

## LOFAR MSSS

*Multifrequency Snapshot Sky Survey*

## Status and early science

George Heald (MSSS Project Leader)  
(on behalf of the MSSS Team)

LOFAR science meeting, 08/04/2014



**LOFAR**

# Thanks to the MSSS Team!

Björn Adebahr, Mike Bell, Laura Bîrzan, Annalisa Bonafede, Justin Bray, Rene Breton, Jess Broderick, Ger de Bruyn, Therese Cantwell, Dario Carbone, Patti Carroll, Yvette Cendes, Alex Clarke, Judith Croston, Soobash Daiboo, Francesco De Gasperin, Emilio Enriquez, Richard Fallows, Chiara Ferrari, Jon Gregson, Martin Hardcastle, Jeremy Harwood, Tom Hassall, Volker Heesen, Andreas Horneffer, Alexander van der Horst, Marco Iacobelli, Vibor Jelic, David Jones, Wojciech Jurusik, Georgi Kokotanekov, Giulia Macario, Poppy Martin, Carlos Martinez, John McKean, Leah Morabito, David Mulcahy, Ronald Nijboer, Błażej Nikiel-Wroczyński, Andre Offringa, Emanuela Orrú, V.N. Pandey, Gosia Pietka, Roberto Pizzo, Mamta Pommier, Peeyush Prasad, Chris Riseley, Huub Röttgering, Antonia Rowlinson, Pepe Sabater, Anna Scaife, Bart Scheers, Kati Sendlinger, Aleksandar Shulevski, Charlotte Sobey, Carlos Sotomayor, Adam Stewart, Andra Stroe, John Swinbank, Cyril Tasse, Bas van der Tol, Jonas Trüstedt, Sander ter Veen, Sjoert van Velzen, Reinout van Weeren, Wendy Williams, Michael Wise



- There are a handful of fields to reobserve, but **congratulations!!** on completing the MSSS-HBA observations!



Goals: obtain broadband sky model, shakedown LOFAR operations

## MSSS-LBA



Frequency: 30-75 MHz  
(8 x 2 MHz bands)

**Resolution:**  $\leq 100$  arcsec

**Sensitivity:**  $\leq 15$  mJy/beam

Area: 20,000 square degrees

**Number of Fields: 660**

Simultaneous beams: 5

## MSSS-HBA



Frequency: 120-160 MHz  
(8 x 2 MHz bands)

**Resolution:**  $\leq 120$  arcsec

**Sensitivity:**  $\leq 5$  mJy/beam

Area: 20,000 square degrees

**Number of Fields: 3616**

Simultaneous beams: 6

MSSS surveys the entire northern sky - **TWICE** - in 45 days

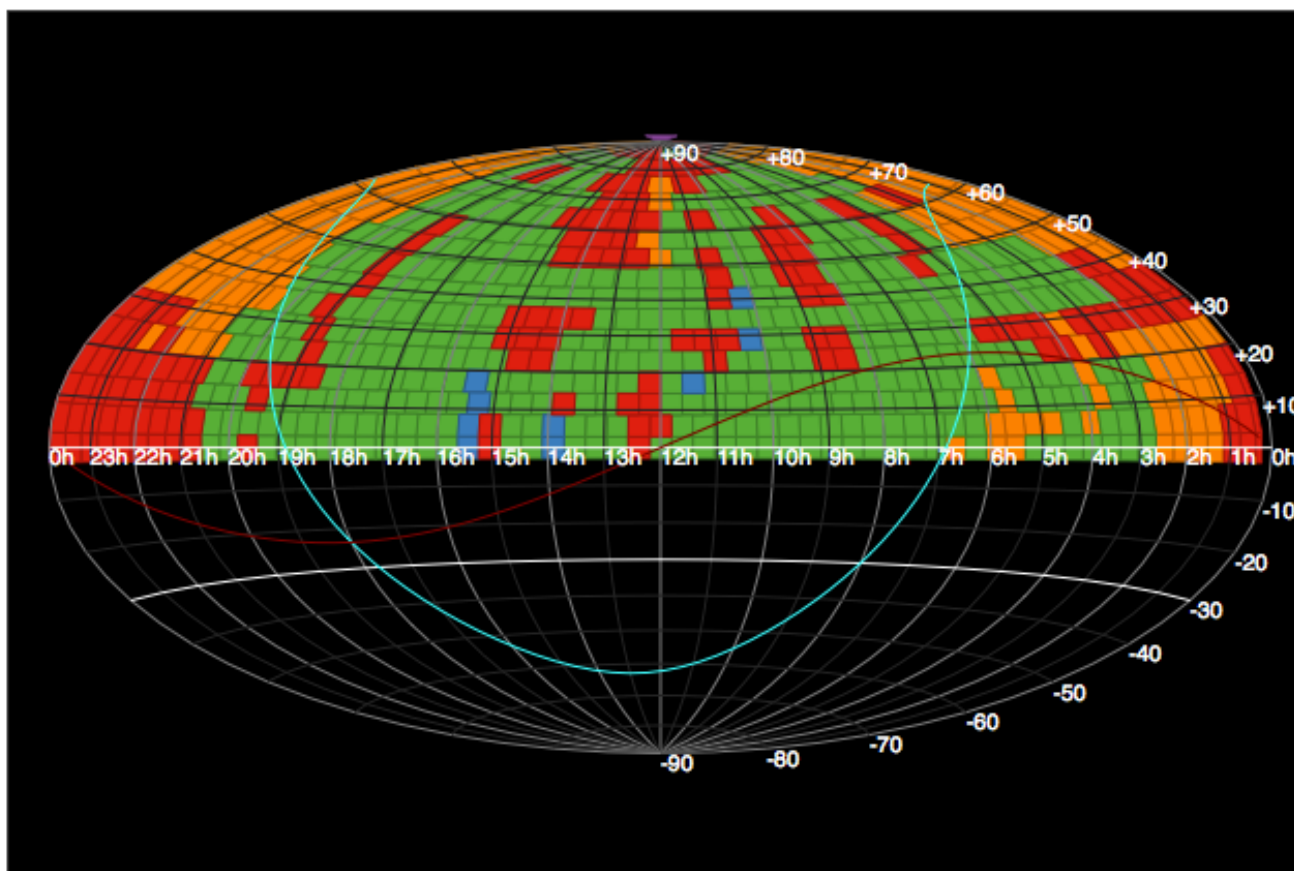
- About 80% observed in 2012; currently being resumed!

LOFAR Observation Database

## MSSS LBA

Number of Targets	661
Number of Calibrators	8
Start Date	4 Nov. 2011
Stop Date	20 Jan. 2013
Completed Fields	378 (57.2%)
Information collected	28 Feb. 2014

Show me the data »



Hammer Projection

Map based on code from [this project](#).  
(mapping library developed by  
the PanSTARRS Project)

Data archived (57.0%)  
Data available on CEP (0.2%)  
Partial data available (1.4%)  
Data missing or invalid (23.0%)  
Not yet observed (18.5%)

*Swinbank*

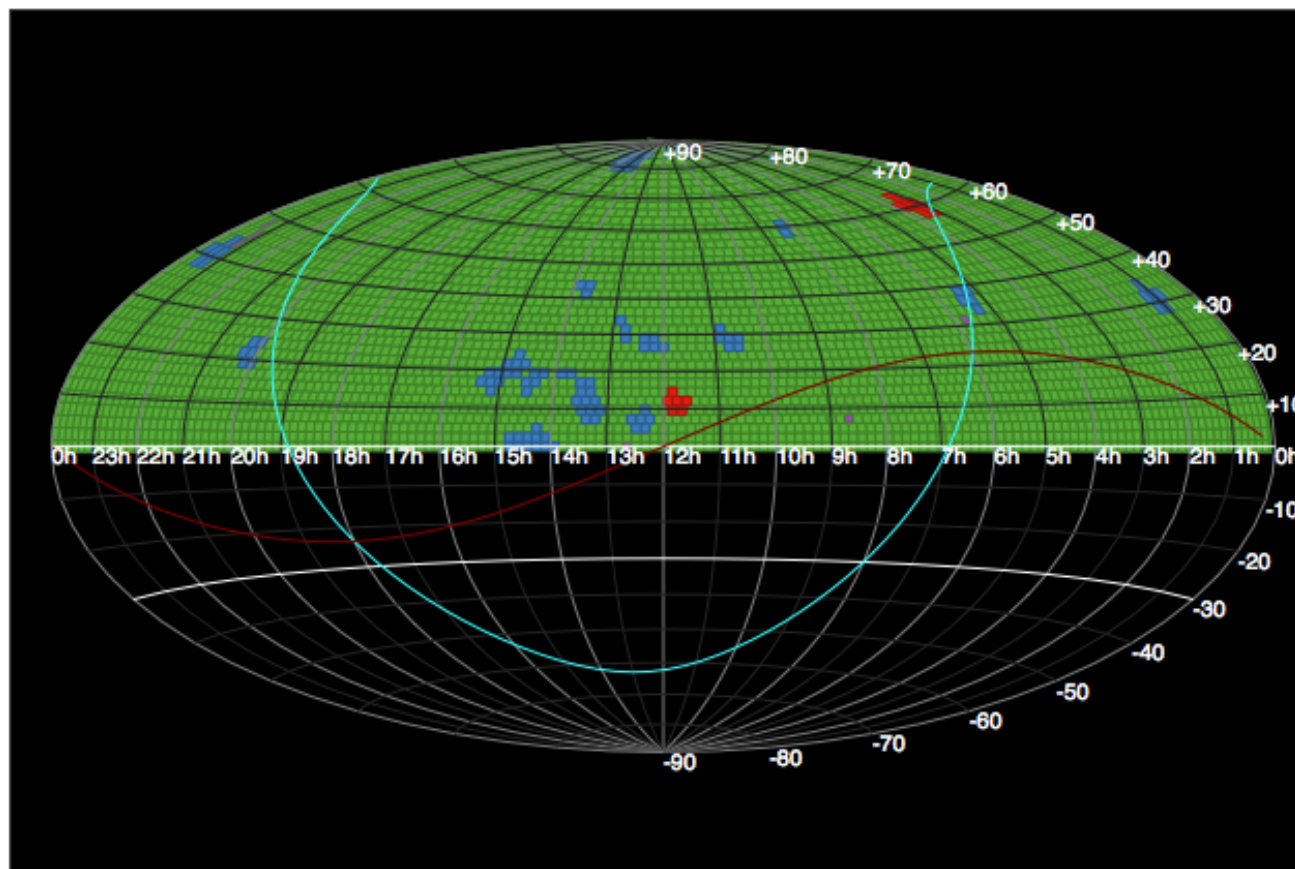
- MSSS-HBA is now  $\sim 100\%$  complete!

## LOFAR Observation Database

### MSSS HBA

Number of Targets	3616
Number of Calibrators	8
Start Date	8 Feb. 2013
Stop Date	21 Feb. 2014
Completed Fields	3514 (97.2%)
Information collected	1 March 2014

Show me the data »

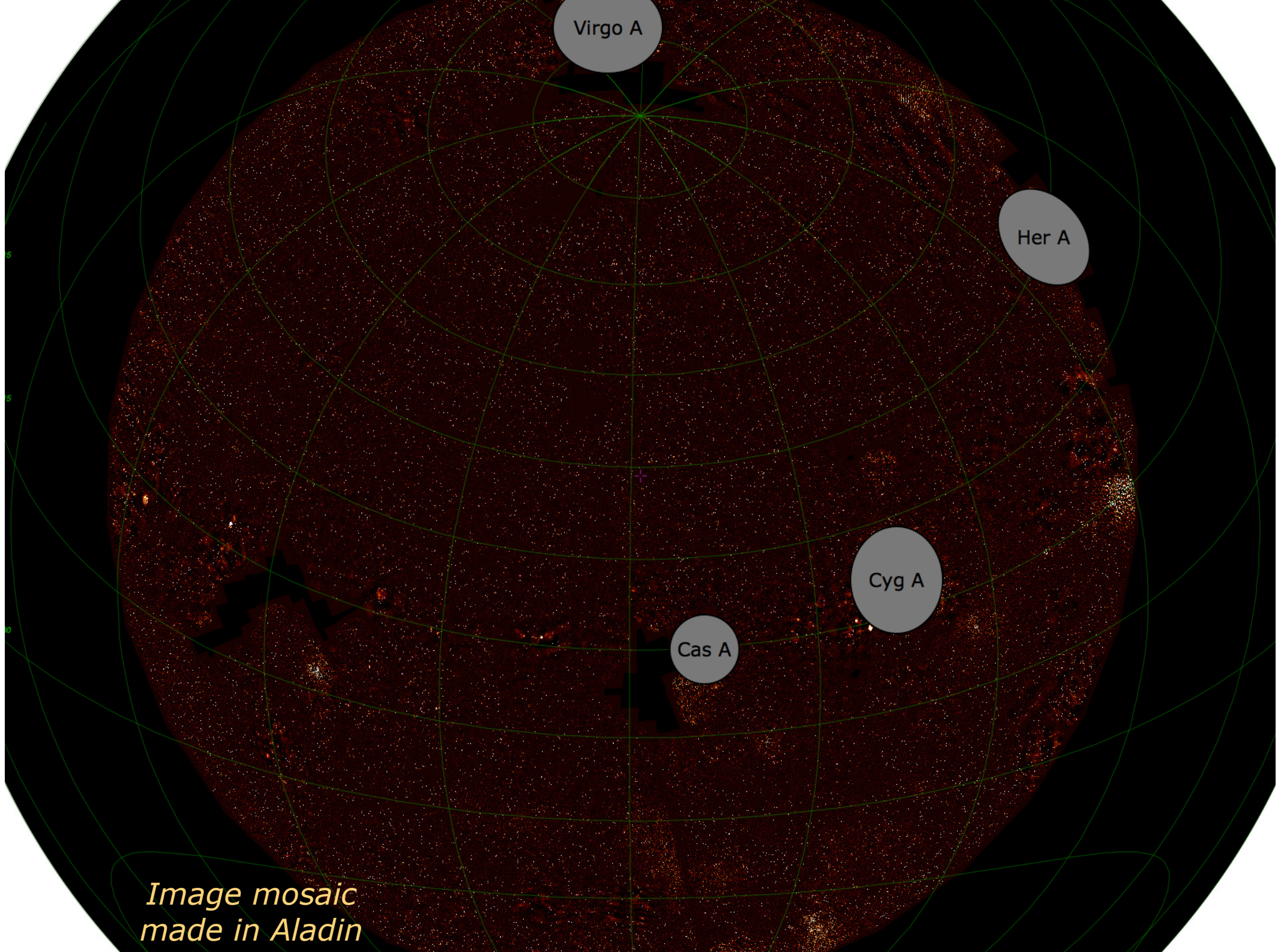


Hammer Projection

Map based on code from [this project](#).

