

# The LOFAR Two Meter Sky Survey(s), jets and other weird radio emission

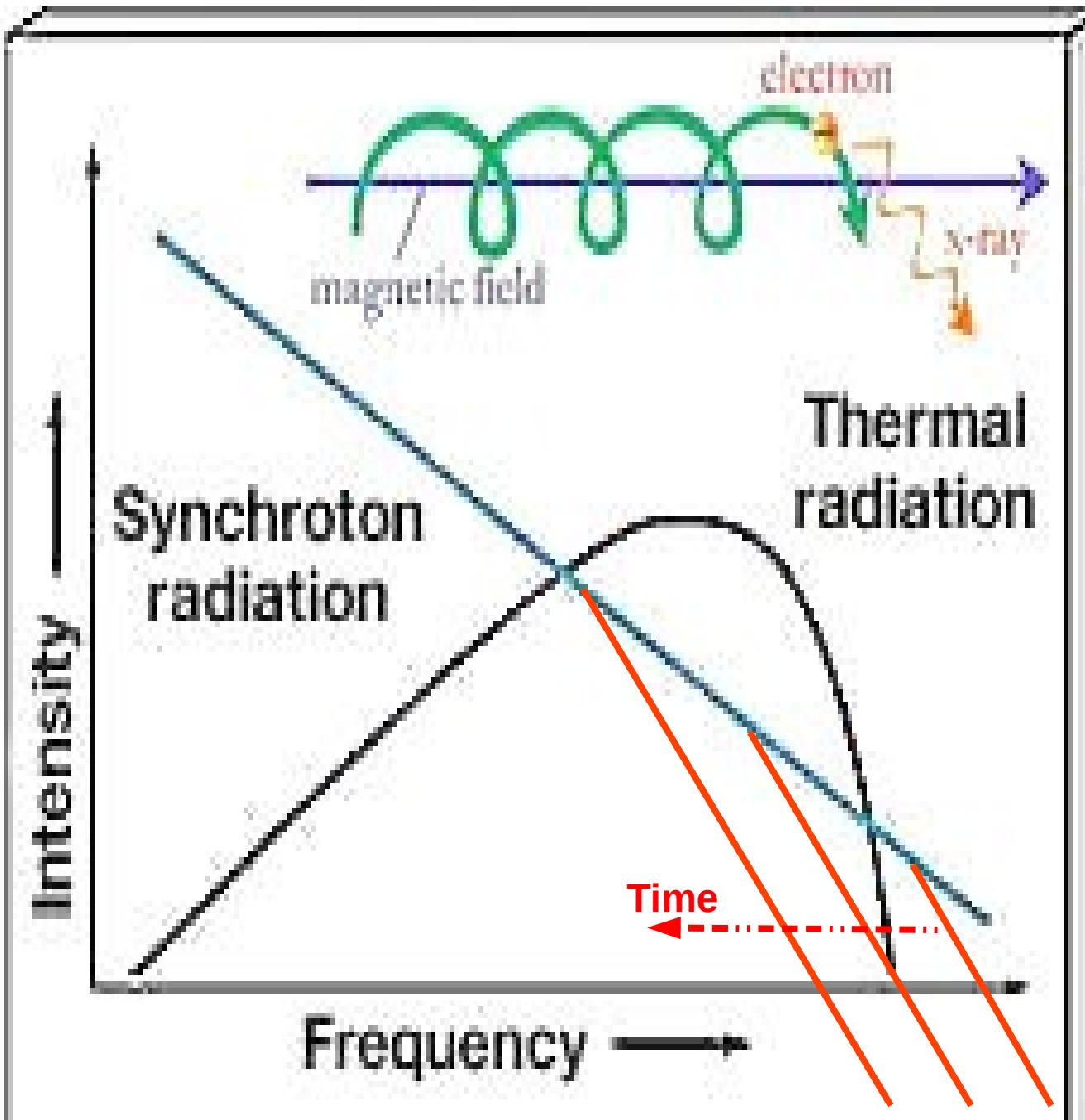
*LoTSS wide & deep*

Cyril Tasse

*Observatoire de Paris – GEPI/USN  
Rhodes University*

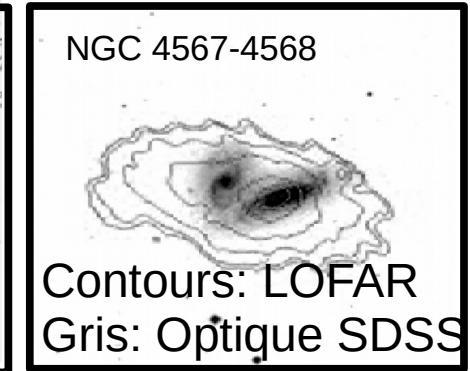
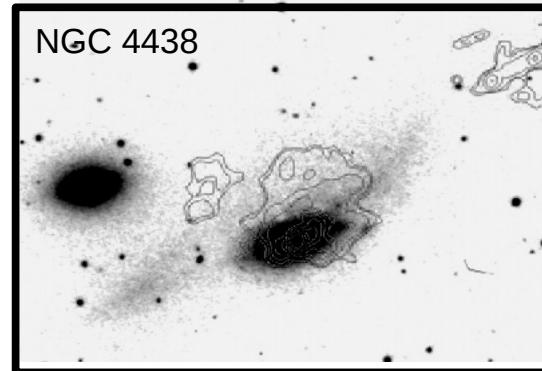
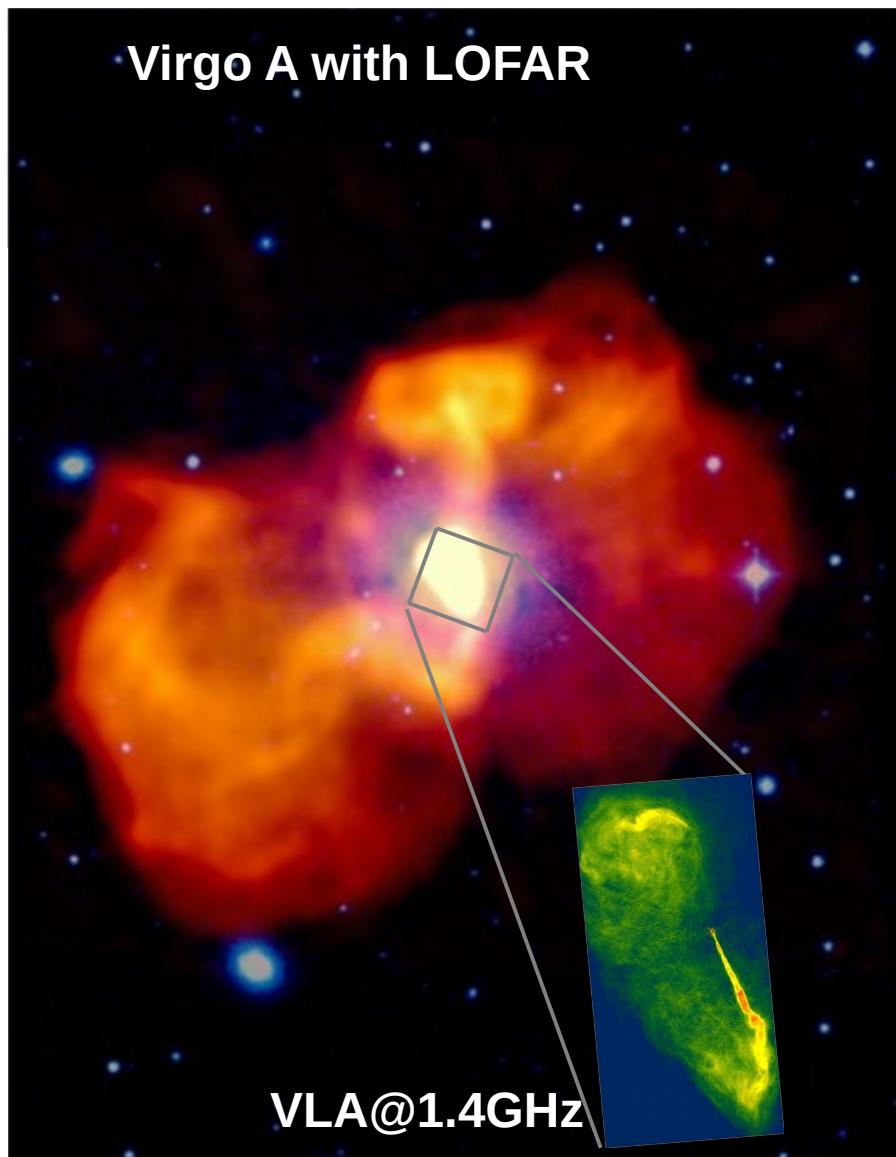
for the LOFAR Surveys KSP

# Spectral aging?



# Virgo A (M87)

De Gasperin et al. 2012



# LOFAR

## International LOFAR Telescope (ILT)



Chilbolton

- 300 – 1000 km
- 3 new stations coming in Poland



Onsala



Dutch stations

LOFAR Core (NL)

Norderstedt

Potsdam

Baldy

Borówiec

Eazy

Jülich

Effelsberg

Tautenburg

Unterweilenbach



Nançay



North American Institute for Radio Astronomy



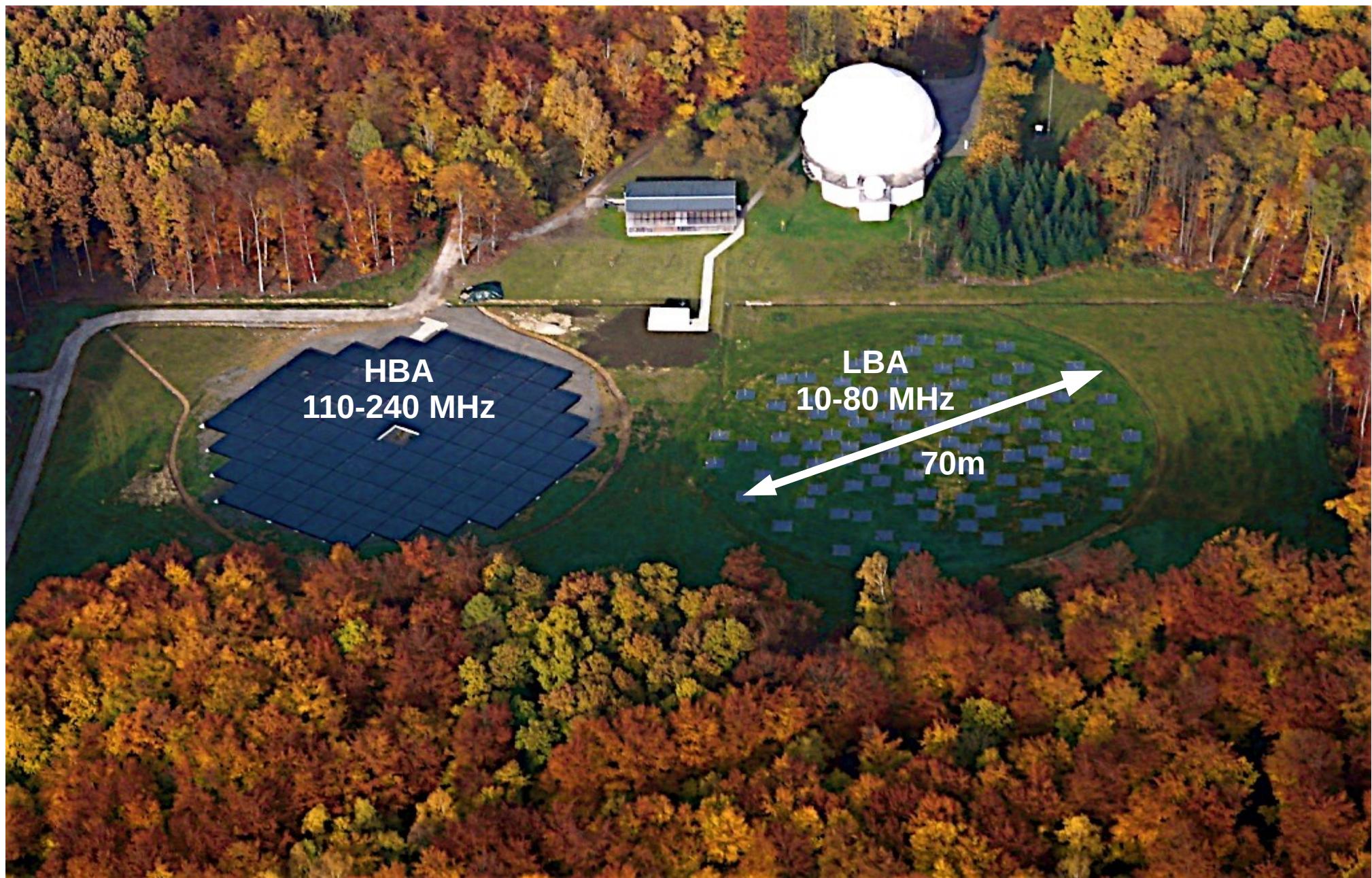
# LOFAR

## An SKA pathfinder

30MHz - 250MHz



# LOFAR station are phased arrays

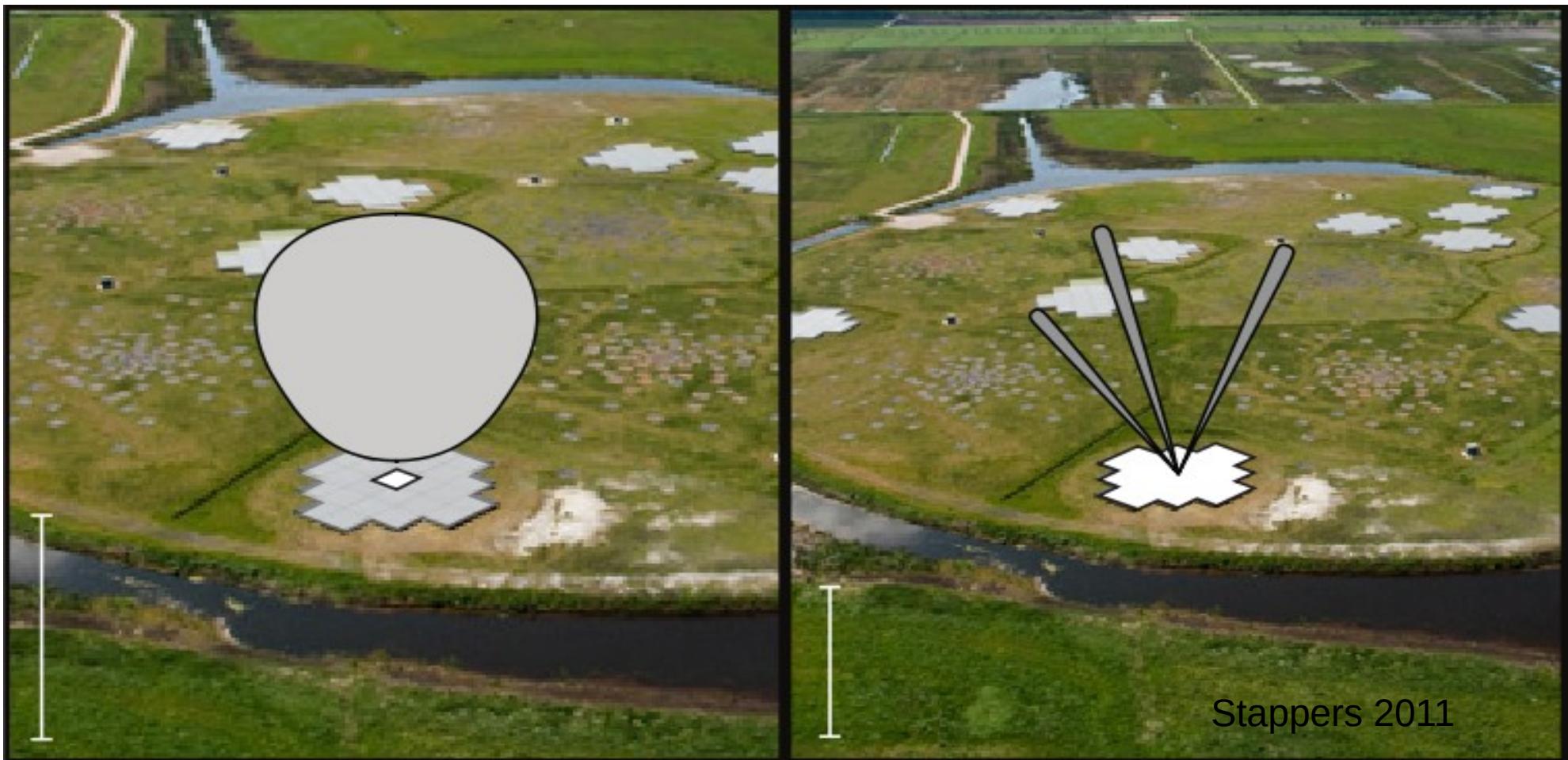


# LOFAR

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- resolution ~5 arcsec @ 200 MHz for the dutch core
- resolution ~0.2 arcsec @ 50 MHz for the international baselines
- Huge data flow
- New types of algorithms (&SKA related)

# LOFAR station are phased arrays

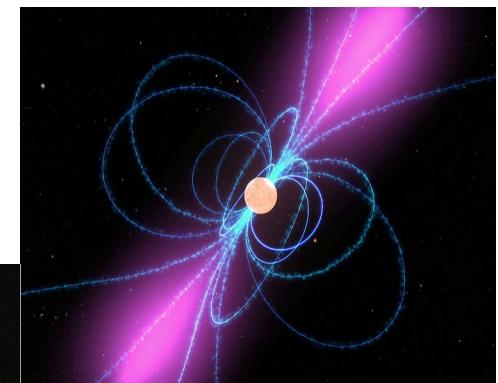


We can point at different directions at the simultaneously :

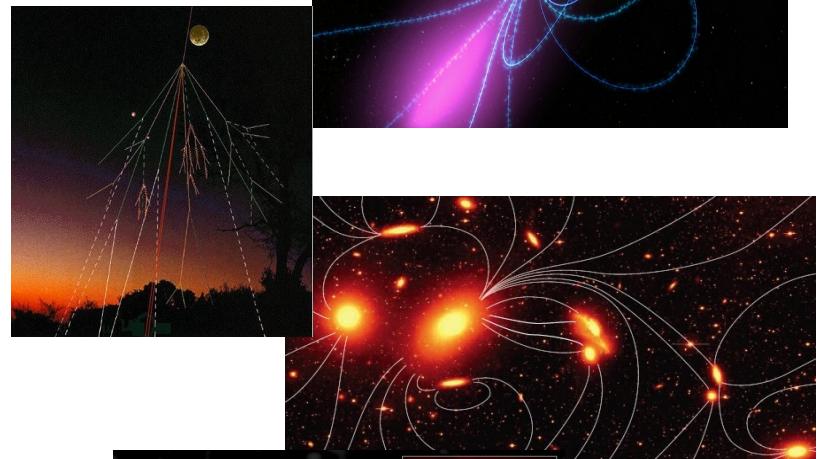
- Great for transient studies
- Cover big areas on the sky
- Calibration

# Scientific Goals

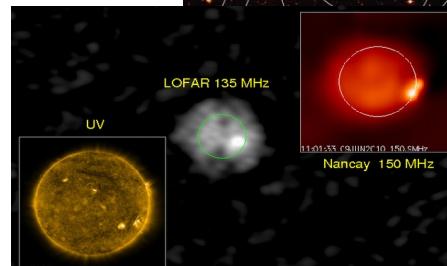
- Transient Universe (pulsars, exoplanets, supernovae, GRBs)



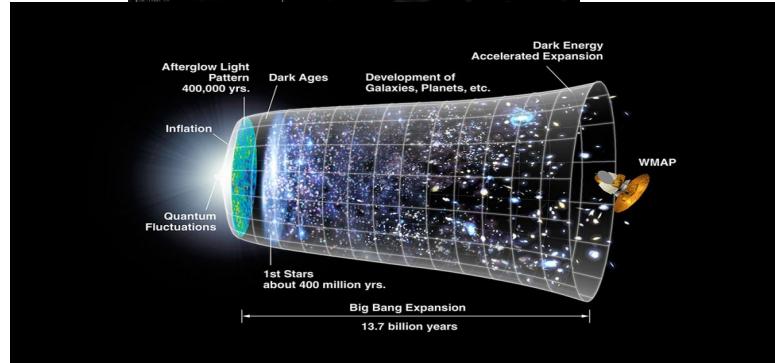
- High energy physics ( $10^{15}$ - $10^{20}$  eV)



- Cosmic magnetism?



- Solar physics



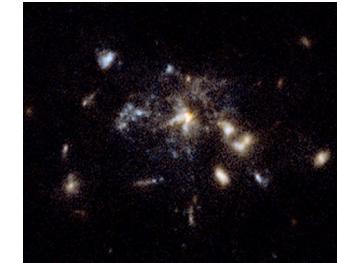
- Epoch of Reionization

# Surveys and LOFAR

## Deep Extragalactic surveys

- 100 z~6 radio galaxies :

**Formation & evolution of massive galaxies and clusters at / after EOR**



- 100 diffuses cluster emission in clusters of galaxies at  $z>0.6$  :

**Dynamics of intracluster gas, cluster-cluster interaction, Large smale magnetism.**



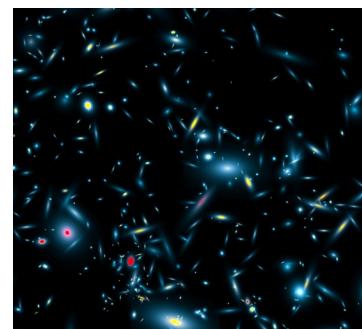
- 10 clusters of galaxies à  $z>2$  :

