LOFAR for SpaceWeather (LOFAR4SW) H2020 program

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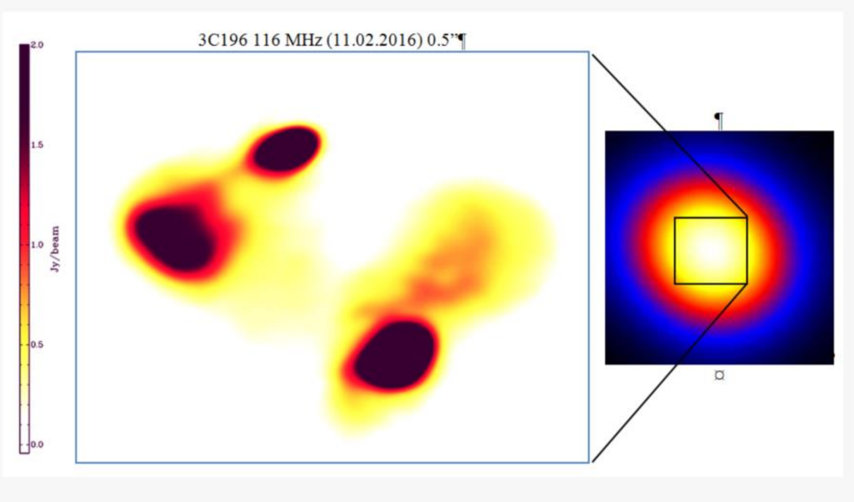
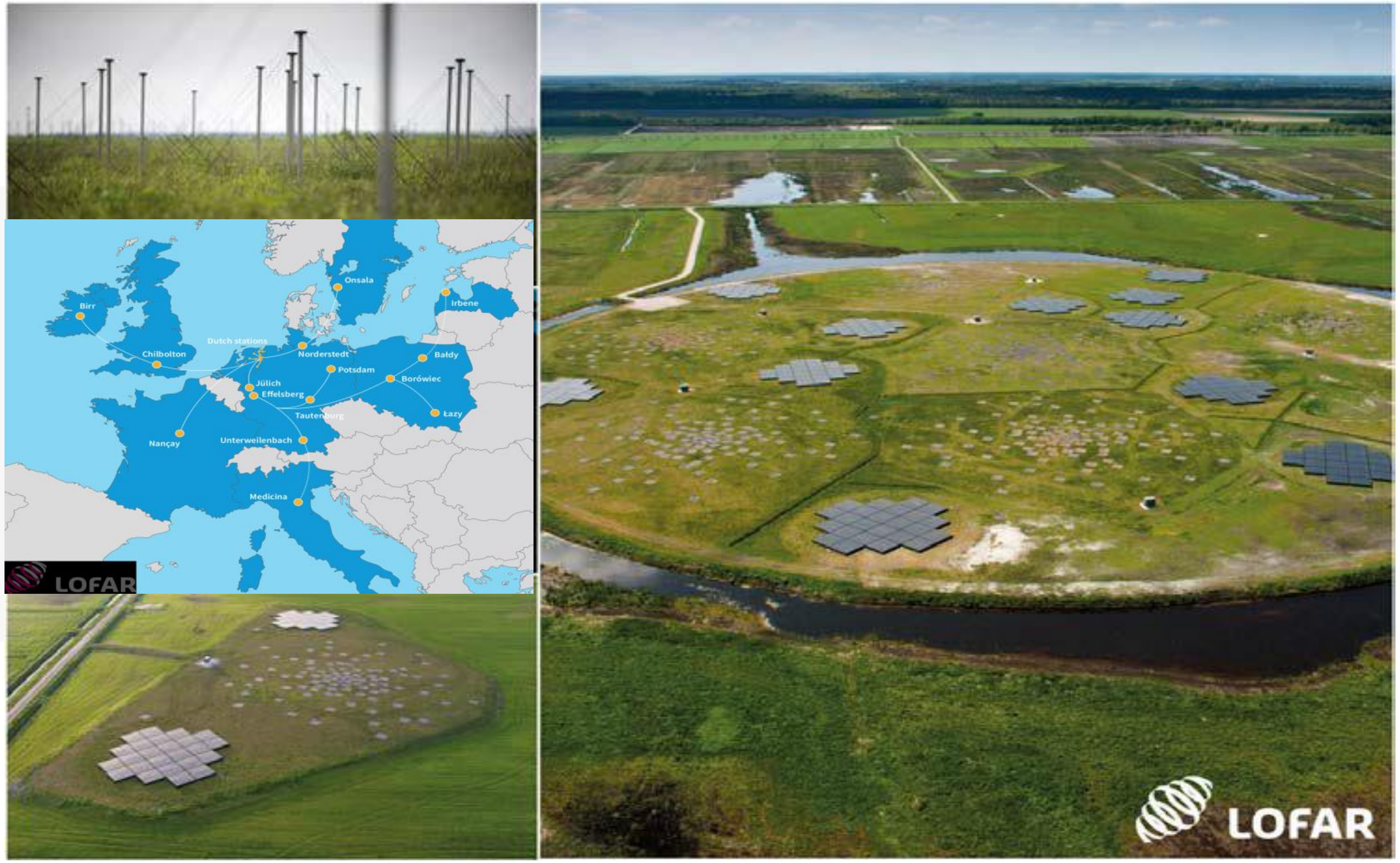
(8) Trinity College Dublin (TCD), Dublin, Ireland

BSS2019 OLSZTYN

LOFAR   International Telescope





40 Nederland, 6 Germany, 3 Poland, 1 United Kingdom, Sweden, France, Ireland

Two new stations to come: - Latvia in 2019-2020; and - Italy in 2021-2022

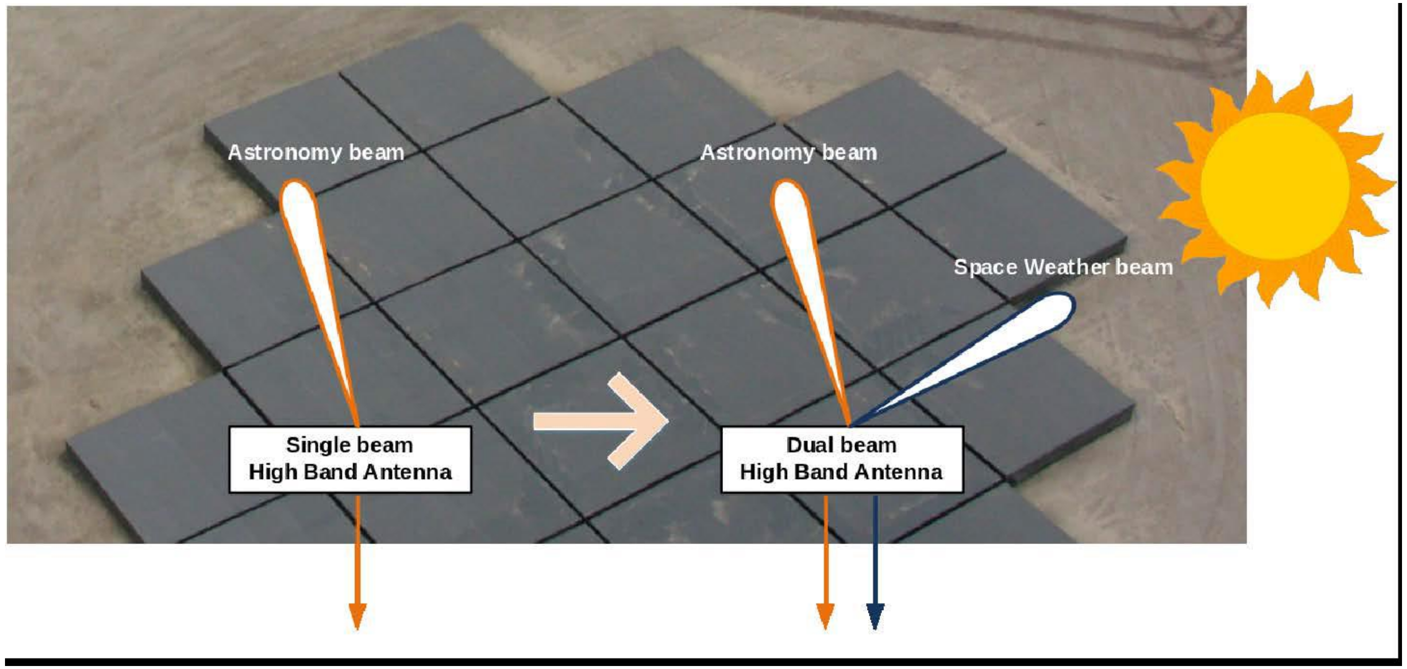
Permanent observation from December 2010

