

# LOFAR imaging surveys

## LOFAR Multifrequency Snapshot Sky Survey (MSSS) and beyond

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CSIRO ASTRONOMY AND SPACE SCIENCE  
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## Outline

- MSSS motivation & setup
- MSSS results & data releases
- Forthcoming & ongoing LOFAR survey efforts



# LOFAR MSSS

## Multifrequency Snapshot Sky Survey

# MSSS: LOFAR's first imaging survey

## MSSS-LBA



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

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

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

Area: 20,000 square degrees

**Number of Fields: 660**

Simultaneous  $\sim 10^\circ$  beams: 5

Test observations continue

## MSSS-HBA



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

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

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

Area: 20,000 square degrees

**Number of Fields: 3616**

Simultaneous  $\sim 4^\circ$  beams: 6

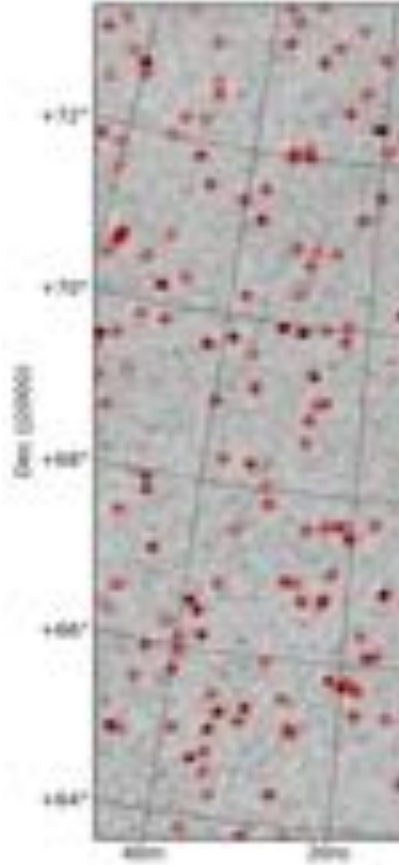
First large-area public catalog in prep

# Thanks to the MSSS team!

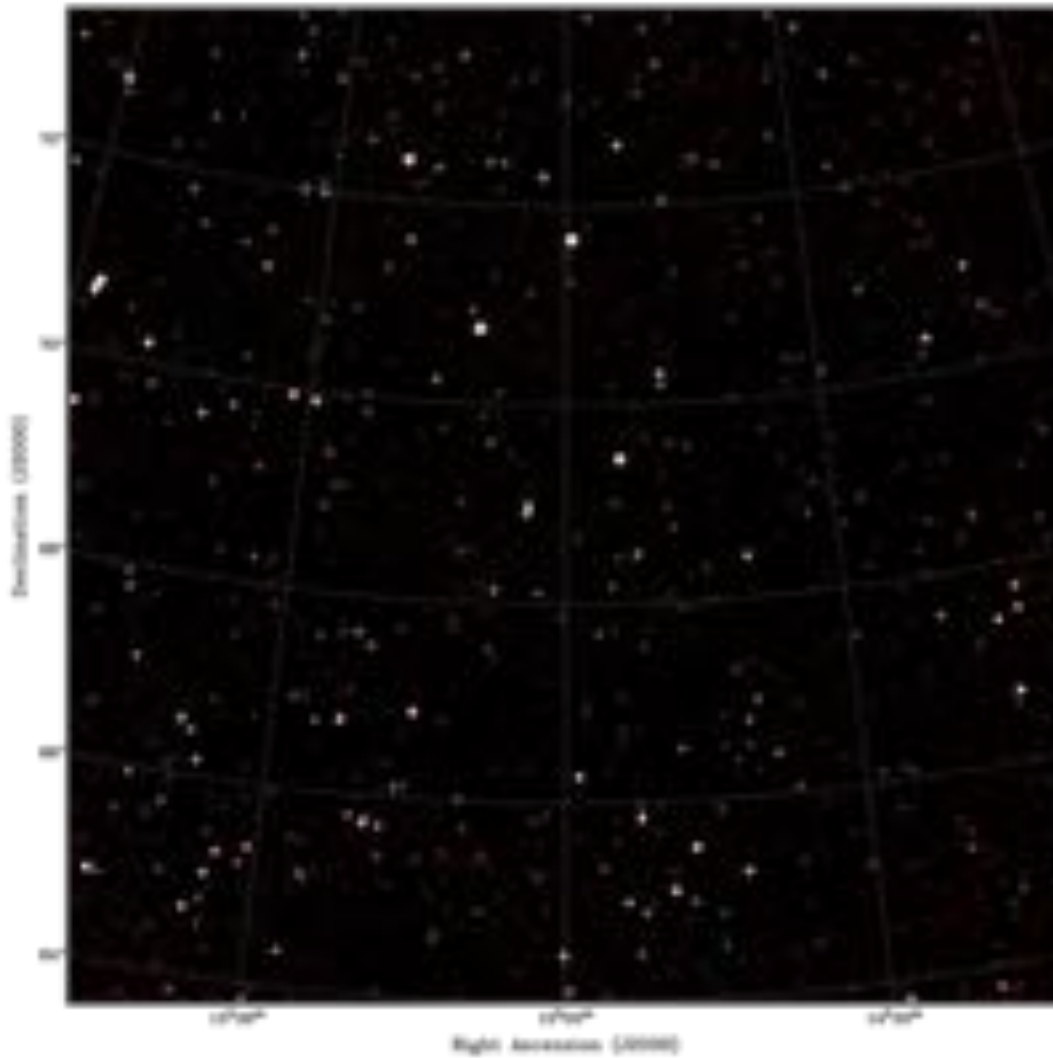
Björn Adebahr, Mike Bell, Laura Bîrzan, Annalisa Bonafede, Justin Bray, Rene Breton, Jess Broderick, Ger de Bruyn, Therese Cantwell, Dario Carbone, Patti Carroll, Yvette Cendes, Alex Clarke, Judith Croston, Soobash Daiboo, Francesco De Gasperin, Emilio Enriquez, Richard Fallows, Chiara Ferrari, Jon Gregson, 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, Luke Pratley, 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



