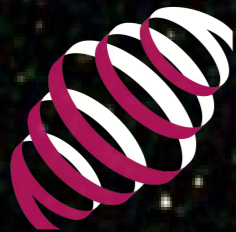


ASTRON

Netherlands Institute for Radio Astronomy



LOFAR



M*S*S*S

MULTIFREQUENCY SNAPSHOT SKY SURVEY

***MSSS: a low-frequency counterpart
to NVSS***

**Jess Broderick (ASTRON)
& George Heald (CSIRO Astronomy
and Space Science)**

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 $\sim 10^\circ$ beams: 5

Test observations resuming

MSSS-HBA



Frequency: 119-158 MHz
(8 x 2 MHz bands)

Resolution: 45 arcsec

Sensitivity: ≤ 5 mJy/beam

Area: 20,000 square degrees

Number of Fields: 3616

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

Observations 100% complete

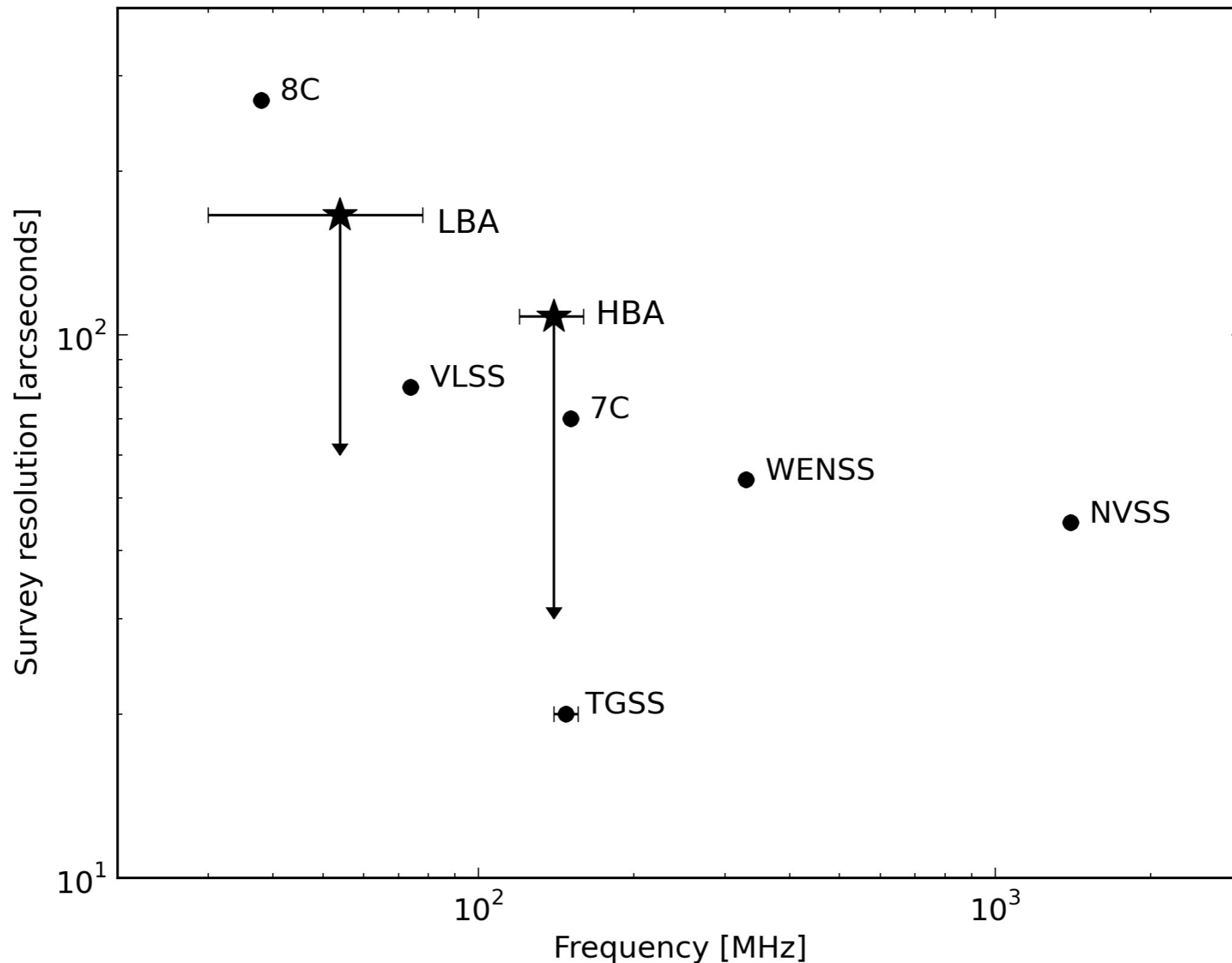
Thanks to the MSSS Team!



Björn Adebahr, Mike Bell, Laura Bîrzan, Annalisa Bonafede, Justin Bray, Rene Breton, Jess Broderick, Joe Callingham, Therese Cantwell, Dario Carbone, Patti Carroll, Yvette Cendes, Krzysztof Chyzy, Alex Clarke, Judith Croston, Soobash Daiboo, Francesco de Gasperin, Emilio Enriquez, Richard Fallows, Jamie Farnes, Chiara Ferrari, Jon Gregson, Gulay Gurkan Uygun, Martin Hardcastle, Jeremy Harwood, Tom Hassall, George Heald, Volker Heesen, Jason Hessels, Andreas Horneffer, Marco Iacobelli, Vibor Jelić, David Jones, Wojciech Jurusik, Georgi Kokotanekov, Giulia Macario, John McKean, Poppy Martin, Carlos Martinez, Leah Morabito, Cornelia Müller, David Mulcahy, Błażej Nikiel-Wroczyński, Natalia Nowak, André Offringa, Emanuela Orrú, Rosita Paladino, V.N. Pandey, Gosia Pietka, Roberto Pizzo, Mamta Pommier, Peeyush Prasad, Luke Pratley, David Rafferty, Aarthi Ramesh, 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, Sander ter Veen, Jonas Trüstedt, Valentina Vacca, Alexander van der Horst, Bas van der Tol, Sjoert van Velzen, Reinout van Weeren, Glenn White, Wendy Williams, Michael Wise



Heald et al. (2015)



* **Improved angular resolution** gives MSSS a niche in the scientific literature, and significant legacy value. **New target → 45 arcsec**, i.e. identical to the 1.4 GHz NRAO VLA Sky Survey (NVSS; Condon et al. 1998). **Only modest computing requirements needed for re-imaging.**

