Manifestations of Accelerated Electrons and Protons in the 20 January 2022 Major Solar Flare Observed with Fermi and the Siberian Radioheliograph

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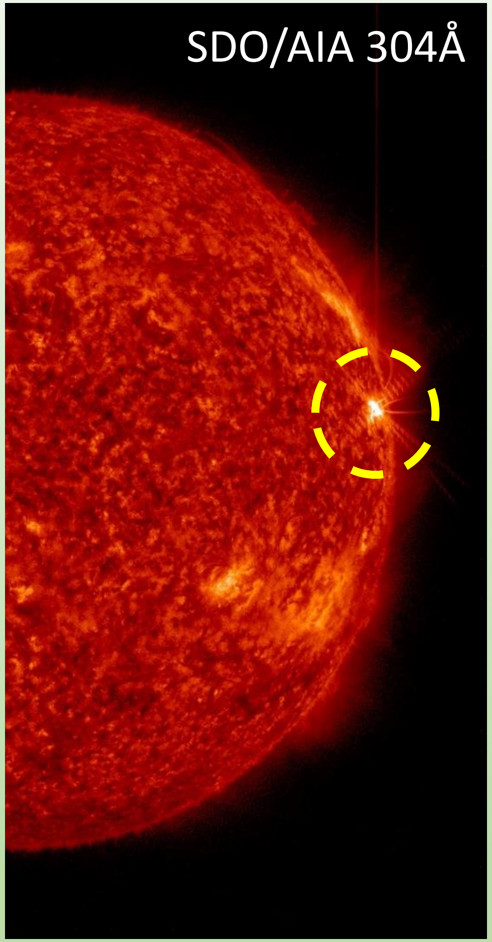
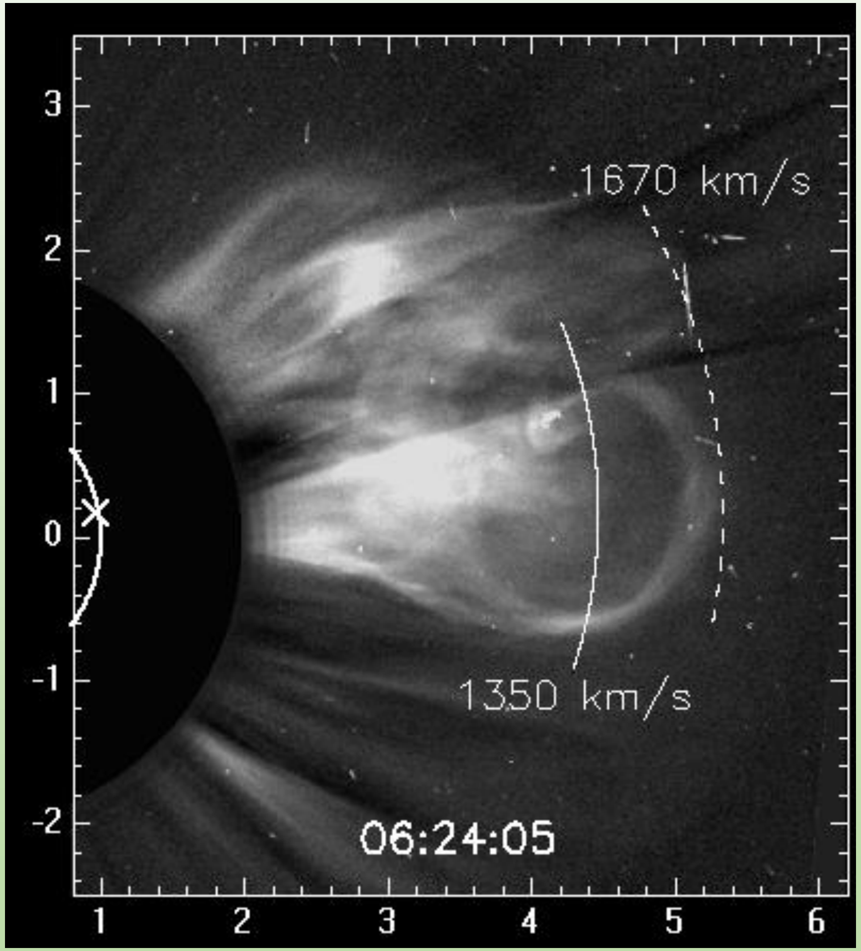
20 January 2022 Solar Event (N07 W83)



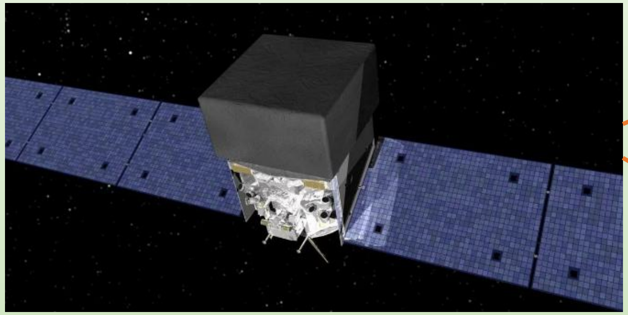
Produced:
- M5.5 flare (≈ 20min duration);
- Shock wave;
- Fast (1430 km/s) CME;
- Energetic electrons and high-energy (sub-GeV) protons;
- Ionizing flare emission and energetic protons that caused disruptions in radio communications.



Sporadic solar activity is responsible for space-weather disturbances that can disrupt ground-based and space-borne systems and threaten human activity and health. Identification of sources of accelerated particles is important both for predicting such events and for understanding the processes of their acceleration.

