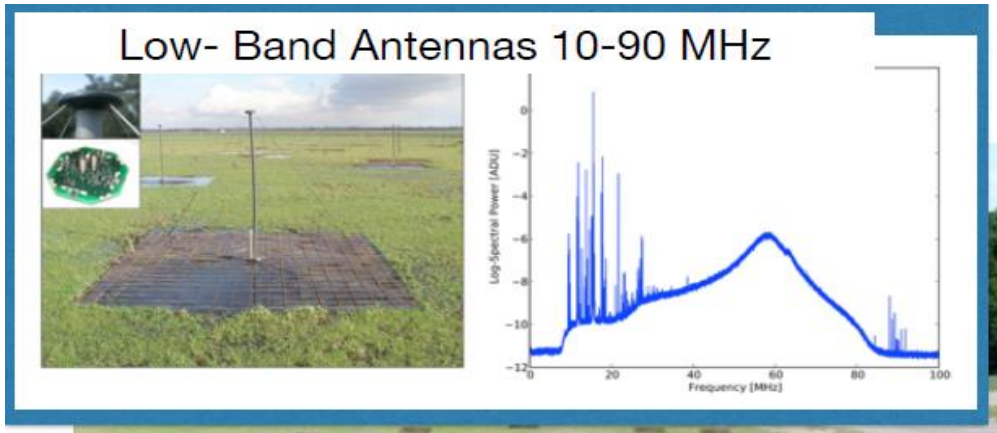
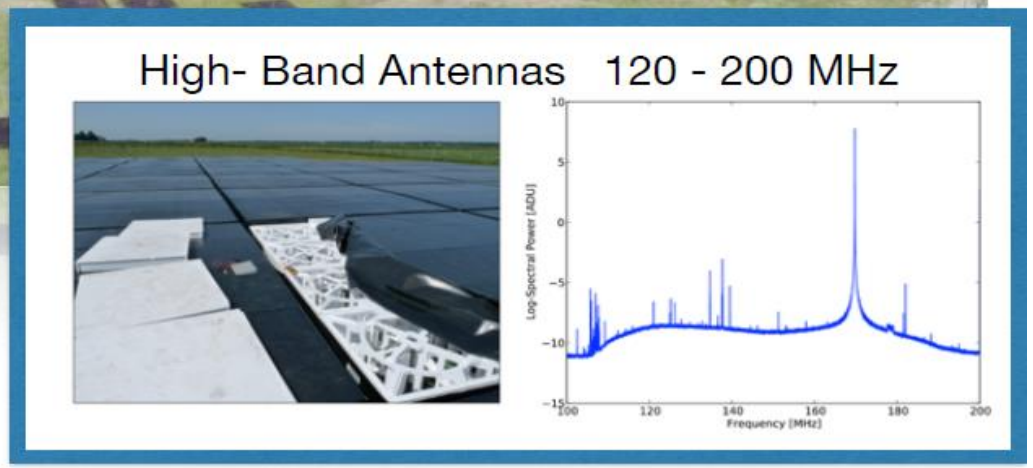
THE LOW FREQUENCY ARRAY

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

- The largest (area & dataflow) pathfinder toward the SKA(low) -





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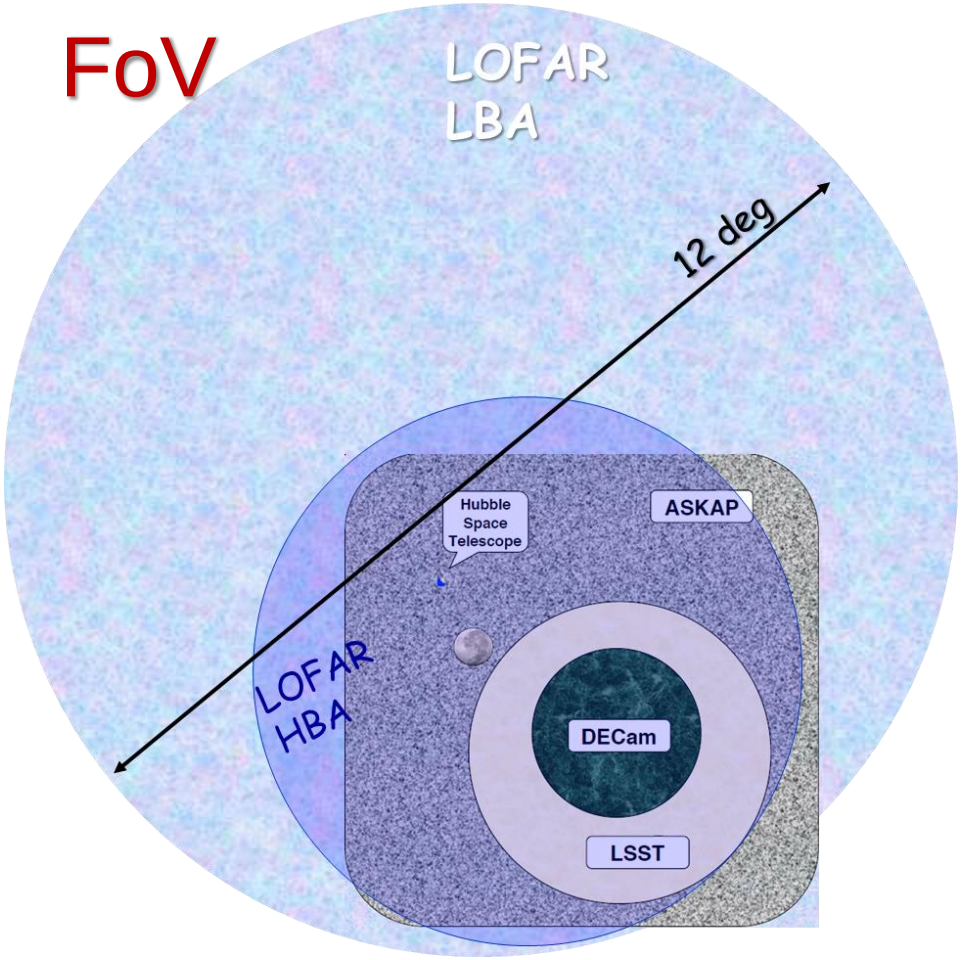
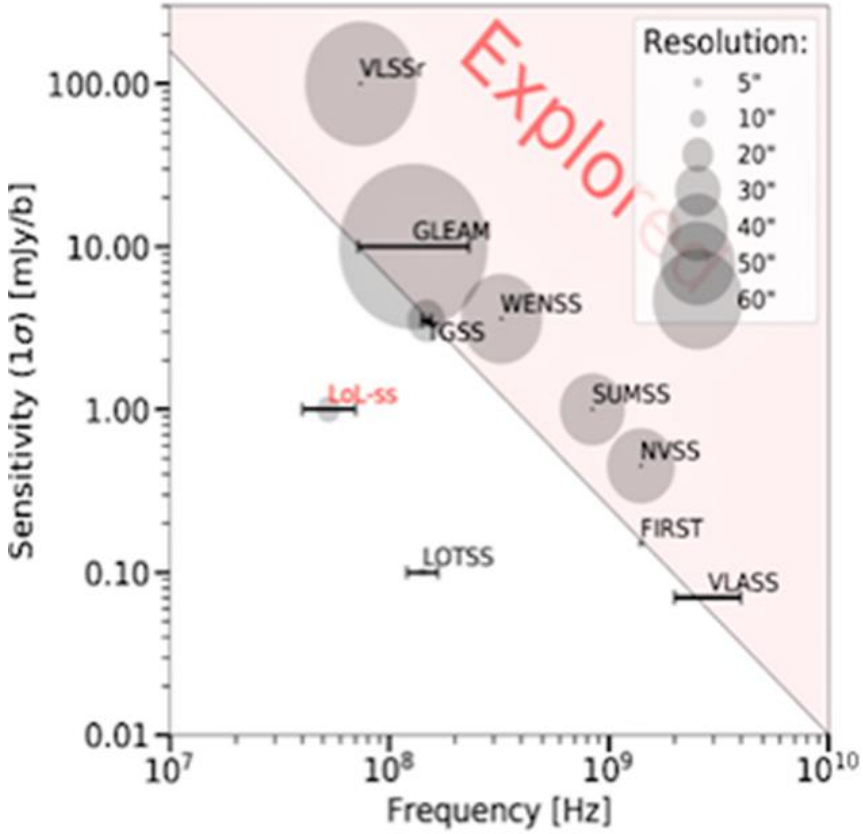


- Opening a new window
- Extreme sensitivity for steep spectrum sources



THE LOW FREQUENCY ARRAY

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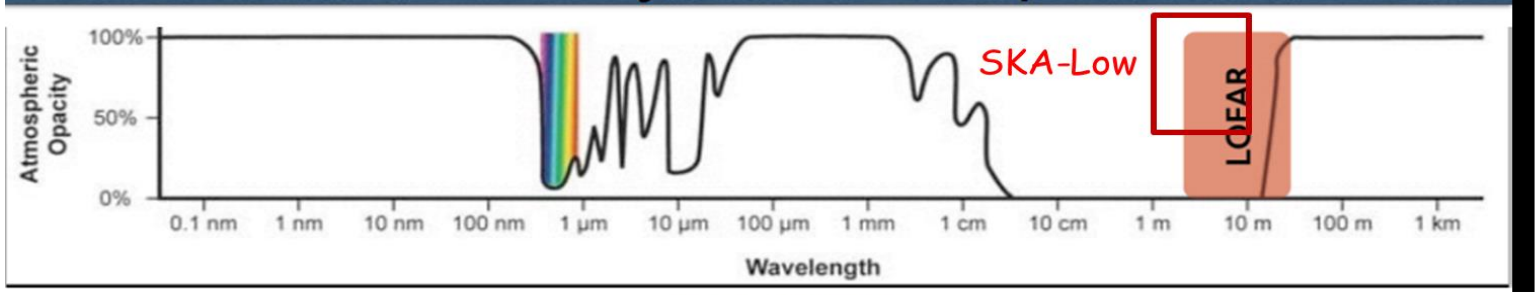
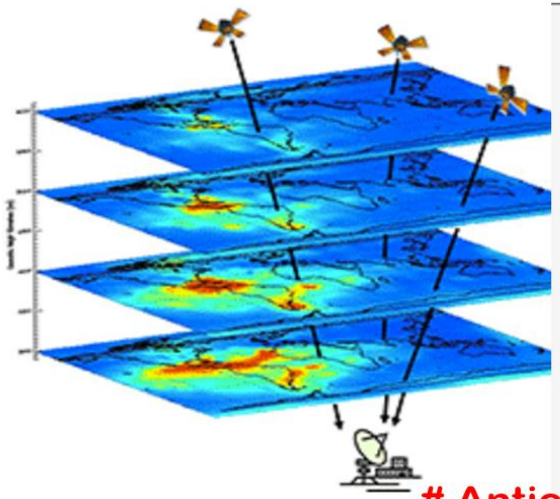
- The largest (area & dataflow) pathfinder toward the SKA(low) -

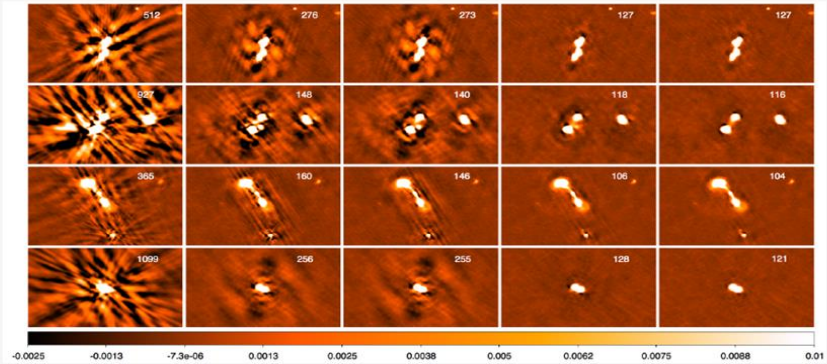
BIG Challenges with data calibration and analysis

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 #

THE LOW FREQUENCY ARRAY

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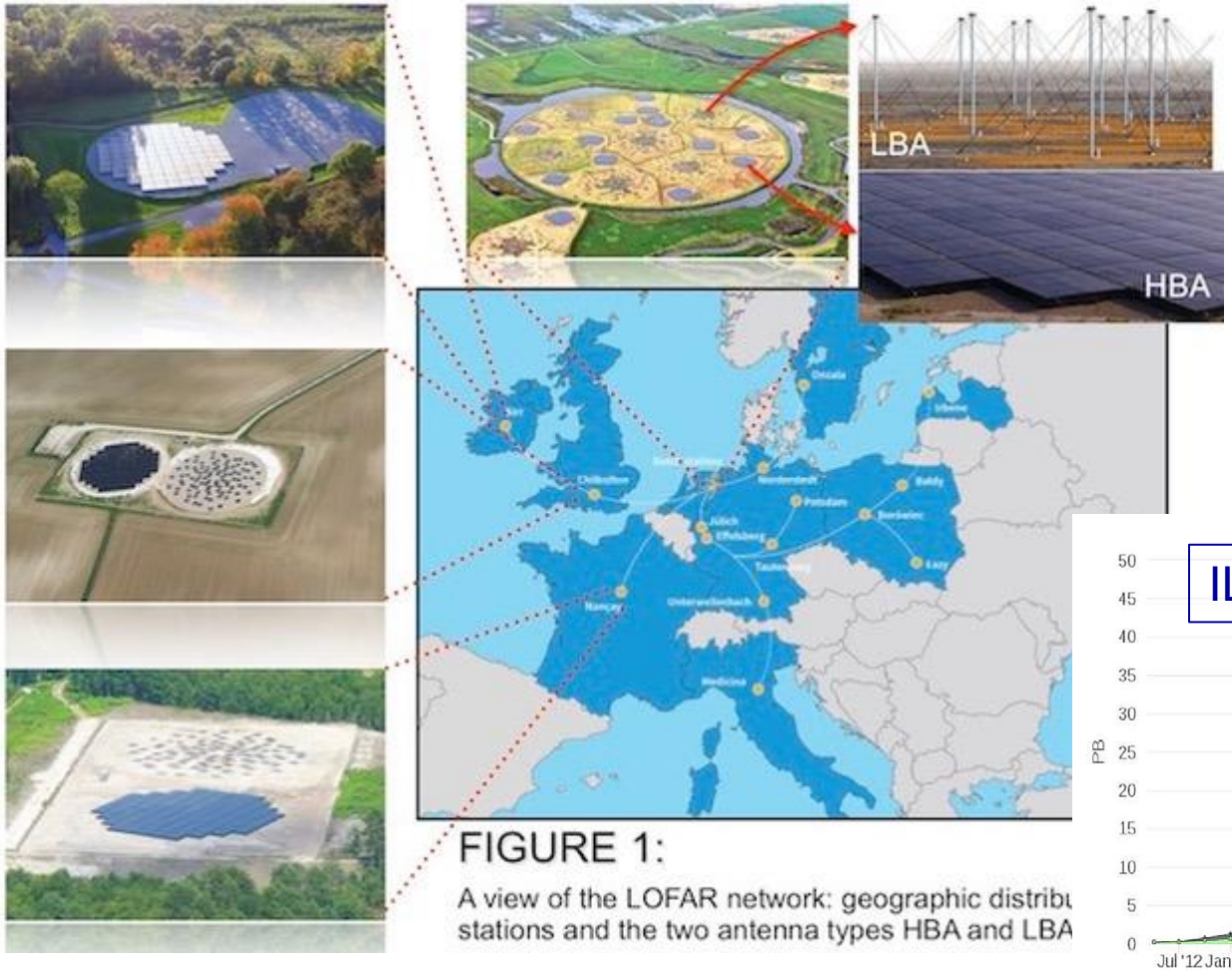
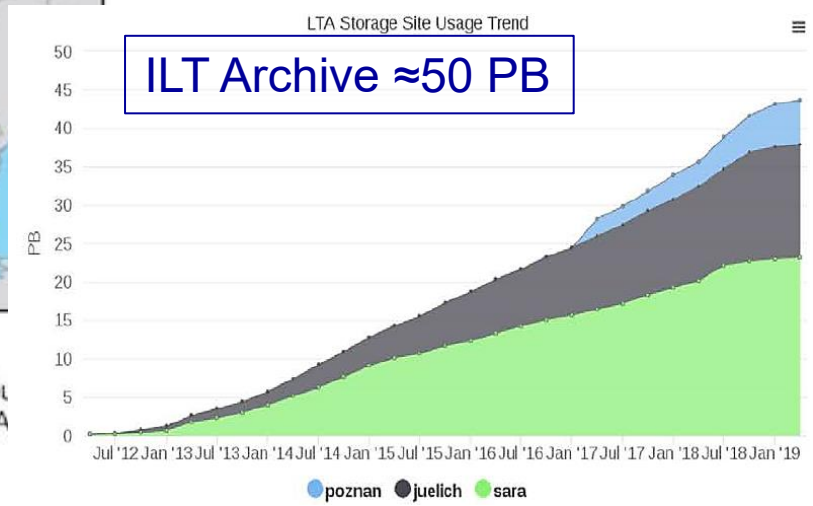


