Solar radio bursts as an indicator of incoming Solar Energetic Particles (SEPs)

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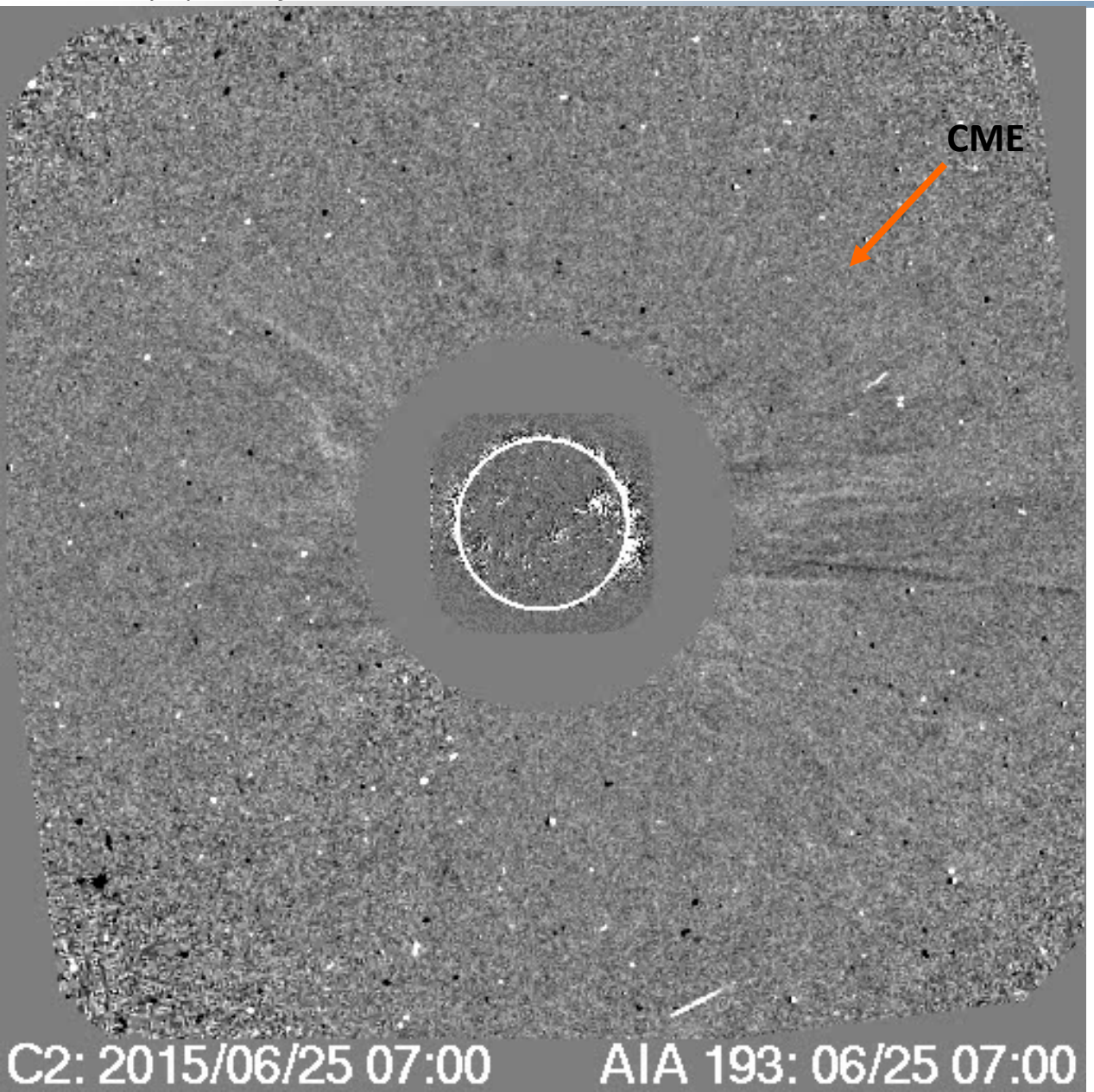
Alliance Meeting, Rome, Italy
20 October 2026

