ASTRON

Netherlands Institute for Radio Astronomy

LOFAR Imaging Surveys

MSSS and Beyond

M*S*S*S

MULTIFREQUENCY SNAPSHOT SKY SURVEY

George Heald (MSSS Project Leader)

Science at Low Frequencies II

3 December 2015

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

Outline

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

MSSS: LOFAR's first imaging survey

Goals: obtain broadband sky model, shakedown LOFAR operations

MSSS-LBA

Frequency: 30-75 MHz
(8 x 2 MHz bands)
Resolution: ≤100 arcsec
Sensitivity: ≤15 mJy/beam
Area: 20,000 square degrees
Number of Fields: 660
Simultaneous ~10° beams: 5
Test observations resuming

MSSS-HBA

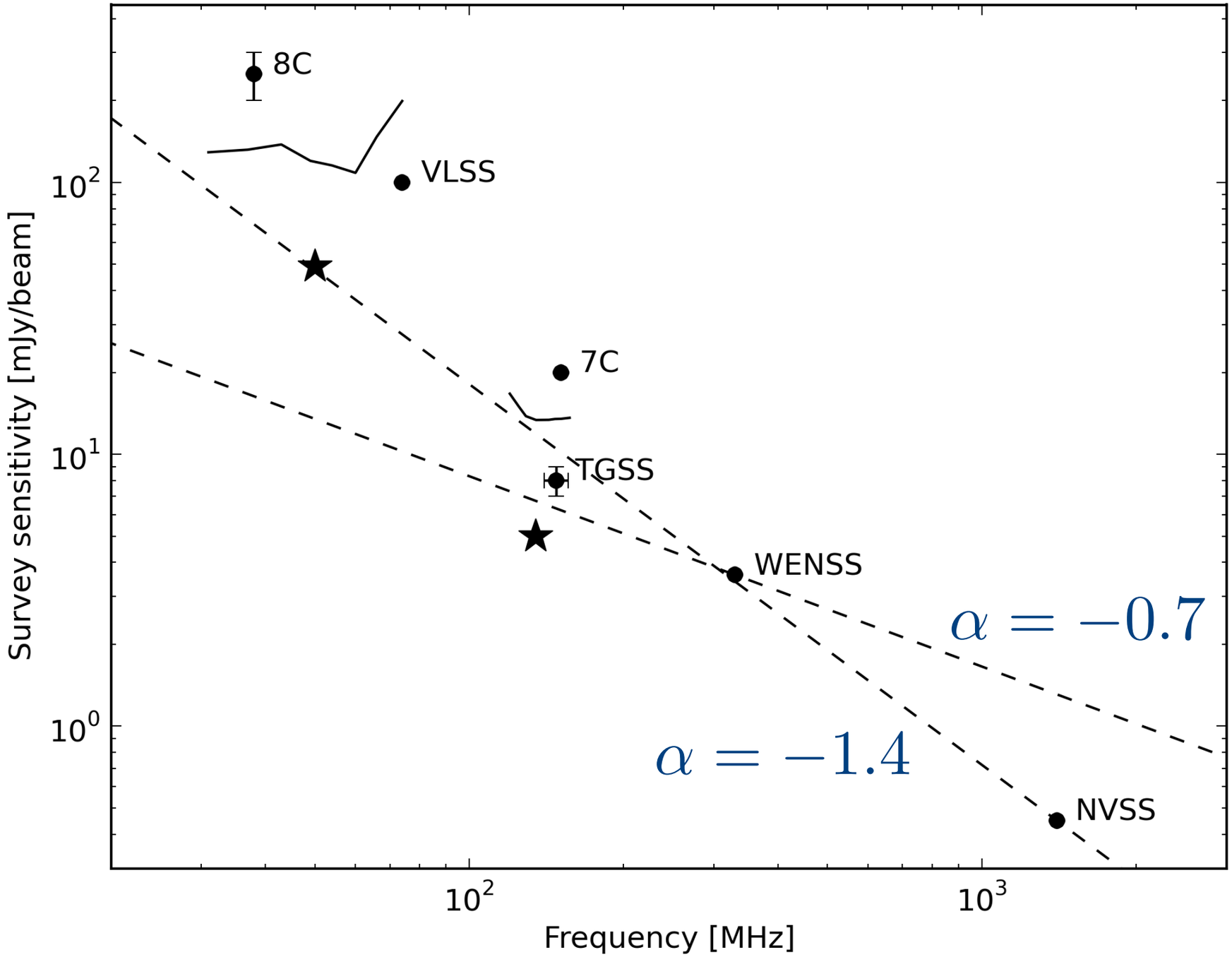
Frequency: 120-160 MHz
(8 x 2 MHz bands)
Resolution: ≤120 arcsec
Sensitivity: ≤5 mJy/beam
Area: 20,000 square degrees
Number of Fields: 3616
Simultaneous ~4° beams: 6
Observations 100% complete

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

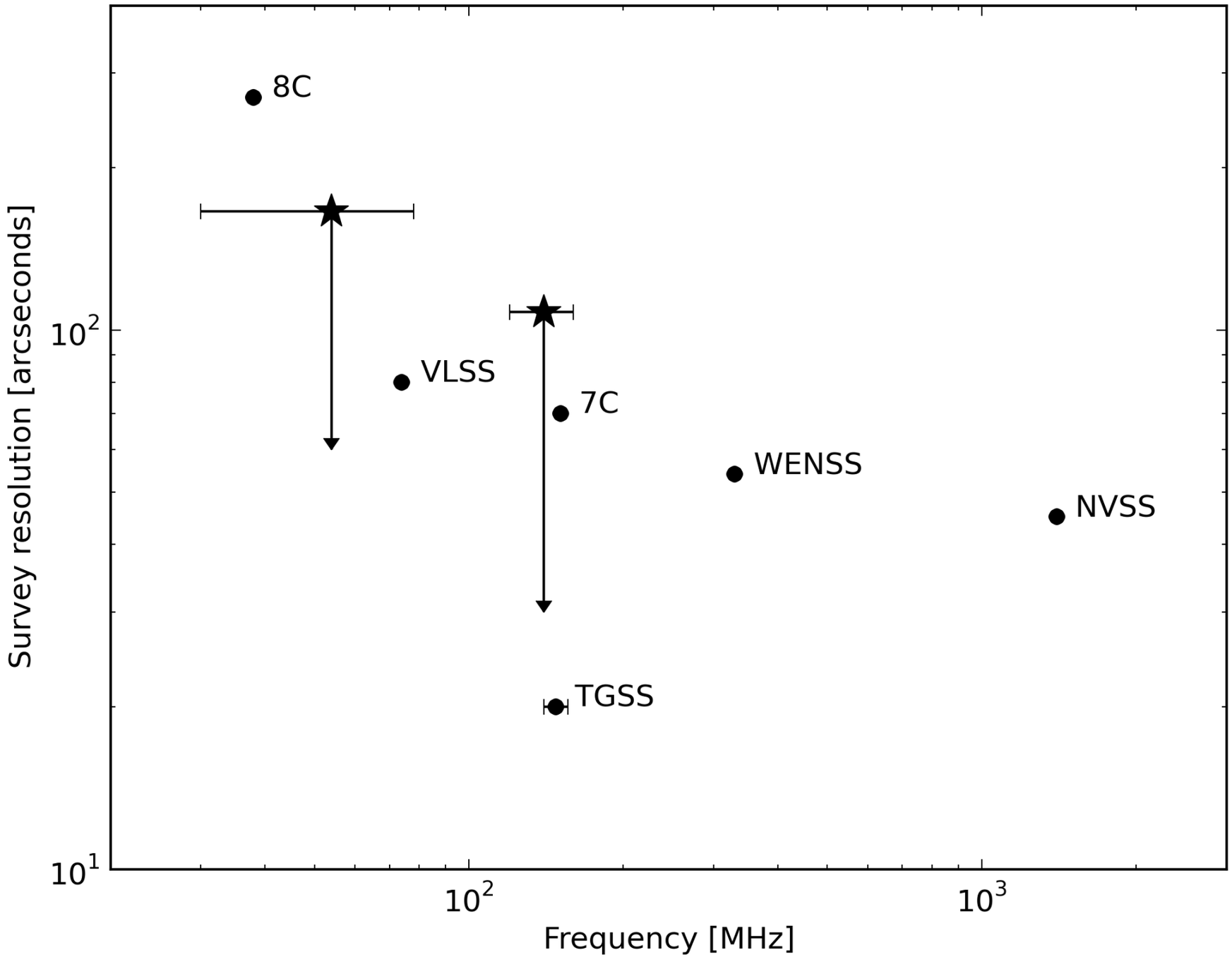
MSSS vital stats

- Highly complementary to MWA's GLEAM: together these surveys will provide a truly all-sky interferometric radio catalog!

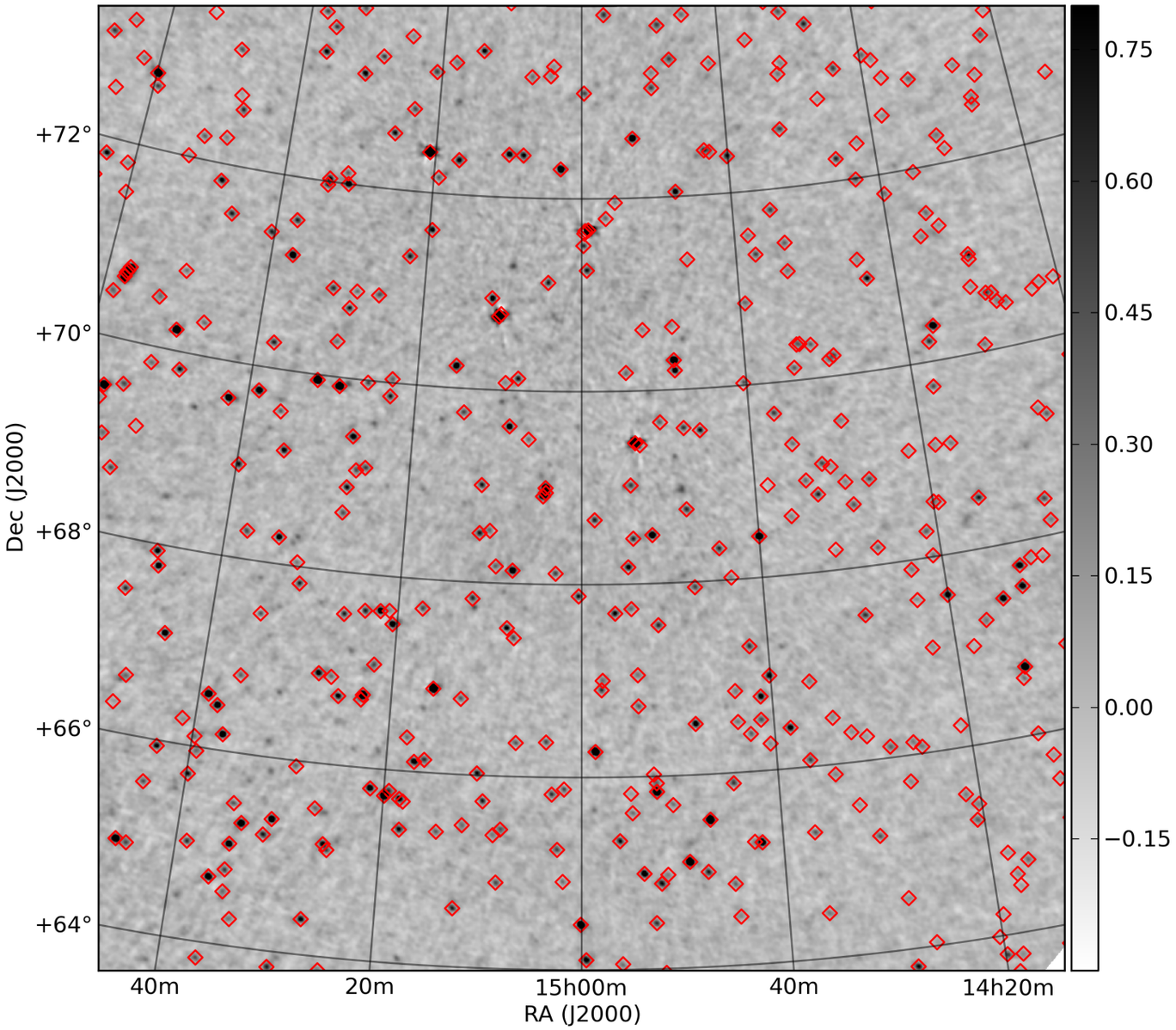


MSSS vital stats

- Highly complementary to MWA's GLEAM: together these surveys will provide a truly all-sky interferometric radio catalog!