Data archived (96.8%)  
Data available on CEP (0.2%)  
Partial data available (2.7%)  
Data missing or invalid (0.3%)  
Not yet observed (0%)

**Swinbank**



Virgo A

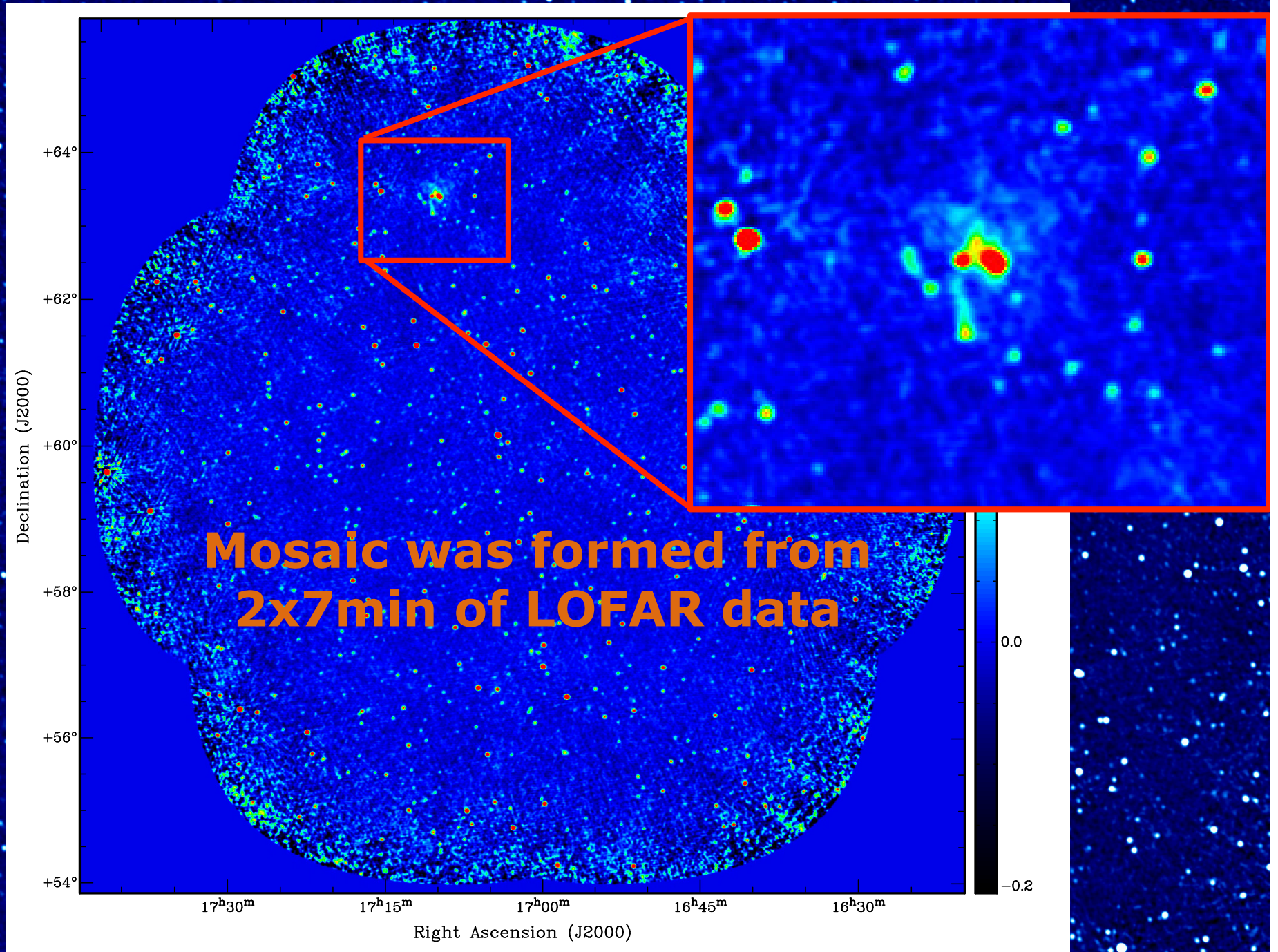
Her A

Cyg A

Cas A

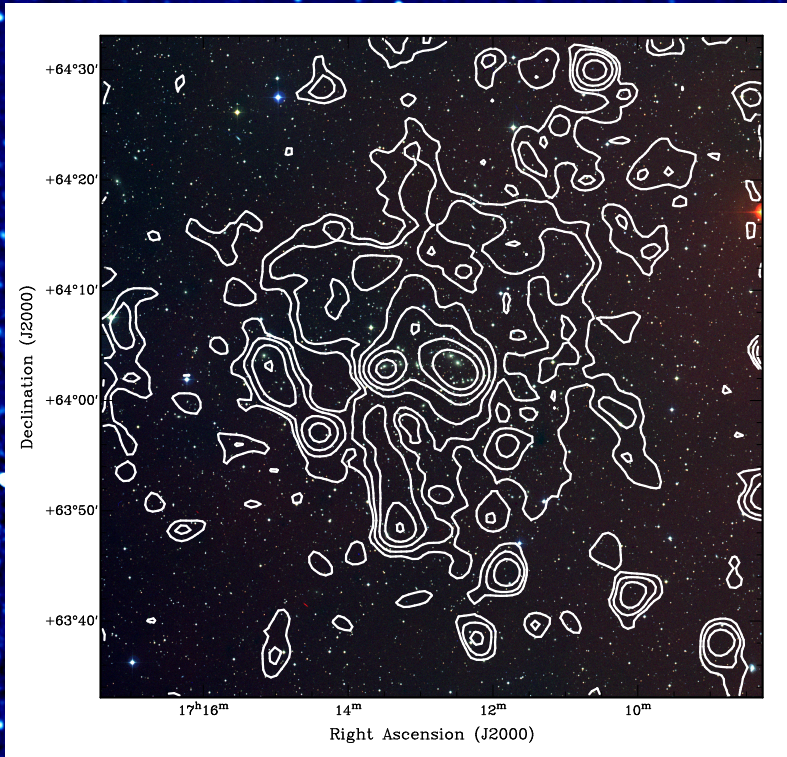
*Image mosaic  
made in Aladin*

# MSSS early images (highlights)

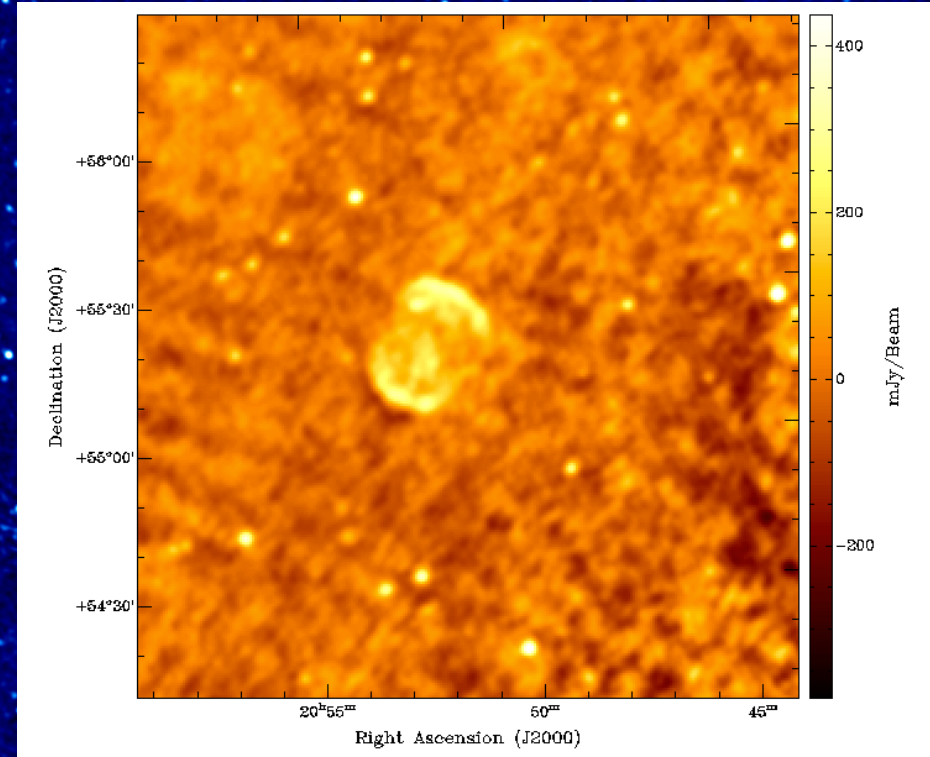




# MSSS early images (highlights)



**Abell 2255**

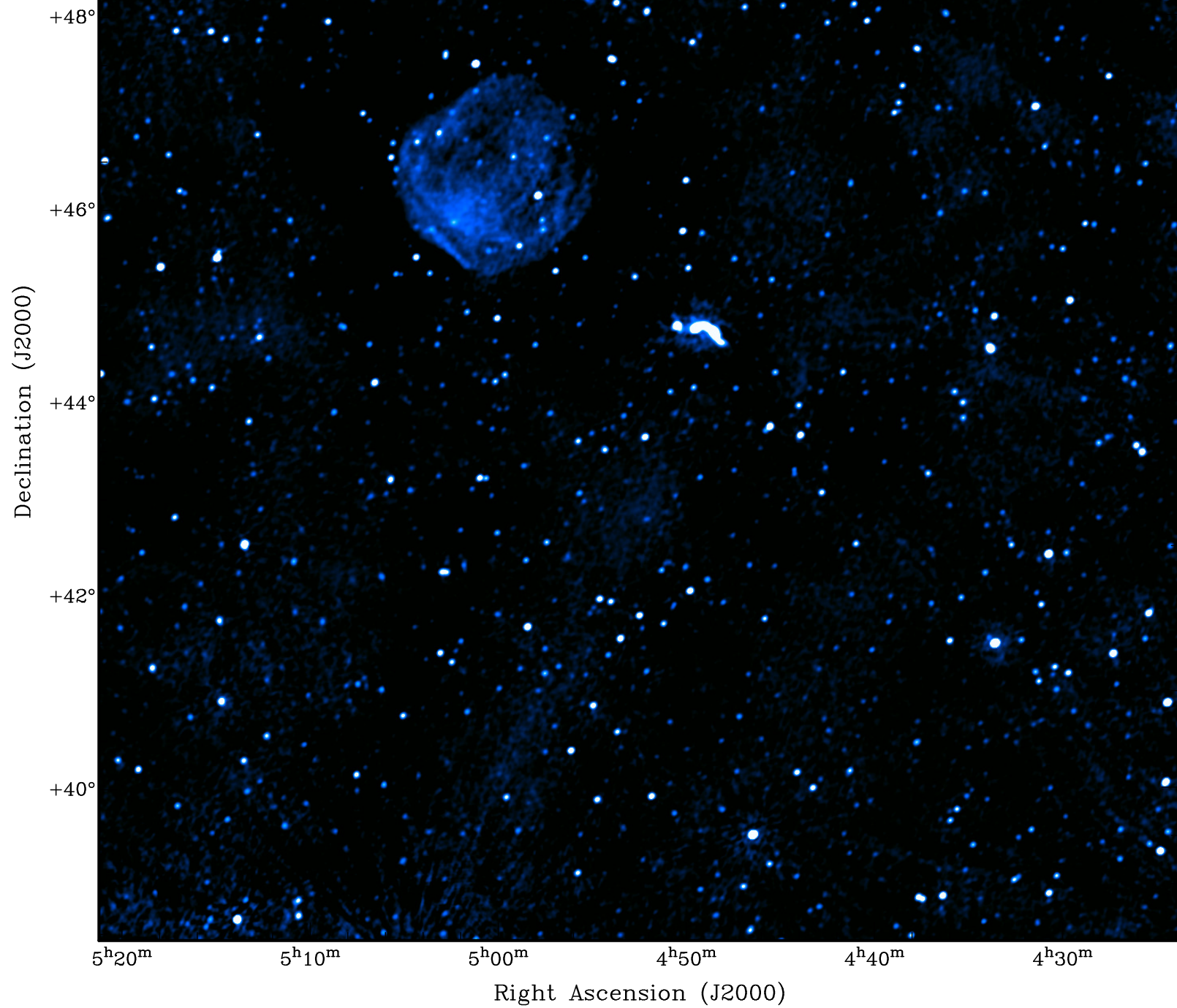


