POLFAR

LOFAR radio-telescope as a novel instrument for ionosphere monitoring

Andrzej Krankowski[1] (Chairman of POLFAR consortium)

Paweł Flisek[1], Biagio Forte[2], Kacper Kotulak[1], AdamFroń1, Richard Fallows[3] and Mario M. Bisi[3]

[1] Space Radio-Diagnostics Research Centre, University of Warmia and Mazury, Poland, [2] Department of Electronic and Electrical Engineering, University of Bath, Bath, United Kingdom, [3] RAL Space, United Kingdom Research and Innovation - Science & Technology Facilities Council - Rutherford Appleton Laboratory

United Nations International Meeting on the Applications of Global Navigation Satellite Systems

Organised Hosted by the United Nations Office for Outer Space Affairs

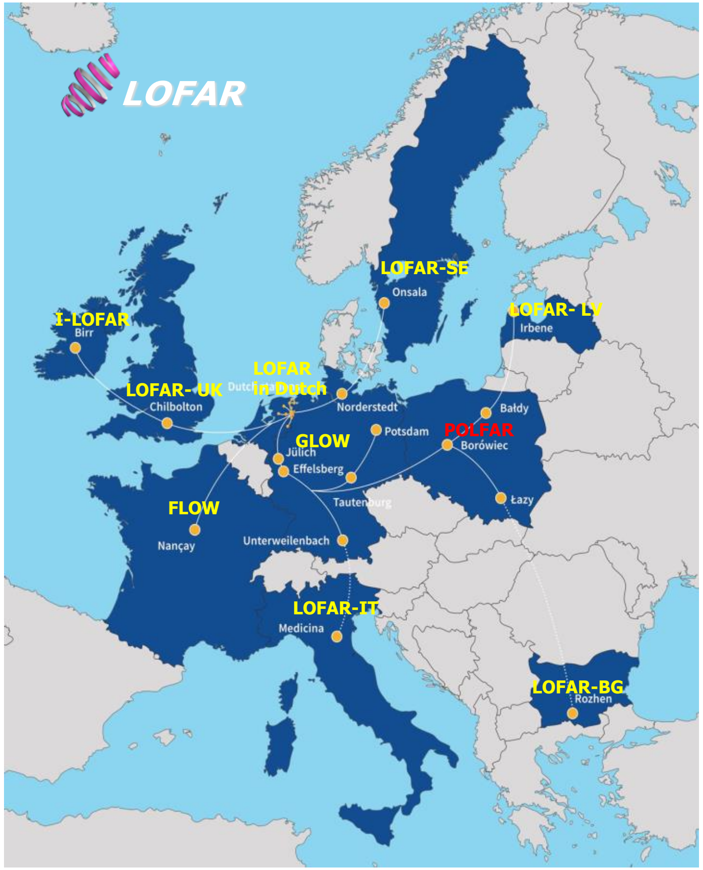
Vienna, Austria, 26 – 30 June 2023

UNITED NATIONS
Office for Outer Space Affairs

Outline

- **International LOFAR Telescope (ILT).**
  - Network
  - Superterp and international stations
  - LOFAR - The Key Science Projects
  - POLFAR
  - LOFAR-ERIC
- **LOFAR Sun monitoring**
- **Scintillation spectra observed with LOFAR PL612**
  - Processing scintillation data
  - LOFAR S4 index
  - LOFAR S4 index
- **Summary**

International LOFAR Telescope (ILT)



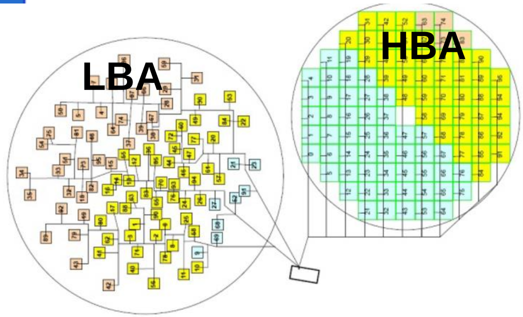
LOFAR (LOw Frequency ARray) – European radio interferometer consisting of **52** stations across **10** countries (with national consortia): LOFAR in Dutch, GLOW, LOFAR-UK, LOFAR-SE, FLOW, **POLFAR**, I-LOFAR, LOFAR-LV, LOFAR-IT, LOFAR-BG)

- **24** core stations in the Netherlands
- **14** remote stations in the Netherlands
- **14** International (ILT) stations: 6 in Germany, **3 in Poland *(PL-610 Borowiec – SRC PAS; PL-611 Lazy – UJ Krakow; PL-612 Baldy – UWM Olsztyn)***, 1 in France, Ireland, Latvia, Sweden and UK
- **2** more planned stations in Bulgaria and Italy

LOFAR Family Meeting 2023 www.lfm2023.uwm.pl

University of Warmia and Mazury in Olsztyn - 12-16 June, 2023

Superterp and PL612 Bałdy Station



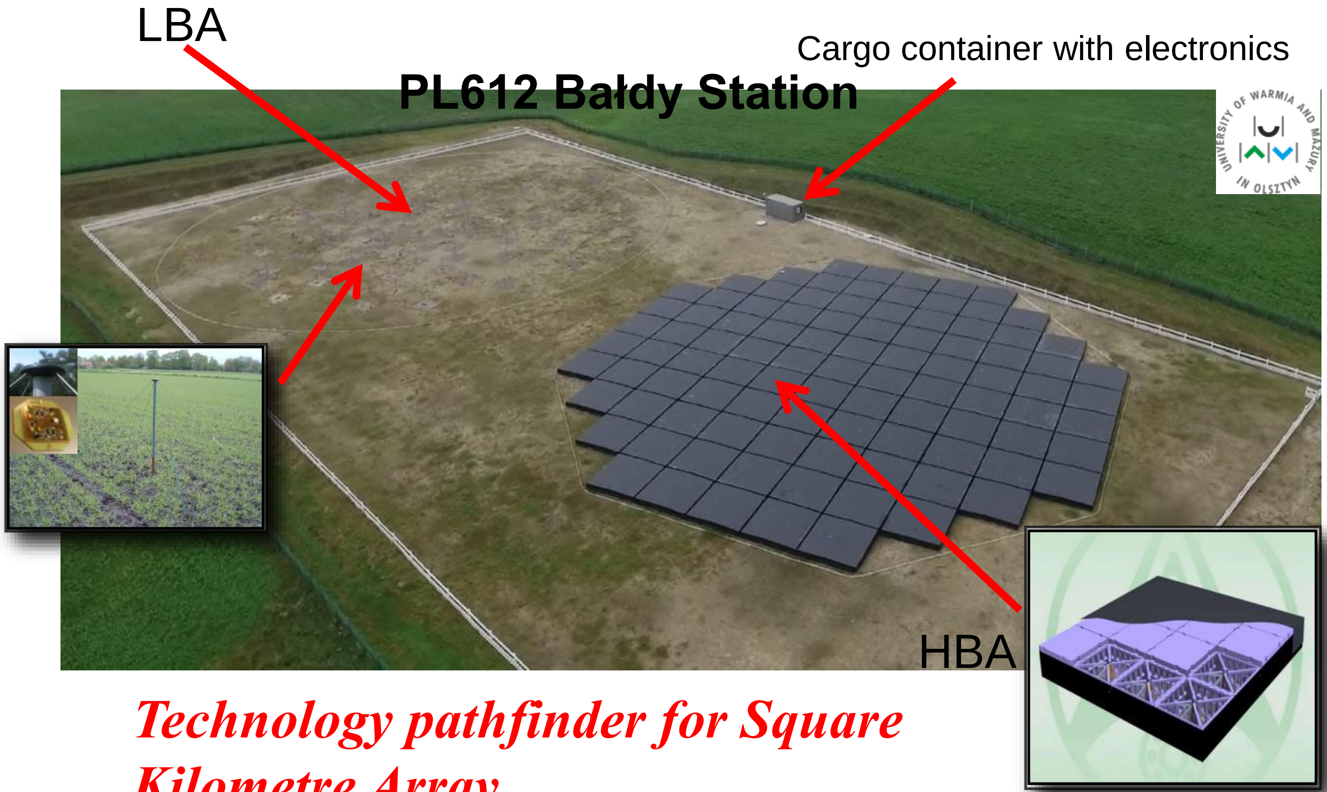
Superterp

Typical International LOFAR station consists of two antenna fields with different observed frequency bands:

- Low band antenna (LBA) field with observable band of 10-90 MHz
- High band antenna (HBA) field with observable band of 110-240 MHz

The gap between the bands is caused by the radio frequency interferences.