A quick comparison

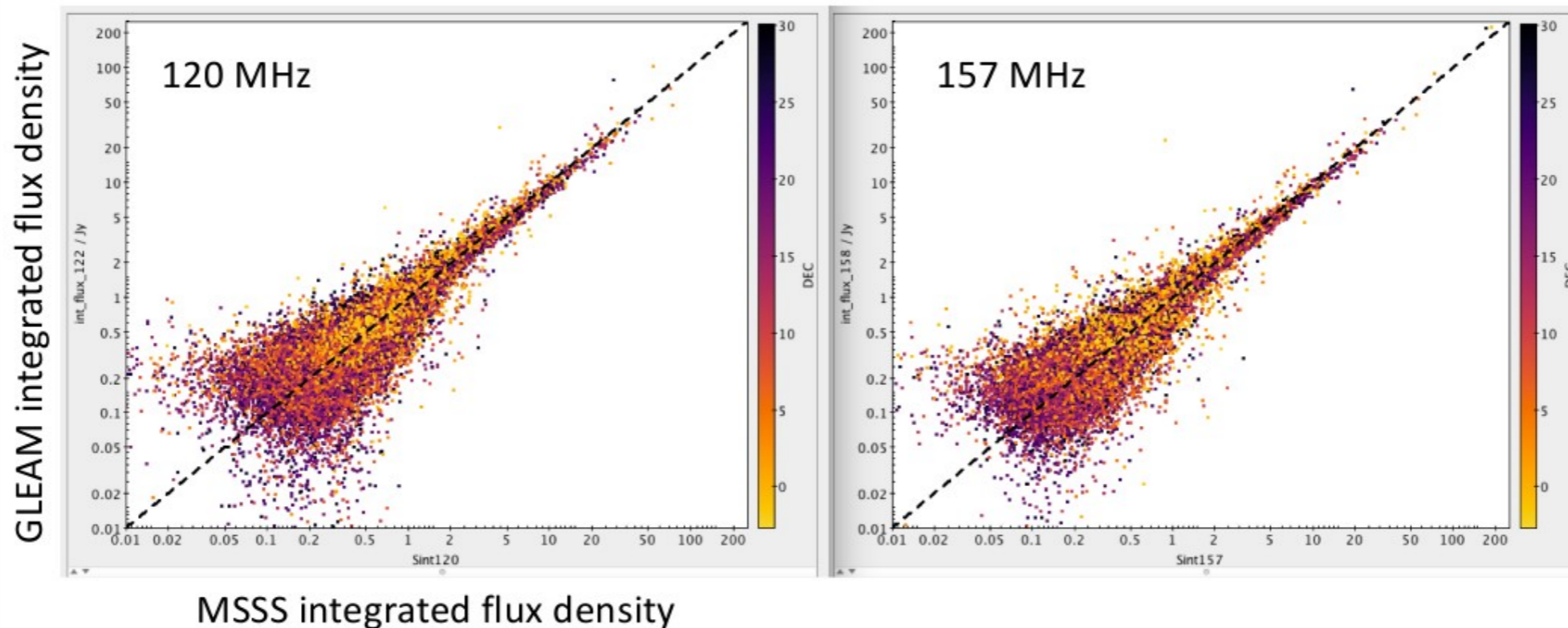


Survey	Sky coverage (deg ²)	Frequency Coverage (MHz)	Resolution (arcsec)	RMS noise level (mJy beam ⁻¹)	No. sources detected
MSSS-HBA (Heald et al. in prep.)	20 600	119-158 MHz (8 x 2 MHz)	45	<5	>350 000
TGSS (Intema et al. 2017)	36 900	140-156	25	3.5	624 000
GLEAM (Hurley-Walker et al. 2017)	24 800	72-231	120	10	307 000

* MSSS highly complementary to the MWA GLEAM survey (Hurley-Walker et al. 2017) and the TIFR GMRT Sky Survey (TGSS; Intema et al. 2017). These three surveys will provide a truly all-sky interferometric low-frequency radio catalogue!

* MSSS verification field (MVF): Heald et al. 2015, A&A, 582, A123 (2 arcmin resolution).

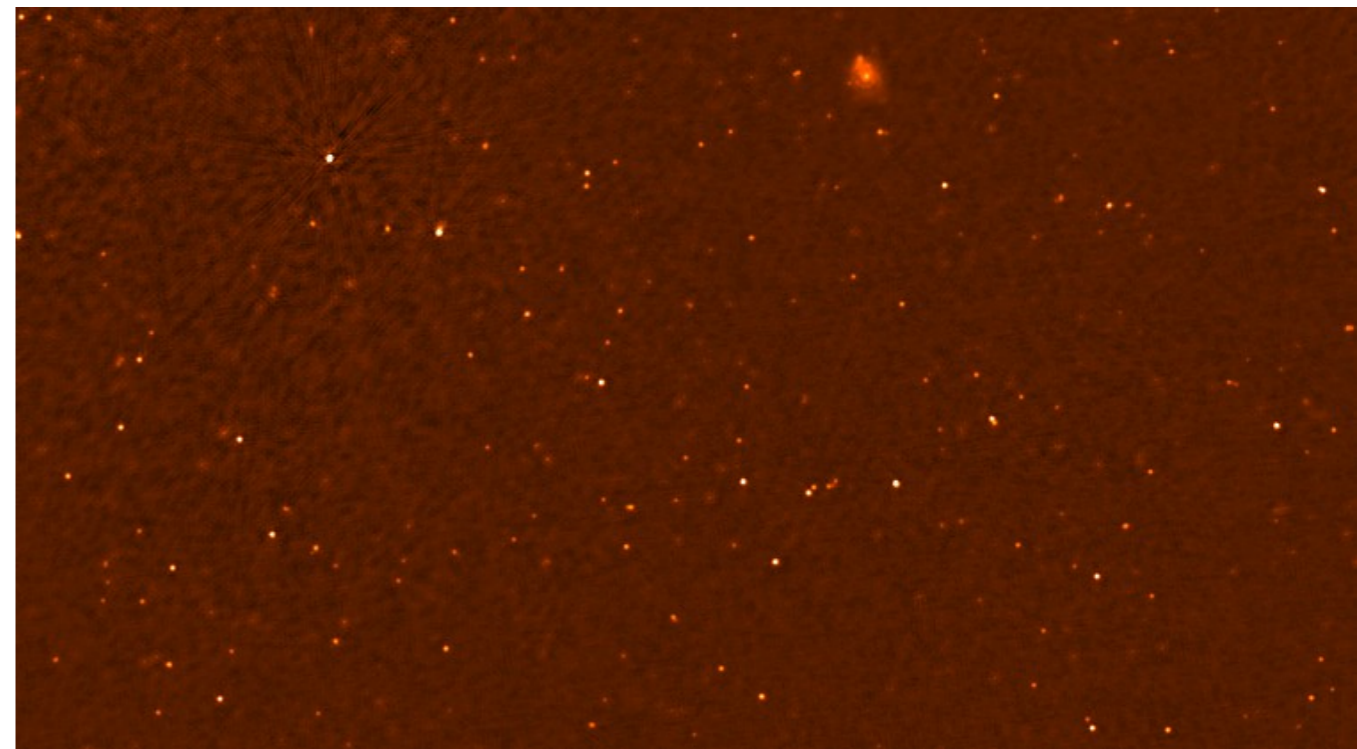
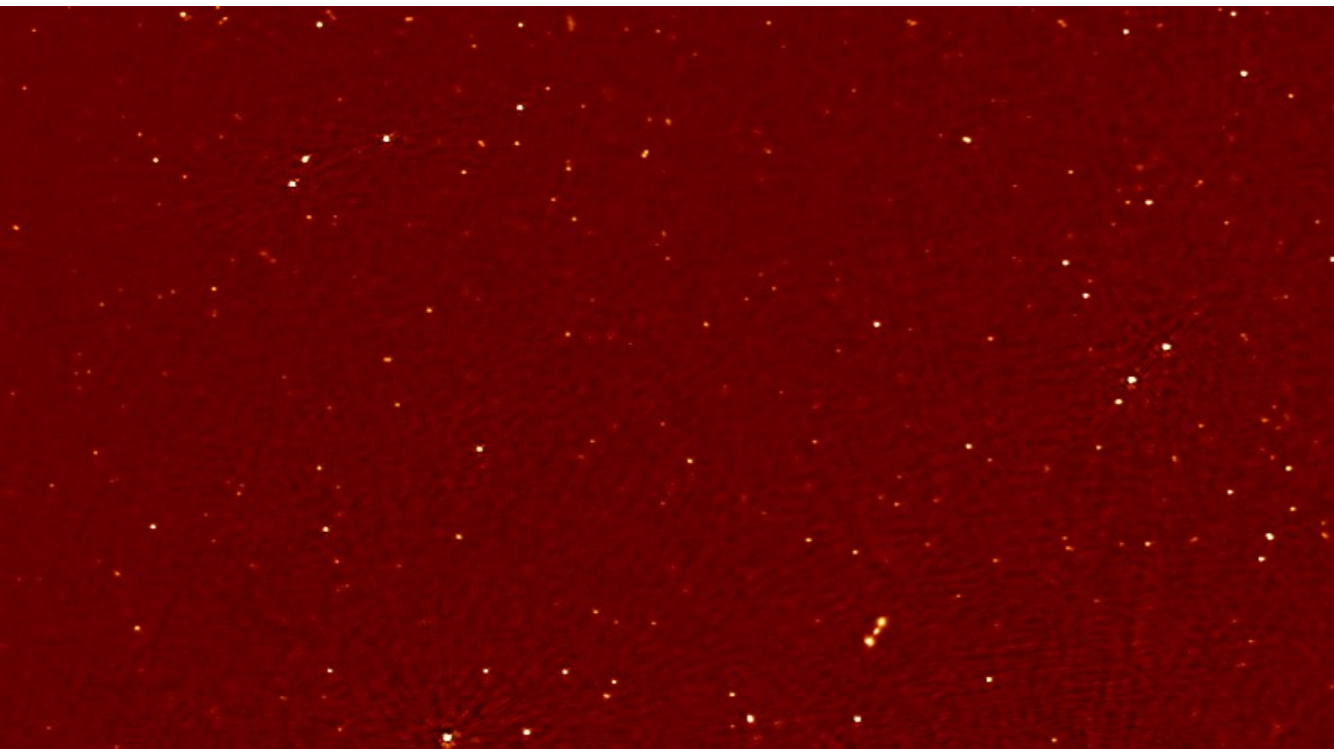
* HBA catalog 'v0.3': internal release late 2016, 138,000 sources, resolution ~ 3 -3.5 arcmin. New flux scale bootstrapping technique (Hardcastle et al. 2016) applied and verified. In-band flux densities now considered reliable; reliability of flux scale checked through cross-matching with GLEAM. **Important step forward!**



