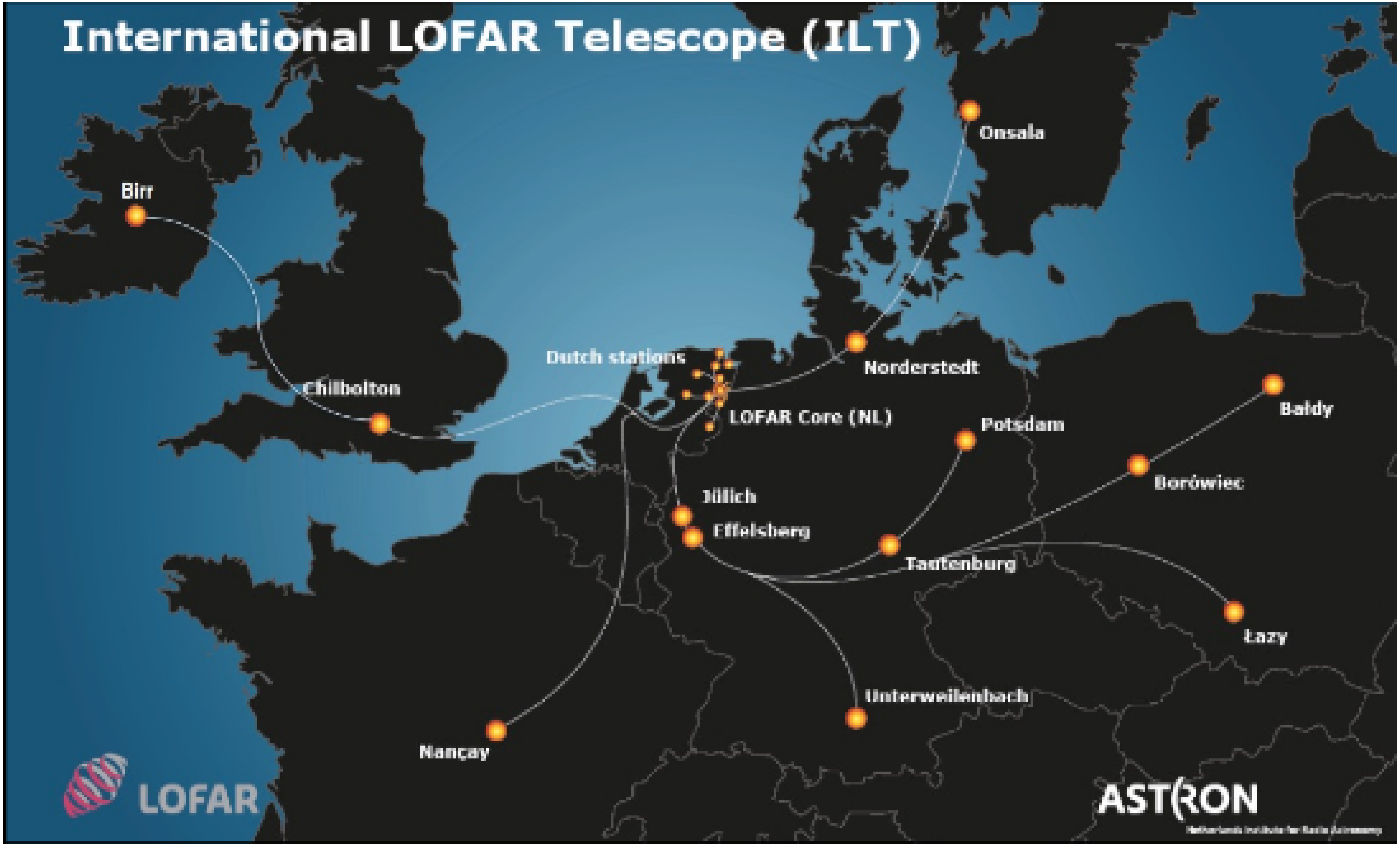
The University of Manchester
Jodrell Bank Observatory

Introduction to the LOFAR Long Baselines

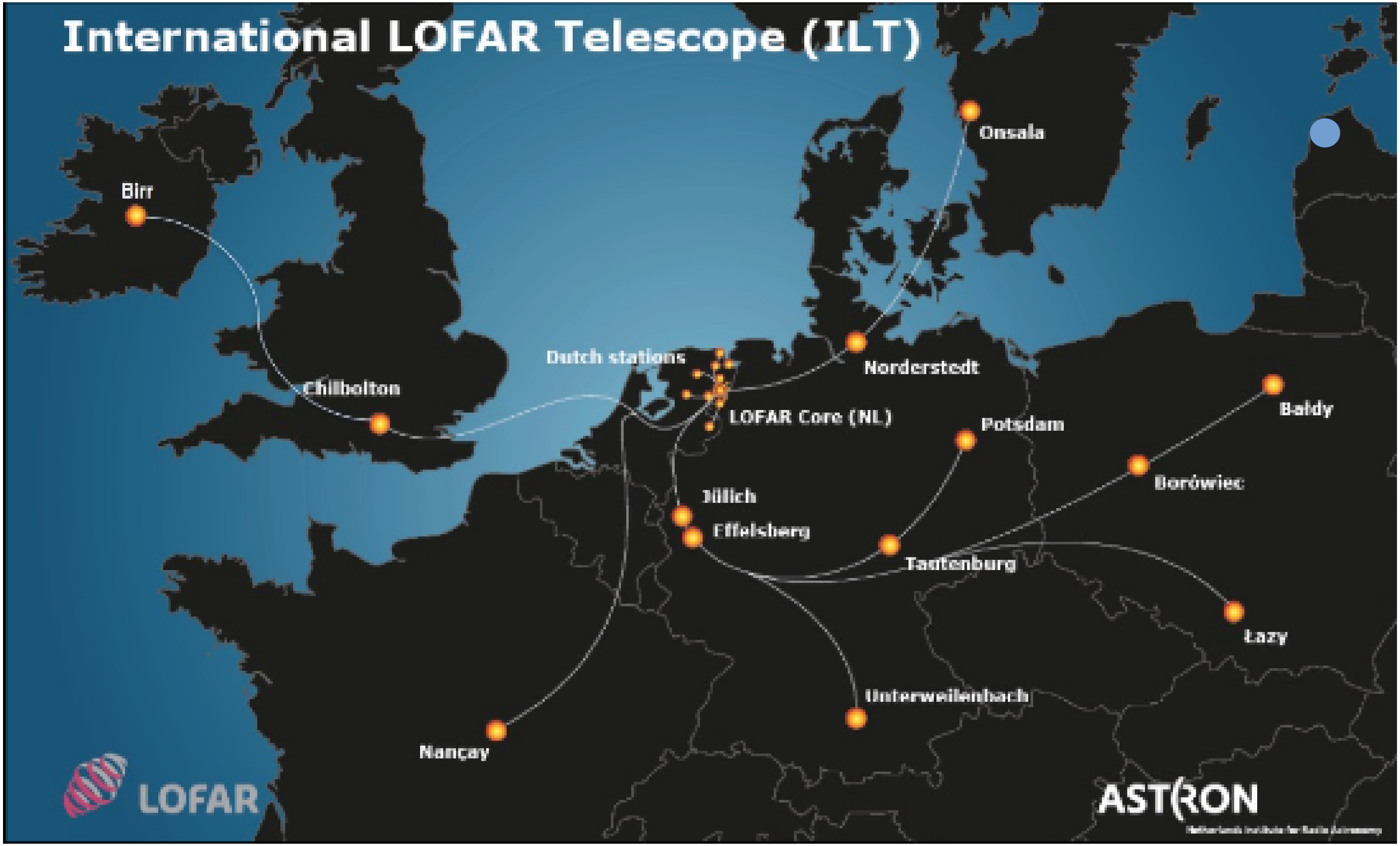
Neal Jackson

BALTICS workshop 5.12.18

Dutch core: 40 telescopes
International stations: 13 (to 2018), shortly Irbene (LV)=14



Dutch core: 40 telescopes
International stations: 13 (to 2018), shortly Irbene (LV)=14
Resolution at 150MHz: 6 arcsec (70km), 1 arcsec (400km), 0.3 arcsec (1200km)
Image fidelity depends on the density of u-v plane coverage → number of baselines



1. Science with long baselines

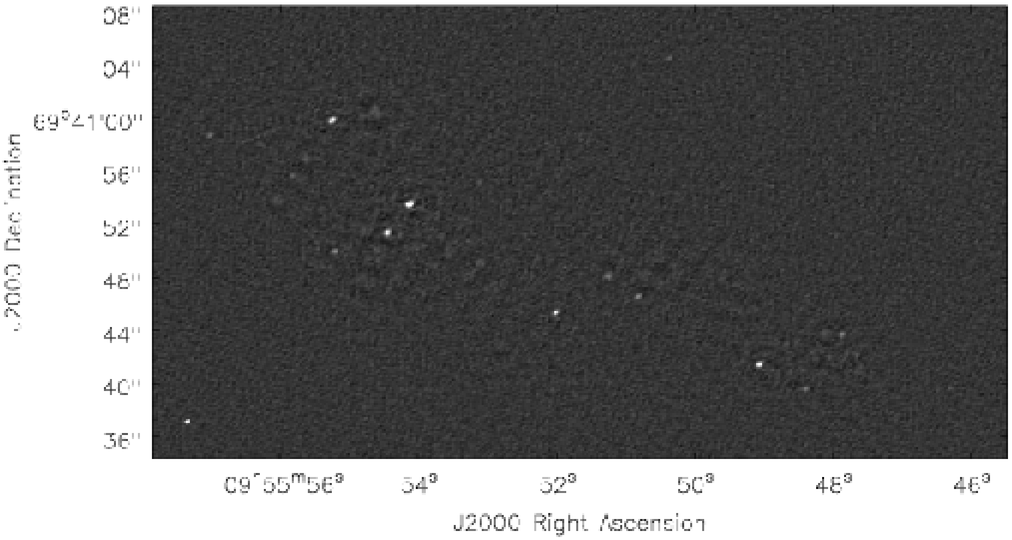
First wide-area, high resolution survey at low frequencies

At sub-galactic resolution for most z

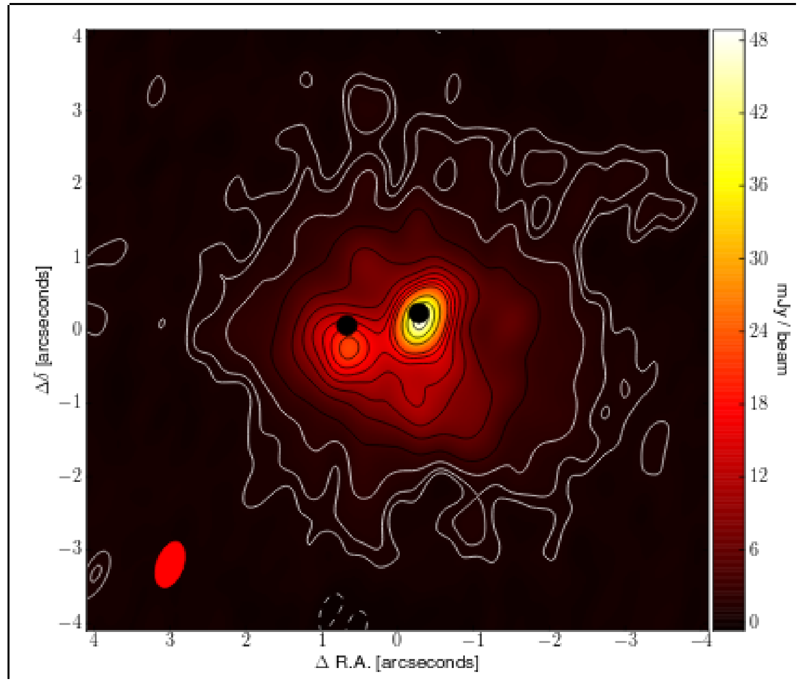
To highly competitive (though <SKA-1) sensitivity for steep-spectrum sources (but with complementary science, and earlier)

And 1-1.2 times resolution of SKA-1

Science with the long baselines: star-forming galaxies

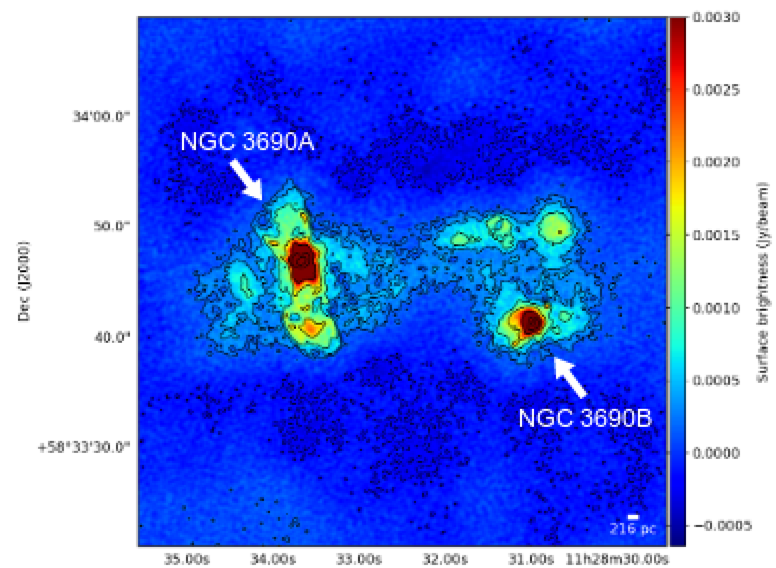


M82 (Varenius et al. 2014) – LOFAR 150MHz



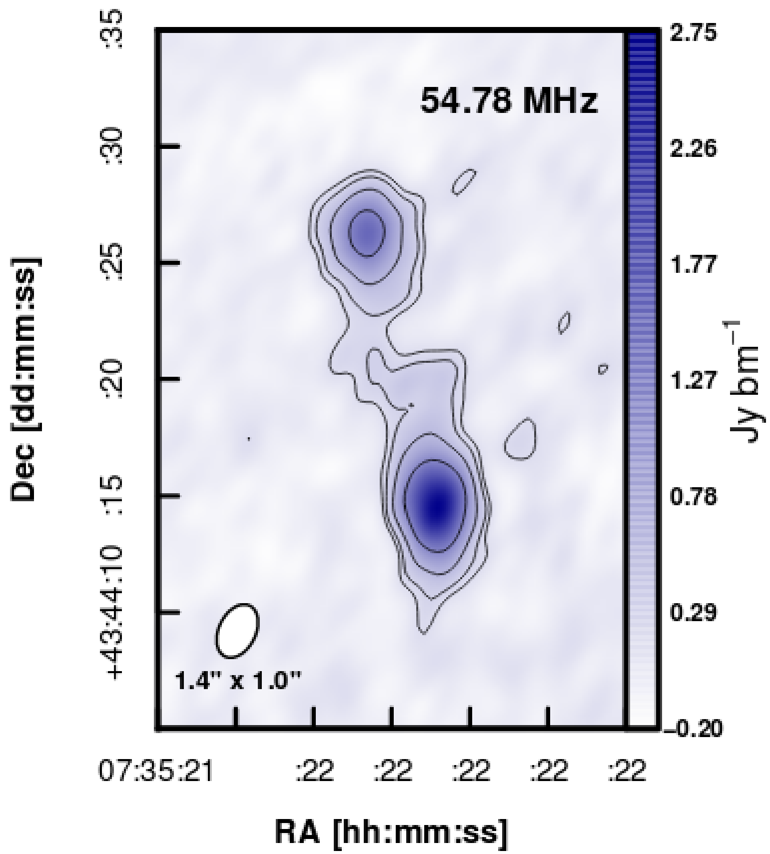
Arp220 (Varenius et al. 2016)

Subarcsecond resolution crucial for SF regions
Extended steep-spectrum emission from outflows visible at low frequencies
Spectral indices – SNRs vs HII regions



Arp299 (Ramirez-Olivencia 2017)

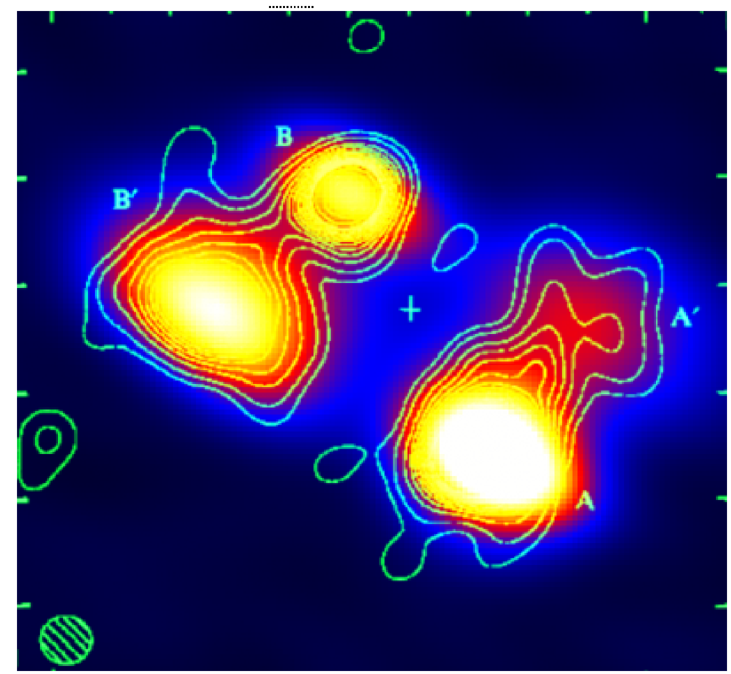
Science with the long baselines: radio galaxies



