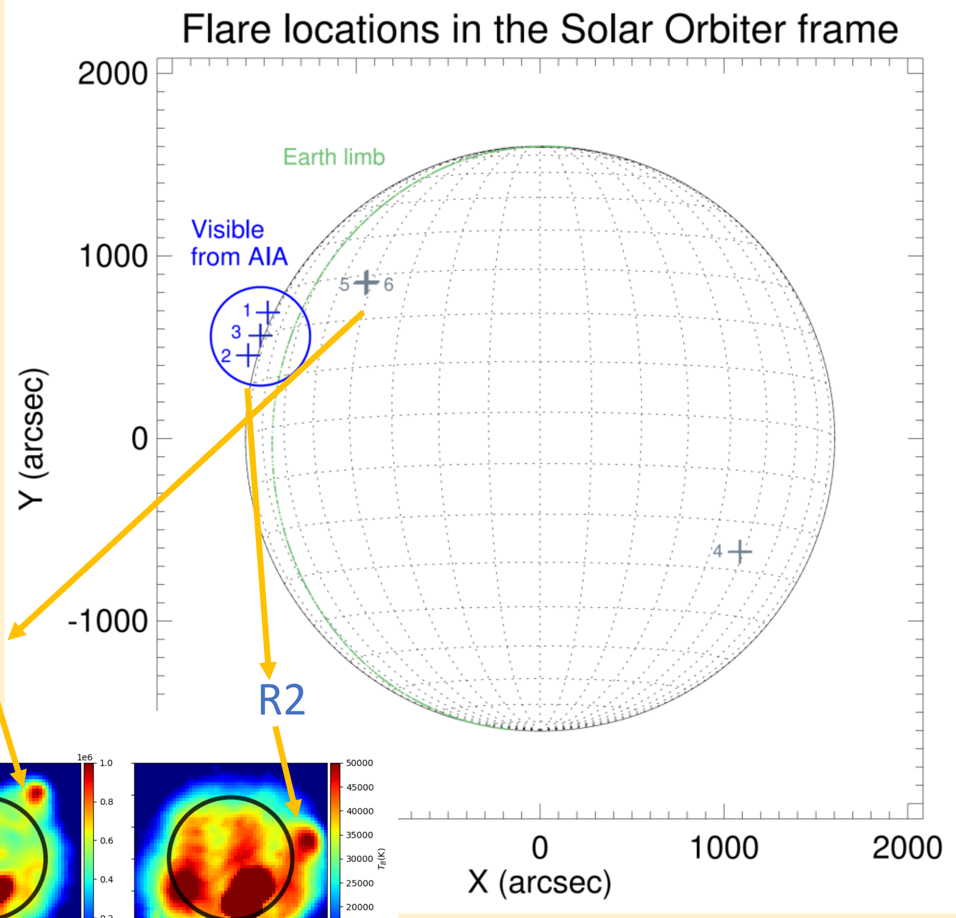


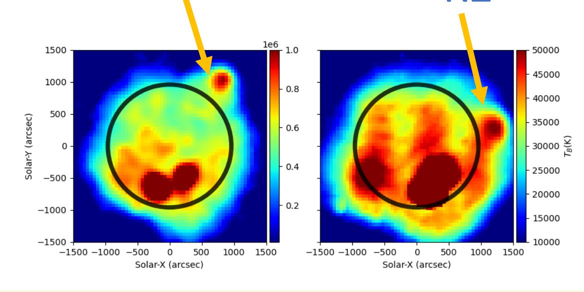
STIX light curve & Source locations



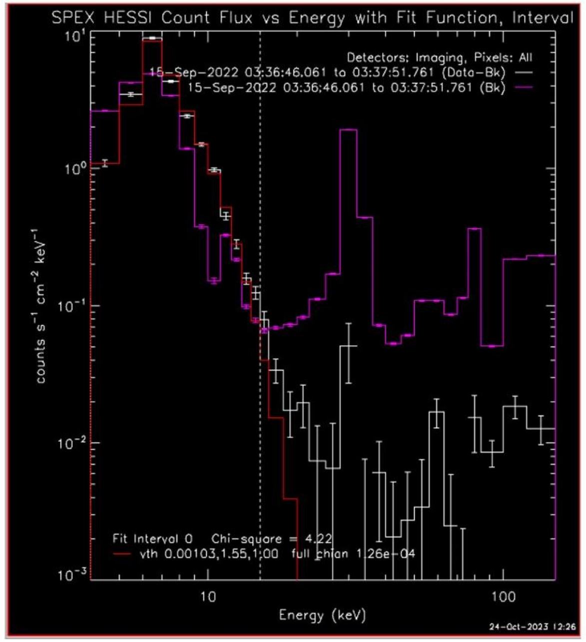




