DEVELOPMENTS IN GROUND-BASED SPACE WEATHER MONITORING: CALLISTO AND GIFDS FOR EVENT ANALYSIS

D. Banyś, D. Wenzel, L. Heinrich, F. Tandler, C. Monstein and M. Bröse

DLR

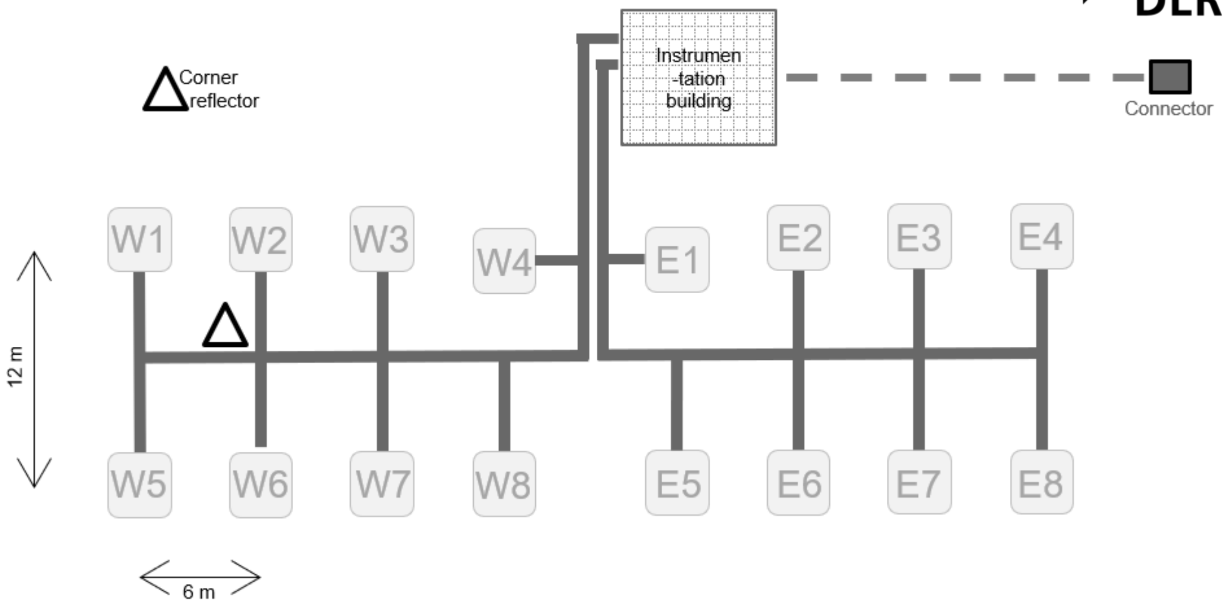
MIRA Multi-Instrument Ionospheric Radio Array

Objectives

- Measurement field for different, passive instruments (10 kHz - 2 GHz) → 16 antenna platforms
- for long-term measurements of various ionospheric and solar disturbances, further development of radio technologies + testing of various instruments before export

Instruments

- GNSS receiver + Bitgrabber
- Beacon receiver
- GIFDS VLF receiver
- CALLISTO solar spectrometer (HF/VHF-, VHF/UHF-, L-Band)
- Etc.



CALLISTO HF/VHF

CALLISTO VHF/UHF

CALLISTO L-Band

GIFDS

GNSS

Beacon

MIRA

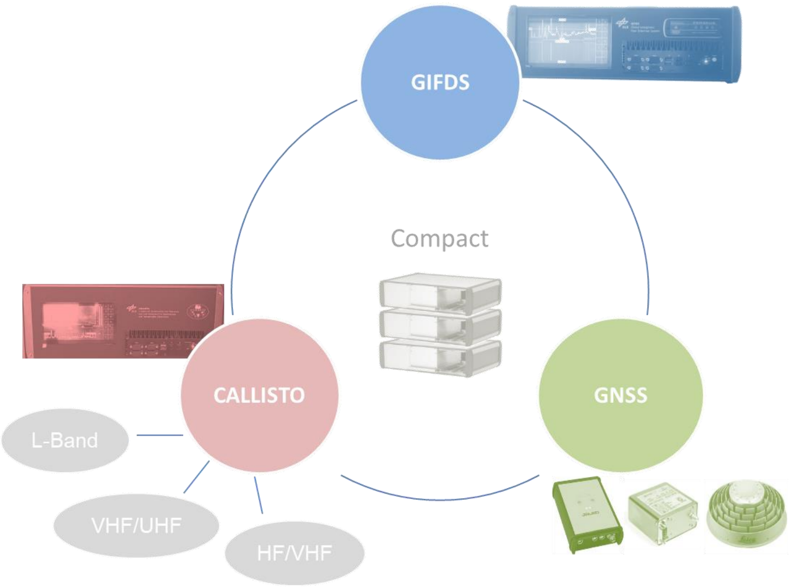
MIRA Multi-Instrument Ionospheric Radio Array

Objectives

- Measurement field for different, passive instruments (10 kHz - 2 GHz) → 16 antenna platforms
- for long-term measurements of various ionospheric and solar disturbances, further development of radio technologies + testing of various instruments before export

Instruments

- GNSS receiver + Bitgrabber
- Beacon receiver
- GIFDS VLF receiver
- CALLISTO solar spectrometer (HF/VHF-, VHF/UHF-, L-Band)
- Etc.



