ASTRON

past, present …
persistence

Violette Impellizzeri

Head of Astronomy & Operations

ASTRON
Netherlands Institute for Radio Astronomy


ASTRON 75
and a 75 year legacy at
the farthest frontiers of
discovery and innovation

ASTRON's 75 year celebration!

1951 construction – 25m antenna

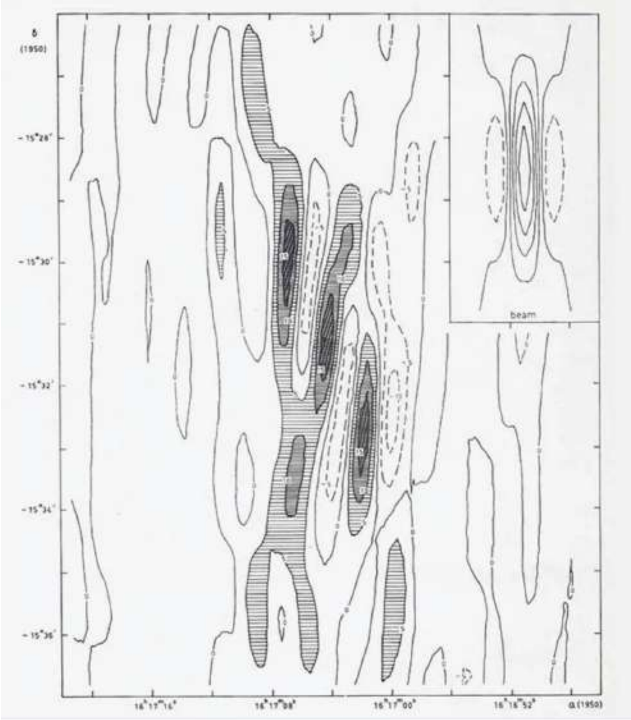
Contributed to discovering the size, distribution of neutal hydrogen and its motions in the Mily Way

ASTRON’s 75 year celebration!

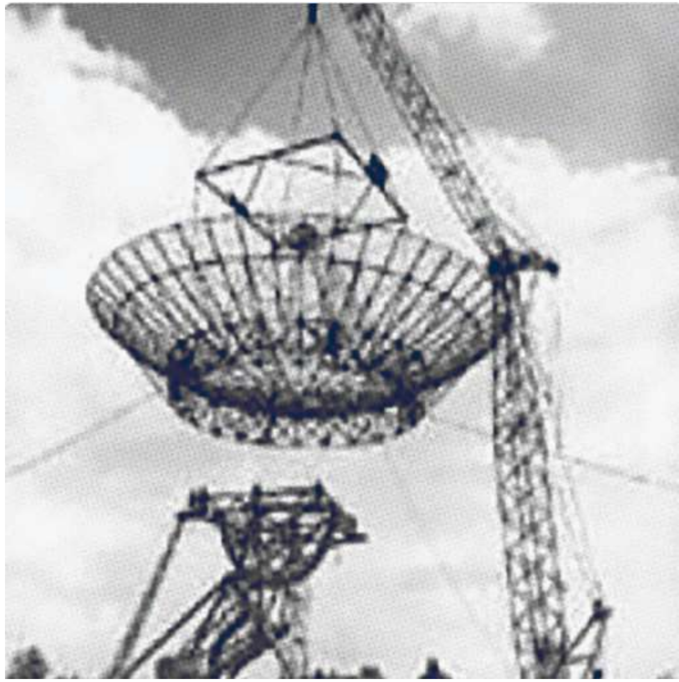
1951 construction – 25m antenna

Contributed to discovering the size, distribution of neutal hydrogen and its motions in the Mily Way

First high resolution images of the Milky Way (Oort 1970)



1966 WRST construction

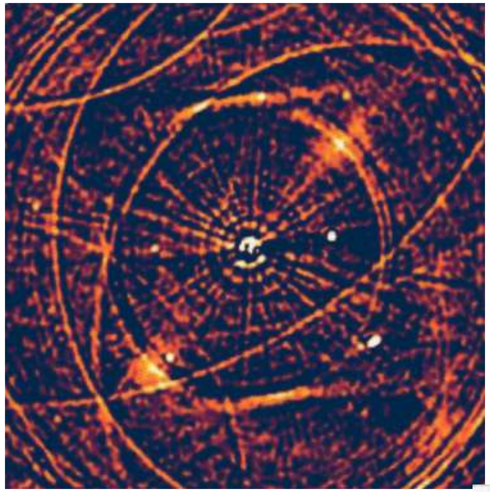


”widening of Science”
First surveys of the radio sky
Discovery of ultra-relativistic jets, dark matter ...

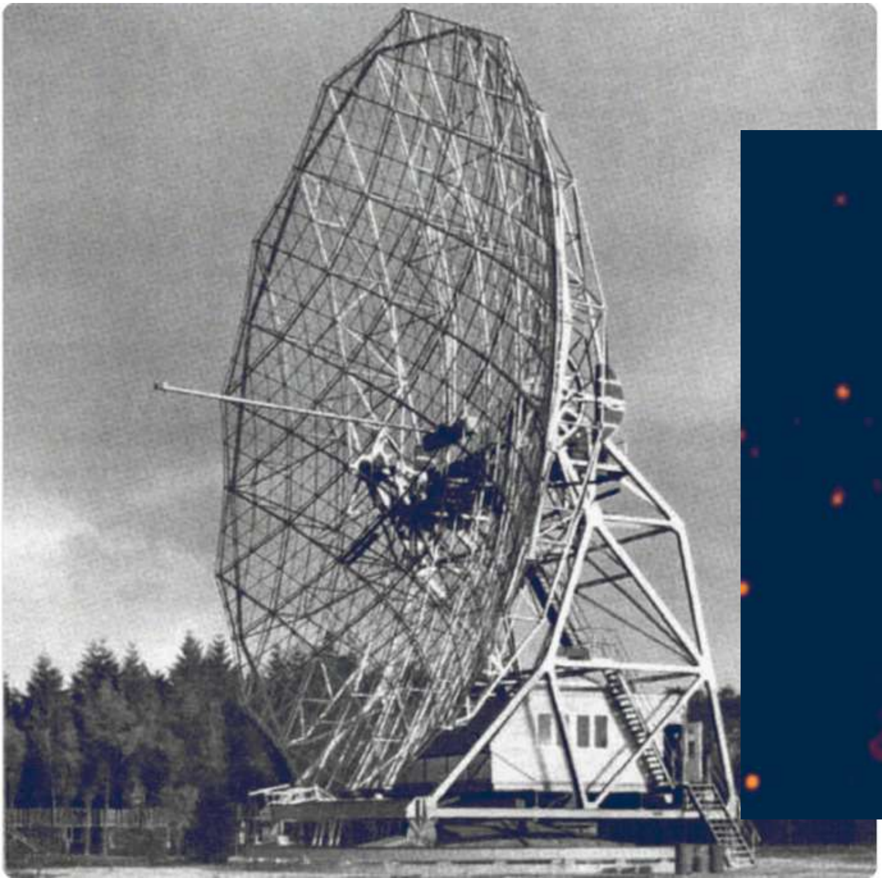
ASTRON’s 75 year celebration!

1966 WRST construction

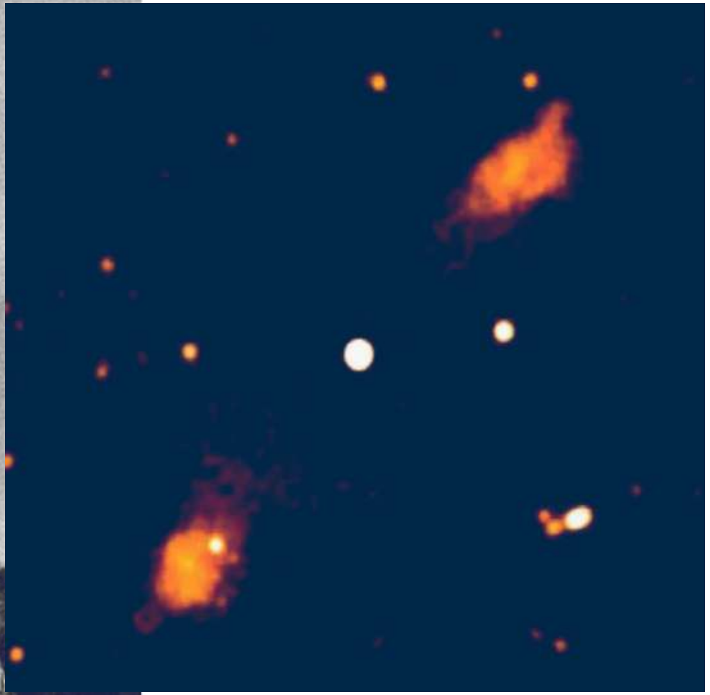
Invention of CLEAN! Revolutionizing data procssing (Högbom 1972)



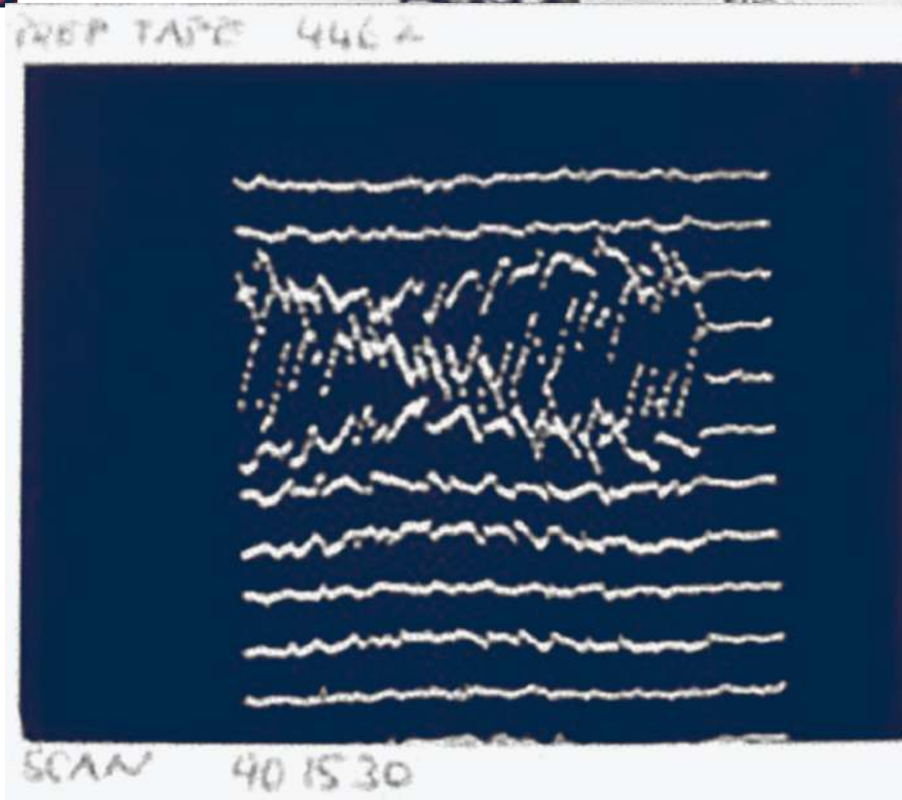
1951 construction – 25m antenna



3C 236



First VLBI Obs



Discovery of Heaven (2001)

Construction of LOFAR

LOFAR - “Low Frequency Array” is designed and built by ASTRON.

Consists 25,000 antennas spread over 40 fields in the Netherlands and in Germany, Sweden, France and England.