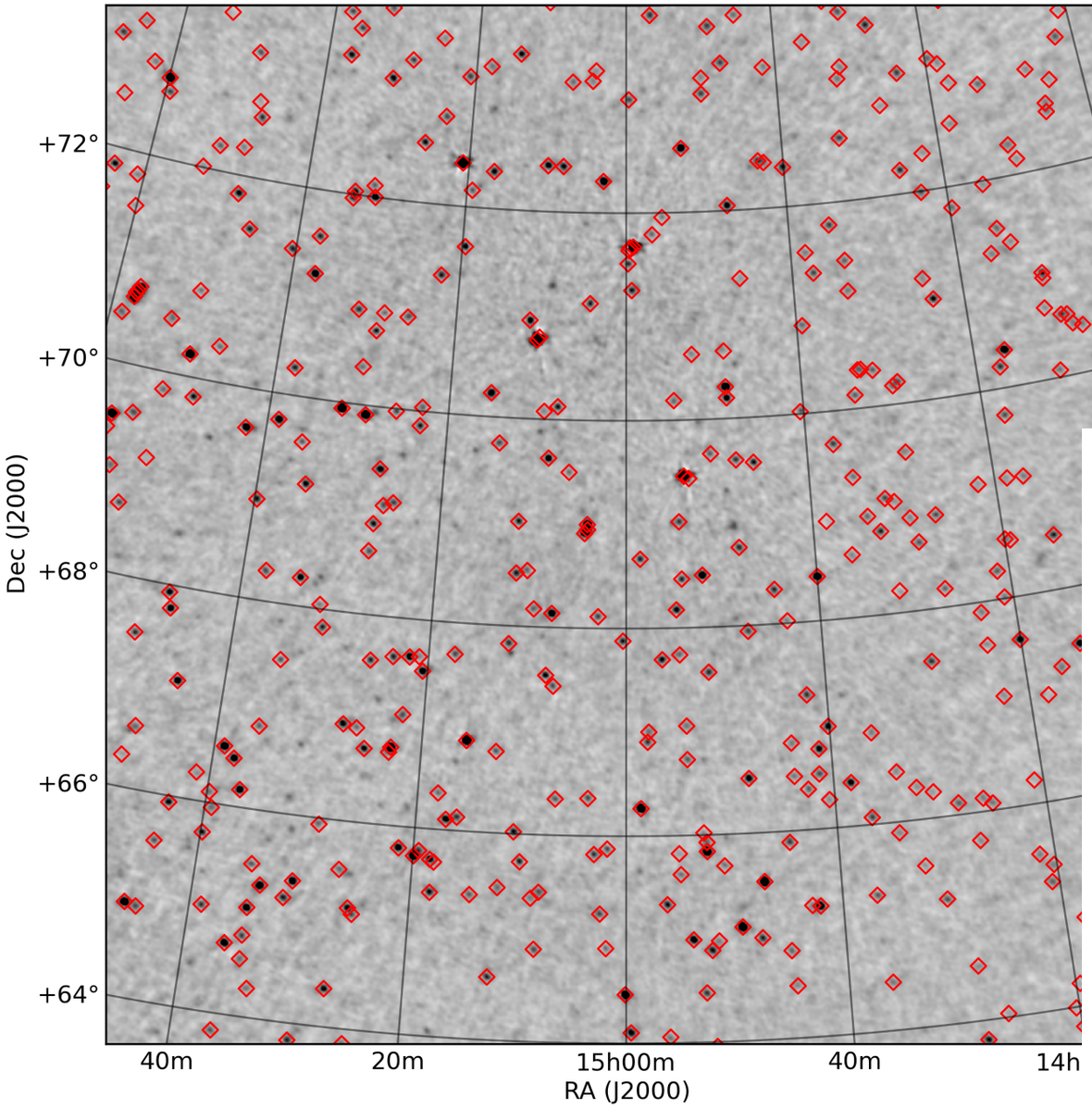
MSSS Verification Field



LBA

Ionospheric correction applied

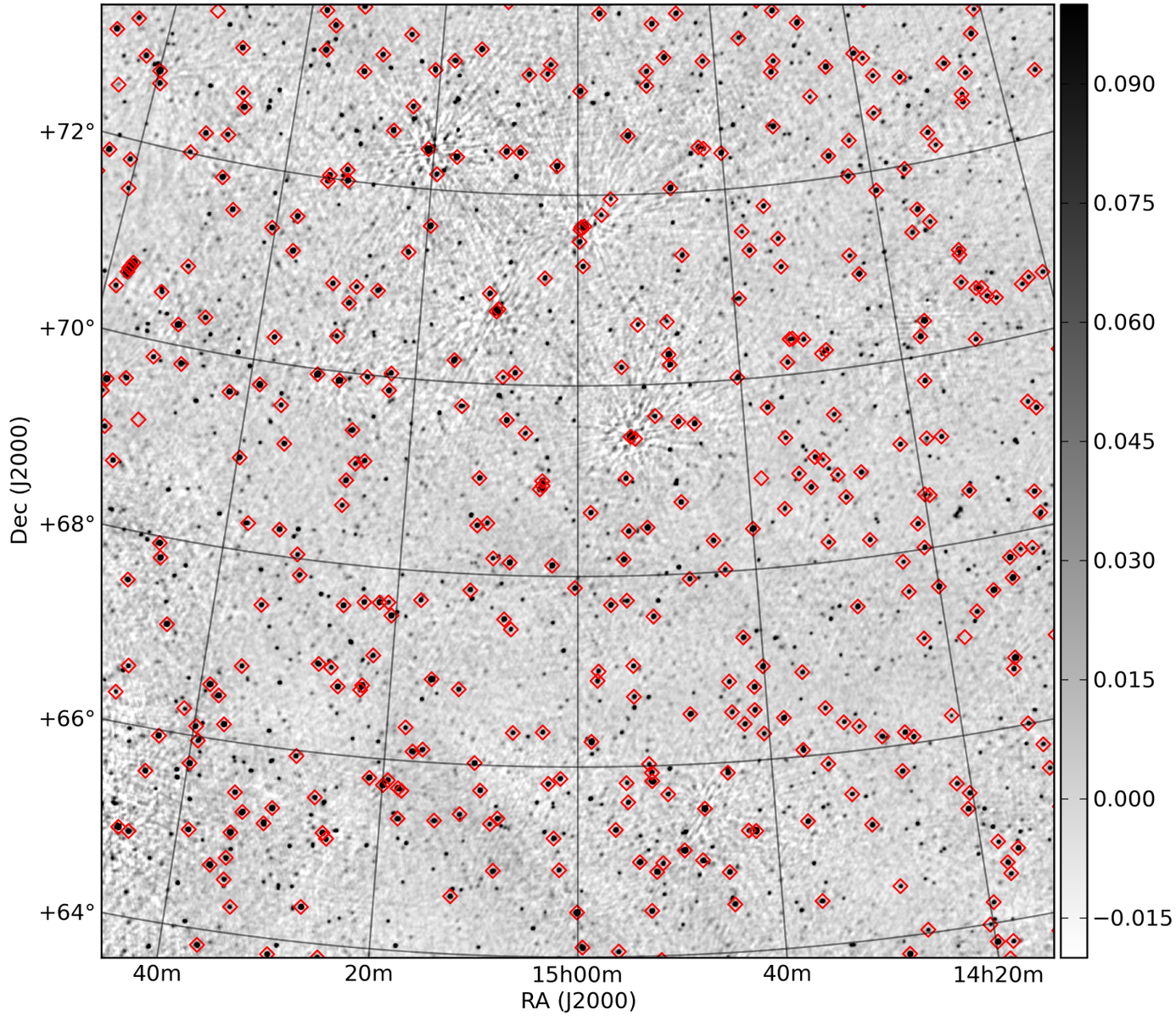
MSSS Verification Field



LBA

Ionospheric correction applied

HBA mosaic



MSSS Verification Field

- Paper accepted in A&A (arxiv:1509.01257)
- Key facts & figures:
  - 100 square degrees, ~1200 sources
  - HBA completeness 100 mJy, LBA completeness 550 mJy
  - ~2’ resolution

Astrophysics > Instrumentation and Methods for Astrophysics

The LOFAR Multifrequency Snapshot Sky Survey (MSSS) I. Survey description and first results

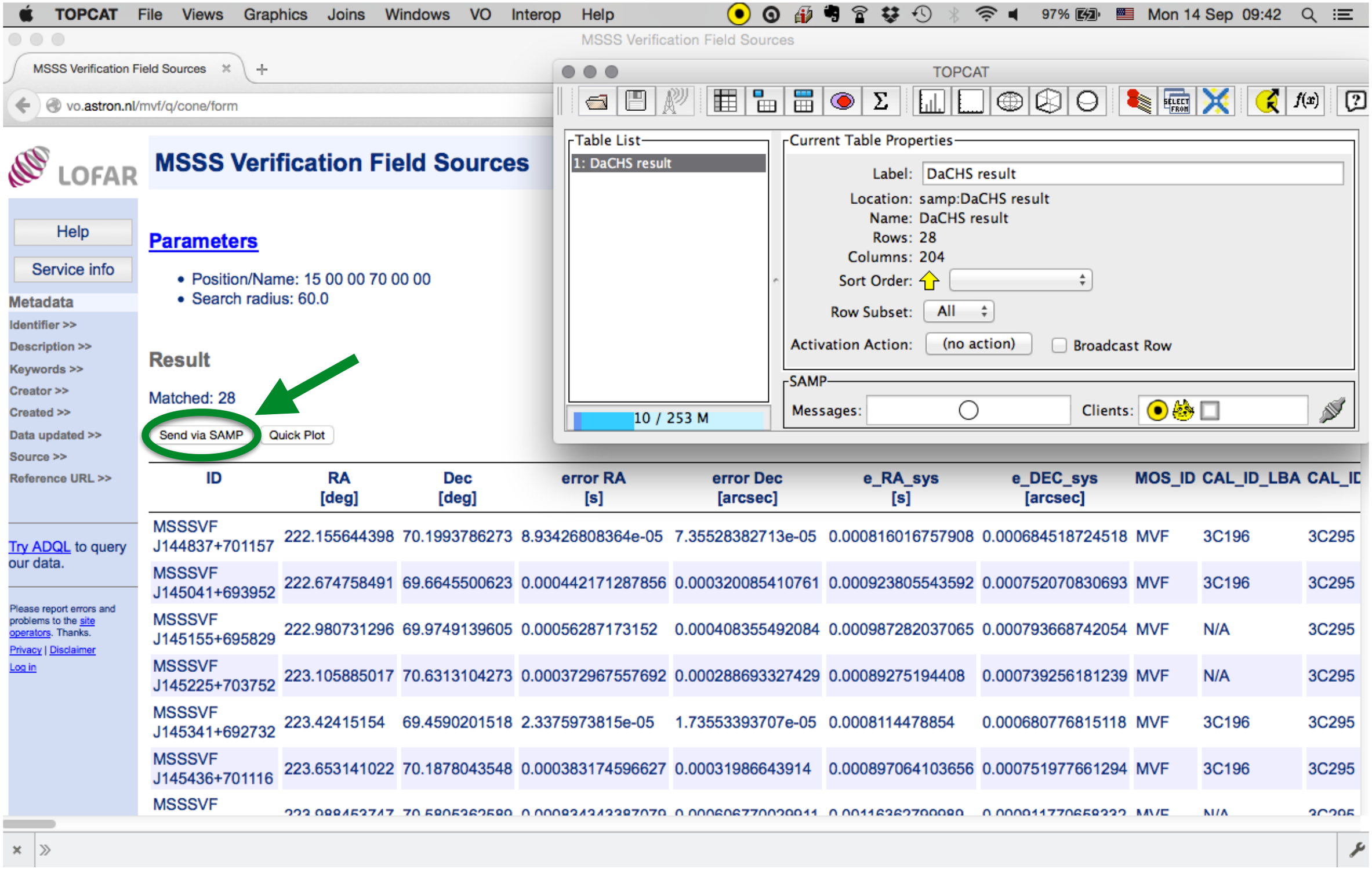
G.H. Heald, R.F. Pizzo, E. Orrú, R.P. Breton, D. Carbone, C. Ferrari, M.J. Hardcastle, W. Jurusik, G. Macario, D. Mulcahy, D. Rafferty, A. Asgekar, M. Brentjens, R.A. Fallows, W. Frieswijk, M.C. Toribio, B. Adebahr, M. Arts, M.R. Bell, A. Bonafede, J. Bray, J. Broderick, T. Cantwell, P. Carroll, Y. Cendes, A.O. Clarke, J. Croston, S. Daiboo, F. de Gasperin, J. Gregson, J. Harwood, T. Hassall, V. Heesen, A. Horneffer, A.J. van der Horst, M. Iacobelli, V. Jelić, D. Jones, D. Kant, G. Kokotanekov, P. Martin, J.P. McKean, L.K. Morabito, B. Nikiel-Wroczyński, A. Offringa, V.N. Pandey, M. Pandey-Pommier, M. Pietka, L. Pratley, C. Riseley, A. Rowlinson, J. Sabater, A.M.M. Scaife, L.H.A. Scheers, K. Sendlinger, A. Shulevski, M. Sipior, C. Sobey, A.J. Stewart, A. Stroe, J. Swinbank, et al. (89 additional authors not shown)

(Submitted on 3 Sep 2015)

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

MVF data release

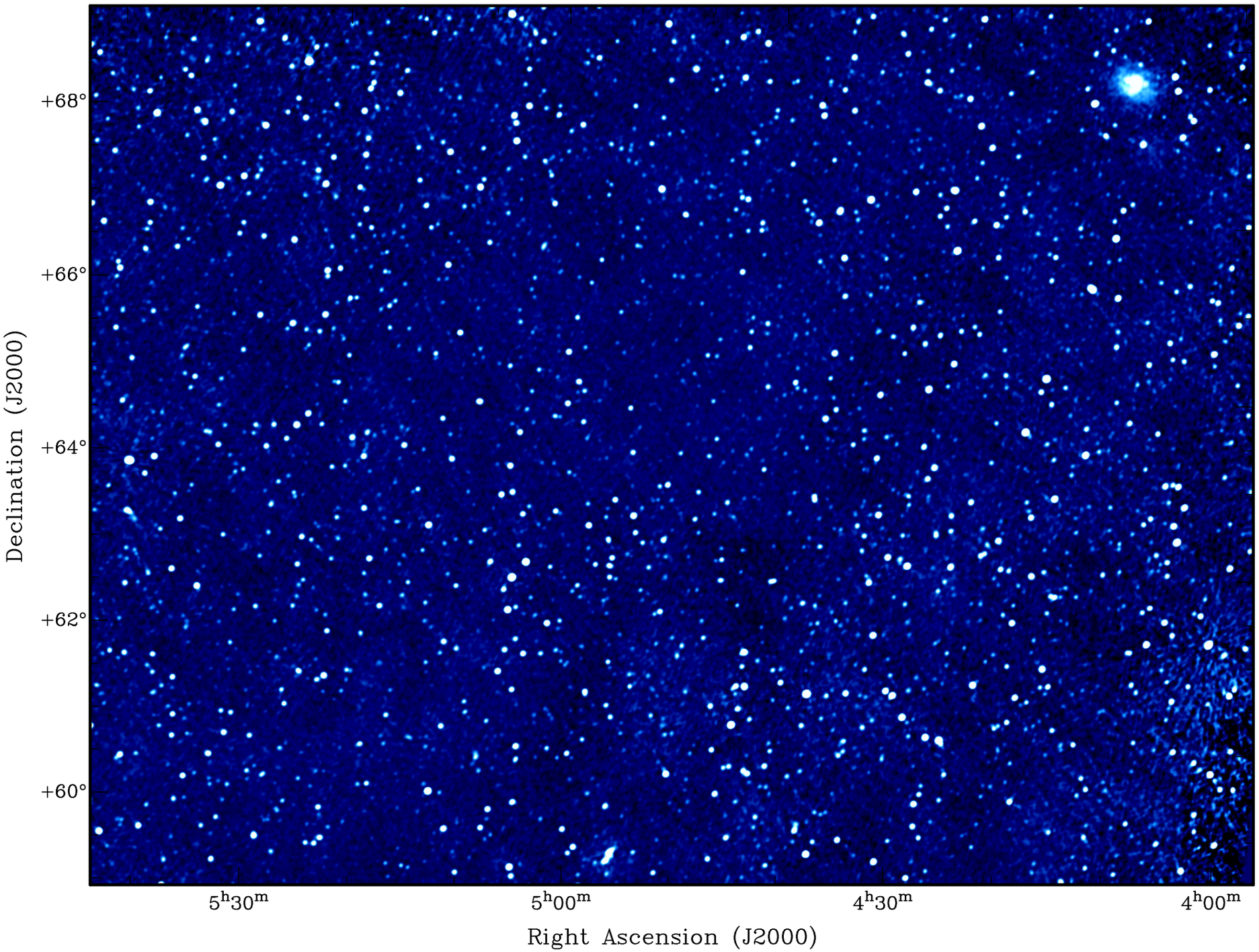
- vo.astron.nl … take note of SAMP connection



ID	RA [deg]	Dec [deg]	error RA [s]	error Dec [arcsec]	e_RA_sys [s]	e_DEC_sys [arcsec]	MOS_ID	CAL_ID_LBA	CAL_ID
MSSSVF J144837+701157	222.155644398	70.1993786273	8.93426808364e-05	7.35528382713e-05	0.000816016757908	0.000684518724518	MVF	3C196	3C295
MSSSVF J145041+693952	222.674758491	69.6645500623	0.000442171287856	0.000320085410761	0.000923805543592	0.000752070830693	MVF	3C196	3C295
MSSSVF J145155+695829	222.980731296	69.9749139605	0.00056287173152	0.000408355492084	0.000987282037065	0.000793668742054	MVF	N/A	3C295
MSSSVF J145225+703752	223.105885017	70.6313104273	0.000372967557692	0.000288693327429	0.00089275194408	0.000739256181239	MVF	N/A	3C295
MSSSVF J145341+692732	223.42415154	69.4590201518	2.3375973815e-05	1.73553393707e-05	0.0008114478854	0.000680776815118	MVF	3C196	3C295
MSSSVF J145436+701116	223.653141022	70.1878043548	0.000383174596627	0.00031986643914	0.000897064103656	0.000751977661294	MVF	3C196	3C295
MSSSVF									

