

SPADE: A Fully Digital Solar Radio Array for Space Weather

Antonio Martínez Picar, Christophe Marqué, Jasmina Magdalenič

Solar-Terrestrial Centre of Excellence

Solar Influences Data analysis Center

Royal Observatory of Belgium

Belgian Science Policy Office
belspo

Motivation for SPADE

Why monitor the Sun at 25–75 MHz

Most bursts of interest for space weather (type II shocks, type III electron beams) occur at 20–300 MHz:

- Type III bursts trace energetic electron beams
- Type II bursts reveal coronal shock signatures
- Dynamic spectra capture burst evolution and fine structure
- Space weather services need sustained radio coverage

Decameter bursts need **continuous** monitoring!

USAF network

Sweep-frequency technology, 3 s time resolution. Real time only for the US military and NOAA SWPC; public release months later.

e-CALLISTO

Civilian and real time, but every station differs in band, resolution and sensitivity. Aging analog technology with an uncertain future.

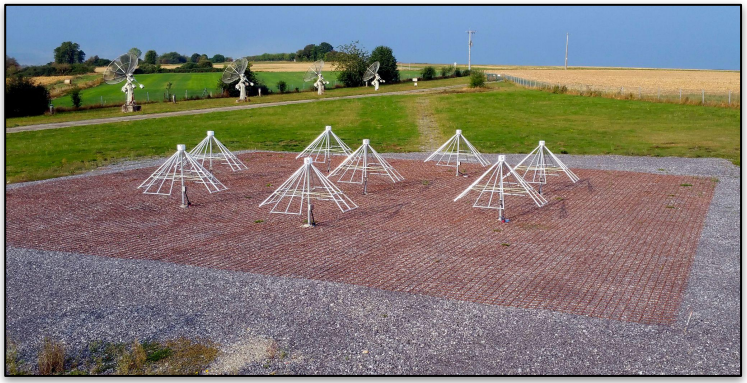
SPADE idea

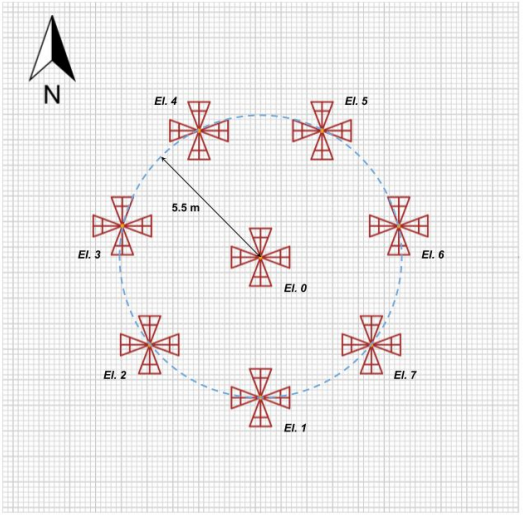
A small, fully digital array built from commercial SDR receivers and open-source software, so identical copies can be replicated worldwide.

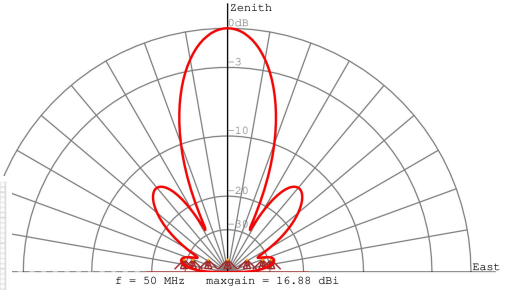
The SPADE concept

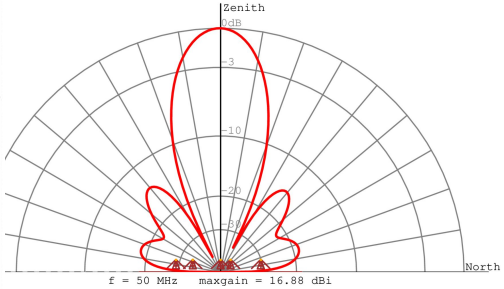
Phased Array of 8 dipoles & ground plane

- 8 fixed active broadband dipoles
- 7 antennas on a 5.5 m ring + centre element
- 20 × 20 m ground plane
- 139 m^2 effective area @ 50 MHz
- Installed at Humain, Belgium









