

LOFAR : opening a new window for the observation of the Universe

- The Italian involvement -



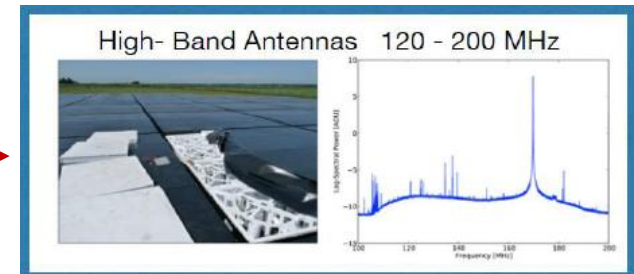
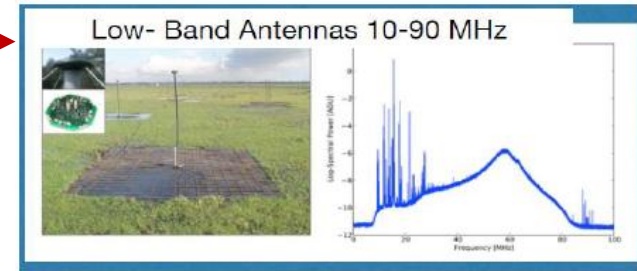
Gianfranco Brunetti



THE LOW FREQUENCY ARray

Giant digital aperture array radio telescope opening up a new window in the electromagnetic spectrum at low radio frequencies

(van Haarlem + 2013)

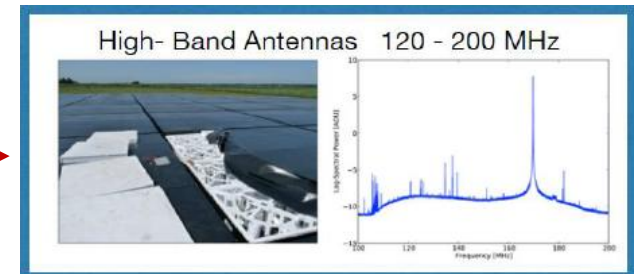
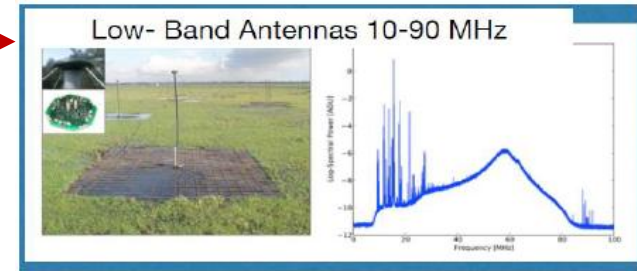


11 Countries (NL, D, Pl, It, Ir, UK, F, Sw, Bul, Latvia, Czech)
24+14+14(17) stations

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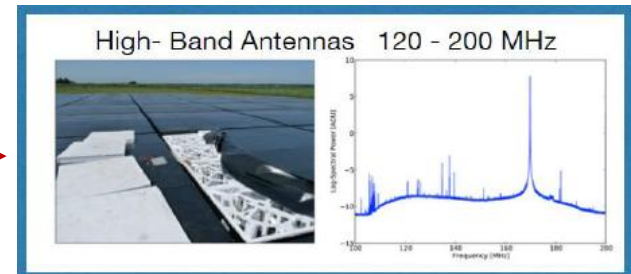
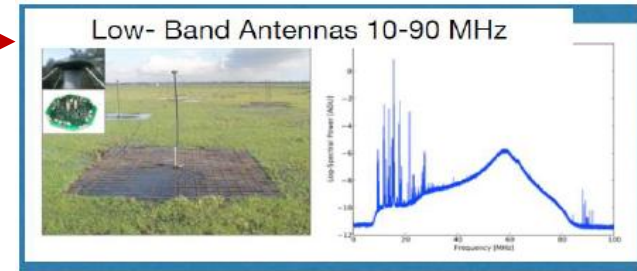


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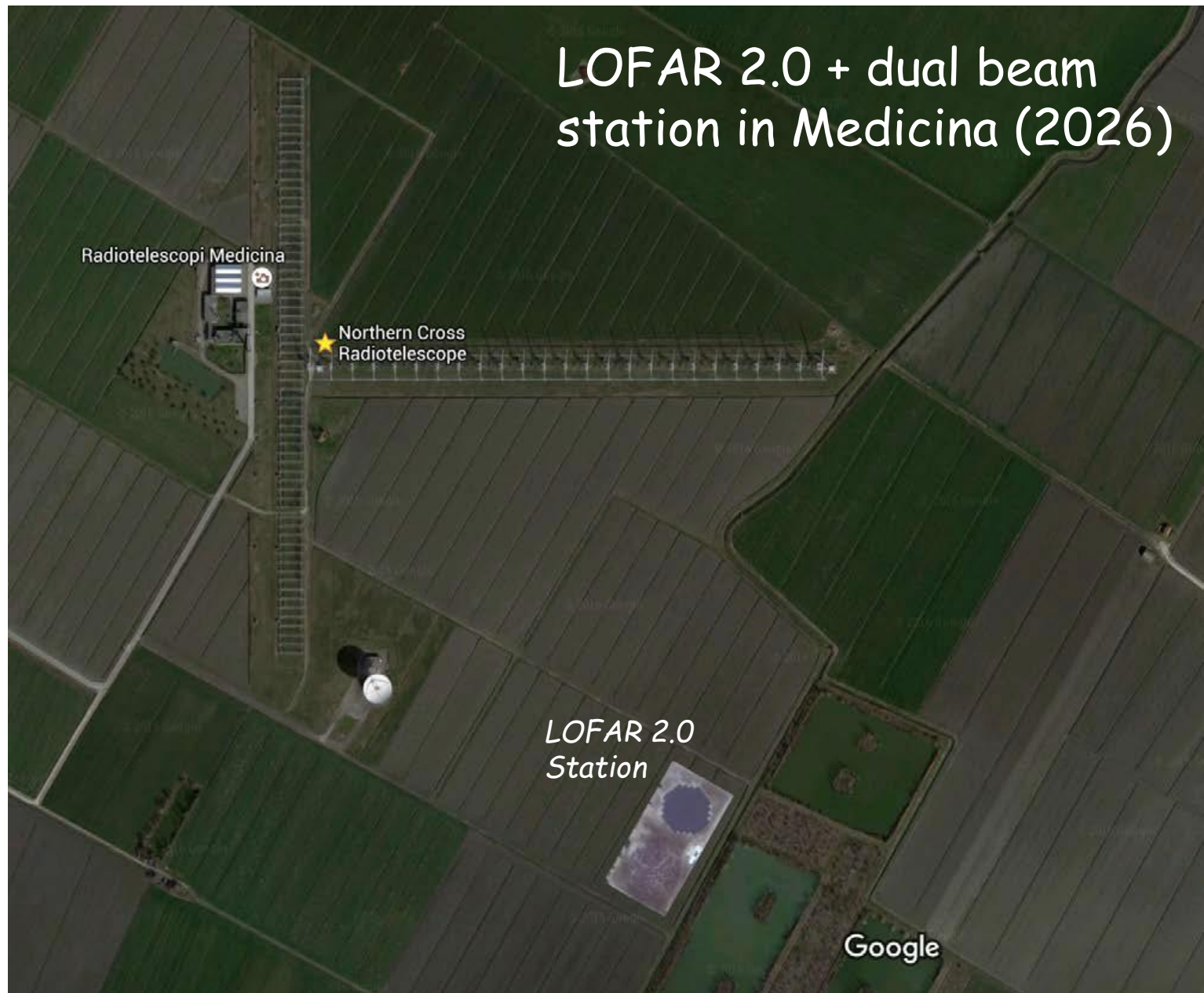
(van Haarlem + 2013)



Upgrade in
LOFAR 2.0
(~4x LOFAR)

11 Countries (NL, D, Pl, It, Ir, UK, F, Sw, Bul, Latvia, Czech)
24+14+14(17) stations

THE LOW FREQUENCY ARray



THE LOW FREQUENCY ARray

Giant digital aperture array radio telescope opening up a new window in the electromagnetic spectrum at low radio frequencies
- The largest (area & dataflow) pathfinder toward the SKA(low) -

(van Haarlem + 2013)