CALLISTO HF/VHF

CALLISTO VHF/UHF

CALLISTO L-Band

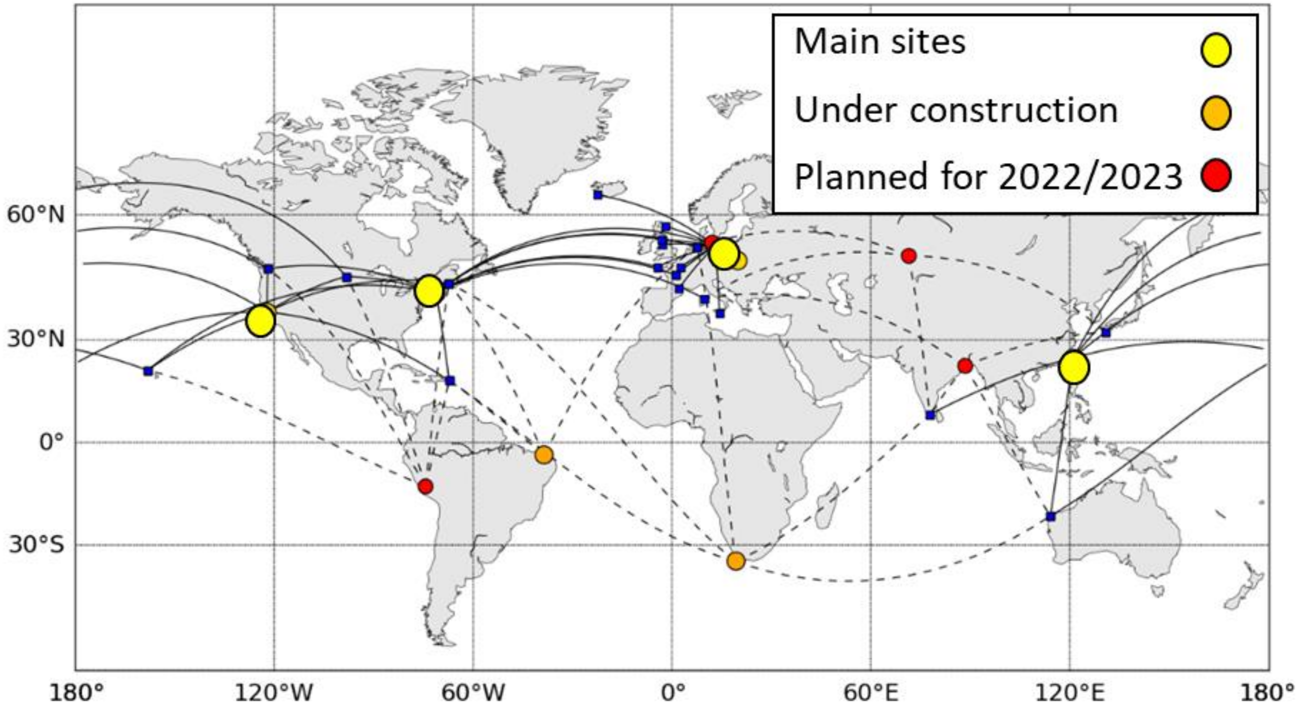
GIFDS

GNSS

Beacon

MIRA

GIFDS Global Ionospheric Flare Detection System

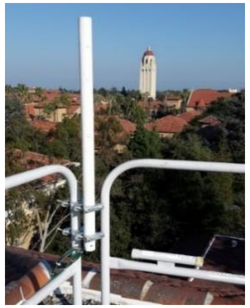


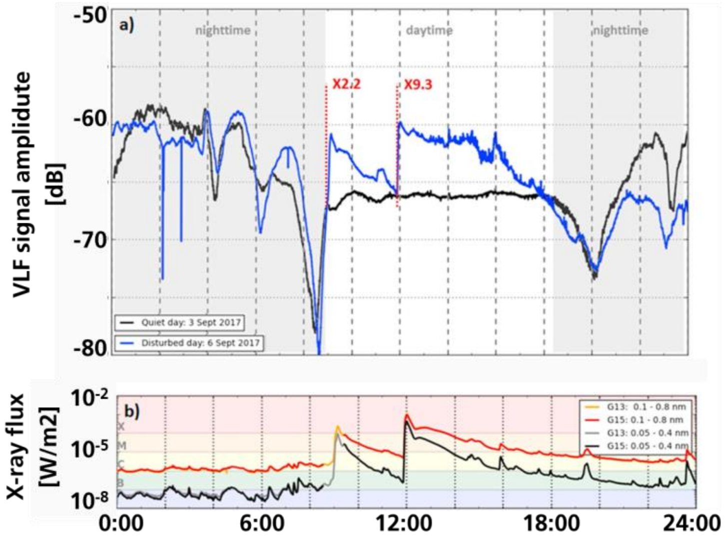
Objectives

- Now cast detection of SIDs caused by solar X-ray flares using a ground-based VLF system
- Integration of real-time VLF data and flare alerts into IMPC with SO-WWE

10 GIFDS sites planned

- 10 Hz amplitude and phase measurements of various VLF transmitters of the electric + magnetic field

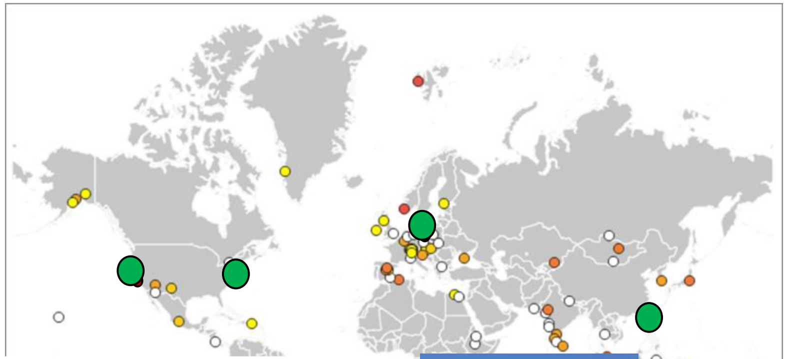




Specifications

- Antenna: Mini-Whip antenna inside tube (ø~7cm) of 3m height
- Spectrum: 0 – 1.7 MHz

CALLISTO Compound Astronomical Low frequency Low cost Instrument for Spectroscopy and Transportable Observatory



Objectives
Monitoring radio frequency interferences and solar radio bursts
Extension of the e-Callisto network in collaboration with ISWI

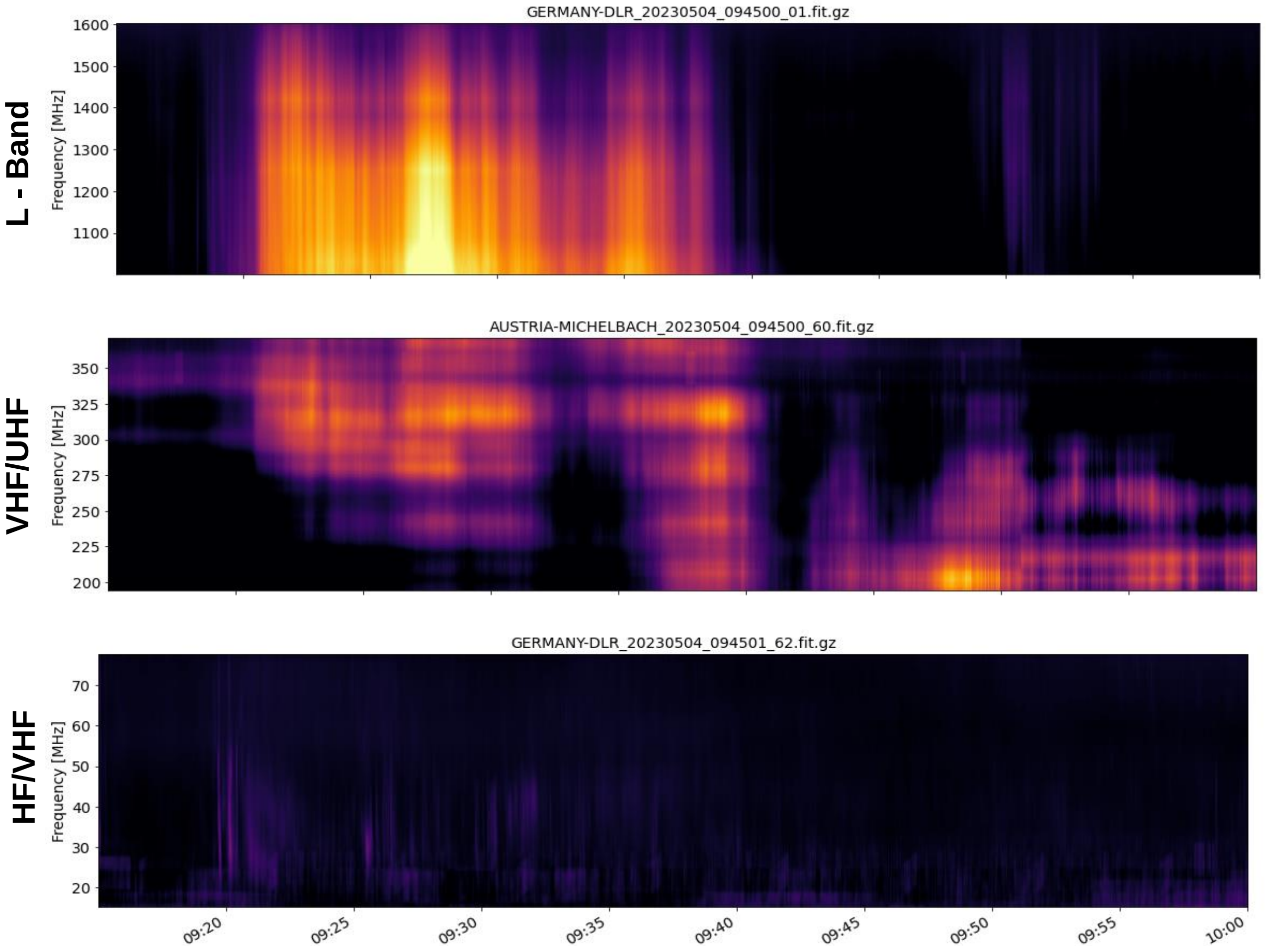
4 full CALLISTO/SIGN sites planned

L-Band spectrum: 1 – 1.6 GHz
LPDA antenna of 1m length installed in 1.5m height

VHF/UHF spectrum: 100 – 870 MHz
LPDA antenne of 2m length installed in 1.5m height

HF/VHF spectrum: 20 – 80 MHz
LWA/DMA antenna of 2 m height

Radio bursts on 4 May 2023



CALLISTO Compound Astronomical Low frequency Low cost Instrument for Spectroscopy and Transportable Observatory

