7th LOFAR DATA SCHOOL

15 - 19 April 2024, ASTRON, Dwingeloo, the Netherlands

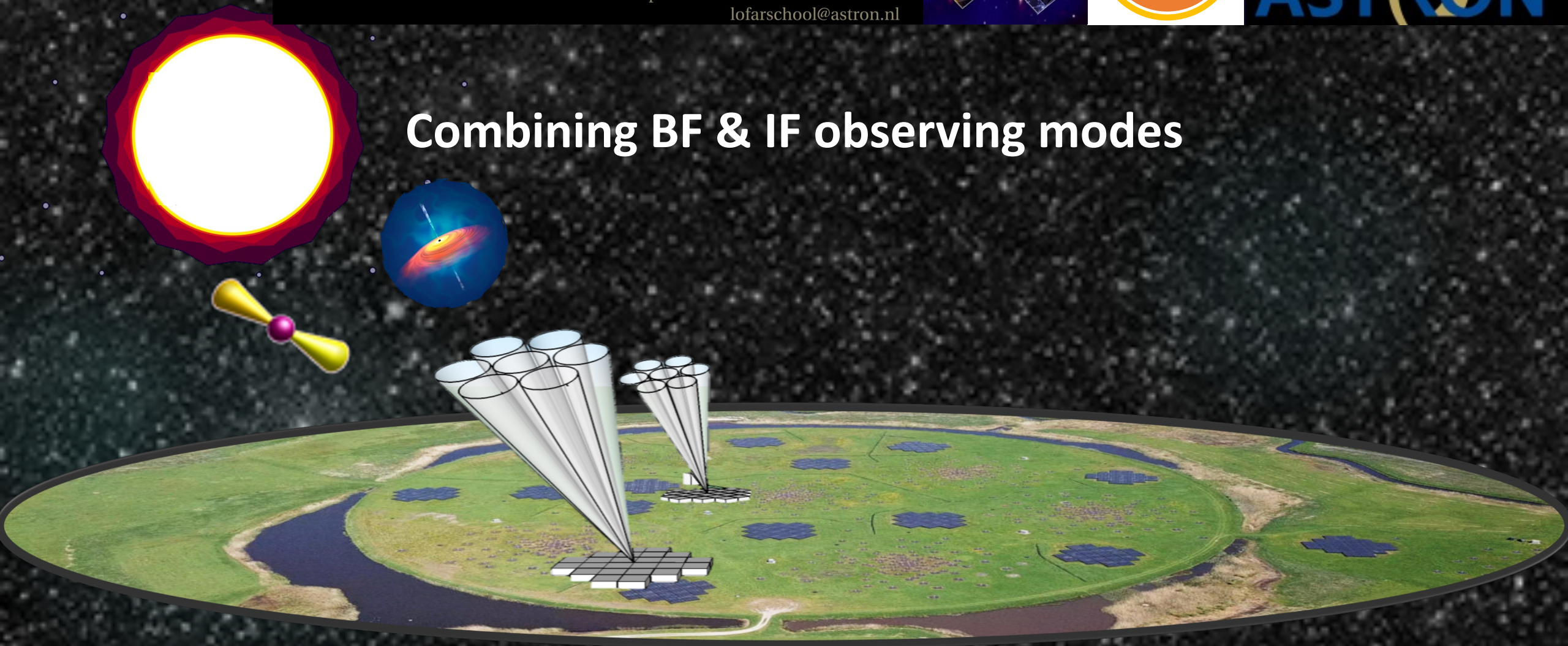
https://indico.astron.nl/event/315/

lofarschool@astron.nl

LOFAR Solar and Space Weather KSP

75 YEARS ASTRON

Combining BF & IF observing modes



Dr. **Pietro Zucca** and the solar and SW KSP

ASTRON Netherlands Institute for Radio Astronomy

7th LOFAR DATA SCHOOL
15 - 19 April 2024, ASTRON, Dwingeloo, the Netherlands
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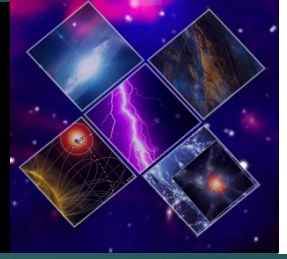
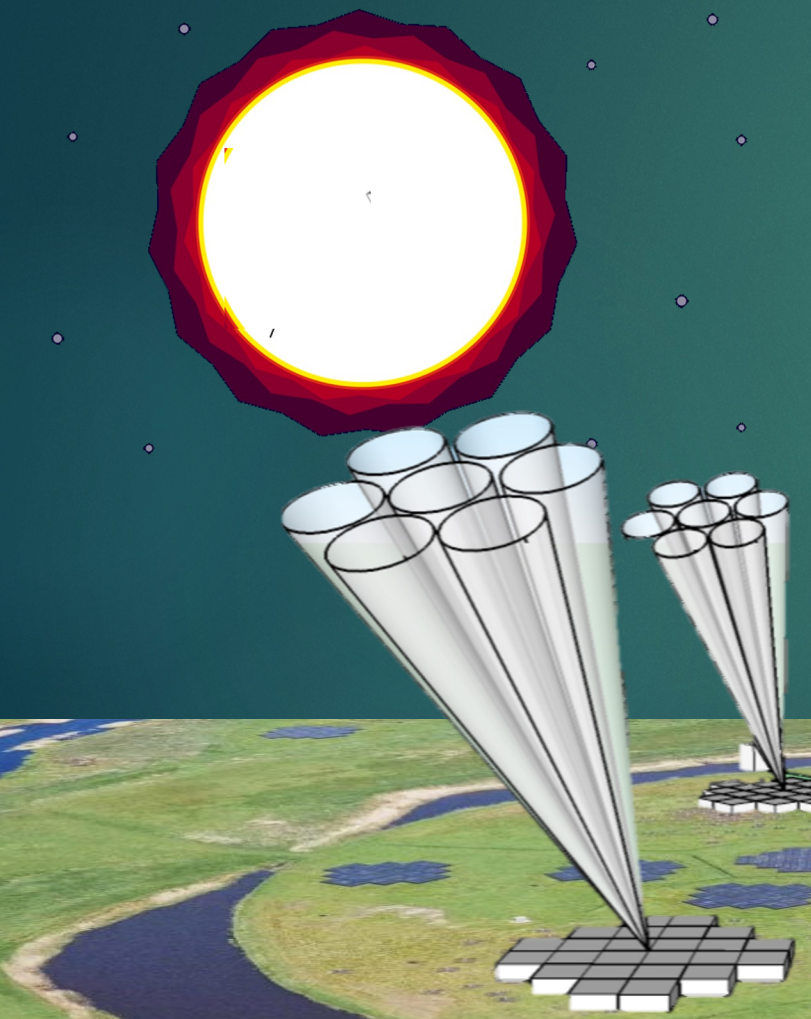
lofarschool@astron.nl



LOFAR Solar and Space Weather KSP

75 YEARS ASTRON

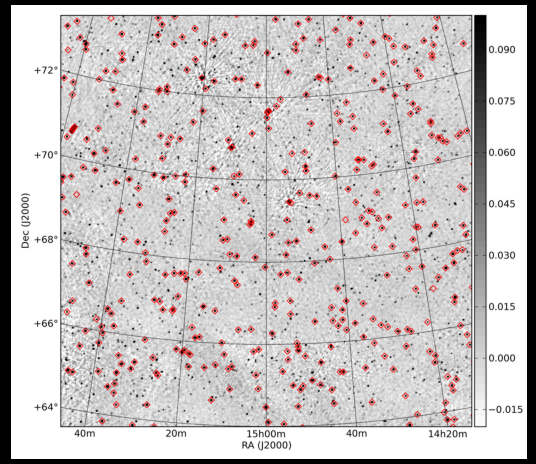
Overview



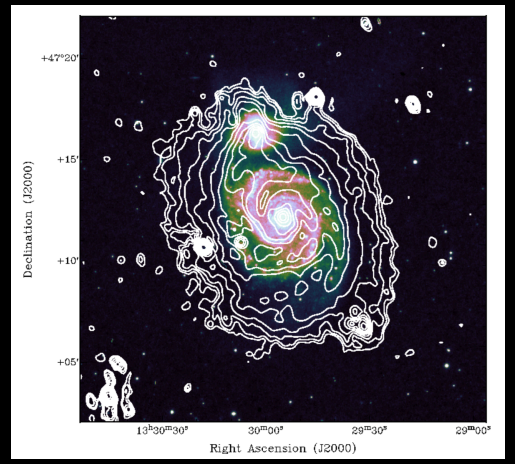
- Using LOFAR to observe simultaneously in BF & IM
- The solar and space weather use case
- BF modes, the dynamic spectrum and the Tied Array Beam
- IM modes, the interferometric imaging
- Hands on – intro to the tutorial

LOFAR KEY SCIENCE PROJECTS

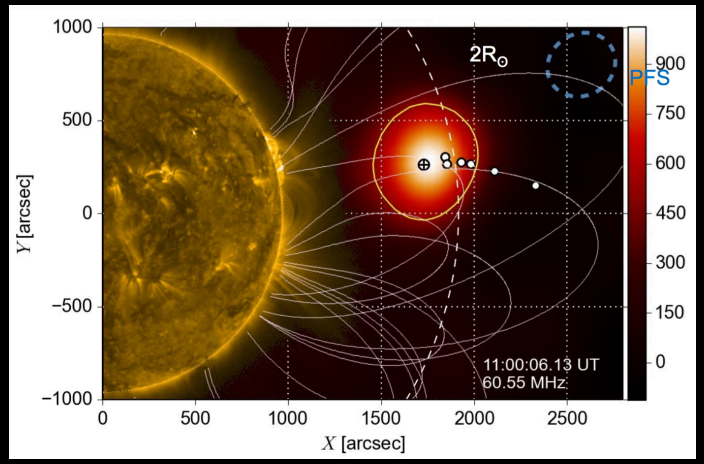
Surveys



Cosmic magnetism

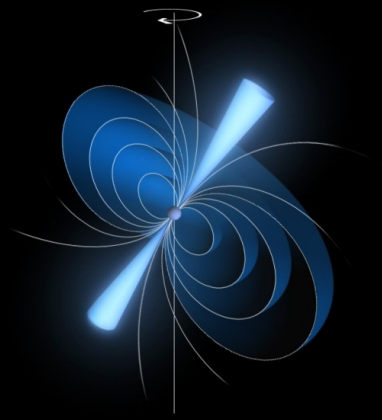


Solar physics & Space weather

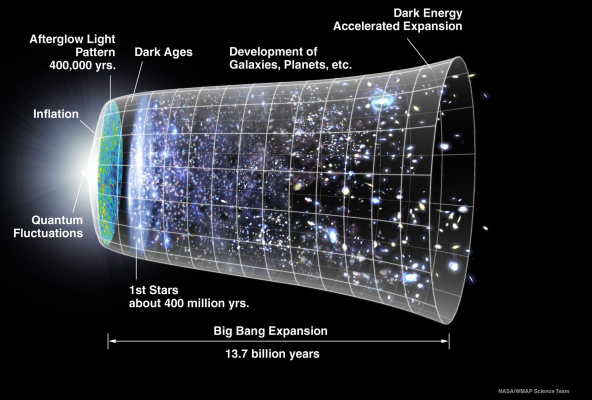


Cosmic rays

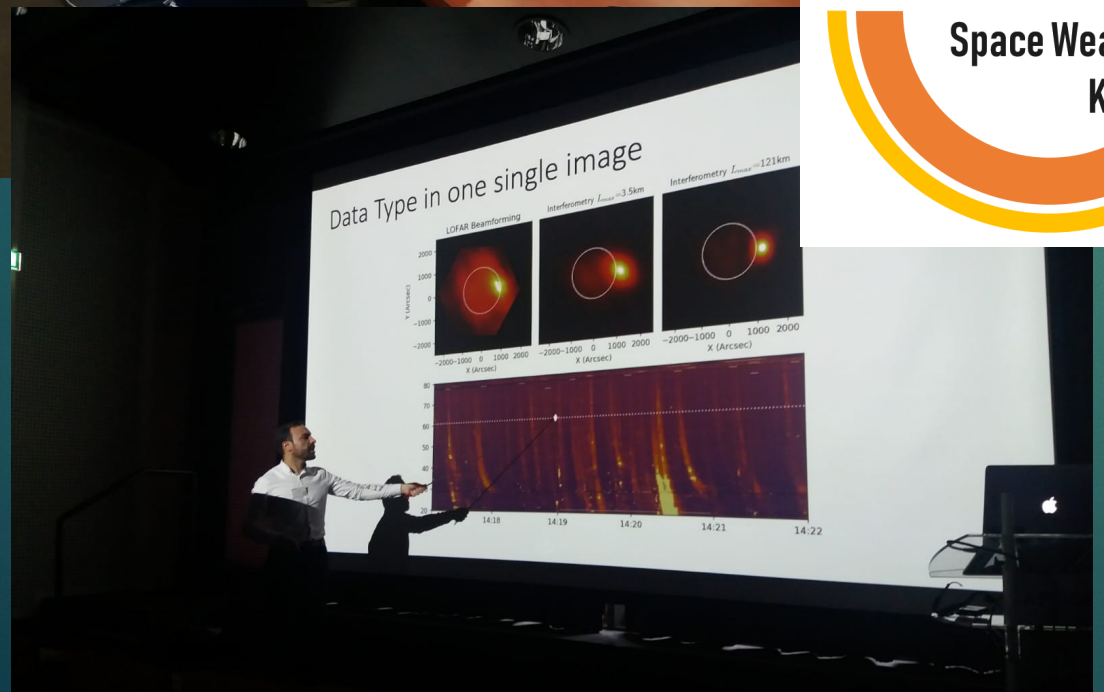
Pulsars & Transient sky

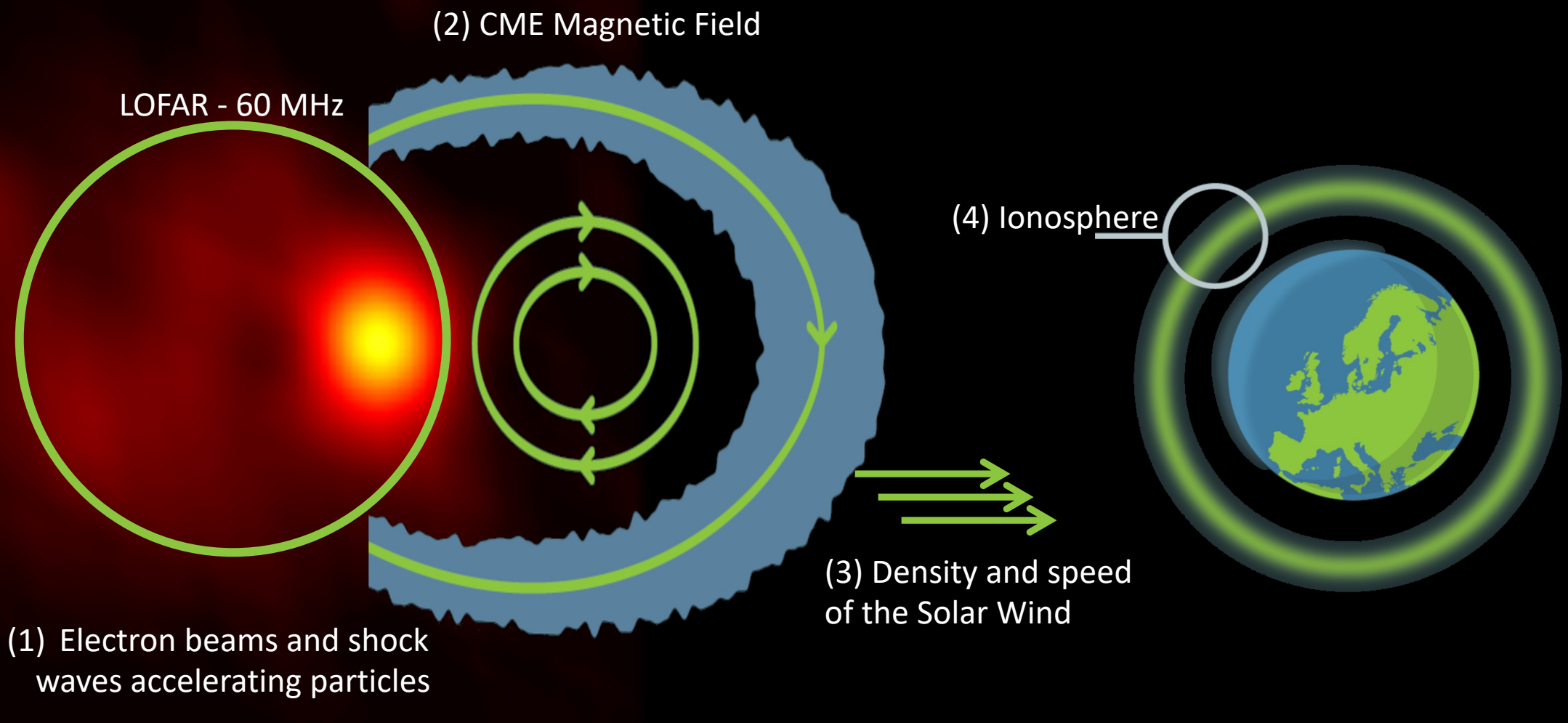


Epoch of Reionization

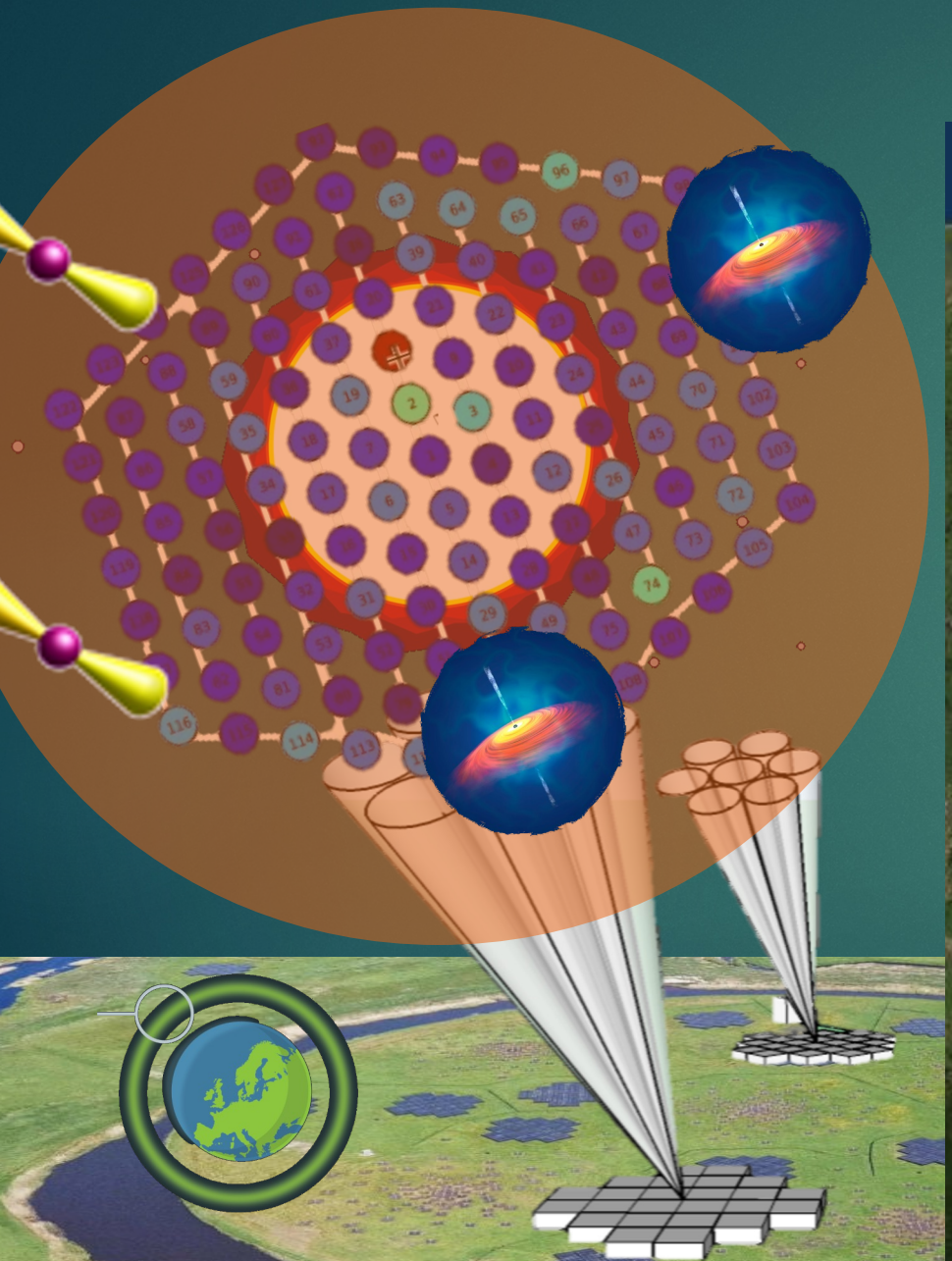


LOFAR
Solar and
Space Weather
KSP

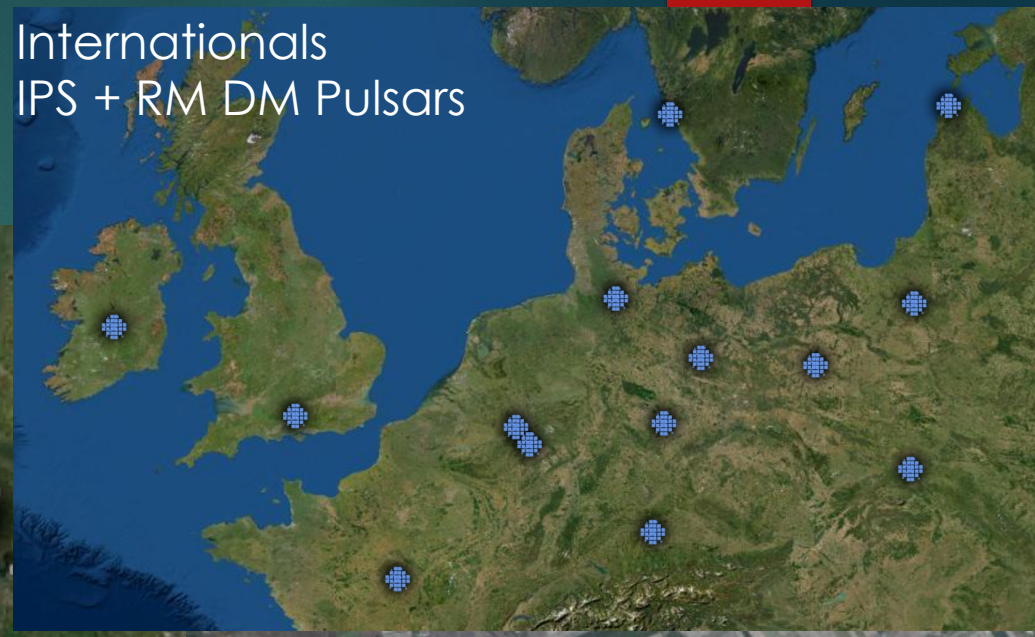



(2) CME Magnetic Field
LOFAR - 60 MHz
(4) Ionosphere
(3) Density and speed of the Solar Wind
(1) Electron beams and shock waves accelerating particles

