THE LOFAR HBA SURVEYS

Reinout van Weeren

Leiden Observatory, Leiden University

on behalf of the LOFAR Surveys team

Special thanks to Tim Shimwell

Outline

- LOFAR
- HBA: High Band Antenna
- HBA surveys
- Calibration
- LoTSS
- LoTSS-deep
- Working with HBA data
- Extraction-selfcal
- Ongoing and future work

LOFAR

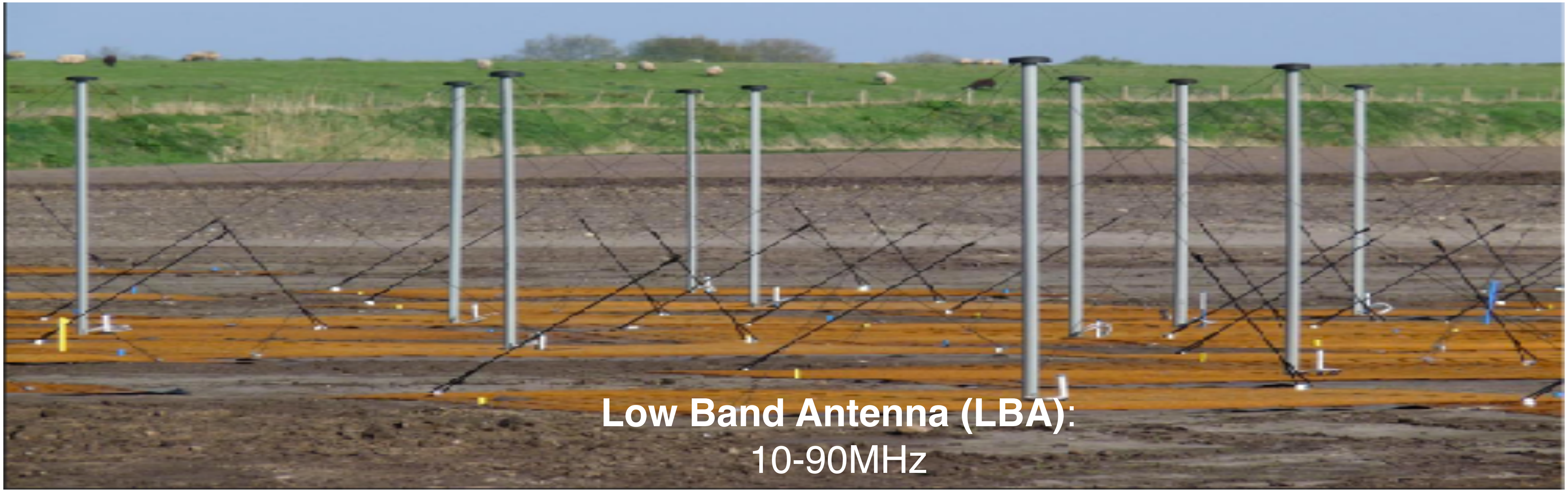
LOFAR; van Haarlem et al. (2013)

The LOFAR core: 24 stations in the north of NL. There are also 14 remote stations and 14 international stations.

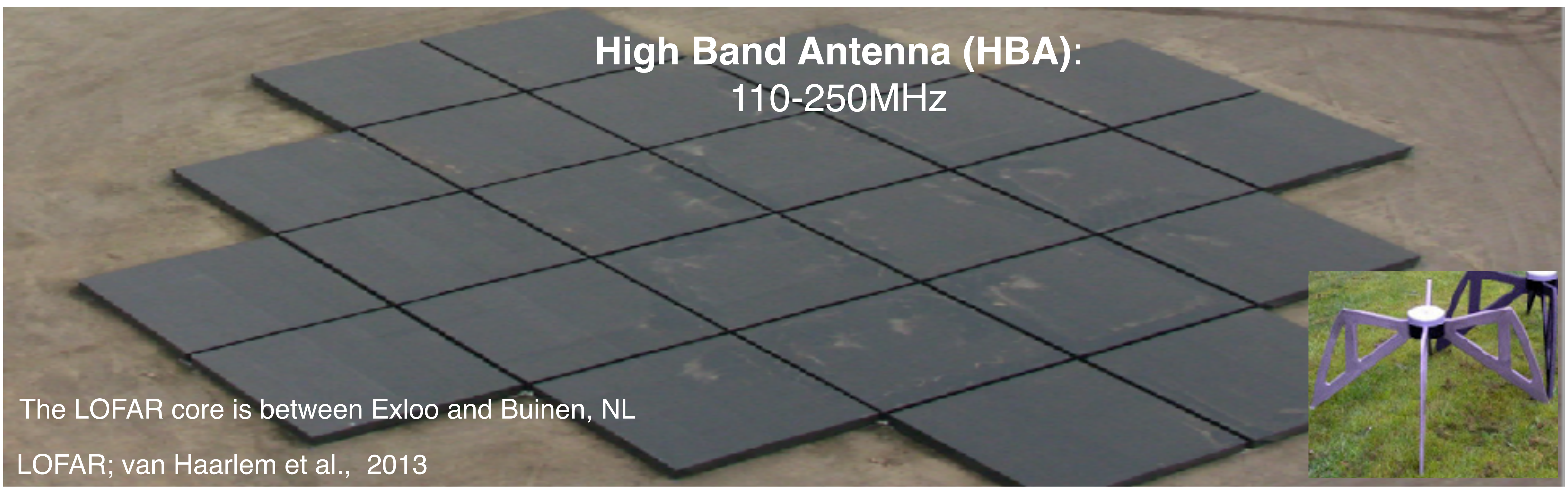
LOFAR **High** (110-250 MHz) **band antenna.** Core ones are 24 antenna arranged with 30.8m diameter, remote ones are 48 antenna with 41m diameter, international ones are 96 antenna with 56m diameter.

LOFAR **Low** (10-80 MHz) **band antenna.** Stations have 96 antenna. Presently only 1/2 antennas can be used at once for core and remote stations.

Low and High band antennas : 10-250 MHz



Low Band Antenna (LBA):
10-90MHz

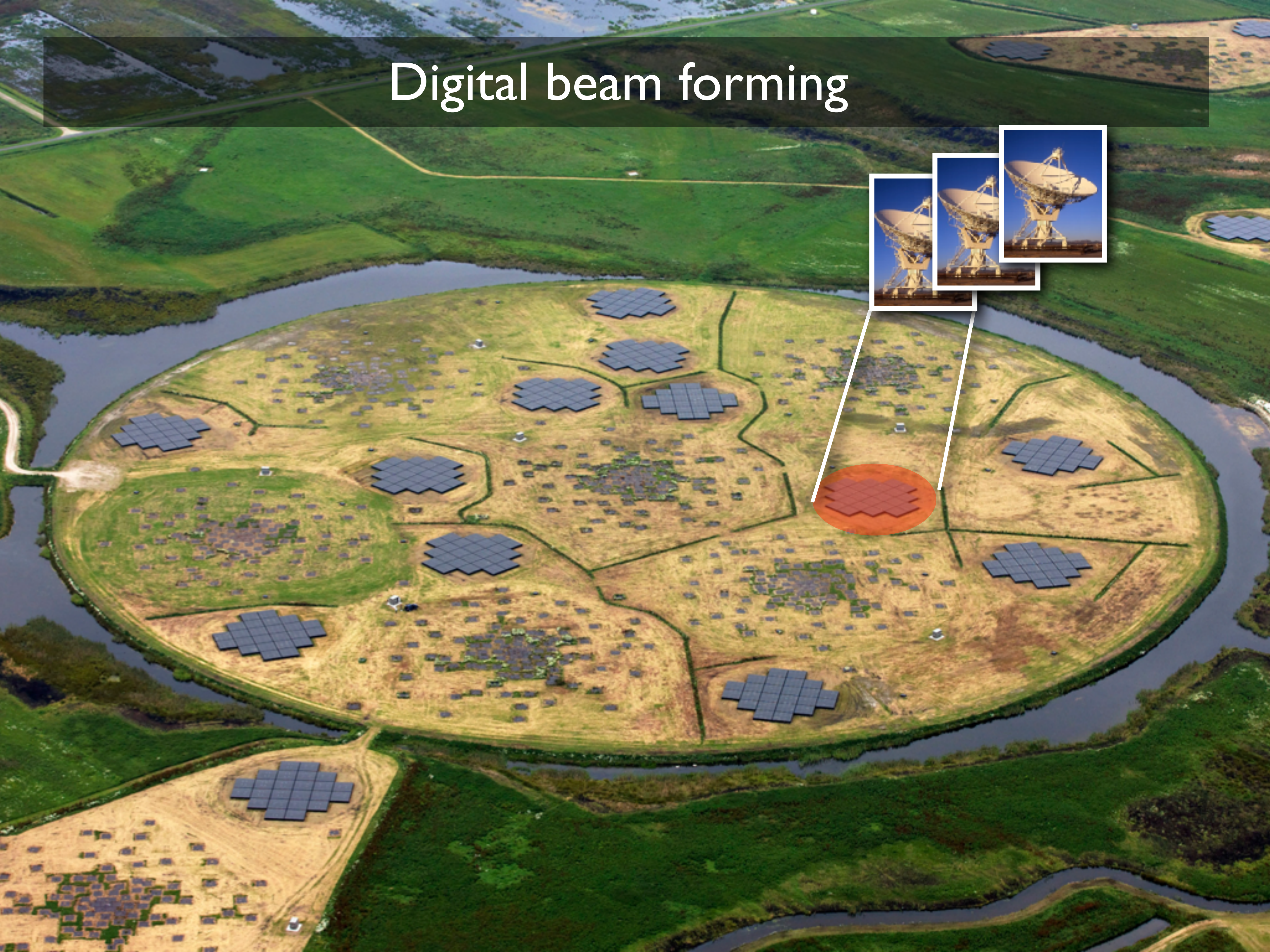


High Band Antenna (HBA):
110-250MHz

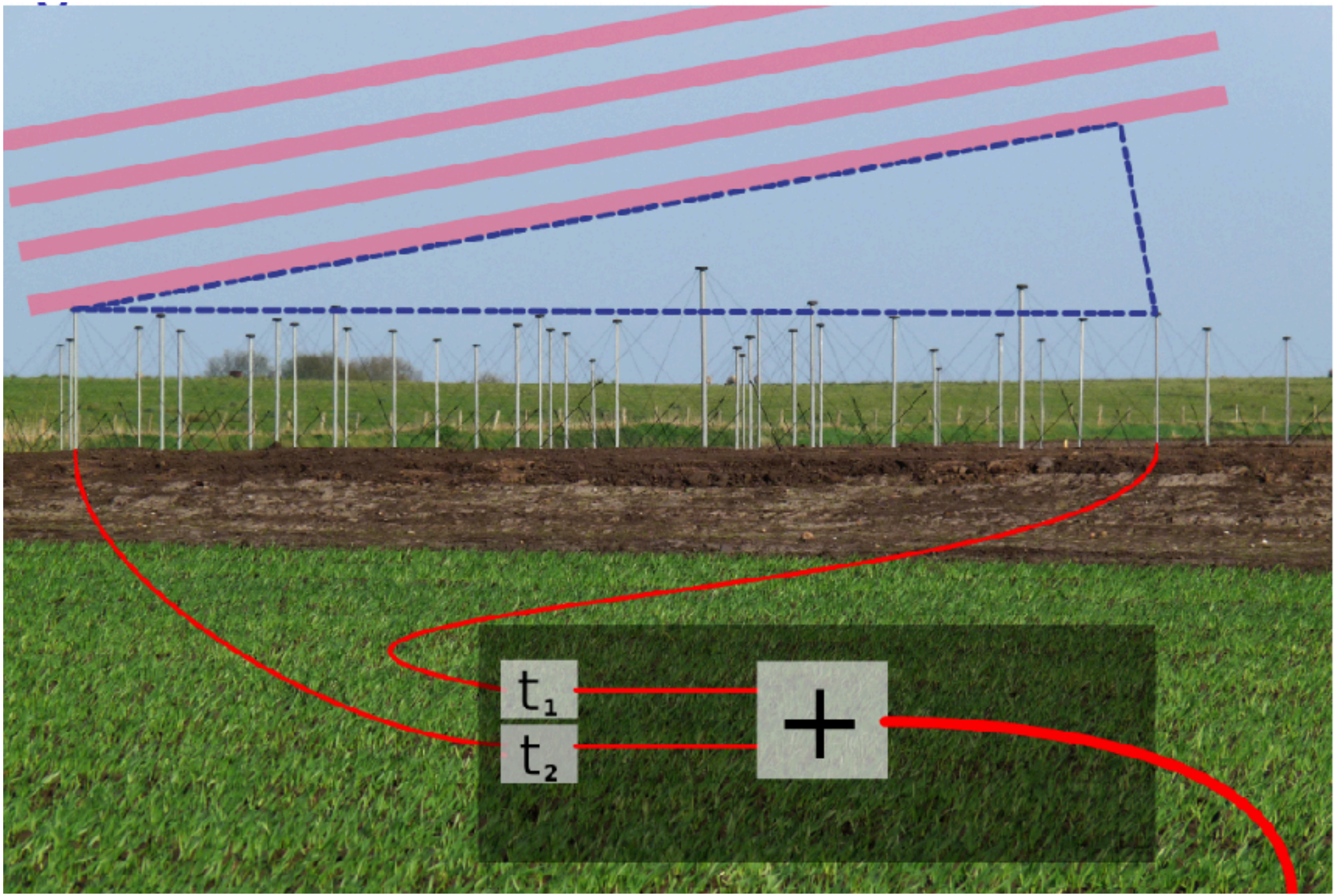
The LOFAR core is between Exloo and Buinen, NL

LOFAR; van Haarlem et al., 2013

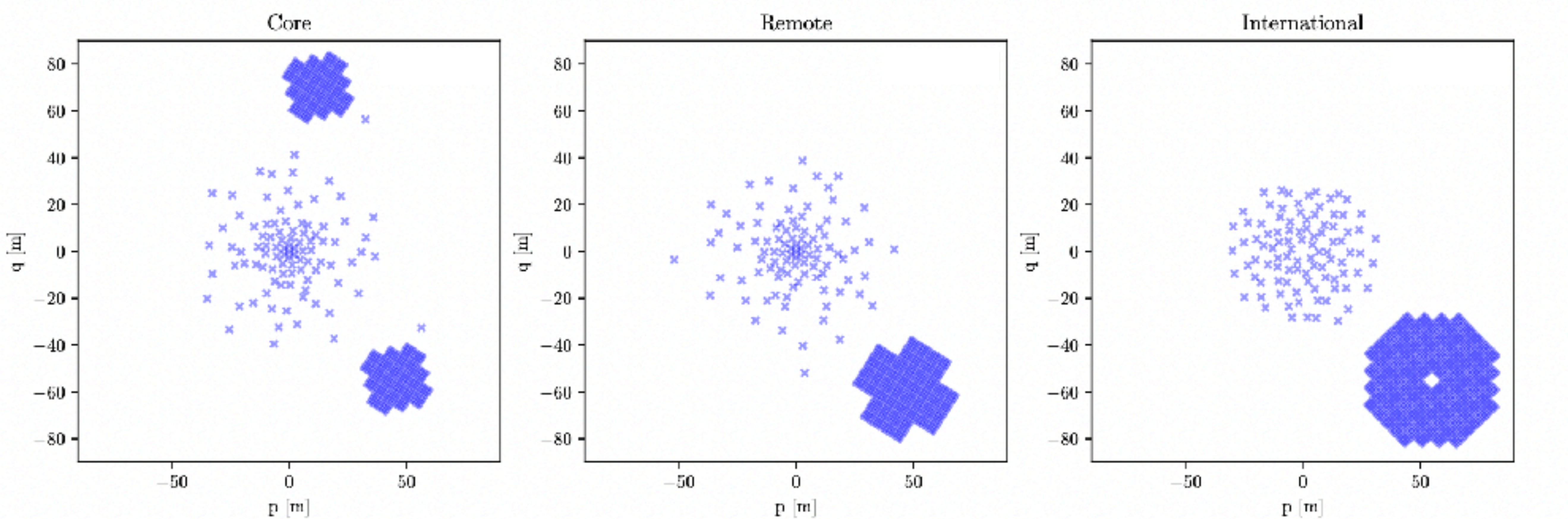
Digital beam forming



Beam forming



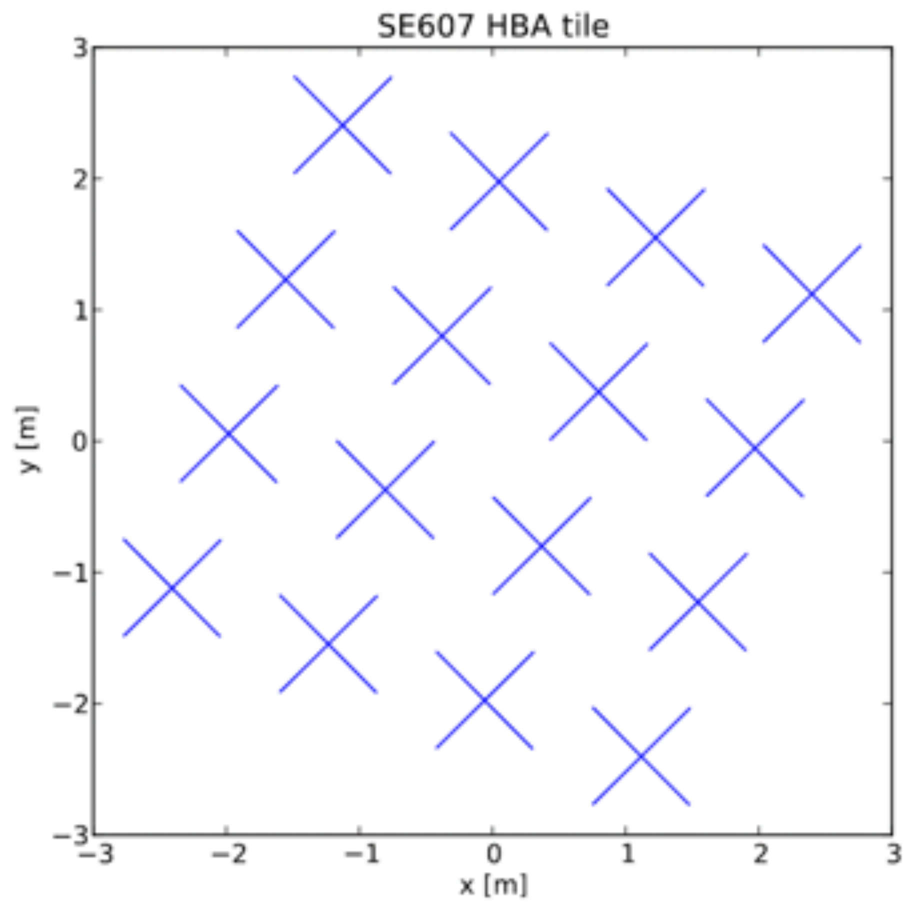
Station types

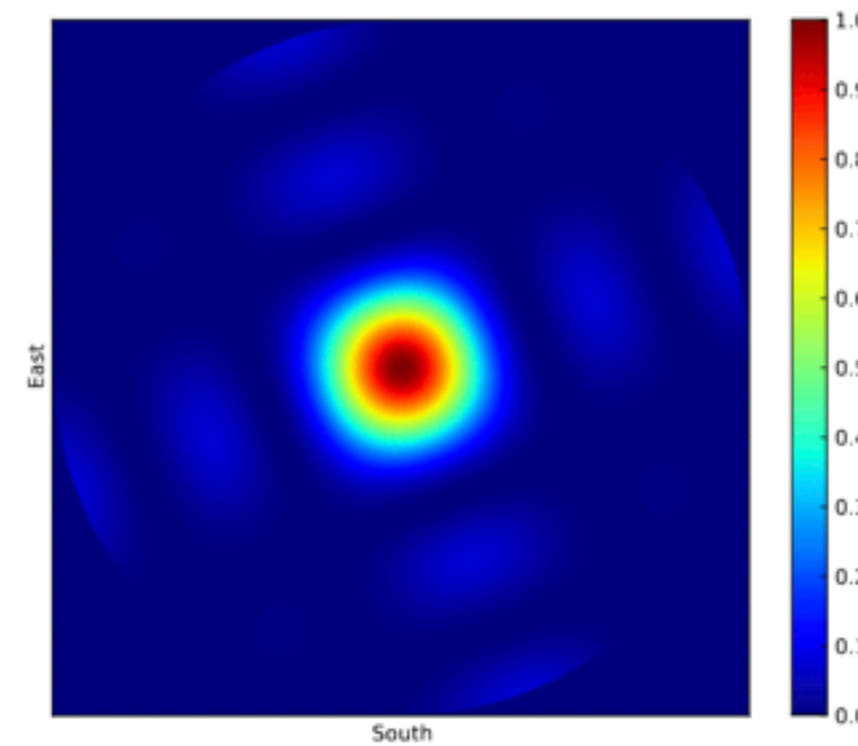


Lofar school 2021

Analog tile beam

HBA analogue tile beam 150 MHz

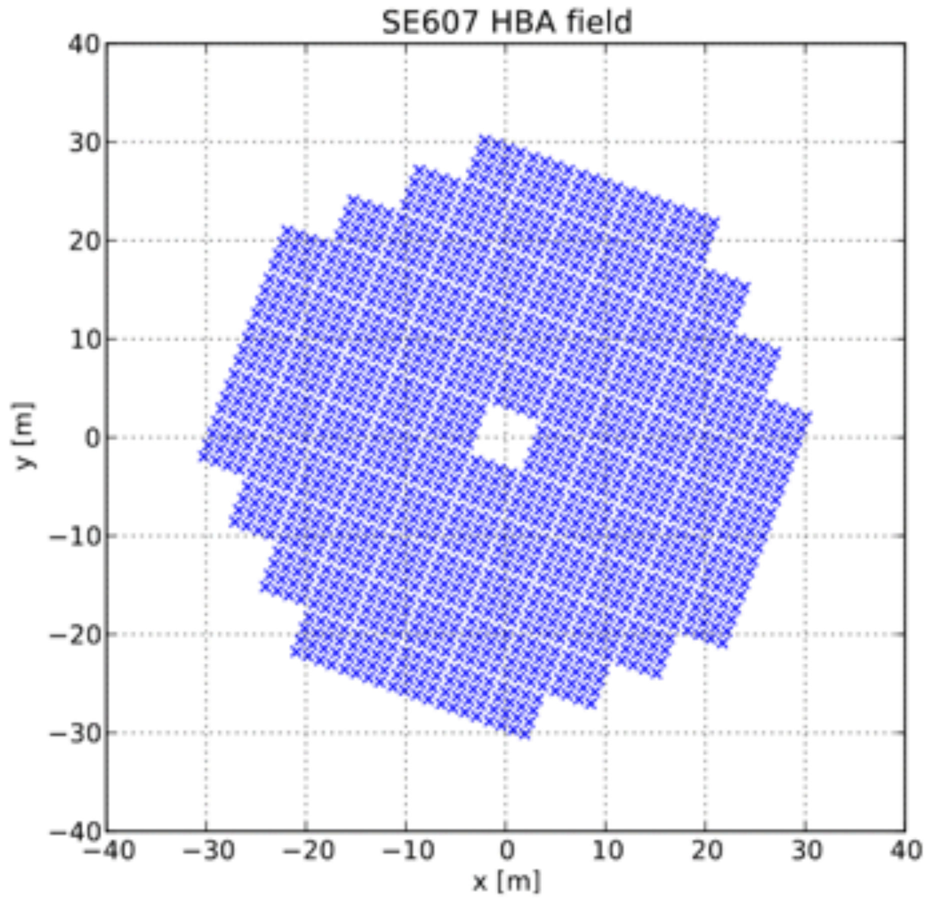


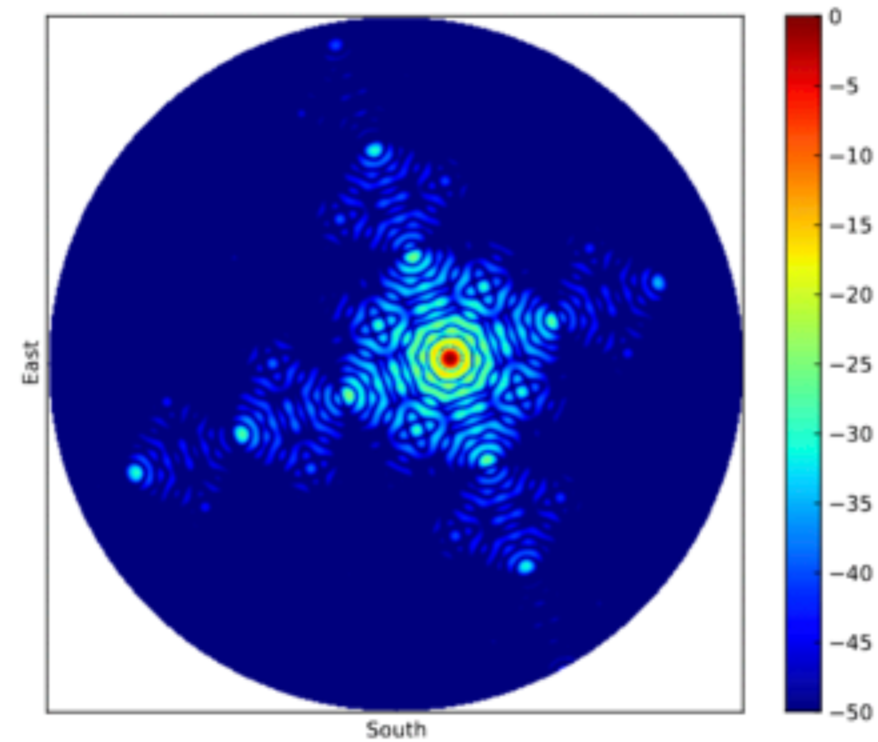


Lofar school 2021

Station beam

HBA station beam tracking 150 MHz (dB)





ASTRON
Netherlands Institute for Radio Astronomy

LOFAR

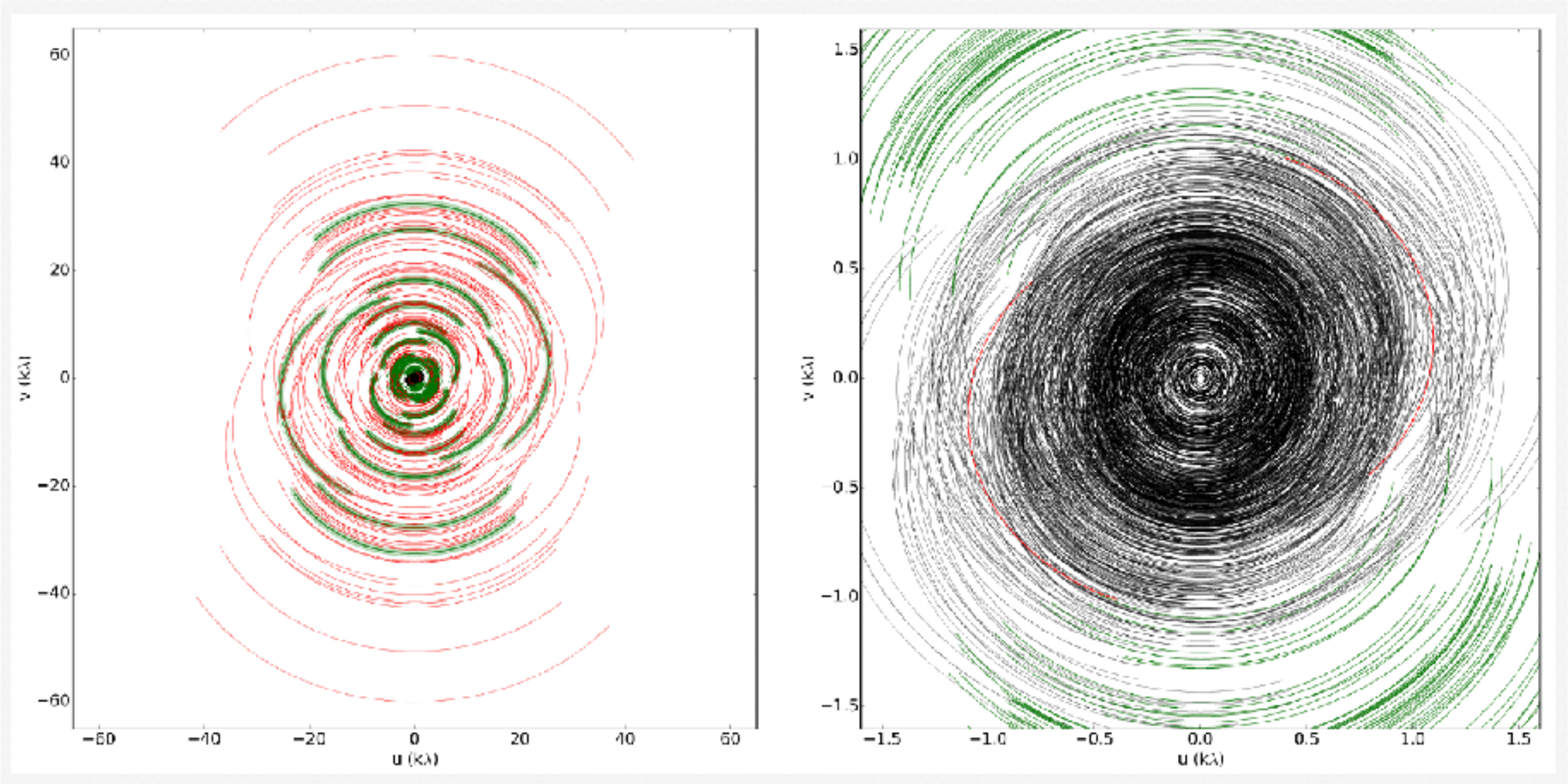
120km (Netherlands only array)

1989km (Full international array)

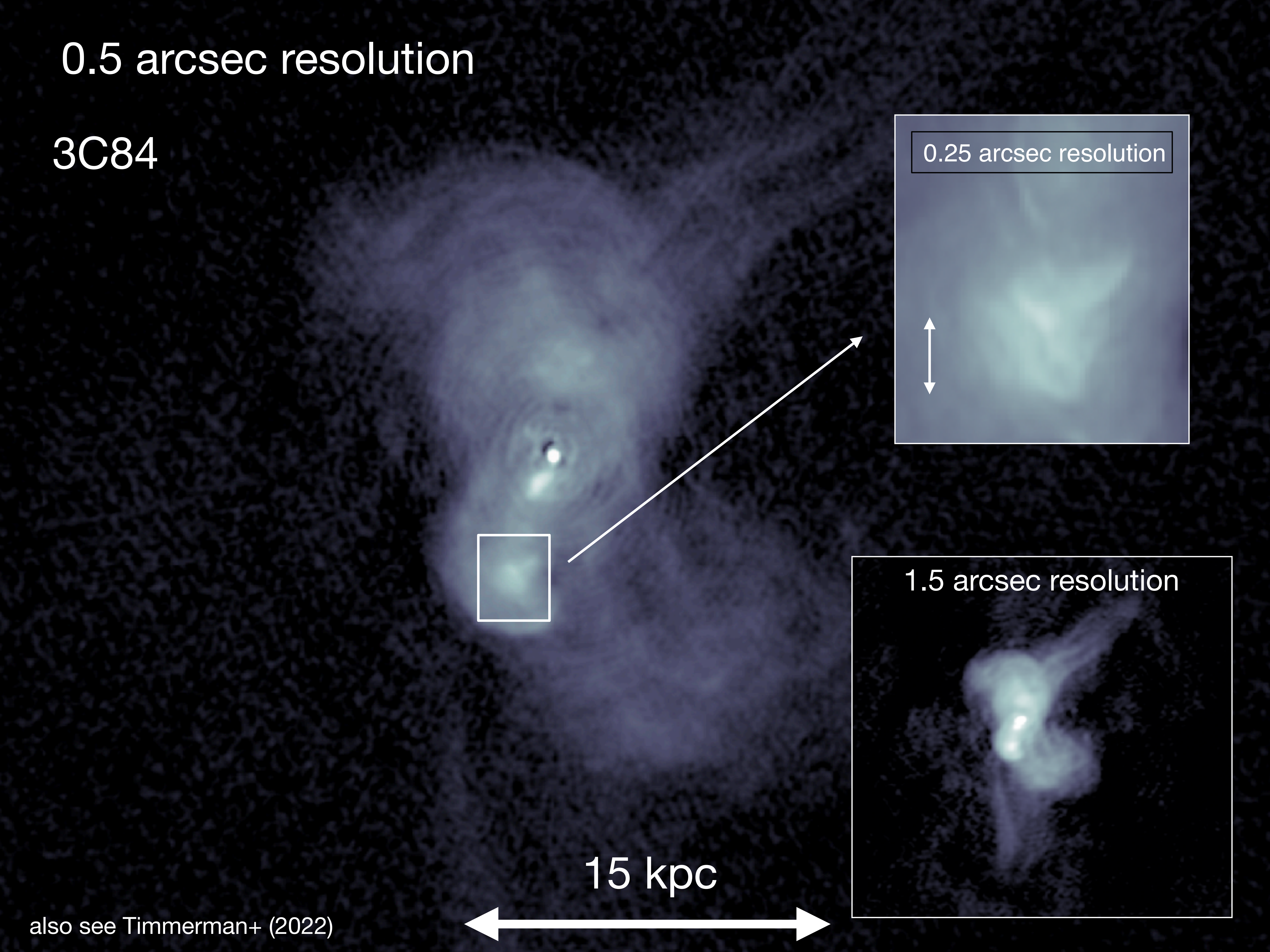
Example properties at 150MHz in 8hrs observing.