Morabito et al. 2016 (LBA! 50MHz)

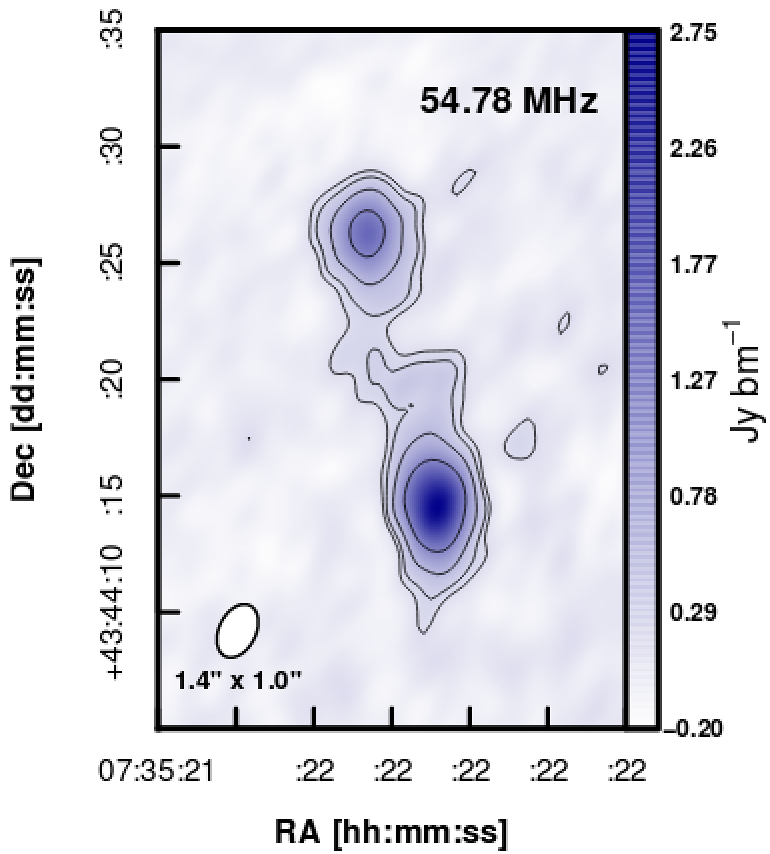
Steep-spectrum emission:

- nature of USS radio galaxies
- spectral indices/physics of extended radio emission



3C196 (Wucknitz 2012)

Science with the long baselines: radio galaxies



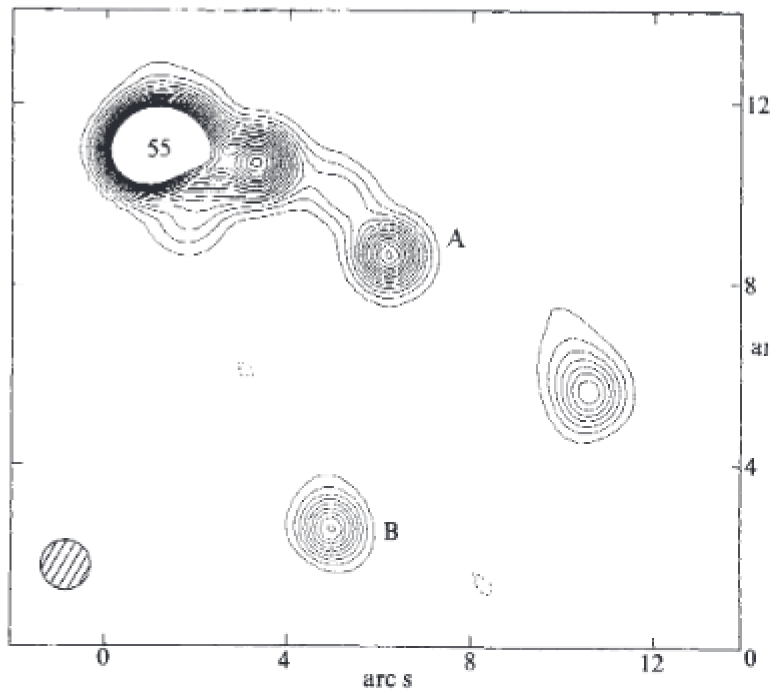
Steep-spectrum emission:

- nature of USS radio galaxies
- spectral indices/physics of extended radio emission

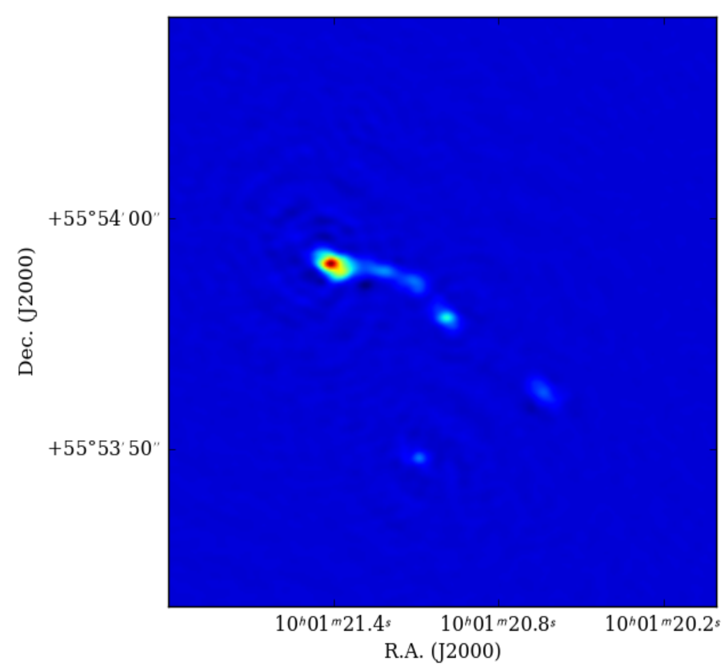
Morabito et al. 2016 (LBA! 50MHz)

Technically very difficult – extreme ionosphere/calibration problems
But seriously unexplored part of parameter space at high resolution

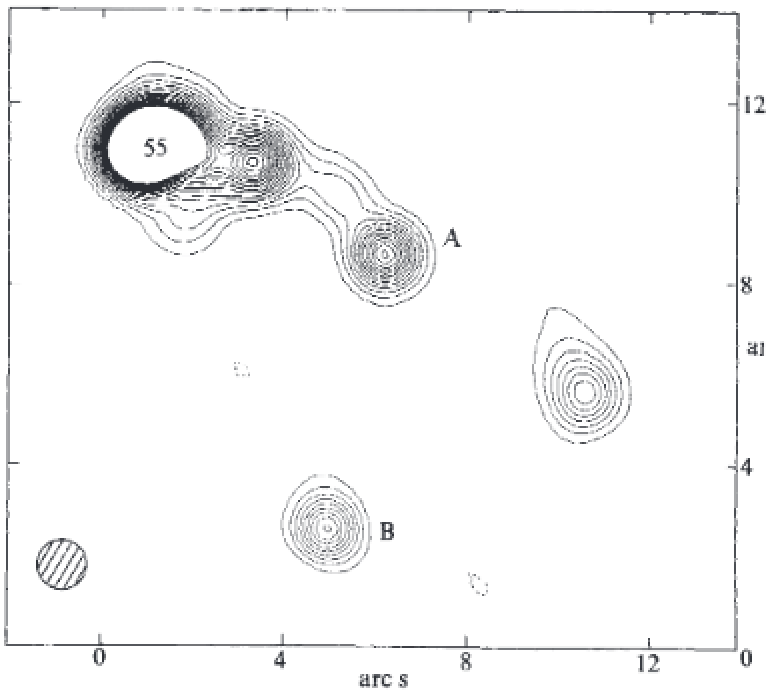
Science with the long baselines: gravitational lenses



Q0957+561 (Noble et al. 1988, 408MHz)
LOFAR LB (Hartley et al. in prep, 151 MHz)



Science with the long baselines: gravitational lenses



Q0957+561 (Noble et al. 1988, 408MHz)
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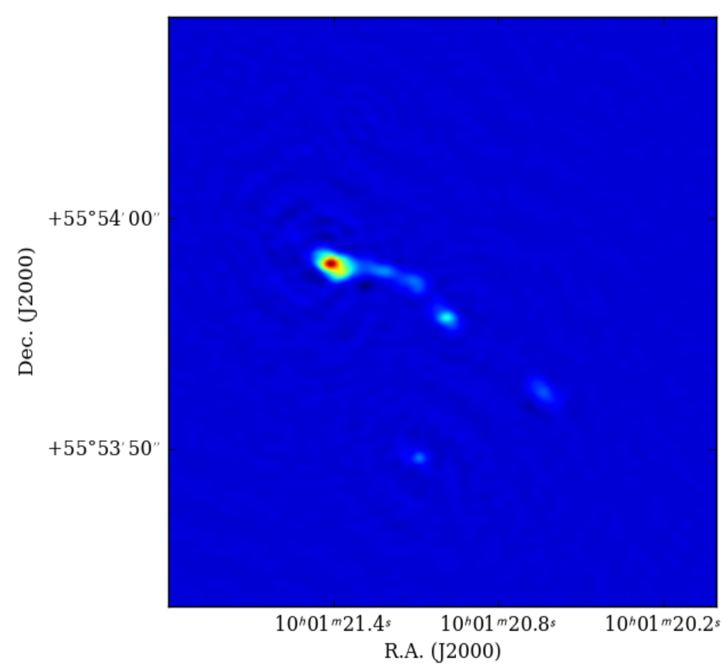
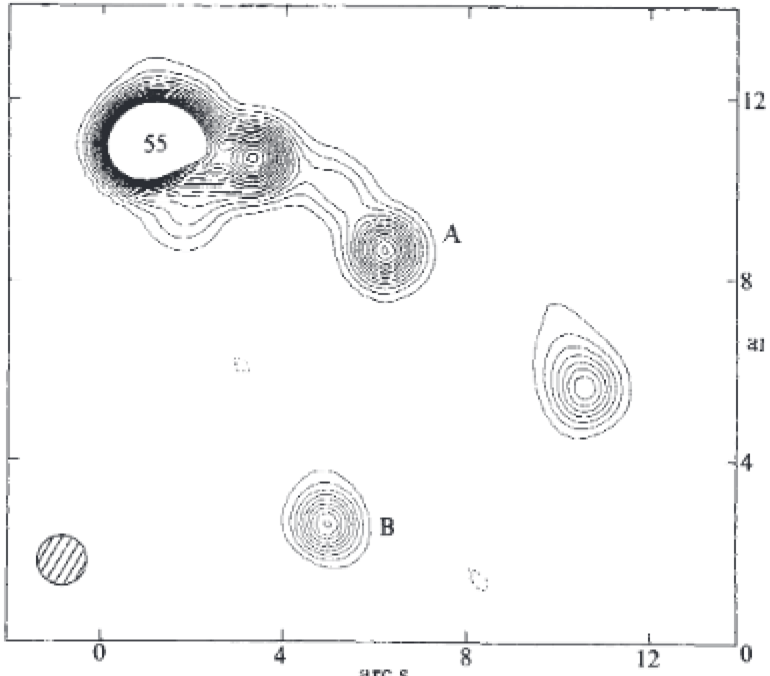
Science from comparison of 2 sightlines, 1 object

- foreground effects / scattering in lens elliptical
- potential for surveys with rare objects



Science with the long baselines: gravitational lenses



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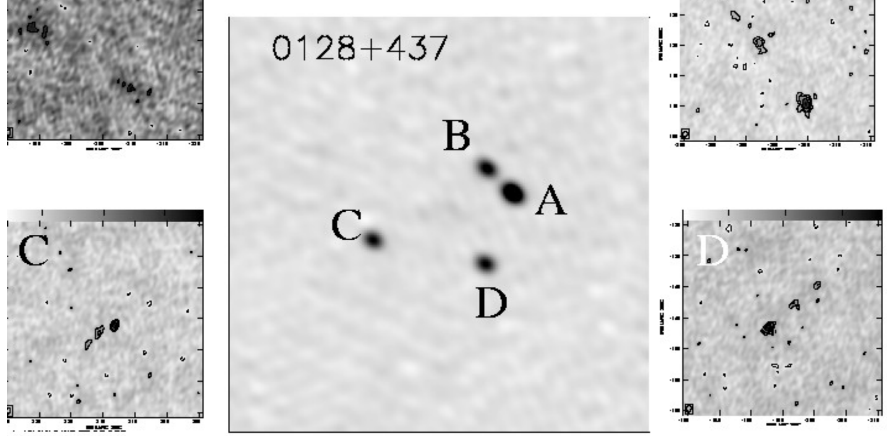
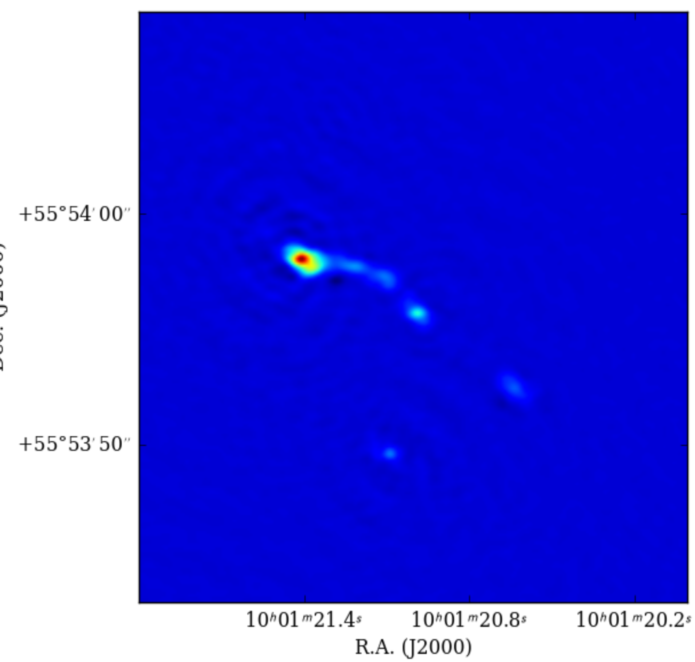
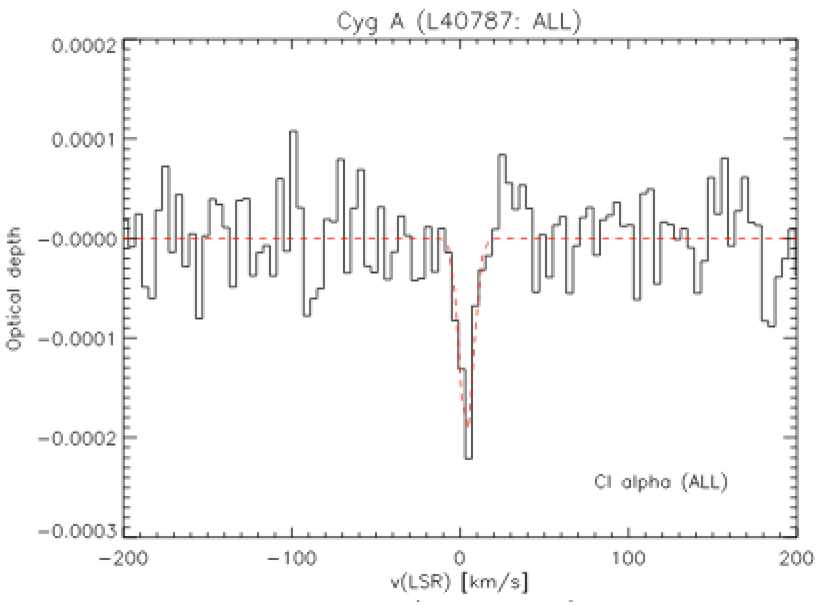
CLASS B0128+437



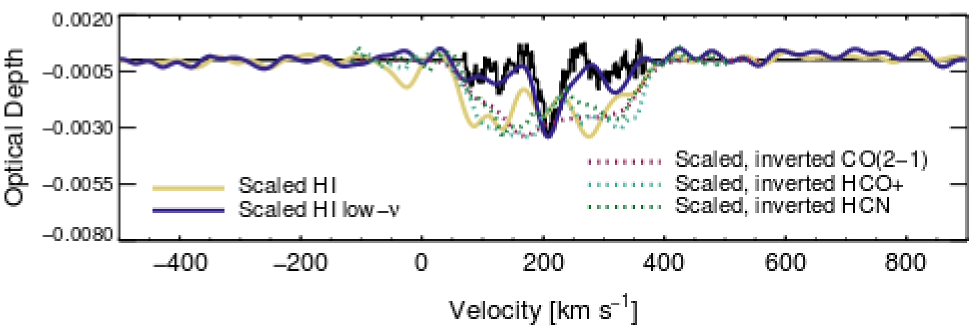
MERLIN full-track+VLBA 2hrs (all at 5GHz)