LOFAR KSP Observing mode

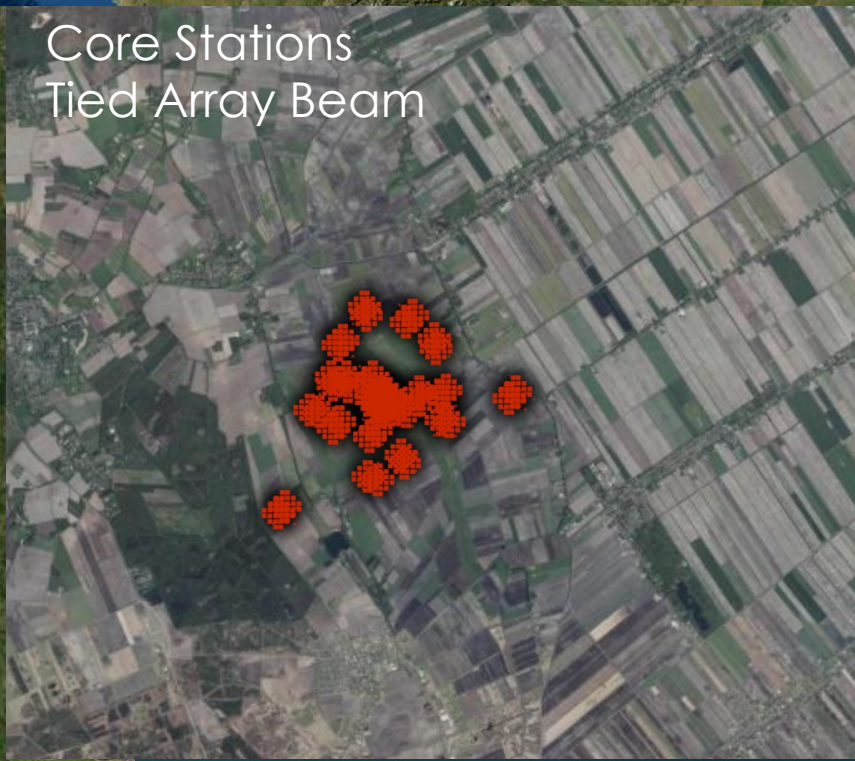


Internationals
IPS + RM DM Pulsars

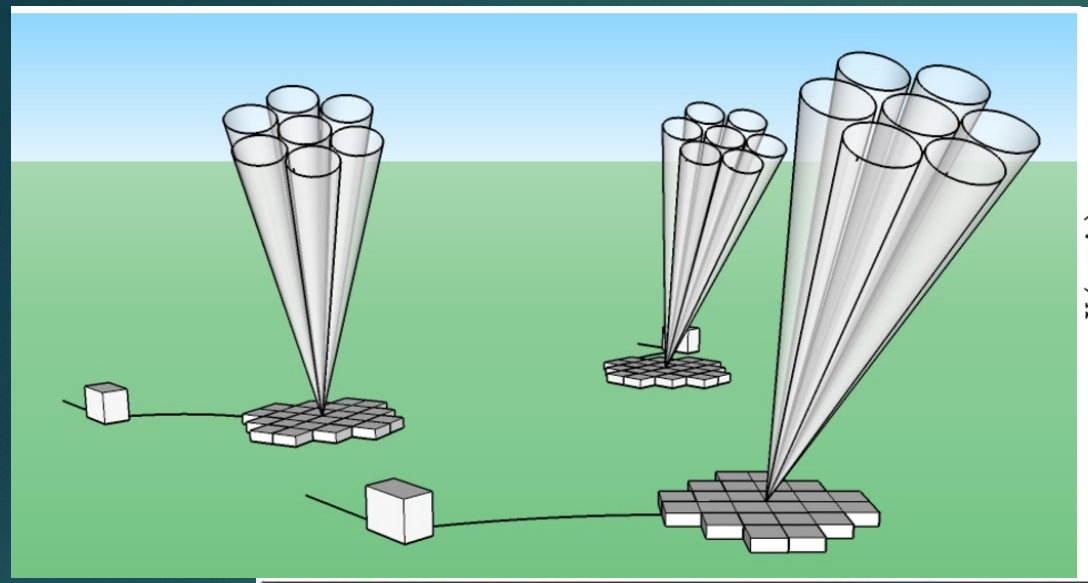


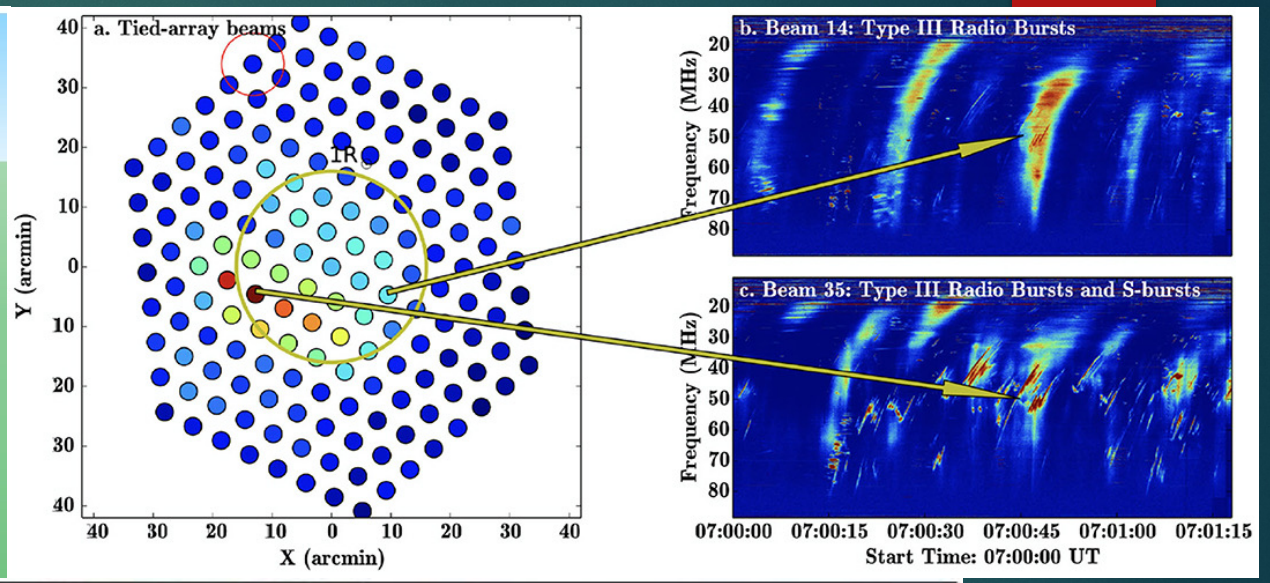
CORE + Remote
Interferometric

Core Stations
Tied Array Beam



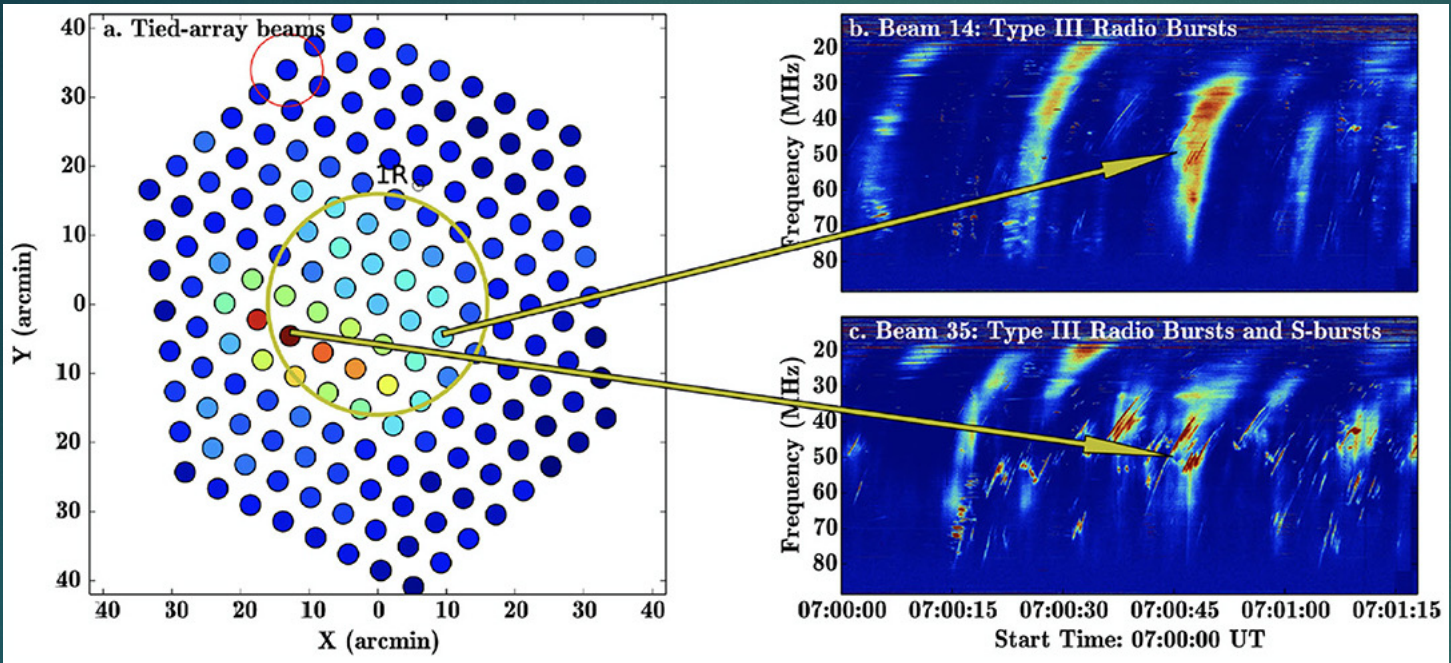
Tied-Array beam mode





- A set of beams in an array around the Sun in order to recreate a micropixel map.

Data types - Beamformed

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L646143_SAP001_BEAM009_S1_P000.raw
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https://support.astron.nl/LOFARBeamformedCookbook/introduction.html

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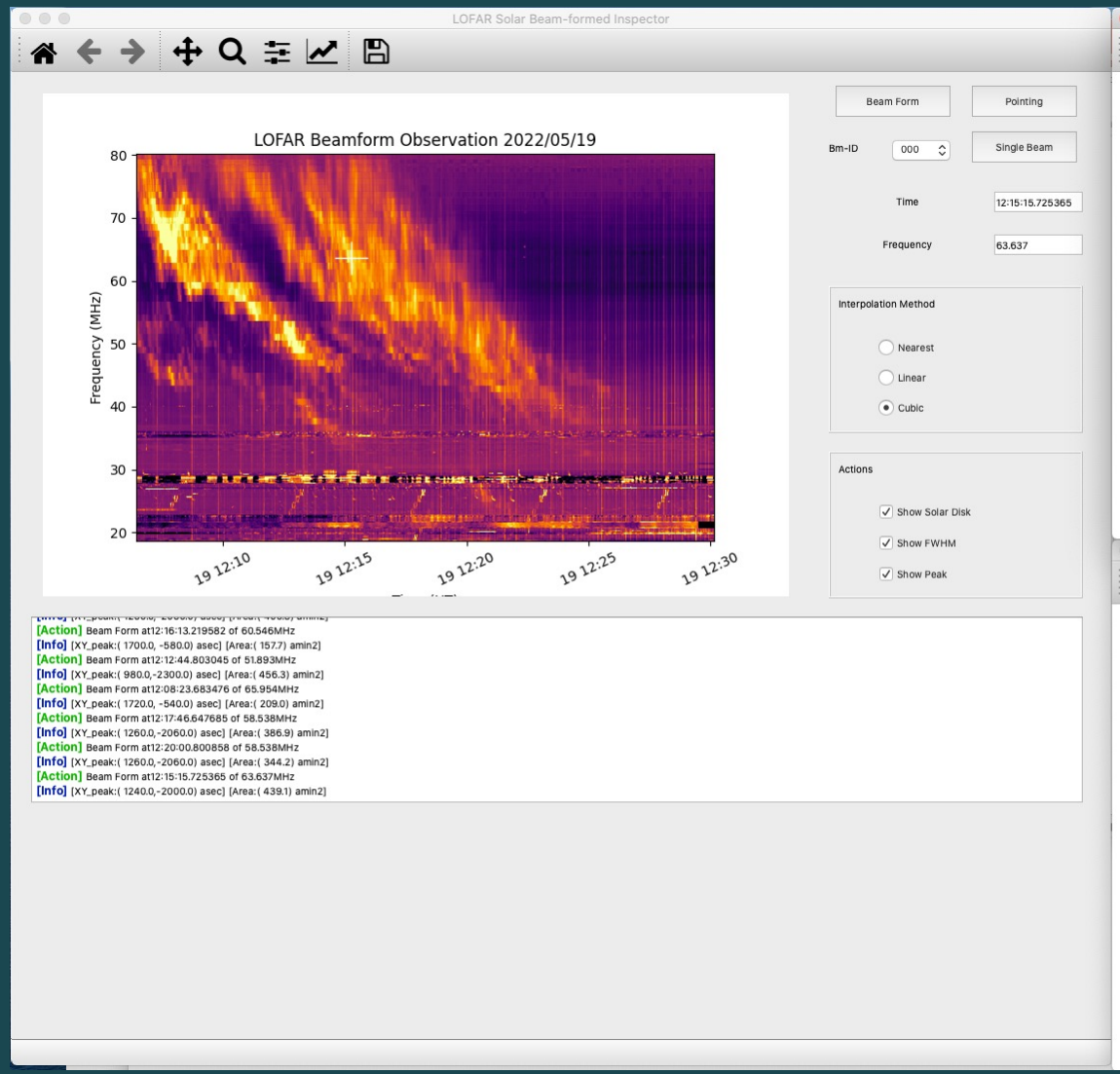
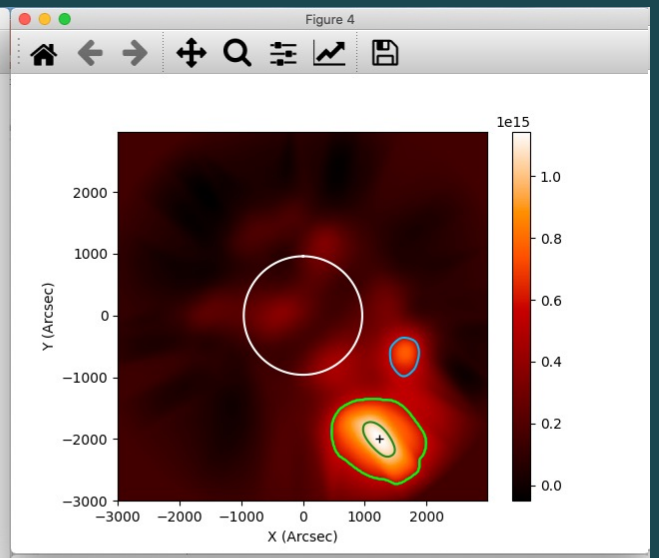
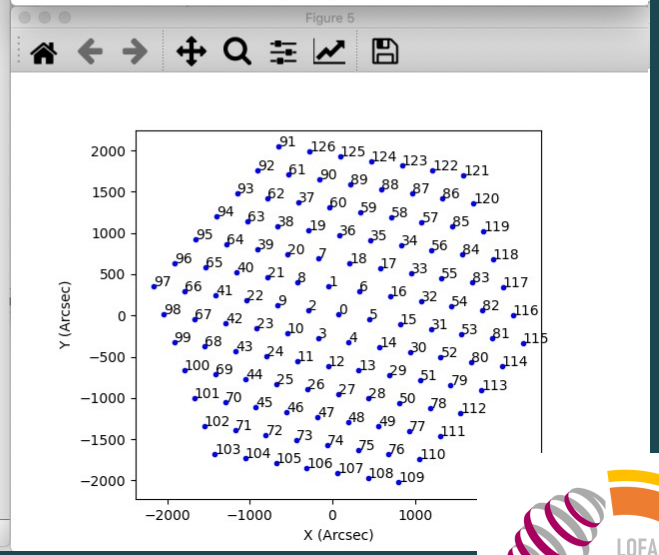
Preview tool







P. Zhang , P. Zucca and Solar SW KSP and IDOLS team

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Solar and Space Weather KSP
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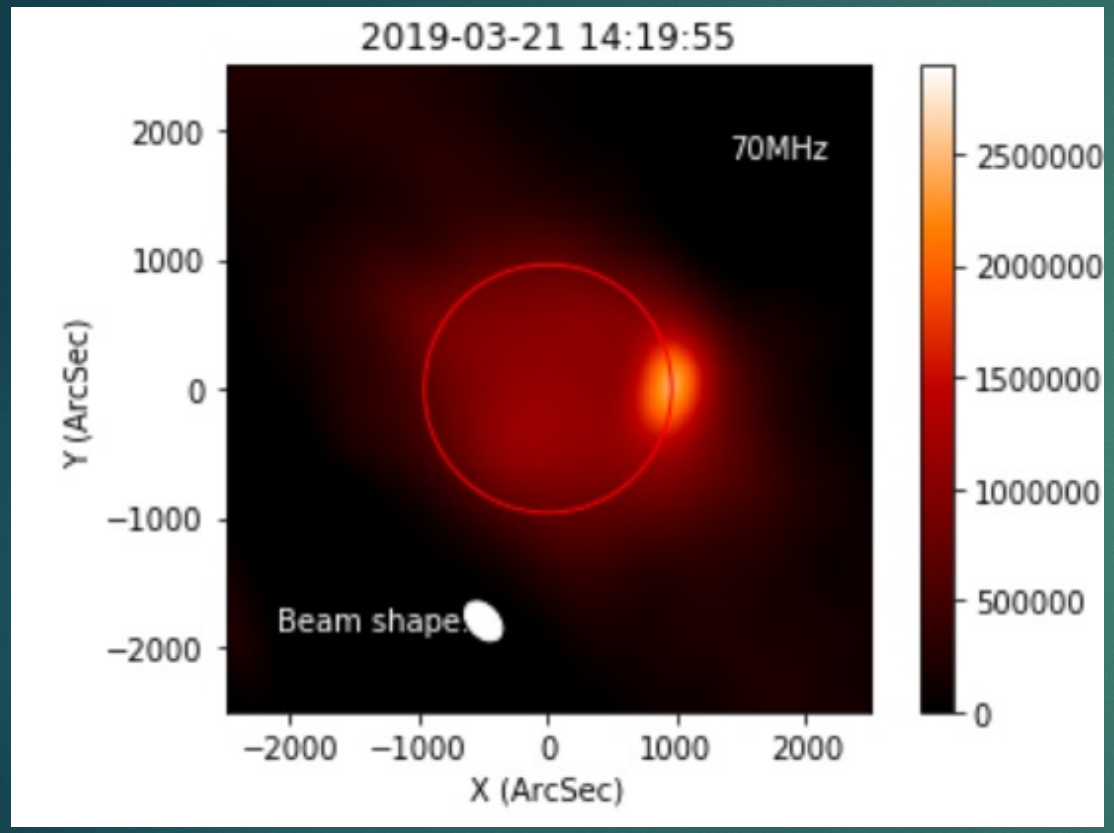
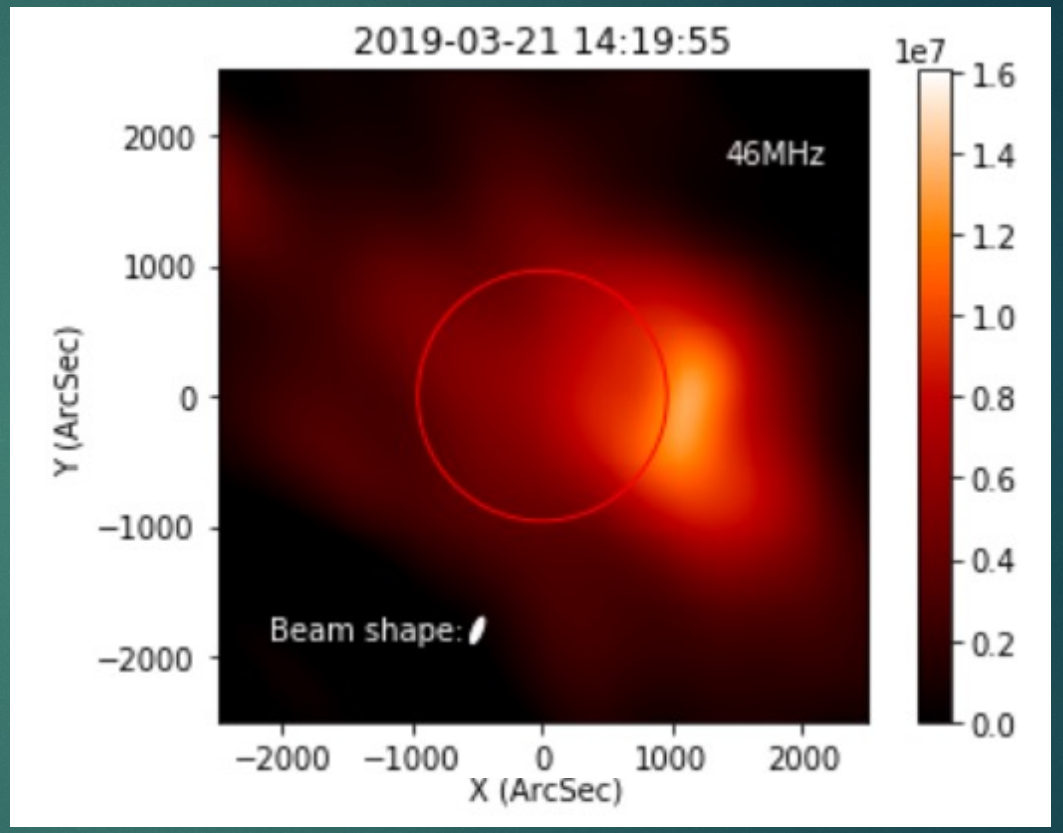
Data types - Interferometric





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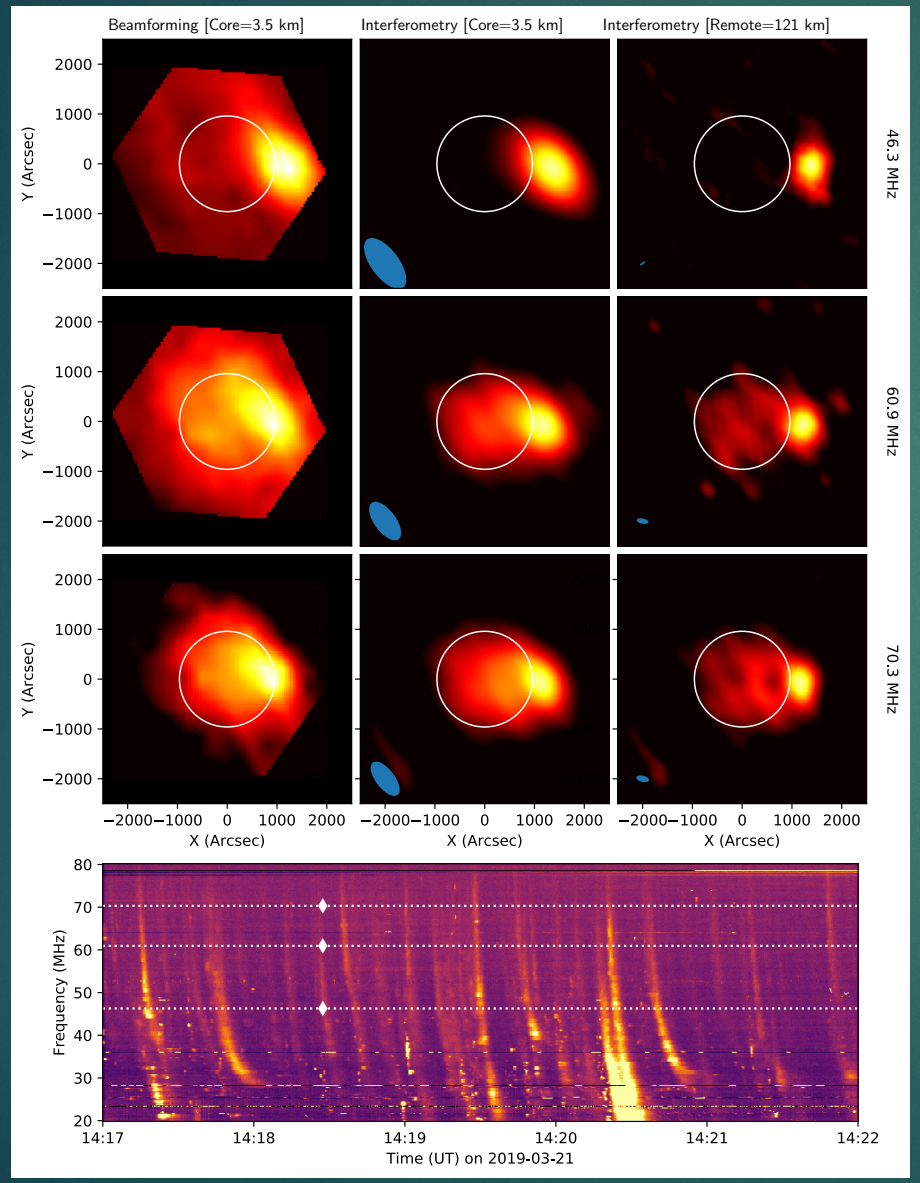
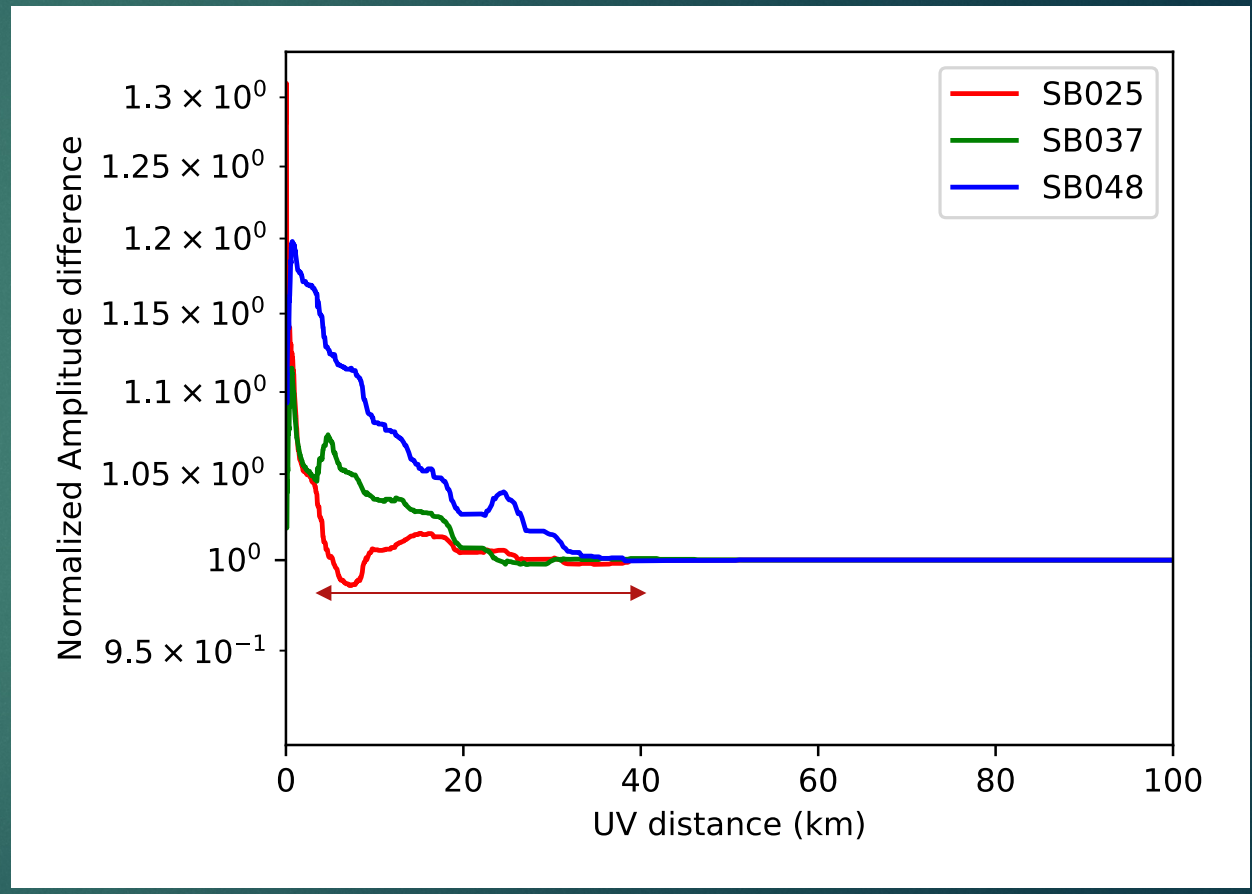
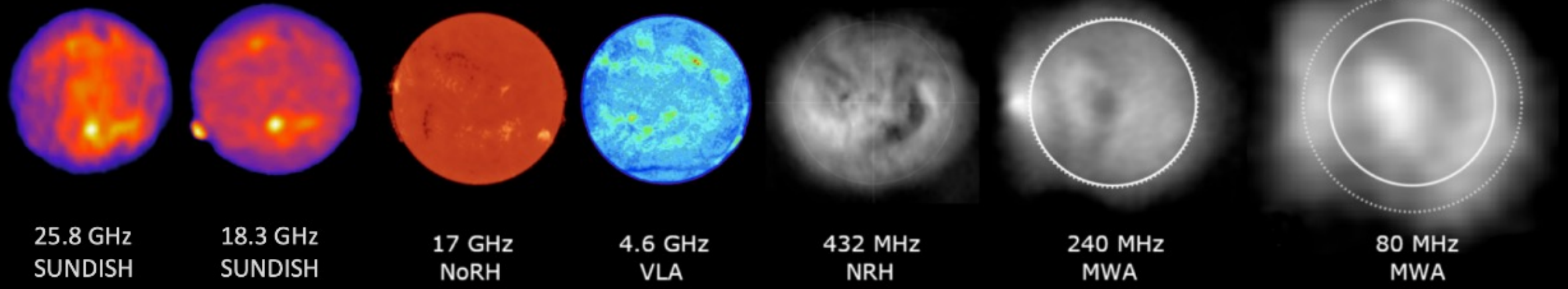
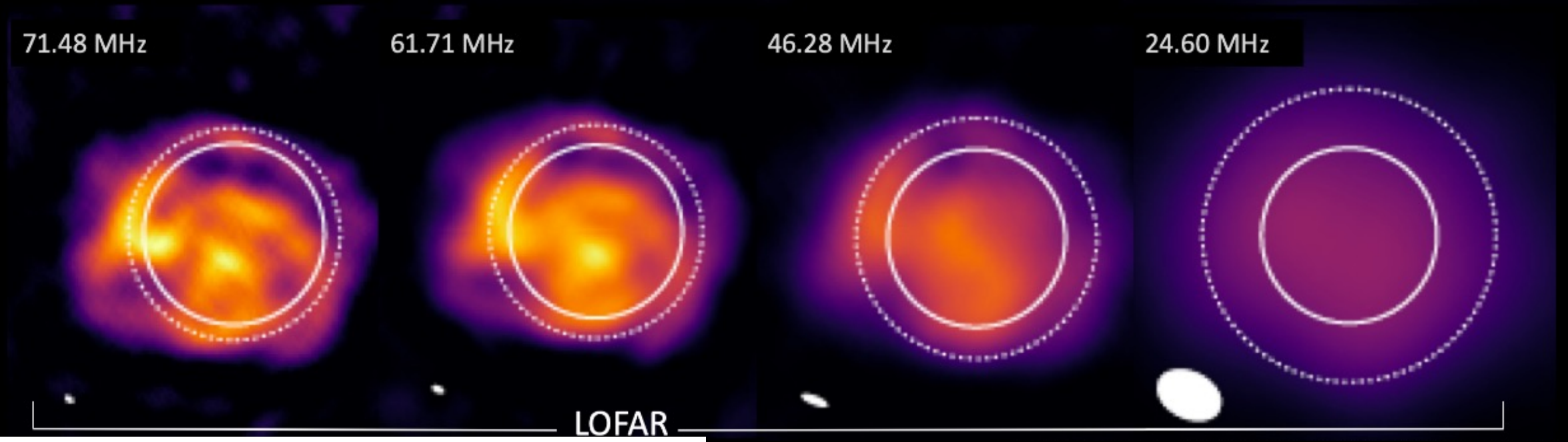
LOFAR

