

Active galactic nuclei and star forming galaxies with LOFAR (and MOONS ?)

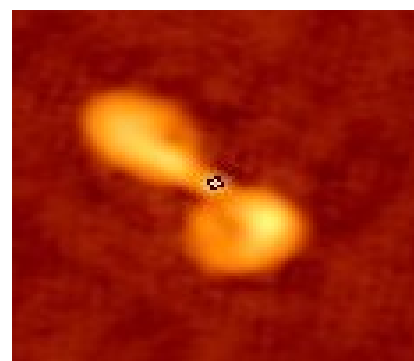
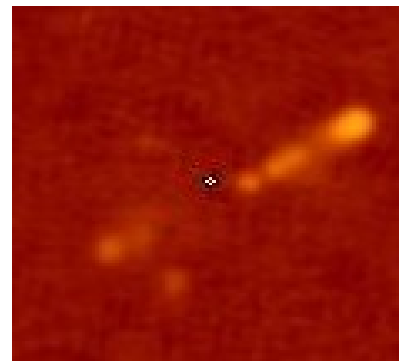
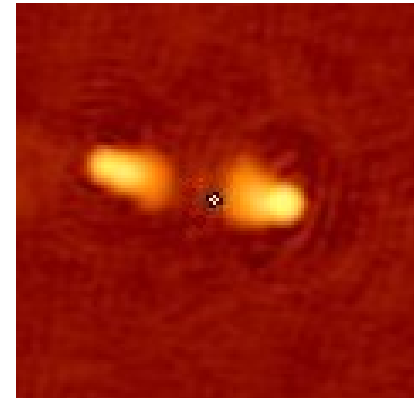
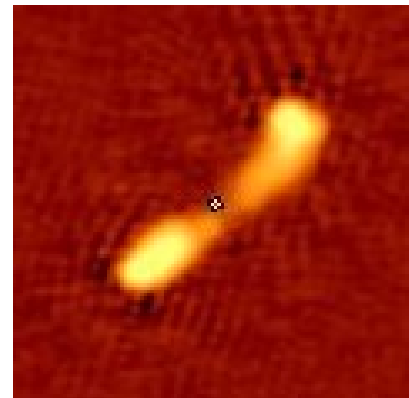
Cyril Tasse

Observatoire de Paris (GEPI) – Rhodes University (RATT)

& the LOFAR Survey Key Science Project

And thanks to some slides of

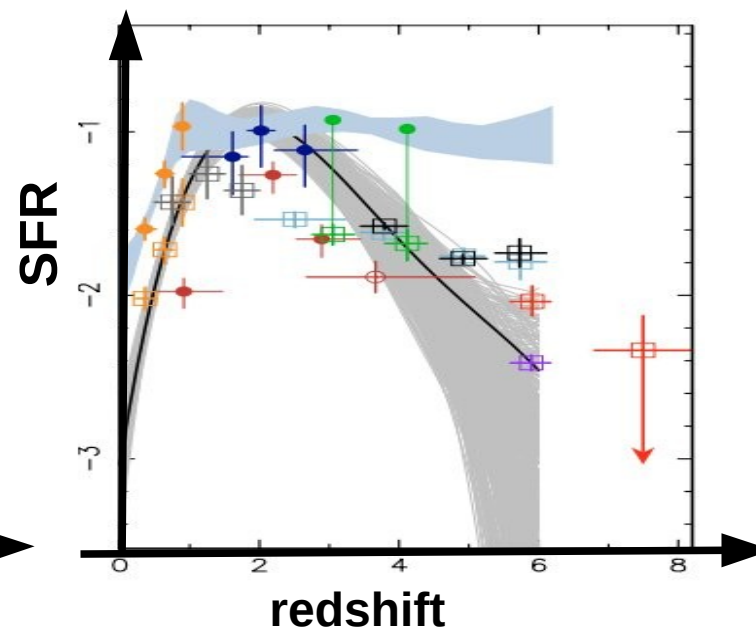
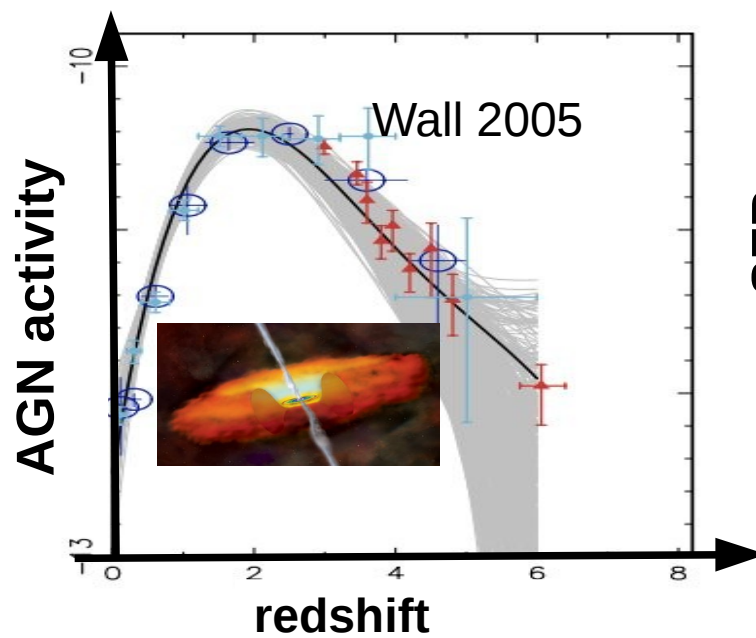
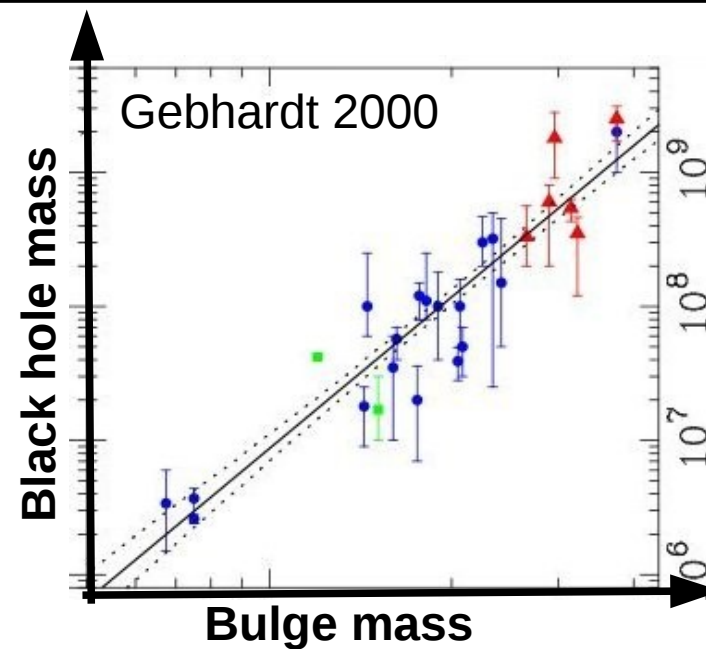
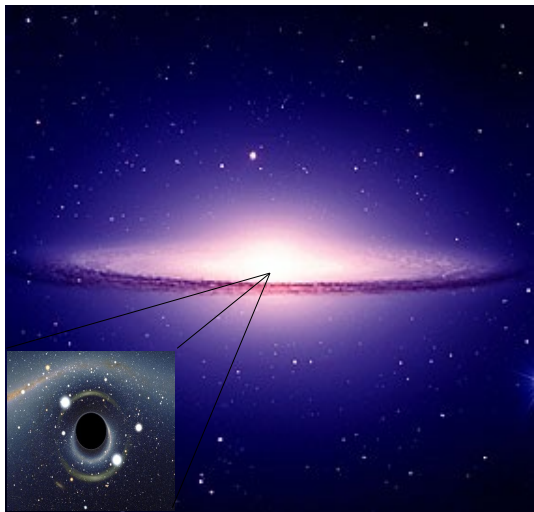
- Martin Hardcastle
- Tim Shimwell
- Wendy Williams
- Isabella Prandoni
- Dan Smith



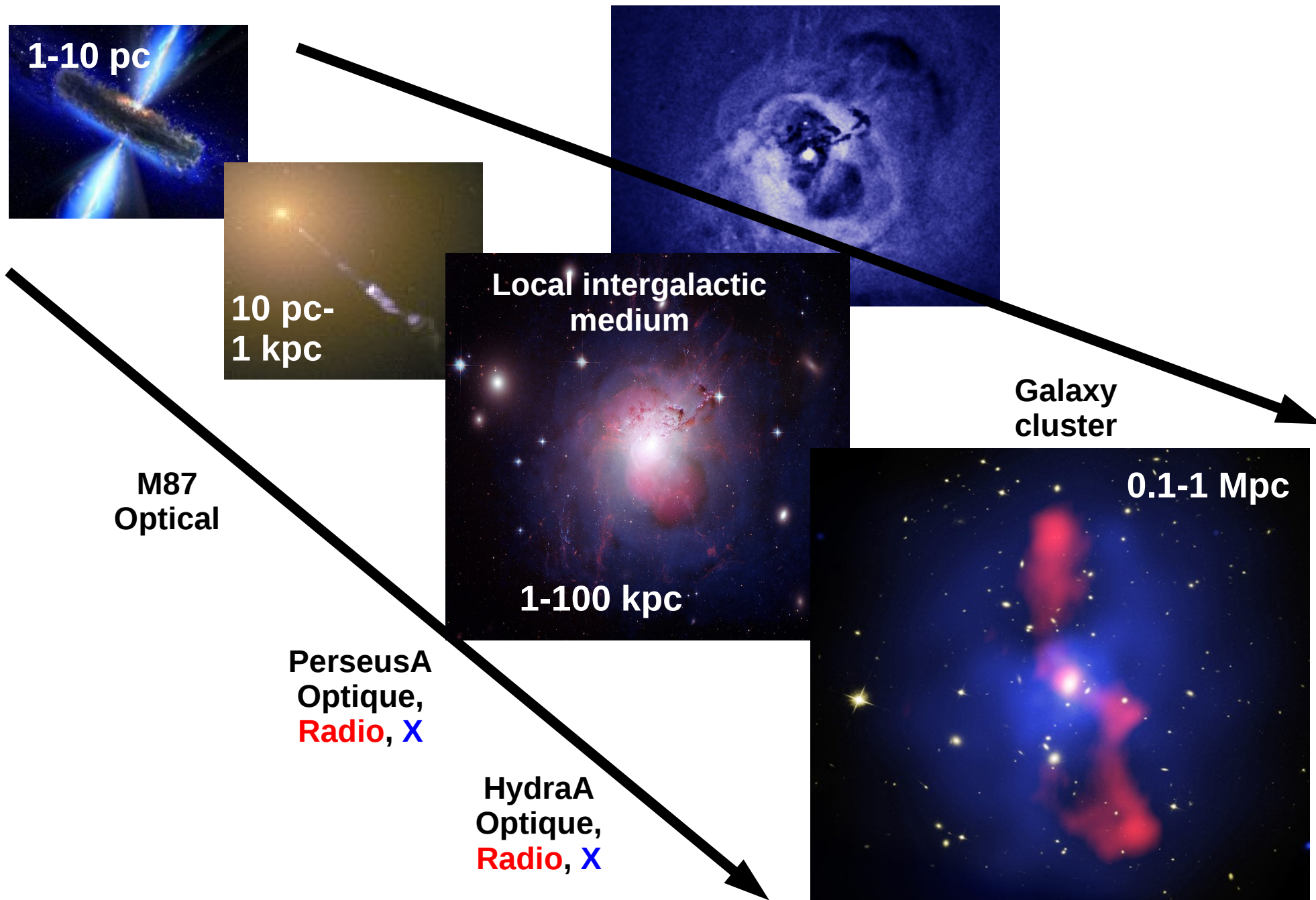
Outline

- Why observing at low frequency ?
- LOFAR extragalactic surveys Key Science Projects
- What's difficult with LOFAR/SKA observations ?
- How far did we get analysing the LOFAR surveys data ?
- Spectroscopic follow up (WEAVE, MOONS)

Galaxy formation and black hole growth



Energetic impact of AGN activity



The star-formation and accretion history of the Universe

Multi-wavelength info + Low-Frequency radio data

No dust obscuration !

→ no selection effects

- What is the relationship between (i) supermassive black hole and their host galaxies, (ii) between star formation and the different AGN accretion modes?
- How star formation & AGN activity varies as a function of Stellar Mass, Environment, Redshift ?
- What is the origin of the radio-loudness dichotomy?
- AGN duty cycle : scale, period and nature of the injected energy
- How was the Universe re-ionized?