Hard X-ray, γ-ray, and microwave emissions in the event

Fermi Gamma-ray Space Telescope

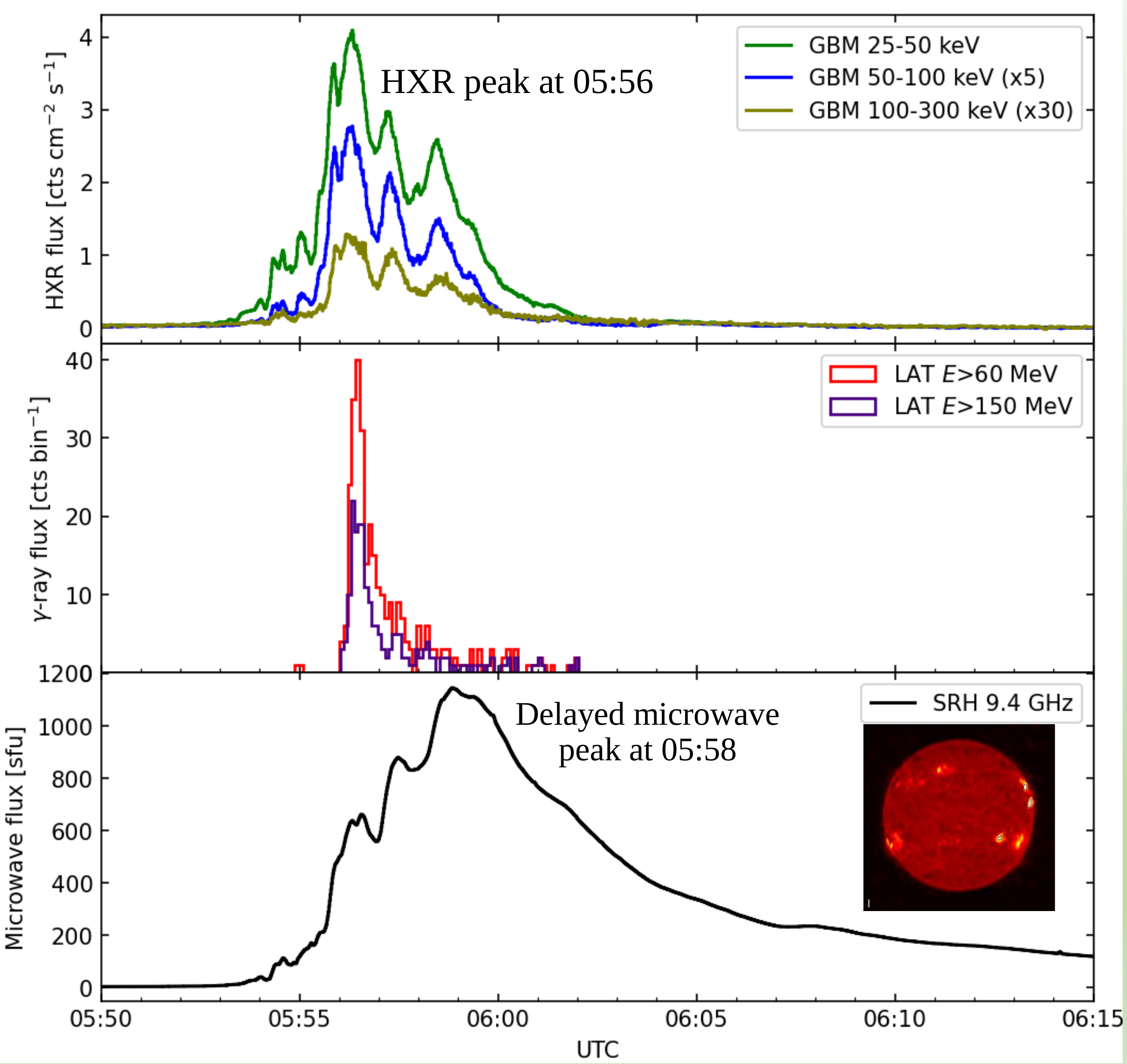


γ-ray Burst Monitor

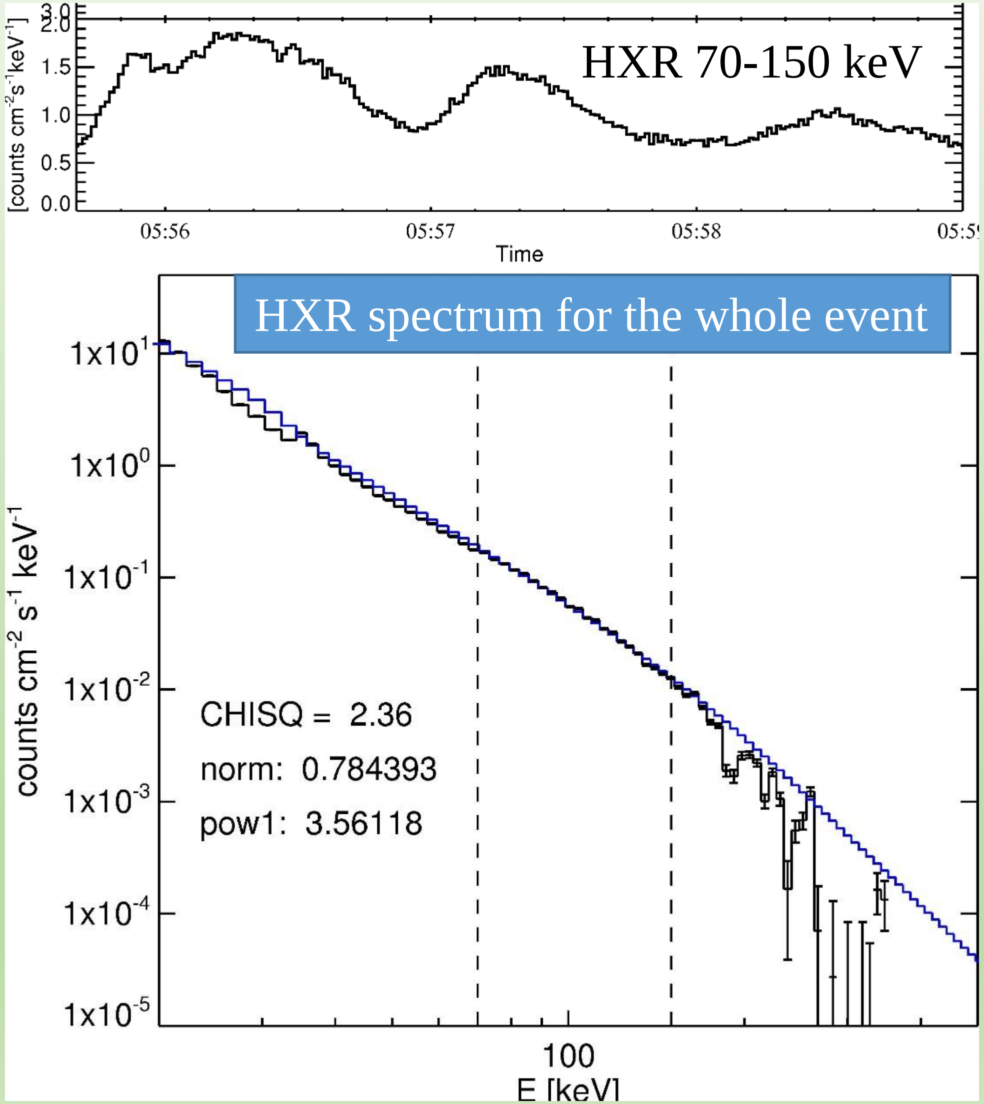
Large-Area Telescope

Multi-frequency Siberian Radioheliograph (SRH)