PL612 Bałdy Station



Technology pathfinder for Square Kilometre Array

POLFAR POLFARO

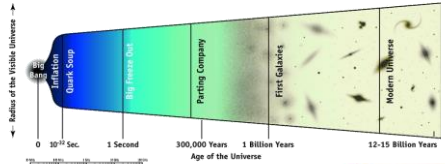
August, 2015

- **University of Warmia and Mazury in Olsztyn, the leader of the POLFARO Consortium** - (coordinator: prof. Andrzej Krankowski)
- **Jagiellonian University, Krakow** - (dr hab. Marian Soida, prof. UJ)
- **Space Research Centre of PAS, Warsaw** - (dr hab. Hanna Rothkaehl, prof. CBK)
- **PCSS/PIONIER**- (Robert Pekal)
- **Nicolaus Copernicus Astronomical Center of PAS in Warsaw, Torun** (dr hab. Jarosław Dyks)
- **The Nicolaus Copernicus University in Torun (NCU)** (dr hab. Magdalena Kunert-Bajraszewska, prof. UMK)
- **Szczecin University** (dr hab. Ewa Szuszkiewicz, prof.US)
- **University of Zielona Góra** (dr hab. Jarosław Kijak, prof.UZ)
- **Wrocław University of Environmental and Life Sciences** (prof. Bernard Kontny)

