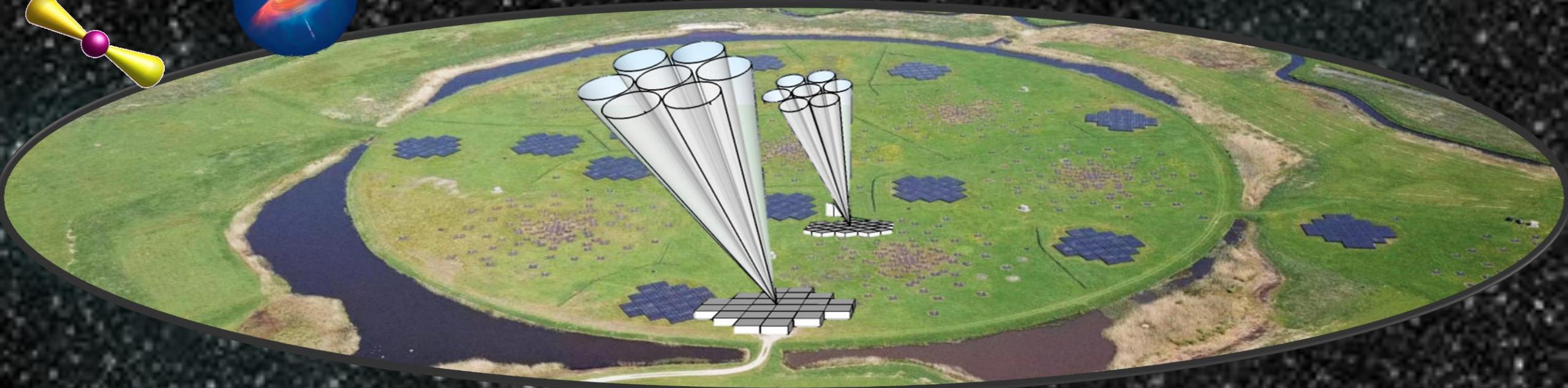
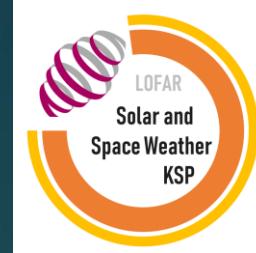


ASTRON

Solar Physics and Space Weather with LOFAR; Recent updates from the KSP



Dr. Pietro Zucca and the solar and SW KSP
ASTRON Netherlands Institute for Radio Astronomy

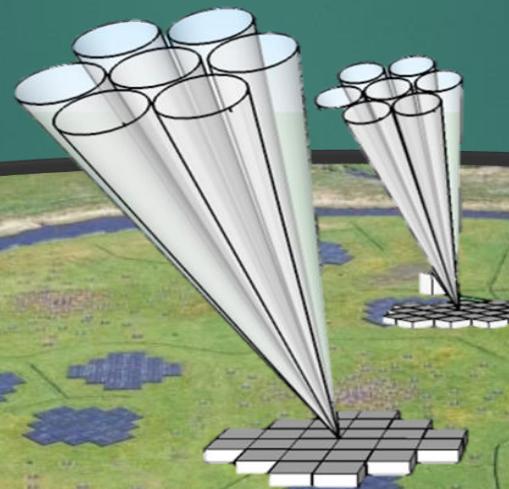


ASTRON

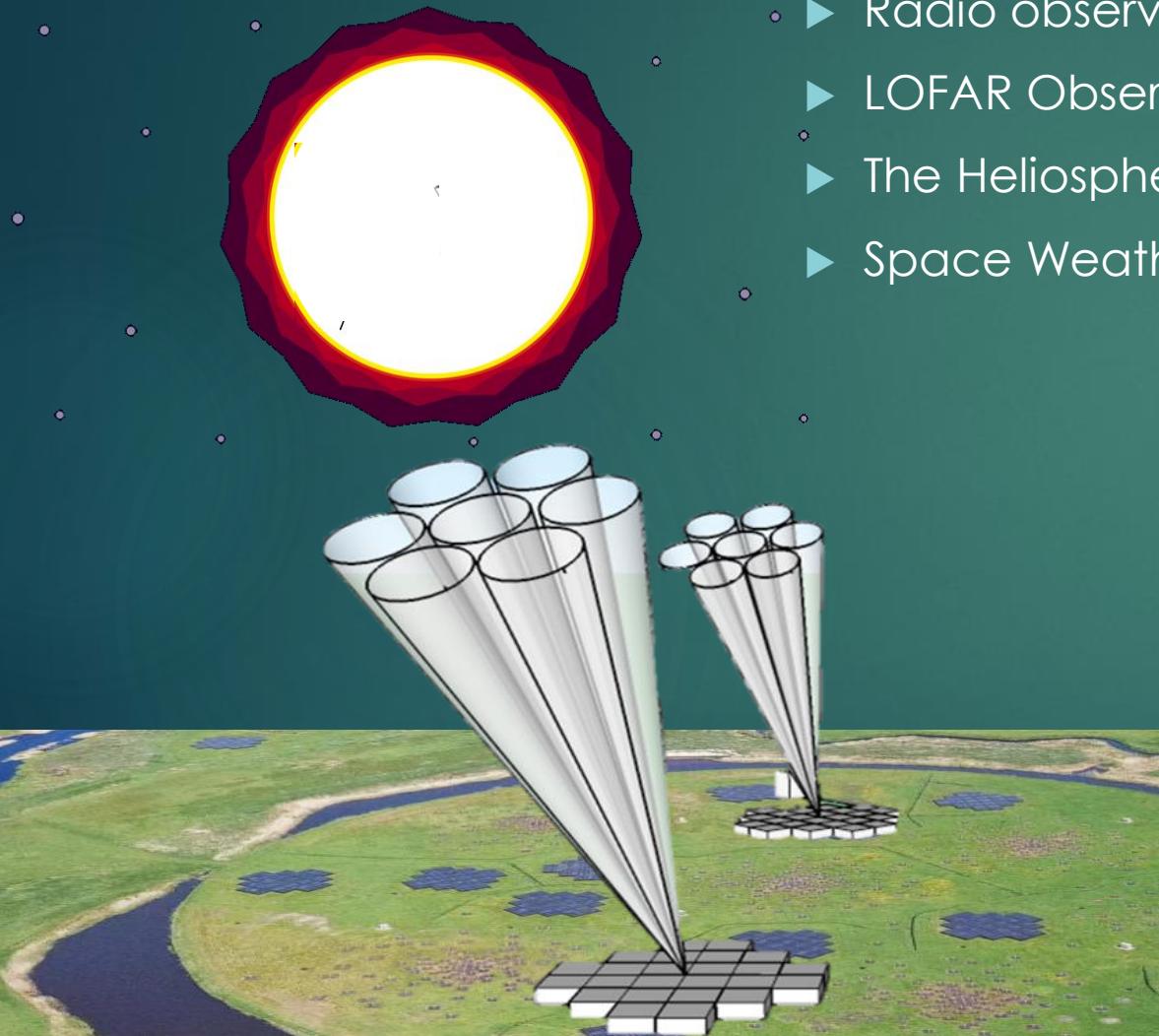
Pietro Zucca and the solar and SW KSP

ASTRON Netherlands Institute for Radio Astronomy

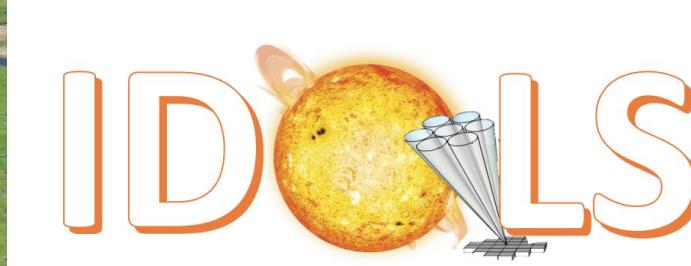
- Diana Morosan, Mario Bisi, Bartosz Dabrowski, Peter Gallagher,
Andrzej Krankowski, Jasmina Magdalenic, Barbara Matyjasik,
Hanna Rothkaehl, Christian Vocks, Kamen Kozarev, Peijn Zhang and
Solar and Space Weather KSP



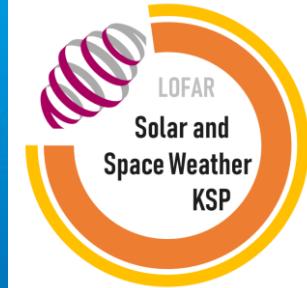
Overview



- ► Radio observations of the Sun
- ► LOFAR Observing modes and coordinated PSP SolO campaign
- ► The Heliosphere
- ► Space Weather

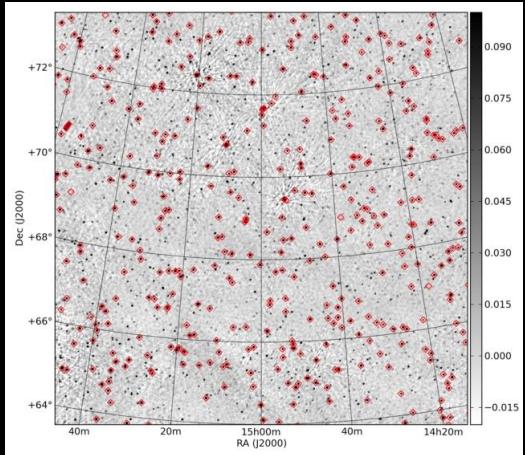


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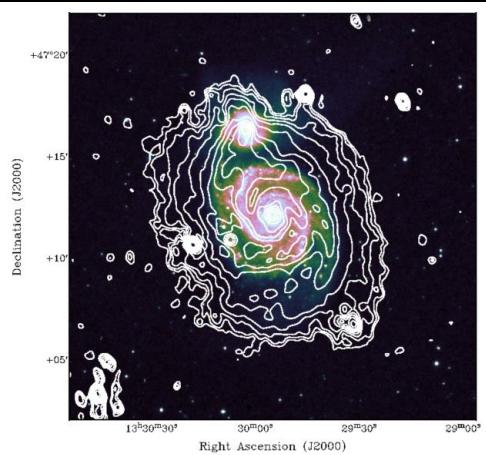


LOFAR KEY SCIENCE PROJECTS

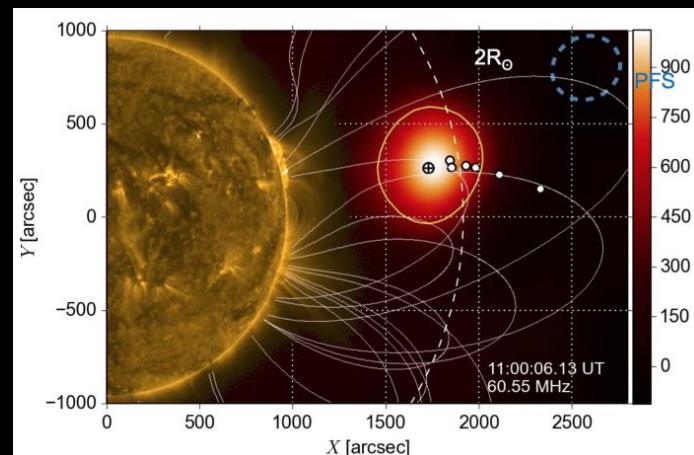
Surveys



Cosmic magnetism



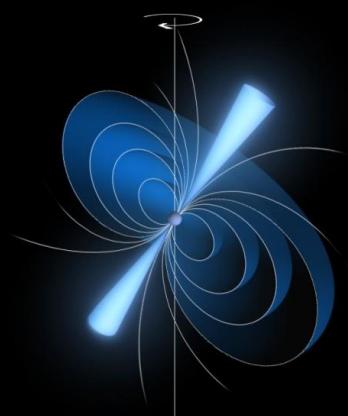
Solar physics & Space weather



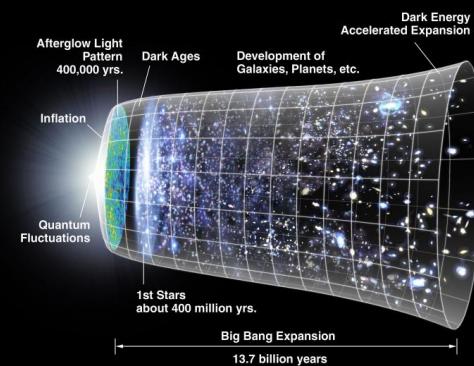
Cosmic rays



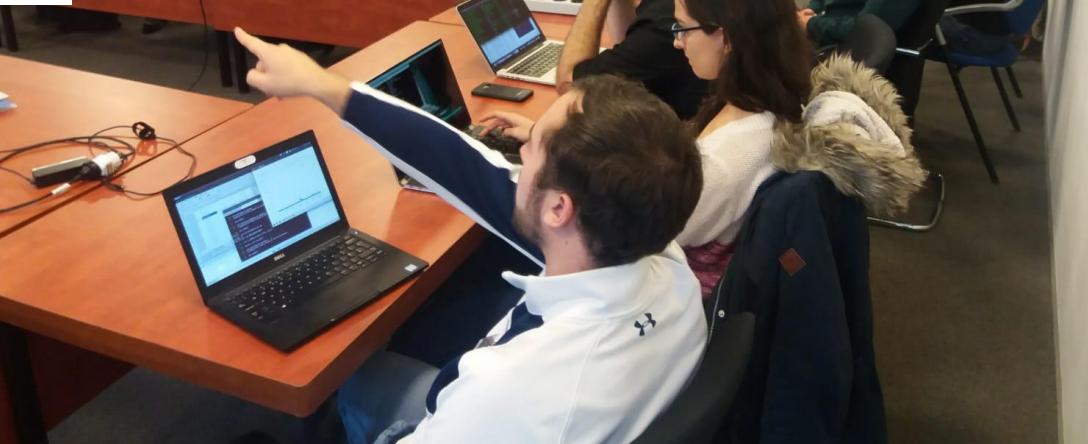
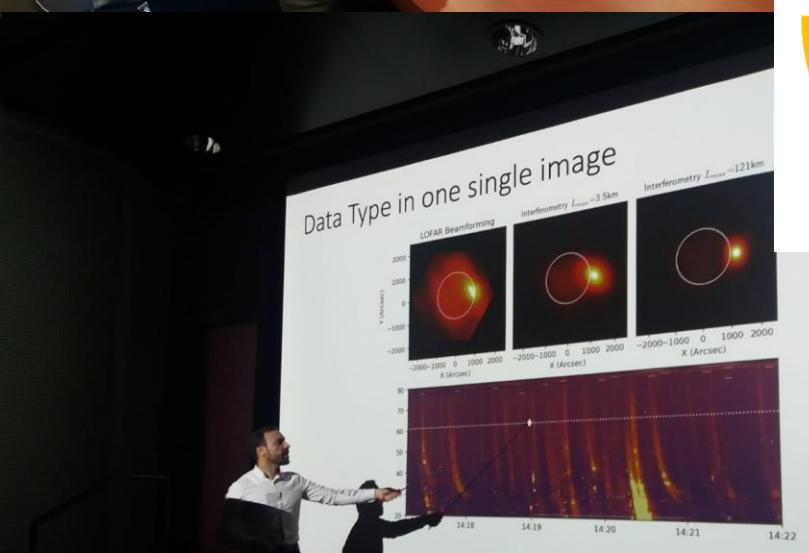
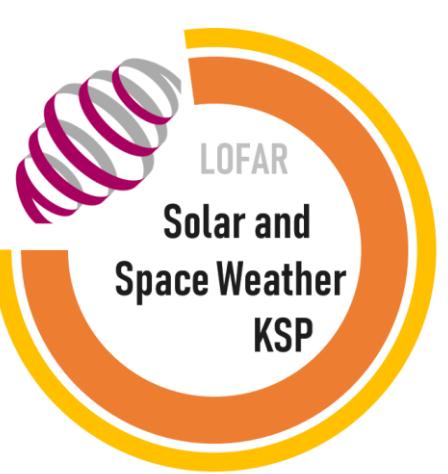
Pulsars & Transient sky

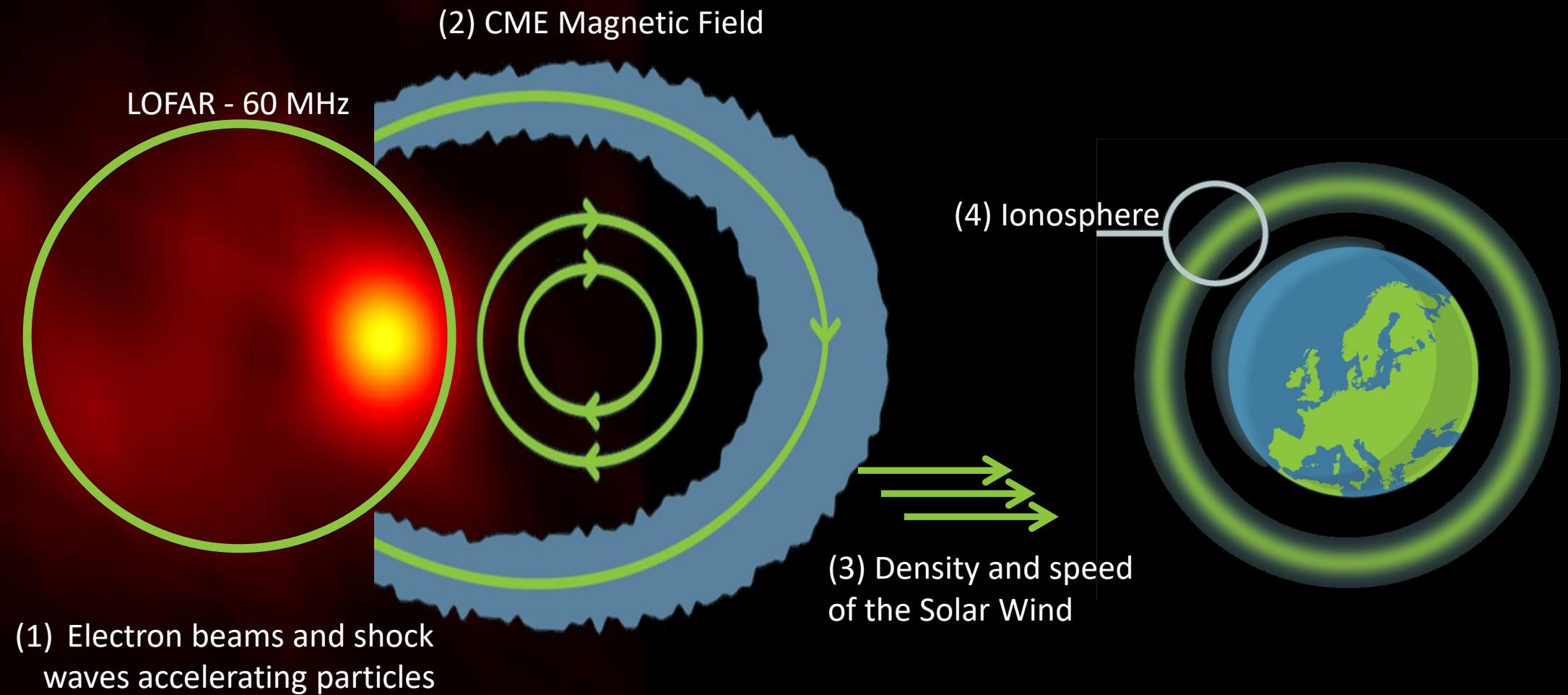


Epoch of Reionization

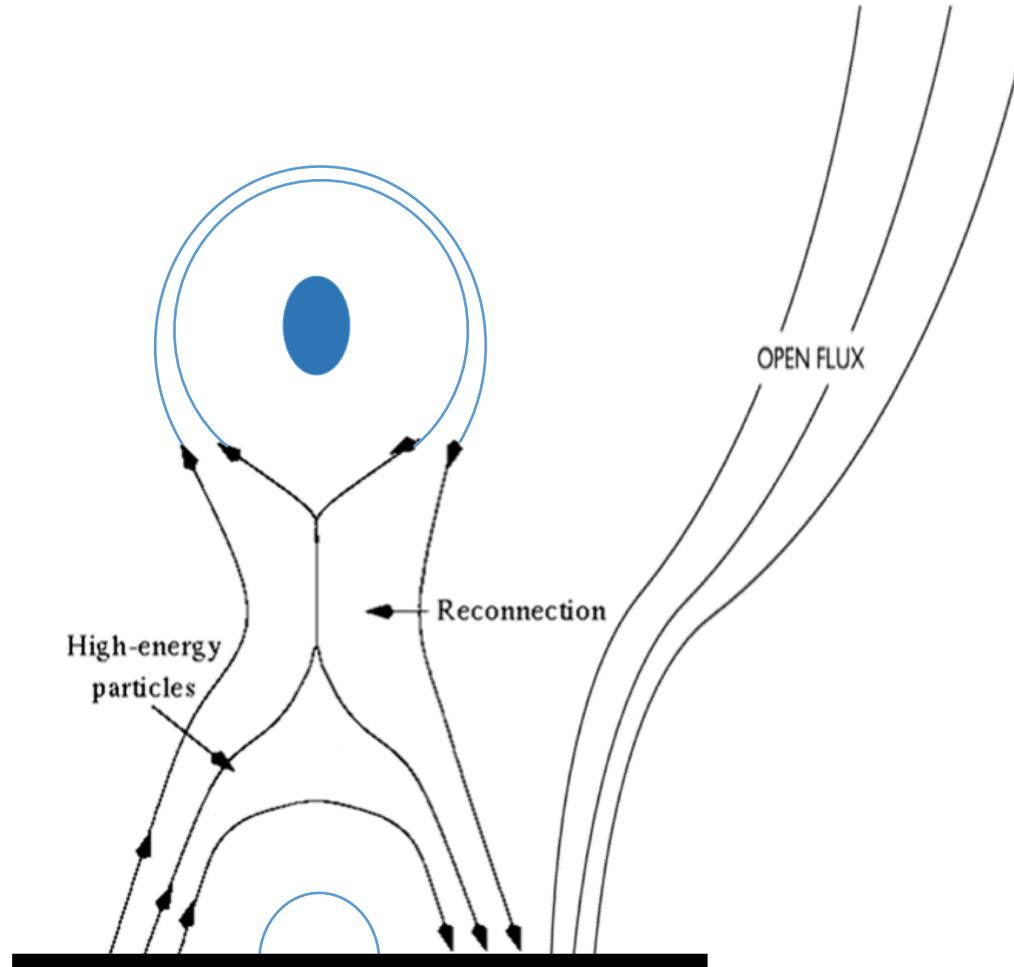


NASA/WMAP Science Team



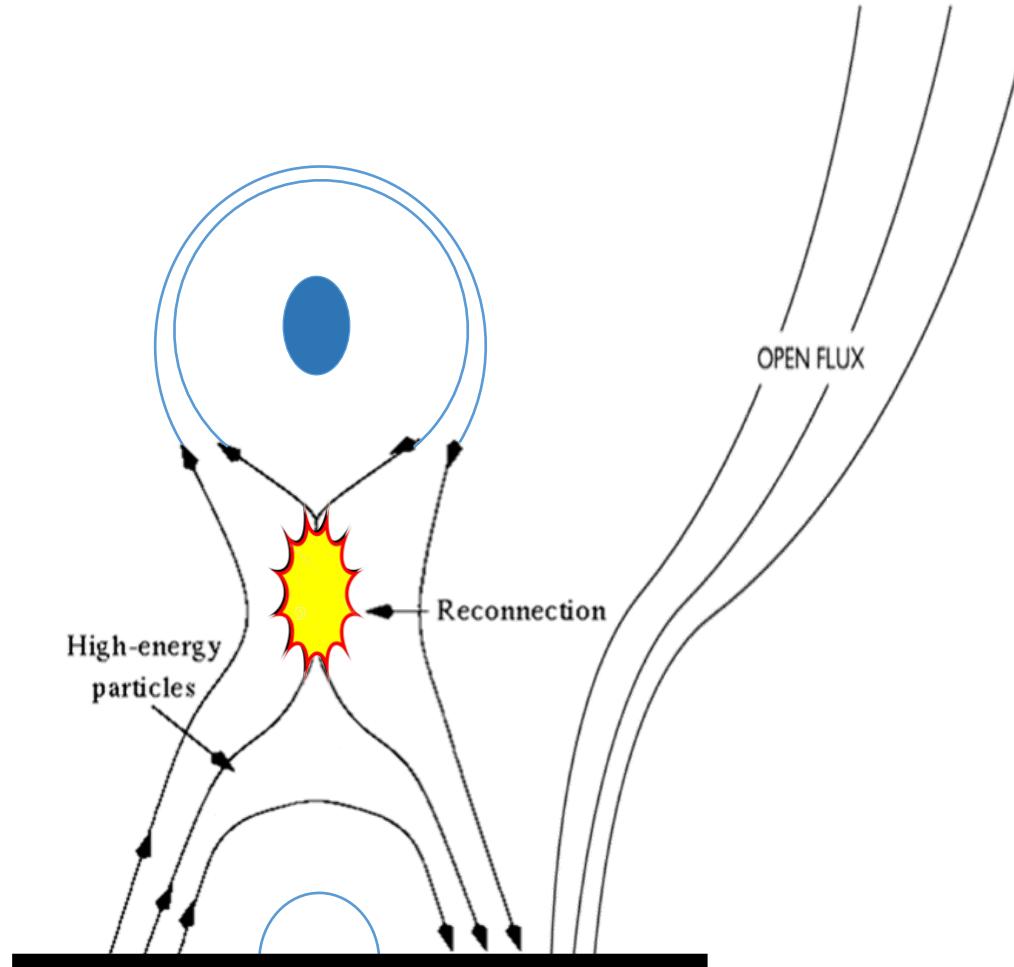
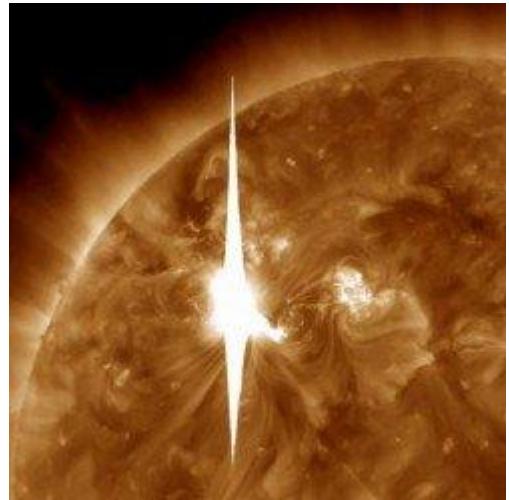


Solar and Heliospheric Radio Emission



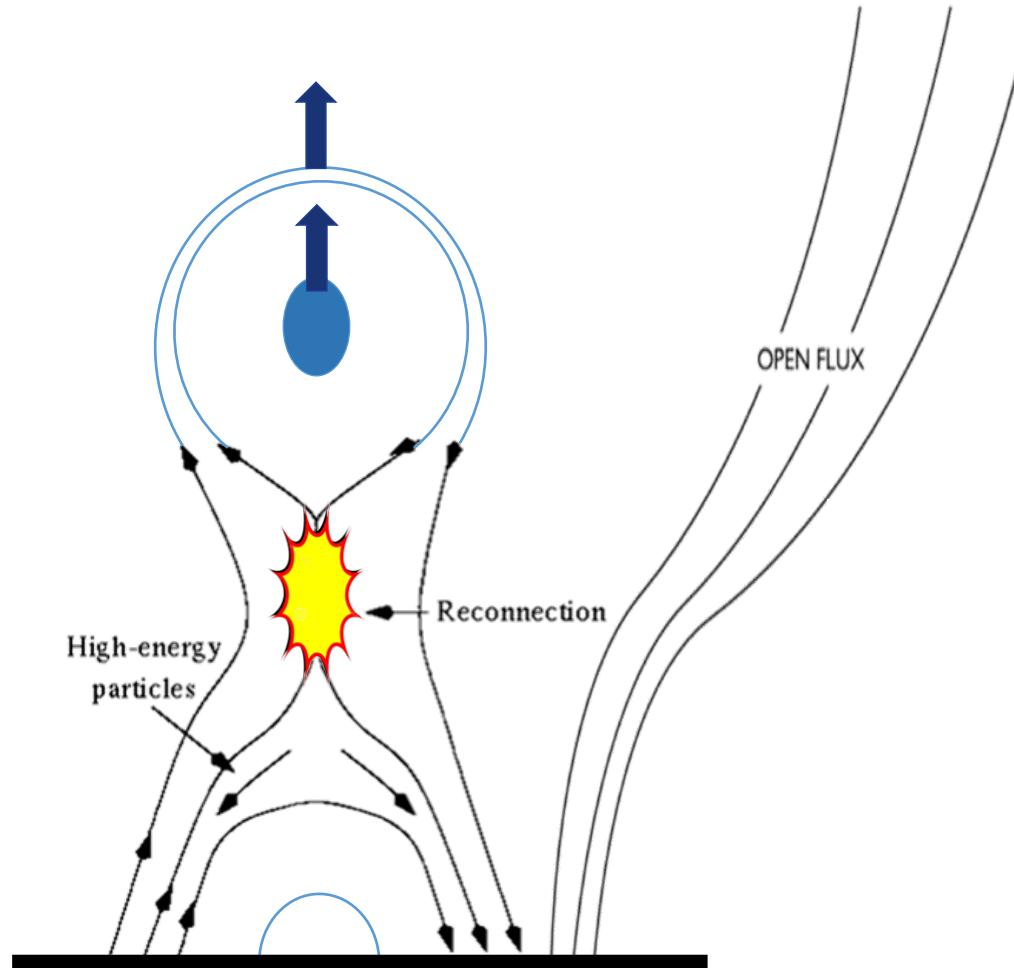
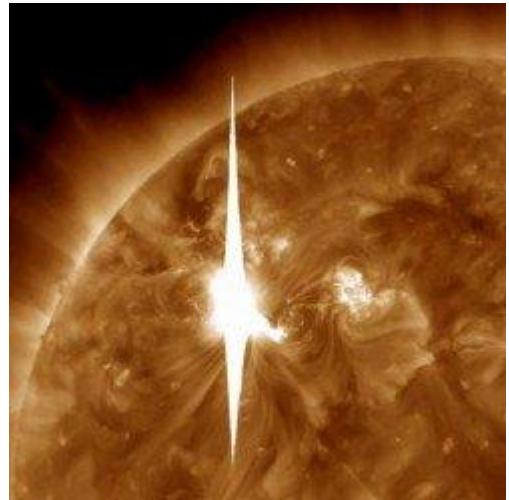
Solar and Heliospheric Radio Emission

Solar Flares



Solar and Heliospheric Radio Emission

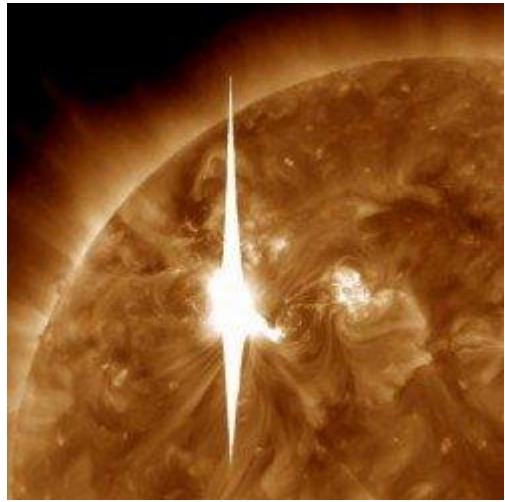
Solar Flares



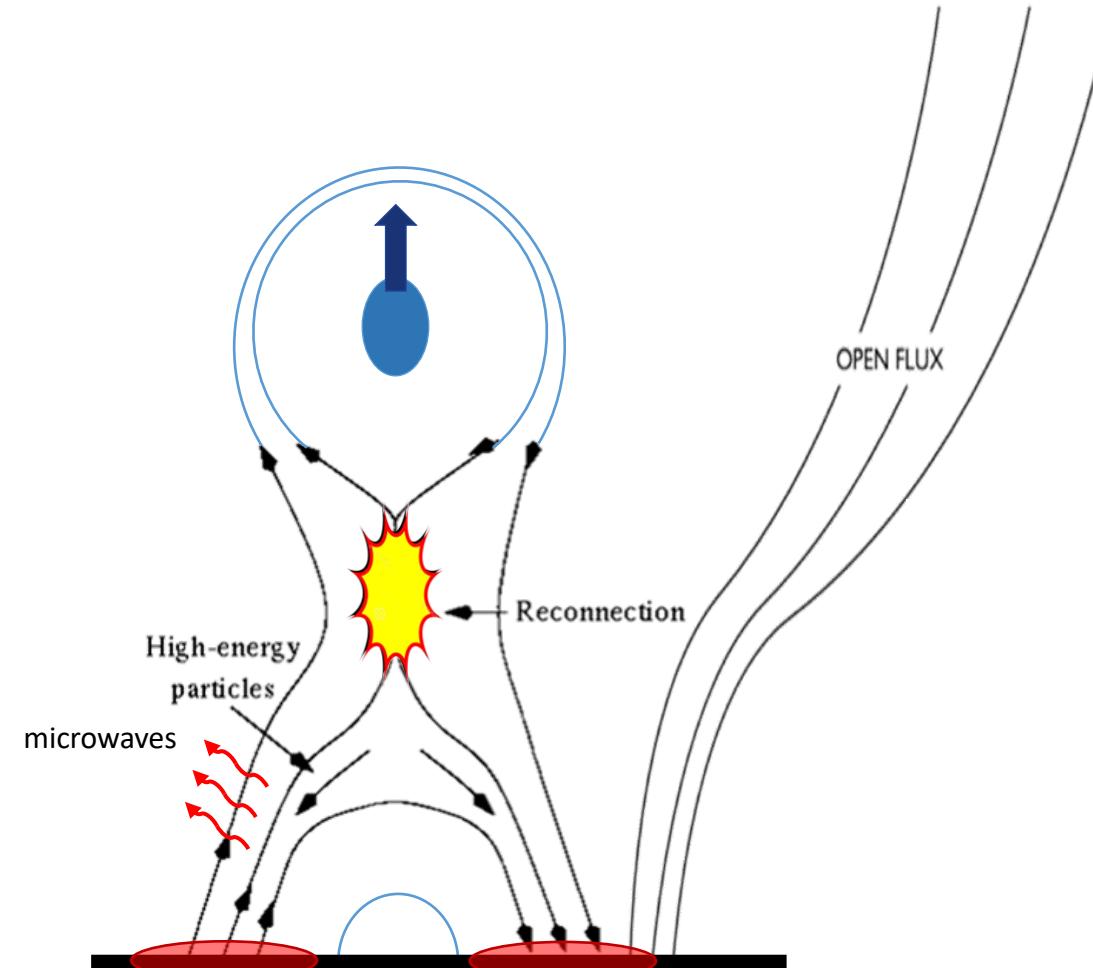
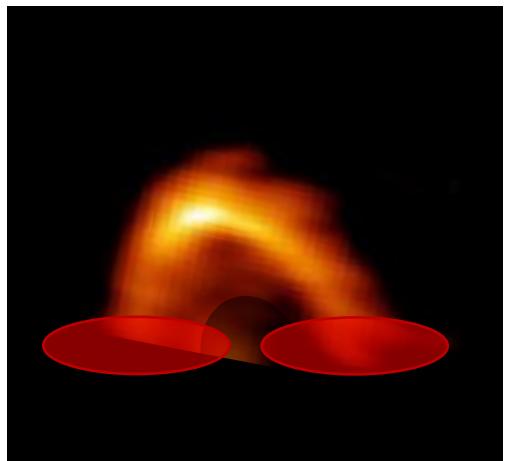
Solar and Heliospheric Radio Emission