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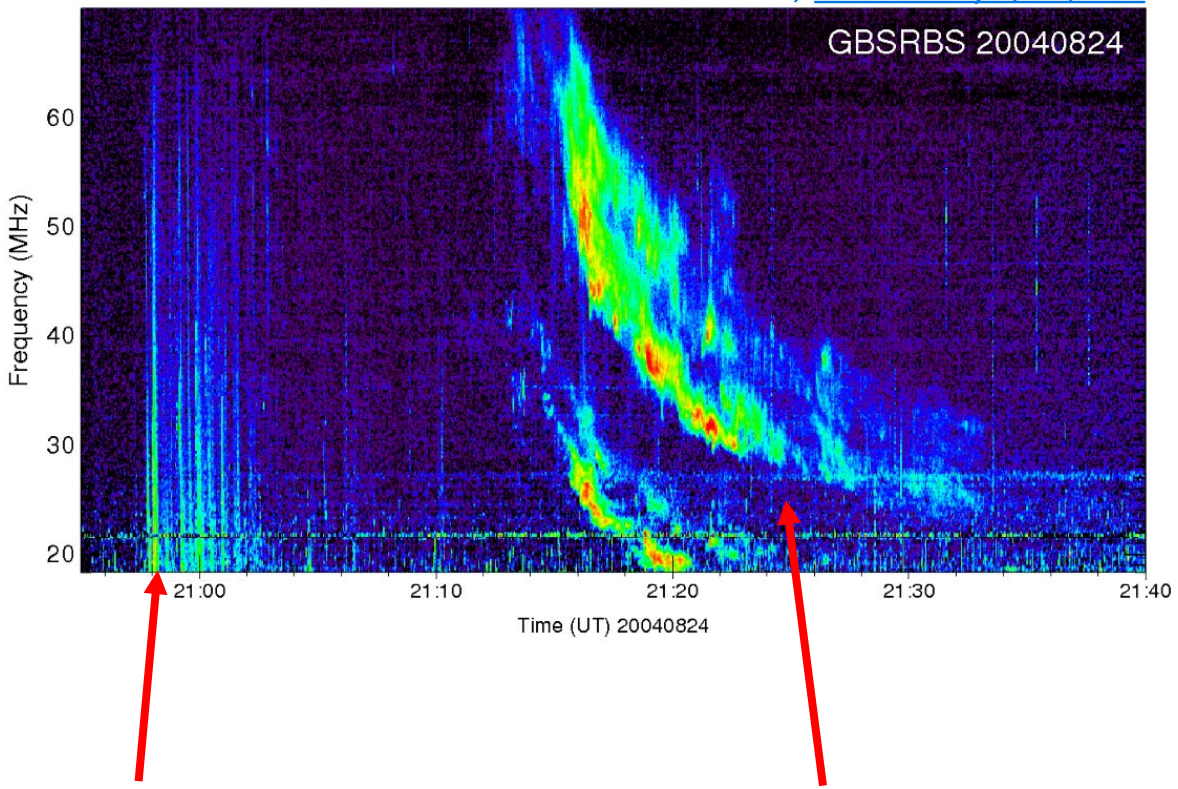
This research is supported by the Space It Up! project funded by the Italian Space Agency, ASI, and the Ministry of University and Research, MUR, under contract n. 2024-5-E.0—CUP n. I53D24000060005.

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Solar eruptions + radio bursts



White 2007, Asian J. Phys., 16, 189



Type III bursts:
related to flares

Type II bursts:
related to shocks driven by
Coronal Mass Ejections (CMEs)

This movie is available online. Data courtesy of the SOHO and SDO teams.

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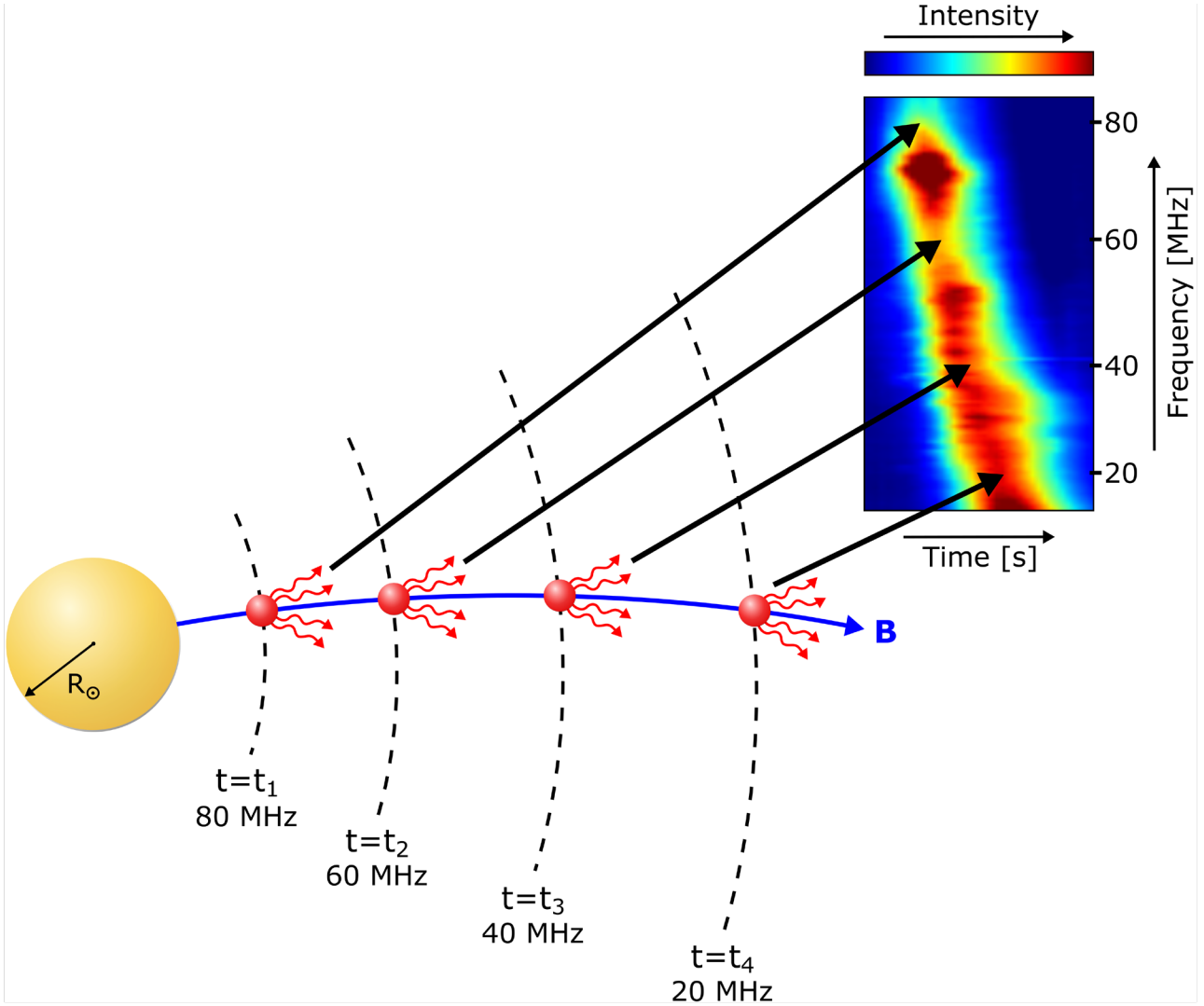
Solar radio bursts