- * Now working in earnest to re-image the HBA survey at 45-arcsec resolution (i.e. working towards a 'v1' public release later this year).
- * Standard imaging product: 100 deg² mosaics, each composed of tens of individual HBA fields. Total number: 212.
- * Imaging with WSClean (Offringa et al. 2014) with full-band deconvolution. Mosaicking with bespoke script (pyrap.images). Flux scale bootstrapping technique as in v0.3. Source finding with PyBDSF.
- * Using previous direction-independent calibration solutions. No further self-calibration.
- * Good progress made over the last few months, prior to very recent CEP3 cluster upgrade. Most of sky $> +35^\circ$ Dec. re-imaged. Approximately 30 mosaics generated; initial assessments of image quality and reliability. Some inconsistencies across survey area currently being addressed. TGSS used as a reference catalogue.

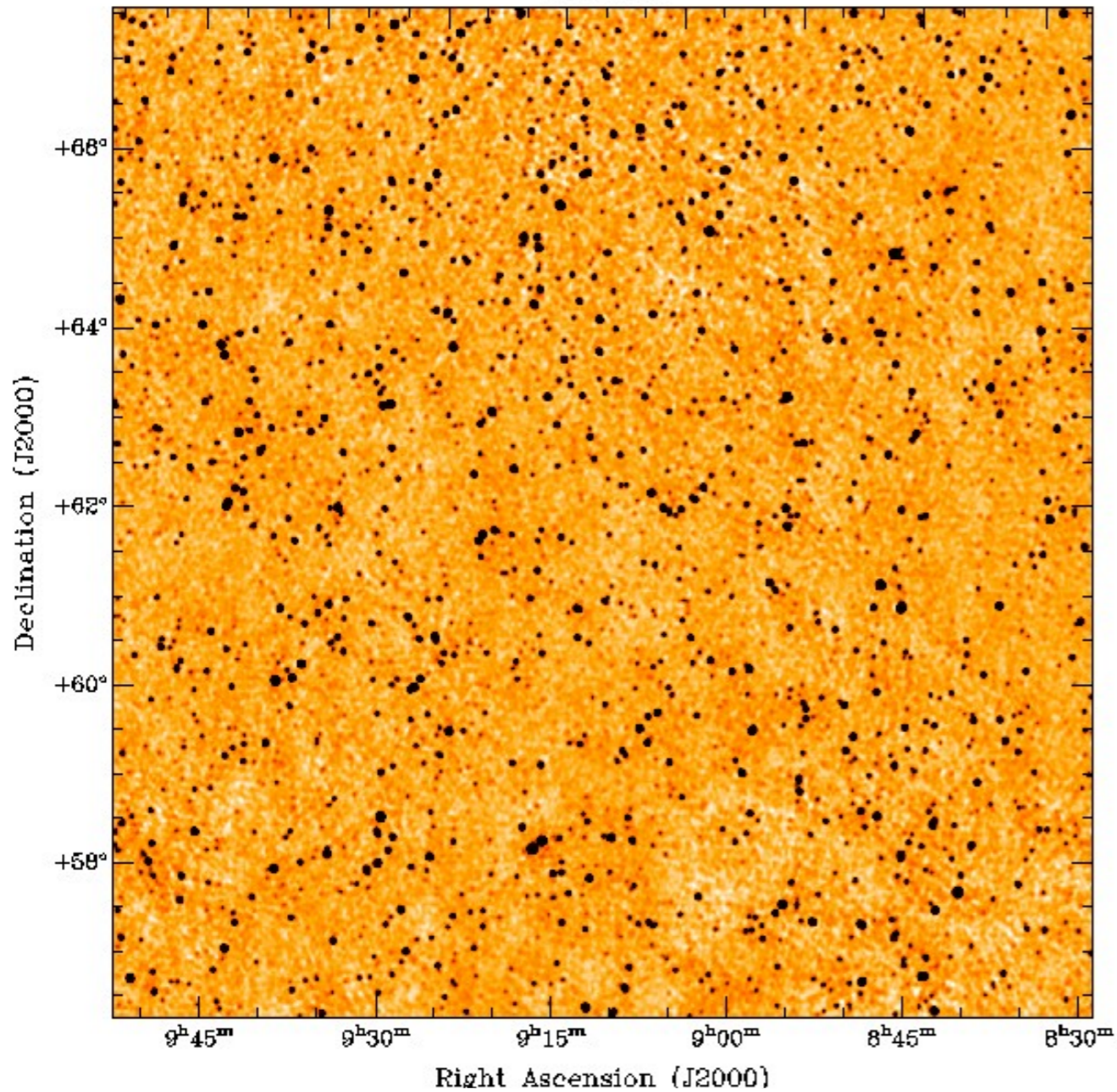
* Re-imaging team: **Chris Riseley, Gulay Gurkan Uygun,** George Heald, Rene Breton, Martin Hardcastle, Alex Clarke, Joe Callingham, Błażej Nikiel-Wroczyński, Jess Broderick.

* Also thanks to Krzysztof Chyży, Glenn White, Marco Iacobelli, Emanuela Orrú and Aleksandar Shulevski for early feedback.



