

LOFAR & the pathway to the SKA-Low

The Contribution of the Italian community



Gianfranco Brunetti



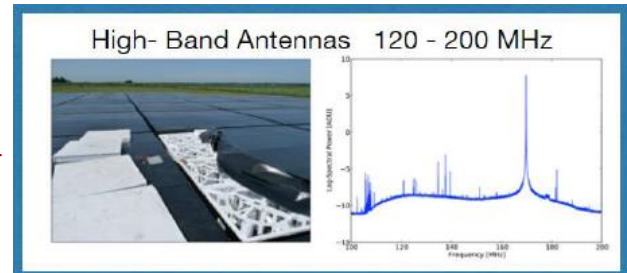
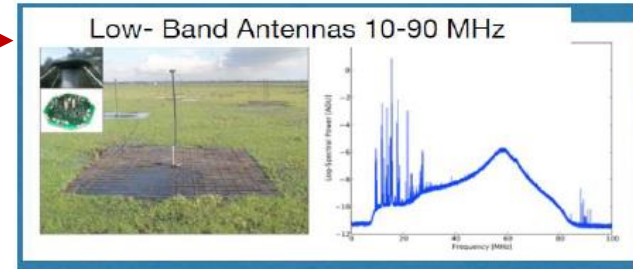
OUTLINE

- 1) LOFAR : Intro & Science with LOFAR
- 2) The impact on the IT community
- 3) What's next step ?

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)



10 Countries
(24+14) + 14(16) stations

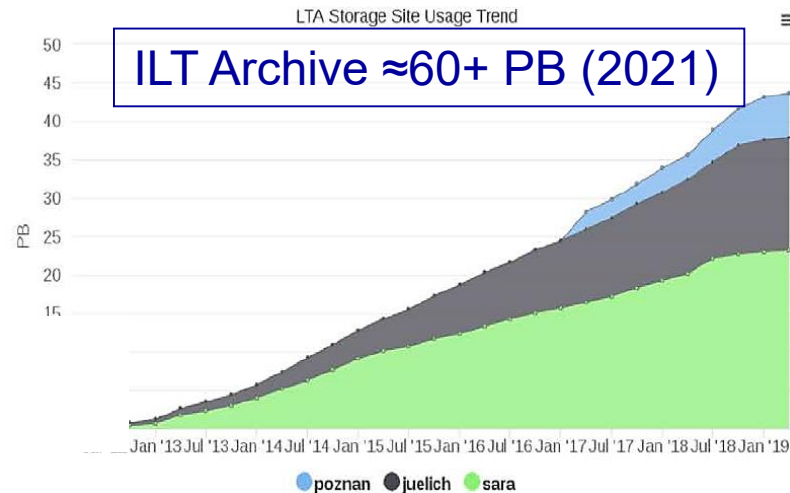
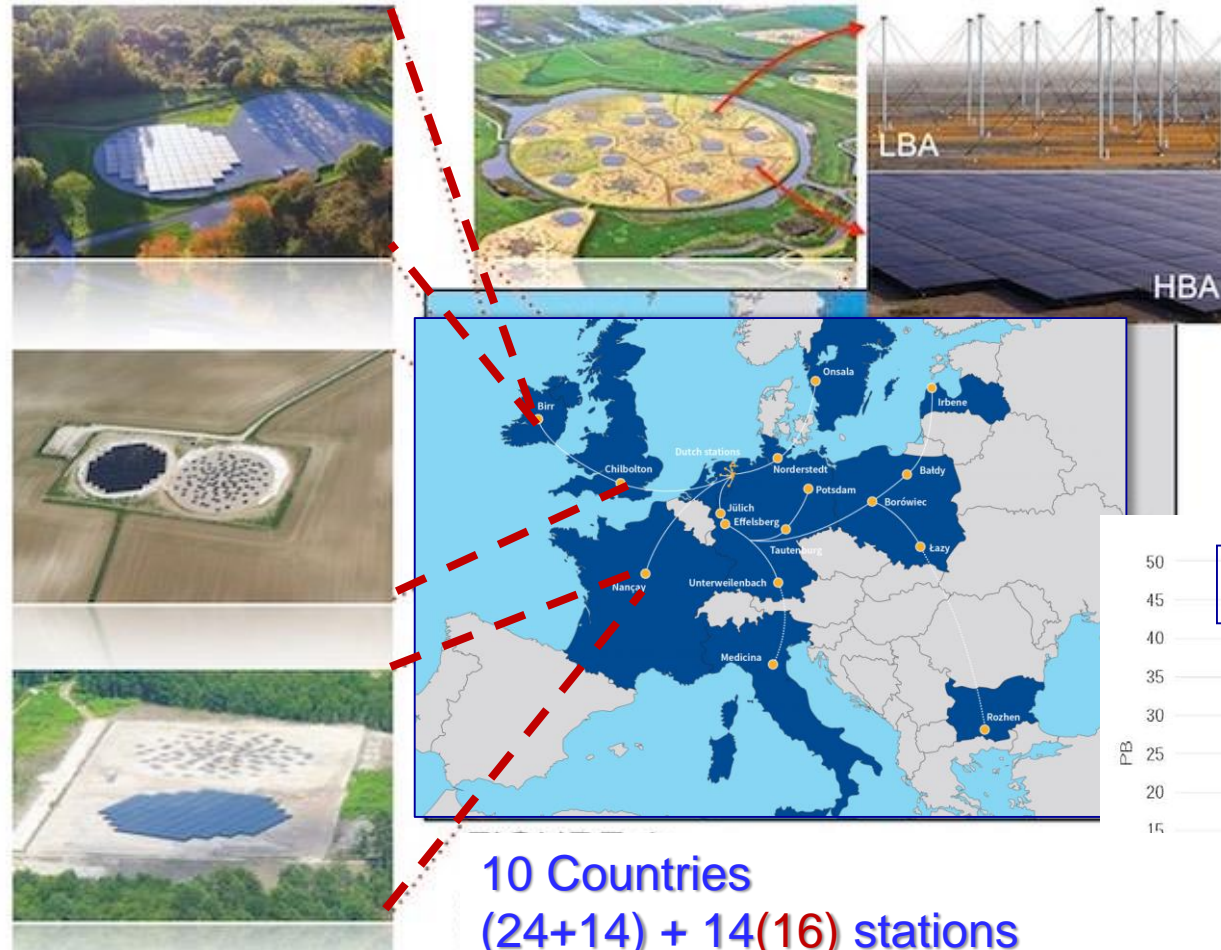


THE LOW FREQUENCY ARray

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)

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

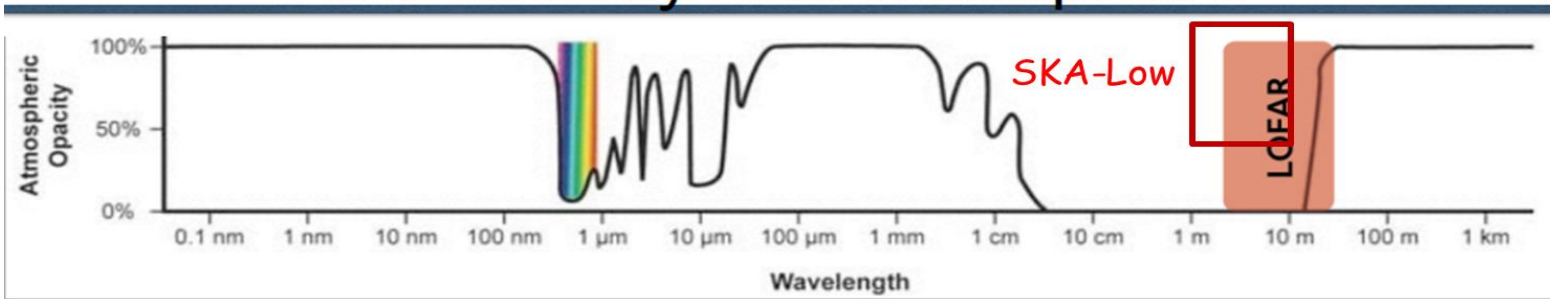


THE LOW FREQUENCY ARray

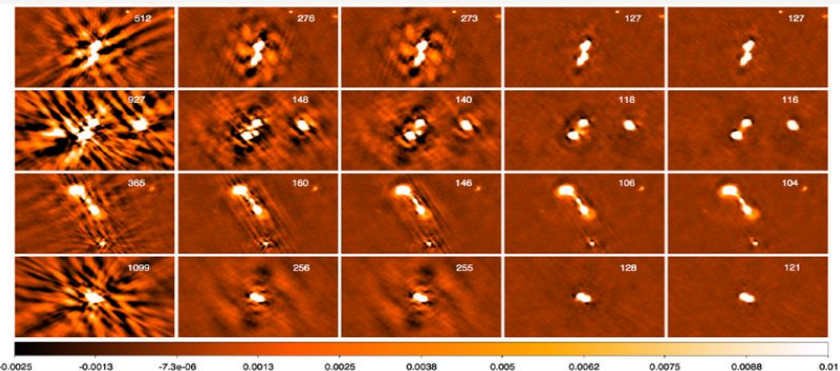
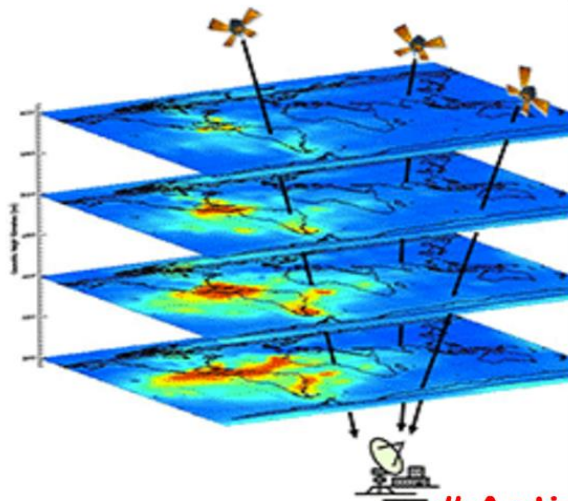
Giant digital aperture array radio telescope opening up a new window in the electromagnetic spectrum at low radio frequencies
- The largest (area & dataflow) pathfinder toward the SKA(low) -

BIG Challenges with data calibration and analysis

Our enemy: the ionosphere



Facet calibration

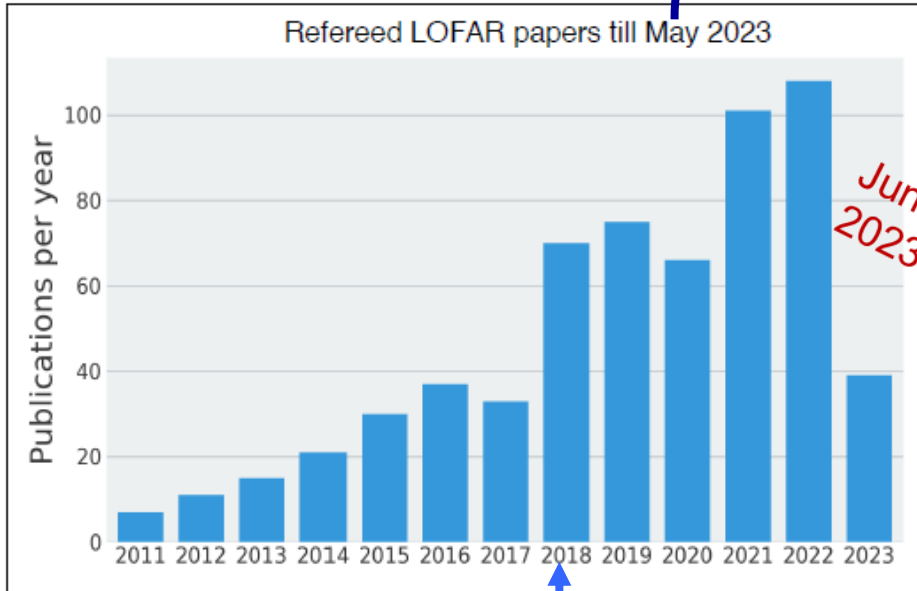


Demonstrating direction dependent calibration (van Weeren R. J., et al., 2016, ApJS, 223, 2)

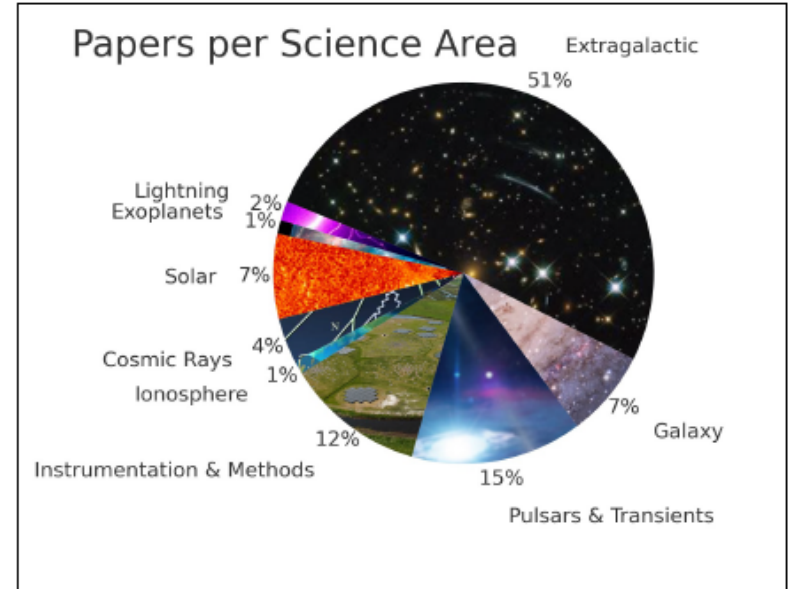
Anticipate the challenges with the SKA LOW

SCIENCE WITH LOFAR

Impact: top 10 among
astro- infrastructures

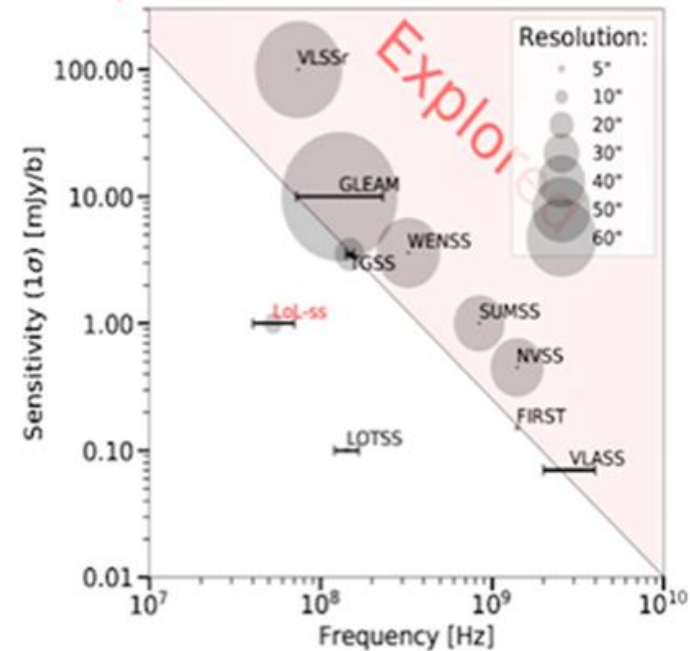
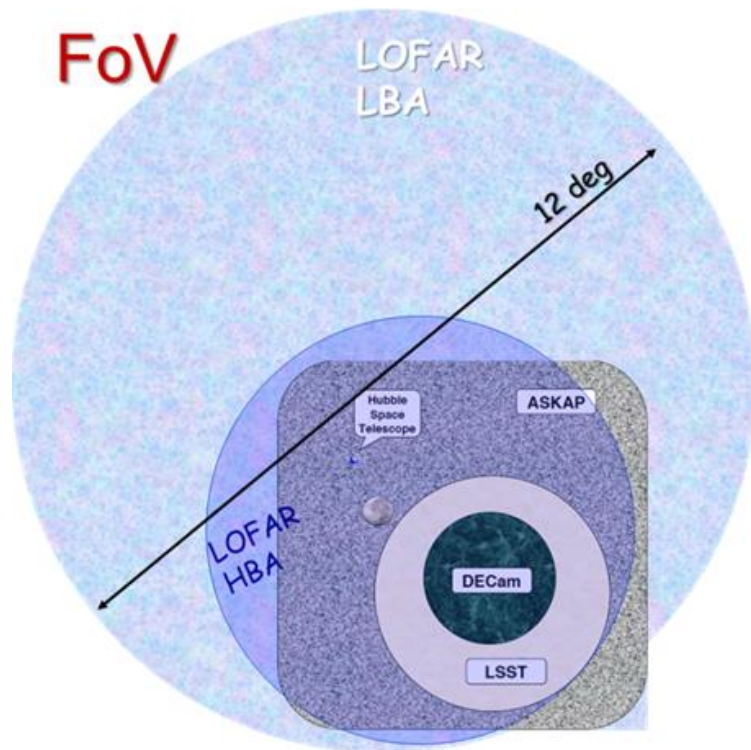


