Recent ELF Studies in Cracow

Two bands: 0.03-300 Hz and 0.03 Hz – 1000 Hz

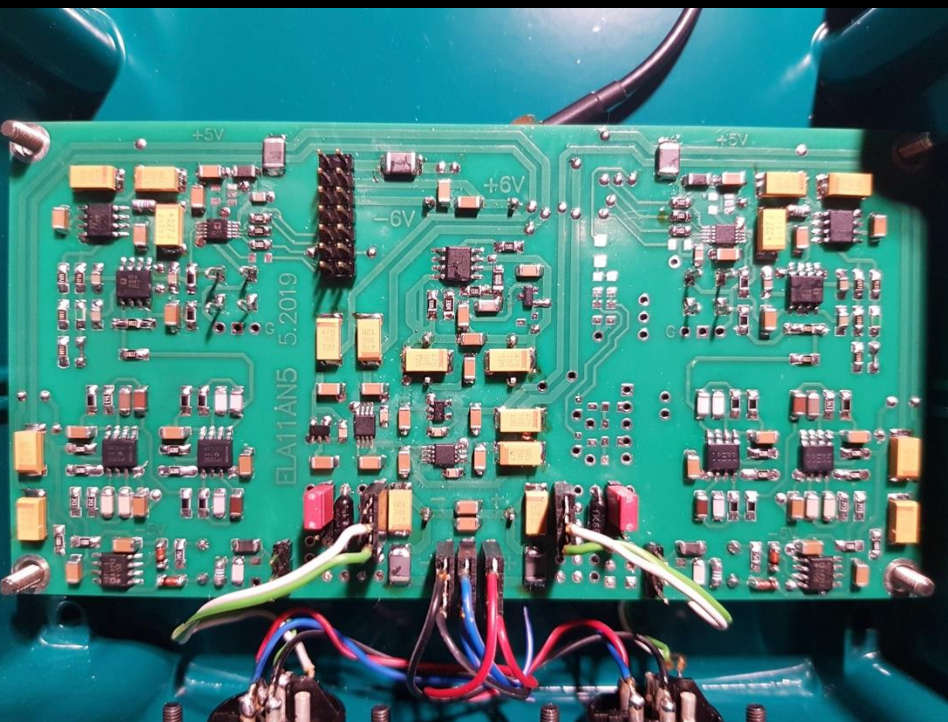
J. Kubisz, Z. Nieckarz, A. Michalec, M. Ostrowski, et al.

Jagiellonian University
Astronomical Observatory & Institute of Physics

J. Młynarczyk, A. Kułak

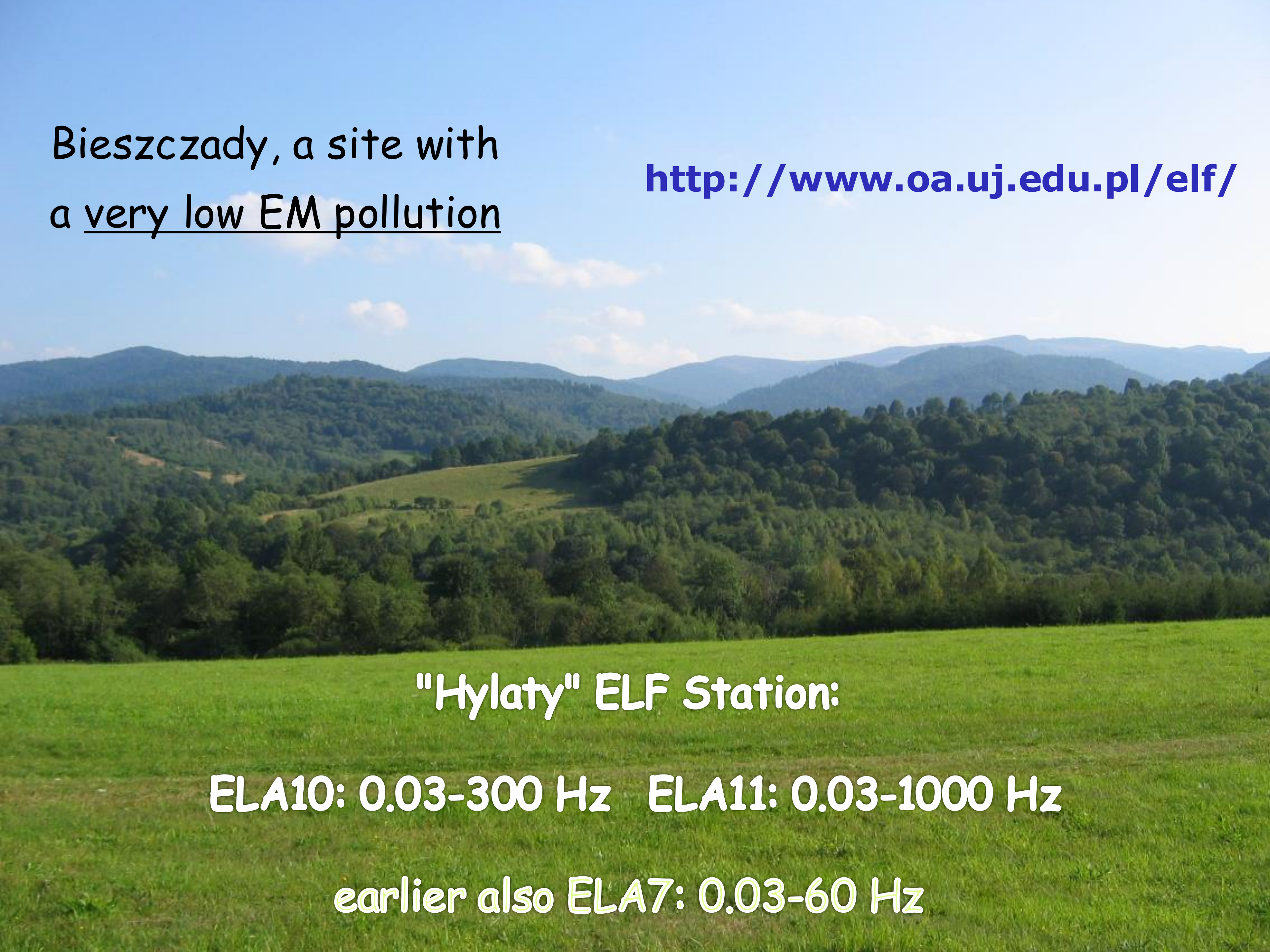
AGH University of Science and Technology
Department of Electronics

a long way since 1992



Magnetic sensors manufactured
in Astronomical Observatory

collaboration with Dept. of Electronics, AGH UST



Bieszczady, a site with
a very low EM pollution

http://www.oa.uj.edu.pl/elf/

"Hylaty" ELF Station:

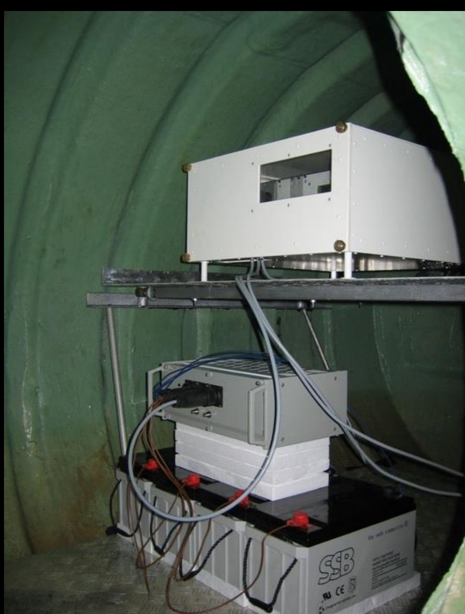
ELA10: 0.03-300 Hz   ELA11: 0.03-1000 Hz

earlier also ELA7: 0.03-60 Hz

A roof cover above a container with electronics

Underground antenna field

Inside the underground container

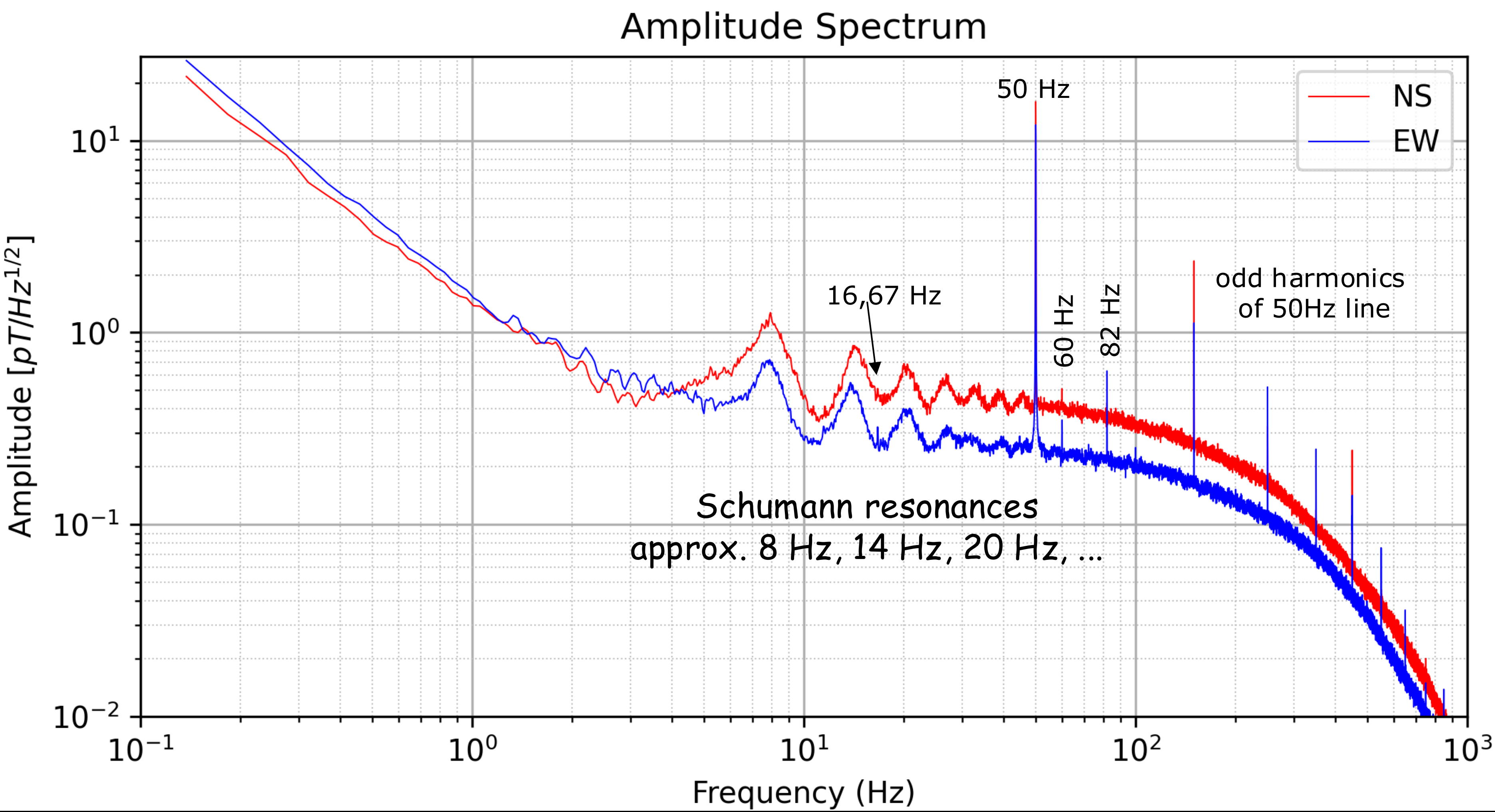


World ELF Radiolocation Array (WERA)