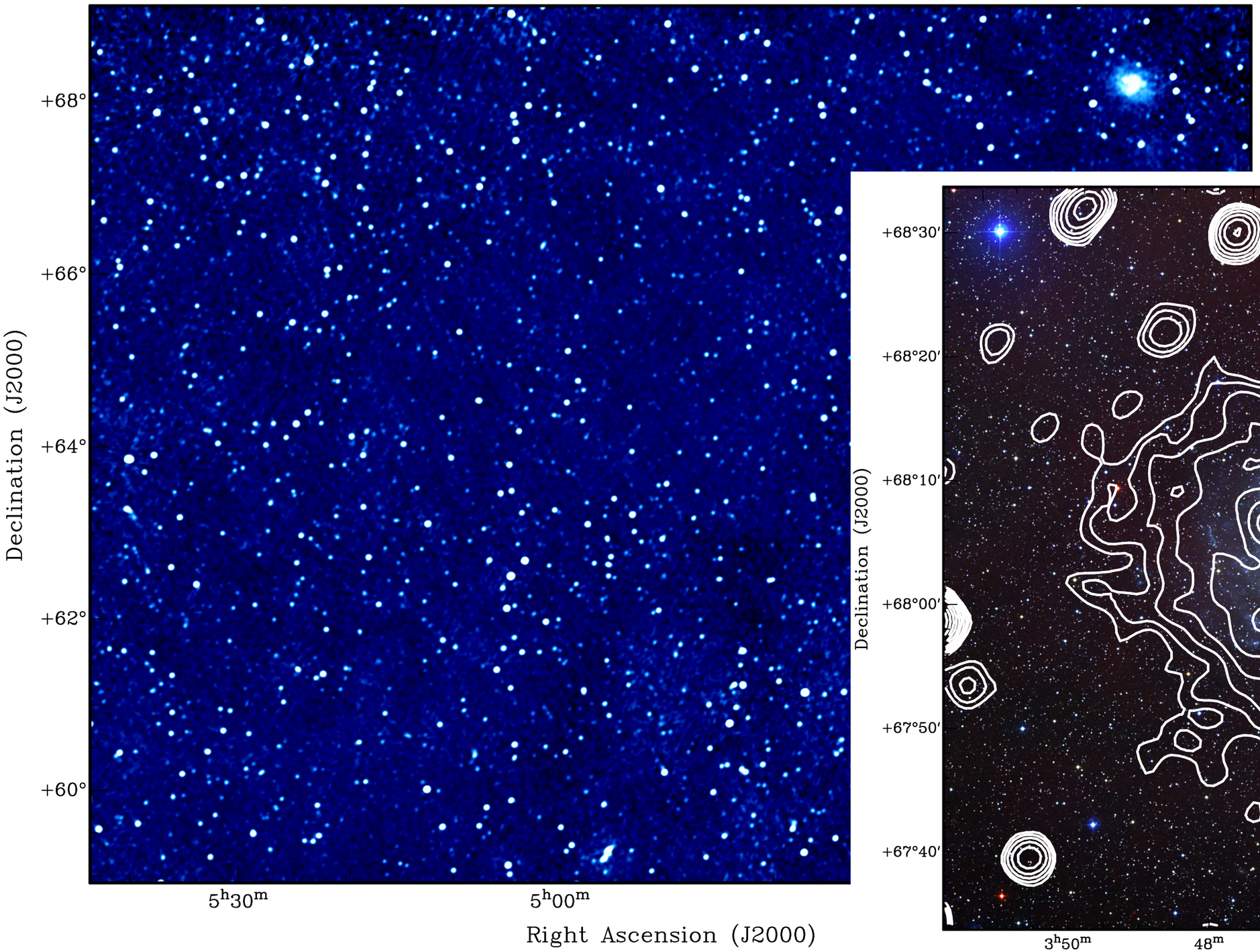
MSSS mosaics

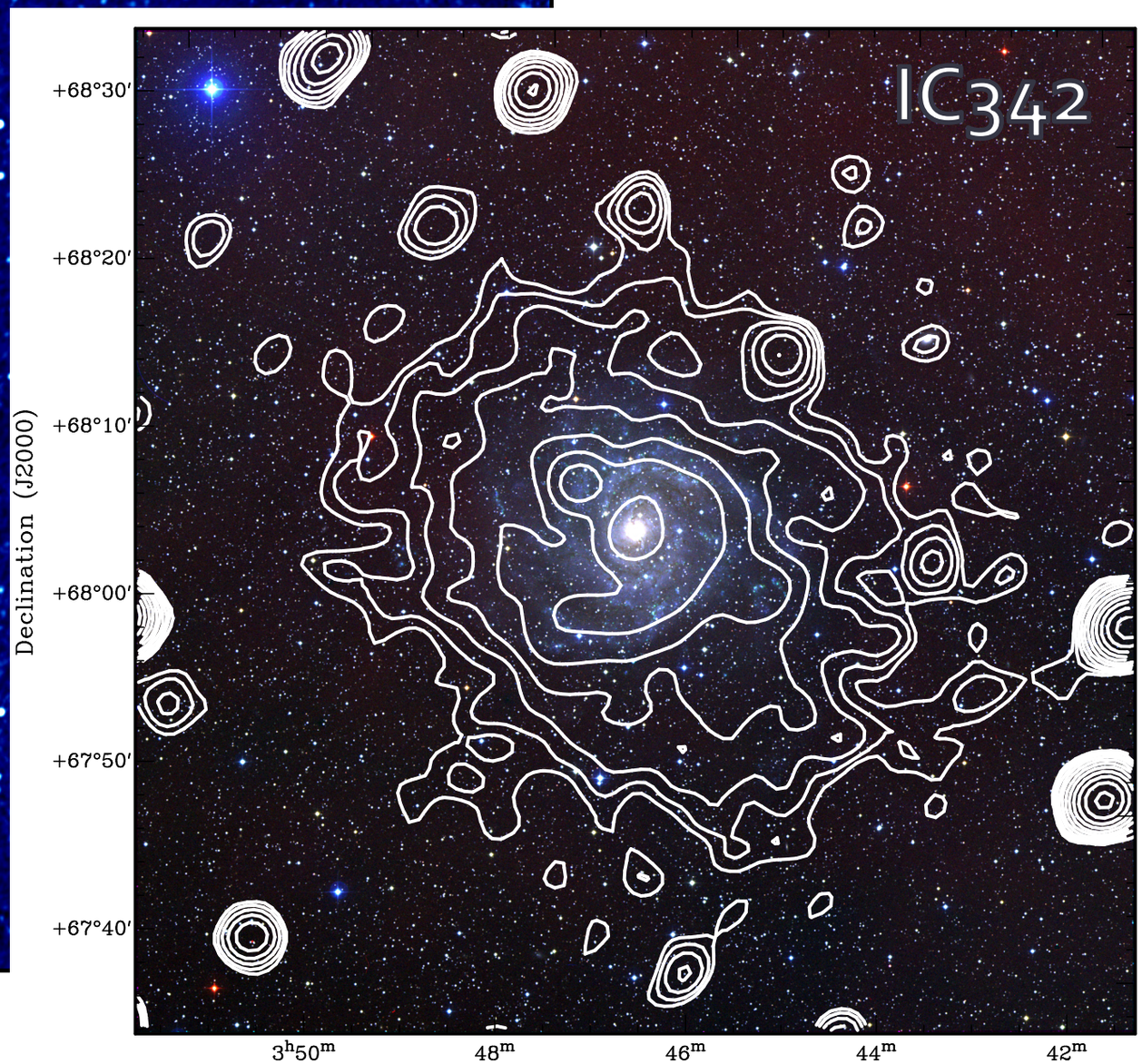
- Standard imaging product: 100 square degree mosaics, each composed of 10s of individual HBA fields



MSSS mosaics

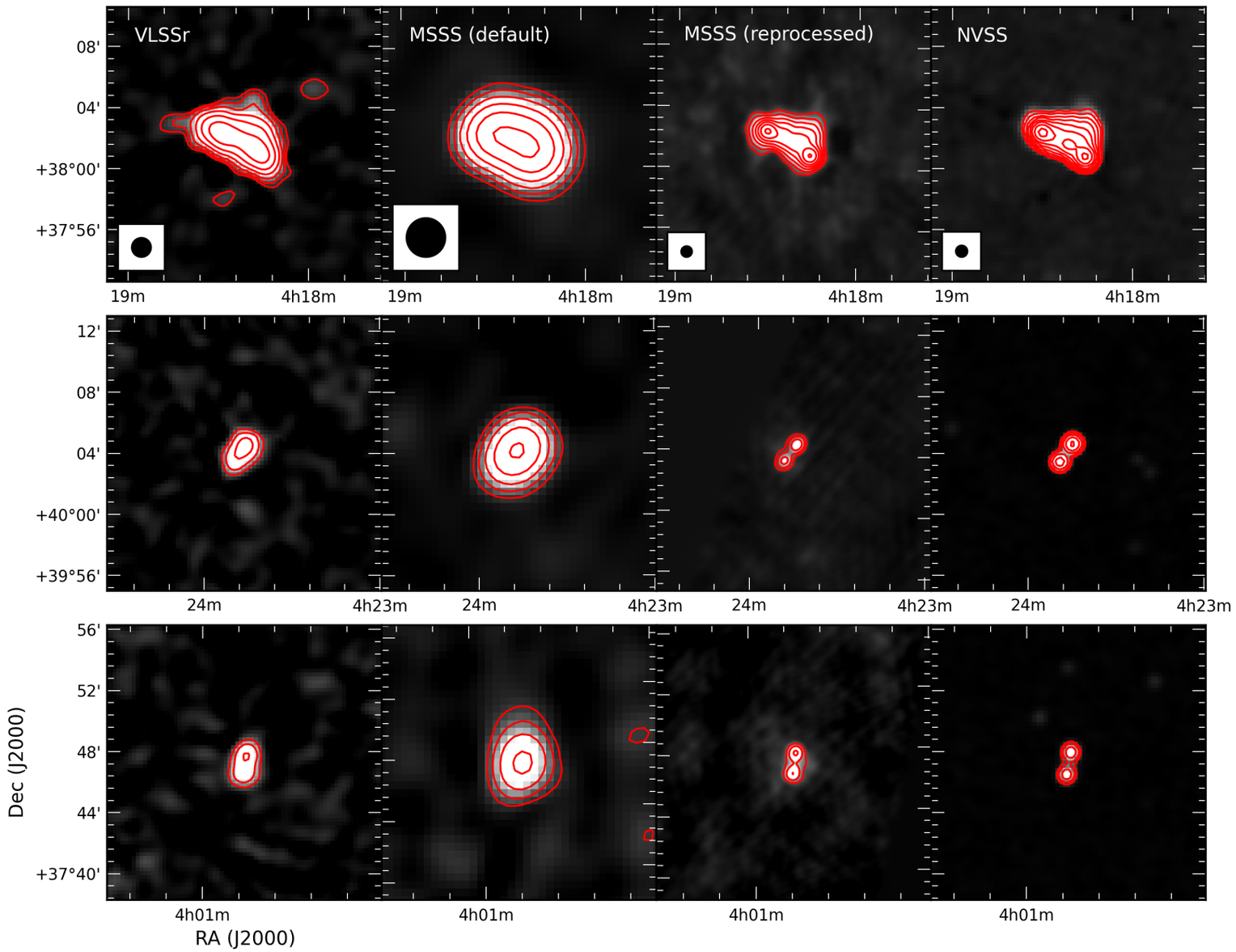
- Standard imaging product: 100 square degree mosaics, each composed of 10s of individual HBA fields



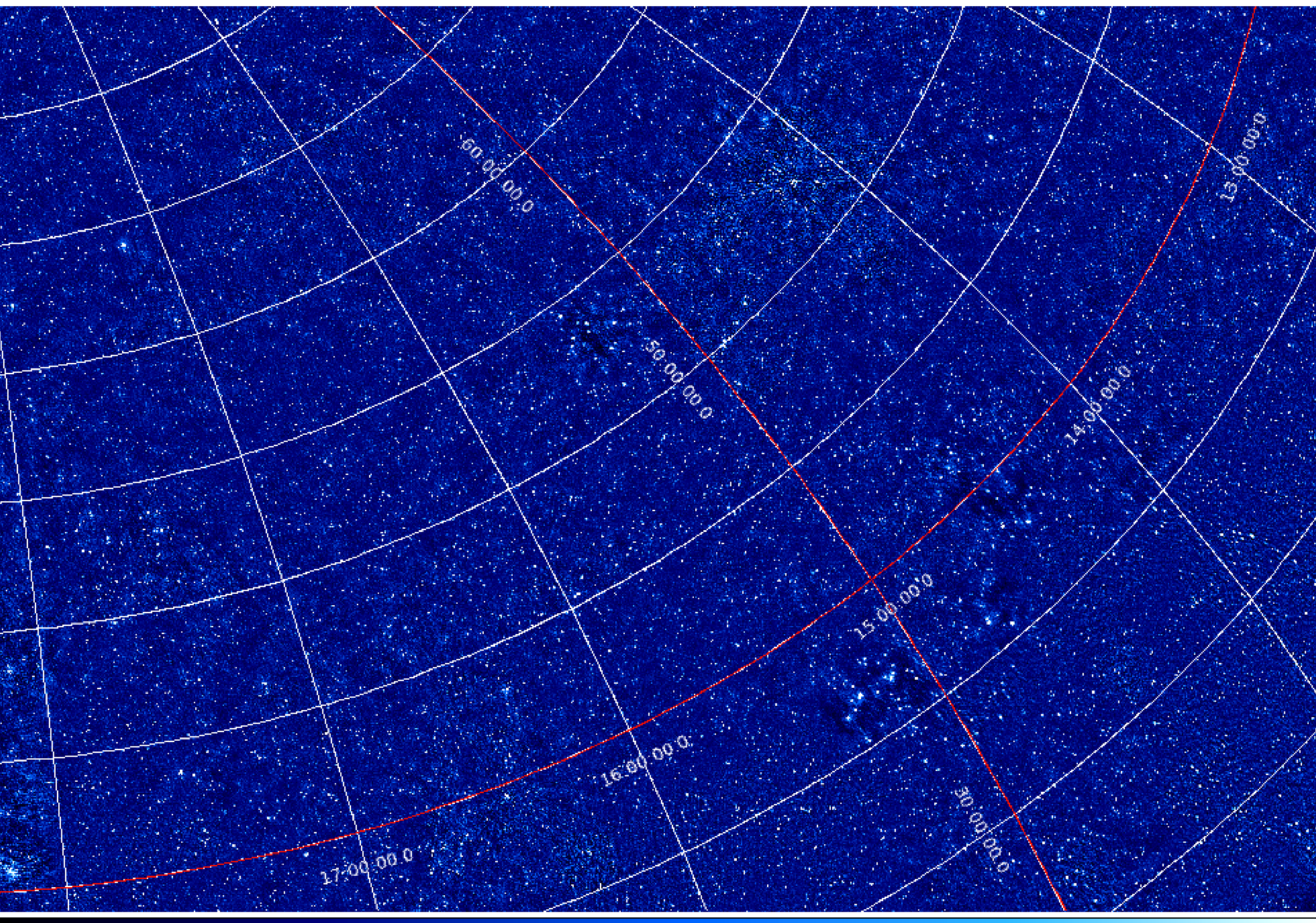


Prospect for higher resolution (v2)

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



- Planned for v2 catalog - AWS/SKA funding granted to facilitate this stage of the MSSS development

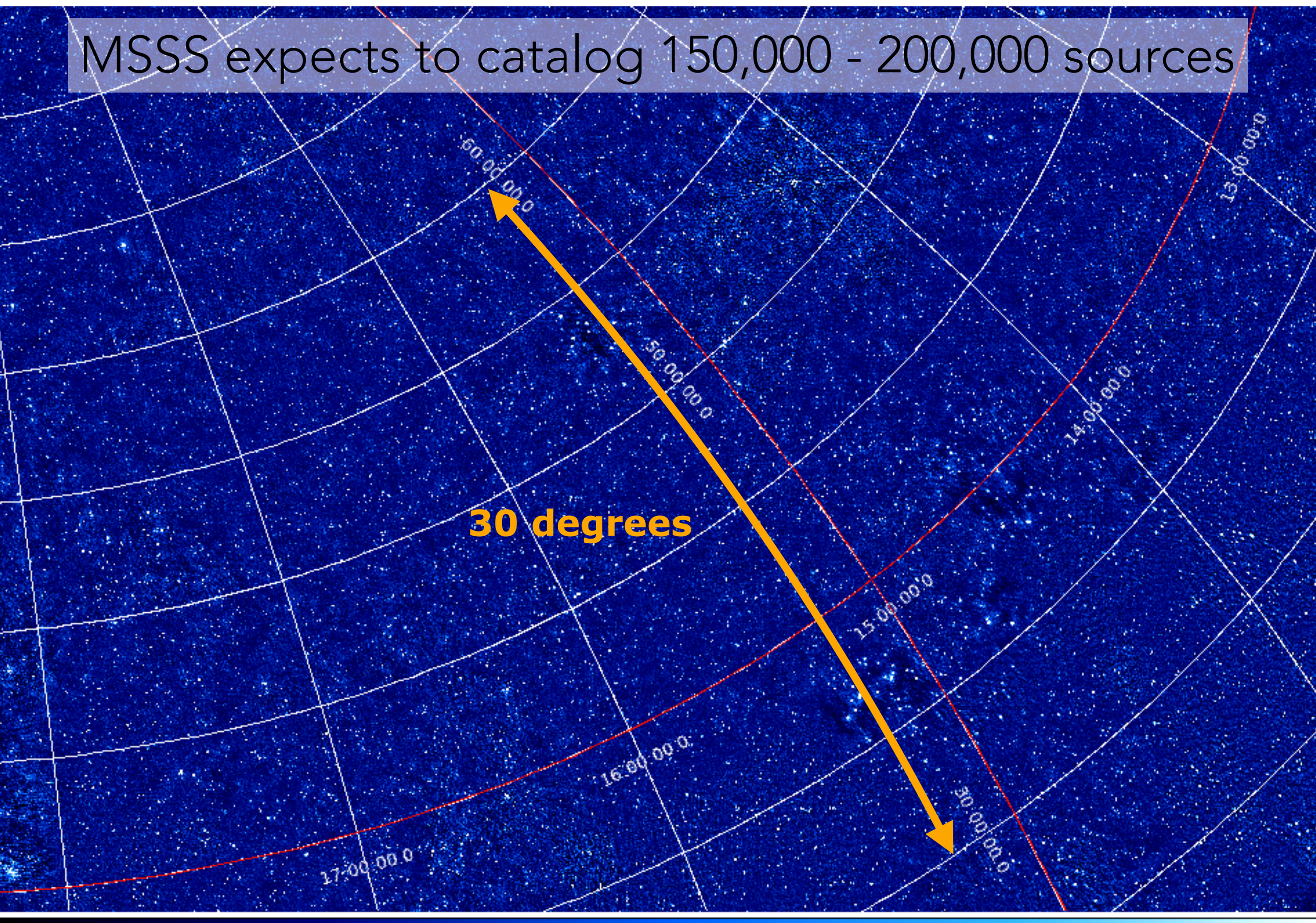

60.00.00.0
50.00.00.0
14.00.00.0
15.00.00.0
16.00.00.0
17.00.00.0
30.00.00.0
-0.034
-0.0098
0.009
0.025
0.039
0.051
0.063
0.074
0.084