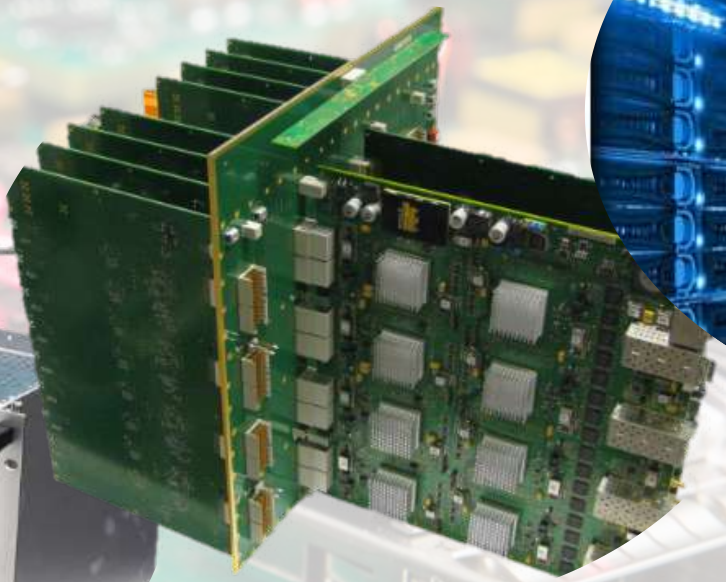
Glass fibres connect the antennas with a supercomputer at the University of Groningen: creating a giant telescope with a diameter of one hundred to one thousand kilometres

Inauguration ceremony in 2010 by Queen Beatrix

ASTRON today

- 200 people across three co-hosting organizations
- ASTRON, hosting JIVE and NOVA
- 75 year history of world-leading astronomy and technical excellence
- Astronomy & Operations operates and harnesses science from the LOFAR and Westerbork telescopes
- Innovation and Systems develops technologies for current and future telescopes

Technology push - Science pull



High performance computing

Pipelines

Storage

Digital signal processing

Correlation

Calibration

Antennas

RFI mitigation

Low noise amplifiers

Mechanics

Photonics, Filtering

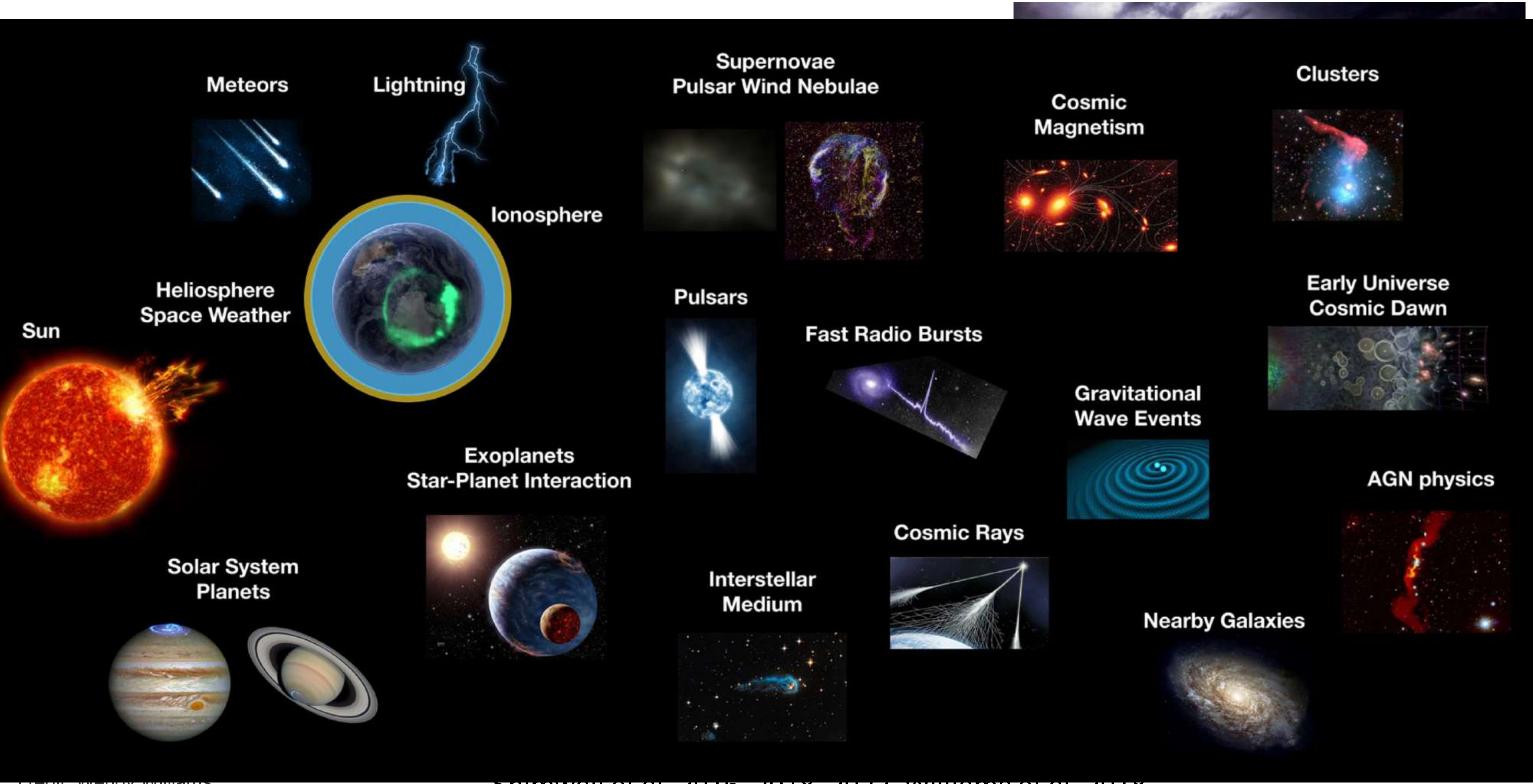
Beamforming

A/D Conversion

ASTRON

Netherlands Institute for Radio Astronomy

Credit: Danielle Futselaar



credit: Wendy Williams

Shimwell et al. 2016, 2018, 2022; Williams et al. 2018

Lightning studies

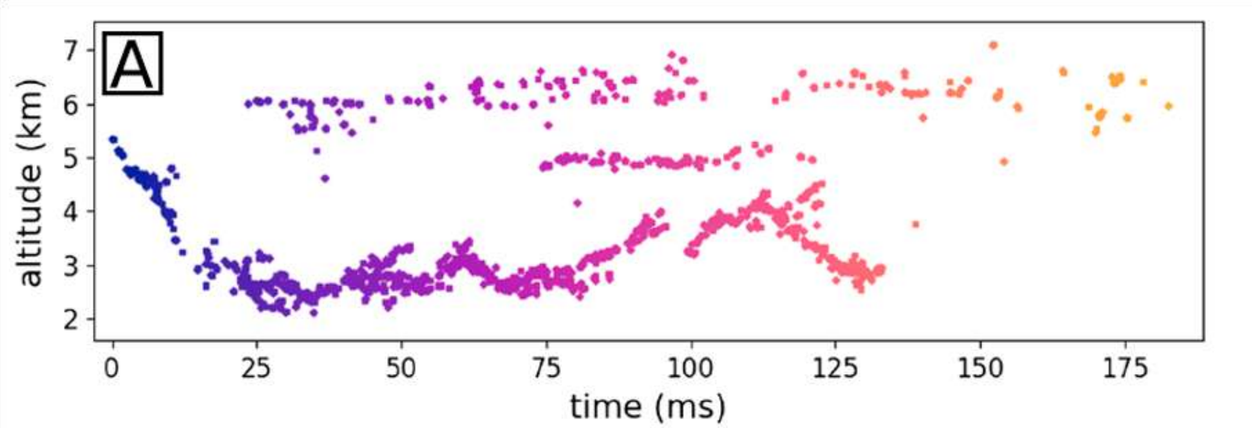
Routine for mapping thunderstorm and lightning events

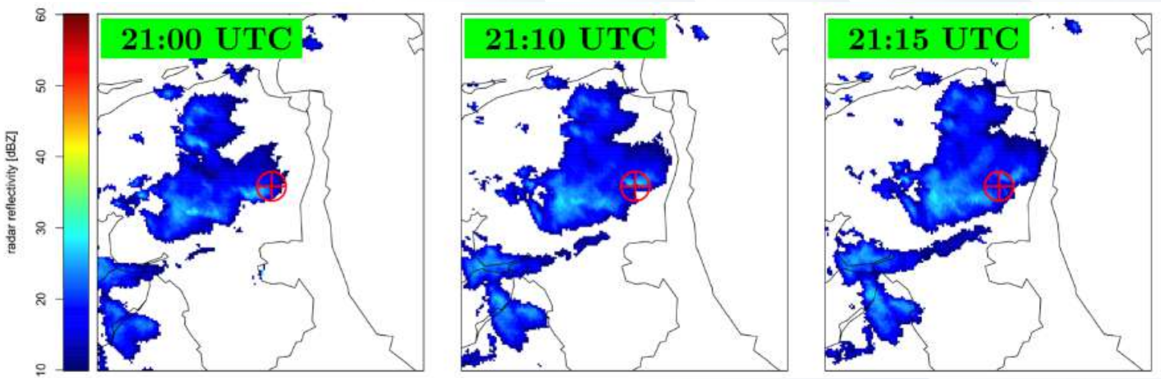
Reconstruction of the on-sky position of the electric discharge

Mapping the electric fields within clouds during thunderstorms, and characterizing their influence on cosmic-rays radio emission

Lightning above the central part of LOFAR. (Credit: Danielle Futselaar)

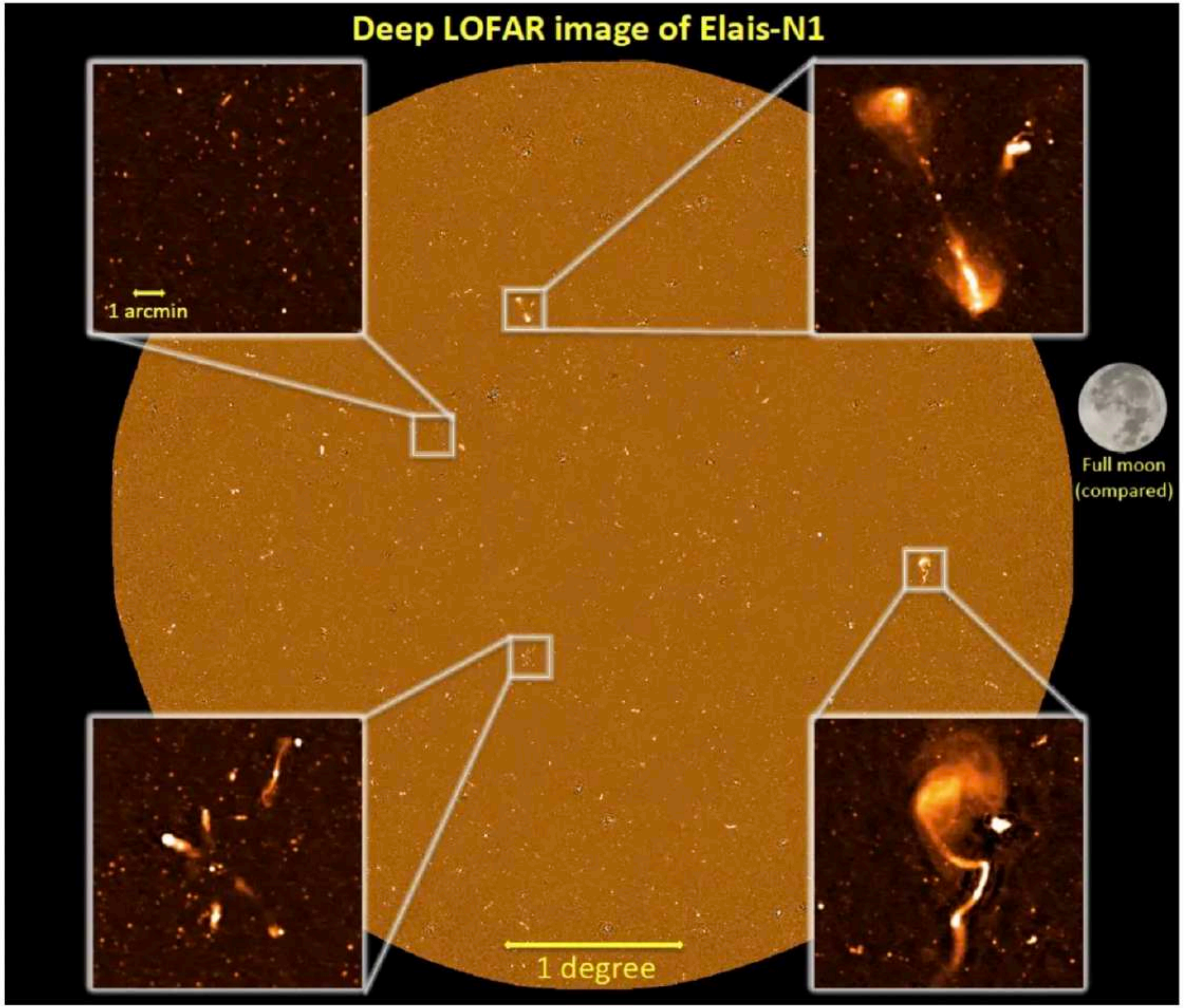
Hare et al. 2019, Nature



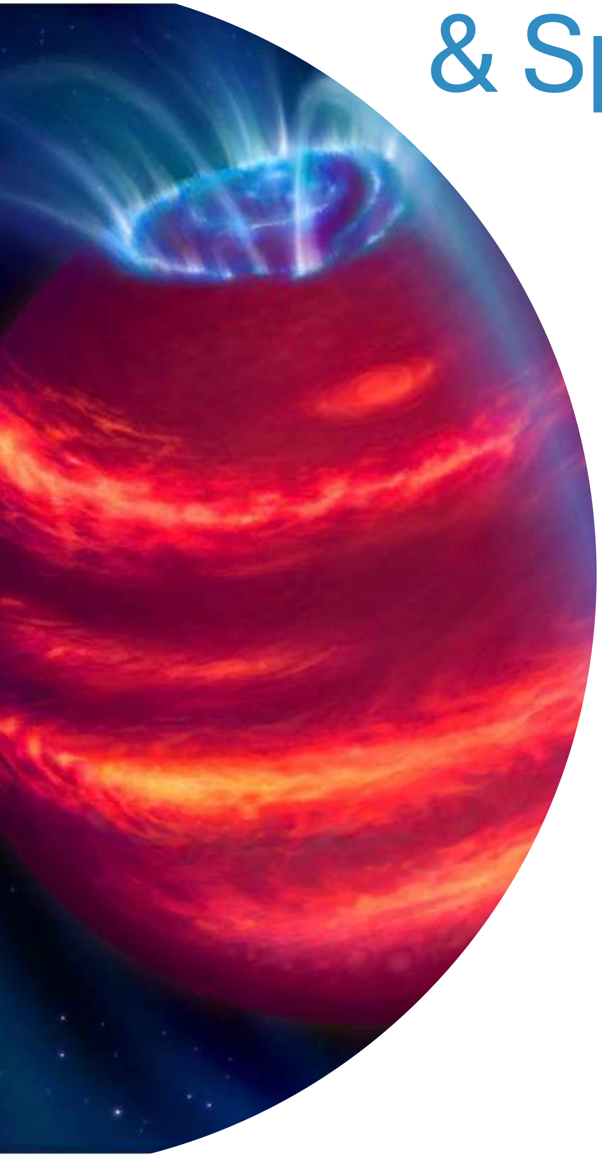


LOFAR ultra-deep field

- The deepest LOFAR image ever made, in the region of sky known as 'Elais-N1'
- 164 hours of observing, 4PB data
- Over 80,000 radio sources are detected; this includes some spectacular large-scale emission arising from massive black holes, but most sources are distant galaxies like the Milky Way, forming their stars.
- Philip Best & Jose Sabater, University of Edinburgh.