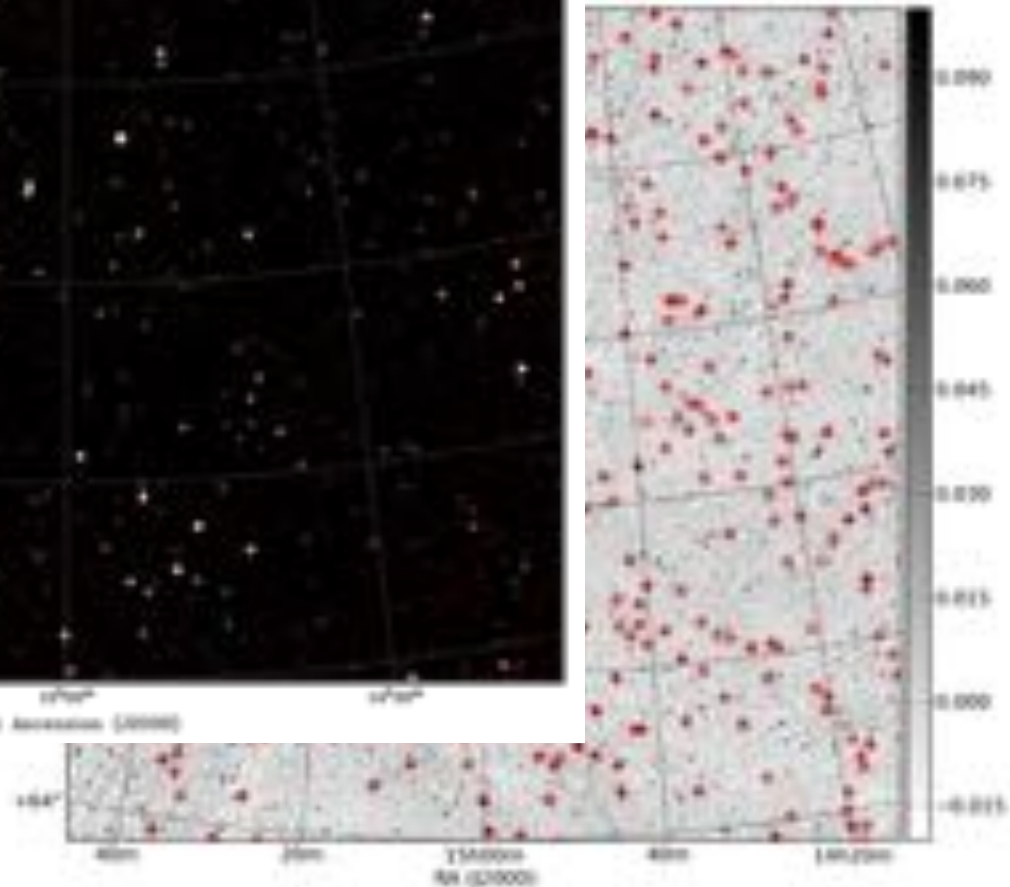
# MSSS Verification Field



LBA  
Ionospheric cor



HBA mosaic



# MSSS Verification Field

- Survey overview published in A&A (2015, A&A 582, 123)
- Key facts & figures:
  - Verification field of 100 square degrees, ~1200 sources
  - HBA completeness 100 mJy
  - LBA completeness 550 mJy
  - ~2' resolution
  - >100,000 sources in full catalog

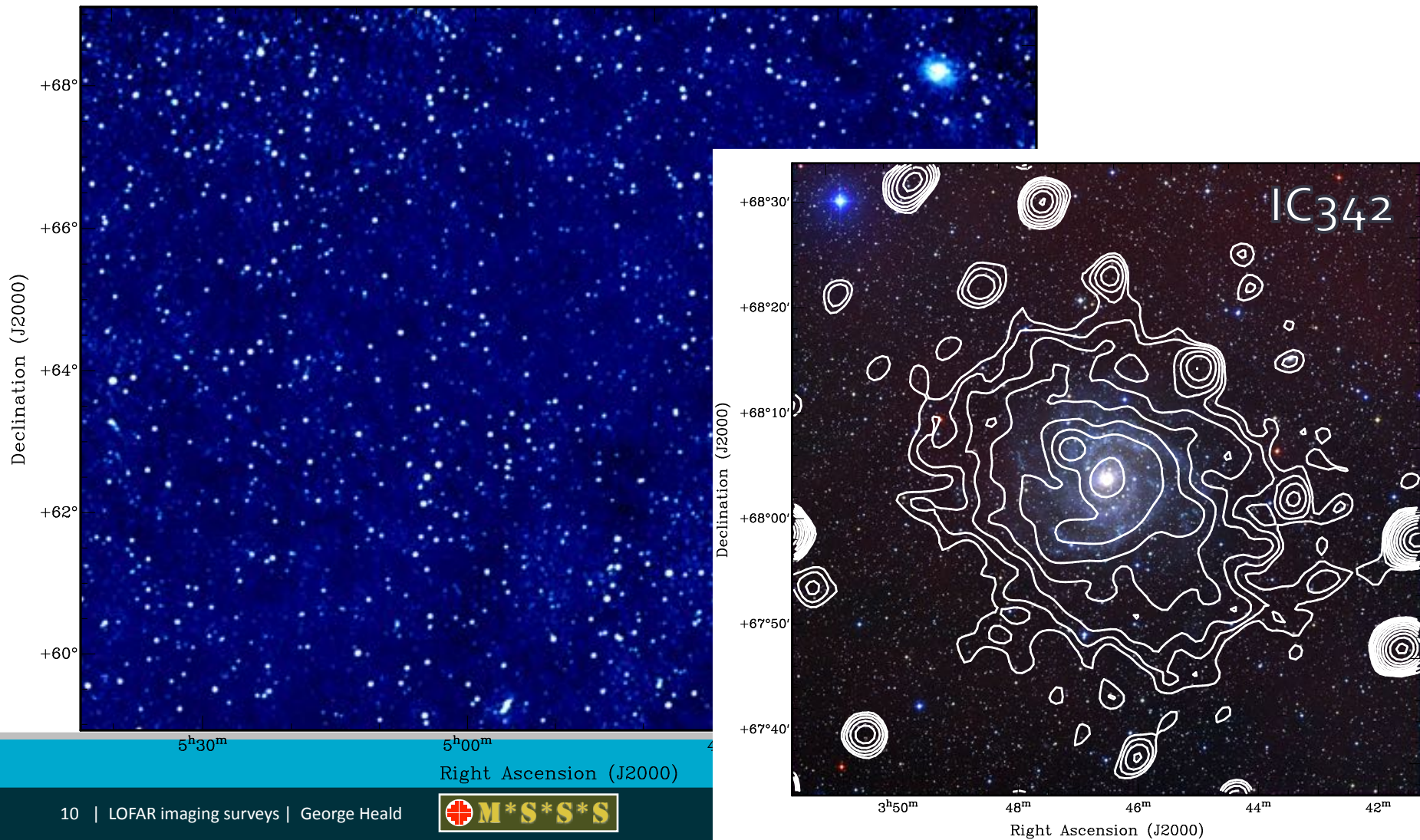






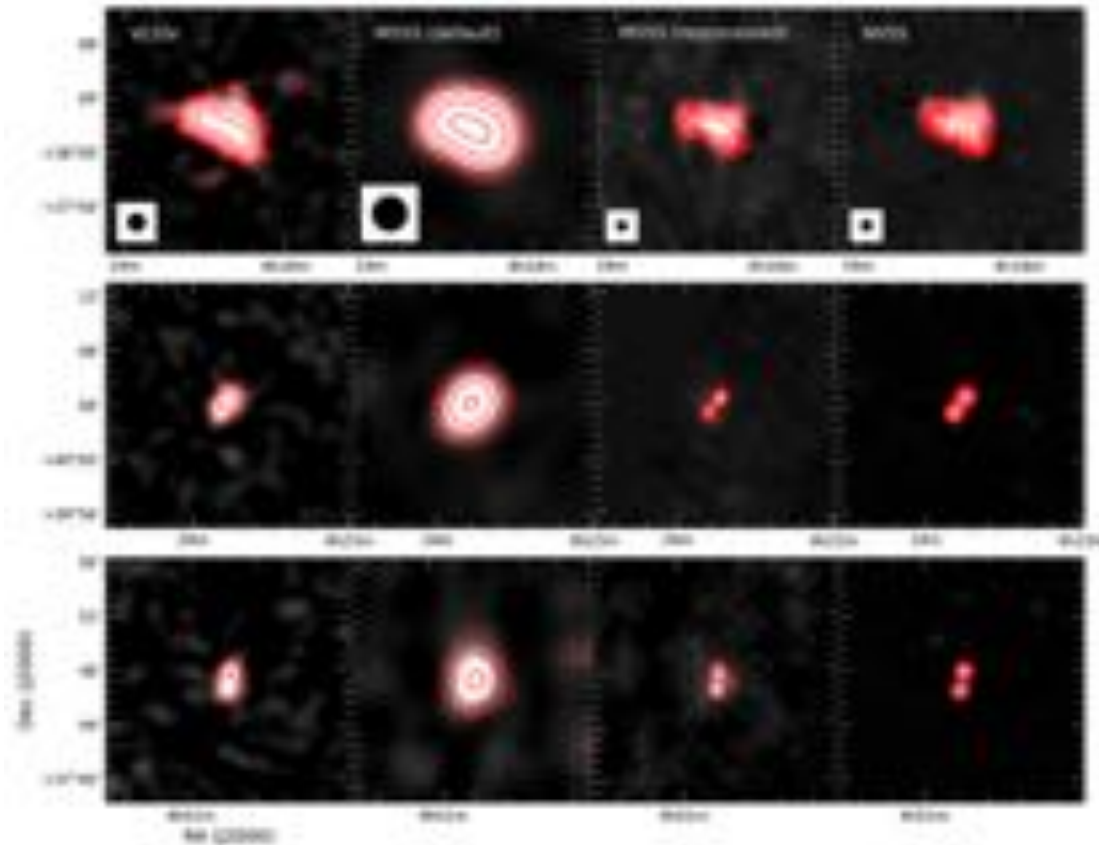
# MSSS mosaics

- Standard imaging product: 100 square degree mosaics, each composed of 10s of individual HBA fields