Tied Array Beam and Interferometric mode





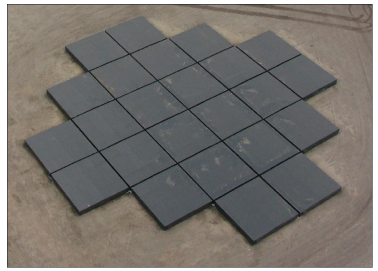


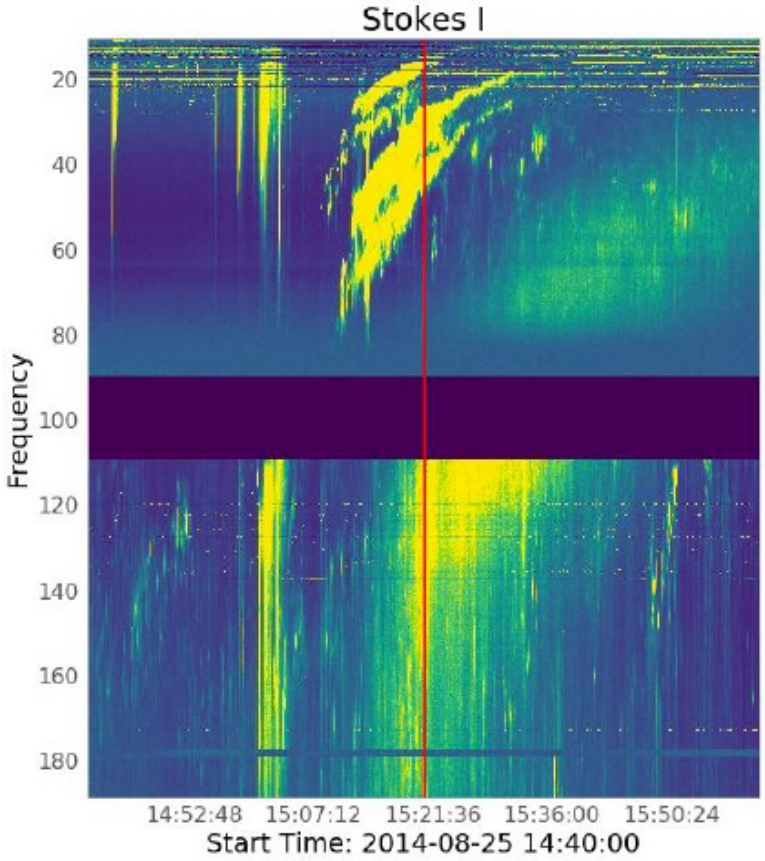


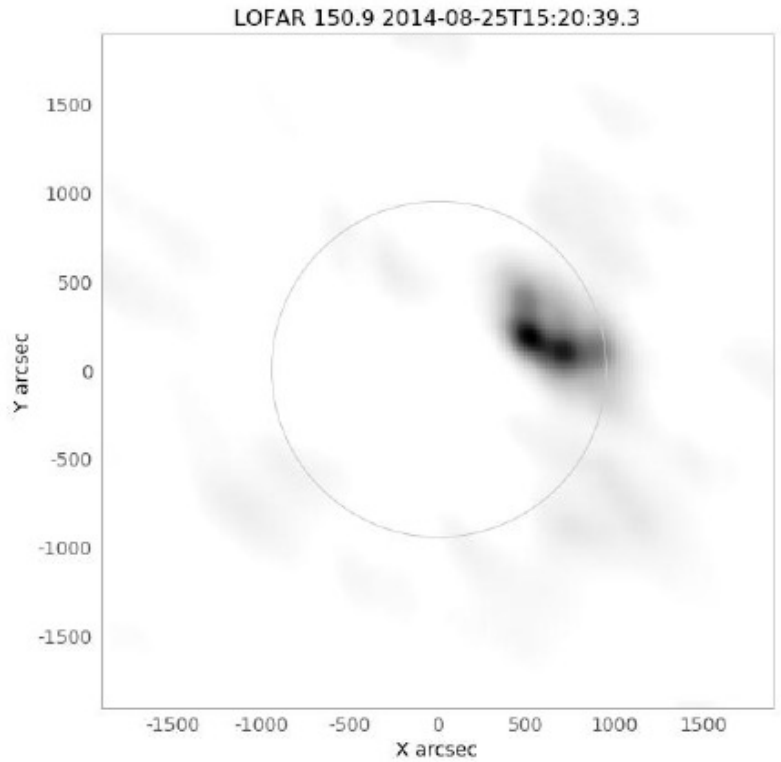
Imaging of the Quiet Sun in the Frequency Range of 20-80 MHz

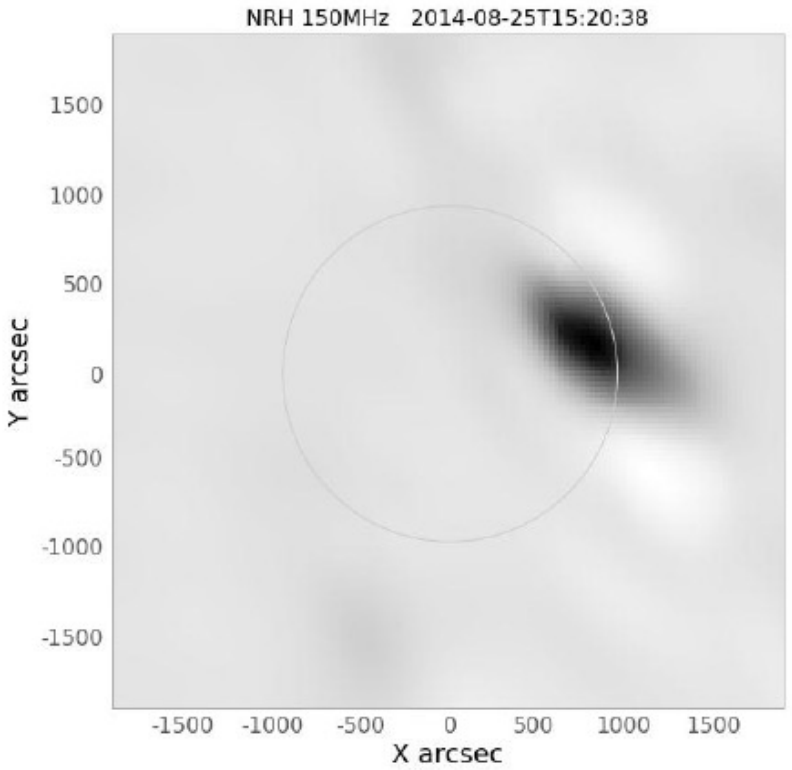
PeiJin Zhang [1,2,3,4] Pietro Zucca* [2] Kamen Kozarev [1] Eoin Carley [5]
ChuanBing Wang [4,6,7] Thomas Franzen [2] Bartosz Dabrowski [8]
Andrzej Krankowski [8] Jasmina Magdalenic [9] and Christian Vocks [10]

