LOFAR2.0

Low frequency science with LOFAR2.0: future perspective

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LOFAR2.0 Project Scientist

LOFAR2.0 Large Programmes

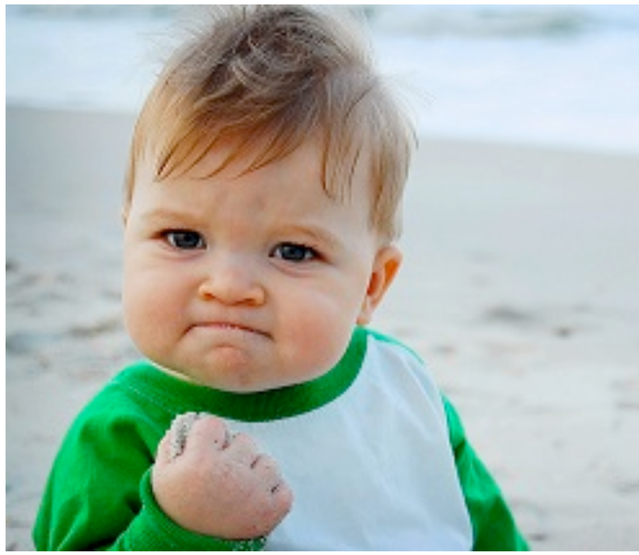
Deadline was: October 12th, 2023 at 12:00 UTC

LOFAR ERIC

LOFAR2.0 Large Programmes

Success Criteria

- **Scientific impact**
  - Publications, citations, theses, prizes, grants
- **Technical impact**
  - Techniques, software
- **Community impact**
  - Partner countries & institutes, support ECRs, develop SKA leadership roles
- **Accessibility & legacy**
  - Data reuse, distilled data products
- **Visibility**
  - Make LOFAR better known to other astronomers, policy makers, the public



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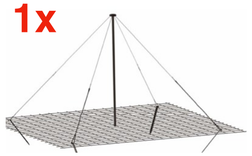
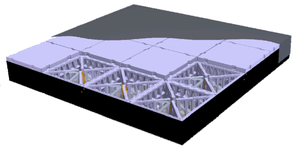
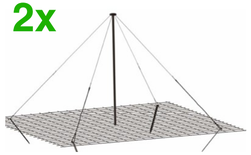
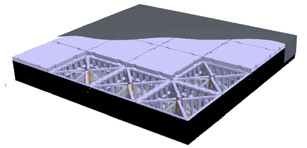
Timeline

2018 2020 2022 2024 2026 2028 2030 2032

1x  or 

LOFAR

DUPLLO Project

2x  and  and 

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Scientific & technical synergy

Square Kilometre Array

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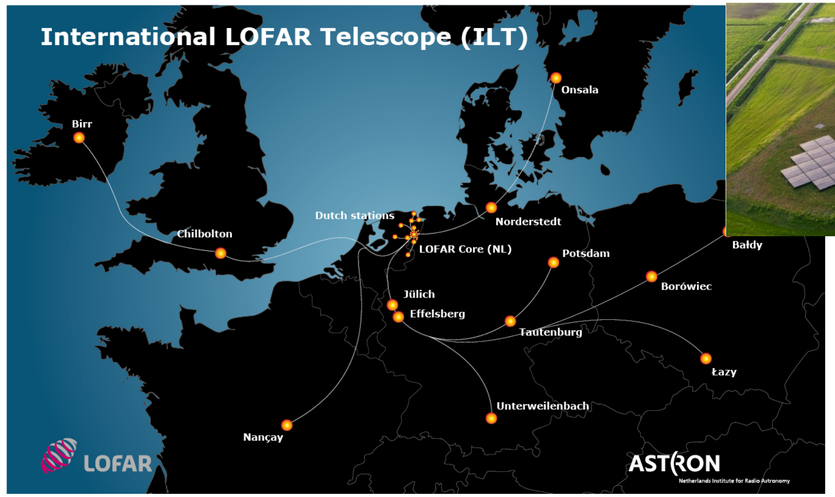
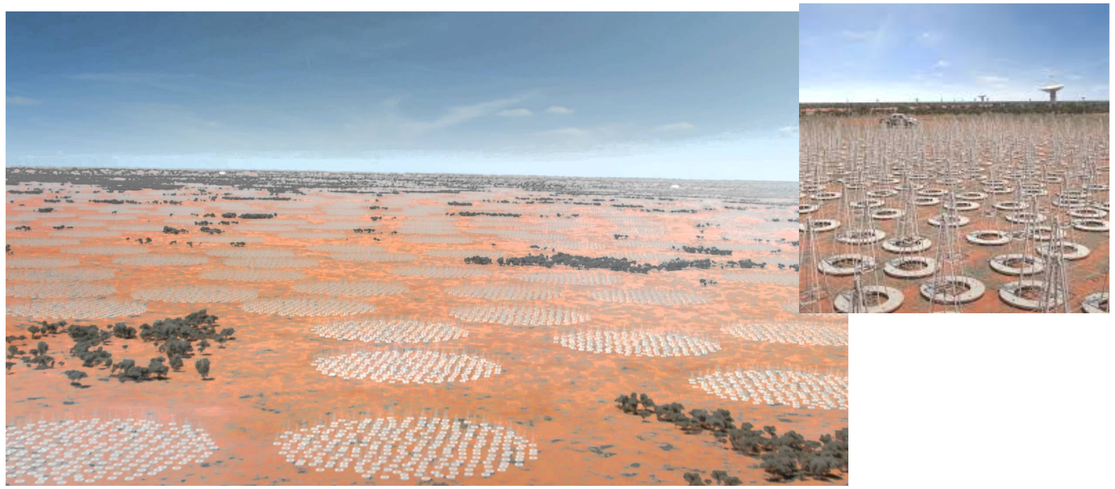
Compared to SKA-Low Phase 1