Brown dwarf detections
& Space Weather of other worlds



- Magnetic fields - circular polarization at ~144 MHz - allowing LOFAR to probe brown dwarfs and - with LOFAR2.0 – exoplanets

- Characterize stellar coronal mass ejections (CMEs) and signs of star-planet interactions via polarized emission ... and how it affects habilability

Vendatham et al., Callingham et al

“Gargantuan” Jets*

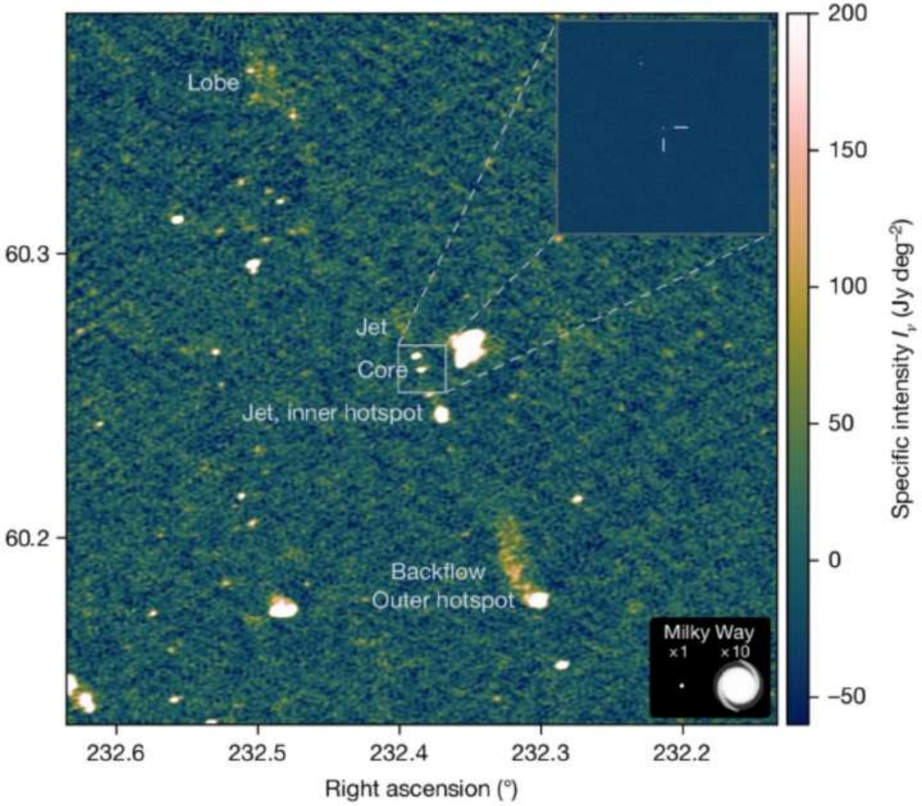
OUT THERE

This Black Hole Has a Cosmic Wingspan

Black hole jets on the scale of the cosmic web

Martijn S. S. L. Oei, Hardcastle et al

Jets spanning over 7 Mpc !



* The actual name given to this record-breaking pair of black hole jets is **Porphyrion**, named after the Greek mythological giant

Recent Apertif highlights

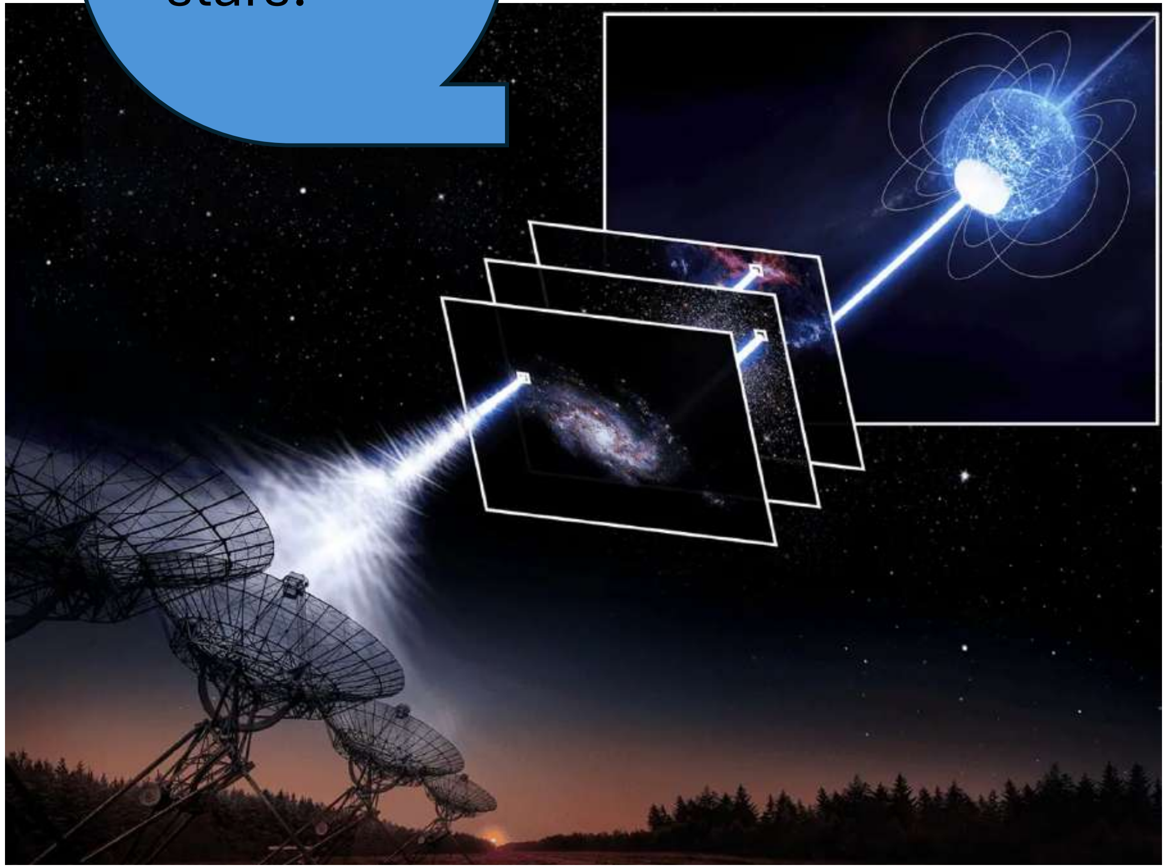
It’s neutron stars!

Comprehensive analysis of the Apertif fast radio burst sample

Similarities with young energetic neutron stars

WSRT discovered 24 new FRBs ... which after a while showed “resemblance with the flashes we know from highly magnetic neutron stars.”

The distant stars that emit these Fast Radio Bursts must somehow generate an astounding one billion times more energy than the nearby ones!



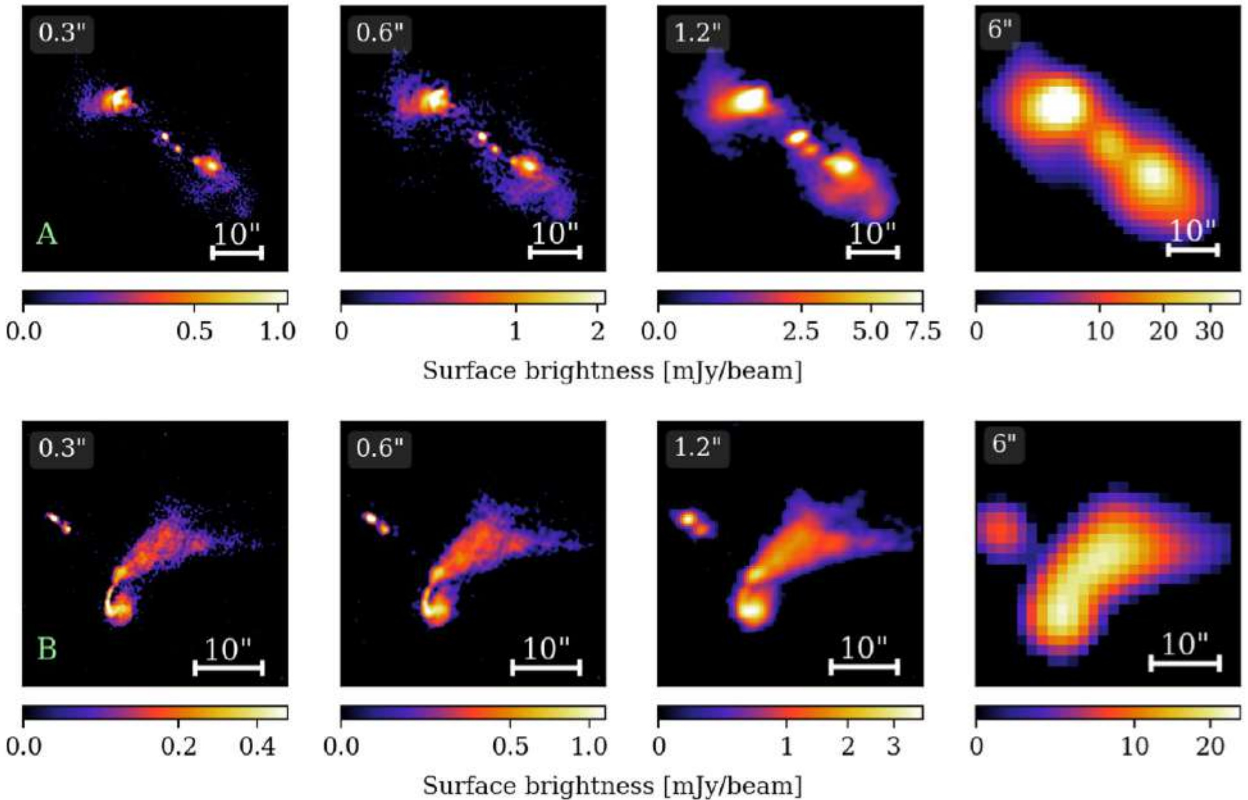
Inés Pastor-Marazuela, Joeri van Leeuwen, and the ARTS Team

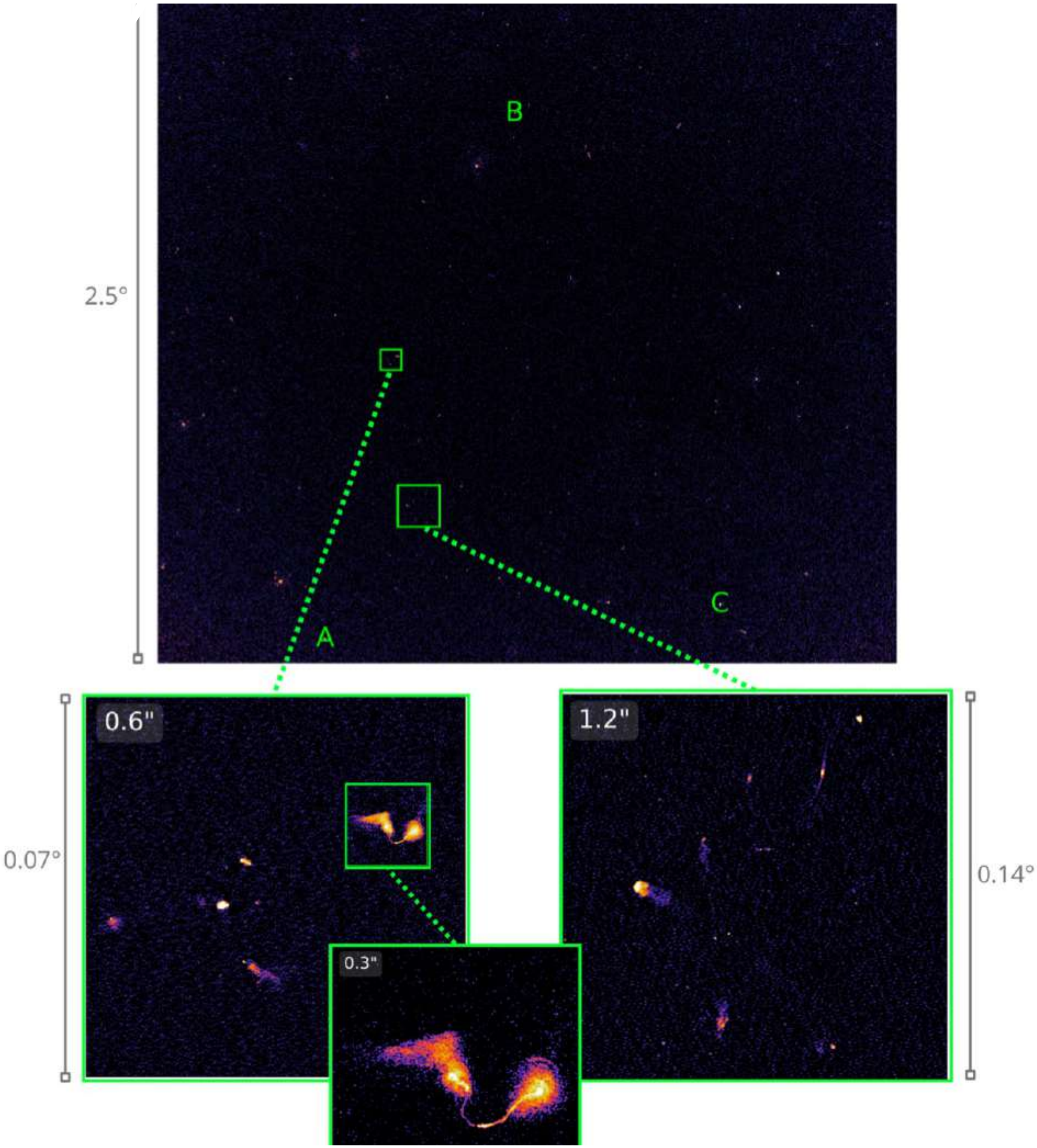
Apertif press release *(Credit: van Leeuwen/ASTRON)*

Improving VLBI capabilities

LOFAR's VLBI imaging capabilities are enabled vis **betterimaging** algorithms, and techniques.

