New possibilities for diagnostics of the near-Earth plasma environment

Hanna Rothkaehl, Marcin Grzesiak, Mariusz Pożoga, Barbara Matyjasiak, Agata Chuchra-Konrad, Katarzyna Beser, Helena Ciechowska, Roman Wronowski, ŁukaszTomasik, Barbara Atamaniuk

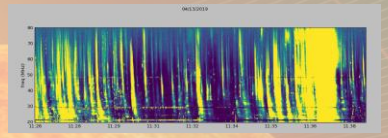
CBK PAN Poland

Space Climat Krarków 2022

LOFAR4SW: A comprehensive Space Weather Observatory
Sun, Heliosphere and Ionosphere observations

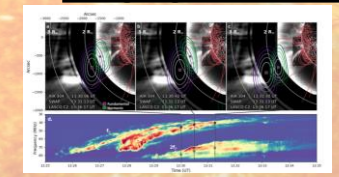
Sun

➔ **Monitoring Solar Radio Activity**



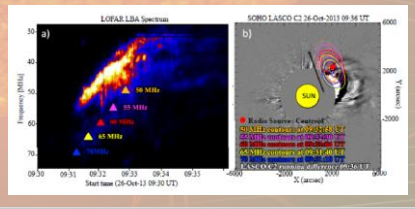
Zucca @ *Twitter*

➔ **Imaging of Radio Emissions**



Maguire et al., 2021

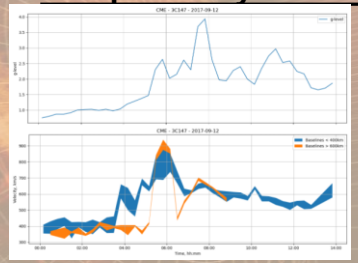
➔ **Solar radio bursts**



Zucca *et al.*, 2018

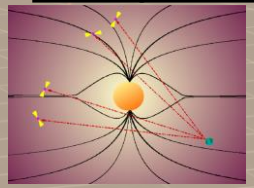
Heliosphere

➔ **Interplanetary Scintillation (IPS)**



Beamformed observations of point-like, distant, astronomical radio sources - determine the plasma outflow velocity(ies) across each line of sight and single-site techniques.

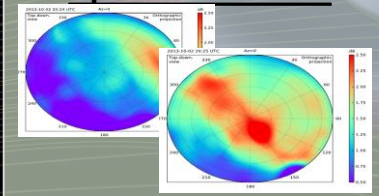
➔ **Faraday Rotation**



Determine the plasma density (and potentially the heliospheric magnetic field) using pulsars.

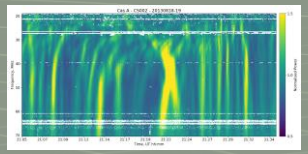
Ionosphere

➔ **Spectral riometer**



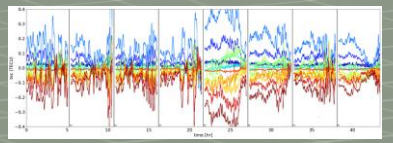
KAIRA data: McKay *et al.* (2015), Radio Science 50

➔ **Ionospheric scintillations**



Single station Scintillation spectrum CasA

➔ **TIDs**



differential TEC vs time, all Dutch stations

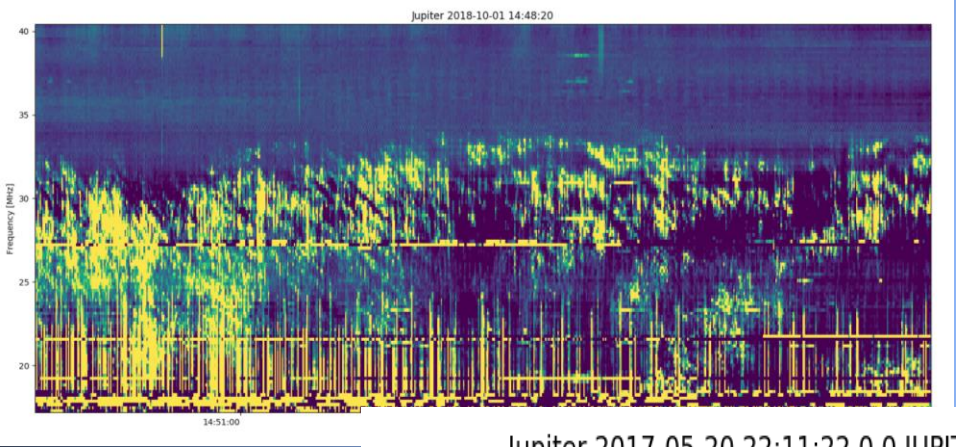
Credit: NASA

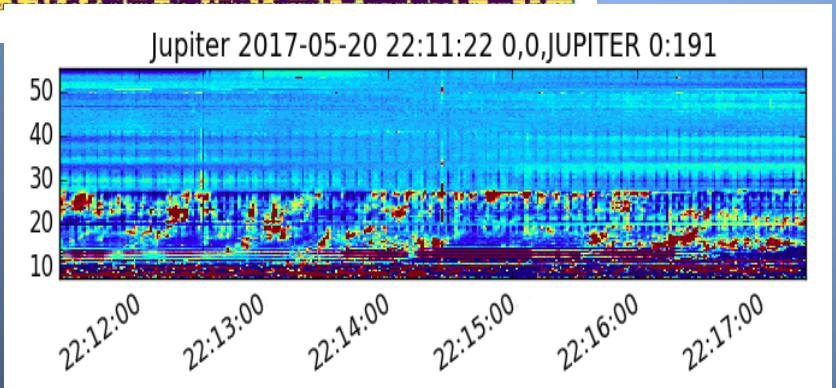
Jupiter observations

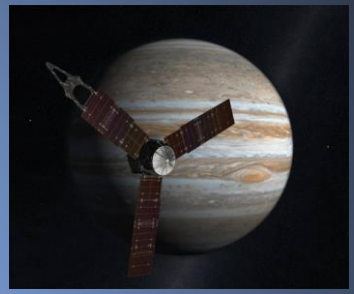
DAM emissions - Jovian decametric radio emission