(1) : dataflow

- ✓ 250 Gb/s across the entire network
- ✓ Large FoV, n baselines, n channels, produce typical **TB-size datasets**

x100 (J)VLA

11 Countries (NL, D, Pl, It, Ir, UK, F, Sw, Bul, Latvia, Czech)
24+14+14(17) stations

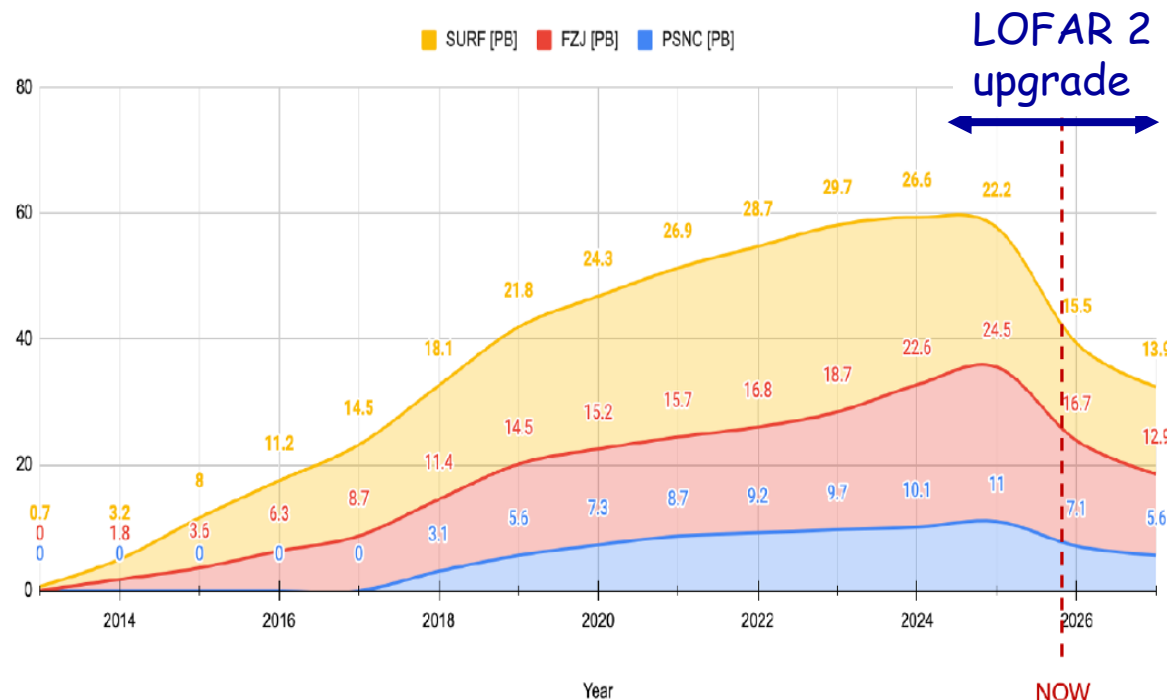


THE LOW FREQUENCY ARray

Giant digital aperture array radio telescope opening up a new window in the electromagnetic spectrum at low radio frequencies
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(van Haarlem + 2013)

LOFAR 1 data volume (including projection)



(1) : dataflow

- ✓ 250 Gb/s across the entire network
- ✓ Large FoV, n baselines, n channels, produce typical **TB-size datasets**
- ✓ Archiving problem and managing Big Data

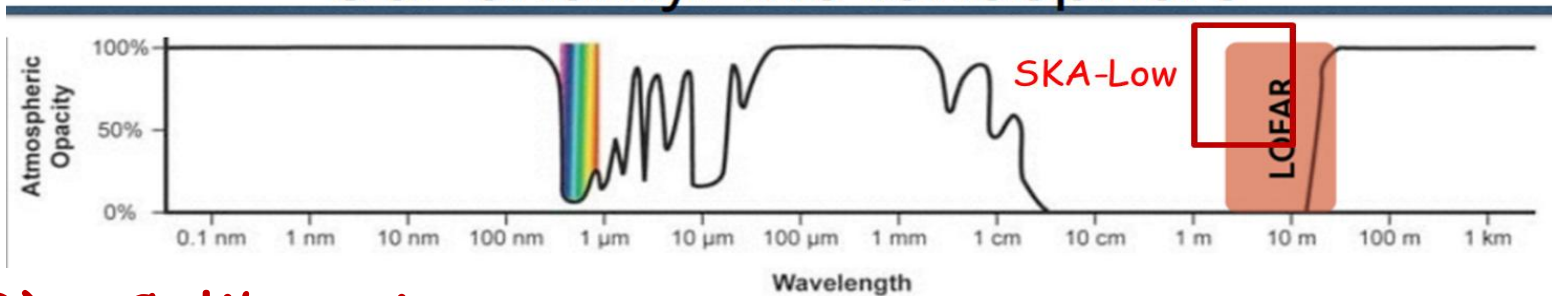
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THE LOW FREQUENCY ARray

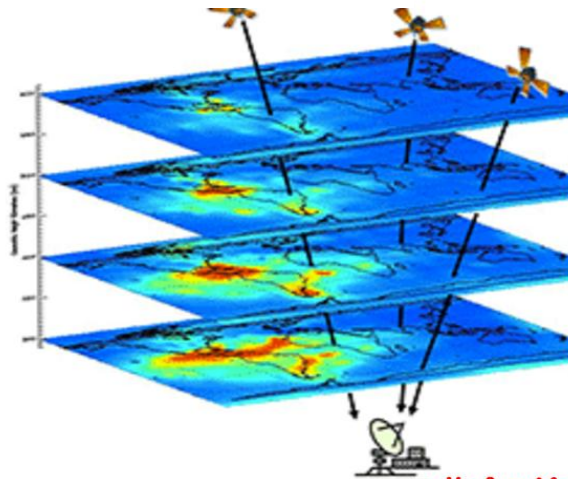
Giant digital aperture array radio telescope opening up a new window in the electromagnetic spectrum at low radio frequencies
- The largest (area & dataflow) pathfinder toward the SKA(low) -

BIG Challenges with data calibration and analysis

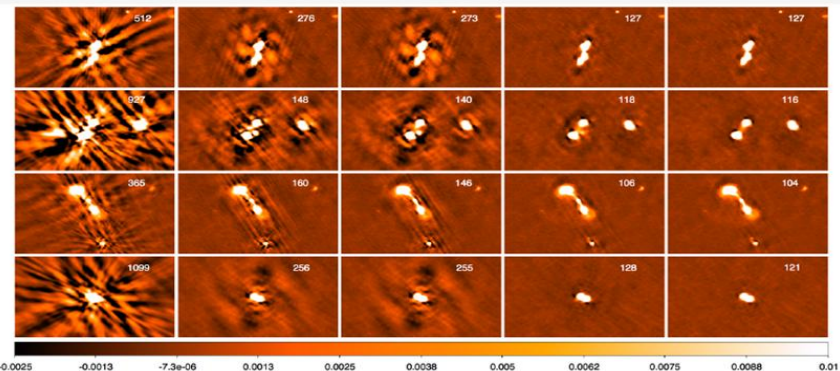
Our enemy: the ionosphere



(2) : Calibration



Facet calibration

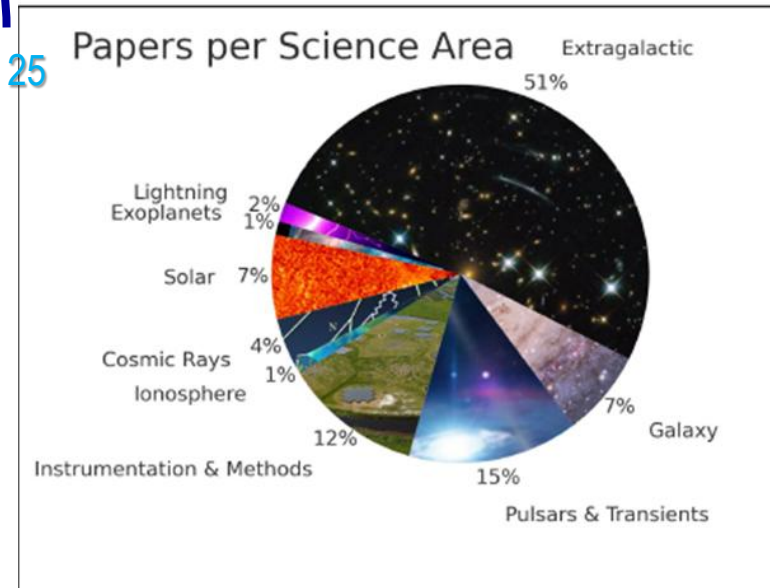
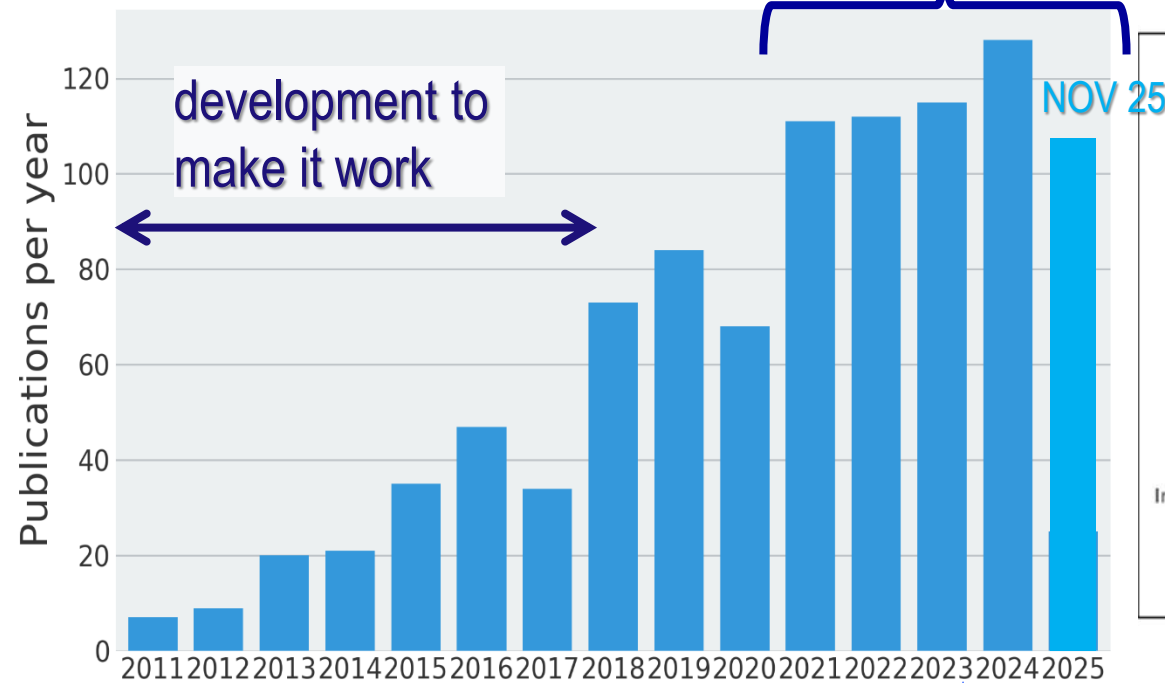


