LOFAR surveys: The formation and evolution of galaxies, AGN and clusters of galaxies

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Leiden Observatory

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

LOFAR
Survey team
PI HR

International LOFAR Telescope (ILT)

Onsala

Dutch stations

Chilbolton

Norderstedt

LOFAR Core (NL)

Potsdam

Bałdy

Borówiec

Jülich

Effelsberg

Tautenburg

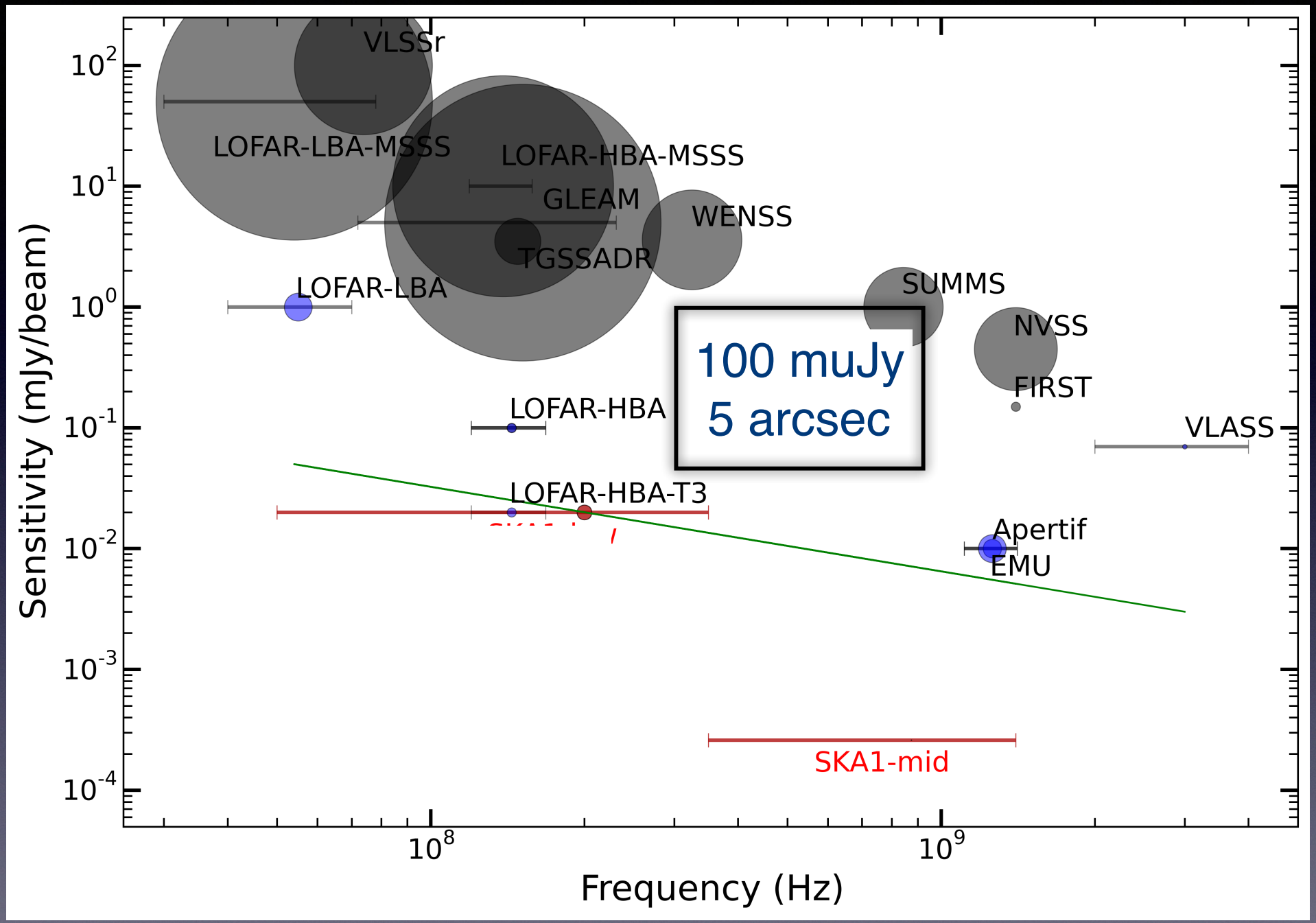
Łazy

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

Nançay

Unterweilenbach

LOFAR



- 12 % of the northern sky already mapped

Activities

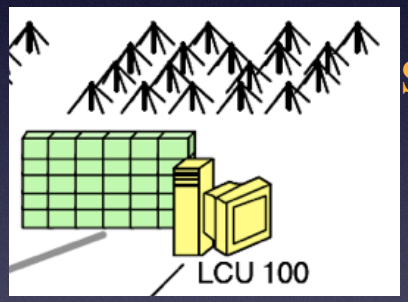
- Survey planning and production (Shimwell)
- Techniques, also to learn how to deal with SKA
  - Calibration techniques (De Gasperin, Intema, Dijkema)
  - Ionospheric simulation (Albert, Mevius)
  - Software profiling, grid enabling, speed and memory optimisation (Mechev)
  - Identifications, phot-z and id characterisations (Duncan)

Science

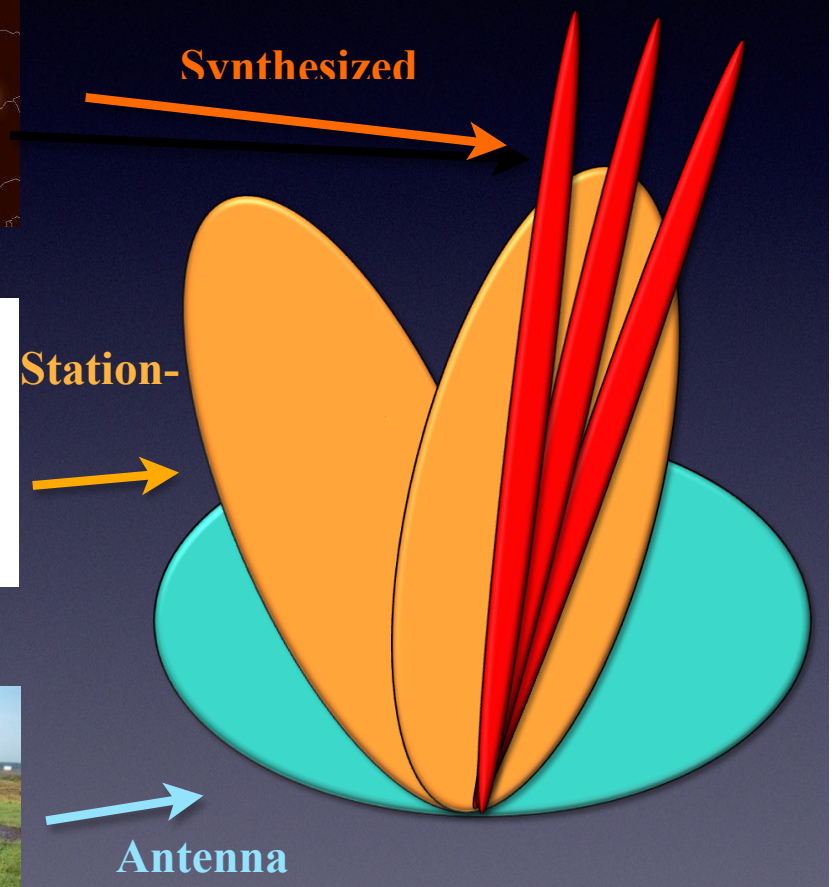
- The most distant radio galaxies to probe the EoR (Miley, Saxena, Retana, Morabito, Stroe, Falcke)
- Carbon recombination lines (Tielens, Emig, Morabito, Oonk, Sales-Munoz)
- Starburst galaxies and proto-clusters (Duncan, Rivera)
- Galaxy (Vink, Haverkorn)
- AGN feedback and the characterisation of AGN hosts (Jansen, Rivera, Williams, Morganti, McKean)
- Merging clusters (Hoang, Shimwell, Intema, de Gasparin, Mandal, Donnert, Albert, Wise)