Follow-up for JUNO and JUICE missions

Observations accessible by VO





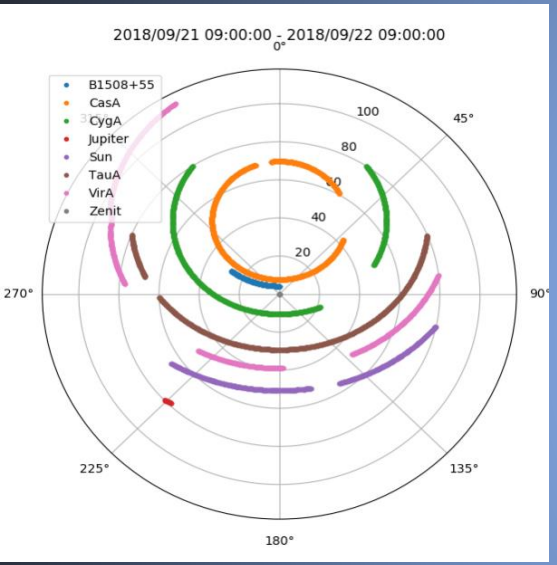


What ionospheric studies are currently possible with LOFAR for Ionosphere?

24 core stations: distances of 30 m – 3 km,
14 remote stations in the Netherlands: ~ 5- 200 km
13 international stations across Europe (6 Germany; 3 Poland; 1 each in France, Ireland, Sweden, UK and Latvia): 100-2000 km
New stations to come: Italy and possible Bulgaria

- Observations made in the frame of ‘Monitoring Ionospheric Scintillation Above LOFAR” proposals. Data available for selected time periods with different configurations of ILT stations.
- Local mode observations focused on ionospheric studies. Data available for selected time periods, only from selected stations.
- Post-processing of astronomy data

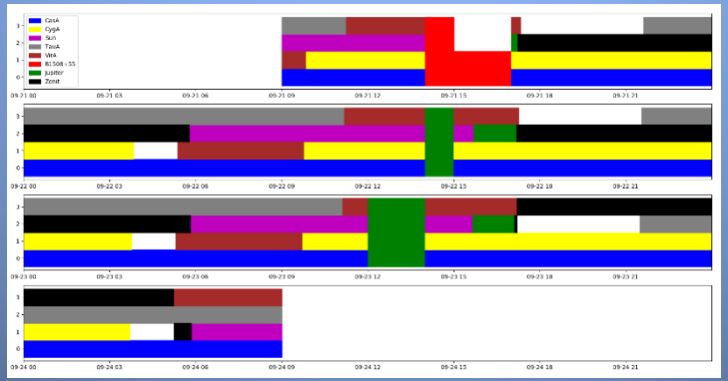
What ionospheric studies are currently possible with LOFAR for Ionosphere?

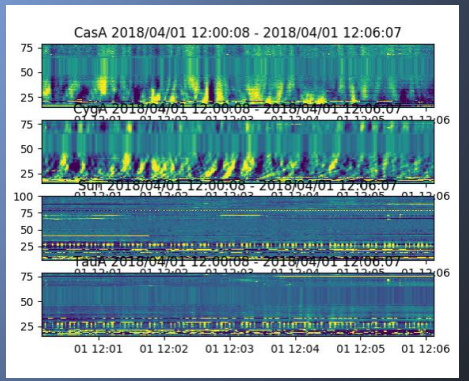


Ionospheric diagnostic piggy back in majority

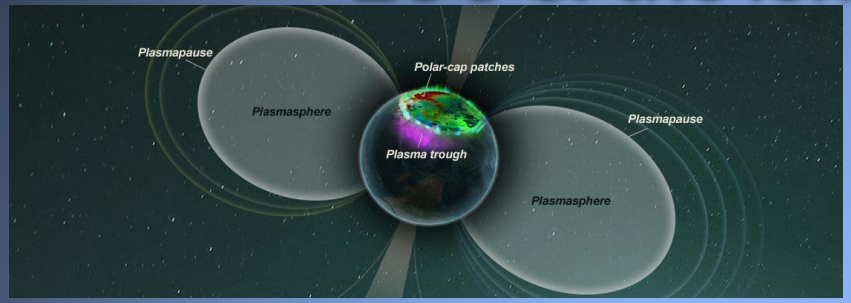
Already existing prototype pipelines at international stations (PL610)

- semi-automated (operator action needed to run the scheduler at the beginning of the local mode)
- simultaneous observations to 4 different objects
- different types of observations (change of bitmode, sources)
- observations are logged to the database – easier searching of files and better control over station work