IT Joins ILT



Credits: ASTRON

THE LOFAR SURVEYS

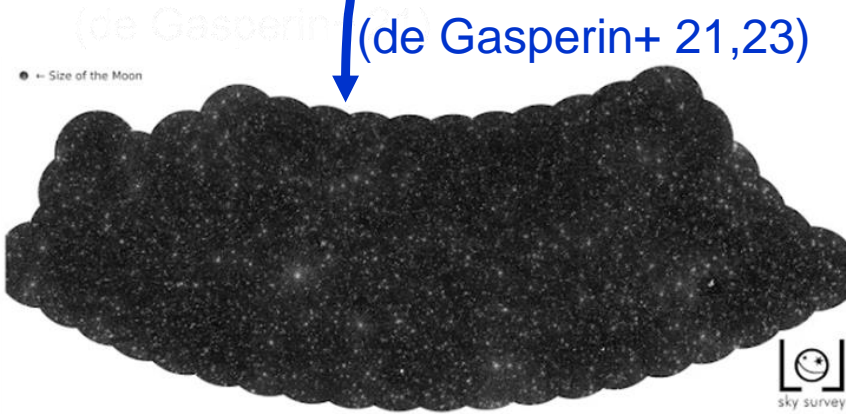
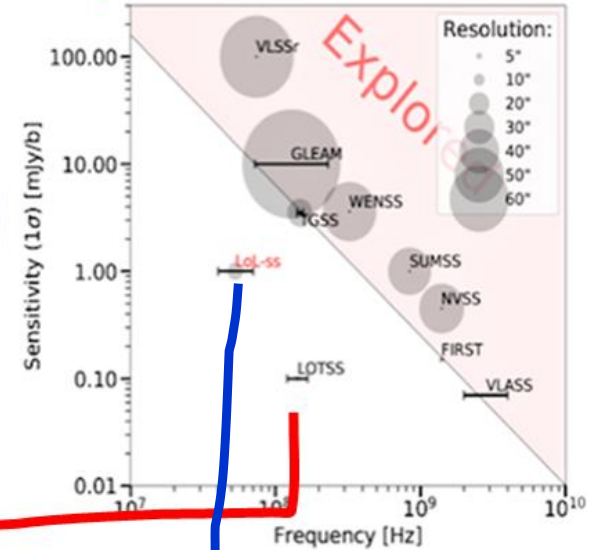
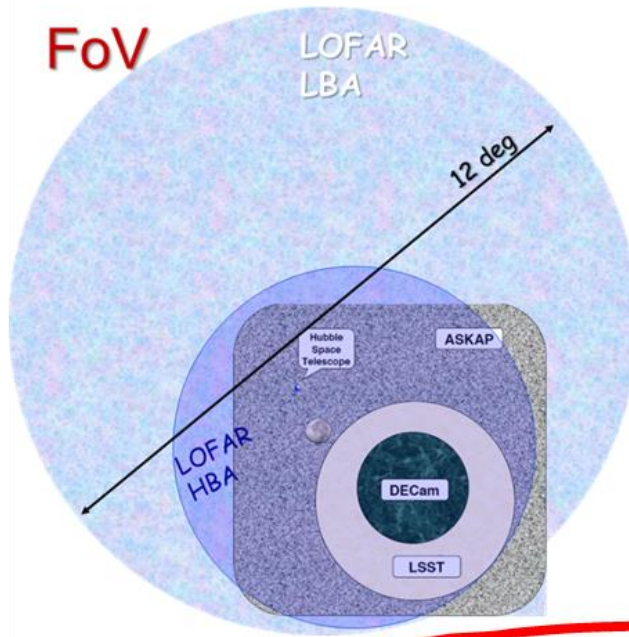


LOFAR Surveys of the entire northern sky are opening a new observational window of the Universe

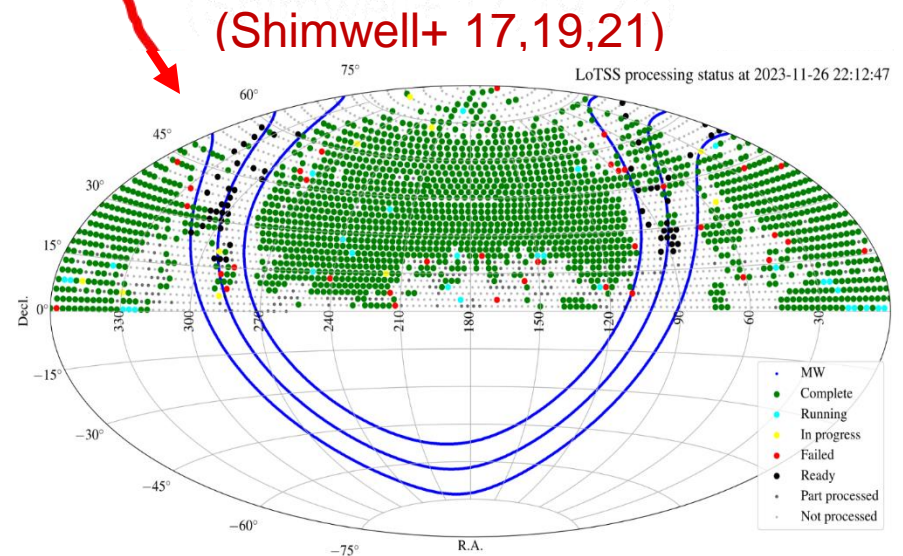
- 10-100x better sensitivity
- 10x better spatial resolution (100x using international baselines)

THE LOFAR SURVEYS

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

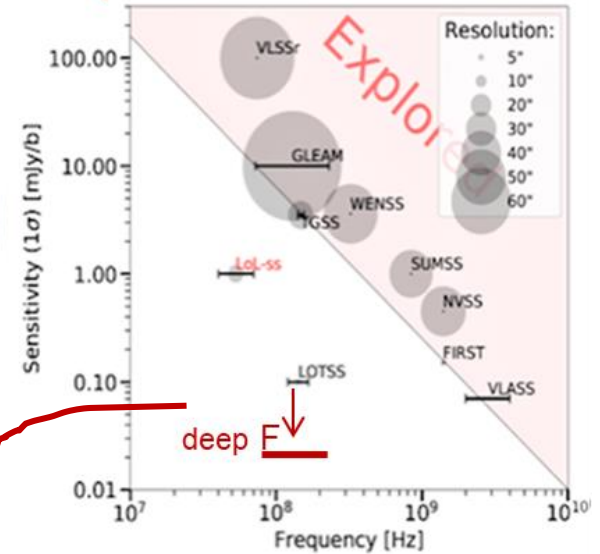
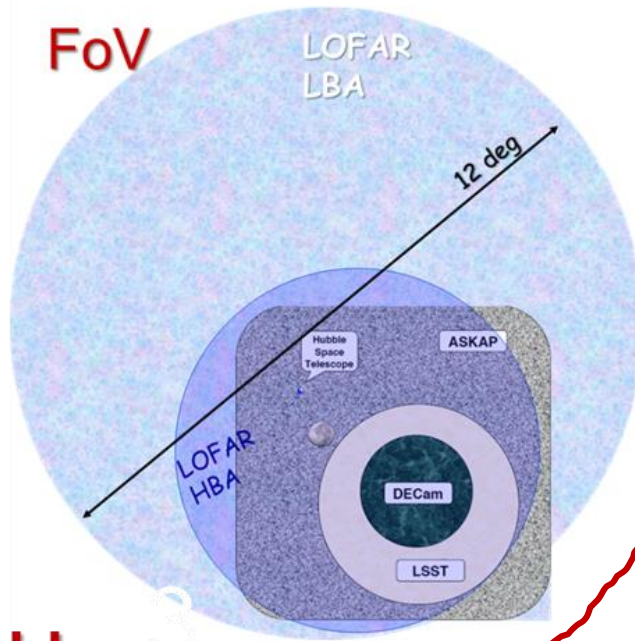


LoLSS 2000+ LBA hrs in 2023-23

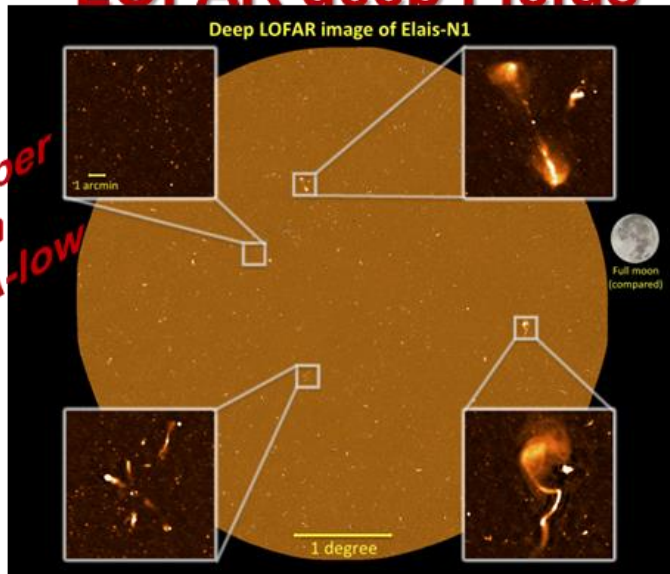


THE LOFAR SURVEYS

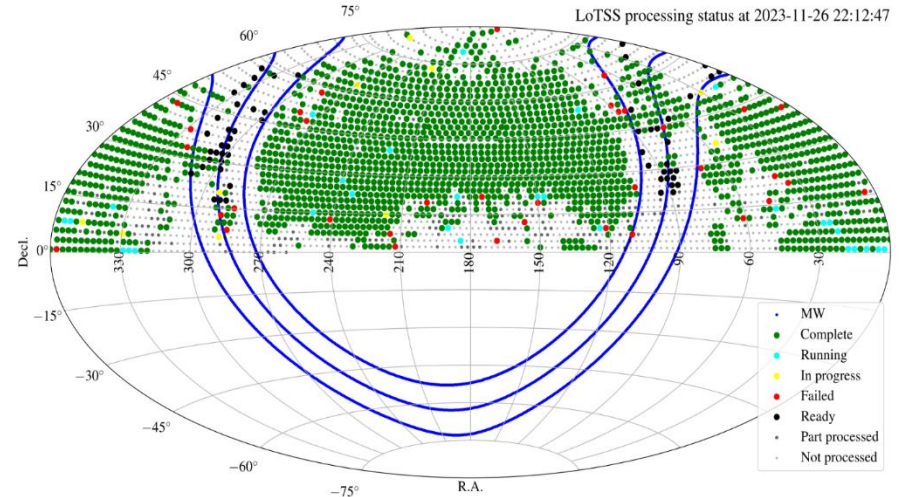
- Opening a new window
- Extreme sensitivity for steep spectrum sources



LOFAR deep Fields



(Shimwell+ 17,19,21)



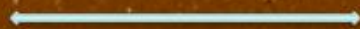
LoTSS-deep



1 degree

ELAIS-N1 ($< 20 \mu\text{Jy}/\text{beam}$)
(Sabater+ 2021; Tasse+ 2021)

LoTSS-deep



1 degree

ELAIS-N1 ($< 20 \mu\text{Jy}/\text{beam}$)
(Sabater+ 2021; Tasse+ 2021)

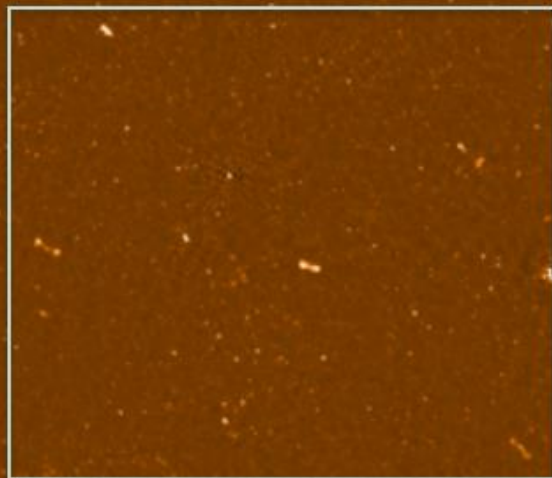
LoTSS-deep



15 arcmin

ELAIS-N1 ($< 20 \mu\text{Jy}/\text{beam}$)
(Sabater+ 2021; Tasse+ 2021)

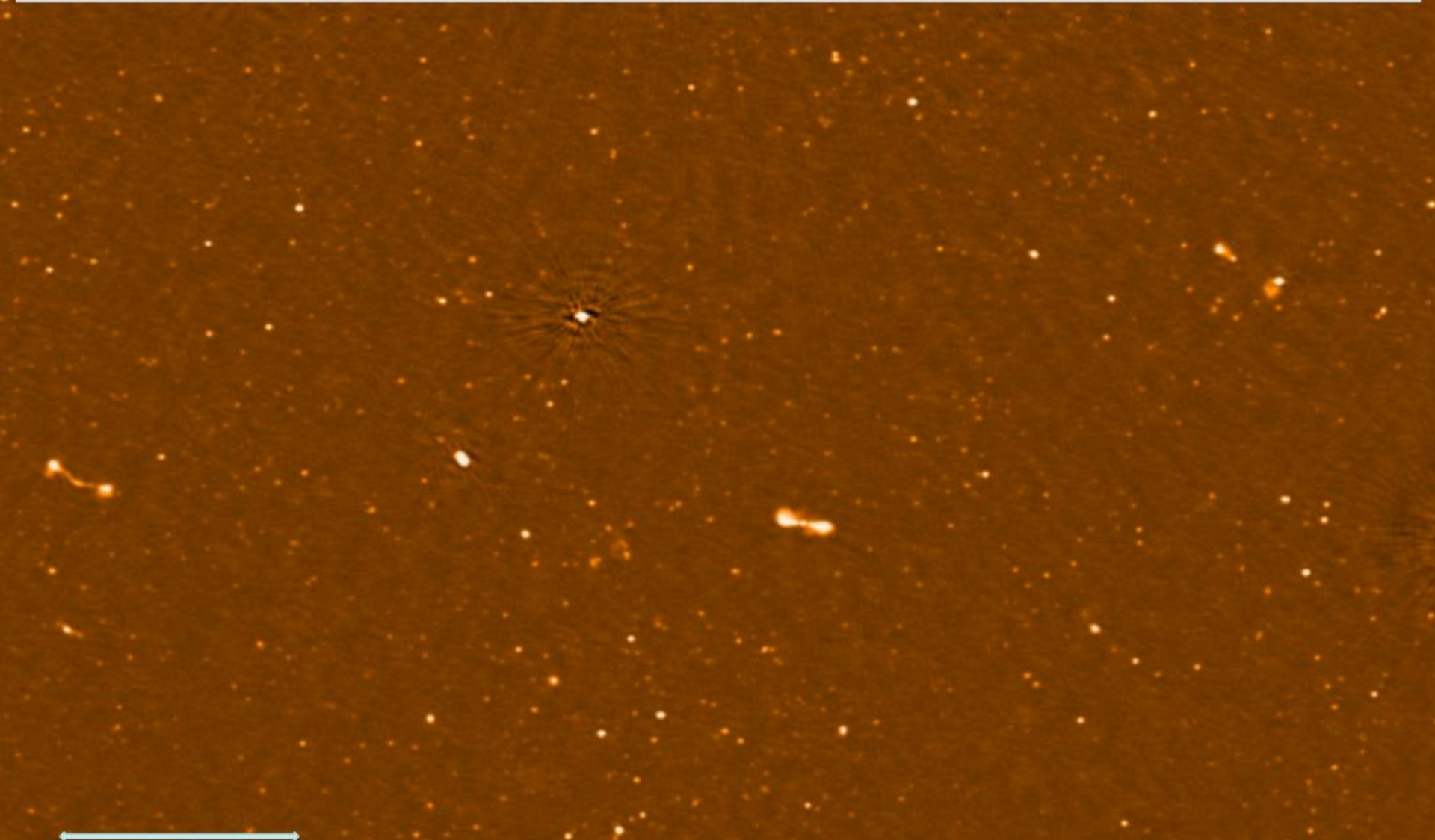
LoTSS-deep



15 arcmin

ELAIS-N1 ($< 20 \mu\text{Jy}/\text{beam}$)
(Sabater+ 2021; Tasse+ 2021)