FIGURE 1:
A view of the LOFAR network: geographic distribu
stations and the two antenna types HBA and LBA

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

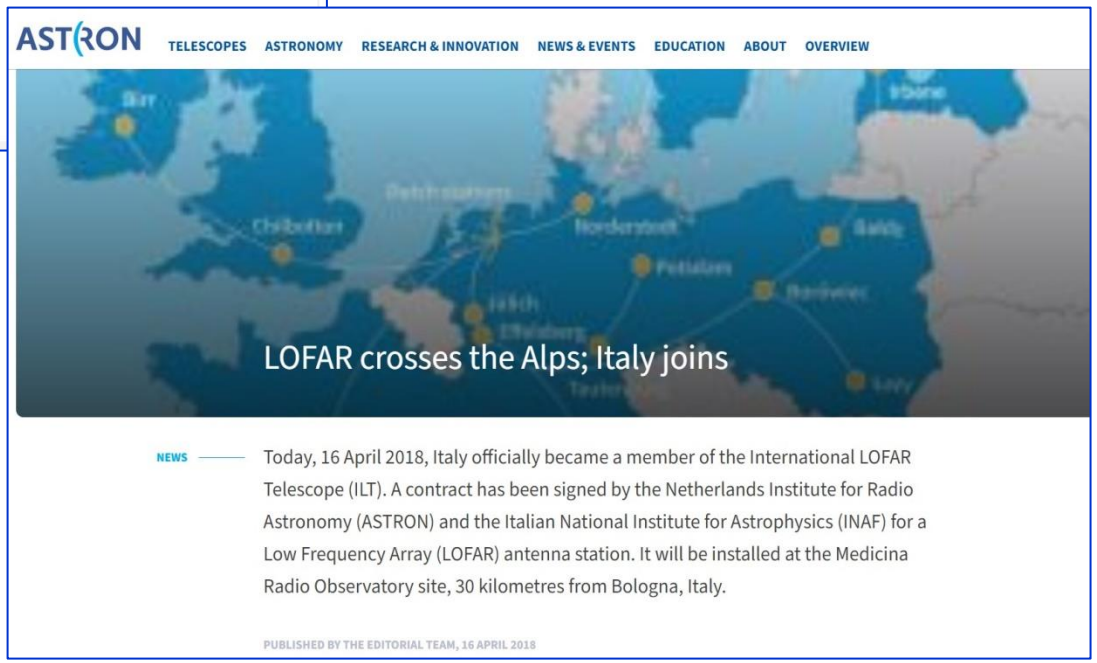


OGGI LA FIRMA NEI PAESI BASSI

L'Italia fa ancor più grande Lofar

Il radiotelescopio europeo si estende anche all'Italia, con il contratto per la realizzazione di una nuova stazione presso Medicina, in provincia di Bologna. Nichi D'Amico: «L'adesione dell'Italia rappresenta un passo importante per Inaf»

Ufficio stampa Inaf 16/04/2018 Tweet



CONDITIONS :

- Technological task (400 kE)
- Annual ILT fee (90 kE/yr)
- Signed Contract for LOFAR 2.0 Station (1.5 ME, 2022+)

BENEFITS :

- National voting member in ILT BOARD
- Reserved access (66 hrs/yr for 2018-24) for short programs
- Involvement in Science KPs (balance of Member return-on-investment/interests)
- 10% use of the Station in Local mode

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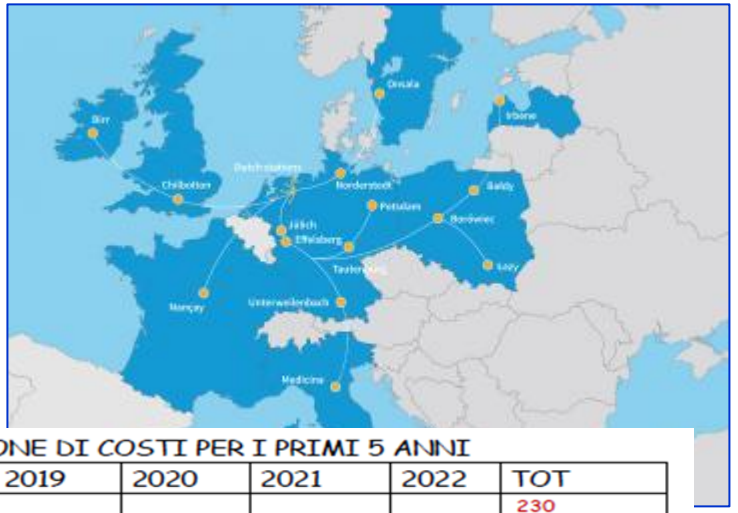

TABELLA 2: PREVISIONE DI COSTI PER I PRIMI 5 ANNI

	2018	2019	2020	2021	2022	TOT
INFRASTR1	230					230
1FTE	45	60	60	60	60	285
RUNNING	15	20	20	20	20	95
RISORSA2	110	110				220
COFIN T2	-55	-55				-110
0.25FTExT2	20	45	45	45	45	200
SUPPORTO		60	60	60*	60*	240*
TECNO	20	90	40	10		160
FTE	30	90	90	30		240
STAZIONE				1650		1650
TERRENO				60		60
RUNNING					40	40
FTE				30	15	45
RUNNING	65	92	92	92*	92*	433*
TRAINING	25	35				60
POST DOC	(50)	(100)	(100)	(50)		(300)
TOT INV	610	702	507	2107	332	4258
INAF INV	320	622	427	2027	252	3648
INAF COST	270	487	292	1922 -60*	192 -60*	3163 -120*
INAF MIN	165(215)	332(432)	192(292)	1872(1922) -60*	192 -60*	2753(3053) -120* 2633/2933

From LOFAR roadmap

CONDITIONS :

- Technological task (400 kE) (in-kind+)
- Annual ILT fee (90 kE/yr)
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BENEFITS :

- National voting member in ILT BOARD
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Scienza e tecnologia con il LOw Frequency Array - LOFAR-It -

- COLLECT SCIENCE (SKPs) & TECHNOLOGY (receivers, software)
- INAF FTE 2021-23 = 22.3
- TOT FTE 2021-23 = **31.6**
- PARTICIPANTS = 61 INAF + 15 ASSOCIATE

G.Brunetti, U.Becciani, F.Govoni, F.Massaro, J.Monari, R.Scaramella, G.Taffoni, F.Perini, R.Baldi, F.Bedosti, G.Bernardi, S.Bertocco, A.Bonafede, M.Bonato, M.Bondi, E.Bonnassieux, C.Bortolotti, M.Brienza, G.Bruni, L.Bruno, A.Capetti, M.Canzari, E.Carretti, R.Cassano, P.Ciliegi, A.Costa, D.Dallacasa, F.De Gasperin, M.Di Carlo, S.Di Frischia, M.Dolci, L.Feretti, C.Feruglio, F.Gastaldello, C.Gheller, S.Guglielmino, M.Gullieuszik, A.Ignesti, A.Ingallinera, P.Leto, S.Loru, G.Maggio, M.Magliocchetti, V.Missaglia, A.Moretti, M.Murabito, M.Murgia, L.Ostorero, R.Paladino, F.Panessa, A.Pellizzoni, L.Pentericci, M.Pilia, B.Poggianti, A.Poli, M.Poloni, I.Prandoni, M.Raciti, K.Rajpurohit, C.Riseley, J.Roda, M.Roma, P.Romano, M.Rossetti, S.Russo, M.Schiaffino, E.Sciacca, C.Stuardi, C.Trigilio, G.Umana, V.Vacca, F.Vazza, T.Venturi, F.Vitello, G.Zamorani

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Connected INAF Programs in this survey (incomplete..) :

- SKA, WEAVE-0, eROSITA, Athena,
- NonthermalWEB, SKA_Galev, METEORA, GASP, WEAVE-ExtraGal,
- MUTE SORCERER, DUTYRAGA, YRG,
- RAGA, MARE,
- EuroEXA, CQC, PLEIADI

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OATs

OATo

IRA

OAS

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
DIPARTIMENTO DI FISICA E ASTRONOMIA

