Leibniz-Institut für
Astrophysik Potsdam
AIP

First joint STIX and LOFAR observations of a flare event on 06 June 2020

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United Nations / Azerbaijan Workshop on the International Space Weather Initiative (ISWI)

Outline

I. Scientific context
   - Standard Solar Flare Model
   - Instruments and their observing range

II. Observations of flare-accelerated electrons
   - Away from the sun – radio (LOFAR)
   - Towards the sun – X-ray (STIX)

III. Magnetic field modelling and joint observations

Scientific Context – Solar Flare

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

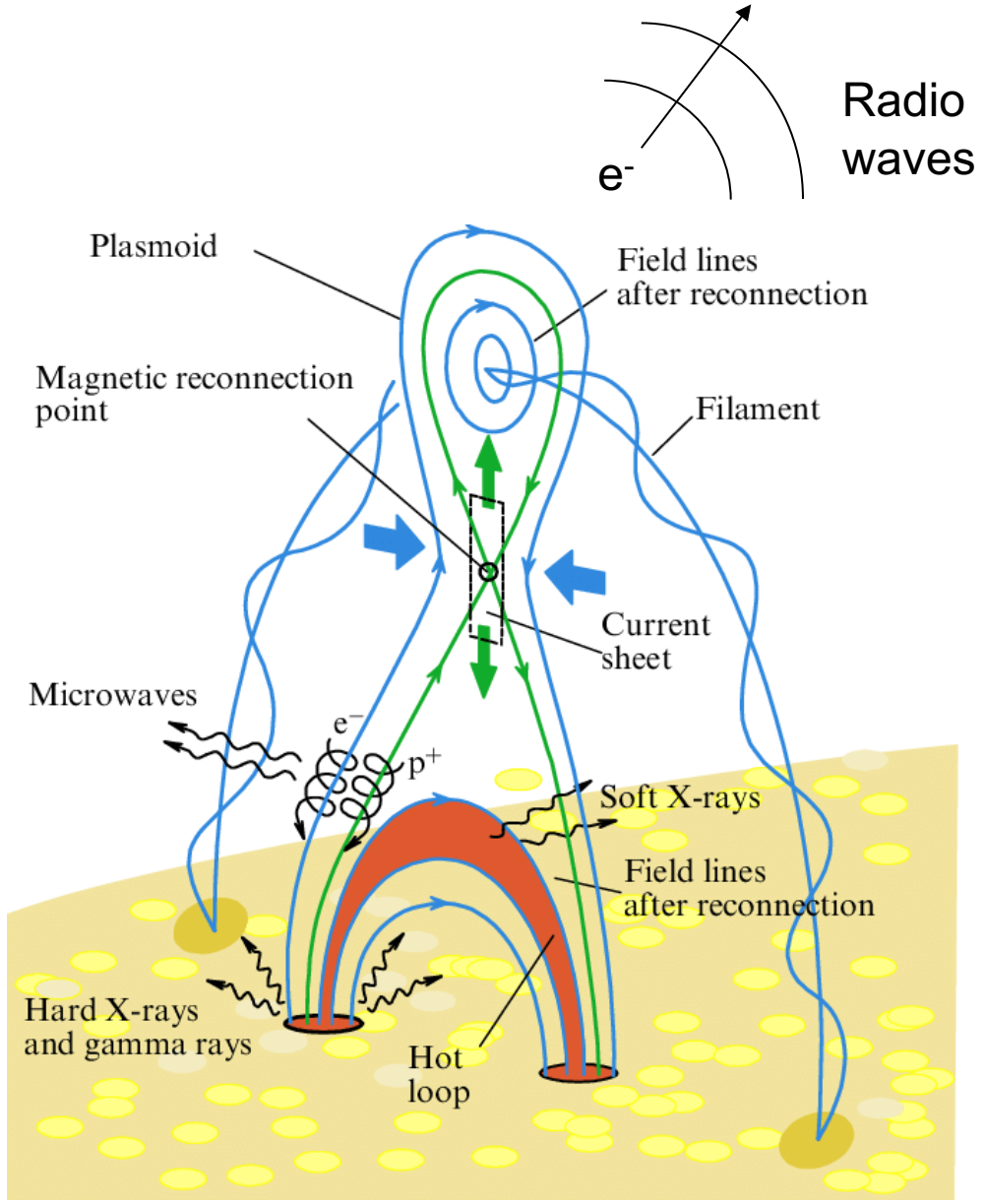
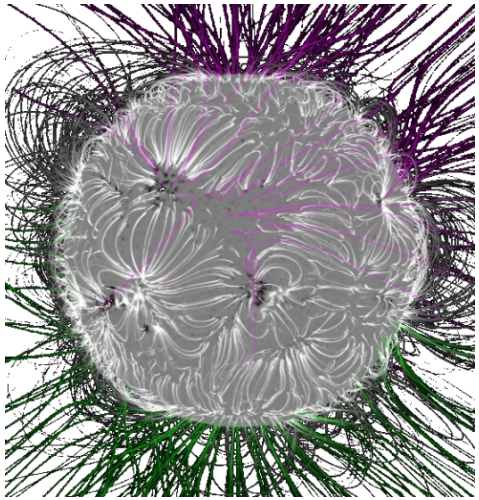


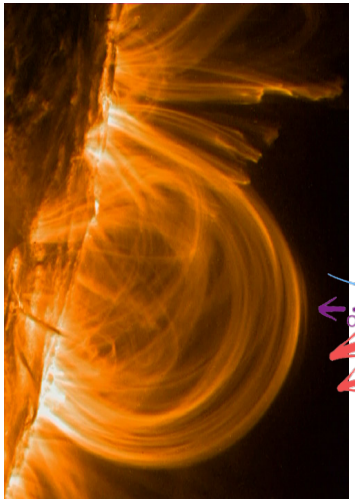
Figure is from A. L. Lysenko et al 2020 Phys.-Usp. 63 818

