
LOFAR surveys
Huub Röttgering
Leiden Observatory

International LOFAR Telescope (ILT)

Onsala

Dutch stations

Chilbolton

Norderstedt

LOFAR Core (NL)

Potsdam

Bałdy

Borówiec

Jülich

Effelsberg

Tautenburg

Łazy

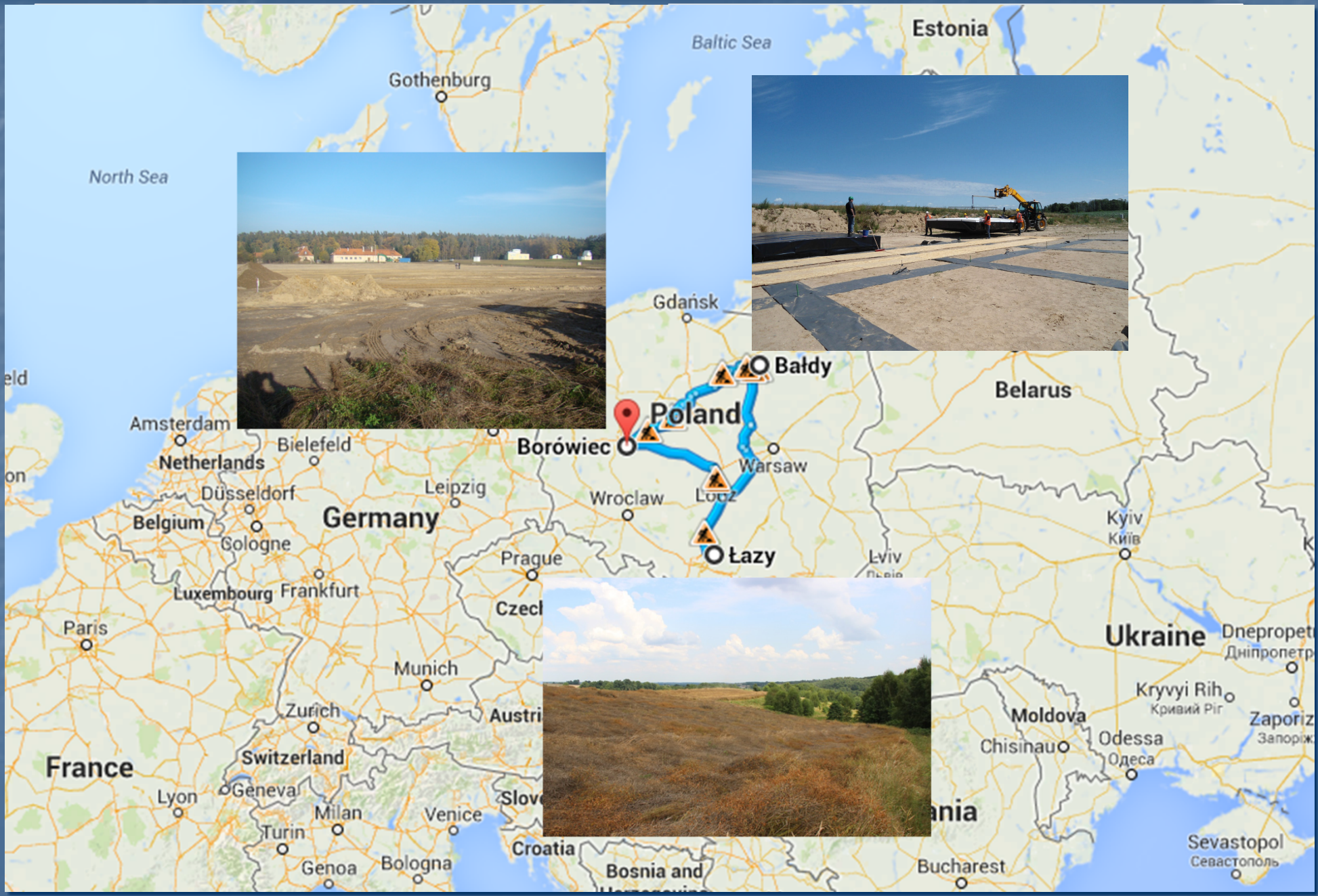
- 47 operational stations completed
- 38 NL stations, 9 international stations
- 3 new stations coming in Poland

Nançay

Unterweilenbach

LOFAR

STATION ROLL OUT: POLAND



LOFAR Survey team

Members Core team Röttgering[12349](Leiden), Barthel[3456](Groningen), Best[12345] (Edinburgh), Brüggen[2] (Bremen), Brunetti[2] (Bologna), Chyży[236] (Kraków), Conway[56t] (Göteborg), Jarvis[1349] (Hertfordshire), Lehnert[36] (Meudon), Miley[1245] (Leiden), Morganti[45] (Dwingeloo), Wise[245] (ASTRON)

Regular members: Haverkorn[8] (ASTRON), Jackson[7] (Manchester), White[38] (Open University), Abdalla[9] (UCL London), Anderson (MPIfR Bonn), Arnaud[2] (Meudon), Bacon[79] (Portsmouth), Beck[6] (Bonn), Beswick[5t6] (Manchester), Brentjens [2] (ASTRON), Britzen[5] (Bonn), Conselice (Nottingham), Croston[2] (Southampton), Dettmar[6] (Bochum), Eales[6] (Cardiff), Edge[2] (Durham), Engels[4] (Hamburg), Enßlin[2] (Garching), Falcke[145] (Nijmegen), Feretti[2] (Bologna), Ferrari[2] (Nice), Franx[3] (Leiden), Garrett[37] (ASTRON), Génova-Santos[1] (IAC), Hardcastle (Hertfordshire), Hendry[9] (Glasgow), Hoeft[2] (Tautenburg), Horellou[256] (Onsala), Isral[6] (Leiden), Ivison[3] (Edinburgh), Jamrozy[45] (Krakow), Kassim[8] (Washington), Kauffmann[4] (Garching), Klein[6] (Bonn), Kuijken[7] (Leiden), Kunert-Bajraszewska[45] (Torun), Lobanov[5] (Bonn), Marecki (Torun), Marti-Vidal[6] (Onsala), Martinez-Sansigre (Portsmouth), McKean[17] (ASTRON), Merloni[45] (Garching), Middelberg[4] (Bochum), Murgia[45] (IAC), Nichol[9] (Portsmouth), Oliver[3] (Sussex), Oosterloo[6] (ASTRON), Otmianowska-Mazur (Krakow), Page[4] (London), Paragi (JIVE), Pentericci[13] (Rome), Percival[9] (Portsmouth), Peters[8] (Washington), Polatidis[5] (ASTRON), Prandoni[34] (IAC), Raychaudhury[2] (Birmingham), Reich[8] (Bonn), Schwarz[9] (Bieleveld), Simpson[14] (Liverpool), Steinmetz[5] (Potsdam), Strom[568] (ASTRON), Tadhunter[5] (Sheffield), Valentijn[26] (Groningen), van der Werf [3] (Leiden), van Driel[6] (Meudon), van Weeren[128] (ASTRON/Leiden), Varenius[6] (Gothenburg), Vink[8] (Amsterdam), White[4] (Garching), Wisotzki[4] (Potsdam), Wucknitz[7] (Bonn), Zarb-Adami[9] (Oxford), Zensus[5] (Bonn)

Postdocs: Asgekar[8] (ASTRON), Bertacca[9] (UWC), Birzan[235] (Leiden), Bonafede[2] (Bremen), Bonfield[9] (Hertfordshire), Cassano[2] (IAC), Deller (ASTRON), Dwelly[3] (Southampton), Faltenbacher[9] (UWC), Heald[6] (ASTRON), Heesen[56] (Hertfordshire), Heywood[9] (Oxford), Johnston[9] (UWC), Kapinska (Portsmouth), Kloeckner[34] (Oxford), Konig (Koln), Macario[2] (Nice), Mahony (ASTRON), Mauch[34] (Oxford), McKay (Chilboton), McKee[1] (Leiden), Oonk[8] (ASTRON), Orru[1235] (Nijmegen), Patel[9] (Portsmouth), Pizzo[2] (ASTRON), Raccanelli[9] (Portsmouth), Rafferty[235] (Leiden), Sabater Montes[4] (Edinburgh), Seymour[1] (Sydney), Smith[9] (Herts), Smith[9] (UWC), Stewart (Bonn), Tasse[4] (Meudon), Tudose (ASTRON), Vaccari[9] (UWC), van Bemmel (ASTRON), Zwart[9] (UWC)

PhDs: Batejat [56] (Gothenburg), De Gasperin[45] (Garching), Deane[3] (Oxford), Drzazga[36] (Krakow), Fielding[4] (Edinburgh), Guglielmino[45] (Bologna), Harwood[5] (Hertfordshire), Heidenreich[2] (Southampton), Israel[3] (Leiden), Junkelwitz[2] (Garching), Jurusik[6] (Krakow), Ker[134] (Edinburgh), Kuligowska[45] (Krakow), Lazell[2] (Birmingham), Lindsay[9] (Hertfordshire), Madhanpall[9] (UWC), McAlpine[9] (UWC), Morabito[1] (Leiden), Natt[8] (Open University), Ogrean[2] (Bremen), Rubart[9] (Bieleveld), Shulevski[5] (Groningen), Stroe[2] (Leiden), Temourian[1] (Hertfordshire), Trasatti[2] (Bonn), van Velzen[1] (Nijmegen), Williams[46] (Leiden).

Science working groups with chairs:

1. High redshift radio galaxies - Miley
2. Galaxy clusters - Brüggen/ Brunetti
3. Cosmic Star-Formation - Lehnert/ Barthel
4. AGN and black hole evolution - Best
5. Physics of nearby AGN - Morganti
6. Nearby galaxies - Conway/ Chyży
7. Strong lensing - Jackson
8. The Galactic plane - Haverkorn/ White
9. Cosmology - Jarvis/ Bacon

Imaging Tigre team (ASTRON)

Heald, Dijkema, van der Tol, Vilchez,Frohlich, Orru Toribito, Rafferty (Bremen), Shimwell (Leiden)

Facet Calibration

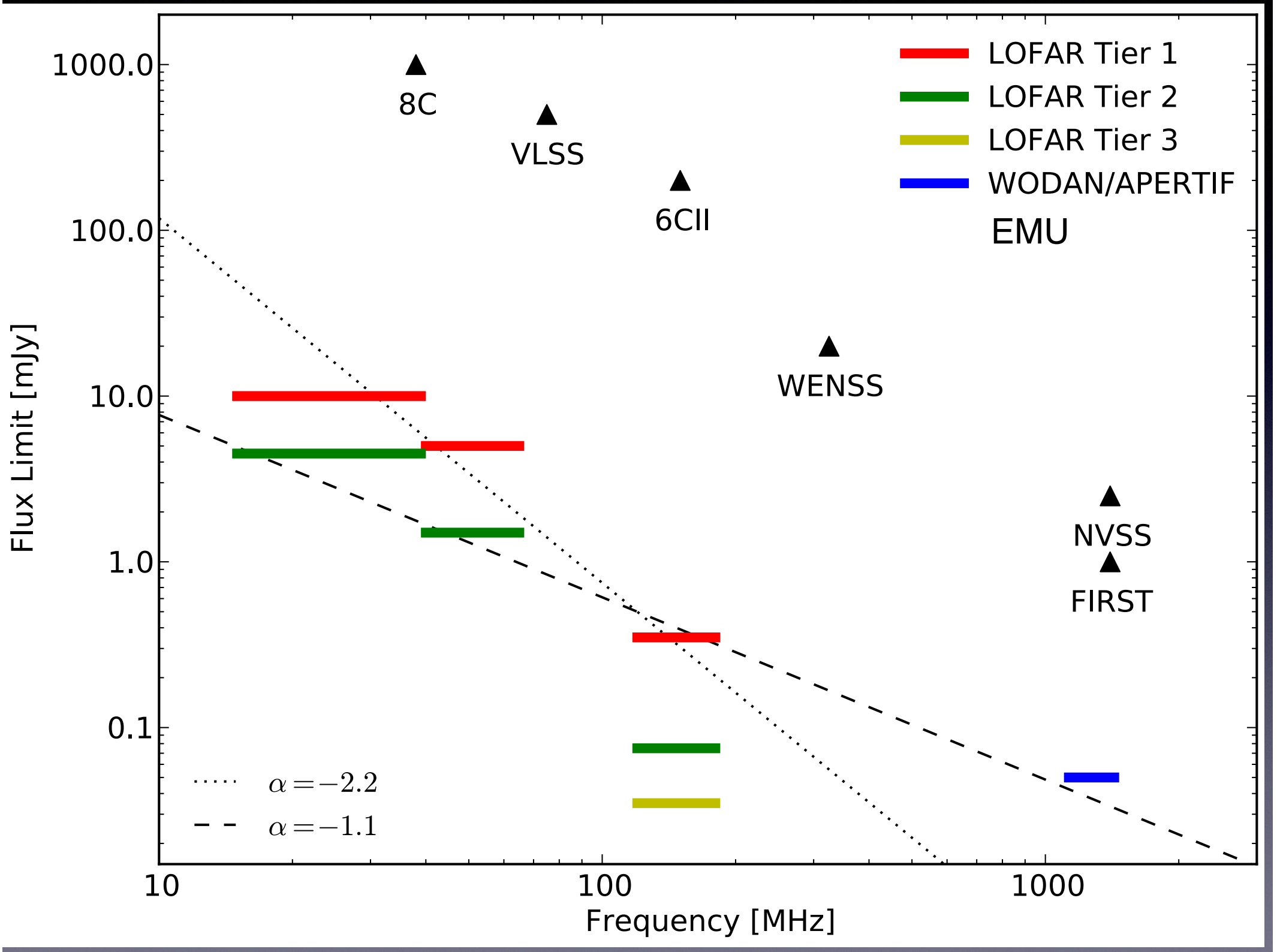
van Weeren, Williams, Shimwell, De Gasperin, Sabater, Hardcastle, Morabito et al.

Why LOFAR surveys?

- Enormous legacy value:
  - 3 × 10^7 radio sources
    - 100,000 clusters, 10^7 starbursting galaxies at z > 1 and virtually all radio-loud AGN in the Universe
- Hunting ground for rare sources
  - z>7 radio galaxies, luminous z>7 starbursts, massive protoclusters, giant radio galaxies, double double radio
- Cosmological studies
  - baryonic oscillations, the integrated Sachs-Wolfe effect, clustering of matter on > 10 Mpc scales
- Complete view of the Galaxy
  - Supernova remnants and HII regions
  - strength and topology of the magnetic fields on the largest Galactic scales.
- Beauty

Surveying the radio sky
15-45, 45-65, 120-180 MHz

1. The highest redshift radio sources - George Miley: ~100 at z>6
2. Starforming galaxies - Lehnert/Barthel: 100 protoclusters at z>2
4. AGN at moderate redshifts - Philip Best
3. Clusters and cluster halo sources - Brüggen/Brunetti: 100 @ z>0.6; 60 nearby clusters
5. Gravitational lensing - Neal Jackson
6. Detailed studies of low-redshift AGN - Raffaella Morganti
6. Nearby galaxies - John Conway/Krzysztof Chyzi
7 Cosmological studies - Matt Jarvis/David Bacon
8. Galactic radio sources – Marijke Haverkorn Glenn White


LOFAR Tier 1
LOFAR Tier 2
LOFAR Tier 3
WODAN/APERTIF
EMU
8C
VLSS
6CII
WENSS
NVSS
FIRST
$\alpha = -2.2$
$\alpha = -1.1$
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Frequency [MHz]
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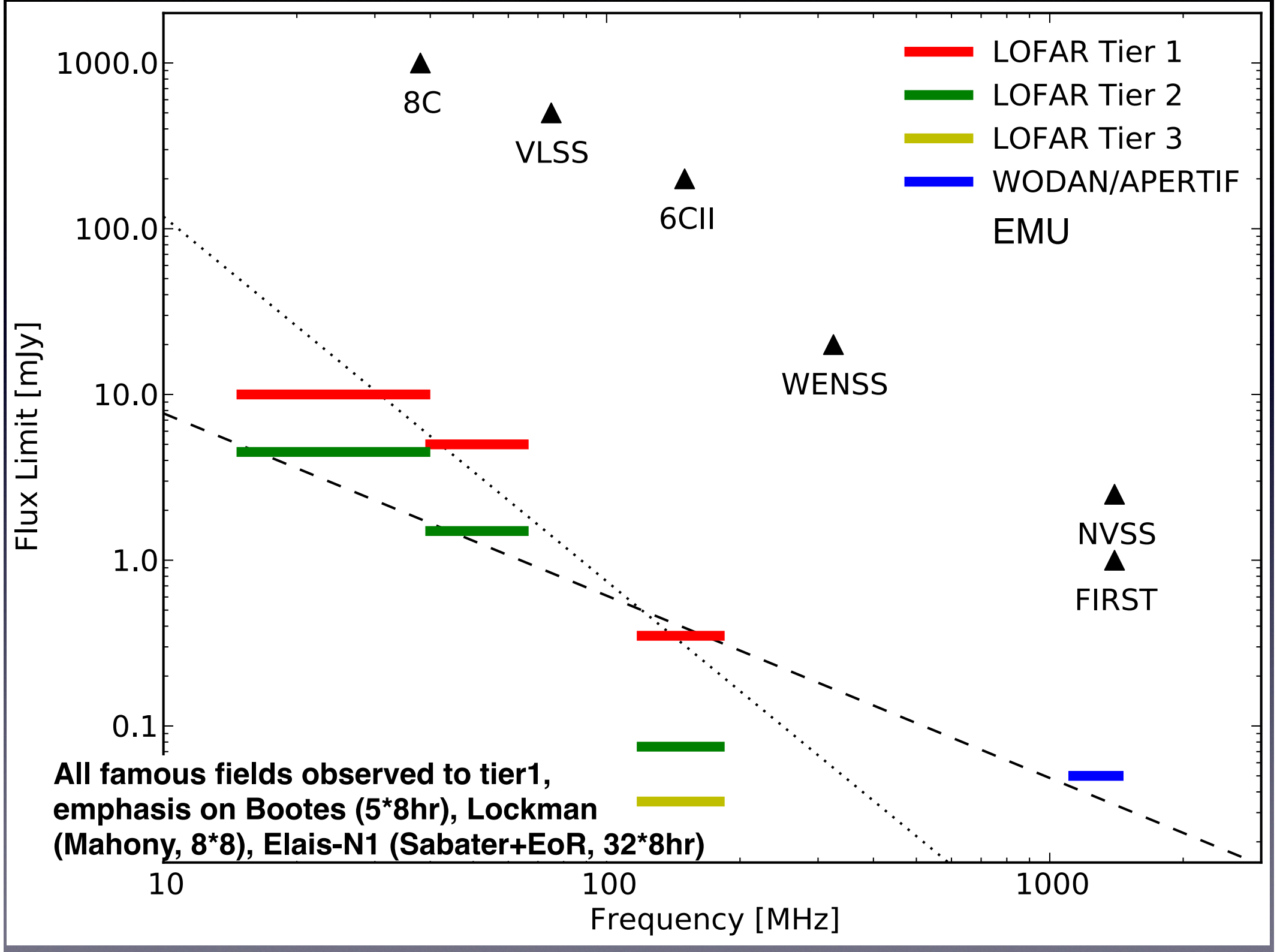
10.0
1.0
0.1
10
100
1000


LOFAR Tier 1
LOFAR Tier 2
LOFAR Tier 3
WODAN/APERTIF
EMU
8C
VLSS
6CII
WENSS
NVSS
FIRST
1000.0
100.0
10.0
1.0
0.1
Flux Limit [mJy]
10
100
1000
Frequency [MHz]
All famous fields observed to tier1,
emphasis on Bootes (5*8hr), Lockman
(Mahony, 8*8), Elais-N1 (Sabater+EoR, 32*8hr)

