# Изследвания на слънчевата активност в радио- и оптичния диапазон

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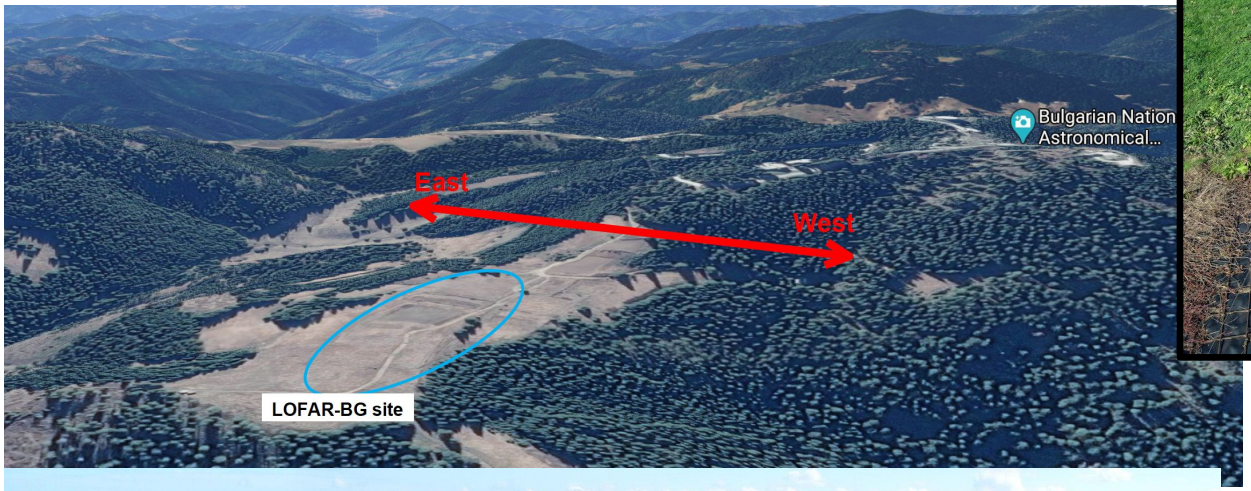
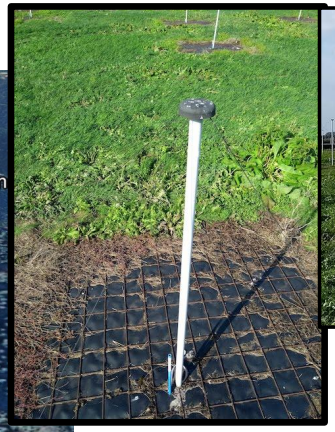
# Какво е LOFAR?

- LOFAR е "**Low Frequency Array**" – един от водещите международни радиотелескопи в света; изцяло Европейски проект, воден от института ASTRON в **Нидерландия**.
- LOFAR комбинира изключително висока резолюция с голяма чувствителност, и предоставя уникален поглед към земната атмосфера, Слънчевата система и Вселената в метровите радиовълни (10-250 MHz).
- Телескопът се състои от 52 свързани помежду си антенни масиви (станции) в 8 европейски държави, всяка от които може да се използва и като **самостоятелен телескоп**;

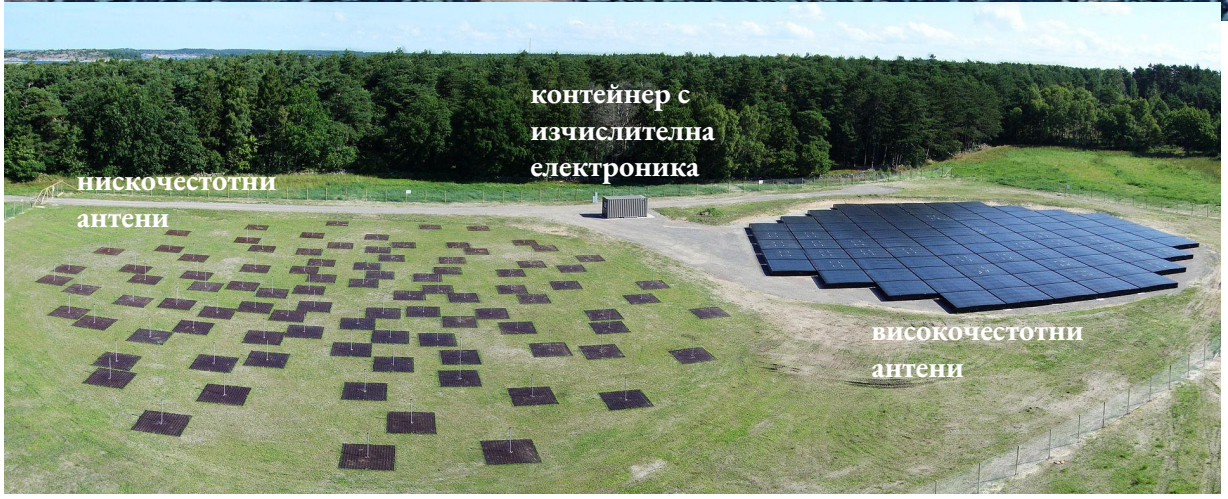

- Базови линии от над 2000 км дават на LOFAR резолюция на голям оптичен телескоп!
- Сигналите от всяка LOFAR станция се пренасят по оптични линии до централния процесор и се комбинират цифрово със сигналите от останалите станции в Европа;
- Първите LOFAR станции са открити през 2012г в Нидерландия. Следват **станции в Германия, Англия, Франция, Швеция, Полша, Ирландия** (открита през 2017г), **Латвия** (2019), Италия и България (2026г).
- Централният изчислителен център за данните е в Грьонинген, Холандия.