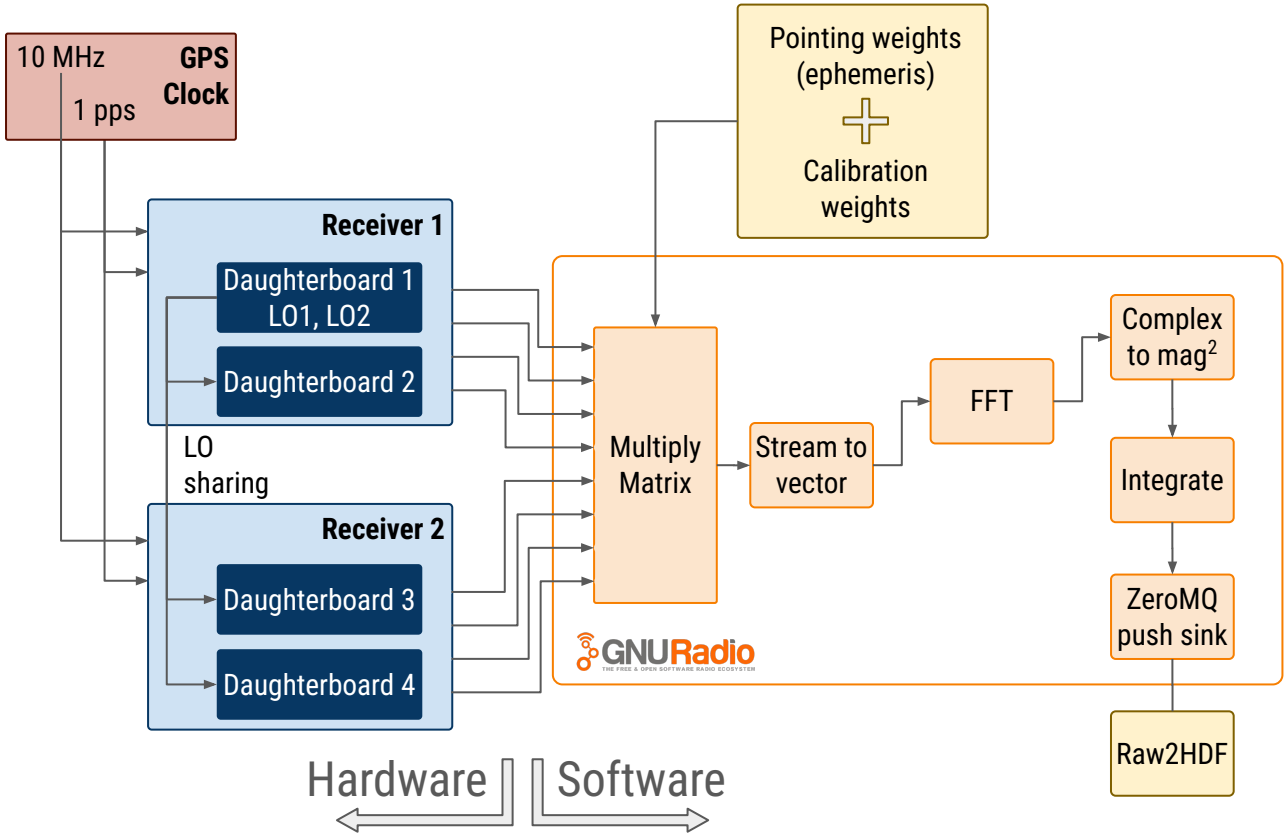
A fully digital signal chain

Beamforming and spectra, all in software

Hardware: two Ettus X300 with 2 daughterboards each, GPS 10 MHz and 1pps reference

GNU Radio: synchronised start, weights from ephemeris, FFT, ZeroMQ, HDF files

Calibration: weekly phase calibration using the BRAMS beacon (49.97 MHz, ~50 km away)



Spectrograph performance

Operation from September 2025 onwards

Daytime solar band	Polarization
25 – 75 MHz	Single (linear)

Spectral resolution	Time resolution
3.052 kHz	49.15 ms

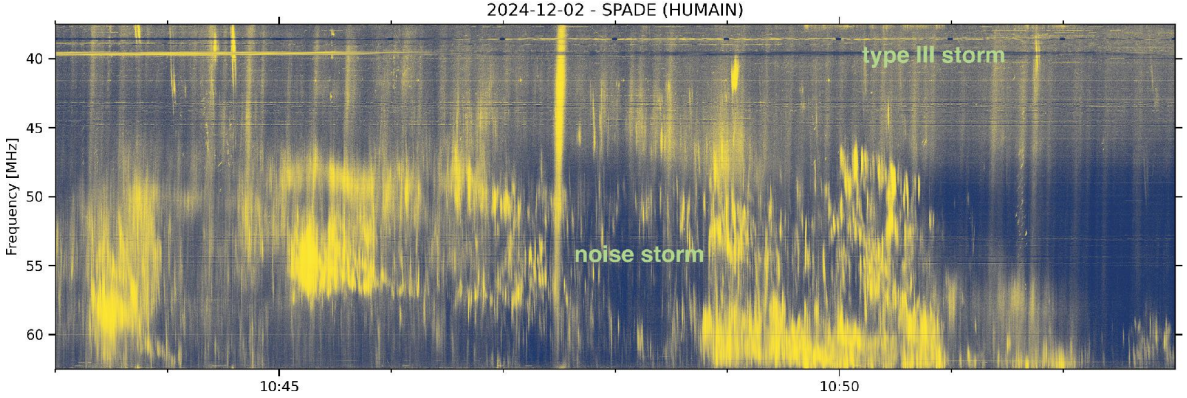
3 dB beamwidth

Frequency	Azimuth	Elevation
35 MHz	35°	> 30°
50 MHz	27°	
65 MHz	22°	

Datafiles (10 minutes)	8 antennas → 1 beam
~766 MB – HDF format	Digital beamforming