**DA 530**



**3C 31 &  
NGC 315**

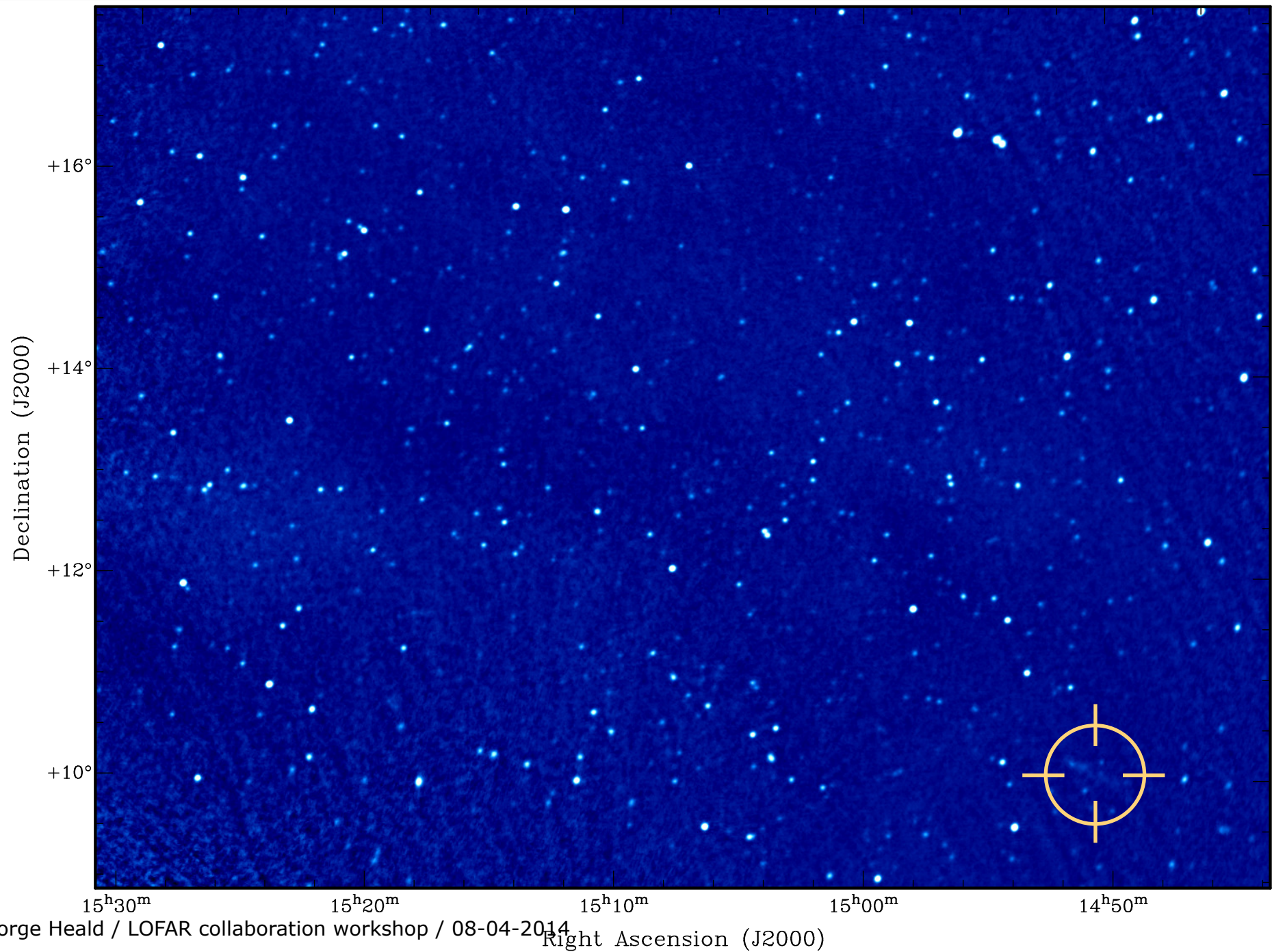
# M073+43, containing SNR G160.4+02.8 and 3C129



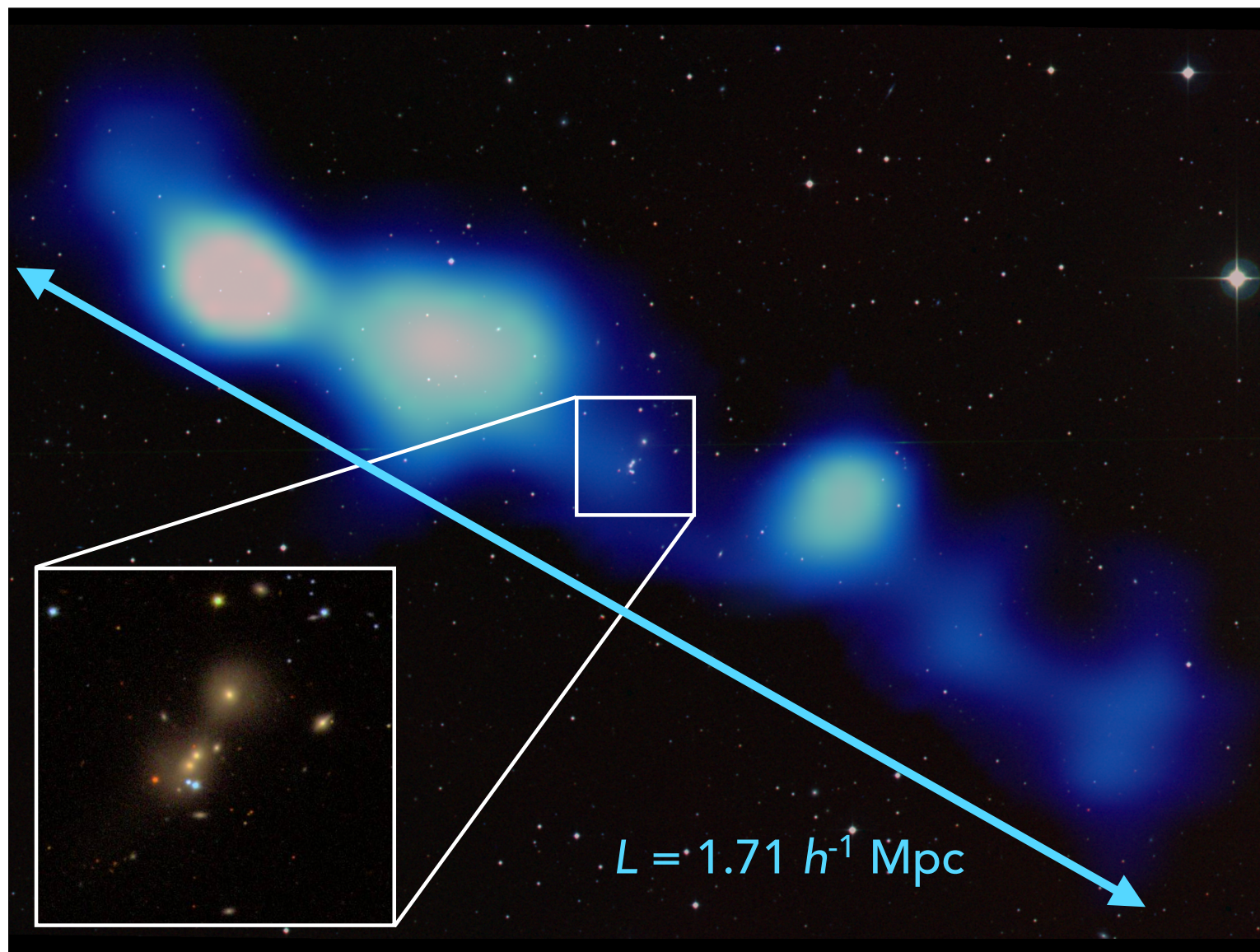
Not all MSSS sources are known...



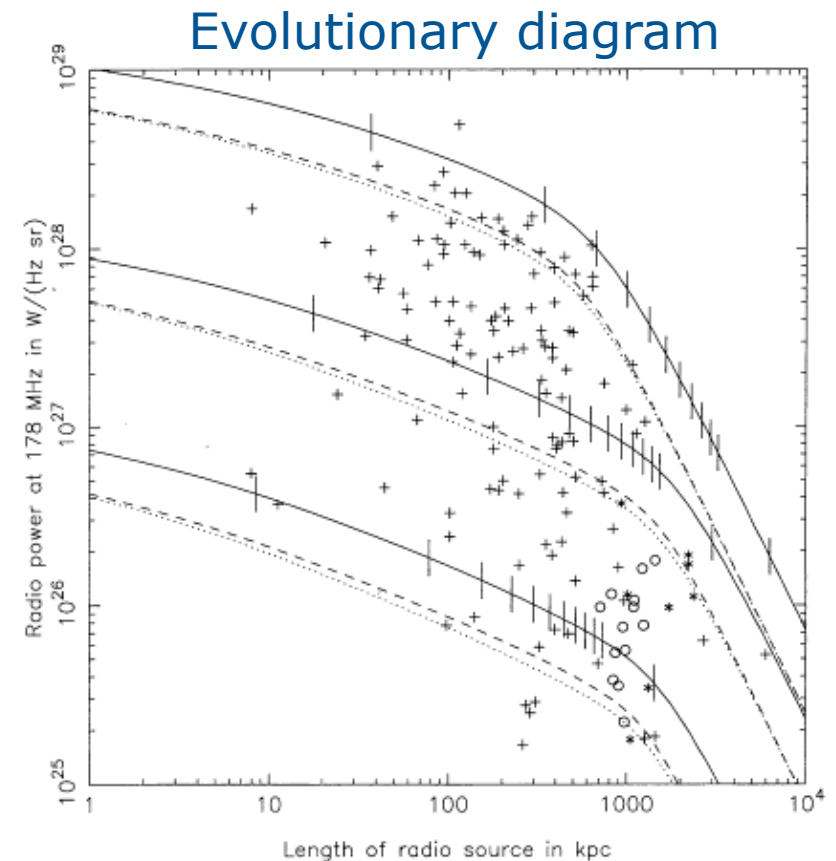
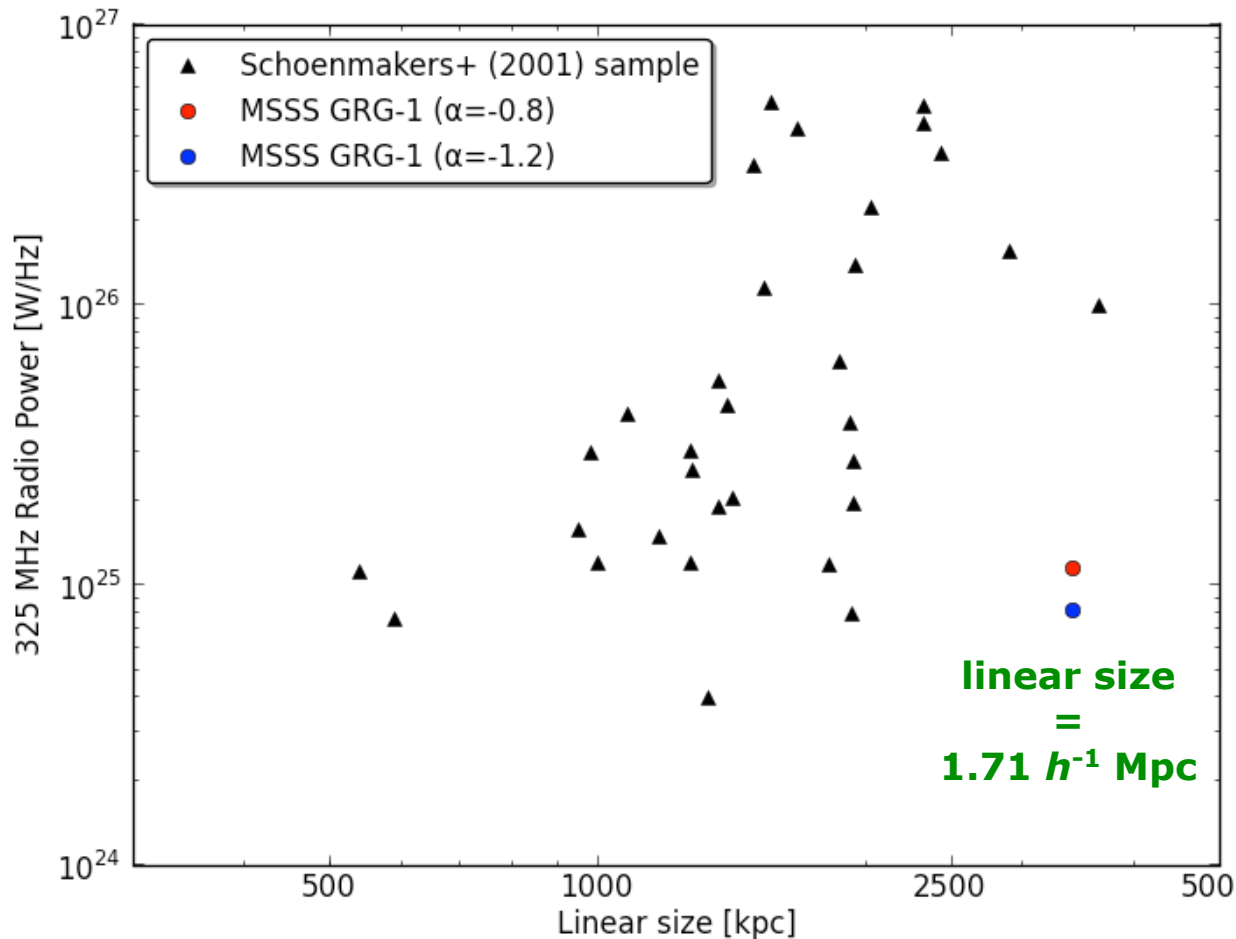
LOFAR ASTRON



- Extended ( $\sim 36'$ ) source centered on flat-spectrum radio source coincident with one member ( $z=0.054536$ ) of a galaxy triplet

