Evolution of the magnetic connectivity during solar flares as seen from type-III radio bursts

Malte Bröse

Prepared at Leibniz-Institute for Astrophysics and Technical University Berlin

PhD supervisors: Dr. Christian Vocks and Prof. Dr. Dieter Breitschwerdt

United Nations/Germany Workshop on the International Space Weather Initiative: Preparing for the Solar Maximum

Outline

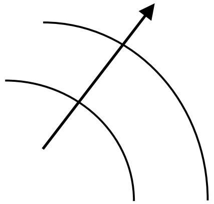
I. Context – magnetic connectivity in solar flares

II. Multi-wavelength observations of two B-class flares:

- X-ray fluxes and thermal evolution of the active region
- Radio observations with LOFAR

III. Summary of observations

Flare-accelerated electrons and their traces



Radio waves

- sudden release of energy
- stored in the non-potential magnetic field
- due to magnetic reconnection
- Consequences
  - particle acceleration
  - heating
  - radiation

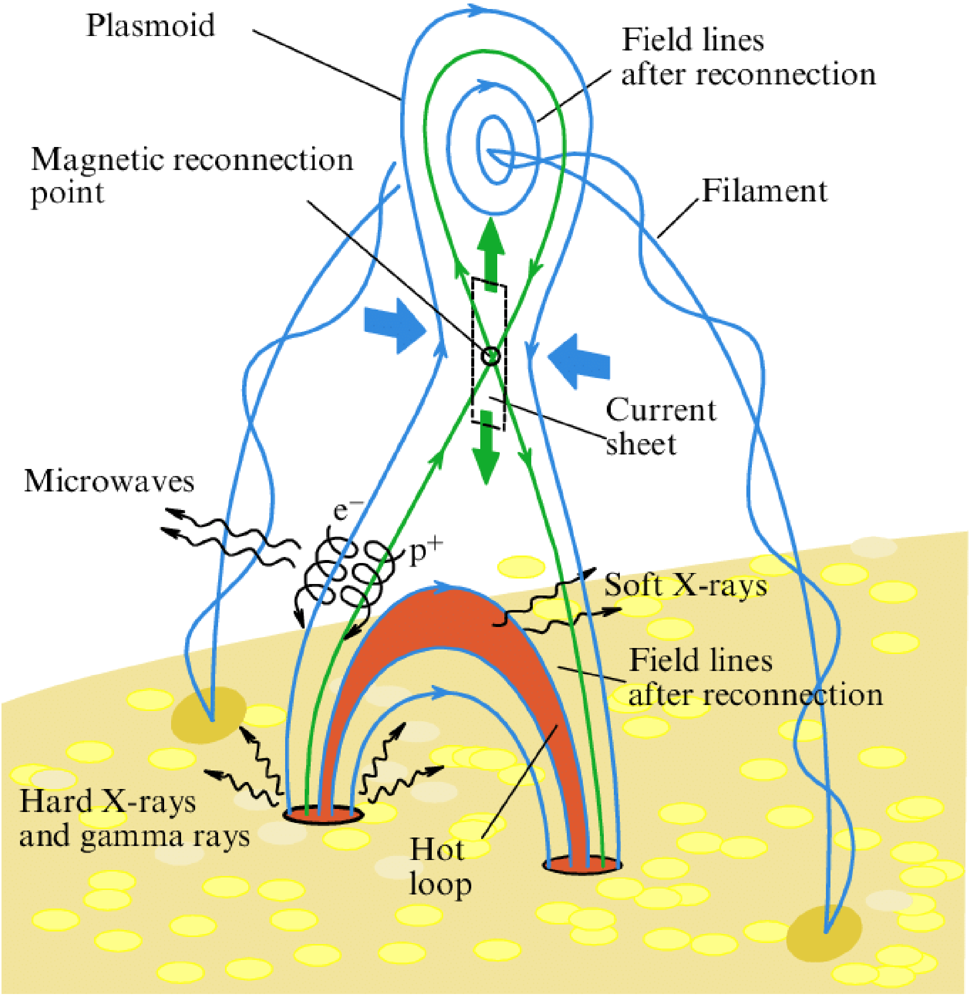


Figure is from A. L. Lysenko et al 2020 Phys.-Usp. 63 818

LOw Frequency Array – Radio Interferometer

LOFAR structure:

- Central core (Exloo, NL) 24 stations
- 14 remote Stations (NL)
- 14 International Stations

Frequency range:

- Low Band: 30 – 90 MHz
- High Band: 110 – 250 MHz

Type-III bursts and magnetic connectivity

- Signs of down- and upward particle propagation are correlated, but do not always appear symmetrically (Kundu et al. (1980), Reid et a. (2011), James & Wilmer (2023)).

- Type-III bursts are very sensitive indicators for changes in the AR.

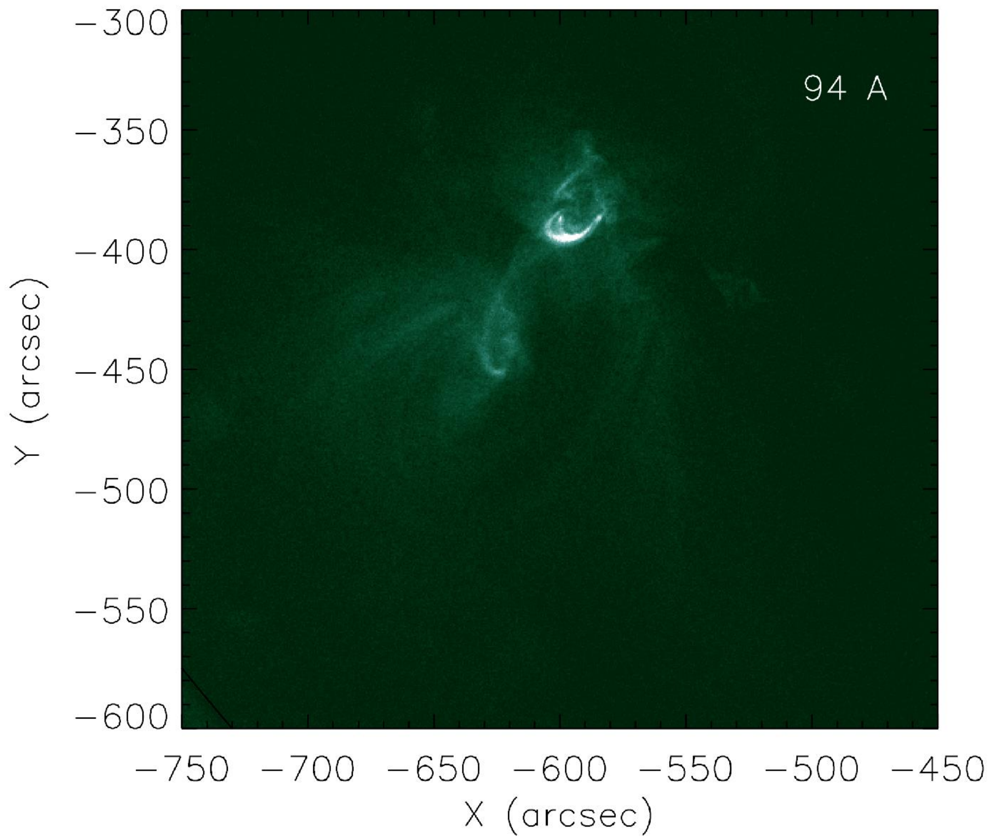
- Number of electrons producing type-III bursts is only around 0.1% of the number of electrons neccessary to produce X-rays (Lin et al. (1973)).

- Large event sizes are not a requirement for type-III bursts.

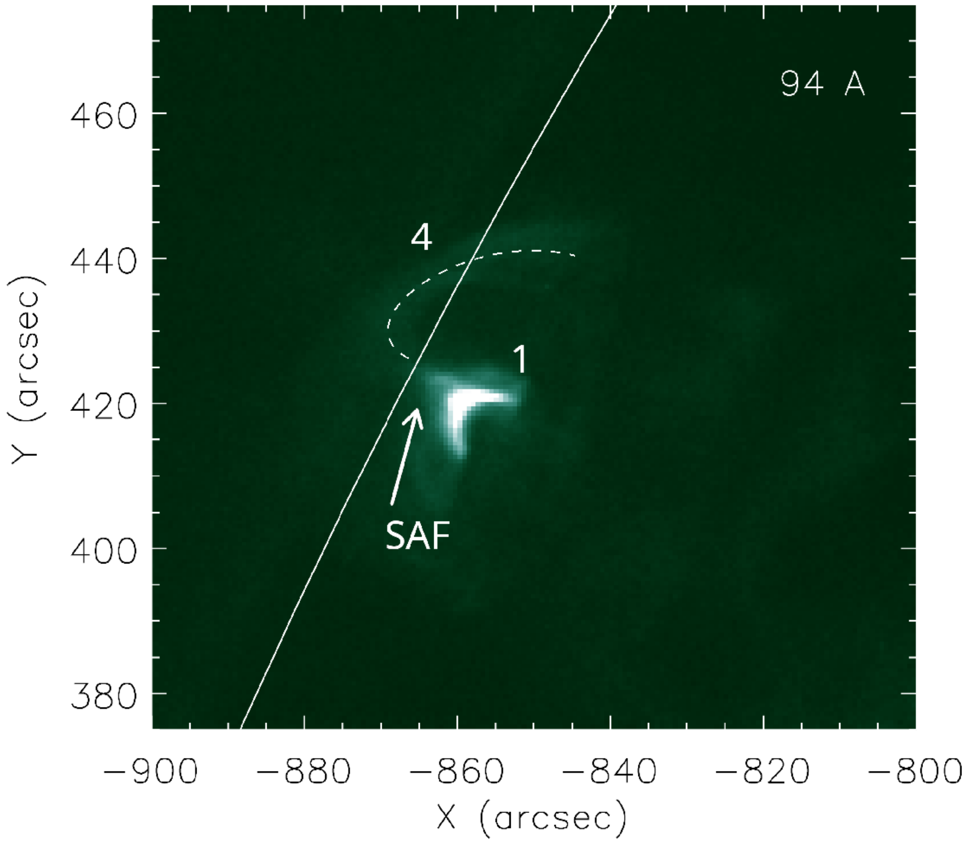
- <u>Magnetic connectivity:</u> The incorporation of small-scale processes leading to particle acceleration into the large-scale magnetic structures (Raulin et al. (2000))