Hylaty - Poland, Hugo – USA, Patagonia - Argentina

ELA11 wave spectrum

3.10.2023 – 3-4 UTC

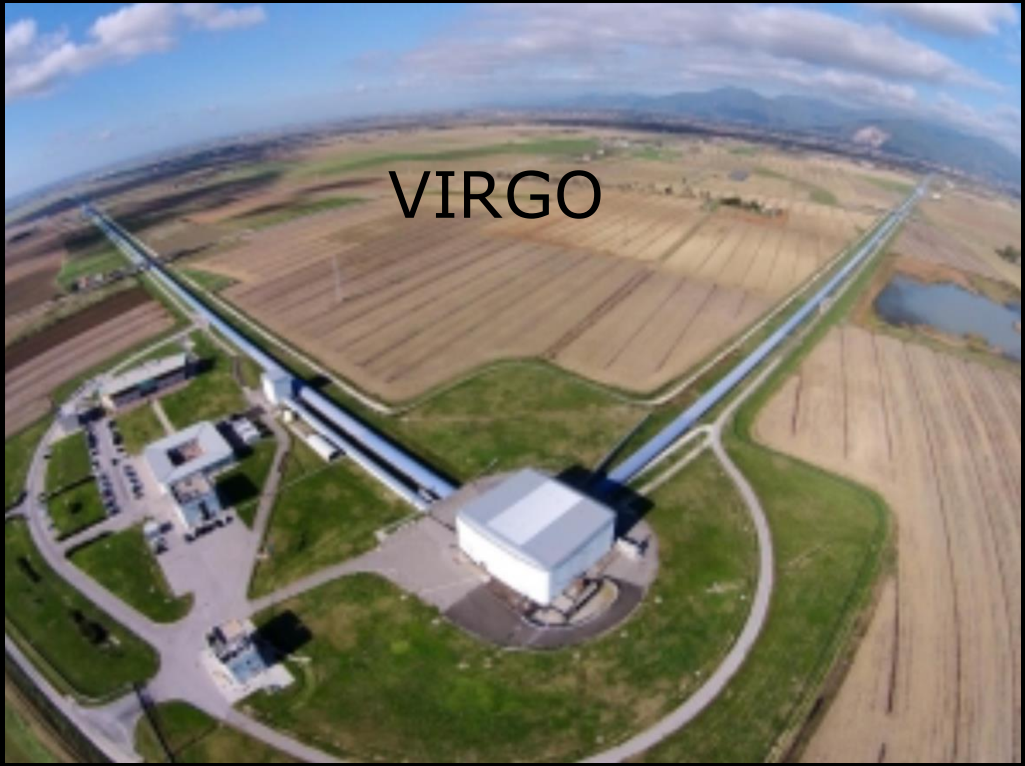


ELF studies supporting

Gravitational Wave detection

Eddy currents

are induced within conductors
by a varying magnetic field



ELF EM waves can penetrate into structures of GW detectors perturbing measurements

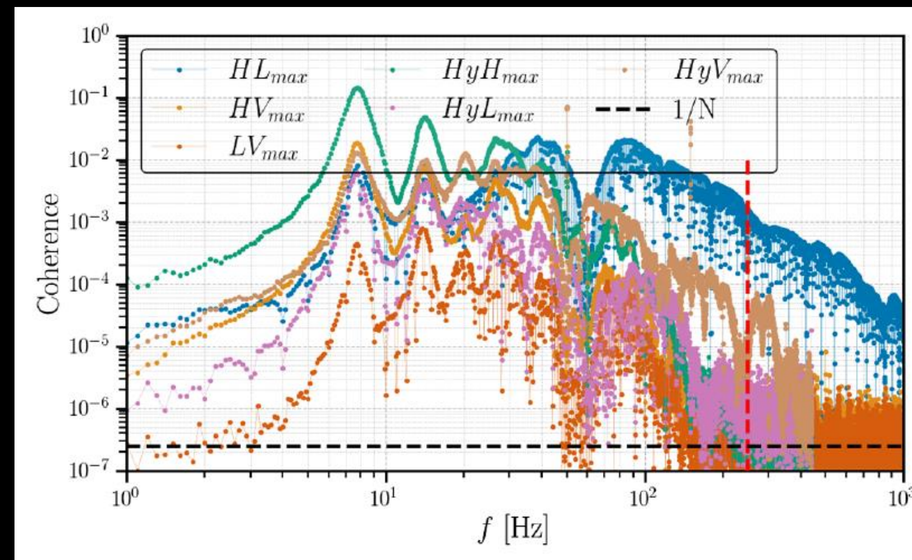
E. Thrane, N. Christensen and R. M. S. Schofield

"Correlated magnetic noise in global networks of gravitational-wave detectors: Observations and implications", PHYS. REV. D (2013)

PHYSICAL REVIEW D **107**, 022004 (2023)

Correlated 1–1000 Hz magnetic field fluctuations from lightning over Earth-scale distances and their impact on gravitational wave searches

Kamiel Janssens,[1,2] Matthew Ball,[3] Robert M. S. Schofield,[3] Nelson Christensen,[2] Raymond Frey,[3] Nick van Remortel,[1] Sharan Banagiri,[4,5] Michael W. Coughlin,[4] Anamaria Effler,[6] Mark Gołkowski,[7] Jerzy Kubisz,[8] and Michał Ostrowski[8]



Third observing run by LIGO and Virgo was free of an impact from correlated magnetic fluctuations,

but future runs could be affected ! .

Thus, future detector design should consider reducing magnetic coupling

Recent work:

Propagation of ELF EM impulses

Ionosphere – refraction, non-uniformities

- solar UV and X-ray emissions
- solar flares

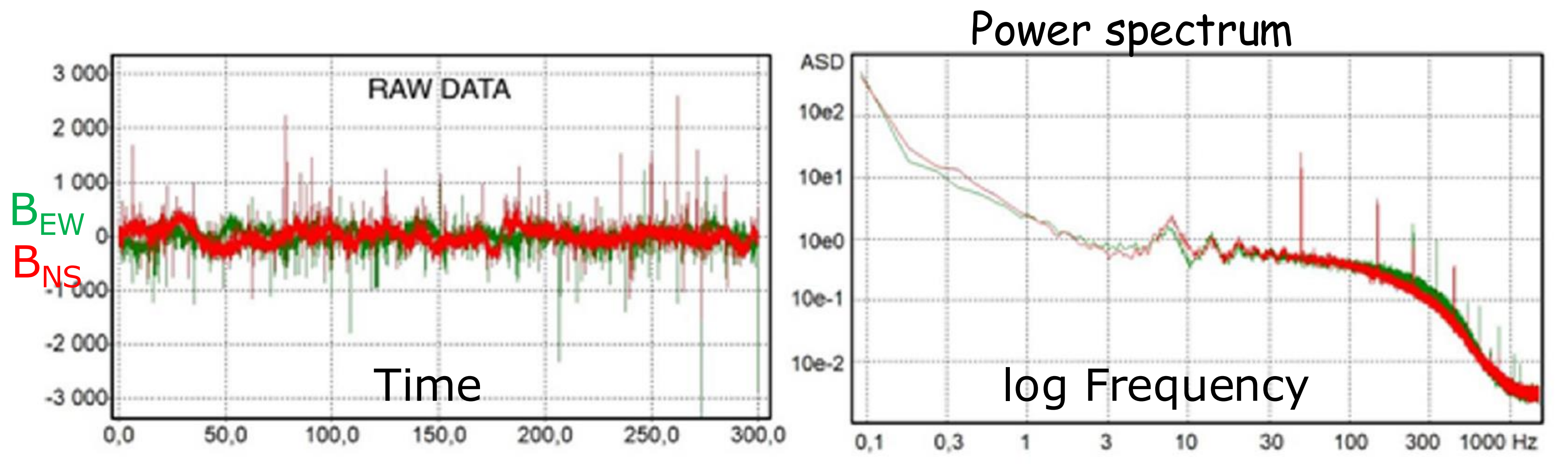
also:

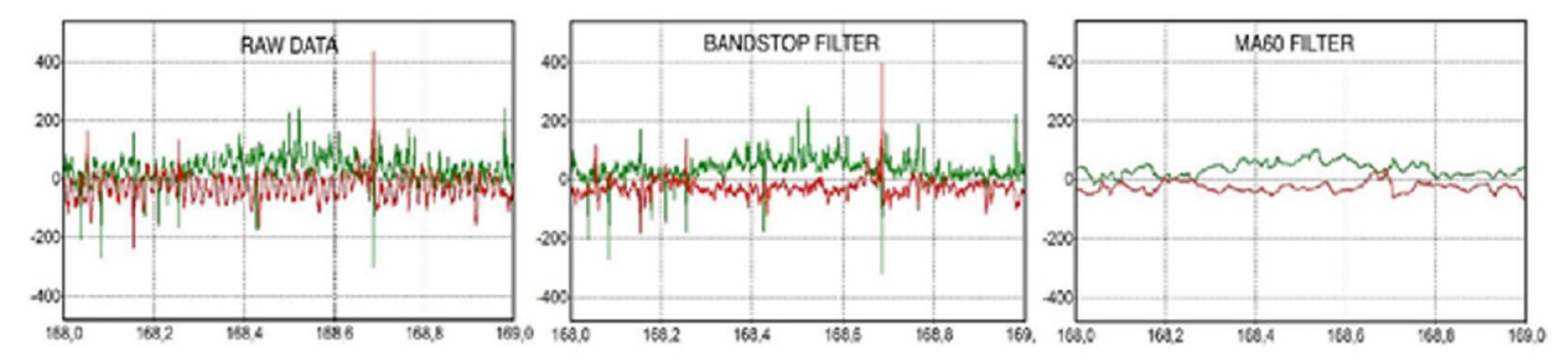
EM signals from volcanos

Space Weather effects
(energetic particles)

EM effects from earthquakes (?)

Data from the ELA11 sensor





JGR Atmospheres

2024

Research Article | Full Access

New Method for Determining Azimuths of ELF Signals Associated With the Global Thunderstorm Activity and the Hunga Tonga Volcano Eruption

J. Kubisz, M. Gołkowski, J. Mlynarczyk, M. Ostrowski, A. Michalec

First published: 12 February 2024 | https://doi.org/10.1029/2023JD040318 | Citations: 1

Parameters:

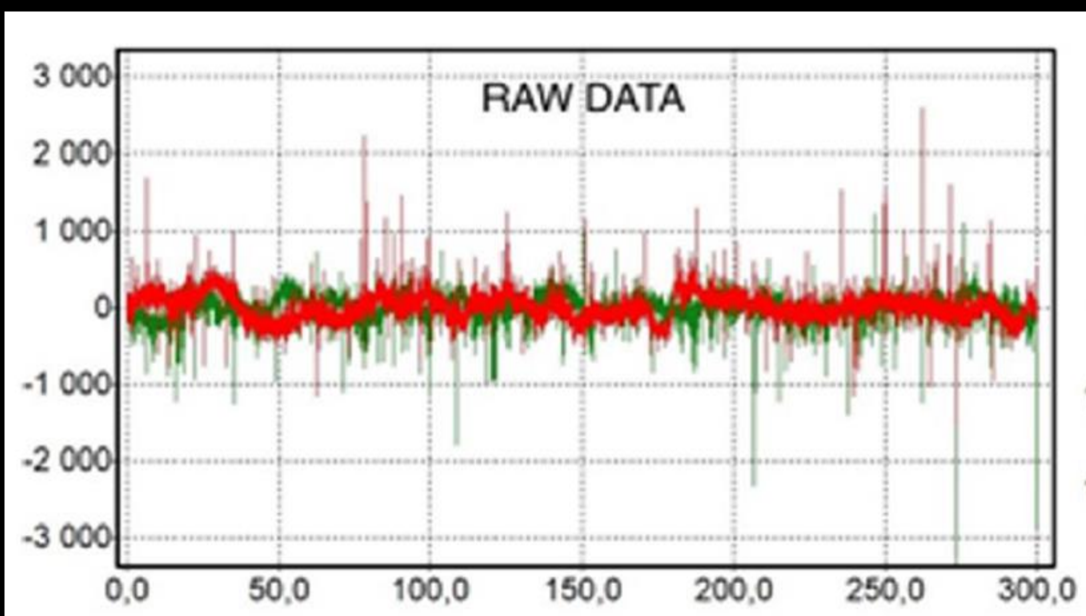
n

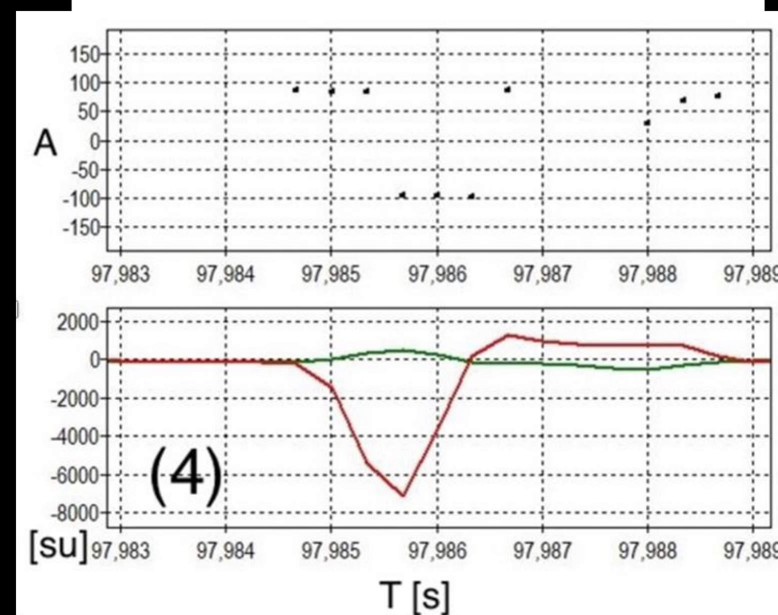
r_{min}

r_{max}

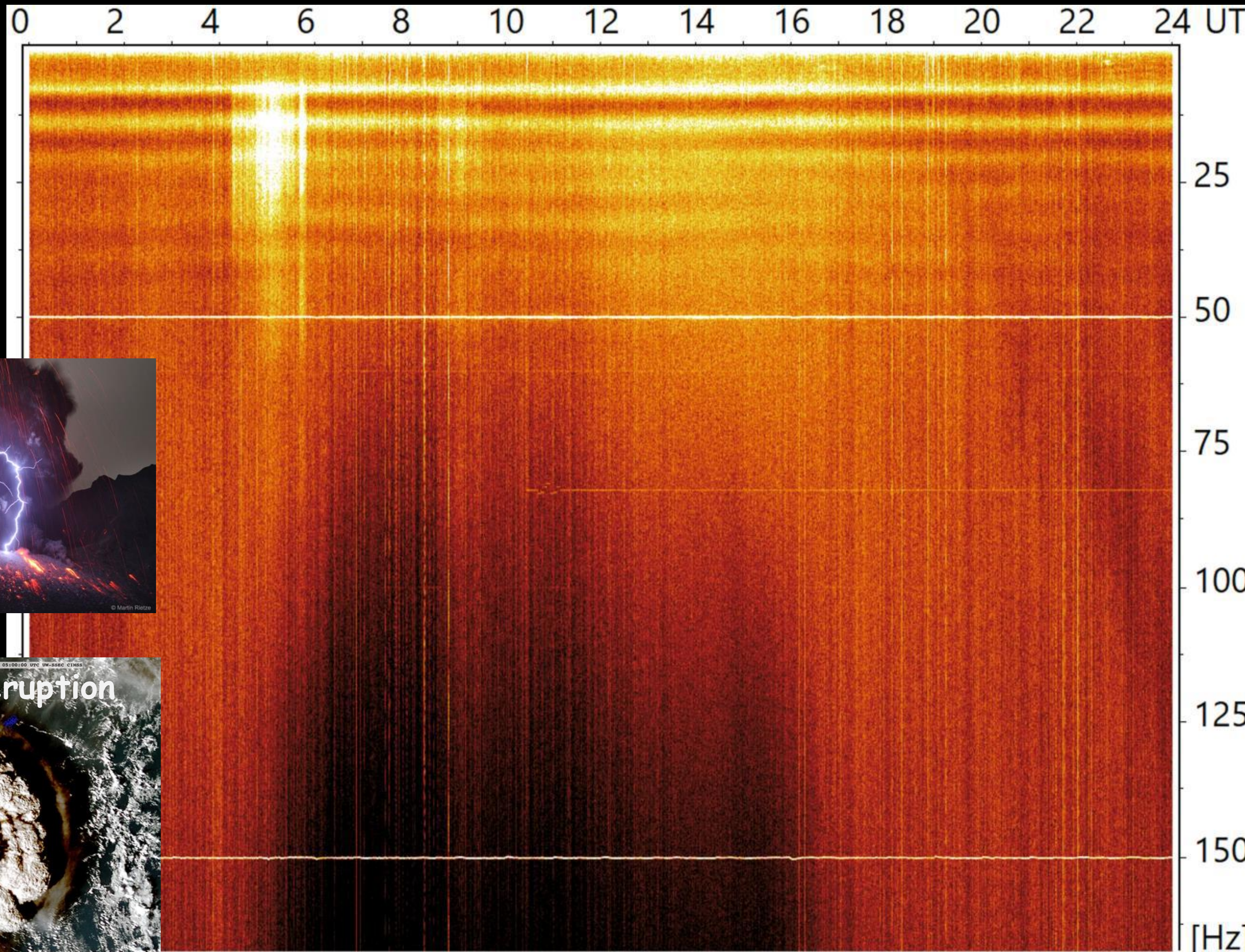
$$\Delta B_{(i,\,n)} = B_{(i+n)} - B_{(i)}$$

$$\tan\left(A_{(i,\,n)}\right) = -\Delta B_{NS(i,\,n)} / \Delta B_{EW(i,\,n)}$$

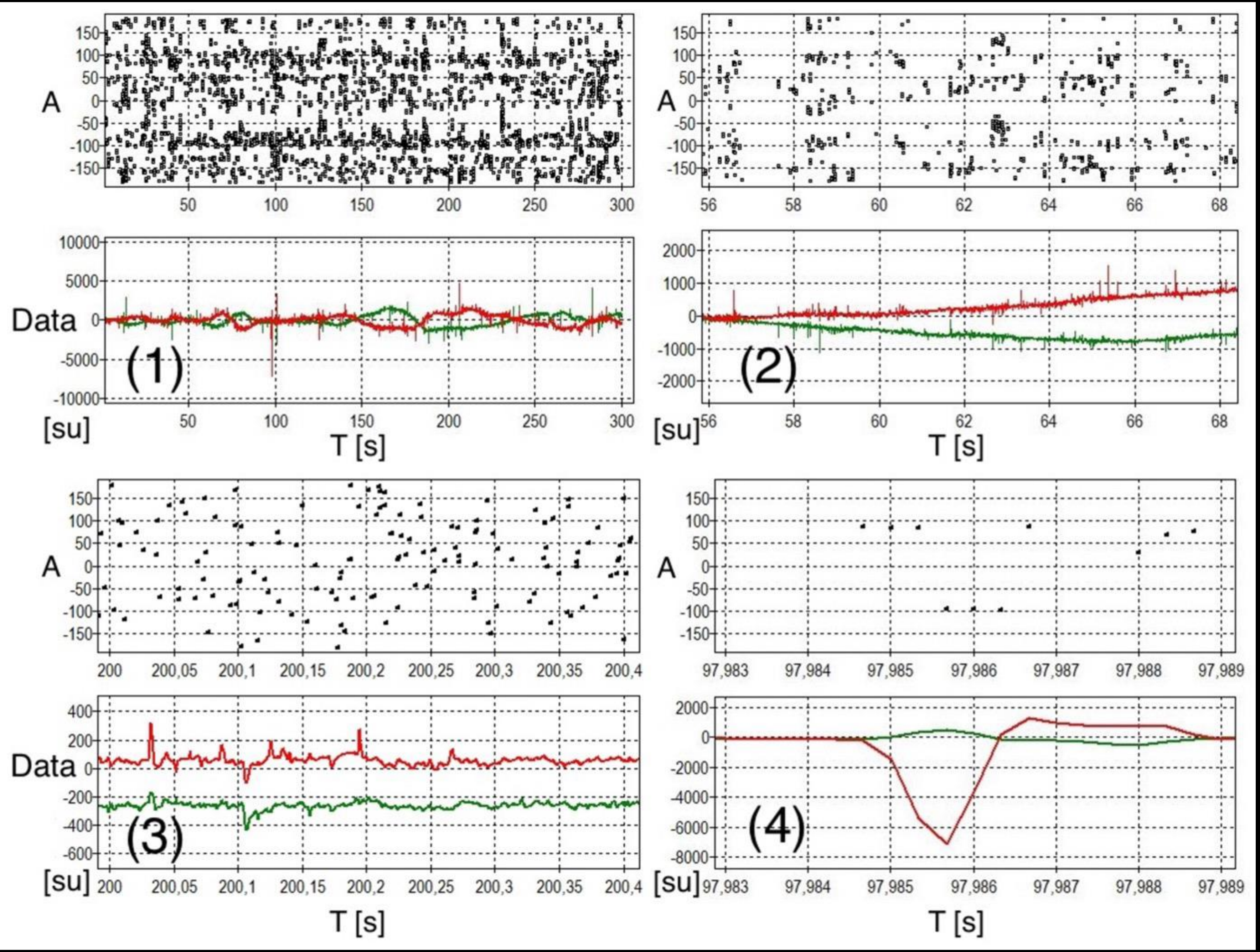




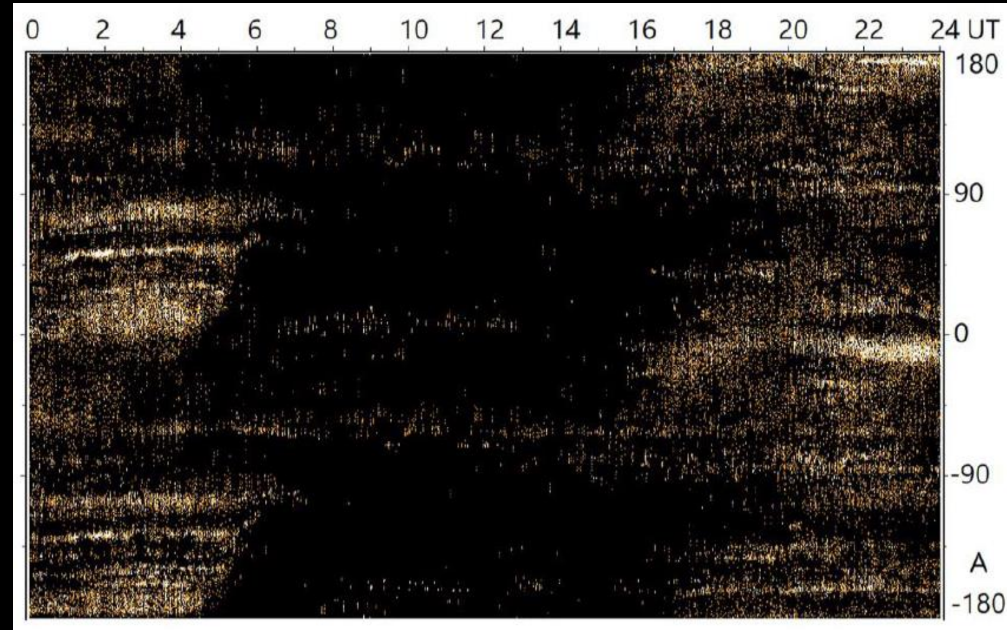
ELF signal power spectrum in the EW antenna on 15 January 2022