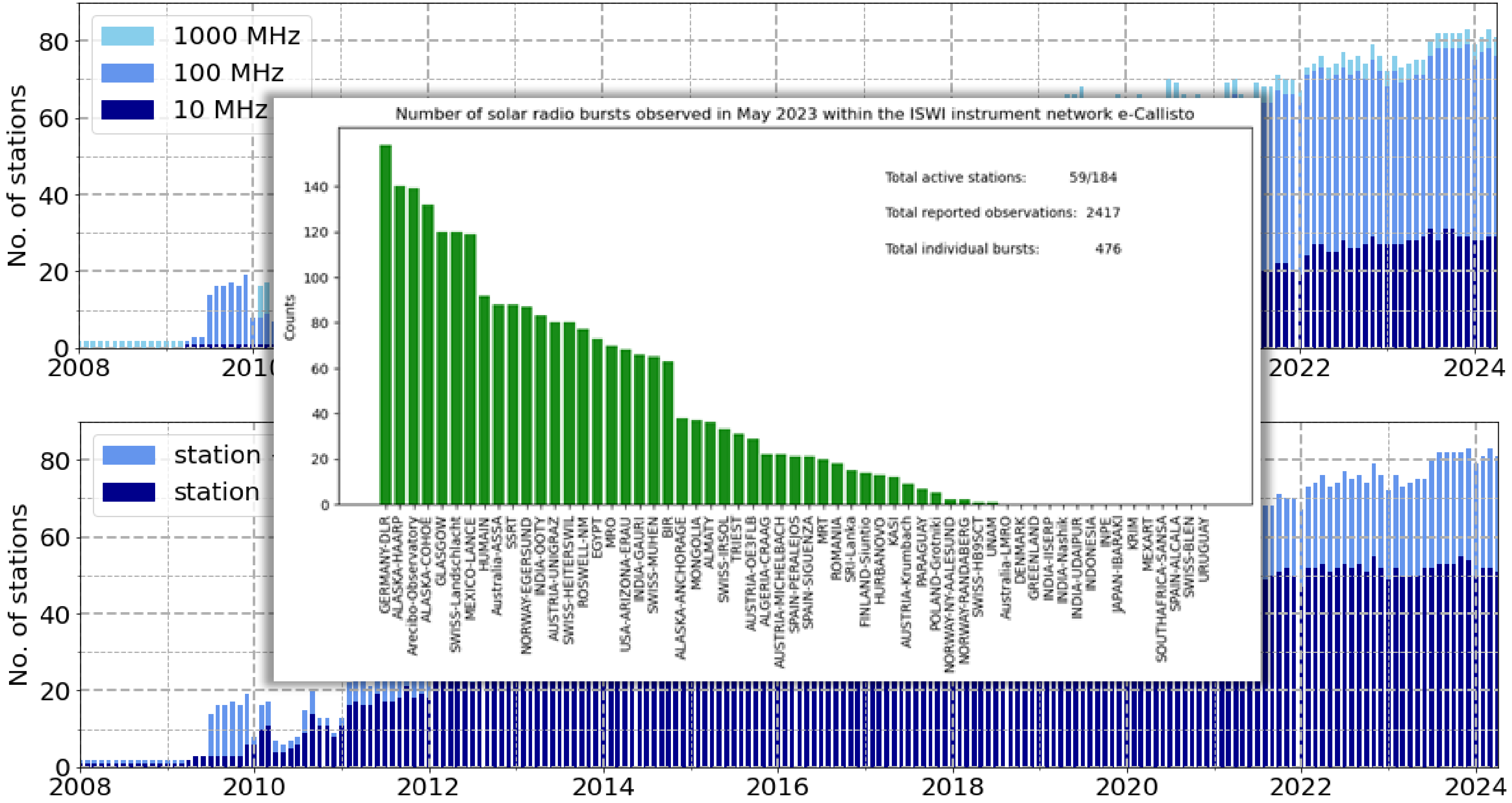
Objectives
Monitoring radio frequency interferences and solar radio bursts
Extension of the e-Callisto network in collaboration with ISWI

4 full CALLISTO/SIGN sites planned

L-Band spectrum: 1 – 1.6 GHz
LPDA antenna of 1m length installed in 1.5m height

VHF/UHF spectrum: 100 – 870 MHz
LPDA antenne of 2m length installed in 1.5m height

HF/VHF spectrum: 20 – 80 MHz
LWA/DMA antenna of 2 m height



Radio burst detection: CALLISTO vs. RSTN

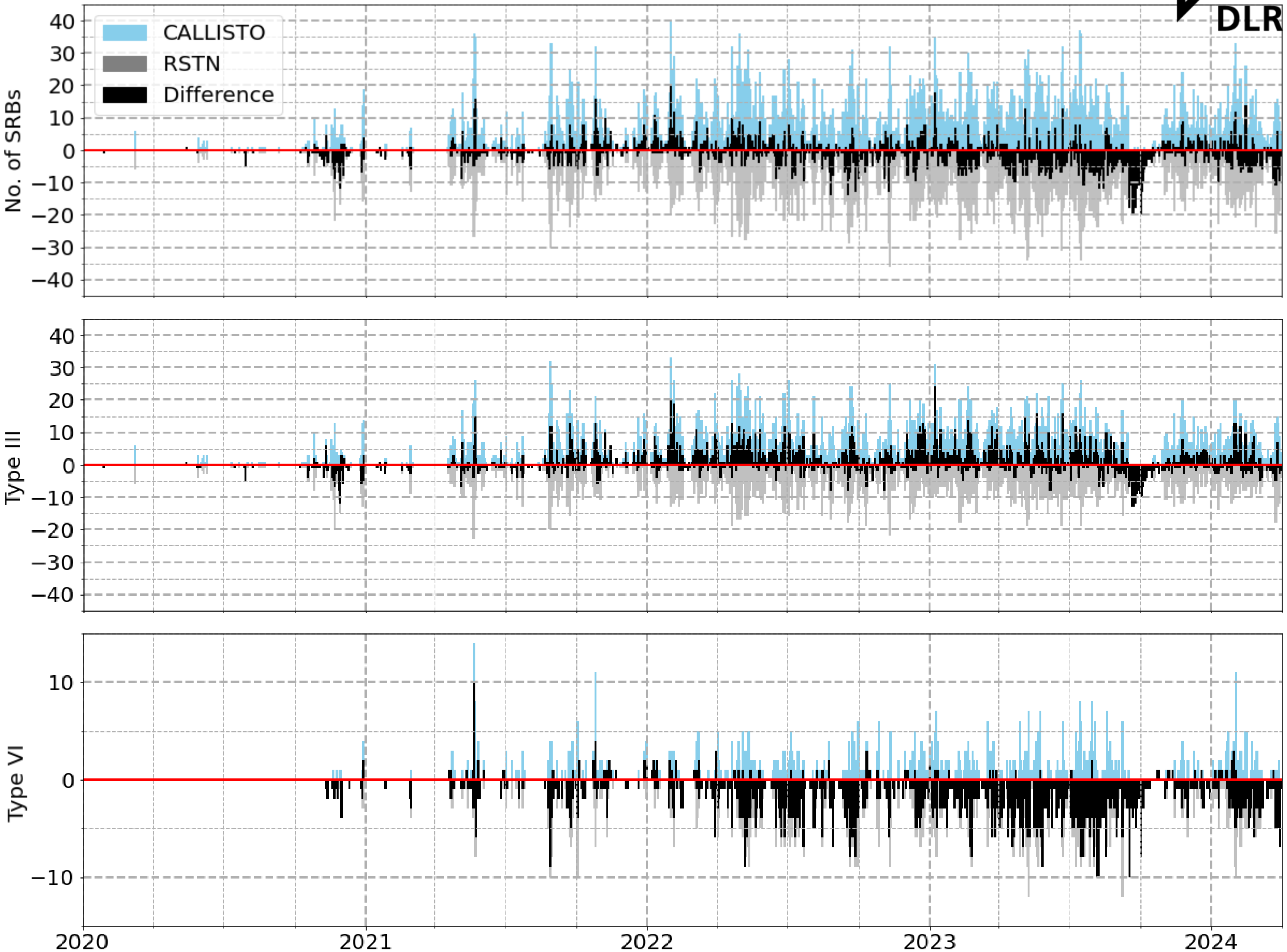
CALLISTO

- e-Callisto event lists by Christian Monstein
- ~ 50 operational sites
  ~ 20 with events
- **Further types:**
  CTM, Type VI, Type VII, CAU, DCIM, J, U, N