Challenges

- Data rates of up to a Tb/s
- Radio interference
- Demixing: removal of A-team sources*
- Timing of the stations clocks
- Ionosphere
- Beam calibration
- Wide-field mapmaking

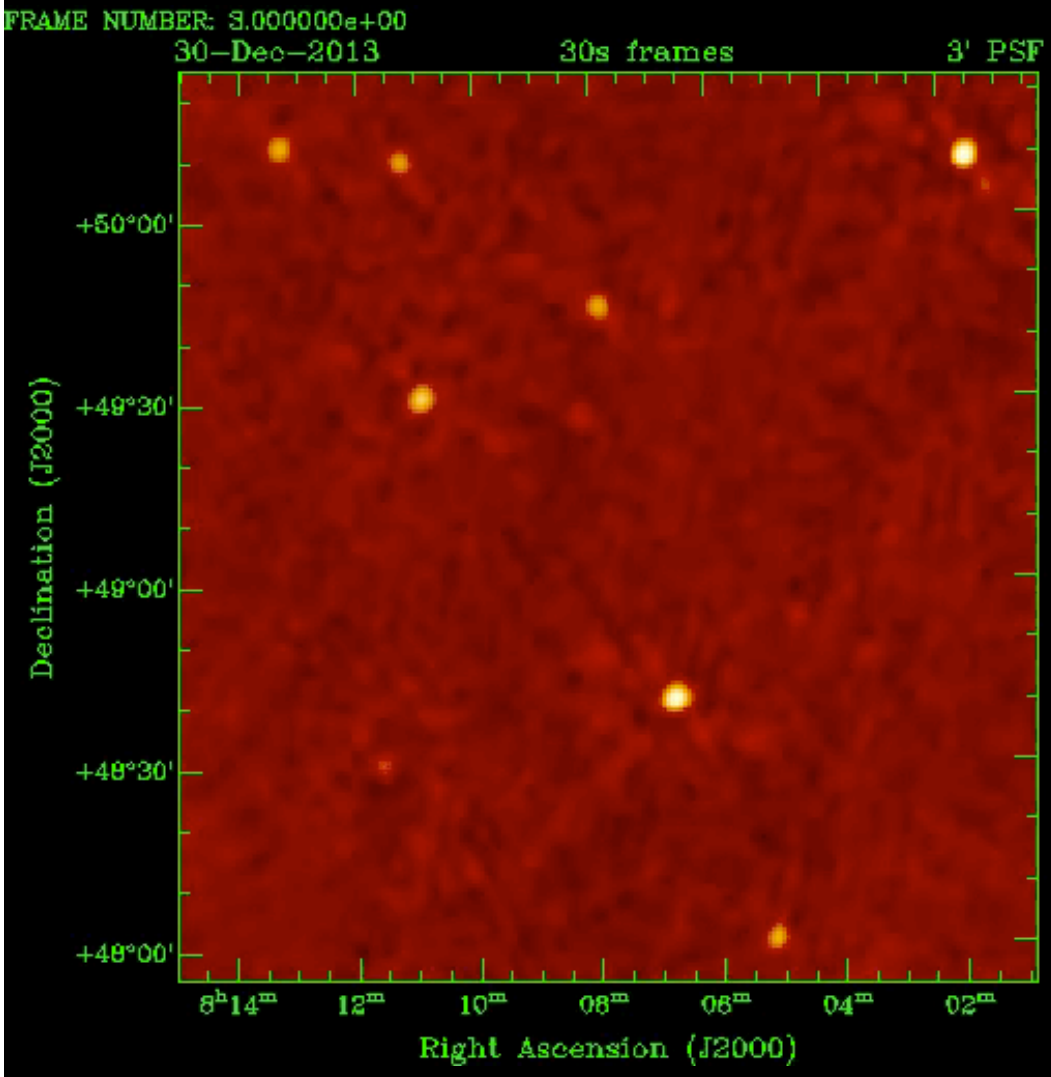


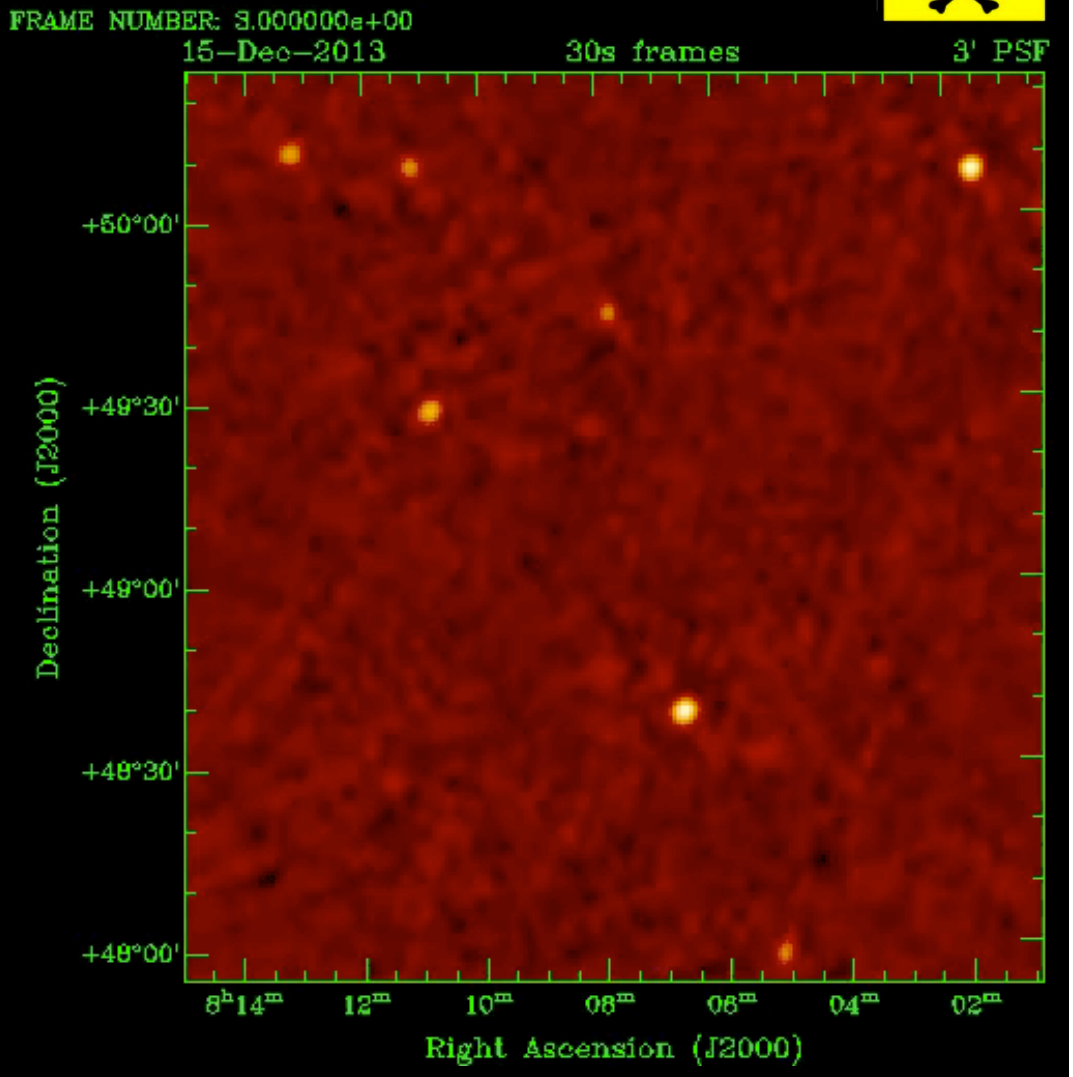
Three Beams



quiet ionosphere

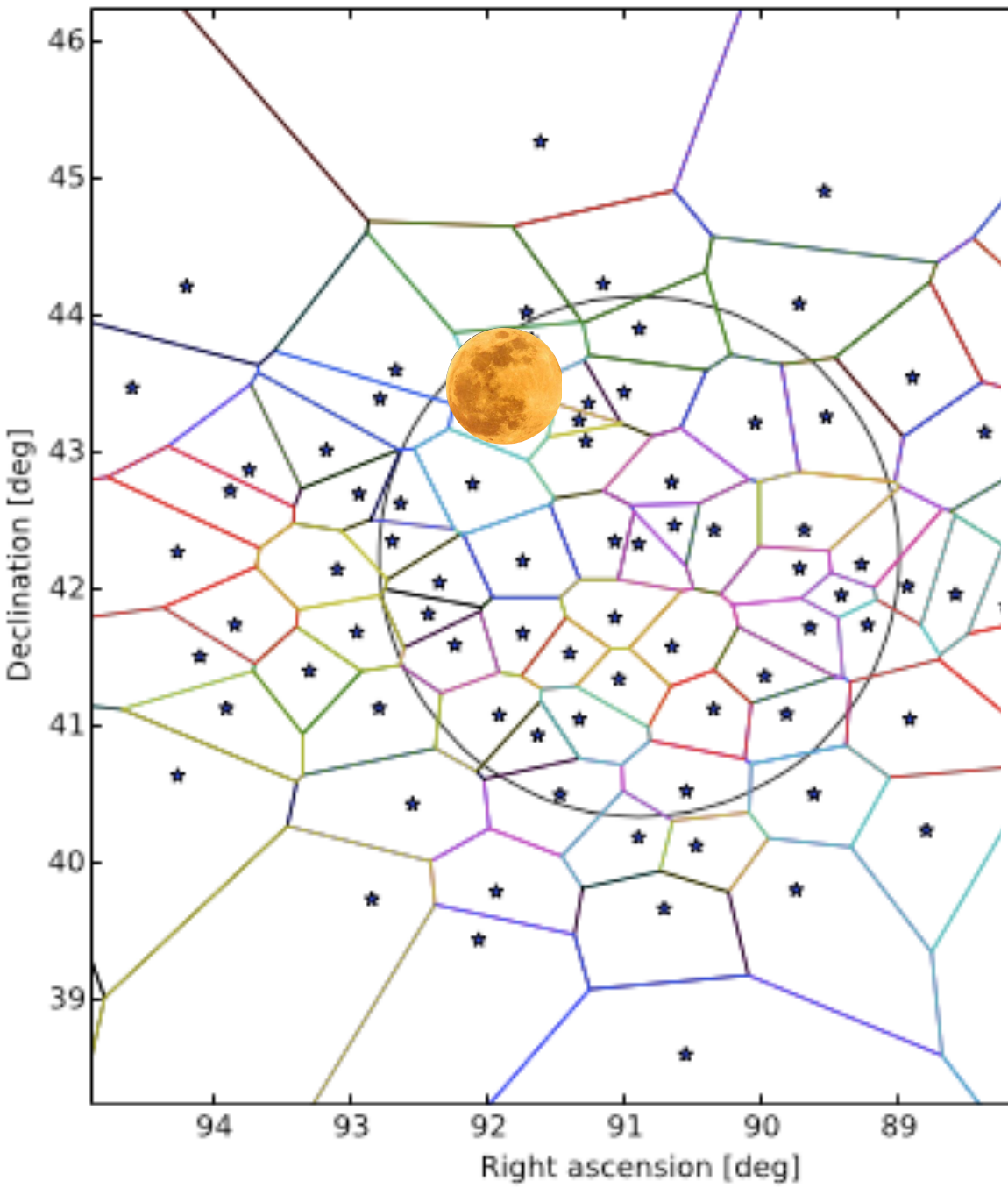
wild ionosphere





