From LOFAR to LOFAR 2.0

Current and future radio surveys at the lowest frequencies

Francesco de Gasperin

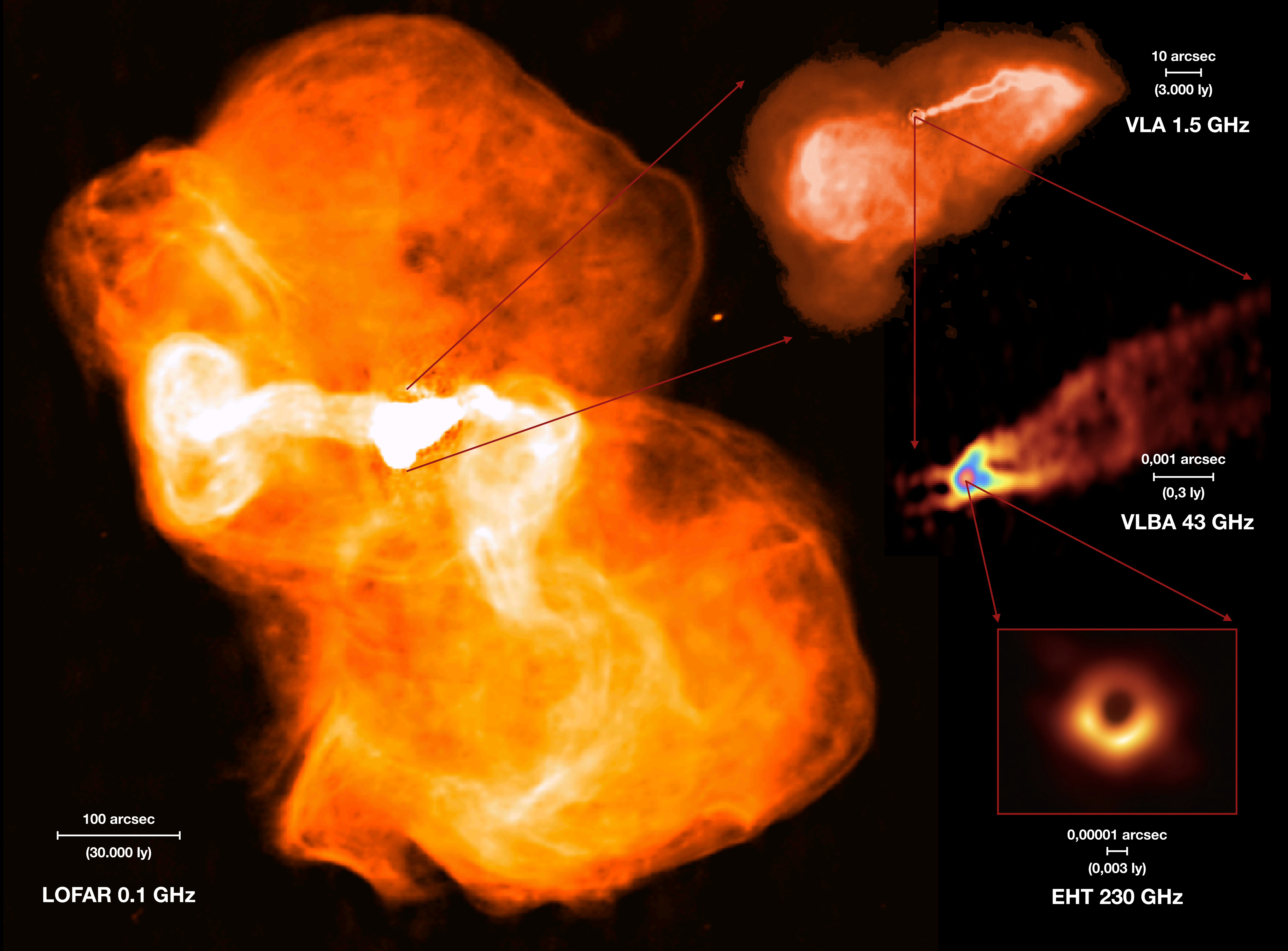
SKA meeting - Catania

28/11/2023

INAF
ISTITUTO NAZIONALE DI ASTROFISICA

erc

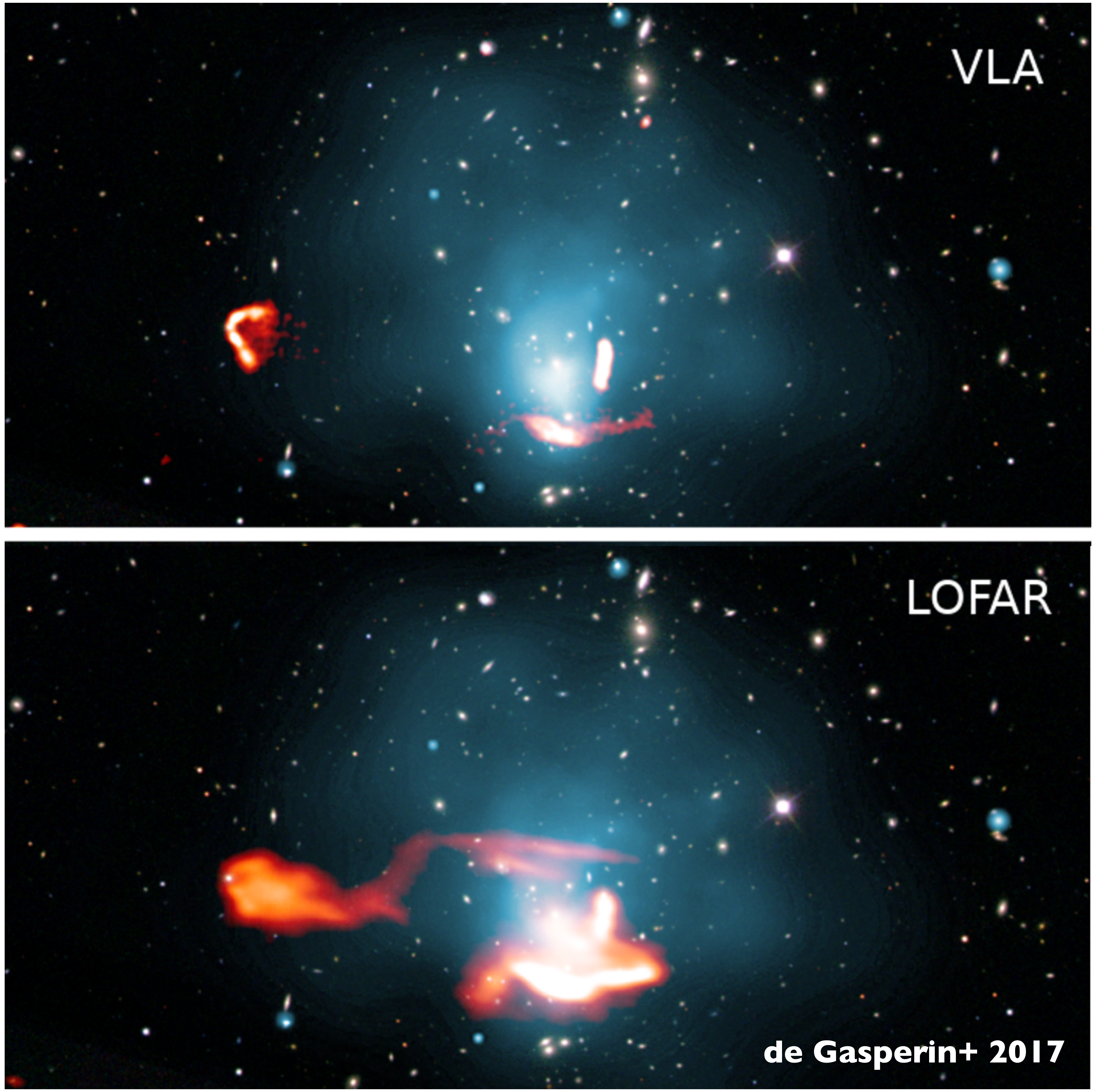
LOFAR HBA
Frequency: 120-240 MHz
Resolution: 5” (0.3”)
Sensitivity: ~100 uJy/b
FWHM: 4 deg
LOFAR LBA
Frequency: 10-90 MHz
Resolution: 15” (1”)
Sensitivity: ~1 mJy/b
FWHM: 6 deg
Multi-beam
HBA
LBA
Birr
Onsala
Irbene
Chilbolton
Dutch stations
Norderstedt
Bałdy
Potsdam
Jülich
Effelsberg
Borówiec
Łazy
Tautenburg
Nançay
Unterweilenbach
Medicina
Rozhen
Atmospheric Opacity
100%
50%
0%
LOFAR
HBA
LBA
IONOSPHERE CUTOFF
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength

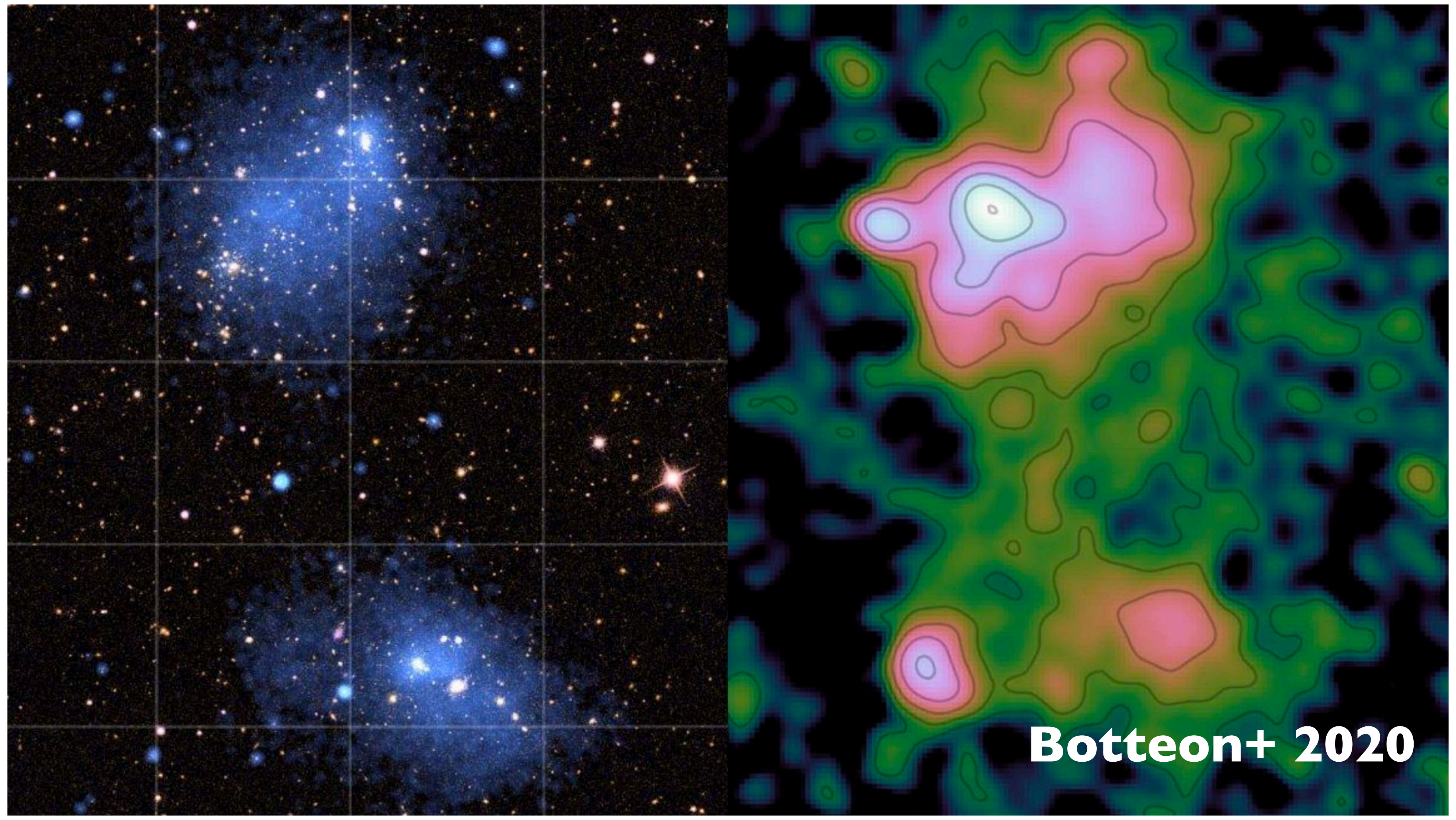


10 arcsec
(3.000 ly)
VLA 1.5 GHz
0,001 arcsec
(0,3 ly)
VLBA 43 GHz
100 arcsec
(30.000 ly)
LOFAR 0.1 GHz
0,00001 arcsec
(0,003 ly)
EHT 230 GHz

Low efficiency phenomena

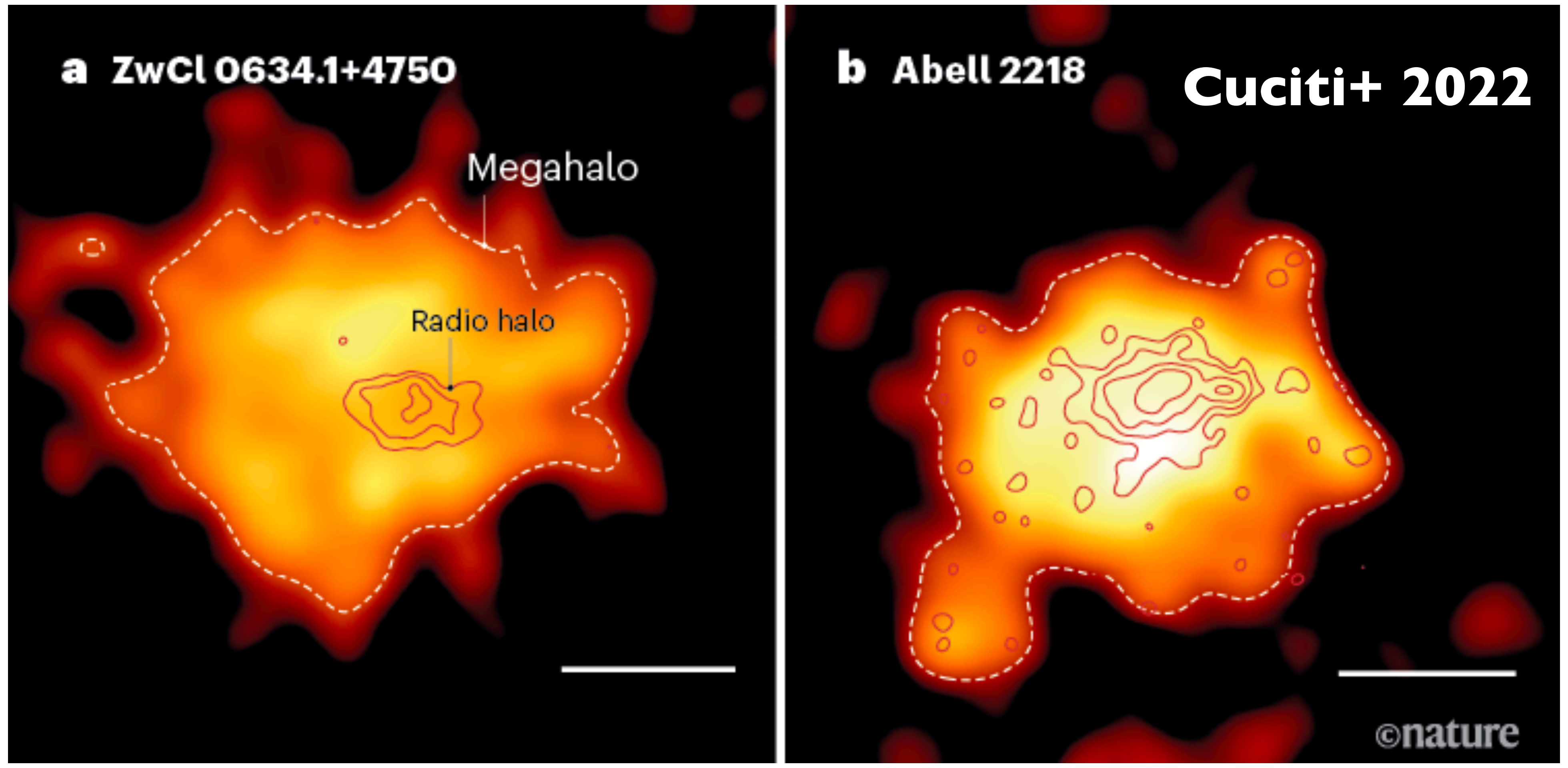
GReETs





Radio Bridges

Radio Megahalos

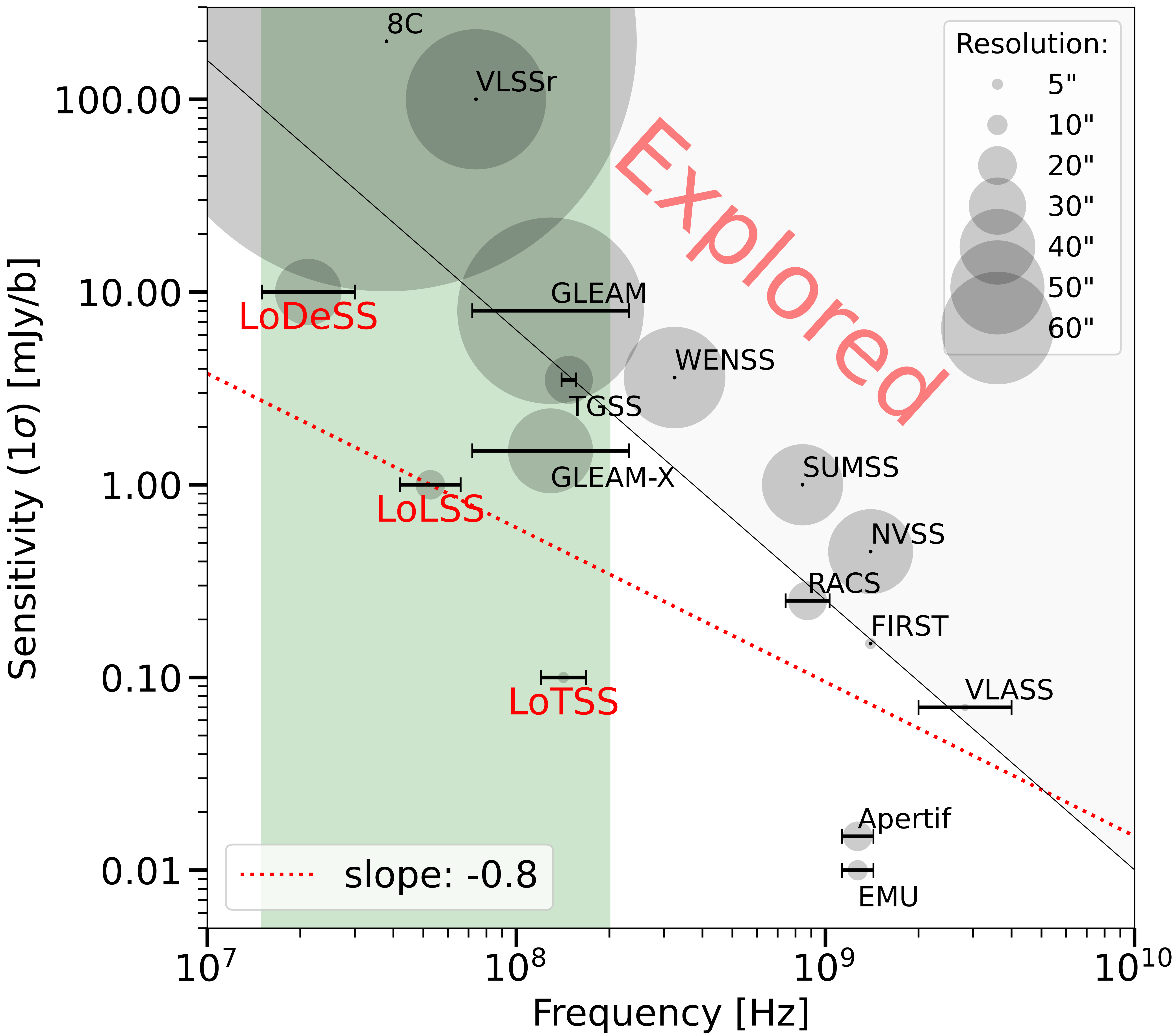


- **LOFAR Surveys**

- LOFAR upgrades
  ➡ LOFAR 2.0
  ➡ LOFAR Next Generation Surveys

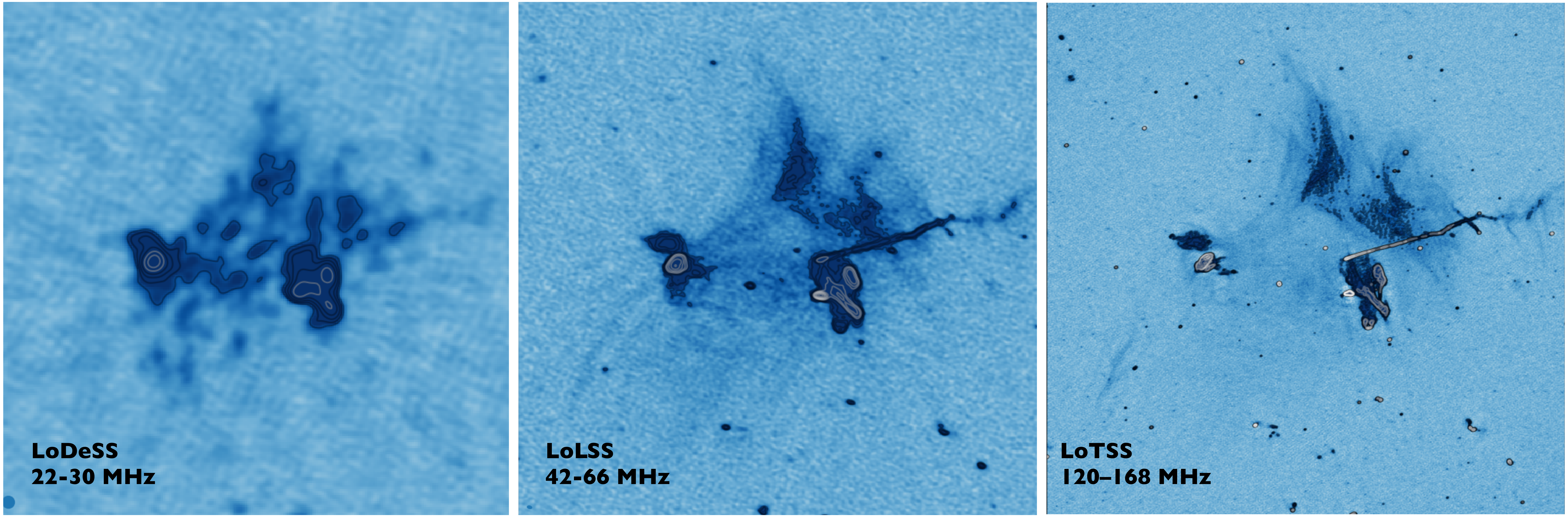
- LOFAR+MeeRKAT - ViCTORIA project

LOFAR Surveys



- **LOFAR Two Metre Sky Survey (LoTSS) 120 - 168 MHz**
- **LOFAR LBA Sky Survey (LoLSS) 42 - 66 MHz**
- **LOFAR Decametre Sky Survey (LoDeSS) 14 - 30 MHz**

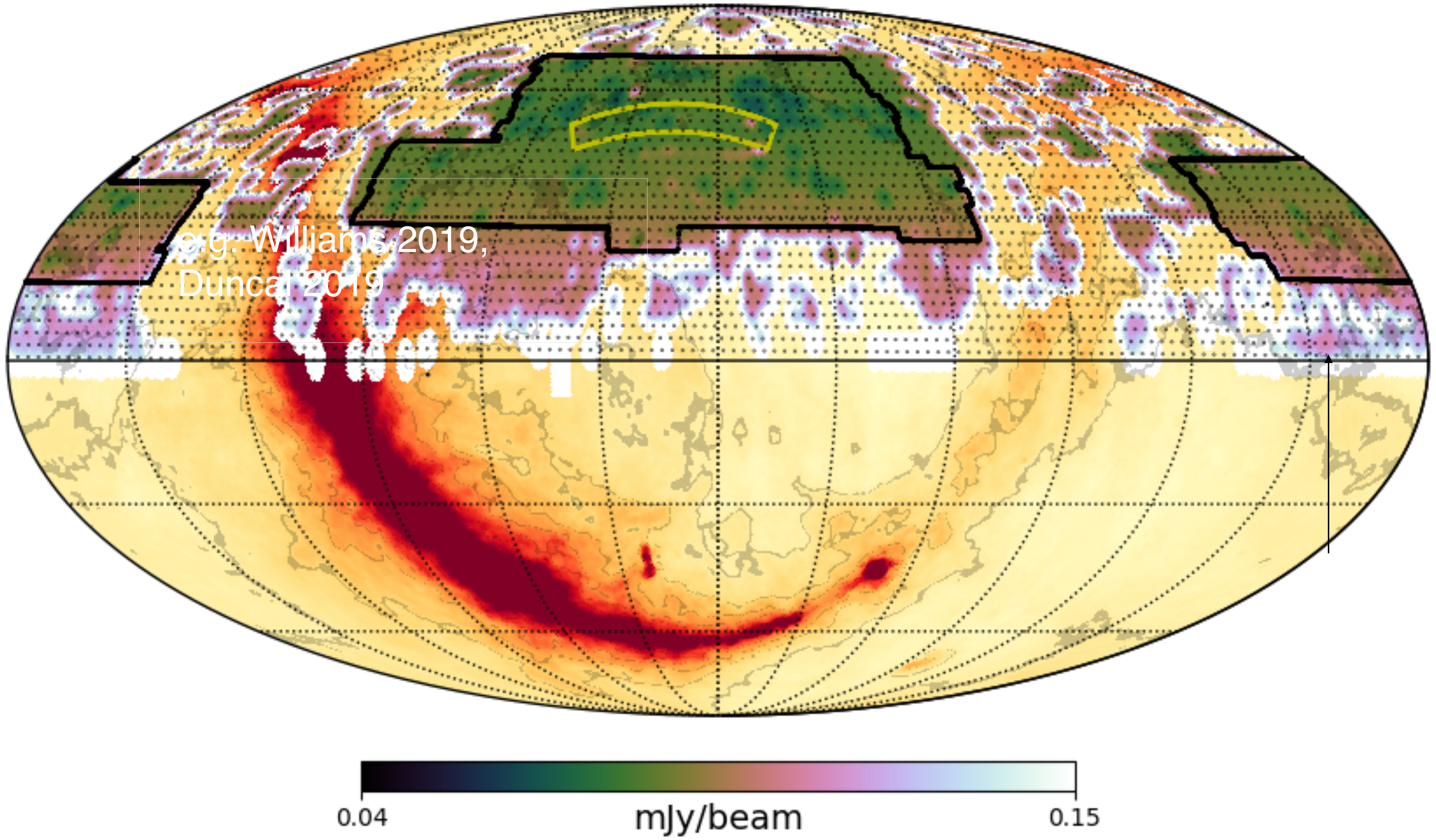
LOFAR Surveys

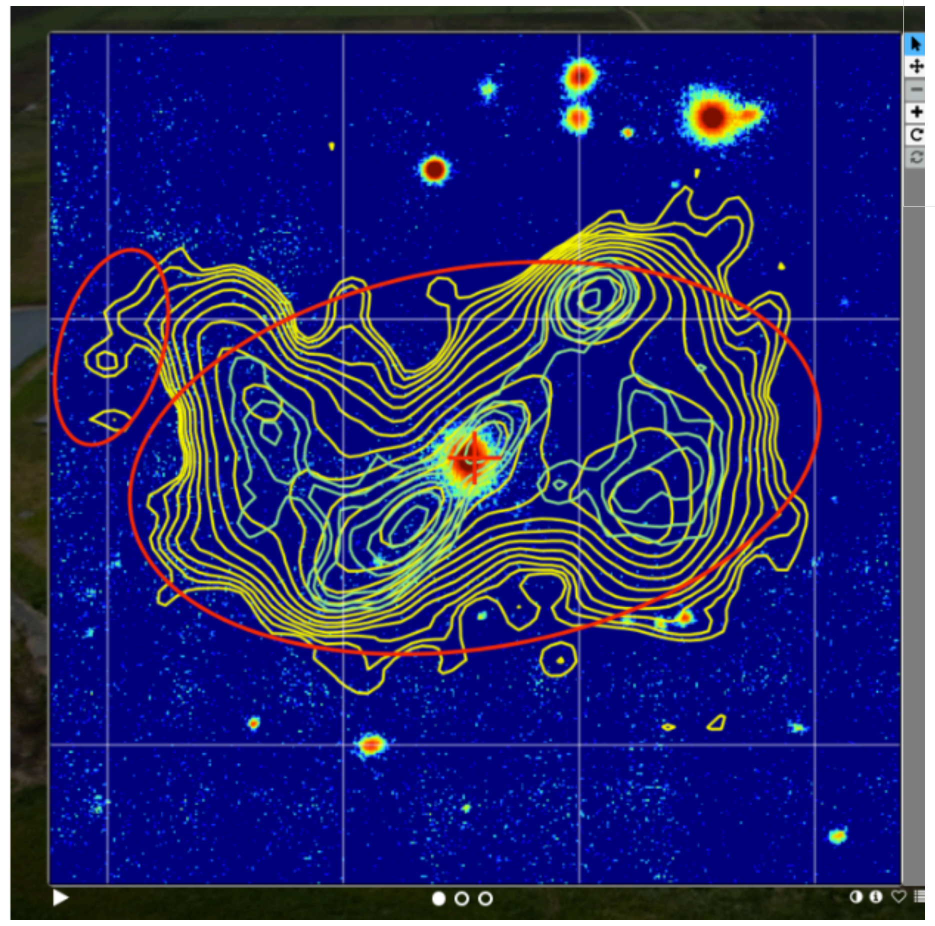


Abell 2256
Osinga+

LOFAR Two Metre Sky Survey

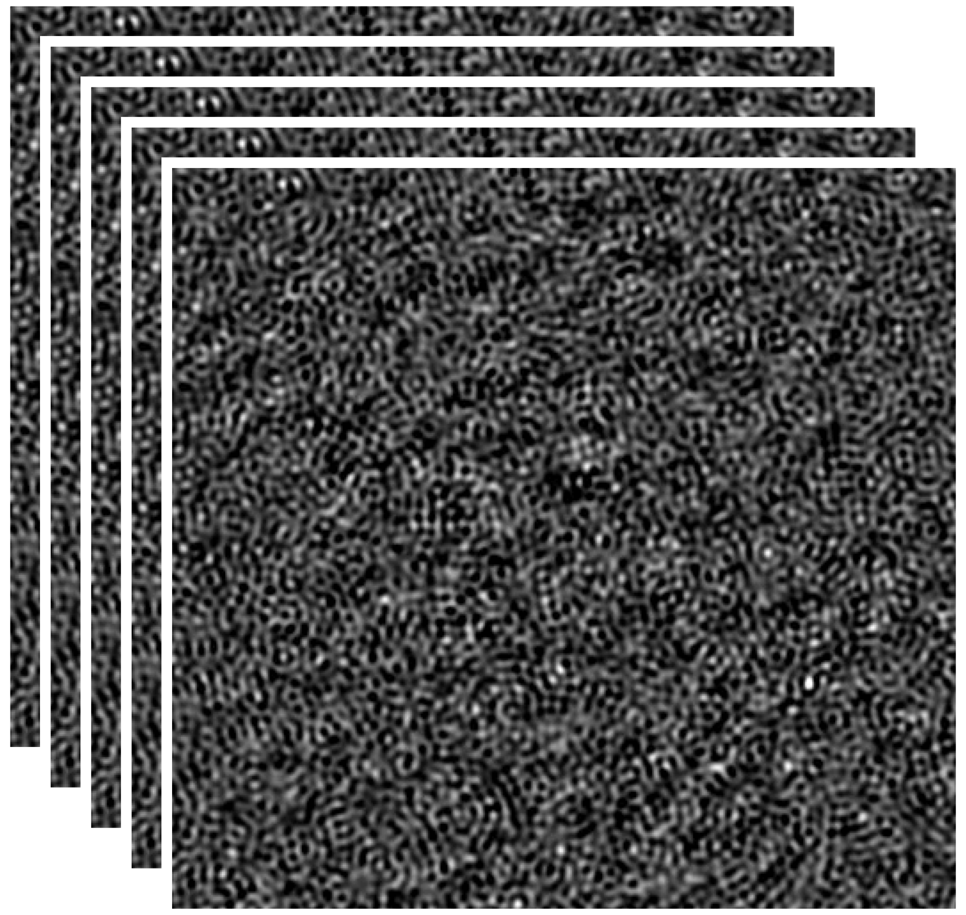
Shimwell+ 2019, 2022



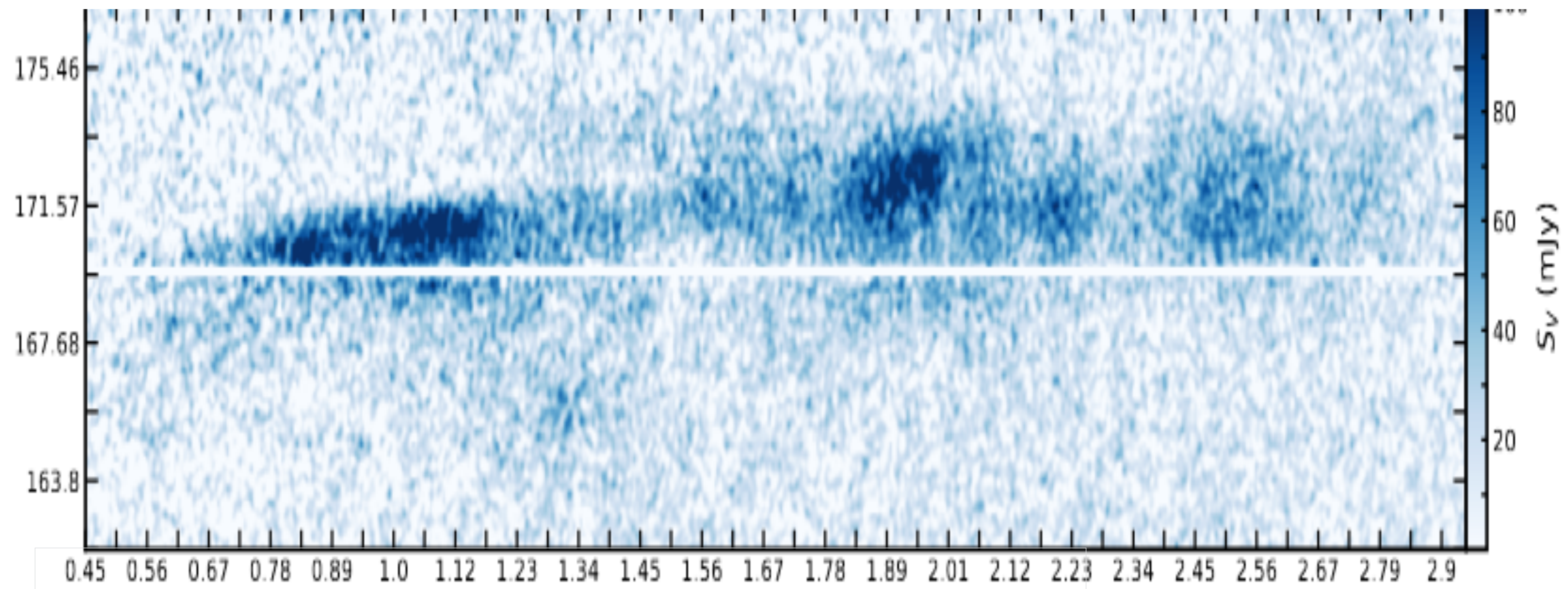


Cross matching
http://lofargalaxyzoo.nl/

Polarisation cubes



Dynamic spectra



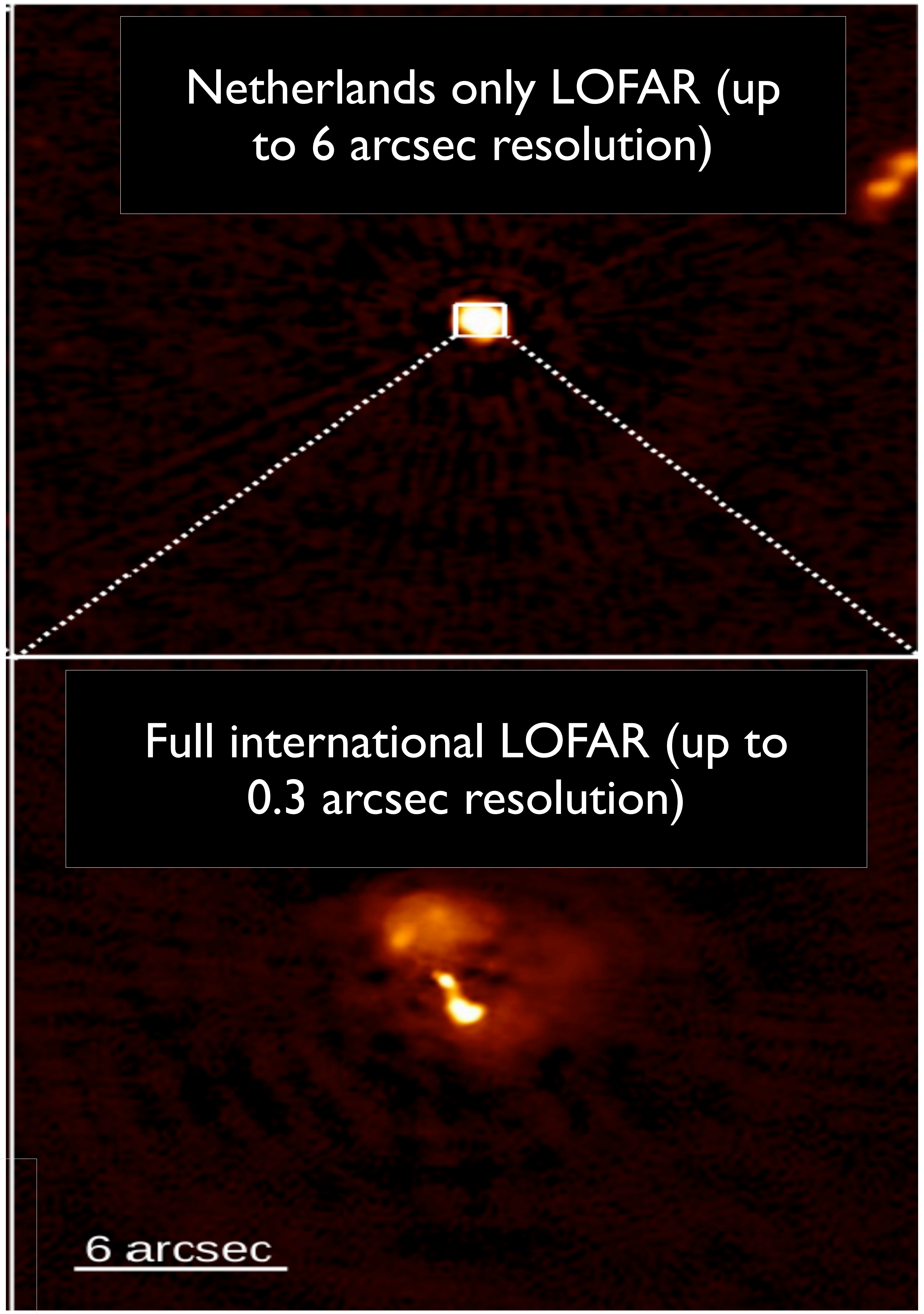
Example from Callingham+ 2021

LoTSS-DR1 (outlined in yellow) and LoTSS-DR2 (outlined in black) are fully public
It consists of 7.6 PB of data processed using ~9 million cpu hours
LoTSS-DR2 is **26%** of the Northern sky at sensitivity of **80 uJy/b** and resolution of **6”**
The source catalogue contains 4,395,448 radio components

www.LOFAR-surveys.org

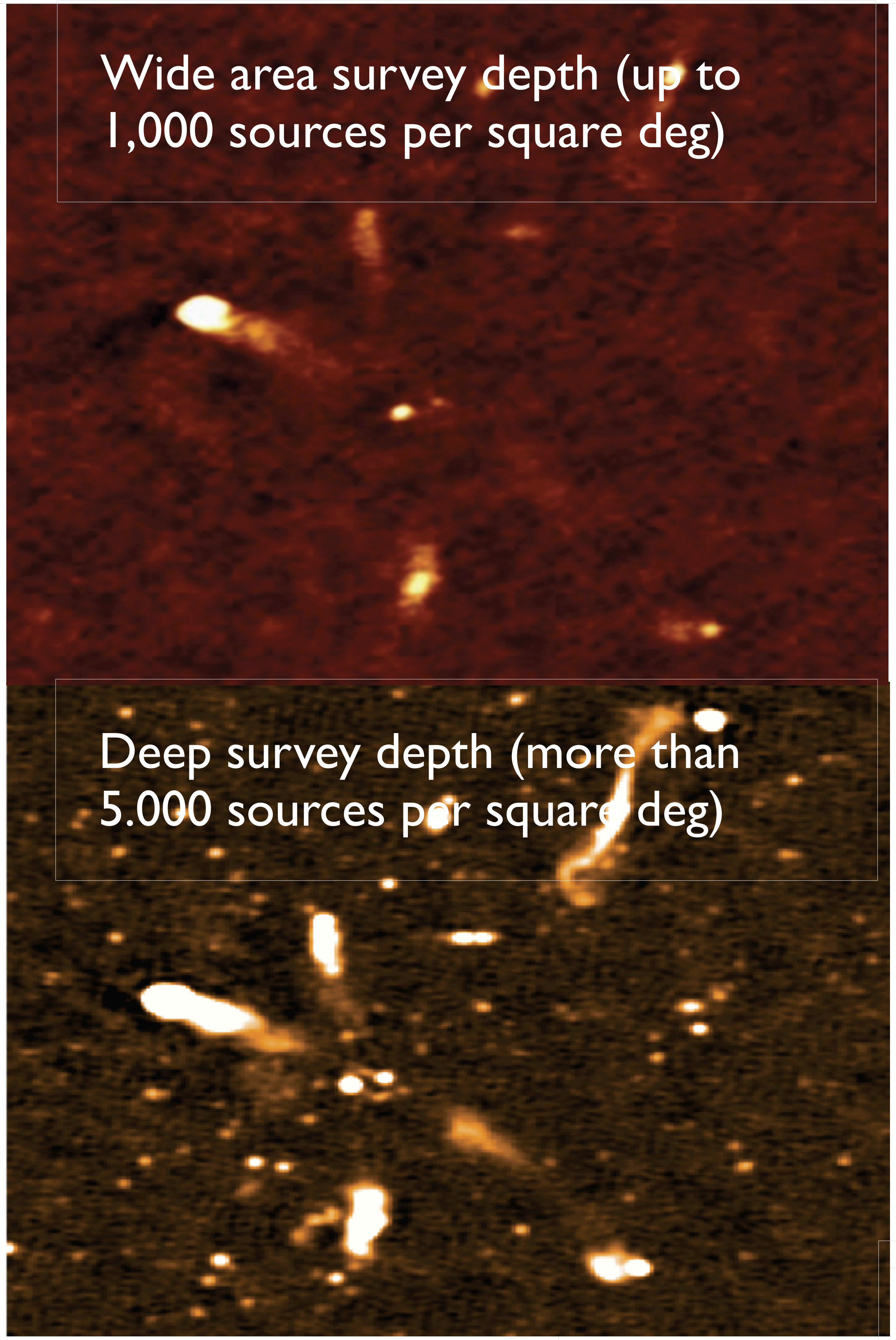
LOFAR Two Metre Sky Survey

Images at up to 0.3 arcsec resolution



Morabito, et al. 2021
Sweijen et al. 2022

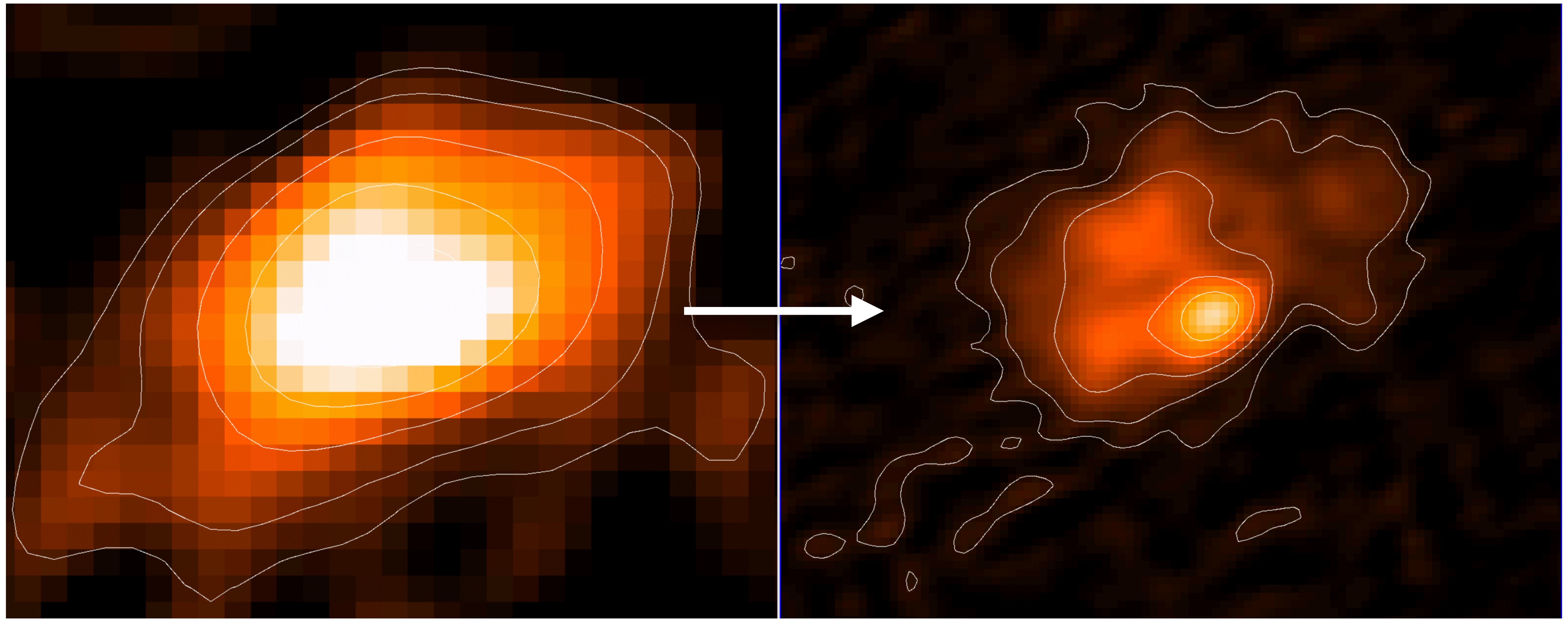
Images as sensitivity as ~12 uJy/b



Sabater et al. 2021

LOFAR LBA Sky Survey

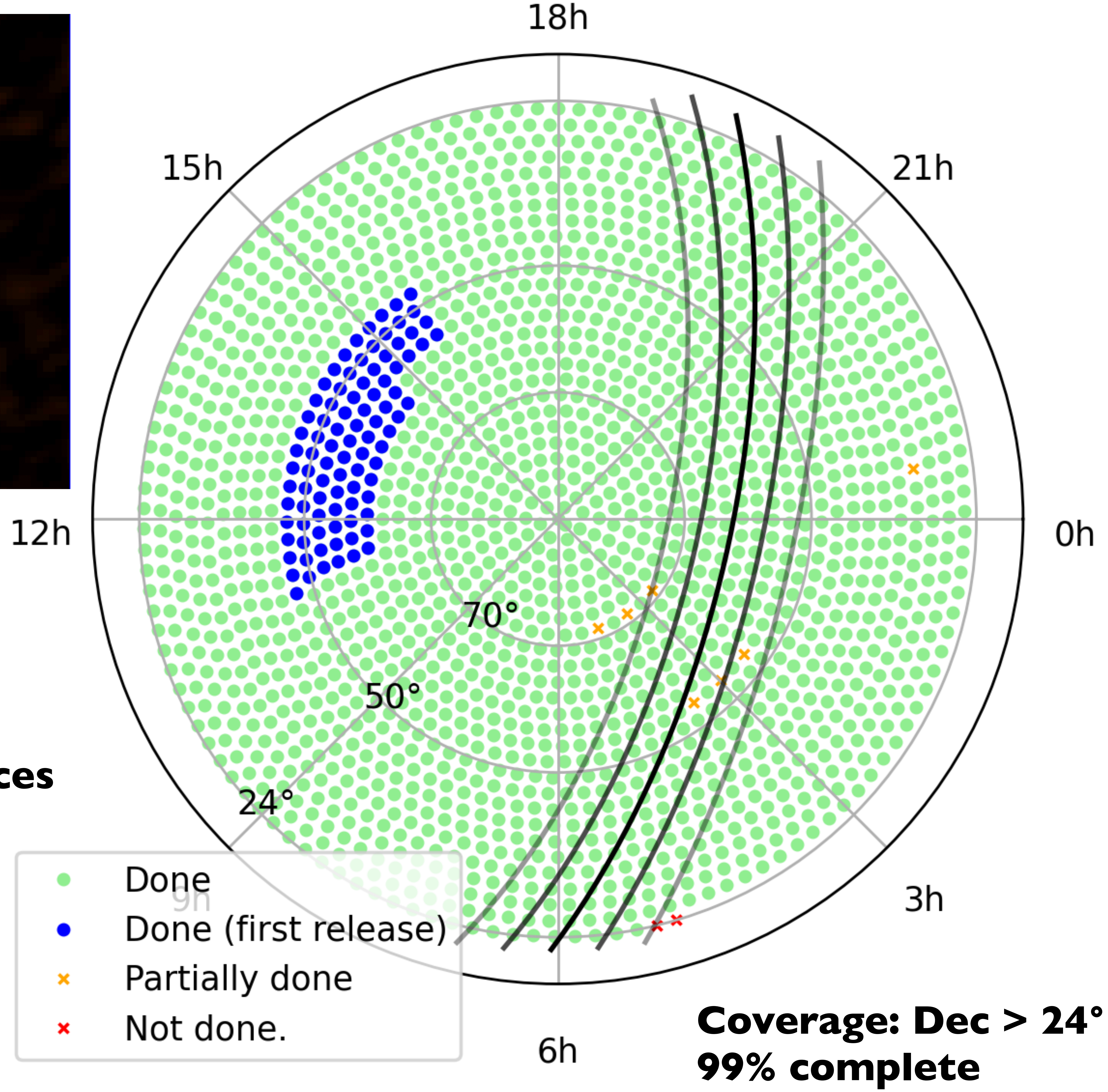
de Gasperin+ 2023



2021:
LoLSS Pr. release
•res.: 45”
•sens.: 5 mJy/b

2023:
LoLSS I release
•res.: 15”
•sens.: 1 mJy/b

Catalogue of 42,463 sources



www.LOFAR-surveys.org

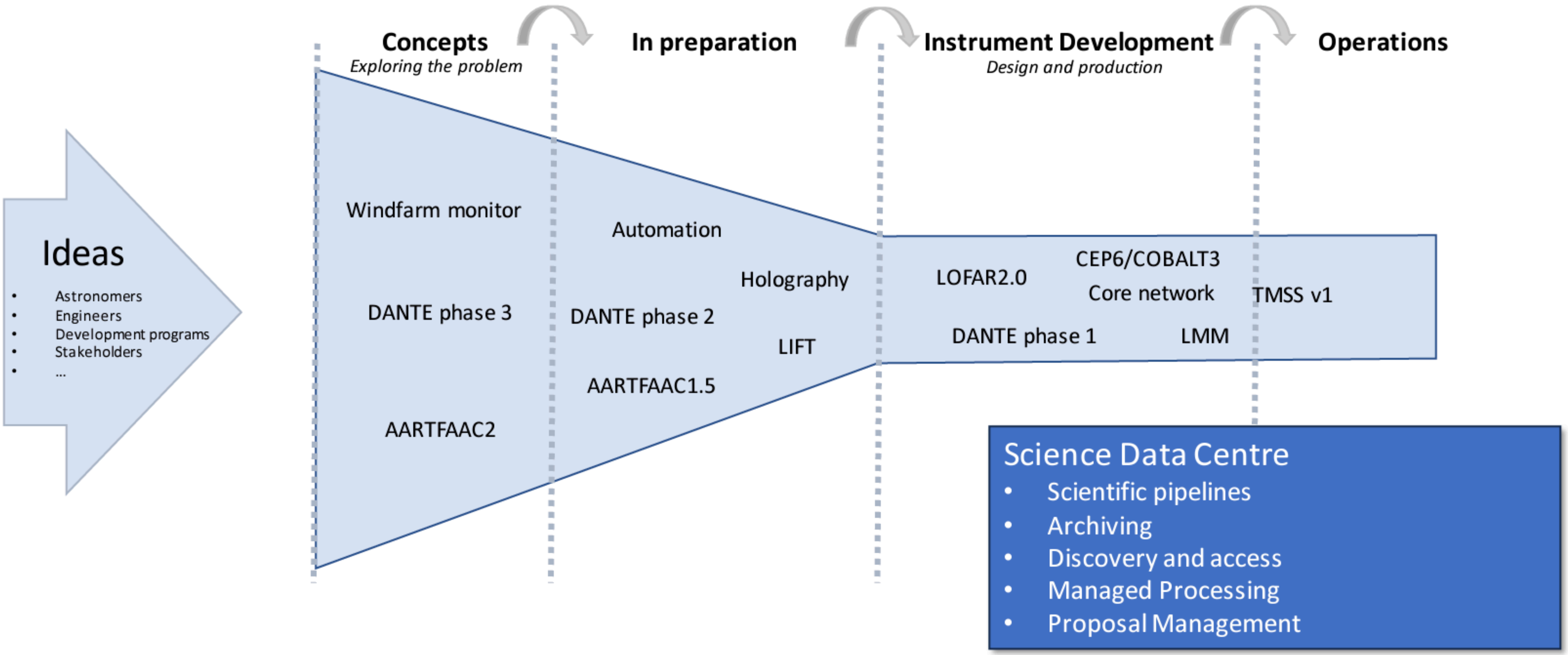
Coverage: Dec > 24°
99% complete

- LOFAR Surveys

- **LOFAR upgrades**
  ➡ **LOFAR 2.0**
  ➡ **LOFAR Next Generation Surveys**

- LOFAR+MeeRKAT - ViCTORIA project

LOFAR Development overview



- Almost every bit of LOFAR will be upgraded in the next 2-3 years
- LOFAR2.0 upgrade period: June 2024 – End of 2025.

LOFAR 2.0 requirements

- Leverage existing investments
  - hardware (stations, networks, data centres)
  - algorithms, software, pipelines

- Remain unique and scientifically impactful (in SKA era):
  - lowest frequencies
  - highest resolution

- Financially, technically feasible on a 3-10 year timescale

LOFAR

LOFAR 2.0 Vs SKA-low (ph.1)

LOFAR 2.0:
- Reaches 2x lower frequencies
- 10x higher resolution
- not confusion limited

SKA-low (ph.1)
- Reaches 2x higher frequencies
- 10x greater collecting area

SKA Low

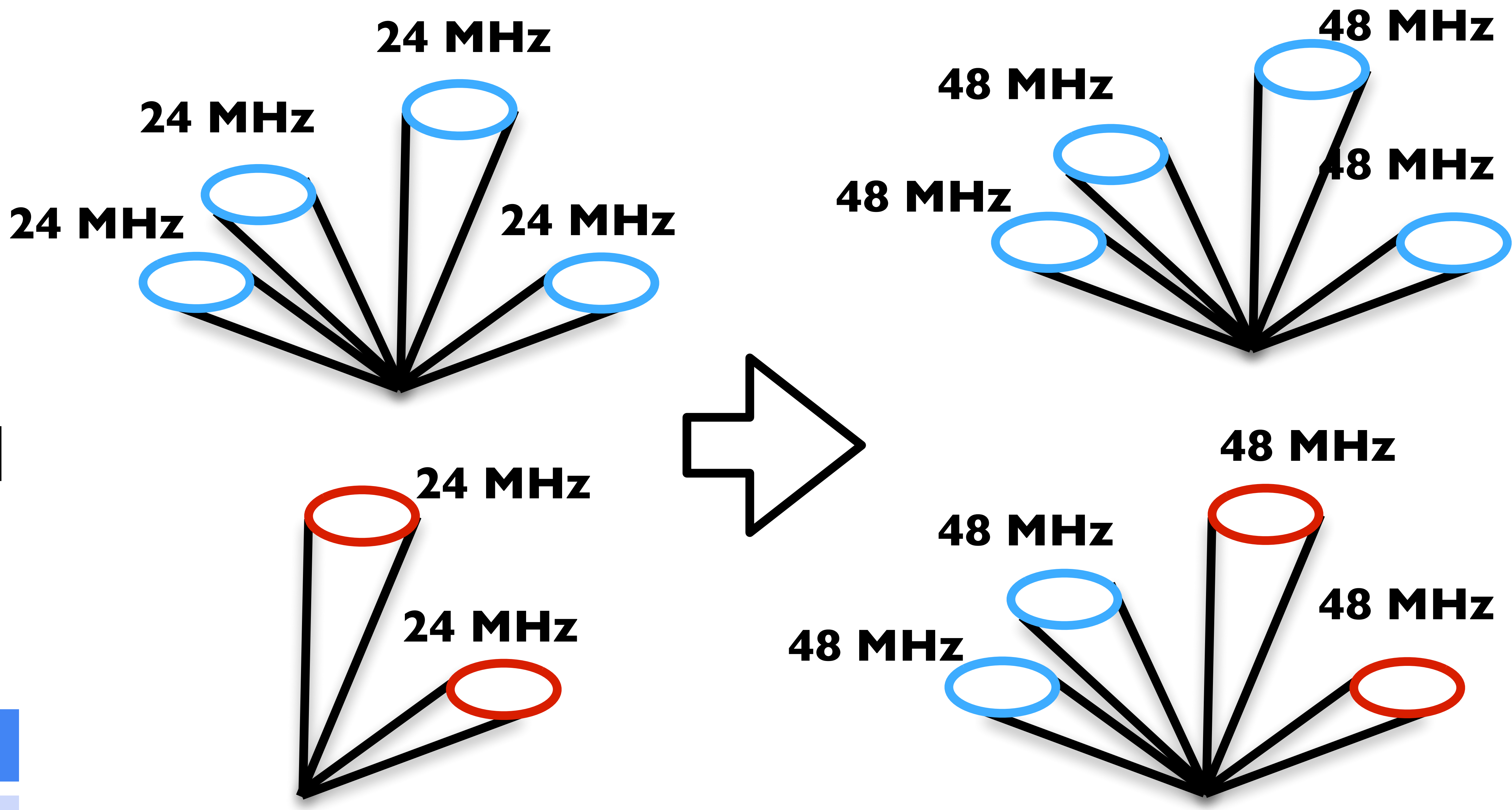
LOFAR 2.0 upgrades

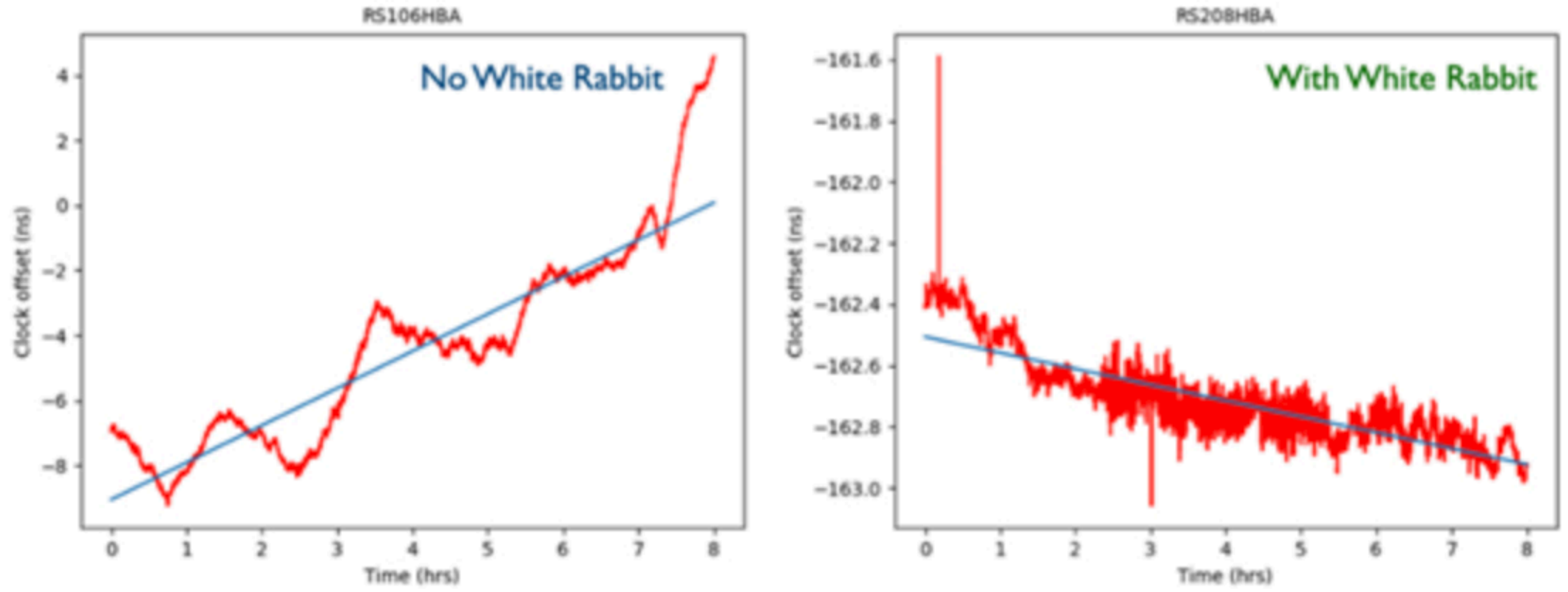
LOFAR 2.0 station upgrade includes:

- **Dual band** (2x96 MHz): enabling simultaneous observation capability for Low Band Antennas and High Band Antennas
- **Receivers**:

	LOFAR	LOFAR 2.0
Dutch Array	48 LBA or 48 HBA	96 LBA and 48 HBA
International	96 LBA or 96 HBA	96 LBA and 96 HBA

- **Clock**: distribution of a central clock to all NL stations (White Rabbit)
- **Filters:** exclude 180-190 MHz in HBA-LOW
- **Hardware**: redesigning and replacing of station electronics, including digital processing systems and receiver units; LOFAR Mega Mode (Cobalt 2.0, simultaneous observations for several science cases)

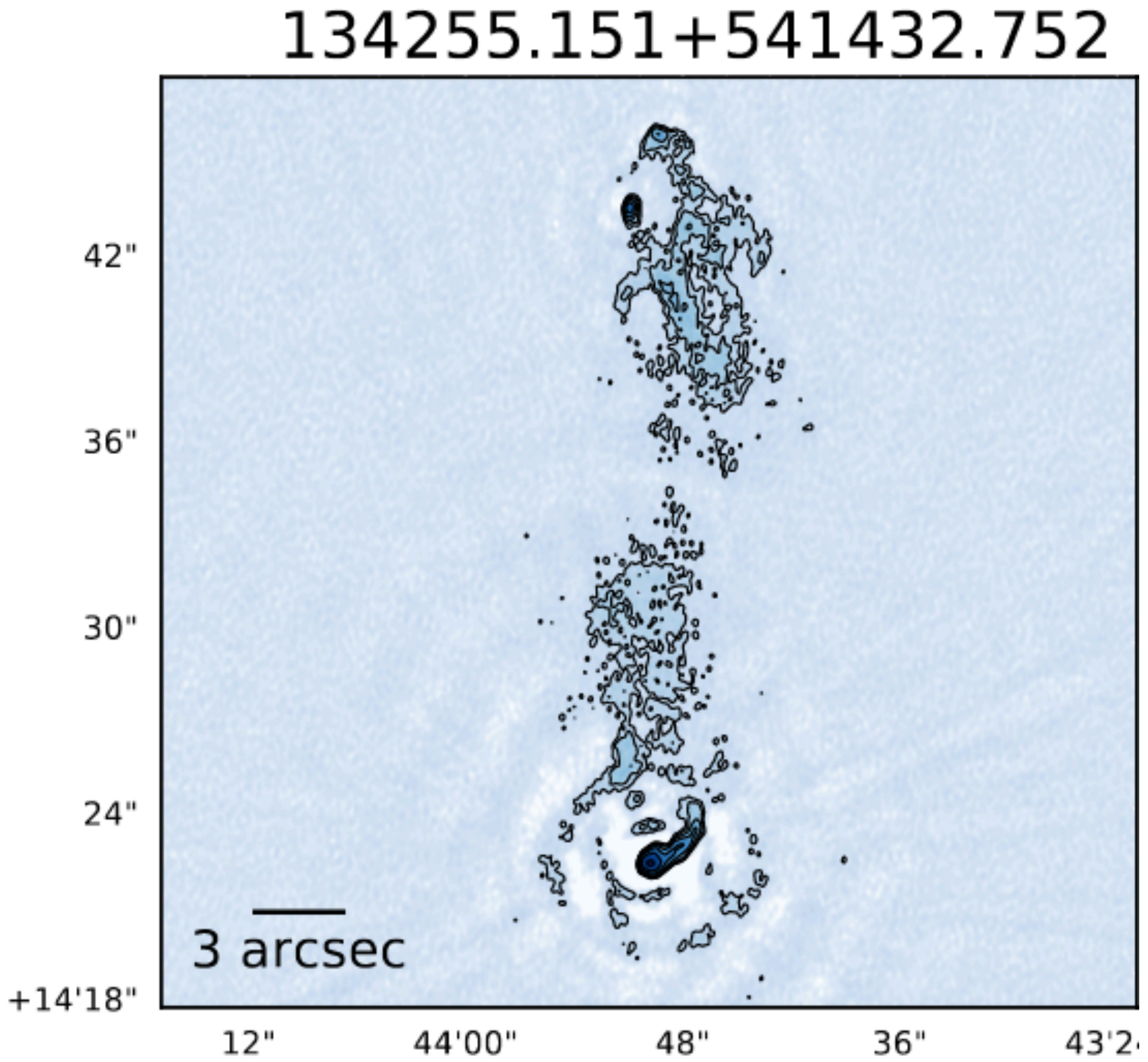




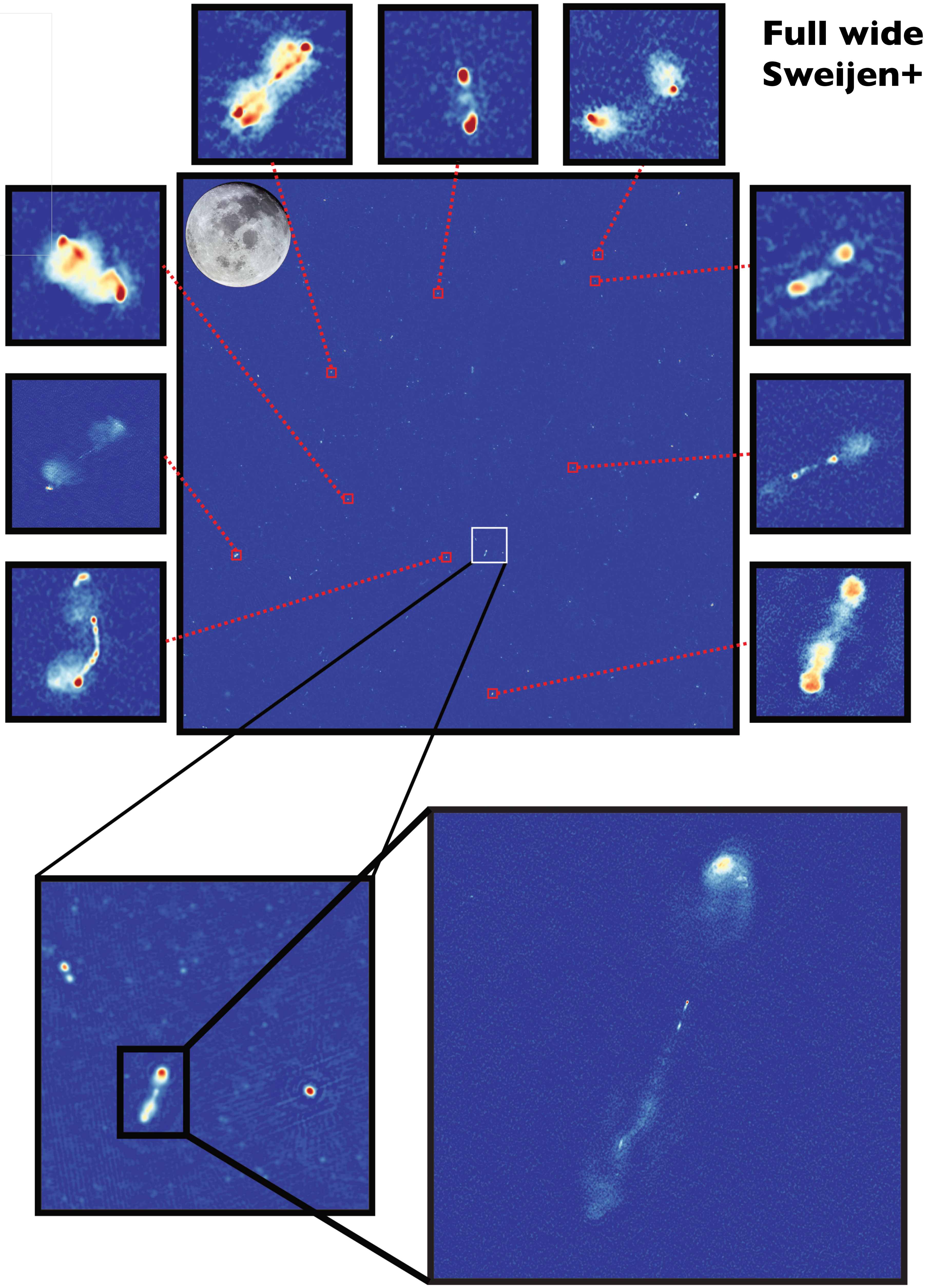
LOFAR Family Meeting
June 2022 in Köln

International LOFAR Telescope

Almost all LoTSS data contains the LOFAR international stations
(up to 1600km)

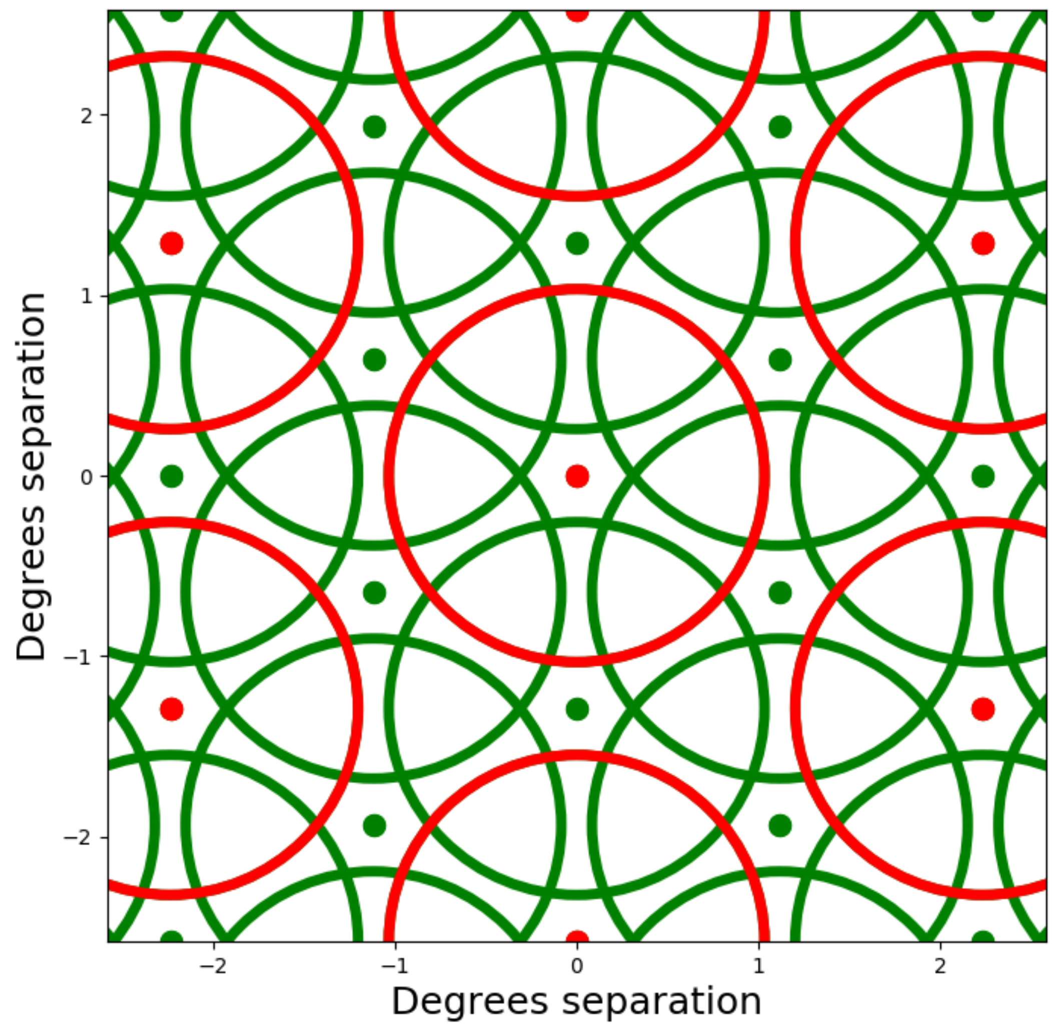


Selected source imagining: Morabito+ 2021

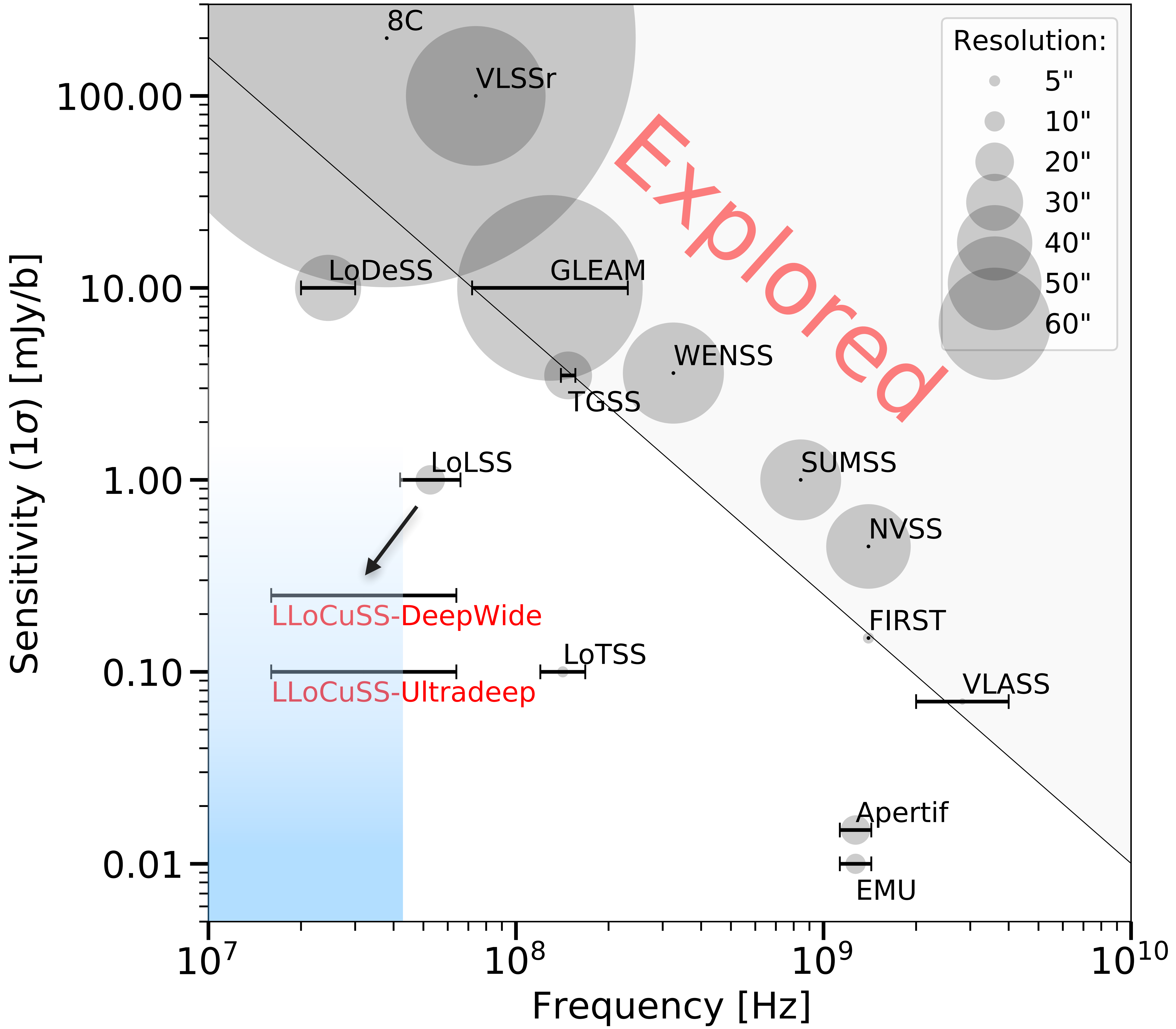


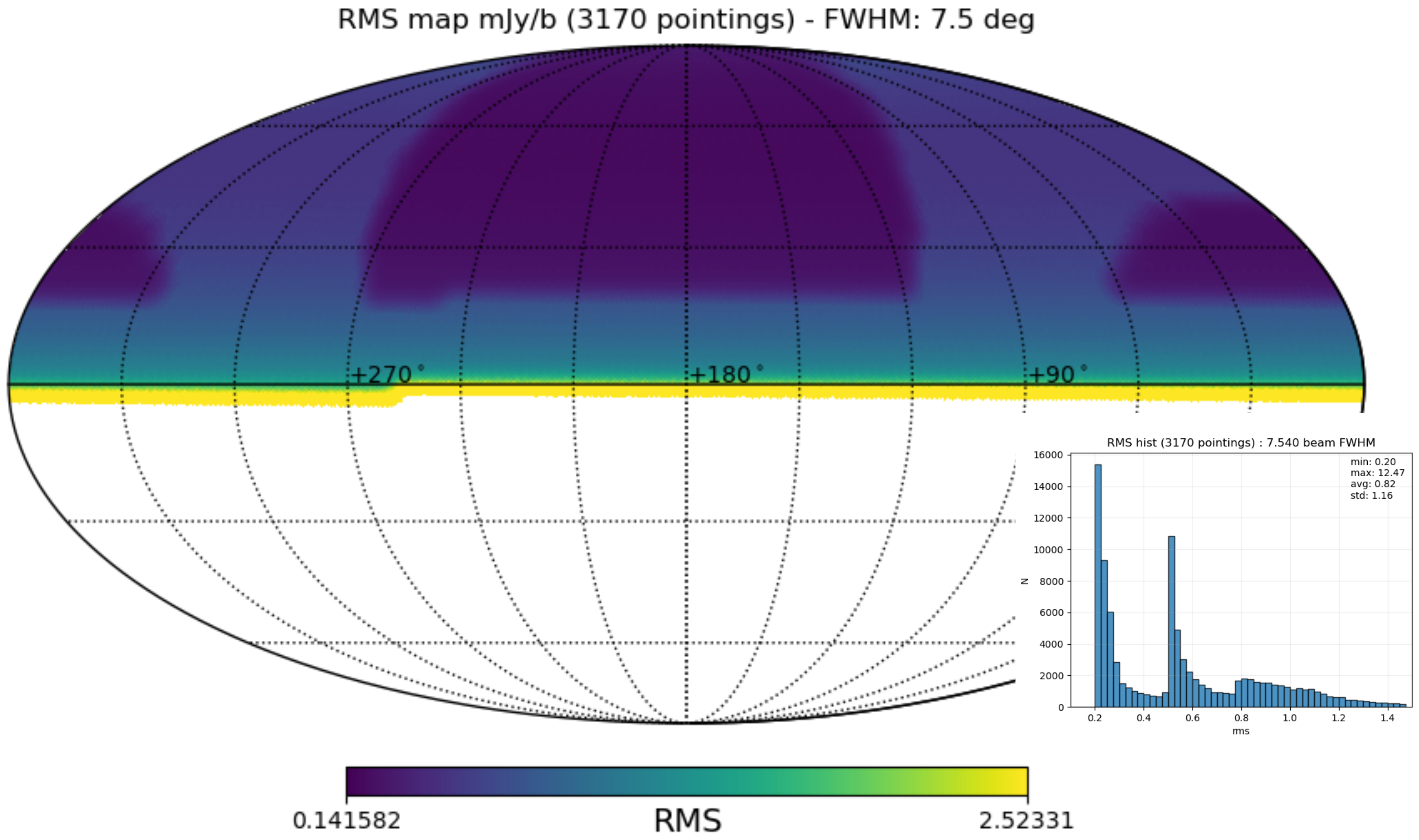
Full wide area imaging: Sweijen+ 2022

LOFAR 2.0: complete LoTSS-IS survey grid doubling the pointings
Aim: entire extragalactic northern sky at 0.3"



LBA LOFAR Community Sky Survey (LLoCuSS)





- **Band: 16 – 64 MHz**
- **Resolution:**
  1" (upper half of the band)
  15" (lower half of the band)

Wide Survey (2004 hrs):
- Coverage: Dec > 0°
- Sensitivity: 500–800 μJy beam^{-1}

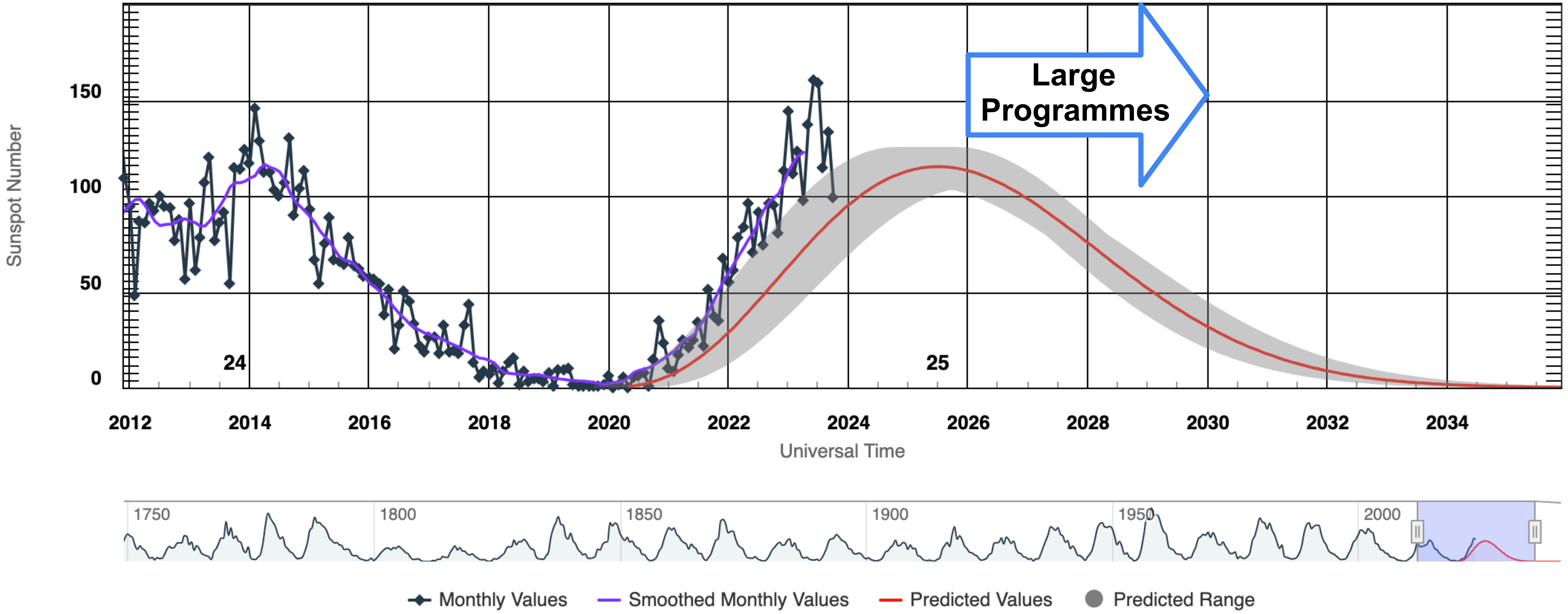
Deep-Wide Survey (5830 hrs):
- Coverage: Dec > 20°, $|b|$ > 23°
- Sensitivity: 350 μJy beam^{-1}

Ultra-deep Fields (100 hrs per field):
- Sensitivity: 130 μJy beam^{-1}

Timeline

LOFAR 2.0 upgrade:
- 2023: 1 LOFAR 2.0 station (L2TS) fully working
- 2024-1q: 3 LOFAR 2.0 stations
- 2024-2q; 2025-1q: roll out of all LOFAR stations
- 2025-2q: data flow

Science programmes:
- 2022: EoI for Large Programme
- 2023: Proposal submission
- 2024: Proposal evaluation
- 2025 - commissioning
- 2026-2030 - observations



- LOFAR Surveys

- LOFAR upgrades
  ➡ LOFAR 2.0
  ➡ LOFAR Next Generation Surveys

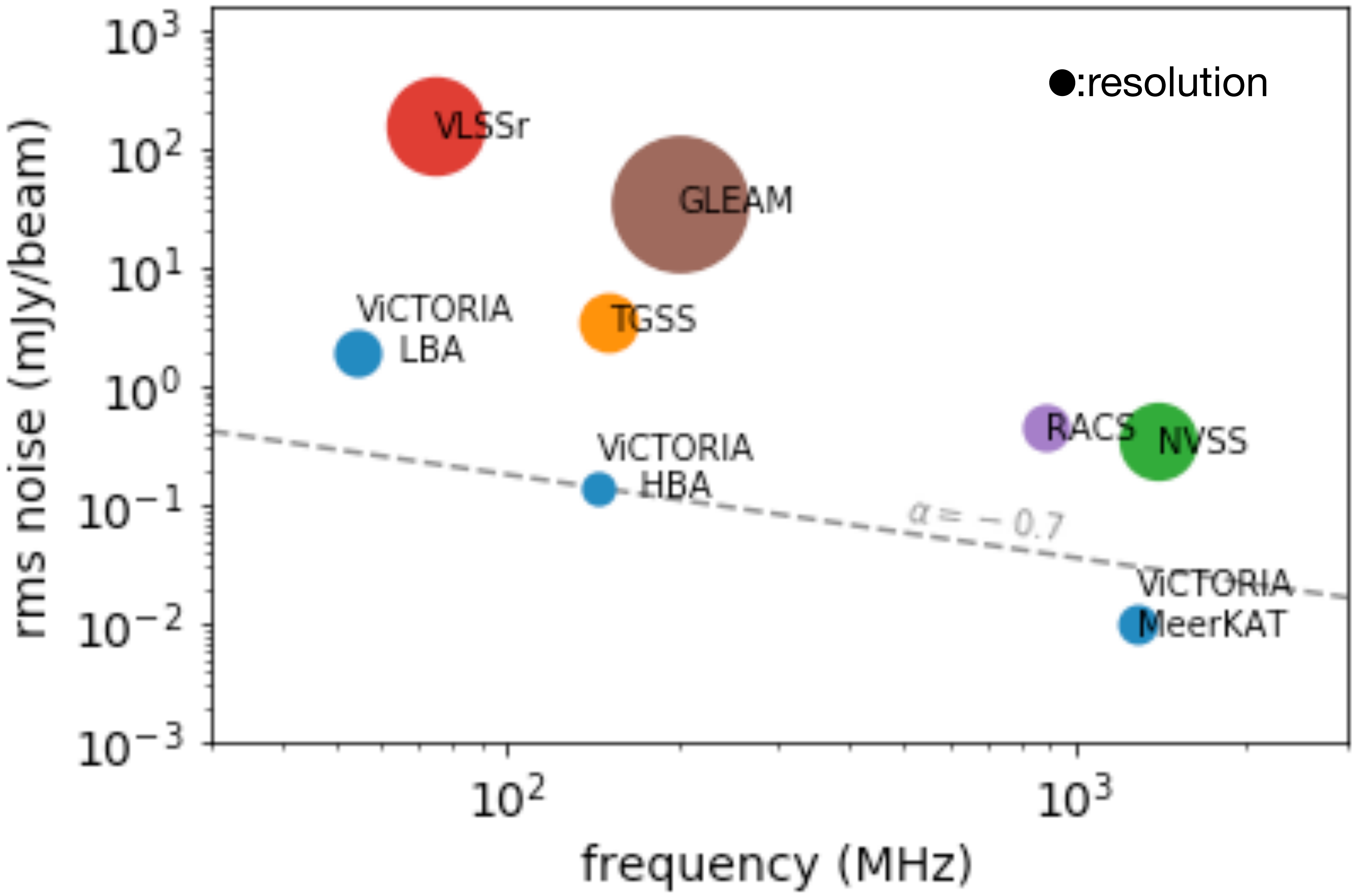
- **LOFAR+MeeRKAT - ViCTORIA project**

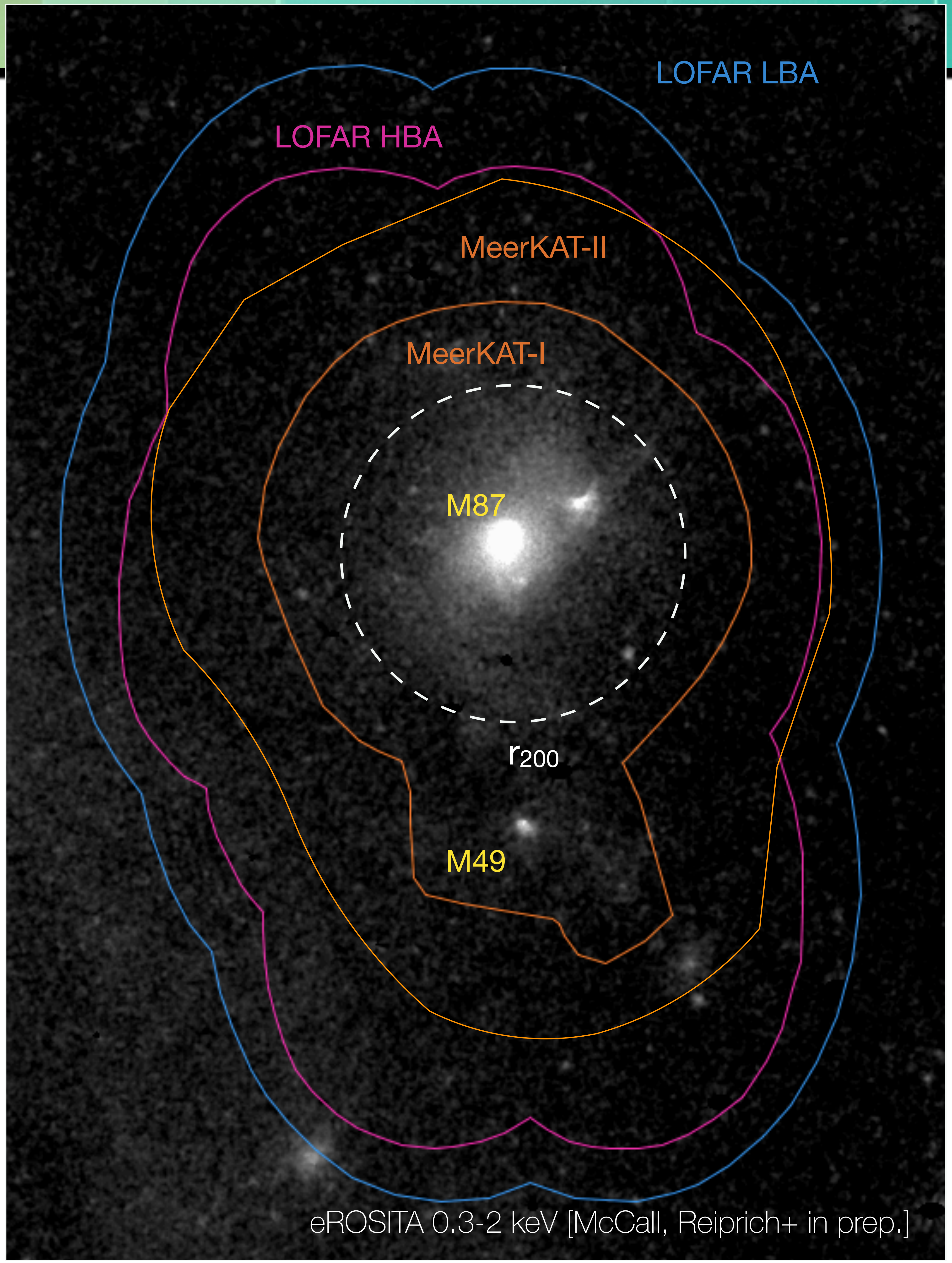
ViCTORIA Project

Virgo Cluster multi-Telescope Observations in Radio of Interacting galaxies and AGN

Aim: Drastically improve the multi-frequency radio-coverage of the Virgo cluster
→ Enable studies of the **environmental effects** in galaxies and AGN

1. LOFAR LBA: 54 MHz (56 hrs)
2. LOFAR HBA: 144 MHz (64 hrs)
3. MeerKAT: 1.3 GHz (125 hrs + 158 hrs)





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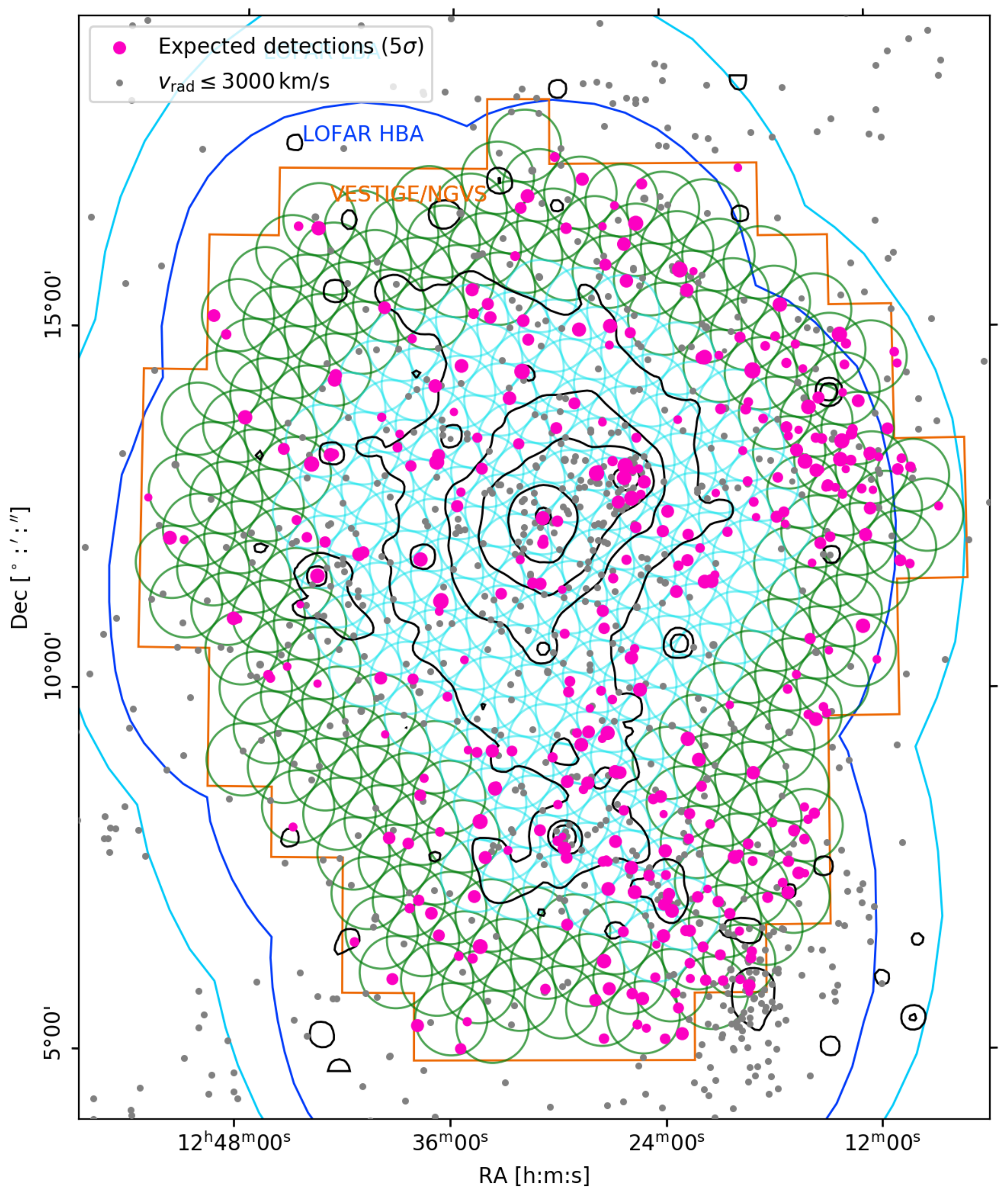
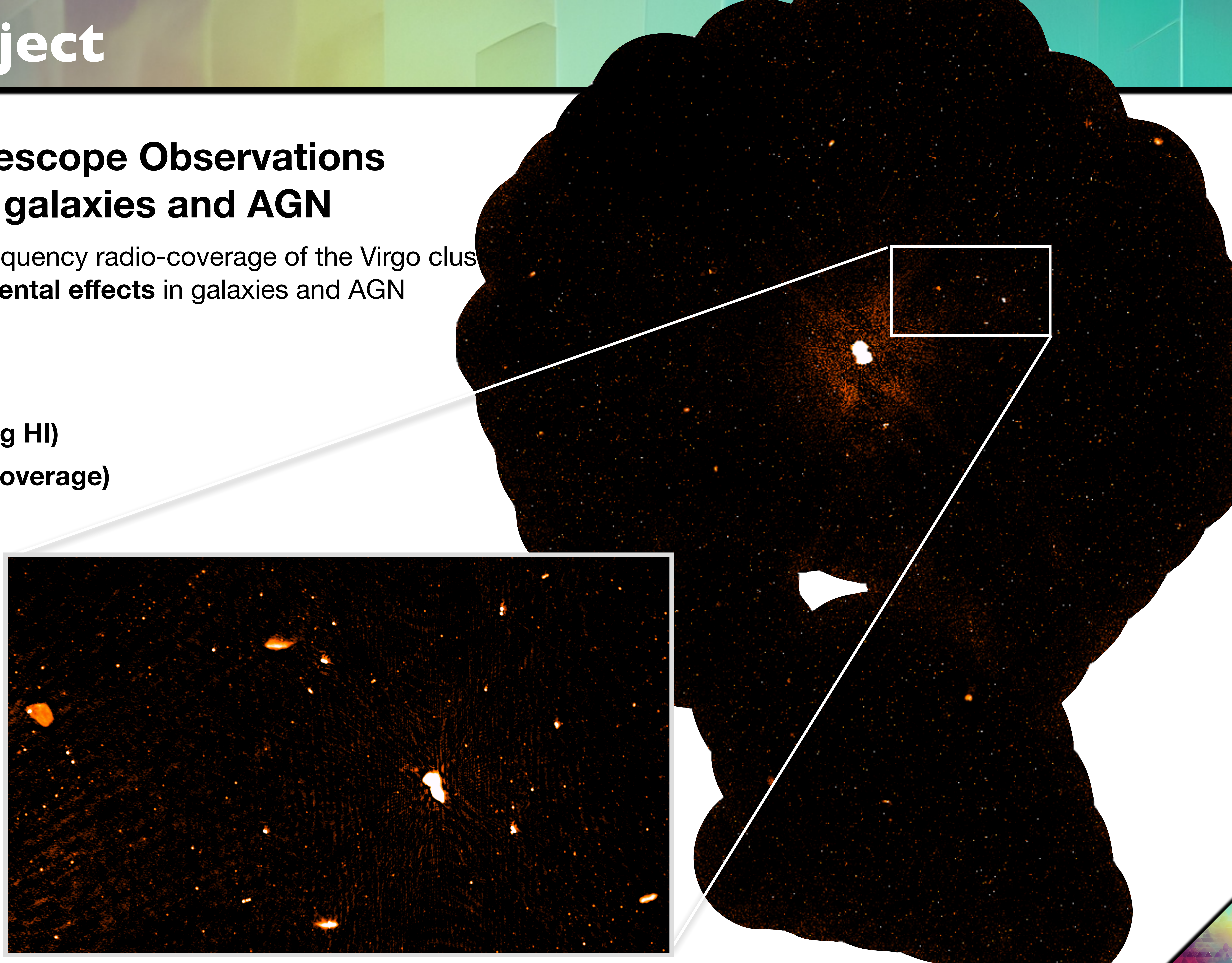
3. **MeerKAT: 1.3 GHz (including HI)**

   (+ expansion to twice the coverage)





Conclusions

- **LoTSS**
  reference person: Tim Shimwell
  - for deep fields: Philip Best
  - for long baselines: Leah Morabito
  - data at www.lofar-surveys.org/dr2.html

- **LoLSS**
  reference person: Francesco de Gasperin
  - for deep fields: Wendy Williams
  - data at www.lofar-surveys.org/lolss.html

- **LOFAR 2.0** upgrade is ongoing with very positive results from the test station. Data flow is expected from 2025.
- **Large Programmes** will be selected in 2024, the community is very open: get involved!

Interested in working with LOFAR surveys / LOFAR 2.0? Postdoc positions open in Bologna, contact me!

- **LLoCuSS (LOFAR 2.0 LBA survey)**
  reference persons: Francesco de Gasperin / Reinout van Weeren

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- **ViCTORIA Project**
  reference persons: Francesco de Gasperin / Henrik Edler / Paolo Serra / Alessandro Boselli

Henrik Edler

Virgo Cluster multi-Telescope Observations in Radio of Interacting galaxies and AGN

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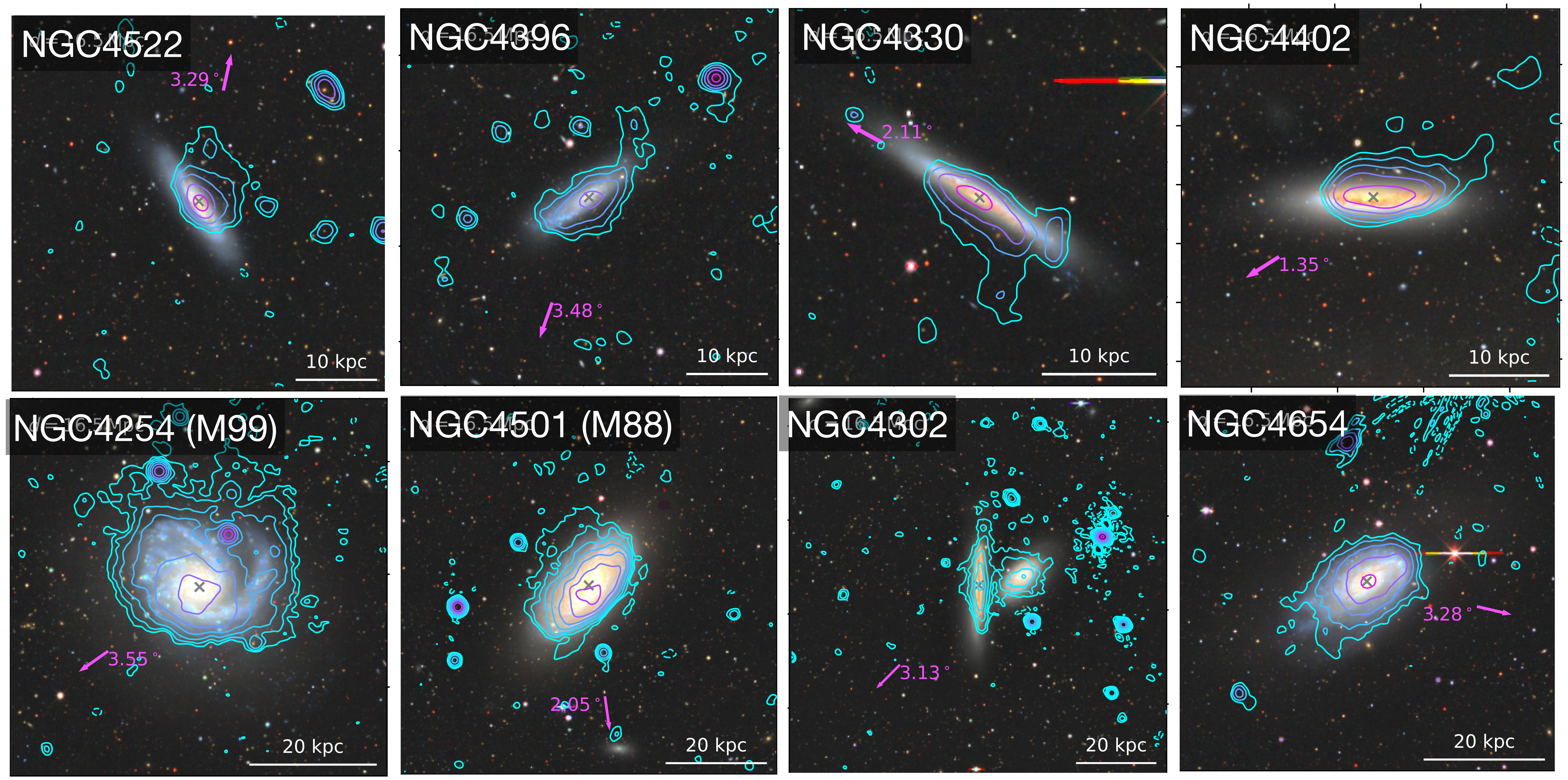
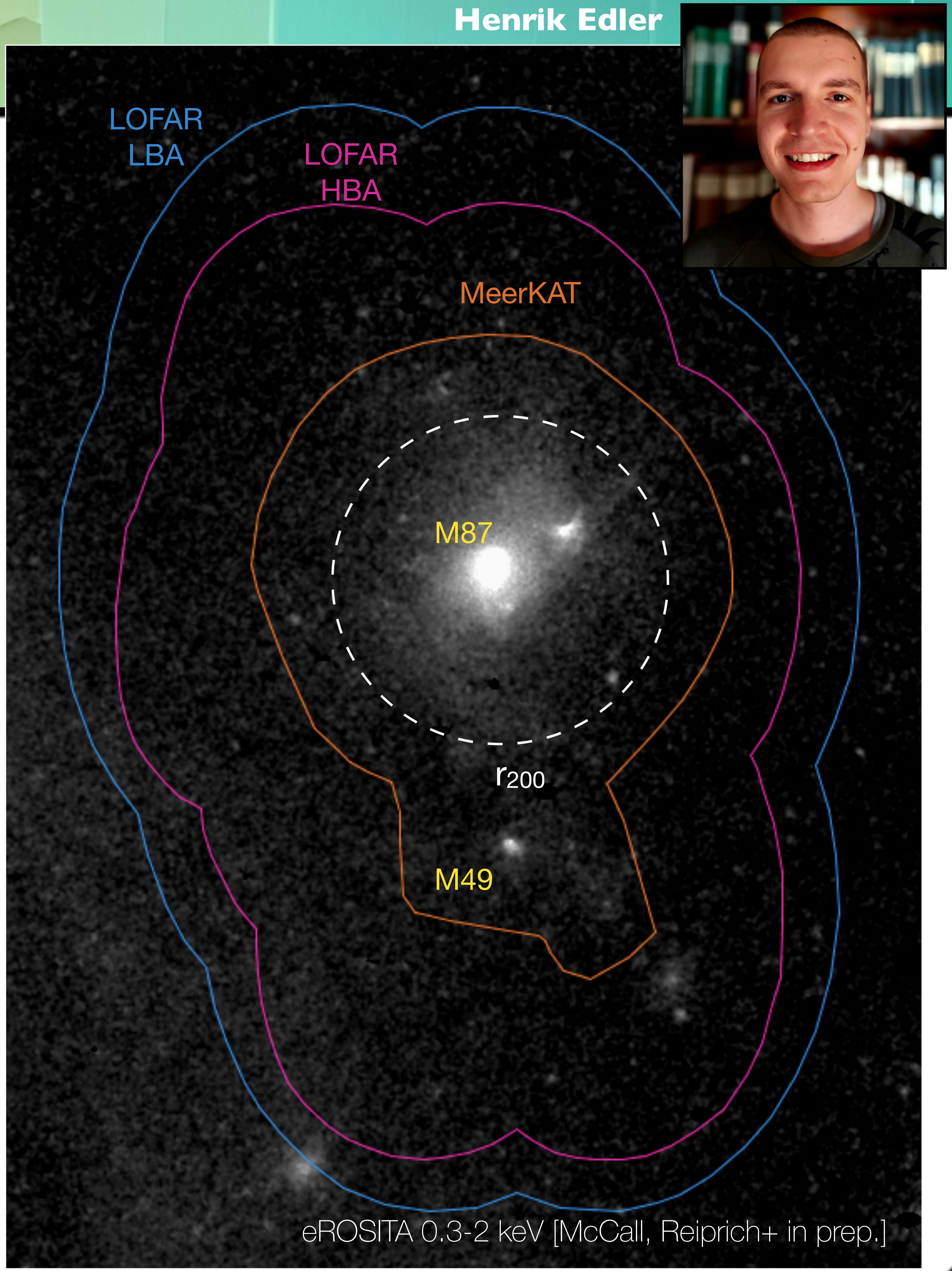
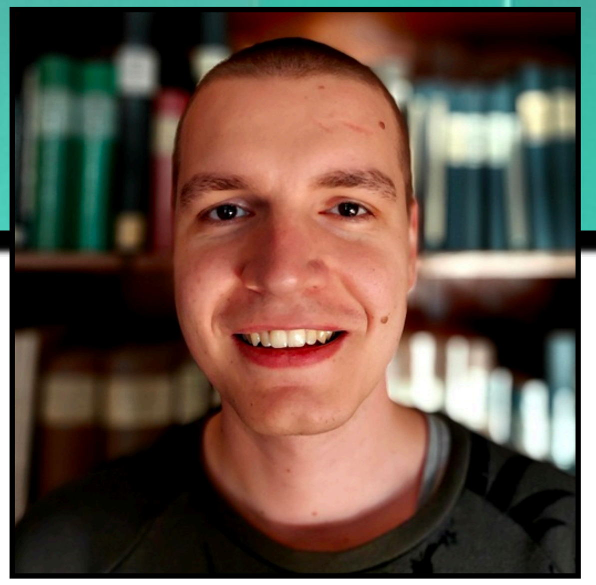




Radio-SFR relation

Henrik Edler
Edler+ (A&A in press)

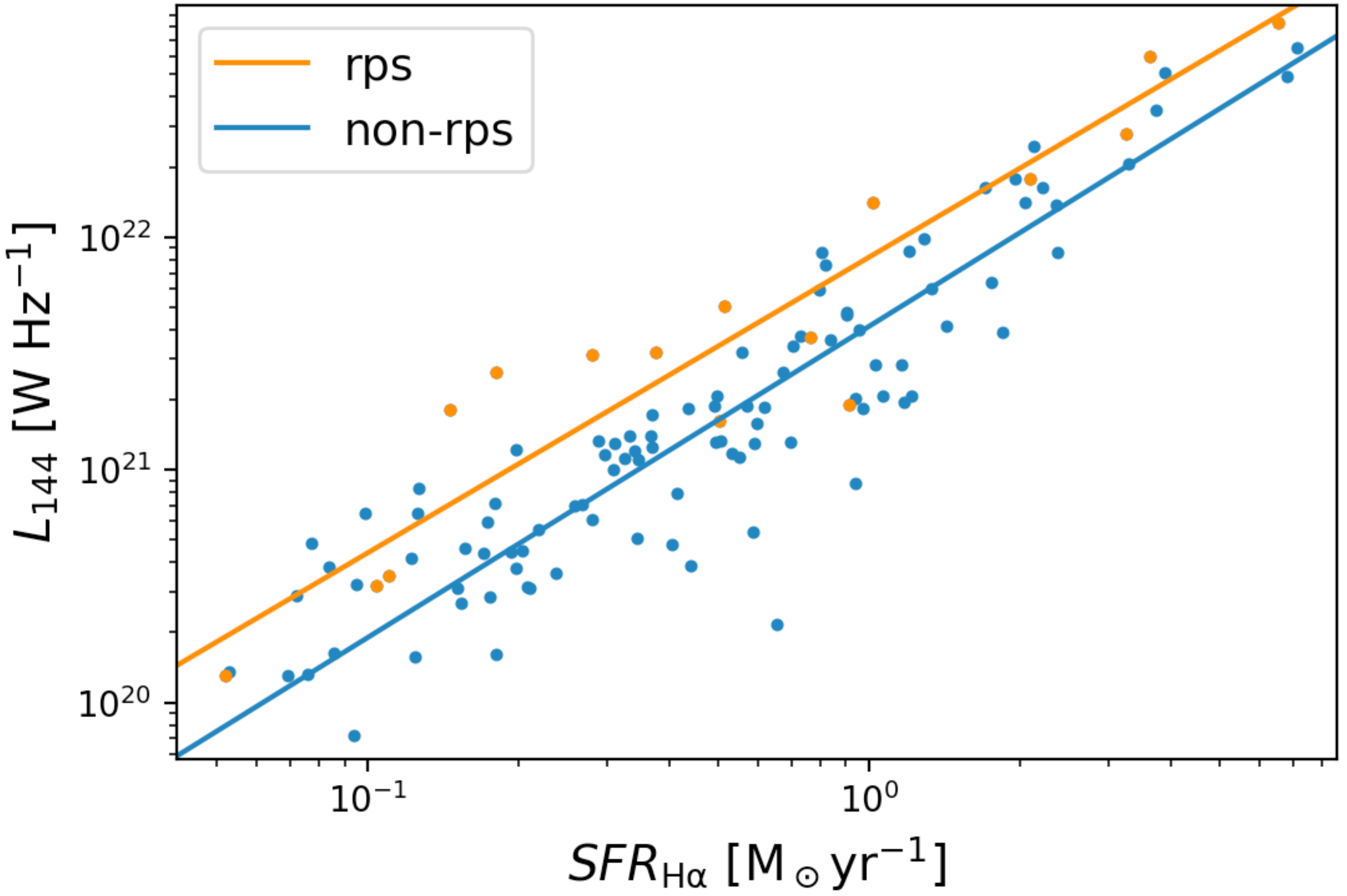


Normal vs. stripped galaxies

- $L_{144} = N_0 \mathrm{SFR}^{\delta}, \delta = 1.33$
- Most of RPS galaxies show radio-excess!

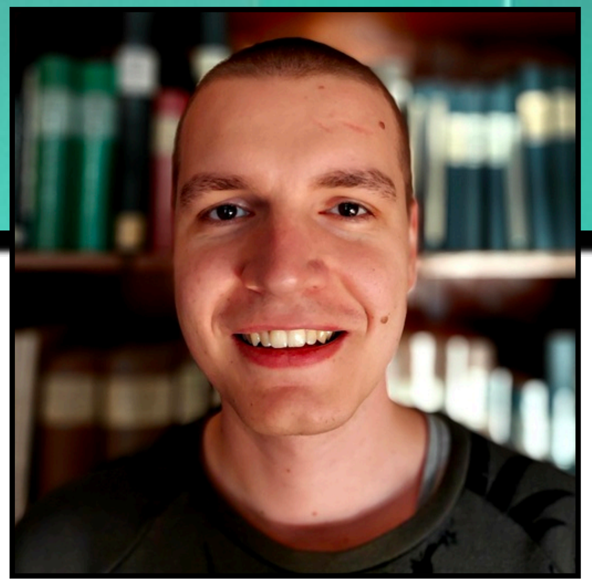
1. Enhanced magnetic field due to compression [Gavazzi+99]
2. Re-acceleration at shocks [Völk+94, Murphy+09]
    - Flatter spectral index + enhanced surf. brightness at location of shock
3. Rapid decline in SFR [Ignesti+22]
    - Steeper spectral index

Sample: Herschel Reference Survey



Spectral Properties of RPS Galaxies

Henrik Edler
Edler+ (A&A in press)

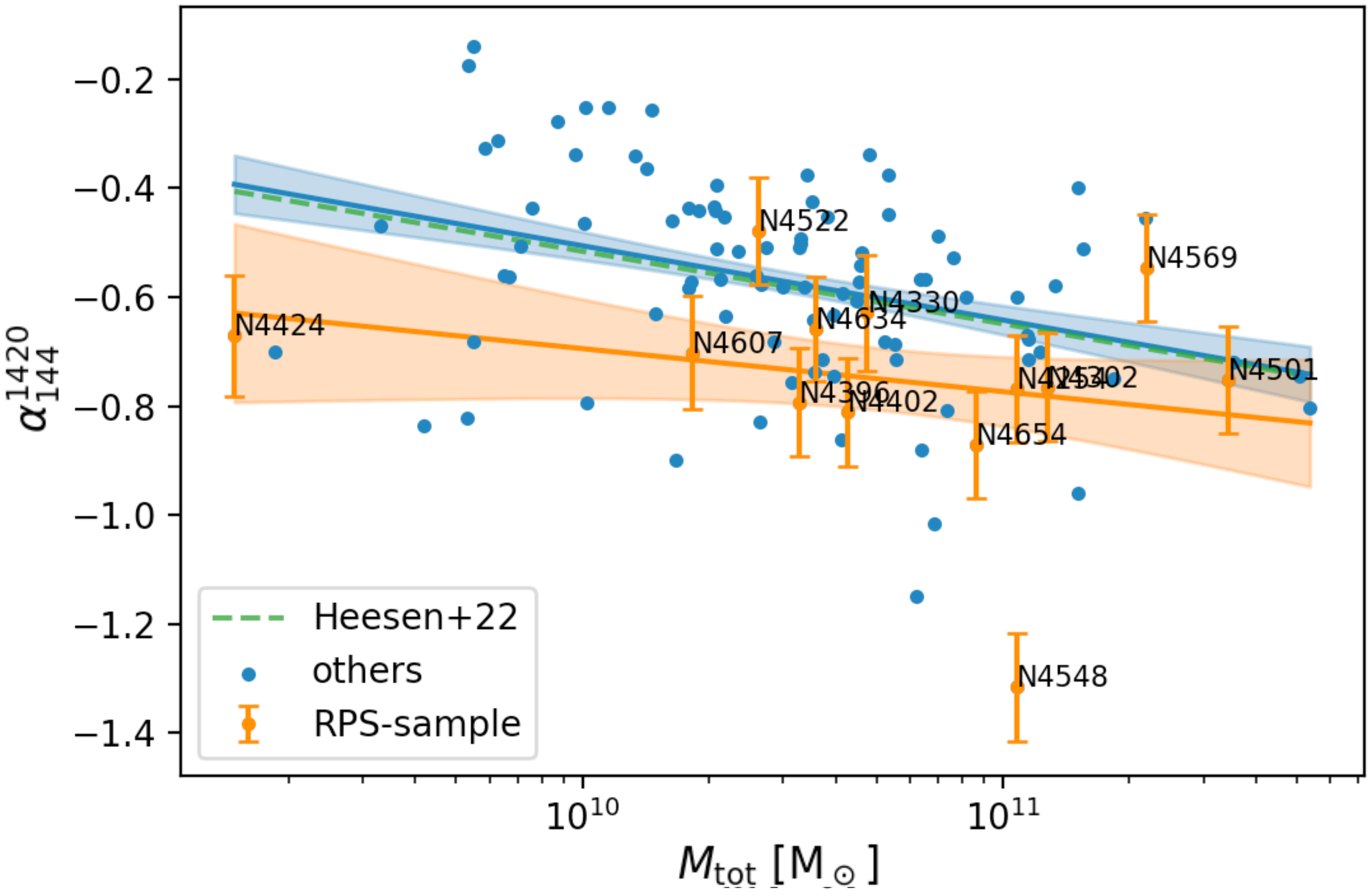


Spectral index-mass relation

- Relation due to mass-dependent CR escape
- Non-stripped sample: good agreement with literature [Heesen+22]
- For RPS galaxies - spectral indices steeper, even though CR-escape likely more efficient
- RPS galaxies host older cosmic ray-populations!

➡ recent quenching of star-formation [e.g. Ignesti+22]

Sample: Herschel Reference Survey



1.4 GHz from Murphy+09, Chung+09, Vollmer+10, Boselli+15

M49: new lobes

Angelina Spasic

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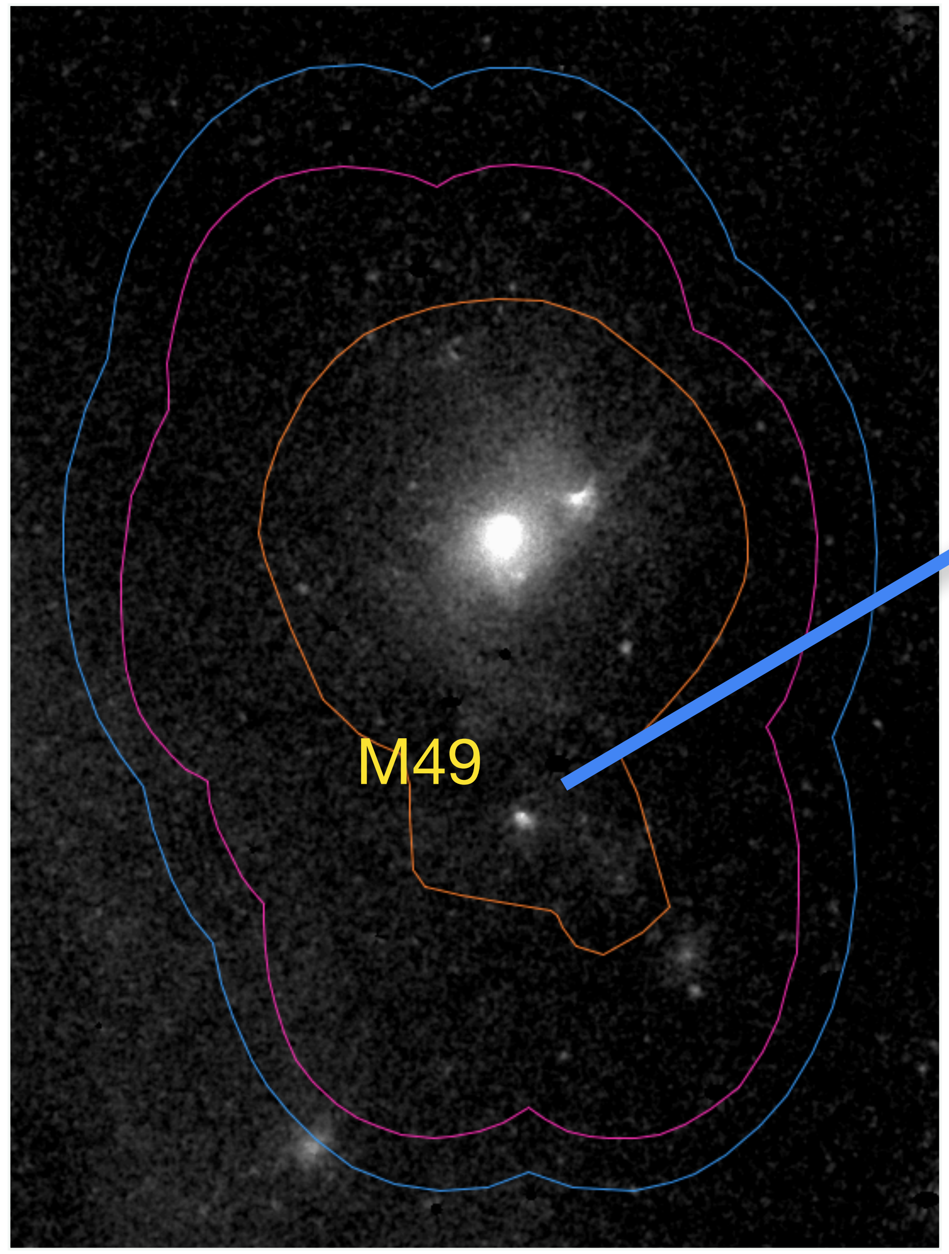
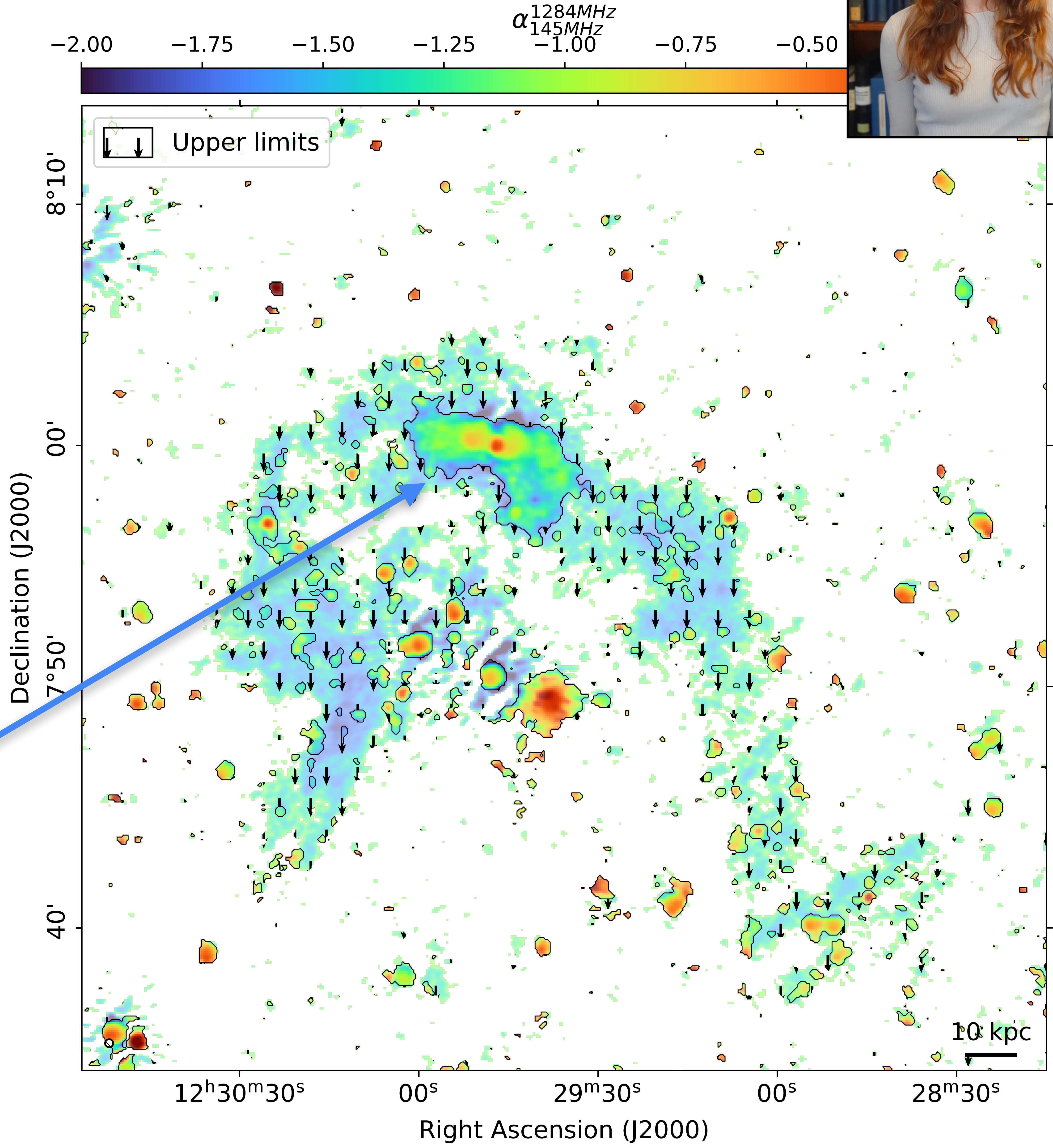




M49: 100 kpc +100 kpc long radio lobes from past AGN activity co-spatial with X-ray cavities

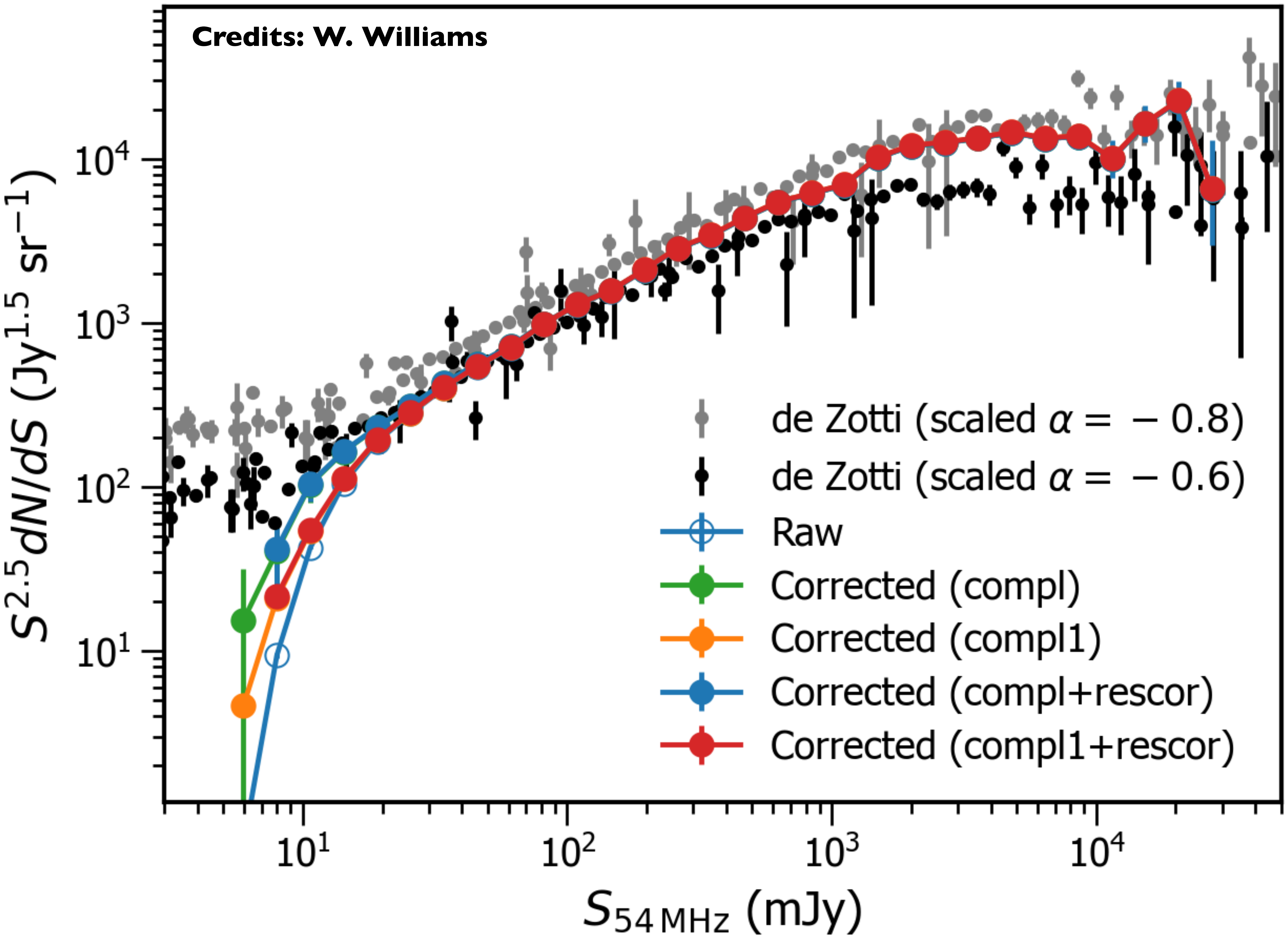
M51: the whirlpool galaxy

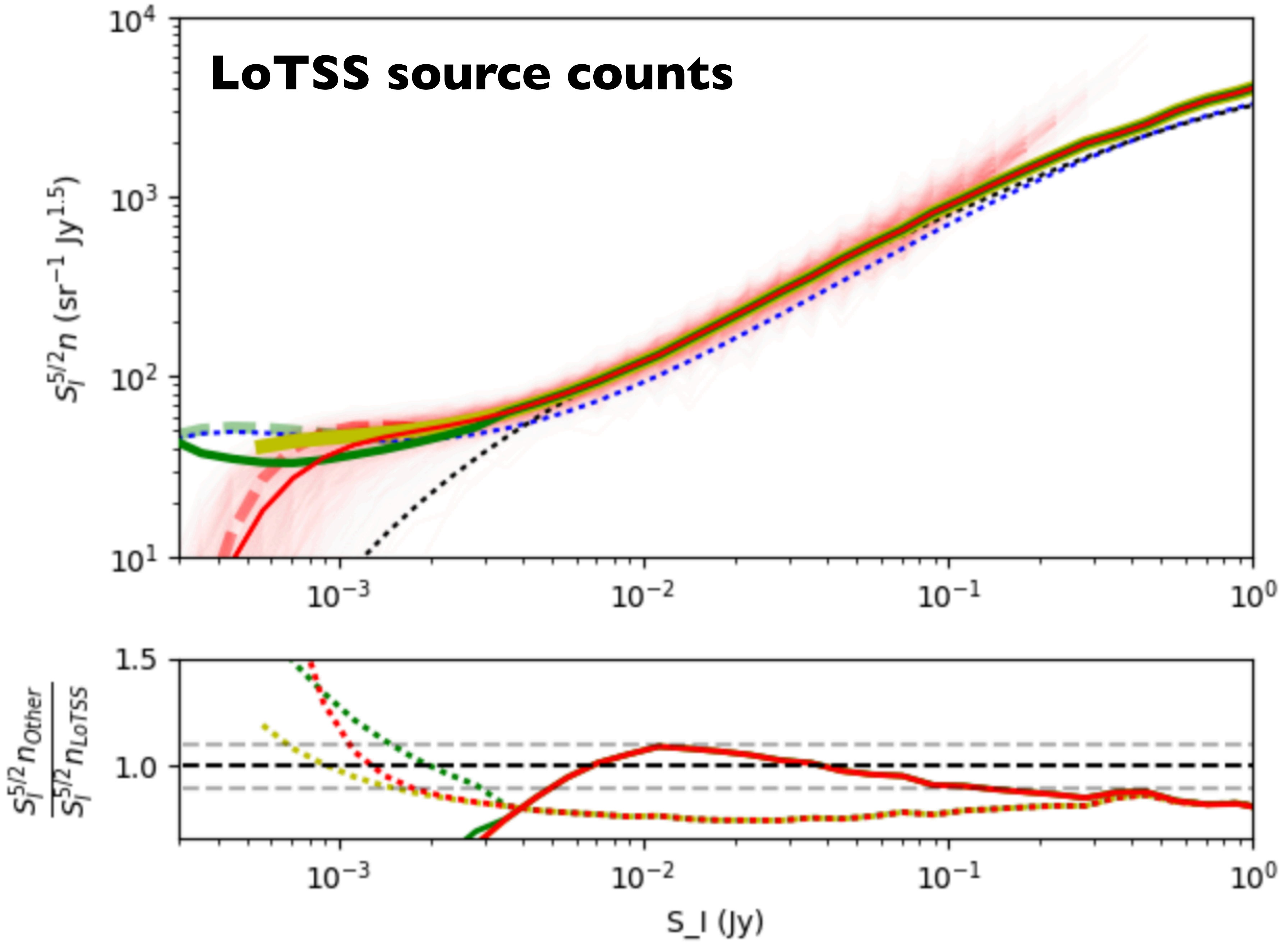
Lovorka Gajovic

We can fit the free-free absorption model to find the emission measure
in HII regions

Source counts

de Gasperin+ 2023





LoLSS not deep enough to see SF galaxy turnover: need deep fields

High flux sources: steep (-0.8)
Low flux sources: flat (-0.6)