RSTN

- Radio Solar Telescope Network
- NOAA/SWPC event reports (with classification, RSP)
- 4 main stations: Australia, Italy, Massachusetts, Hawaii
- **Further types:**
  CTM, Type VI, Type VII
- **Additional information:** relative intensity, shock speed

Manual event detection & classification:
→ Statistical event analysis from 2020 – today

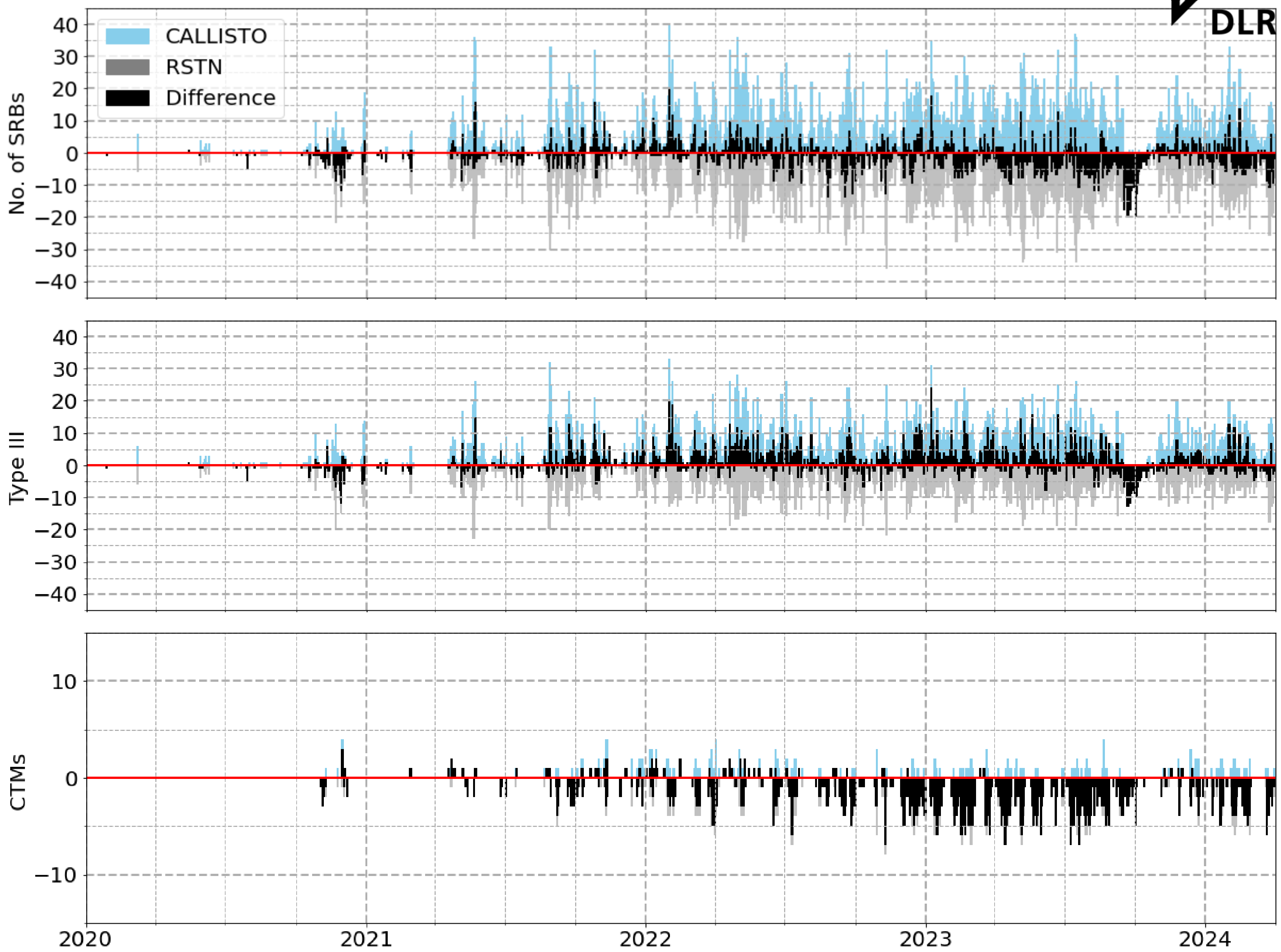


Radio burst detection: CALLISTO vs. RSTN

CALLISTO
- e-Callisto event lists by Christian Monstein
- ~ 50 different operational sites
- **Further types:** CTM, Type VI, Type VII, CAU, DCIM, J, U, N

RSTN
- Radio Solar Telescope Network
- NOAA/SWPC event reports (with classification, RSP)
- 4 main stations: Australia, Italy, Massachusetts, Hawaii
- **Further types:** CTM, Type VI, Type VII
- **Additional information:** relative intensity, shock speed

Manual event detection & classification:
→ Statistical event analysis from 2020 – today



Radio burst detection: CALLISTO vs. RSTN

CALLISTO

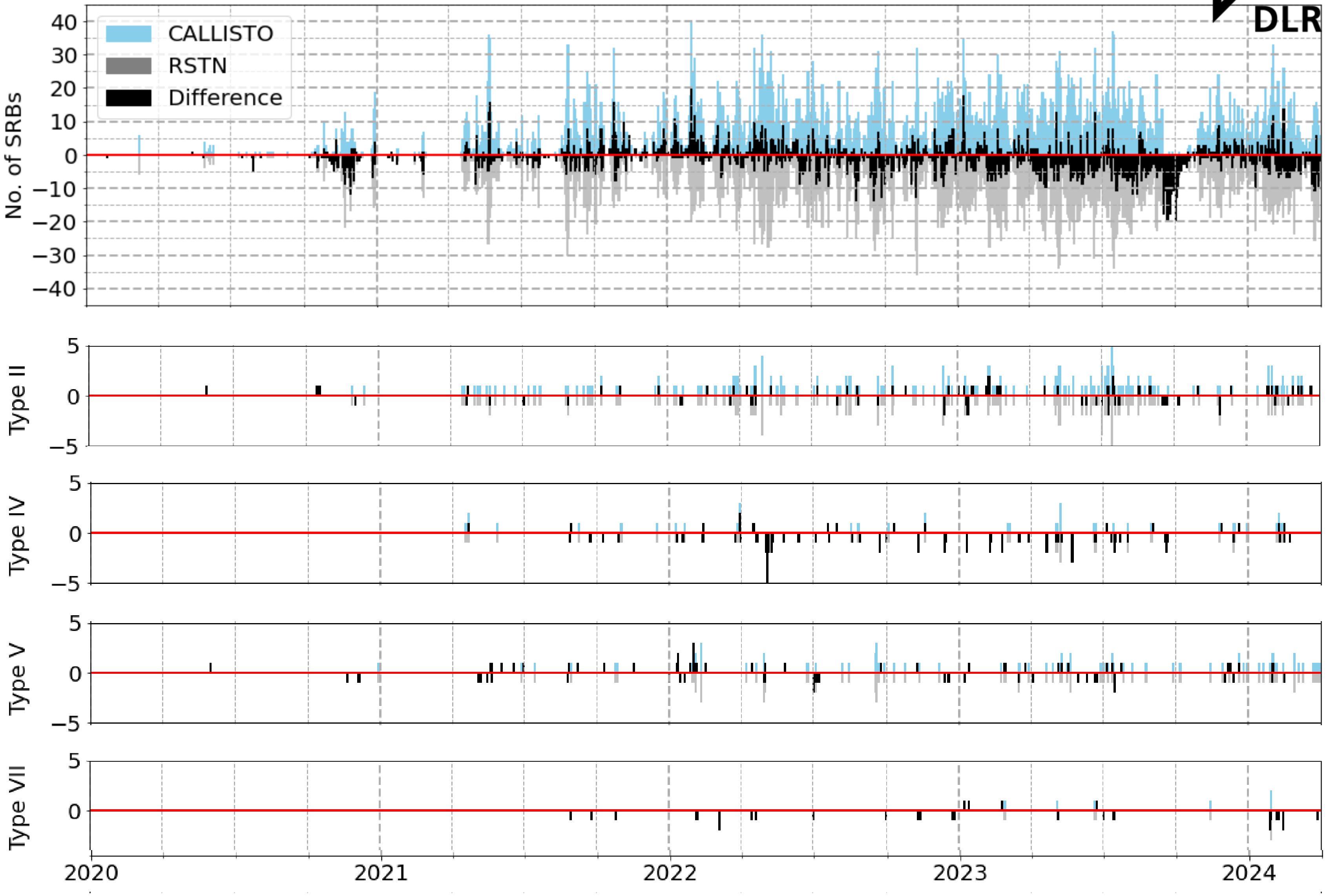
- e-Callisto event lists by Christian Monstein
- ~ 50 different operational sites
- **Further types:** CTM, Type VI, Type VII, CAU, DCIM, J, U, N

