INSTITUTE OF SOLAR-TERRESTRIAL PHYSICS
OF SIBERIAN BRANCH OF THE RUSSIAN ACADEMY OF SCIENCES

Spatial and spectral evolution of microwave and X-ray sources during the limb solar flare February 5, 2023

Julia Shamsutdinova[1], Larisa Kashapova[1], Zhentong Li[2] and Yang Su[2,3]

[1] *Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia*

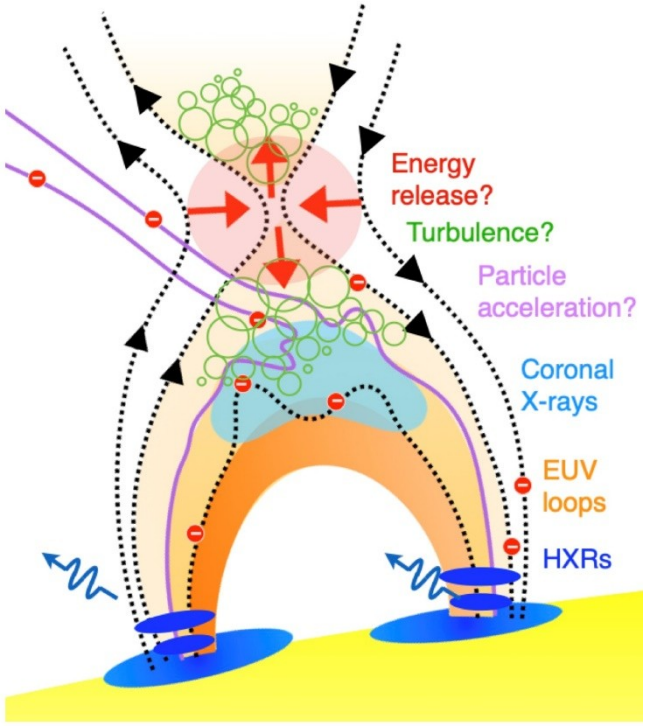
[2] *Key Laboratory of Dark Matter and Space Astronomy, PMO CAS, Nanjing, China*

[3] *School of Astronomy and Space Science, University of Science and Technology of China, Hefei, China*

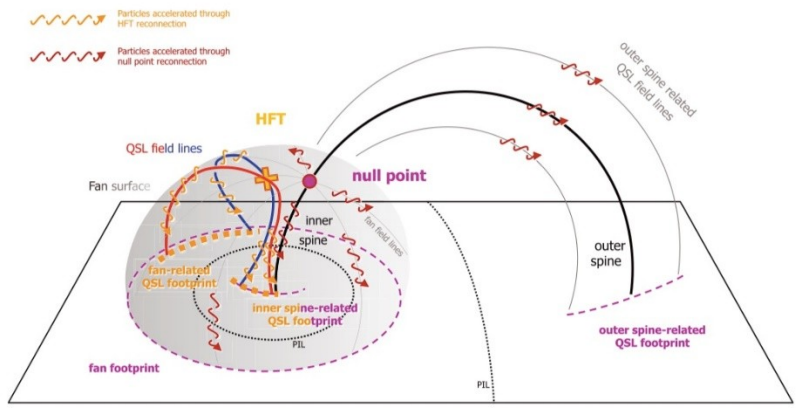
The 15th Russian-Chinese Workshop on Space Weather, September 9-13, 2024, Irkutsk

MOTIVATION

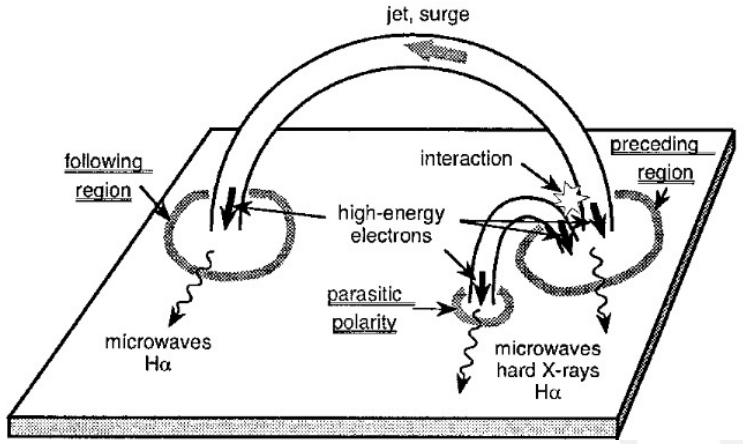
CSHKP model (standard model)



[Jeffrey, Natasha L.S., 2020]



Model of circle flare *[Reid, H.A.S., 2012]*



Hanaoka model *[Hanaoka, 1997]*

For the same population of electron:

1. Microwave (MW) and X-Ray temporal profiles coincide
2. Plasma parameters obtained from the X-ray and microwave ranges must be consistent

For numerical flare models, it is important to study events where there is a consistency between parameters taken from different spectral ranges without any theoretical speculation.

BUT – in reality, it is rare ->

It should be very simple and weak flare (!!) but with 2D observations in MW and X-rays.

Siberian Radioheliograph (SRH)

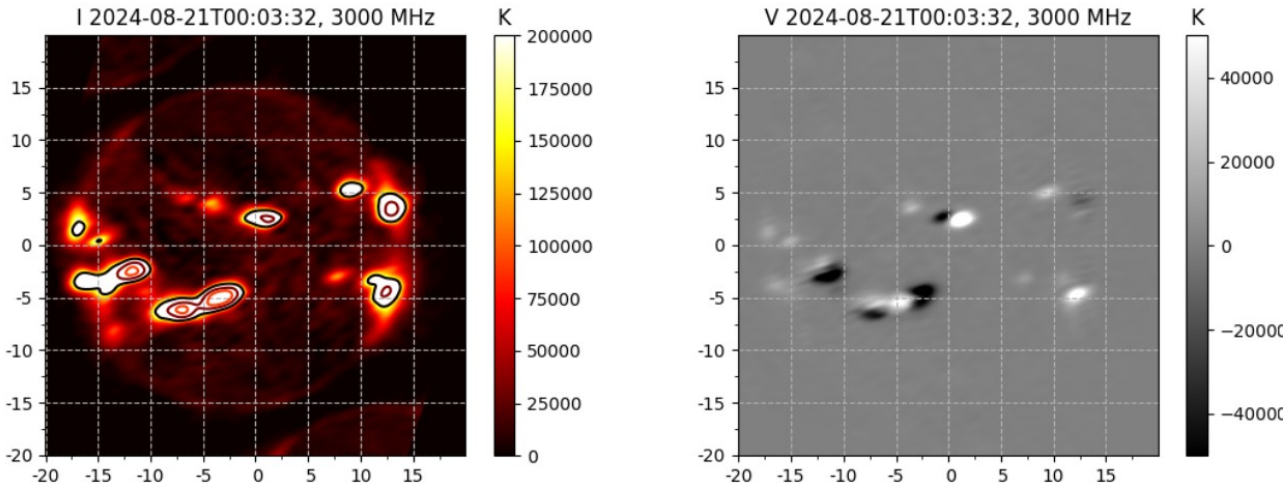
- T-shape grid
- Frequency range: 3 – 24 GHz
- Temporal resolution: 2 – 3 seconds
- Spatial resolution: 30 – 7 arcsec
- Sensitivity: 4 – 25*10^{-3} s.f.u.