Test-mode Observations



Fermi/GBM observations of HXR: electrons

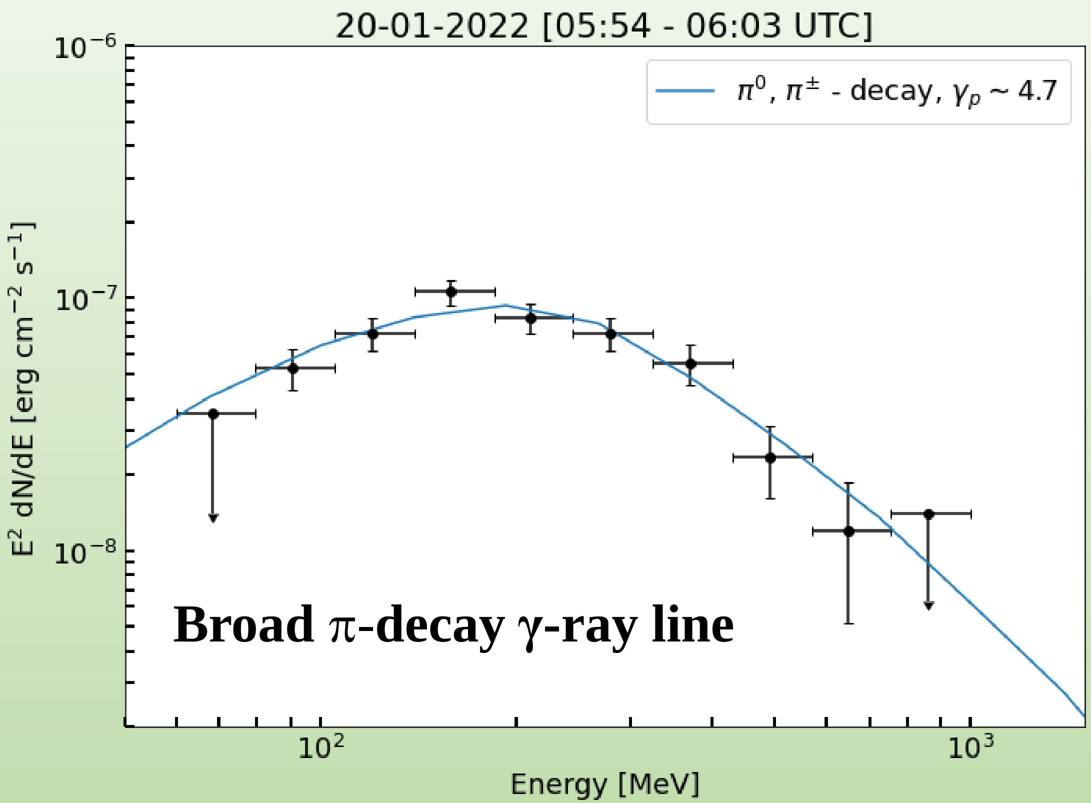


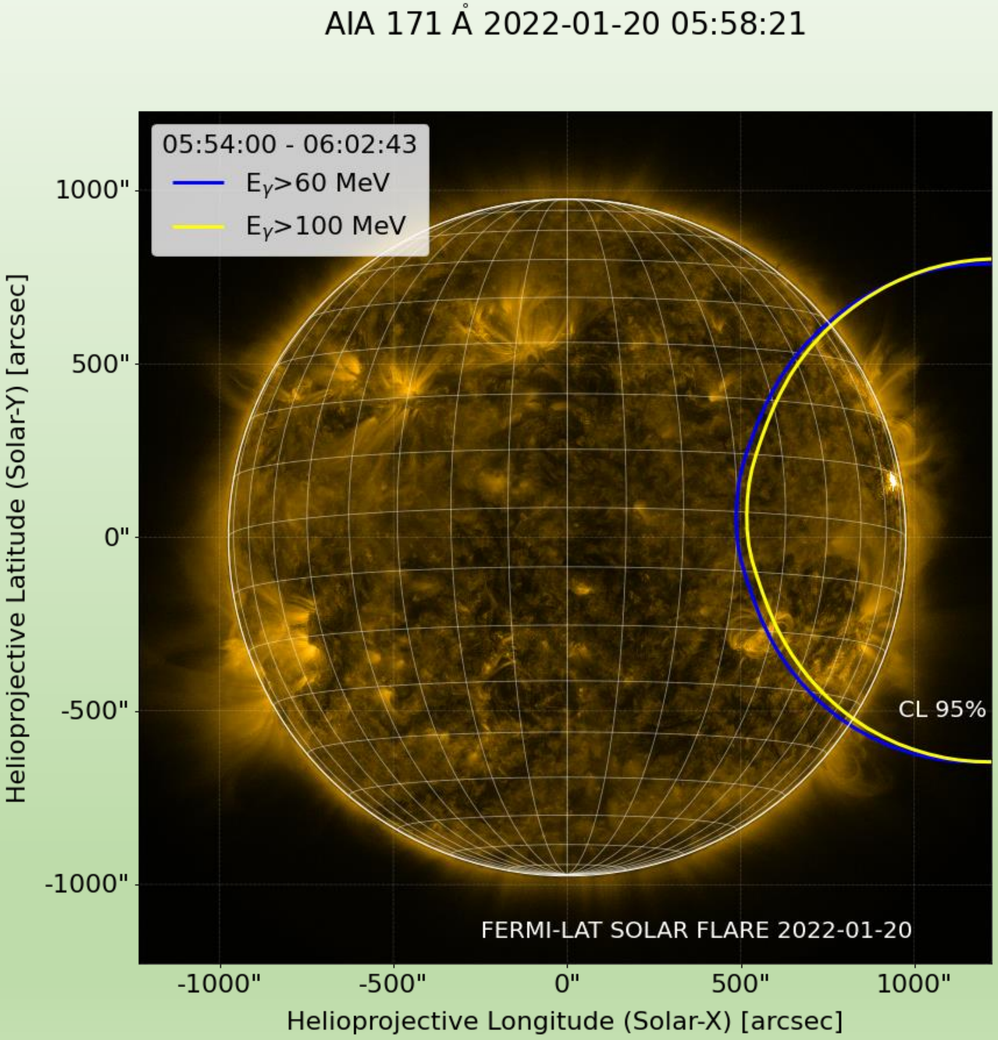
- HXR spectrum was obtained using a single power-law model fit to the data in the 70–150 keV range with a power-law index $\gamma \approx 3.6$

- Orbital background was estimated taking the data two days before the event and two days after that corresponding to ±30 orbits.

Electron power-law index: $\delta = \gamma+1 \approx 4.6$