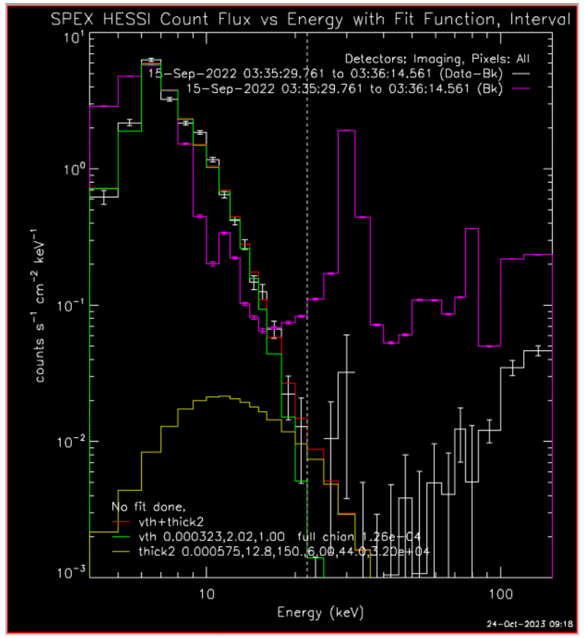




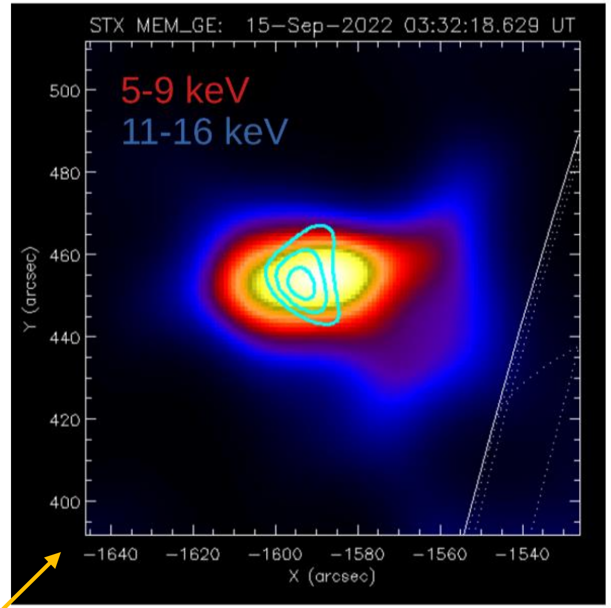
Flare #2, peak 2



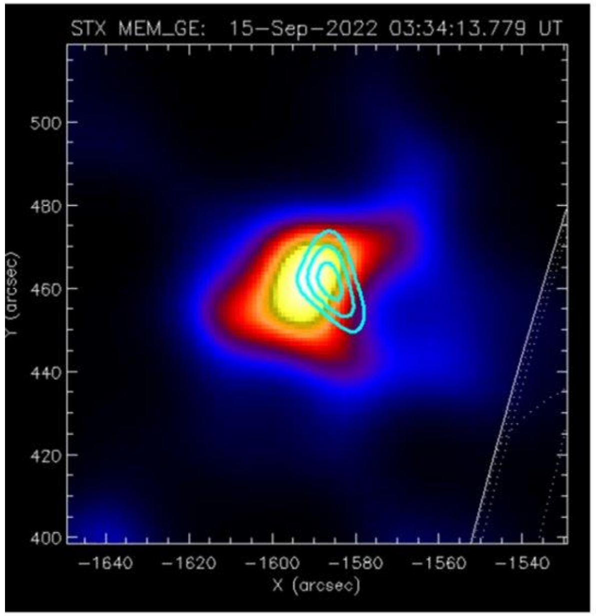
Flare #2, peak 1