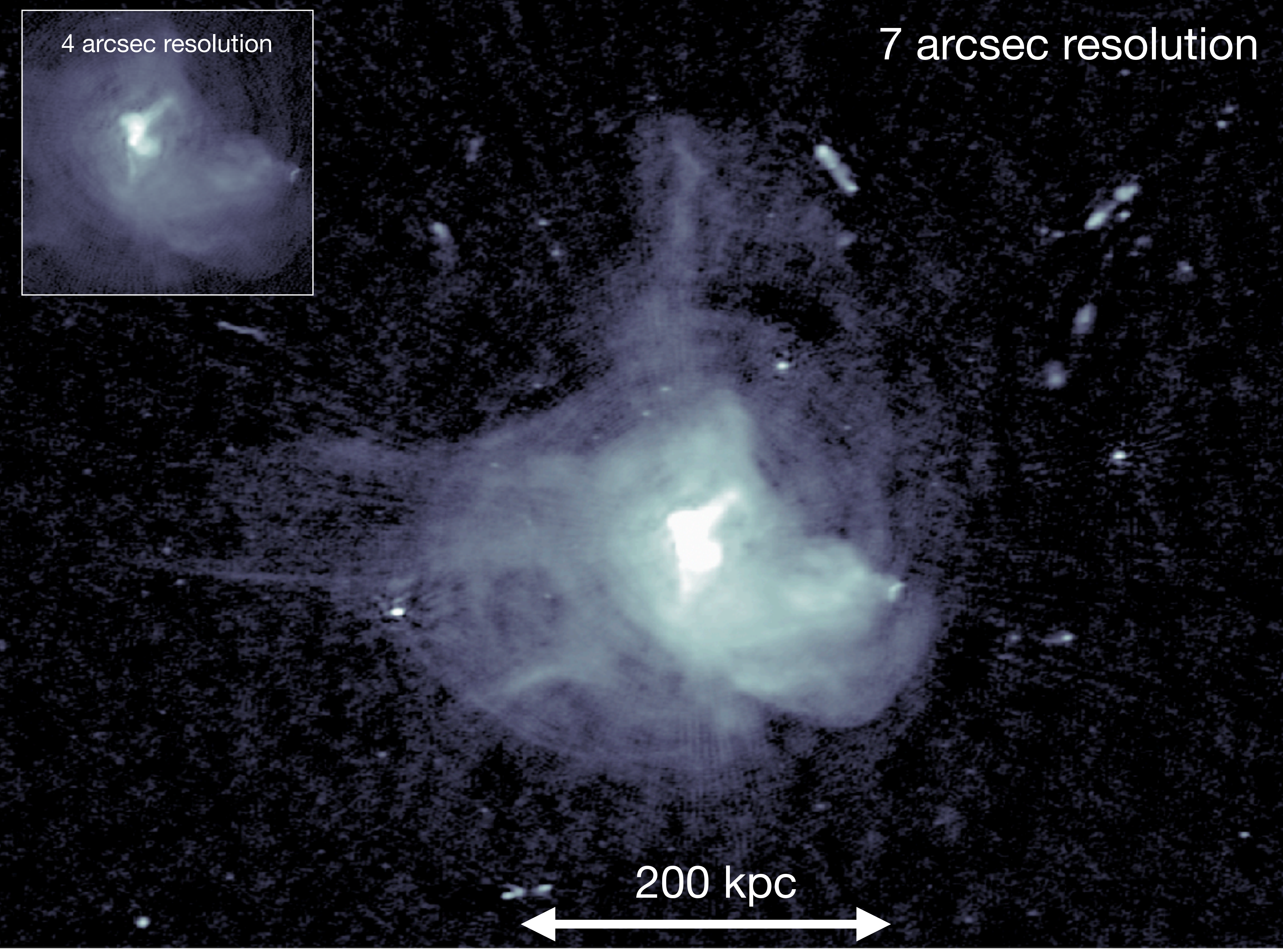
- ~13 square degree coverage (FWHM)
- 48MHz bandwidth and 2 pointings simultaneously
- 0.1mJy/beam sensitivity
- Up to ~0.3arcsec resolution (requiring ~14 billion pixels)
- About 10TB of data
- Presently about 250,000 core hours for full resolution processing or 20,000 for Netherlands only stations…

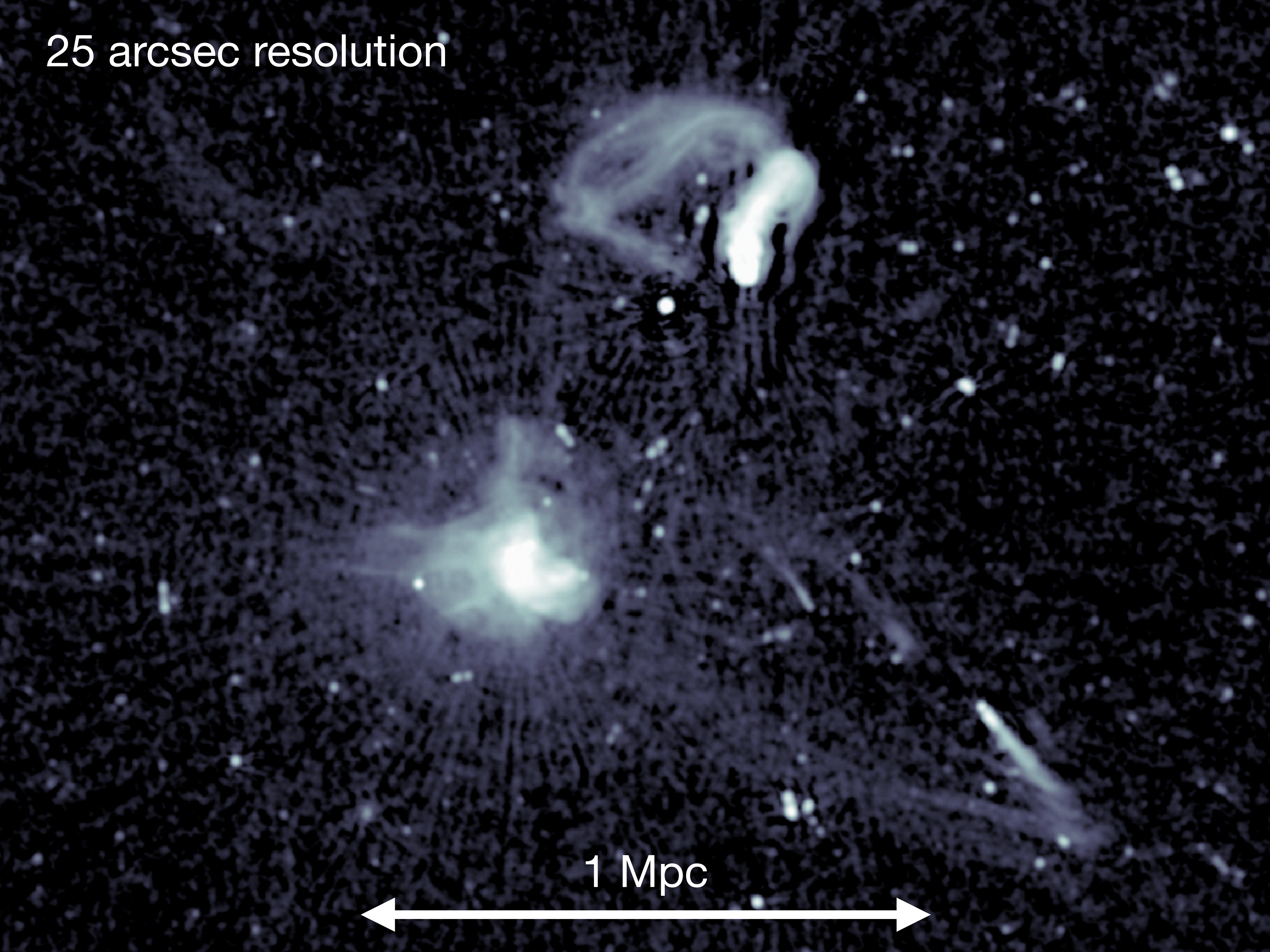
LOFAR uv-coverage

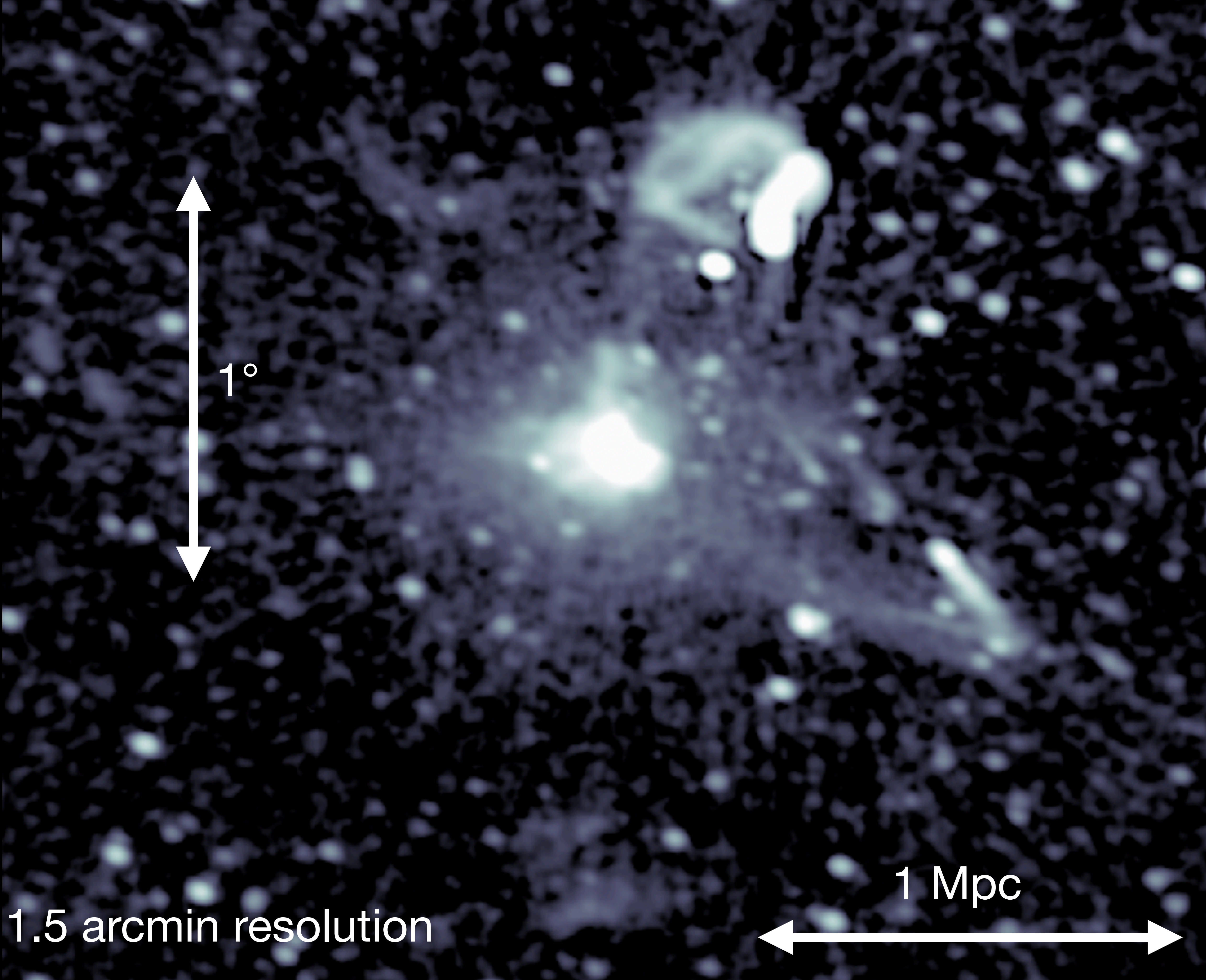


The uv-coverage of the LOFAR core + remote stations gives high angular resolution (6” at 140 MHz or 15” at 50 MHz) combined with excellent surface brightness sensitivity for recovering very extended emission.

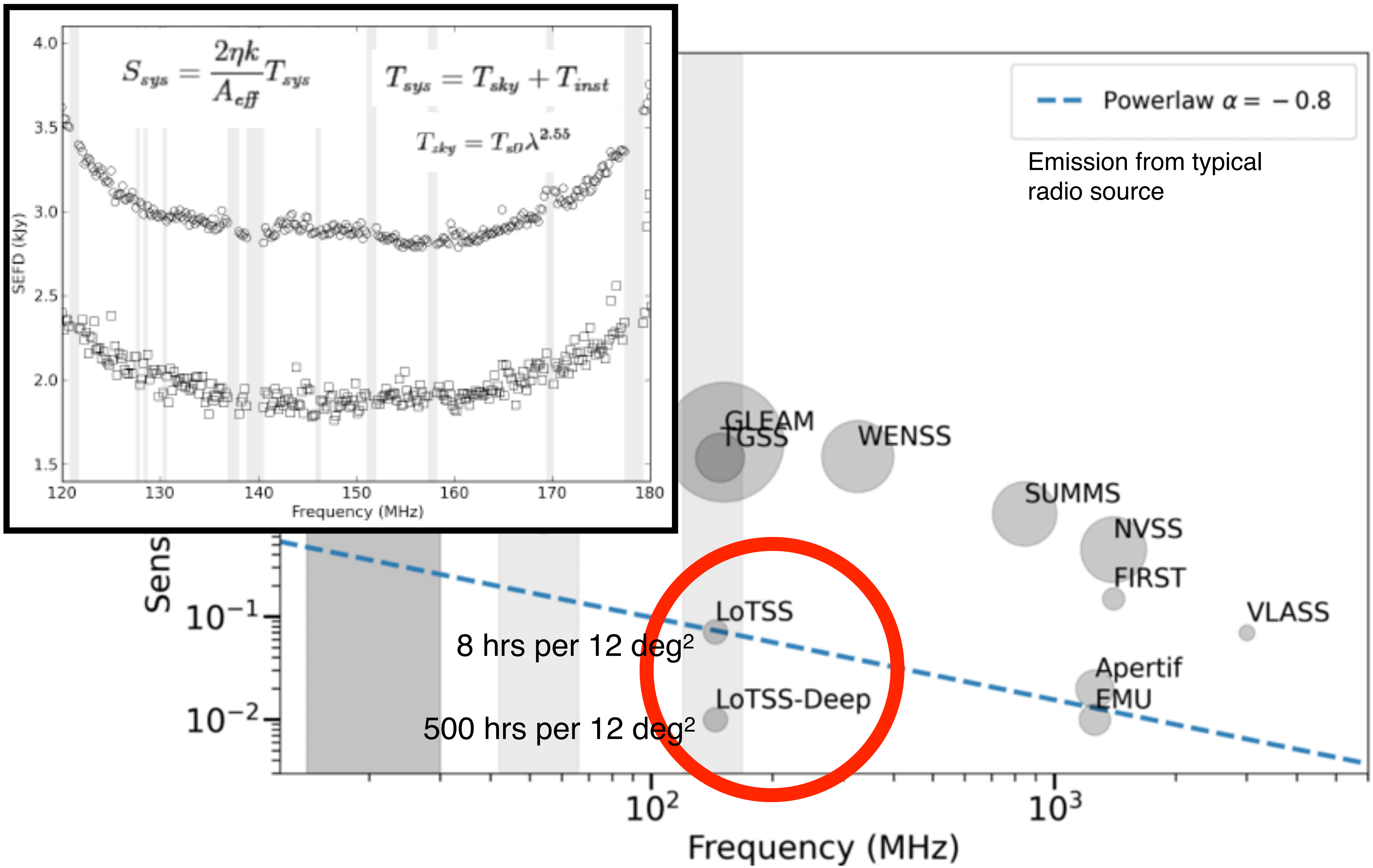

0.5 arcsec resolution
3C84
0.25 arcsec resolution
1.5 arcsec resolution
15 kpc
also see Timmerman+ (2022)


4 arcsec resolution
7 arcsec resolution
200 kpc


25 arcsec resolution
1 Mpc


1°
1.5 arcmin resolution
1 Mpc

The LOFAR surveys: Overview



- LoTSS: Shimwell et al., 2017 & 2019, 2022 Williams et. al., 2019, Duncan et al 2019
- LoTSS-Deep: Tasse et al., Sabater et al., Kondapally et al., Duncan et al., all 2021
- ILoTSS: Morabito et al., Sweijen et al., 2022
- LoLSS: de Gasperin et al., 2021
- LoLSS-Deep: Williams et al., 2021

Scientific aims of the LOFAR surveys

PI: Röttgering. About 300 collaboration members.

Scientific working groups

- Highest redshift radio sources: George Miley
- Clusters and cluster halo sources: Reinout van Weeren, Gianfranco Brunetti, Marcus Brüggen
- Evolution of AGN and star forming galaxy populations: Philip Best
- Detailed studies of low-redshift AGN: Raffaella Morganti & Martin Hardcastle
- Nearby Galaxies: Krzysztof Chyzy & John Conway
- Galactic radio sources: Glenn White, Marijke Haverkorn, Harish Vedantham
- Cosmological studies: Dominik Schwarz

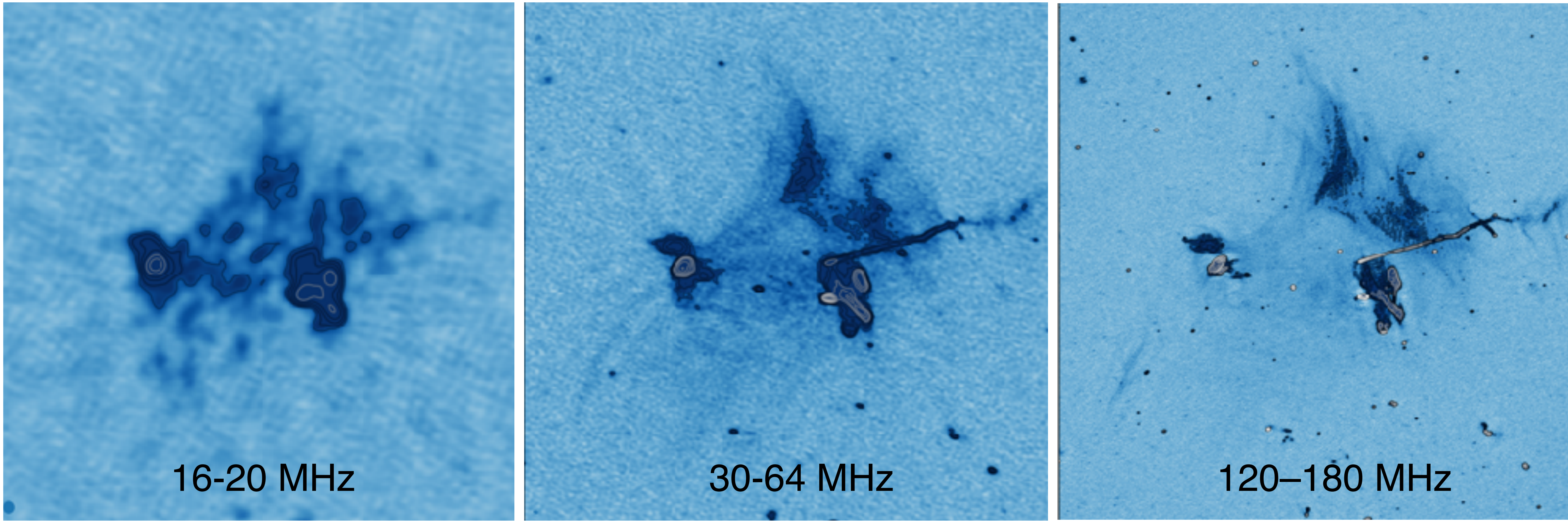
Technical working groups

- LOFAR international baselines (Leah Morabito, Neal Jackson)
- WEAVE-LOFAR (Daniel Smith)
- LOFAR Low-Band Antenna (Francesco de Gasperin)
- LOFAR High-Band Antenna (Tim Shimwell & Cyril Tasse)

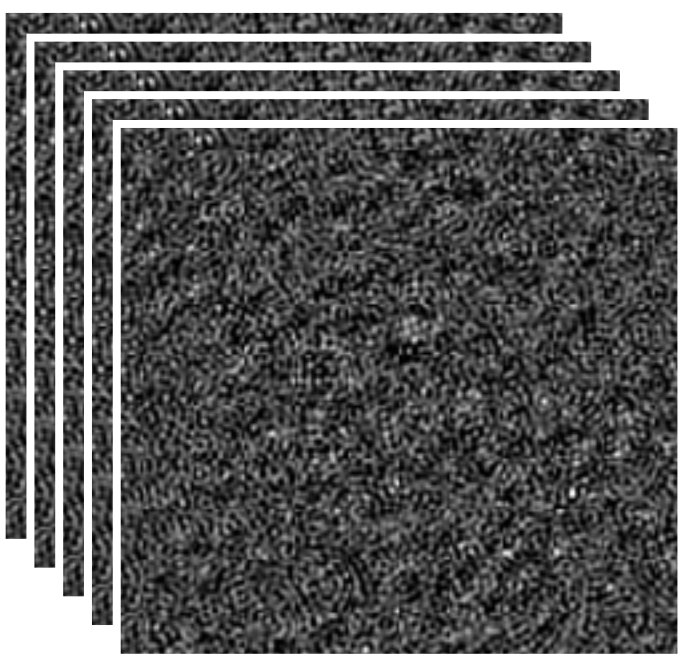
Data sharing memorandum of understanding

- LOFAR magnetism key science project
- WEAVE
- Apertif surveys
- eBOSS cosmology
- Many others for particular projects