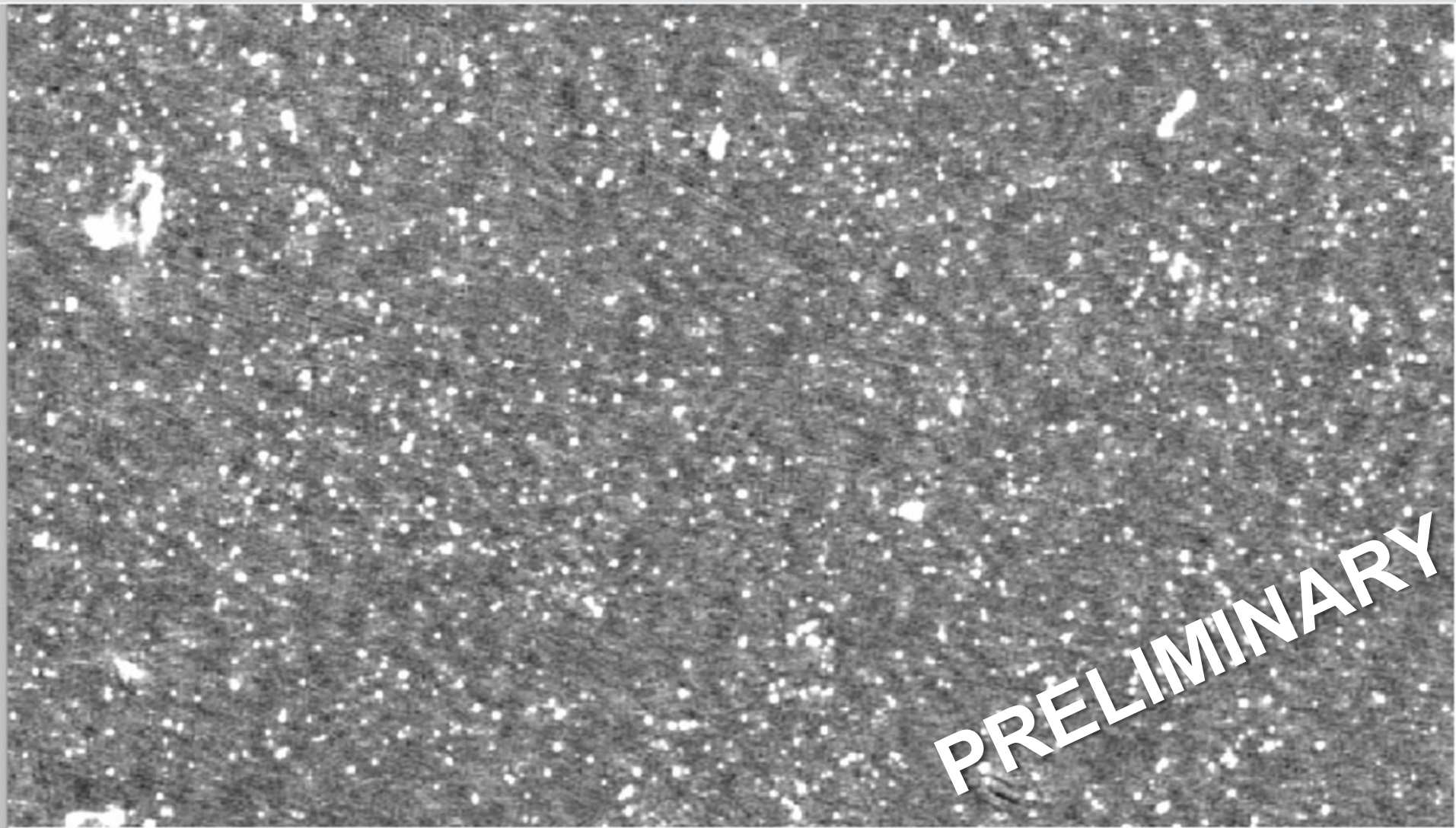
LoTSS-deep



5 arcmin

ELAIS-N1 ($< 20 \mu\text{Jy}/\text{beam}$)
(Sabater+ 2021; Tasse+ 2021)

Next: Deeper field (550hrs on ELAIS-N1)



PRELIMINARY

-6.4e-05 -4.8e-05 -3.2e-05 -1.7e-05 -6.8e-07 1.5e-05 3.1e-05 4.6e-05 6.2e-05

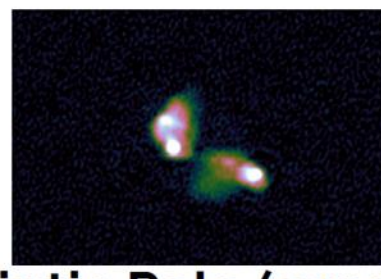
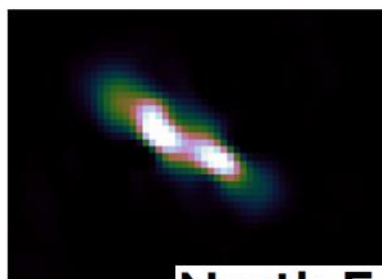
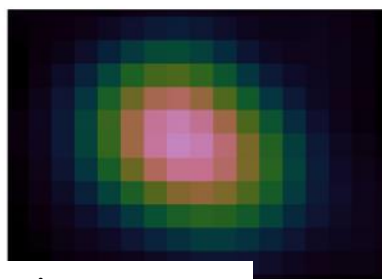
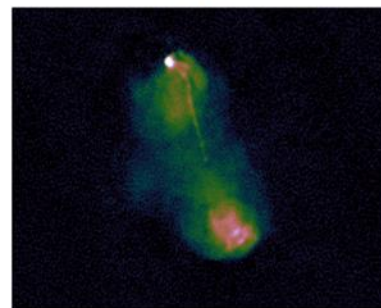
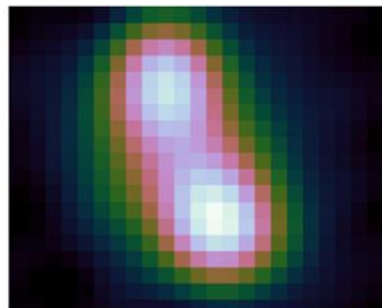
Around 10-12 $\mu\text{Jy}/\text{beam}$ rms at 6" resolution. Final images produced but not yet fully released.

LoTSS Deep Fields - ELAIS-N1

6"

1.2"

0.3"

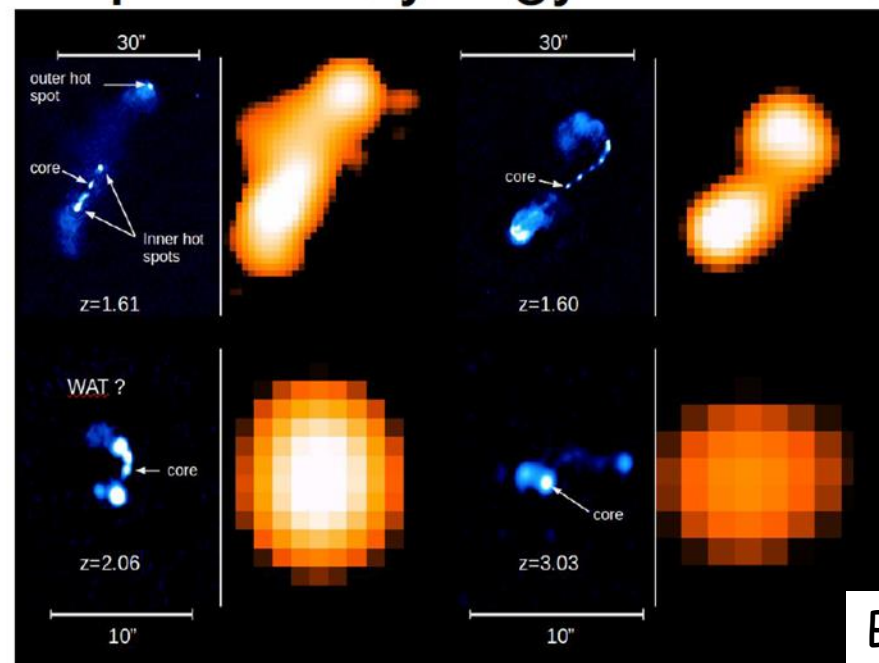


de Jong+

LONG-EU Baselines

North Ecliptic Pole (synergy with JWST)

Computationally expensive !!

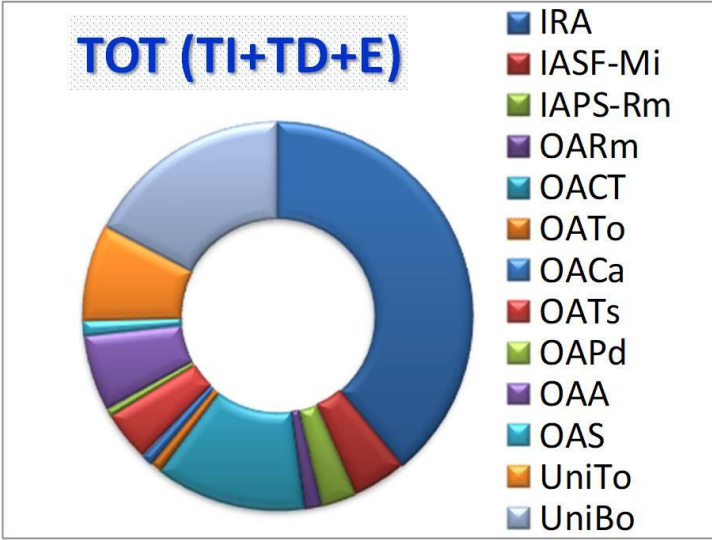


Bondi+

OUTLINE

- 1) LOFAR : Intro & Science with LOFAR
- 2) The impact on the IT community
- 3) What's next step ?

LOFAR is @ top priorities in PNIR 2021-27



~90 Staff/ass, UniTo, postdoc, PhD

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA DIPARTIMENTO DI FISICA E ASTRONOMIA



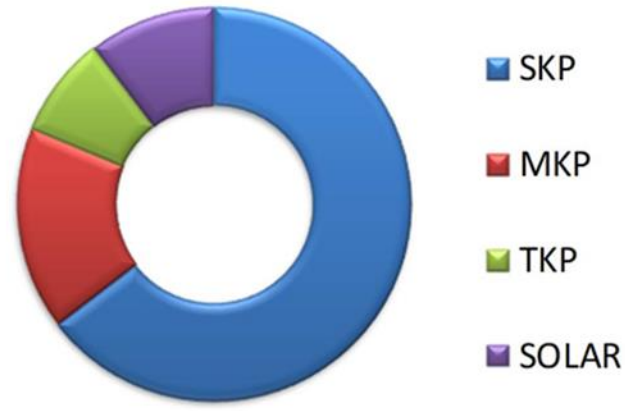
~90
 Staff/ass, UniTo,
 postdoc, PhD

LOFAR KEY SCIENCE PROJECTS

The most impactful scientific activity and technical solutions are developed within these communities

1 Surveys
 2 Transient sky
 3 Pulsars
 4 Cosmic Magnetism
 5 Solar System
 6 Cosmic Rays
 Epoch of Reionization

SCIENTIFIC MEMBERSHIP



LOFAR-It COMPUTING

(Cofin: PRIN,EU)

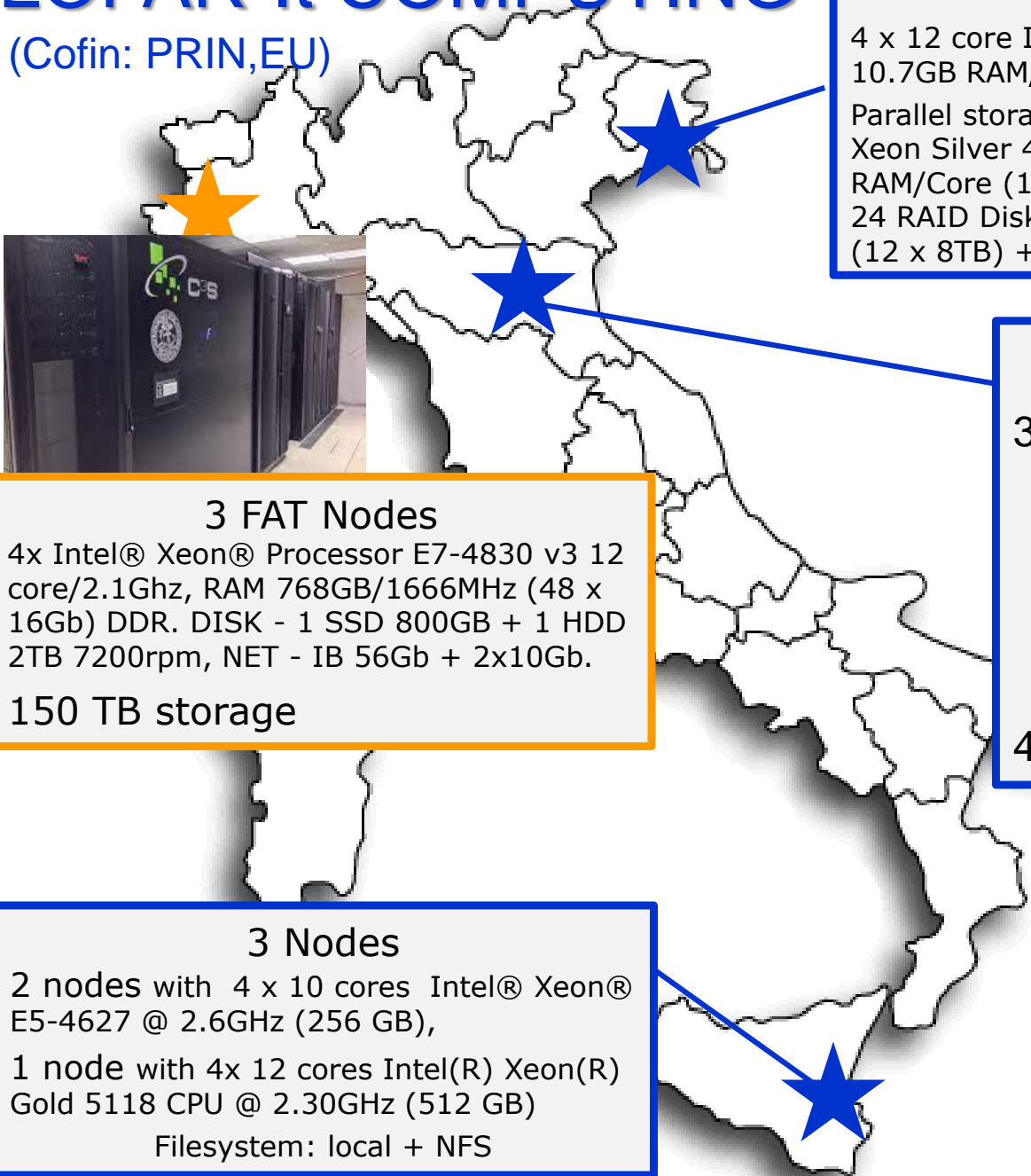


3 FAT Nodes
4x Intel® Xeon® Processor E7-4830 v3 12 core/2.1Ghz, RAM 768GB/1666MHz (48 x 16Gb) DDR. DISK - 1 SSD 800GB + 1 HDD 2TB 7200rpm, NET - IB 56Gb + 2x10Gb.
150 TB storage

3 Nodes
2 nodes with 4 x 10 cores Intel® Xeon® E5-4627 @ 2.6GHz (256 GB),
1 node with 4x 12 cores Intel(R) Xeon(R) Gold 5118 CPU @ 2.30GHz (512 GB)
Filesystem: local + NFS