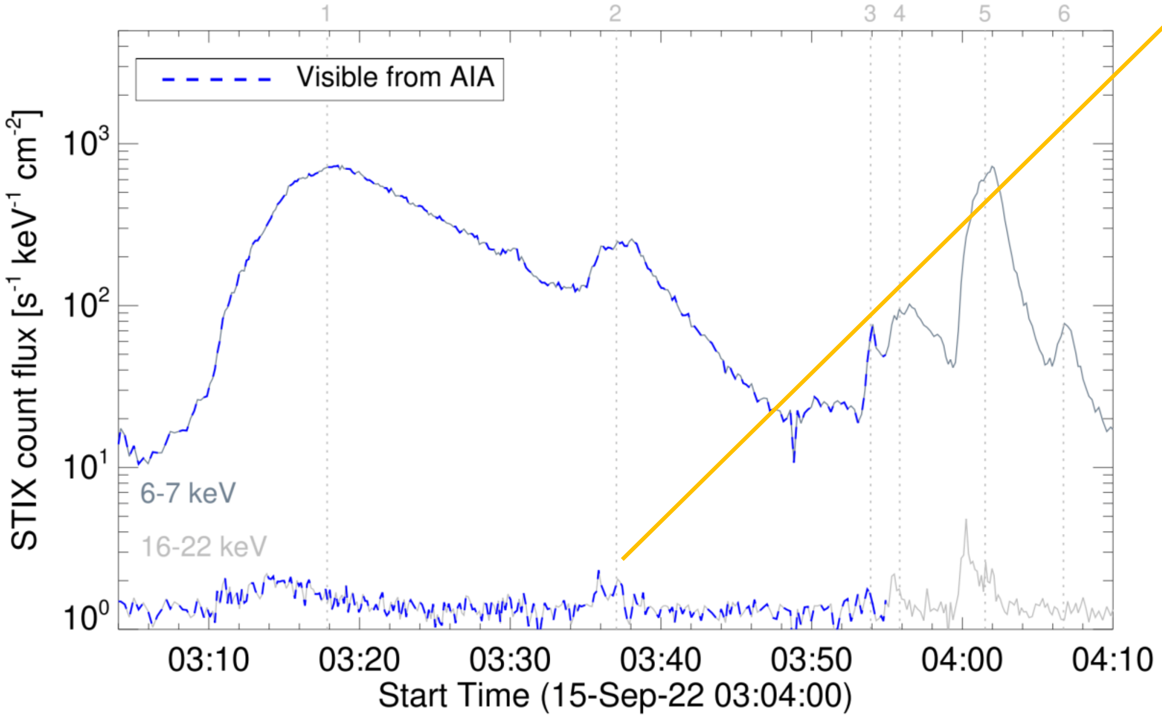


Flare #2, peak 1

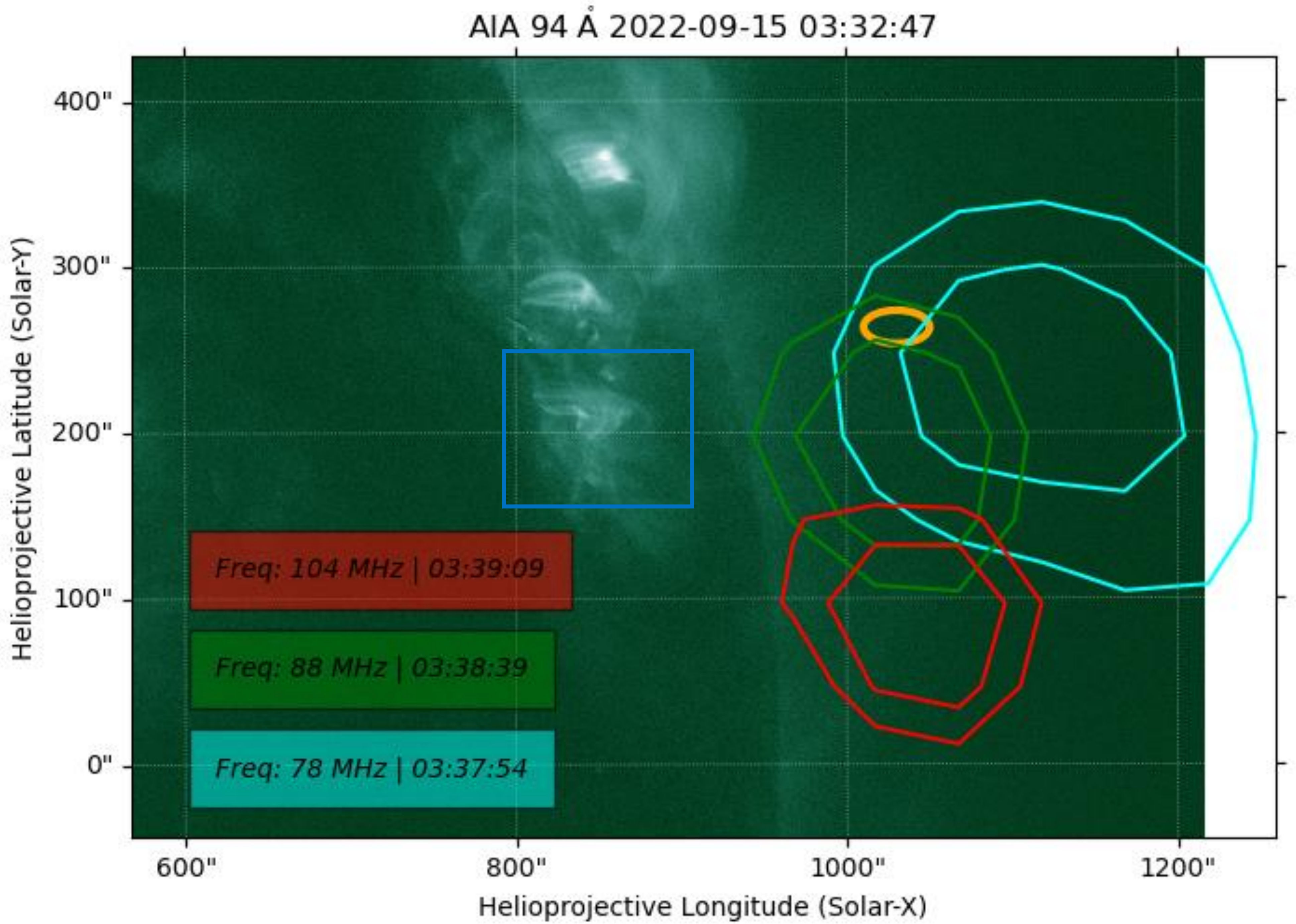


Flare #2, peak 2

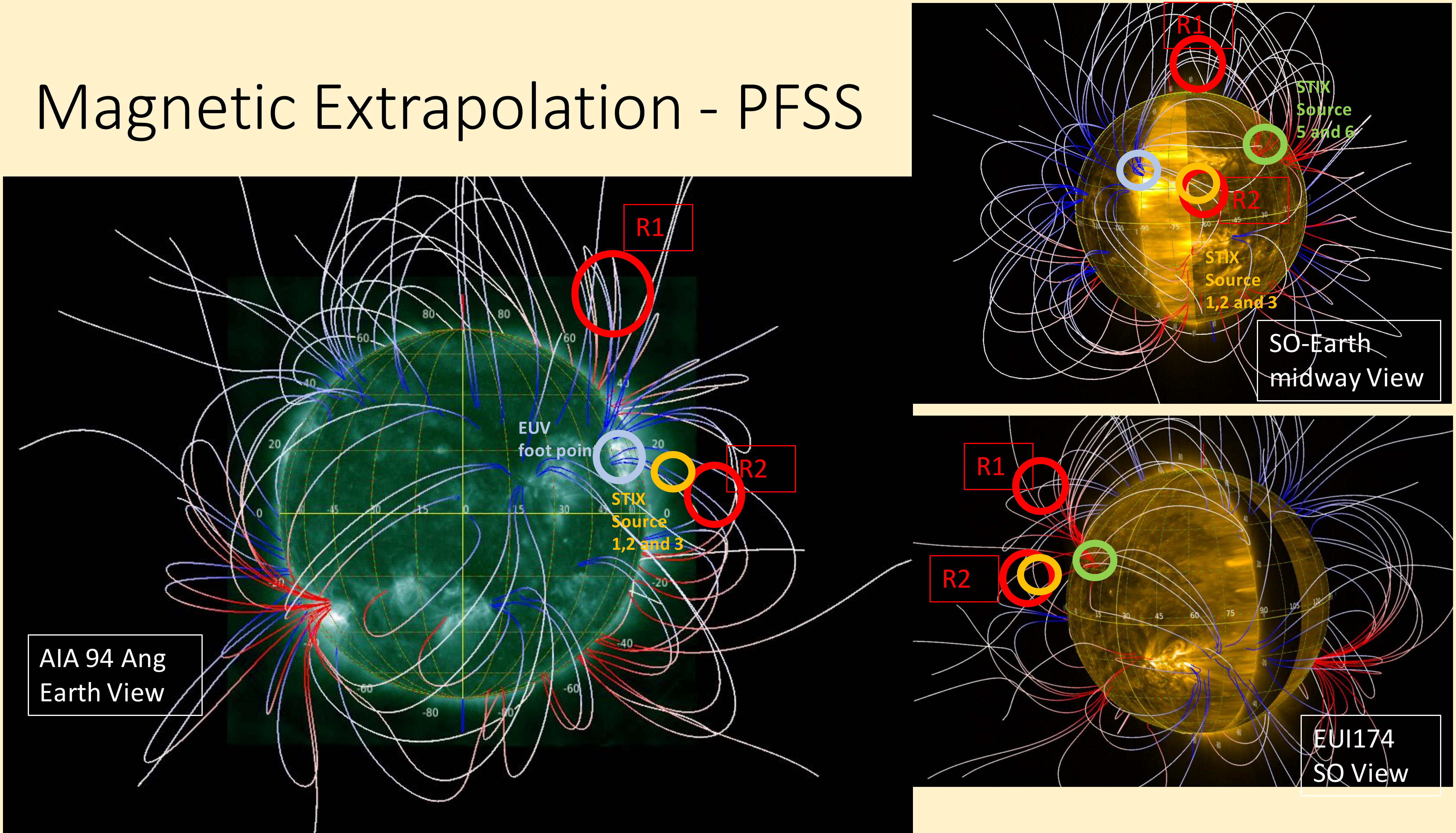