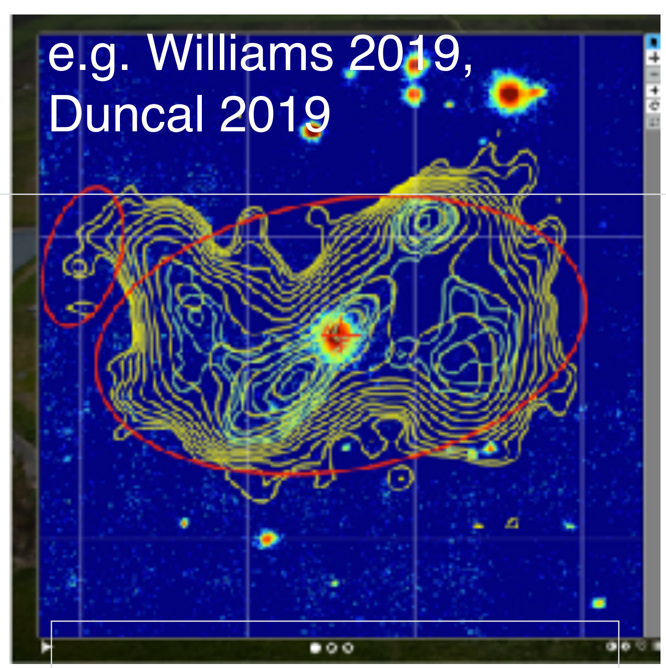
The LOFAR surveys: Overview



Images from Osinga, van Weeren+

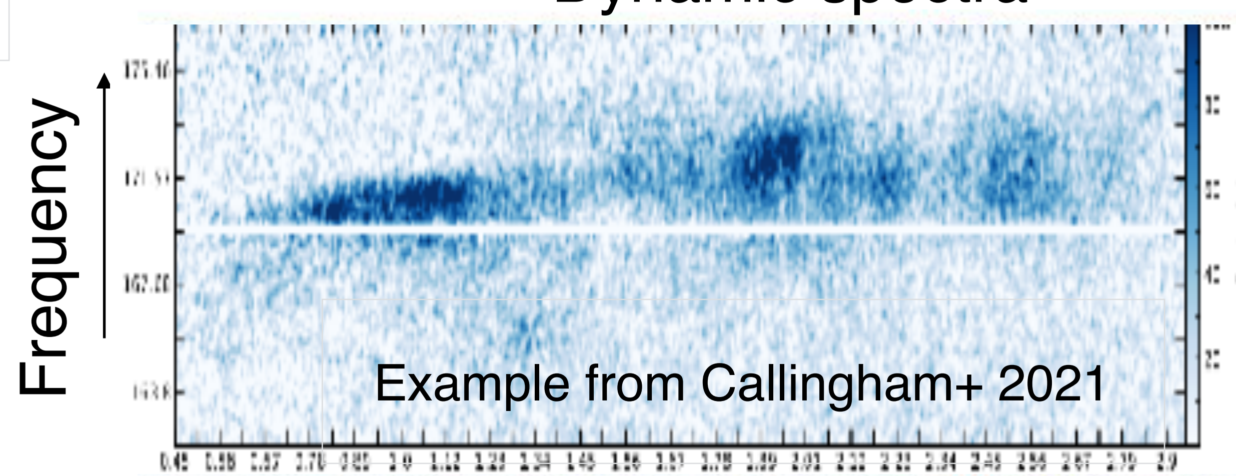


Polarisation cubes

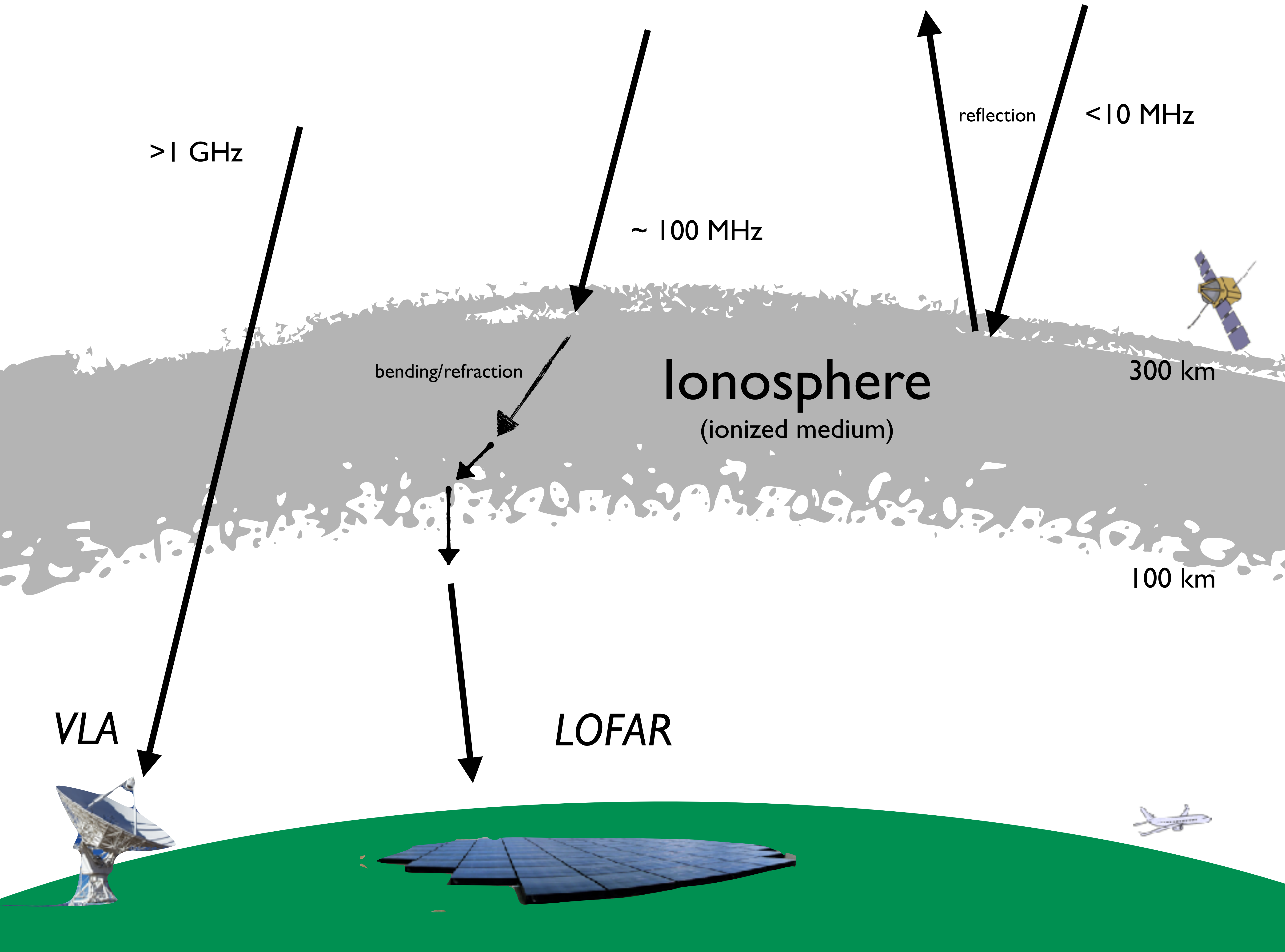


Cross matching

Dynamic spectra



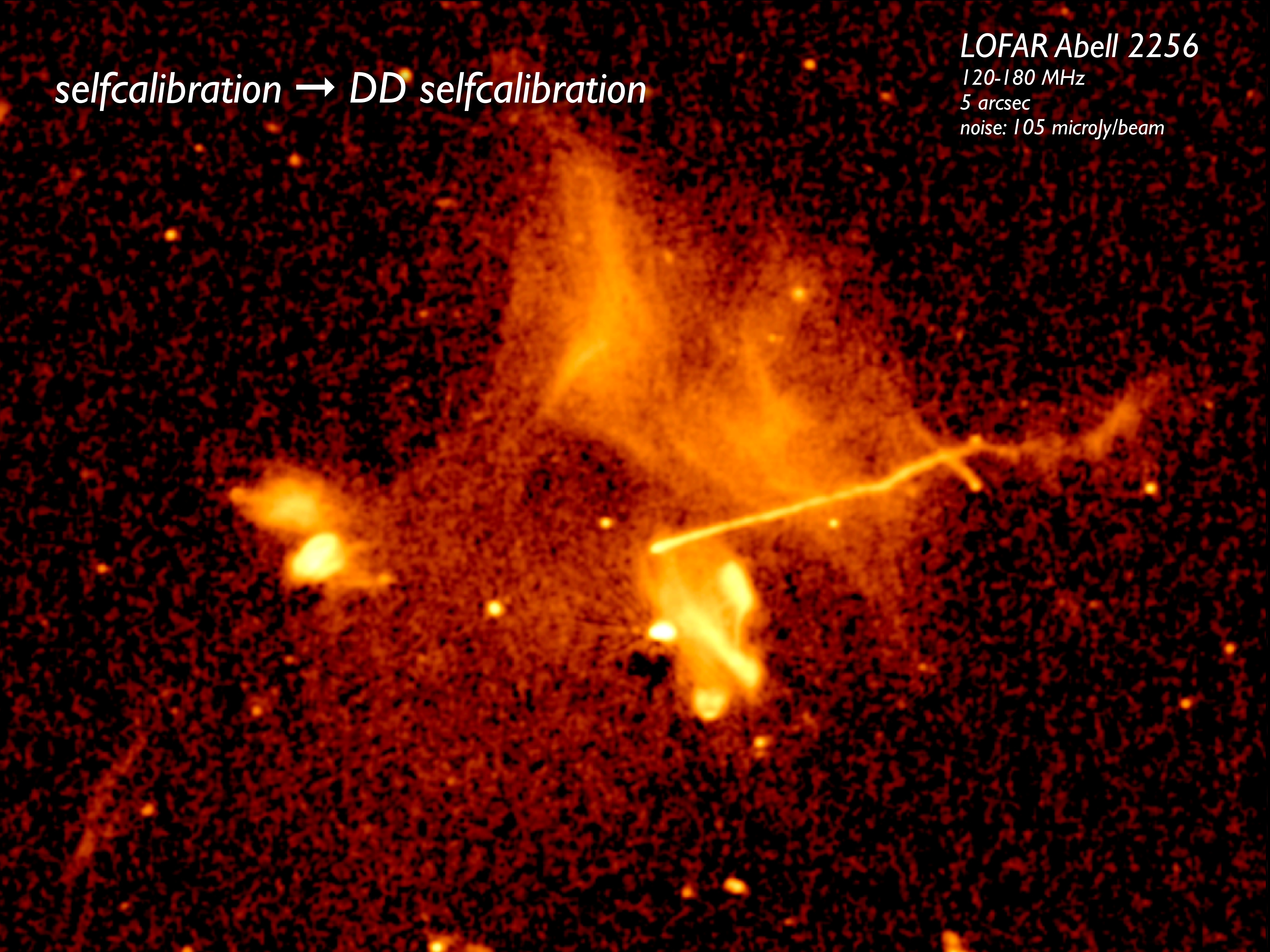
Time



>1 GHz
~ 100 MHz
reflection
<10 MHz
bending/refraction
Ionosphere
(ionized medium)
300 km
100 km
VLA
LOFAR

The challenge

The challenge


selfcalibration → DD selfcalibration
LOFAR Abell 2256
120-180 MHz
5 arcsec
noise: 105 microJy/beam

The LOFAR surveys: Status

Many technical developments required to process large quantities of data with complex processing strategies.

Current processing **pipelines** includes:

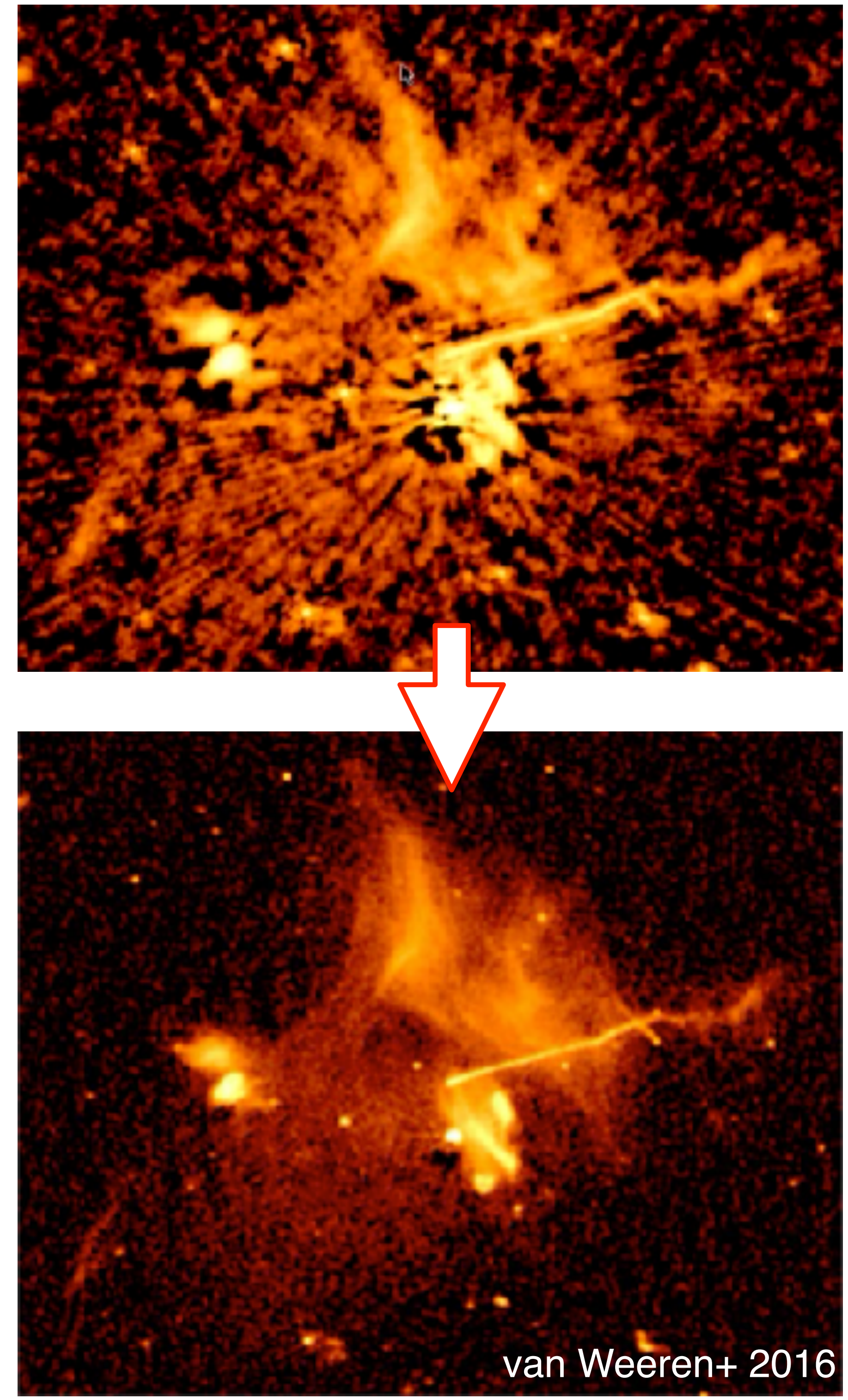
- HBA Netherlands only resolution processing: Tasse+ 2021, van Weeren+ 2016, Williams+ 2019, Mechev+ 2019, Drabent+ 2019, de Gasperin+ 2019, Sabater+ 2021, van Weeren+ 2021, Shimwell+ 2022, O’ Sullivan+., prep
- HBA International baseline resolution processing: Morabito+2022, Sweijen+, 2022; van Weeren+ 2021
- LBA Netherlands only processing: de Gasperin 2019, 2021; van Weeren+ 2021

And uses many **software** packages including:

van Diepen+ 2019, de Gasperin+ 2019, Offringa+ 2012, 2014, 2016, van der Tol+ 2018, Tasse+ 2014, 2018, Smirnov+ 2015

There are also many other ongoing efforts to improve calibration, imaging and processing techniques

To-date we have accumulated ~30PB of data



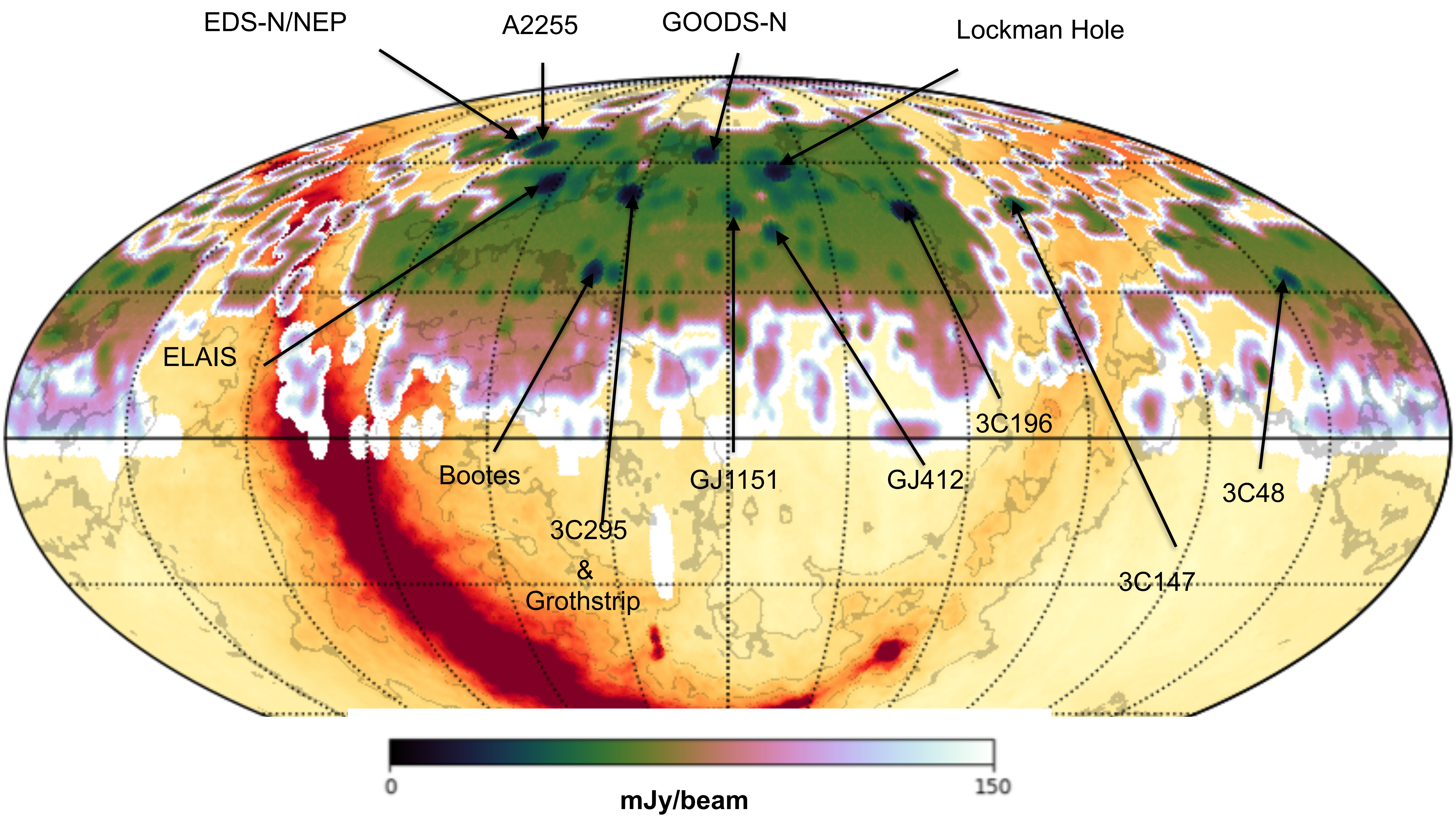
van Weeren+ 2016

LOFAR data requires extensive processing.

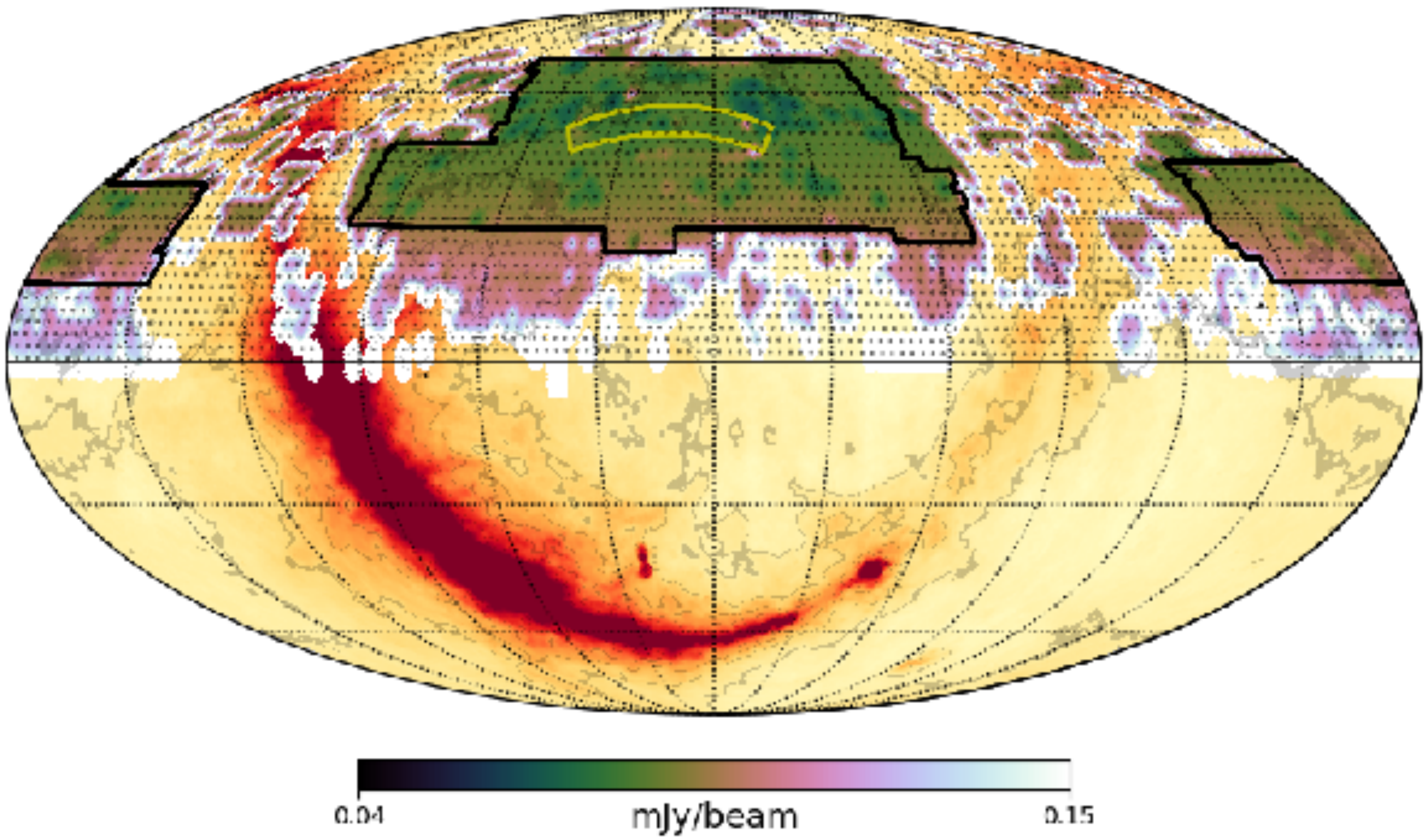
The LOFAR HBA surveys

The LOFAR HBA surveys: Status

LOFAR HBA imaging data (almost all with full international LOFAR) - next 1 year to 85% coverage and deep fields complete.



Wide area 150 MHz— LoTSS



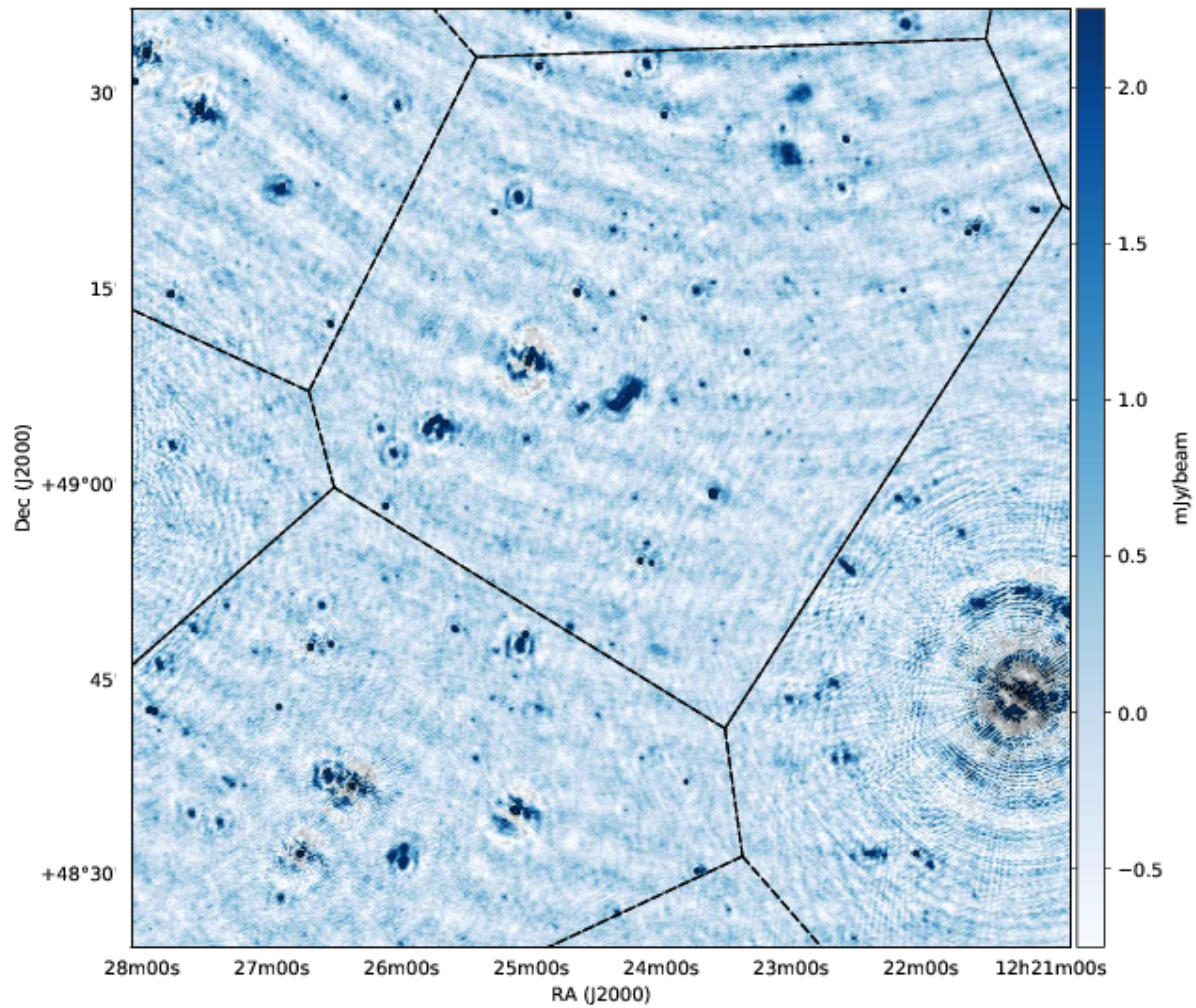
- Northern sky 120-168 MHz
- 3170 pointings of 8 hrs
- 0.1 PB raw data/pointing
- 6 arcsec resolution
- 0.08 mJy beam^{-1} noise
- GRID processing
- 5 deep fields (300-500 hrs)

LoTSS-DR1 (outlined in yellow) and LoTSS-DR2 (outlined in black) are fully public. This contains **4,395,448** radio components. It consists of 7.6PB of data from 26 different projects processed using ~9million cpu hours. LoTSS-DR2 is **26%** of the Northern sky at sensitivity of **0.08 mJy/beam** and resolution of **6"**.

LoTSS is initially processed with PreFactor/LINC (van Weeren 2016, Williams 2016, de Gasperin 2019) before direction dependent calibration with DDF-pipeline (https://github.com/mhardcastle/ddf-pipeline; Tasse+ 2021)

LoTSS processing

- Wide field image created covering 8x8 deg field of view (20,000 x 20,000 pixels)
- Image tessellated to define facets.
- Calibration solutions obtained for all directions simultaneously using the model from entire wide field image.
- Imaging repeated with direction dependent calibration solutions applied and a better model constructed.
- Direction independent polarization corrections
- Several self calibration cycles performed.



DDF-pipeline is public. It makes use of DDFacet and kMS for calibration and imaging (Tasse+ 2014, Smirnov+ 2015, and Tasse+ 2017). It produces science quality images in 4-6 days of processing.

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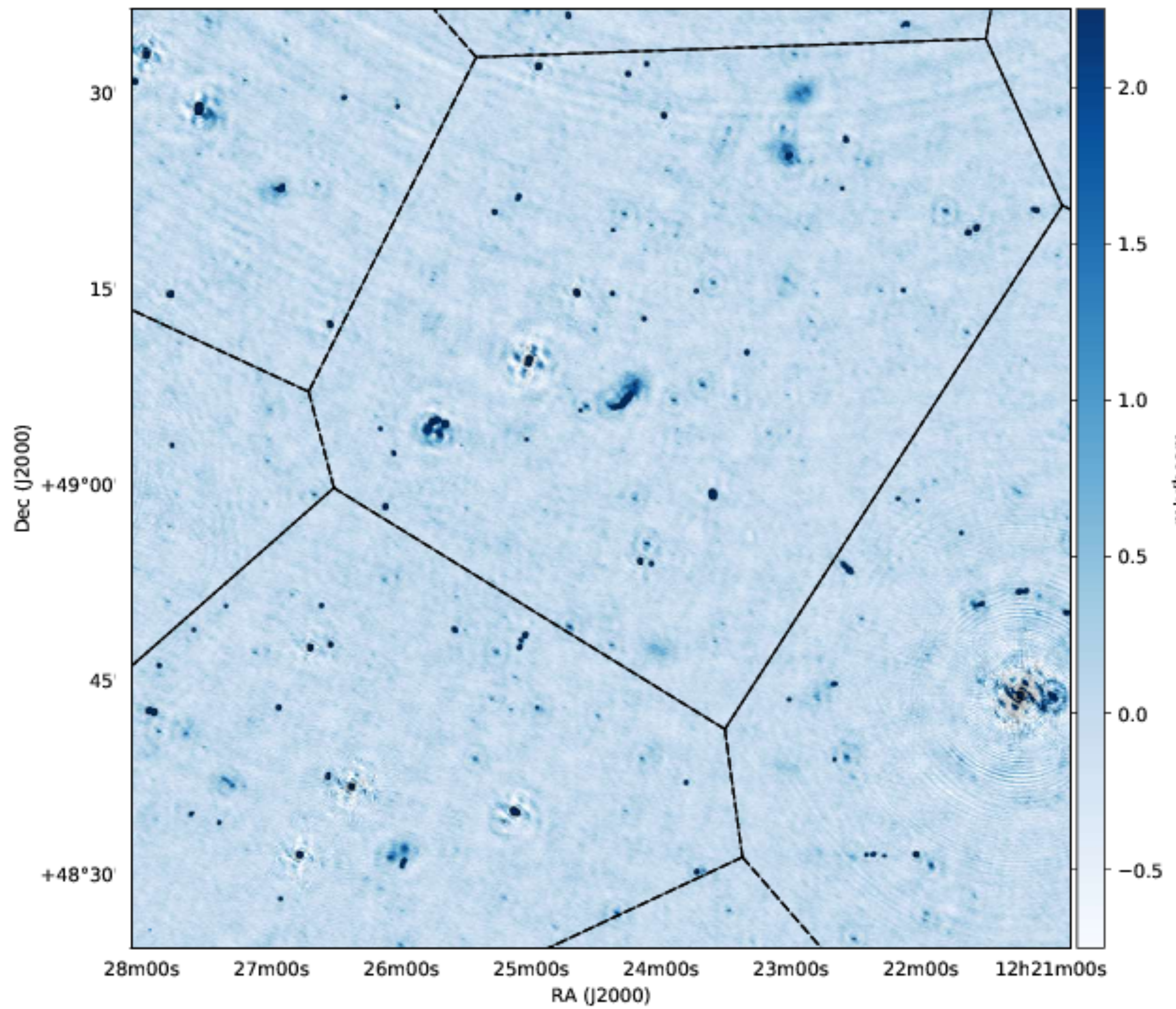

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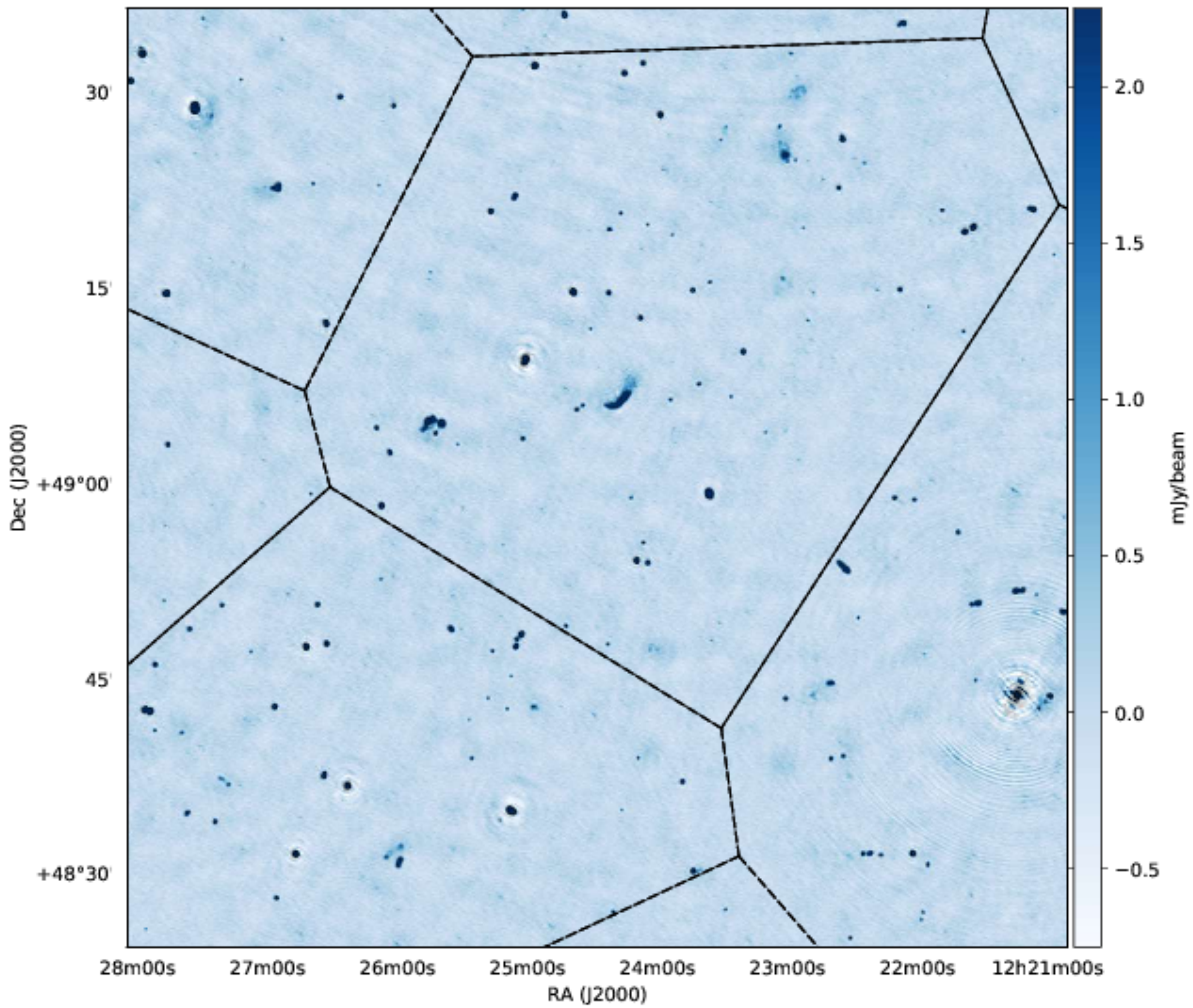