LOFAR: Europe's largest and most-flexible radio telescope

LBA 10 – 90 MHz **HBA 110 – 240 MHZ**

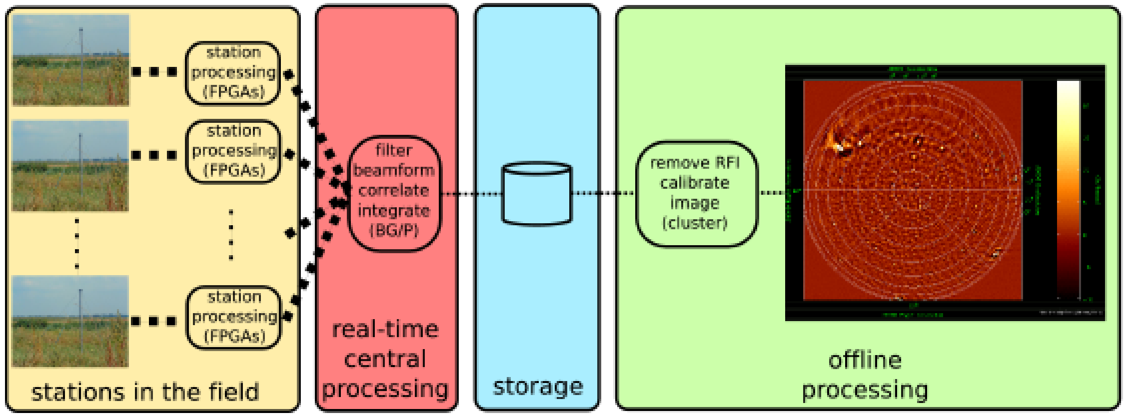


"Low-band" dipoles:-
- All-sky coverage

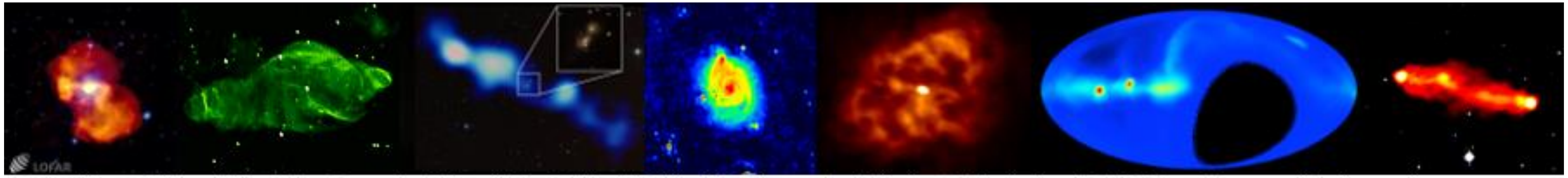


"High-band" tiles:-
- 4x4 array of bow-tie antennas
- Analogue beam-former points single ~20-degree wide beam

CEP +depositories
- Groningen
- Podsdam
- Poznan

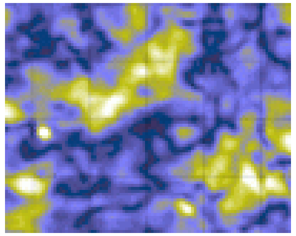


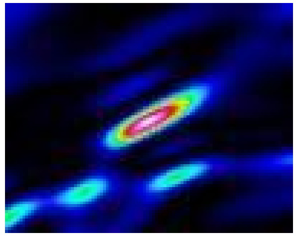
Key Science Projects



Credits (from left to right): F. De Gasperin, J. Broderick, G. Heald & the MSSS team, D. Mulcahy, O. Wucknitz, LOFAR Planetarium, and J. Harwood