12-24 GHz 1 m. 207 antennas

6-12 GHz 2 m. 192 antennas

3-6 GHz 3 m. 129 antennas

[Altyntsev et al., 2020, STP]

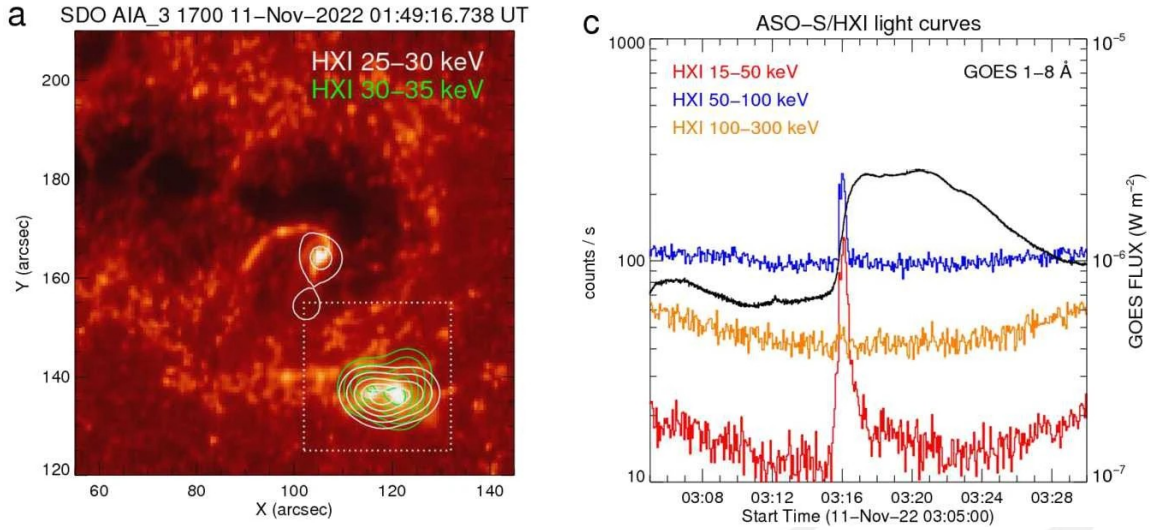


[badary.iszf.irk.ru]

Advanced Space-based Solar observatory / Hard X-ray Imager (ASO-S/HXI)

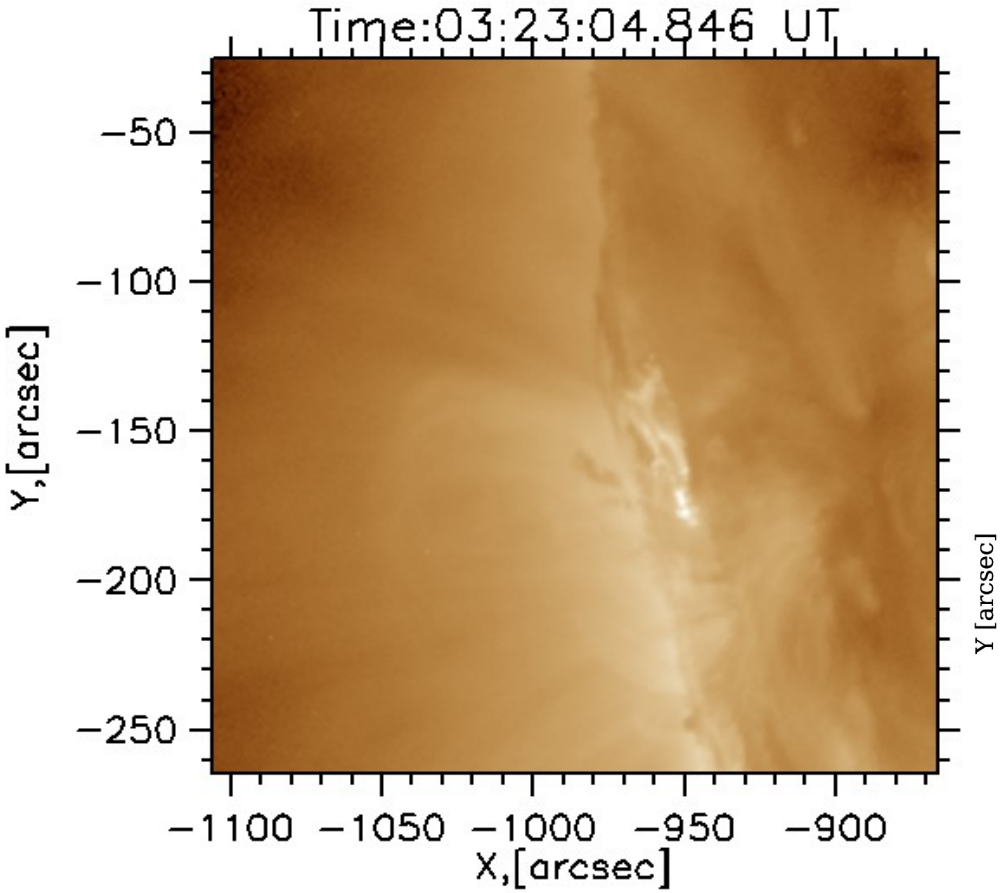
- Energy range: 10 – 300 keV
- Temporal resolution: 0.125 – 1 seconds
- Spatial resolution: 3.2`` @ 32 keV
- FOV: 40.3 arcsec

[Gan et al., 2023, Solar Physics]



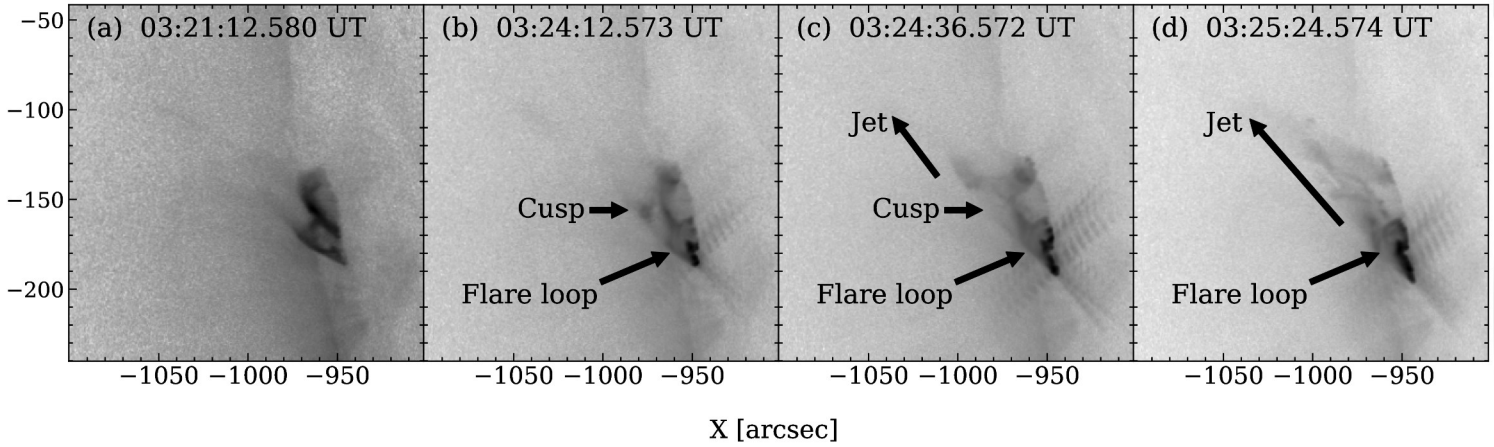
[http://aso-s.pmo.ac.cn/en_index.jsp]