Demonstrating direction dependent calibration (van Weeren R. J., et al., 2016, ApJS, 223, 2)

Anticipate the challenges with the SKA LOW

(3) SCIENCE WITH LOFAR: A LEAP FORWARD IN SEVERAL (SKA-) AREAS

Top 10 among astro-
infrastructures



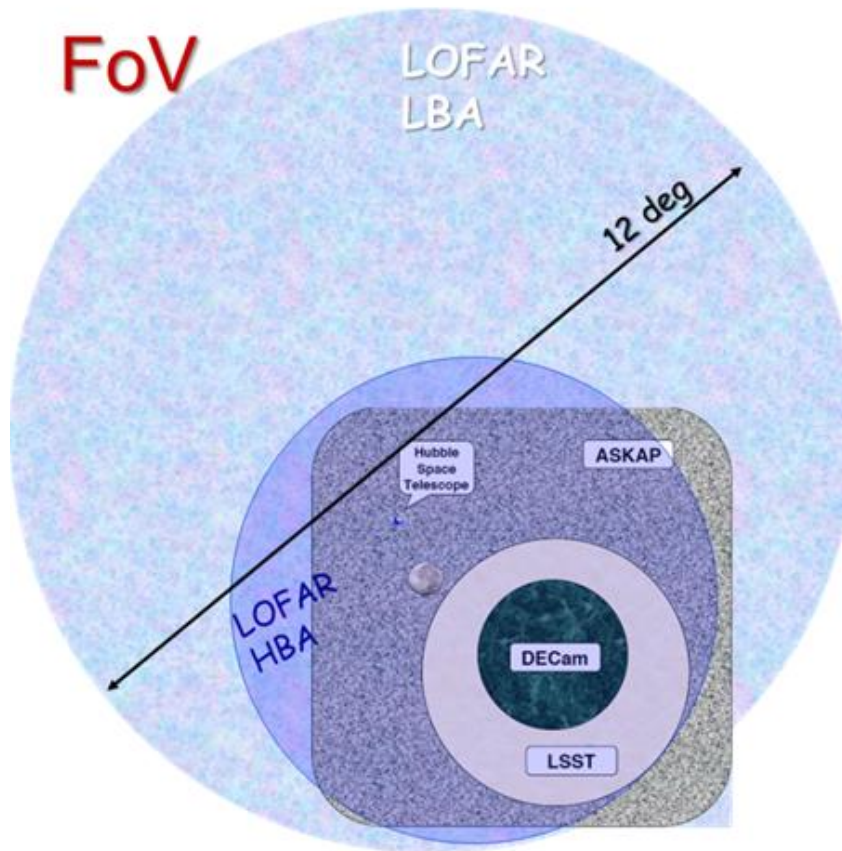
Credits: ASTRON

IT joins ILT

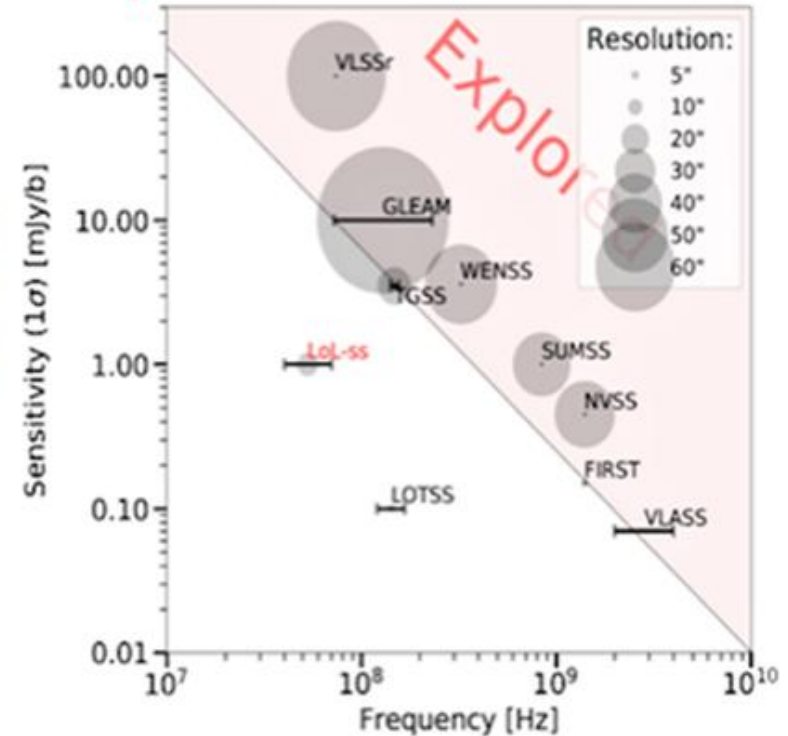
LOFAR-ERIC

IT funding member

THE LOFAR SURVEYS



- Opening a new window
- Extreme sensitivity for steep spectrum sources



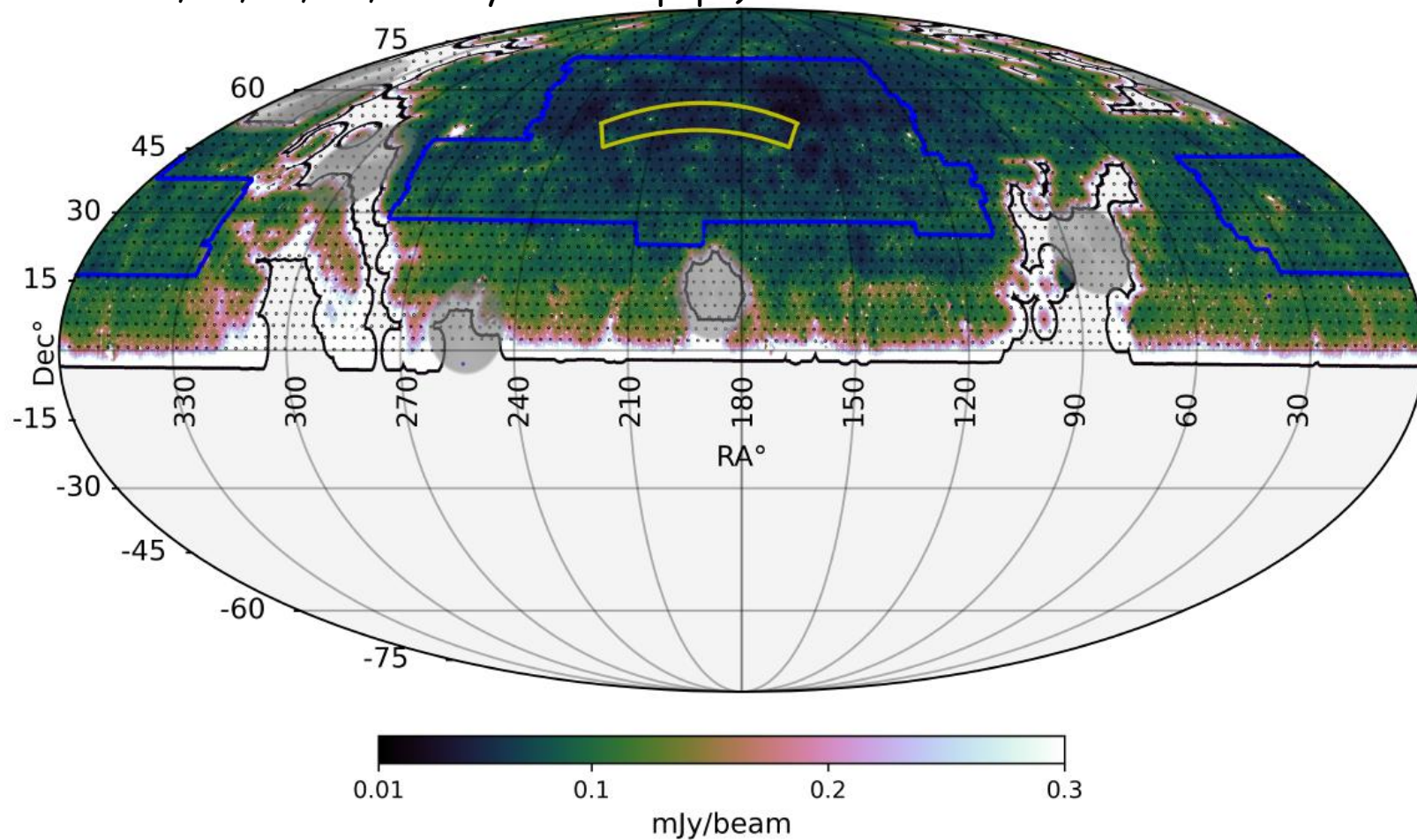
LOFAR Surveys of the entire northern sky are opening a new observational window of the Universe

- 10-100x better sensitivity
- 10x better spatial resolution (100x using international baselines)

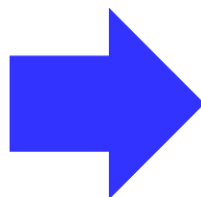
THE LOTSS Survey

(Shimwell+ 17, 19, 21, 25, + many related paps)