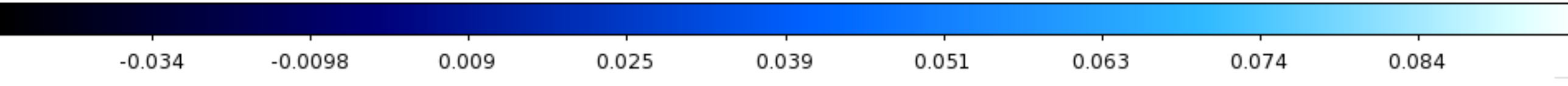
30 degrees

60.00.00.0
50.00.00.0
14.00.00.0
15.00.00.0
16.00.00.0
17.00.00.0
30.00.00.0

-0.034 -0.0098 0.009 0.025 0.039 0.051 0.063 0.074 0.084

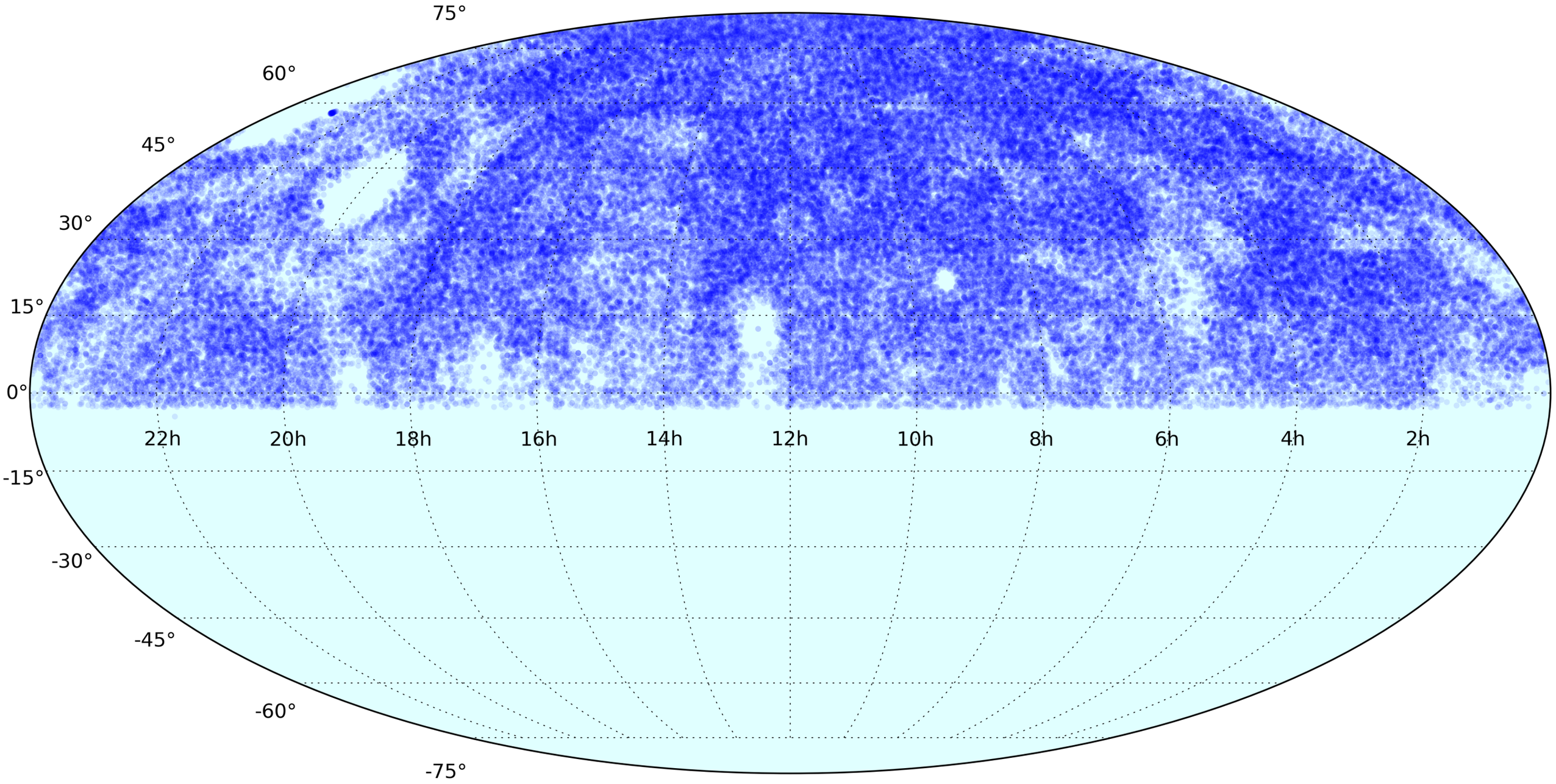
MSSS expects to catalog 150,000 - 200,000 sources





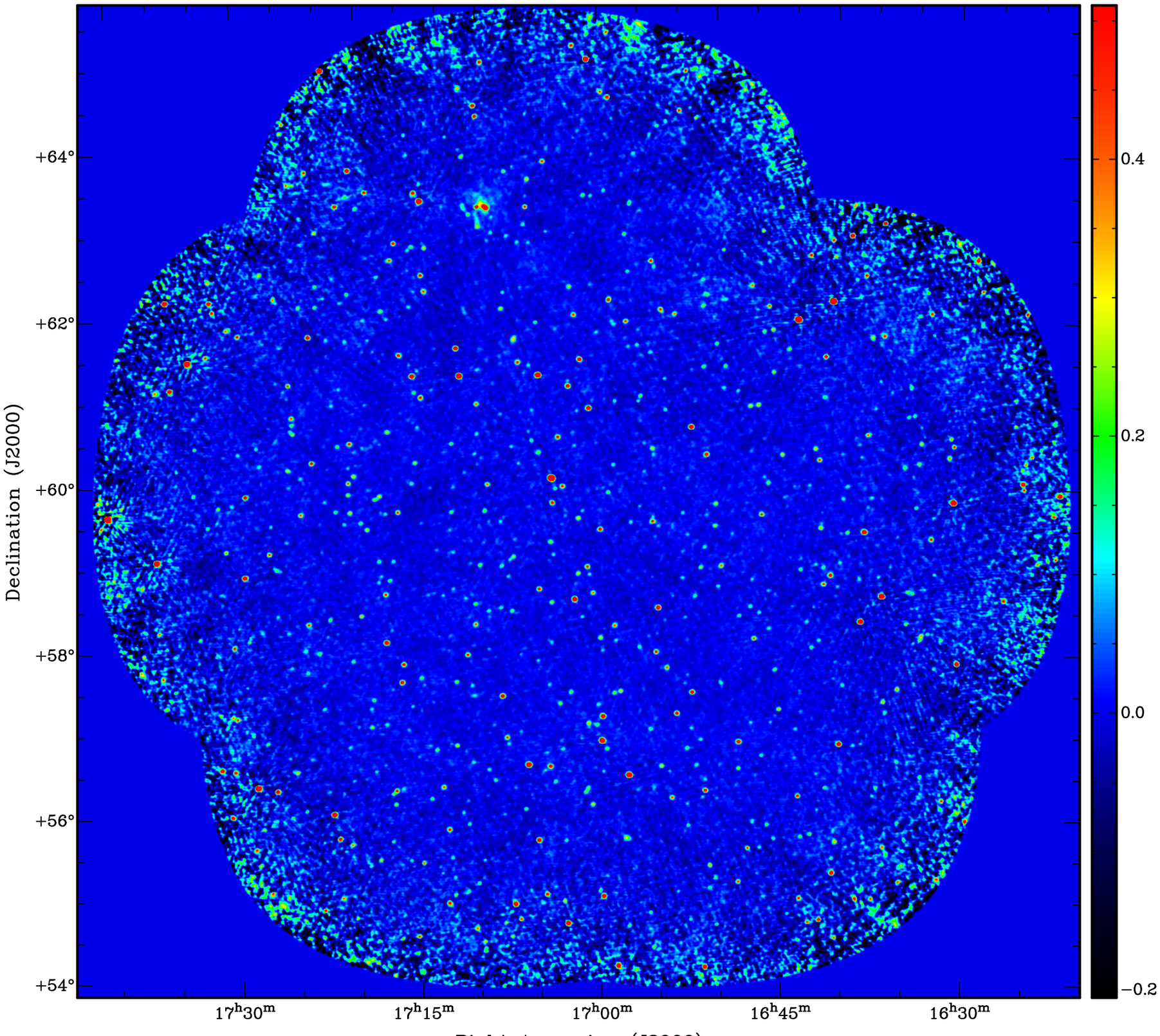
MSSS-HBA catalog (v0.1): ~130,000 sources