Science with long baselines: radio recombination lines



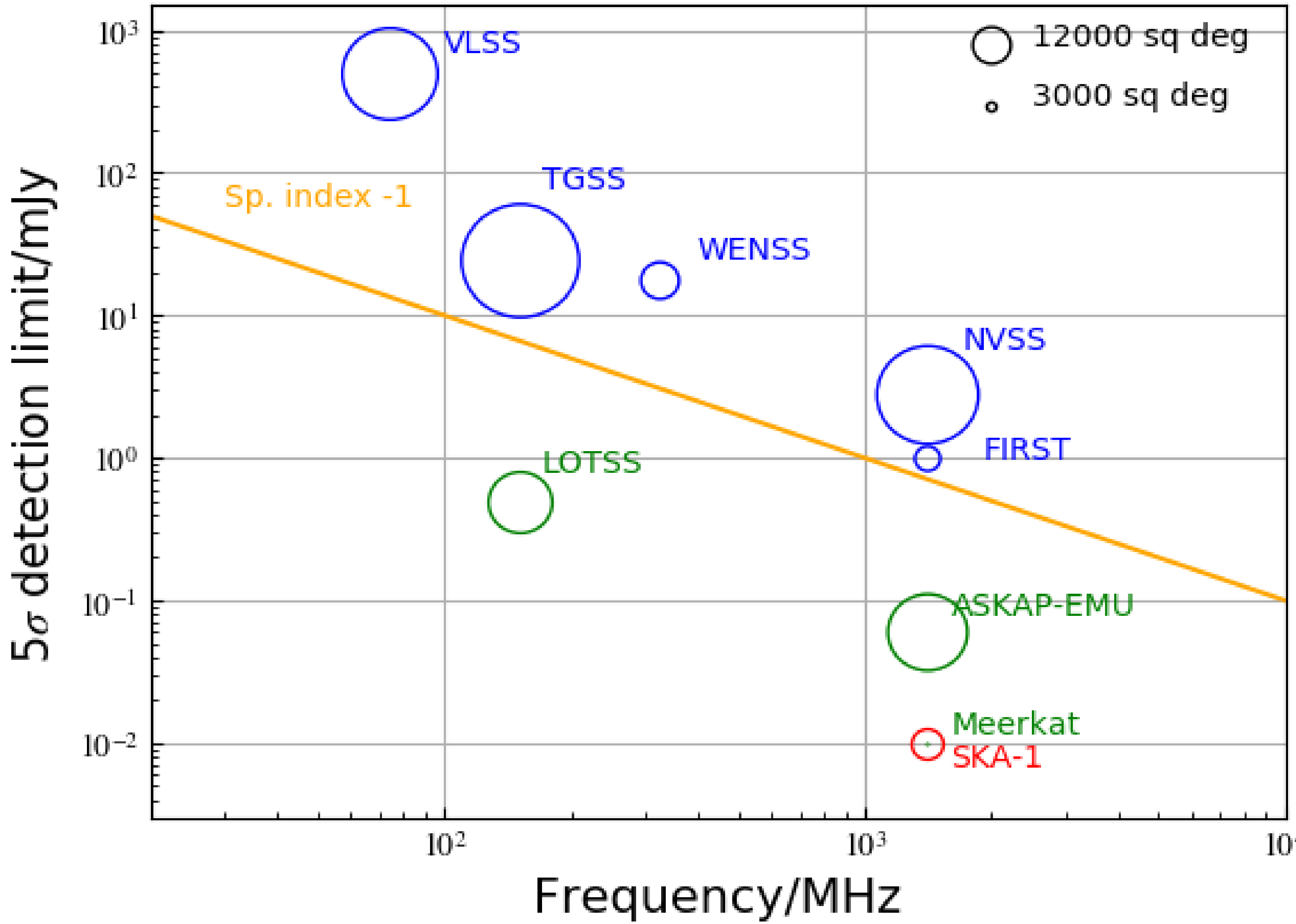
CRRL Cyg A (Oonk et al. 2014)



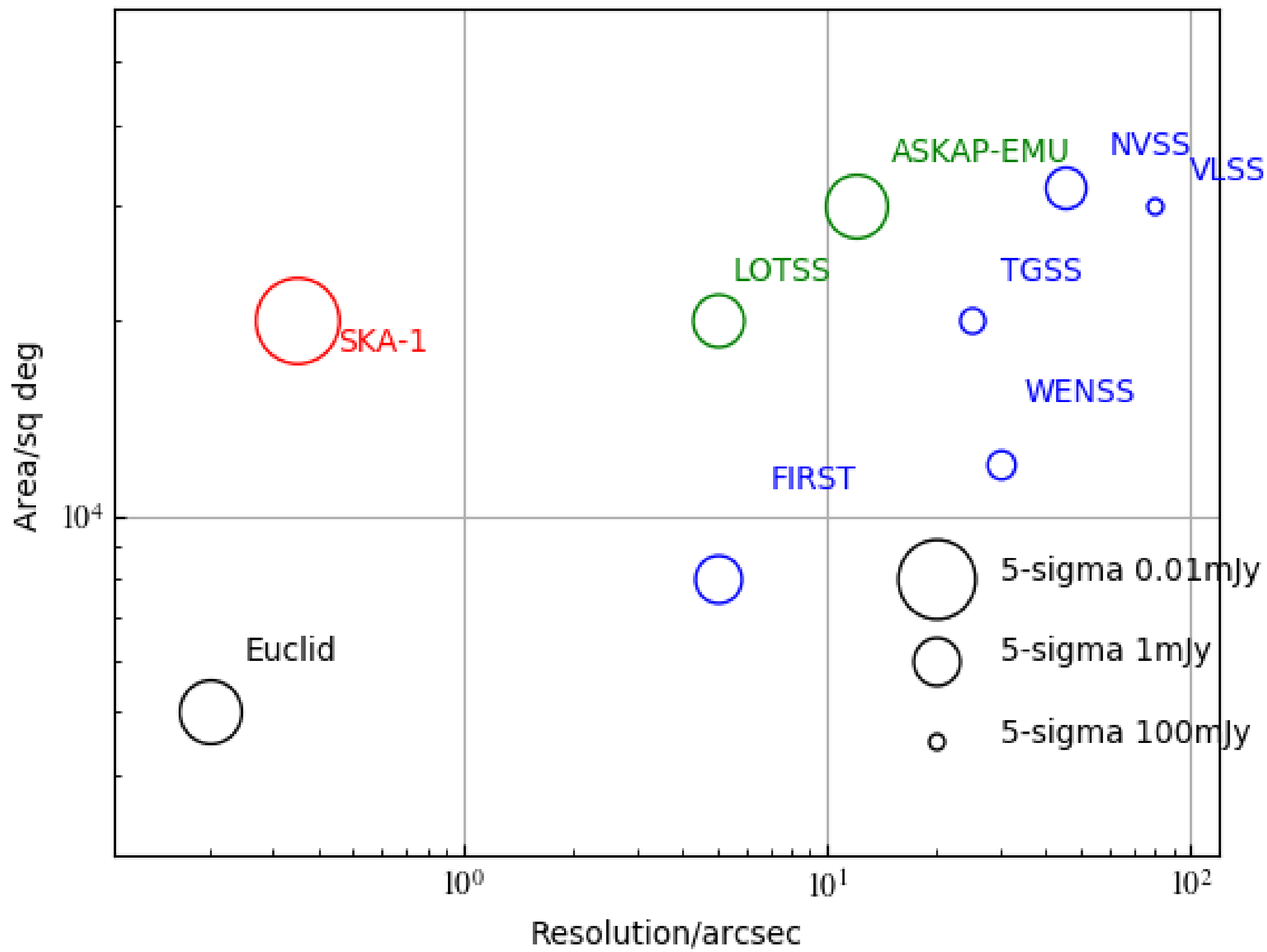
CRRL M82 (Morabito et al. 2014)

Studies of cold neutral gas → geometry, physics of CNM
Current work with Dutch array
With LB, spatially resolved absorption (cf. current HI)

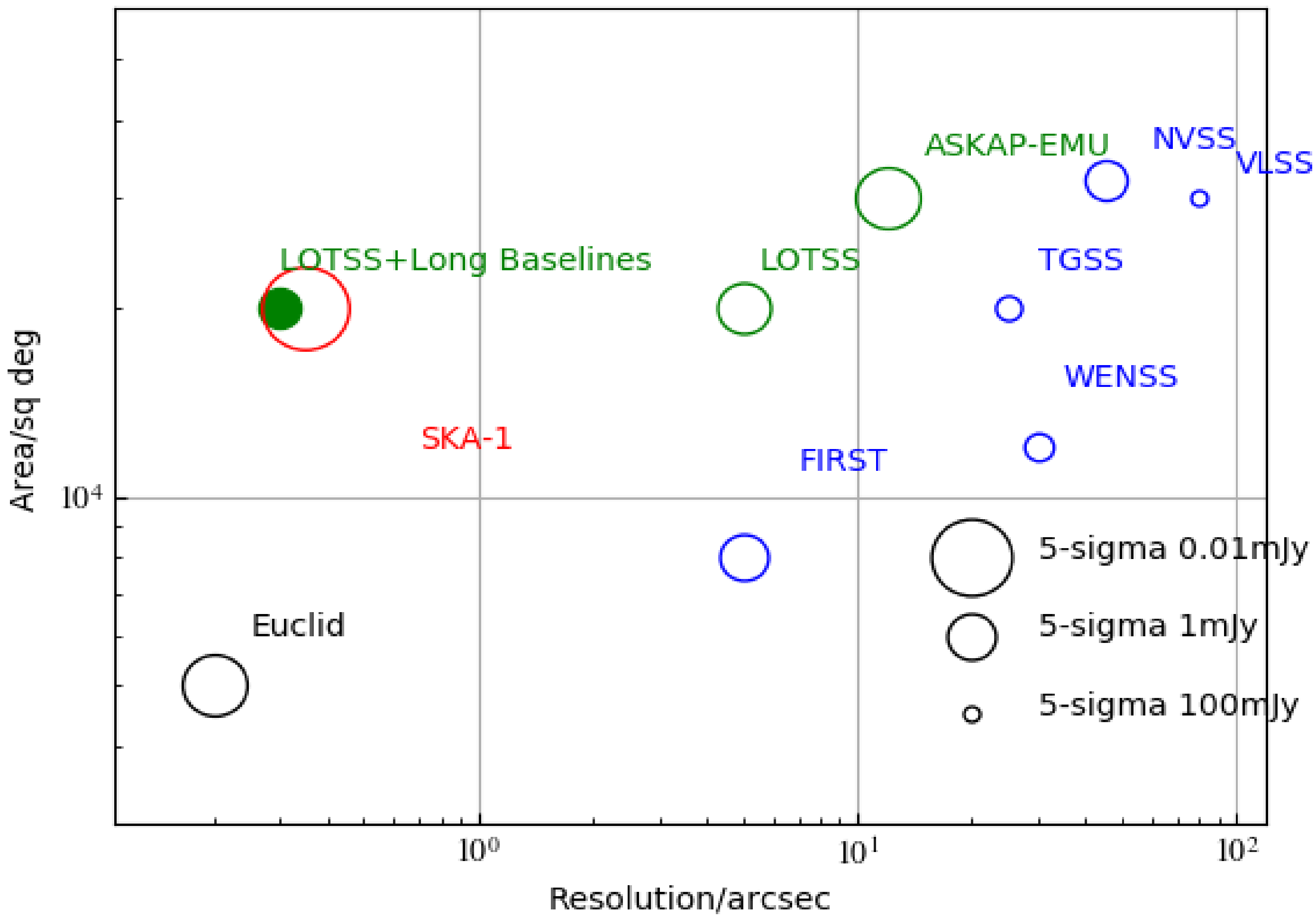
2. The LOFAR surveys



Current large sky surveys: LOFAR LOTSS survey is extremely competitive
But data analysis so far only Dutch data (6” resolution)



Alternative 'survey pixel volume' space
Higher resolution makes huge areas very difficult (even for SKA)
Relevant survey space for e.g. gravitational lens surveying, parallel studies of many objects



Alternative 'survey pixel volume' space
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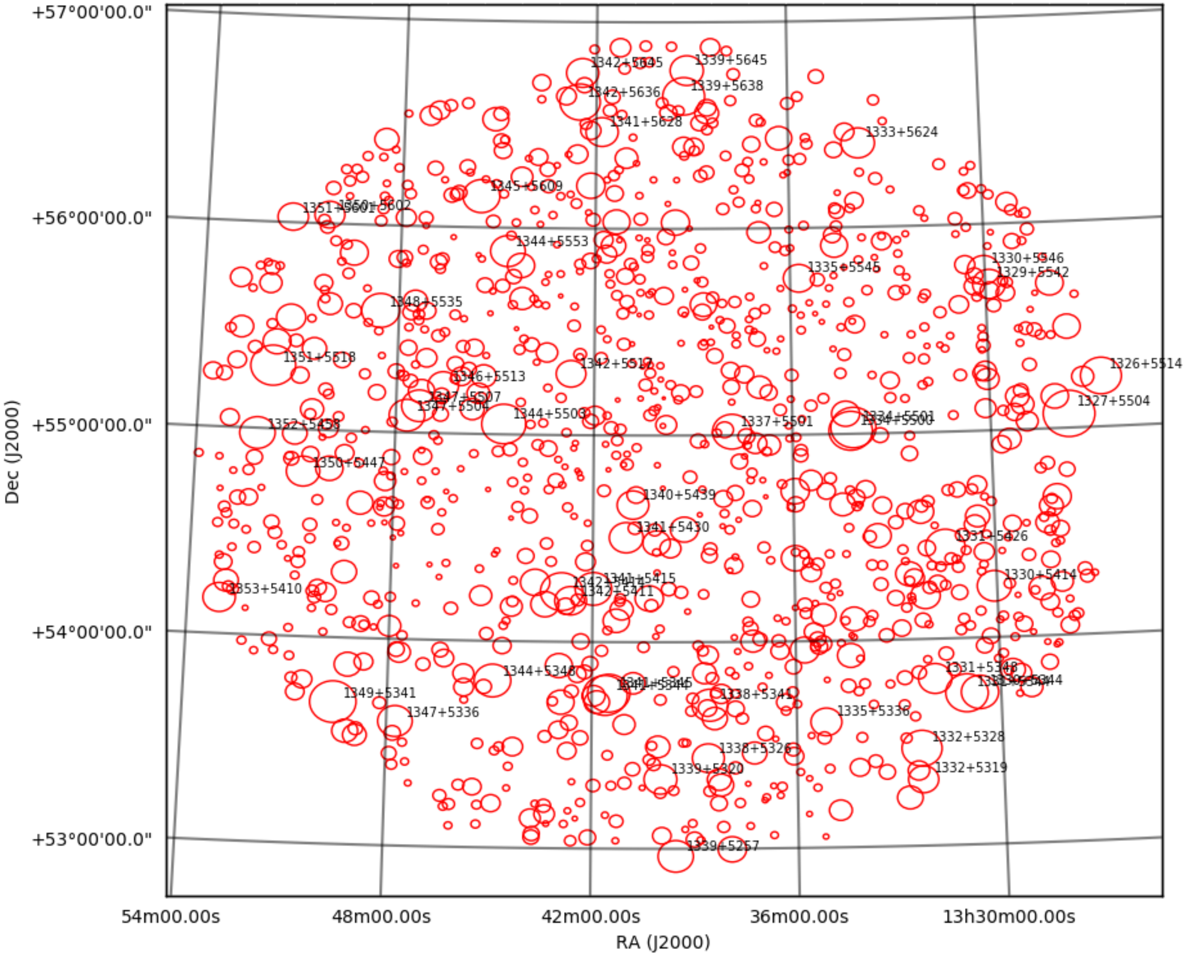
Relevant survey space for e.g. gravitational lens surveying, parallel studies of many objects
Extension of LOTSS to long baselines can be a leading survey in this space (even with SKA1)