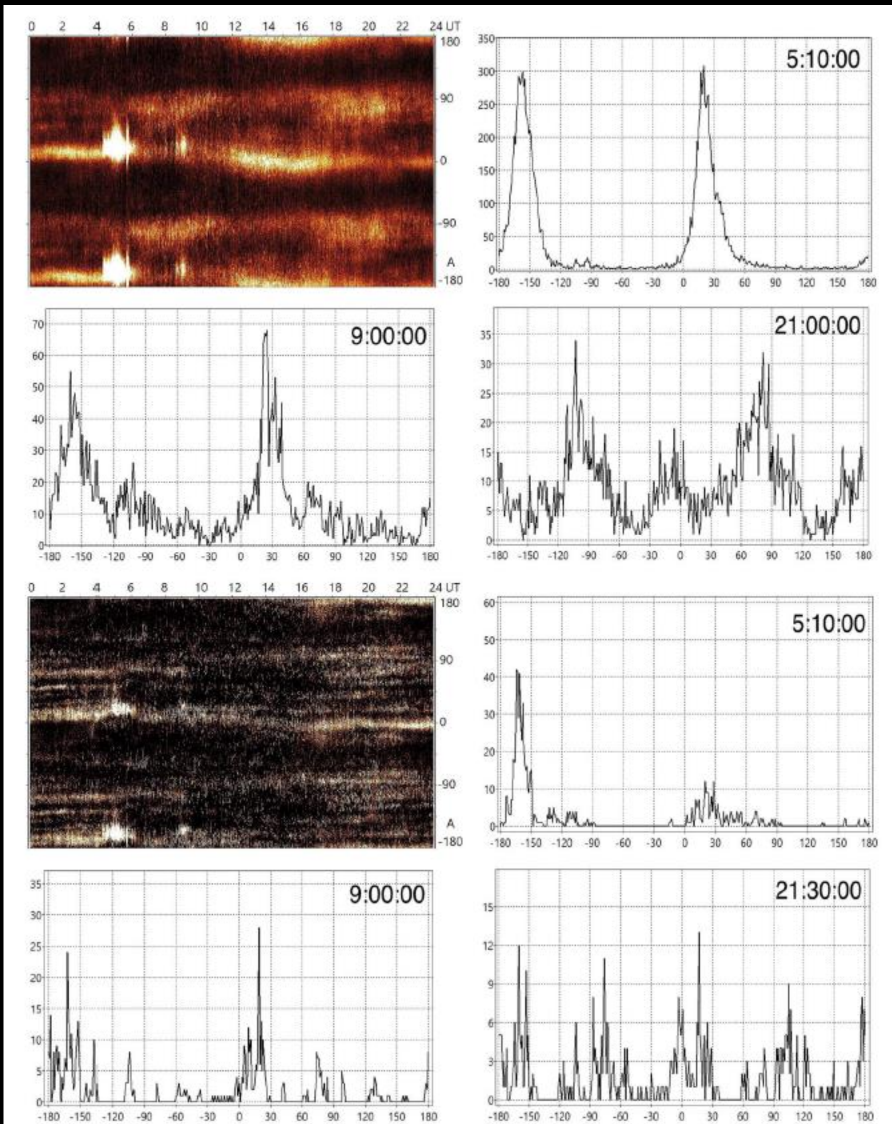
Measurements of ELF waves' azimuths

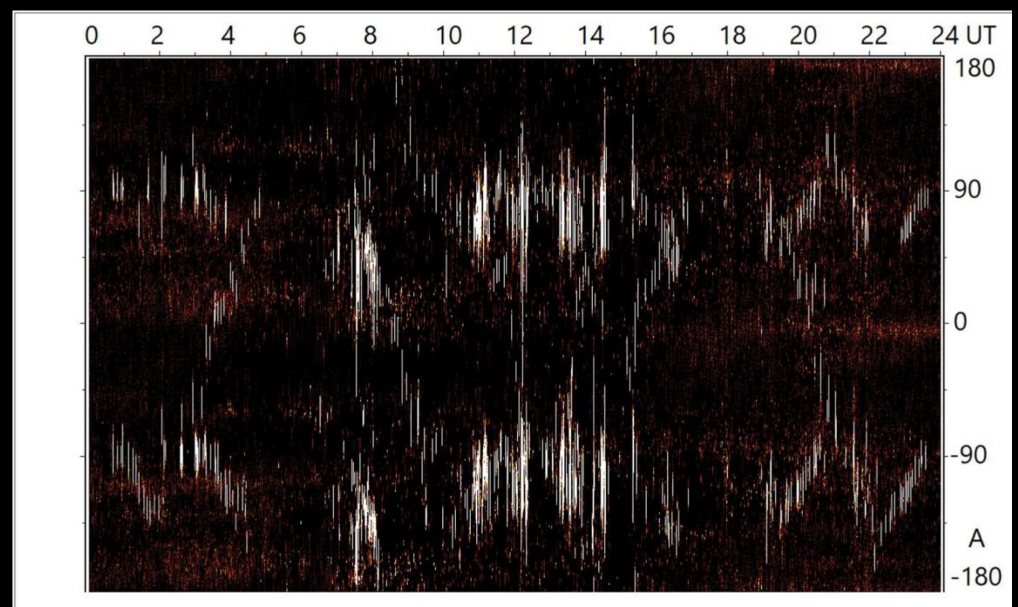


$$\tan\left(A_{(i,\,n)}\right) = -\Delta B_{NS(i,\,n)}/\Delta B_{EW(i,\,n)}$$



n=3000 (Δt =1 s)





n=1 (Δt =1/3 ms)

Ionospheric effects

Refraction of ELF electromagnetic waves by the ionospheric gradients at the day/night terminator measured at the Hylaty station

M. Ostrowski[1], M. Gołkowski[2], J. Kubisz[1], A. Michalec[1], J. Mlynarczyk[3], Z. Nieckarz[4]

JGR Space Physics **2024**

Effects of a Solar Flare on Global Propagation of Extremely Low Frequency Waves

M. Ostrowski[1], M. Gołkowski[2], J. Kubisz[1], Z. Nieckarz[3], A. Michalec[1], J. Mlynarczyk[4], J. Lichtenberger[5,6], A. Maxworth[7]

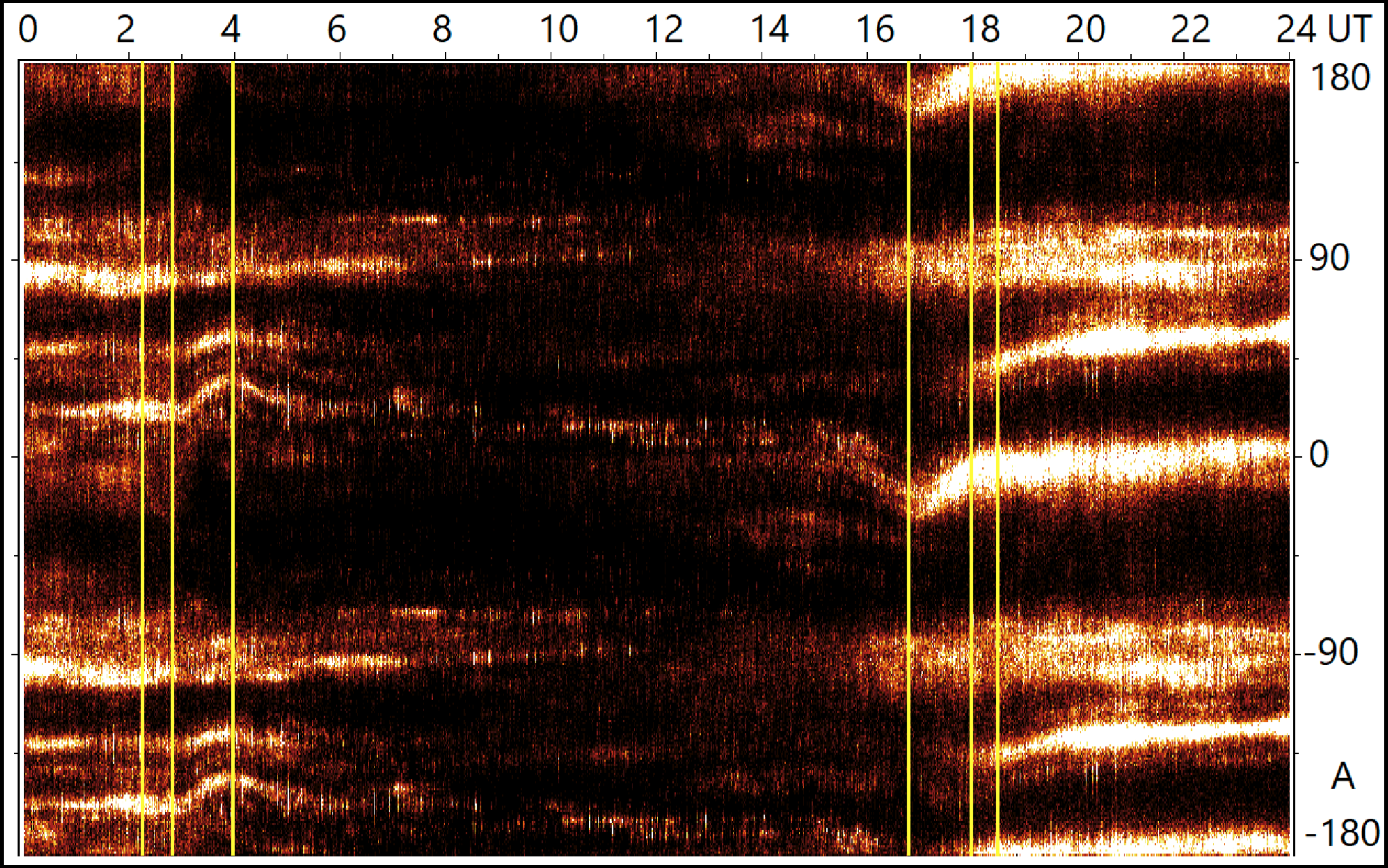
JGR Space Physics **2024**

Monitoring Global Ionospheric Conditions With Electromagnetic Lightning Impulses Registered In Extremely Low Frequency Measurements

Z. Nieckarz[1], M. Gołkowski[2], J. Kubisz[3], M. Ostrowski[3], A. Michalec[3], J. Mlynarczyk[4], J. Lichtenberger[5], A. Maxworth[6]

Radio Science (accepted) **2025**

Refraction of ELF electromagnetic waves by the ionospheric gradients at the day/night terminator

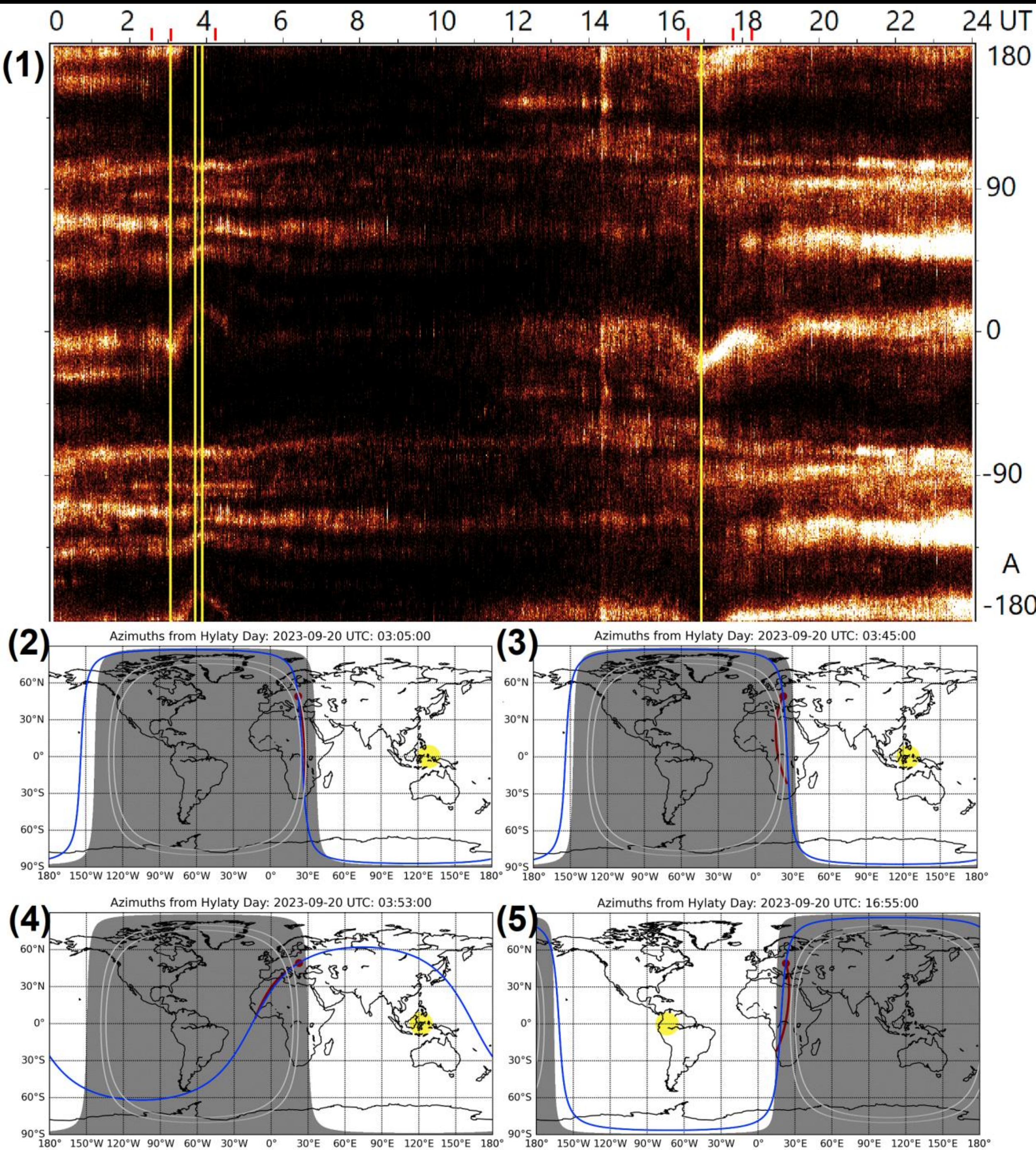


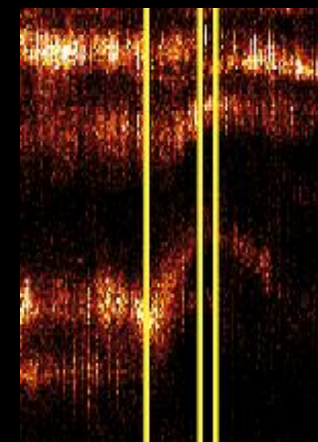
ELF waves' refraction at sunrise and sunset