Final catalog still under development

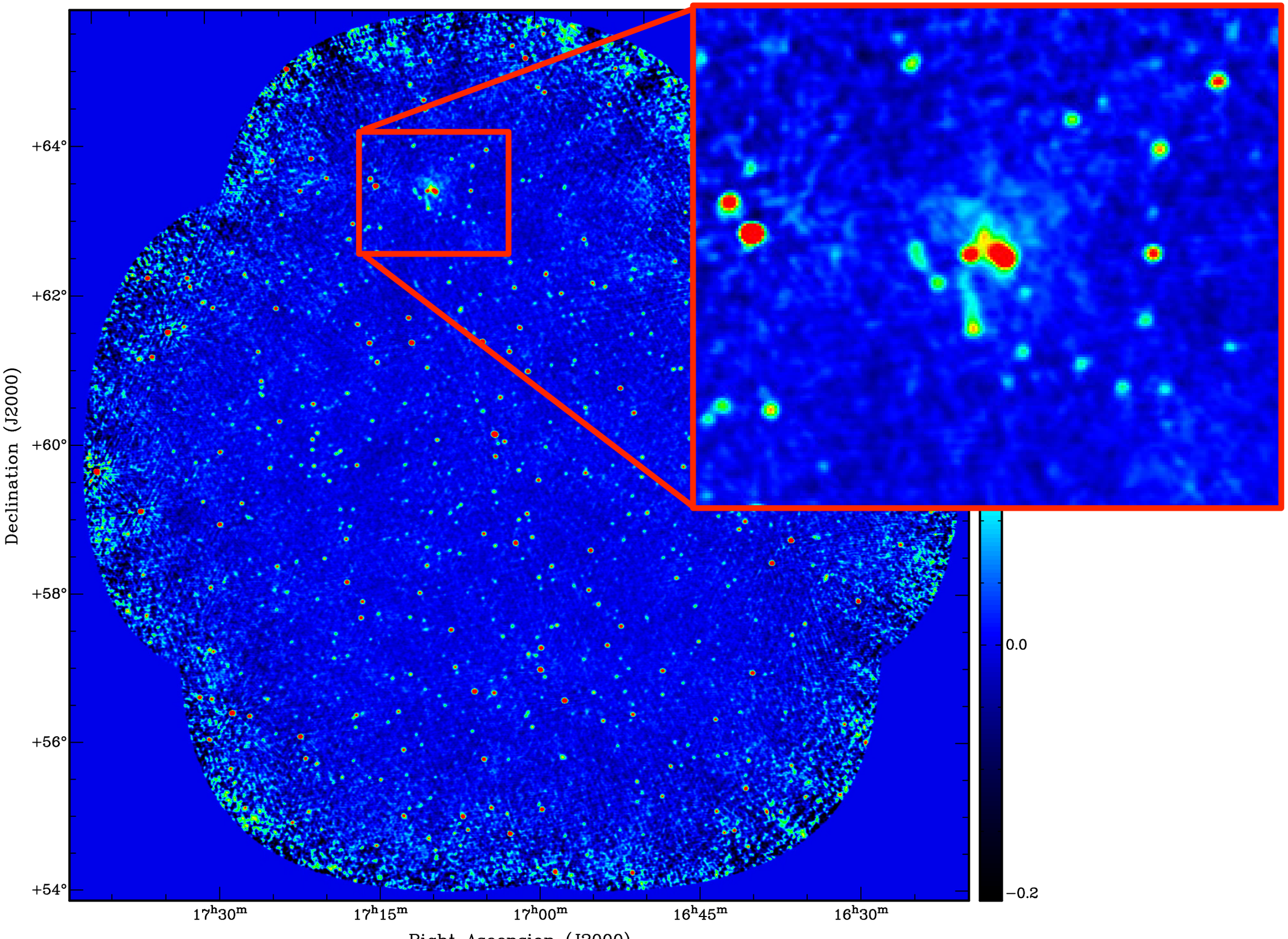


Science with MSSS

One of the first MSSS-HBA mosaics

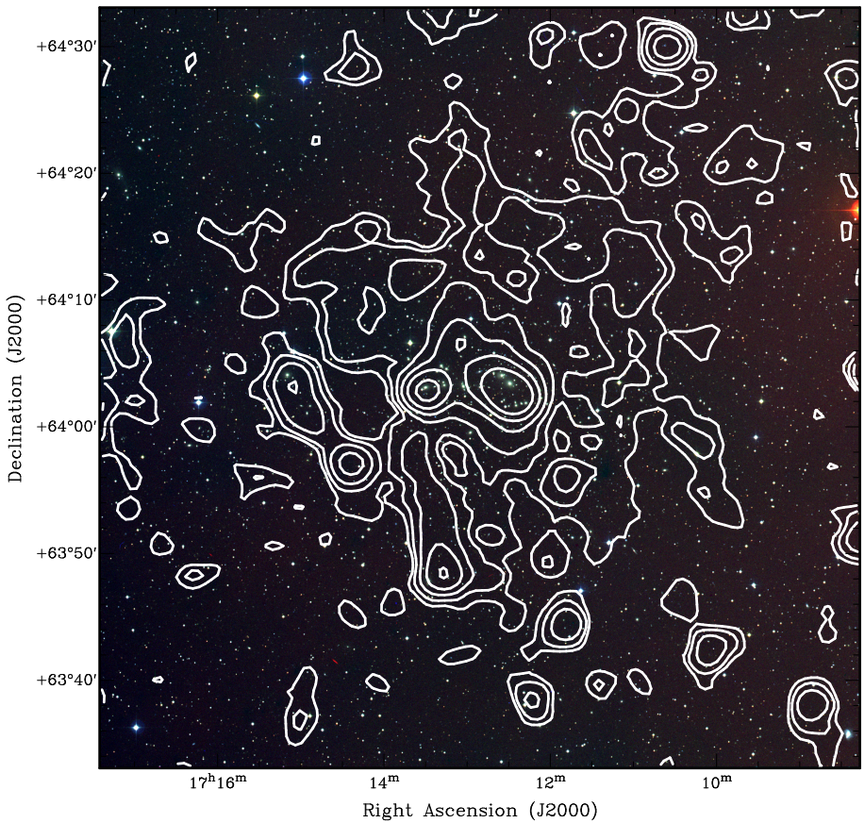


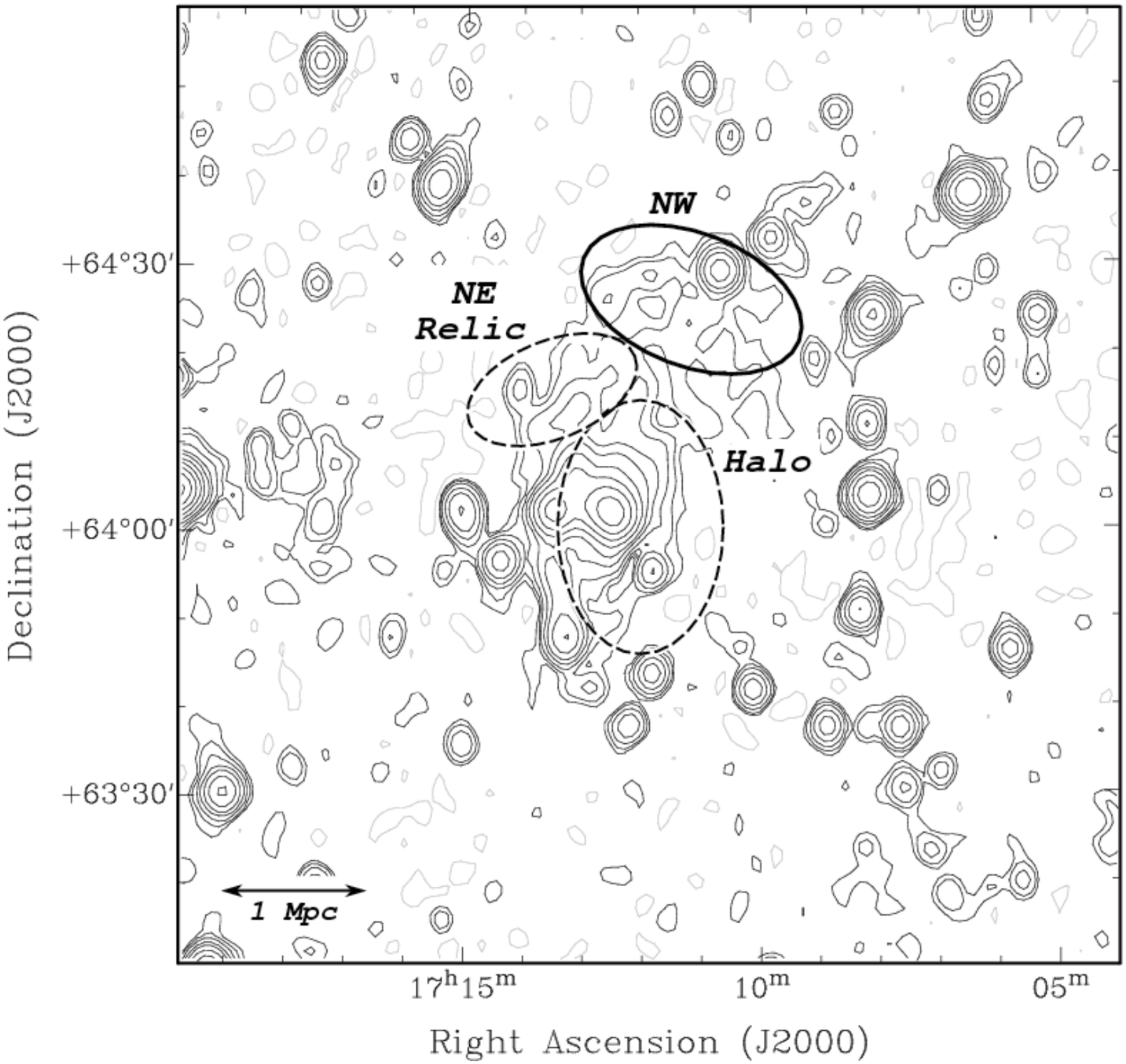
One of the first MSSS-HBA mosaics



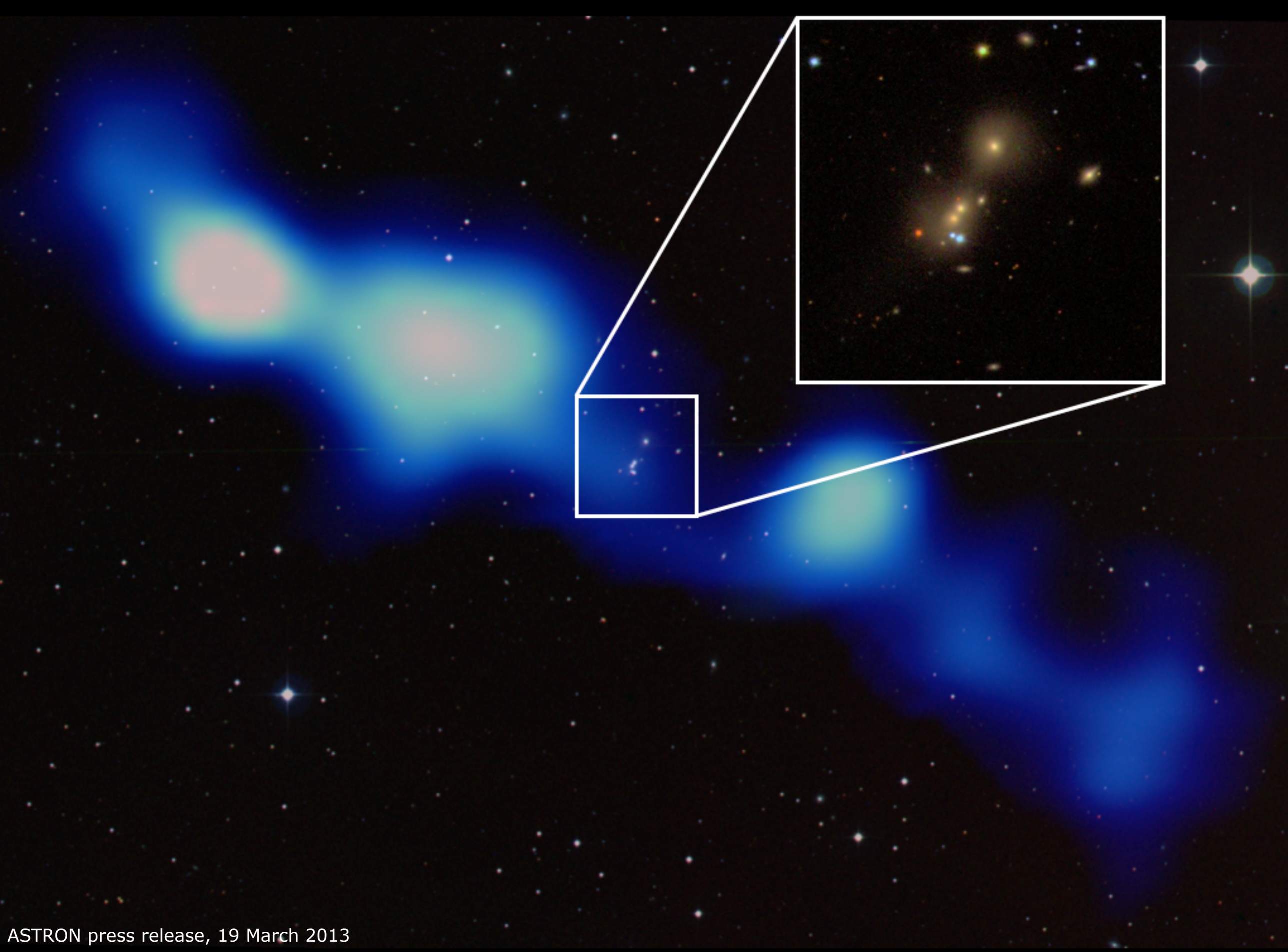
MSSS-HBA: Abell 2255

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

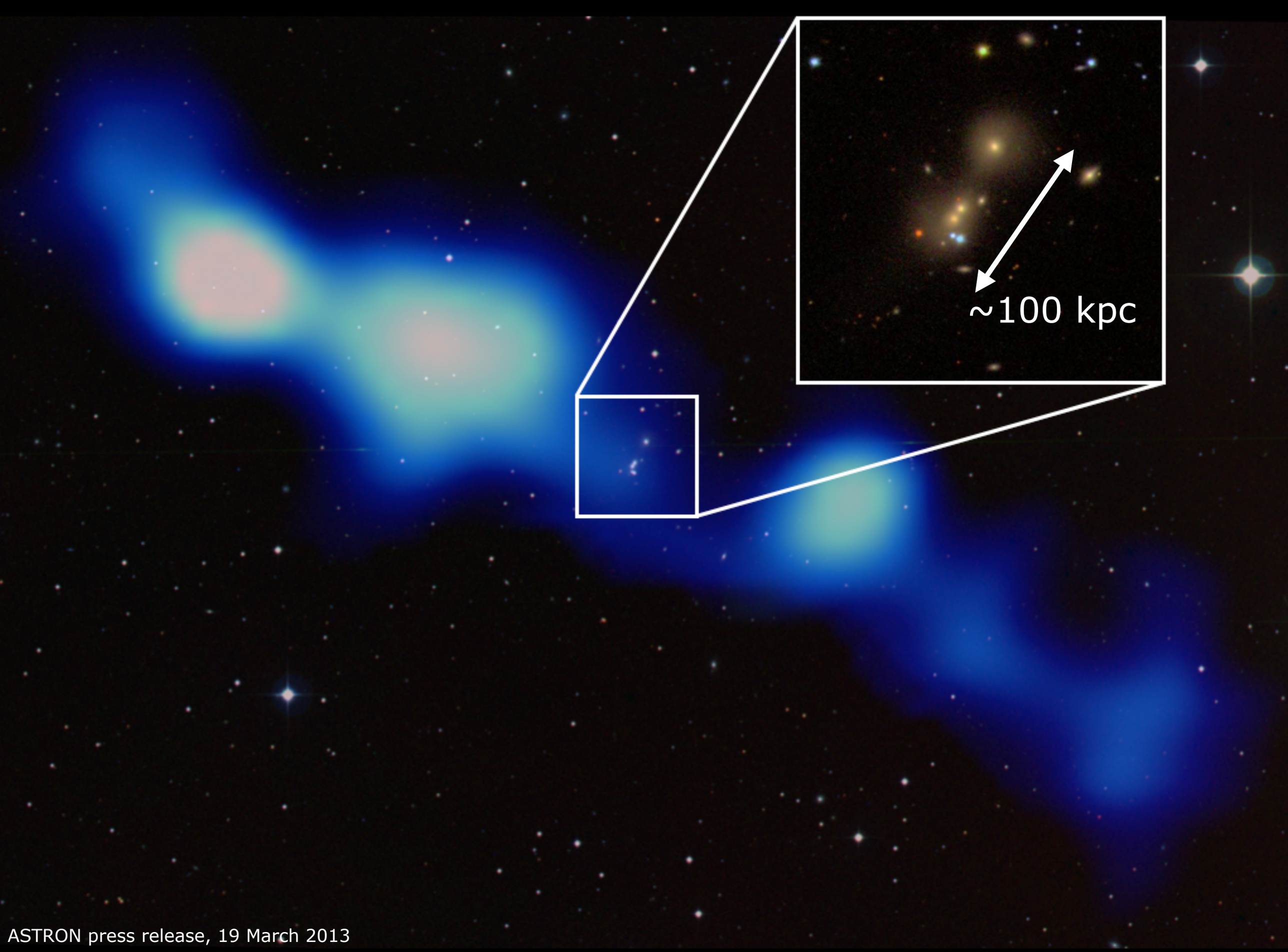




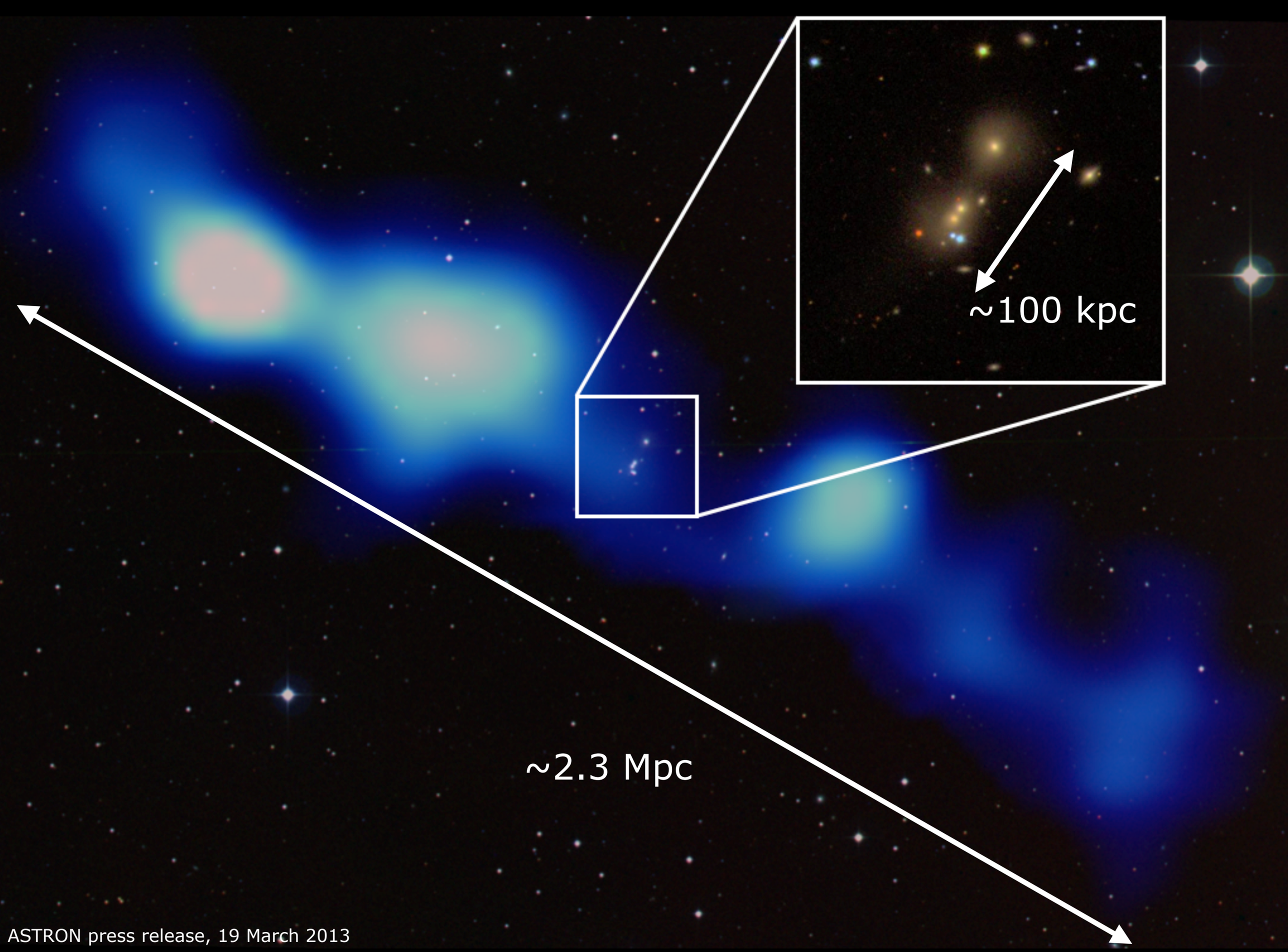
MSSS-HBA: 14 min!



ASTRON press release, 19 March 2013



ASTRON press release, 19 March 2013



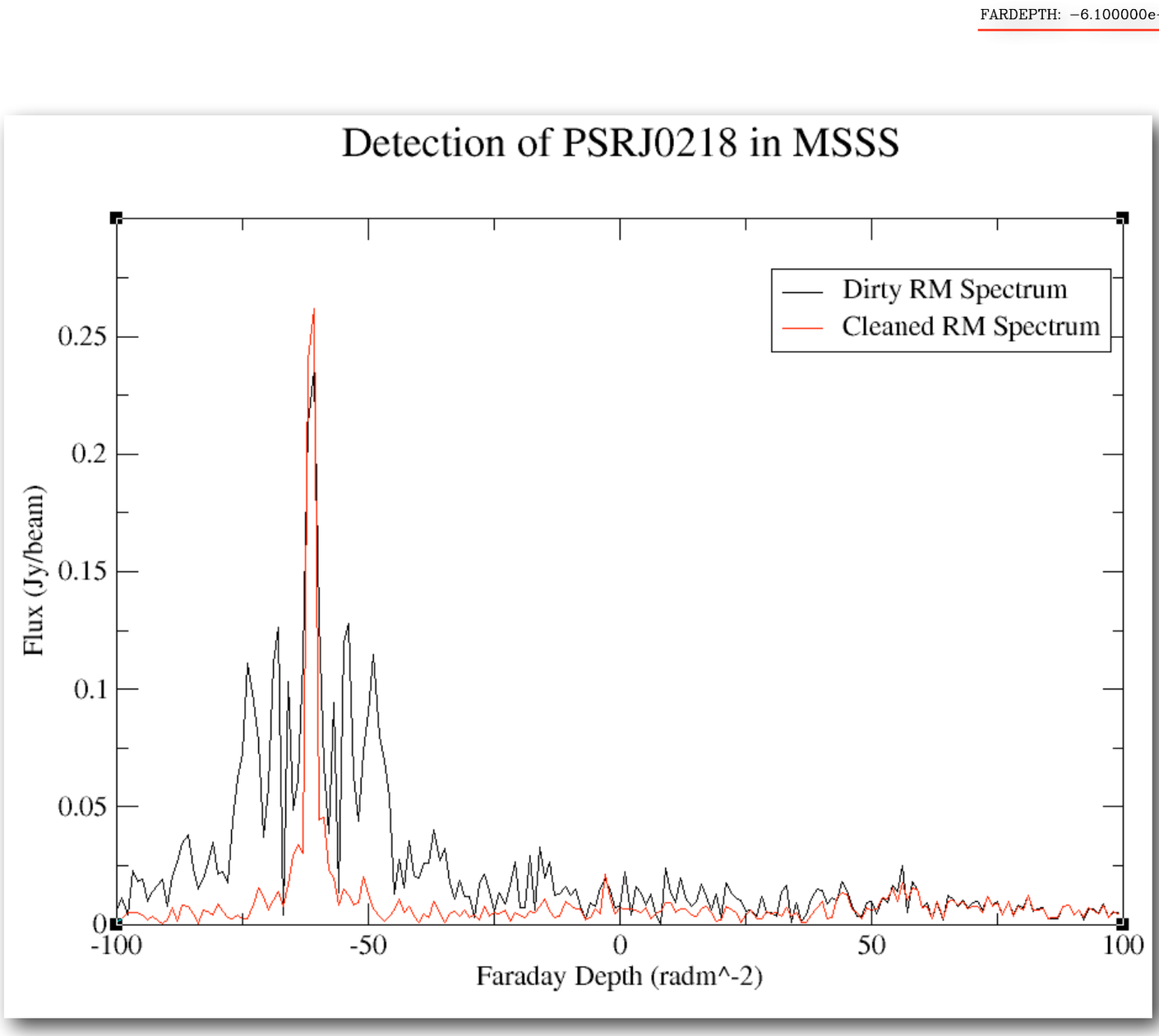
ASTRON press release, 19 March 2013

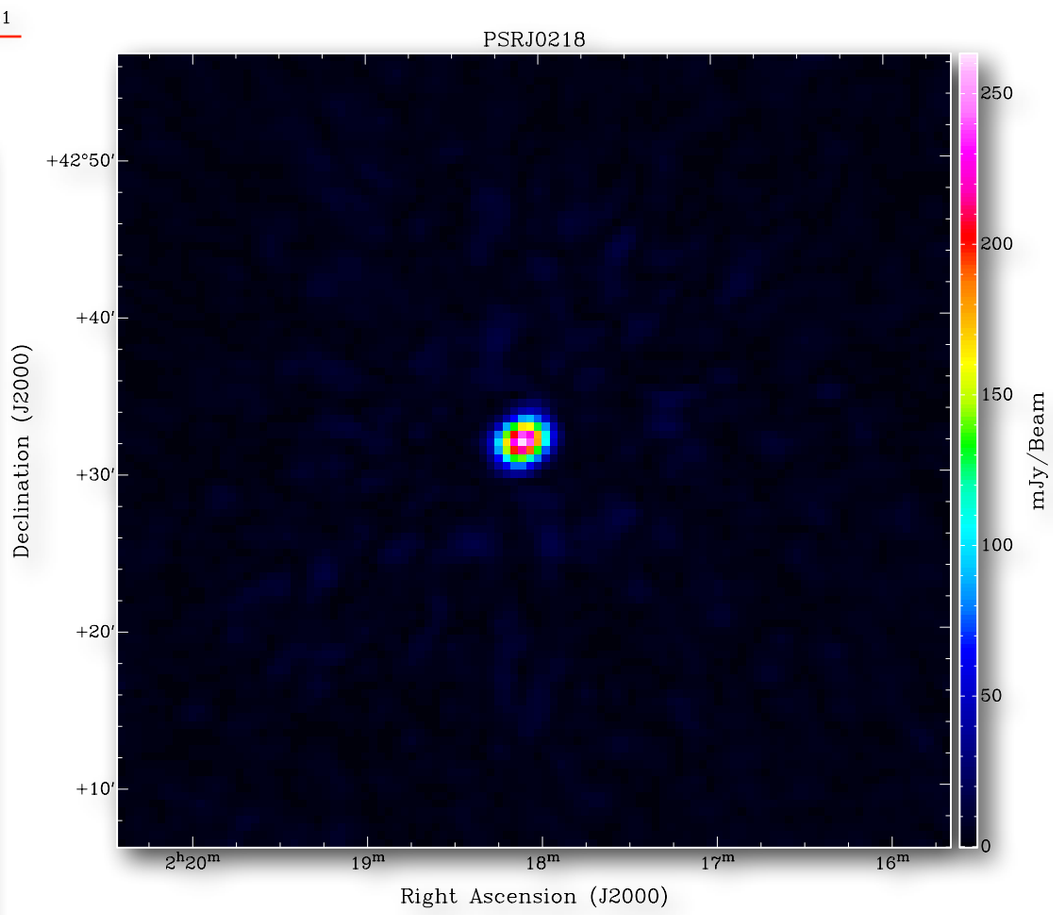
“Great MSSS Supernova Remnant Hunt”

