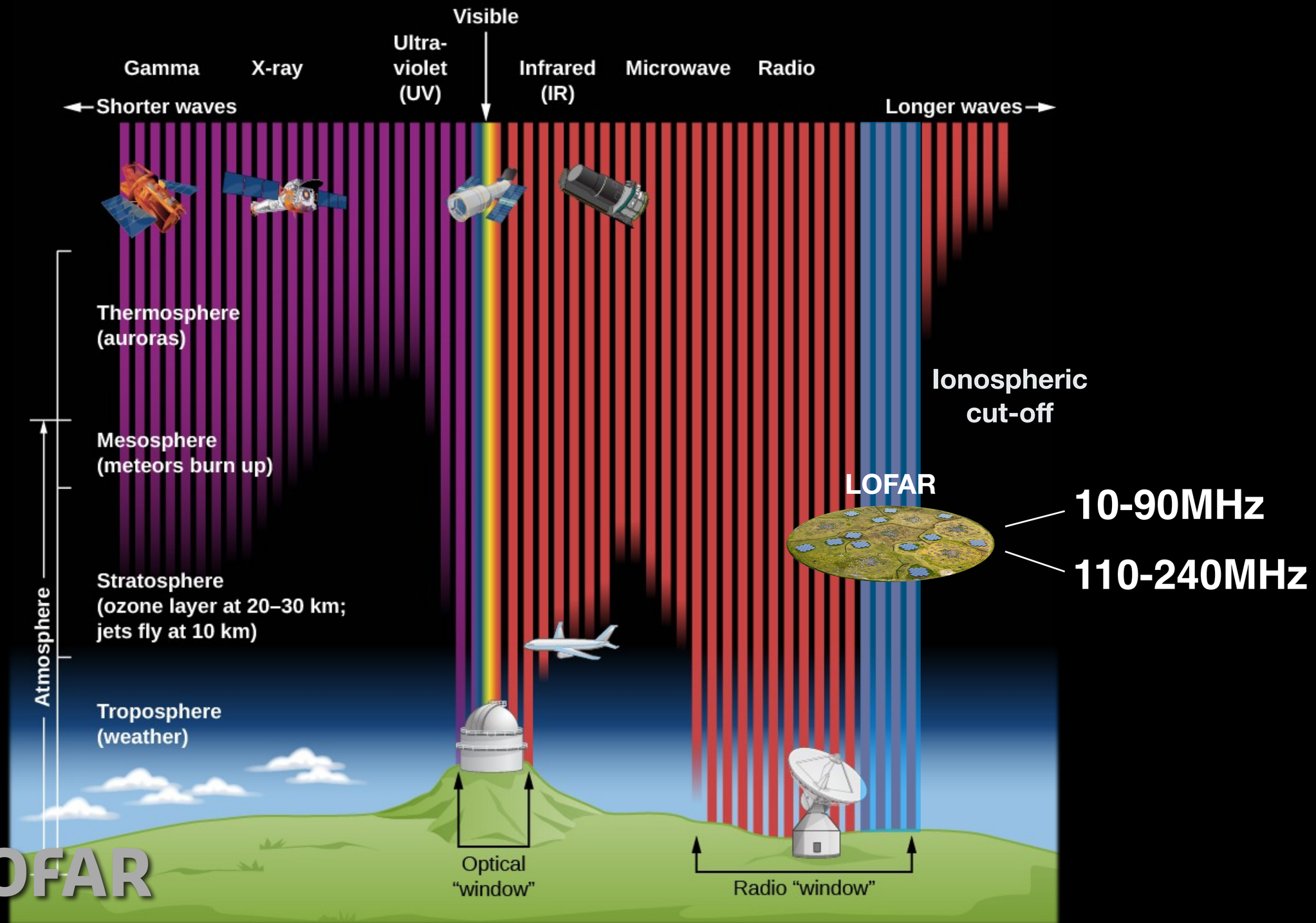
LOFAR2.0

Scientific highlights from the metre wavelength SKA precursor telescope LOFAR and LOFAR 2.0 goals

Jason Hessels - LOFAR2.0 Project Scientist

National SKA Science Day Sweden - Feb. 2nd, 2023


Visible
Ultra-violet (UV)
Gamma
X-ray
Infrared (IR)
Microwave
Radio
Shorter waves
Longer waves
Thermosphere (auroras)
Mesosphere (meteors burn up)
Stratosphere (ozone layer at 20–30 km; jets fly at 10 km)
Troposphere (weather)
Atmosphere
Ionospheric cut-off
LOFAR
10-90MHz
110-240MHz
Optical "window"
Radio "window"