Riseley, Gurkan Uygun, Heald

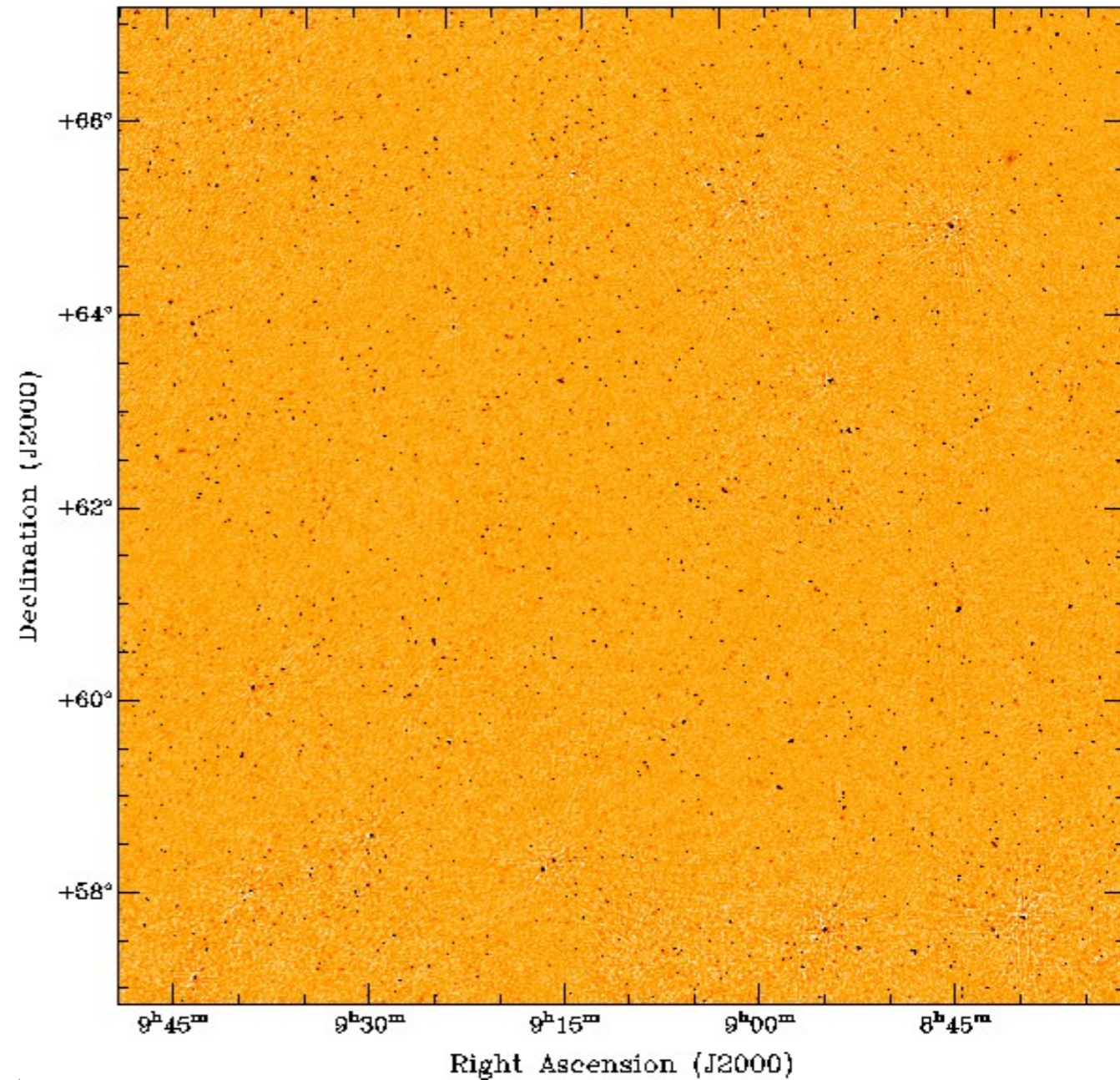
M138+63



Resolution 185 arcsec

RMS 10.5 mJy beam⁻¹

M138+63

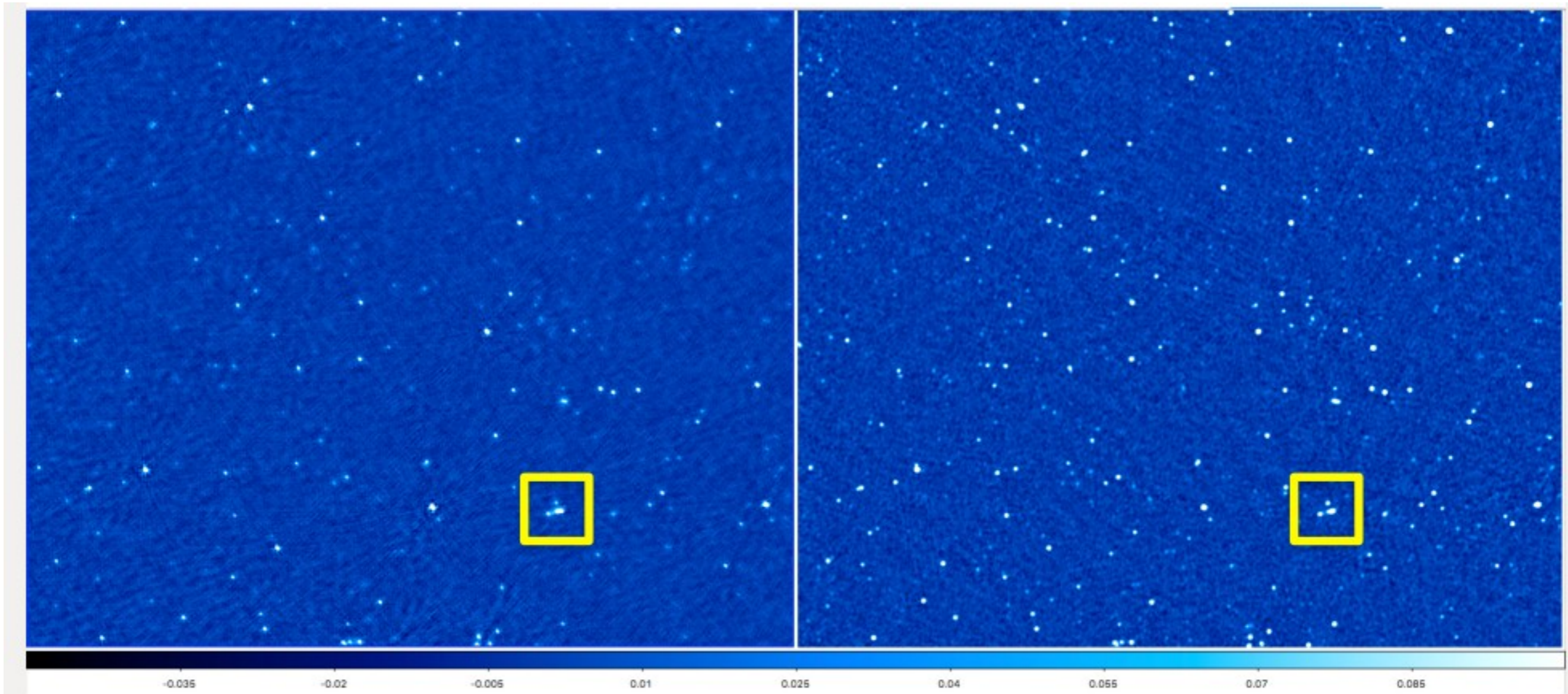


Resolution 45 arcsec

RMS 2.6 mJy beam⁻¹

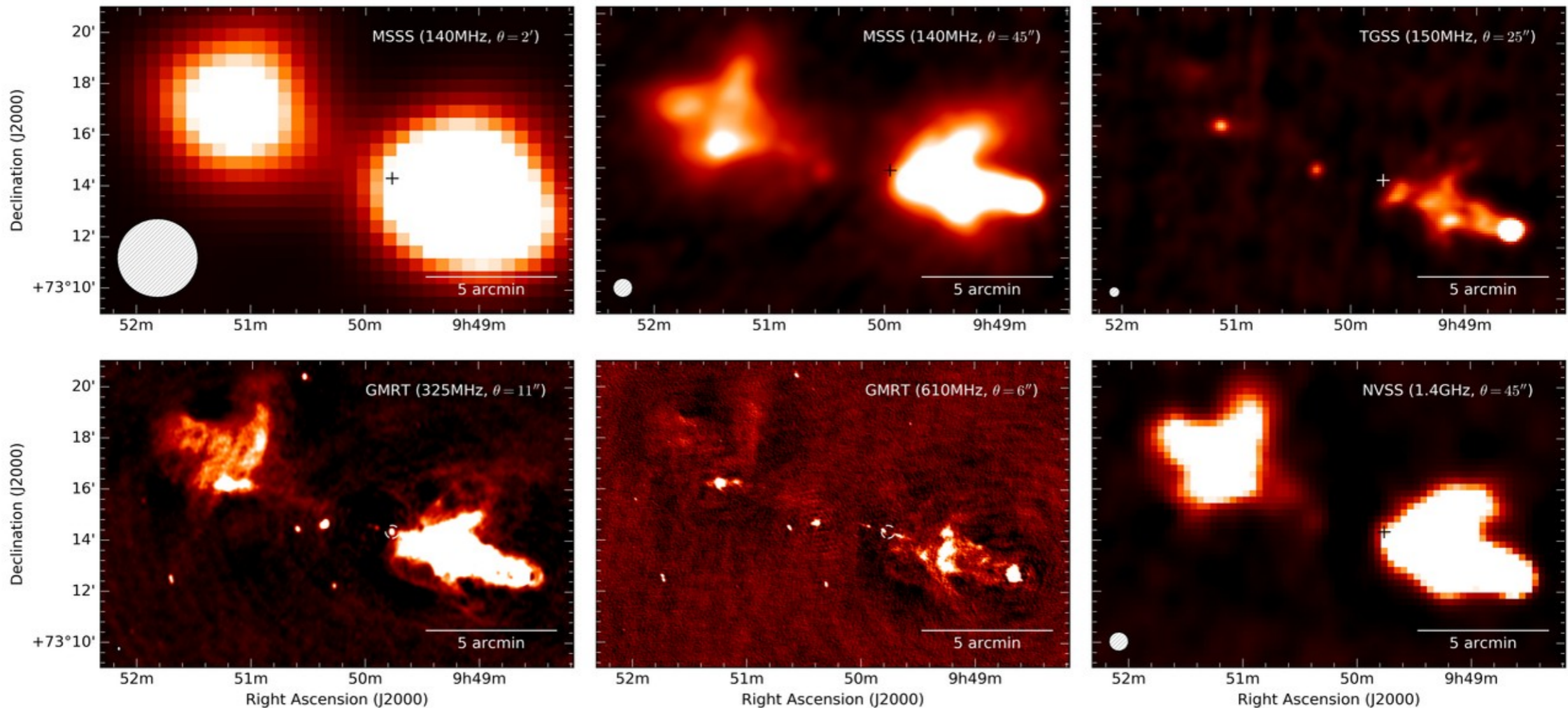
MSSS 45 arcsec

NVSS 45 arcsec



Riseley, Gurkan Uygun, Heald

Riseley