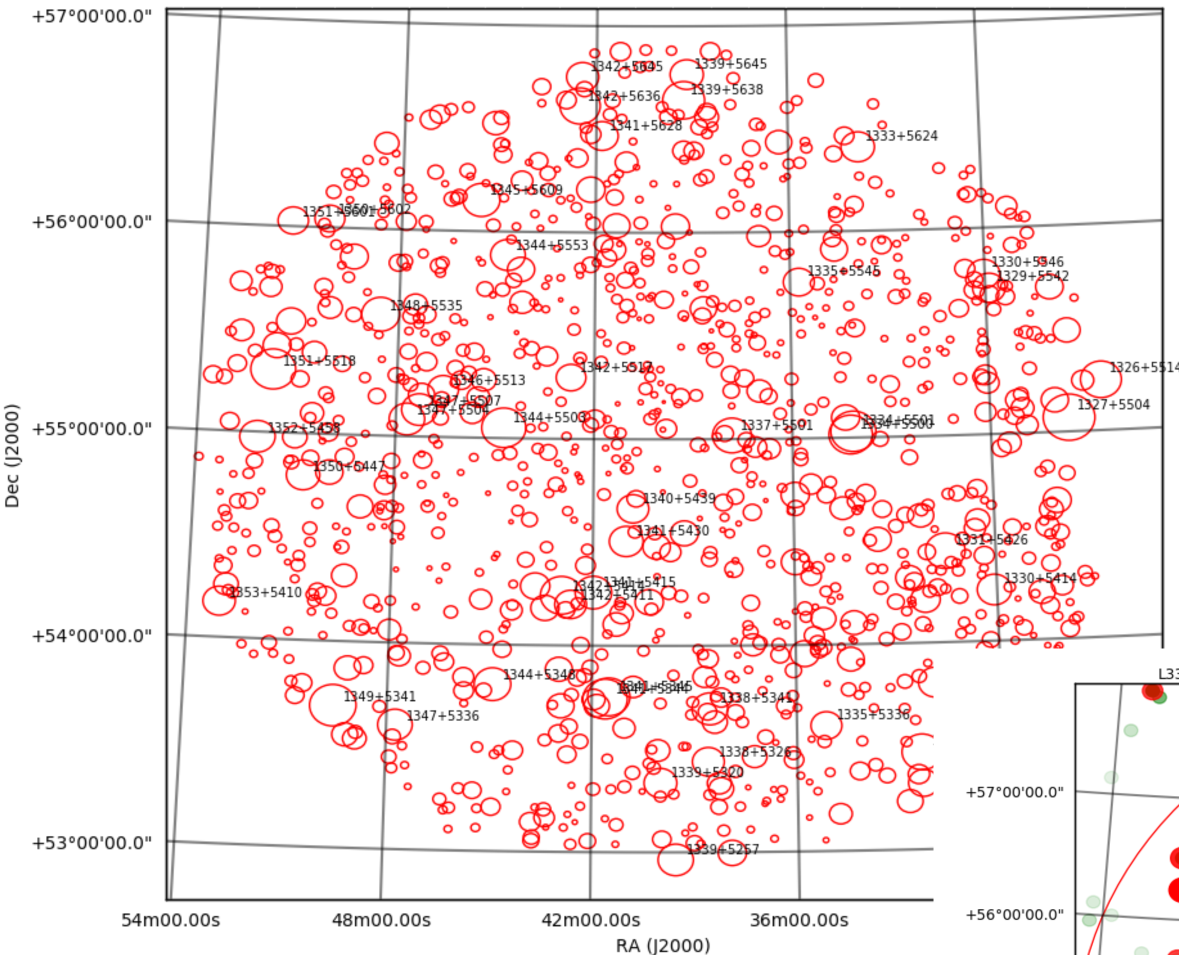
Survey test field

Data kept at 16ch/sub, 1 sec

BW, integration smearing and HPBW all about 1-1.5 degree

→ expect noticeable holes given 2.5 degree pointing throws

More details: A. Nikolajevs talk



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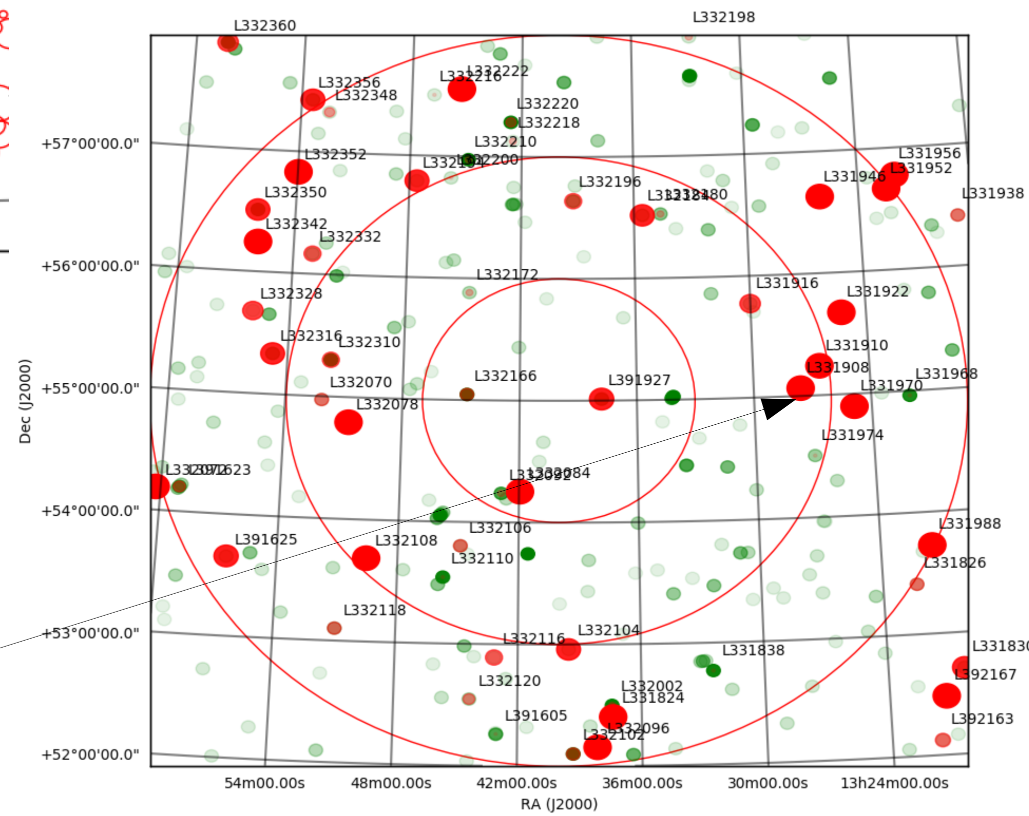
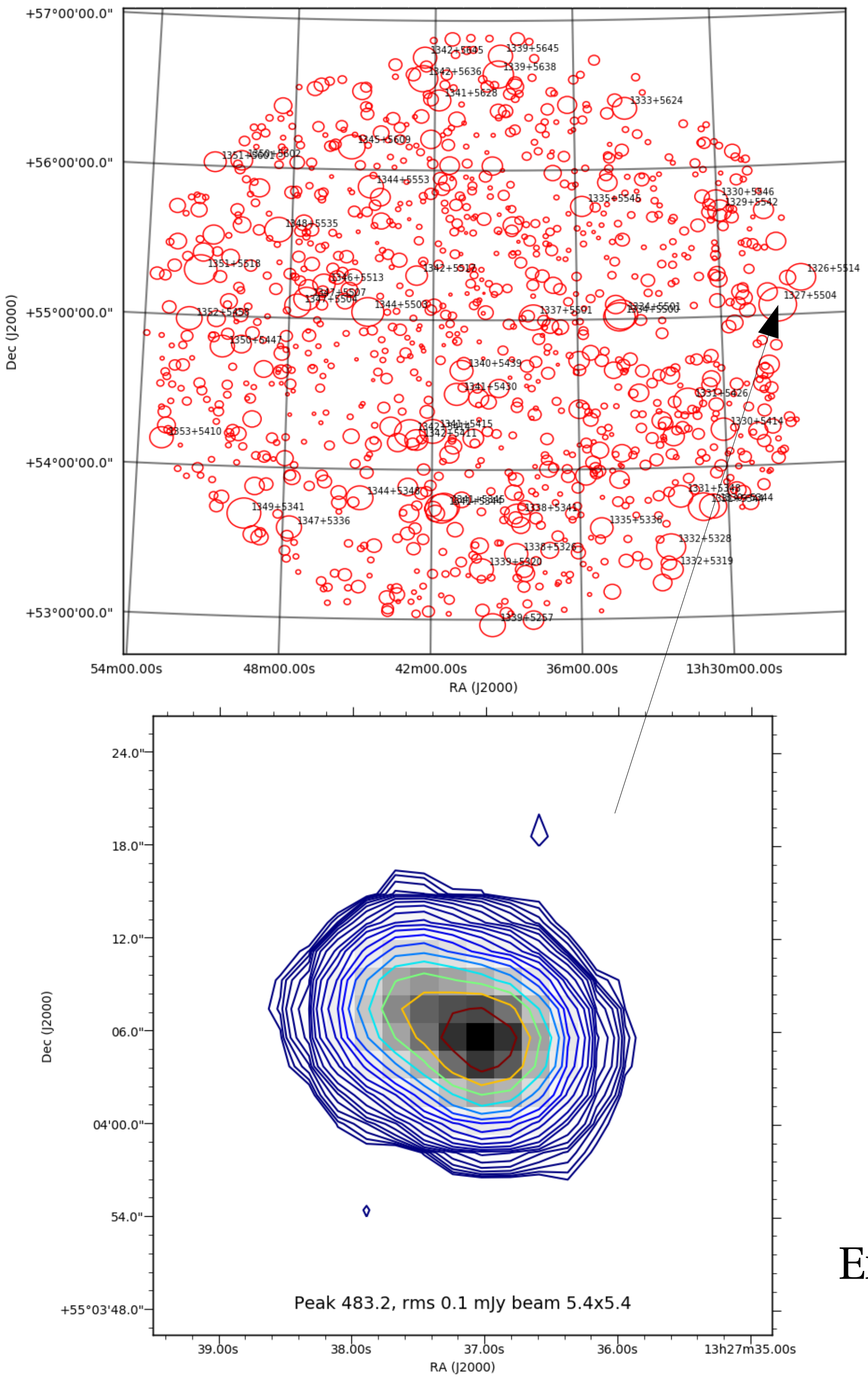
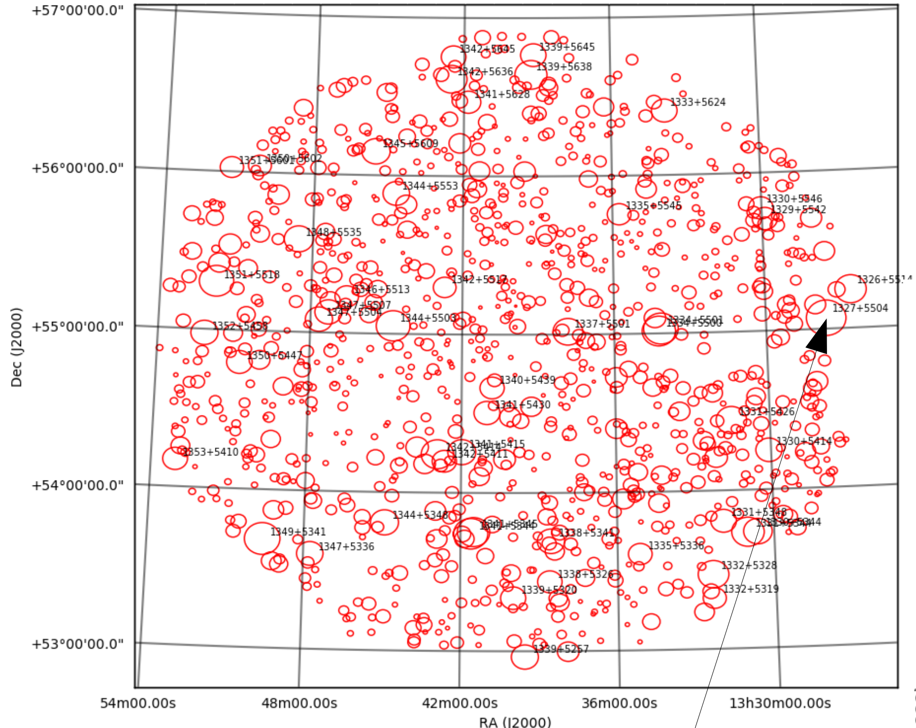


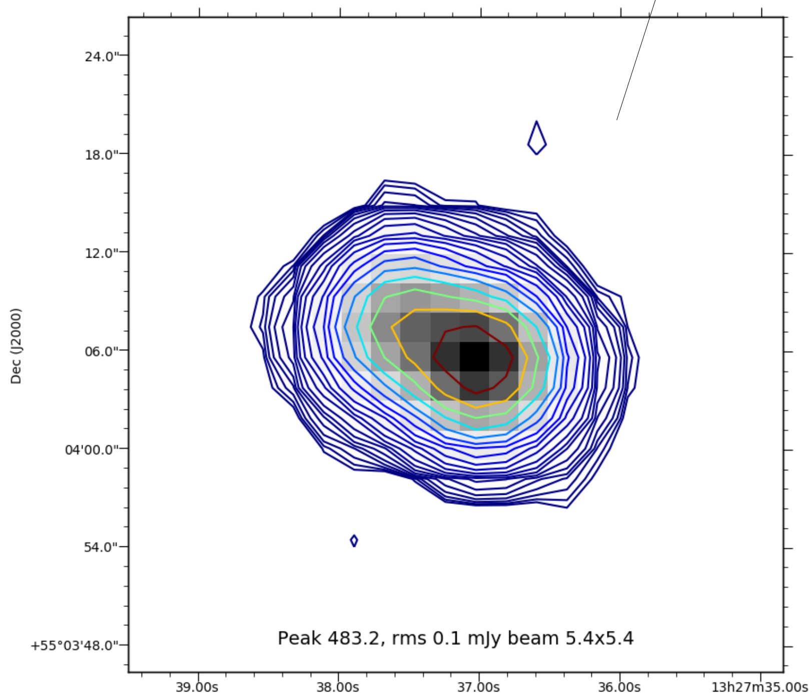
LBCS survey calibrators →
(see A. Nikolajevs later)

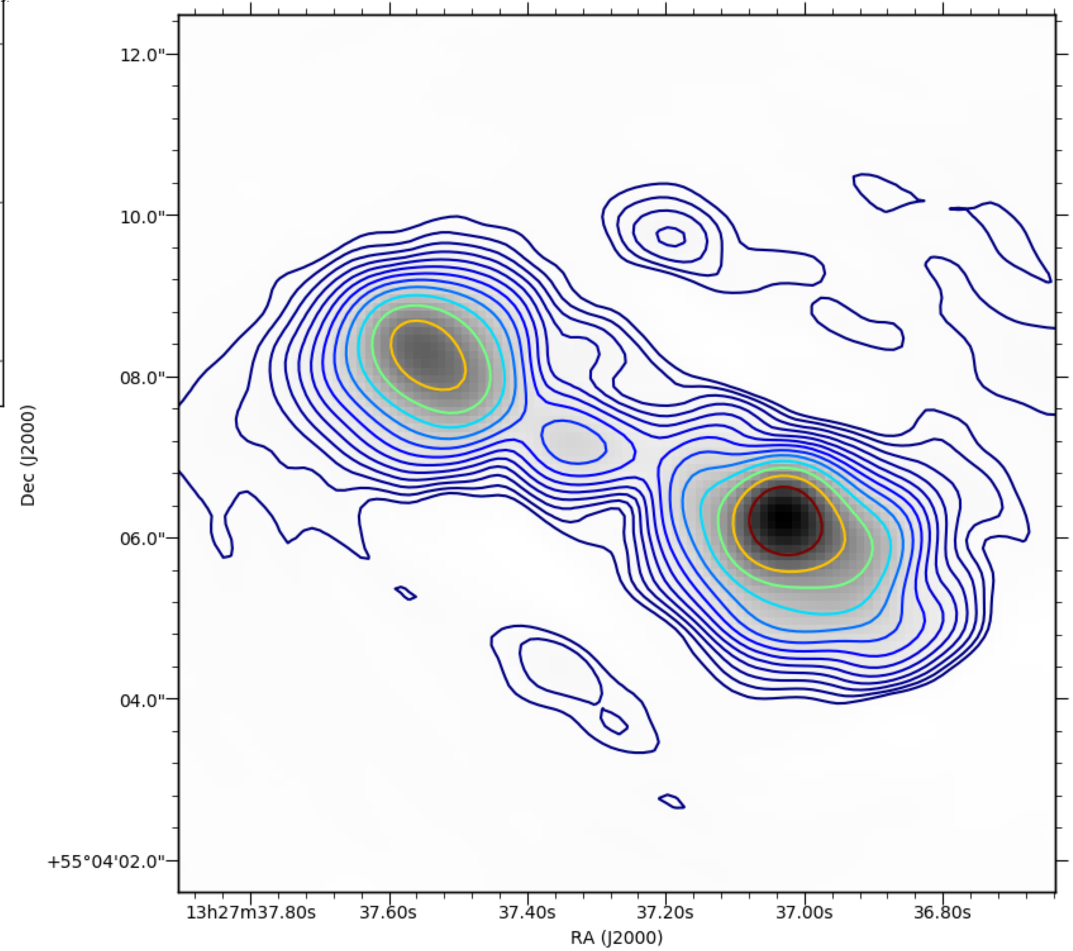
Primary calibrator
(for delay solution)