Comparison of LOFAR imaging with NRH



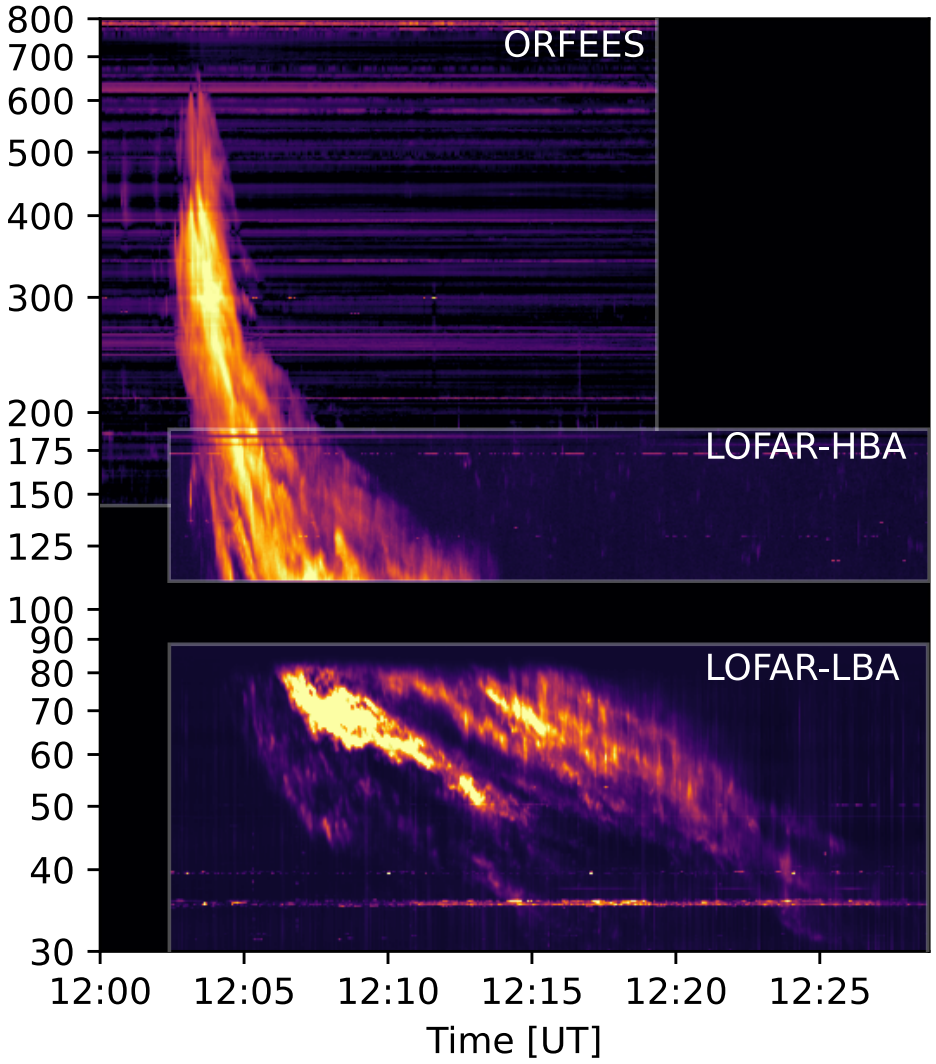


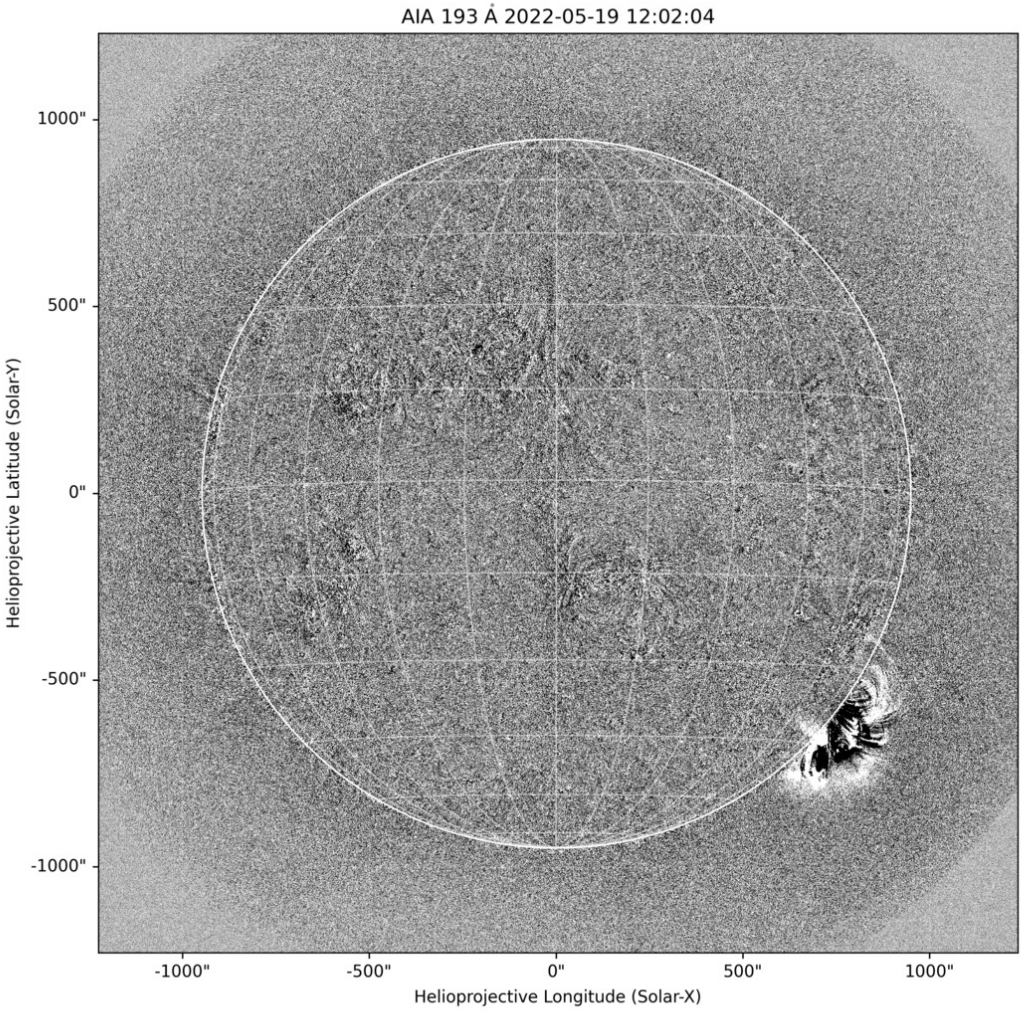




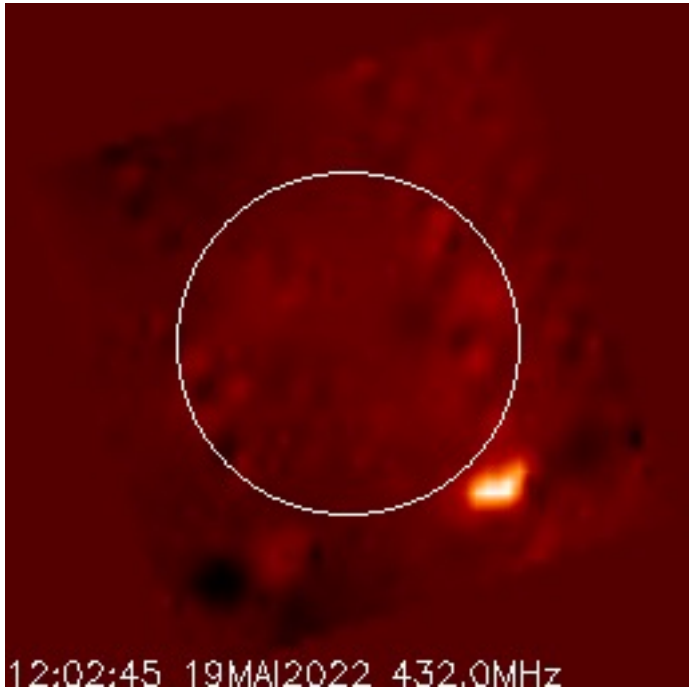
H.Liu, P. Zucca et al. 2022

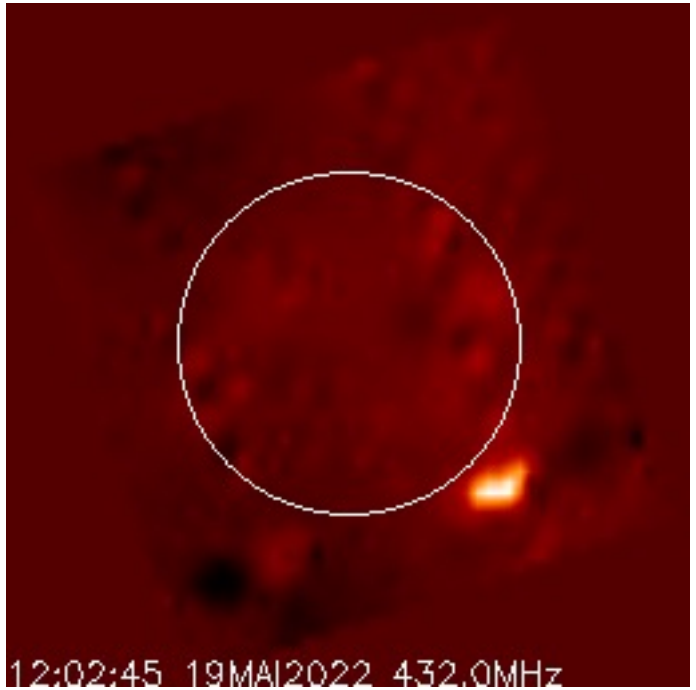
New Opportunities with LOFAR

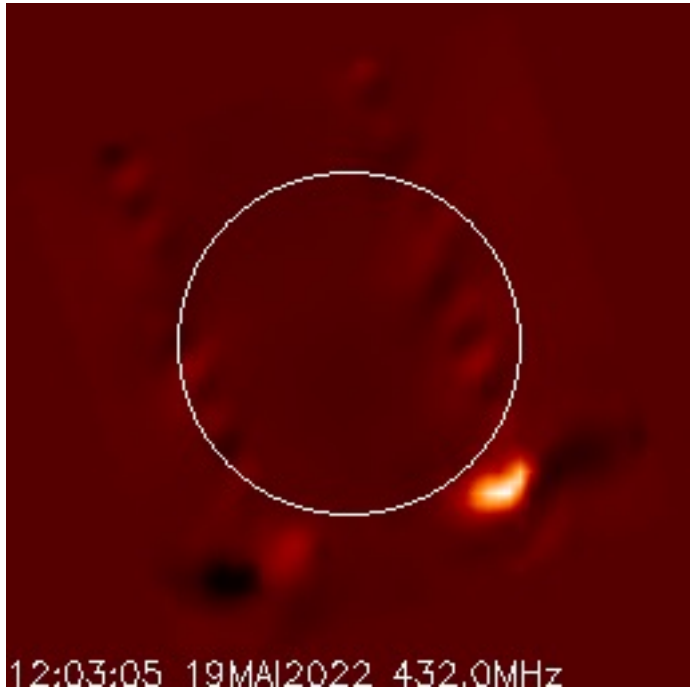


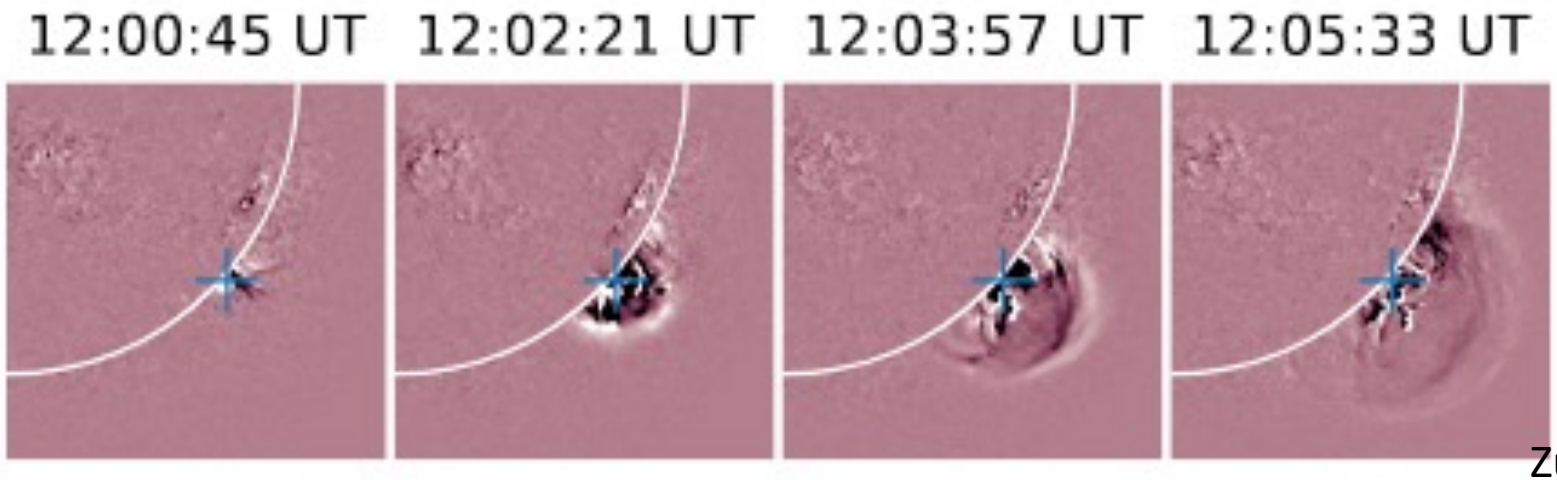


Zucca, Zhang, Kozarev, Nedal in prep

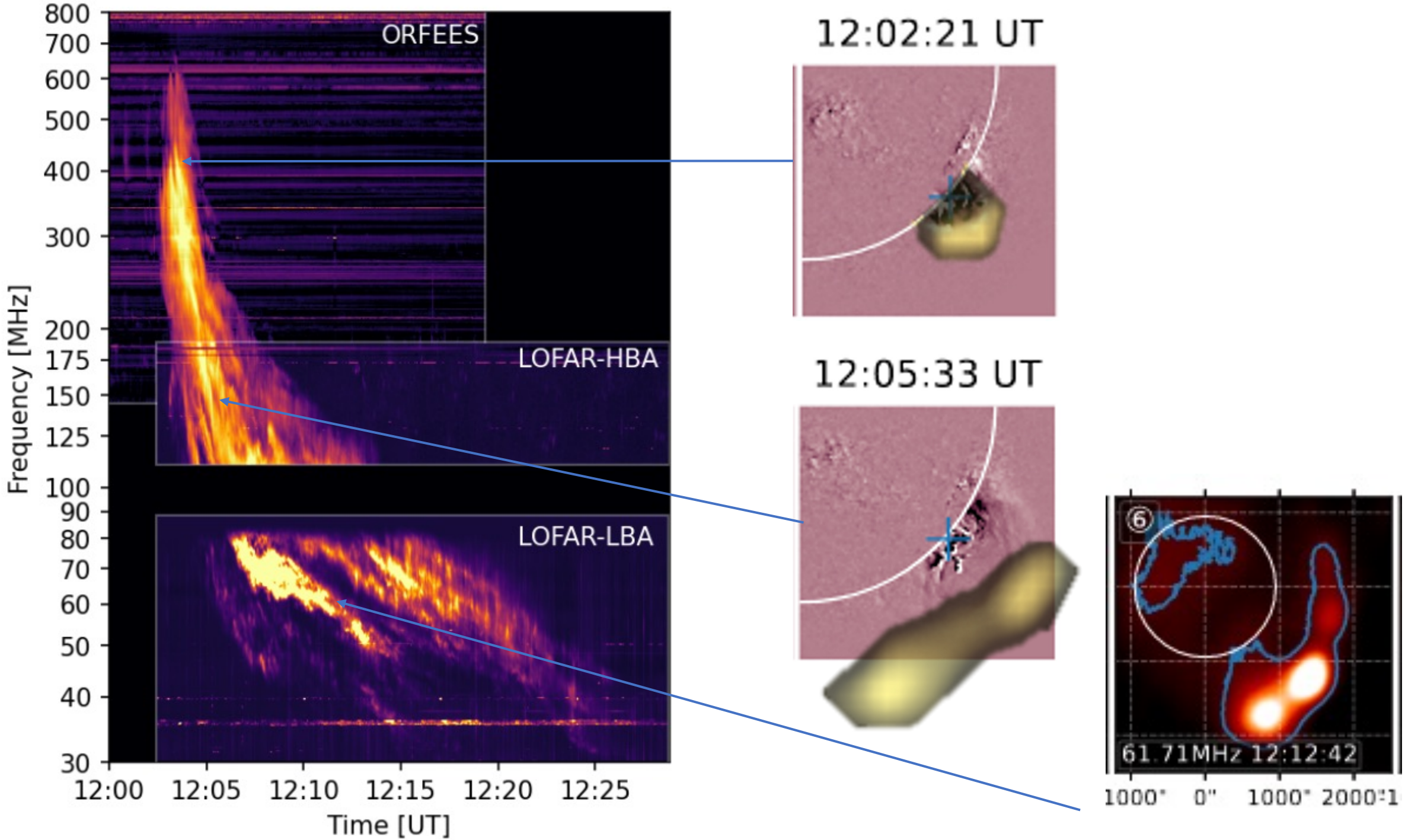


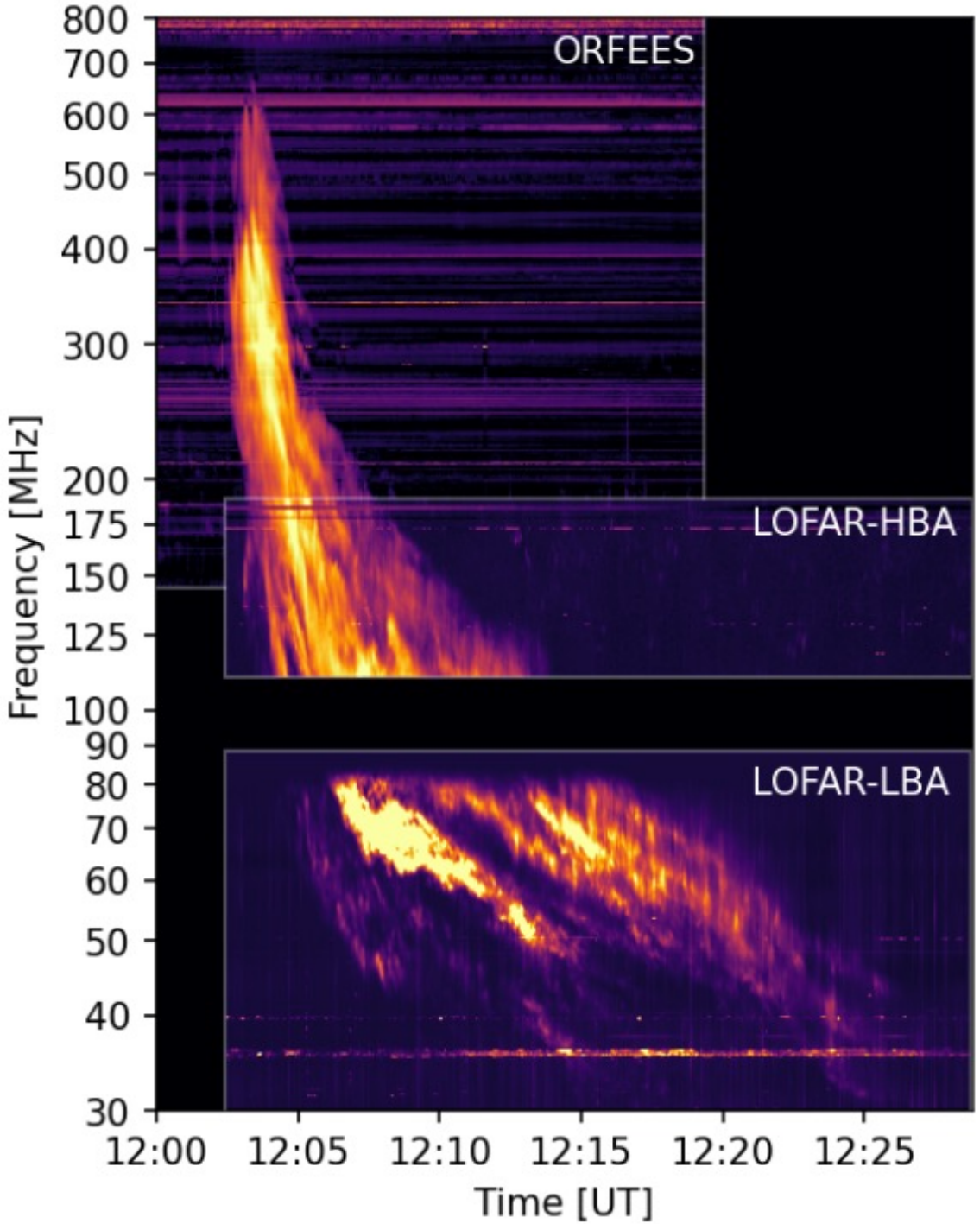


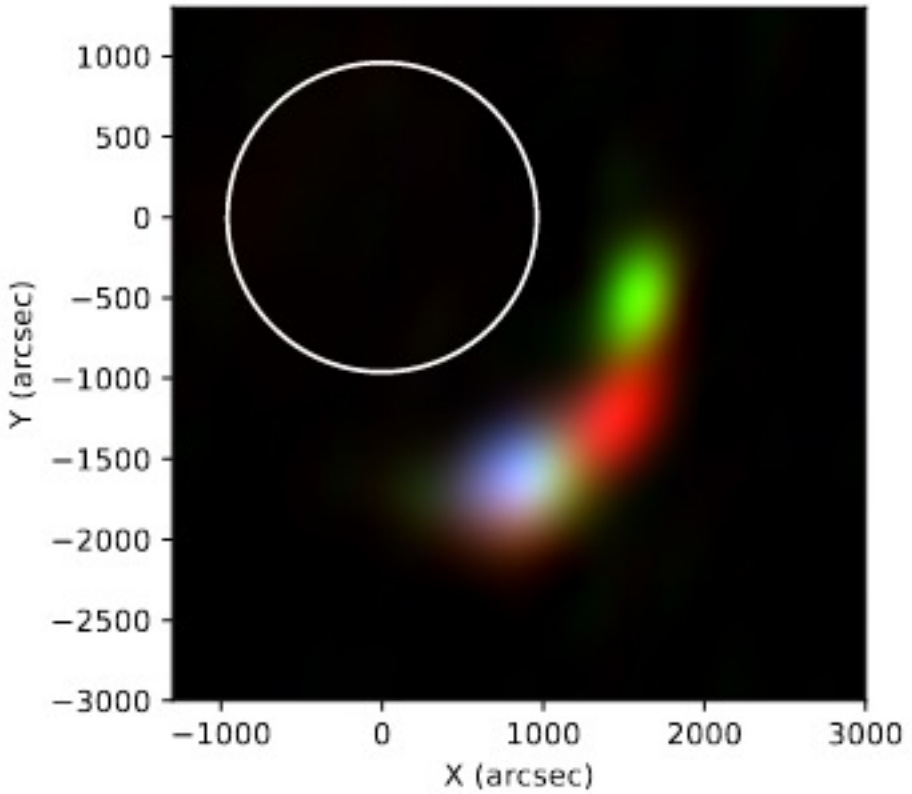


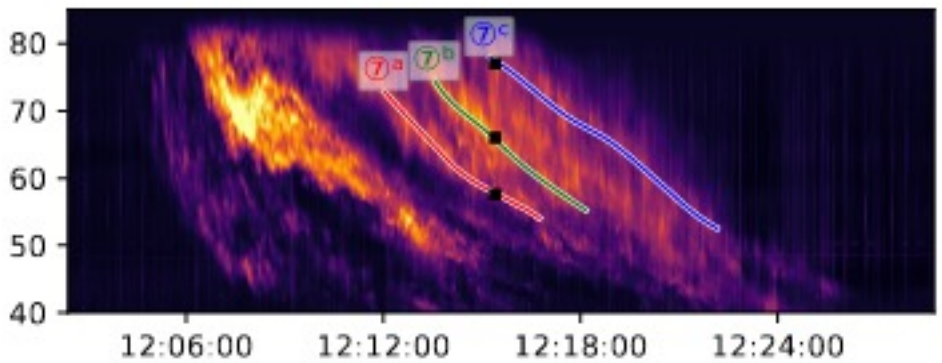


Zucca et al. in prep

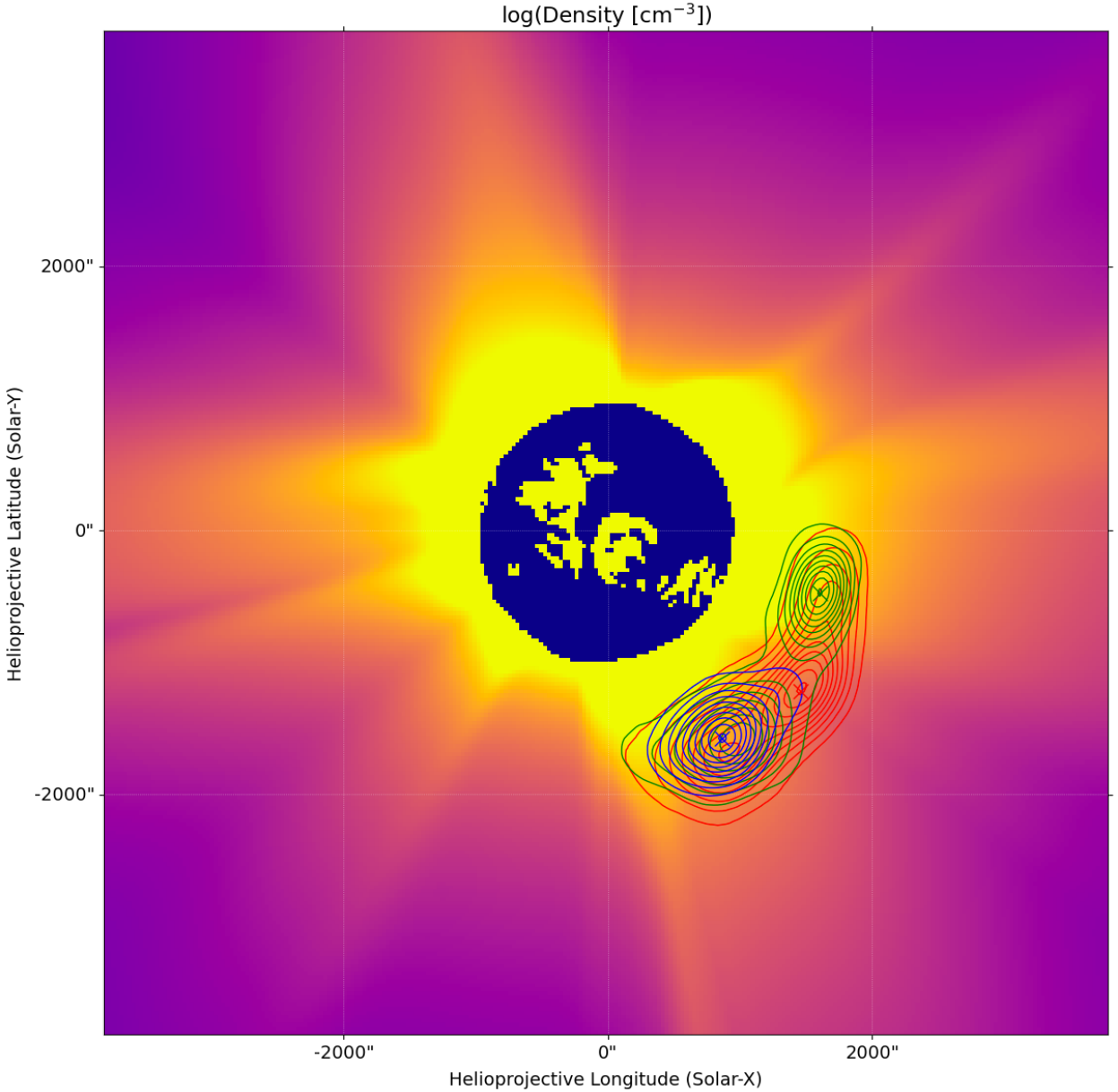

ORFEES
LOFAR-HBA
LOFAR-LBA
Frequency [MHz]
800
700
600
500
400
300
200
175
150
125
100
90
80
70
60
50
40
30
12:00
12:05
12:10
12:15
12:20
12:25
Time [UT]
12:02:21 UT
12:05:33 UT
61.71MHz 12:12:42
1000"
0"
1000"
2000"