Thick-target model by John Brown (1971)

Fermi/LAT observations of γ-rays: protons





Protons with ≥ 300 MeV energies can be identified by the appearance of a specific feature in the spectrum of high-energy γ-ray emission, a broad π-decay line

Mechanism of proton acceleration to high energies in solar flares is not clear…

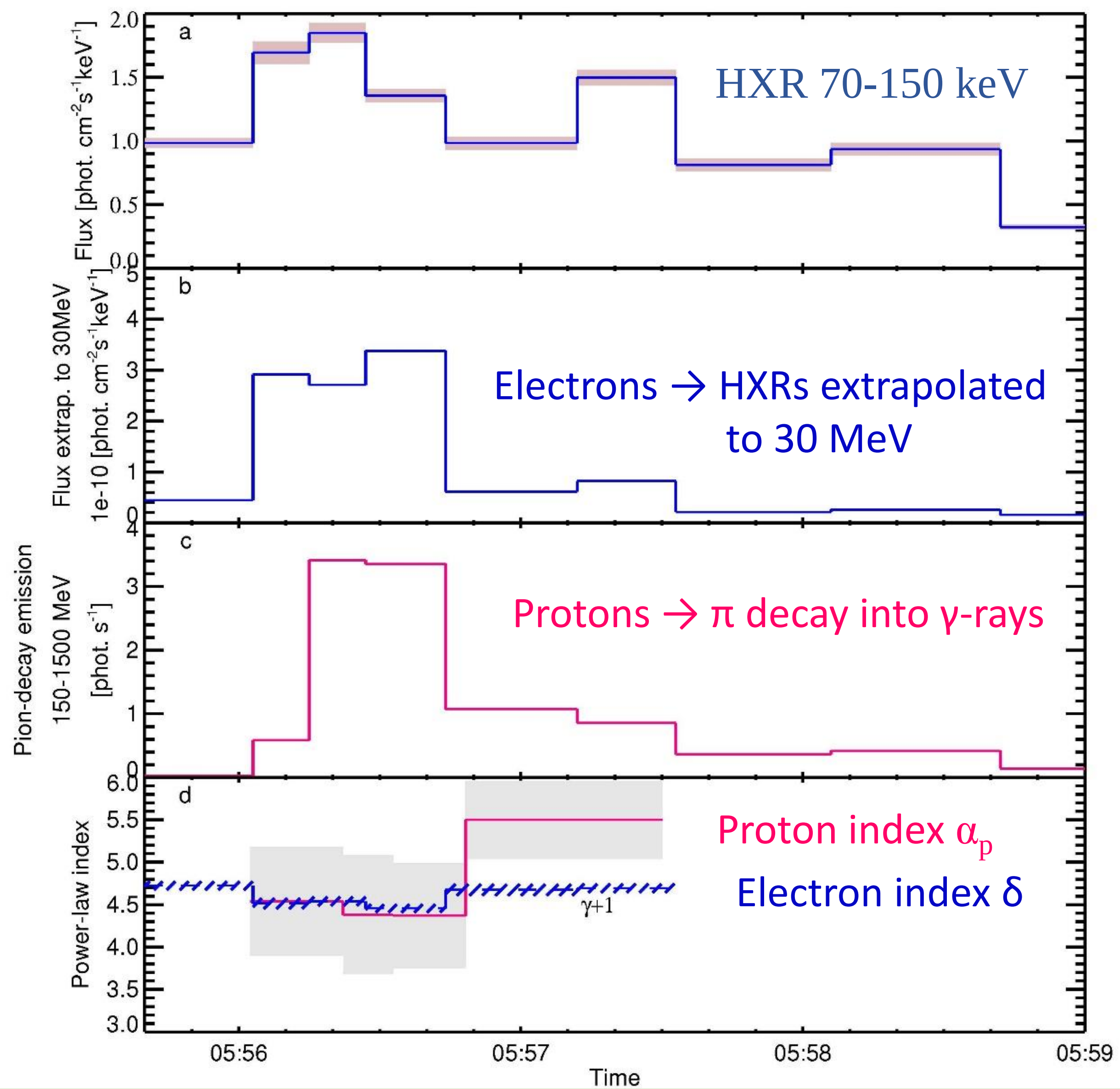
Spectral indices

Flare-integrated spectra of electrons and protons show similar power-law indices:

Electrons: $\delta \approx 4.6$

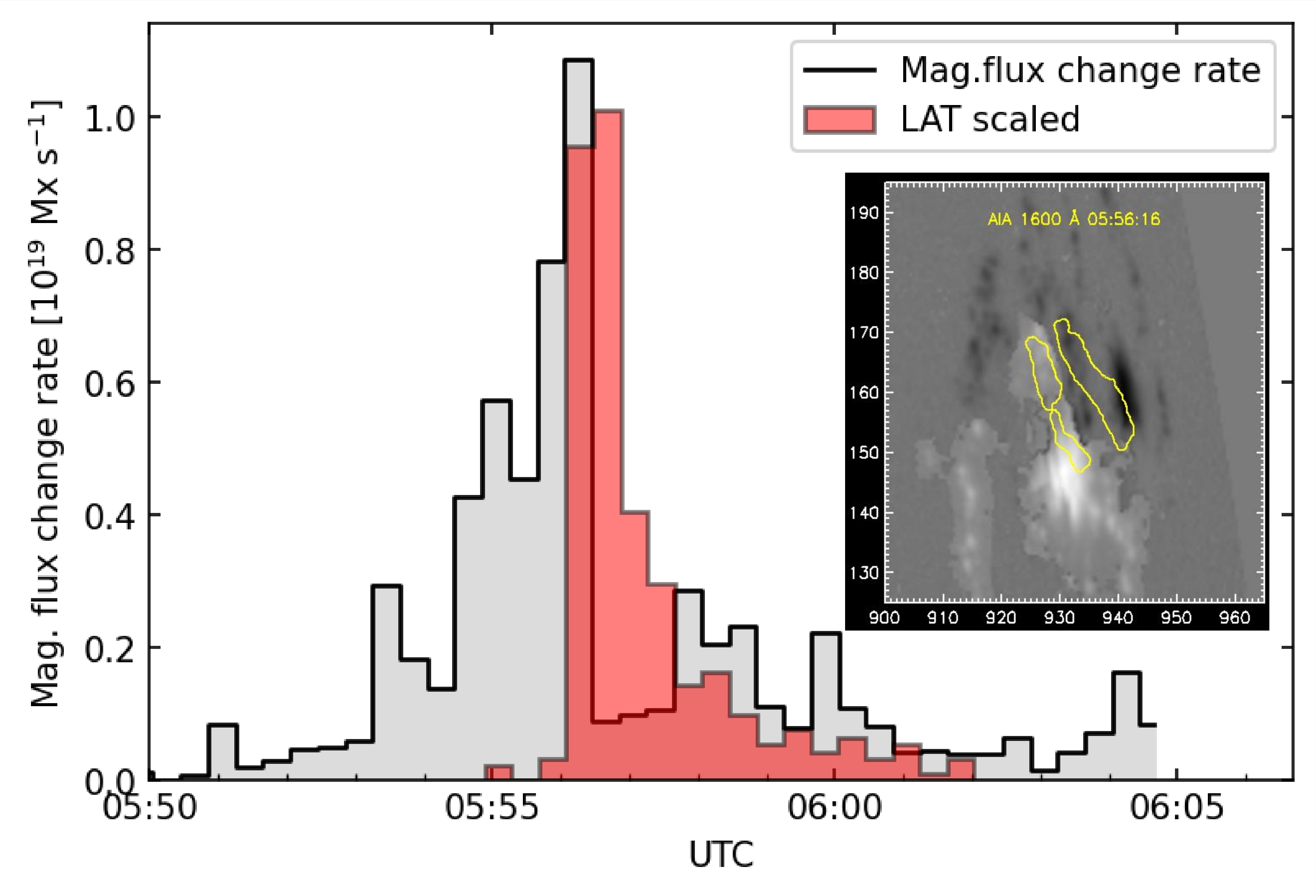
Protons: $\alpha_p \approx 4.7$

Temporal variations of electron and proton spectral indices



Similarities apparently indicate a common mechanism for particle acceleration to high energies and a probable similarity of injection functions in their common source