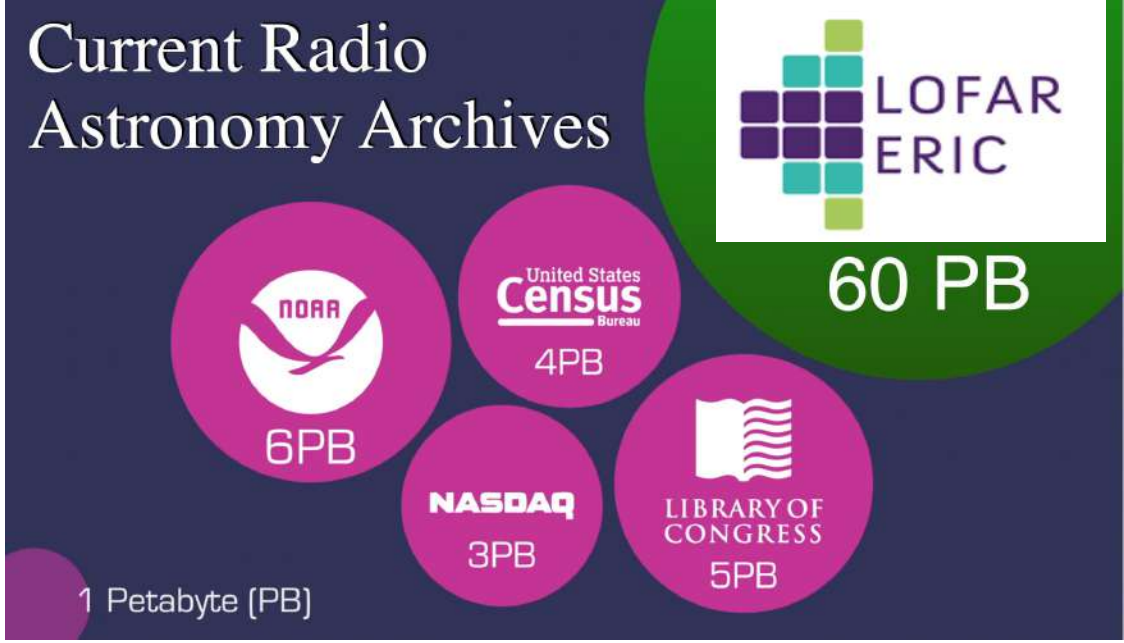
de Jong et al. 2024





LOFAR Achievements

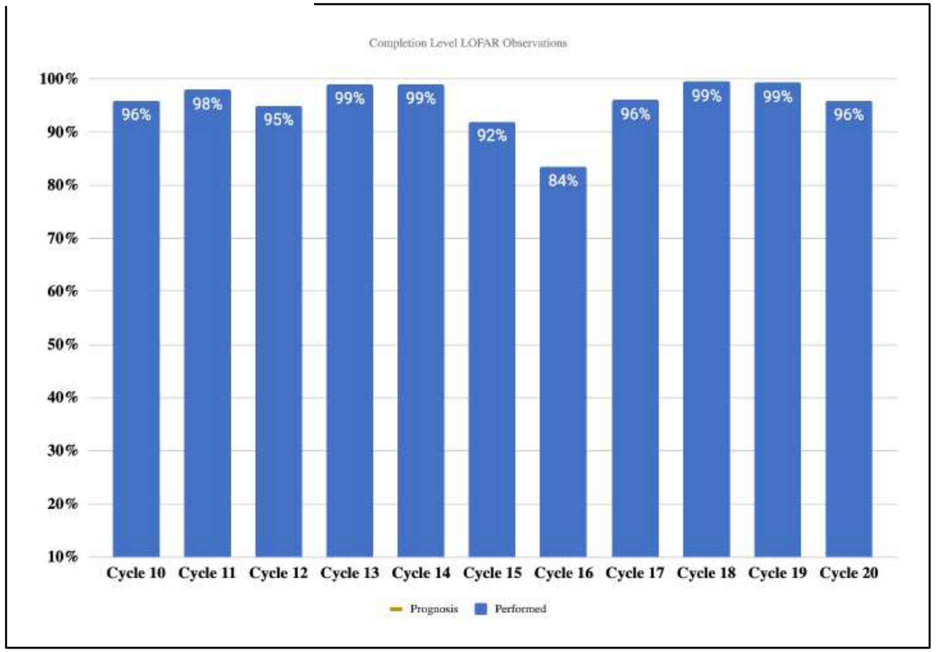
- Completed 21 operational Cycles
- ~65000 hours successfully observed – >70% operational efficiency
- Operating a massive array growing in size and capabilities
- 60 PB (!) ingested into the LTA - <u>Largest astronomical data collection to date.</u>
- Started LTA (archive) operations (this is being compressed!)
- Support an ever-growing community
- Brought the instrument closer to our users:
  - LOFAR Schools (400+ participants)
  - 60 Busy Weeks
  - Traineeships

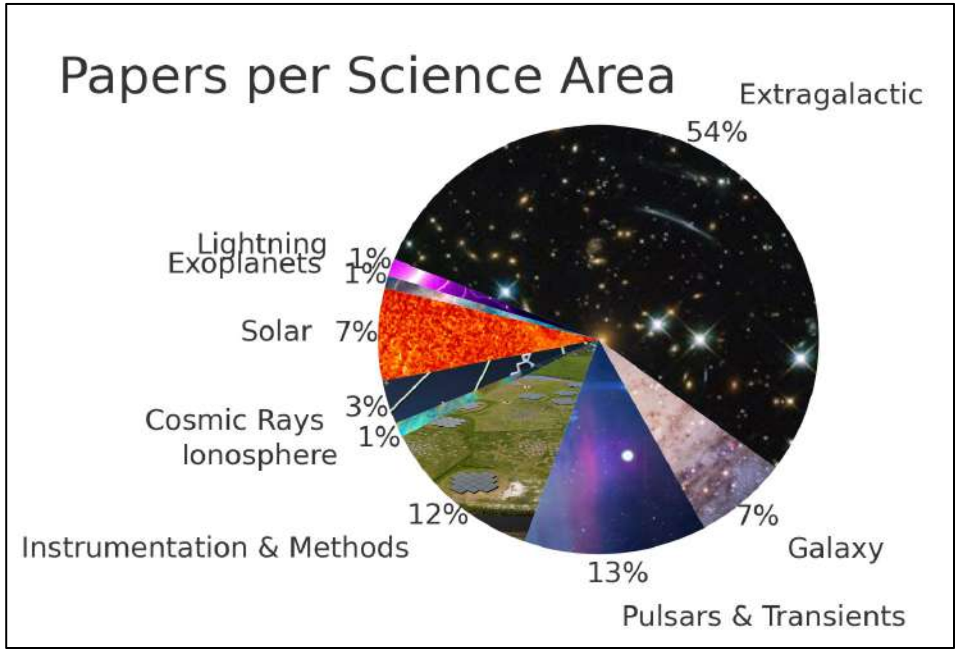



LOFAR School 2024

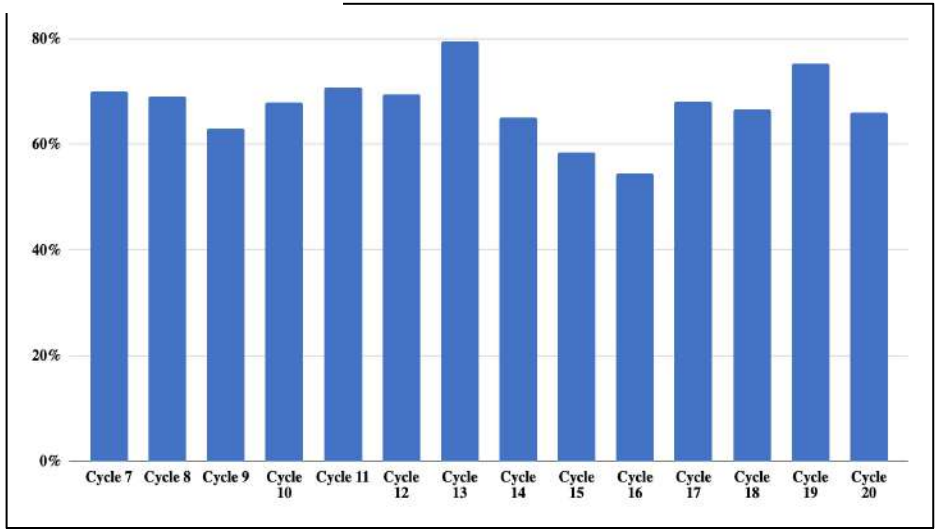
LOFAR Production operations – The end of a successful era

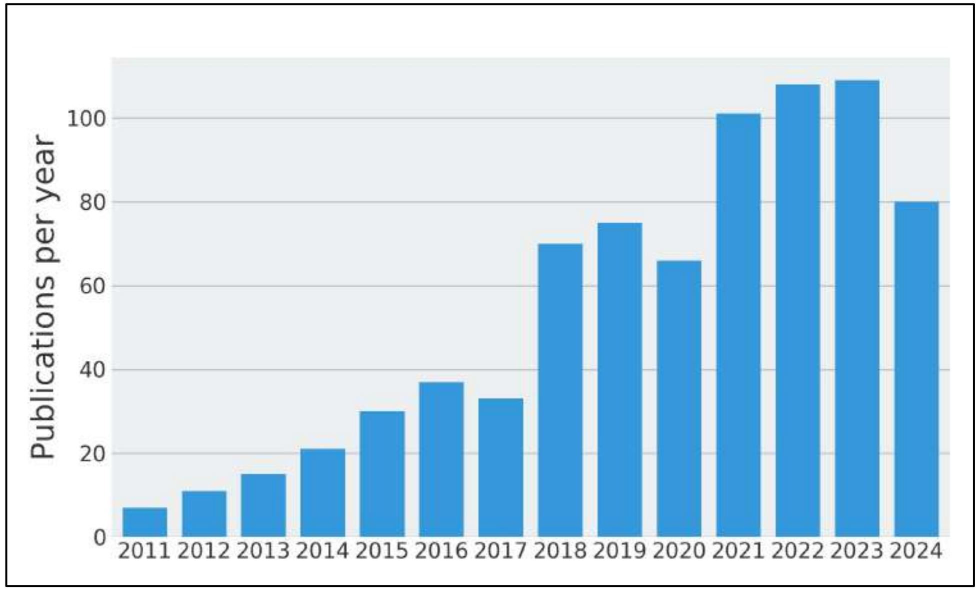
Cycle Completion





Observing Efficiency





- LOFAR1 operations closed on August 31 2024
- Exceeded target efficiency (70%) and target Cycle completion (95%) in many semesters
- > 750 refereed publications
- Publication rate:

2 papers per week – top 10% of all astronomical facilities

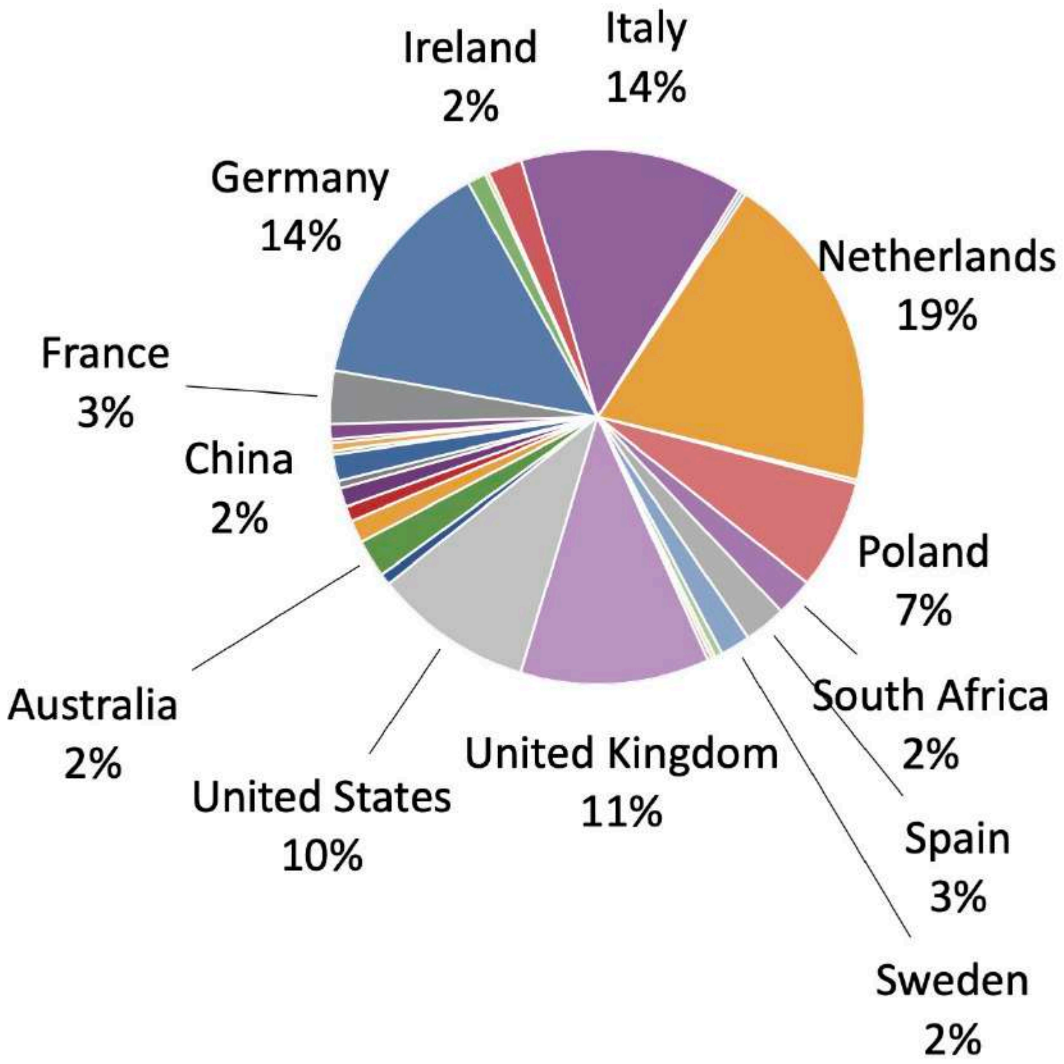
LOFAR – collaborations at the heart

10 countries - more than 50 antennas , 38 in the Netherlands

13 years of operation

150 publications per year

Over 1500 users, 430 PIs from 31 countries - demand from every key radio astronomy community in the world

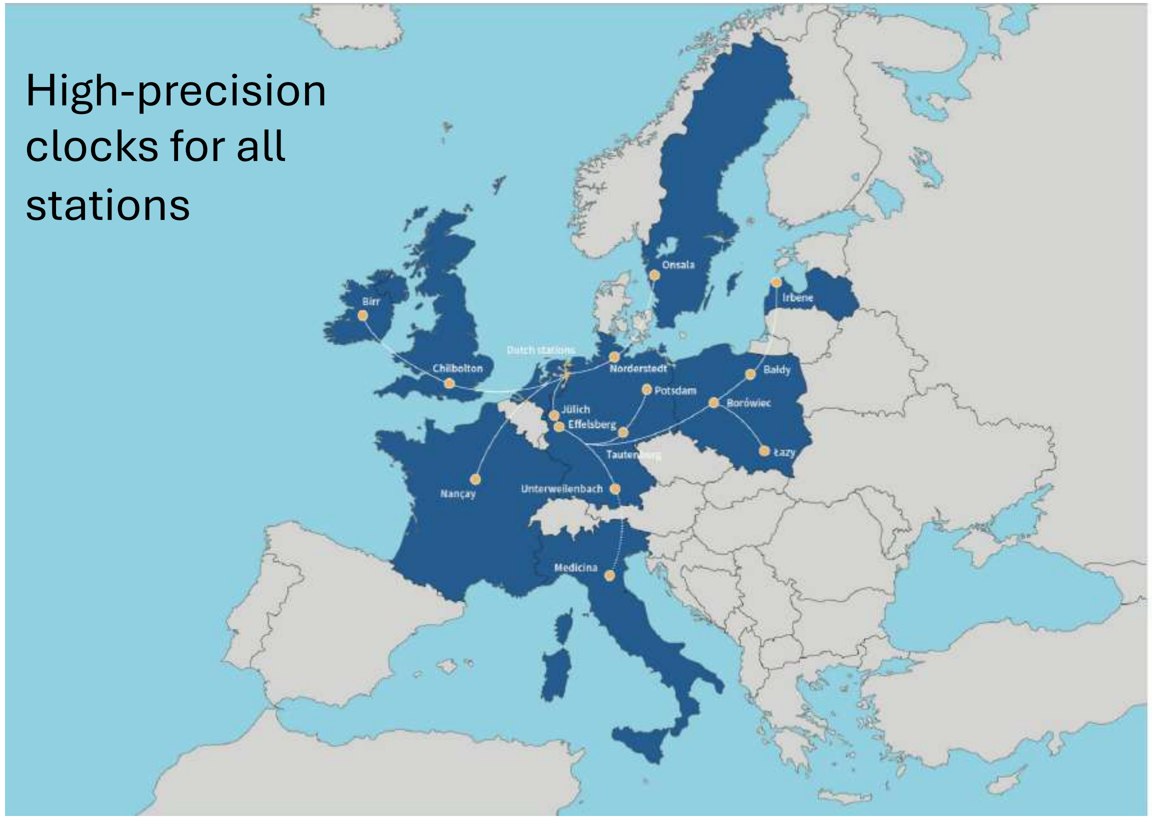


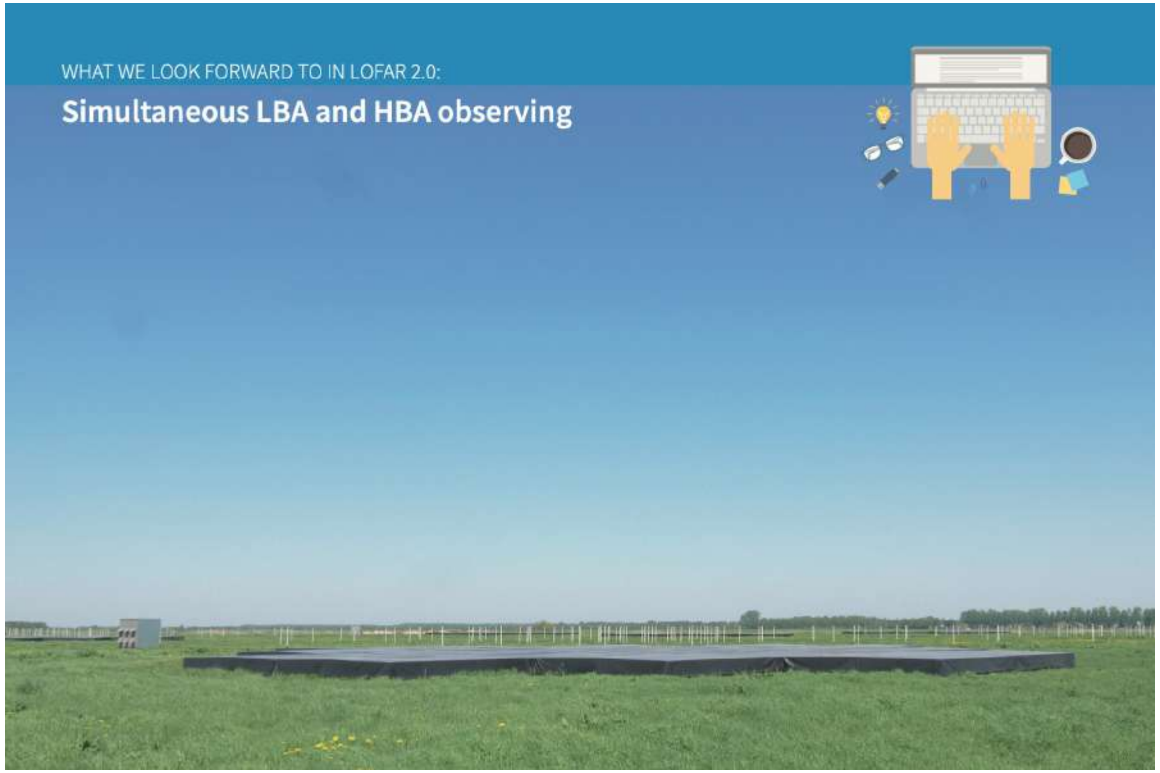
Where are we headed?

2025: deep breath before the plunge

ASTRON in a time of critical change

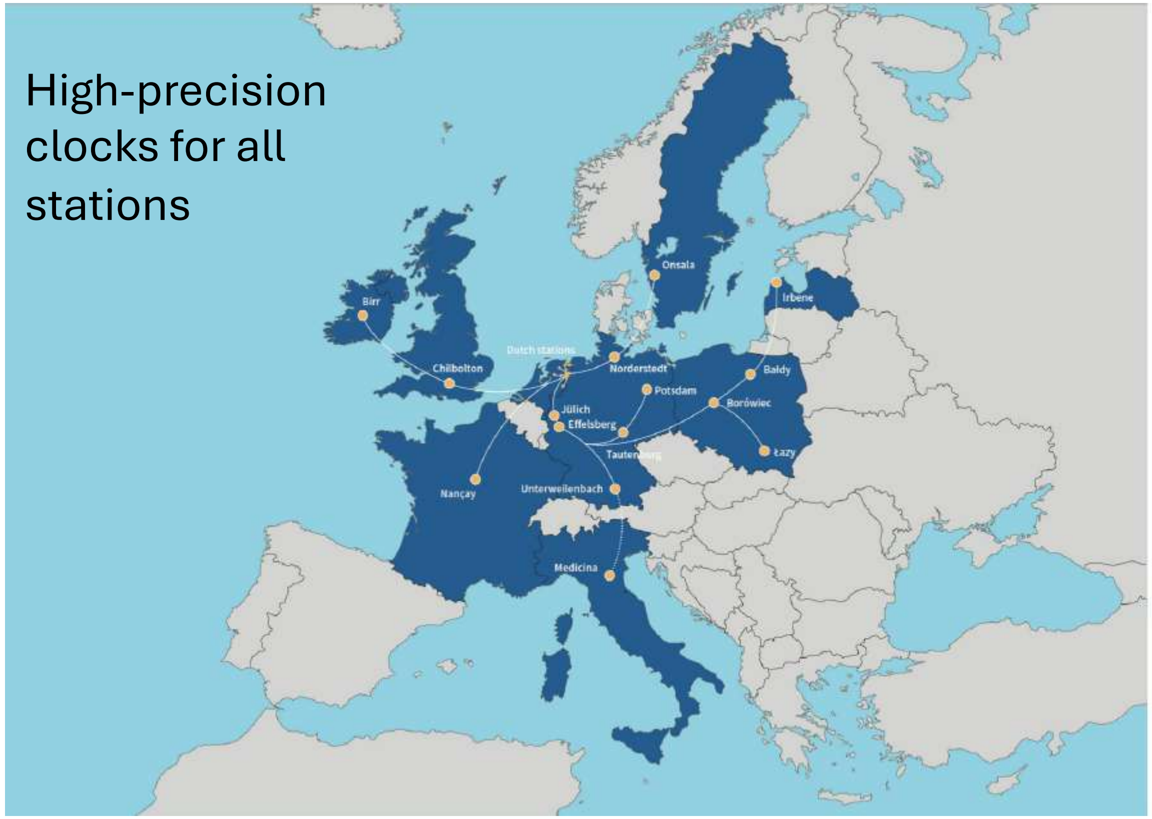
- LOFAR2.0 upgrade underway
- SKA construction underway





LOFAR 2.0

- New correlator/beamformer COBALT 2.0 – increase data throughput by 3-6
- New clock synchronization White Rabbit – ns precision
- A new scheduling system (TMSS)
- New statiosn (Italy, Bulgaria)
- Increased bandwidth (800 GBps links improve data rates, survey efficiency)