LOFAR

Dutch stations

Onsala

Irbene

Birr

Chilbolton

Norderstedt

Bałdy

Potsdam

Borówiec

Jülich

Effelsberg

Tautenburg

Łazy

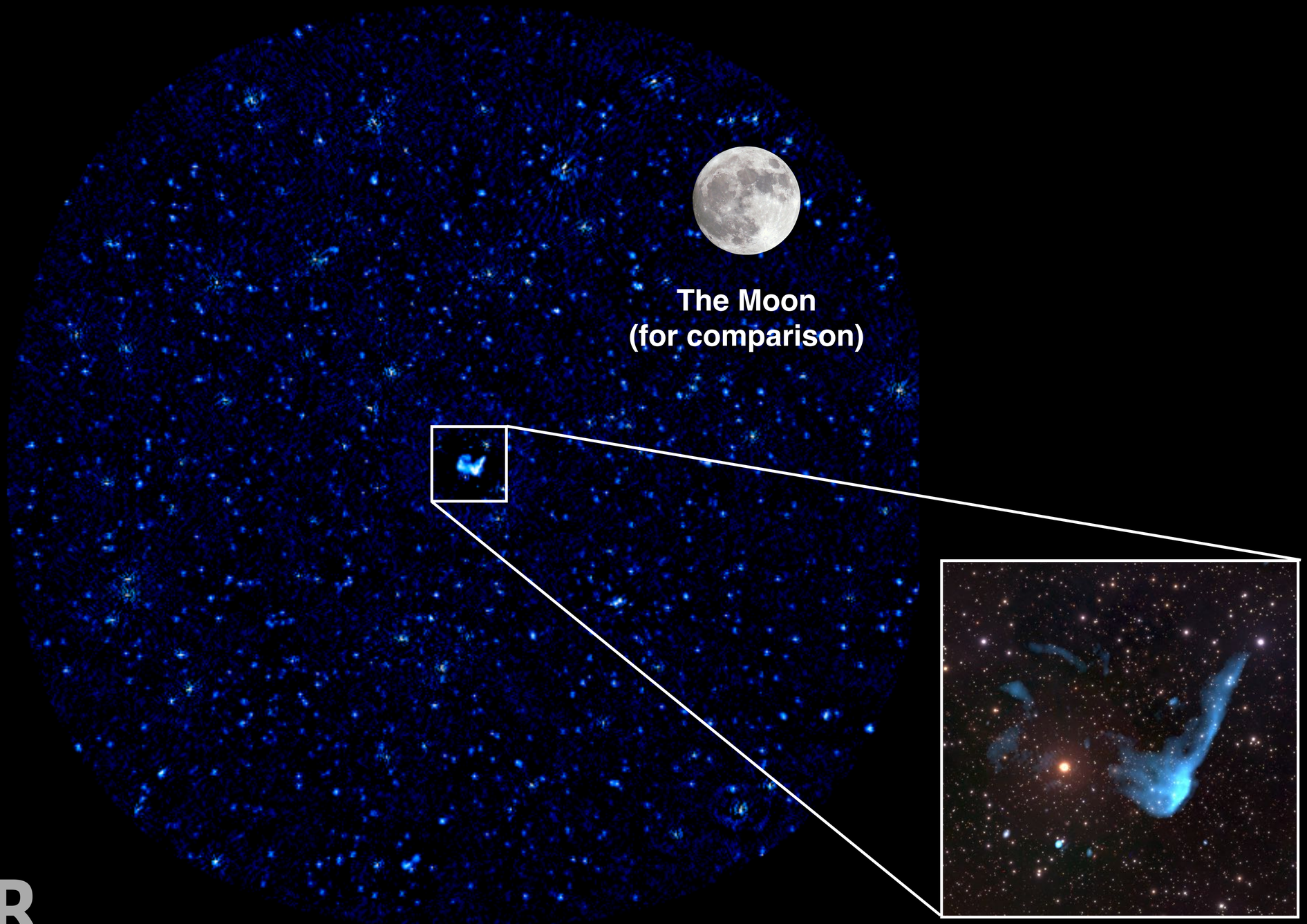
Nançay

Unterweilenbach

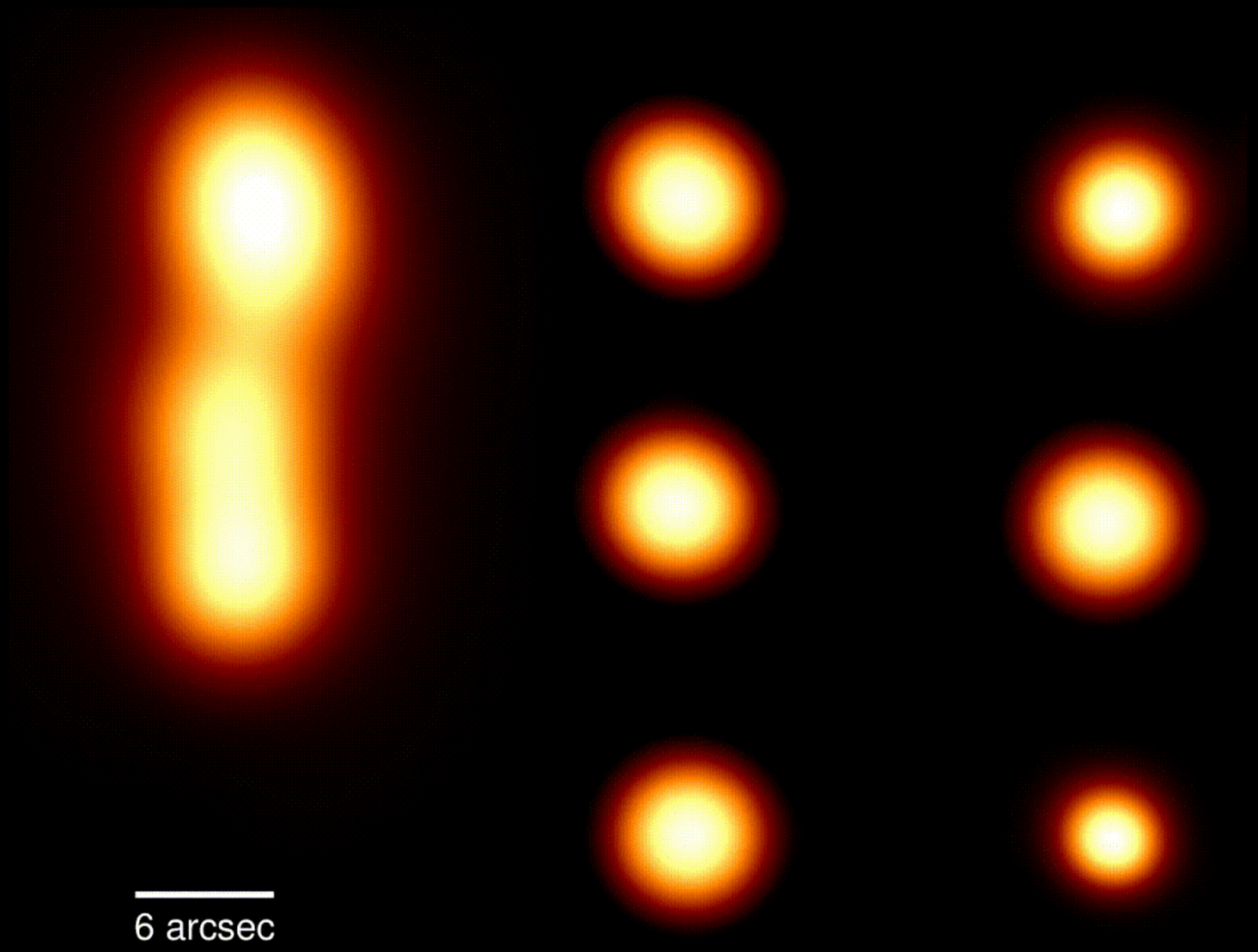
Medicina

Rozhen

LOFAR



LOFAR

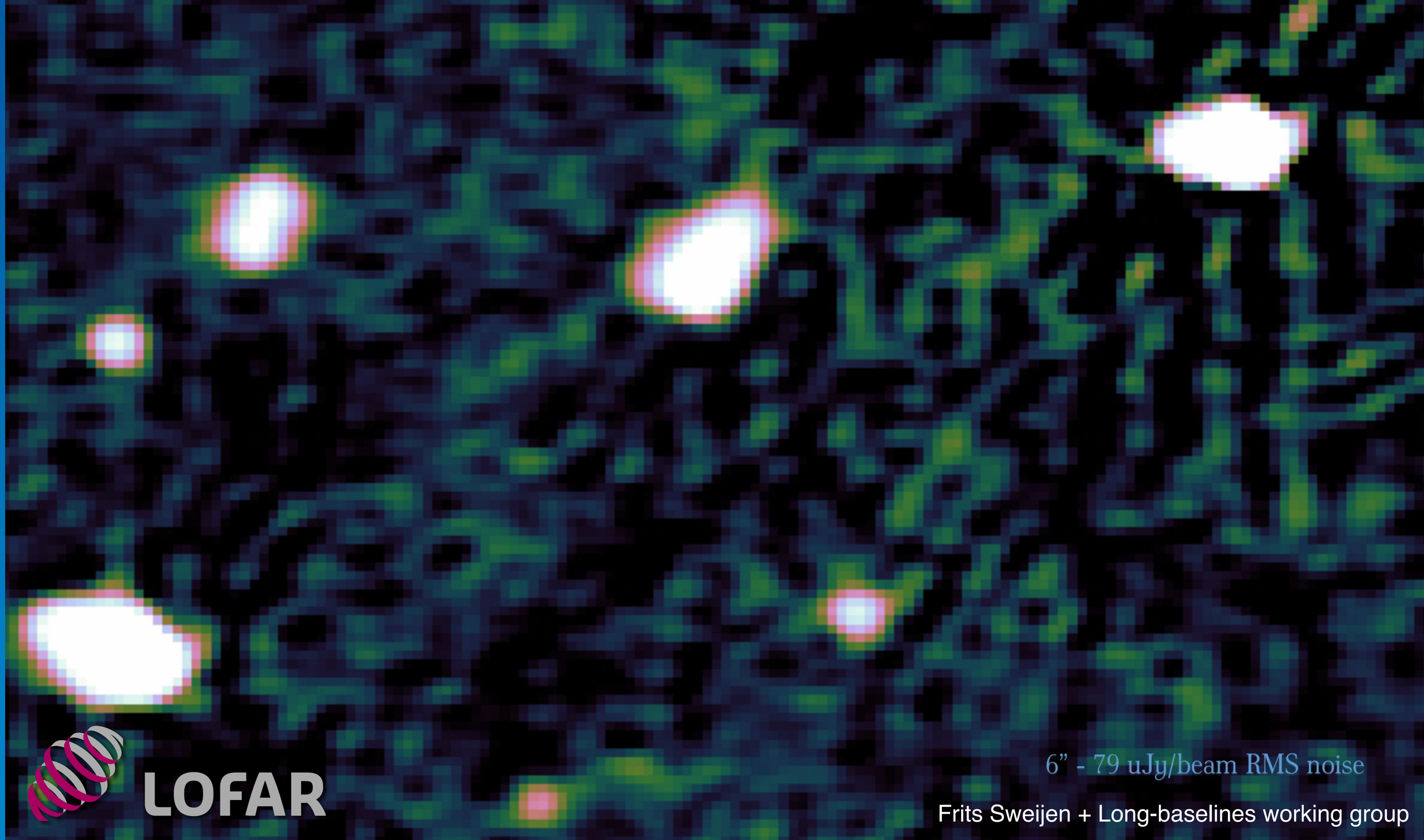


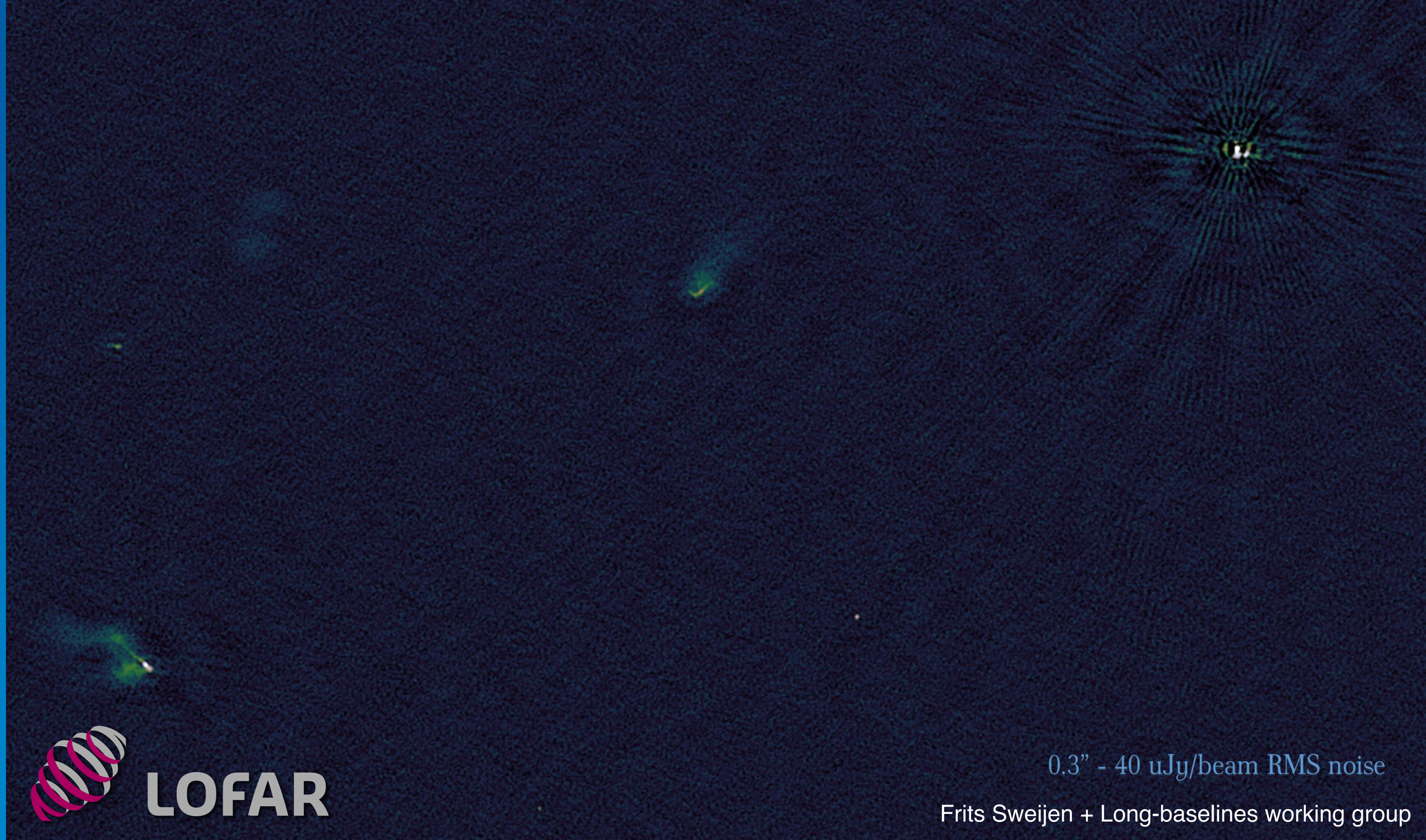
LOFAR

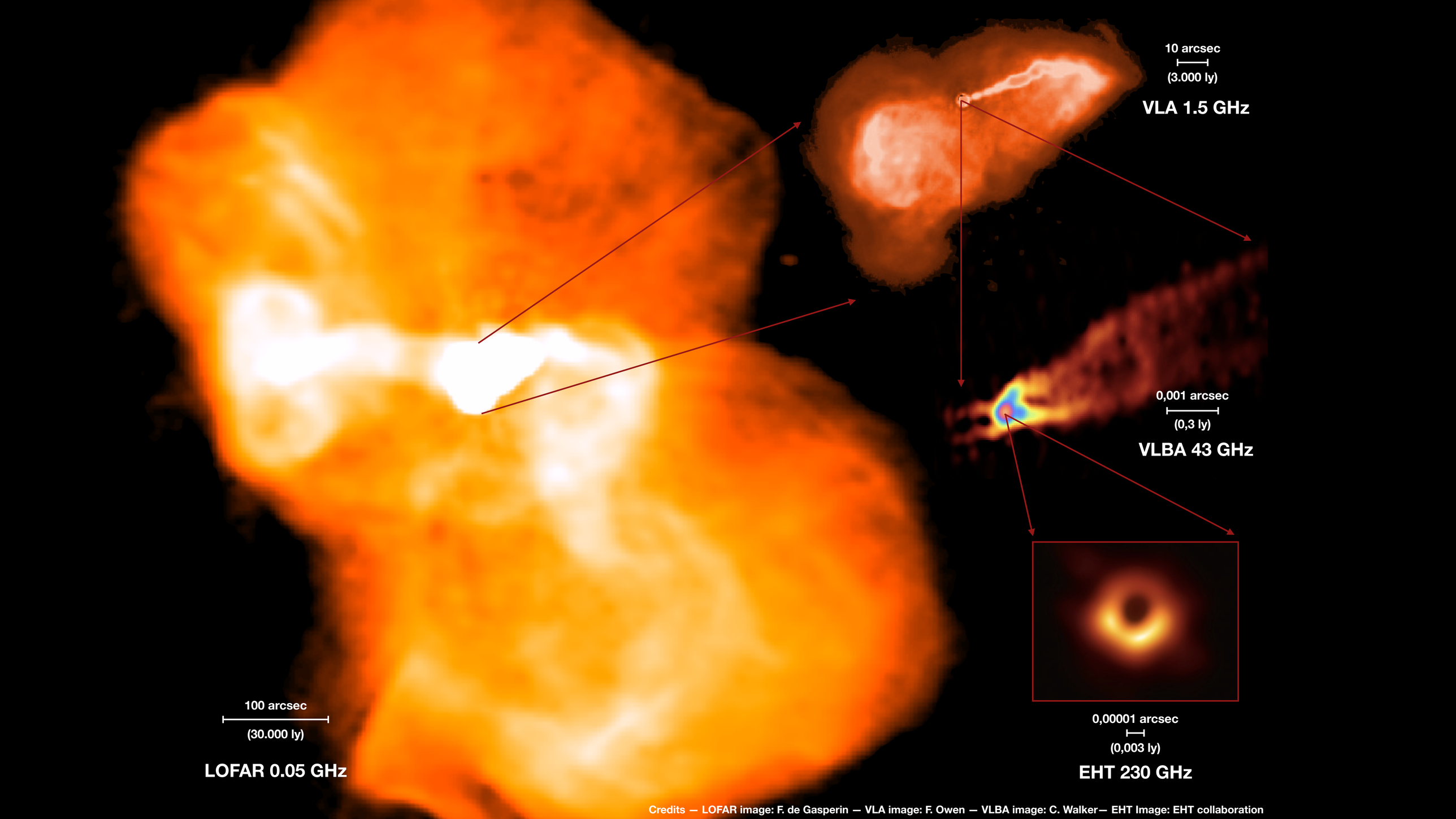
Morabito et al.

LOFAR

Morabito et al.


LOFAR
6” - 79 uJy/beam RMS noise
Frits Sweijen + Long-baselines working group


LOFAR
0.3” - 40 uJy/beam RMS noise
Frits Sweijen + Long-baselines working group



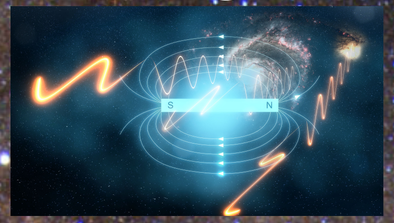
Credits — LOFAR image: F. de Gasperin — VLA image: F. Owen — VLBA image: C. Walker— EHT Image: EHT collaboration


