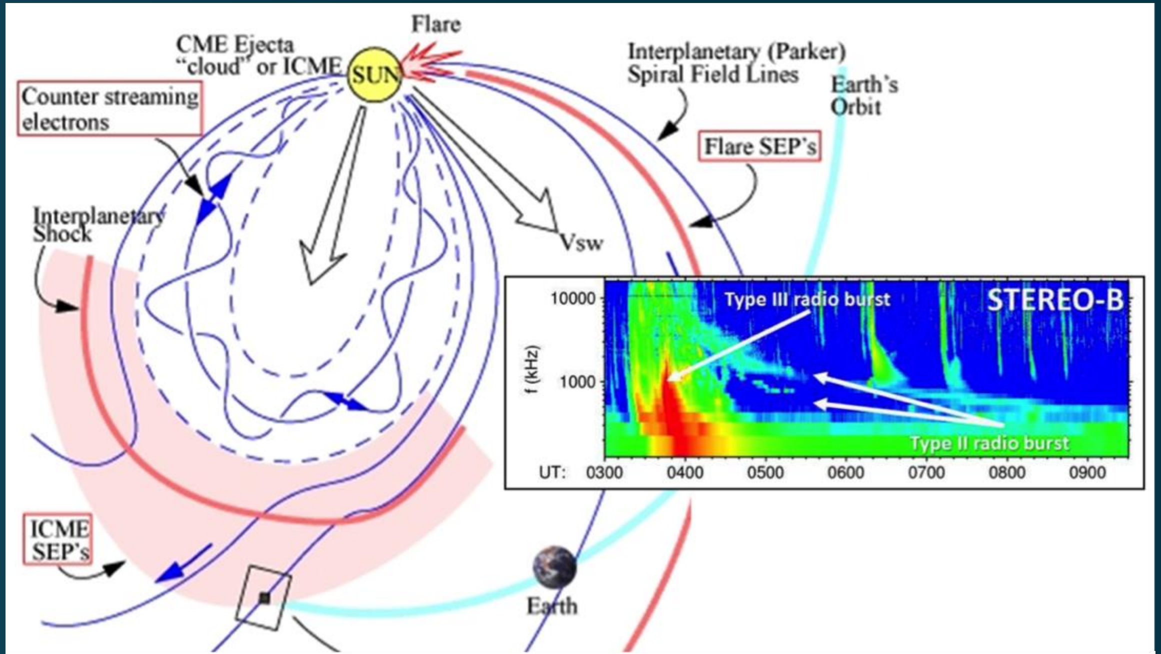
Unveiling the Interplanetary Solar Radio Bursts of the 2024 Mother's Day Solar Storm

O. Kruparova, V. Krupar, A. Szabo, D. Lario, T. Nieves Chincilla, J. C. Martinez Oliveros
2024, ApJL 970 L13, doi: 10.3847/2041-8213/ad5da6