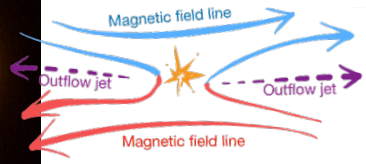
Instruments and their observing range

Photosphere

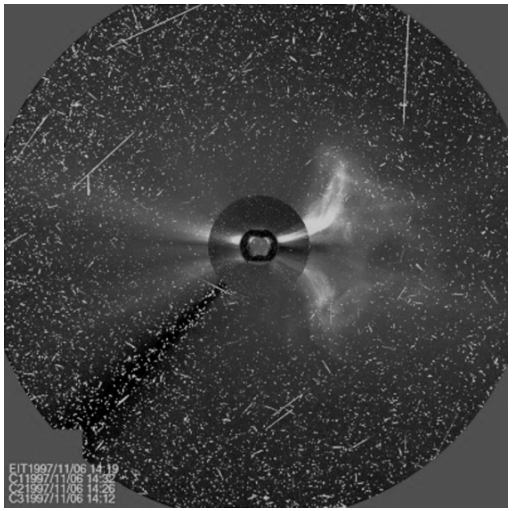


Corona





Heliosphere -
Space Weather



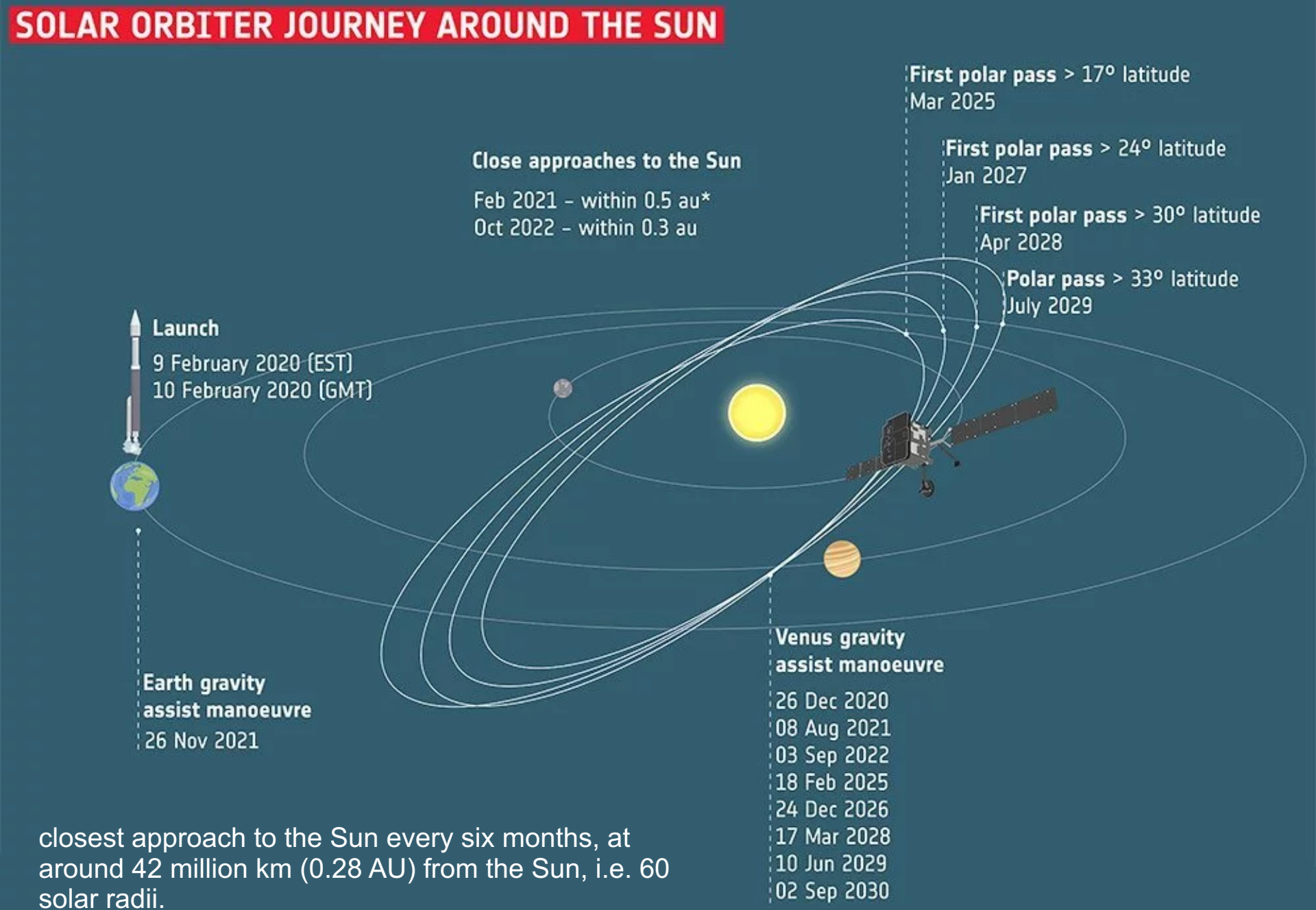
LOw Frequency Array – Radio Interferometer

LOFAR structure:

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

Frequency range:

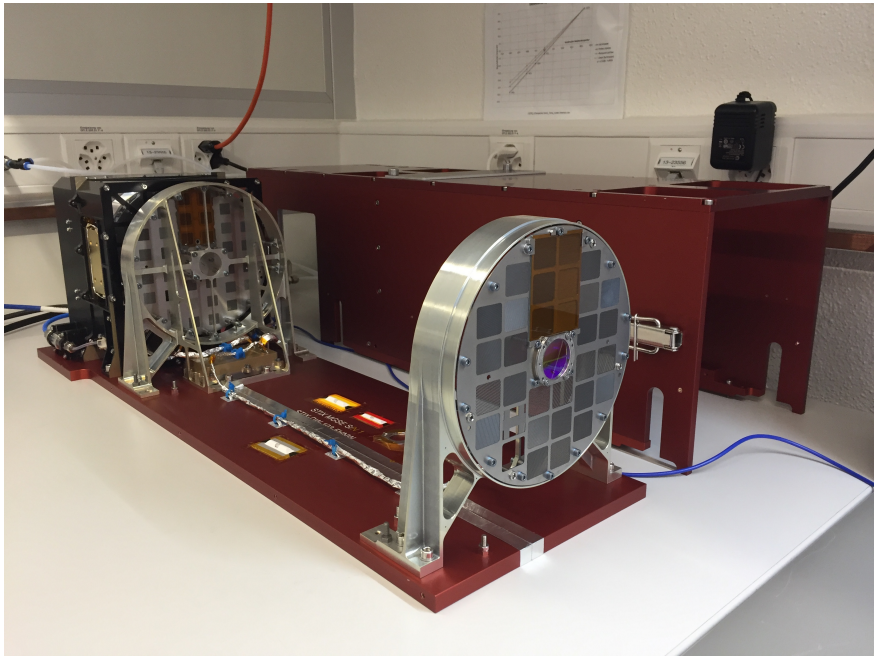
- Low Band: 10 – 90 Mhz
- High Band: 110 – 250 MHz



closest approach to the Sun every six months, at around 42 million km (0.28 AU) from the Sun, i.e. 60 solar radii.

Spectrometer/Telescope for Imaging X-rays (STIX)

- imaging spectroscopy of solar thermal and non-thermal X-ray emission
- from 4 to 150 keV
- STIX provides quantitative information on the timing, location, intensity, and spectra of accelerated electrons



Project description

- analysis of flare signatures both in the low and higher corona.
- radio, EUV and X-ray data provide an extensive picture about different aspects of flare characteristics.
- investigation of the origin of flare accelerated electrons and their link to other flare phenomena, e.g. plasma heating.
- binding element: Solar magnetic field (PFSS modelling)

II. Observations of flare-accelerated electrons

Away from the sun – radio (LOFAR)

Towards the sun – x-ray (STIX)

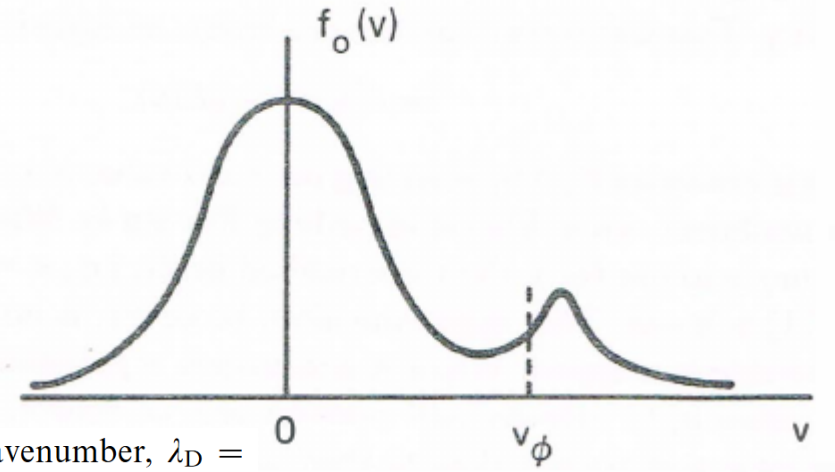
Event from joint observing campaign: 06 June 2020