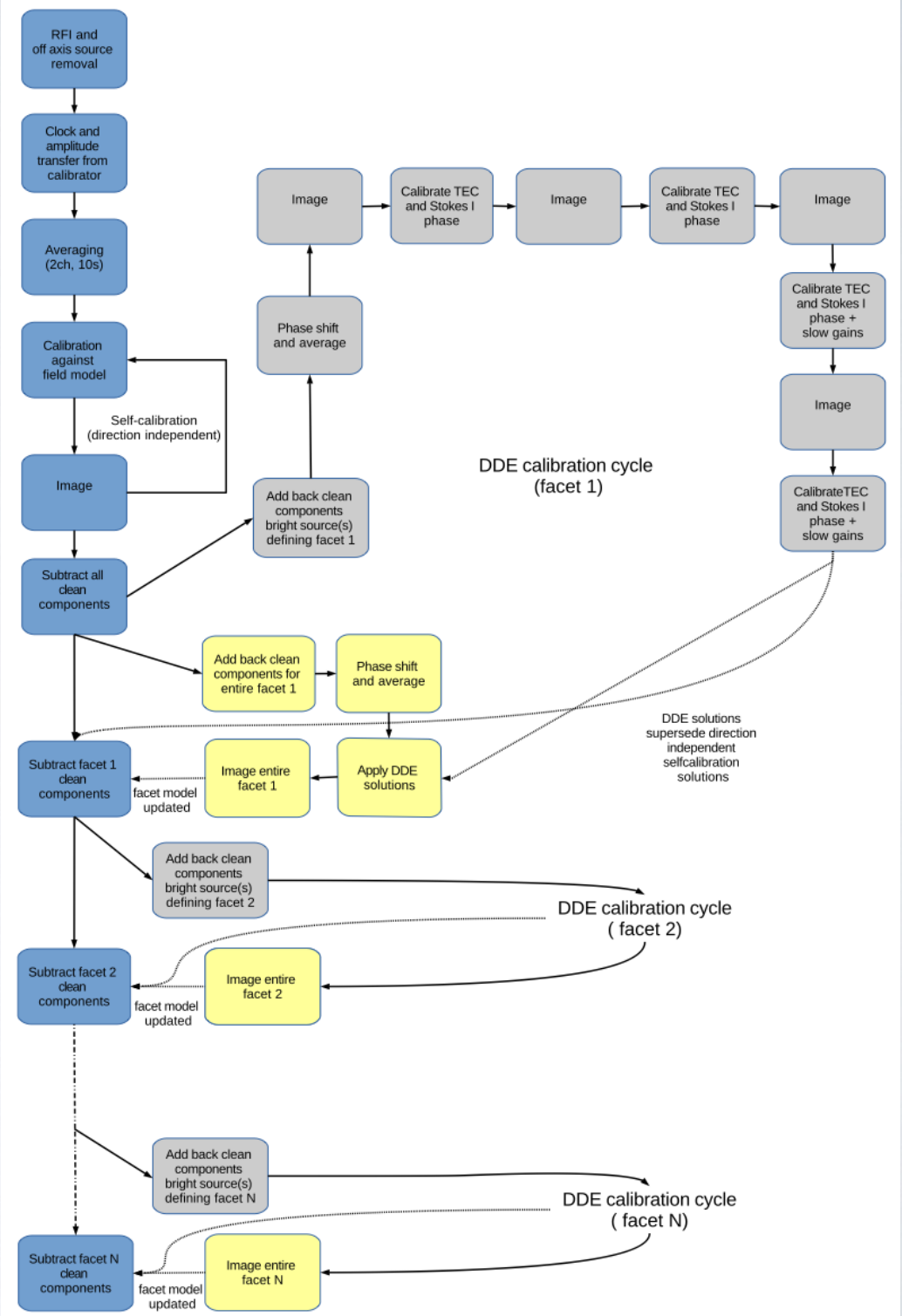
FACET CALIBRATION

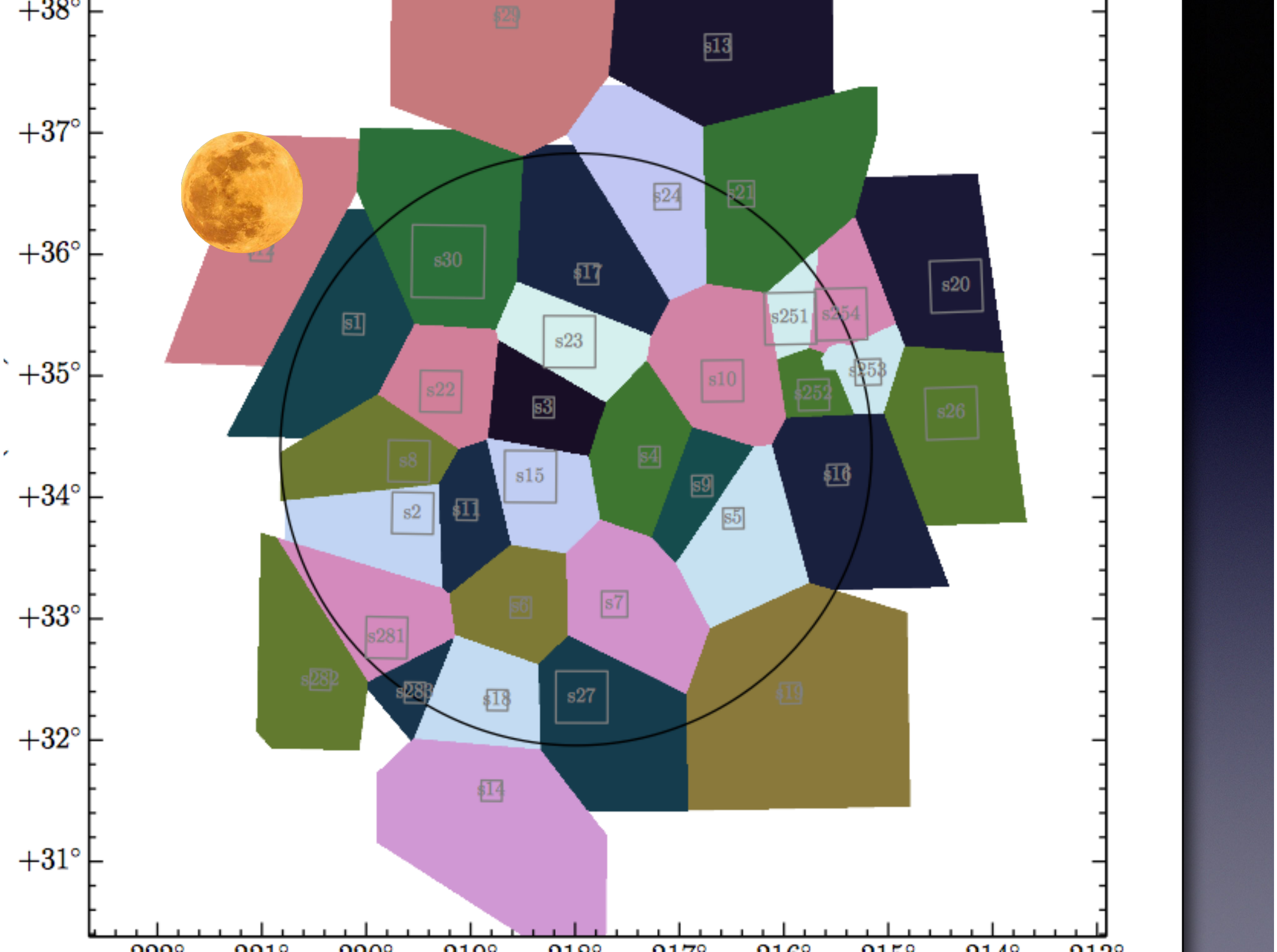
- Subtract all sources from data
- Define facet centers

- Add back central source(s) defining facet
- Phase shift + average
- *DDE self-calibration Cycle*

- Add back all sources in facet
- Correct with solutions
- Image
- Subtract updated facet model with solutions

loop over facet




+38°
+37°
+36°
+35°
+34°
+33°
+32°
+31°
s29
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s21
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s20
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s251
s254
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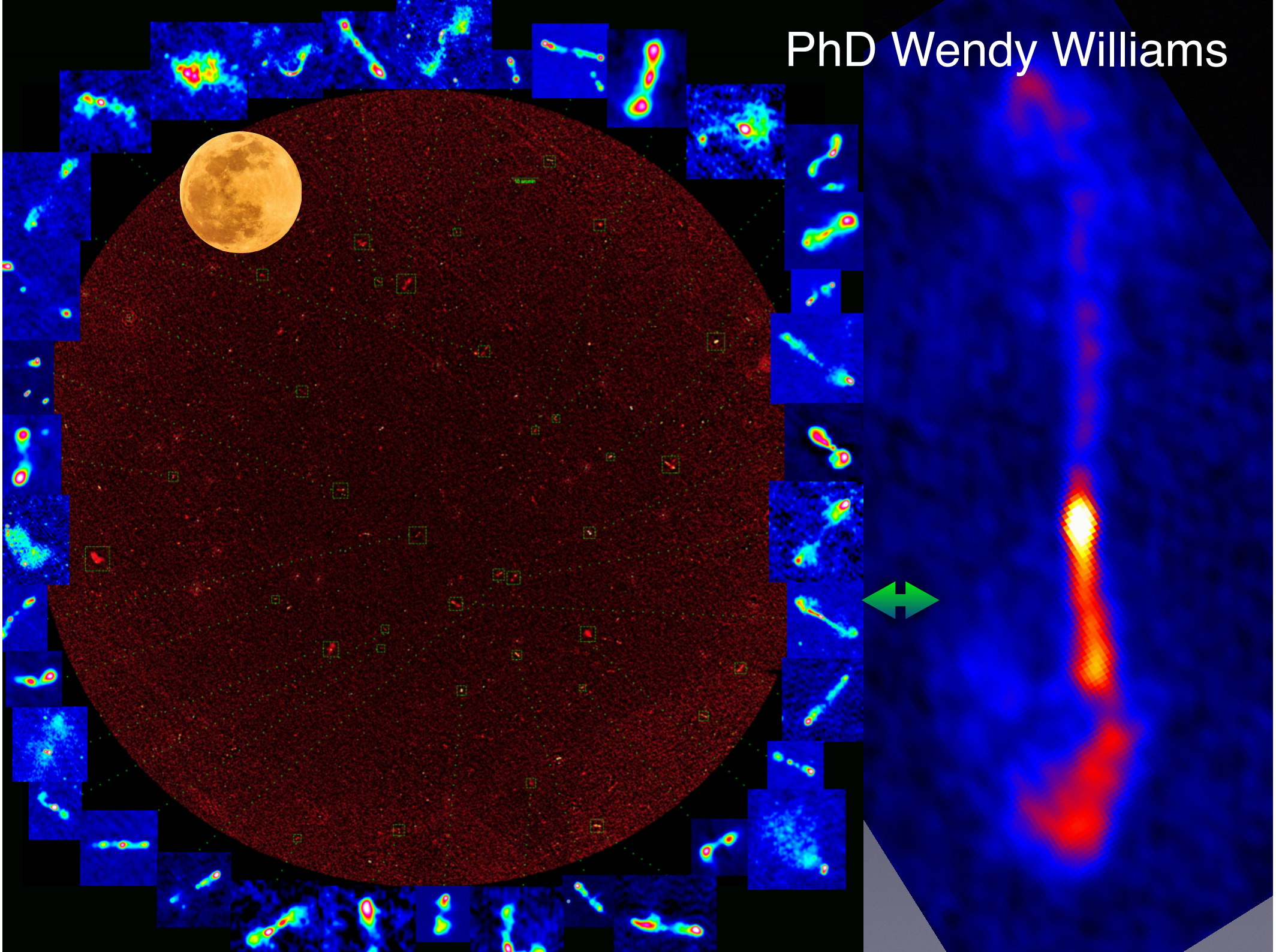
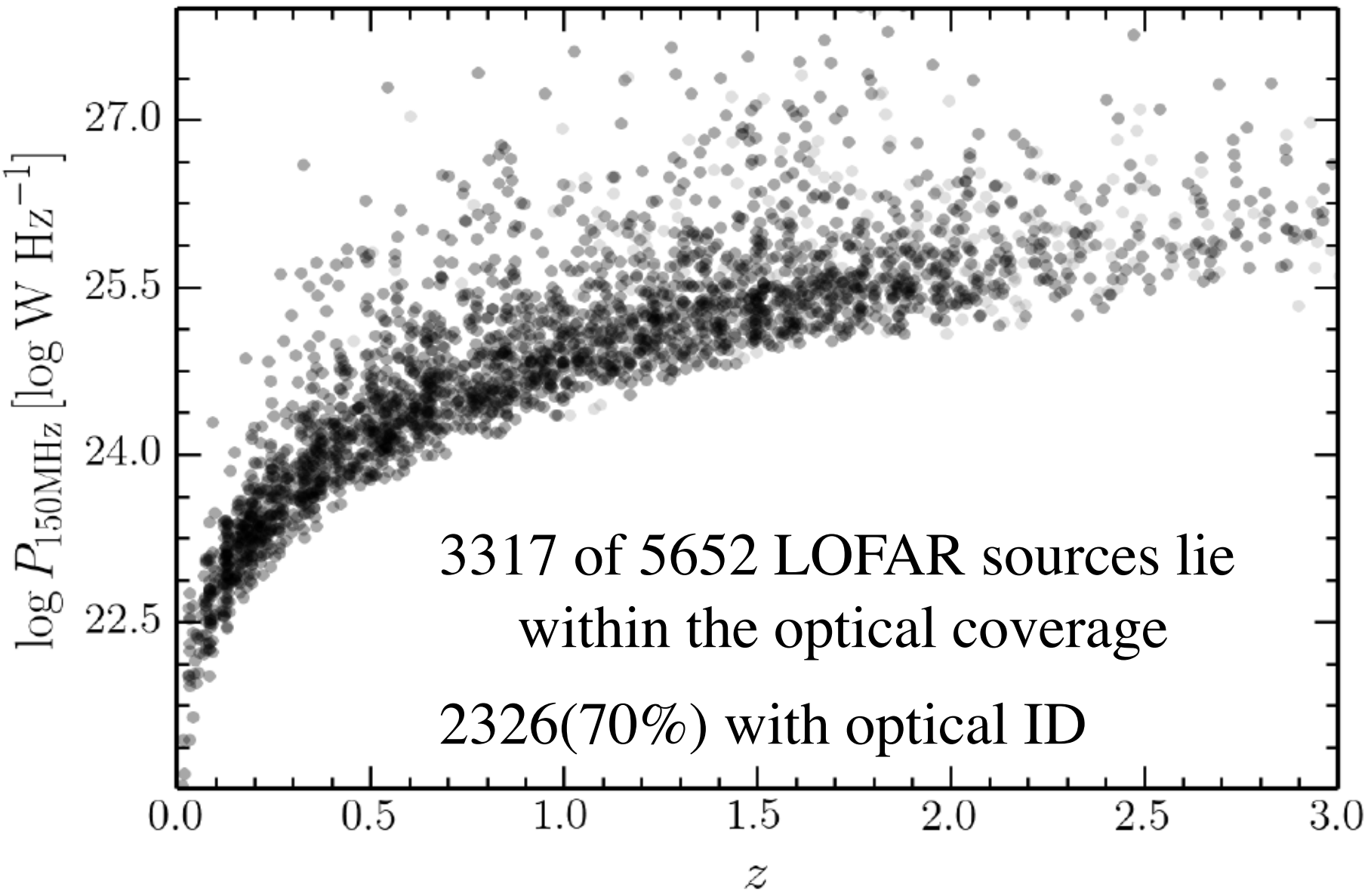
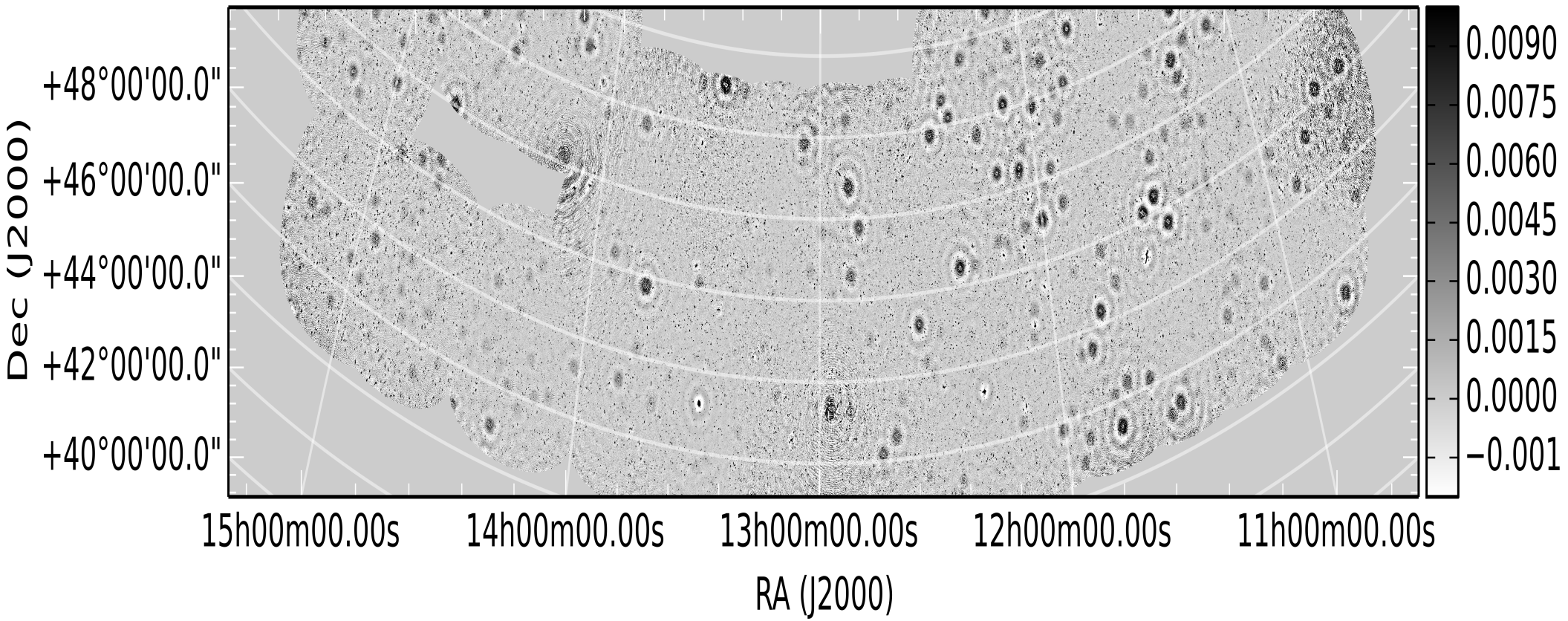
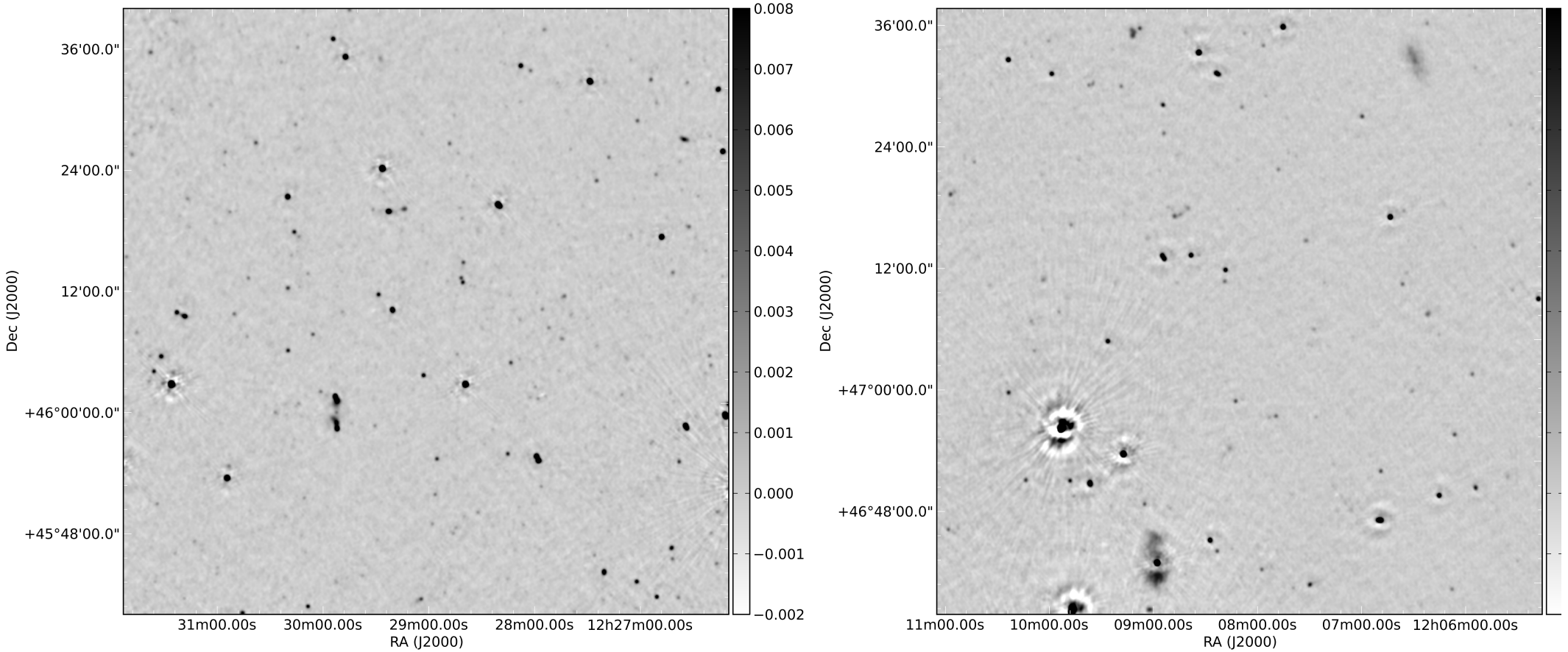

PhD Wendy Williams

Radio-power vs Redshift



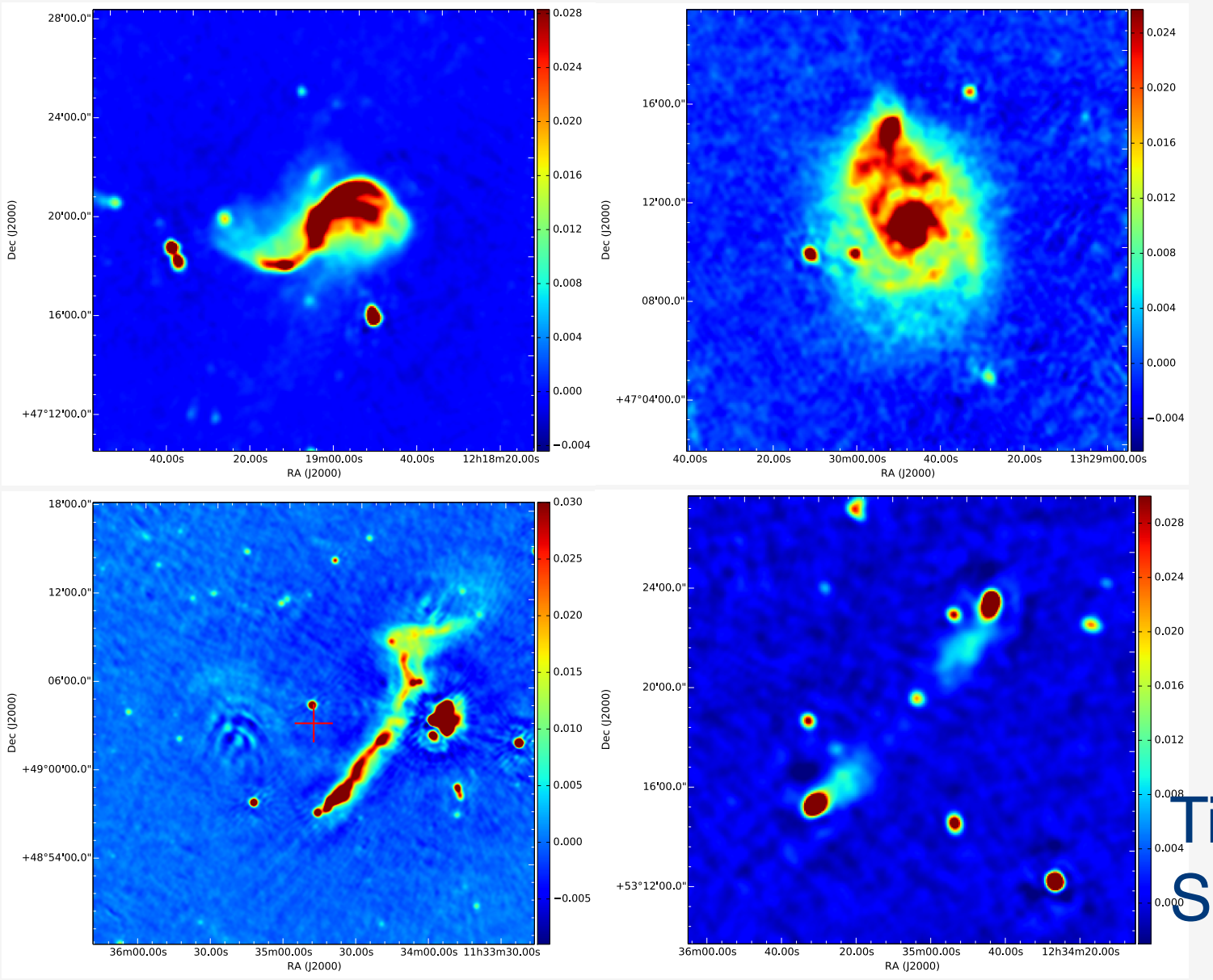


A HBA mosaic of 55 Cycle 2 and Cycle 3 pointings that covers approximately 600 square degrees. The resolution of the images is ≈20" and the rms noise level in regions away from bright sources is 200-500μJy/beam.



Two example degree square regions from the mosaiced image.