Observations

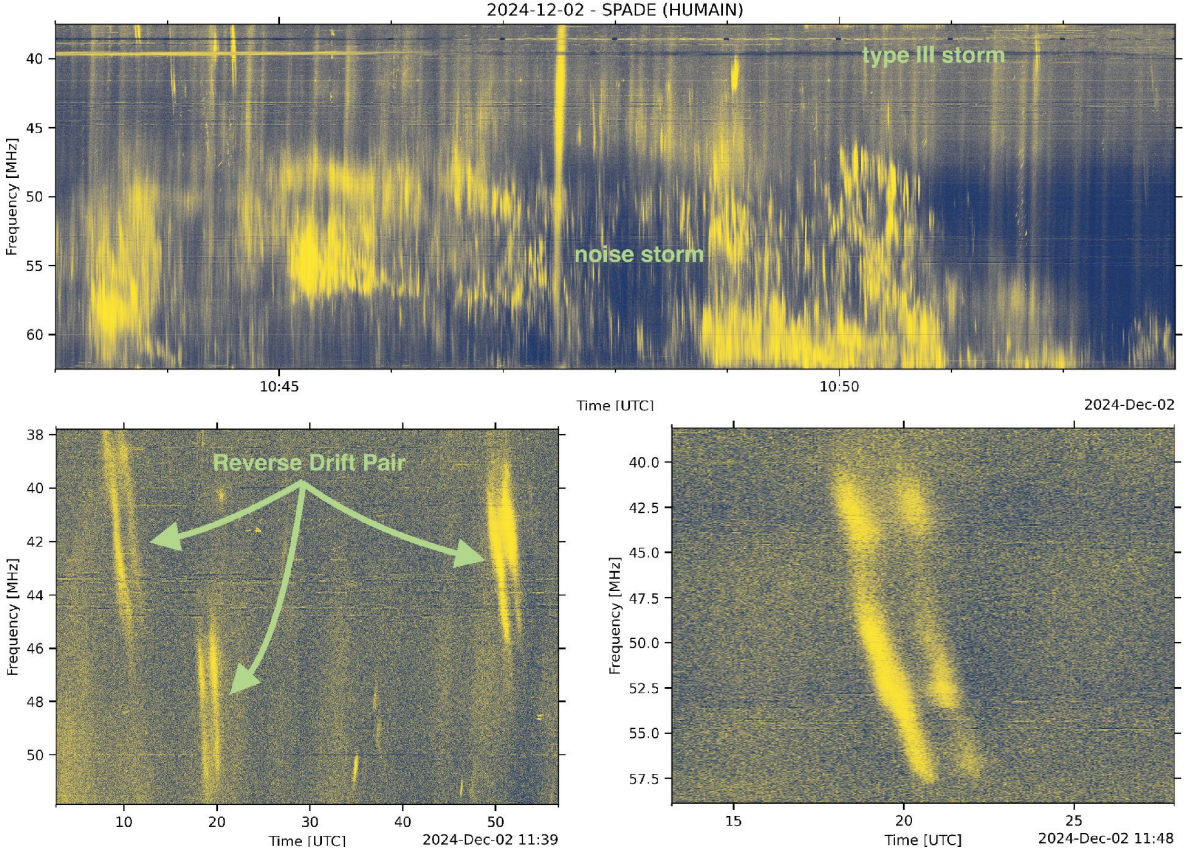
2 Dec 2024 – Noise storm, type III storm, reverse-drift pairs



SPADE config (pre-Sep 2025)	
Total bandwidth	33.333 MHz
FFT	8192 points
Freq. Resolution	4.07 kHz
Time Resolution	49.15 ms

Observations

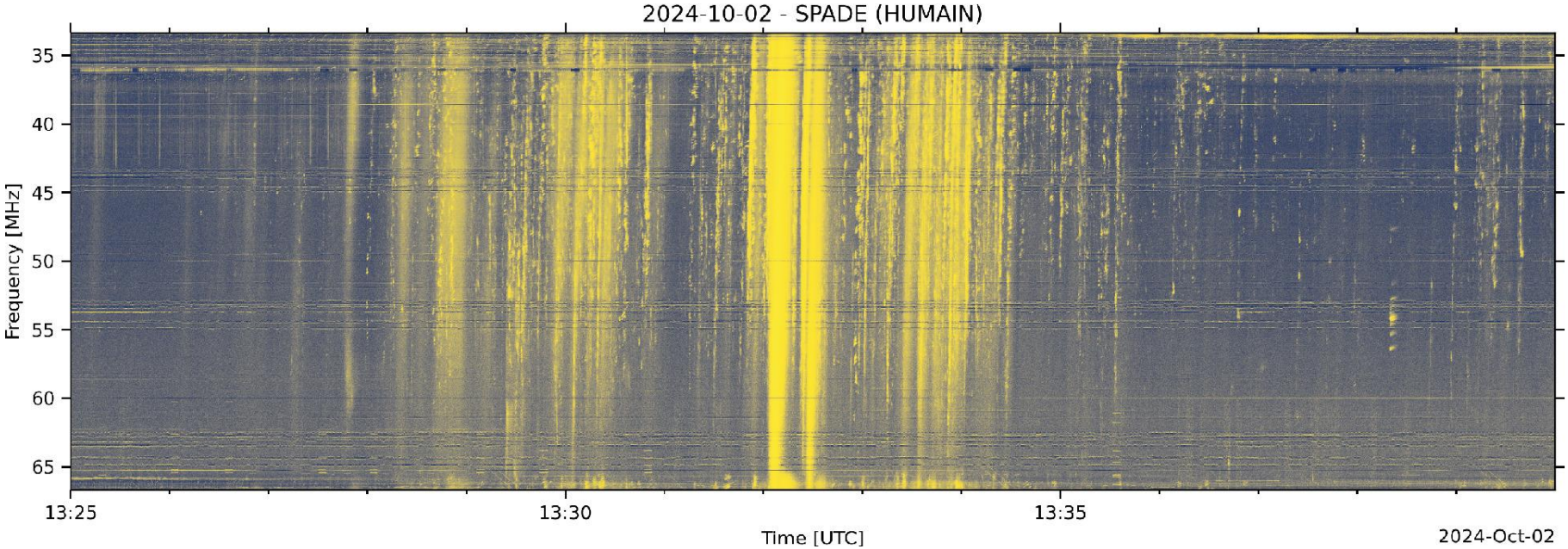
2 Dec 2024 – Noise storm, type III storm, reverse-drift pairs