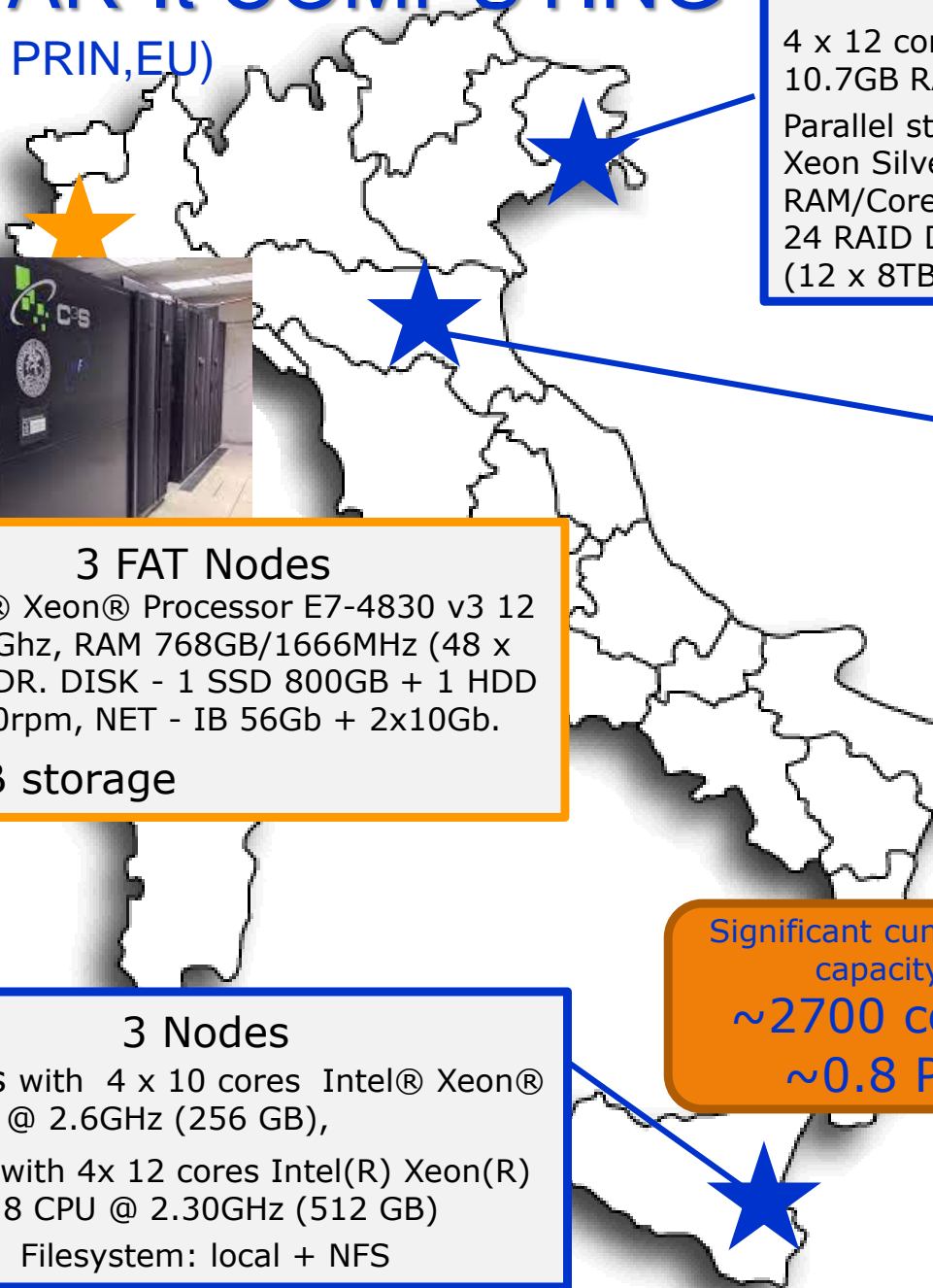
4 Nodes
4 x 12 core Intel Xeon Gold 5118 @ 2.30GHz
10.7GB RAM/Core (512 RAM)
Parallel storage BeeGFS: 4 Nodes IO : 16 Intel Xeon Silver 4110 CPU @ 2.10GHz 8 GB RAM/Core (128 RAM)
24 RAID Disks on 1883IX Areca RAID 2 raid6 (12 x 8TB) + (12 x 4TB)

IRA
36x 256 GB Nodes @ PLEIADI
1x FAT Node (1 TB)
4x Nodes (512/384 GB)
4x Nodes (512/384 GB) *DRANOEL*
6x Nodes (512 GB) *ULU*
400 TB storage



LOFAR-It COMPUTING

(Cofin: PRIN,EU)



4 Nodes
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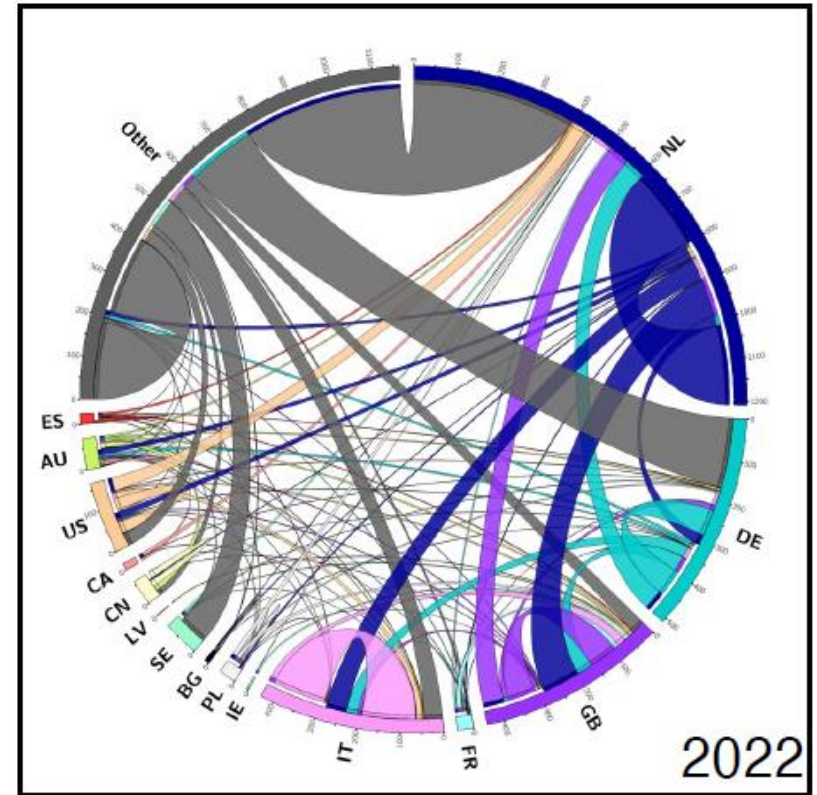
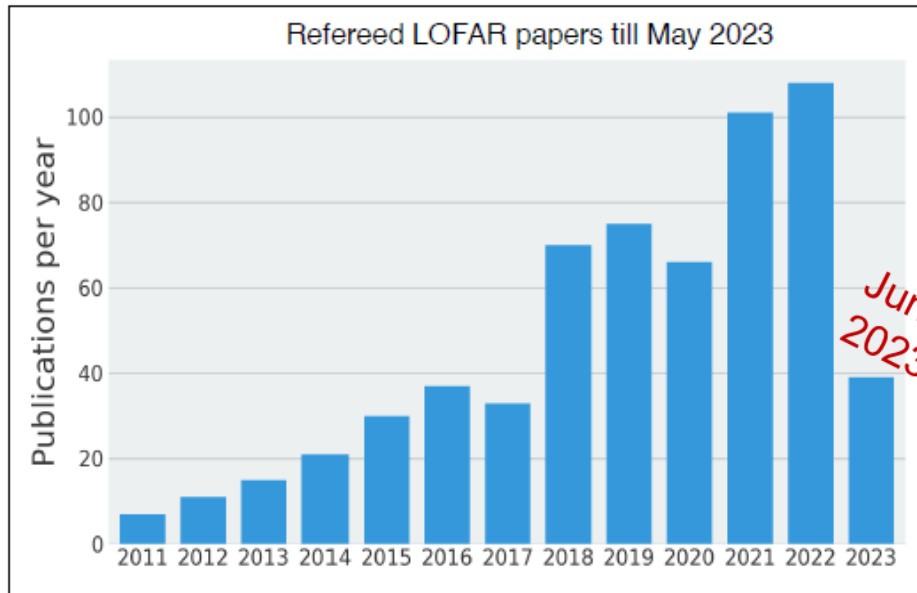
Significant computing capacity
 ~2700 cores
 ~0.8 PB

3 Nodes
 2 nodes with 4 x 10 cores Intel® Xeon® E5-4627 @ 2.6GHz (256 GB),
 1 node with 4x 12 cores Intel(R) Xeon(R) Gold 5118 CPU @ 2.30GHz (512 GB)
 Filesystem: local + NFS


 Start up of
 ERC Grants

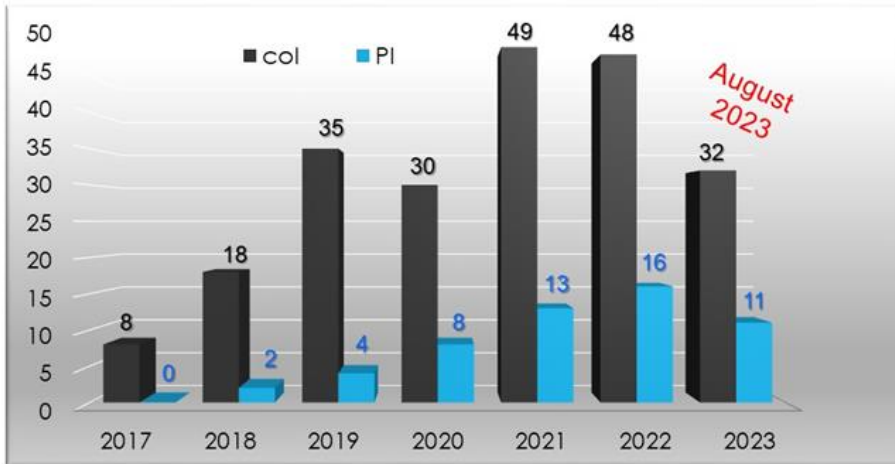
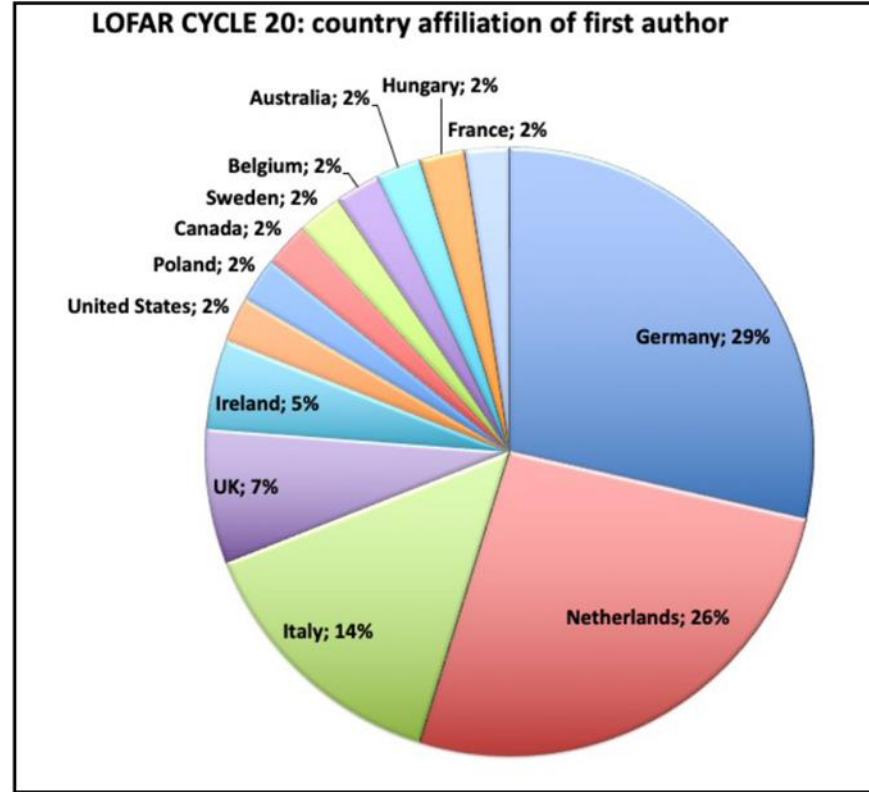
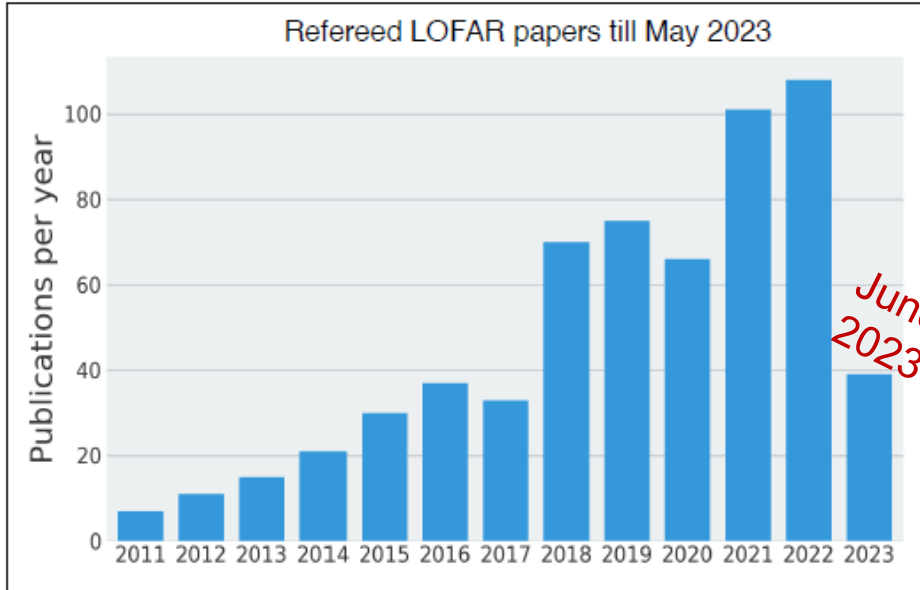