- Radio waves excited through the plasma emission mechanism

- $f \propto \sqrt{n(r)}$, where f = frequency
  n = plasma density
  r = heliocentric distance

  ⟹ **frequency relates to distance**

- "**Dynamic spectrum**" ⟹ intensity as a function of frequency and time



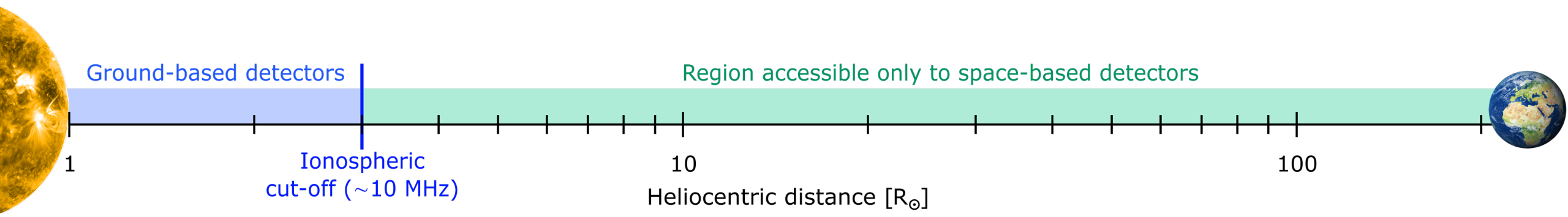
Chrysaphi PhD thesis (2021)

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Advantages of solar radio bursts

Why use solar radio emissions?

- Very frequent → quasi-continuous source of information
- Occur at any longitude
  - ➢ multi-vantage measurements → semi-constant monitoring of all solar longitudes
    → vast amounts of data
- Reflect the local heliospheric environment
- Observed from ~ 1 GHz down to a few kHz
  - ➢ cover the entire space between the Sun and the Earth



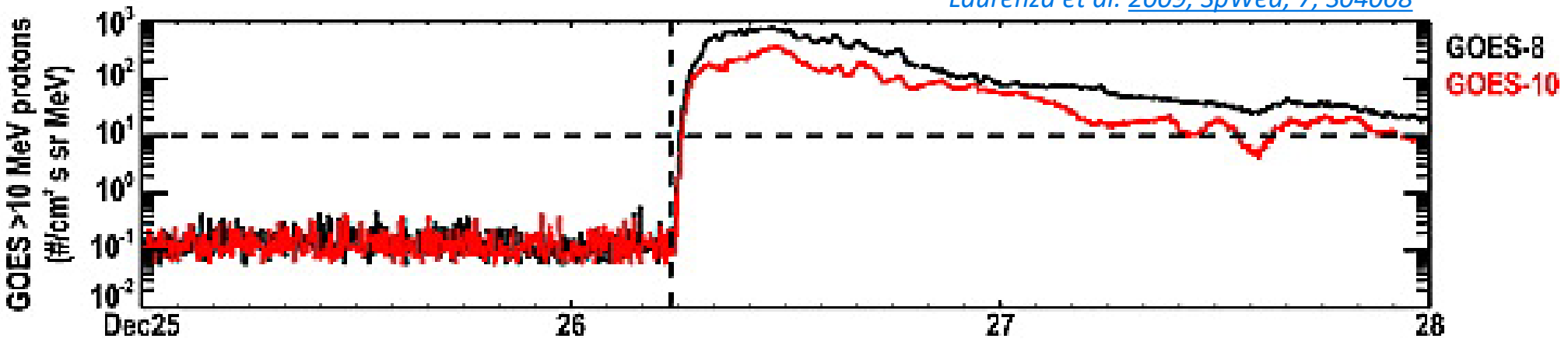
Chrysaphi et al. 2026a,
in Advancing Astrophysics with the SKA – II