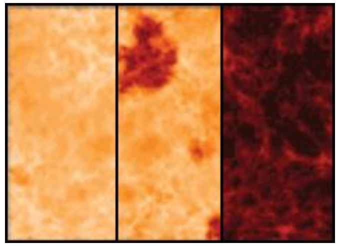
COSMIC MAGNETISM
OF THE NEARBY UNIVERSE

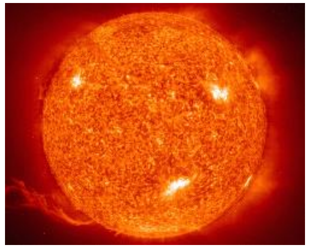




ULTRA HIGH ENERGY
COSMIC RAYS

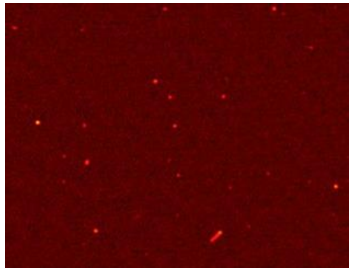
EPOCH OF REIONISATION

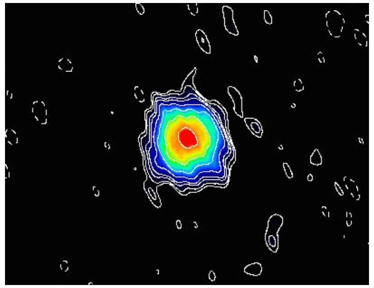




SOLAR PHYSICS AND SPACE WEATHER

DEEP EXTRAGALACTIC SURVEYS



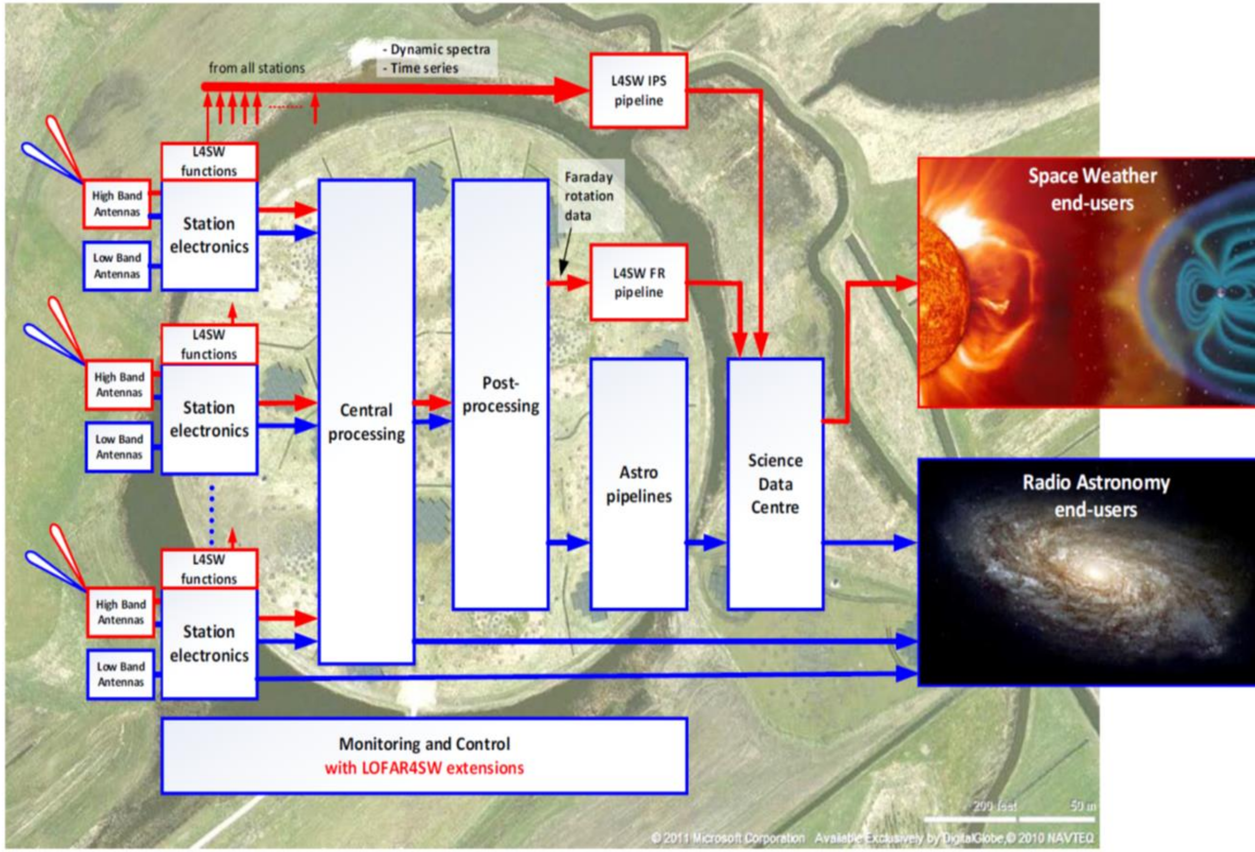


TRANSIENTS AND PULSARS

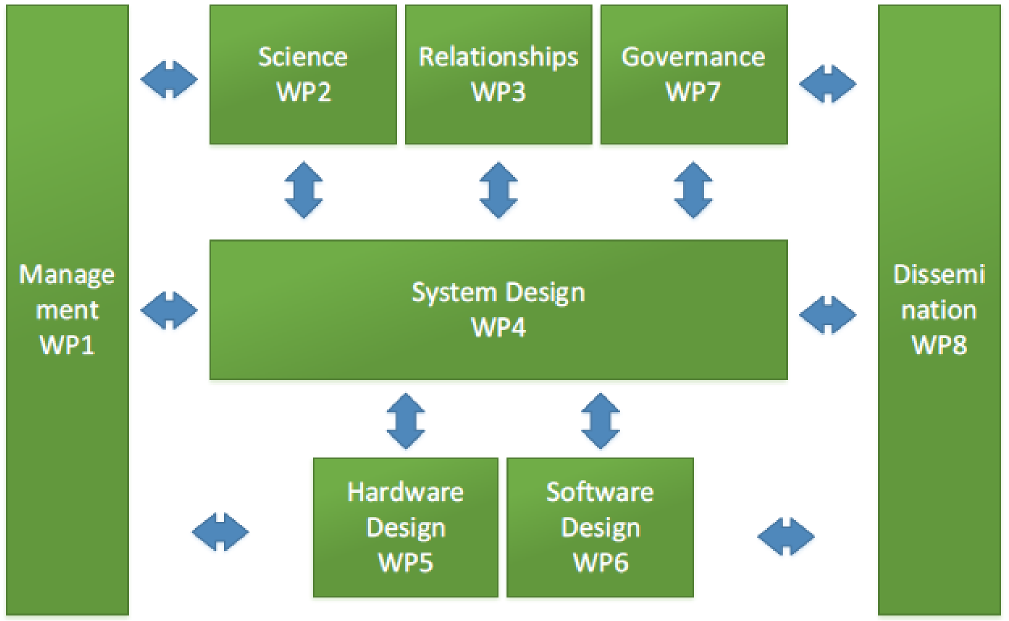
List of participants

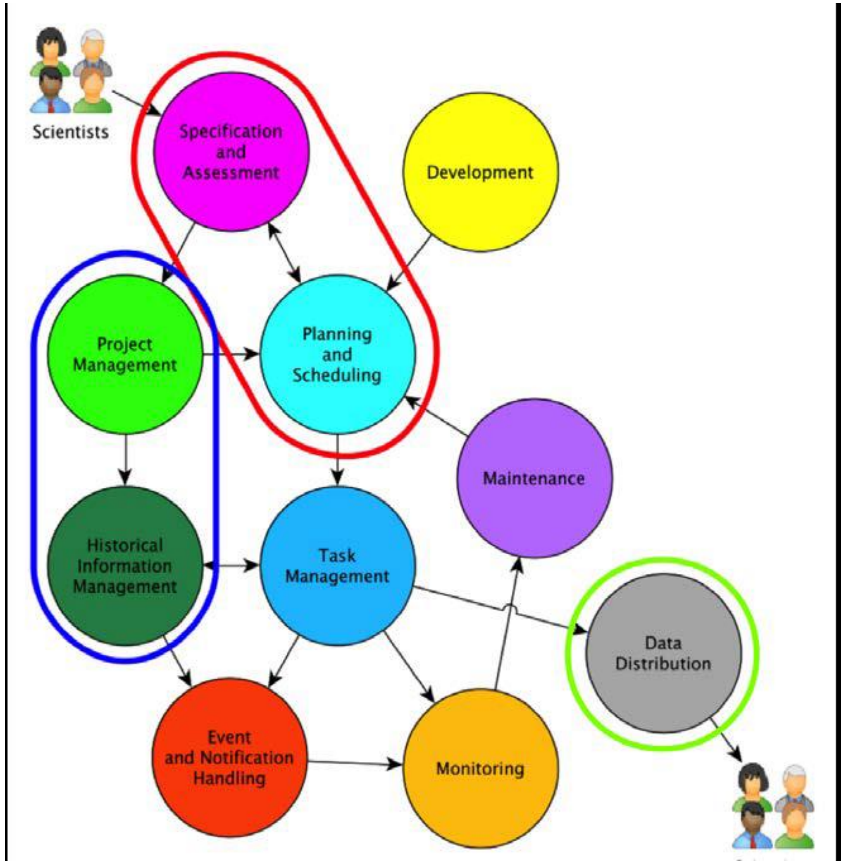
Participant No *	Participant organisation name	Country
1 (Coordinator)	Stichting ASTRON, Netherlands Institute for Radio Astronomy (ASTRON)	NL
2	Universität Bielefeld (UNIBI)	DE
3	Centrum Badan Kosmicznych Polskiej Akademii Nauk (CBK PAN)	PL
4	Stichting International LOFAR Telescope (ILT)	NL
5	Observatoire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

Horizon 2020 Programme H2020-INFRADEV-2017-1
under grant agreement 777442



Work flow



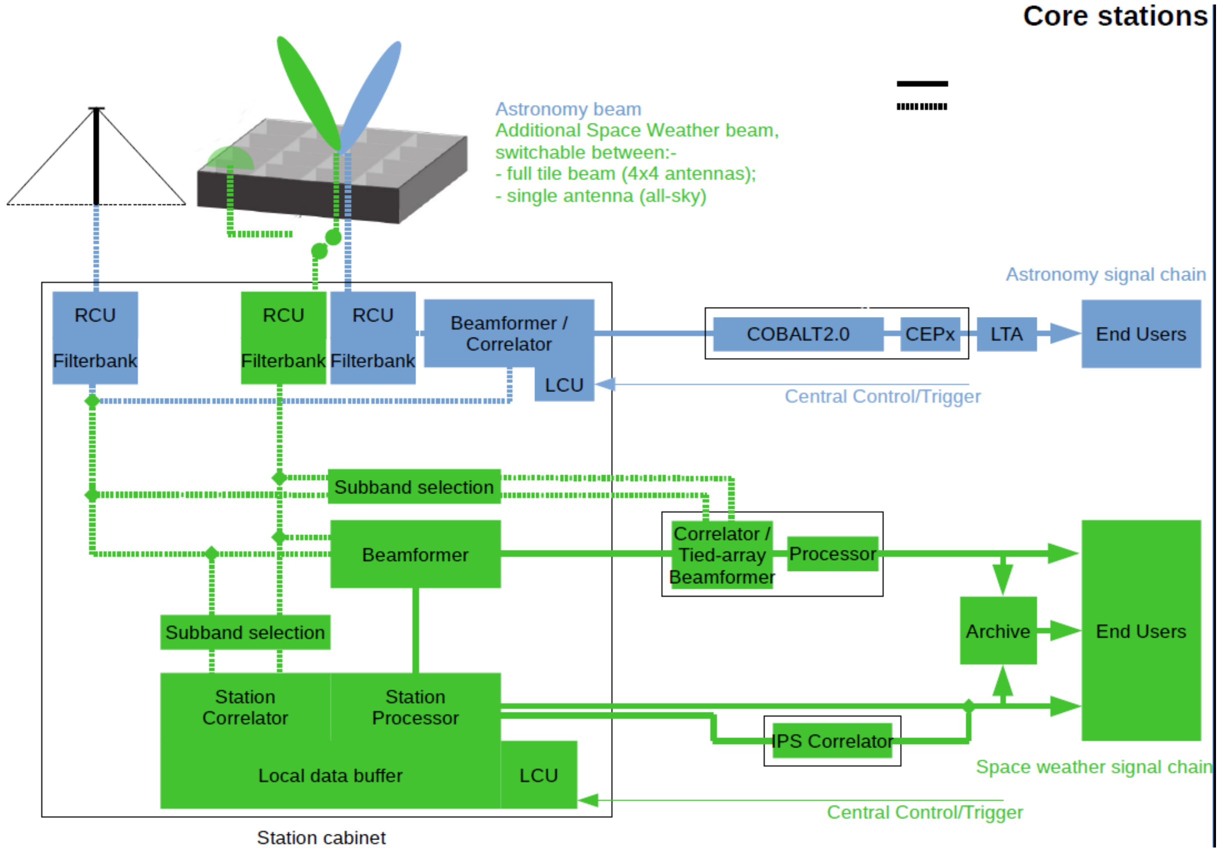


Red must be to be extended to allow parallel space weather and radio astronomy observation
Blue upgrading to allow both operators and end science users
Green updated with regard to the Open Access functionality of the Science Data Centre