* 4C +73.08 ($z = 0.0581$). GRG; projected linear size 1.38 Mpc.

* 45-arcsec MSSS image comparable to NVSS map; much better in terms of resolving structure than previous 2-arcmin image. MSSS recovering more diffuse emission than in TGSS.

MSSS science

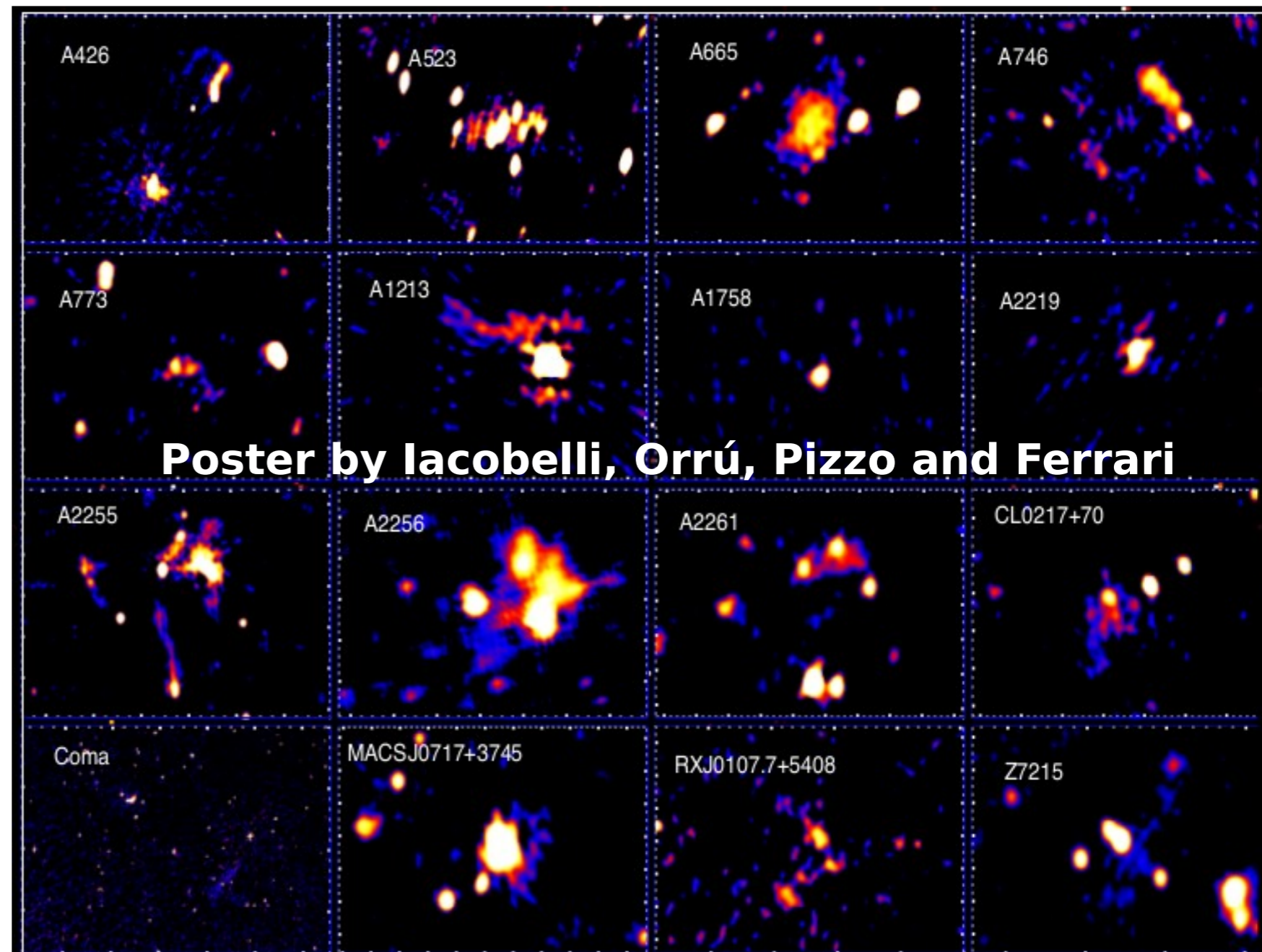


* Planning under way for 37 science projects (current internal review by both myself and George Heald).