# Какво е LOFAR?
# Международна LOFAR станция

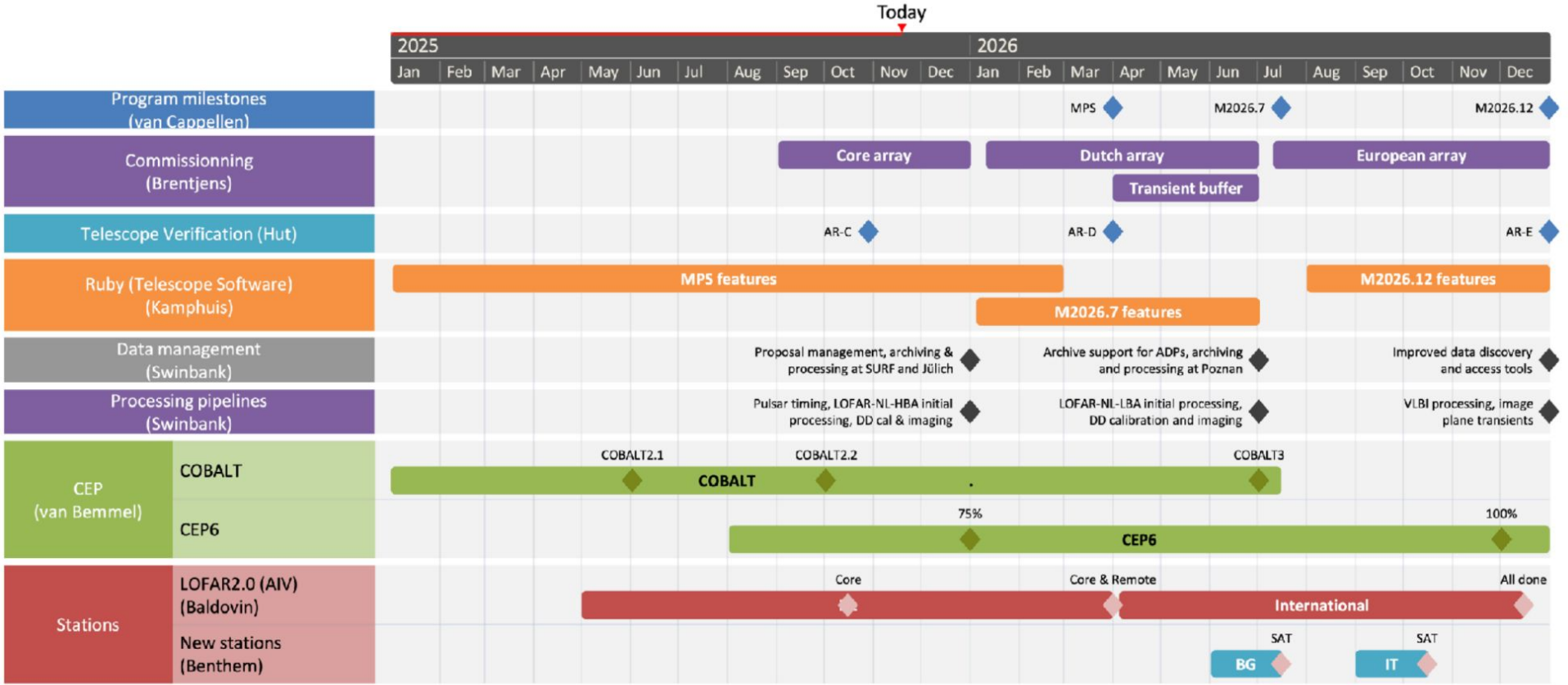






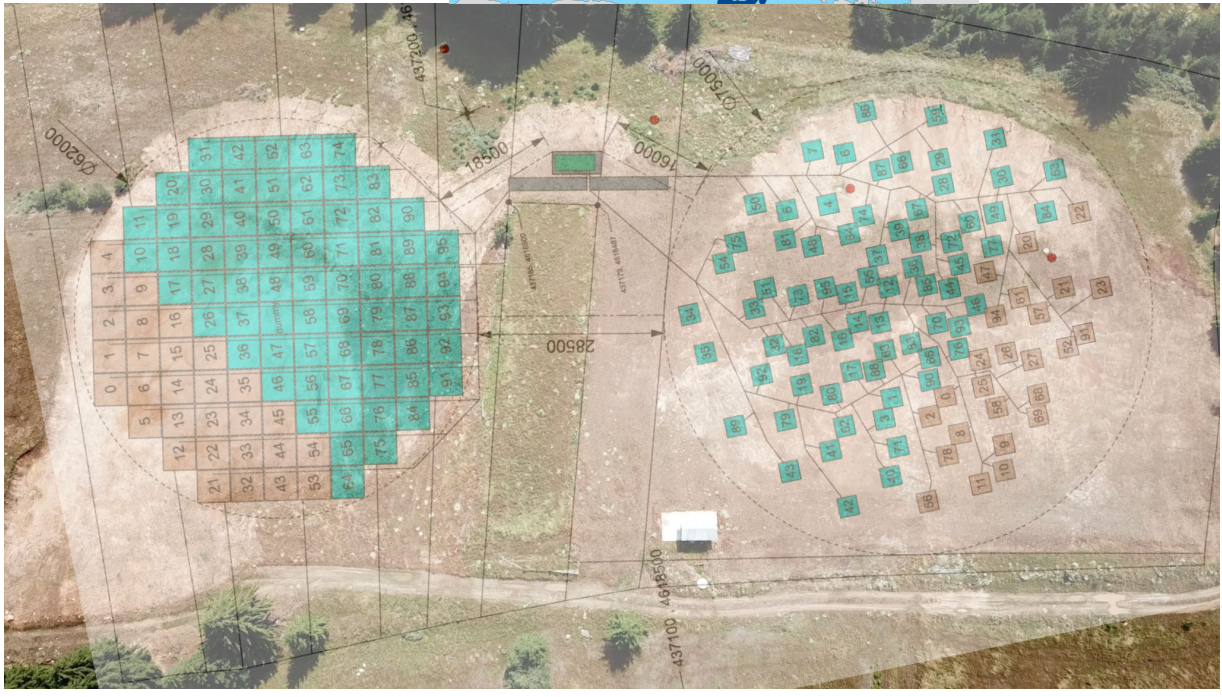
# LOFAR2 Delivery schedule



# LOFAR-BG инсталация

# LOFAR-BG инсталация


LOFARBG

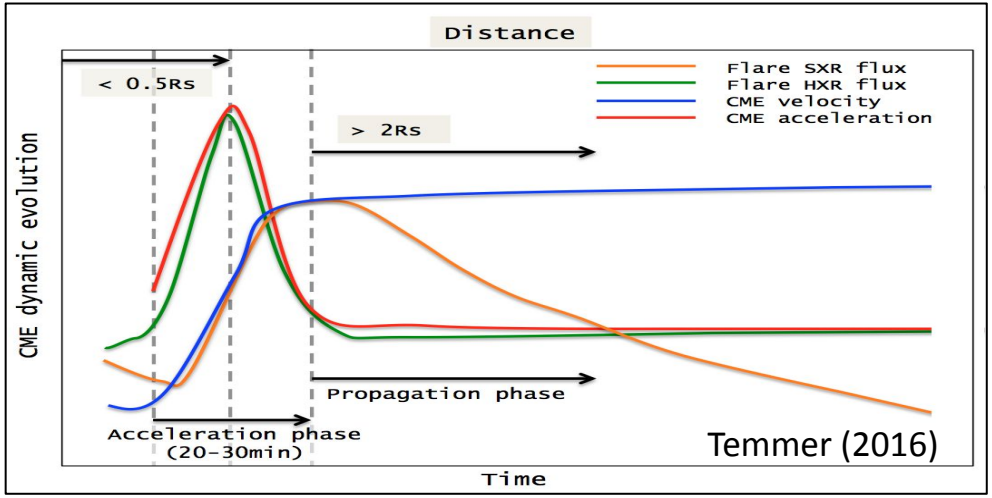


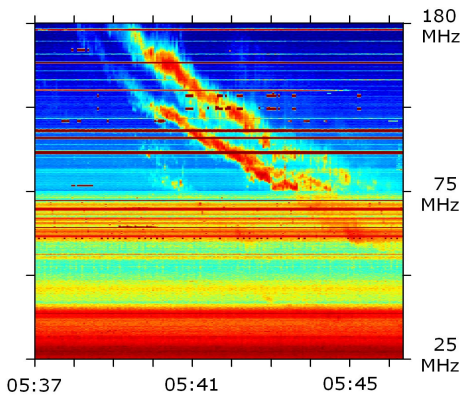
# LOFAR-BG: Подготовка на инсталацията

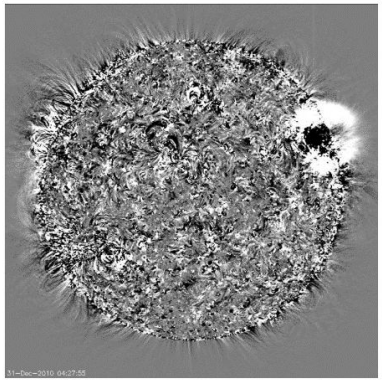
- Очаквана инсталация юни-август 2026 г.


# Ускорение на частици в слънчевата корона

- Слънчевите високоенергитични частици (SEP) са ускорени от слънчеви изригвания и коронални изхвърляния на маса (консенсус)
- Освобождаването на енергия от изригванията е импулсивно
- Най-динамичният регион за еволюция на короналните масови изригвания в рамките на 5 Rsun (Temmer 2016);
- Ударни вълни могат да се образуват с ниски стойности от 1.2 Rsun в слънчевата корона (Gopalswamy et al. 2013)
- И в двата случая по-голямата част от ускорението на частиците се случва в ранните етапи (за повечето събития)
- Наша основна цел е  дистанционно да характеризираме събития с коронални ударни вълни



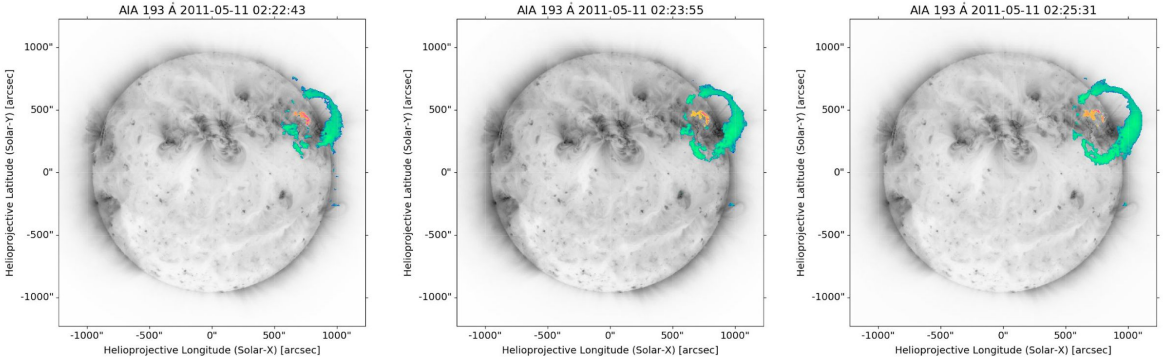



# Tracking Large-Scale Optical/EUV Eruptions

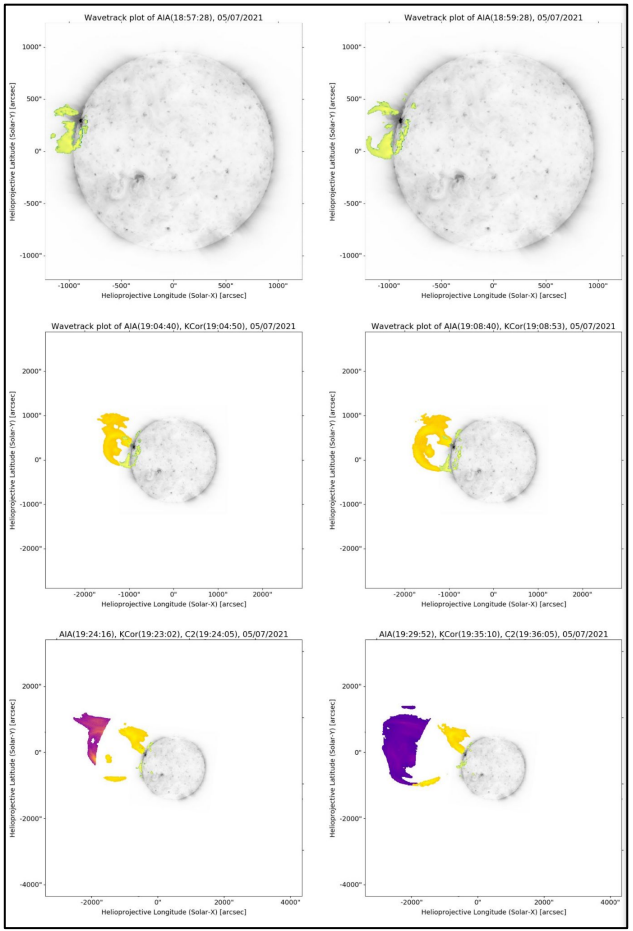
## Wavetrack

- Algorithmic a-trous wavelet-based tracking code in Python
- Developed for tracking EUV waves in AIA observations
- Recently applied to K-Cor and LASCO obs.
- Showing great results on base difference data!
- Software freely available!




Stepanyuk & Kozarev, 2022

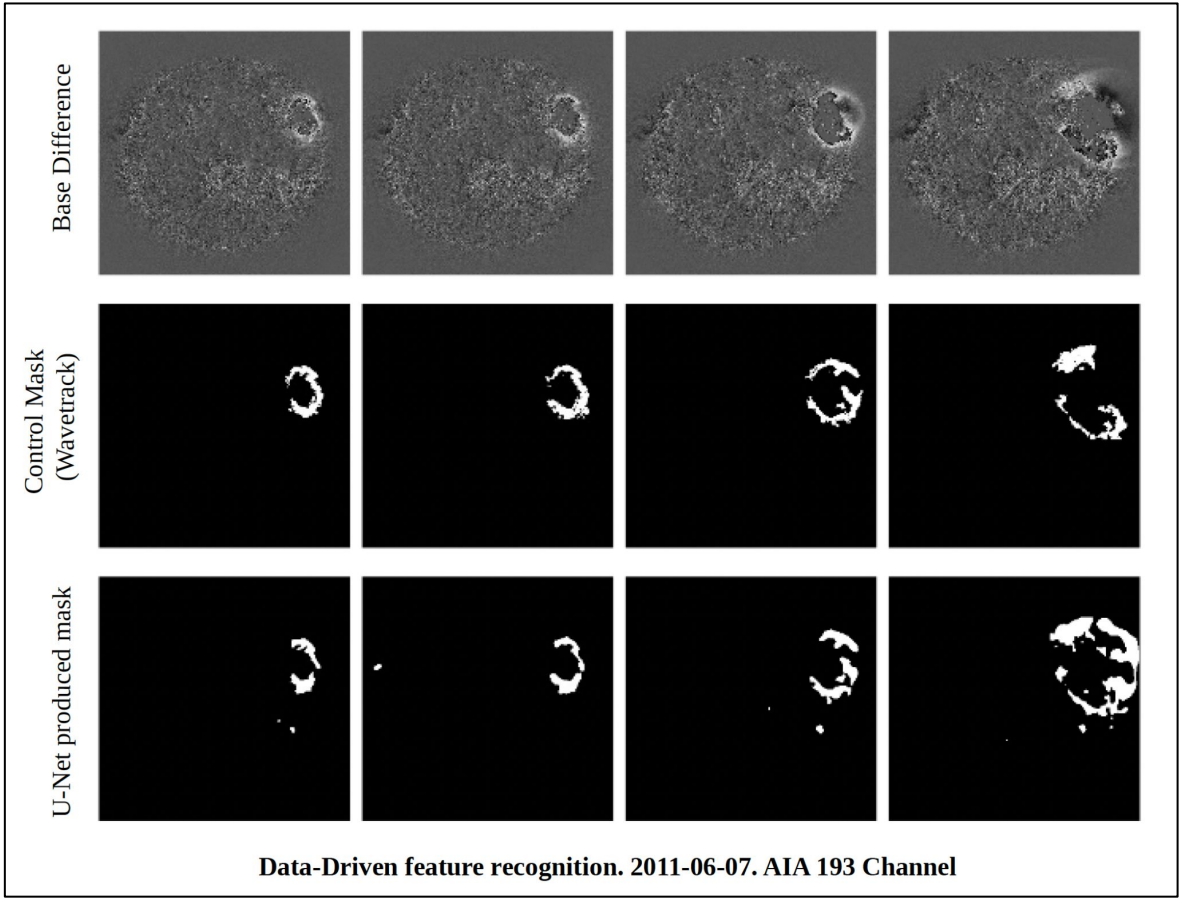
https://gitlab.com/iahelio/mosaiics/wavetrack