LOFAR


LOFAR

LOFAR

Cosmic magnetism



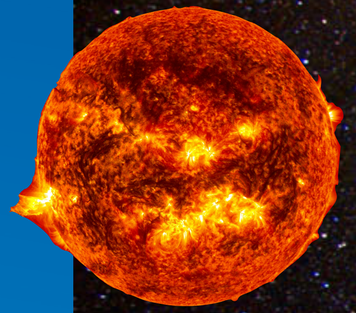
Supermassive black holes

Early Universe

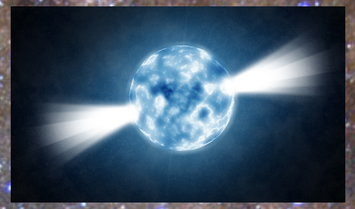
Supernovae

Galaxy clusters

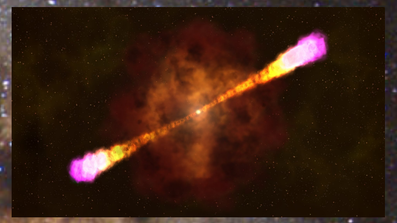
Sun



Pulsars



Gravitational wave events

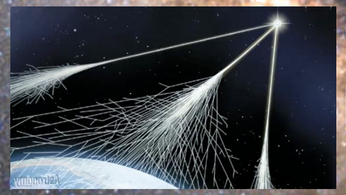


Solar System Planets

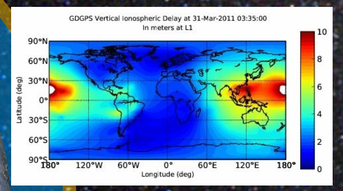
Meteors

Nearby galaxies

Cosmic rays



Ionosphere

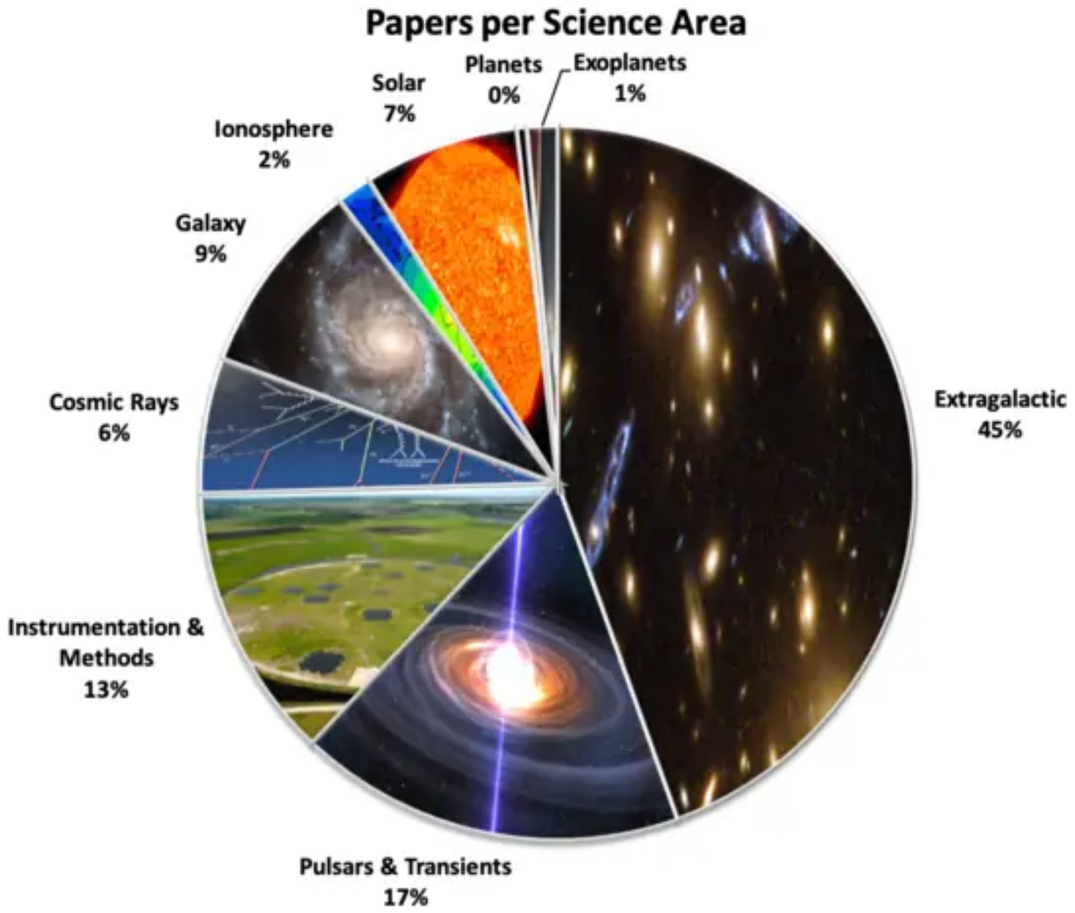


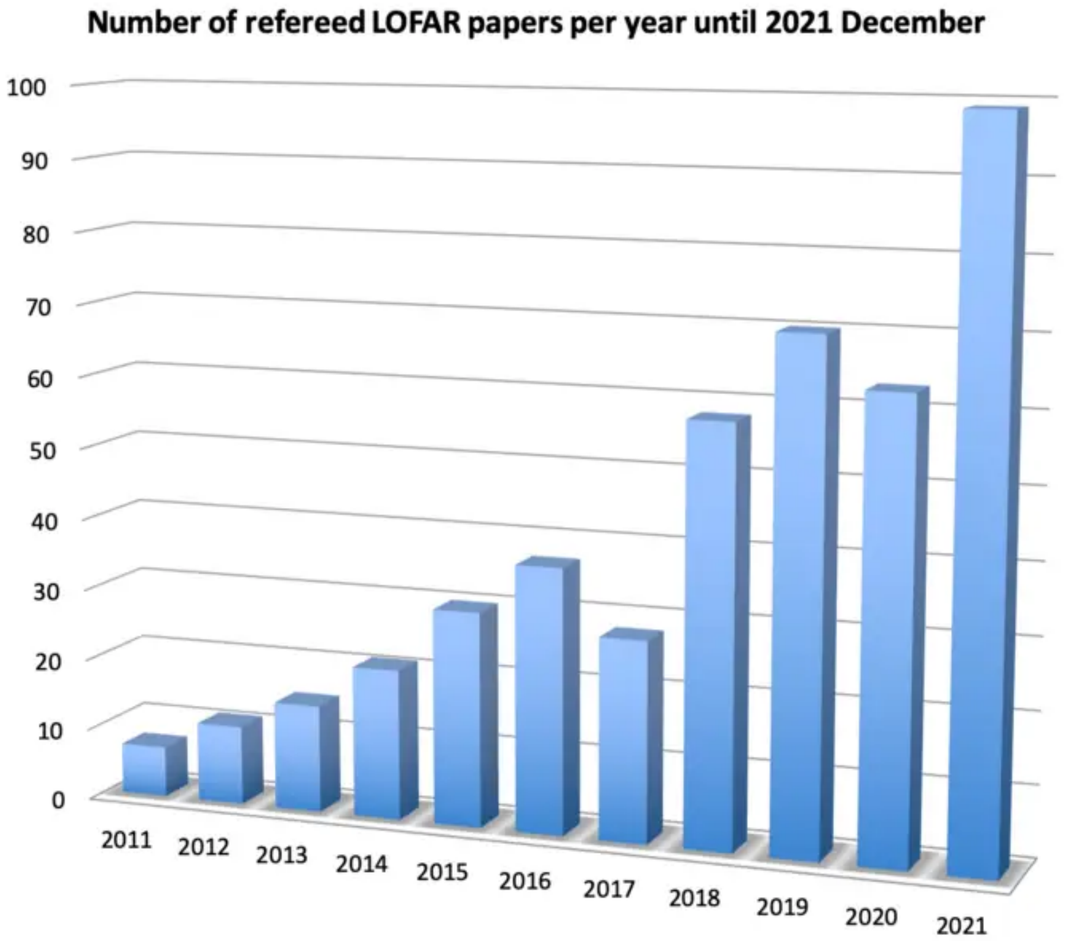
Interstellar medium

Fast radio bursts

Lightning

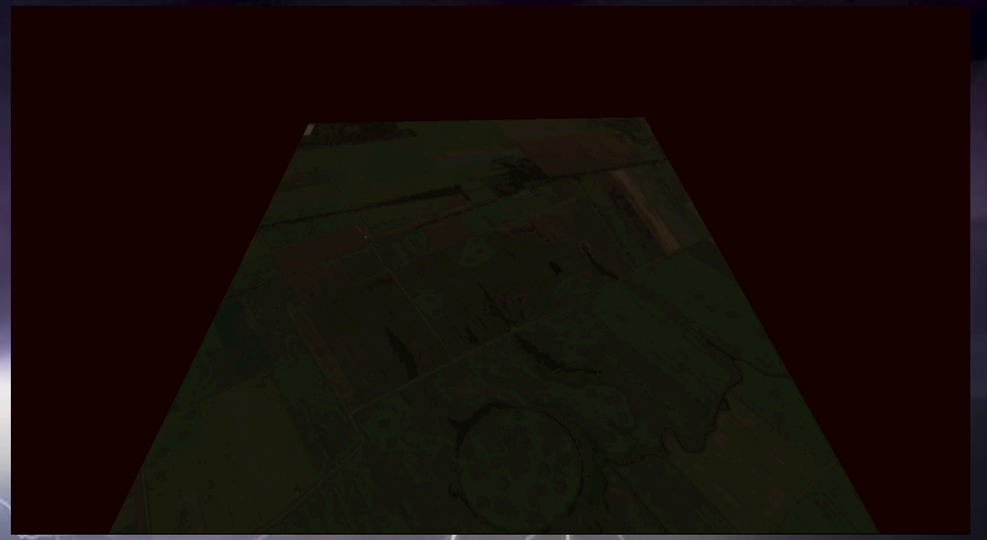
Space weather


Papers per Science Area
Solar 7%
Planets 0%
Exoplanets 1%
Ionosphere 2%
Galaxy 9%
Cosmic Rays 6%
Extragalactic 45%
Instrumentation & Methods 13%
Pulsars & Transients 17%


Number of refereed LOFAR papers per year until 2021 December
100
90
80
70
60
50
40
30
20
10
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

LOFAR

Lightning



Hare et al. 2019

Image credit: Daniëlle Futselaar

Pulsars

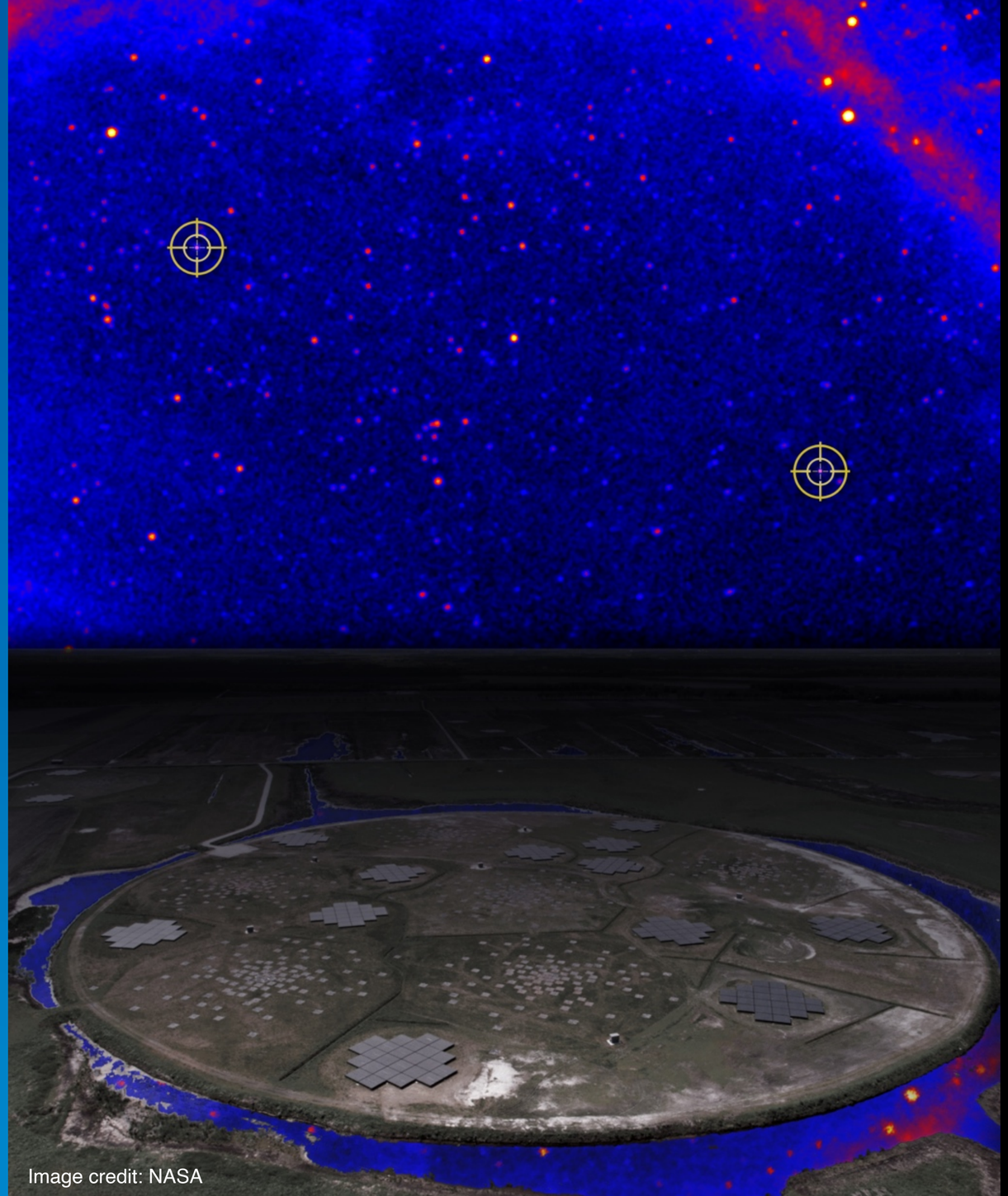
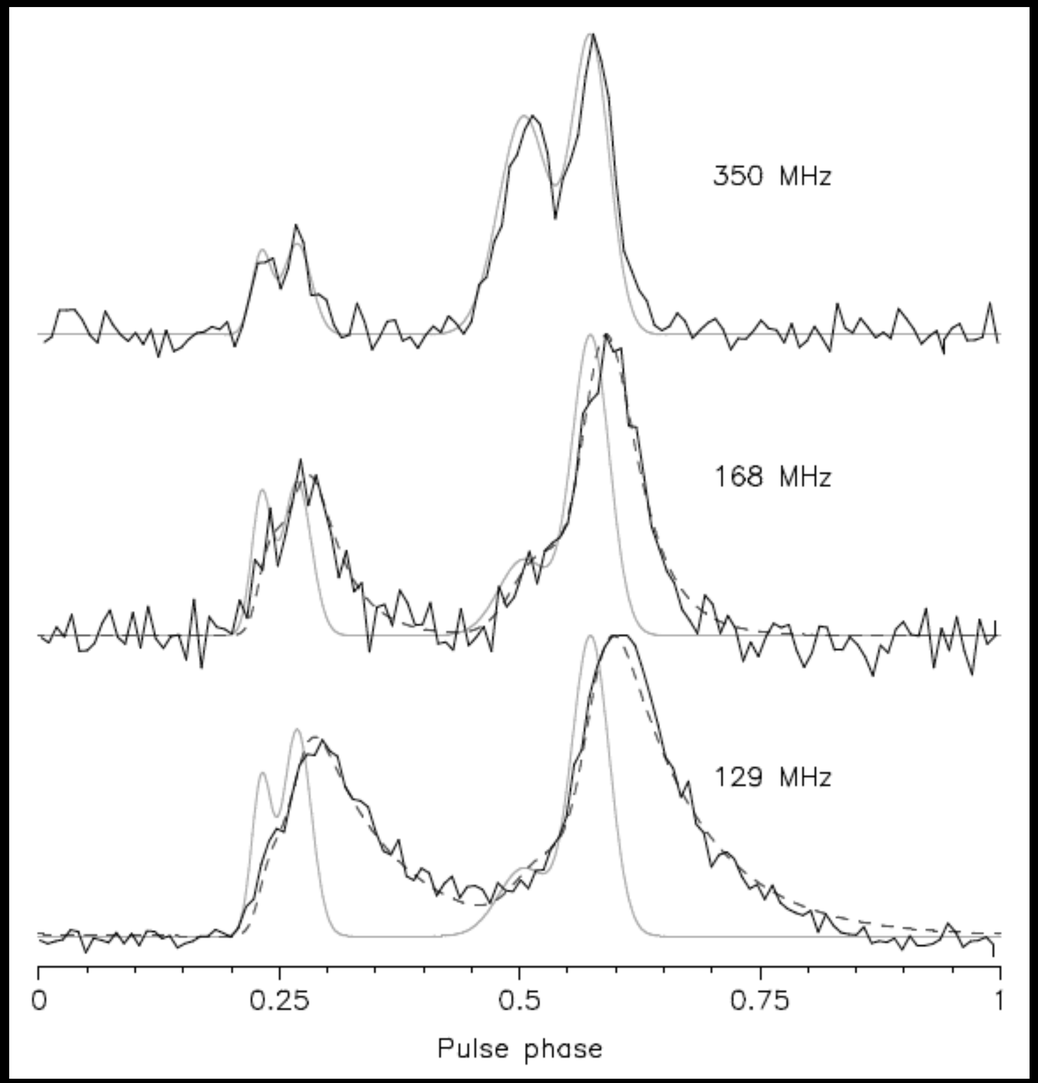
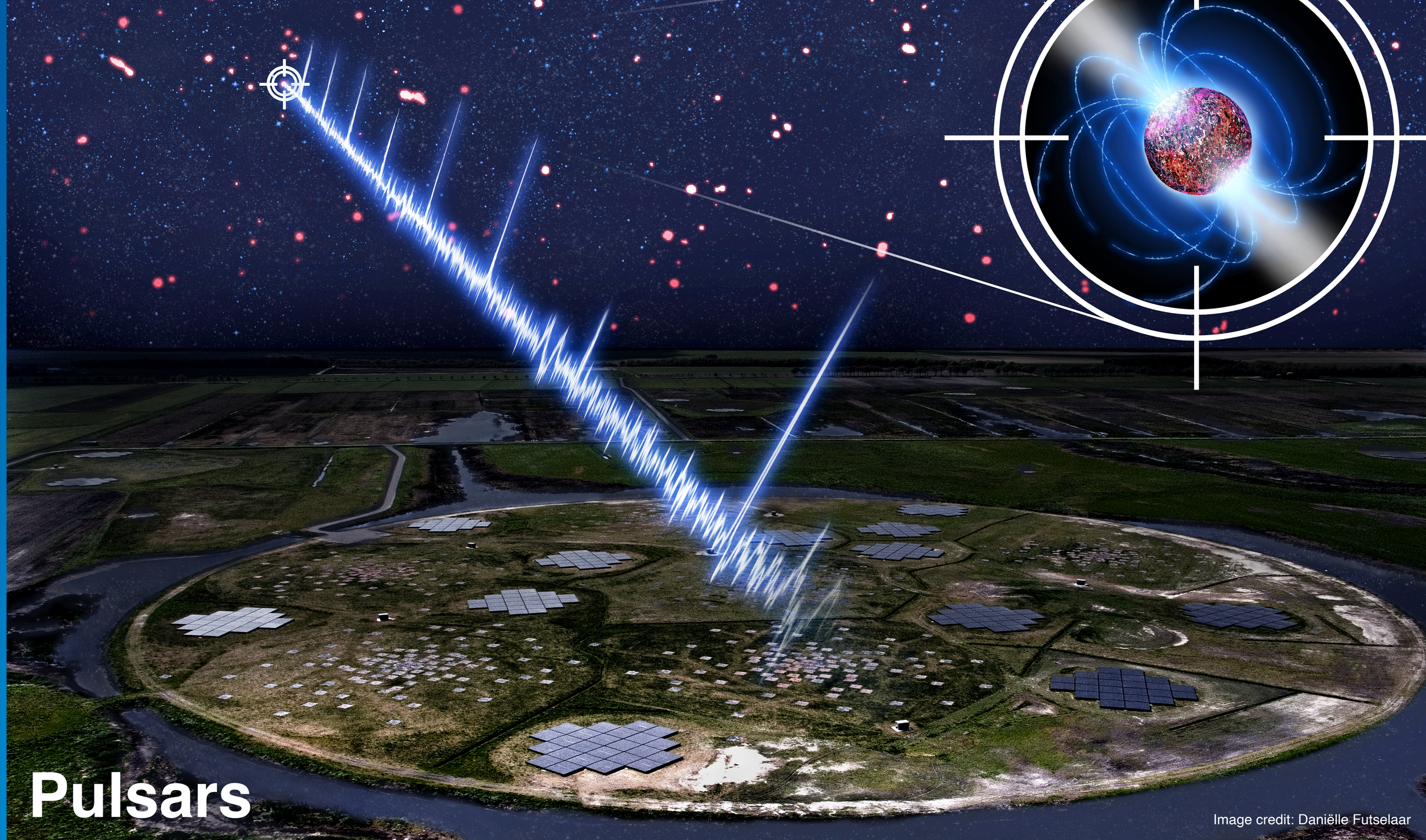