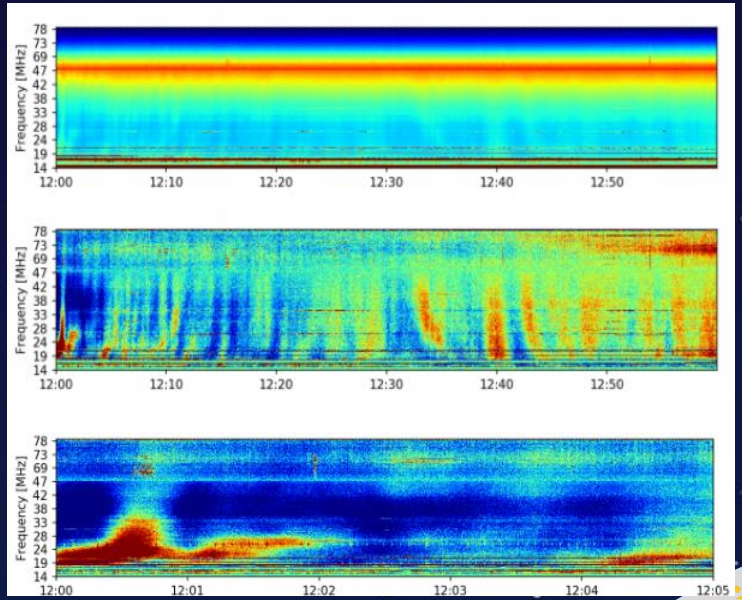




ZOO of the ionospheric phenomena



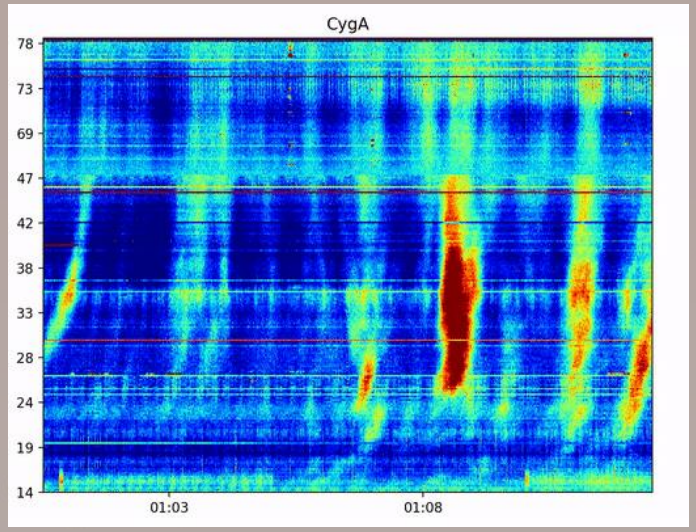
- Ionospheric irregularities – from small to large scales
- Monitoring the sub auroral and auroral region, Ionospheric trough, plasma depletion and mid-latitude region
- Scintillation activities
- Plasma absorption properties
- Neutral wind properties
- Monitoring EM noises and Thunderstorm activities, and vulcanic eruption .....

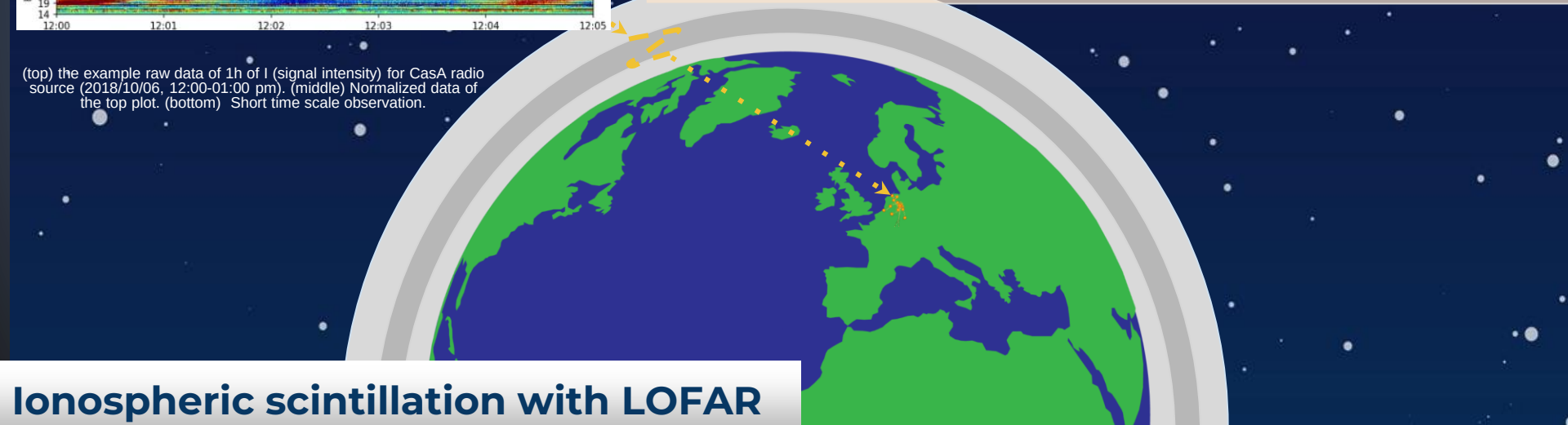


(top) the example raw data of 1h of I (signal intensity) for CasA radio source (2018/10/06, 12:00-01:00 pm). (middle) Normalized data of the top plot. (bottom) Short time scale observation.

Dynamic spectrum of measured intensity of Casiopea A signal with clearly visible scintillation pattern.

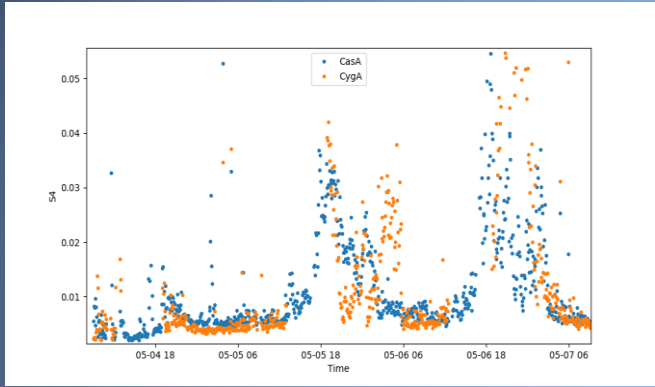
Observations made on 25.02.2018 at polish LOFAR station PL610.
Y axis: frequency in MHz, X axis: time.
(M.Pozoga, B.Matyjasiak)