Stepanyuk & Kozarev, 2024

# Tracking Large-Scale Coronal Eruptions - Wavetrack & U-Net

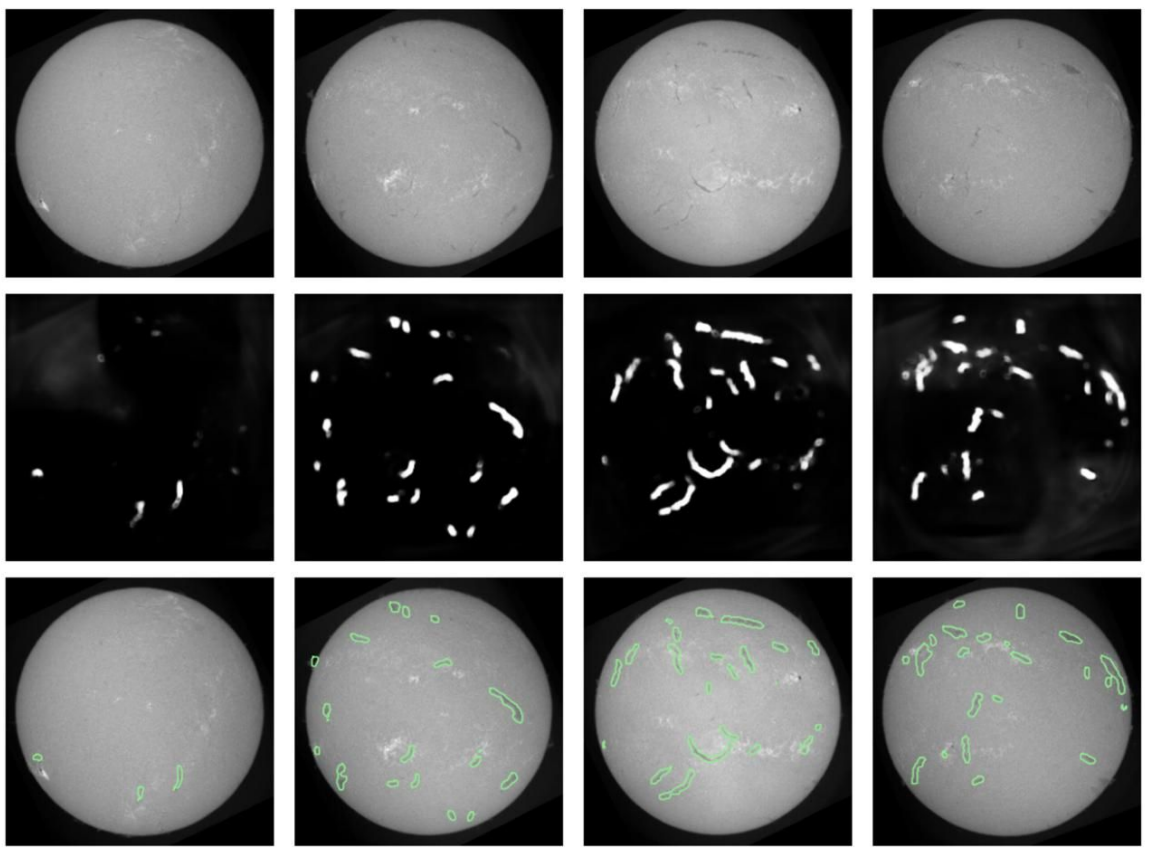
- Recently developed a hybrid, U-Net-based ML approach
- Training data from Wavetrack algorithmic solutions
- Data augmentation on the fly reduces data overhead
- Results are very promising!



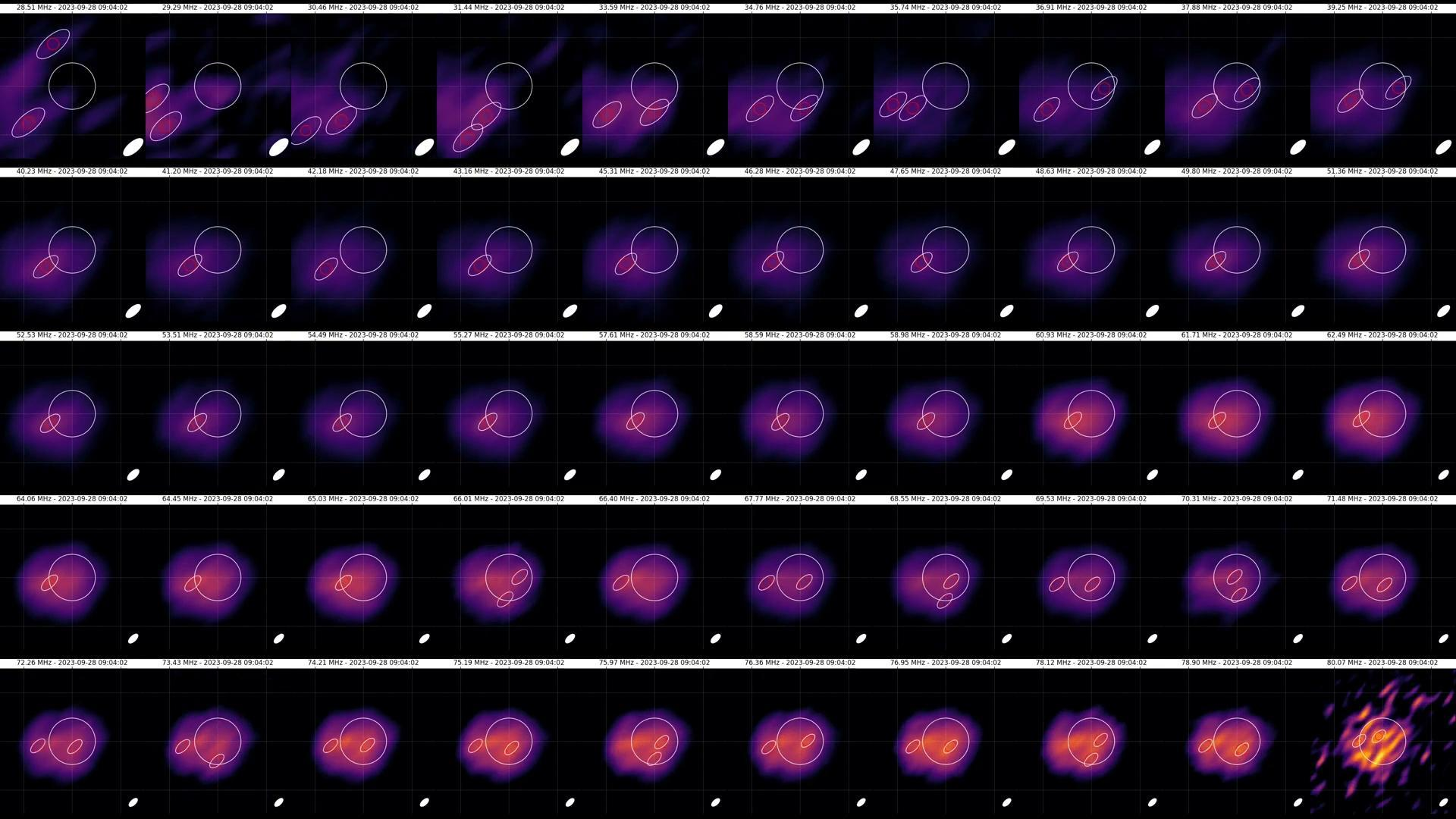

Stepanyuk & Kozarev, under review

# Filament Detection

- Adopted our wavelet and data-driven image segmentation techniques for ground-based optical instrument data (K-Cor, Kanzelhöhe, Belogradchik, Rozhen data)
- Trained and optimized a U-Net ensemble of models for **filament recognition and tracking**
- Used Kanzelhöhe full-disk synoptic observations for training data
- Average IOU 0.76 on validation set
- Figure shows sample output masks (middle row) and overlays on observations (bottom row)



Stepanyuk et al., in prep.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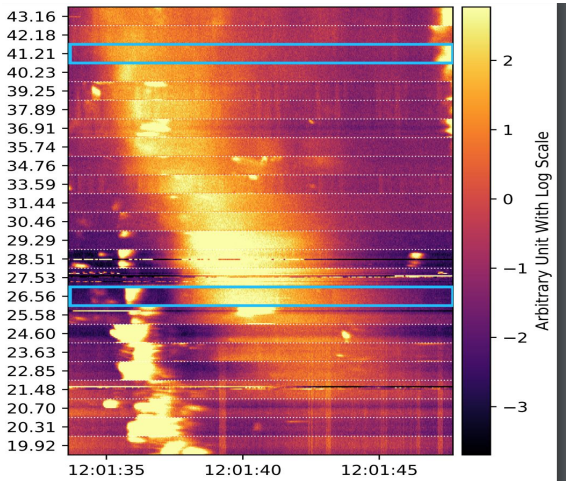
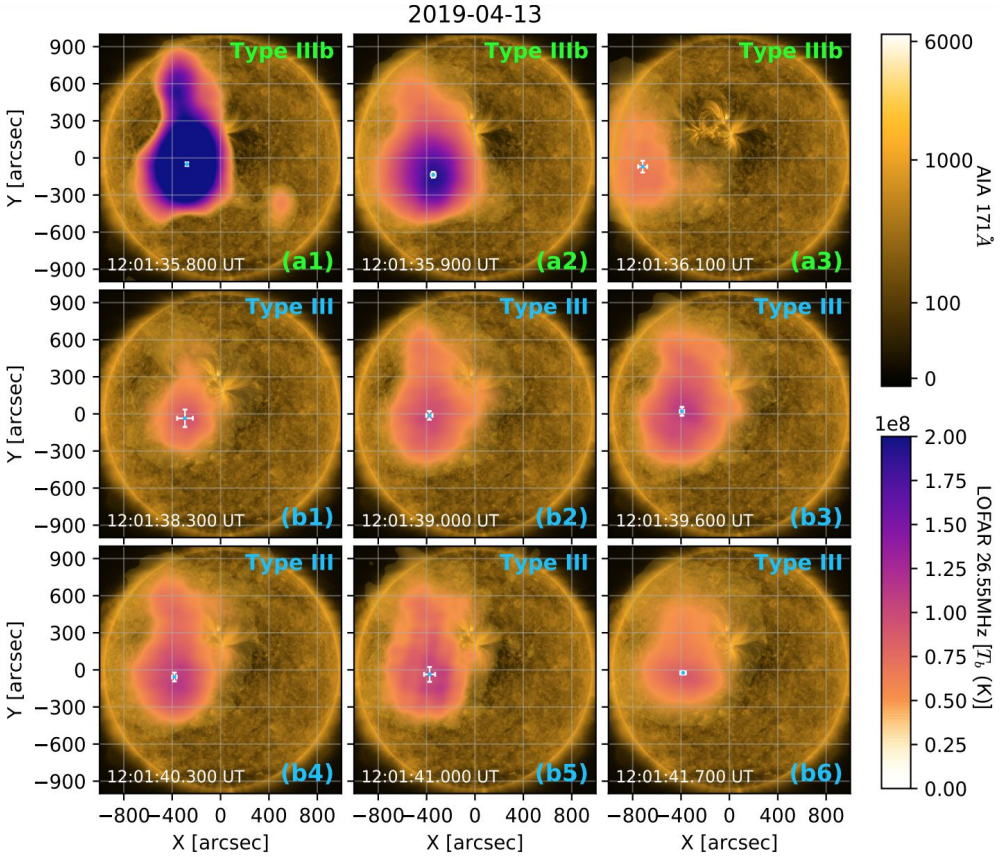
78.12 MHz - 2023-09-28 09:04:02
78.90 MHz - 2023-09-28 09:04:02
80.07 MHz - 2023-09-28 09:04:02

# Solar radio burst observations

- Type II, III, IV radio observations provide important information about
    - nature and dynamics of eruptions
    - particle acceleration
    - heliospheric connectivity
- recently, imaging in metric-decametric band (10-300 MHz)
- **LOFAR, MWA, NRH telescopes**