DR1 , DR2 , ... DR3

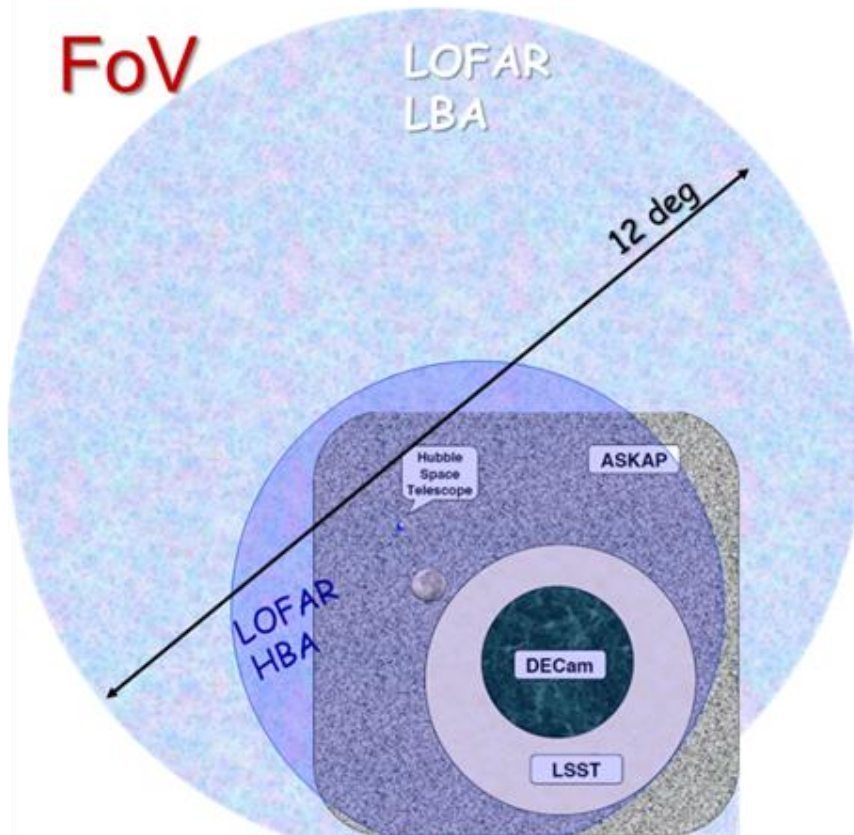


- ❑ ~13,000 observing hrs in 10 yrs
- ❑ ~19 PB of data
- ❑ ~20 Million Core hrs

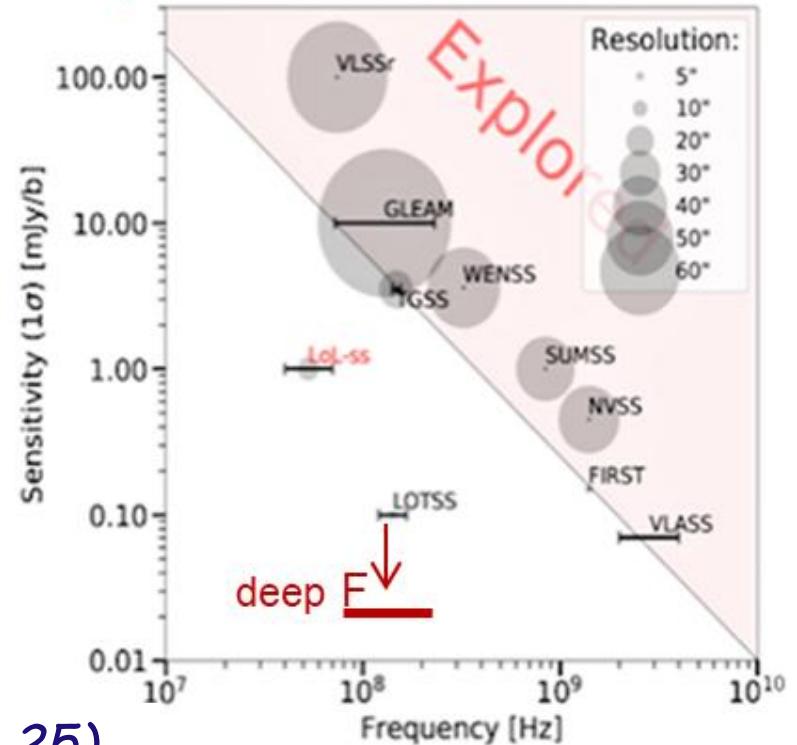


DR3 catalogue
~ 14 Million sources

THE LOFAR SURVEYS



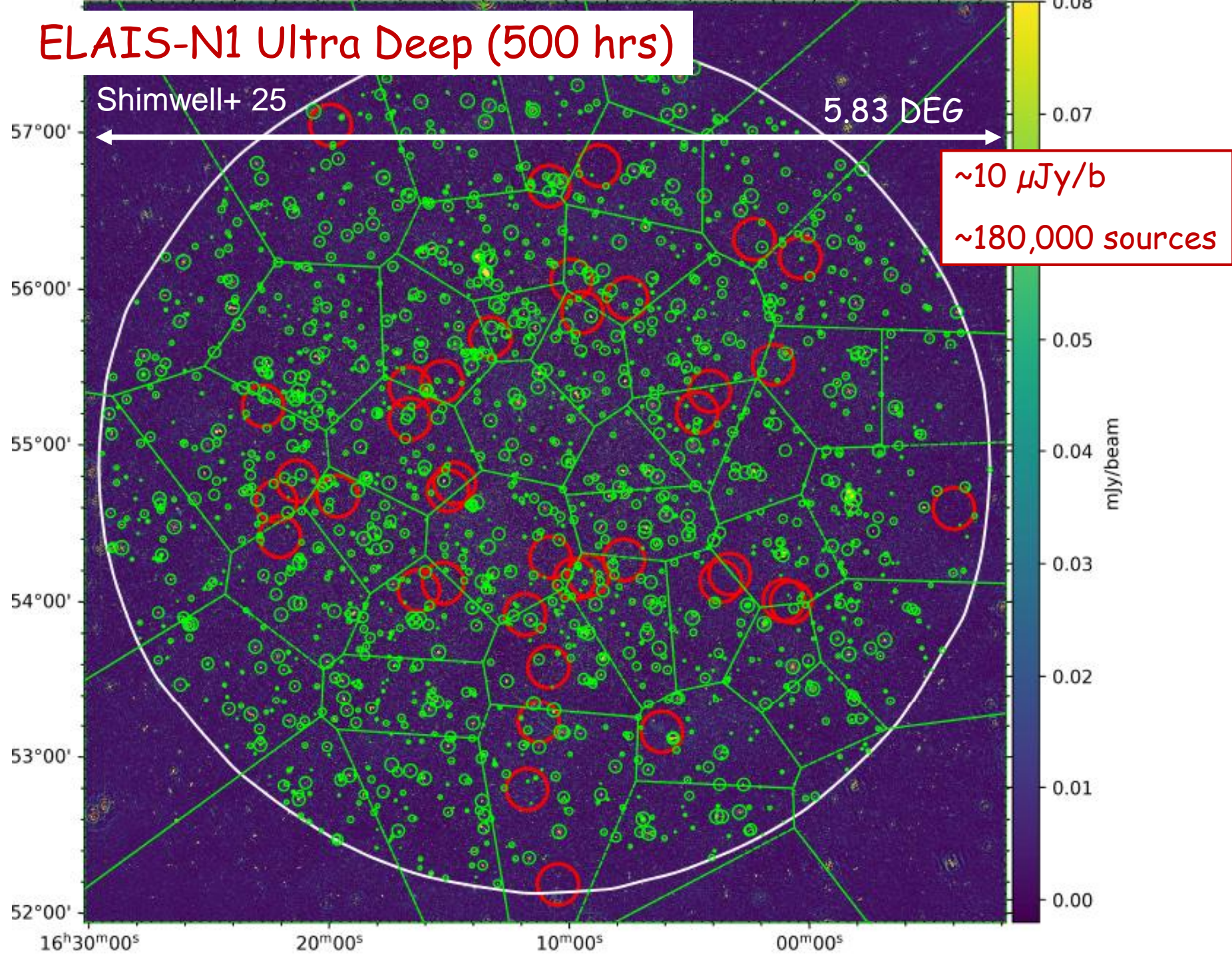
- Opening a new window
- Extreme sensitivity for steep spectrum sources



- ELAIS-N1 (Sabater+ 21, Shimwell+ 25)
- Bootes (Tasse+ 21)
- Lockman Hole (Tasse+ 21, Bonato+ 21)
- EDFN (Bondi+ 24, Bisigello+ 25)
- A2255 (Botteon+)
- GOODS-N (Magnetism KP)

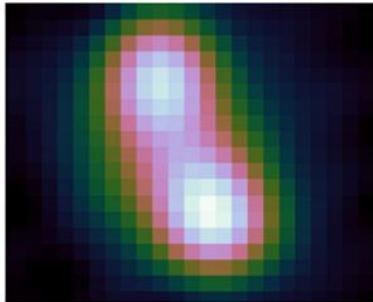
Anticipating SKA: in some cases deep fields reach sensitivities better than SKA(low)

ELAIS-N1 Ultra Deep (500 hrs)