SPADE config (pre-Sep 2025)	
Total bandwidth	33.333 MHz
FFT	8192 points
Freq. Resolution	4.07 kHz
Time Resolution	49.15 ms

Observations

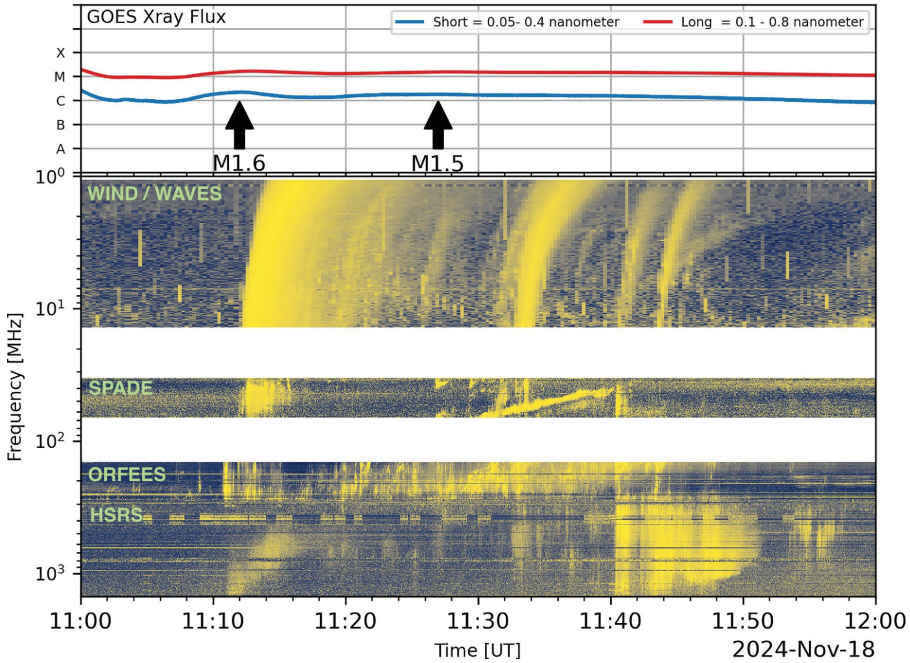
2 Oct 2024 – Group of type III bursts



- Narrowband striae and fast drift
- Fine structure is visible at high time–frequency resolution