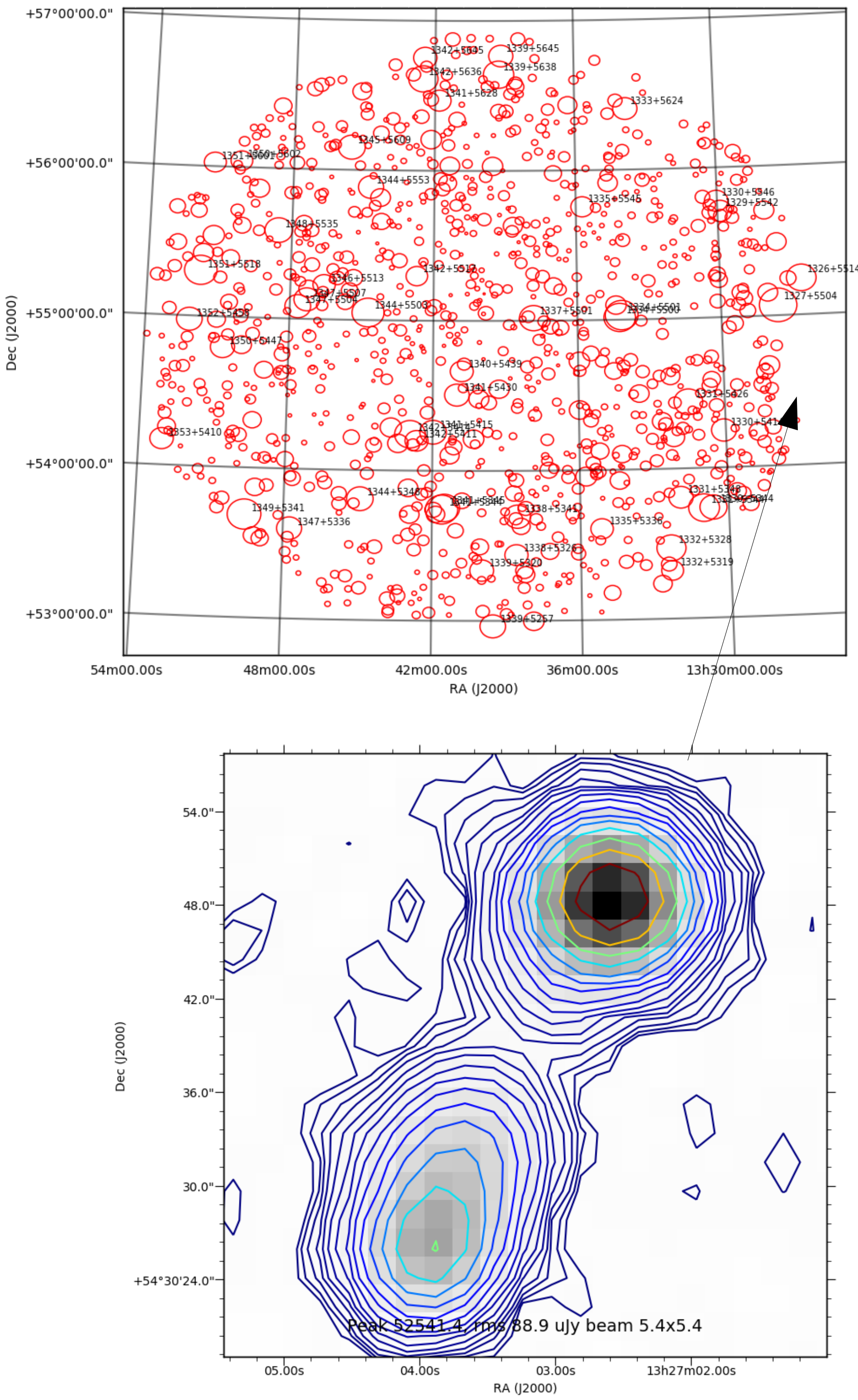
Existing VLA survey



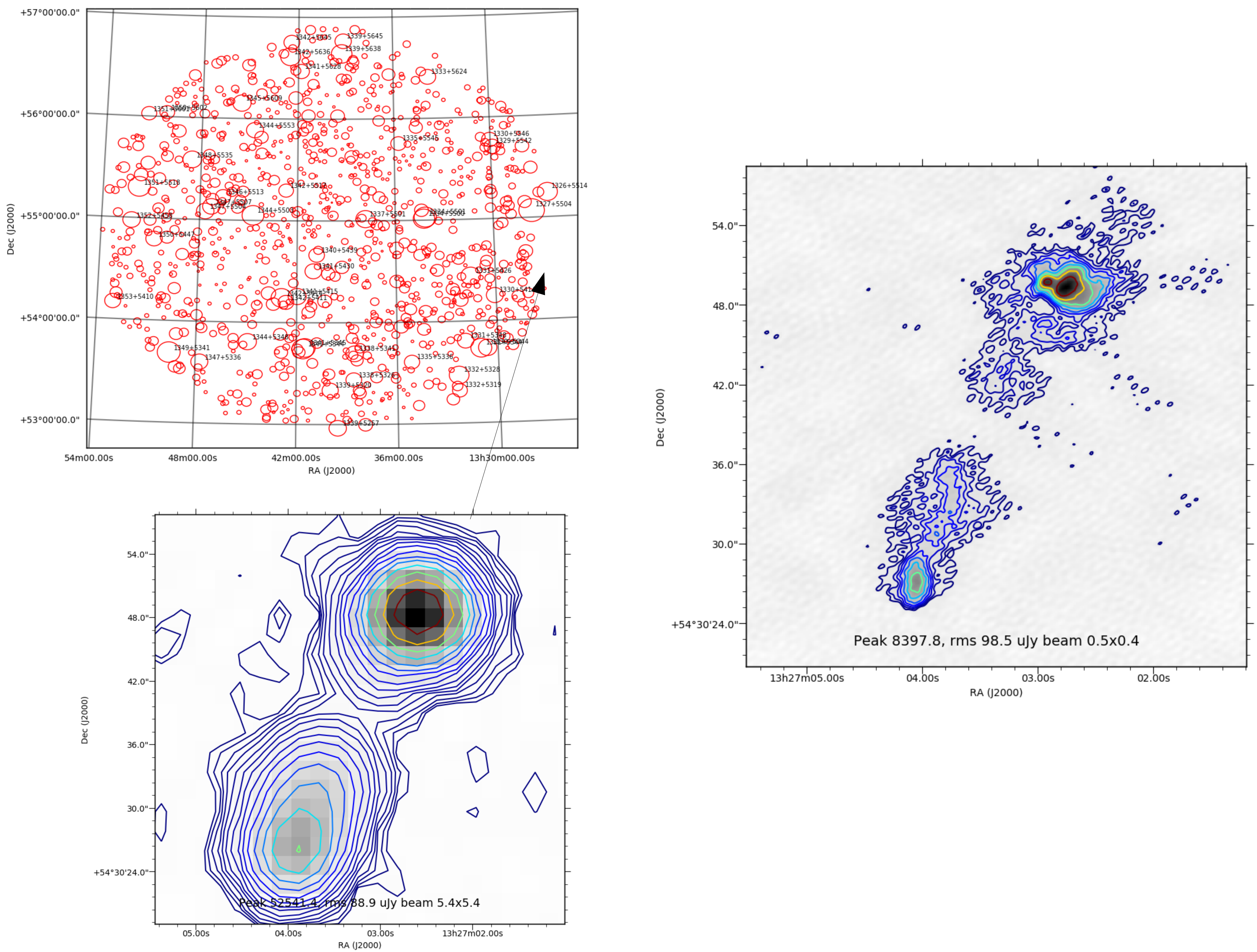




With LOFAR long baselines



+57°00'00.0"
+56°00'00.0"
+55°00'00.0"
+54°00'00.0"
+53°00'00.0"
Dec (J2000)
54m00.00s
48m00.00s
42m00.00s
36m00.00s
13h30m00.00s
RA (J2000)
54.0"
48.0"
42.0"
36.0"
30.0"
+54°30'24.0"
Dec (J2000)
Peak 52541.4, rms 88.9 uJy beam 5.4x5.4
05.00s
04.00s
03.00s
13h27m02.00s
RA (J2000)



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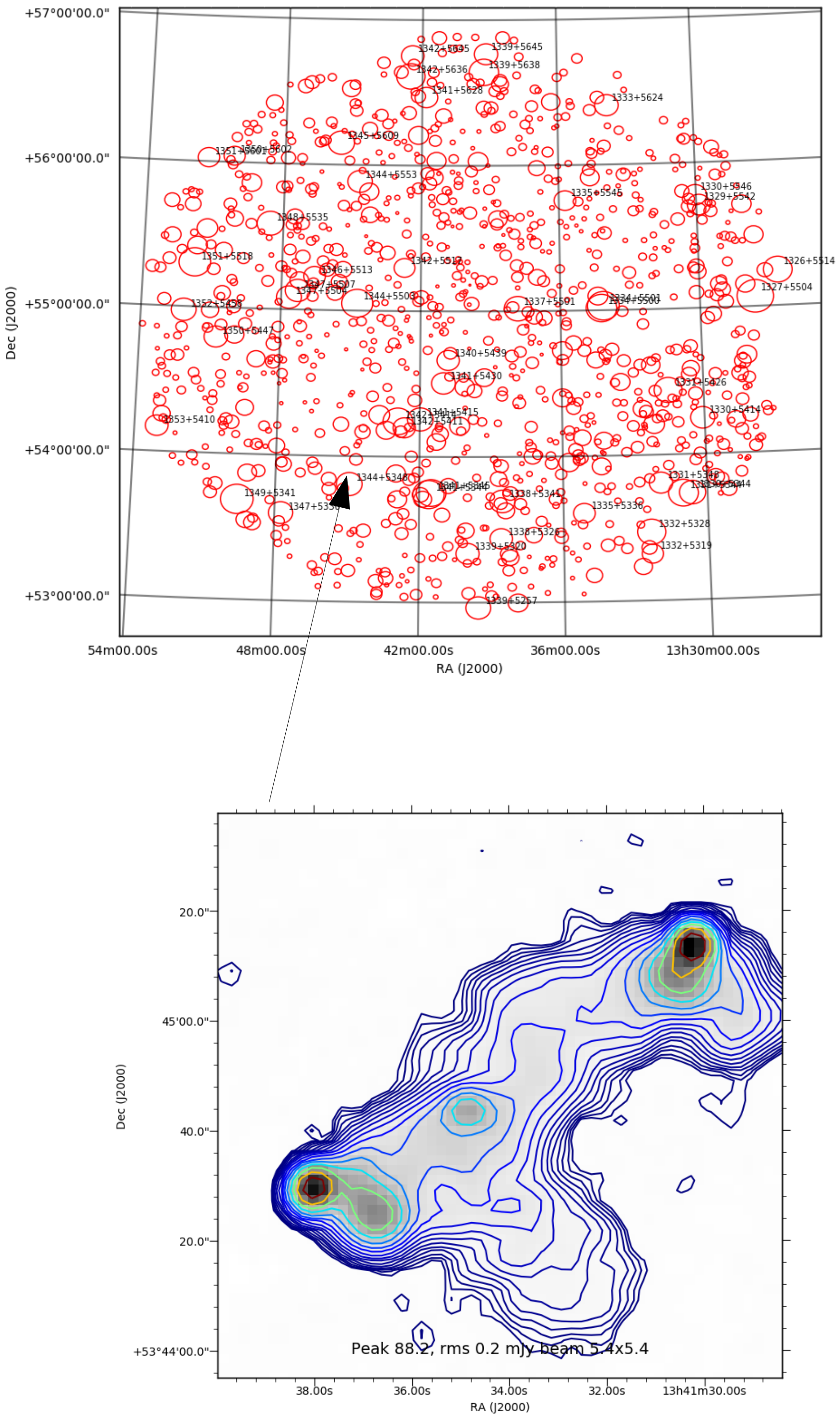
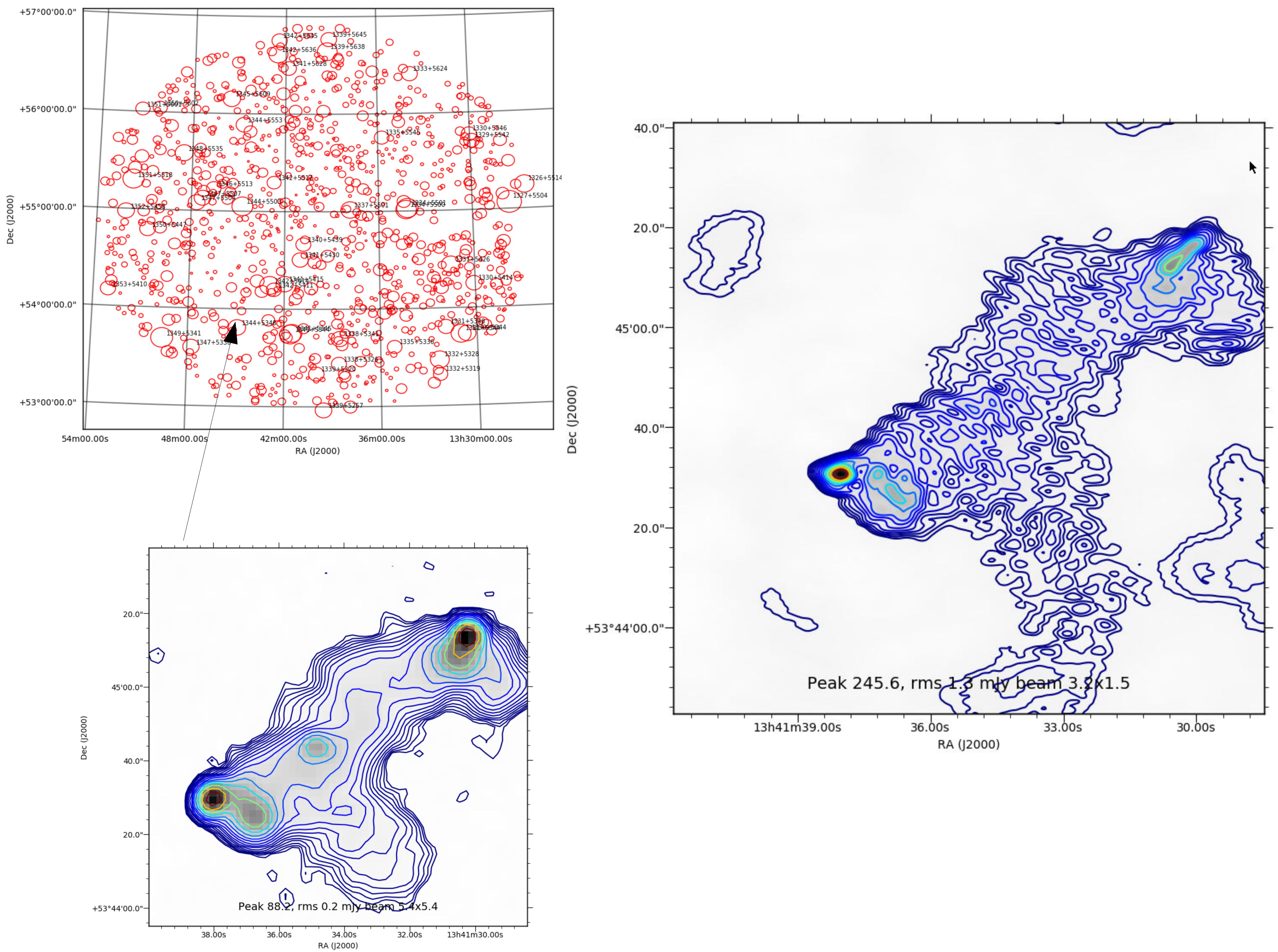
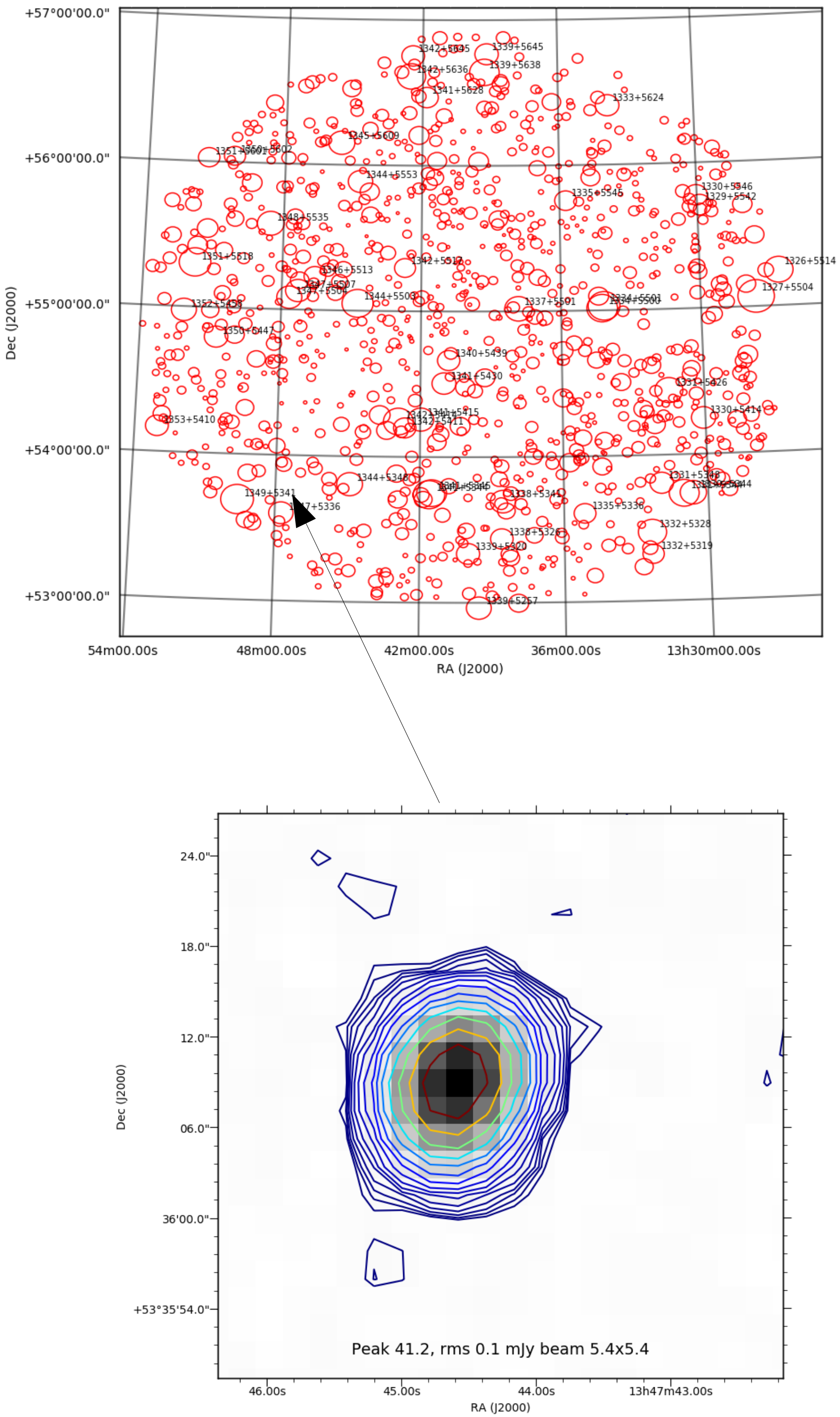
05.00s
04.00s
03.00s
13h27m02.00s
RA (J2000)
54.0"
48.0"
42.0"
36.0"
30.0"
+54°30'24.0"
Dec (J2000)
Peak 8397.8, rms 98.5 uJy beam 0.5x0.4
13h27m05.00s
04.00s
03.00s
02.00s
RA (J2000)