SCIENCE WITH LOFAR



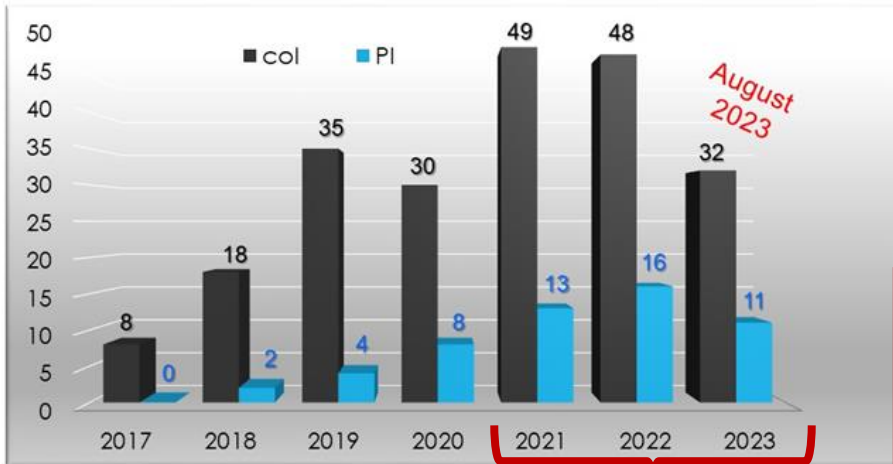
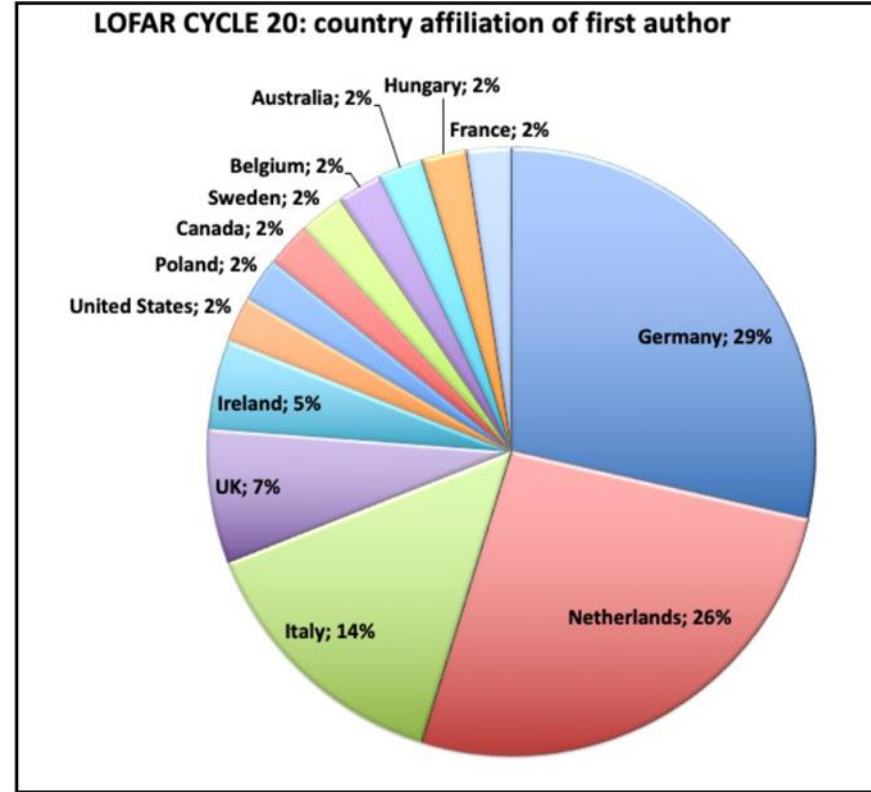
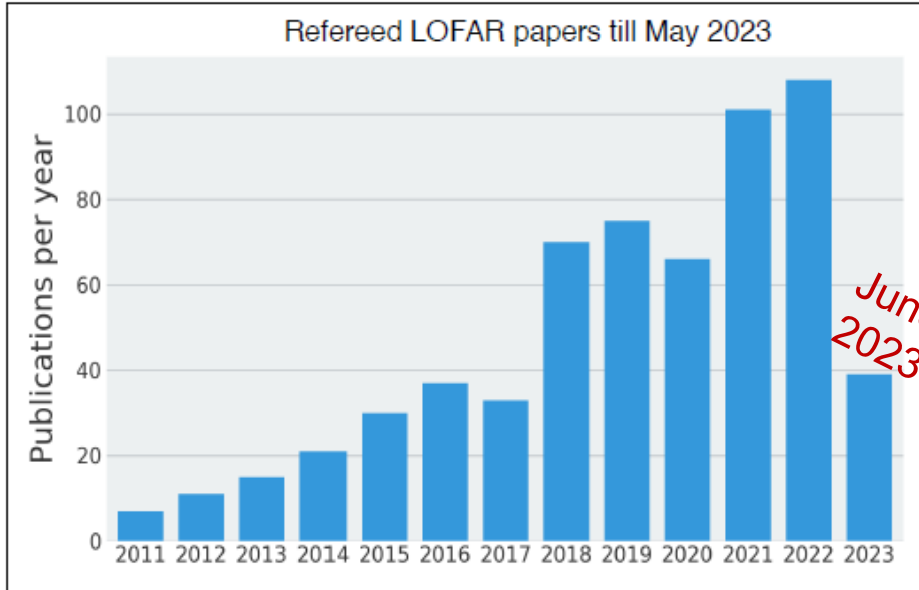
Courtesy of J. Dempsey

SCIENCE WITH LOFAR



Courtesy of R. Pizzo

SCIENCE WITH LOFAR



Courtesy of R. Pizzo

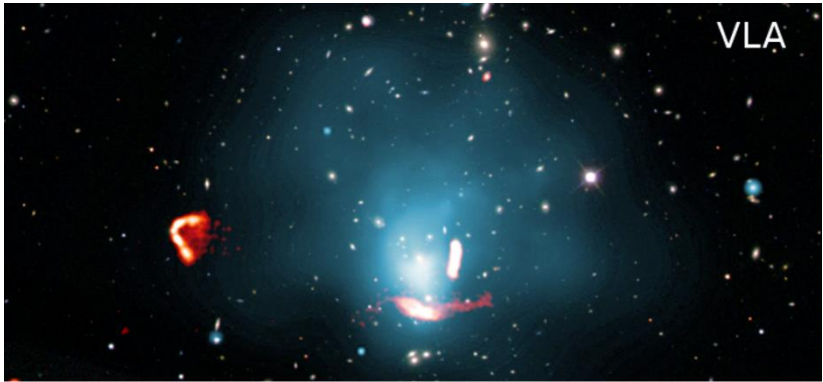
400+ TB/yr of HBA and LBA data are transported and processed/analysed on LOFAR-IT nodes

~3.5x <return/investment> !!

PHYSICAL SCIENCES

Gentle reenergization of electrons in merging galaxy clusters

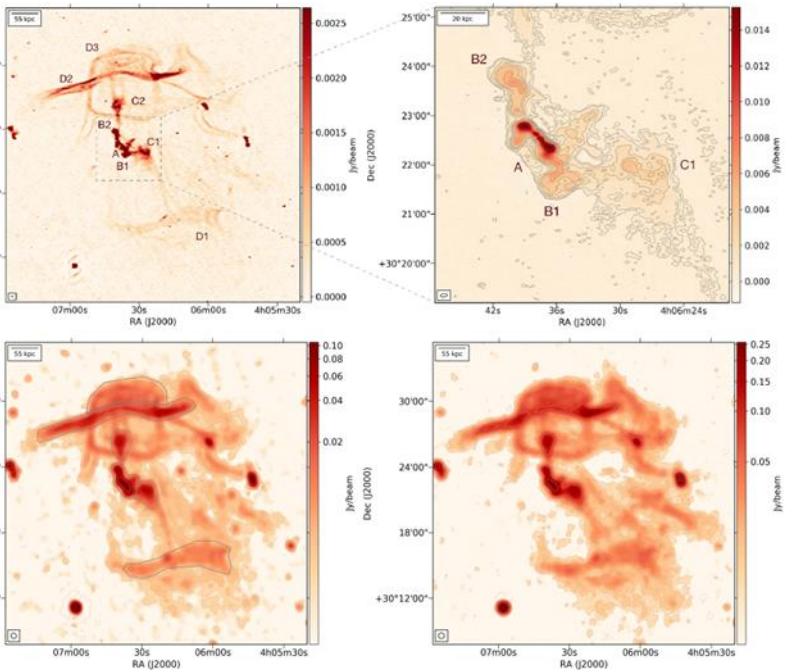
Francesco de Gasperin,^{1,2*} Huib T. Intema,¹ Timothy W. Shimwell,¹ Gianfranco Brunetti,³ Marcus Brüggén,² Torsten A. Enßlin,⁴ Reinout J. van Weeren,^{1,5} Annalisa Bonafede,^{2,3} Huub J. A. Röttgering¹



BH activity & their impact



Oldest AGN feedback phases (Brienza+ 21)



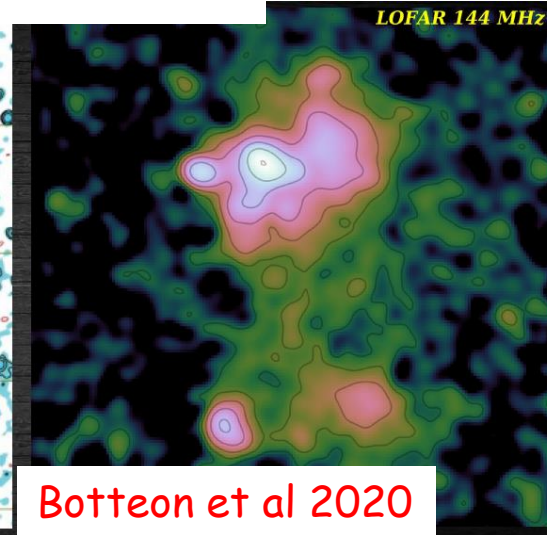
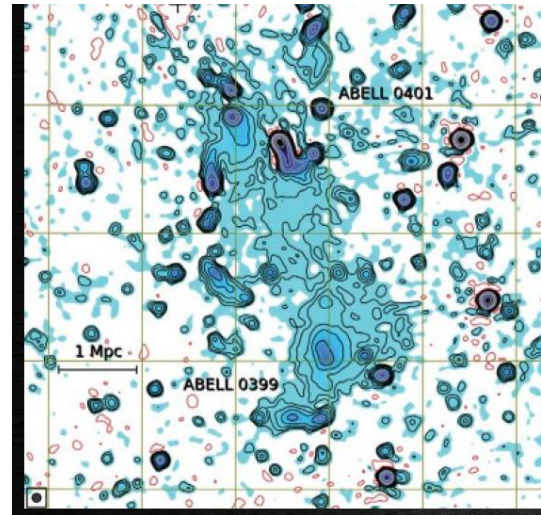
Evidence for gentle particle reacceleration in astrophysical jets from supermassive BH : new (astro-)physics ??

RADIO EMISSION BEYOND GALAXY CLUSTERS

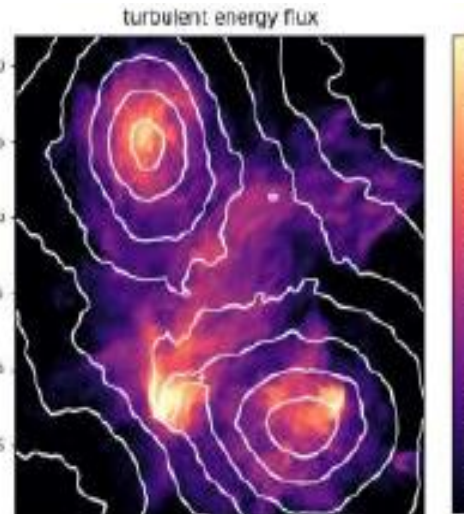
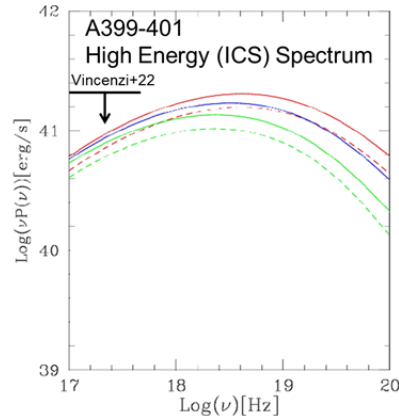
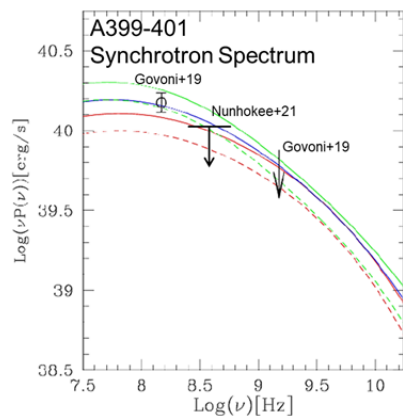
A radio ridge connecting two galaxy clusters in a filament of the cosmic web

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

- ❑ PARTICLE ACCELERATION AND
- ❑ MAGNETIC FIELD AMPLIFICATION



Botteon et al 2020



2nd ORDER FERMI MECHANISMS ACCELERATE ELECTRONS IN THE LSS ? NEW PHYSICS ?

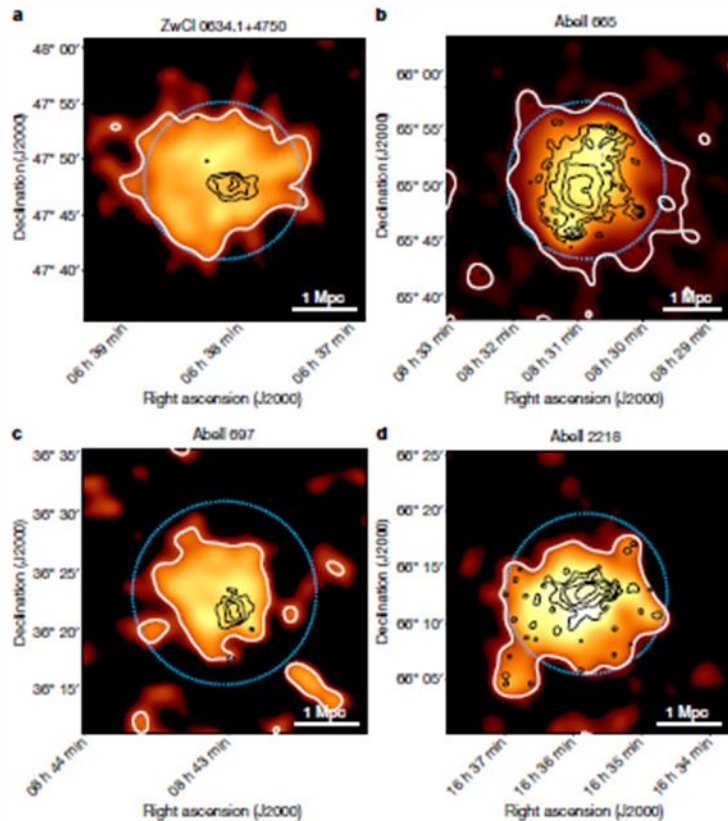
Galaxy clusters enveloped by vast volumes of relativistic electrons

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

Received: 23 February 2022

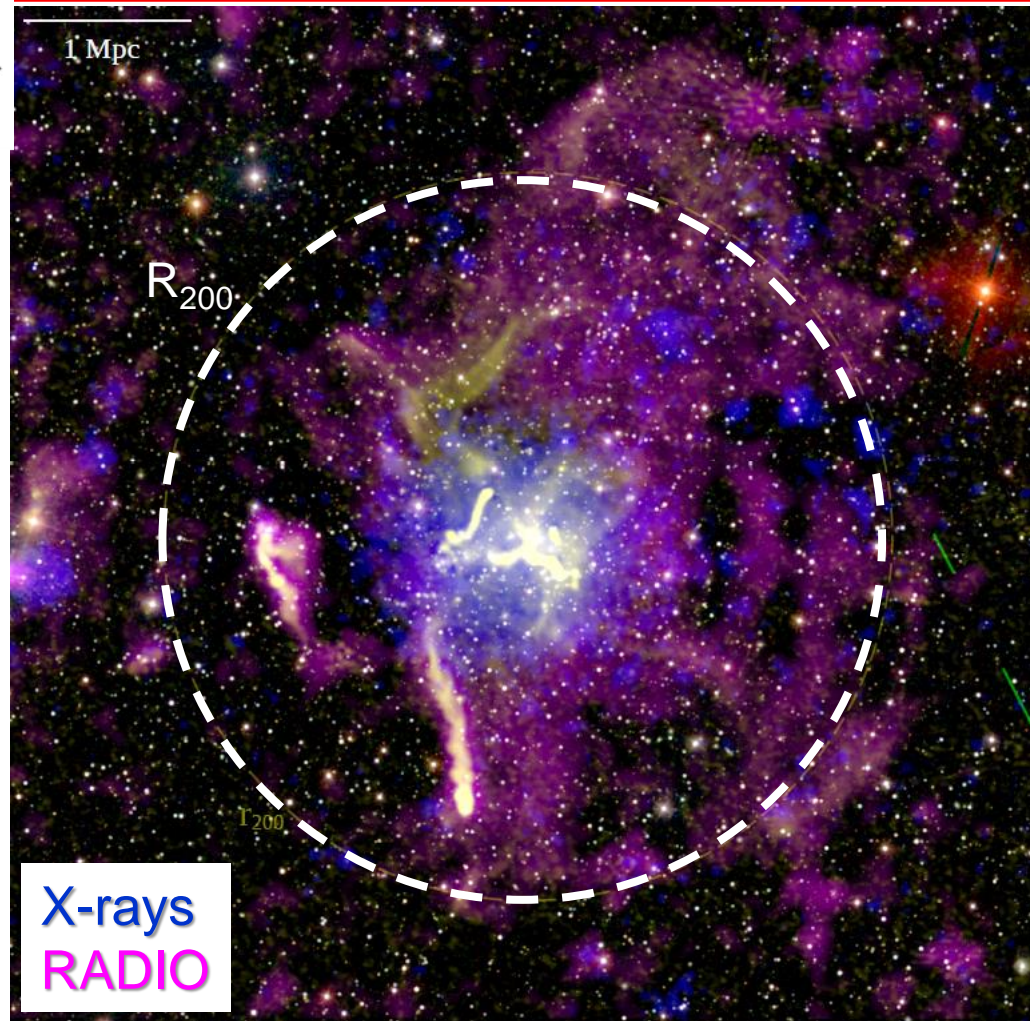
Accepted: 26 July 2022

V. Cuciti^{1,2*}, F. de Gasperin^{1,2}, M. Brüggen¹, F. Vazza^{2,3}, G. Brunetti², T. W. Shimwell⁴, H. W. Edler¹, R. J. van Weeren⁵, A. Botteon^{2,3}, R. Cassano³, G. Di Gennaro¹, F. Gastaldello⁵, A. Drabant¹, H. J. A. Röttgering⁶ & C. Tasse^{4,5}