RSTN

- Radio Solar Telescope Network
- NOAA/SWPC event reports (with classification, RSP)
- 4 main stations: Australia, Italy, Massachusetts, Hawaii
- **Further types:** CTM, Type VI, Type VII
- **Additional information:** relative intensity, shock speed

Manual event detection & classification:

→ Statistical event analysis from 2020 – today

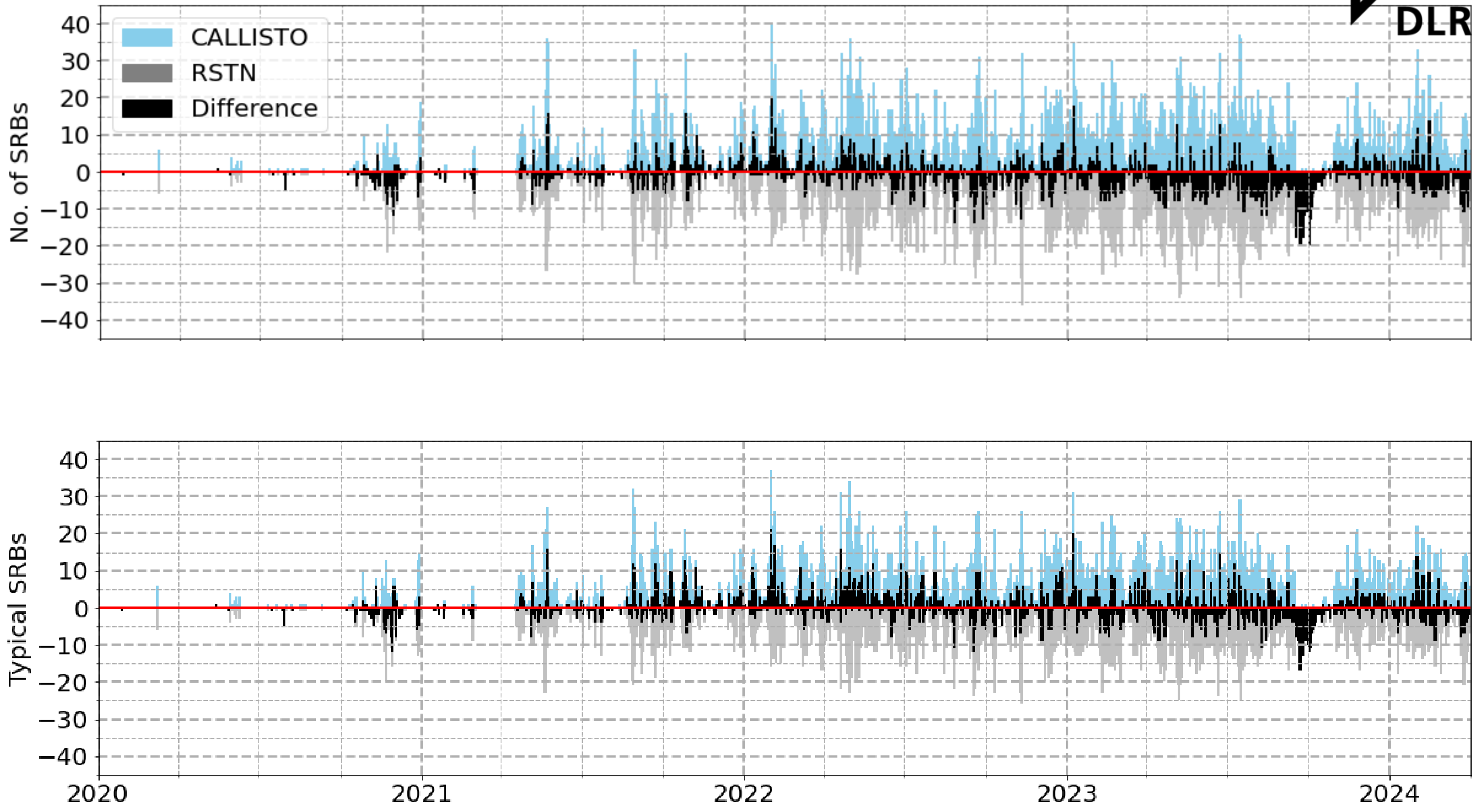


Radio burst detection: CALLISTO vs. RSTN

CALLISTO
- e-Callisto event lists by Christian Monstein
- ~ 50 different operational sites
- **Further types:** CTM, Type VI, Type VII, CAU, DCIM, J, U, N

RSTN
- Radio Solar Telescope Network
- NOAA/SWPC event reports (with classification, RSP)
- 4 main stations: Australia, Italy, Massachusetts, Hawaii
- **Further types:** CTM, Type VI, Type VII
- **Additional information:** relative intensity, shock speed

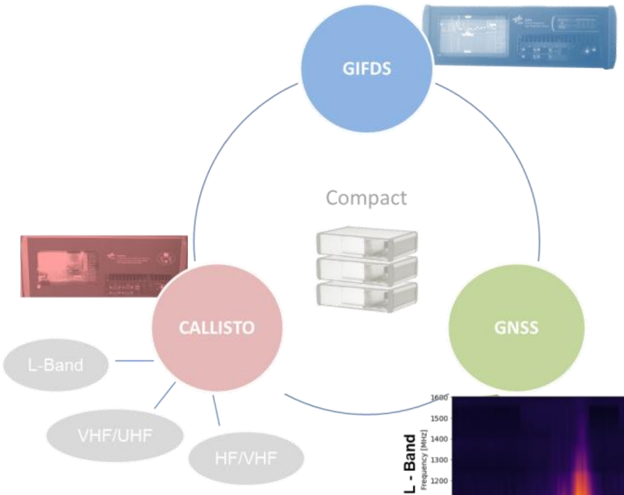
Manual event detection & classification:
→ Statistical event analysis from 2020 – today