Note: these images have only 3 arcmin resolution, the NL array has 5 arcsec resolution…

Ger de Bruyn & LOFAR EoR team


Declination [deg]
Right ascension [deg]
46
45
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42
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40
39
94
93
92
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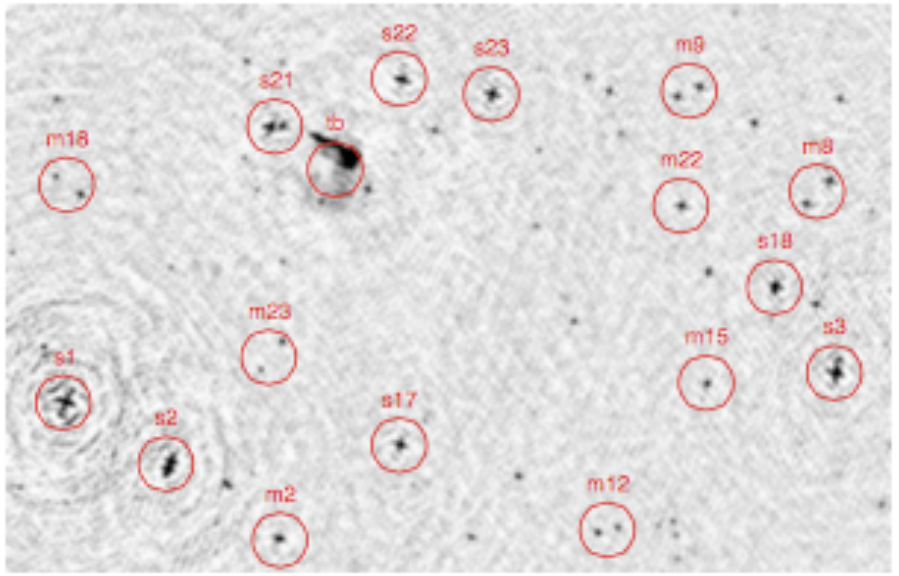
88
87