Observations

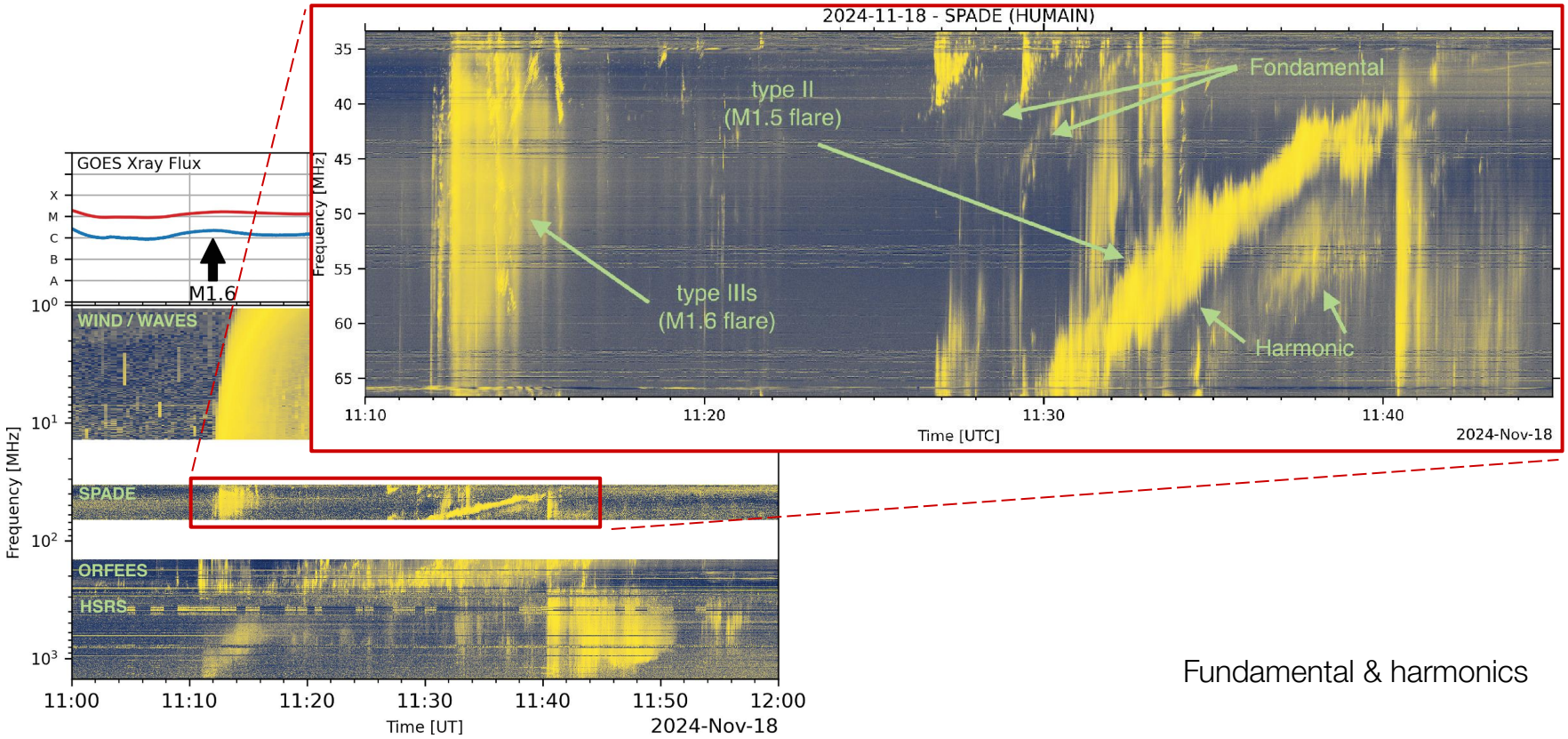
18 Nov 2024 – Type II burst



Both flares originated from NOAA Active Region 13897

Observations

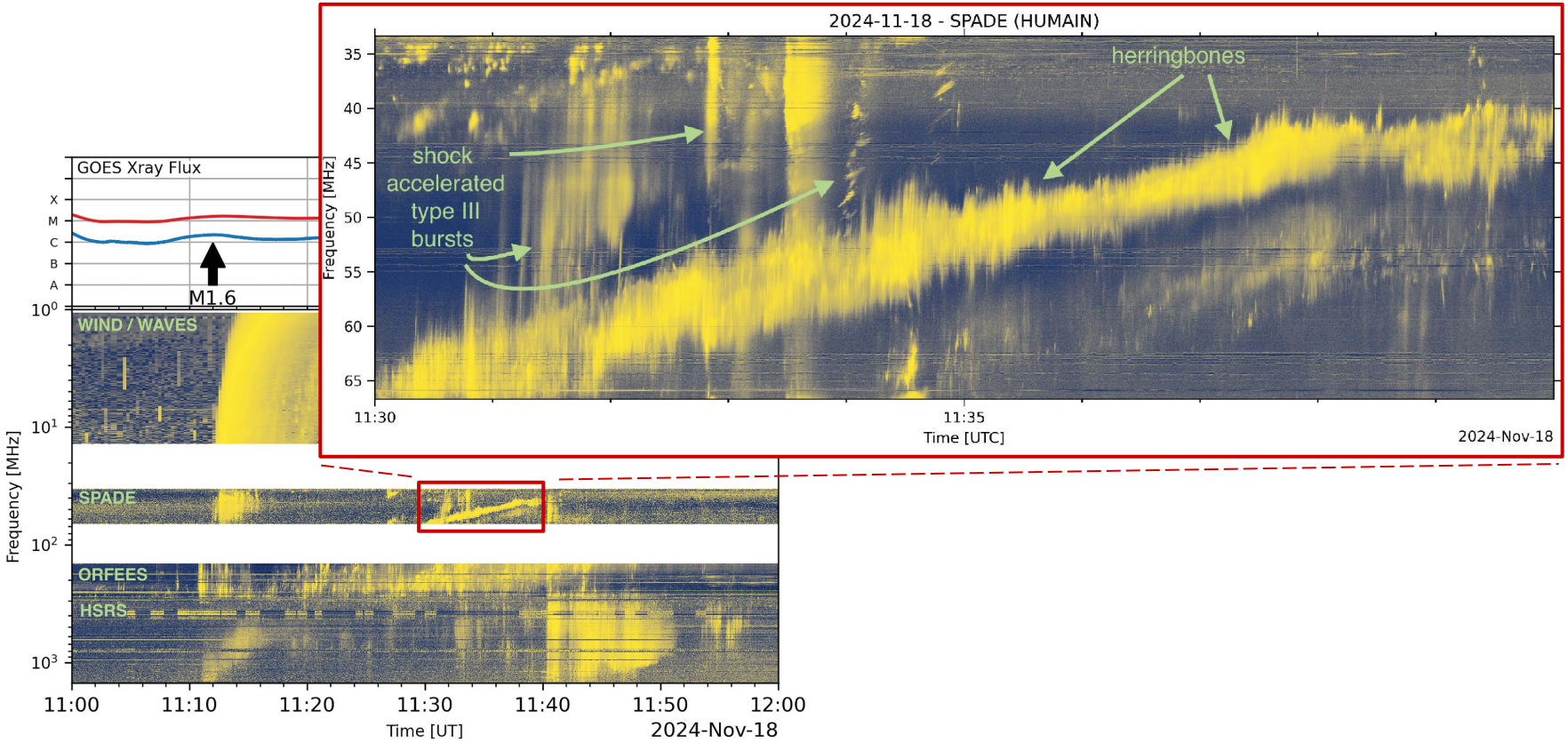