Brief theory – flare accelerated electrons and radio beam formation

- Electrons become accelerated (power law) and propagate to higher altitutes in the corona.
- Interact with their ambient plasma and contribute to an unstable distribution function.
- Frequency of radio waves depends on the height in the solar atmosphere.

$$\omega_{\mathrm{pe}} = \sqrt{\frac{n_{\mathrm{e}} e^2}{m^* \varepsilon_0}}$$

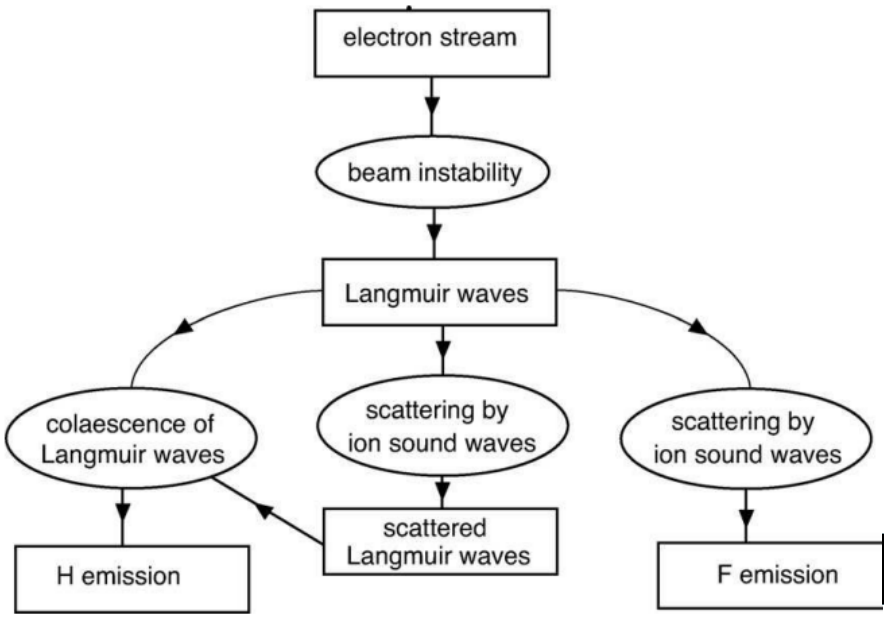
Unstable electron distribution function



$$\omega = \omega_p \left(1 + i \frac{\pi}{2} \frac{\omega_p^2}{k^2} \left[\frac{\partial f_0}{\partial v} \right]_{v=\omega_p/k} \right)$$

where ω_p is the electron plasma frequency, $\kappa = k\lambda_{\mathrm{D}}$, k is the wavenumber, $\lambda_{\mathrm{D}} = v_T/\omega_p$ is the Debye length, $v_T = \sqrt{T/m_e}$ is the electron thermal velocity, T is the electron temperature unperturbed by the waves, and m_e is the electron mass.

Solar Type-III Radio Bursts



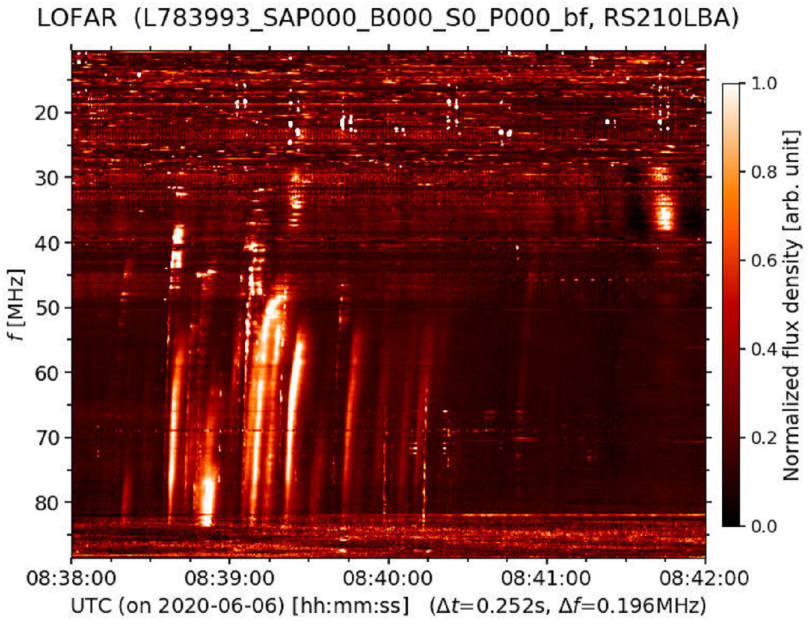
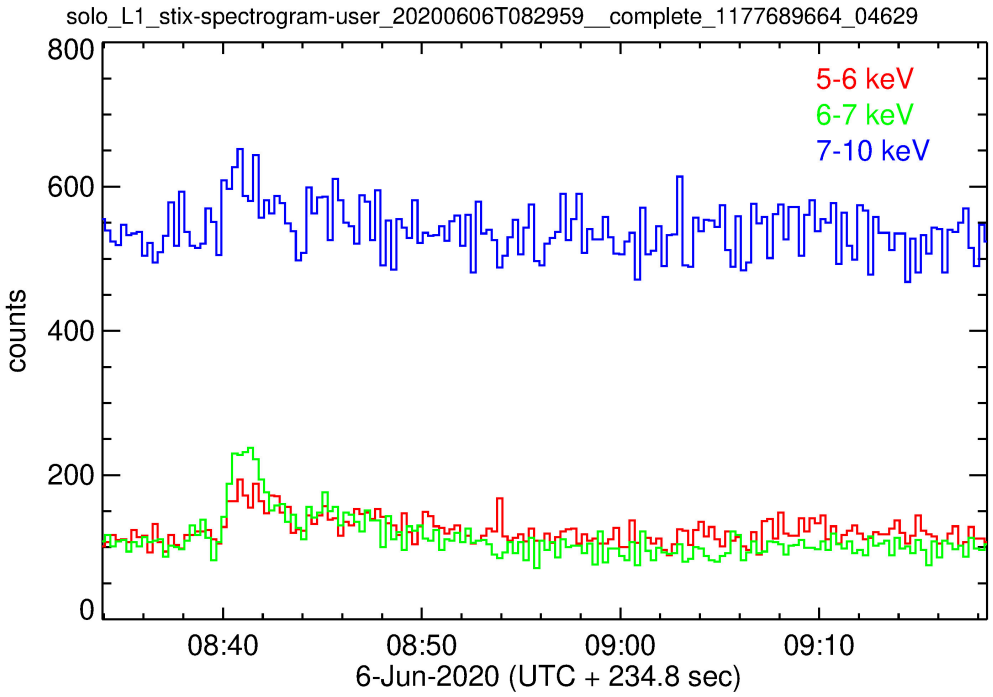