**Star formation in dense environment at  $SFR\sim 10$**

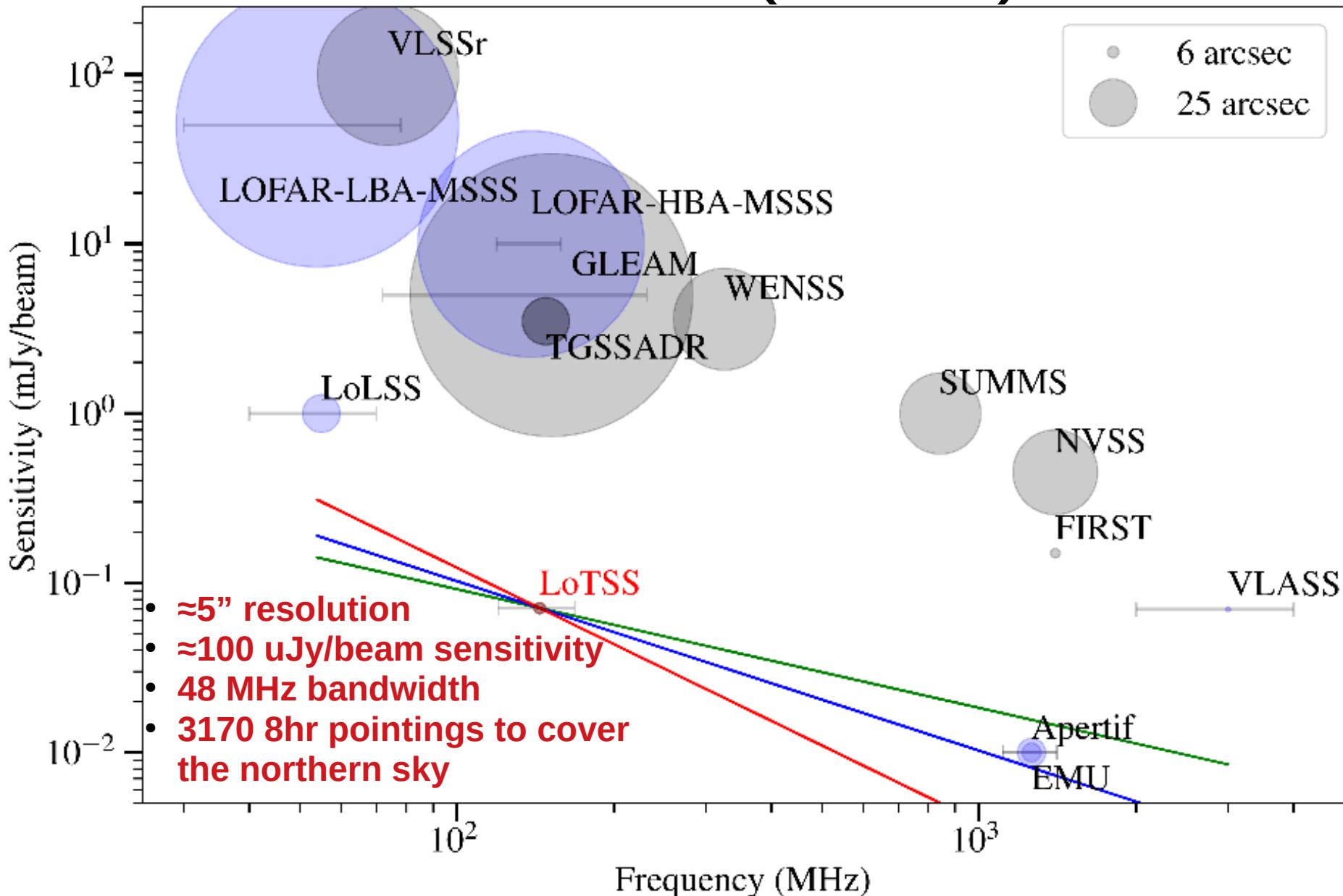
**$M_{\odot}/yr$  @  $z = 2-3$**



- 10-100s millions galaxies at  $z<2$



# The LOFAR Two-meter Sky Survey : LOTSS (Tier-1)



# The LOFAR Two-metre Sky Survey (LoTSS) – data release 1

T. W. Shimwell, C. Tasse, M. J. Hardcastle, A. P. Mechev, W. L. Williams, P. N. Best, H. J. A. Rottgering, J. R. Callingham, T. J. Dijkema, F. de Gasperin, D. N. Hoang, B. Hugo, M. Mirmont, J. B. R. Oonk, I. Prandoni, D. Rafferty, J. Sabater, O. Smirnov, R. J. van Weeren, G. J. White, M. Atemkeng, L. Bester, E. Bonnassieux, M. Bruggen, G. Brunetti, K. T. Chyzy, R. Cochrane, J. E. Conway, J. H. Croston, A. Danezi, K. Duncan, M. Haverkorn, G. H. Heald, M. Iacobelli, H. T. Intema, N. Jackson, M. Jamrozy, M. J. Jarvis, R. Lakhoo, M. Mevius, G. K. Miley, L. Morabito, R. Morganti, D. Nisbet, E. Orru, S. Perkins, R. F. Pizzo, C. Schrijvers, D. J. B. Smith, R. Vermeulen, M. W. Wise, L. Alegre, D. J. Bacon, I. M. van Bemmel, R. J. Beswick, A. Bonafede, A. Botteon, S. Bourke, M. Brienza, G. Calistro Rivera, R. Cassano, A. O. Clarke, C. J. Conselice, R. J. Dettmar, A. Drabent, C. Dumba, K. L. Emig, T. A. Ensslin, C. Ferrari, M. A. Garrett, R. T. Genova-Santos, A. Goyal, G. Gurkan, C. Hale, J. J. Harwood, V. Heesen, M. Hoeft, C. Horellou, C. Jackson, G. Kokotanekov, R. Kondapally, M. Kunert-Bajraszewska, V. Mahatma, E. K. Mahony, S. Mandal, J. P. McKean, A. Merloni, B. Mingo, S. Mooney, B. Nikiel-Wroczyński, S. P. O'Sullivan, J. Quinn, W. Reich, C. Roskowinski, A. Rowlinson, F. Savini, A. Saxena, D. J. Schwarz, A. Shulevski, S. S. Sridhar, H. R. Stacey, S. Urquhart, M. H. D. van der Wiel, E. Varenius, B. Webster, A. Wilber

W. L. Williams, M. J. Hardcastle, P. N. Best, J. Sabater, J. H. Croston, K. J. Duncan, T. W. Shimwell, H. J. A. Rottgering, D. Nisbet, G. Gurkan, L. Alegre, R. K. Cochrane, A. Goyal, C. L. Hale, N. Jackson, M. Jamrozy, R. Kondapally, M. Kunert-Bajraszewska, V. H. Mahatma, B. Mingo, L. K. Morabito, I. Prandoni, C. Roskowinski, A. Shulevski, D. J. B. Smith, C. Tasse, S. Urquhart, B. Webster, G. J. White, R. J. Beswick, J. R. Callingham, K. T. Chyzy, F. de Gasperin, J. J. Harwood, M. Hoeft, M. Iacobelli, J. P. McKean, A. P. Mechev, G. K. Miley, D. J. Schwarz, R. J. van Weeren

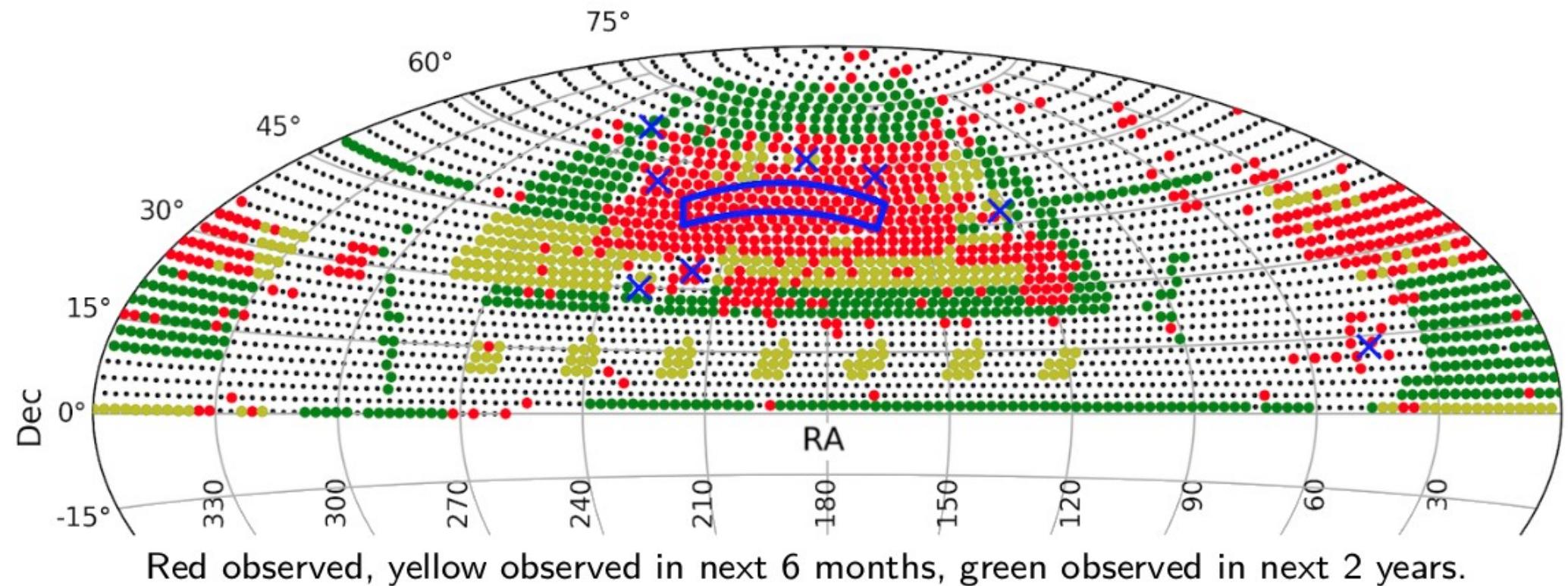
Kenneth J Duncan, J. Sabater, H. J. A. Rottgering, M. J. Jarvis, D. J. B. Smith, P. N. Best, J. R. Callingham, R. Cochrane, J. H. Croston, M. J. Hardcastle, B. Mingo, L. Morabito, D. Nisbet, I. Prandoni, T. W. Shimwell, C. Tasse, G. J. White, W. L. Williams, L. Alegre, K. T. Chyzy, G. Gurkan, M. Hoeft, R. Kondapally, A. P. Mechev, G. K. Miley, D. J. Schwarz, R. J. van Weeren

# LOTSS : LOFAR Two-meter Sky Survey

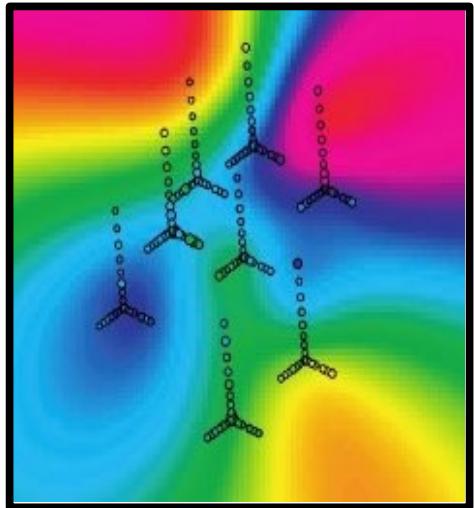
20% of the northern sky is observed.

50% of the observed data is partially processed.

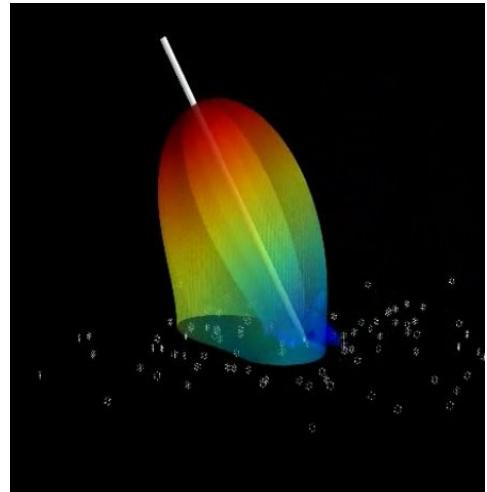
Allocated 3750 hrs of observations to reach 50% completeness in 2 years



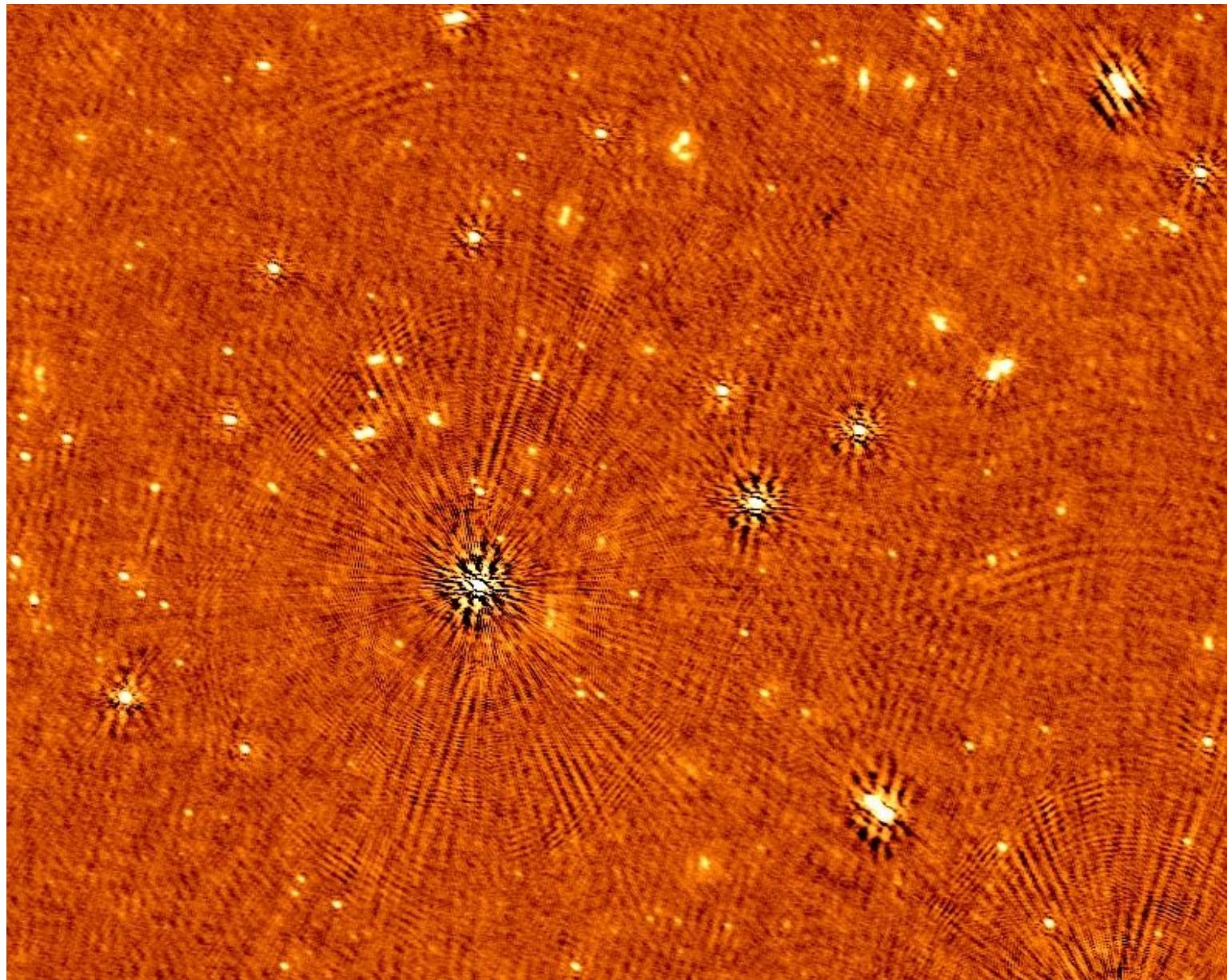
# The best image you can ever get in selfcal