Solar Flares

SDO EUV



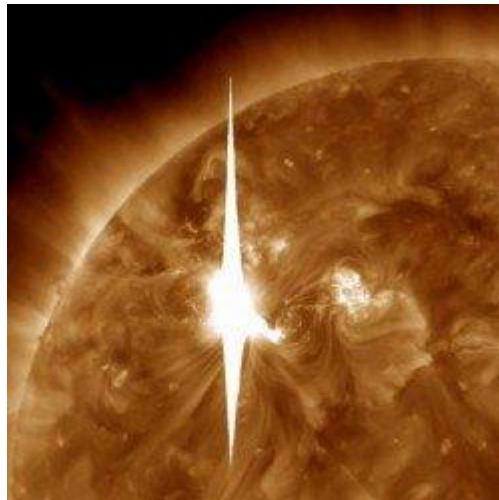
Nobeyama 17 GHz



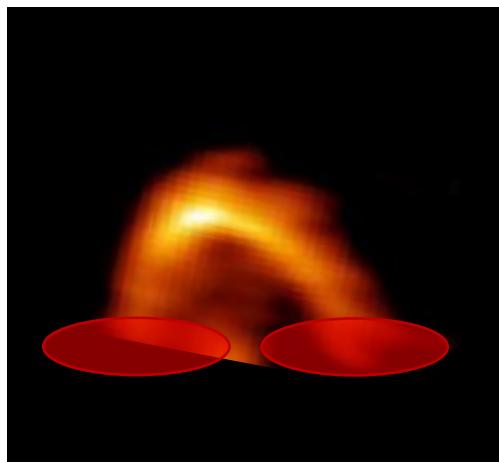
Solar and Heliospheric Radio Emission

Solar Flares

SDO EUV

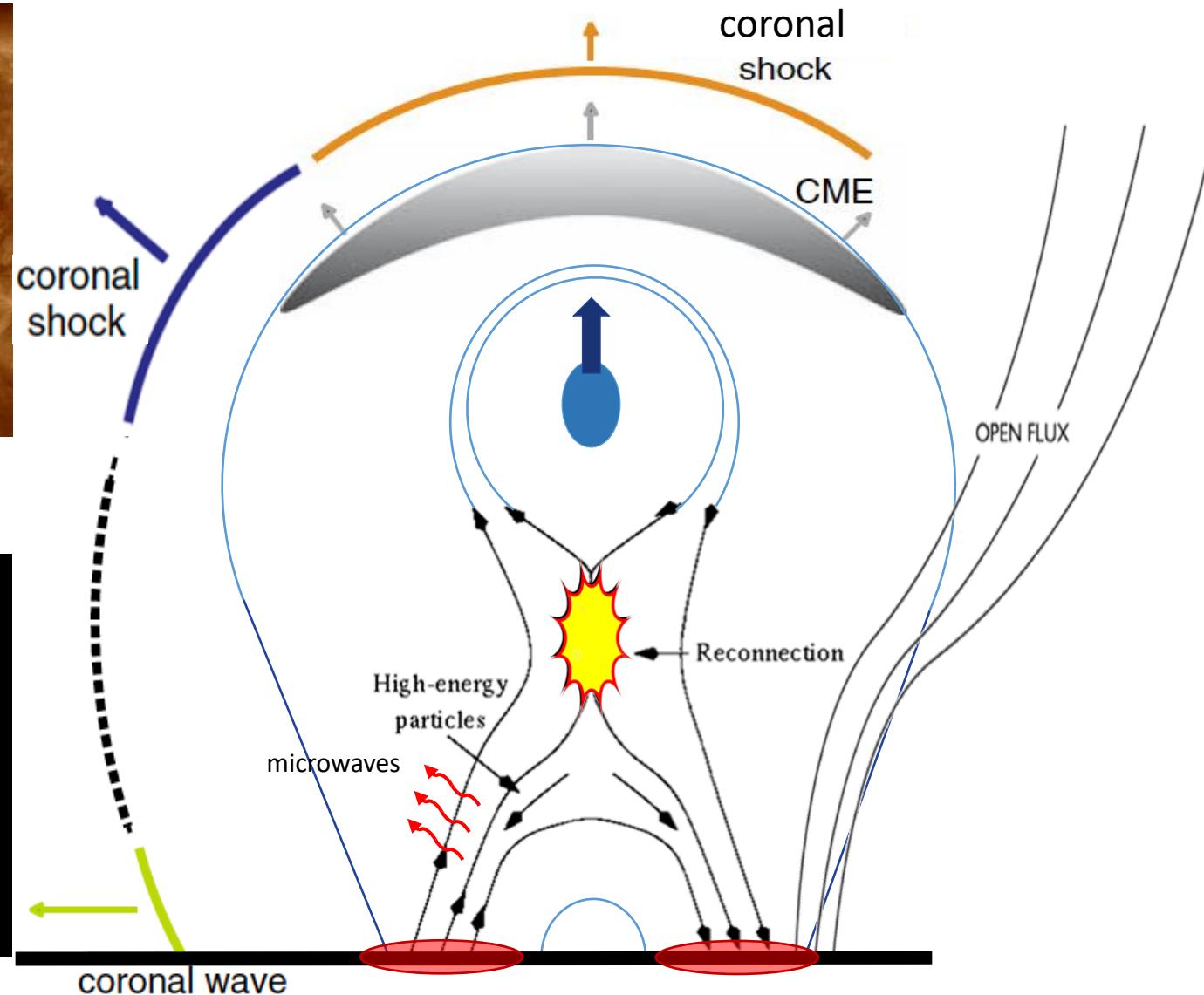
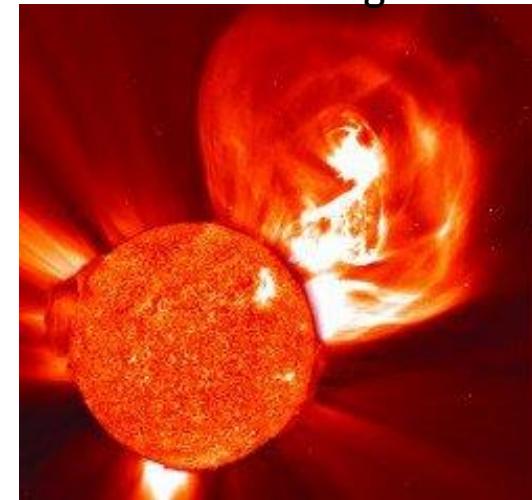


Nobeyama 17 GHz



Coronal Mass Ejections

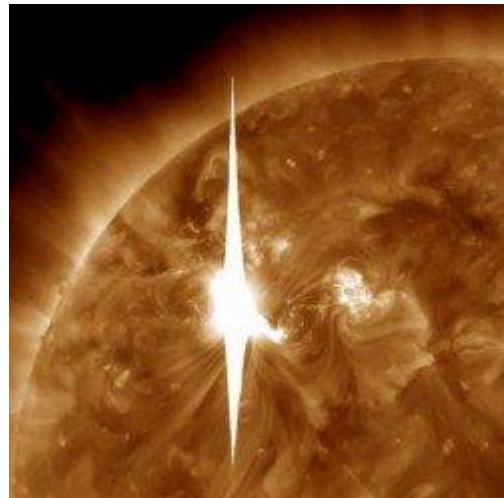
SOHO white light



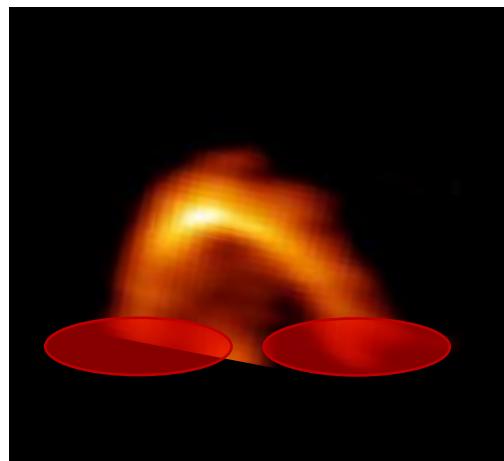
Solar and Heliospheric Radio Emission

Solar Flares

SDO EUV

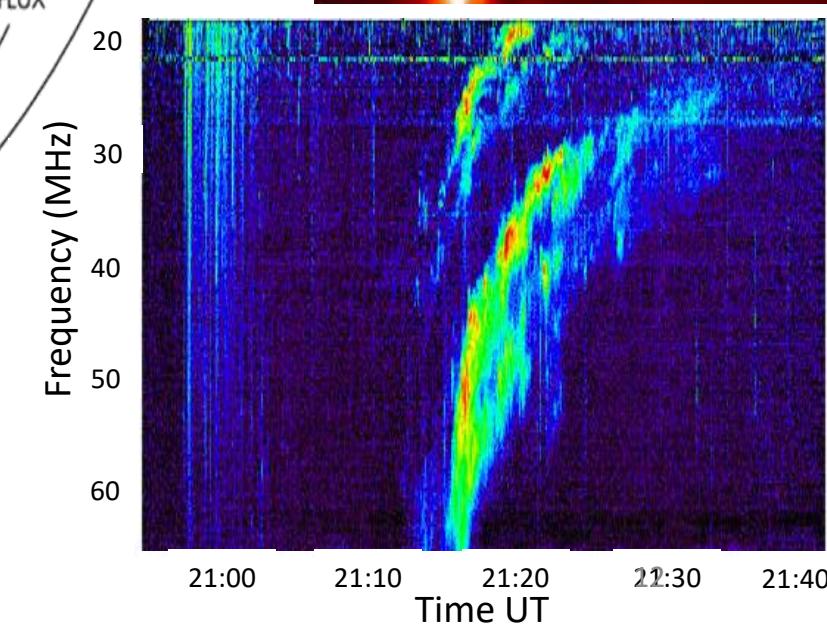
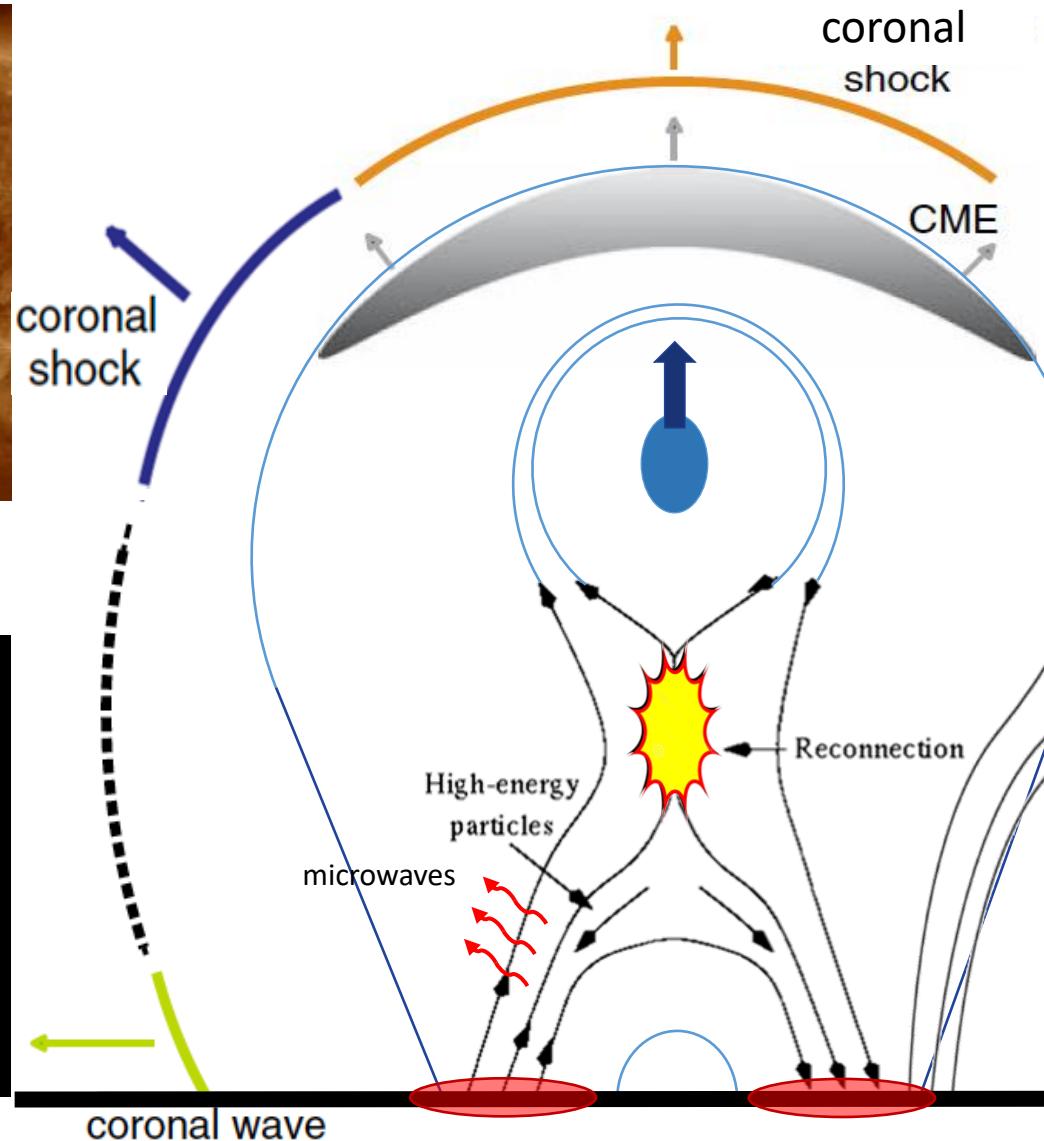
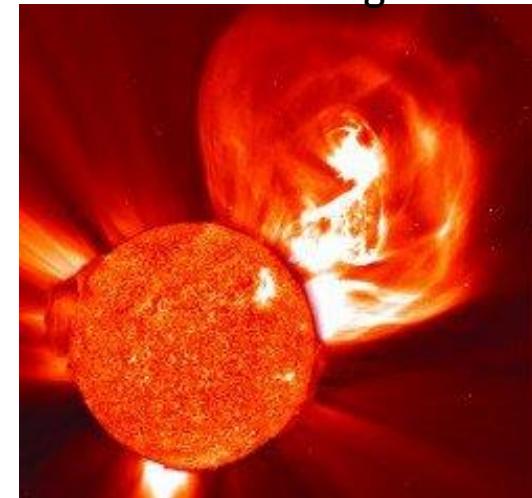


Nobeyama 17 GHz



Coronal Mass Ejections

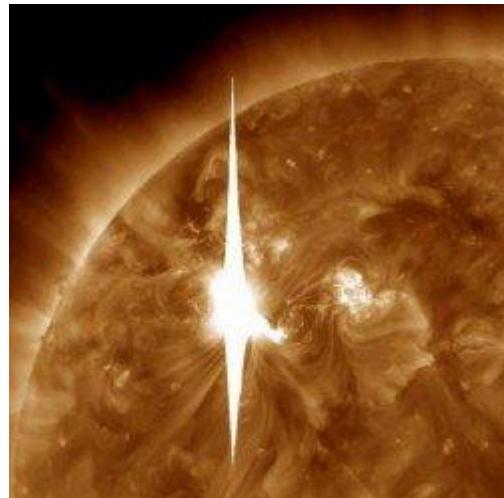
SOHO white light



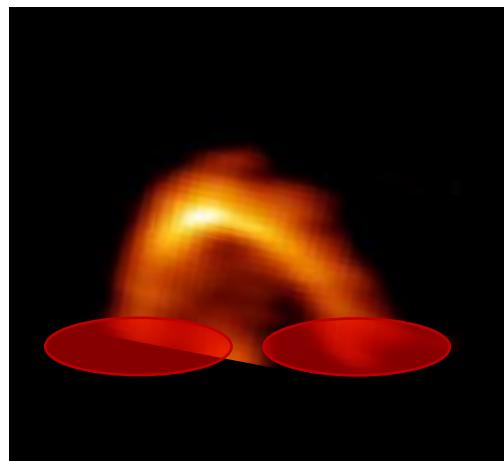
Solar and Heliospheric Radio Emission

Solar Flares

SDO EUV

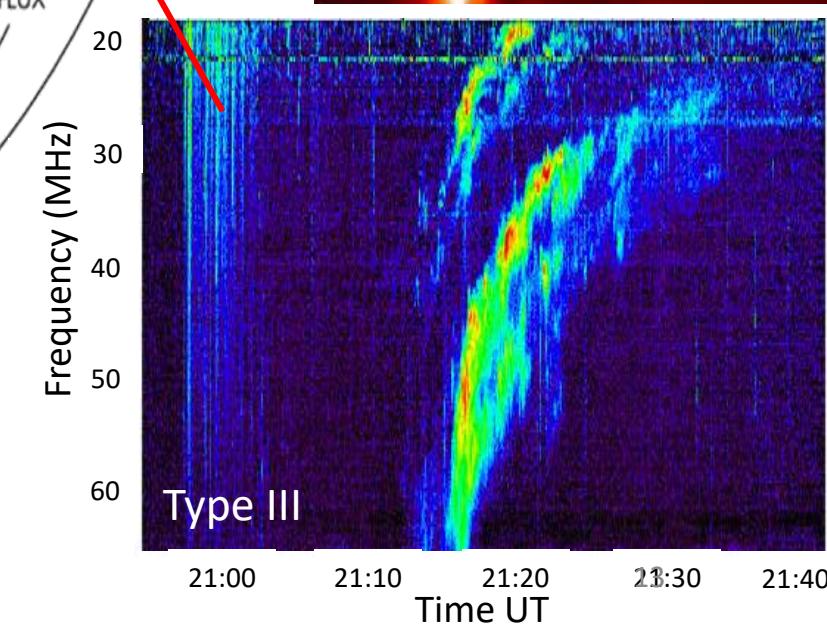
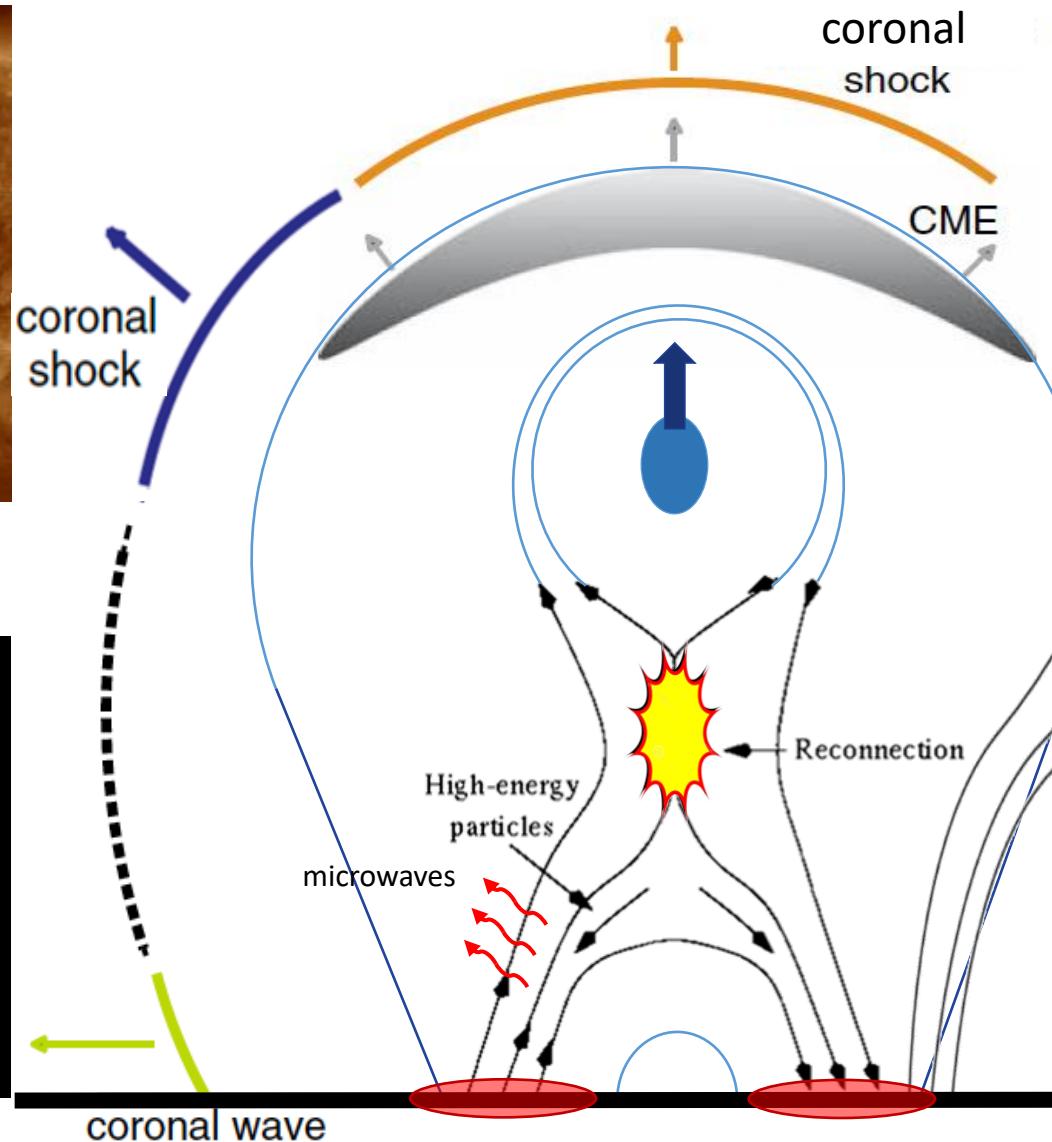
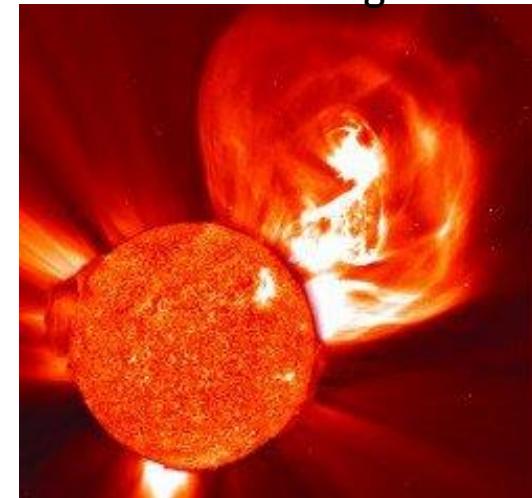


Nobeyama 17 GHz



Coronal Mass Ejections

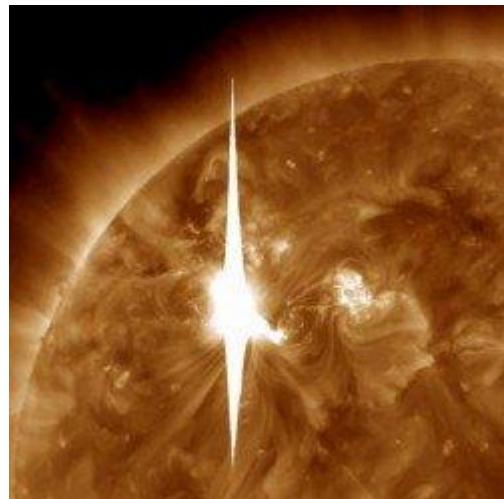
SOHO white light



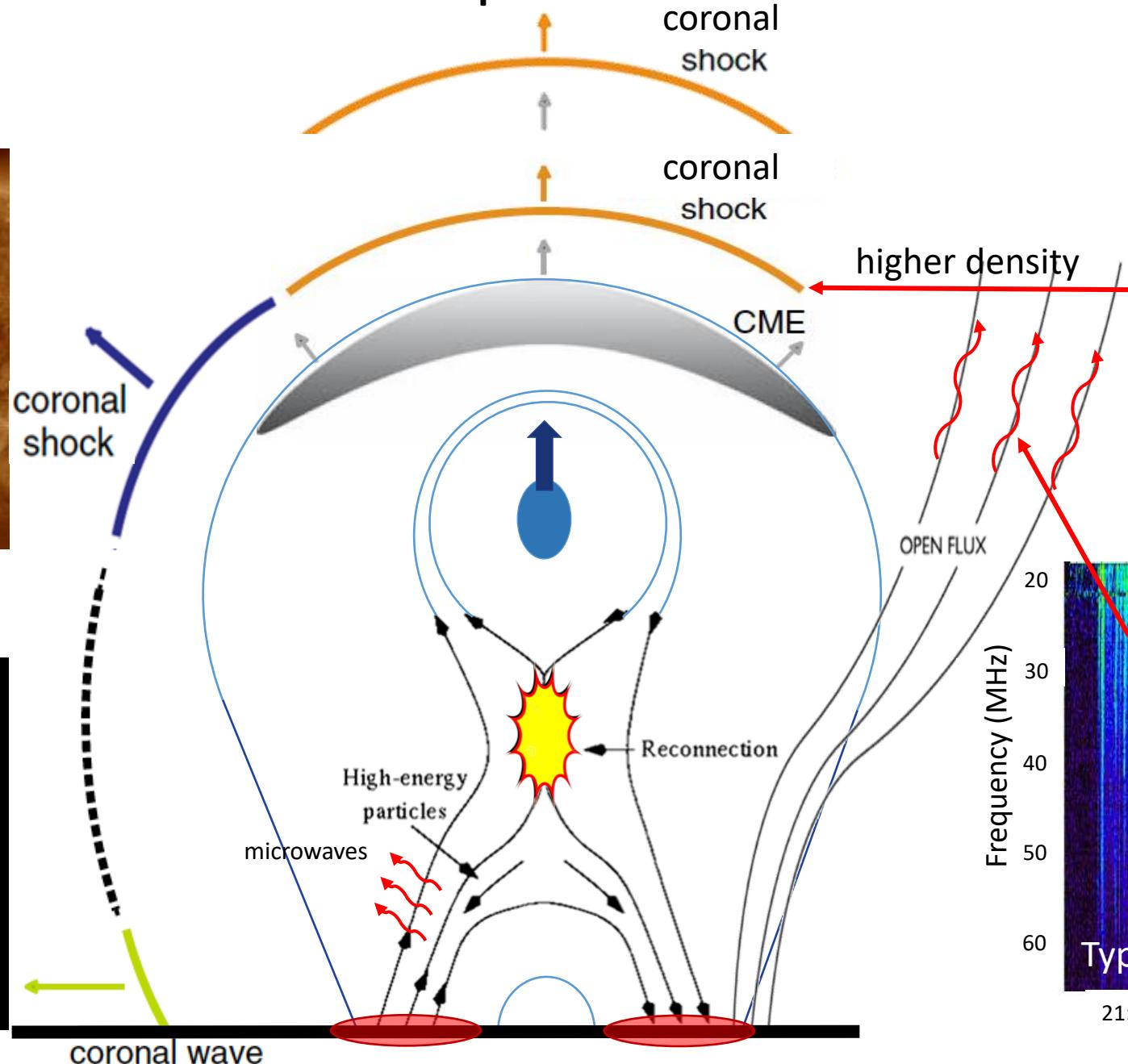
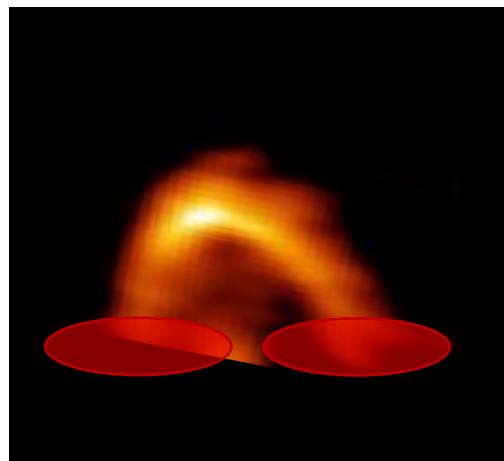
Solar and Heliospheric Radio Emission

Solar Flares

SDO EUV

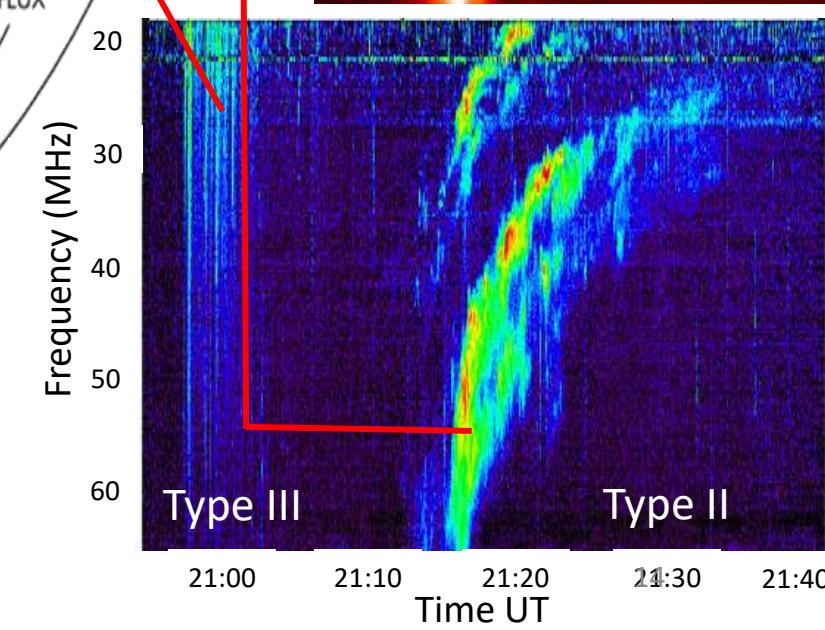
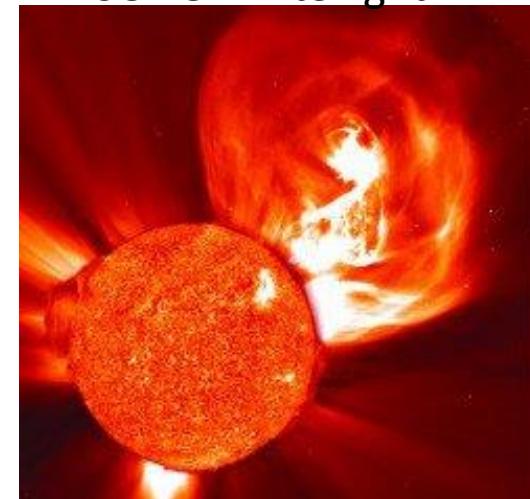


Nobeyama 17 GHz



Coronal Mass Ejections

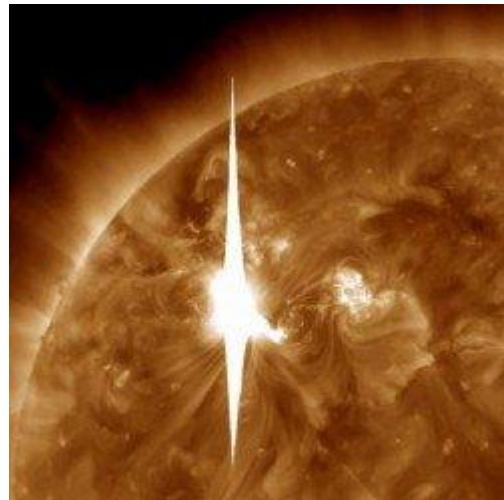
SOHO white light



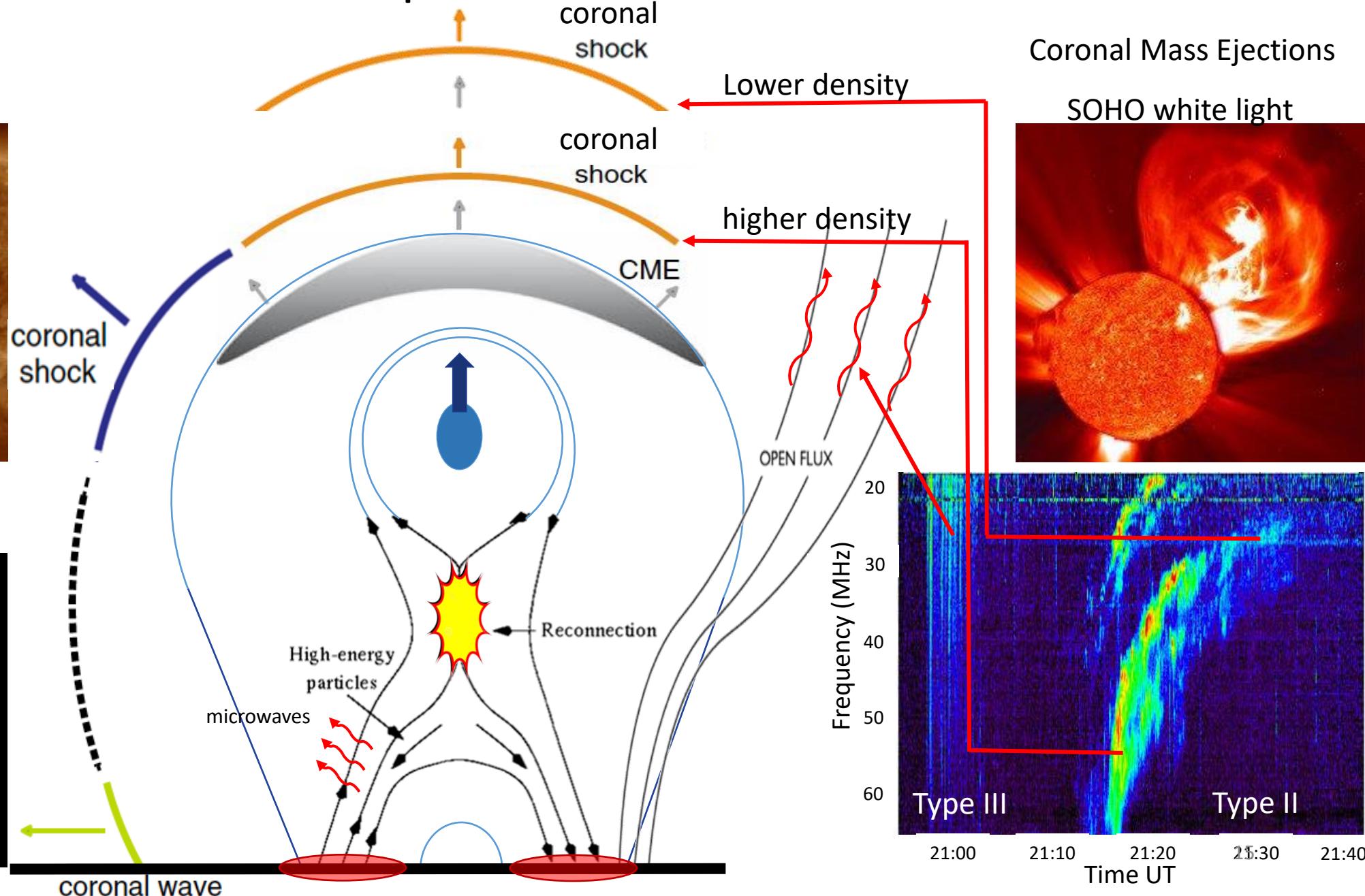
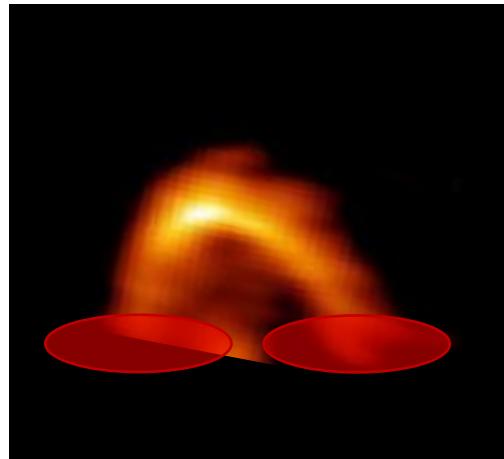
Solar and Heliospheric Radio Emission

Solar Flares

SDO EUV

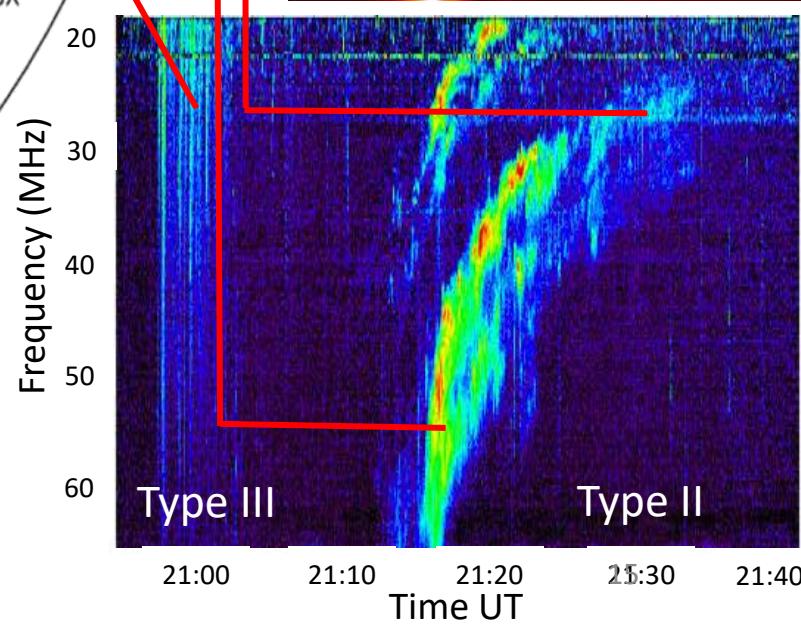
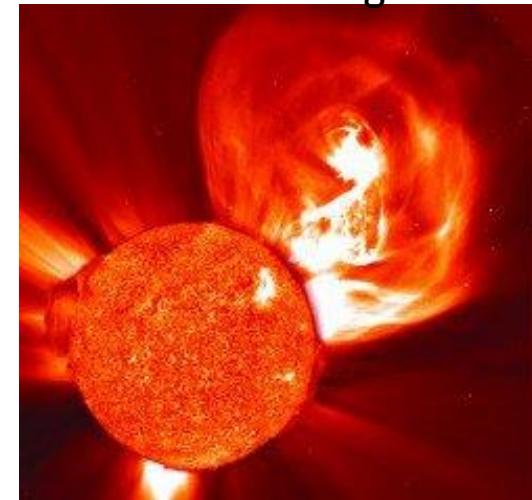