LOFAR + DUPLLO

Reaches 2x lower frequency

>10x higher resolution



SKA-Low Phase 1

Reaches to 2x higher frequencies

>10x higher collecting area

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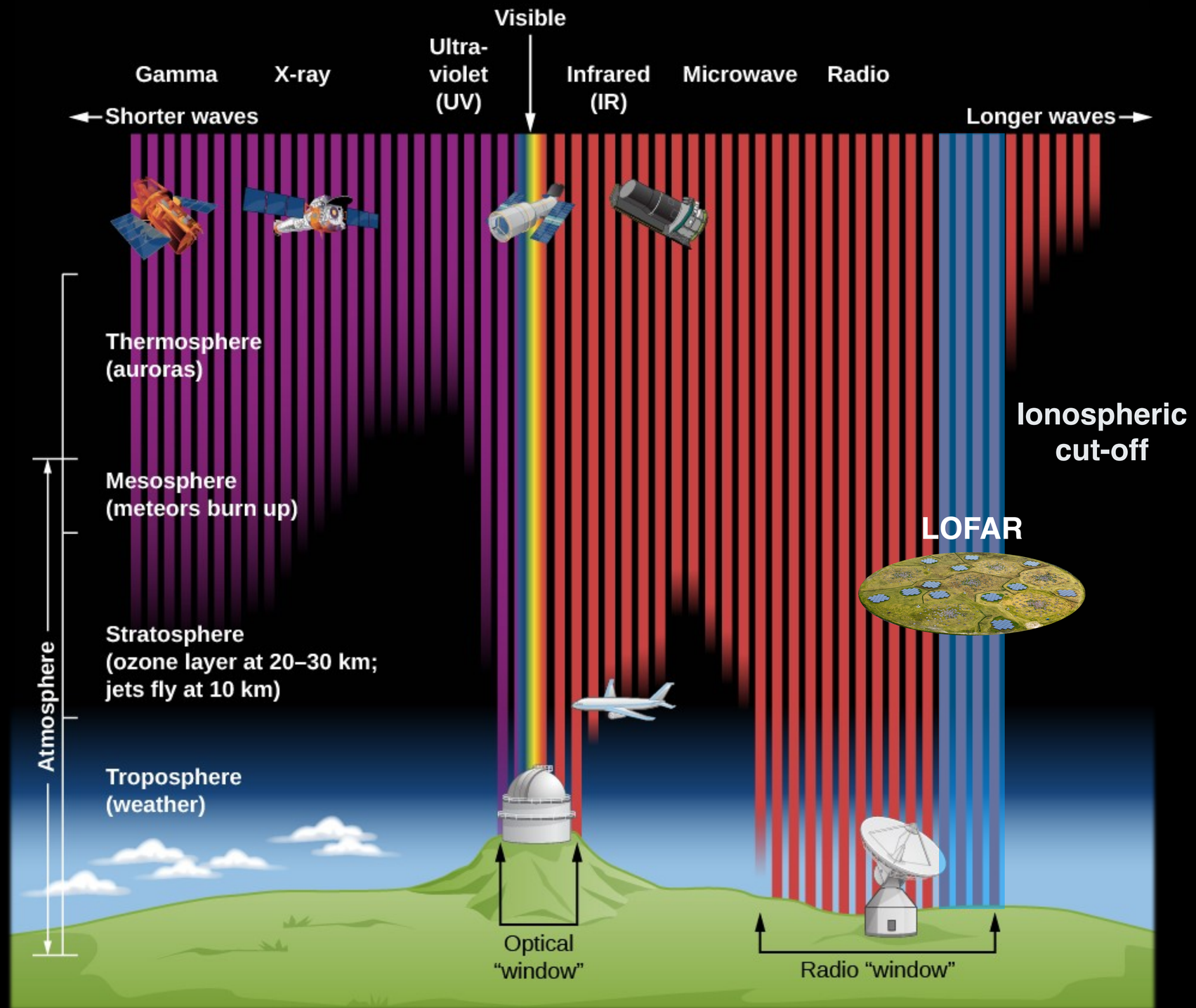
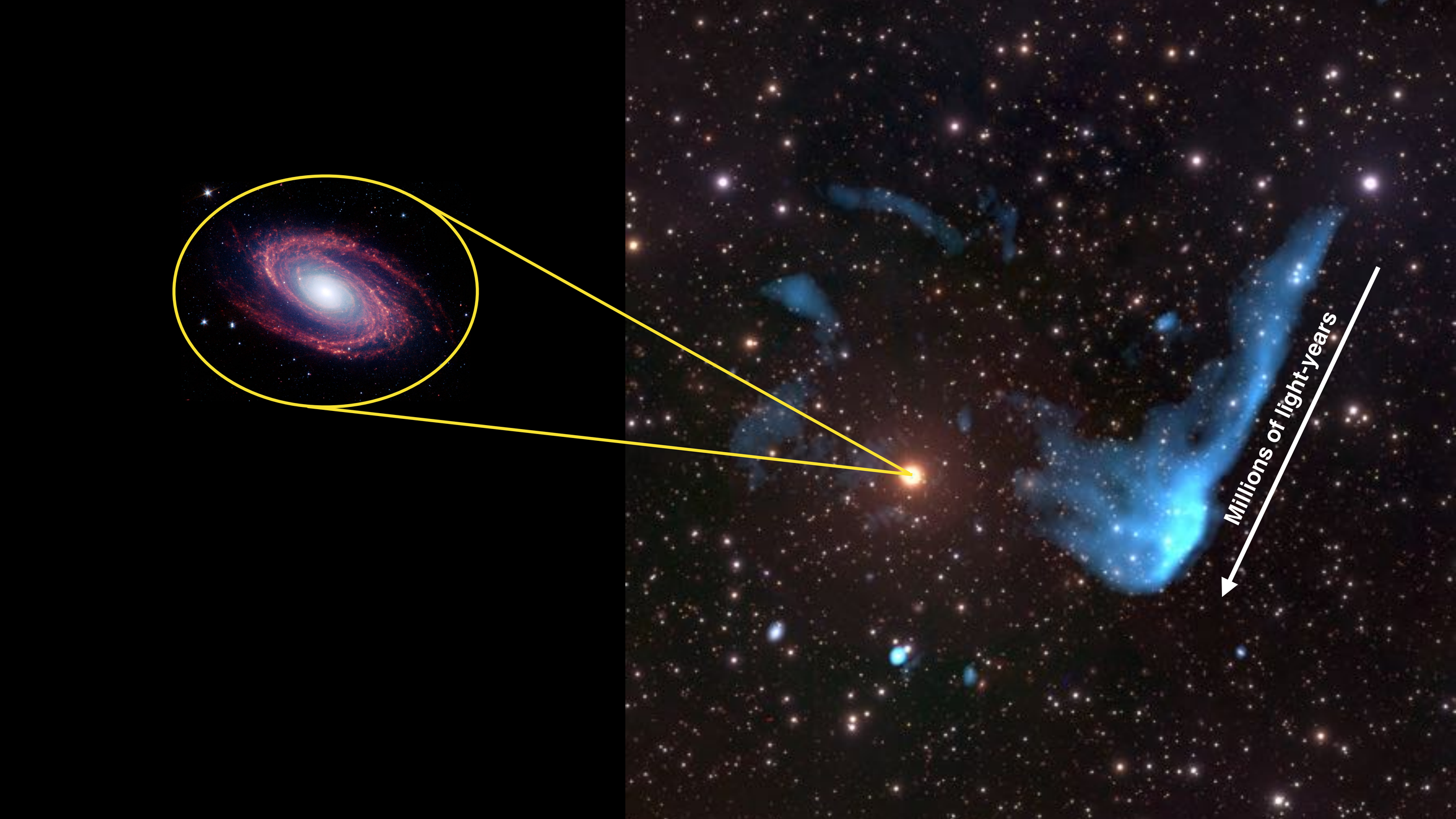

Visible
Gamma
X-ray
Ultra-violet (UV)
Infrared (IR)
Microwave
Radio
Shorter waves
Longer waves
Thermosphere (auroras)
Mesosphere (meteors burn up)
Stratosphere (ozone layer at 20–30 km; jets fly at 10 km)
Troposphere (weather)
Atmosphere
Ionospheric cut-off
LOFAR
Optical "window"
Radio "window"