18 Nov 2024 – Type II burst



Fundamental & harmonics

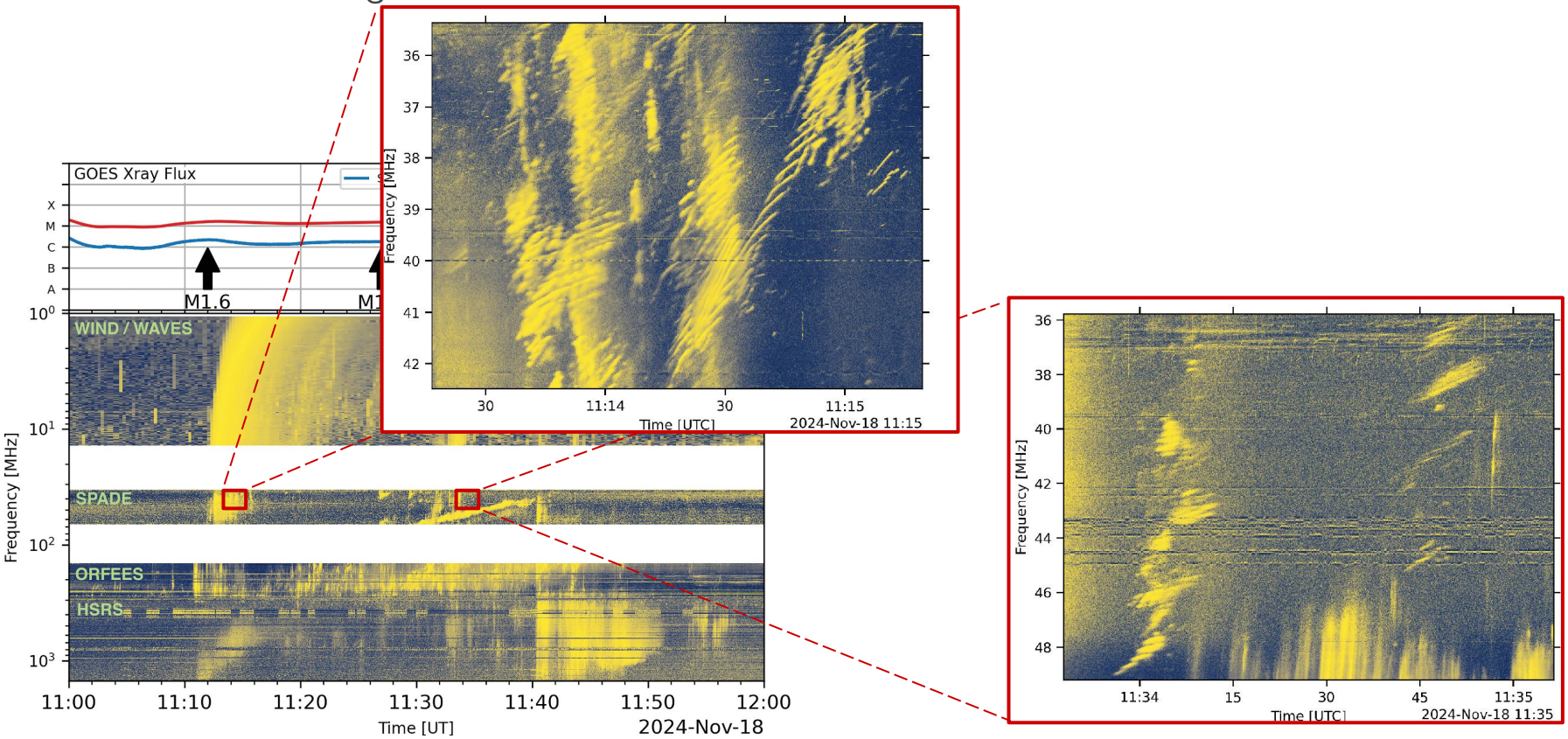
Observations

18 Nov 2024 – Herringbones and fibre-like bursts



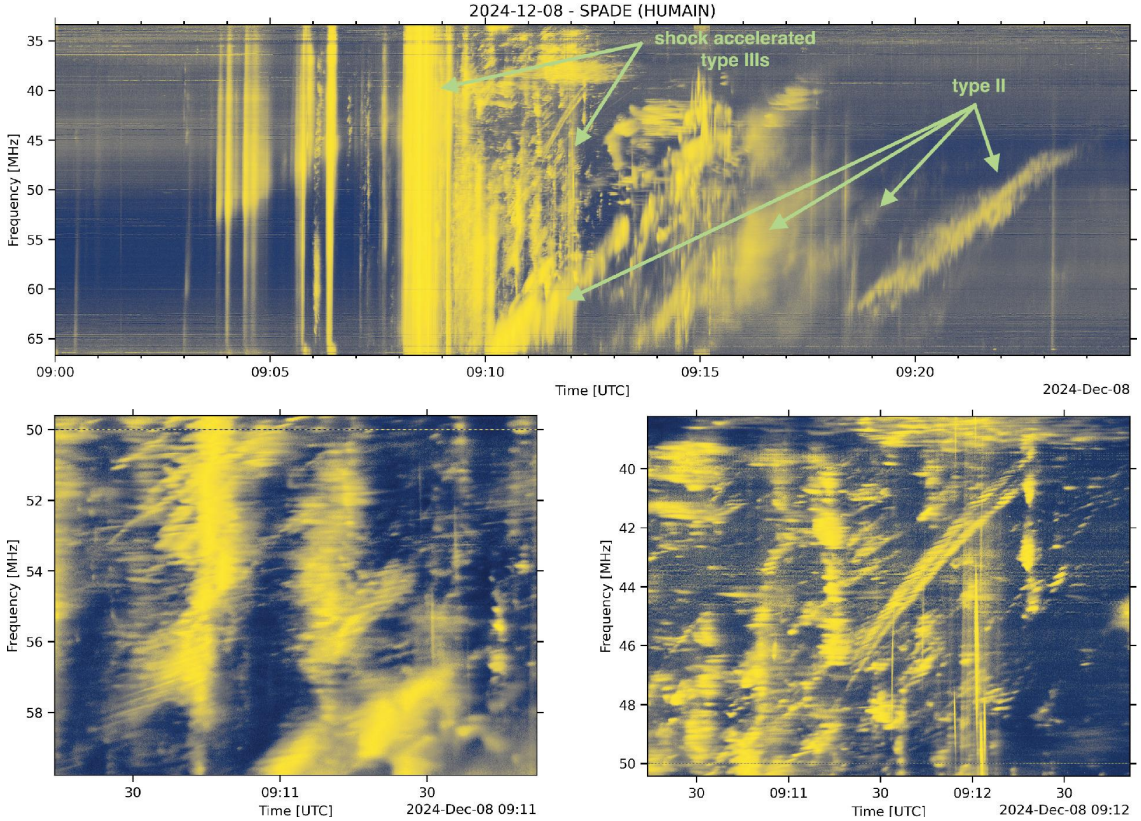
Observations