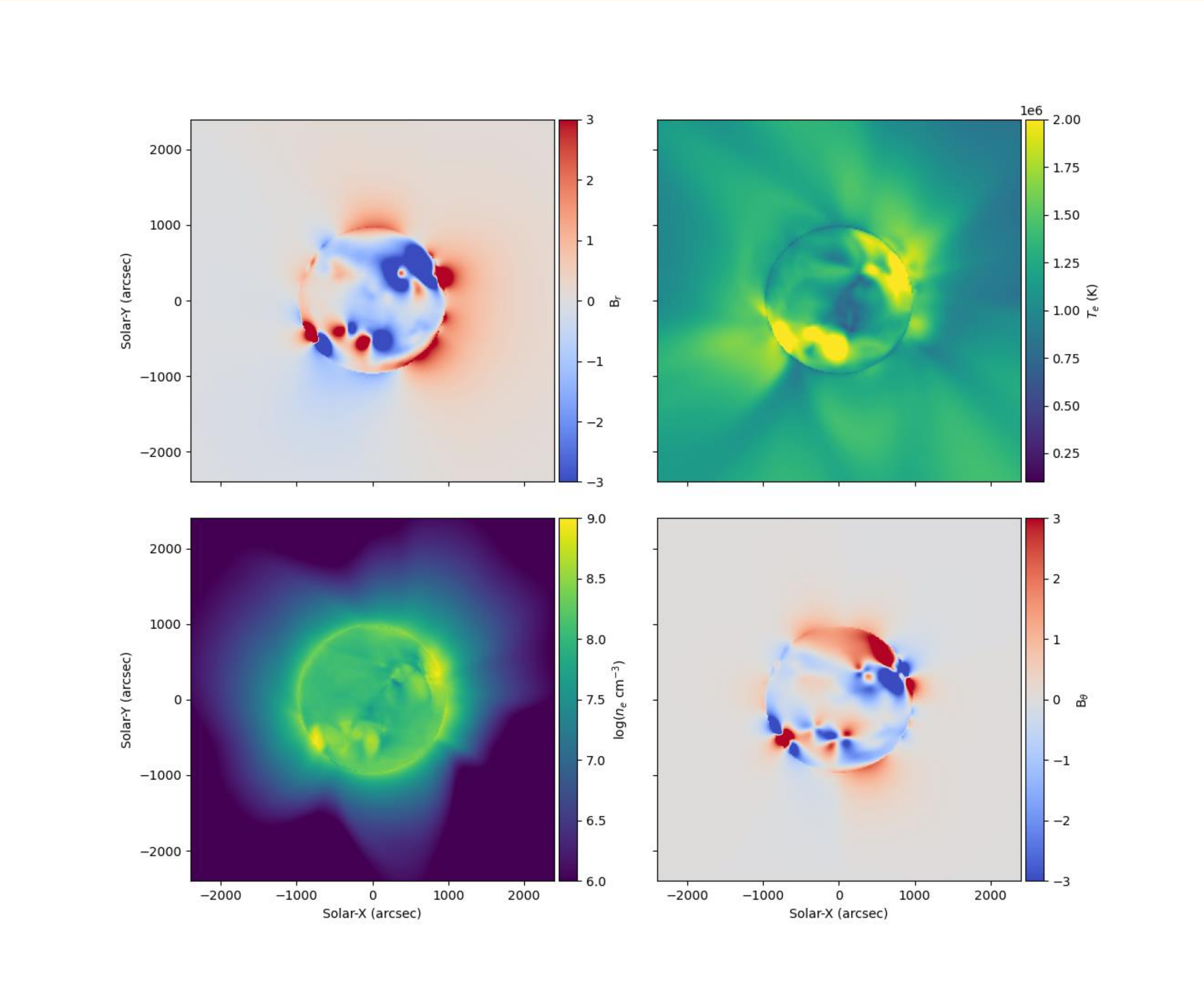
- Peak1: EM ~ $3.23*10^{45}$ cm^{-3}
- Peak2: EM ~ $1.03*10^{46}$ cm^{-3}
- Volume: $(40''*20'')^{1.5}$ = $(1.5^{18}$ cm$^2)^{1.5}$ = $1.8*10^{27}$ cm^3
- Thermal density Peak 1 : 6.1e8 cm^-3 / Fundamental Plasma frequency ~ 220 MHz
- Thermal density Peak 2 : 1.1e9 cm^-3 / Fundamental Plasma frequency ~ 300 MHz