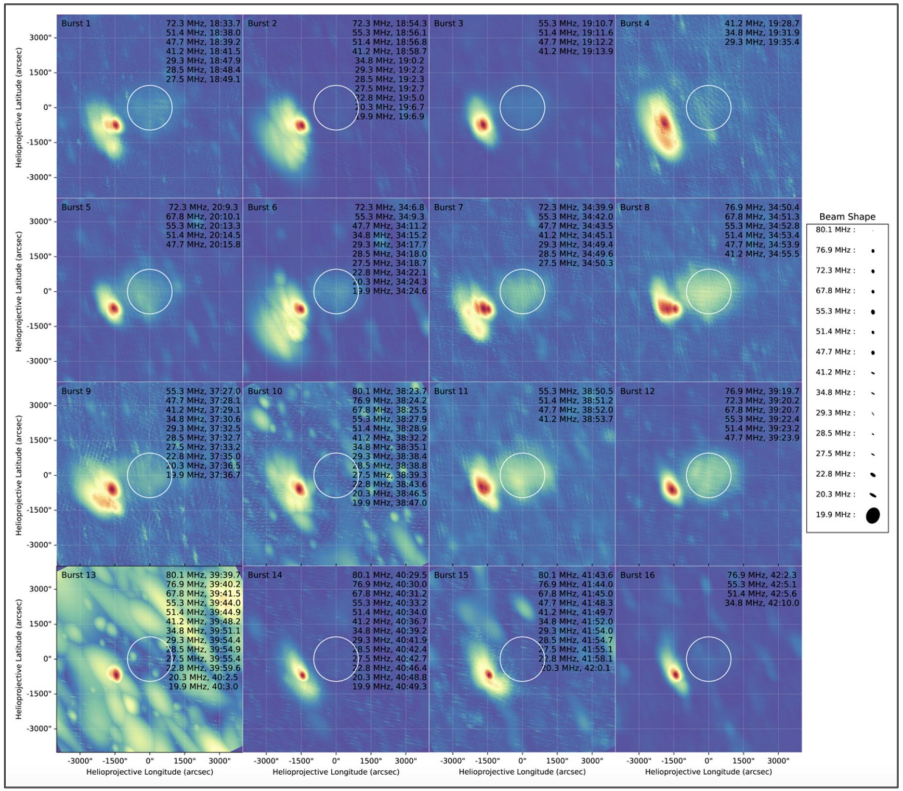

# Type III bursts

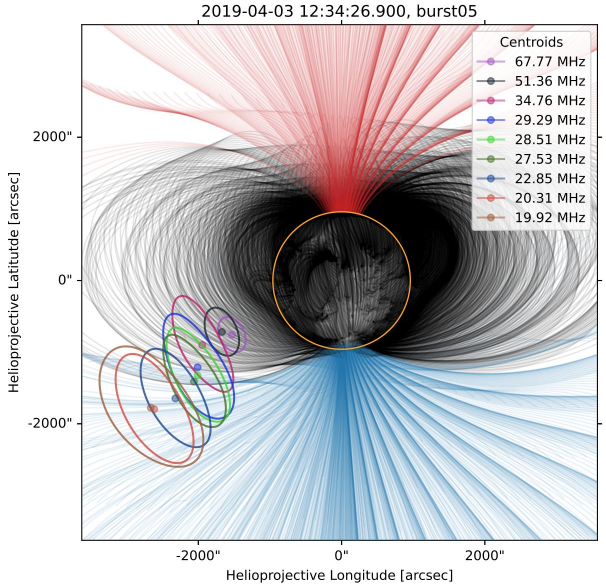


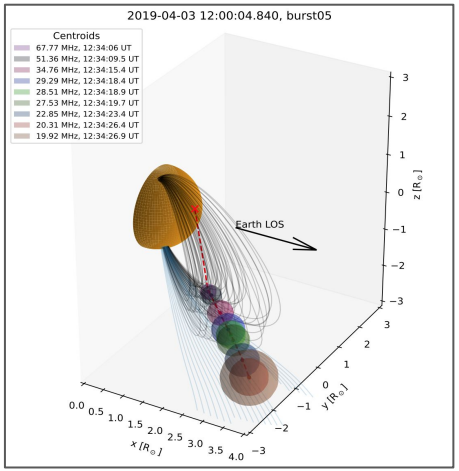

(Zhang et al. 2020)

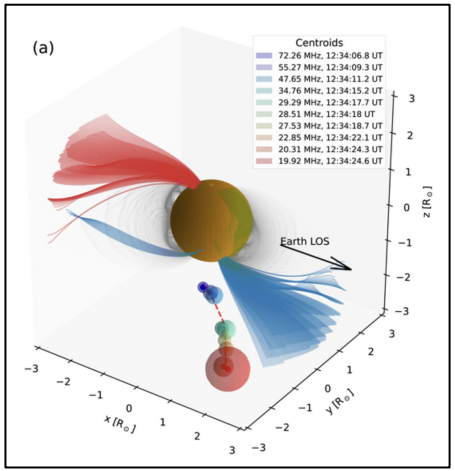
# LOFAR type III observations

- Nedal et al., 2023 imaged LOFAR data
- Observed 15 bursts in 20 minutes of quiet time
- Same source determined, no EUV or X-ray signature