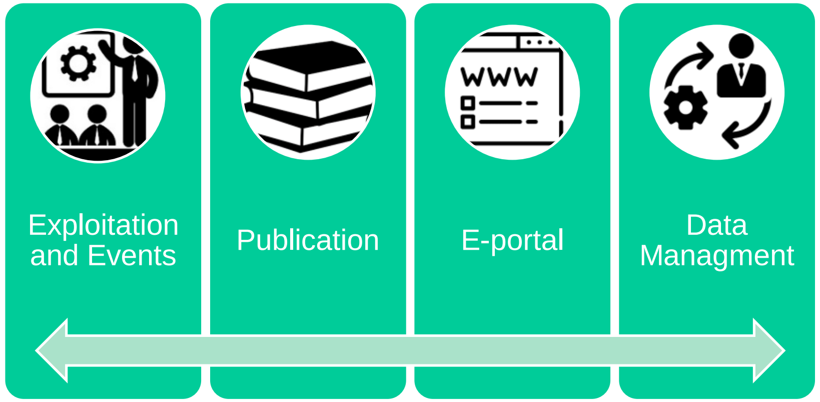
Desired Observing Modes with LOFAR4SW

Observation to run:	Stations required	Bands required (MHz)	Number of beamlets required in each band	Data output	Notes
Solar dynamic spectrum	single international station, varying east to west	10-90*, 110-190, 210-290, 310-390	300+460+460+460 = 1680 (~915)	Stokes IQUV dynamic spectrum at 0.01s/12kHz resolution	Need to use subsets of HBA tiles to cover multiple bands. 915 beamlets assumes coverage up to the current ~240MHz.
Solar imaging (interferometry)	Core[+remote?]	10-90*, 110-190, 210-290, 310-390	3+3+3+3 = 12 (8)	Stokes IQUV visibilities flagged and averaged to 1ch/sb and 0.1-10s Quicklook images	Need to use subsets of HBA tiles to cover multiple bands. 8 beamlets assumes coverage up to the current ~240MHz. Central processing may allow a greater number of subbands. Recent research indicates that high resolution can be achieved using the remote stations.
Solar imaging (tied-array BF)	Core	10-90*, 110-190, 210-290, 310-390	300+460+460+460 = 1680 (~915)	Stokes IQUV dynamic spectra at 0.01s/12kHz for 9 (18?) tied-array rings	Need to use subsets of HBA tiles to cover multiple bands. 915 beamlets assumes coverage up to the current ~240MHz.
IPS monitoring	Int+remote+core	110-190, 210-290, 310-390	205|205|205	- Stokes I dynamic spectra per station at 0.01s/12kHz (for 1 tied-array ring with combined core) - Time series	Using the core would compete with solar imaging for use of the HBA tile beam. Only one band is used per observation.
IPS imaging	Core+6 remote	110-190	100	Stokes I visibilities flagged and averaged to 1ch/sb and all subbands concatenated together, 0.1s.	Very challenging to keep up with, as the raw data rate is ~9TB/hr. Competes with solar imaging for use of the HBA tile beam. An initial survey of IPS sources can be accomplished using current survey data.
IPS Science	Int+remote+core	110-190, 210-290, 310-390	460+460+460 = 1380 (615)	Stokes I[QUV] dynamic spectra per station at 0.01s/12kHz (for 1 tied-array beam with combined core)	Need to use subsets of HBA tiles to cover multiple bands, but sensitivity concerns make this unrealistic for remote and international stations.
Faraday rotation pulsars	Int(TBC)+core	10-90*, 110-190, 210-290, 310-390	300+460+460+460 = 1680 (760)	Pulsar pipeline data per station (for 1 tied-array beam with combined core)	Competes with solar imaging for use of the HBA tile beam at the core stations. Lower frequencies are preferred, so unnecessary to observe above 190MHz.
Faraday rotation imaging	Core+filler stations	110-190	460	Stokes IQUV visibilities flagged and averaged to 1ch/sb and integrated to 300s.	Extremely challenging to the extent that it is not yet known whether this is even possible with LOFAR.
Ionospheric scintillation monitoring	Int+remote+core	10-90*, 110-190	2x 6+6 = 24	Single-subband time series' of Stokes I	Can be accomplished with far more sources simultaneously with the all-sky imaging mode.
Ionospheric scintillation science	Int+remote+core	10-90*, 110-190	3x 300+460 = 2280 (~1060)	Stokes I dynamic spectrum at 0.01s/195kHz resolution	It is likely to be unrealistic to expect that the station beamformer will have the capacity for full bandwidth observing on more than one beam. Therefore the full band may need to be sampled sparsely to observe more than one source.
Ionospheric scintillation single-station all-sky imaging	Int+remote+core	10-90*, 110-190	*[subbands] 30+30 = 60*	All-sky images in Stokes I from combined X and Y, integrated over 10 subbands, centred on each frequency, and 0.1s.	Bypasses the beamformer.
Ionospheric scintillation full-core all-sky imaging	Core	10-90*, 110-190	*[subbands] 60+60 = 120*	All-sky images in Stokes I from combined X and Y, integrated over 10 subbands, centred on each frequency, and 0.1s.	Bypasses the beamformer.
Ionosphere passive radar	Int+remote	10-90*, 110-190	*[subbands] 4*	X- and Y- voltages combined via on-line pipeline to obtain meteor/ionosphere echoes.	Bypasses the beamformer.
Ionosphere riometry	Int+remote	10-90*	*[subbands] 128*	All-sky images in Stokes I from combined X and Y, integrated over 10 subbands, centred on each frequency, and 0.1s.	Bypasses the beamformer.
Jupiter space weather	Core+remote	14-45,110-190,210-240	154+20+20	Stokes IQUV dynamic spectrum at 0.1s/12kHz resolution; Stokes IQUV visibilities flagged and averaged to 1ch/sb and 60s (TBC), taken once each hour.	Competes with solar imaging and pulsar observations for use of the HBA tile beam at the core[+remote] stations. However, only one image an hour is required, which could interleave with solar.

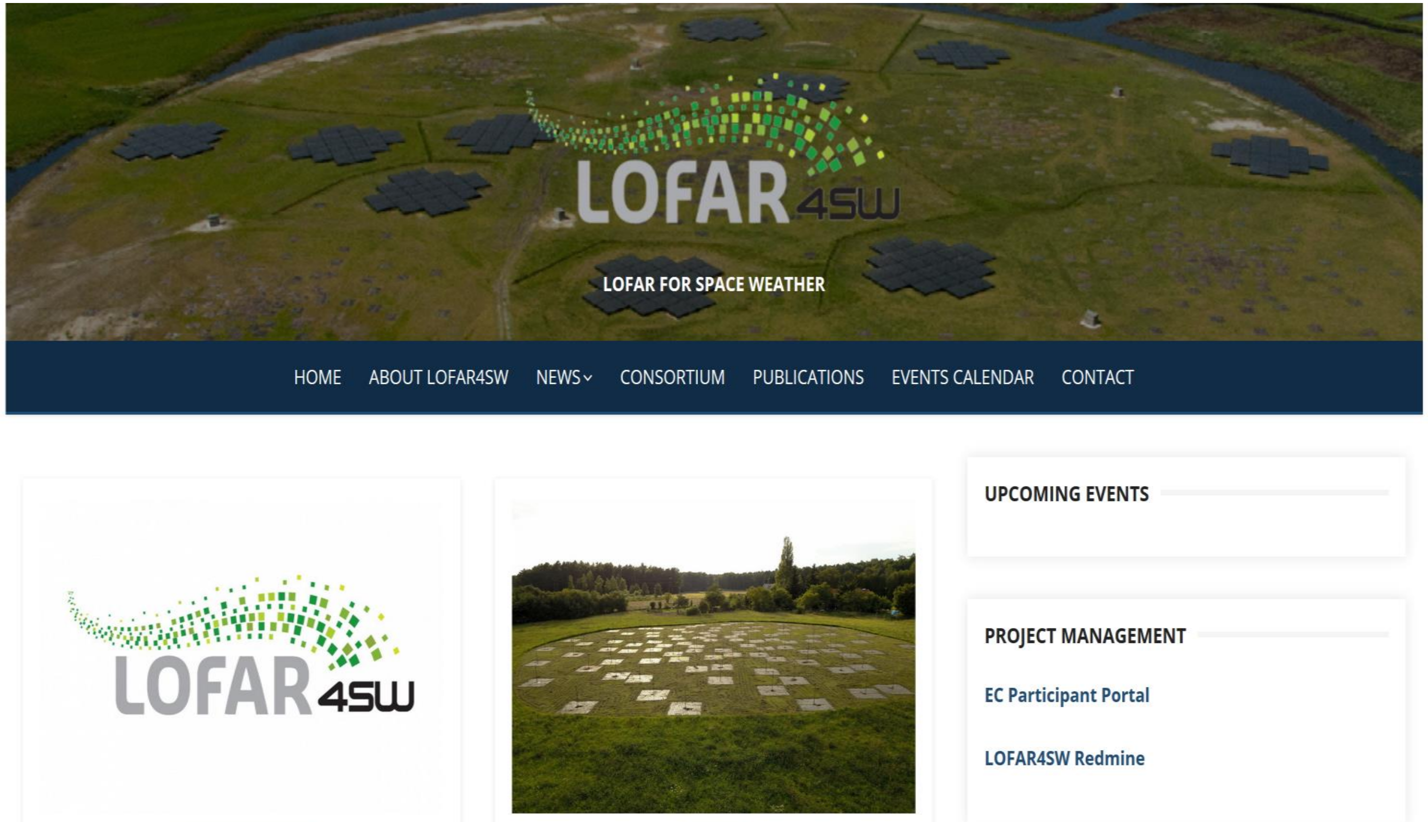
* 10-90MHz is the current LBA filter, but 20-78MHz is the realistically-usable band. The number of beamlets required reflects this.
Items in red indicate desired functionality which may prove too expensive for an initial implementation.



Lofar4sw.eu



The LOFAR4SW governance model with the close participation of stakeholders such as the, sintific societies, LOFAR partners, European and international space weather services, and policy makers.