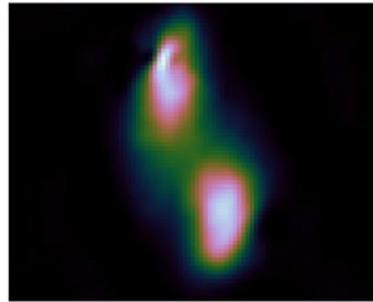


x20 baseline of SKA-Low : UNIQUE also in the SKA era

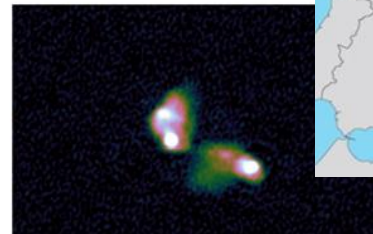
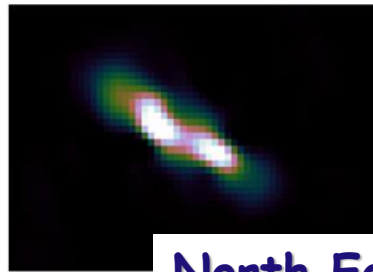
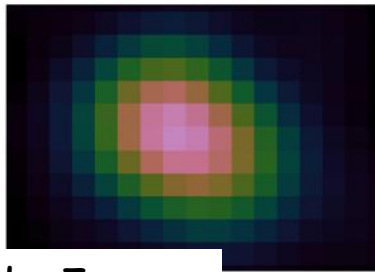
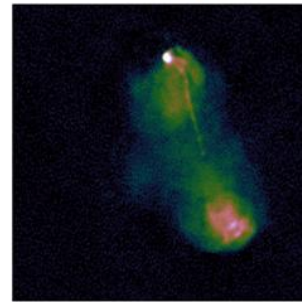
6"



1.2"



0.3"



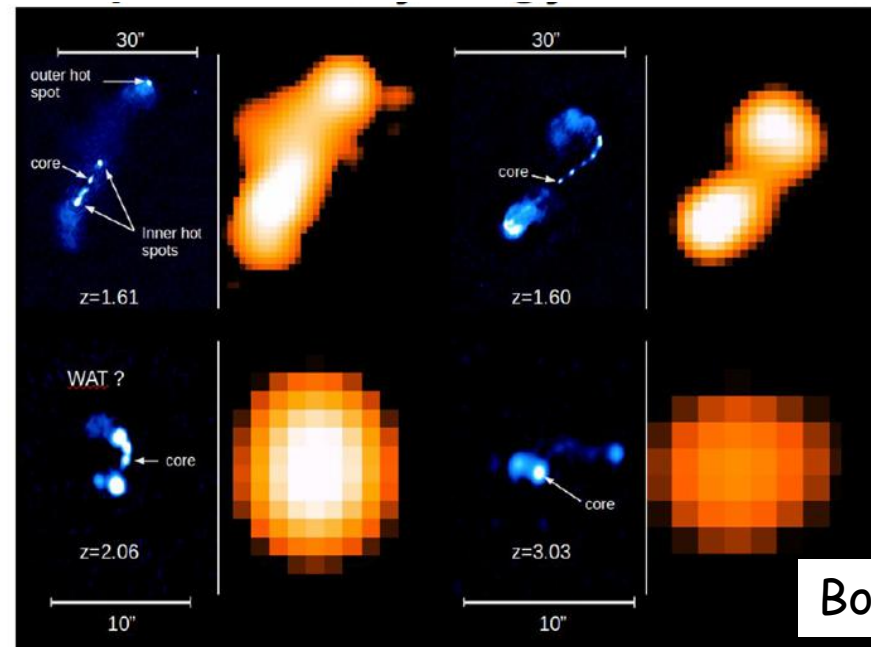
de Jong+ on

North Ecliptic Pole (synergy with EUCLID+JWST)

Computationally expensive !!

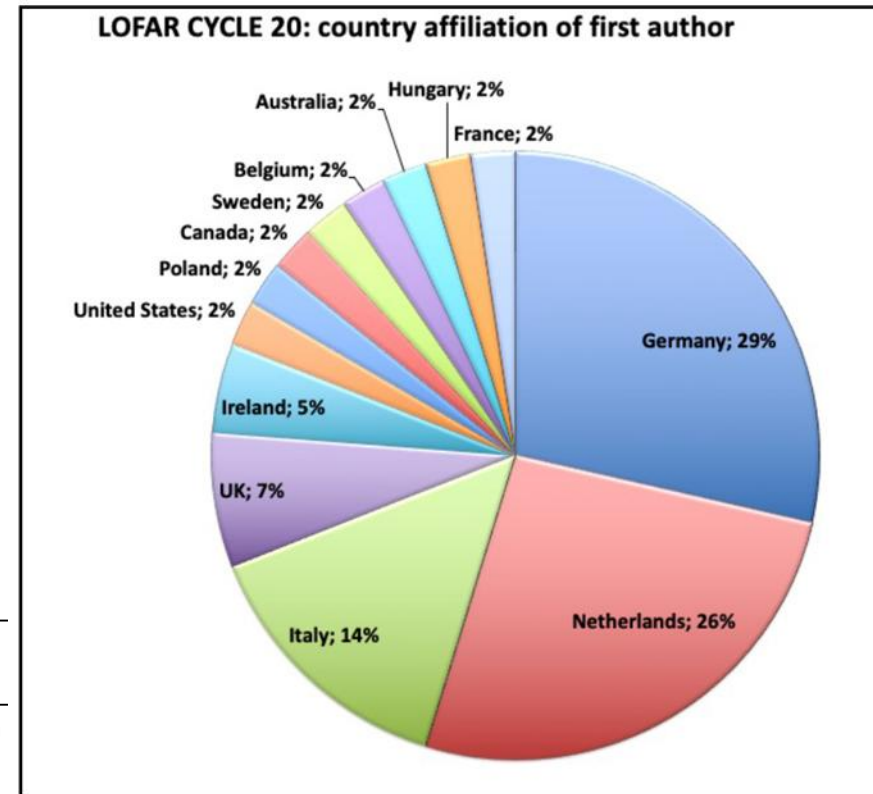
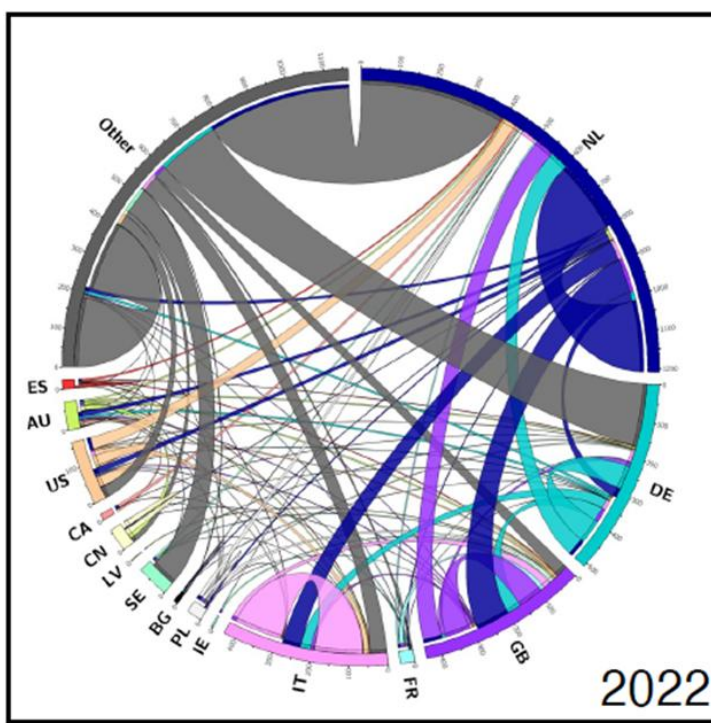
300,000 core hours necessary to image $\sim 5 \text{ deg}^2$ field observed with 8 hrs at **0.3 arcsec resolution** (eg Sweijen+ 2022, Nat Astr)

Imaging large regions with deep observations at sub-arcsec resolution is a **major computational challenge**



Bondi+

IT SCIENCE WITH LOFAR



Courtesy of R. Pizzo

Refereed papers IT-authors ~50 pap/yr



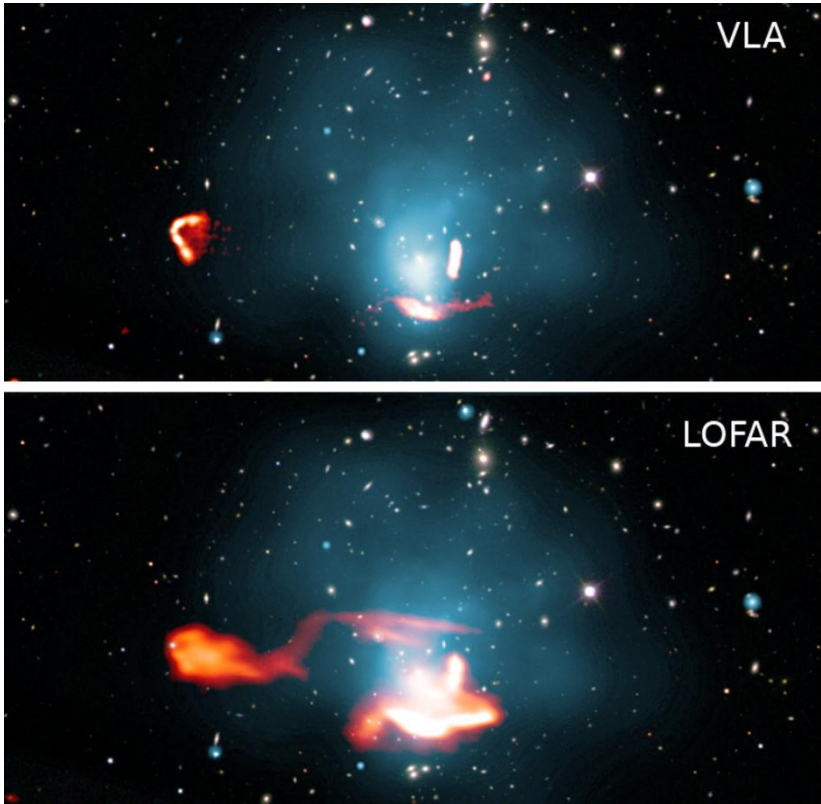
300+ TB/yr of HBA and LBA data are transported and processed on LOFAR-IT nodes