* Examples (see the LOFAR wiki for further details):

- SNRs and HII regions
- Galaxy SEDs (talk by Krzysztof Chyzy)
- Cluster halos
- Pulsars
- Transients (e.g. MSSS-LBA NCP transient; Stewart et al. 2016)
- GRGs

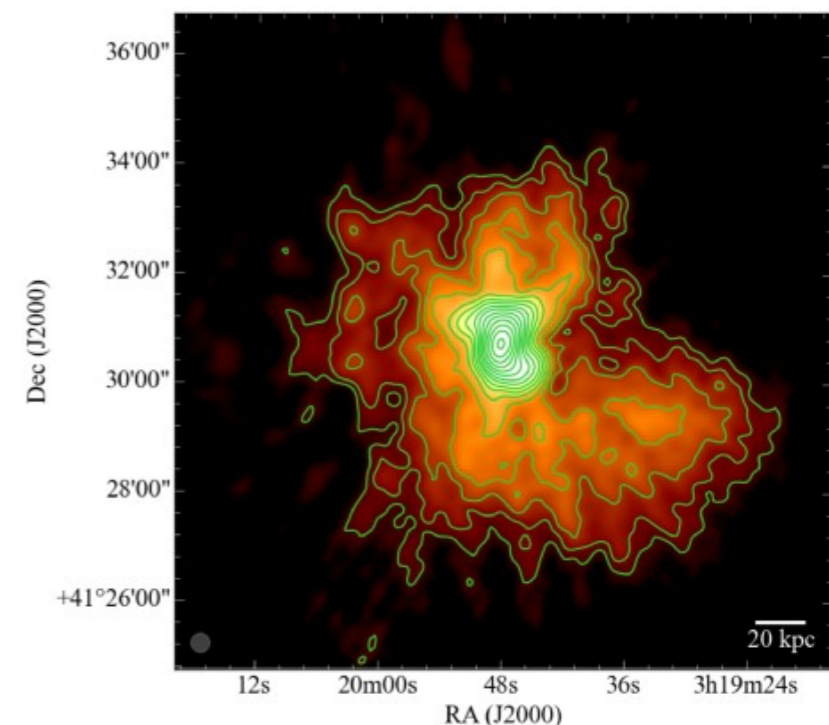
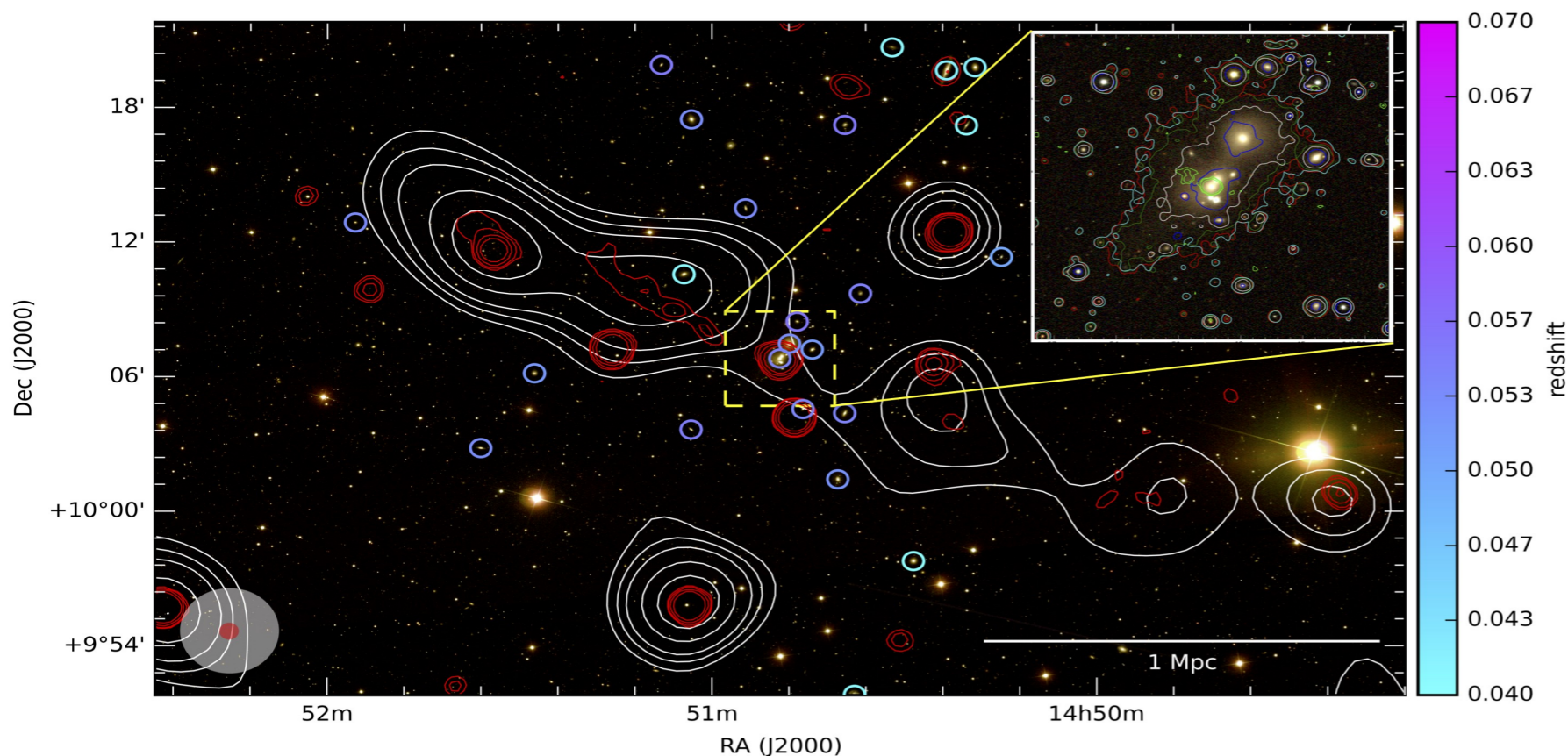
* Early science for MSSS team members, prior to public release.