Ionospheric  
disturbance + Faraday  
rotation

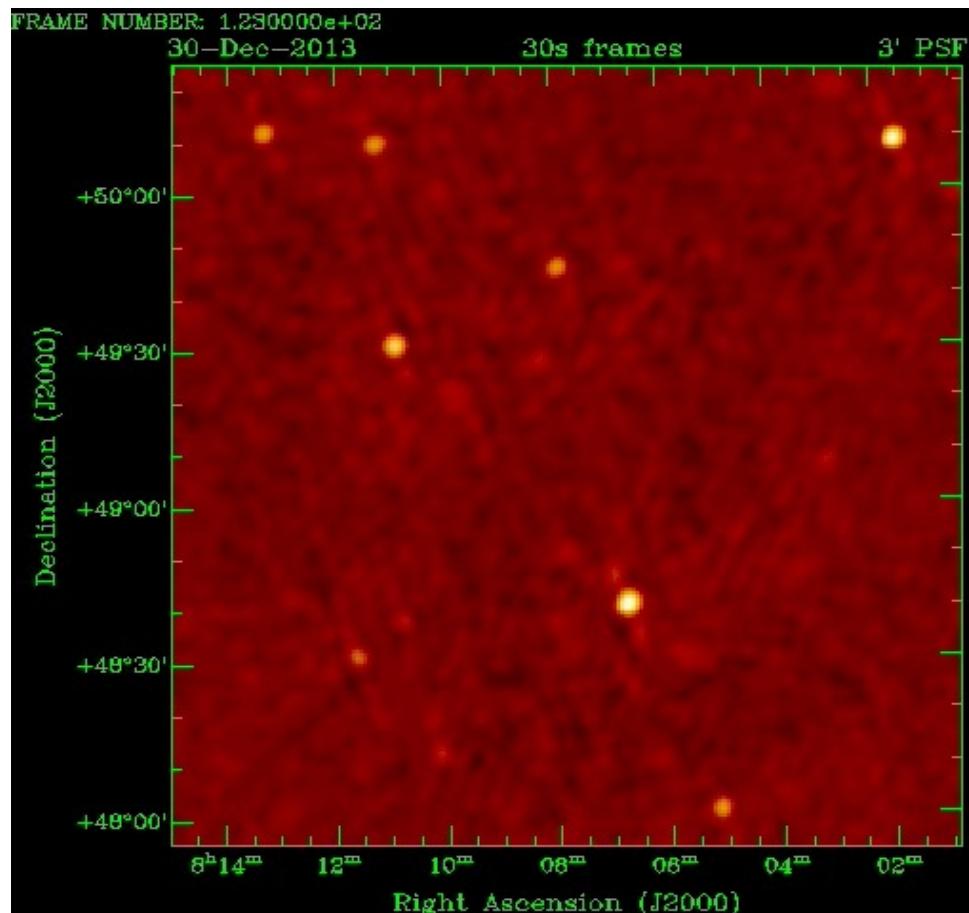


Station lobes

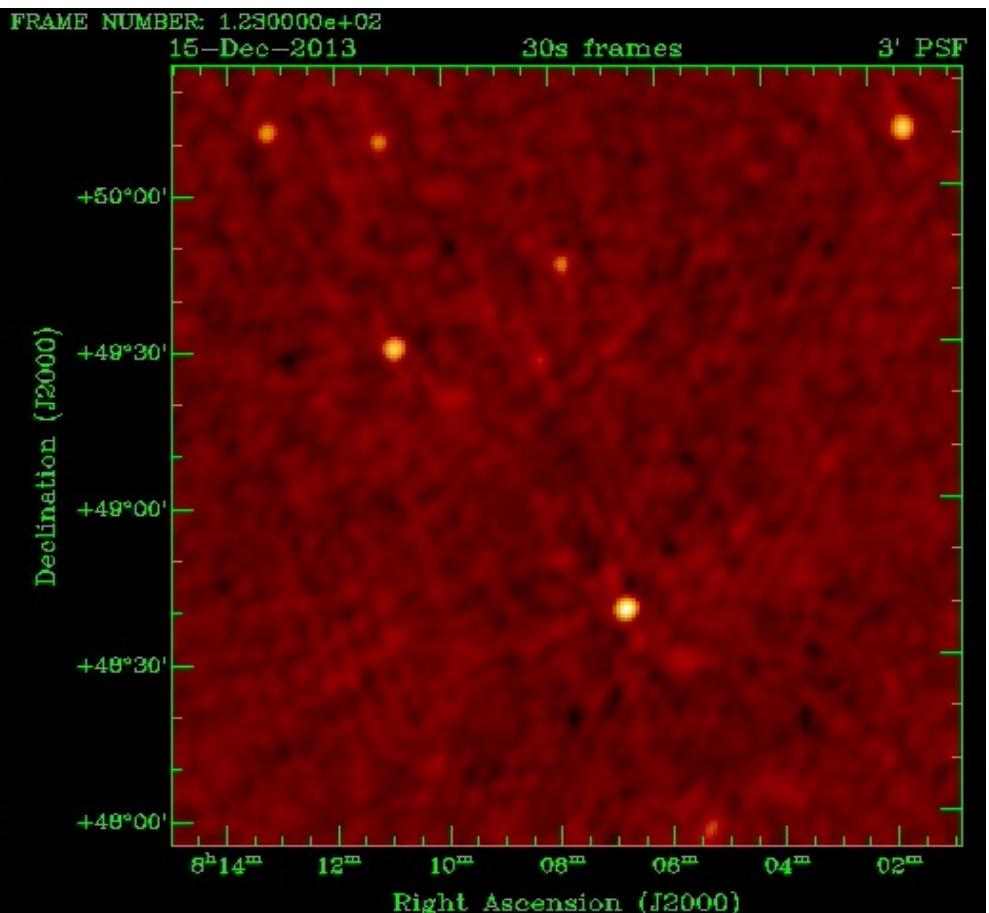


# Ionosphere

Good ionosphere



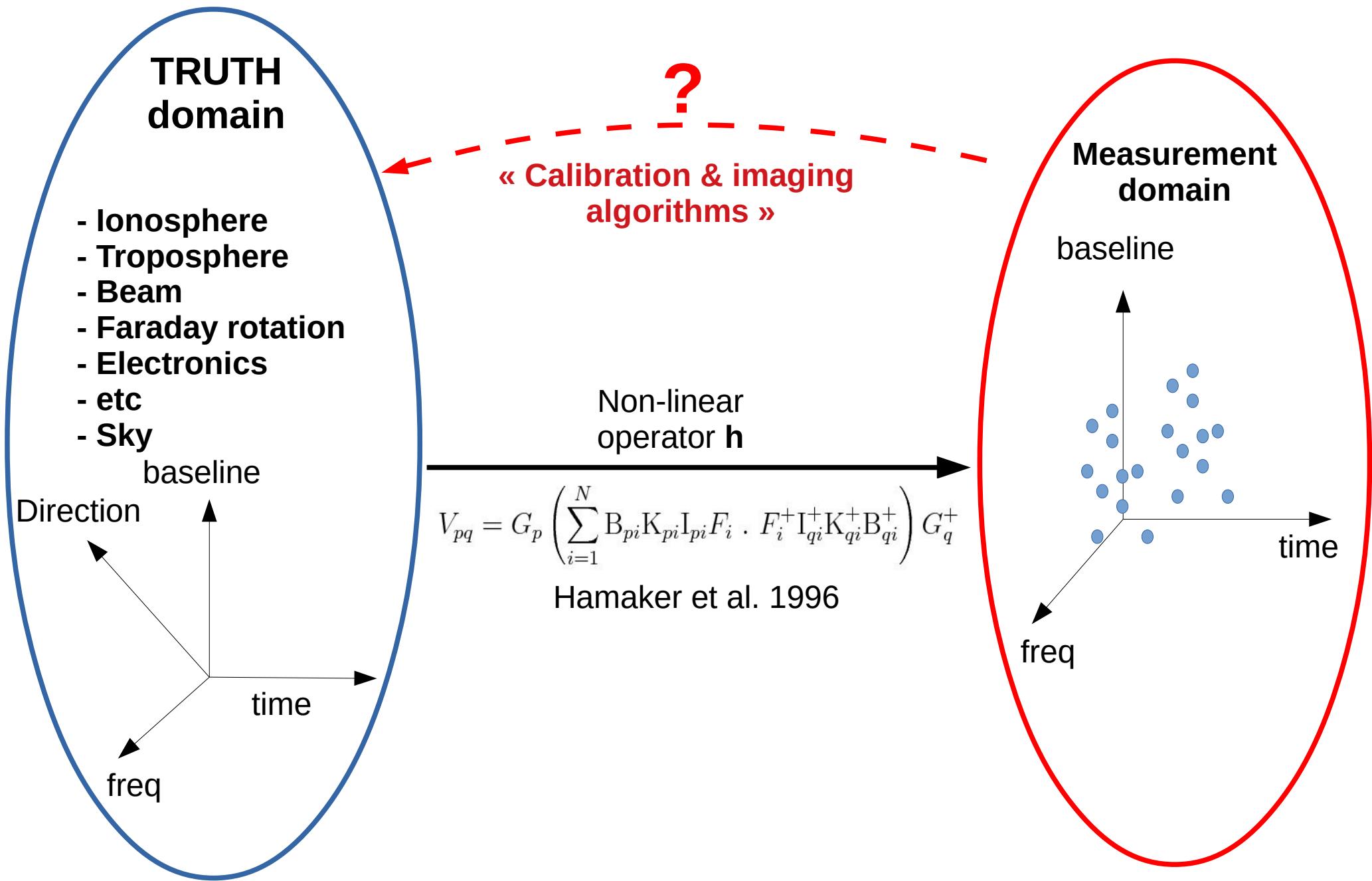
Bad ionosphere



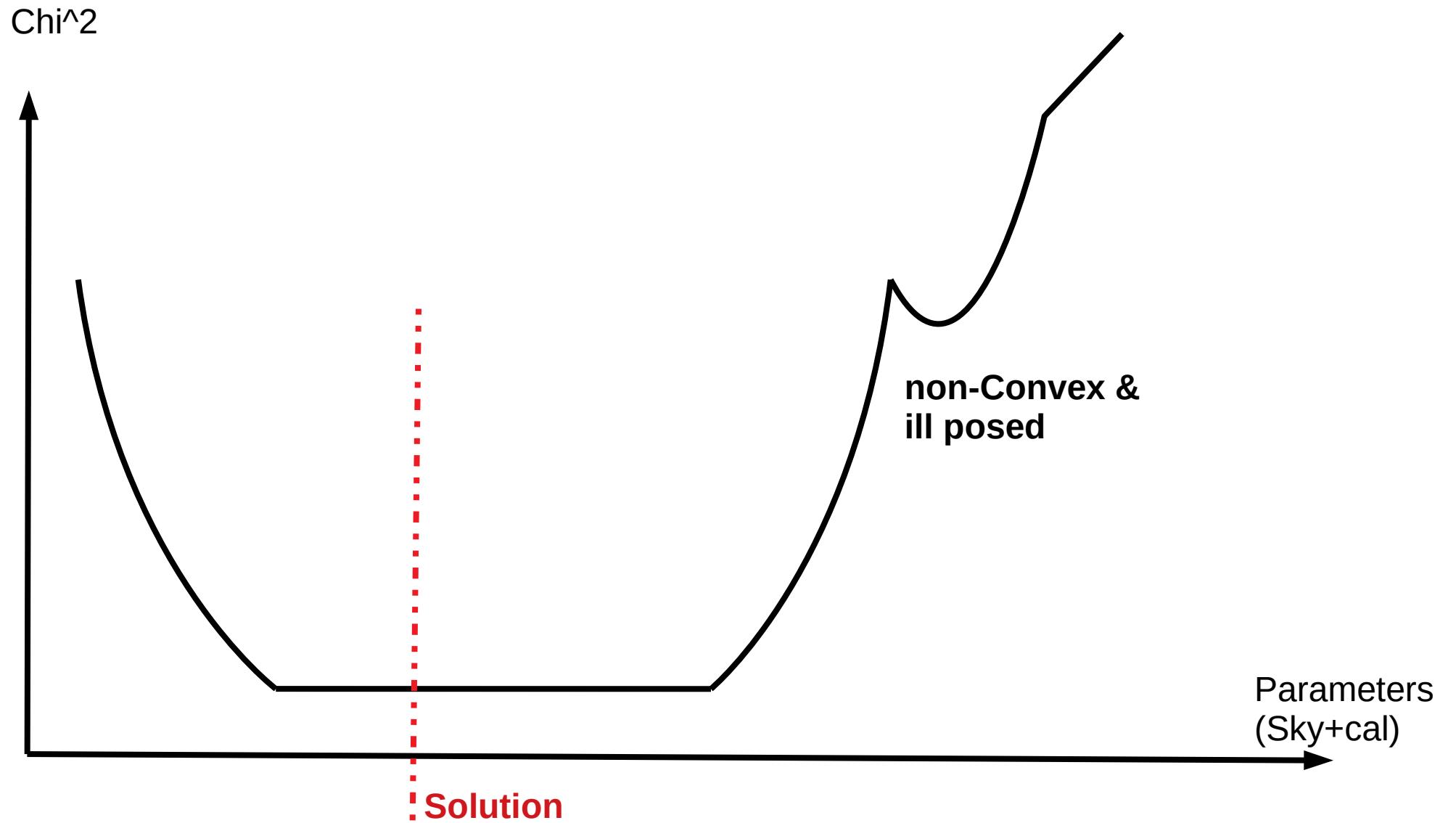
Images have 3 arcmin resolution

Ger de Bruyn & LOFAR EoR team

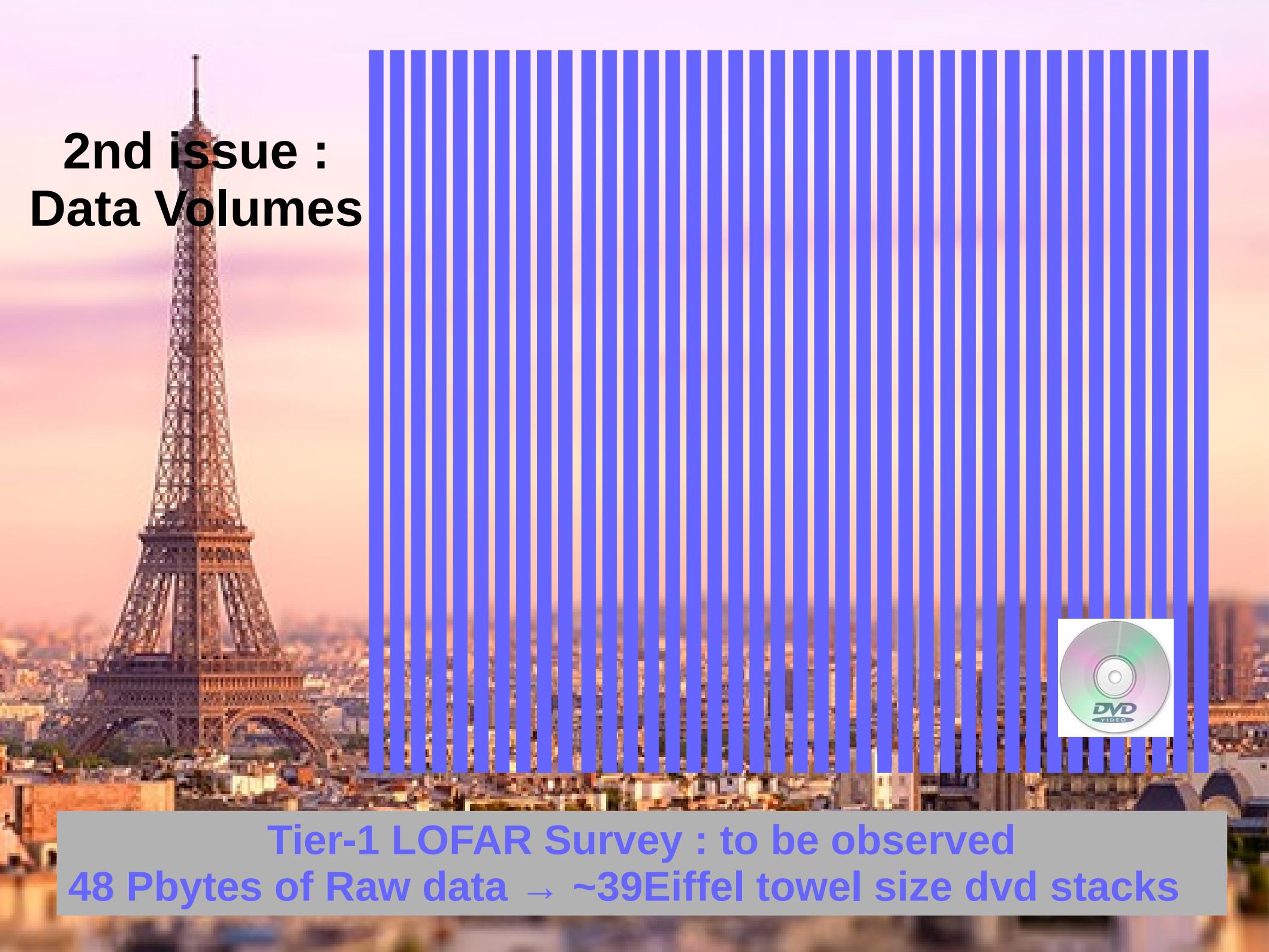
# Interferometry



# First issue : Convexity, Conditionning



## 2nd issue : Data Volumes



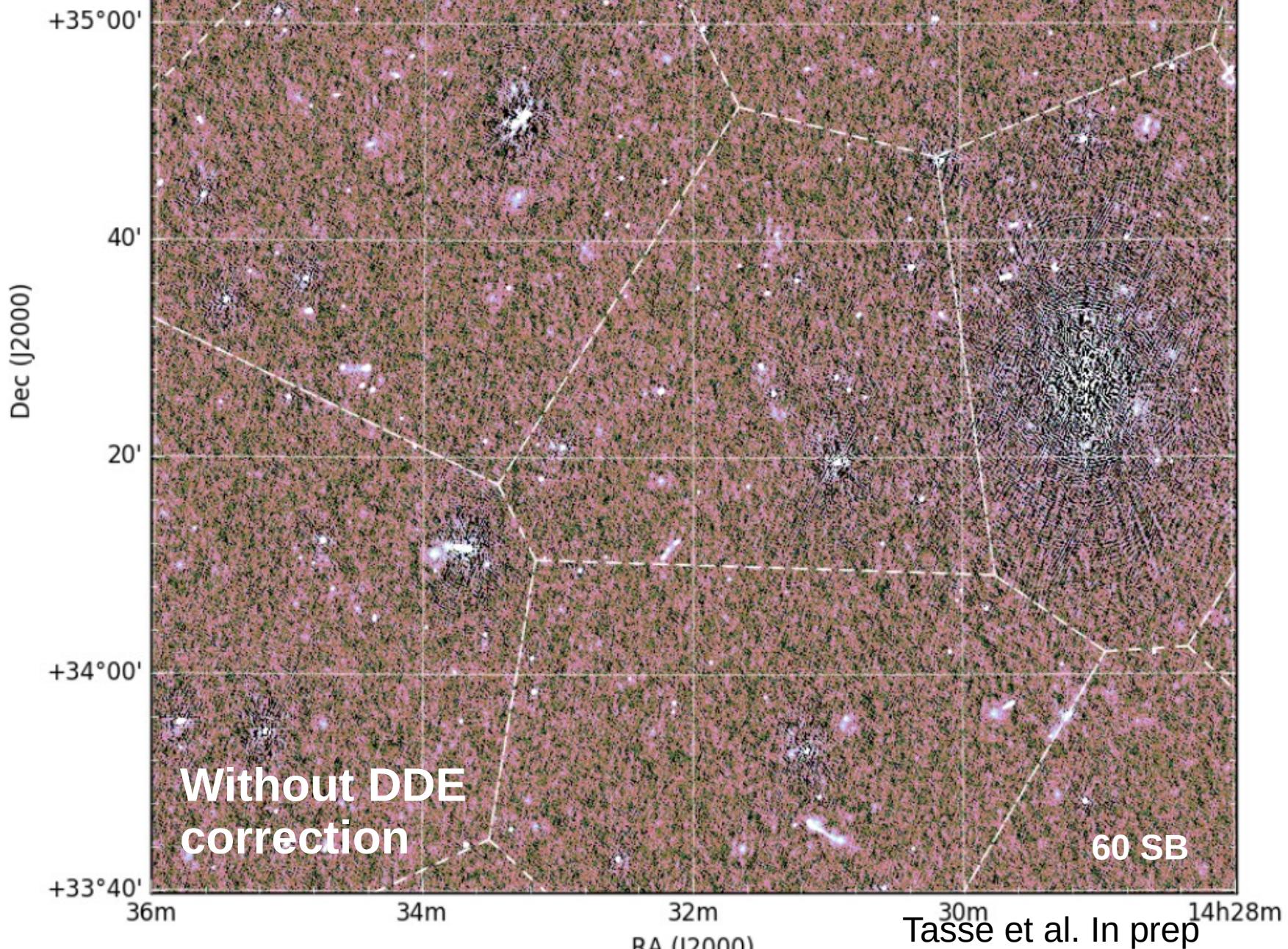
Tier-1 LOFAR Survey : to be observed  
48 Pbytes of Raw data → ~39Eiffel towel size dvd stacks

# Third issue : software

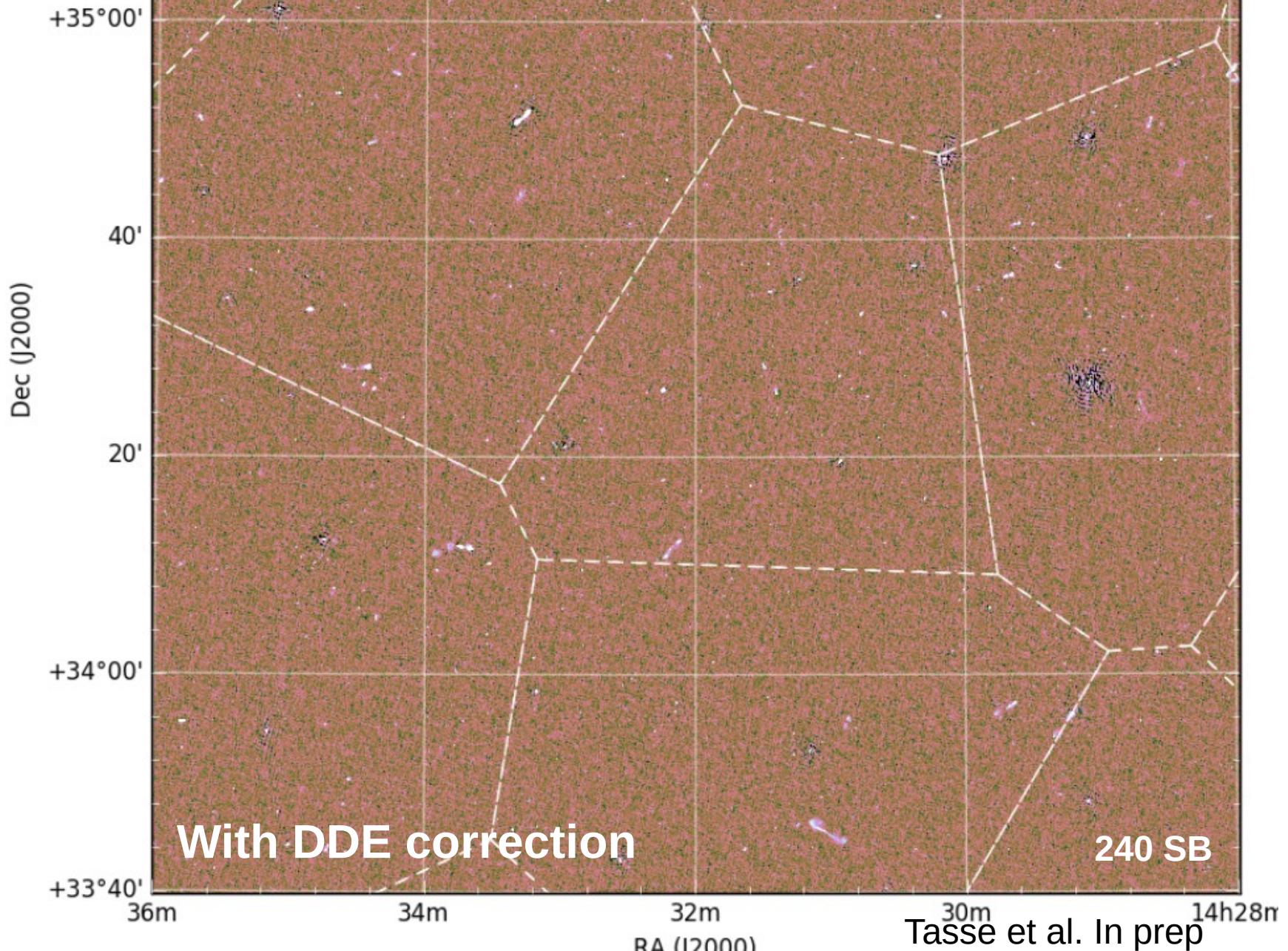
No existing software implementing

- (i) generic piecewise constant,
- (ii) DD-simultaneous,
- (iii) full Jones,
- (iv) (Cal+Im) RIME solving

8 hours integration with  
LOFAR@~150MHz

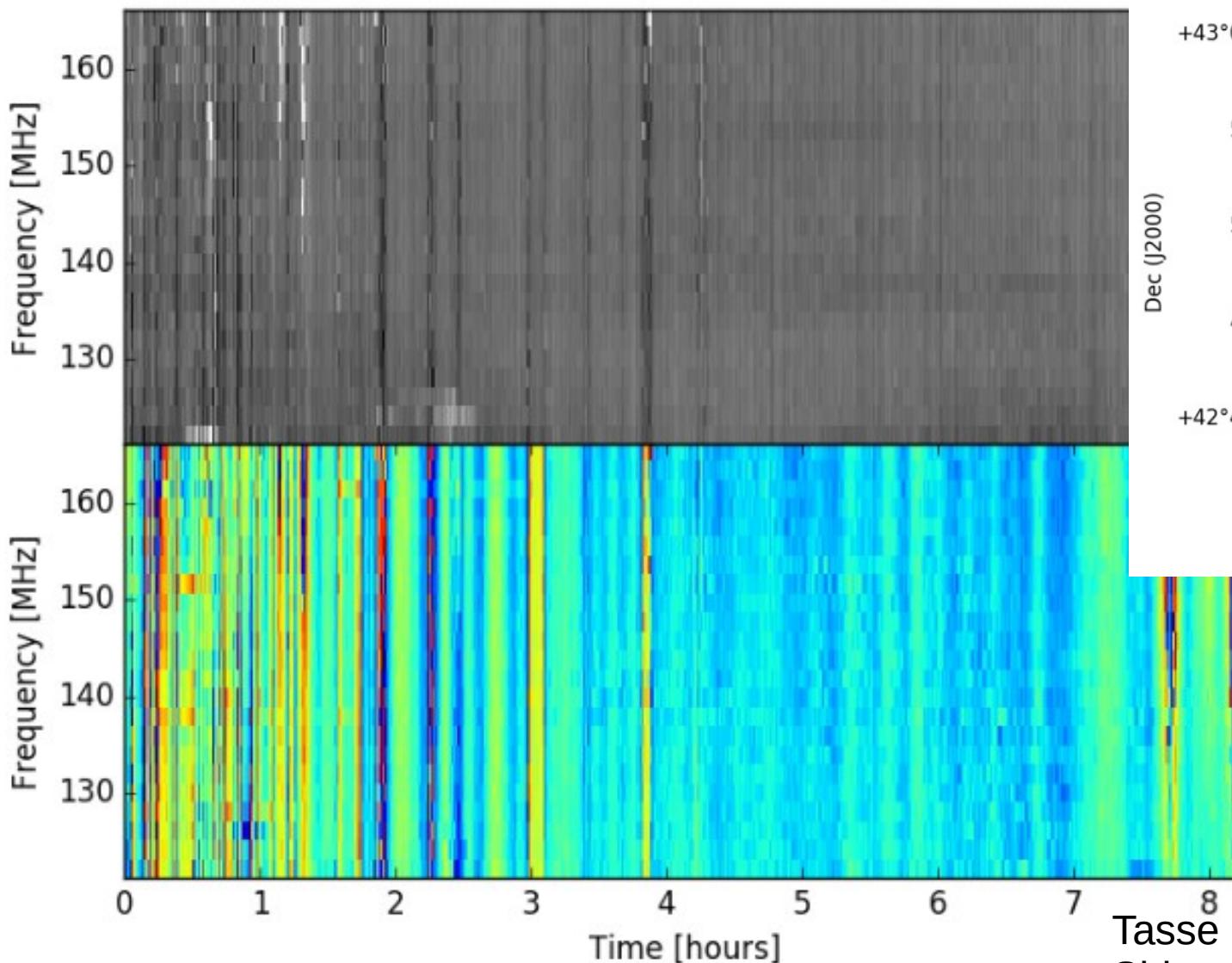


8 hours integration with  
LOFAR@~150MHz

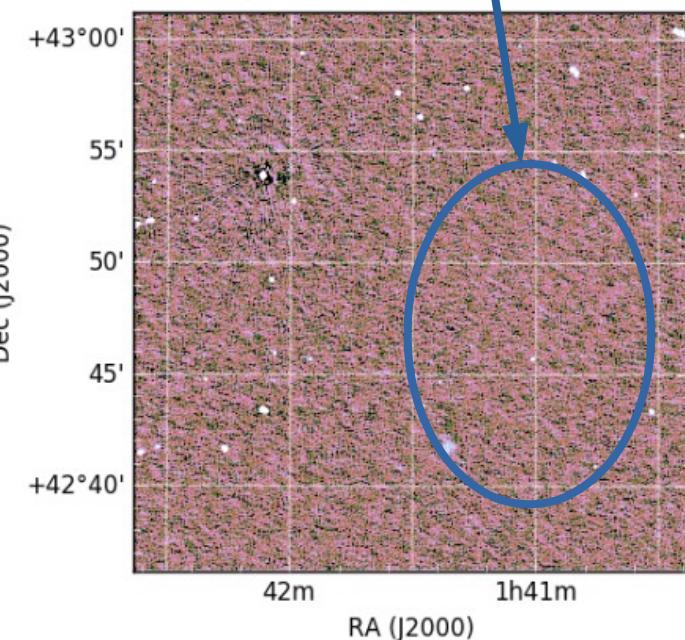


# Ddf-pipeline & LOTSS/DR2 : Gains for different stations

Station RS509HBA



Absorbed  
unmodeled  
emission

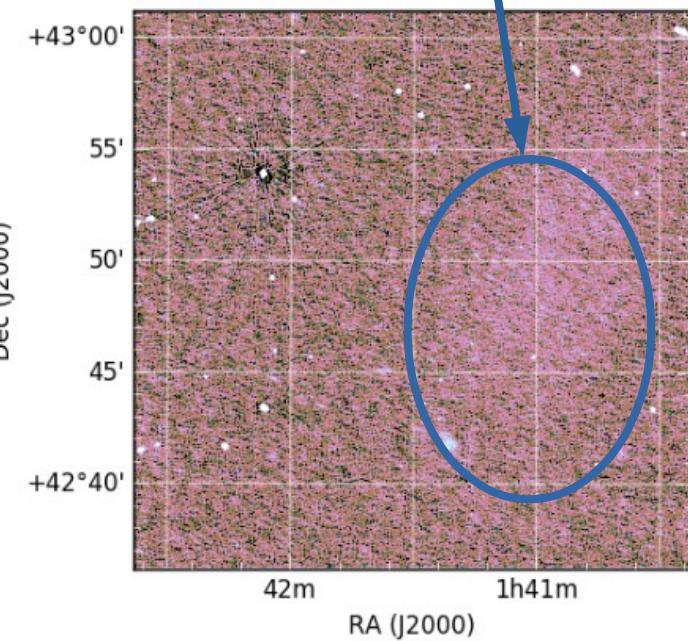
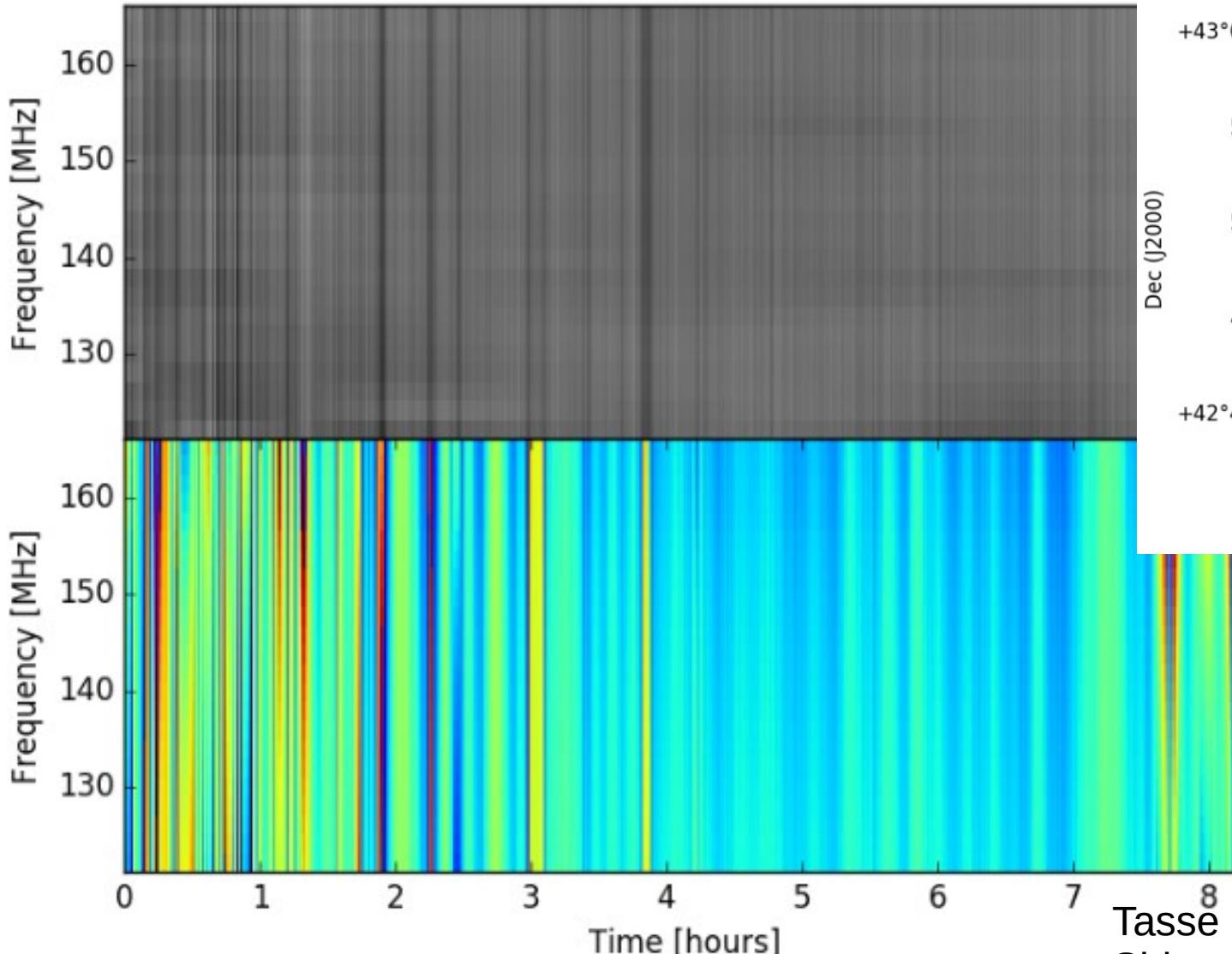