Background

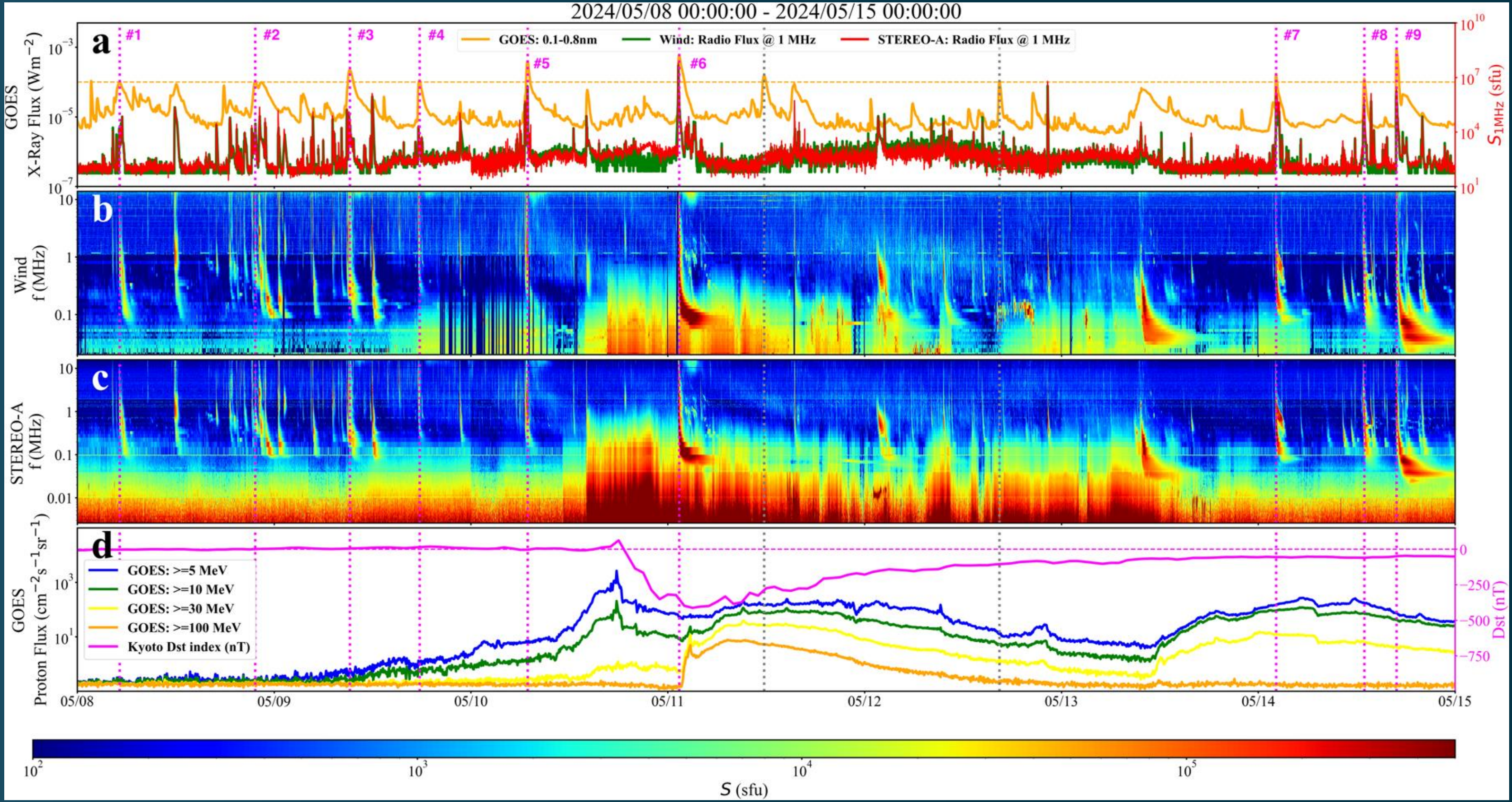
- In 2024, the Sun unleashed an intense solar storm over the Mother's Day weekend. This storm, the strongest in over two decades, originated from NOAA active region 13664 and resulted in a geomagnetic storm measured at −412 nT (Dst index). This event, accompanied by powerful X-class solar flares, provided a unique opportunity for scientists to study the propagation of interplanetary type III radio bursts—fast radio signals generated by electron beams traveling through space.
- Type III radio bursts are emitted by solar flares as beams of high-energy electrons shoot through the solar atmosphere and into space, producing radio emissions at progressively lower frequencies as they move away from the Sun. These signals give us insight into both the density of the solar wind and the behavior of energetic particles traveling through the interplanetary medium.



Above: Illustration of ICMEs (Interplanetary Coronal Mass Ejections), solar flares, and associated radio emissions. Electrons streaming along magnetic field lines are the sources of Type III radio emission. Credits: NASA