18 Nov 2024 – Herringbones and fibre-like bursts



Observations

8 Dec 2024 – Herringbones and fibre-like bursts



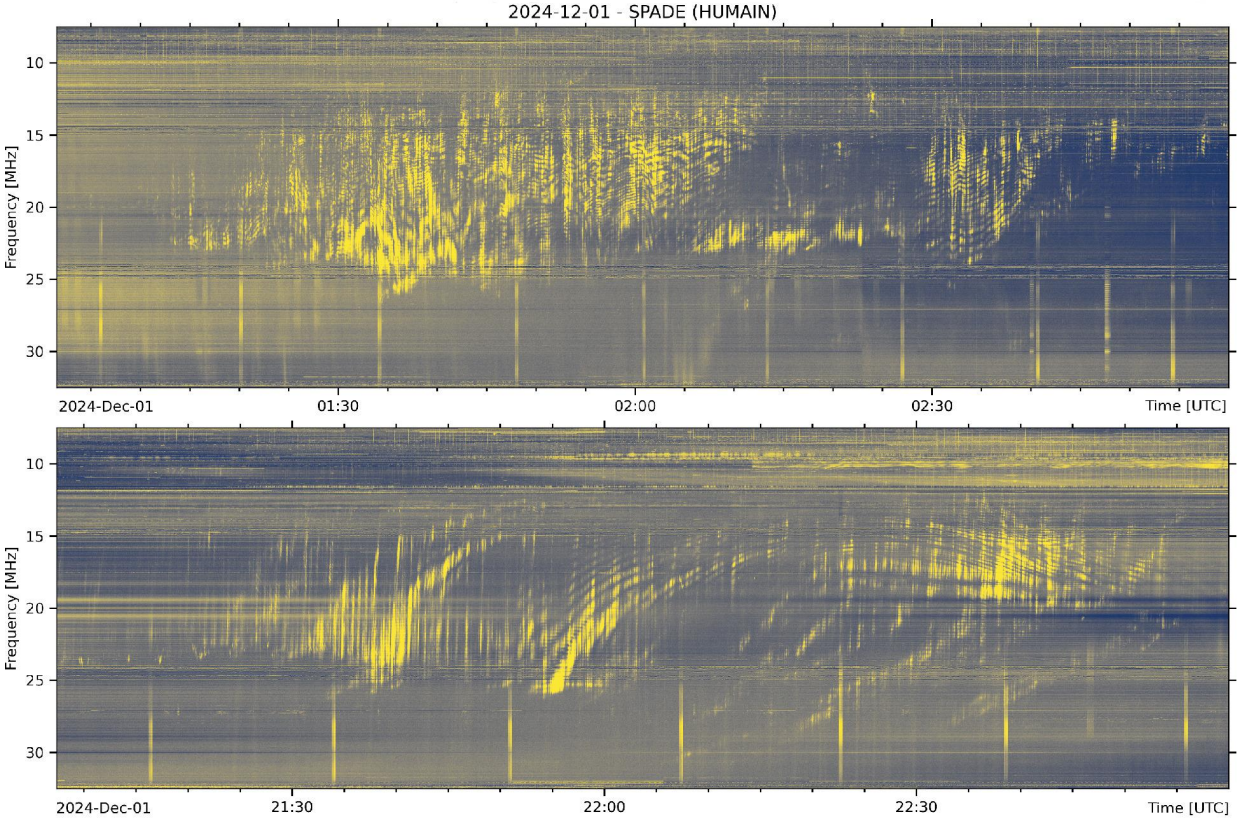
X2.2 flare, peak 09:06 UTC, followed by a type II burst