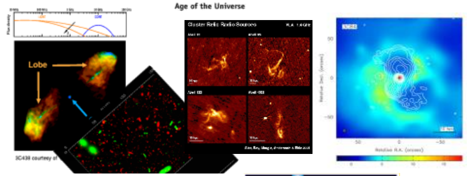
LOFAR

LOFAR - The Key Science Projects

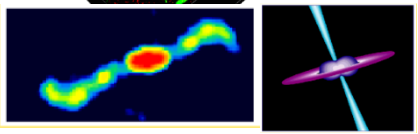
Epoch of Reionisation



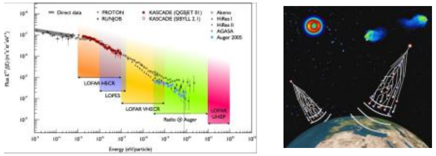
Surveys



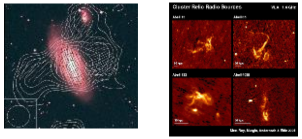
Transients



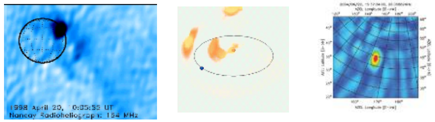
Cosmic Rays

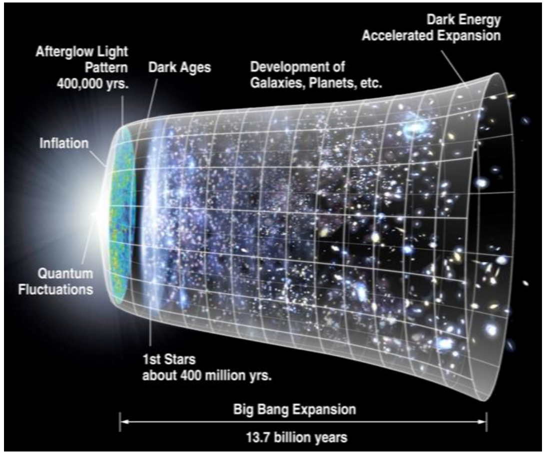


Magnetism

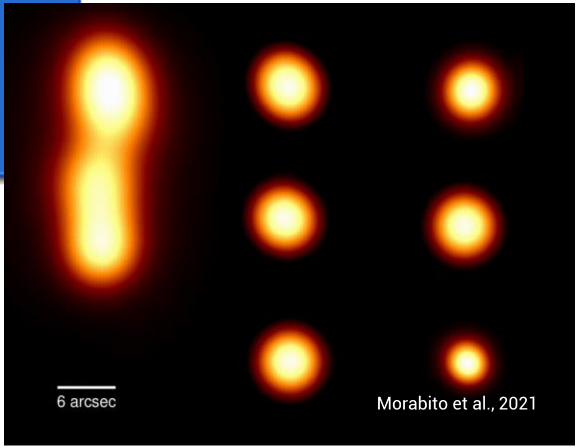


Sun & Space Weather

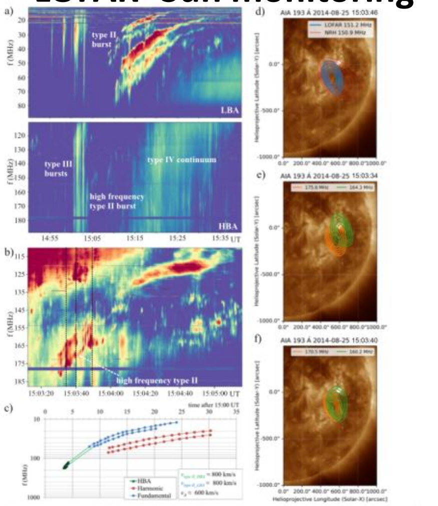




LOFAR-VLBI



LOFAR- Sun monitoring



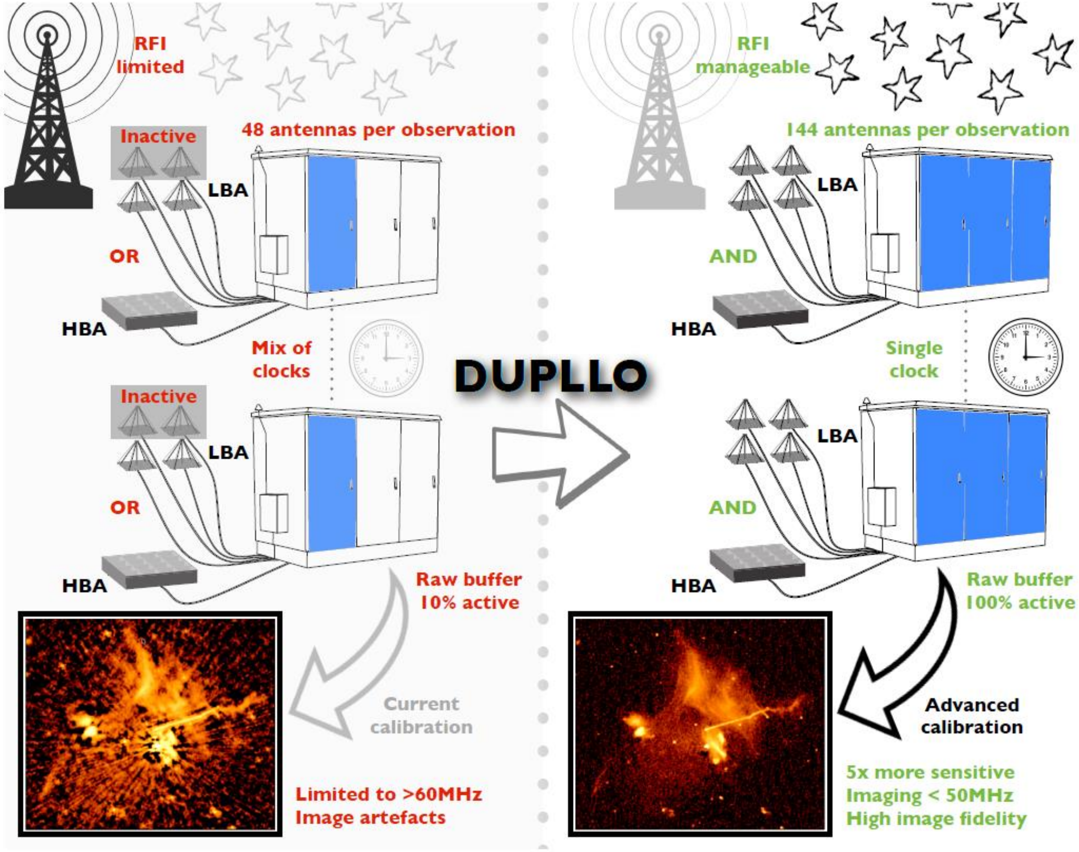
LOFAR4SW

H2020
INFRADEV-01-2017

Participant No *	Participant organisation name	Country
1 (Coordinator)	Stichting ASTRON, Netherlands Institute for Radio Astronomy (ASTRON)	NL
2	Universität Bielefeld (UNIBI)	DE
3	University of Warmia and Mazury in Olsztyn, Space Research Centre of PAS, Warsaw	PL
4	Stichting International LOFAR Telescope (ILT)	NL
5	Observatoire de Paris (OBSPARIS)	FR
6	Chalmers Tekniska Hoegskola AB (CHALMERS)	SE
7	Science and Technology Facilities Council (STFC)	UK
8	The Provost, Fellows, Foundation Scholars& the other members of Board of the College of the Holy & Undivided Trinity of Queen Elizabeth near Dublin (TCD)	IE

LOFAR

LOFAR 2.0 (2024-2025)



LOFAR2.0 Enhancements

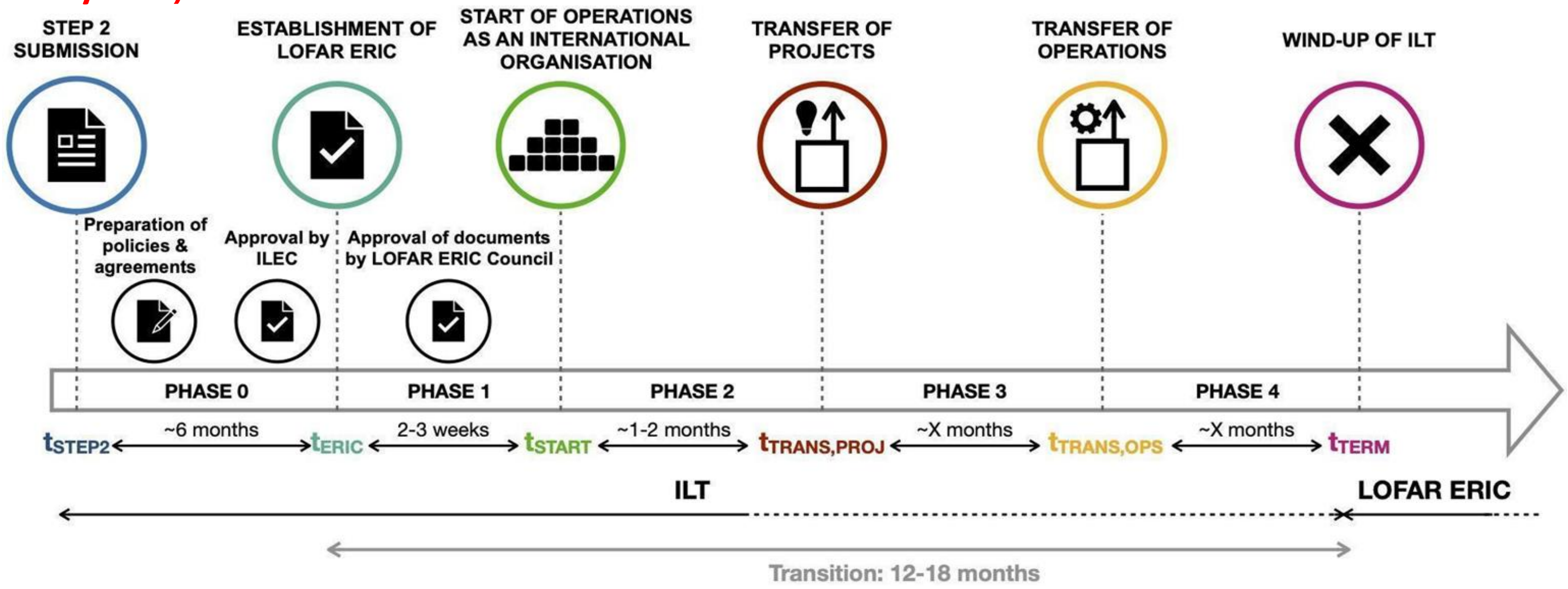
- LOFAR Enhancement 1: Expand, modernise station cabinet electronics:
  - allow observations simultaneously using LBA and HBAs;
  - more flexible station beam forming, e.g. for running simultaneous projects anywhere on the sky.
- LOFAR Enhancement 2: Double the number of active LBAs per station and possibly change their design to increase sensitivity from 20-50MHz.
- LOFAR Enhancement 3: Improve HBA front-end electronics & tile beamformer.
- LOFAR Enhancement 4: a) Increase the number of HBA antenna stations in the LOFAR core. b) Increase the number of Remote and International stations to obtain a sufficient number of baselines up to roughly 250-km distances.

ILT / POLFARO / LOFAR-ERIC

1. Submission of documentation for step 1. (Septemeber 2021)

Statutes (incl Financial Model)
Technical and Scientific annex
User Access policy
Transition model
Terms of Reference Interim Council

(17 May 2023) (October 2023)



POLFARO

The solar radio bursts observations with LOFAR

Work within international cooperation under KSP "Solar Physics and Space Weather with LOFAR" team:

B. Dabrowski, A. Wołowska, C. Vocks, P. Flisek, A. Krankowski, P. Zhang, J. Magdalenic, H. Rothkaehl, A. Warmuth, D. E. Morosan, M. Bröse, M. M. Bisi, B. Matyjasiak, L. Błaszkiewicz, E. P. Carley, R. A. Fallows, A. Froń, P. T. Gallagher, M. Hajduk, K. Kotulak, G. Mann, P. Rudawy, T. Sidorowicz, Y. Wu, P. Zucca, and K. Mikuła

Space Radio-Diagnostics Research Centre, University of Warmia and Mazury in Olsztyn, Poland

LOFAR
Solar and Space Weather
KSP

National Science Centre Poland

Deutsche Forschungsgemeinschaft
German Research Foundation

Beethoven Classic 3
LOFAR observations of the solar corona during Parker Solar Probe perihelion passages

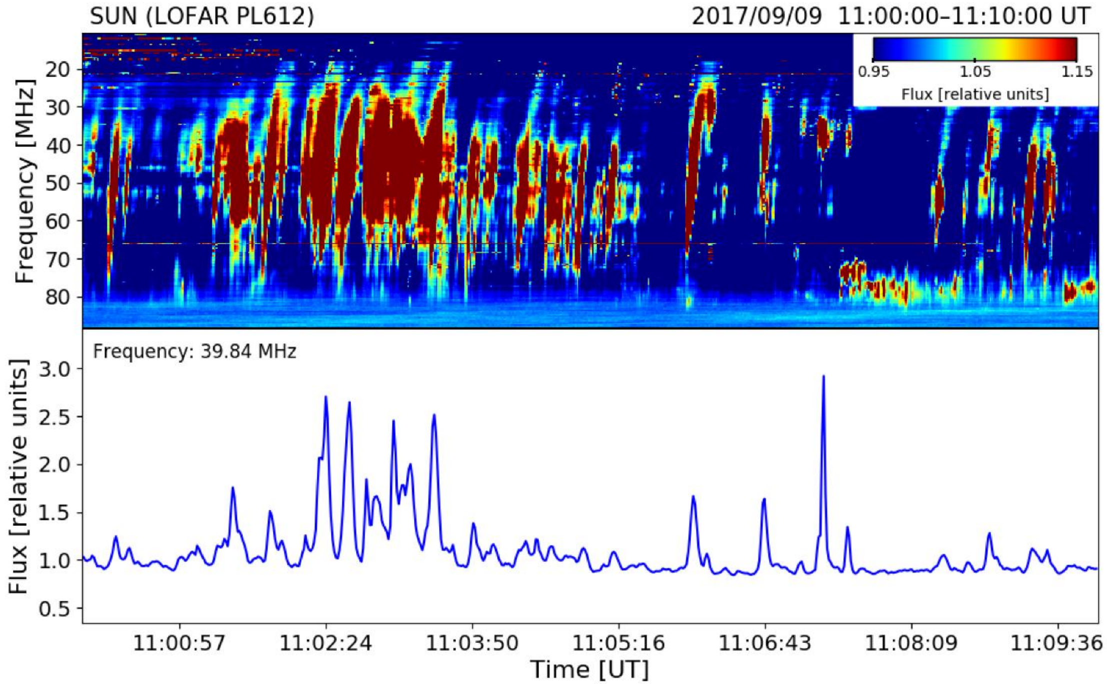
Uniwersytet Warmińsko-Mazurski w Olsztynie