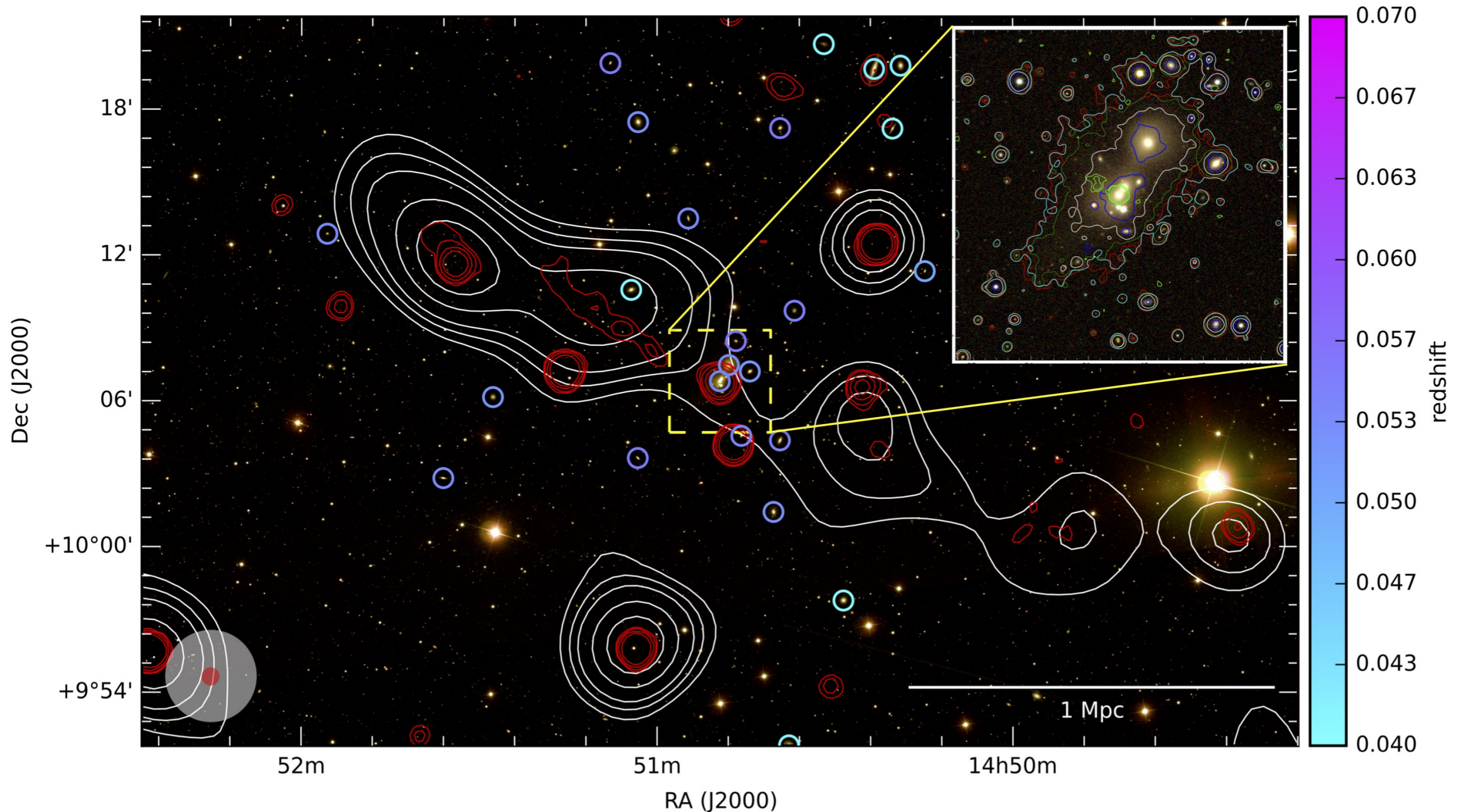
* Alex Clarke et al., 'Discovery of a 2.56 Mpc giant radio galaxy associated with a disturbed galaxy group', 2017, A&A, 601, A25 (arXiv:1702.01571)

and

* Georgi Kokotanekov et al., 'The Scaling Relation between AGN Cavity Power and Radio Luminosity at Low Radio Frequencies', 2017, A&A, in press; arXiv:1706.00225)



Clarke et al.

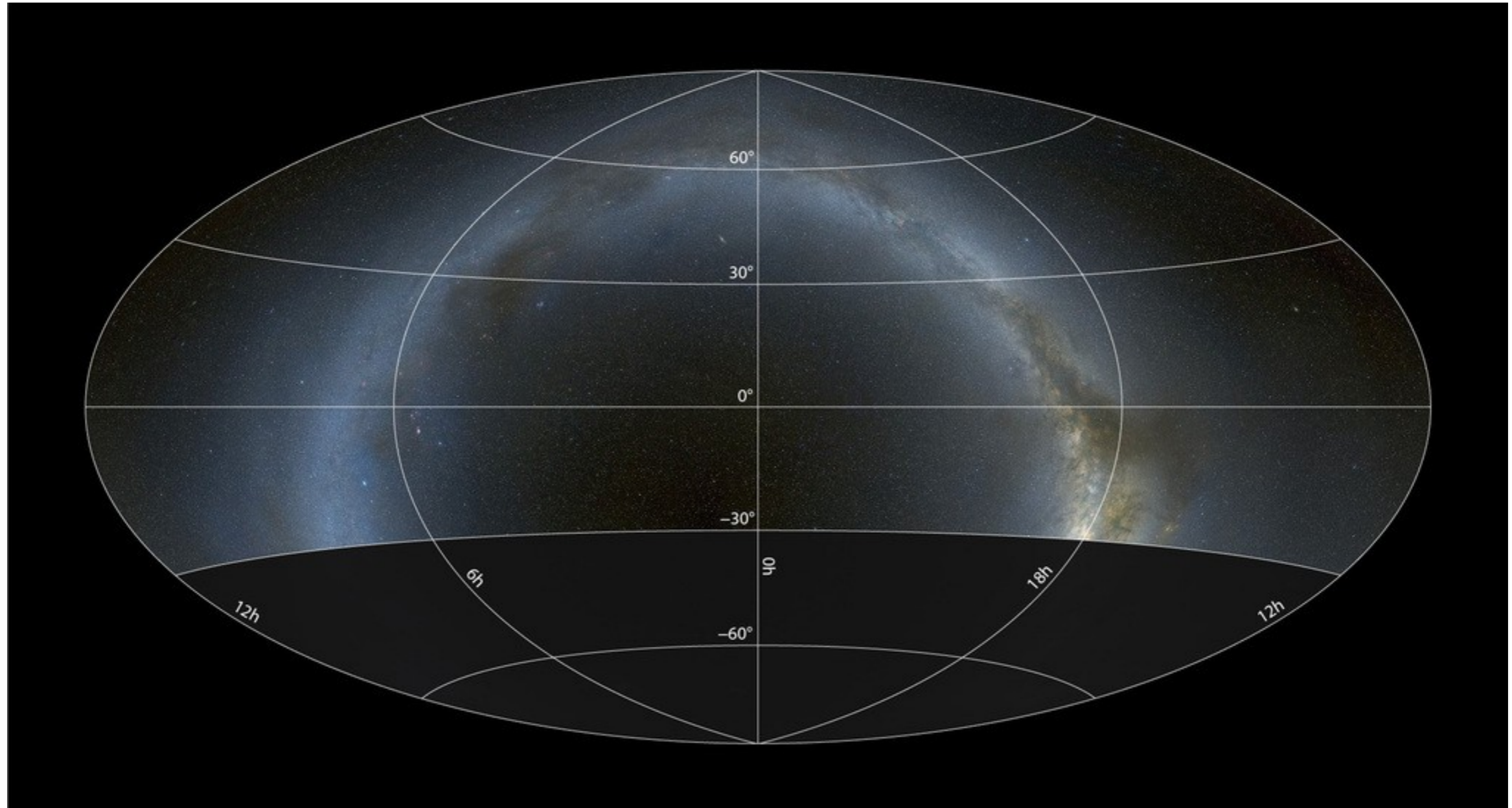


* ASTRON image of the day 2017 Feb. 10. LOFAR (white) and NVSS (red) contours overlaid on composite SDSS image. Inset: FIRST (lime green) contours; other contours smoothed SDSS bands.

* Projected linear size 2.56 Mpc; physical size > 2.72 Mpc. One of the largest known radio galaxies!

- * MAPS: MSSS All-sky Polarisation Survey
- * Further processing of MSSS data on Radboud University Nijmegen cluster ('Coma').
- * High angular resolution → avoid beam depolarisation.
- * Superb Faraday depth resolution ($\sim 1.3 \text{ rad m}^{-2}$).
- * Good inner *uv* coverage → sensitive to Galactic foreground.
- * Range of science topics, including Galactic ISM magnetism, RM grids, searches for low-frequency polarisation calibrators, depolarisation of radio galaxies, and searches for pulsars and brown dwarfs.