Millions of light-years

Observing capabilities

FoV

Observing cadence

Commensal observing

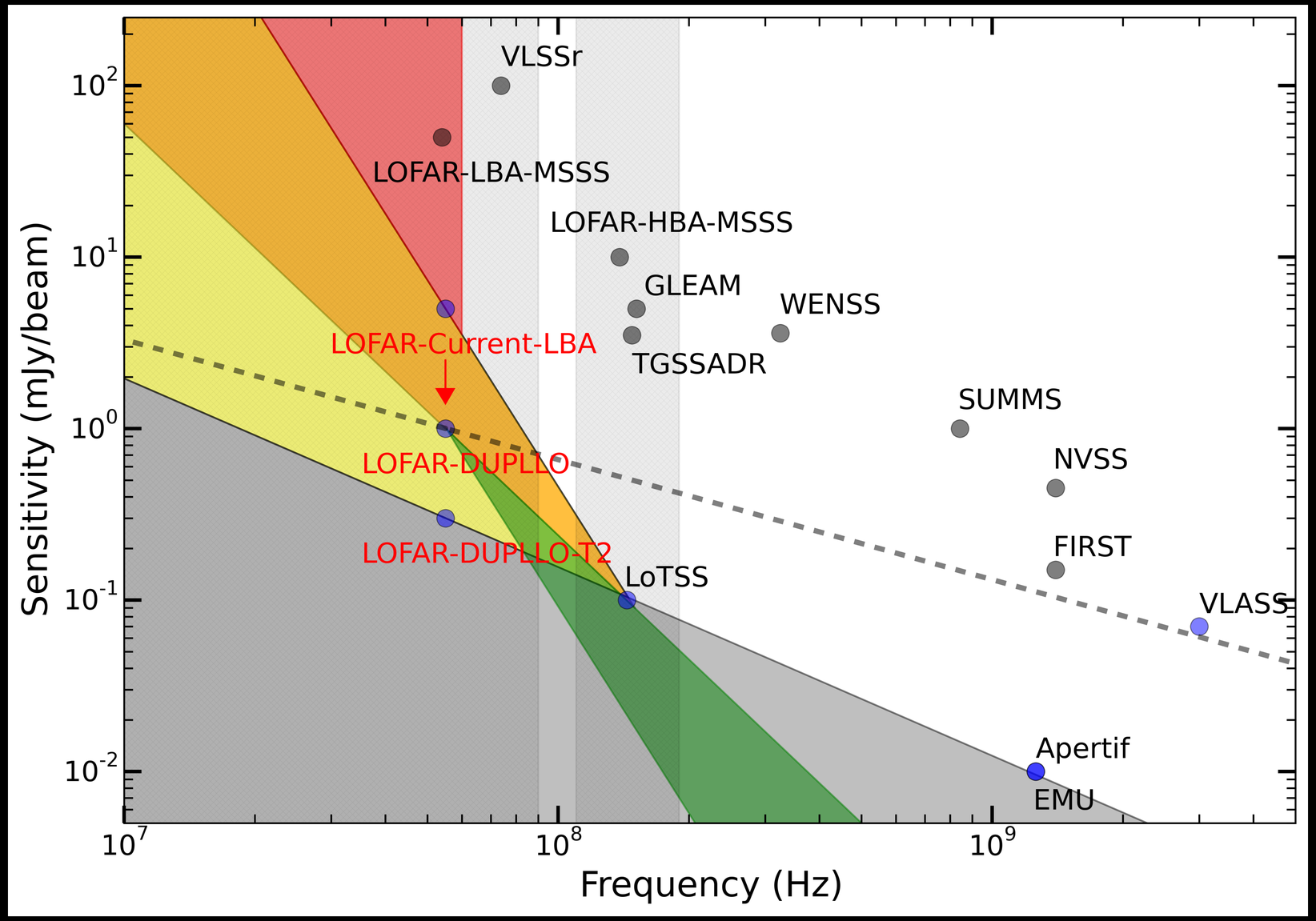
Angular resolution

Spectral range

Time resolution

discoveryplace.org

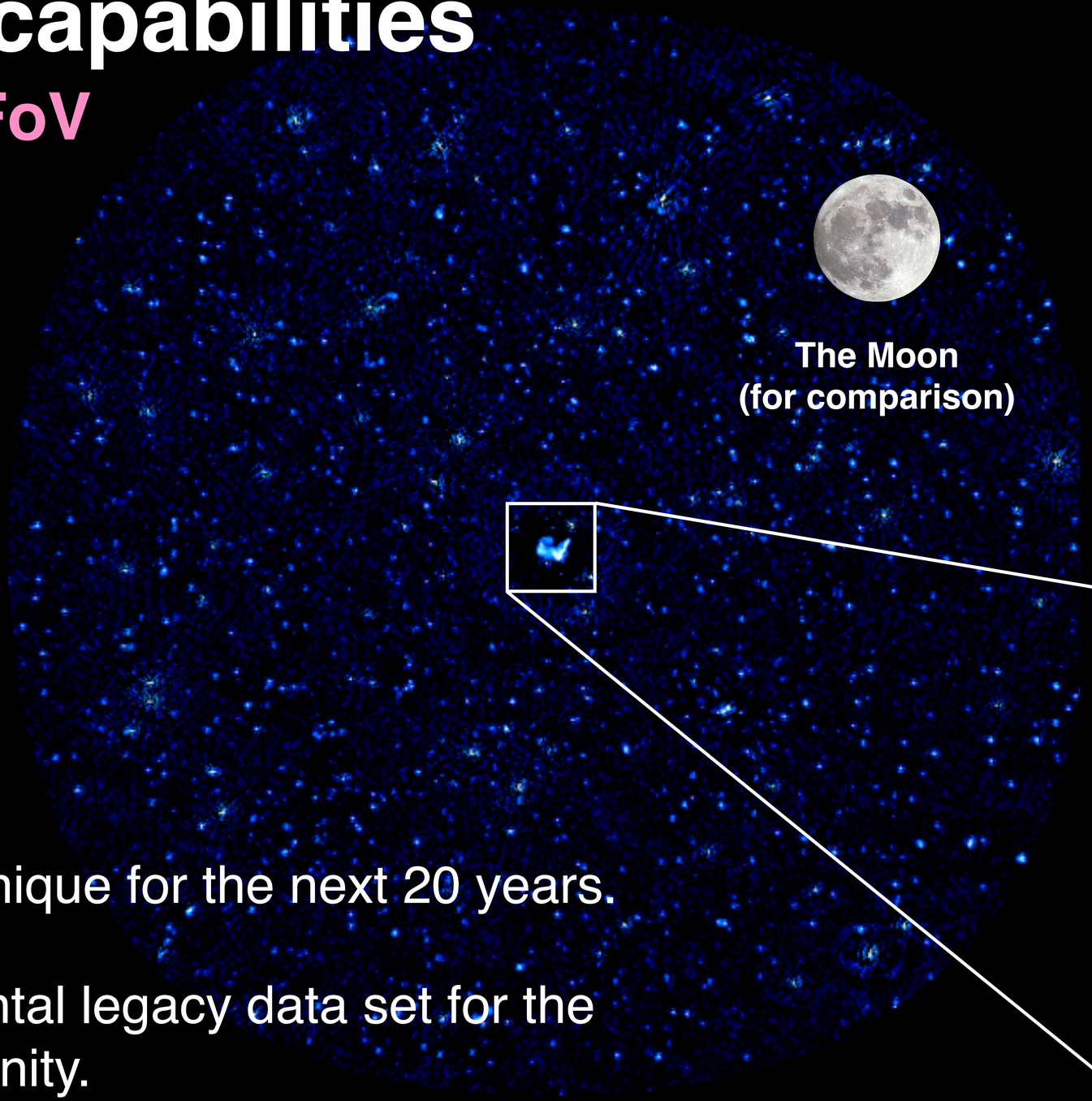
Observing capabilities



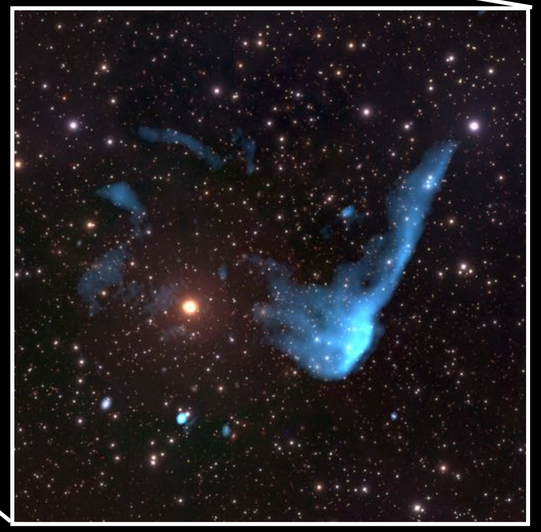
Shimwell

Observing capabilities

10s of sq. deg FoV



The Moon
(for comparison)