BRERA

IASF-Mi

OAA

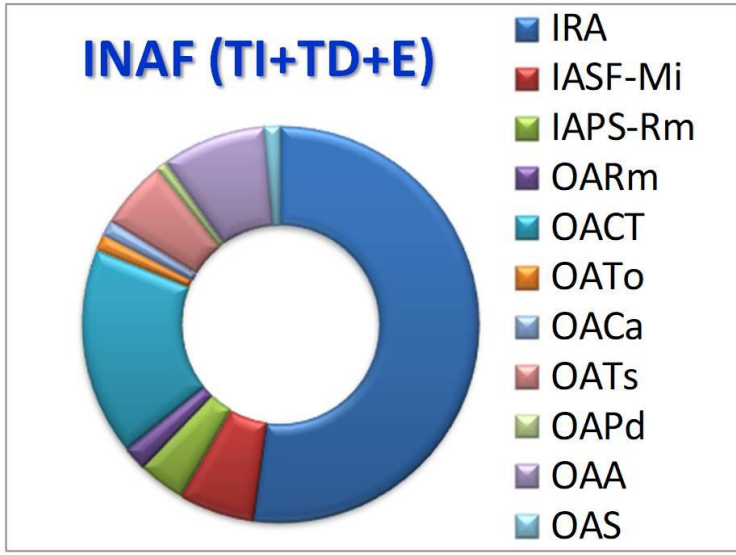
OACa

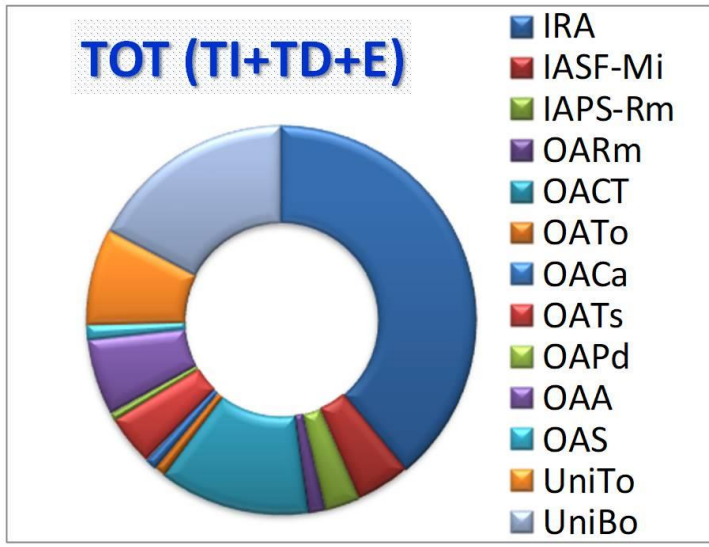
IAPS-Rm

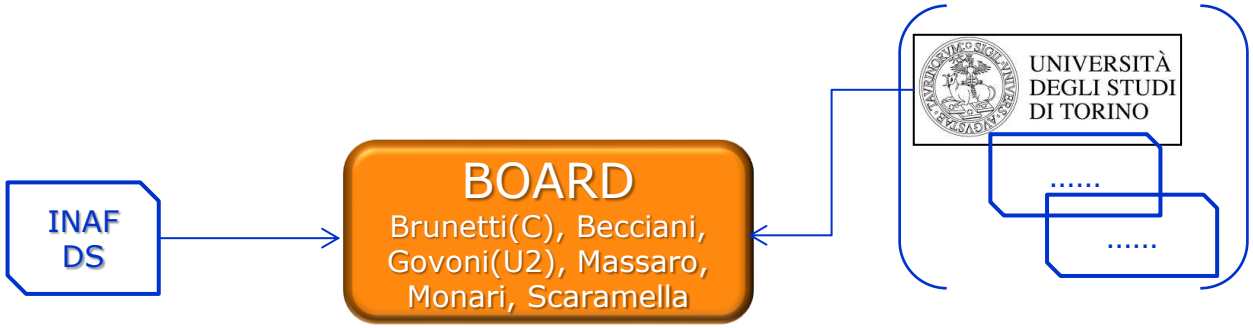
OA-Rm

OACt

~32 FTE



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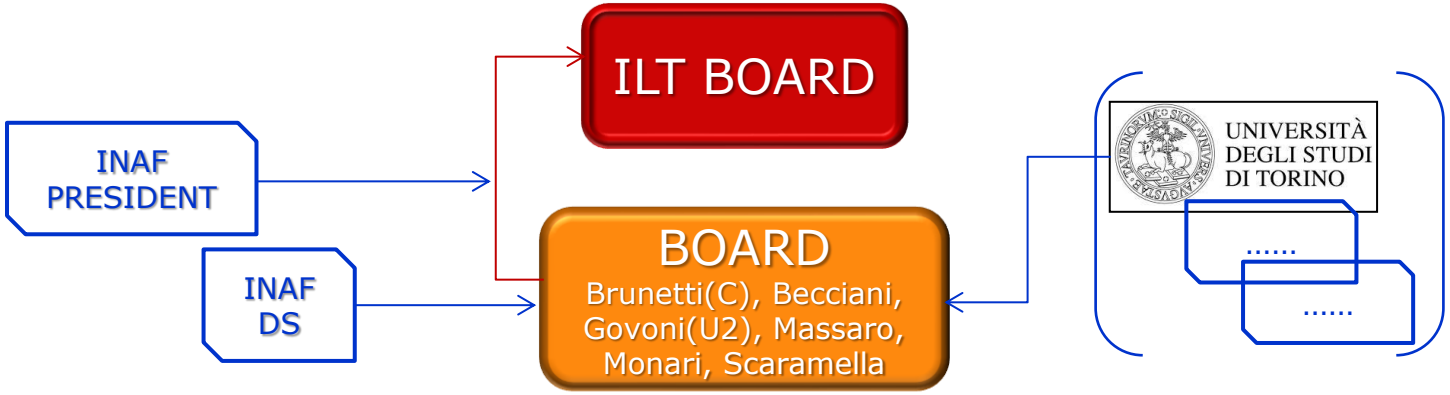
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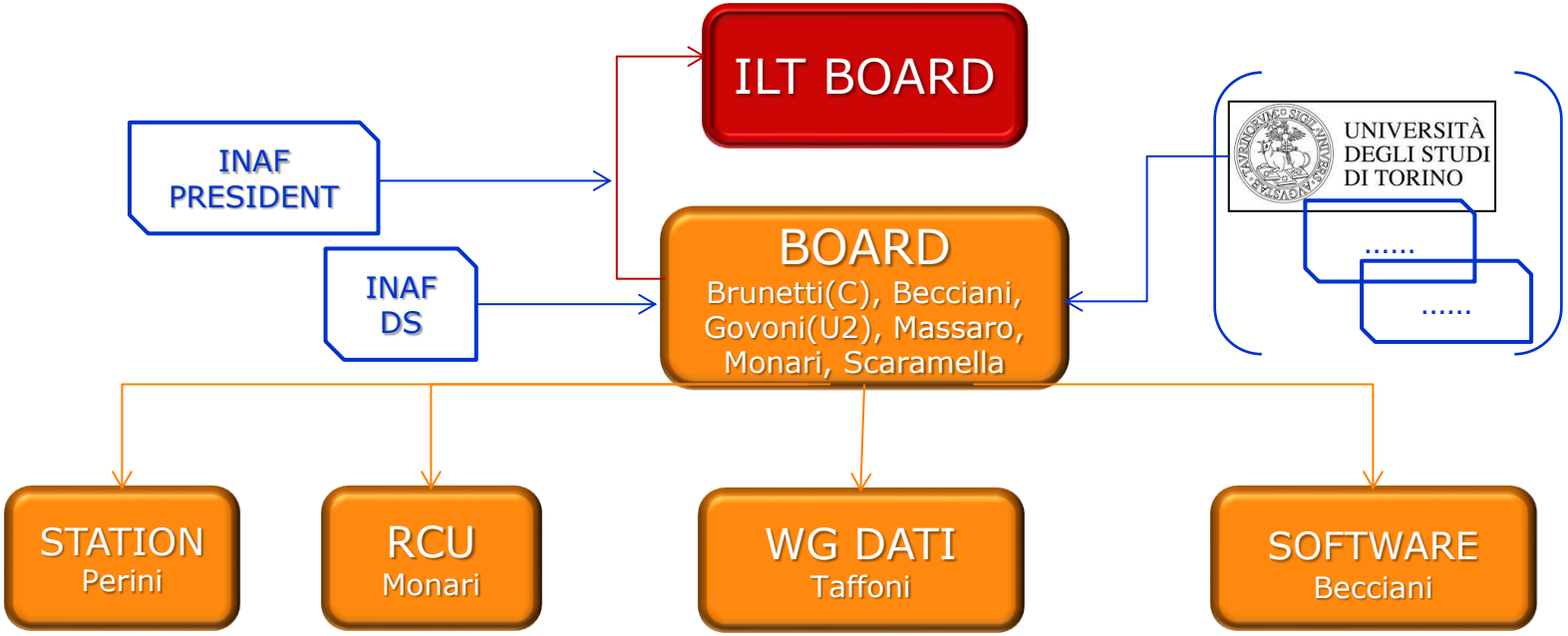
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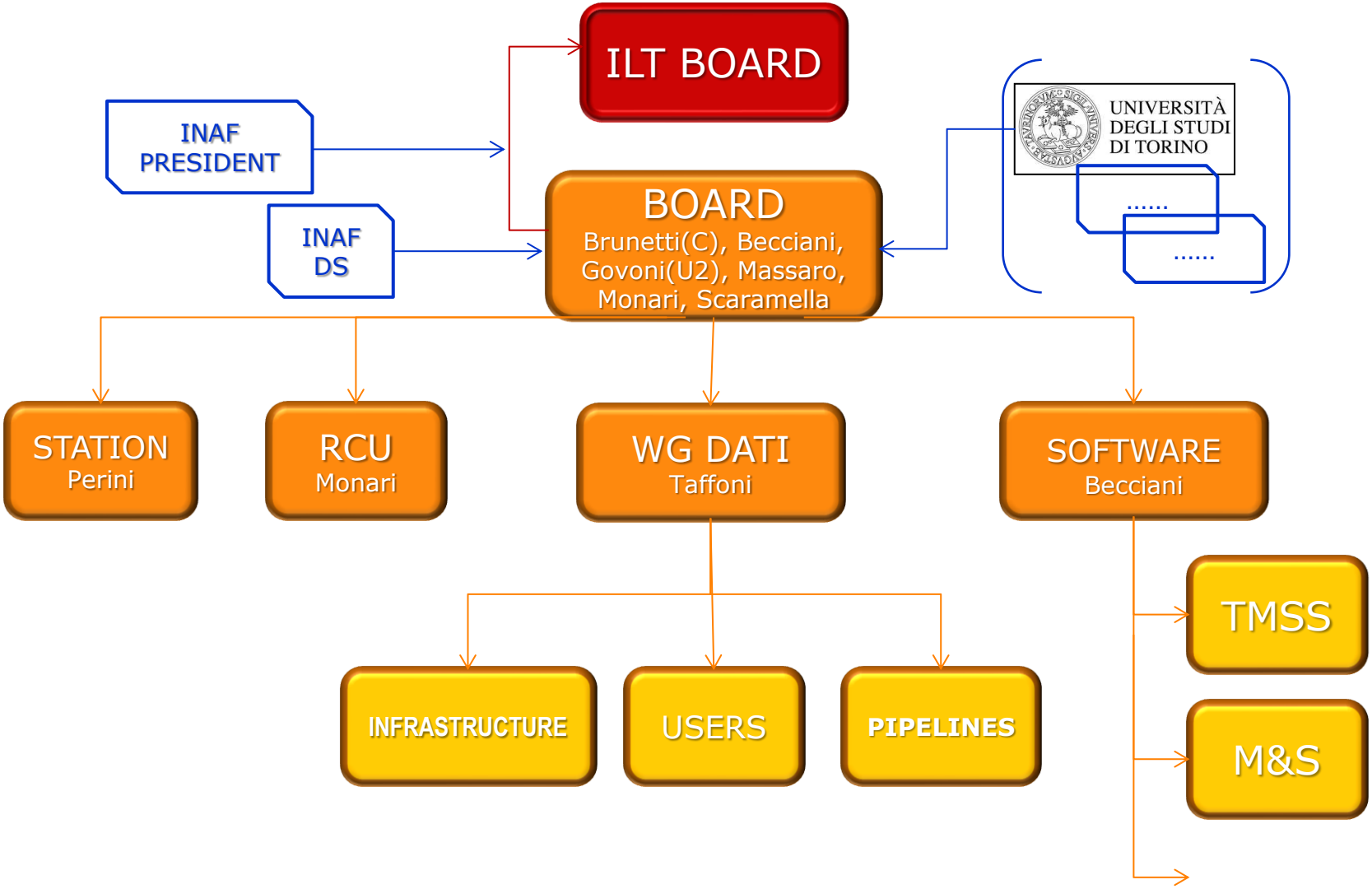
Monari
WG DATI
Taffoni
SOFTWARE
Becciani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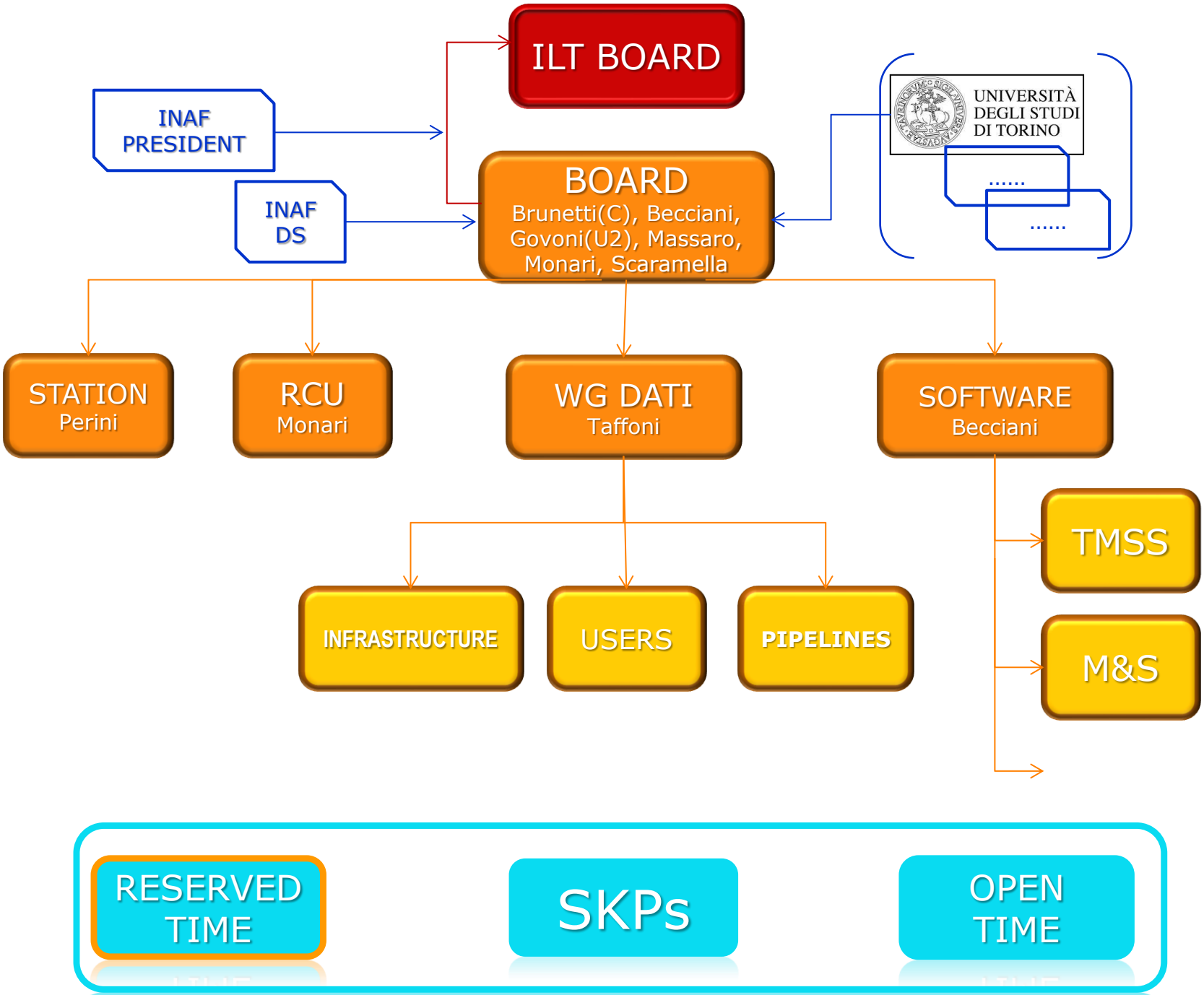
M&S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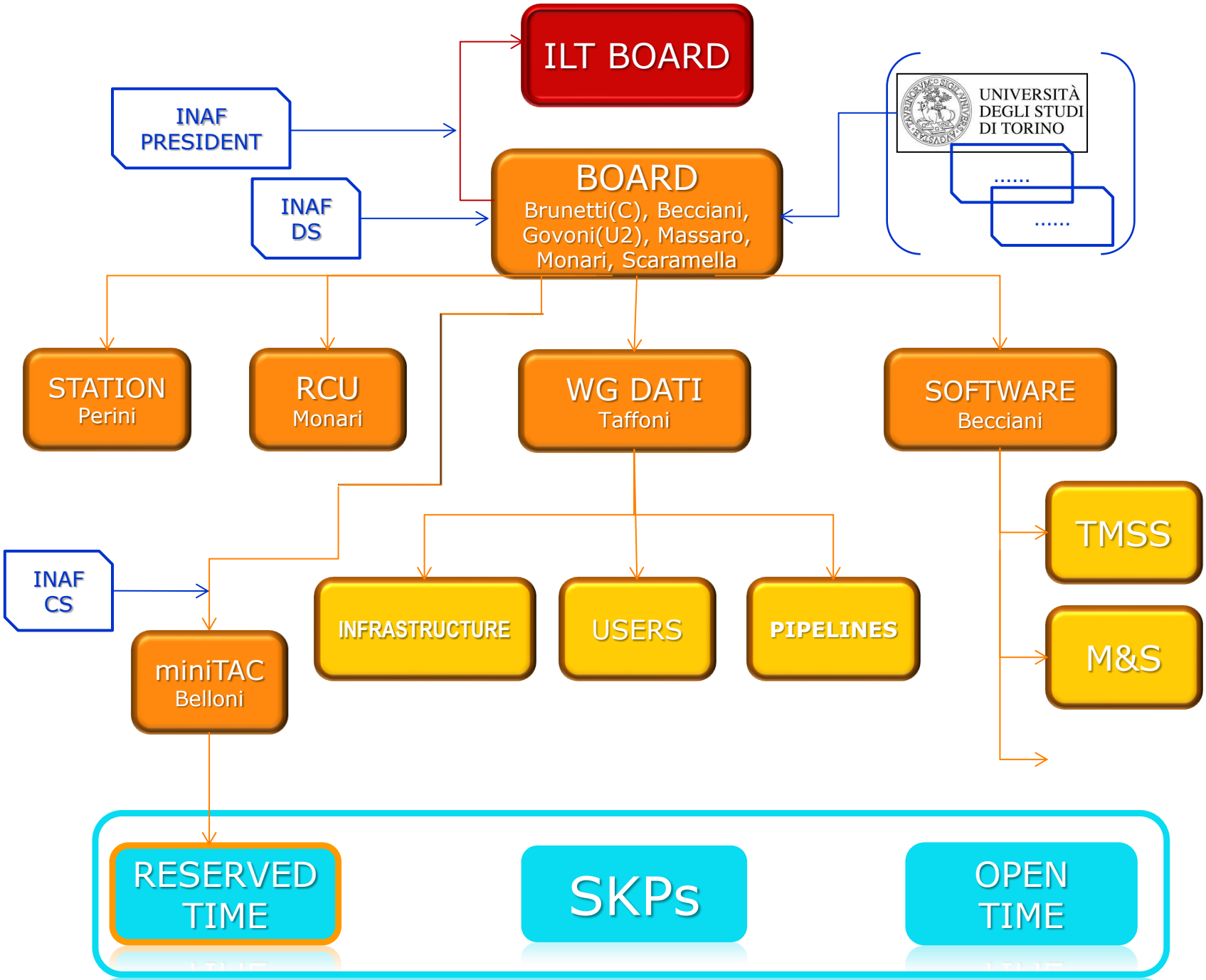
SKPs
OPEN TIME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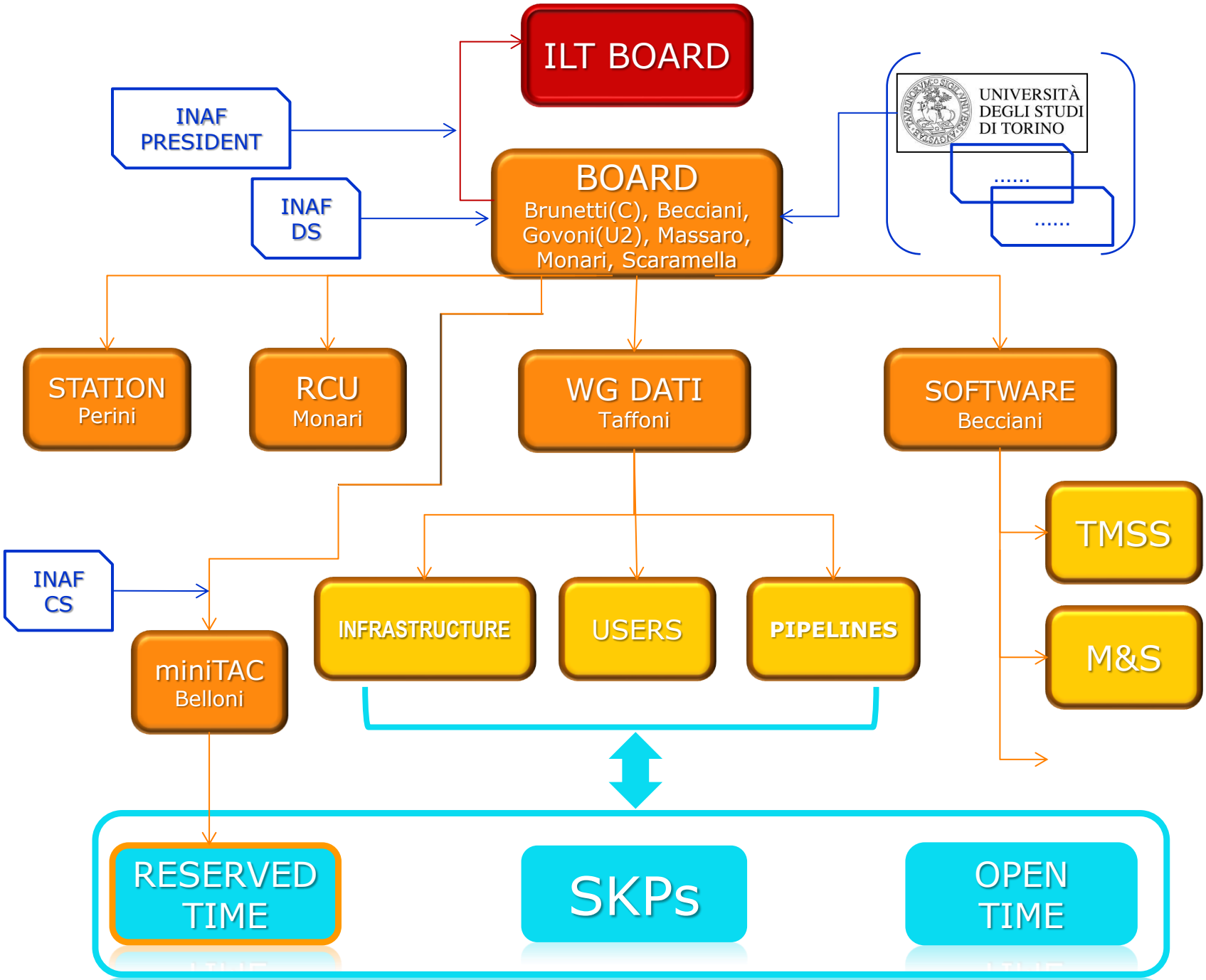
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PIPELINES
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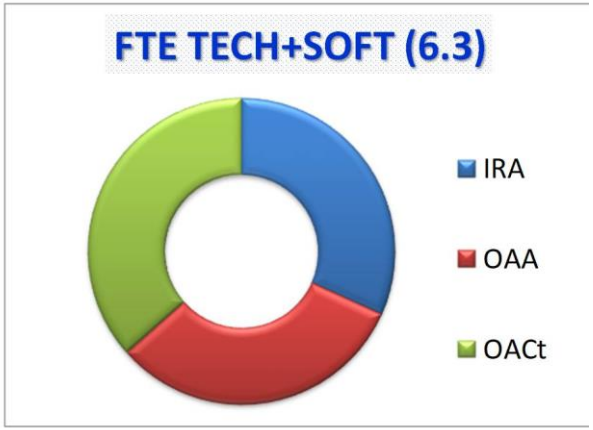
M&S
RESERVED TIME
SKPs
OPEN TIME