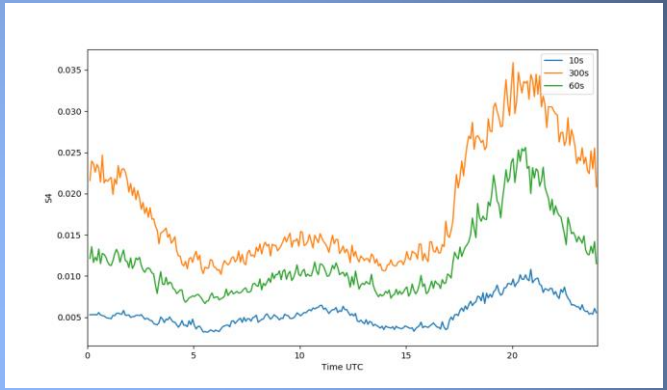


Ionospheric scintillation with LOFAR

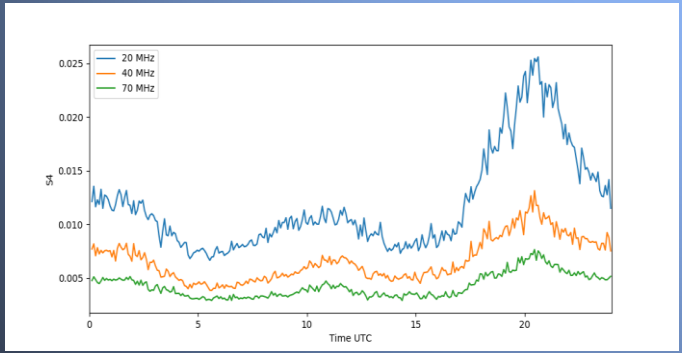
Pipeline for S4 index computed from beamformed data was developed.
We use 100Hz amplitude recorded from single station PL610 W processed 8500 hour of observation for 4 brignest radio sources CasA,CygA,VirA, TauA



S4 value computed from 60s segment of data frequency 30MHz for 2 s source CasA and Cyg A 4-7 May 2018

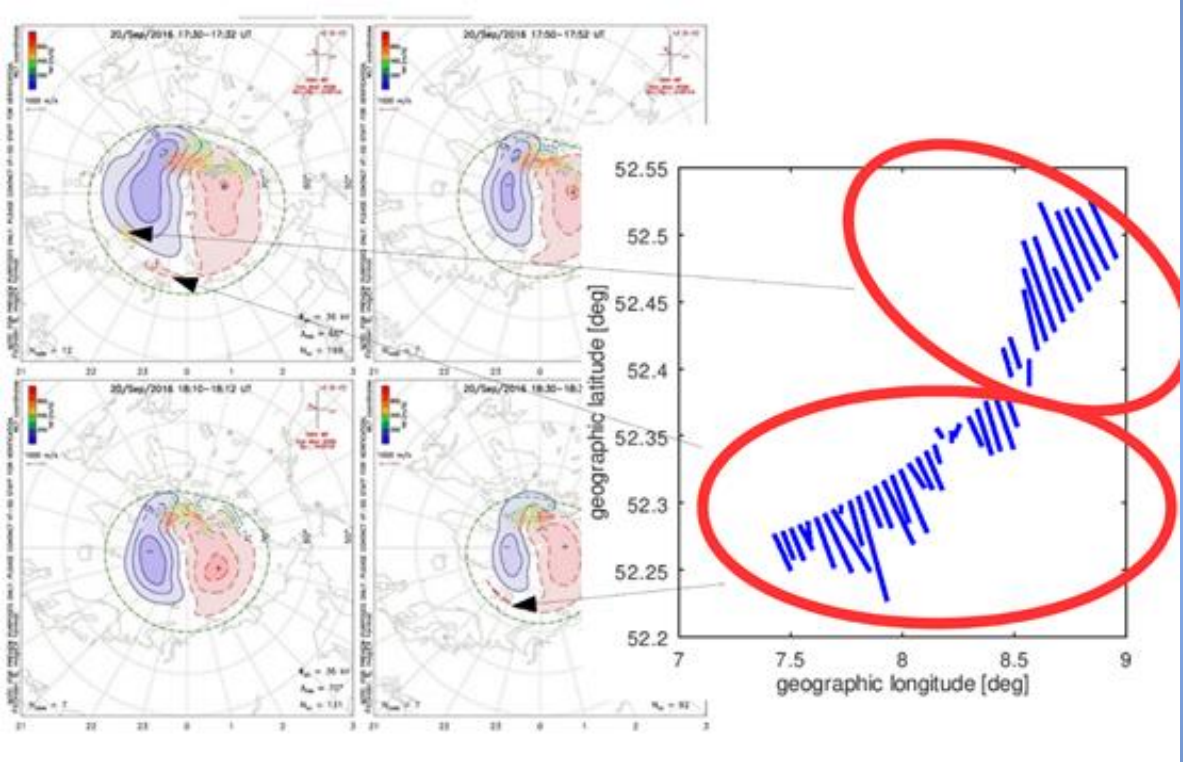


Comparison of daily median of s4 index at 30MHz for CasA for different length of data segment used to computation



Comparison of daily median course of s4 index at 20,40,70MHz for 60s segment for CasA

What ionospheric studies are currently possible with LOFAR for Ionosphere?

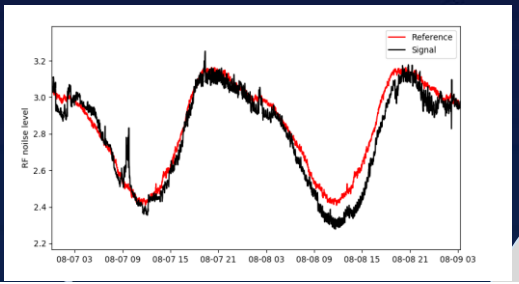


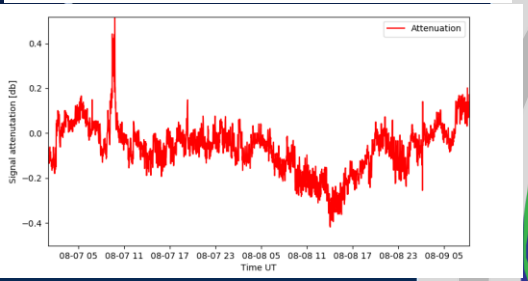
Large-, Medium- and small-scale ionospheric structures: Size and movement