Magnetic-flux change rate and high-energy protons



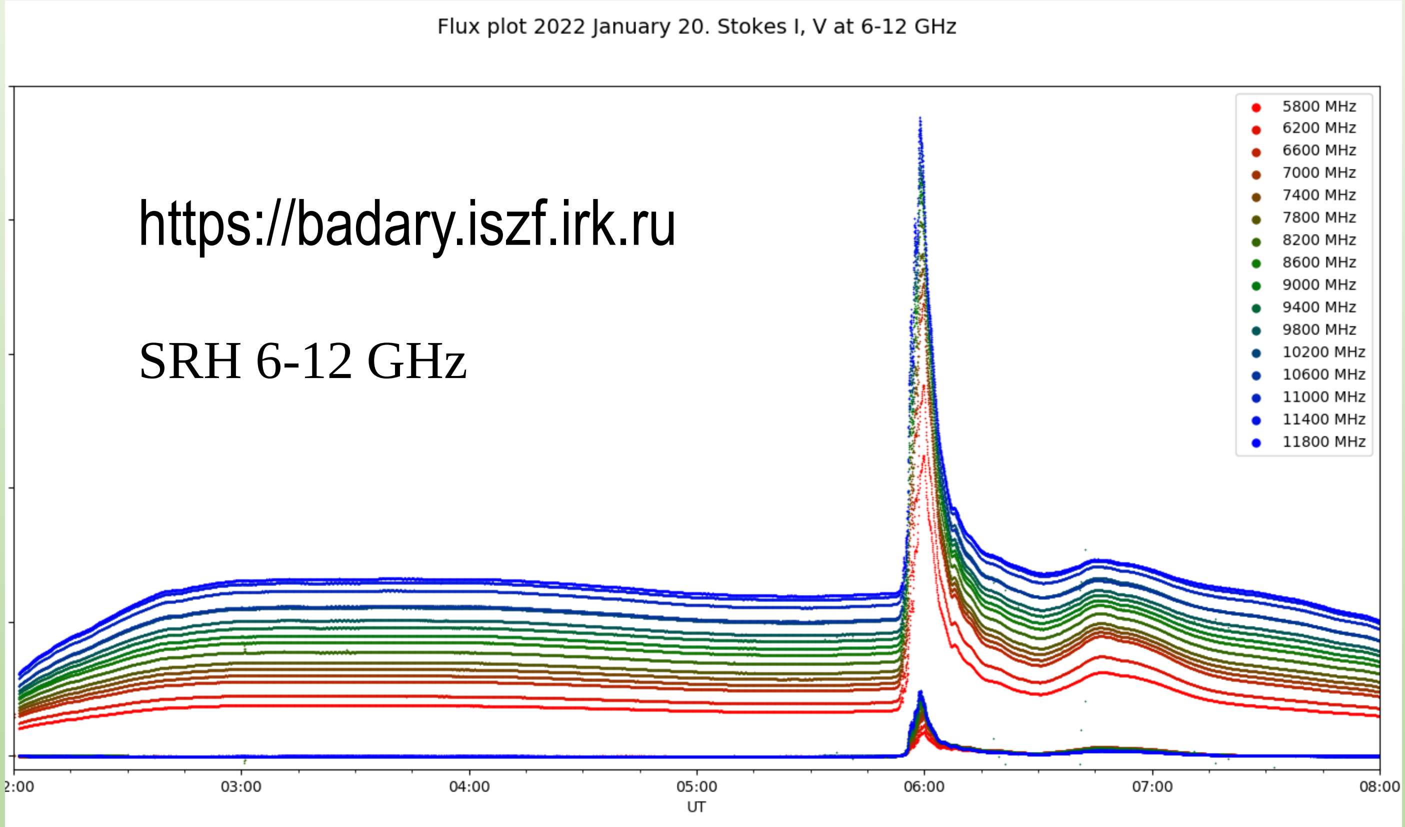
Background: radial magnetic-field component calculated from HMI vector magnetogram obtained on 2022-01-20 at 00:00:00 and rotated to 05:56:00.

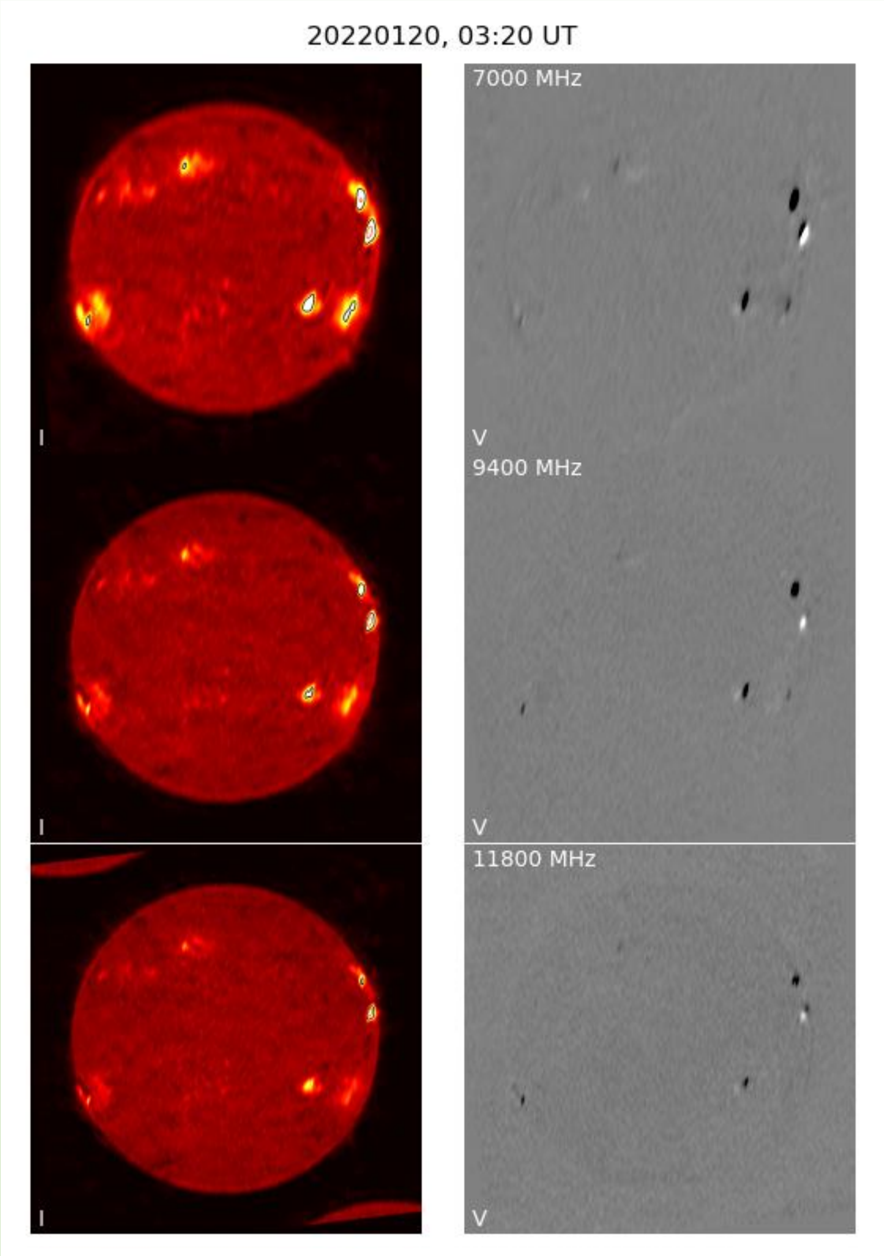
The strongest fields in this frame are -1911, 2065 G.