SOFTWARE & TECNOLOGY

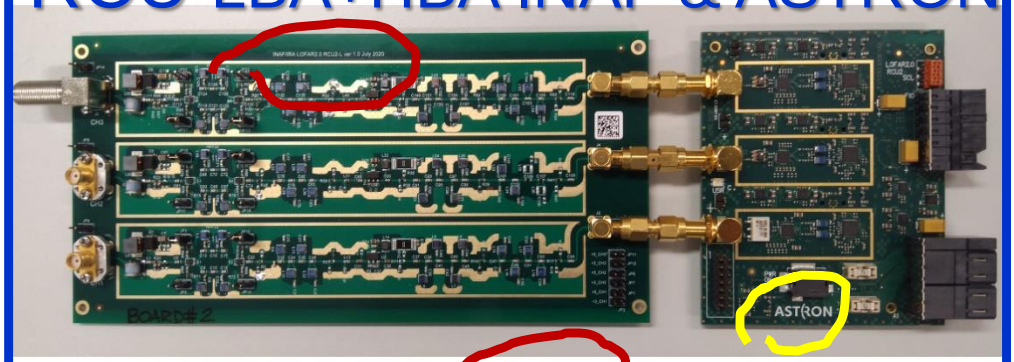
- Telescope Manager Specification System (TMSS)
- Monitor and Control (M&C) Subsystem for LOFAR 2 Station
- ARCHIVE/DATA…..

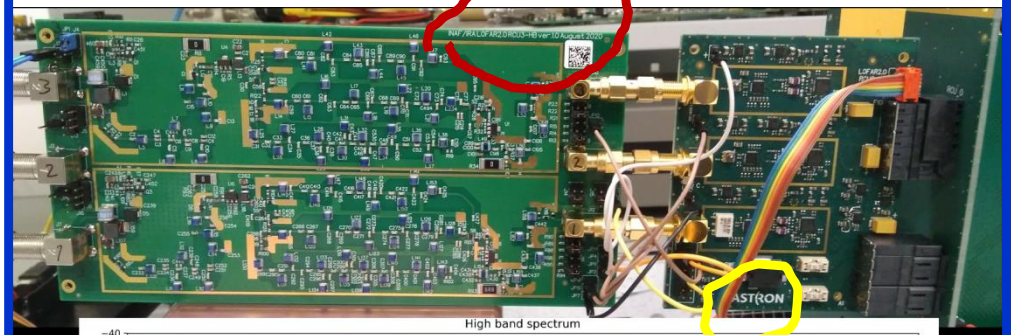
Entrance fee + in-kind contribution

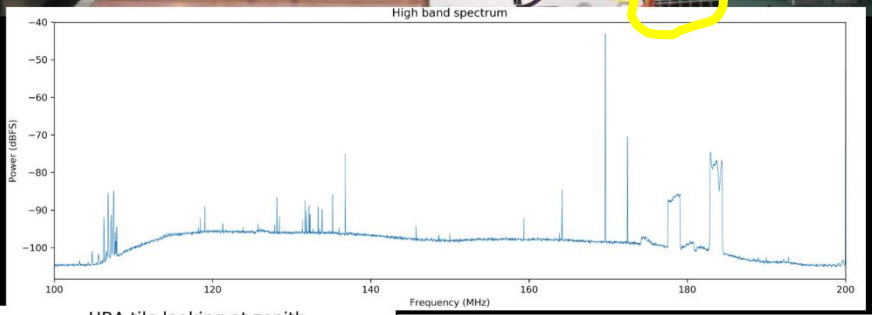


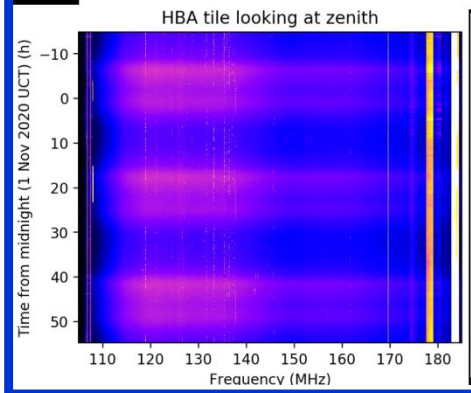
- RCU
- STATION (2022+)
  - INTERFERENCES (2021)
  - POWER (2021+)
  - TERRAIN (2022+)
  - ROLLOUT (2023)
  - TESTING (2023)
  - CALIBRATION (2023)
  - MAINTAINANCE (2023+)

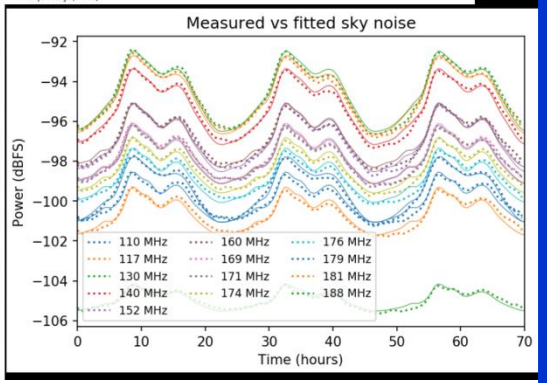
RCU LBA+HBA INAF & ASTRON











LOFAR-It COMPUTING

(Cofin: PRIN,EU)

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: 8 Nodes, 250 TB storage

Name	RAM	CPU	Cores	Clock	Data Net	Work Disk (DAS HD)	Scratch Disk (DAS SSD)	GPU	schedul
lofar1	512G	Intel Xeon E5-2640 v4	2 x 10/20	2400/3400	1GbE	28TB (4x6TB)	196GB		N
lofar2	384G	Intel Xeon Gold 6130	2 x 16/32	2100/3700	10GbE	19TB (2x10TB)	65GB		N
lofar3	384G	Intel Xeon Gold 6130	2 x 16/32	2100/3700	10GbE	10TB (1x10TB)	65GB		N
lofar4	384G	Intel Xeon Gold 6130	2 x 16/32	2100/3700	10GbE	19TB (2x10TB)	65GB		N
lofar5	384G	Intel Xeon Gold 6130	2 x 16/32	2100/3700	10GbE	19TB (2x10TB)	65GB		N
lofar6	384G	AMD EPYC 7401	2 x 24/48	2000/3000	10GbE	19TB (2x10TB)	65GB		N
lofar7	512G	AMD EPYC 7452	2 x 32/64	2350/3350	10GbE	33TB (4x10TB)	169GB	RTX 2080 Ti	N
lofar8	512G	AMD EPYC 7452	2 x 32/64	2350/3350	10GbE	33TB (4x10TB)	169GB	RTX 2080 Ti	N

Storage edit

Name	RAM	CPU
lofarnas0	32G	Intel Xeon Silver 41

3 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

Cofund DRANOEL

erc

LOFAR-It COMPUTING

(Cofin: PRIN,EU)

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: 8 Nodes, 250 TB storage

Name	RAM	CPU	Cores	Clock	Data Net	Work Disk (DAS HD)	Scratch Disk (DAS SSD)	GPU	schedul
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lofar3	384G	Intel Xeon Gold 6130	2 x 16/32	2100/3700	10GbE	10TB (1x10TB)	65GB		N
lofar4	384G	Intel Xeon Gold 6130	2 x 16/32	2100/3700	10GbE	19TB (2x10TB)	65GB		N
lofar5	384G	Intel Xeon Gold 6130	2 x 16/32	2100/3700	10GbE	19TB (2x10TB)	65GB		N
lofar6	384G	AMD EPYC 7401	2 x 24/48	2000/3000	10GbE	19TB (2x10TB)	65GB		N
lofar7	512G	AMD EPYC 7452	2 x 32/64	2350/3350	10GbE	33TB (4x10TB)	169GB	RTX 2080 Ti	N
lofar8	512G	AMD EPYC 7452	2 x 32/64	2350/3350	10GbE	33TB (4x10TB)	169GB	RTX 2080 Ti	N

3 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.