Nobeyama 17 GHz

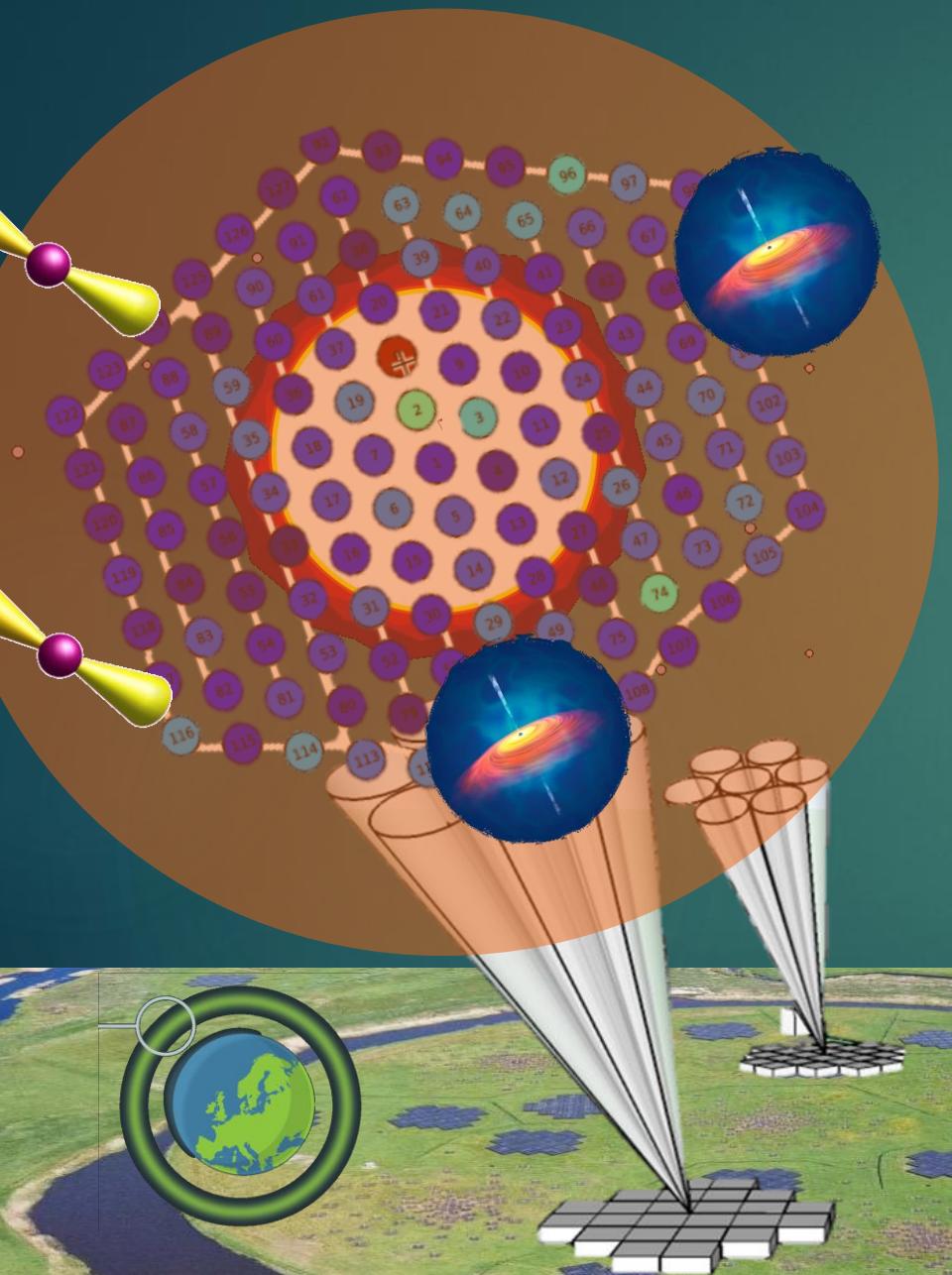


Coronal Mass Ejections

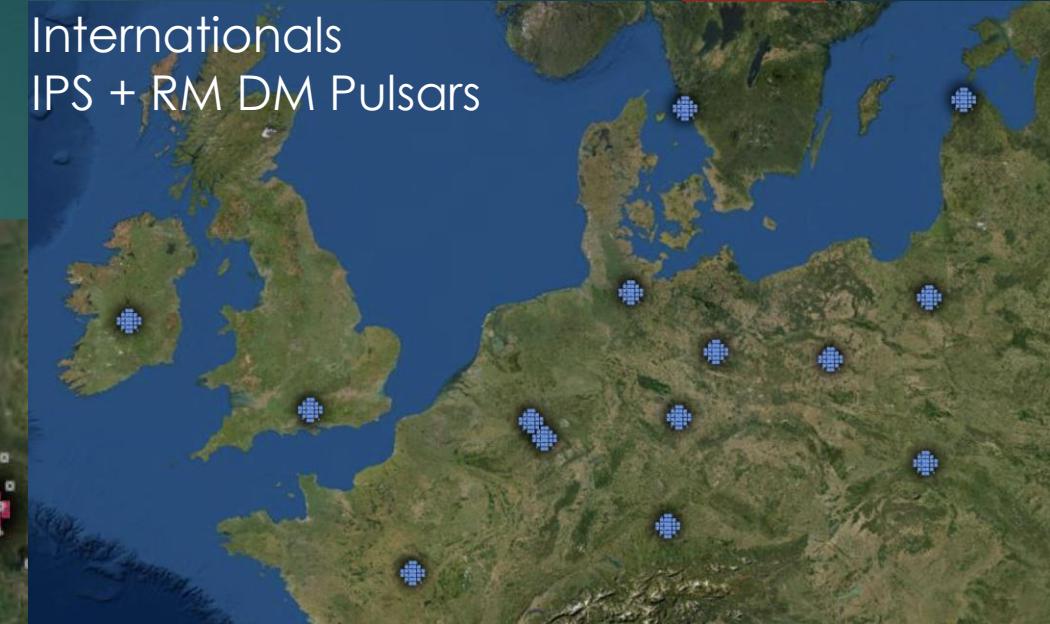
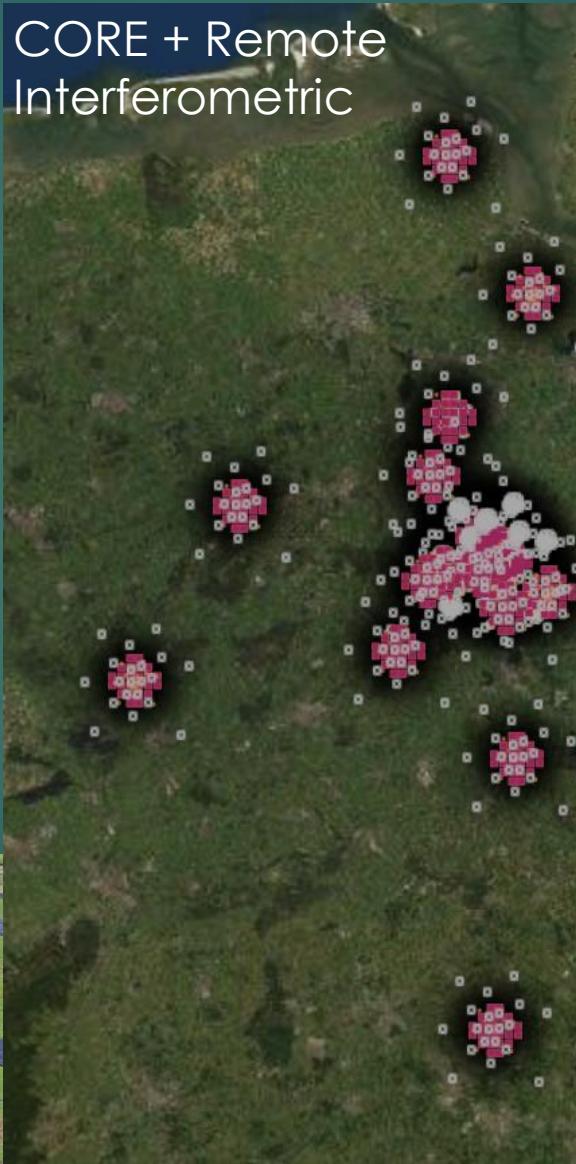
SOHO white light



LOFAR KSP Observing mode



CORE + Remote
Interferometric

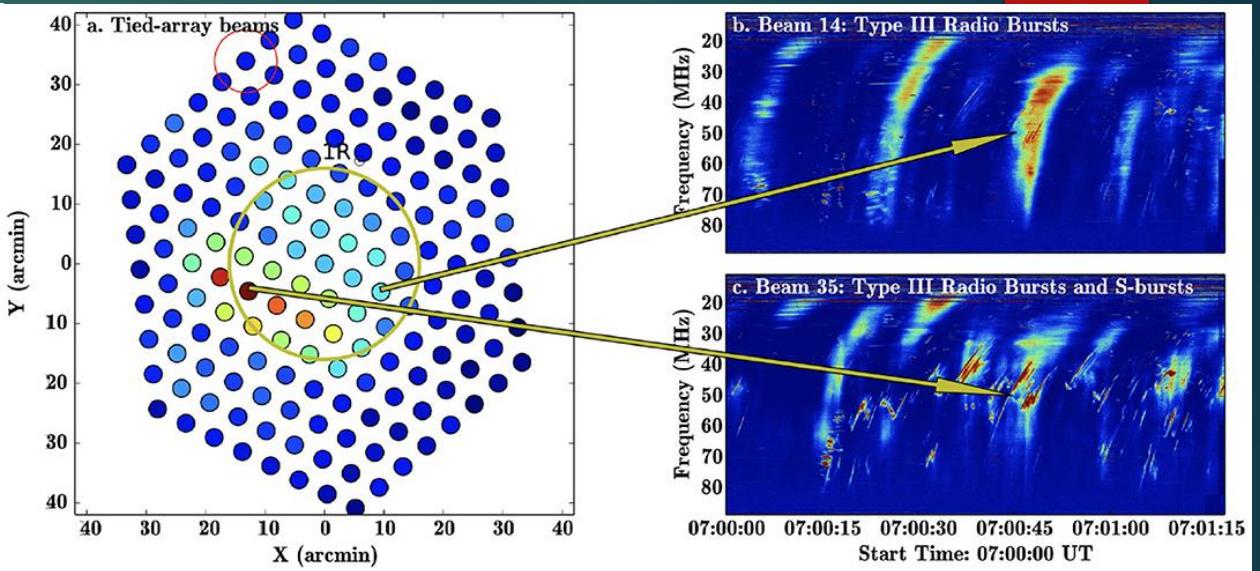
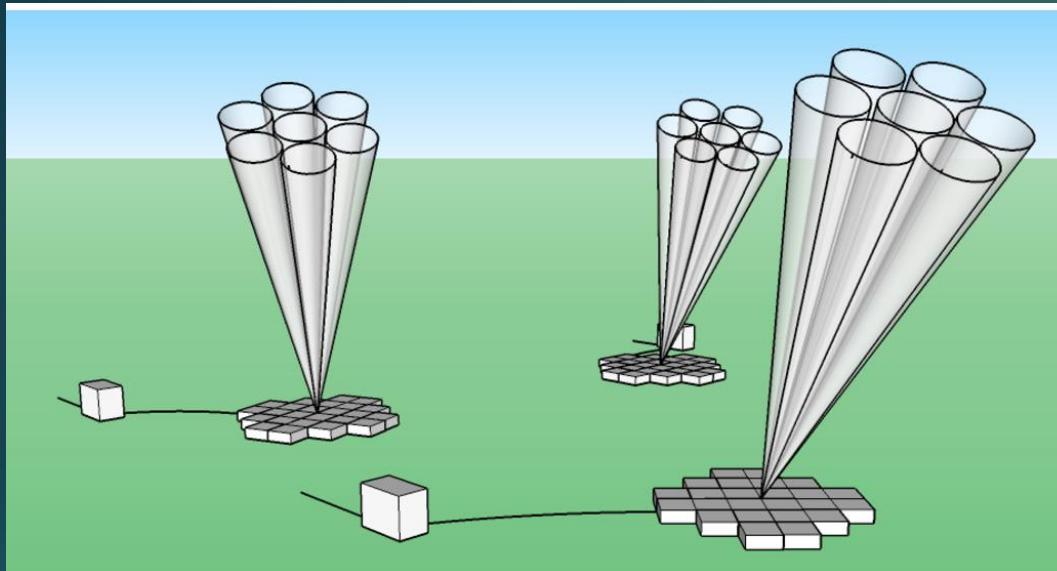


Internationals
IPS + RM DM Pulsars

Core Stations
Tied Array Beam

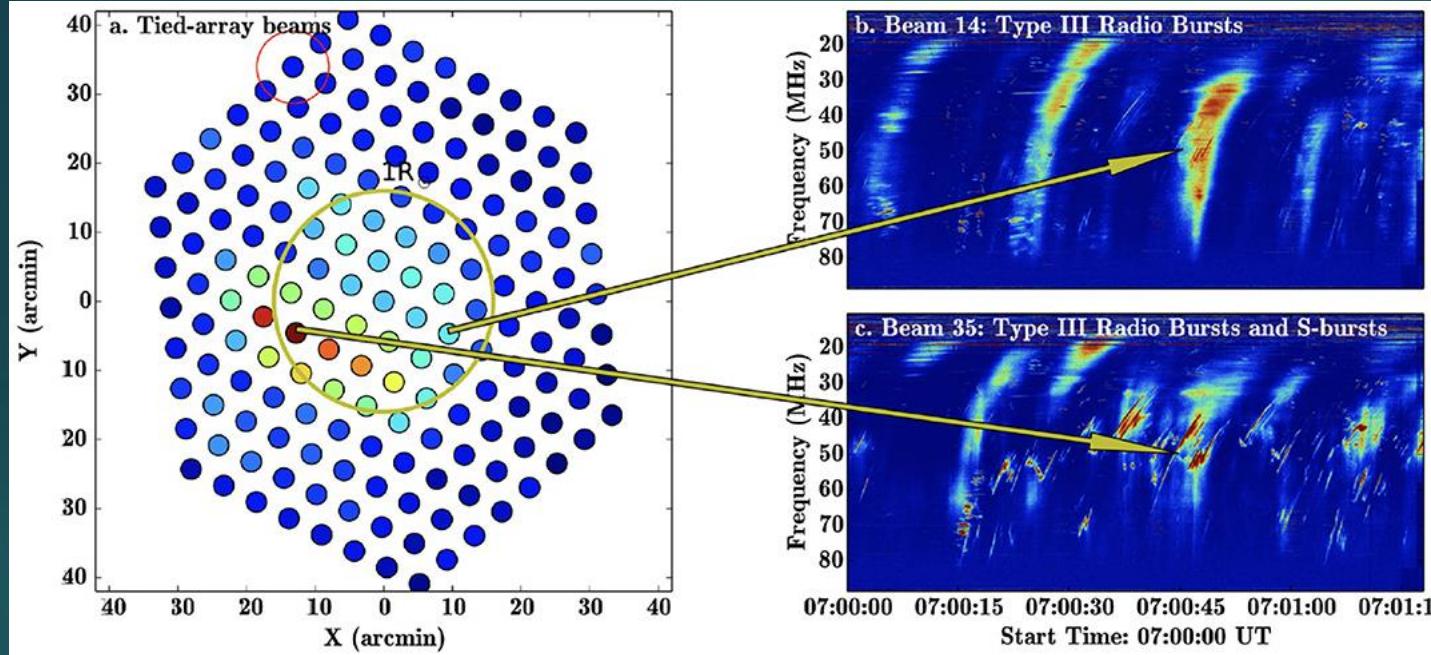


Tied-Array beam mode



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

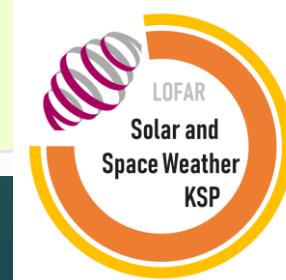
Data types - Beamformed



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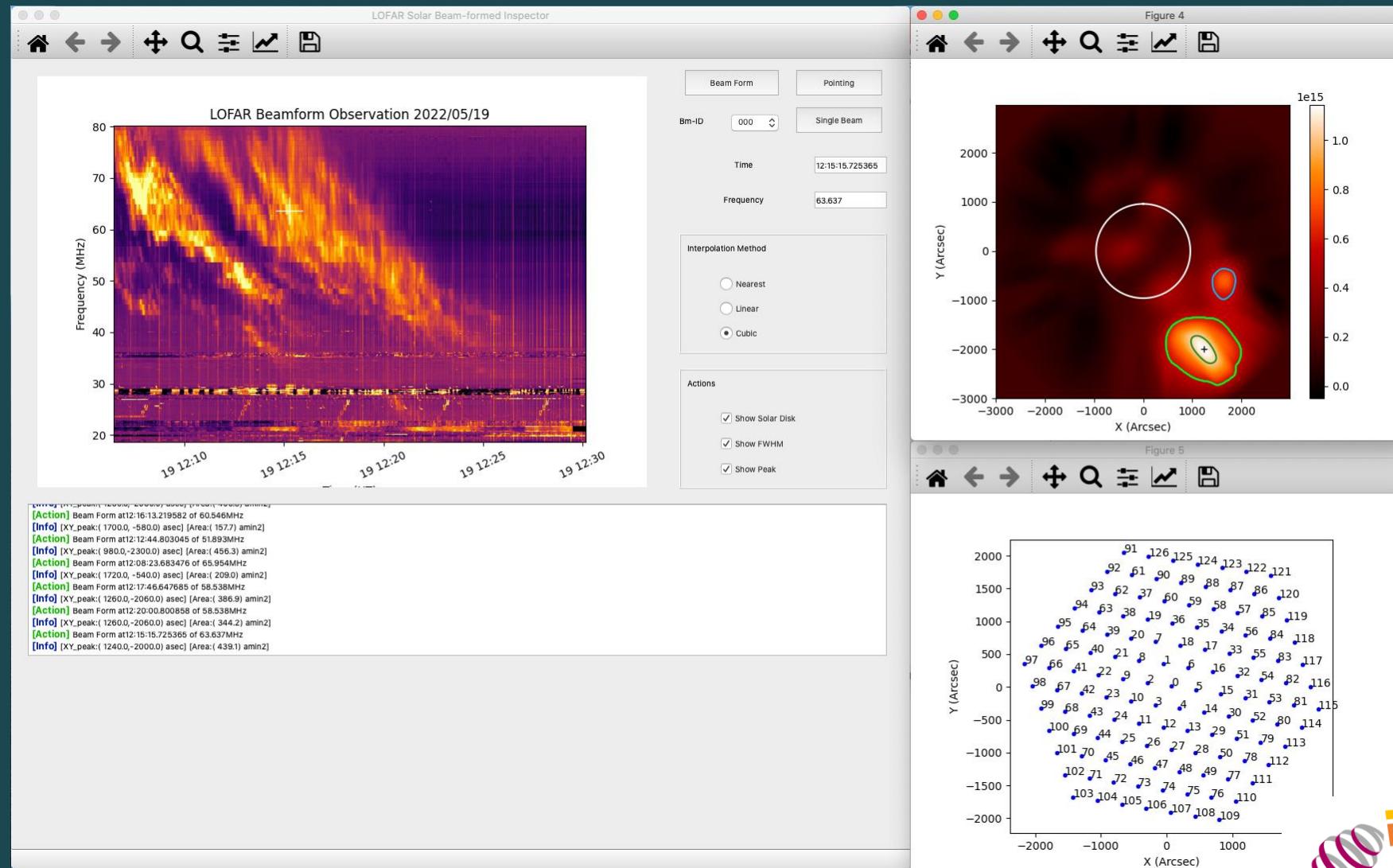
<https://support.astron.nl/LOFARBeamformedCookbook/introduction.html>



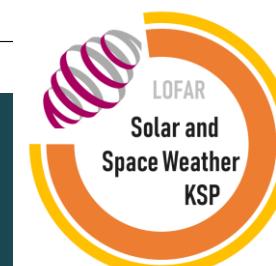
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Preview tool



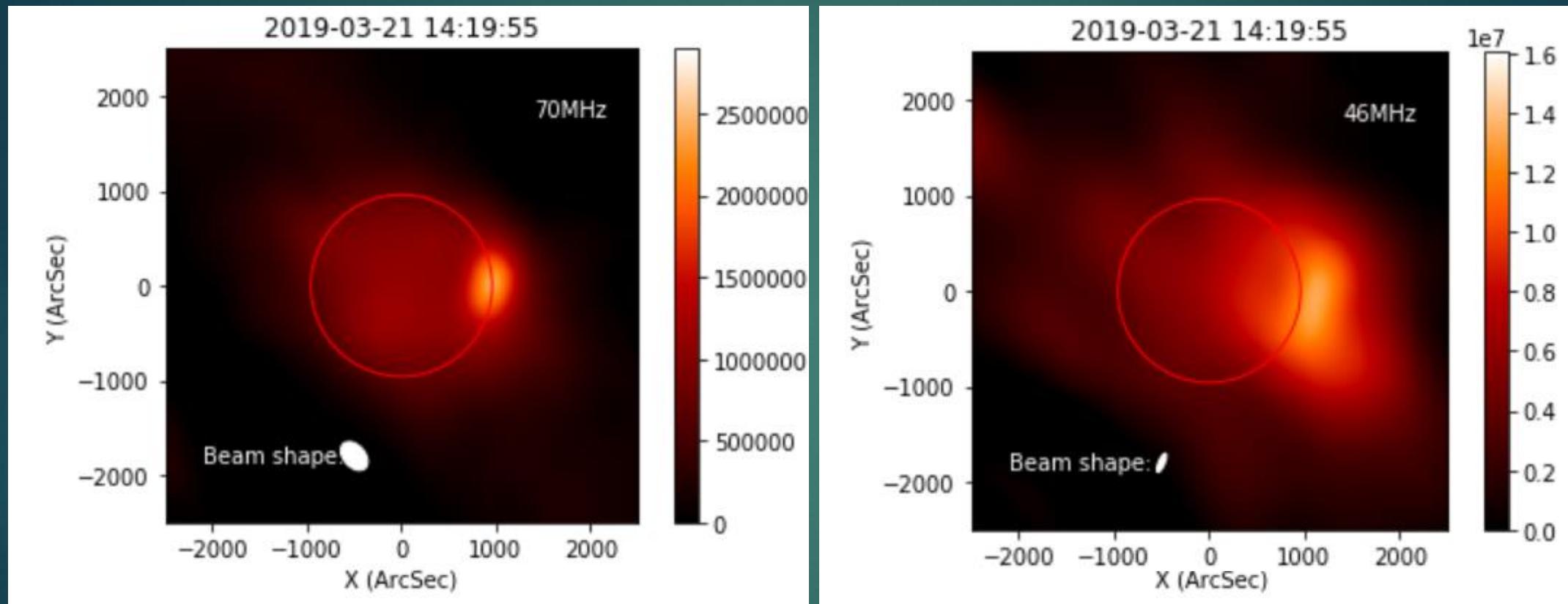
P. Zhang , P. Zucca and Solar SW KSP and IDOLS team



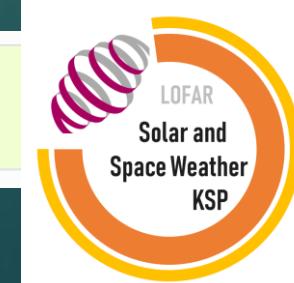
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Netherlands Institute for Radio Astronomy

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Data types - Interferometric



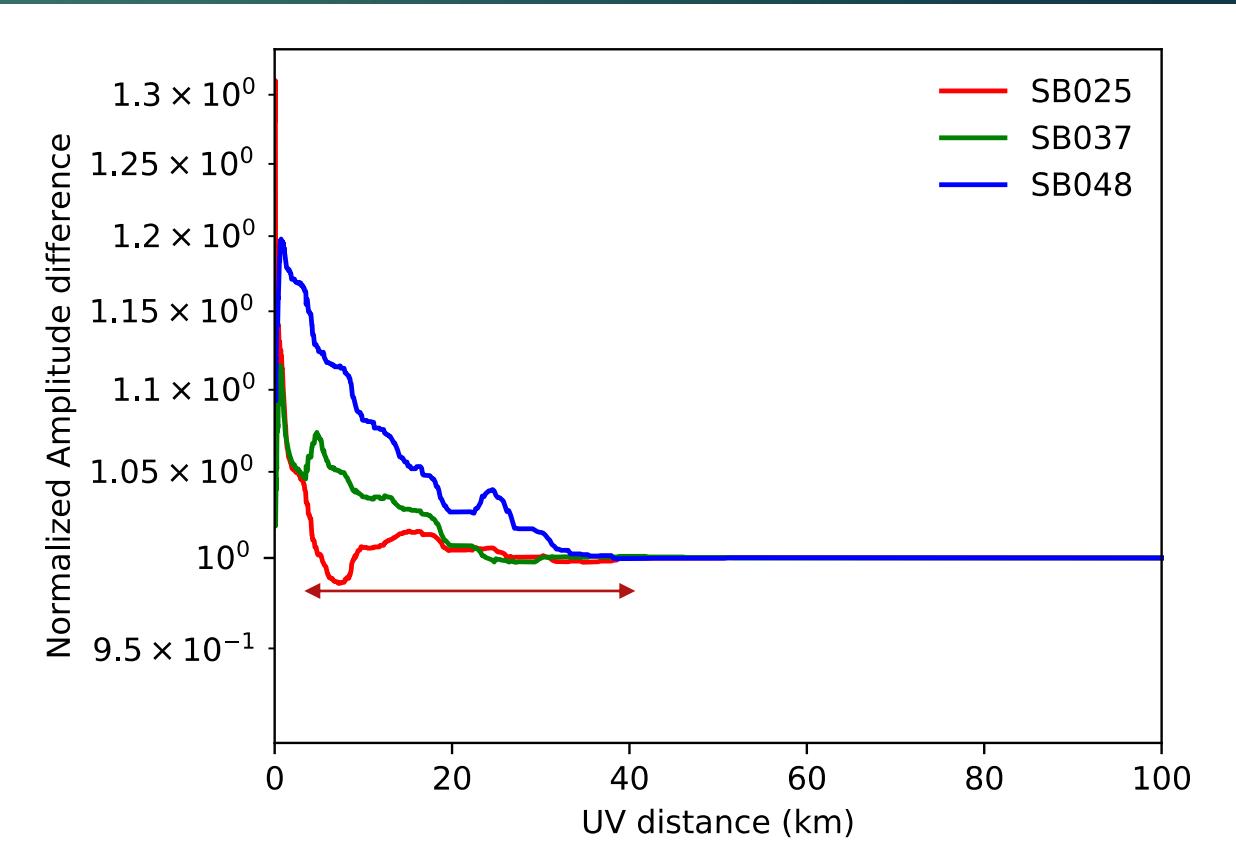
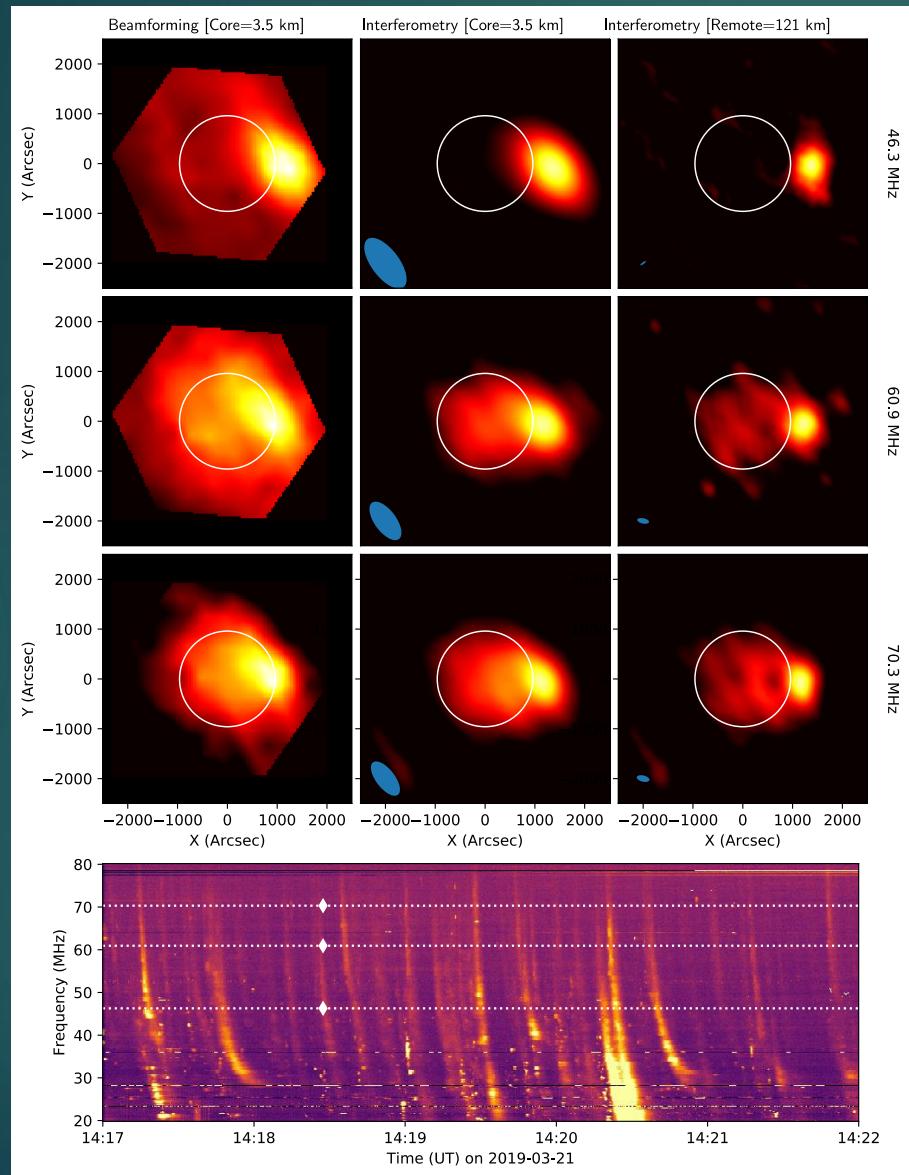
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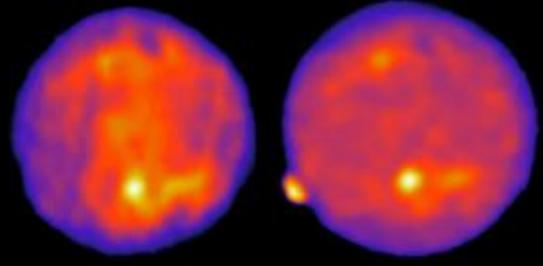


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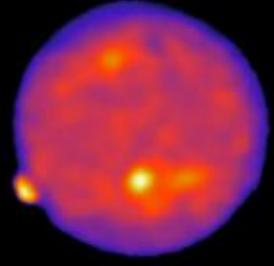
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Tied Array Beam and Interferometric mode





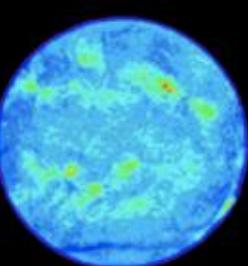
25.8 GHz
SUNDISH



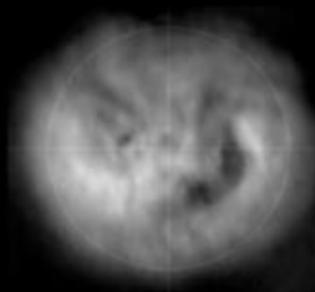
18.3 GHz
SUNDISH



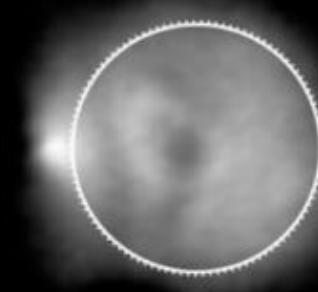
17 GHz
NoRH



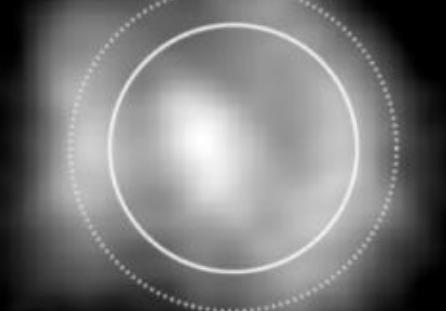
4.6 GHz
VLA



432 MHz
NRH



240 MHz
MWA



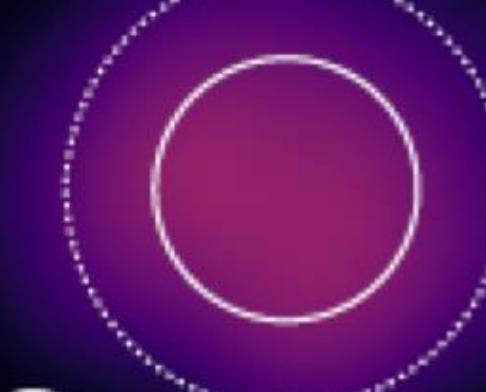
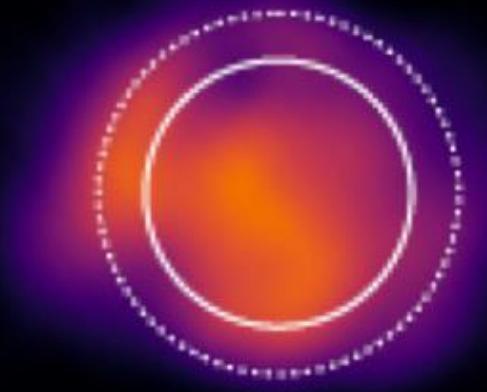
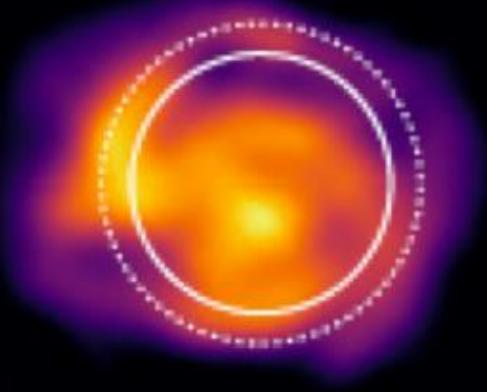
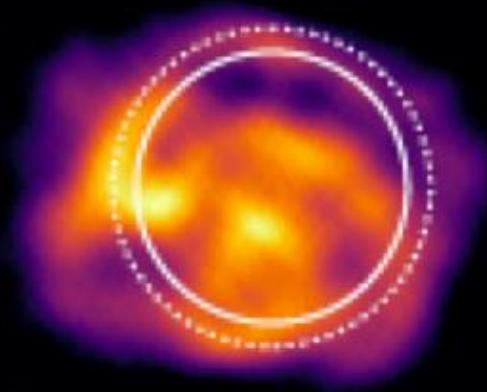
80 MHz
MWA