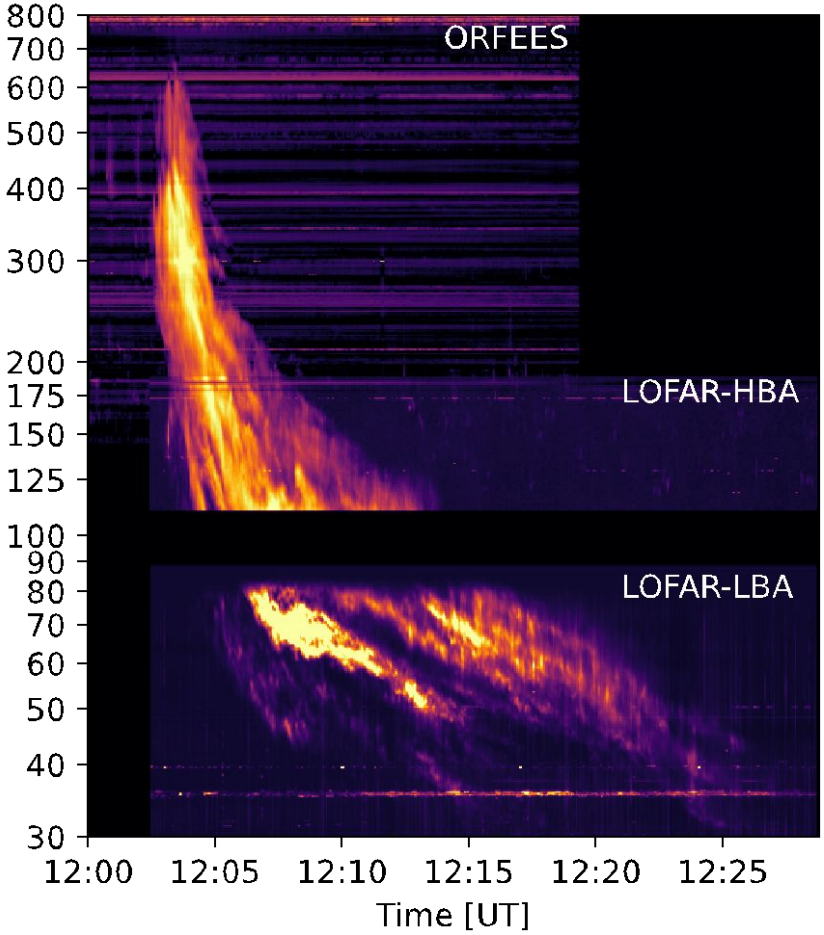


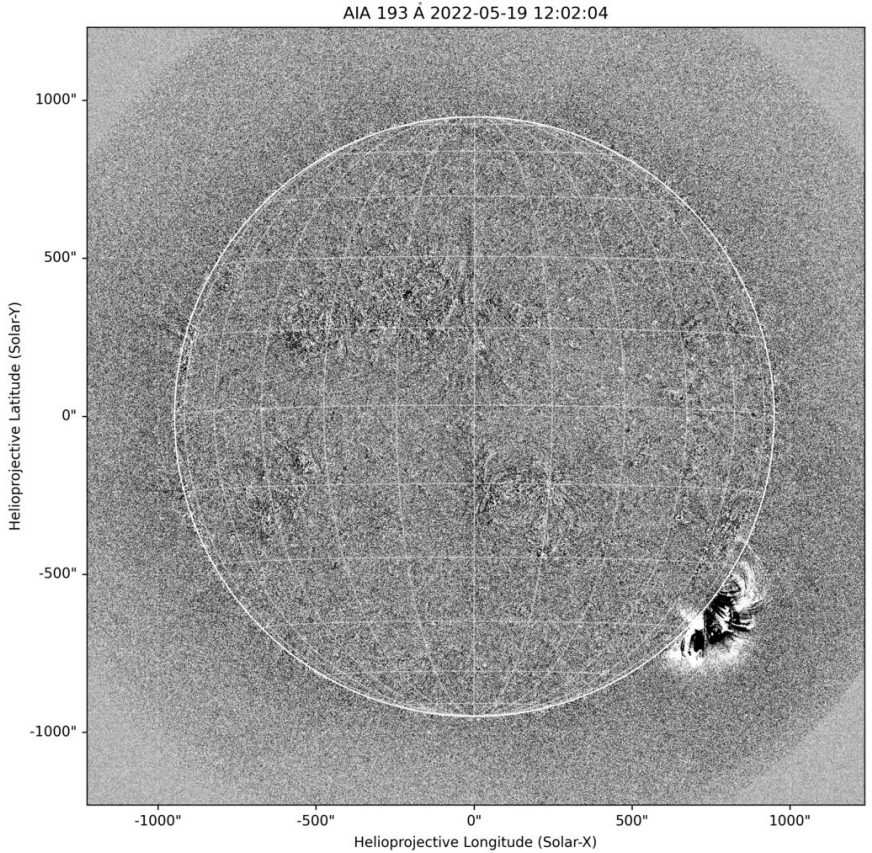



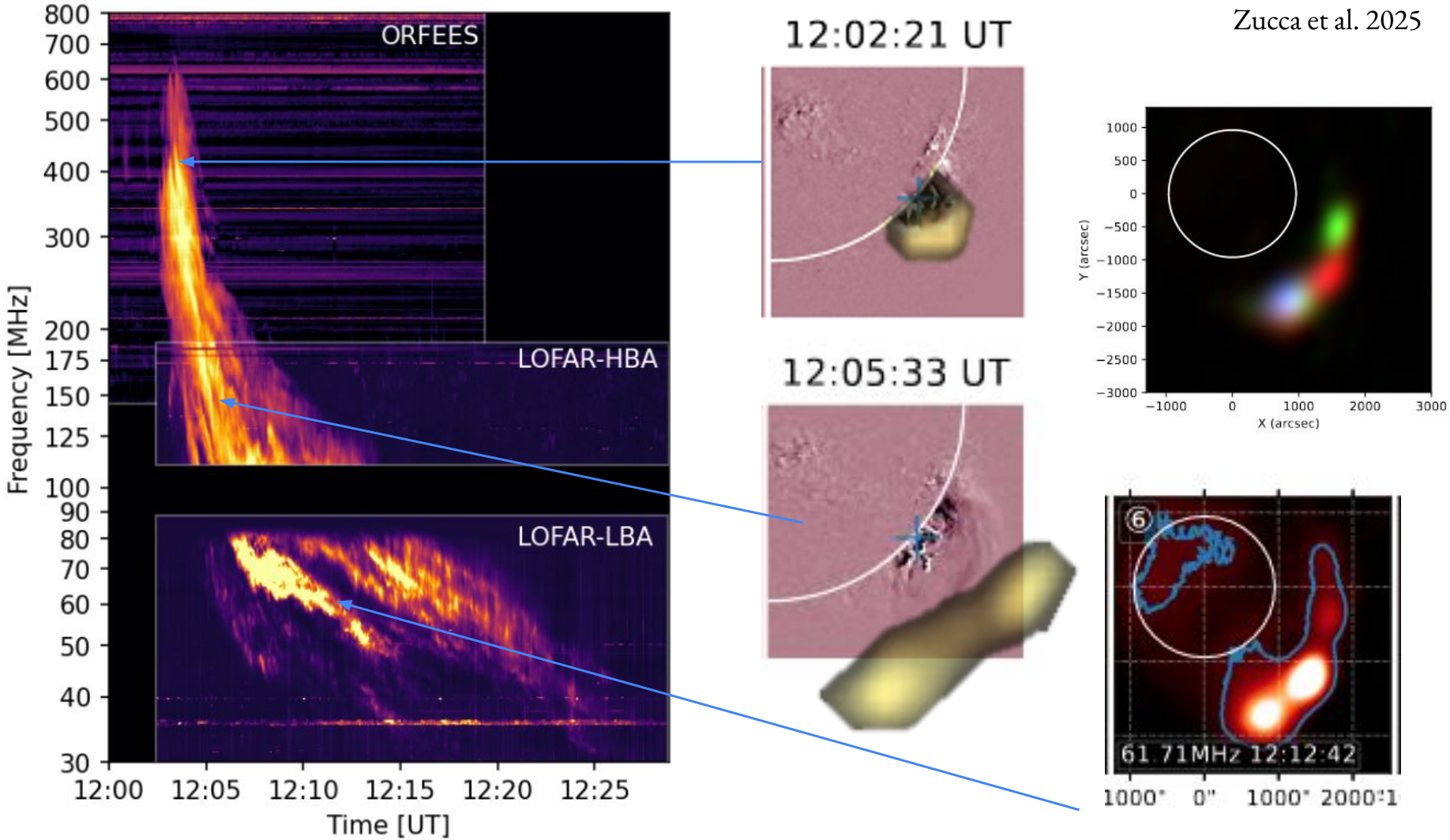



# Multi-Lane Type II Burst Imaged with LOFAR LBA – Zucca+ 2025

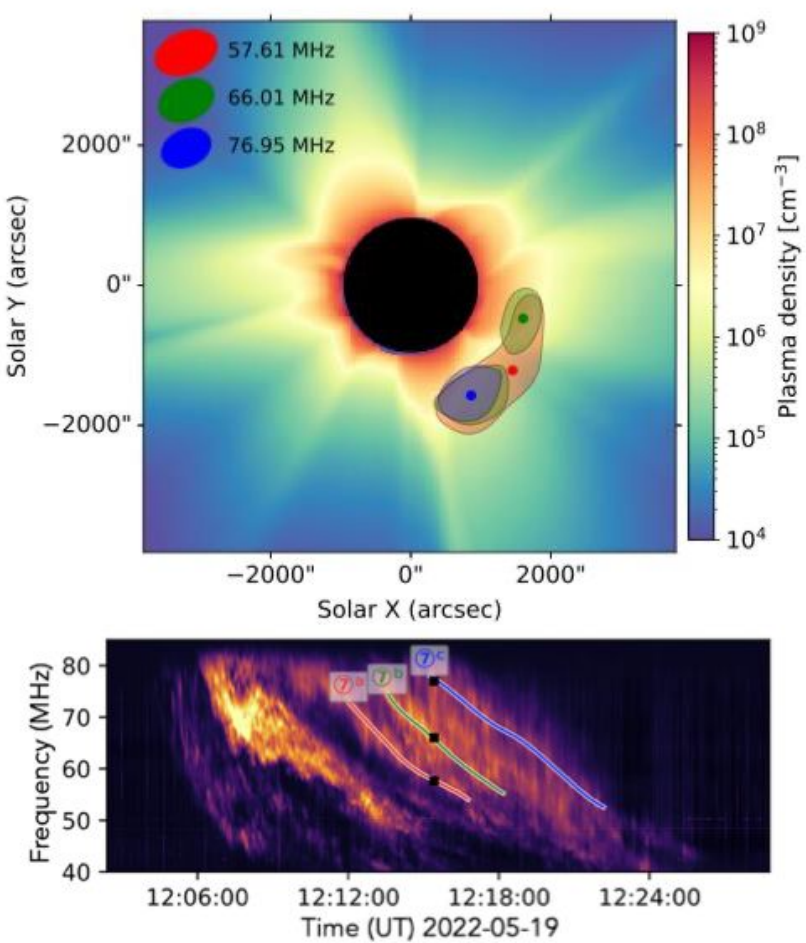


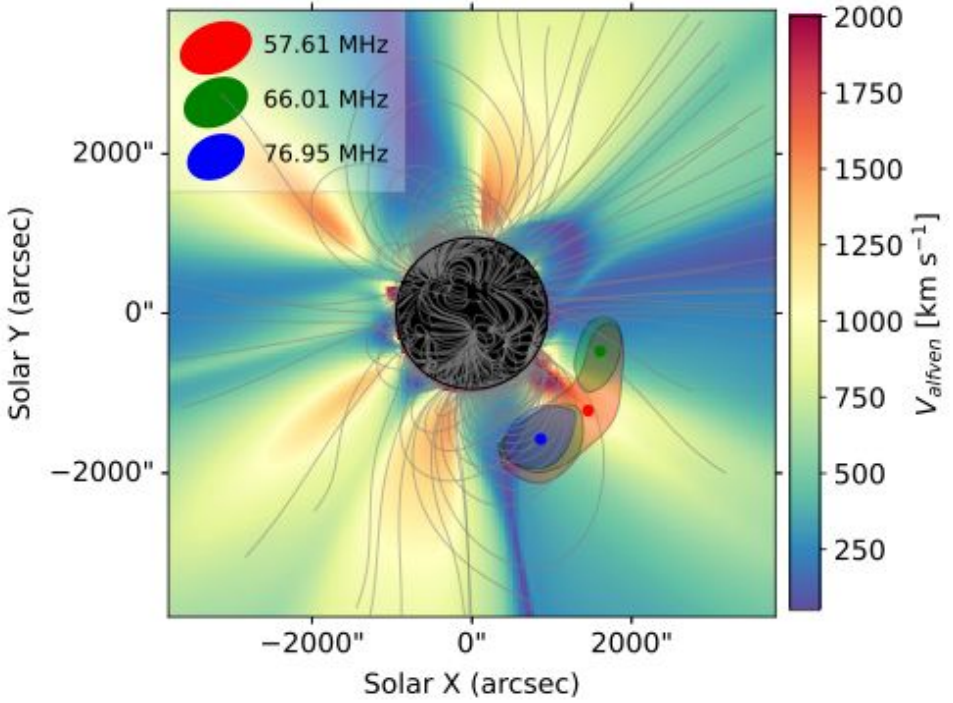



Zucca et al. 2025



# Comparison with coronal MHD model

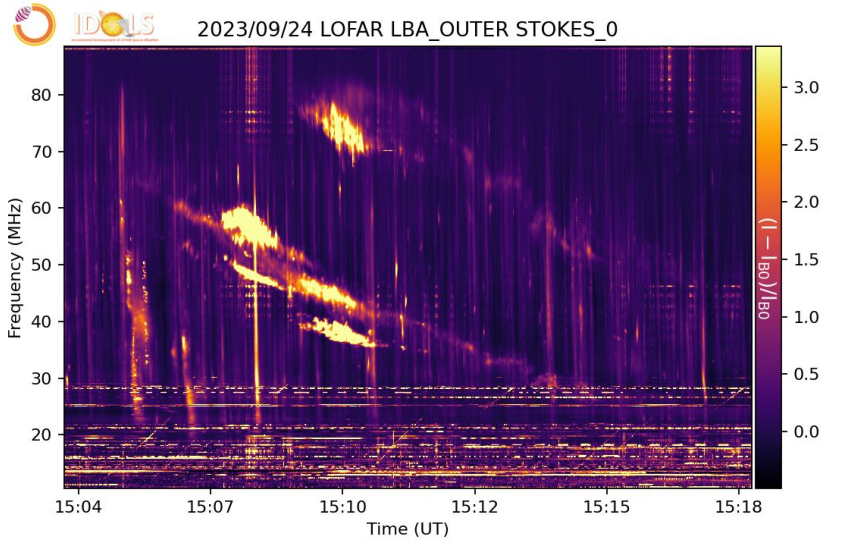


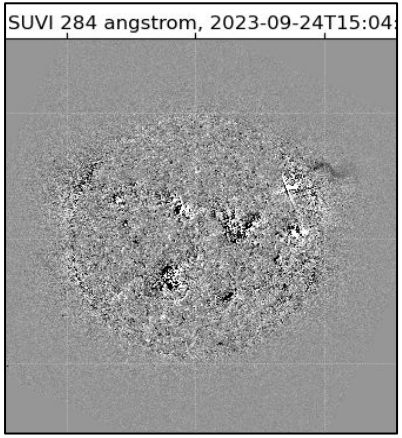



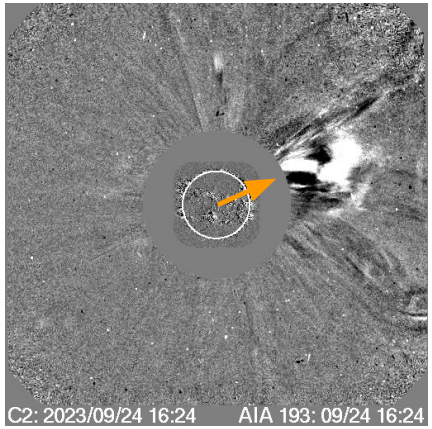

- Separate emission sources originate from different coronal environments on front along the shock propagation direction

Zucca et al. 2025

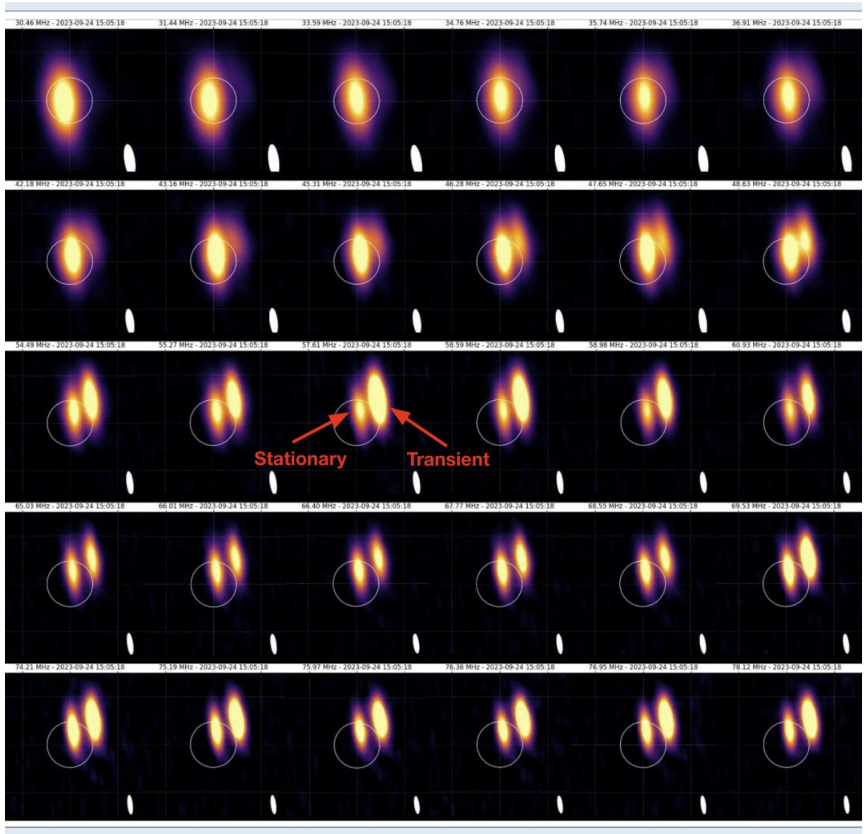
# Tracking of a type II burst with LOFAR/LBA – Yotov, Kozarev+ (in prep)