Shock-accelerated type III bursts are strongly fragmented in frequency, like type IIIb bursts

Implication: if the type IIIb mechanism applies, plasma turbulence is high in the wake of the flare

Observations

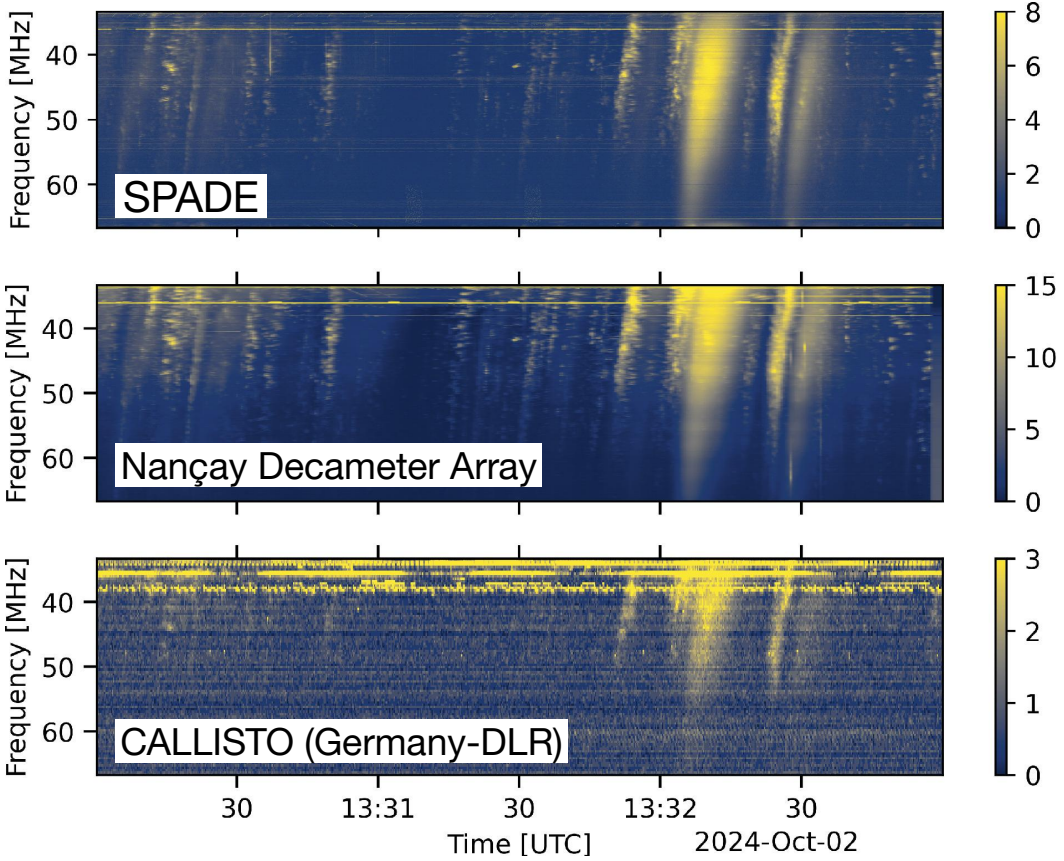
1 Dec 2024 – Io-related Jovian emission



- Night-time observations of Jupiter-Io radio emission
- Broadband scintillating emission and arc-shaped bursts
- Faraday fringes arise as polarised Jovian emission propagates through Earth's ionosphere

Comparison

2 Oct 2024



- Comparable fine-structure visibility to NDA in this event
- Better fine-structure detection than the compared CALLISTO station
- Compact array; not a substitute for large imaging arrays

The Humain Radio-Astronomy Observatory data is available here

https://www.sidc.be/humain/home

Summary

Key results and outlook

- **Compact and replicable**
  Eight fixed antennas, commercial SDRs and open-source GNU Radio enable fully digital solar tracking and spectroscopy.
- **High-resolution observations**
  25–75 MHz coverage, 3.052 kHz spectral and 49.15 ms temporal resolution; type II/III bursts and fine structures are resolved.
- **Space-weather potential**
  Autonomous daytime monitoring and public quicklooks support future distributed coverage. Next steps include polarimetry, flux calibration and frequency-dependent beam steering.

Thank you – questions welcome

antonio.martinez@observatory.be

C. Marqué et al. (2026)
J. Space Weather Space Clim.