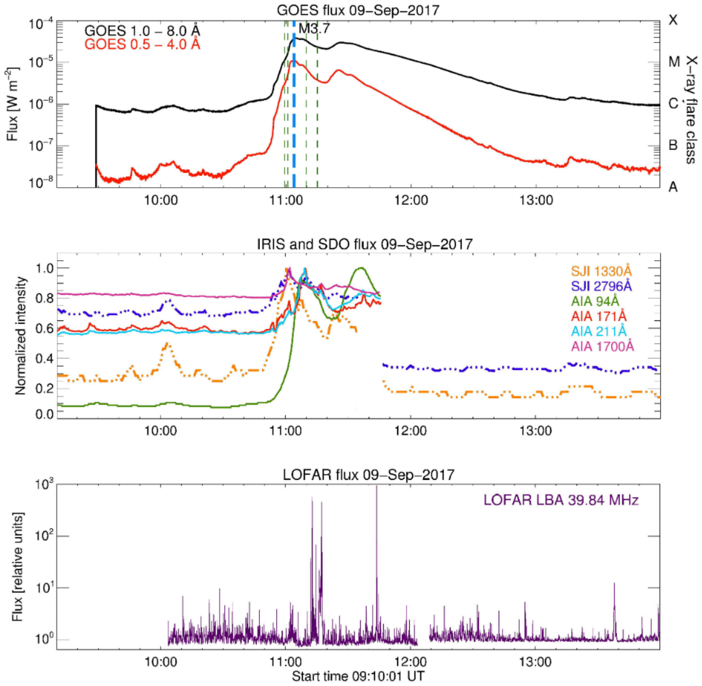
AIP Leibniz-Institut für Astrophysik Potsdam

LOFAR

Storm of type III radio bursts recorded on 9th September 2017

In this work we presented study of the two solar radio events consisting of type III bursts, observed by LOFAR telescope in Bałdy in the single mode.





Dabrowski et al., *Type III Radio Bursts Observations on 20th August 2017 and 9th September 2017 with LOFAR Bałdy Telescope*, 2021, Remote Sens., **13**, 148

Interferometric imaging of the type IIIb and U radio bursts

LOFAR

UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

In this study the source size of type IIIb and U solar bursts in a relatively wide frequency band from 20 to 80 MHz was determined (LC8_013: Interferometric Observations of the Active Regions in Radio Domain Before and After the Total Solar Eclipse on 21 August 2017, PI: B. Dabrowski).

TYPE U BURST
burst #1

TYPE IIIb BURST
burst #2

TYPE IIIb BURST
burst #3

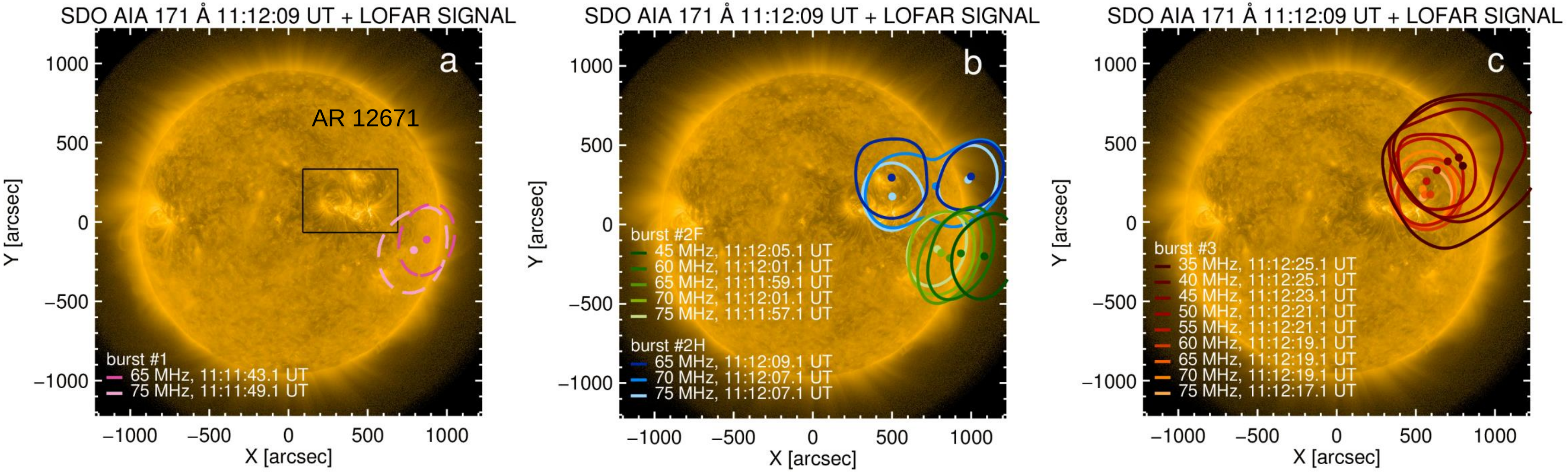
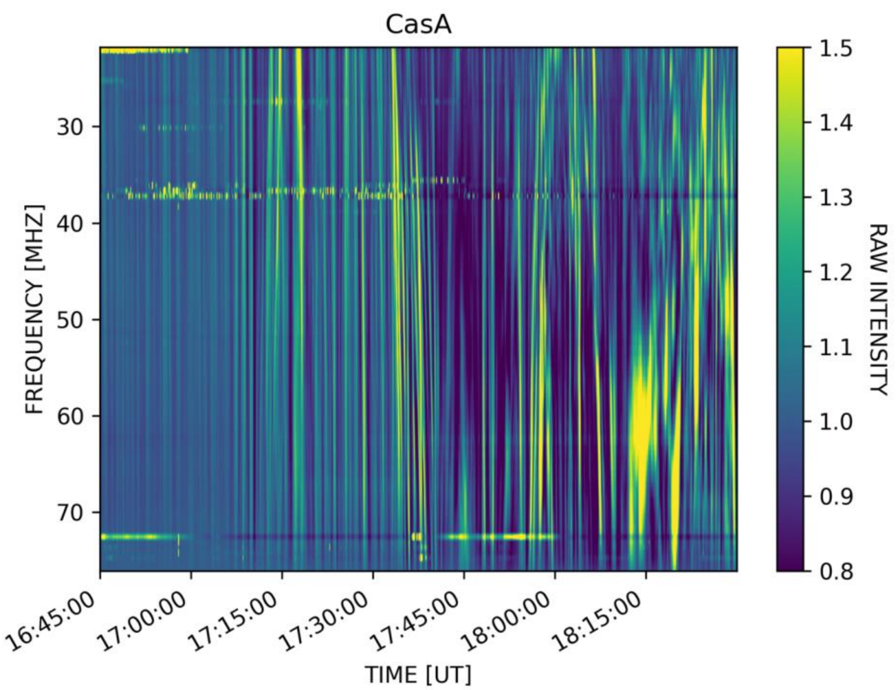