s22
s23
m9
s21
tb
m18
m22
m8
s18
m23
m15
s3
s1
s17
s2
m12
m2


s22
s23
m9
s21
tb
m18
m22
m8
s18
m23
m15
s3
s1
s17
s2
m12
m2

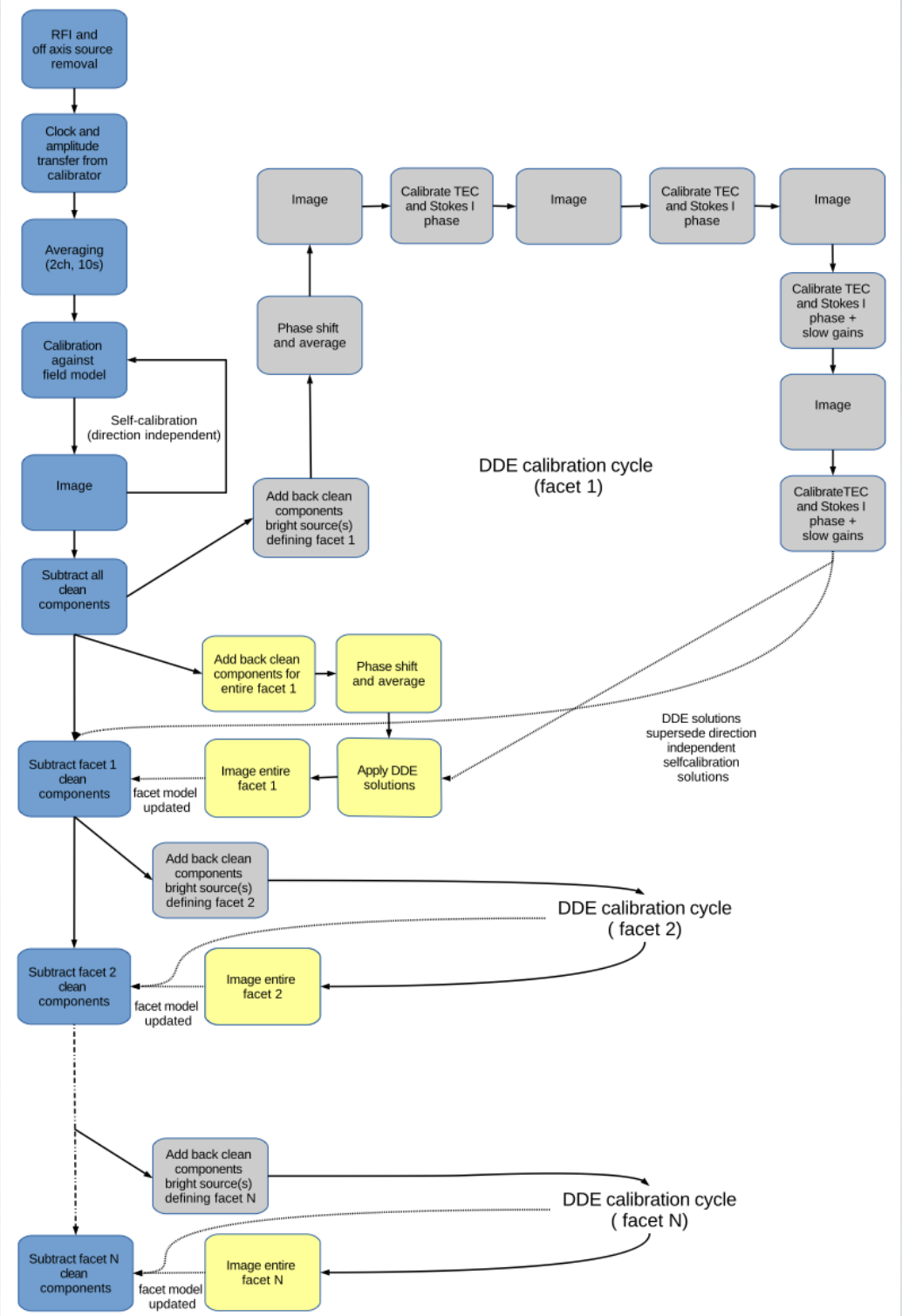
FACET CALIBRATION

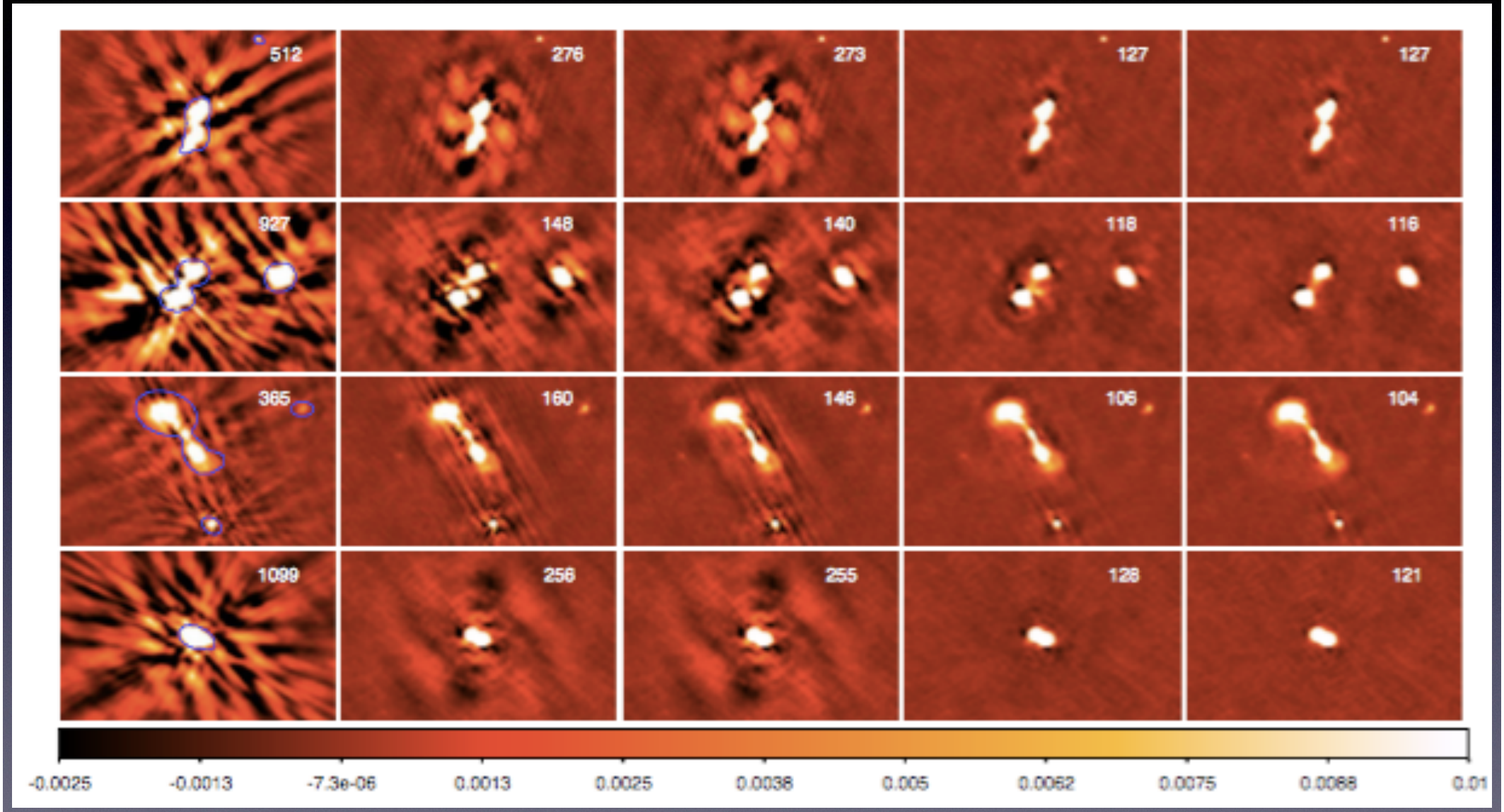
- Subtract all sources from data
- Define facet centers