LOFAR [30-250 MHz]

- 55 operational stations
- ~40000 HF antenna , 5000 LF Antenna
- Twice as big as arecibo
- ~ 15% SKA



Chilbolton

Potsdam

Jülich

Effelsberg

Tautenburg

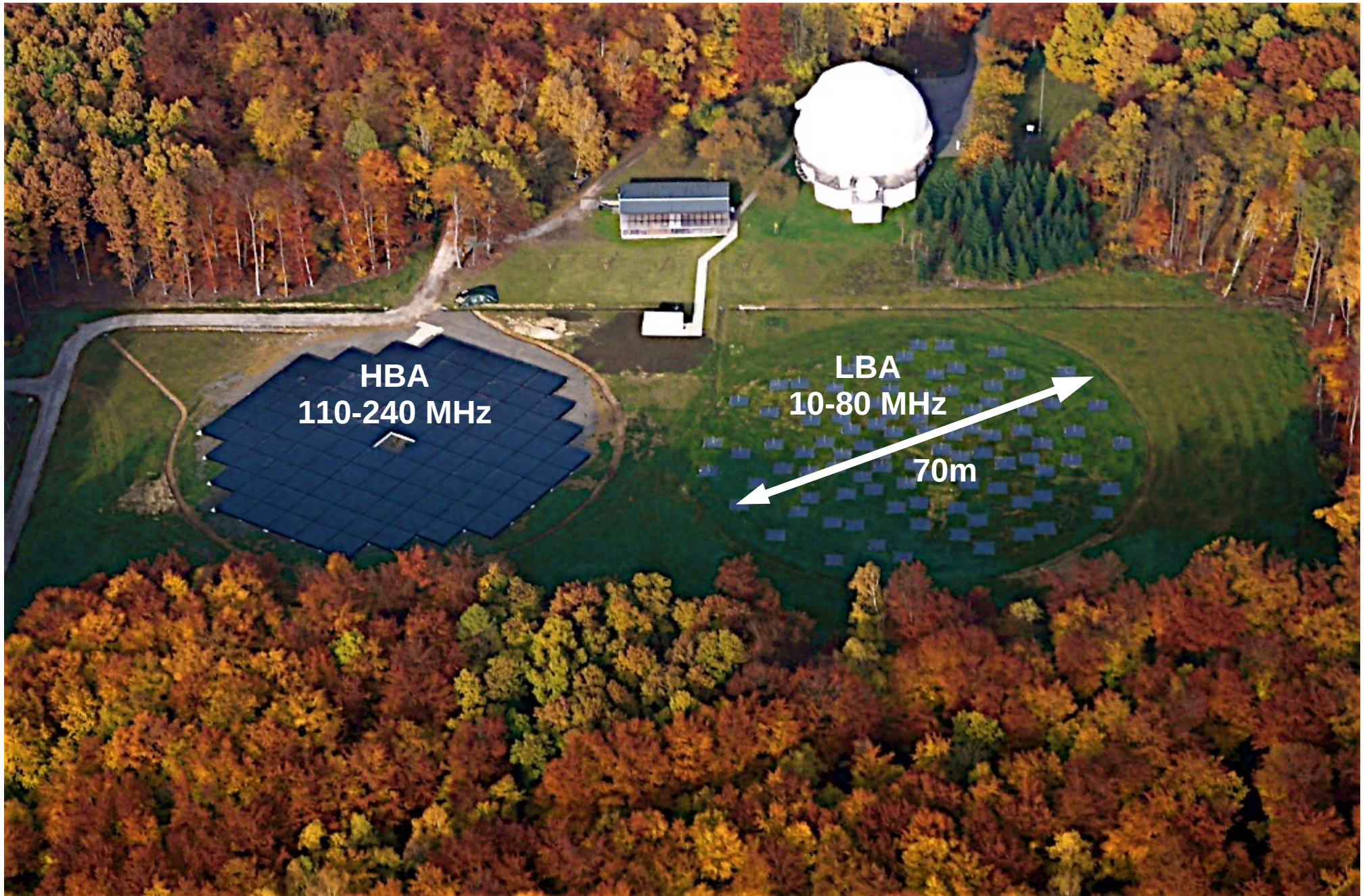
Nançay

Unterweilenbach

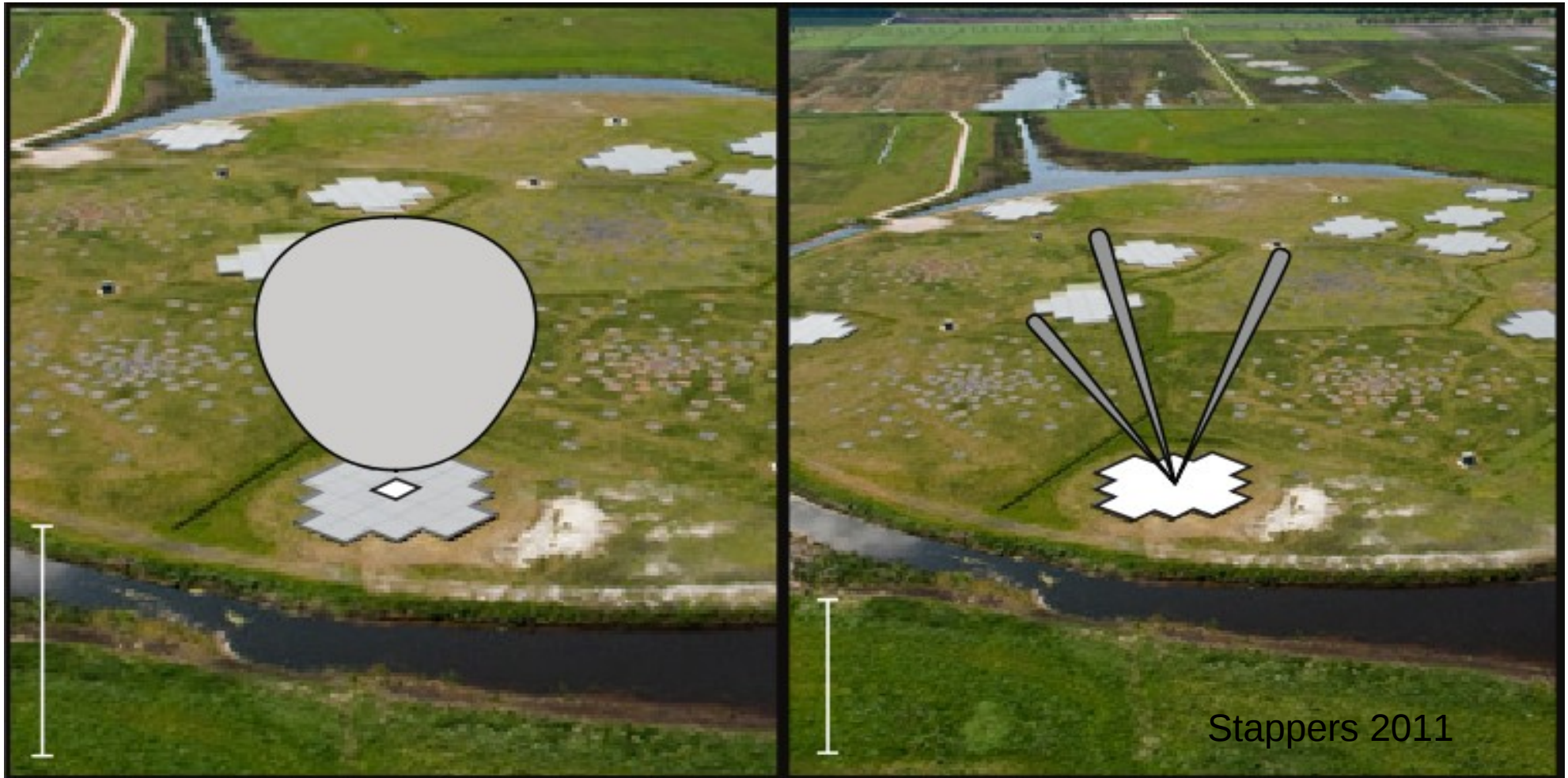


Nançay station

LOFAR station are phased arrays



LOFAR station are phased arrays



- We can point at different directions at the same time :**
- Great for transient studies
 - Cover big areas on the sky
 - Calibration

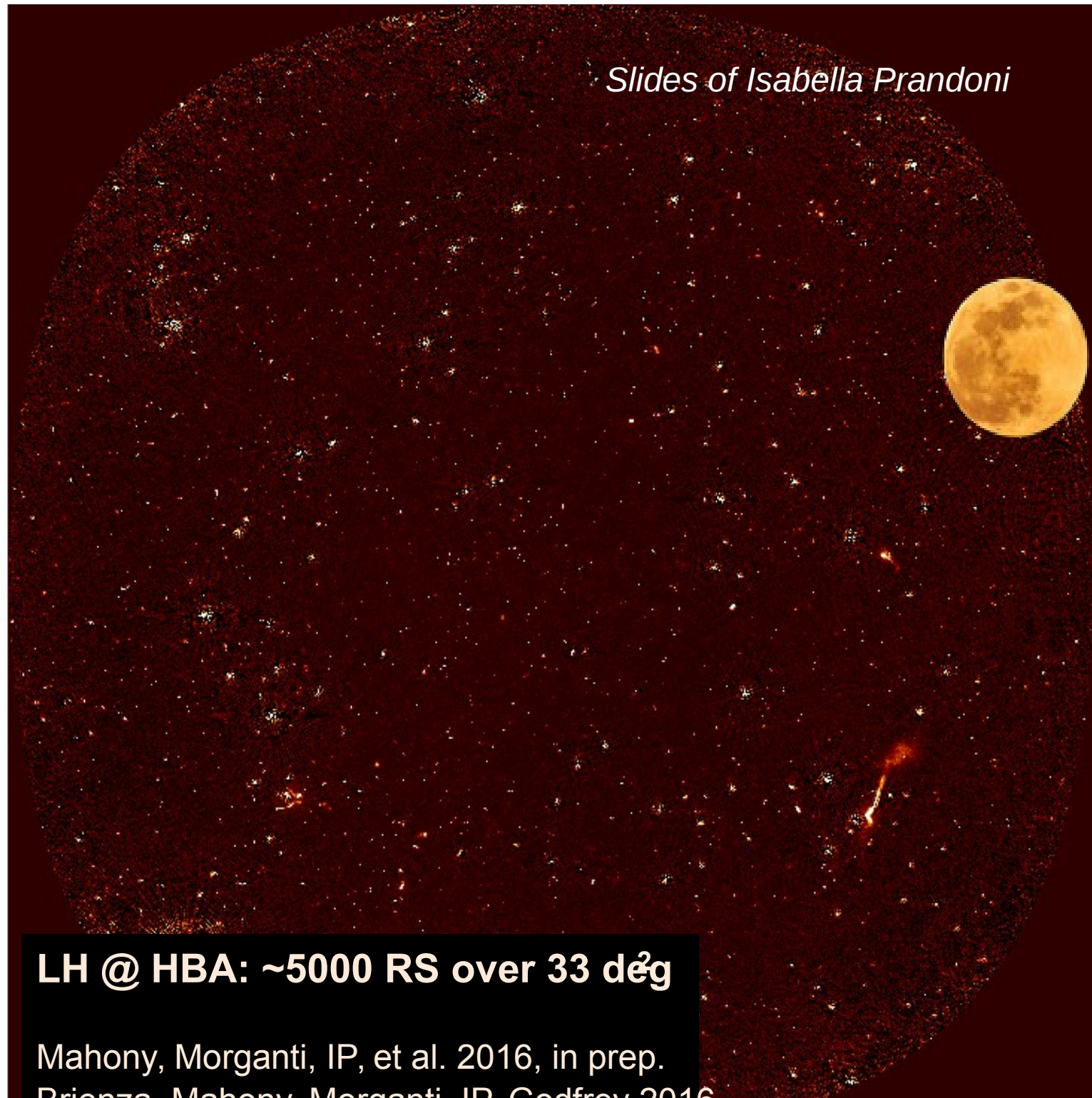
Why LOFAR Surveys?

- Large FoV:
>30 deg² @ HBA
- Sensitivity:
10h @ HBA
100 uJy rms
[EMU: 10 uJy @1.4 GHz]
- Resolution:
NL 5" @ HBA
ILT 0.5" @ HBA
[~100 pc scale @z~0
few kpc scale @ z>1]
- New spectral window(+ Surface Brightness)

LH @ HBA: ~5000 RS over 33 deg²

Mahony, Morganti, IP, et al. 2016, in prep.
Brienza, Mahony, Morganti, IP, Godfrey 2016

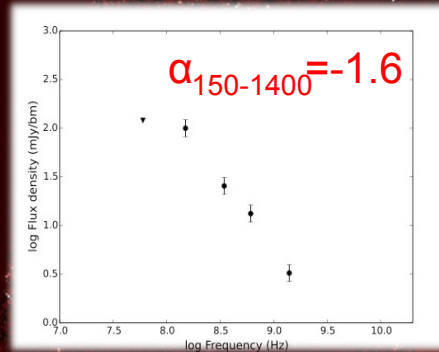
Slides of Isabella Prandoni



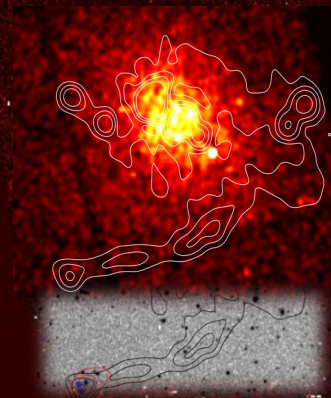
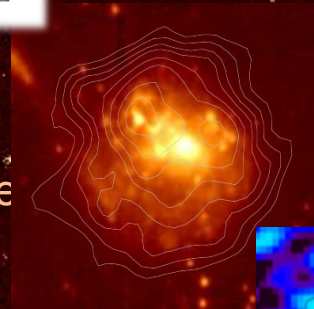
Why LOFAR Surveys?