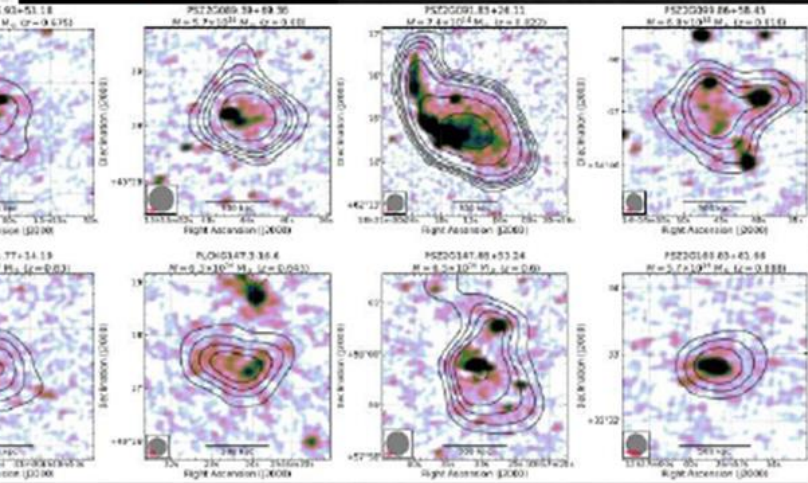
Magnetic fields and relativistic electrons fill entire galaxy cluster

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



MAGNETIC FIELDS IN THE LSS

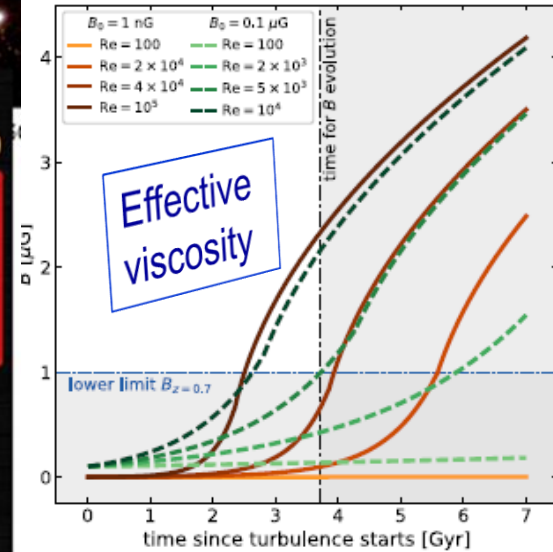
High-z radio halos ($z > 0.6$)



Di Gennaro, van Weeren, GB, + 2020

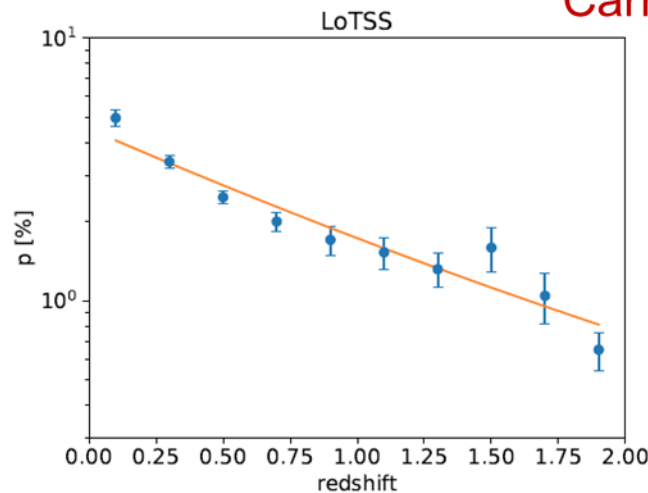
Fast magnetic field amplification in distant galaxy clusters

nature astronomy

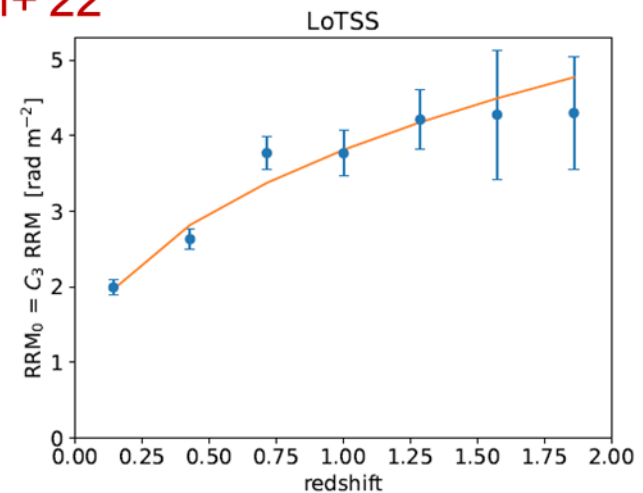


Constraints on magnetic fields in Cosmic Filaments

Evolution of magnetic fields in distant clusters & ICM microphysics



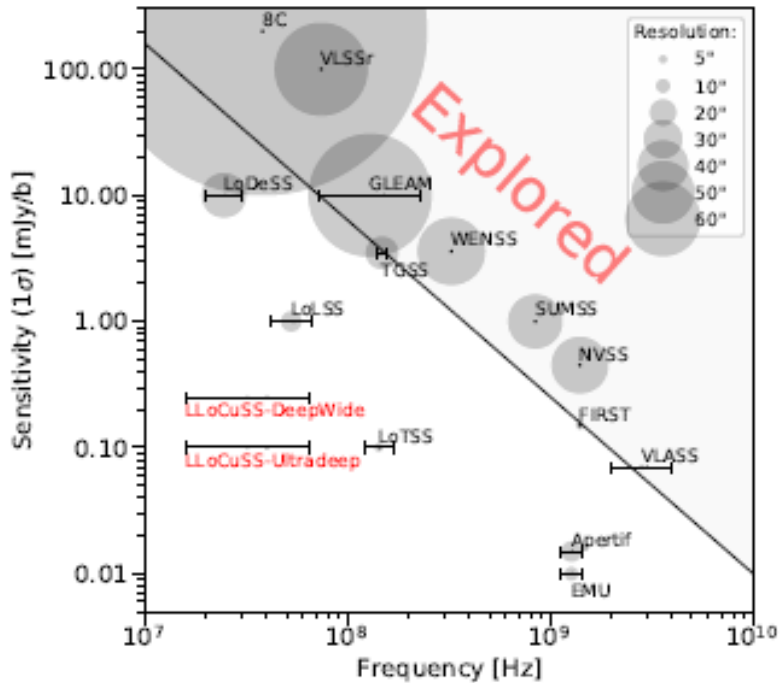
Carretti+ 22



OUTLINE

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LOFAR 2.0 upgrade (2025+...)



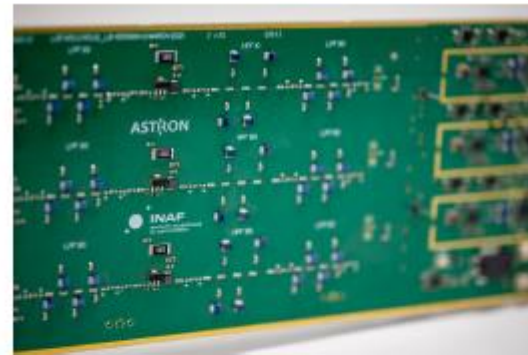
Upgrade :

- electronics
- correlator

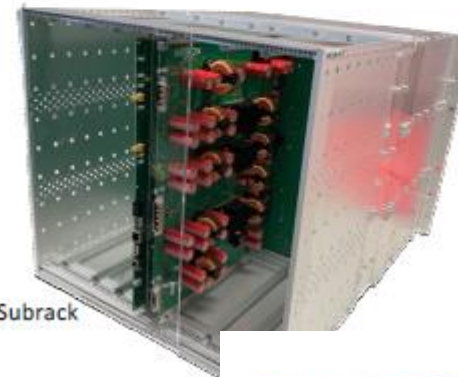
will bring LOFAR into a new regime entering an uncharted territory at the very low frequencies (10-60 MHz)

NEW ELECTRONICS

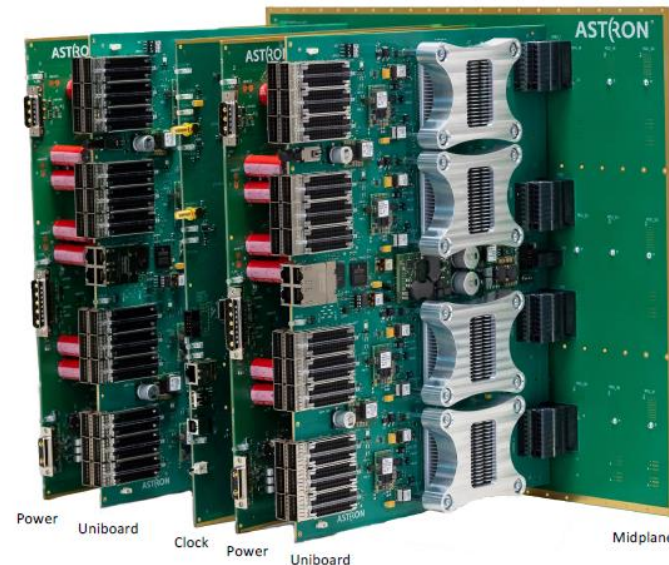
(ASTRON+INAF)



RCU



Subrack



Power

Uniboard

Clock

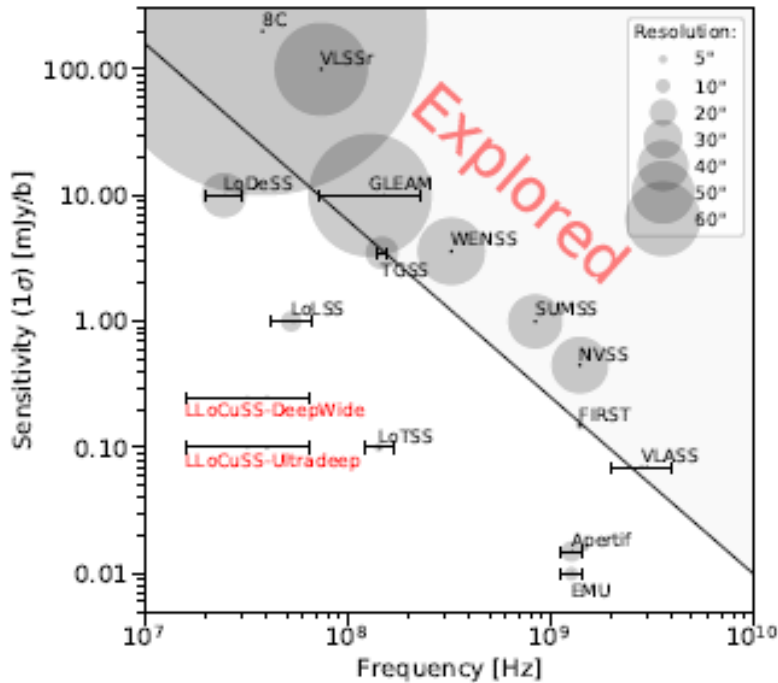
Power

Uniboard

Midplane

LOFAR 2.0 upgrade (2025+...)

2024+



- PIs/coPIs of the largest LOFAR 2 surveys: data flux in IT will increase **x4**
- Use of long baselines to avoid confusion limit: **critical for computing**
- Unique synergies with **EUCLID** and **LSST** and MeerKAT in 2024-30



- Strong case for **BIG data in IT**
- Strong case for **proto-SRC**

Upgrade :

- electronics
- correlator

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



**TECNOPOLO
MANIFATTURA**

DATA VALLEY HUB

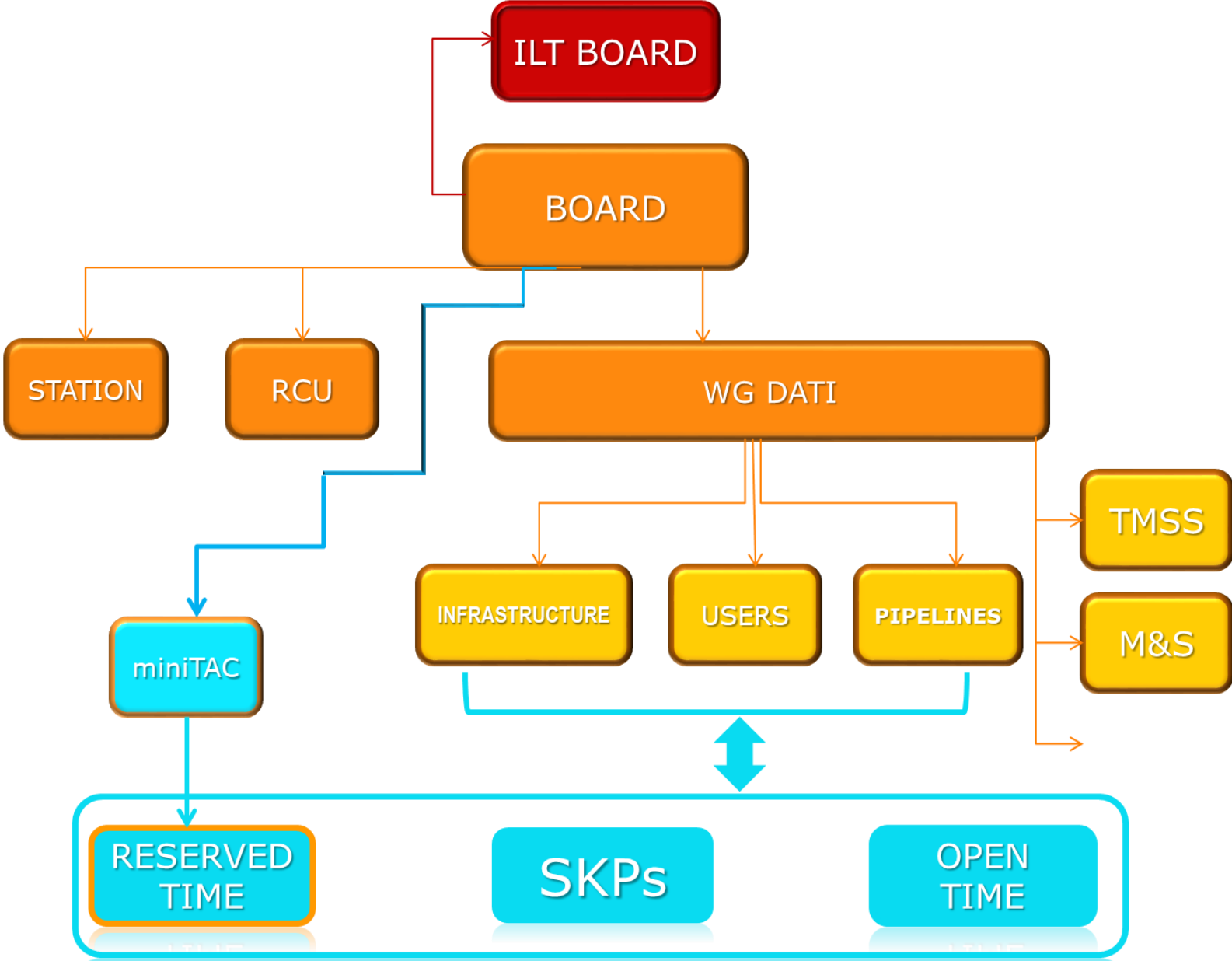
TAKE HOME

- ❑ LOFAR is the largest SKA-low pathfinder
- ❑ Among the most productive astronomical infrastructures
- ❑ Top science: entering new parameter space in several fields