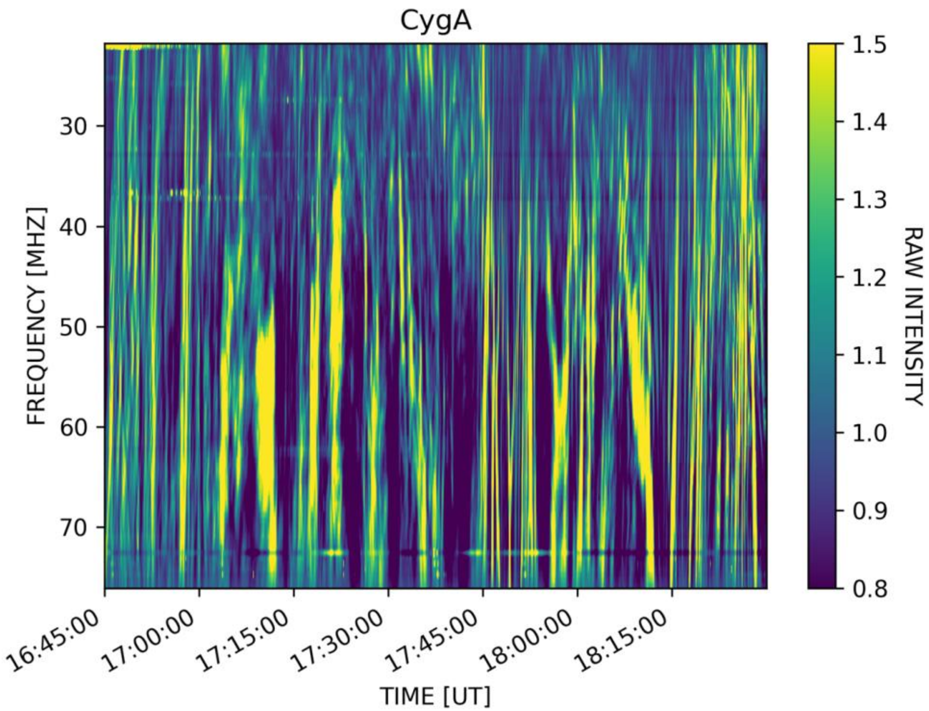
Image of the Sun received in the AIA 171 Å channel by SDO with superimposed color contours showing bursts #1, #2, and #3, at a range of frequencies.

Dabrowski et al., *Interferometric imaging of the type IIIb and U radio bursts observed with LOFAR on 22 August 2017*, 2023, A&A, **669**, A52

Scintillation spectra observed with LOFAR PL612

PL612

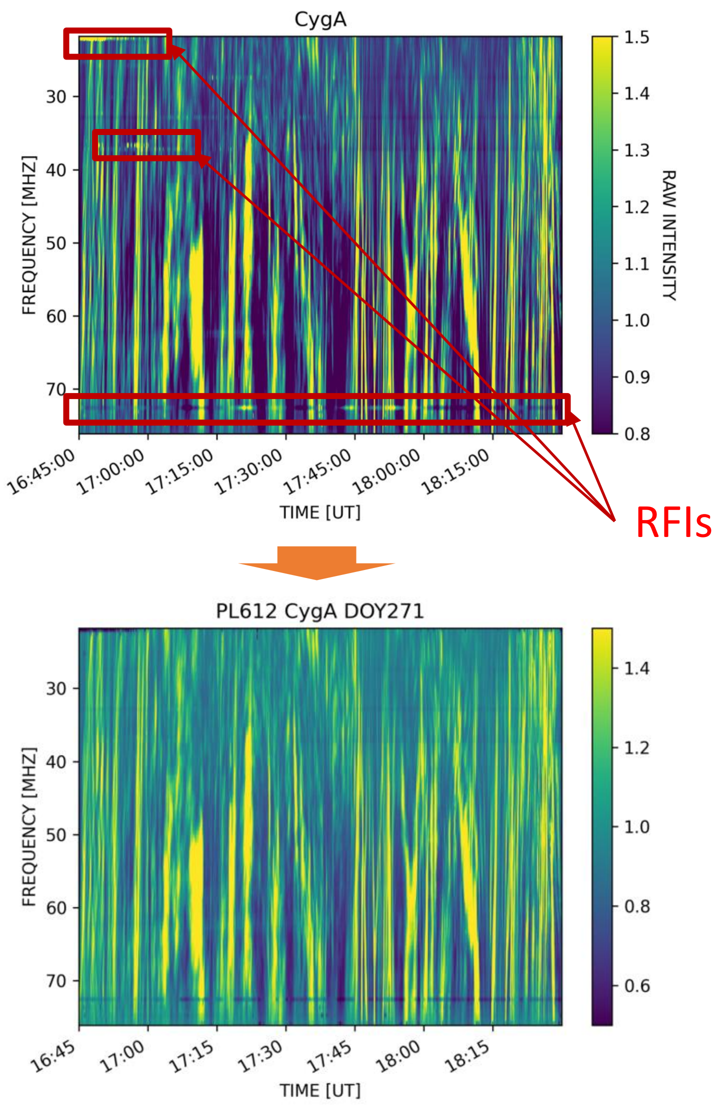




Processing scintillation data

LOFAR observations of radio waves intensities utilised in this analysis were sporadically affected by RFI.

In the RFI-mitigation process, the median filter for each frequency band is applied. The threshold for the RFI detection is set on the level of the 10th percentile (5σ threshold) for each channel. Spikes remaining after the filtering and larger than the threshold are cut out from the dynamic spectra.

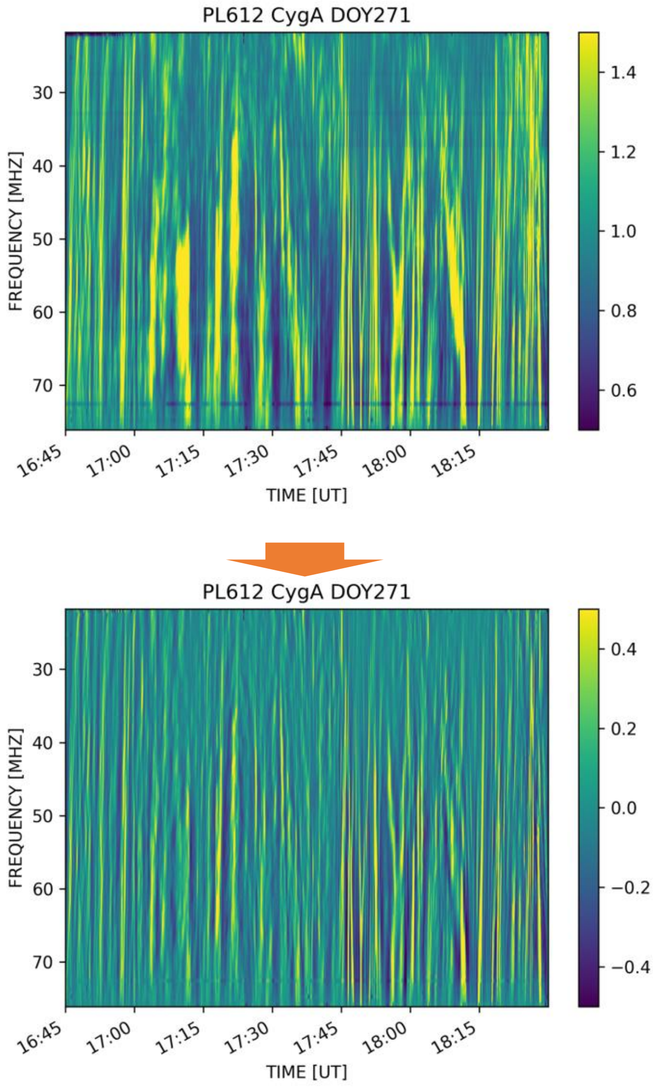


Processing scintillation data

RFI-free intensities are detrended and normalized to zero-mean values.

Zero-mean normalized intensity allows to estimate the temporal fluctuations on the radio waves intensities induced by scintillation.