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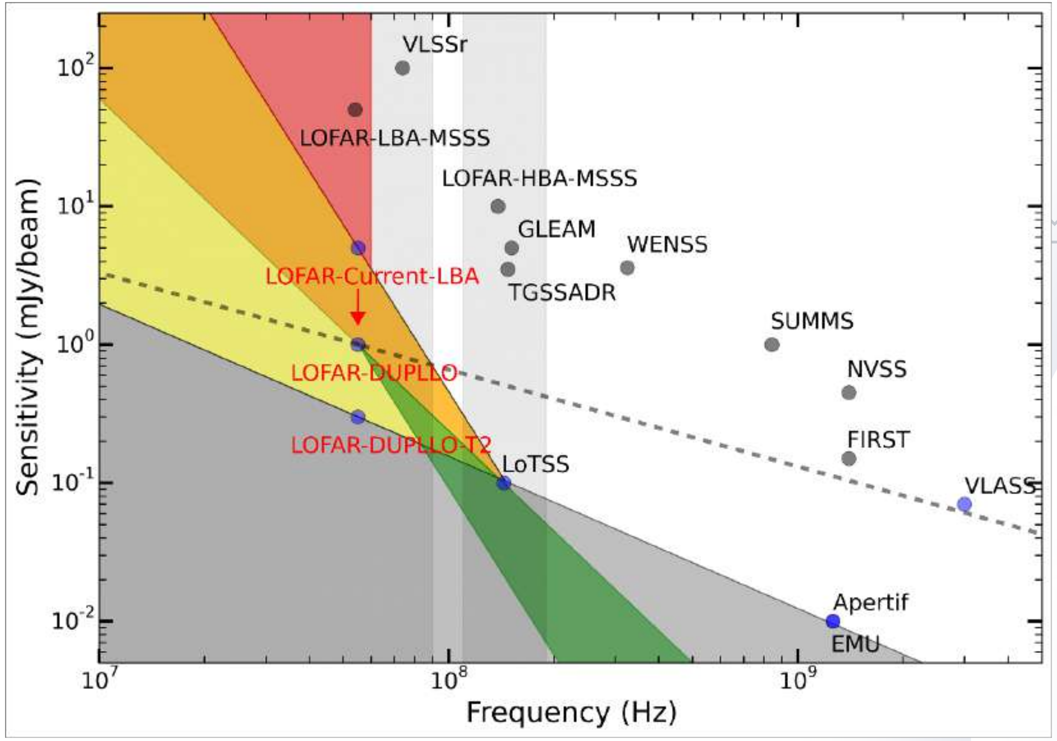
LOFAR 2.0 new science



- Transients: Compare 2-epoch all-sky coverage, Coherent emitters (compact objects, Gravitational wave counterparts
- 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
- AGN: Feedback of energy that regulates star formation, Study the radio jets that probe the energetics, “Fossil” emission gives the history of activity level
- Exoplanets, pulsars, nearby galaxies, galactic science
- Space weather, earth lightning, cosmic rays

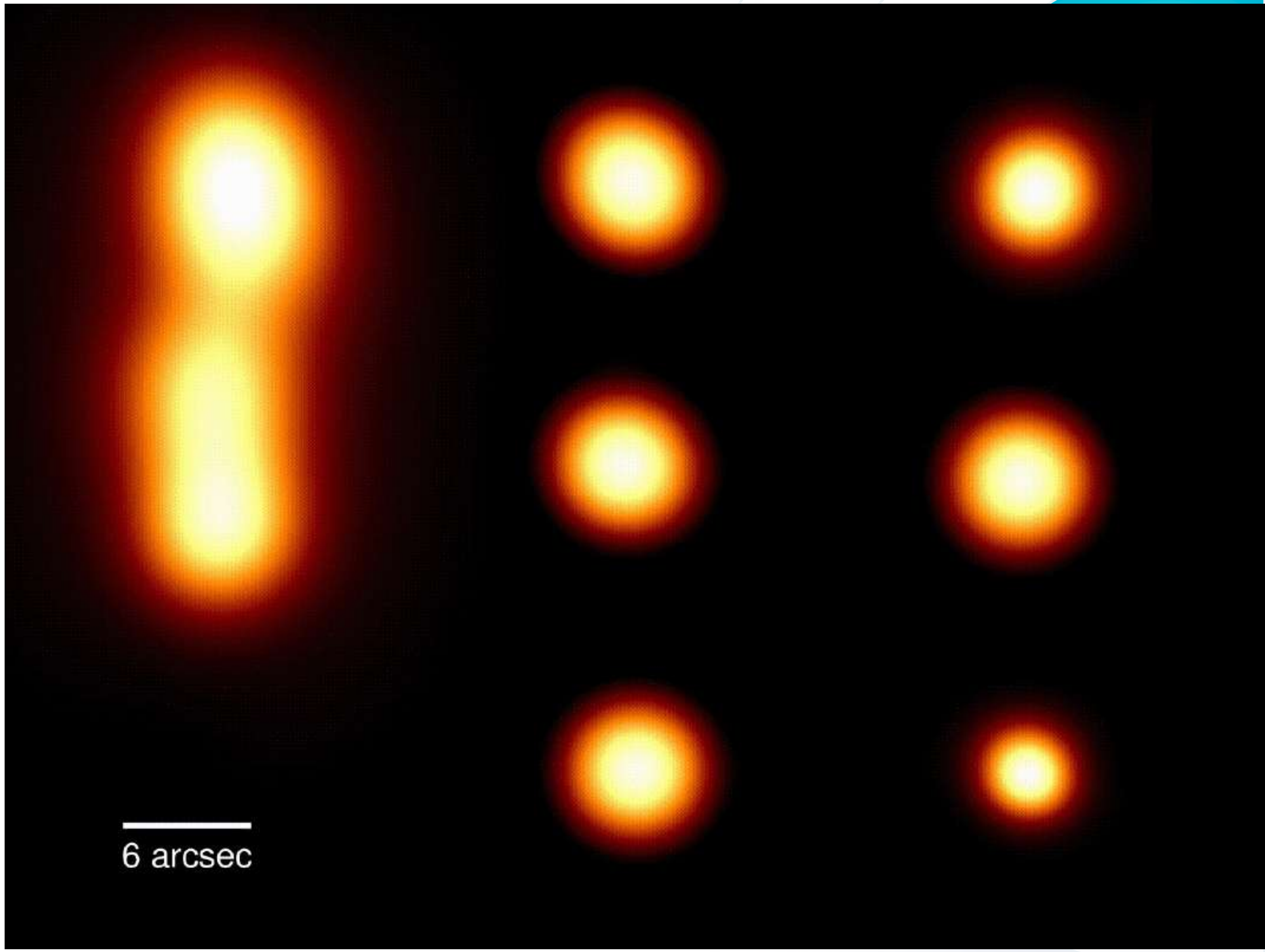
LENSS

In April 2025 ASTRON was awared LENSS:

IMPROVE LOFAR's field of view, resolution over 2000 km baselines and data processind speed
→ boost computing efficiency! x40 faster

To **coordinate and enhance scientific and technical cooperation** among European partners, particularly for **long baselines**, **calibration**, and **joint development**

Sharing of **software, expertise, and tools** for long-baseline calibration and imaging



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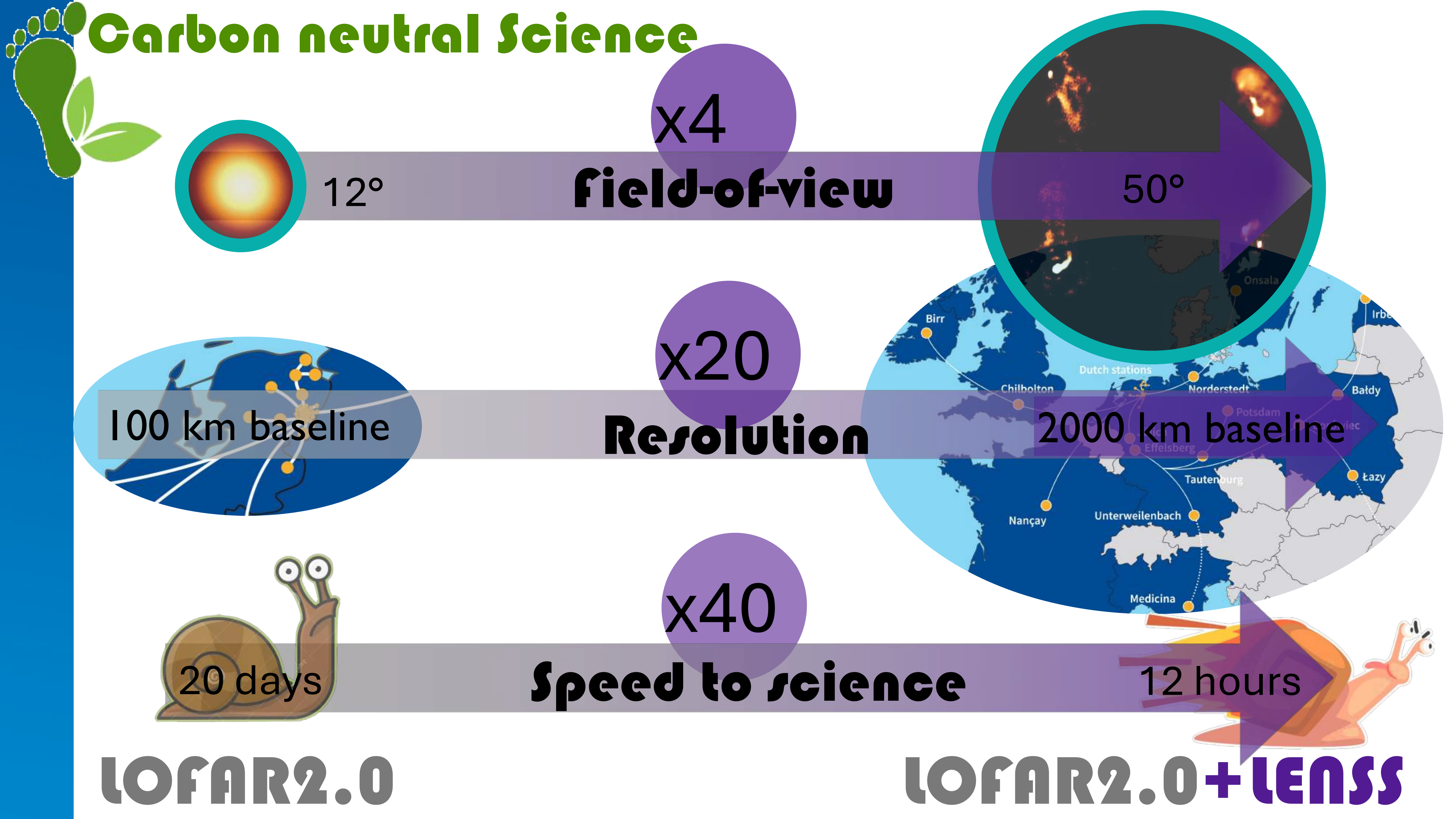


Carbon neutral Science
x4
12°
Field-of-view
50°
x20
100 km baseline
Resolution
2000 km baseline
Birr
Chilbolton
Dutch stations
Norderstedt
Potsdam
Effelsberg
Tautenburg
Nançay
Unterweilenbach
Medicina
Onsala
Bałdy
Łazy
x40
20 days
Speed to science
12 hours
LOFAR2.0
LOFAR2.0+LENSS

Square Kilometre Array

The international SKA will be the world's largest radio telescope of which the first phase will be operational in the late 2020's

ASTRON is focussing on its SKA Regional Centres (SRC) development, industry contracts and potential AIV and commissioning support

Construction phase now underway and new partnerships are evolving

Square Kilometre Array

3 sites (Australia, South Africa, UK)

2 telescopes (Low & Mid)

1 Observatory

- Project managed by SKA Observatory

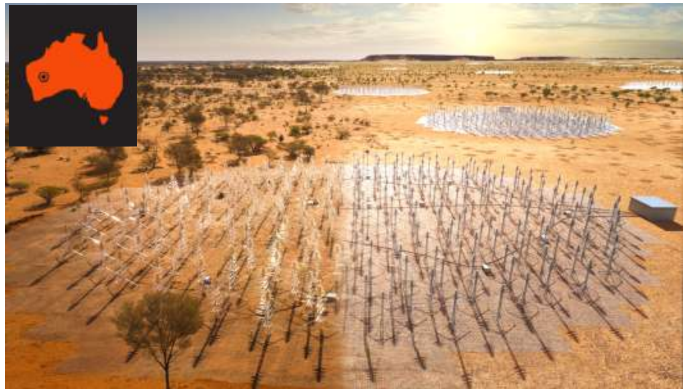
- New Intergovernmental Organisation
- SKA Convention signed in 2019
- SKA Observatory set up in 2021

- Construction started: August 2021
- Construction complete: 2027

- ~75% of funding in place (2021-2030)

- Lifetime of facility ~50 years

- First (global) collaboration to build a facility by the radio astronomy community



SKA1-Low

512 x 256 low frequency dipoles

50-350 MHz

65 km baselines

Murchison, Western Australia

SKA1-Mid

144 x 15m + 64 x 13.5m MeerKAT

0.35 - 15 GHz

150 km baselines

Karoo, South Africa

SKAO Headquarters at Jodrell Bank near Manchester (UK)