- Cycle4-6: We aim to complete a 4200 deg2 region (568 pointings) that overlaps with both the FIRST and SDSS surveys (7.5 < RA < 17.5 hrs, 25 < Dec < 65 deg)

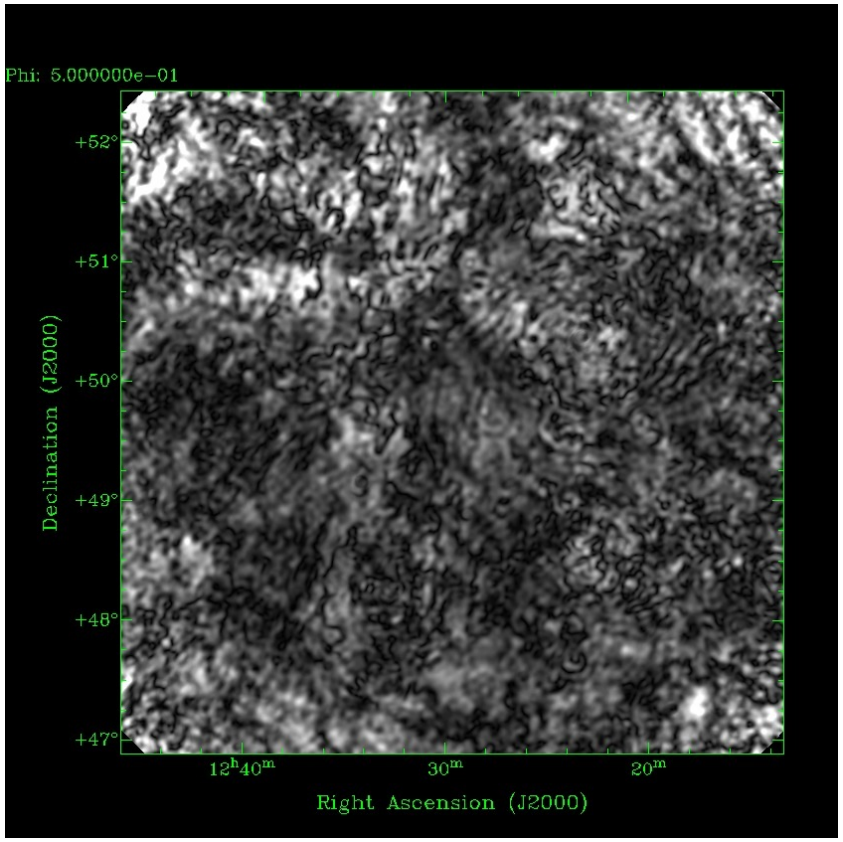


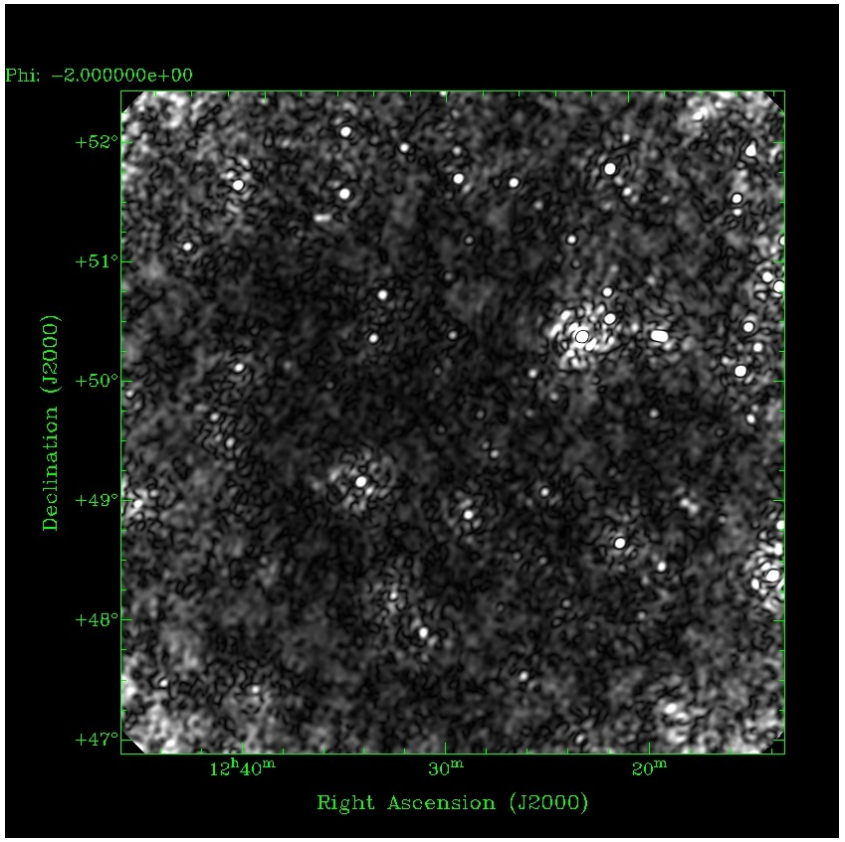
Tim Shimwell

Clockwise from top left: NGC 4258, NGC 5194, NGC 4517, Abell 1314

MKSP/SKSP shared project: Tier1 HBA Polarimetry

Two example Faraday slices in Tier1 field #26:





"Good" slice at Faraday depth +0.5 rad m^{-2}: clear diffuse polarized structure

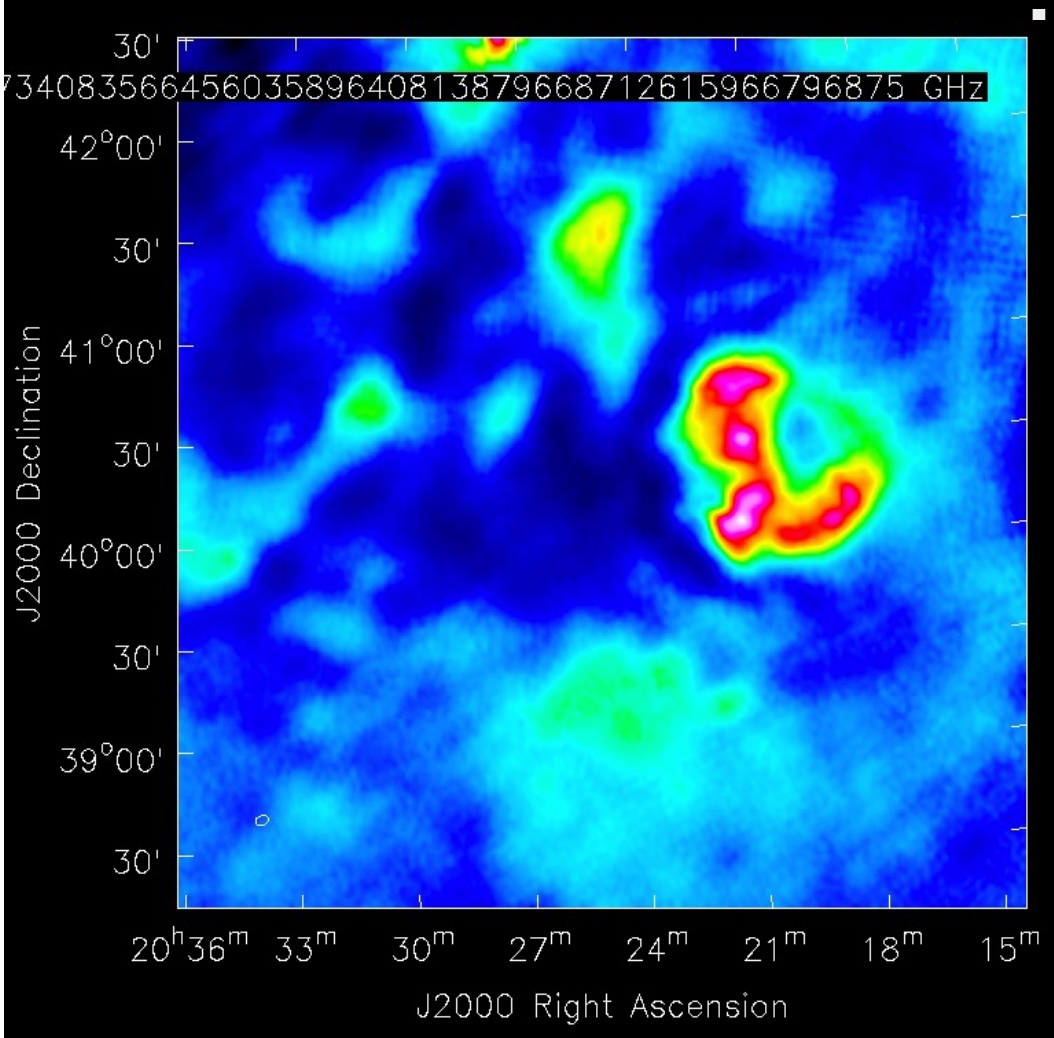
"Bad" slice at Faraday depth -2 rad m^{-2}: dominated by instrumental polarization in and around point sources

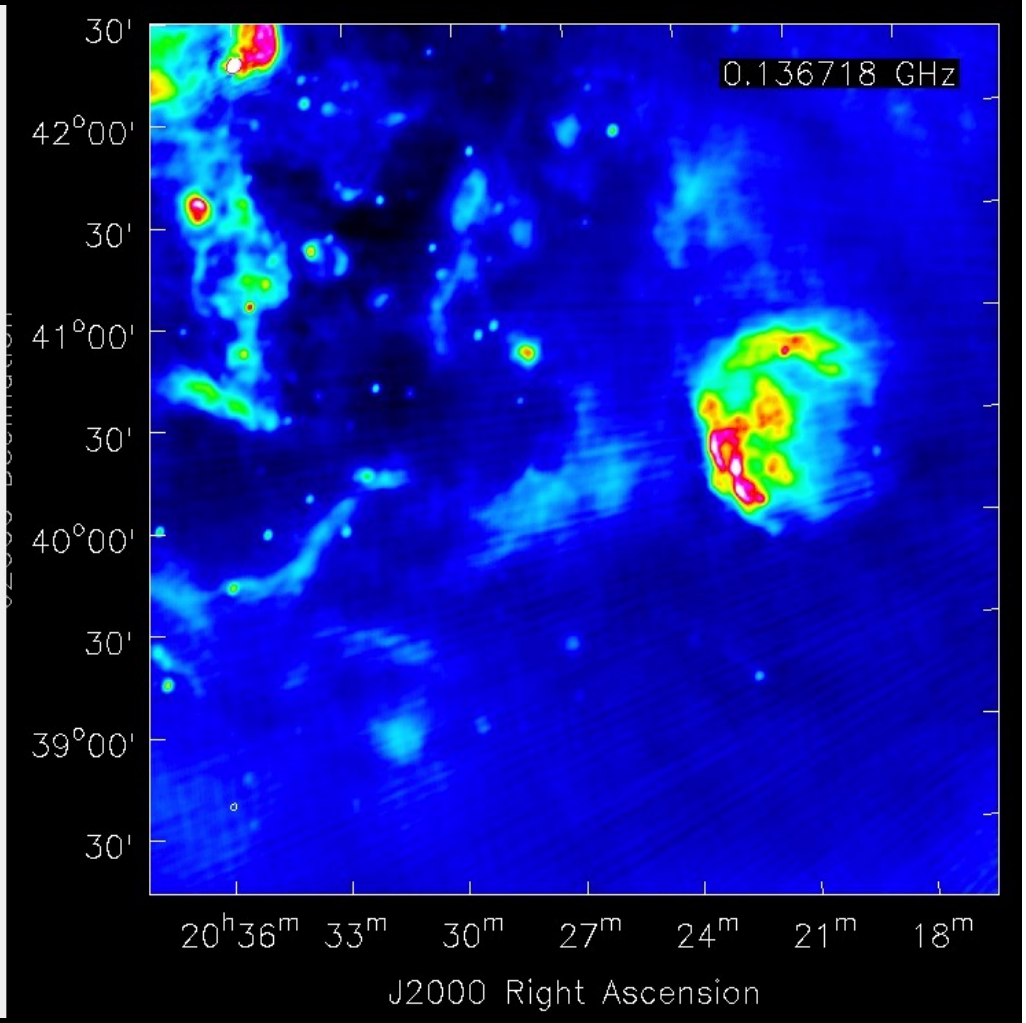
Haverkorn et al.

CYGNUS X

LBA

HBA

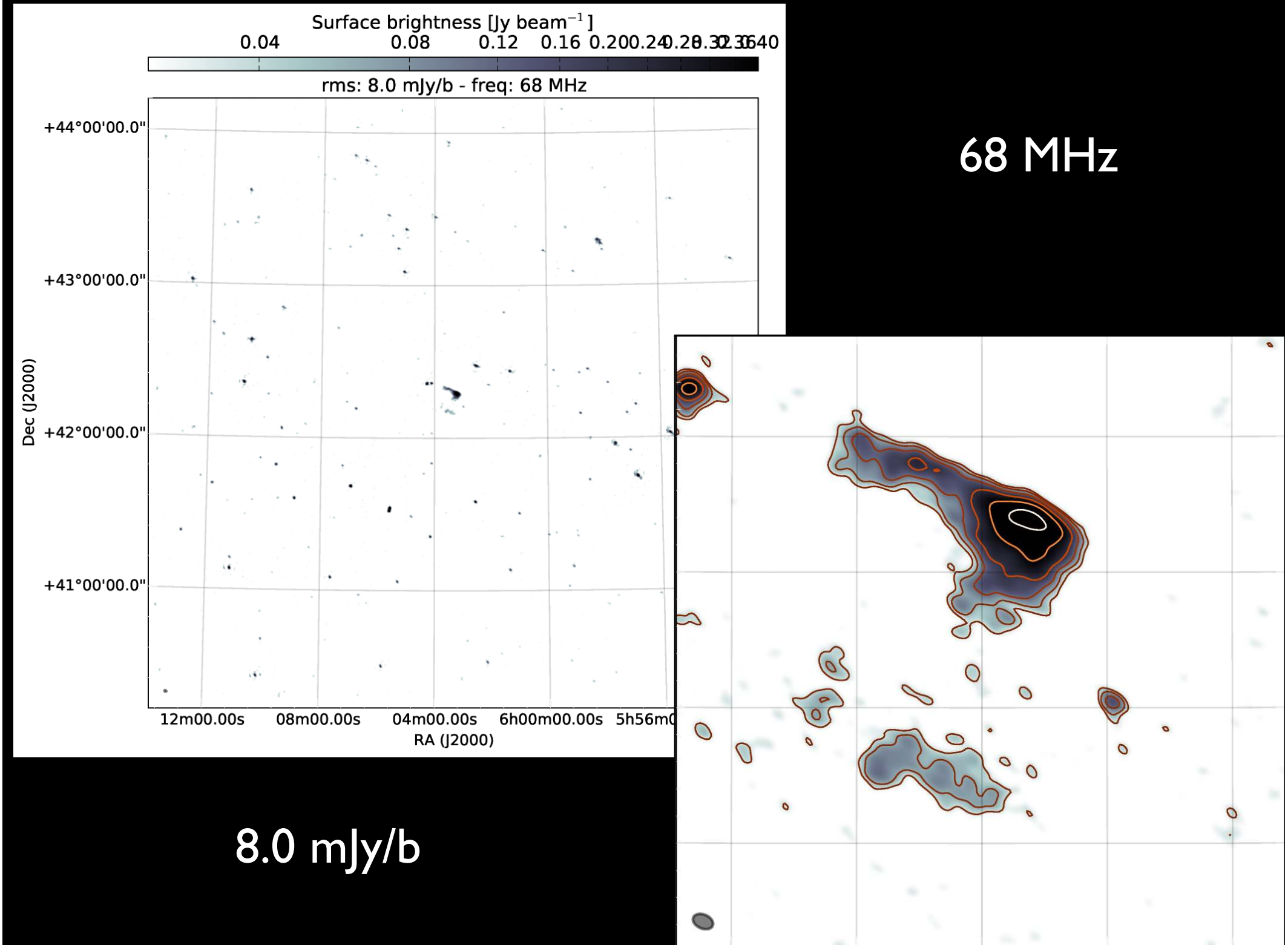


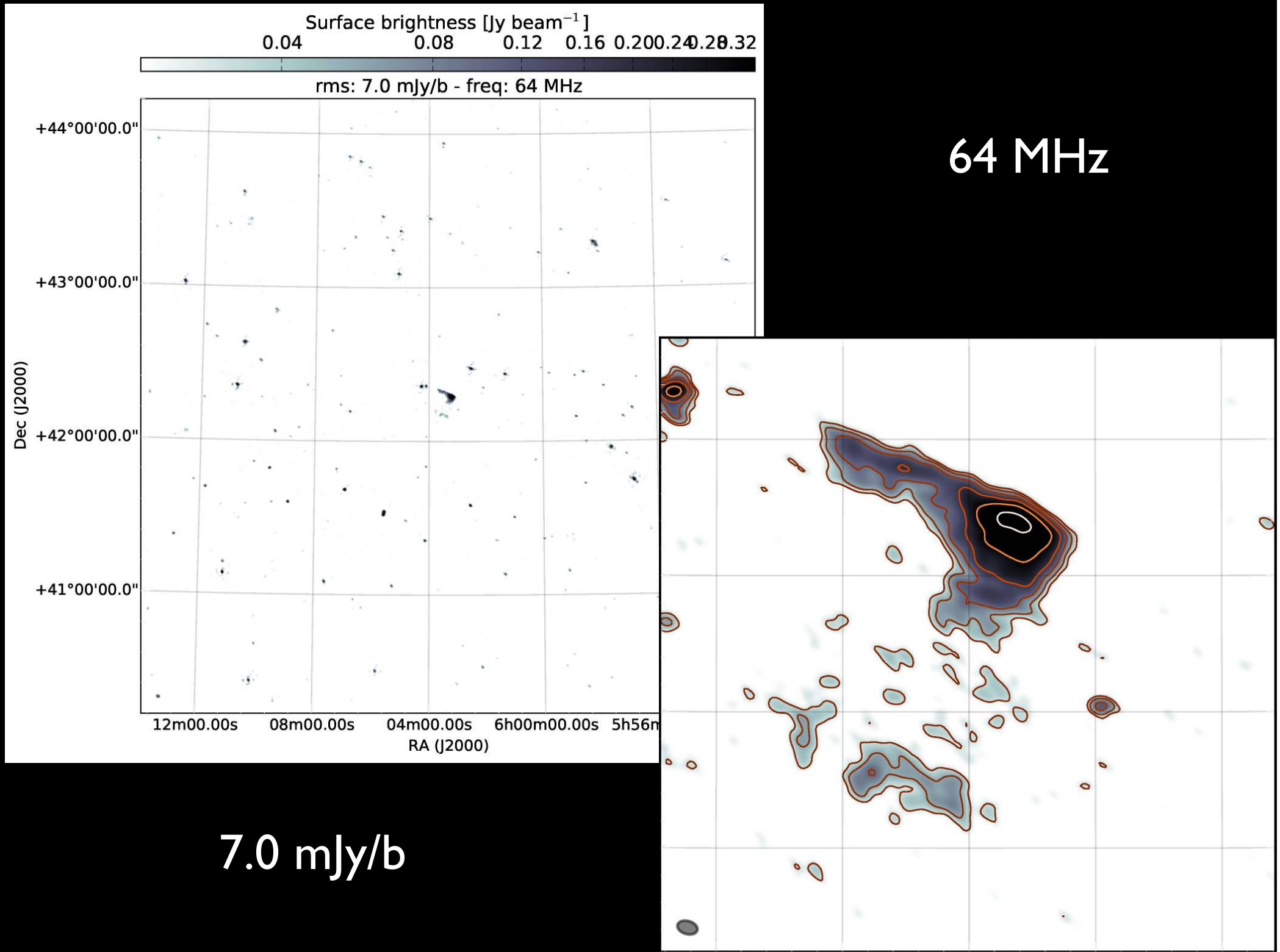


Glenn White

What about LBA?

Francesco de Gasperin


Surface brightness [Jy beam^{-1}]
0.04
0.08
0.12
0.16
0.20
0.24
rms: 8.0 mJy/b - freq: 68 MHz
+44°00'00.0"
+43°00'00.0"
+42°00'00.0"
+41°00'00.0"
Dec (J2000)
12m00.00s
08m00.00s
04m00.00s
6h00m00.00s
RA (J2000)
68 MHz
8.0 mJy/b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0.12
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0.20
0.24
0.28
0.32
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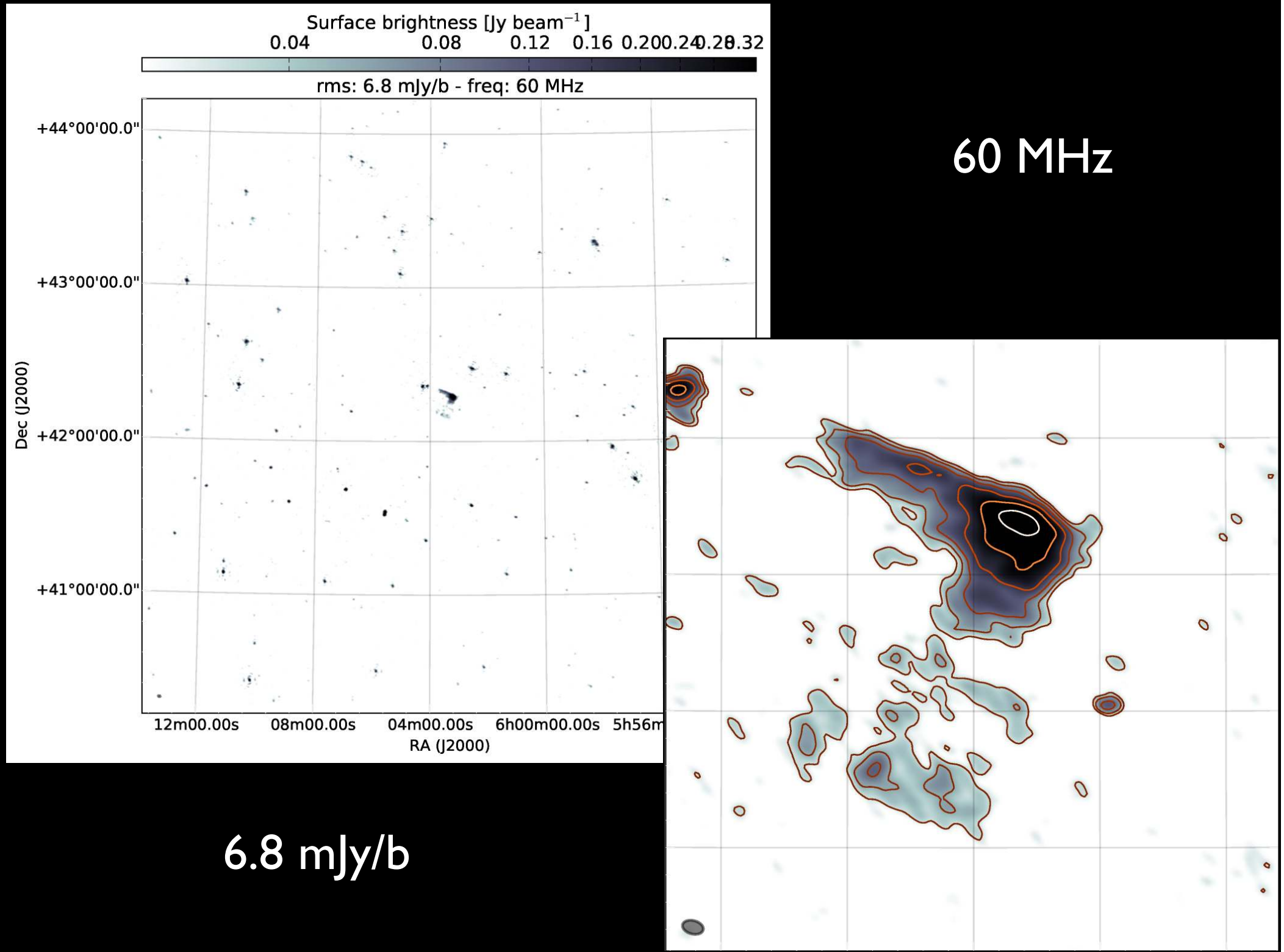
+44°00'00.0"
+43°00'00.0"
+42°00'00.0"
+41°00'00.0"
Dec (J2000)
12m00.00s
08m00.00s
04m00.00s
6h00m00.00s
5h56m
RA (J2000)
64 MHz
7.0 mJy/b