SOL2023-02-05T03:24:38



- 03:24:00 – 03:30:32 UT
- GOES class – C6.6

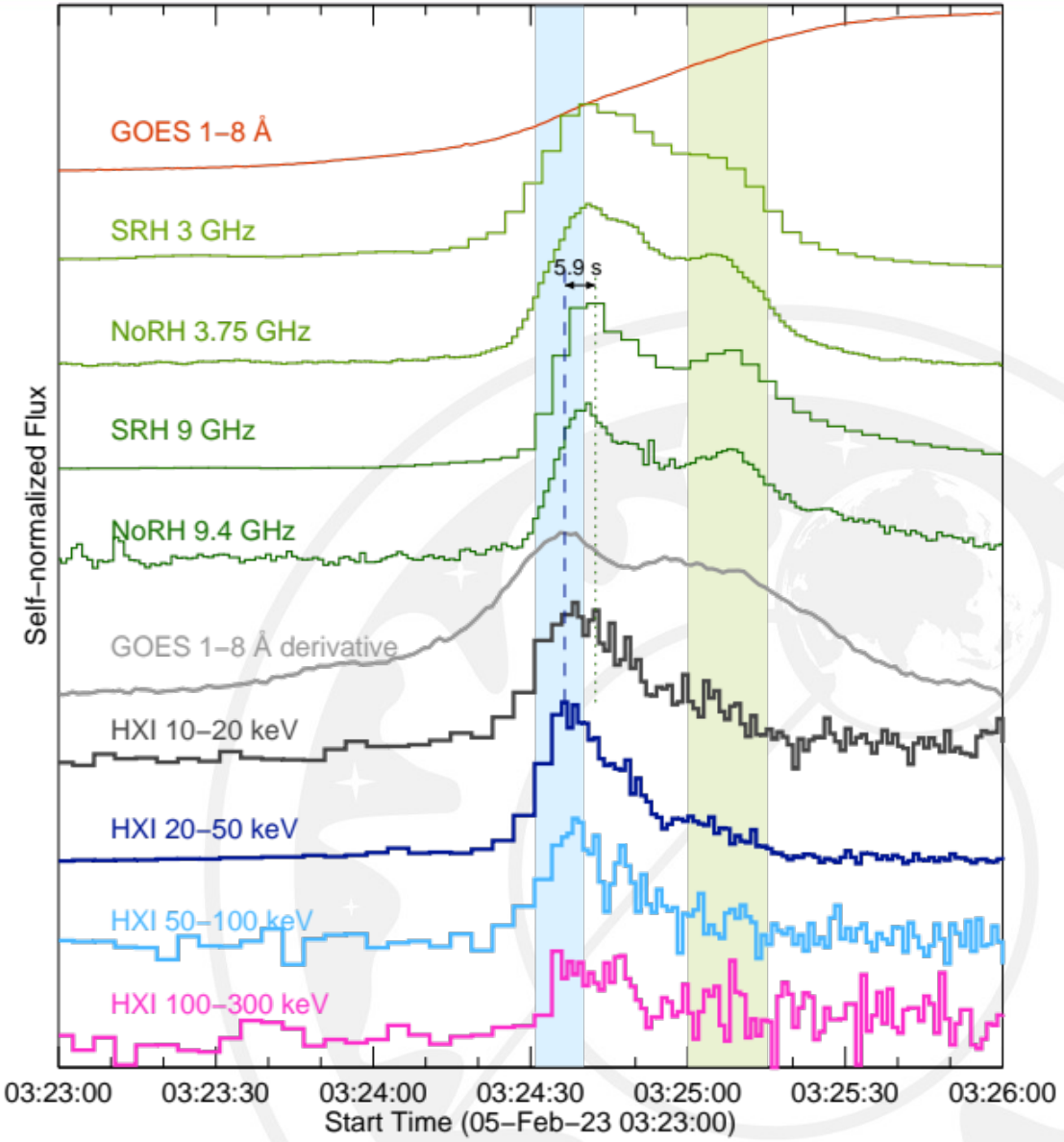
SDO/AIA 94 Å



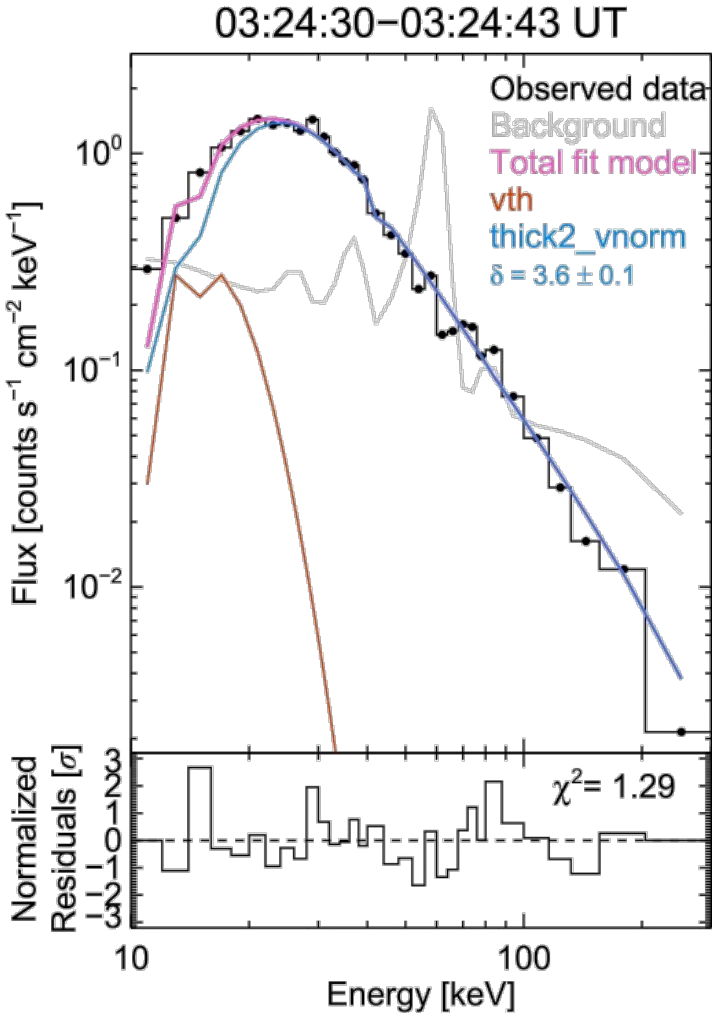
Hanaoka model (1997) **?**

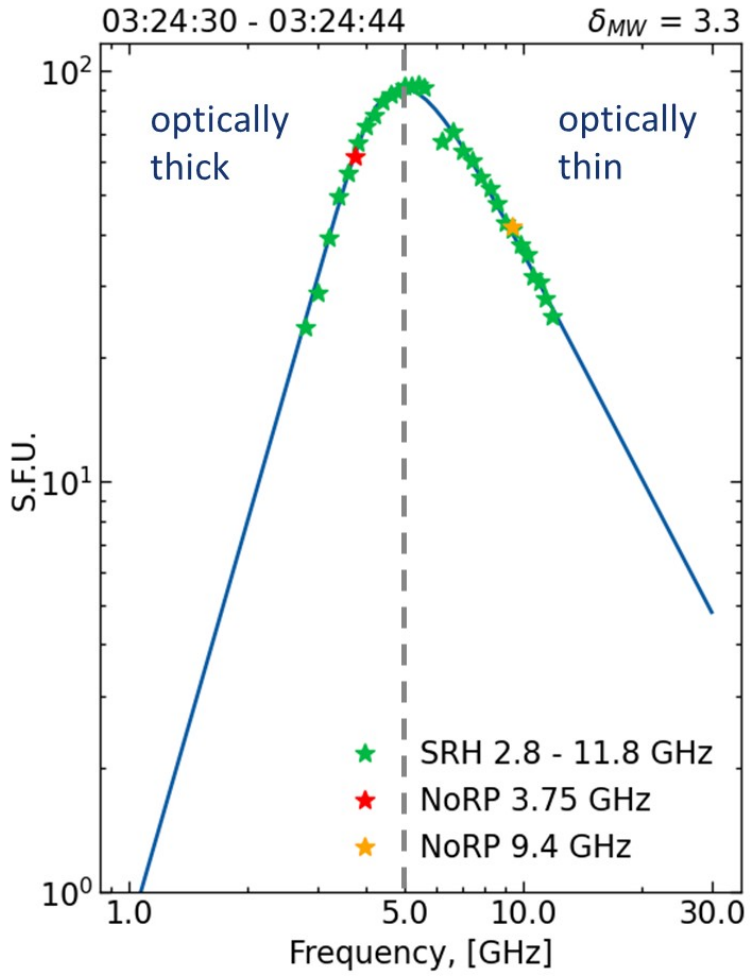
INSTRUMENTS

- ASO-S/HXI 10–300 keV
- GOES 1–8 Å
- SRH 3–12 GHz