- Large FoV:
>30 deg² @ HBA
- Sensitivity:
10h @ HBA
100 uJy rms
[EMU: 10 uJy @1.4 GHz]
- Resolution:
NL 5" @ HBA
ILT 0.5" @ HBA
[~100 pc scale @z~0
few kpc scale @ z>1]
- New spectral window(+ Surface Brightness)

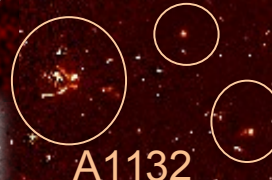
Slides of Isabella Prandoni



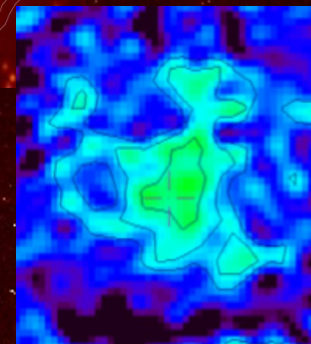
USS
z>4th
candidate



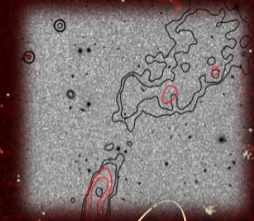
NGC3445



A1132



AGN Remnant



GRG HB13

LH @ HBA: ~5000 RS over 33 deg²

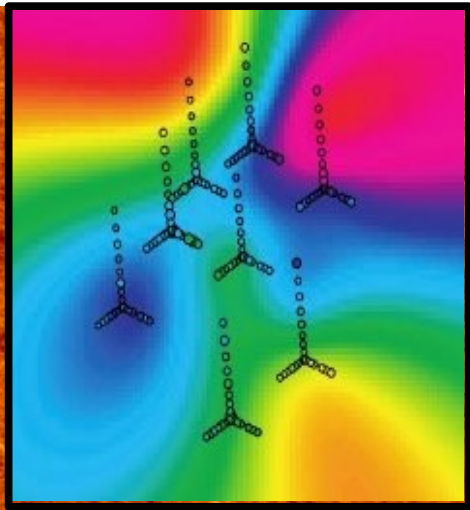
Mahony, Morganti, IP, et al. 2016, in prep.

Brienza, Mahony, Morganti, IP, Cadzow 2016

LOFAR Surveys Key Science Project

- PI: Huub Röttgering
- Highest redshift radio sources: George Miley
- Clusters and cluster halo sources: Gianfranco Brunetti & Marcus Brüggen
- Starforming galaxies at moderate and high redshifts: Peter Barthel & Matt Lehnert
- AGN at moderate redshift: Philip Best
- Detailed studies of low-redshift AGN: Raffaella Morganti
- Nearby Galaxies: Krzysztof Chyży & John Conway
- Galactic radio sources: Glenn White
- Cosmological studies: Matt Jarvis
- 164 members from 54 institutions.

3rd generation calibration on the Bootes field : 8 hours integration with LOFAR@~150MHz



Ionospheric
disturbance + Faraday
rotation



Station lobes



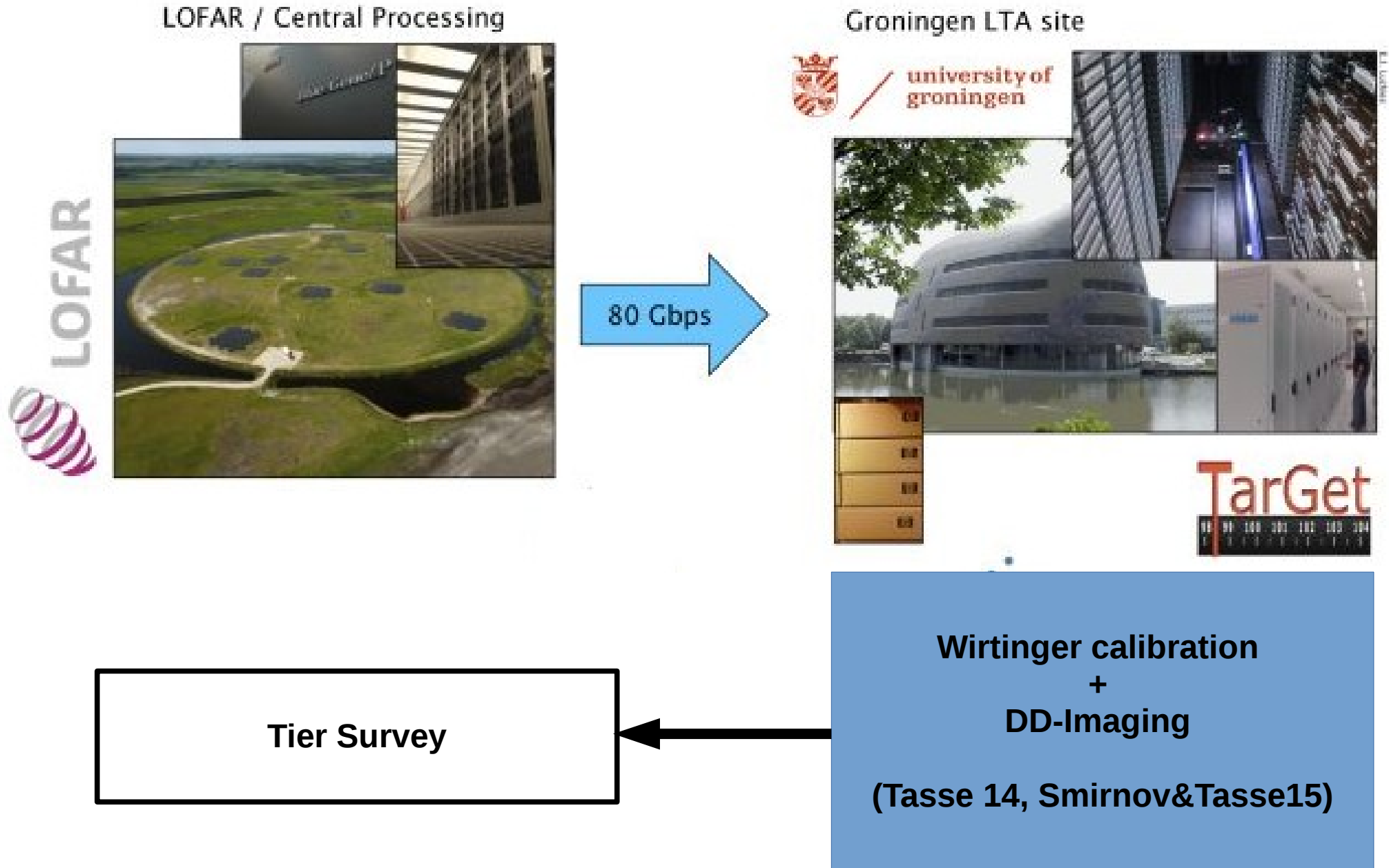
The best one can
get with DI self
calibration

3rd generation calibration on the Bootes field : 8 hours integration with LOFAR@~150MHz

With Wirtinger
calibration and
imaging

~ 100 μ Jy/Beam rms

Wirtinger pipeline developed @OP/GEPI for LOFAR production mode



LOFAR Survey KSP – Tiered Strategy

- **Tier 1:** All Sky (2π sr) @ LBA & HBA; ~ 100 $\mu\text{Jy/b}$ rms @HBA; $\sim 10\times$ @ LBA

Science Drivers: Rare populations; Galaxy/Local Universe; Cosmology; EoR

- **Tier 2:** 25 fields @ HBA & LBA
(clusters, nearby gals/AGN, blank)
 ~ 25 $\mu\text{Jy/b}$ rms @ HBA

$10\times$ @ LBA $10 M_{\text{solar}}/\text{yr}$ @ $z=1$

Science Drivers:

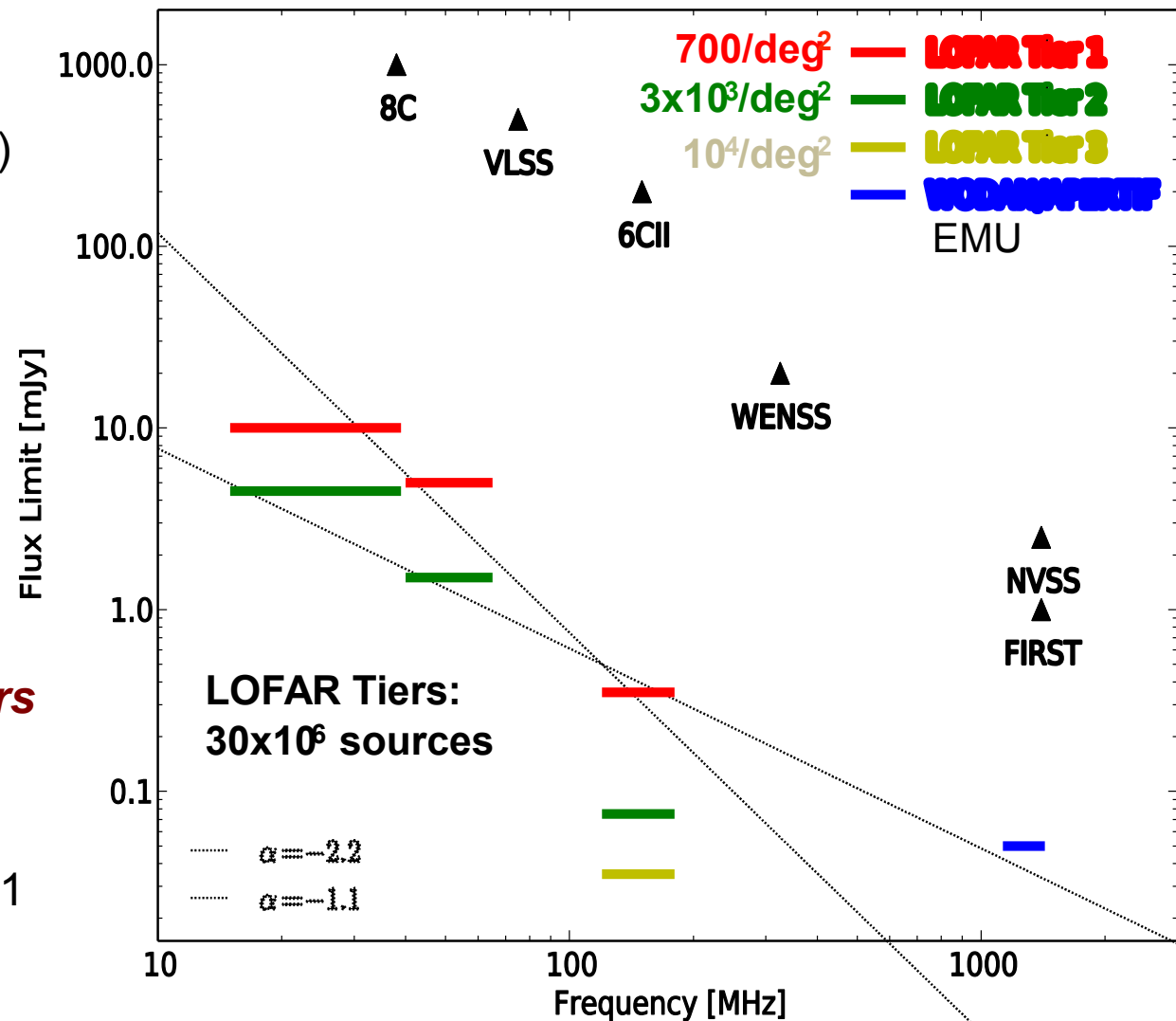
Detailed physics; SF/AGN ev.

- **Tier 3:** 5 deep fields @ HBA
rms ~ 5 $\mu\text{Jy/b}$ @ HBA $10^4/\text{deg}^2$

Science Drivers: SF/AGN ev.