Image credit: NASA



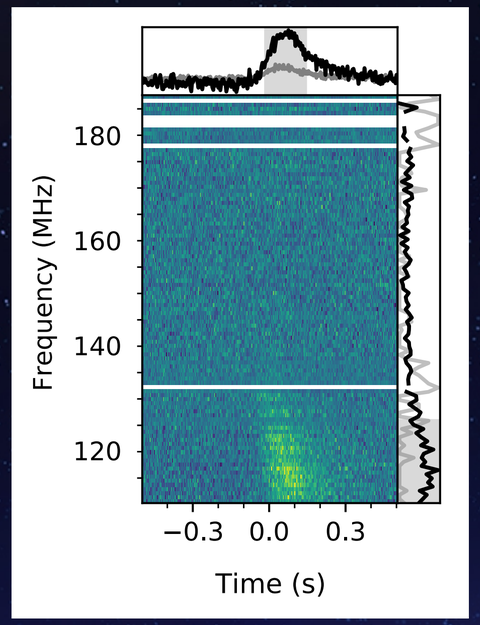
Bassa et al. 2017



Pulsars

Image credit: Daniëlle Futselaar

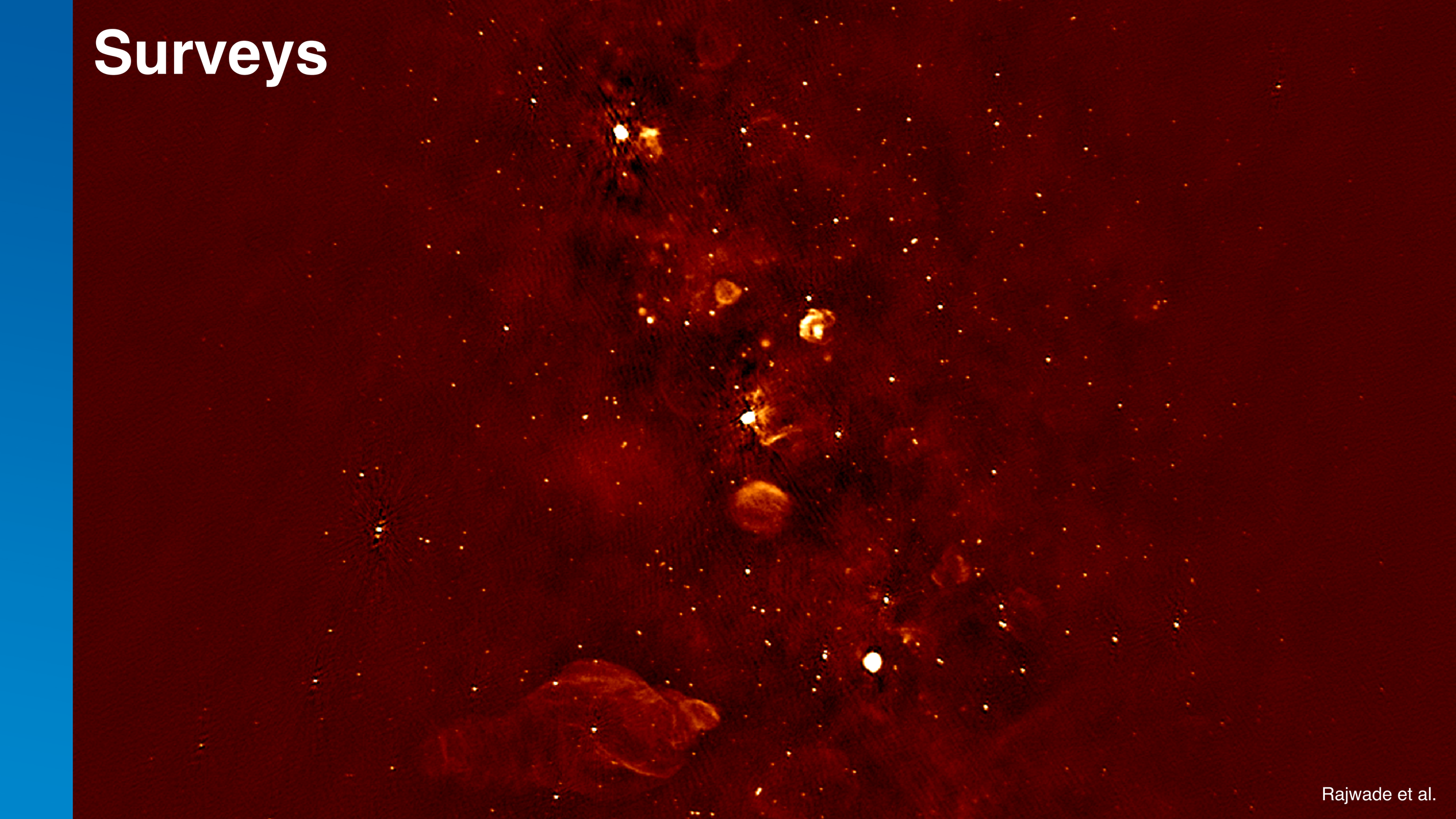
Fast radio bursts



Pleunis et al. 2021
(see also Pastor-Marazuela et al.)

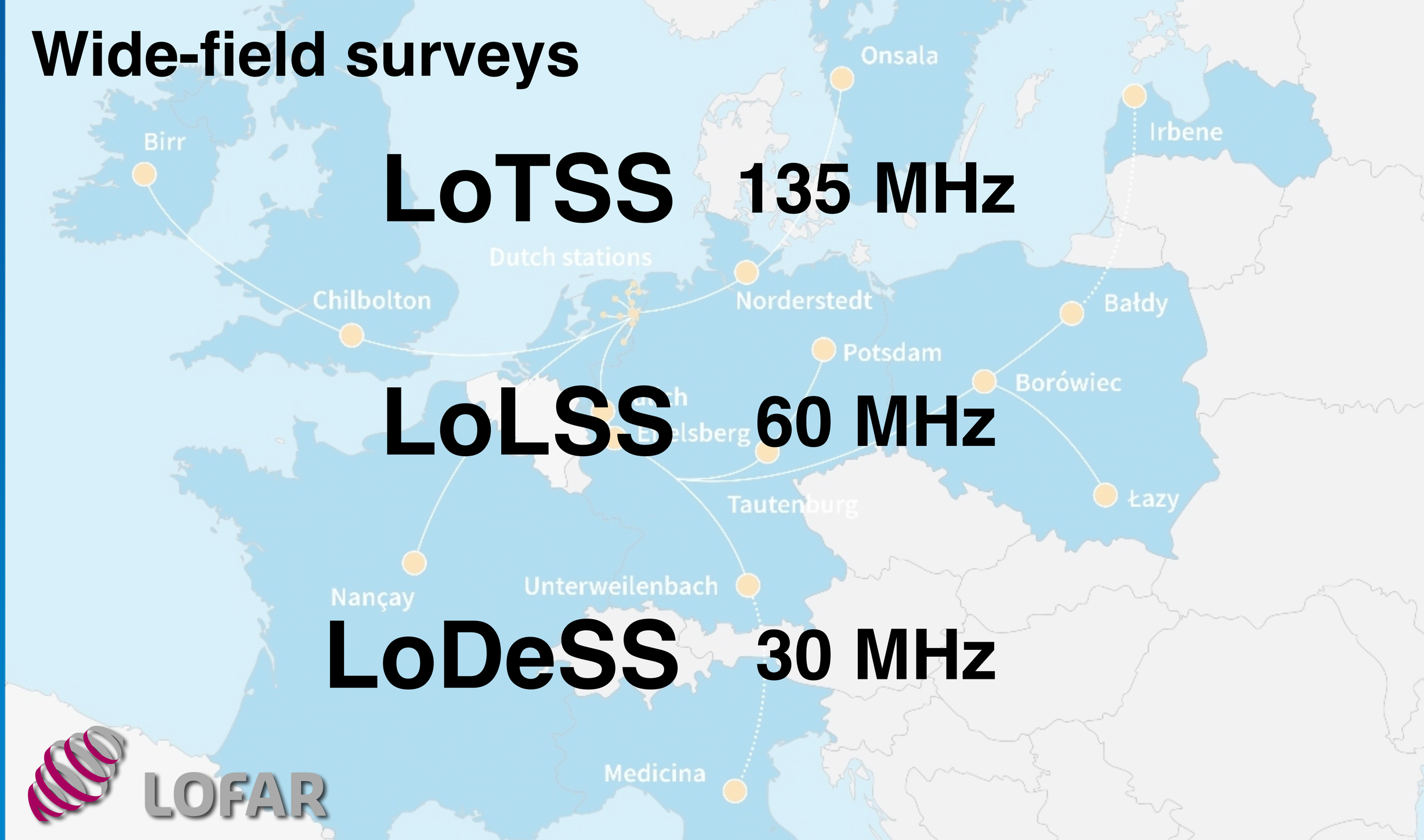
Image credit: Danielle Futselaar

Surveys



Rajwade et al.