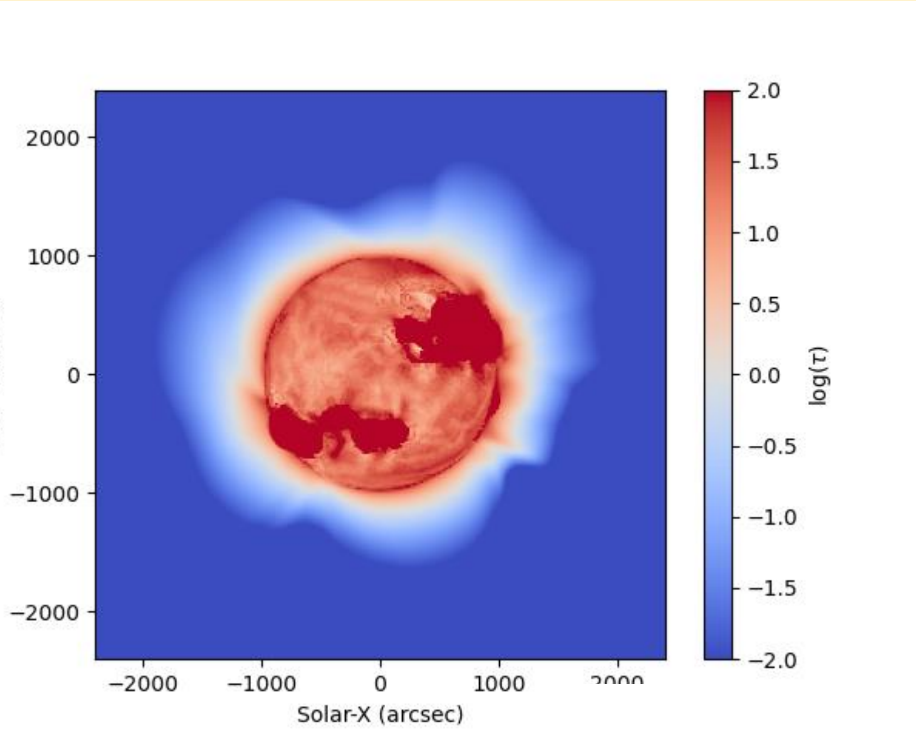

AIA 94 Å 2022-09-15 03:32:47
Helioprojective Latitude (Solar-Y)
Helioprojective Longitude (Solar-X)
400"
300"
200"
100"
0"
600"
800"
1000"
1200"
Freq: 104 MHz | 03:39:09
Freq: 88 MHz | 03:38:39
Freq: 78 MHz | 03:37:54