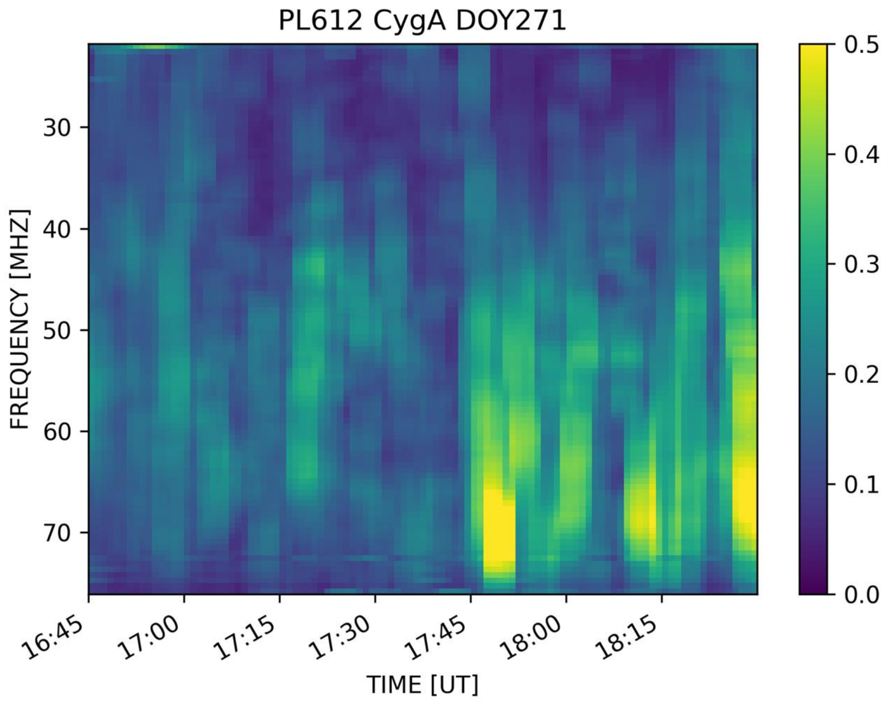
Detrending is done by subtracting a moving average with a 3-minute window



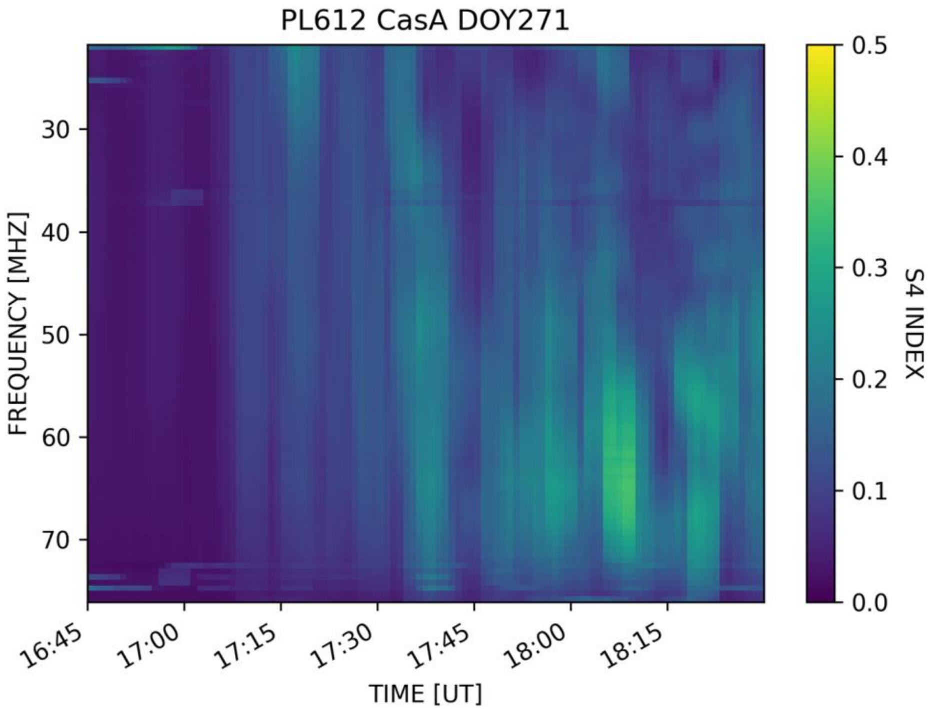
LOFAR S4 index

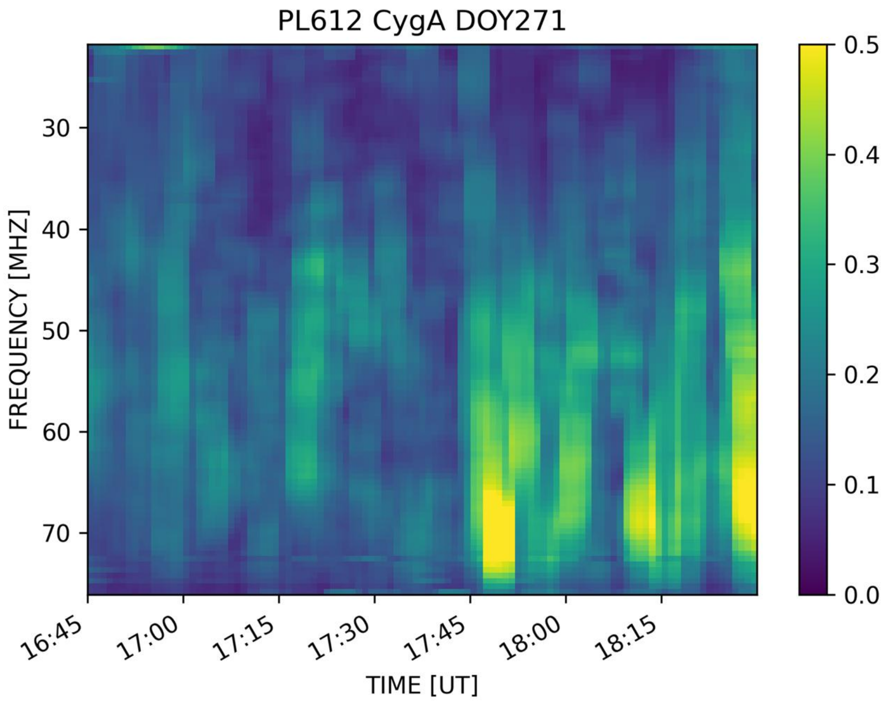
Finally, the S_4 index is calculated as a standard deviation of the zero-mean intensity fluctuation. S_4 is calculated over 3-minute intervals:

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$



LOFAR S4 index





Scintillation observations are routinely done for 3 bright radio sources – in the presented case Taurus A was below the horizon.

Publications

J. Space Weather Space Clim. 2020, 10, 10

https://doi.org/10.1051/swsc/2020010

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Topical Issue - Scientific Advances from the European Commission H2020 projects on Space Weather

RESEARCH ARTICLE OPEN ACCESS

A LOFAR observation of ionospheric scintillation from two simultaneous travelling ionospheric disturbances

Richard A. Fallows[1,*], Biagio Forte[2], Ivan Astin[2], Tom Allbrook[2,a], Alex Arnold[2,b], Alan Wood[3], Gareth Dorrian[4], Maaijke Mevius[1], Hanna Rothkaehl[5], Barbara Matyjasiak[5], Andrzej Krankowski[6], James M. Anderson[7,8], Ashish Asgekar[9], I. Max Avruch[10], Mark Bentum[1], Mario M. Bisi[11], Harvey R. Butcher[12], Benedetta Ciardi[13], Bartosz Dabrowski[6], Sieds Damstra[1], Francesco de Gasperin[14], Sven Duscha[1], Jochen Eislöffel[15], Thomas M.O. Franzen[1], Michael A. Garrett[16,17], Jean-Matthias Grießmeier[18,19], André W. Gunst[1], Matthias Hoeft[15], Jörg R. Hörandel[20,21,22], Marco Iacobelli[1], Huib T. Intema[17], Leon V.E. Koopmans[23], Peter Maat[1], Gottfried Mann[24], Anna Nelles[25,26], Harm Paas[27], Vishambhar N. Pandey[1,23], Wolfgang Reich[28], Antonia Rowlinson[1,29], Mark Ruiter[1], Dominik J. Schwarz[30], Maciej Serylak[31,32], Aleksander Shulevski[29], Oleg M. Smirnov[33,31], Marian Soida[34], Matthias Steinmetz[24], Satyendra Thoudam[35], M. Carmen Toribio[36], Arnold van Ardenne[1], Ilse M. van Bemmel[37], Matthijs H.D. van der Wiel[1], Michiel P. van Haarlem[1], René C. Vermeulen[1], Christian Vocks[24], Ralph A.M.J. Wijers[29], Olaf Wucknitz[28], Philippe Zarka[38], and Pietro Zucca[1]