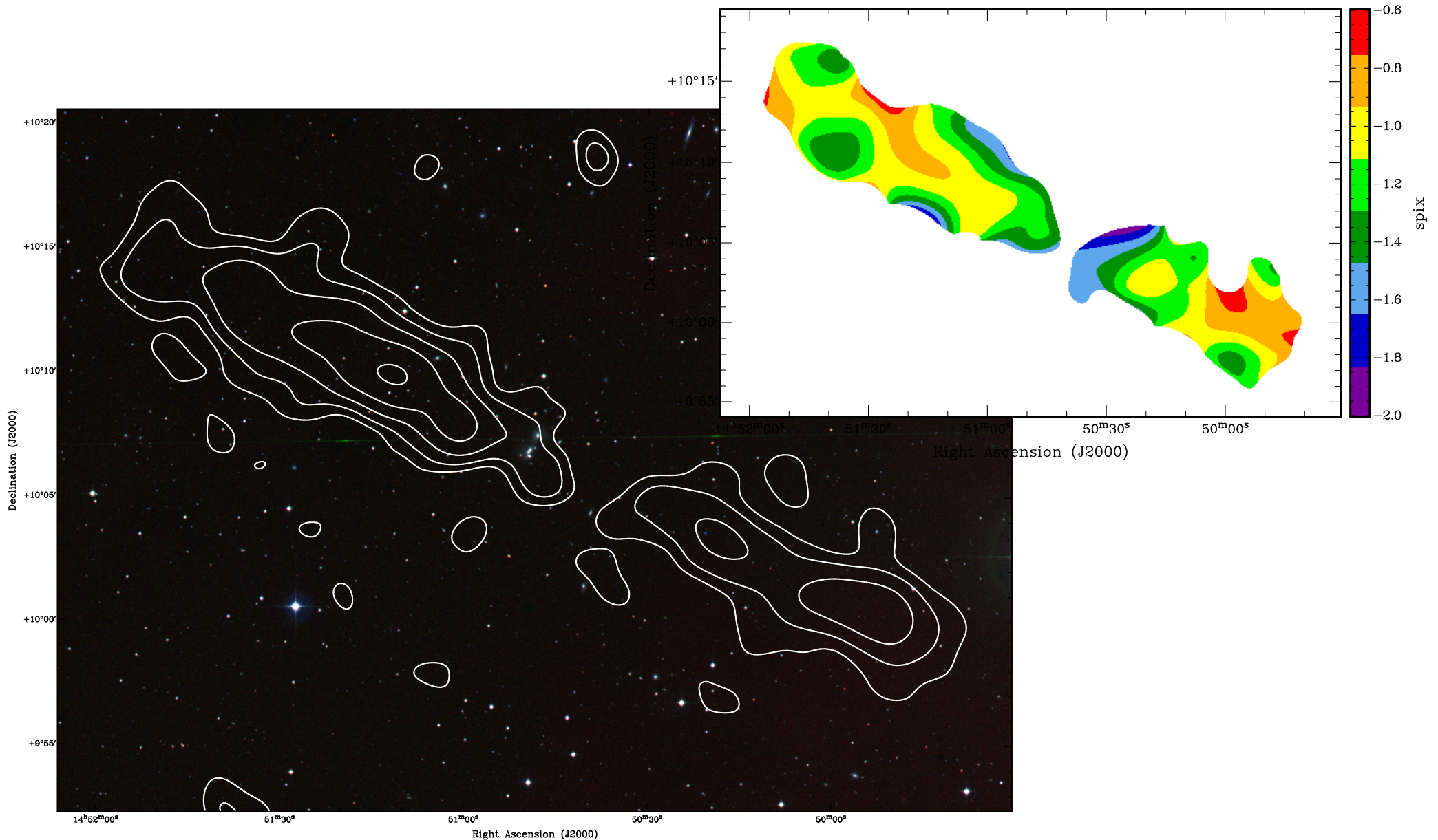


- Identified as a GRG associated with the central flat-spectrum NVSS source
- Large size for its radio power - particularly old GRG? First of a new population to be revealed by LOFAR?

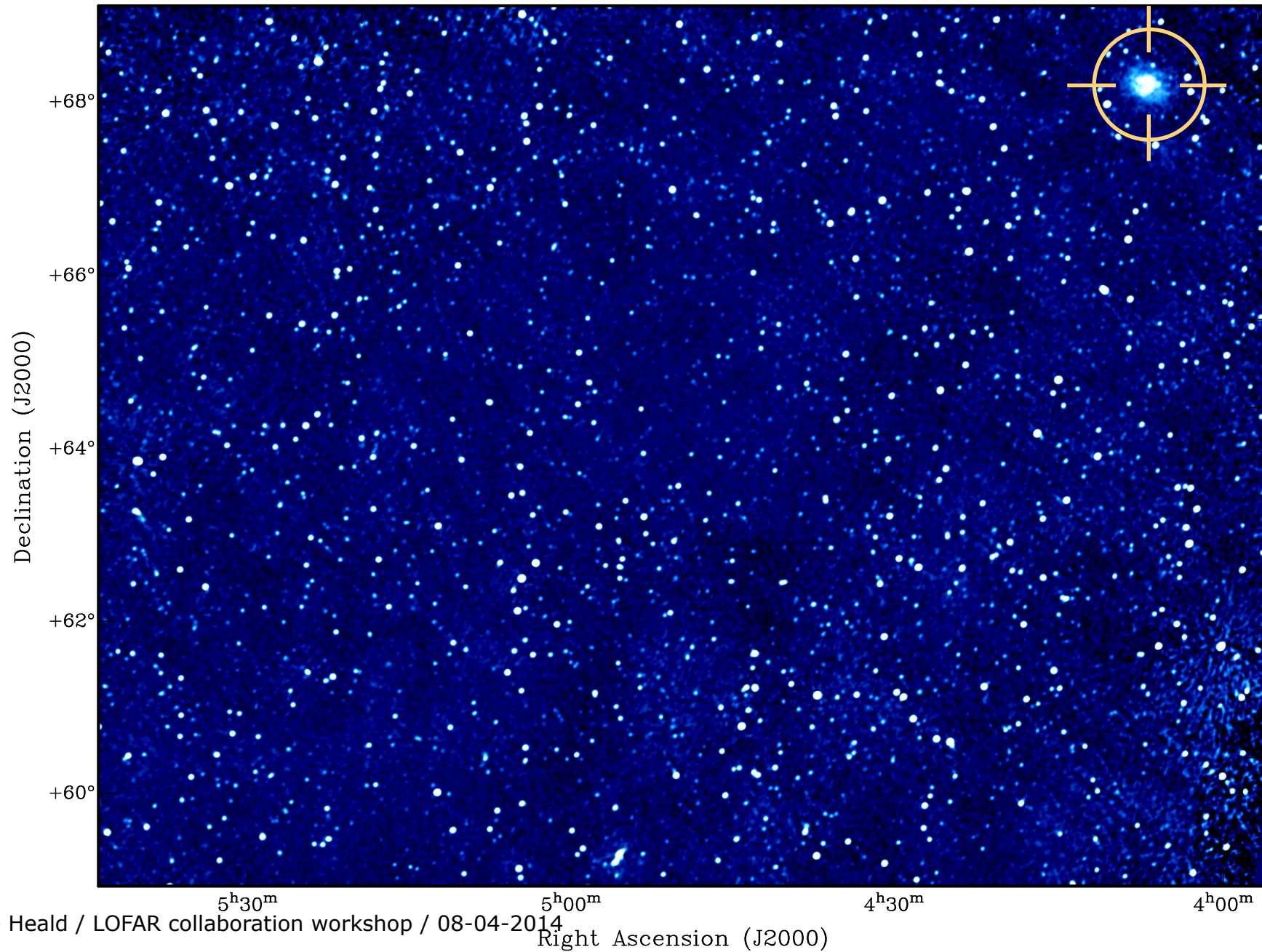


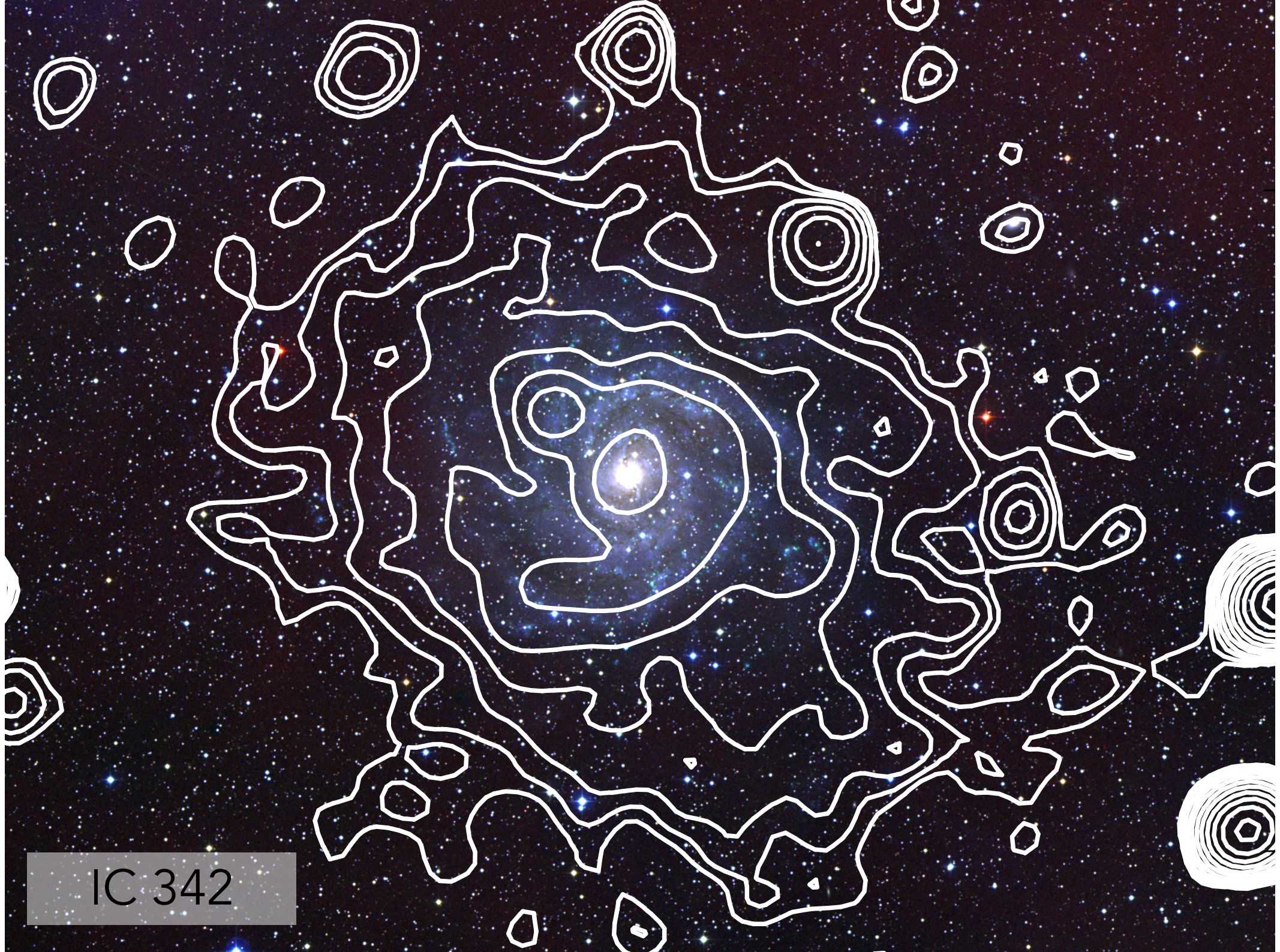
**Kaiser et al (1997)**

- Followup observations with WSRT, GMRT (new!), LOFAR (soon!)



- From another 100 sq deg mosaic:

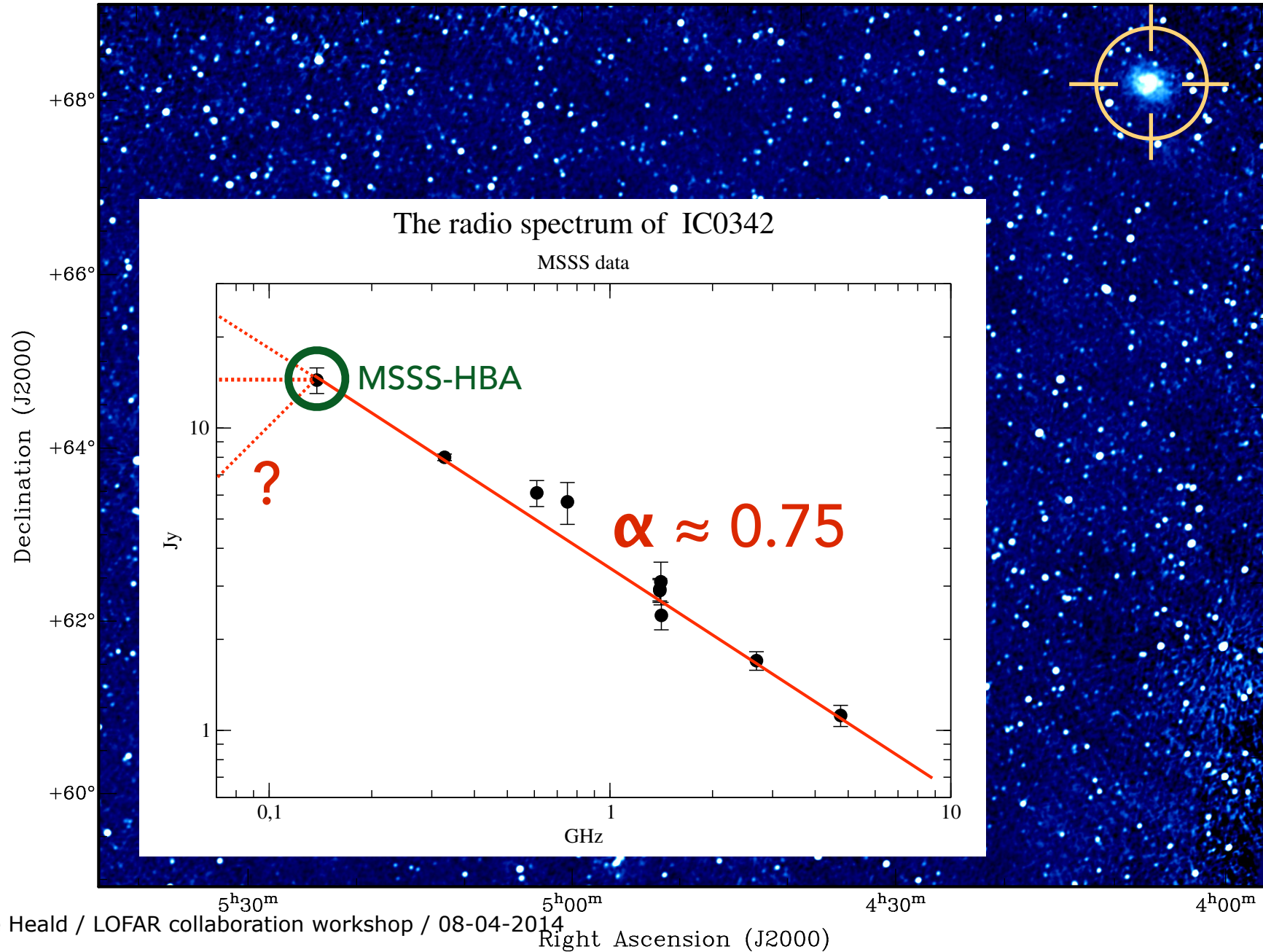




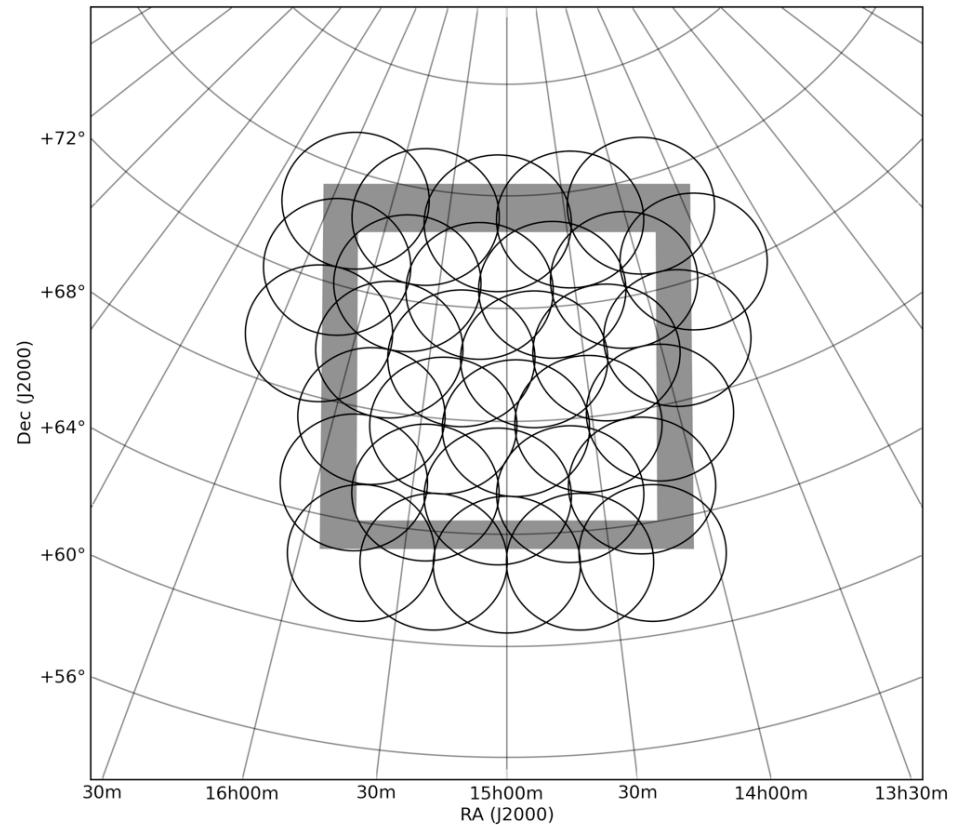
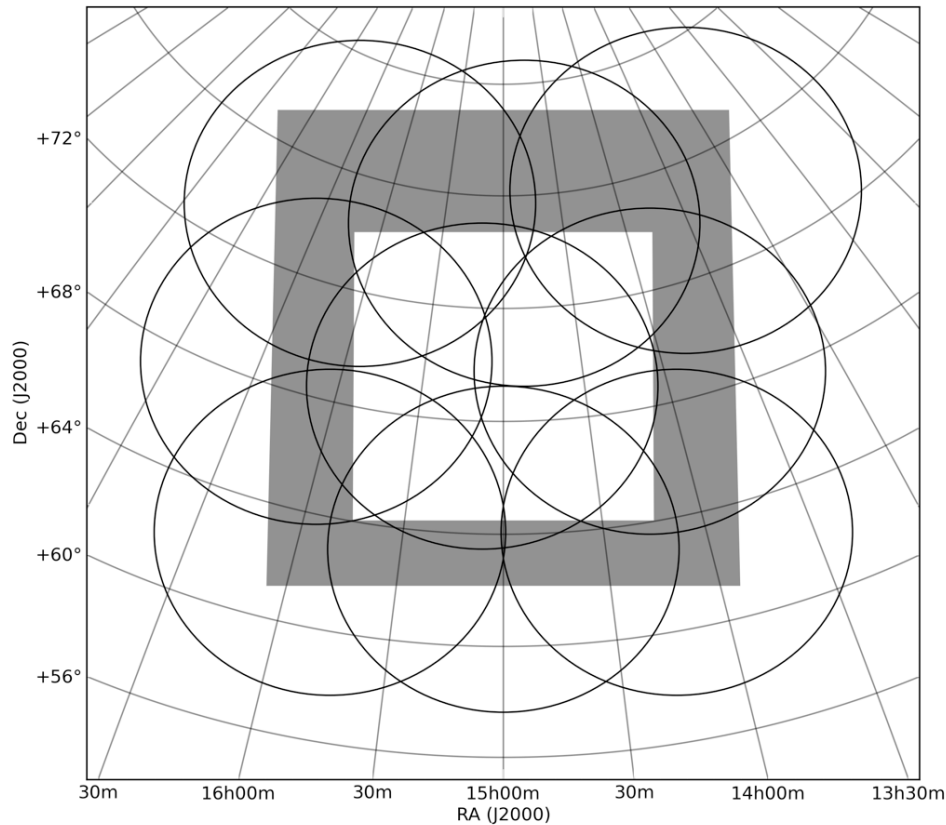
IC 342

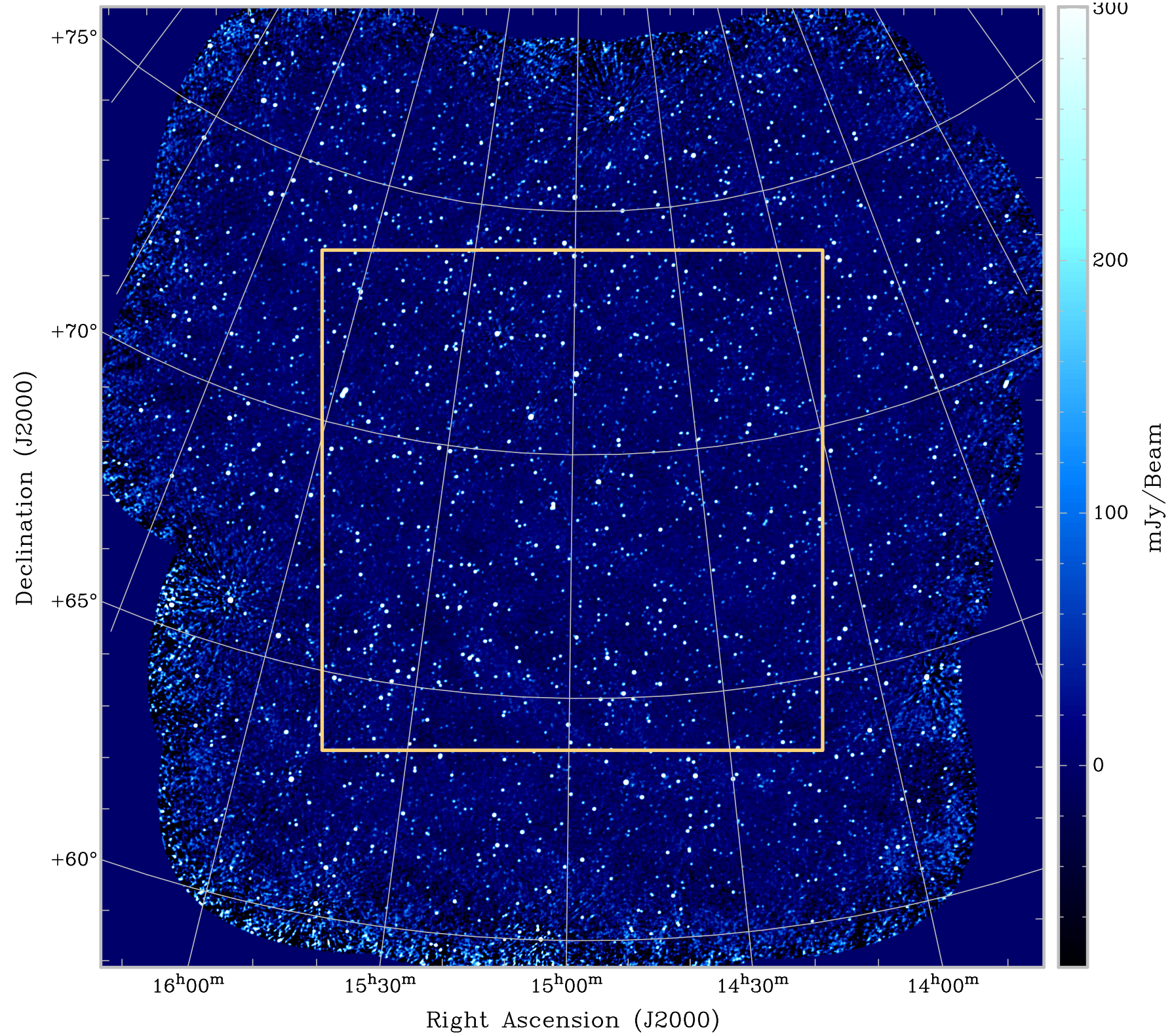


- From another 100 sq deg mosaic:

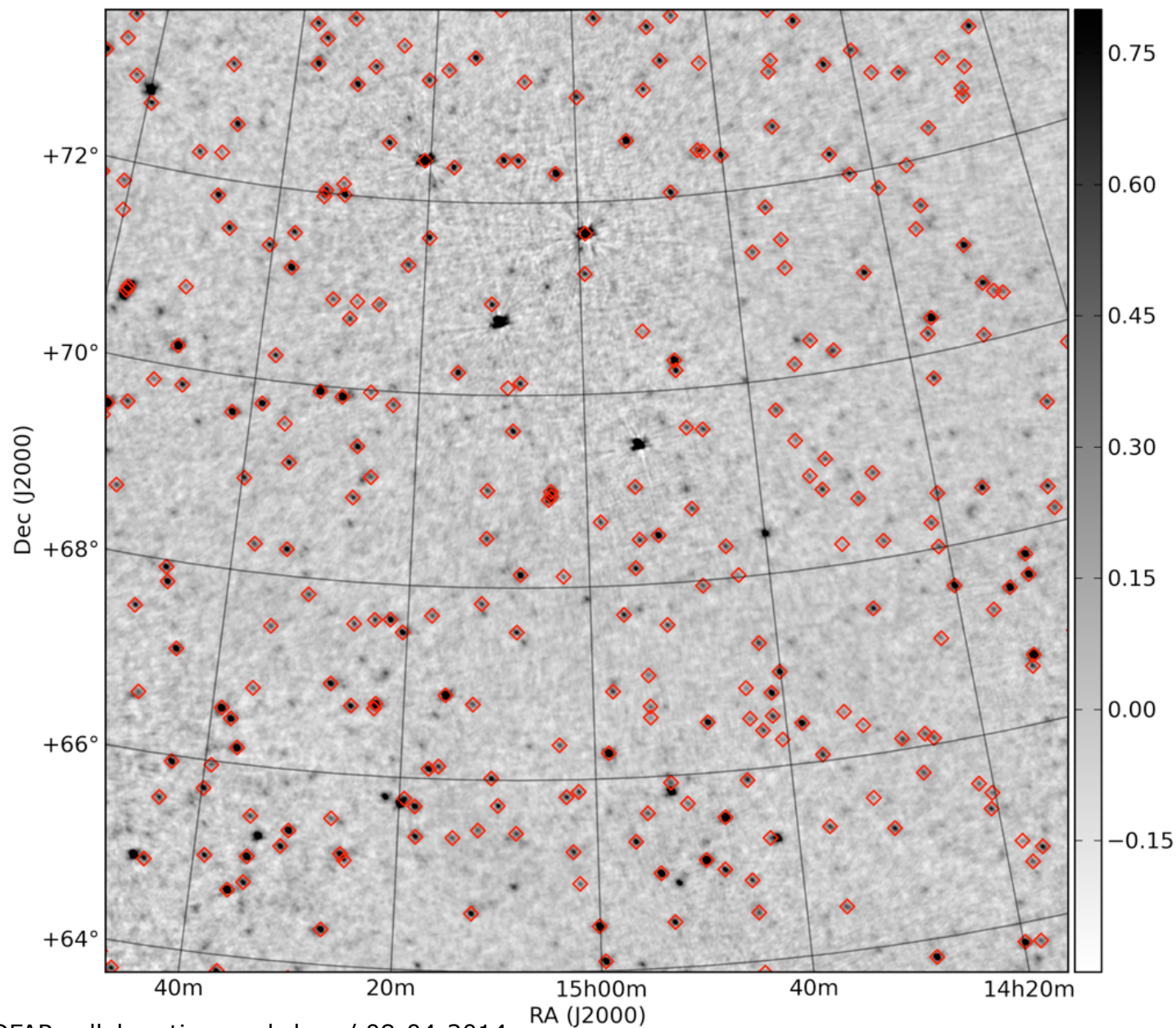


- Mosaics formed from 9 LBA fields and 32 HBA fields



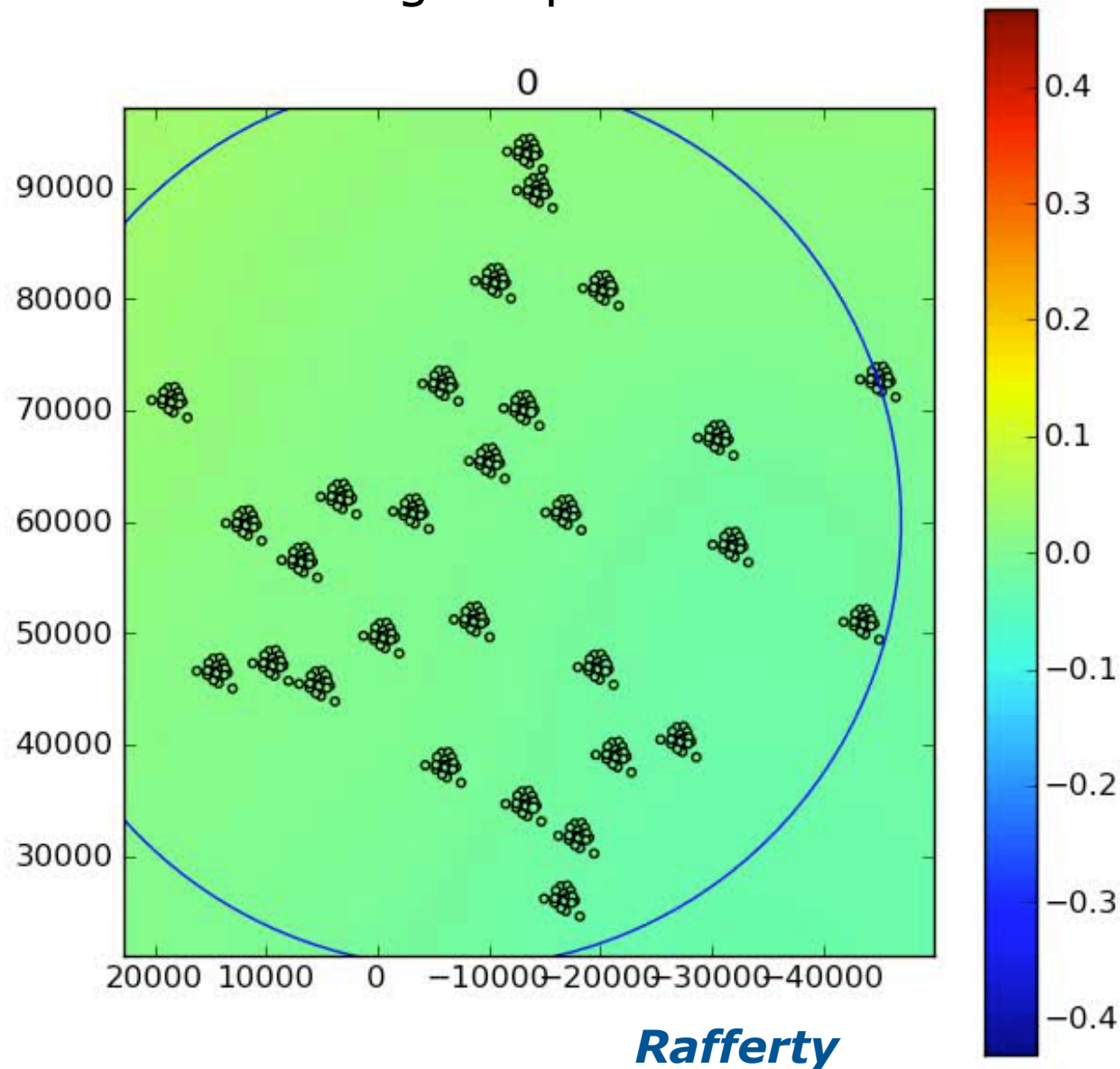


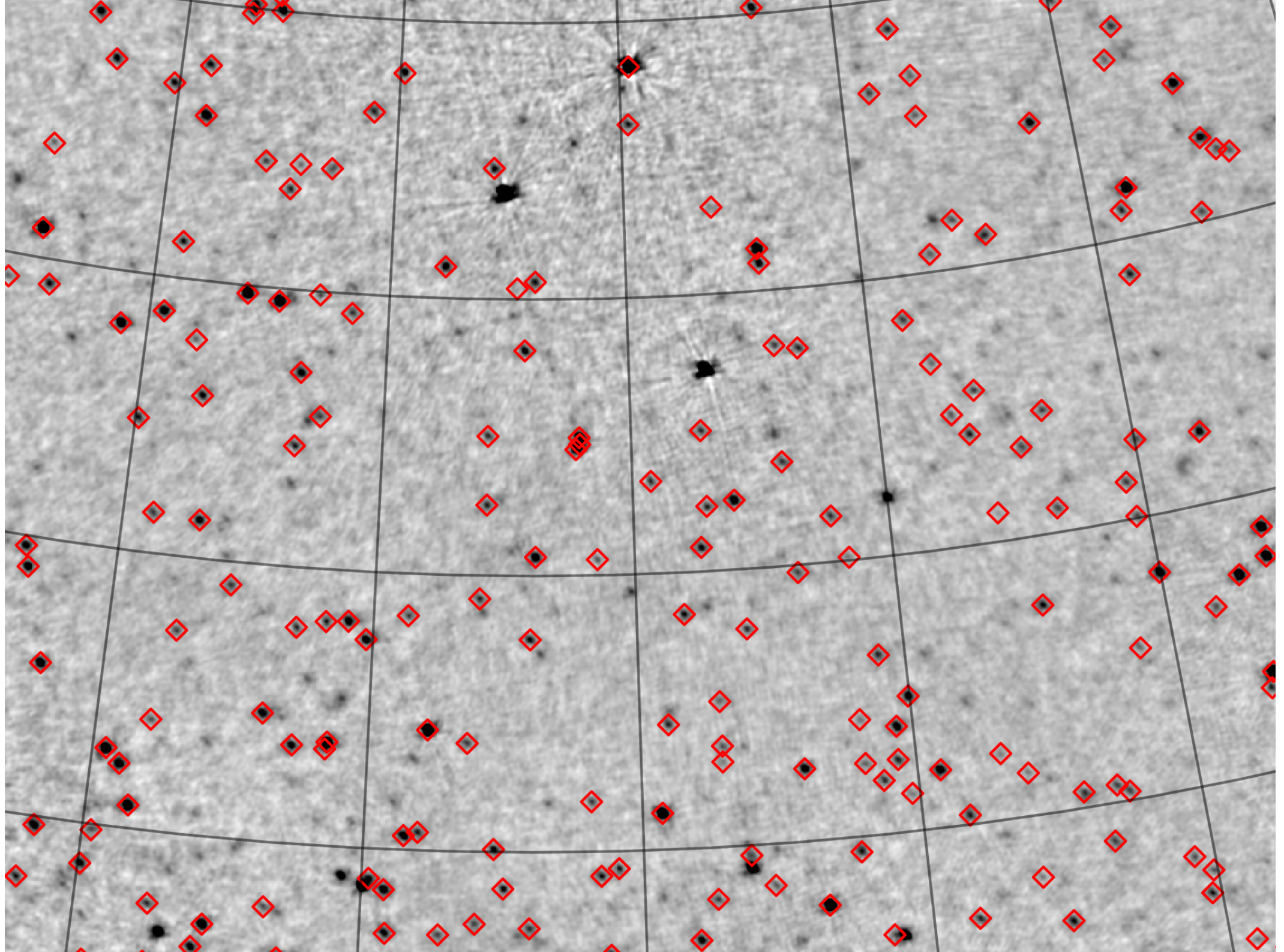
- LBA 46 mJy/beam, 2' resolution

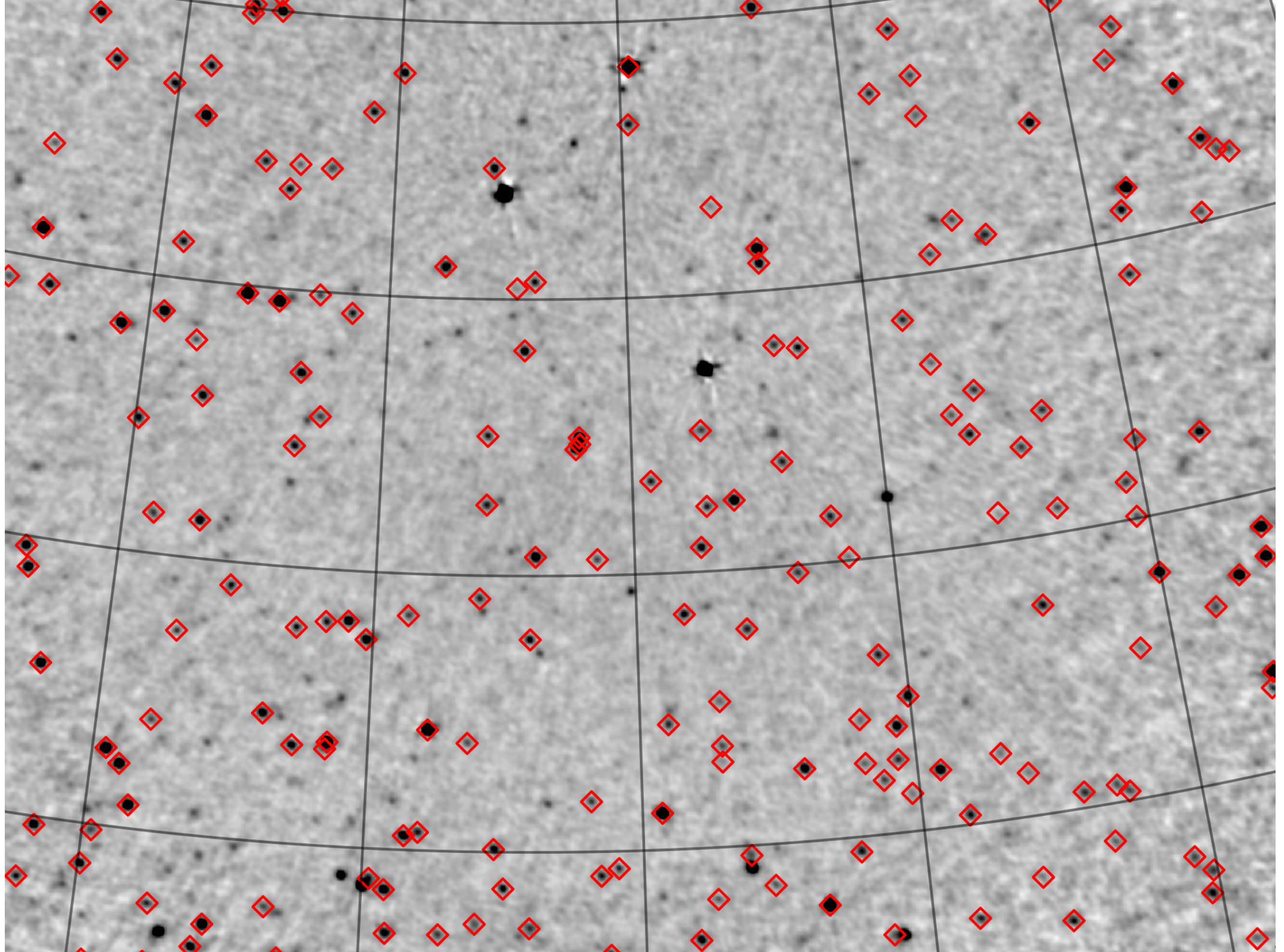




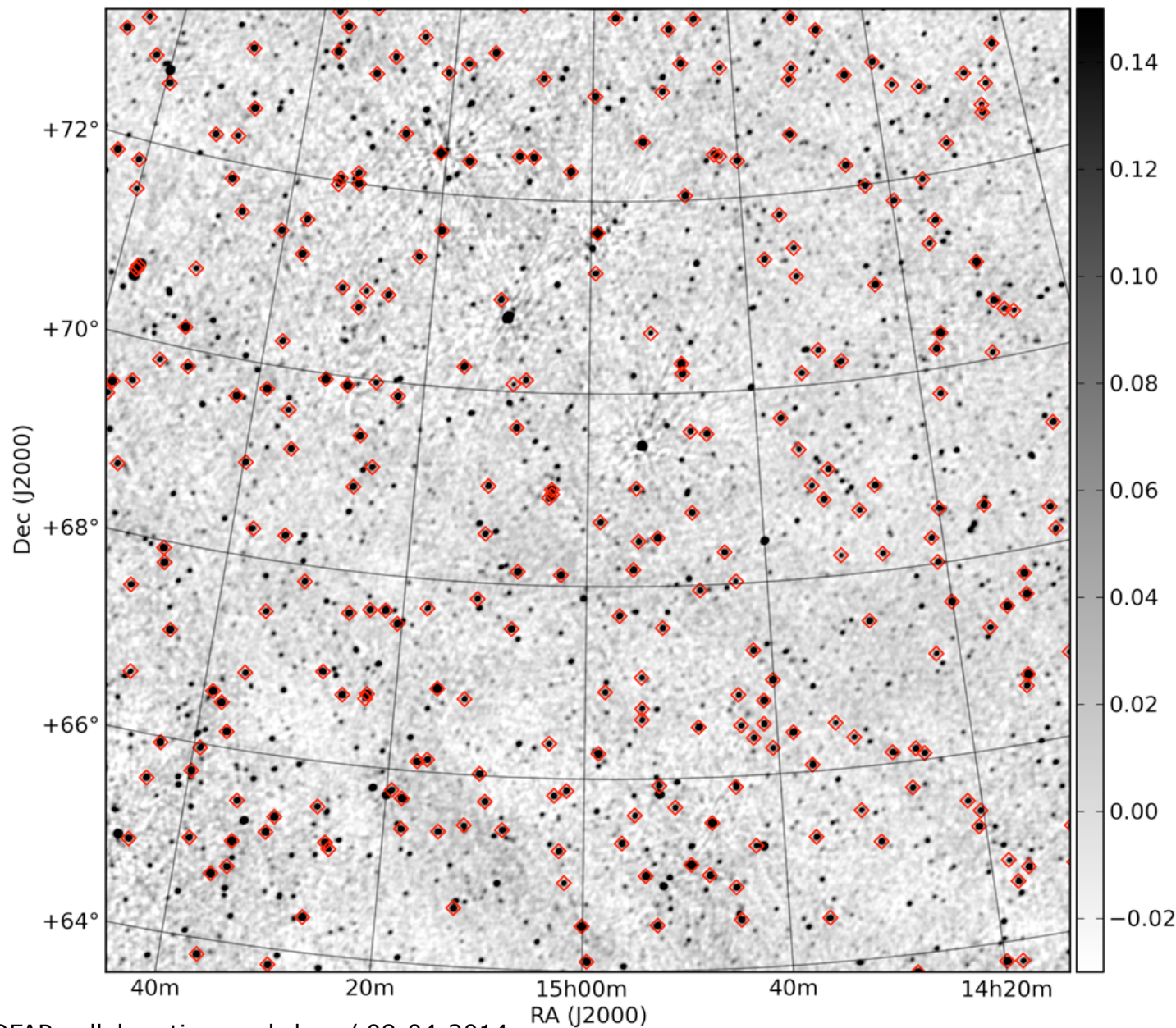
- Using BBS direction-dependent gain solutions, now on patches
- Up to 30 directions with good phases





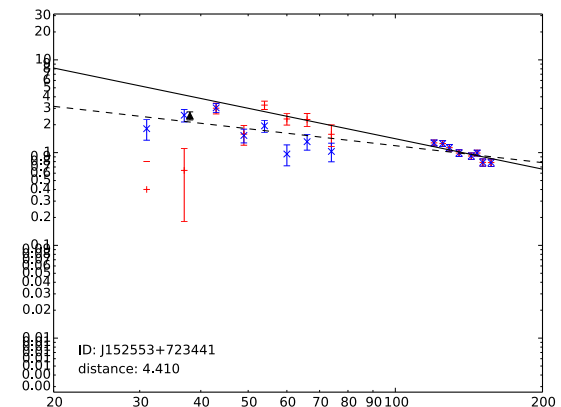
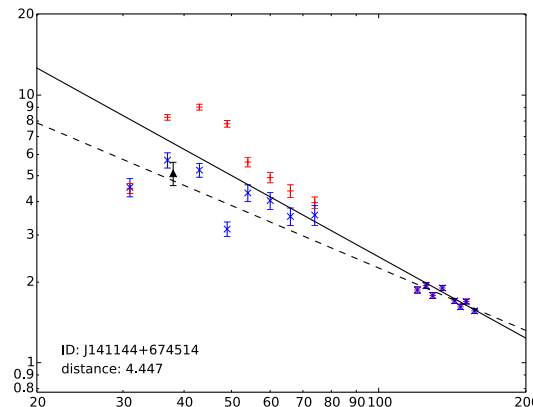
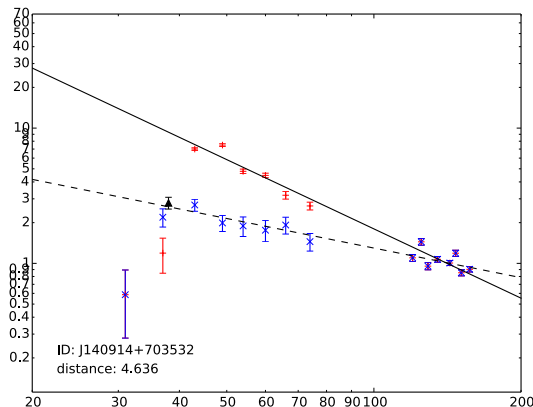
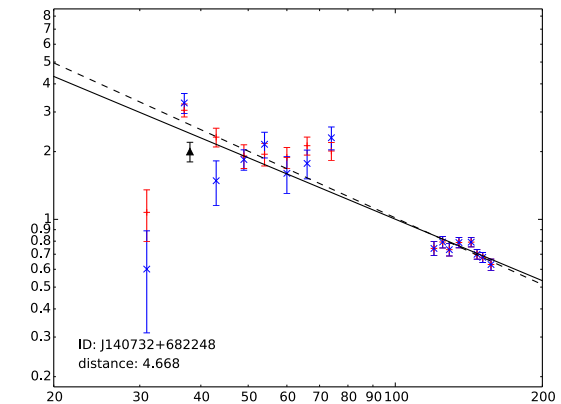
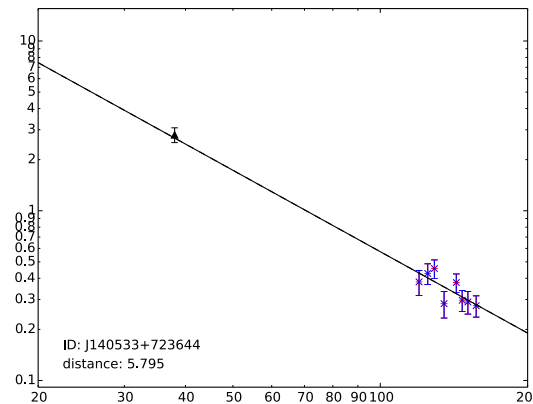
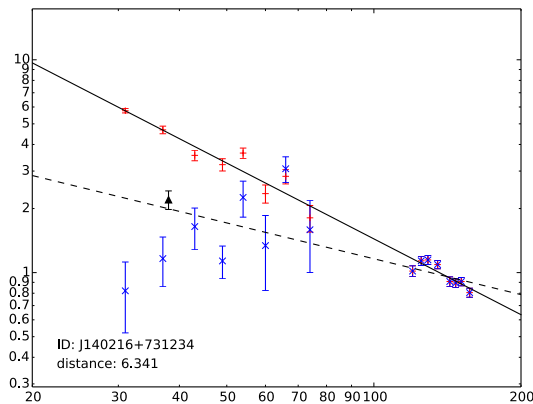


- HBA 11 mJy/beam, 2' resolution - 986 sources detected in all 8 bands!





- Currently focused on producing MVF mini-catalog for public release
- Catalog has  $\sim 48$  columns for points, 144 for extended sources;  $\sim 1.7$  MB - final catalog estimated  $\sim 350$  MB (VOTable  $\sim 2.5x$  larger)



- Outlines survey design & strategy, data handling, catalog creation

## The LOFAR Multifrequency Snapshot Sky Survey (MSSS)

### I. Survey description and first results

G. Heald<sup>1,2</sup>, R. Pizzo<sup>1</sup>, support scientists, contributing MSSS authors, active MSSS team, A. G. de Bruyn<sup>1,2</sup>, R. Nijboer<sup>1</sup>, M. Wise<sup>1</sup> and LOFAR Builders List

<sup>1</sup> Netherlands Institute for Radio Astronomy (ASTRON), Postbus 2, 7990 AA Dwingeloo, The Netherlands

<sup>2</sup> Kapteyn Astronomical Institute, University of Groningen, PO Box 800, 9700 AV, Groningen, The Netherlands

Preprint online version: December 16, 2013

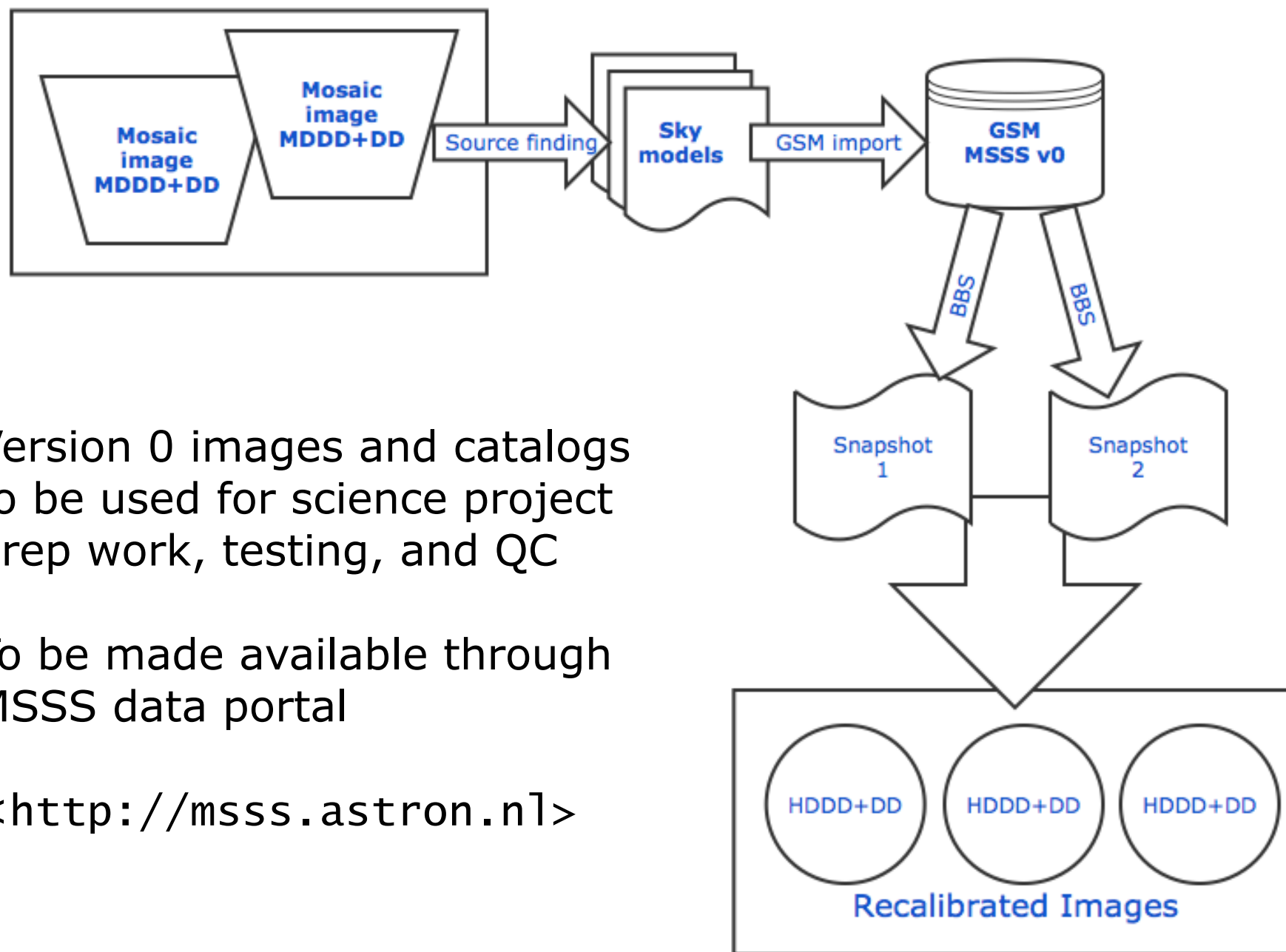
#### ABSTRACT

We present the Multifrequency Snapshot Sky Survey (MSSS), the first northern-sky LOFAR imaging survey. In this introductory paper, we first describe in detail the motivation and design of the survey. Compared to previous radio surveys, MSSS is exceptional due to its intrinsic multifrequency nature providing information about the spectral properties of the detected sources over more than two octaves (from 30 to 160 MHz). The broadband frequency coverage, together with the fast survey speed generated by LOFAR's multibeaming capabilities, make MSSS the first survey of the sort anticipated to be carried out with the forthcoming Square Kilometre Array (SKA). Two of the sixteen frequency bands included in the survey exactly overlap the frequency coverage of large-area Very Large Array (VLA) and Giant Metrewave Radio Telescope (GMRT) surveys at 74 MHz and 151 MHz respectively. The survey performance is illustrated within the "MSSS Verification Field" (MVF), a region of 100 square degrees centered at  $(\alpha, \delta)_{J2000} = (15^h, 69^\circ)$ . The MSSS results from the MVF are compared with previous radio survey catalogs. We assess the flux and astrometric uncertainties in the catalog, as well as the completeness and reliability considering our source finding strategy. Images and catalogs for the full survey will be released to a public web server. We outline the plans for the ongoing production of the final survey products, and the ultimate public release of images and source catalogs.

**Key words.** Surveys — Radio continuum: general

#### 1. Background

telescopes is the Low Frequency Array (LOFAR; van Haarlem et al. 2012) operating between 10 and 240 MHz. The array is



- Version 0 images and catalogs to be used for science project prep work, testing, and QC
- To be made available through MSSS data portal

`<http://msss.astron.nl>`


LOFAR Observation Database

msss.astron.nl

LOFAR Observation Database

# MSSS

This site marshalls information about interferometric data which has been recorded by LOFAR. Primarily, it aims to support the ongoing MSSS ("Multifrequency Snapshot Sky Survey") commissioning effort.



LOFAR  
ASTRON  
ASTRONOMICAL INSTITUTE  
ANTON PANNEKOEK

Image: LOFAR LBA, © Hans Hordijk

## Surveys

Data on the following surveys is available:

- [MSSS HBA](#)
- [MSSS LBA](#)

## Fields

4293 fields are being tracked.

[View details »](#)

## Observations

9540 separate observations are known.

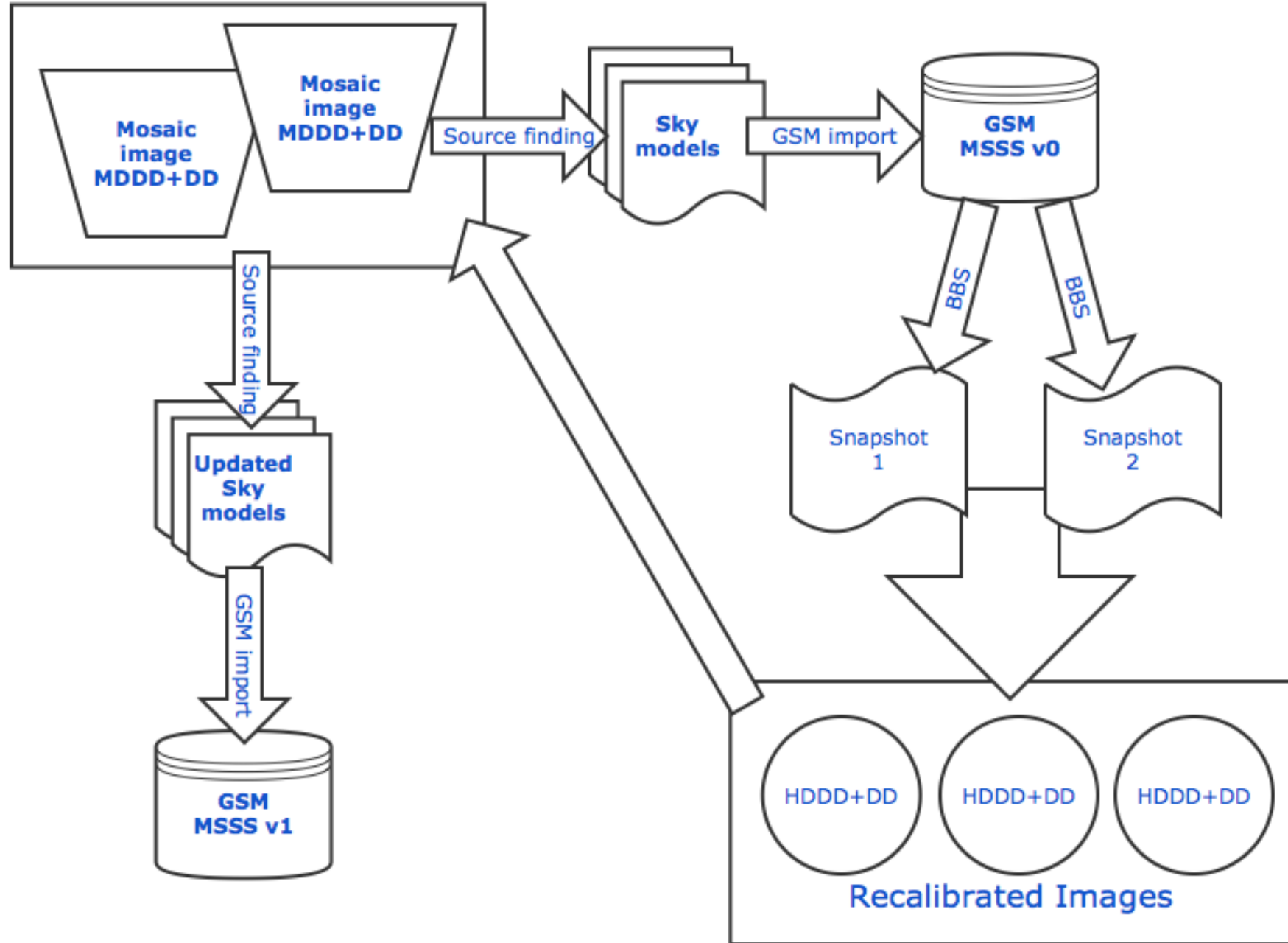
[View details »](#)

Or, jump straight to your data:

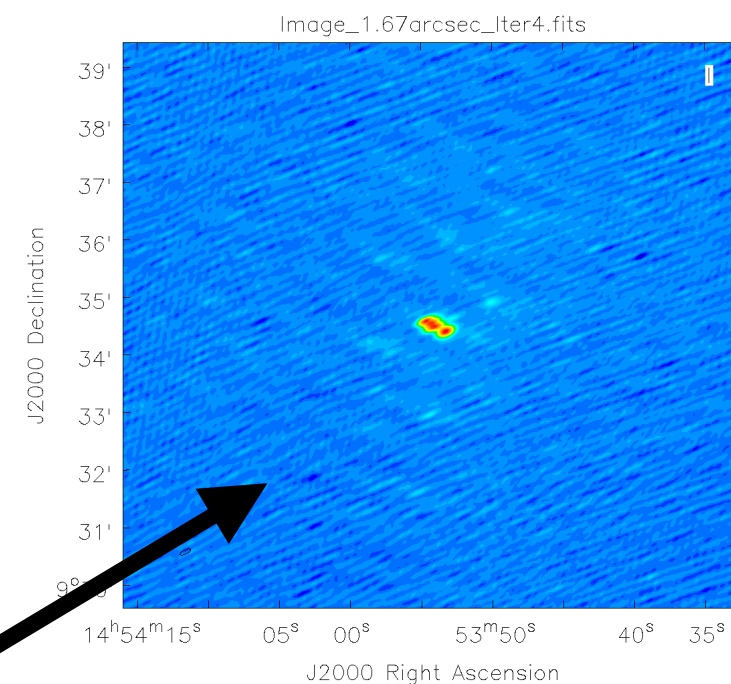
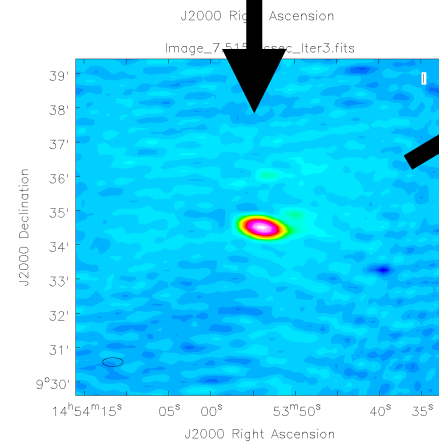
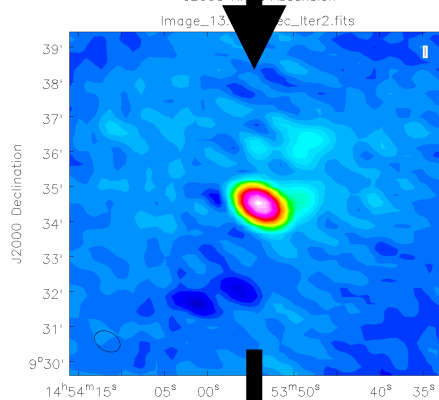
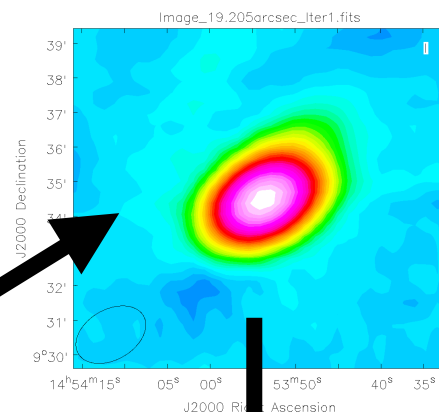
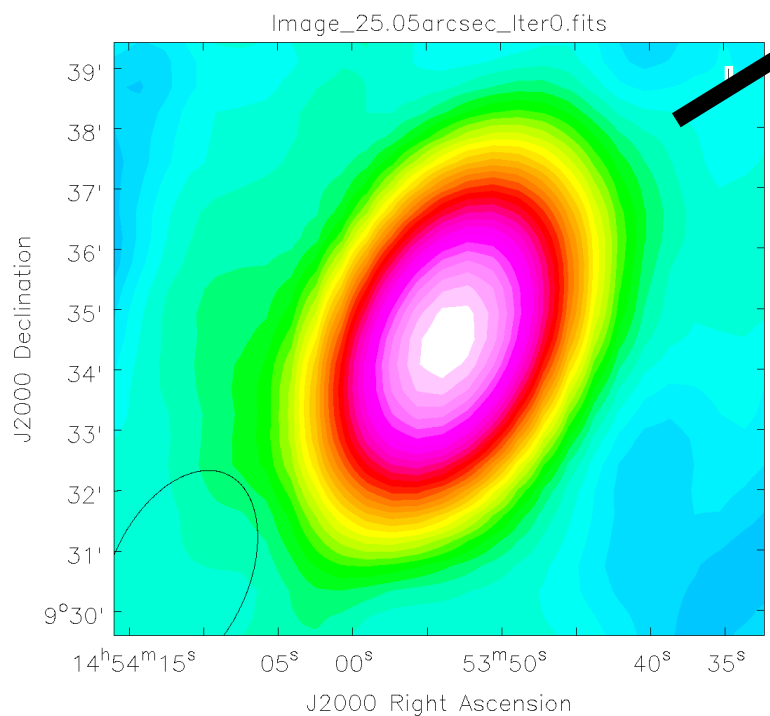
Any Survey Field Observation

Built by [John Swinbank](#). Code available on [GitHub](#). Feedback welcome.

<http://msss.astron.nl>



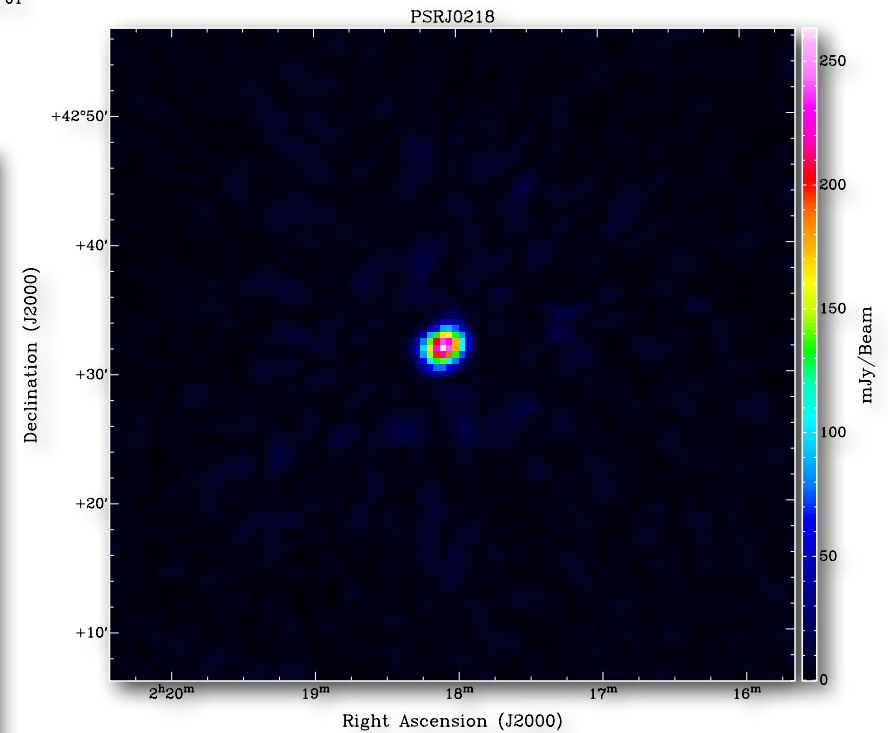
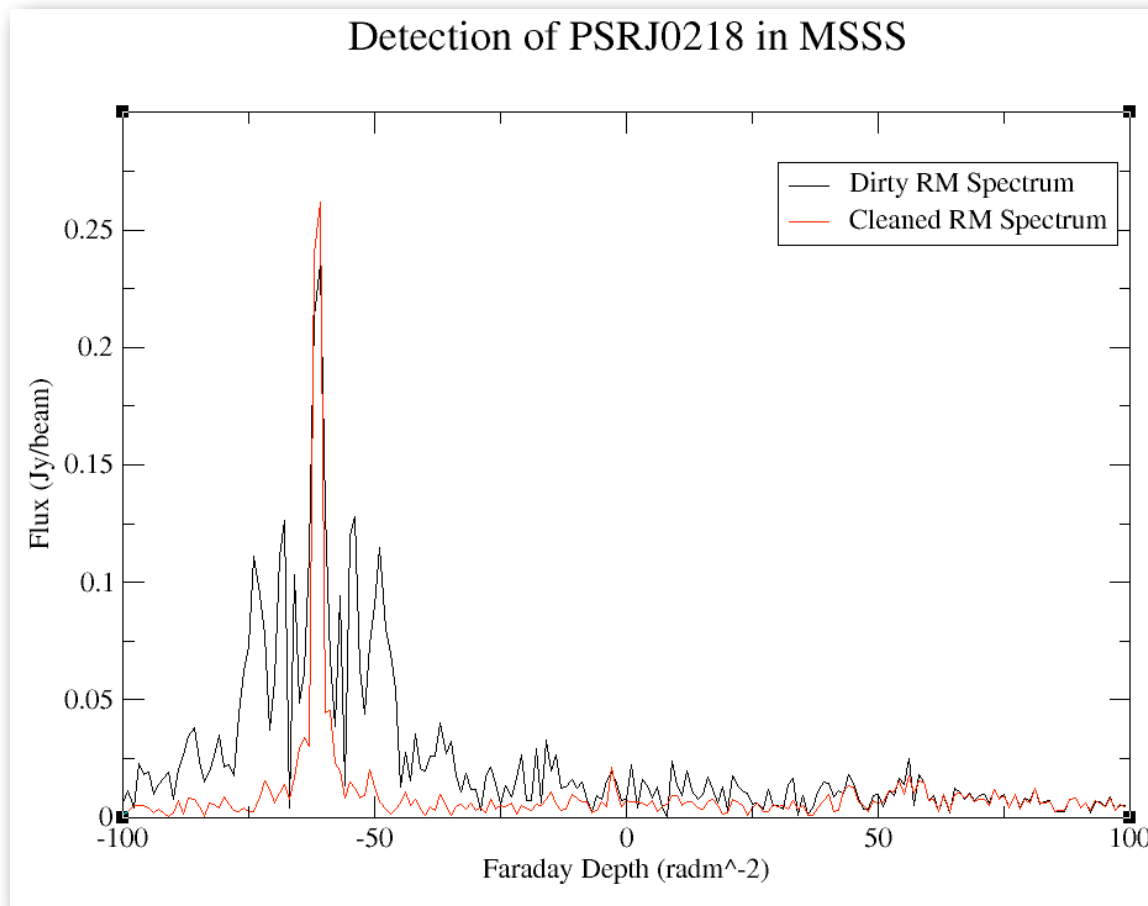
- Higher angular resolution



**McKean**  
**Using selfcal (Vilchez)**  
**See talk by Kokotanekov**

- Polarization imaging, e.g. PSR J0218 and diffuse Galactic emission
  - Detected with correct linear polarization fraction and RM

FARDEPTH:  $-6.100000e+01$



*Mulcahy*

- This week (Thursday & Friday)
- Topics:
  - **Technical**: survey design, calibration & imaging, source finding & catalog creation
  - **Strategy**: Setup of new LBA observations
  - **Extragalactic**: clusters, galaxies, GRG, LIRGs/ULIRGs, blazars
  - **Galactic**: pulsars, SNRs, PWN, brown dwarfs + more
  - **Added value**: related surveys, enhanced processing
  - **Data products**: Accessibility & VO
  - **Discussion sessions**: data access, publication policy, etc
    - Summaries to be posted on MSSS wiki