Radio burst detection: Overview on automatic algorithms

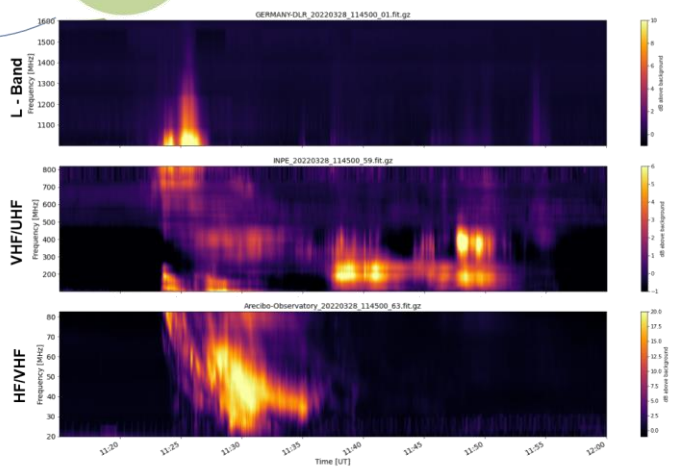
Publication	Algorithm name	Approach	Data set	Specifications
Lobzin et al. 2009, 2010	ARBIS (Automated Radio Burst Identication System)	Statistical		70% accuracy for Type III
Zhang et al. 2018	image binarization	Statistical	Nançay Decameter Array, 2012 – 2017	
Salmane et al. 2018	CFAR-like approach (Constant False Alarm Rate)	Statistical	Nançay Decameter Array June 2012 + June 2014	81 % accuracy for Type III Possible events: Type II, III, IV and regions of interest
Xu et al. 2019	LSTM neural network (long short-term memory)	AI	Huairou Solar Observing Station (HSOS)	True Positive Ratio (TPR) 85.4% False positive Ratio 6.7%
Singh et al. 2019	Via area slope index (ASI)	Statistical	e-Callisto, Gauribudanur 2013 – 2014	Precision of 50 – 61.7 % for Type III
Afandi et al. 2020	Burst-Finder	Statistical	e-Callisto, 11 February 2014	89% accuracy
Liu et al. 2021	DBSCAN clustering algorithm	AI		Type III
Scully 2021, 2023 a,b	You Only Look Once (YOLO)	AI		
Guo 2022		AI		
Wang et al. 2022	YOLOv7	AI		
Bussons et al. 2023	deARCE (deep Automatic Radioburst Compilation Engine)	AI	e-Callisto, ASSA, Glasgow, Humain, Landschlacht, 2021	88% accuracy, 8% false alarms
Höfig et al. 2023	ROBUST	Statistical		
Zhang et al. 2024	YOLOv7	AI	RSTN, Learmonth 2001–2022	Precision of 73.5% for Type II + III

Summary

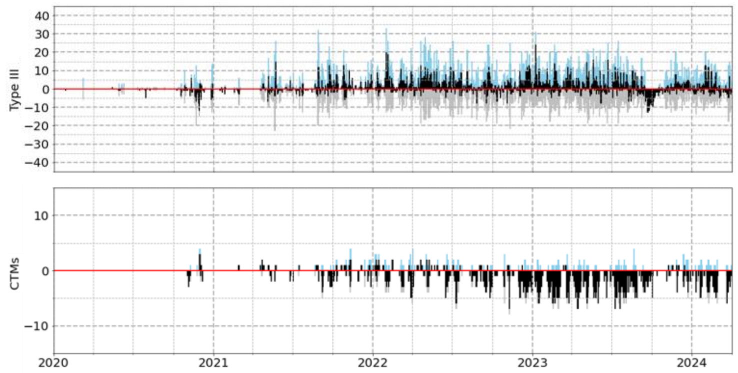


Summary

- Development of compact receivers for GIFDS and CALLISTO
- Combination of different receivers for continuous monitoring of solar flares and radio bursts in near real time
- Comparison of event reports from CALLISTO and RSTN show significant differences
- Variety of automatic radio burst detection

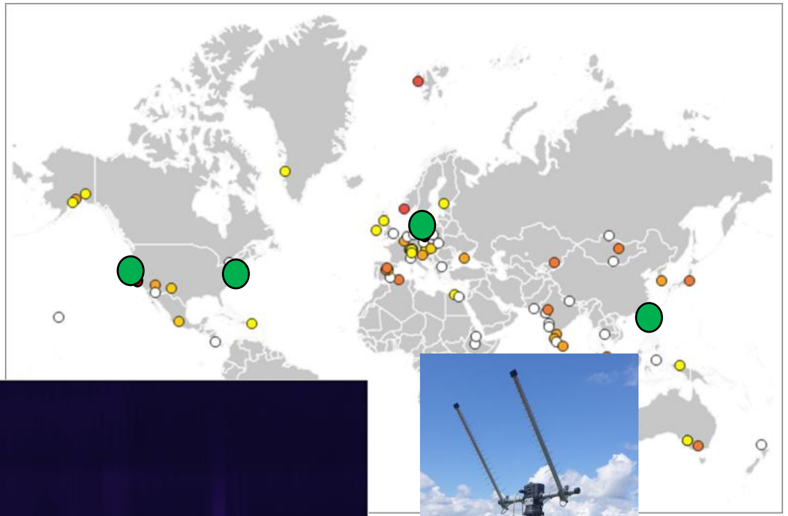


→ Need for automatic detection
→ Reconsidering SRB classification / constraints for specific purpose:
  → Investigation of solar processes
  → Warning of tech. infrastructure



Thank you!

CALLISTO Compound Astronomical Low frequency Low cost Instrument for Spectroscopy and Transportable Observatory



Objectives

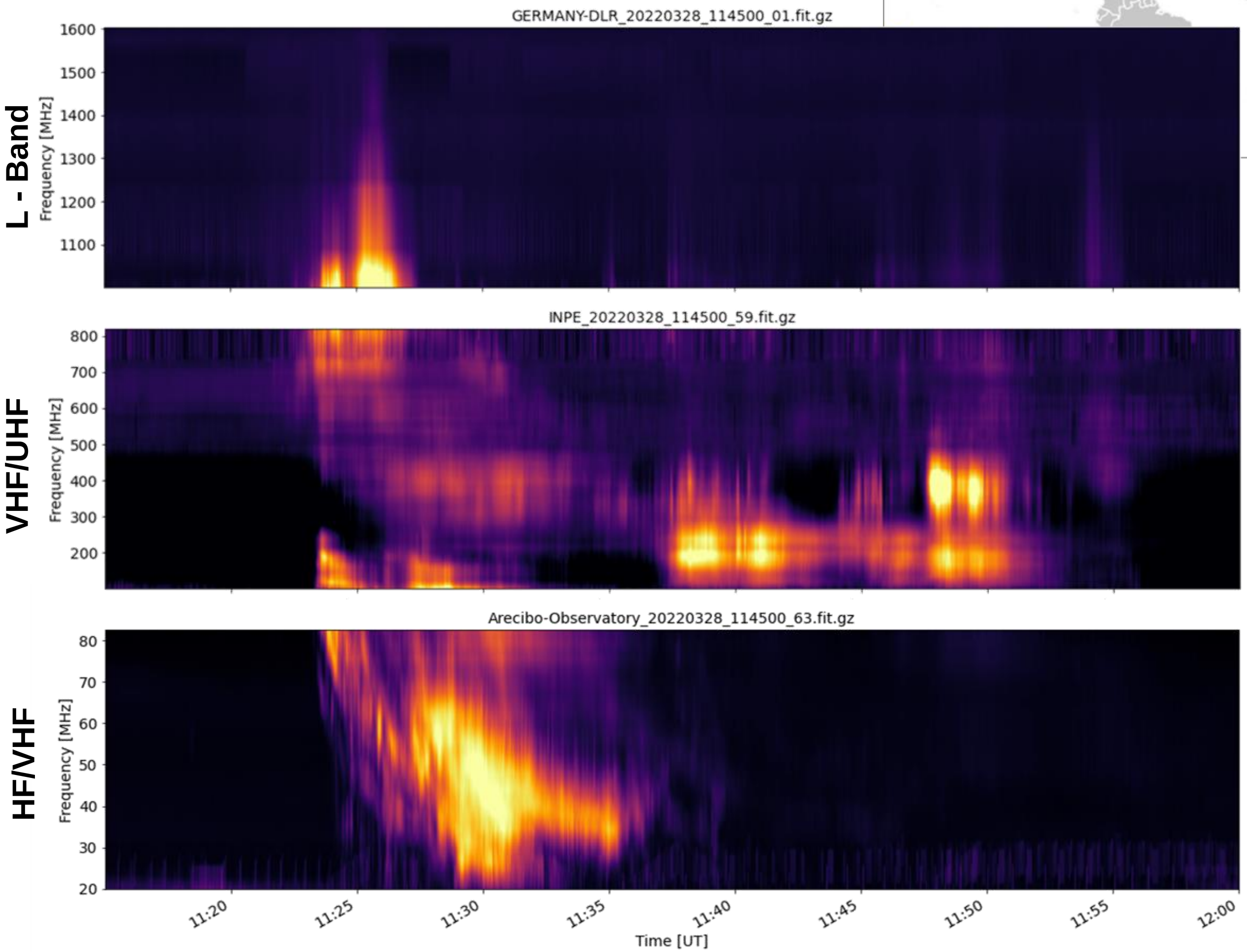
Monitoring radio frequency interferences and solar radio bursts