Surface brightness [Jy beam^{-1}]
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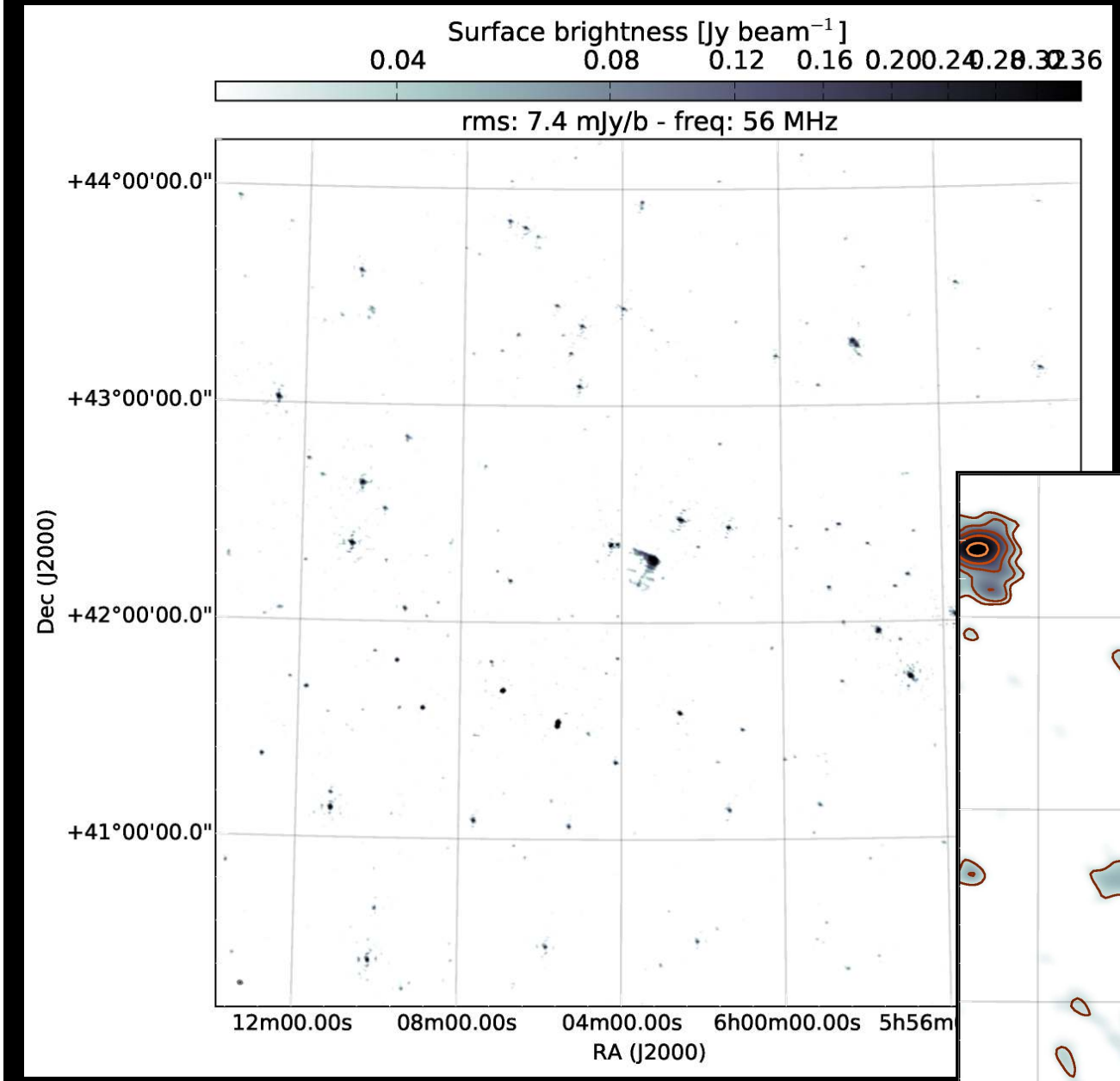
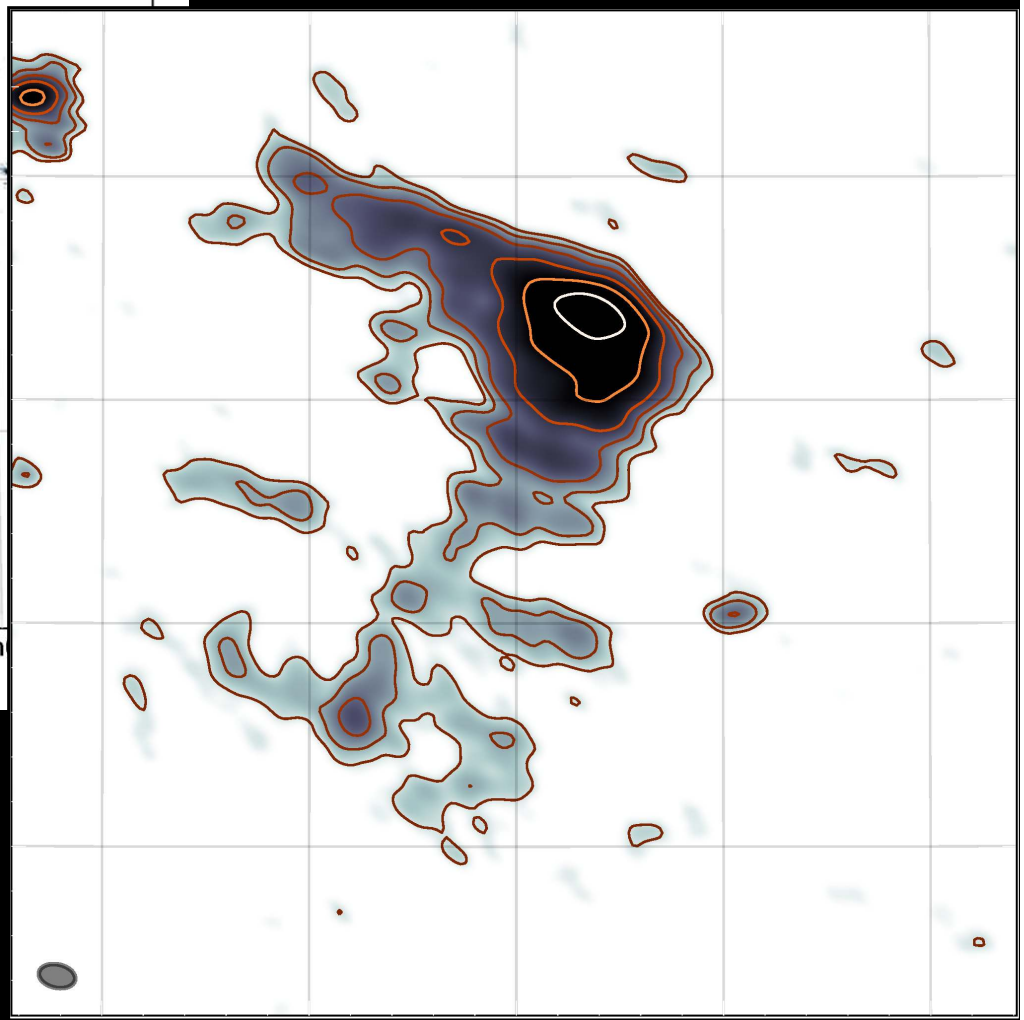
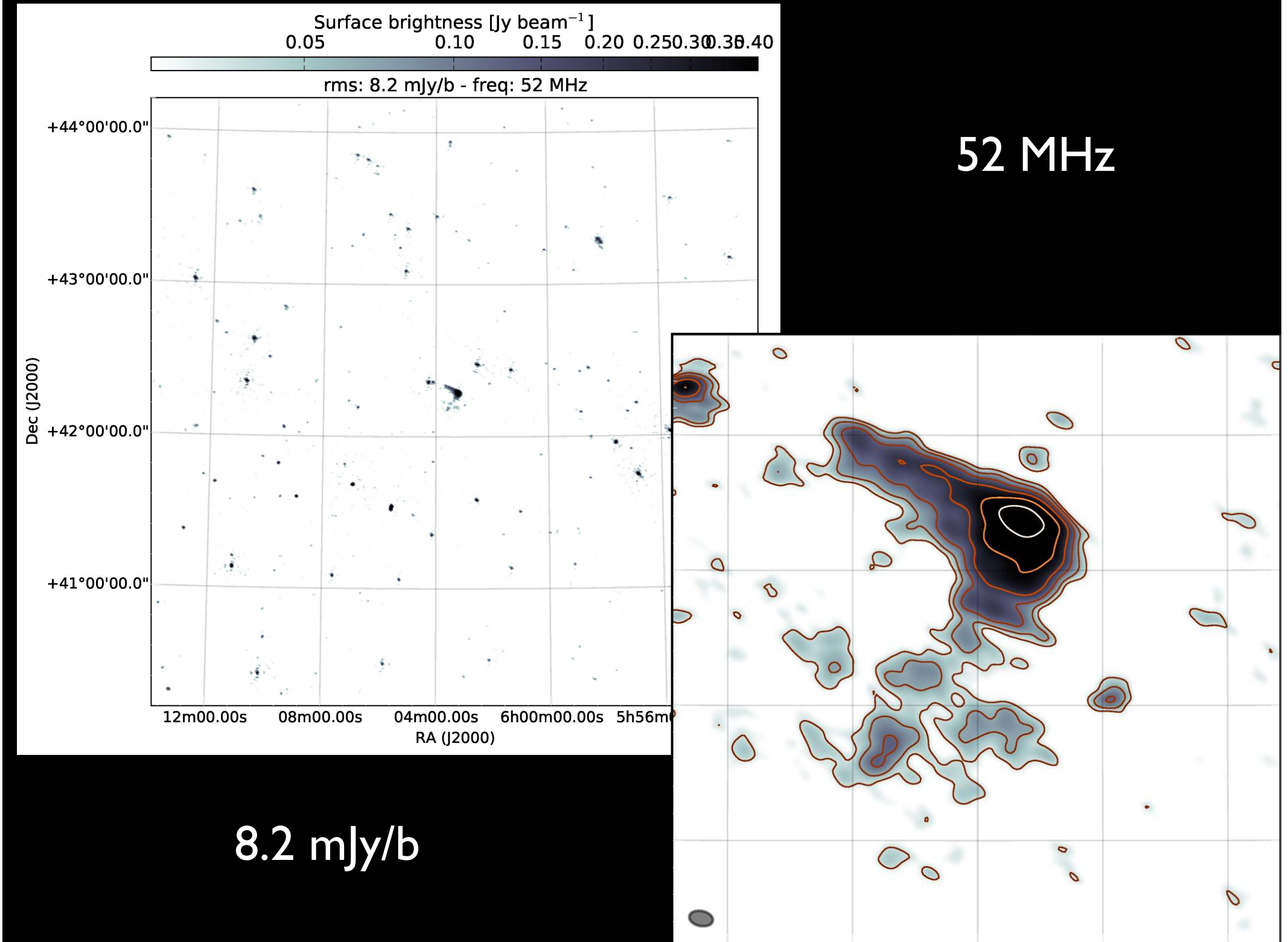
rms: 6.8 mJy/b - freq: 60 MHz
+44°00'00.0"
+43°00'00.0"
+42°00'00.0"
+41°00'00.0"
Dec (J2000)
12m00.00s
08m00.00s
04m00.00s
6h00m00.00s
5h56m
RA (J2000)
60 MHz
6.8 mJy/b



56 MHz



7.4 mJy/b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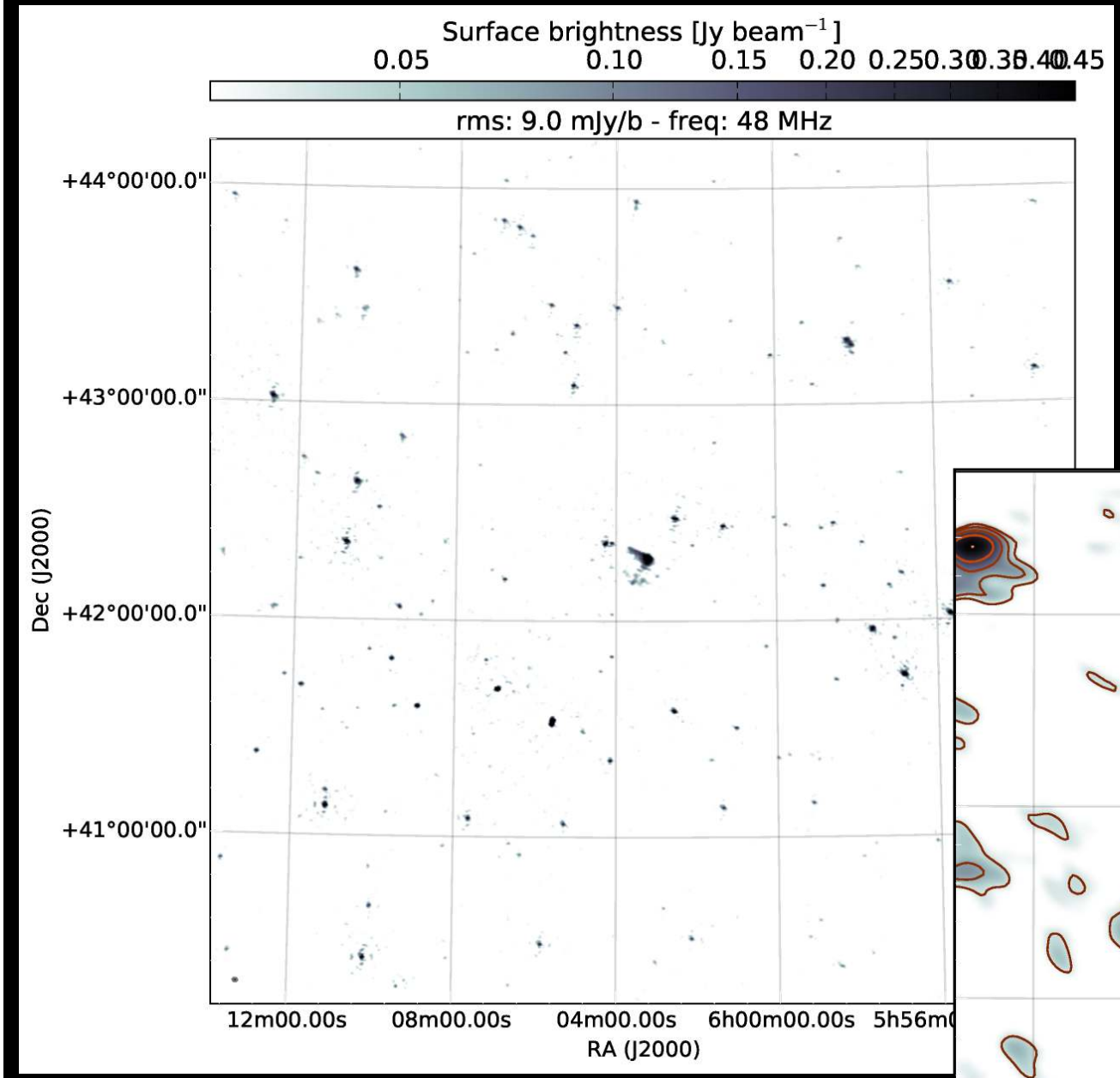
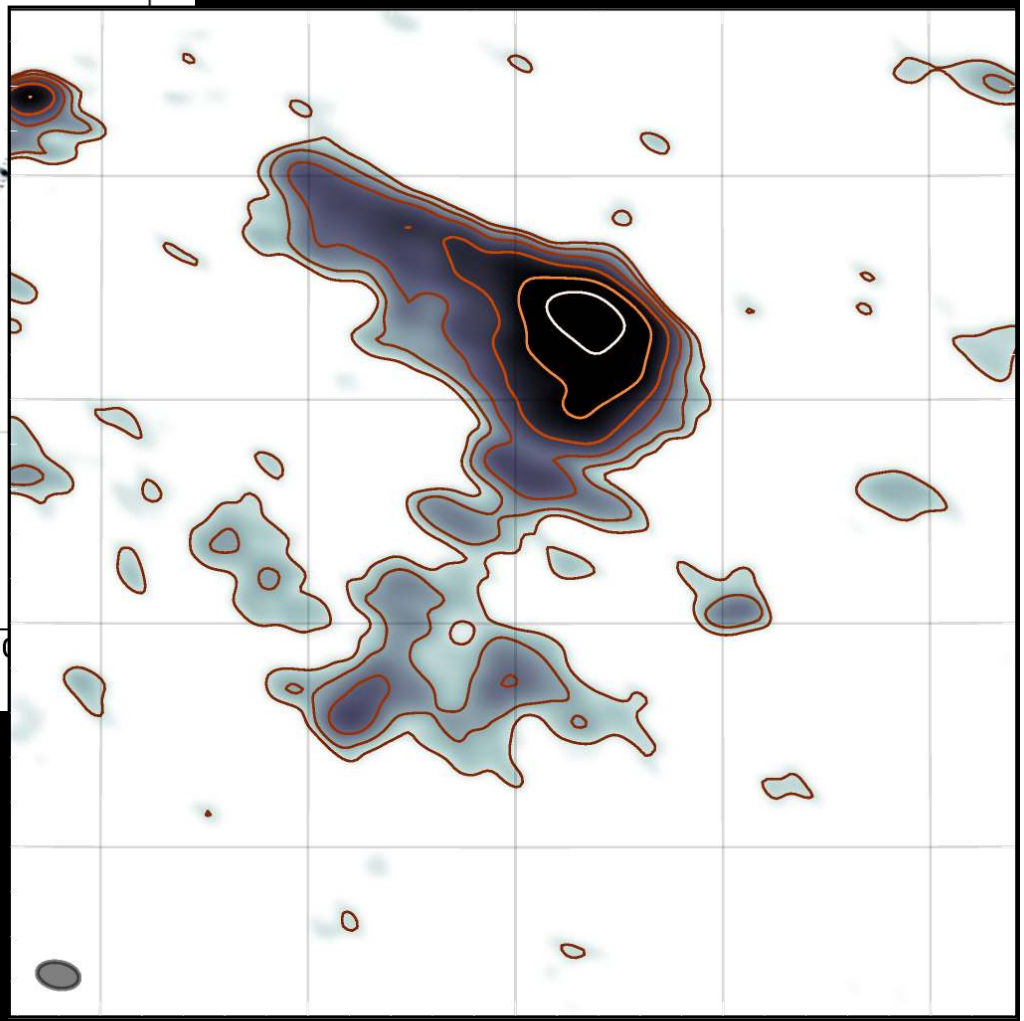
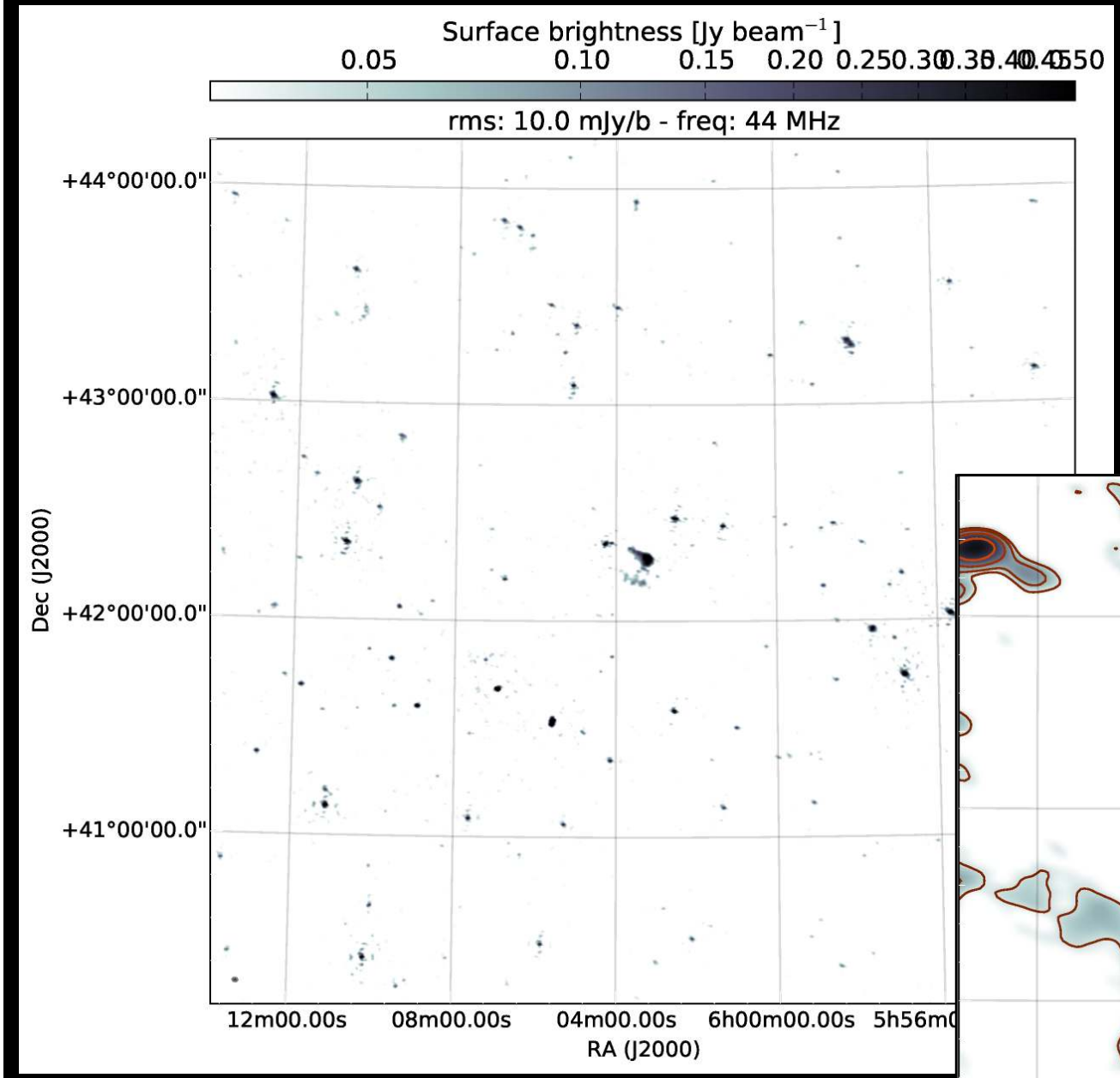
0.15
0.20
0.25
0.30
0.35
0.40
rms: 8.2 mJy/b - freq: 52 MHz
+44°00'00.0"
+43°00'00.0"
+42°00'00.0"
+41°00'00.0"
Dec (J2000)
12m00.00s
08m00.00s
04m00.00s
6h00m00.00s
5h56m
RA (J2000)
52 MHz
8.2 mJy/b