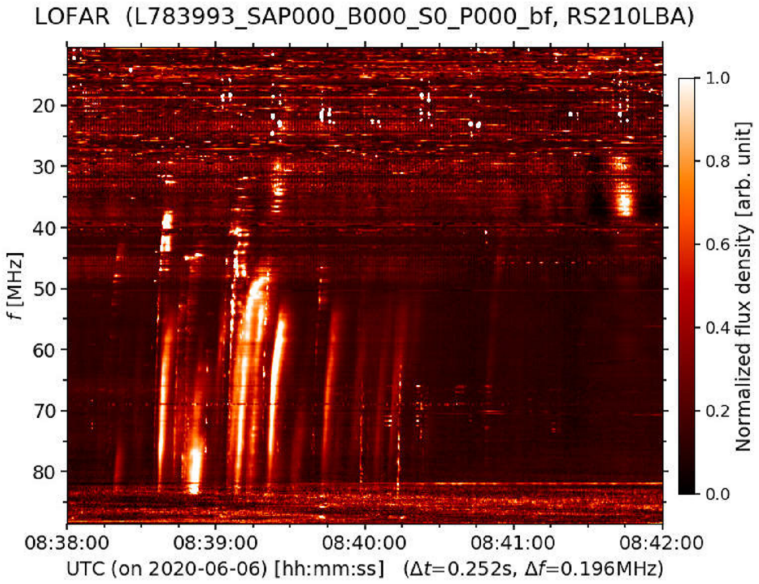
Figure by Melrose, 2009.

Observing campaign with STIX and LOFAR: Joint observations of flare-accelerated electrons

Changed magnetic field configuration?

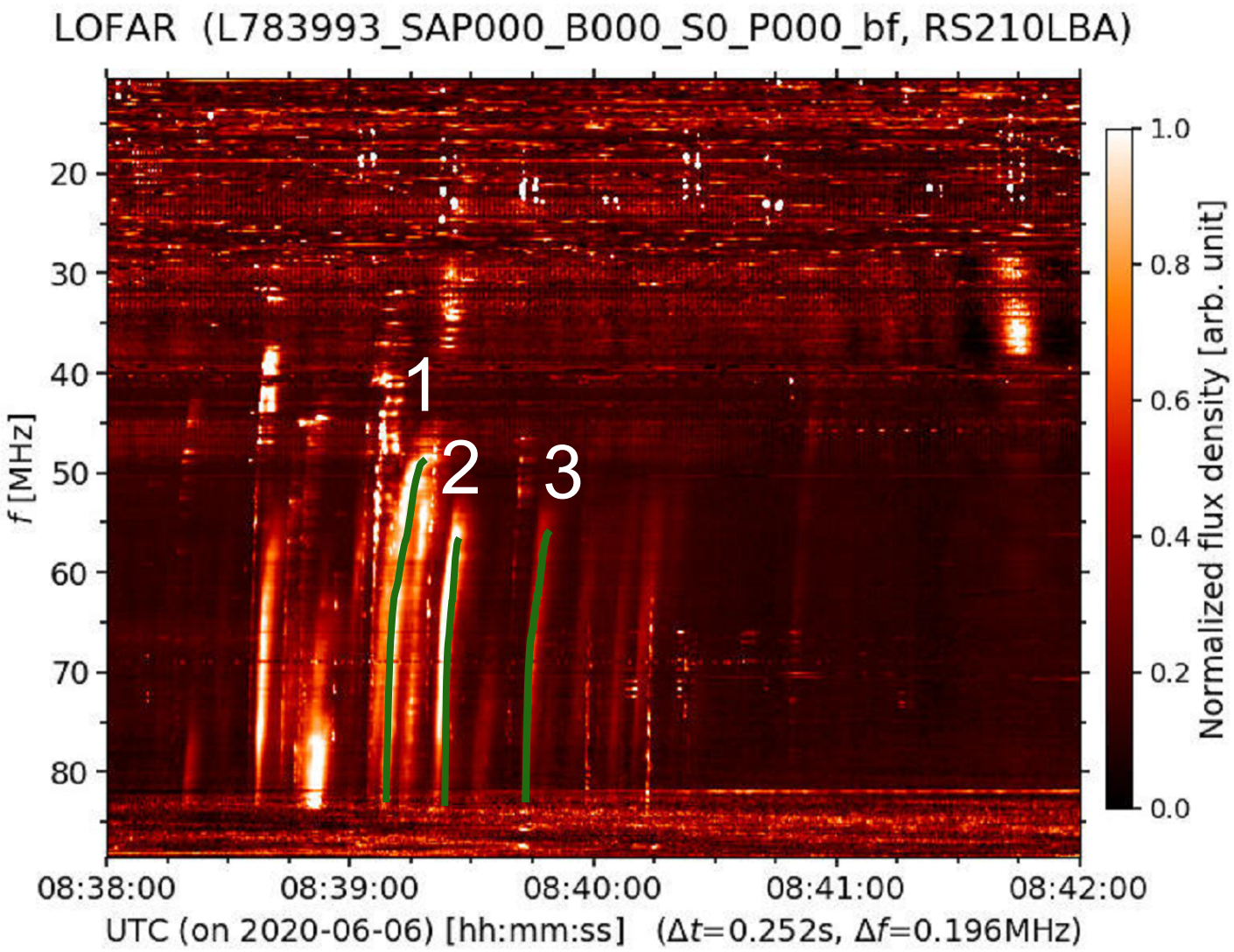
X-ray fluxes observed by STIX





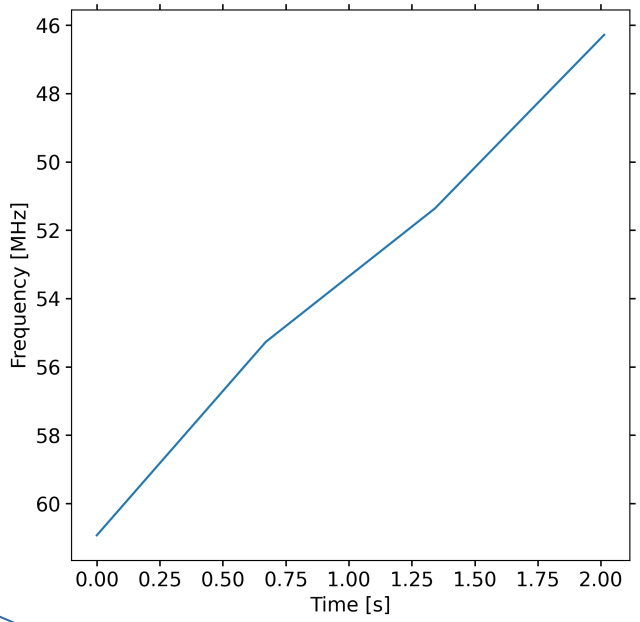
- Neupert-Theorem: Hard X-ray flux is related to the derivative of soft X-ray flux
- Time delay between X-ray and radio data not in accordance with delay due to propagation

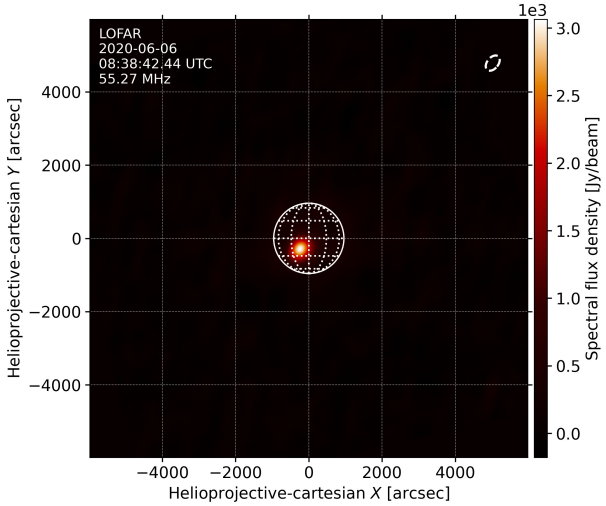
Solar Type-III Radio Bursts during solar flare on 06 June 2020