~260 papers in 2021--2025

PHYSICAL SCIENCES

Gentle reenergization of electrons in merging galaxy clusters

Francesco de Gasperin,^{1,2*} Huib T. Intema,¹ Timothy W. Shimwell,¹ Gianfranco Brunetti,³ Marcus Brüggen,² Torsten A. Enßlin,⁴ Reinout J. van Weeren,^{1,5} Annalisa Bonafede,^{2,3} Huub J. A. Röttgering¹

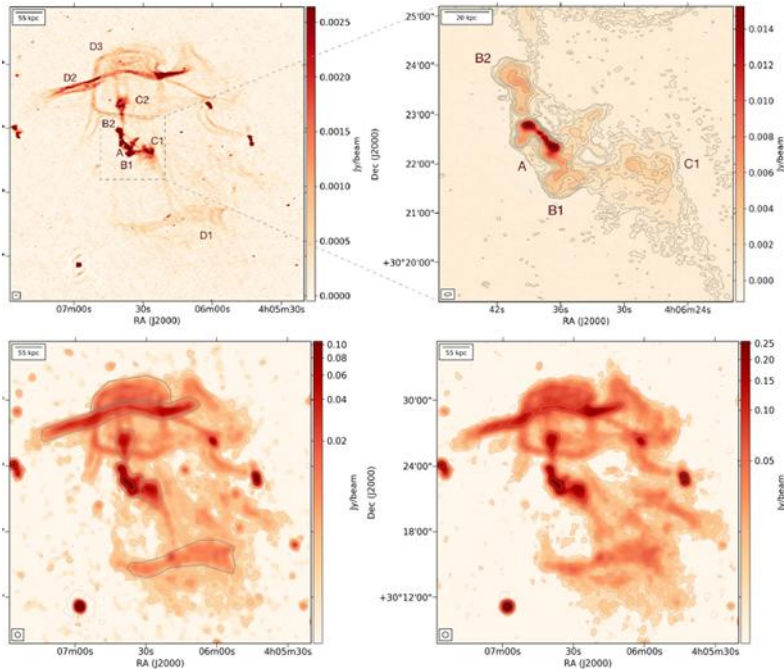


Evidence for gentle particle reacceleration in astrophysical jets from supermassive BH : new (astro-)physics ??

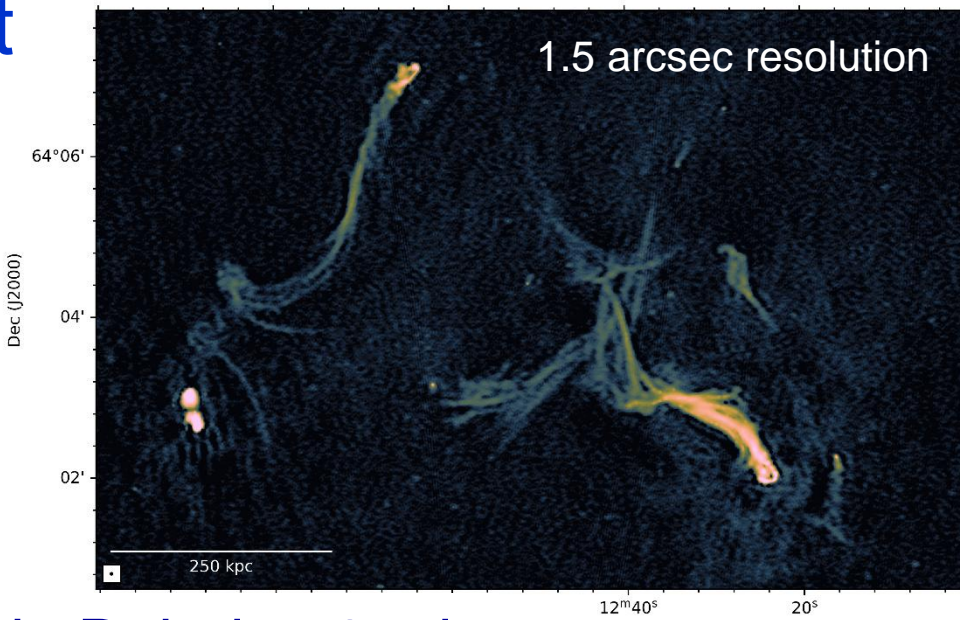
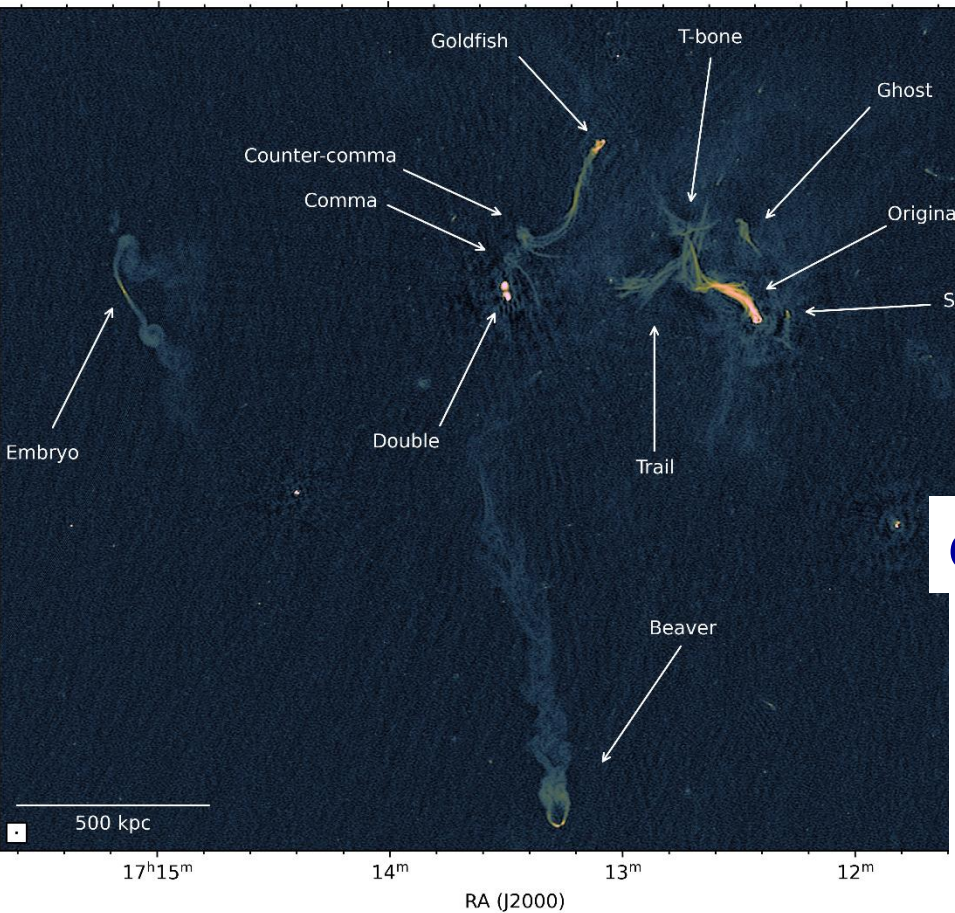
BH activity & their impact



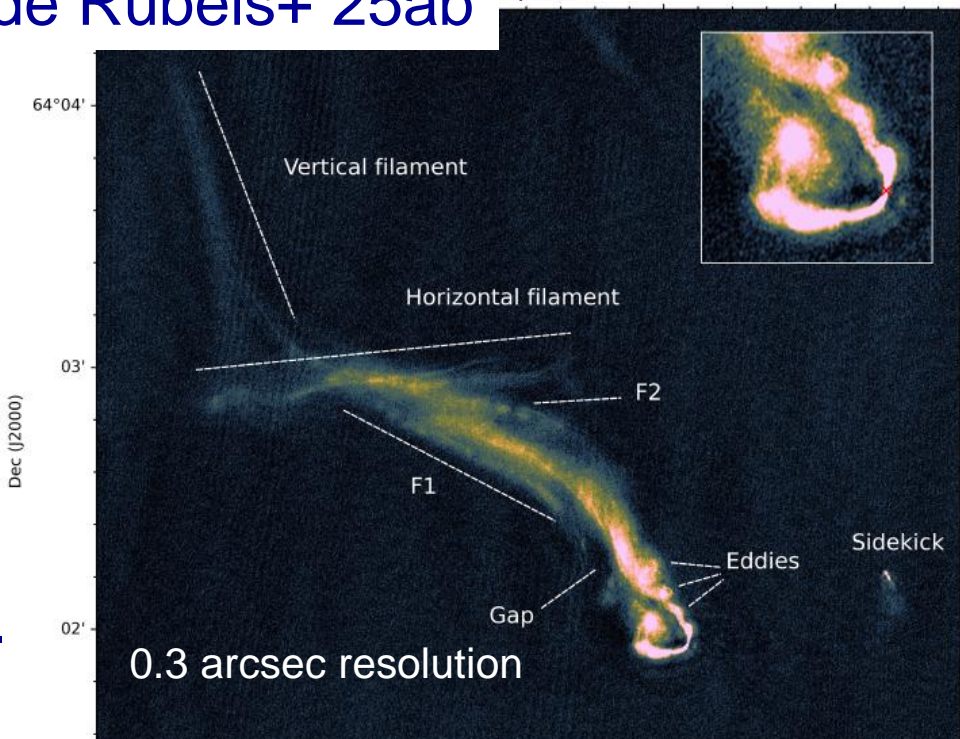
Oldest AGN feedback phases (Brienza+ 21)



BH activity & their impact



de Rubeis+ 25ab



generation & growth of instabilities,
extraction and advection of magnetic
filaments, mixing in the turbulent ICM....