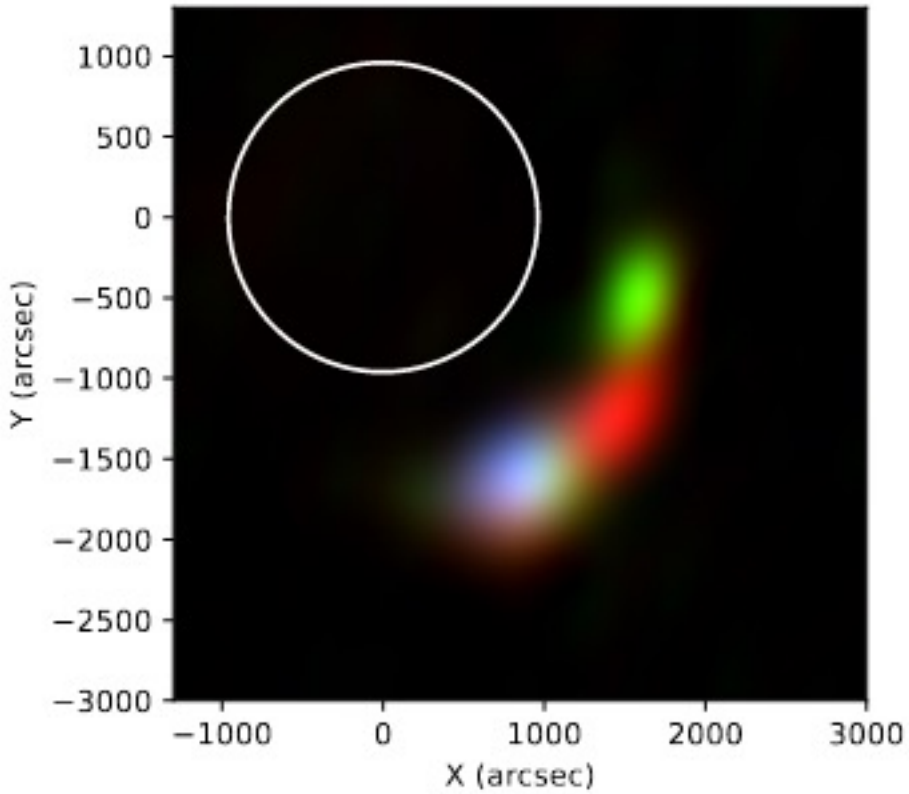


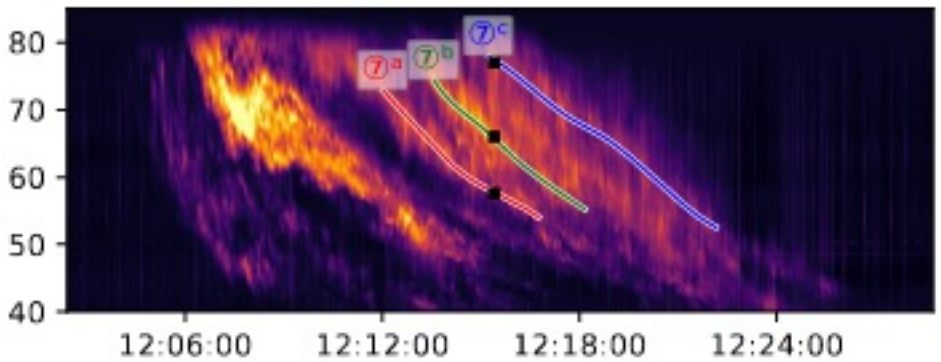




Zucca, Zhang, Kozarev, Nedal in prep



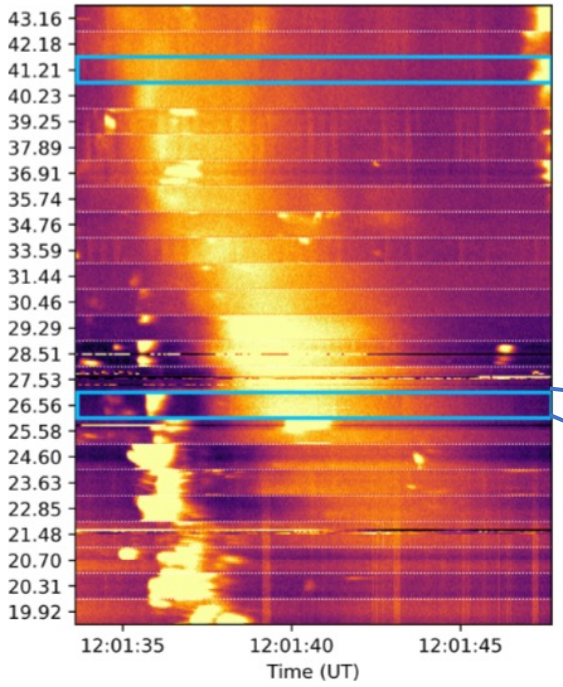


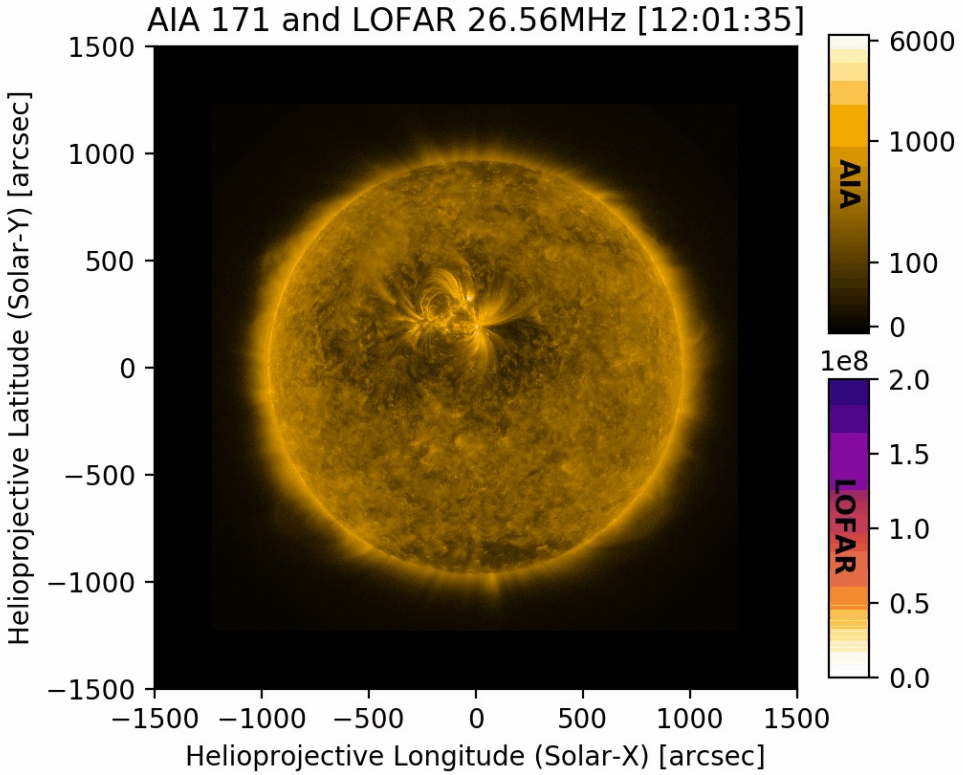


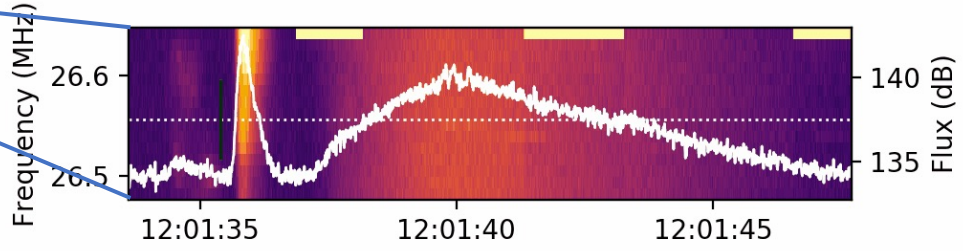
Zucca, Zhang, Kozarev, Nedal in prep

Type IIIb pair

- **The dynamic spectrum and the interferometric imaging**

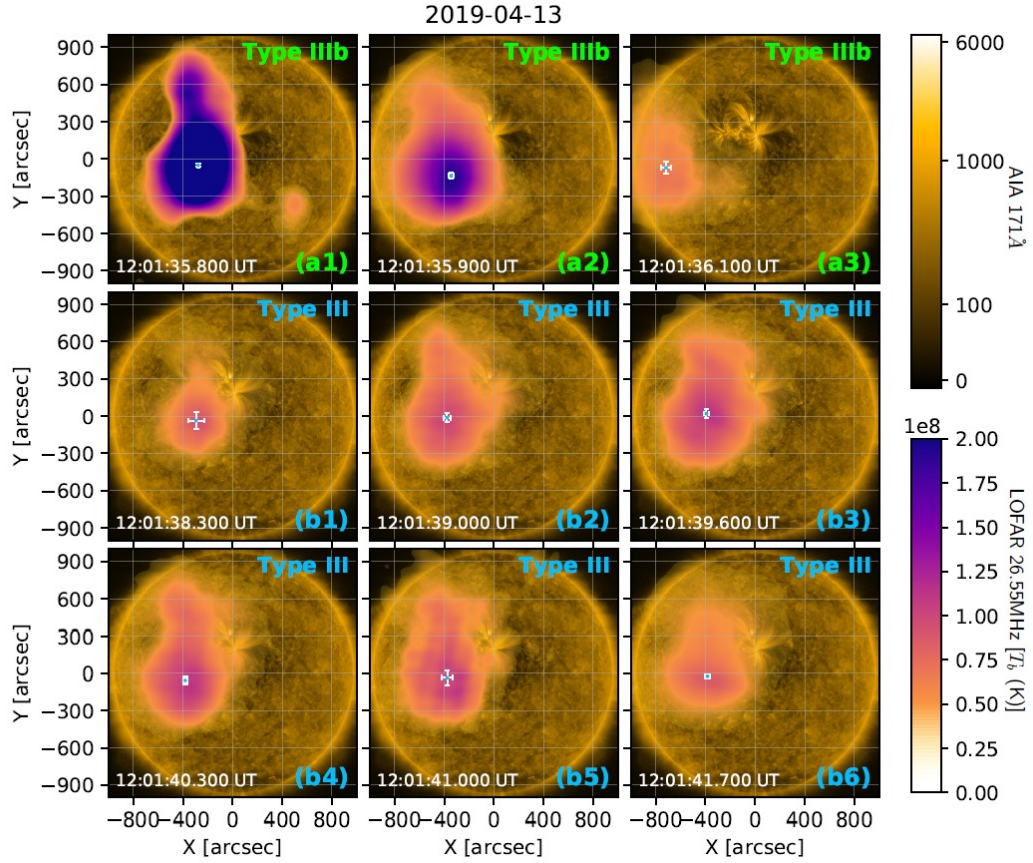


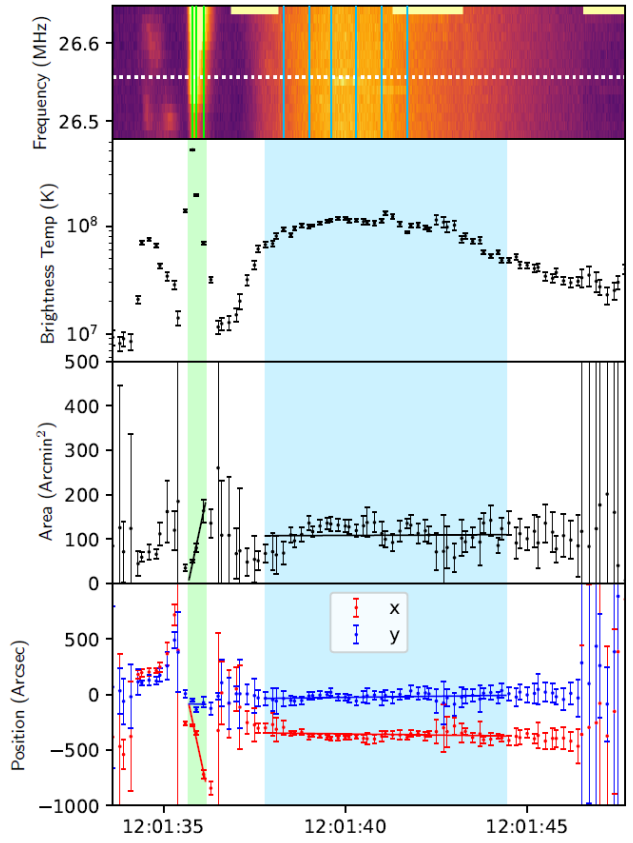


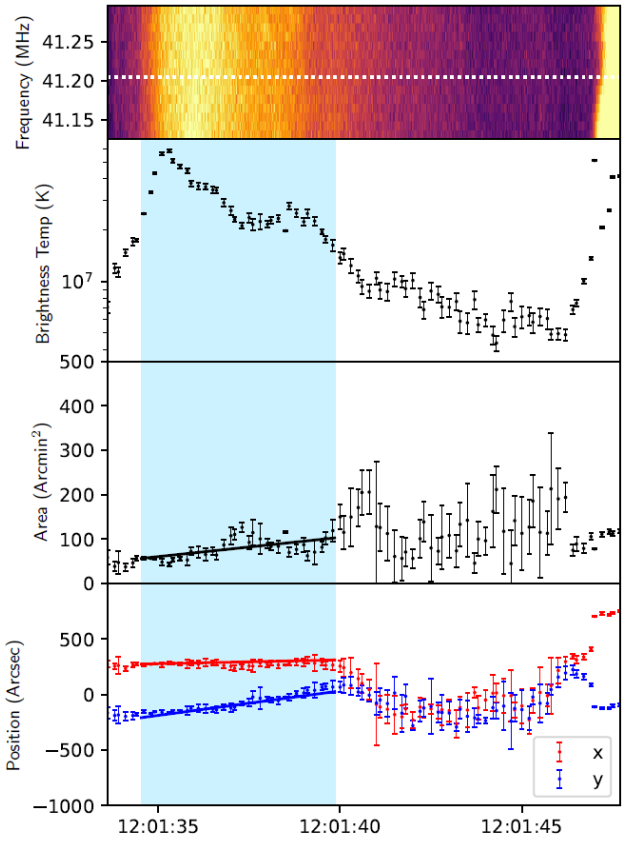


Zhang, Zucca, Sridhar, Wang and al. A&A 2020

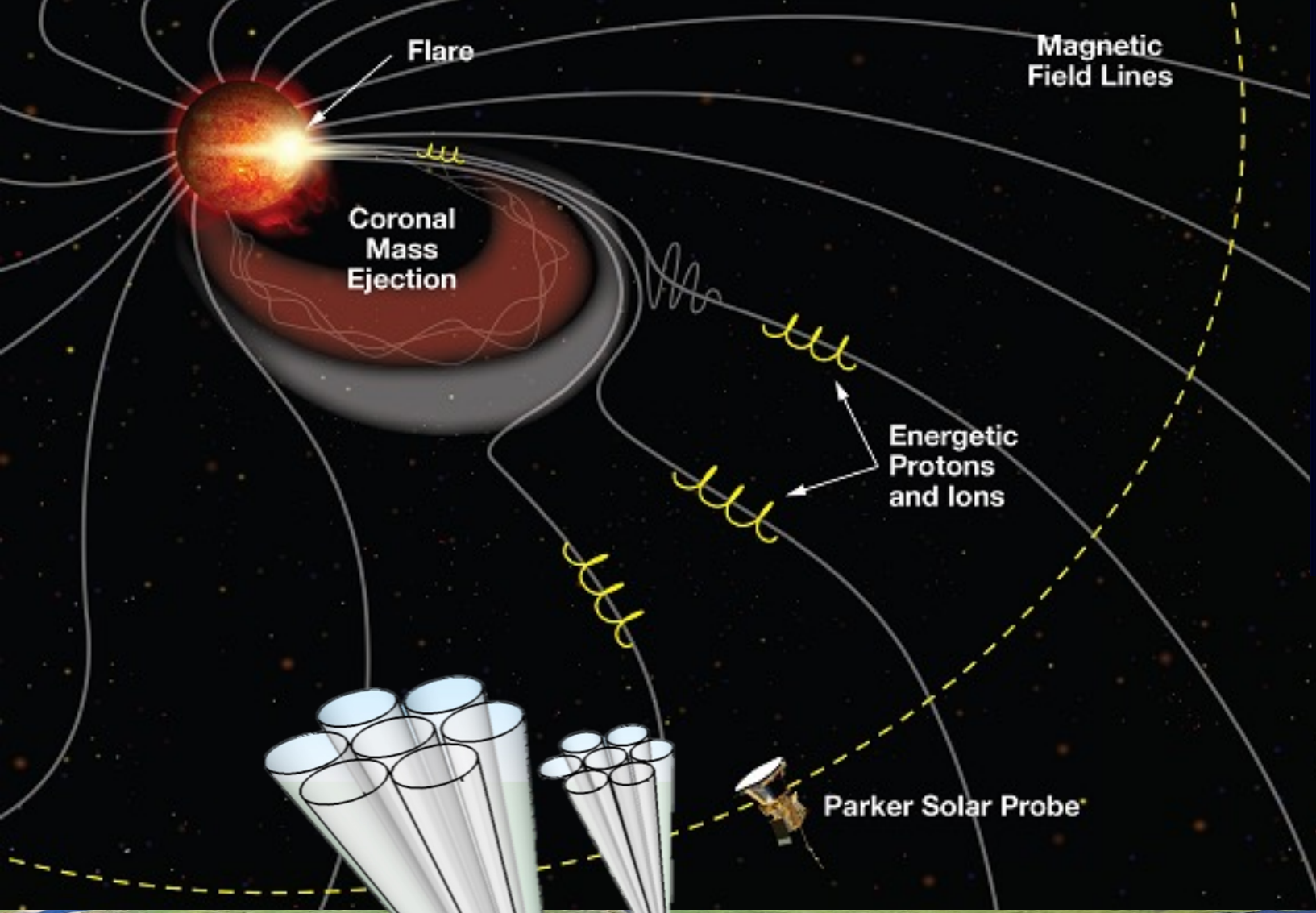
Size and Source Position

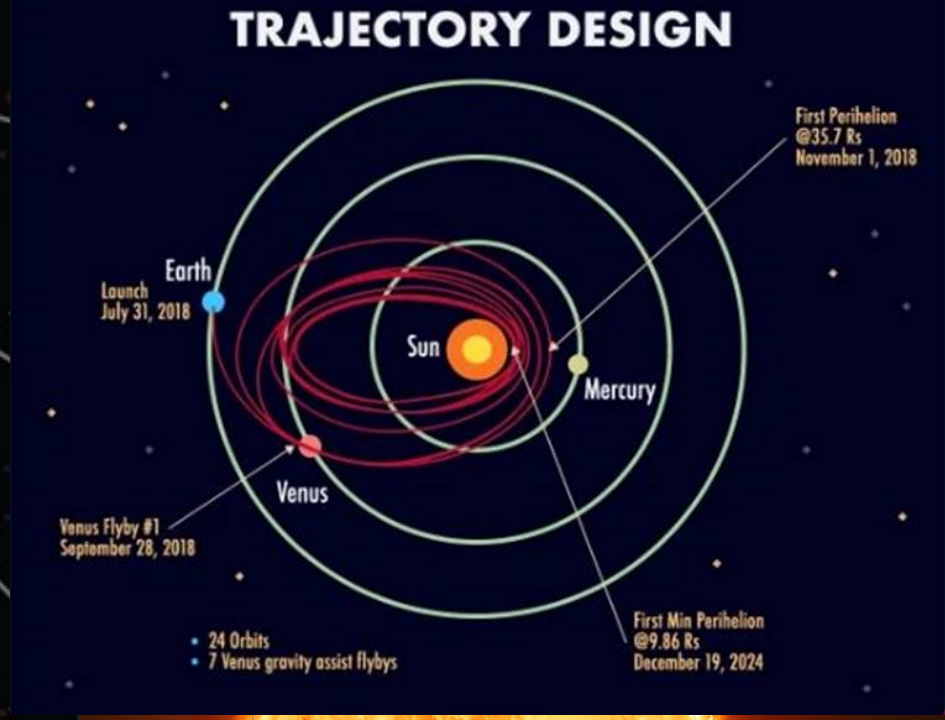


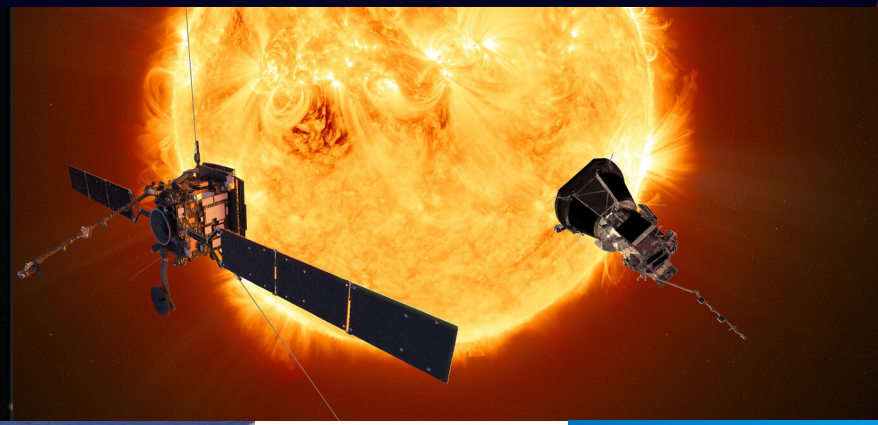


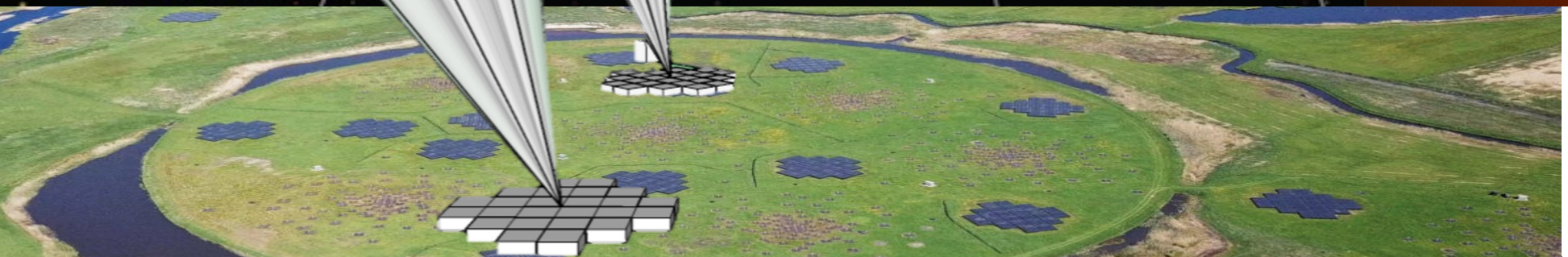


Zhang, Zucca, Sridhar, Wang and al. A&A 2020









LOFAR
Solar and
Space Weather
KSP

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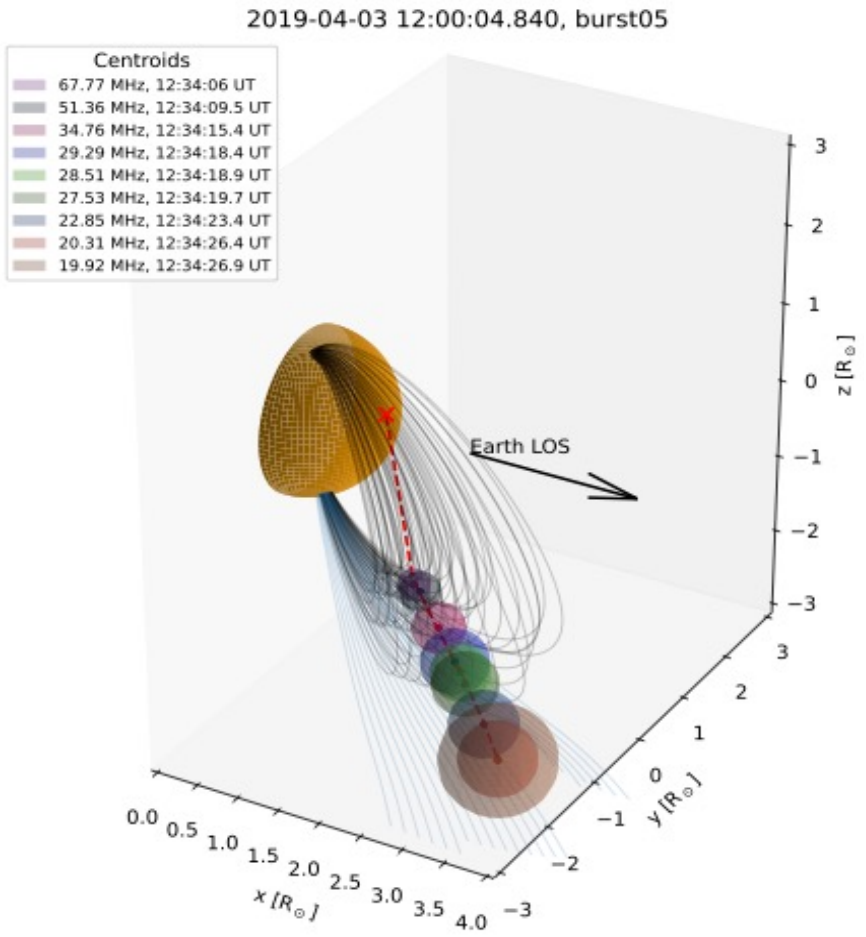
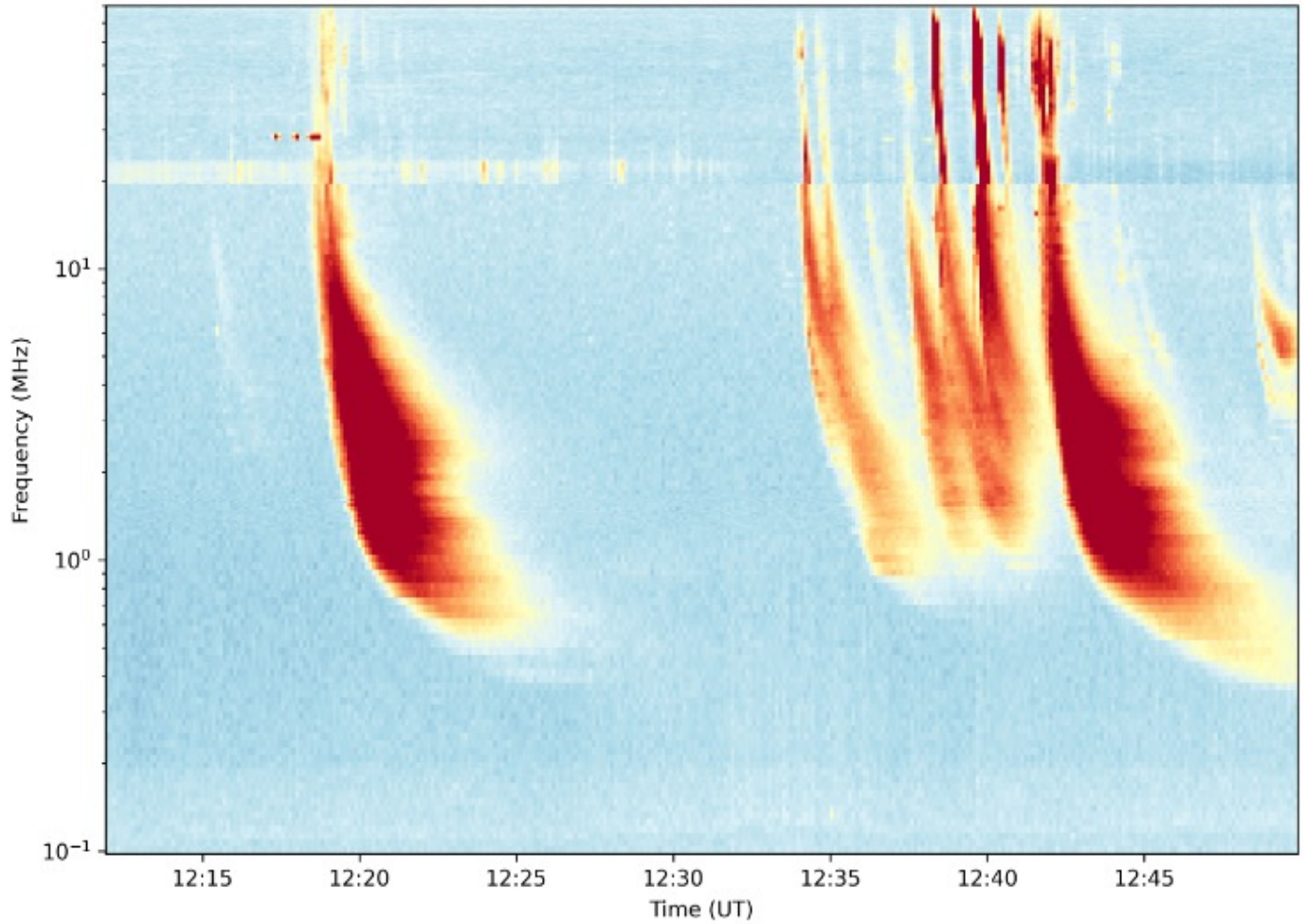
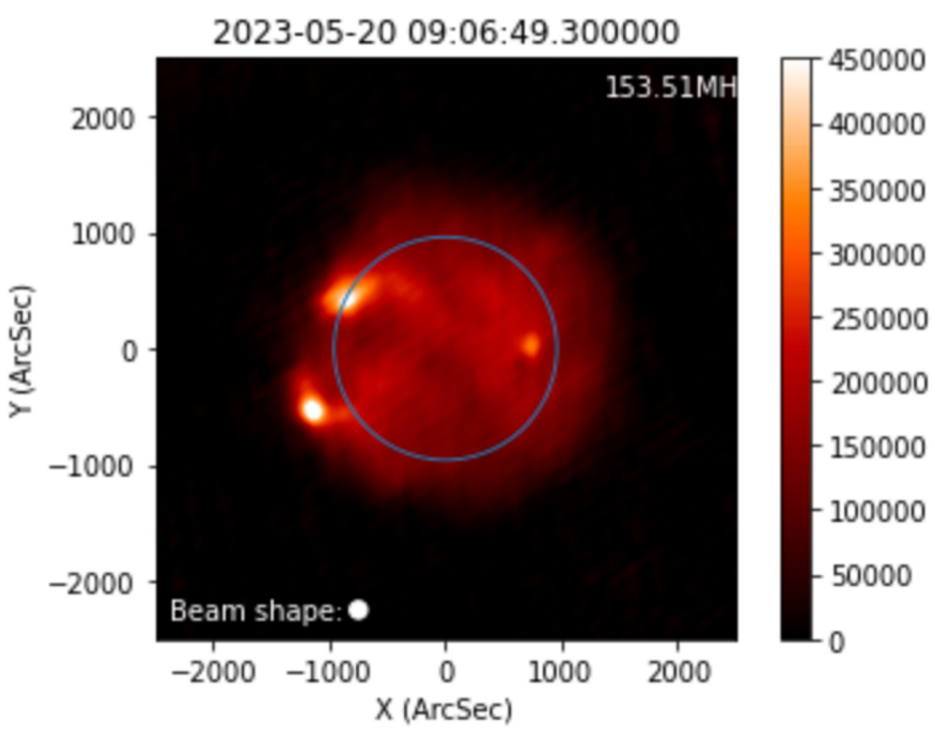
Using LOFAR and PSP to track the radio bursts.

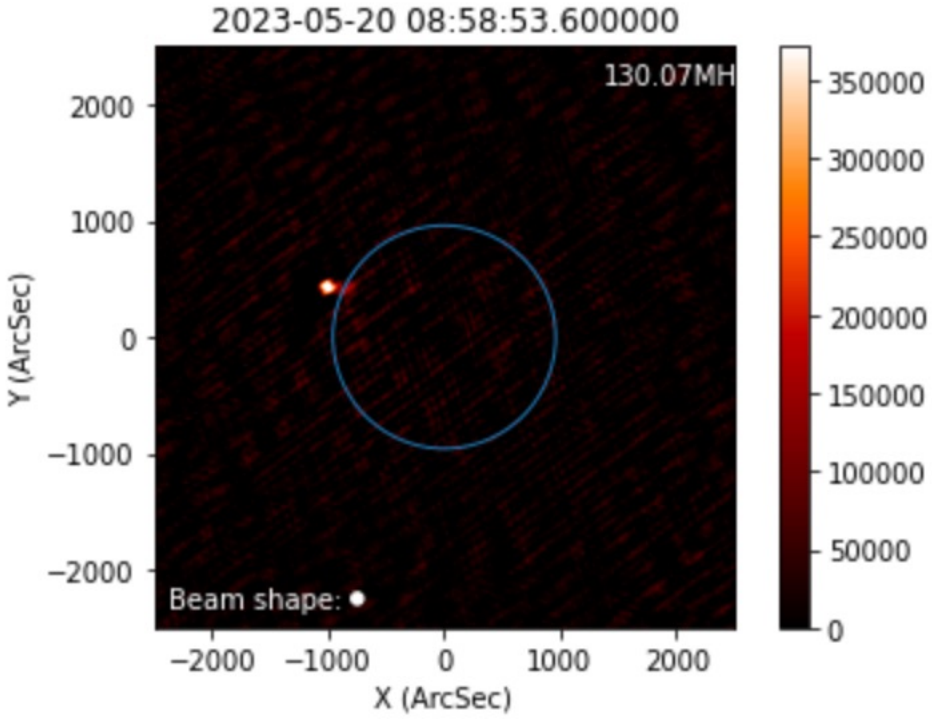




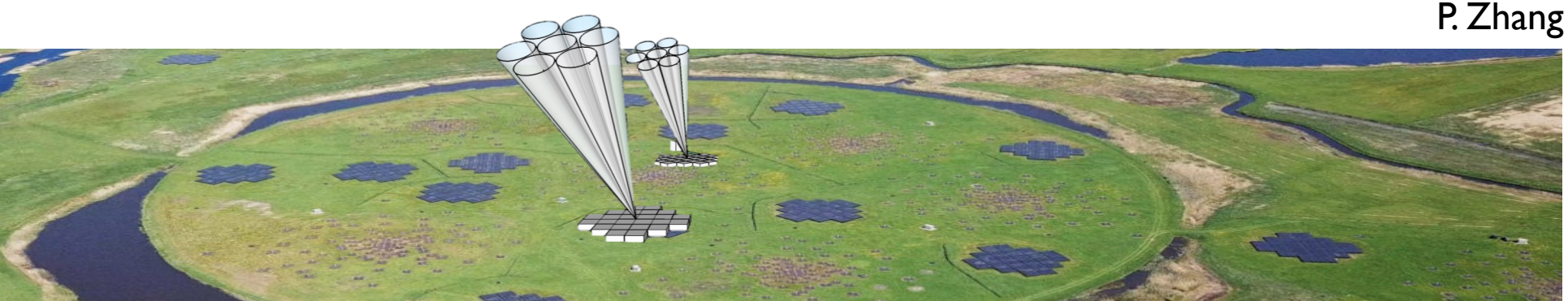
M. Nedal et al 2023

HBA Imaging





P. Zhang and P. Zucca preliminary



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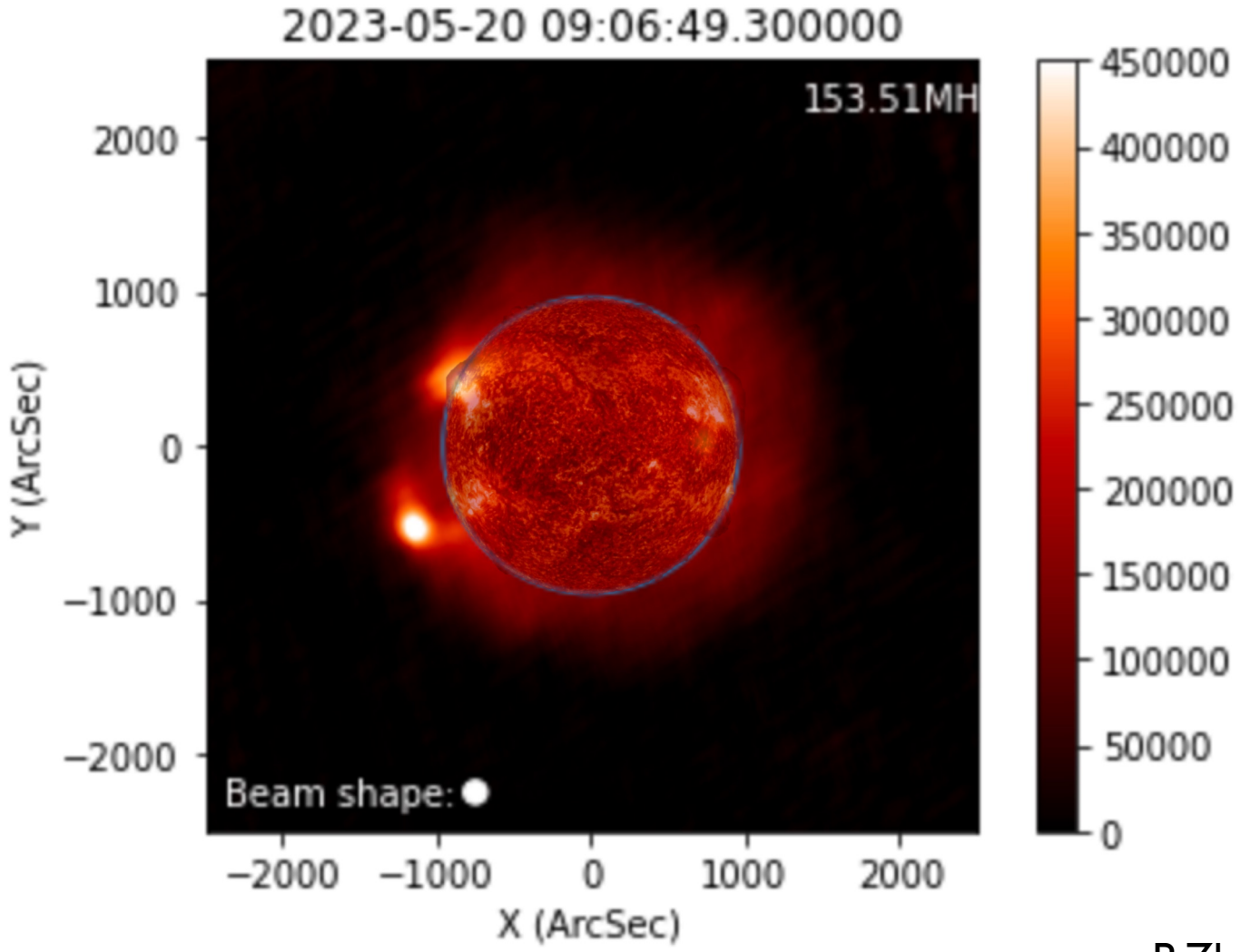
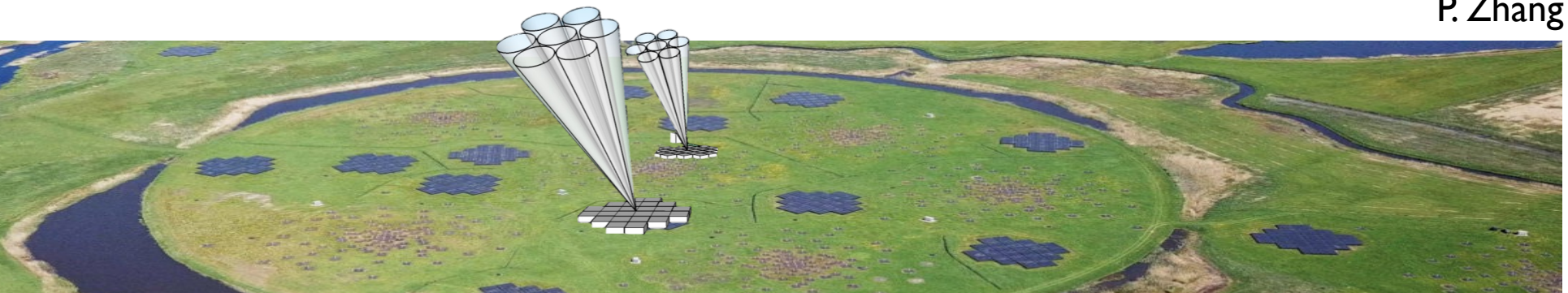


P. Zhang and P. Zucca preliminary



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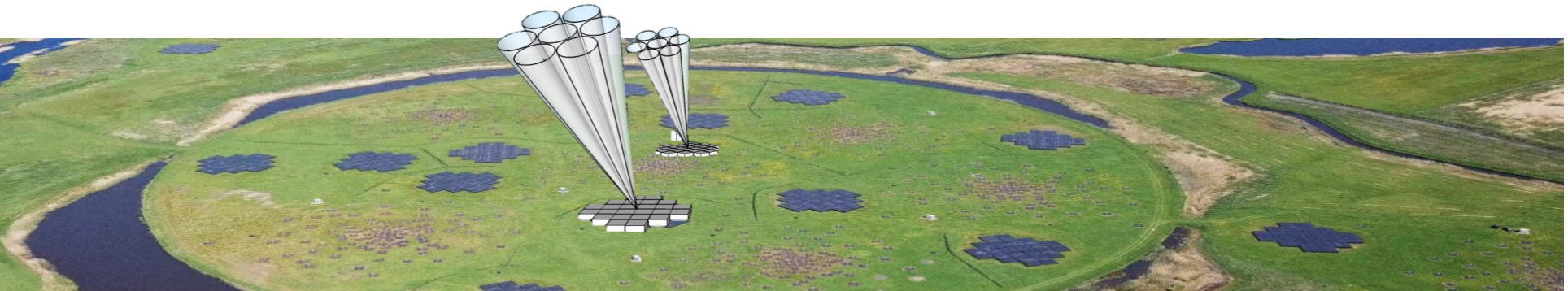
LOFAR
Solar and
Space Weather
KSP

IDOLS

Incremental Development of LOFAR Space-Weather



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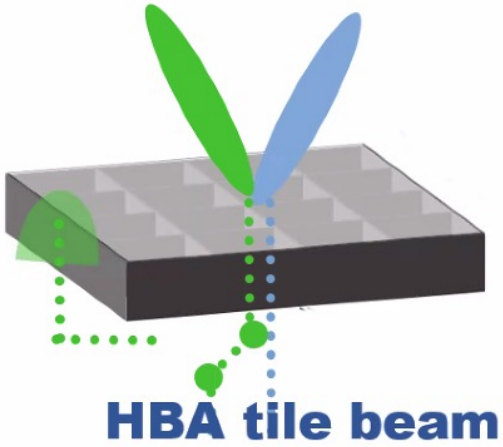
LOFAR
Solar and
Space Weather
KSP

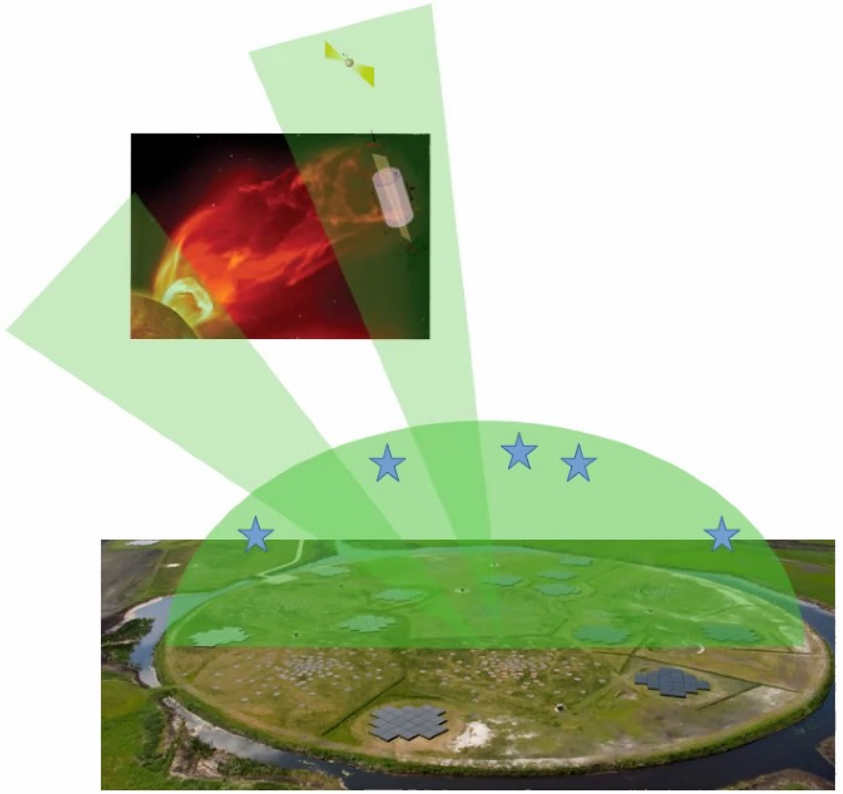
Dual Beam Concept

Slide Courtesy of C. Baldovin

By seizing the opportunity

PHASE 2

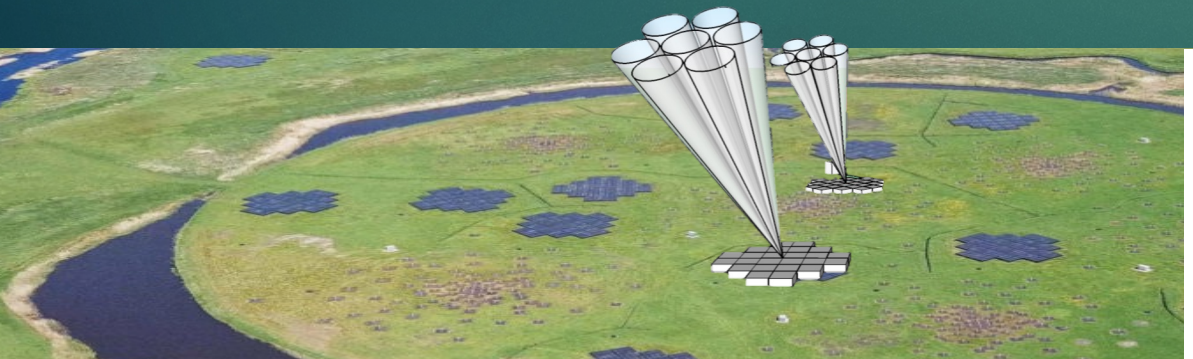





CS030
CS101
CS031
CS021
CS013
CS017
CS026
CS007
CS006
CS005
CS401
CS032
CS001
CS024
CS301
IDOLS

Status

- First Light 2022-04-13
- Live monitoring tests Summer-2022
- Live monitoring operational end-2022
- Archive processing (Surf Sara) Updated daily



IDOLS

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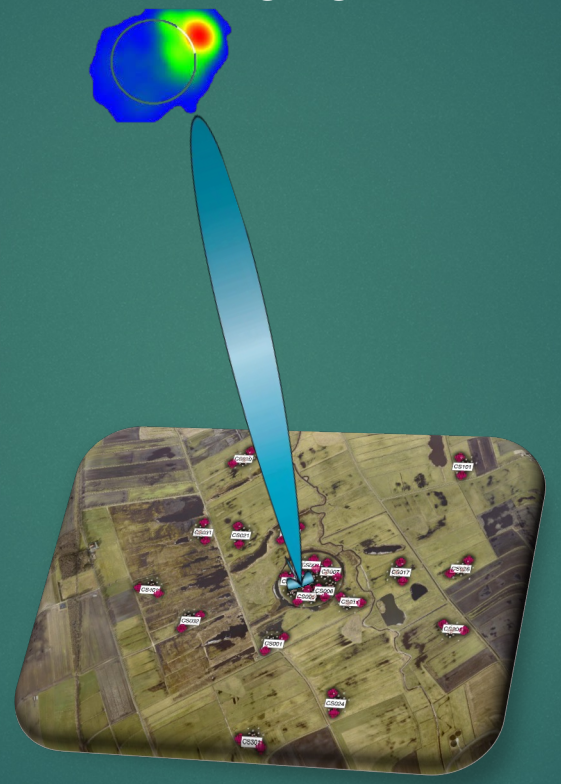
LOFAR Solar and Space Weather KSP