The Astrophysical Journal Supplement Series, 263:36 (15pp), 2022 December https://doi.org/10.3847/1538-4365/ac6deb

OPEN ACCESS

CrossMark

Interpretation of Radio Wave Scintillation Observed through LOFAR Radio Telescopes

Biagio Forte[1], Richard A. Fallows[2,3], Mario M. Bisi[3], Jinge Zhang[4], Andrzej Krankowski[5], Bartosz Dabrowski[5], Hanna Rothkaehl[6], and Christian Vocks[7]

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[2] ASTRON, Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands
[3] RAL Space, United Kingdom Research and Innovation (UKRI) – Science & Technology Facilities Council (STFC) – Rutherford Appleton Laboratory (RAL), Harwell Campus, Oxfordshire, OX11 0QX, UK
[4] Mullard Space Science Laboratory, University College London, UK
[5] Space Radio-Diagnostics Research Centre, University of Warmia and Mazury in Olsztyn, Poland
[6] Space Research Centre, Polish Academy of Sciences, Bartycka 18A, 00-716 Warsaw, Poland
[7] Leibniz-Institut für Astrophysik Potsdam (AIP), Potsdam, Germany
Received 2021 April 16; revised 2022 April 14; accepted 2022 May 2; published 2022 December 6

Abstract

Radio waves propagating through a medium containing irregularities in the spatial distribution of the electron density develop fluctuations in their intensities and phases. In the case of radio waves emitted from astronomical objects, they propagate through electron density irregularities in the interstellar medium, the interplanetary medium, and Earth's ionosphere. The LOFAR radio telescope, with stations across Europe, can measure intensity across the VHF radio band and thus intensity scintillation on the signals received from compact astronomical objects. Modeling intensity scintillation allows the estimate of various parameters of the propagation medium, for example, its drift velocity and its turbulent power spectrum. However, these estimates are based on the assumptions of ergodicity of the observed intensity fluctuations and, typically, of weak scattering. A case study of single-station LOFAR observations of the strong astronomical source Cassiopeia A in the VHF range is utilized to illustrate deviations from ergodicity, as well as the presence of both weak and strong scattering. Here it is demonstrated how these aspects can lead to misleading estimates of the propagation medium properties, for example, in the solar wind. This analysis provides a method to model errors in these estimates, which can be used in the characterization of both the interplanetary medium and Earth's ionosphere. Although the discussion is limited to the case of the interplanetary medium and Earth's ionosphere, its ideas are also applicable to the case of the interstellar medium.

Unified Astronomy Thesaurus concepts: Interplanetary scintillation (828); Ionospheric scintillation (861); Radio telescopes (1360)

sensors MDPI

Article

Finding the Ionospheric Fluctuations Reflection in the Pulsar Signals' Characteristics Observed with LOFAR

Leszek P. Błaszkiewicz [1,*], Paweł Flisek [1], Kacper Kotulak [1], Andrzej Krankowski [1], Wojciech Lewandowski [2], Jarosław Kijak [2] and Adam Froń [1]

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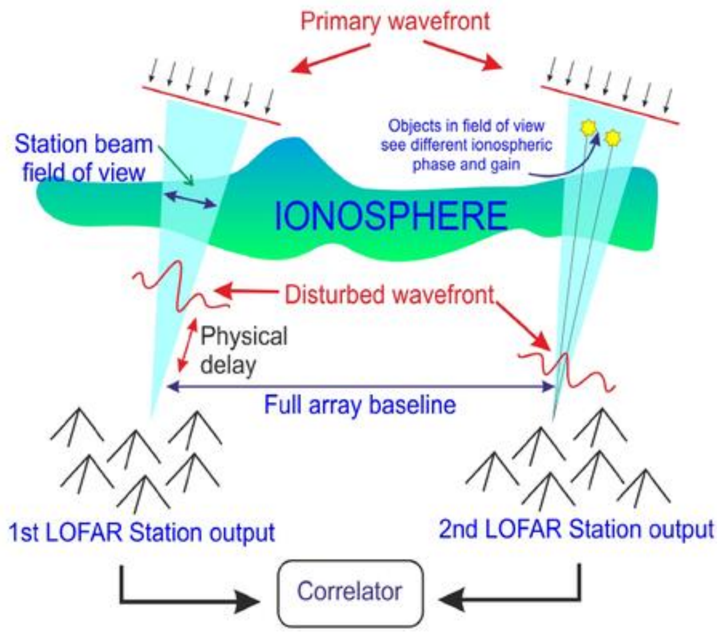
[2] Janusz Gil Institute of Astronomy, University of Zielona Gora, 65-417 Zielona Gora, Poland; w.lewandowski@ia.uz.zgora.pl (W.L.); J.Kijak@ia.uz.zgora.pl (J.K.)
* Correspondence: leszekb@matman.uwm.edu.pl; Tel.: +48-510-041-396

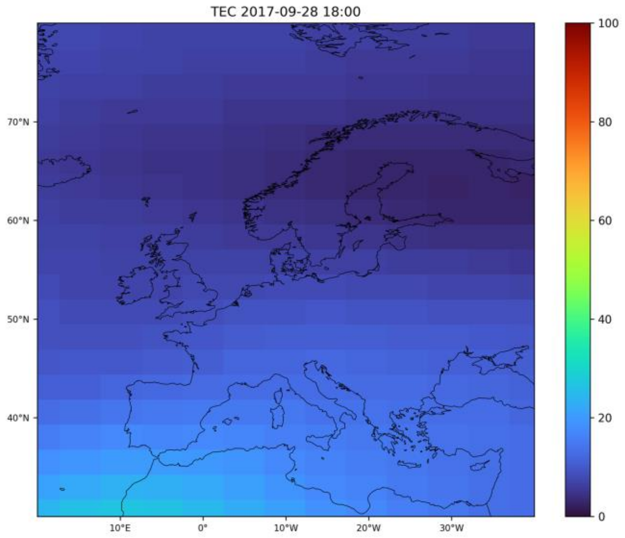
Abstract: Pulsars' signals reaching the atmosphere can be considered being stable under certain assumptions. In such a case the ionosphere remains the main factor distorting signal from the extraterrestrial sources, particularly if we observe them at long radio waves. In this article we present the results of the analysis of relative peak flux changes for two selected pulsars: PSR J0332+5434 (B0329+54) and PSR J1509+5531 (B1508+55), observed with the long radio wave sensor (The PL612