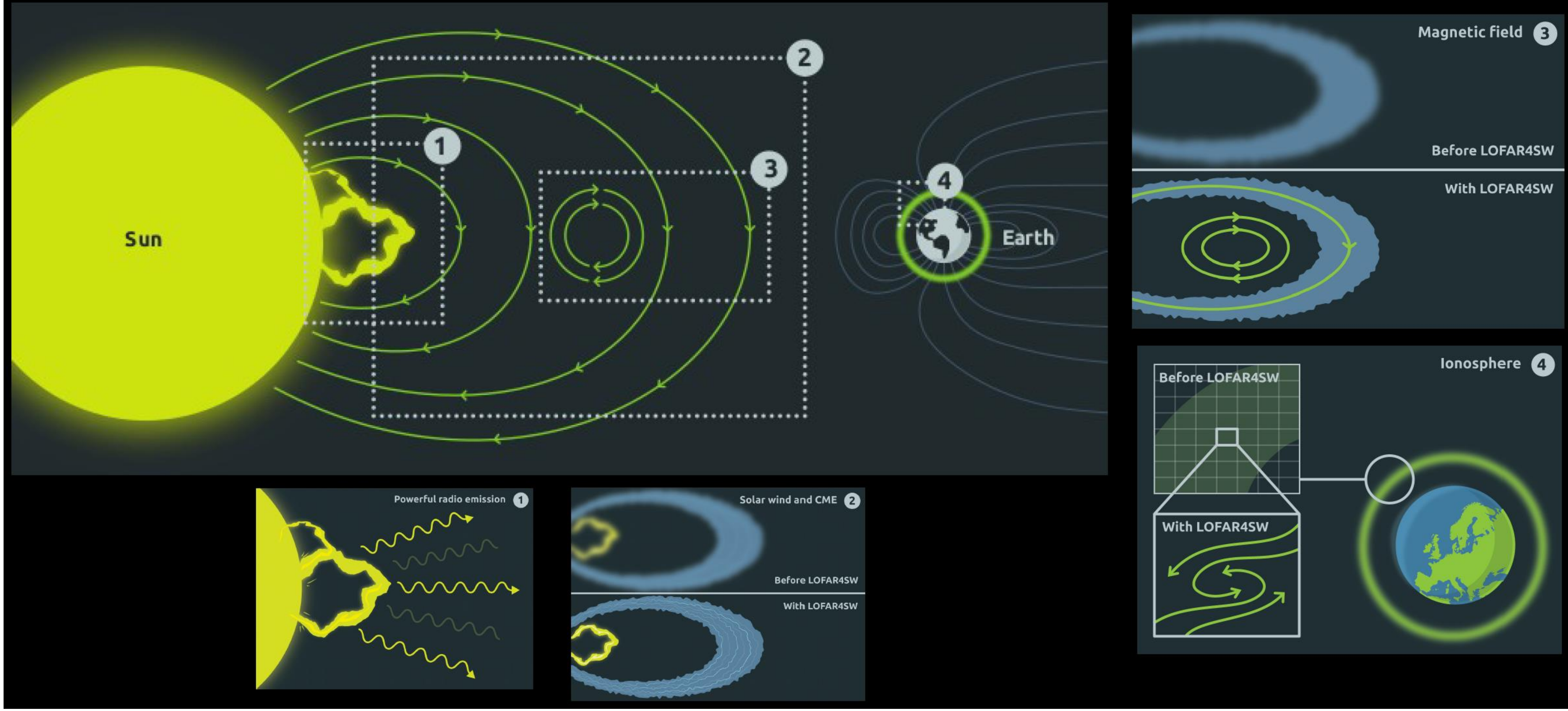


USER WORKSHOP

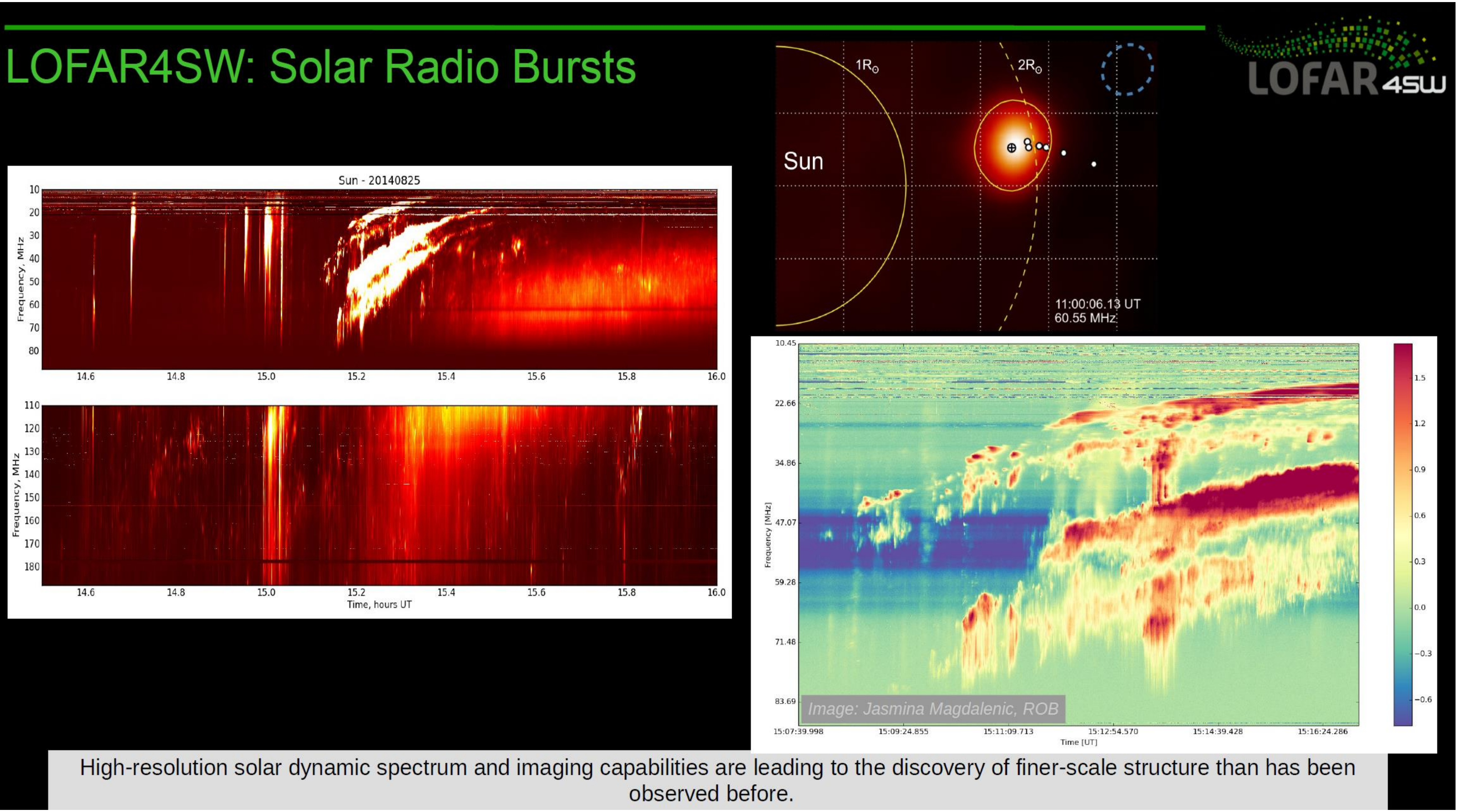
6-7 November 2019

WARSAW

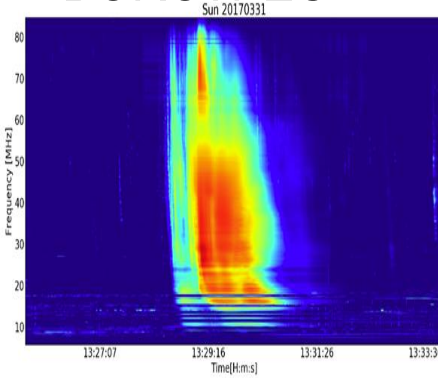
LOFAR4SW: A Comprehensive Space Weather Observatory