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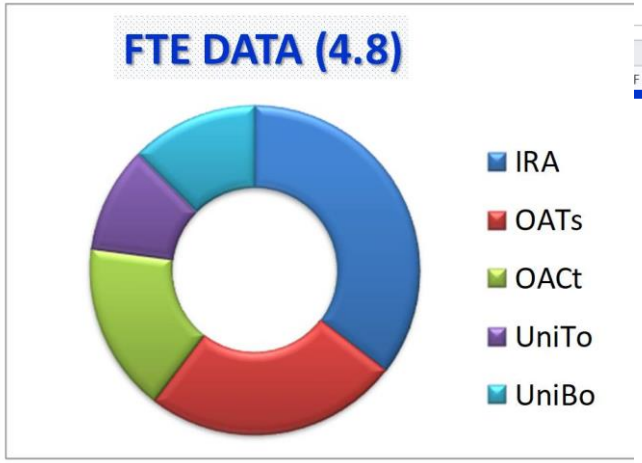
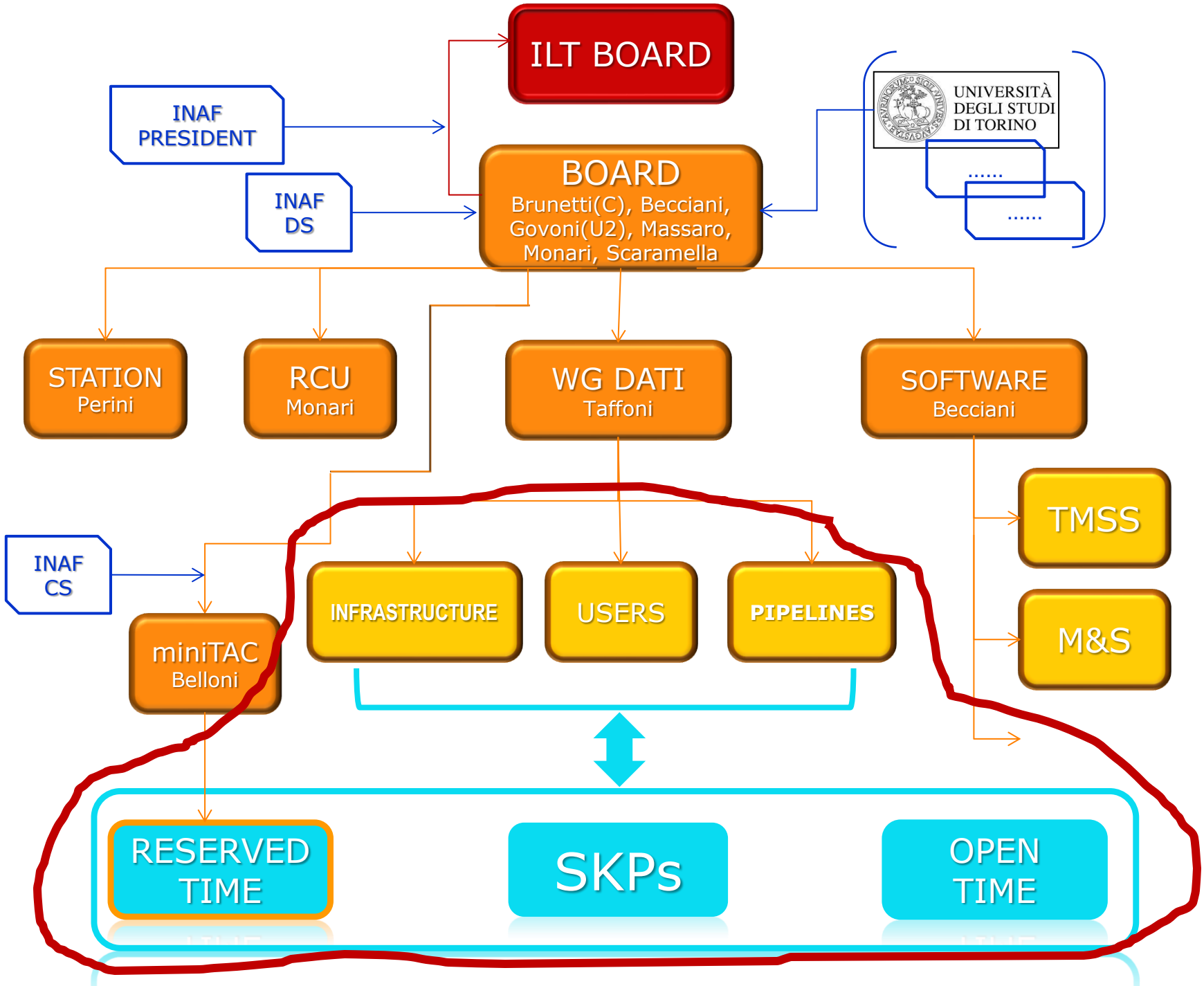
Filesystem: local + NFS




ILT BOARD
INAF PRESIDENT
INAF DS
BOARD
Brunetti(C), Becciani, Govoni(U2), Massaro, Monari, Scaramella
UNIVERSITÀ DEGLI STUDI DI TORINO
.....
.....
STATION
Perini
RCU
Monari
WG DATI
Taffoni
SOFTWARE
Becciani
INAF CS
miniTAC
Belloni
INFRASTRUCTURE
USERS
PIPELINES
TMSS
M&S
RESERVED TIME
SKPs
OPEN TIME

GROWTH OF THE IT COMMUNITY
- OBSERVING TIME -

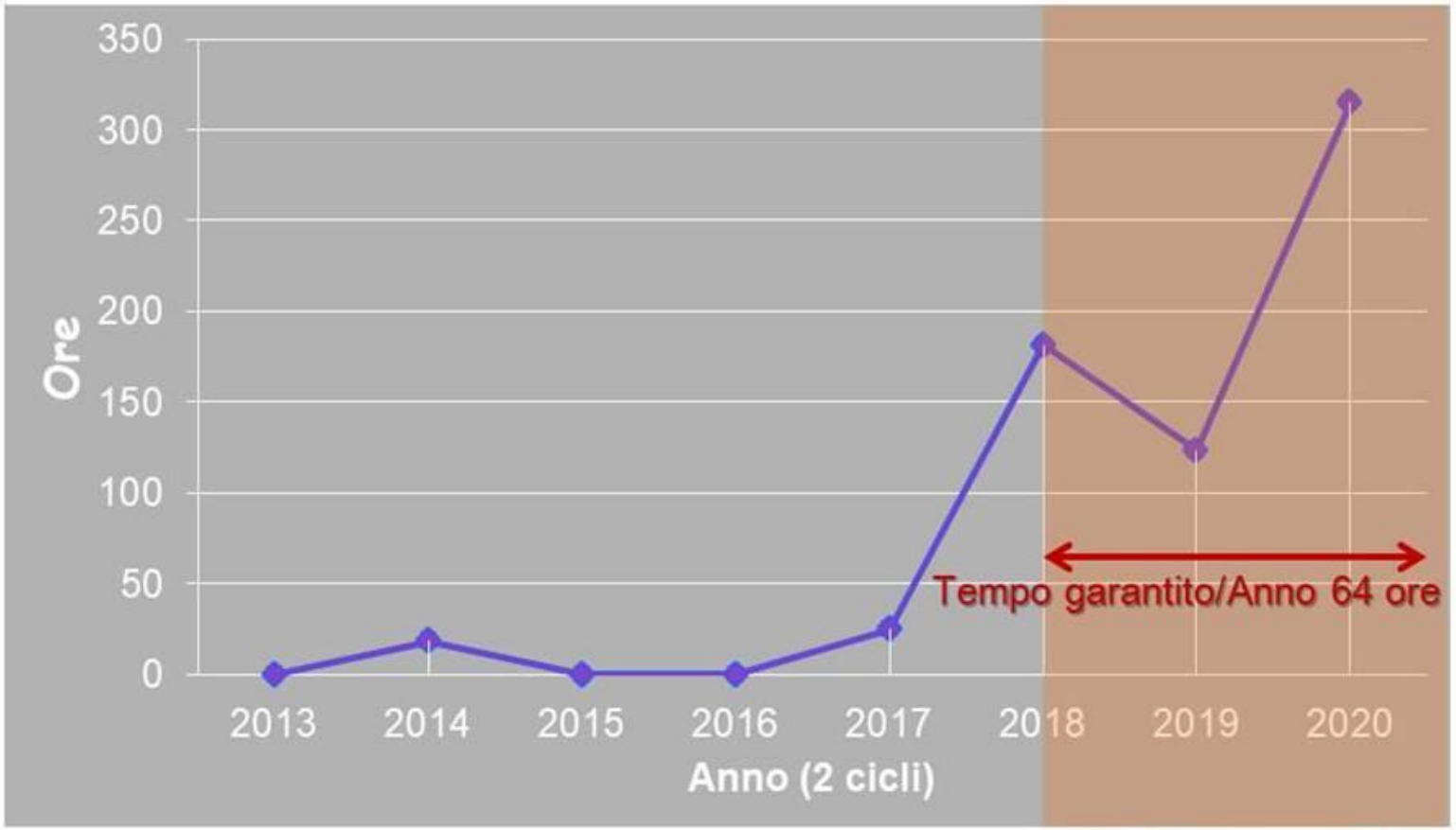
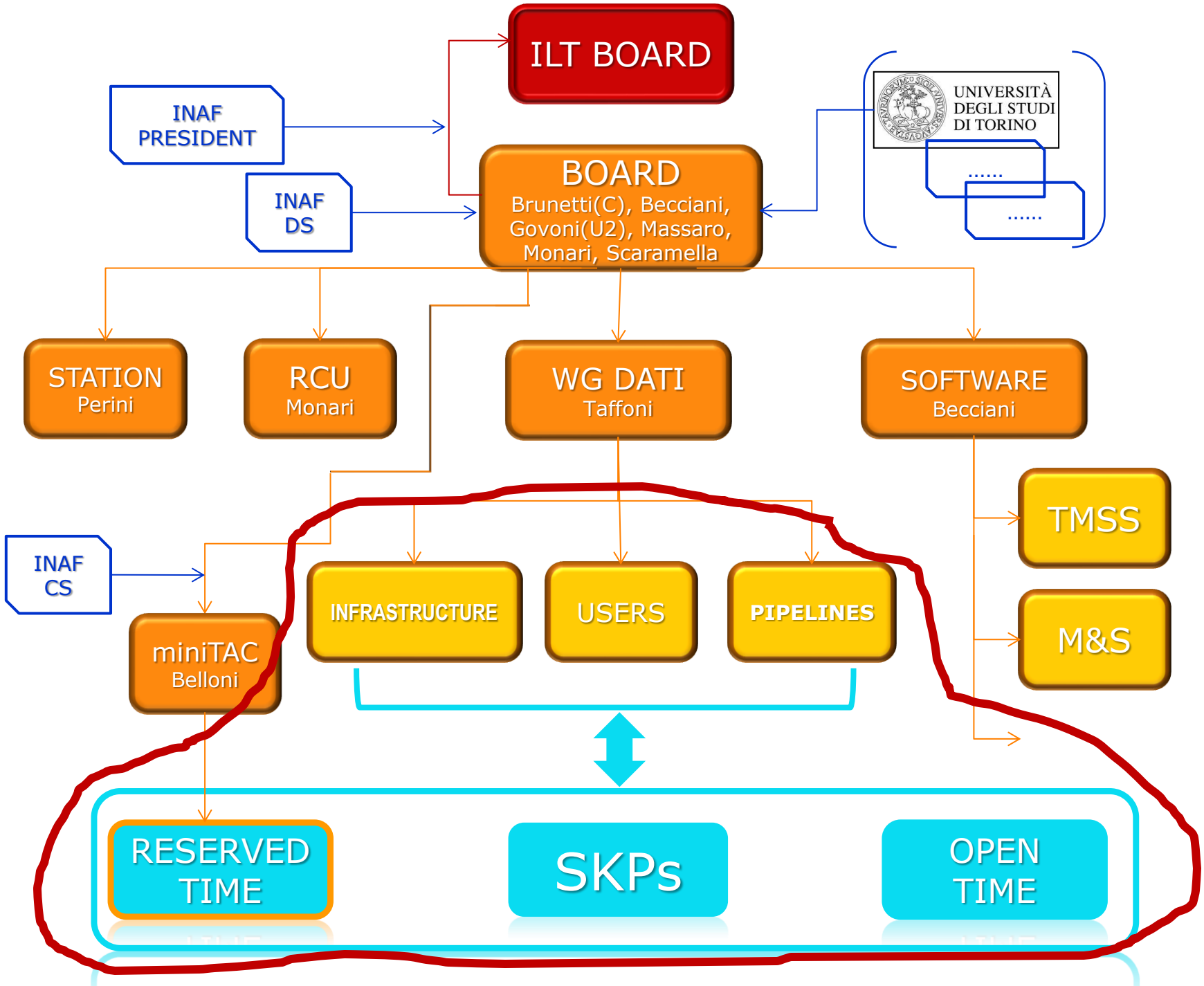


FIGURE 4: observing hrs (GO call) obtained by INAF PIs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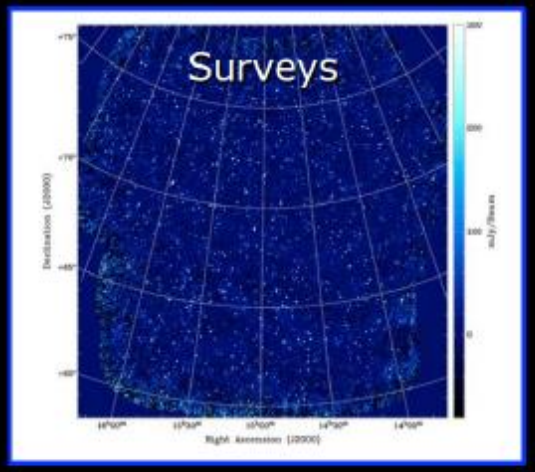
TMSS
M&S
RESERVED TIME
SKPs
OPEN TIME

LOFAR KEY SCIENCE PROJECTS

1



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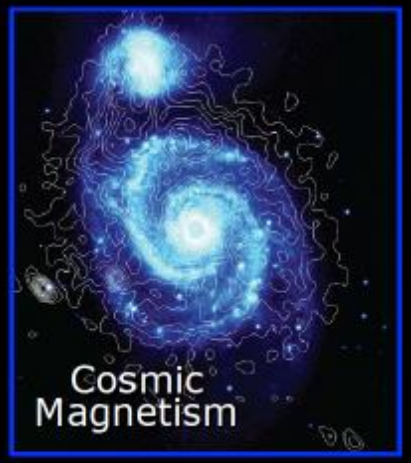

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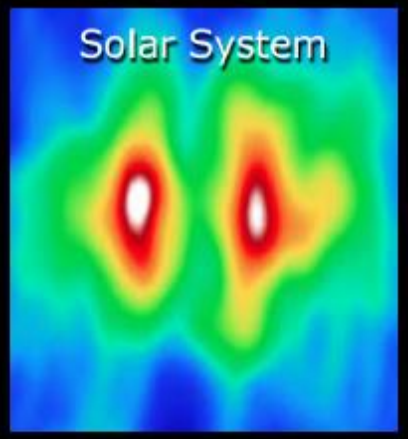

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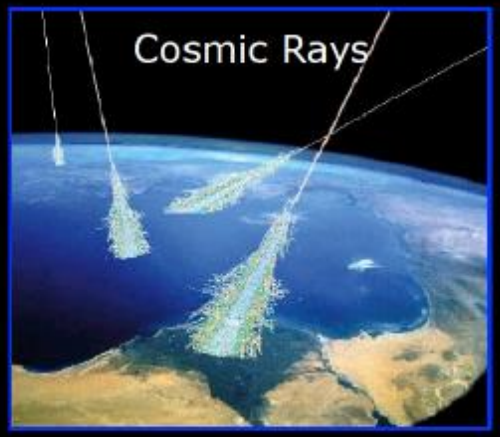