- NoRP (3.75 and 9.4 GHz)
- SDO/HMI and SDO/AIA

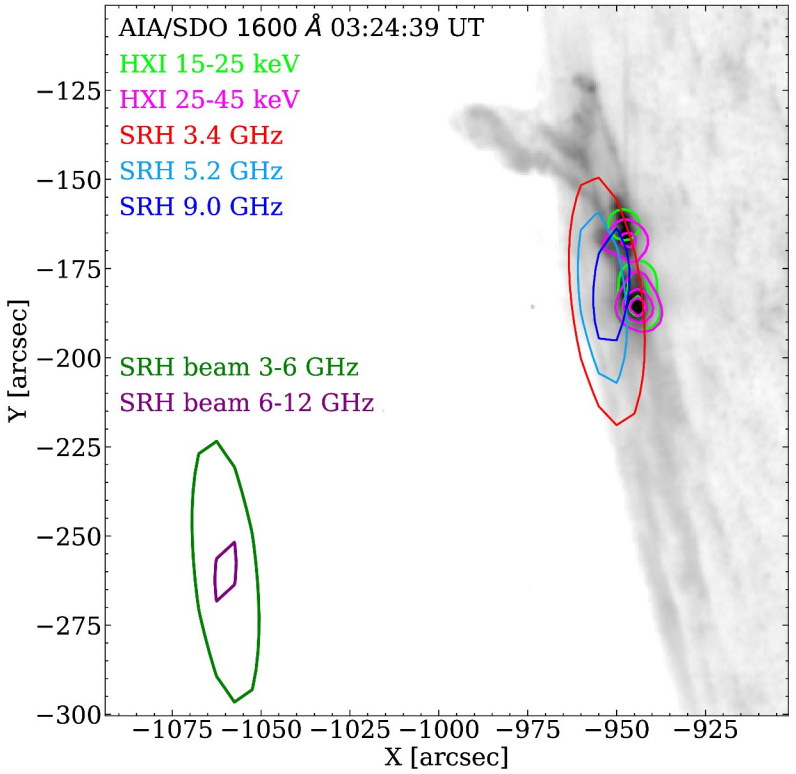


SPECTRAL ANALYSIS





SPATIAL STRUCTURE OF THE FLARE LOOP



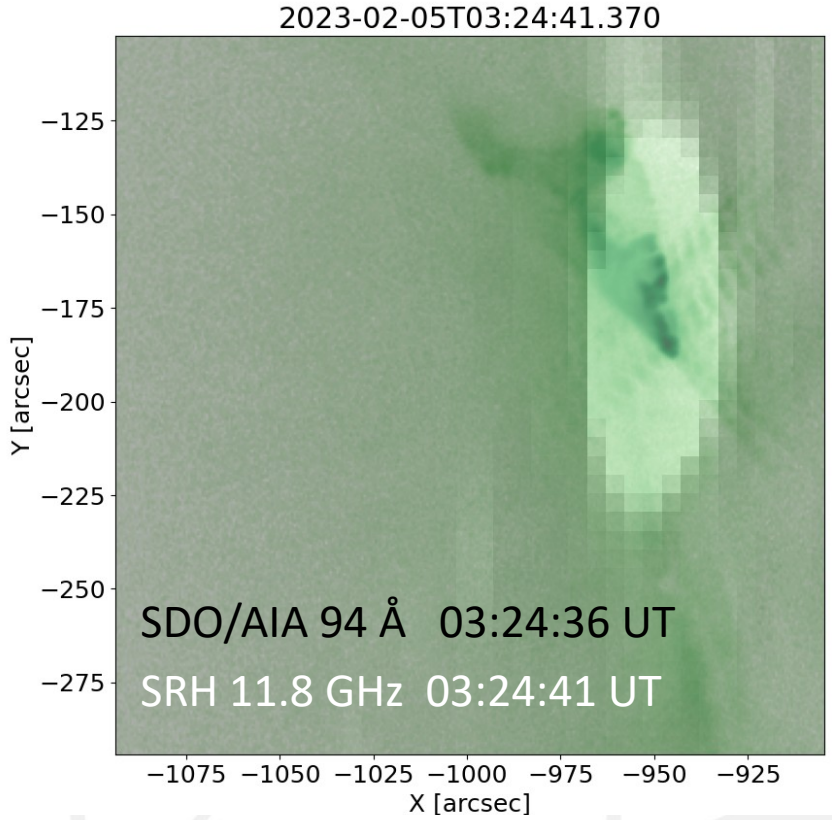
Estimation the magnetic field strength at the observed MW flare source using Dulk (1985) formula:

Size of the flare source = 30 arcsec

Photon spectral index = 3.3

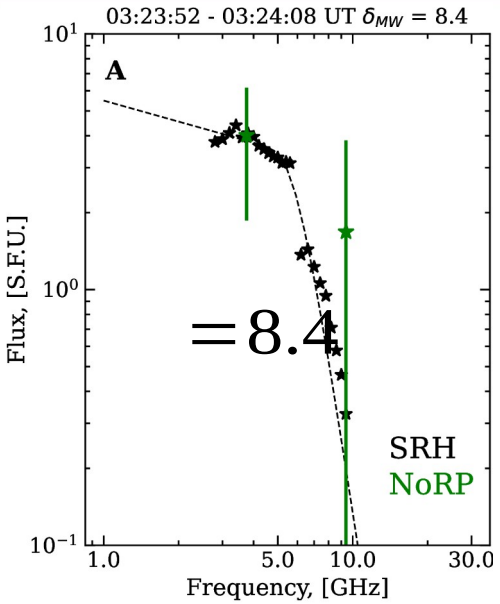
Electron flux = $3 \cdot 10^{27}$ erg/s

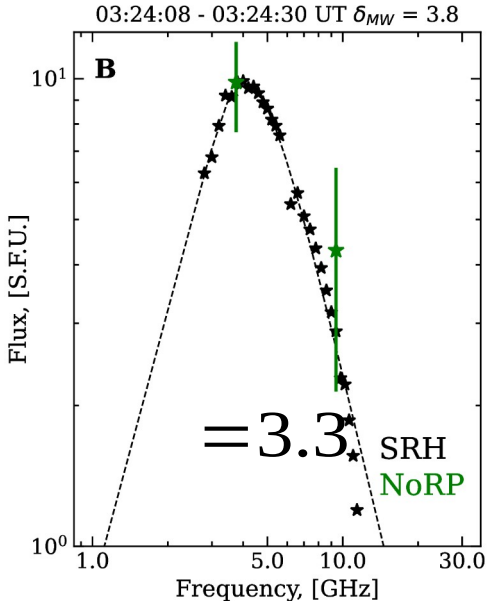
Magnetic field = 130 G



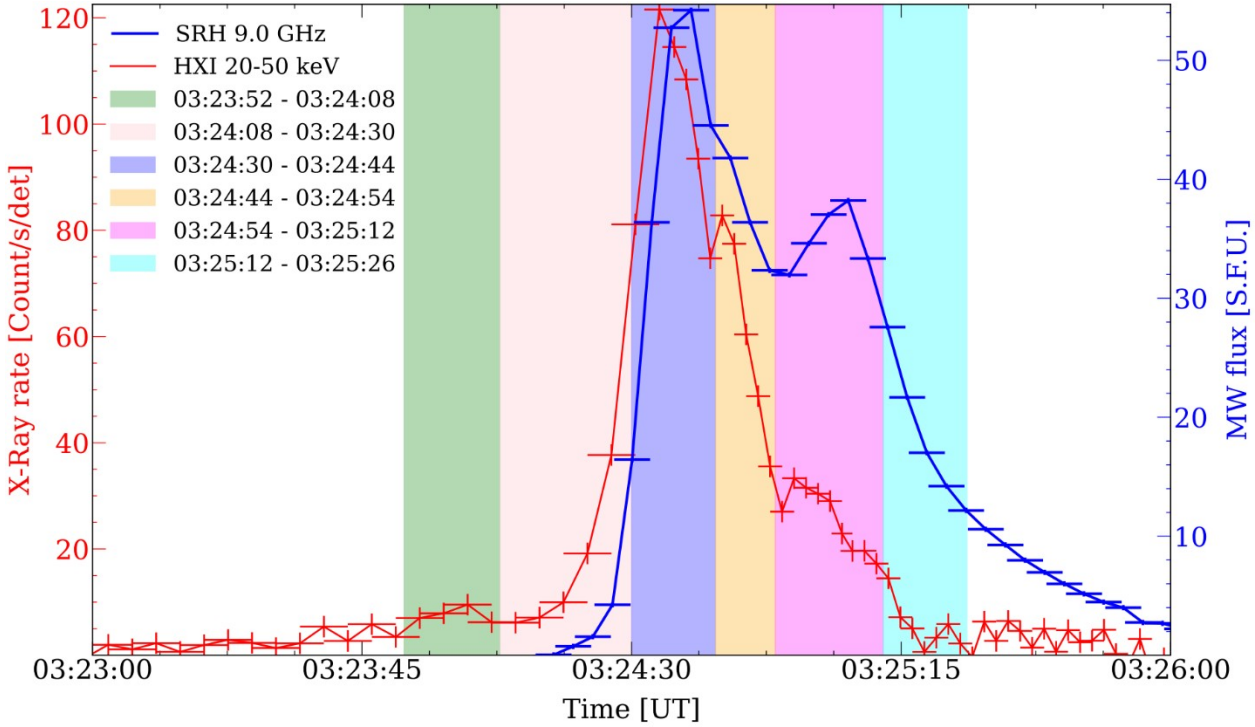
Small compact flare loop

SPECTRAL ANALYSIS OF THE FLARE LOOP

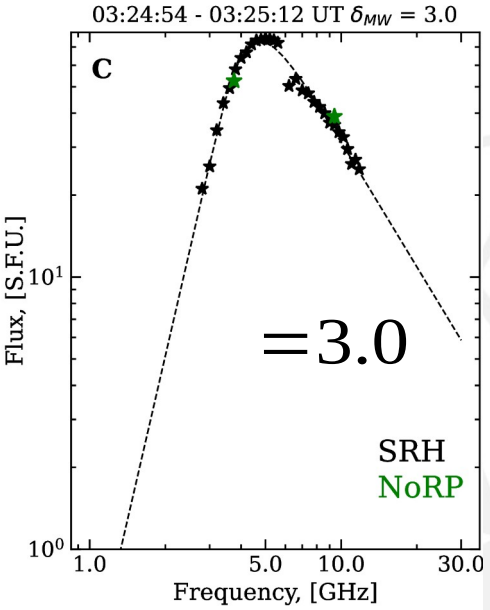




Gyrosynchrotron emission of thermal electrons



Gyrosynchrotron emission of nonthermal electrons



Gyrosynchrotron emission of nonthermal electrons