Peak 88.2, rms 0.2 mJy beam 5.4x5.4



+57°00'00.0"
+56°00'00.0"
+55°00'00.0"
+54°00'00.0"
+53°00'00.0"
Dec (J2000)
54m00.00s
48m00.00s
42m00.00s
36m00.00s
13h30m00.00s
RA (J2000)
1344+5346
20.0"
45'00.0"
40.0"
20.0"
+53°44'00.0"
Dec (J2000)
38.00s
36.00s
34.00s
32.00s
13h41m30.00s
RA (J2000)
Peak 88.2, rms 0.2 mJy beam 5.4x5.4
40.0"
20.0"
45'00.0"
40.0"
20.0"
+53°44'00.0"
Dec (J2000)
13h41m39.00s
36.00s
33.00s
30.00s
RA (J2000)
Peak 245.6, rms 1.3 mJy beam 3.2x1.5



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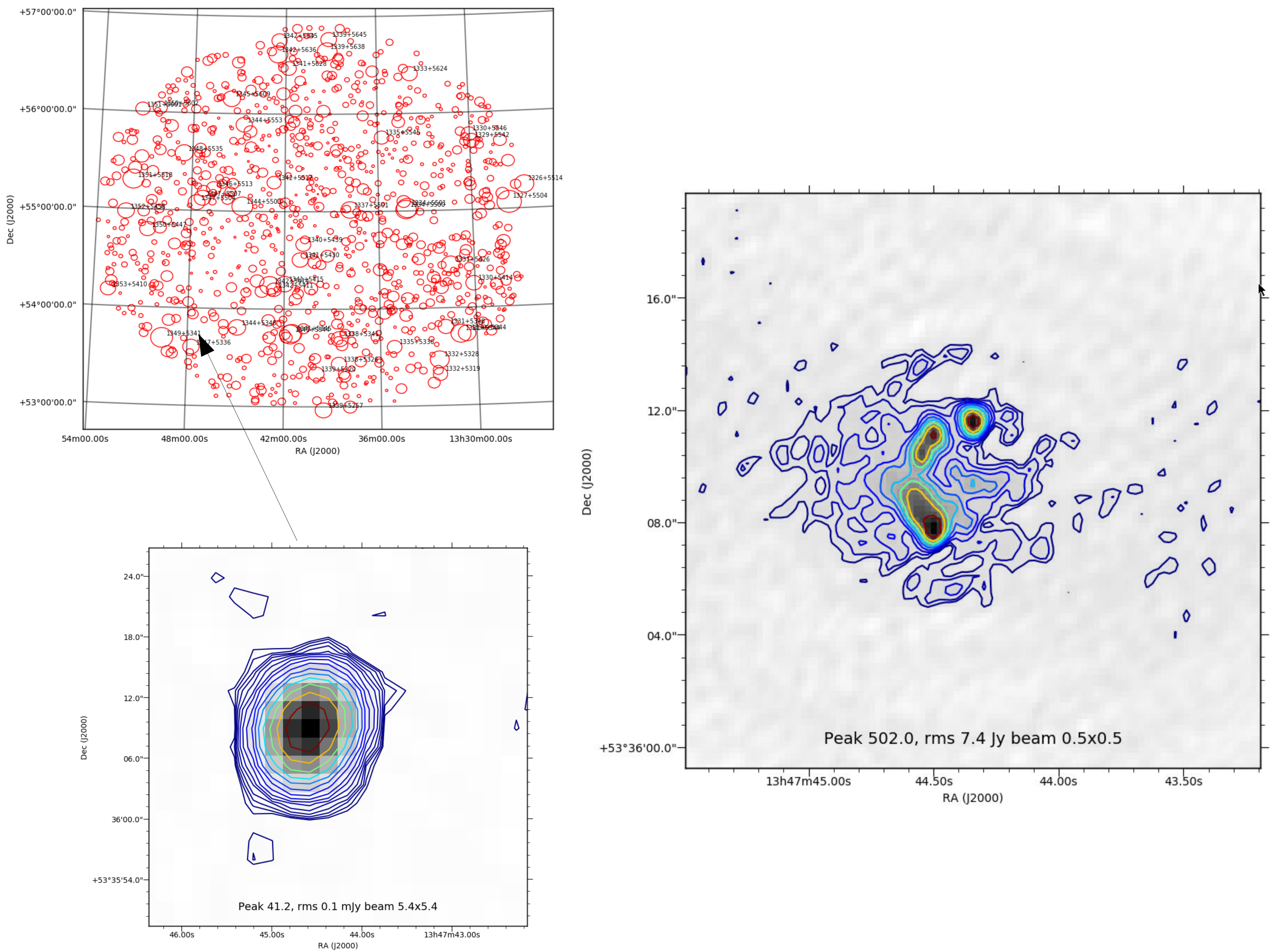
+53°00'00.0"
Dec (J2000)
54m00.00s
48m00.00s
42m00.00s
36m00.00s
13h30m00.00s
RA (J2000)
24.0"
18.0"
12.0"
06.0"
36'00.0"
+53°35'54.0"
Dec (J2000)
Peak 41.2, rms 0.1 mJy beam 5.4x5.4
46.00s
45.00s
44.00s
13h47m43.00s
RA (J2000)



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13h30m00.00s
RA (J2000)
24.0"
18.0"
12.0"
06.0"
36'00.0"
+53°35'54.0"
Peak 41.2, rms 0.1 mJy beam 5.4x5.4
46.00s
45.00s
44.00s
13h47m43.00s
16.0"
08.0"
04.0"
+53°36'00.0"
Peak 502.0, rms 7.4 Jy beam 0.5x0.5
13h47m45.00s
44.50s
44.00s
43.50s

Current development work in image-making led by Long-Baseline Working Group

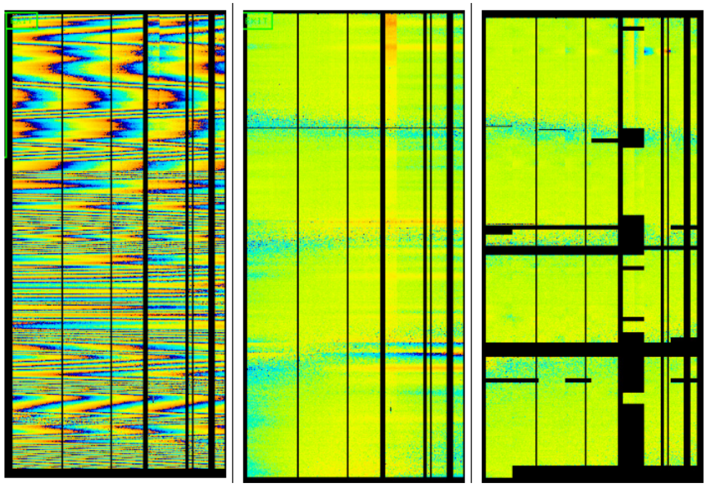
Neal Jackson (Manchester), Leah Morabito (Oxford)

with active members in numerous countries including Latvia (KP, AK),
France, Germany, Ireland, Netherlands

Pipeline currently allows routine imaging of individual sources

Working towards mass-production of survey field images

Calibration challenges



Phase against
Time (y-axis)
Frequency (x-axis)

DELAYS

- give phase variation with frequency
  Non-dispersive: clock errors
    Constant time vs. frequency
    d(phi)/df constant
  Dispersive: ionosphere
    Effective delay increases with decreasing f

PHASE

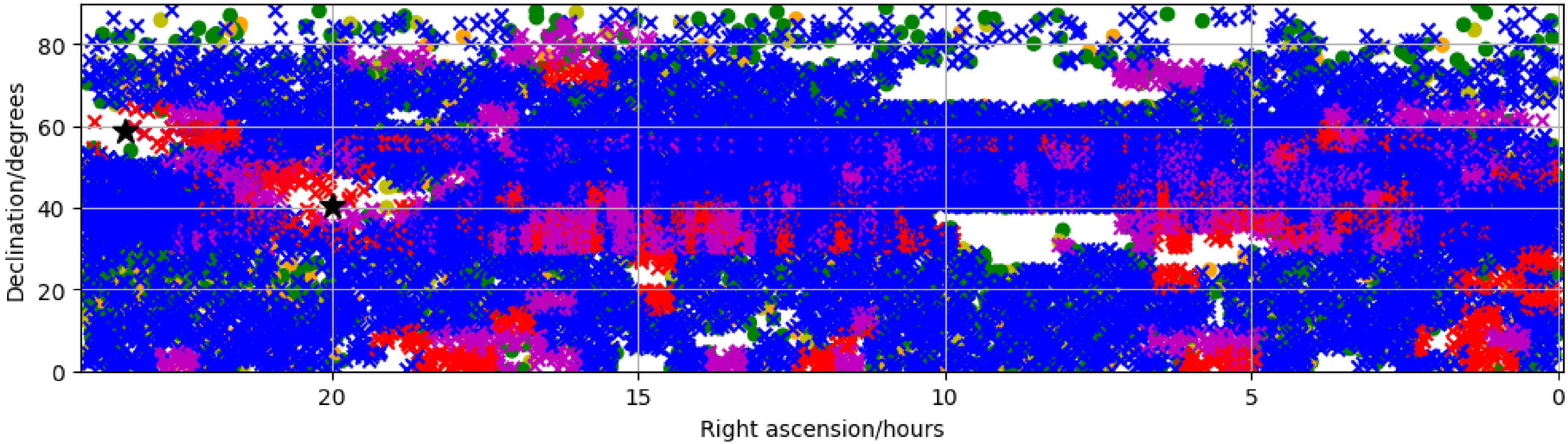
- phase variation with time
  Rapid changes in atmosphere (ionosphere at LF)

Need calibrator sources to remove these effects:
- initial calibrator (delays, first guess of phases)
- subsequent in-field calibration (by FACET or individual sources)

Initial calibrator information provided by LBCS survey……

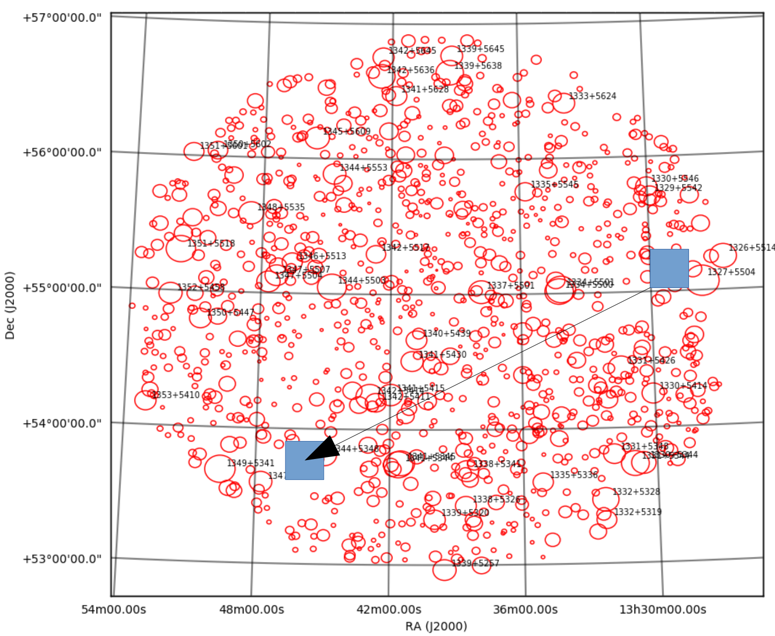
LBCS survey making good progress towards completion

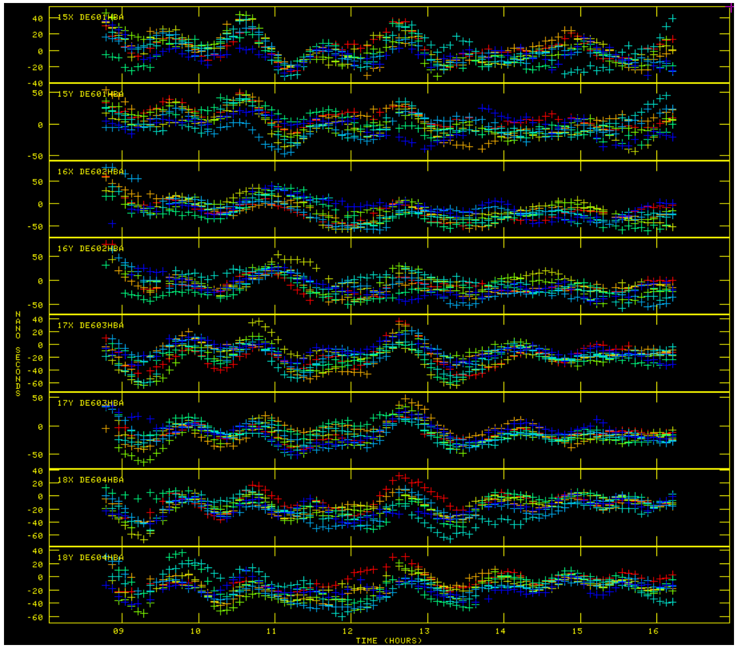
- Calibrator sources necessary for ionospheric phase calibration
- More compact sources for long-baseline calibration are rarer
- First paper at 20% completion (Jackson et al. 2016)
- 1 per sq deg available in many parts of the sky (at
- Now over 90% and finishing up final fiddly bits (→ Paper 2)
- Many thanks to all at Observatory for efforts!

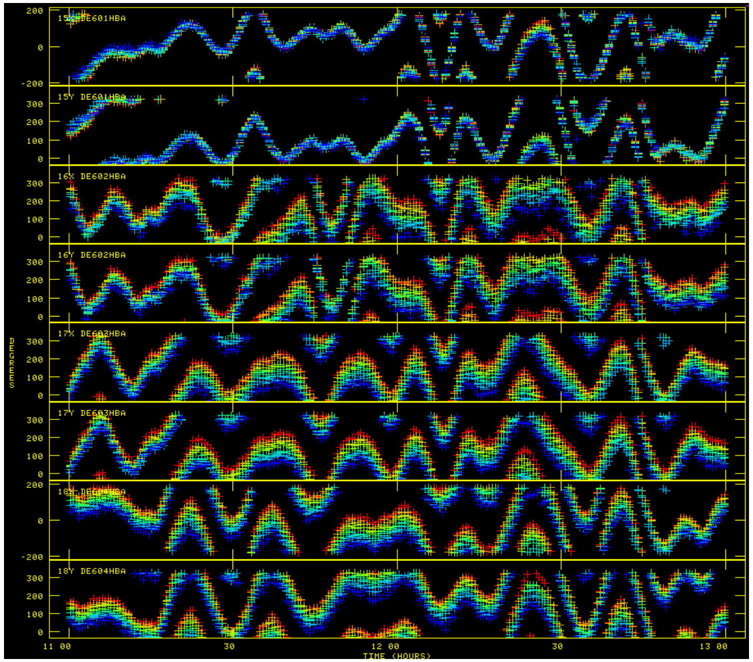


Current status of LBCS calibrator survey (Sept 2018)
Released on ASTRON VO; beta-version updates on
http://www.jb.man.ac.uk/~njj/lbcs_stats.sum

After initial delay/phase solution, need to get the direction-dependent corrections...