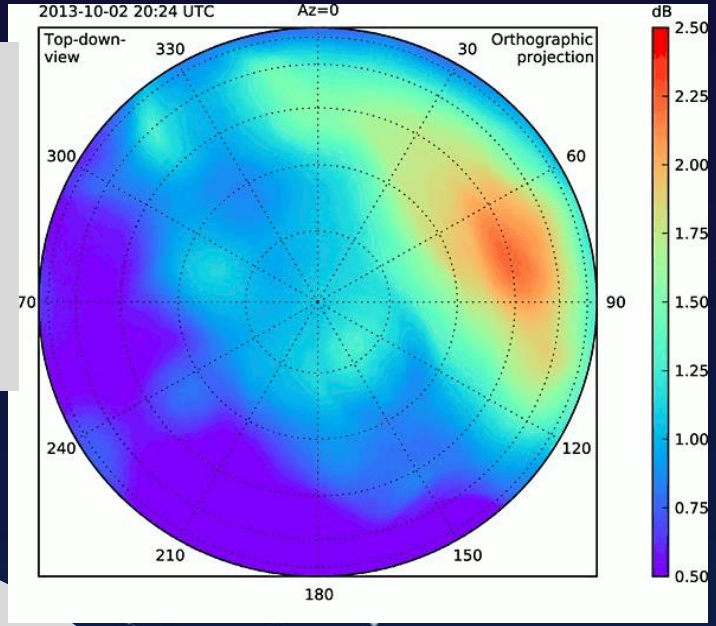
Use of a model with the diffraction pattern's temporal decorrelation to obtain drift velocity estimates. Accomplished by fitting a three-dimensional polynomial to the spatio-temporal correlations obtained from LOFAR's scintillation amplitude measurements

Comparative plots between velocity observations from LOFAR (right) and SuperDARN (left). M. Grzesiak et al sub 2022.

A few 1 min frames of **all-sky interferometric riometry.** These reveal the true direction of the arrival of the absorption, sweeping from the northeast to the southwest. (McKay et al. 2015, Radio Science 50)

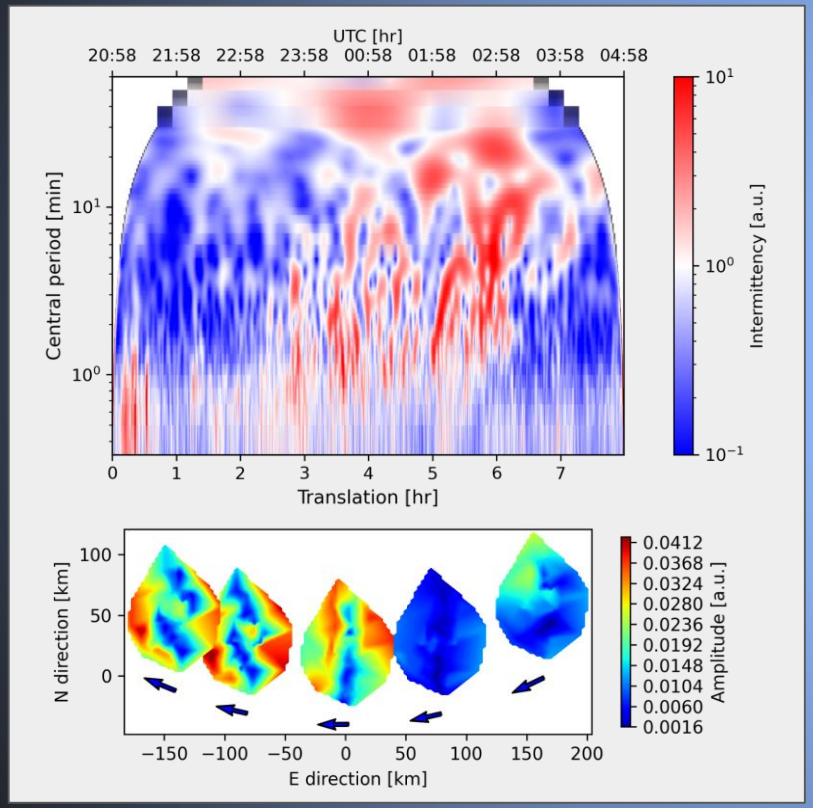




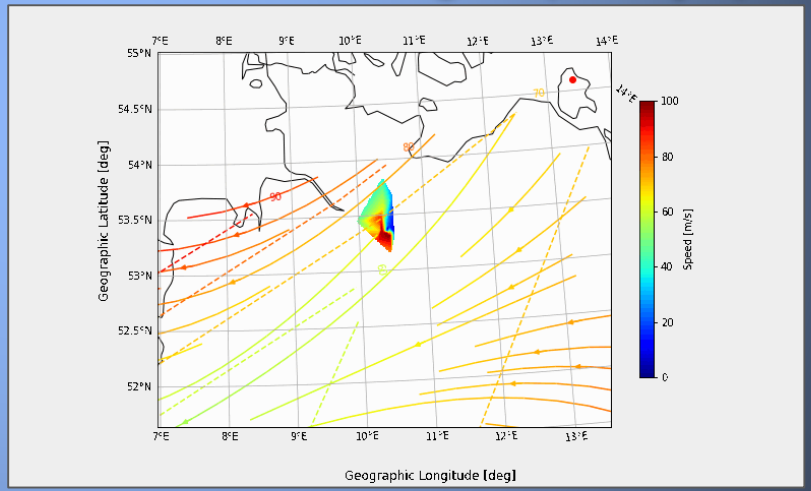


All-sky interferometric riometry

What ionospheric studies are currently possible with LOFAR for Ionosphere?