71.48 MHz

61.71 MHz

46.28 MHz

24.60 MHz

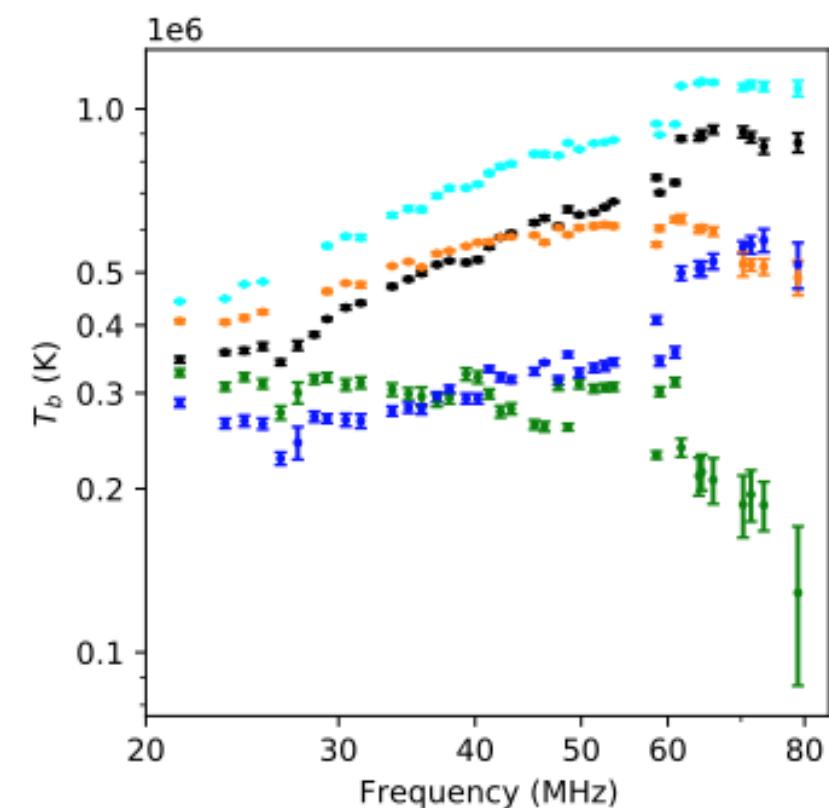
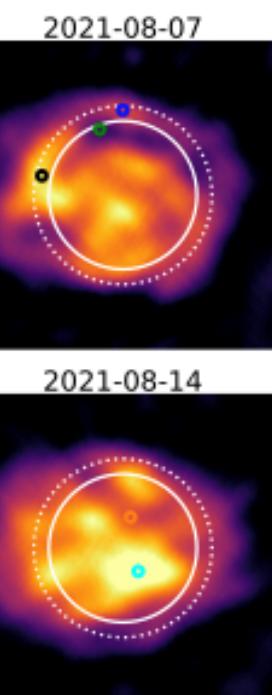
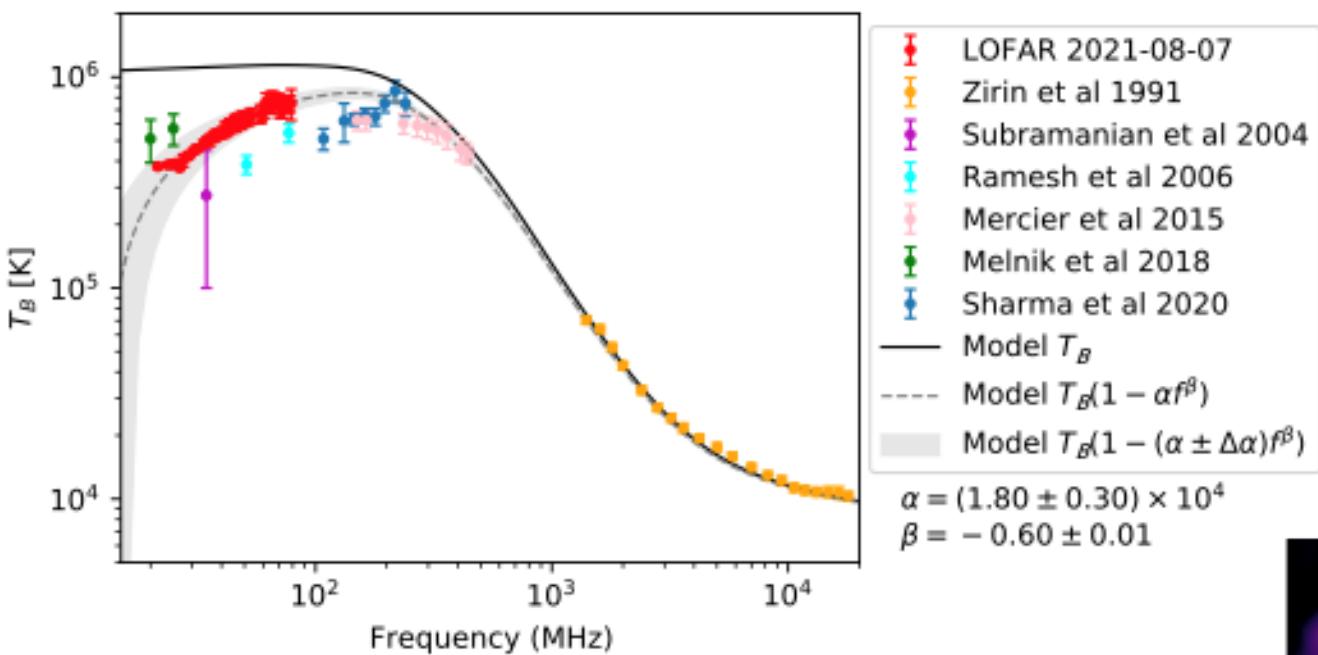


LOFAR

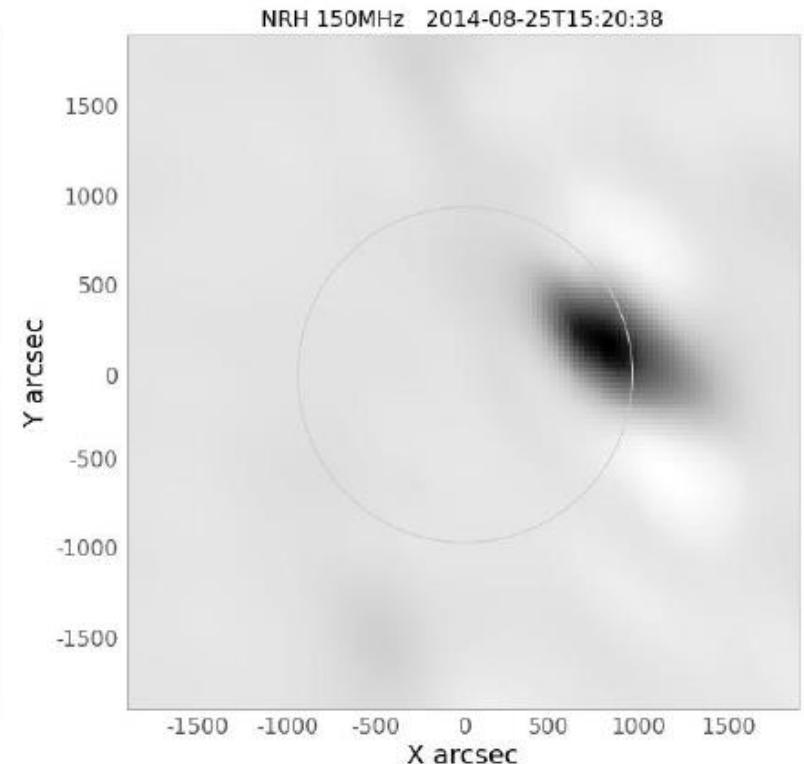
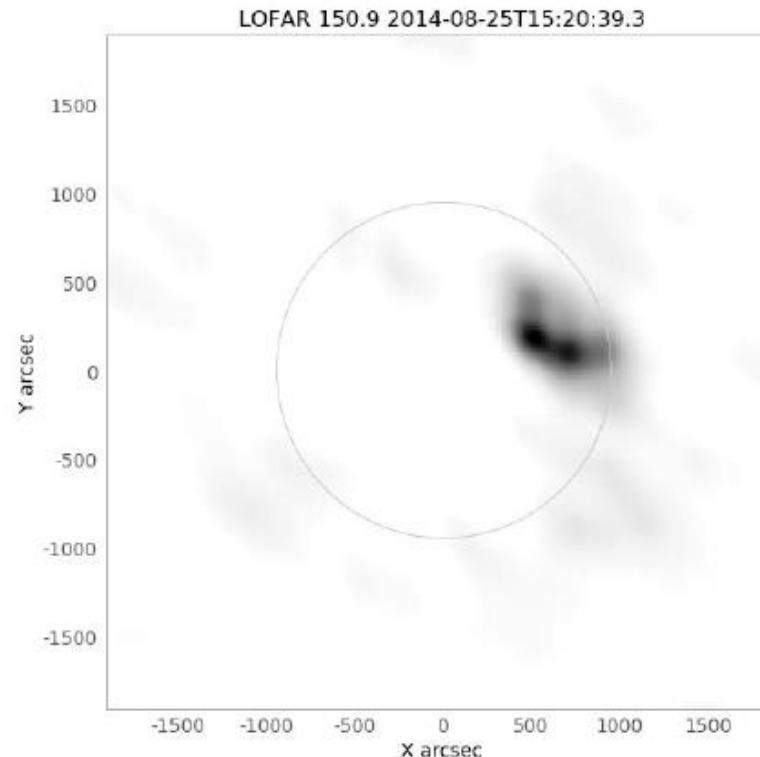
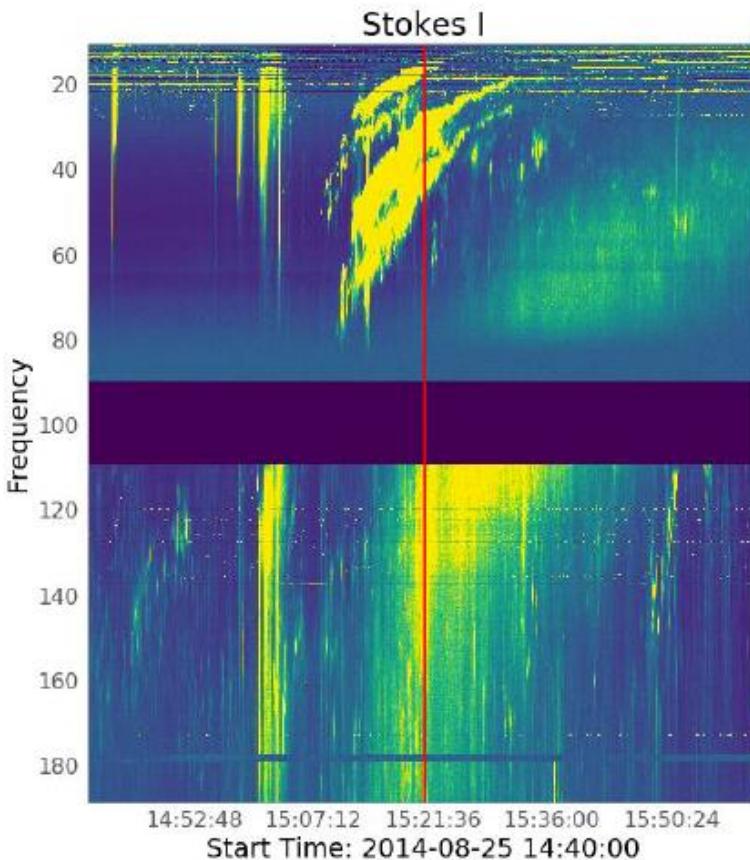
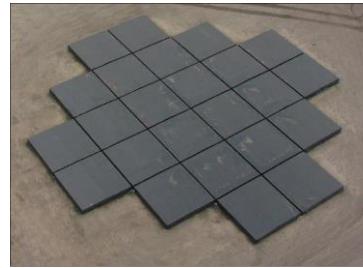
Imaging of the Quiet Sun in the Frequency Range of 20-80 MHz

PEIJIN ZHANG^{1, 2, 3, 4}, PIETRO ZUCCA*², KAMEN KOZAREV¹, EOIN CARLEY⁵,
CHUANBING WANG^{4, 6, 7}, THOMAS FRANZEN², BARTOSZ DABROWSKI⁸,
ANDRZEJ KRANKOWSKI⁸, JASMINA MAGDALEVIC⁹, AND CHRISTIAN VOCKS¹⁰

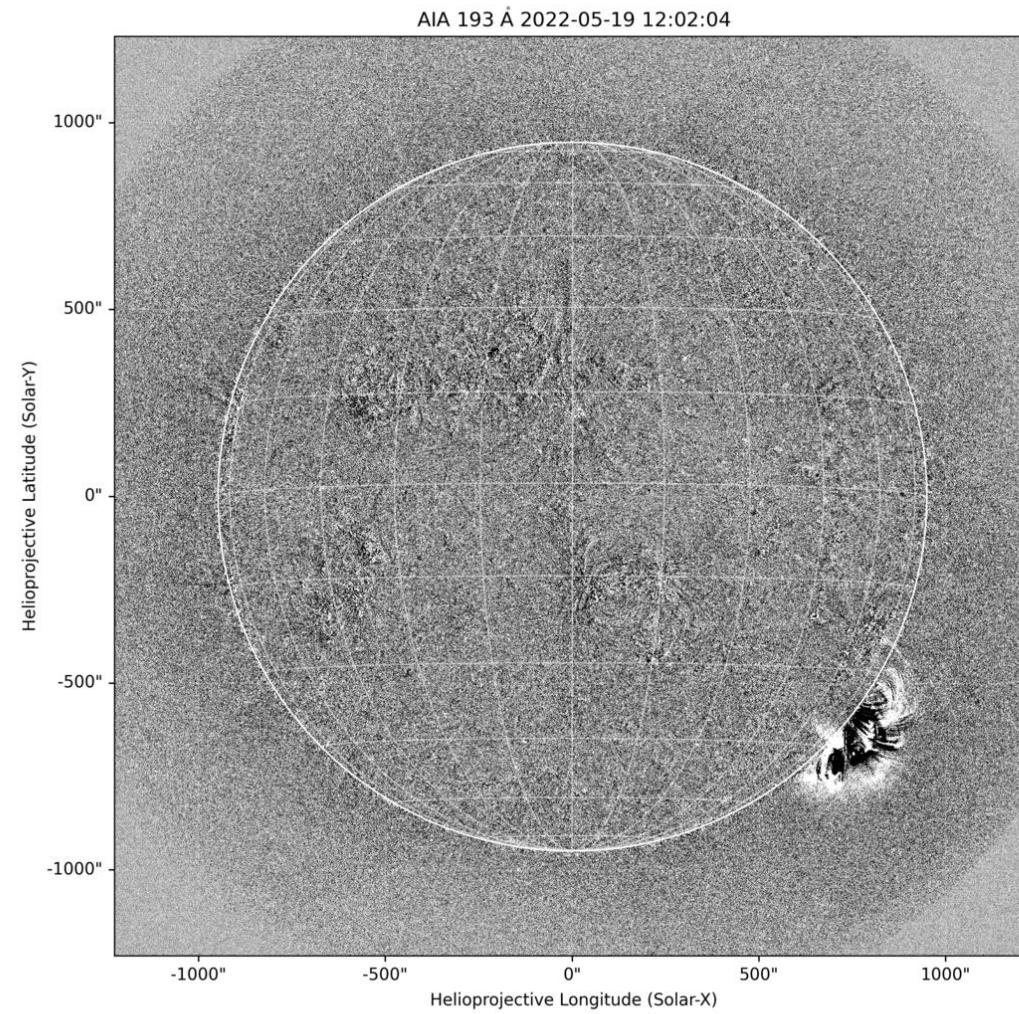
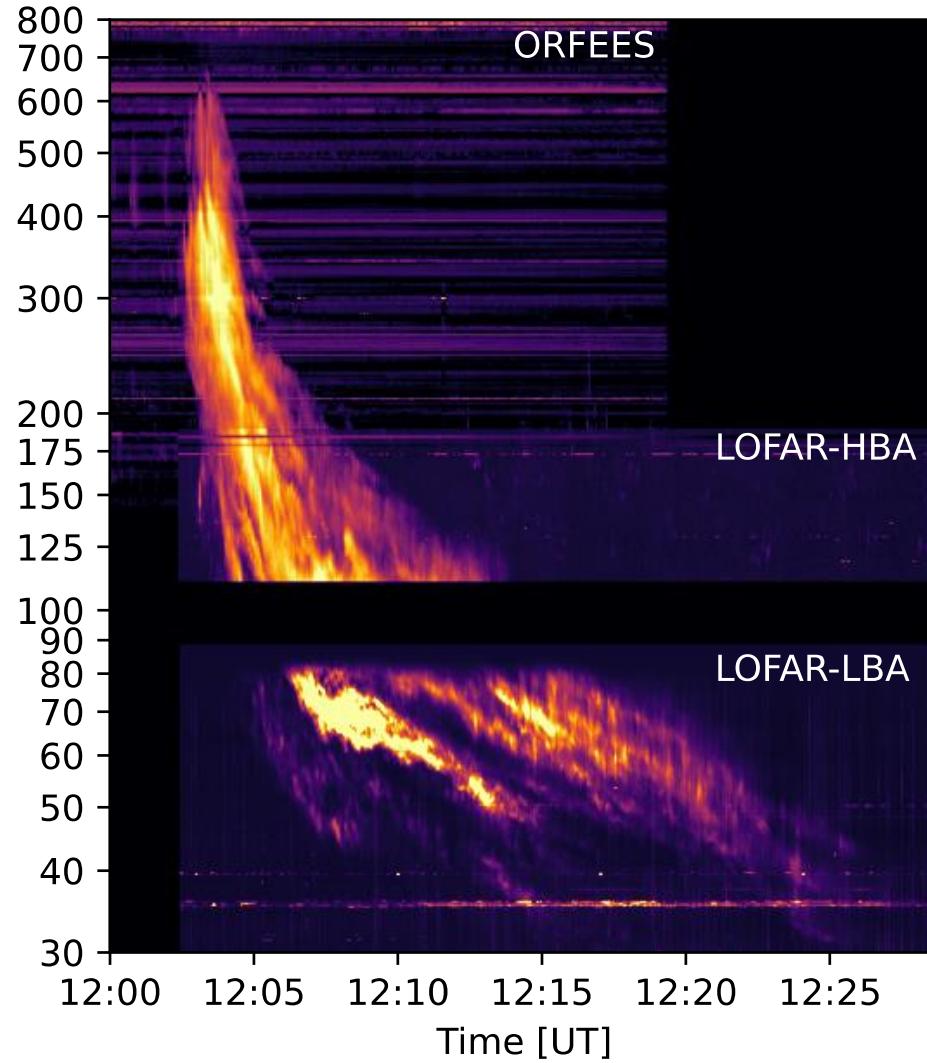
QUIET SUN IMAGING OF 20-80 MHz

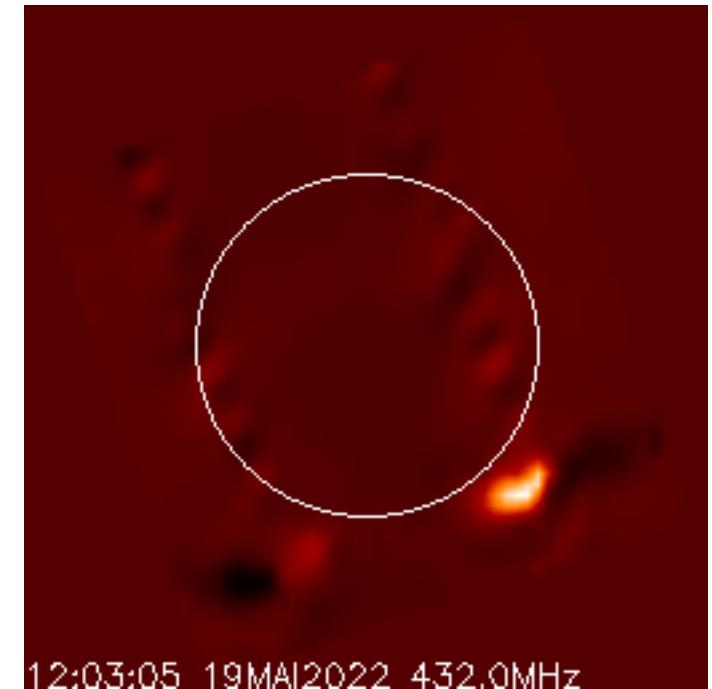
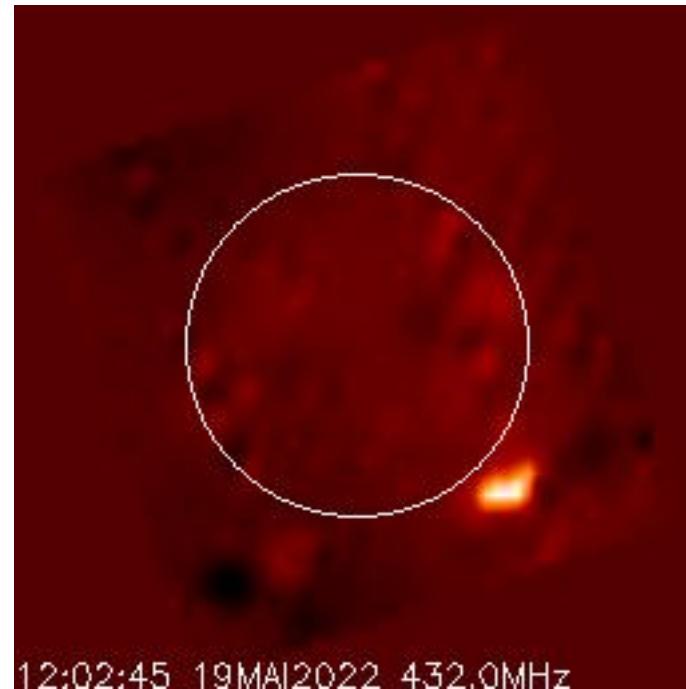
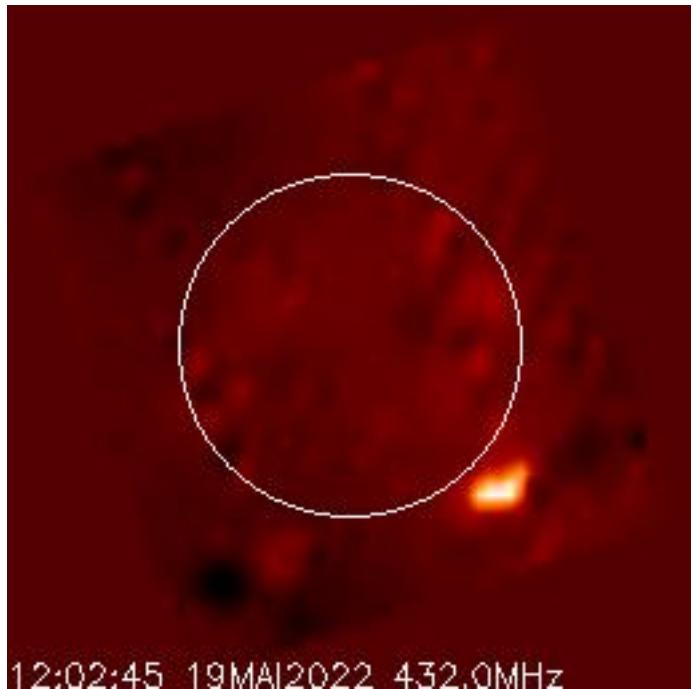


Comparison of LOFAR imaging with NRH

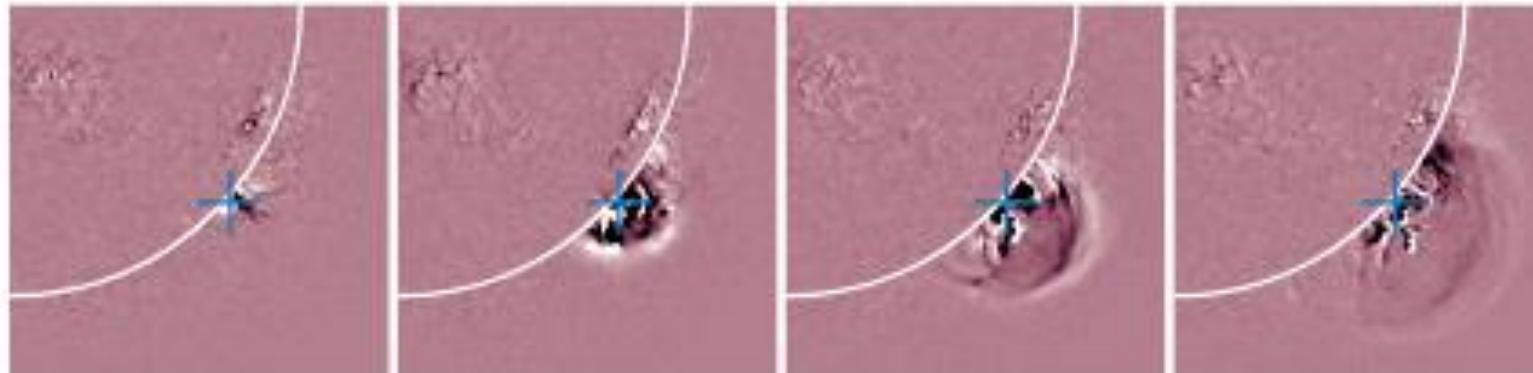


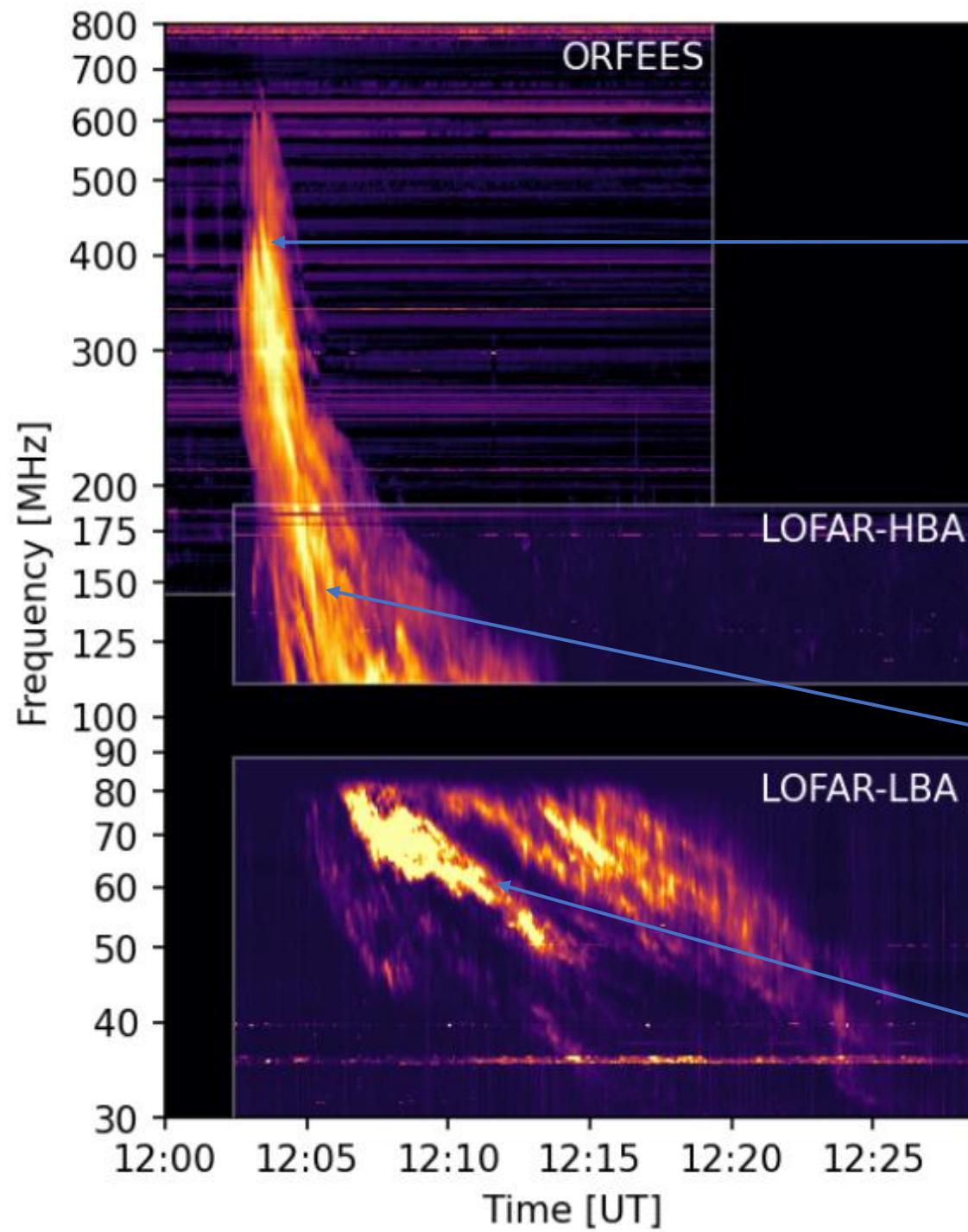
New Opportunities with LOFAR



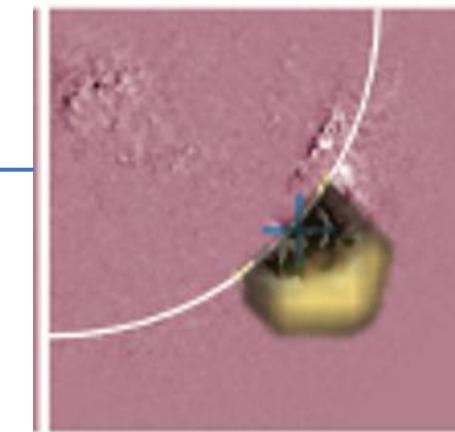


12:00:45 UT 12:02:21 UT 12:03:57 UT 12:05:33 UT

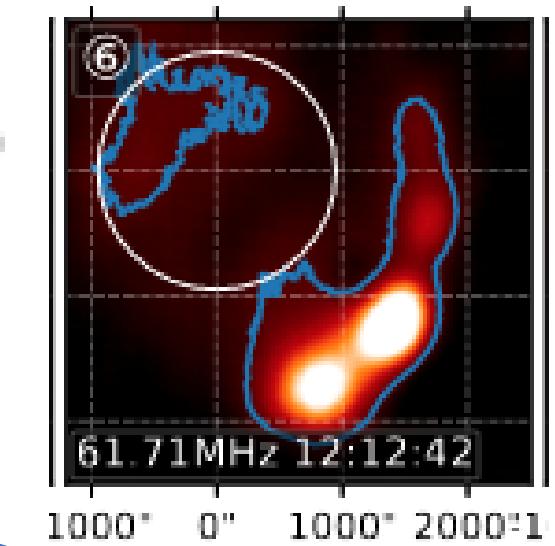
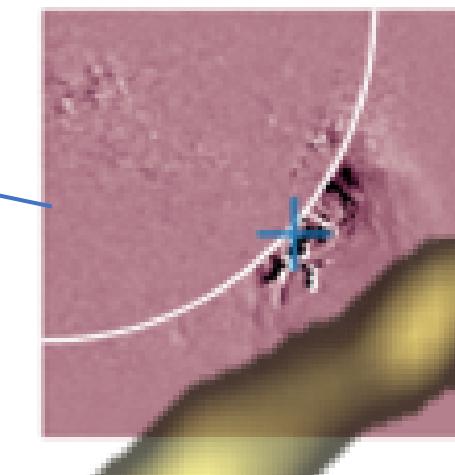


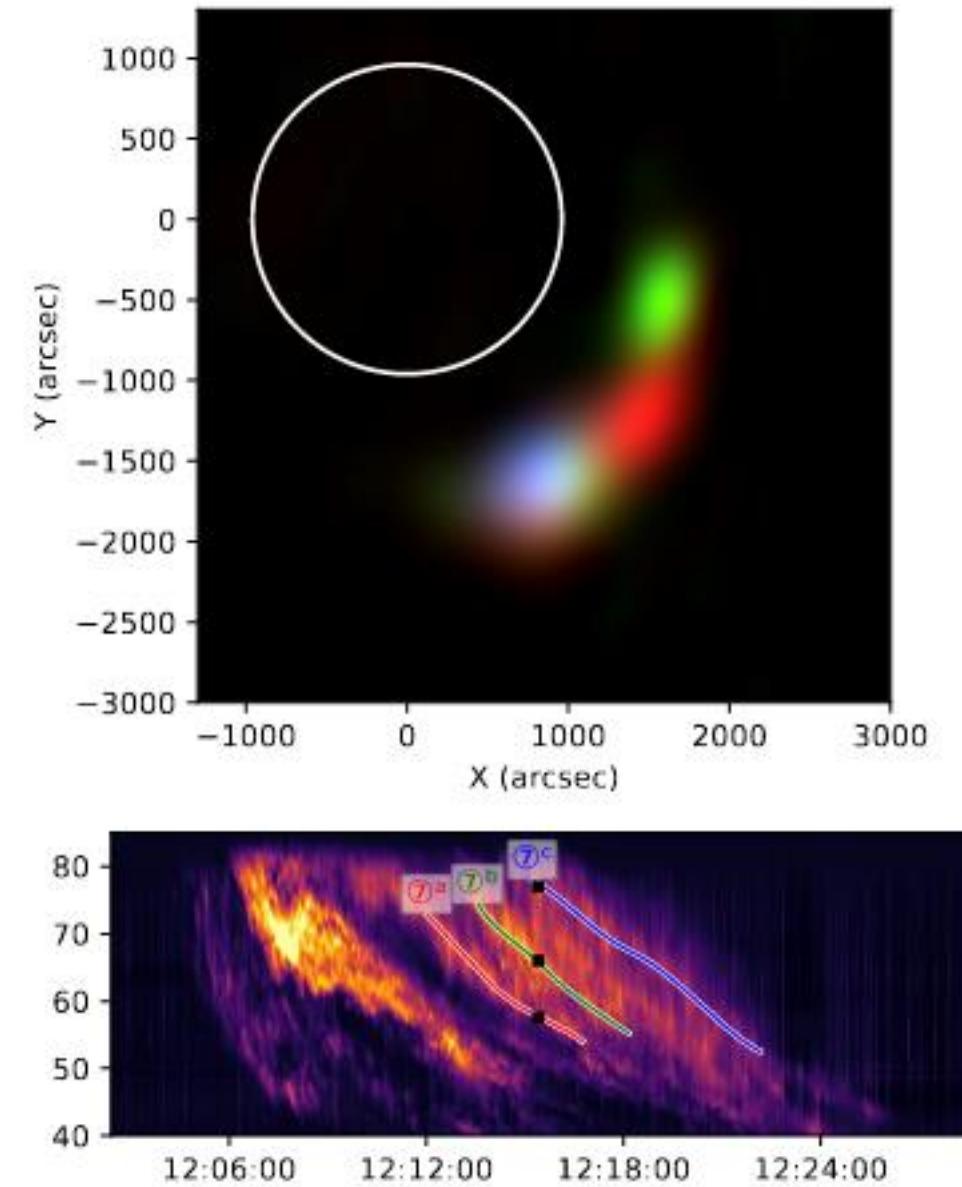
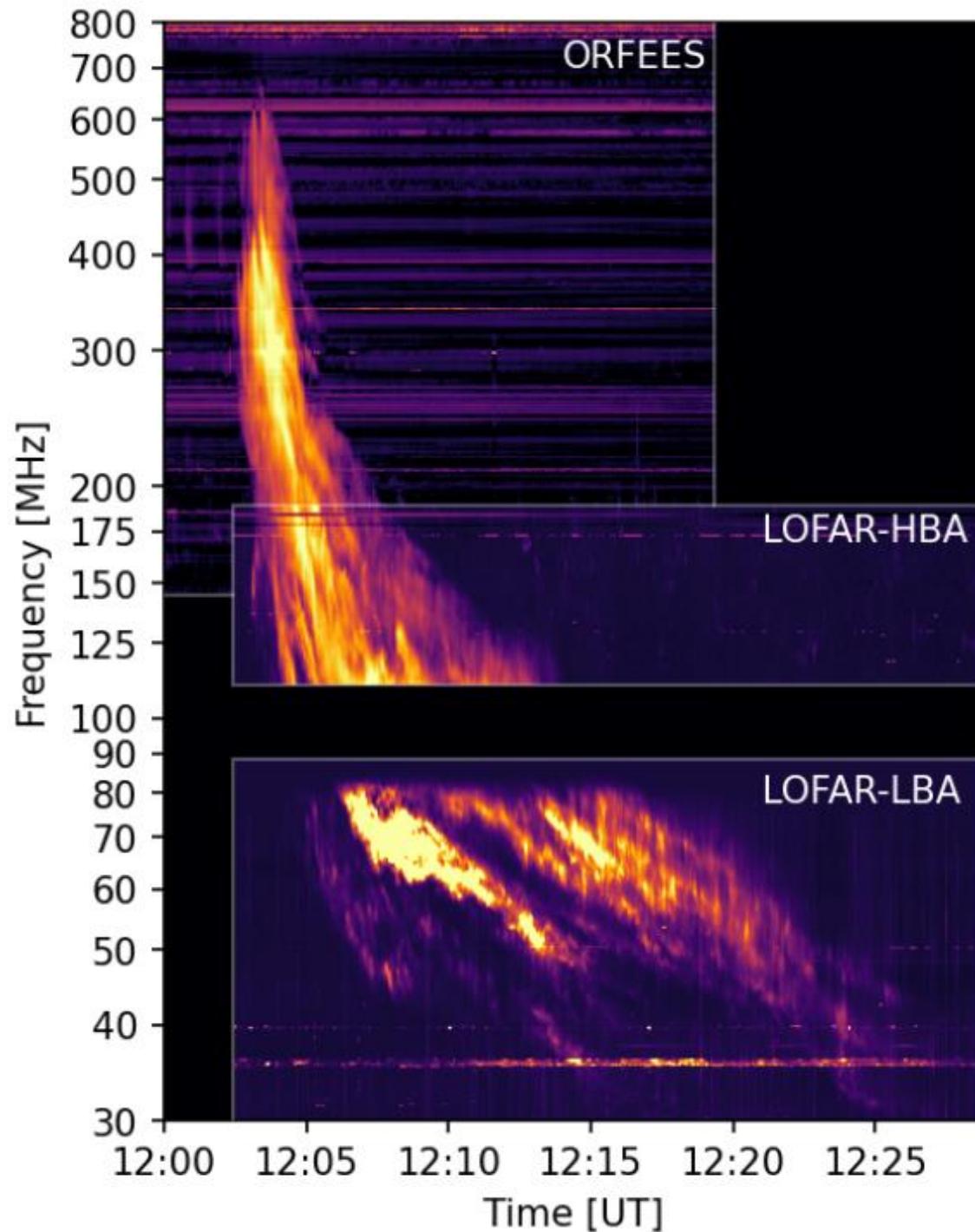