Wide-field surveys



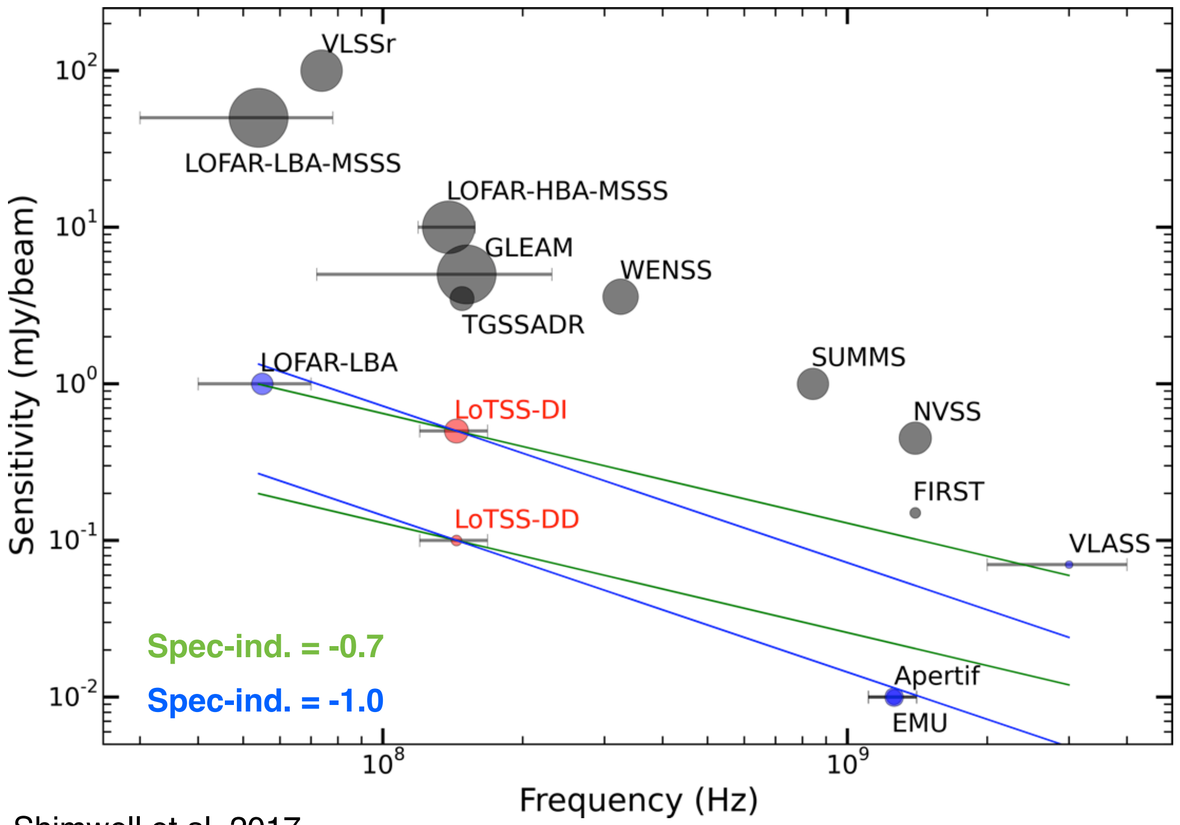
LoTSS 135 MHz

LoLSS 60 MHz

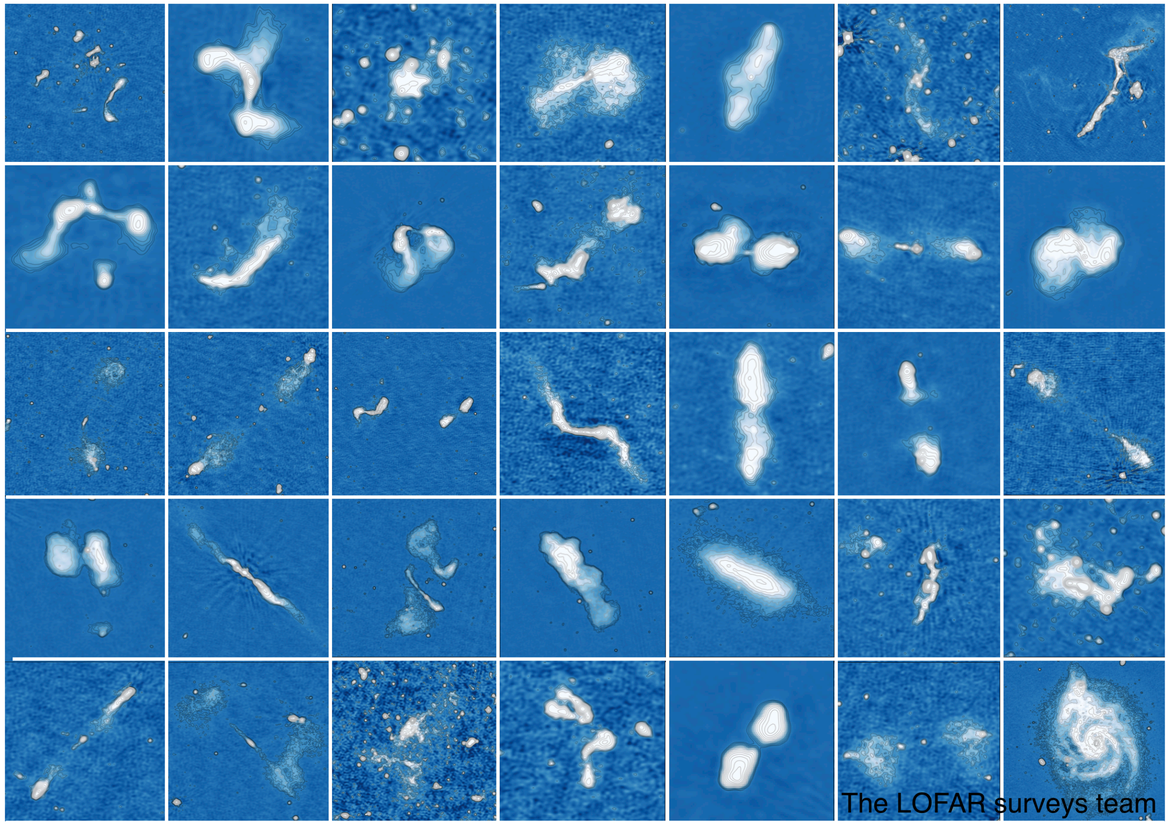
LoDeSS 30 MHz

LOFAR

LoTSS

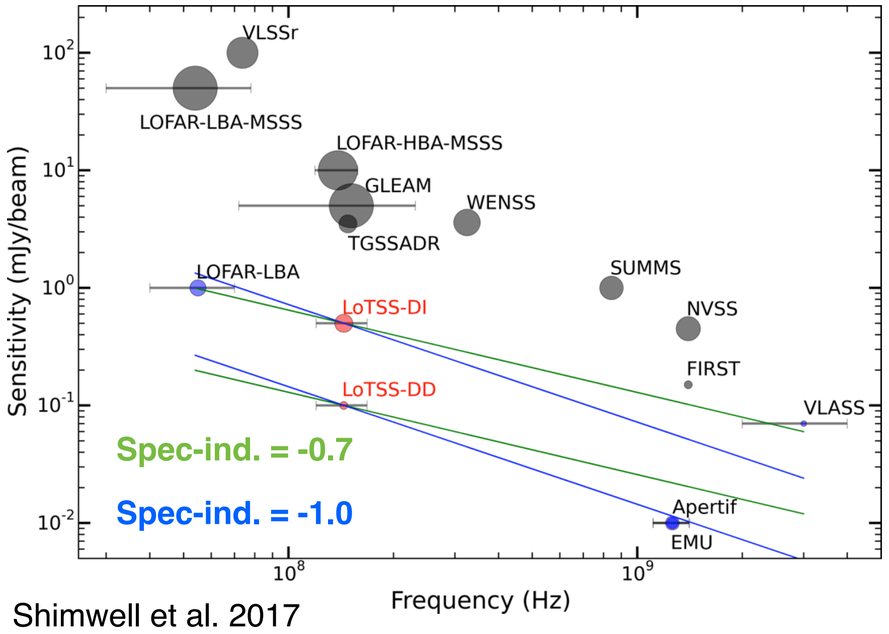


Shimwell et al. 2017

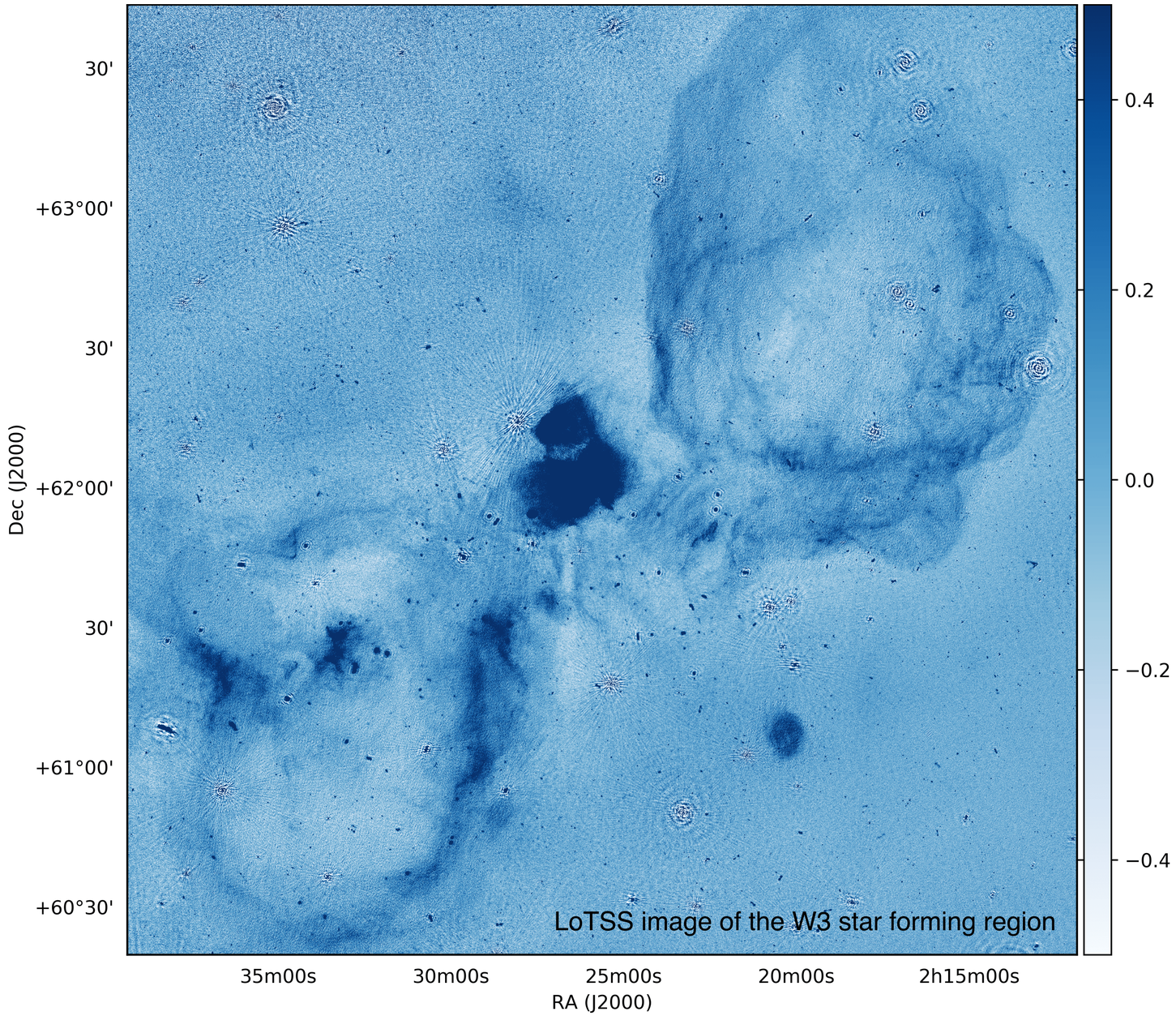


The LOFAR surveys team

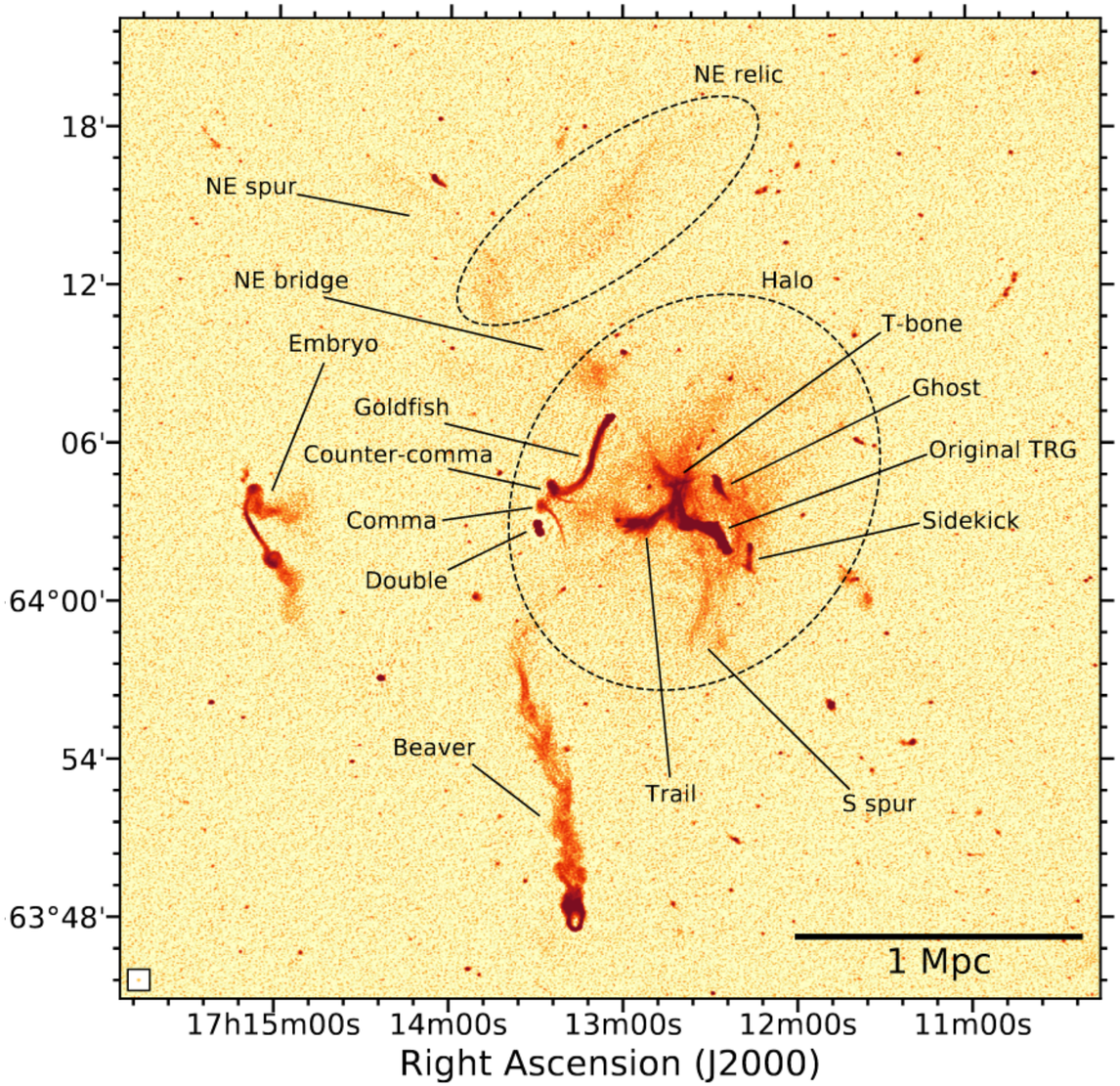
LoTSS



Shimwell et al. 2017

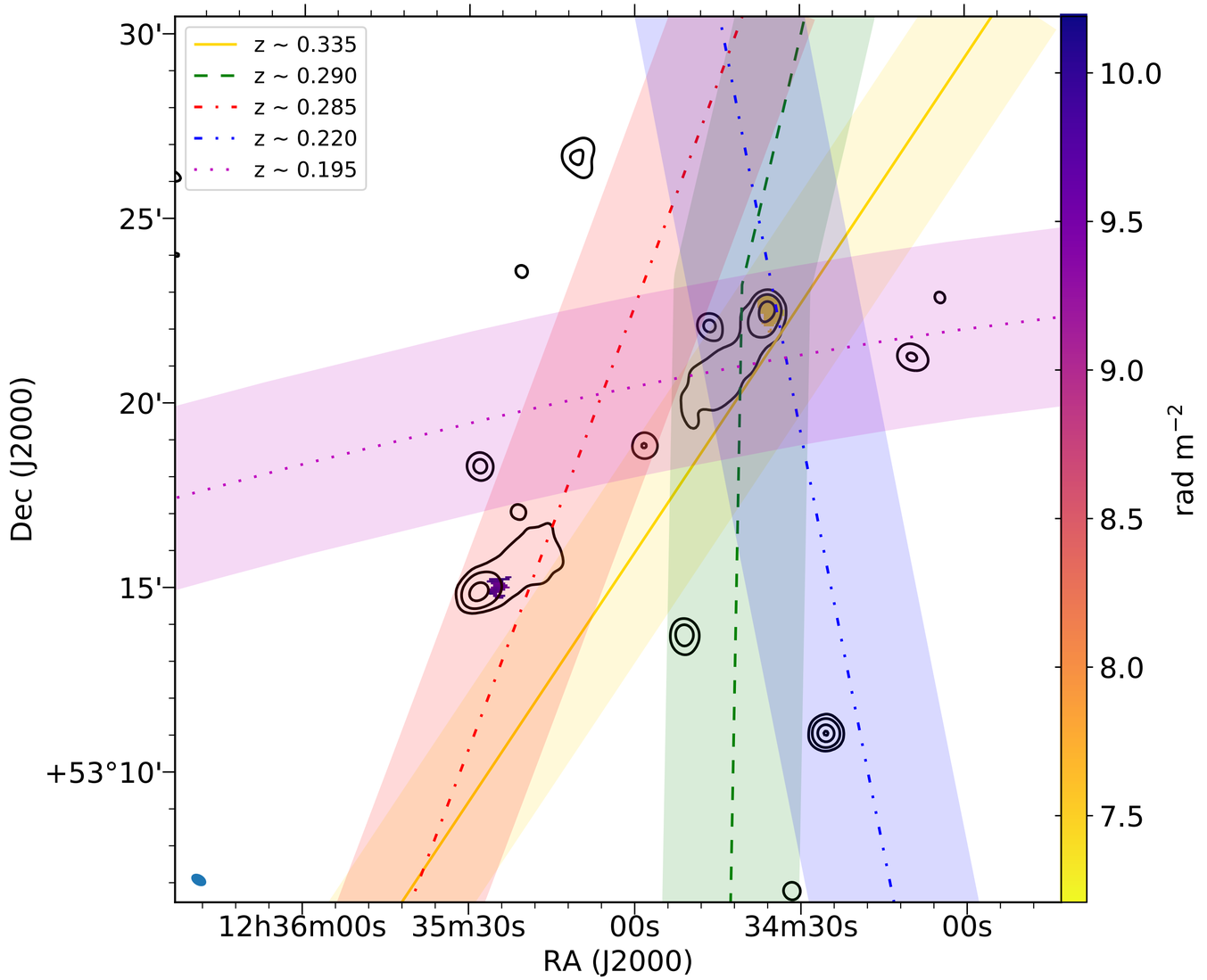


Galaxy clusters

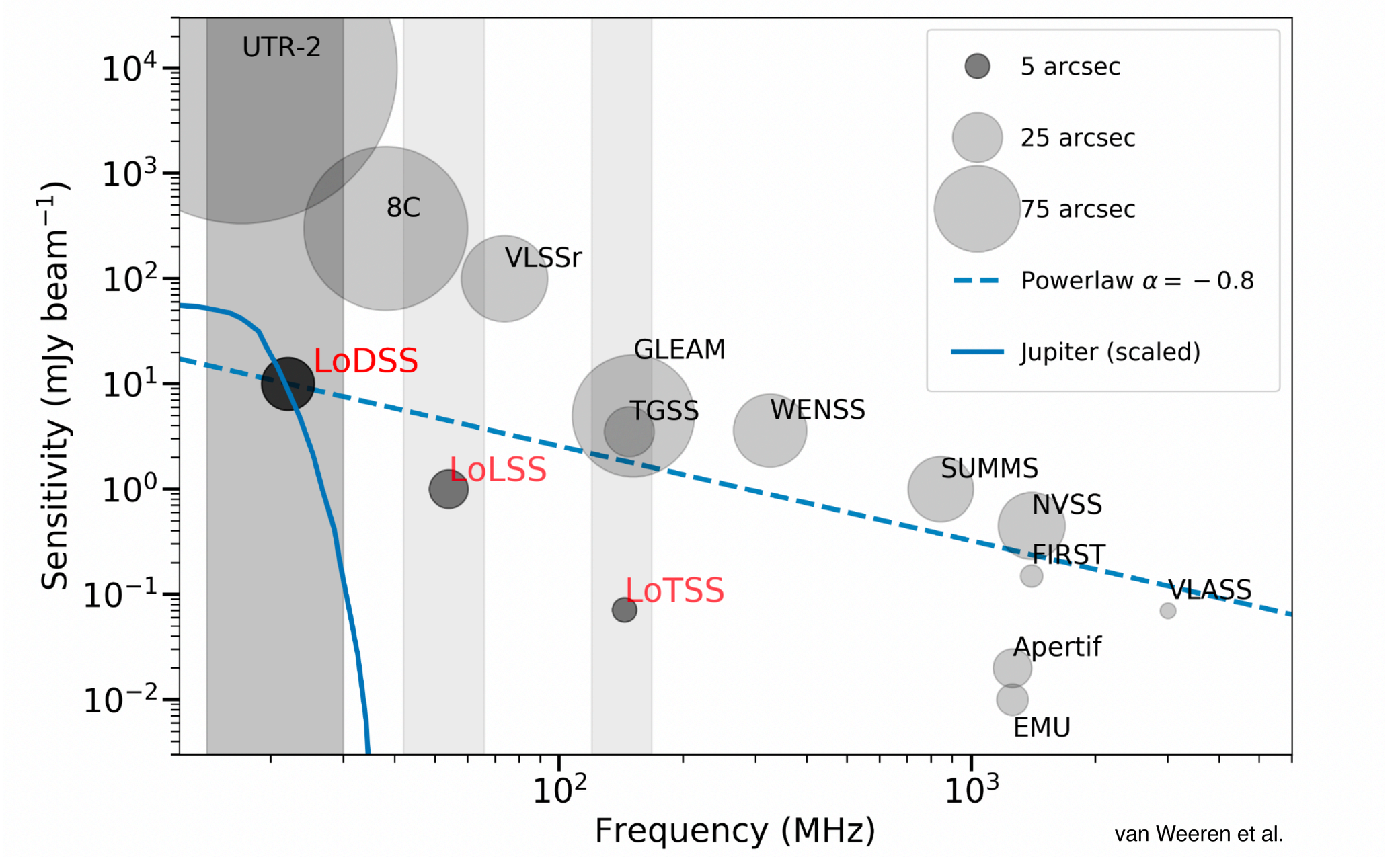


Particle acceleration in the intracluster medium in unprecedented detail: Botteon et al. 2020

Cosmic web



Probing the intergalactic magnetic field with Faraday rotation measurements of a giant radio galaxy - O' Sullivan et al. 2019.
A direct detection of cosmic filaments: Govoni et al. 2019, Botteon et al. 2018, 2020