Multispectral analysis of calibration solutions determination of dynamical changes in the ionosphere based on wavelet transform of an interferometric dTEC signal (K. Beşer)



IONOSPHERIC TROUGH

Ionospheric conditio during geomagnetic disturbancec

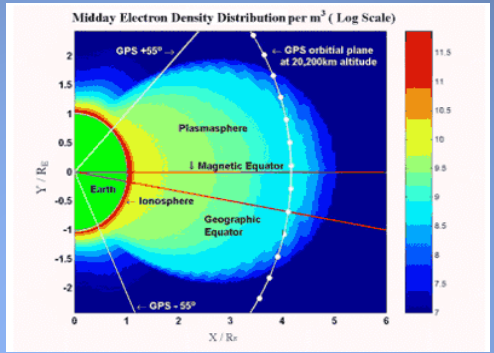
Ionospheric trough and plasmopause around 42-44 geographic latitude below Core and PL610 station.

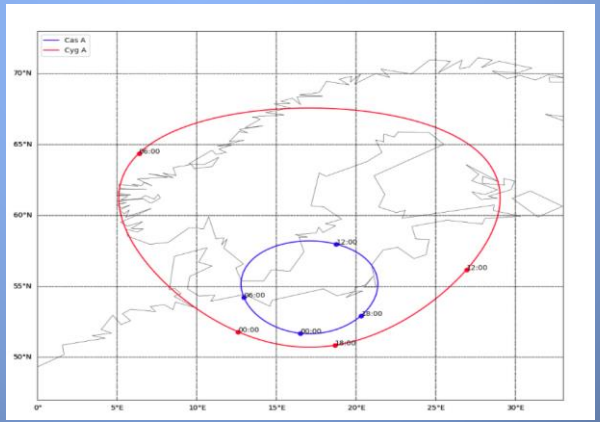
Field aligned current .

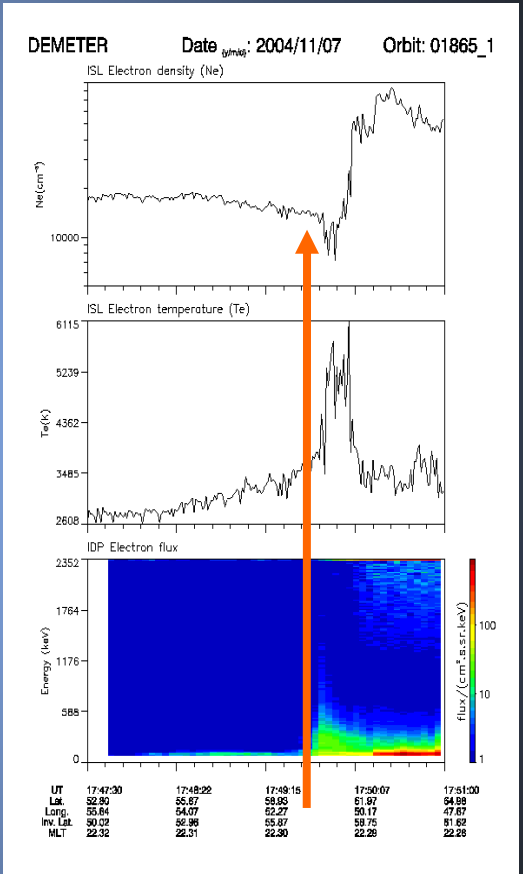
Absorption small scales

Enhancements of Spread-F layers

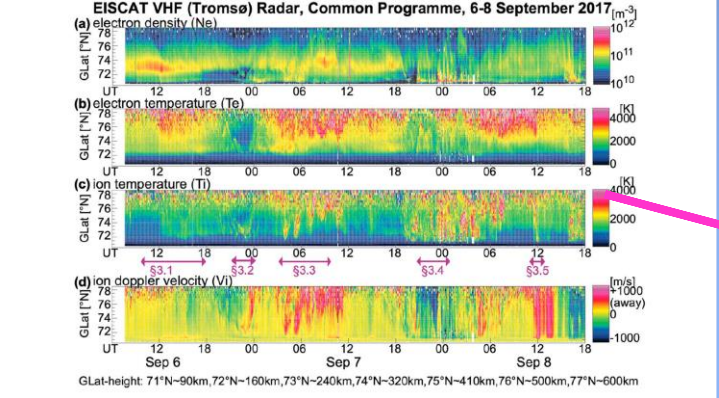
Turbulent structures of ionosphere structures