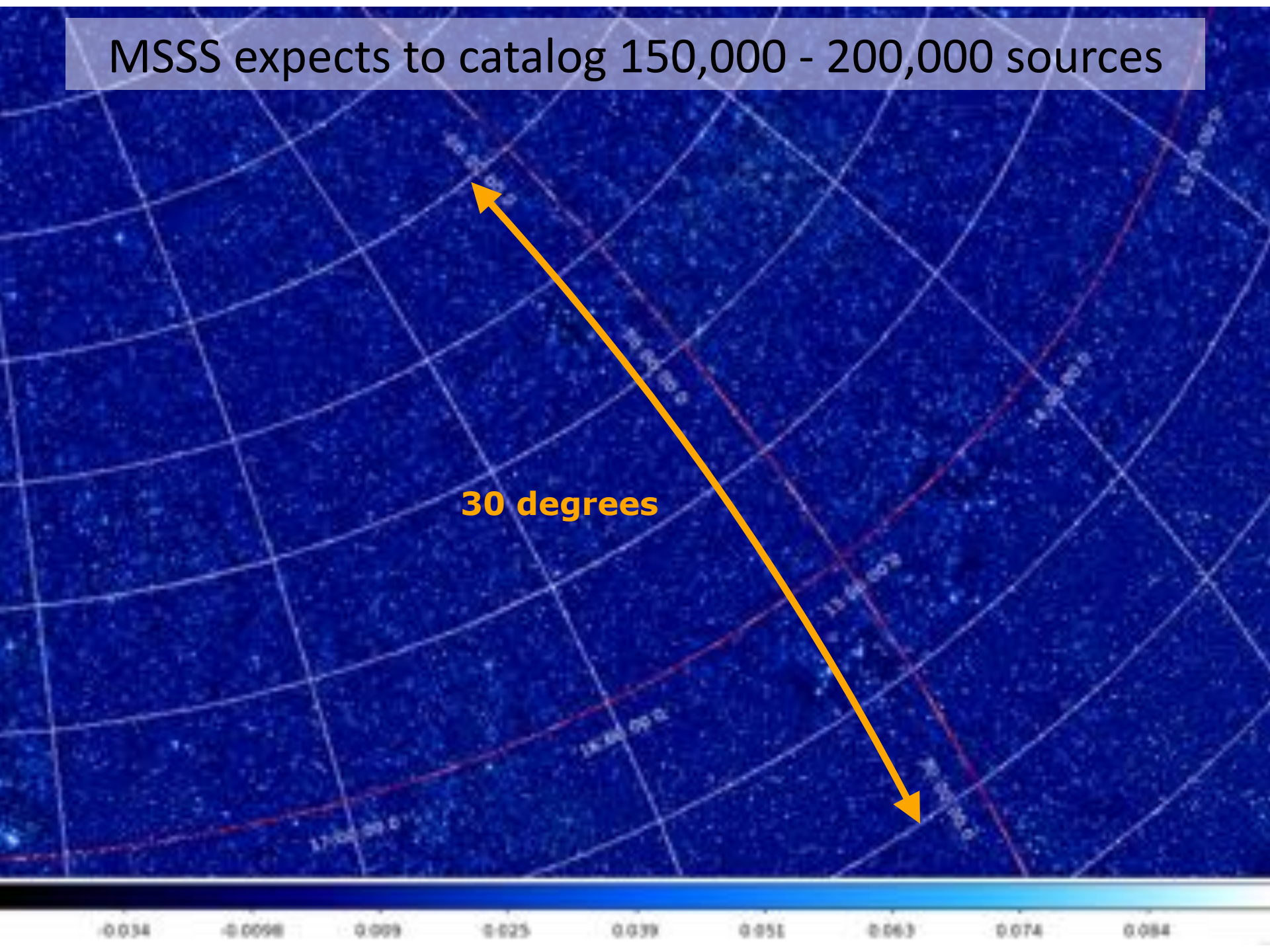
# MSSS at higher resolution (target v2)

- All Dutch station baselines included in MSSS-HBA observations
- Imaging at 20-30'' resolution feasible with modest computing