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SEPs

- Solar radio bursts are indicators of semi-relativistic electrons accelerated into the heliosphere → correlated with Solar Energetic Particle (SEP) events
- SEP event: when the >10 MeV proton flux exceeds 10 pfu (particle flux units) for 3 consecutive data points

Laurenza et al. 2009, SpWea, 7, S04008



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ESPERTA

ESPERTA: Empirical model for Solar Proton Events Real Time Alert

- Designed to provide (automated) SEP alerts → no human input
- Utilises electron signatures → precursors of the heavier + more hazardous protons
- **First forecasting model to incorporate radio data**
- Aimed to maximise the warning time + adopt an empirical approach
- Designed to work in real time (including onboard spacecraft)

  → provides a very fast warning (within 10 minutes of flare peak)

Laurenza et al. 2009, SpWea, 7, S04008

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ESPERTA

- **ESPERTA inputs:**
  - Flare longitude
  - Flare fluence (soft X-ray; ≥M2 class flares)
  - Radio fluence (single-frequency measurement)

- **ESPERTA outputs:**
  - 0 or 1 → defines whether or not an SEP event occurs from a given eruption (using logistic regression)
  - Probability of detection calculation adapted to different longitudinal ranges (reflecting varying levels of magnetic connectivity)

- **Warning time:** difference between ESPERTA alert (10 mins after flare peak) and SEP event identification