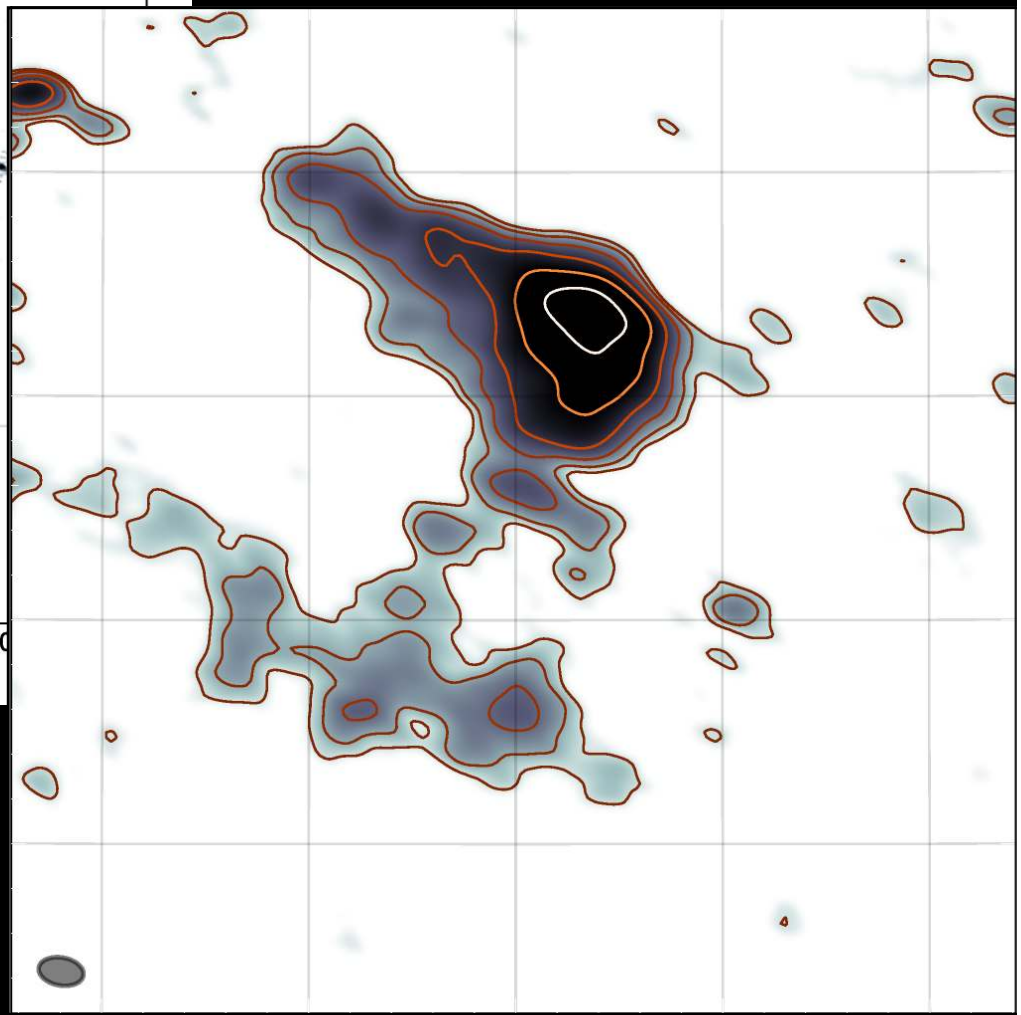
48 MHz



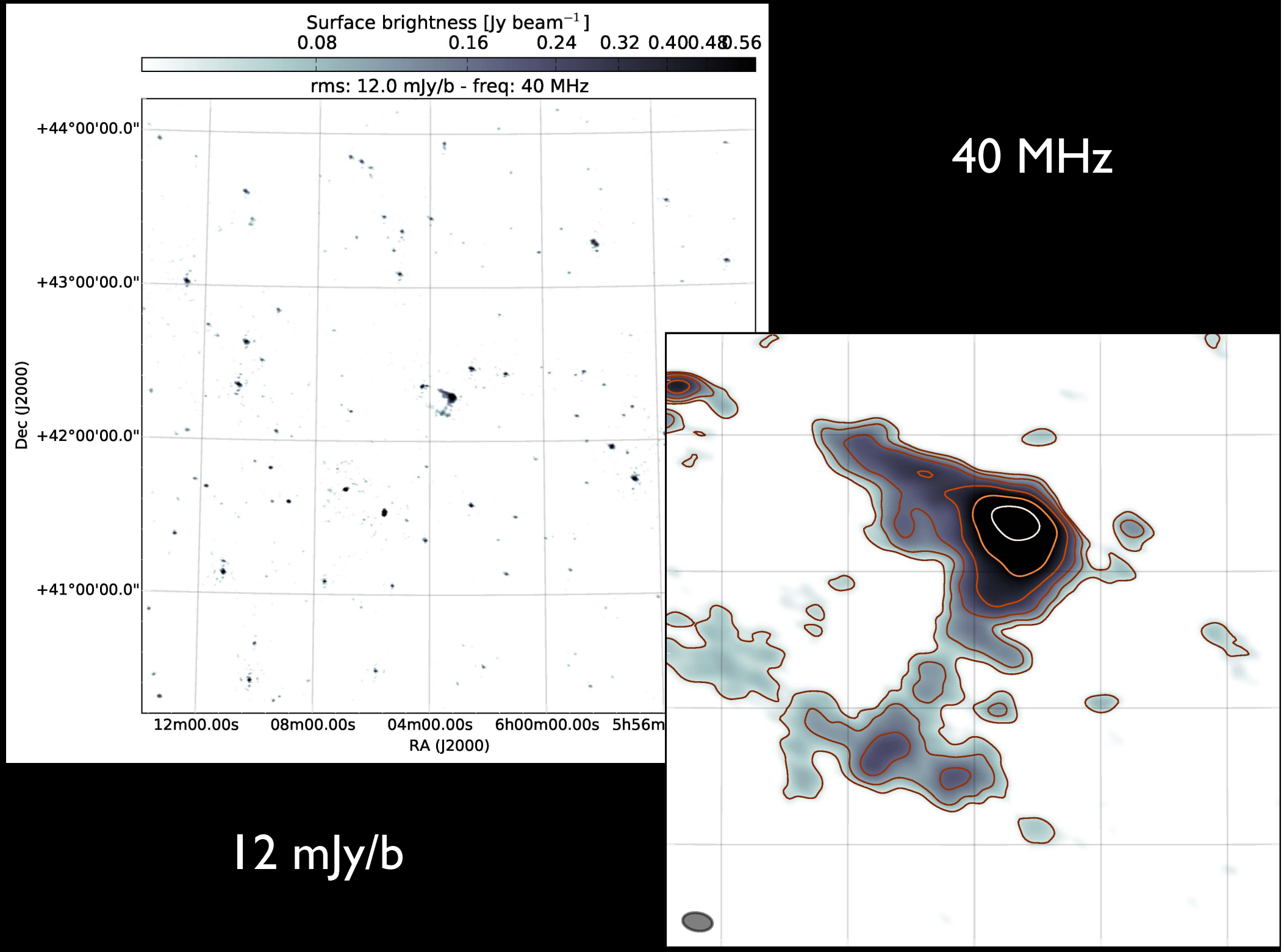
9.0 mJy/b



44 MHz



10 mJy/b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0.24
0.32
0.40
0.48
0.56
rms: 12.0 mJy/b - freq: 40 MHz
+44°00'00.0"
+43°00'00.0"
+42°00'00.0"
+41°00'00.0"
Dec (J2000)
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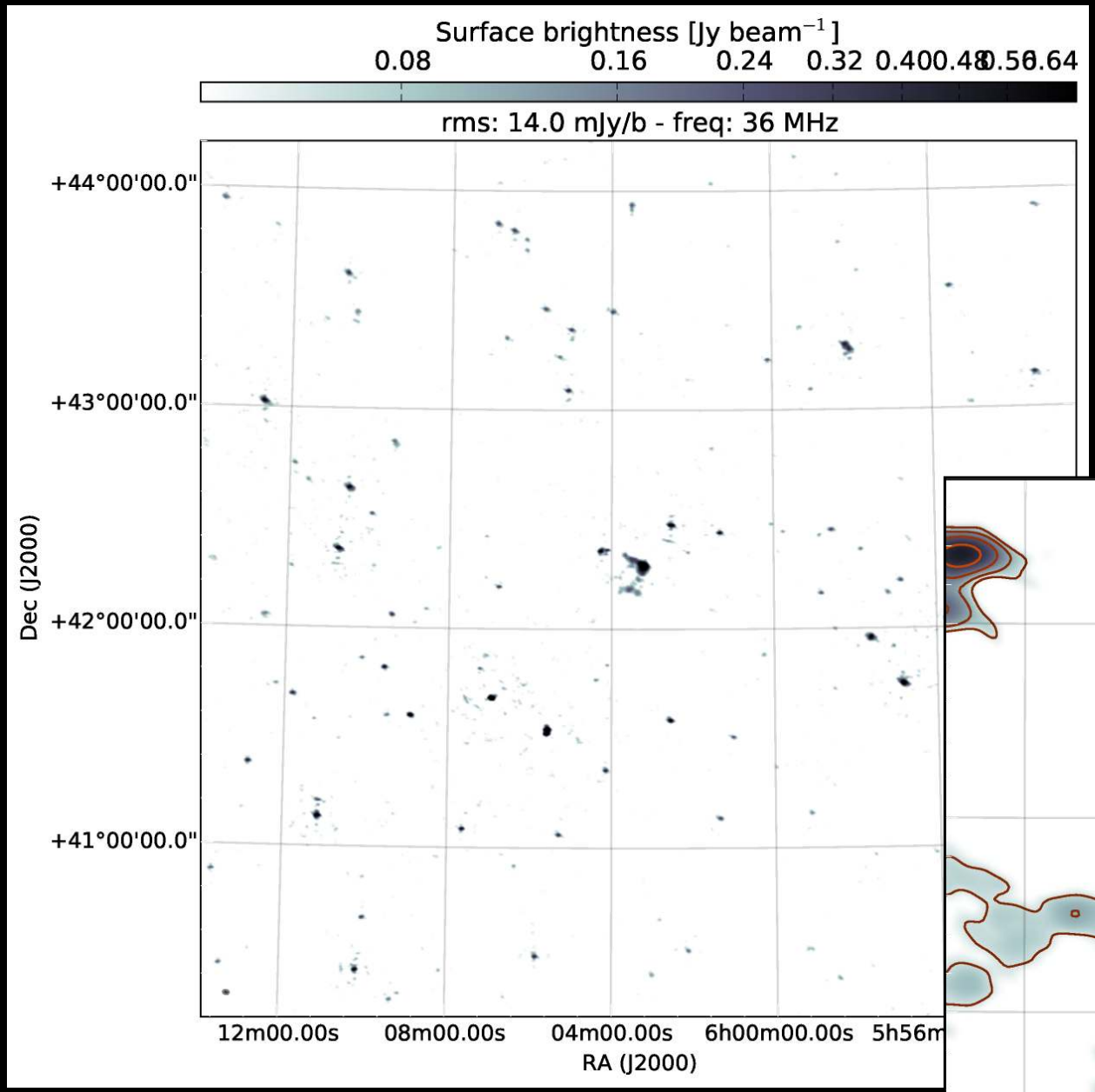
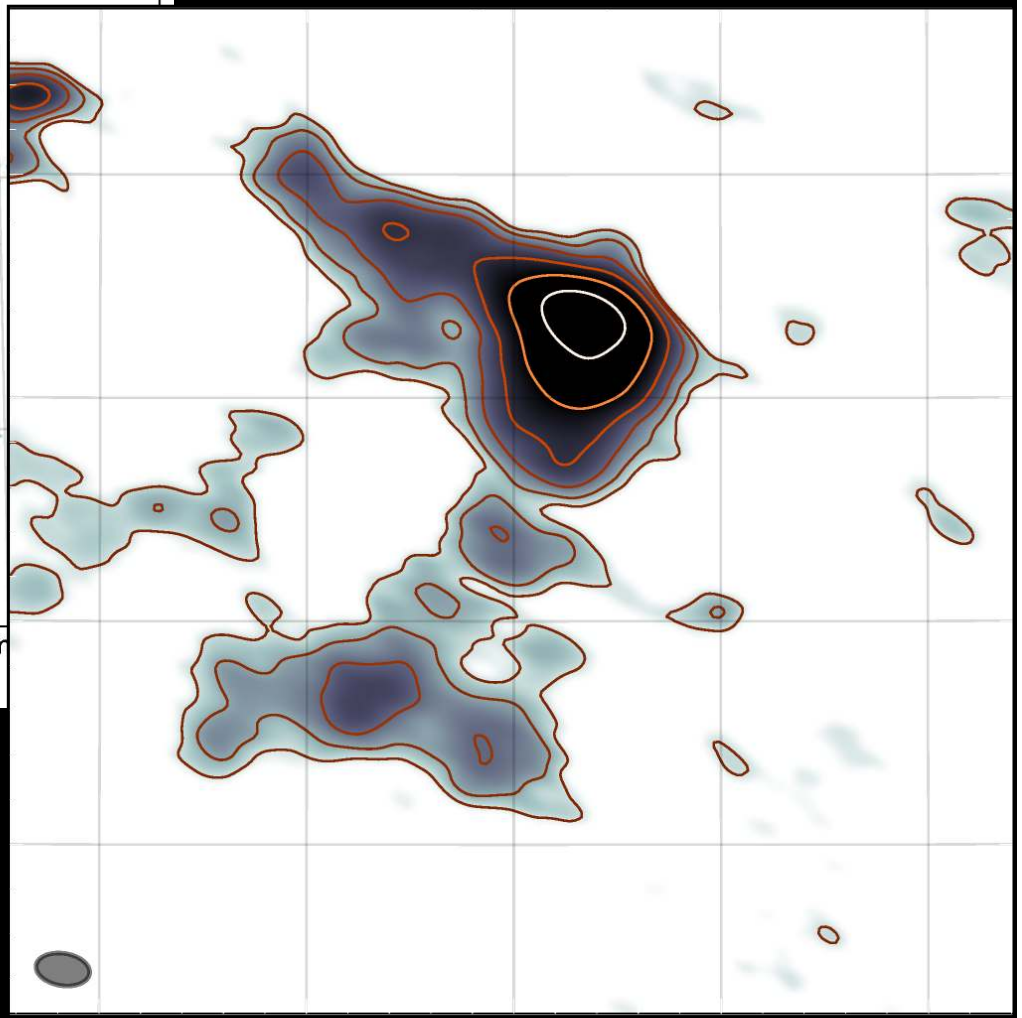
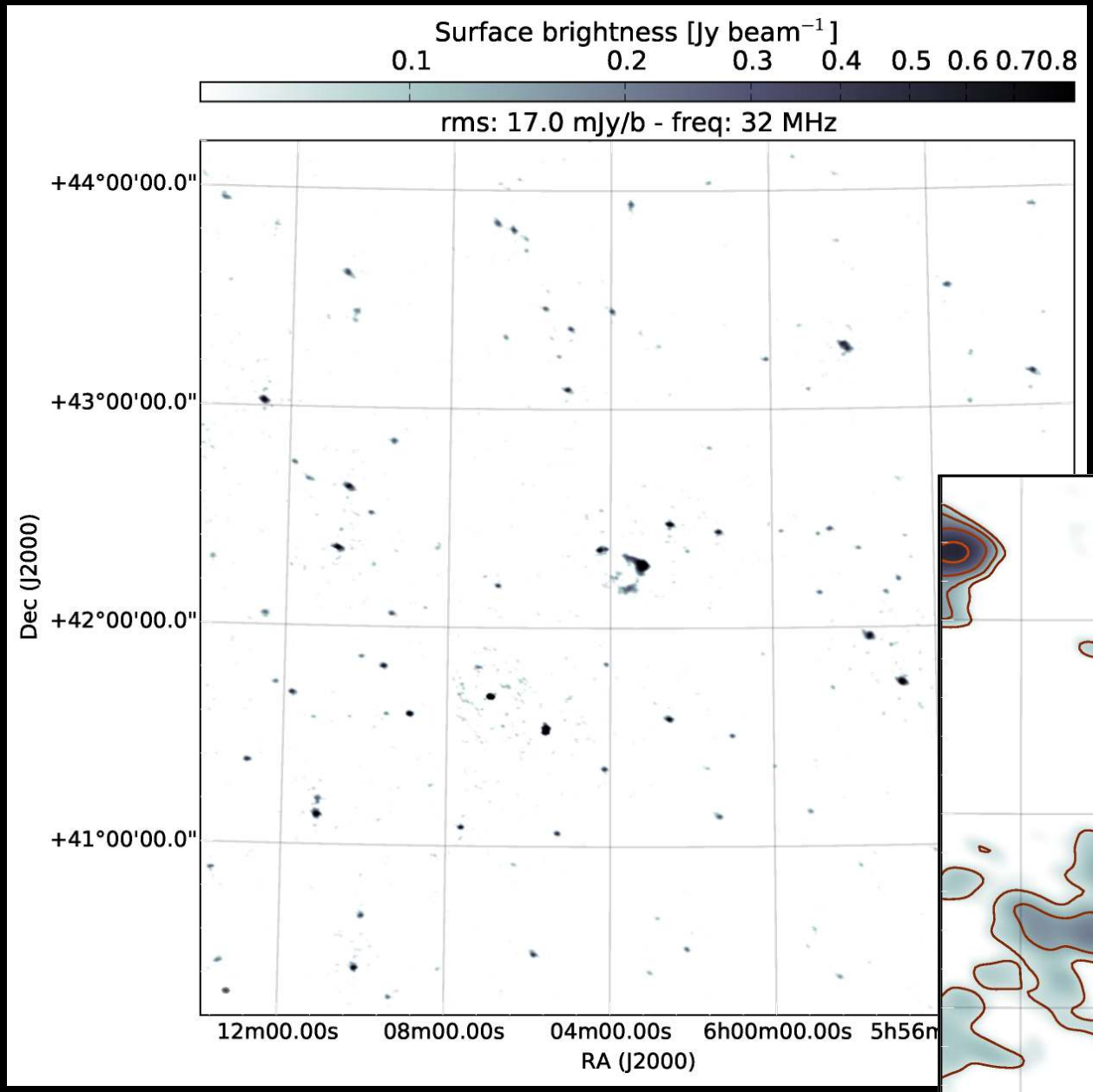
5h56m
RA (J2000)
40 MHz
12 mJy/b