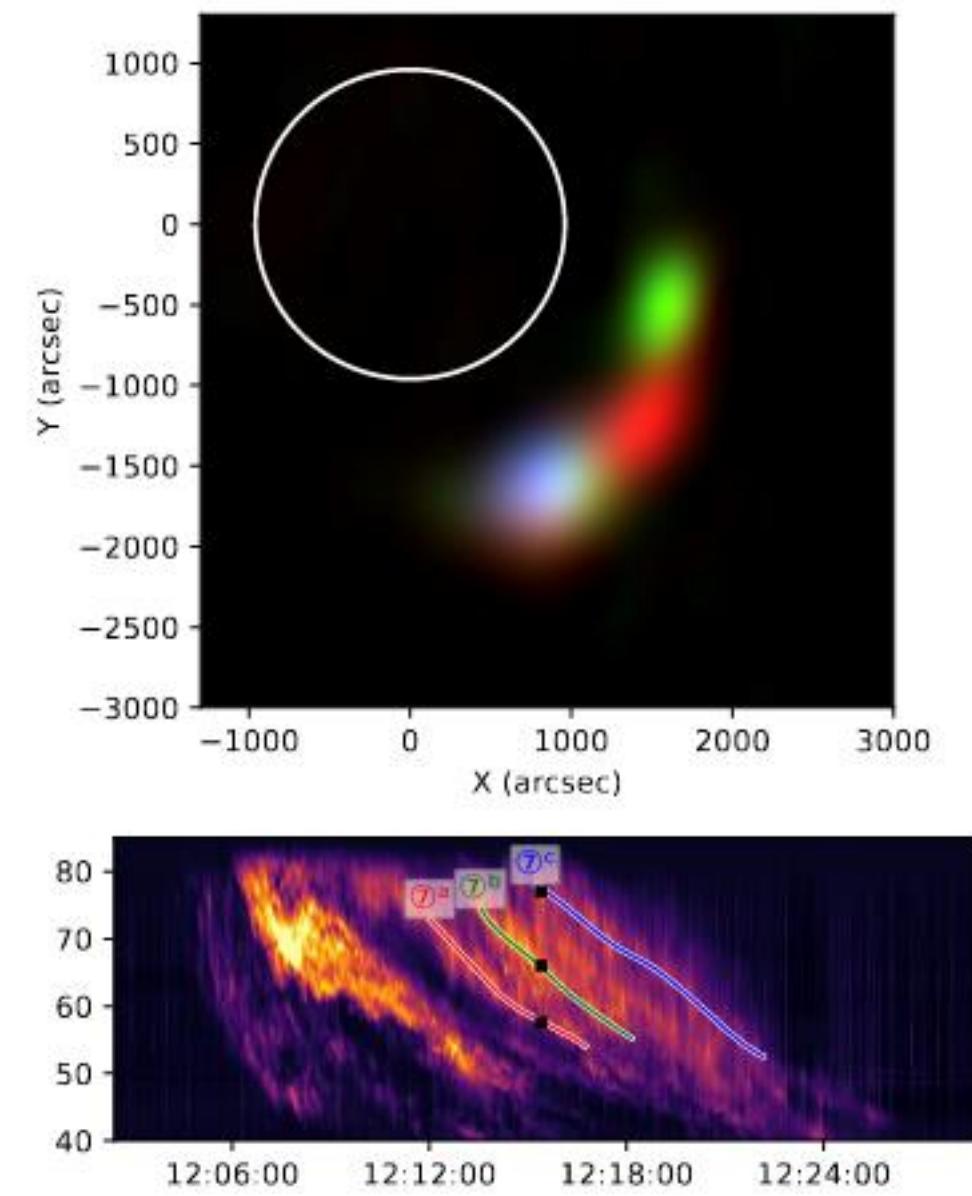
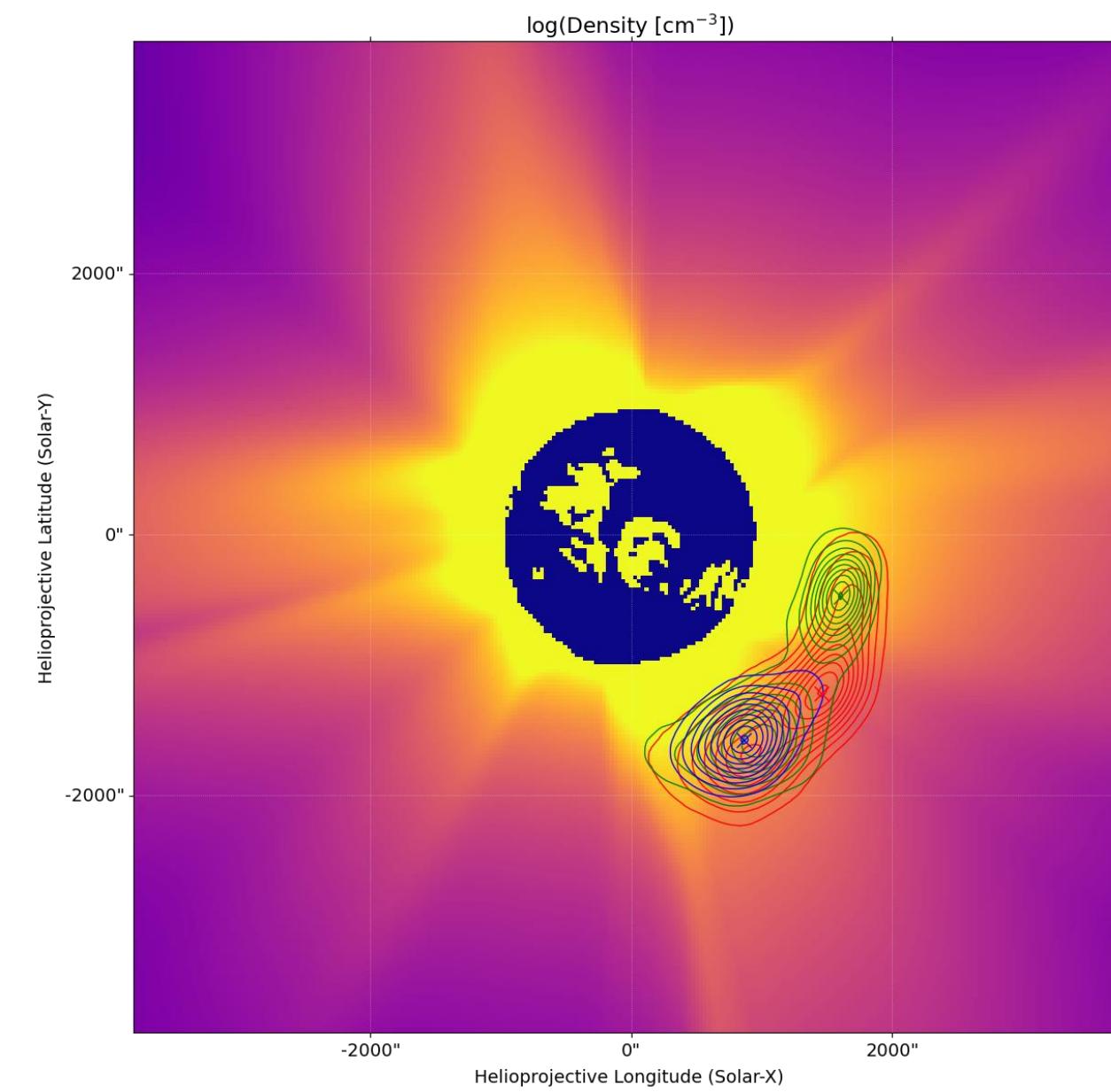
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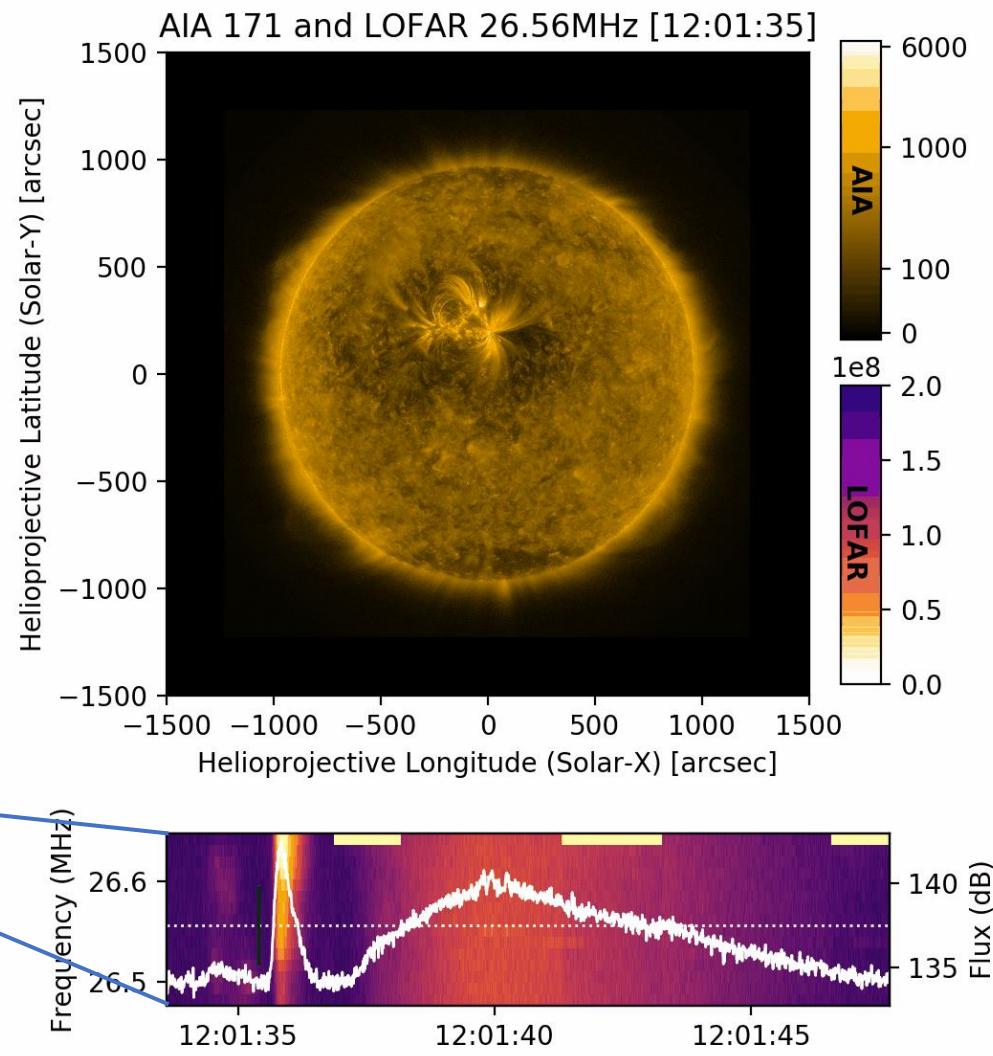
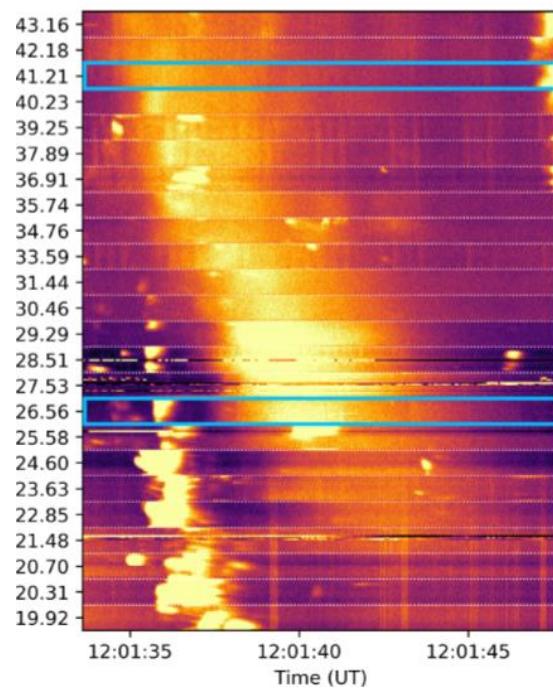




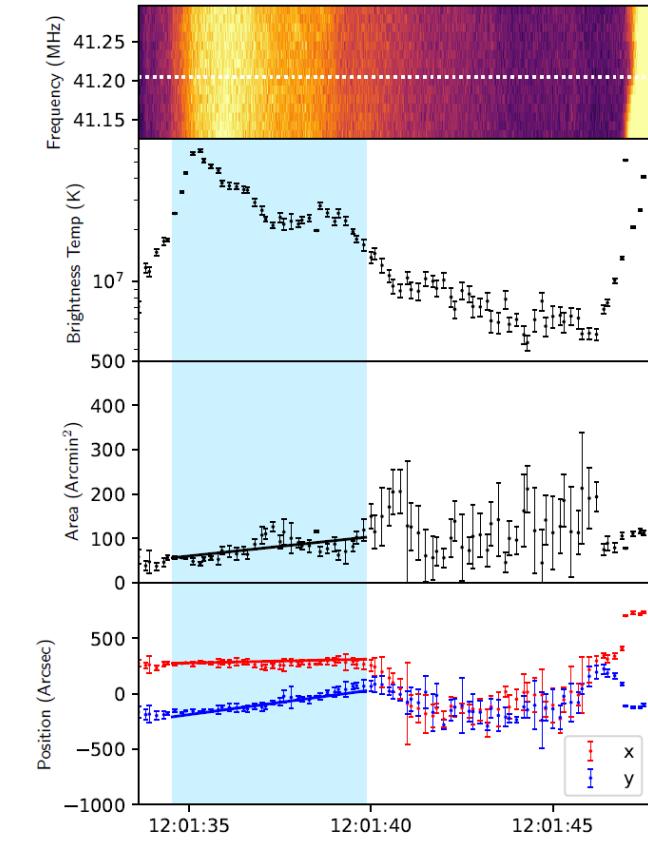
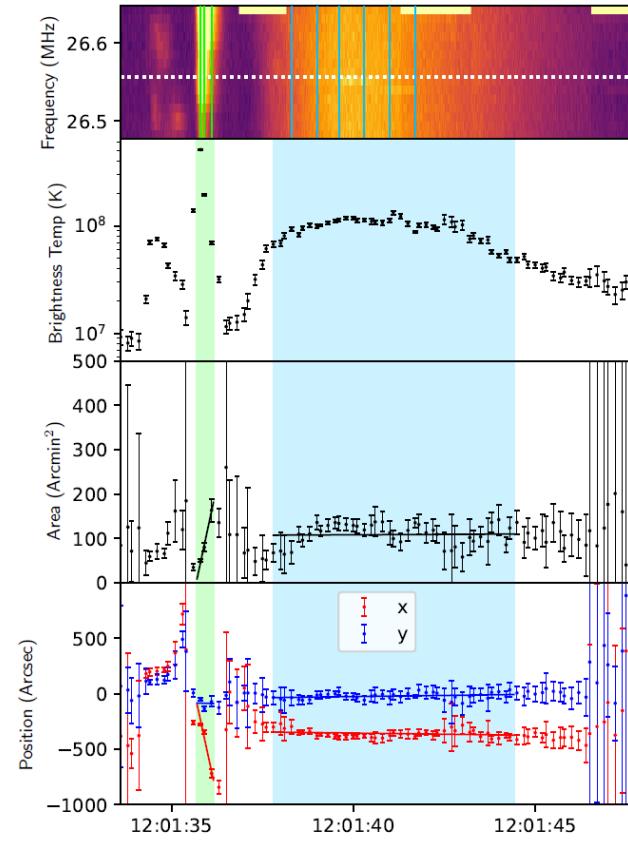
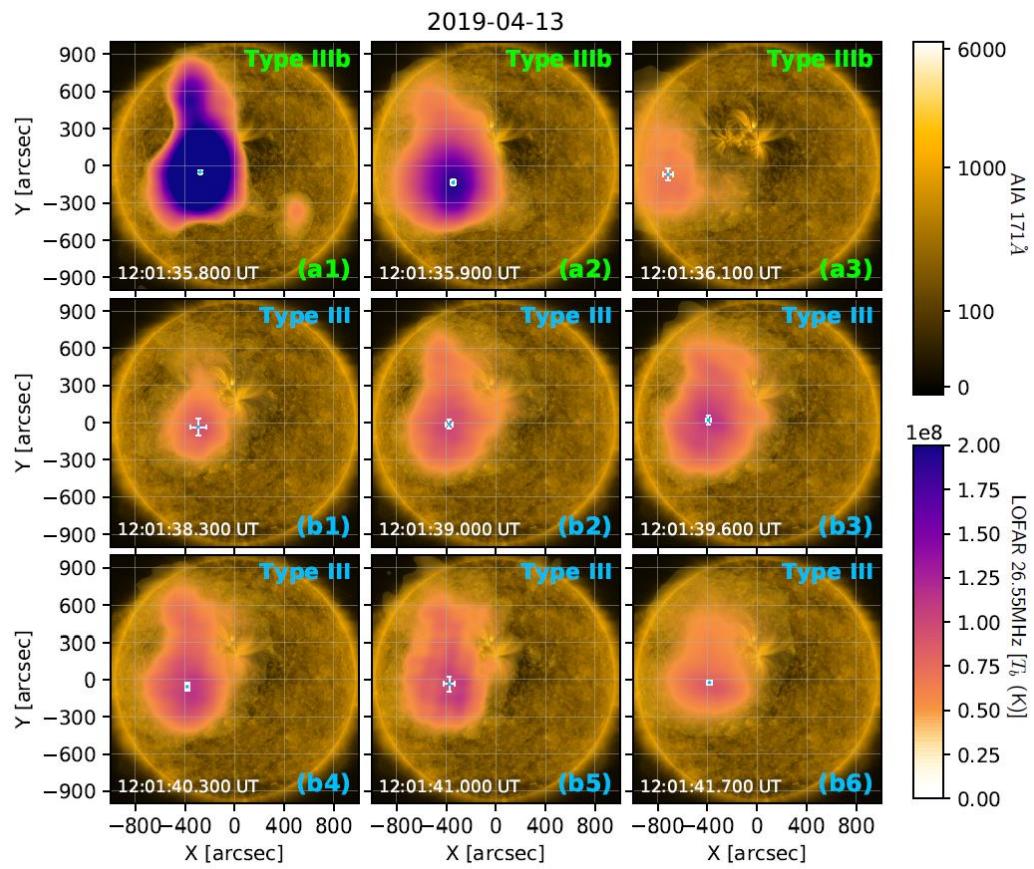


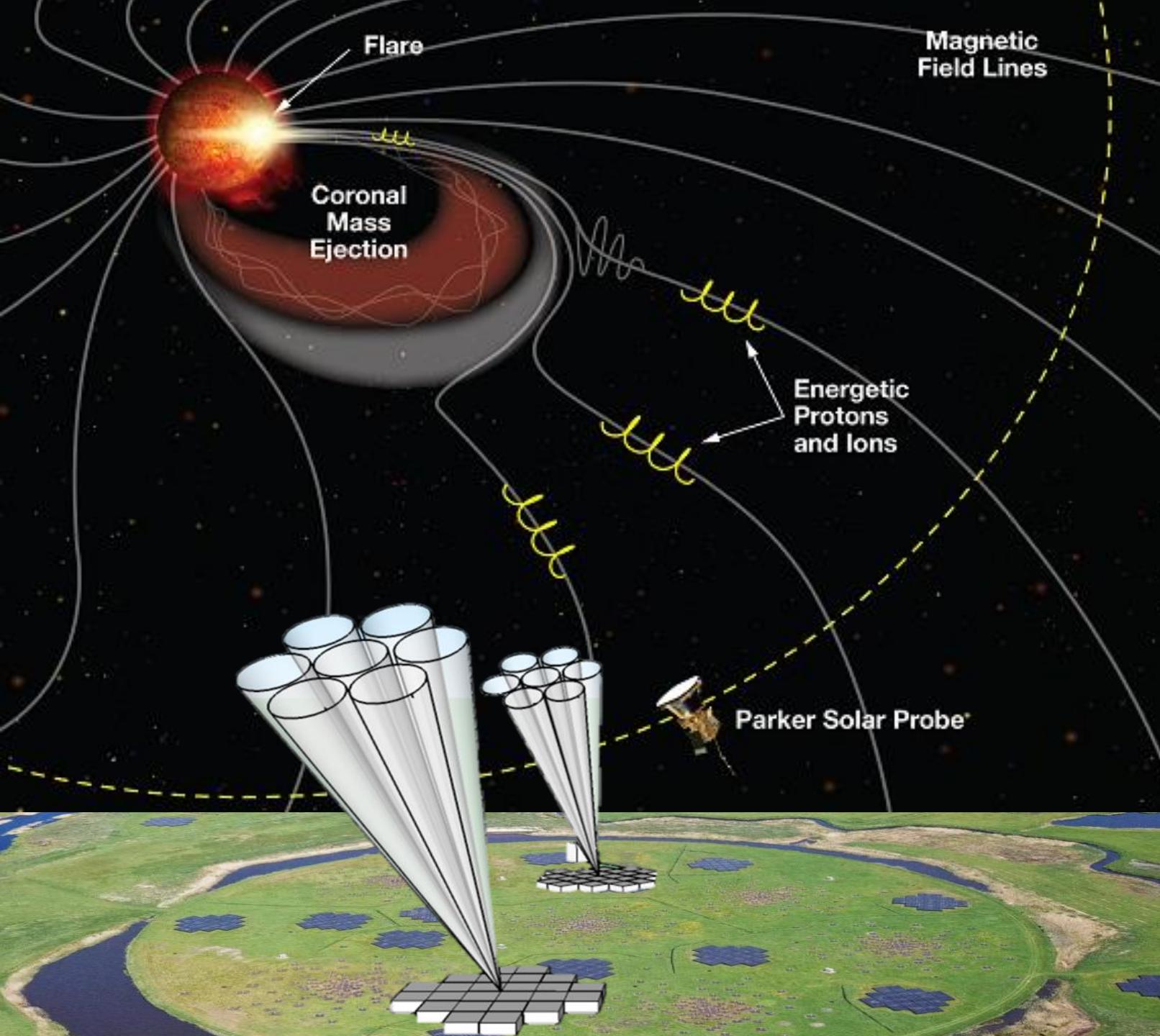
Type IIIb pair

- The dynamic spectrum and the interferometric imaging

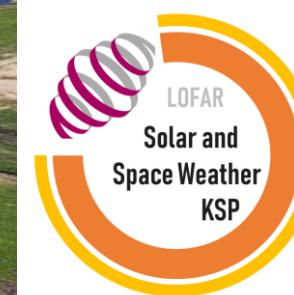
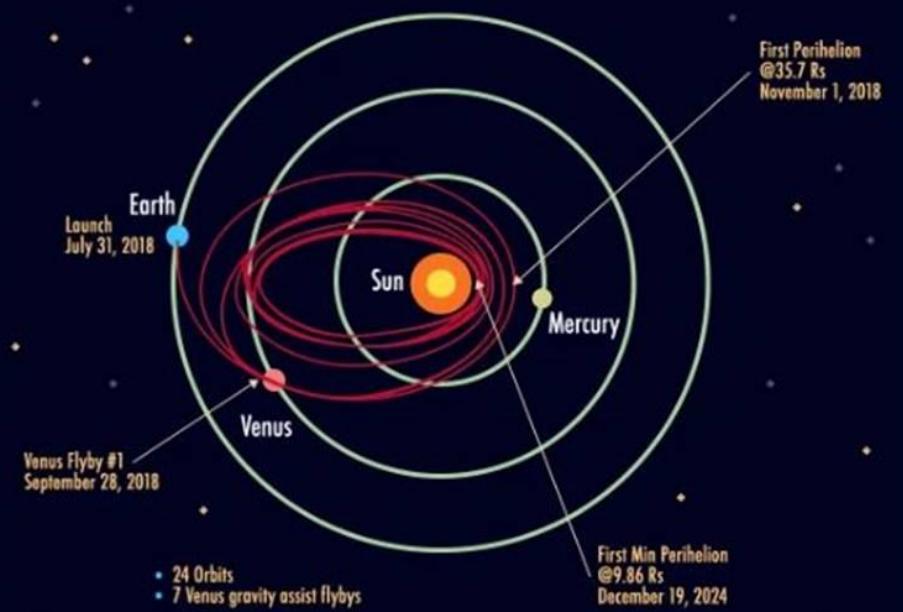


Size and Source Position



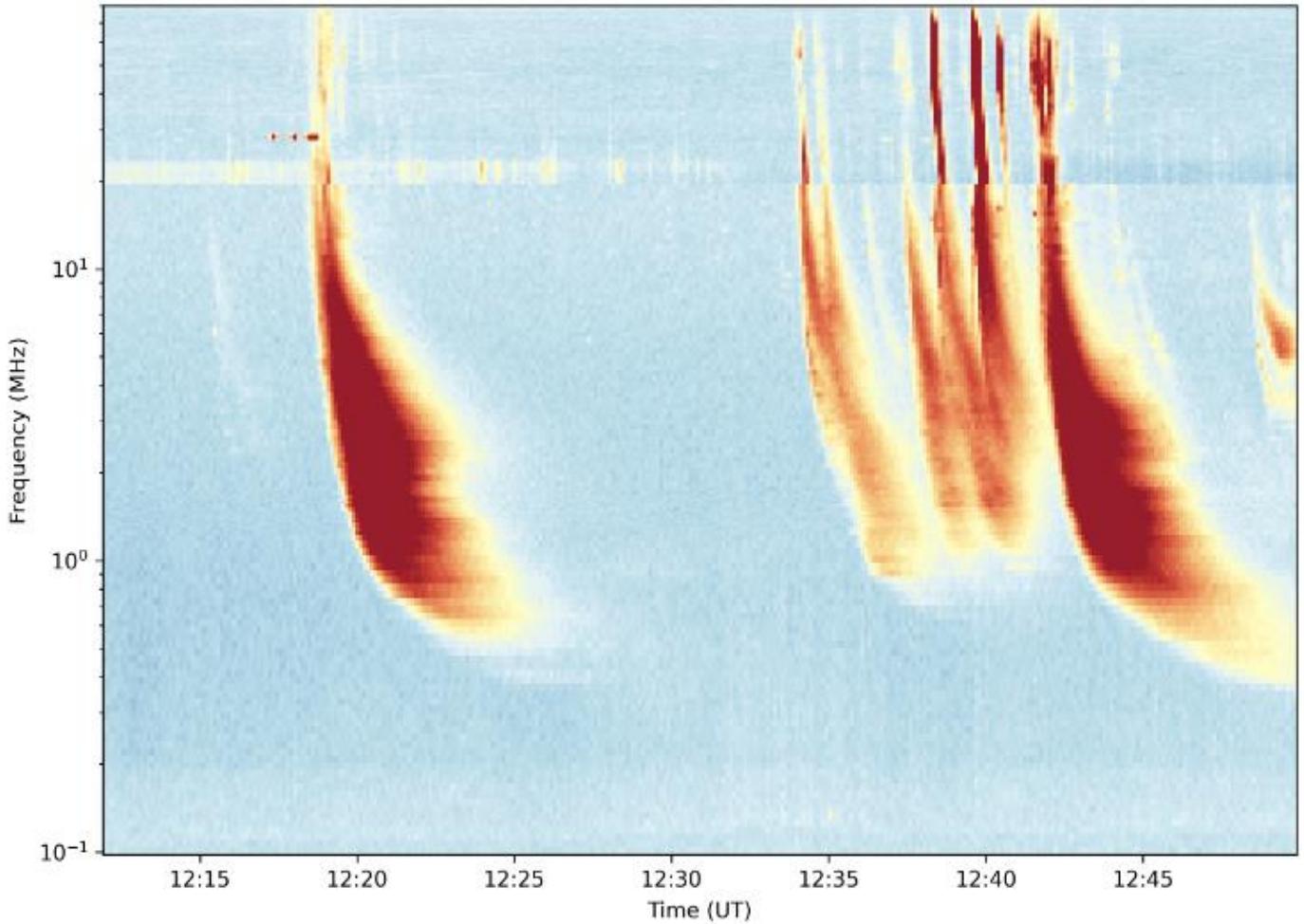
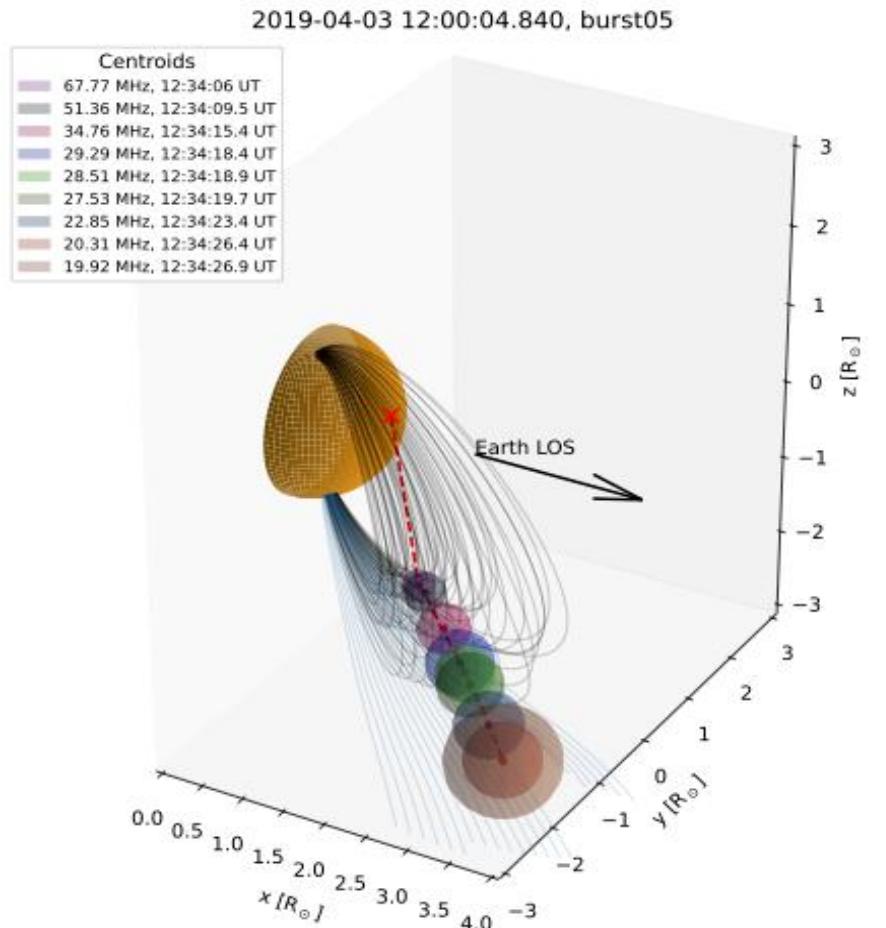


TRAJECTORY DESIGN

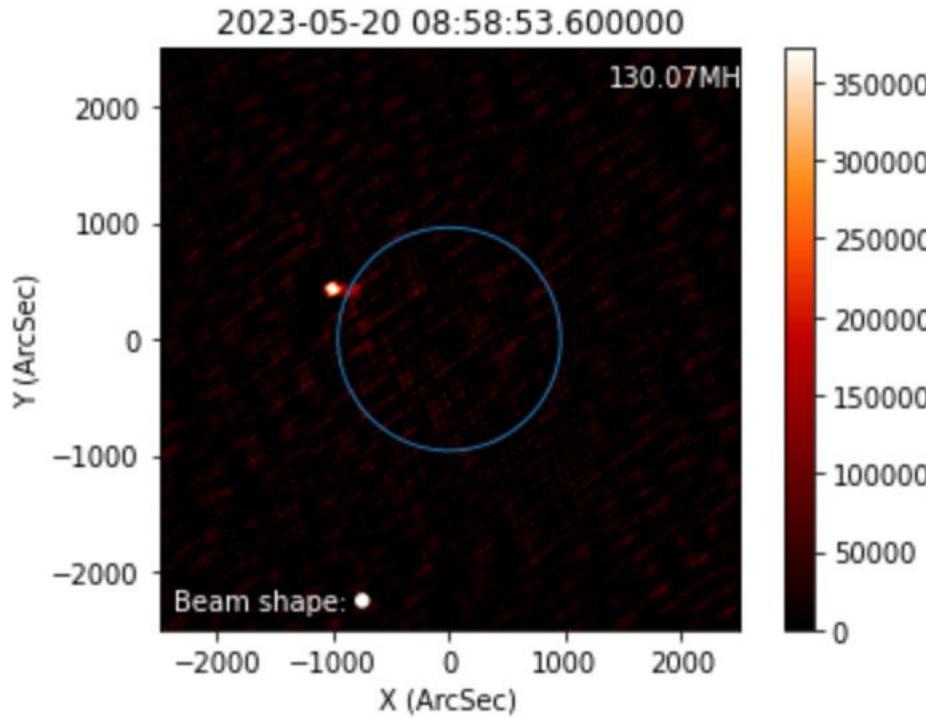
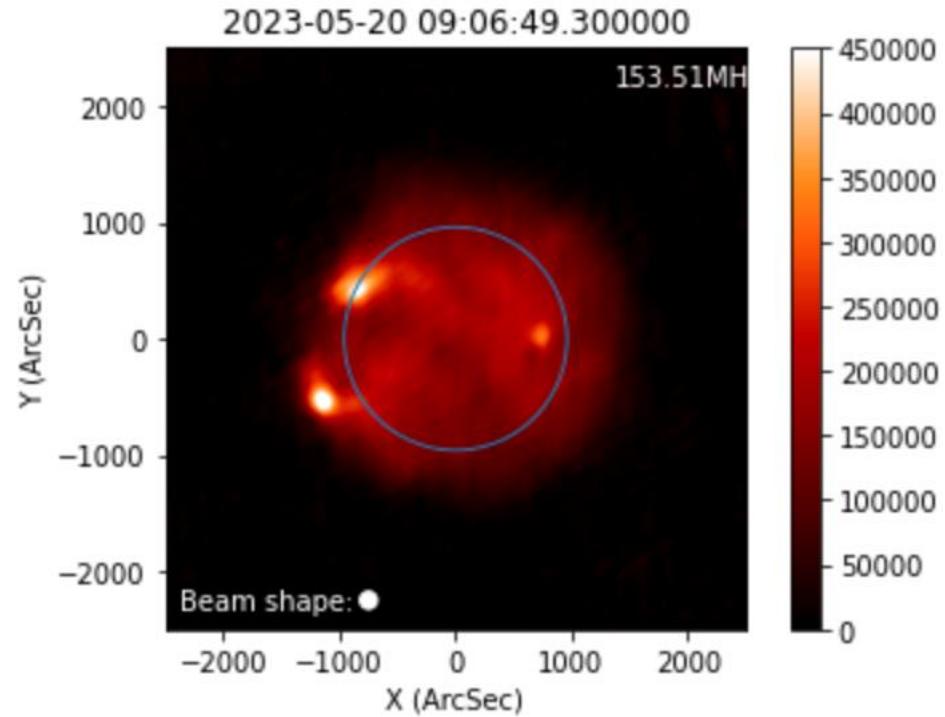


ASTRON

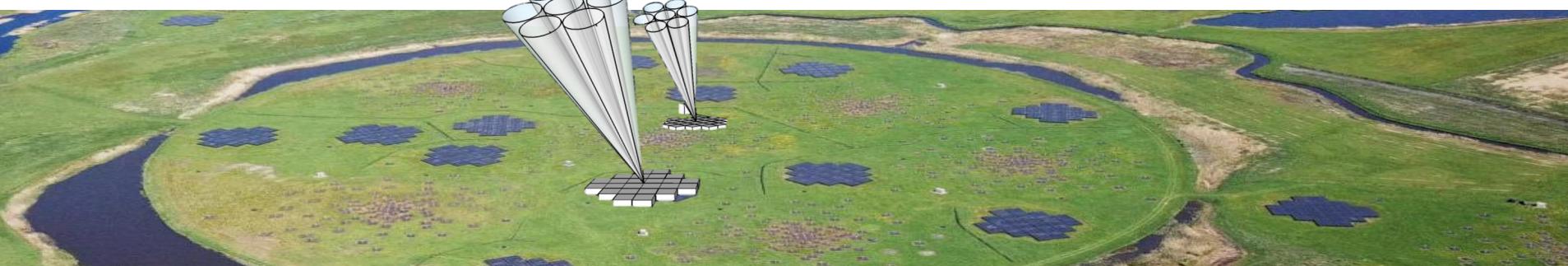
Using LOFAR and PSP to track the radio bursts.