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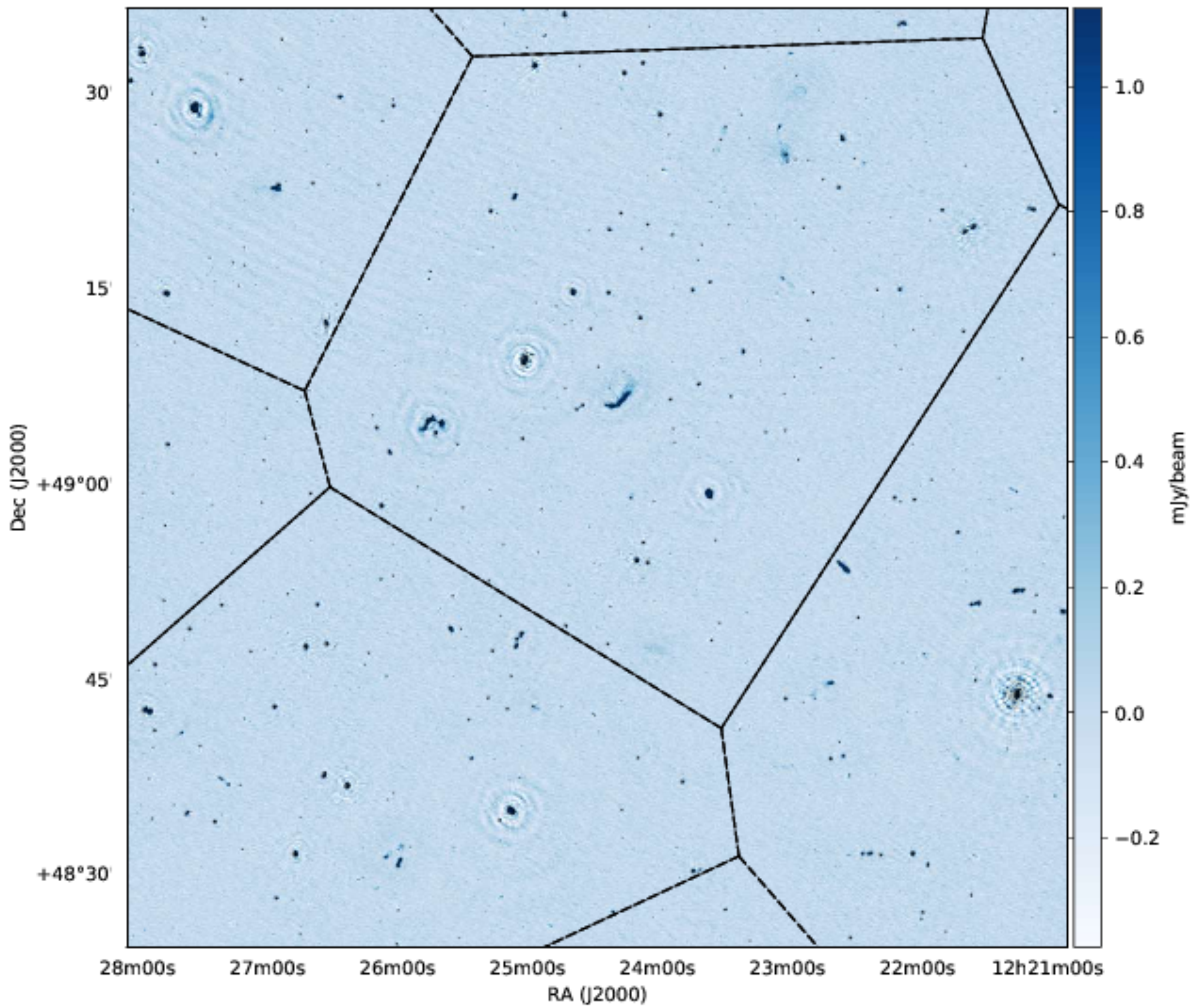

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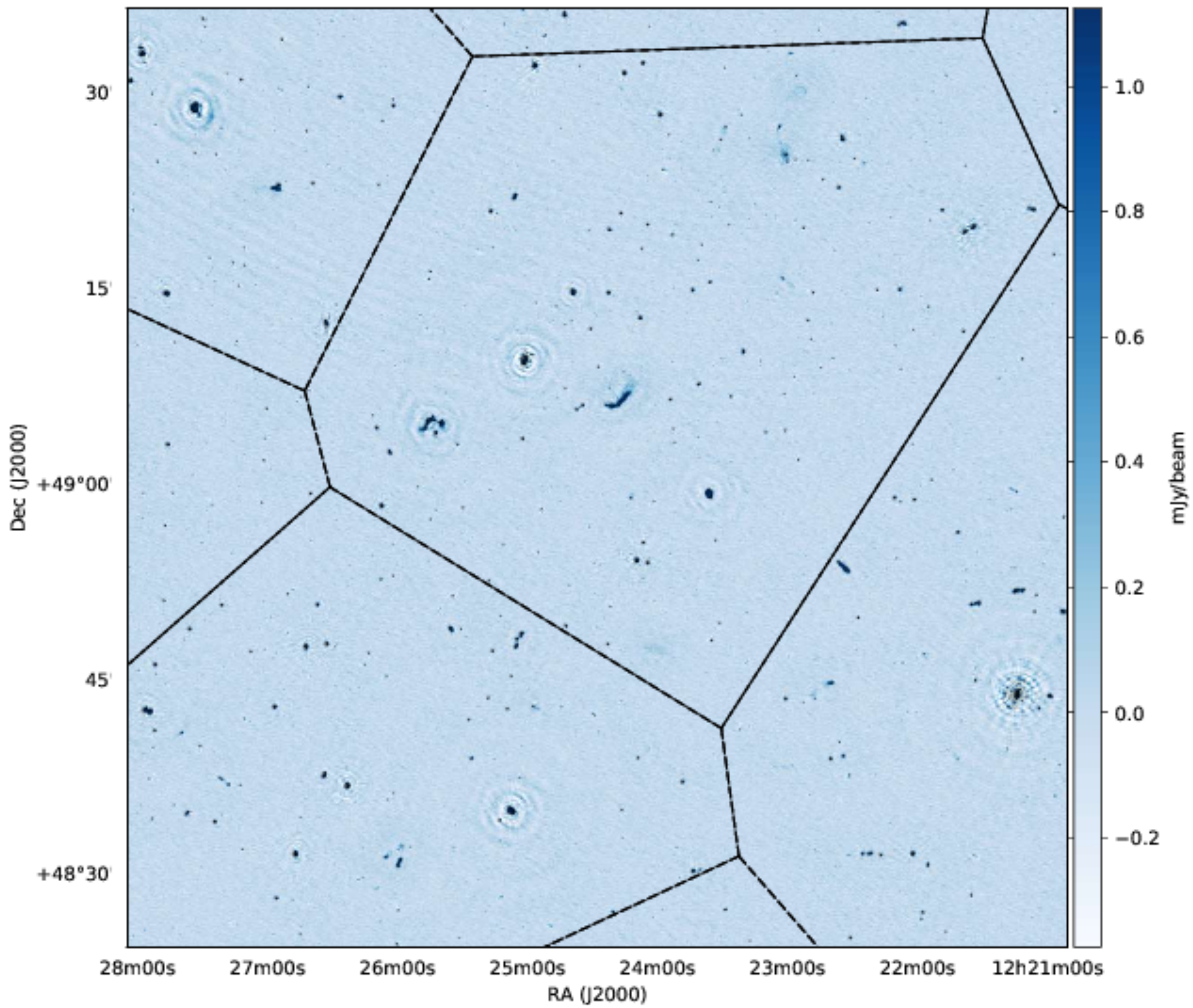
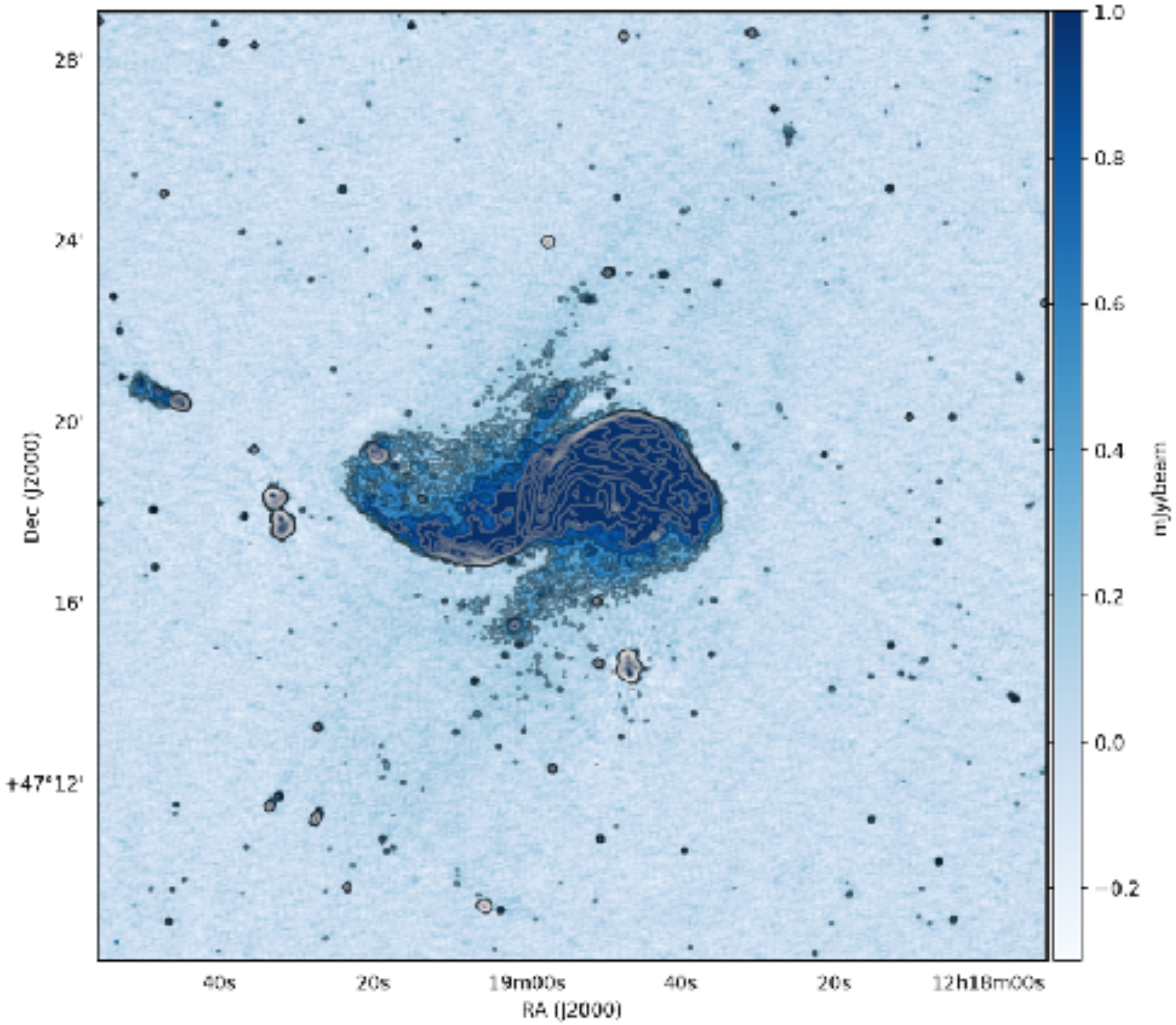
LoTSS processing remarks

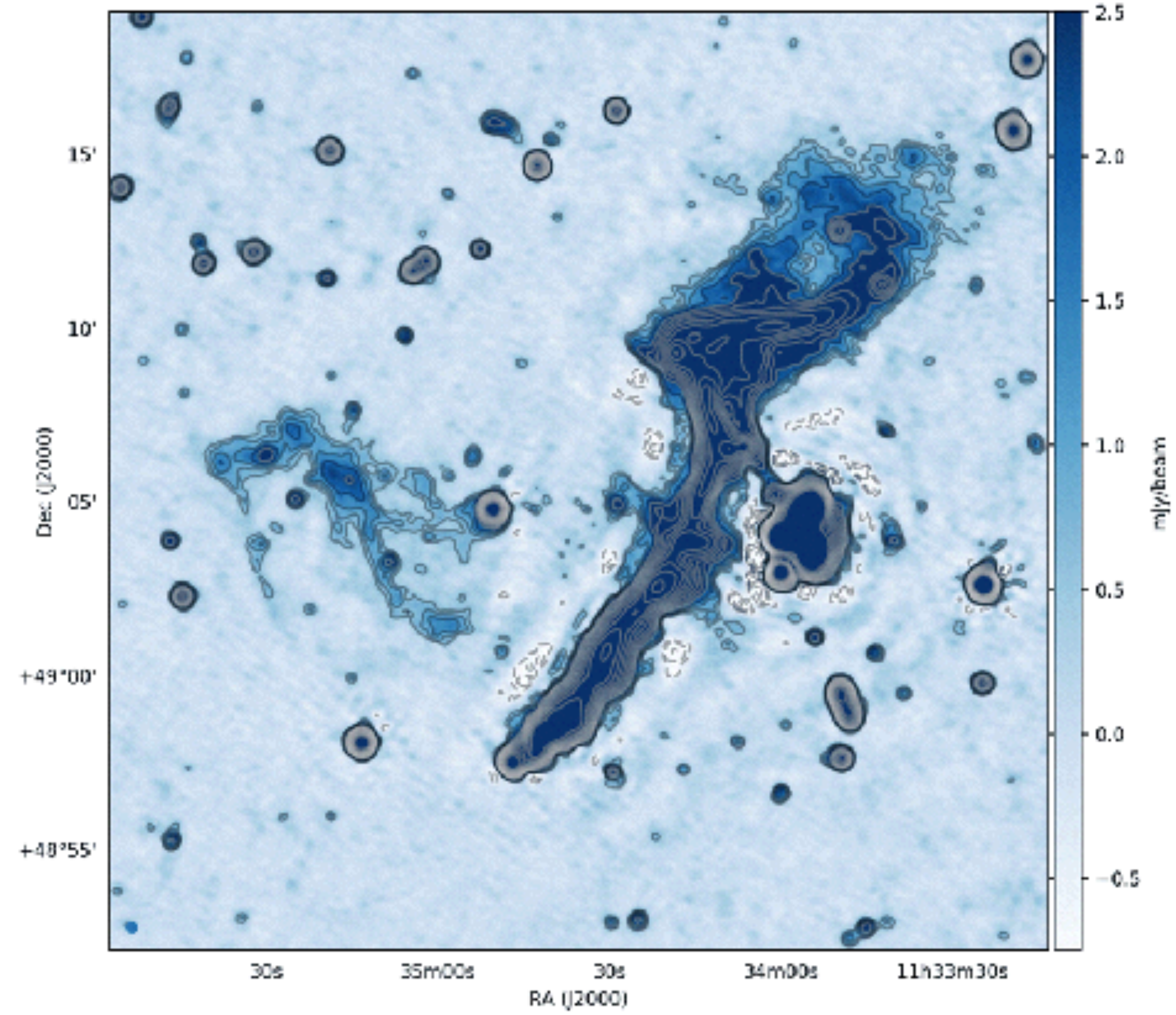
- Polarization correction is not DD, assumes general source population is unpolarized
- If there is a bright polarized source in the field the polarization calibration is affected (rare)
- SSD(2) deconvolution (this is not CLEAN). Determines flux & spectral index (and curvature for SSD2)
- No multiscale deconvolution, sources are modeled with delta functions
- Inner uv-cut of 100 meters used

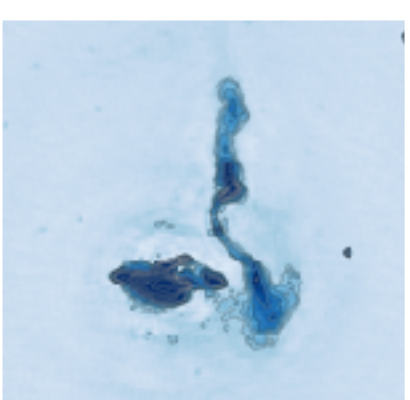
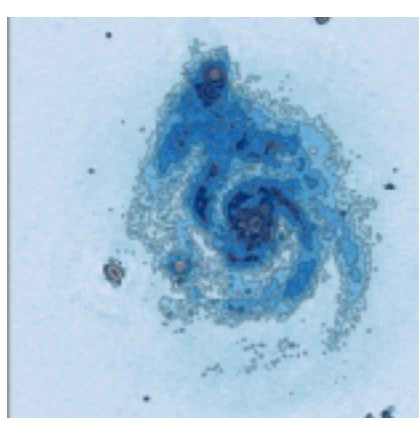
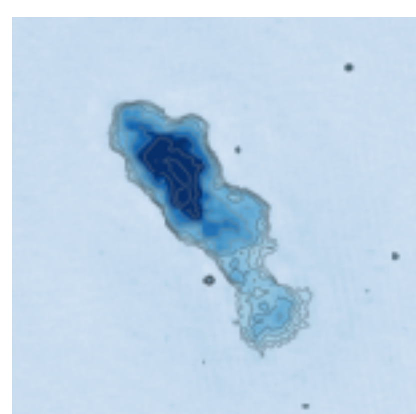
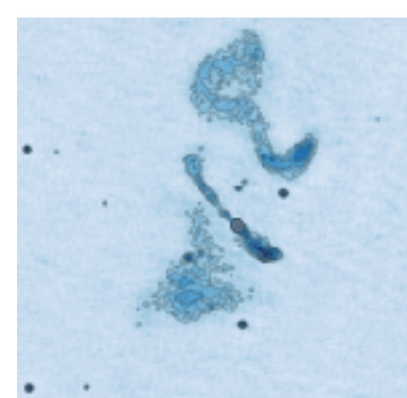
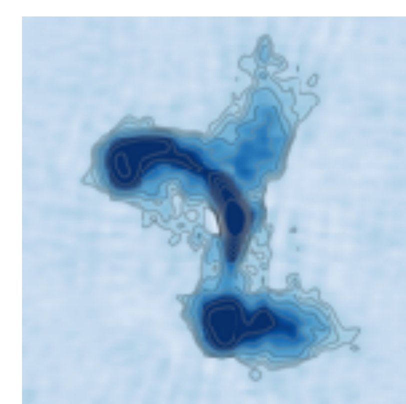
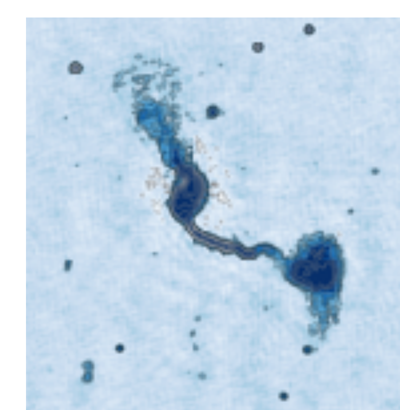


DDF-pipeline is public. It makes use of DDFacet and kMS for calibration and imaging (Tasse+ 2014, Smirnov+ 2015, and Tasse+ 2017). It produces science quality images in 4-6 days of processing.

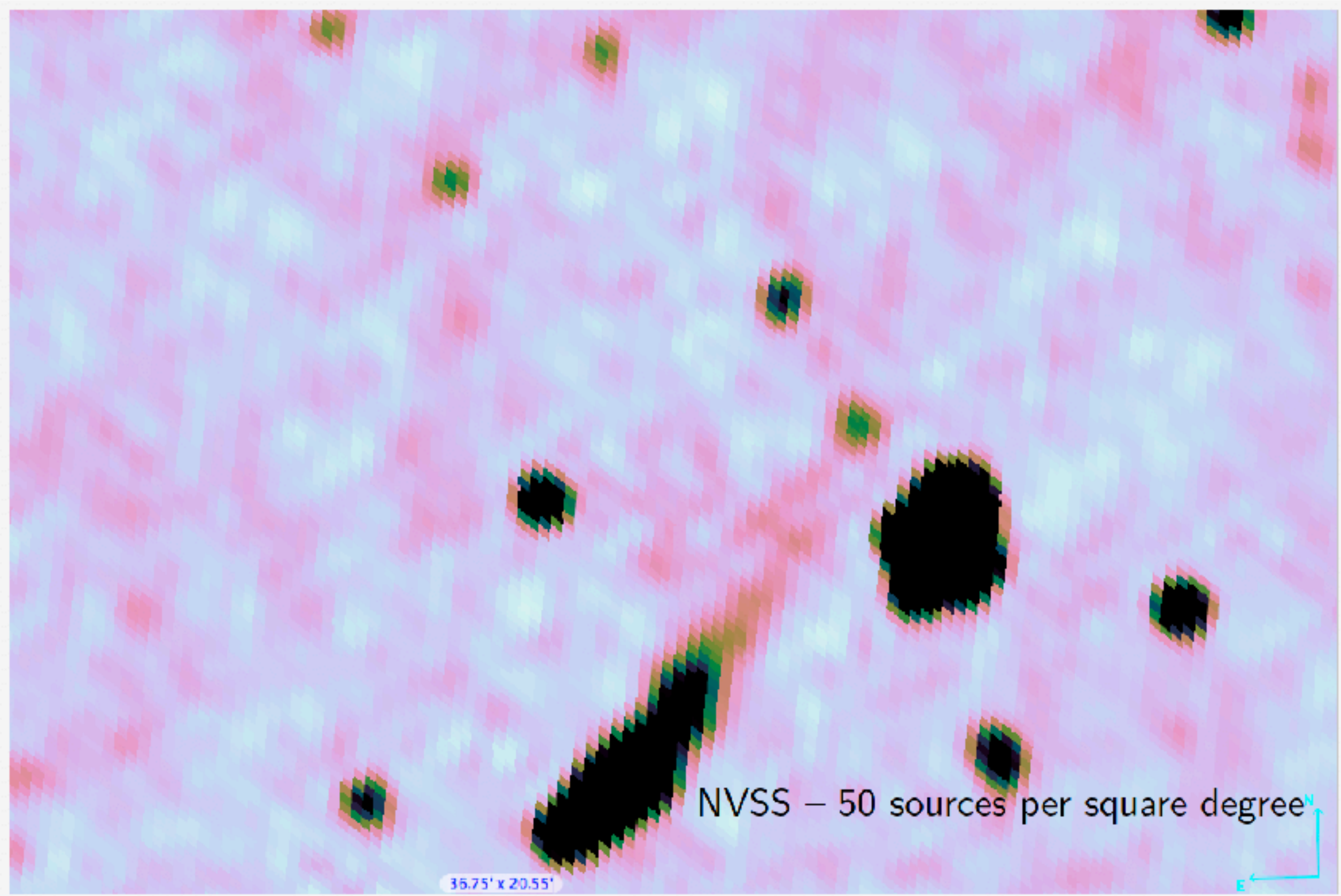
LoTSS DR2 - example images



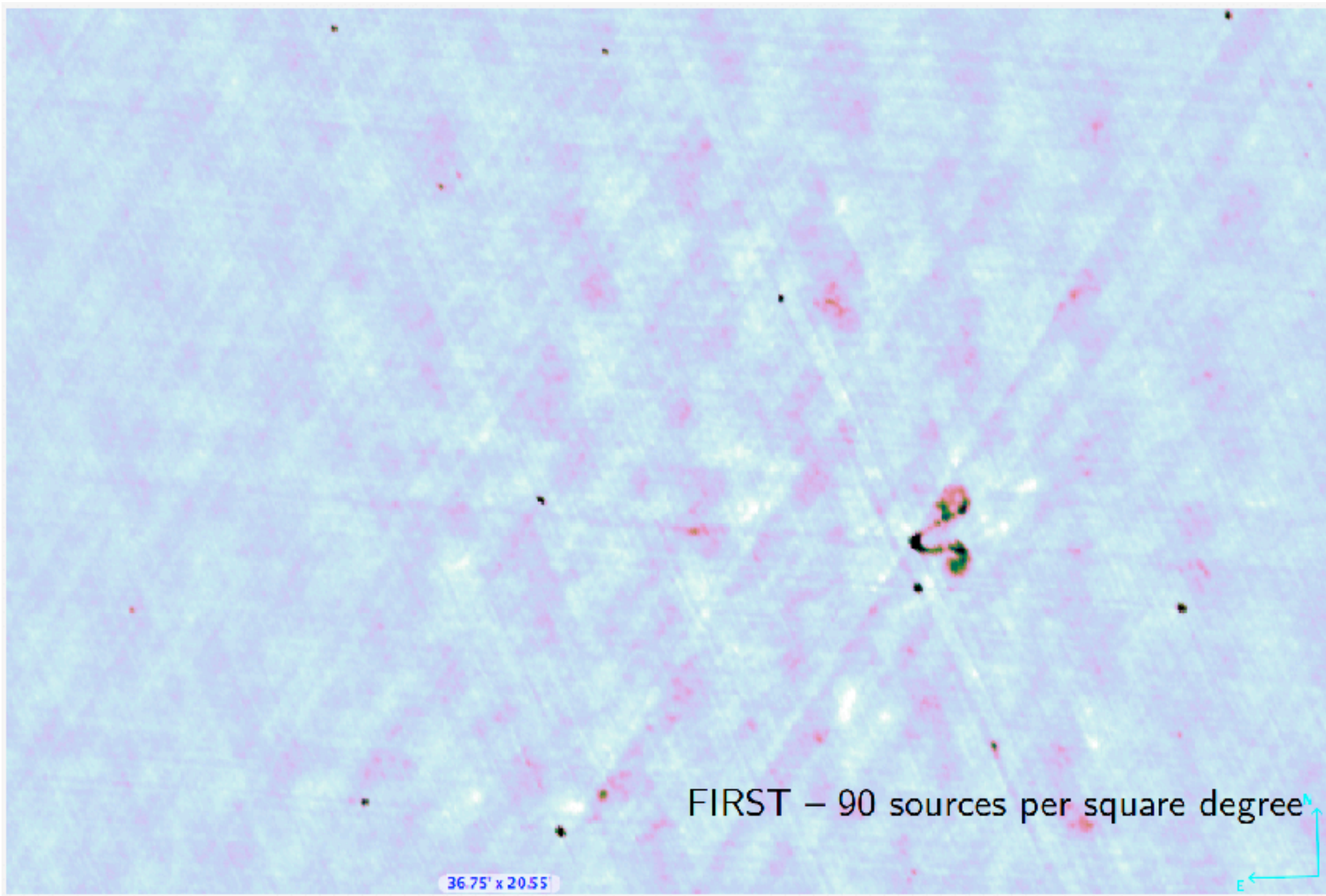


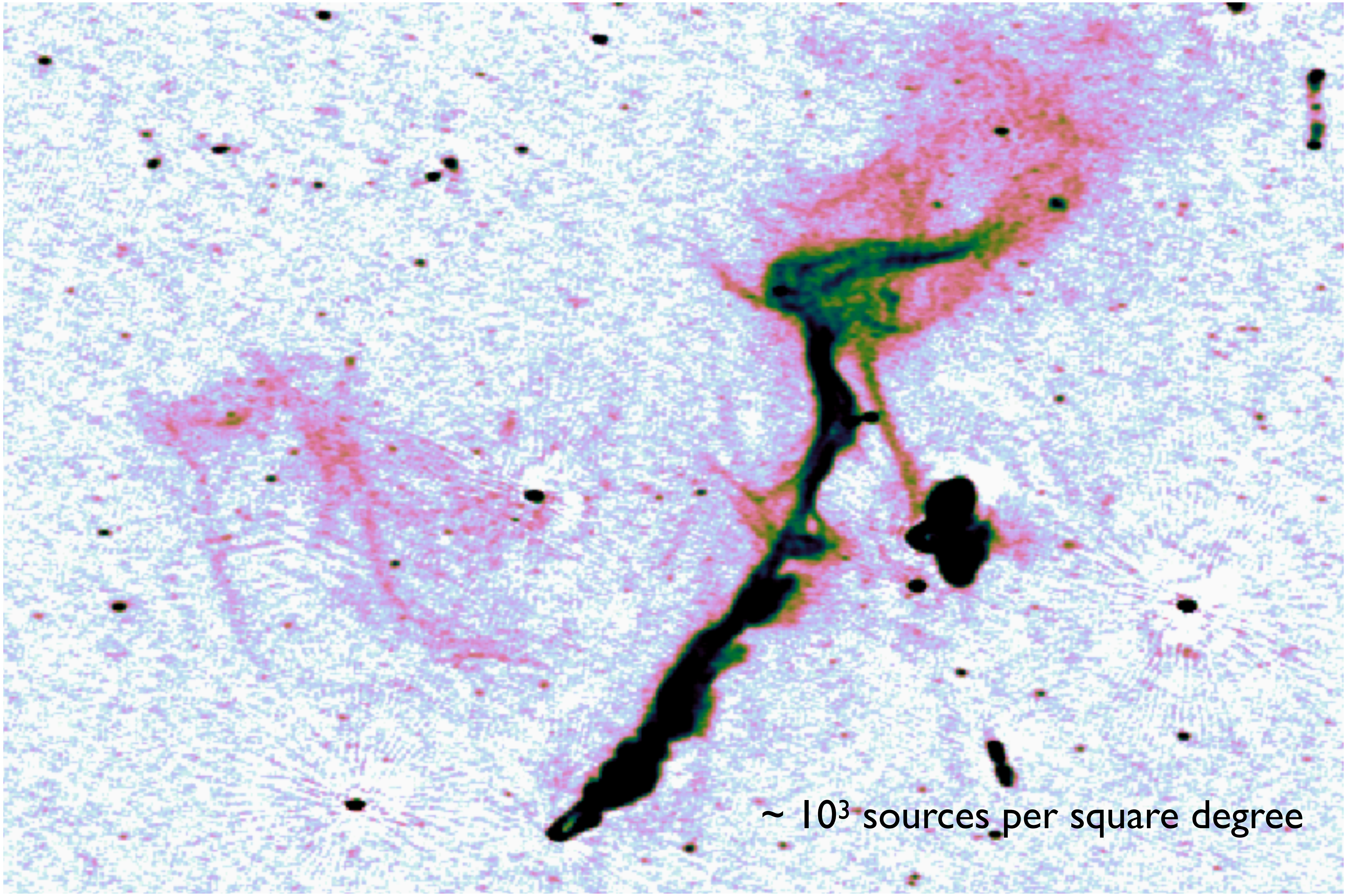
NVSS (1.4 GHz)