- 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

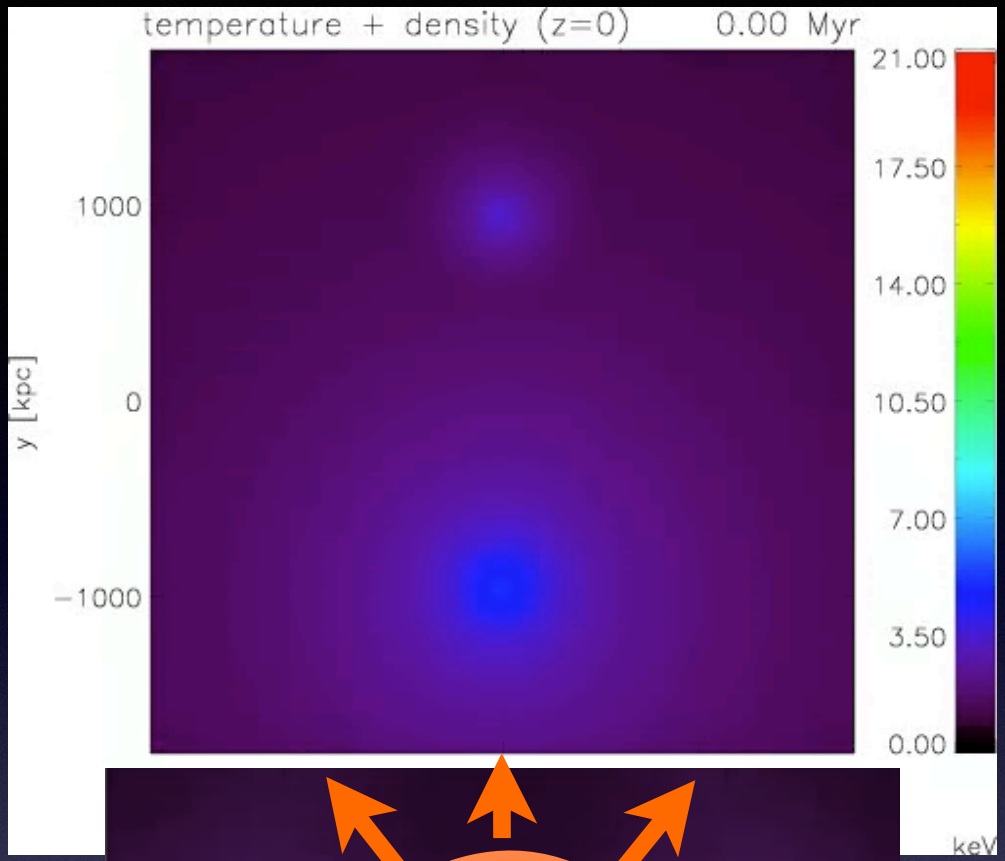
loop over facet

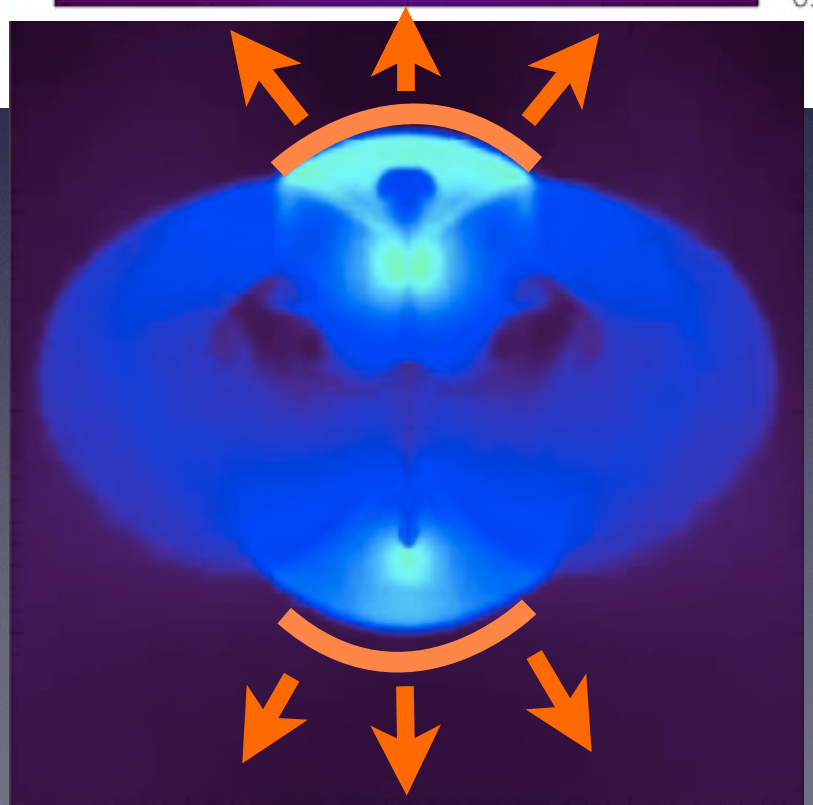




van Weeren etal. 2016

Simulation X-ray gas of two colliding clusters