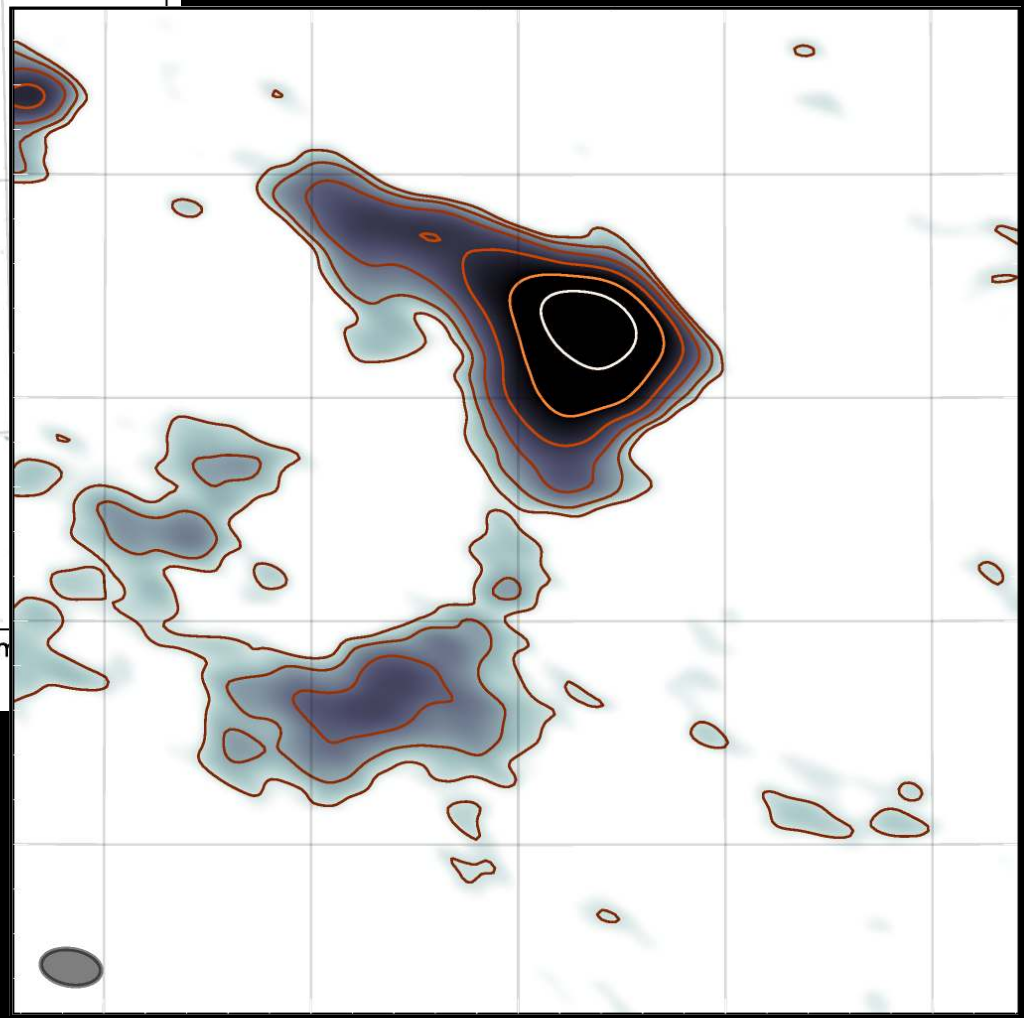
36 MHz



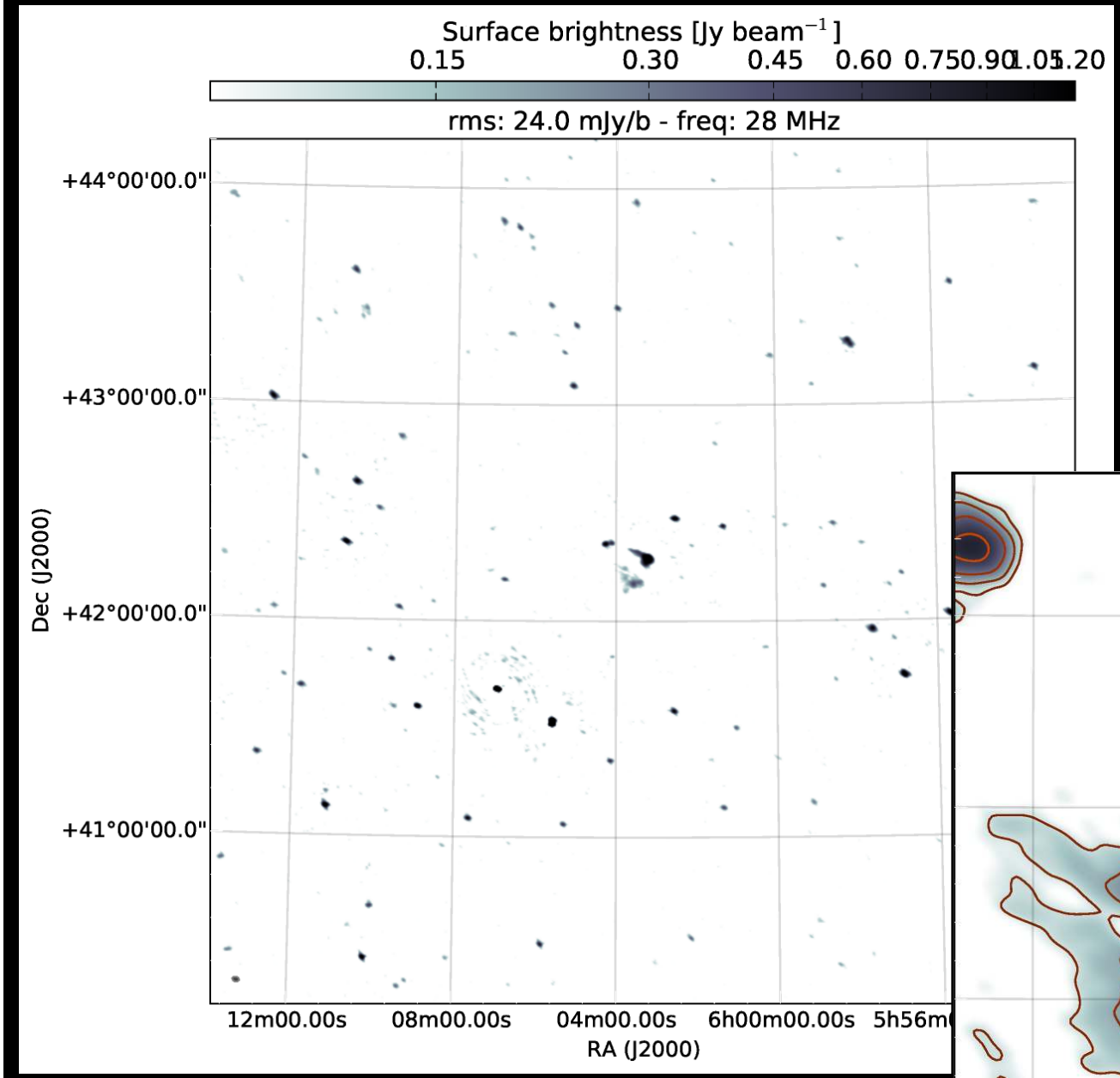
14 mJy/b



32 MHz



17 mJy/b



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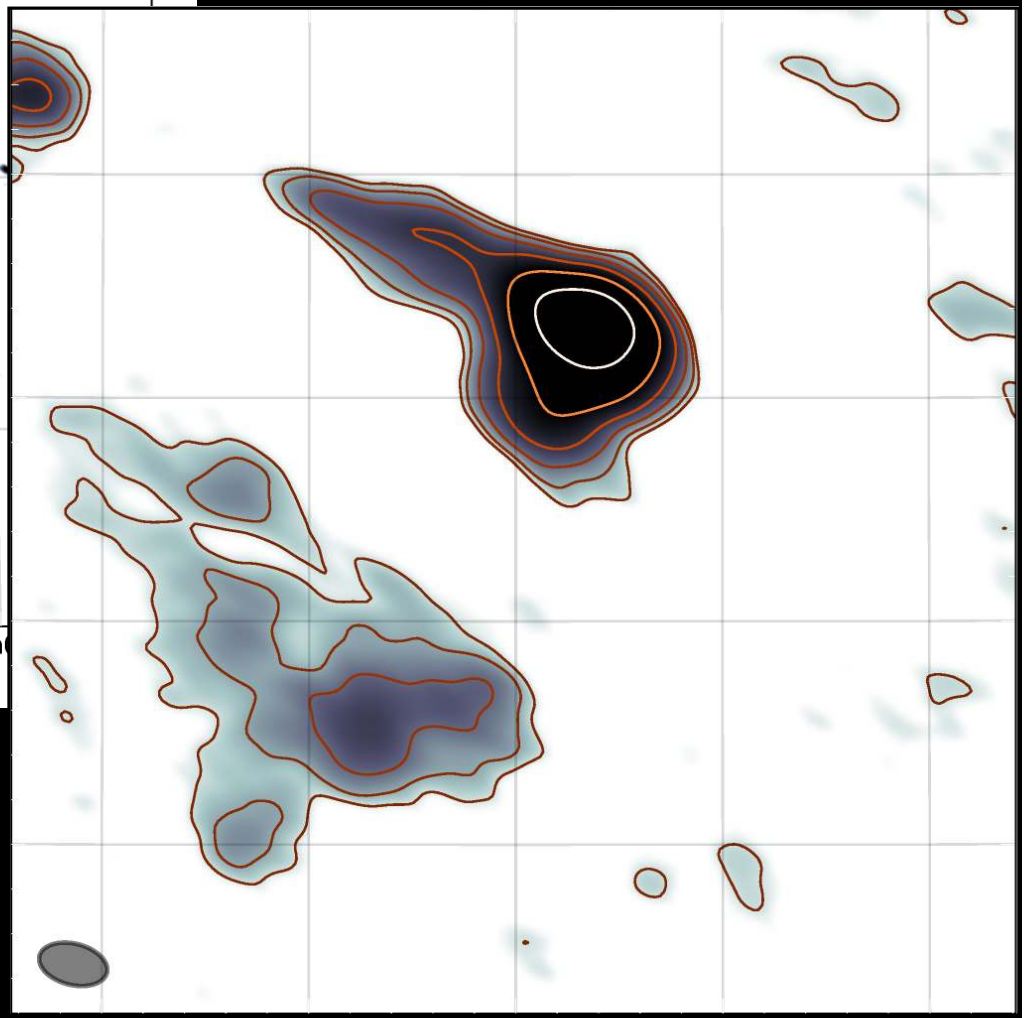
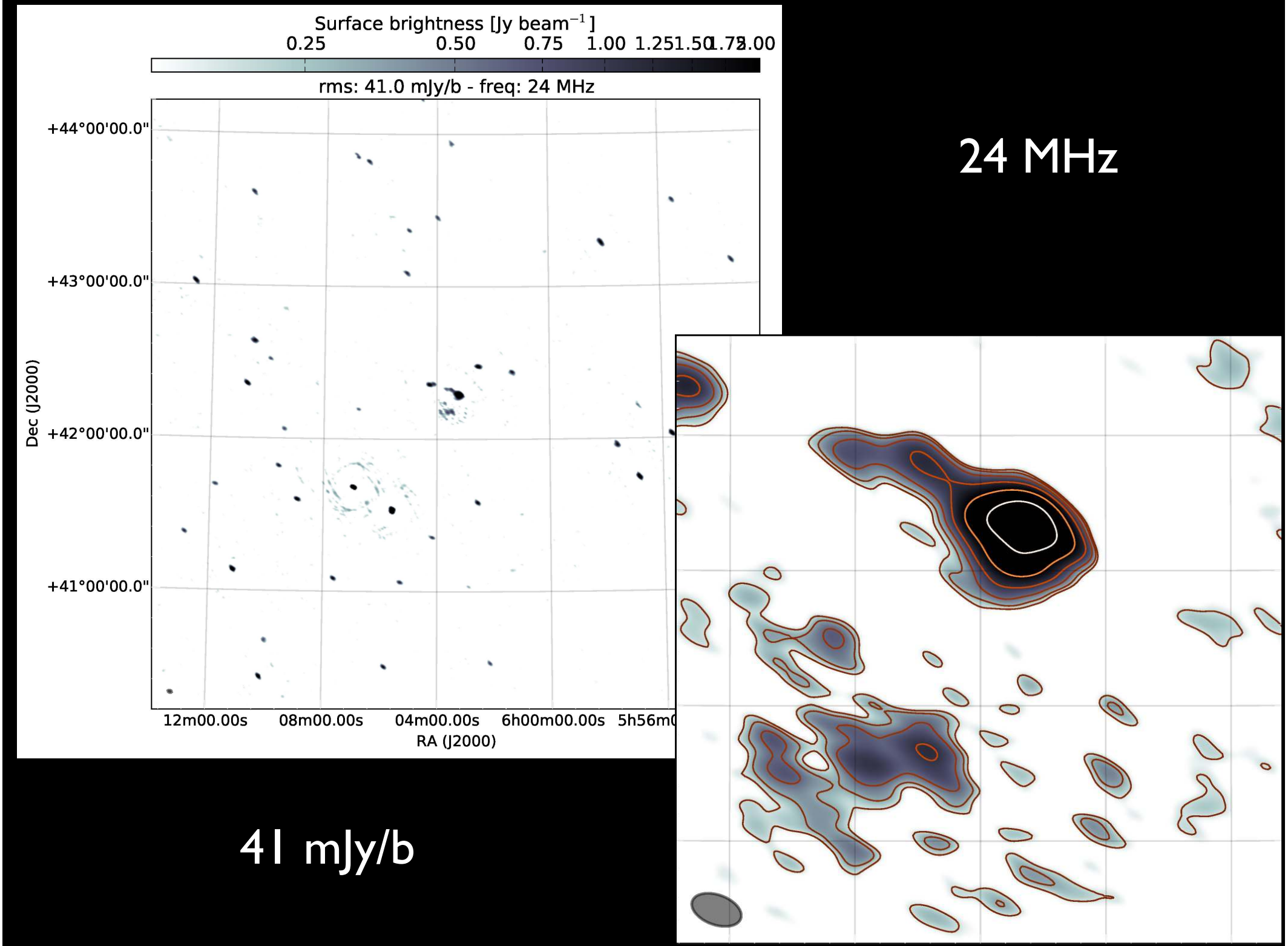


28 mJy/b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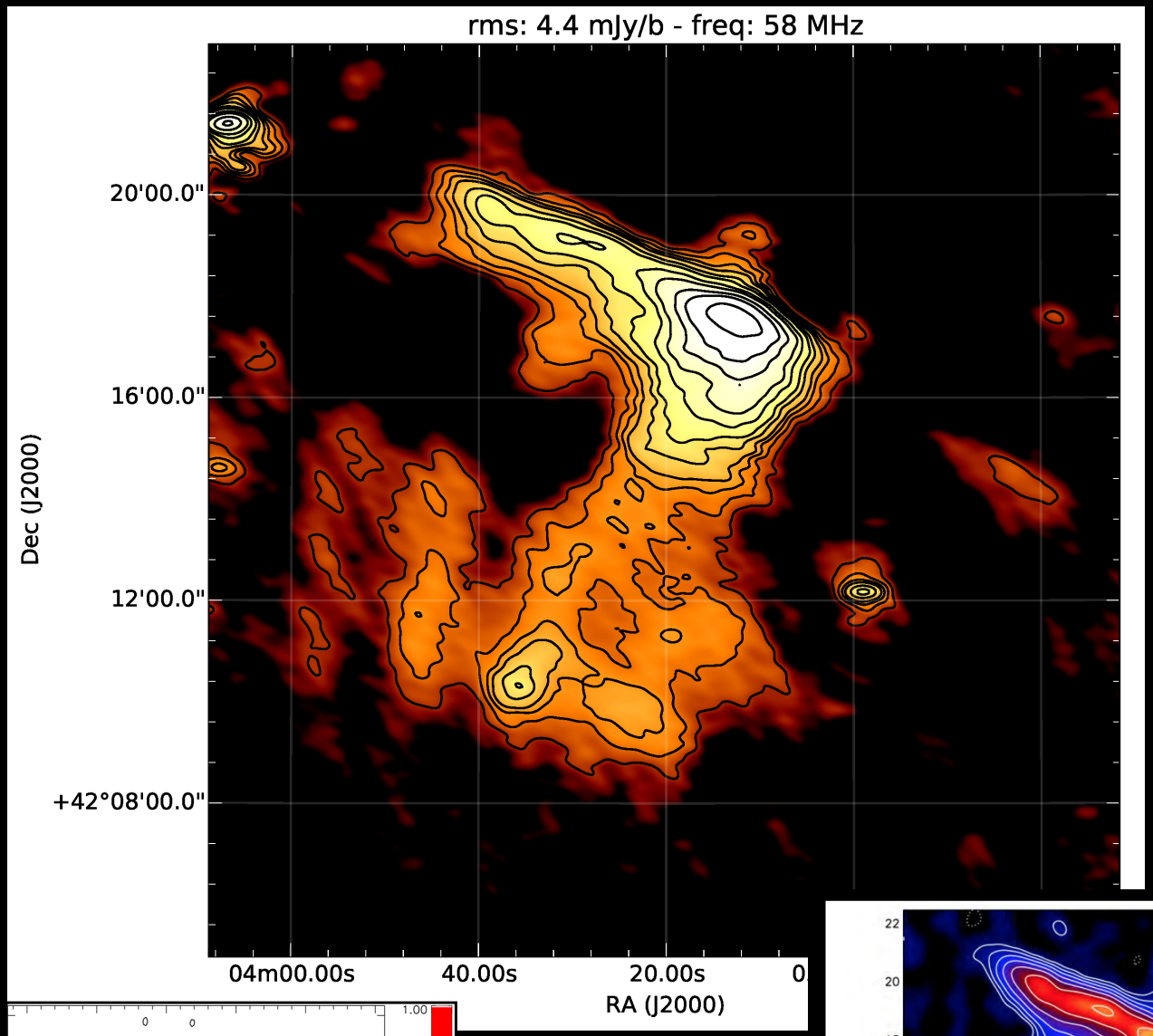
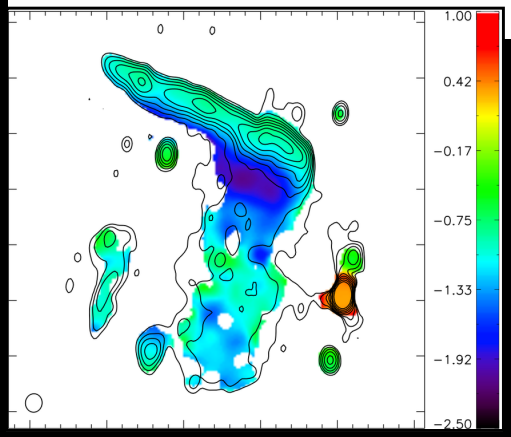
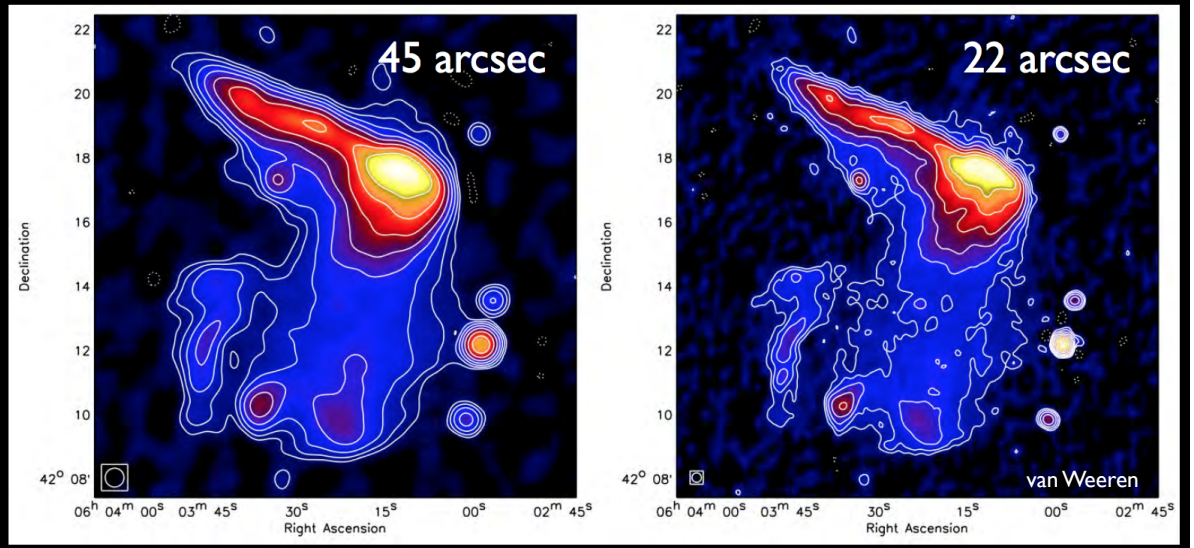
1.75
2.00
rms: 41.0 mJy/b - freq: 24 MHz
+44°00'00.0"
+43°00'00.0"
+42°00'00.0"
+41°00'00.0"
Dec (J2000)
12m00.00s
08m00.00s
04m00.00s
6h00m00.00s
5h56m0
RA (J2000)
24 MHz
41 mJy/b

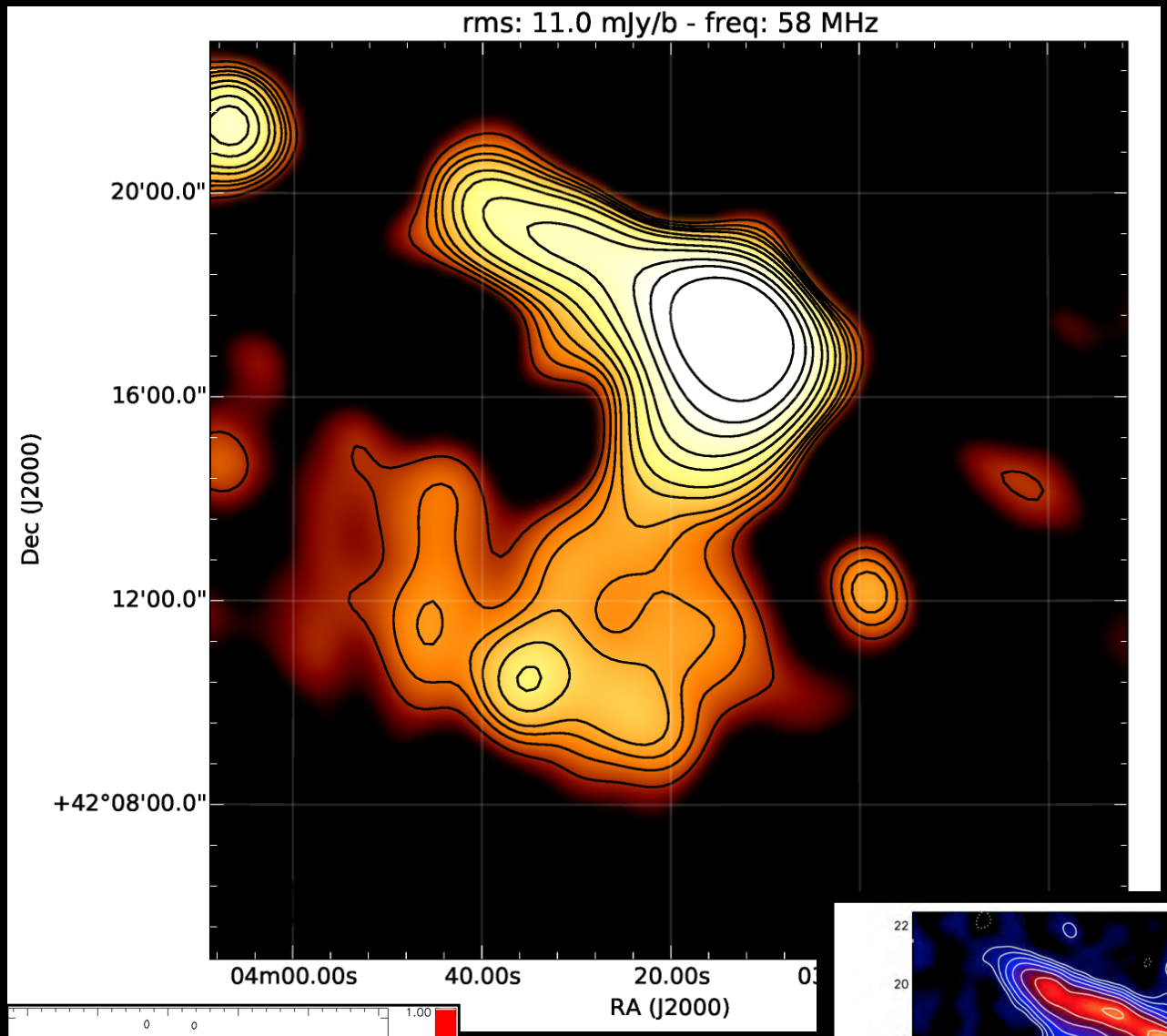


LBA
4 mJy/b
20” resolution
58 MHz (50% bw)

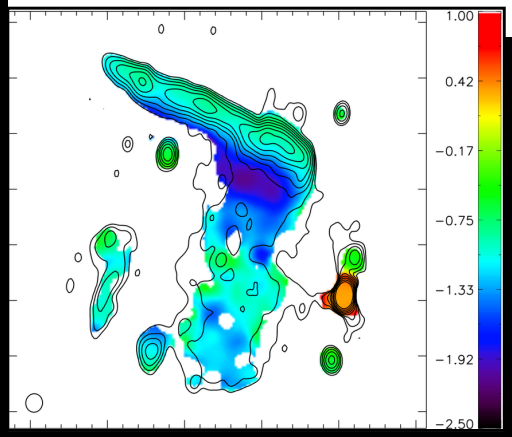


HBA

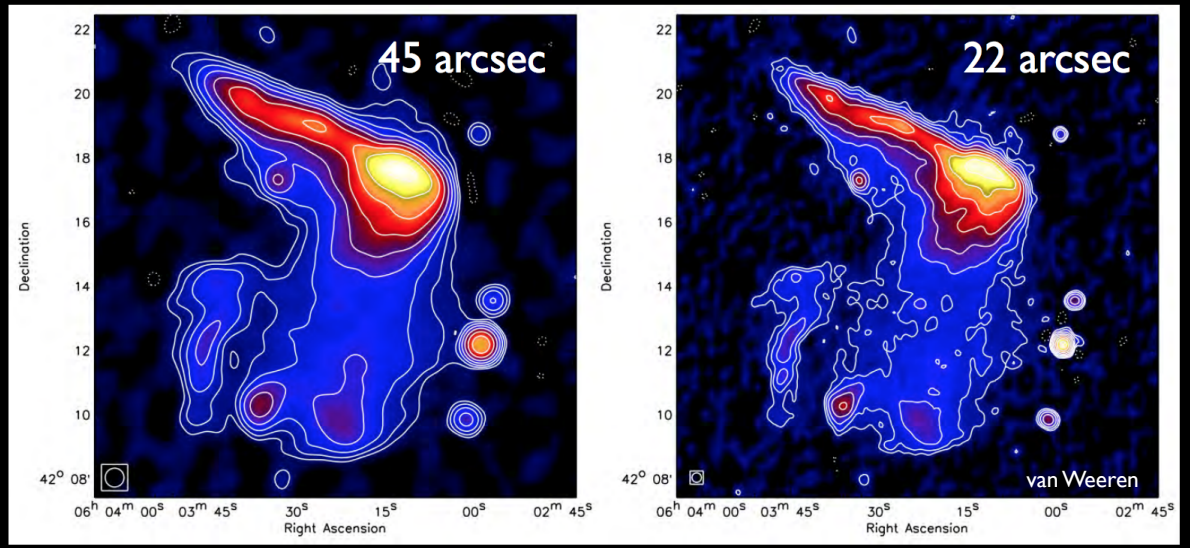




LBA
11 mJy/b
80” resolution
58 MHz (50% bw)