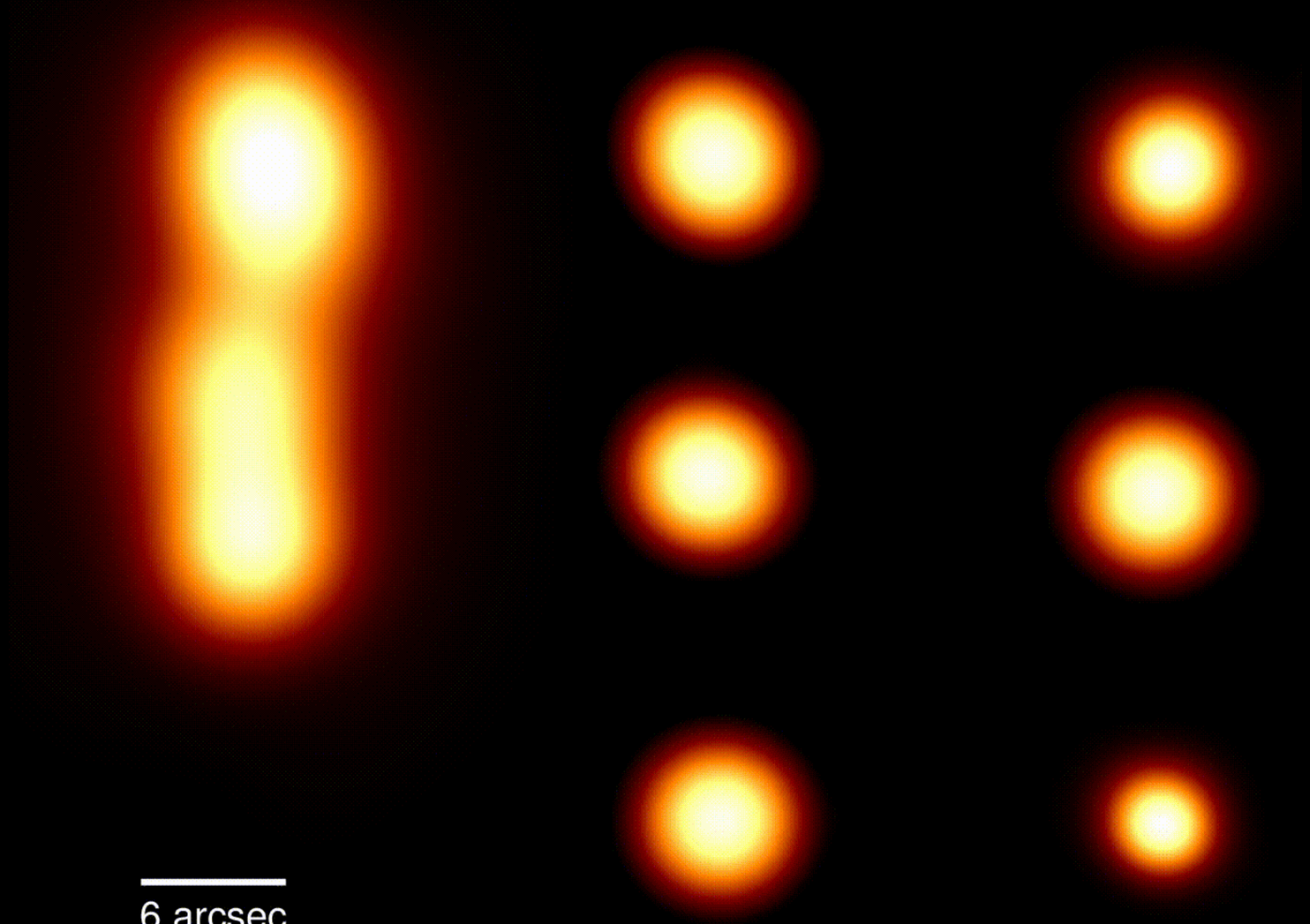


All-sky map that is unique for the next 20 years.

Provides a monumental legacy data set for the astronomical community.

Observing capabilities

(sub-)arcsecond angular resolution



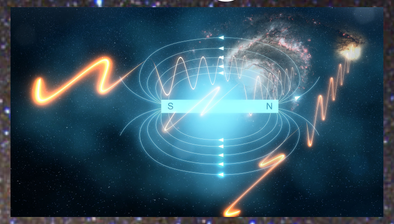
Morabito + Surveys KSP

Observing capabilities

(sub-)millisecond time resolution

Futselaar

Cosmic magnetism



Supermassive black holes

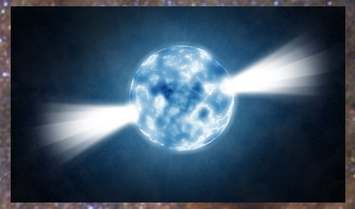
Early Universe

Supernovae

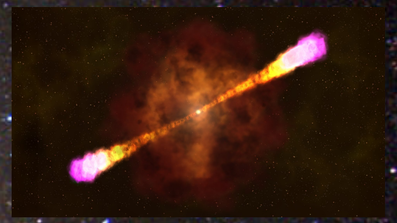
Galaxy clusters

Sun

Pulsars



Gravitational wave events



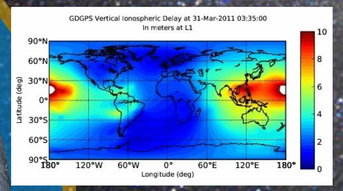
Solar System Planets

Meteors

Nearby galaxies

Cosmic rays

Ionosphere



Interstellar medium

Lightning

Space weather

LOFAR2.0 Science White Paper

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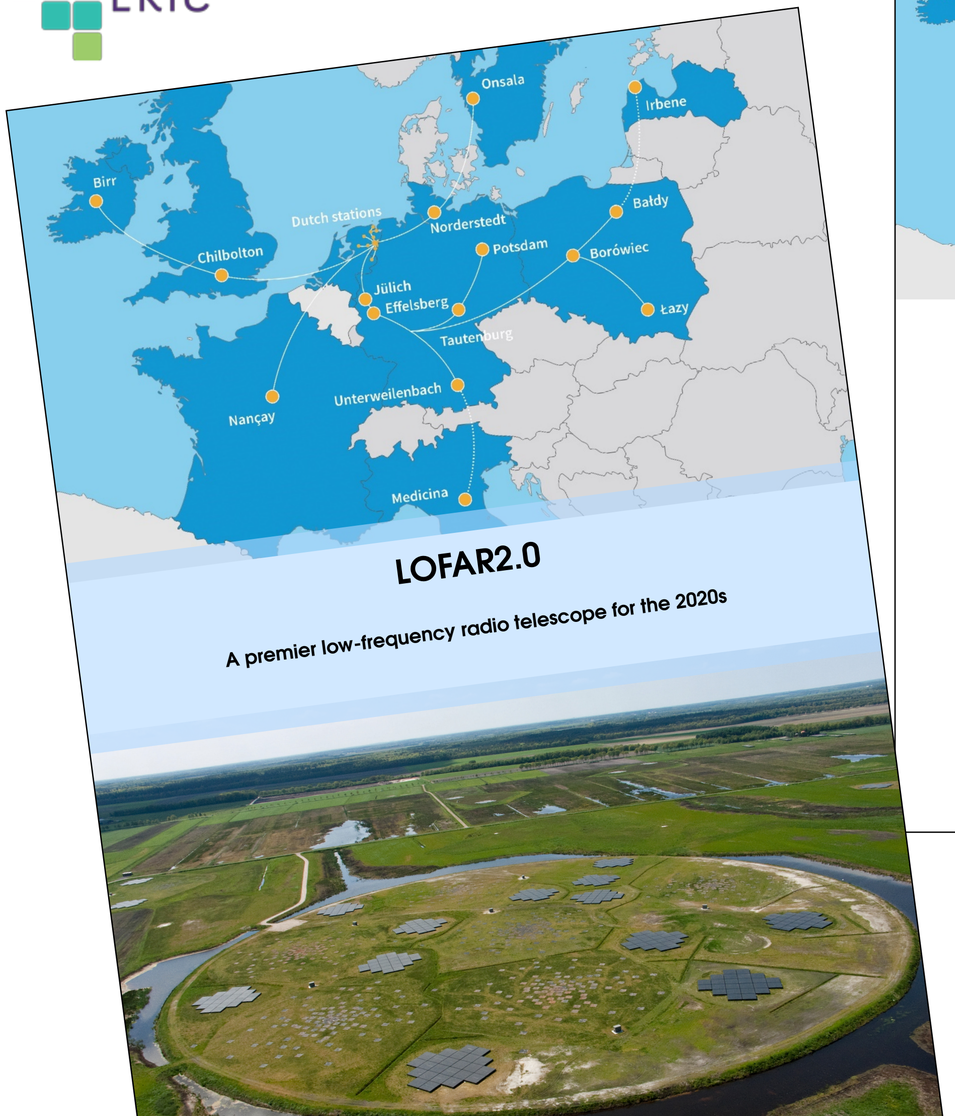
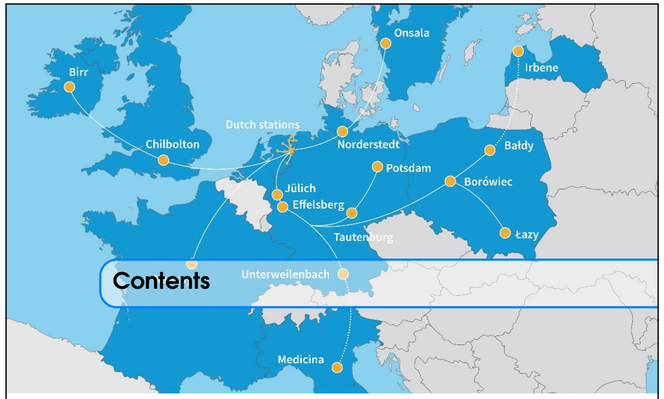
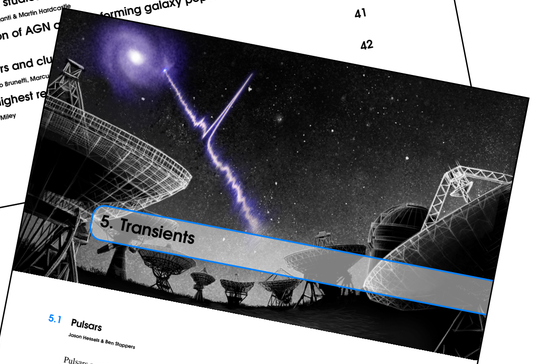






5.1 Pulsars

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**].