II. Multi-wavelength observations of two flare events

06-Jun-2020

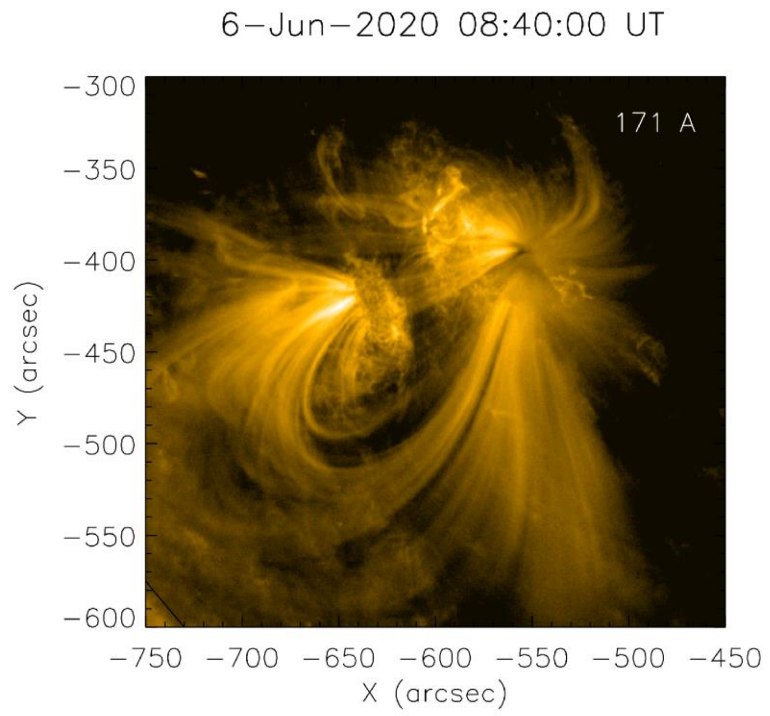


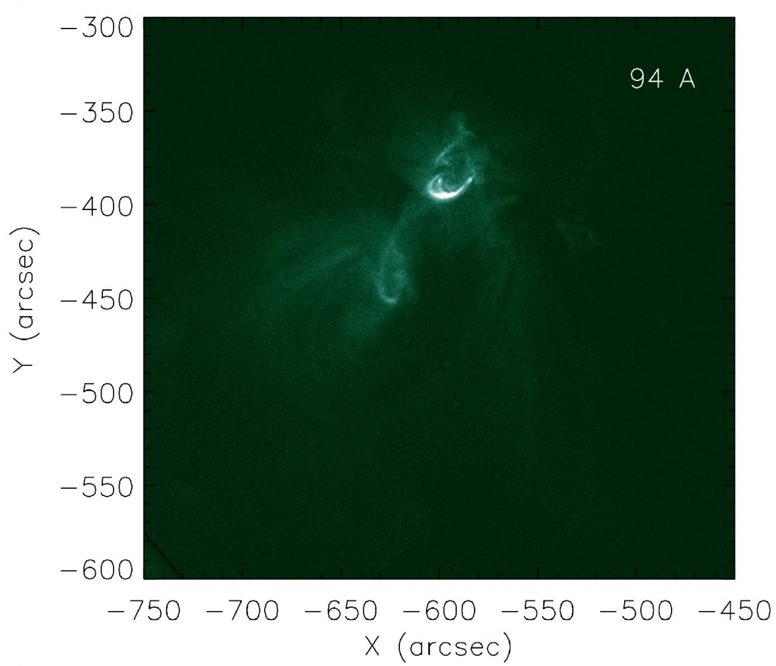
22-Oct-2022

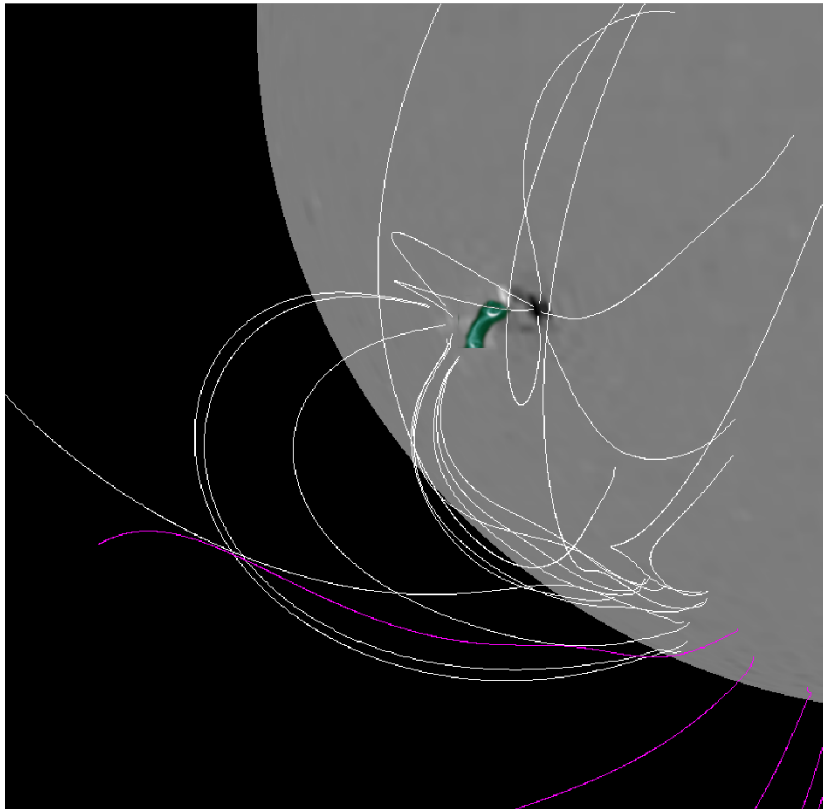


Magnetic configuration

- electrons propagate along magnetic field lines in encapsulated loop systems

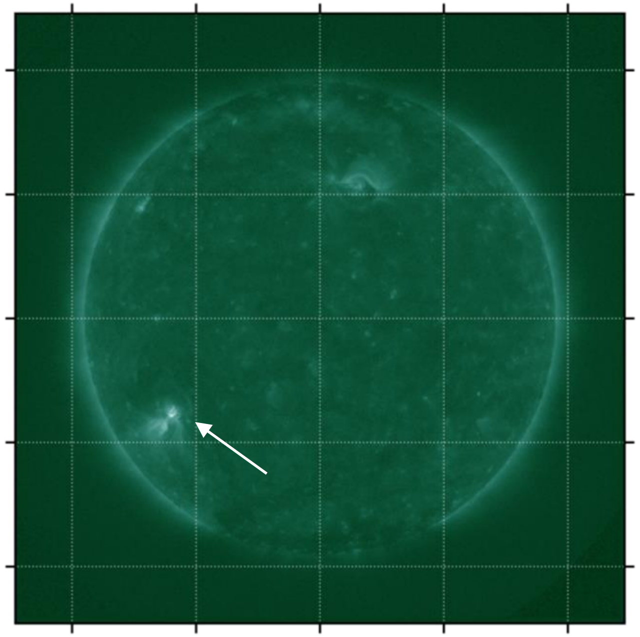


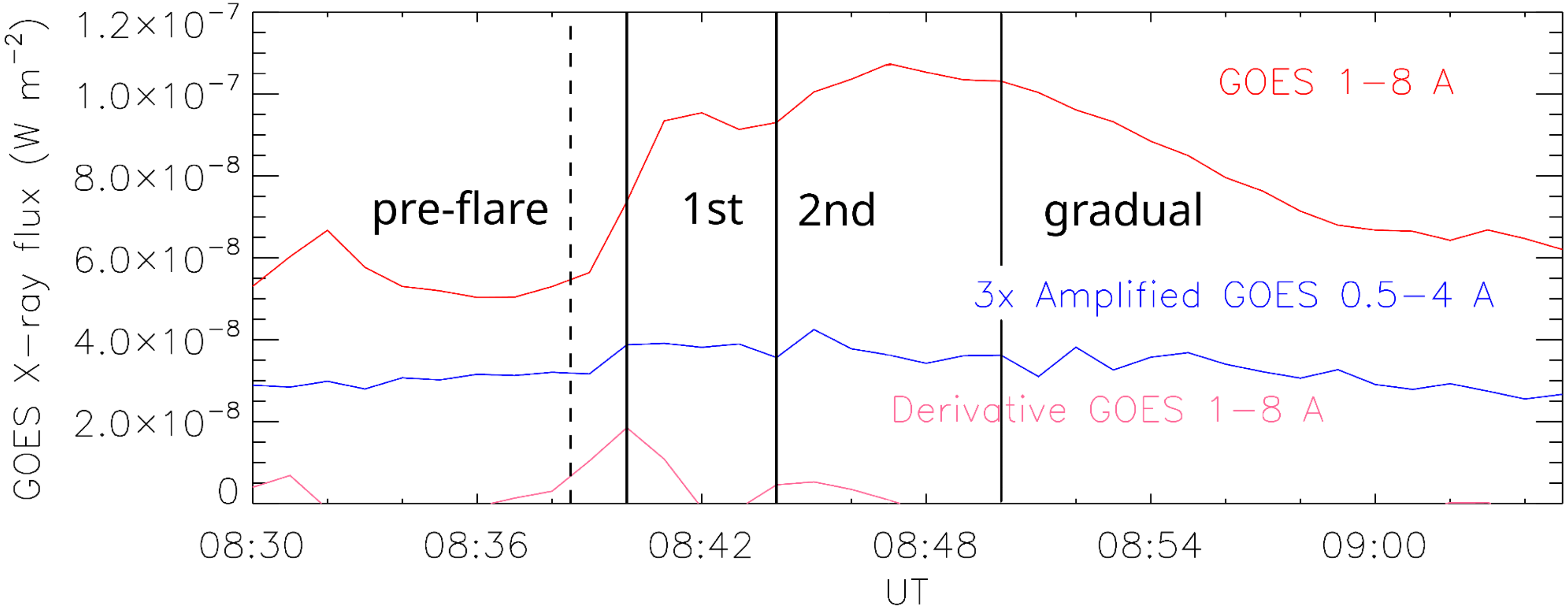