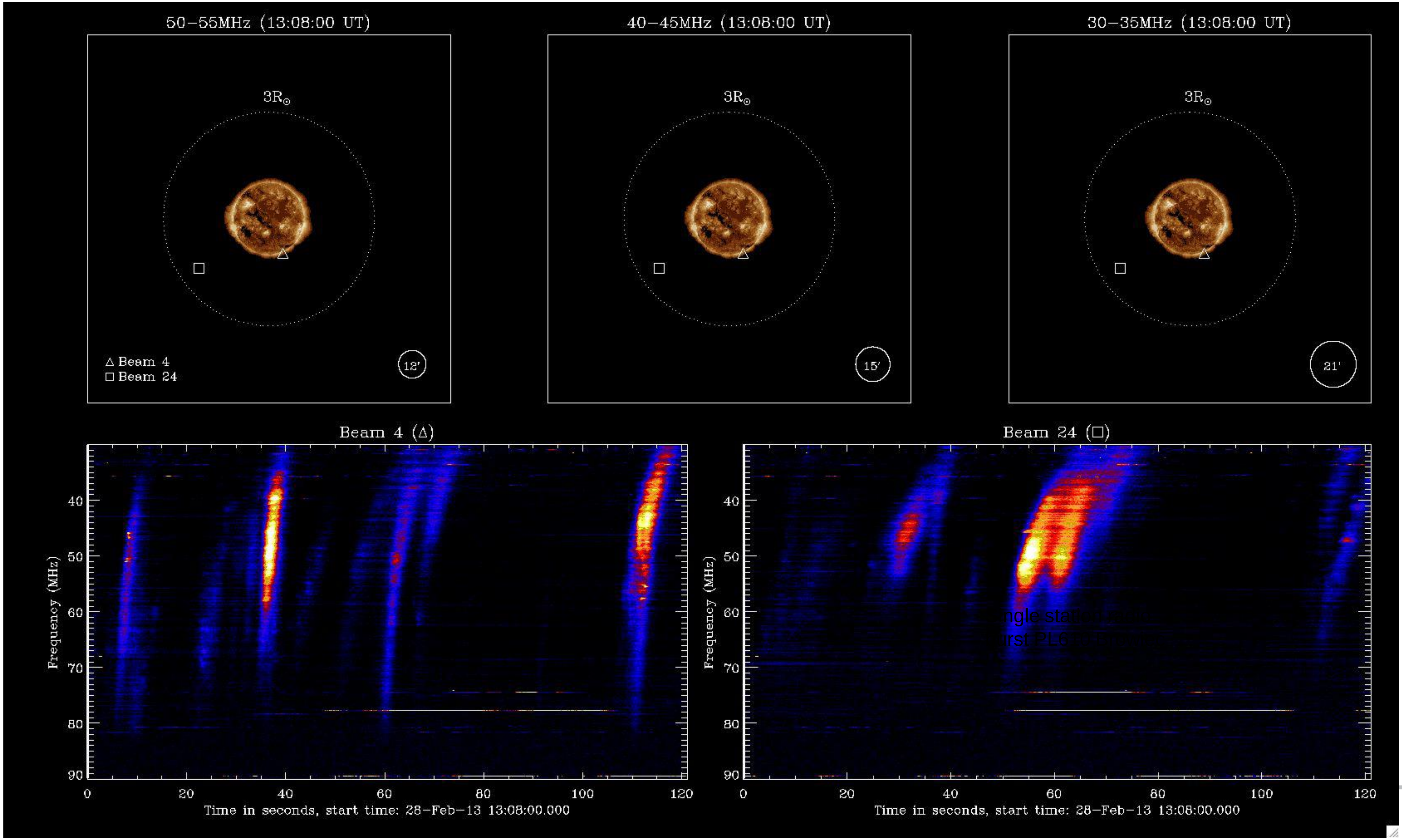


SUN



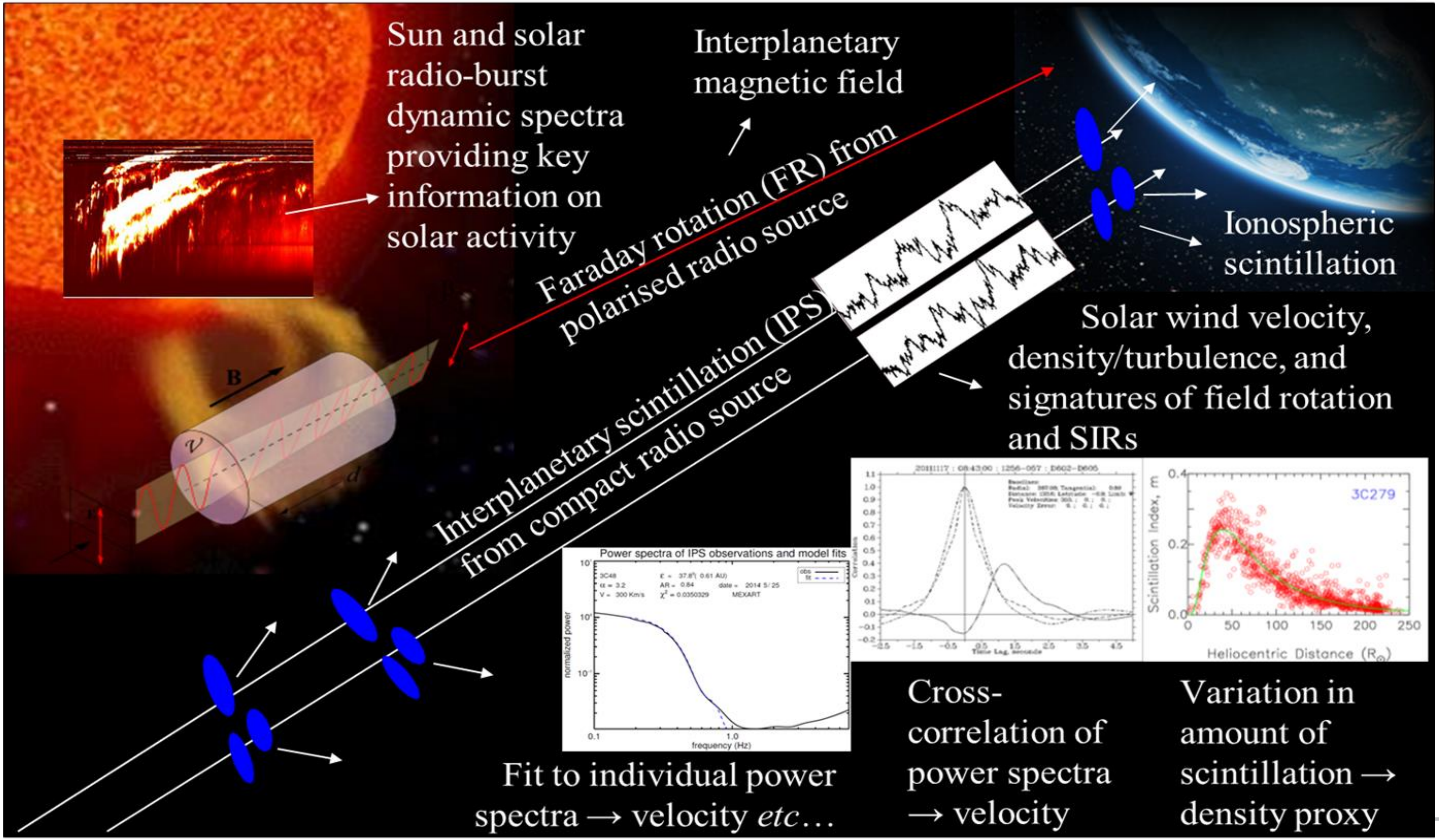
PL610
BORÓWIEC





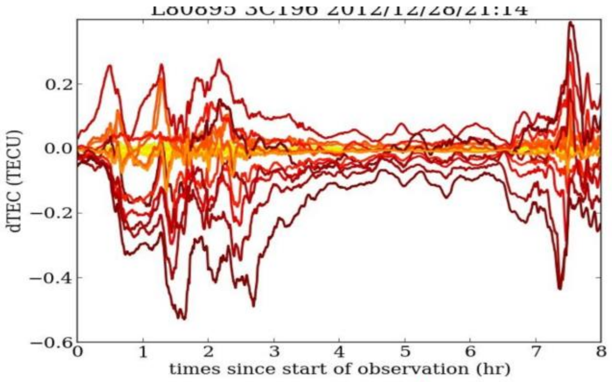
Morosan et al., A&A ,

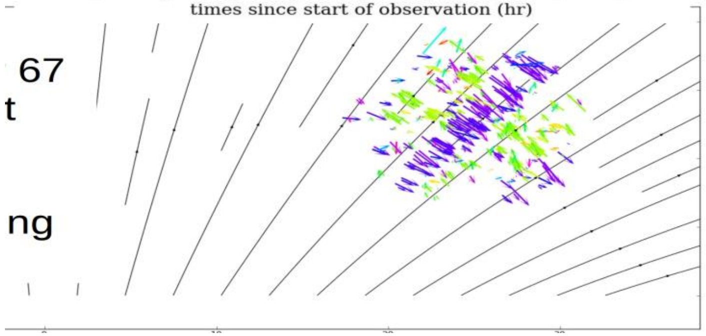
SOLAR WIND

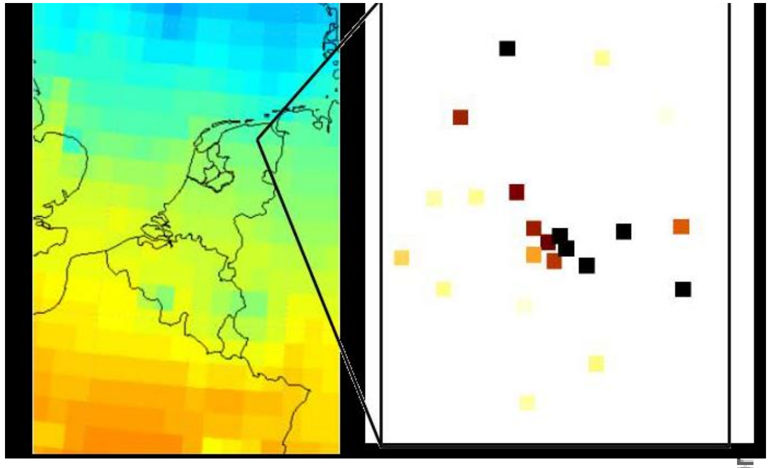


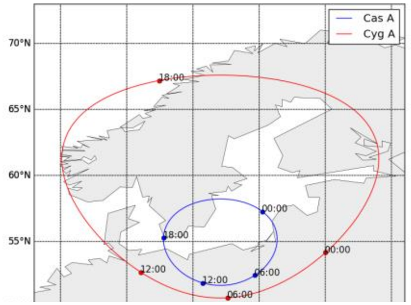
Sun and solar radio-burst dynamic spectra providing key information on solar activity
Interplanetary magnetic field
Faraday rotation (FR) from polarised radio source
Interplanetary scintillation (IPS) from compact radio source
Ionospheric scintillation
Solar wind velocity, density/turbulence, and signatures of field rotation and SIRs
B
Power spectra of IPS observations and model fits
frequency (Hz)
normalized power
Heliocentric Distance ($R_\odot$)
Scintillation Index, m
3C279
Fit to individual power spectra → velocity *etc*…
Cross-correlation of power spectra → velocity
Variation in amount of scintillation → density proxy