- Planned for v2 catalog - updated pipeline in development

MSSS expects to catalog 150,000 - 200,000 sources



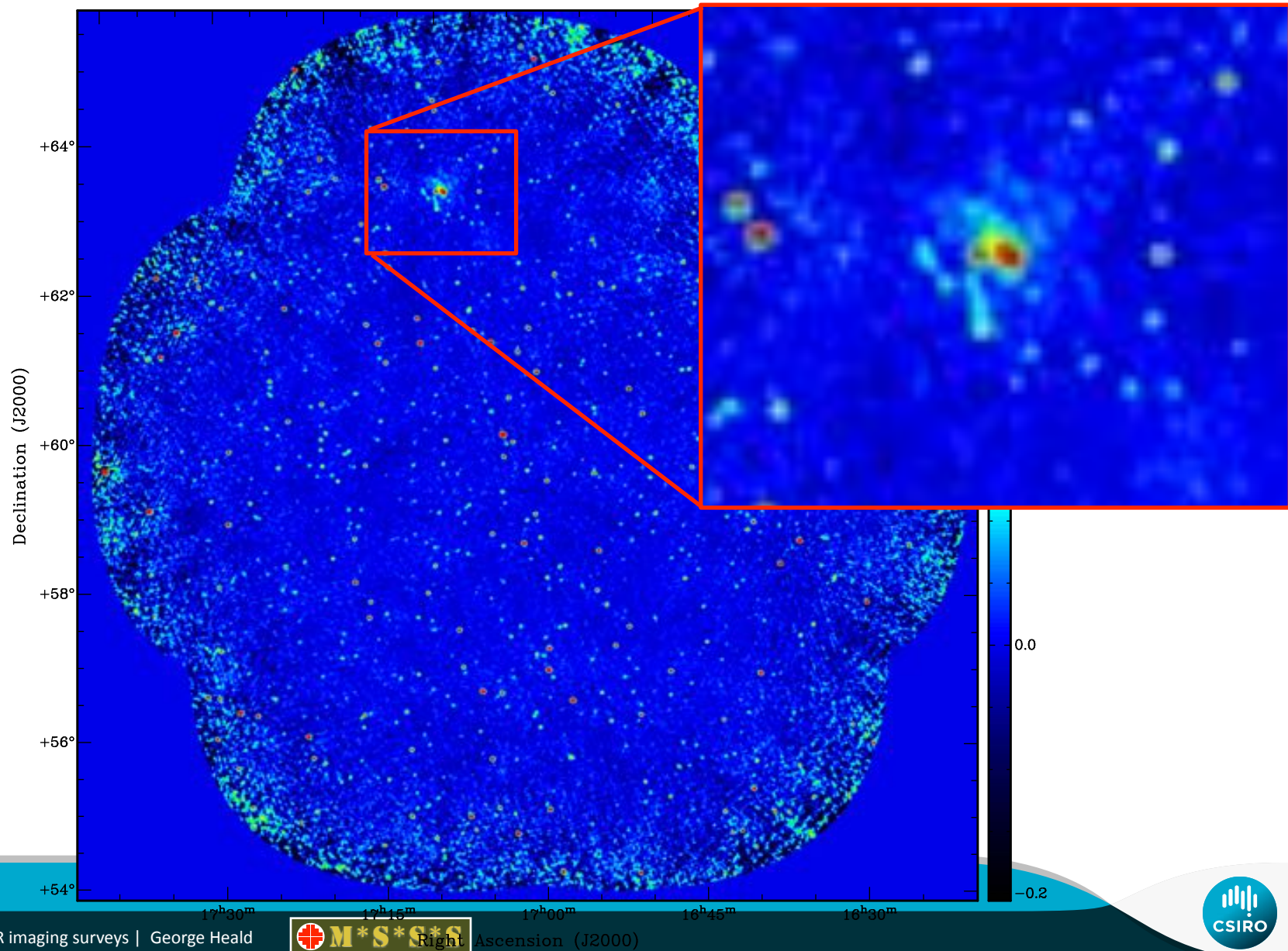
**30 degrees**

-0.034 -0.0098 0.009 0.025 0.039 0.051 0.063 0.074 0.084

# Science from MSSS

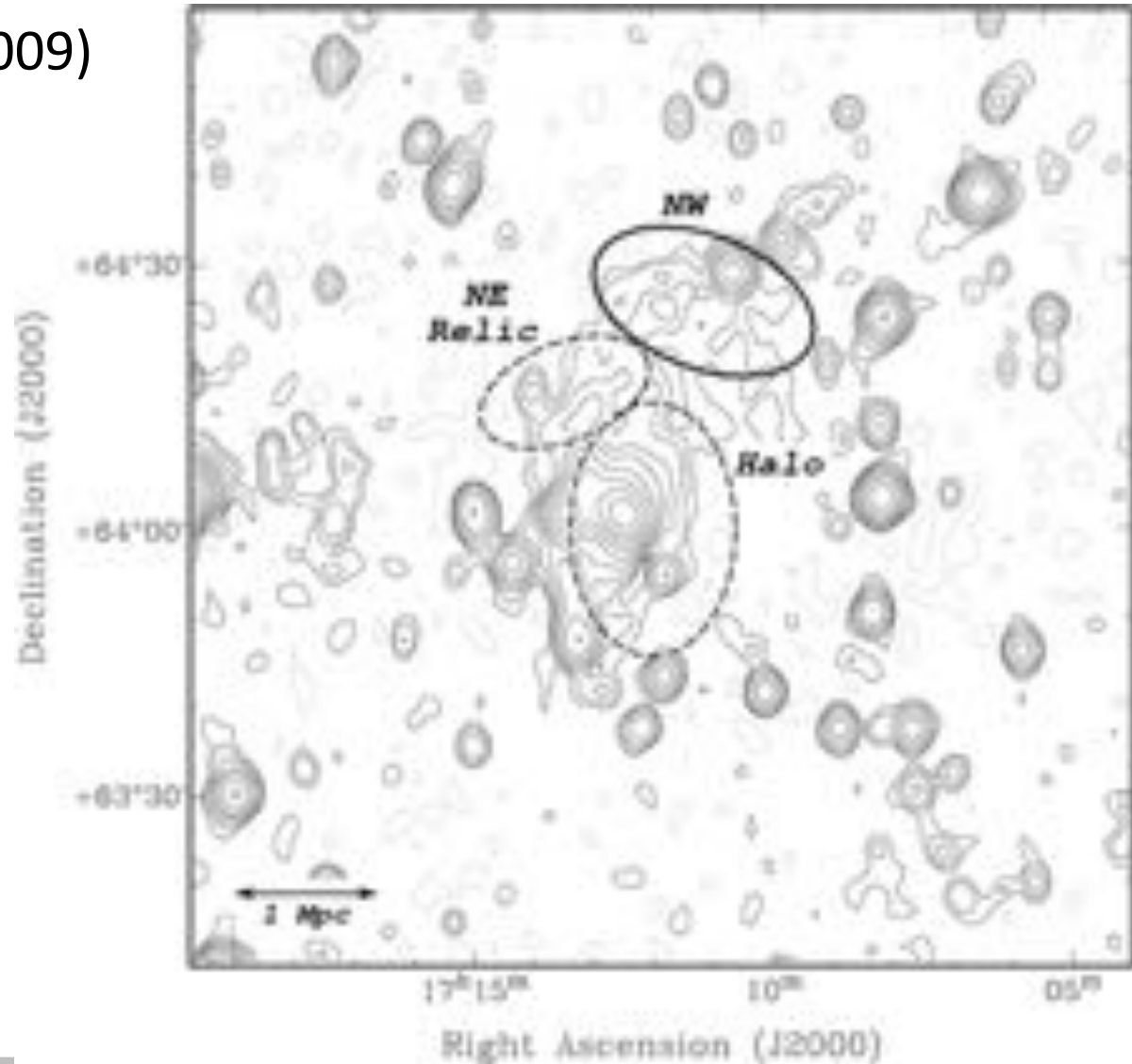
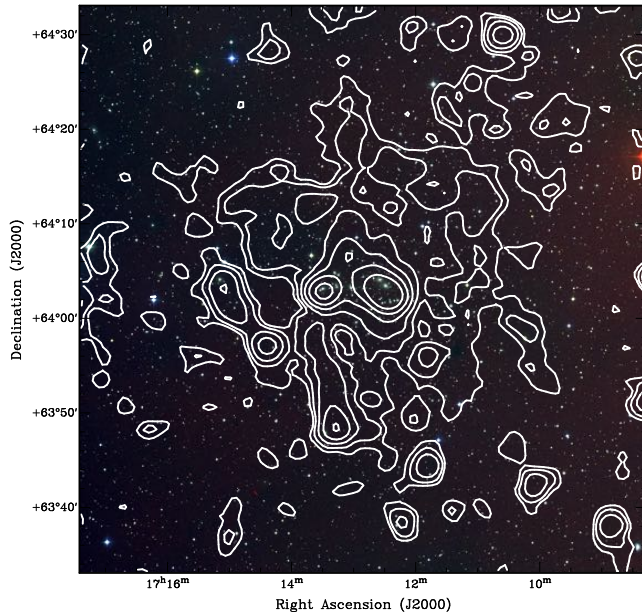
Some highlights