Mulcahy et al

MSSS-HBA polarization

- Polarized pulsar (PSRJ0218) detected with MSSS image data!
- 51% polarized, and with correct RM of -61 rad m^2 (ionospheric RM correction was applied to the data)

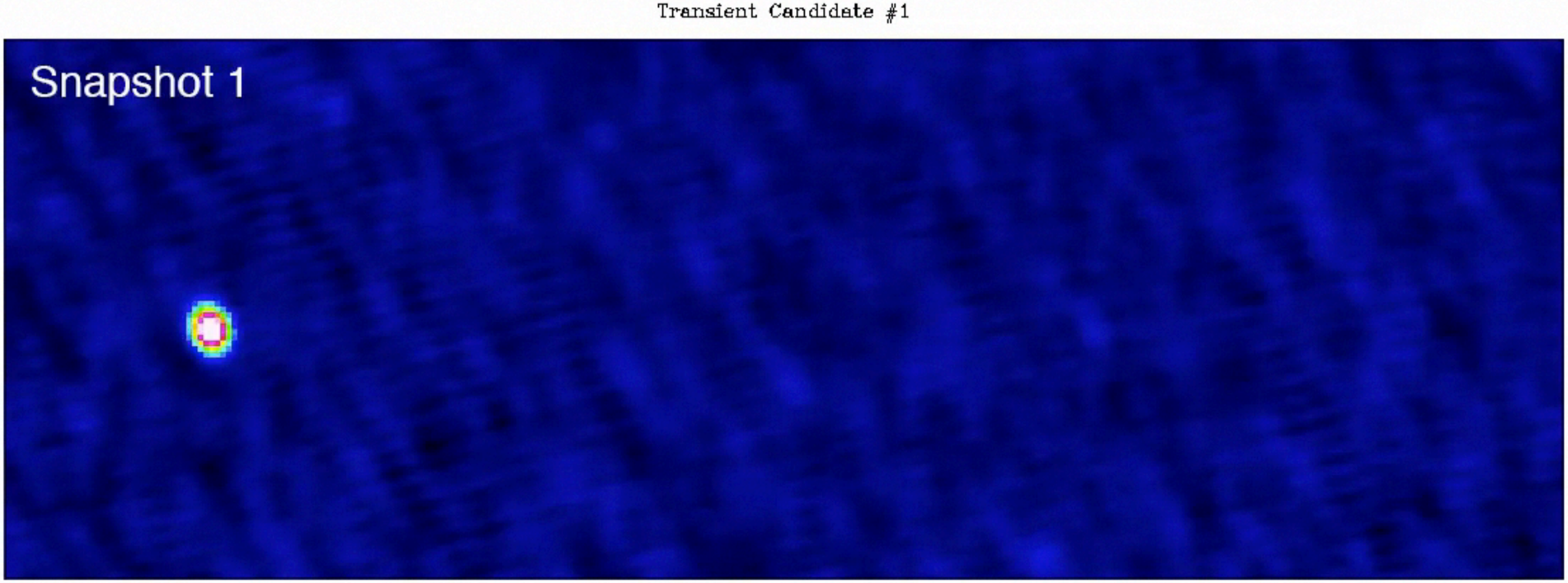




David Mulcahy

Transients with MSSS

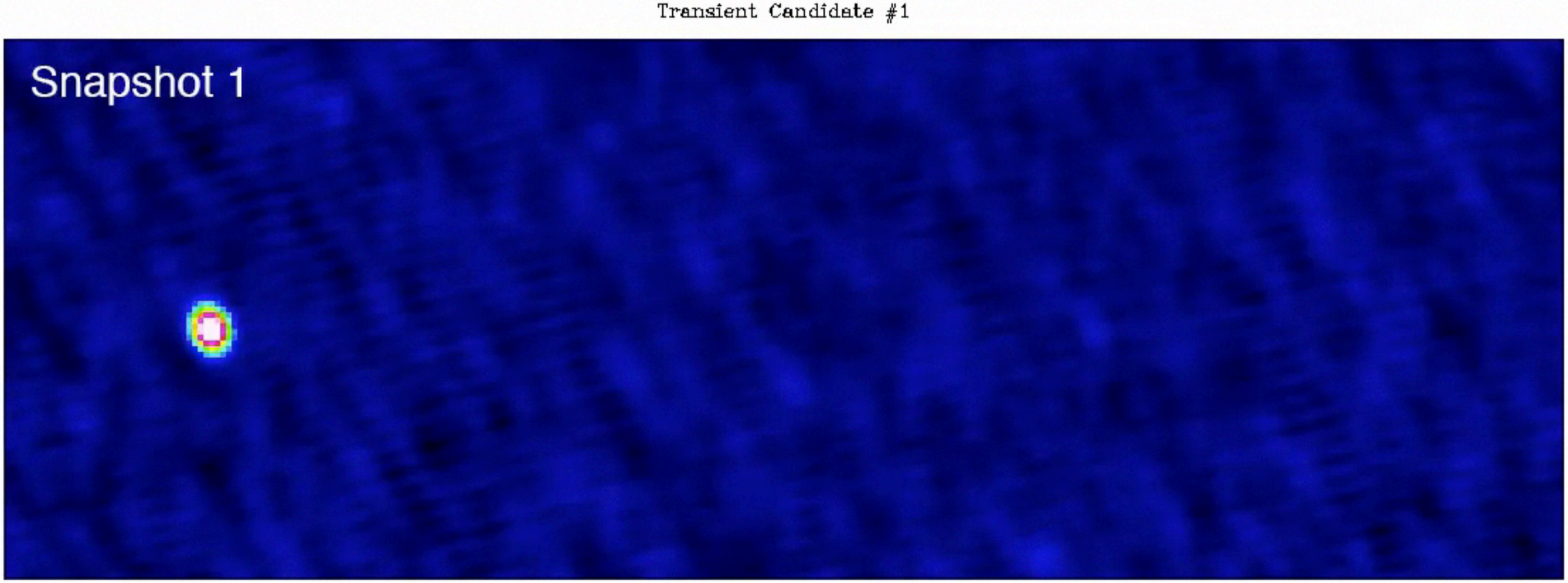
- In MSSS-LBA, 1 subband always on NCP (200 kHz bw at 60 MHz)
- In both MSSS-LBA and MSSS-HBA, multiple epochs (9 & 2 resp.)



- First MSSS-LBA transient (*Stewart+ accepted*); arxiv:1512.00014
  - Appears in one 11-min snapshot, flux density 15-25 Jy beam^{-1}
  - Implied rate for $\Delta t \sim 10$min is 3.9 (+14.7, -3.7) x 10^{-4} day^{-1} deg^{-2} (~8 transients of this nature per hemisphere per day!)

Transients with MSSS

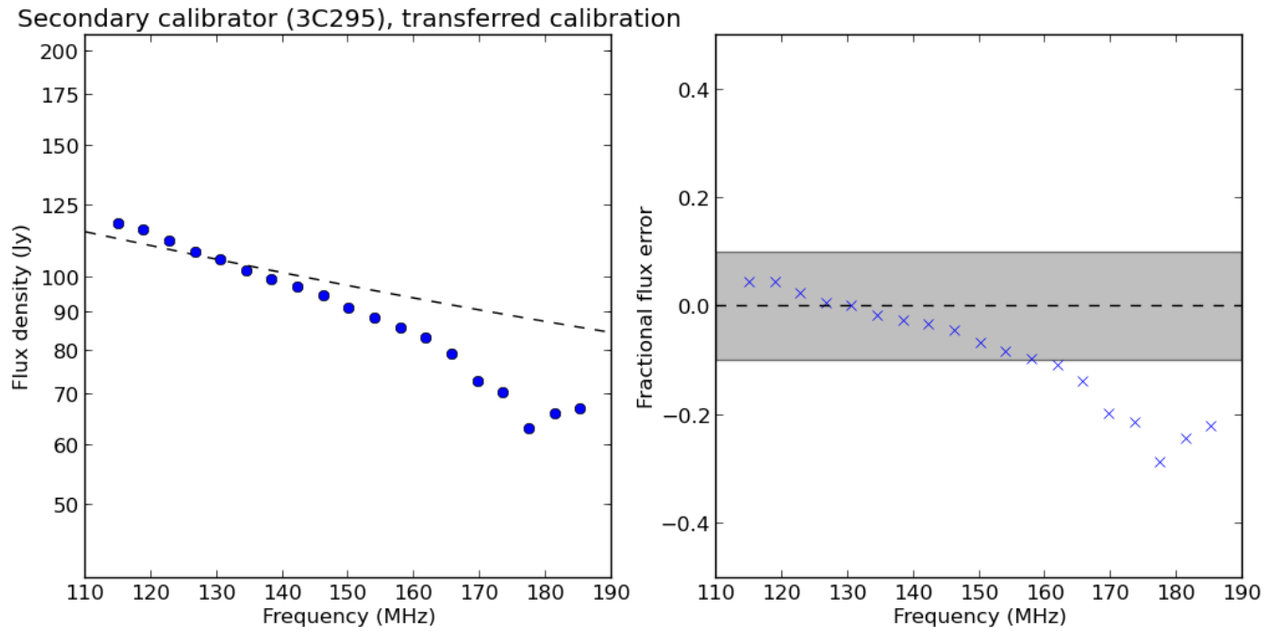
- In MSSS-LBA, 1 subband always on NCP (200 kHz bw at 60 MHz)
- In both MSSS-LBA and MSSS-HBA, multiple epochs (9 & 2 resp.)



- First MSSS-LBA transient (*Stewart+ accepted*); arxiv:1512.00014
  - Appears in one 11-min snapshot, flux density 15-25 Jy beam^{-1}
  - Implied rate for $\Delta t \sim 10$min is 3.9 (+14.7, -3.7) x 10^{-4} day^{-1} deg^{-2} (~8 transients of this nature per hemisphere per day!)

What to look forward to from MSSS

- HBA: upgrade to first all-sky public data release, and beyond…
  - Application of final flux scale definition

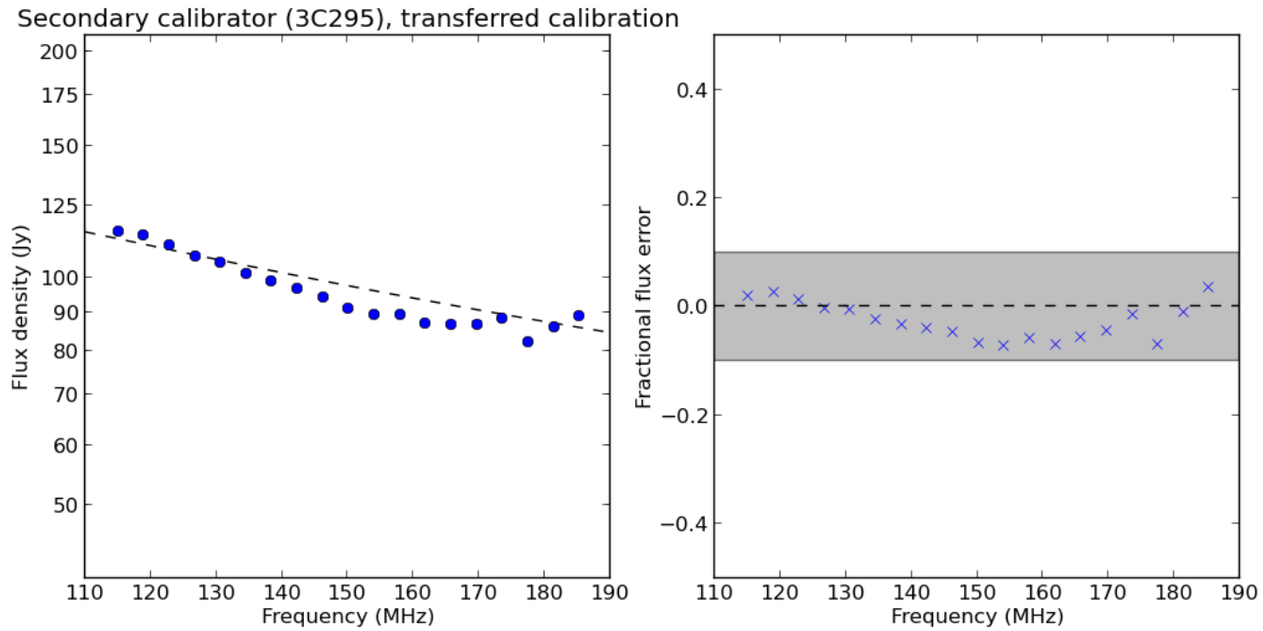


GH & Dijkema (in prep)

  - Production of HBA v1 (early 2016)
    - Verification of LOFAR broadband flux scale across the sky
  - Publication and release of HBA v1 (early 2016)
  - High resolution, polarization (late 2016)
  - Science papers! (starting now)
- LBA: now resuming observational testing

What to look forward to from MSSS

- HBA: upgrade to first all-sky public data release, and beyond…
  - Application of final flux scale definition



GH & Dijkema (in prep)

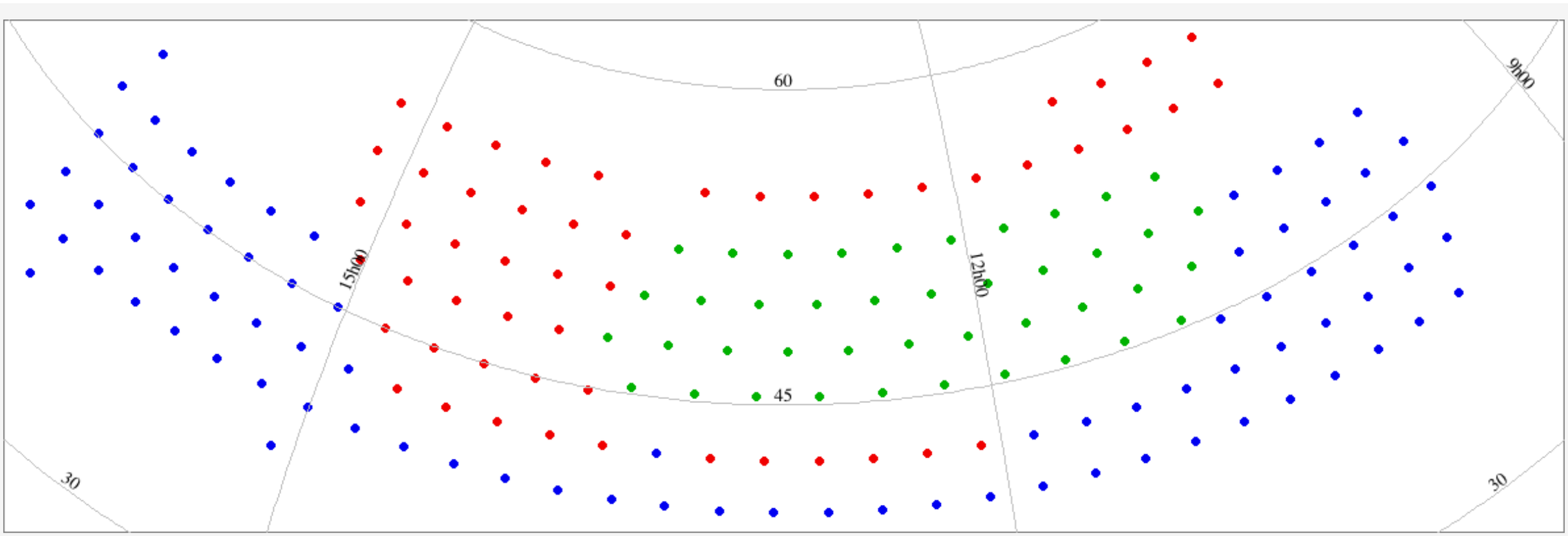
  - Production of HBA v1 (early 2016)
    - Verification of LOFAR broadband flux scale across the sky
  - Publication and release of HBA v1 (early 2016)
  - High resolution, polarization (late 2016)
  - Science papers! (starting now)
- LBA: now resuming observational testing