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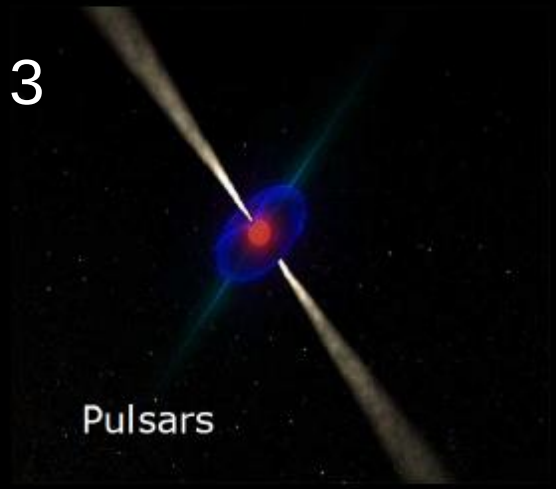
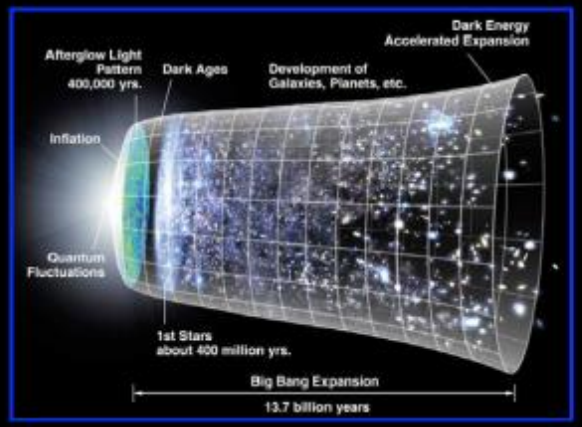




2

Epoch of Reionization

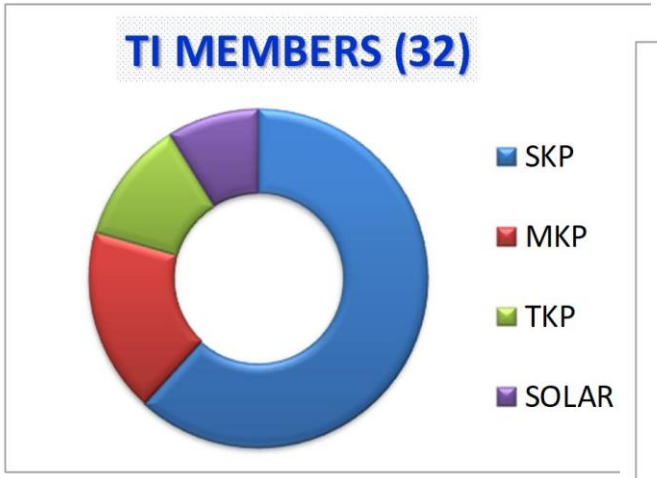
SCIENCE INVOLVEMENT

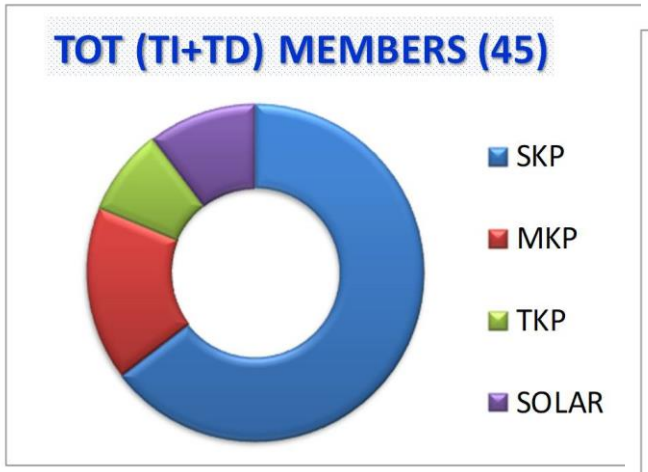
Involvement in Science KPs is based on balance of Member return-on-investment

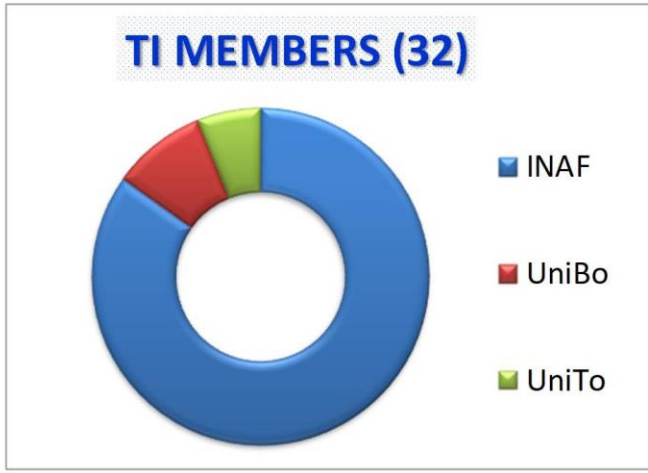
- IT investment is (only) about 1/50 of the ILT.
- IT science community is much bigger/active than other communities from Member countries with larger investment
- IT science community has potential to activate synergies with other large facilities

1. Call for Interest :
   - July 2018
   - Feb 2019

   LOFAR-It Board mediated between applicants and KPs management
2. Sporadic requests from researchers to the KPs management







LEADERSHIP & IMPACT ON IT SCIENCE

SurveyKP :

- 2 members in the KP Board
- Leading **2/12 SWG** (galaxy clusters, LBA)
- PI of LoLSS (1/2 Tier 1 surveys)
- Leading EDFN (1/4 deep fields)
- *Over-represented (21 TI members)*

MagnetismKP :

- 2 members in the KP Board
- Leading **1/6 SWG** (cosmic filaments)
- PI of 1/2 (GOODS-N) deep field (..in coll with SKP)

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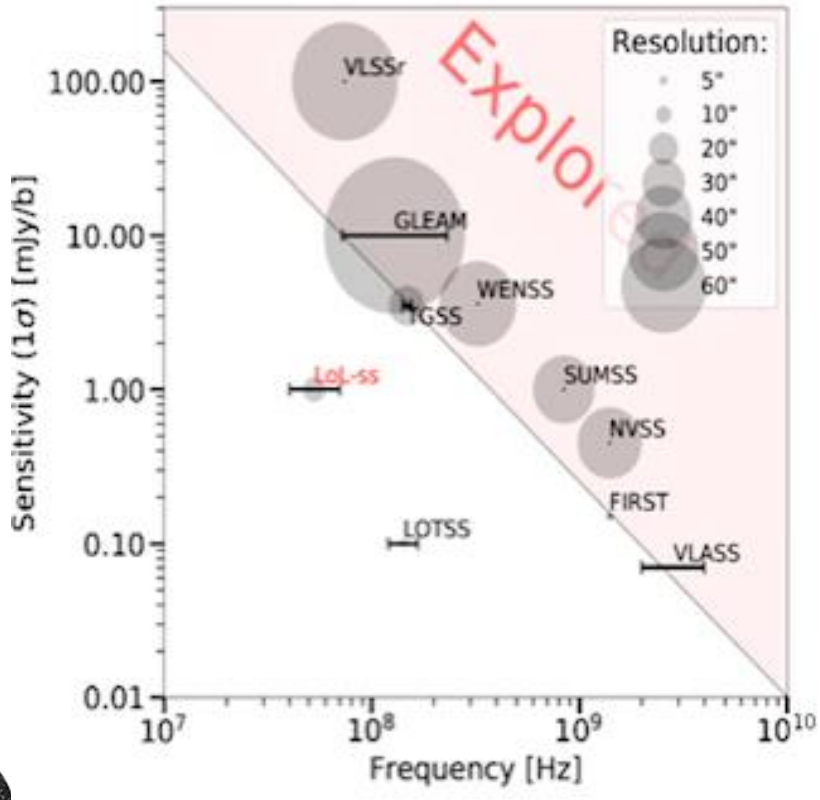
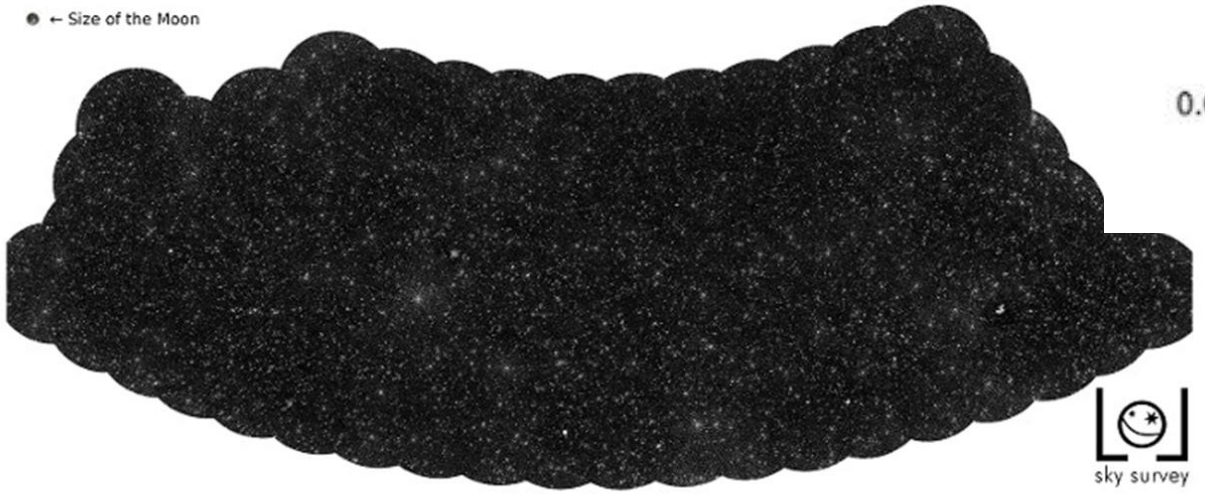


de Gasperin+ 2021



LOFAR 2.0 precursor !

Additional 1400 observing hrs have been awarded in 2021-22

LEADERSHIP & IMPACT ON IT SCIENCE

SurveyKP :

- 2 members in the KP Board
- Leading **2/12 SWG** (galaxy clusters, LBA)
- PI of LoLSS (1/2 Tier 1 surveys)
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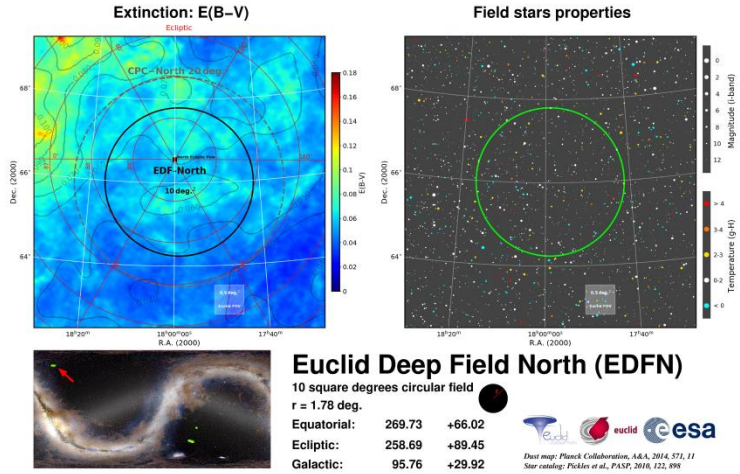

LOFAR

75 hrs HBA,
led R.Scaramella

LEADERSHIP & IMPACT ON IT SCIENCE

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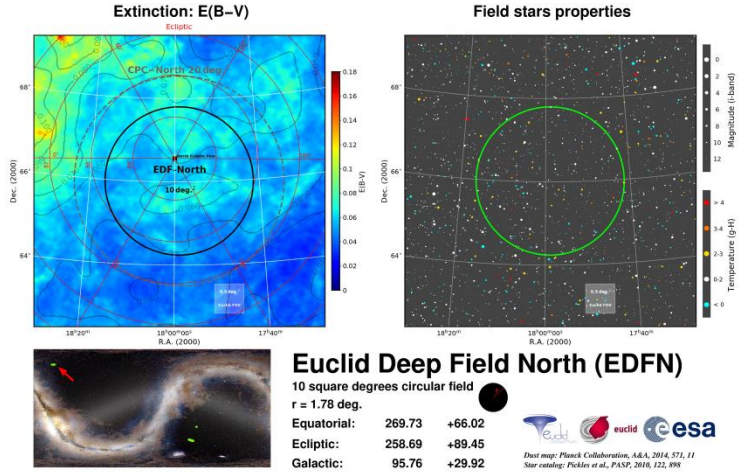

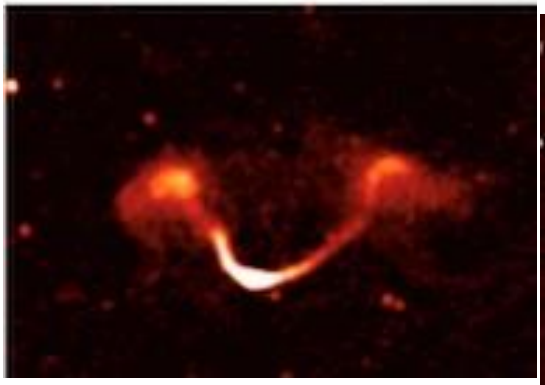

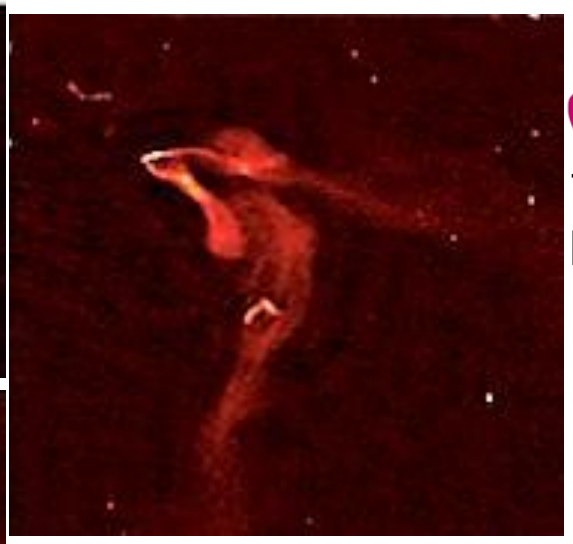

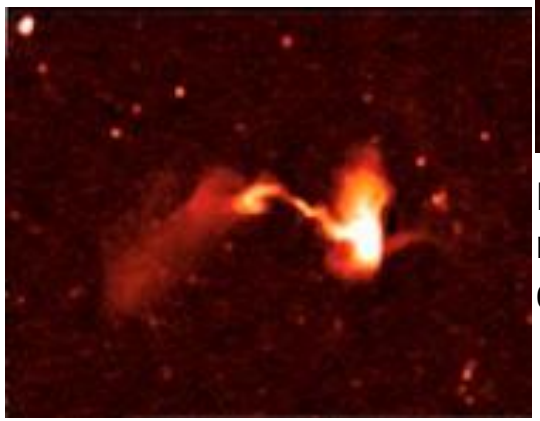

Bondi et al.
rms=30-40 µJy/b @144 MHz
data/products = 60 TB

LOFAR

75 hrs HBA,
led R.Scaramella

LEADERSHIP & IMPACT ON IT SCIENCE

SurveyKP :