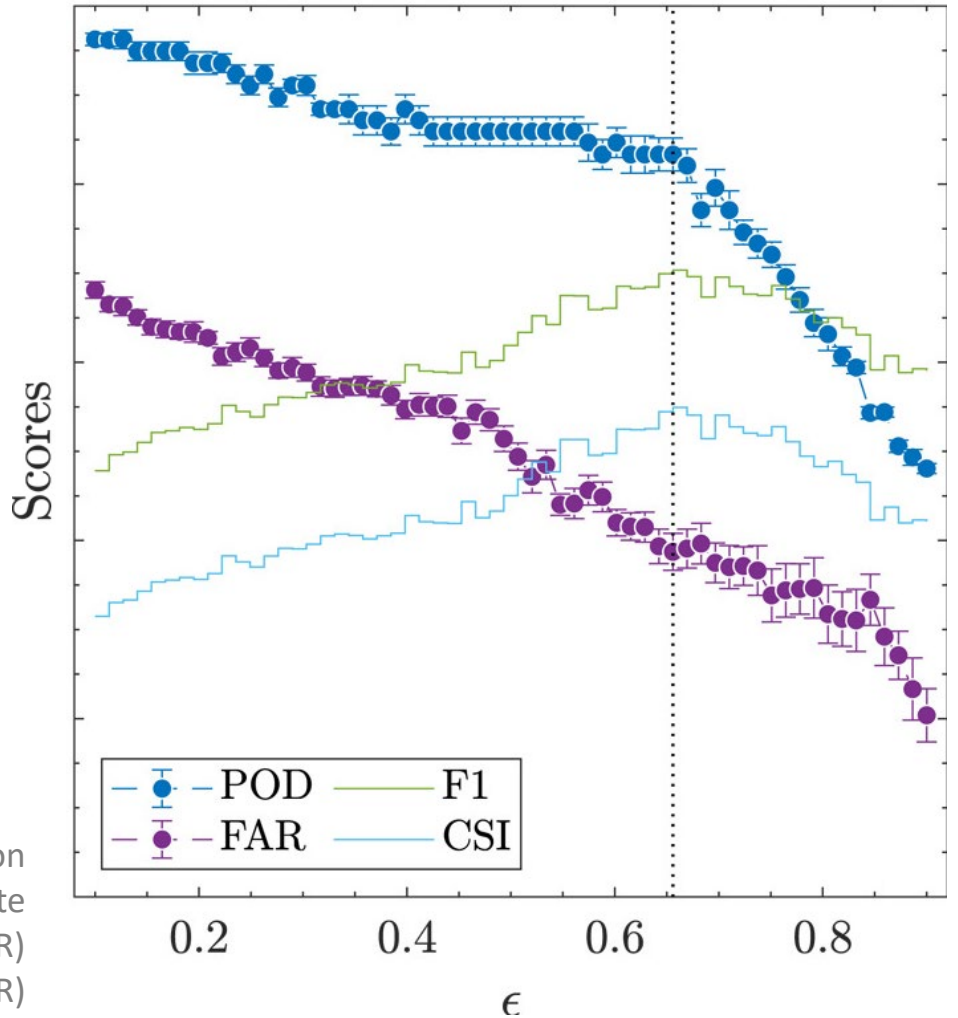
Laurenza et al. 2009, SpWea, 7, S04008

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ESPERTA

- ESPERTA's prediction is based on a defined probability threshold
- The probability threshold is defined as the probability that maximises the correct predictions and minimises false alarms within the (training) dataset
- A probability threshold can be calculated for events within different longitudinal ranges
  → eastern flares, western flares, intermediate flares

Stumpo et al. 2021, SpWea, 19, e2021SW002794

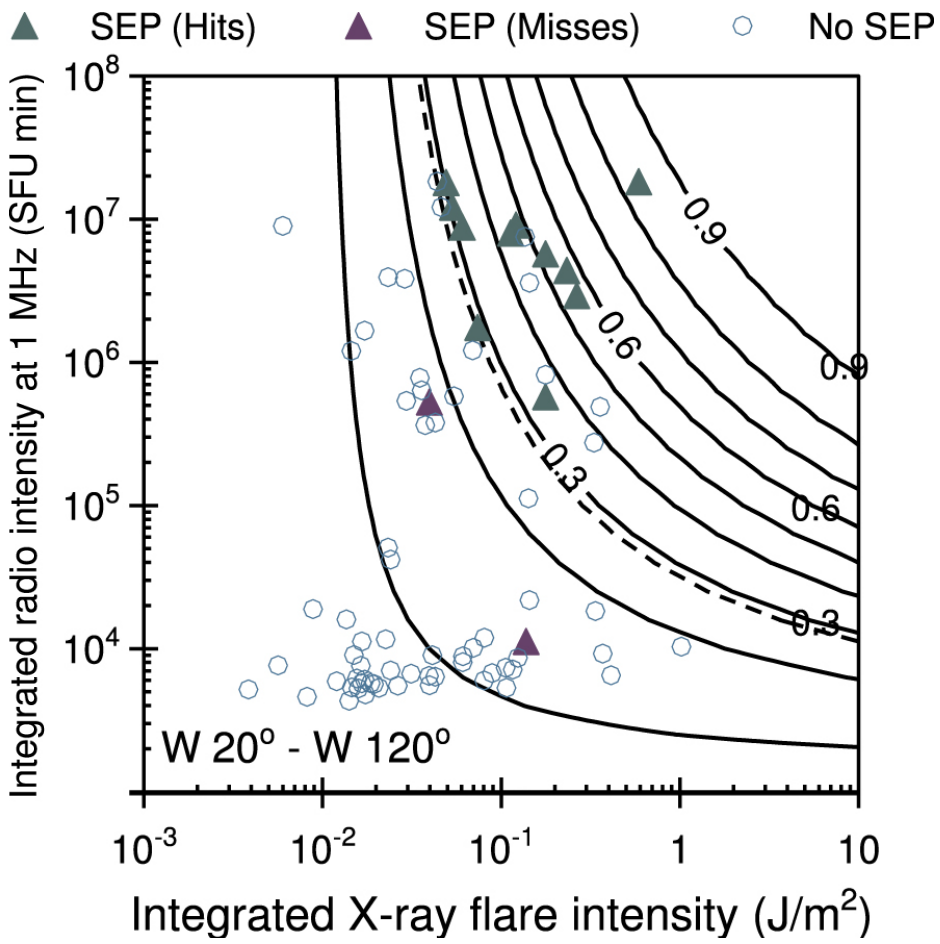


POD = Probability of Detection
FAR = False Alarm Rate
CSI = Critical Success Index (related to POD + FAR)
F1 index (related to POD + FAR)