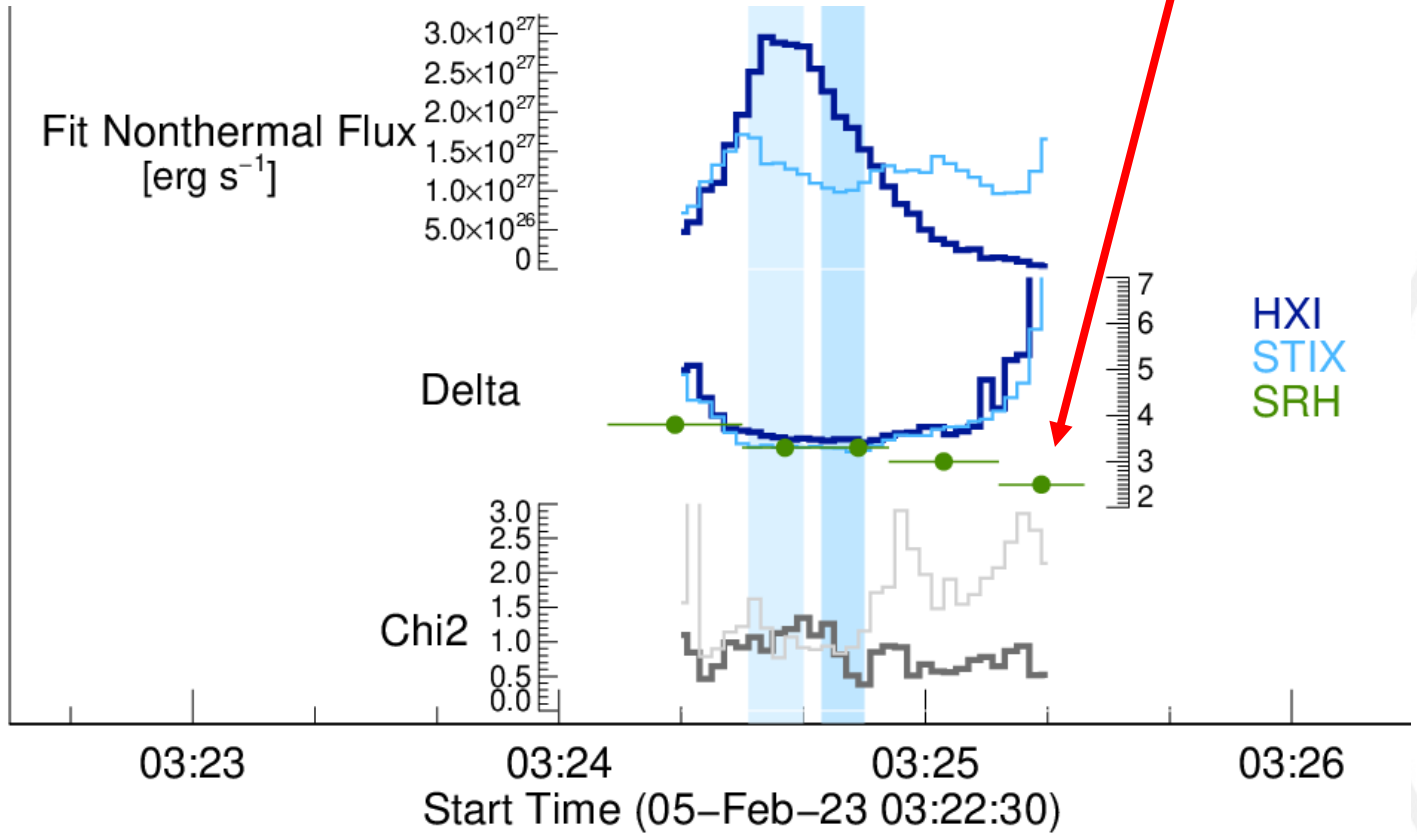
Heating -> acceleration

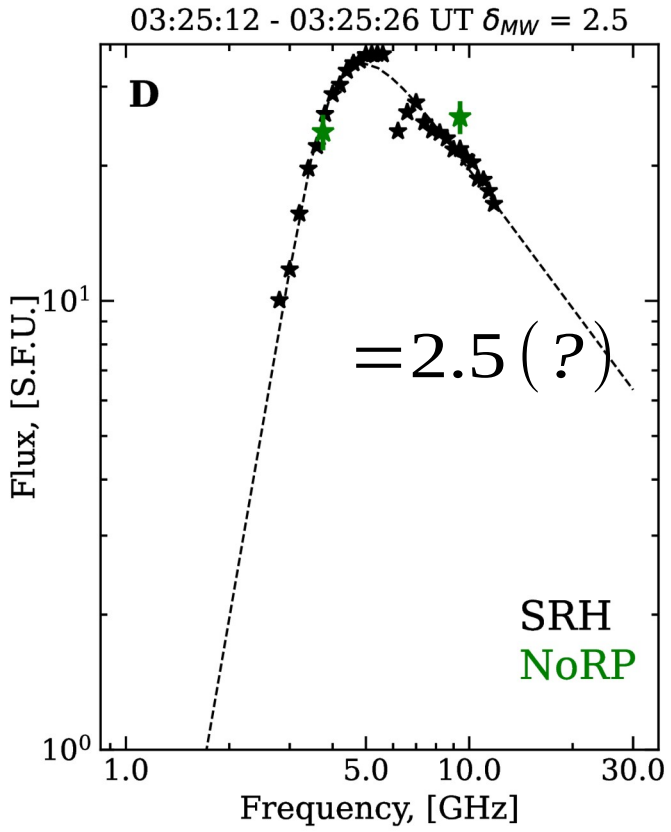
Time intervals UT	δ_{MW}	δ_{HXI}	T_{HXI}, MK	EM_{HXI}, 10^{47} cm^{-3}	T_{GOES}, MK
03:23:52 – 03:24:08	8.4 ± 1.3[1]	–	–	–	11.9 ± 0.7

High temperature in the preflare phase

MICROWAVE AND X-RAY SPECTRAL INDICES

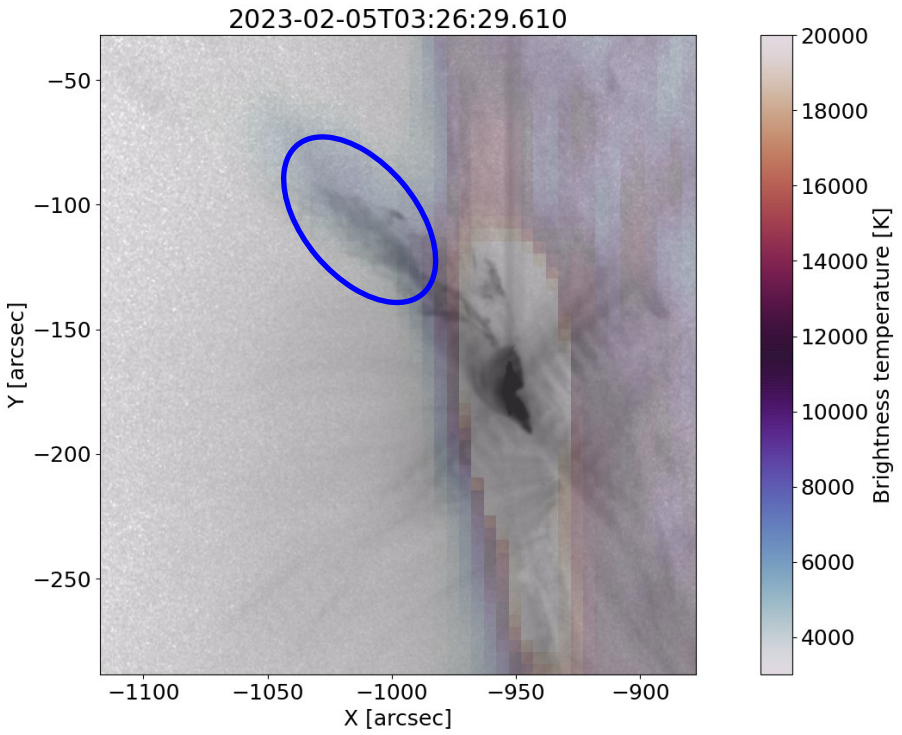
Is the index getting harder?





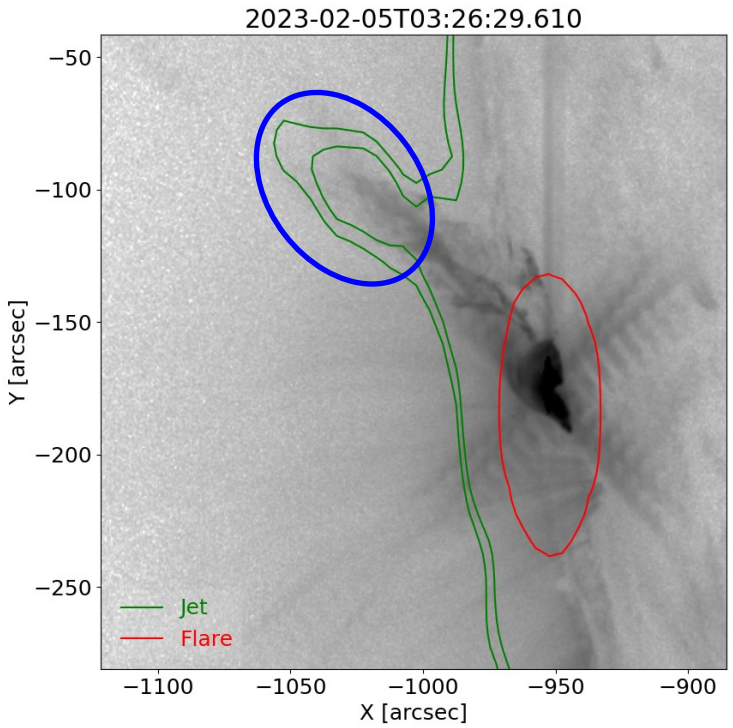
Have the accelerated parameters changed only in microwaves?