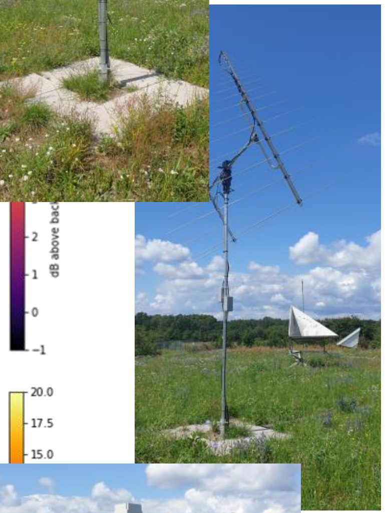
Extension of the e-Callisto network in collaboration with ISWI

4 full CALLISTO/SIGN sites planned

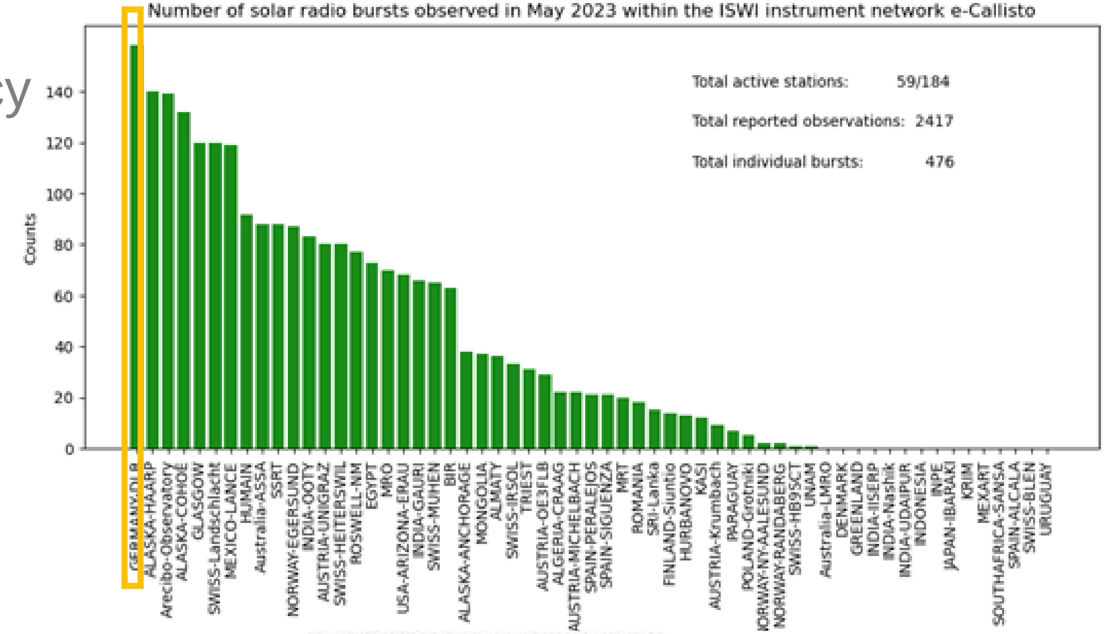
- Instrument natively operates between 45 and 870 MHz
- Frequency range expanded via heterodyne up- or down-converter
- Frequency resolution: 62.5 KHz
- Time resolution: 0.25s at 200 channels per spectrum
- Integration time: 1ms
- Radiometric bandwidth: 300 KHz
- Dynamic range: > 50 dB

Radio bursts on 28 March 2022

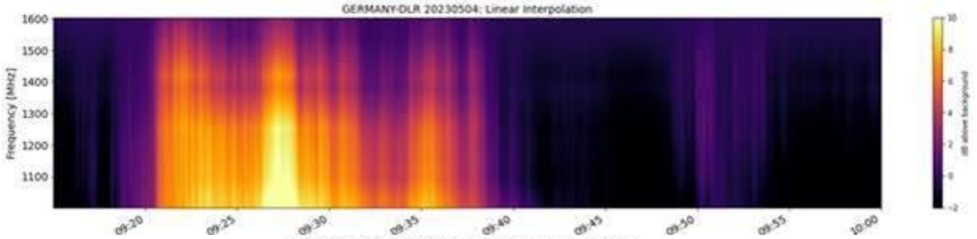




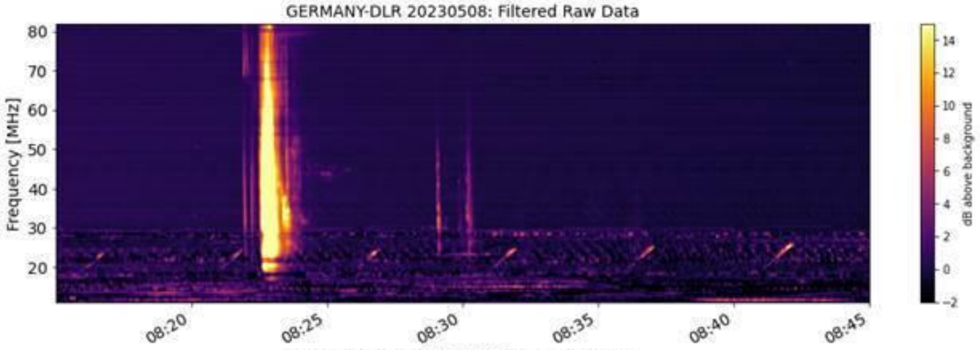
CALLISTO Compound Astronomical Low frequency Low cost Instrument for Spectroscopy and Transportable Observatory