Raw DDE  
solutions

Tasse et al. In prep  
Shimwell et al. In prep

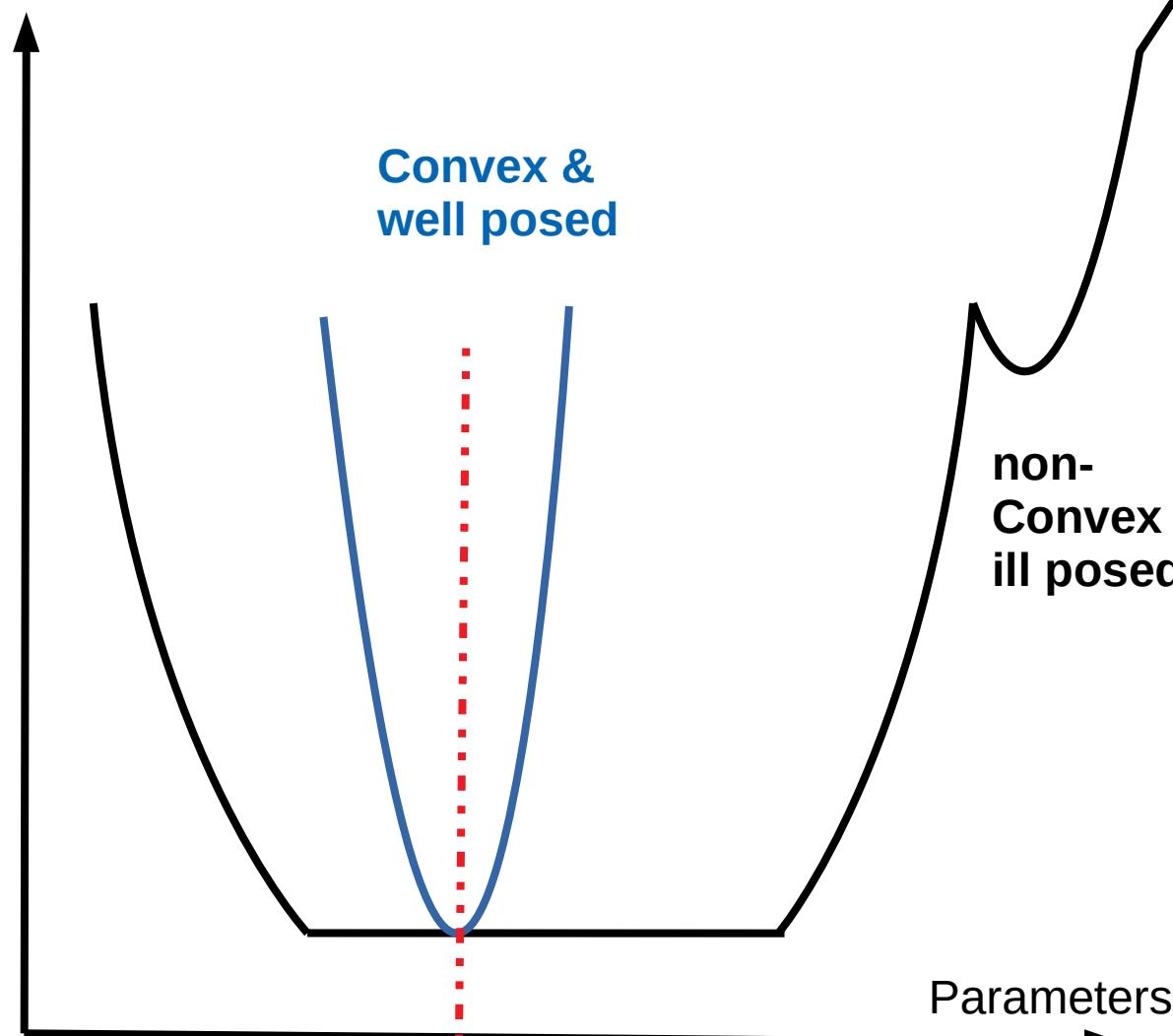
# Ddf-pipeline & LOTSS/DR2 : Gains for different stations

Station RS509HBA

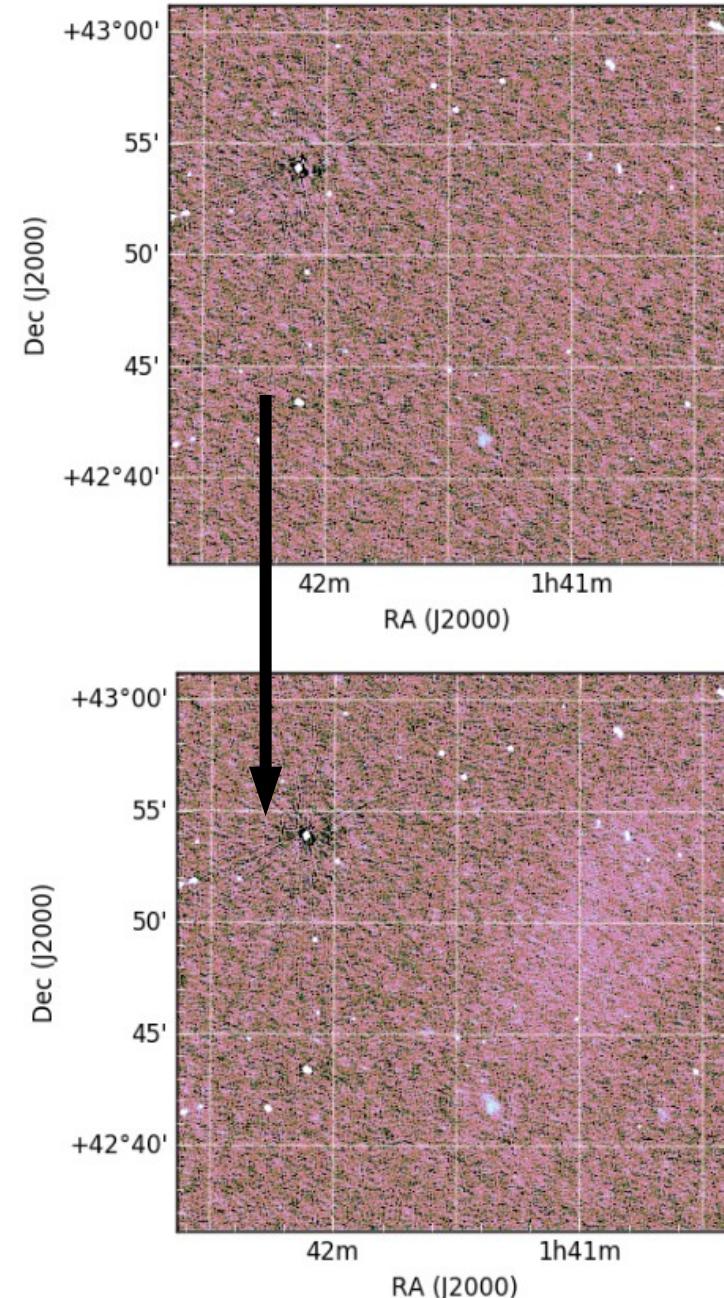


# Convexity, Conditionning

Chi<sup>2</sup>

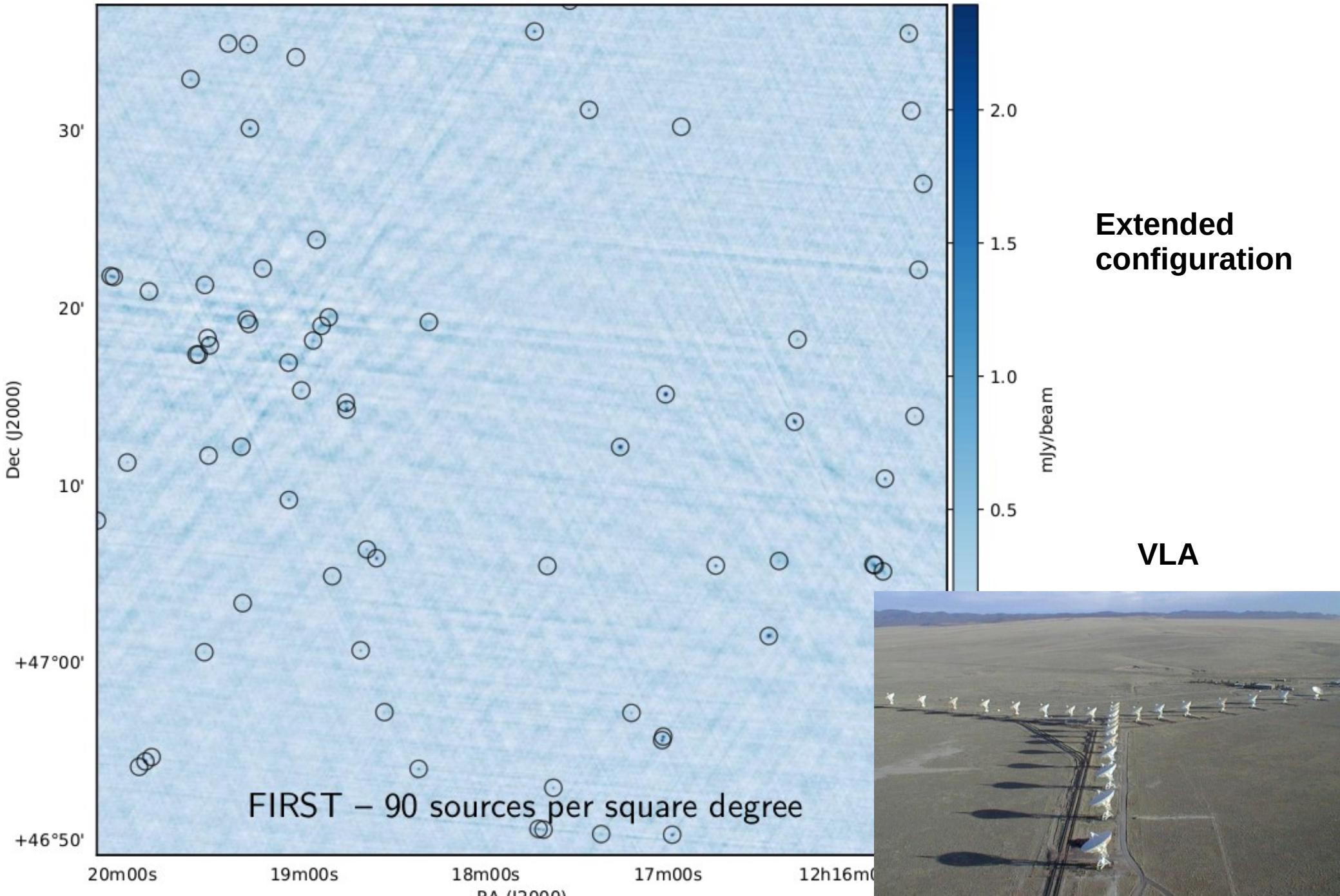


Tasse et al. In prep  
Shimwell et al. In prep

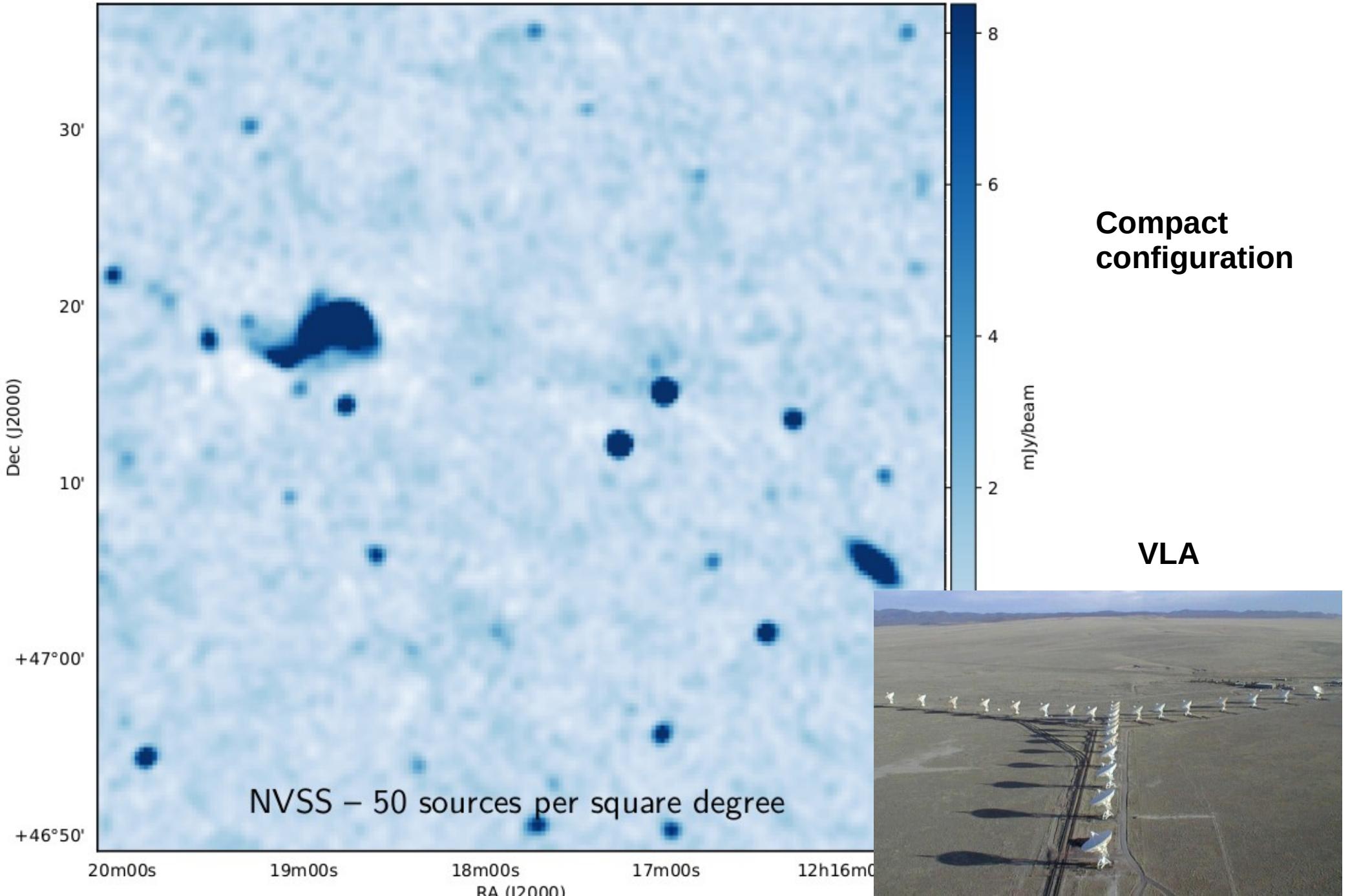


See also  
Yatawatta et al. 2017, 2018  
Repetti et al. 2017

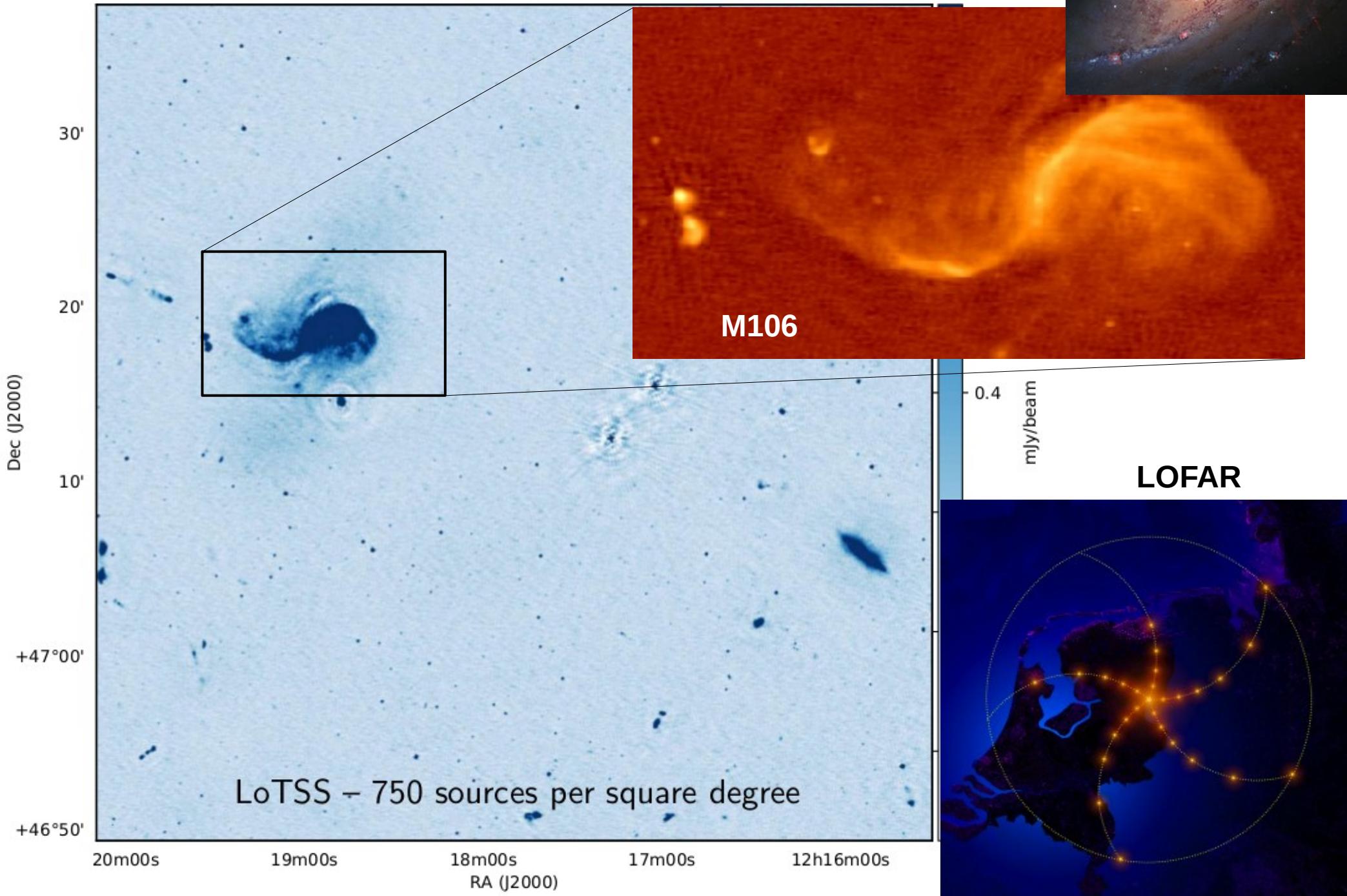
# LOTSS – First Data Release



# LOTSS – First Data Release



# LoTSS – First Data Release



# Interactive session

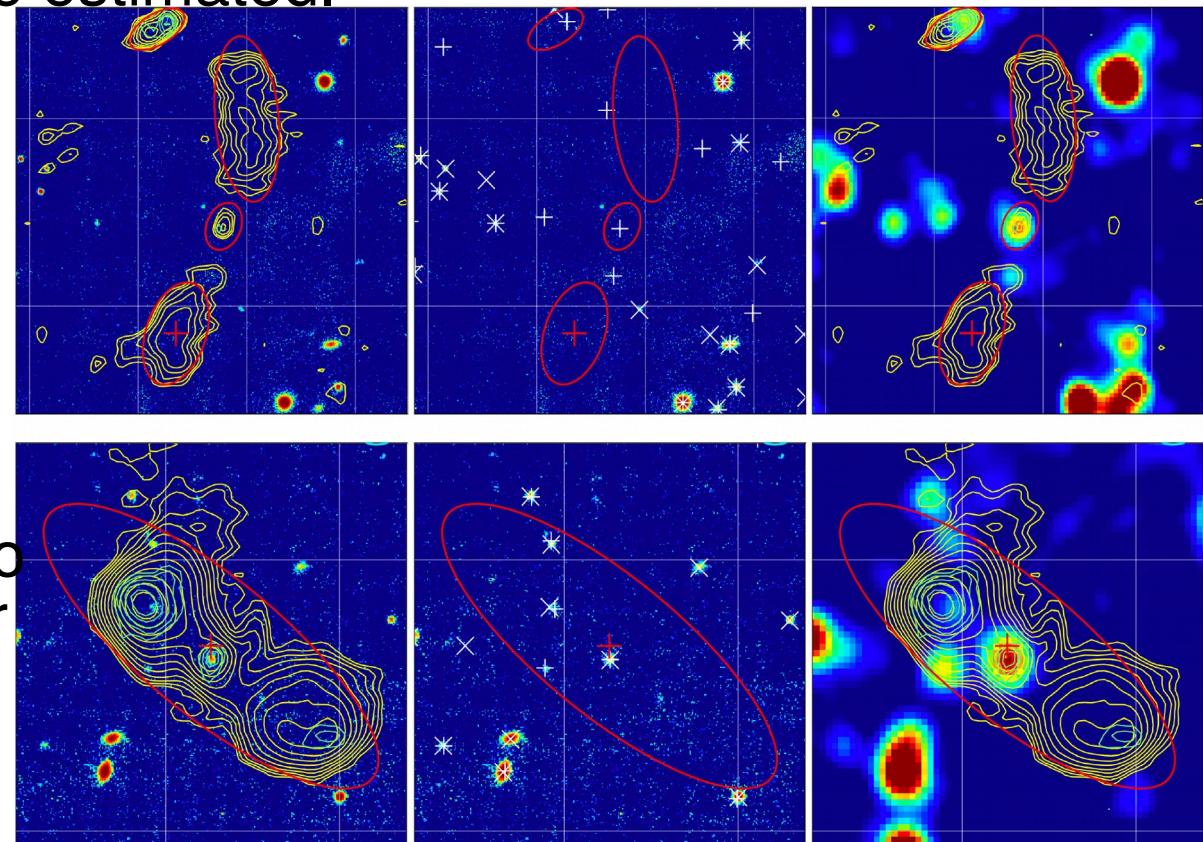
# LoTSS data release 1

325,694 entries in the raw PyBDSF catalogue.

Corresponds to 318,520 radio sources after deblending, artefact rejection and joining multiple component sources (including extensive efforts to visually inspect ~10,000 sources).

231,716 have counterparts in Pan-STARRS or WISE and for these photometric redshifts are estimated.

	Number	Number with ID	ID fraction
All Sources	318,520	231,716	0.73
LR	299,730	221,269	0.74
LGZ	11,989	7,144	0.60
Deblending	2,435	2,338	0.96
Bright galaxy	965	965	1.00
No ID possible	3,401	0	0.00



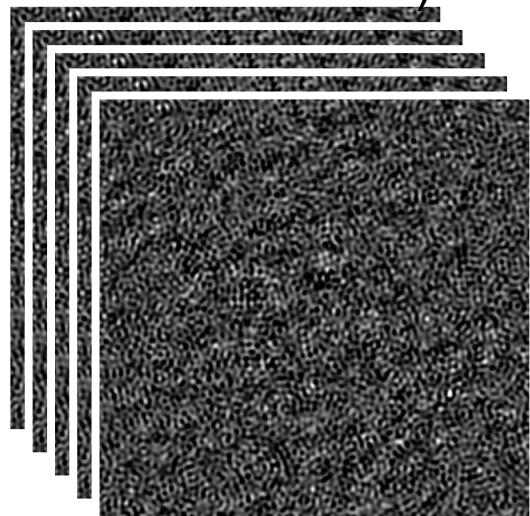
The final LoTSS-DR1 catalogue contains radio sources, optical counterparts and photometric redshifts.

Examples of LOFAR galaxy zoo entries showing

# New data products in LoTSS -DR2

Current pipeline products:

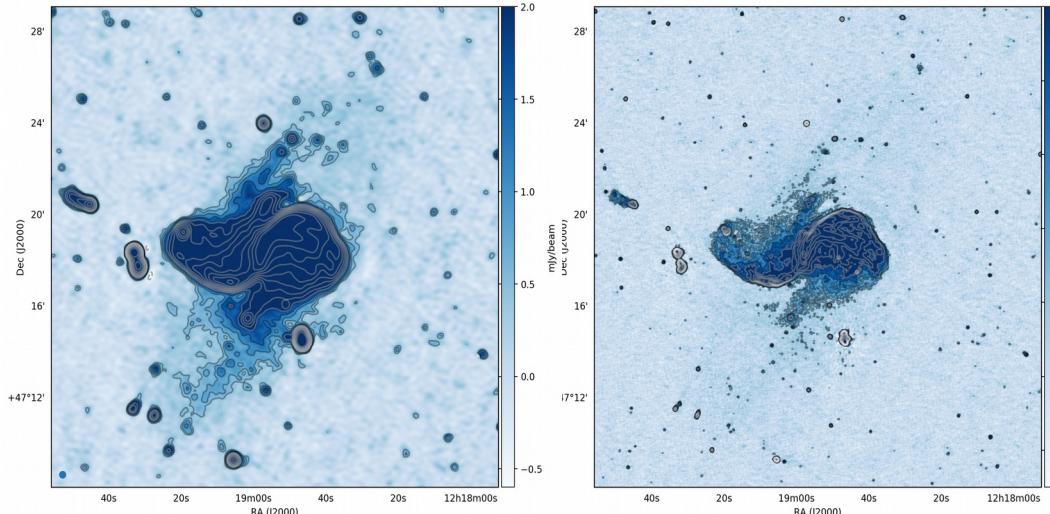
- 6" resolution Stokes I image
- 20" resolution Stokes I image
- 3 channel images over band
- 20" resolution Stokes V image
- 20" resolution Stokes QU cubes (480 planes)
- Very low resolution Stokes QU cubes (480 planes)
- Dynamic spectra of targeted sources
- Data calibrated in a particular direction with all other source subtracted (allows easy reimaging, source subtraction etc)



Frequency



Time



Stokes I images at high (6")  
and low (20") resolution

To enable further  
processing we also  
keep:

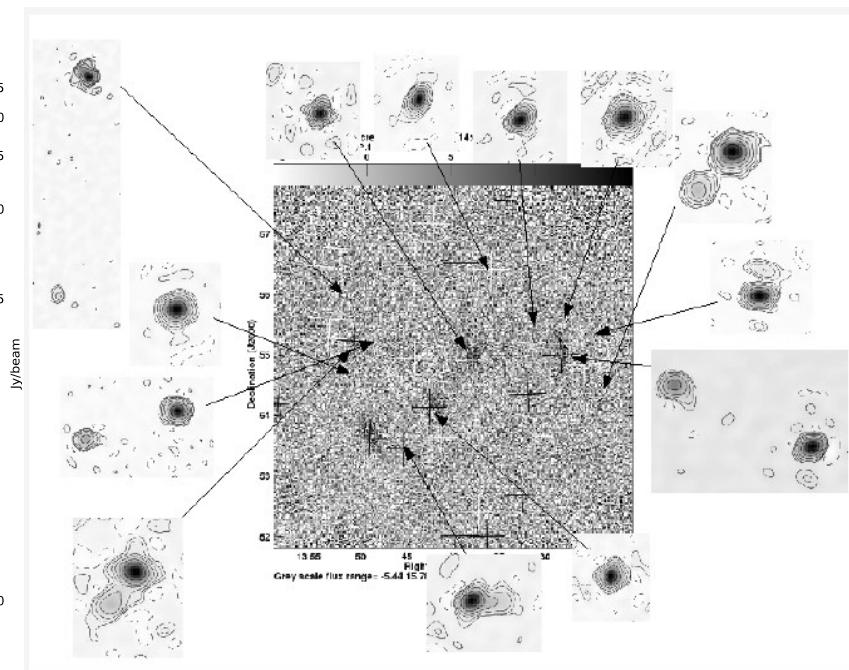
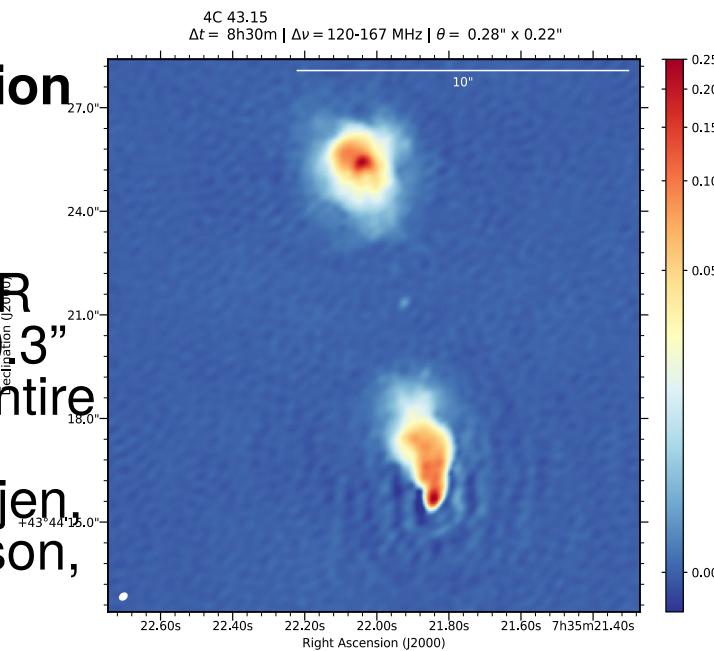
- Facet layout
- Calibration  
solutions
- Data

# Furthering the LOFAR surveys

**Optical followup — WEAVE-LOFAR**  
(Smith+ 2016) will use WEAVE on the  
WHT and soon begin obtaining  
spectra for ~a million LOFAR sources.

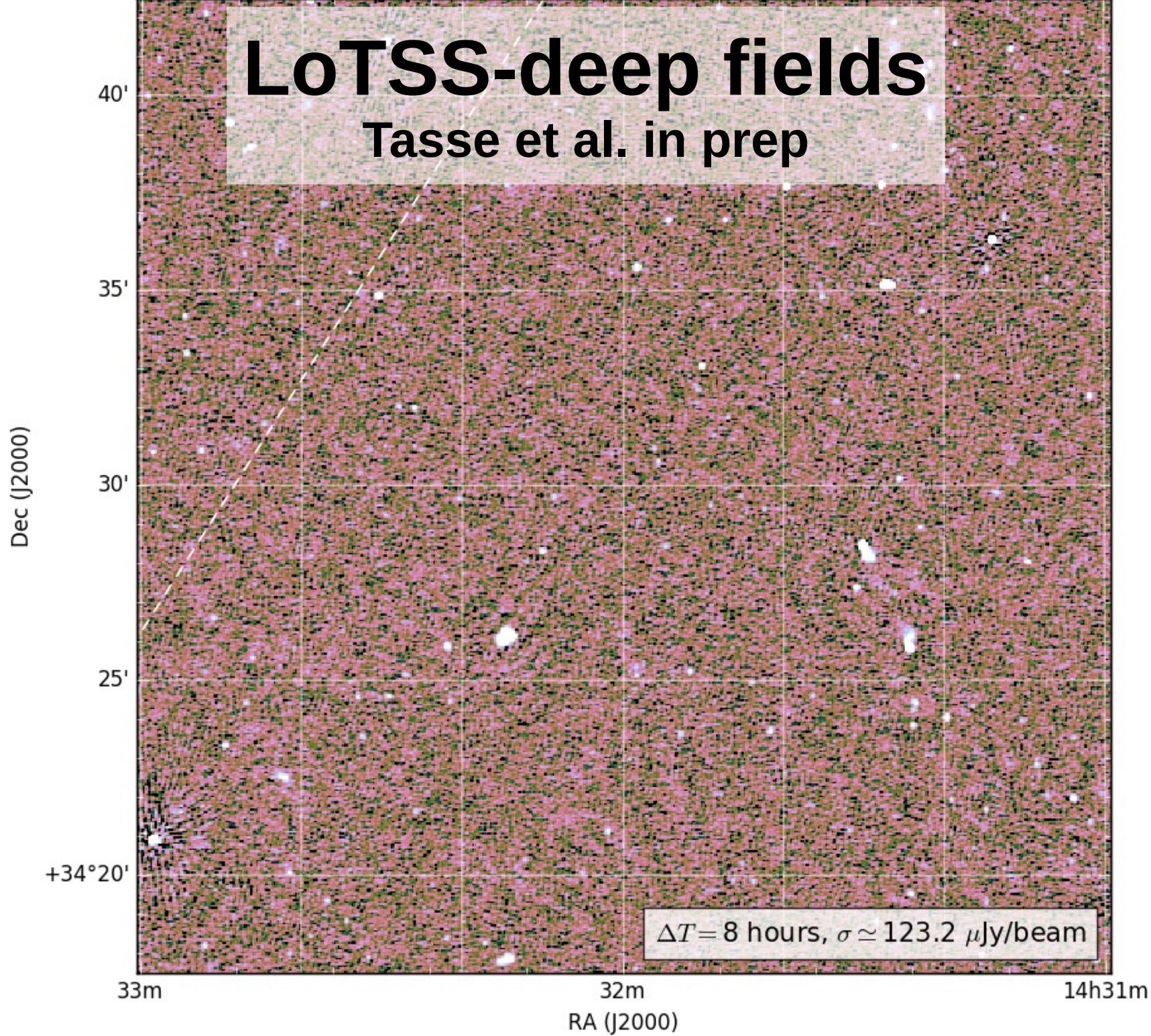
**Radio recombination lines —**  
LoTSS data have sufficient frequency  
resolution for spectral line work and  
the data are being analysed to search  
for RRLs (e.g. Emig+ 2018).

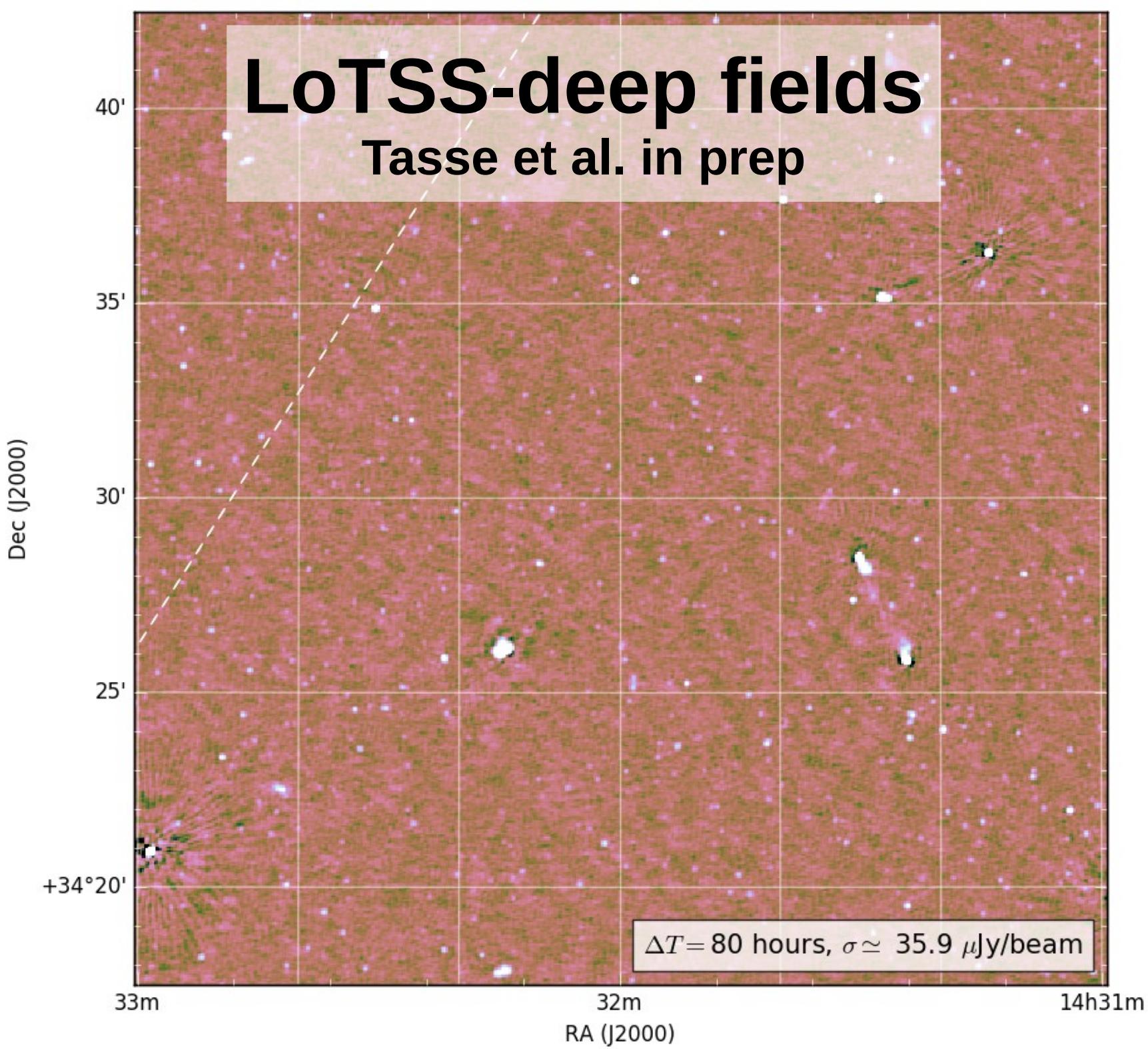
**0.3arcsec resolution**  
— LOFAR surveys  
data are recorded  
using the full  
international LOFAR  
array allowing for 0.3"  
imaging over the entire  
surveyed region  
(images from Sweijen,  
van Weeren, Jackson,  
Morabito+)



# LoTSS-deep fields

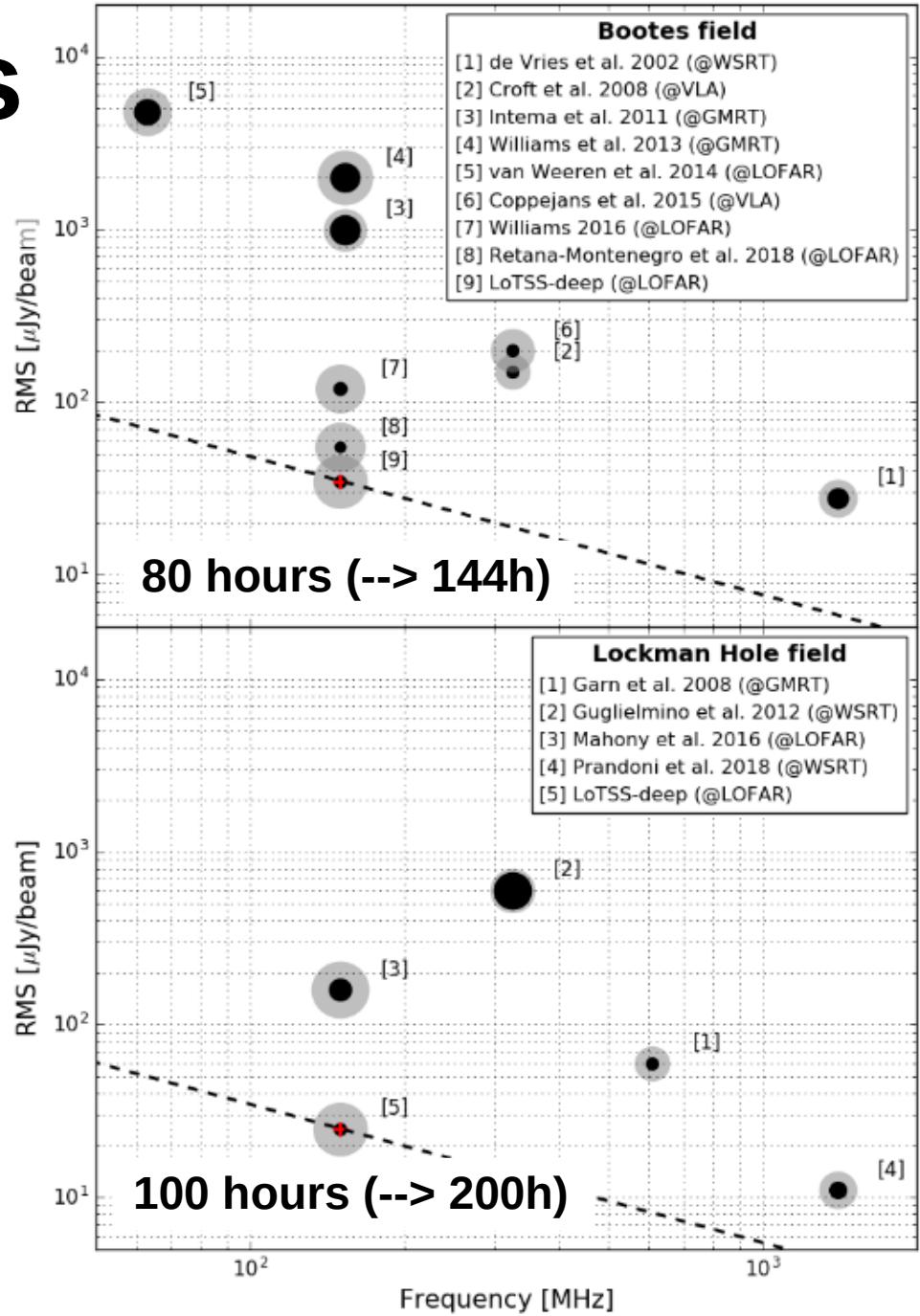
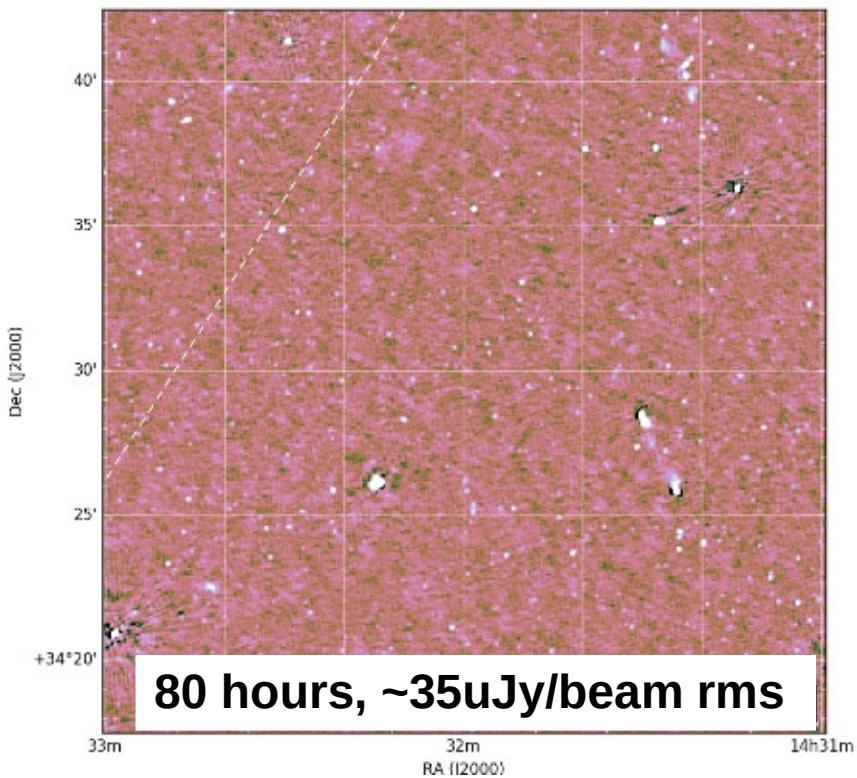
Tasse et al. in prep





# LoTSS-deep fields

Tasse et al. in prep



+ ELAIS-N1  
+ NCP

# ELAIS-N1

(~160h integration

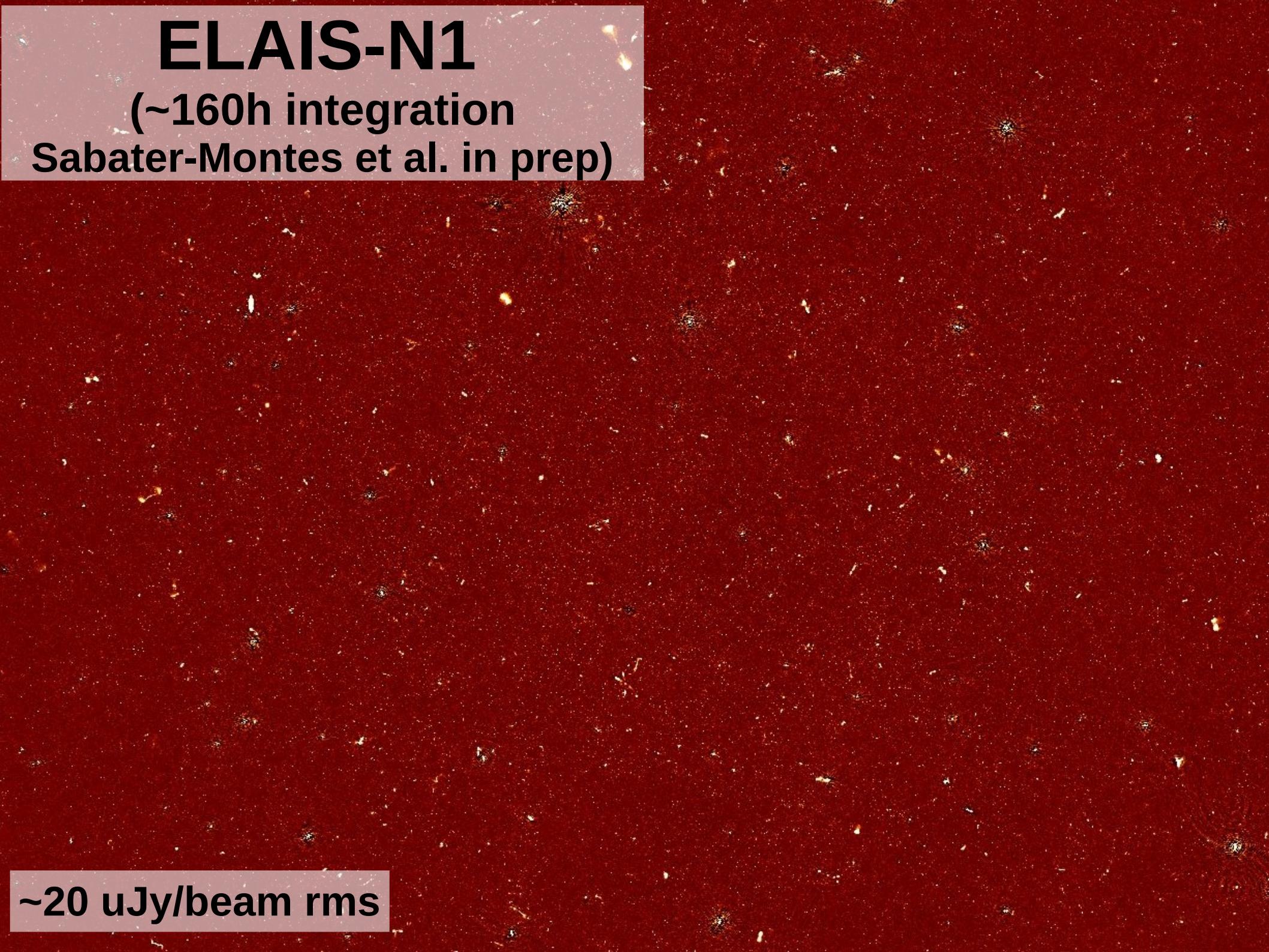
Sabater-Montes et al. in prep)

~20 uJy/beam rms

# ELAIS-N1

(~160h integration

Sabater-Montes et al. in prep)

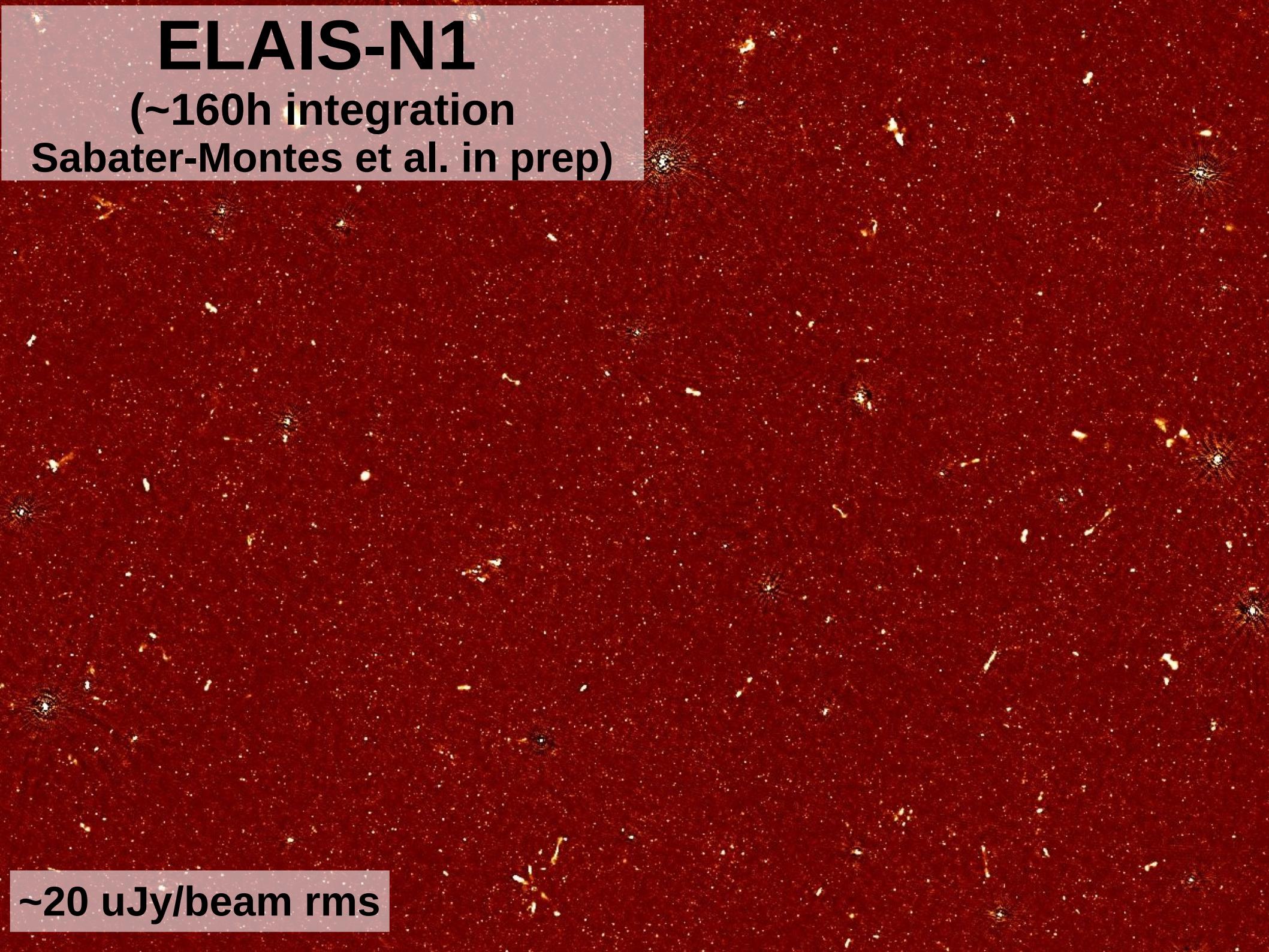


~20 uJy/beam rms

# ELAIS-N1

(~160h integration)

Sabater-Montes et al. in prep)



~20 uJy/beam rms

# ELAIS-N1

(~160h integration)

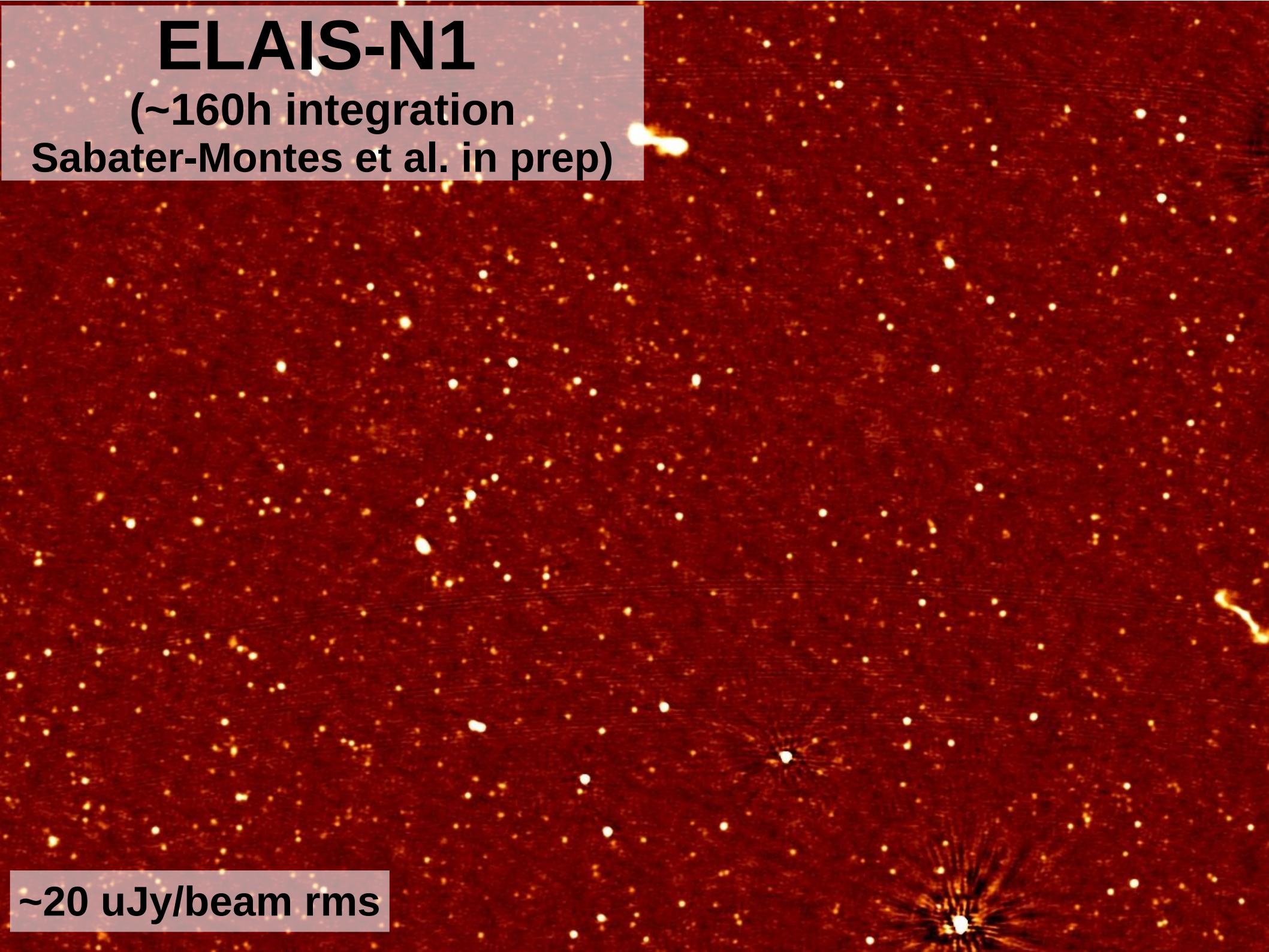
Sabater-Montes et al. in prep)

~20 uJy/beam rms

# ELAIS-N1

(~160h integration)

Sabater-Montes et al. in prep)

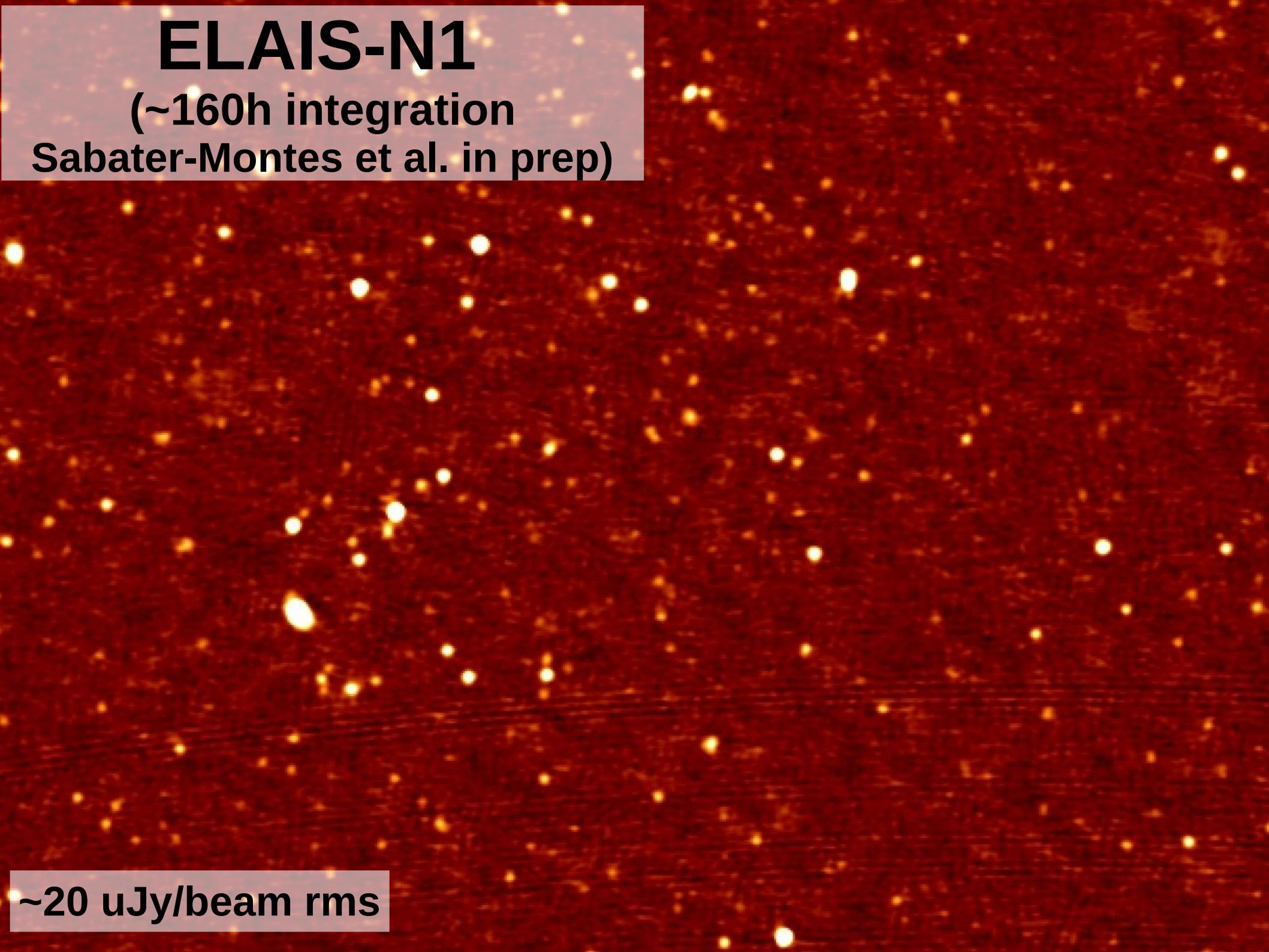


~20 uJy/beam rms

# ELAIS-N1

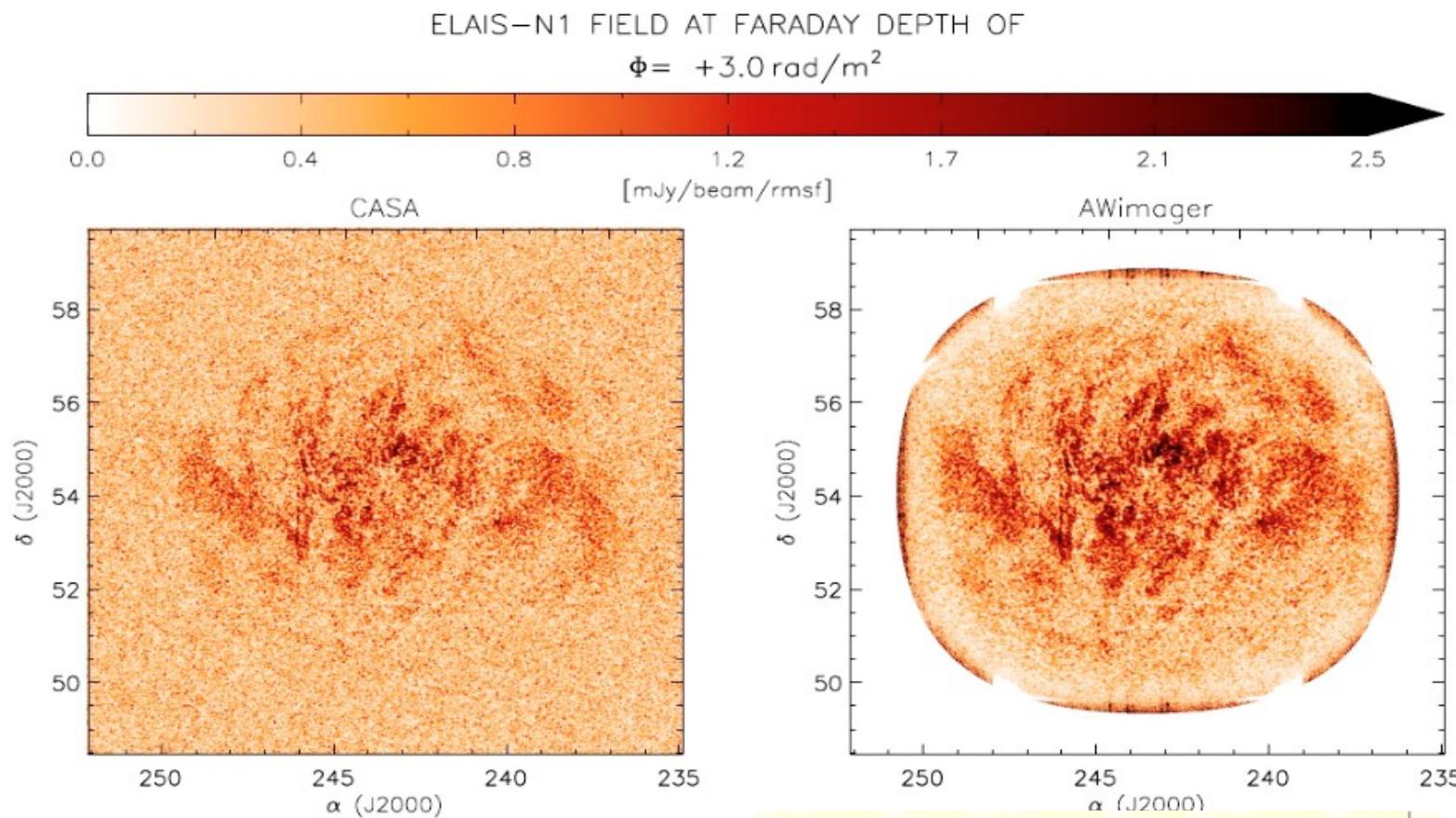
(~160h integration)

Sabater-Montes et al. in prep)



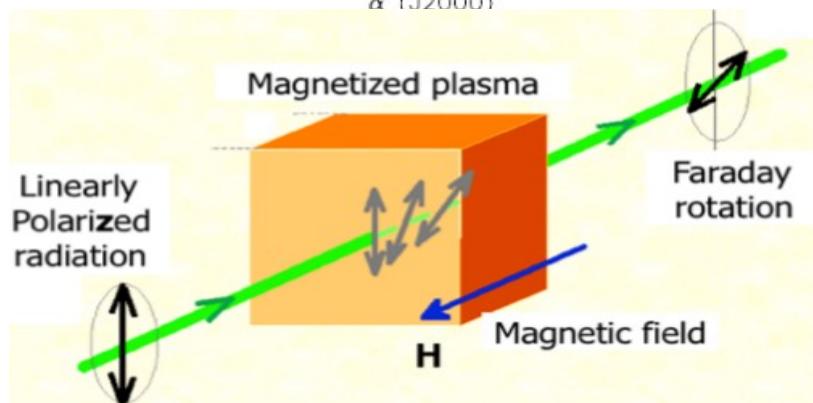
~20 uJy/beam rms

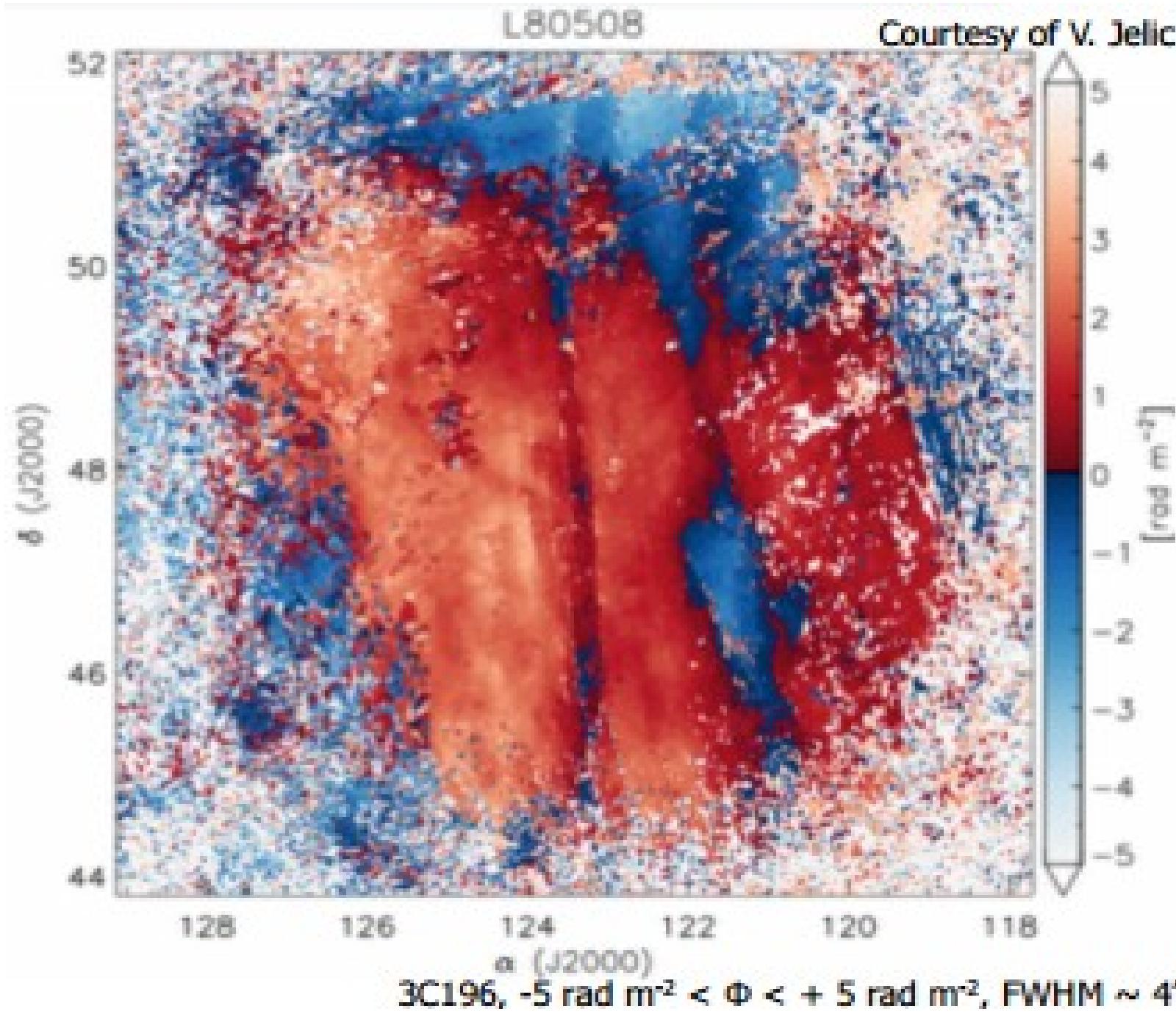
# Mesure de rotation ELAIS



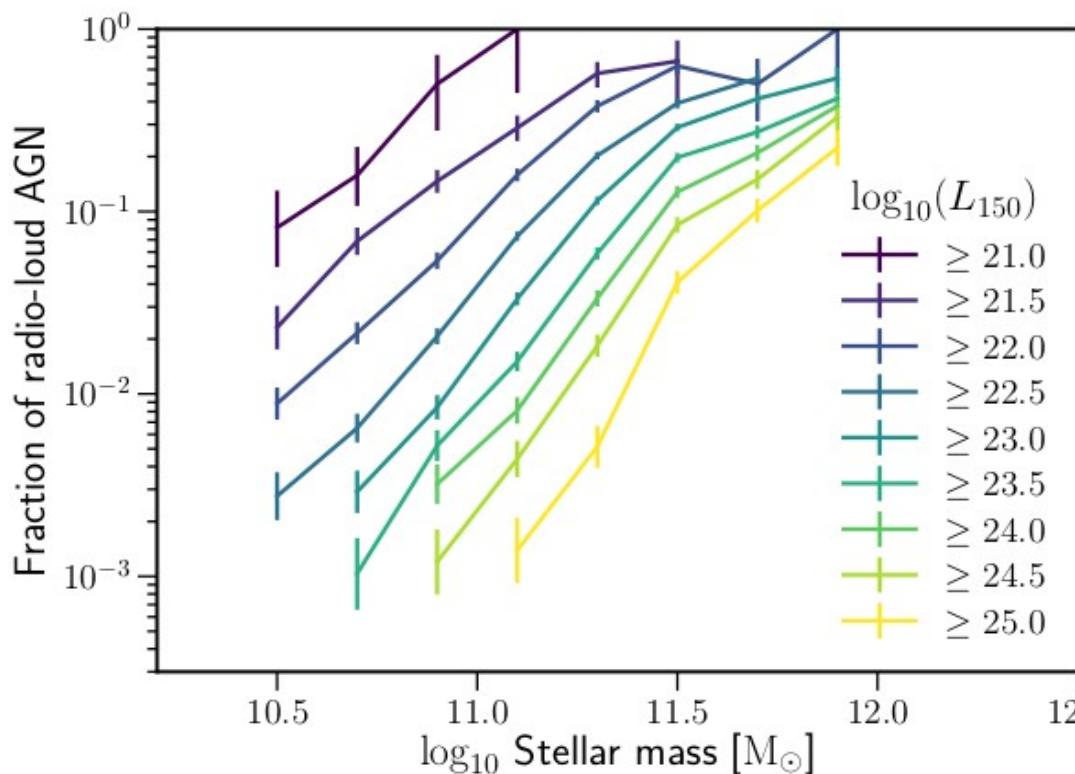
Credit:  
Vibor  
Jelic

**Faraday rotation  
converts Q in U stokes,  
and angle depends on  
 $\lambda^2$**

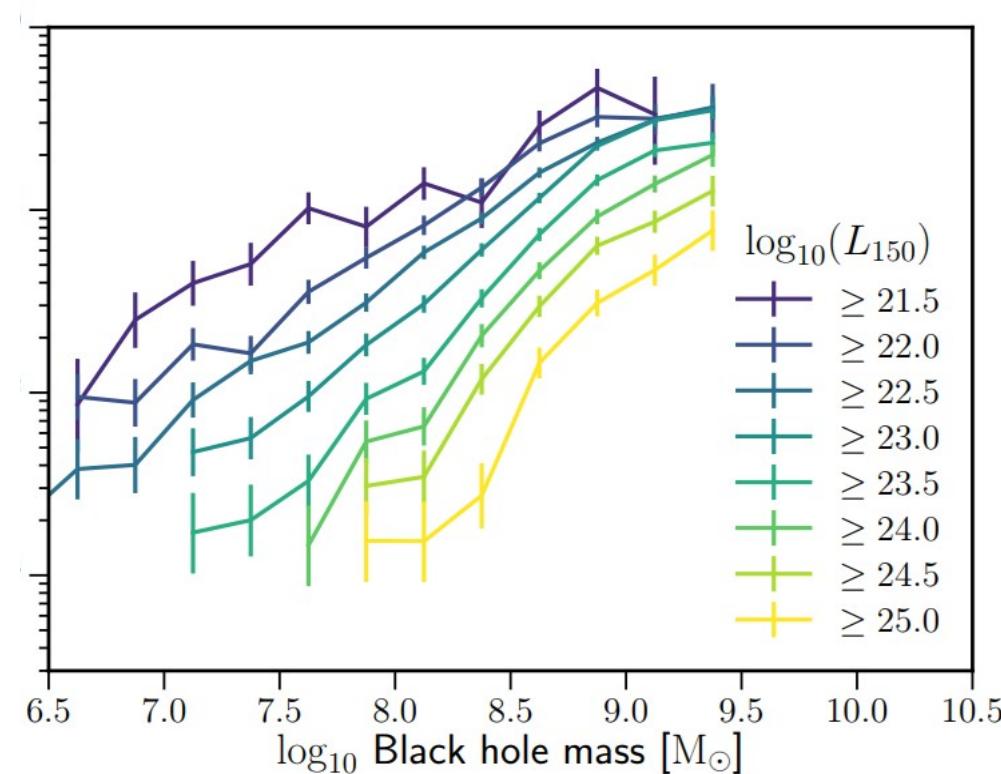




# In the local universe, AGN in massive galaxies *are always on*



**Stellar mass**

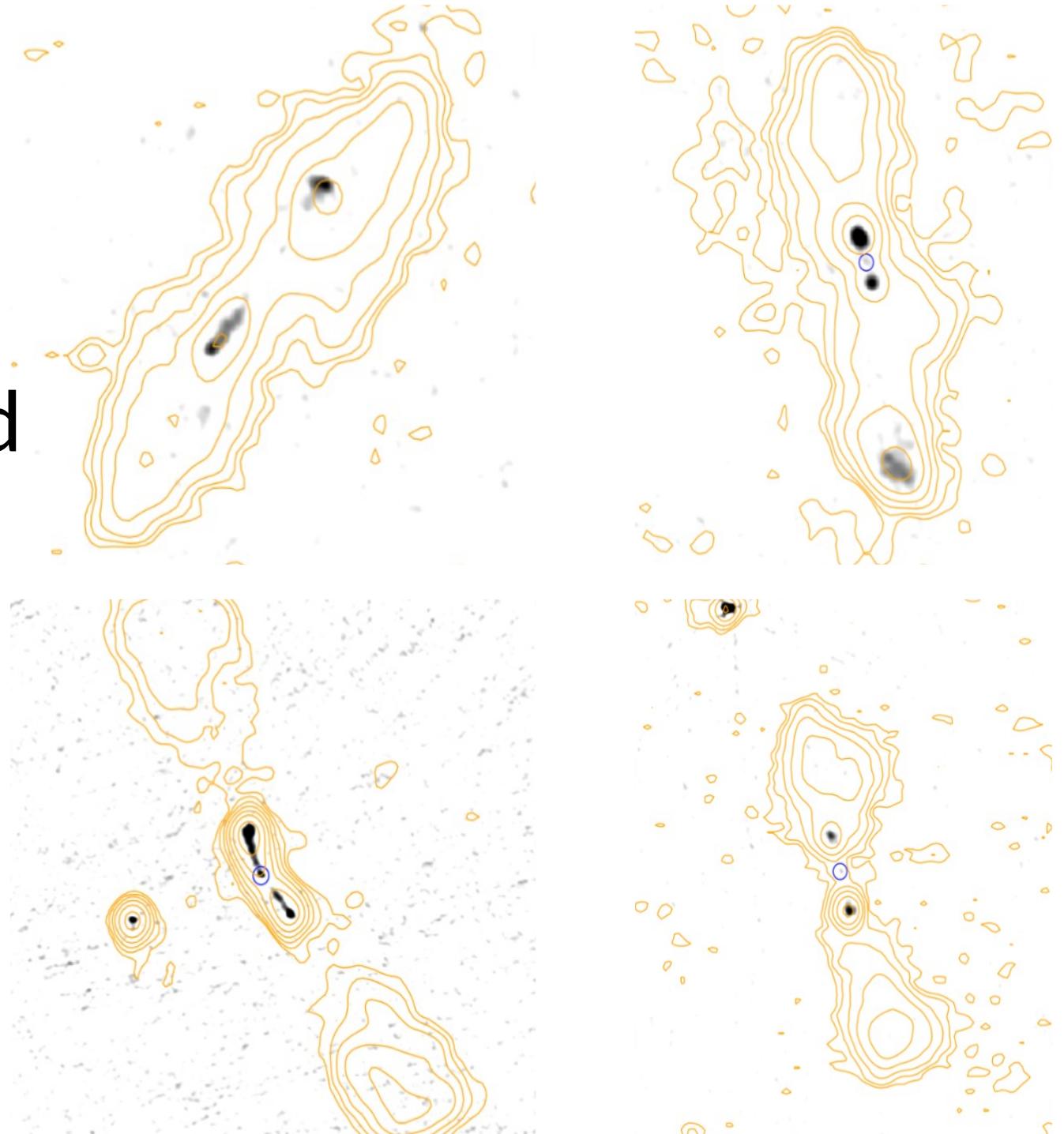


**Black-Hole mass**

**Sabater et al.**

# Relic AGN or restarted?

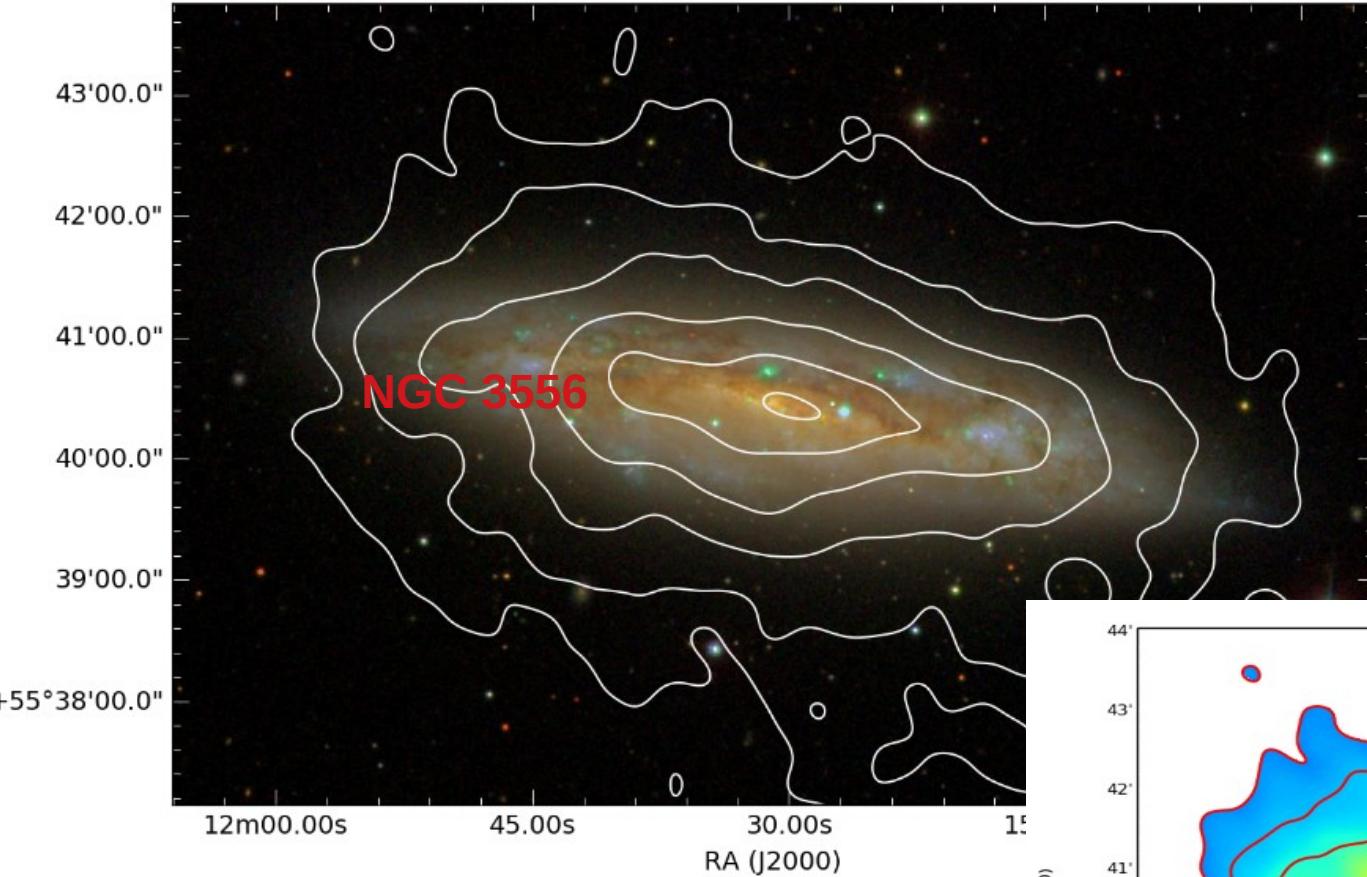
Jet dynamics  
Feedback and  
duty cycle



Mahatma et al.

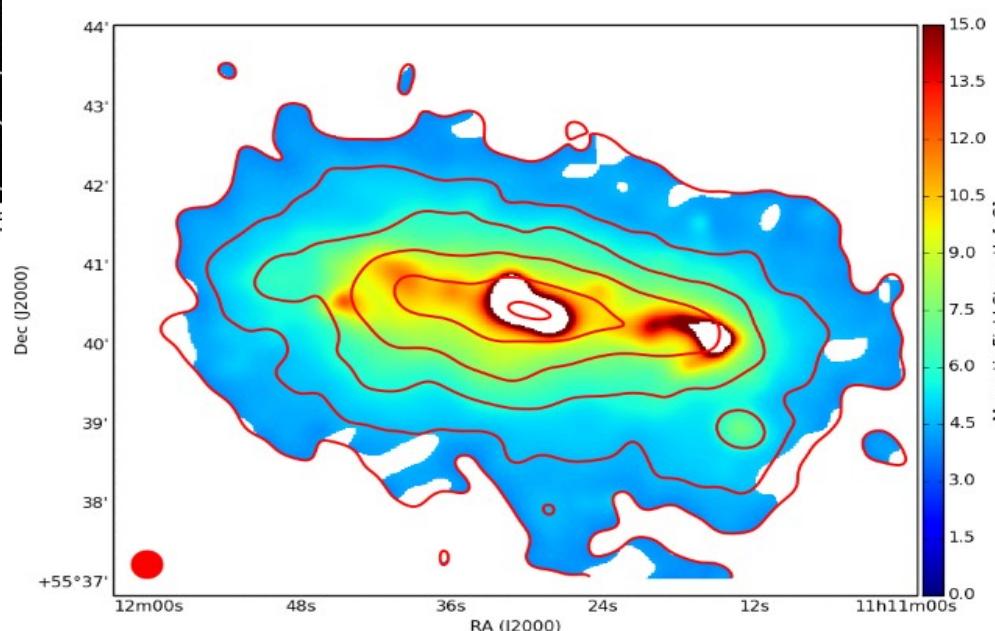
# Nearby galaxies

Dec (J2000)



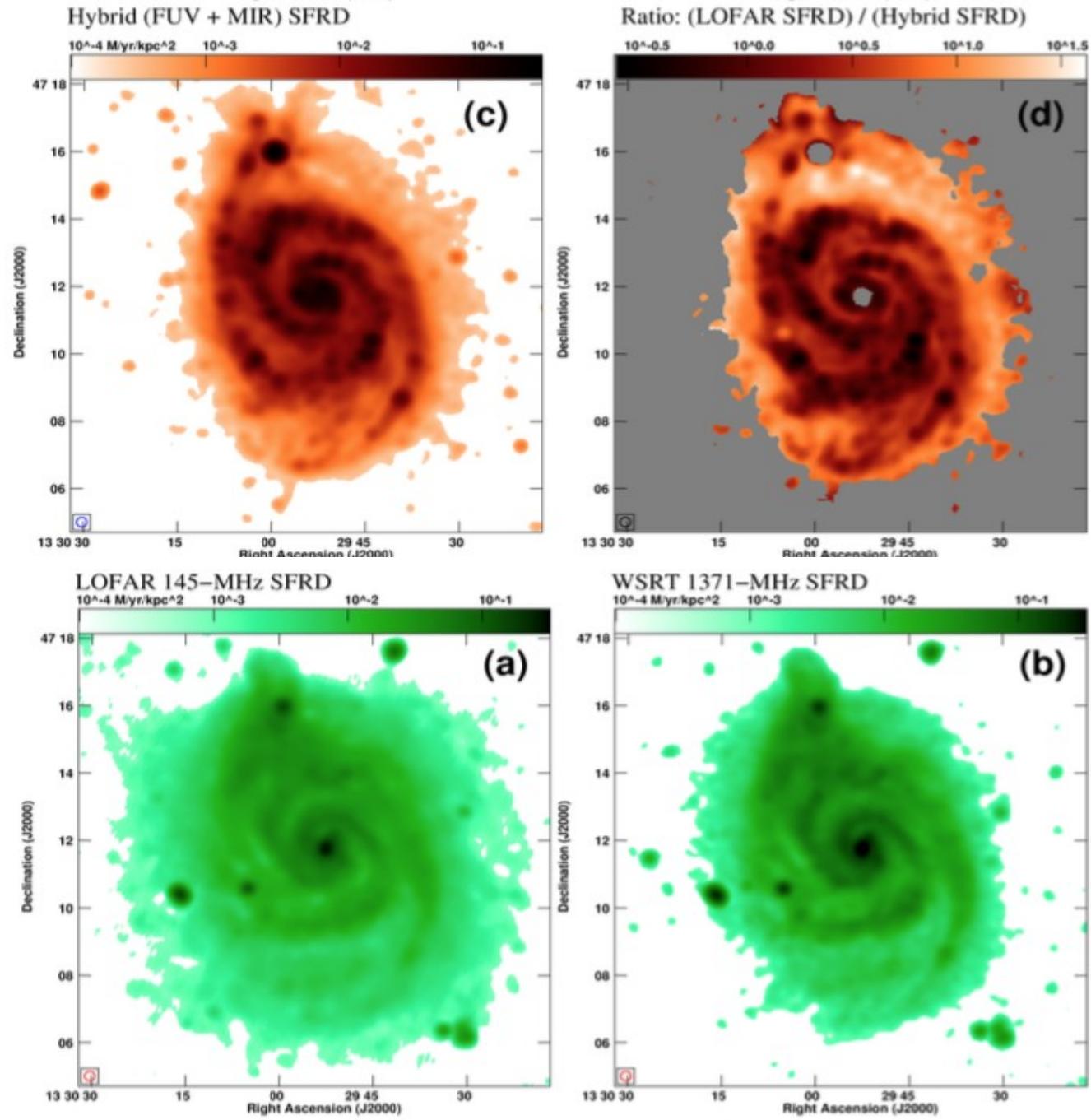
**Miskolczi et al.**

- Cosmic rays emitting synchrotron in a galactic Haloe
- Constrains on CR Energy, magnetic field and galactic winds speed



# Nearby galaxies

- Study the Radio to Star Formation relation (FIR & UV)
- Cosmic ray electron transport



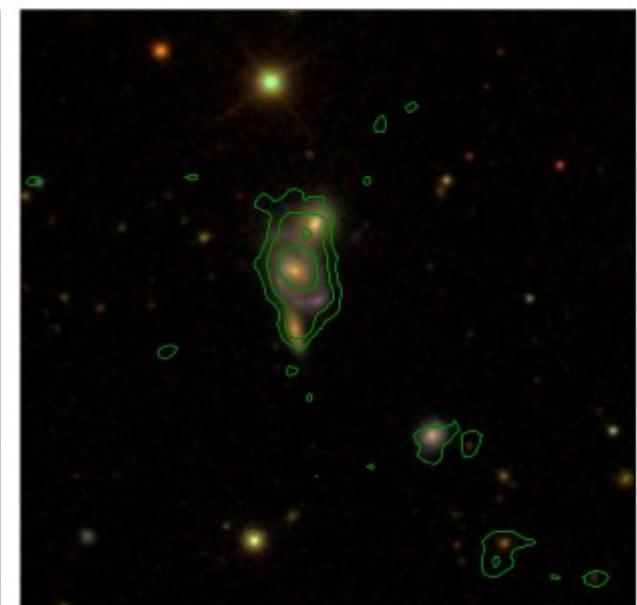
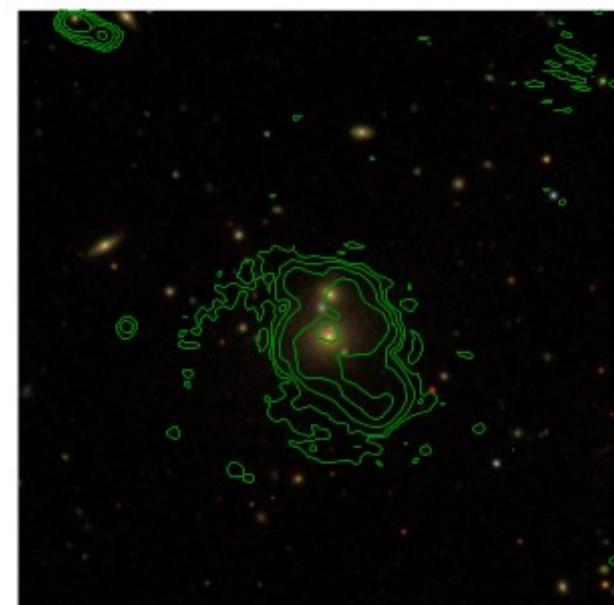
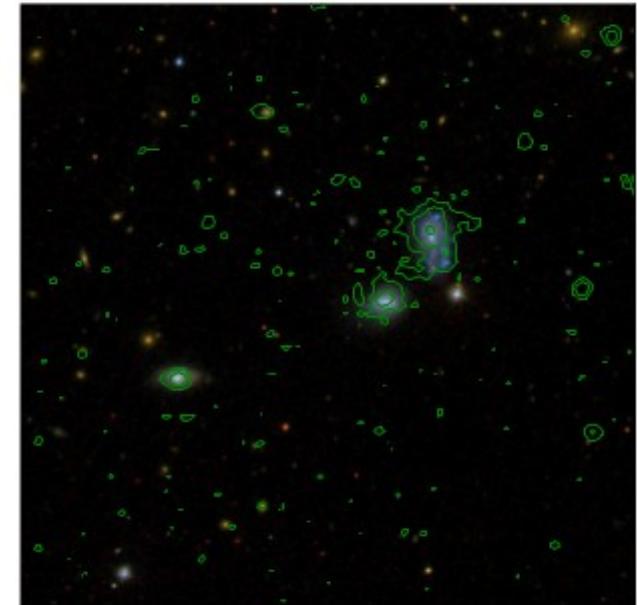
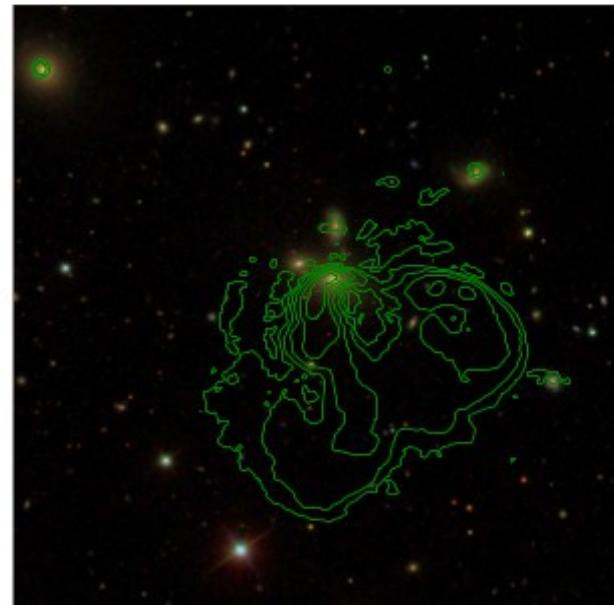
# Nearby galaxy groups

Nikiel-Wroczyński et al. In  
prep

Using

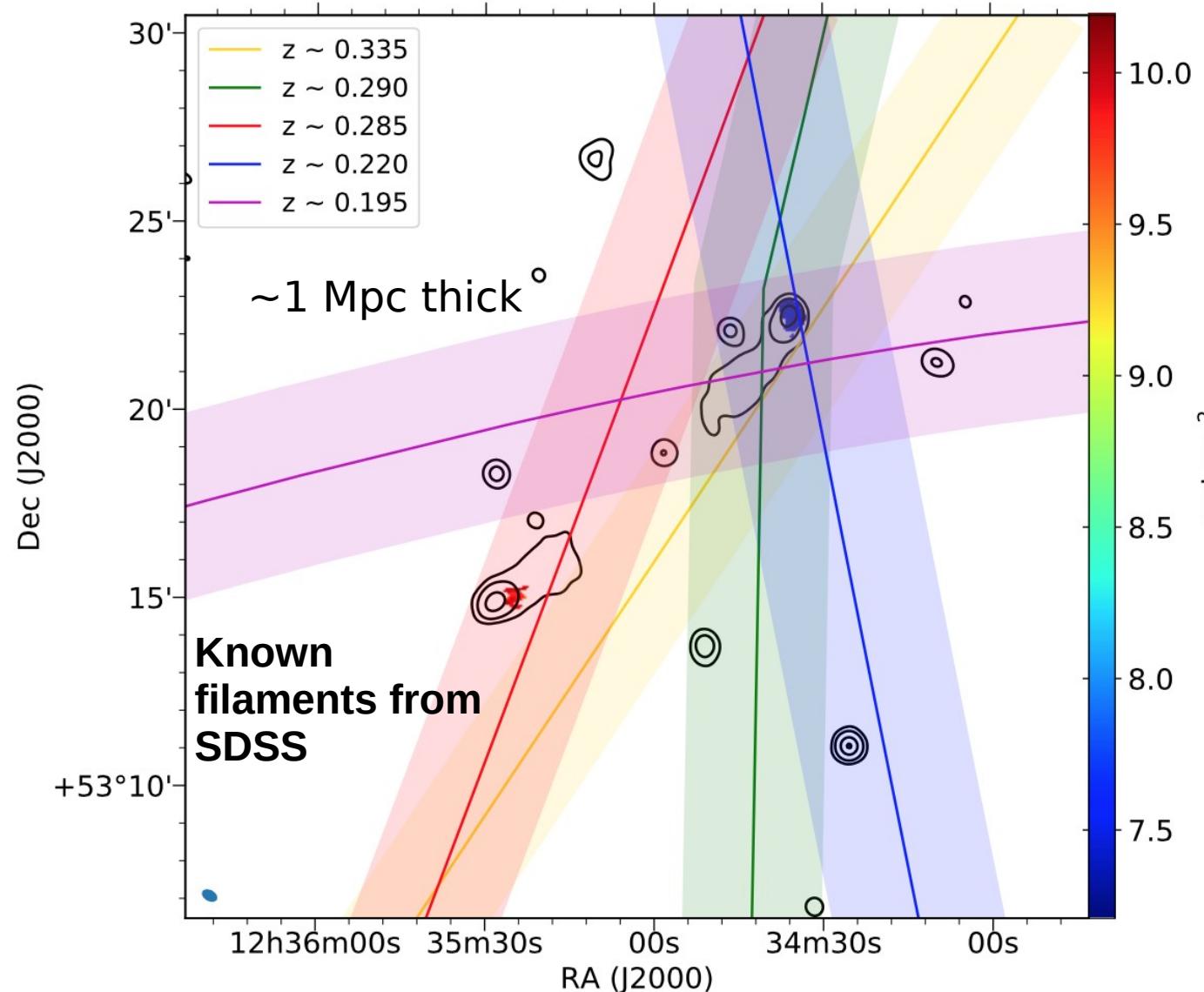
- SDSS
- NVSS
- FIRST

- 17/107 show signs of intergalactic structure
- Study of the magnetic field of the IGM



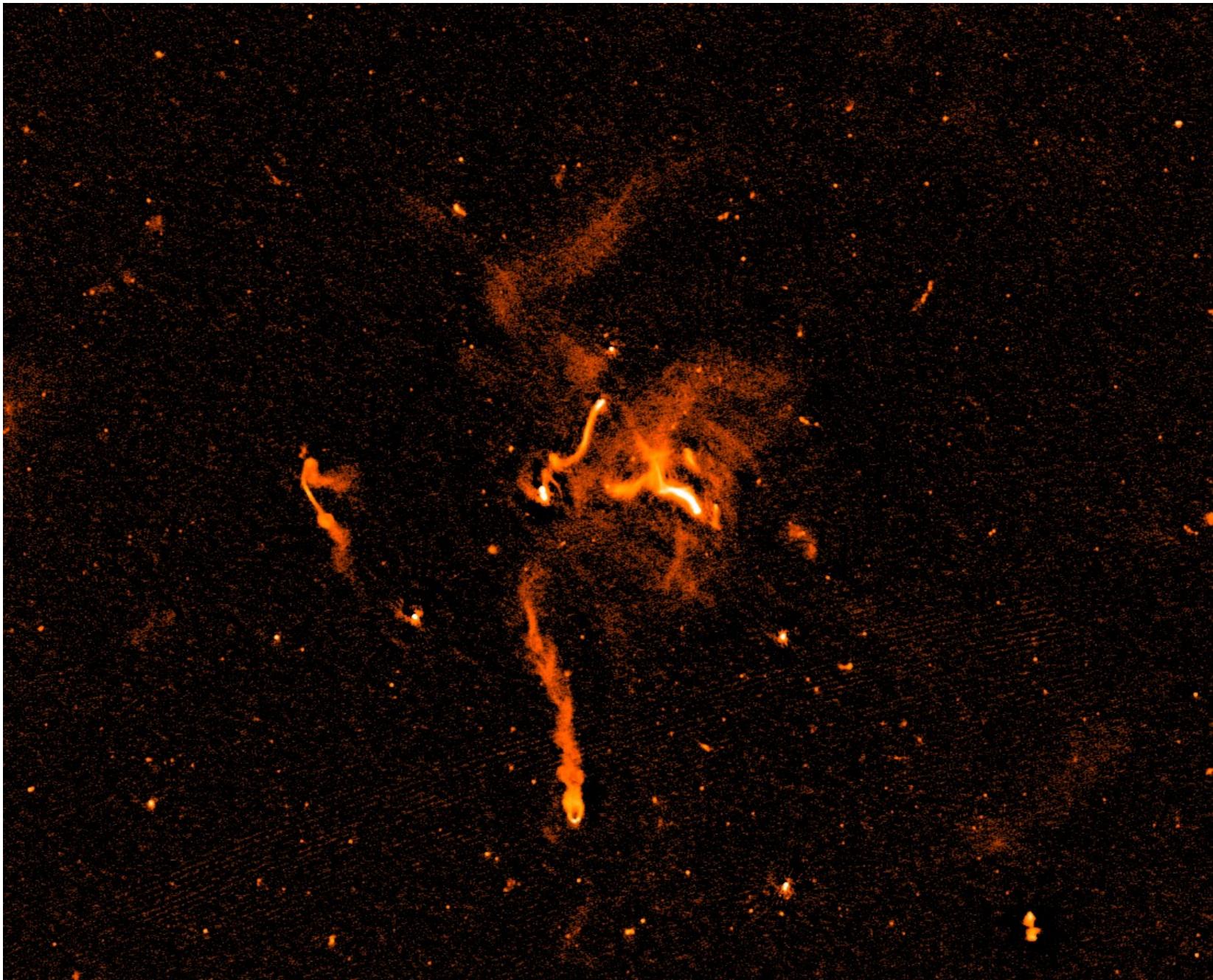
# LSS Filaments

- Relativistic electrons don't do RM
  - How large? 3.4 Mpc
  - Lobes expanding in an empty region
  - Large-scale structure filaments ? from SDSS by Chen+15, 16
- Excess of 3 filaments for North lobe



O'Sullivan et al.

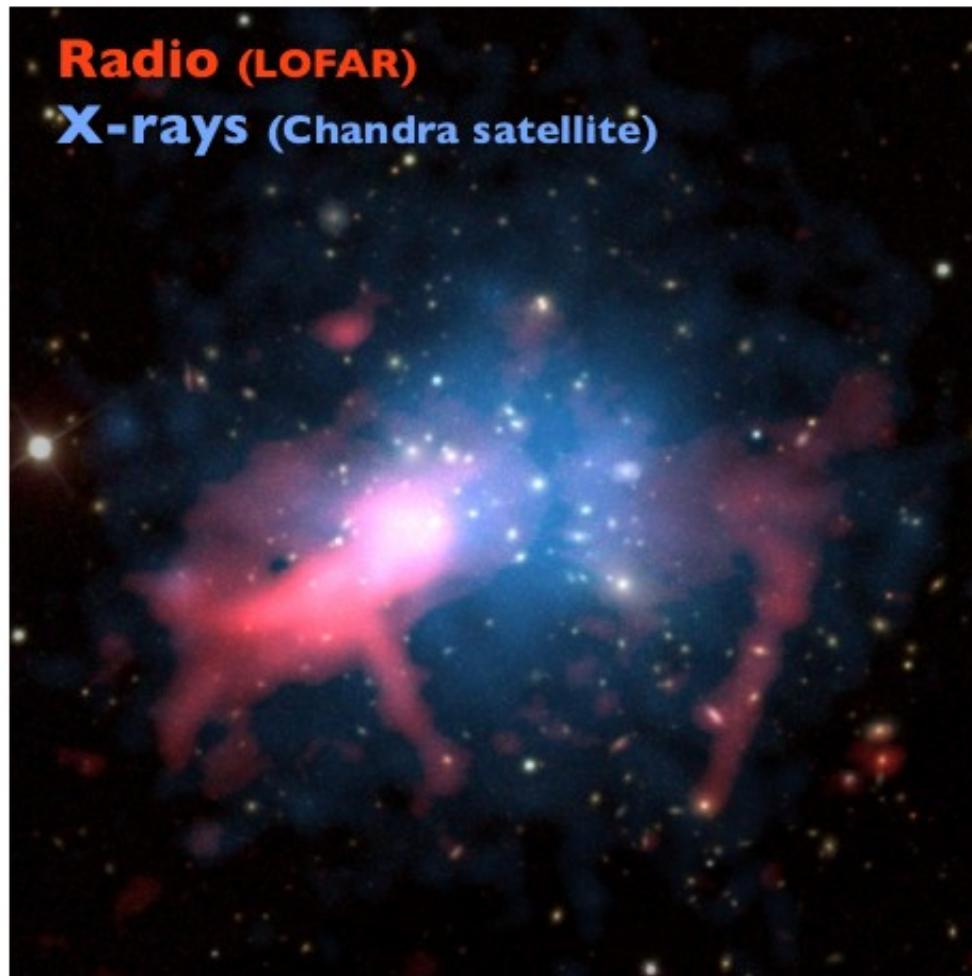
# Galaxy clusters



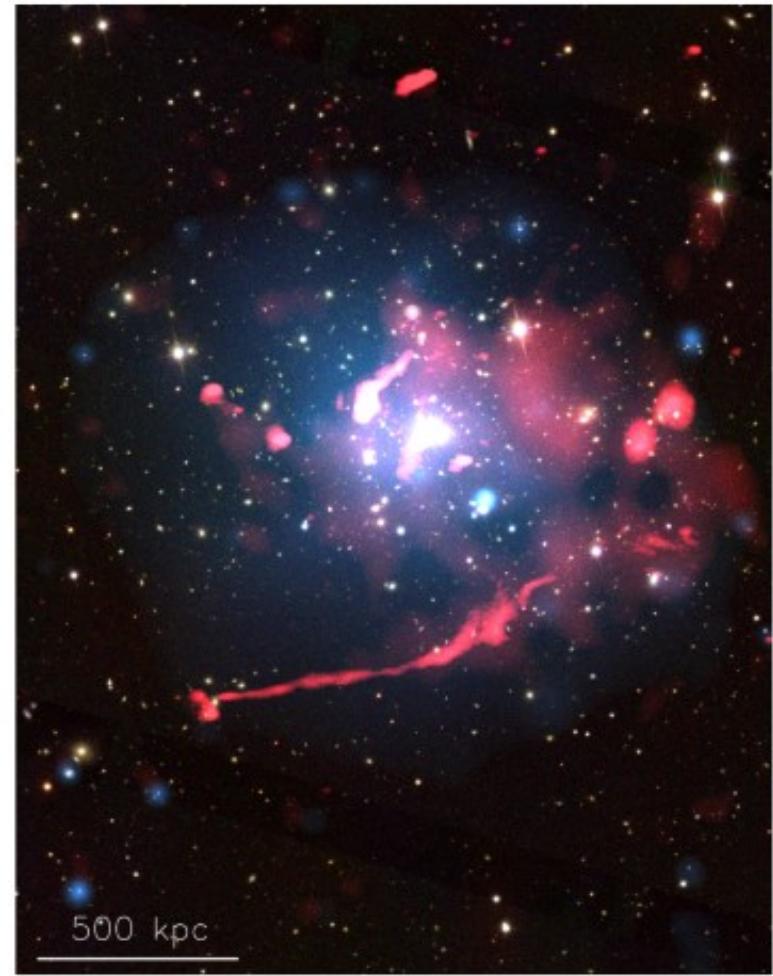
# Galaxy clusters

See Chiara Ferri talk

Abell 1914



Abell 1132

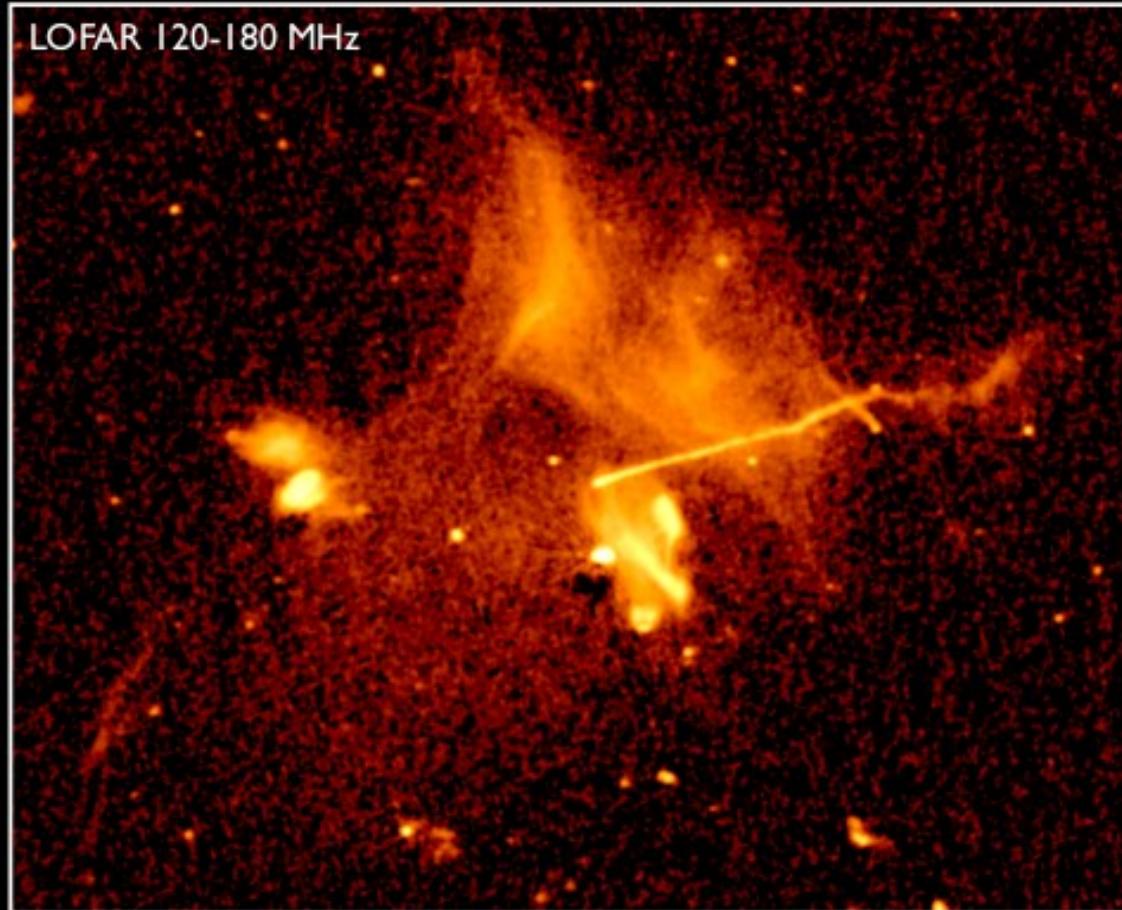


Mandal+ (2018, in prep)

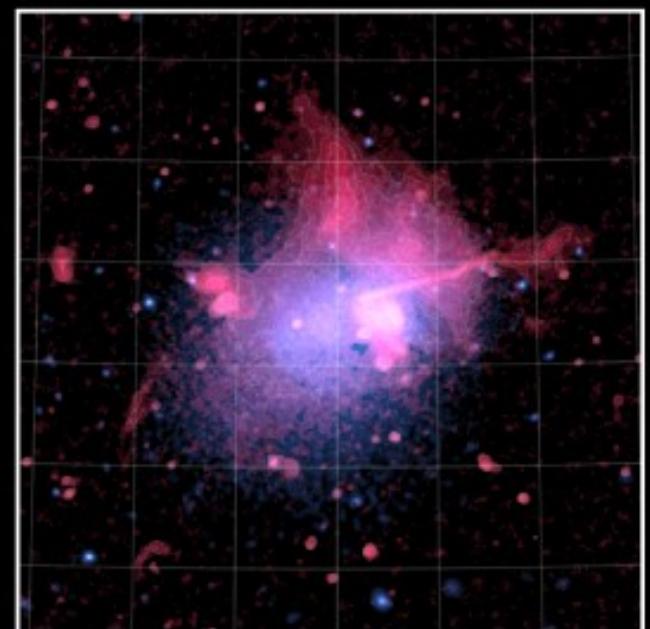
Wilber+ (2017)

# ABELL 2256

LOFAR 120-180 MHz



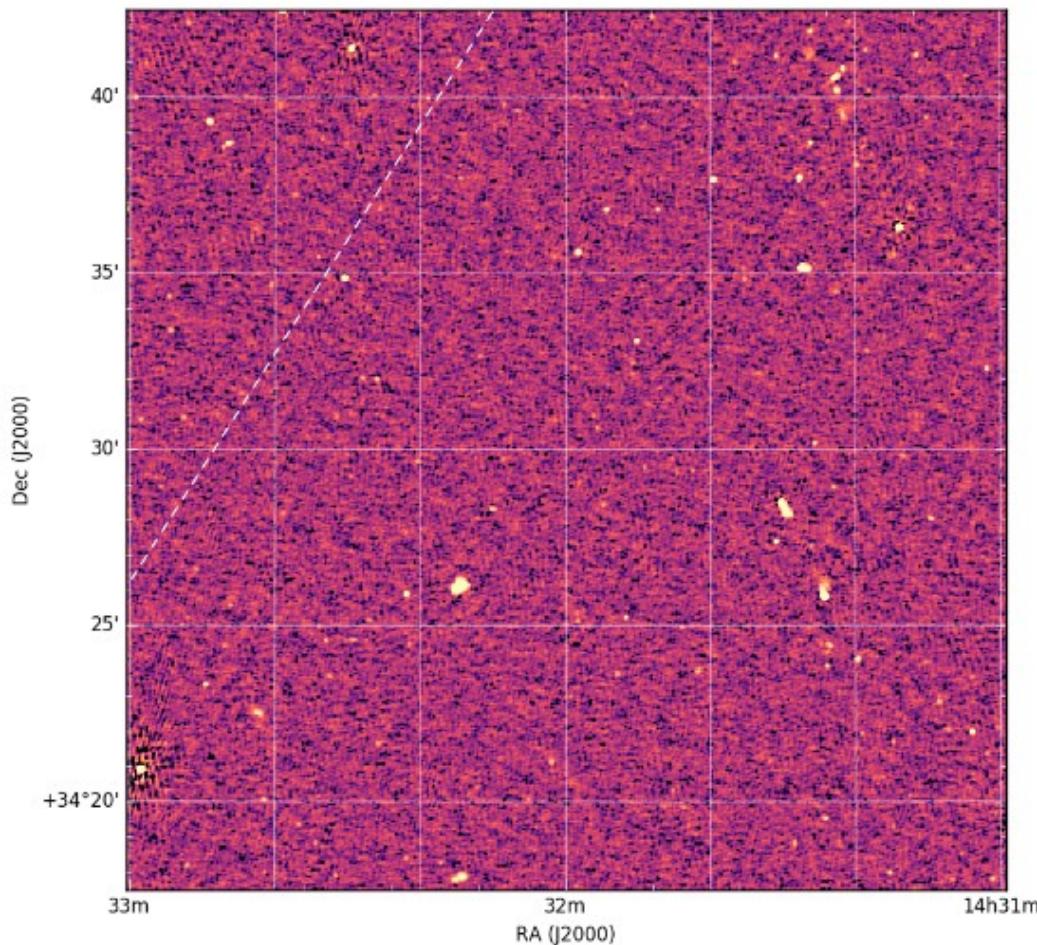
**Radio (LOFAR)**  
**X-rays (XMM)**



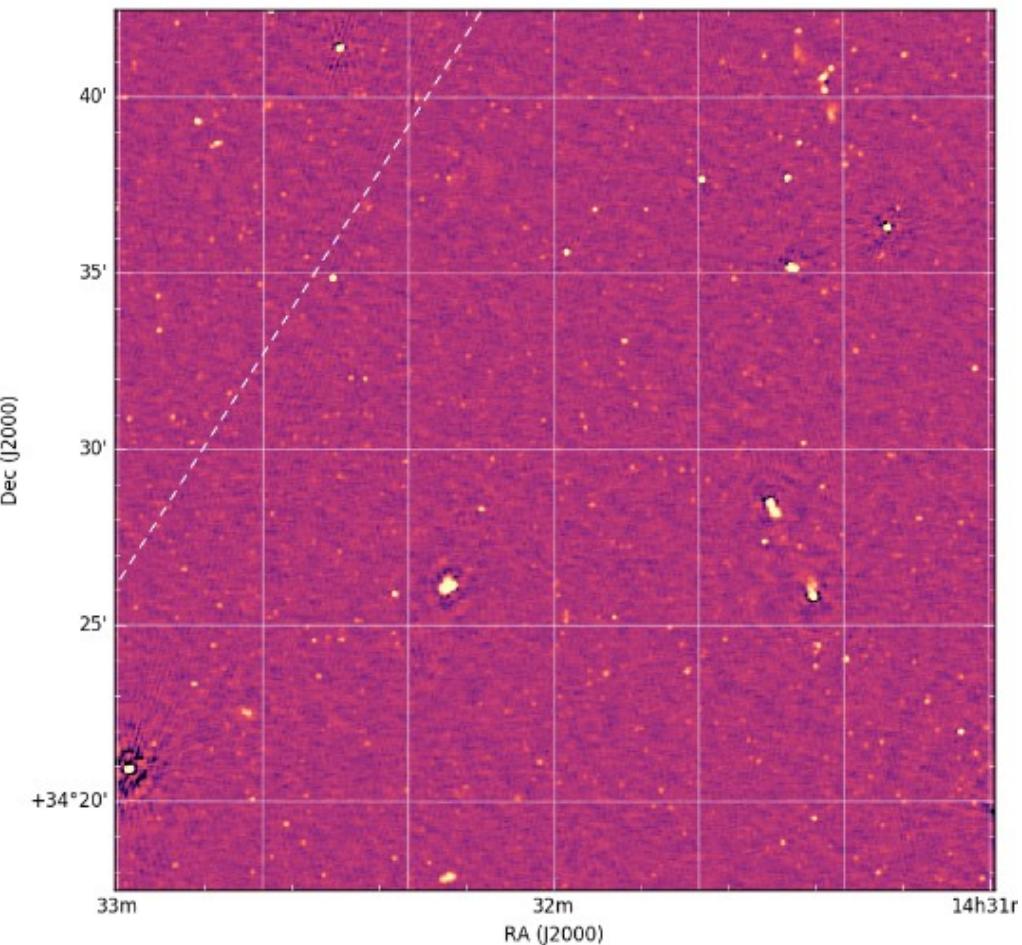
- Merging cluster
- $z = 0.05$

Van Weeren et al. In prep

# Tier-2 deep fields



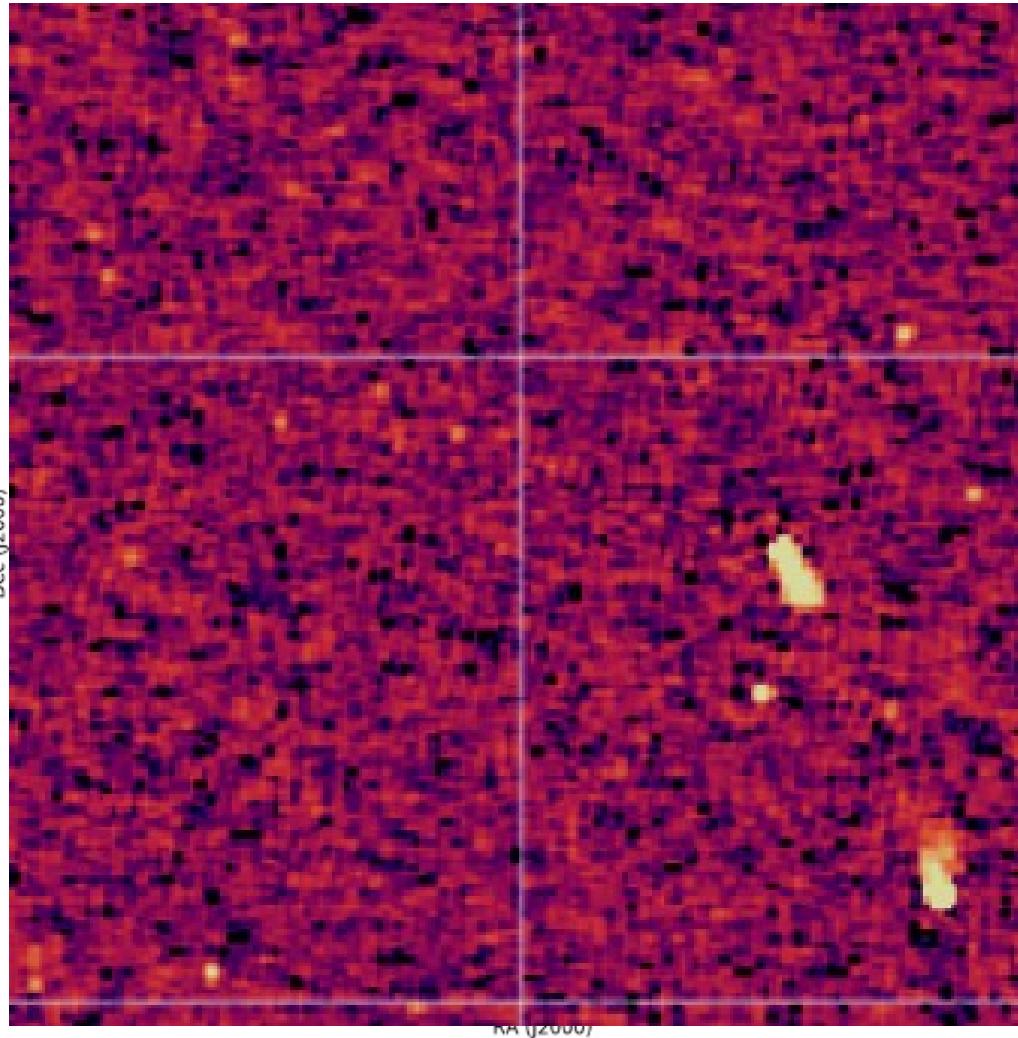
8 hours



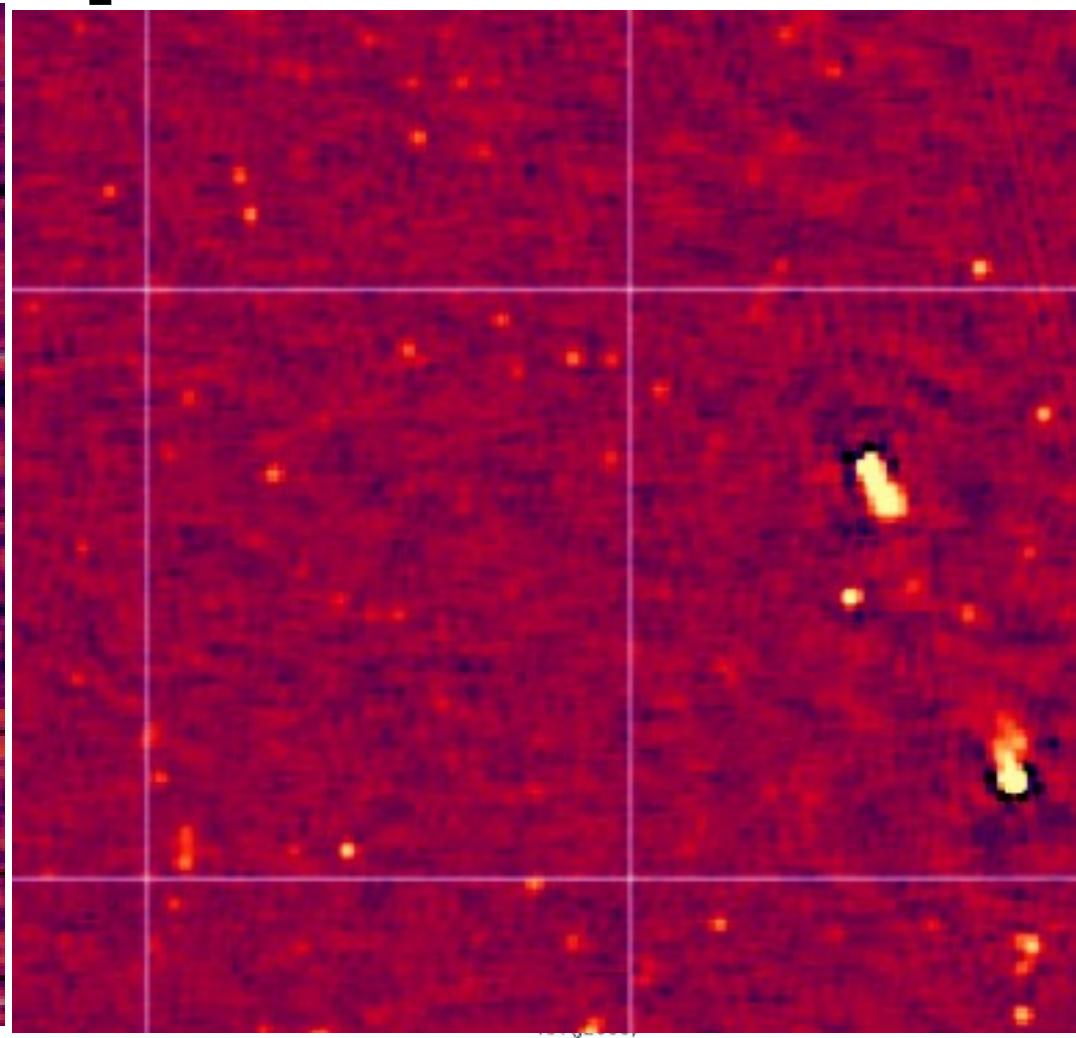
80 hours

Tasse et al. in prep  
Mandal et al. In prep

# Tier-2 deep fields



8 hours



80 hours

Tasse et al. in prep  
Mandal et al. In prep

**Thank you !**