- 2 members in the KP Board
- Leading **2/12 SWG** (galaxy clusters, LBA)
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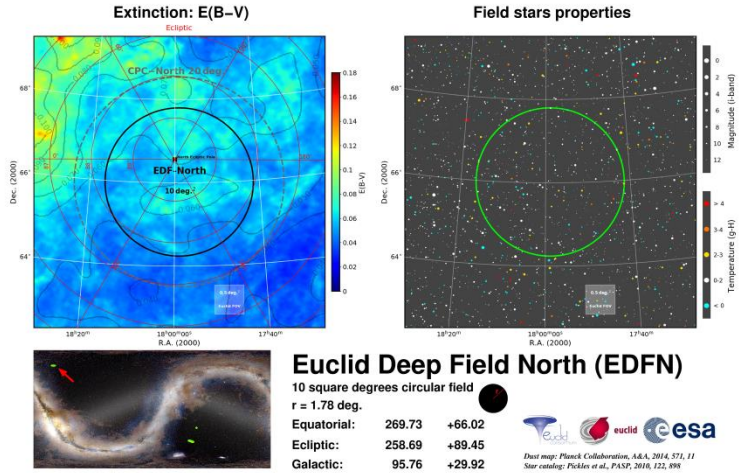
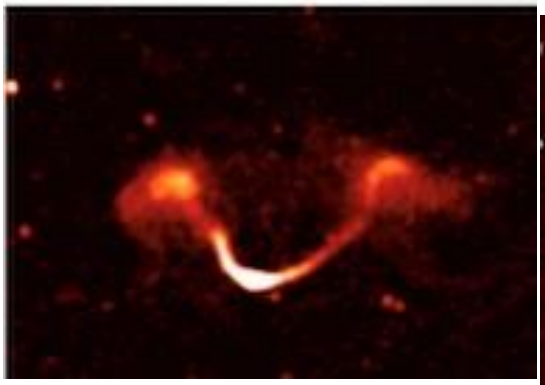
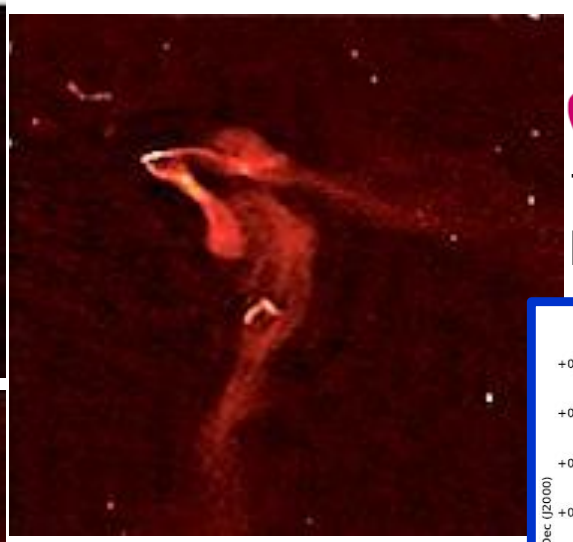
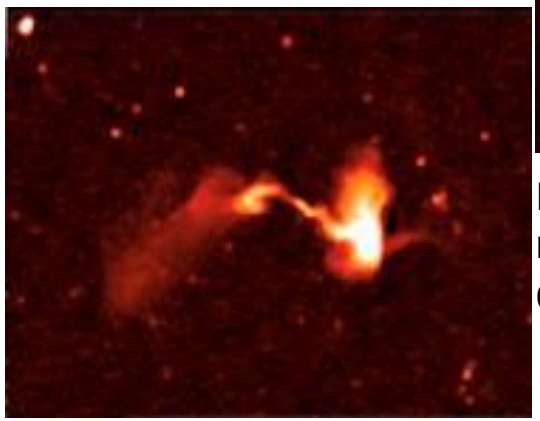




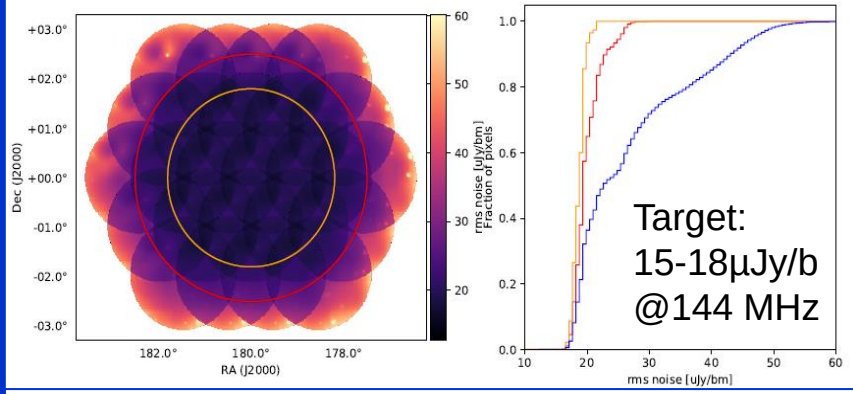




Bondi et al.
rms=30-40 µJy/b @144 MHz
data/products = 60 TB

LOFAR

75 hrs HBA,
led R.Scaramella



Additional 250 hrs awarded in 2022+

LEADERSHIP & IMPACT ON IT SCIENCE

SurveyKP :

- 2 members in the KP Board
- Leading **2/12 SWG** (galaxy clusters, LBA)
- PI of LoLSS (1/2 Tier 1 surveys)
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MagnetismKP :

- 2 members in the KP Board
- Leading **1/6 SWG** (cosmic filaments)
- PI of 1/2 (GOODS-N) deep field

LEADERSHIP & IMPACT ON IT SCIENCE

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- *Over-represented (21 TI members)*

MagnetismKP :

- 2 members in the KP Board
- Leading **1/6 SWG** (cosmic filaments)
- PI of 1/2 (GOODS-N) deep field (V.Vacca)
  250+ hrs in coll with SKP

(100+ TB data/products expected)

SYNERGIES WITH OTHER IT PROGRAMS

SurveyKP :

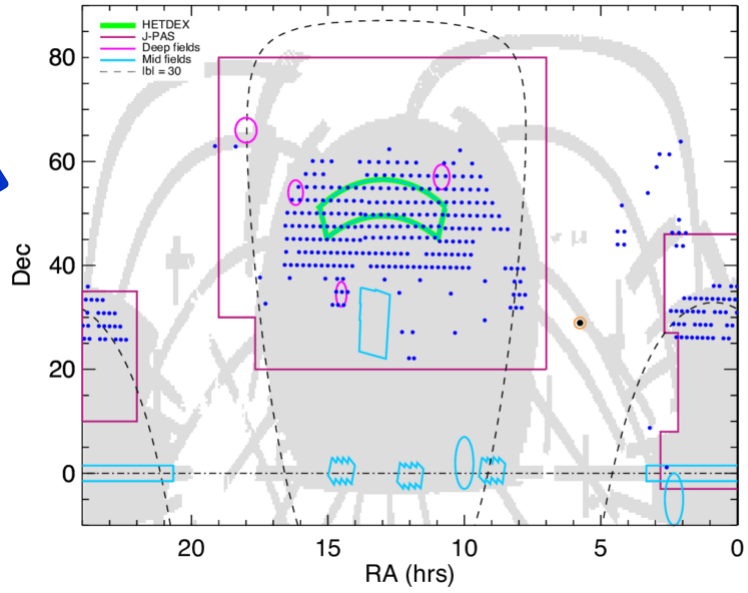
- 2 members in the KP Board
- Leading **2/12 SWG** (galaxy clusters, LBA)
- PI of LoLSS (1/2 Tier 1 surveys)
- Leading EDFN (1/4 deep fields)
- *Over-represented (21 TI members)*

PI D.Smith, UK

MagnetismKP :

- 2 members in the KP Board
- Leading **1/6 SWG** (cosmic filaments)
- PI of GOODS-N deep field
  (..in coll with SKP)

WEAVE-LOFAR 10 IT members
(WEAVE-ExtraGal, Iovino)



SYNERGIES WITH OTHER IT PROGRAMS

SurveyKP :

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- Leading **2/12 SWG** (galaxy clusters, LBA)
- PI of LoLSS (1/2 Tier 1 surveys)
- Leading EDFN (1/4 deep fields)
- *Over-represented (21 TI members)*

MagnetismKP :

- 2 members in the KP Board
- Leading **1 SWG** (cosmic filaments)
- PI of GOODS-N deep field
  (..in coll with SKP)

WEAVE-LOFAR 10 IT members
(WEAVE-ExtraGal, Iovino)

eROSITA MoU
(eROSITA, Brusa)

GASP MoU LOFAR-OAPd
(GASP, Poggianti)

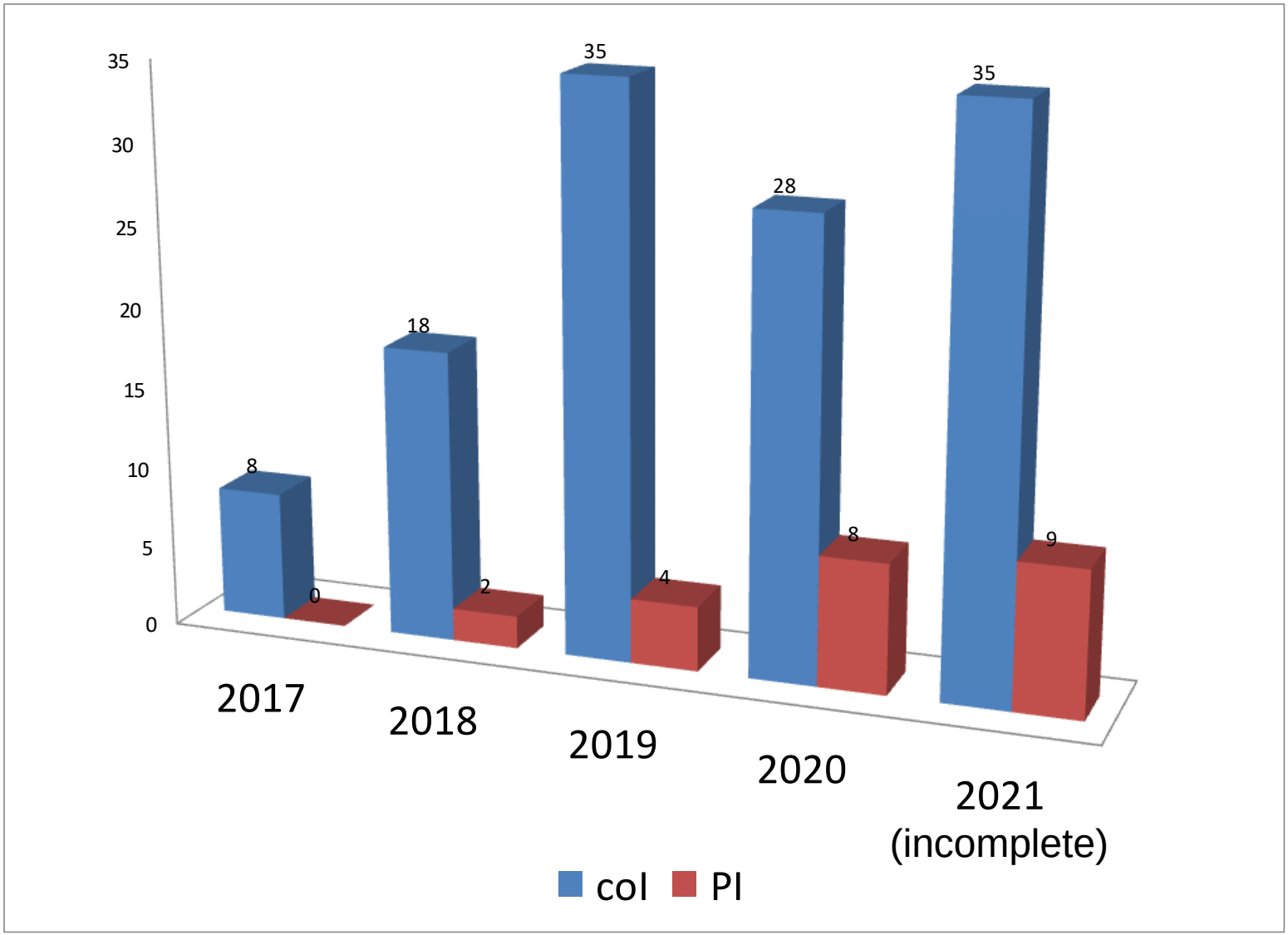
…

…


IL FOLLOW-UP IN BANDA RADIO È STATO CONDOTTO CO…

Scoperto da eRosita il colosso dell'Idra

Il telescopio spaziale per le alte energie tedesco si conferma la macchina perfetta per individuare le strutture più grandi dell'universo: i superammassi di galassie. Come quello da quasi due milioni di miliardi di masse solari appena identificato da un team guidato da Vittorio Ghirardini del Max-Planck. I risultati su Astronomy & Astrophysics



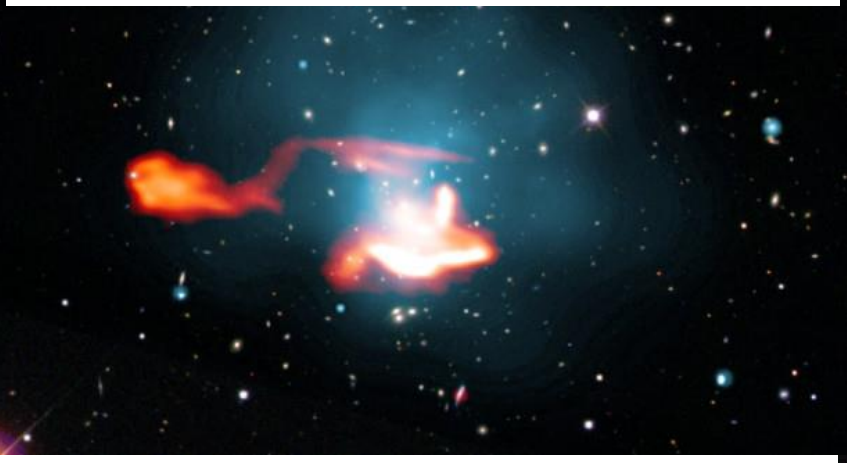
LOFAR-It refereed papers published with SKPs (35-40 papers/yr 2021+)