To be completed within next 5 years

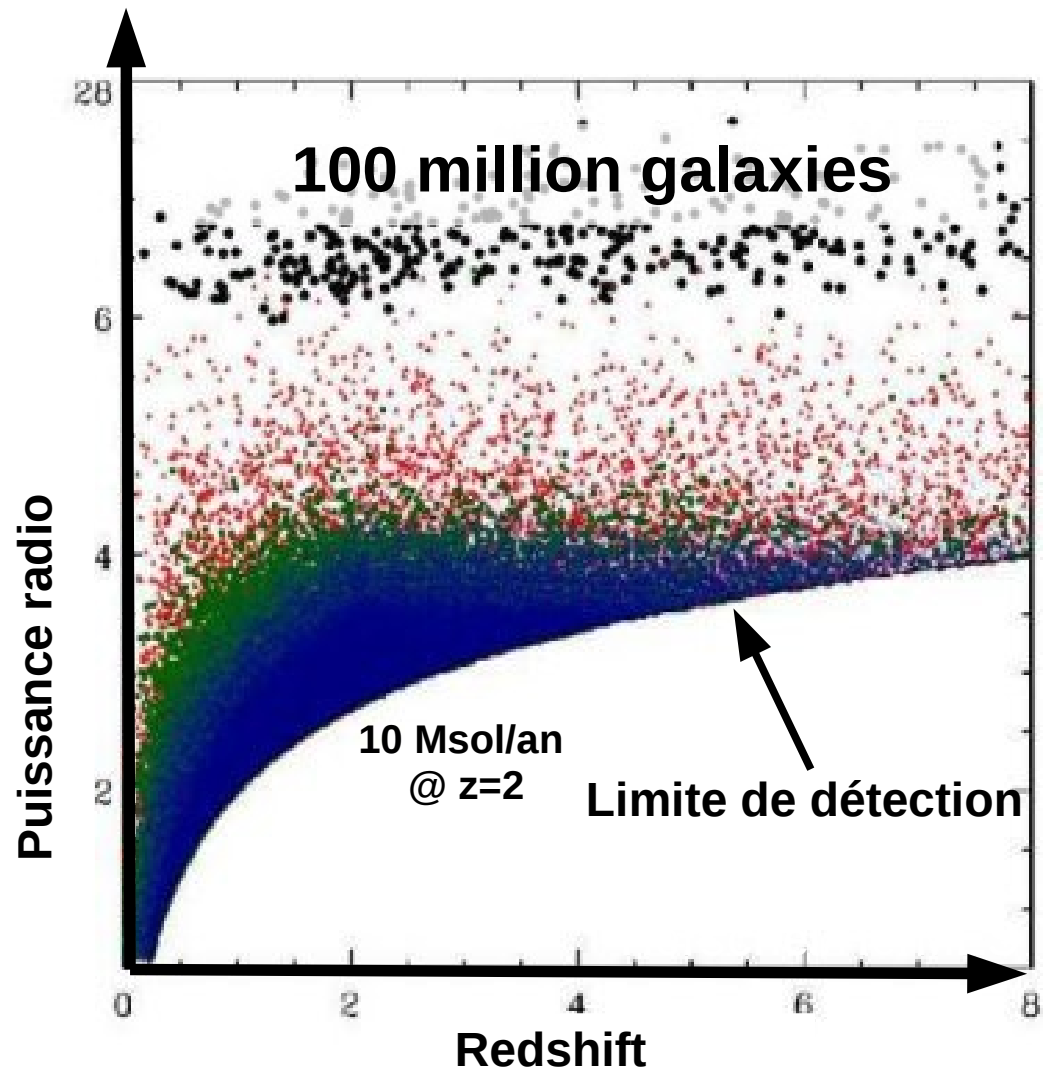
Details: Röttgering et al. 2011



LOFAR Survey KSP – Tiered Strategy

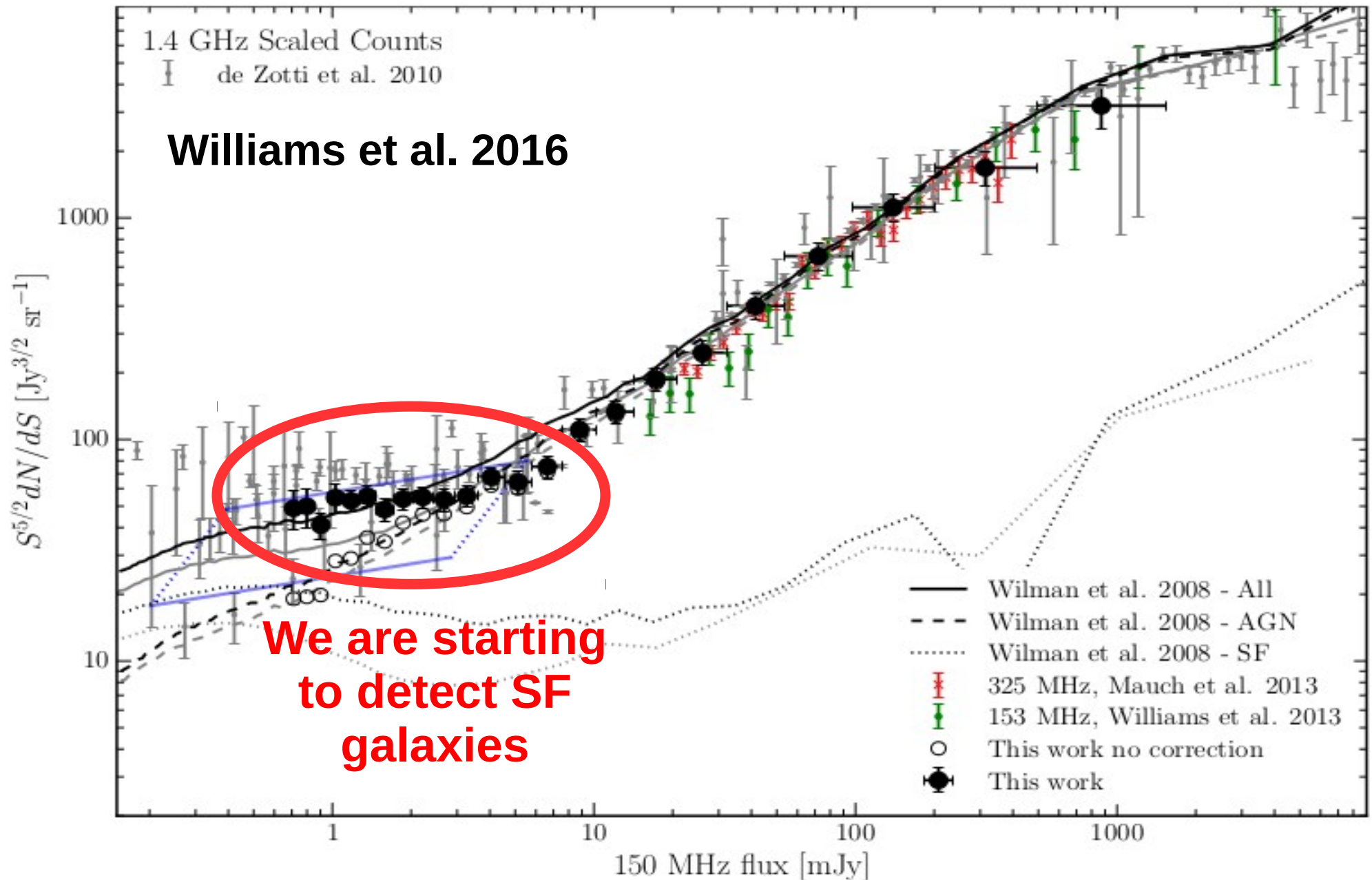
- **Tier 1:** All Sky (2π sr) @ LBA & HBA; ~ 100 $\mu\text{Jy/b}$ rms @HBA; $\sim 10\times$ @ LBA
Science Drivers: Rare populations; Galaxy/Local Universe; Cosmology; EoR
- **Tier 2:** 25 fields @ HBA & LBA
(clusters, nearby gals/AGN, blank)
 ~ 25 $\mu\text{Jy/b}$ rms @ HBA
 $10\times$ @ LBA $10 M_{\text{solar}}/\text{yr}$ @ $z=1$
Science Drivers: Detailed physics; SF/AGN ev.
- **Tier 3:** 5 deep fields @ HBA
rms ~ 5 $\mu\text{Jy/b}$ @ HBA $10^4/\text{deg}^2$
Science Drivers: SF/AGN ev.
To be completed within next 5 years

Details: Röttgering et al. 2011



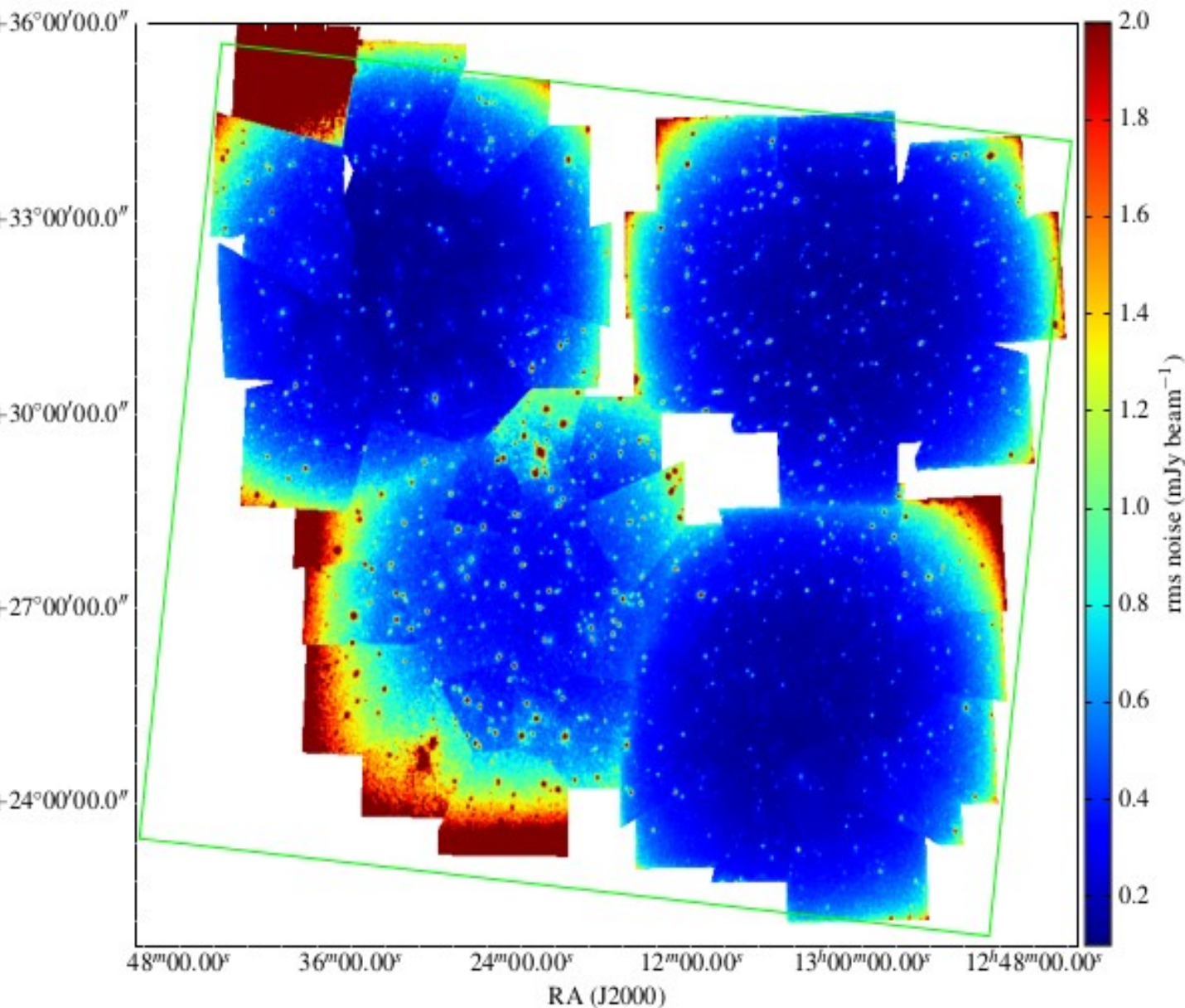
Where we are analysing the LOFAR
surveys data

Euclidian normalised differential source count



LOFAR survey of HATLAS

(Hardcastle et al. 2016 in prep.)



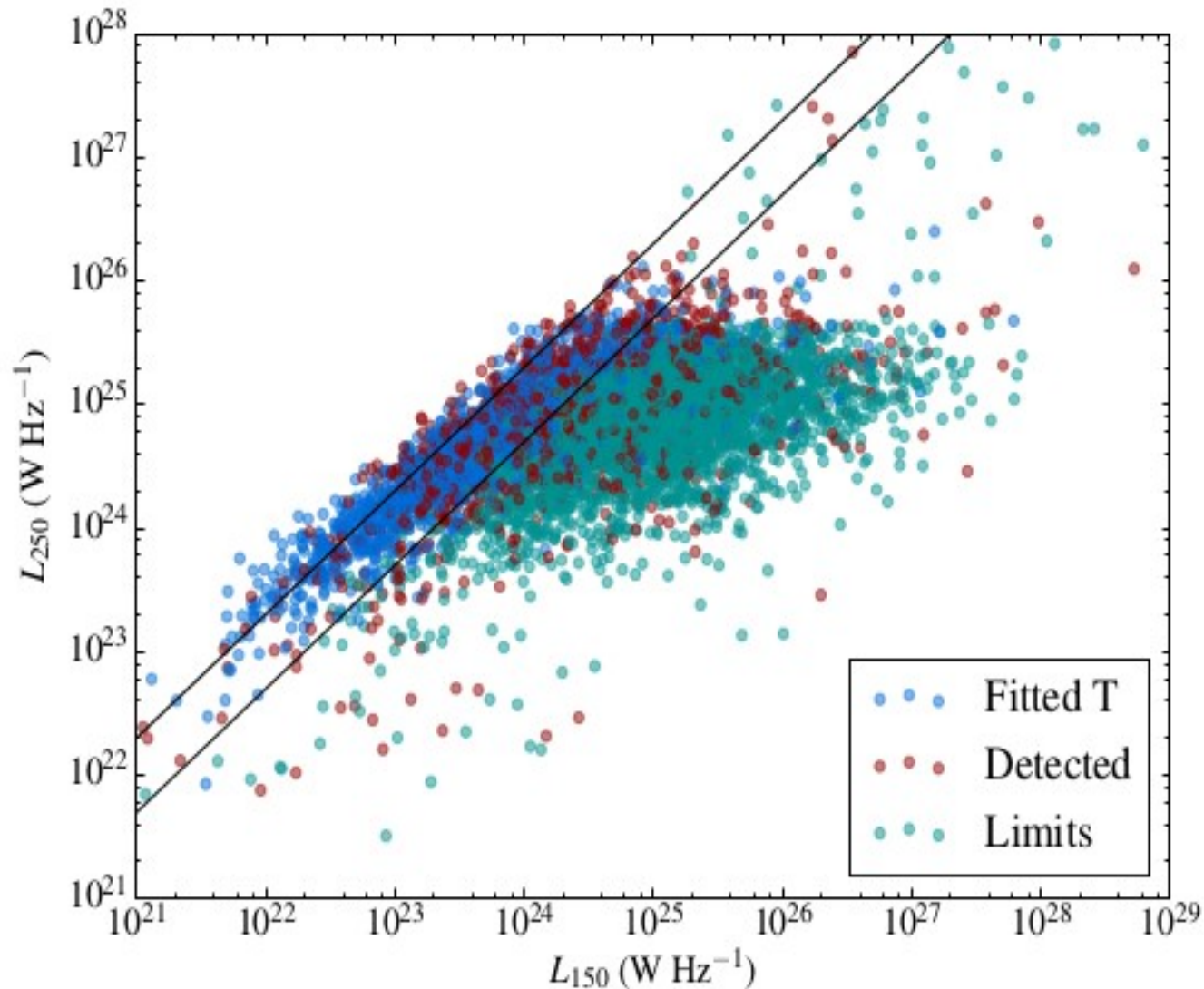
**Herschel-ATLAS North
Galactic Pole survey area
(up to 500 μm with SPIRE)**

+

**LOFAR @150 MHz
($\sim 100 \mu\text{Jy/beam rms}$)**

Disentangling Star formation and AGN activity

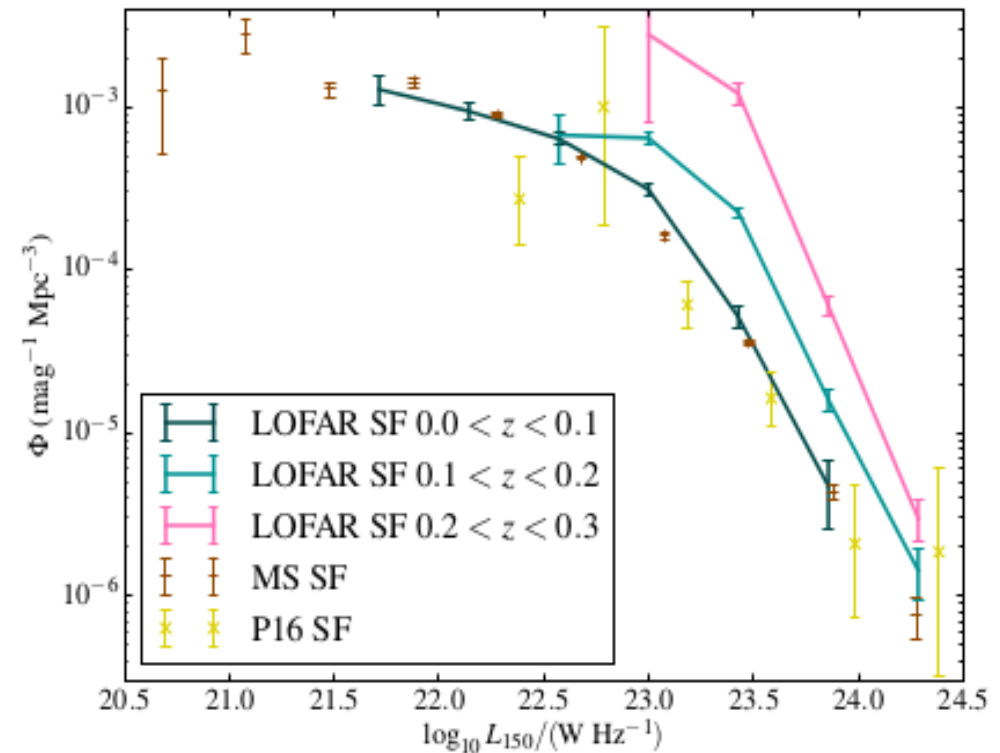
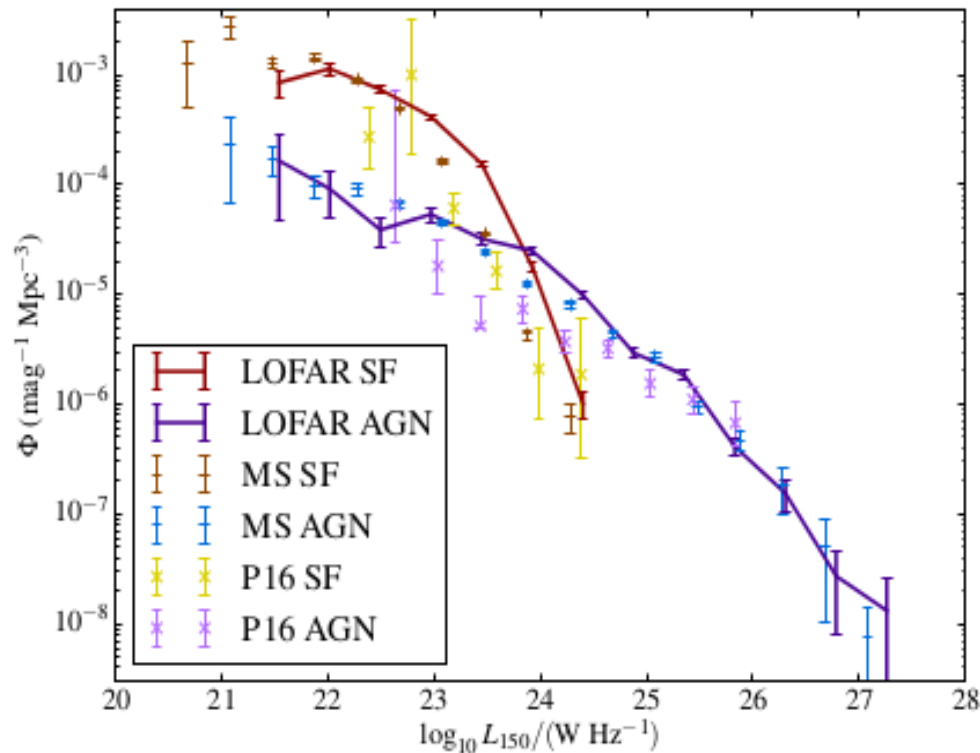
(Hardcastle et al. 2016 in prep.)



- Radio-FIR correlation
- Spectroscopy with SDSS and GAMA data
- Mix of AGN/SF galaxies
- Radio « quiet » AGN are detected

Disentangling Star formation and AGN activity

(Hardcastle et al. 2016 in prep.)



- (local) AGN & SF galaxies Luminosity function in agreement with previous results
- Strong evolution of SF luminosity functions with redshift

Follow up of LOFAR samples

- WEAVE**

- MOONS ?**



What is WEAVE?

The WHT Enhanced Area Velocity Explorer

- A multi-object spectrograph, with:
 - 1,000 x 1.3" fibres
 - 2 deg diameter field of view
 - $R=5,000$ with coverage from 370nm to $1\mu\text{m}$
 - $R=20,000$ with reduced coverage
 - mIFU and LIFU modes
 - See Dalton et al. (2012) for details
- First light in 2017, then five years of survey operations. *One of the primary surveys that it will do is follow-up of LOFAR targets*
- www.ing.iac.es/weave/



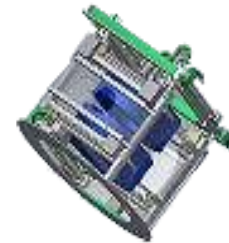
WEAVE mounted on WHT



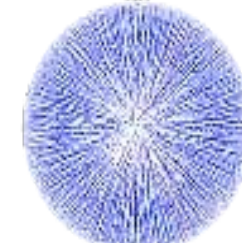
Installation of WEAVE



New prime focus corrector



Twin-robot fibre positioner, and tumbler



MOS: ~1000 science targets per observation



IFUs: 20 mIFU 11" x 12"; or 1 LIFU 78" x 90"



Double arm spectrograph



Low resolution ($R=5000$)



High resolution ($R=20,000$)

Weave Preliminary allocations

Note: based on 5-year survey at 236 nights/year, 7 hours/night, 950 fibres/hour

Survey	Fibre hours (1000's h)
Galactic Archaeology	4600
SCIP	750
Clusters	750
Galaxy Evolution	435
LOFAR	1000
QSO	350

What is WEAVE?

The WHT Enhanced Area Velocity Explorer

WEAVE-LOFAR represents a unique capability in the Northern hemisphere

Spectroscopic follow-up of:

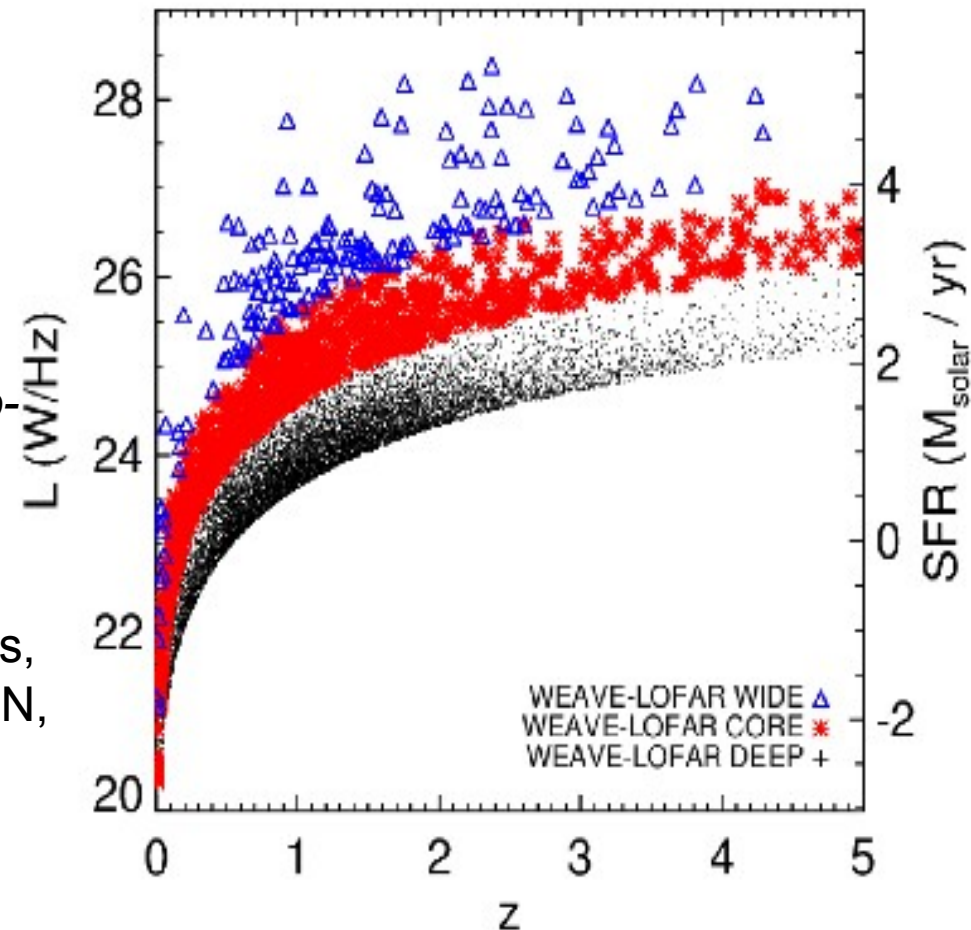
- 100,000s of LOFAR-selected sources
- in three tiers

We will get a *complete picture of SF and AGN co-evolution since $z < 1.3$ and $z > 2$*

- *(and a lot more!)*

Fields include: ELAIS-N1, Lockman Hole, Bootes, XMM-LSS, COSMOS, HATLAS-NGP, HETDEX-N, etc

First light: end of 2017 then 5 years of surveys

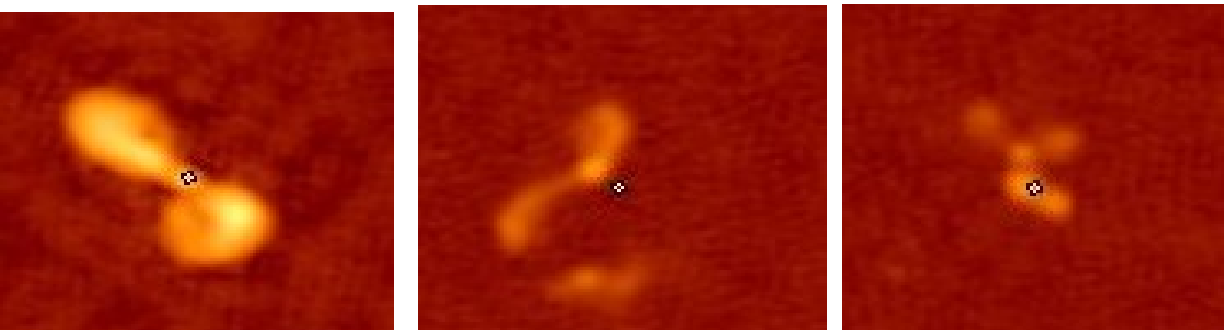
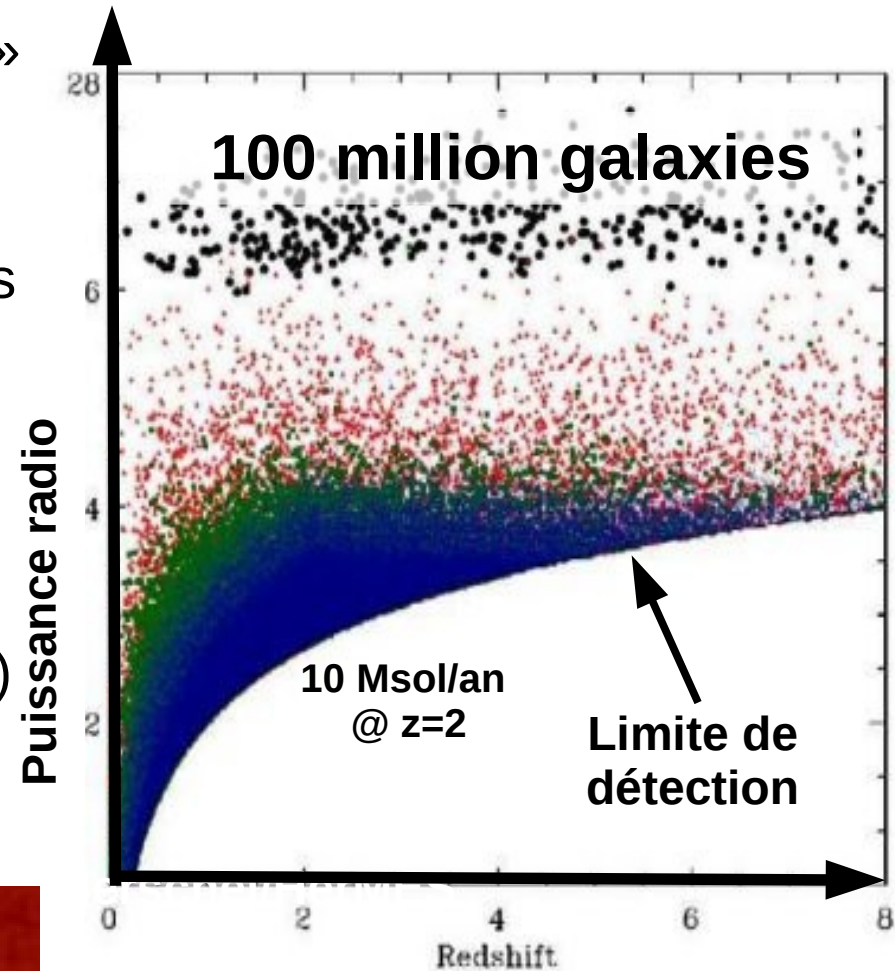


MOONS

- MOONS would be useful for follow up of deep Tier-3 LOFAR surveys ($1 < z < 3$ obs. cosmology)
- Independent SFR indicator based on emission lines (?)
- (Better complement of MeerKAT Mightee surveys ?)
- XMM-LSS, Cosmos, Bootes, etc.
- FIR data (Herschell) is probably mandatory

Conclusion

- Sensitive new radio telescope = new algorithms
- We are currently surveying many « famous » fields (BOOTES, HATLAS, GrothStrip, ELAIS-N,), etc etc
- We are building the Tier-1 ~1000 sq degrees survey, for which we will have ~1000 hours on WEAVE
- We aim at integrating much longer (up to ~200 hours/ pointing) : BOOTES, ELAIS
- MOONS follow up of (LOFAR/MeerKAT) +Herschell southern field would be great (Coordination with Mightee survey ?)



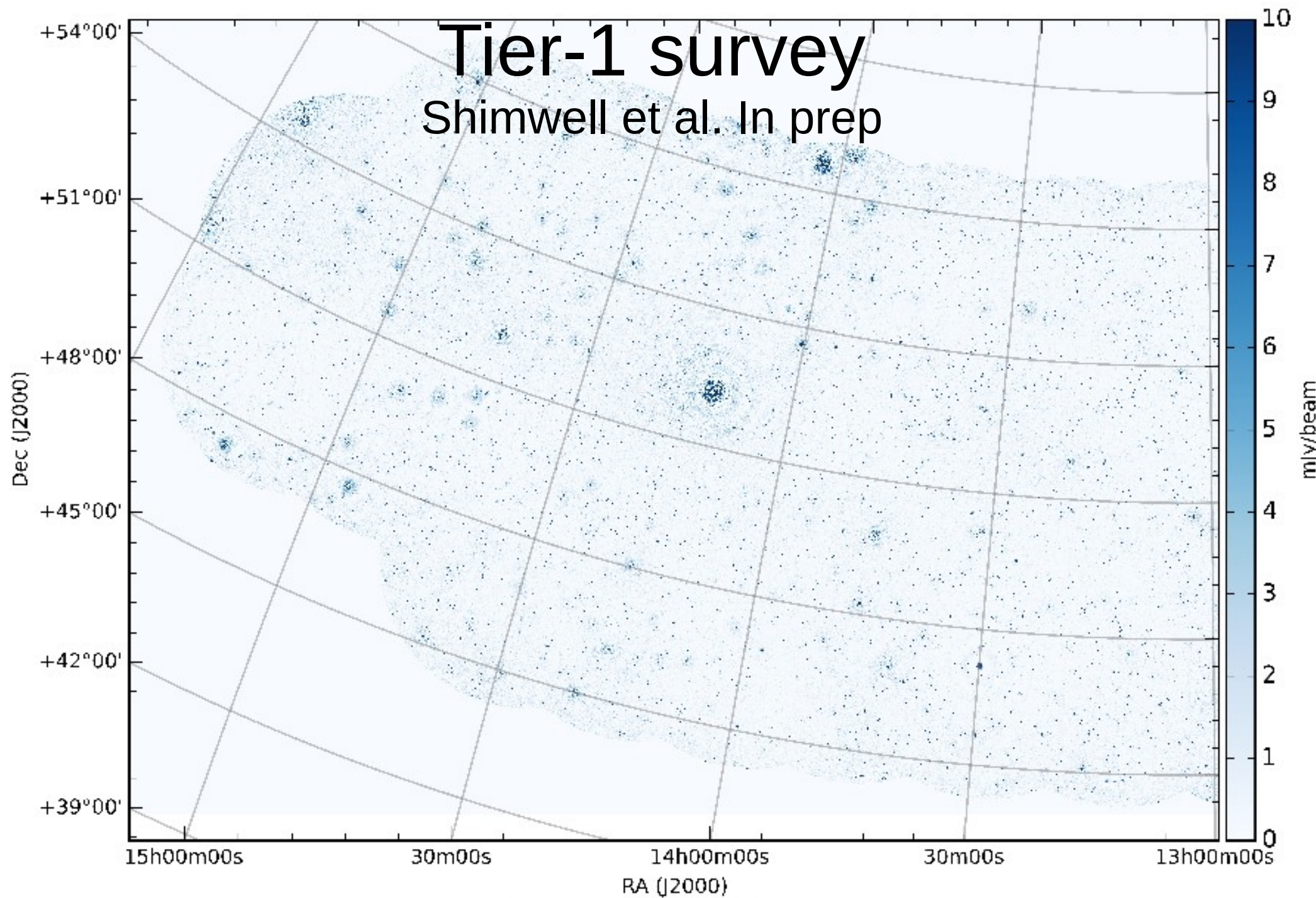
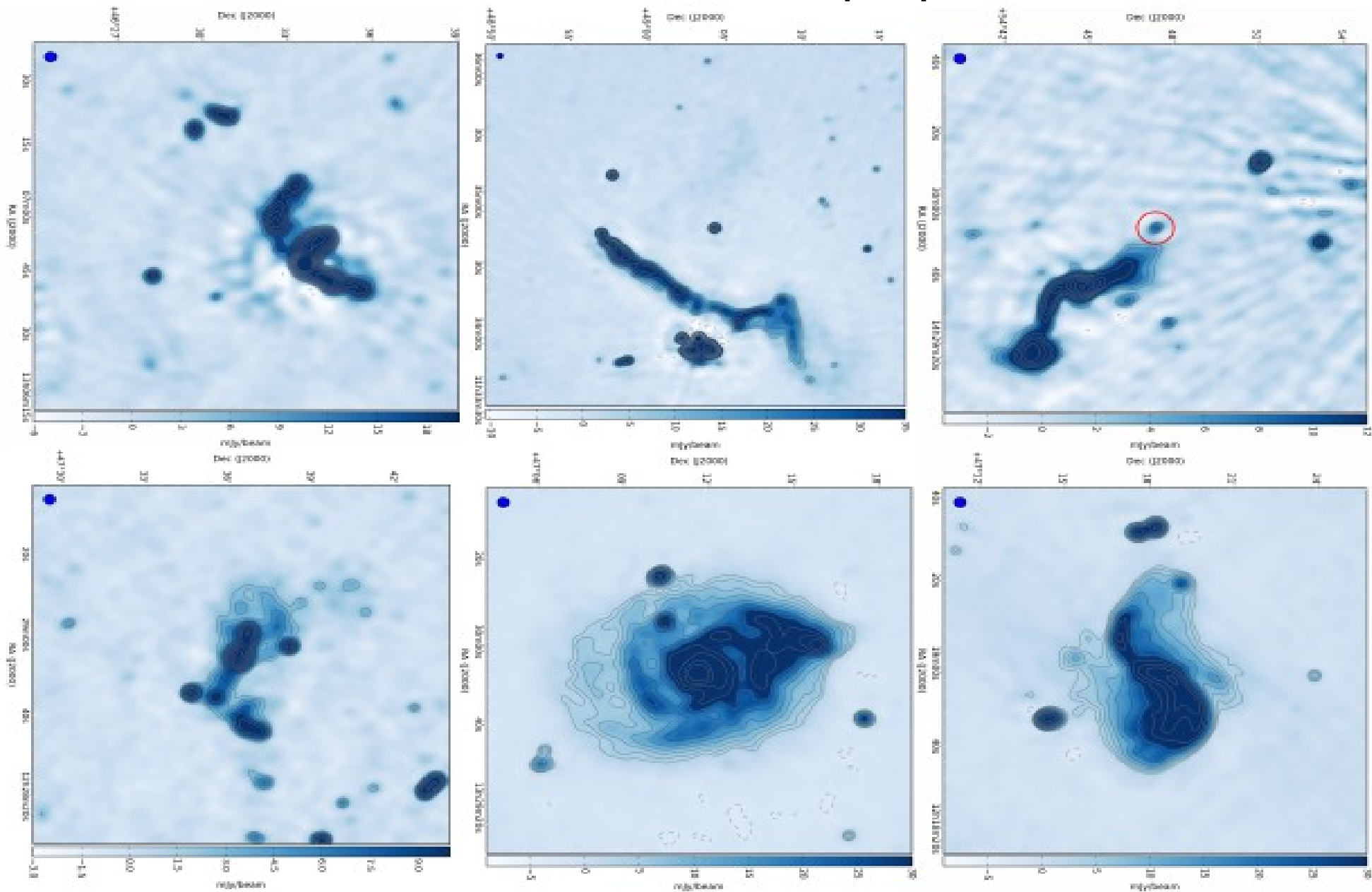


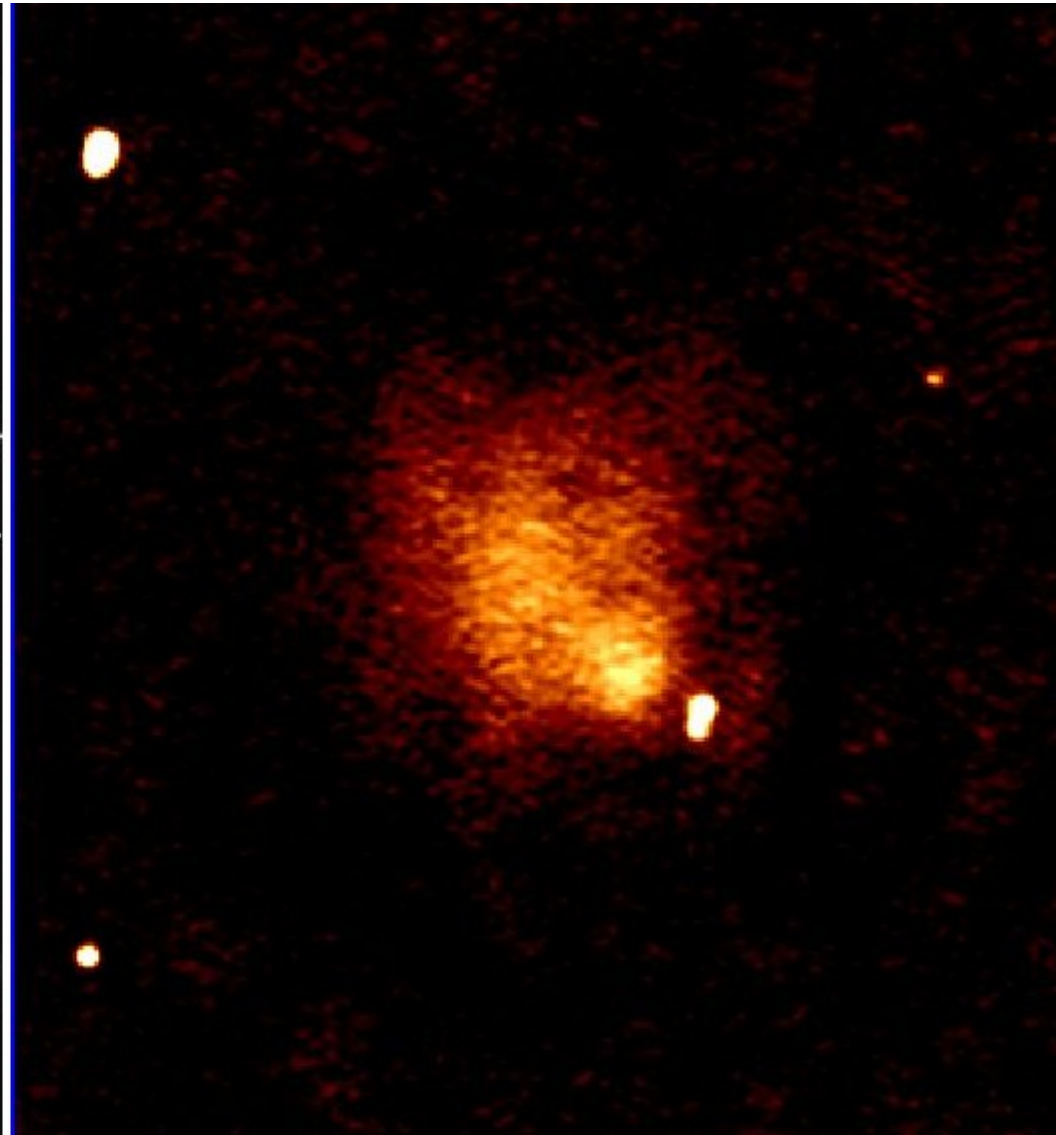
Figure 15: The eastern half of the HETDEX Spring Field.

Tier-1 survey

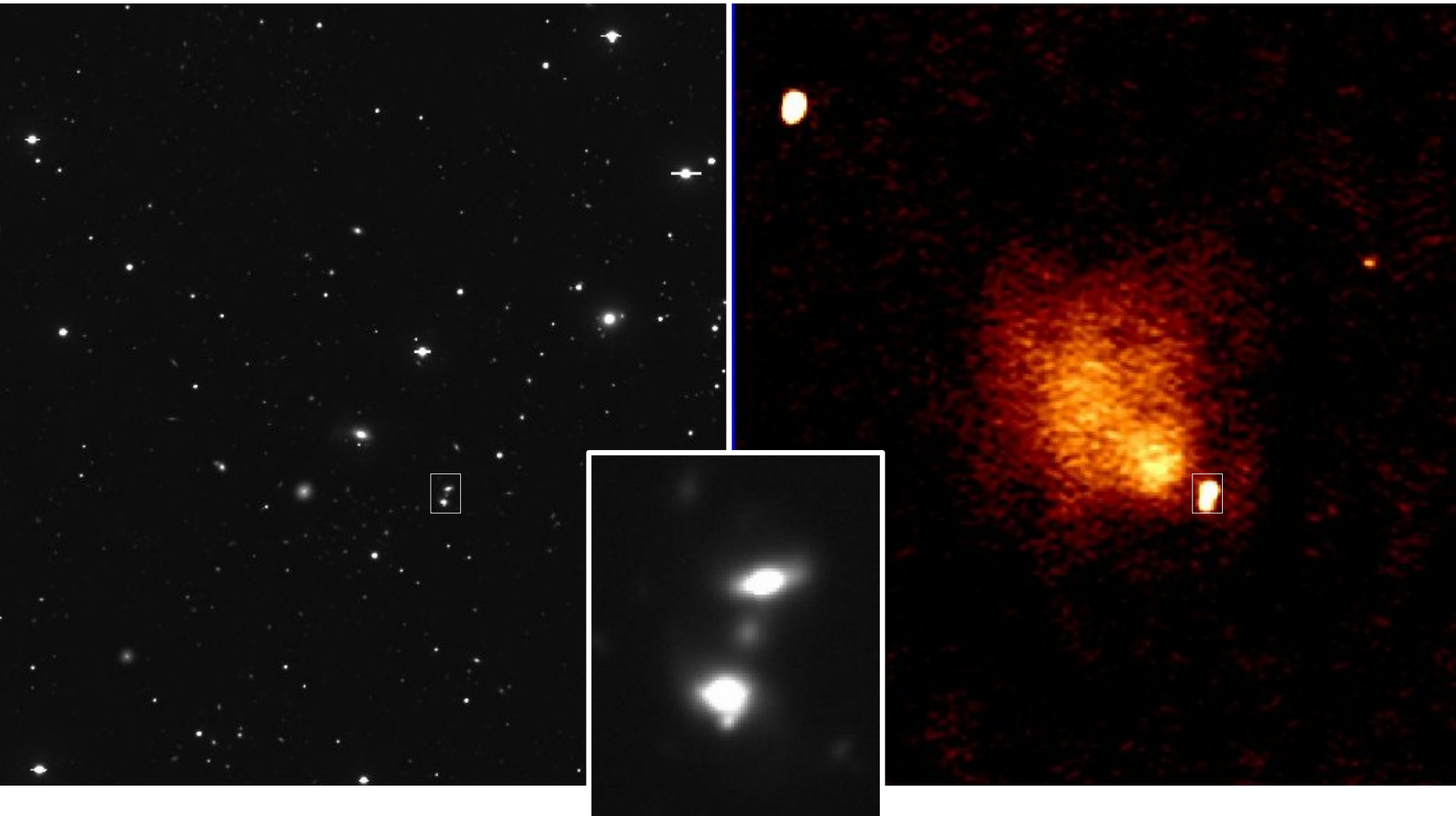
Shimwell et al. In prep



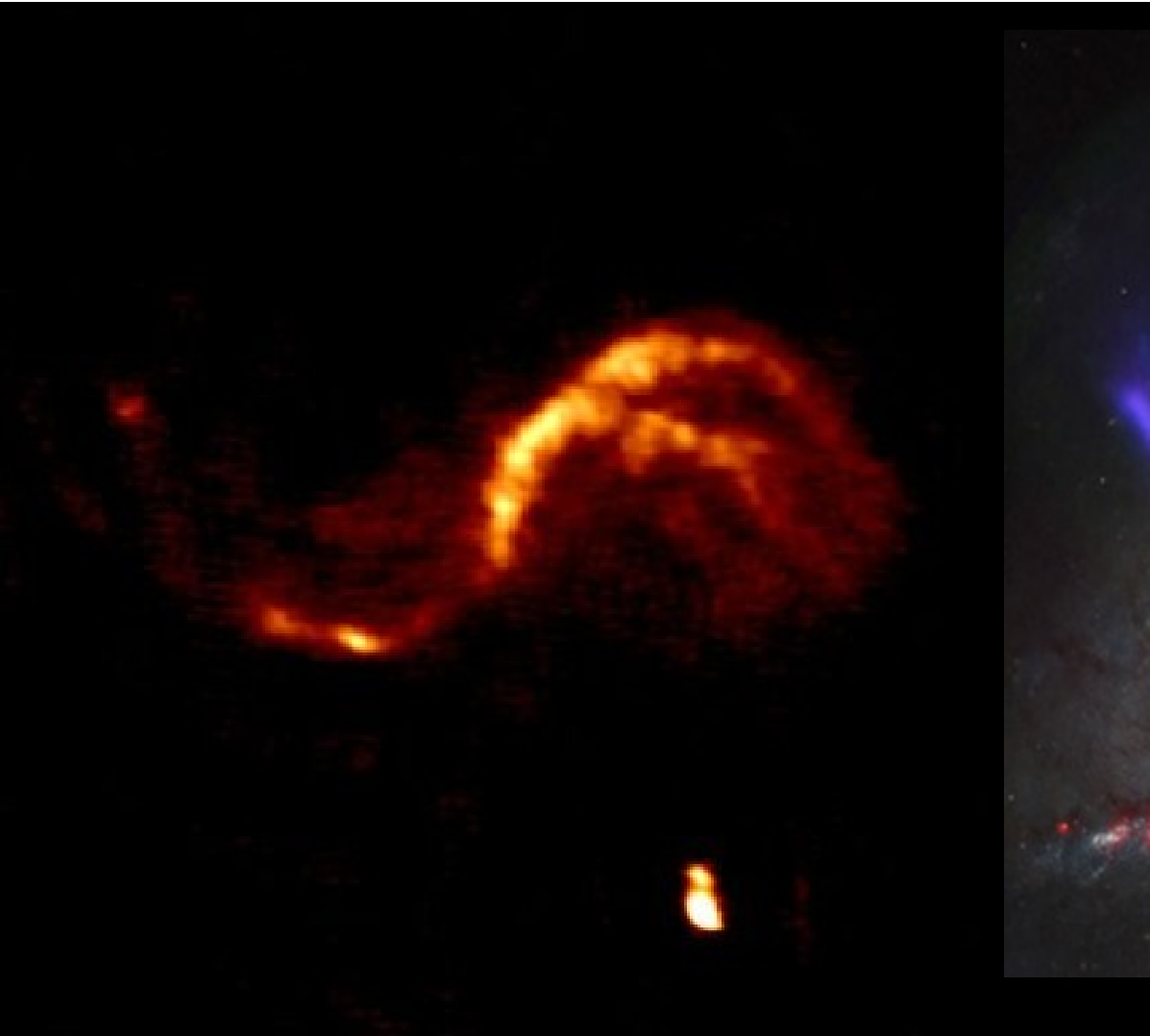
Somewhere in the Bootes field ...



Somewhere in the Bootes field ...



NGC 4258 (M106)



LOFAR ~ 130 MHz

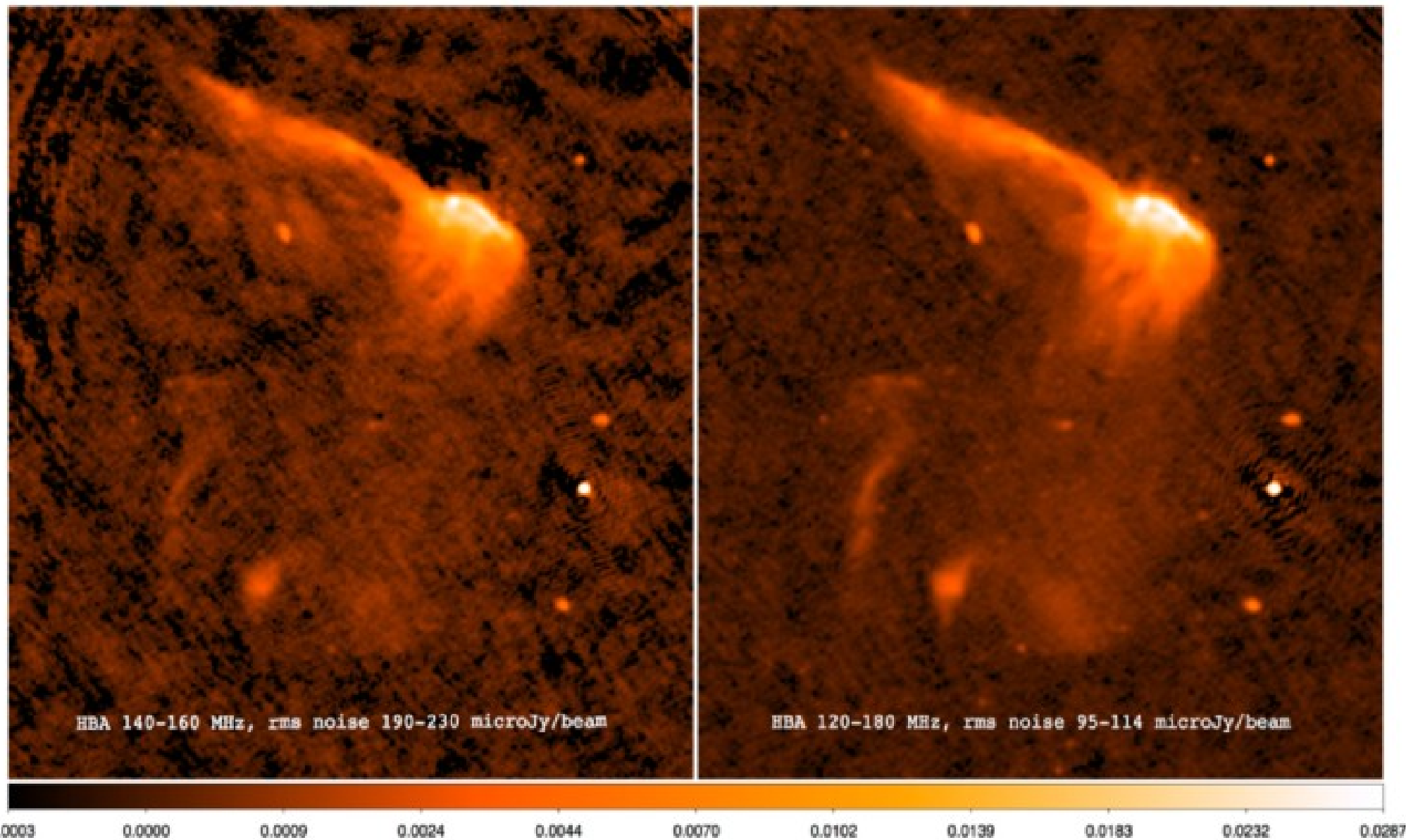


Optical + Chandra

Dataset from Tim Shimwell reduced with Wirtinger calibration

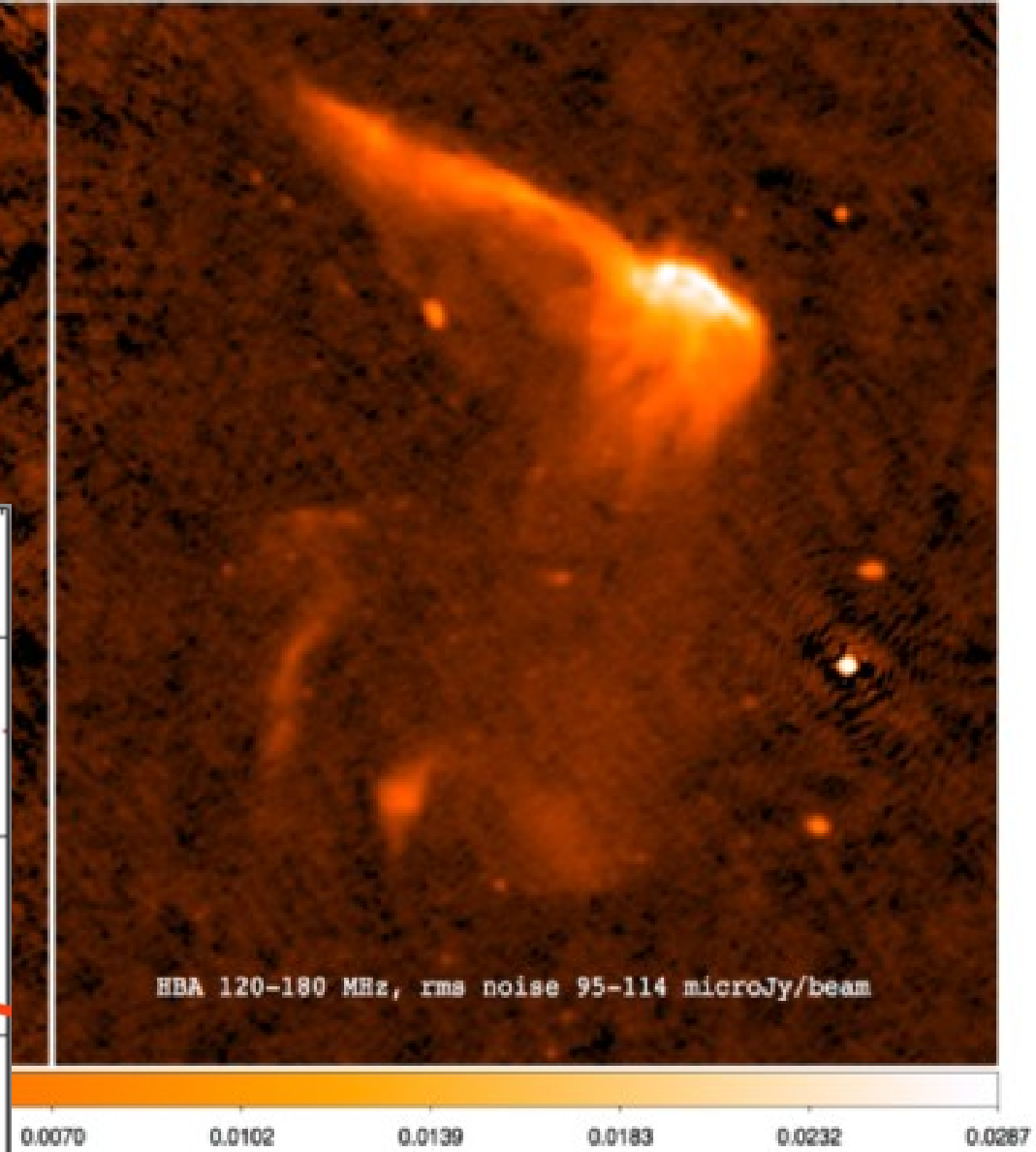
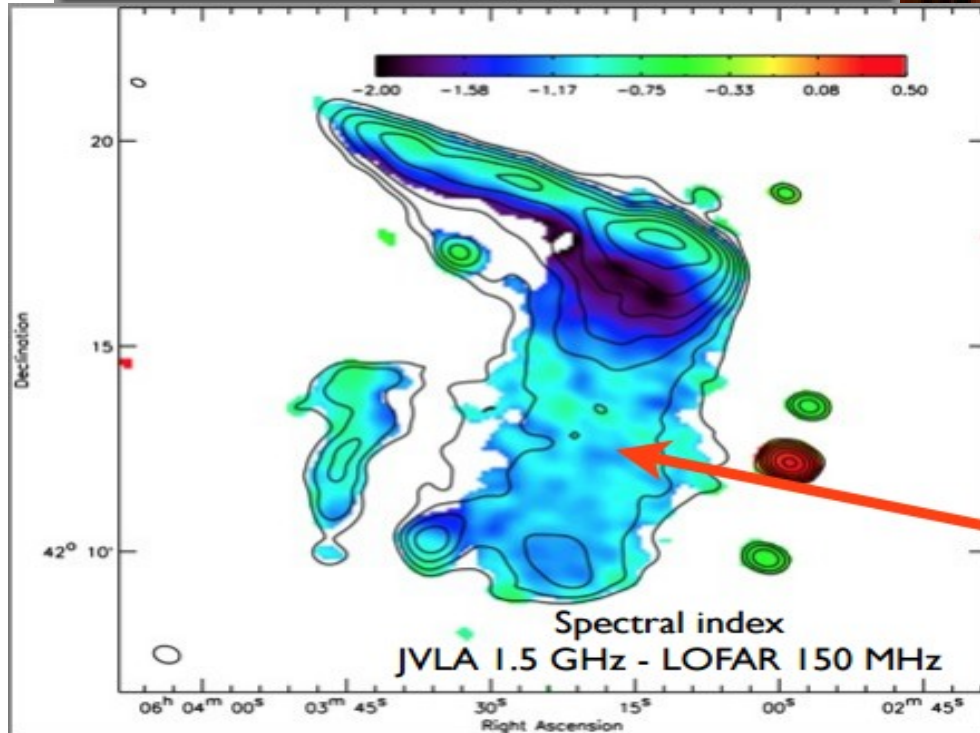
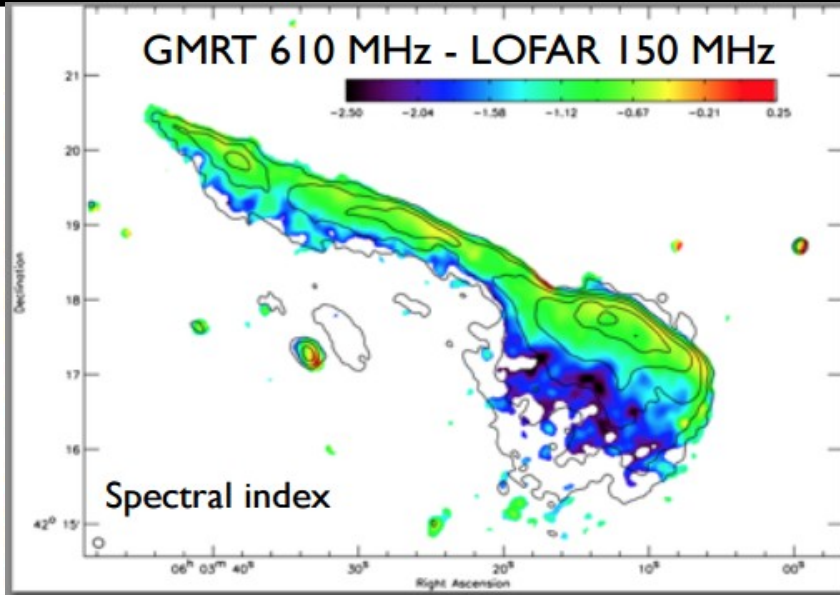
Toothbrush cluster

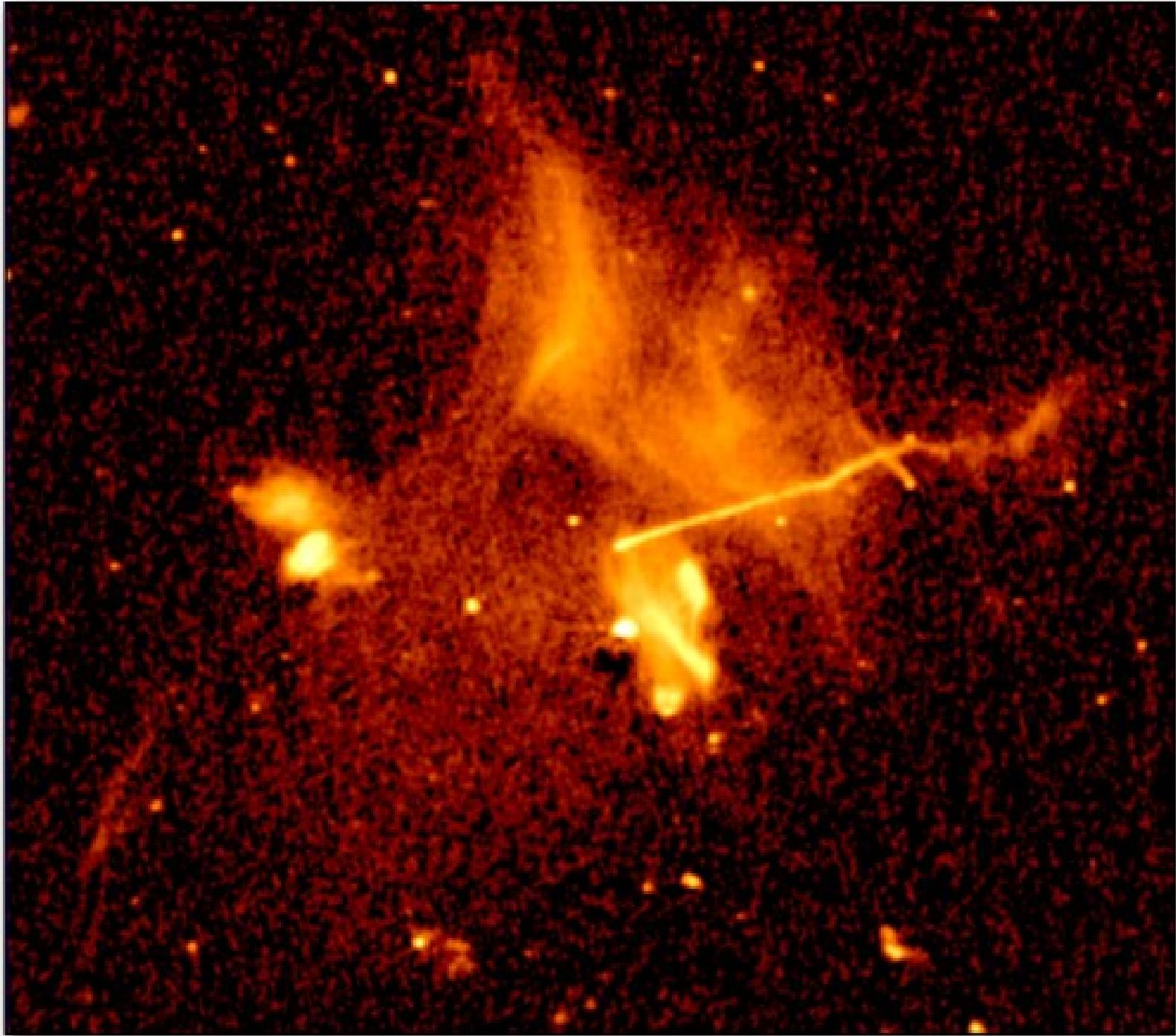
van Weeren 2014



Toothbrush cluster

van Weeren 2014





Abell 2256

120-180 MHz

5 arcsec

130 μ Jy/beam

*Image courtesy:
R. van Weeren*

... and slide
taken from
Chiara Ferarri