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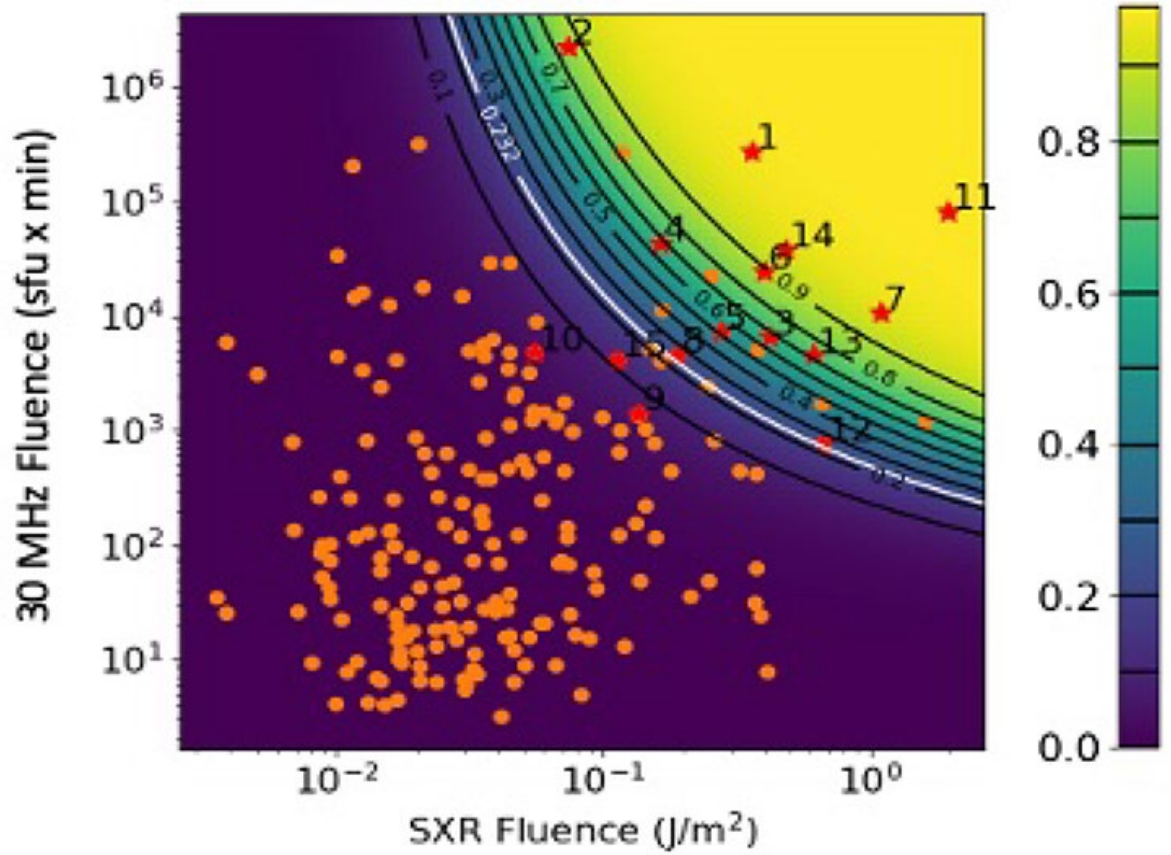
Near-Earth radio detectors

Spacecraft at L1 (WIND)



- **POD = 59%, FAR = 30%**
- **Median warning time ≈ 4.8 hours**

Ground-based detector (LOFAR)



- **POD = 79%, FAR = 32%**
- **Median warning time ≈ 2 hours**

Alberti et al. 2019, ApJ, 838, 59

(POD = Probability of Detection; FAR = False Alarm Rate)

Laurenza et al. 2024, JSWSC, 14, 8

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Sun-orbiting spacecraft

- Solar-orbiting spacecraft → enable quasi-continuous monitoring of radio emissions at virtually all longitudes

- Evaluate the effectiveness of space weather forecasting models at off-Earth locations