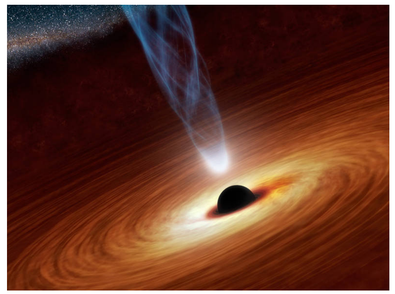
Highlight 12 LOFAR has discovered both the fastest- and slowest-spinning radio pulsars in the Galactic field.

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).

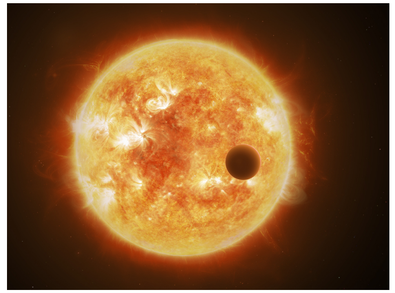
LOFAR

LOFAR2.0 Science Goals

- When do the first stars start to shine? What is the history of star-formation over cosmic time?



- How do supermassive black holes and galaxy clusters shape the Universe?



- What is the habitability around low-mass stars and can we directly detect exoplanets?

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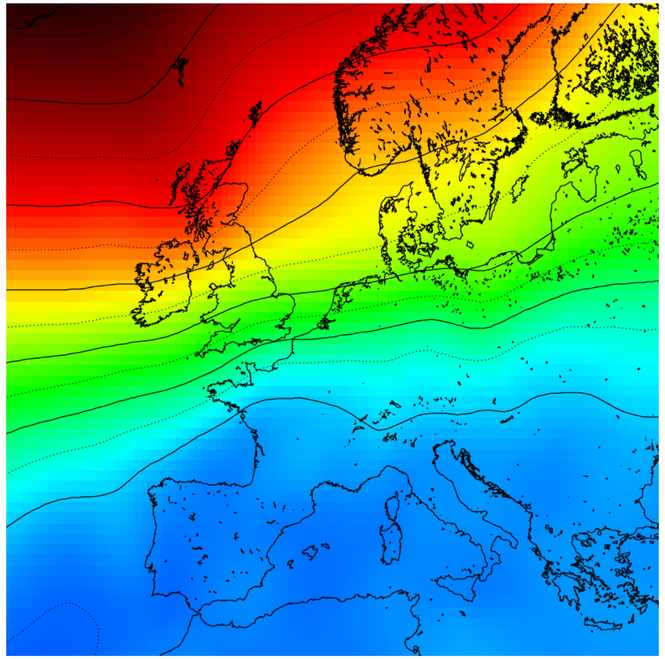
Beyond astronomy

Data products with broader societal relevance & applications

Lightning

Lightning protection Systems

Ionosphere



High-precision GPS

Space weather

Protect satellites & power grids

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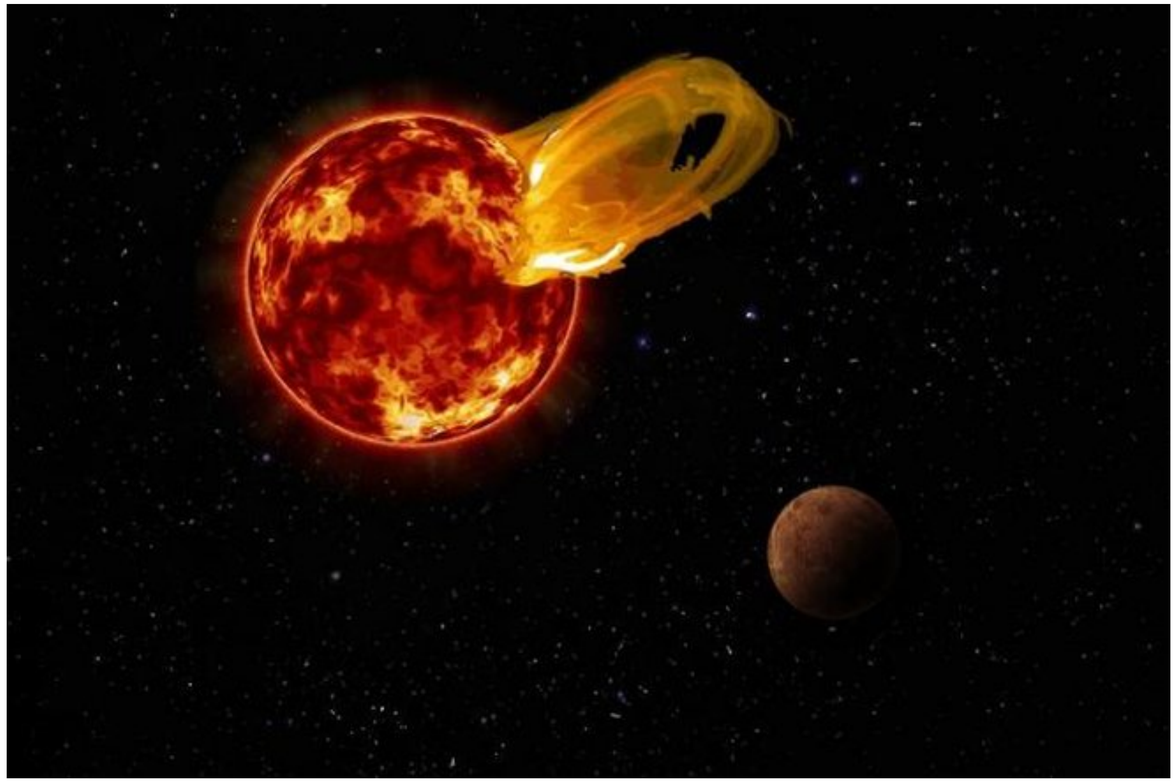
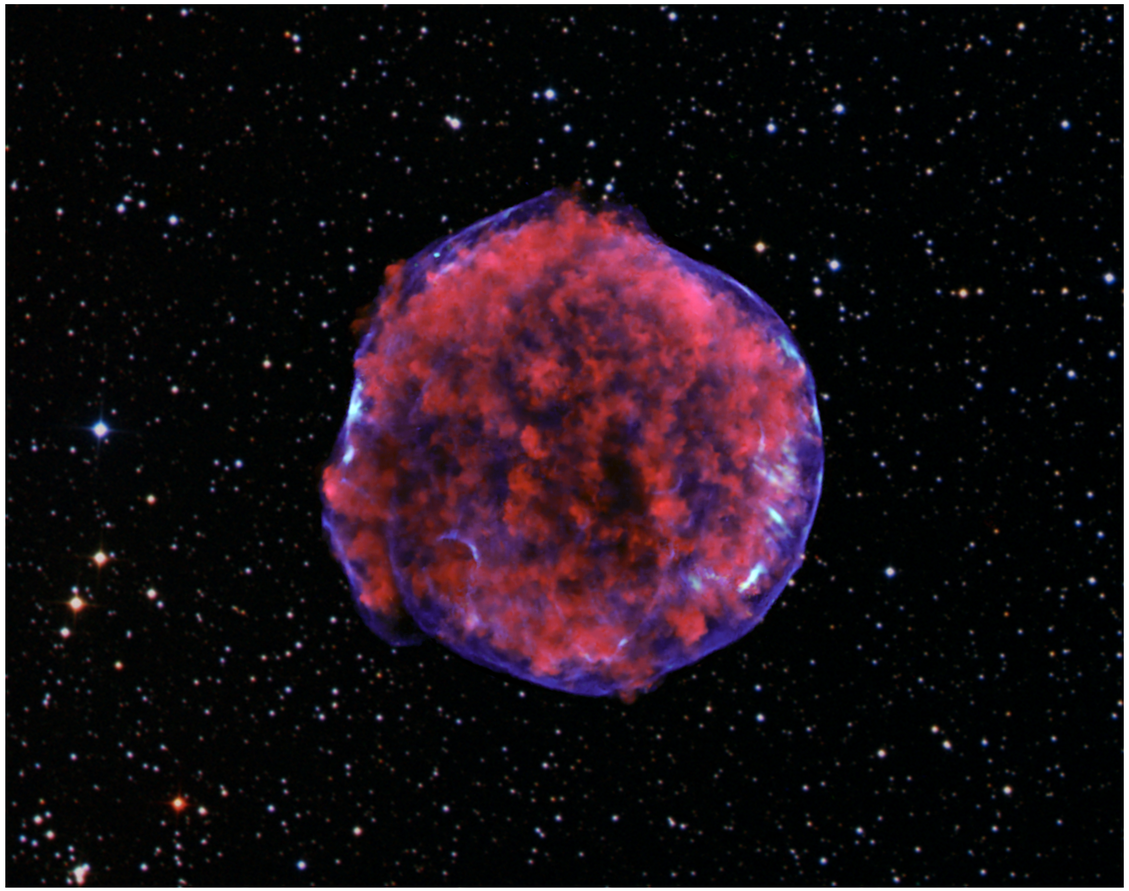
Survey-enabled science