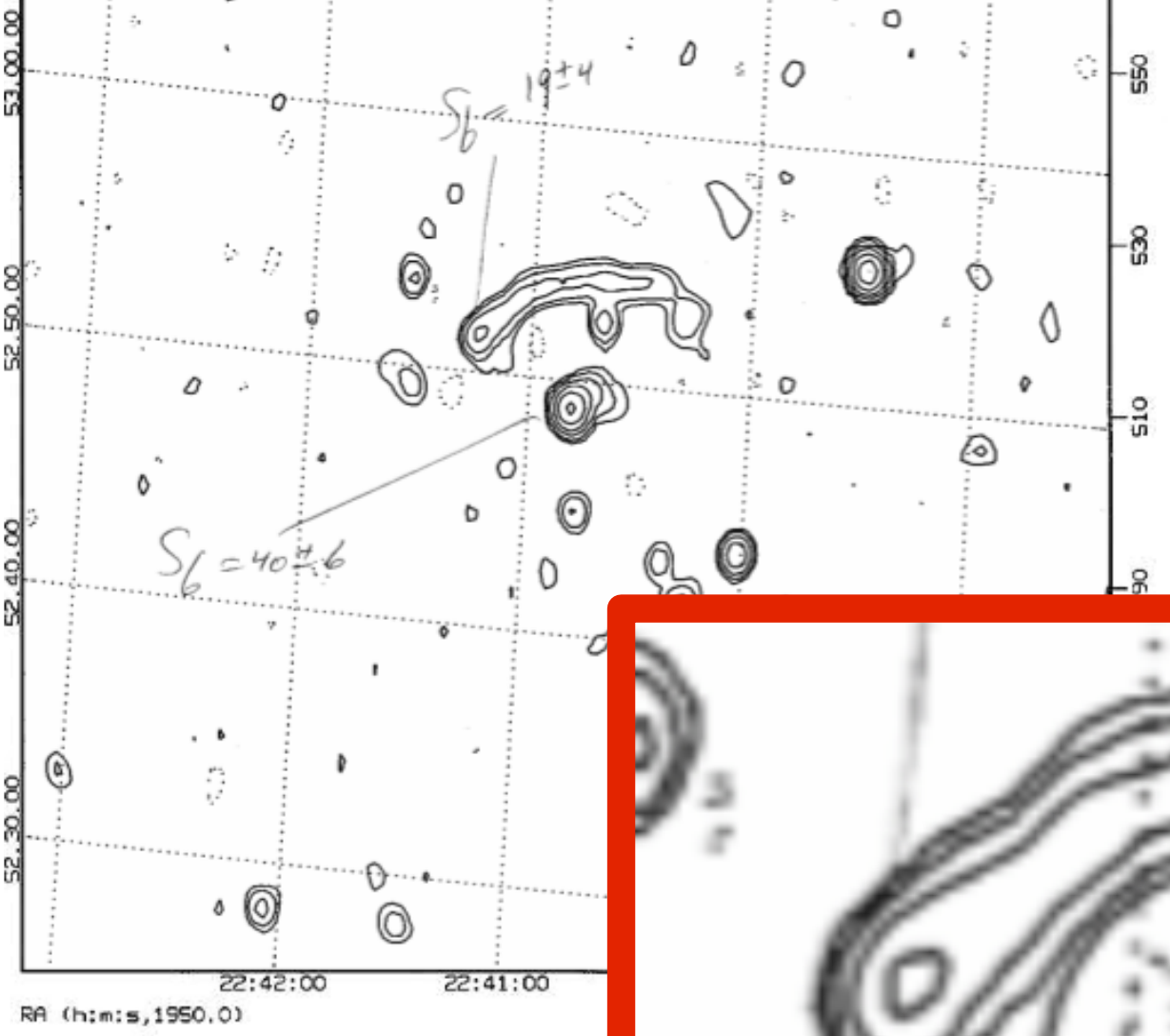


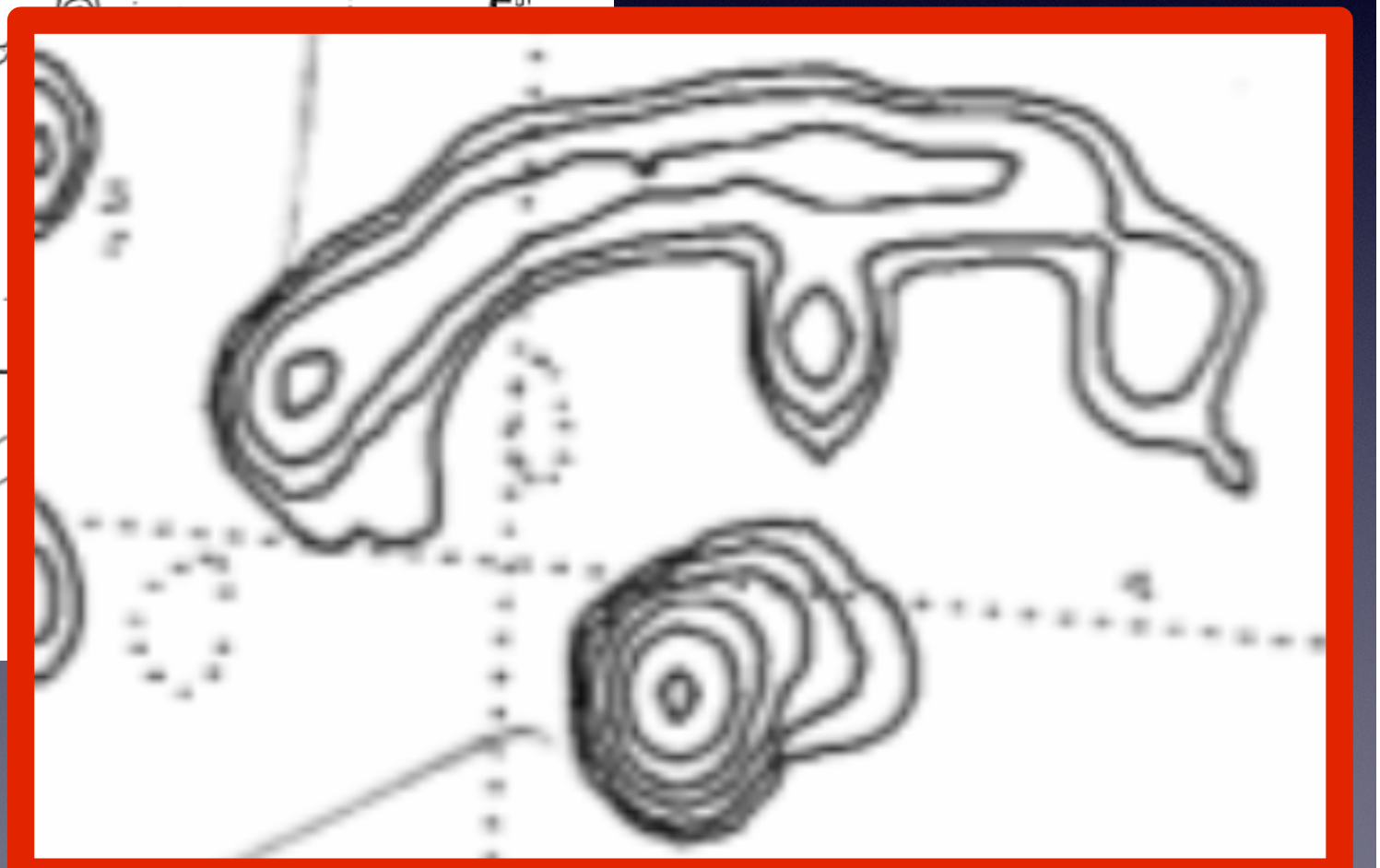


At the shock: particle acceleration
with a bit of magnetic field this gives synchrotron radiation