Credit: ESA-ATG medialab



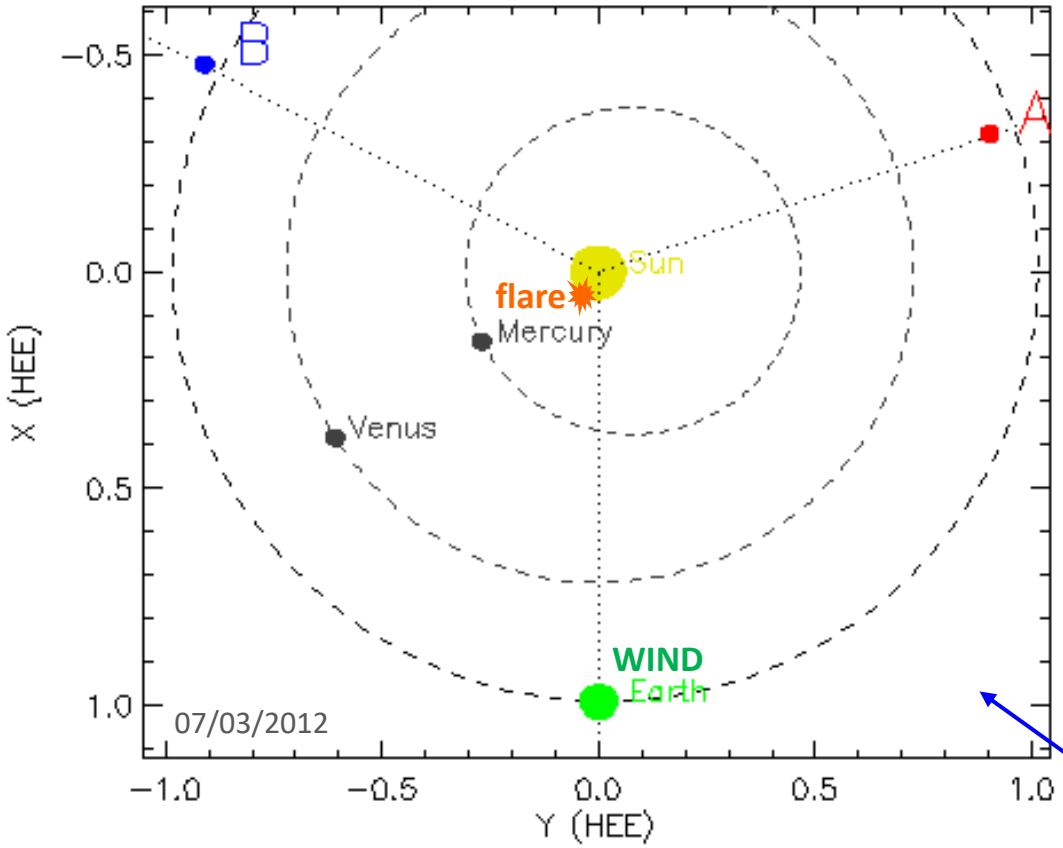
STEREO

Parker Solar Probe

Solar Orbiter

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Off-Earth radio detectors



- Used the Sun-orbiting STEREO (A + B) spacecraft to evaluate the probability of an SEP event occurring
- Radio measurements at ~1 MHz
- Events between 2011-2014
- Considered 222 flares → total of 105 within the observable longitudinal range

Results (based on 105 events):

- POD = 94%
- FAR = 39%
- Percent Correct = 88.6%

this SEP event (recorded by WIND + STEREO-A + STEREO-B) was correctly predicted by ESPERTA