Magnetic Extrapolation - PFSS



Magnetic Extrapolation – PSIMAS models / FORWARD

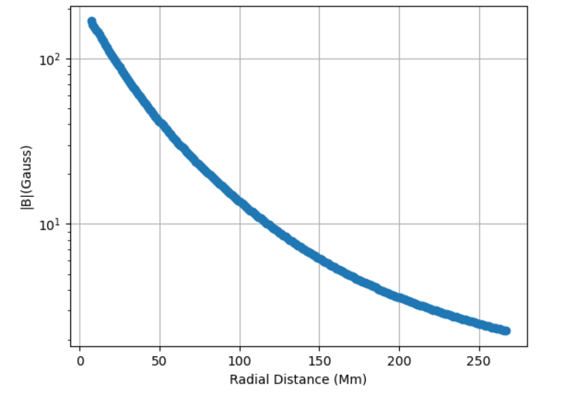




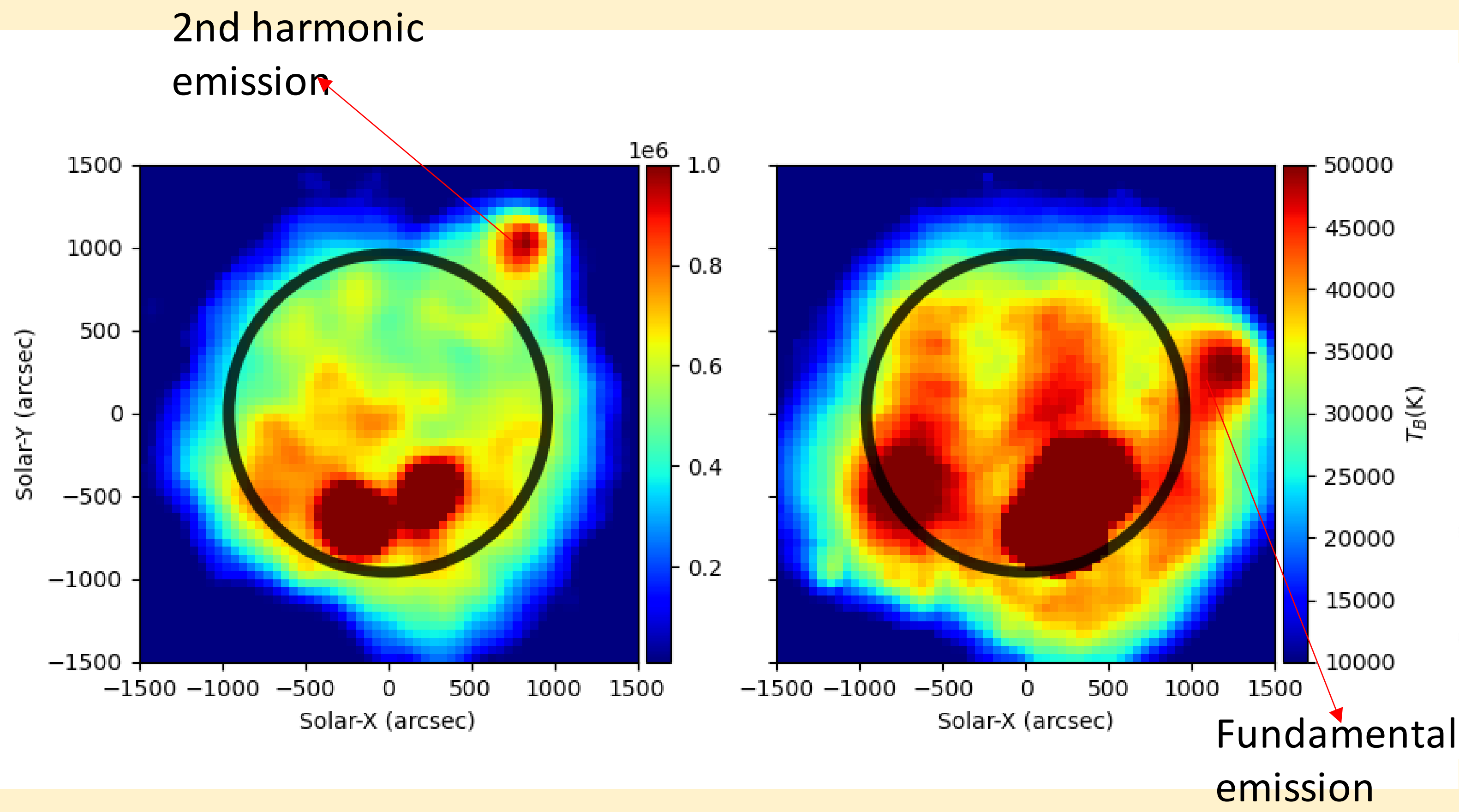
R1- Electron density $1.4*10^7$ cm^{-3}

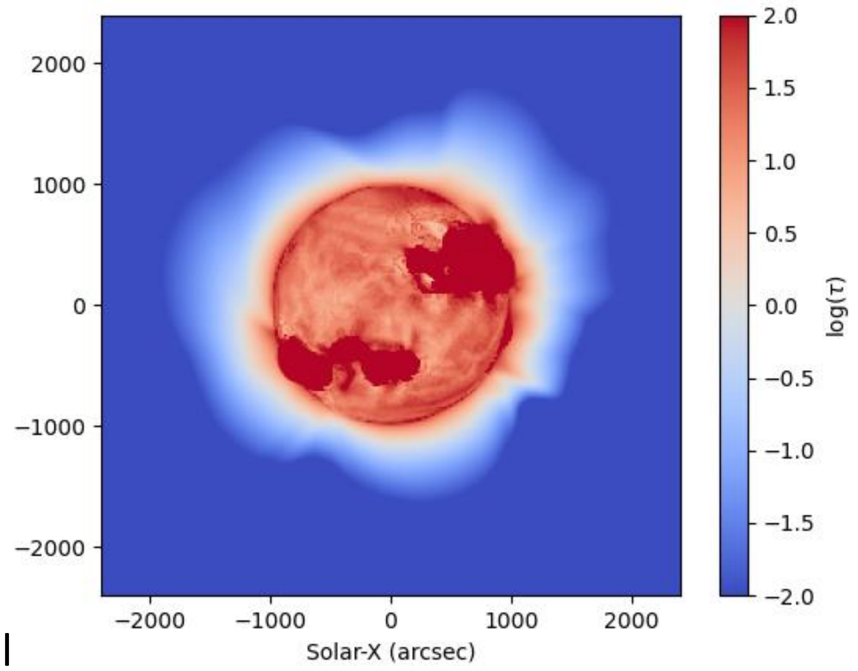
R2- Electron density $1.1*10^8$ cm^{-3}

R2 lower than STIX estimate



Dense large loops hosting radio sources





Estimation of drifts rates

Frequency (MHz)	Newkirk height (Mm)	Newkirk harmonic (n=2) height (Mm)	Electron density (cm^-3)	Electron density (n=2) (cm^-3)	Magnetic Field (Gauss)	FORWARD densities (n=1 heights)	Alfven speed (Mm/s)
78	229	439	7.5e7	1.2e7	3	1.8e7	2.7
88	200	395	9.6e7	2.7e7	4	2.6e7	3.2
110	186	324	1.3e8	3.4e8	12	3.8e7	8.3

+ Drift speed for electron: 1.88 Mm/s ~1880 km/s assuming fundamental emission for R1 source
+ HXR & 110 MHz peak time difference: 60 sec / rate ~ 2.3 Mm/s
+ Slow drift rates (< 0.5 keV) - Unlikely to sustain transport, however plasma perturbations could be produced by a moving driver
+ Different population electrons producing thermal loop top source

Summary & Future Work

- Radio and X-ray emissions are complimentary in ideal situations
- Weak radio features are important to establish correlation with EUV brightening and X-rays
- Total dynamic spectrum is not a smart way to draw initial impressions for weak variability

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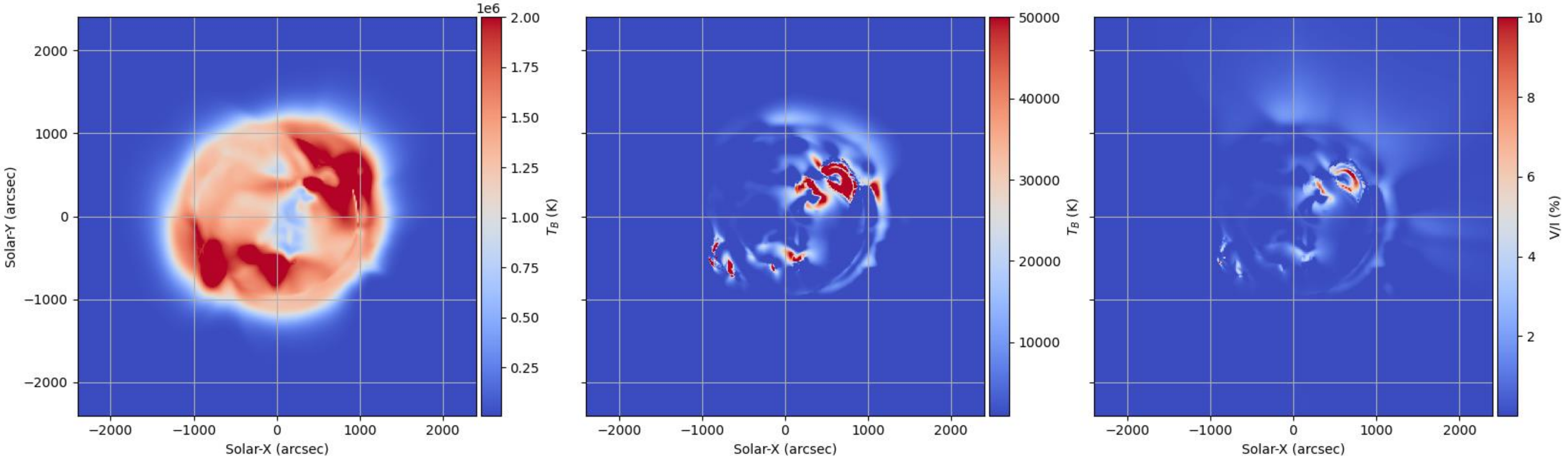
- Particle acceleration study under 3-D magnetic field topology - EUV close to the footpoints, STIX loop top and radio loop top
- Large scale magnetic loops host two radio source at the loop tops and can be seen in meterwaves near the limb (< 1 Rsun)
- R1 source could be connected to STIX flares 5 and 6
- Emission mechanism of the loop top is likely plasma emission mechanism for R2 source, while R1 source at harmonic emission
- STIX captured the X-ray dense thermal loop top source in the occulted flare
- Initial PFSS magnetic extrapolation suggests magnetic connectivity to the far away different active regions
- Slow drift rates and brightness of R2 source suggests different electron population than thermal STIX source
- Drift rates more closer to plasma flow (evaporation) / Alfven waves !!

Proper projection

Finer MWA data at 0.5 s resolution

Cycle 2023 data / Next year 2024 data with 256 tiles

Stokes V maps



HMI Carrington