– Separate and track stationary and transient sources
– Imaging gives important information on dynamics



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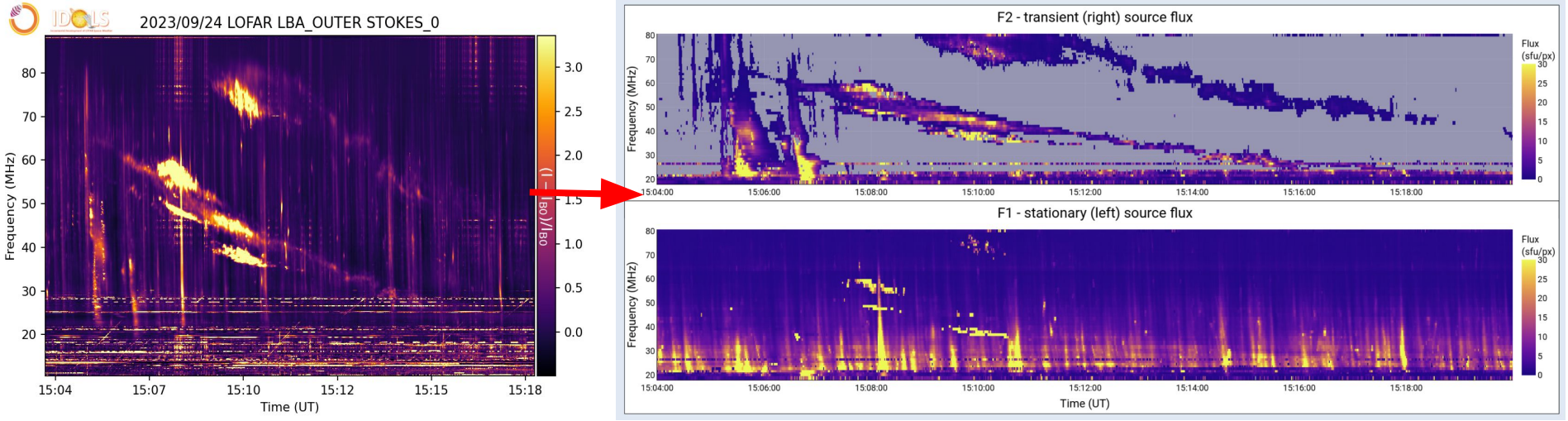
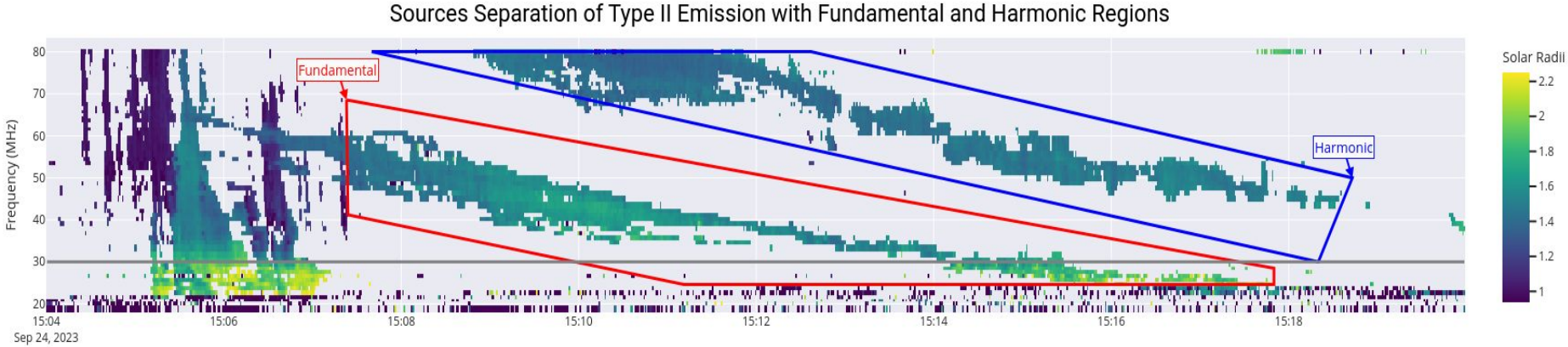
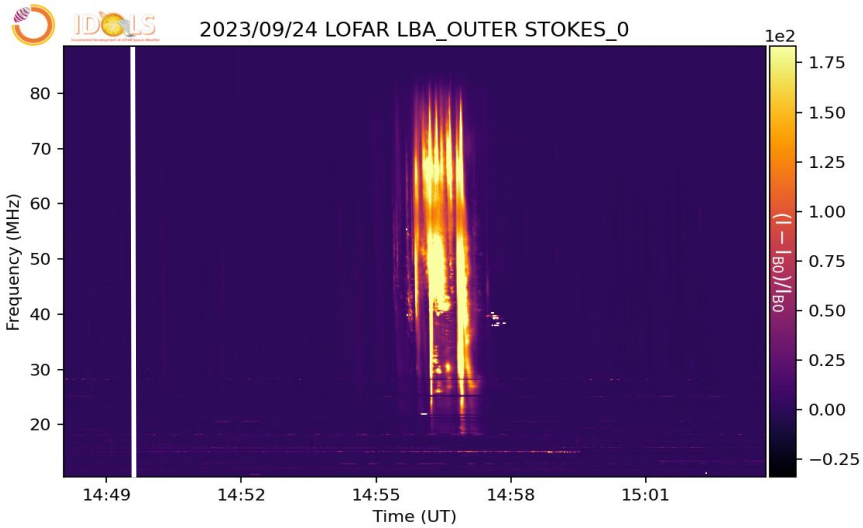
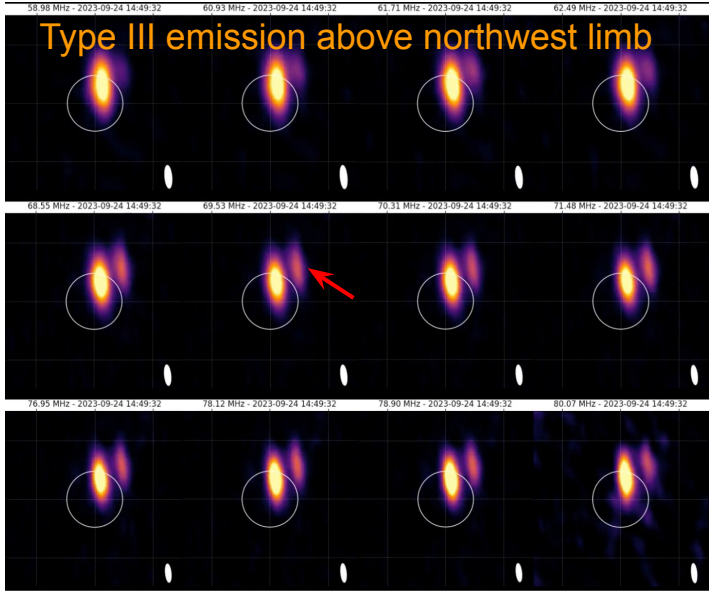


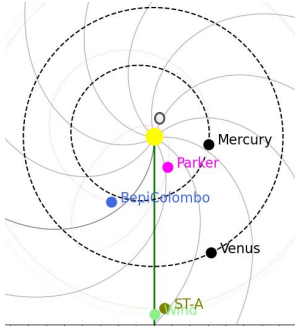
# In situ and remote detection of flare electrons with LOFAR and PSP - Kozarev, Yotov+ (in prep.)

– M1.0 flare on 24 September, 2023
– Type III burst storm 5 minutes after flare start
– LBA imaging reveals source above northwest limb

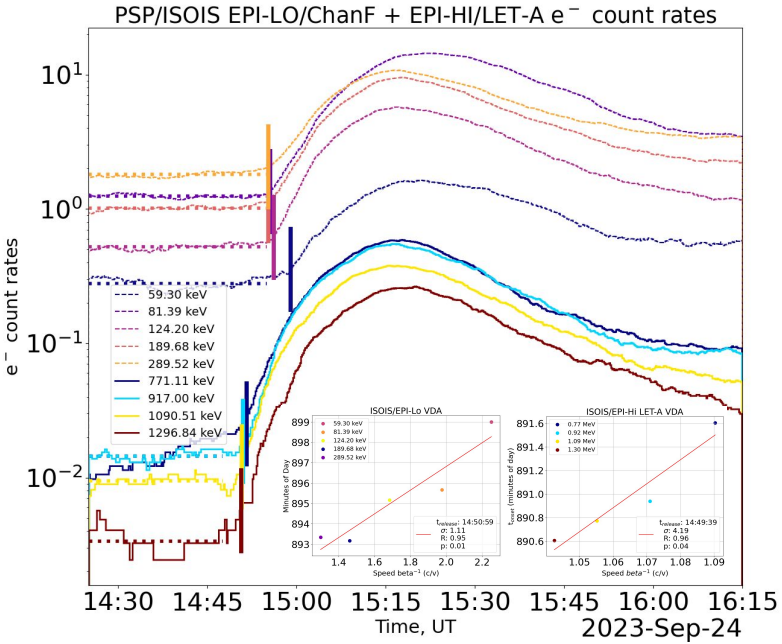



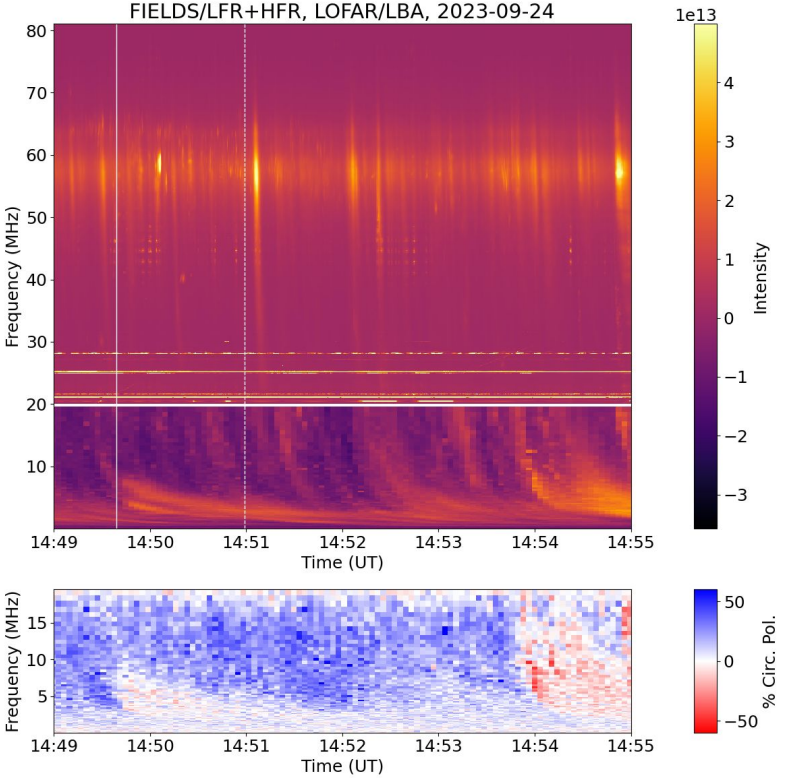
# In situ and remote detection of flare electrons with LOFAR and PSP - Kozarev, Yotov+ (in prep.)