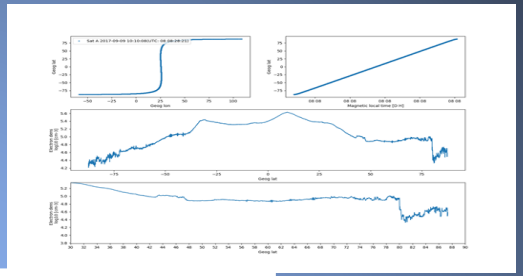




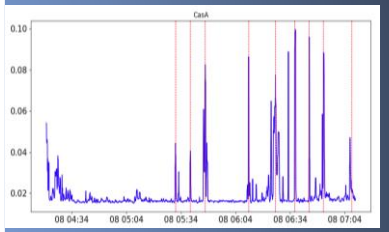
Multi-diagnostics



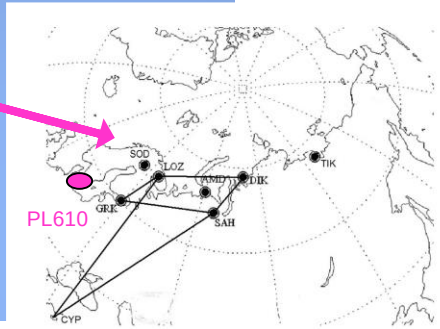
Yamauchi 2018



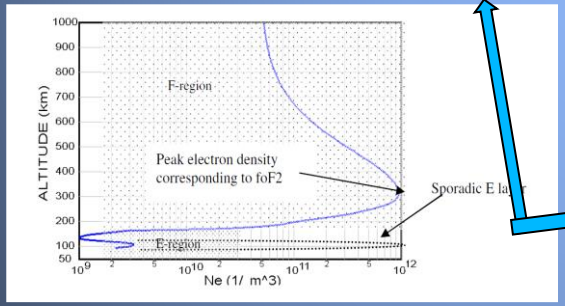
SWARM

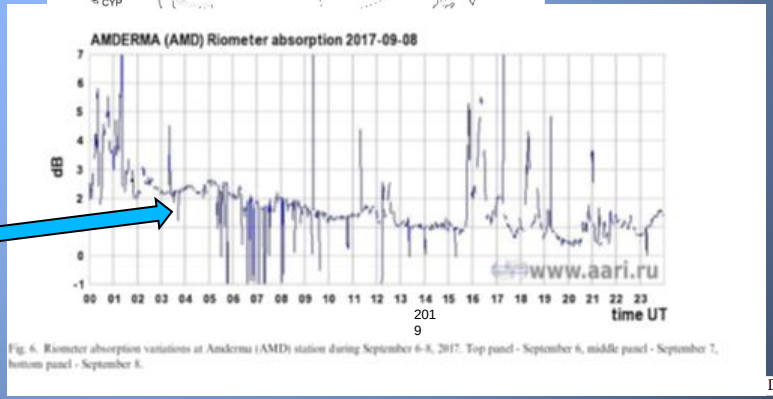


PL610 LOFAR



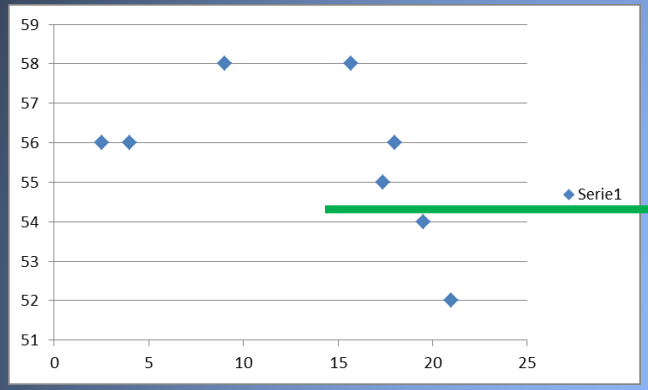
PL610

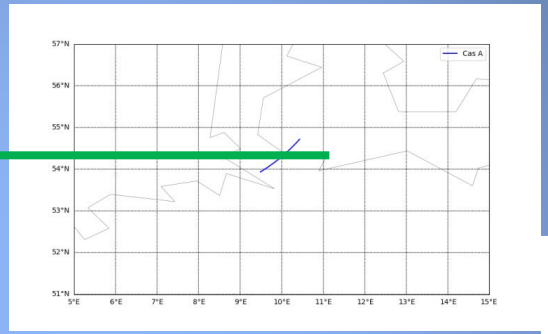


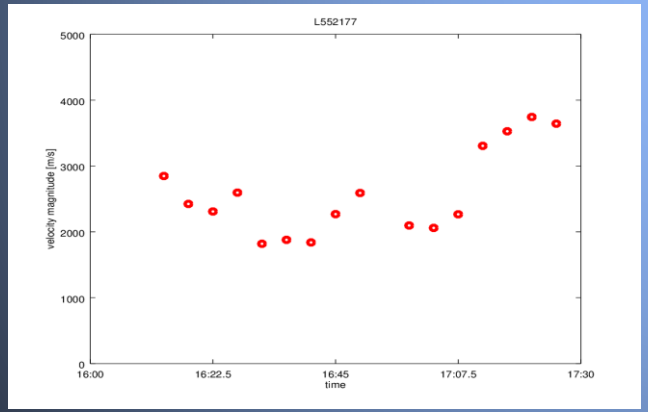


D.V. Blagoveshchensky

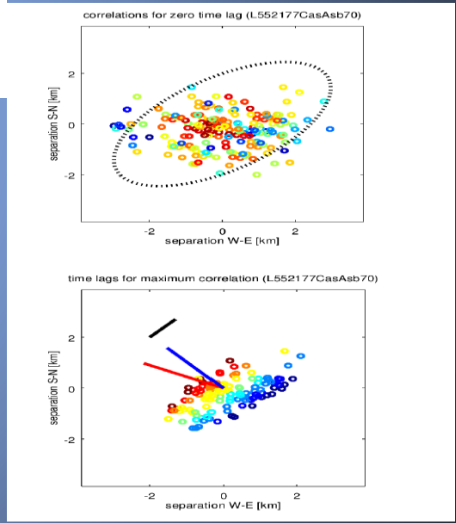
The determination of main ionospheric trough by LOFAR diagnostics







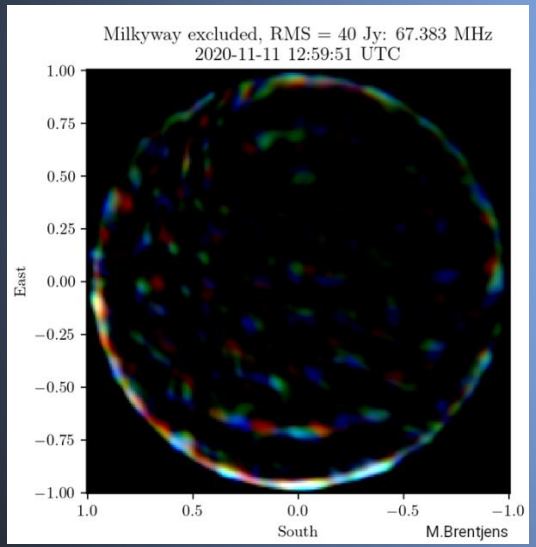
Geomagnetic storm
13 10 2016



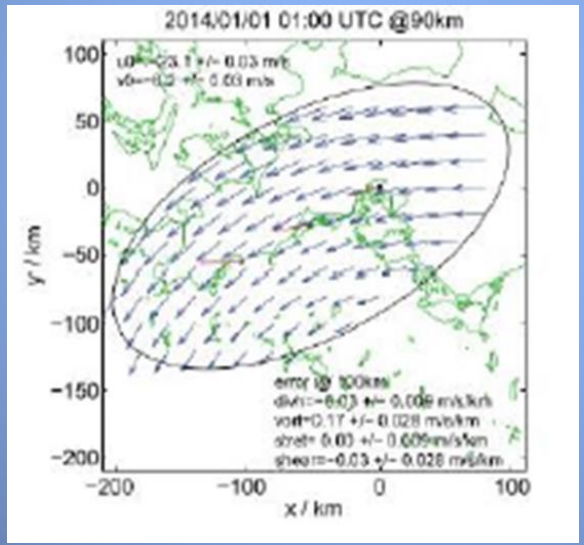
What ionospheric studies are currently possible with LOFAR for Ionosphere?