Operation

Noon

Sun Imaging Snapshot



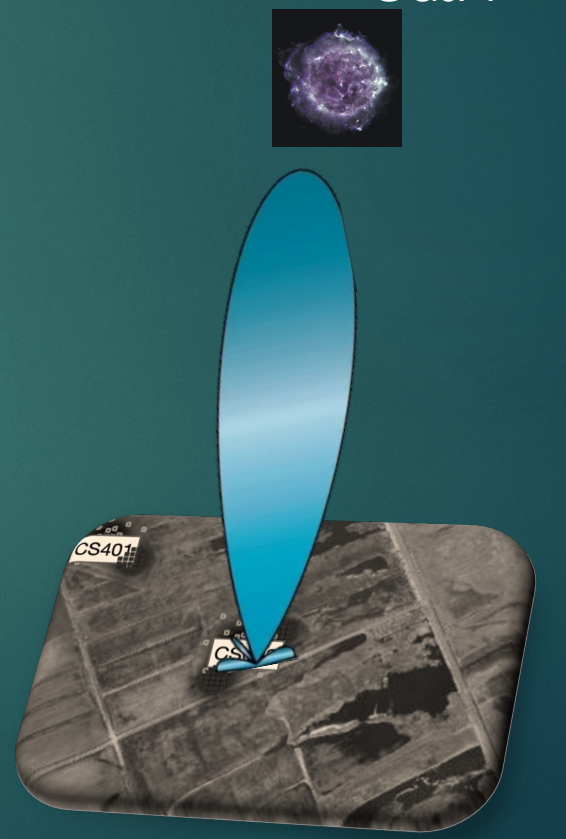
Day

Sun

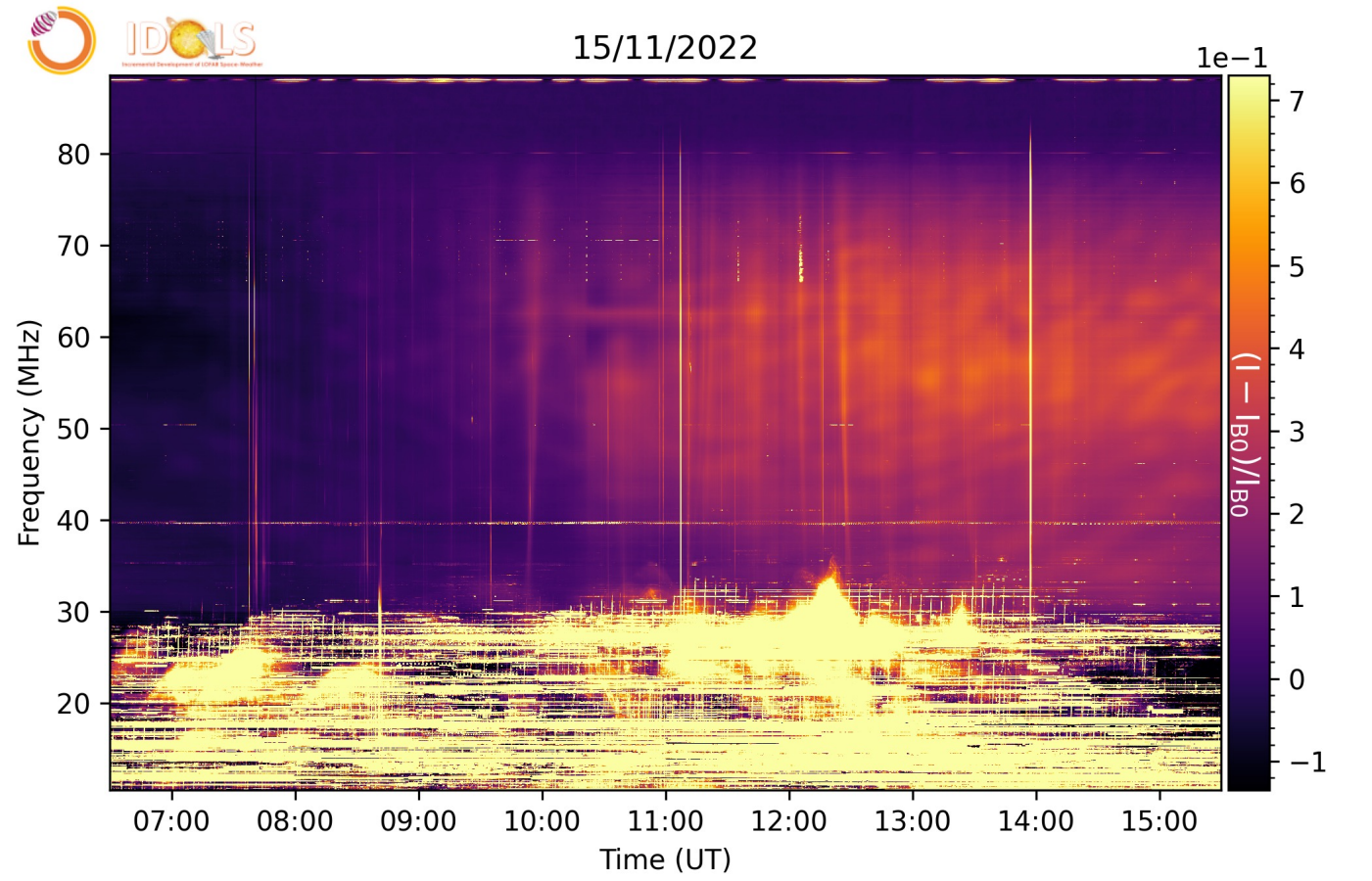
CasA

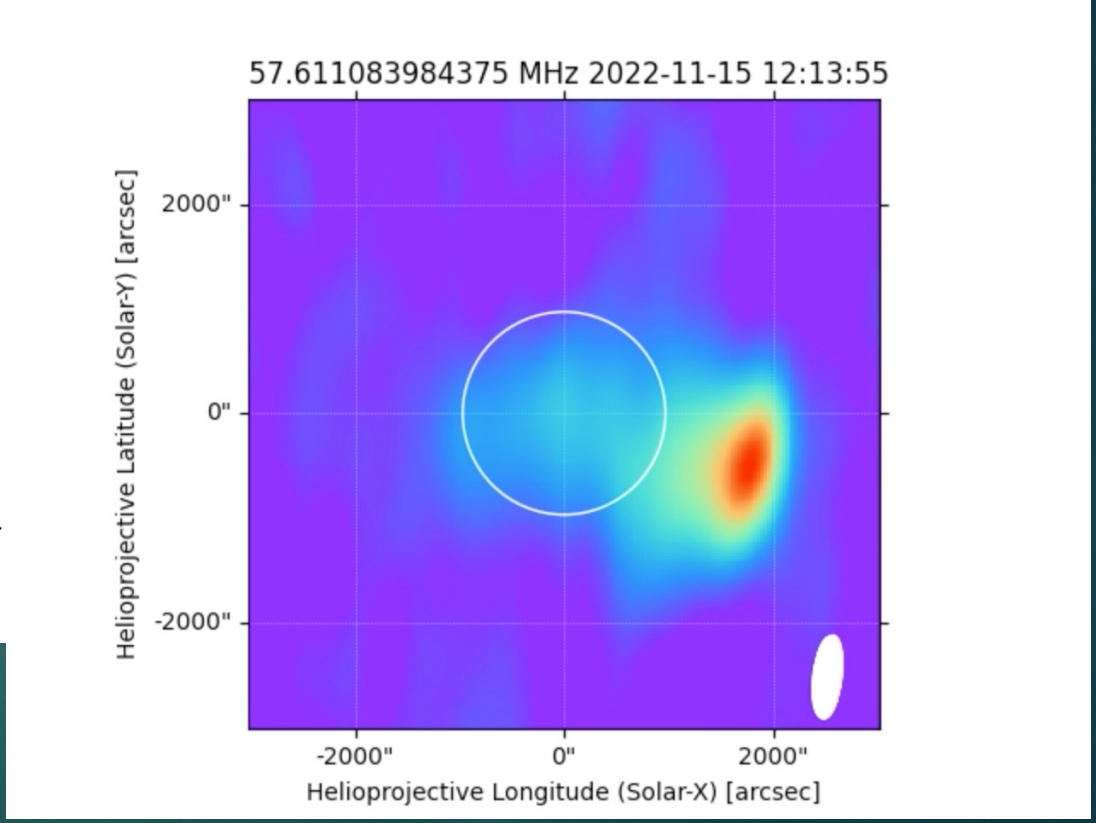
Night

CasA

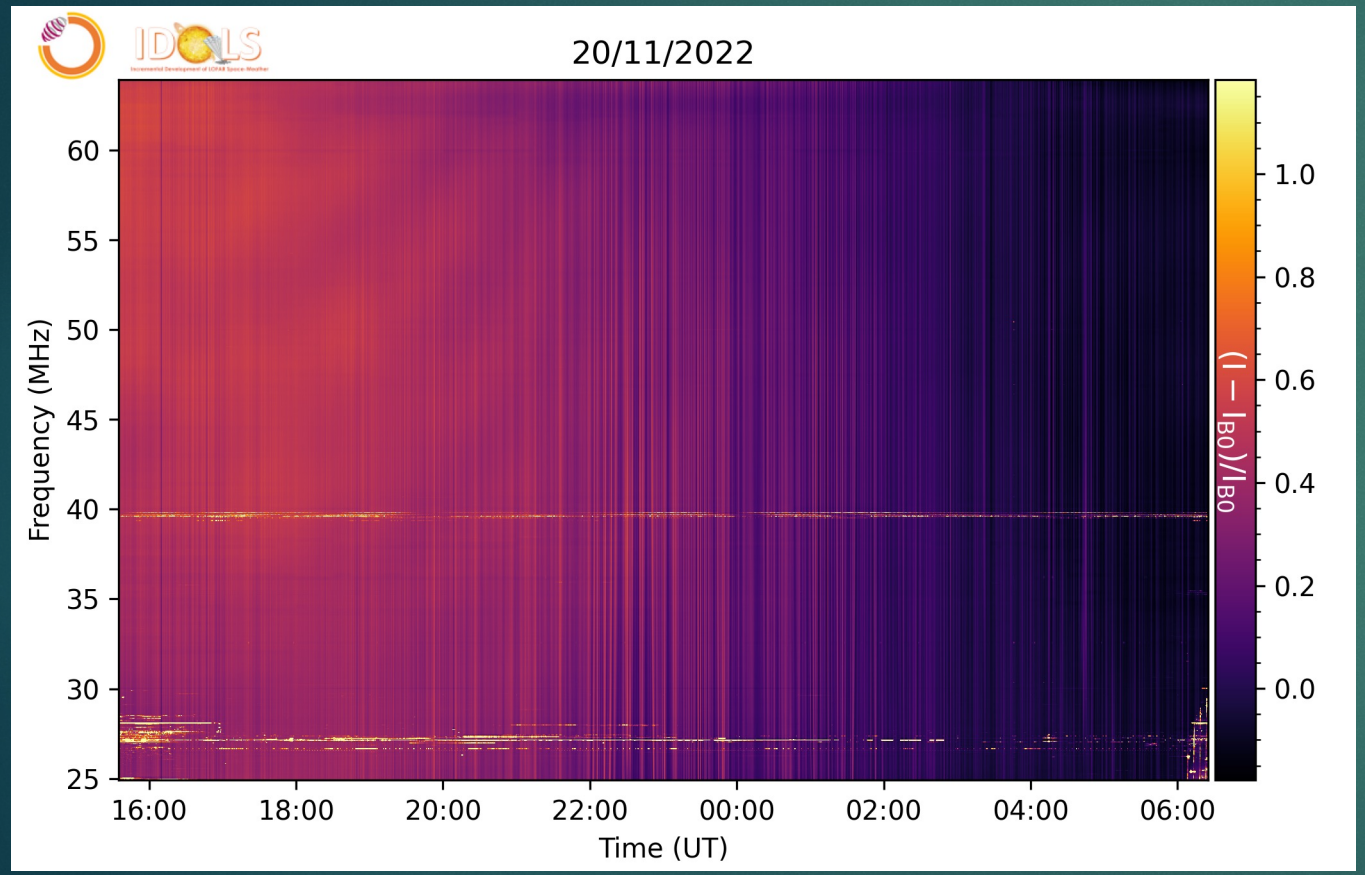


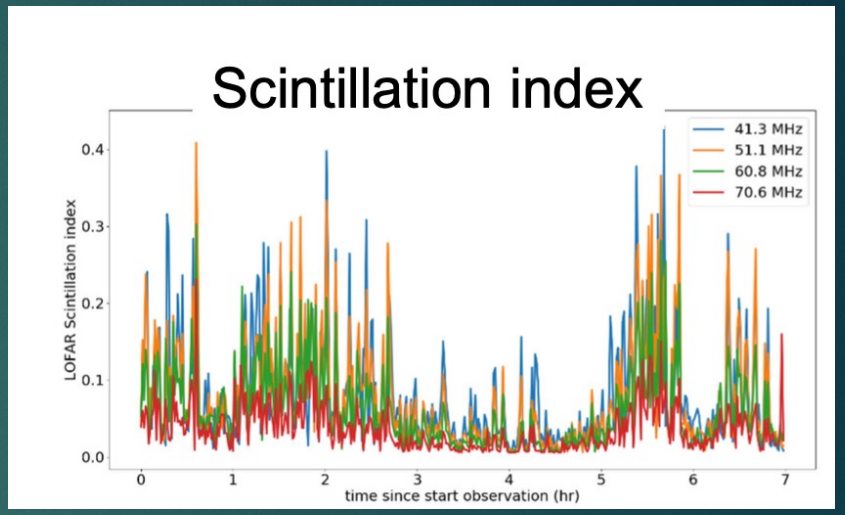
Solar Example



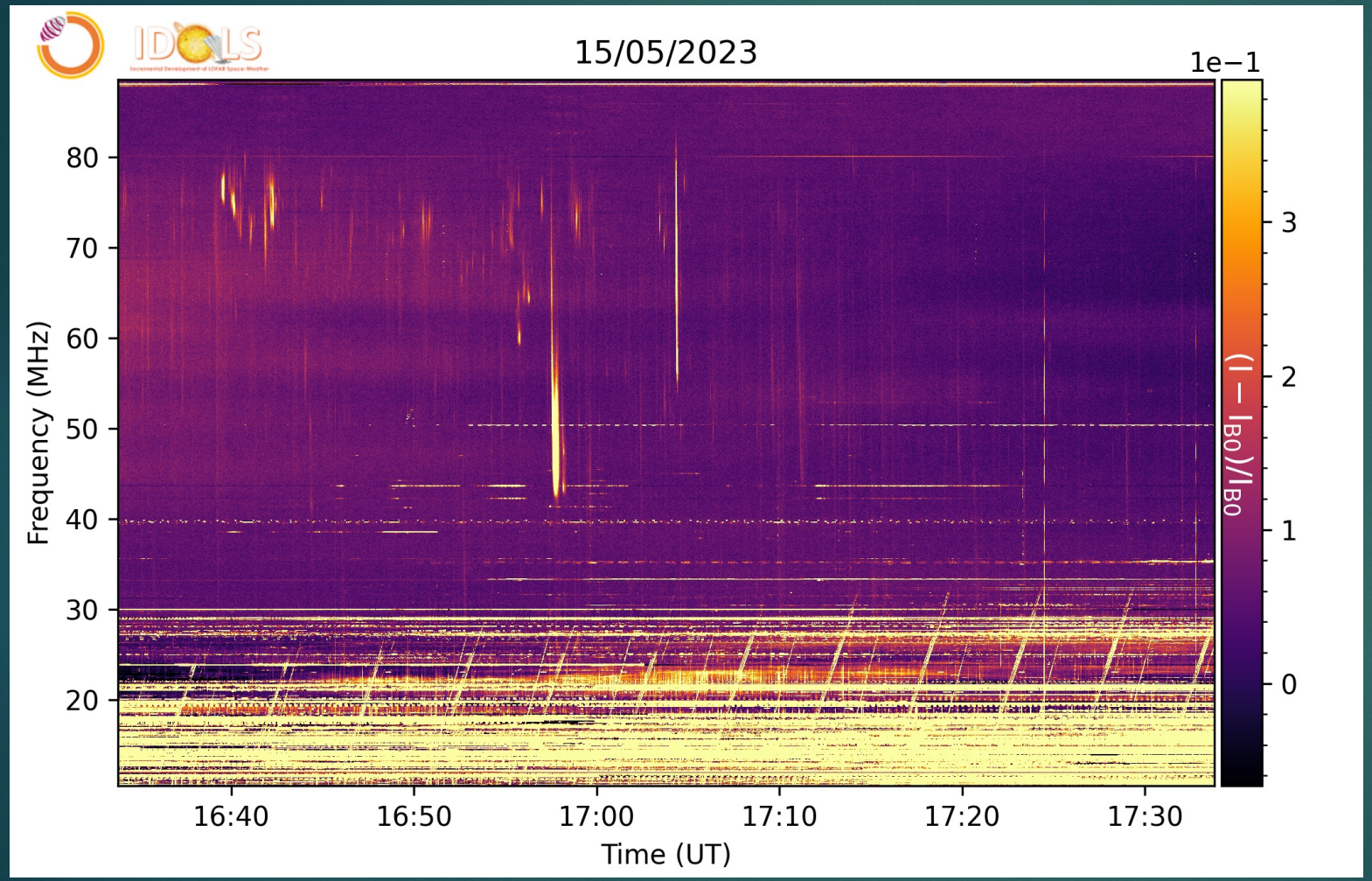


Ionosphere Example





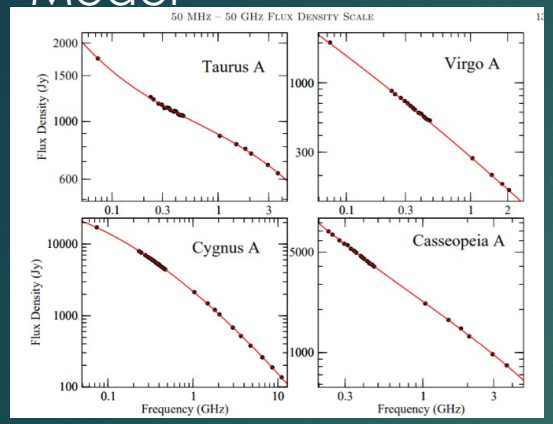
IDOLS Live



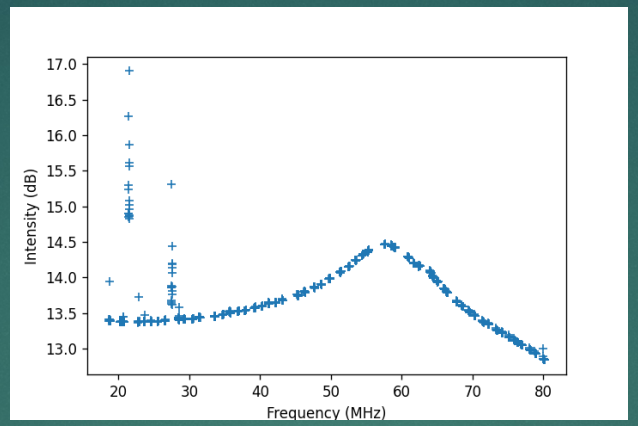
https://spaceweather.astron.nl/SolarKSP/data/website/

Calibrated Spectrum

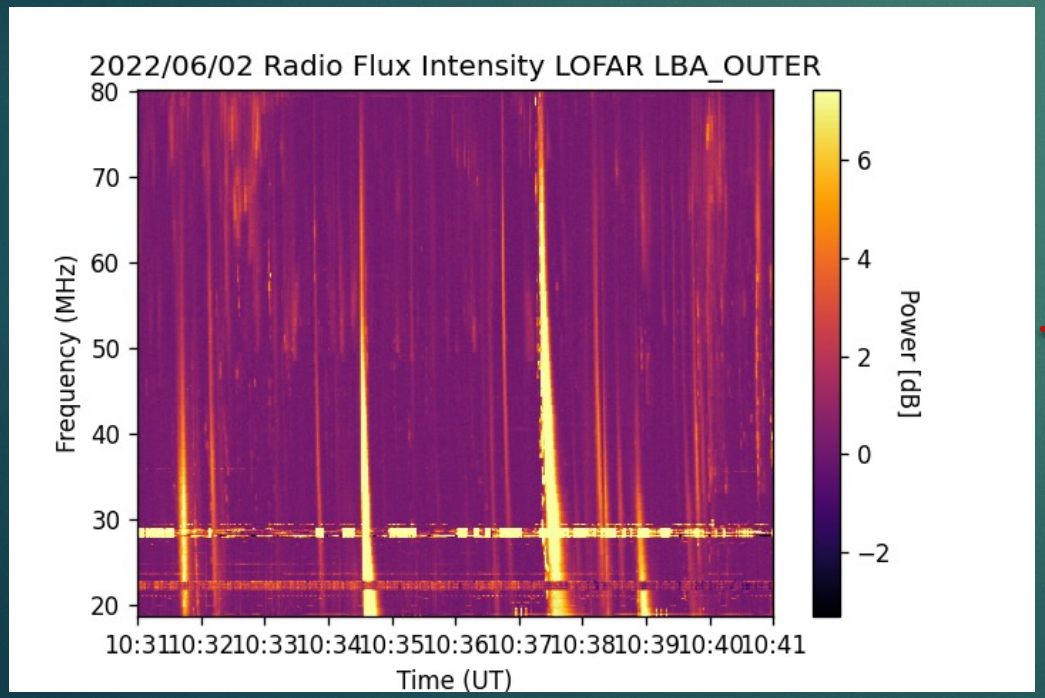
Model

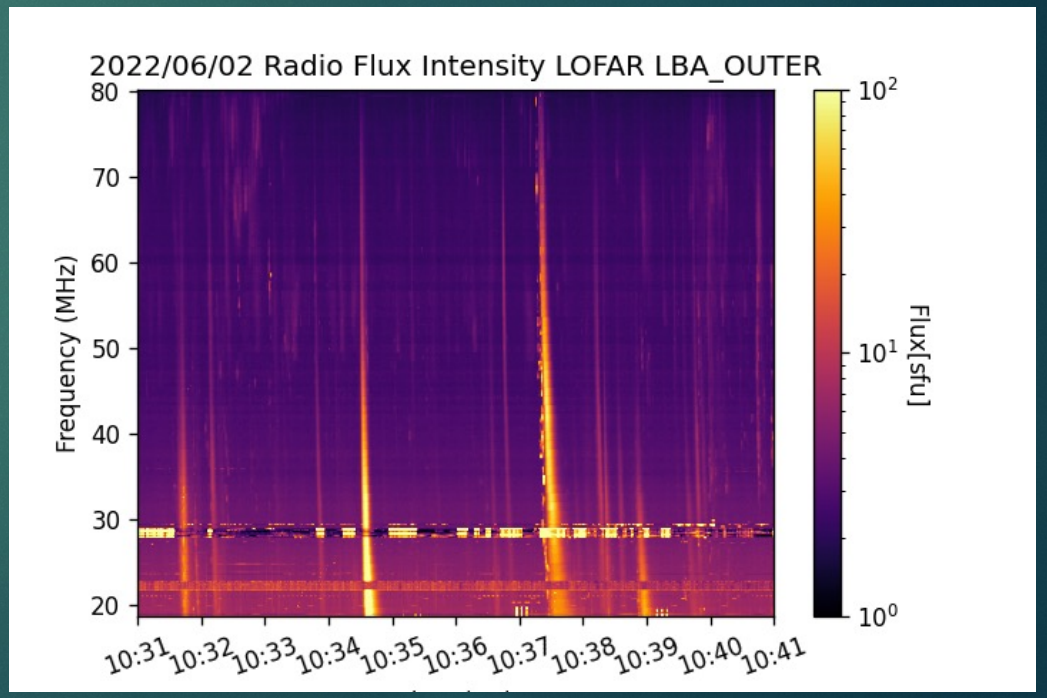


Bandpass in quasi real time



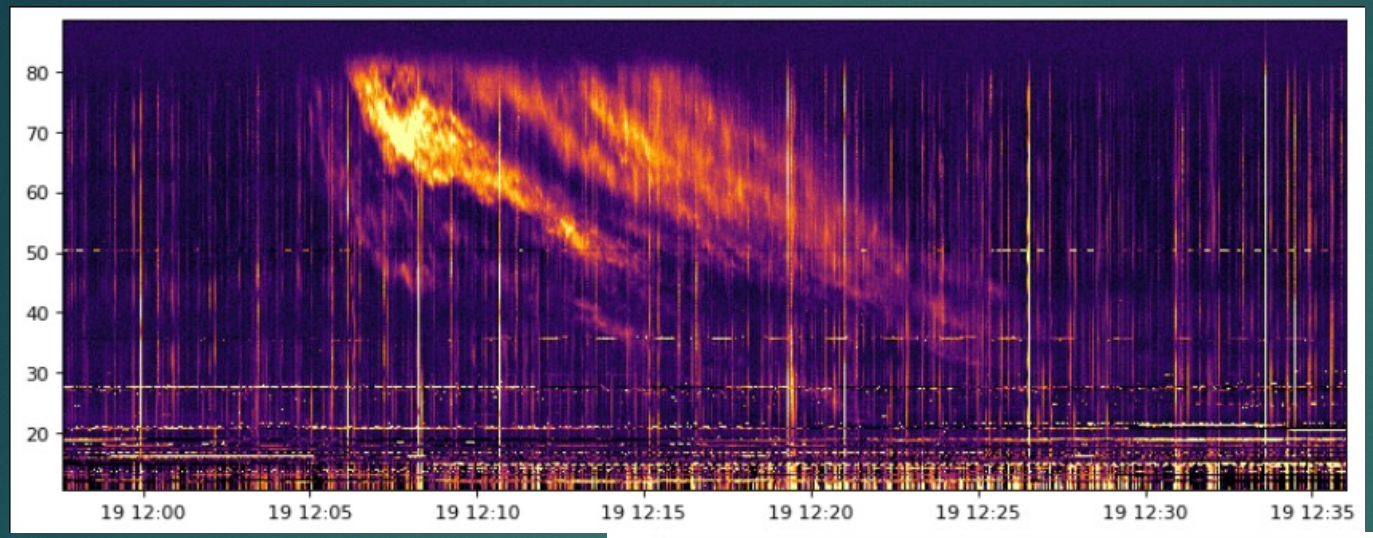
Calibrated Flux and Fluence available for monitoring tools and science