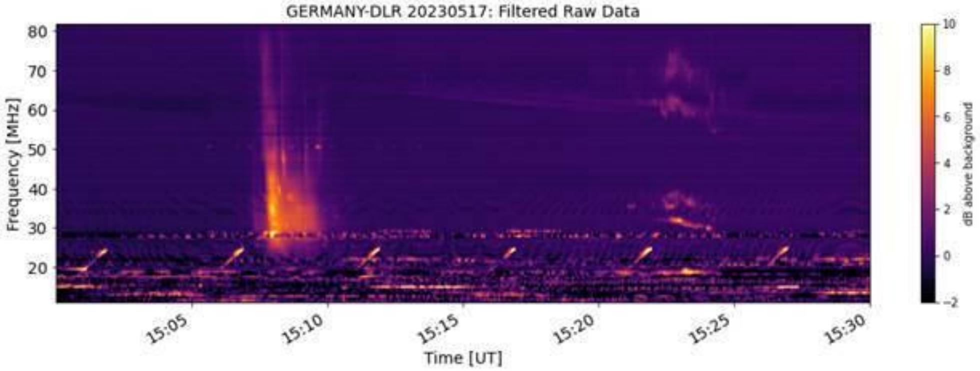
Type IV



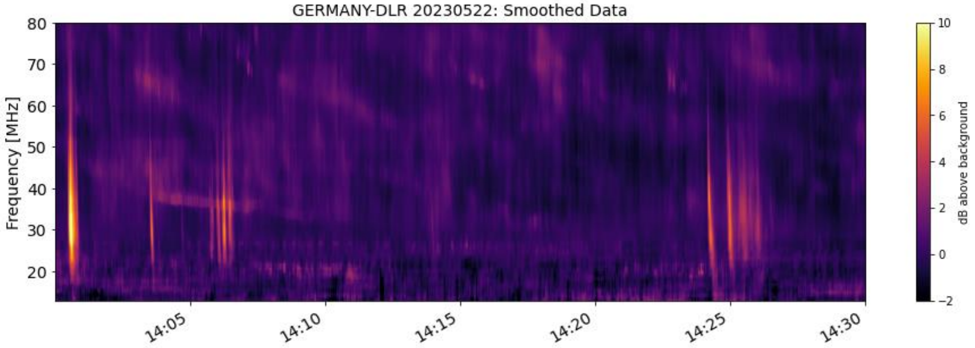
Type III



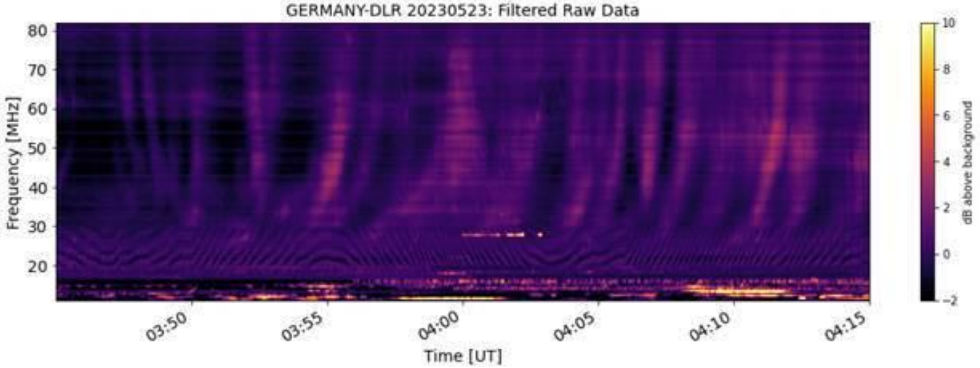
Type V



Type VI



CTM / CAU

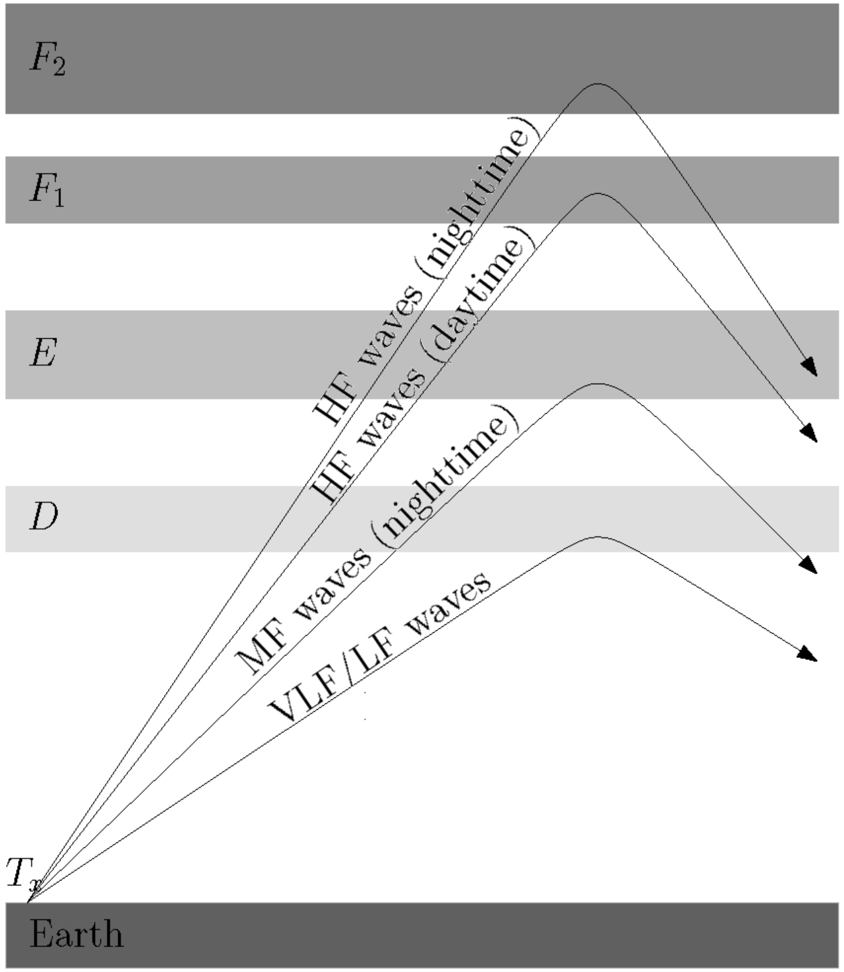


Appendix: Radio wave propagation

Fundamentals of radio waves

Band	Frequency	Wavelength	Propagation characteristic	Application
ELF	$\leq 3\ kHz$	$\geq 100\ km$	Earth-ionosphere waveguide penetrating sea water	Communication with (submerged) submarines
VLF	$3 - 30\ kHz$	$100 - 10\ km$	Sky wave: Earth-ionosphere waveguide from ground to lower ionosphere, Ground wave	Submarine communication, Alpha (navigation), Beta (time signal)
LF	$30 - 300\ kHz$	$10 - 1\ km$	Earth-ionosphere waveguide, Ground wave	Maritime navigation, Loran C (until 2015), AM broadcasting, standard time signals
MF	$300 - 3000\ kHz$	$1000 - 100\ m$	Ground wave, At night: E-region reflection	Non-Directional (radio) Beacon (NDBs) for maritime and aeronautical navigation, AM broadcasting, Maritime and land mobile
HF	$3 - 30\ MHz$	$1000 - 100\ m$	E- and F-region reflection	Maritime and aeronautical fixed services, shortwave broadcasting, amateur and citizens' band radio
VHF	$30 - 300\ MHz$	$1000 - 100\ m$	Line of sight, Scattered from the ionosphere	Television, FM broadcasting, Public safety, Aeronautical Space communications
UHF	$300 - 3000\ MHz$	$1000 - 100\ m$	Line of sight (affected by ionospheric irregularities)	Television, Radar, Broadcasting, Navigation (fixed, mobile)
SHF	$3 - 30\ GHz$	$1000 - 100\ m$	Line of sight (tropospheric, affected by ionospheric irregularities)	Space communications, Television, Radar, Broadcasting, Navigation (fixed, mobile)

Davies 1990



Banyś 2017

German ground-based space weather instruments

CALLISTO spectrometer:
- HF (10-80 MHz): Neustrelitz
- VHF/UHF (100 – 800 MHz): Neustrelitz
- L-Band1-1.6 GHz: Neustrelitz

VLF receivers
- **GIFDS**: Neustrelitz, Boston, Stanford, Taiwan
- **SOFIE:** Neustrelitz, Berlin, Huntsville, Hermanus
- **SID Monitor:** Göttingen, Bergen

Riometer: Neustrelitz → Longyearbyen

GNSS / Scintilation receiver: EVnet, EUREF

Bitgrabber: Neustrelitz (mobil), Tromsø, Abuja

Beacon receiver: Neustrelitz

Airglow Imager Neustrelitz

Magnetometer: Potsdam, Braunschweig

Neutron monitors: Kiel (NMDB)

DLR instruments on MIRA

CALLISTO HF/VHF

CALLISTO VHF/UHF

CALLISTO L-Band

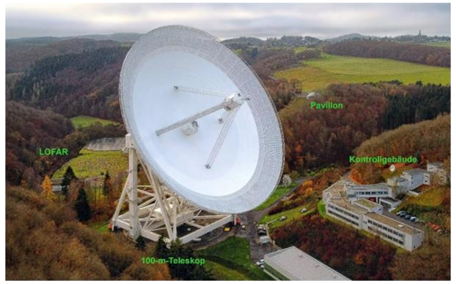
GIFDS

GNSS

Beacon

Ionosonde (IAP)

Radiotelescope Effelsberg (MPIfR)



LOFAR in Potsdam (AIP)

OSWIN (IAP)

Teide Observatory on Tenerife (KIS, AIP, MPS)

Radio telescopes: Neustrelitz, Effelsberg, Stockert, Wetzell

Solar telescope: Tenerife

LOFAR: Effelsberg, Tautenburg, Garching, Potsdam, Jülich, Norderstedt

Ionosonde: Kühlungsborn

MST radars: MAARSY (Andøya), OSWIN (Kühlungsborn)

Specular meteor radars:
- **Monostatic meteor radars:** Juliusruh (32.55 MHz), Collm (36.2 MHz)
- **MMARIA multi-frequency receiving station** Neustrelitz, Potsdam, Juliusruh, Kühlungsbor Straumen,
- **SIMONe:** Santa Cruz, Peru

MF radars: Juliusruh, Andenes, Saura

indirect phase height measurements: Juliusruh, Collm