Passive Radars

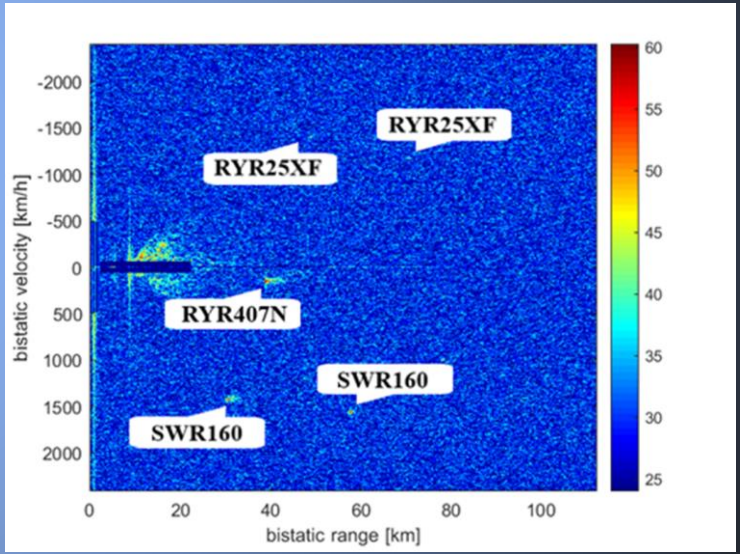
Man made noises



Neutral wind

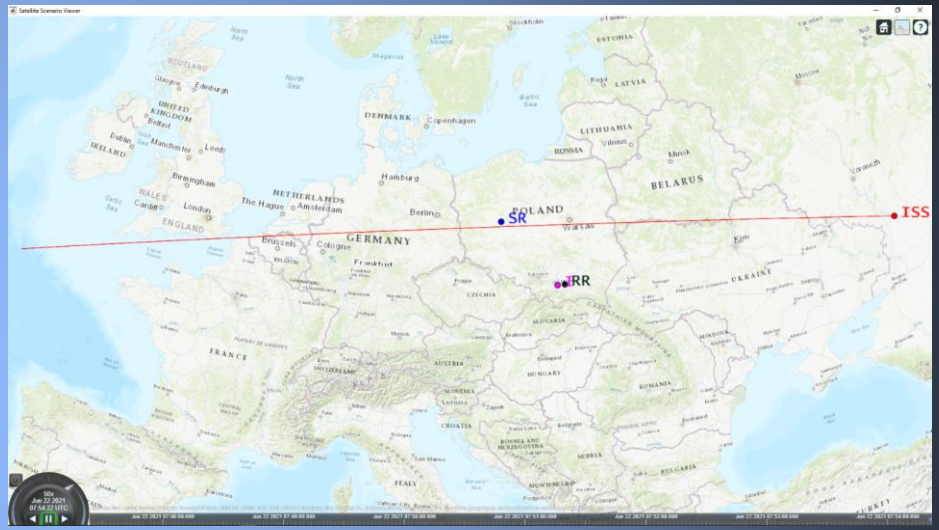


Aircraft and ISS

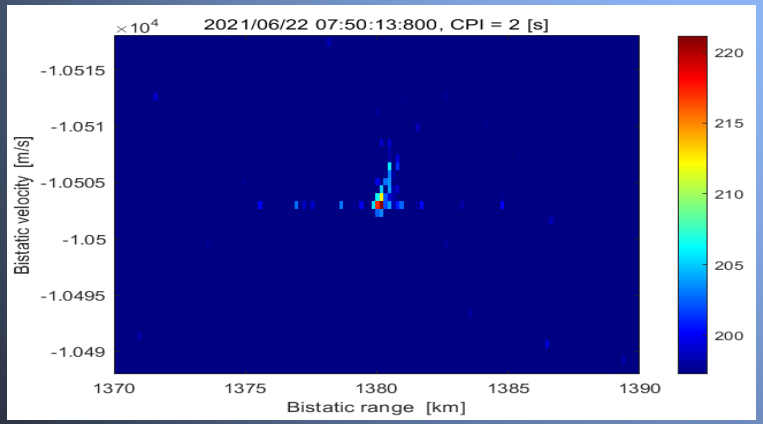


Space Object Detection using LOFAR as a passive radar

- Project led in collaboration with Warsaw University of Technology (Politechnika Warszawska),
- Receivers, such as LOFAR, can be used in **passive radiolocation systems** (aircraft detection, space targets detection),
- DAB+ commercial transmitters are being used as illuminators of opportunity, while two LOFAR stations were used as a surveillance receiver and as a reference receiver.



ISS (red line), surveillance receiver (SR), reference receiver (RR) and illuminator of opportunity (I) positions during measurements.



Zoom on the ISS echo in the range-velocity maps obtained for subsequent time moments.

An exemplary ionospheric observation scenario

Normal observing → **Trigger** → **Triggered observations**

- Ionospheric scintillation S4 index
- all-sky imaging at each station (piggy back)

trigger example:

- internal: **elevated S4 index value**
- or external: **SYM-H/Dst** indicating geomagnetic disturbance, prediction of the **time of CME arrival** to the Earth's magnetosphere
- mix of both

- Ionospheric scintillation -> wide-band dynamic spectras
- higher cadence and increased resolution versions of the normal observations
- core observations of moving structures