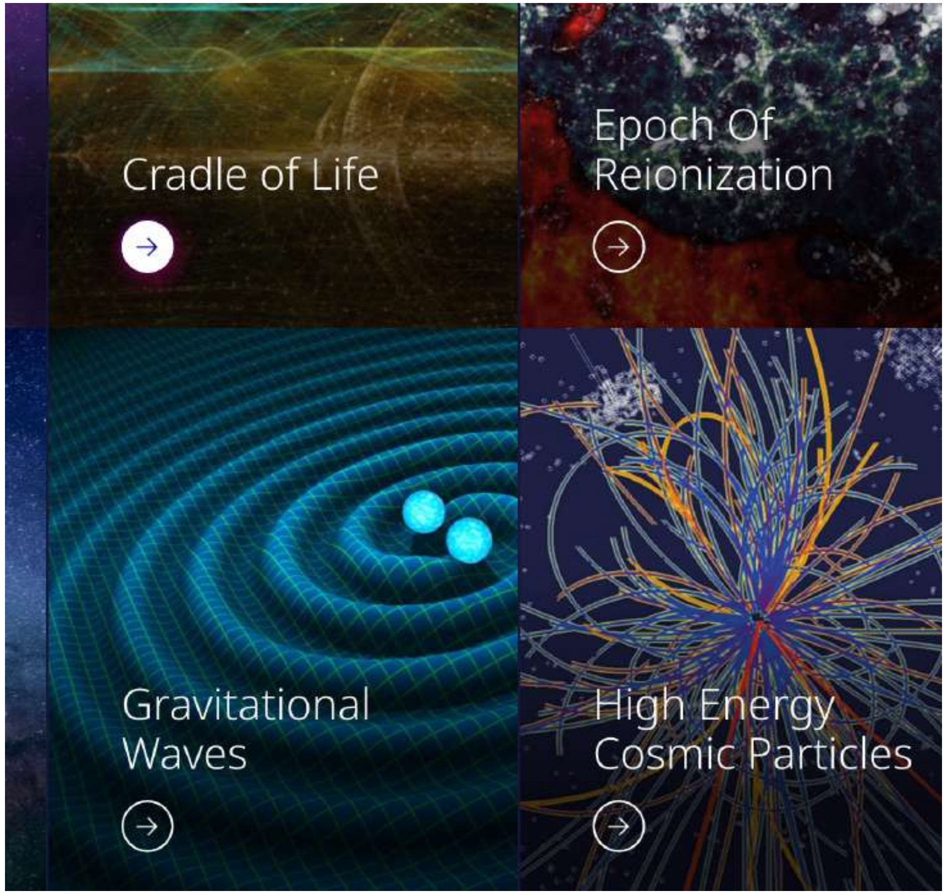
First Data
to Users

Milestone Event (earliest)		SKA-Mid	SKA-Low
Construction Approval		**2021 Jul**	**2021 Jul**
AA0.5 AIV start	**4 dishes** **4 stations**	**2025 Aug**	**2024 Jul**
AA0.5 end	**4 dishes** **4 stations**	2026 Feb	2024 Dec
AA1 end	**8 dishes** **16 stations**	2026 Oct	2026 Jan
AA2 end	**64 dishes** **64 stations**	2027 Aug	2026 Nov
AA* end	**144 dishes** **307 stations**	2028 Jun	2028 Feb
Operations Readiness Review		2028 Sep	2028 May
End of Staged Delivery programme		Formal end of construction (including contingency): 2029 Mar	
AA4	**197 dishes** **512 stations**	TBD	TBD

SKA involvement in the NL SKA Science Working Groups

Dutch members in SKA SWG

- 3 Cosmology
- 7 CoL (2 core)
- 7 EoR (1 past-chair)
- 10 Extragalactic continuum
- 5 Extraglactic spectral lines
- 10 Gravitational Waves (1 current chair)
- 8 High Energy Particles (4 core)
- 10 HI Galaxy Science (2 past chairs, 1 current chair)
- 5 Magnetism (1 core)
- 6 Our Galaxy
- 6 Pulsars (1 core)
- 1 Solar (1 chair)
- 12 Transients (1 current chair, 2 core)
- 12 VLBI (1 previous chair)



- Need to ensure our investment is comensurate with our science participation (raw membership at ~6% of SKA)
- Need to ensure that our investment in precusor instruments is capitalised as a community

ASTRON astronomers are members of many of the 14 SKA Science Working Groups (SWGs), including being SWG co- Chairs past and present (e.g., Oosterloo, Adams, Hessels).

SKA Regional Centre (SRC)

- FUSE funding for **development of SRCs** for European/Dutch SKA community
- Balance of harnessing existing needs and capabilities with **LOFAR**
- The opportunity for highly resourced **co-creation** with the **distributed SKA network**
- High level of **engagement in the SKA partner countries** for SRC development - where these can be synergized remains the question

Challenges ...

Secure a strong position in the SKA Observatory

- Generate more support and momentum for SKA within the early and mid-careers **astronomers in NL**
- Network in **Europe** to strengthen collaborative opportunities for scientists and data centres
- Focus campaign to the ministry for further SKA support for access and **data centre development**

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SDC: big data solutions and FAIR access to radio astronomy

- Data pipelines that produce **science-ready products** for non-experts
- A **data portal** that provides findable science and access to our (non)experts and analysis tools
- Leading collaborations with out European partners to prototype true **distributed networking** with LOFAR as a pathfinder for the SKA regional centre networks

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030s: the radio stronomy renaissance

Radio astronomy has until now had a high barrier of access

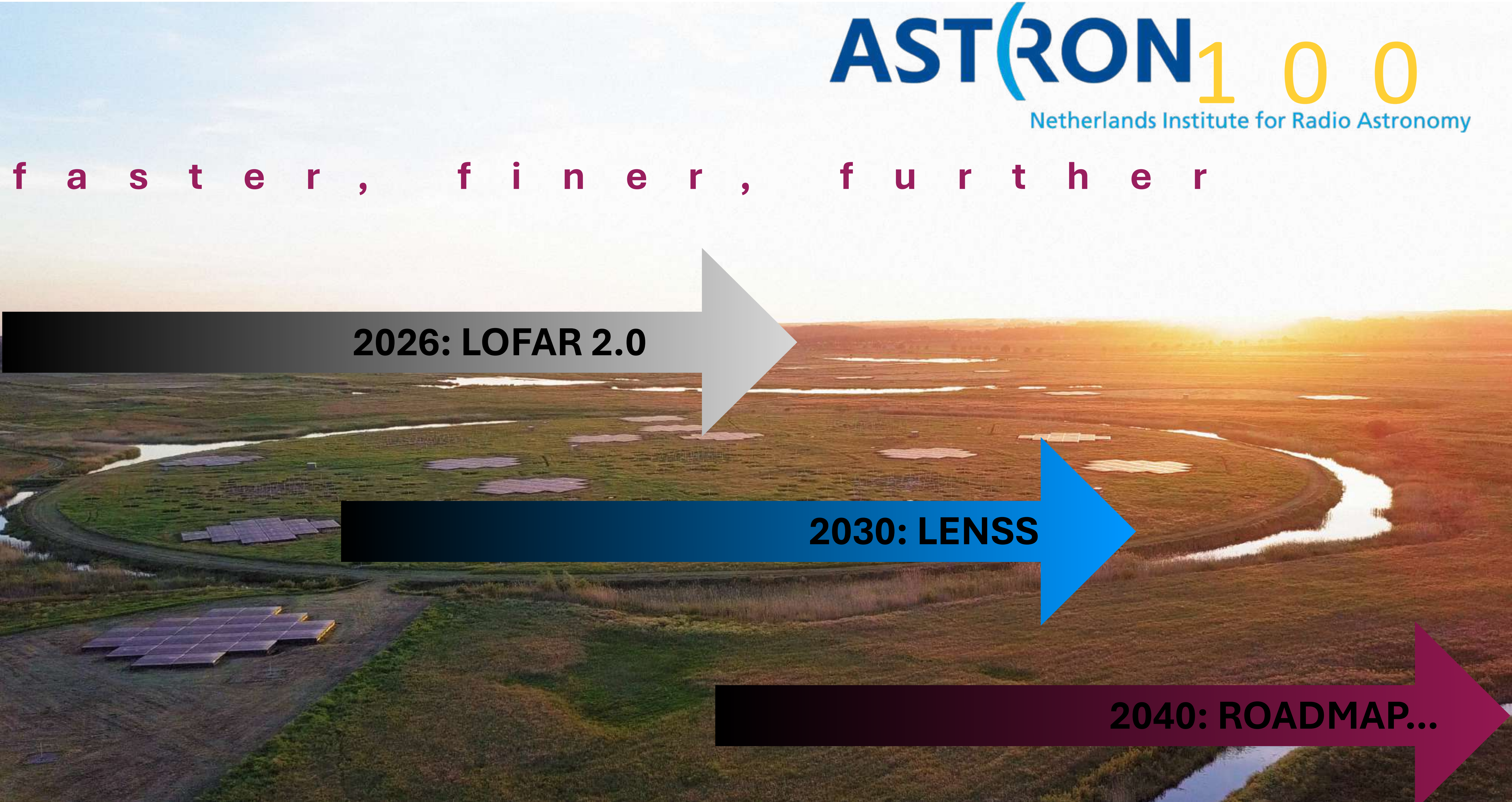
Why? interferometric and calibration techniques, huge processing requirements, bespoke one-of-a-kind reduction methods

- With these billion dollar facilities, as with ALMA before it, the **paradigm shift** to science-ready data products will lower these barriers

The radio astronomy community will expand

- Nearly every ngVLA and SKA partner are investing heavily in data capabilities and next gen technology

Slide Name


ASTRON 100
Netherlands Institute for Radio Astronomy
faster, finer, further
2026: LOFAR 2.0
2030: LENSS
2040: ROADMAP...