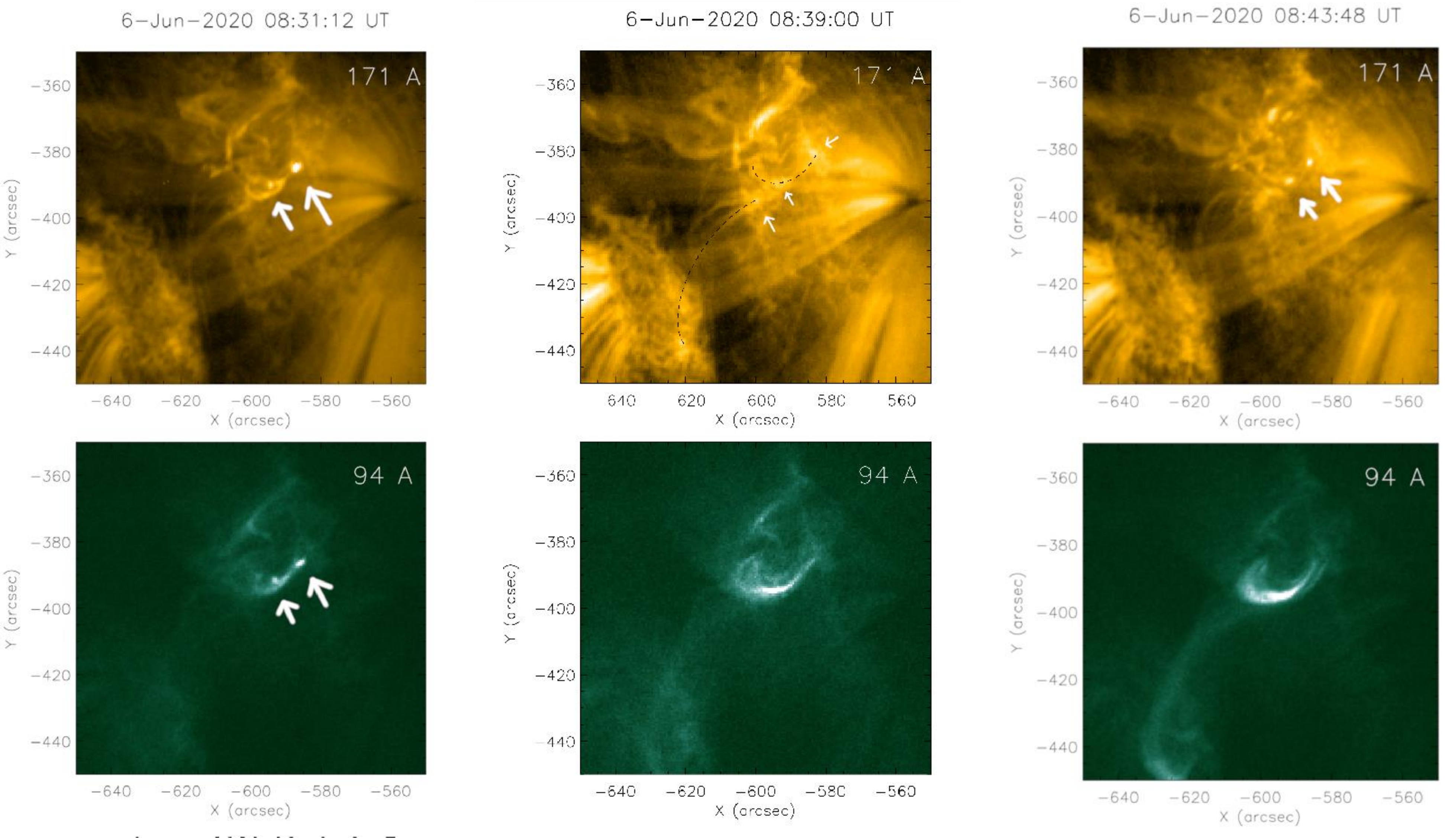
B-class flare on 06 June 2020

- Small event with several X-ray peaks

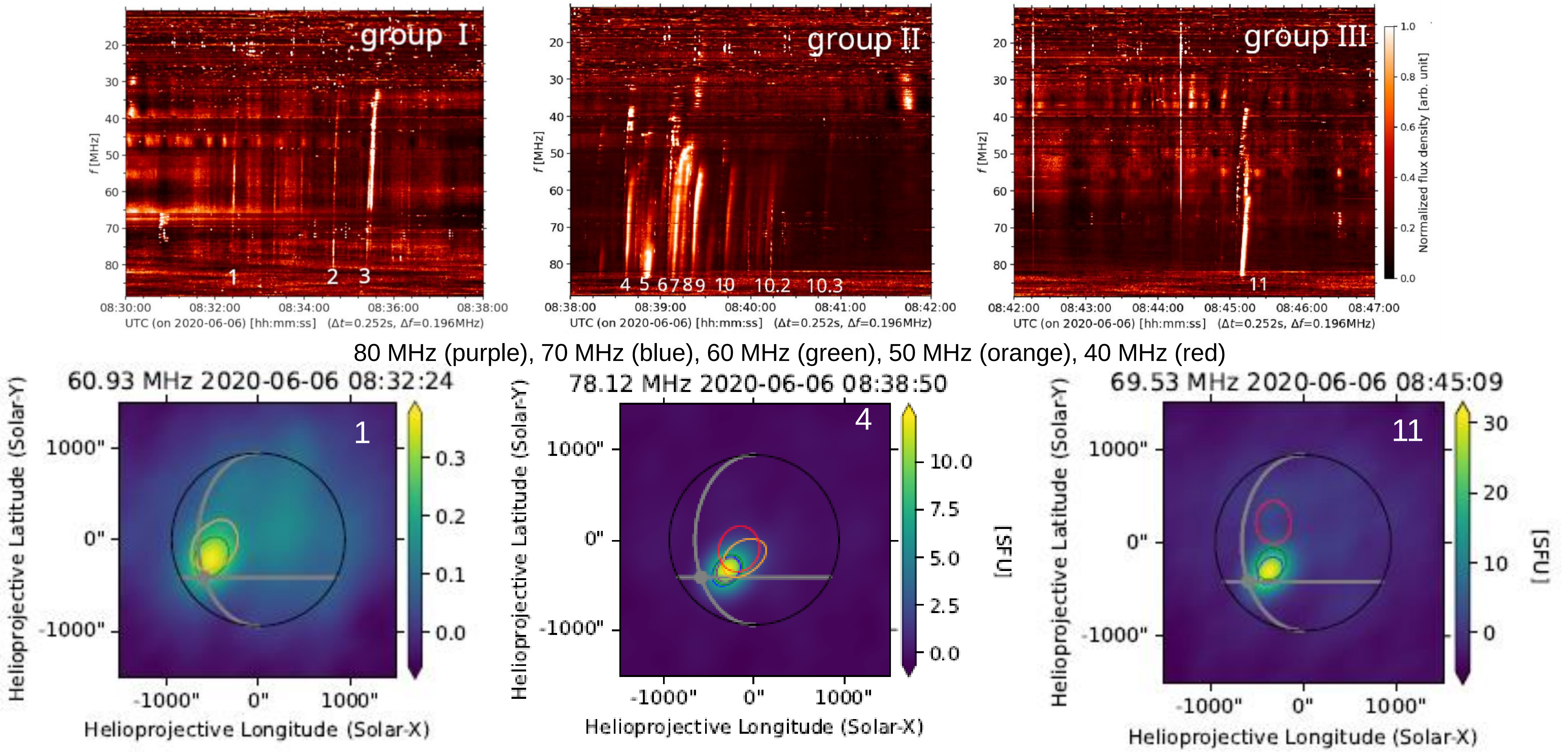




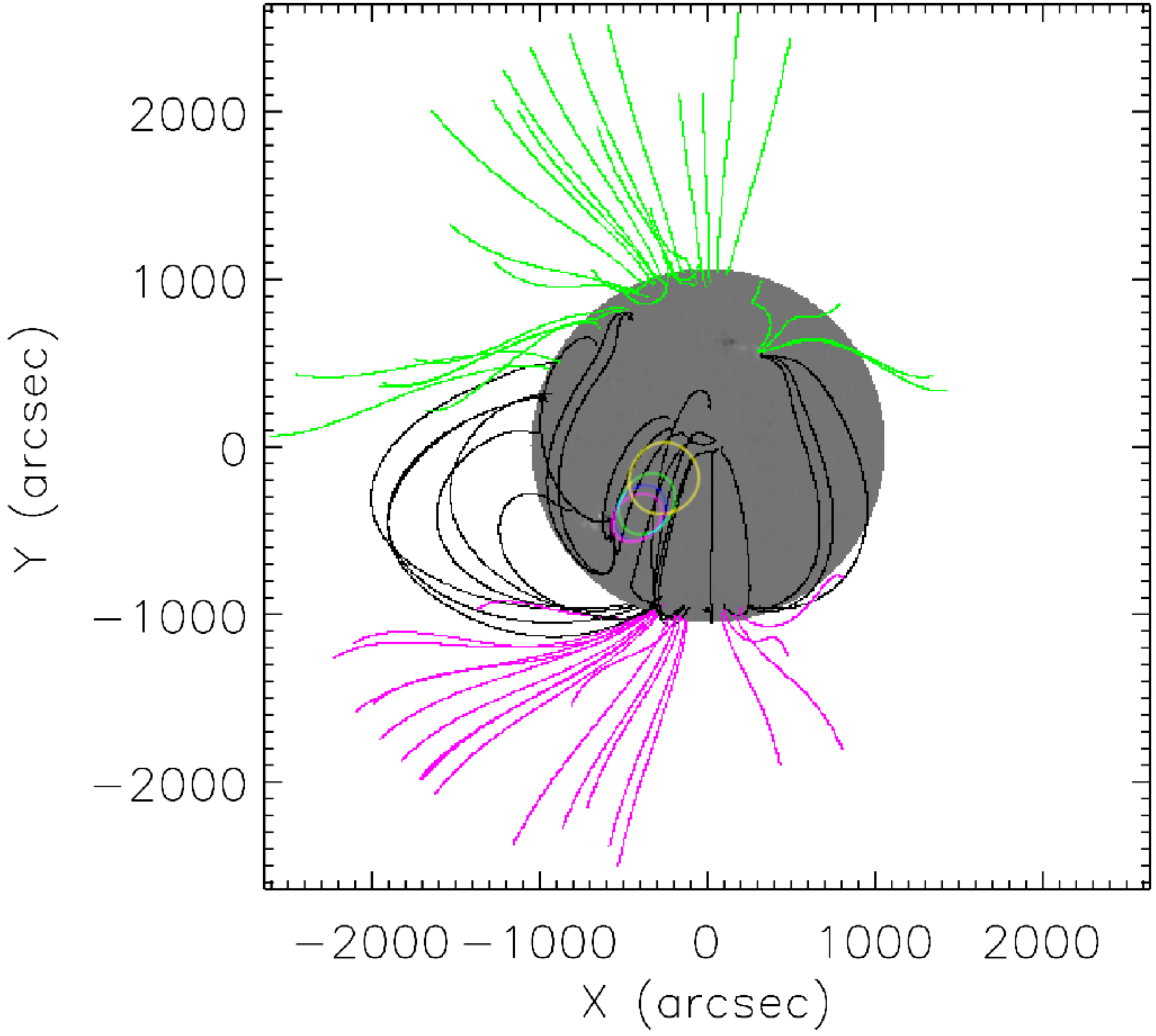
Concentrated energy release in the active region



Selected bursts related to a similar energy release in the AR



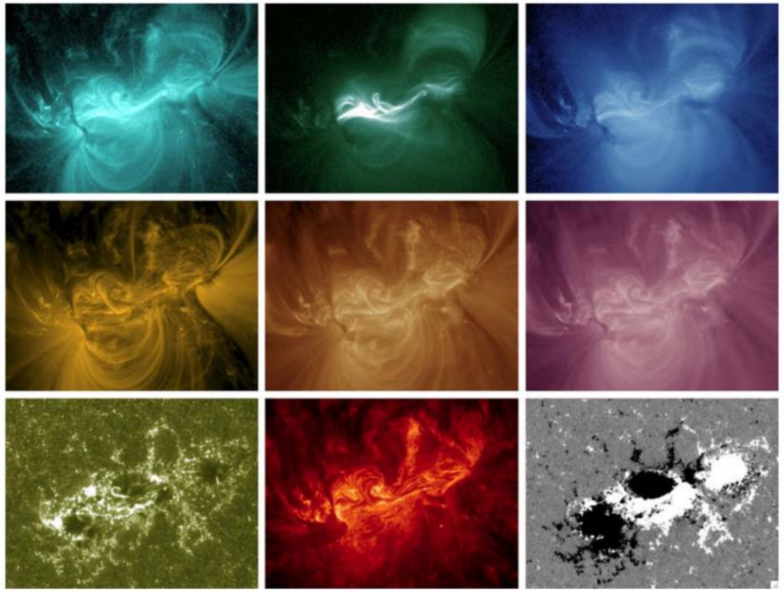
Solar Type-III Radio Bursts and PFSS model