Exoplanets, stars, and habitability



- Magnetically active stars (M-dwarfs) irradiating their nearby planets
- Directly detect exoplanets (cf. Io-Jupiter interaction)
- Non-synchrotron emission only visible at very low frequencies

Galactic science in our Milky Way



- Discover the 90% “missing” supernova remnants
- Pulsar wind nebulae as particle accelerators
- Probe interstellar medium using RRLs

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Nearby galaxies

- Look at the global properties of galaxies in a spatially resolved way
- See how the interstellar gas absorbs energy
- Understand the cycles of star-formation

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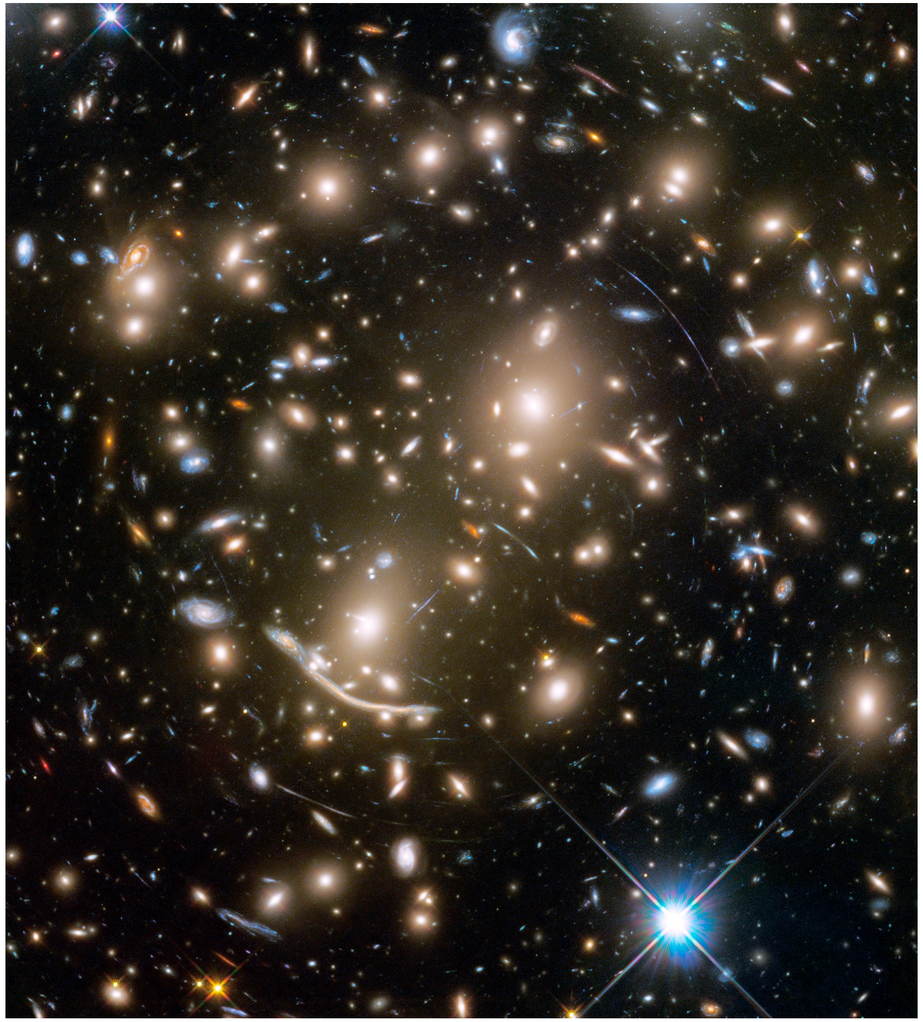
Active galactic nuclei

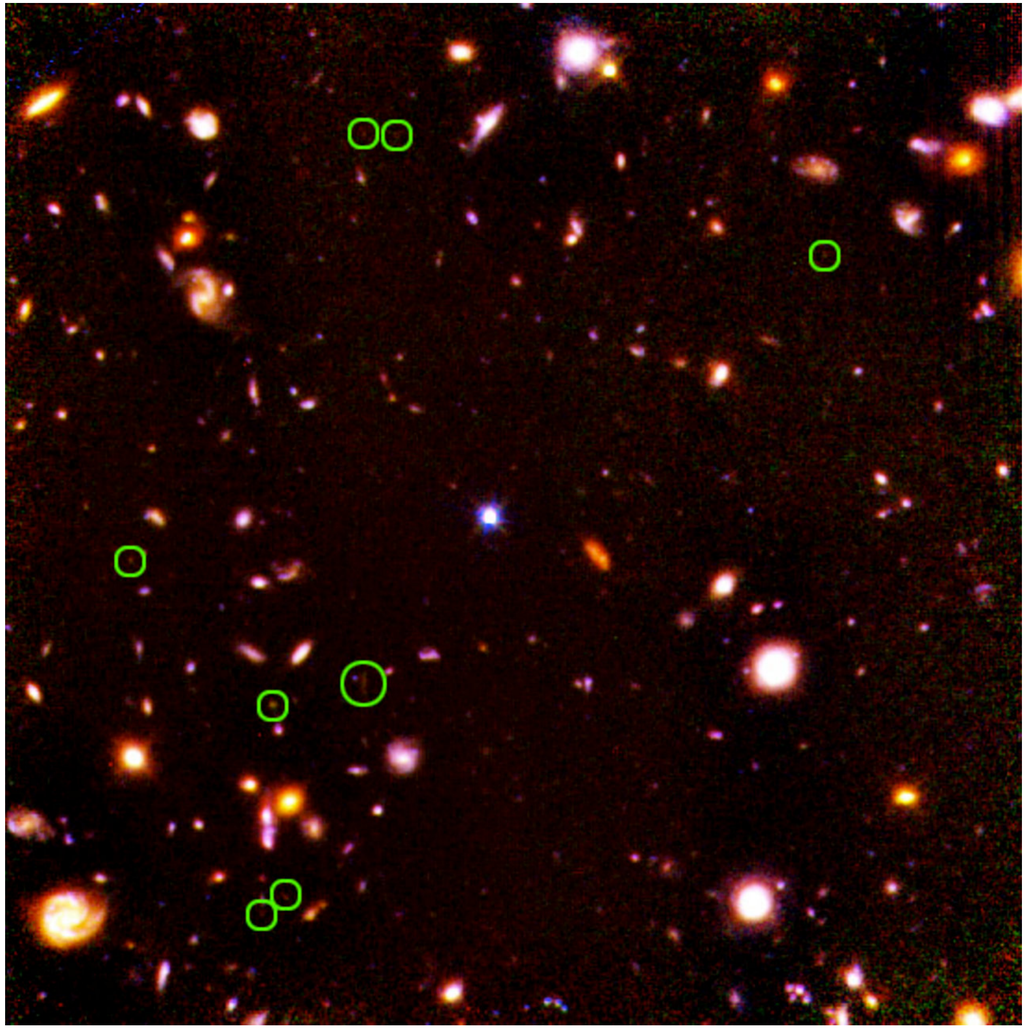
- Feedback of energy that regulates star formation
- Study the radio jets that probe the energetics
- “Fossil” emission gives the history of activity level

Galaxy clusters



- Cluster mergers are most energetic events since the Big Bang
- Radio haloes and relics trace energetics and history of merger
- Understand structure formation in Universe

High-redshift Universe



- Discover high-redshift (z > 2) radio galaxies
- Large sample to study galaxy formation and evolution
- Probe EOR with >100 high-redshift radio galaxies at z > 6