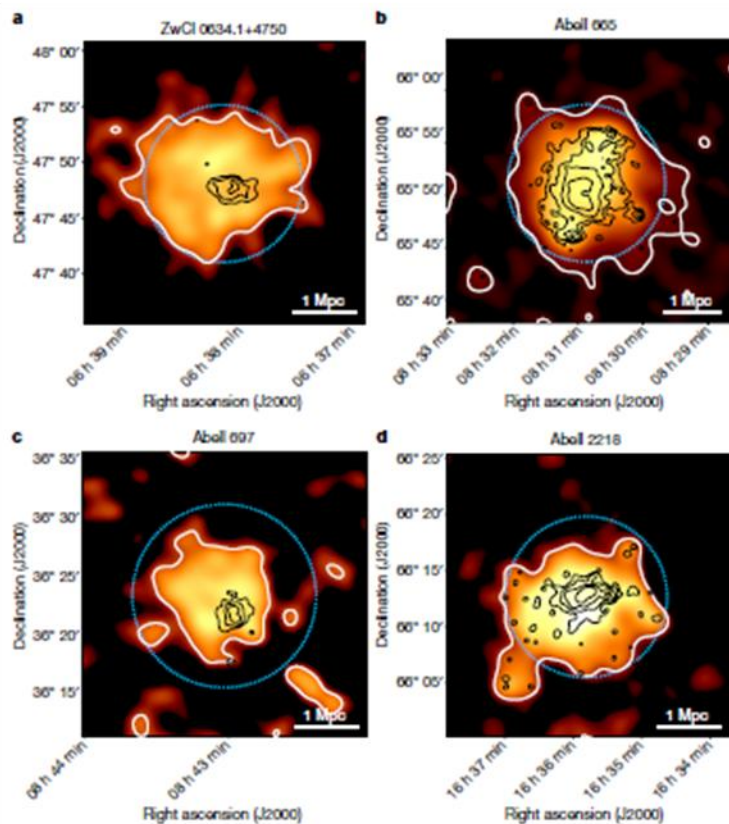
Galaxy clusters enveloped by vast volumes of relativistic electrons

<https://doi.org/10.1038/s41586-022-05149-3>

Received: 23 February 2022

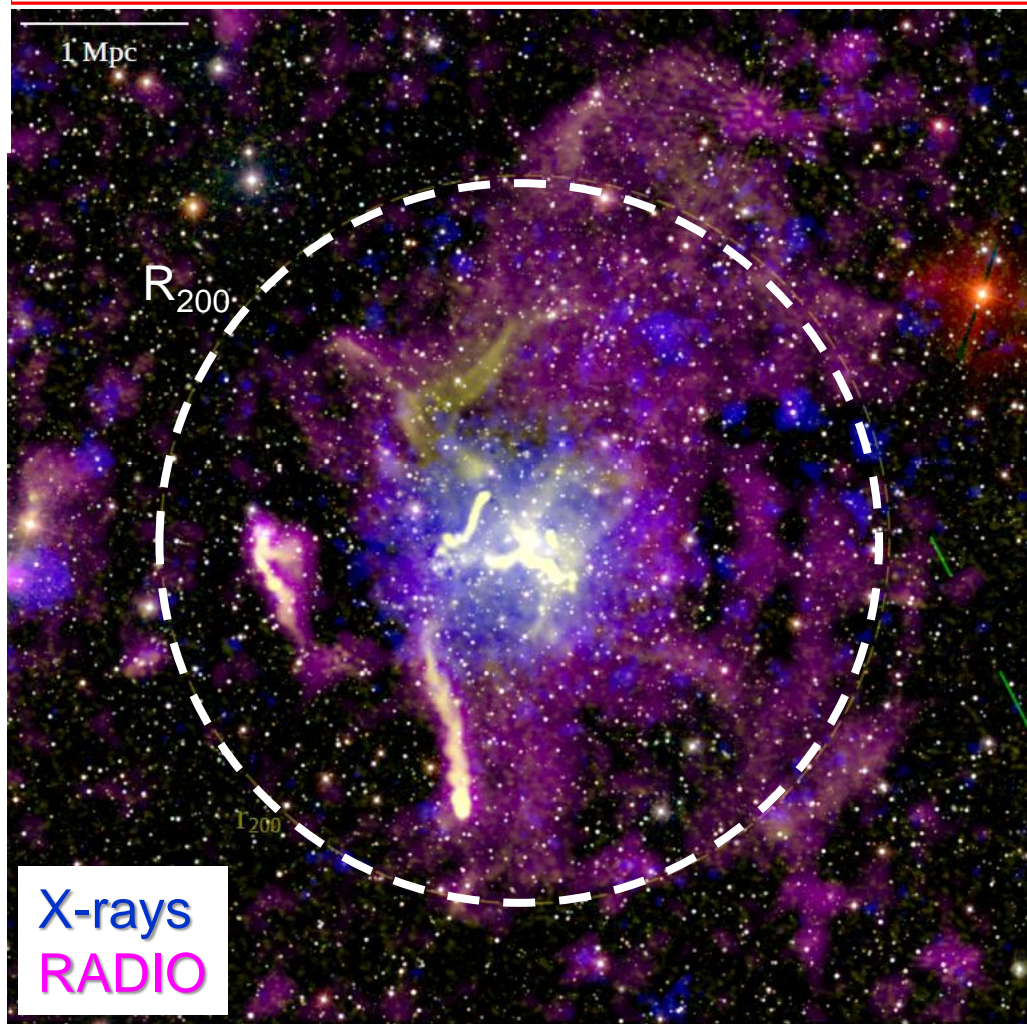
Accepted: 26 July 2022

V. Cuciti^{1,2,3*}, F. de Gasperin^{1,2}, M. Brüggen¹, F. Vazza^{2,3}, G. Brunetti², T. W. Shimwell⁴, H. W. Edler¹, R. J. van Weeren¹, A. Botteon^{2,3,5}, R. Cassano², G. Di Gennaro¹, F. Gastaldello⁴, A. Drabant², H. J. A. Röttgering² & C. Tasse^{4,5}



Magnetic fields and relativistic electrons fill entire galaxy cluster

Andrea Botteon^{1,2,3*}, Reinout J. van Weeren¹, Gianfranco Brunetti³, Franco Vazza^{2,3}, Timothy W. Shimwell^{1,4}, Marcus Brüggen⁵, Huub J. A. Röttgering¹, Francesco de Gasperin^{3,5}, Hiroki Akamatsu⁶, Annalisa Bonafede^{2,3}, Rossella Cassano³, Virginia Cuciti^{3,5}, Daniele Dallacasa^{2,3}, Gabriella Di Gennaro⁵, Fabio Gastaldello⁷

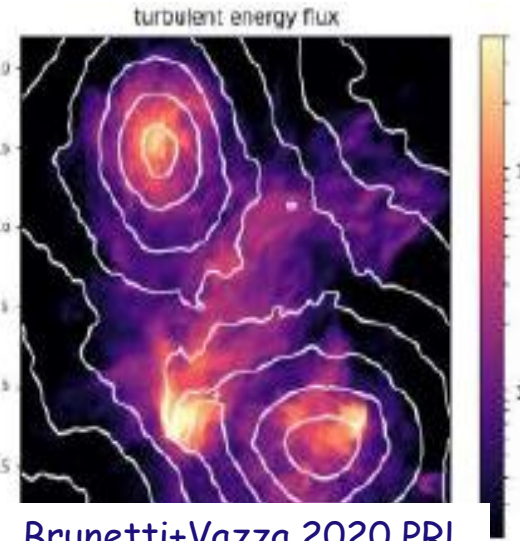
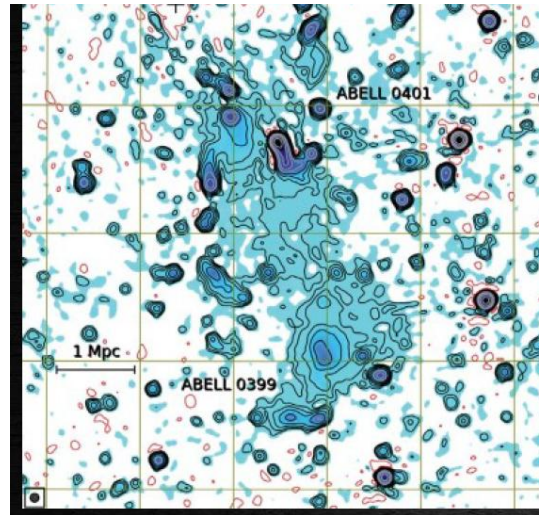


RADIO EMISSION BEYOND GALAXY CLUSTERS

RADIO OBSERVATIONS PROBE THE DISSIPATION OF DM-DRIVEN KINETIC ENERGY IN NON-THERMAL COMPONENTS IN THE LSS :