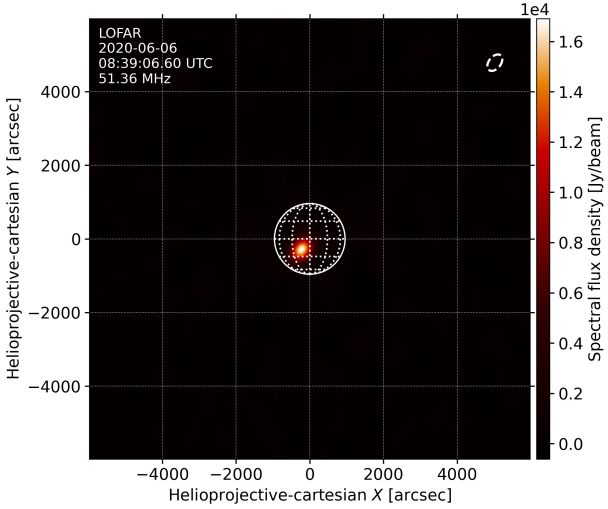


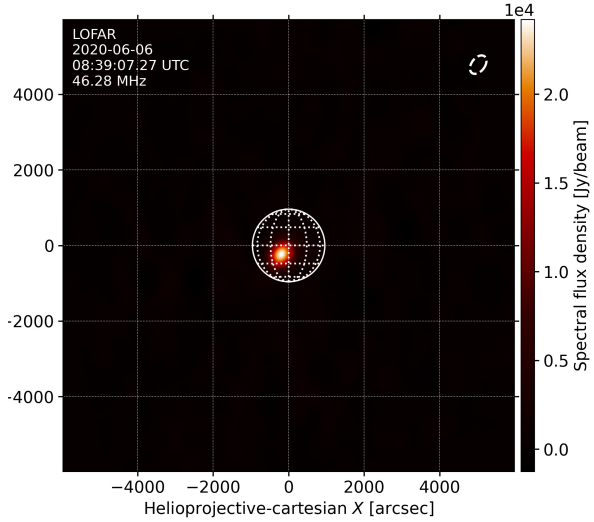
Following the electron beam through the Corona

Time [s]	0.6	1.3	2.
f [MHz]	55	51	46









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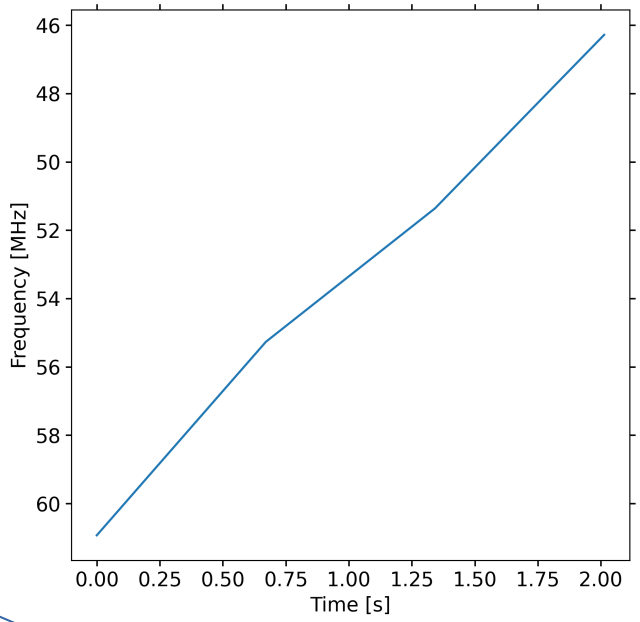
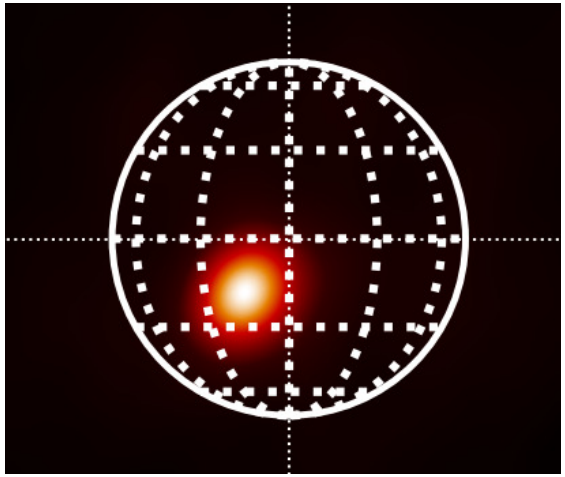
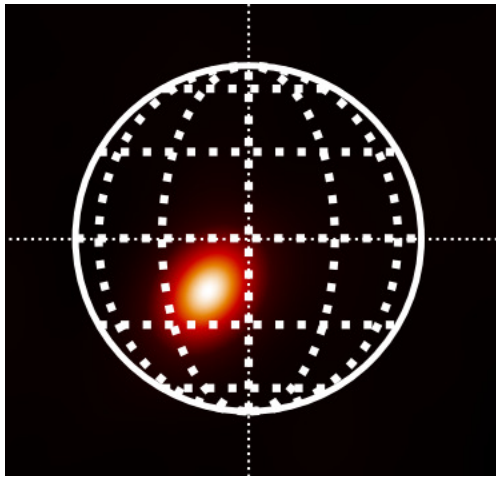
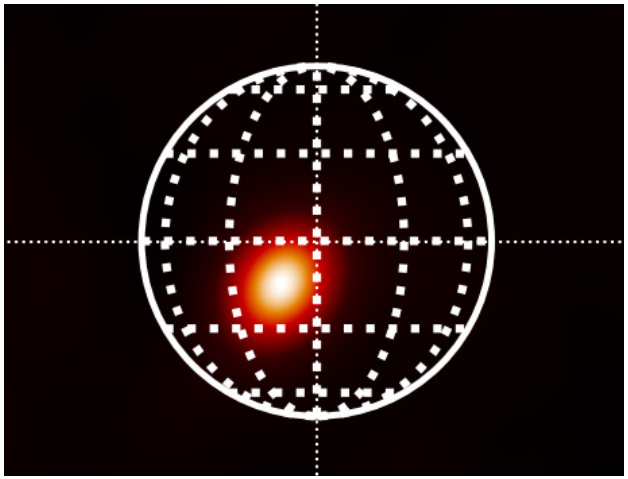
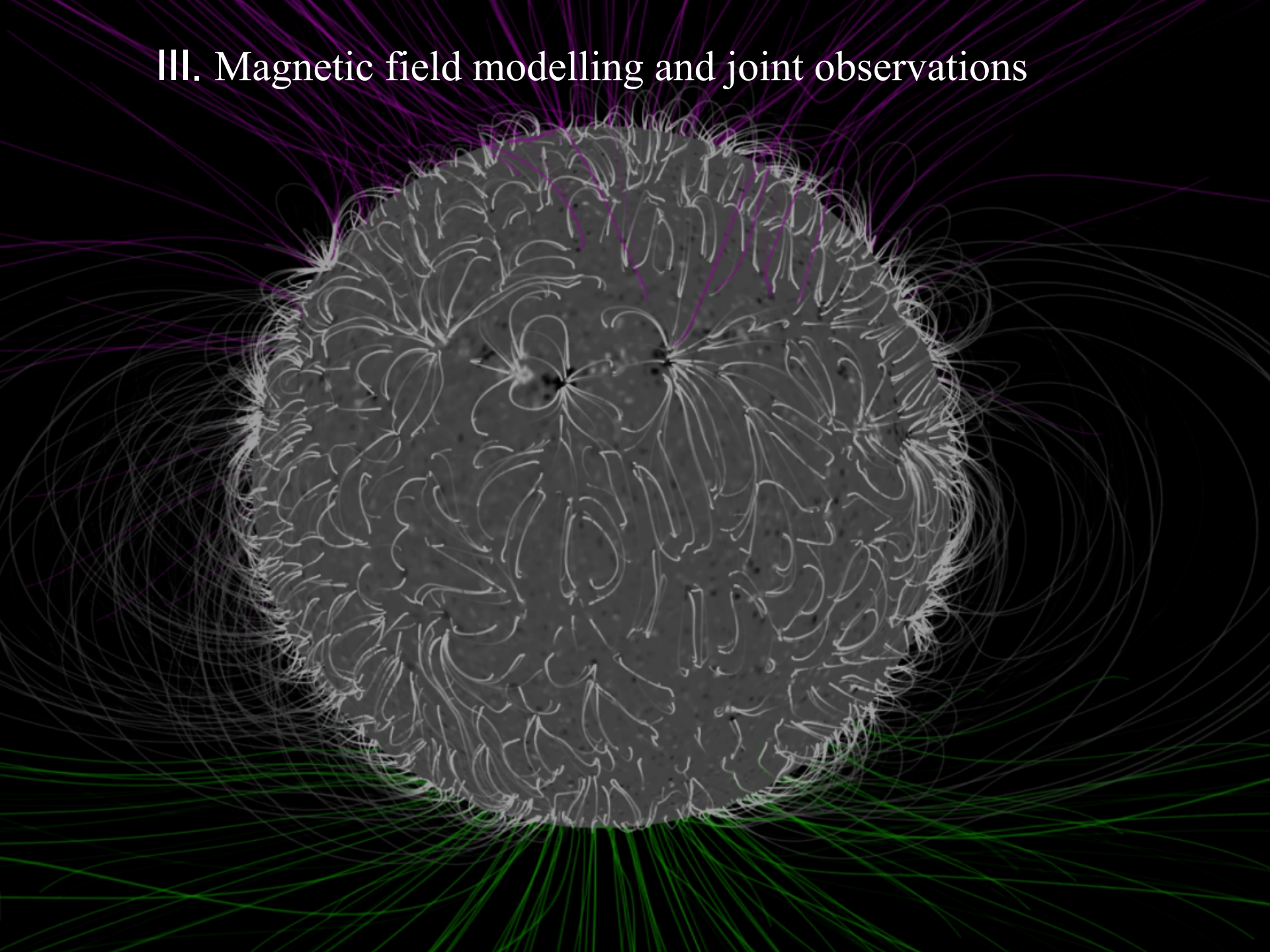