Ionopsheric scintilation

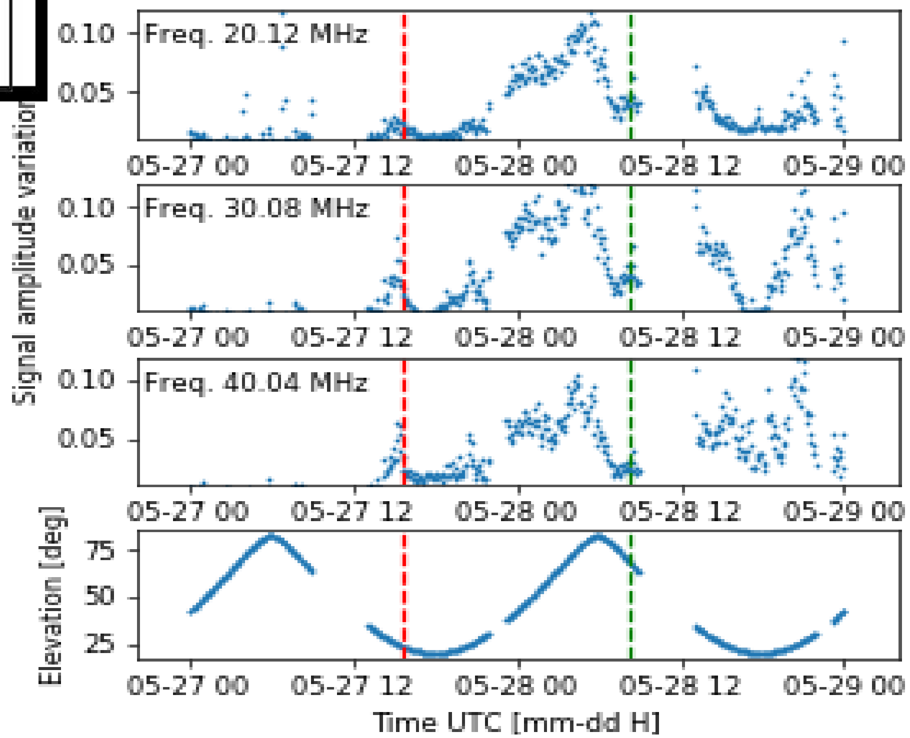


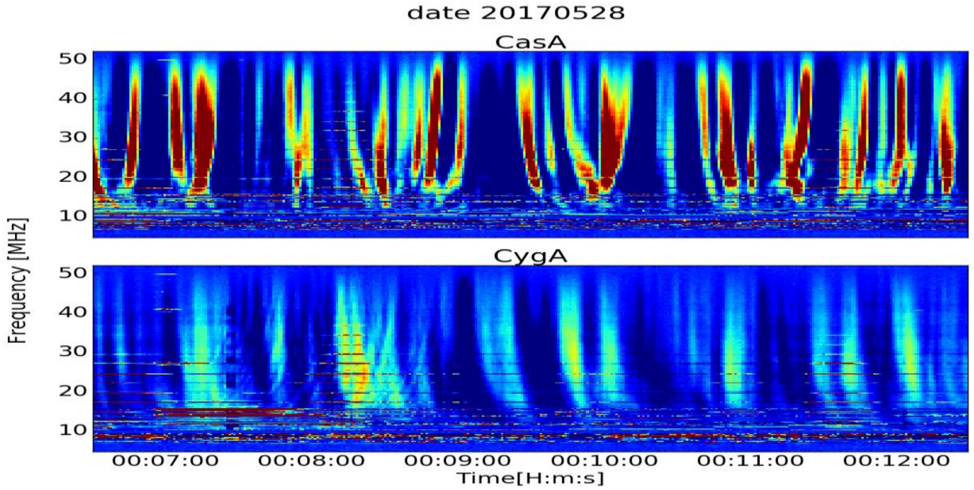






The ionospheric scintillation pattern is observed to flow and eddy over the LOFAR core stations (rightmost plot – dark colours indicate greater intensity in the received power), giving detail which lies well within a single pixel of a GPS TEC map.





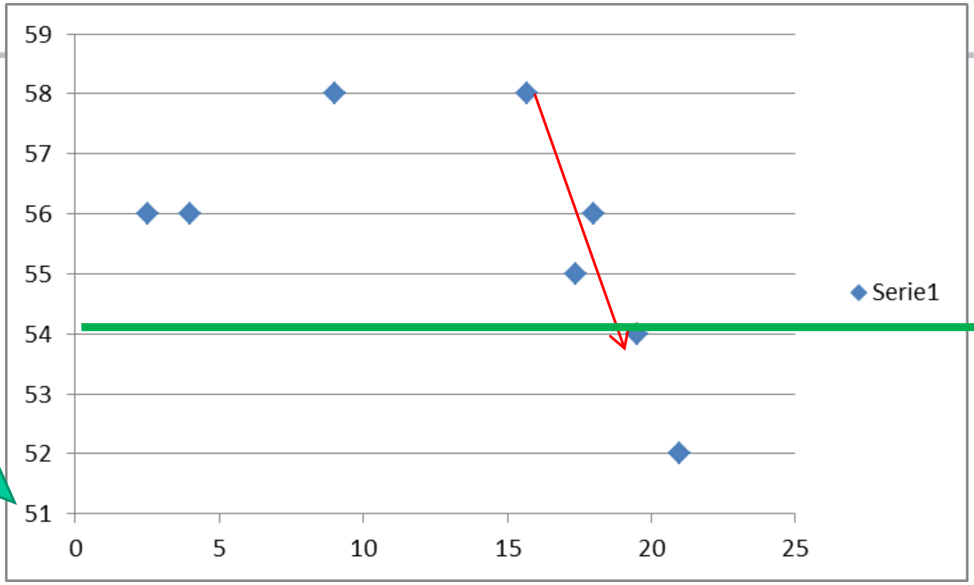
PL610 Borowiec

The signal amplitude variation calculated for 3 different frequencies (3 top panels) of the radio sources Cas A for a time period of 26-29.05.2017. Bottom panels: elevation of observed radio sources