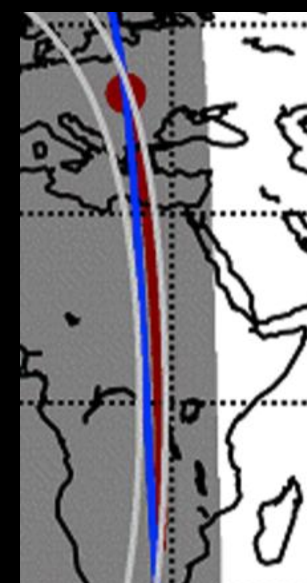
ELF “grey path” propagation

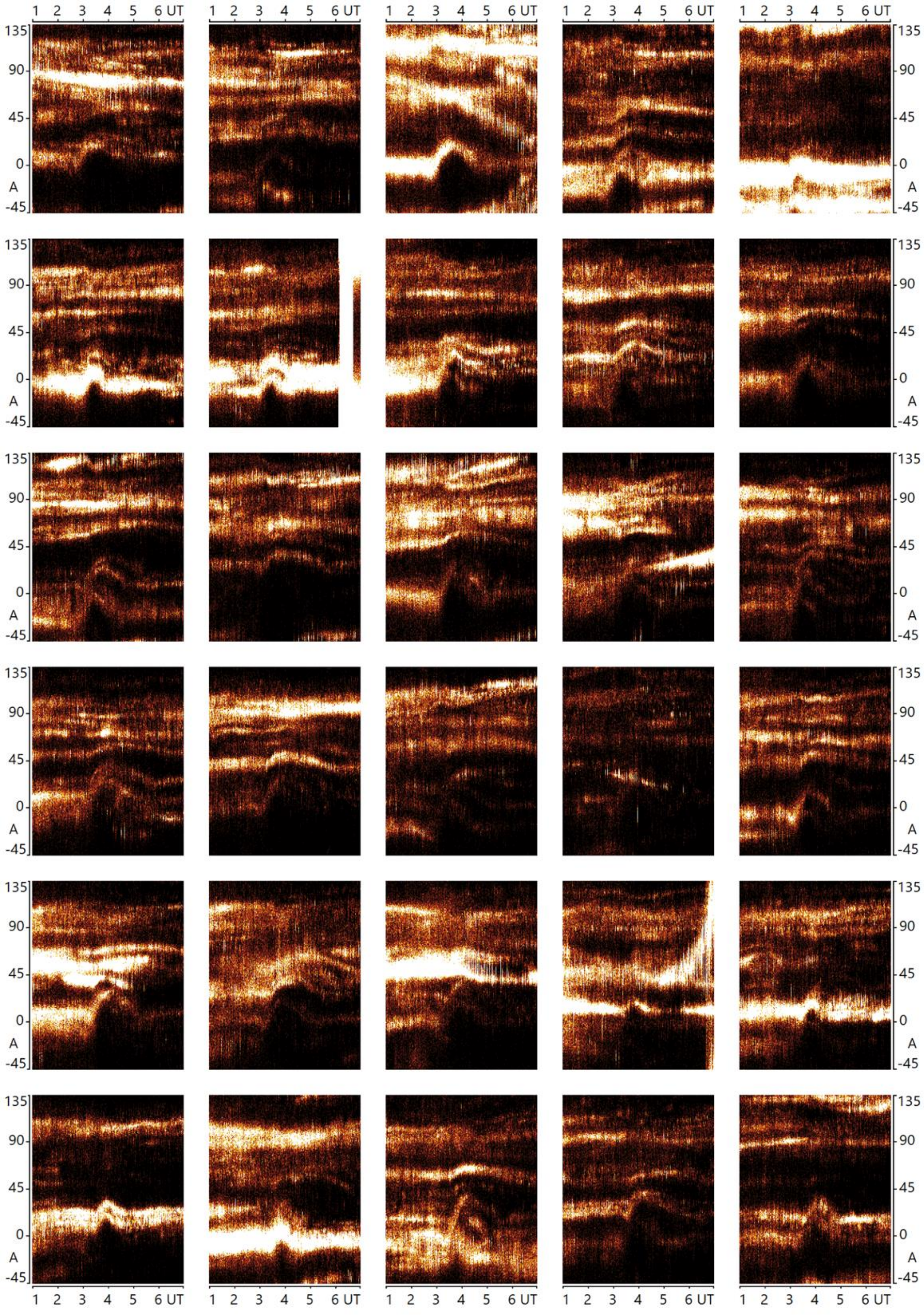
in analogy to

grey line HF radio propagation









Refraction effects

during the morning hours

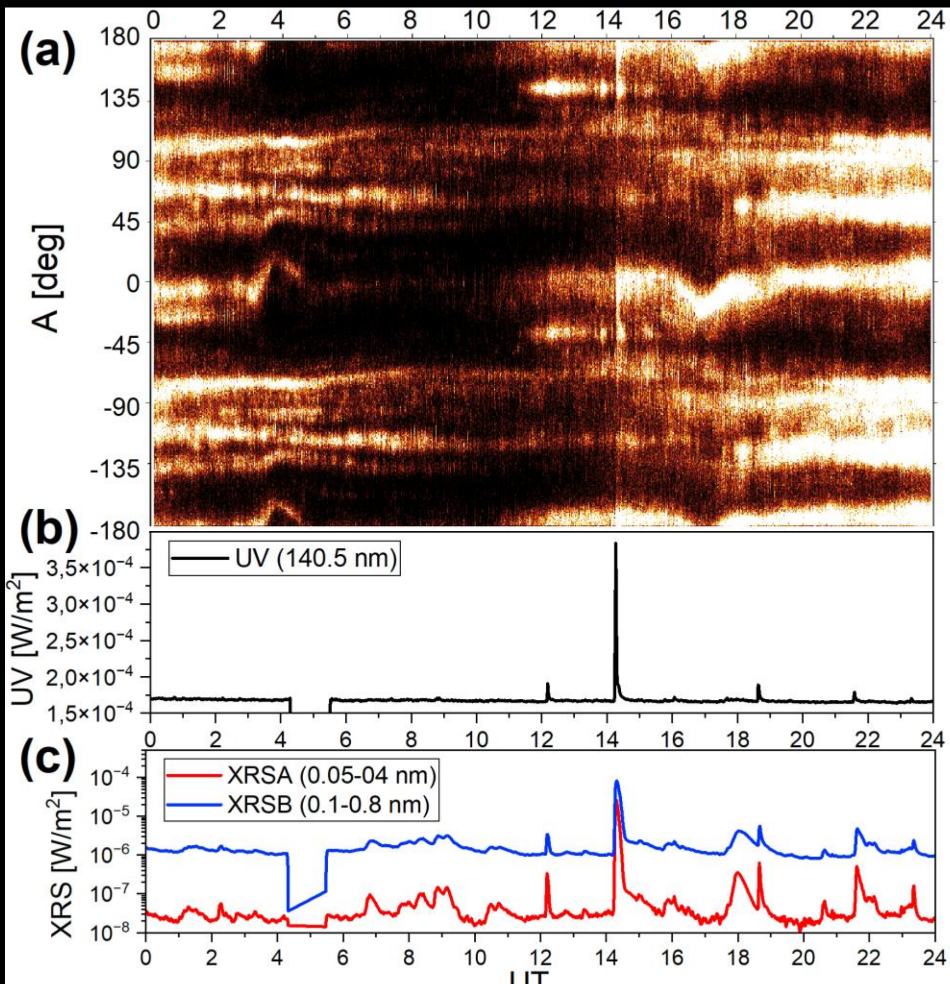
in days of September 2023

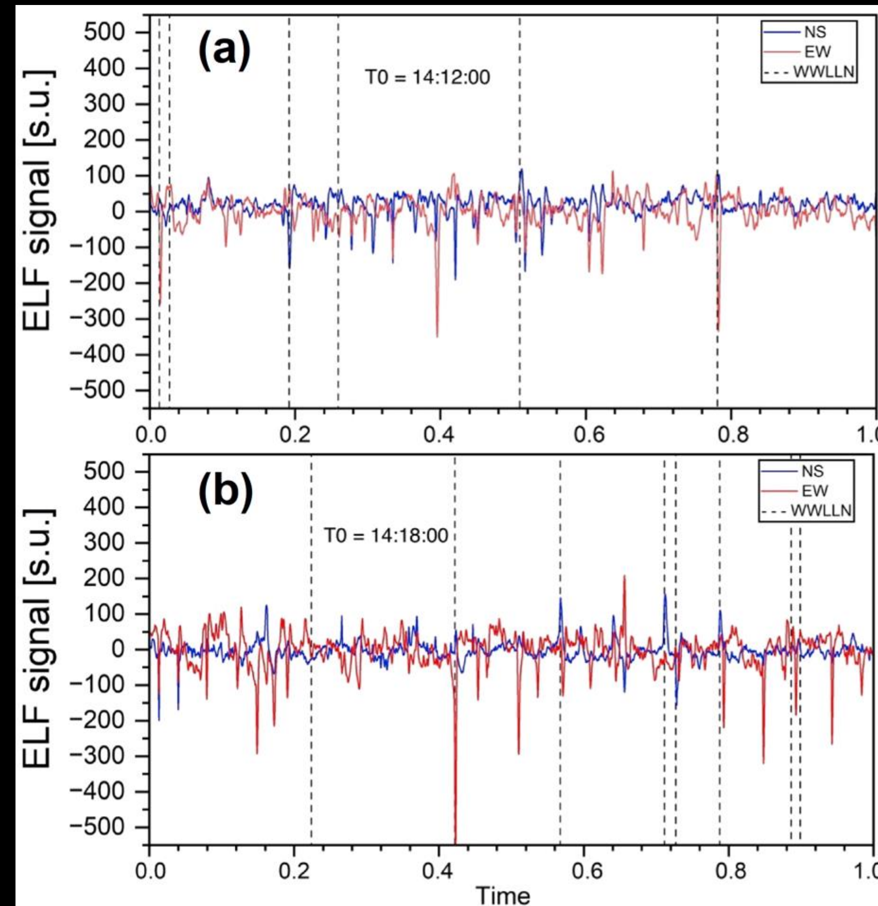
Panels:

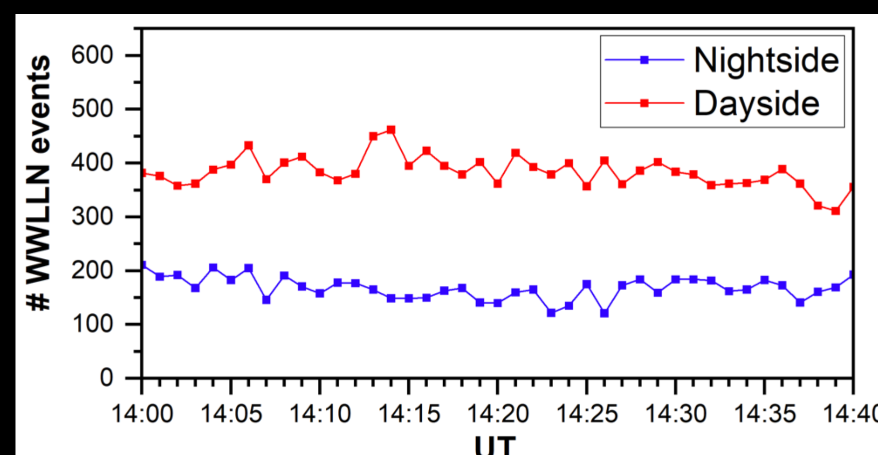
Time 1 – 7 UT

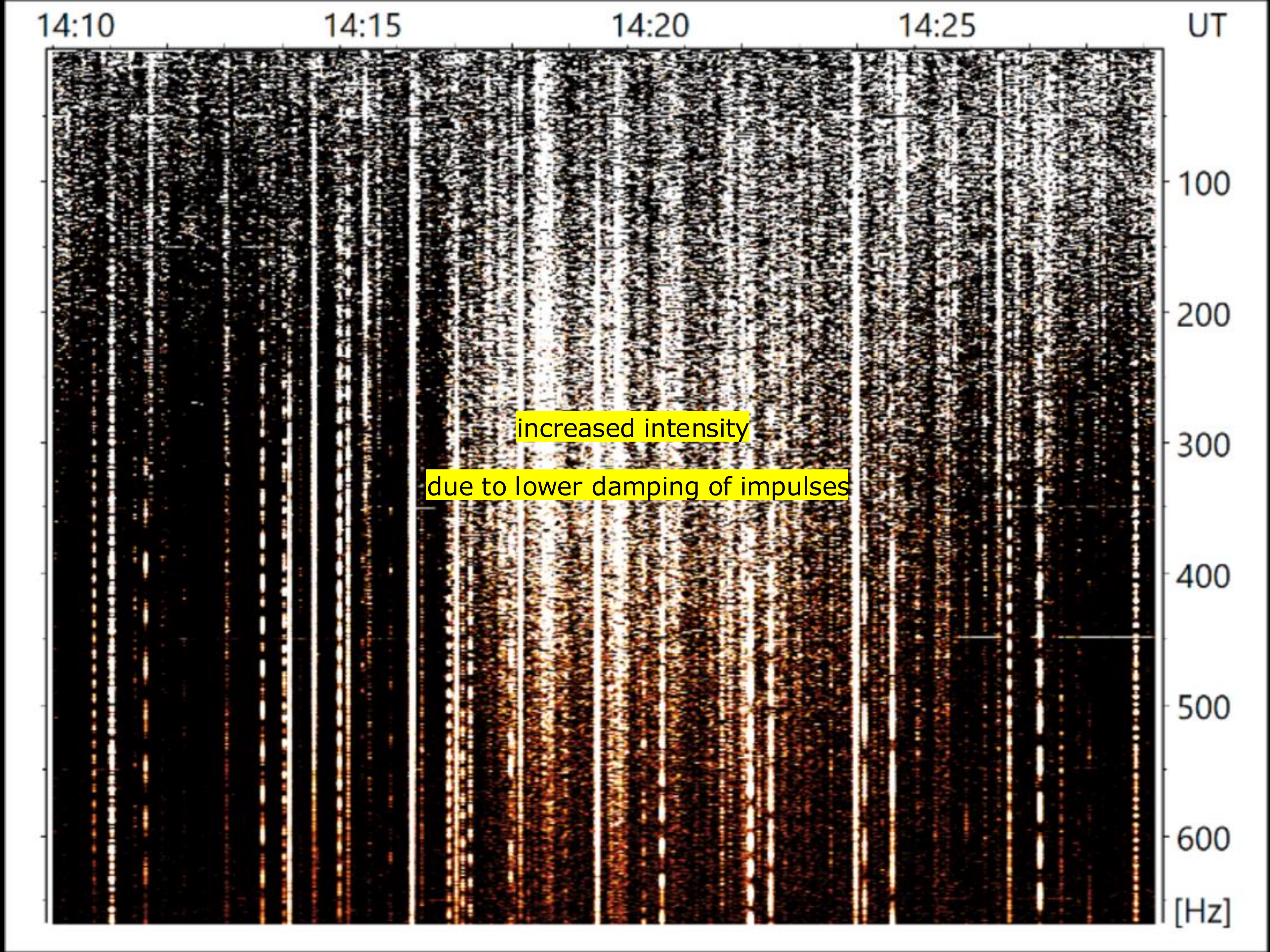
Azimuth -45 - +135 deg

Solar flare M8







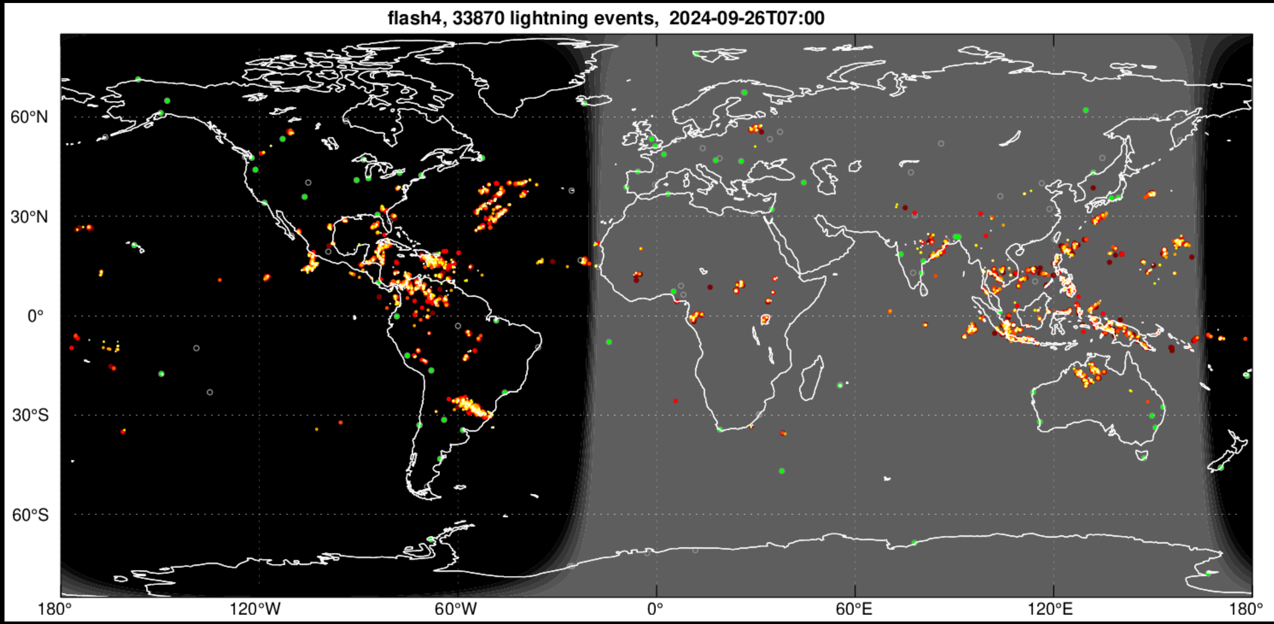


14:10
14:15
14:20
14:25
UT
100
200
300
400
500
600
[Hz]
increased intensity
due to lower damping of impulses

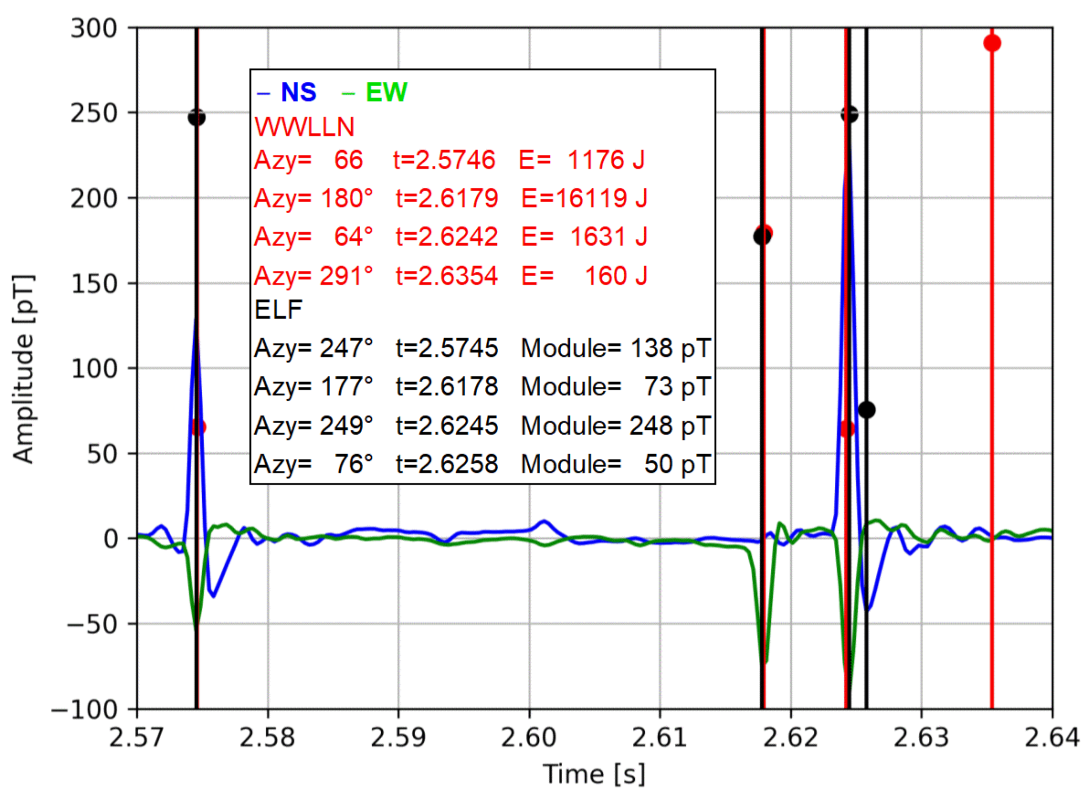
World Wide Lightning Location Network (WWLLN)

VLF (3-30 kHz)

http://wwlln.net



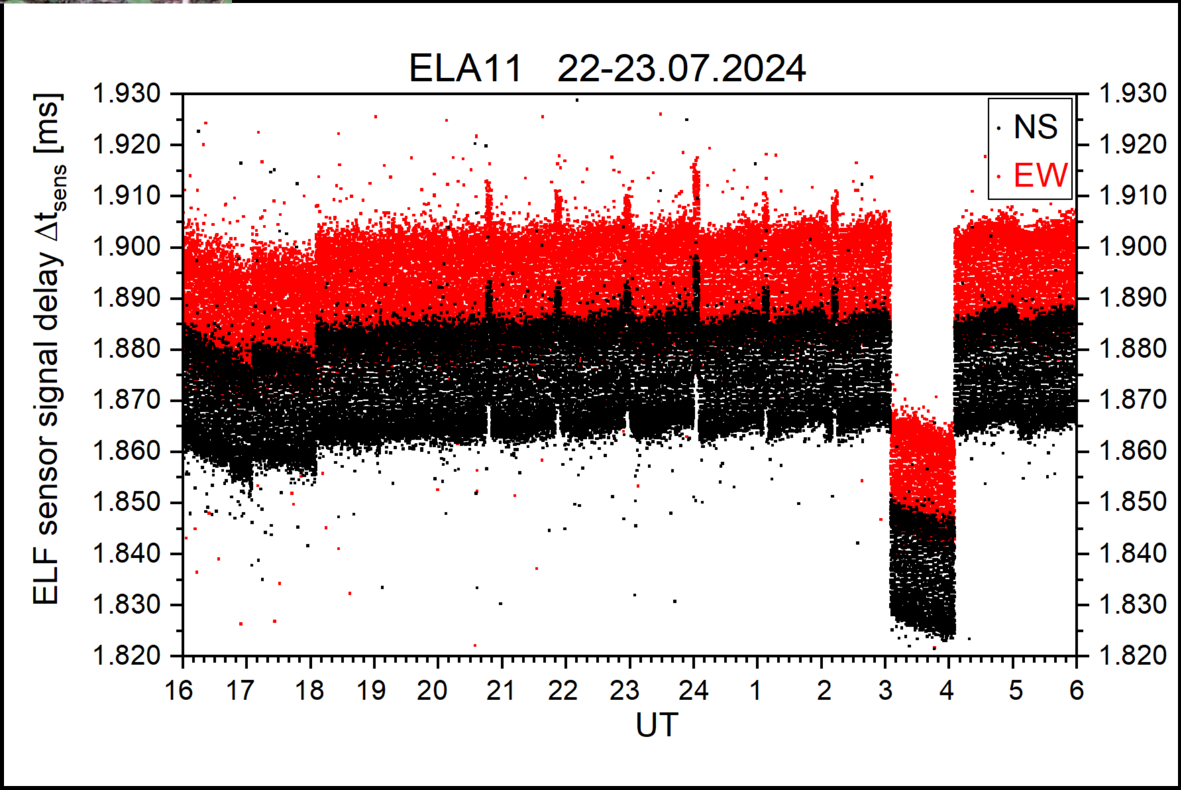
Monitoring Global Ionospheric Conditions with EM Impulses Registered in ELF