SCIENCE ADVANCES | RESEARCH ARTICLE

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. Röttgering[1]

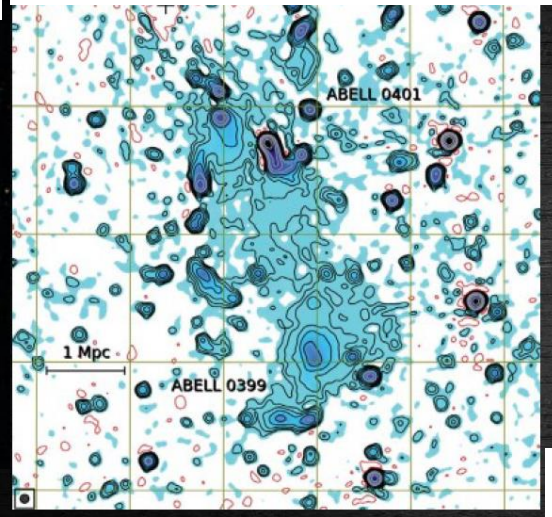


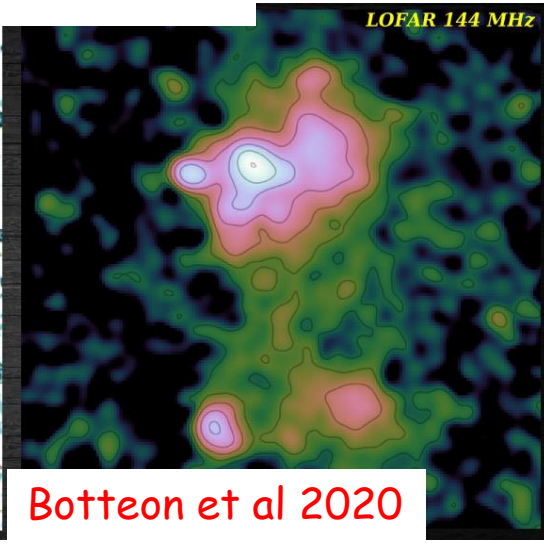
RESEARCH

RADIO ASTRONOMY

Govoni et al 2019

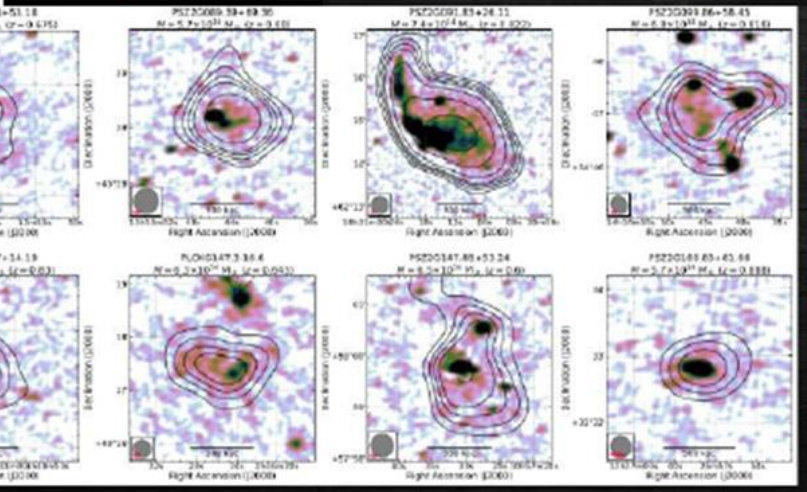
A radio ridge connecting two galaxy clusters in a filament of the cosmic web





Botteon et al 2020

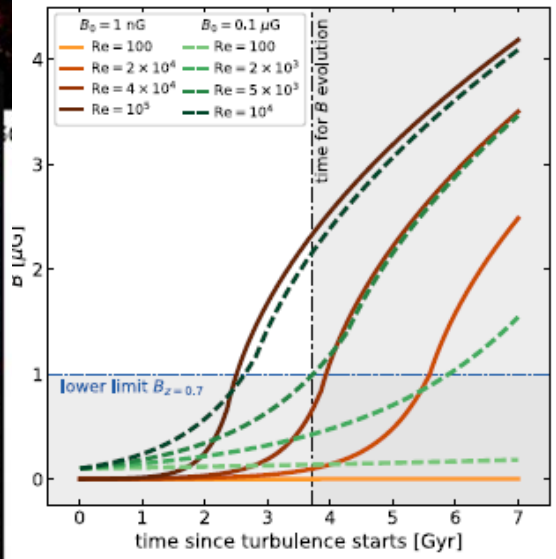
High-z radio halos (z>0.6)



Di Gennaro, van Weeren, GB ,+ 2020

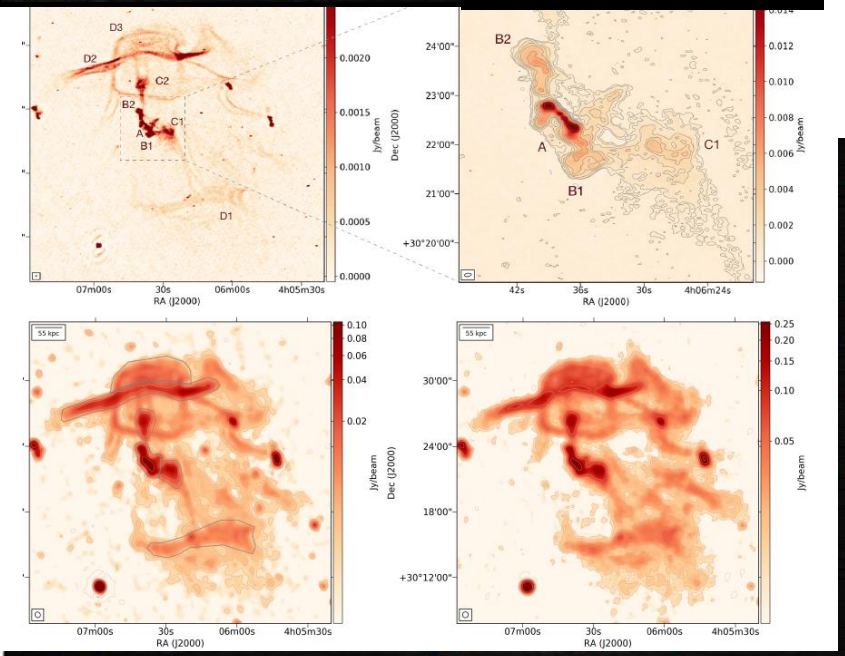
Fast magnetic field amplification in *distant* galaxy clusters

nature astronomy



nature astronomy

Oldest AGN feedback phases (Brienza+)



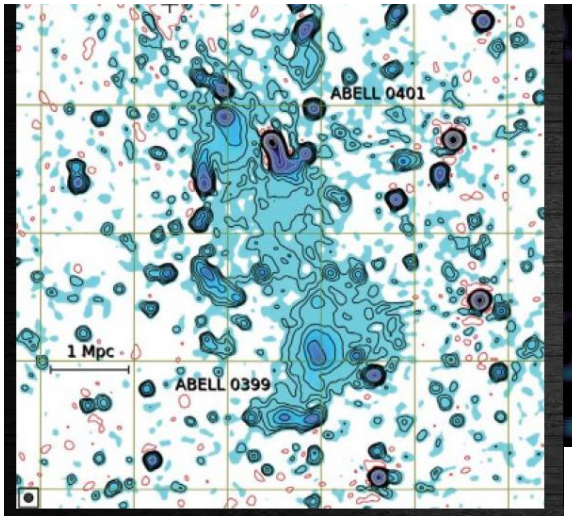
RESEARCH

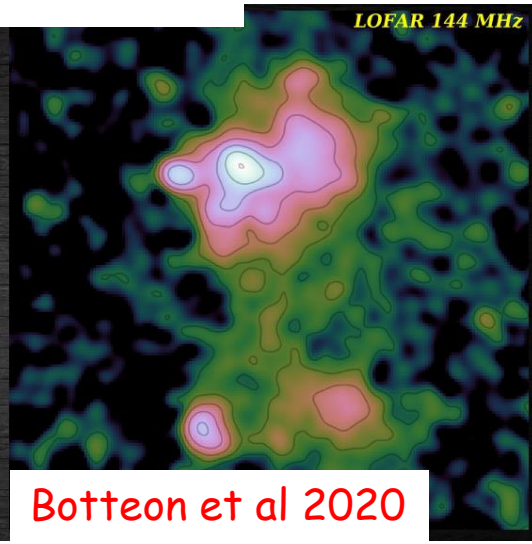
RADIO ASTRONOMY

Govoni et al 2019

Science AAAS

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





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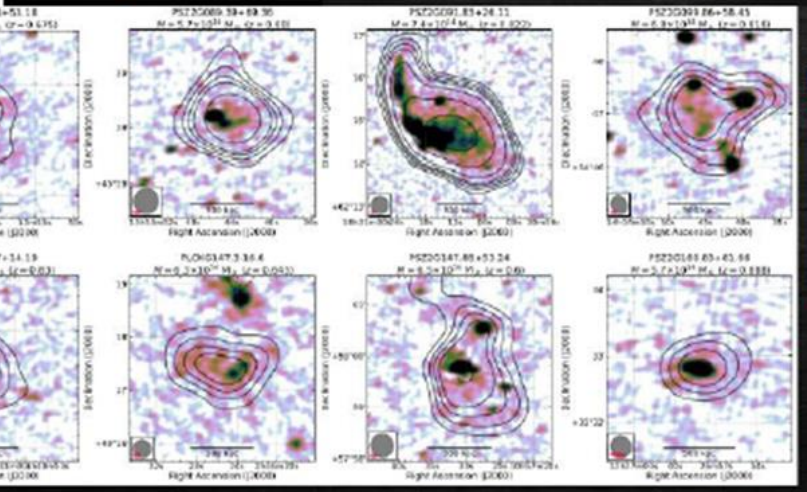

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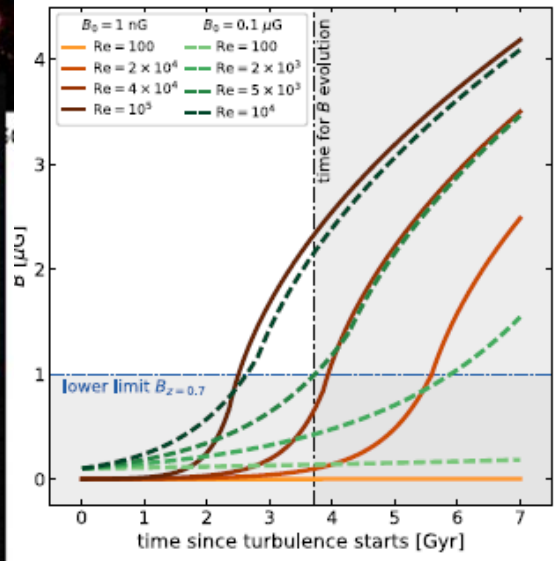

CRITICAL ASPECTS 1.

Even in the SKA era, LOFAR will remain a unique instrument at low frequencies, mainly thanks to the long baselines (1000 km) which allow obtaining angular resolutions 20 times better than SKA_low.
Furthermore, LOFAR will remain the only large interferometer sensitive to very low frequencies (20-60 MHz) and for this reason the LOFAR 2 upgrade (2021-2024) will improve the instrumental performances especially in the LBA band.
In this context, it is essential to further improve strategic competencies in INAF to allow for the optimization of the scientific return of the investment.

1. Personnel.

INAF is currently funding infrastructure, fee and technical personnel for in-kind contribution (construction cost). Post doc program to contribute optimizing the scientific return (using D.M. 450) is planned but has been delayed (1+ yrs) due to admin reasons…

2. Synergies.

Important to capitalize on the investment by creating synergies with other large INAF programs (e.g. use INAF access to LOFAR data to strengthen participation in other programs.. and *viceversa*)

CRITICAL ASPECTS 2.

1. COMPUTING POWER & LOFAR-VLBI.

LOFAR-It manages an infrastructure for data analysis which is currently used at about 70%. However, from 2021 we expect a very strong increase in computational needs (deep fields, LoLSS, and especially LOFAR VLBI) which will require the addition of 1000+ cores platforms. The LOFAR-It Board requested DS to use a Galileo rack, in this case the critical issue derives from the time-scale of delivery and operation of the system.

Investment in computing/archive provides a way to increase INAF weight in LOFAR, use LOFAR (MeerKAT?) computing as seeds for SKA RC is also desirable (current approach in NL !)

2. LOFAR 2.0 : 2024+

LOFAR 2.0 upgrade is intended to maximally leverage the existing infrastructure through a major renovation of the station electronics and correlator, improving the observational sensitivity especially at the very low frequencies, in the LBA band (INAF is PI of LoLSS!). Large Programs for LOFAR 2.0 will be discussed at the beginning of 2022. Internal discussion, critical mass and priorities need to be established in IT to guarantee a desirable matching of our ambitions.

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.

TABELLA 2: PREVISIONE DI COSTI PER I PRIMI 5 ANNI

	2018	2019	2020	2021	2022	TOT
INFRASTR1	230					230
1FTE	45	60	60	60	60	285
RUNNING	15	20	20	20	20	95
RISORSA2	110	110				220
COFIN T2	-55	-55				-110
0.25FTExT2	20	45	45	45	45	200
SUPPORTO		60	60	60*	60*	240*
TECNO	20	90	40	10		160
FTE	30	90	90	30		240
STAZIONE				1650		1650
TERRENO				60		60
RUNNING					40	40
FTE				30	15	45
RUNNING	65	92	92	92*	92*	433*
TRAINING	25	35				60
POST DOC	(50)	(100)	(100)	(50)		(300)
TOT INV	610	702	507	2107	332	4258
INAF INV	320	622	427	2027	252	3648
INAF COST	270	487	292	1922 -60*	192 -60*	3163 -120*
INAF MIN	**165(215)**	**332(432)**	**192(292)**	**1872(1922) -60***	**192 -60***	**2753(3053) -120* 2633/2933**

Stima fondi acquisiti da INAF fino al 2020 (k€): 653

470 kEuro INAF
183 kEuro external

Tabella fondi:

#	Provenienza	Certi 2021 (k€)	Certi 22 (k€)	Certi 23 (k€)	Presun. 2021 (k€)	Presun. 22 (k€)	Presun. 23 (k€)	Totale Certi (k€)	Totale Presunti (k€)
1	COFIN EUROPEI	138	52	0	0	0	0	190	0
2	INAF	290	290	1495	0	144	252	2075	396