# An early MSSS mosaic

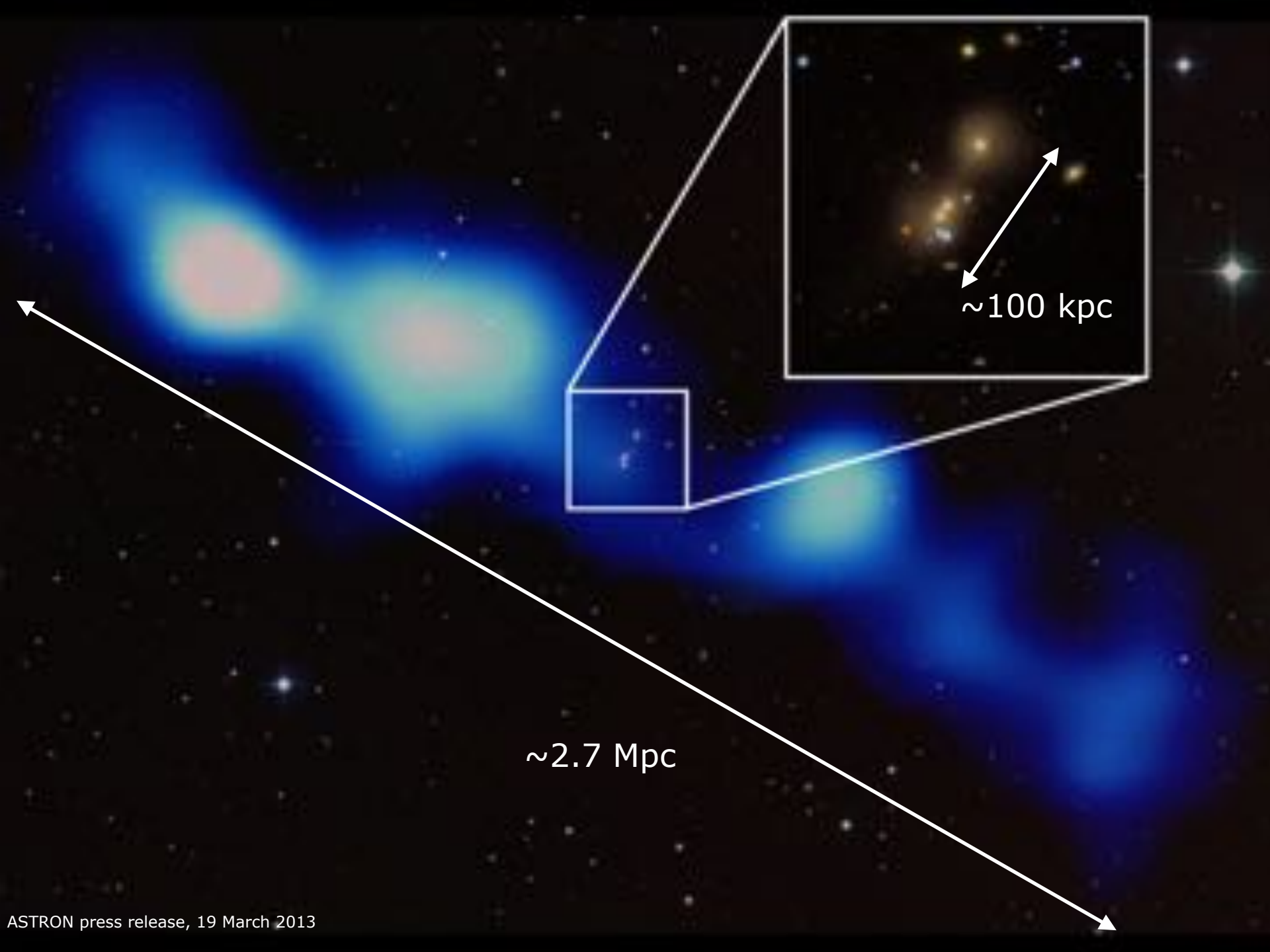


# MSSS-HBA: Abell 2255

- cf Pizzo & de Bruyn (2009)  
WSRT, 150 MHz



MSSS-HBA: 14 min!



$\sim 100$  kpc

$\sim 2.7$  Mpc



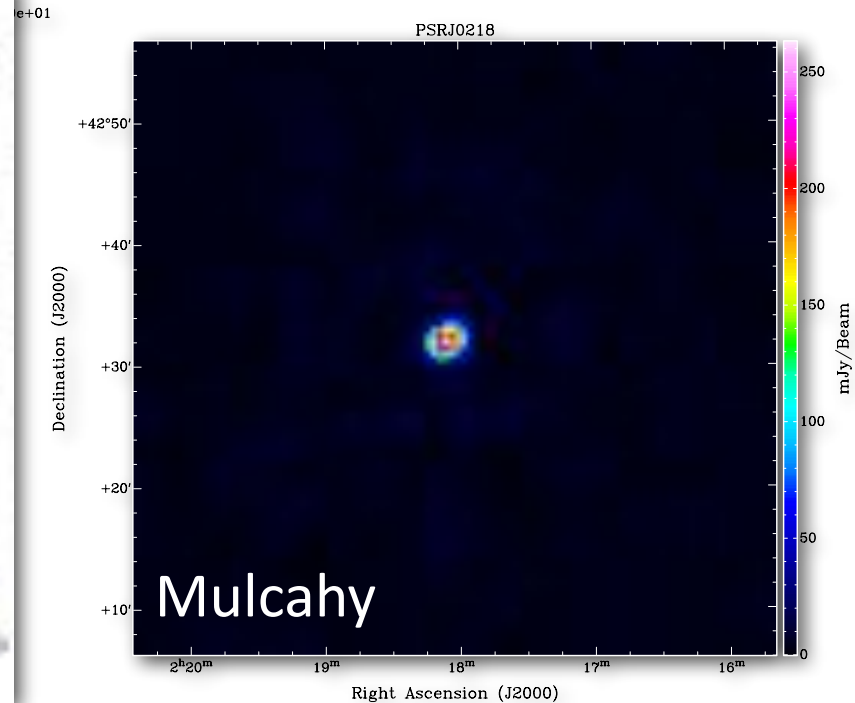
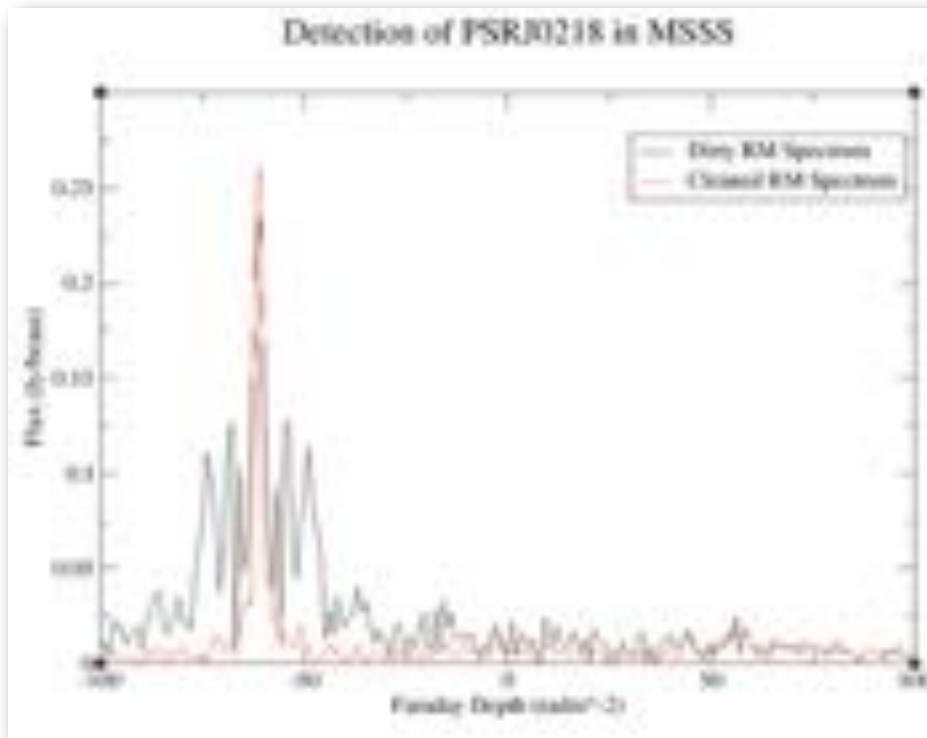


“Great MSSS Supernova Remnant Hunt”