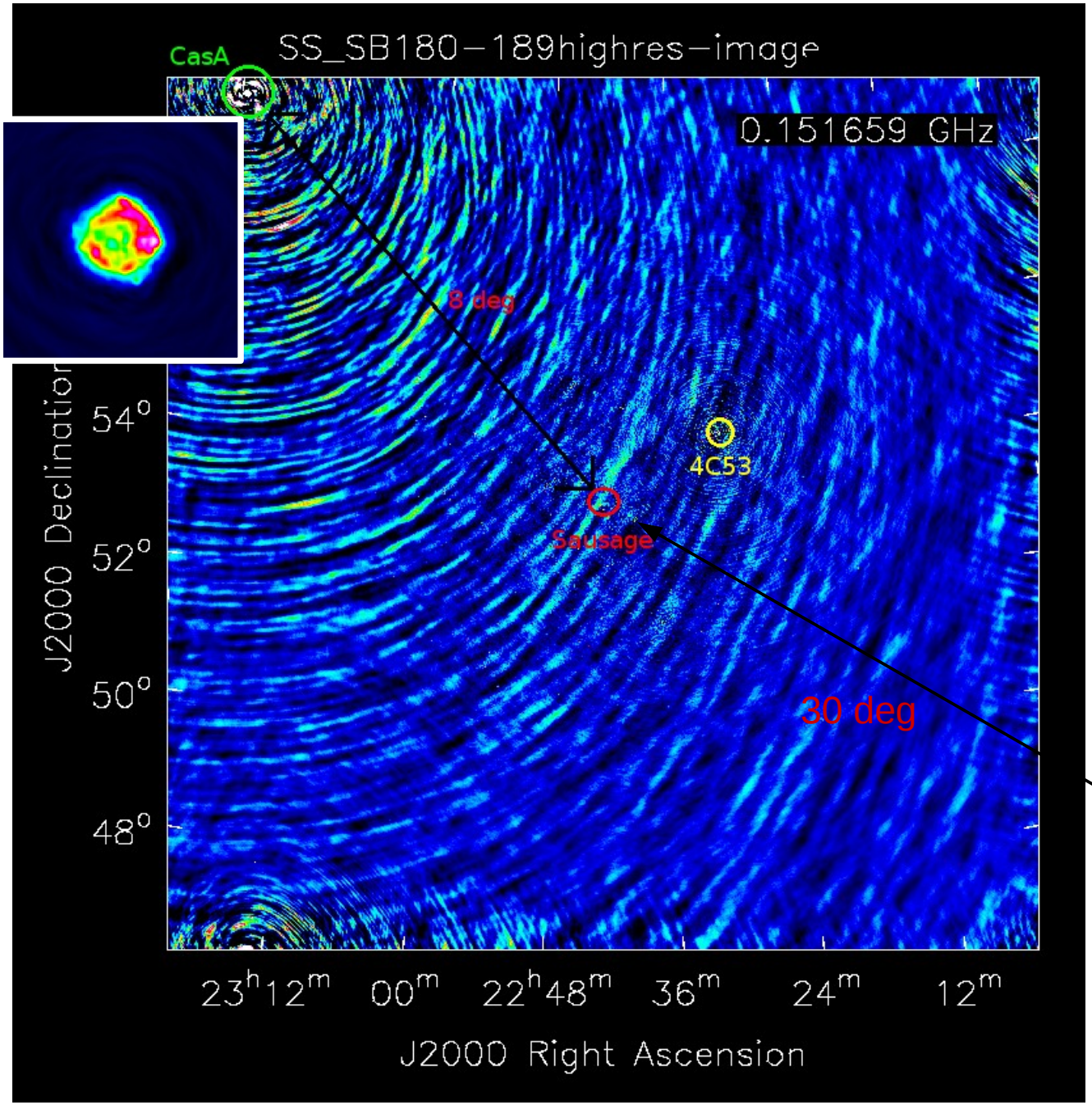
classification:
relic radio sources

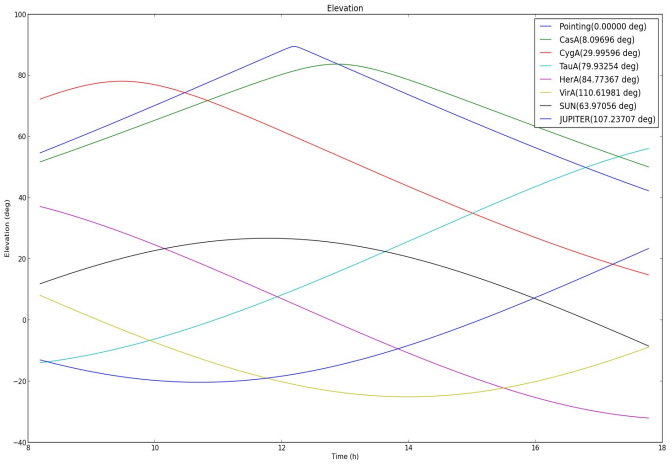
~ 20 years earlier....(Ger de Bruyn)



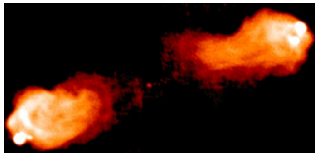


10' head-tail ?