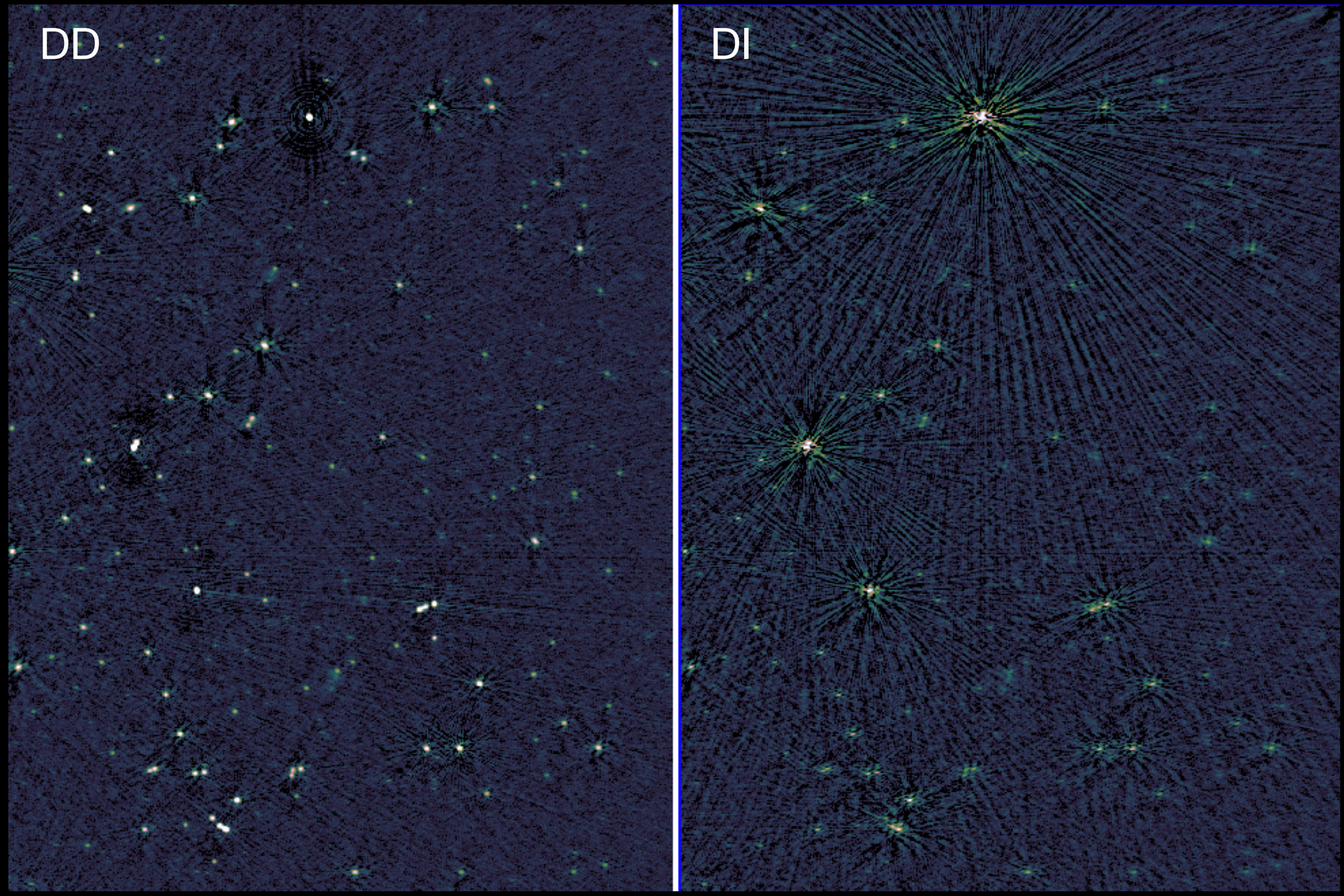


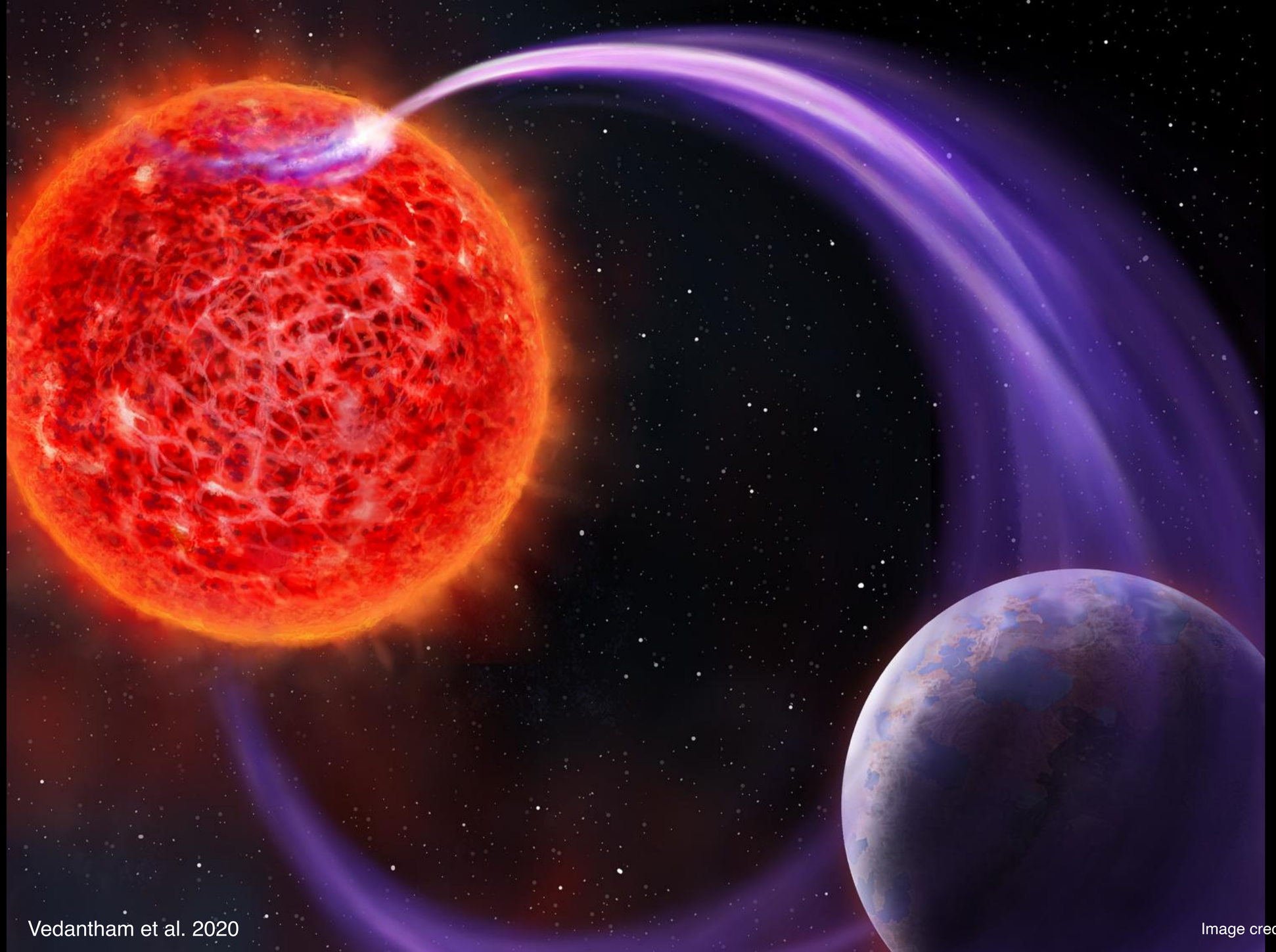
van Weeren et al.

resolution: 35″
noise: 12 mJy/beam

14-30 MHz

3C196 field zoom

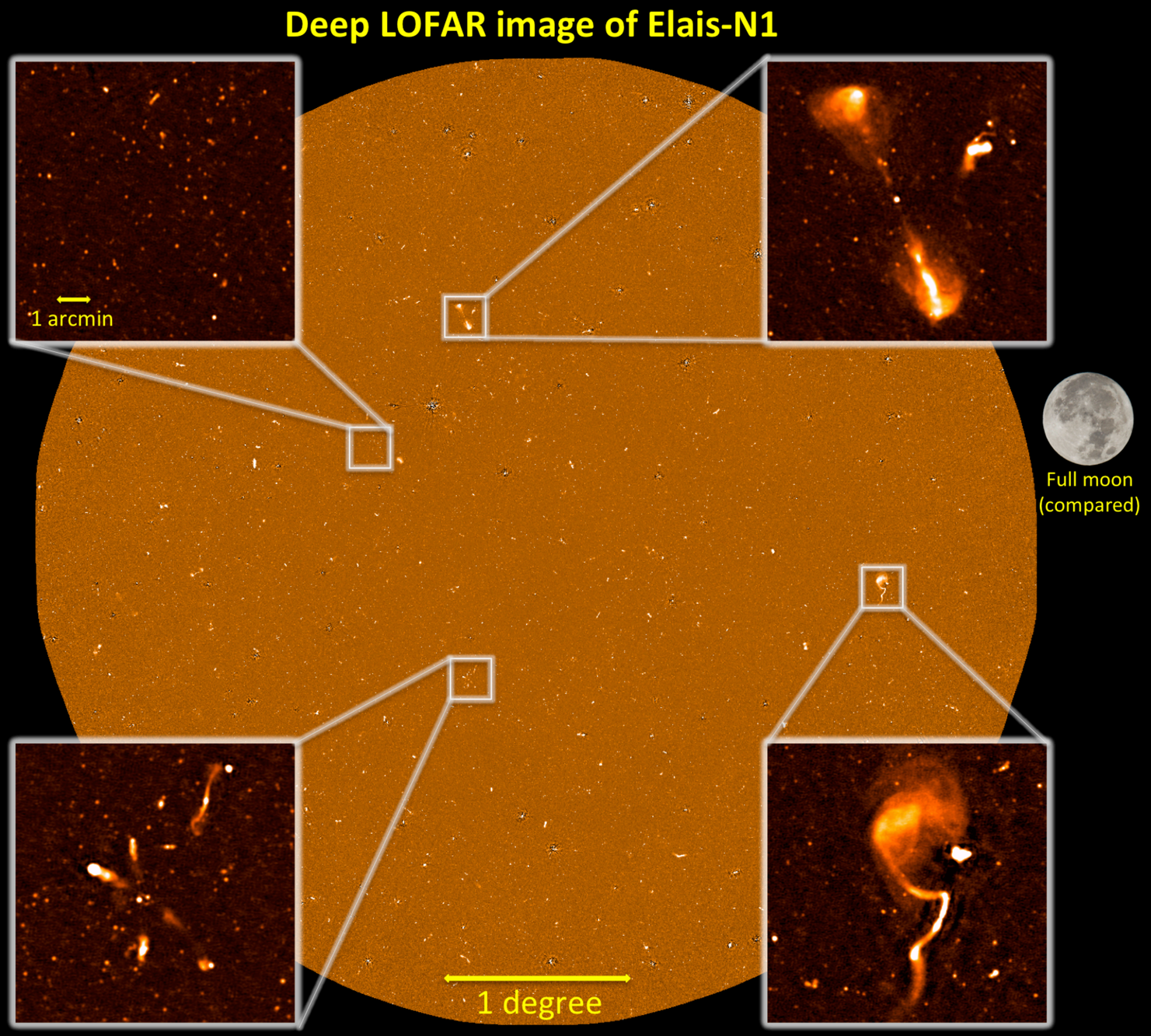




Vedantham et al. 2020

Image credit: Daniëlle Futselaar

Ultra-deep surveys



Ultra-wide field of view: probe 10s of millions of radio sources & study galaxy formation throughout cosmic time

Dr. Becky

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In conversation with Frits Sweijen (PhD student on th...

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In conversation with Dr Leah Morabito (LOFAR long...

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Incredibly detailed black hole jet images! | LOFAR...

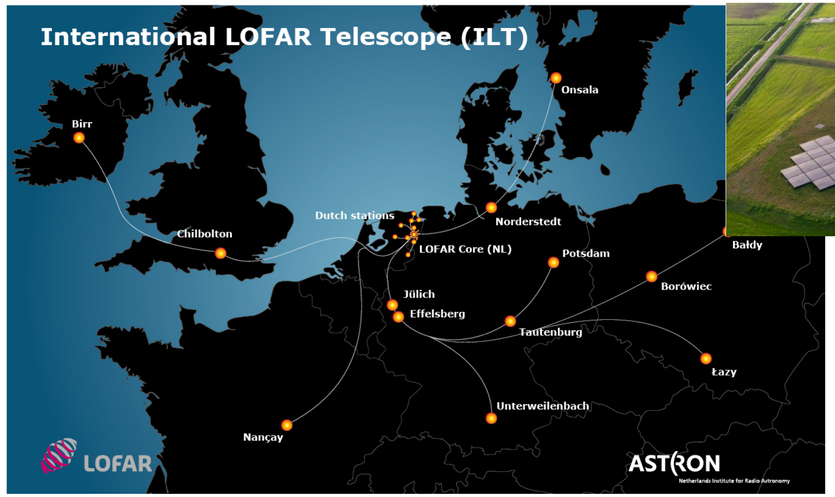
67K views • 2 weeks ago

What is LOFAR2.0?

- LOFAR2.0 is a staged programme of upgrades to keep LOFAR cutting edge well into the 2030s… soon hopefully as an “ERIC”!
- Stage 1 of the LOFAR2.0 programme includes, e.g., the DUPLLO and COBALT2.0 upgrades as well as the LOFAR4SW design project.
- Further community consultation to define possible future stages.