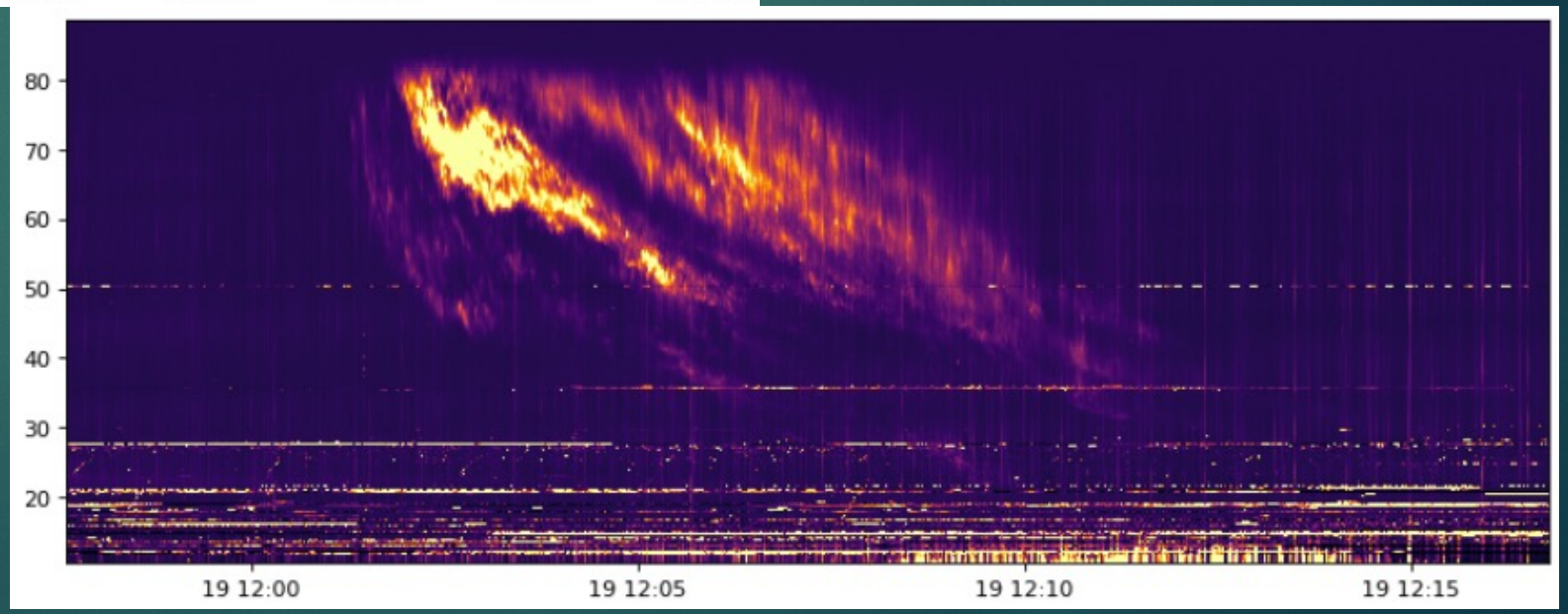




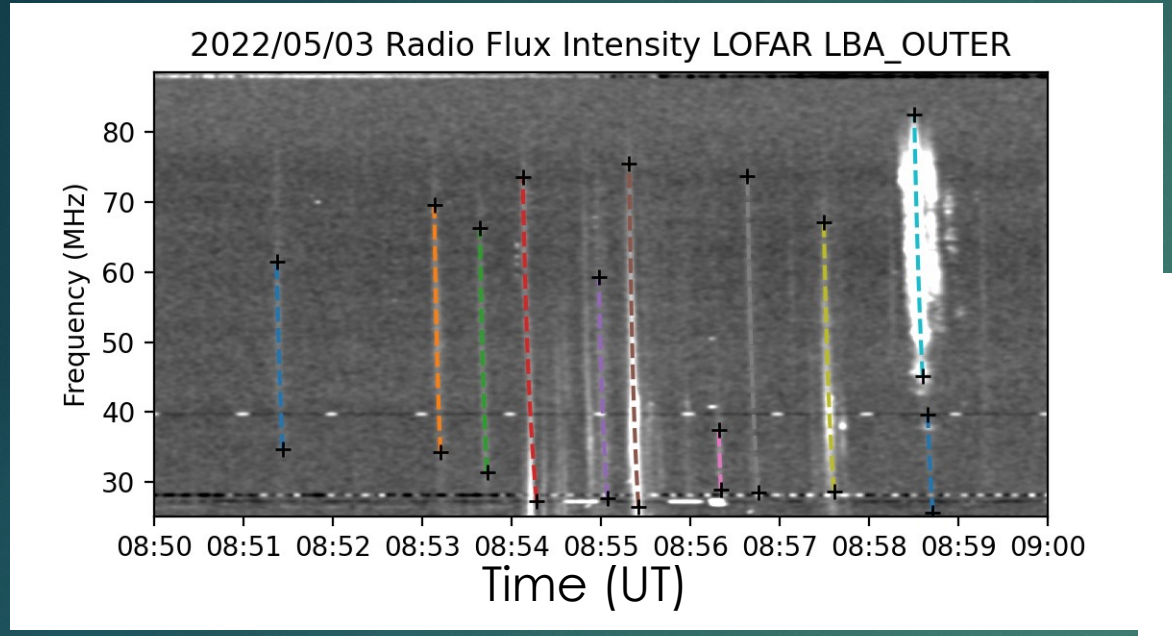
C. Cordun, M. Nedal, P. Zhang P. Zucca

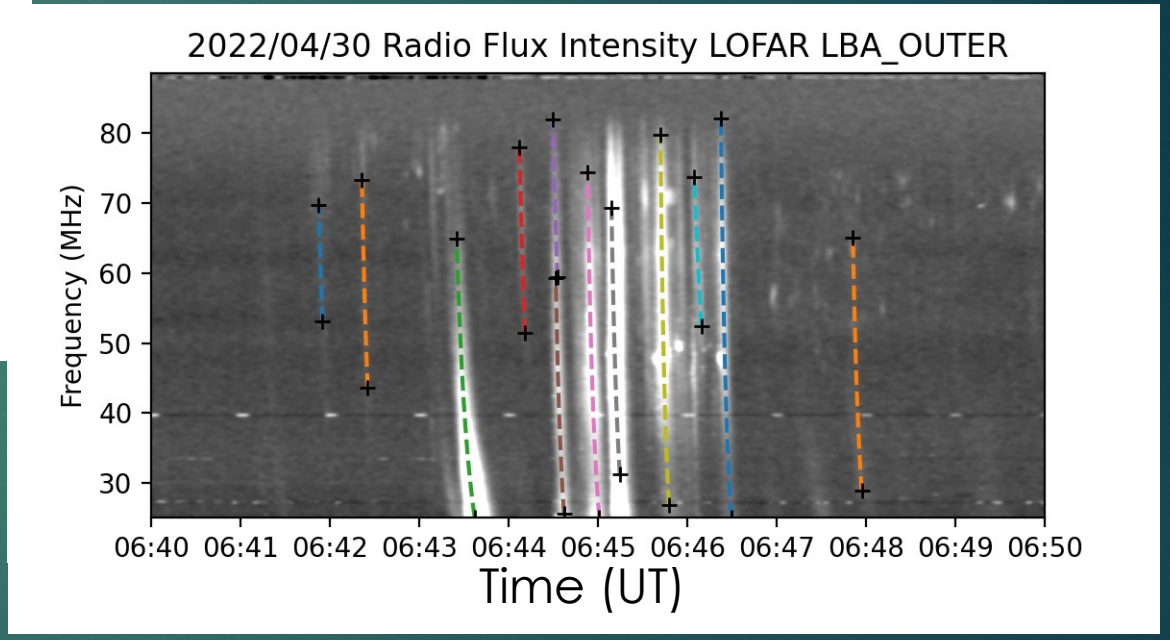
Flagging and Instrumental Corrections





Detection of Events

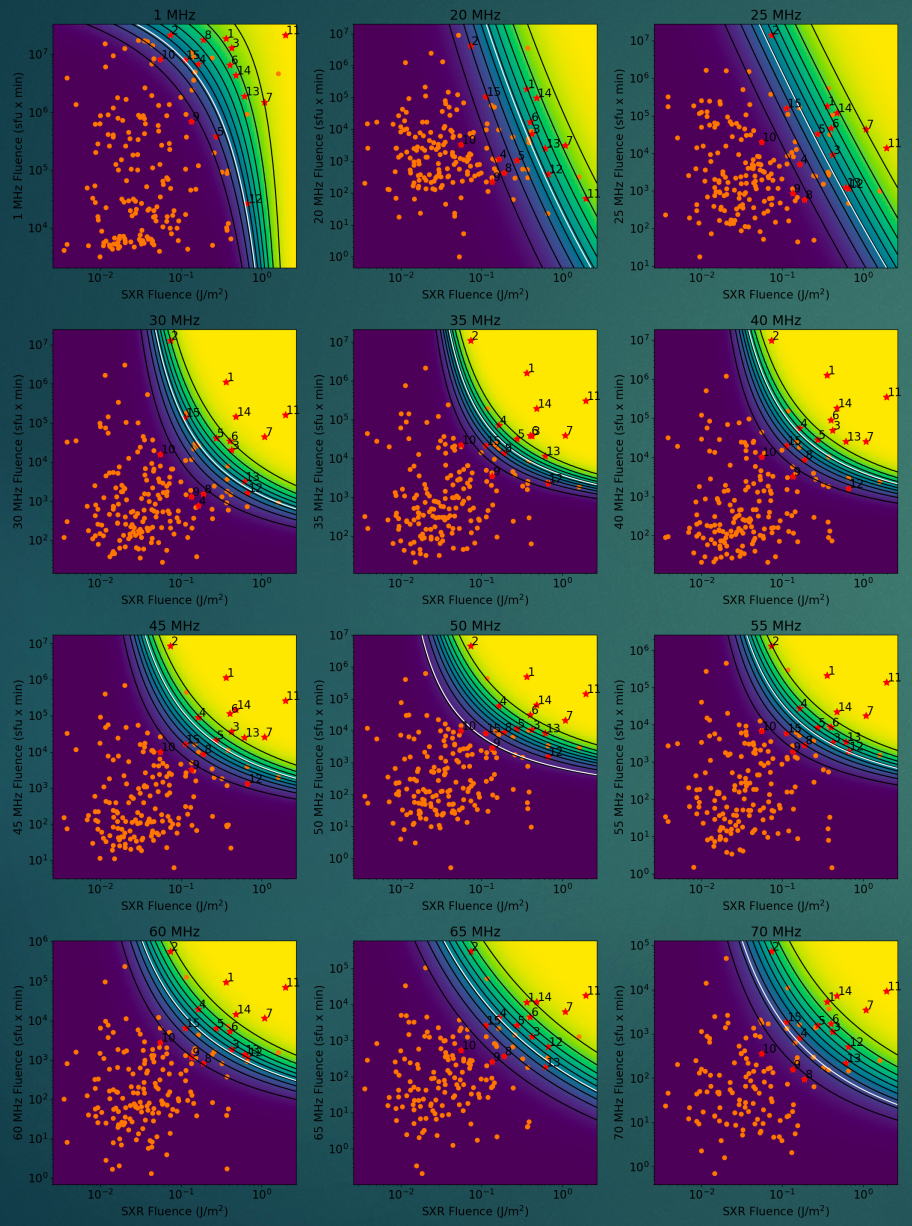


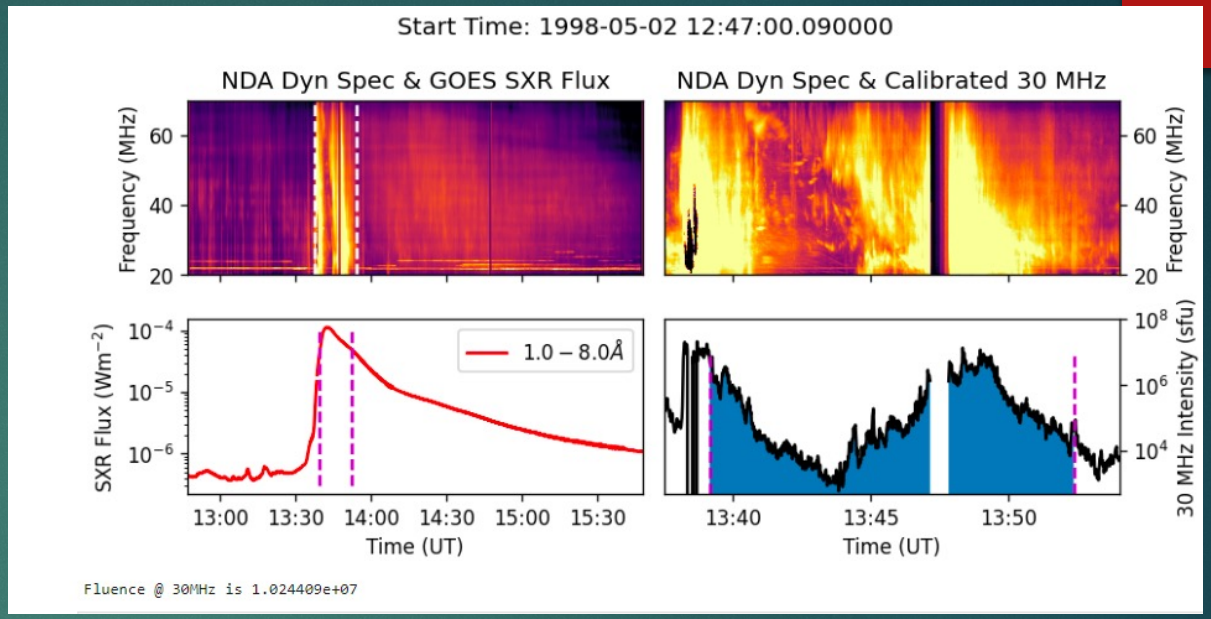


List of detection available
ID, t, t0_num, t1_num,f_0,f_1, dfdt(MHz/s), v_b(c)

P. Zhang and STELLAR project

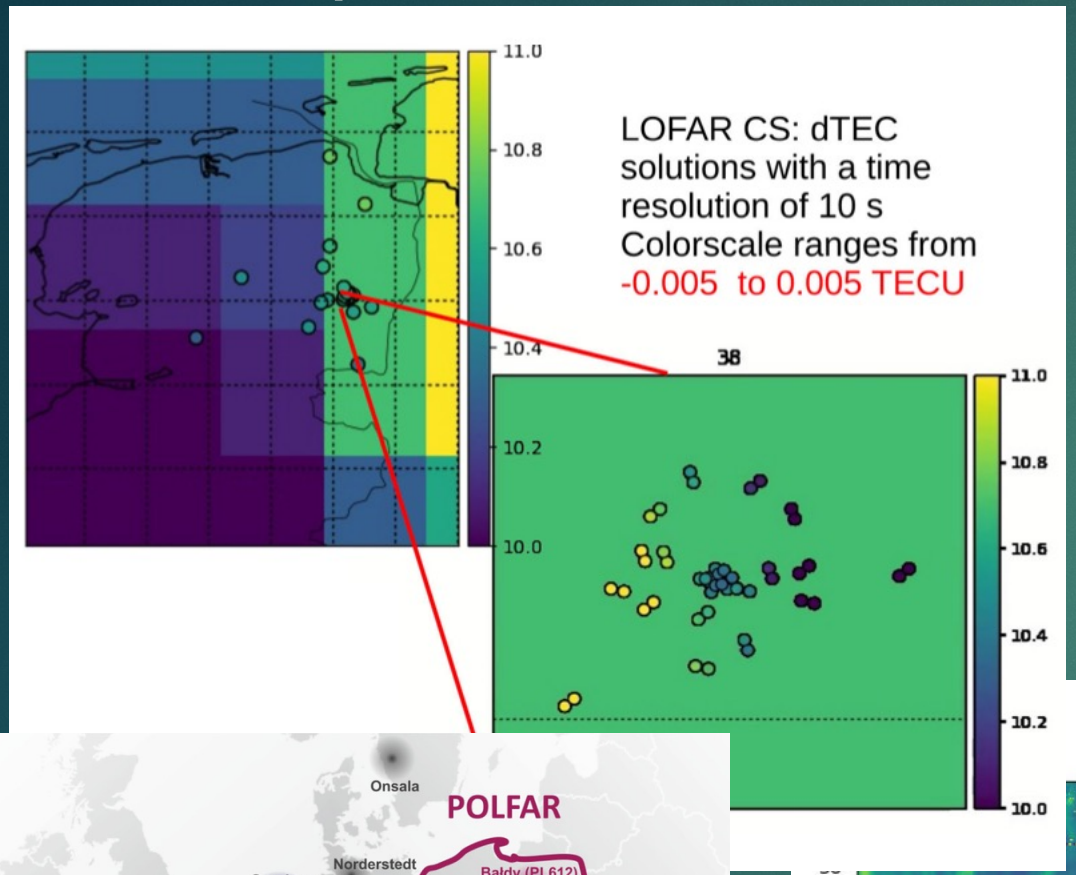
Examples of tools based on radio monitoring

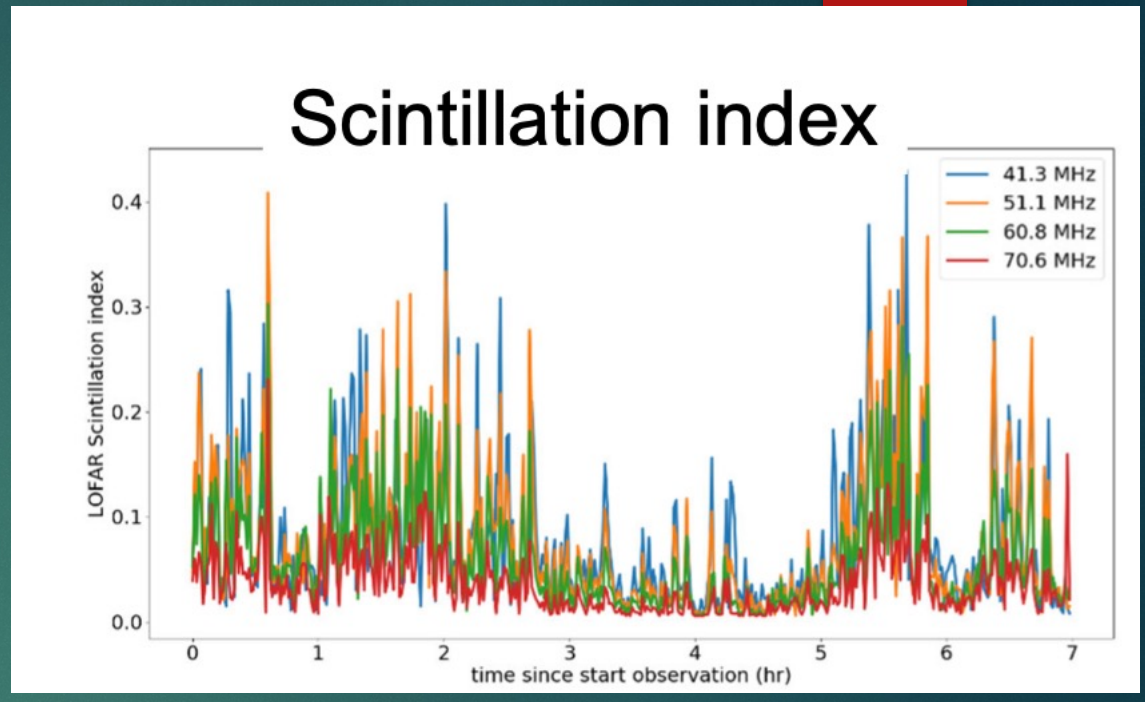


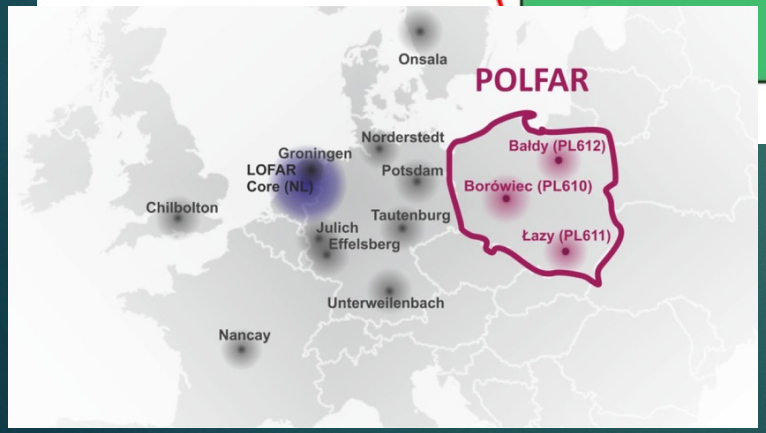


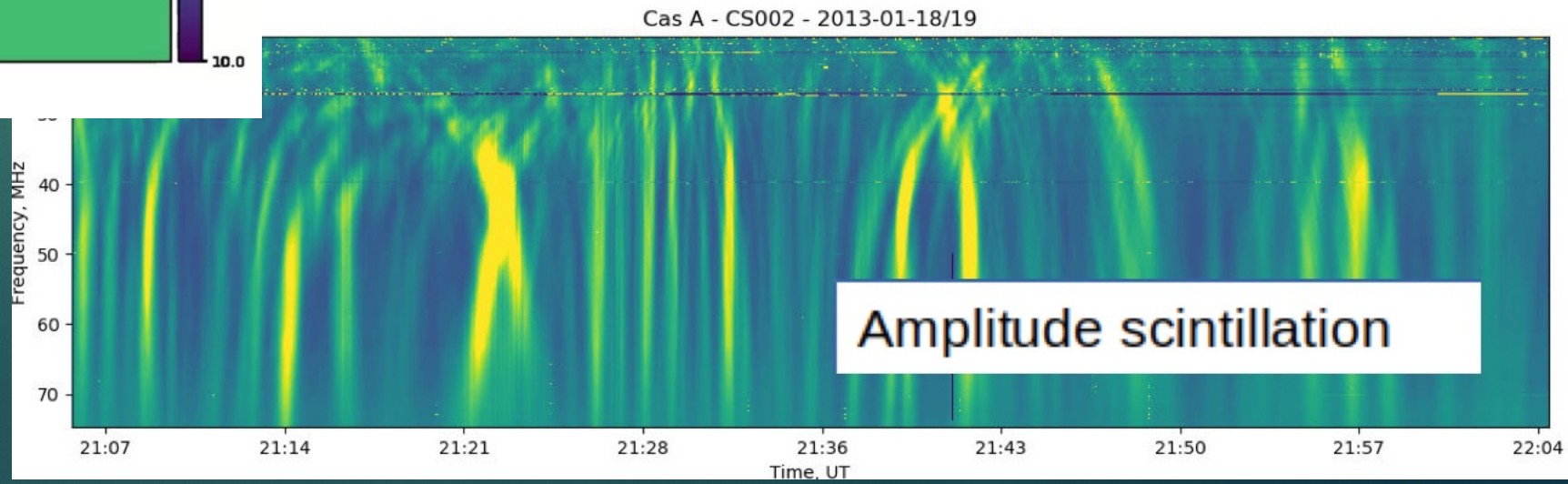
Prediction Model	Input Parameters	Forecast Statistics
LOFAR IDOLS	SXR fluence, 45 MHz fluence	POD: 0.71, FAR: 0.33
Laurenza (2018) (ESPERTA)	SXR fluence, 1 MHz fluence, flare longitude	POD: 0.63, FAR: 0.42
Kubo & Akioka (2004)	SXR flux	POD: 1.00, FAR: 0.85
Garcia (2004a)	SXR peak intensity, peak flare temp.	POD: 0.58, FAR: 0.46
Garcia (2004b) & (Kiplinger (1995))	HXR spectral index	POD: 0.52, (0.96) FAR: 0.18, (0.27)
Posner (2007)	Relativistic electrons	POD: 0.8, FAR: 0.56
Anastasiadas (2017) (FORSPEF)	Flare longitude, historical flare data	POD: 0.4, FAR: 0.57
Anastasiadas (2017) (FORSPEF)	Peak SXR flux, flare longitude, CME speed and width	POD: 0.71, FAR: 0.41

Ionosphere









Polfar Team and M. Mevius

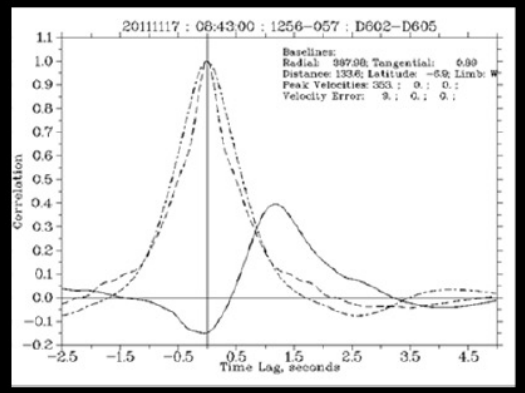
Interplanetary magnetic field

Faraday Rotation from polarised source

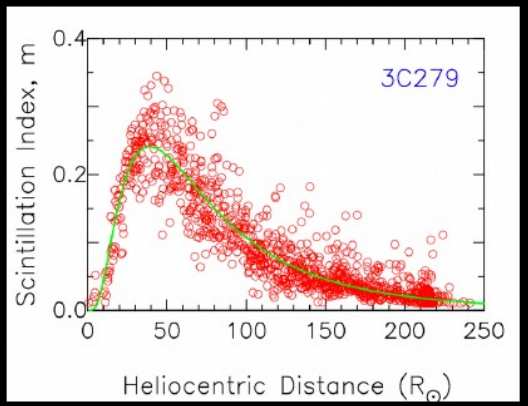
Interplanetary Scintillation from compact source

Solar wind density and velocity

Ionospheric scintillation

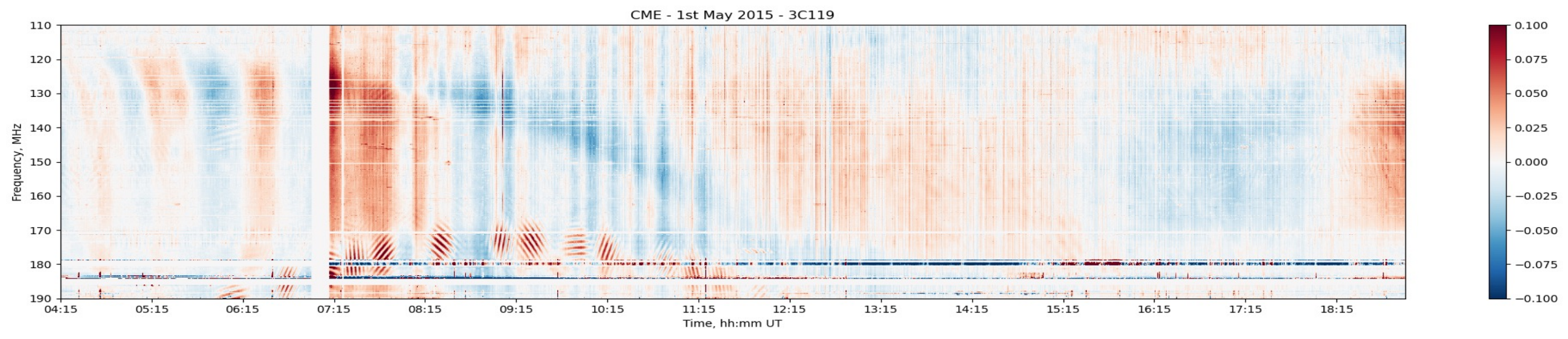


Cross-correlation of time series -> velocity

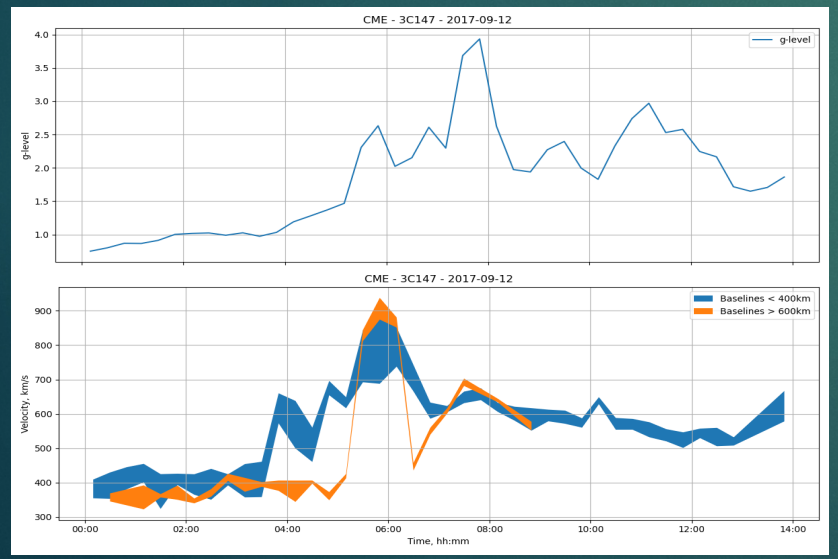


Variation in amount of scintillation -> density

CME Observations - Demonstrating IPS Techniques

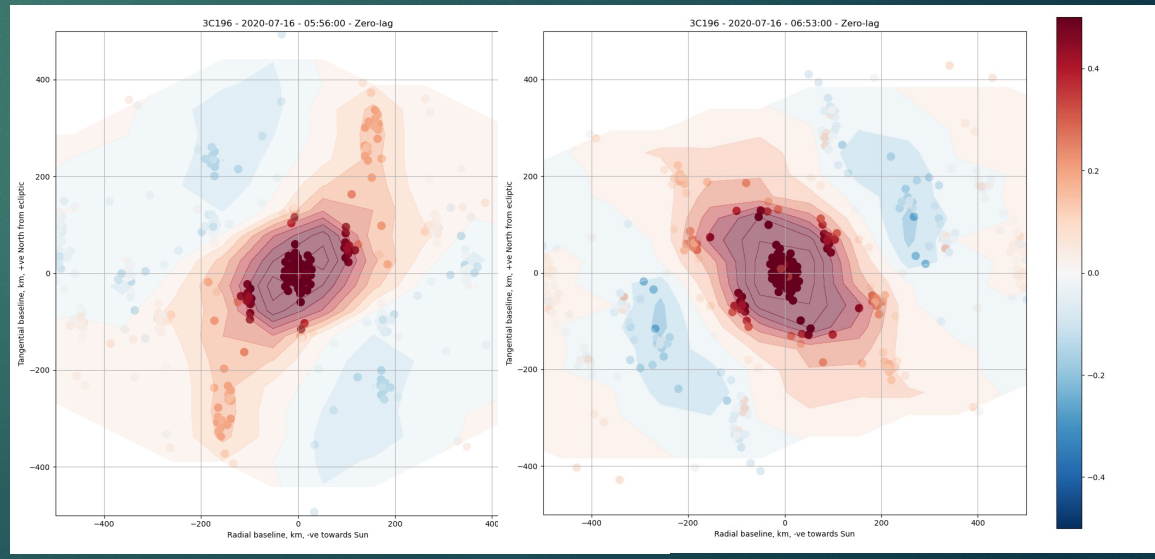


Wideband dynamic spectra of intensity show features invisible to traditional single-frequency time series. This 15-hour observation of a CME (above) shows structure on a ~30-minute time-scale for the first few hours, probably related to large-scale structure in the CME.