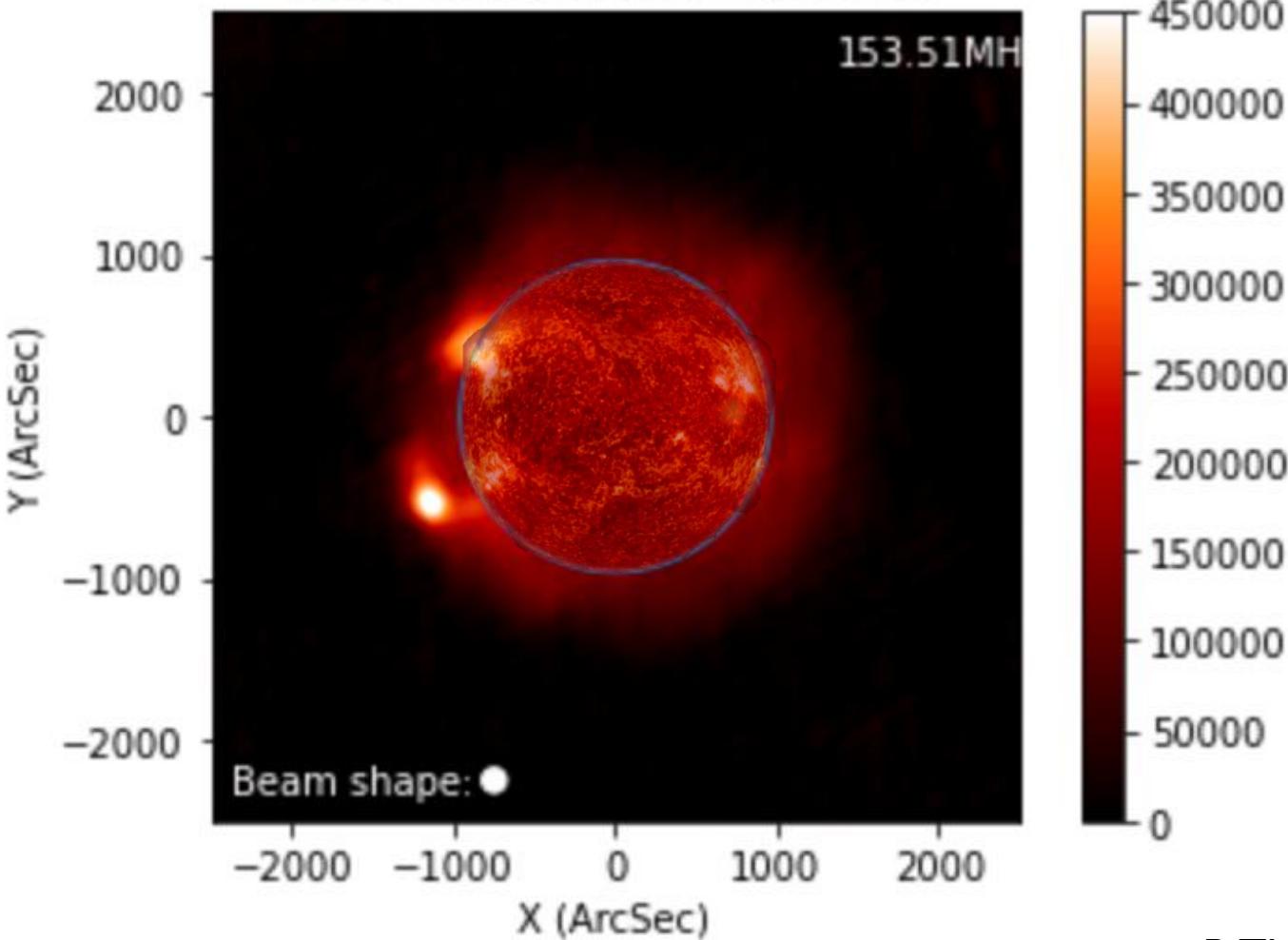
HBA Imaging



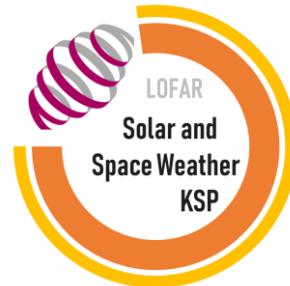
P. Zhang and P. Zucca preliminary

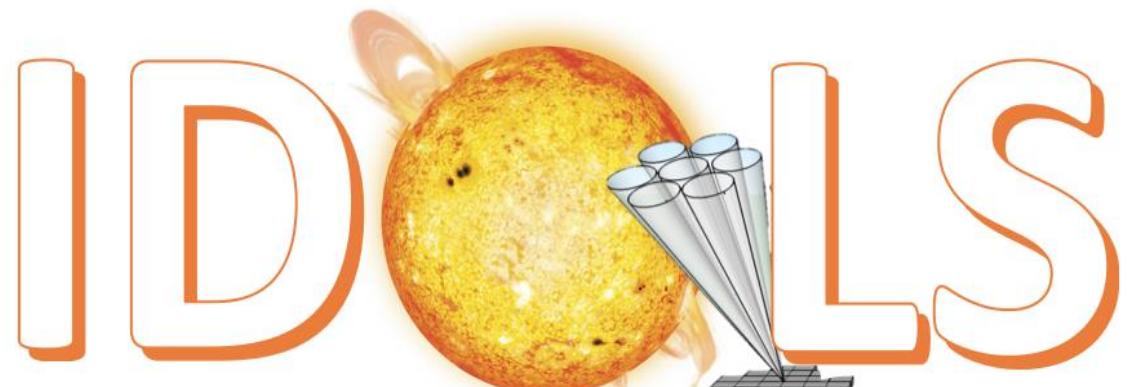


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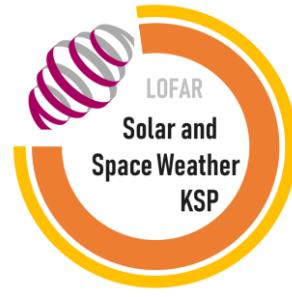


P. Zhang and P. Zucca preliminary





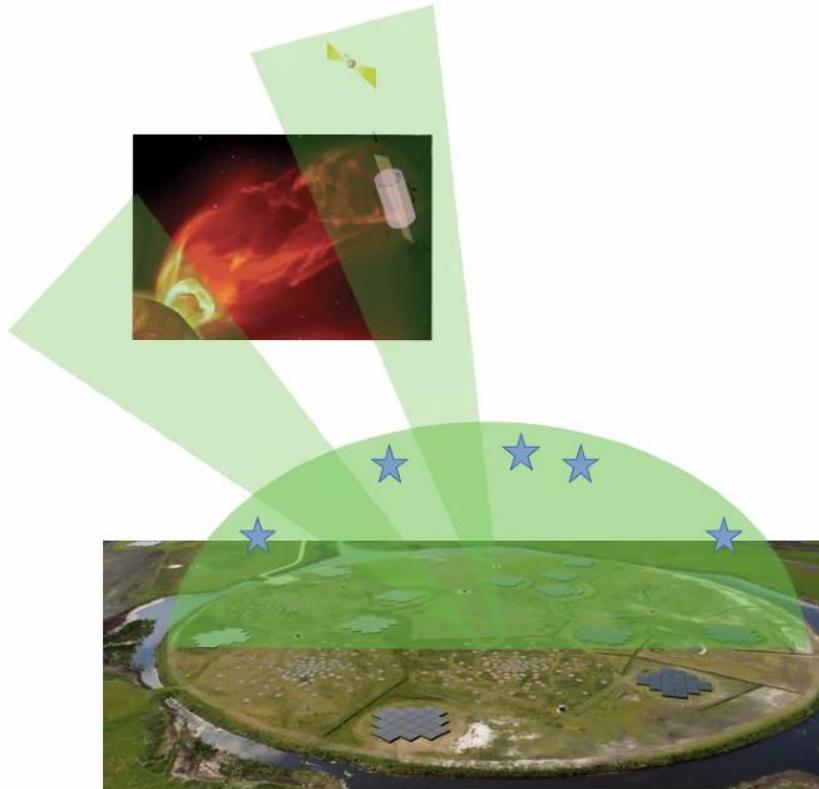
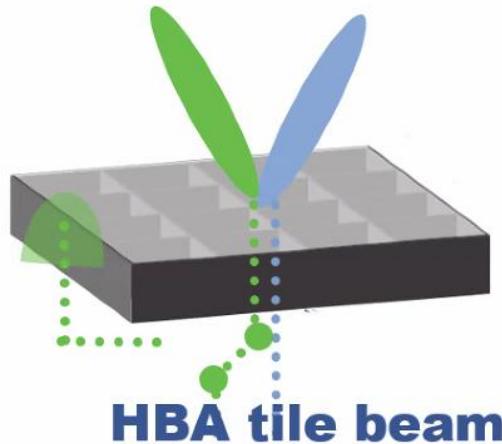
Incremental Development of LOFAR Space-Weather

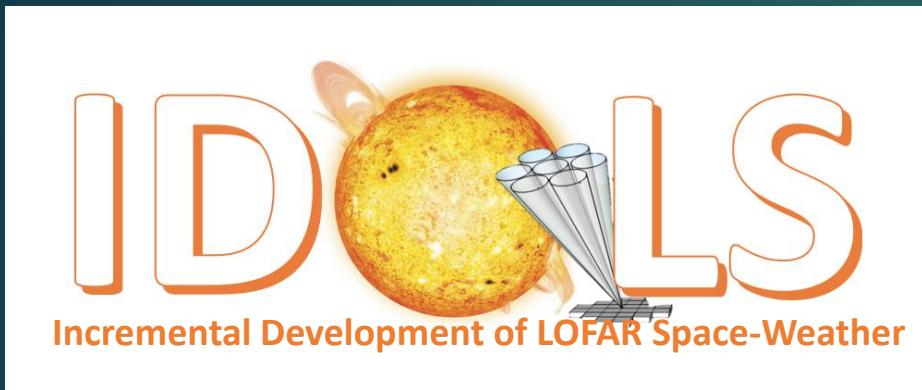


Dual Beam Concept

Slide Courtesy of C. Baldovin

By seizing the opportunity
PHASE 2

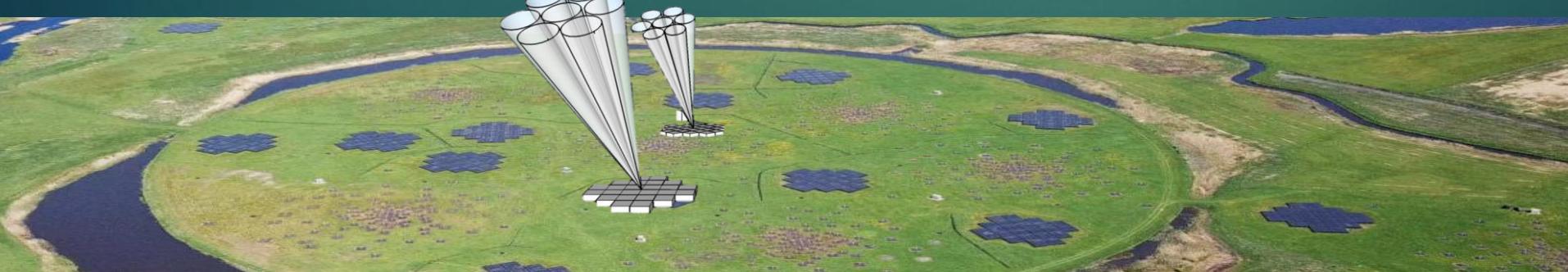




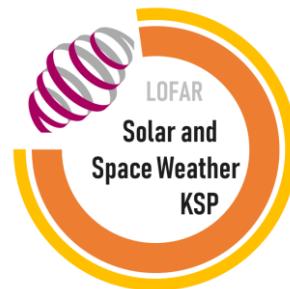
Objectives:

- Demonstrate with a single station Space weather science and monitoring with LOFAR
- Incrementally include to the project stations upgraded to dual beam
- Involve collaborators and ILT partners in the development of the project, including related science and monitoring tools.

Duration 2 years



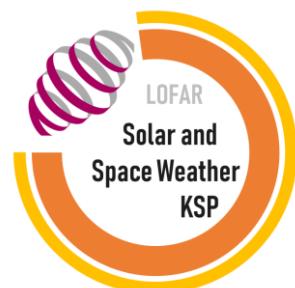
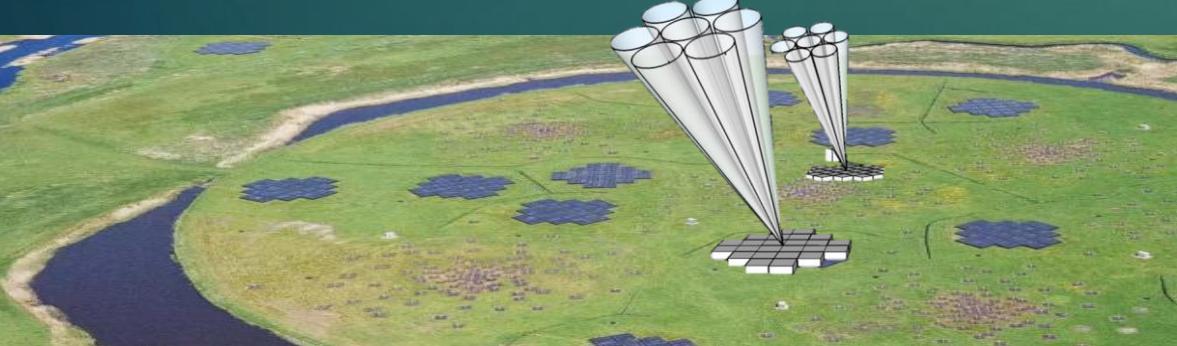
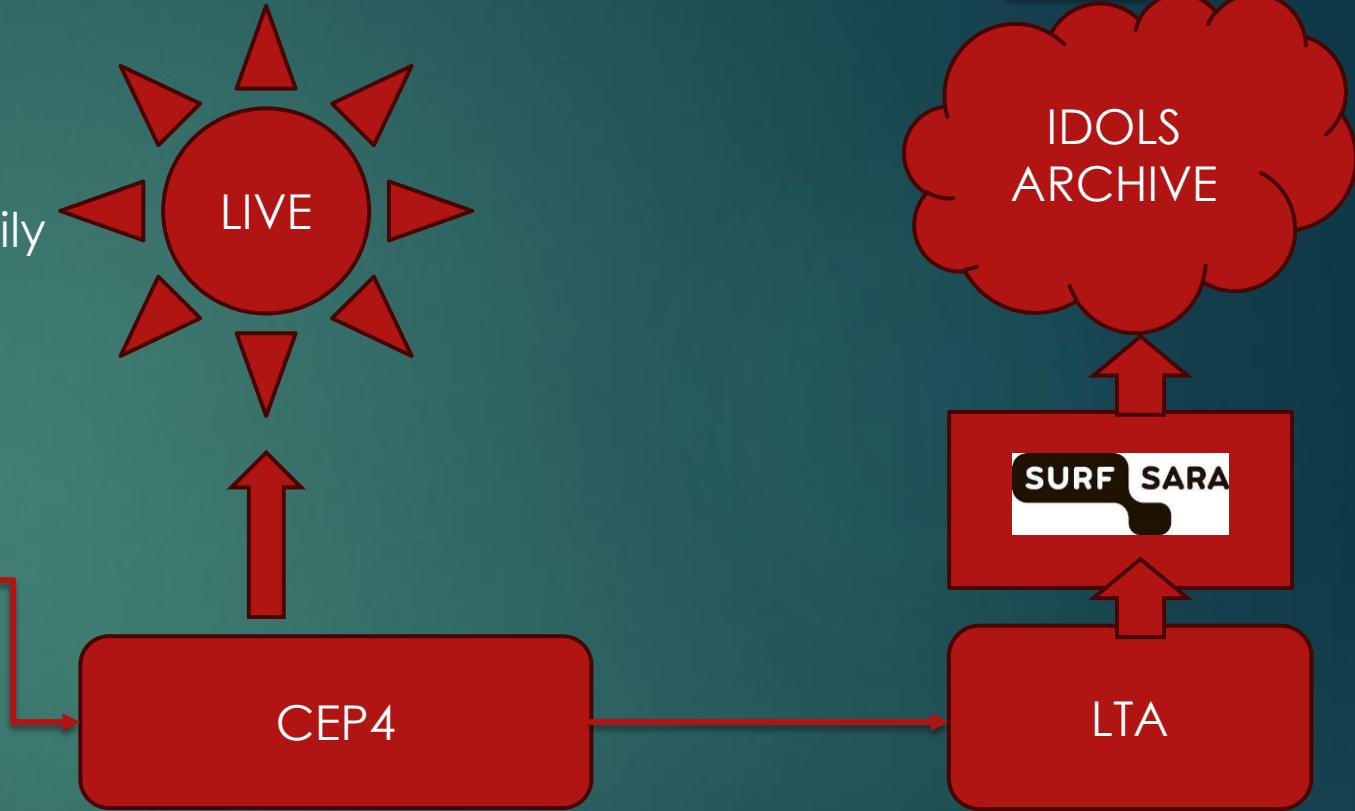
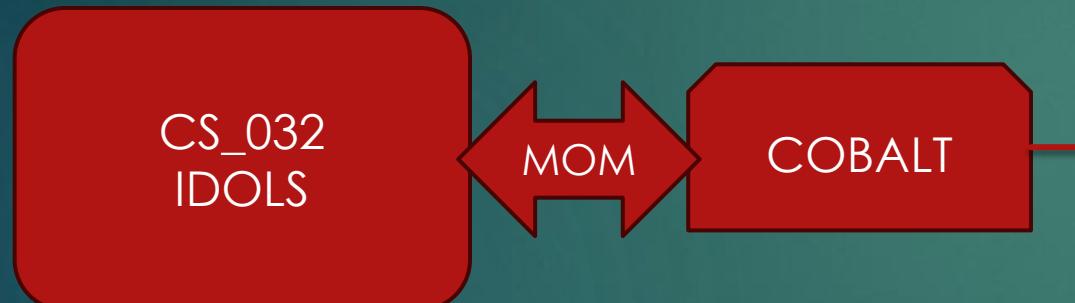
ASTRON



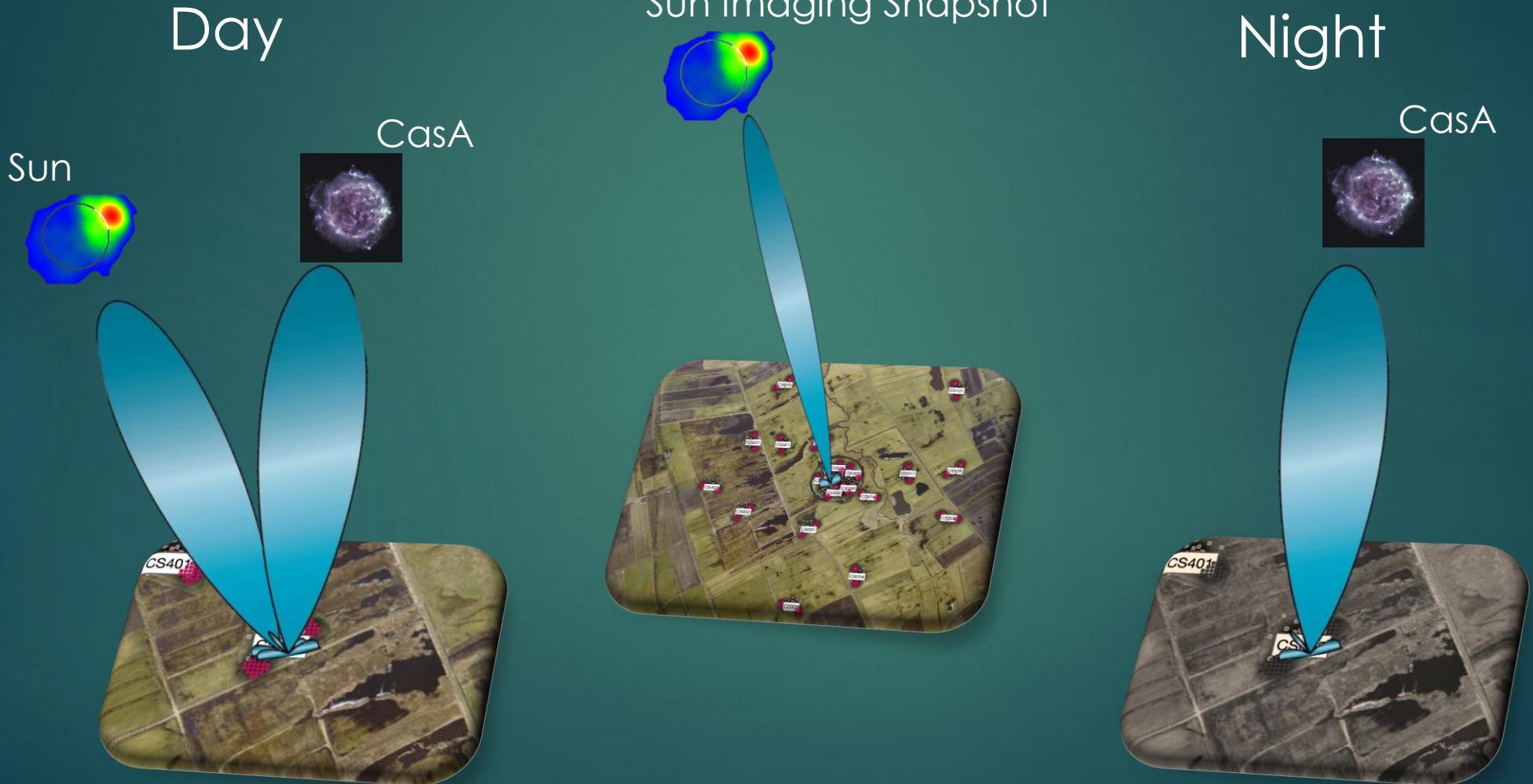


Status

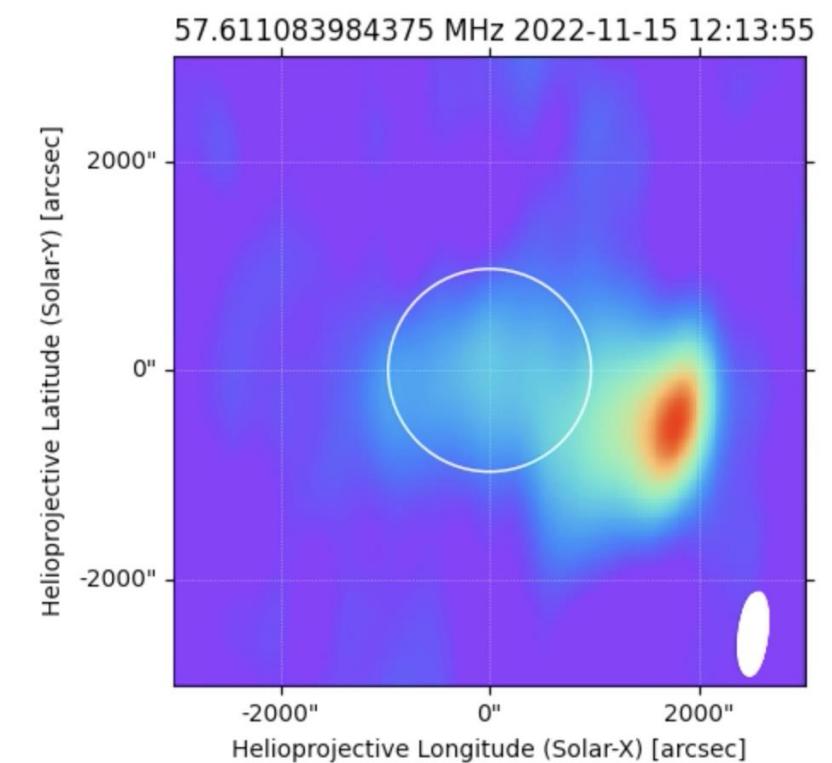
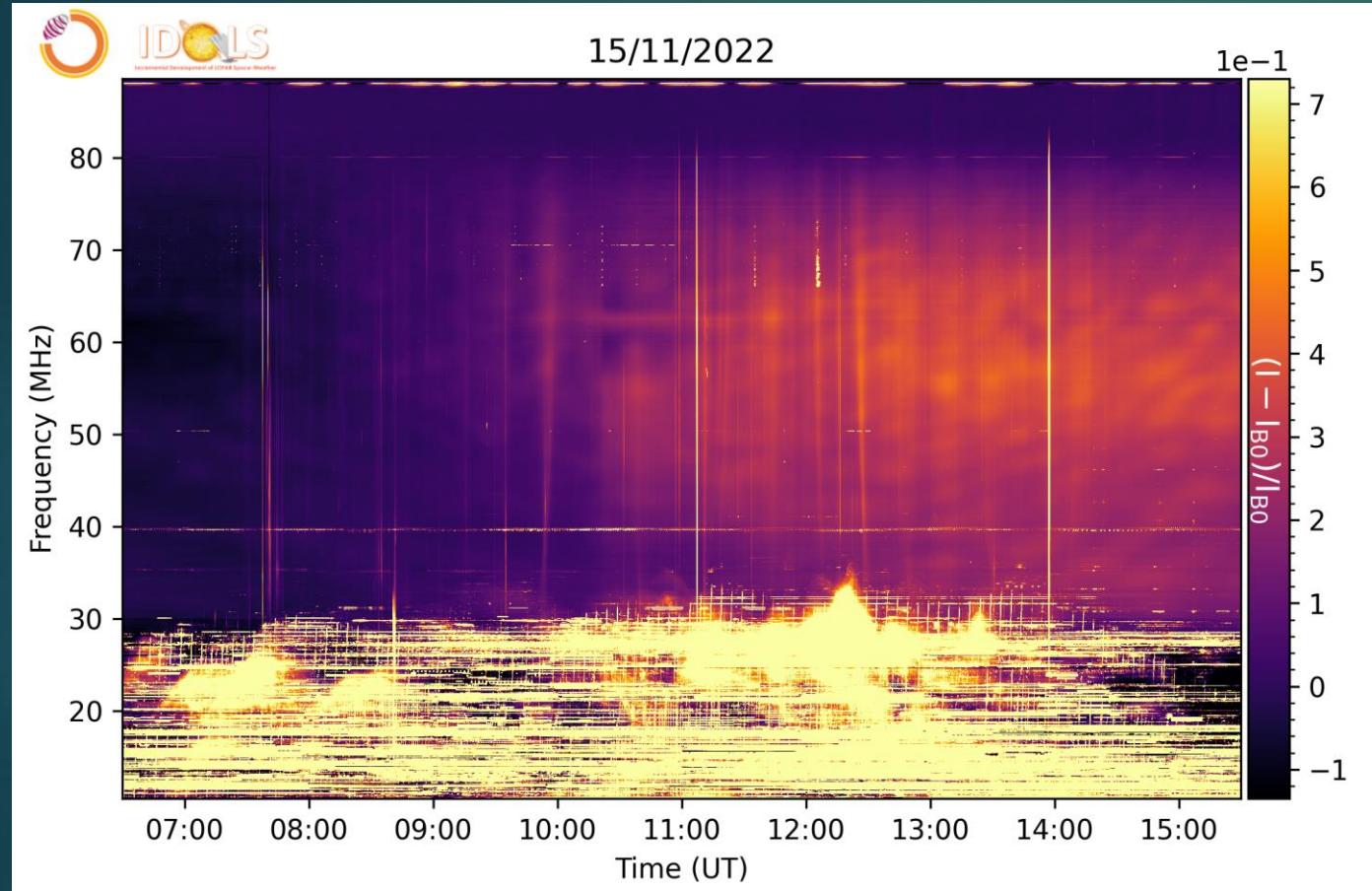
- First Light 2022-04-13
- Live monitoring tests Summer-2022
- Live monitoring operational end-2022
- Archive processing (Surf Sara) Updated daily
- Preparing teams (now) from Summer 2023



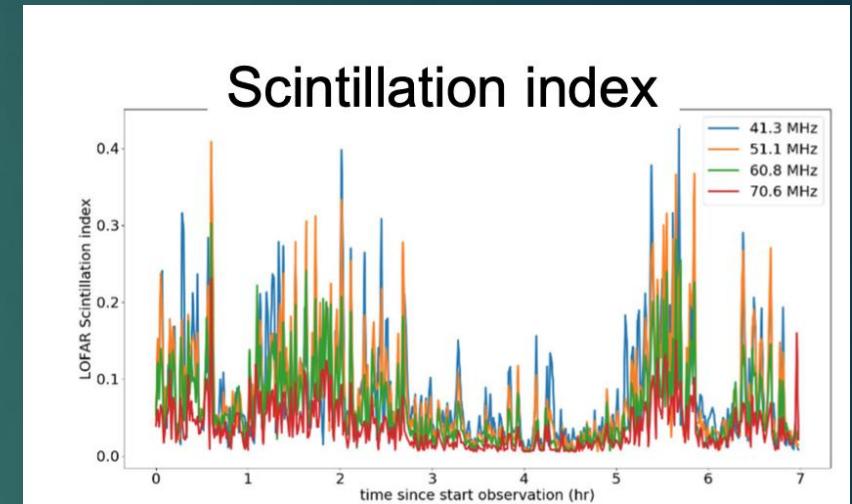
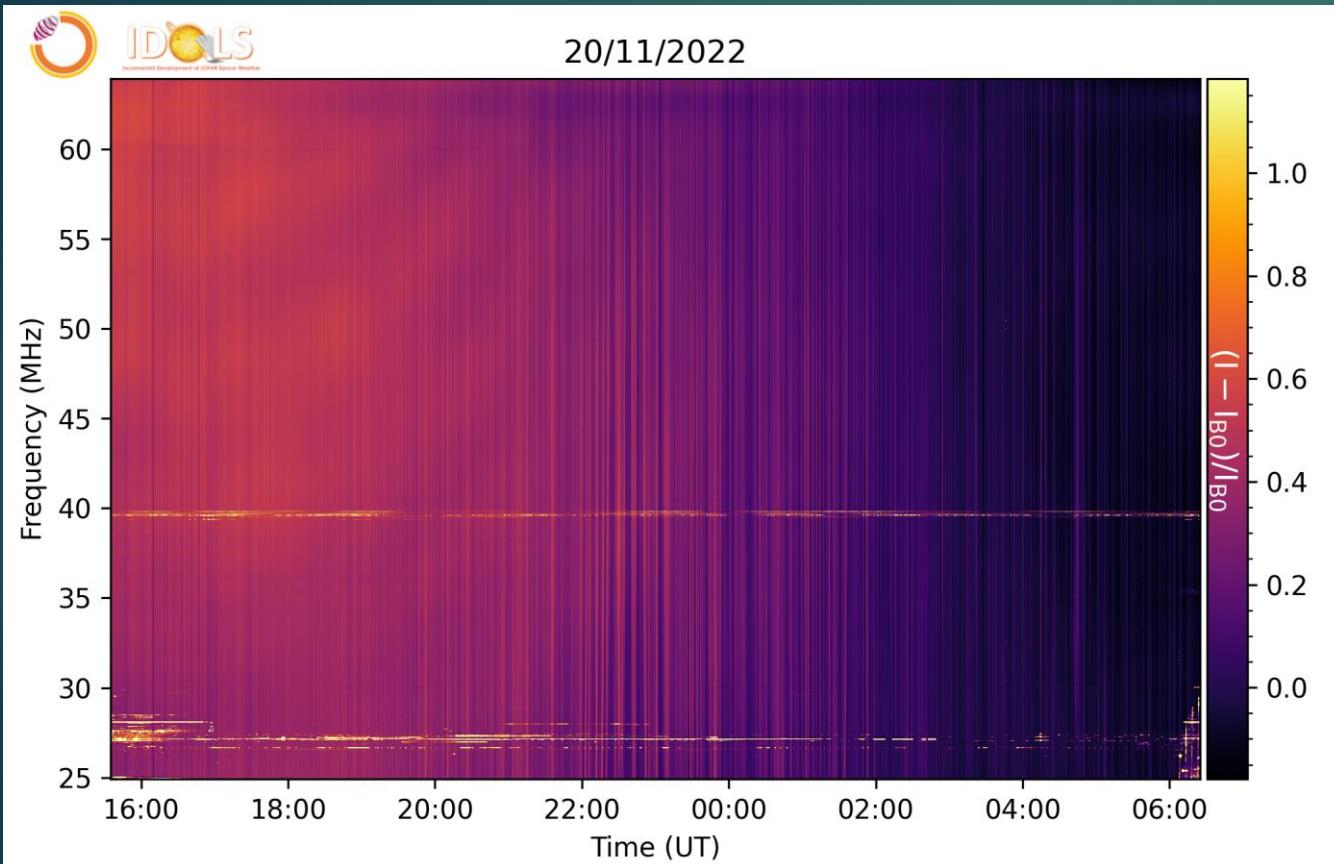
Operation



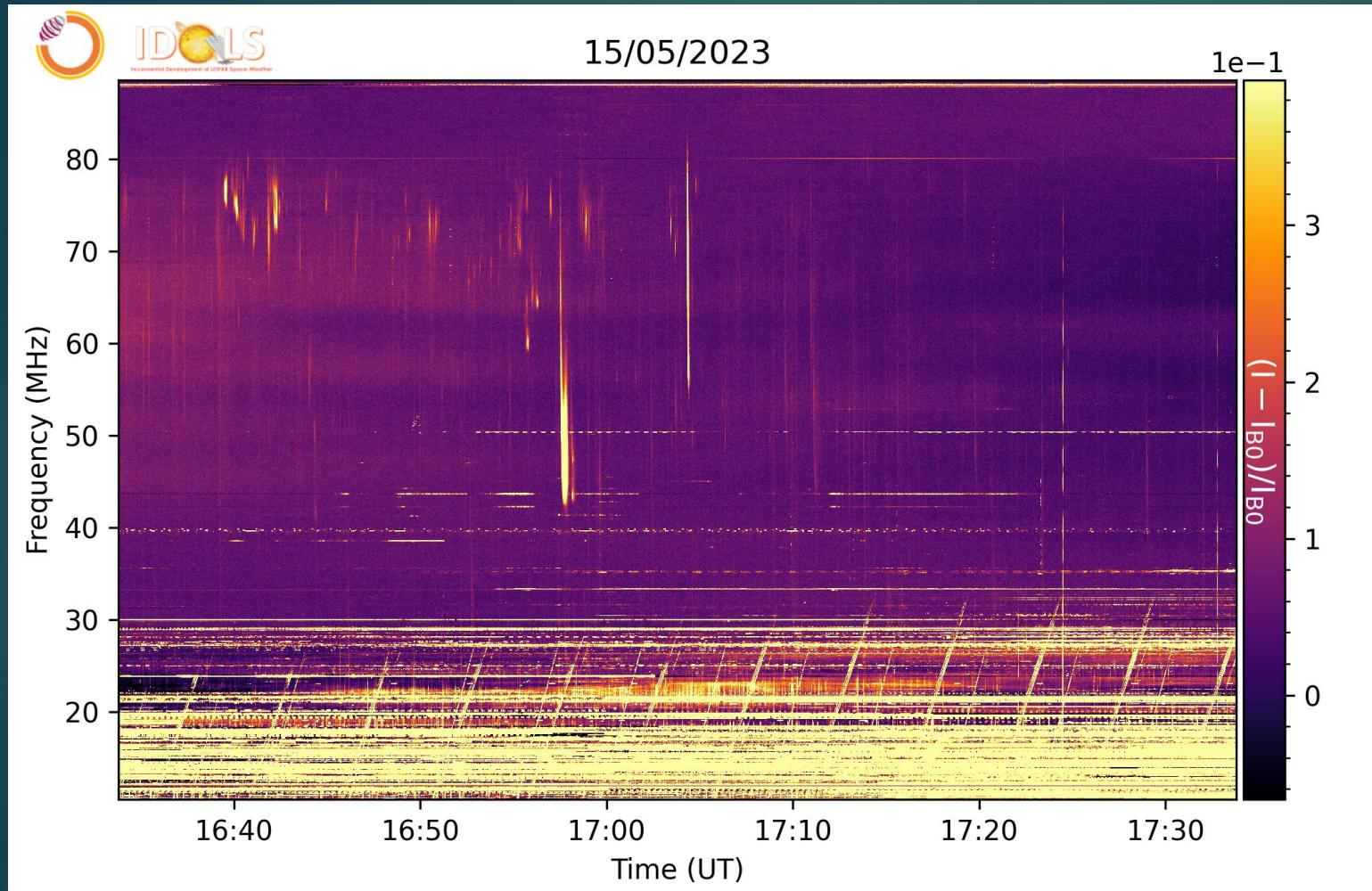
Solar Example



Ionosphere Example



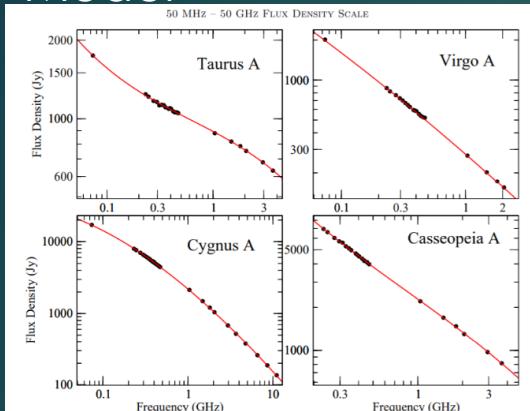
IDOLS Live



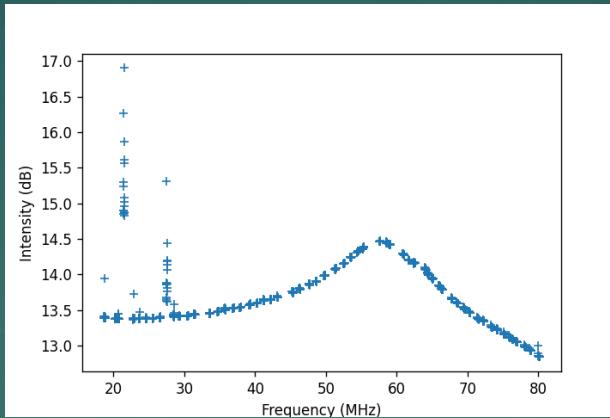
<https://spaceweather.astron.nl/SolarKSP/data/website/>