FIRST (1.4 GHz)



LoTSS (144 MHz)



THE LOFAR HBA SURVEYS

Reinout van Weeren

Leiden Observatory, Leiden University

on behalf of the LOFAR Surveys team

Special thanks to Tim Shimwell

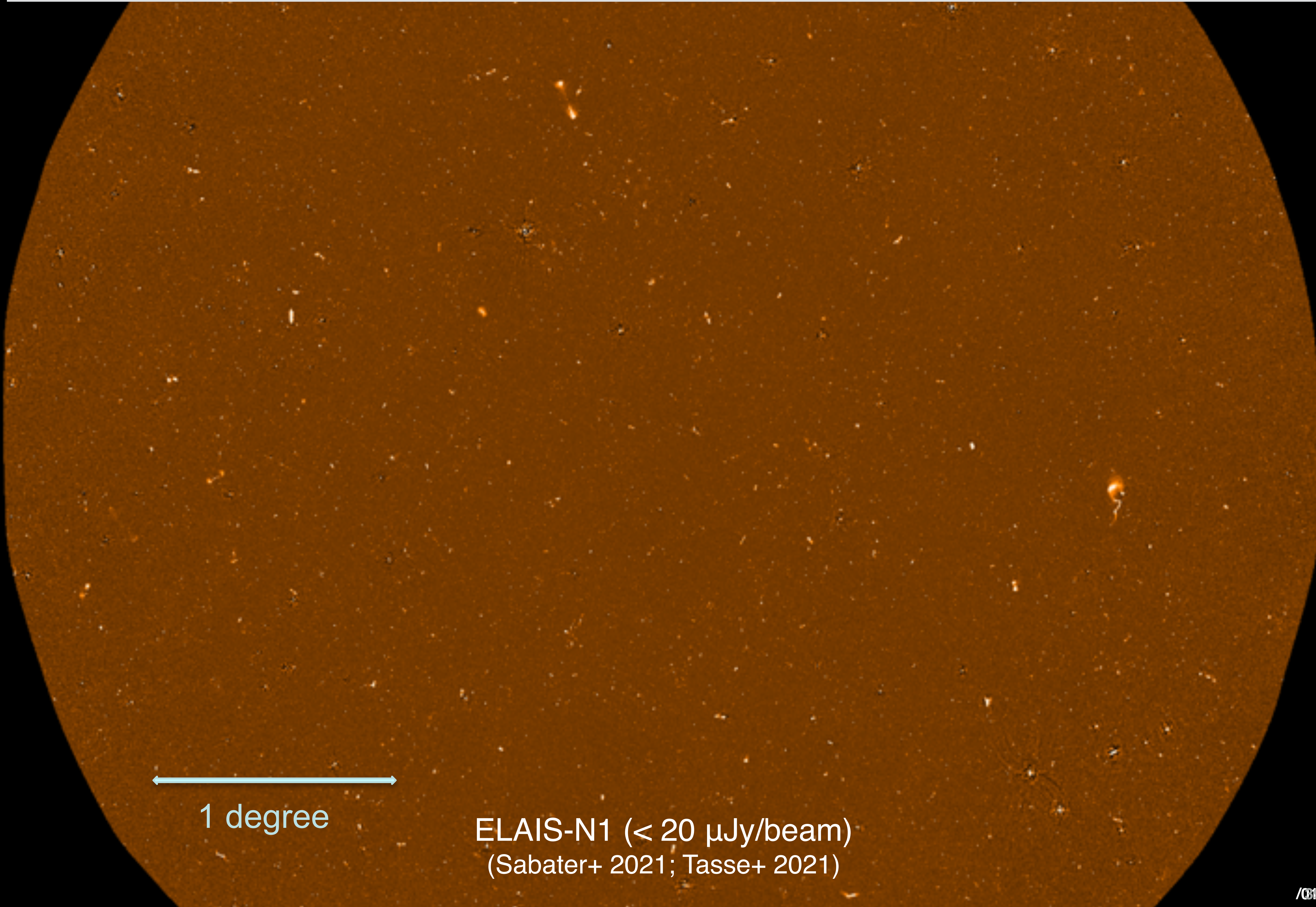
Summary

- The LOFAR HBA allows deep imaging of the northern sky at a nominal resolution of 6”.
- LOFAR Two-metre Sky Survey (LoTSS): Northern sky HBA survey at 0.1 mJy/beam - 8 hrs (85% observed)
- LoTSS-DR2 covers 26% of the Northern sky and contains 4,395,448 sources. This includes thee best regions of the sky for LOFAR imaging and is large enough for almost all statistical studies.
- 200TB of I, Q, U, V images, catalogues and uv-data are available through lofar-surveys.org
- LoTSS positional accuracy: < 0.5”
- LoTSS flux density scale uncertainty: ~ 10%

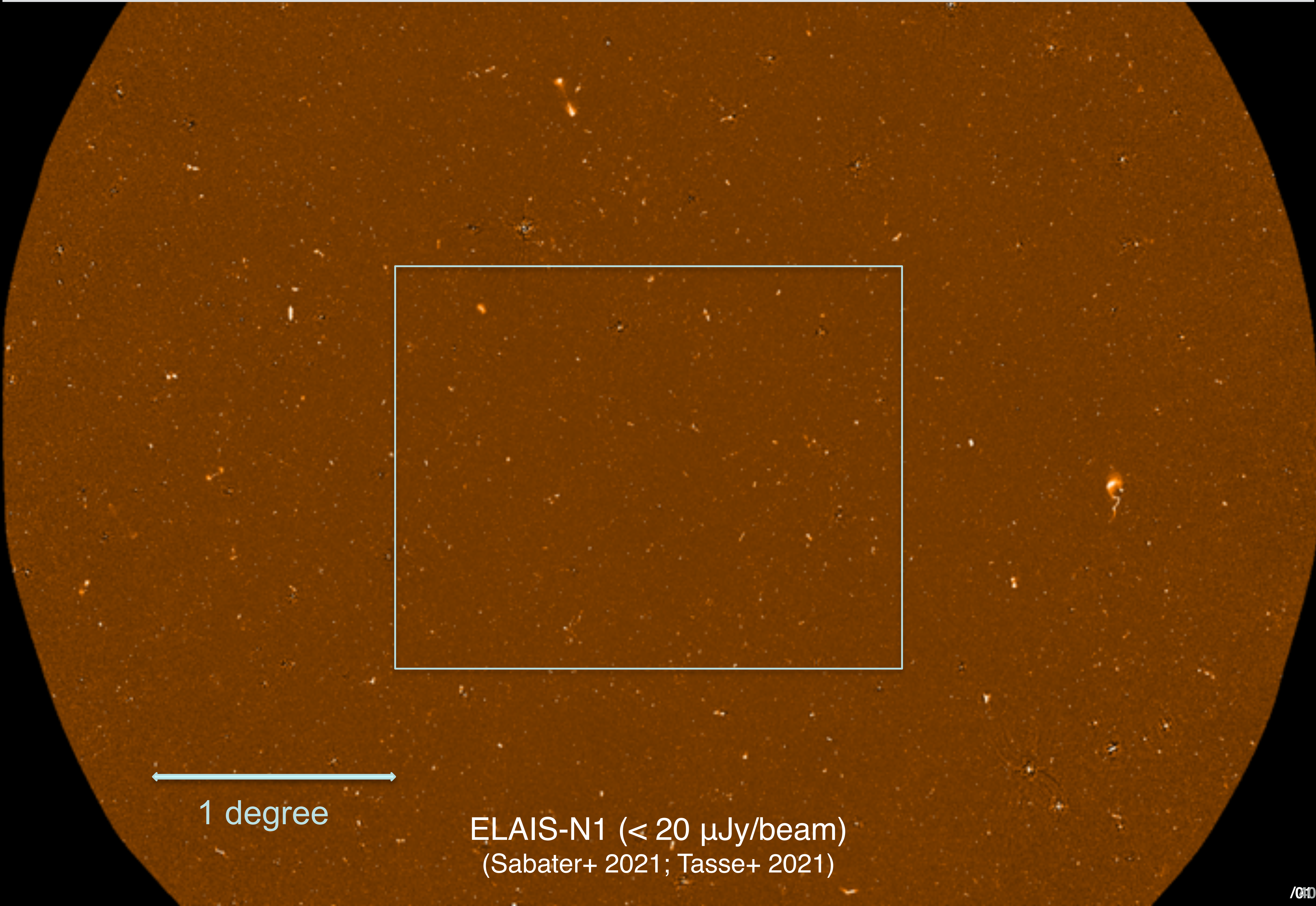
Outline

- ✓ LOFAR
- ✓ HBA: High Band Antenna
- ✓ HBA surveys
- ✓ Calibration
- ✓ LoTSS
- LoTSS-deep & characterization
- Working with HBA data
- Extraction-selfcal
- Ongoing and future work

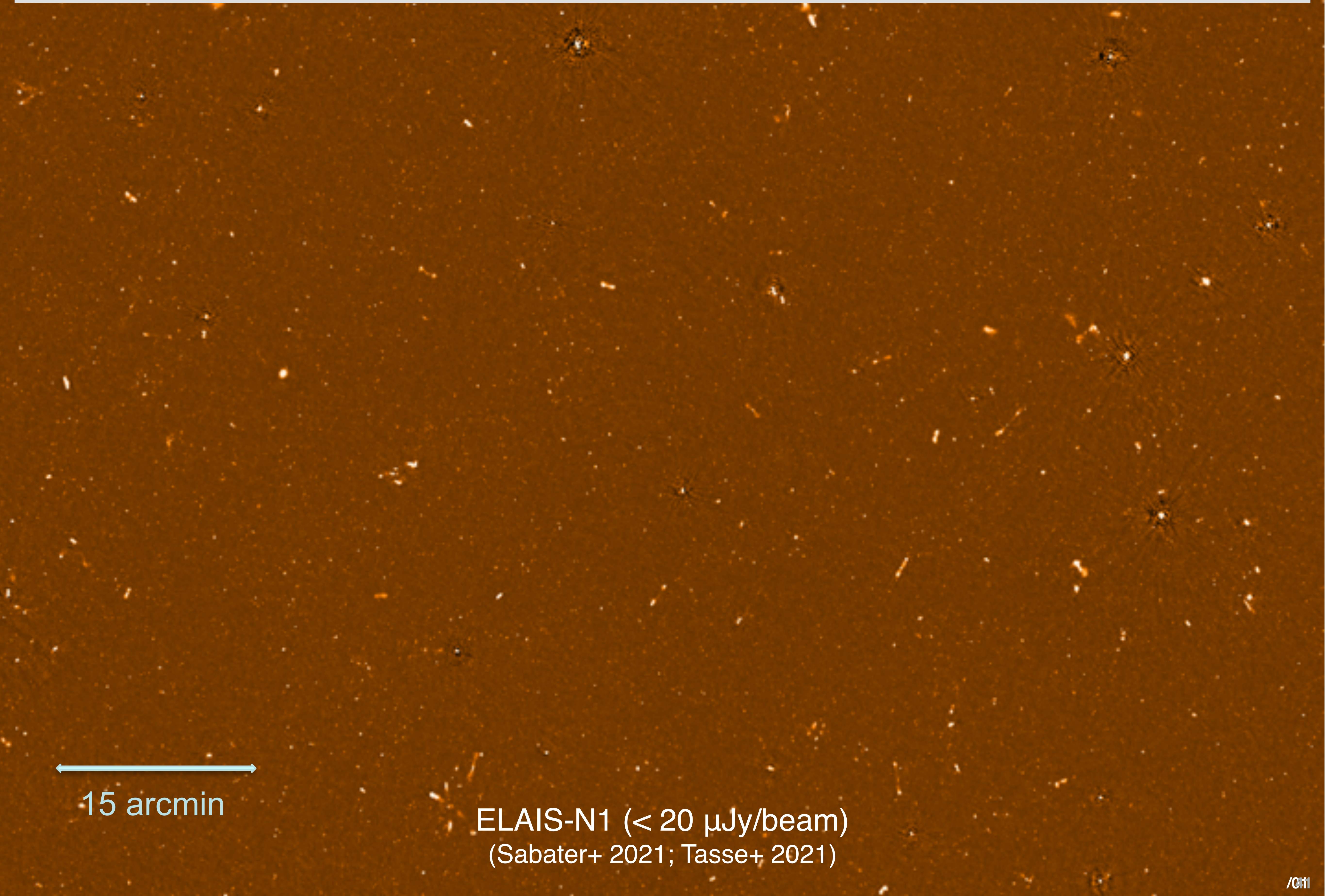
LoTSS-deep



LoTSS-deep

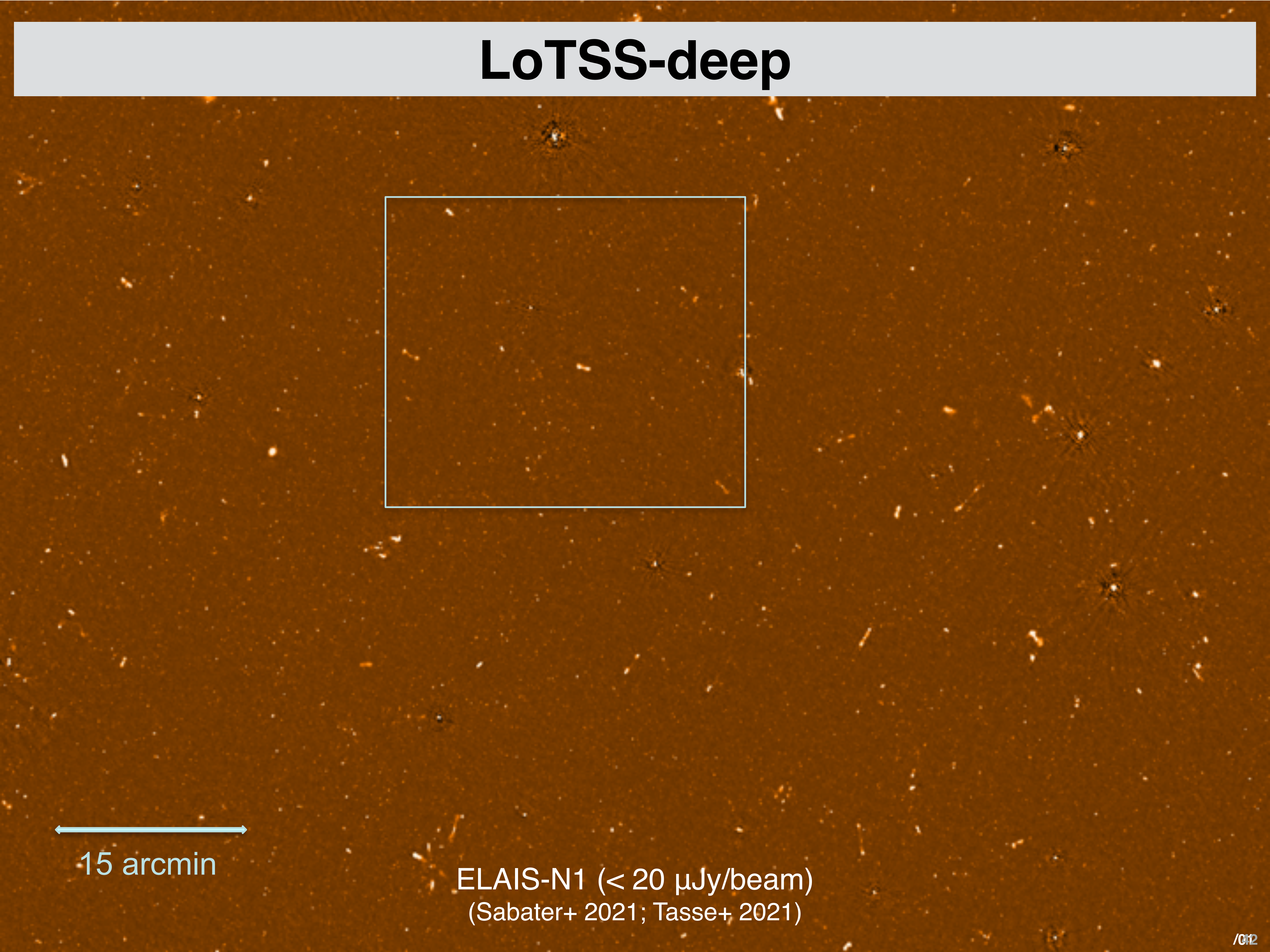


LoTSS-deep



ELAIS-N1 (< 20 µJy/beam)
(Sabater+ 2021; Tasse+ 2021)

LoTSS-deep



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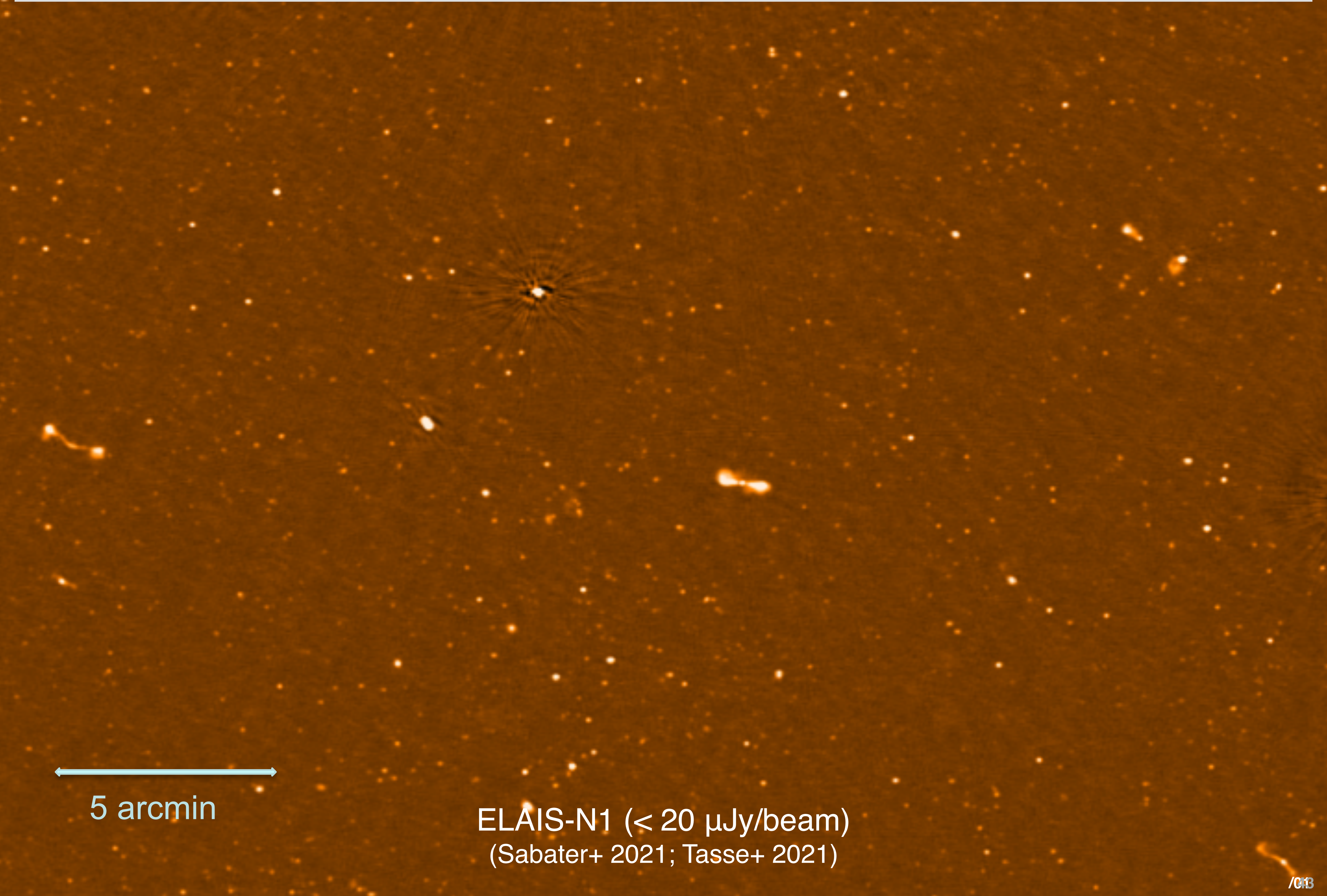
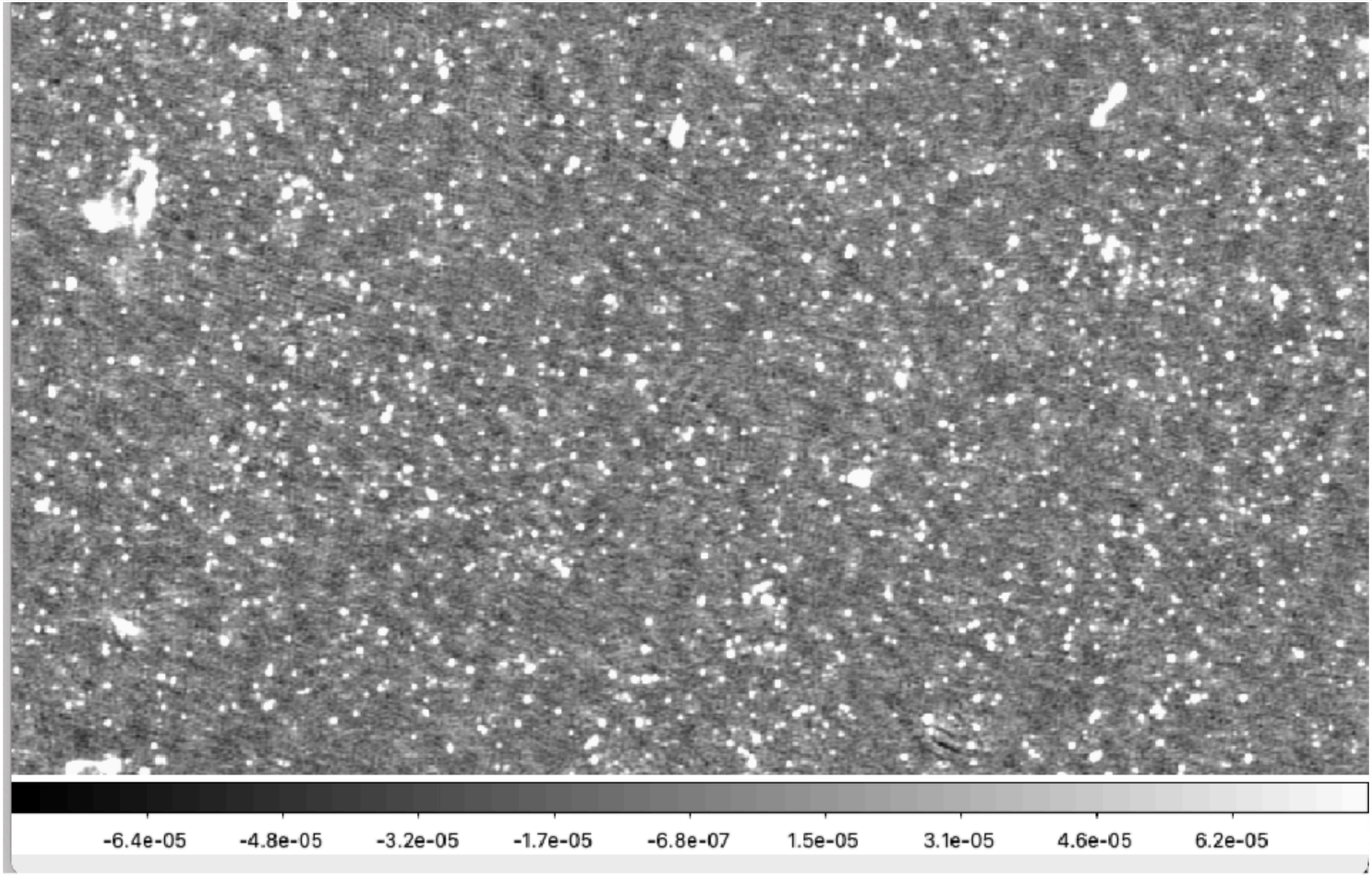
(Sabater+ 2021; Tasse+ 2021)

LoTSS-deep



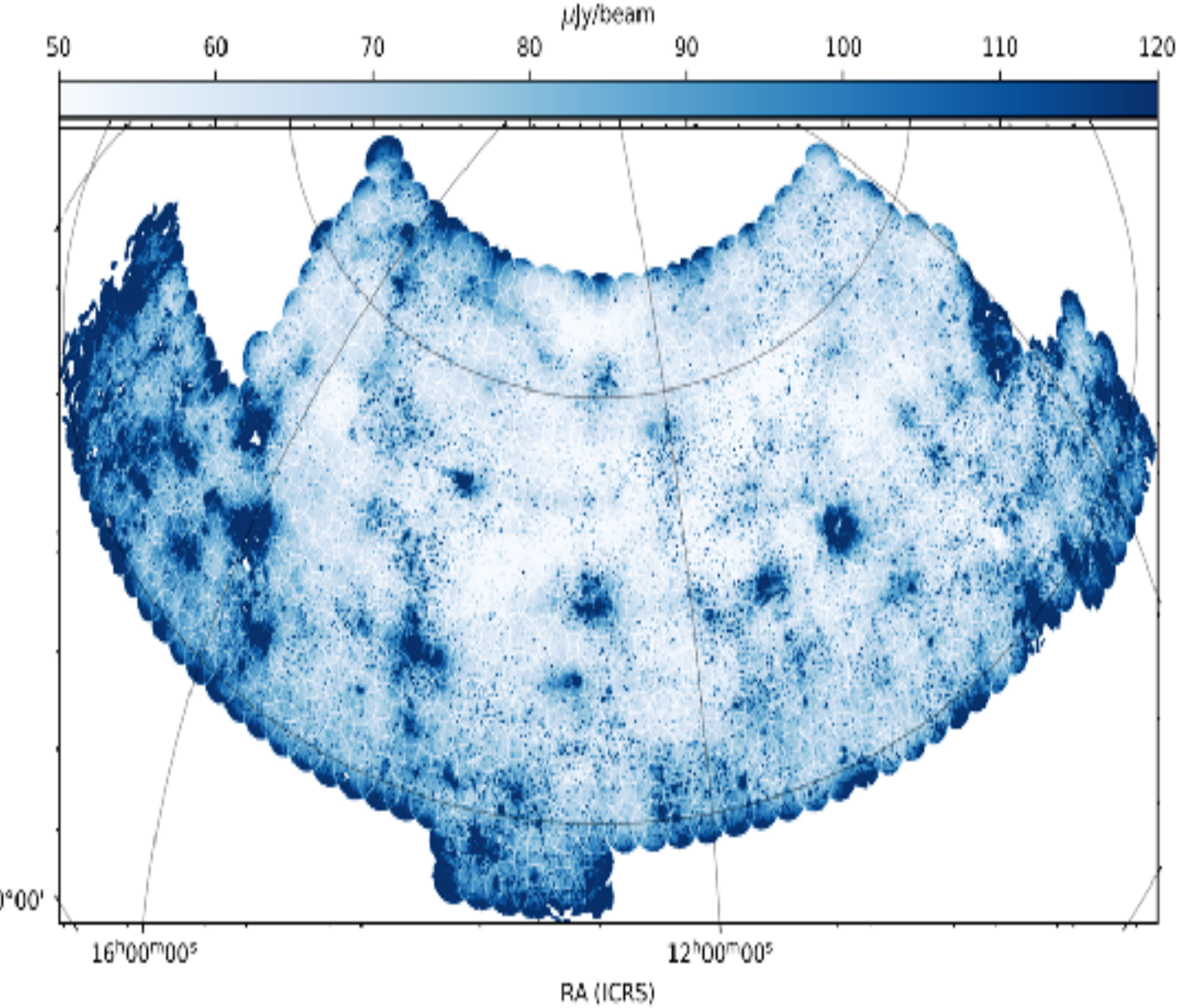
ELAIS-N1 (< 20 µJy/beam)
(Sabater+ 2021; Tasse+ 2021)

Next: Deeper field (550hrs on ELAIS-N1)



Around 10-12 µJy/beam rms at 6” resolution. Final images produced but not yet fully released.

LoTSS - example images



LoTSS-DR2 Stokes I products:

Mosaiced 6” and 20” resolution maps

Individual observation 6” and 20” resolution maps (plus model, residual, mask images)

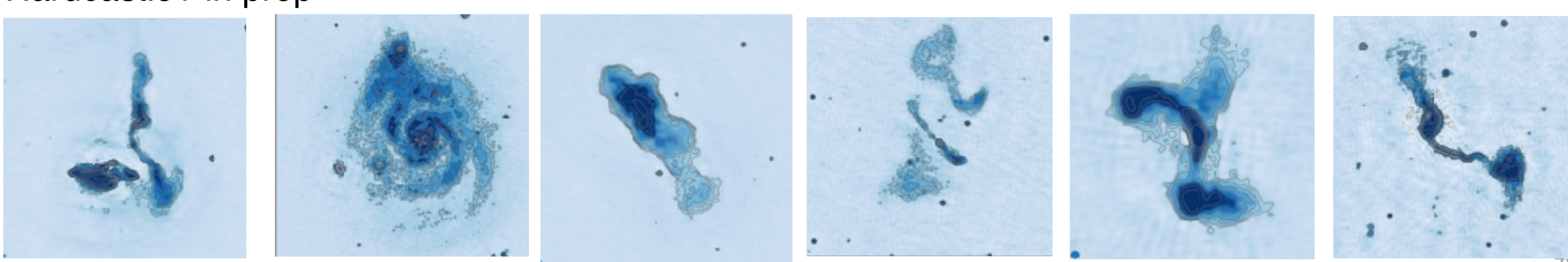
6” in-band (128, 144, and 160MHz) images

Catalogue of 4.4 million sources.