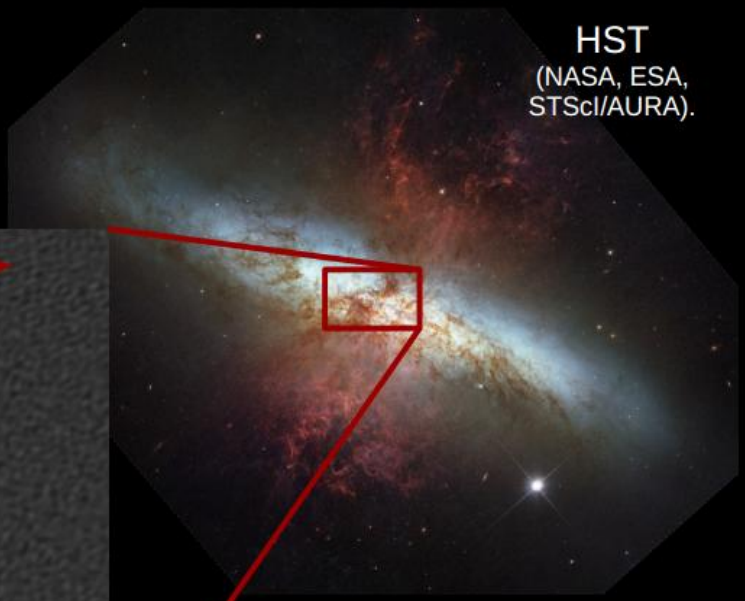
HBA

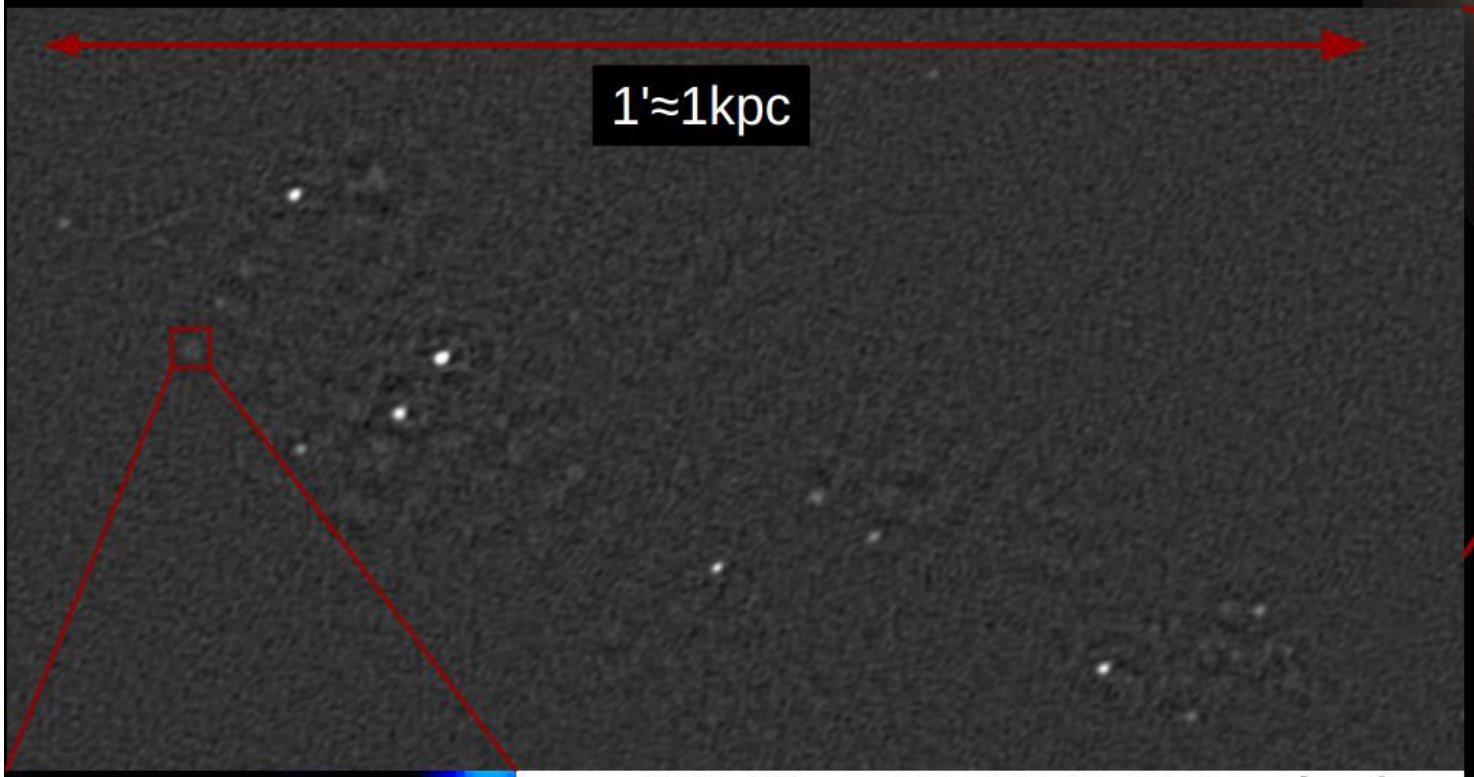


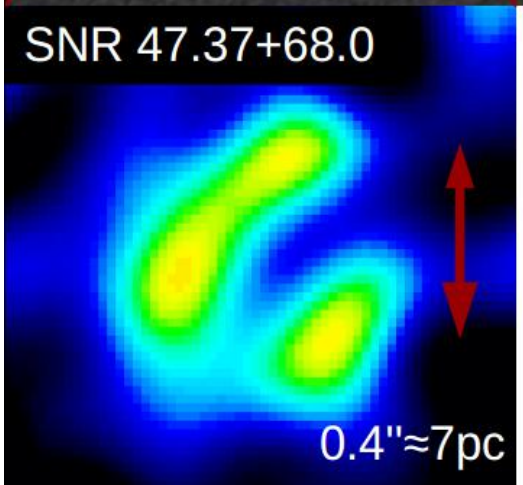
International baseline imaging: M82 at 150 MHz

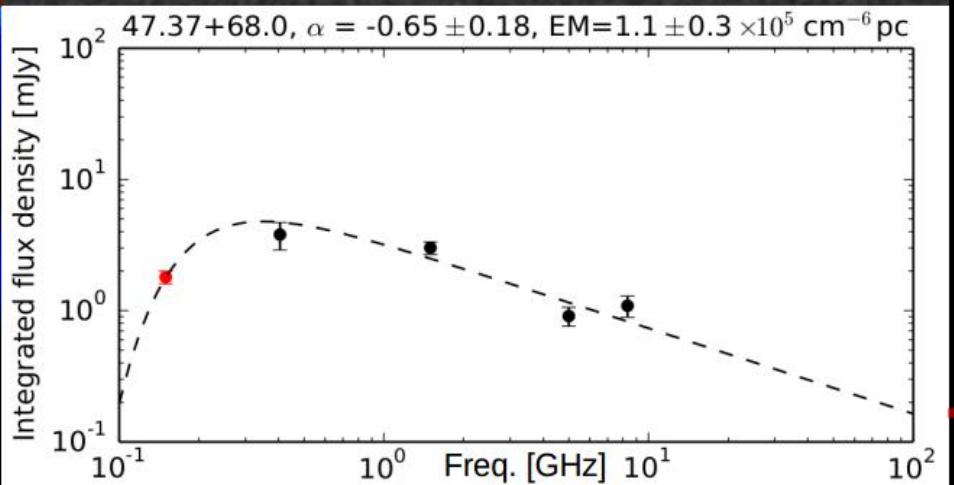
Star forming galaxy, 3.6 Mpc.

Resolution 0.3", image noise σ=0.15 mJy/beam.









Some results

- Detect 16 objects (7 new)
- Resolve SNR shells
- Probe ISM structure through low-freq turnovers in SNR spectra.

Varenius et al. (2015), A&A.

Surveying the radio sky
15-45, 45-65, 120-180 MHz

1. The highest redshift radio sources - George Miley: ~100 at z>6
2. Starforming galaxies - Lehnert/Barthel: 100 protoclusters at z>2
3. Clusters and cluster halo sources - Brüggen/Brunetti: 100 @ z>0.6; 60 nearby clusters
4. AGN at moderate redshifts - Philip Best
5. Gravitational lensing - Neal Jackson
6. Detailed studies of low-redshift AGN - Raffaella Morganti
7. Nearby galaxies - John Conway/Krzysztof Chyzi
8. Cosmological studies - Matt Jarvis/David Bacon
9. Galactic radio sources – Marijke Haverkorn Glenn White

This conference

LEAH MORABITO
LOFAR SURVEY OF SPATIALLY RESOLVED ULTRA STEEP SPECTRUM SOURCES

MARISA BRIENZ
A DYING AND RESTARTED RADIO GALAXIES IN THE LOFAR SKY

ANNALISA BONAFEDE
CONSTRAINING MAGNETIC FIELDS AND PARTICLE ACCELERATION PROCESSES IN GALAXY CLUSTERS: A JOINT VLA/LOFAR VIEW ON COMA AND SKA PERSPECTIVES

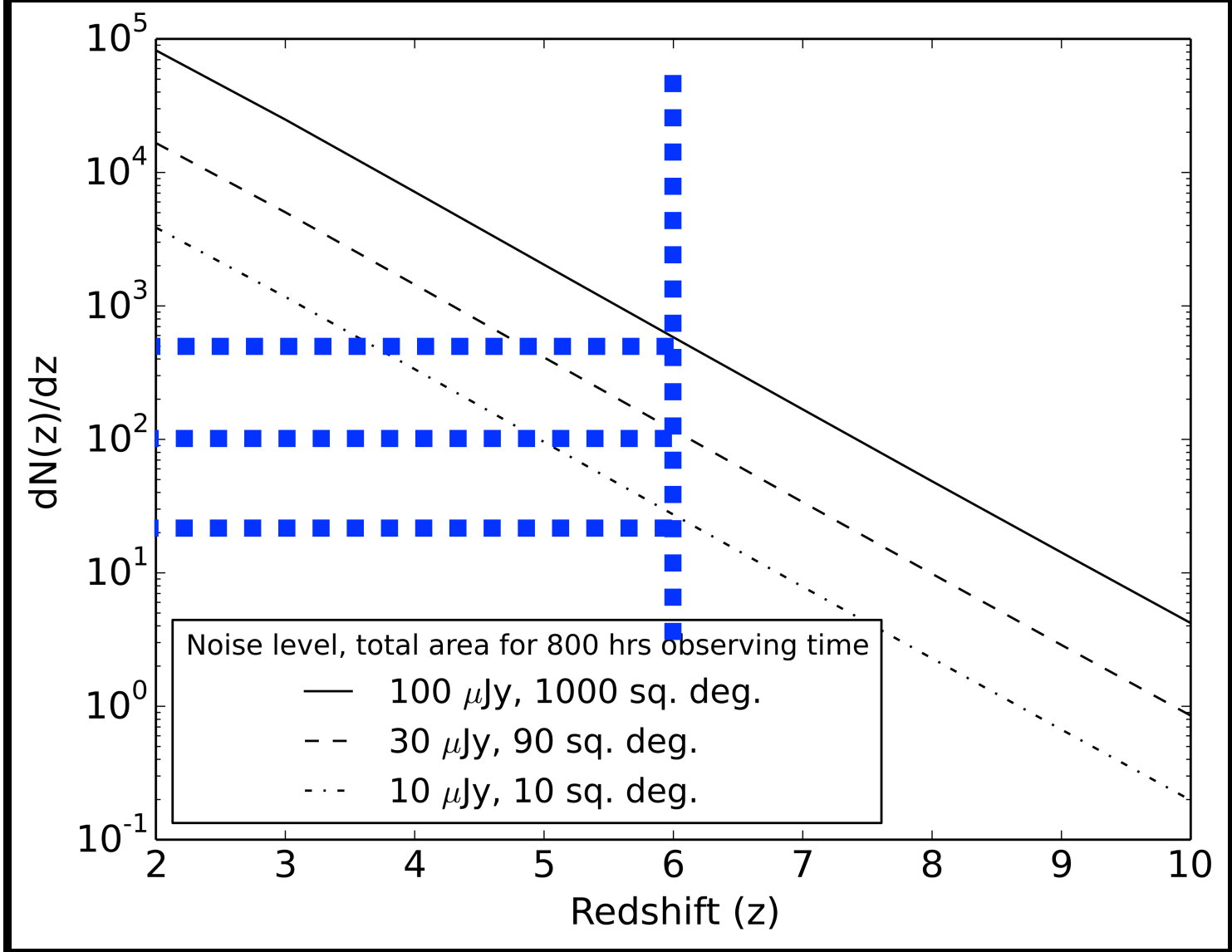
REINOUT VAN WEEREN
DIFFUSE CONTINUUM RADIO EMISSION IN CLUSTERS: OBSERVATIONAL EVIDENCES

WENDY WILLIAMS
FEEDING THE MONSTERS AT LOW FREQUENCIES: LOFAR & THE EVOLUTION OF RADIO-LOUD AGN

GEORGE HEALD
MAGNETIC FIELDS ON A WIDE RANGE OF SCALES IN STAR-FORMING GALAXIES

EMANUELA ORRU'
B1834+620: A RESTARTED AGN SEEN BY LOFAR

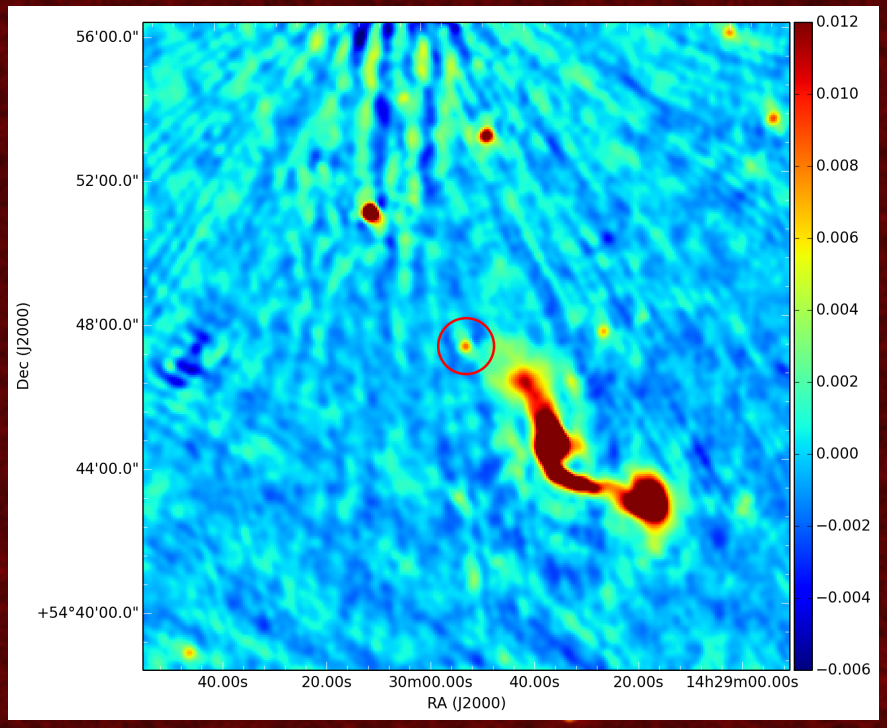
Hunting for high-z radio AGN: Do they they exist?



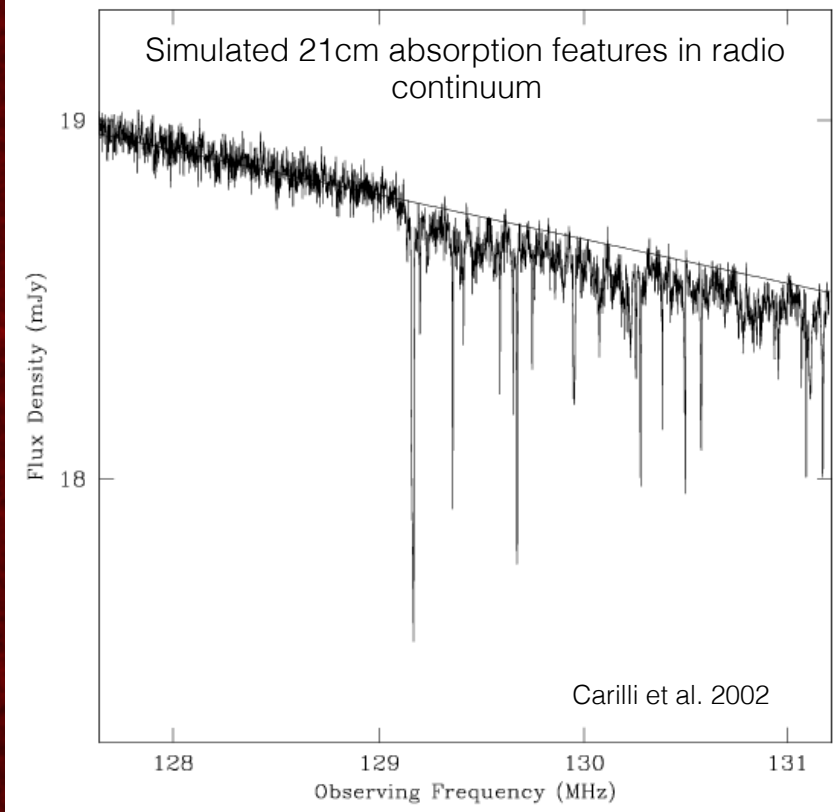
Survey	Total N at z>6
Large Area	**16.750**
Deep	**1.030**
Ultra Deep	**310**

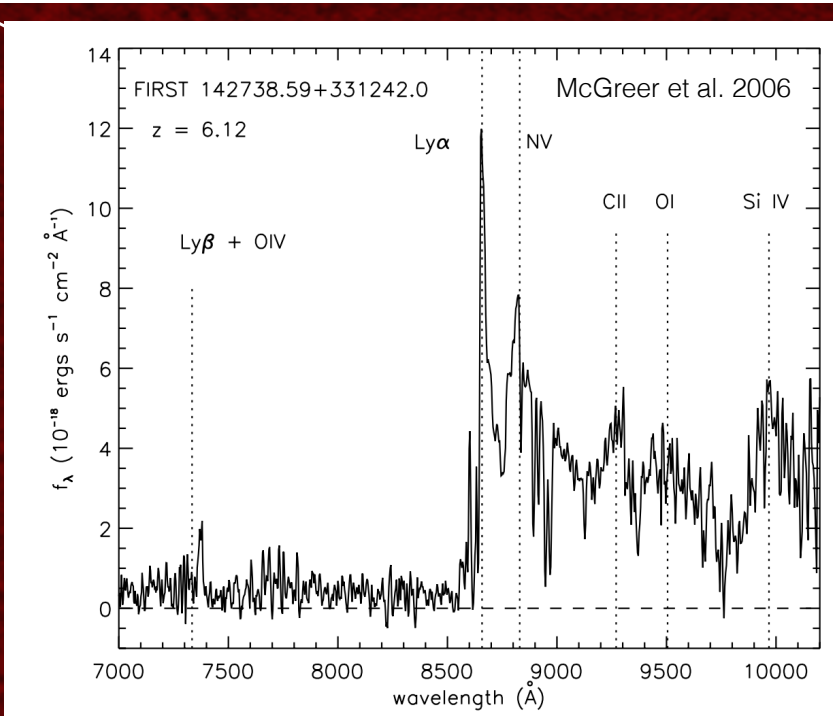
Modeled radio loud LF: high-z QSO LF scaled to radio AGN LF at z=2 (Saxena, HR in prep)

z = 6.12 Radio Loud QSO as seenin Bootes field



z = 6.20 RL QSO in an early LOFAR image



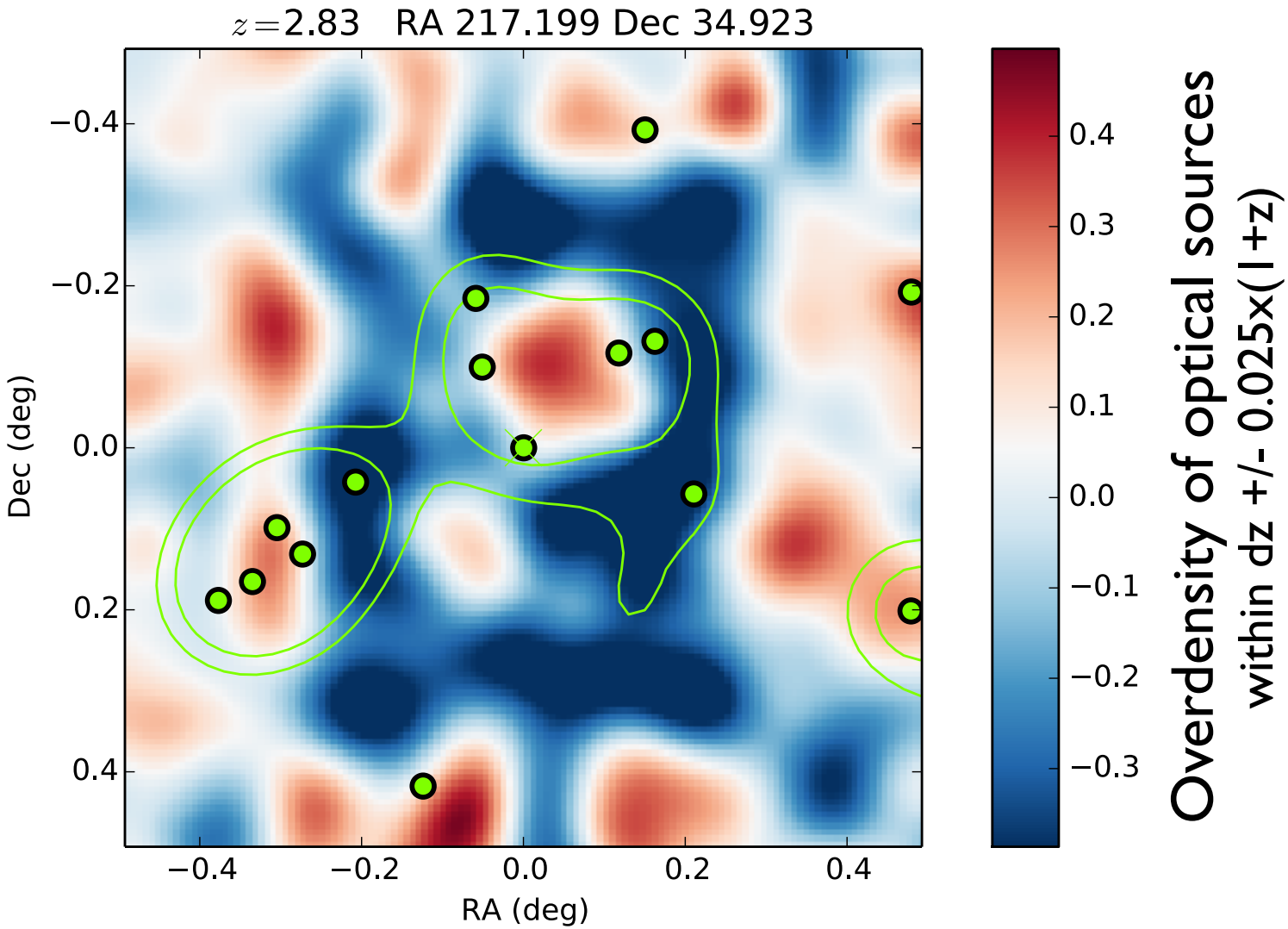


Williams, Retana, Saxena, Duncan

Proto-clusters

- Progenitors of nearby clusters at z>2
- Large conglomerates of galaxies over tens of arc minutes
- LOFAR and Herschel surveys have the good combination of depth plus area
- Use LOFAR and Herschel fluxes combined with radio-IR correlation to obtain radio-IR phot-z (Rigby, HR, in prep).