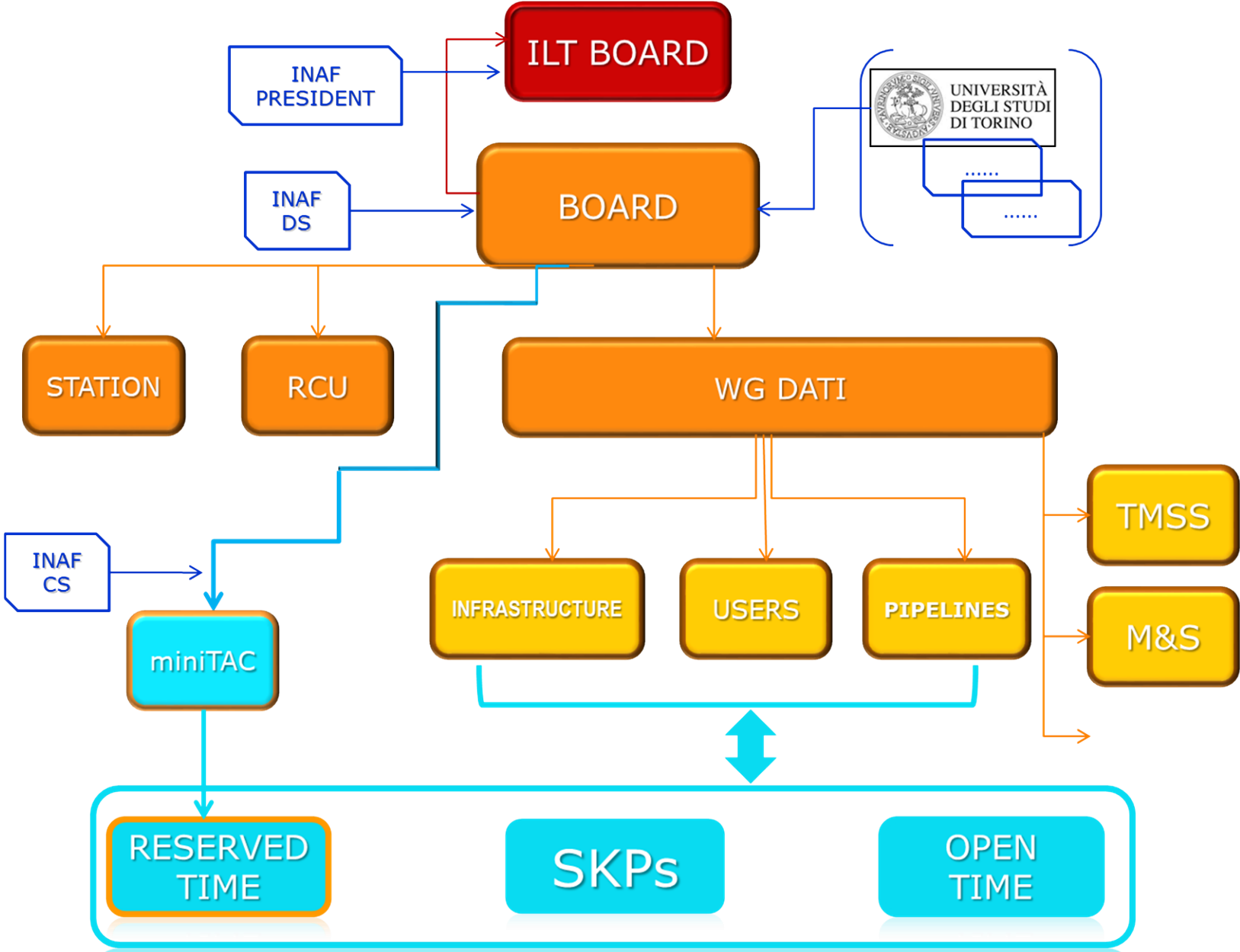
- ❑ The IT community is among the most active with clear leadership in a number of fields
- ❑ Important technological contribution for LOFAR 2

- ❑ LOFAR/LOFAR 2
 - second ERIC in EU radioastronomy (n.2 in INAF ..)
 - will pave the way for SKA-low .. 2028-30
 - will be a unique telescope also in the SKA era :
 - due to the long baselines
 - due to the window at very low frequencies