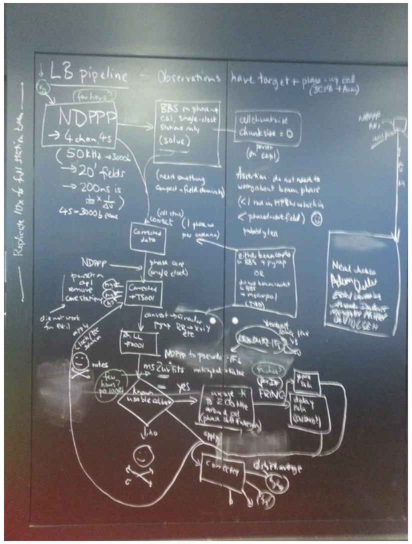
Phase/delay differences between
2 calibrators:

Delay ~20ns → decoherence over 20-30MHz
Phase rotations over ~3 min (cf. 30s raw)

Also possible to make phase screen

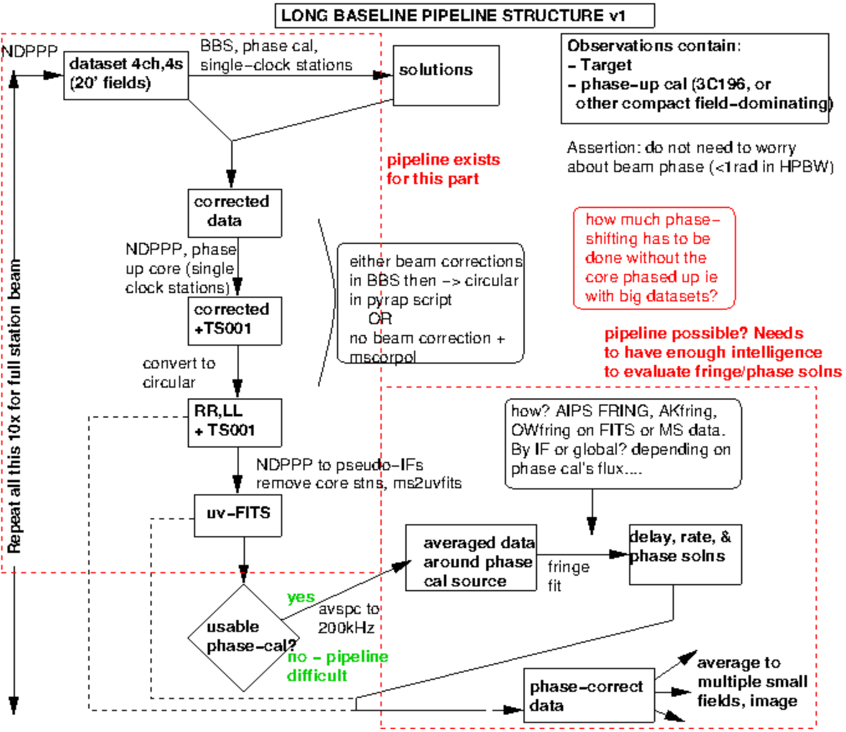
- done initially by hand
- transfer phase solutions around field
- iterate on each source to model (otherwise source phase structure)
- use model to determine phases as function of time

https://www.youtube.com/watch?v=0txM62315Ik&feature=youtu.be

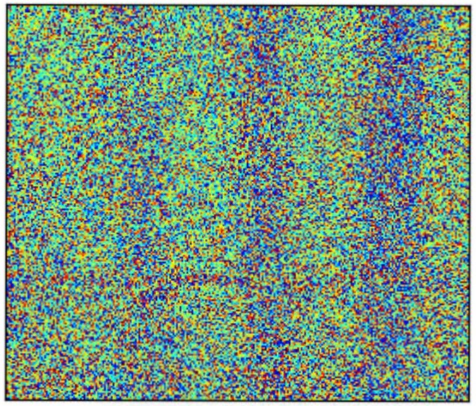


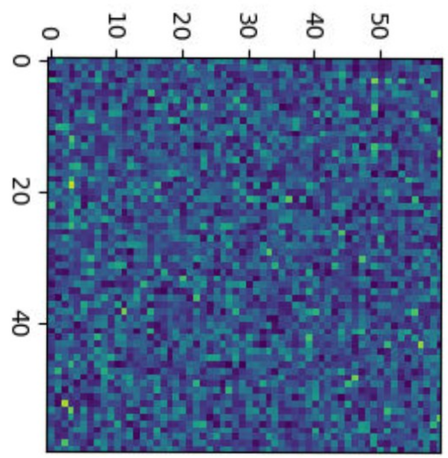
We have come a long way!

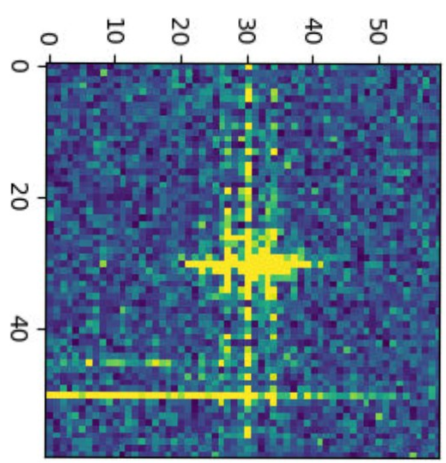
- Basic operation of long baselines is now routine
- Science is now possible with same expertise as standard VLBI
- LOFAR-International now 7 countries, shortly 8 with Latvia
- Internationally competitive instrument into and through SKA era



Thank you!





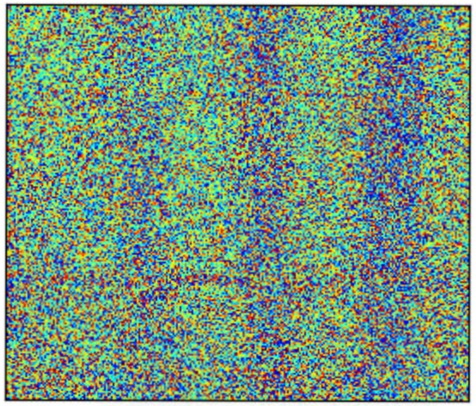


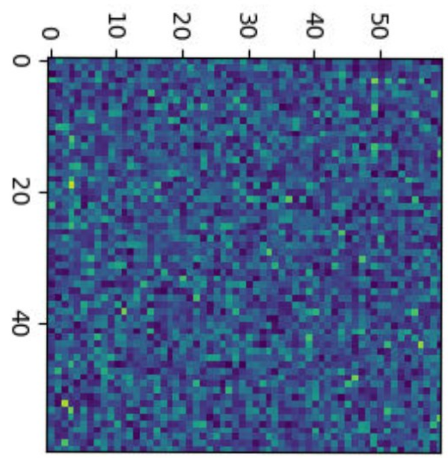
Number of visible sources per field

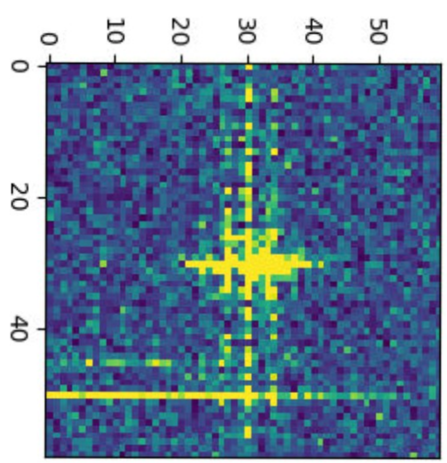
Assess using transformed closure phase measure per station

L1324+5454	15.3	3.7	7.1	7.3	61.5	1.3	1.7	3.1
L1325+5540	6.4	3.4	0.5	3.3	34.4	0.0	2.4	3.3
L1326+5514	27.3	6.4	21.5	12.9	47.5	3.5	5.7	0.4
L1326+5637	1.1	0.0	2.3	2.0	2.8	3.3	2.3	3.3
L1327+5504	147.0	58.7	148.9	130.6	280.3	49.6	62.0	41.0
L1330+5546	3.1	3.2	3.3	3.3	28.9	1.6	0.0	1.7
L1334+5631	1.6	2.1	2.3	0.8	3.0	3.5	1.3	1.5
L1335+5631	3.2	0.3	1.6	2.8	4.9	1.4	2.1	2.0
L1337+5501	10.9	13.2	17.8	15.8	27.4	15.8	14.1	12.3
L1339+5257	1.5	1.4	1.3	1.3	4.8	3.9	3.2	3.2
L1339+5638	3.6	2.1	6.5	3.7	17.2	3.2	1.0	3.0
L1341+5415	5.4	2.7	7.1	9.7	13.6	4.5	2.0	7.8
L1342+5707	1.1	2.1	2.6	2.8	1.2	4.6	2.6	2.7
L1342+5717	3.0	2.1	0.9	1.5	3.2	1.1	0.8	0.9
L1343+5253	2.4	4.0	0.9	0.1	0.9	2.8	2.2	1.4
L1344+5233	0.0	3.0	0.0	1.5	0.7	0.2	2.3	1.4
L1344+5348	2.7	3.1	3.1	1.4	2.3	0.1	2.4	2.4
L1344+5503	4.2	8.9	17.8	17.9	19.1	3.9	2.5	3.8
L1344+5658	0.5	3.4	0.0	2.4	2.1	3.2	1.8	3.0
L1347+5647	3.7	1.3	2.0	2.9	1.3	3.6	1.1	2.0
L1349+5341	34.5	14.1	28.9	32.1	78.6	25.5	21.3	20.7
L1350+5447	1.4	2.9	3.7	4.0	3.0	4.7	2.8	1.8
L1351+5306	1.7	1.0	0.9	2.4	4.5	0.0	3.9	3.2
L1351+5518	10.2	2.4	4.0	3.0	29.4	0.8	2.7	2.0
L1352+5458	3.2	3.1	3.6	2.9	2.8	2.8	3.3	1.4
L1353+5610	0.5	2.1	4.4	1.9	4.5	0.9	3.0	3.6
L1353+5725	2.3	1.0	3.4	2.7	1.2	2.5	3.0	4.7
L1354+5520	2.9	1.0	0.9	4.2	3.9	2.9	2.1	2.2
L1354+5650	9.6	1.1	1.0	1.6	2.2	5.0	3.4	2.0
L1355+5540	2.7	0.0	3.1	3.2	4.4	0.0	4.1	1.7
L1355+5614	1.4	1.7	2.1	3.0	0.9	2.0	0.0	1.9
L1356+5339	1.3	1.1	4.9	1.3	1.0	3.2	2.0	1.9
L1356+5630	4.4	2.6	3.3	1.8	2.0	1.7	2.6	1.8

LBCS well-detected sources







Number of visible sources per field

Assess using transformed closure phase measure per station

Source	S_{peak}	S_{int}	DE601	DE602	DE603	DE604	DE605	FR606	SE607	UK608
ILTJ132737.2+550406.2	5420.7	5886.4	**143.5**	**58.9**	**145.3**	**129.6**	**286.0**	**48.0**	**64.4**	**38.3**
ILTJ134934.6+534117.9	2266.8	2634.5	**35.6**	**13.9**	**28.2**	**34.2**	**74.8**	**24.0**	**22.1**	**20.8**
ILTJ134136.6+534430.1	1646.4	2515.7	1.5	**4.8**	1.8	2.0	**4.5**	**3.2**	1.1	**5.1**
ILTJ133409.4+550149.0	1817.1	2334.8	**6.6**	2.7	**4.5**	1.9	**26.1**	1.2	1.7	1.3
ILTJ135146.8+551818.7	1728.5	1989.8	**8.7**	1.9	**3.6**	2.9	**27.3**	0.3	**3.7**	**3.0**
ILTJ133414.5+550053.4	1367.9	1738.8	**5.1**	2.7	**4.5**	**4.2**	**25.7**	1.5	2.6	1.3
ILTJ132703.1+543041.0	526.7	805.9	**7.7**	1.0	**3.1**	**3.2**	**25.0**	2.3	2.1	1.0
ILTJ134455.0+534829.2	443.8	488.4	**5.0**	1.8	**3.8**	0.8	**3.8**	2.0	1.8	1.7
ILTJ134744.5+533609.1	314.6	354.2	**6.3**	2.2	**3.7**	**8.1**	**11.6**	2.5	1.3	2.8
ILTJ135303.5+541026.9	218.7	252.7	1.0	1.4	**3.6**	2.7	**3.5**	0.0	2.0	2.9
ILTJ134911.1+535216.2	85.0	99.5	**5.5**	1.0	**4.5**	**5.7**	**15.4**	2.0	**3.4**	2.4
ILTJ134923.3+541905.0	64.8	97.1	**3.1**	**3.3**	**5.4**	1.6	**5.3**	1.7	**3.0**	1.5
ILTJ134911.9+533257.2	74.2	86.6	**10.7**	2.6	**11.8**	**11.1**	**37.3**	**4.7**	**3.6**	**9.2**
ILTJ134706.2+534003.6	57.6	80.8	**3.7**	**3.8**	**3.1**	**4.8**	**6.7**	**3.9**	0.0	2.0
ILTJ135252.7+541525.7	58.8	69.3	2.1	2.7	2.6	0.8	2.8	**3.1**	2.3	2.7
ILTJ134854.7+533151.1	51.4	62.2	**4.5**	**4.1**	**7.2**	**11.2**	**22.9**	**4.0**	**3.4**	**7.0**
ILTJ134156.9+534422.0	46.5	61.8	1.5	**4.8**	1.8	2.0	**4.5**	**3.2**	1.1	**5.1**
ILTJ134740.9+535610.3	42.7	57.5	1.7	0.9	2.3	2.3	**8.2**	**4.8**	1.6	1.2
ILTJ134759.8+540343.7	47.4	52.8	2.5	2.1	1.8	2.7	**4.6**	1.0	**3.1**	**3.5**
ILTJ134955.3+541259.0	33.7	43.5	2.5	1.7	**4.8**	0.8	**3.1**	**3.6**	1.6	2.1
ILTJ134518.8+541305.7	39.5	43.4	2.7	2.1	0.9	1.2	**4.6**	1.5	**3.5**	**3.7**
ILTJ134424.0+541003.9	36.8	41.0	2.0	0.0	2.6	**4.0**	**4.1**	0.0	2.3	1.8
ILTJ134546.5+535027.3	32.5	36.6	2.5	1.9	1.9	0.8	1.3	1.6	2.1	2.2
ILTJ134418.1+532922.8	30.8	36.3	2.8	2.4	2.0	1.4	2.6	2.3	**4.0**	1.6
ILTJ135030.4+534732.9	27.7	34.8	**3.3**	**3.1**	**3.5**	**3.8**	**13.3**	2.0	1.7	**3.1**
ILTJ134843.1+535310.3	22.6	33.5	1.9	2.2	**4.8**	**4.6**	**4.7**	2.8	1.4	**3.0**
ILTJ134545.5+534626.2	26.4	31.1	1.1	1.6	1.9	0.5	**3.3**	2.9	2.2	0.0
ILTJ135042.0+534351.5	21.7	30.8	**3.2**	2.0	2.1	1.7	**10.7**	1.2	**5.5**	1.3
ILTJ135009.6+541418.4	19.2	29.5	**3.1**	1.5	**5.8**	1.2	**5.2**	1.6	**4.5**	**3.1**
ILTJ134621.4+535445.8	25.4	28.4	2.6	**3.6**	**3.6**	2.3	**3.9**	3.0	2.9	1.7
ILTJ134454.2+531252.1	24.0	27.9	1.5	1.9	**3.1**	**3.3**	2.9	1.3	**4.7**	1.2
ILTJ134527.1+531734.0	21.4	24.4	1.8	2.7	2.1	0.6	**4.1**	1.4	**3.1**	1.4
ILTJ134439.2+535840.3	20.0	23.0	1.6	0.8	2.2	1.3	1.8	2.4	2.5	2.7
ILTJ135259.4+542046.2	18.3	22.8	0.6	**4.2**	**3.8**	2.5	**5.1**	0.9	**3.2**	2.4
ILTJ134500.4+541550.1	14.4	21.9	2.2	2.8	1.6	**3.6**	2.2	1.3	1.6	1.8
ILTJ134746.1+535700.9	14.6	21.2	**4.1**	**3.3**	**4.8**	**3.5**	**6.3**	**3.4**	0.3	2.7
ILTJ134850.4+540409.5	17.7	20.9	2.4	2.6	**3.6**	**5.5**	**9.4**	1.7	1.9	1.2
ILTJ134748.6+533241.6	15.2	19.8	**8.8**	**3.7**	**4.0**	**8.0**	**16.1**	**3.4**	**3.1**	**3.2**
ILTJ134628.6+535710.0	15.0	18.9	1.2	2.2	**5.2**	2.3	**5.0**	0.4	2.6	2.8
ILTJ134753.6+532647.4	11.6	15.9	**5.9**	2.3	**4.5**	**3.9**	**11.8**	1.8	0.0	**4.1**
ILTJ134700.2+534002.1	8.9	15.0	**3.7**	**3.8**	**3.1**	**4.8**	**6.7**	**3.9**	0.0	2.0
ILTJ134832.8+541143.8	12.5	14.5	**3.7**	**5.9**	2.0	2.0	2.0	2.0	**3.3**	1.9
ILTJ134510.4+534642.6	13.5	14.3	1.1	1.6	1.9	0.5	**3.3**	2.9	2.2	0.0
ILTJ135131.6+535855.8	11.8	13.5	**5.2**	1.8	**5.0**	2.8	**8.6**	0.0	1.5	0.1

Bright sources

Number of visible sources per field

Assess using transformed closure phase measure per station

Likely to see ~50% with 200-km >20mJy

Less (5-10%?) with 800-km

But…..

1) differences e.g. DE601/DE605 in table
   (station calibration?)