The ASTRON edge

OPPORTUNITY FROM
OVERLAPPING DEVELOPMENT

1956

1970

2010

2030

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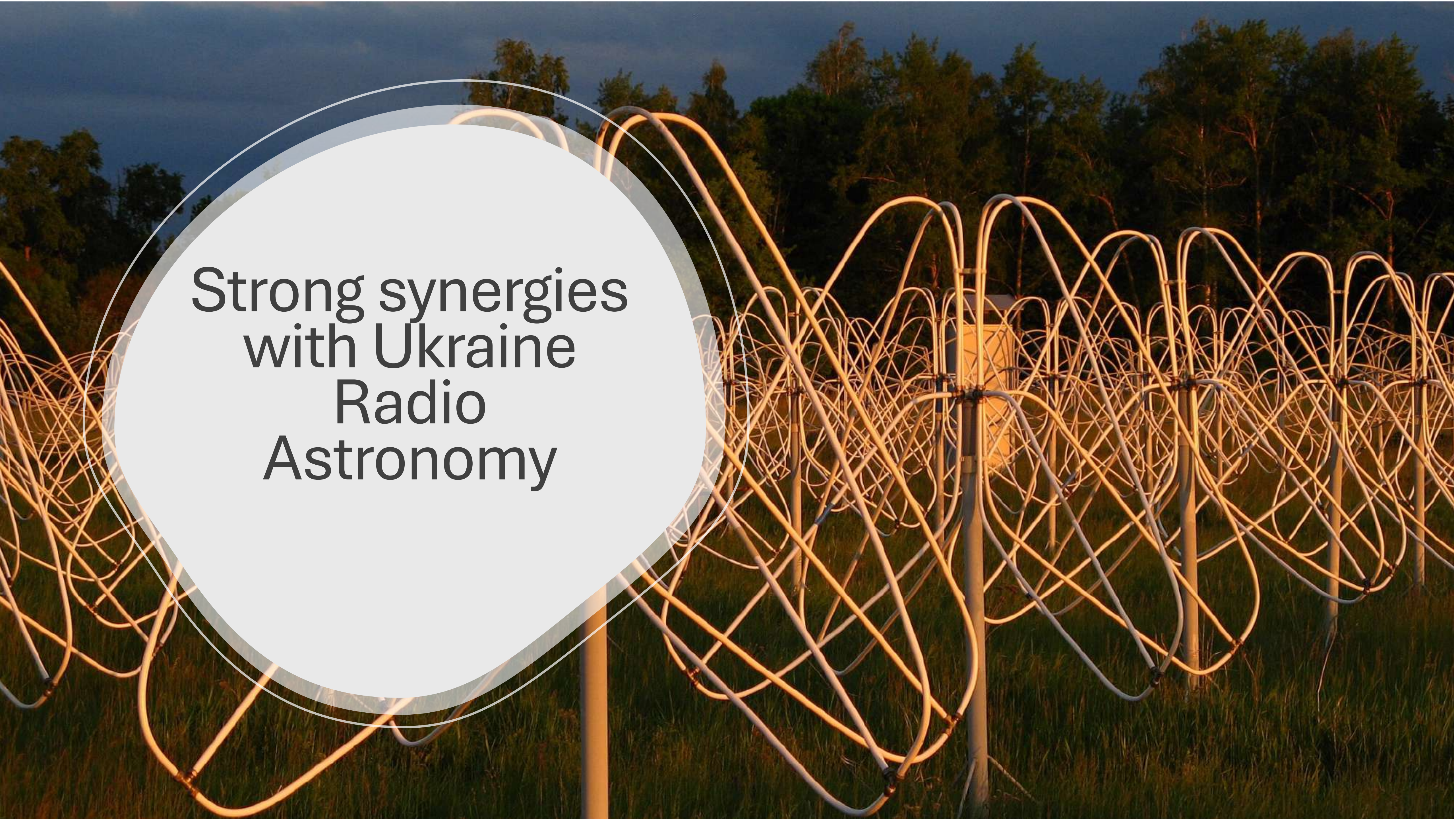
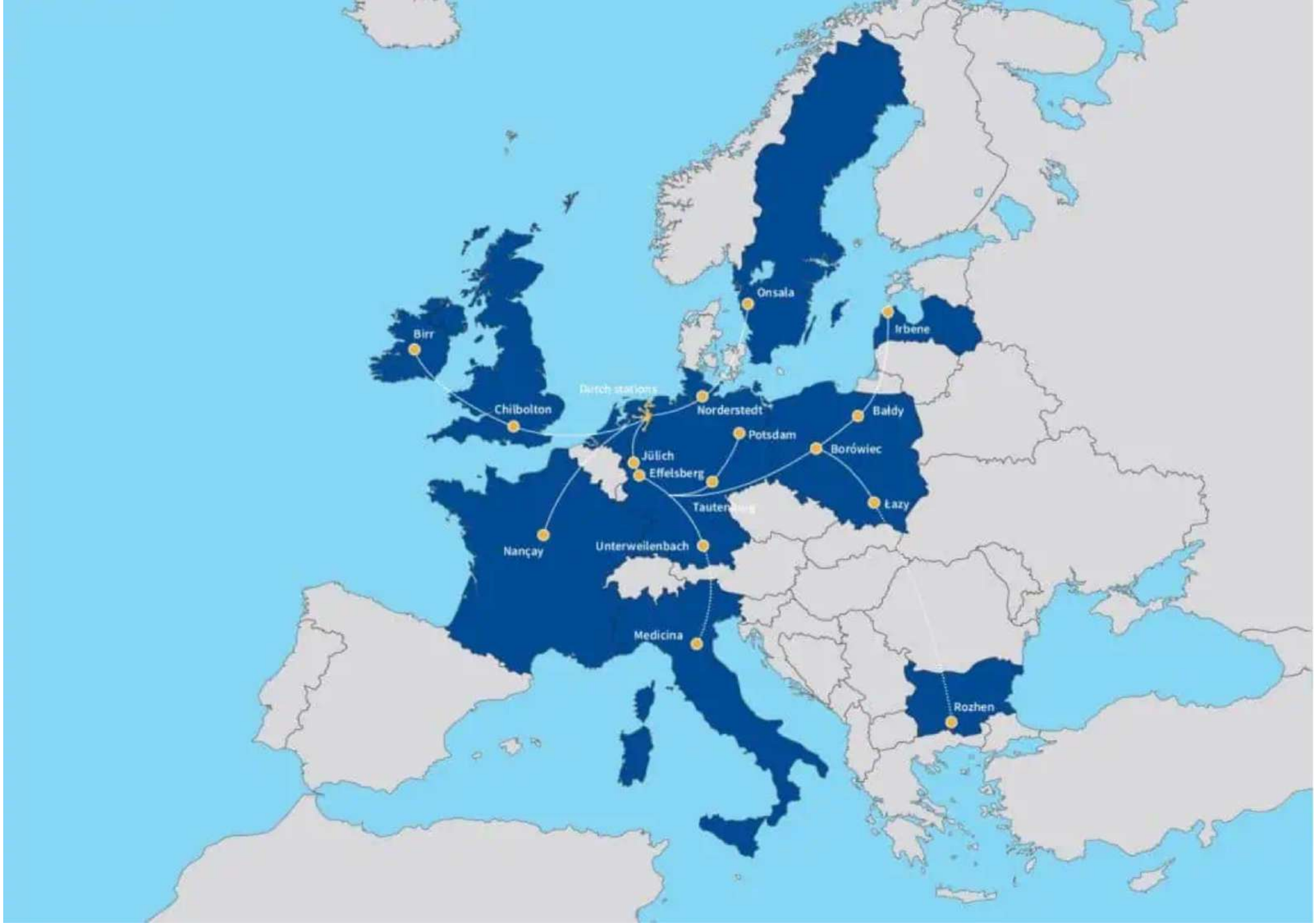
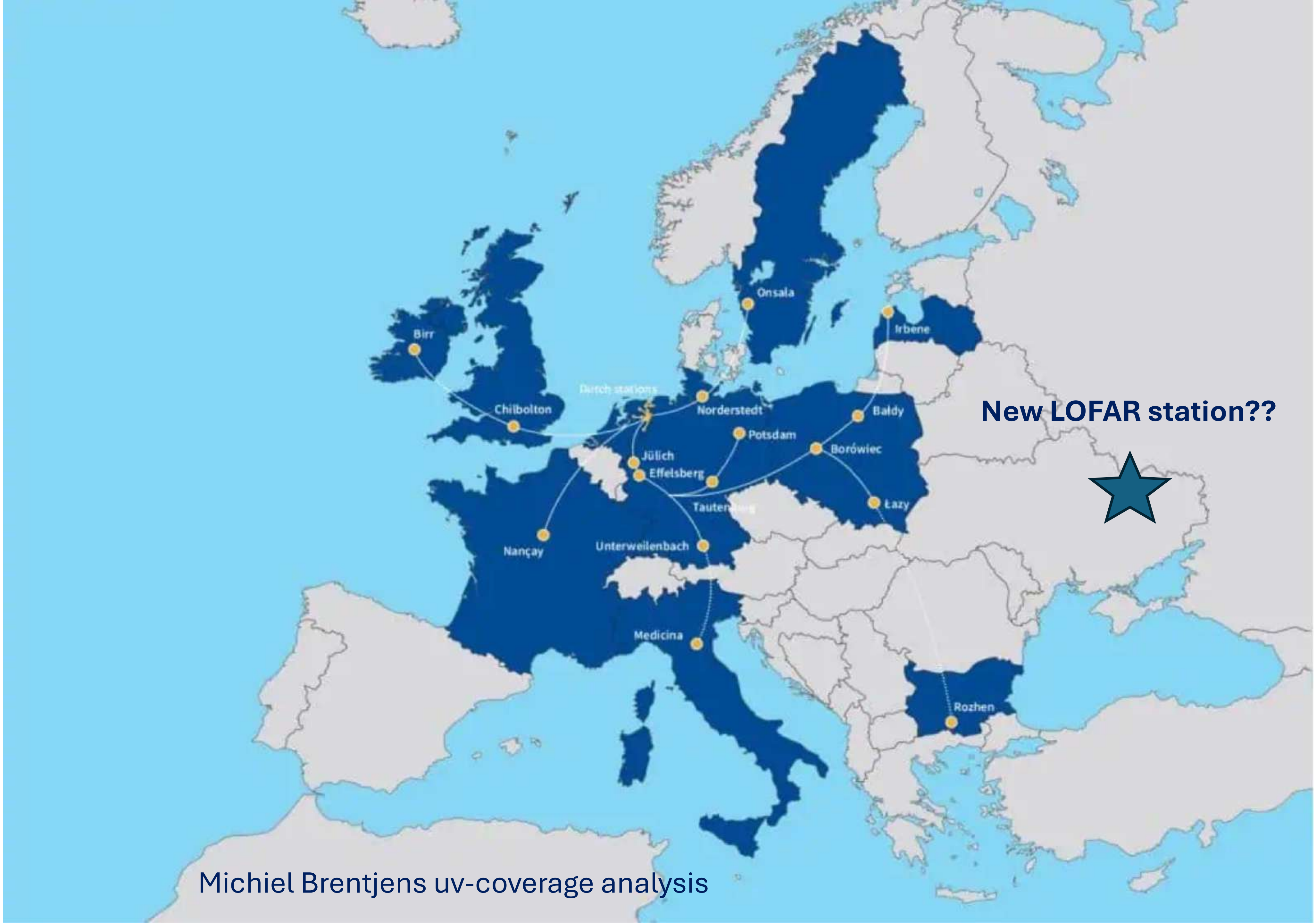
Strong synergies with Ukraine Radio Astronomy



🇺🇦 ASTRON-Ukraine Collaboration

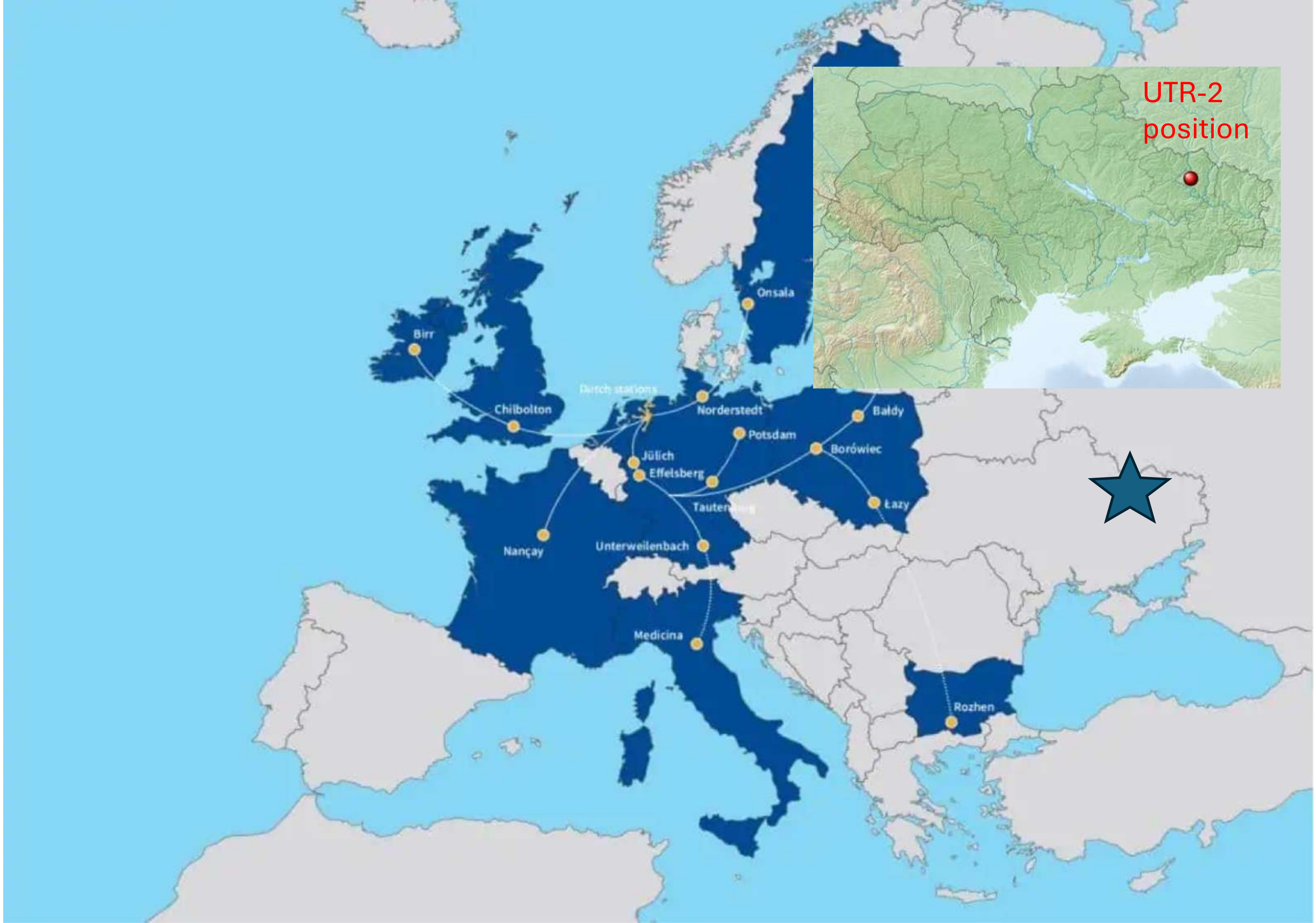
- Scientific and technical partnership
  - LOFAR-Ukraine partnership via **scientific collaborations**, e.g. low frequency, VLBI studies leveraging on URAN/UTR-2 experience
  - Joint VLBI research programs
  - Offer data access and training (e.g. Apertif, LOFAR)
- Educational & outreach collaboration
  - Co-host summer schools or workshops
  - Pair Ukranian students with ASTRON scientists
  - Host postdocs and visiting scientists
- Strategic & Reconstruction Support
  - Provide technical expertise and In-kind donationations, e.g. spare equipment
  - Advocate for Ukraine’s inclusion in RadioNet, EVN, ILAF, SKA regional plans
  - Explore a future **LOFAR outpost** or lightweight node in Ukraine…


Onsala
Birr
Irbene
Dutch stations
Chilbolton
Norderstedt
Bałdy
Potsdam
Jülich
Effelsberg
Borówiec
Tauten
Łazy
Nançay
Unterweilenbach
Medicina
Rozhen



New LOFAR station??

Michiel Brentjens uv-coverage analysis



UTR-2
position
Onsala
Birr
Dutch stations
Chilbolton
Norderstedt
Bałdy
Potsdam
Borówiec
Jülich
Effelsberg
Tauten
Łazy
Nançay
Unterweilenbach
Medicina
Rozhen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h o w f a r c a n w e g o ?


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CENTENNIAL
Niels Vertegaal et al.
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY


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Making discoveries in radio astronomy happen