Contours: flare ribbons in AIA 1600 Å image at 05:56:16.


Siberian Radioheliograph 3-24 GHz
Prof. G.Ya. Smolkov Radio Astronomical Observatory

SRH test-mode observations of the 20 January 2022 flare

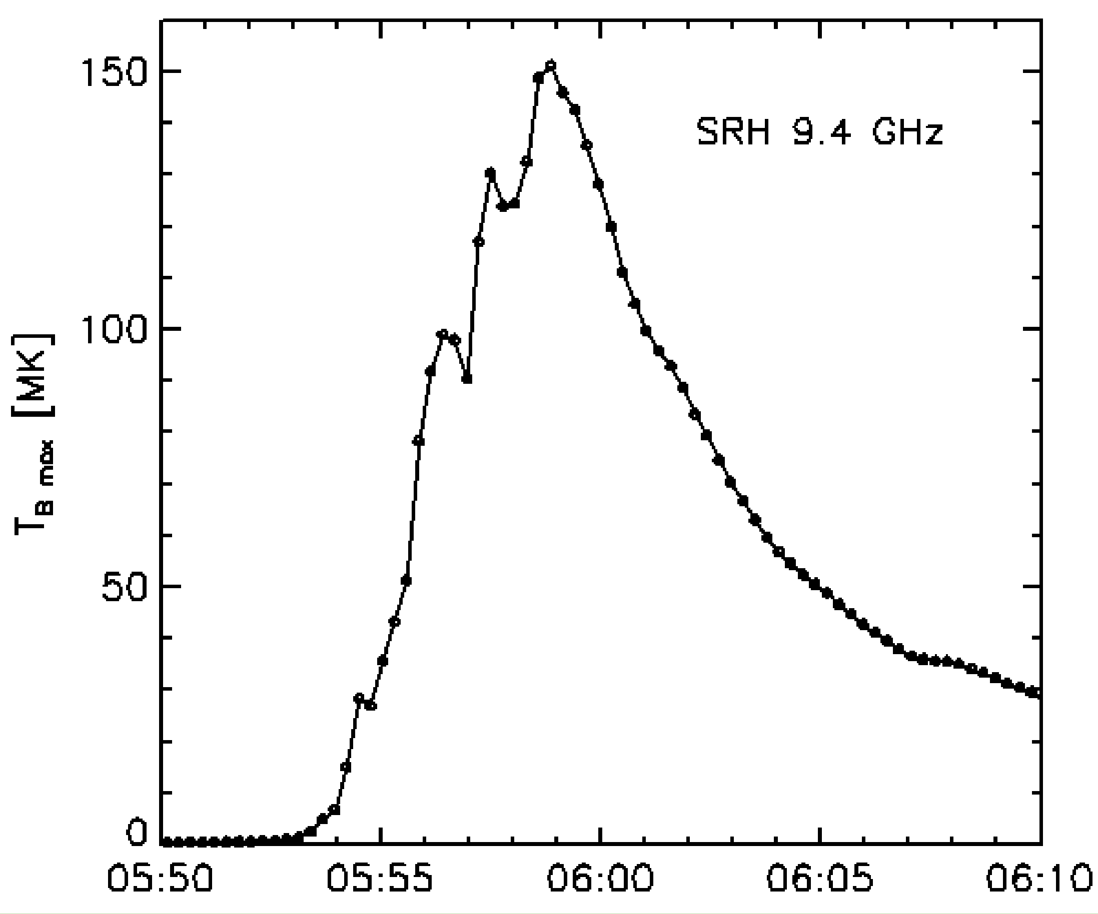




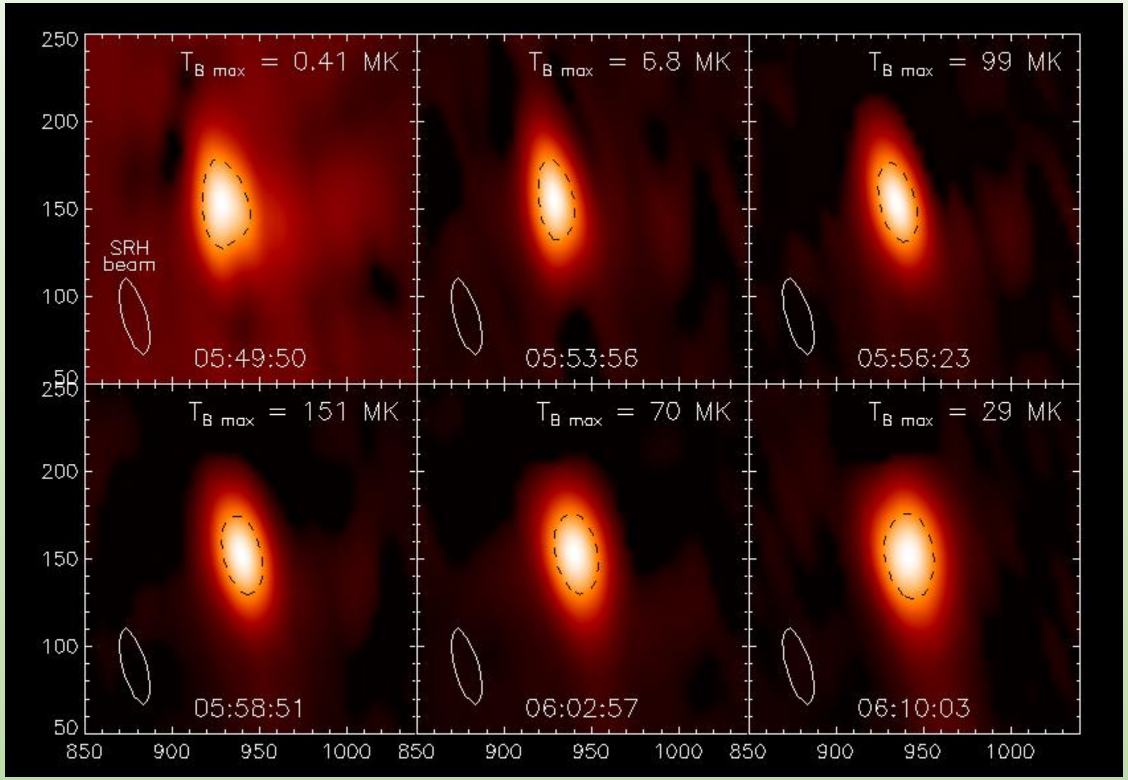
Peak flux ≈ 1200 sfu at 9.4 GHz

Evolution of microwave source at 9.4 GHz

Flare Source Maximal Brightness temperature



Peak brightness temperature during the flare is 150 MK

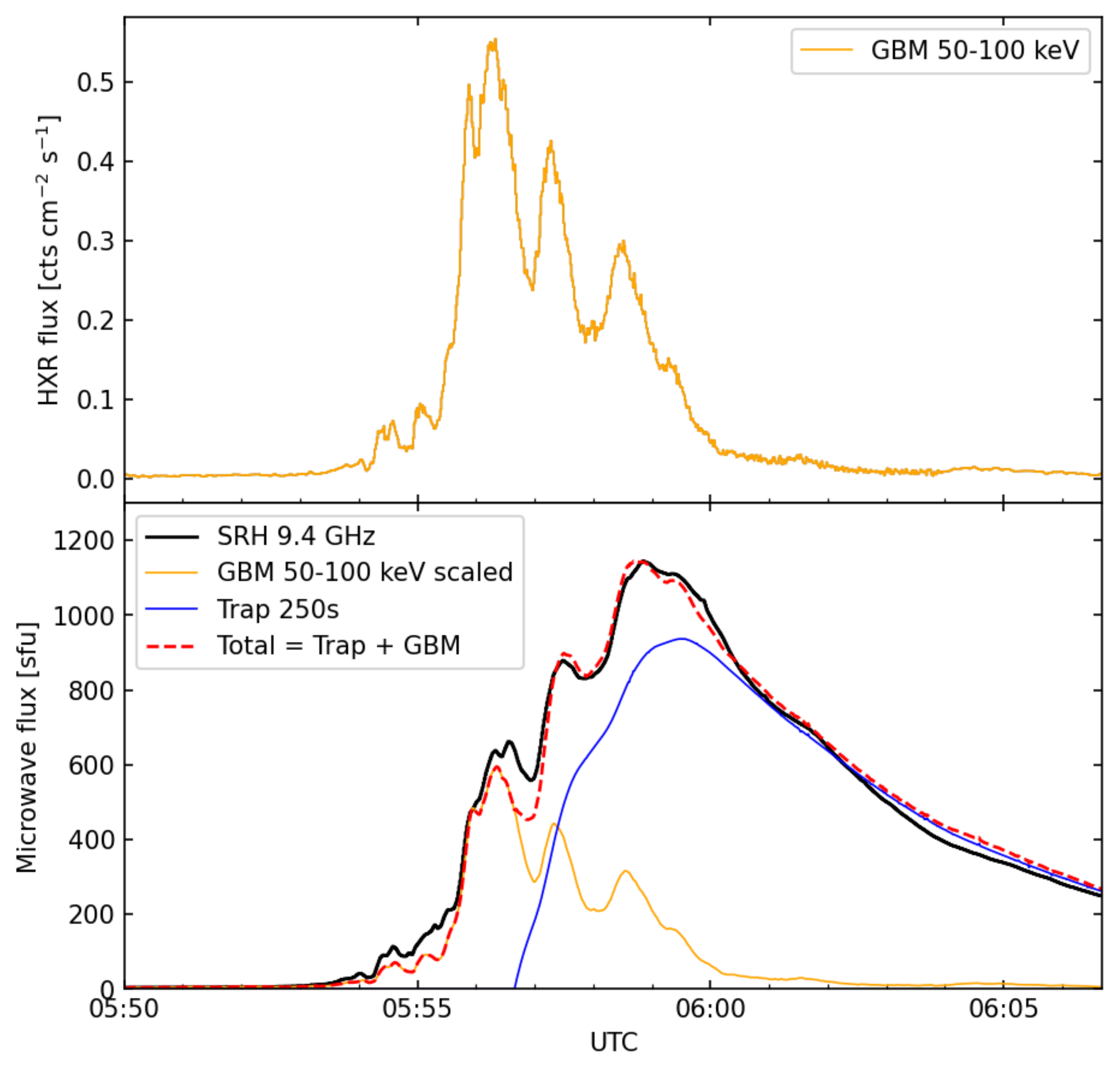


Real T_B is higher due to spatial resolution

Evidence of strong nonthermal emission of accelerated electrons

Trapping of energetic electrons in magnetic structures

- Energy is first released in acceleration of electrons, which then follow reconnected magnetic-field lines down to denser layers of the solar atmosphere, where they produce HXR emission
- Another portion of energetic electrons followed to flare-associated magnetic loops and retained there for several minutes. This “trapped” component is well reproduced by the model of M. Kundu et al.
- Both portions of accelerated electrons generated strong nonthermal microwave emission successfully detected by SRH



Summary

- Joint analysis of observational data from SRH and Fermi mission revealed the evolution of accelerated electrons and protons in the flare
- The spectra of electrons and protons show similarities that apparently indicate a common mechanism for particle acceleration to high energies and a probable similarity of injection functions in their common source
- The proton flux was greatest and had the hardest spectral index at the maximum rate of flare magnetic reconnection
- Microwave flux caused by accelerated electrons reached $\approx$1200 sfu at 9.4 GHz
- Analysis of Fermi and SRH data suggests that electrons were trapped in flare-associated magnetic structures and retained there for several minutes. Apparently, the same thing happened to protons