Calibrated Spectrum

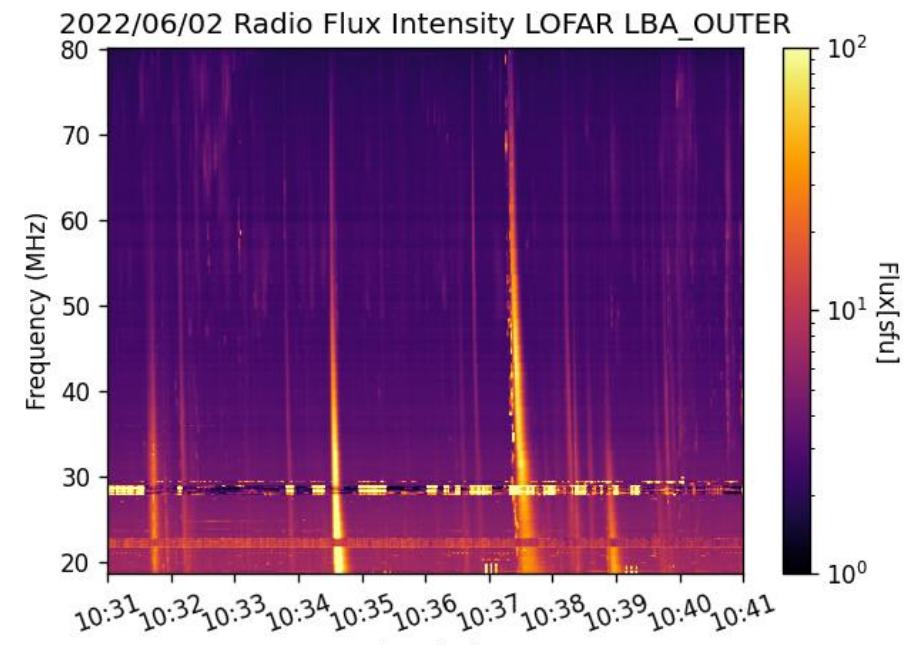
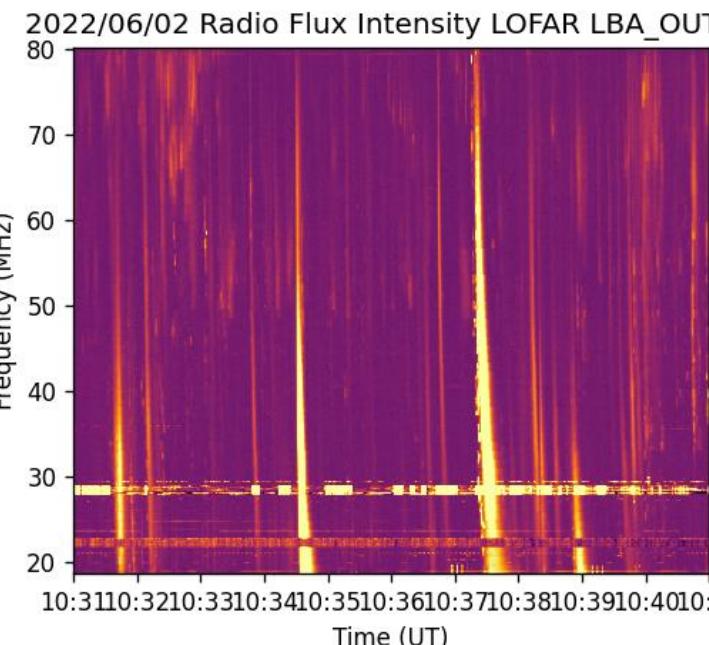
Model



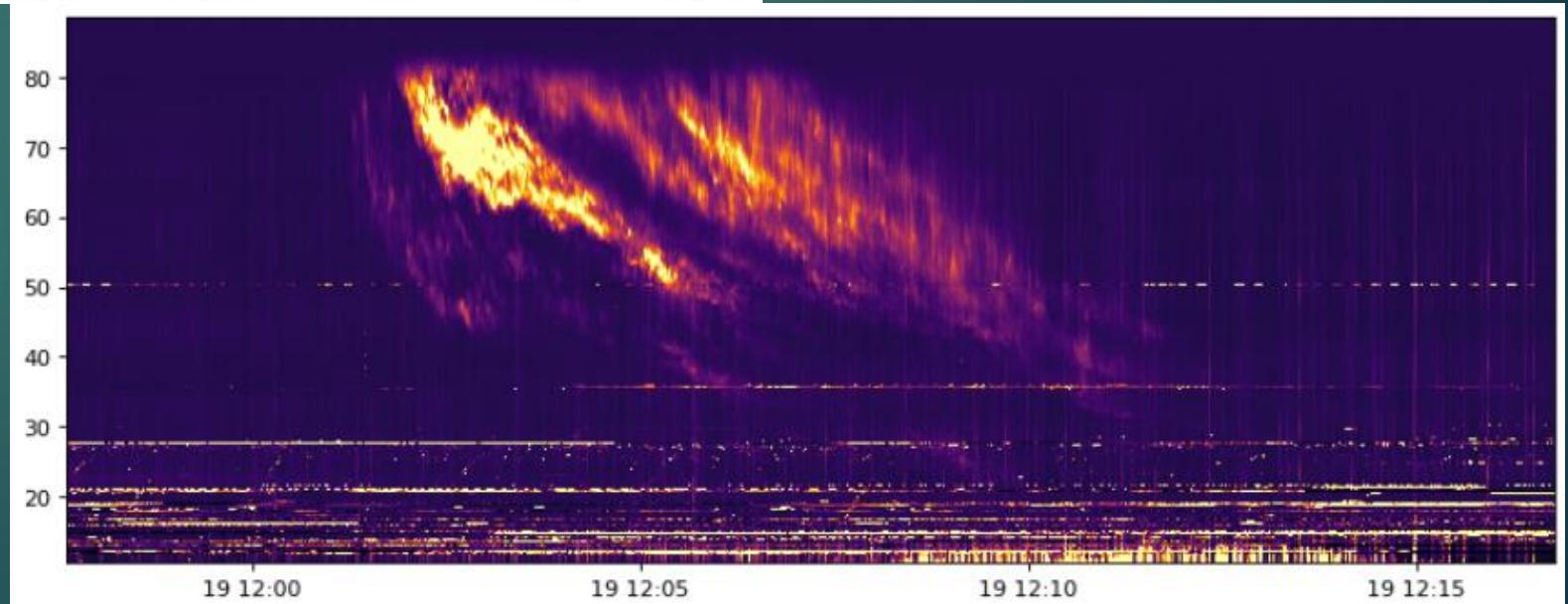
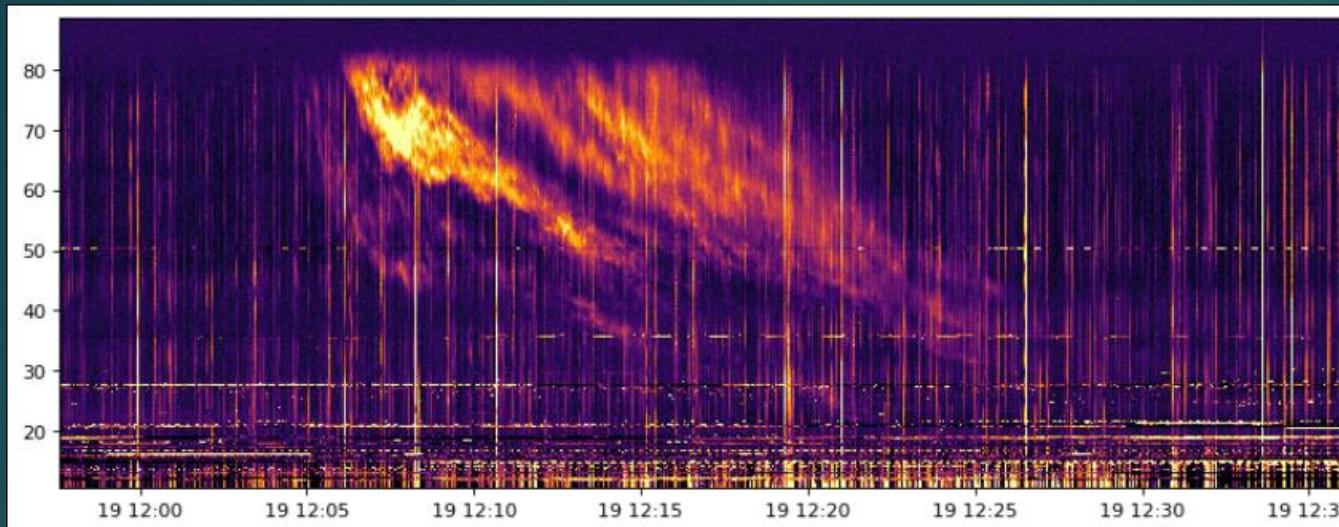
Bandpass in quasi real time



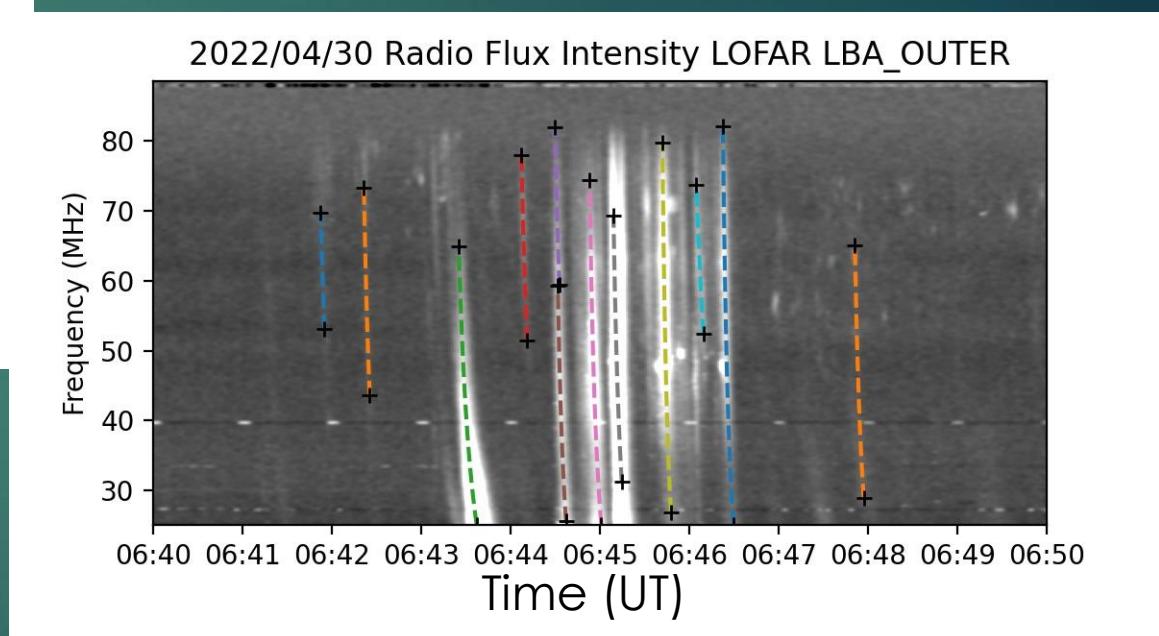
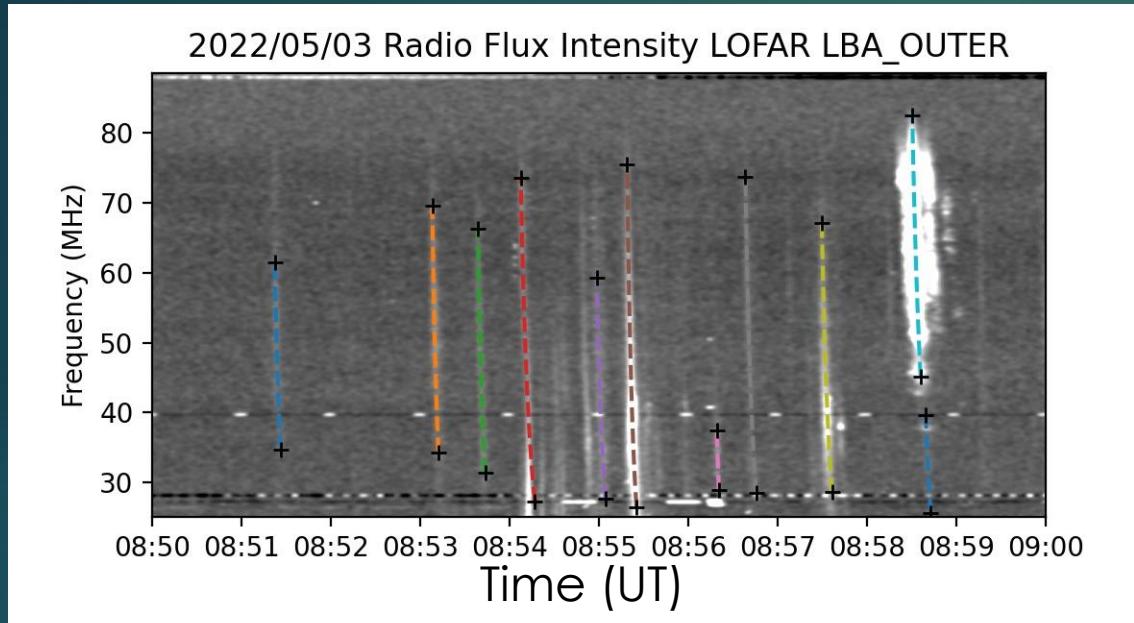
Calibrated Flux and Fluence
available for monitoring tools
and science



Flagging and Instrumental Corrections

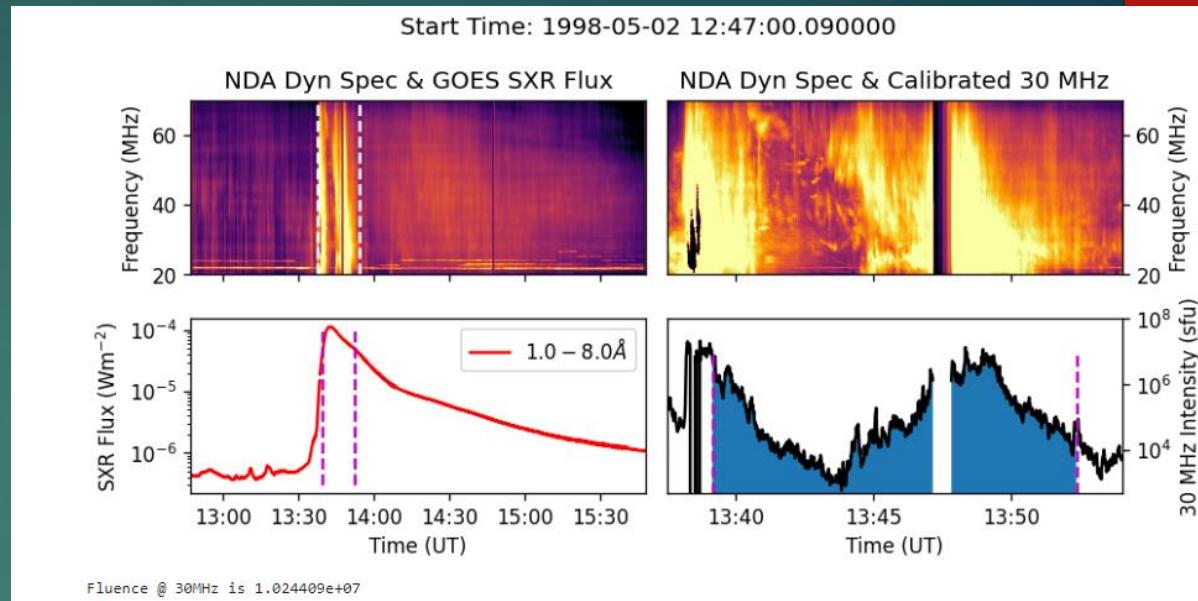
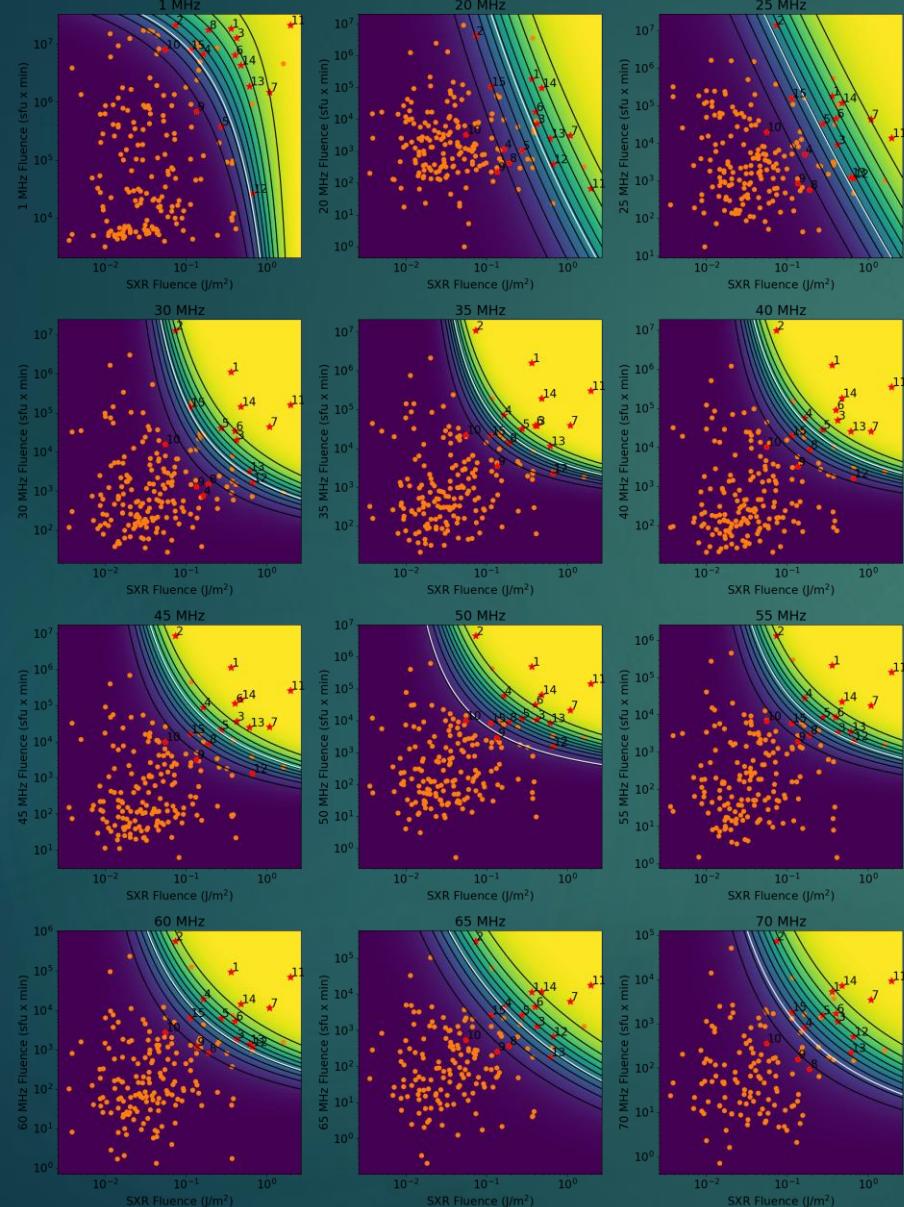


Detection of Events



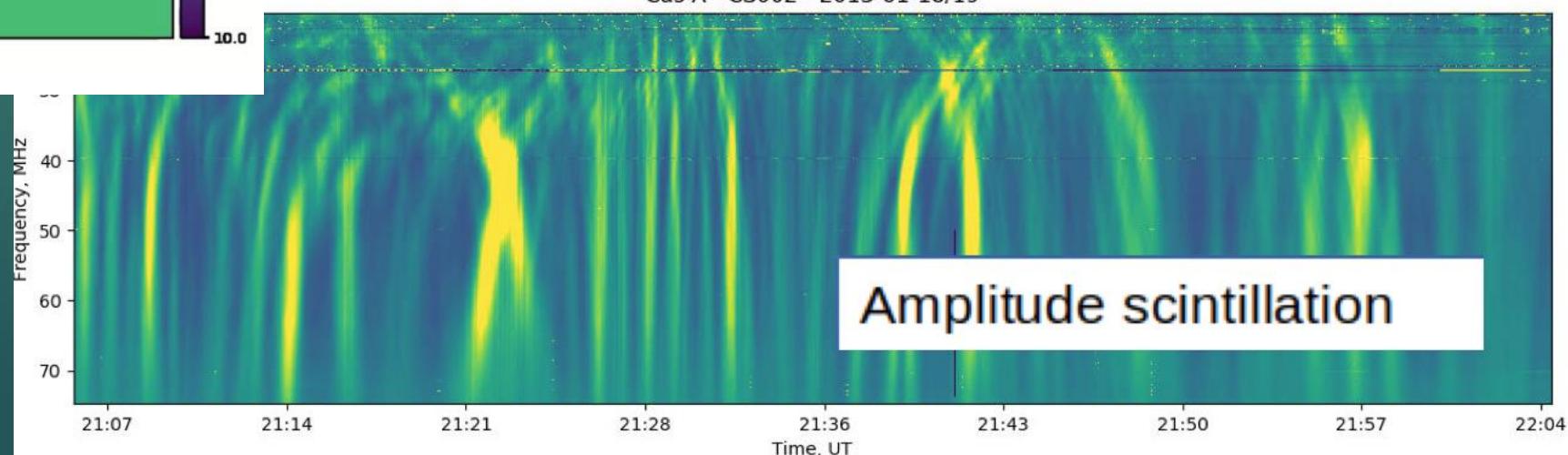
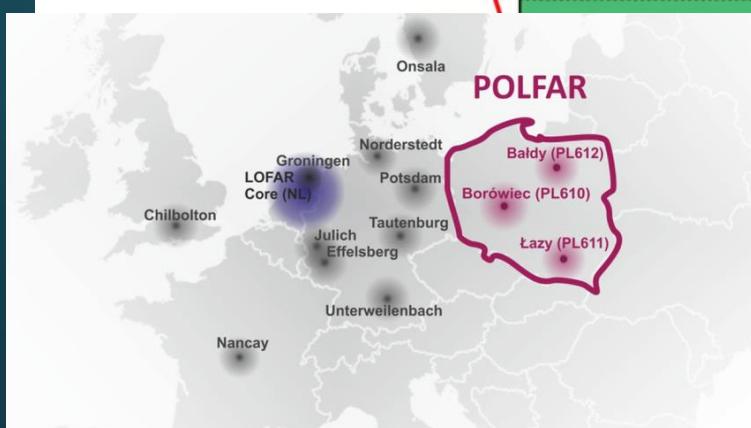
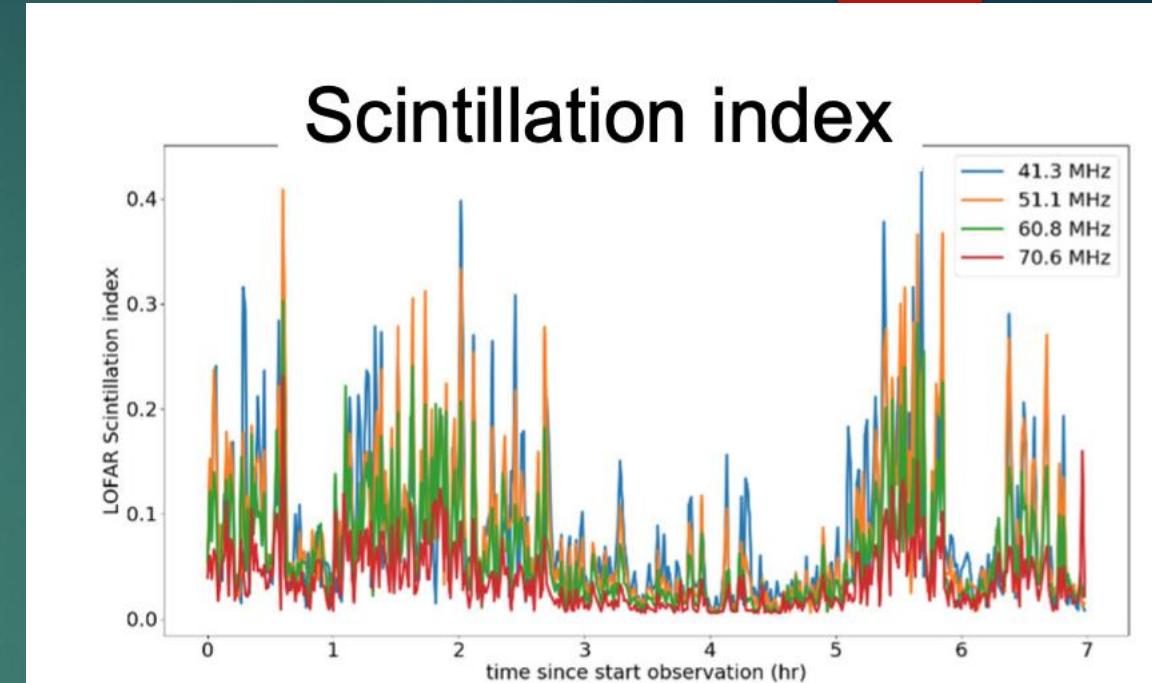
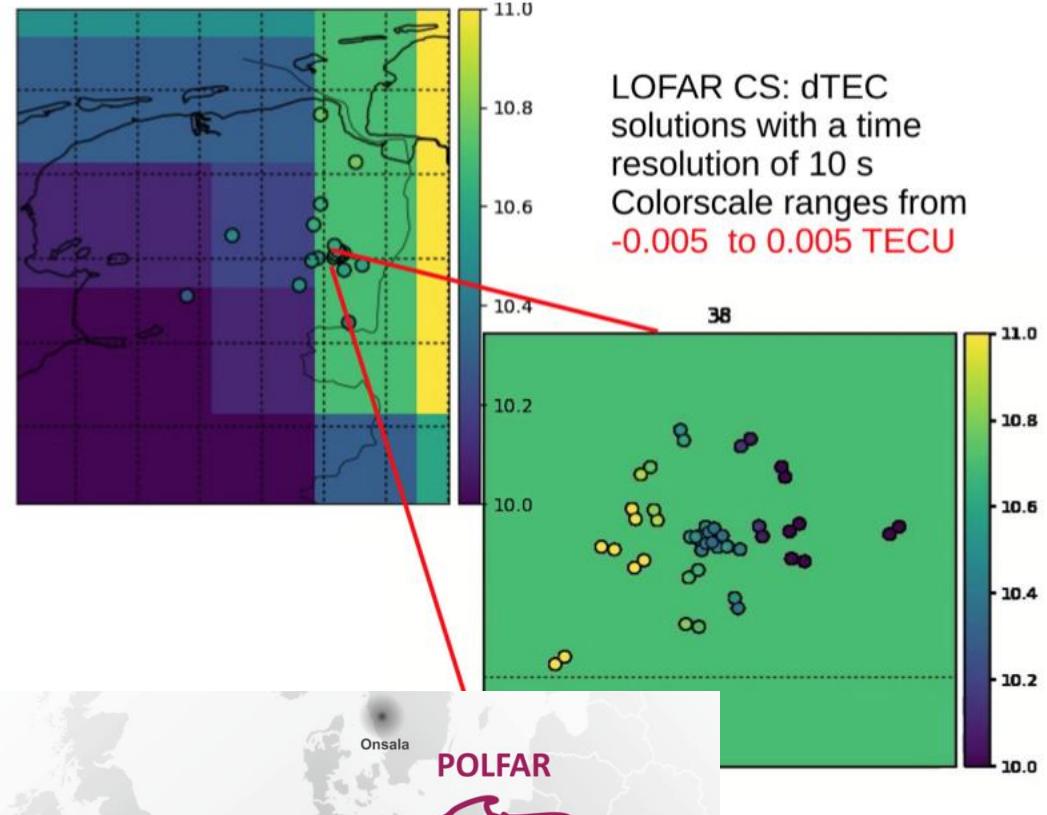
List of detection available
ID, t, t0_num, t1_num, f_0, f_1, dfdt(MHz/s), v_b(c)

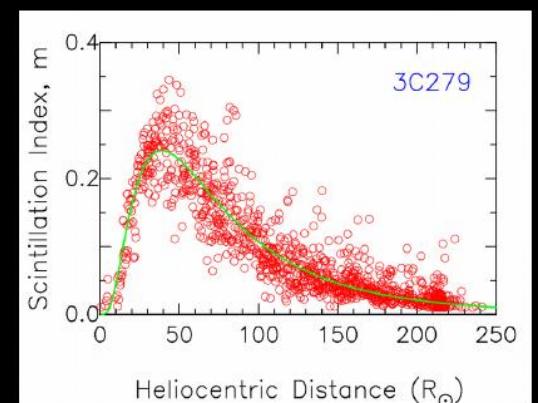
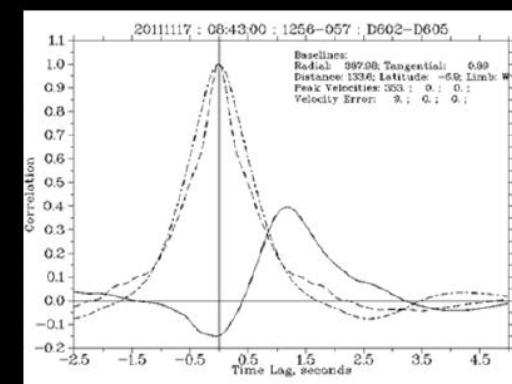
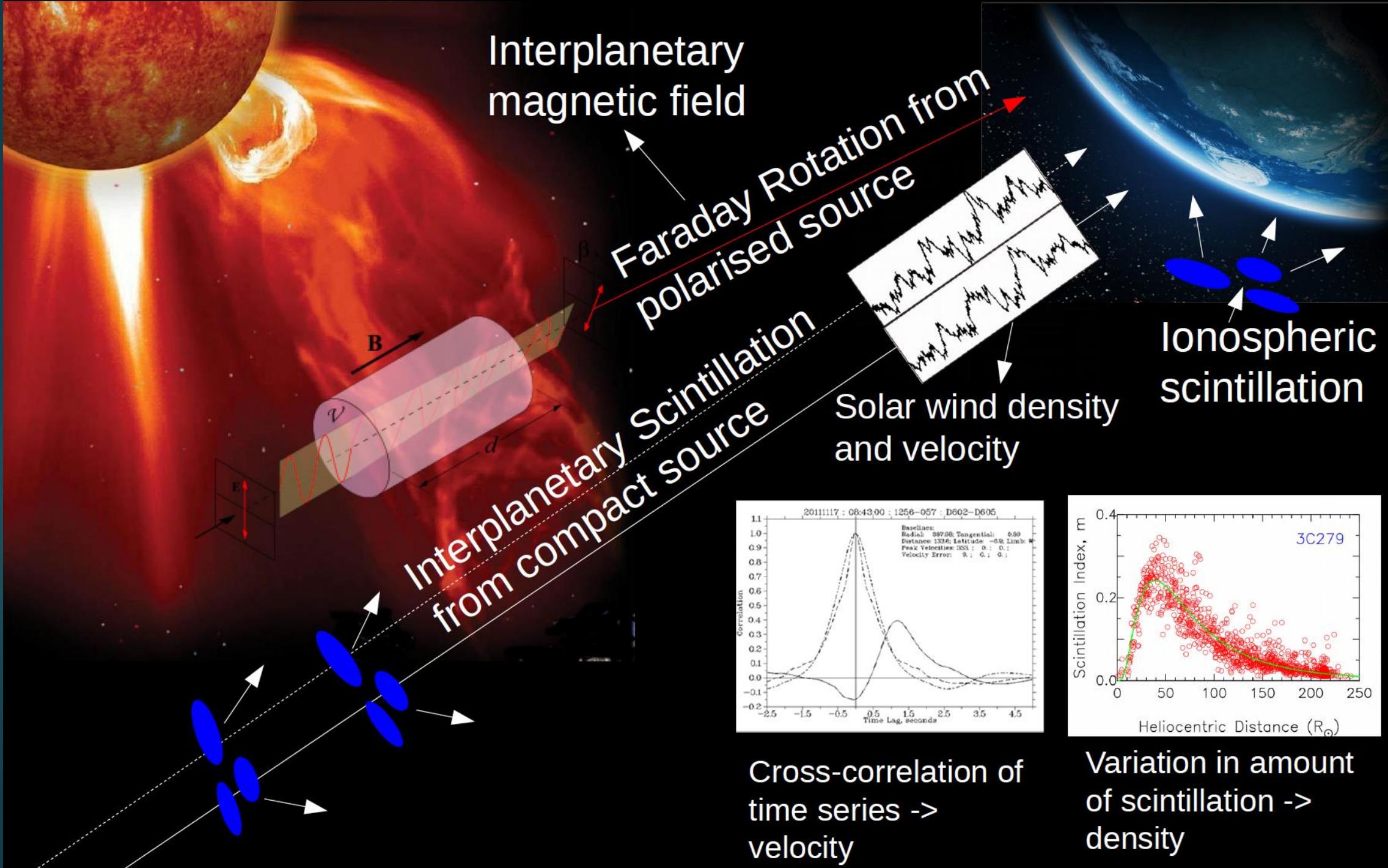
Examples of tools based on radio monitoring



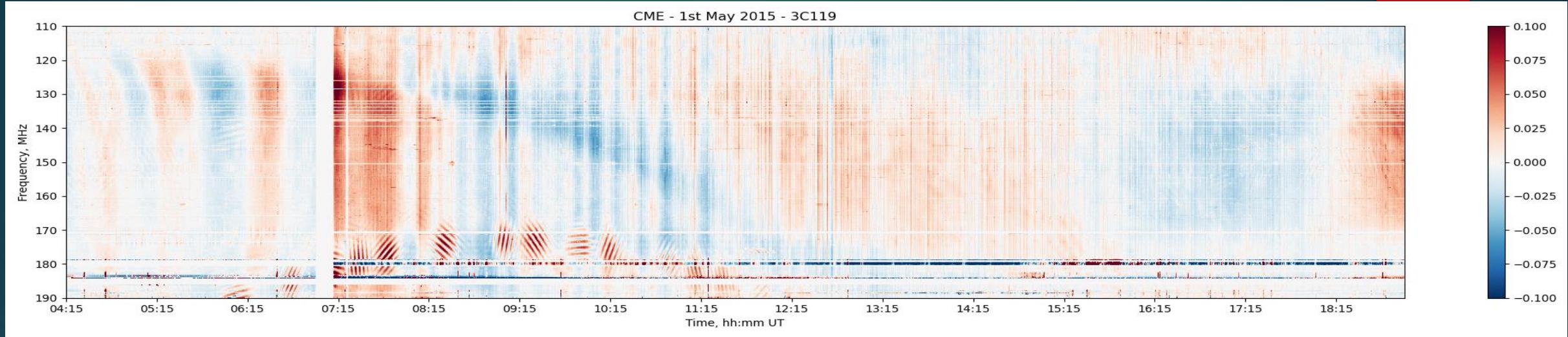
Prediction Model	Input Parameters	Forecast Statistics
LOFAR IDOLS	SXR fluence, 45 MHz fluence	POD: 0.71, FAR: 0.33
Laurenza (2018) (ESPERTA)	SXR fluence, 1 MHz fluence, flare longitude	POD: 0.63, FAR: 0.42
Kubo & Akioka (2004)	SXR flux	POD: 1.00, FAR: 0.85
Garcia (2004a)	SXR peak intensity, peak flare 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

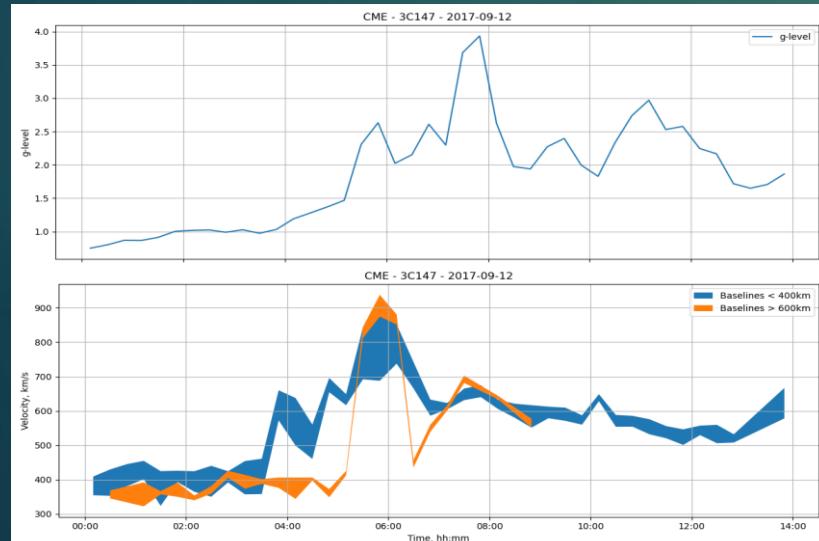




CME Observations - Demonstrating IPS Techniques

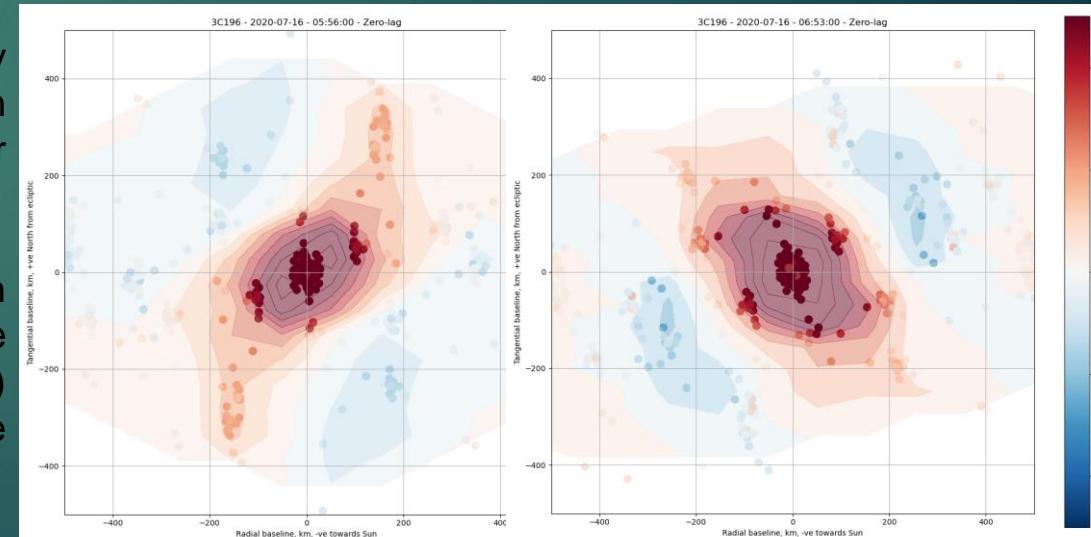


Wideband dynamic spectra of intensity show features invisible to traditional single-frequency time series. This 15-hour observation of a CME (above) shows structure on a ~30-minute time-scale for the first few hours, probably related to large-scale structure in the CME.

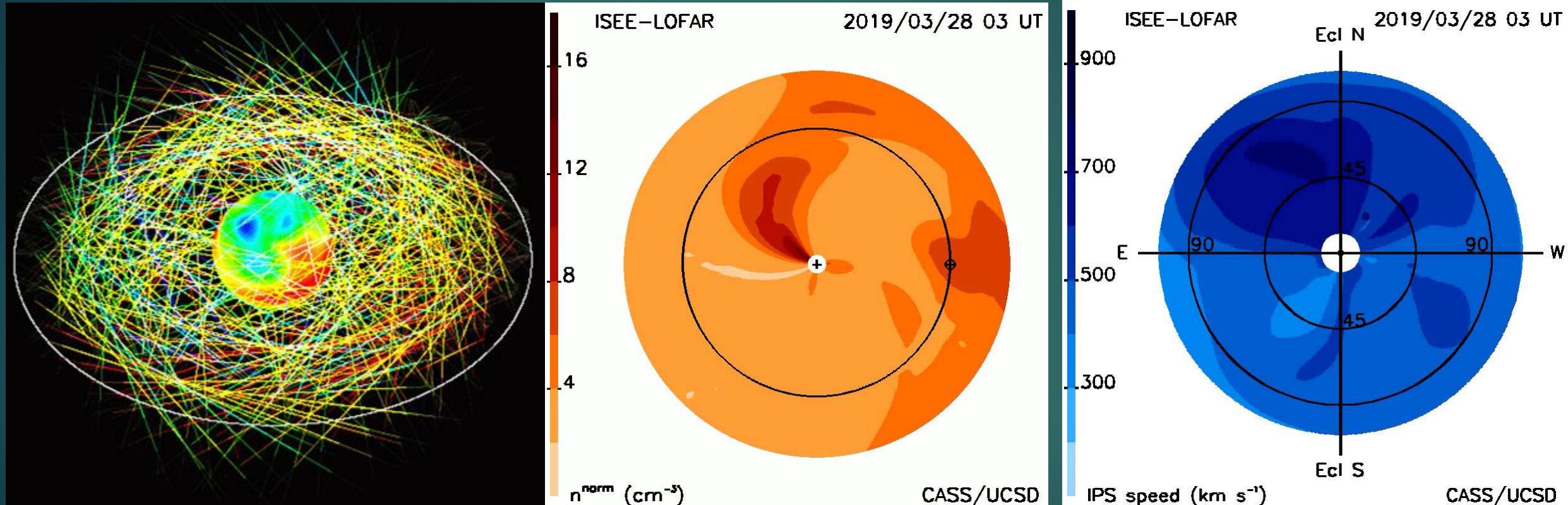


Left: g-level (related to density - top) and velocity from an ultra-fast CME in September 2017.

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

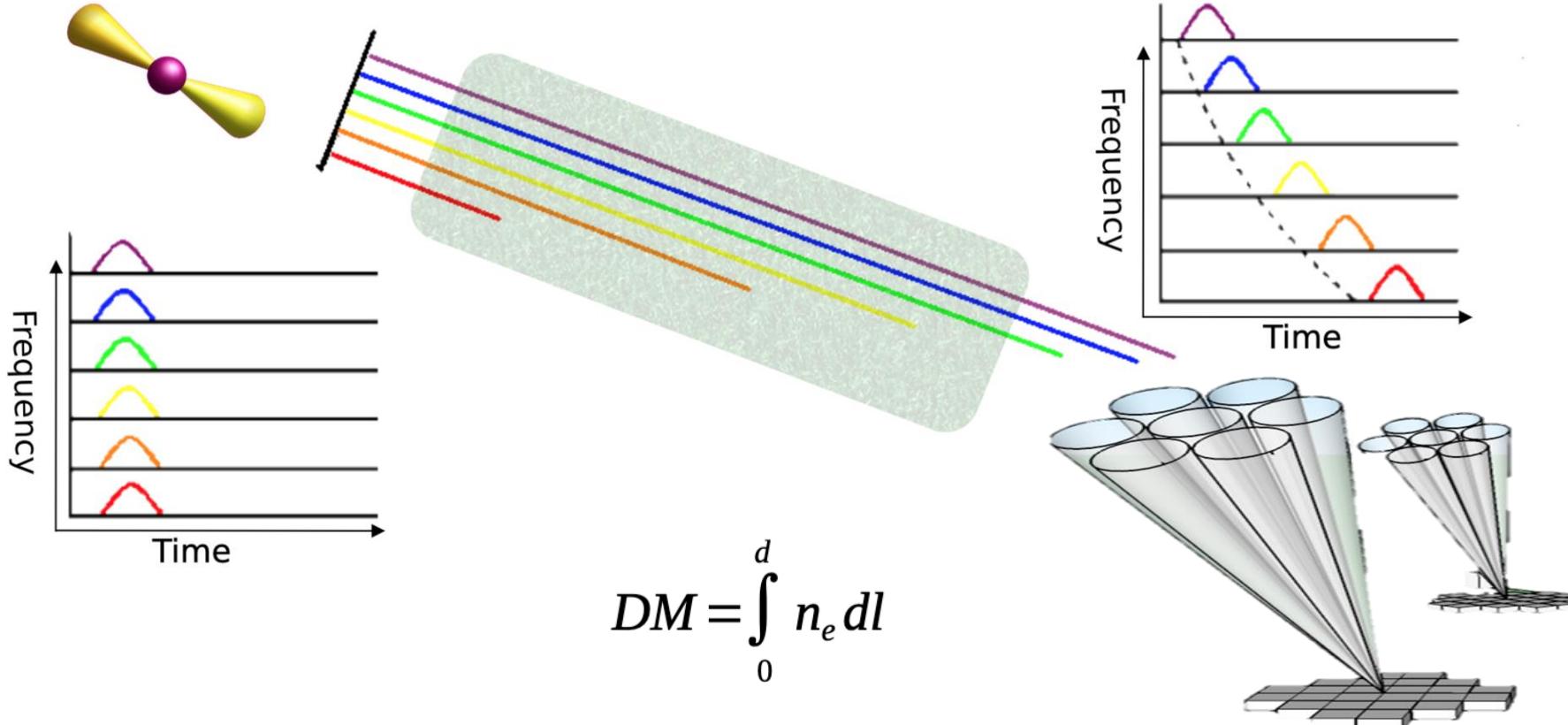


IPS and Tomography



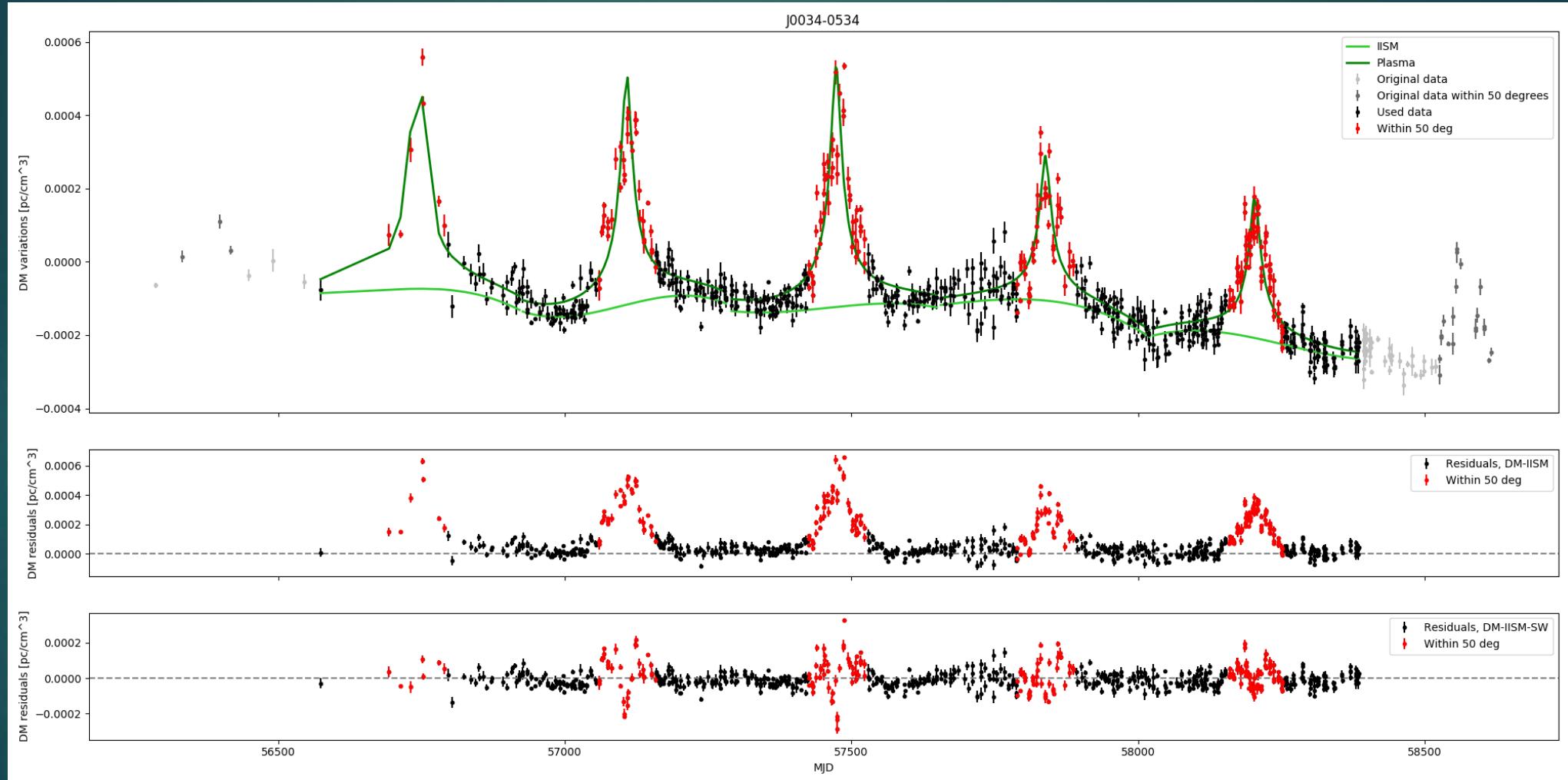
Bernard Jackson, Richard Fallows, Mario Bisi and the ISEE LOFAR working group

Using Pulsars

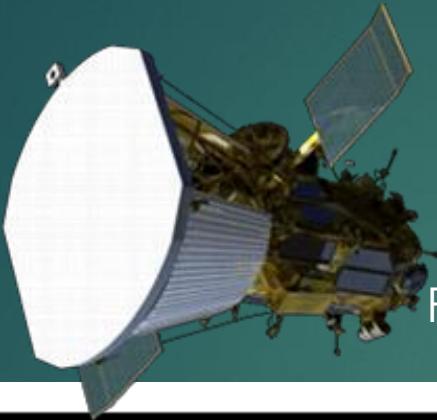


Slide Courtesy of Caterina Tiburzi

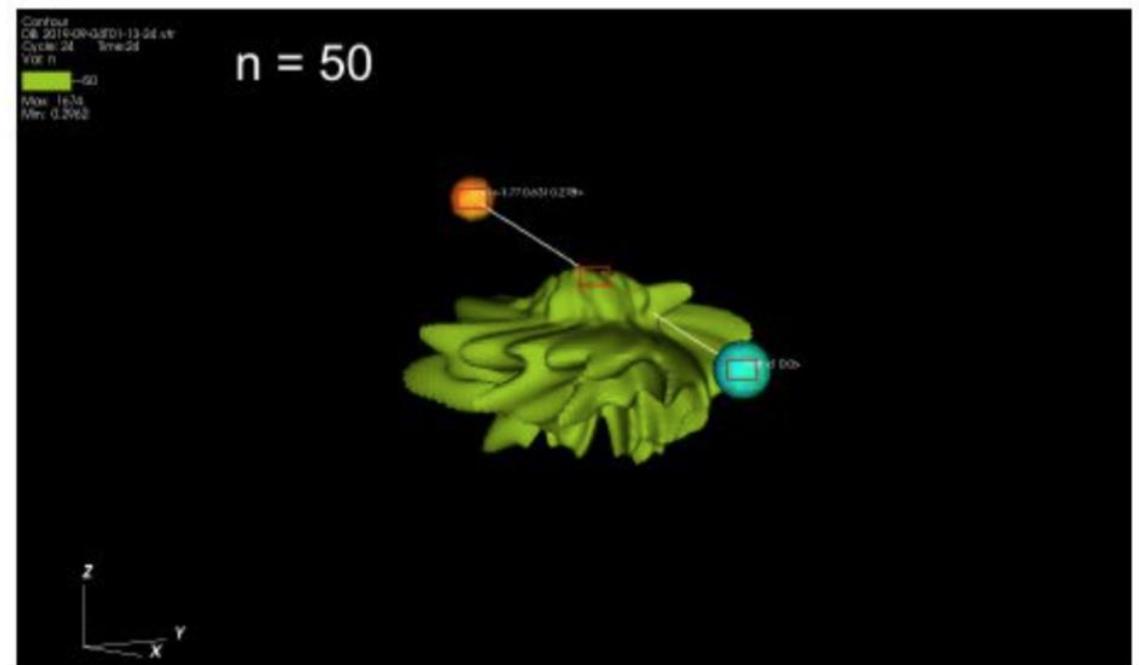
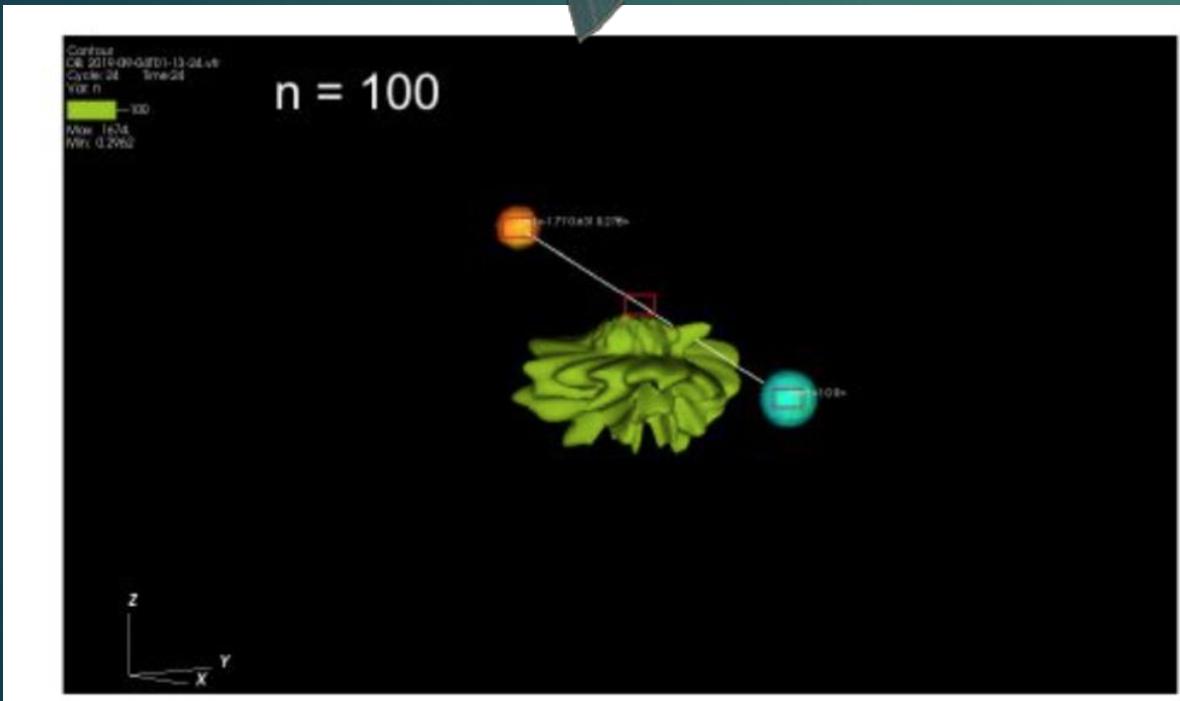
Solar Wind Variability



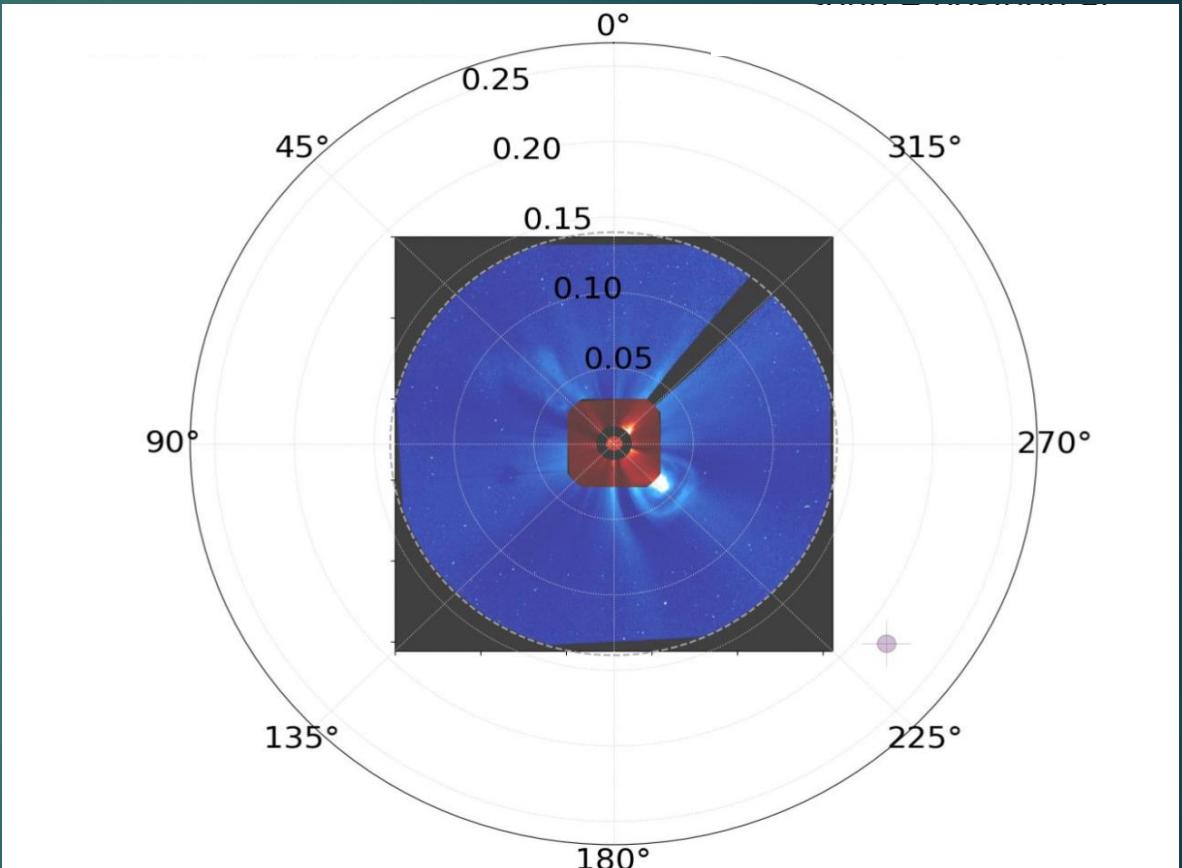
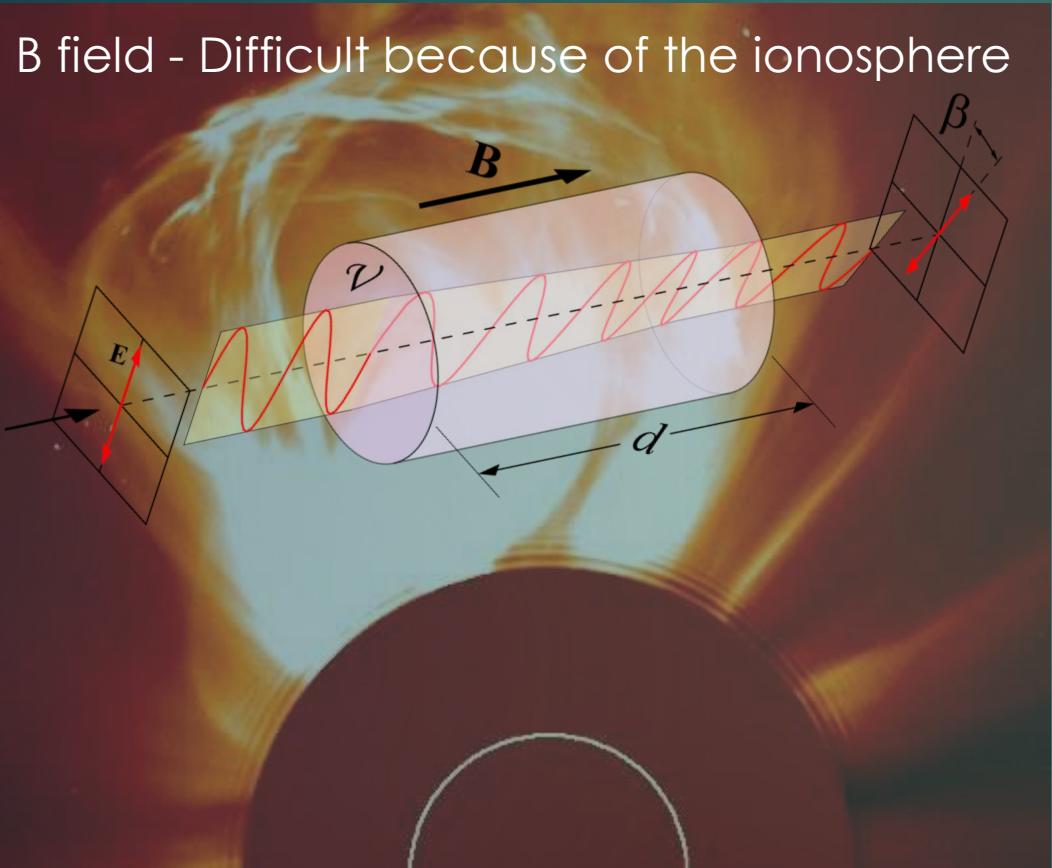
Model validation - EUHFORIA



PSP in-situ measurements



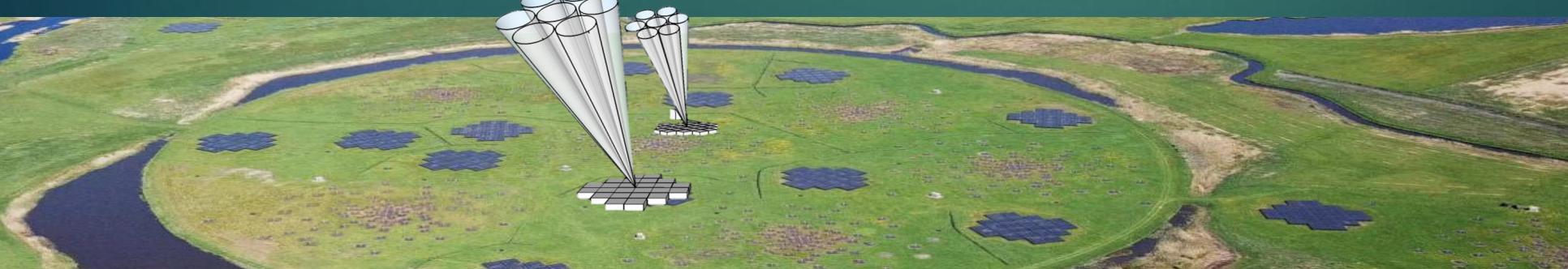
Pulsars to extract Density and B field



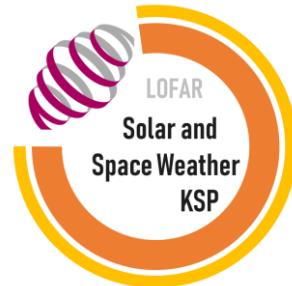
Caterina Tiburzi, Golam Shaifullah, Pietro Zucca and the LOFAR KSP team
Work on the B-field ongoing from Bisi and Fallows and team

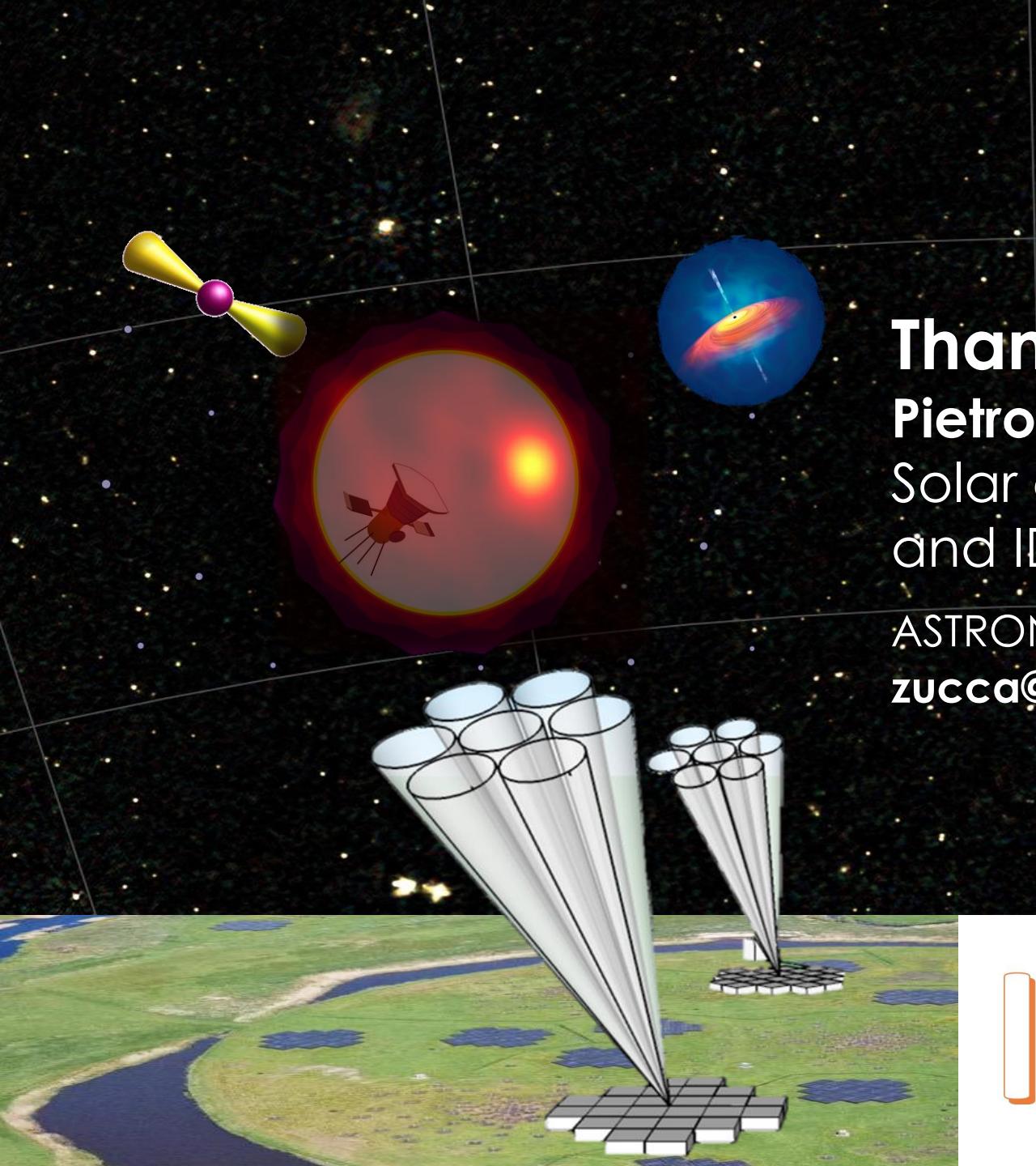
Summary

- ▶ 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 unexplored features of the solar atmosphere and heliosphere, to understand how the Sun works and to monitor/predict space weather events.



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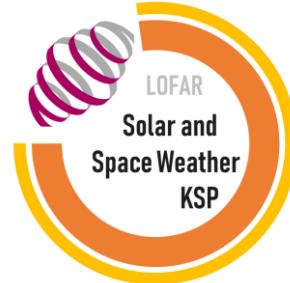


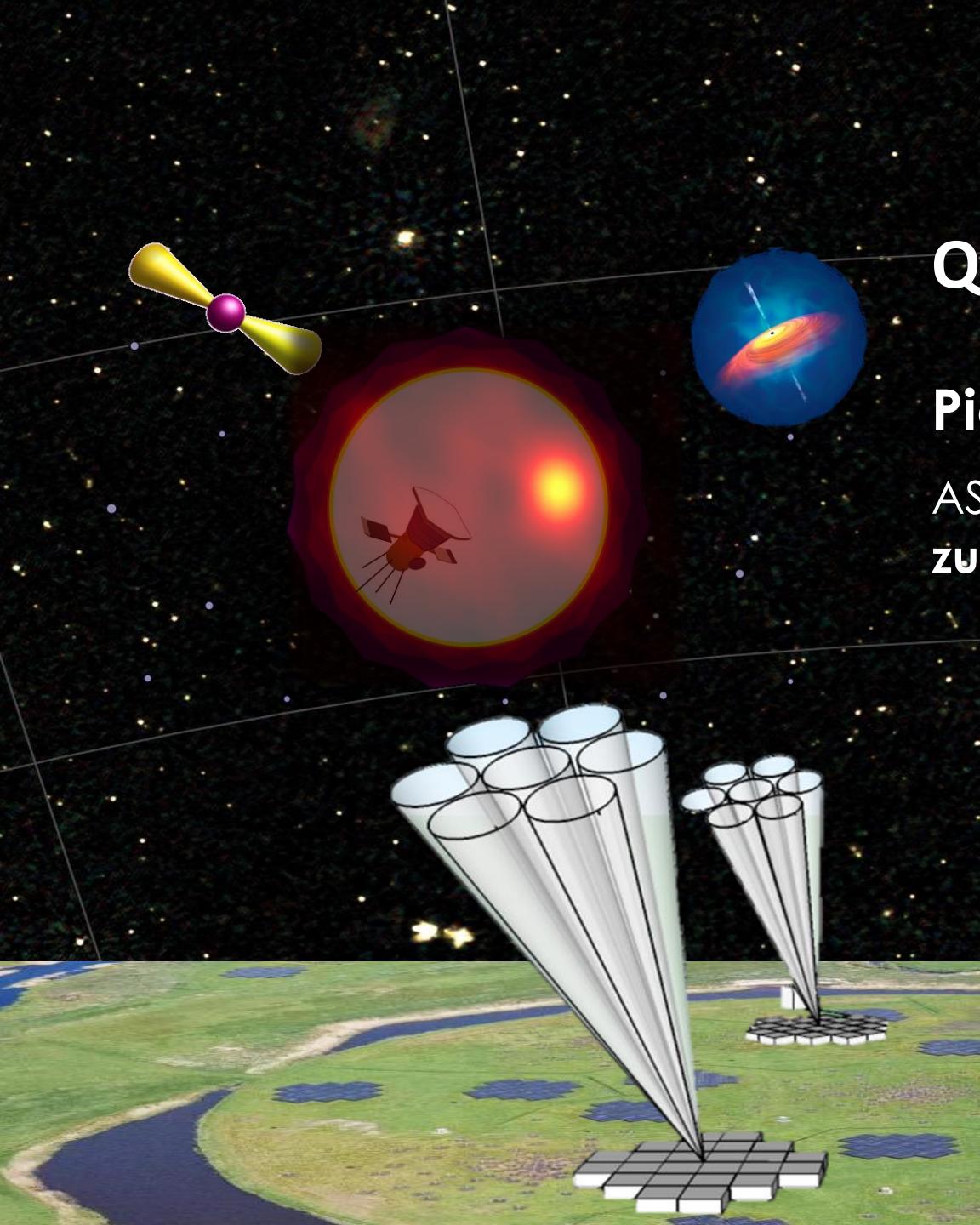
Thanks for your attention
Pietro Zucca
Solar and Space weather KSP
and IDOLS team.

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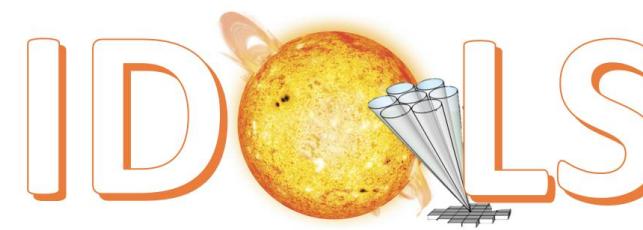




Questions?

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