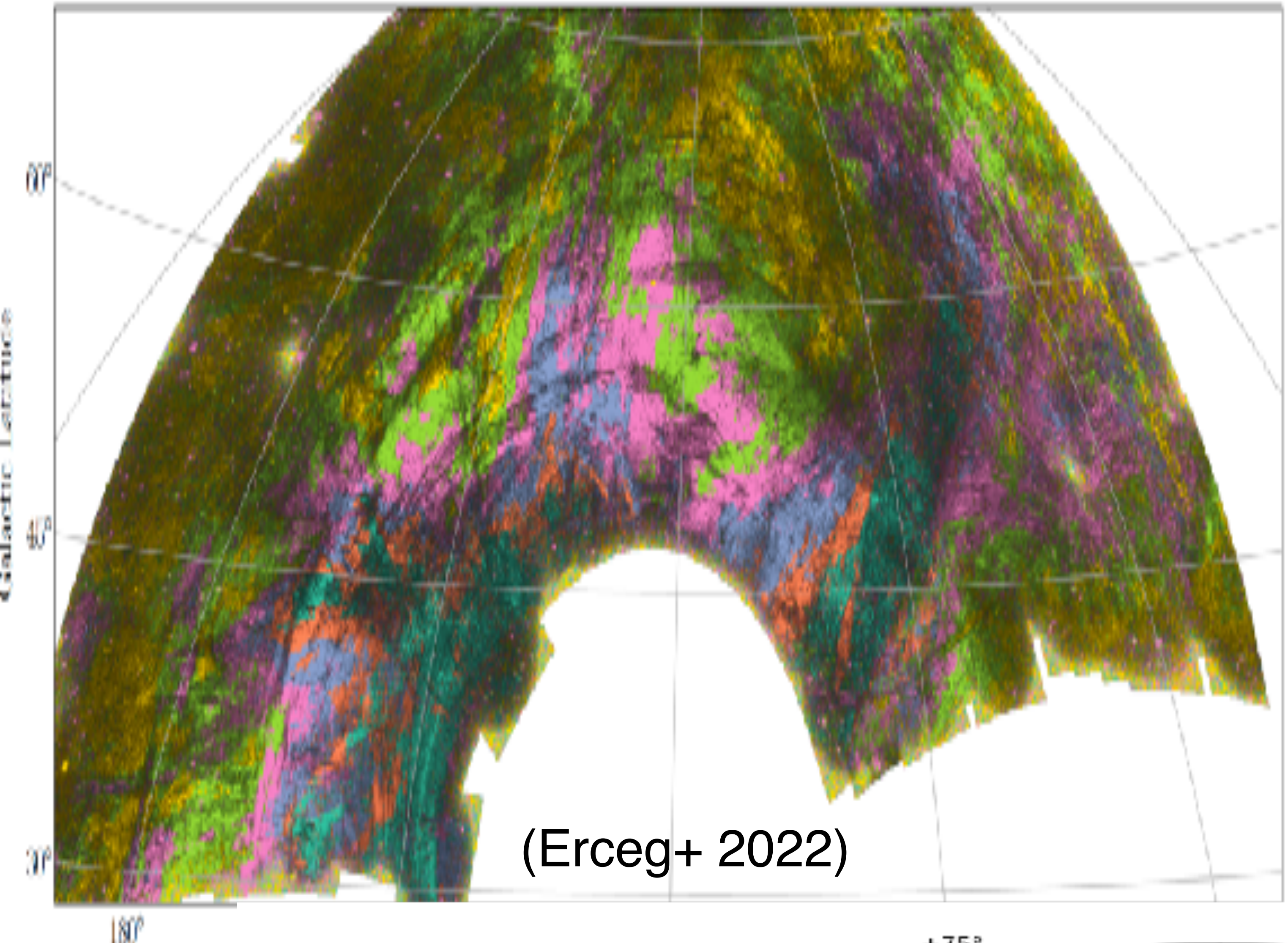
HIPS file for visualization

uv-data and full direction dependent calibration solutions (enabling full reimaging and flexible post processing)

Coming soon: optical identifications for 84% of LoTSS-DR2 sources and 57% with z estimate. Hardcastle+ in prep



LoTSS - example images



(Erceg+ 2022)

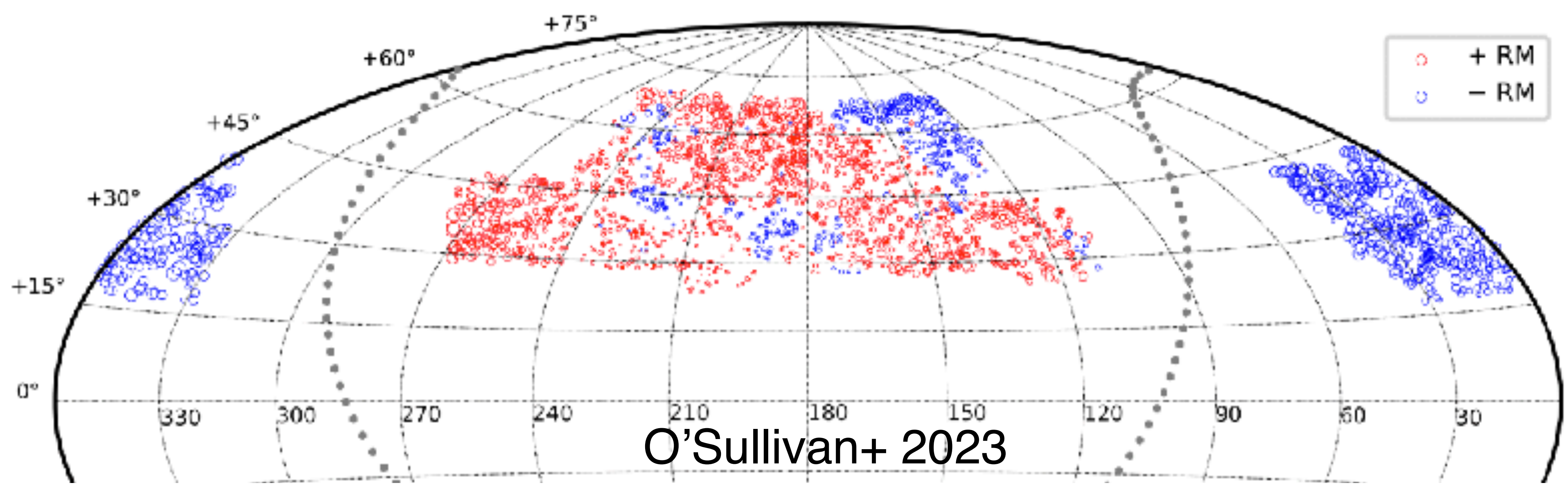
LoTSS-DR2 other products:

Stokes QU 480-plane image cubes at 20” containing 2,461 sources (O’Sullivan+ 2023)

Stokes QU 480-plane image cubes at 4’ resolution containing our galaxy (Erceg+ 2022)

Stokes V 20” resolution images containing 68 sources (Callingham+ 2023)

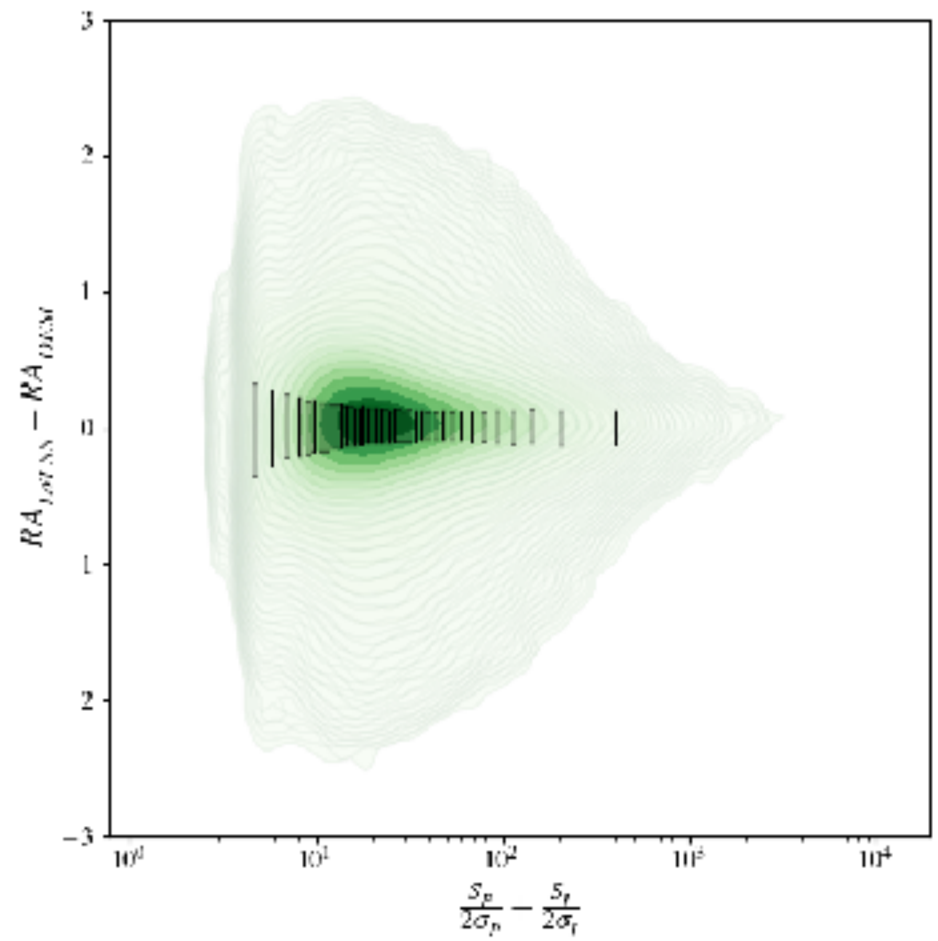
Note: No deconvolution for polarized LoTSS images

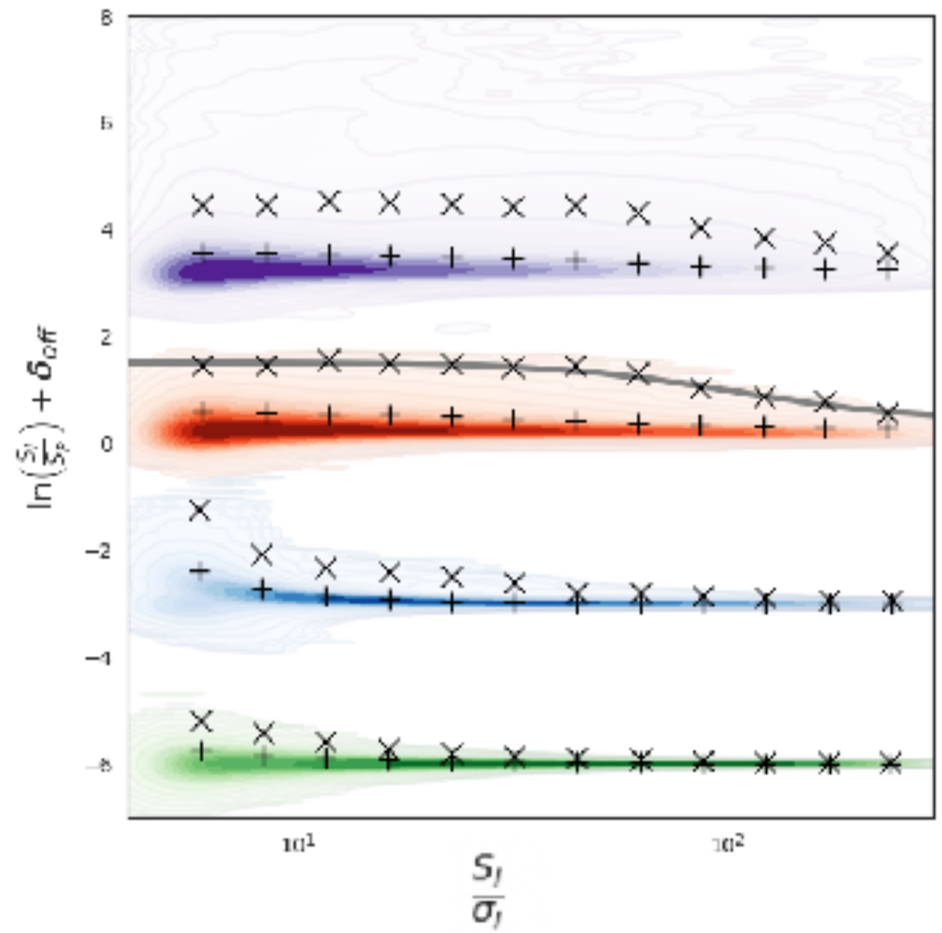


O’Sullivan+ 2023

LoTSS-DR2 — Characterization

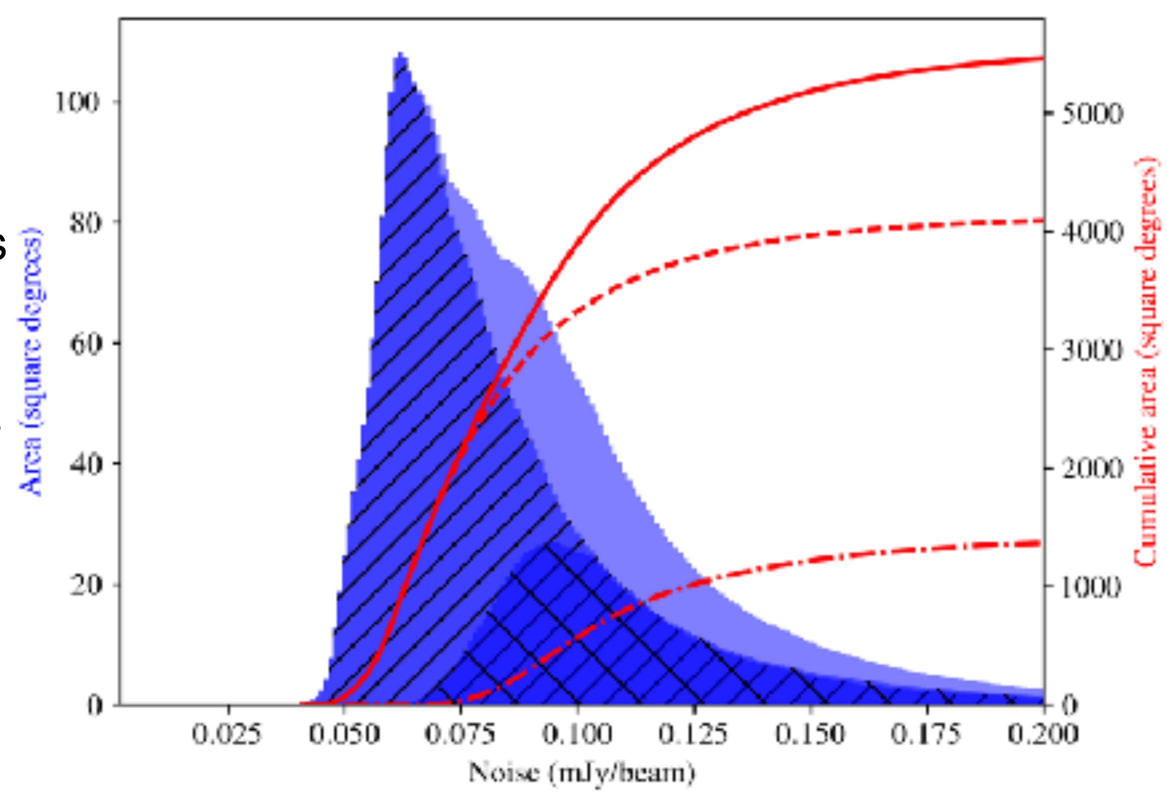
Astrometry about 0.2” in RA and in DEC increasing to 0.5” at low SNR.

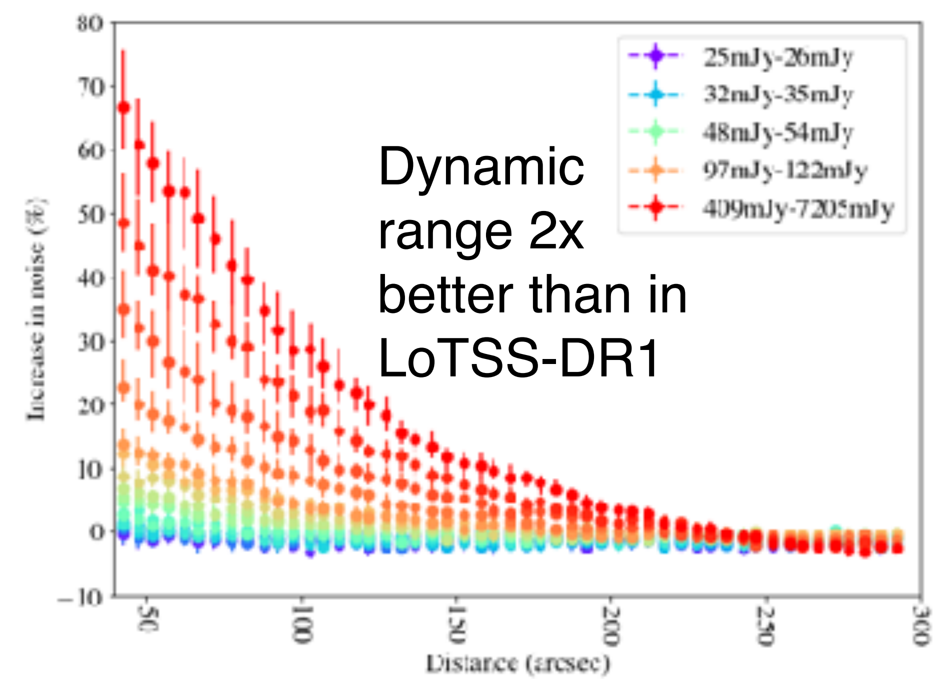




8.4% of sources resolved

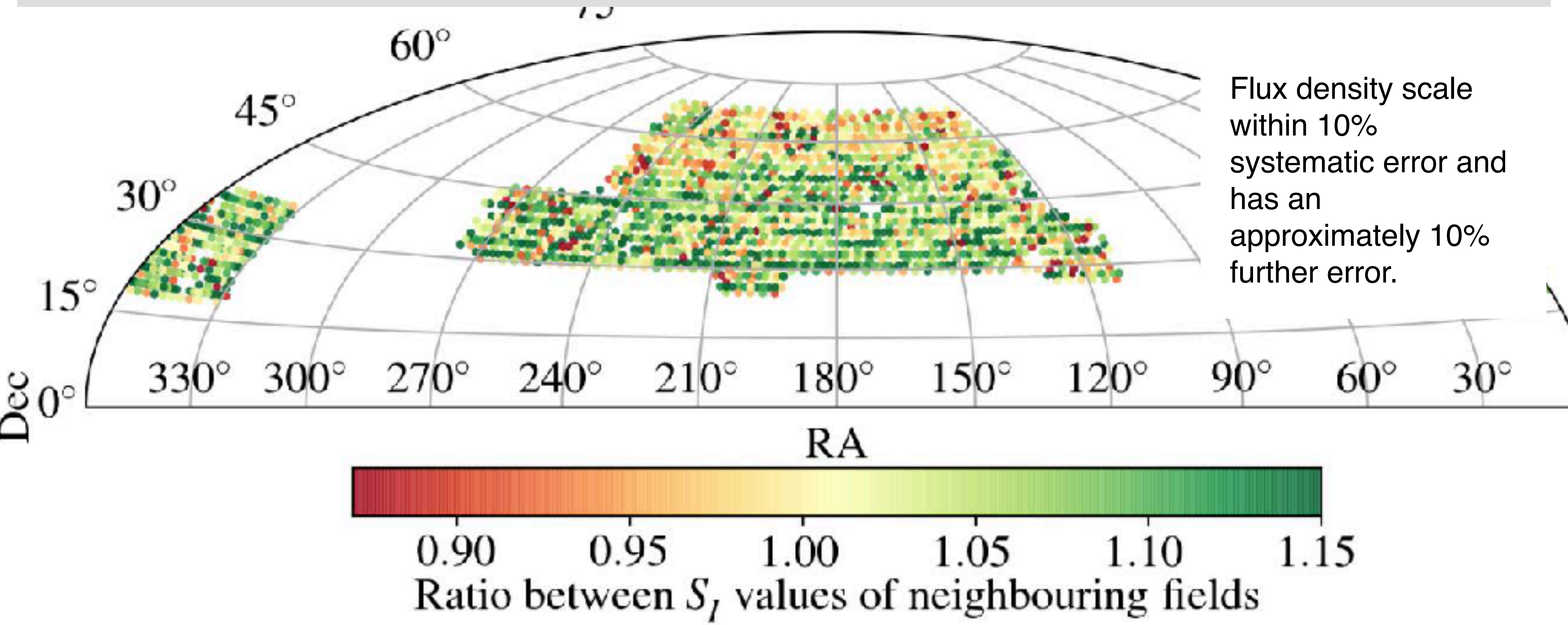
Median sensitivity is 83uJy/beam. Individual pointing sensitivity scales as ~cos(elevation)$^{-2}$



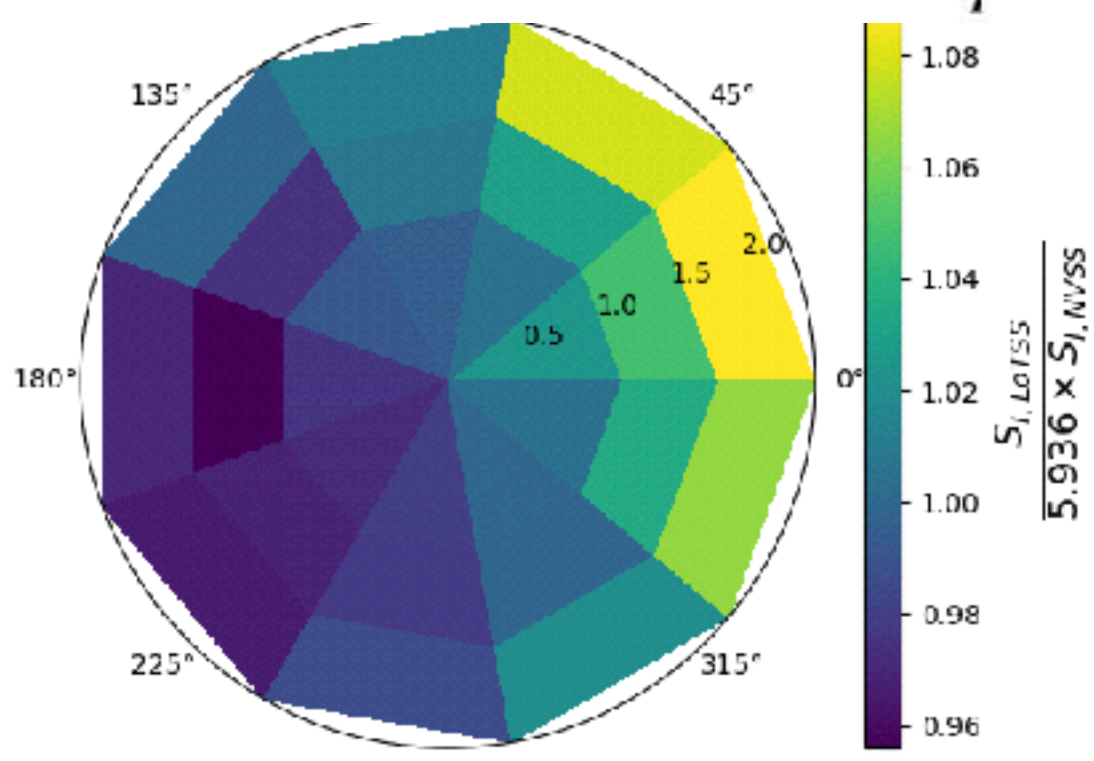


Dynamic range 2x better than in LoTSS-DR1

LoTSS-DR2 — Characterization



Flux density scale within 10% systematic error and has an approximately 10% further error.



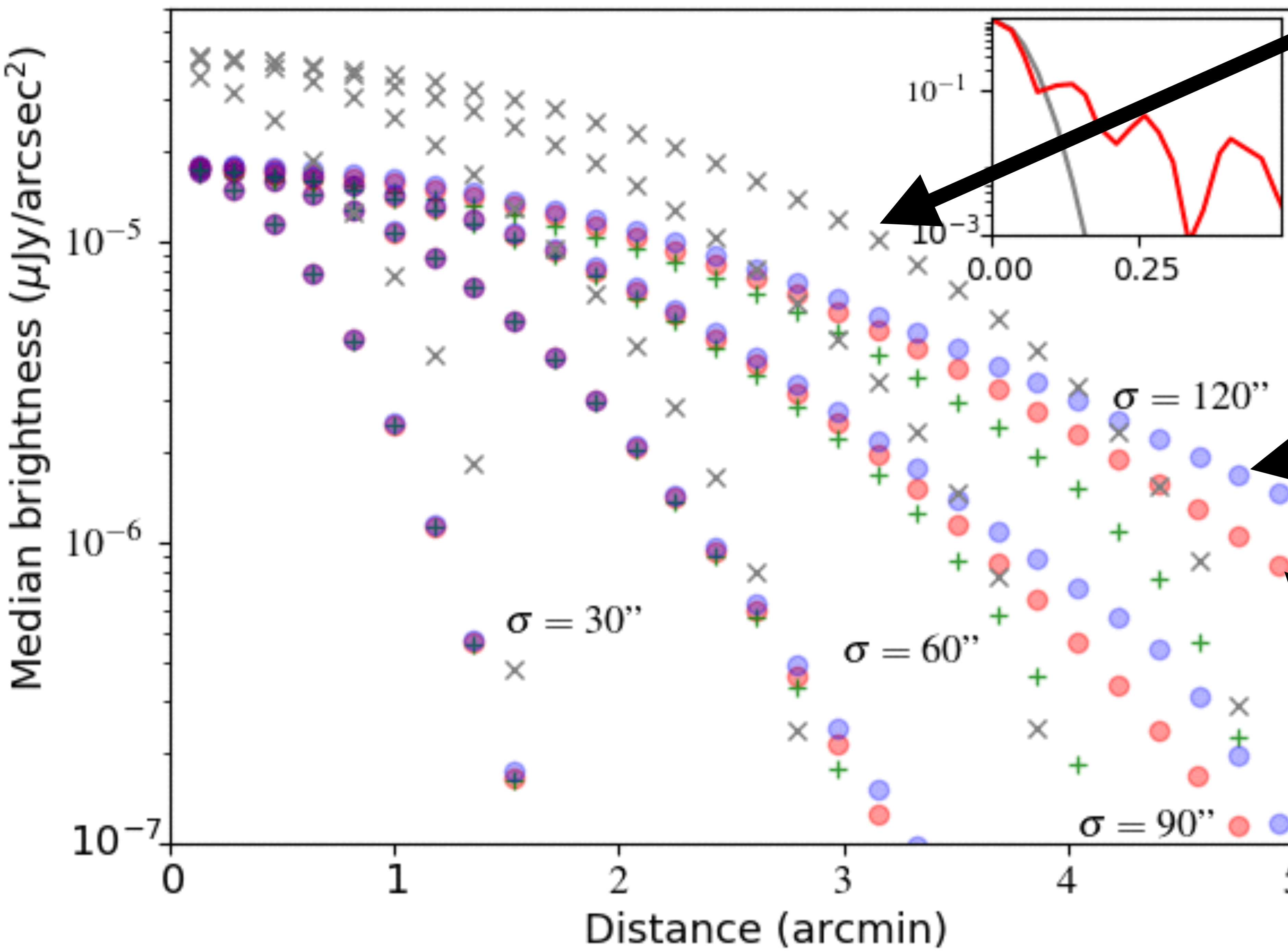
Northern region of a given pointing systematically brighter than southern region.

Complicates flux scale and apparently more severe at lower dec. Still being investigated but fortunately largely cancels out in mosaicing

LoTSS-DR2 — Characterization

Uv-plane injection of Gaussians

Injecting after calibration



Deconvolution critical - undeconvolved emission is artificially over 2 times too bright.