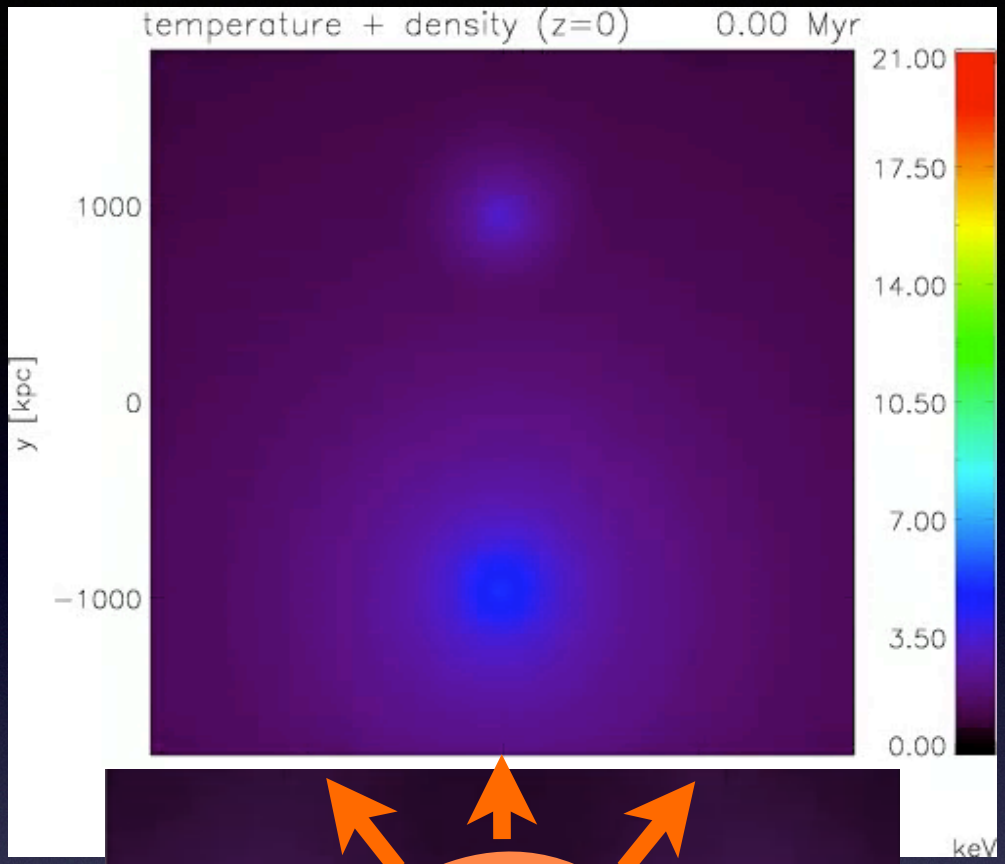
HIGH REDSHIFT PROTOCLUSTERS

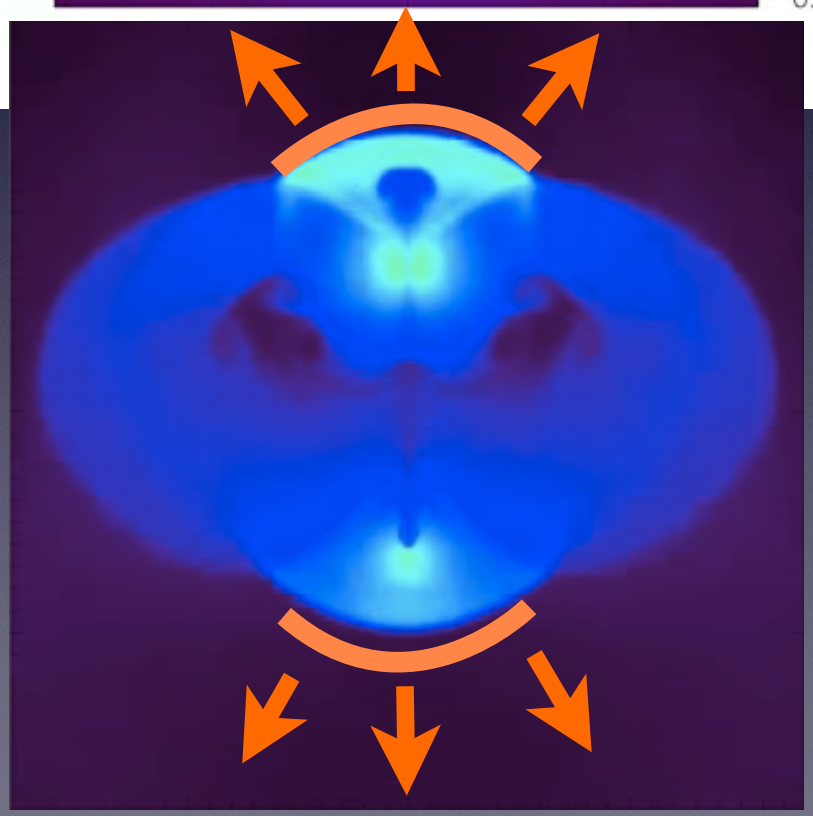


Clear over densities of high-z LOFAR + Herschel Sources

6+ candidate overdensities at
2.3 < z < 4 in Boötes field alone

Ken Duncan, Emma Rigby
Gaby Rivera





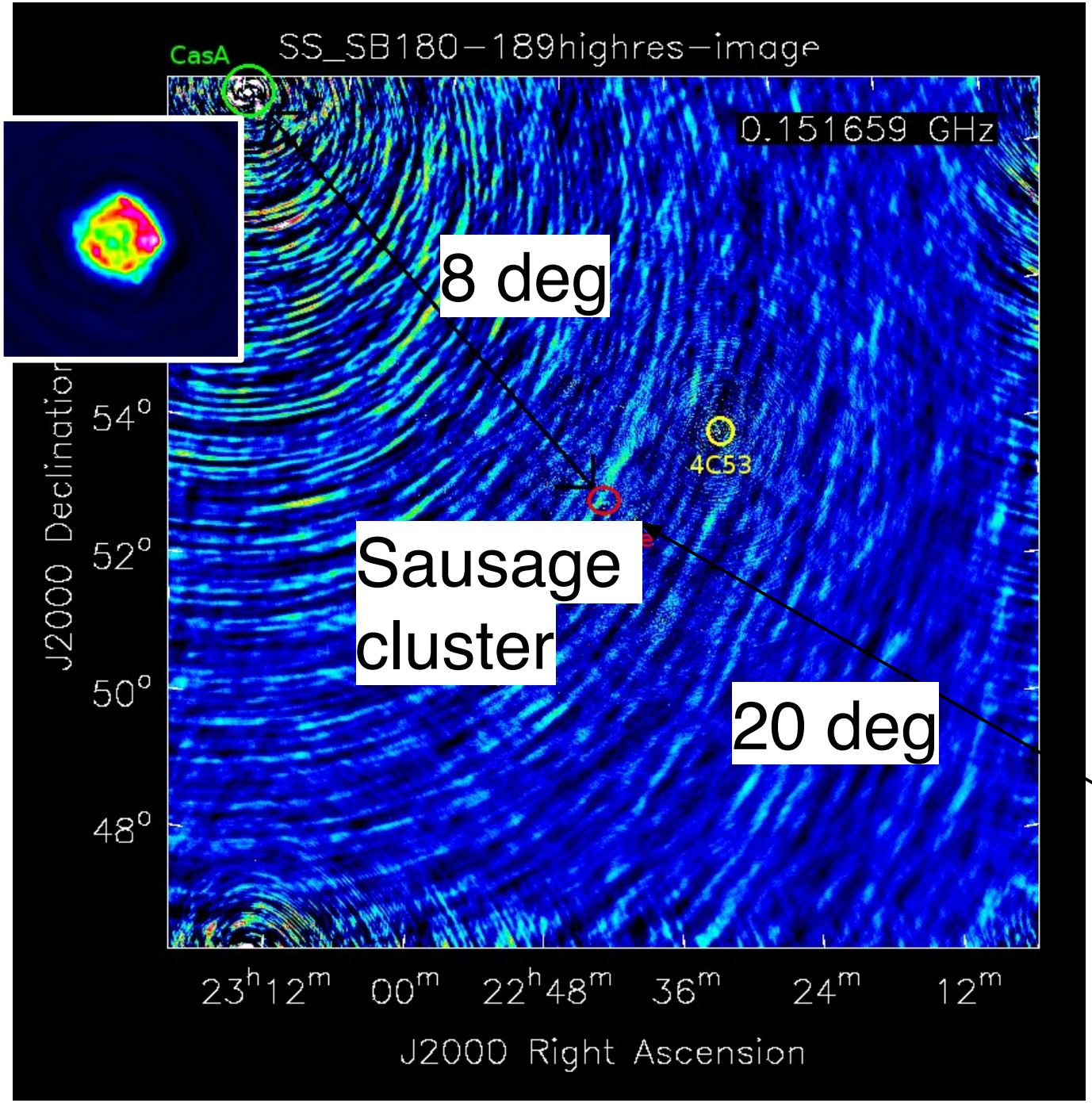
Simulation X-ray gas of two colliding clusters van Weeren et al.

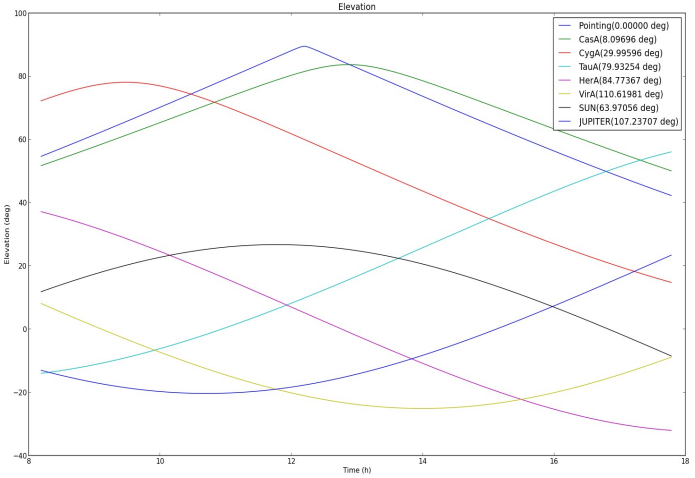
At the shock: particle acceleration
with a bit of magnetic field this gives synchrotron radiation

classification:
relic radio sources

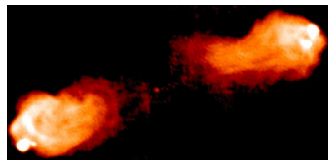
See talks by van Weeren, Govoni, Venturi, Cuciti, Bernardi, Gitti, Ruta Kale, Cassano, Venturi

Field image with CasA

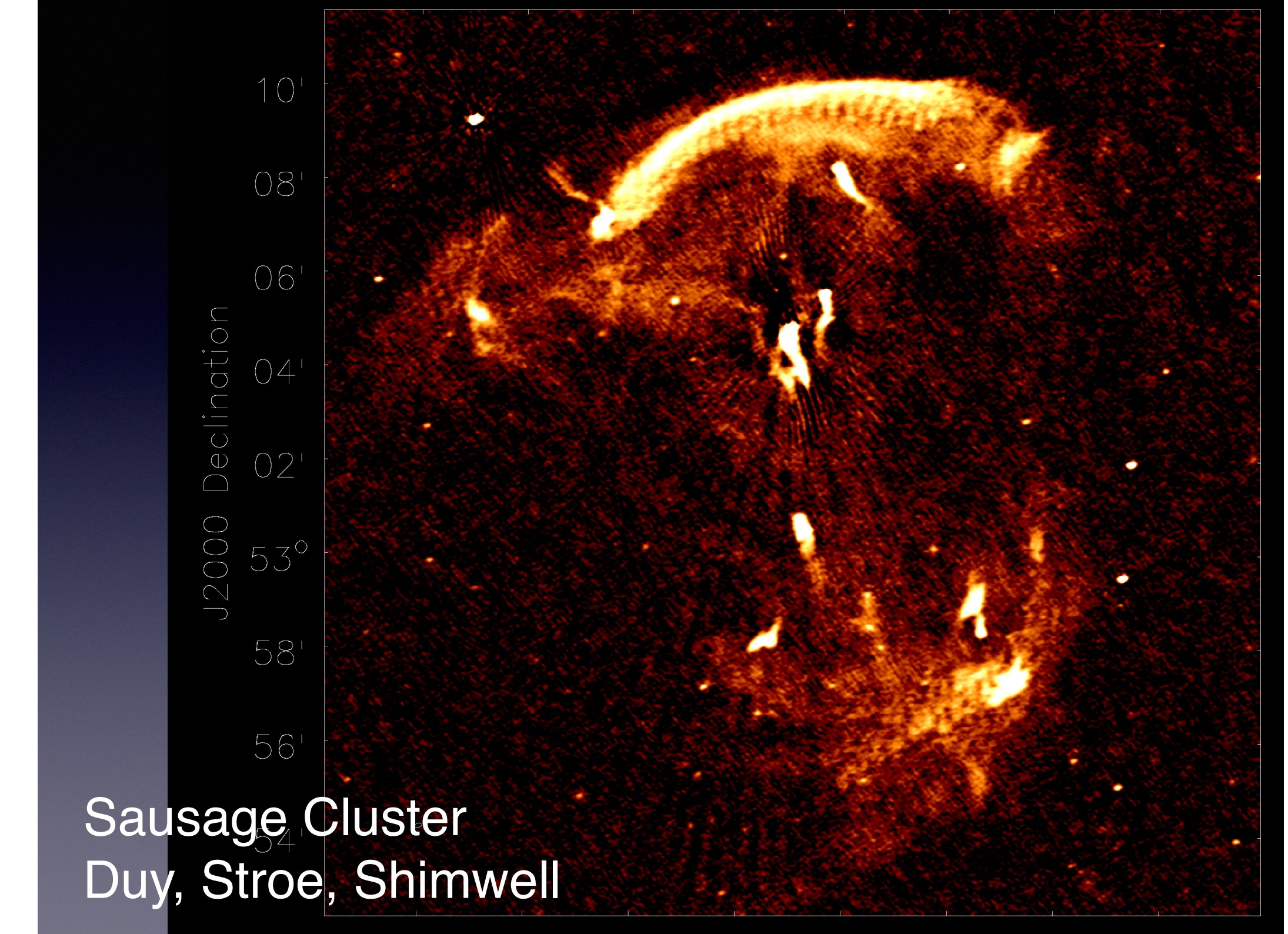




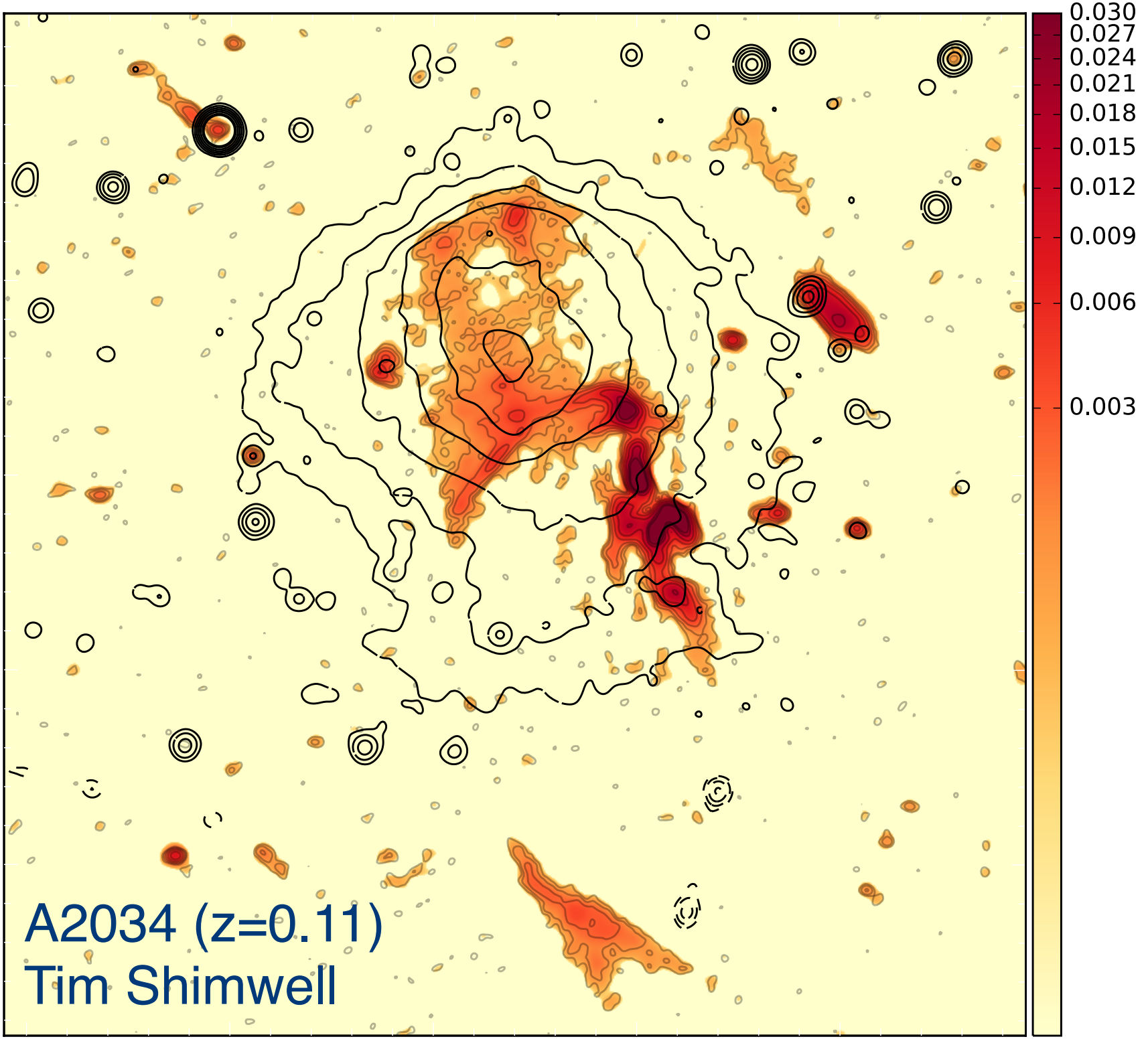
- CasA skymodel: 69MHz, 10” (Reinout van Weeren)
- Data resolution: 64ch, 1s
- Time step: 4s
- Freq. step: 16ch

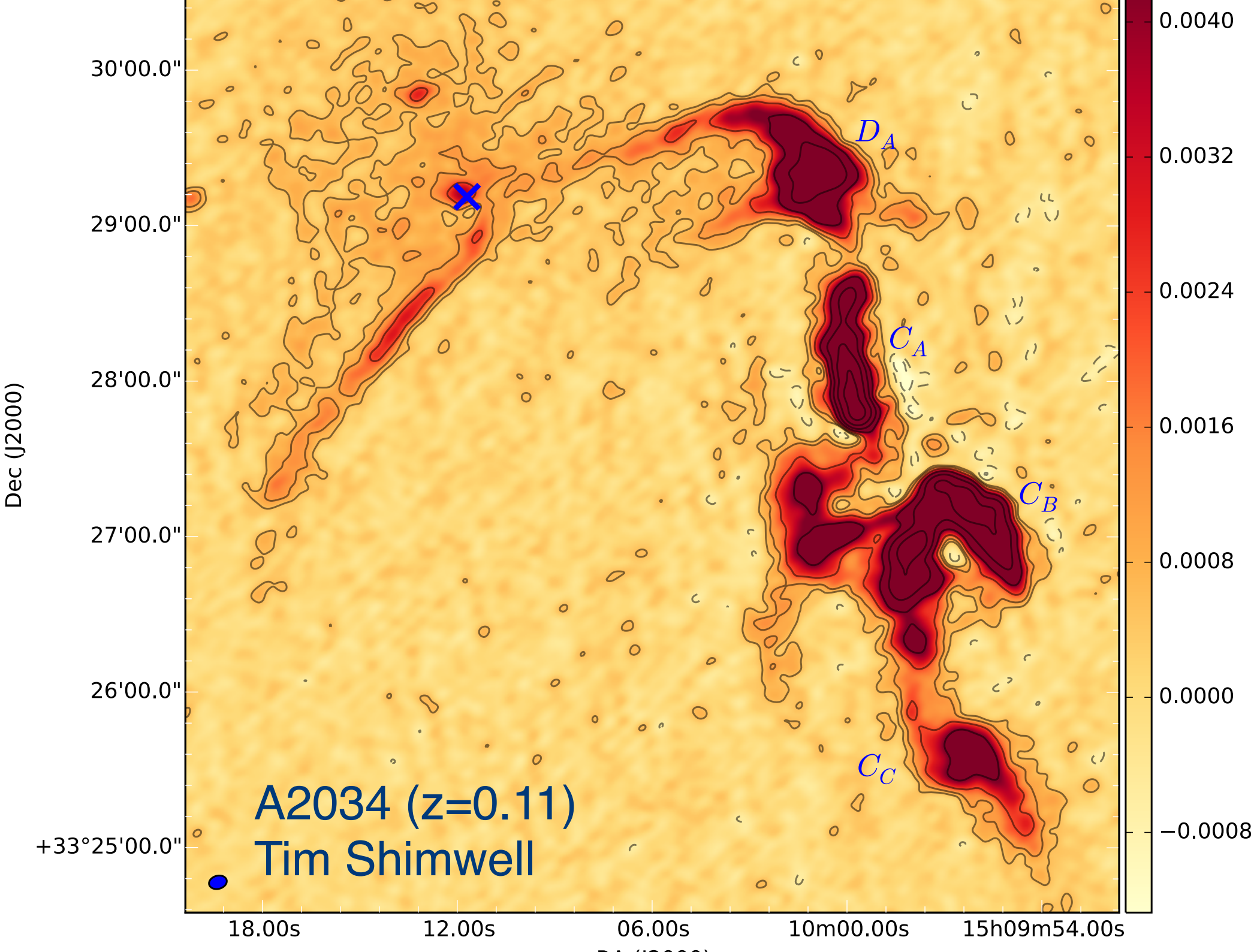


CygA



Sausage Cluster
Duy, Stroe, Shimwell


0.030
0.027
0.024
0.021
0.018
0.015
0.012
0.009
0.006
0.003
A2034 (z=0.11)
Tim Shimwell


30'00.0"
29'00.0"
28'00.0"
27'00.0"
26'00.0"
+33°25'00.0"
Dec (J2000)
18.00s
12.00s
06.00s
10m00.00s
15h09m54.00s
D_A
C_A
C_B
C_C
A2034 (z=0.11)
Tim Shimwell
0.0040
0.0032
0.0024
0.0016
0.0008
0.0000
−0.0008