Mulcahy et al

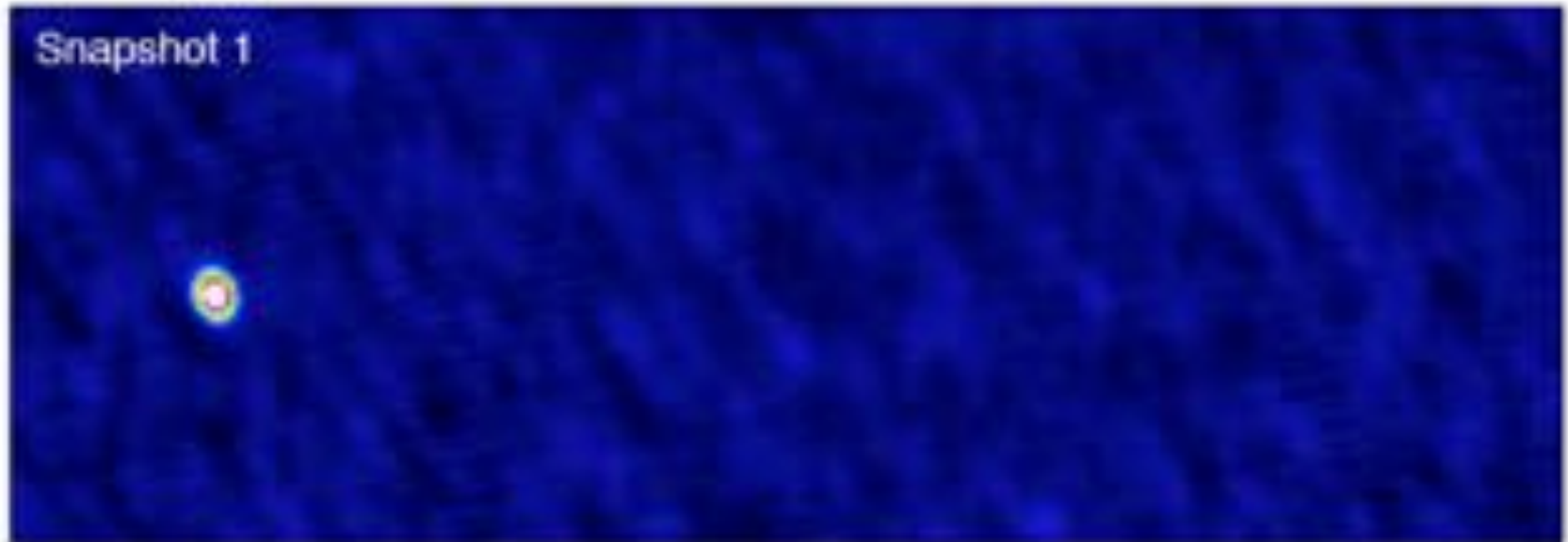
# MSSS-HBA polarization

- Polarized pulsars (e.g. PSRJ0218) detected with MSSS image data
- This case: 51% polarized, and with correct RM of  $-61 \text{ rad m}^{-2}$  (ionospheric RM correction was applied to the data)
- Diffuse (MW foreground) polarization imaging also ongoing



# MSSS Transients

- In MSSS-LBA, 1 subband always on NCP (200 kHz bw at 60 MHz)
- In both MSSS-LBA and MSSS-HBA, multiple epochs (9 & 2 resp.)



- First MSSS-LBA transient (Stewart et al 2016, MNRAS 456, 2321)
- Appears in one 11-min snapshot, flux density 15-25 Jy beam<sup>-1</sup>
- Implied rate for  $\Delta t \sim 10$  min is  $3.9 (+14.7, -3.7) \times 10^{-4} \text{ day}^{-1} \text{ deg}^{-2}$  (~8 transients of this nature per hemisphere per day!)

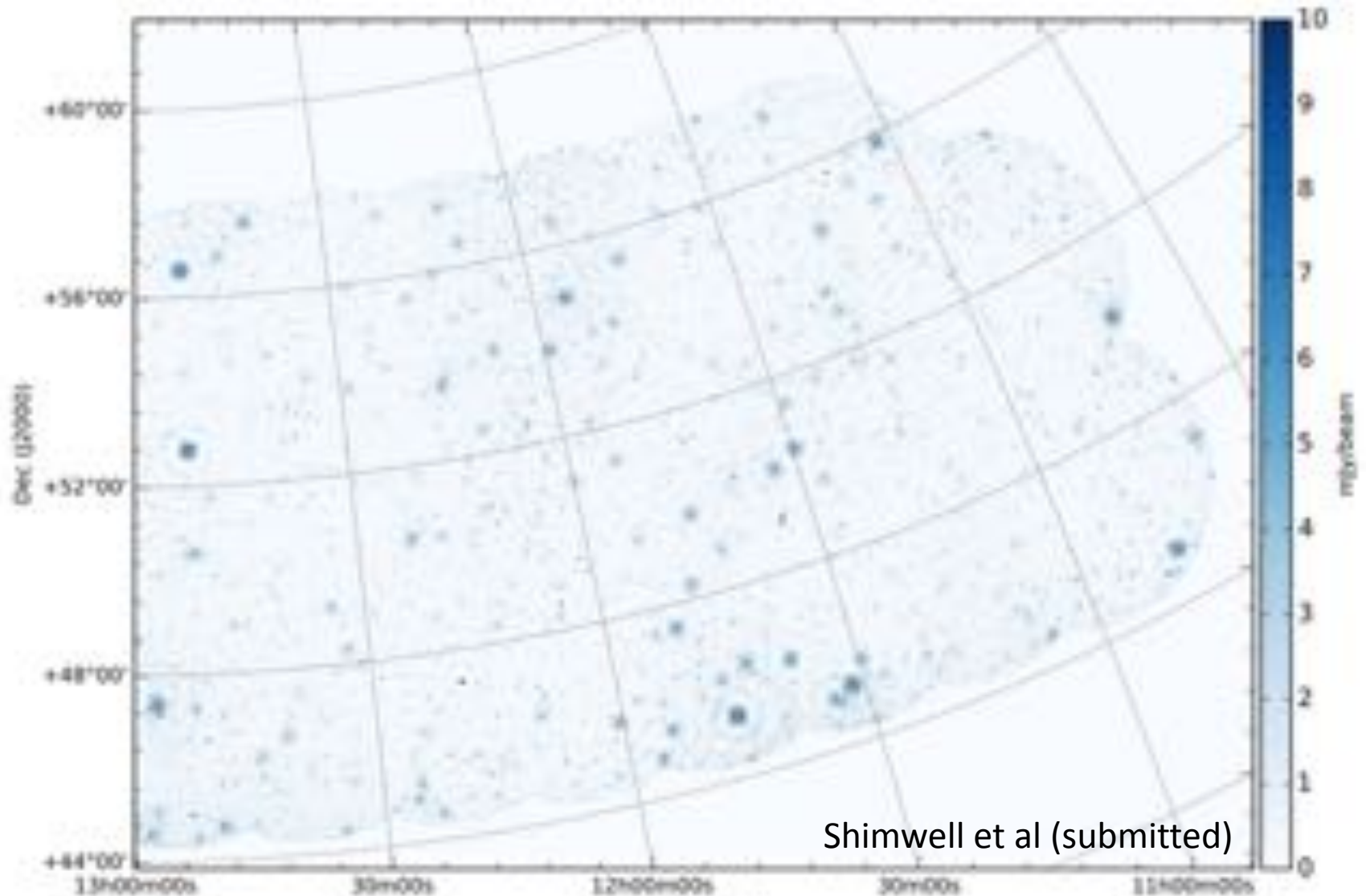
# Further LOFAR surveys

To arcsecond resolution and beyond!