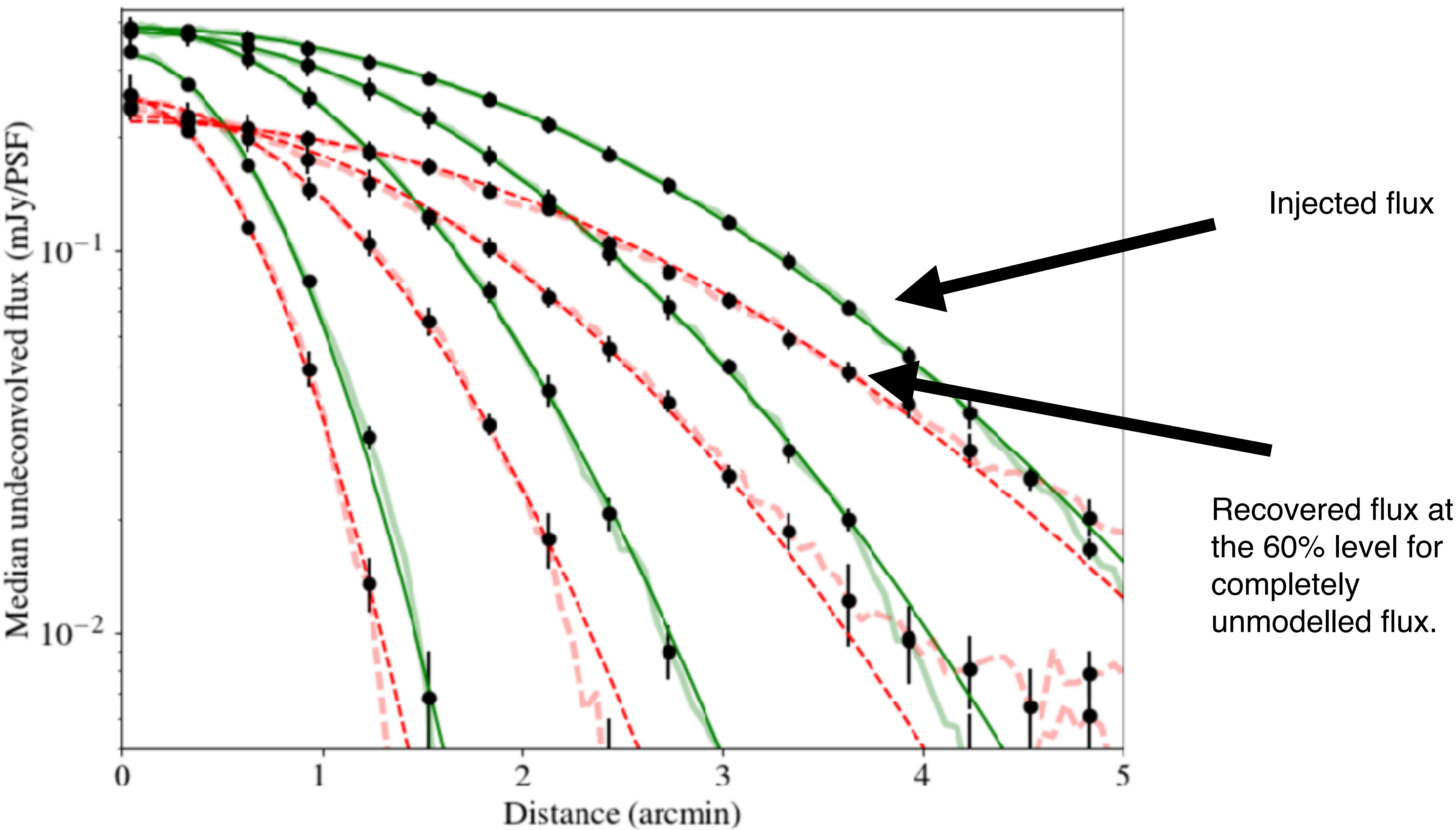
Injected flux

Recovered flux (>95% for e.g. several arcmin scale objects)

LoTSS-DR2 — Characterization

Uv-plane injection of Gaussians

Injecting prior to calibration (worst case scenario absorption)



Working with HBA/LoTSS data

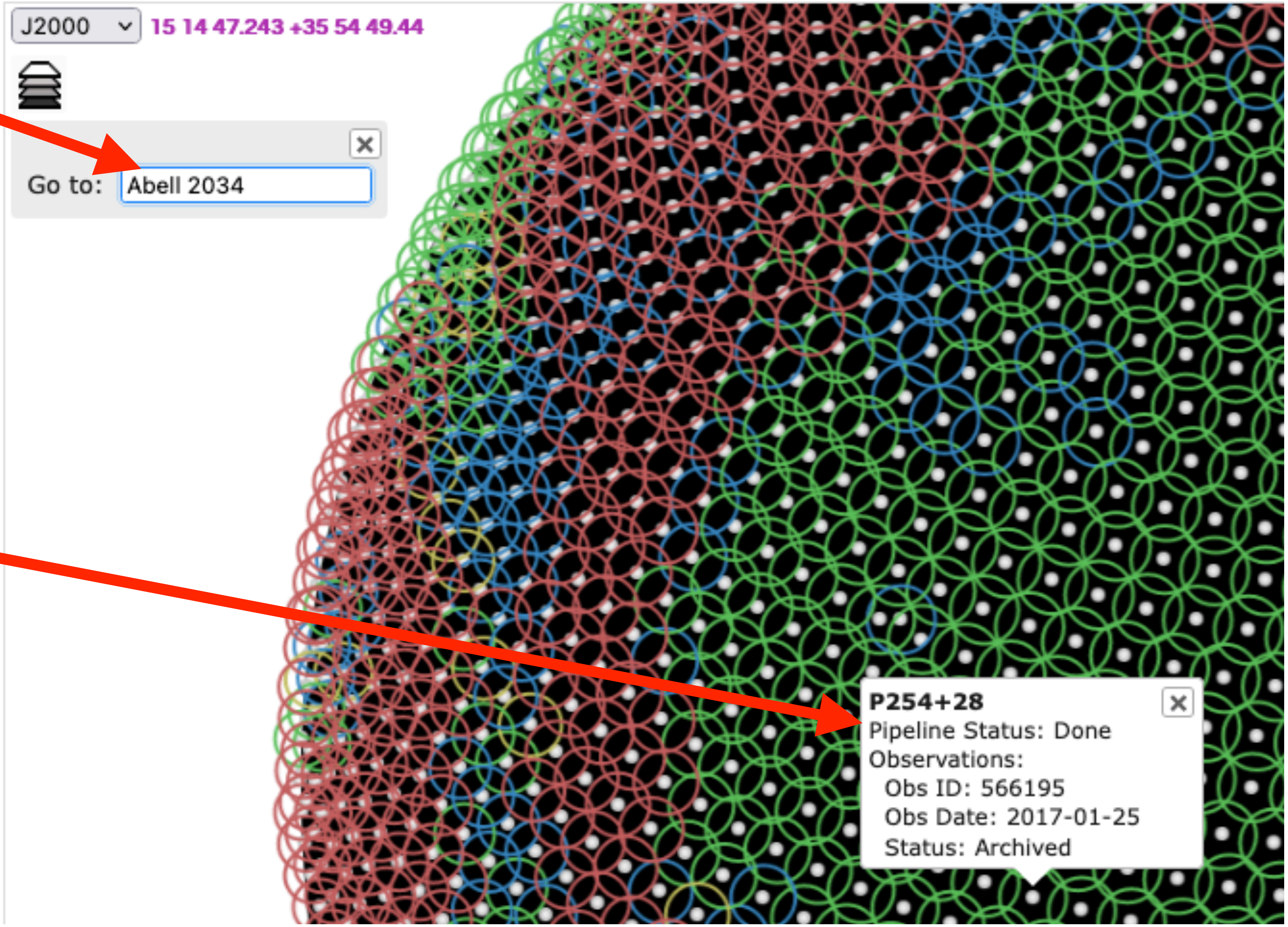
Using LoTSS

Status of observing and processing

https://lofar-surveys.org/lotss-tier1.html

Enter target name or RA/ DEC.

See observations of a pointing and status of data processing.



Using LoTSS

Status of observing and processing

https://lofar-surveys.org/lotss-tier1.html

Fields database: https://lofar-surveys.org/fields.html

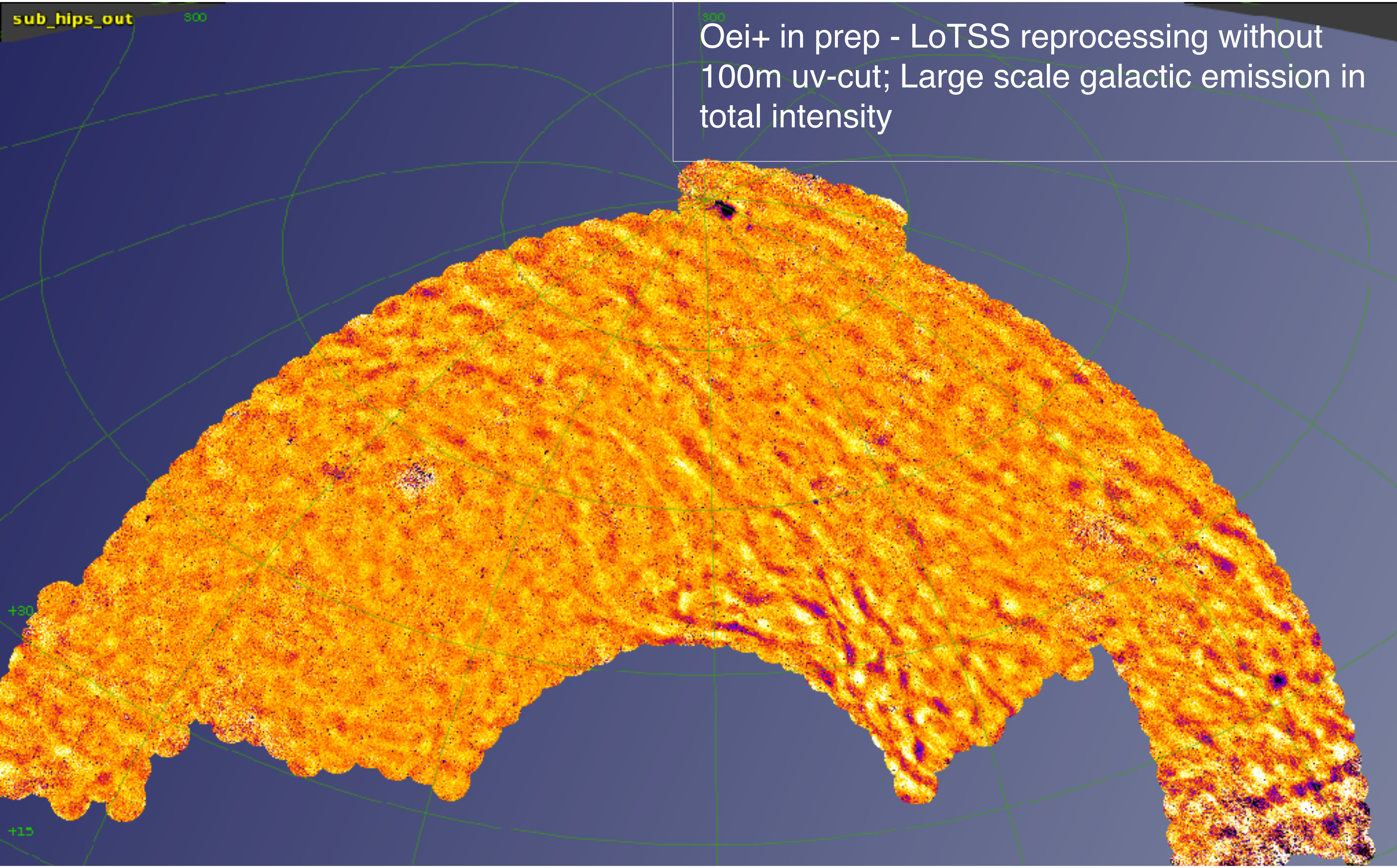
Observations database: https://lofar-surveys.org/observations.html

ID	Field	Status	Project code	Location	Integration	dt	nchan	nsb	Date
868300	P034+11	Archived	LT16_012	Juelich	4.0	1.001	16	231	2022-08-22 01:45:04
868096	P310+13	READY	LT16_012	Juelich	4.0	1.001	16	231	2022-08-21 20:10:43
868098	P311+08	Archived	LT16_012	Juelich	4.0	1.001	16	231	2022-08-21 20:10:43

Calibrator ID	Calibrator dt	Calibrator nchan	Calibrator nsb	Calibrator name	Calibrator date	Bad baselines	No. international stations	Priority	Int. processed?
868100	1.001	16	231	3C48	2022-08-22 00:11:43		14	1	None
868094	1.001	16	231	3C295	2022-08-21 19:59:43		14	-10	None
868094	1.001	16	231	3C295	2022-08-21 19:59:43		14	418	None

LoTSS - reprocessing example

Oei+ in prep - LoTSS reprocessing without 100m uv-cut; Large scale galactic emission in total intensity



Using LoTSS

Retrieving images and catalogues:

Public data:

https://lofar-surveys.org/dr2_release.html
Contains links to uv-data, images, mosaics, catalogues, HIPS, polarization products

To bulk download uv-data, images etc use ddf-pipeline (https://github.com/mhardcastle/ddf-pipeline).

```
export SDR_TOKEN=c49c6bb3-d074-a44d-4fca-1d3f7458055d
```

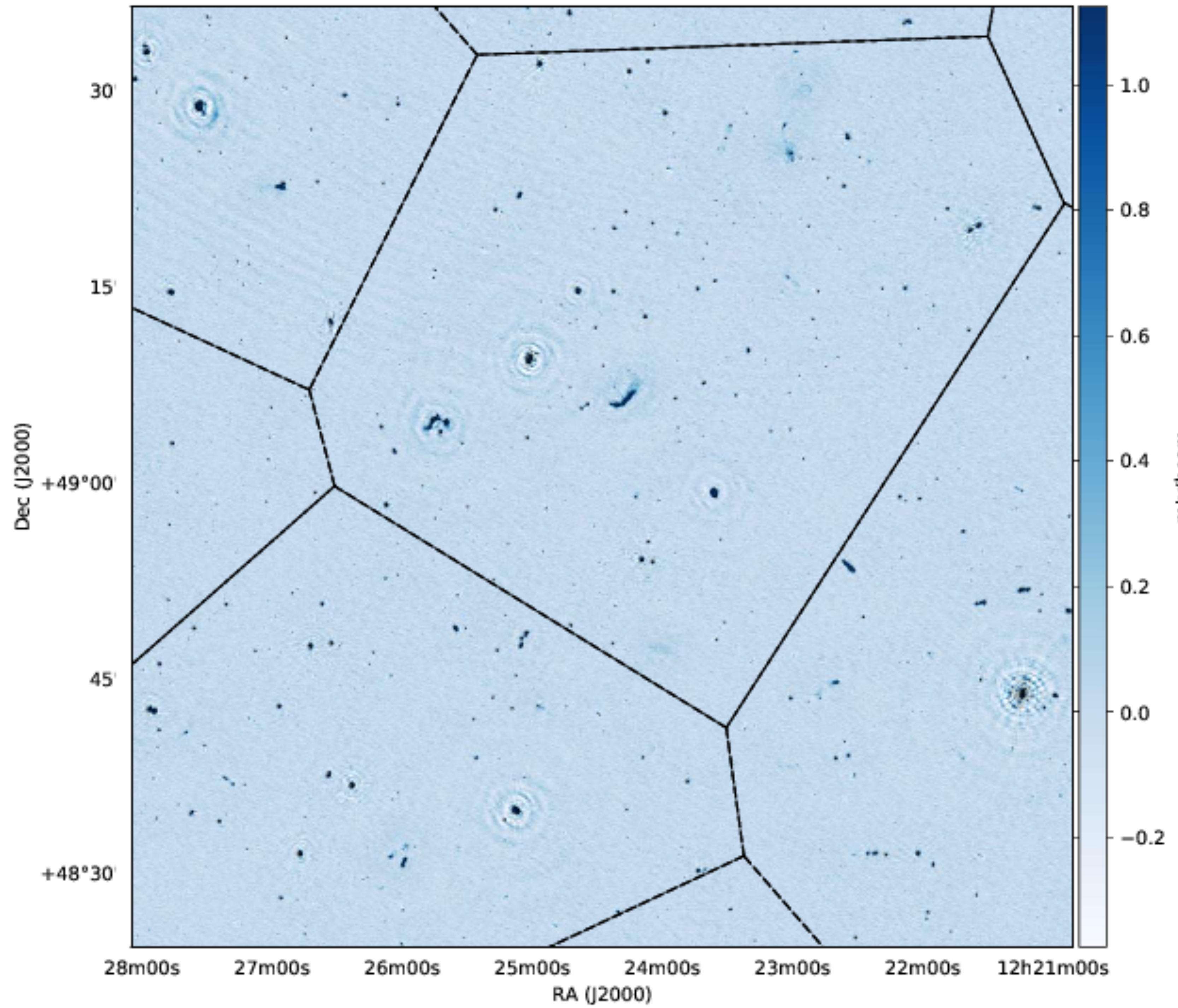
```
from reprocessing_utils import *
do_sdr_and_rclone_download(fieldname,processingdir)
```

Post-postprocessing with facetselfcal.py

van Weeren+ 2021 (& significant number of further improvements since then)

https://github.com/rvweeren/lofar_facet_selfcal

- Facet layout can be non-optimal for target-of-interest
- Joint deconvolution of obs. with different pointing centers
- Improved deconvolution (e.g., multiscale)
- Fast re-imaging with different settings for science (uv-tapers, weightings, etc.)
- Improved calibration quality
- Q, U, and V deconvolutio.



Using LoTSS

Studying individual targets of interest - extract pipeline:

1) Download field (as before) and subtract sources away from target (e.g. using ddf-pipeline script:

`sub-sources-outside-region.py -b Abell2034.ds9.reg -p Abell2034`)

2) Self calibrate (direction independent) on the resulting data:

https://github.com/rvweeren/lofar_facet_selfcal

Then e.g.

```
python facetselfcal.py --auto -b Abell2034.ds9.reg -i Abell2034
P228+32subtractedfile.ms P226+35subtractedfile.ms
```

Produces msfiles calibrated in direction of target with beam taken out. Can be reimaged again however you like.

Step 1: “extract”

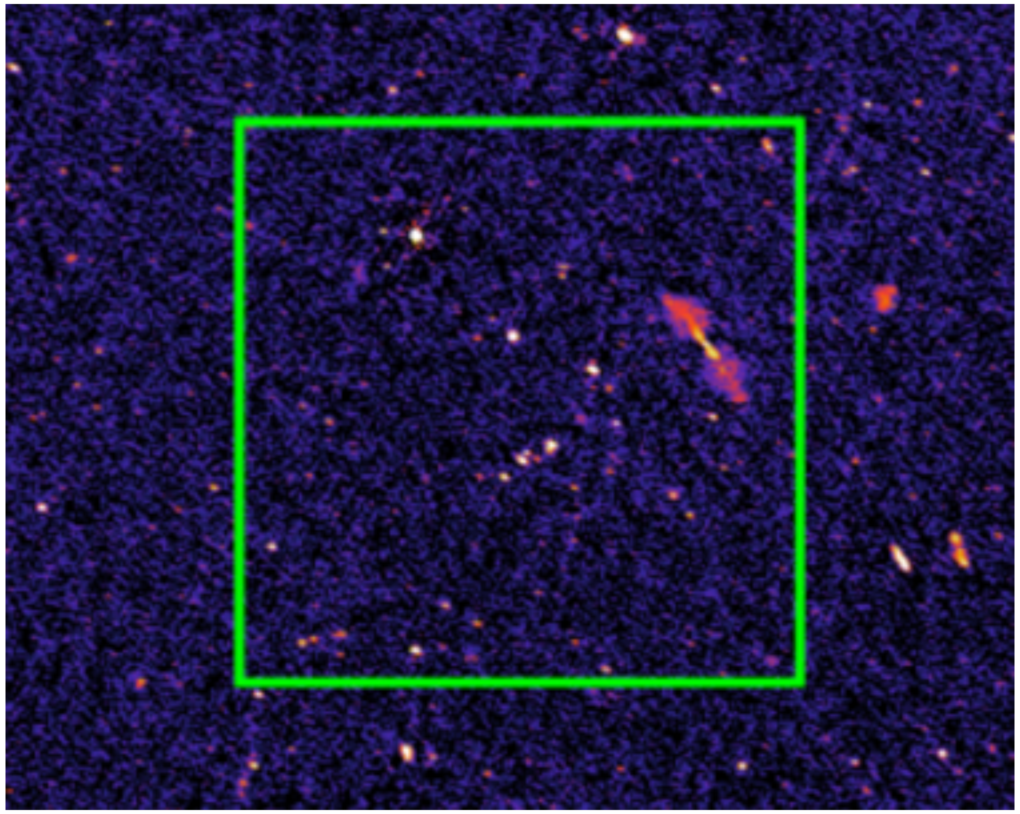
van Weeren+ 2021 (& significant number of further improvements since then)

https://github.com/rvweeren/lofar_facet_selfcal

`sub-sources-outside-region.py`

Requirements:

1. Box not too large, avoid beam variations across the box (0.5° to 1.0°)
2. Box not too large, avoid calibration to vary across the box (0.5° to 1.0°)
3. Enough flux in the box for calibration ($\gtrsim$0.2 Jy compact source Dutch-HBA)



large beam variations can be handled using `--idg` option in `facetselfcal.py`, but note point 2.

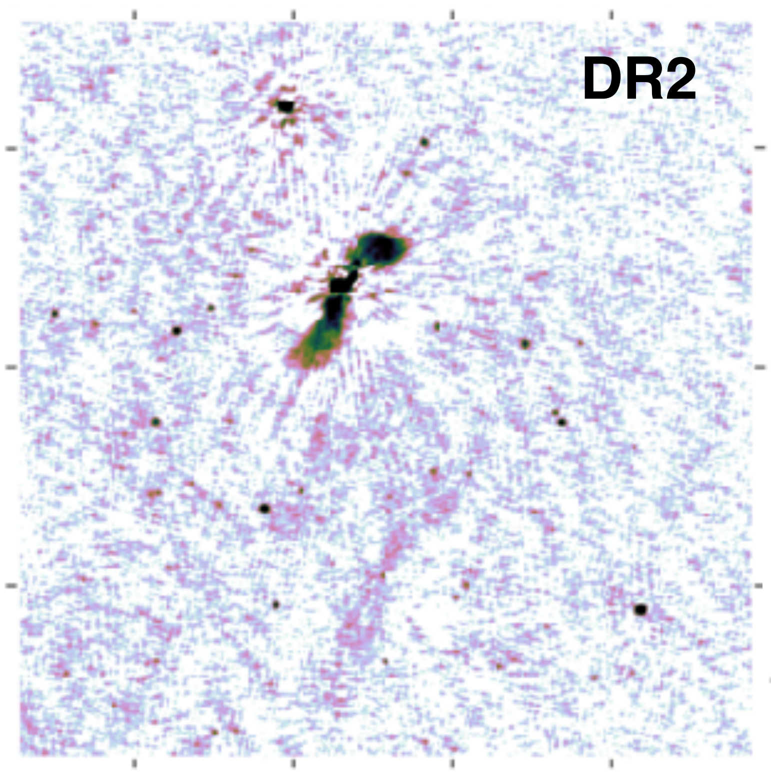
Step 1: "facetselfcal"

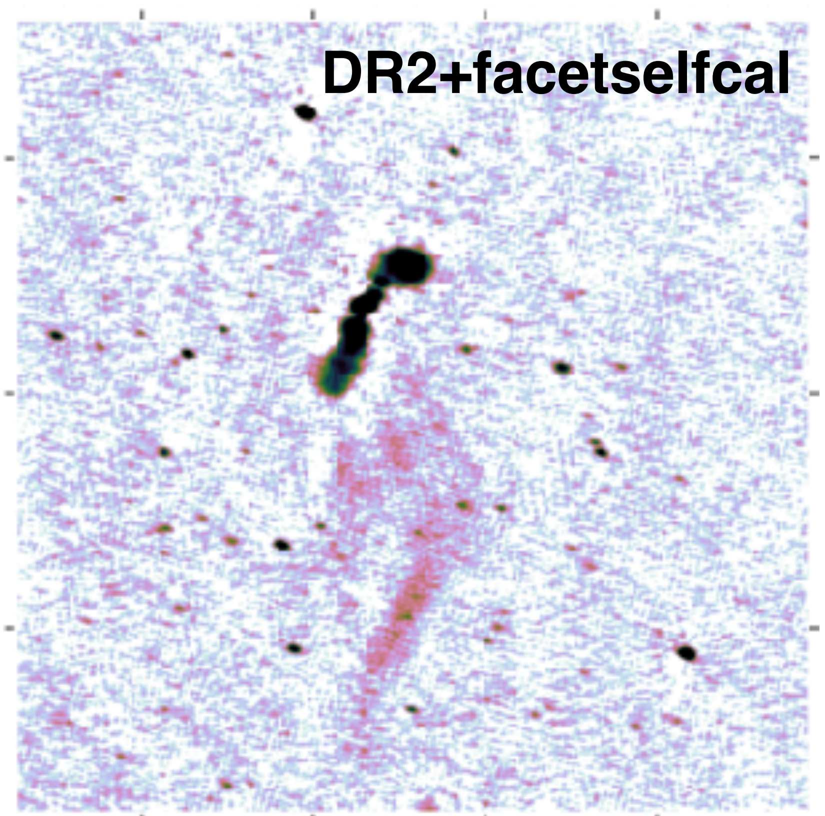
van Weeren+ 2021 (& significant number of further improvements since then)

https://github.com/rvweeren/lofar_facet_selfcal

`facetselfcal.py`

1. Easiest to use the `--auto` setting (determines solution interval and effects to solve for)
2. Script can handle many types of LOFAR data, Dutch-HBA, ILT-HBA, LBA, ILT-LBA, LBA-low (but `--auto` only available for commonly used modes, e.g. not ILT-LBA)
3. Script has many options for tuning

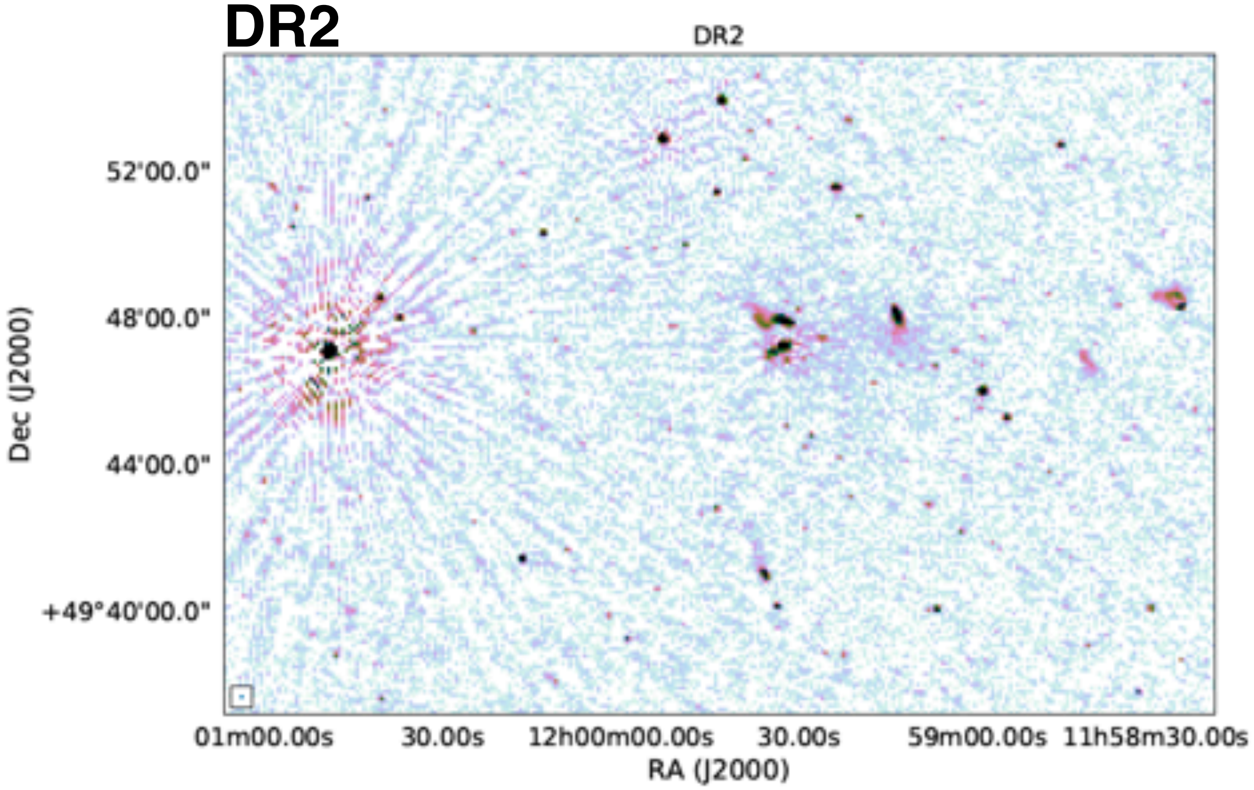




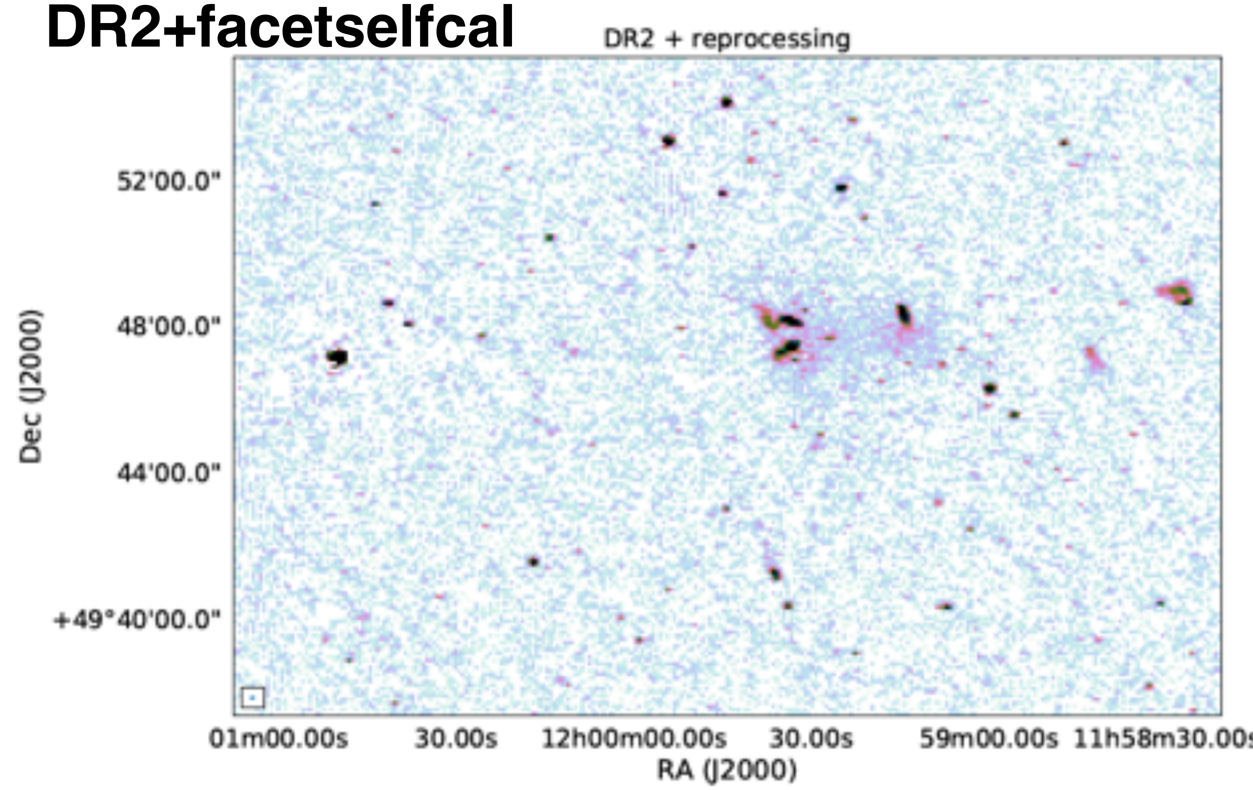
- improved calibration
- multiscale clean
- no uvmin cut