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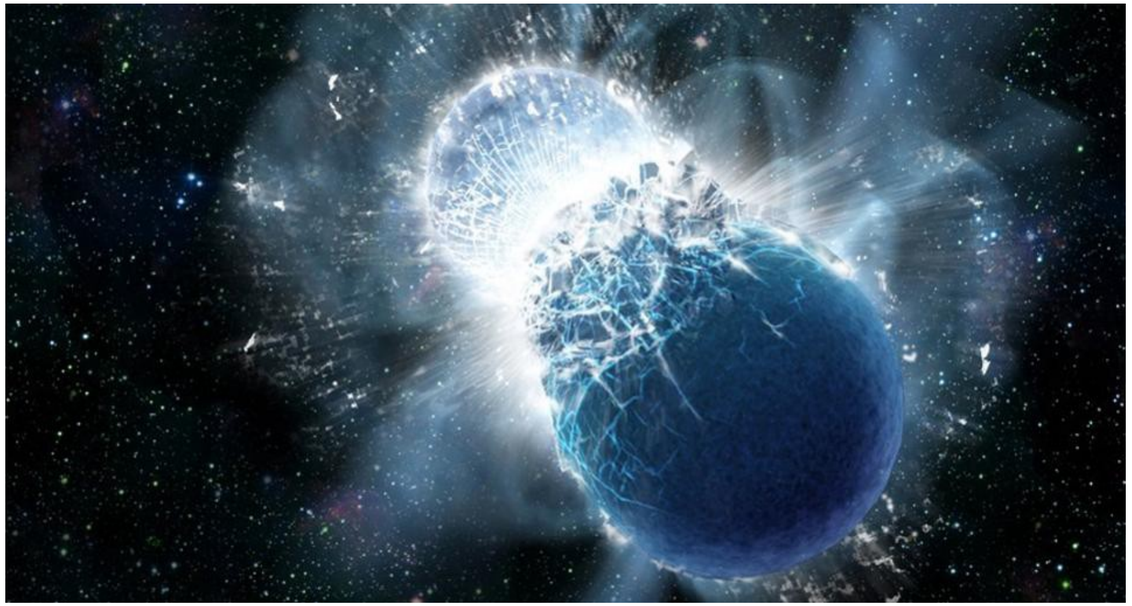
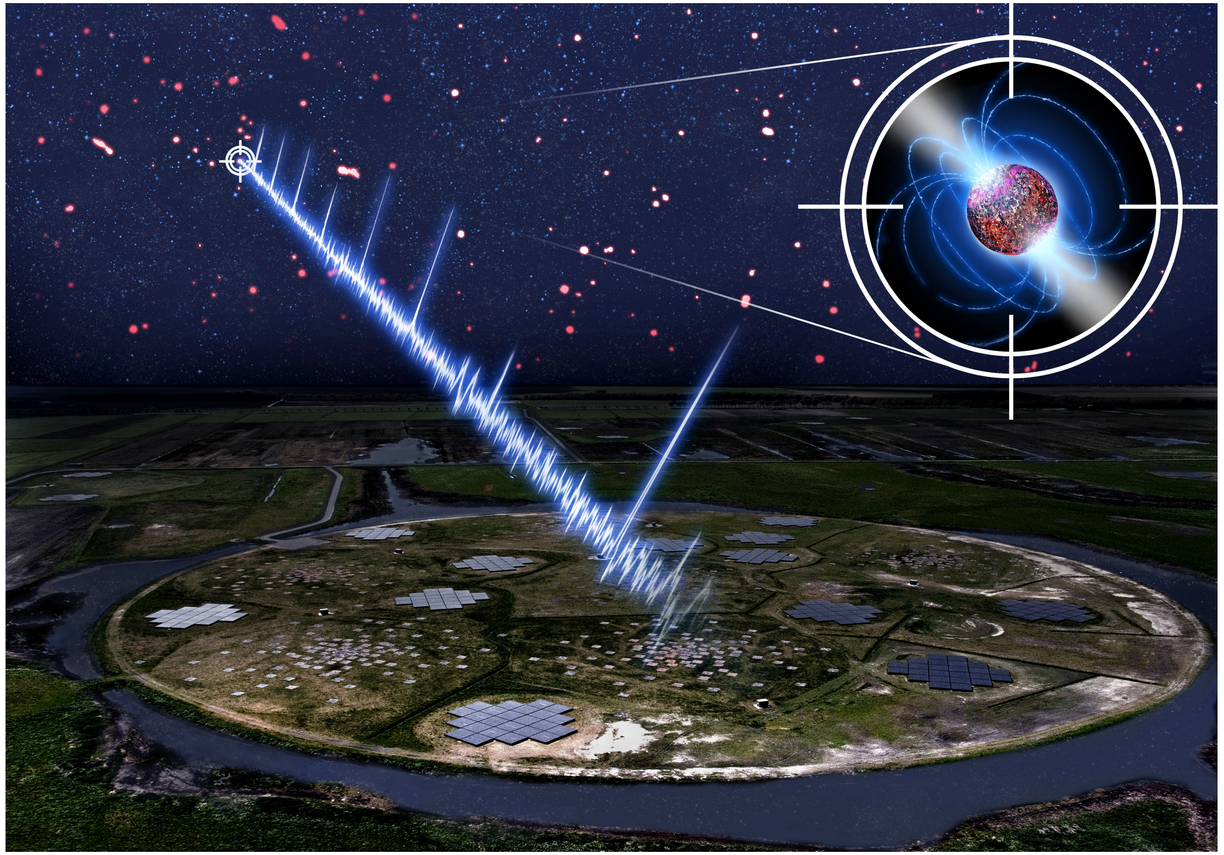
Transients



- Compare 2-epoch all-sky coverage
- Coherent emitters (compact objects)
- Gravitational wave counterparts

Pulsars



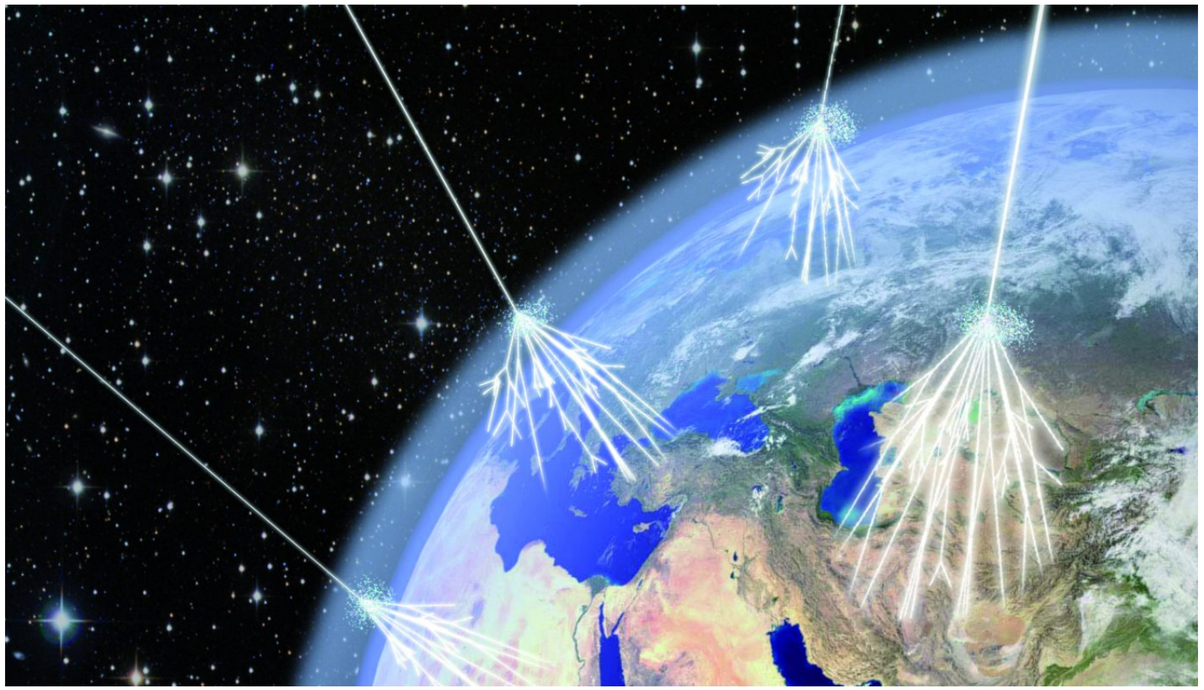
- Ultra-steep spectrum point sources in imaging surveys
- Find super-fast- or super-slow-spinning neutron stars
- Constrain neutron star equation of state