SPECTRUM FOR TIME MOMENT WITH A JET



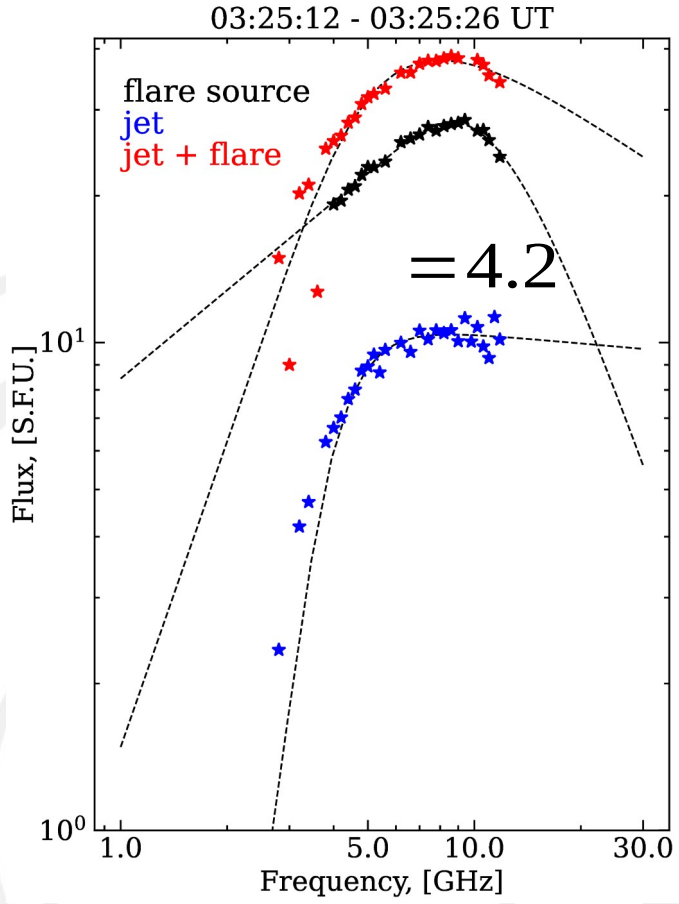
SRH 11.8 GHz (color palette)

SDO/AIA 131 Å (black palette)



SDO/AIA 94 Å

Green contours SRH 11.8 GHz



Time intervals UT	δ_{MW}	δ_{HXI}	T_{HXI}, MK	EM_{HXI}, 10^{47} cm^{-3}	T_{GOES}, MK	EM_{GOES}, 10^{47} cm^{-3}
03:23:52 – 03:24:08	8.4 ± 1.3[1]	–	–	–	11.9 ± 0.7	3.1 ± 2.0
03:24:08 – 03:24:30	3.8 ± 0.3[1]	4.4 ± 0.3	15.0 ± 5.3	1.9 ± 55.0	12.8 ± 0.7	5.0 ± 2.0
03:24:30 – 03:24:44	3.3 ± 0.2[1]	3.6 ± 0.1	31.5 ± 0.8	0.1 ± 0.2	13.3 ± 0.7	10.0 ± 2.0
03:24:44 – 03:24:54	3.3 ± 0.3[1]	3.5 ± 0.1	25.2 ± 0.6	0.4 ± 0.5	13.7 ± 0.7	13.2 ± 2.0
03:24:54 – 03:25:12	3.0 ± 0.4[1]	3.4 ± 0.1	24.3 ± 0.9	0.3 ± 0.6	14.2 ± 0.7	16.7 ± 2.0
03:25:12 – 03:25:26	$[2.5 \pm 0.1]$[1] 4.2 ± 0.1[2]	3.7 ± 0.5	13.3 ± 0.9	10.8 ± 79.0	14.4 ± 0.7	20.2 ± 2.0

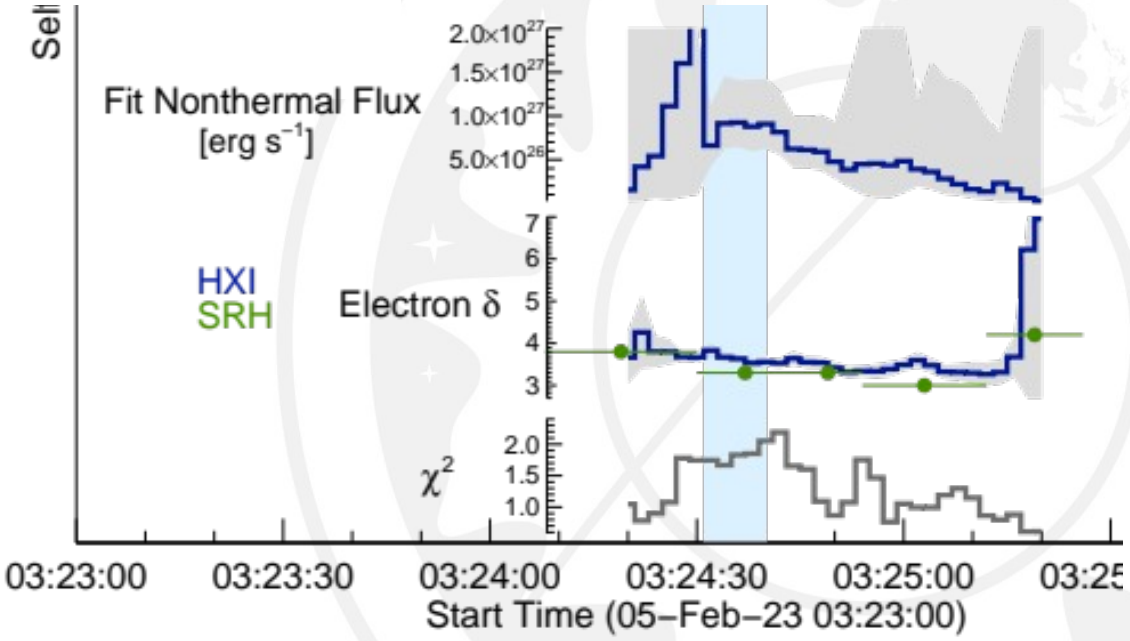
[1] The electron index obtained from the average MW spectrum.

[2] The electron index obtained from imaging spectroscopy.

More details in the paper
doi:10.1007/s11207-024-02331-w

soft-hard-soft

(false hardening of the microwave spectral index due to the jet contribution)



SUMMARY

- The main source of energy release was a small compact loop with a magnetic field of 130 G;
- At the preflare phase the microwave spectrum indicates gyrosynchrotron emission of thermal electrons, which preceded the appearance of accelerated electrons (heating -> acceleration). Is it typical for the Hanaoka model?
- Spectral indices of accelerating electrons obtained from the data of the two ranges are consistent at all stages of the flare evolution, that indicates a simple topology of the event;
- Hardening of average microwave spectra at the end of impulsive phase was caused by the contribution of jet MW emission.