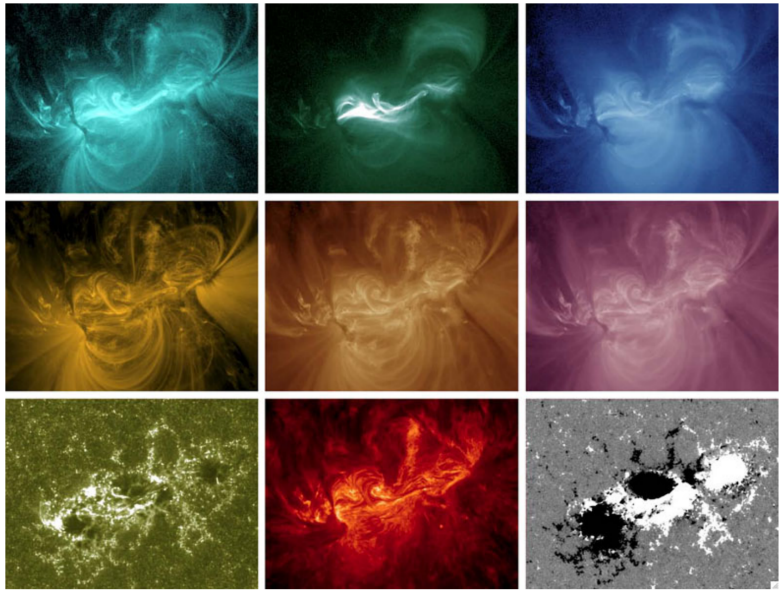


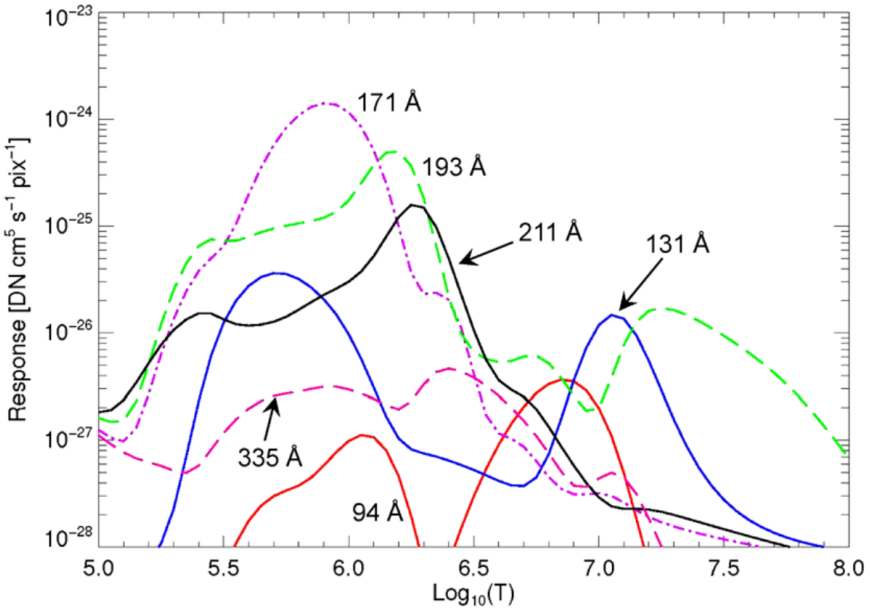
III. Magnetic field modelling and joint observations