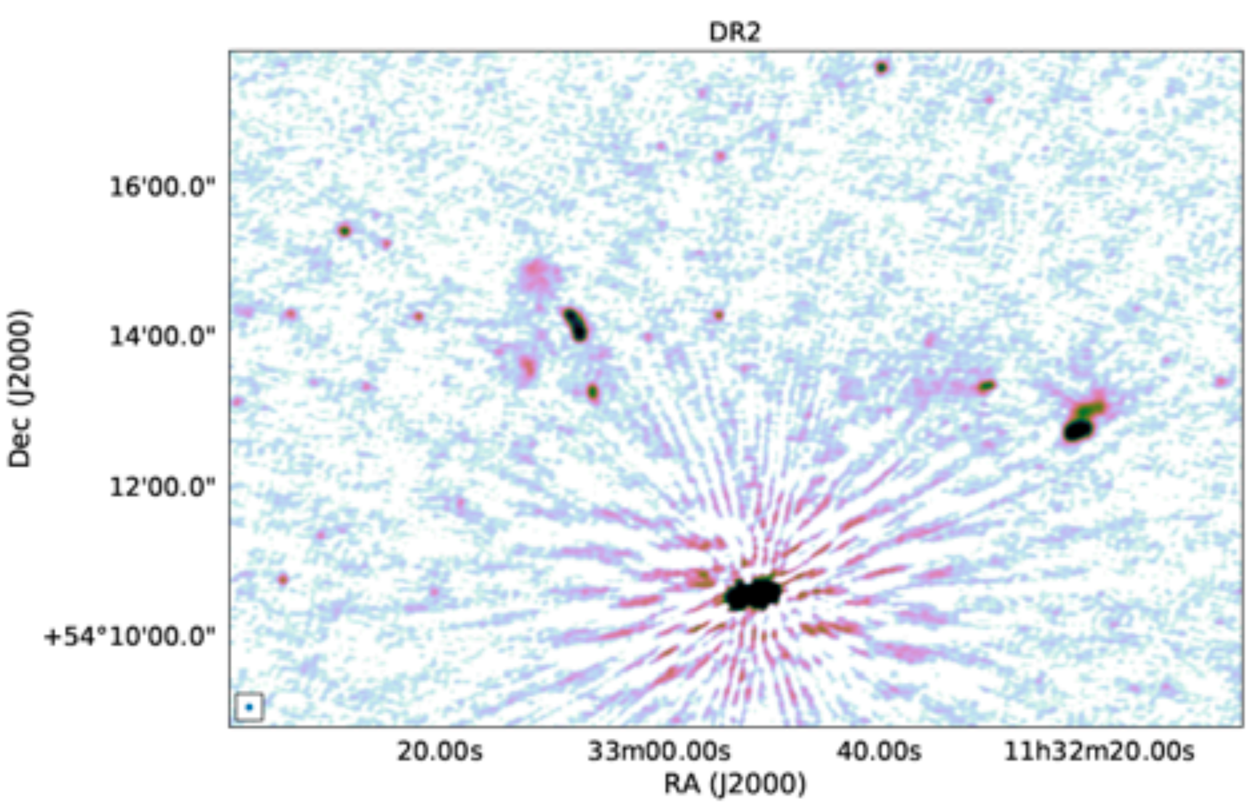
LoTSS DR2 re-processing

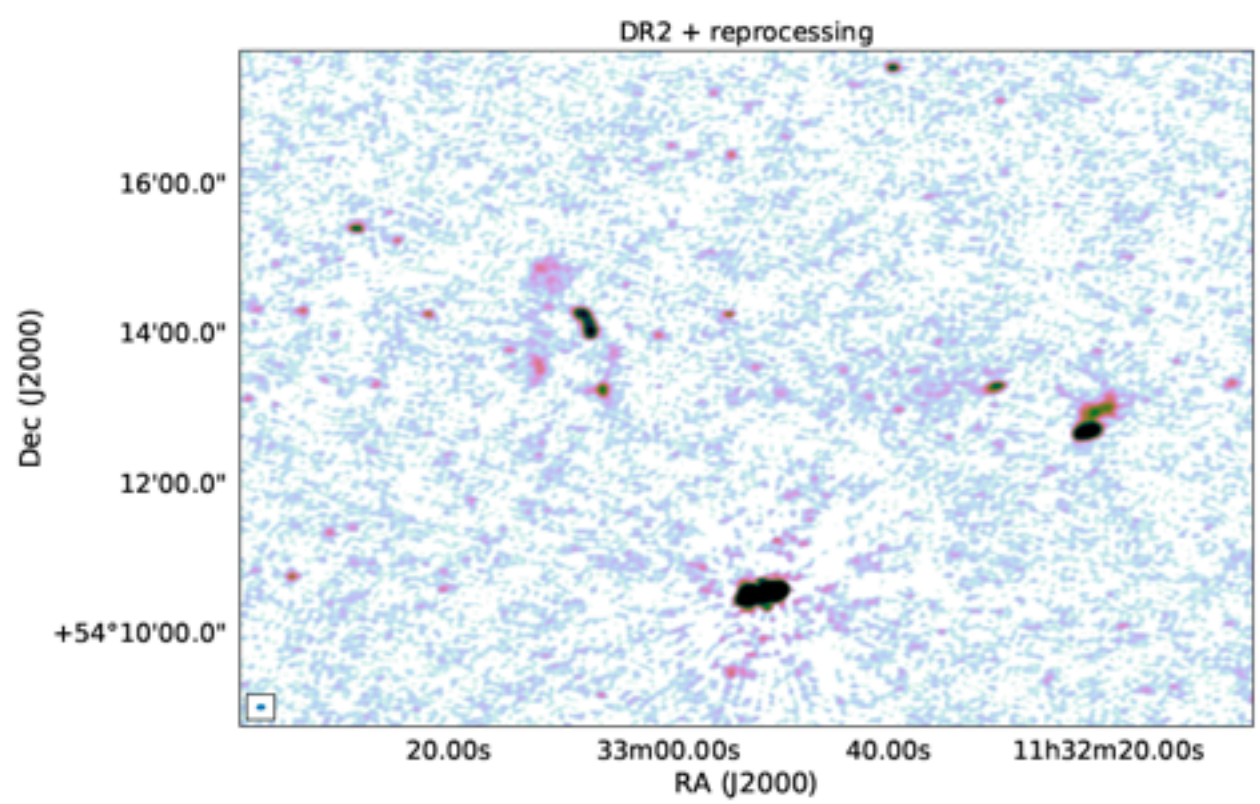
DR2



DR2+facetselfcal



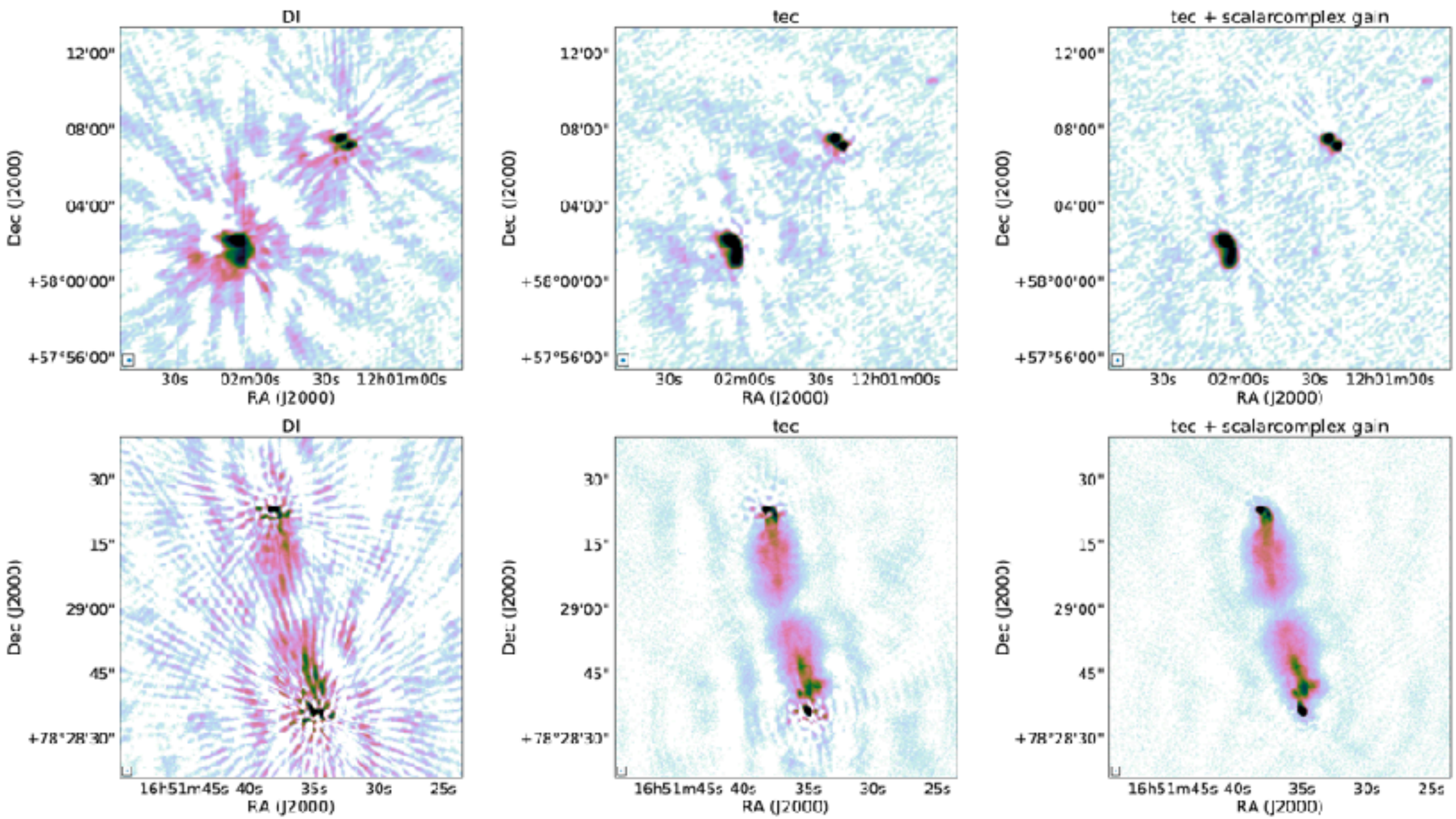




HBA European baselines & LBA

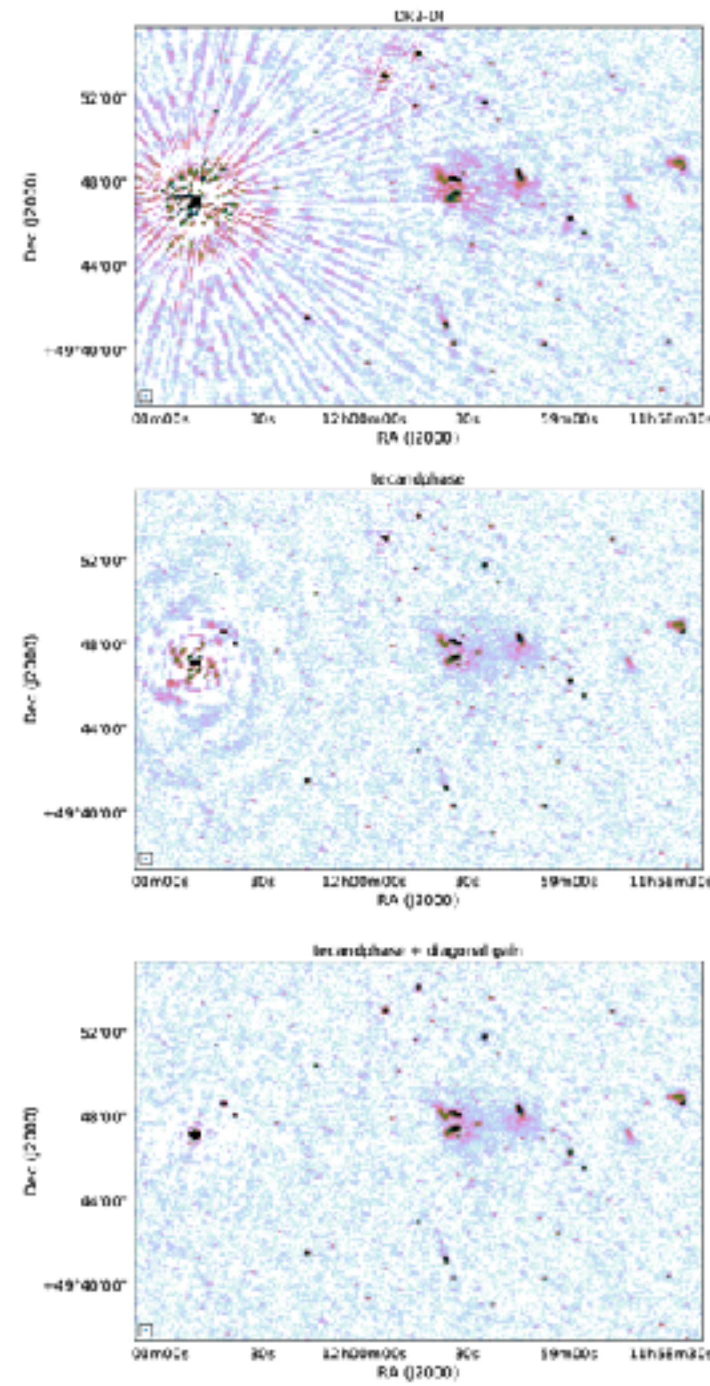
LBA

ILT-HBA



`facetselfcal.py` does the corrections for the infield (LBCS) delay calibrator + facet calibrators for widefield ILT imaging

Facetselfcal



1. Perturbative solves (non-DDE)
2. Start with biggest effect first, usually tec/phase
3. Continue with longer time interval gain solve
4. Solution interval computed via visibilities (signal and noise estimation)
5. WSClean is the default imager (DDFacet can also be used)

Standard DR2 HBA re-processing example

```
facetselfcal.py --auto -b mytargetbox.ds9.reg
-i myimagename myms1.ms myms2.ms mymsN.ms
```

Advanced tuned example (delay calibrator)

```
facetselfcal.py --robust=-1.5 --uvminim=1500 --skymodel=7C1604+5529.skymodel
--soltype-list="['scalarphasediff','scalarphase','scalarphase','scalarphase','scalarcomplexgain','fulljones']"
--soltypecycles-list="[0,0,0,0,0,0]" -solint-list="['8min','32s','32s','2min','20min','20min','40min']"
--nchan-list="[1,1,1,1,1]" --smoothnessconstraint-list="[10.0,1.25,10.0,20.,7.5,5.0]" --normamps=False
--smoothnessreffrequency-list="[120.,120.,120.,120,0.,0.]"
--antennaconstraint-list="['core',None,None,None,None,'alldutch']" --forwidefield --avgfreqstep='488kHz'
--avgtimestep='32s' --docircular --resetsols-list="[None,'alldutch','core',None,None,None]" *.ms
```

facetselfcal.py –h

```
Self-Calibrate a facet from a LOFAR observation

positional arguments:
  ms                    msfile(s)

optional arguments:
  -h, --help            show this help message and exit
  --imager IMAGER       Imager to use WSClean or DDFACET. The default is
                        WSCLEAN.
  -i IMAGENAME, --imagename IMAGENAME
                        Prefix name for image. This is by default "image".
  --imsize IMSIZE       Image size, required if boxfile is not used. The
                        default is None.
  -n NITER, --niter NITER
                        Number of iterations. This is computed automatically
                        if None.
  --maskthreshold MASKTHRESHOLD
                        Mask noise thresholds used from image 1 to 10 made by
                        MakeMask.py. This is by default [5.0,4.5,4.5,4.5,4.0].
  --removenegativefrommodel REMOVENEGATIVEFROMMODEL
                        Remove negative clean components in model predict.
                        This is by default turned off at selfcalcycle 2. See
                        also option autoupdate-removenegativefrommodel.
  --autoupdate-removenegativefrommodel AUTOUPDATE_REMOVENEGATIVEFROMMODEL
                        Turn off removing negative clean components at
                        selfcalcycle 2 (for high dynamic range imaging it is
                        better to keep all clean components). The default is
                        True.
  --fitsmask FITSMASK   Fits mask for deconvolution (needs to match image
                        size). If this is not provided automasking is used.
  --robust ROBUST       Briggs robust parameter. The default is -0.5.
  --multiscale-start MULTISCALE_START
                        Start multiscale deconvolution at this selfcal cycle.
                        This is by default 1.
  --deepmultiscale      Do extra multiscale deconvolution on the residual.
  --uvminim UVMINIM     Inner uv-cut for imaging in lambda. The default is 80.
  --pixelscale PIXELSCALE, --pixelsize PIXELSCALE
                        Pixels size in arcsec. Typically, 3.0 for LBA and 1.5
                        for HBA (these are also the default values).
  --channelsout CHANNELSOUT
                        Number of channels out during imaging (see WSClean
                        documentation). This is by default 6.
  --multiscale          Use multiscale deconvolution (see WSClean
                        documentation).
  --multiscalescalebias MULTISCALESCALEBIAS
                        Multiscalescale bias scale parameter for WSClean (see
                        WSClean documentation). This is by default 0.8.
  --usewgridder USEWGRIDDER
                        Use wgridder from WSClean, mainly useful for very
                        large images. This is by default True.
  --paralleldeconvolution PARALLELDECONVOLUTION
                        Parallel-deconvolution size for WSCLean (see WSClean
                        documentation). This is by default 0 (no parallel
                        deconvolution). Suggested value for very large images
                        is about 2000.
  --parallelgridding PARALLELGRIDDING
                        Parallel-gridding for WSClean (see WSClean
                        documentation). This is by default 1.
  --deconvolutionchannels DECONVOLUTIONCHANNELS
                        Deconvolution channels value for WSClean (see WSClean
                        documentation). This is by default 0 (means
                        deconvolution-channels equals channels-out).
  --idg                 Use the Image Domain gridder (see WSClean
                        documentation).
  --fitspectralpol FITSPECTRALPOL
                        Use fit-spectral-pol in WSClean (see WSClean
                        documentation). The default is True.
  --fitspectralpolorder FITSPECTRALPOLORDER
                        fit-spectral-pol order for WSClean (see WSClean
                        documentation). The default is 3.
  --gapchanneldivision  Use the -gap-channel-division option in wsclean
                        imaging and predicts (default is not to use it)
  --taperinnertukey TAPERINNERTUKEY
                        Value for taper-inner-tukey in WSClean (see WSClean
                        documentation), useful to supress negative bowls when
                        using --uvminim. Typically values between 1.5 and 4.0
                        give good results. The default is None.
  --wscleanskymodel WSCLEANSKYMODEL
                        WSclean basename for model images (for a WSClean
                        predict). The default is None.
  --avgfreqstep AVGFREQSTEP
                        Extra DP3 frequency averaging to speed up a solve.
                        This is done before any other correction and could be
                        useful for long baseline infield calibrators. Allowed
                        are integer values or for example '195.3125kHz';
                        options for units: 'Hz', 'kHz', or 'MHz'. The default
                        is None.
  --avgtimestep AVGTIMESTEP
                        Extra DP3 time averaging to speed up a solve. This is
                        done before any other correction and could be useful
                        for long baseline infield calibrators. Allowed are
                        integer values or for example '16.1s'; options for
                        units: 's' or 'sec'. The default is None.
  --msinnchan MSINNCHAN
                        Before averaging, only take this number of input
                        channels. The default is None.
  --msinntimes MSINNTIMES
                        DP3 msin.ntimes setting. This is mainly used for
                        testing purposes. The default is None.
  --autofrequencyaverage-calspeedup
                        Try extra averaging during some selfcalcycles to speed
                        up calibration.
  --autofrequencyaverage
                        Try frequency averaging if it does not result in
                        bandwidth smearing
  --phaseupstations PHASEUPSTATIONS
                        Phase up to a superstation. Possible input: 'core' or
                        'superterp'. The default is None.
  --phaseshiftbox PHASESHIFTBOX
                        DS9 region file to shift the phasecenter to. This is
                        by default None.
  --weightspectrum-clipvalue WEIGHTSPECTRUM_CLIPVALUE
                        Extra option to clip WEIGHT_SPECTRUM values above the
                        provided number. Use with care and test first manually
                        to see what is a fitting value. The default is None.
  -u UVMIN, --uvmin UVMIN
                        Inner uv-cut for calibration in lambda. The default is
                        80 for LBA and 350 for HBA.
  --uvminscalarphasediff UVMINSCALARPHASEDIFF
                        Inner uv-cut for scalarphasediff calibration in
                        lambda. The default is equal to input for --uvmin.
  --update-uvmin        Update uvmin automatically for the Dutch array.
  --update-multiscale   Switch to multiscale automatically if large islands of
                        emission are present.
  --soltype-list SOLTYPE_LIST
                        List with solution types. Possible input:
                        'complexgain', 'scalarcomplexgain', 'scalaramplitude',
                        'amplitudeonly', 'phaseonly', 'fulljones', 'rotation',
                        'rotation+diagonal', 'tec', 'tecandphase',
                        'scalarphase', 'scalarphasediff', 'scalarphasediffFR',
                        'phaseonly_phmin', 'rotation_phmin', 'tec_phmin',
                        'tecandphase_phmin', 'scalarphase_phmin',
                        'scalarphase_slope', 'phaseonly_slope'. The default is
                        [tecandphase,tecandphase,scalarcomplexgain].
  --solint-list SOLINT_LIST
                        Solution interval corresponding to solution types (in
                        same order as soltype-list input). The default is
                        [1,1,120].
  --nchan-list NCHAN_LIST
                        Number of channels corresponding to solution types (in
                        same order as soltype-list input). The default is
                        [1,1,10].
  --smoothnessconstraint-list SMOOTHNESSCONSTRAINT_LIST
                        List with frequency smoothness values (in same order
                        as soltype-list input). The default is [0.,0.,5.].
  --smoothnessreffrequency-list SMOOTHNESSREFFREQUENCY_LIST
                        List with optional reference frequencies (in MHz) for
                        the smoothness constraint (in same order as soltype-
                        list input). When unequal to 0, the size of the
                        smoothing kernel will vary over frequency by a factor
                        of smoothnessreffrequency*(frequency^smoothnessspectra
                        lexponent). The default is [0.,0.,0.].
  --smoothnessspectralexponent-list SMOOTHNESSSPECTRALEXPONENT_LIST
                        If smoothnessreffrequency is not equal to zero then
                        this parameter determines the frequency scaling law.
                        It is typically useful to take -2 for scalarphasediff,
                        otherwise -1 (1/nu). The default is [-1.,-1.,-1.].
  --smoothnessrefdistance-list SMOOTHNESSREFDISTANCE_LIST
                        If smoothnessrefdistance is not equal to zero then
                        this parameter determines the freqeuency smoothness
                        reference distance in units of km, with the smoothness
                        scaling with distance. See DP3 documentation. The
                        default is [0.,0.,0.].
  --antennaconstraint-list ANTENNACONSTRAINT_LIST
                        List with constraints on the antennas used (in same
                        order as soltype-list input). Possible input:
                        'superterp', 'coreandfirstremotes', 'core', 'remote',
                        'all', 'international', 'alldutch', 'core-remote',
                        'coreandallbutmostdistantremotes',
                        'alldutchbutnoST001'. The default is [None,None,None].
  --resetsols-list RESETSOLS_LIST
                        Values of these stations will be rest to 0.0 (phases),
                        or 1.0 (amplitudes), default None, possible settings
                        are the same as for antennaconstraint-list (alldutch,
                        core, etc)). The default is [None,None,None].
  --soltypecycles-list SOLTYPECYCLES_LIST
                        Selfcalcycle where step from soltype-list starts. The
                        default is [0,999,3].
  --BLsmooth            Employ BLsmooth for low S/N data.
  --dejumpFR            Dejump Faraday solutions when using scalarphasediffFR.
  --usemodeldataforsolints
                        Determine solints from MODEL_DATA.
  --preapplyH5-list PREAPPLYH5_LIST
                        List of H5 files to preapply (one for each MS). The
                        default is [None].
  --iontimefactor IONTIMEFACTOR
                        BLsmooth ionfactor. The default is 0.01. Larger is
                        more smoothing (see BLsmooth documentation).
  --ionfreqfactor IONFREQFACTOR
                        BLsmooth tecfactor. The default is 1.0. Larger is more
                        smoothing (see BLsmooth documentation).
  --blscalefactor BLSCALEFACTOR
                        BLsmooth blscalefactor. The default is 1.0 (see
                        BLsmooth documentation).
  -b BOXFILE, --boxfile BOXFILE
                        DS9 box file. You need to provide a boxfile to use
                        --startfromtgss. The default is None.
  --skymodel SKYMODEL   Skymodel for first selfcalcycle. The default is None.
  --skymodelsource SKYMODELSOURCE
                        Source name in skymodel. The default is None (means
                        the skymodel only contains one source/patch).
  --skymodelpointsource SKYMODELPOINTSOURCE
                        If set, start from a point source in the phase center
                        with the flux density given by this parameter. The
                        default is None (means do not use this option).
  --predictskywithbeam  Predict the skymodel with the beam array factor.
  --startfromtgss       Start from TGSS skymodel for positions (boxfile
                        required).
  --startfromvlass      Start from VLASS skymodel for ILT phase-up core data
                        (not yet implemented).
  --tgssfitsimage TGSSFITSIMAGE
                        Start TGSS fits image for model (if not provided use
                        SkyView). The default is None.
  --beamcor BEAMCOR     Correct the visibilities for beam in the phase center,
                        options: yes, no, auto (default is auto, auto means
                        beam is taken out in the curent phase center,
                        tolerance for that is 10 arcsec)
  --losotobeamcor-beamlib LOSOTOBEAMCOR_BEAMLIB
                        Beam library to use when not using DP3 for the beam
                        correction. Possible input: 'stationreponse',
                        'lofarbeam' (identical and deprecated). The default is
                        'stationresponse'.
  --docircular          Convert linear to circular correlations.
  --dolinear            Convert circular to linear correlations.
  --forwidefield        Keep solutions such that they can be used for
                        widefield imaging/screens.
  --doflagging DOFLAGGING
                        Flag on complexgain solutions via rms outlier
                        detection (True/False, default=True). The default is
                        True (will be set to False if --forwidefield is set).
  --clipsolutions       Flag amplitude solutions above --clipsolhigh and below
                        --clipsollow (will be set to False if --forwidefield
                        is set).
  --clipsolhigh CLIPSOLHIGH
                        Flag amplitude solutions above this value, only done
                        if --clipsolutions is set.
  --clipsollow CLIPSOLLOW
                        Flag amplitude solutions below this value, only done
                        if --clipsolutions is set.
  --dysco DYSCO         Use Dysco compression. The default is True.
  --restoreflags        Restore flagging column after each selfcal cycle, only
                        relevant if --doflagging=True.
  --remove-flagged-from-startend
                        Remove flagged time slots at the start and end of an
                        observations. Do not use if you want to combine DD
                        solutions later for widefield imaging.
  --flagslowamprms FLAGSLOWAMPRMS
                        RMS outlier value to flag on slow amplitudes. The
                        default is 7.0.
  --flagslowphaserms FLAGSLOWPHASERMS
                        RMS outlier value to flag on slow phases. The default
                        7.0.
  --doflagslowphases DOFLAGSLOWPHASES
                        If solution flagging is done also flag outliers phases
                        in the slow phase solutions. The default is True.
  --useaoflagger        Run AOflagger on input data.
  --useaoflaggerbeforeavg USEAOFLAGGERBEFOREAVG
                        Flag with AOflagger before (True) or after averaging
                        (False). The default is True.
  --normamps NORMAMPS   Normalize global amplitudes to 1.0. The default is
                        True (False if fulljones is used).
  --normampsskymodel NORMAMPSSKYMODEL
                        Normalize global amplitudes to 1.0 when solving
                        against an external skymodel. The default is False
                        (turned off if fulljones is used).
  --resetweights        If you want to ignore weight_spectrum_solve.
  --start START         Start selfcal cycle at this iteration number. The
                        default is 0.
  --stop STOP           Stop selfcal cycle at this iteration number. The
                        default is 10.
  --stopafterskysolve   Stop calibration after solving against external
                        skymodel.
  --noarchive           Do not archive the data.
  --skipbackup          Leave the original MS intact and work and always work
                        on a DP3 copied dataset.
  --helperscriptspath HELPERSCRIPTSPATH
                        Path to file location pulled from
                        https://github.com/rvweeren/lofar_facet_selfcal.
  --helperscriptspathh5merge HELPERSCRIPTSPATHH5MERGE
                        Path to file location pulled from
                        https://github.com/jurjen93/lofar_helpers.
  --auto                Trigger fully automated processing (HBA only for now).
  --delaycal            Trigger settings suitable for ILT delay calibration,
                        HBA-ILT only - still under construction.
  --targetcalILT TARGETCALILT
                        Type of automated target calibration for HBA
                        international baseline data when --auto is used.
                        Options are: 'tec', 'tecandphase', 'scalarphase'. The
                        default is 'tec'.
  --makeimage-ILTlowres-HBA
                        Make 1.2 arcsec tapered image as quality check of ILT
                        1 arcsec imaging.
  --makeimage-fullpol   Under development, make Stokes IQUV version for
                        quality checking.
  --blsmooth_chunking_size BLSMOOTH_CHUNKING_SIZE
                        Chunking size for blsmooth. Larger values are slower
                        but save on memory, lower values are faster. The
                        default is 8.
  --tecfactorsolint TECFACTORSOLINT
                        Experts only.
  --gainfactorsolint GAINFACTORSOLINT
                        Experts only.
  --phasefactorsolint PHASEFACTORSOLINT
                        Experts only.
```