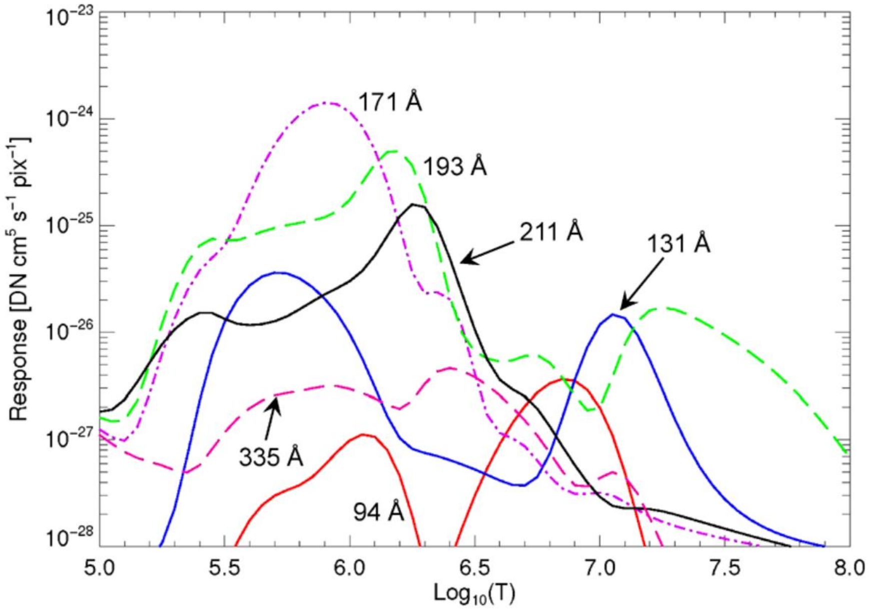


80 MHz (purple),
70 MHz (blue),
60 MHz (green),
50 MHz (orange)

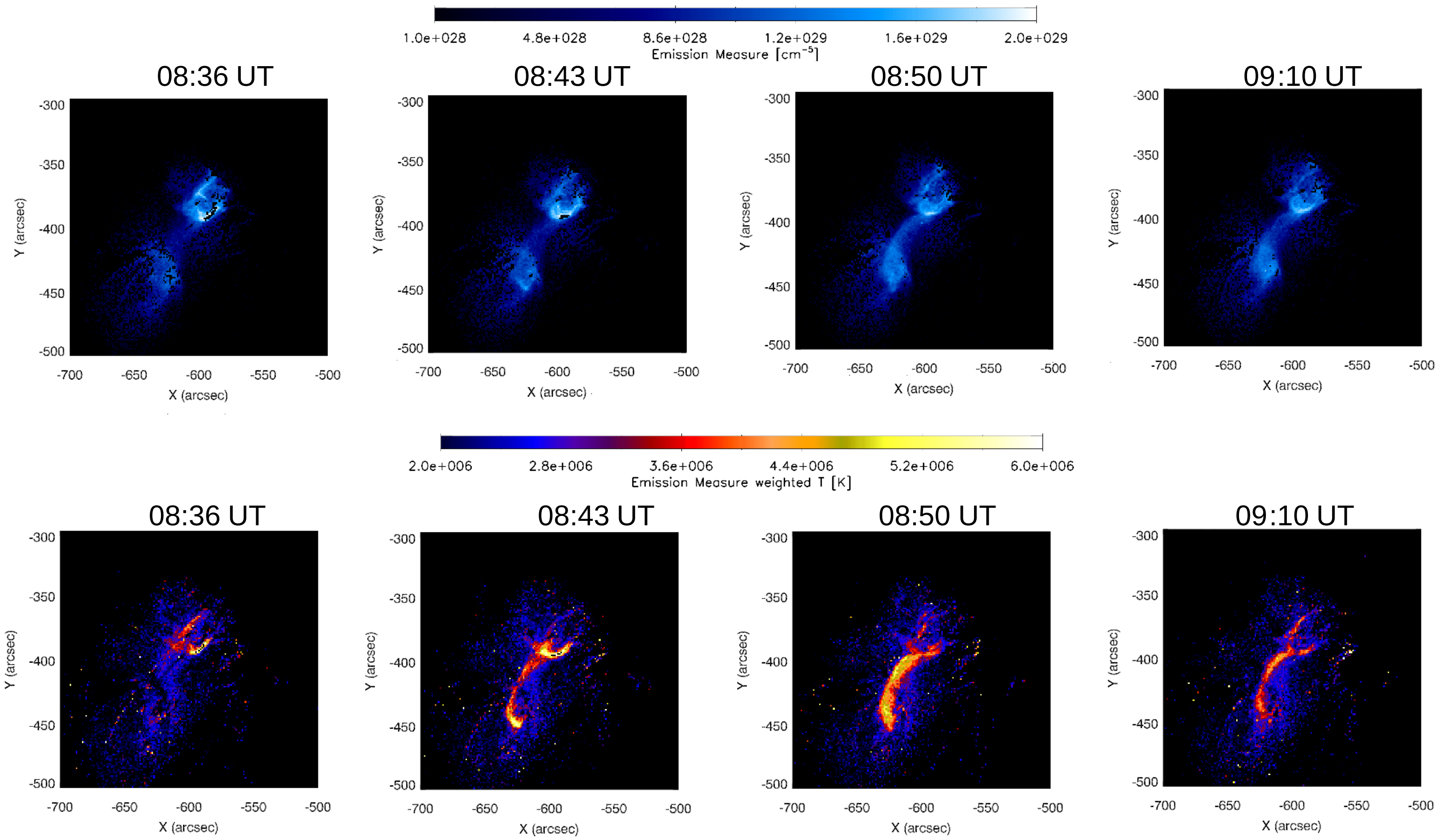
Atmospheric Imaging Assembly (AIA) Data

- Imager on the Solar Dynamics Observatory
- multiple simultaneous high-resolution full-disk images of the corona and transition region
- 1.5-arcsec spatial resolution and 12-second temporal resolution





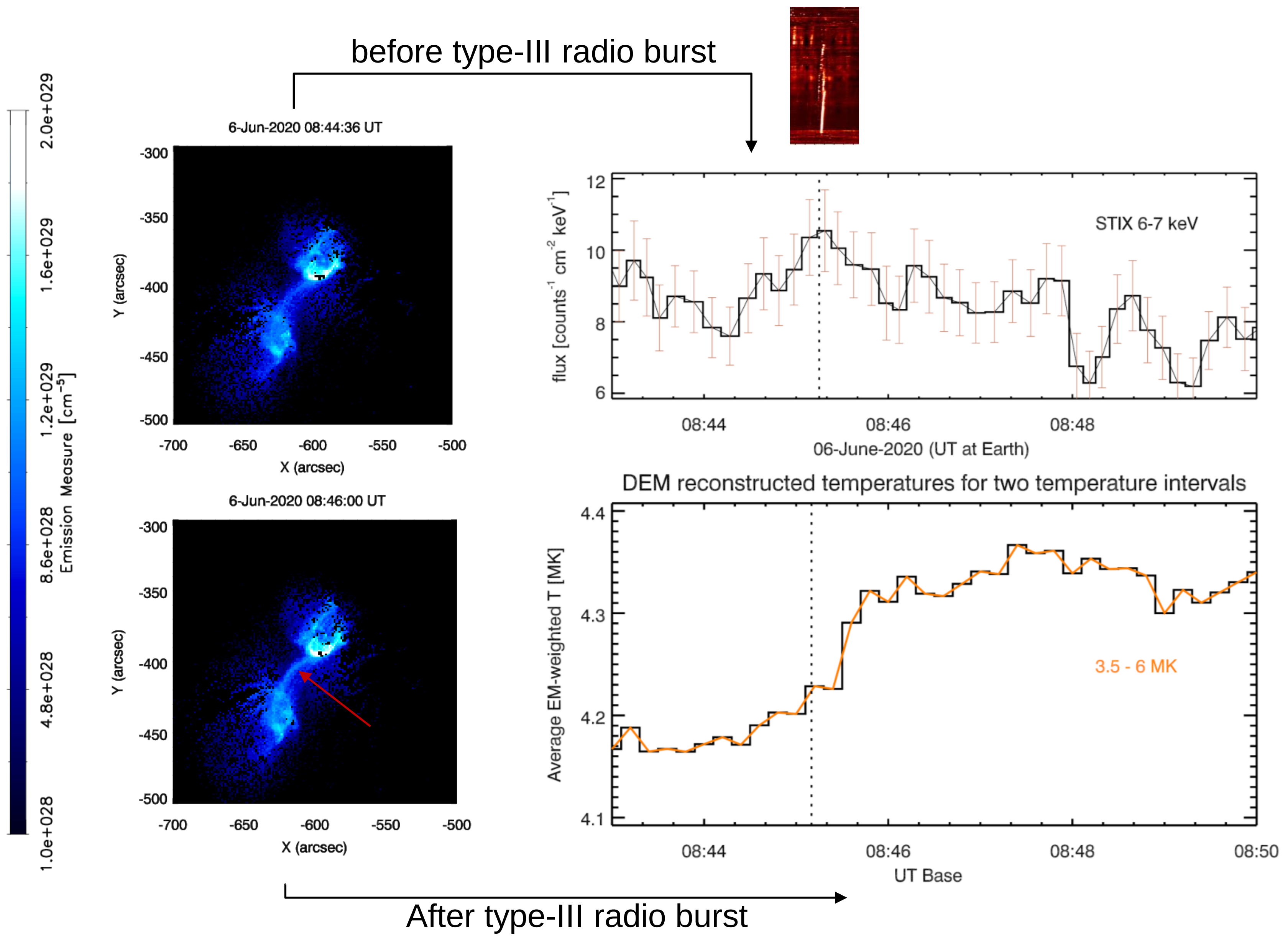
DEM Anaylsis based on EUV data



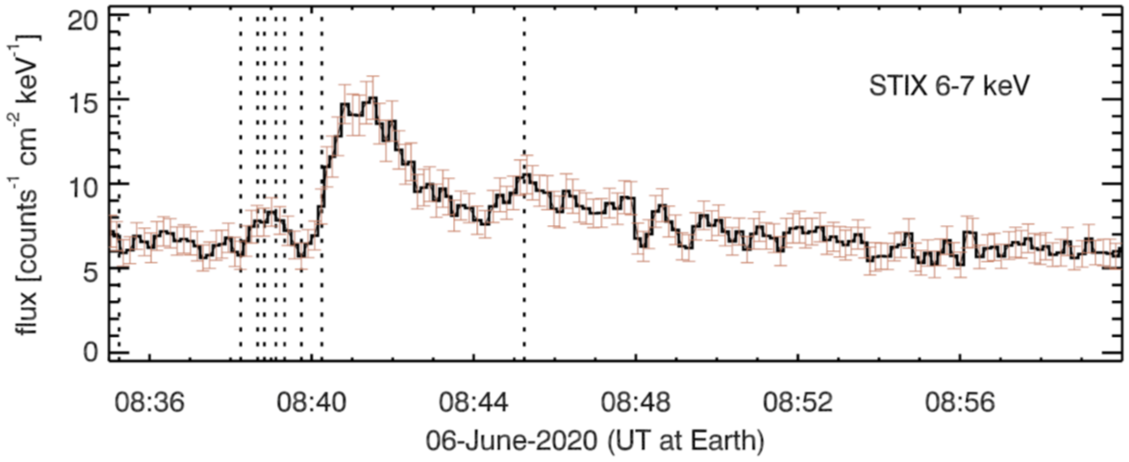
Differential Emission Measure (DEM) describes the amount of thermal plasma along the line-of-sight as a function of the temperature T.