LOFAR

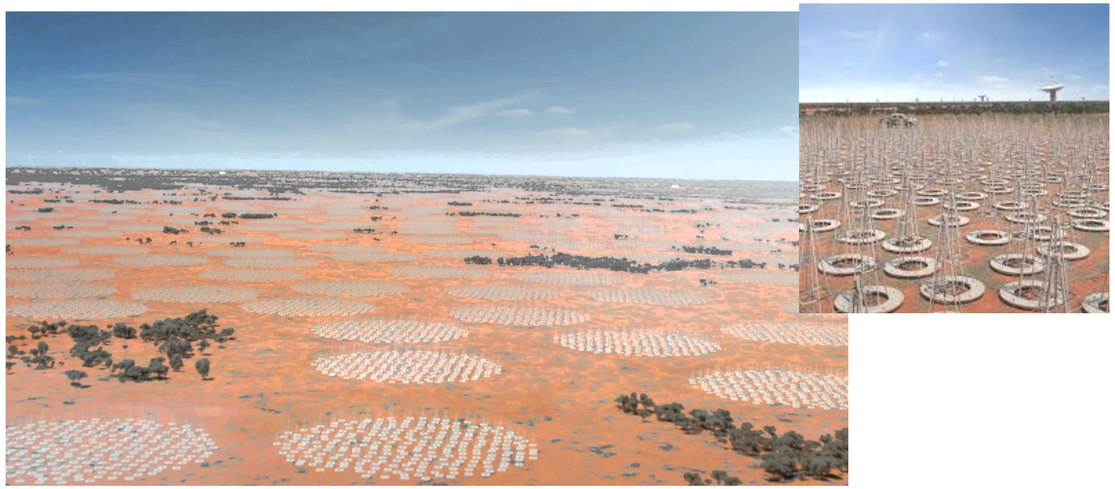
Compared to SKA-Low Phase 1



LOFAR + DUPLLO

Reaches 5x lower frequency

>10x higher resolution

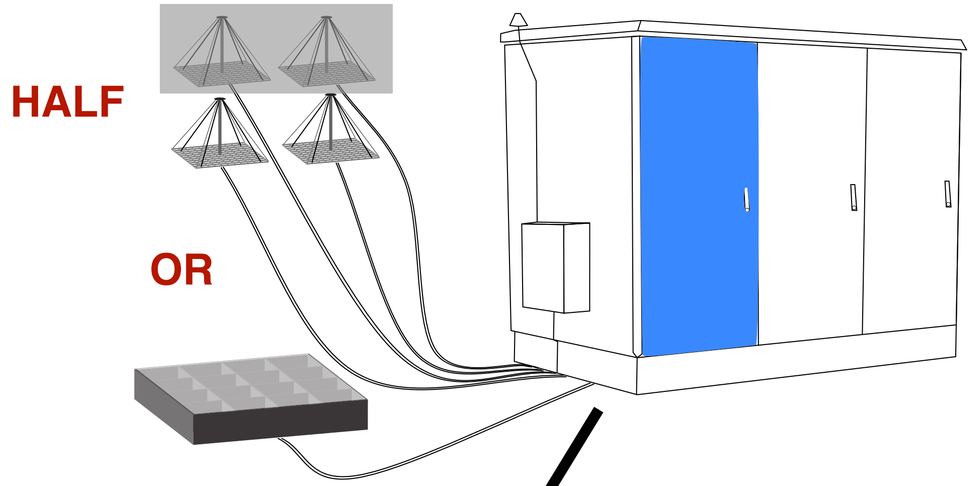


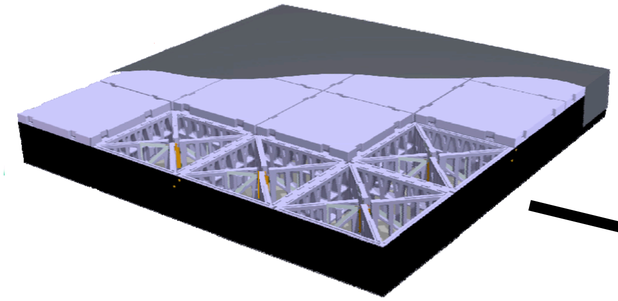
SKA-Low Phase 1

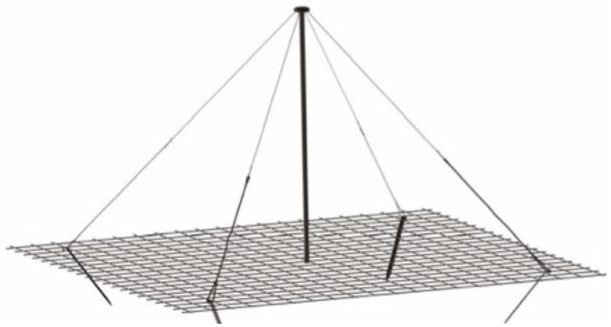
Reaches to 2x higher frequencies

>10x higher collecting area

LOFAR Stations







High-Band Antennas

Frequency = 110-240 MHz

Wavelength = 1-3 metres

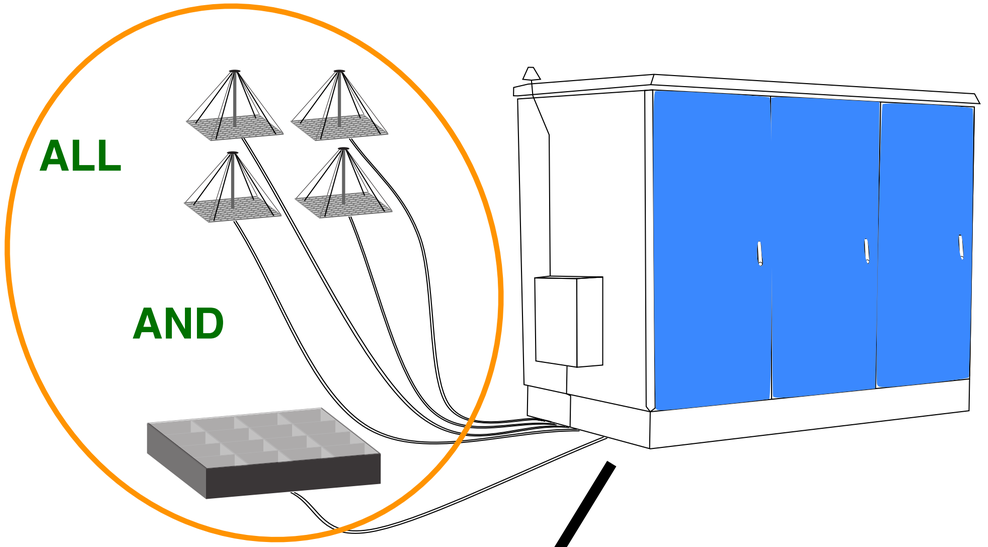
Low-Band Antennas

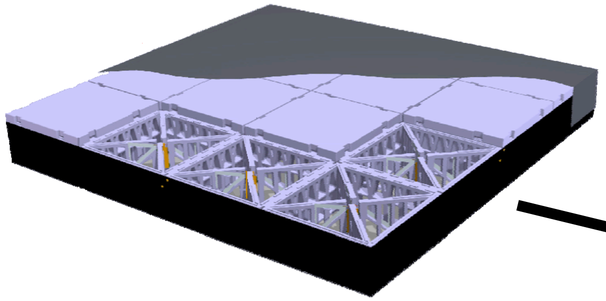
Frequency = 10-90 MHz

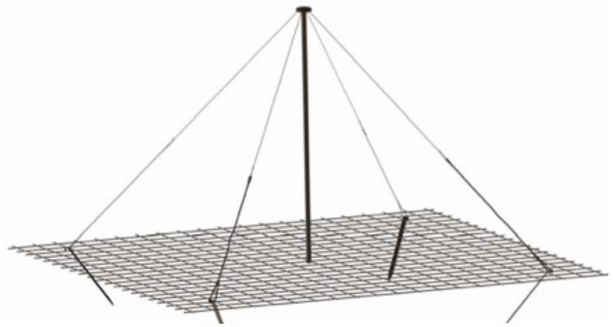
Wavelength = 3-30 metres

LOFAR Stations

Triple station electronics capacity







High-Band Antennas

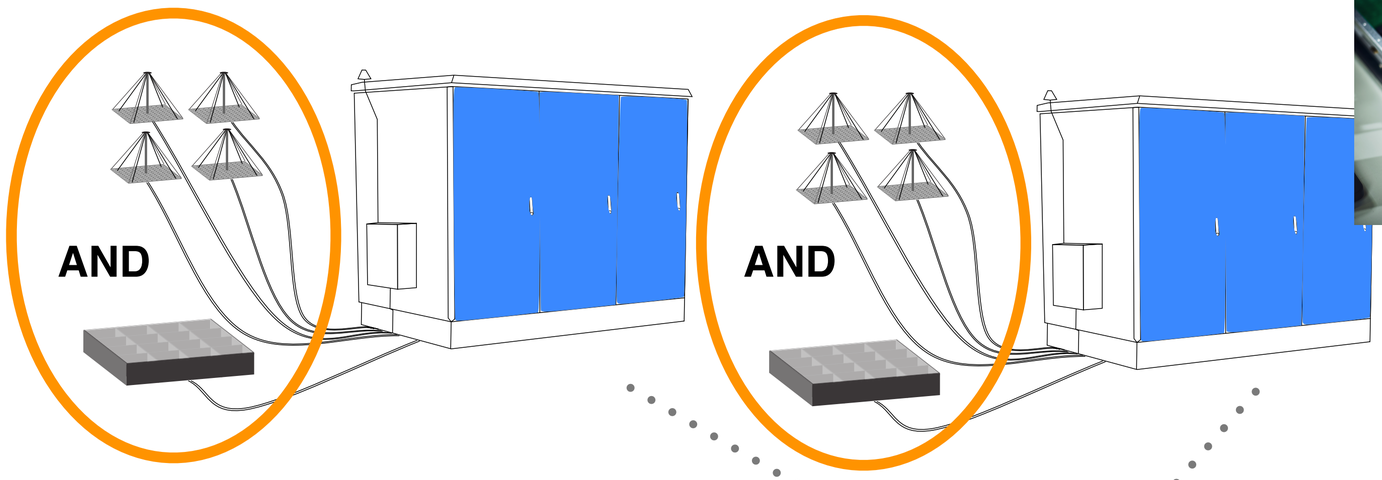
Frequency = 110-240 MHz

Wavelength = 1-3 metres

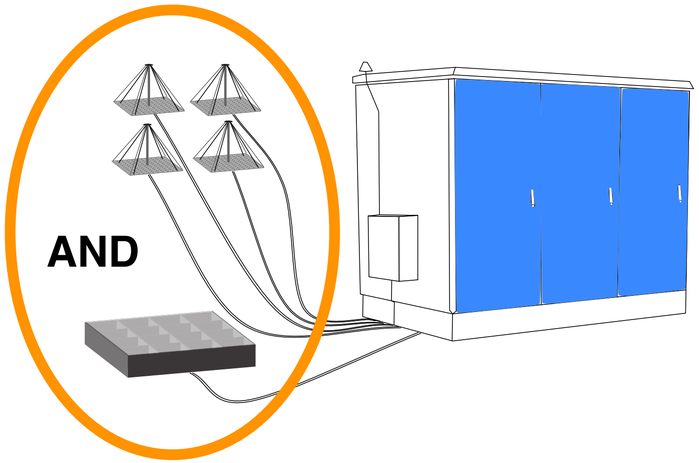
Low-Band Antennas

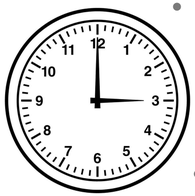
Frequency = 10-90 MHz

Wavelength = 3-30 metres



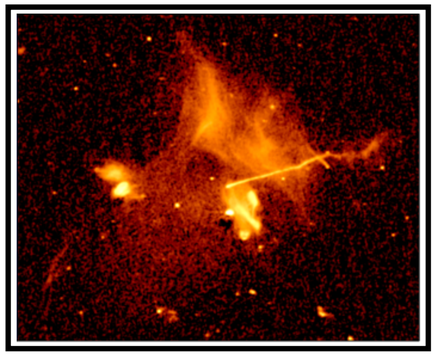
Triple station electronics capacity



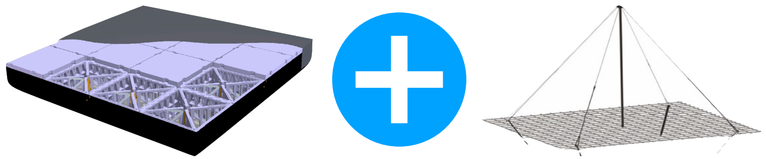


Single clock

Low and high-band observe together



All antennas used, in sync, for maximal calibration precision



Dutch stations

Onsala

Irbene

Birr

Chilbolton

Norderstedt

Bałdy

Potsdam

Borówiec

Jülich

Effelsberg

Tautenburg

Łazy

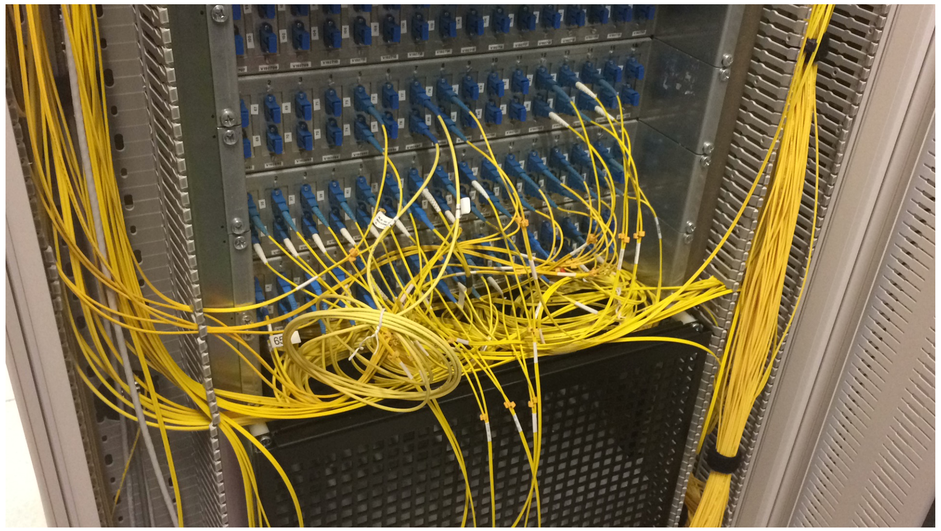
Nançay

Unterweilenbach

Medicina

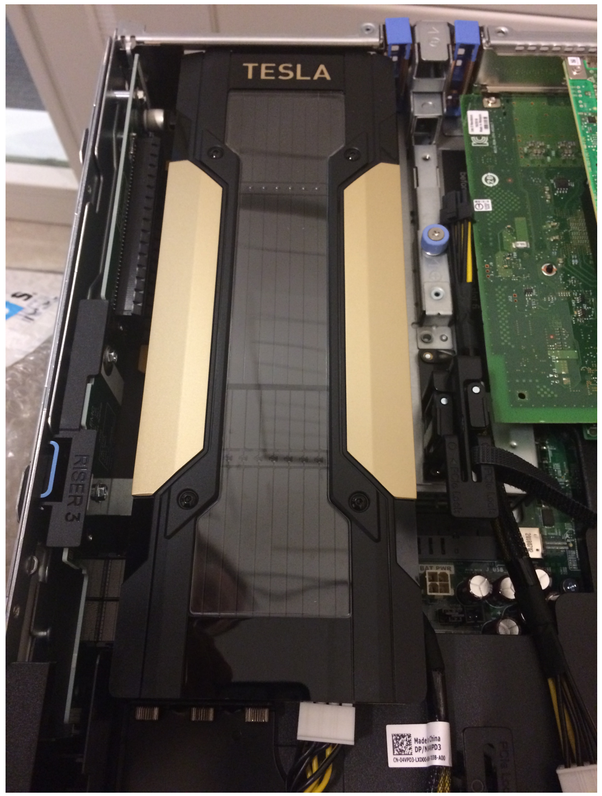
Rozhen

LOFAR

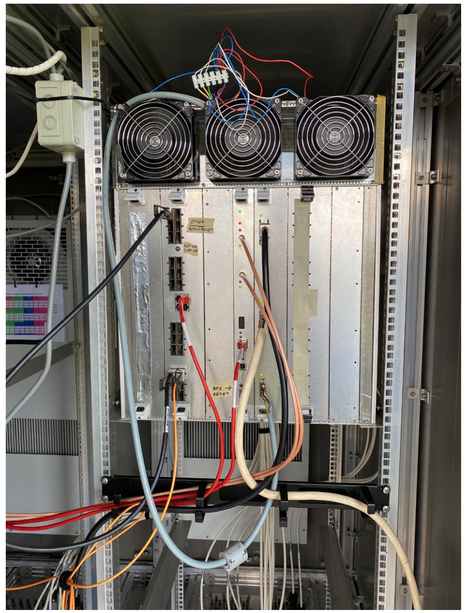


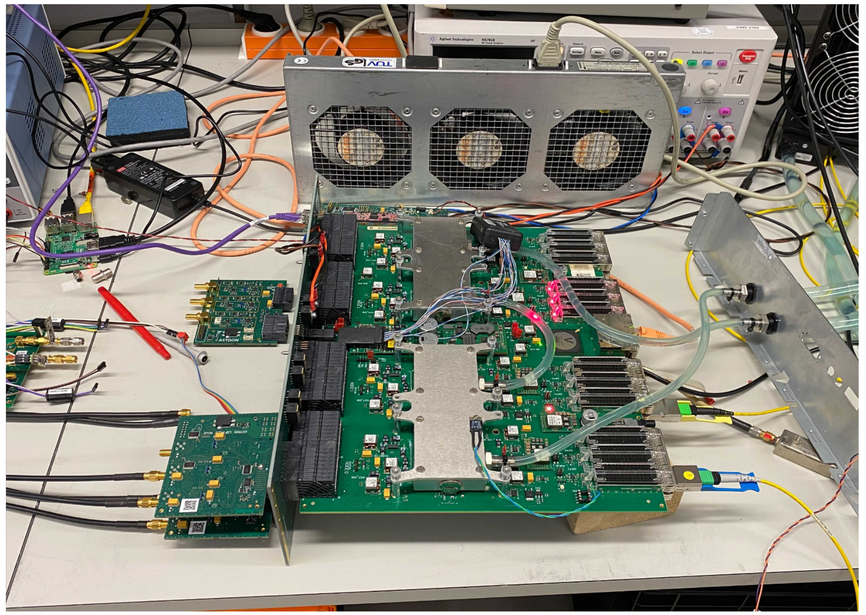
COBALT2.0

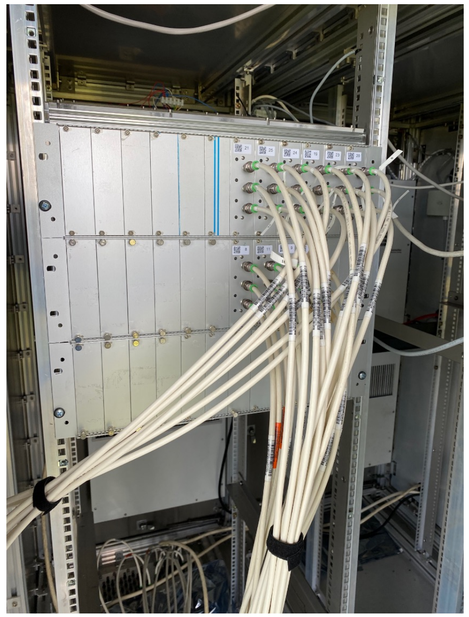
- Order of magnitude increase in online computing.
- Enables massively parallel observing modes.