Geomagnetic storm 13 10 2016   trough evolution

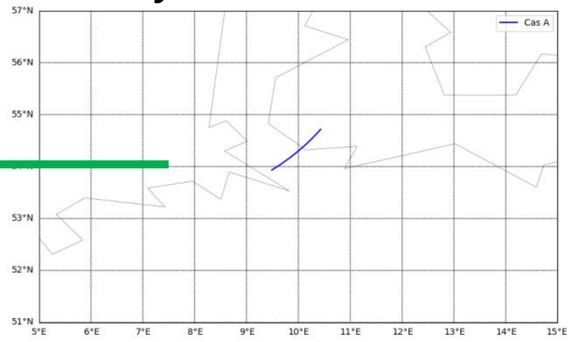
Lat

SWARM

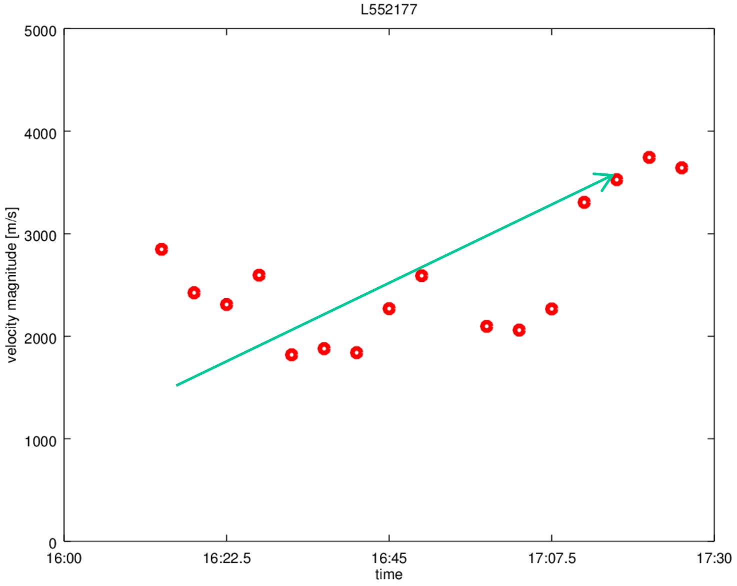


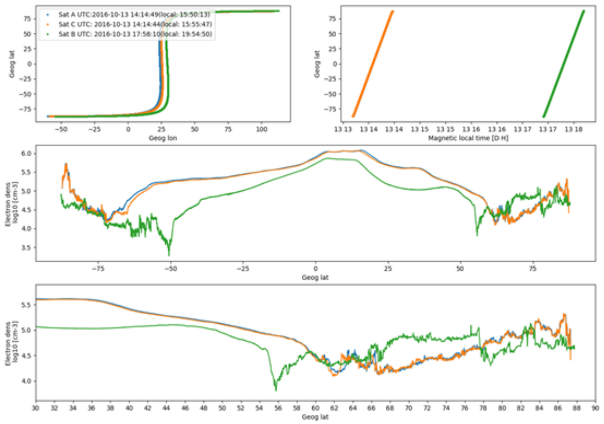
Time

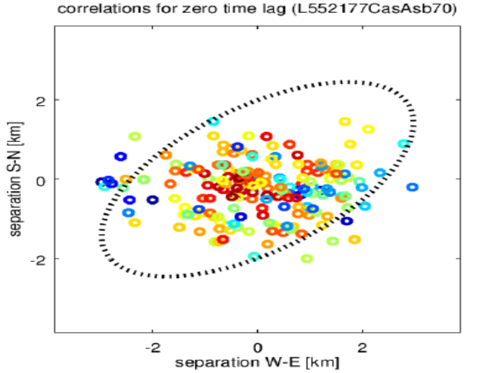
Combination of different scales dynamic

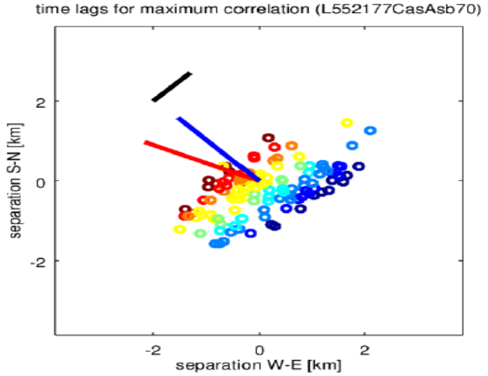


LOFAR







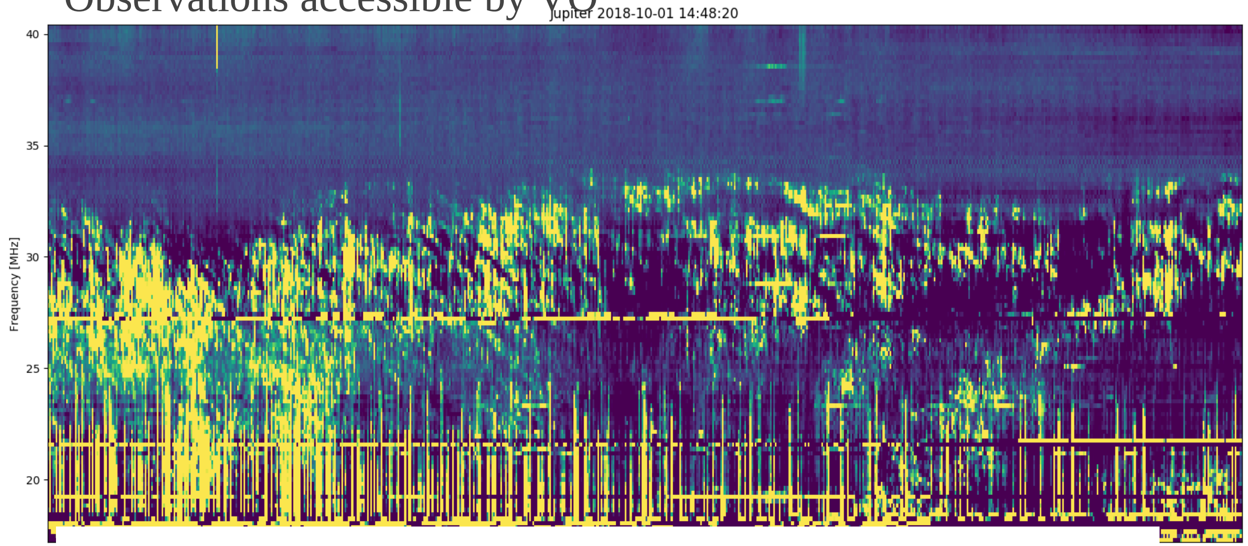


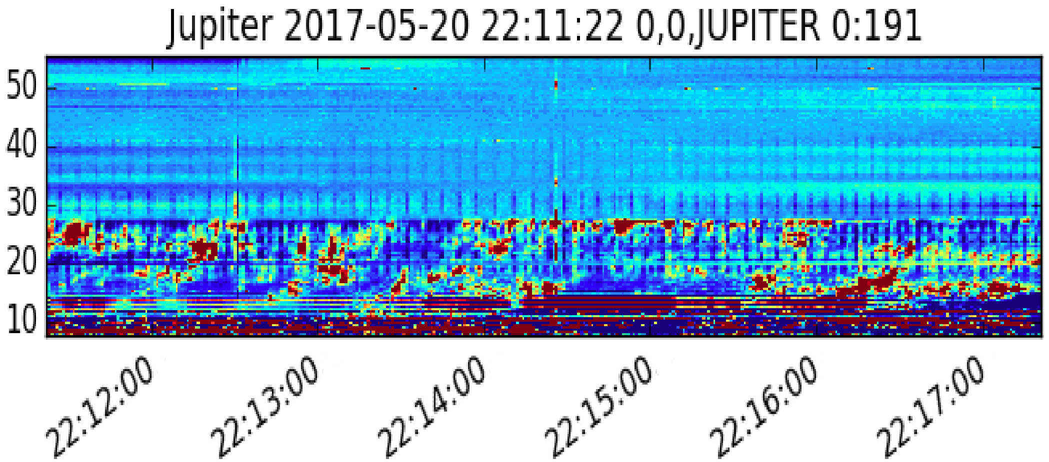
Jupiter observations

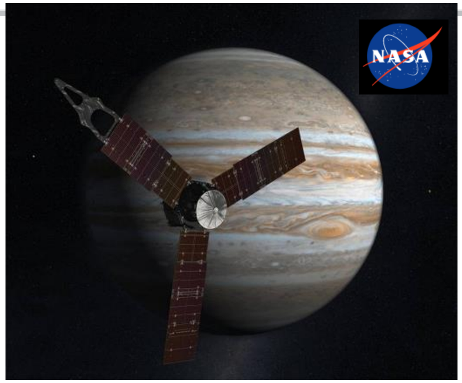
DAM emissions - Jovian decametric radio emission

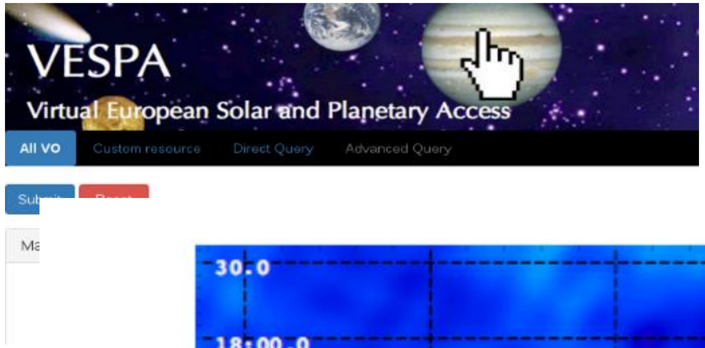
Follow-up for JUNO and JUICE missions

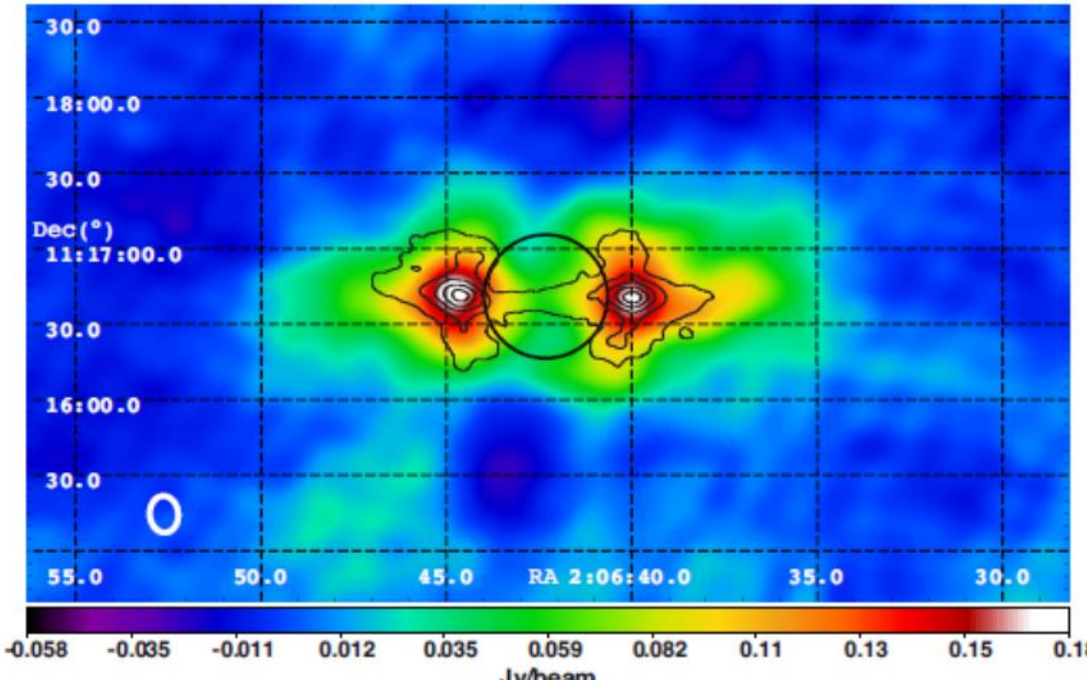
Observations accessible by VO











- Very constructive and positive feedback from the Preliminary Design Review (PDR) in February 2019:
  - Included a formal review of the initial design documents.
- Several project deliverables have been provided to the EC on time and an updated comprehensive set of requirements has now been produced and formalised.
- Prepartions are underway for the European Comission (EC) Mid-Term Review (MTR) in September 2019 where the entire project is reviewed by the EC.
- Work will progress towards the finalised conceptual and technical design: