LOFAR Key Project "Surveys"
&
First Results on Galaxy Clusters

Chiara Ferrari

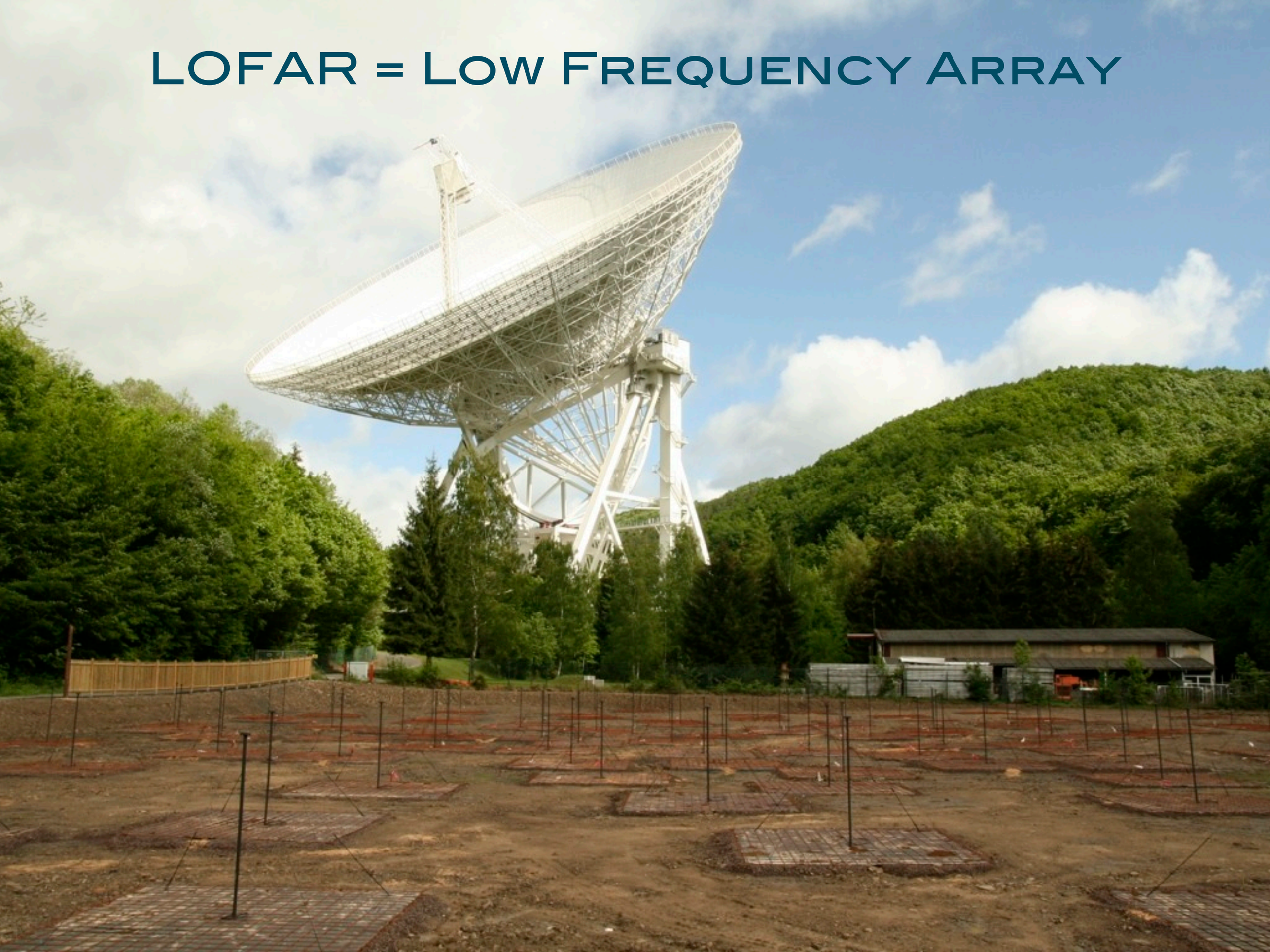
for the LOFAR Galaxy Cluster Working Group

P.I.s Brüggen & Brunetti

and the Surveys Commissioning Team

Batejat, Birzan, Bonafede, Conway, Ferrari, de Gasperin, Heald, Jackson, Macario, McKean, Orrù, Pizzo, Rafferty, Röttgering, Shulevsky, Tasse, Trasatti, Van Bemmel, van der Tol, van Weeren, van Zwieten, Wucknitz

LOFAR = Low Frequency Array



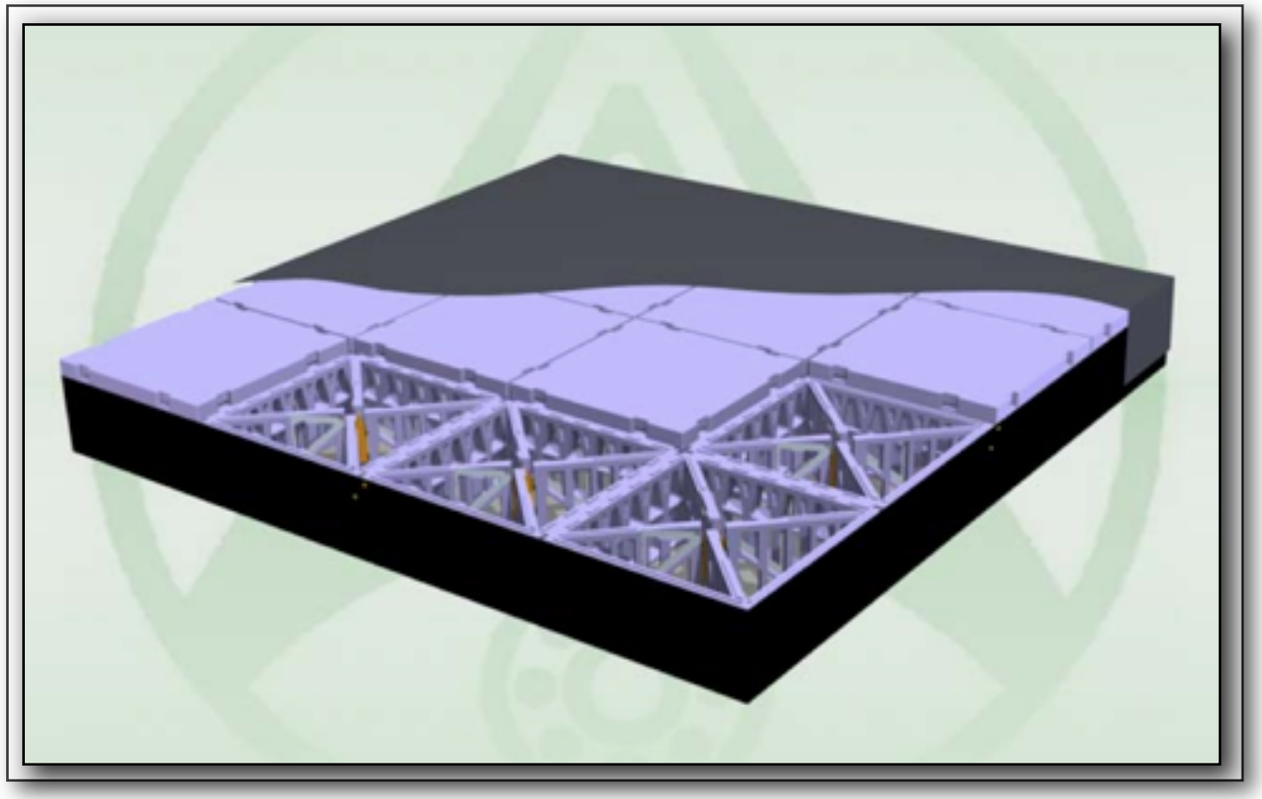
LOFAR = Low Frequency Array

Old !

New !

LOFAR ANTENNAS

Low band antenna: 30 – 80 MHz
48/96 antennas/station



High band tiles: 120 – 240 MHz
48/96 tile/station, 4x4 antennas/tile

- Huge parabolic antennas replaced by much cheaper simple dipoles
- 41 stations of dipoles in Holland & in Europe (one station ≡ hundreds of dipoles)
- No moving parts: the beam is formed in a digital and flexible way

LOFAR core region (The Netherlands)

LOFAR core region (The Netherlands)

Station LOFAR

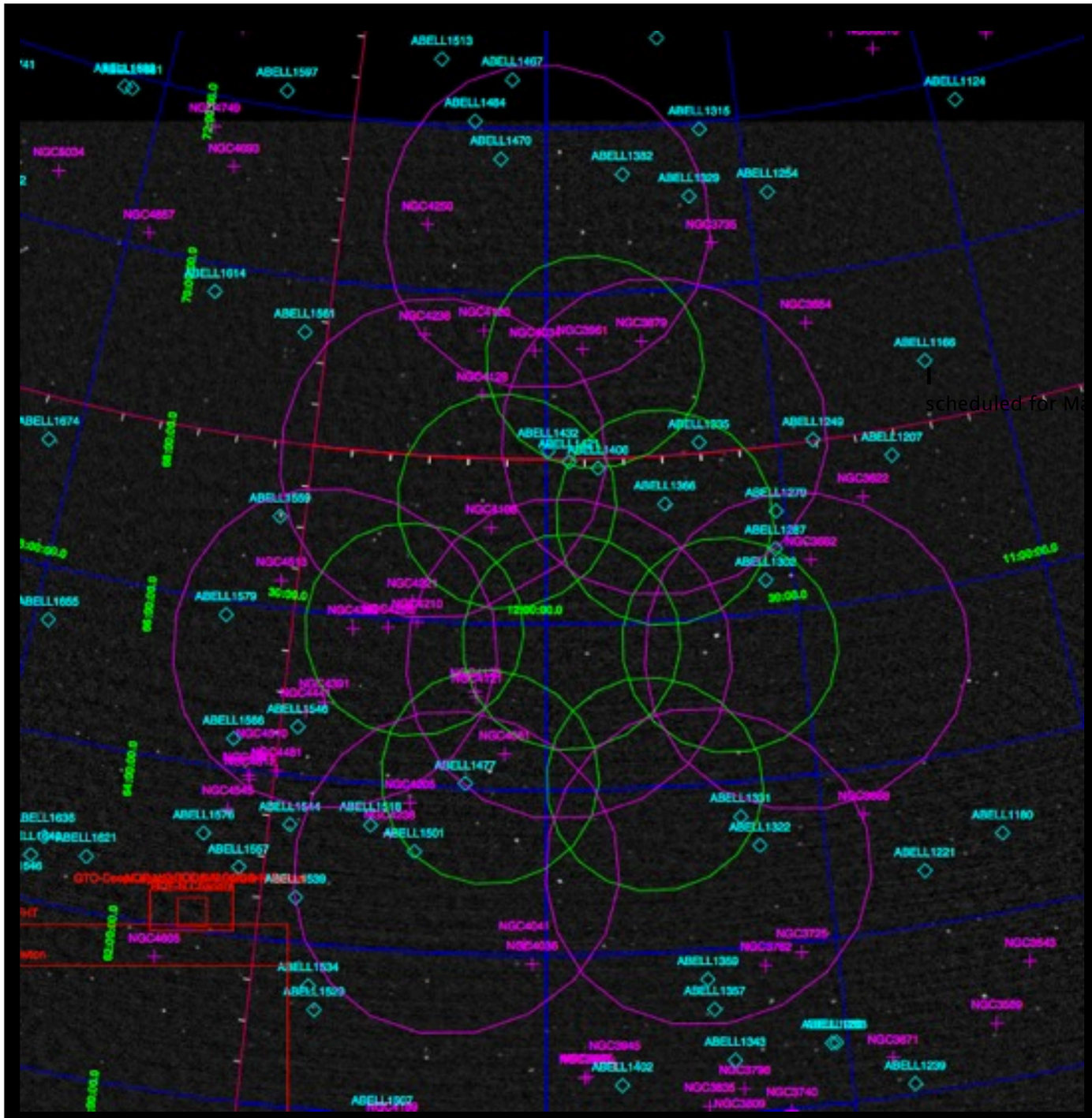
LOFAR core region (The Netherlands)

LOFAR core region (The Netherlands)

LOFAR ≡ software telescope

Multiple, parallel observations
Rapid response and repointing
Multiple, simultaneous pointings

LOFAR : A SURVEY INSTRUMENT



8 pointings @ 130 MHz (HBA)
(FWHM ~ 3 deg)

8 pointings @ 50 MHz (LBA)
(FWHM ~ 7.5 deg)

◊ = Abell clusters
+ = NGC galaxies

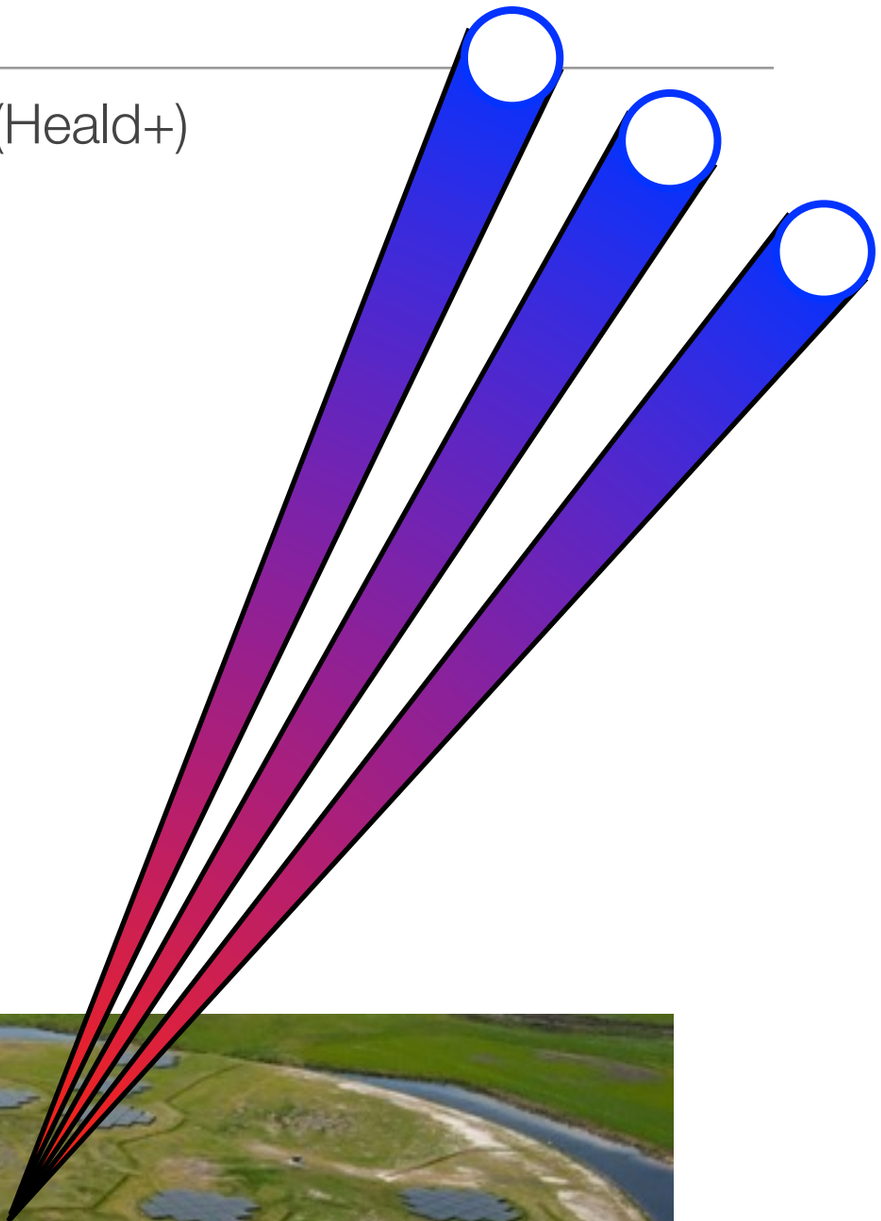
(Courtesy: Rafferty & Mohan)

Röttgering et al. 2010

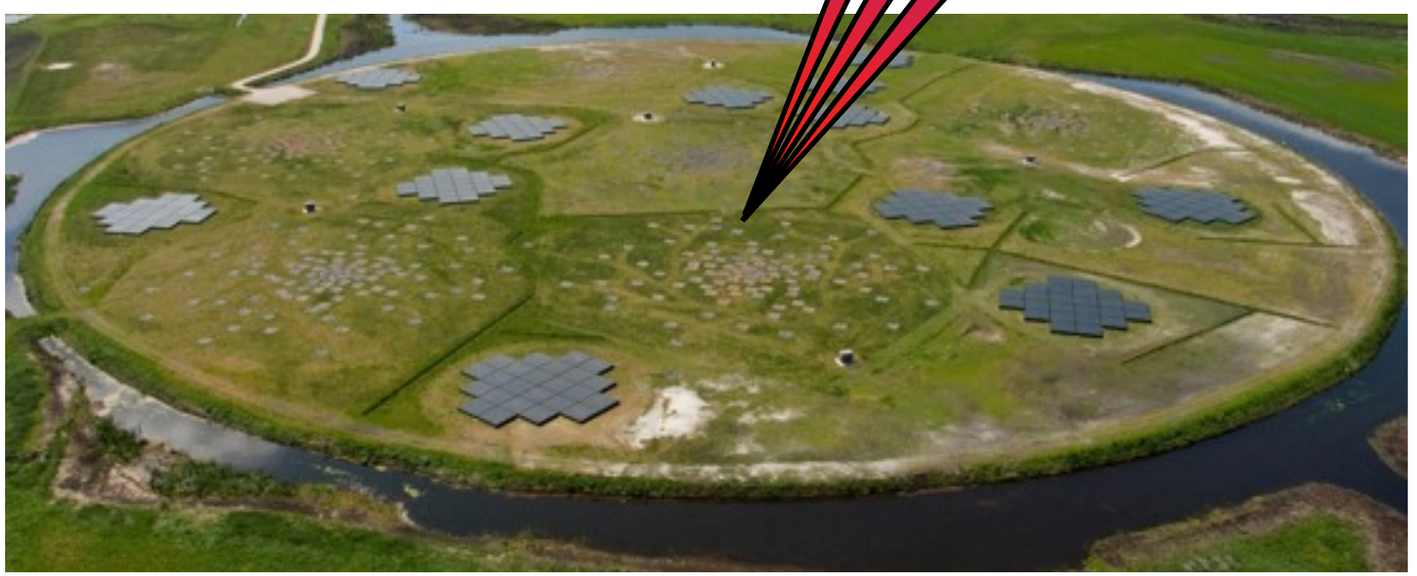
MSSS: FIRST LOFAR IMAGING SURVEY

LOFAR MSSS: Multifrequency Snapshot Sky Survey (Heald+)

- Multifrequency: 16 2-MHz bands from 30-180 MHz
  Throws open a HUGE new frequency window
- Snapshot: Multi-epoch short observation mode
  Groundbreaking search for transient sources
- Sky: Quickly cover entire northern sky
  LOFAR's first all-sky catalog, from the most sensitive survey at extreme low frequencies
- Survey: First large LOFAR imaging program
  Paves the way for still deeper surveys...



*MSSS uses 3 simultaneous **broadband** beams*



Courtesy: Heald

LOFAR Key Project Surveys

P.I.
Röttgering

- ***Large Area Survey (Tier 1)***

- 2π ster. @ 15, 30, 60, 120
- 783 deg^2@ 200 MHz

→ **100 amas de galaxies @ z > 0.6**

→ **200 radio-galaxies @ z > 7**

- ***Deep Area Survey (Tier 2)***

- Quelque centaine de deg^2 @ 30, 60, 120, 200 MHz

→ **SFR ≥ 10 M_{Sun}/yr @ z = 0.5**

→ **SFR ≥ 100 M_{Sun}/yr @ z = 2.5**

- ***Ultra-Deep Area Survey (Tier 3)***

- ~70 deg^2 @ 150 MHz

→ **20 proto-amas @ z > 2**

LOFAR Key Project Surveys

- ***Large Area Survey (Tier 1)***

- 2π ster. @ 15, 30, 60, 120
- 783 deg^2@ 200 MHz

→ **100 amas de galaxies @ z > 0.6**

→ **200 radio-galaxies @ z > 7**

- ***Deep Area Survey (Tier 2)***

- Quelque centaine de deg^2 @ 30, 60, 120, 200 MHz

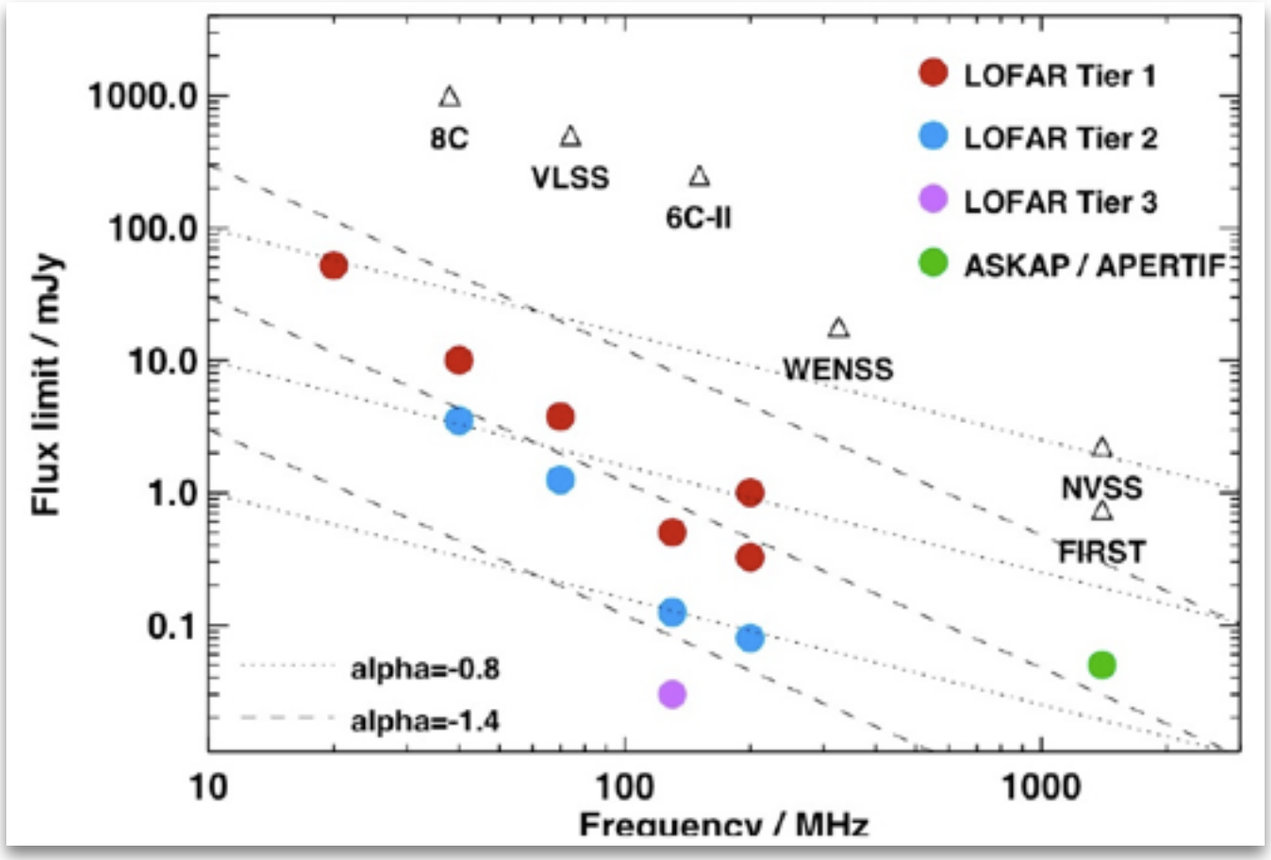
→ **SFR ≥ 10 M_{Sun}/yr @ z = 0.5**

→ **SFR ≥ 100 M_{Sun}/yr @ z = 2.5**

- ***Ultra-Deep Area Survey (Tier 3)***

- ~70 deg^2 @ 150 MHz

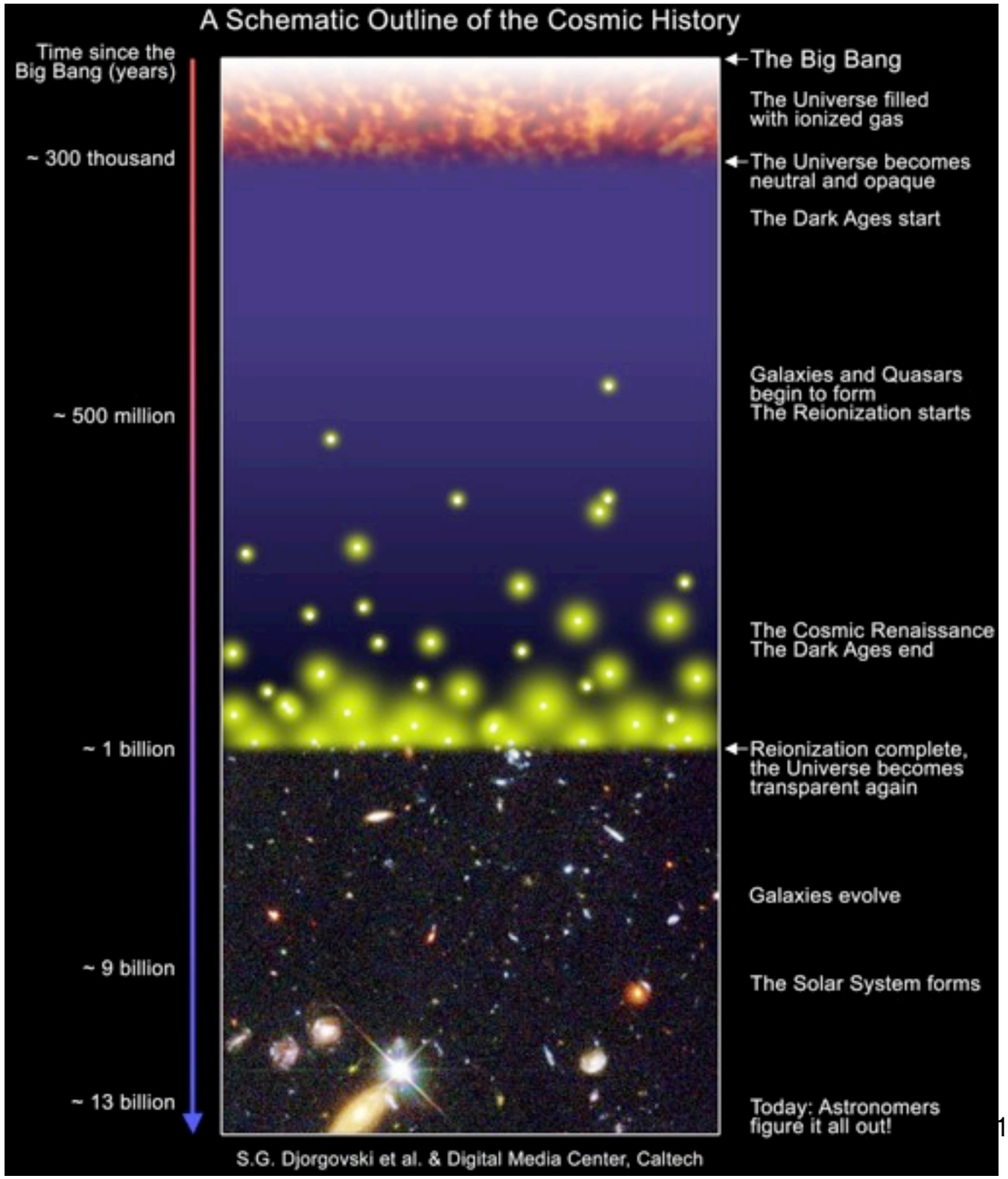
→ **20 proto-amas @ z > 2**



Morganti et al. 2010

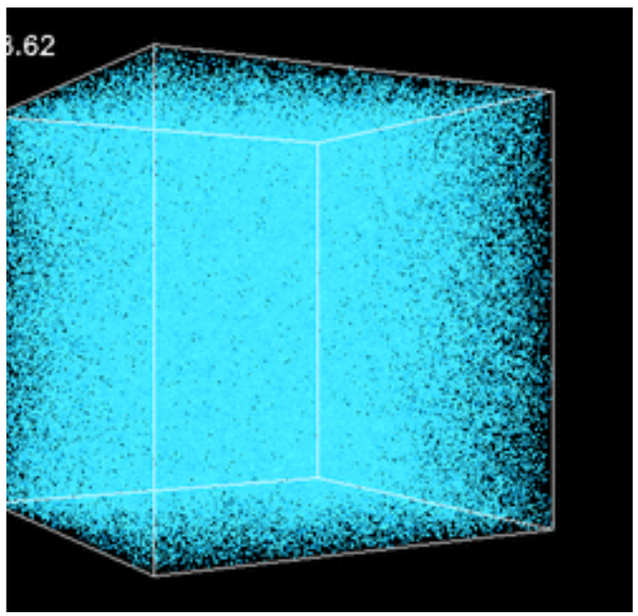
Scientific drivers of LOFAR Surveys

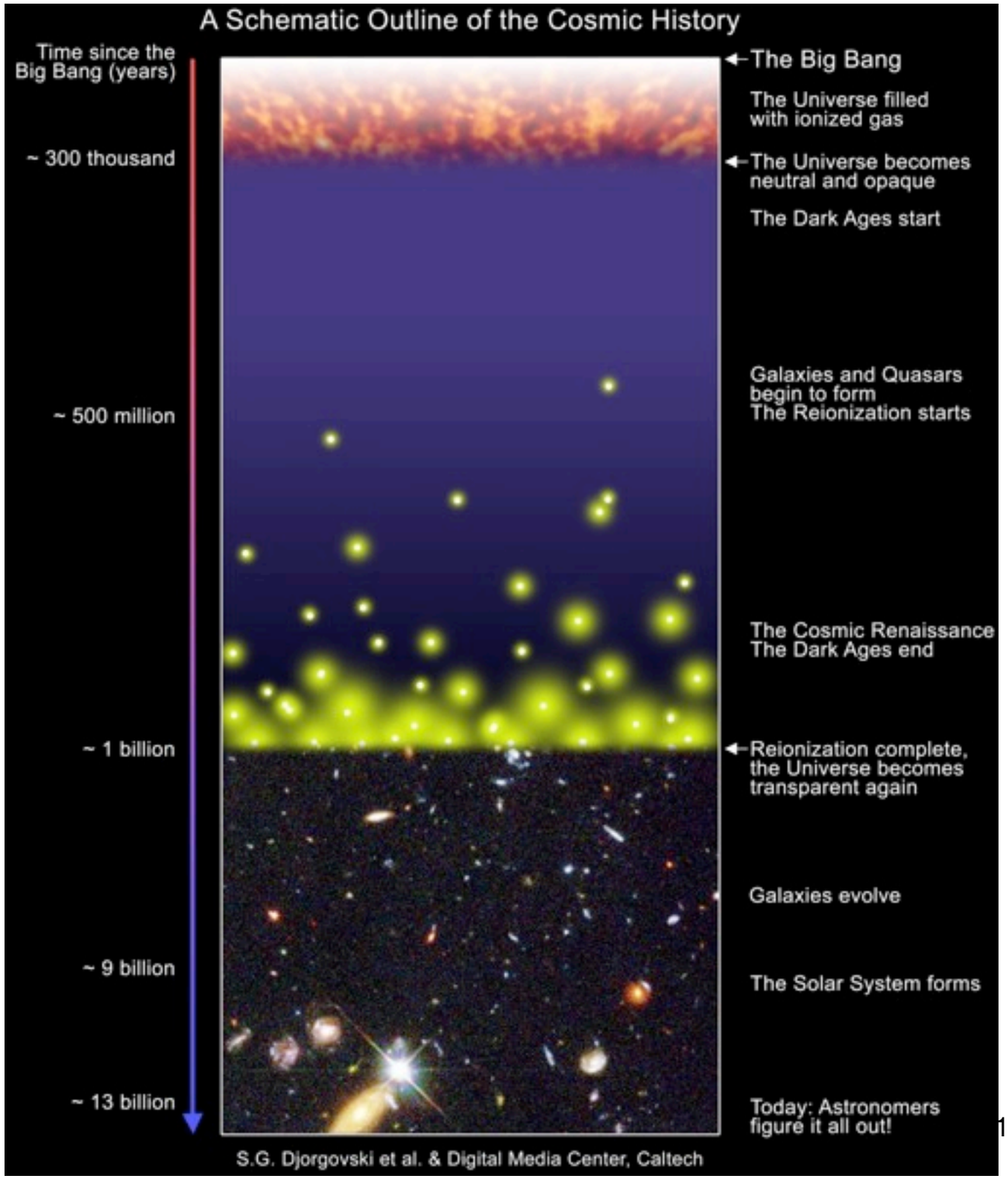
- Starburst galaxies
- Distant radio galaxies
- Galaxy clusters
- New parameter space discoveries



Scientific drivers of LOFAR Surveys

- Starburst galaxies
- Distant radio galaxies
- Galaxy clusters
- New parameter space discoveries





80 % : dark matter

15 % : hot intracluster gas

3 % : galaxies

Galaxy clusters:

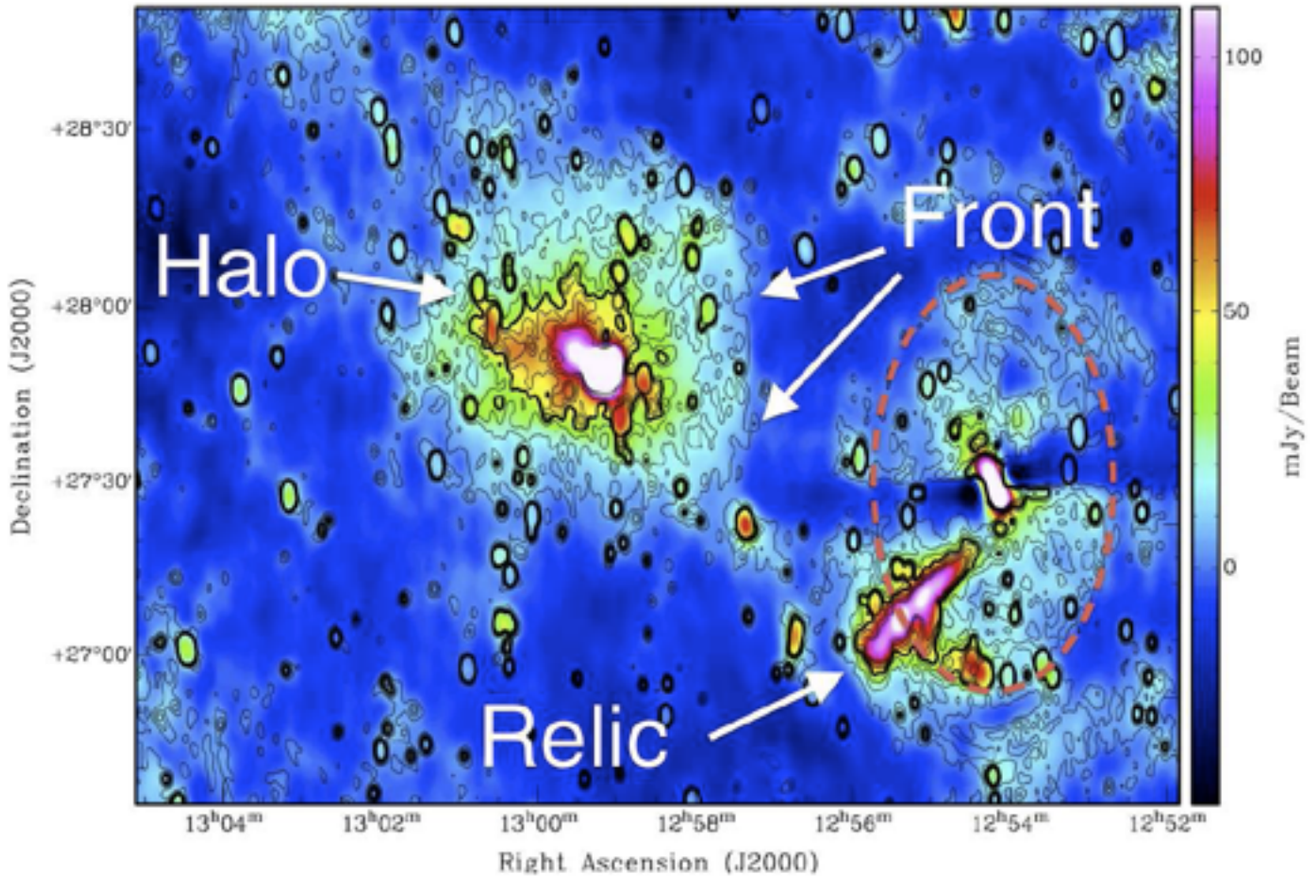
➡ *complex astrophysical systems*

➡ *complex evolutionary physics*

Image Credits: X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.

Galaxy cluster physics:
Importance of low frequency observations

- **Hierarchical formation of clusters**
  - i. Energy budget of thermal and non-thermal components
  - ii. Gravitational energy dissipation processes
- **Non-gravitational processes**
  - i. Galaxy feedback
  - ii. Environmental effects
  - iii. Transport processes



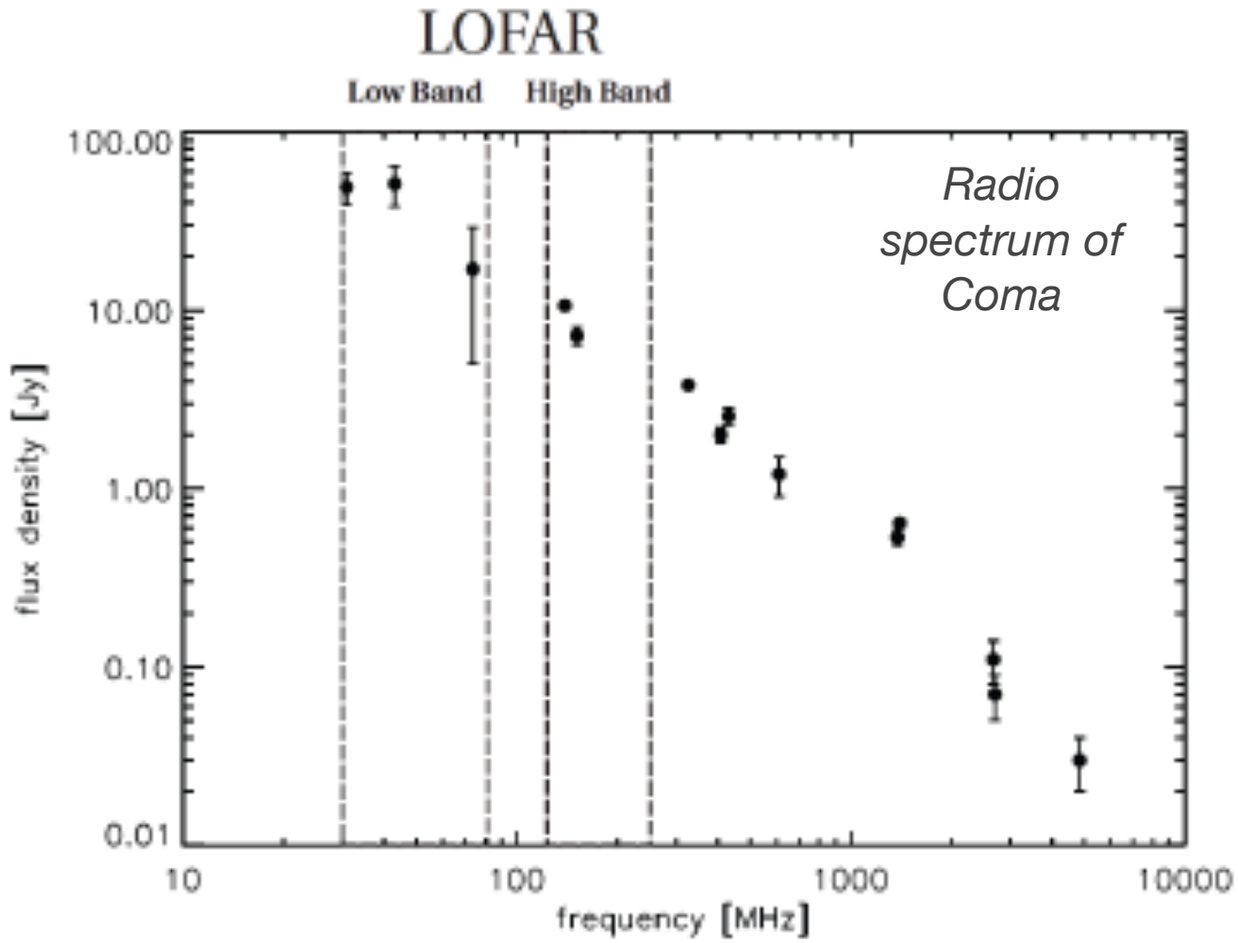
The Coma cluster observed at 352 MHz with WSRT (resolution: 135” x 68”)

Brown & Rudnick+ 11

Galaxy cluster physics:
Importance of low frequency observations

- **Hierarchical formation of clusters**
  i. Energy budget of thermal and non-thermal components
  ii. Gravitational energy dissipation processes

- **Non-gravitational processes**
  i. Galaxy feedback
  ii. Environmental effects
  iii. Transport processes



LOFAR OBSERVATIONS OF GALAXY CLUSTERS

- **LOFAR ≡ largest low-frequency telescope** (10-250 MHz)

    i. Large field of view (~5 - 10 deg)

    ii. High sensitivity

➜ Survey telescope ≡ rms ~ few μJy & res ~ few arcsec

- **LOFAR ≡ software telescope & direction dependent effects**

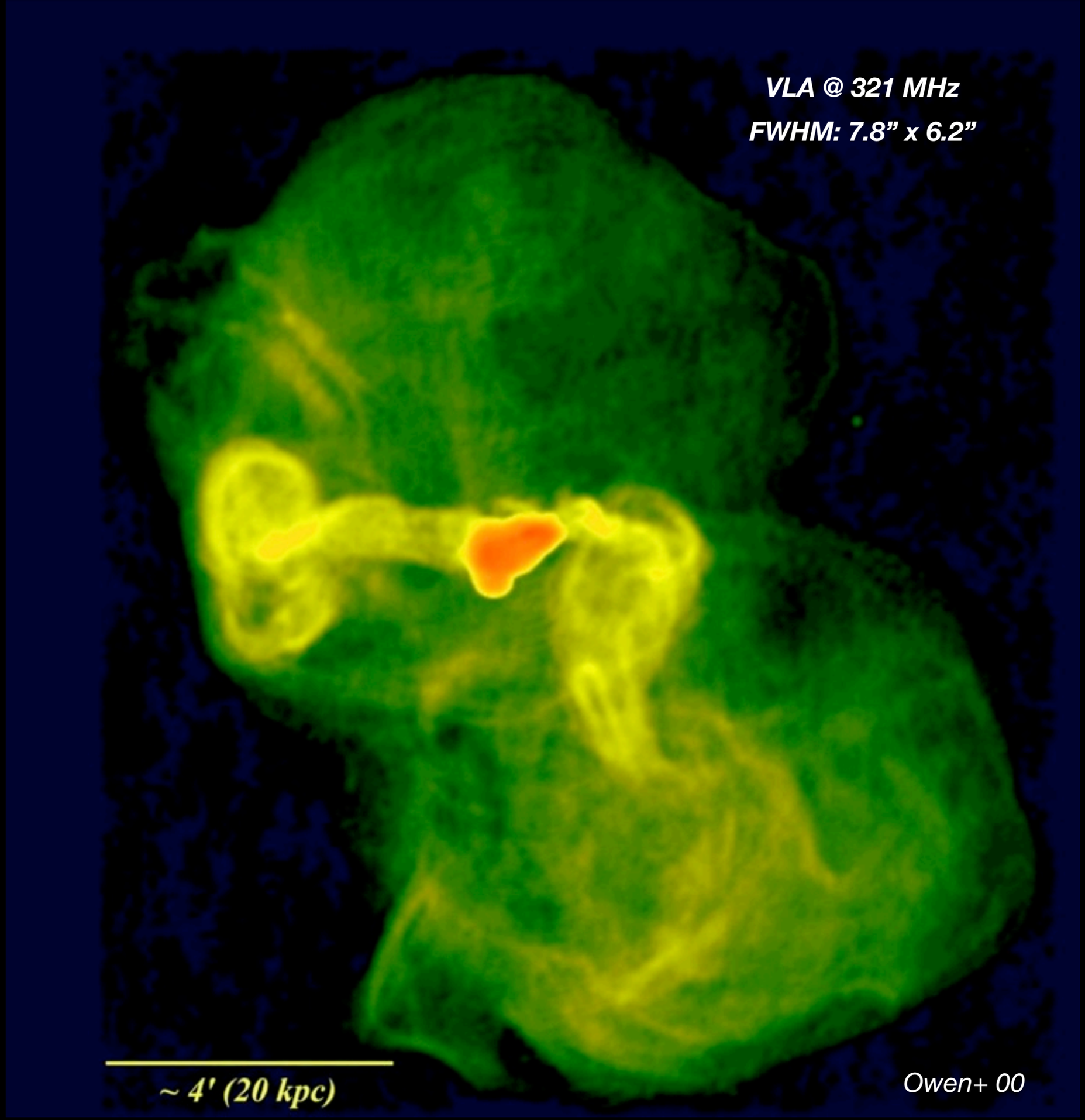
    i. Specific algorithms for calibration

    ii. Specific algorithms for wide field imaging

➜ Imaging step ≡ difficult task !!!

- ☑ **Flag & Compress**
- ☑ **Removal of "A-team" sources**
- ☑ **Calibration**
- ☑ **Imaging**

Virgo

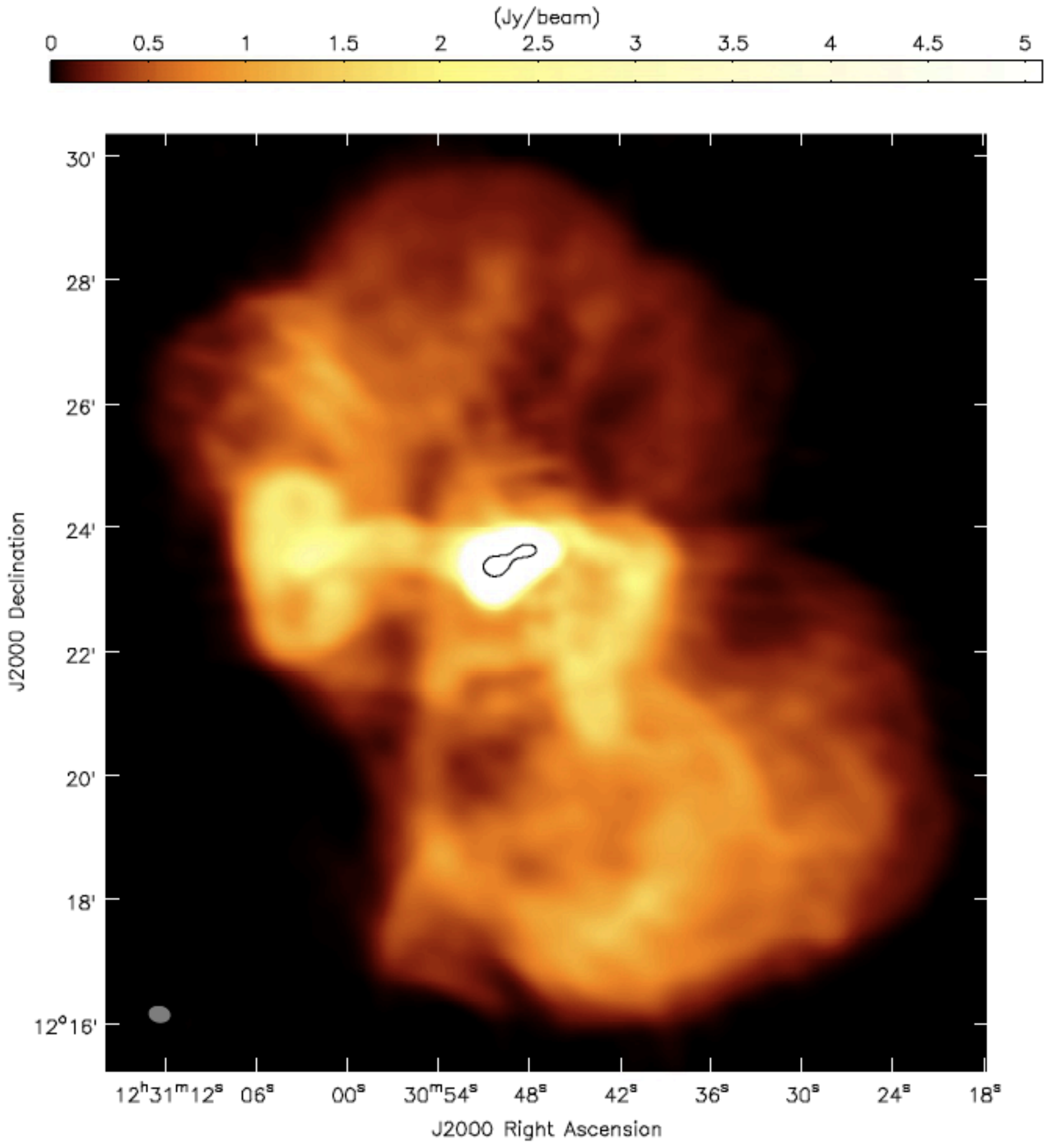


LOFAR & THE VIRGO CLUSTER

LOFAR @ 140 MHz

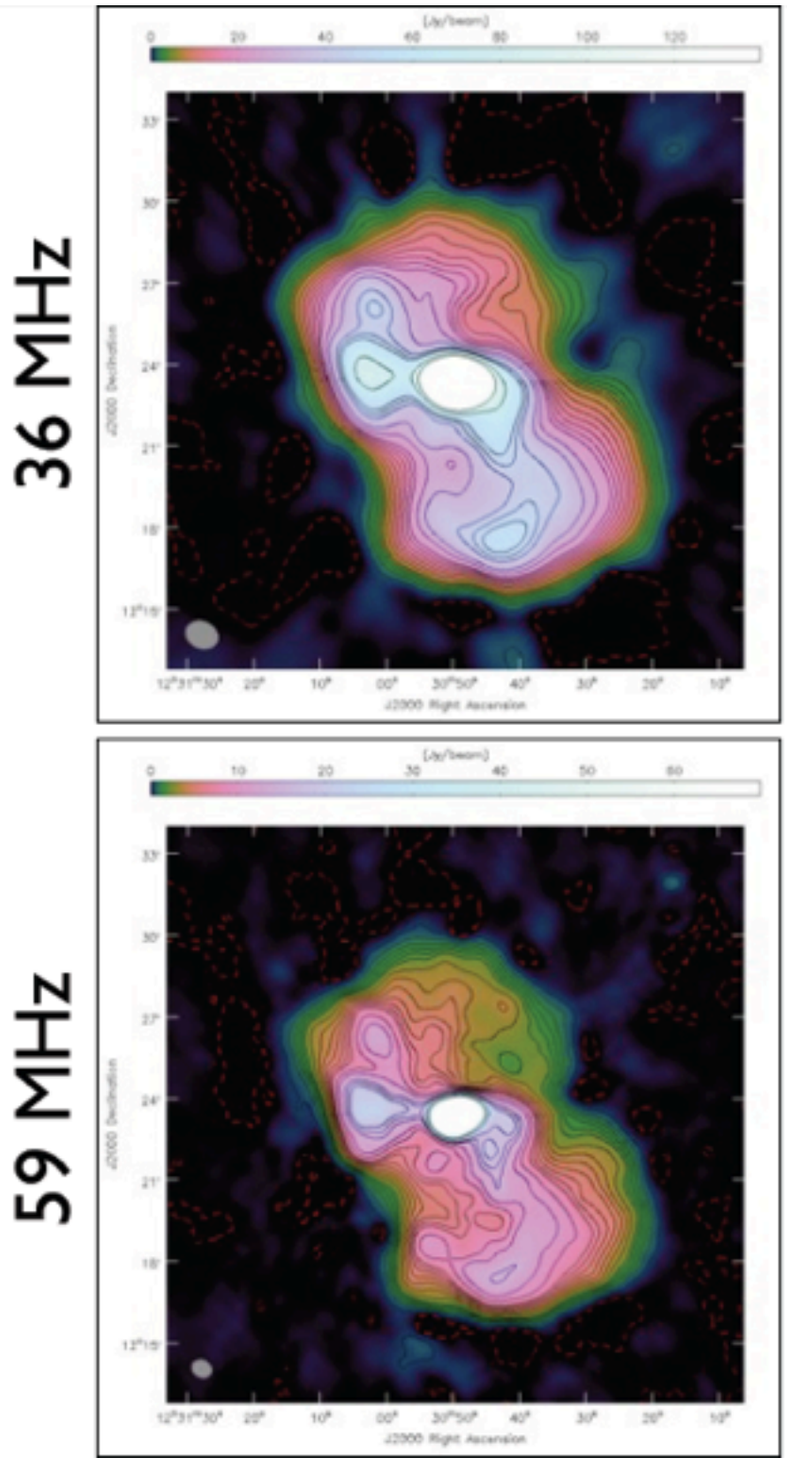
Mean rms ~ 6x10^{-3} Jy/beam

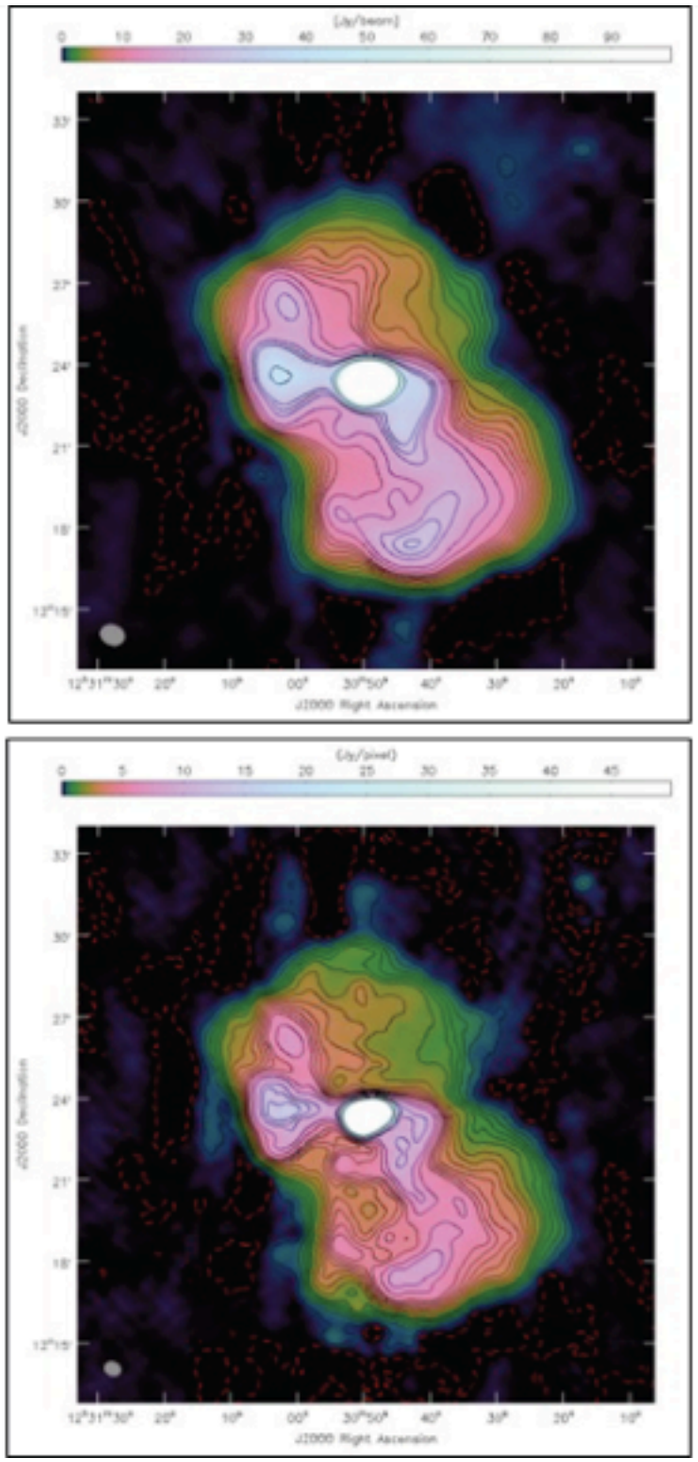
FWHM: 19” x 14”



De Gasperin+, to be submitted

Very low-frequency images of M87





LBA maps:

Freq: 36 MHz
Beam: 73” x 58”
RMS: 0.2 Jy/beam

Freq: 48 MHz
Beam: 55” x 43”
RMS: 0.09 Jy/beam

Freq: 59 MHz
Beam: 55” x 36”
RMS: 0.08 Jy/beam

Freq: 71 MHz
Beam: 37” x 30”
RMS: 0.05 Jy/beam

De Gasperin+, to be submitted

LOFAR & THE VIRGO CLUSTER

Spectral index map:

LOFAR LBA +

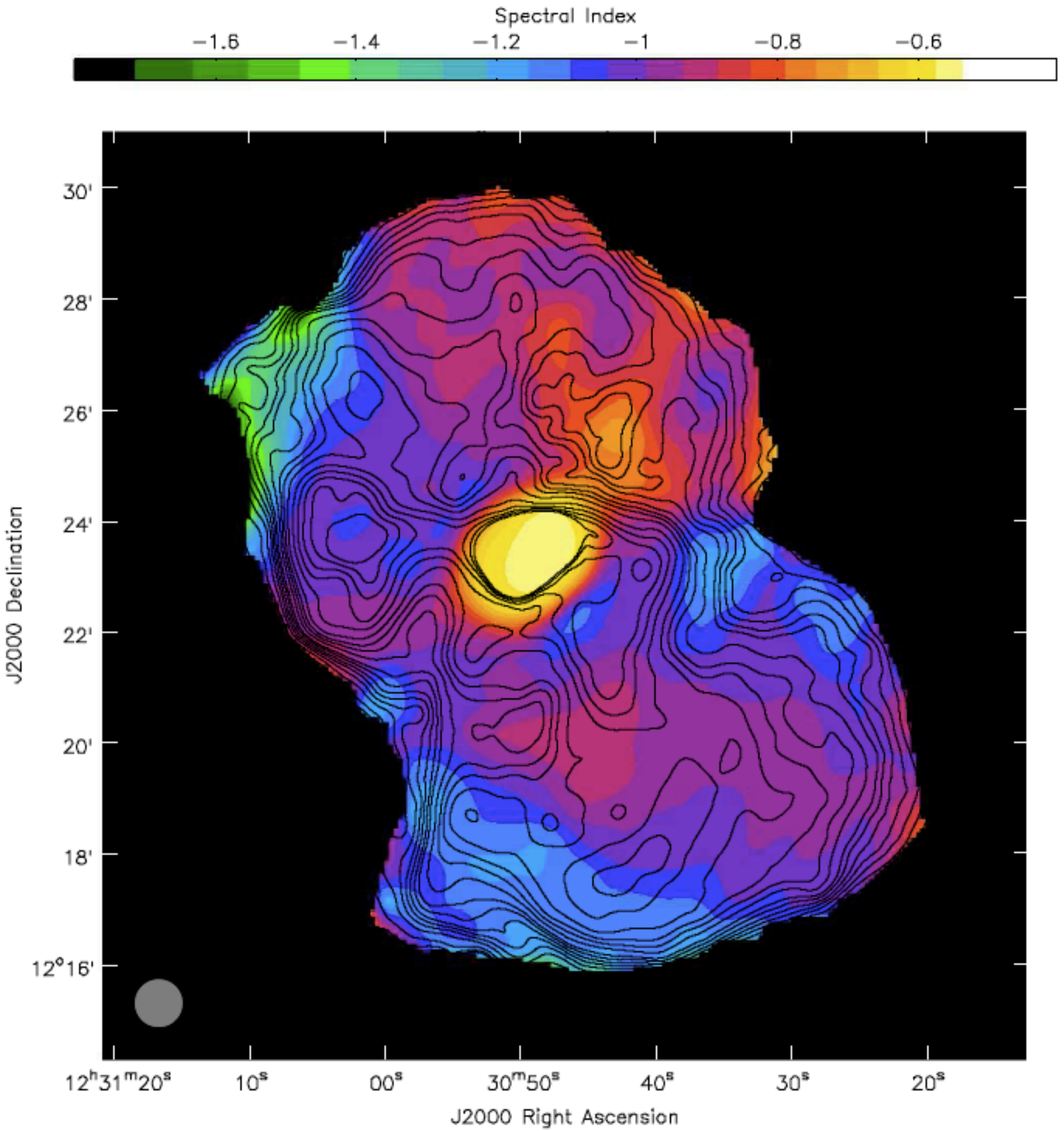
LOFAR HBA +

VLA @ 325, 1400 & 1600 MHz

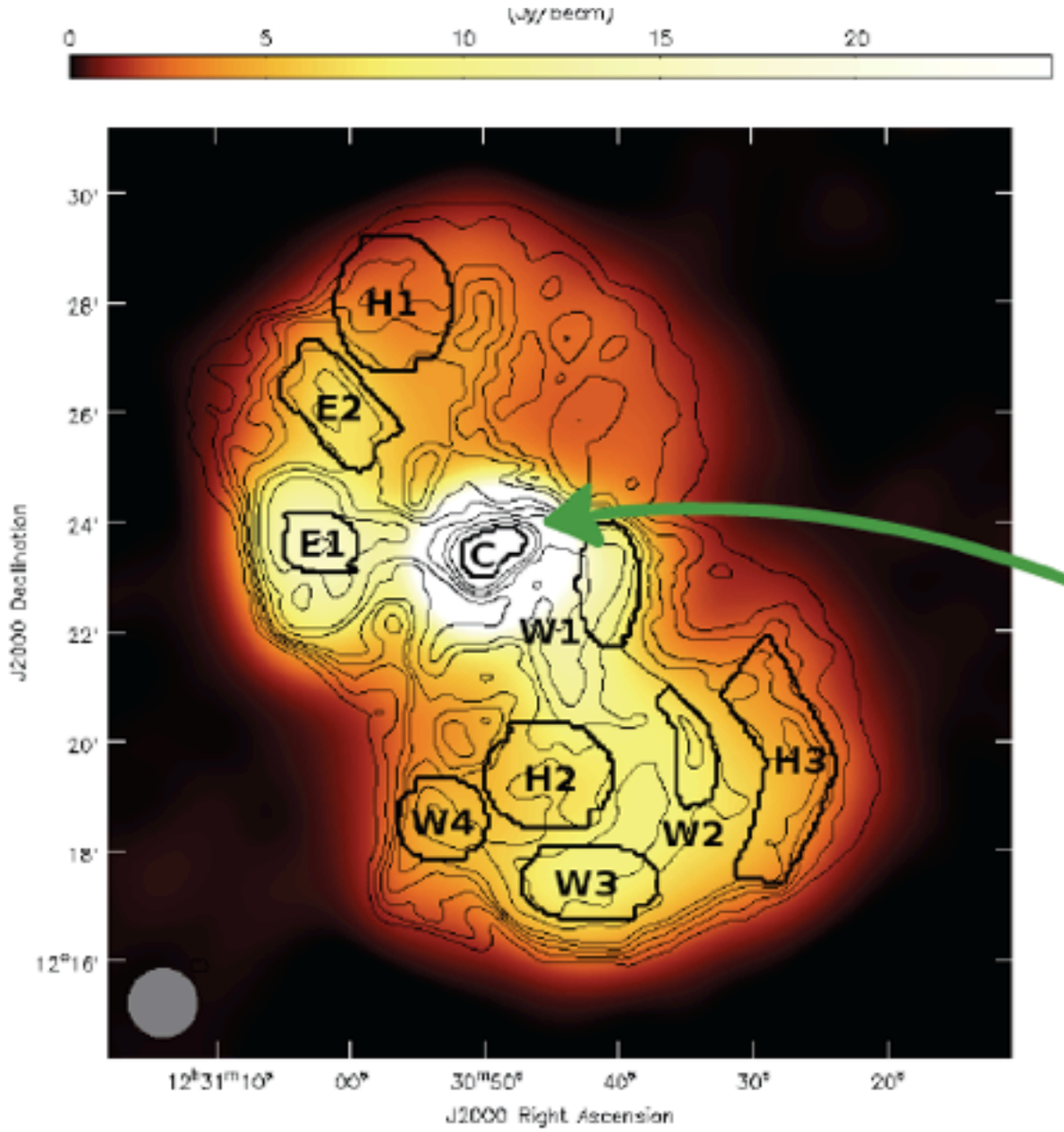
Resolution = 50”

Contours from LOFAR HBA map

De Gasperin+, to be submitted

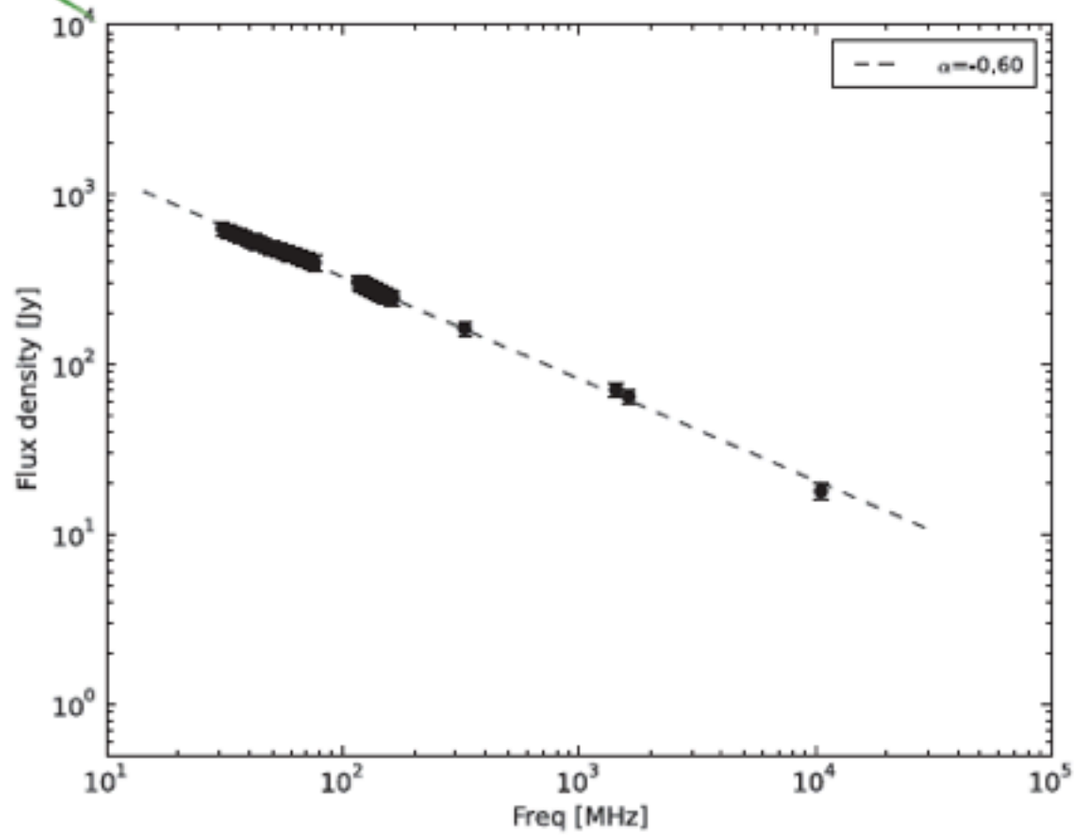


LOFAR: A POWERFUL TOOL FOR SYNCHROTRON SPECTRAL ANALYSIS

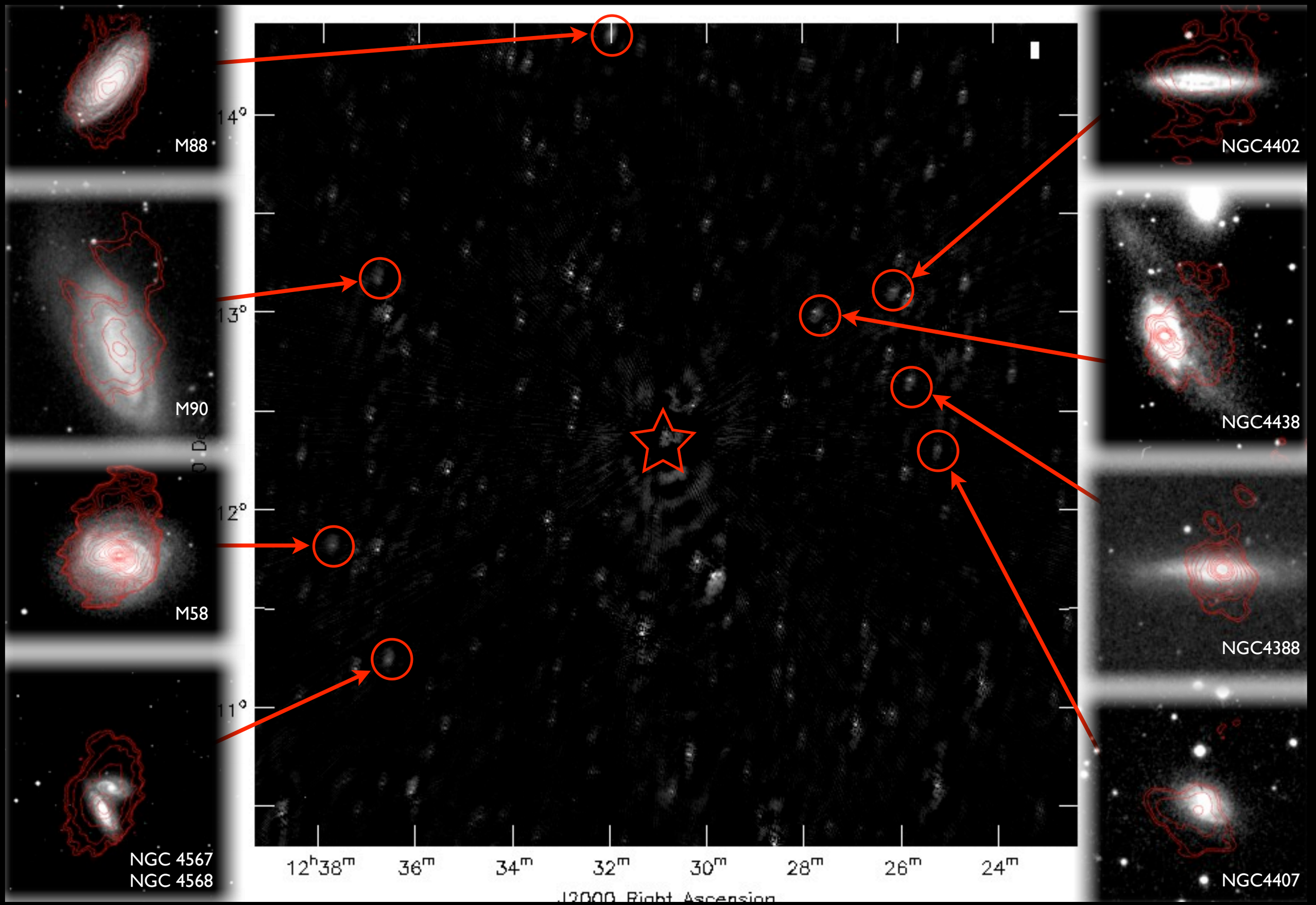


Spectral index analysis:

- LOFAR-LBA @ 30-77 MHz
- LOFAR HBA @ 115-162 MHz
- VLA @ 327 MHz
- VLA @ 1.4-1.6 MHz
- Effelsberg @ 10.55 GHz

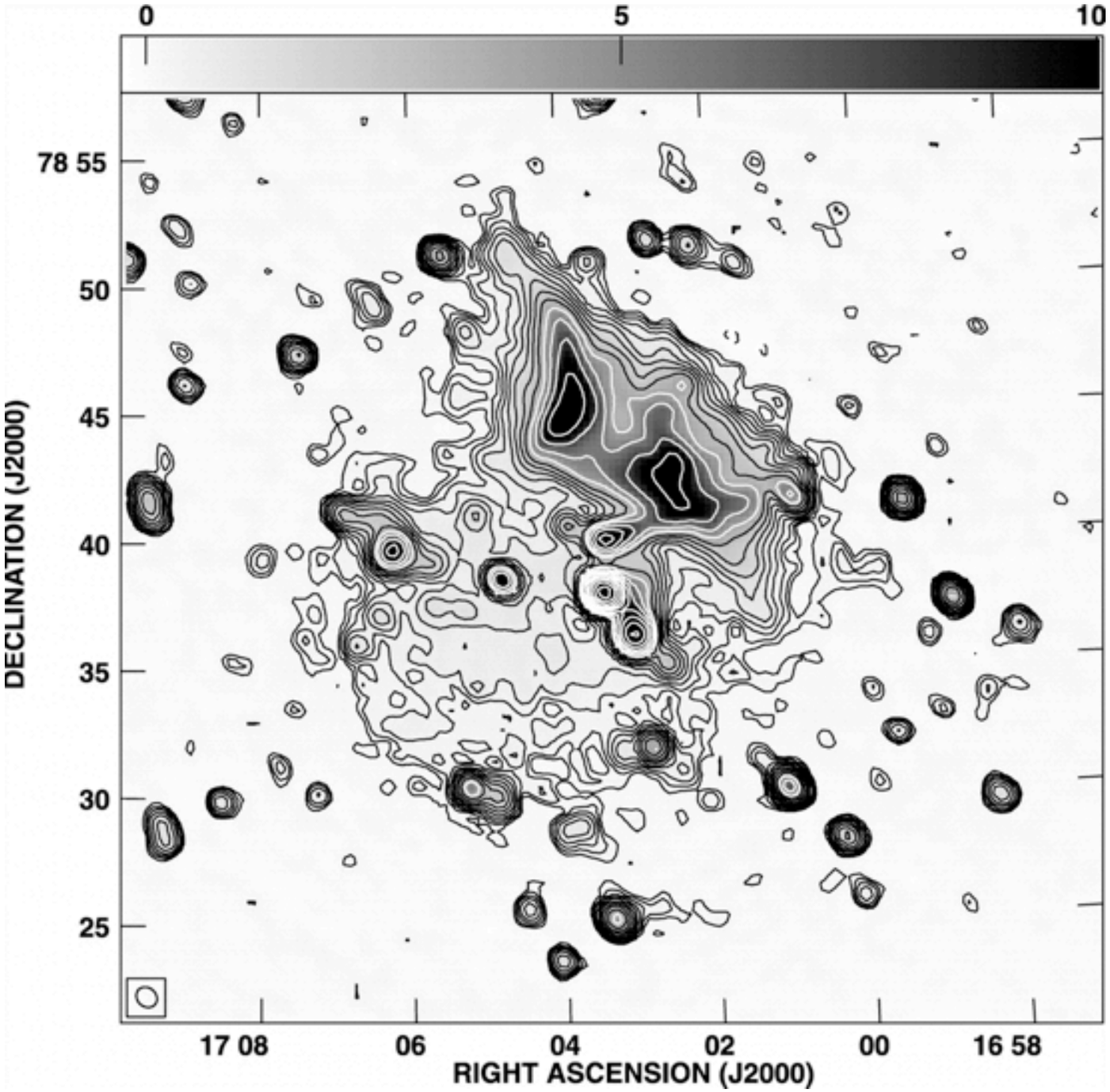


De Gasperin+, to be submitted



De Gasperin+ in prep.

LOFAR observations of Abell 2256



VLA @ 1369 MHz

Mean rms ~ 5.9×10^{-5} Jy/beam

FWHM: 52” x 45”

Clarke & Enßlin 06

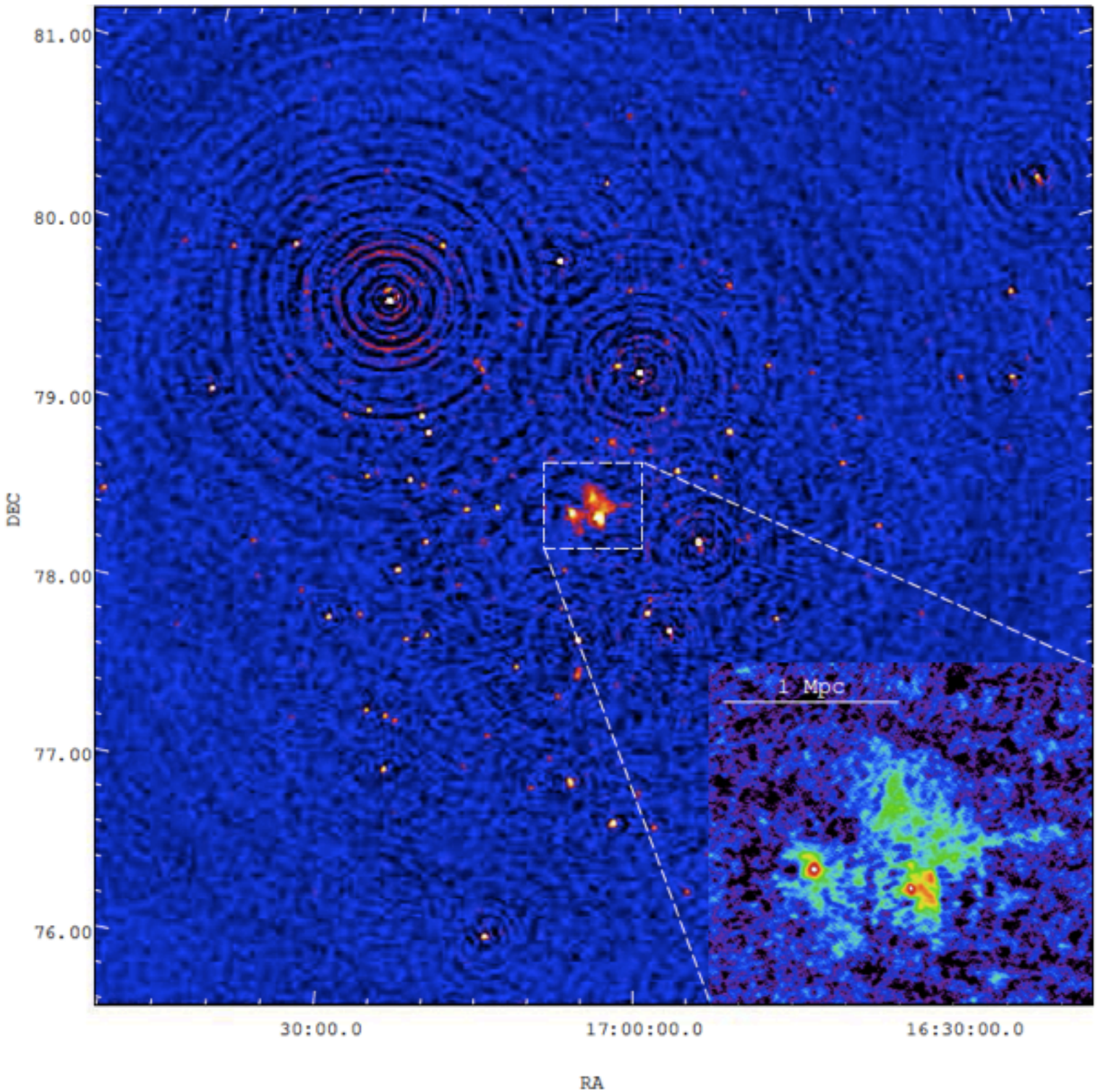
See also:

Kale & Dwarakanath 10 @150 MHz GMRT

van Weeren+ 09 @ 325 MHz GMRT

Brentjens+ 08 @ 350 MHz WSRT

LOFAR observations of Abell 2256



LOFAR @ 61-67 MHz

Robust -0.1:

Mean rms ~ 10×10^{-3} Jy/beam

FWHM: 22” x 26”

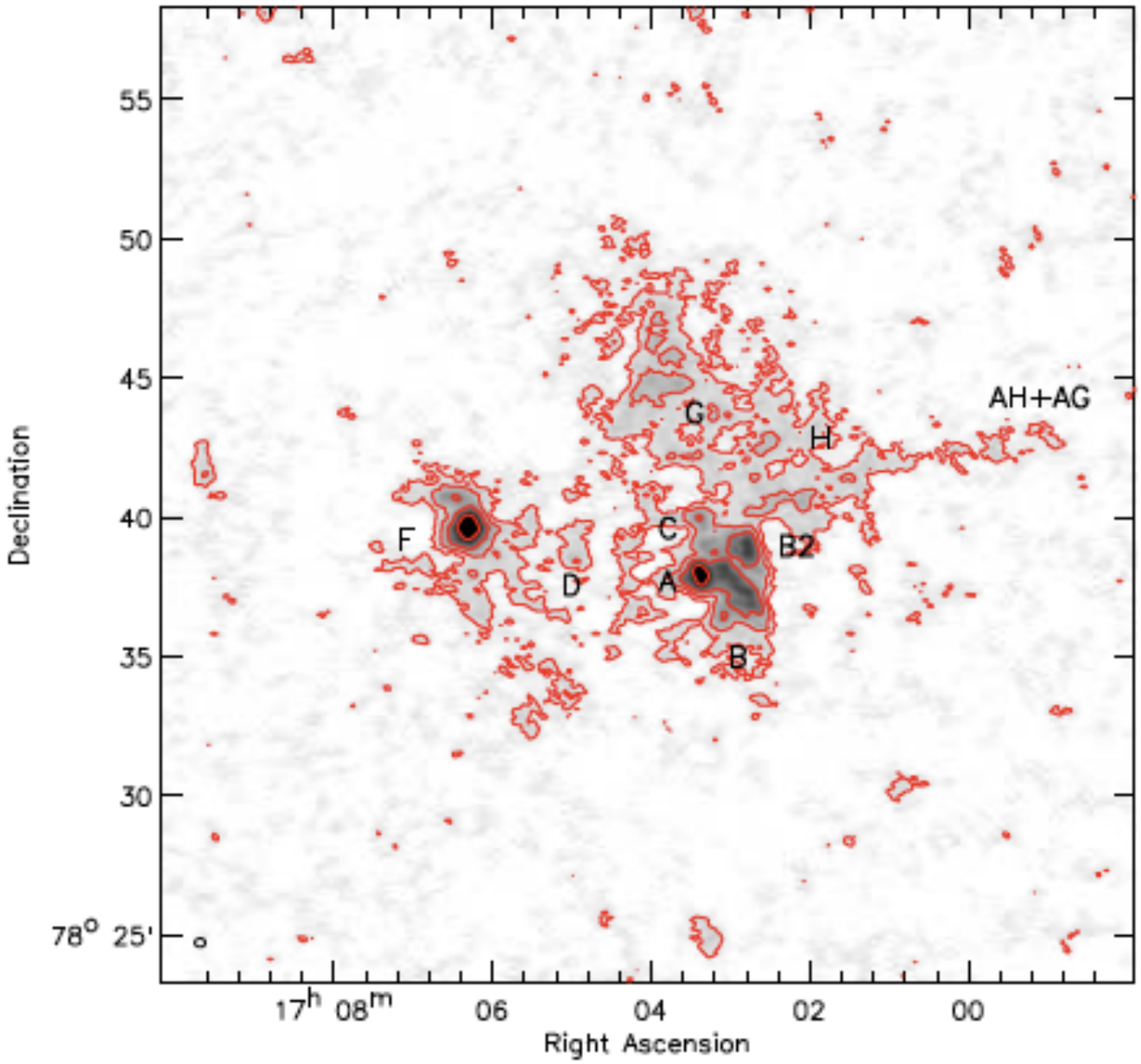
Robust 0.5:

Mean rms ~ 25×10^{-3} Jy/beam

FWHM: 52” x 62”

van Weeren+ 12

LOFAR observations of Abell 2256



LOFAR @ 63 MHz

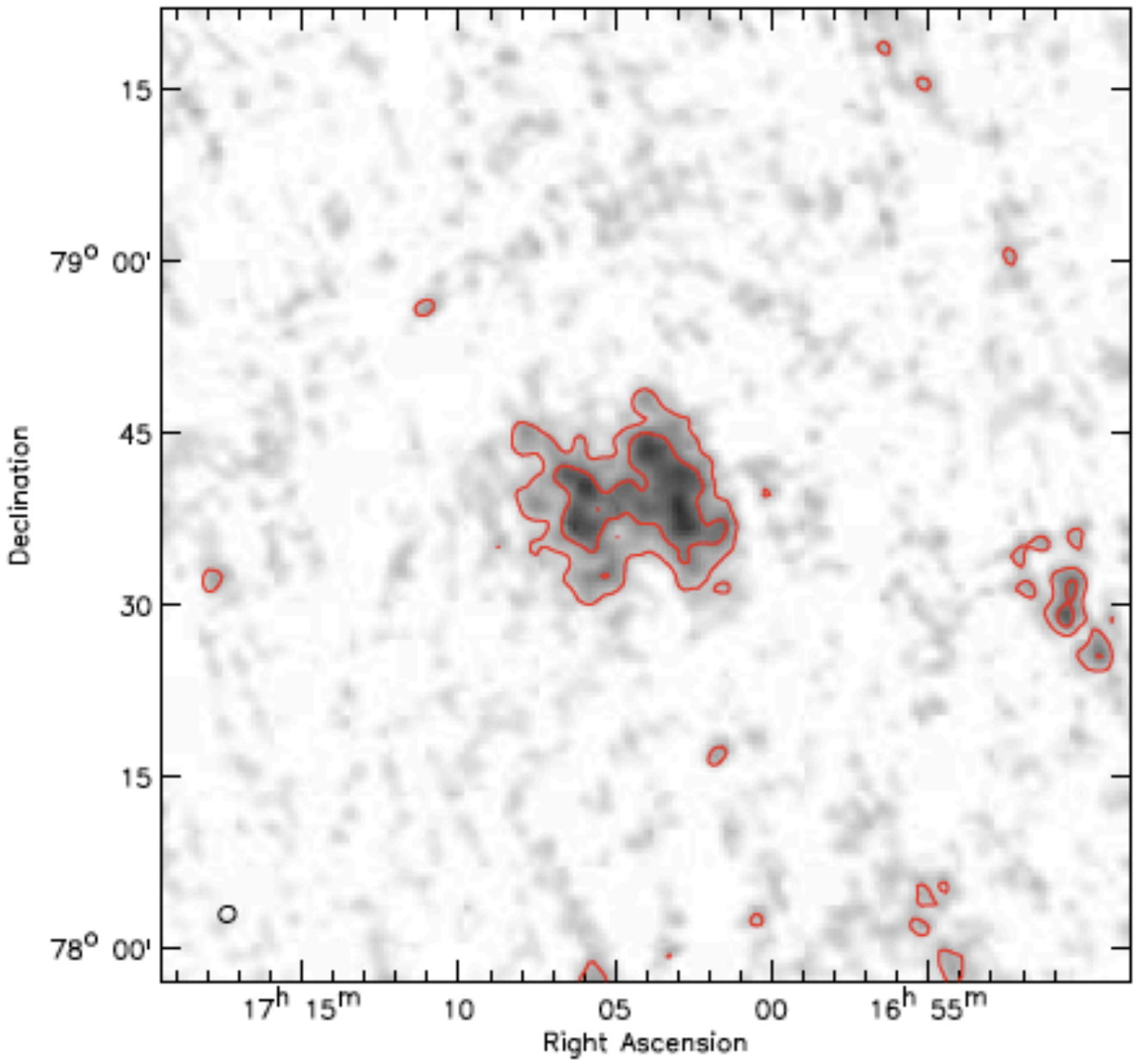
BW = 5.5 MHz

Mean rms ~ $10x10^{-3}$ Jy/beam

FWHM: 22” x 26”

Van Weeren+ 12

LOFAR observations of Abell 2256



LOFAR @ 20 MHz

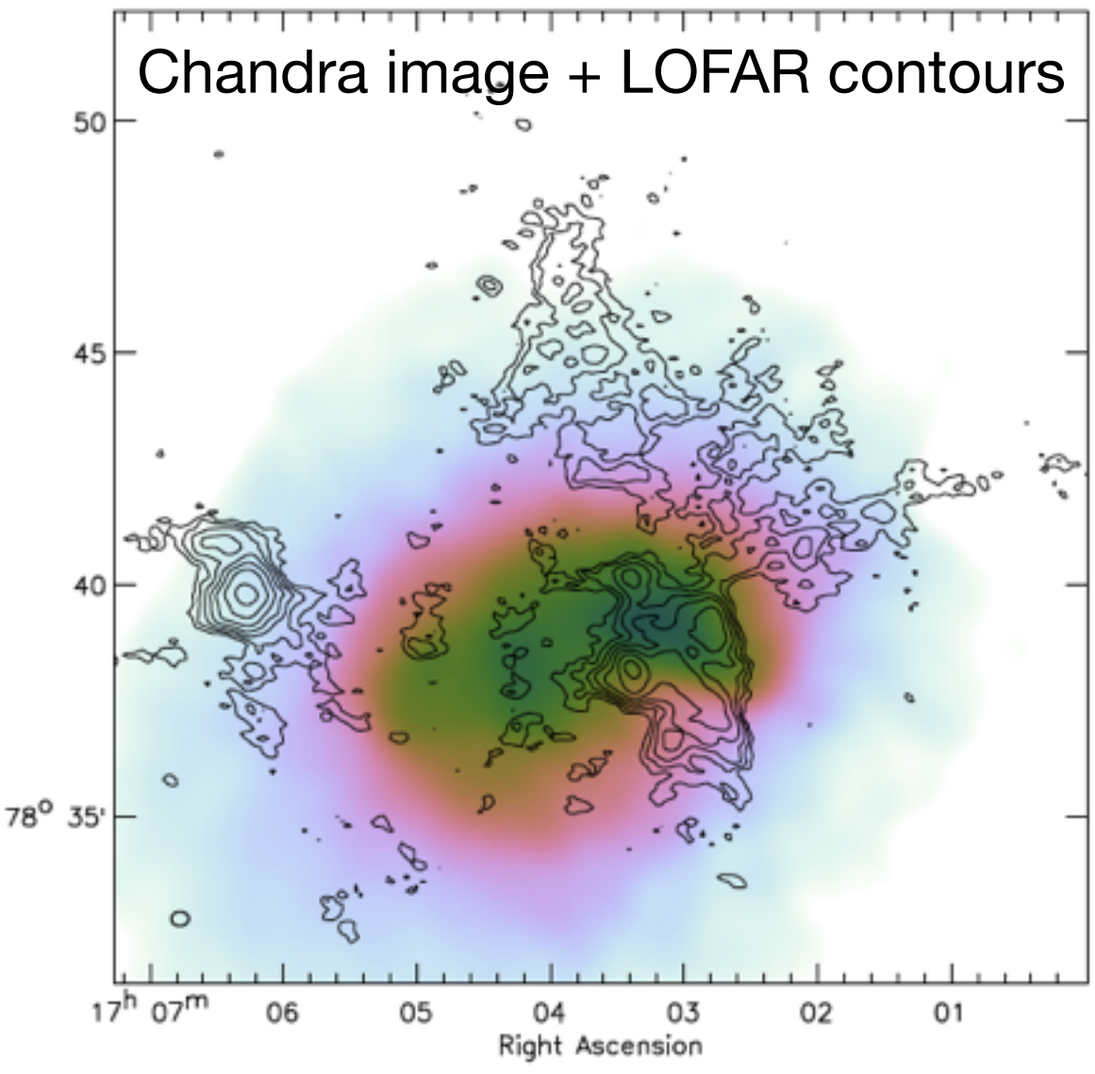
BW = 3.7 MHz

Mean rms ~ 250x10^{-3} Jy/beam

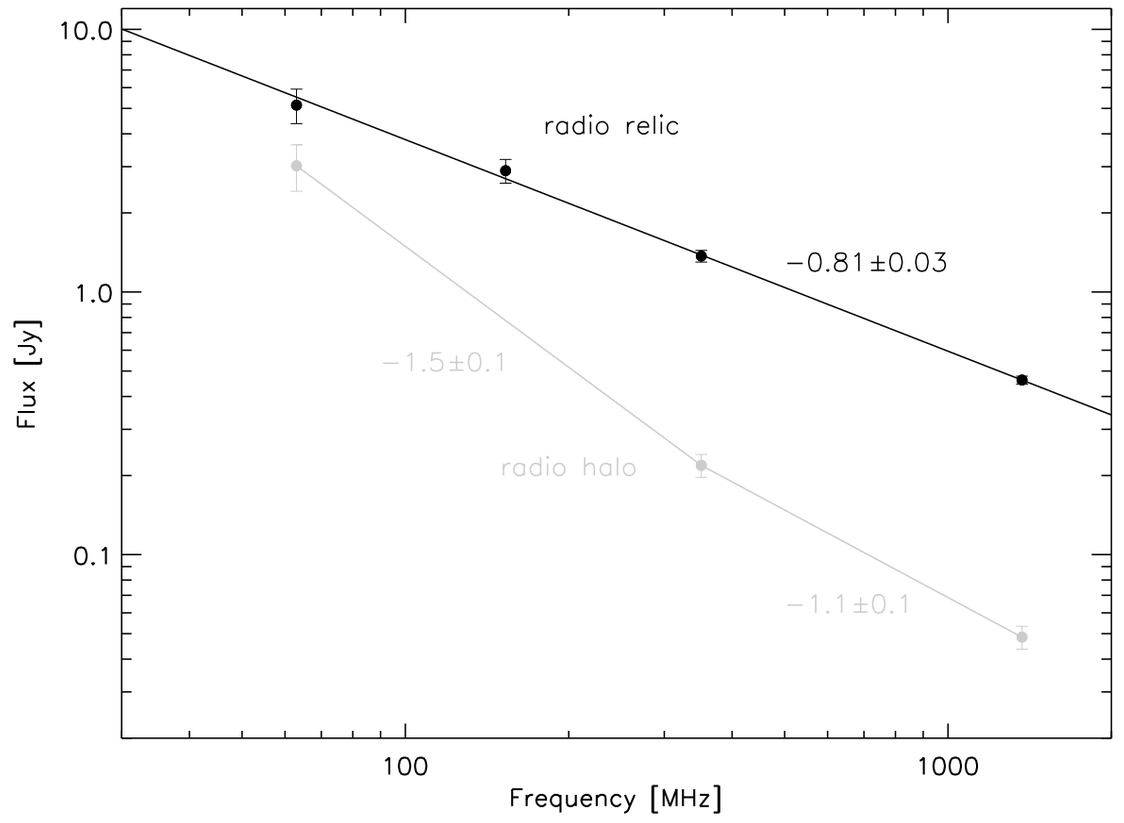
FWHM: 108” x 116”

Van Weeren+ 12

LOFAR observations of Abell 2256



Van Weeren+ 12



If $\tau_{shock} > \tau_{cool} \rightarrow \alpha_{inj} = \alpha_{obs} + 0.5 = -0.3$

But: $\alpha_{inj,max} = -0.5$

(diffusive shock acceleration model - DSA)

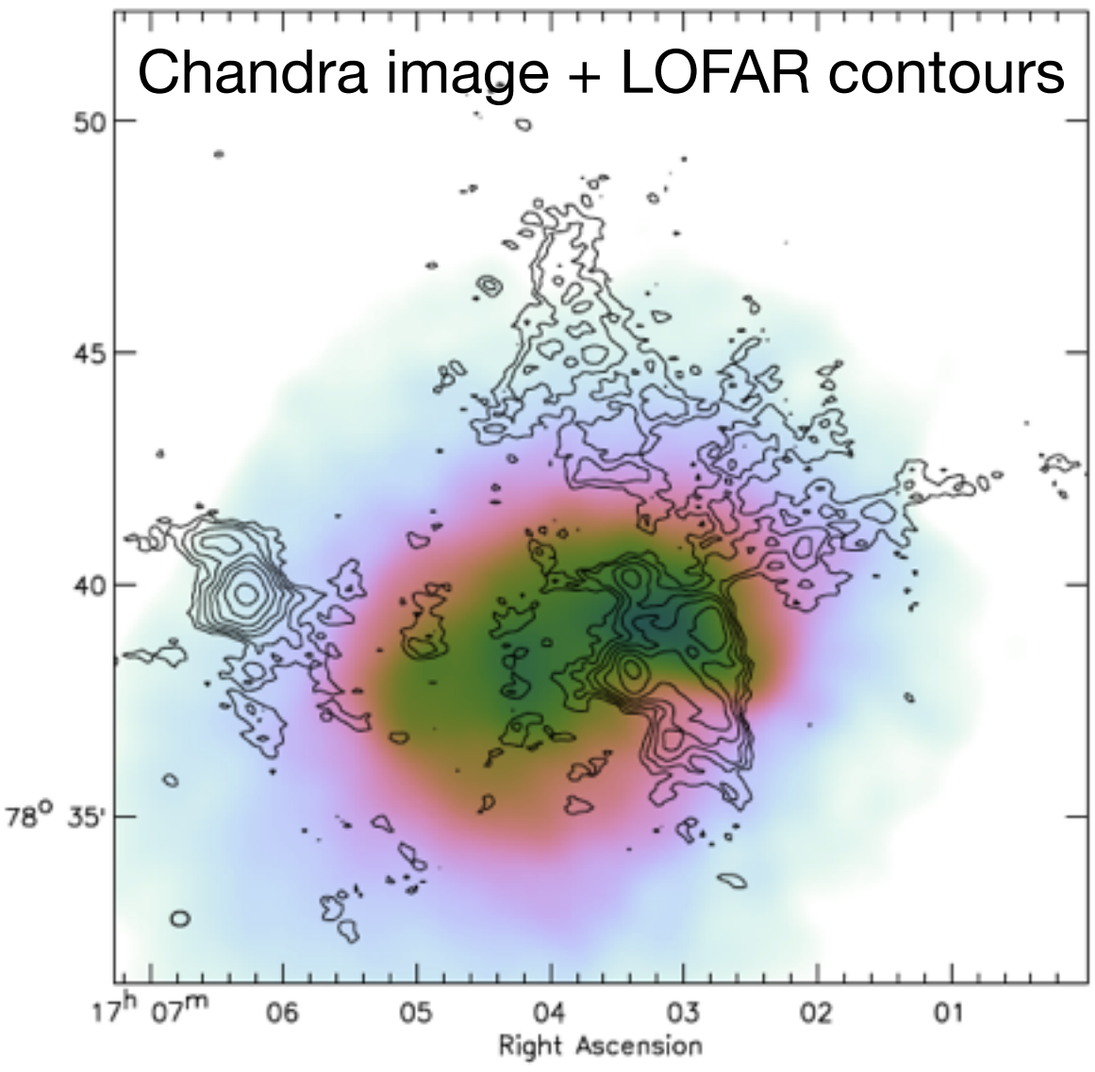
→ Recently formed shock ?

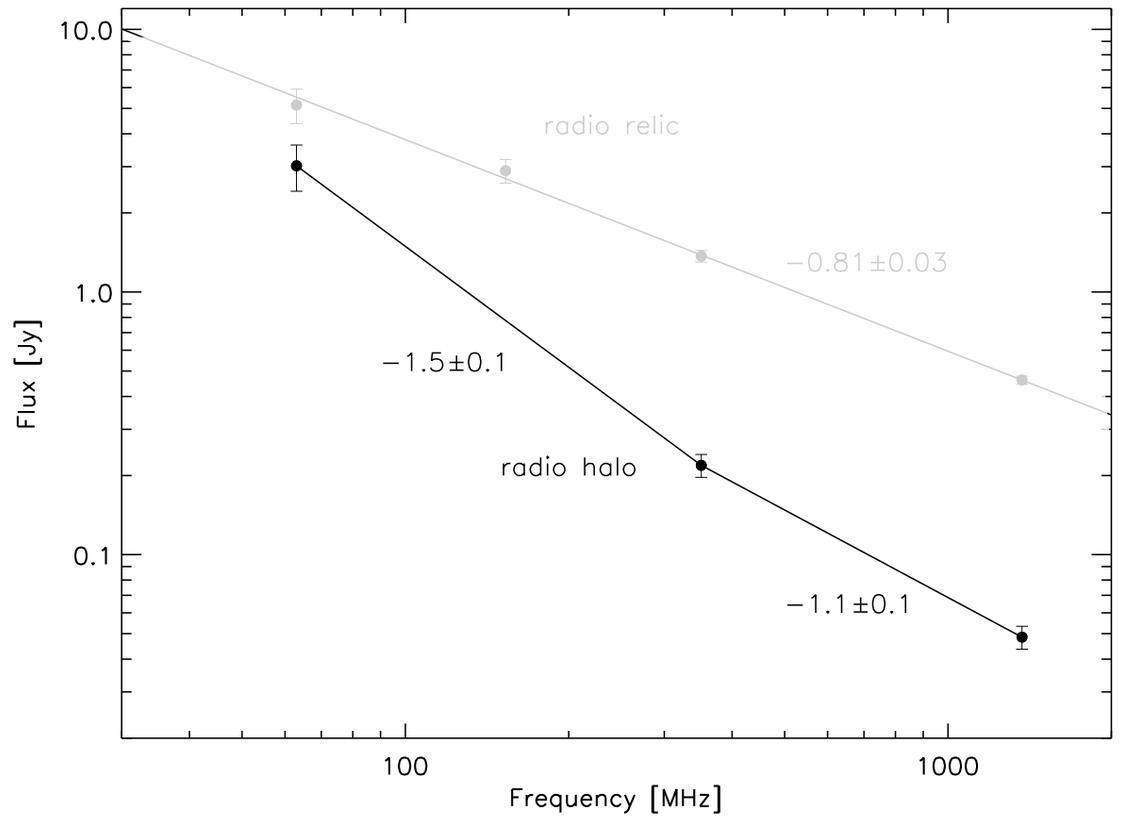
→ Missed flux at low frequencies ?

→ Re-acceleration in shock downstream region?

→ DSA to be reviewed ?

LOFAR observations of Abell 2256





Two population of relativistic electrons

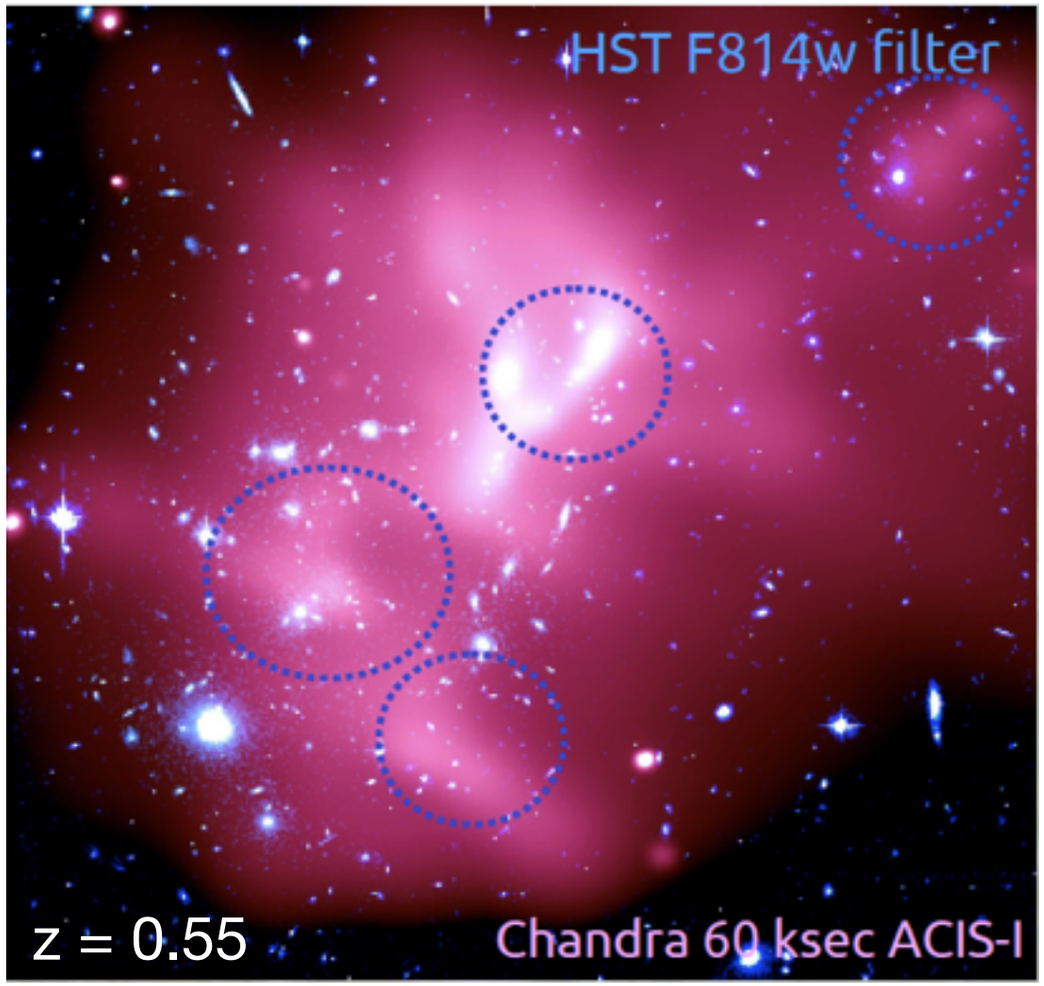
→ Secondary + turbulent re-acceleration ?

→ Projected emission from the relic ?

→ Inhomogeneous turbulent re-acceleration ?

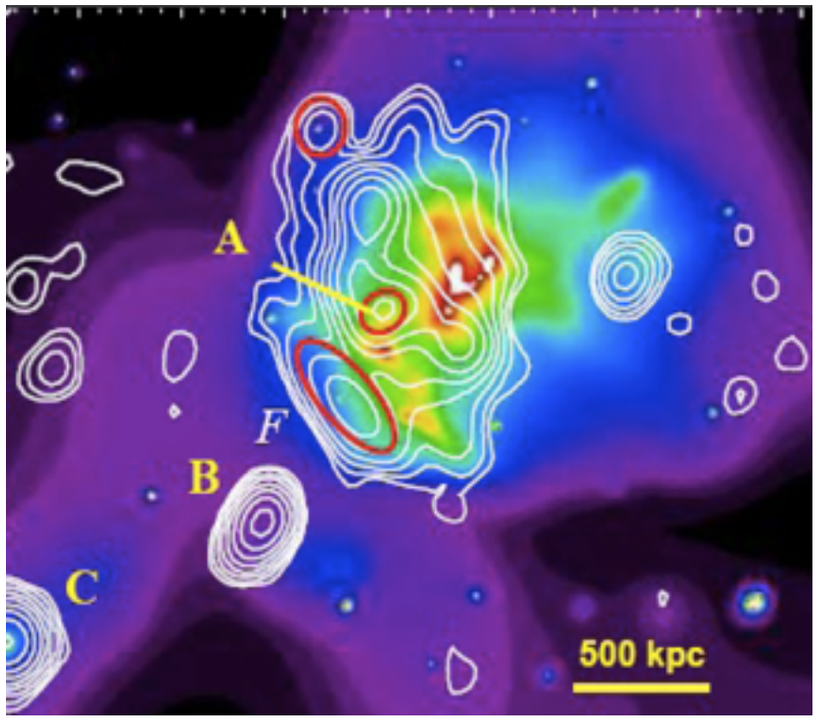
Van Weeren+ 12

LOFAR OBSERVATIONS OF MACS J0717



Optical & X-ray cluster emission: complex major cluster merger

Edge+ 03 & Ma+ 09



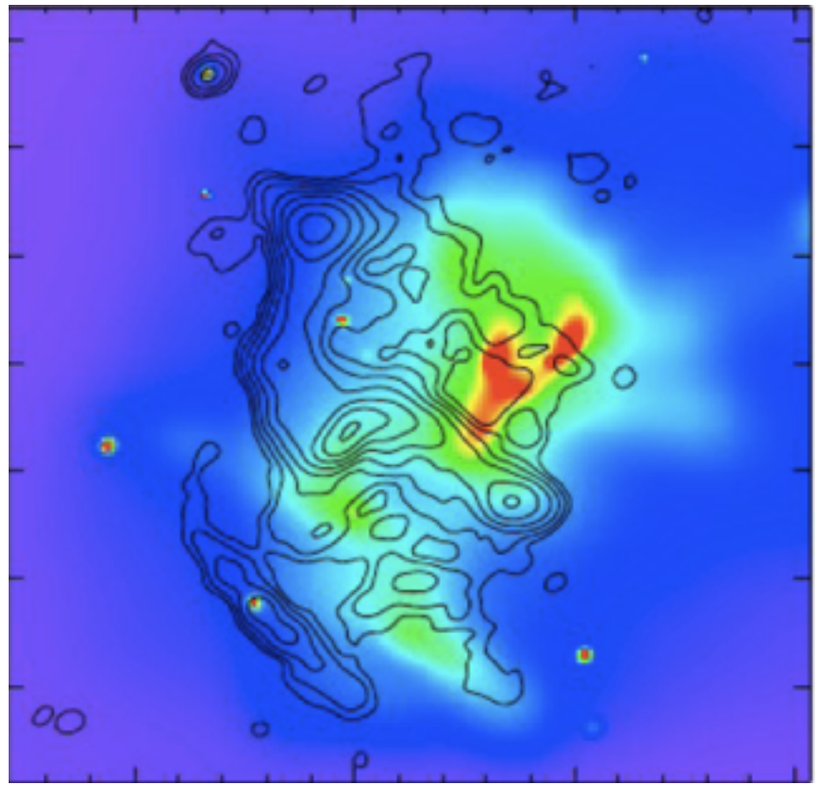
Chandra + Radio contours

← @ 1.4 GHz

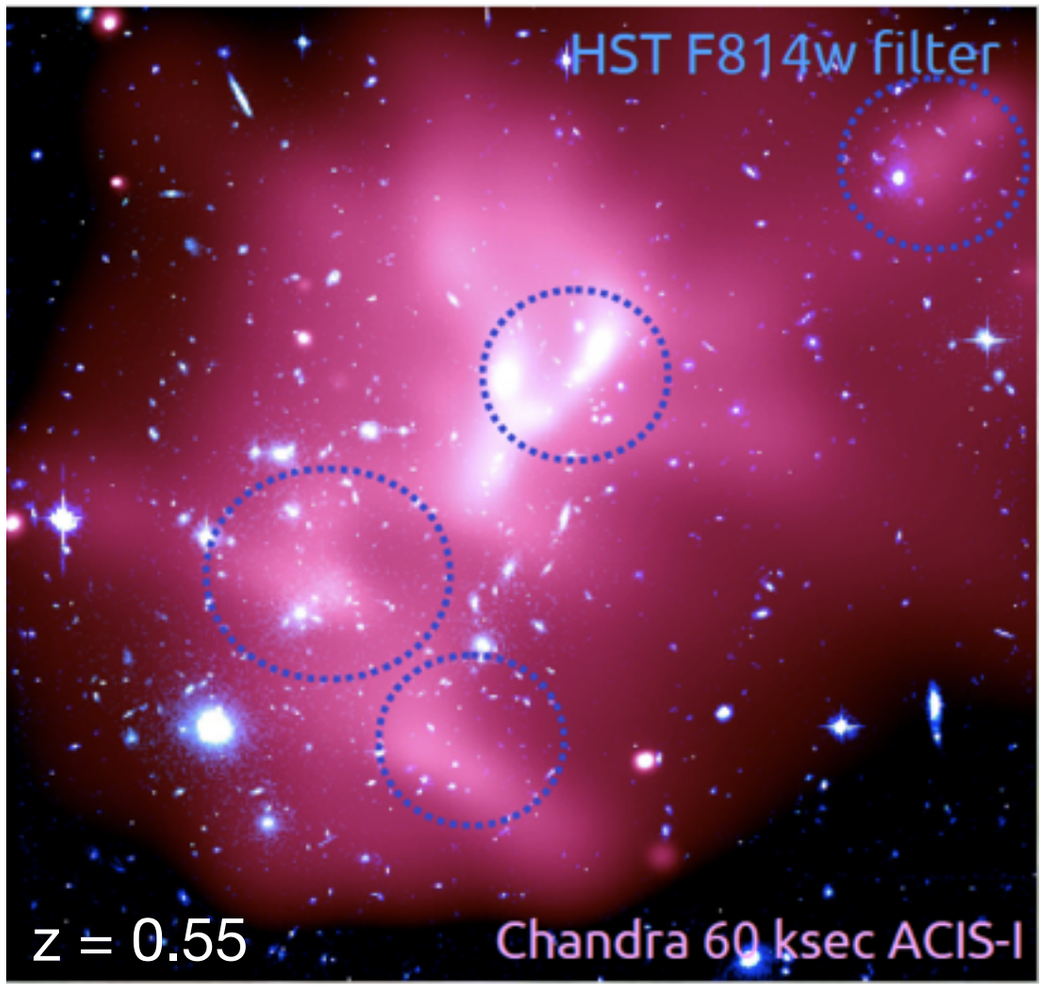
↓@ 610 MHz

The most distant & most powerful radio halo

Bonafede+ 09 & van Weeren+ 09



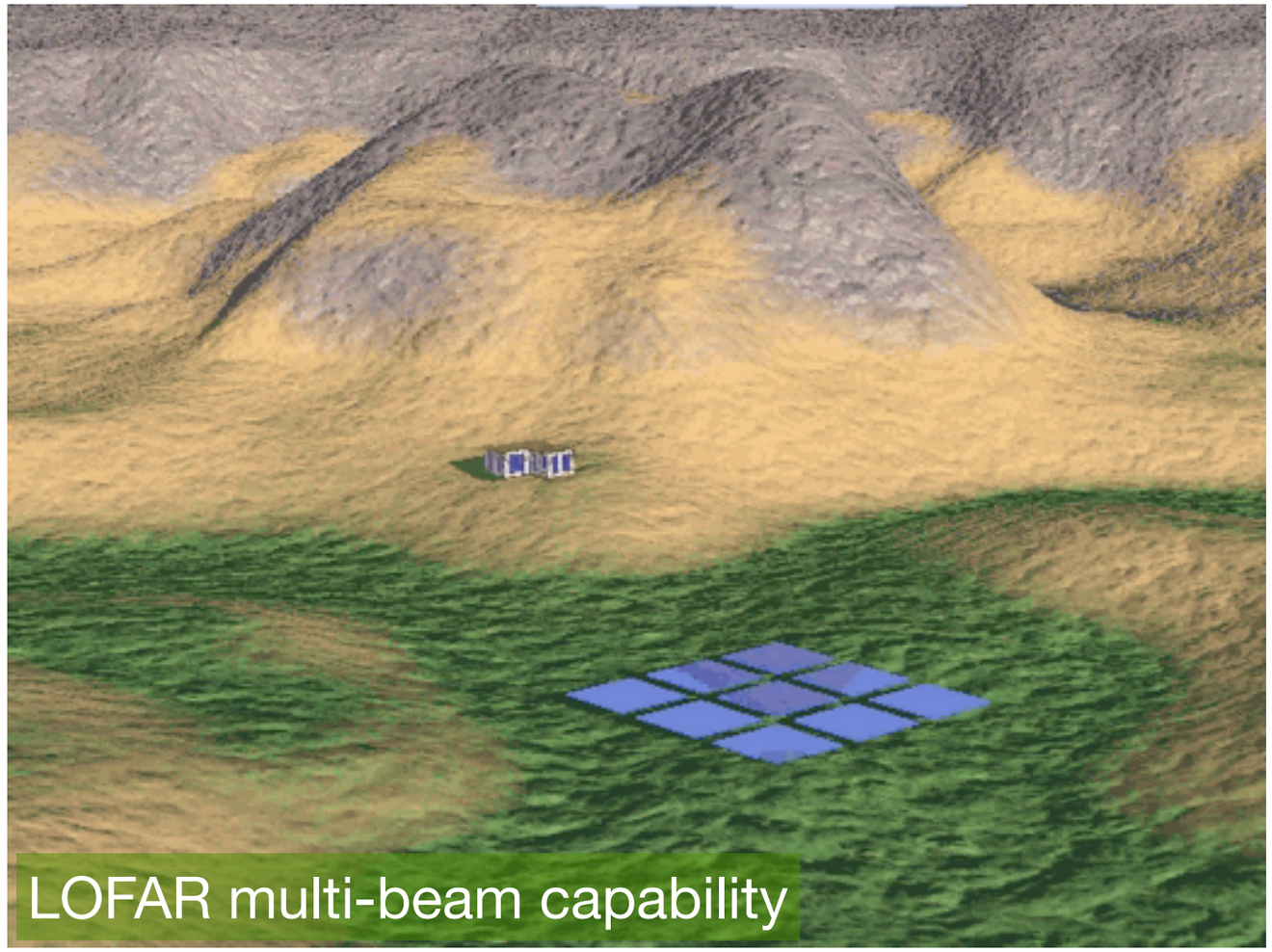
LOFAR OBSERVATIONS OF MACS J0717



Optical & X-ray cluster emission:

complex major cluster merger

Edge+ 03 & Ma+ 09



122 sub-bands on target & 122 sub-bands on calibrator

among which:

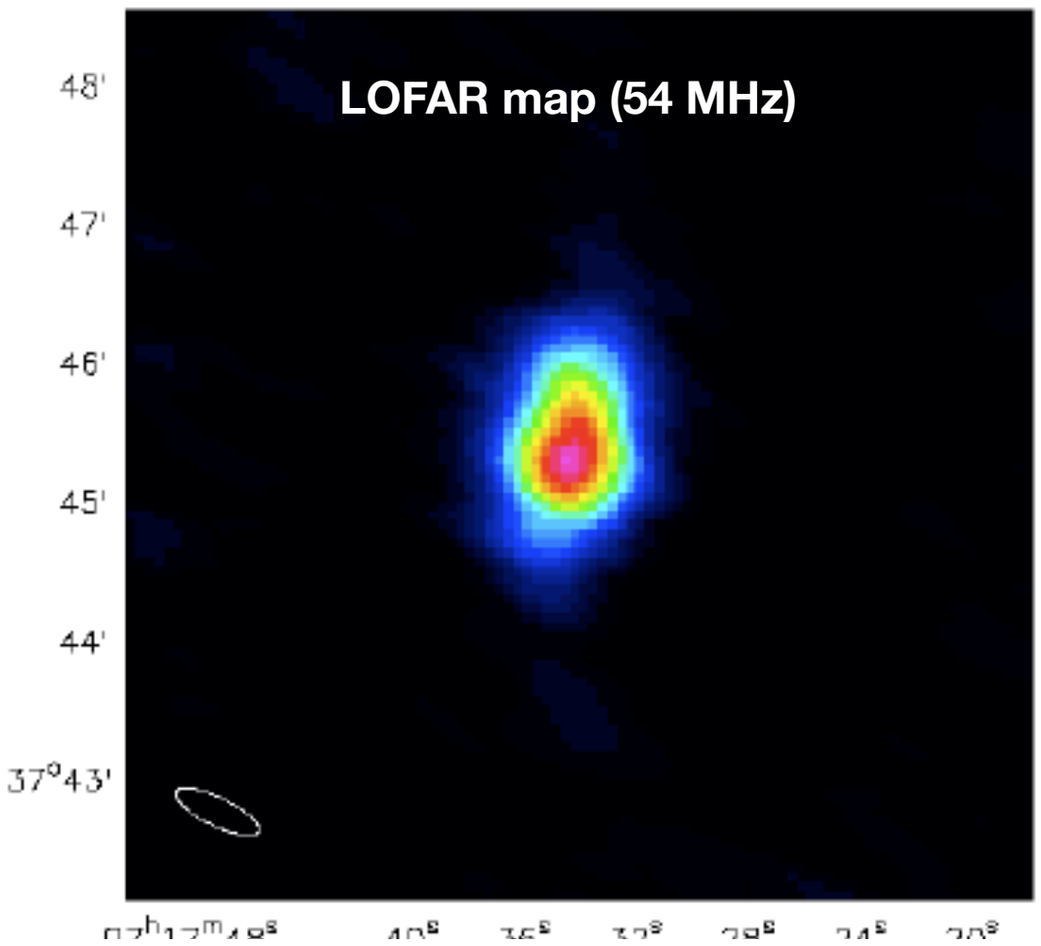
41 SBs @ ~34 MHz

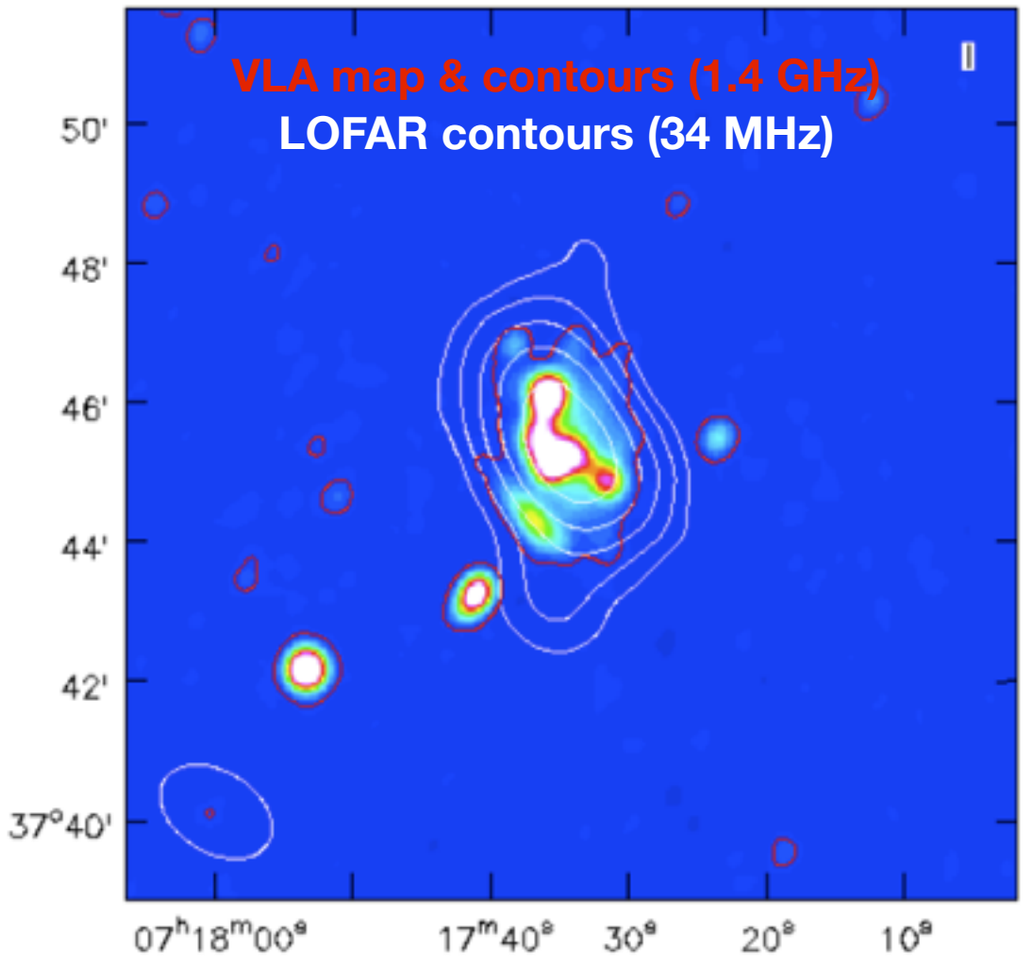
40 SBs @ ~58 MHz

41 SBs @ ~74 MHz

Bonafede+ in prep.

LOFAR OBSERVATIONS OF MACS J0717





LOFAR @ 54 MHz

Mean rms ~ 1.2x10^{-2} Jy/beam

FWHM: 12” x 38”

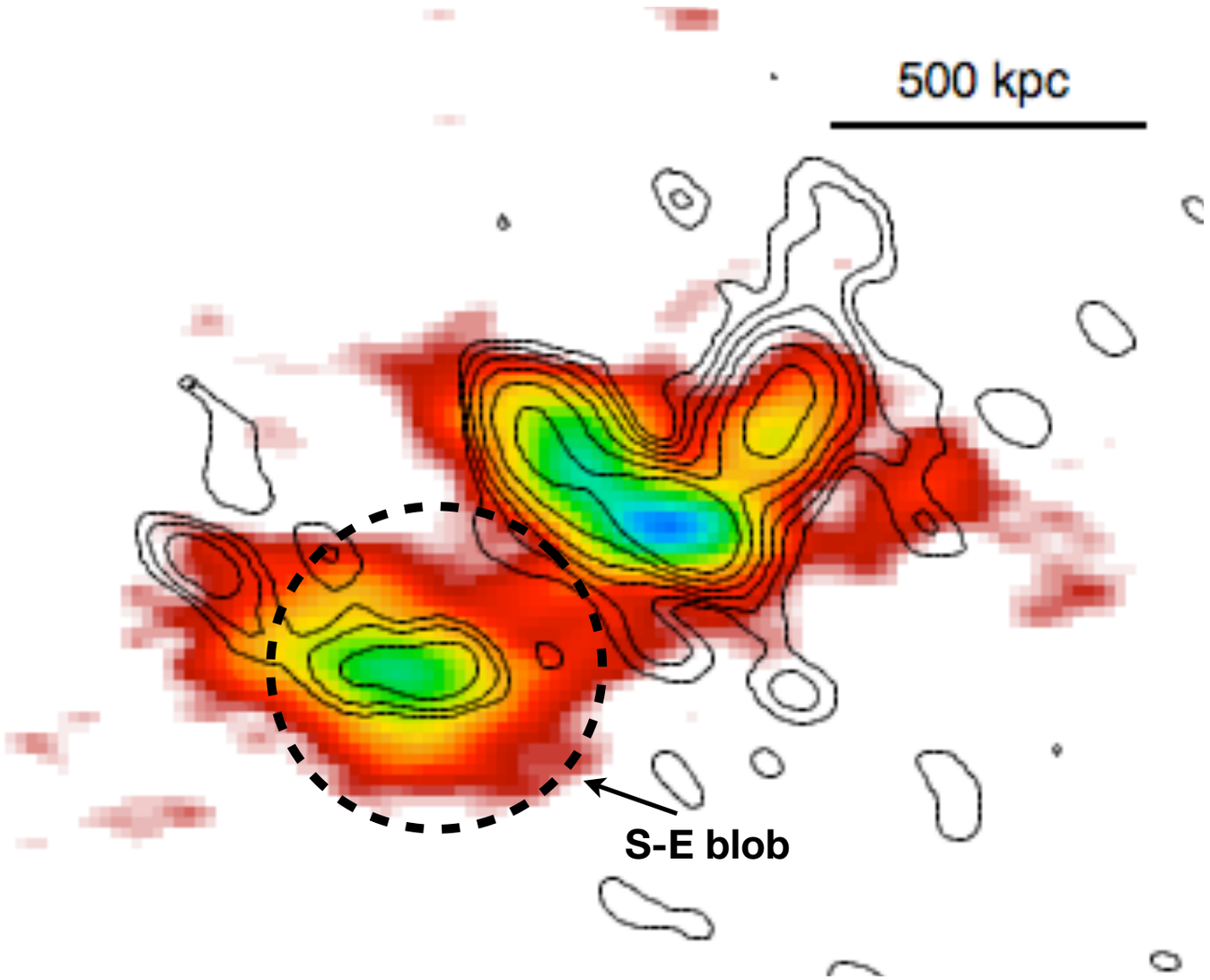
LOFAR @ 34 MHz

Mean rms ~ 2x10^{-1} Jy/beam

FWHM: 104” x 69”

Bonafede+ in prep.

LOFAR observations of Abell 1682



ALL components detected @ 60MHz,

LOFAR analysis - work in progress!

Macario, Ferrari+

LOFAR PERSPECTIVES

- Important developments required

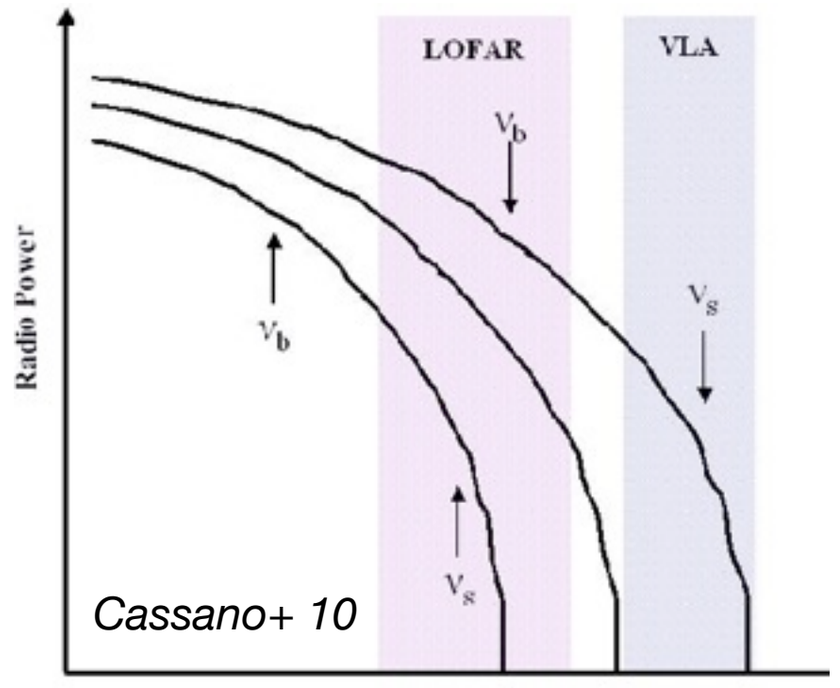
  i. Time-variable direction dependent effects to be fully included in calibration & imaging

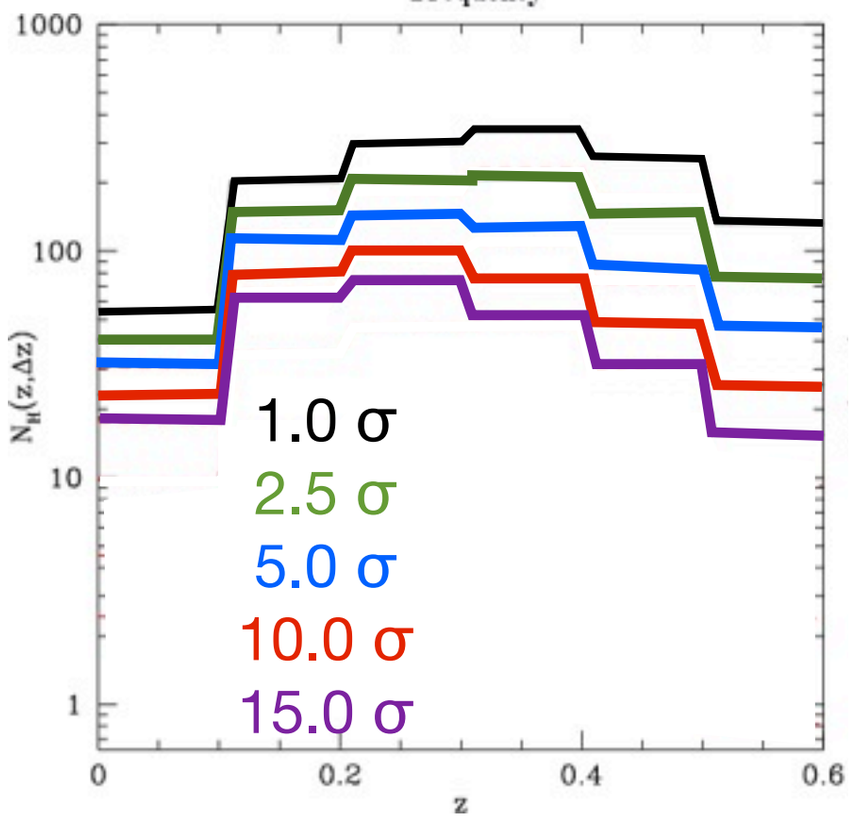
  ii. Proper beam model

- Scientific perspectives

  i. Hundreds of diffuse cluster sources expected (see plots →)

  ii. Number counts dominated by star forming galaxies (with SFR ~ 10-50 M_{Sun}/yr @ z~2)





LOFAR Source Finder group

article | edit this page | old revisions | subscribe page changes

Trace: » start » commissioning:start » commissioning:source_finders

A ***'Source finders Working Group'*** was formed and started his activities.

The group is leaded by *Chiara Ferrari* and currently hosts (in alphabetic order): *Rene Breton*, *Dario Carbone*, *Hugh Garsden*, *Alexander van der Horst*, *Rosita Paladino*, *David Rafferty (PyBDSM developer)*, *Aleksandar Shulevski*, *John Swinbank (PySE developer)*. Updates on the activities of the Source finders WG will be given regularly at the LSMs and at the Busy Thursdays. If you would like to join the group or for any question, please contact chiara.ferrari@oca.eu.

Main tasks of the working group

Points to be tested with the highest priority:

1. **Tests on extracted parameters -** Comparison between position and fluxes of sources found through different extraction algorithms and in published catalogs. We may start by running PyBDSM, PySE, Duchamp/Buildsky on VLSS maps and compare source catalogs using different tools (e.g. TOPCAT and private programs). It is of course important to make tests on different maps and using different tools for associating output catalogs.
2. **Identify statistics to state if automatic source extraction was successful or not -** We can start from the analysis of map or residuals, rms maps, … (see for instance this report by C. Ferrari).
3. **Tests on the different methods to produce/associate multi-band source catalogs -** In order to produce multi-band catalogs, we can either extract catalogs on each band's image and then associate them with ad-hoc programs, or define objects on a combined map and extract parameters from each band's image resulting in an immediate multi-band catalog. Hybrid solutions may also be adopted (see for instance this report by R. Breton).

Tests and results on the different tasks are reported in the following.

LOFAR Source Finder group

Active collaboration between all SKA-pathfinder projects (see e.g. SPARCS2 meeting, Sydney 2012)

article | edit this page | old revisions | subscribe page changes

Trace: » start » commissioning:start » commissioning:source_finders

A ***'Source finders Working Group'*** was formed and started his activities.

The group is leaded by *Chiara Ferrari* and currently hosts (in alphabetic order): *Rene Breton*, *Dario Carbone*, *Hugh Garsden*, *Alexander van der Horst*, *Rosita Paladino*, *David Rafferty (PyBDSM developer)*, *Aleksandar Shulevski*, *John Swinbank (PySE developer)*. Updates on the activities of the Source finders WG will be given regularly at the LSMs and at the Busy Thursdays. If you would like to join the group or for any question, please contact chiara.ferrari@oca.eu.

Main tasks of the working group

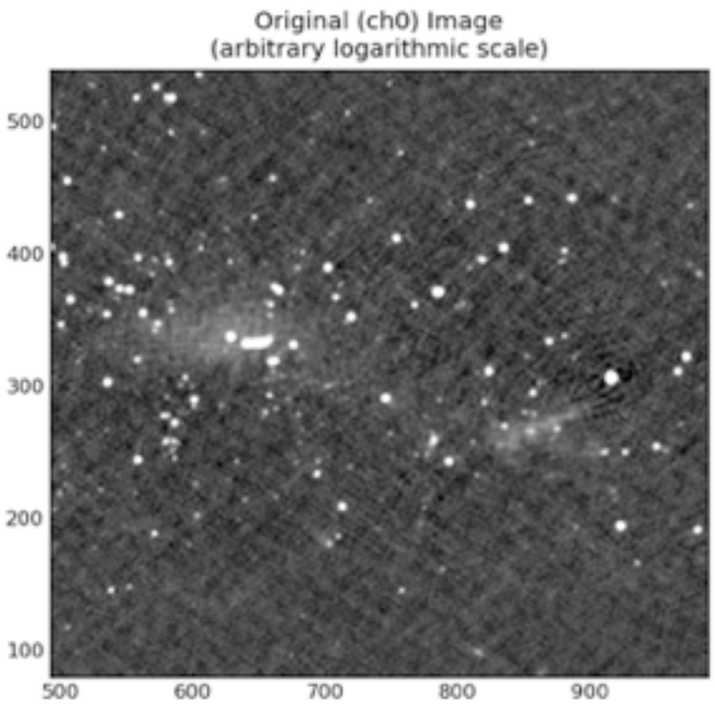
Points to be tested with the highest priority:

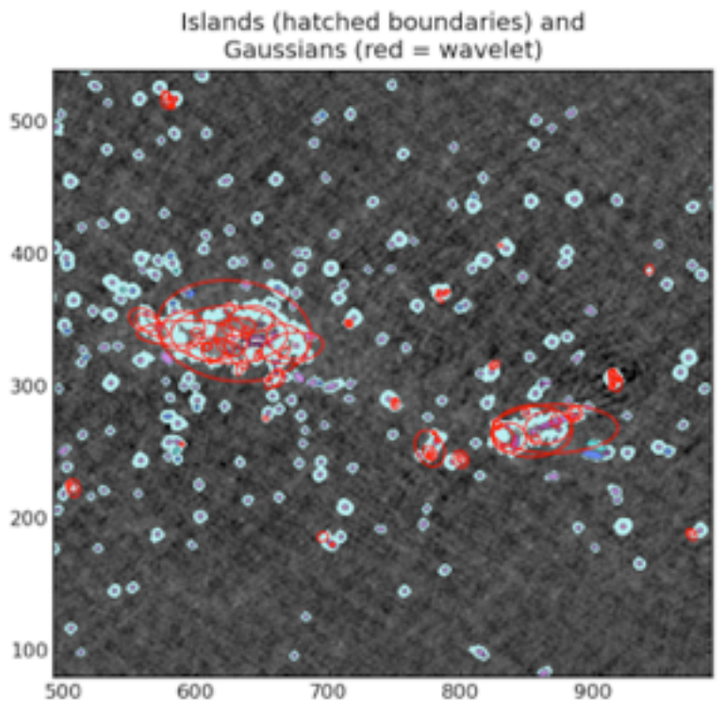
1. **Tests on extracted parameters -** Comparison between position and fluxes of sources found through different extraction algorithms and in published catalogs. We may start by running PyBDSM, PySE, Duchamp/Buildsky on VLSS maps and compare source catalogs using different tools (e.g. TOPCAT and private programs). It is of course important to make tests on different maps and using different tools for associating output catalogs.
2. **Identify statistics to state if automatic source extraction was successful or not -** We can start from the analysis of map or residuals, rms maps, … (see for instance this report by C. Ferrari).
3. **Tests on the different methods to produce/associate multi-band source catalogs -** In order to produce multi-band catalogs, we can either extract catalogs on each band's image and then associate them with ad-hoc programs, or define objects on a combined map and extract parameters from each band's image resulting in an immediate multi-band catalog. Hybrid solutions may also be adopted (see for instance this report by R. Breton).

Tests and results on the different tasks are reported in the following.

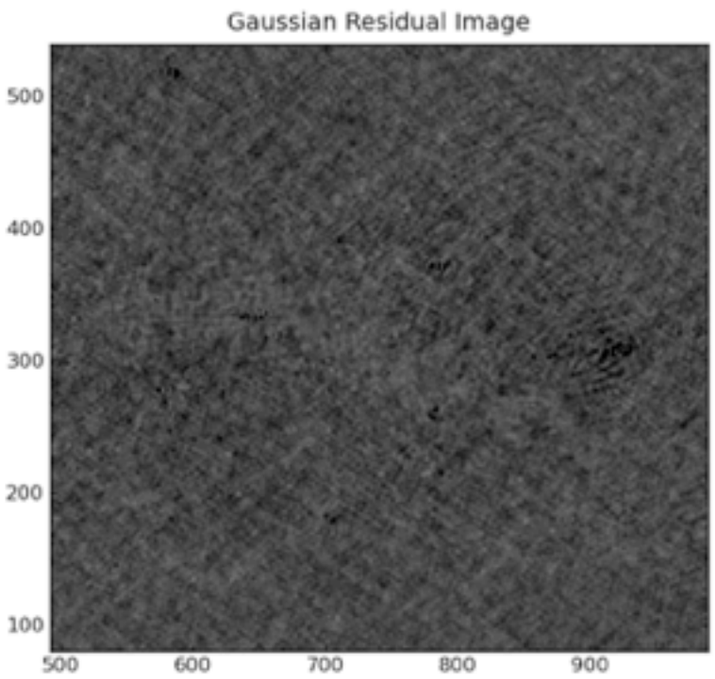
Coma WSRT observations

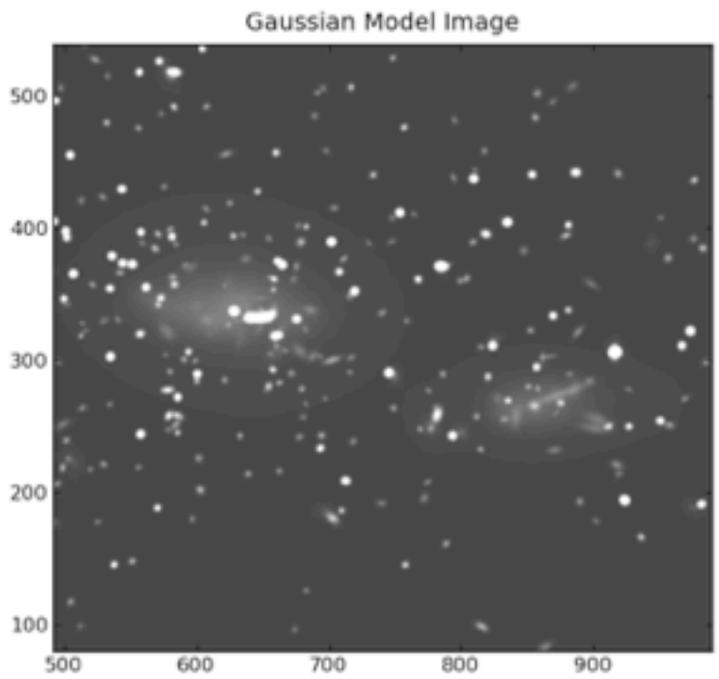
(@ 90 cm - res. 55” x 125”)





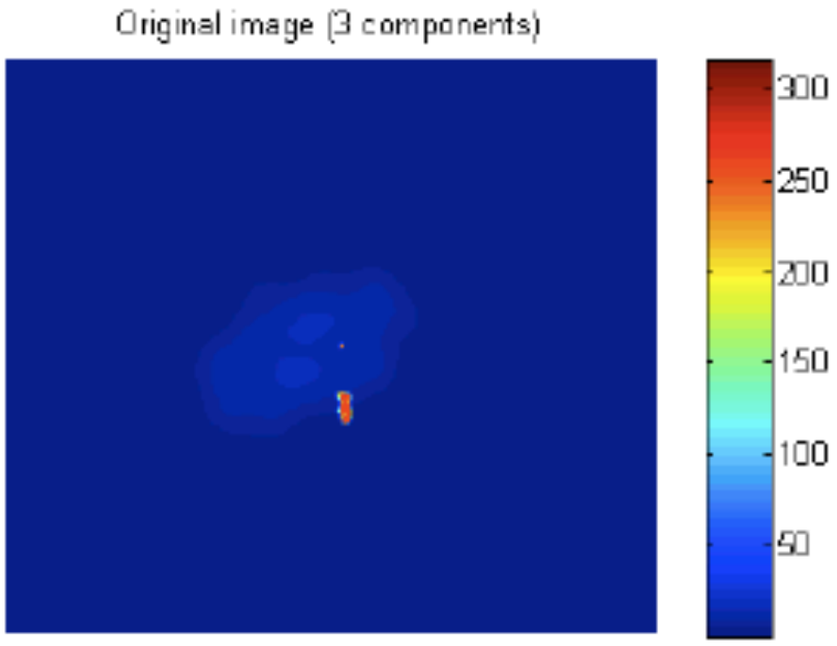
PyBDSM
(Mohan, Rafferty+)

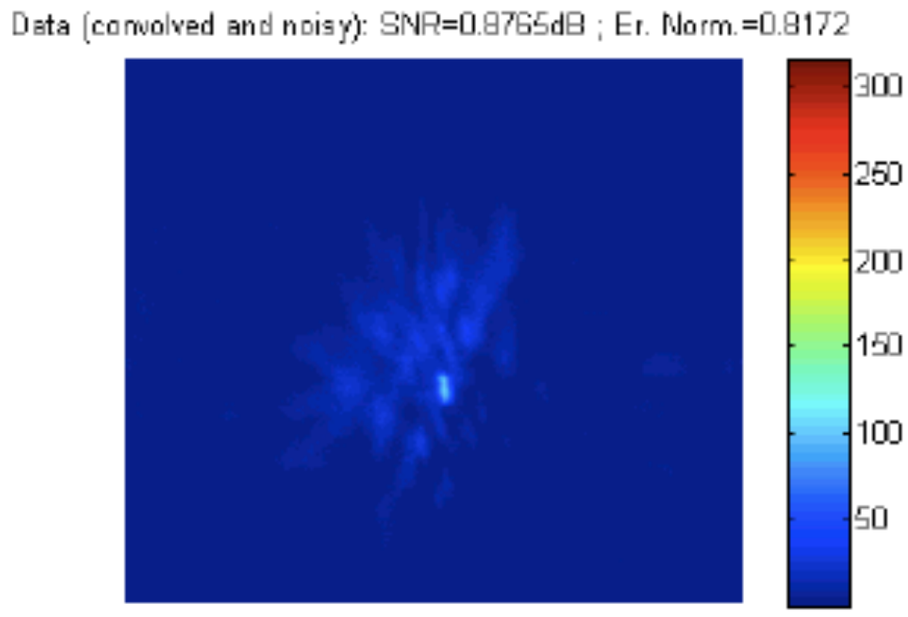


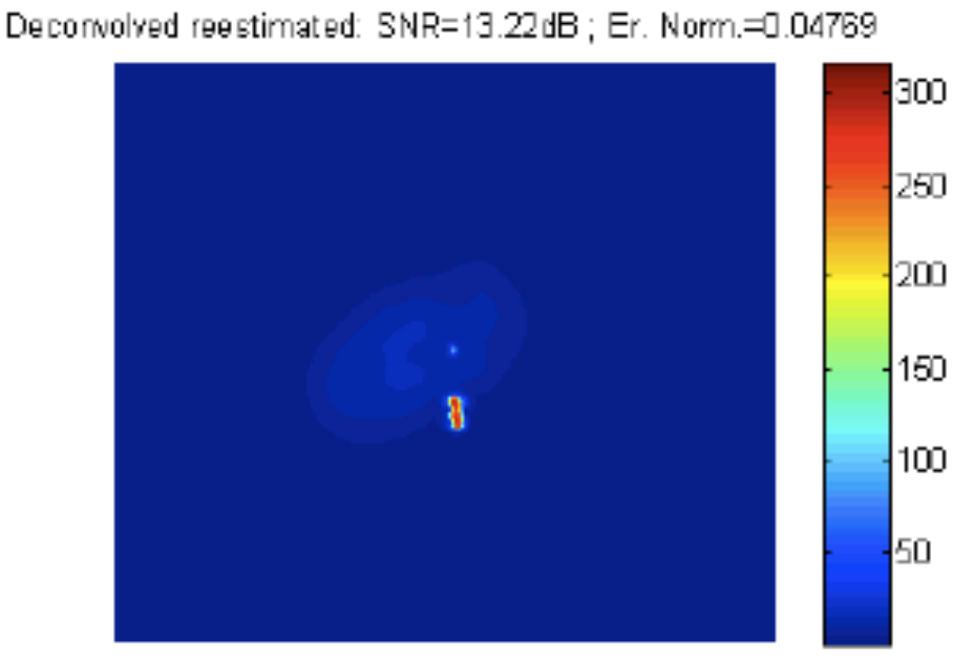


Radio map courtesy:
Feretti & Giovannini

New deconvolution method:
Synthesis & Analysis using Sparse Representation

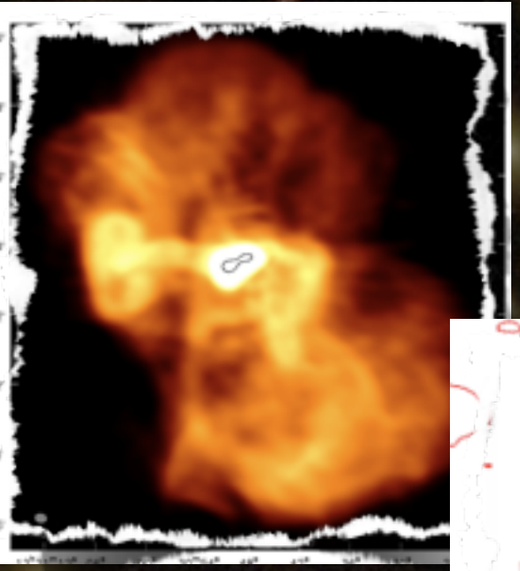


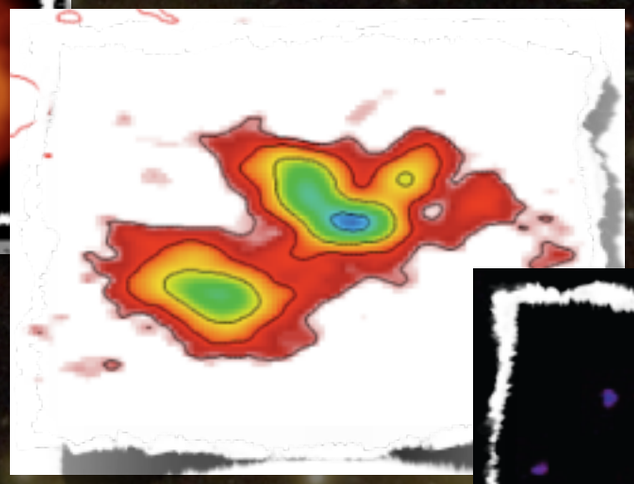


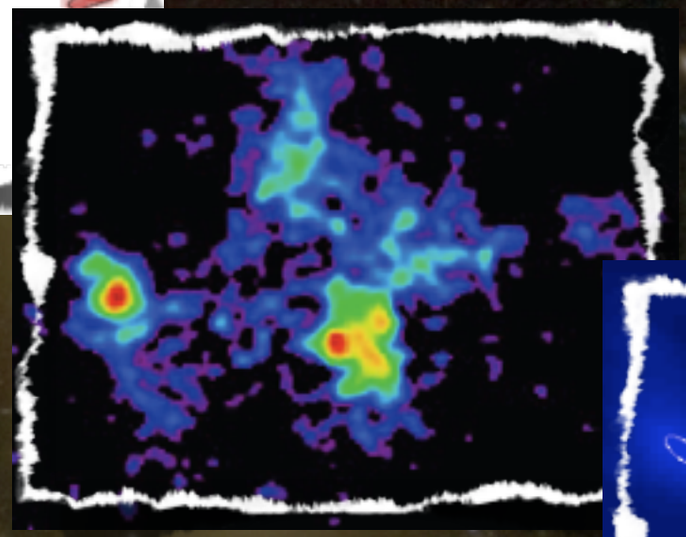


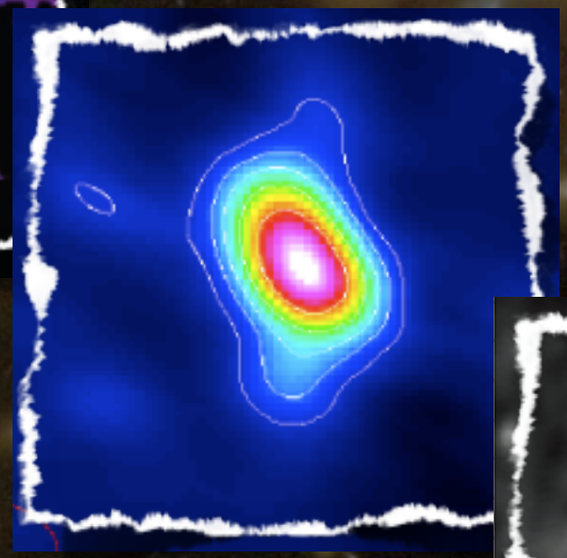
Dabbech+ 12

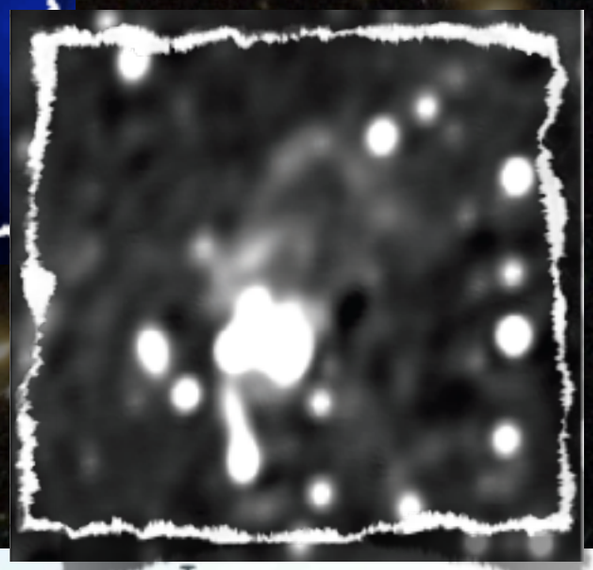
(+ ongoing PhD Thesis@OCA)











Thanks !