David Mulcahy, Jamie Farnes, George Heald, Andreas Horneffer and the MSSS team, in collaboration with the LOFAR magnetism key science project



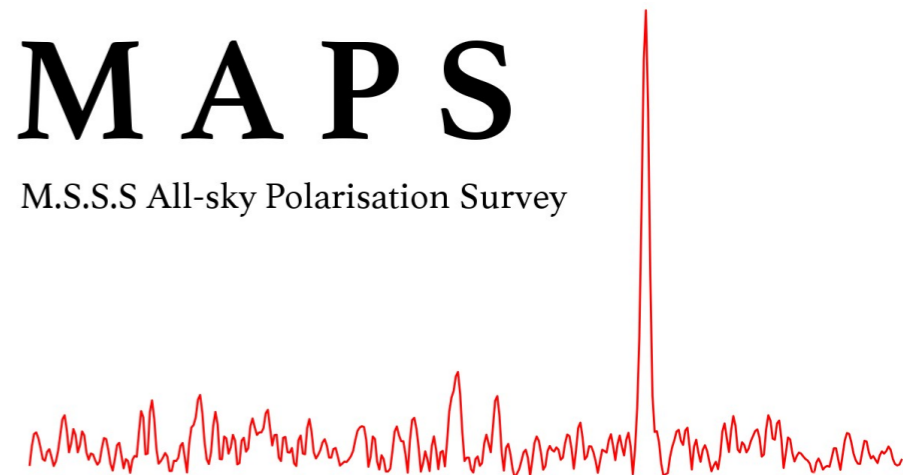
Farnes, Mulcahy

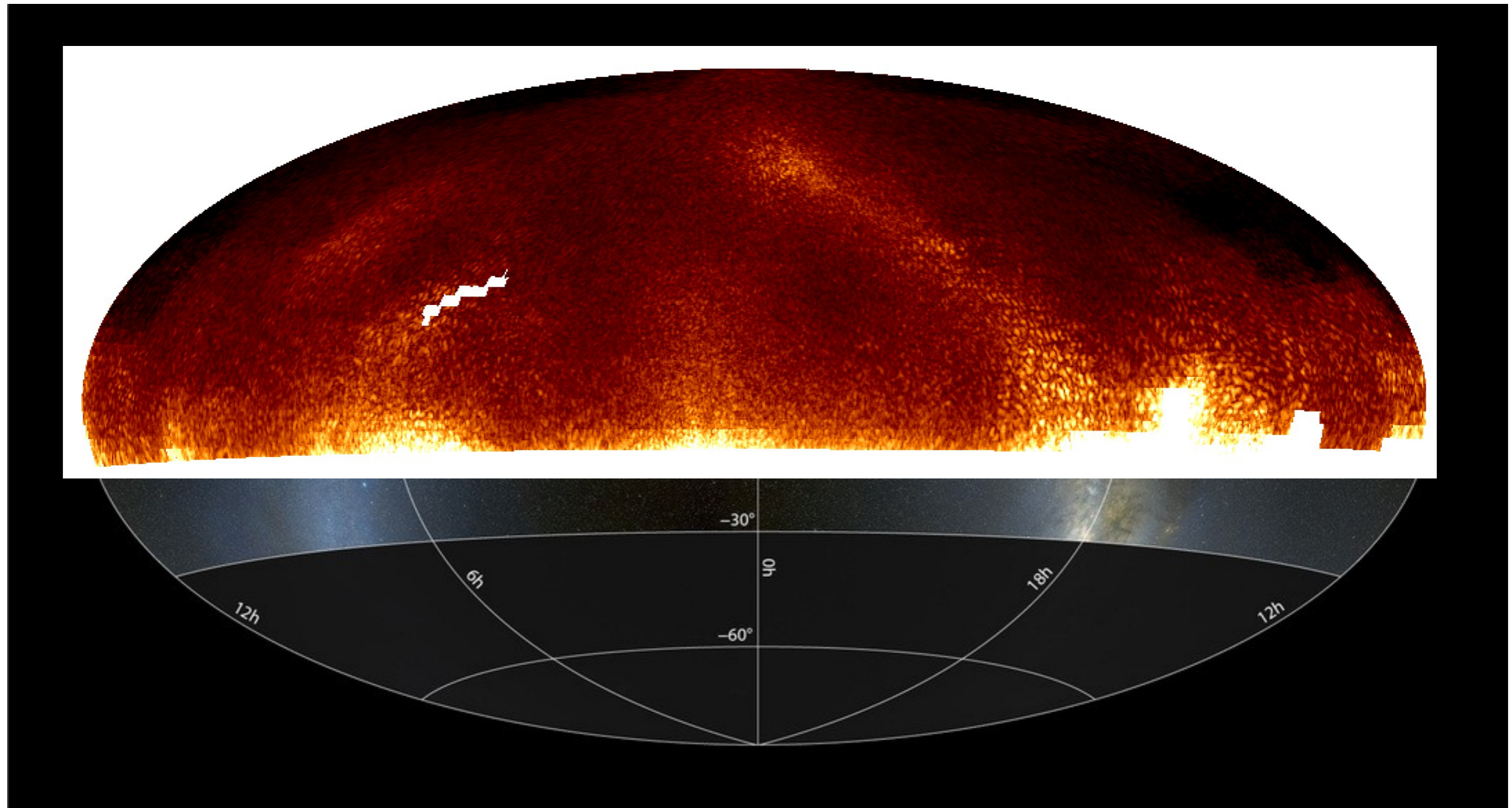
* *Very(!) preliminary* map of LOFAR polarised intensity at 150 MHz. 50 arcmin resolution ('MAPS-Low'). Internal data release later this year.

* Working towards a 45-arcsec data product over the next few years.

MAPS

M.S.S.S All-sky Polarisation Survey





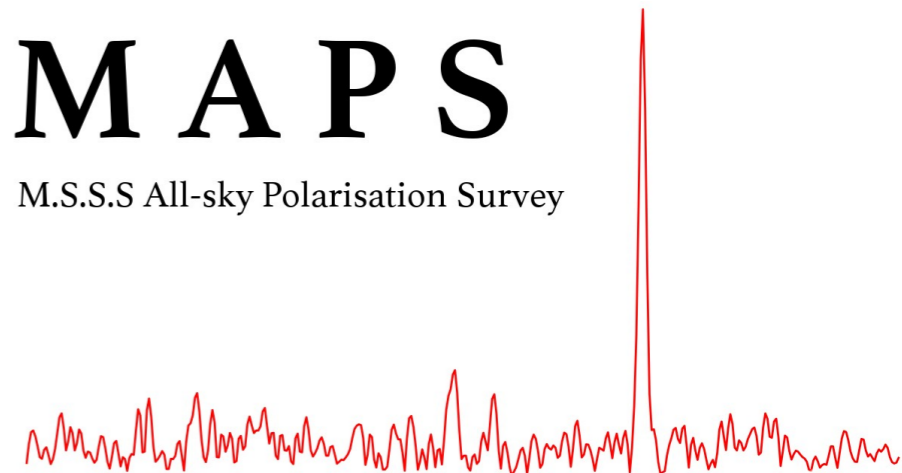
Farnes, Mulcahy

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MAPS

M.S.S.S All-sky Polarisation Survey



- * Mosaicking effort now restarting on five CEP3 nodes.
- * HBA data products in hand by ~August/September. Data products remain password-protected before public release; loaded into MSSS VO server (vo.astron.nl).
- * Early science papers: late 2017 + 2018.
- * **HBA public release and accompanying paper (Heald et al., in prep.) by end of 2017.**
- * Exact catalogue format to be determined, but will be ~40 columns per source.
- * VO server flexibility - SAMP connection (e.g. enabling use of TOPCAT and Aladin). Also investigating ways to better visualise and query the data (e.g. using the WorldWide Telescope - Aleksandar Shulevski leading efforts).

Grazie!