– PSP very well positioned, electron beams observed in situ

– VDA relates them to pre-flare bursts with circular polarization



# Пилотен антарктически астрономически проект

**“Въздействие на слънчевата активност върху йоносферната динамика и потоците високоенергитични частици над Антарктида”**

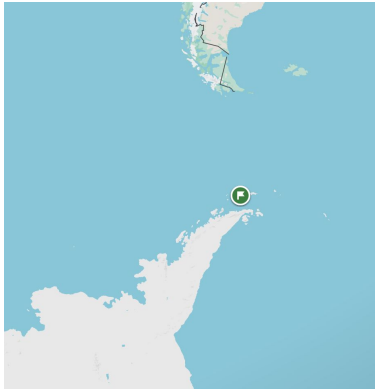
Финансираща организация: **Софийски университет**

Период на изпълнение: **2024-2025**

Базова организация: **Институт по астрономия с НАО**

Партньорски организации:

- **Технически университет-София**
- **Висше военноморско училище “Никола Вапцаров”**



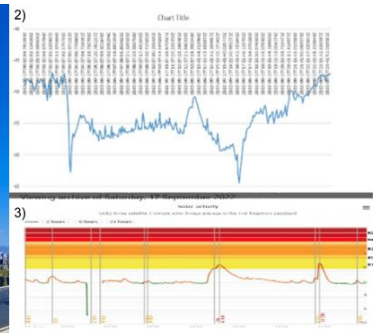
## Цели

**1)** Наблюдение на слънчевата активност на радио честоти 50-500 MHz;

**2)** Наблюдение на ефектите на слънчевите избухвания върху D-слоя на йоносферата чрез VLF наблюдения на далечни наземни източници;

**3)** Наблюдения на потоците космични лъчи над Антарктида

**4)** Наблюдения на измененията на Земното магнитно поле в района на българската полярна станция.

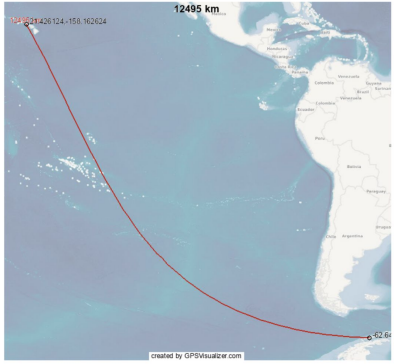



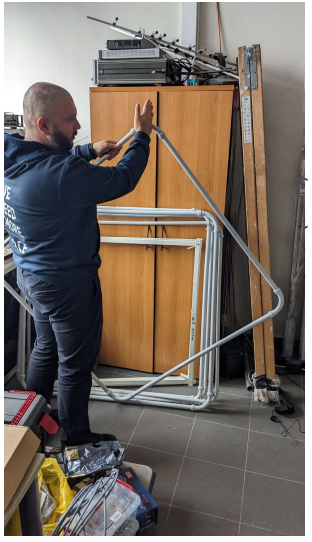
POLAR ASTRONOMICAL OBSERVATORY BULGARIA

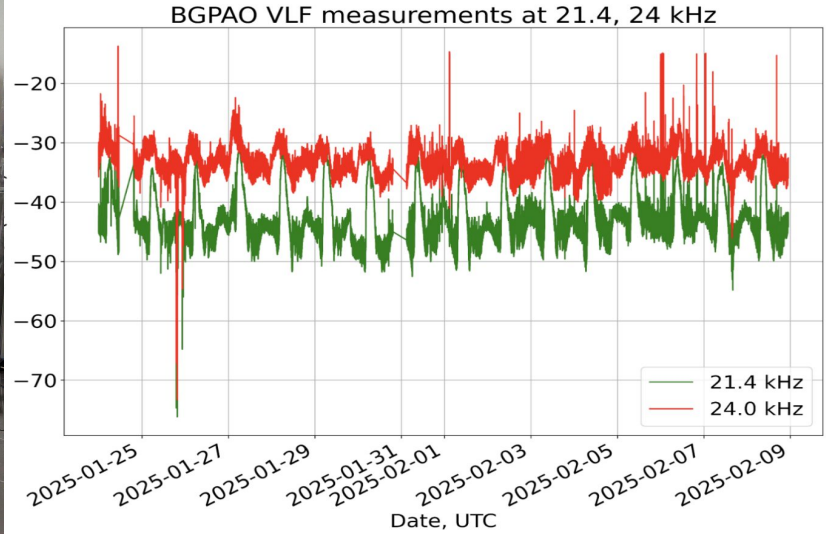
# VLF наблюдения на йоносферна динамика

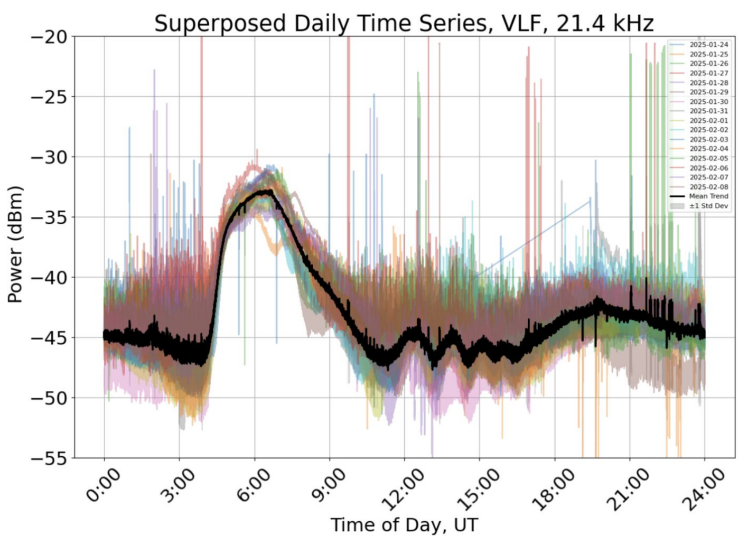
VLF emitter in Suttler, Maine (24.0 kHz)

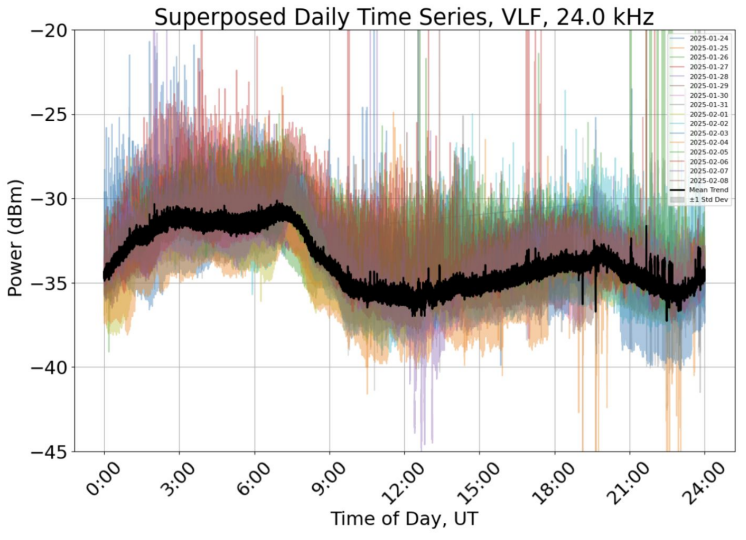

VLF emitter in Lualualei, Hawaii (21.4 kHz)