Objective

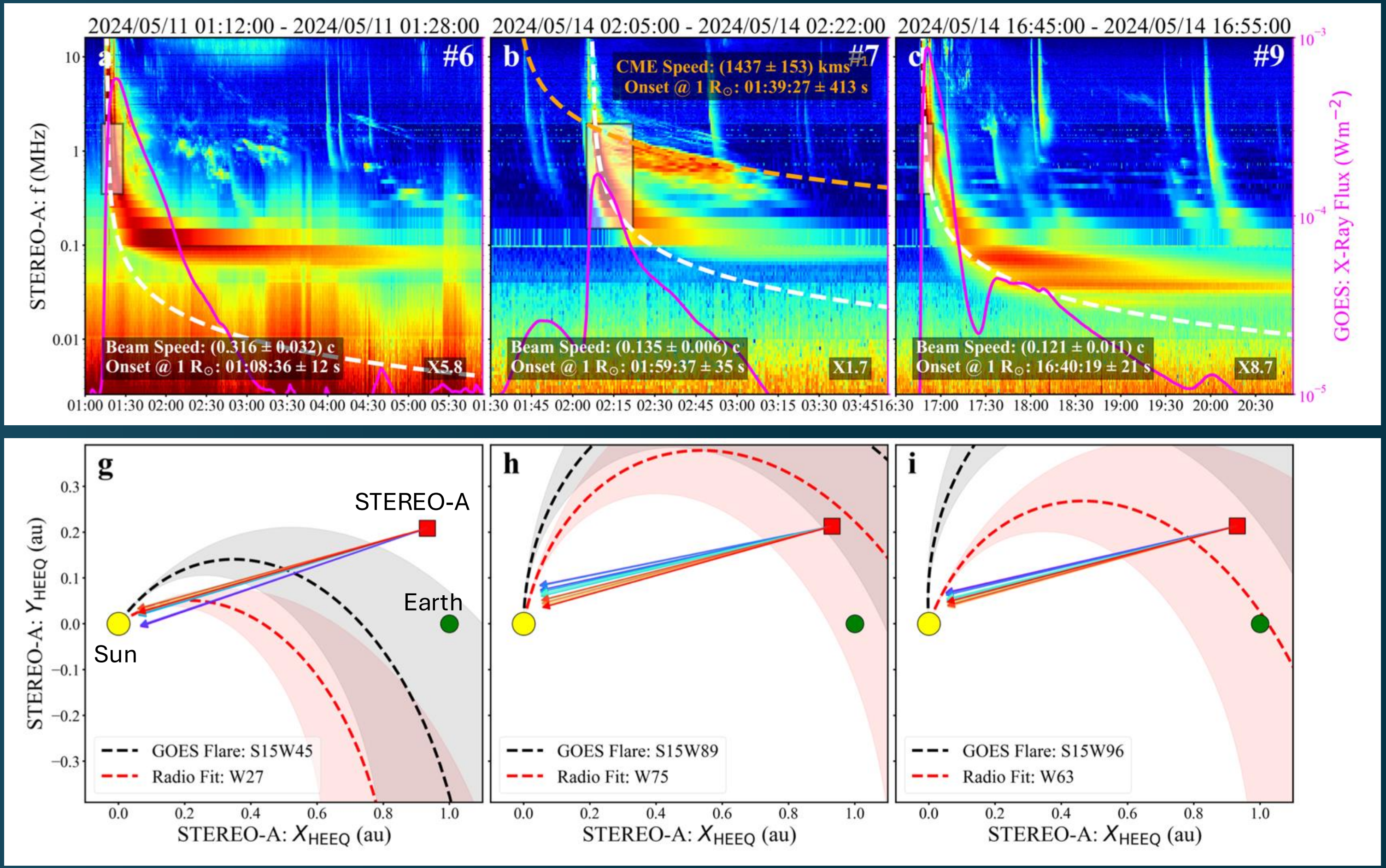
- The key goal of this study is to better understand the relationship between X-class solar flares and type III radio bursts. The team set out to measure the drift in the source locations of these radio bursts, compared to their associated solar flares, and to quantify the intensity of both the radio emissions and the flares. They aimed to refine space weather forecasting models by improving the localization of these bursts.



Overview of solar activity from May 8 to May 15, 2024, showing X-ray and radio emissions during the 2024 Mother's Day solar storm (a.k.a. the Gannon Storm). The graph captures intense X-class solar flares, associated type III radio bursts, and proton flux increases that indicate space weather impacts. Credit: Kruparova et al. 2024

Analysis

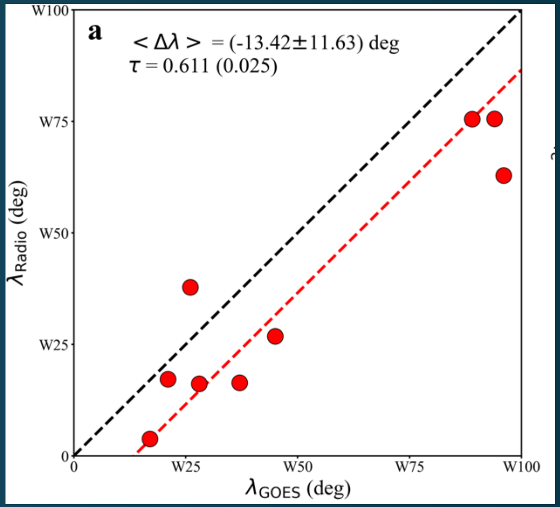
- Using data from the STEREO-A/Waves instrument, the researchers localized the radio emissions produced by nine X-class solar flares that occurred between May 8 and May 14, 2024. This included a detailed case study of the May 11 event, which was associated with the most intense radio emission.
- Wind/Waves data were also used to measure radio intensity from the Earth view point.
- The study employed a combination of radio direction-finding techniques and statistical analysis of the GOES flare data. By comparing the flare longitudes and the radio burst longitudes, the authors sought to determine if there were systematic drifts in the radio source locations, and what that might reveal about solar wind conditions.
- The radio burst direction-finding data were made available as a STEREO/Waves Level 3 data product two years ago.