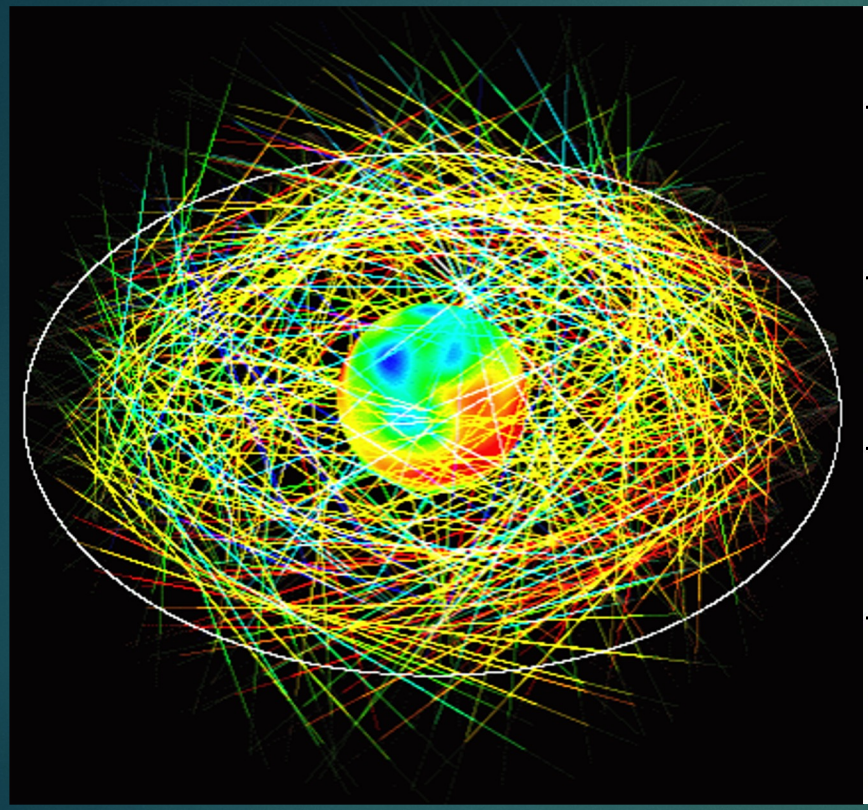
Left: g-level (related to density - top) and velocity from an ultra-fast CME in September 2017.

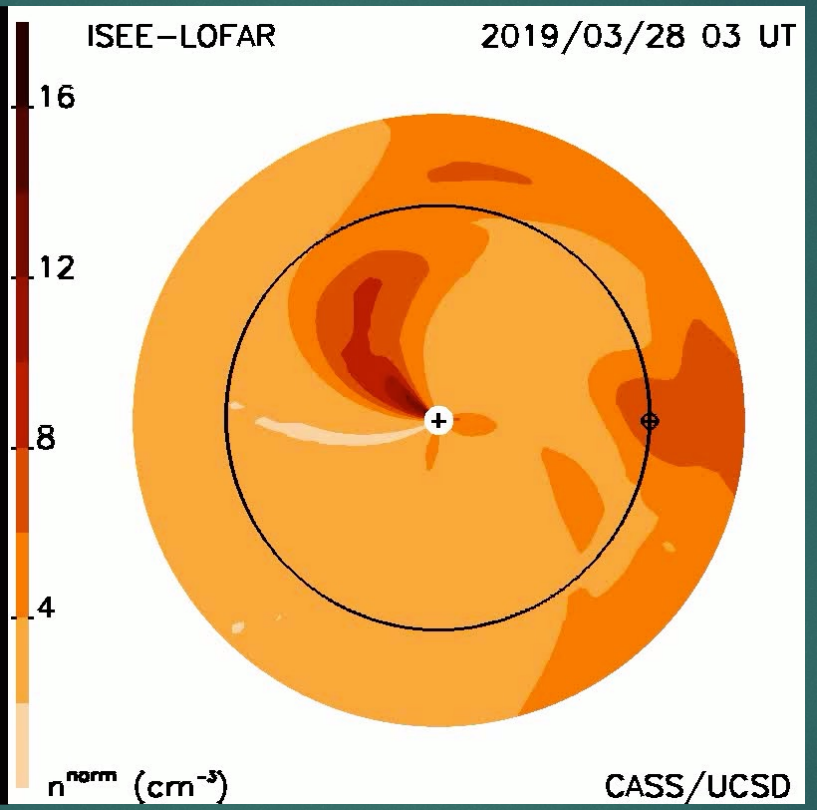
Right: two spatial correlation functions (a reflection of the small-scale density structure) show rotation related to the interplanetary magnetic field.

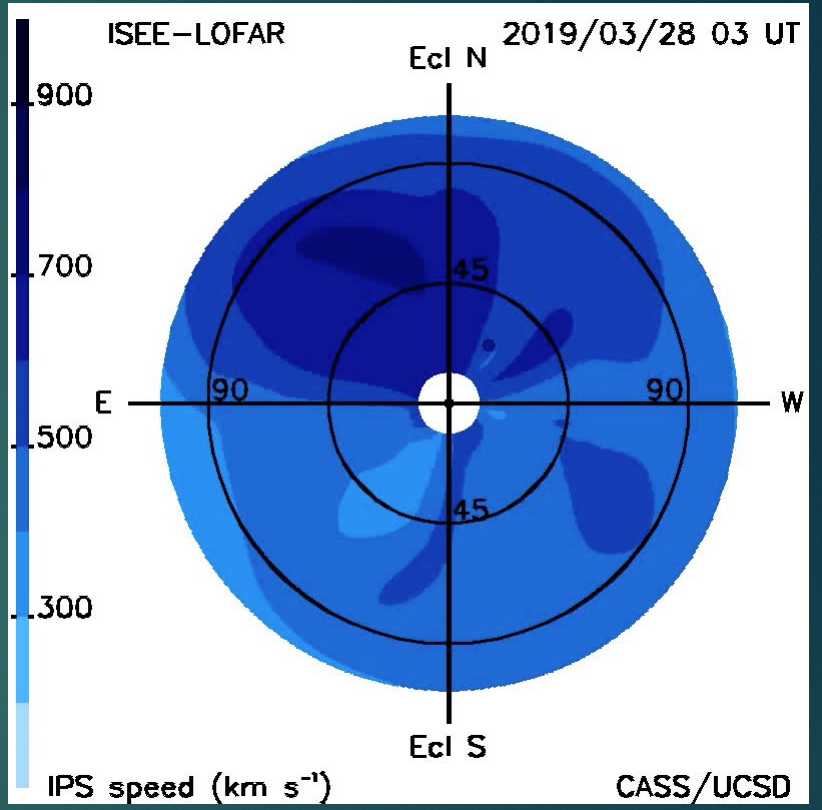


Slide Courtesy of R. Fallows

IPS and Tomography

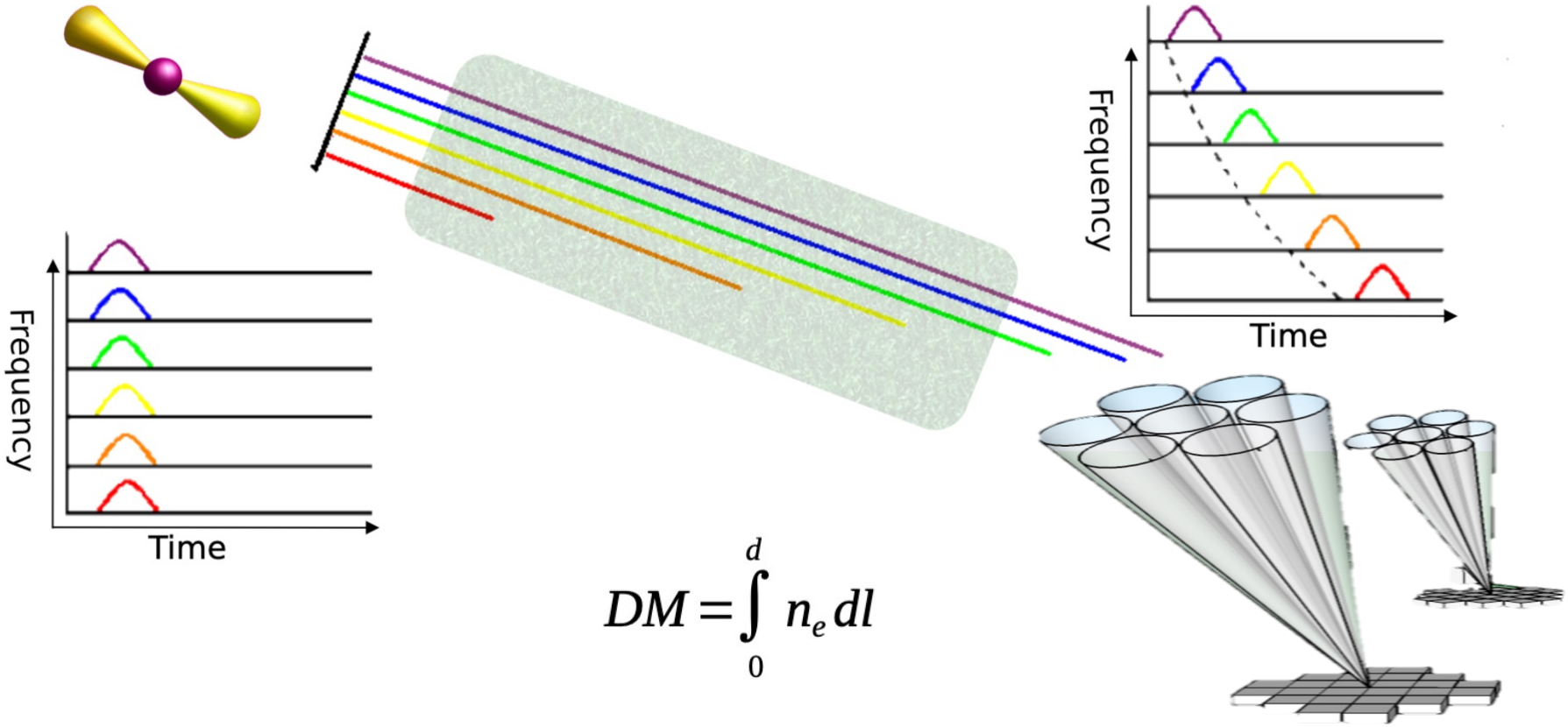






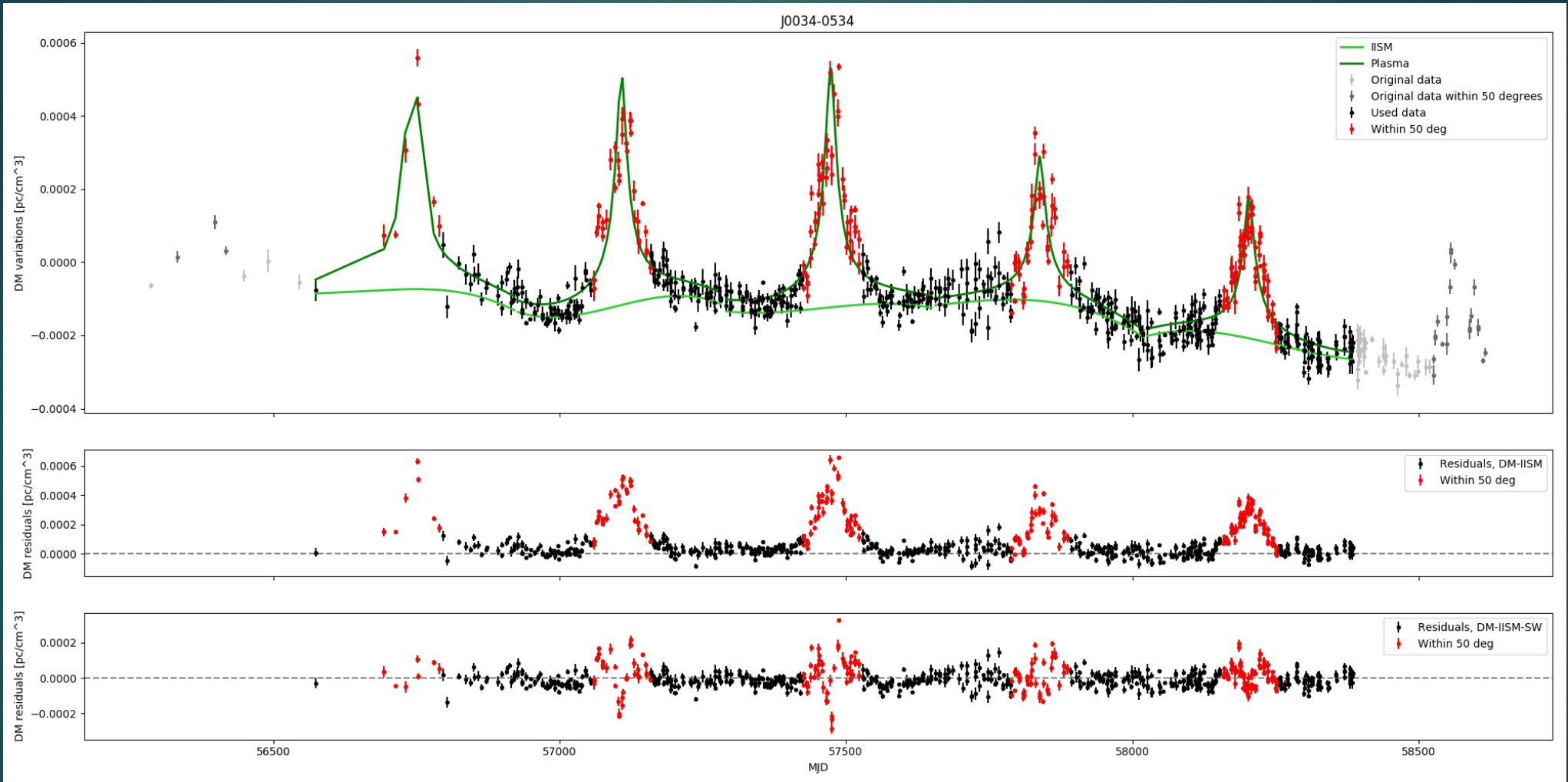
Bernard Jackson, Richard Fallows, Mario Bisi and the ISEE LOFAR working group

Using Pulsars



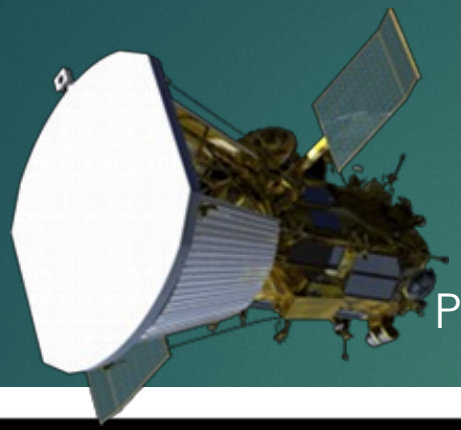
Slide Courtesy of Caterina Tiburzi

Solar Wind Variability

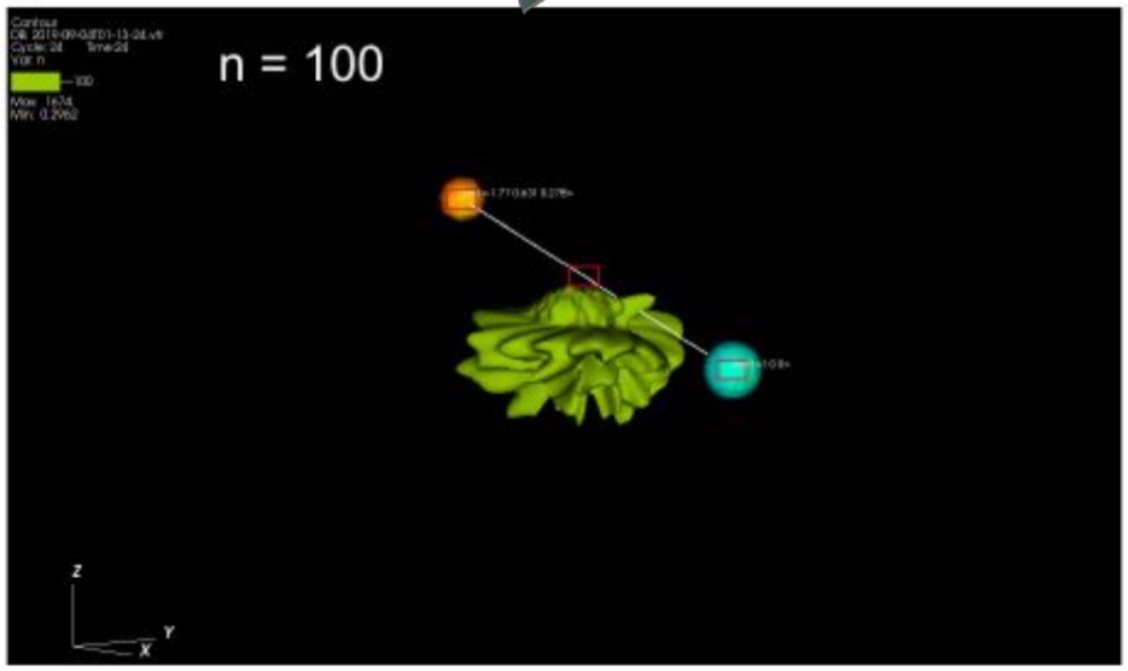


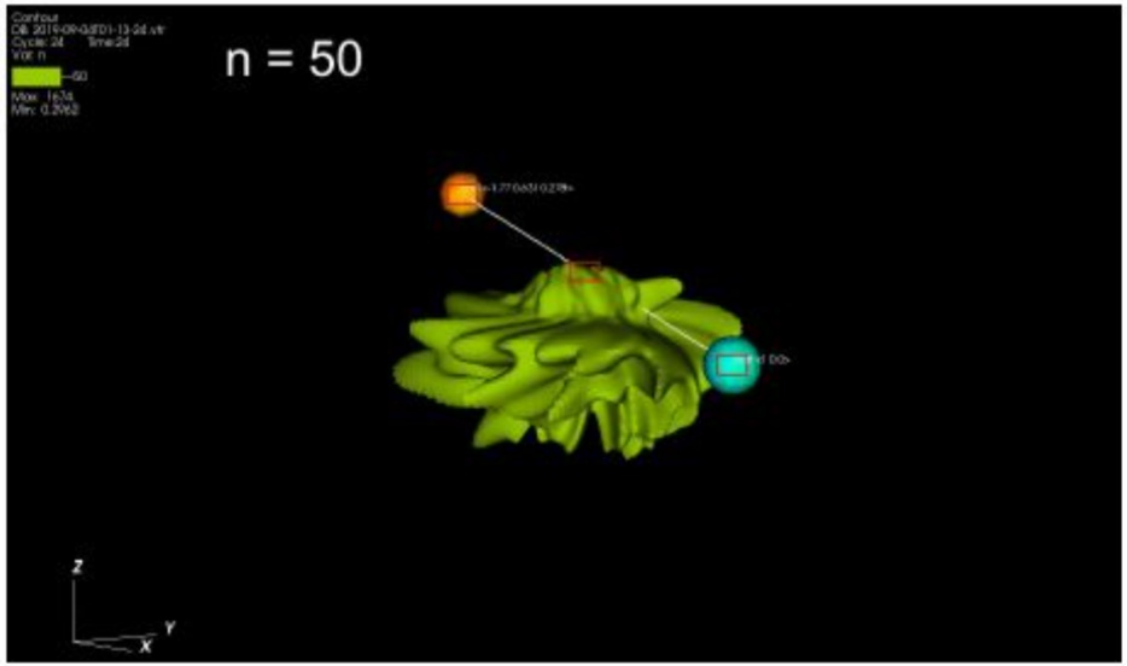
Tiburzi et al. 2020

Model validation - EUHFORIA



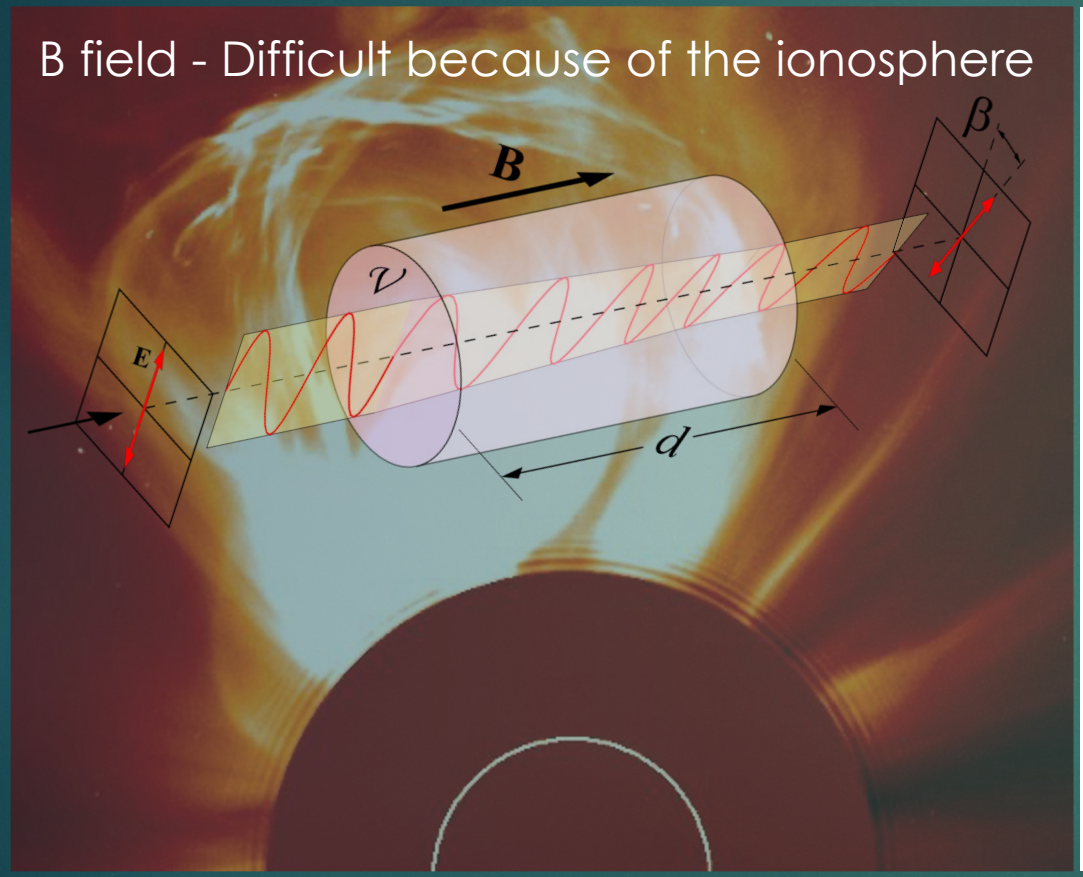
PSP in-situ measurements

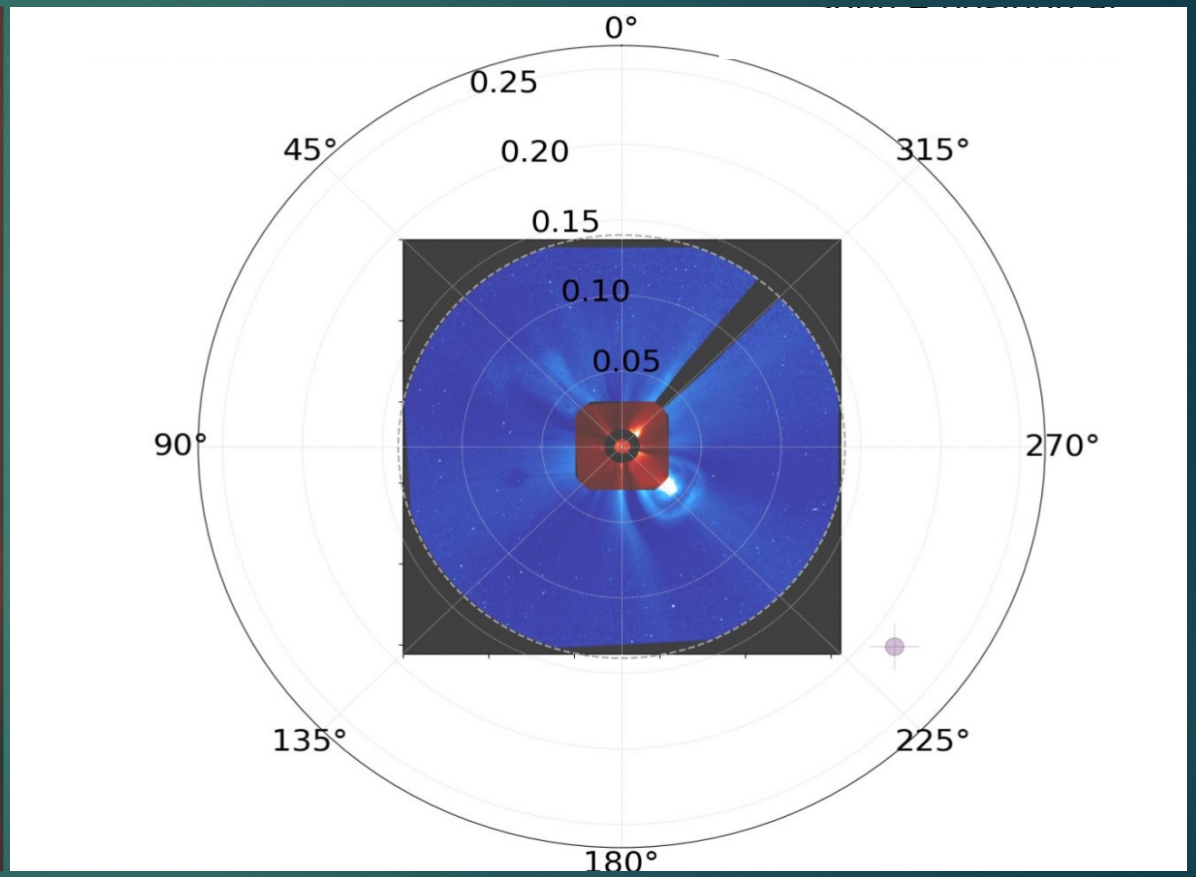




Tiburzi et al. 2022

Pulsars to extract Density and B field



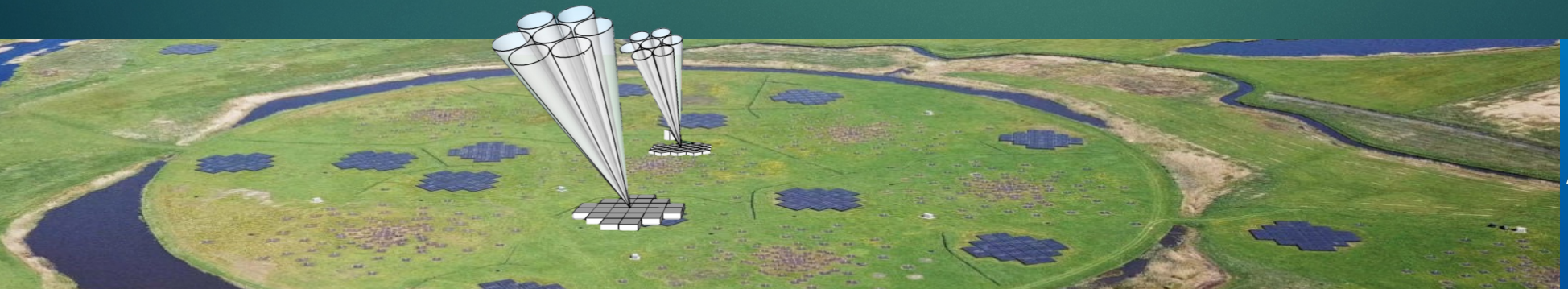


Caterina Tiburzi, Golam Shaifullah, Mario Bisi et al.

Summary

- Radio emission is a great tool to study the Sun the Heliosphere and space weather.
- LOFAR is an excellent instrument that allow us to observe unexplered fetures of the solar atmosphere and heliosphere, to understand how the Sun works and to monitor/predict space weather events.

- NOW Tutorial! Let's try some data…



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LOFAR Solar and Space Weather KSP