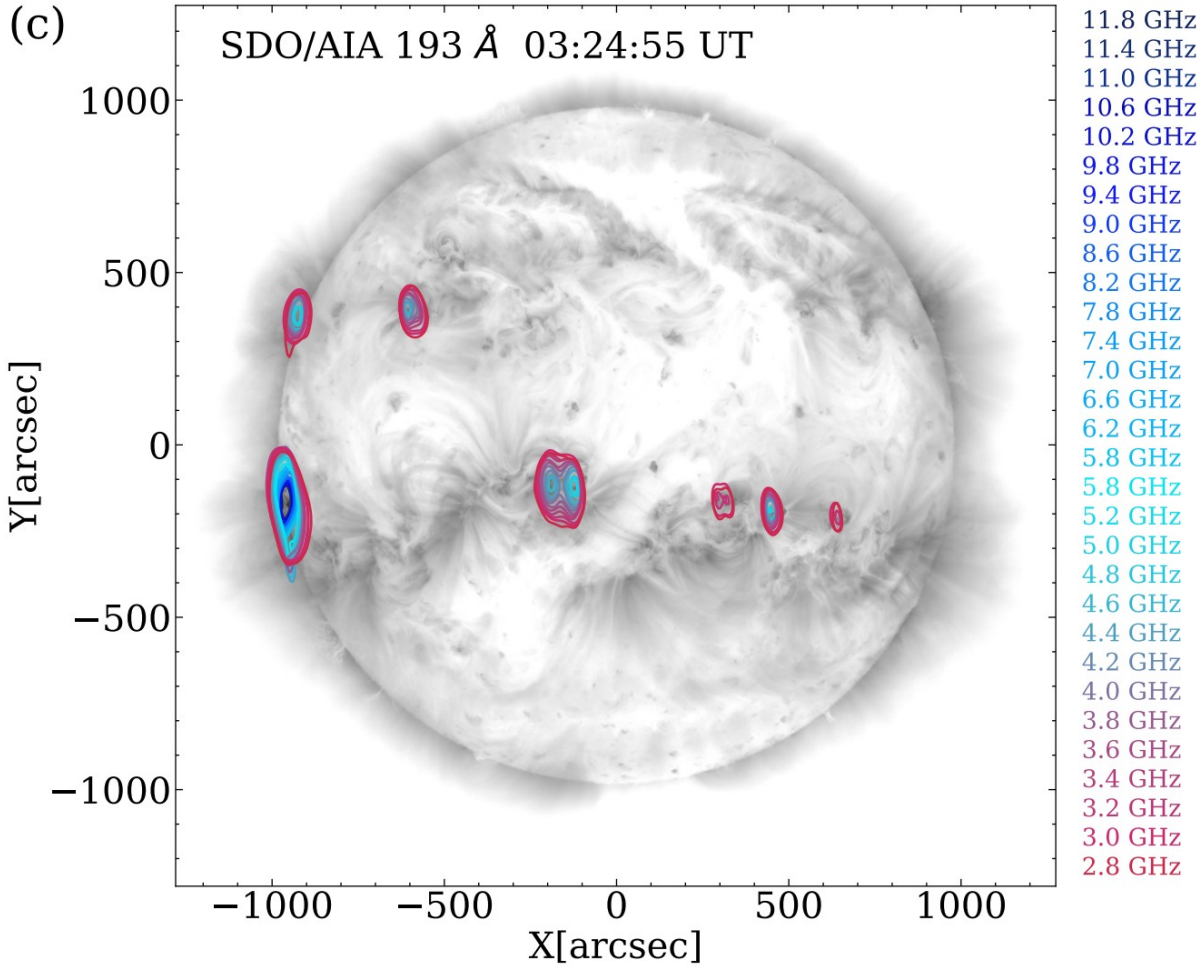
SUMMARY

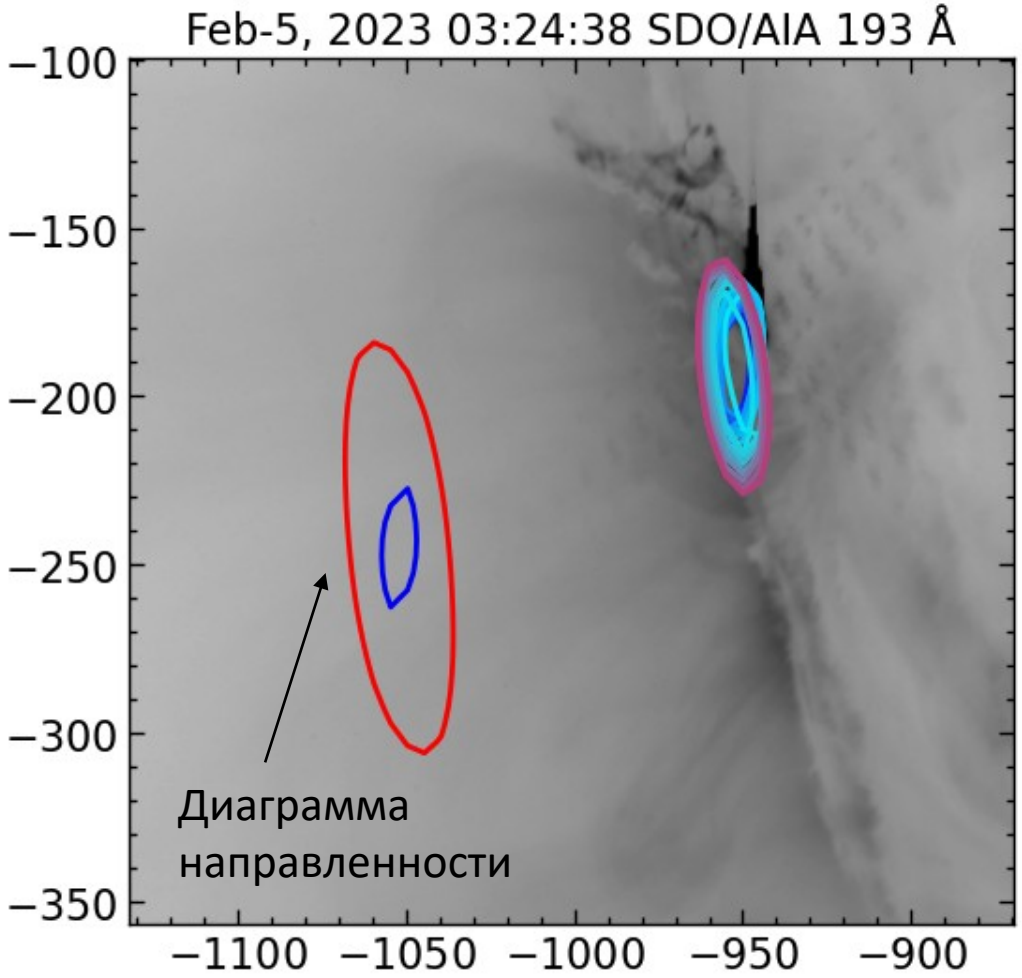
- The main source of energy release was a small compact loop with a magnetic field of 130 G;
- At the preflare phase the microwave spectrum indicates gyrosynchrotron emission of thermal electrons, which preceded the appearance of accelerated electrons (heating -> acceleration). Is it typical for the Hanaoka model?
- Spectral indices of accelerating electrons obtained from the data of the two ranges are consistent at all stages of the flare evolution, that indicates a simple topology of the event;
- Hardening of average microwave spectra at the end of impulsive phase was caused by the contribution of jet MW emission.

THANK YOU FOR ATTENTION!

THANK YOU FOR ATTENTION!

Метод восстановления пространственной структуры микроволновых источников по данным СРГ





Вычтенные источники в момент максимума 03:24:38