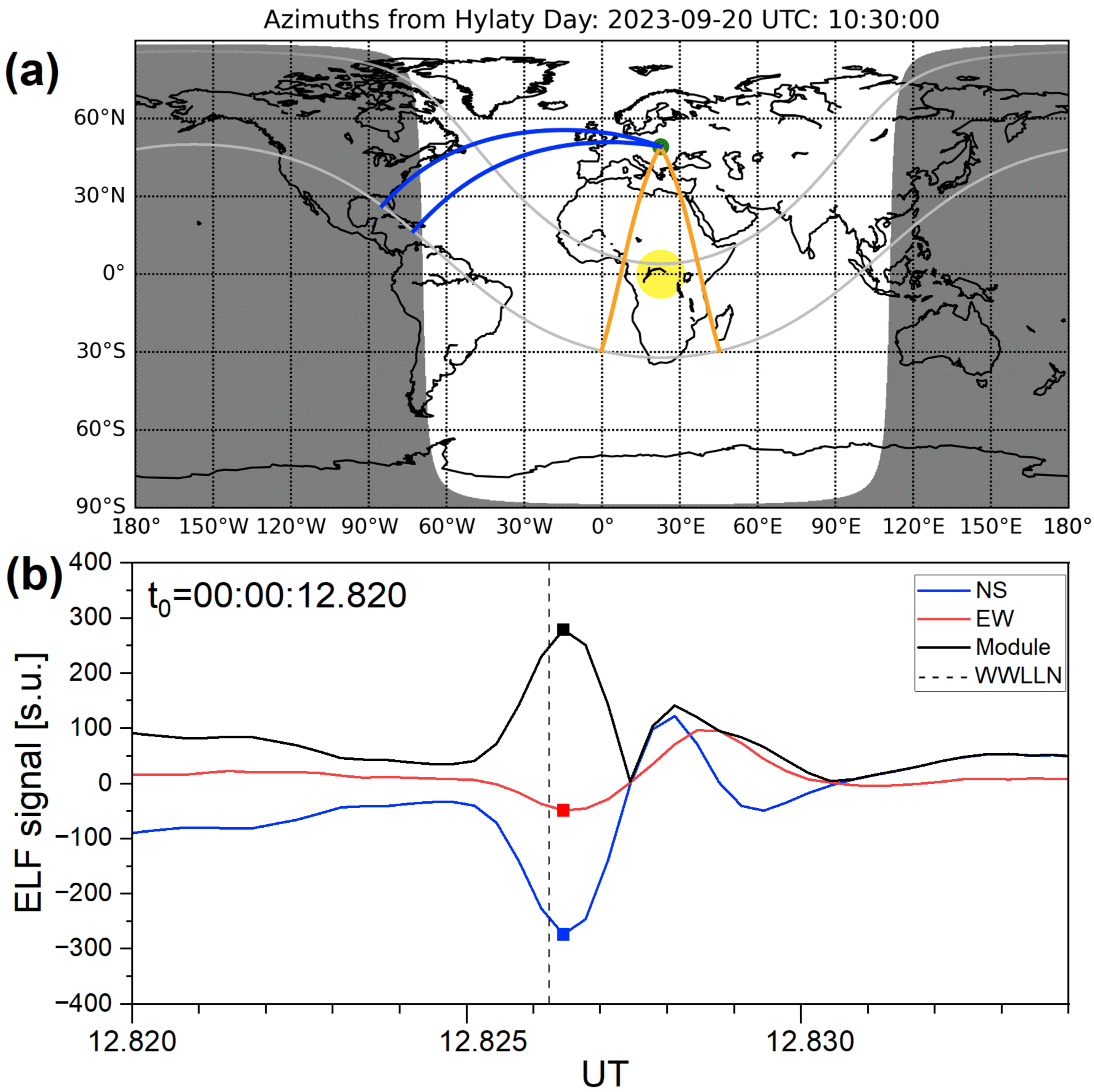


The work led by Zenon Nieckarz

ELA11 timing accuracy better than 0.1 ms

Calibration of a signal delay in ELA11 electronics

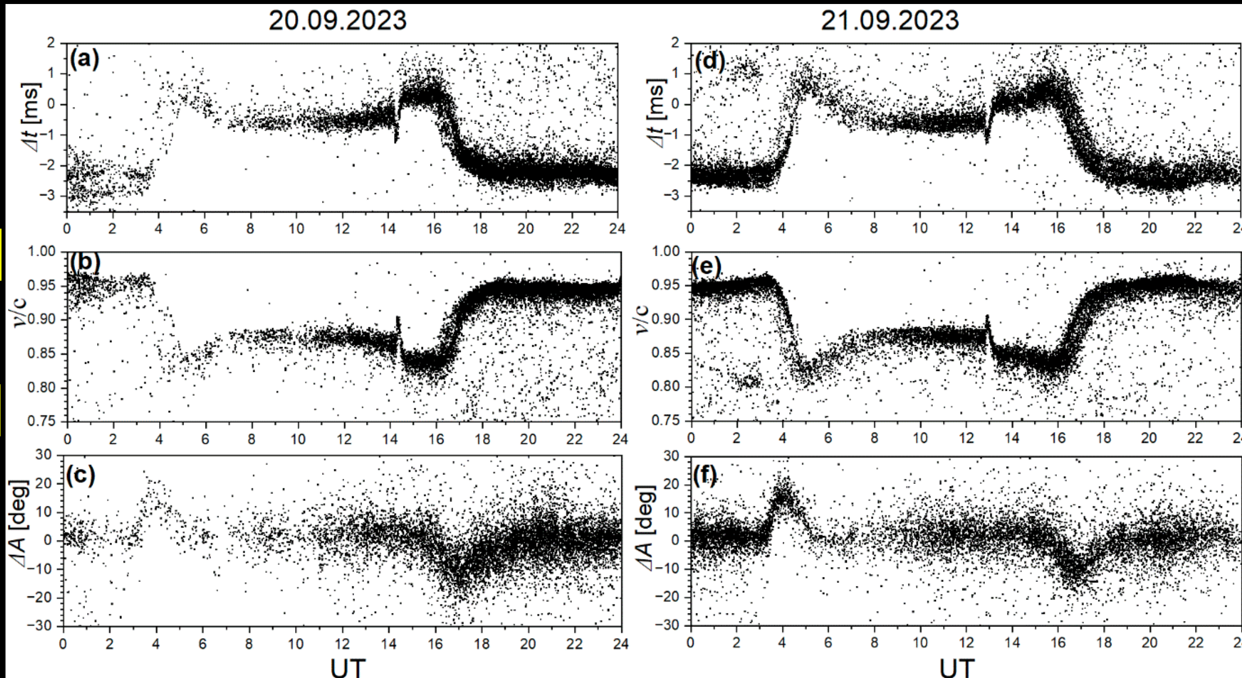



Azimuths from Hylaty Day: 2023-09-20 UTC: 10:30:00
(a)
60°N
30°N
0°
30°S
60°S
90°S
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
180°
(b)
t_0=00:00:12.820
NS
EW
Module
WWLLN
ELF signal [s.u.]
400
300
200
100
0
−100
−200
−300
−400
12.820
12.825
12.830
UT

$v_{test}=0.85c$

1.00

0.75



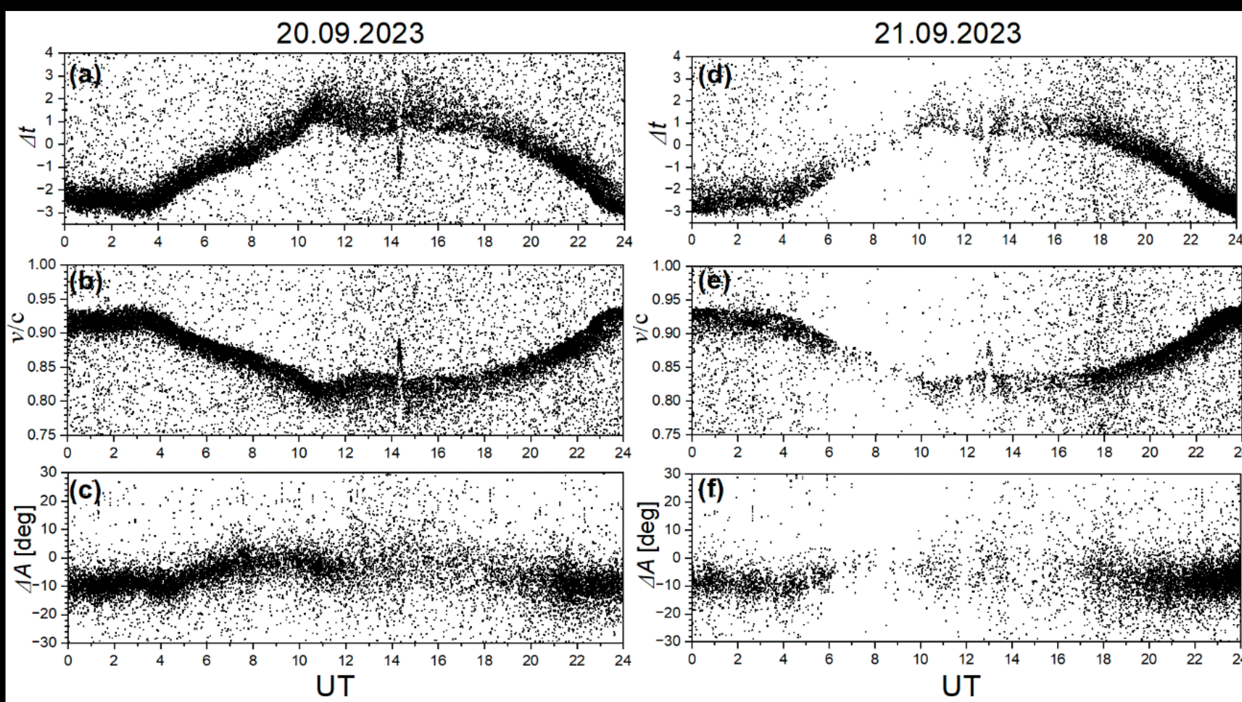
Δt

v/c

ΔA

"African" impulses

vs.



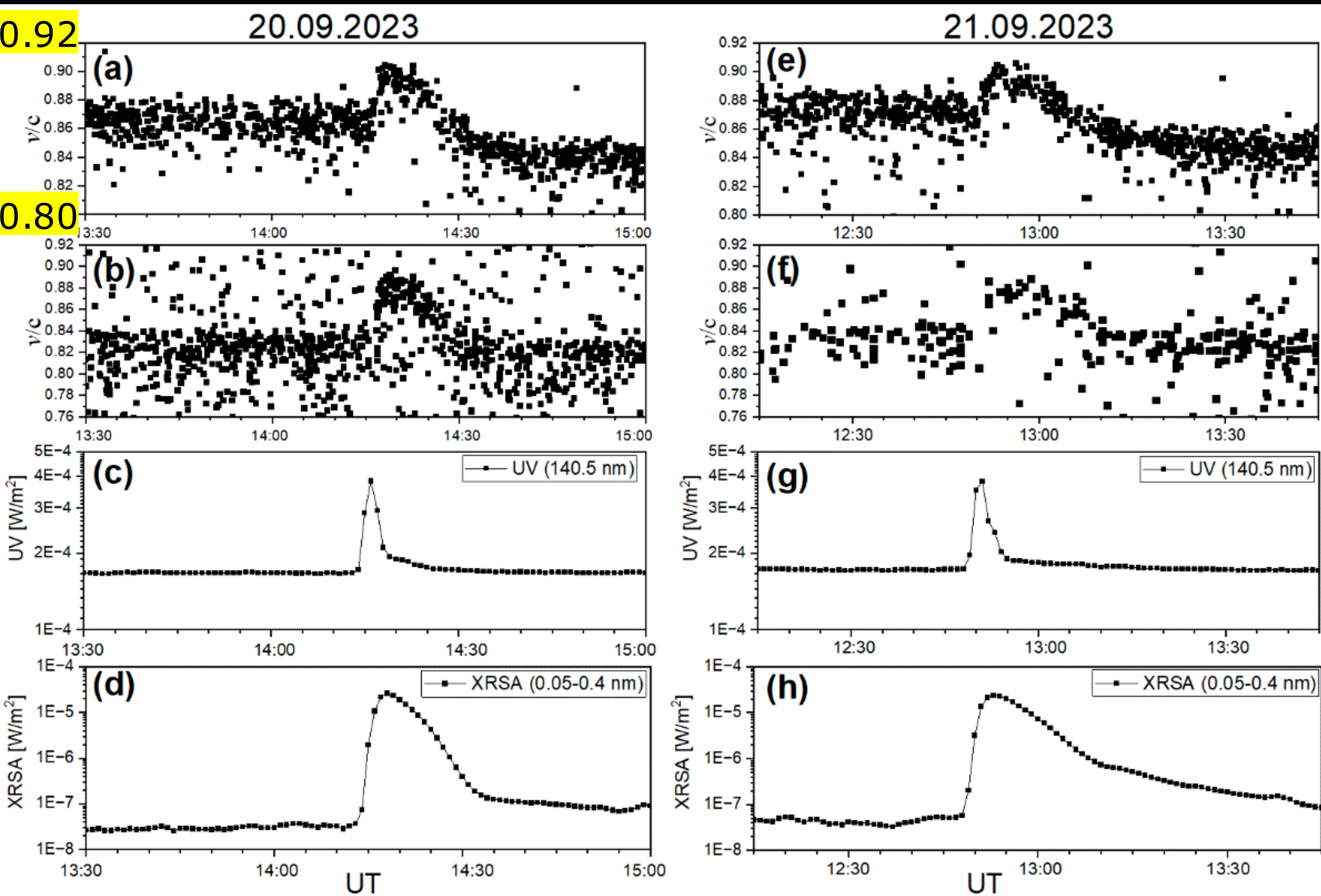
Δt

v/c

ΔA

"American impulses"

SOLAR FLARES (1.5 h data)