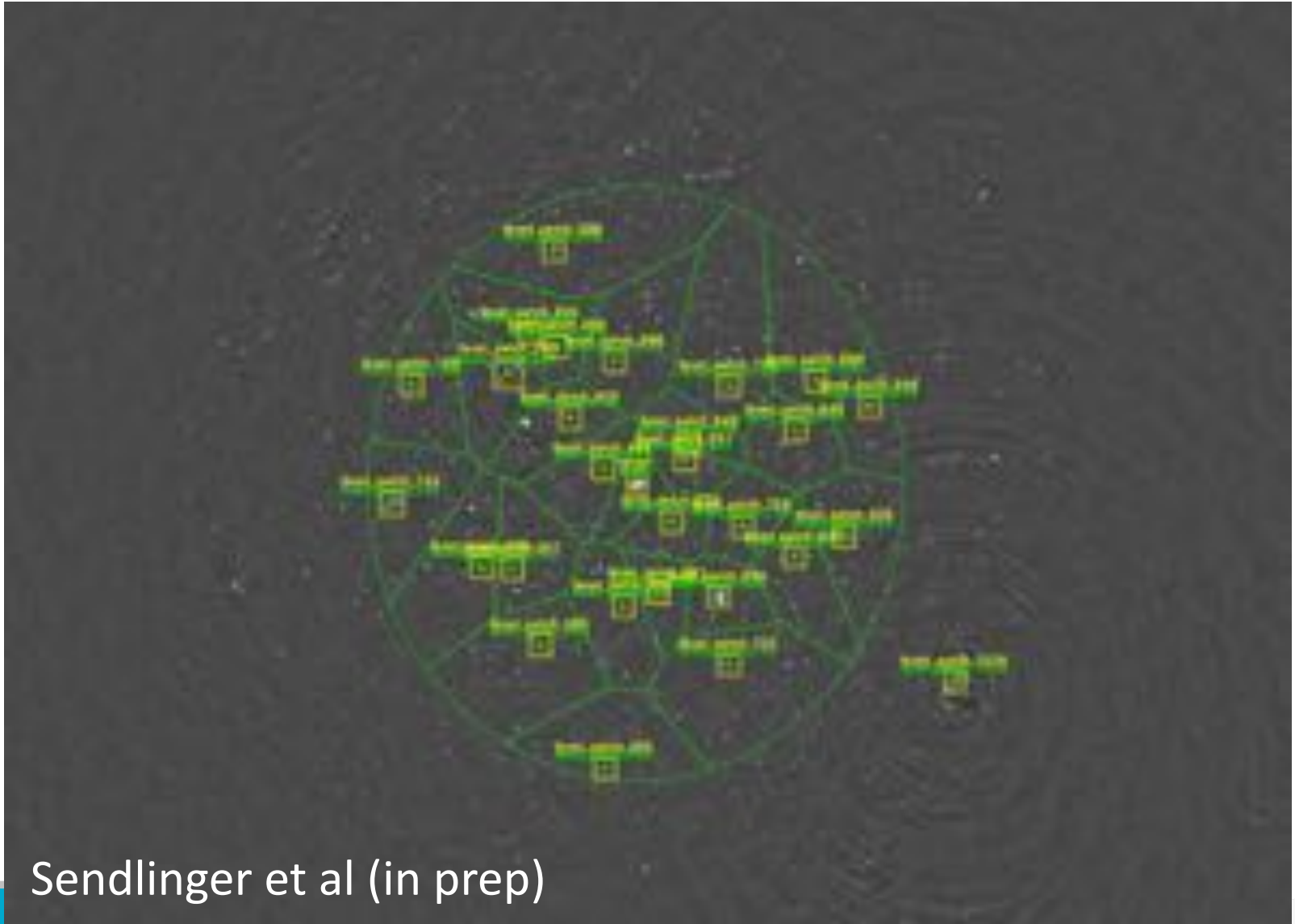


# LoTSS: Direction independent survey products

- After robust initial processing stage, image products with typical resolution of 25" and sensitivity of 0.5 mJy/beam are reached

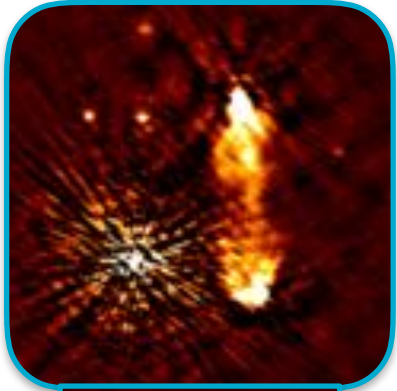


# Direction dependent calibration: Factor



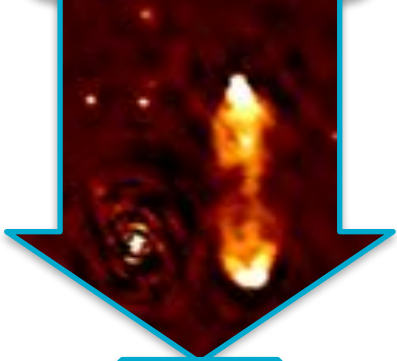
Sendlinger et al (in prep)

# Direction dependent calibration: Factor



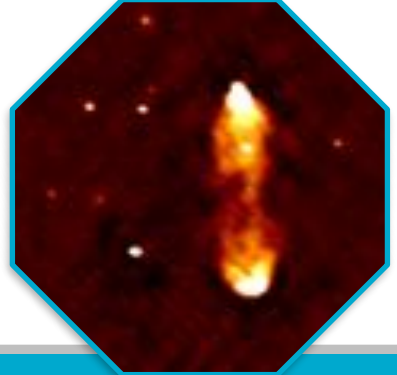
## Step 0:

Begin with direction-independent data per facet



## Step 1:

Solve and correct ionosphere (fast phase selfcal)