- ❑ PARTICLE ACCELERATION AND
- ❑ MAGNETIC FIELD AMPLIFICATION

A radio ridge connecting two galaxy clusters in a filament of the cosmic web

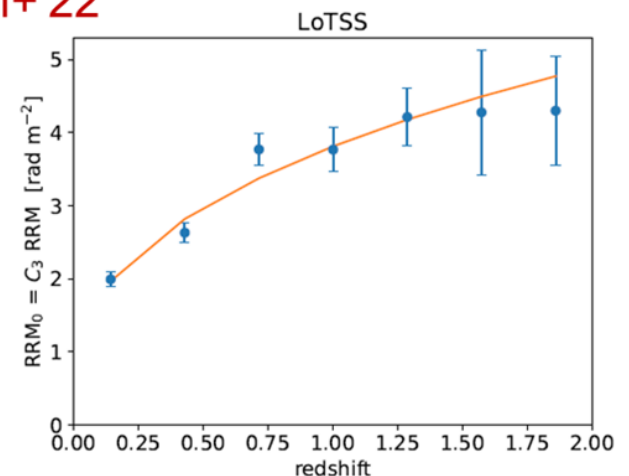
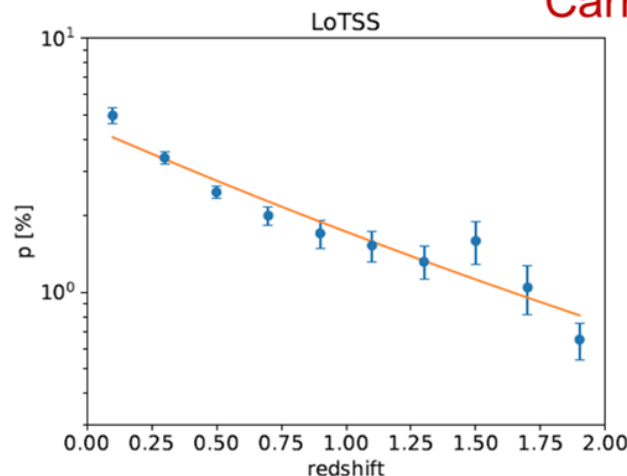


Brunetti+Vazza 2020 PRL

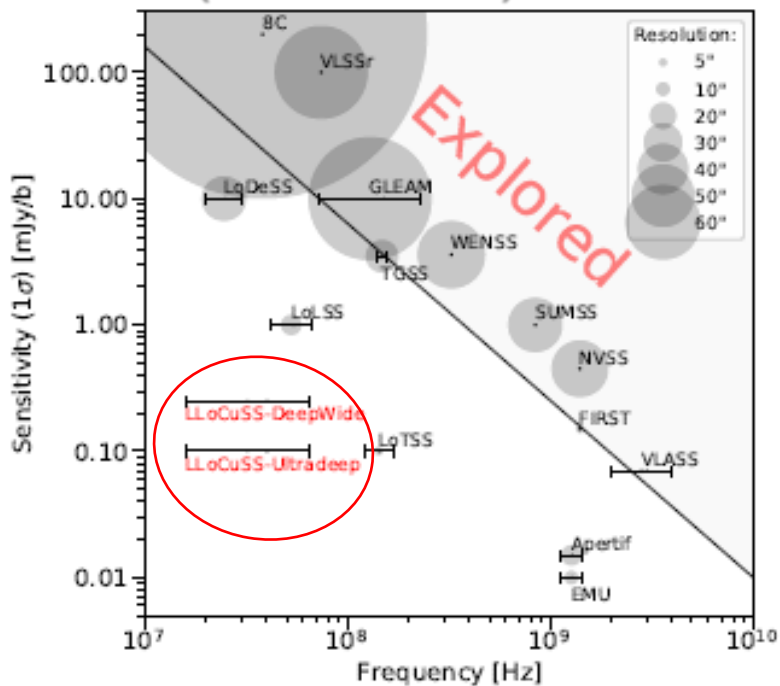
Constraints on magnetic fields in Cosmic Filaments

Evolution of magnetic fields in distant clusters & ICM microphysics

Carretti+ 22



LOFAR 2.0 upgrade (2026+...)



Upgrade :

- **Electronics**
- Correlator
- **Dual beam (IT co-PI, DANTE)**

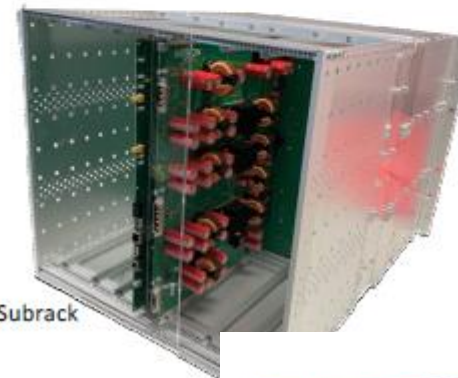
will bring LOFAR into a new regime entering an uncharted territory at the very low frequencies (10-60 MHz)

NEW ELECTRONICS

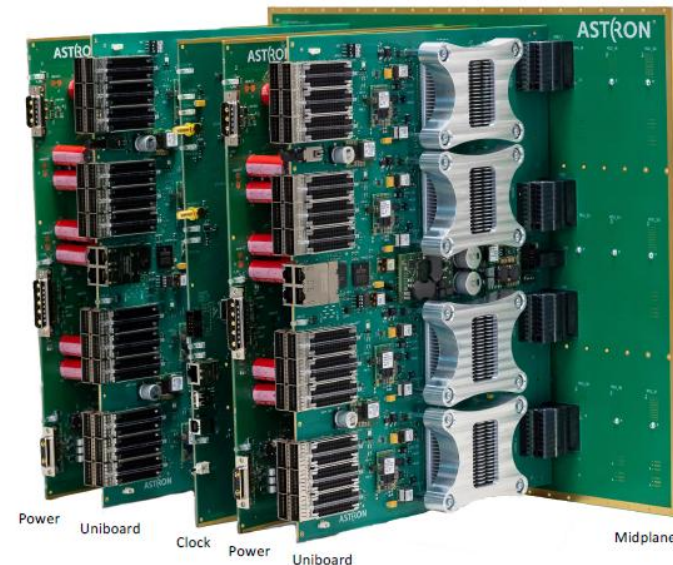
(ASTRON+INAF)



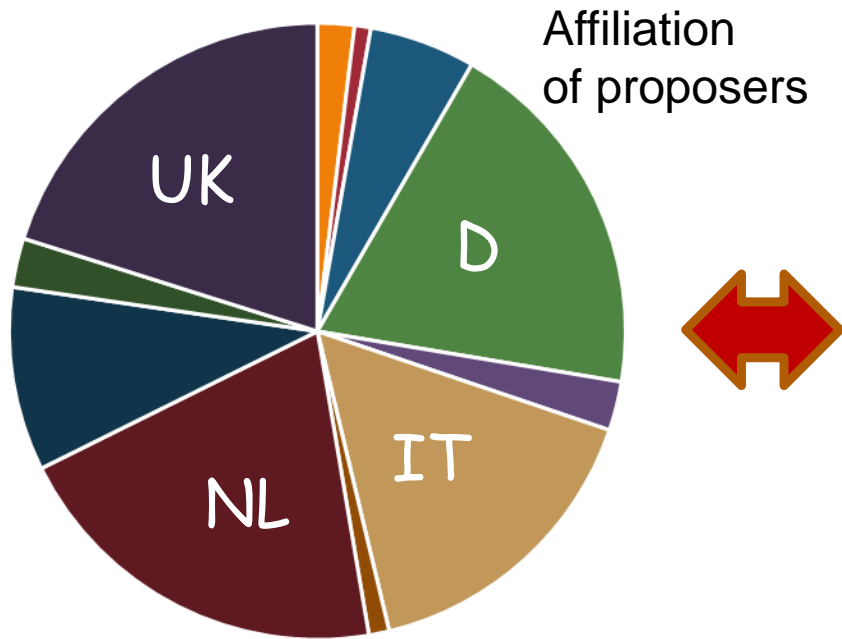
RCU



Subrack



LOFAR 2.0 upgrade



■ BG ■ CZ ■ FR ■ D ■ IR ■ IT ■ LV ■ NL ■ PL ■ SW ■ UK

LOFAR 2 data rate ~4 x LOFAR

Large Programs:

12-20 PB/yr

120 PB total



Large Portfolio of interconnected Large Programs

Surveys

- LUDO
- ILoTSS
- LLoCuSS
- ECOLE
- L2GPS

Exoplanets

- ExLoo

Transients & Pulsars

- PFTS
- LORAX
- PURR

Cosmology

- ARES
- LoDMax
- NearGal

CRs

- UHECR

Solar Physics

- Helio

TAKE HOME



LOFAR is @
top priorities in
PNIR 2021-27

- ❑ **LOFAR** is the largest SKA-low pathfinder
- ❑ Among the most productive astronomical infrastructures (50% from extragalactic wide/deep surveys)
- ❑ The IT community has clear leadership in a number of fields (clusters, magnetism, surveys)

- ❑ Leadership of IT in several **LOFAR 2** KPs (Surveys..Pulsars..)
- ❑ LOFAR 2 will be a unique telescope also in the SKA era :
 - due to the long baselines
 - due to the window at very low frequencies

- ❑ MAJOR Computational Challenges :
 - Size of the data & Archiving
 - Computing for long baseline
- ❑ Important SRC pathfinder & chance for IT

LOFAR is limited
by computing !