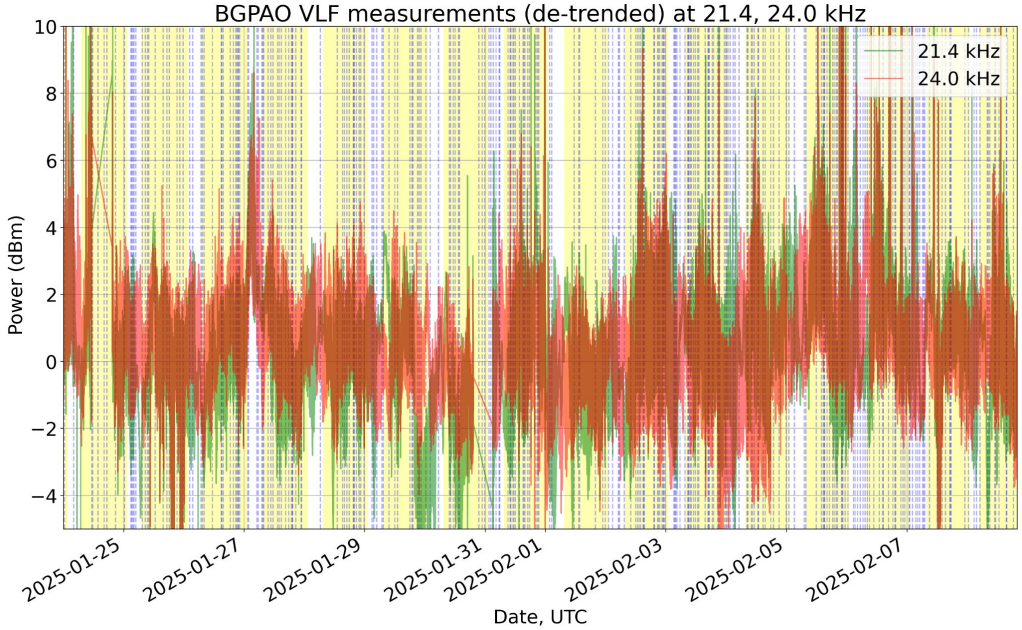


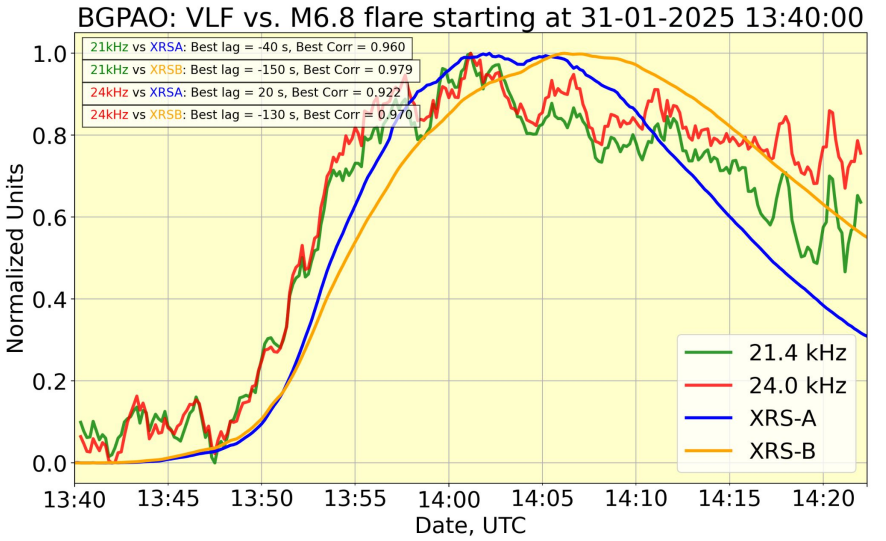



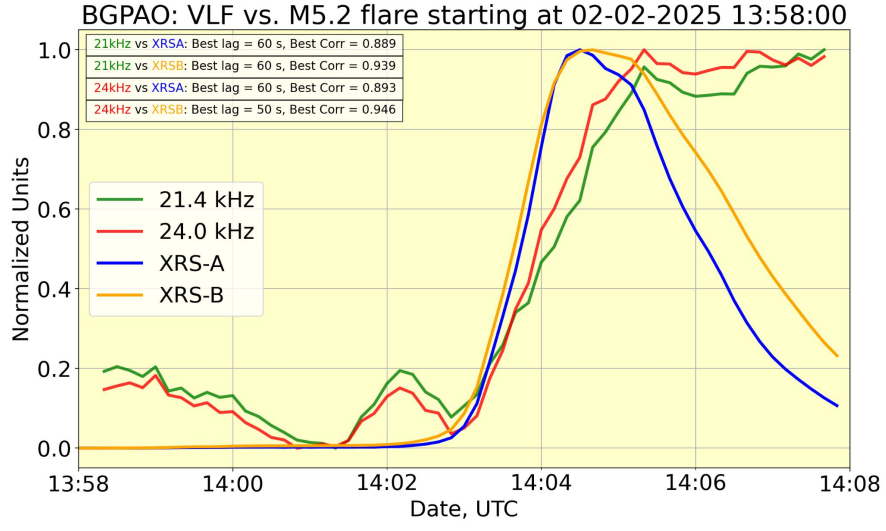



POLAR ASTRONOMICAL OBSERVATORY BULGARIA

# VLF наблюдения на йоносферна динамика



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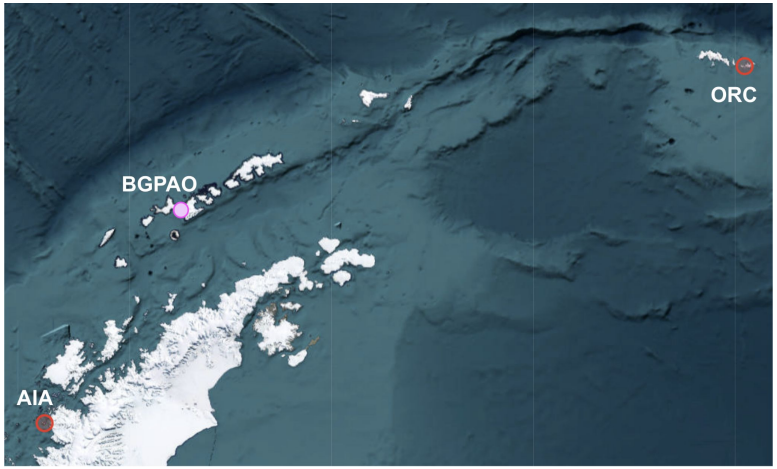
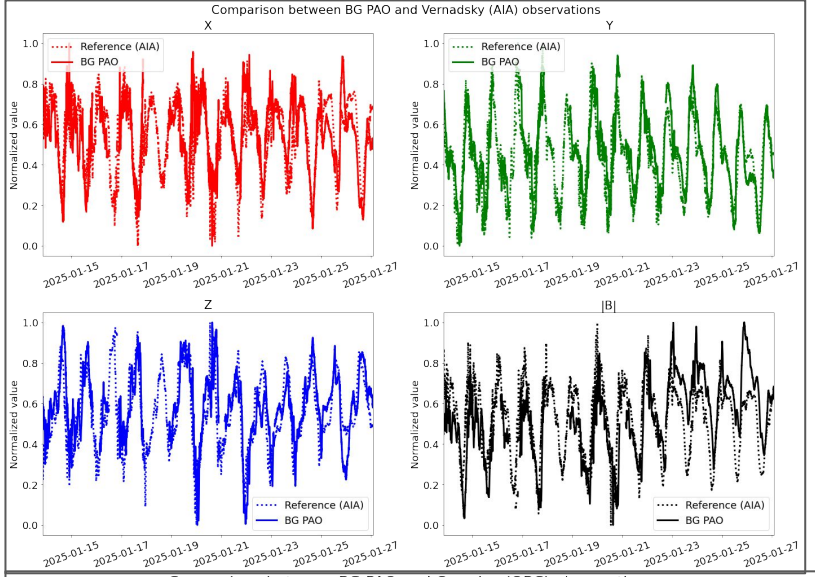
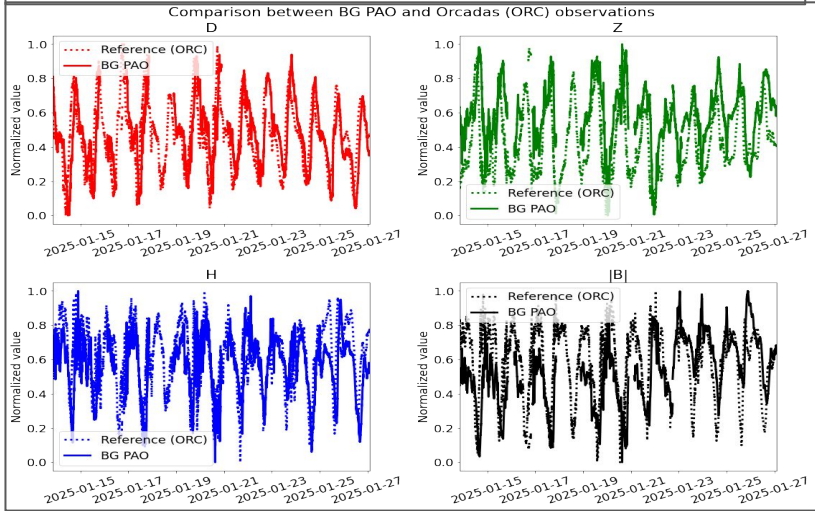
# Наблюдения на магнитно поле



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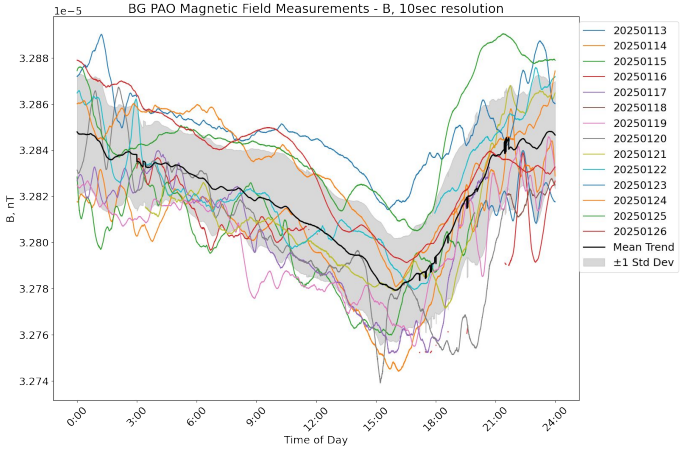
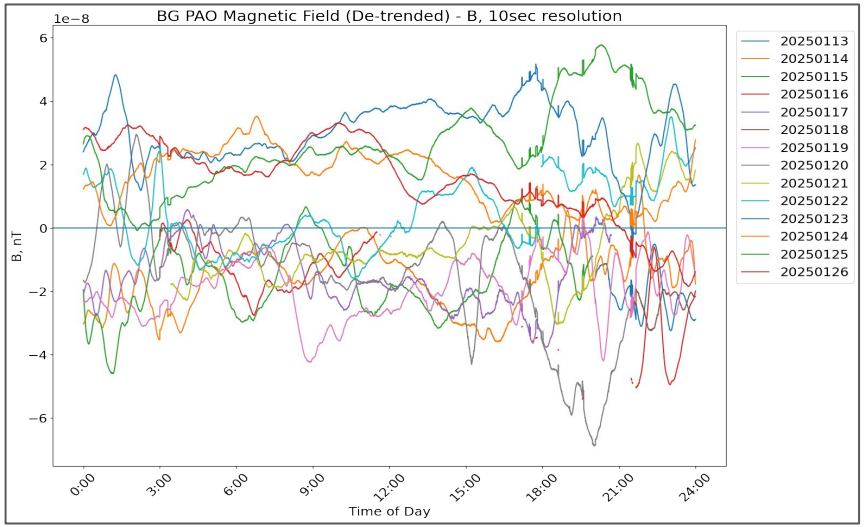
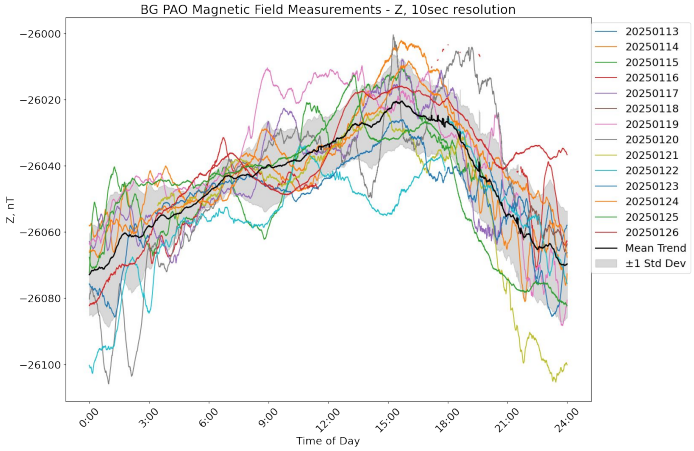
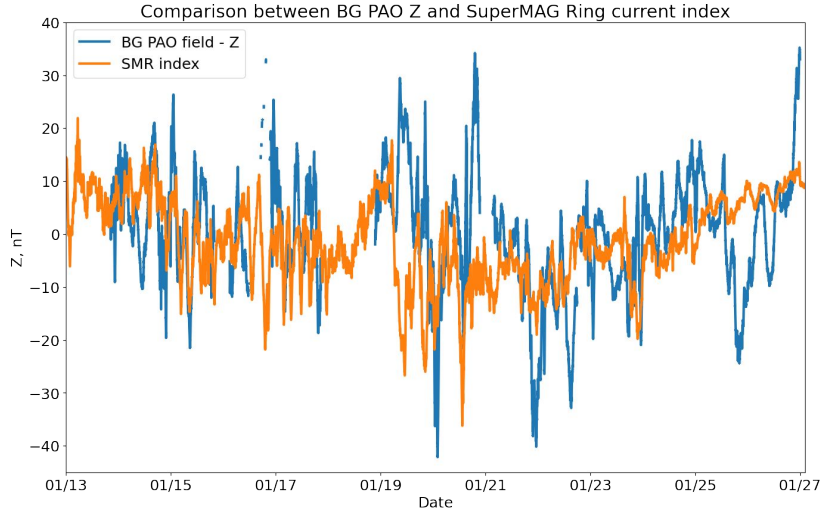
# Наблюдения на магнитно поле



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Дейностите по проекта “**Въздействие на слънчевата активност върху йоносферната динамика и потоците високоенергитични частици над Антарктида**” са финансирани от СУ "Св. Климент Охридски" по процедура "Финансиране на полярни научни изследвания", дог. 70-25-44 / 12.04.2024г.

Bilateral project: Bulgaria-Austria ( https://astro.bas.bg/project-sun/ )
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