## Step 2:

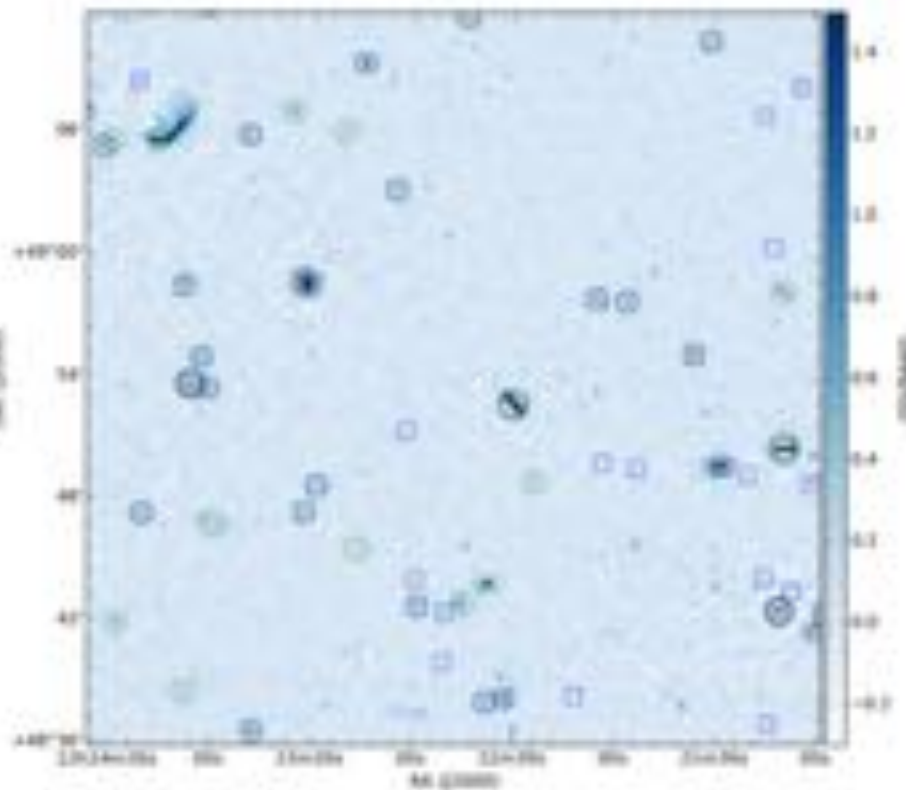
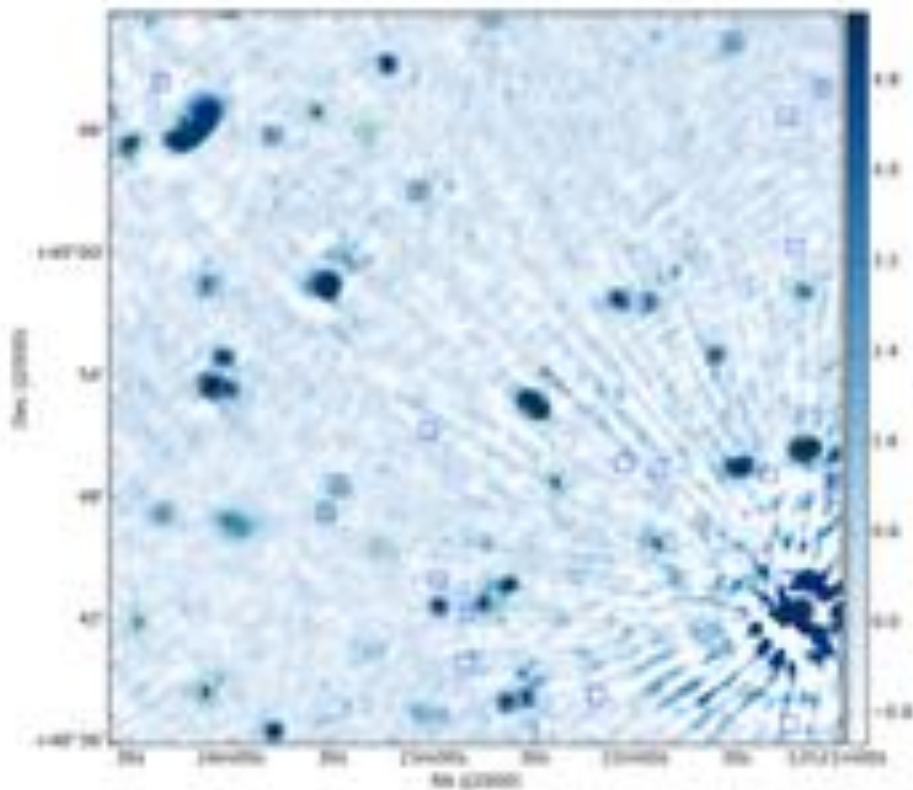
Solve and correct beam errors (slow amp selfcal)



# LoTSS: direction dependent survey products

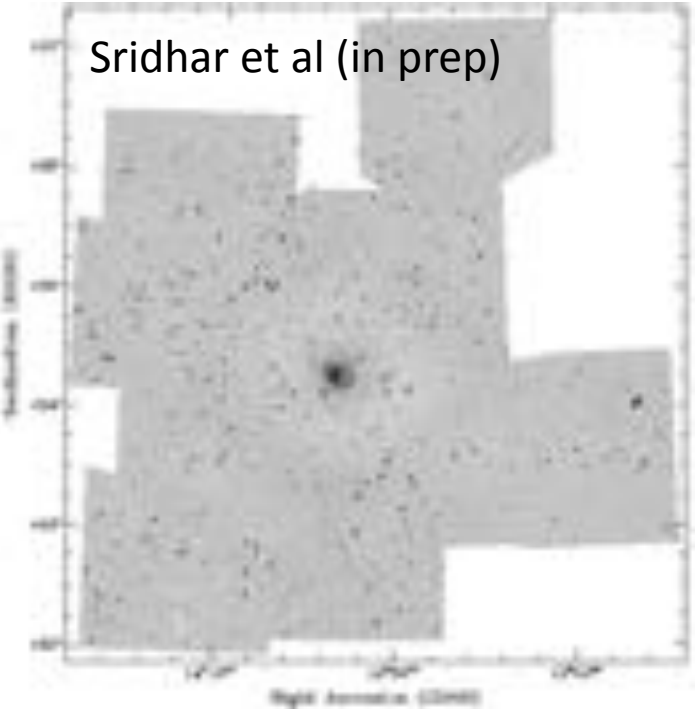
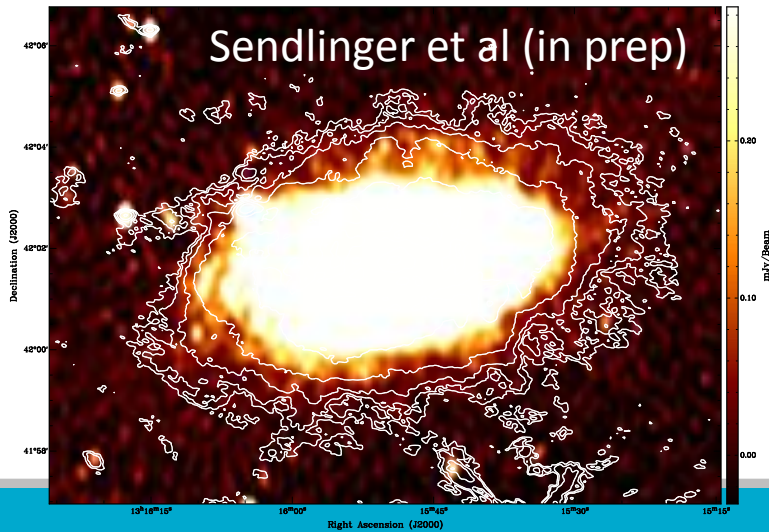
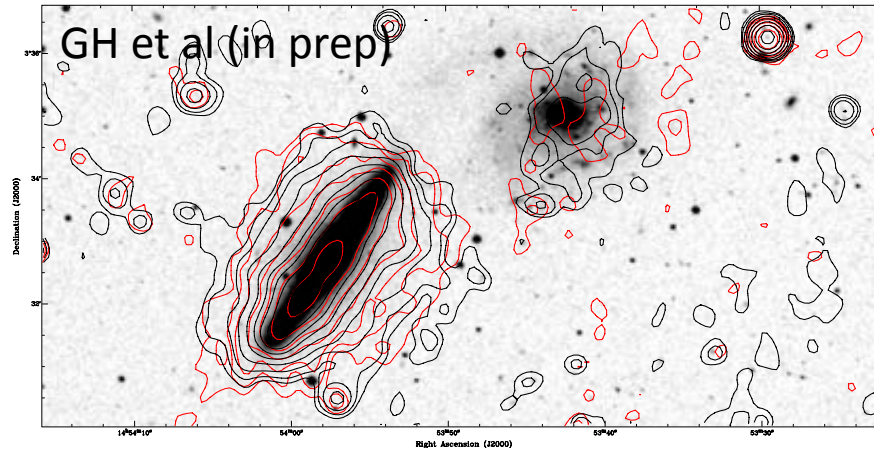
- After Factor, typical improvement:
  - 25"  $\rightarrow$  5-10"
  - 0.5 mJy/beam  $\rightarrow$  0.1 mJy/beam

Shimwell et al (submitted)



# Single objects with Factor

- Individual targets and fields are being studied with these techniques in the leadup to LoTSS (DD):



Deep fields  
... see Elizabeth Mahony's  
presentation tomorrow!



# Final remarks

- LOFAR survey work proceeding well on all angular scales (arcminute to sub-arcsecond)
- MSSS data release slated for this year
- Techniques being developed are well suited for application to forthcoming MWA long baselines, and SKA1-LOW

# Thank you

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