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



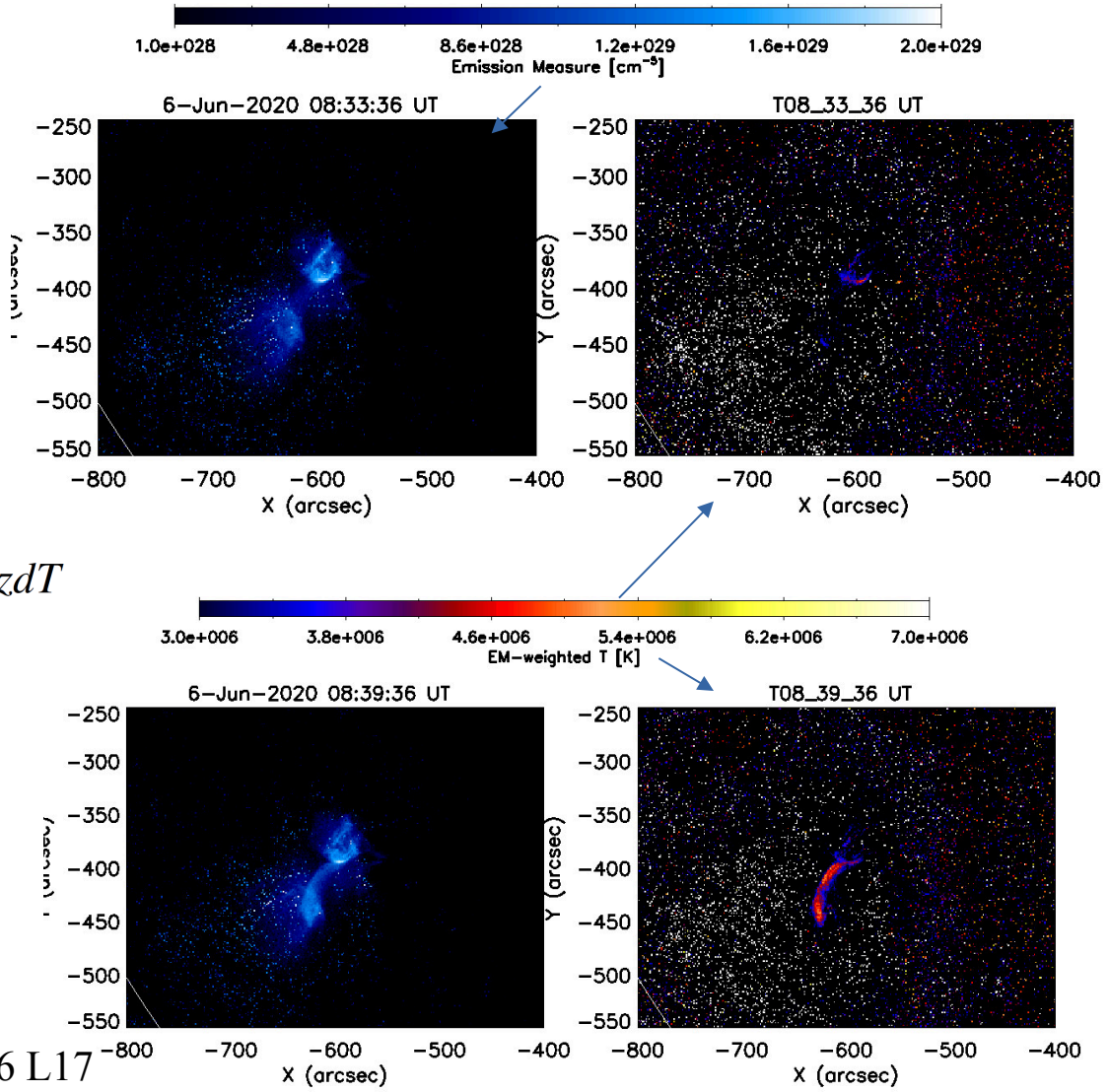


DEM Anaylsis based on EUV data

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

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

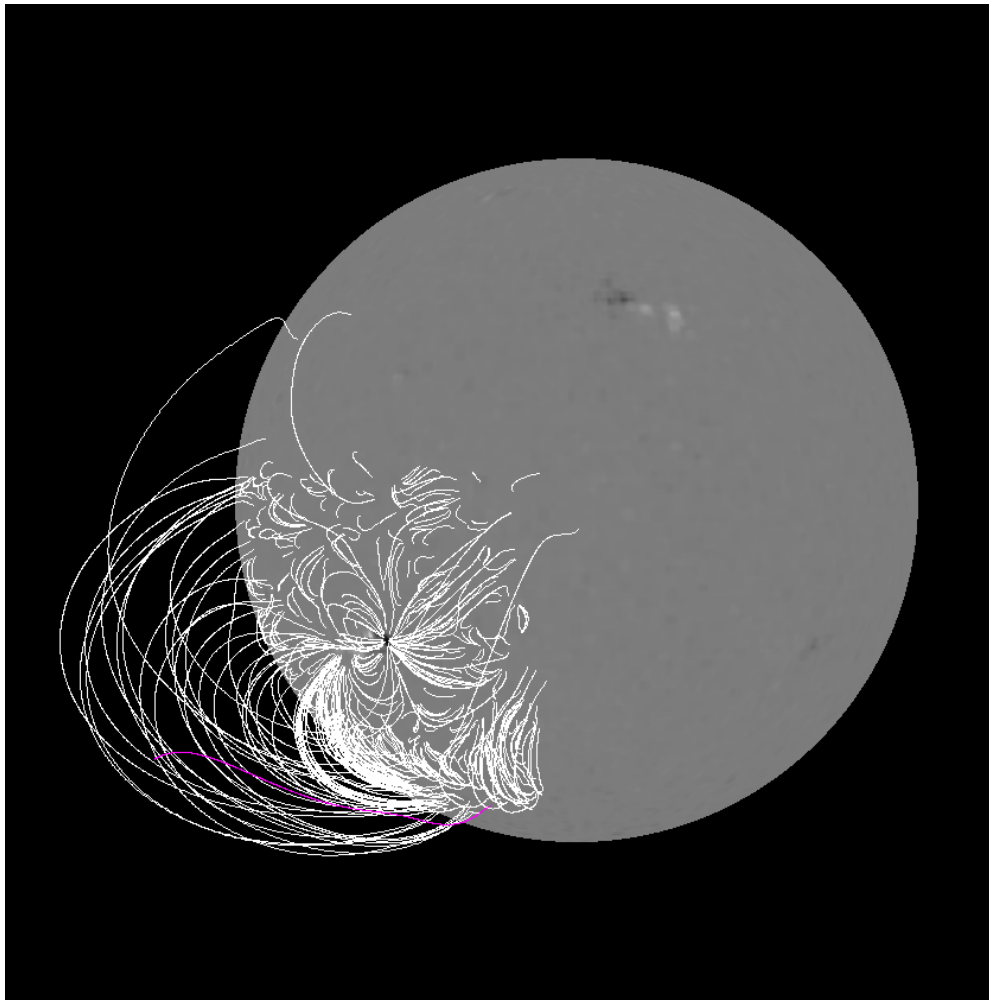
$$T_{EM} = \frac{\int T \cdot DEM(T) dT}{EM}$$



DEM Method: Yang Su et al 2018 ApJL 856 L17

Potential field source surface (PFSS) model

- method to extrapolate the photospheric magnetic field through the corona
- Based on HMI (SDO) data