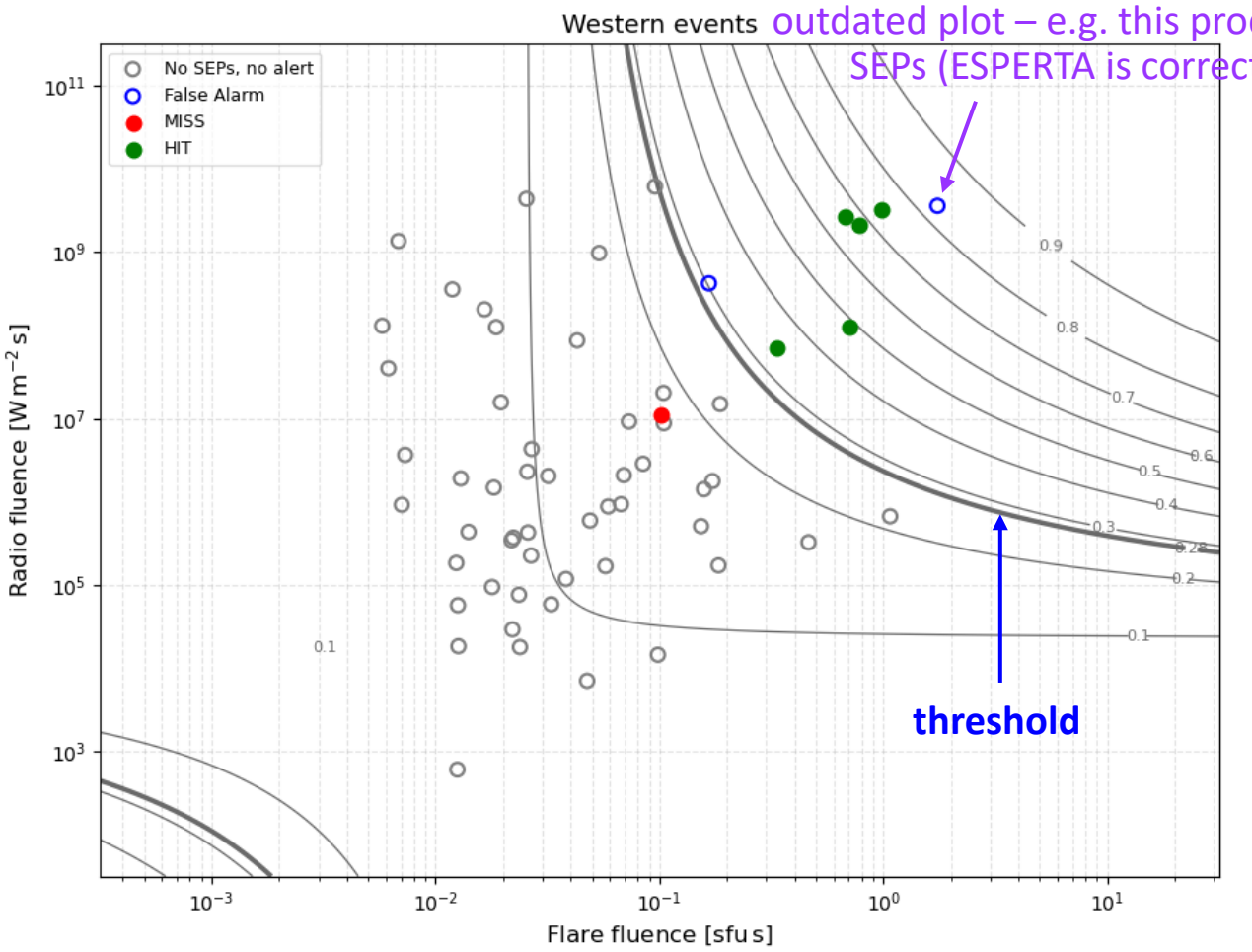
* preliminary results

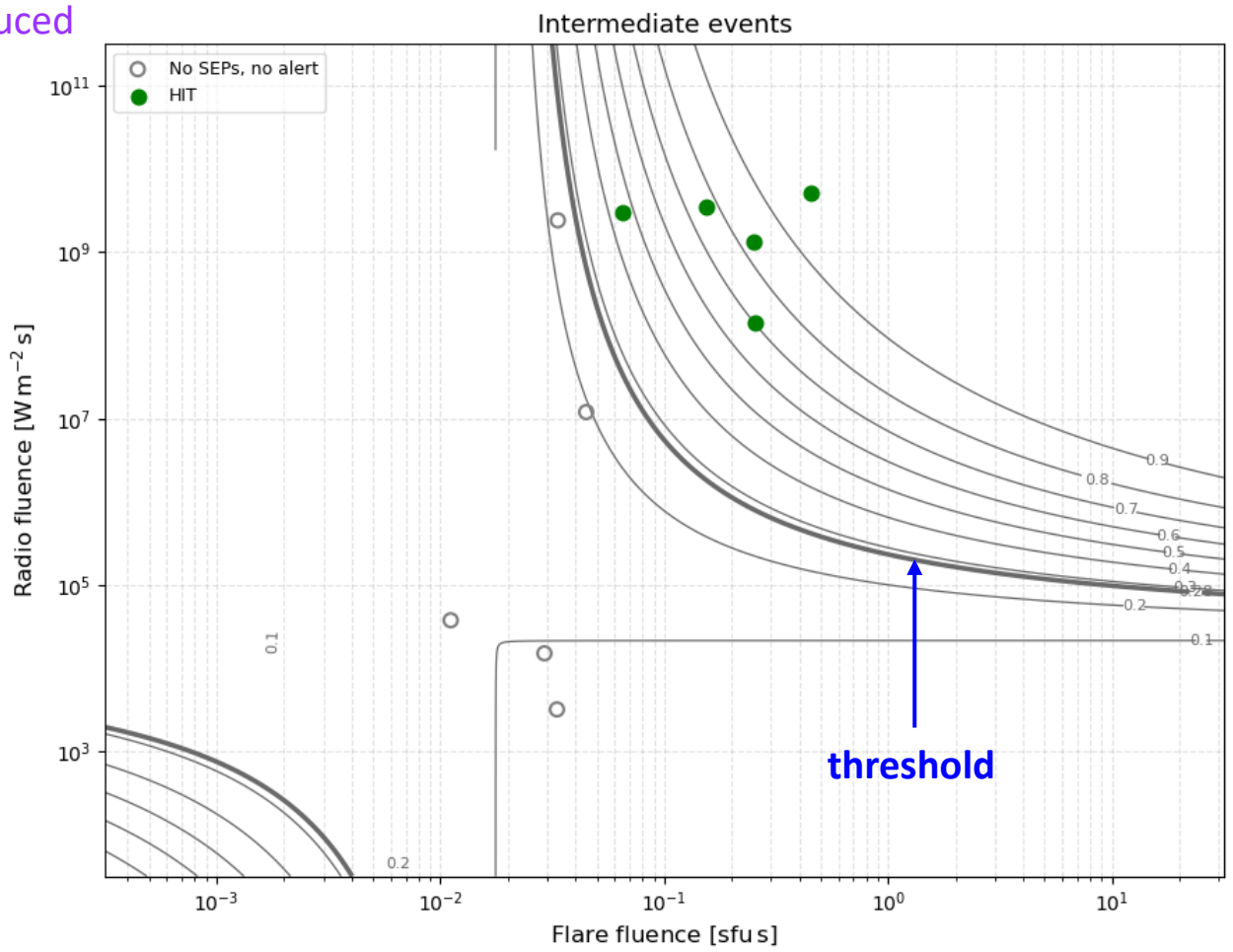
Chrysaphi et al. 2026b (in prep.)

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Off-Earth radio detectors

STEREO-A and STEREO-B





* preliminary results

Chrysaphi et al. 2026b (in prep.)

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Summary

- Implementation of solar radio emissions in space weather models is beneficial

- ESPERTA model provides consistent (and reliable) results using radio measurements at various longitudes
  → quick predictions (median warning times of some hours)
  → can be used onboard spacecraft

Chrysaphi et al. 2026b (in prep.)