$$EM_T = DEM(T) \cdot \Delta T = \int_{T_0}^{T_1} \int n_e^2(T,z) dz dT$$

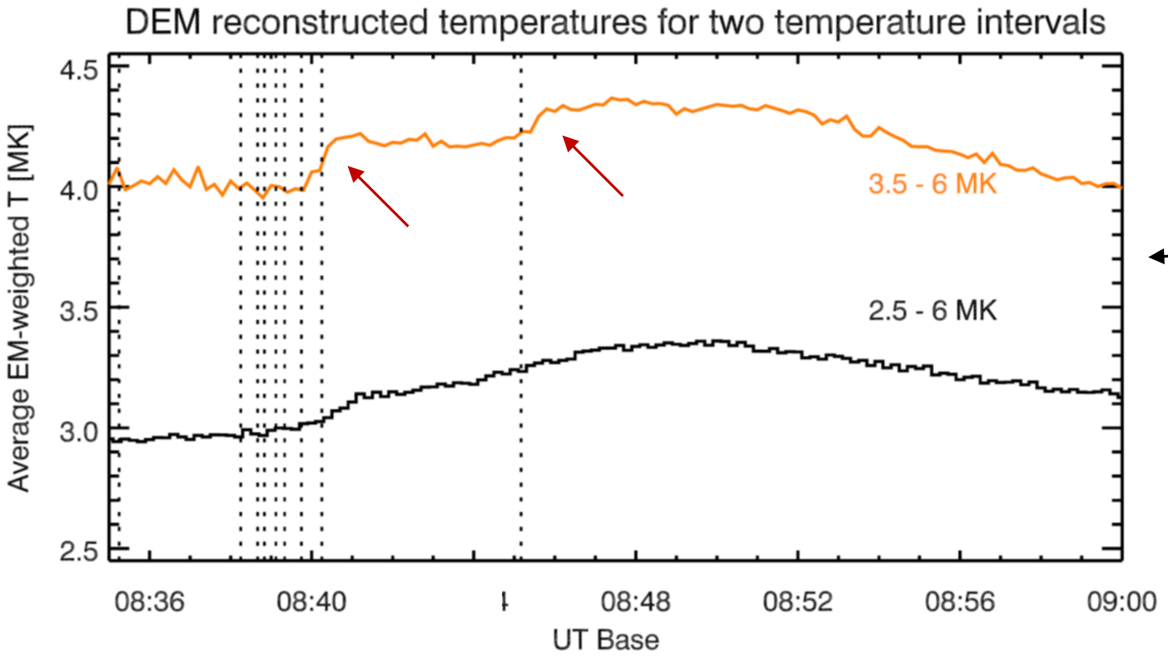
DEM Method: Yang Su et al. 2018 ApJL 856 L17

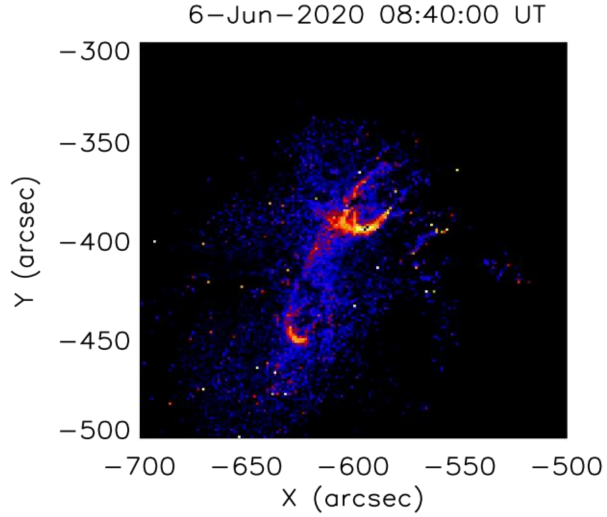

before type-III radio burst
6-Jun-2020 08:44:36 UT
6-Jun-2020 08:46:00 UT
Y (arcsec)
X (arcsec)
Emission Measure [cm^{-5}]
2.0e+029
1.6e+029
1.2e+029
8.6e+028
4.8e+028
1.0e+028
STIX 6-7 keV
flux [counts^{-1} cm^{-2} keV^{-1}]
06-June-2020 (UT at Earth)
DEM reconstructed temperatures for two temperature intervals
Average EM-weighted T [MK]
3.5 - 6 MK
UT Base
After type-III radio burst

Average EM-weighted temperatures of the active region

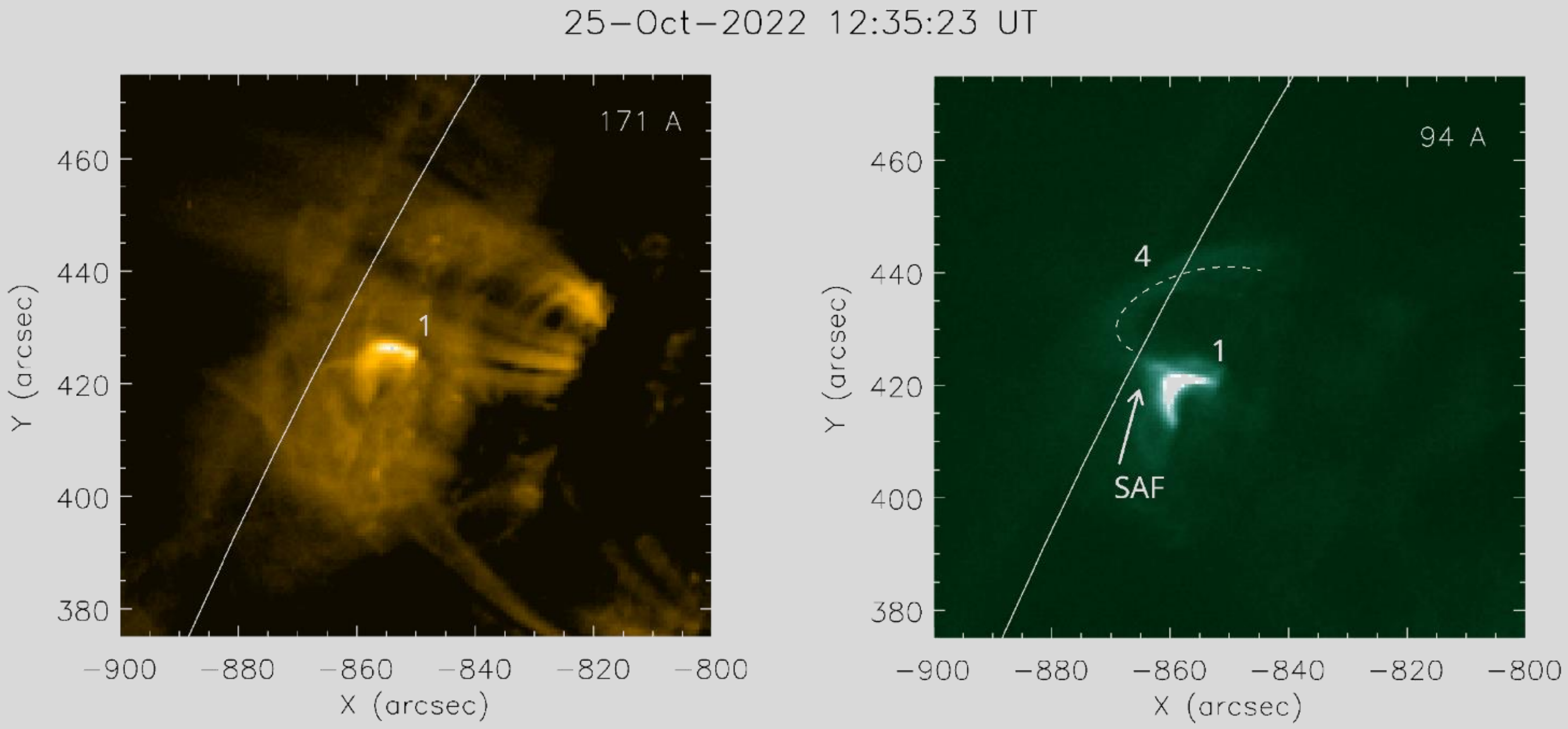


Type-III radio bursts observed by LOFAR

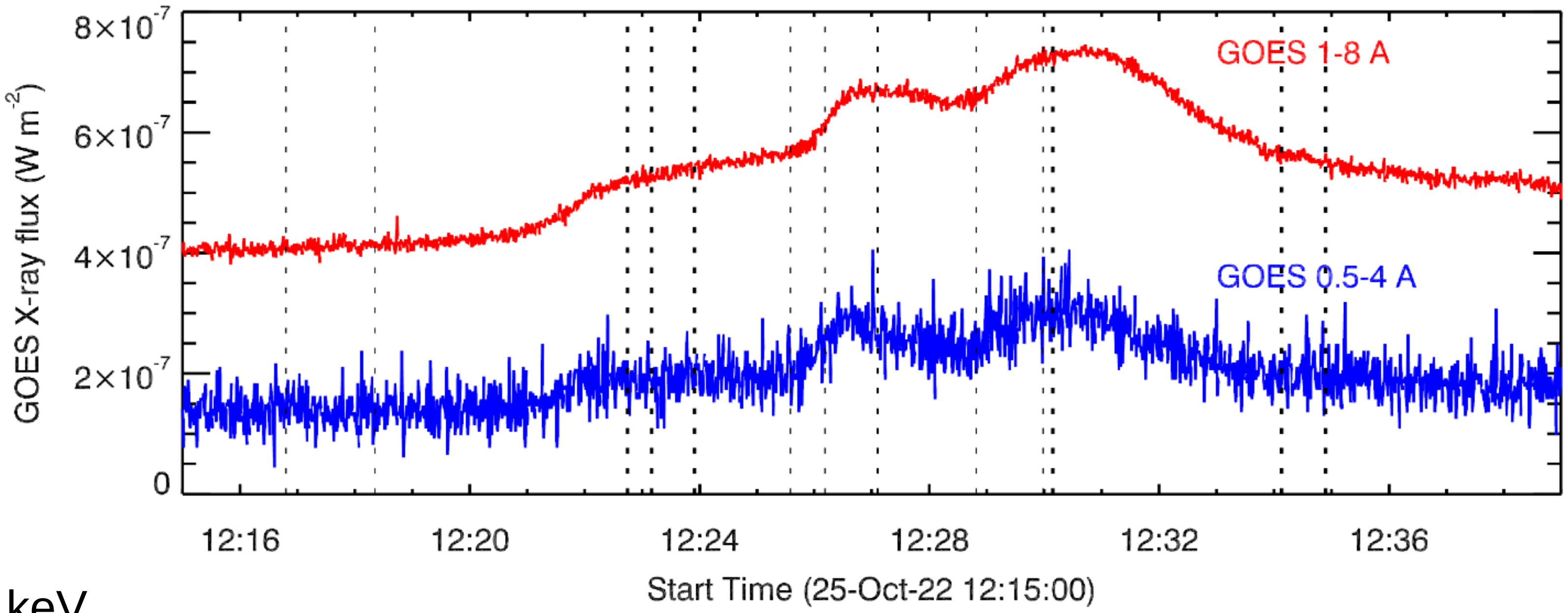




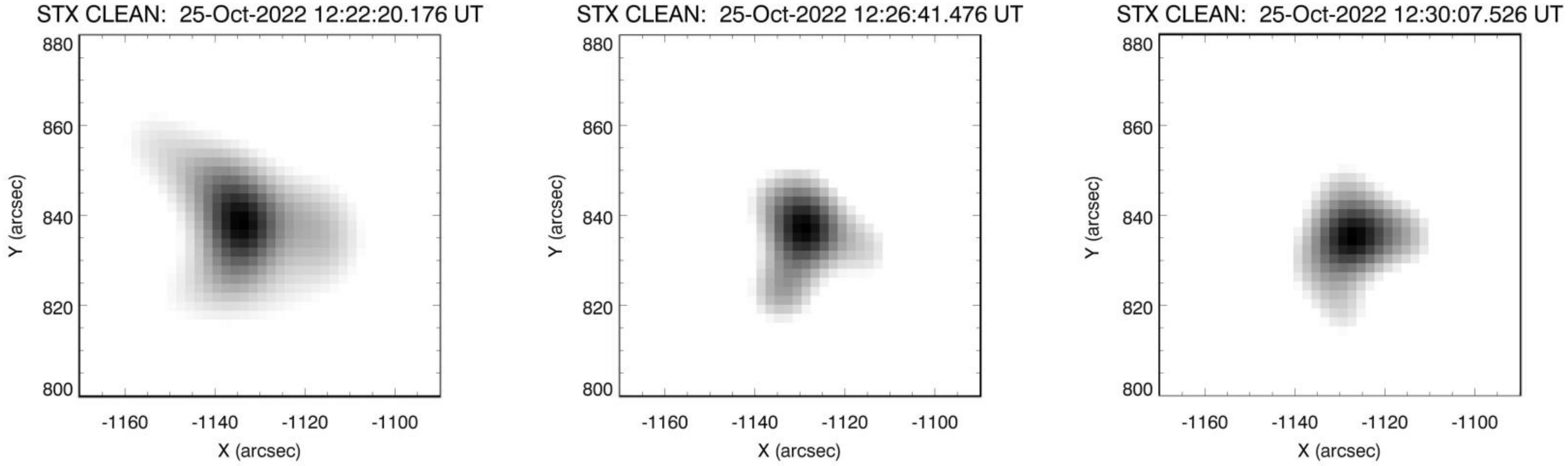
EUV observations of the limb event – 25 October 2022



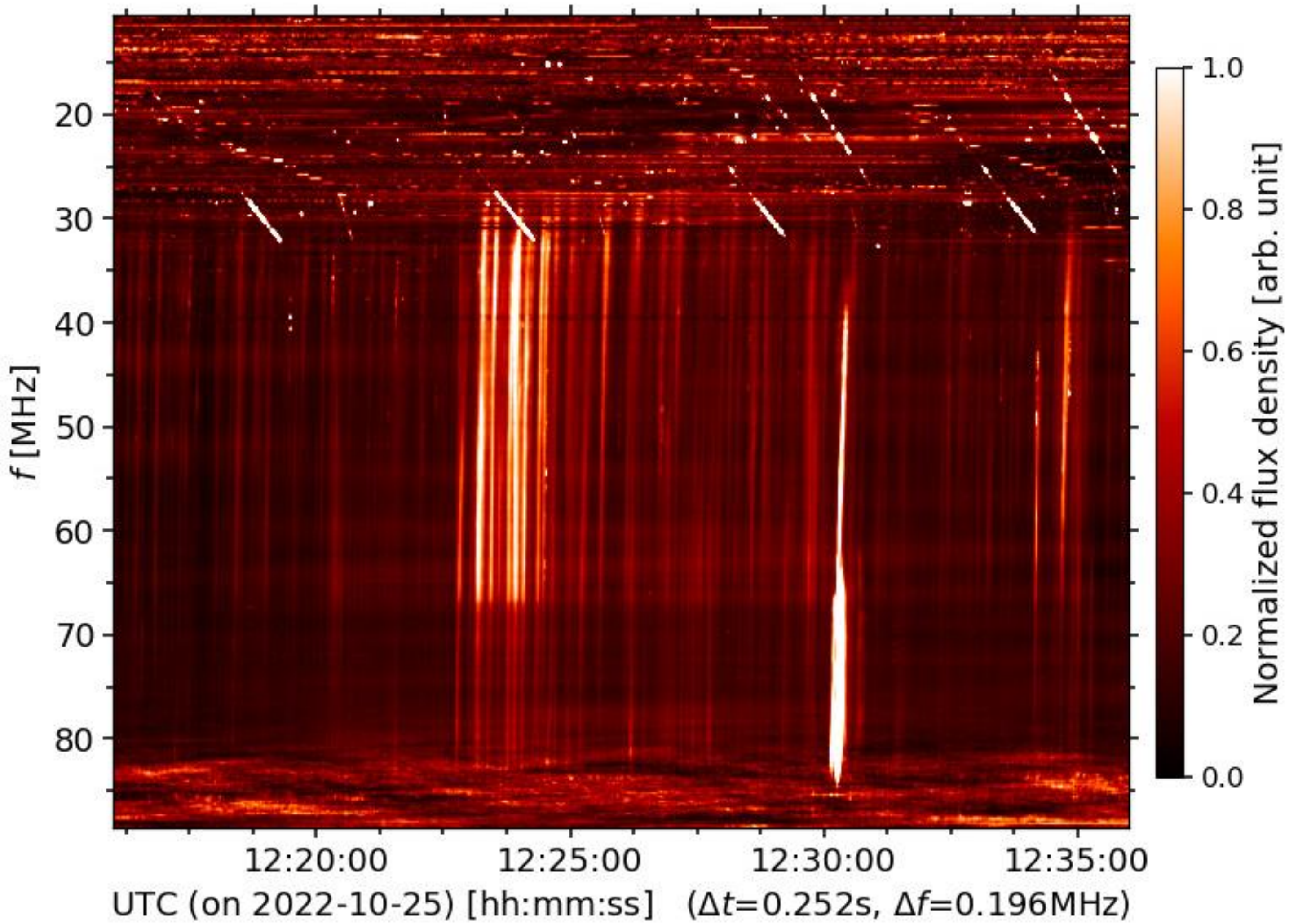
2nd Event – 25 October 2022



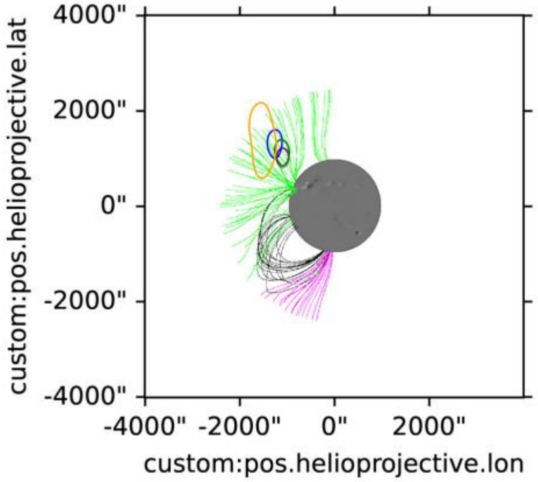
STIX imaging – 6-7 keV



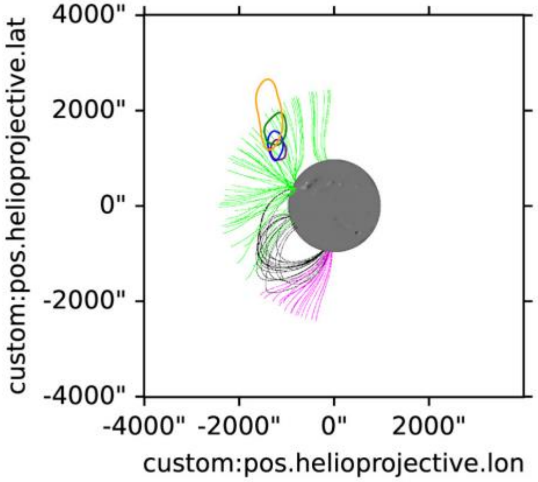
Dynamic radio spectra



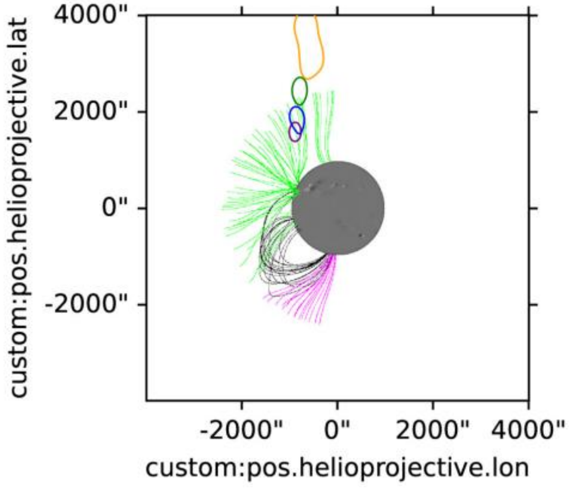
Radio source positions for selected bursts