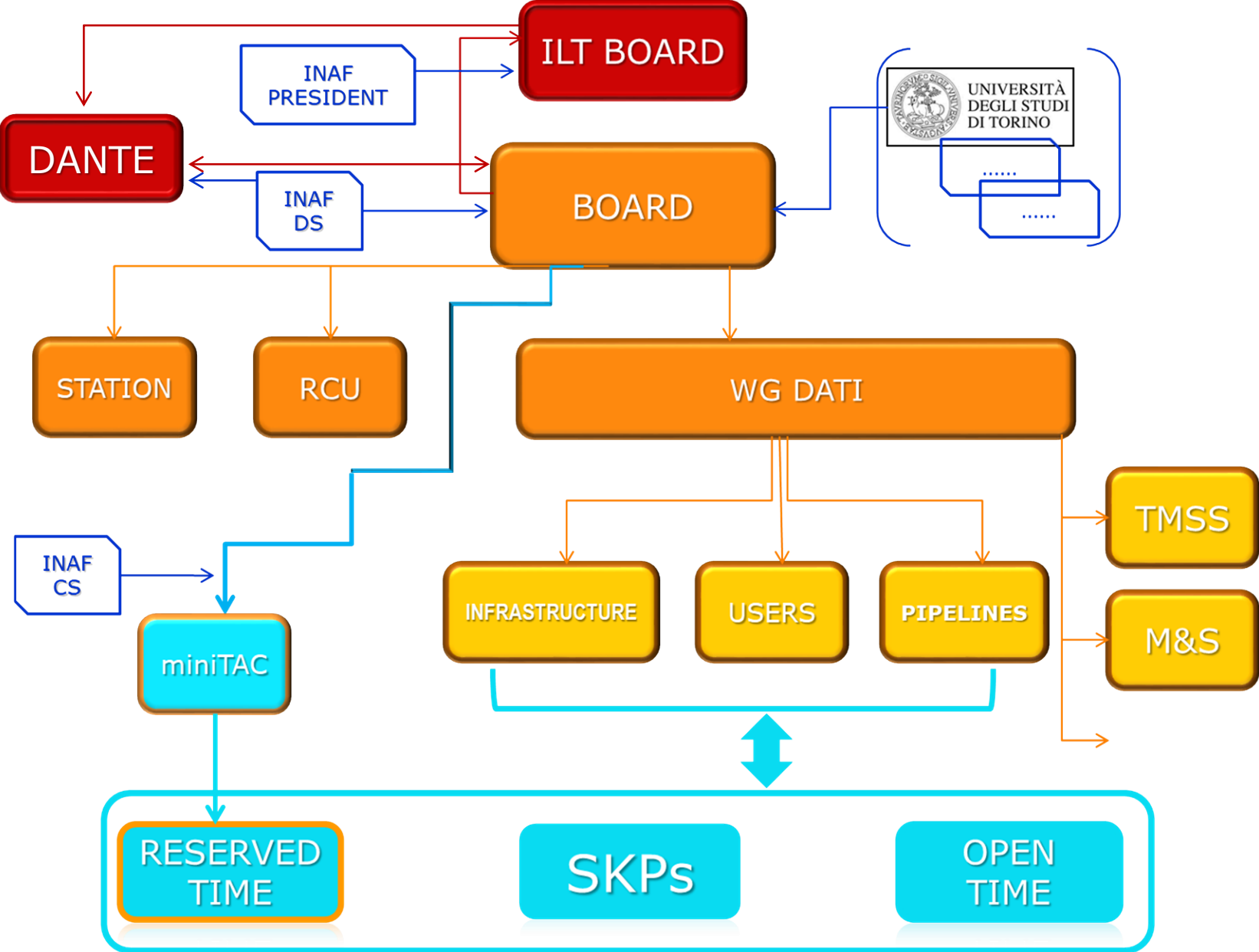
LOFAR-It: Management & Organization

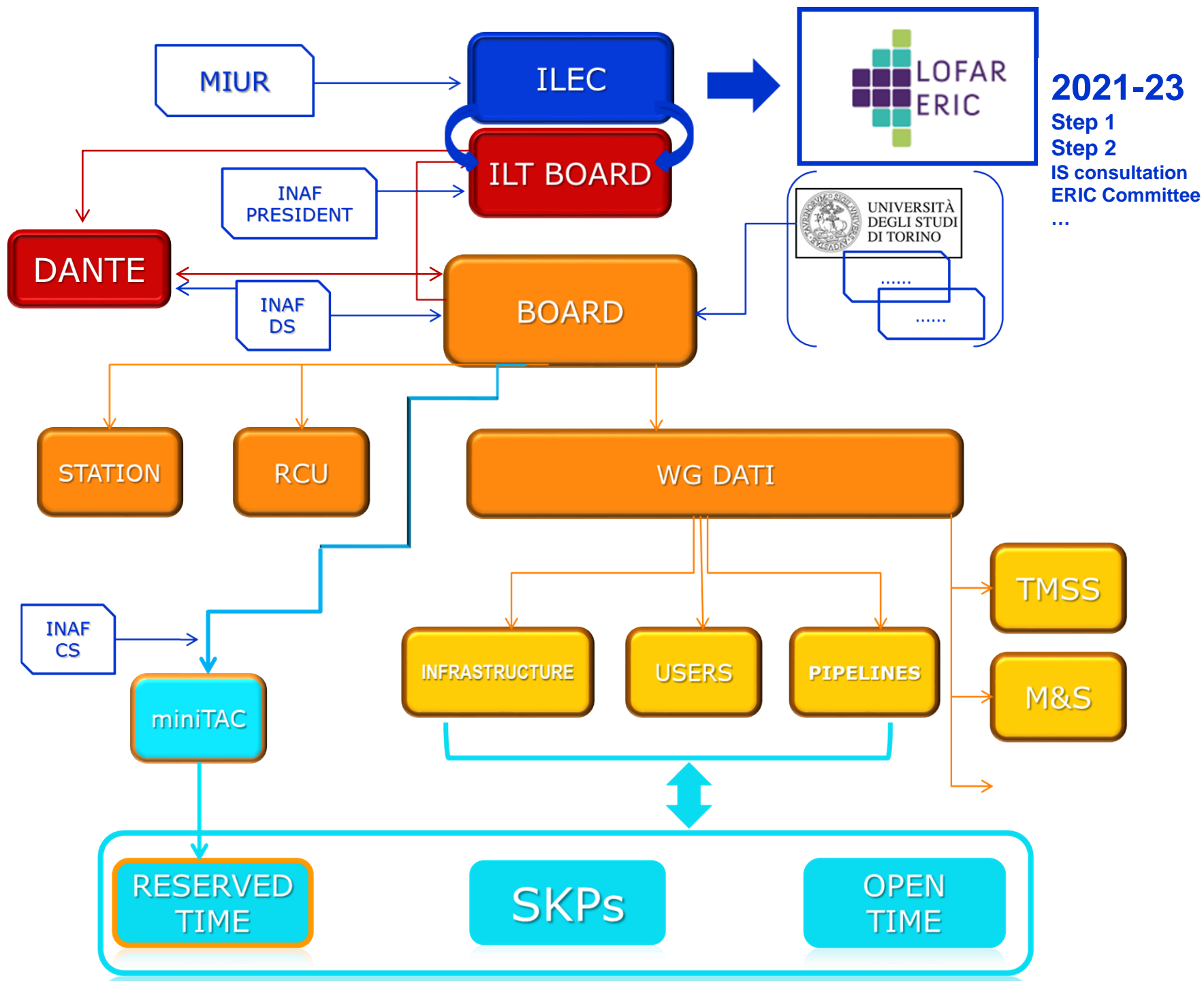


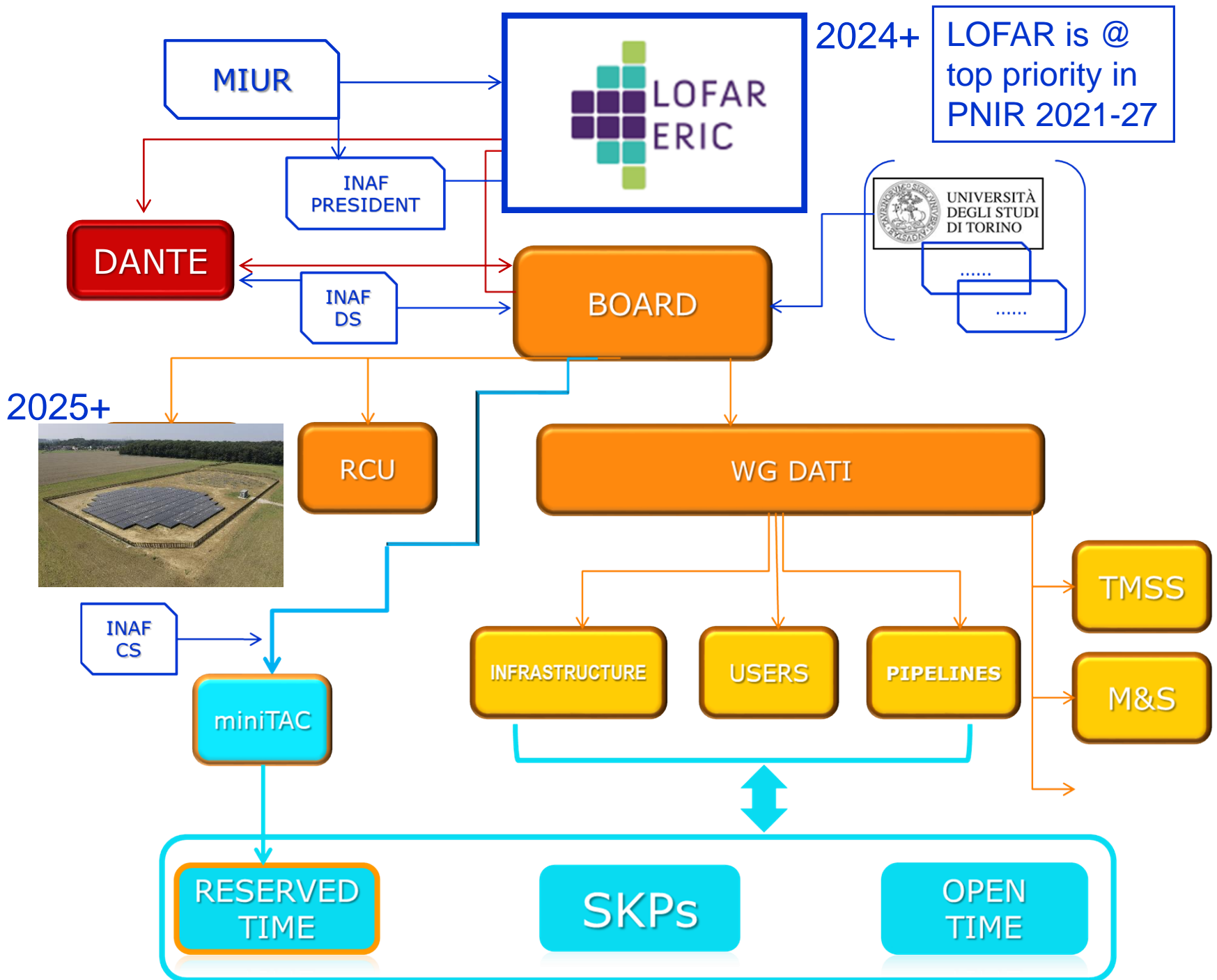
LOFAR-It: Management & Organization



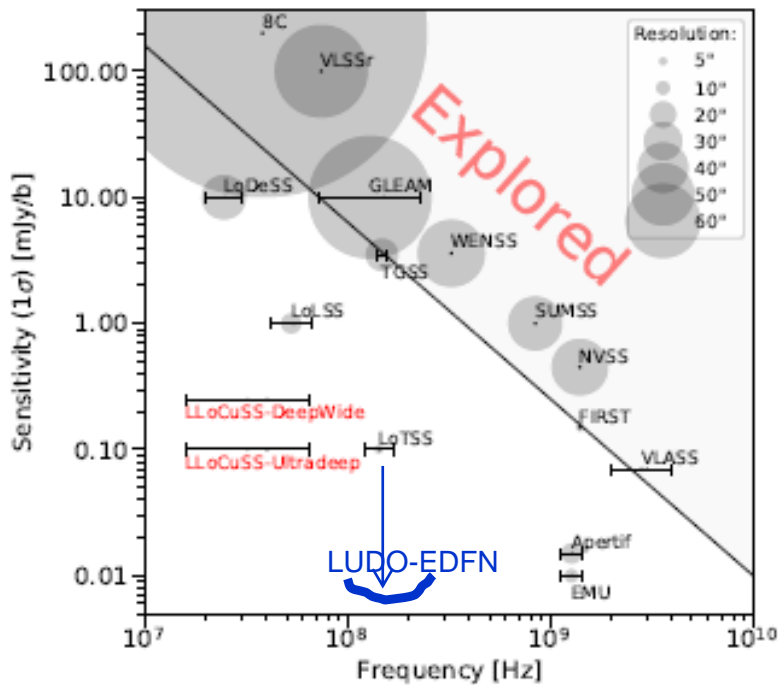
LOFAR-It: Management & Organization



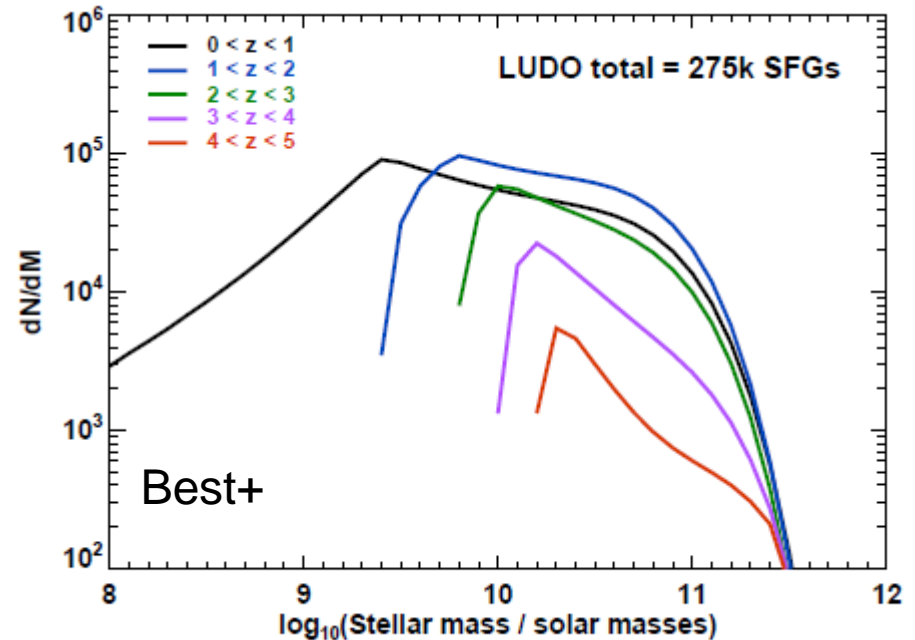




LOFAR 2.0 upgrade (2025+...)



Number of star-forming galaxies

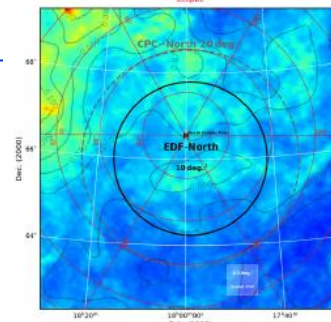


Upgrade :

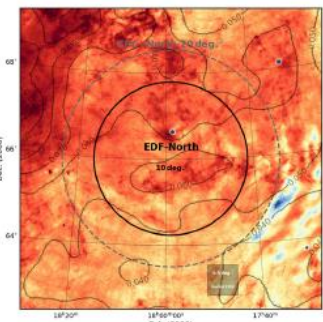
- electronics
- correlator

High resolution (LONG baselines)
will allow reaching extreme sensitivities with
HBA in selected areas (1000+ hrs pointings)

Extinction: E(B-V)



Galactic cirrus patchiness



Euclid Deep Field North (EDFN)

10 square degrees circular field
r = 1.78 deg.

Equatorial:	269.73	+66.02
Ecliptic:	258.69	+89.45
Galactic:	95.76	+29.92



Dist map: Planck Collaboration, et al. 2014, 571, 71
WISE 12w: Munn & Finlator, ApJ, 2004, 761, 5

LOFAR KEY SCIENCE PROJECTS

The most impactful scientific activity and technical solutions are developed within these communities

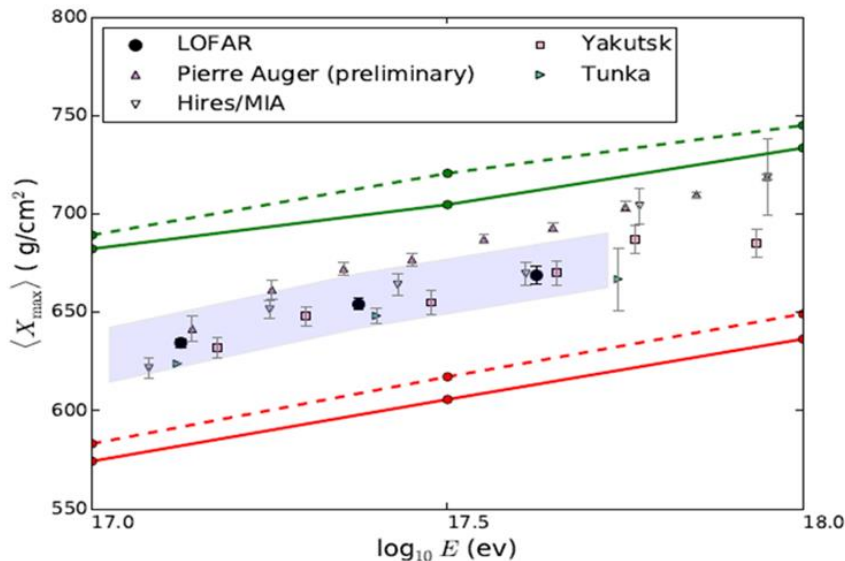
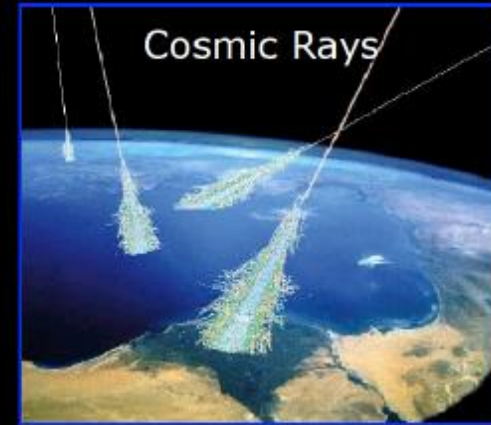
LETTER

doi:10.1038/nature16976

6

A large light-mass component of cosmic rays at $10^{17} - 10^{17.5}$ electronvolts from radio observations

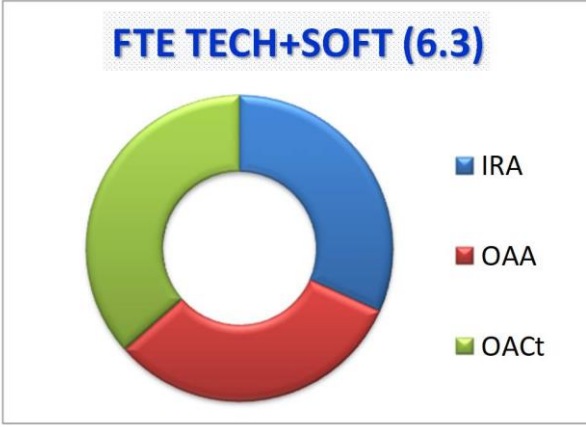
S. Buitink^{1,2}, A. Corstanje², H. Falcke^{2,3,4,5}, J. R. Hörandel^{2,4}, T. Huege⁶, A. Nelles^{2,7}, J. P. Rachen², L. Rossetto², P. Schellart², O. Scholten^{2,8}, S. ter Veer², S. Thoudam², T. N. G. Trinh⁹, J. Anderson¹⁰, A. Angelescu^{11,12}, I. M. Avrukh^{12,13}, M. E. Bell¹⁴, M. J. Bentum^{14,5}, G. Bernardi^{15,16}, P. Best¹⁷, A. Bonafede¹⁸, F. Breitsling¹⁹, J. W. Broderick²⁰, W. N. Brown^{14,5}, M. Brüggemann¹⁹, H. R. Butcher²², D. Carbone²³, B. Ciardi²⁴, J. E. Conway²⁵, F. de Gasperi¹⁹, E. de Geus^{2,26}, A. Deller³, R.-J. Dettmar²⁷, G. van Diepen², S. Duscha², J. Eisköffel²⁸, D. Engels²⁹, J. E. Enriquez³, R. A. Fallows³, R. Fender³⁰, C. Ferrari²⁸, W. Frieswijk², M. A. Garrett^{31,32}, J. M. Grieffraser^{33,34}, A. W. Guast³, M. P. van Haarlem³, T. E. Hassall³⁵, G. Heald^{34,3}, J. W. T. Hessels^{3,32}, M. Hoefler³⁶, A. Hornegger³, M. Isacbelli³, H. Insema^{32,35}, E. Juette²⁷, A. Karastergiou³⁰, V. I. Kondratiev^{3,38}, M. Kramer³, M. Kuniyoshi³⁹, G. Kuper³, J. van Leeuwen^{3,23}, G. M. Looze³, P. Maat³, G. Mann³⁰, S. Markoff³³, R. McFadden³, D. McKay-Bukowski^{39,40}, J. P. McKean^{3,42}, M. Mevius^{3,33}, D. D. Mulcahy³⁸, H. Munk³, M. J. Norden³, E. Orru³, H. Paas⁴⁴, M. Pandey-Pommier⁴², V. N. Pandey³, M. Pietka³⁰, R. Pizo³, A. G. Polatidis³, W. Reich³, H. J. A. Röttgering³⁸, A. M. M. Scaife³¹, D. J. Schwarz⁴³, M. Serylak³⁰, J. Shuman³, O. Smirnov^{27,44}, B. W. Stappers³⁸, M. Steinmetz³⁰, A. Stewart³⁰, J. Swinbank^{23,45}, M. Tagger³¹, Y. Tang³, C. Tasse^{44,46}, M. C. Toribio^{3,22}, R. Vermeulen³, C. Vocks³⁰, C. Vogt³, R. J. van Weeren¹⁶, R. A. M. J. Wijers²³, S. J. Wijnholds³, M. W. Wise^{3,23}, O. Wucknitz³, S. Yatawatta³, P. Zarka⁴⁶ & J. A. Zensus³



SOFTWARE & TECNOLOGY

- ❑ Telescope Manager Specification System (TMSS)
- ❑ Monitor and Control (M&C) Subsystem for LOFAR 2 Station
- ❑

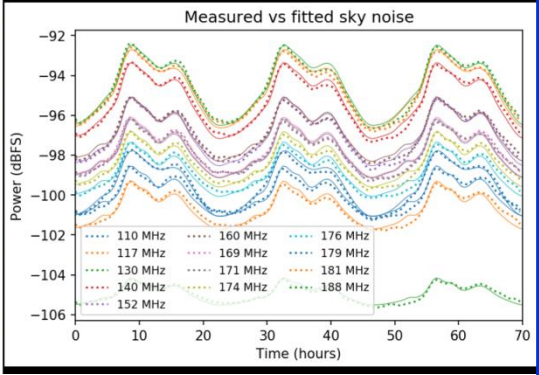
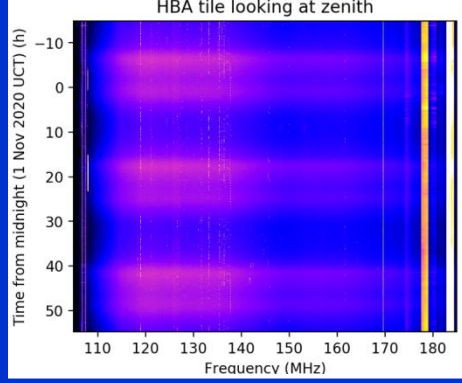
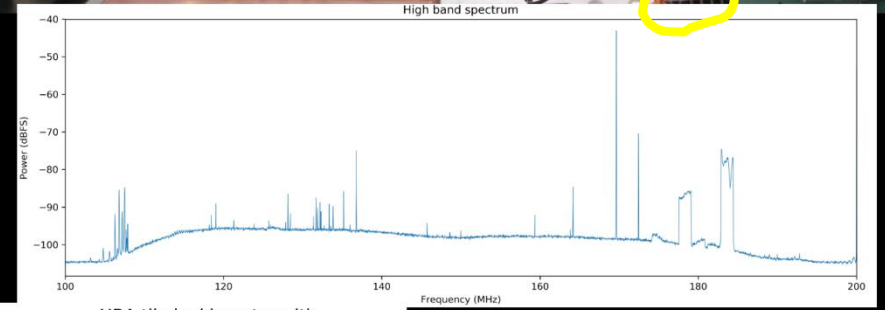
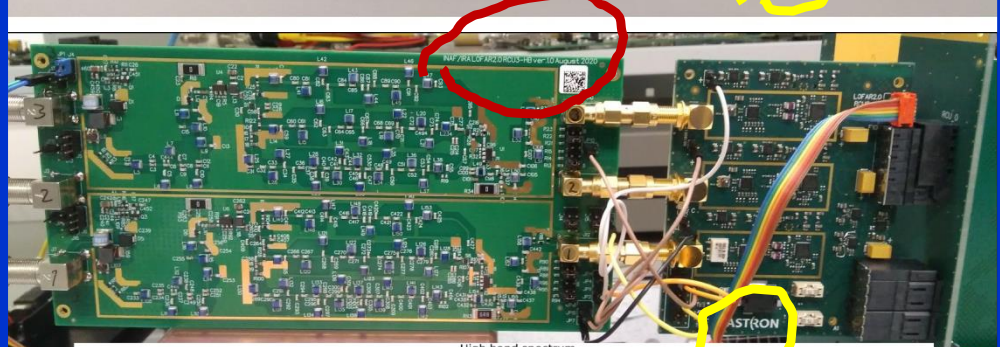
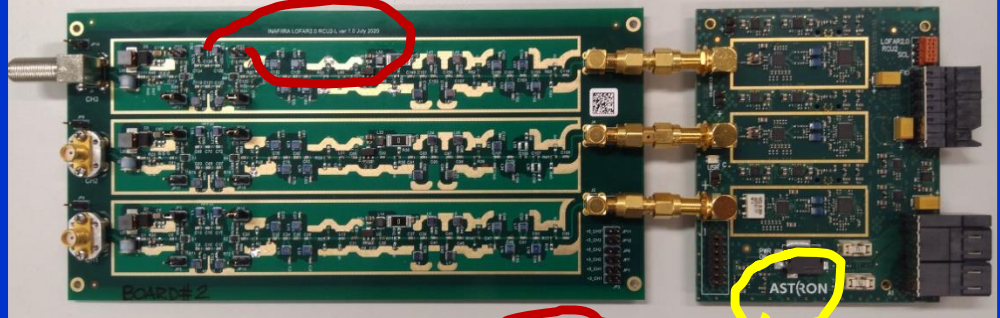
Entrance fee
+
in-kind
contribution



❑ RCU

- ❑ STATION (2022+)
 - INTERFERENCES (2021)
 - POWER (2021+)
 - TERRAIN (2022+)
 - ROLLOUT (2023)
 - TESTING (2023)
 - CALIBRATION (2023)
 - MAINTAINANCE (2023+)

RCU LBA+HBA INAF & ASTRON



CRITICAL ASPECTS 3.

1. LOFAR ERIC.

MIUR and INAF (LOFAR-It chair, INAF offices) are involved in the ERIC process. Step 1 is expected in September 2021, target is to establish/start ERIC LOFAR in 2022-23.

IT will be among the four initial ERIC member countries. ERIC provides important chances for fundraising, personnel, politics...

2. MEDICINA Station.

Rollout expected in 2023, preparation needs to start in 2022.

One problem is that the land is still owned by the CNR ! Urgent task for INAF DG.