Serendipity

- Sky never before probed at such low frequencies, with such high sensitivity and angular resolution
- Other types of non-synchrotron emitters

Piggy-backing

Cosmic rays



- Most energetic particles in the Universe, but their origin is still unclear
- What sources, and what acceleration mechanism(s)
- LOFAR can study the transition from Galactic to extragalactic sources

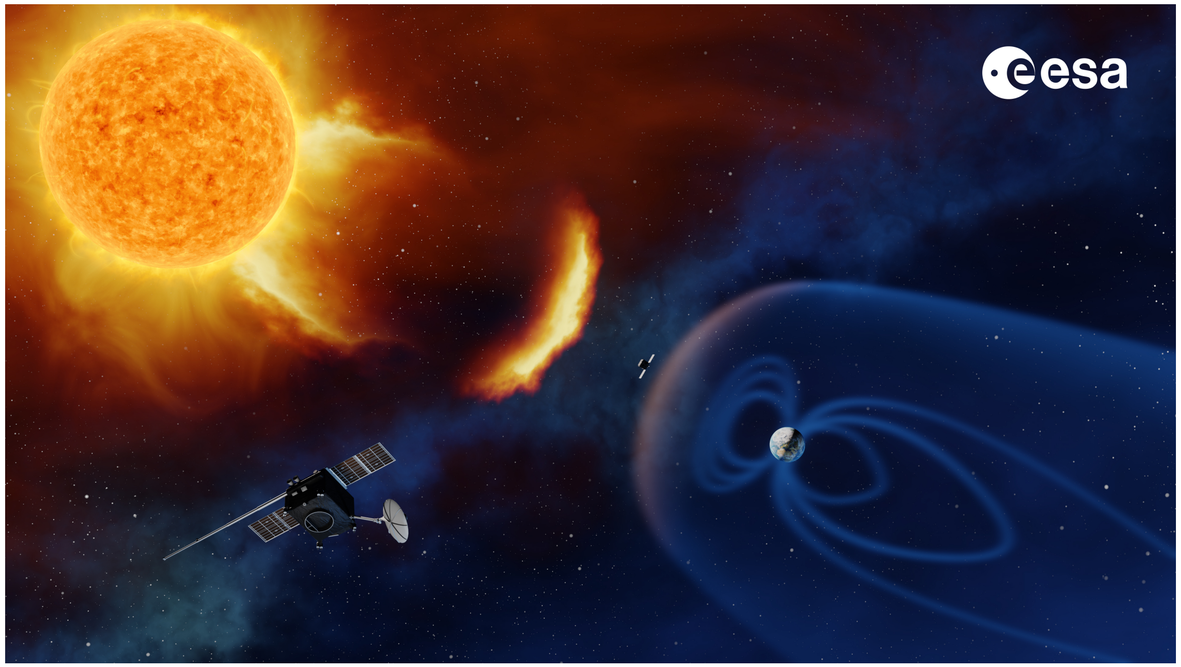
Earth lightning

- Buffer boards can also capture lightning strikes
- Lightning formation and propagation still not well understood
- Much higher precision imaging of where lightning is forming

Earth ionosphere

- Calibration will give insight into the structure and dynamics of the ionosphere
- Detect 2nd and 3rd order effects
- Model the scattering conditions giving rise to scintillation

Sun & space weather



- Solar flares and coronal mass ejections create space weather
- Early detection of these bursts in radio
- This space weather can disrupt artificial satellites and the Earth’s magnetosphere

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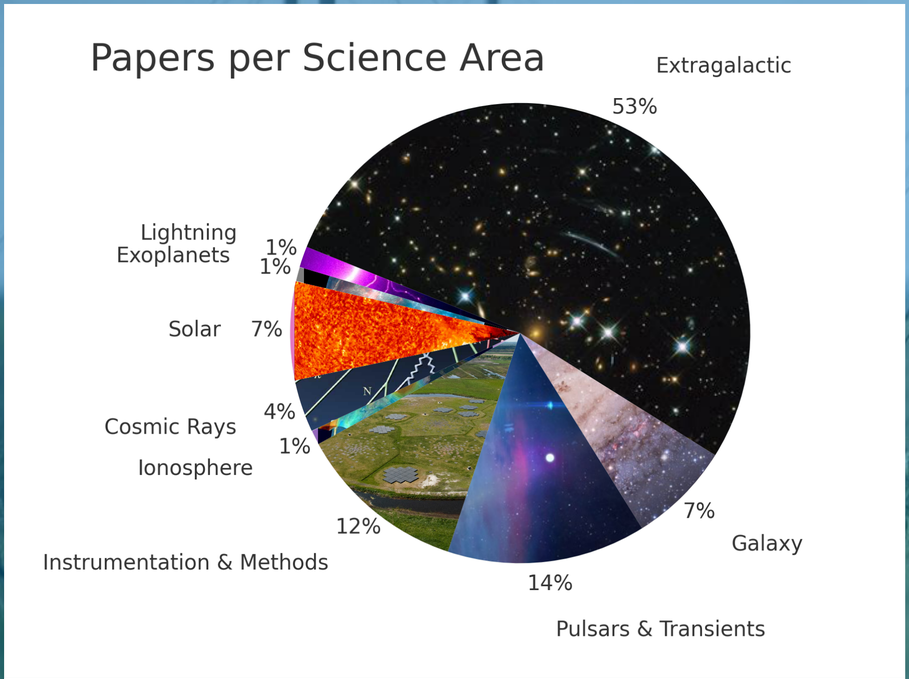
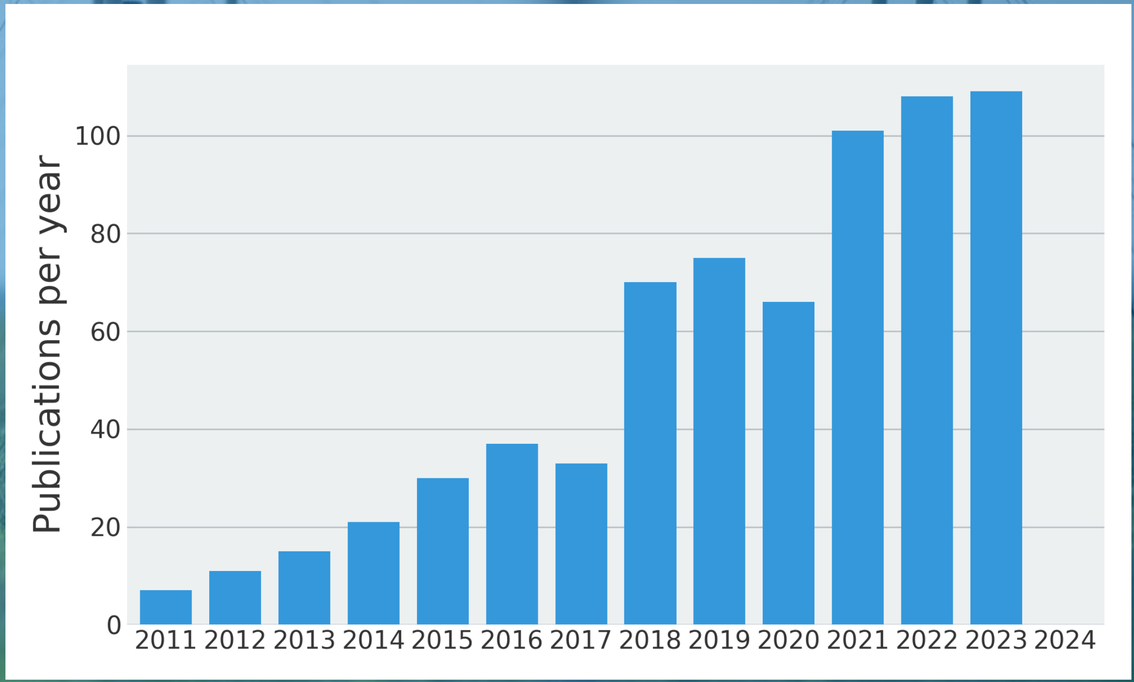
Impact of LOFAR2.0





Major new suite of science at a fraction of the original investment in LOFAR