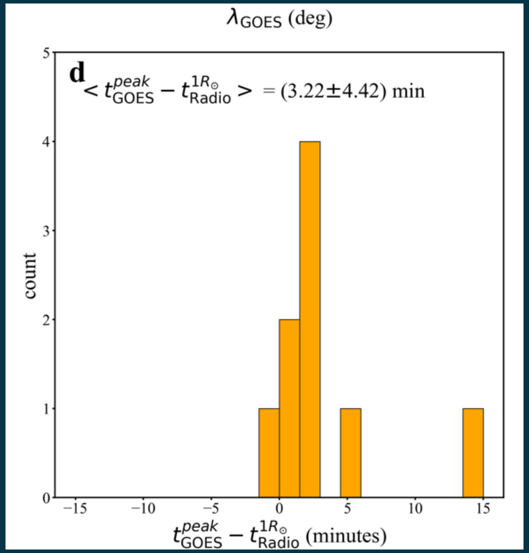


Case studies of three intense type III radio bursts captured by STEREO-A. Each event highlights radio frequency patterns, speeds, and direction analyses, illustrating how different solar flares produce unique radio and particle emissions that affect Earth. Top: Radio burst intensity as a function of frequency and time. Bottom: Grey: Connection of flare location to heliosphere based on Parker spiral (expected solar wind structure given solar rotation and a range of likely solar wind speeds). Red: location of energetic electrons causing type III radio bursts based on STEREO-A direction finding analysis. Arrows show direction to radio emission source determined from S/WAVES data. Credit: adapted from Kruparova et al. 2024

Findings

- The analysis showed a consistent eastward drift in the radio burst locations, with an average shift of 13.42°. This shift likely resulted from velocity and density gradients in the solar wind associated with the spiral structure of the interplanetary magnetic field.
- Moreover, the study found a strong correlation between the intensity of the solar flares and the radio emissions, with higher X-ray fluxes from GOES correlating with stronger radio bursts. Additionally, the timing analysis showed that peak soft X-ray emissions usually follow electron beam liftoff, further deepening our understanding of particle acceleration associated with solar flares and of the relation between flare timing and ratio burst origins.





Statistical trends of type III radio bursts from X-class solar flares. The analysis reveals a consistent eastward drift of radio sources (left) and timing differences between radio and soft X-ray bursts, contributing to insights into solar flare localization and energy release patterns. Adapted from Kruparova et al. 2024

Impacts

- This study provides important insights into
  - The nature of solar radio bursts and their connection to solar flares
  - How solar wind density variations affect radio-wave propagation
  - How solar energetic electrons propagate through space and how better to track them.

  These are important for refining radio triangulation techniques, developing better space weather models, and being able to predict space weather effects.
- The 2024 Mother's Day solar storm was a rare and valuable opportunity to study solar radio emissions on an unprecedented scale. With further data from ongoing missions in the Heliophysics System Observatory, scientists hope to continue improving their models and ability to predict and mitigate the impacts of solar storms.

Publication Information

- Publication information

  “Unveiling the Interplanetary Solar Radio Bursts of the 2024 Mother's Day Solar Storm”

  O. Kruparova[1,2,] V. Krupar,[1,2] A. Szabo[2], D. Lario[2] T. Nieves Chincilla,[2] J. C. Martinez Oliveros[3]

  Astrophysical Journal Letters, 970 L13, 2024 July 16, doi: 10.3847/2041-8213/ad5da6

  [1] U. Maryland, Baltimore County,

  [2] NASA GSFC,

  [3] U. California Berkeley

  Sponsors/Awards: NASA grant 19-HSR-19_2-0143, STEREO/Waves and Wind/Waves projects