Source	S_{peak}	S_{int}	**DE601**	**DE602**	**DE603**	**DE604**	**DE605**	**FR606**	**SE607**	**UK608**
ILTJ132737.2+550406.2	5420.7	5886.4	**143.5**	**58.9**	**145.3**	**129.6**	**286.0**	**48.0**	**64.4**	**38.3**
ILTJ134934.6+534117.9	2266.8	2634.5	**35.6**	**13.9**	**28.2**	**34.2**	**74.8**	**24.0**	**22.1**	**20.8**
ILTJ134136.6+534430.1	1646.4	2515.7	1.5	**4.8**	1.8	2.0	**4.5**	**3.2**	1.1	**5.1**
ILTJ133409.4+550149.0	1817.1	2334.8	**6.6**	2.7	**4.5**	1.9	**26.1**	1.2	1.7	1.3
ILTJ135146.8+551818.7	1728.5	1989.8	**8.7**	1.9	**3.6**	2.9	**27.3**	0.3	**3.7**	**3.0**
ILTJ133414.5+550053.4	1367.9	1738.8	**5.1**	2.7	**4.5**	**4.2**	**25.7**	1.5	2.6	1.3
ILTJ132703.1+543041.0	526.7	805.9	**7.7**	1.0	**3.1**	**3.2**	**25.0**	2.3	2.1	1.0
ILTJ134455.0+534829.2	443.8	488.4	**5.0**	1.8	**3.8**	0.8	**3.8**	2.0	1.8	1.7
ILTJ134744.5+533609.1	314.6	354.2	**6.3**	2.2	**3.7**	**8.1**	**11.6**	2.5	1.3	2.8
ILTJ135303.5+541026.9	218.7	252.7	1.0	1.4	**3.6**	2.7	**3.5**	0.0	2.0	2.9
ILTJ134911.1+535216.2	85.0	99.5	**5.5**	1.0	**4.5**	**5.7**	**15.4**	2.0	**3.4**	2.4
ILTJ134923.3+541905.0	64.8	97.1	**3.1**	**3.3**	**5.4**	1.6	**5.3**	1.7	**3.0**	1.5
ILTJ134911.9+533257.2	74.2	86.6	**10.7**	2.6	**11.8**	**11.1**	**37.3**	**4.7**	**3.6**	**9.2**
ILTJ134706.2+534003.6	57.6	80.8	**3.7**	**3.8**	**3.1**	**4.8**	**6.7**	**3.9**	0.0	2.0
ILTJ135252.7+541525.7	58.8	69.3	2.1	2.7	2.6	0.8	2.8	**3.1**	2.3	2.7
ILTJ134854.7+533151.1	51.4	62.2	**4.5**	**4.1**	**7.2**	**11.2**	**22.9**	**4.0**	**3.4**	**7.0**
ILTJ134156.9+534422.0	46.5	61.8	1.5	**4.8**	1.8	2.0	**4.5**	**3.2**	1.1	**5.1**
ILTJ134740.9+535610.3	42.7	57.5	1.7	0.9	2.3	2.3	**8.2**	**4.8**	1.6	1.2
ILTJ134759.8+540343.7	47.4	52.8	2.5	2.1	1.8	2.7	**4.6**	1.0	**3.1**	**3.5**
ILTJ134955.3+541259.0	33.7	43.5	2.5	1.7	**4.8**	0.8	**3.1**	**3.6**	1.6	2.1
ILTJ134518.8+541305.7	39.5	43.4	2.7	2.1	0.9	1.2	**4.6**	1.5	**3.5**	**3.7**
ILTJ134424.0+541003.9	36.8	41.0	2.0	0.0	2.6	**4.0**	**4.1**	0.0	2.3	1.8
ILTJ134546.5+535027.3	32.5	36.6	2.5	1.9	1.9	0.8	1.3	1.6	2.1	2.2
ILTJ134418.1+532922.8	30.8	36.3	2.8	2.4	2.0	1.4	2.6	2.3	**4.0**	1.6
ILTJ135030.4+534732.9	27.7	34.8	**3.3**	**3.1**	**3.5**	**3.8**	**13.3**	2.0	1.7	**3.1**
ILTJ134843.1+535310.3	22.6	33.5	1.9	2.2	**4.8**	**4.6**	**4.7**	2.8	1.4	**3.0**
ILTJ134545.5+534626.2	26.4	31.1	1.1	1.6	1.9	0.5	**3.3**	2.9	2.2	0.0
ILTJ135042.0+534351.5	21.7	30.8	**3.2**	2.0	2.1	1.7	**10.7**	1.2	**5.5**	1.3
ILTJ135009.6+541418.4	19.2	29.5	**3.1**	1.5	**5.8**	1.2	**5.2**	1.6	**4.5**	**3.1**
ILTJ134621.4+535445.8	25.4	28.4	2.6	**3.6**	**3.6**	2.3	**3.9**	3.0	2.9	1.7
ILTJ134454.2+531252.1	24.0	27.9	1.5	1.9	**3.1**	**3.3**	2.9	1.3	**4.7**	1.2
ILTJ134527.1+531734.0	21.4	24.4	1.8	2.7	2.1	0.6	**4.1**	1.4	**3.1**	1.4
ILTJ134439.2+535840.3	20.0	23.0	1.6	0.8	2.2	1.3	1.8	2.4	2.5	2.7
ILTJ135259.4+542046.2	18.3	22.8	0.6	**4.2**	**3.8**	2.5	**5.1**	0.9	**3.2**	2.4
ILTJ134500.4+541550.1	14.4	21.9	2.2	2.8	1.6	**3.6**	2.2	1.3	1.6	1.8
ILTJ134746.1+535700.9	14.6	21.2	**4.1**	**3.3**	**4.8**	**3.5**	**6.3**	**3.4**	0.3	2.7
ILTJ134850.4+540409.5	17.7	20.9	2.4	2.6	**3.6**	**5.5**	**9.4**	1.7	1.9	1.2
ILTJ134748.6+533241.6	15.2	19.8	**8.8**	**3.7**	**4.0**	**8.0**	**16.1**	**3.4**	**3.1**	**3.2**
ILTJ134628.6+535710.0	15.0	18.9	1.2	2.2	**5.2**	2.3	**5.0**	0.4	2.6	2.8
ILTJ134753.6+532647.4	11.6	15.9	**5.9**	2.3	**4.5**	**3.9**	**11.8**	1.8	0.0	**4.1**
ILTJ134700.2+534002.1	8.9	15.0	**3.7**	**3.8**	**3.1**	**4.8**	**6.7**	**3.9**	0.0	2.0
ILTJ134832.8+541143.8	12.5	14.5	**3.7**	**5.9**	2.0	2.0	2.0	2.0	**3.3**	1.9
ILTJ134510.4+534642.6	13.5	14.3	1.1	1.6	1.9	0.5	**3.3**	2.9	2.2	0.0
ILTJ135131.6+535855.8	11.8	13.5	**5.2**	1.8	**5.0**	2.8	**8.6**	0.0	1.5	0.1

Bright sources

Number of visible sources per field

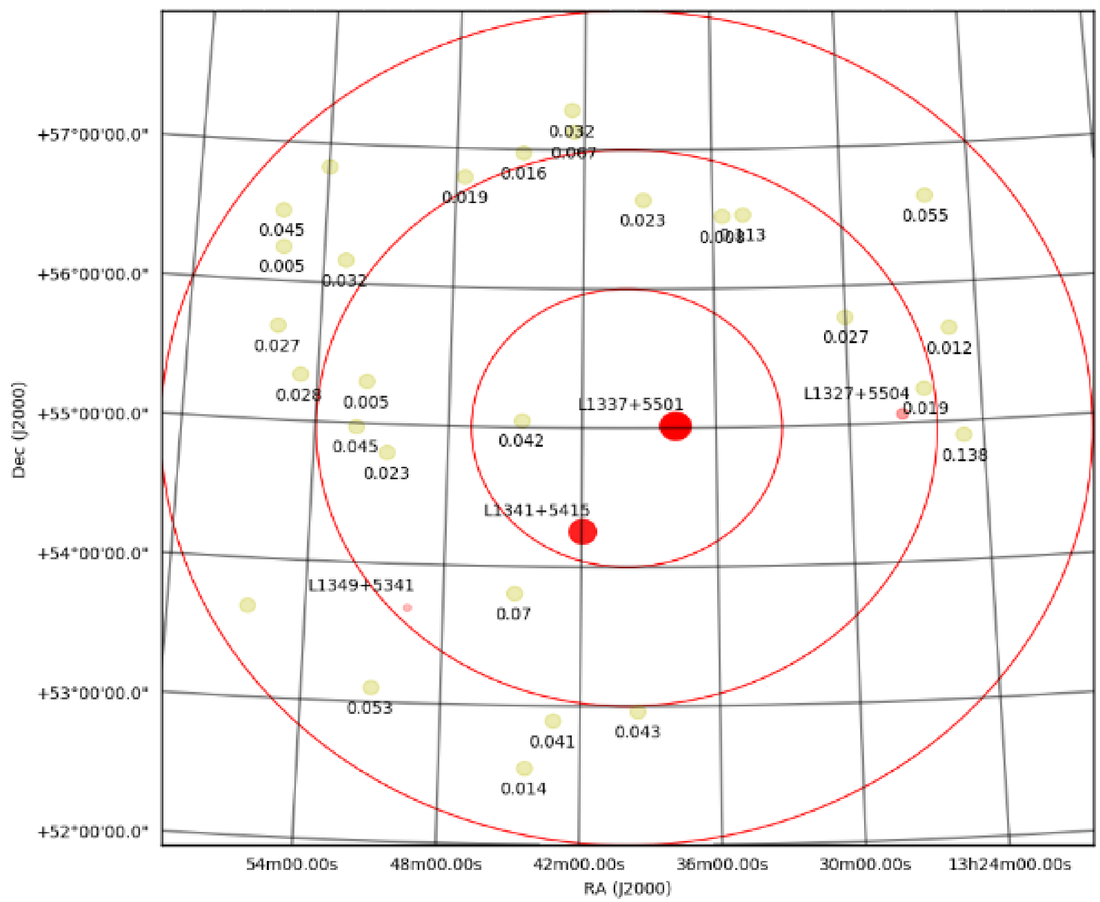
Assess using transformed closure phase measure per station

Likely to see ~50% with 200-km >20mJy

Less (5-10%?) with 800-km

But…..

1) differences e.g. DE601/DE605 in table
   (station calibration?)
2) differences LoTSS/LBCS



Shruti Badole

Current state of pipeline

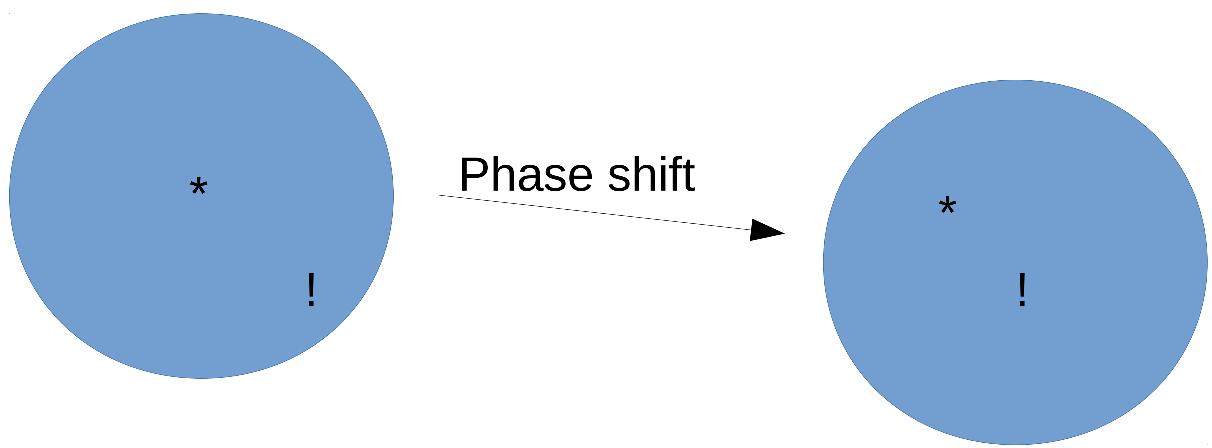
- Existing pipeline makes it relatively easy to calibrate single source in field

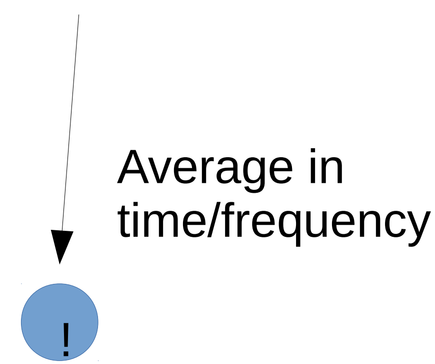
- Being done: propagation of phase solutions through field, either

    - through FACTOR DD calibration (Sweijen/van Weeren)
    - propagating between individual sources in field (as above, Morabito/Mooney/NJ etc).
    - Paper 1 aim end of year!

With long baselines, can use bandwidth and time smearing to your advantage:

Start with wide-field dataset





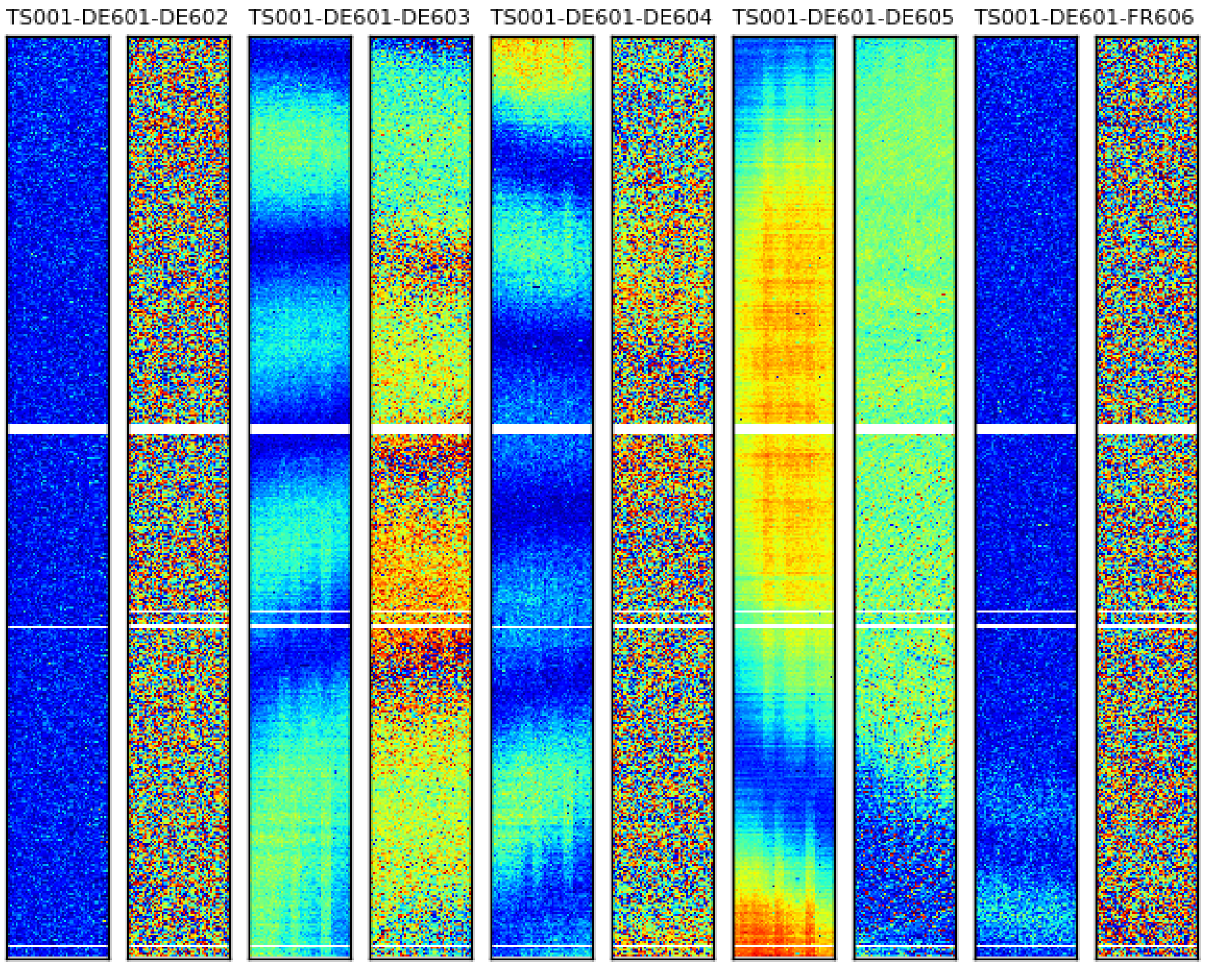
Phase shift dataset to a different position
Then average in time/frequency

2 advantages:
- dataset becomes much smaller
- can isolate sources; here, can map
  source ! without interference from source *

But need to be very careful when averaging – only average over times and frequencies which are coherent! (So if not calibrated = atm. Coherence time / delay length)

1. VLBI imaging problems

c) Final remark: closure phase



UNCALIBRATED DATA!

But with phase 1-2 added to 2-3 added to 3-1

Phase variation effects cancel

Leaves only source information

(Could map using only CP, but this is very hard in practice)

Then propagate phase solutions across field from initial calibrator to bootstrap sources