LOFAR ionospheric calibration



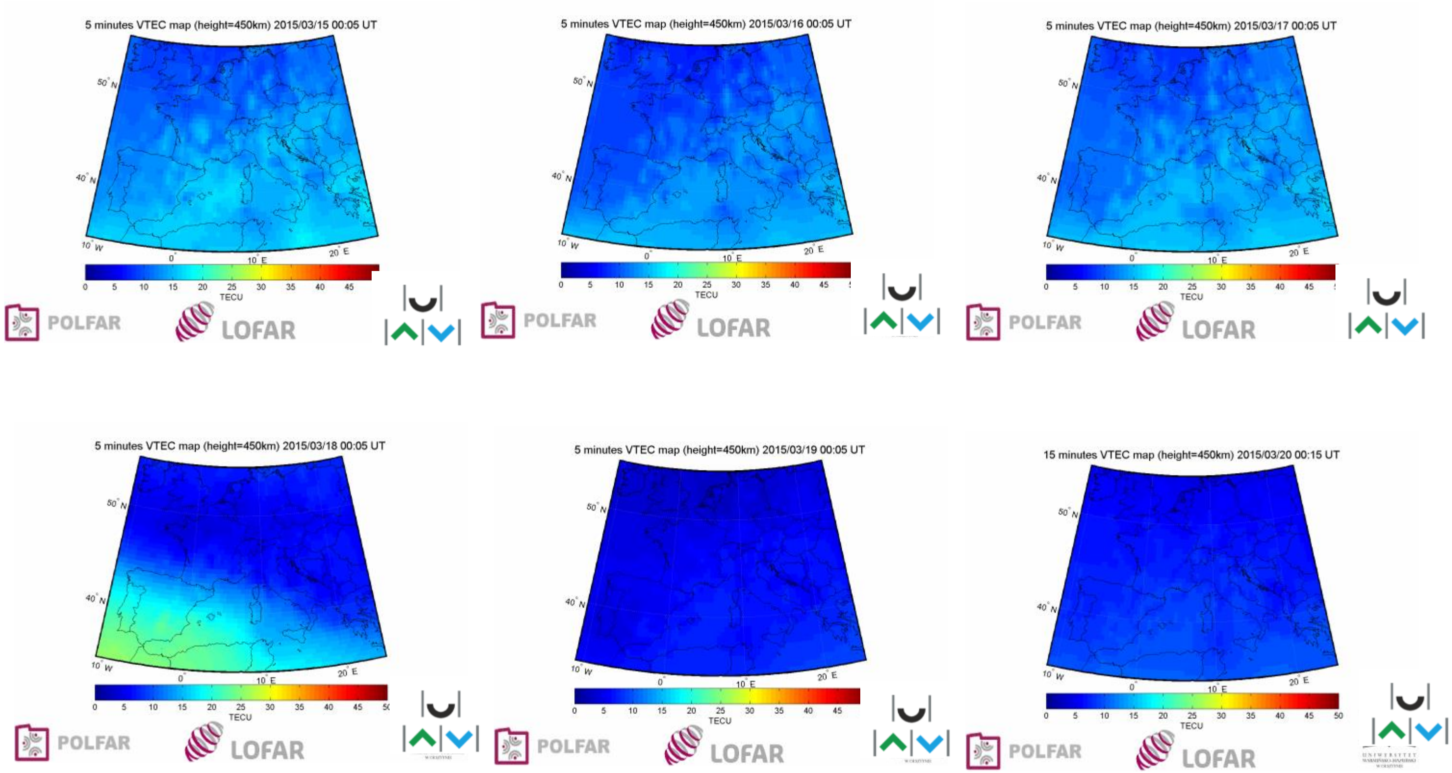
As an instrument based on relatively long baselines (hundreds of km), the International LOFAR Telescope requires careful ionospheric calibration routines.

For this purpose the SRRC/UWM prepares regional TEC maps based on the IGS rapid solutions.



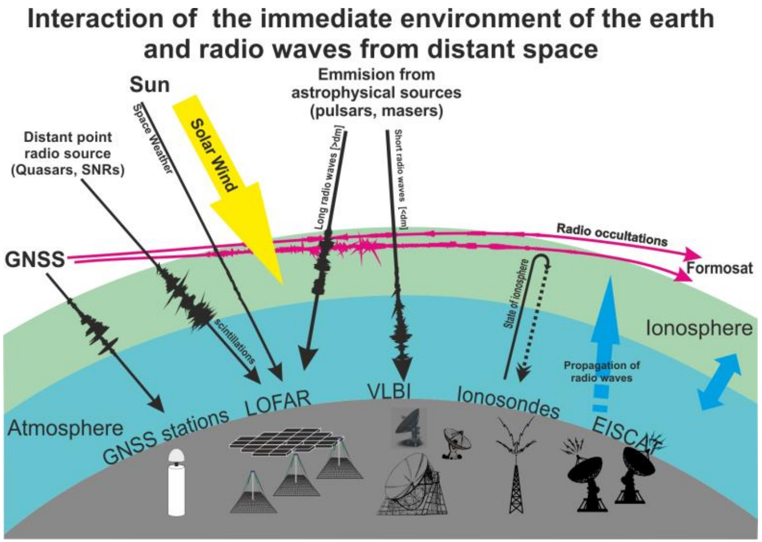
LOFAR ionospheric calibration

5-minute European TEC maps, 2015-03-15 - 2015-03-20



POLFAR

Summary

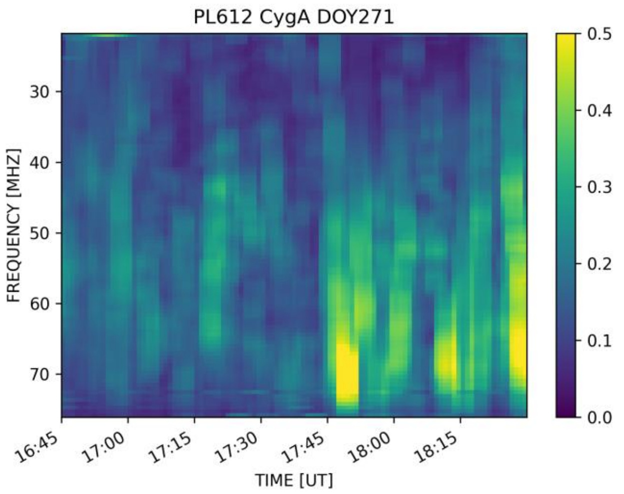


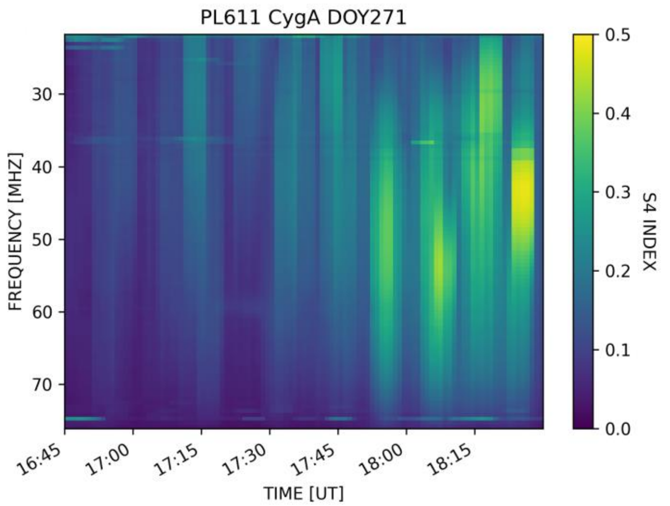
LOFAR is a novel instrument with unique capabilities of ionospheric sounding, especially in field of ionospheric irregularities.

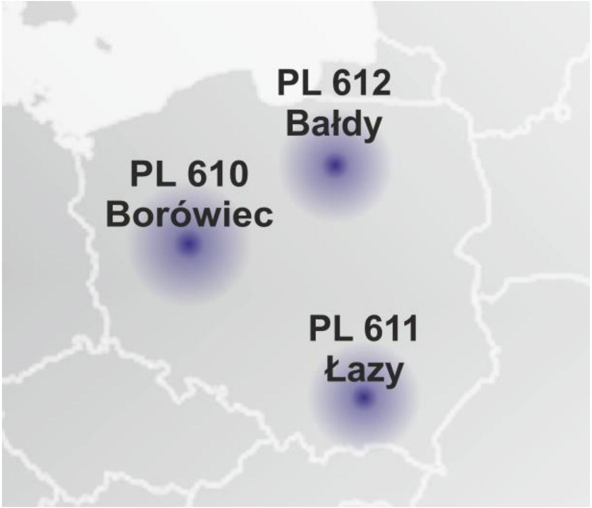
In combination with traditional techniques, LOFAR can give a new insight to the scale of the structures in the ionosphere.

Summary

Cooperation between three Polish LOFAR stations can provide the additional data and analysis. Observations made with those unique network can be used to describe ionospheric irregularities like it has never been before.







Summary

PL612 LOFAR station in Olsztyn has a unique configuration. In Bałdy a GNSS scintillation reciver is established. Moreover, around 30 kilometers away an ionosonde is located.