Africa

America

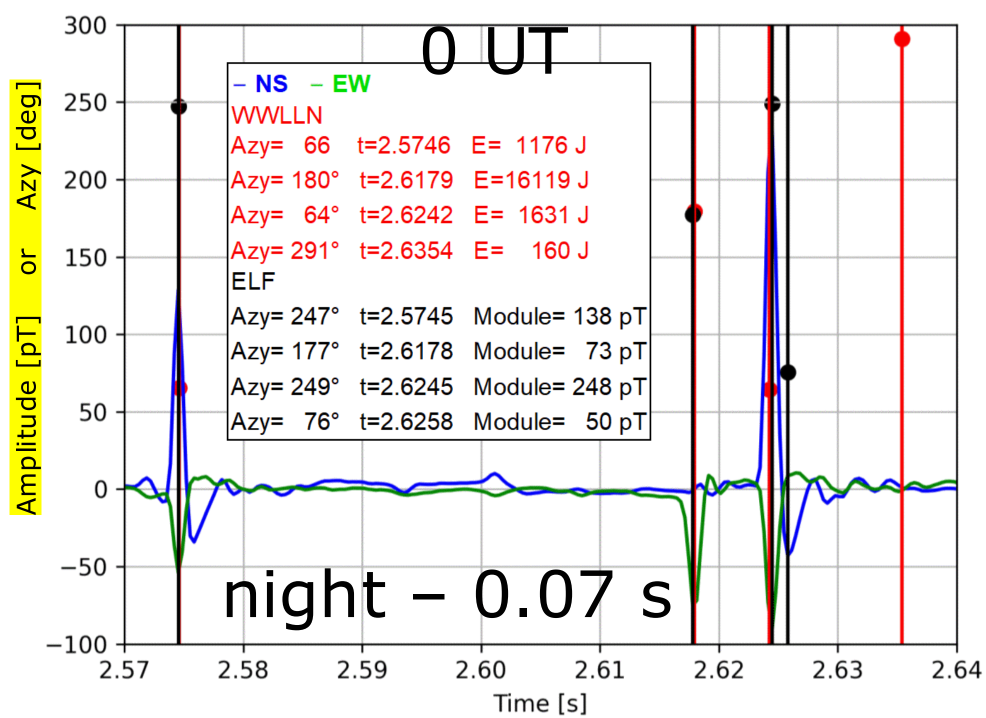
GOES-16:

UV

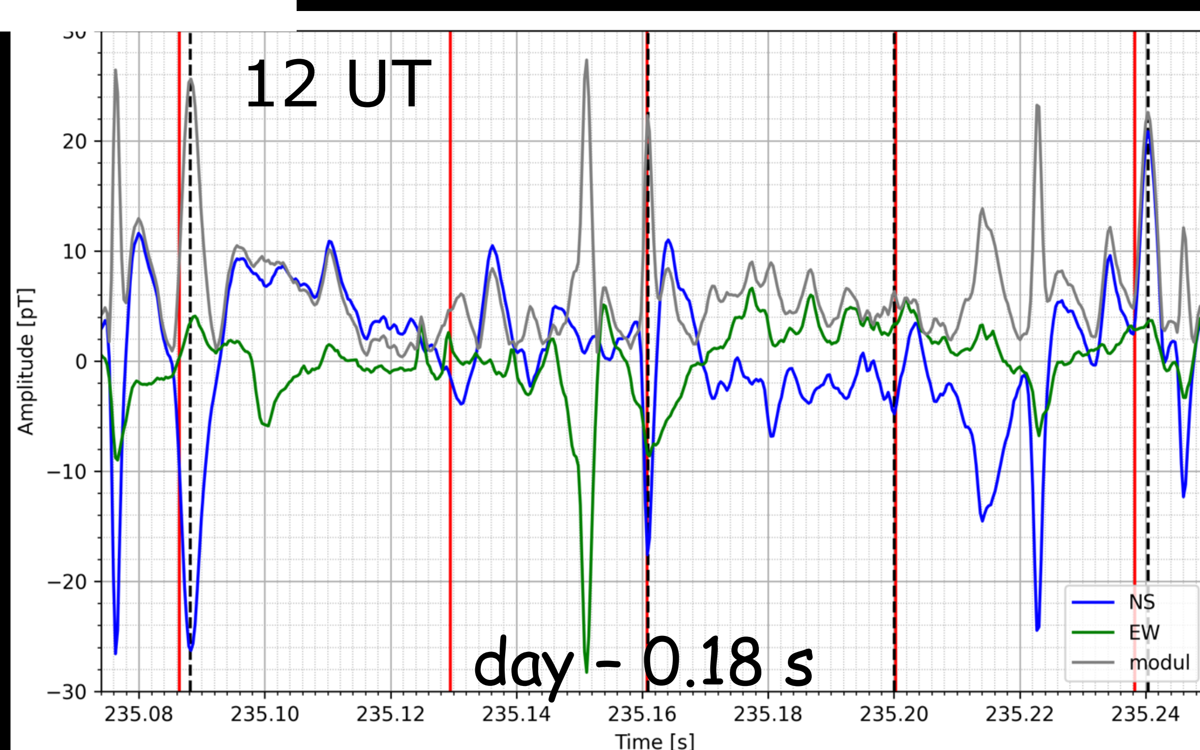
X-ray

Note lower velocities after flares with relatively higher X-ray fluxes

long modification of the low ionosphere structure (?)



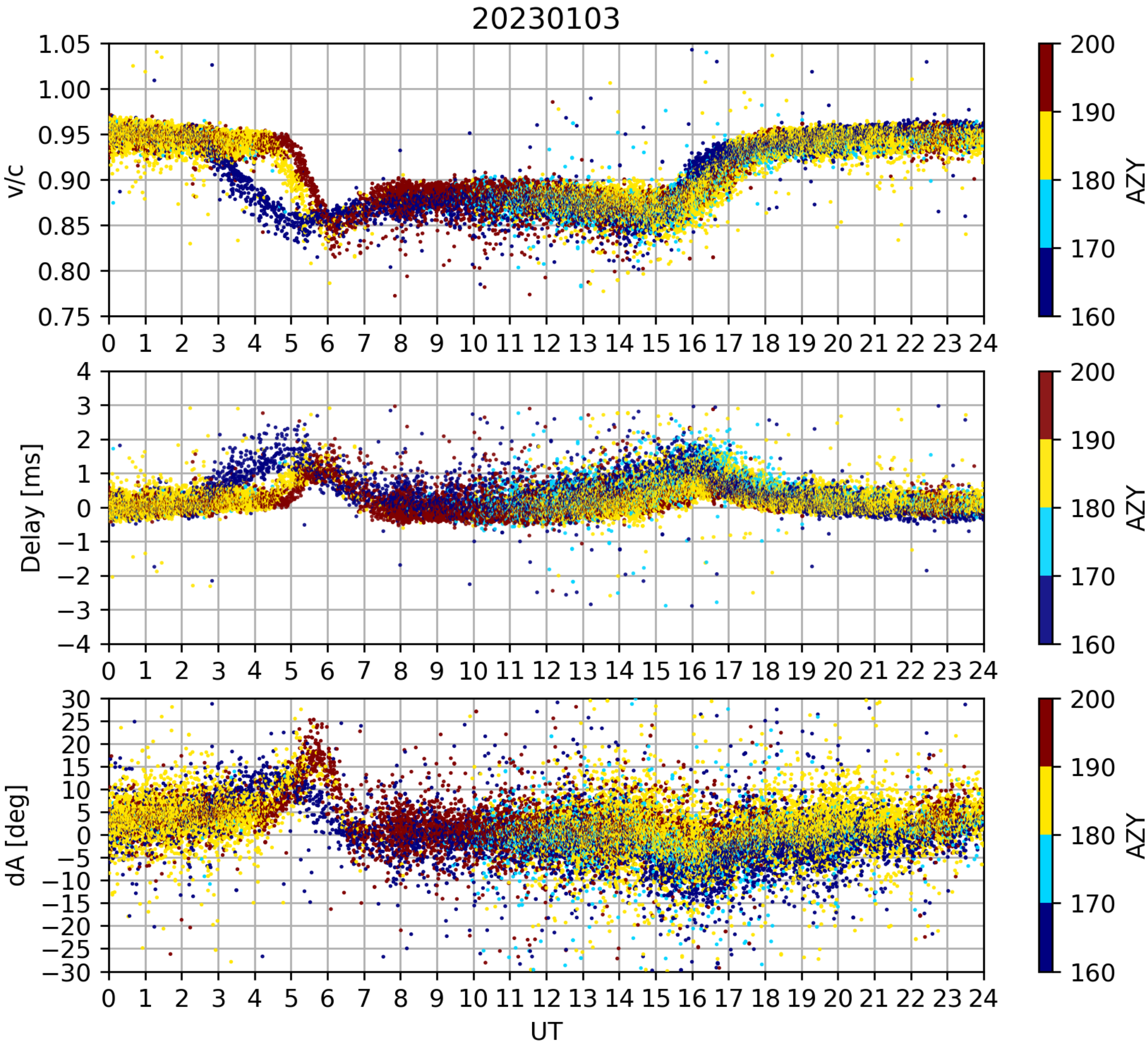
More accurate time using day/night propagation speeds



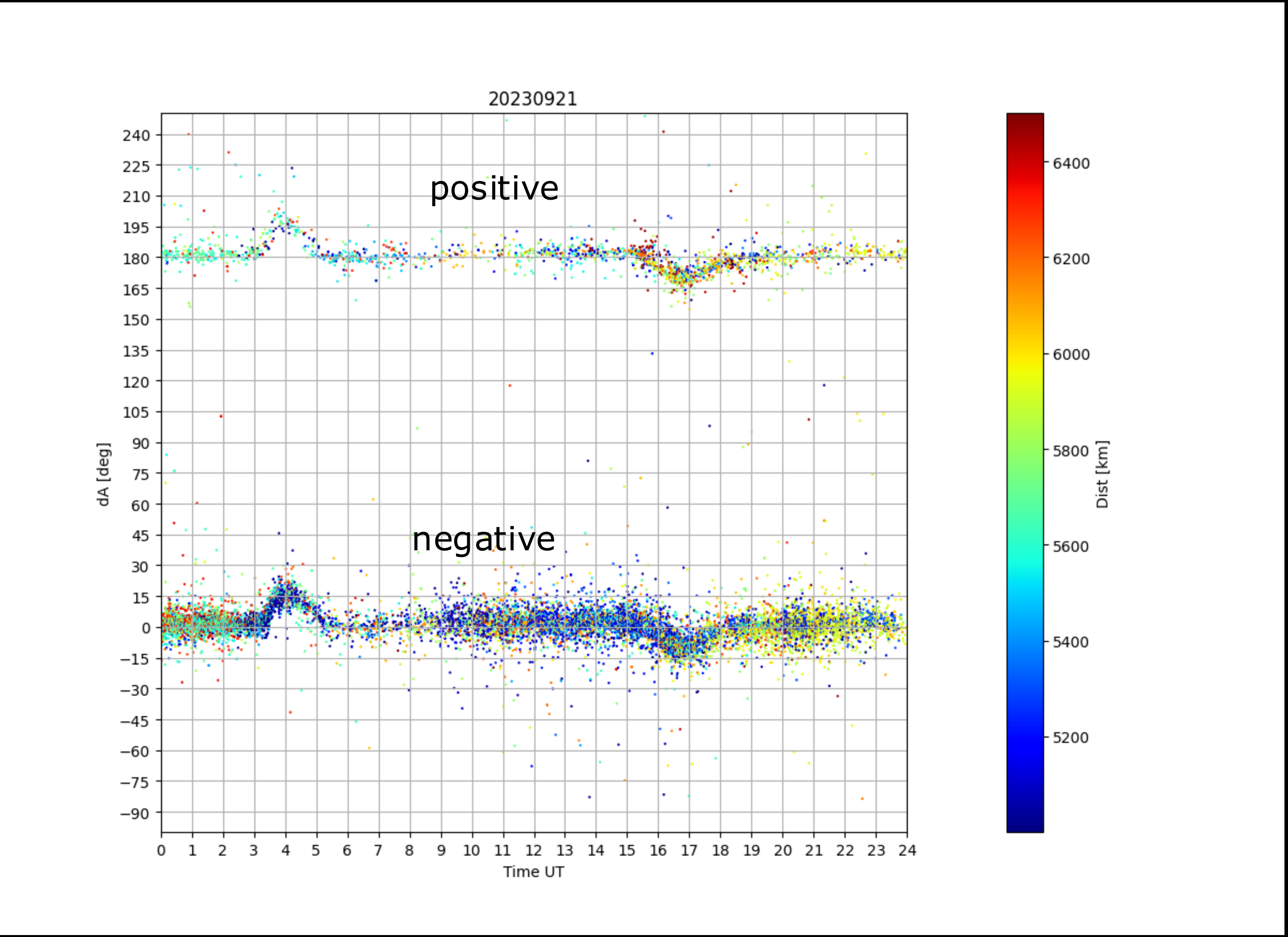
Red line – expected WWLLN

Black/dashed line – identified impulse above 3 pT

Additional info in colour: azimuth distribution



Separation of positive and negative WWLLN discharges with measured azimuths



2024 Earthquake in Slovakia