Receivers & processing



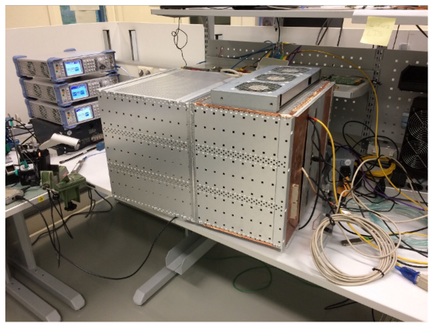




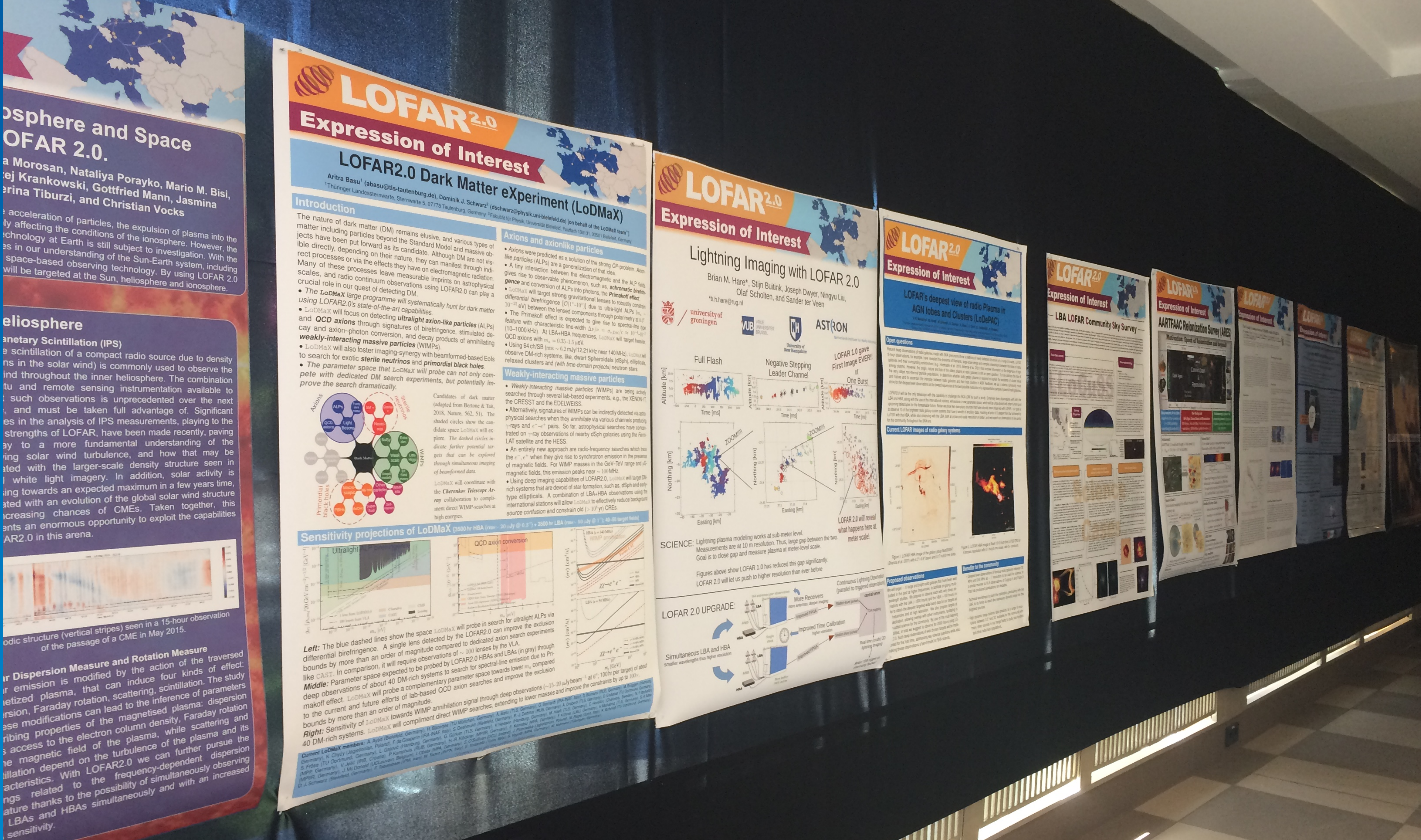
LOFAR

Test stations

- ✓ **Lab Test station (LTS)**
  - Test pcb's and interfaces
- ✓ **Dwingeloo Test Station (DTS)**
  - ✓ Cabinet thermal tests
  - ✓ Test complete signal chain (antenna to station output)
  - ✓ Monitoring and control
- ✓ **LOFAR2.0 Test Station (L2TS)**
  - ✓ CS001 is used as LOFAR2.0 test station from June 2022 (start of cycle 18)
  - ✓ Start with DTS hardware, upgrade to a fully equipped station
  - ➢ Full-scale station verification in operational environment (March 2023)



LOFAR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OFAR 2.0.
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Introduction
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Lightning Imaging with LOFAR 2.0
Brian M. Hare*, Stijn Buitink, Joseph Dwyer, Ningyu Liu, Olaf Scholten, and Sander ter Veen
Full Flash
Negative Stepping Leader Channel
LOFAR 1.0 gave First Image EVER!! of One Burst
SCIENCE:
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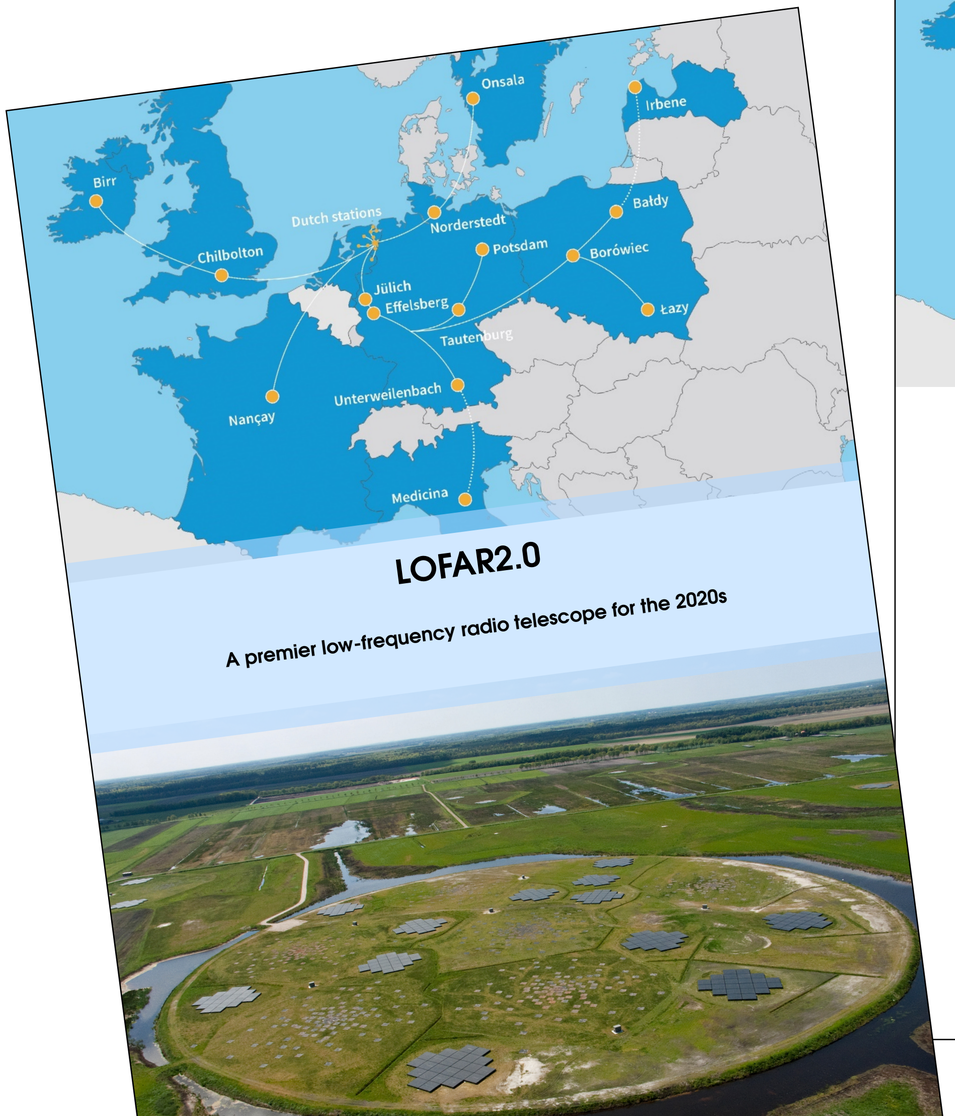
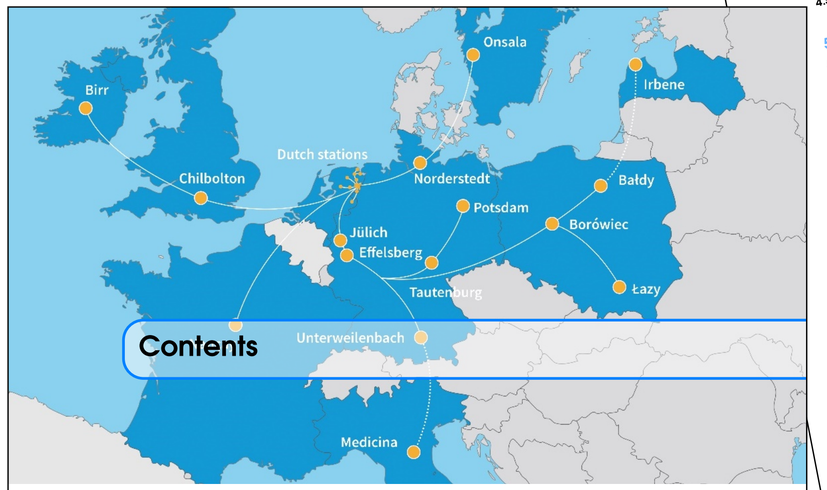
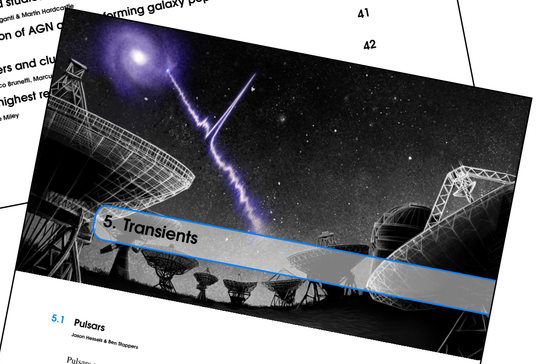
LBA LOFAR Community Sky Survey
Expression of Interest
AARTFAAC Reionization Survey (ARES)

LOFAR2.0 Science White Paper





Contents



5.1 Pulsars
Jason Hessels & Ben Stappers

Pulsars are highly magnetised neutron stars that produce beams of radio waves that sweep across the sky like a cosmic lighthouse. These radio pulsations allow us to study the properties and evolution of neutron stars, which are some of the most extreme objects in the Universe. Using the technique of pulsar 'timing', we can detect gravitational waves, constrain the neutron star equation of state and test Einstein's theory of gravity. Pulsars are exceptionally steep-spectrum radio sources. LOFAR is a unique pulsar telescope because of its high sensitivity across the lowest 4 octaves of the radio band, and its ability to provide voltage tied-array data for multiple sources at once. LOFAR has discovered close to 100 radio pulsars to date[**sanidas2019**]. LOFAR pulsar discoveries include a record-breaking slow 23.5-sec pulsar, which may be a magnetar descendent[**tan2018**], and a 1.41-ms pulsar that is the fastest-spinner in the Galactic field[**bassa2017**]. We have also used LOFAR in tandem with the X-ray telescope *XMM-Newton* to demonstrate broadband modeling, in which a pulsar rapidly changes between two distinct and characteristic emission modes[**hermsen2013**].

Highlight 12 LOFAR has discovered both the fastest- and slowest-spinning radio pulsars in the Galactic field.

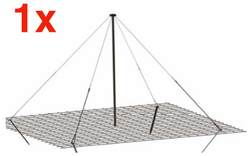
With LOFAR2.0 we will perform an ultra-deep pulsar survey by targeting compact, highly polarised sources found in LOFAR imaging surveys like LoTSS. We aim to find the most exotic radio pulsars, and to use them as probes of gravity and dense matter physics. The NL single clock will provide higher-quality and higher-sensitivity tied-array observations. COBALT2.0 allows the parallel observing modes that are needed to conduct such observations. COBALT2.0 allows the imaging surveys. The LOFAR stations, especially the large International stations, are sensitive telescopes in their own right. By using sub-arrays, we can also monitor dozens of pulsars in parallel and use these pulsar timing data to measure neutron star orbits, probe the interstellar medium, and measure the density and magnetization of the solar wind (see also §3.2).

LOFAR

Timeline

2018 2020 2022 2024 2026 2028 2030 2032

1x



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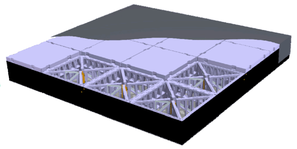

LOFAR

DUPLLO Project

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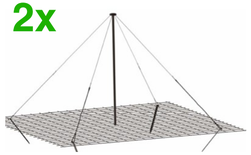

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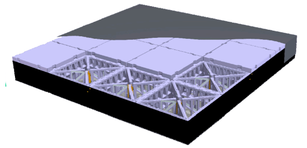

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LOFAR2.0

Scientific & technical synergy

Square Kilometre Array

LOFAR