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

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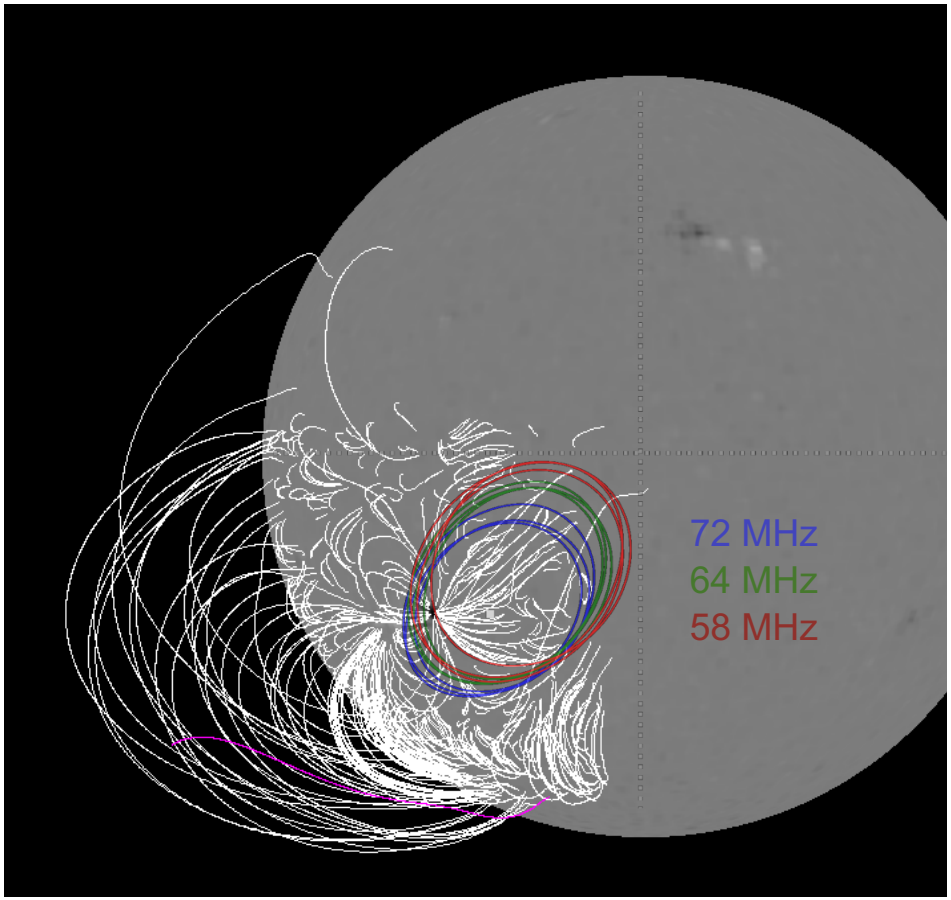

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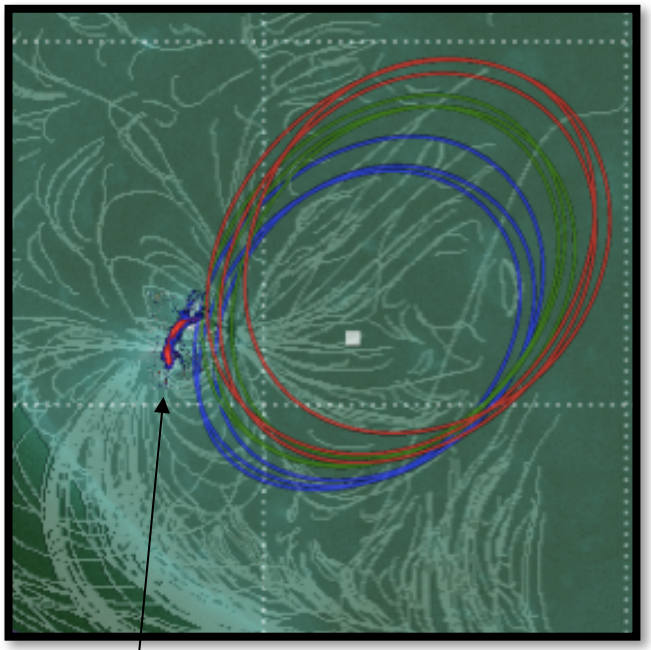
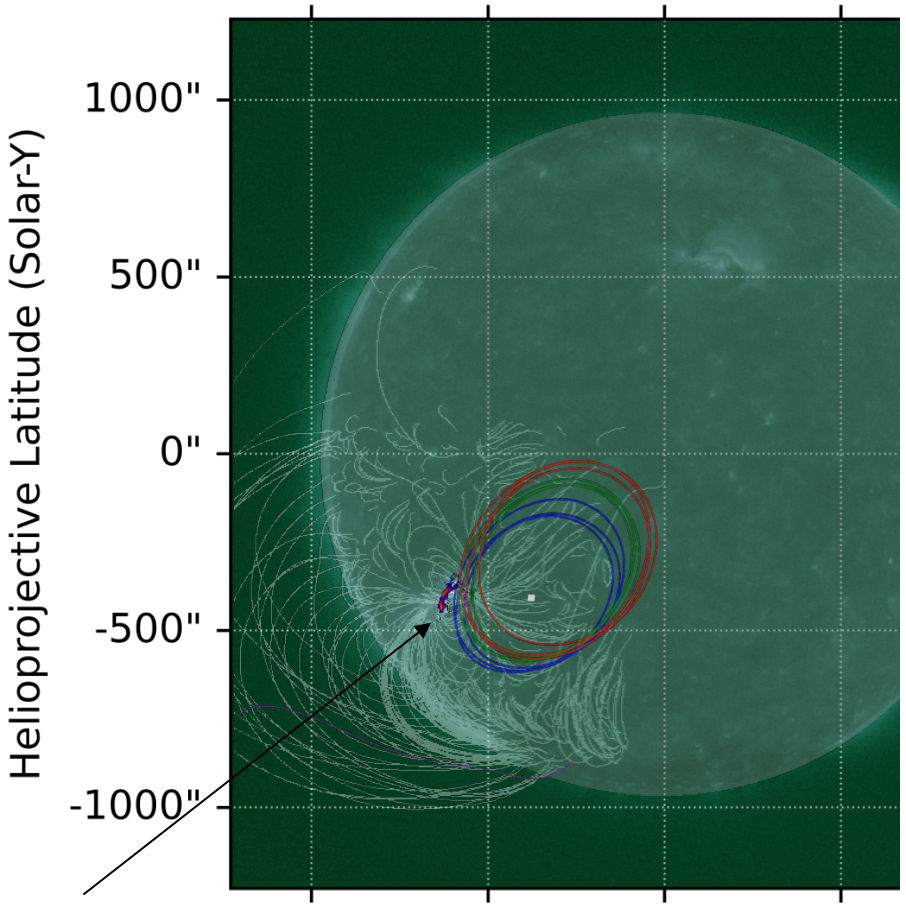
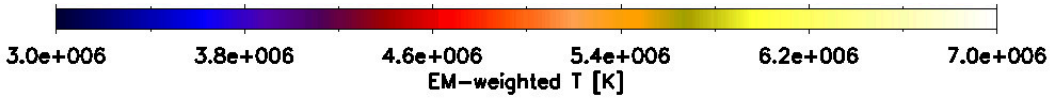
Combination of ground and space based obseravtions with the PFSS model

Radio beam (LOFAR) at 72 MHz, 64 MHz, 58 MHz.







Summary

- analysis of flare signatures both in the low and higher corona.
- sets of type-III bursts originate from similar locations
- reduced radio flux at 08:40 UT
- Comprehensive results by various observations across the solar flare

Outlook

- application to further events
- link to changes in the active region and magnetic field

Funding

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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.

Images

https://phys.org/news/2016-01-magnetic-sun.html
https://www.todaysmedicaldevelopments.com/article/medium-voltage-electron-beams/
Photo Humboldthaus by Rainer Arlt.

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Thank you for your attention!