Burst 1: 12:16:49 UT

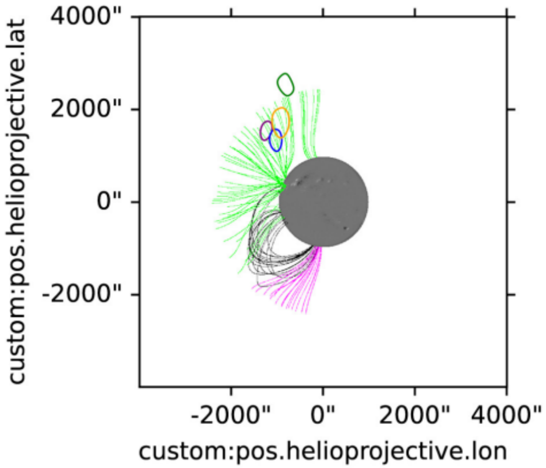


Burst 2: 12:18:22 UT

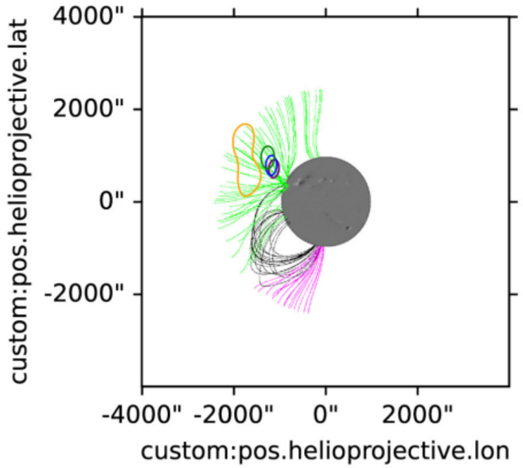


Burst 3: 12:22:46 UT

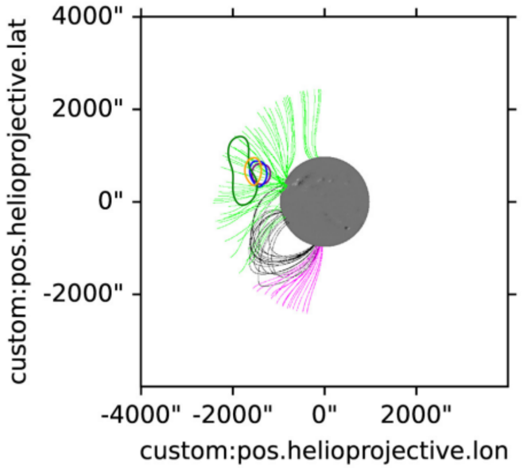
80 MHz (purple),
70 MHz (blue),
60 MHz (green),
50 MHz (orange)



Burst 11: 12:30:10 UT

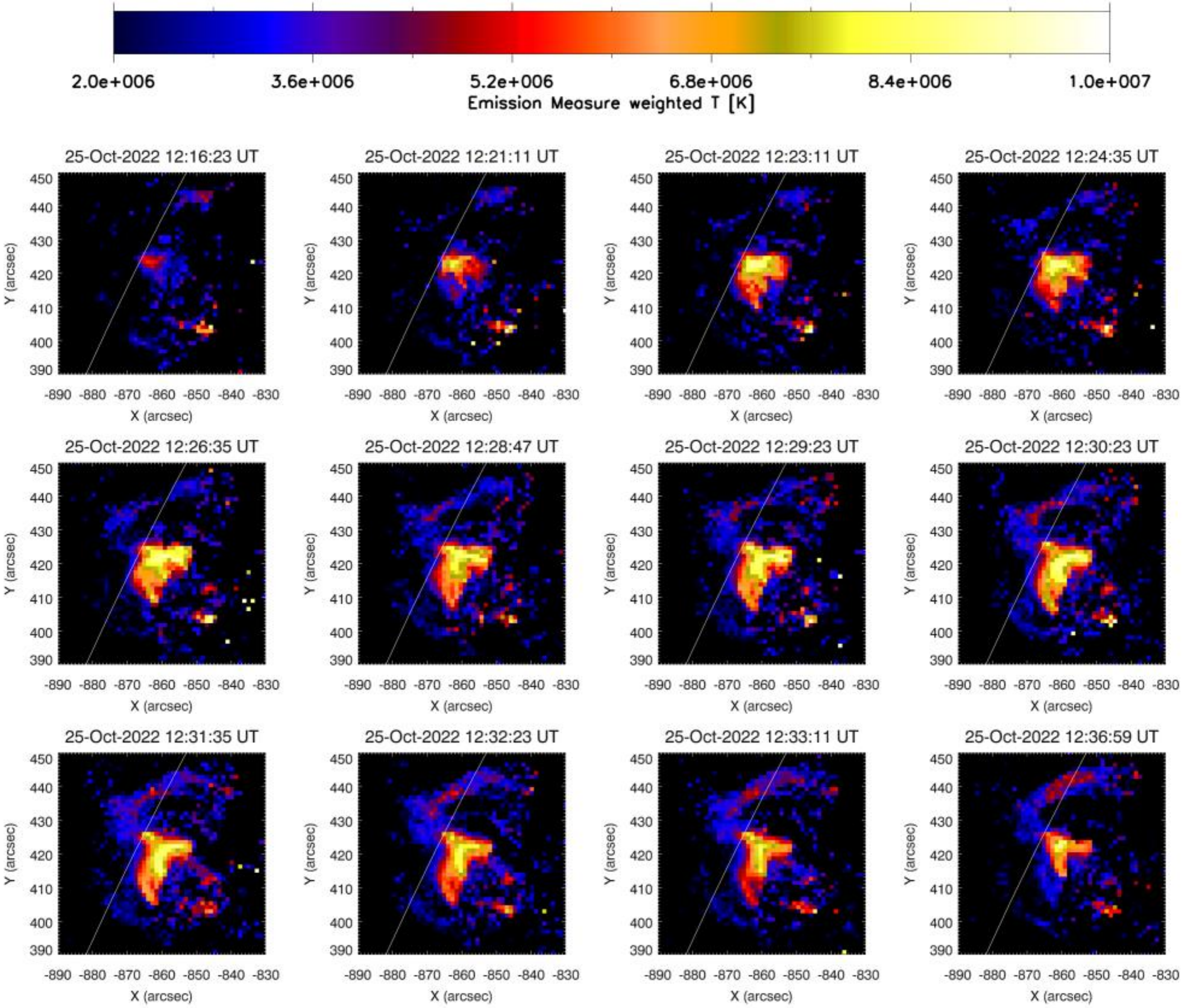


Burst 12: 12:34:09 UT



Burst 13: 12:34:55 UT

Thermal evolution (DEM analysis)



III. Summary

- **Magnetic connectivity** can be indirectly studied with multi-wavelength observations.
- In the event on 06 June 2020 **type-III radio bursts** mark the on-set of the heating process. **Suppressed access to the higher altitudes** in the corona was accompanied by strong heating.

- The radio **source position** stays rather constant within each phase.
- The **large-scale magnetic field** is rather stable, while the ability to access certain field lines changes over time.
- It was possible to **identify single loops** affected by the energy release by conducting detailed DEM analysis of AIA/EUV data

Data Acknowledgements

We thank the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) and the National Science Centre, Poland, and for granting “LOFAR obser- vations of the solar corona during Parker Solar Probe perihelion passages” in the Beethoven Classic 3 funding initiative under project numbers VO 2123/1-1 and 2018/31/G/ST9/01341, respectively.

This research is based (in part) on data obtained with the International LOFAR (van Haarlem et al. 2013) Telescope (ILT) under project code LT16_ 001. Furthermore we have used data from AIA on NASA’s SDO satellite and STIX on the Solar Orbiter satellite.

Software Acknoledgment

PFSS model: Schrijver, C.J., DeRosa, M.L. Photospheric and heliospheric magnetic fields. Sol Phys 212, 165–200 (2003).

DEM Method: Yang Su et al 2018 ApJL 856 L17.

This research used version 4.0.6 of the SunPy open source software package.

Thank you for your attention!

Imprint

Topic: **Evolution of the magnetic connectivity during solar flares as seen from type-III radio bursts**

Date: 2024-06-11

Author: M. Bröse

Institute: Leibniz Institut für Astrophysik Potsdam,

Technische Universität Berlin

Image sources: https://phys.org/news/2016-01-magnetic-sun.html

https://www.todaysmedicaldevelopments.com/article/medium-voltage-electron-beams/