Deeper LOFAR surveys

Special thanks to Tim Shimwell and Wendy Williams

Observational aims of Tier-1 survey

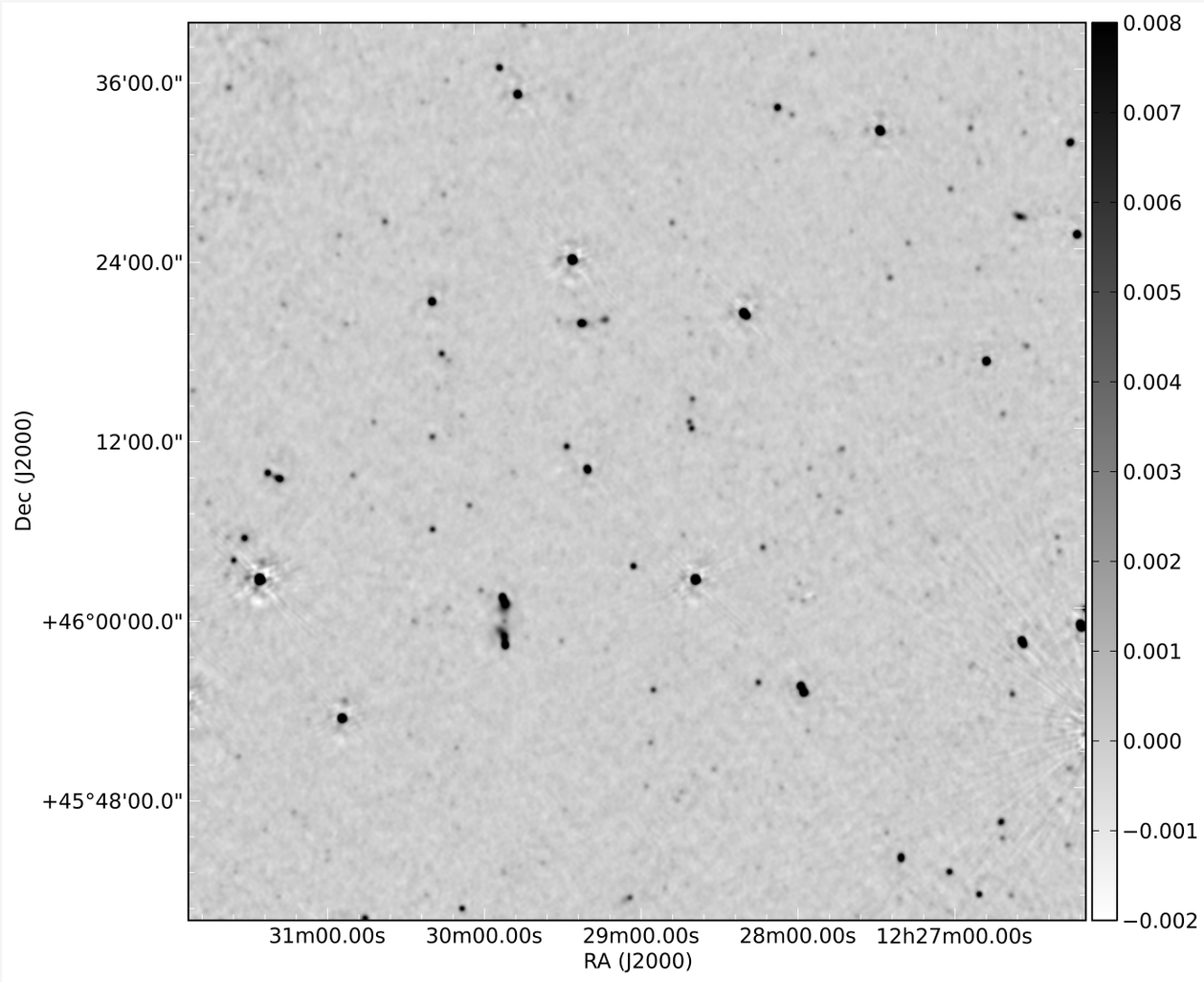
- ~100 μJy/beam sensitivity at ~5” resolution
- 48 MHz bandwidth (120-168 MHz) toward each pointing
- 3200 pointings to cover the northern sky
  (pointings separated by 2.6°; beam FWHM from 3.35° to 4.75°)
- Observations began in June 2014
- ~100 x 8h pointings observed, ~80 more scheduled

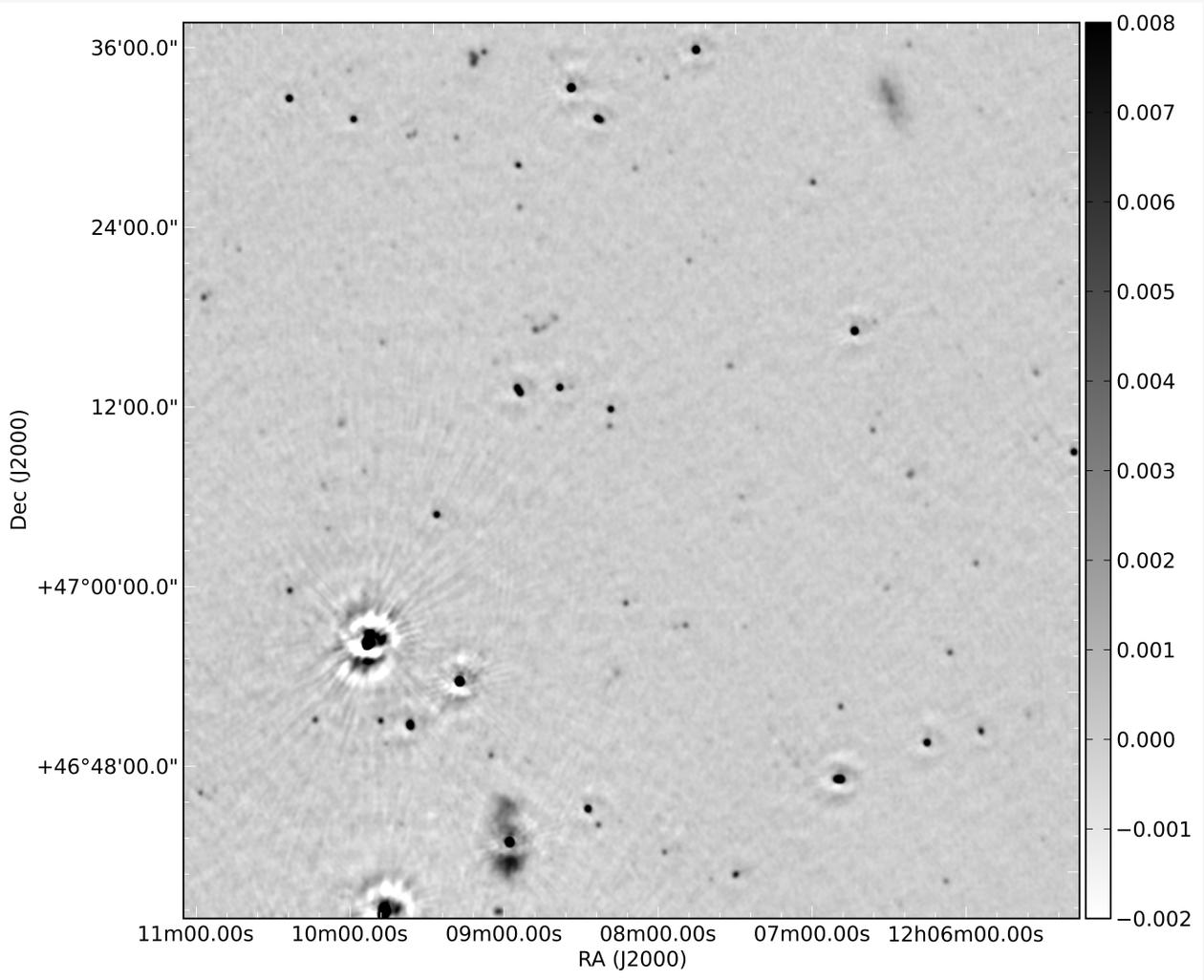


Cycle 2 (green) and cycle 3 (red) and cycle 4 (blue) pointings.

Current (DI) reduction - subimages

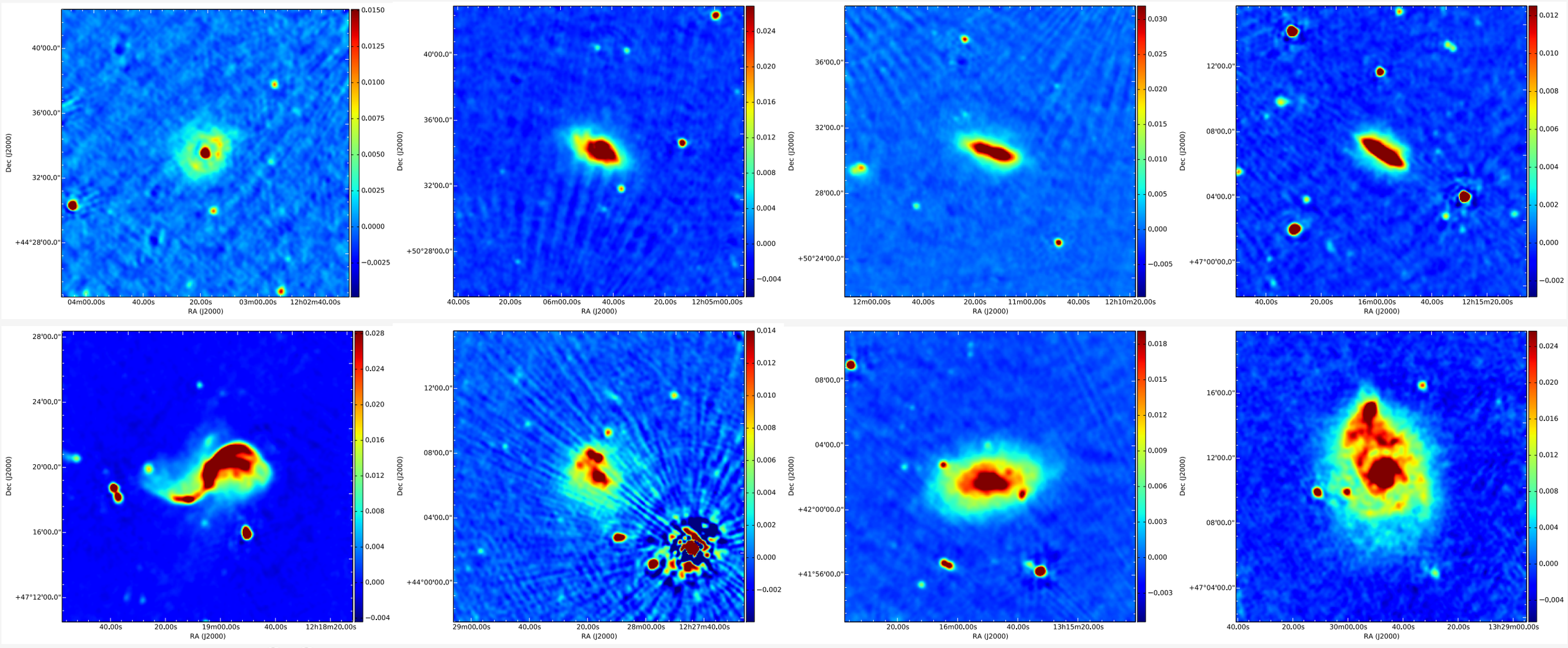
- Current image quality somewhat better than displayed here, thanks to tweaks in the initial processing





Two example degree square regions from the mosaiced image.

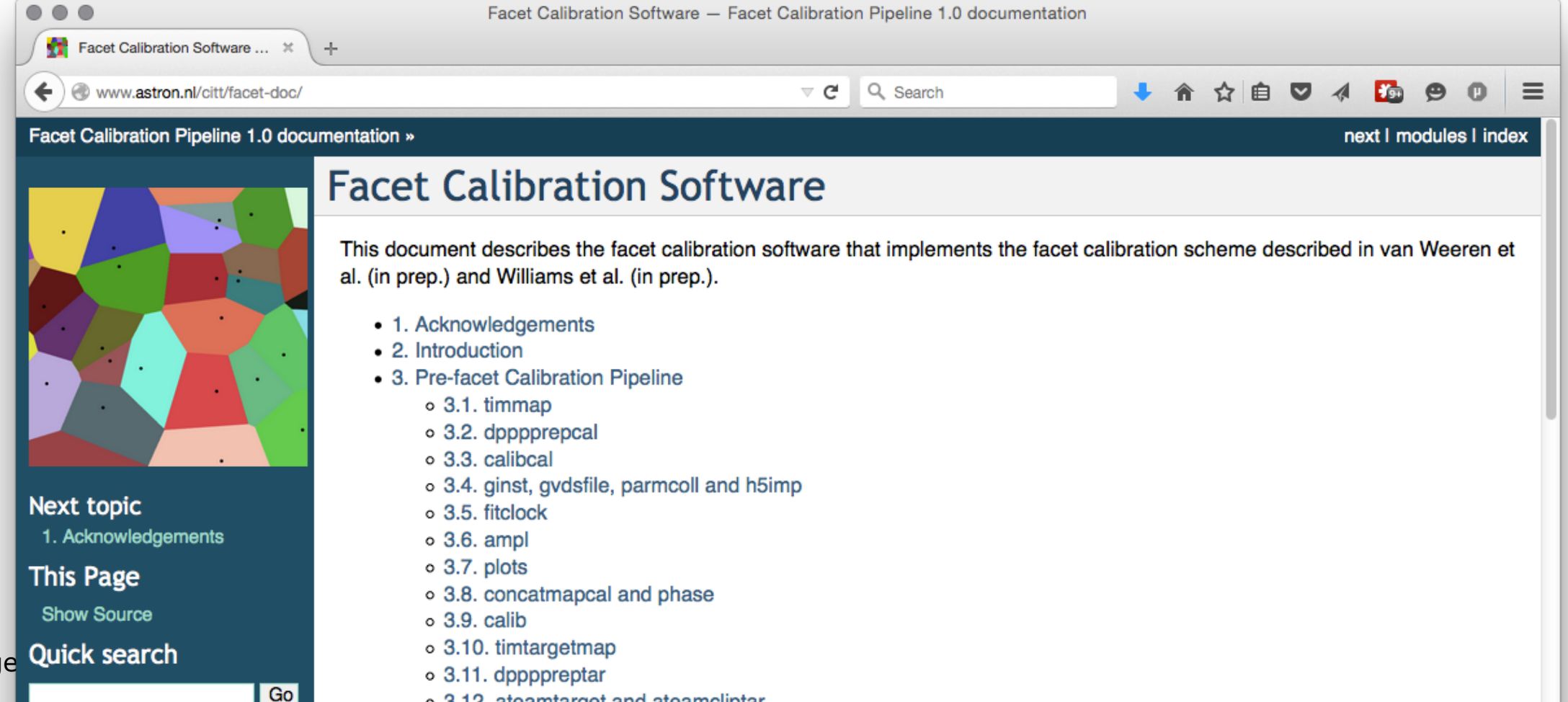
Current (DI) reduction - galaxies

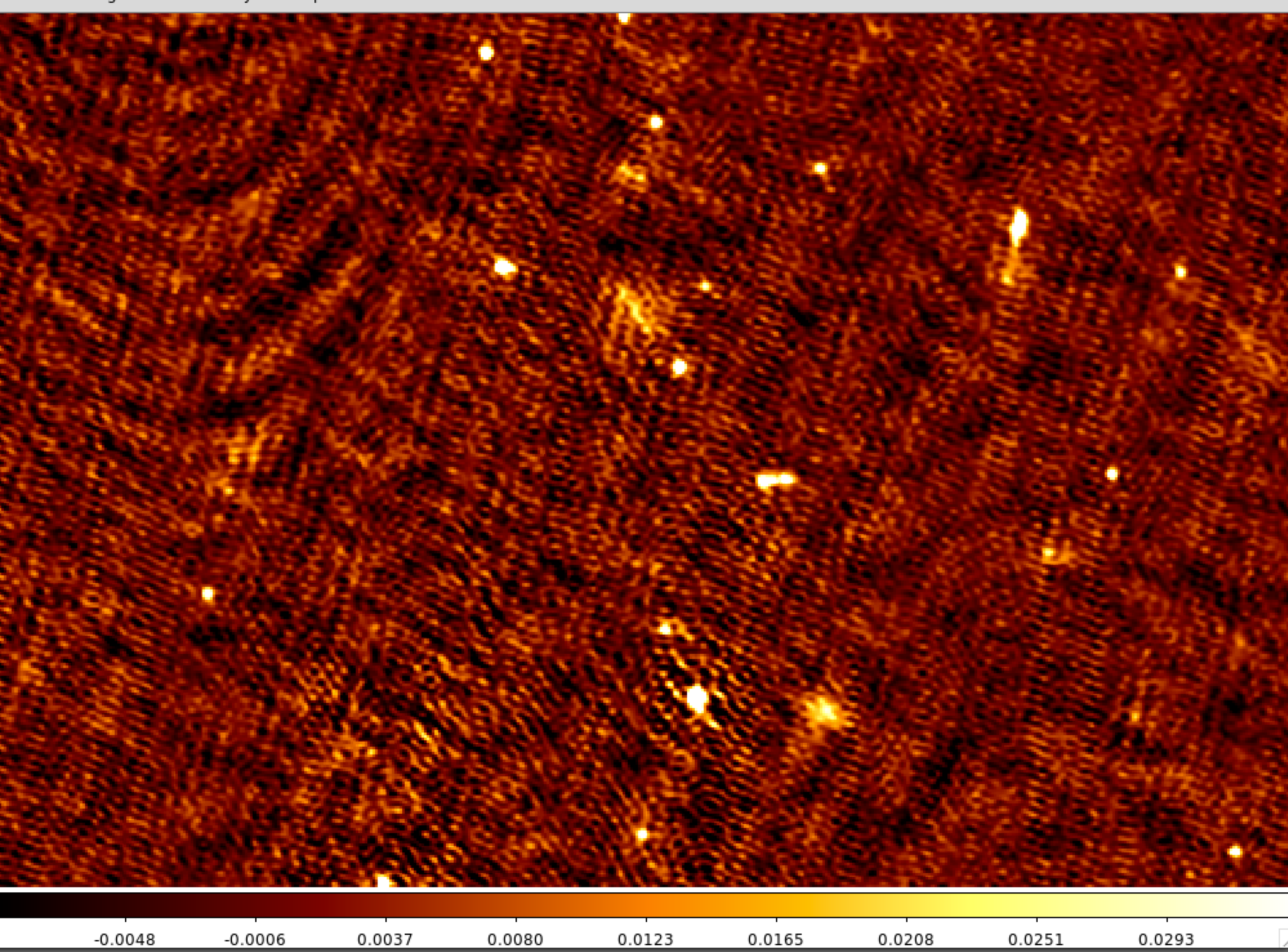


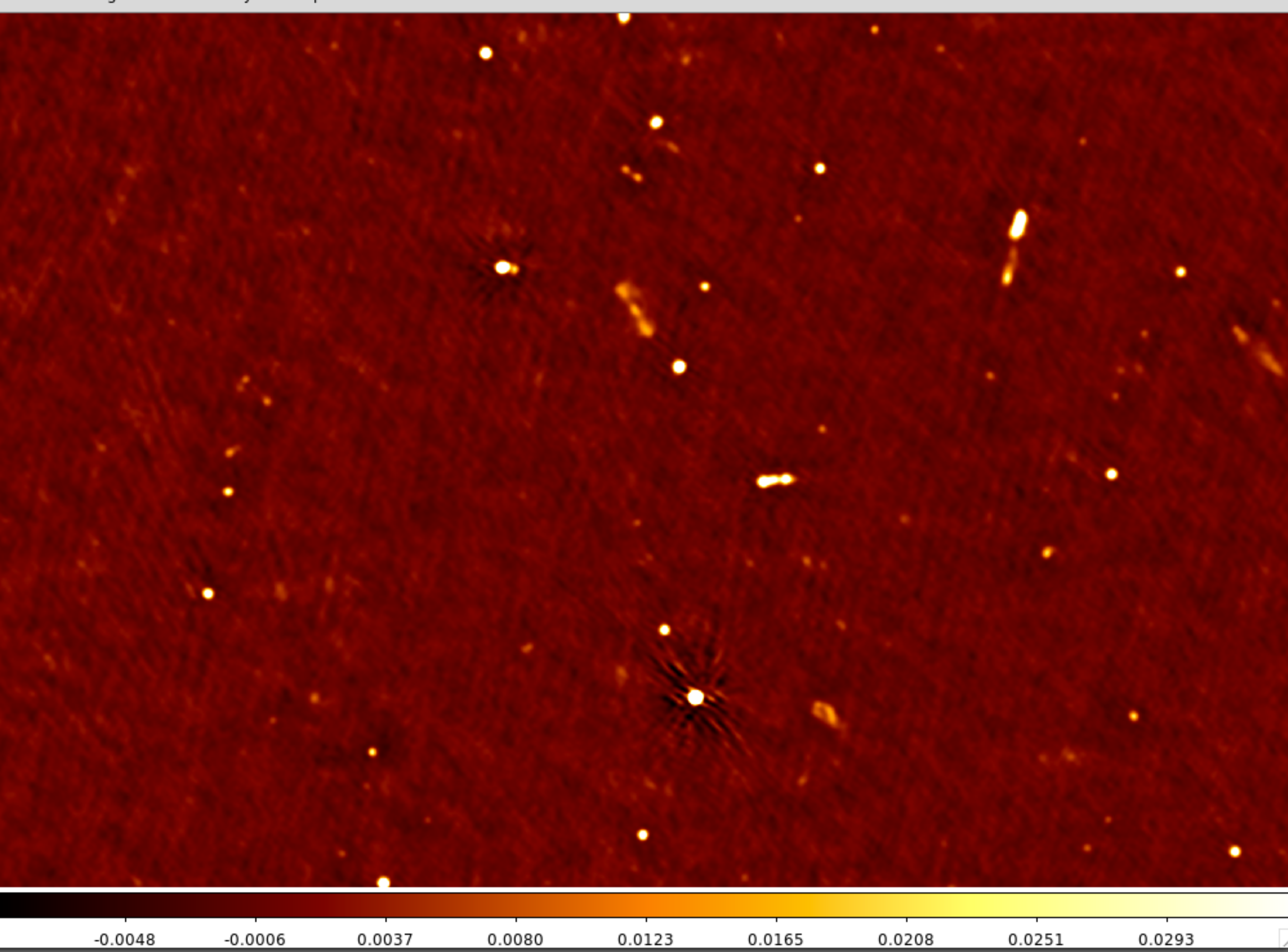
NGC 4051, 4088, 4157, 4217, 4258, 4449, 5055, 5194

Next step: facet calibration

- Facet calibration: direction-dependent calibration and imaging developed by Reinout van Weeren (CfA), Wendy Williams (Leiden)
  - Corrects for ionospheric distortions and beam errors
  - Enables imaging at 5” resolution and 100 μJy/beam rms
- Automated version developed by ASTRON’s Calibration & Imaging Tiger Team, becoming available to the community for general use

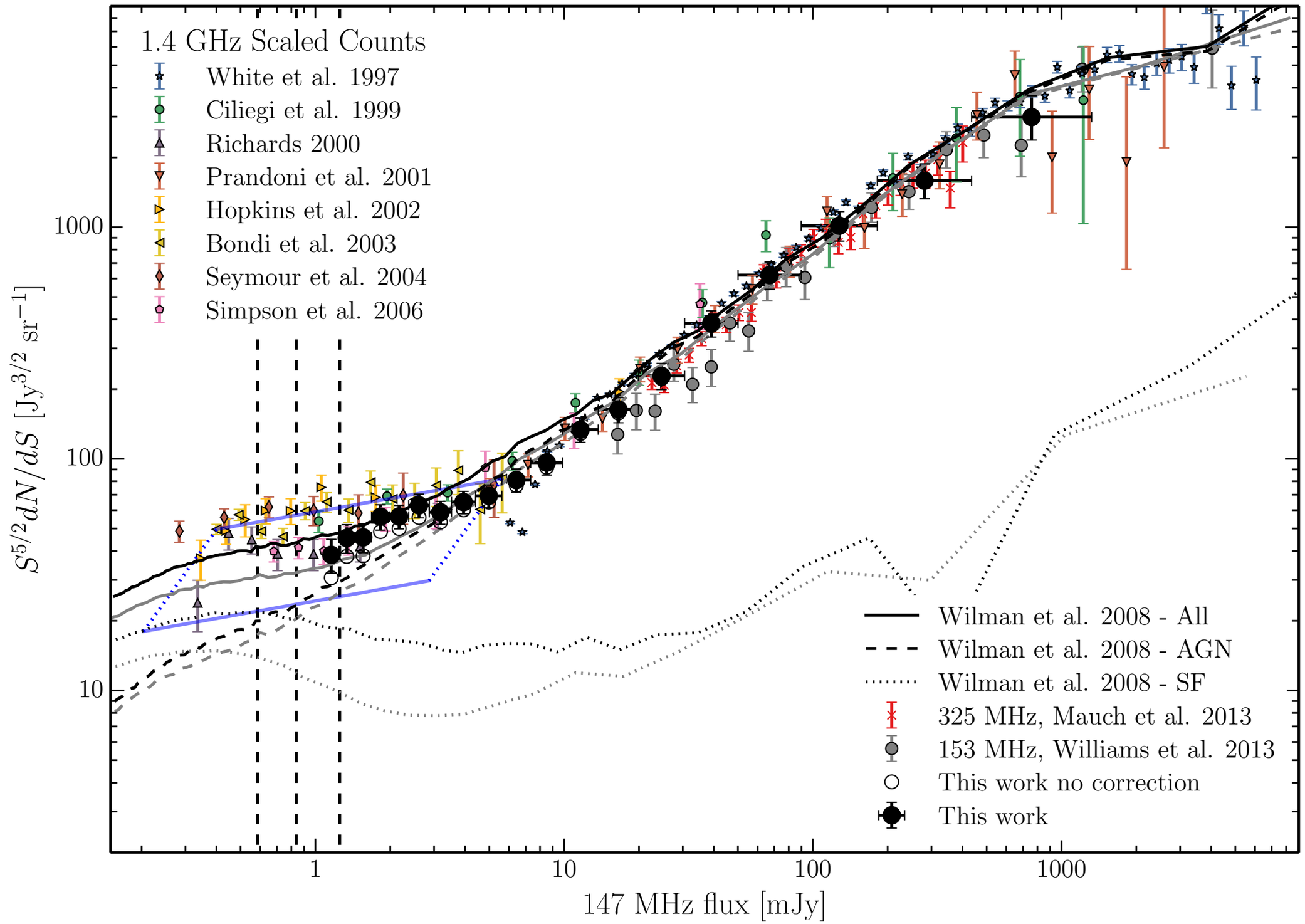



-0.0048
-0.0006
0.0037
0.0080
0.0123
0.0165
0.0208
0.0251
0.0293

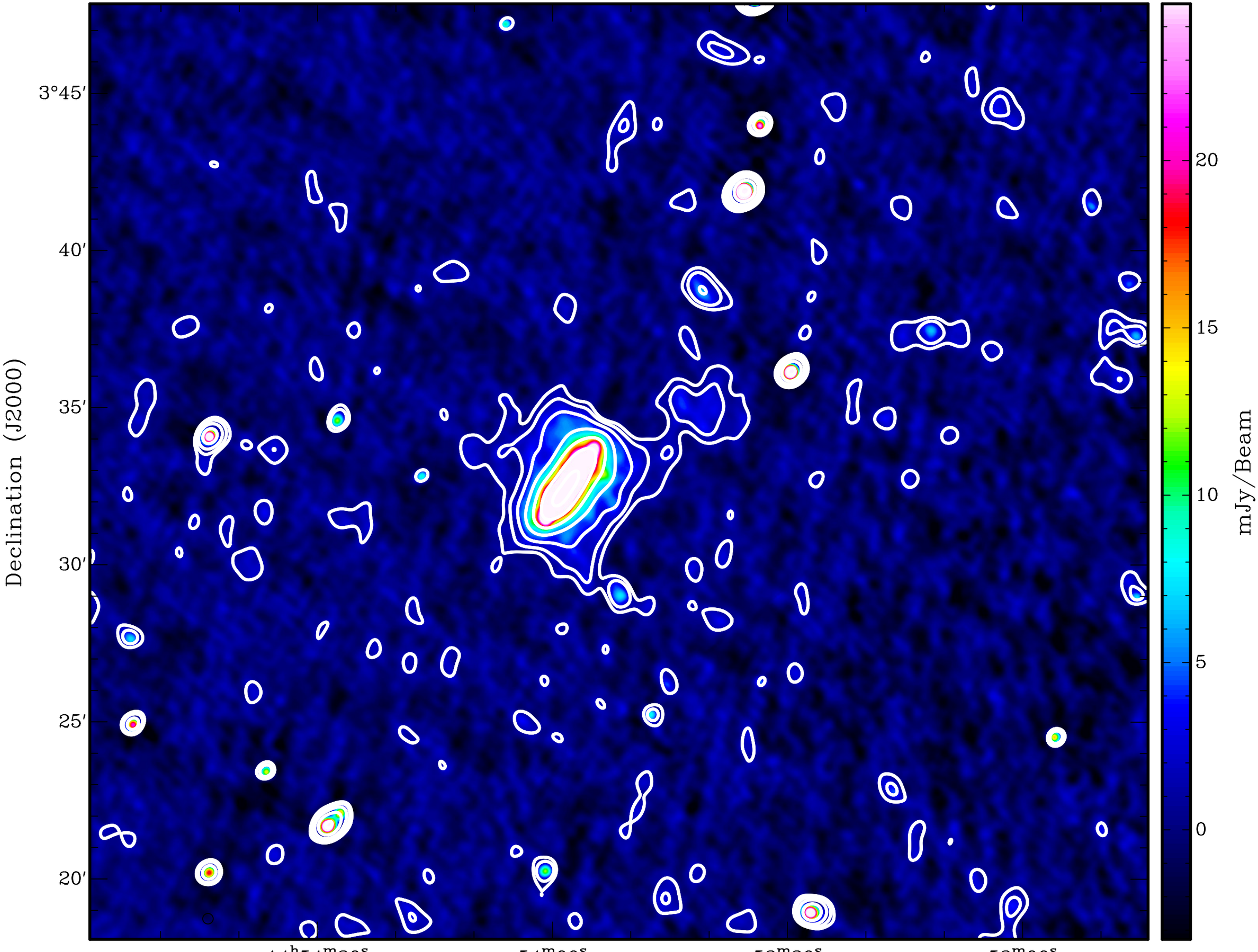

-0.0048
-0.0006
0.0037
0.0080
0.0123
0.0165
0.0208
0.0251
0.0293

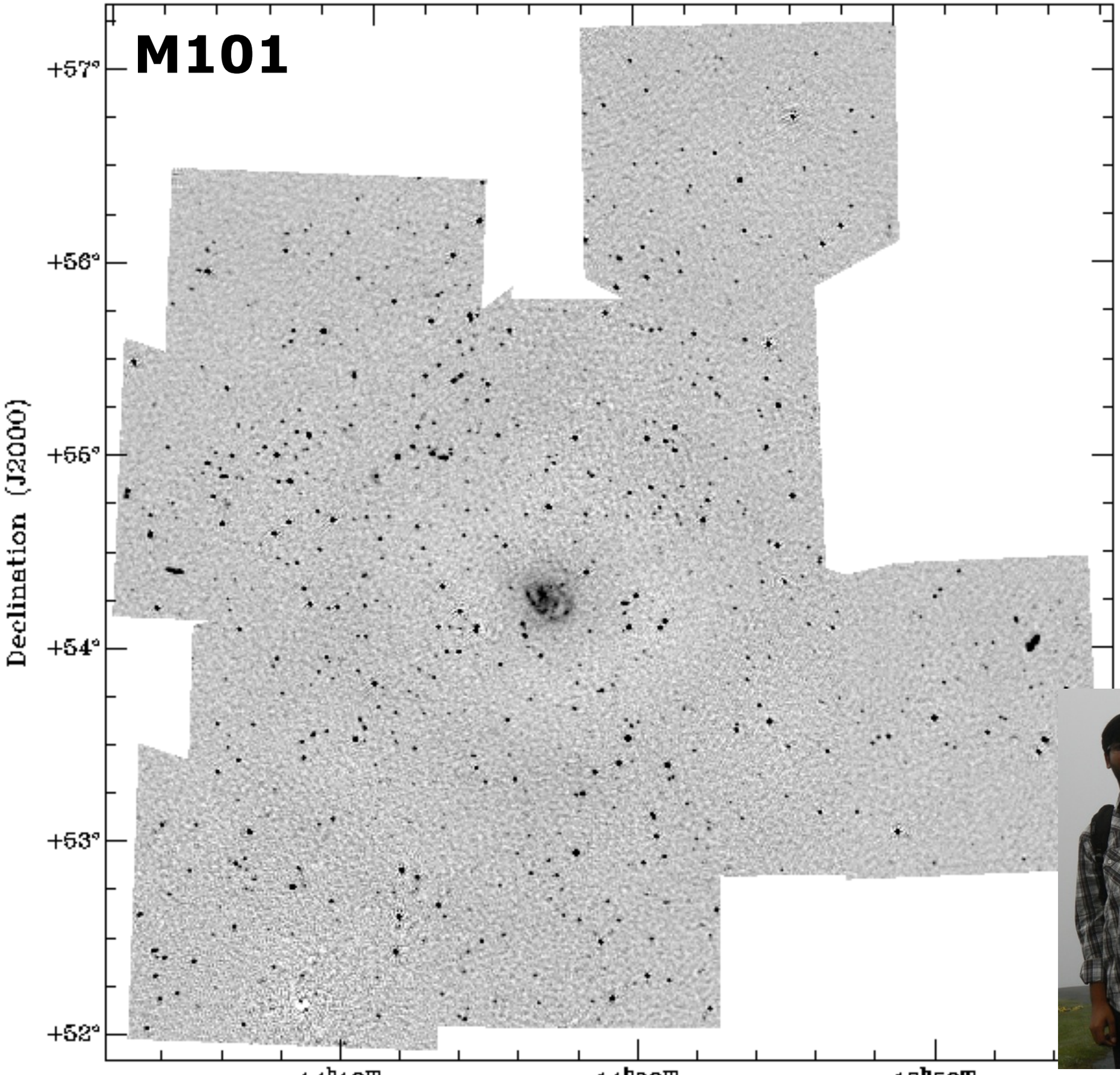
Every LOFAR pointing is a survey!

- Boötes field source counts (Wendy Williams, submitted)



NGC 5775


3°45′
40′
35′
30′
25′
20′
Declination (J2000)
14h54m30s
54m00s
53m30s
53m00s
Right Ascension (J2000)
20
15
10
5
0
mJy/Beam



Sarrvesh Sridhar

LOFAR Surveys

LOFAR ASTRON

MSSS

- MSSS initial data products online now (**vo.astron.nl**)
- MSSS-HBA to be completed and released early next year
- Will initially provide ~150,000 sources at 2’ resolution
  - Later: ~30” resolution, including polarization!

LOFAR TIER-1 SURVEY

- Over the next couple of years we will complete a 4200 deg^2 region (568 pointings) that overlaps both FIRST and SDSS (7.5h < RA < 17.5h; 25d < dec < 65d)
- Volume sufficient to contain e.g. 25 z>6 radio galaxies, 125 Planck clusters, 4000 nearby galaxies and 4000 lensed radio sources
- Will provide ~100 μJy/beam sensitivity at ~5” resolution