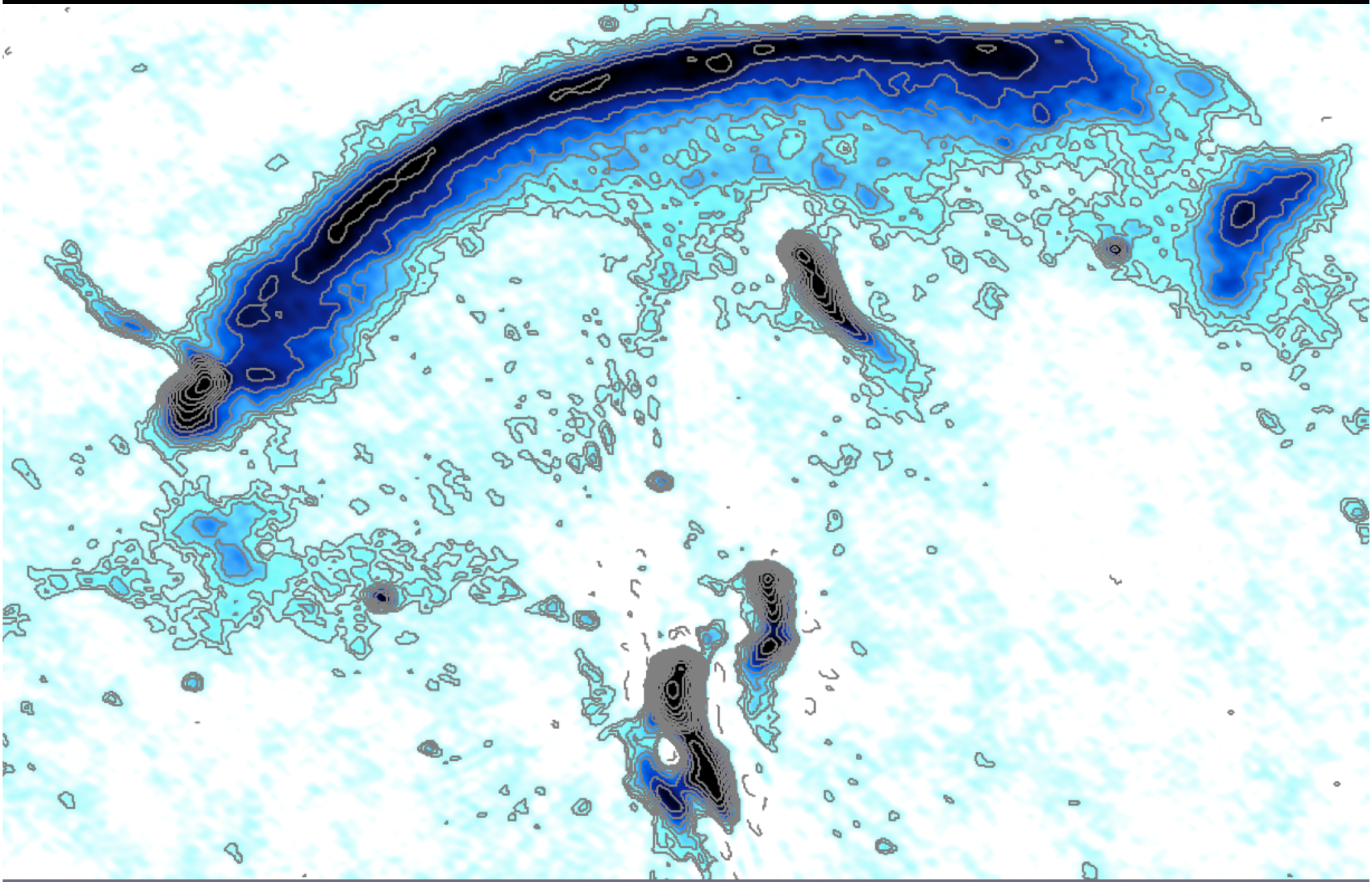


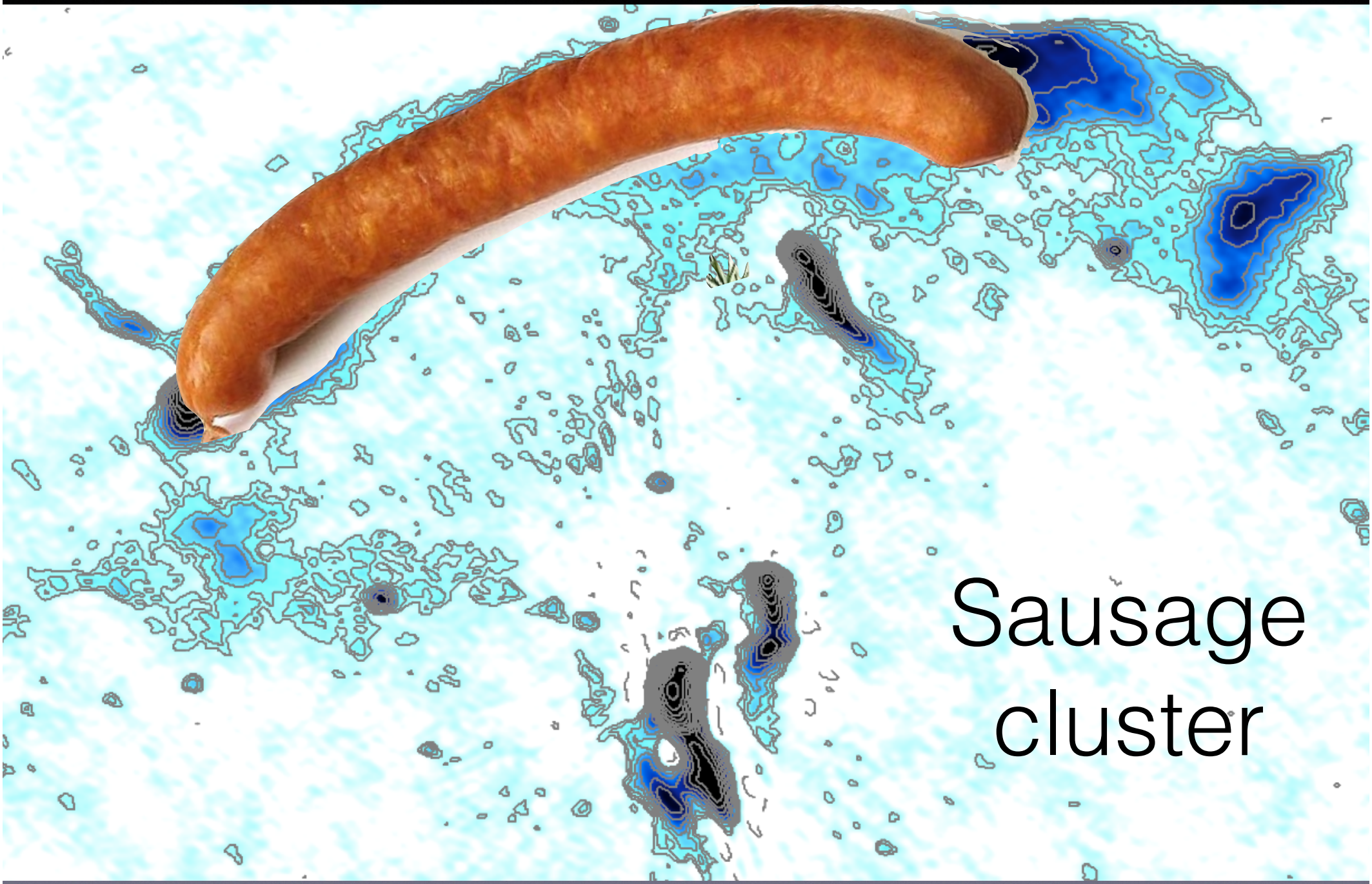


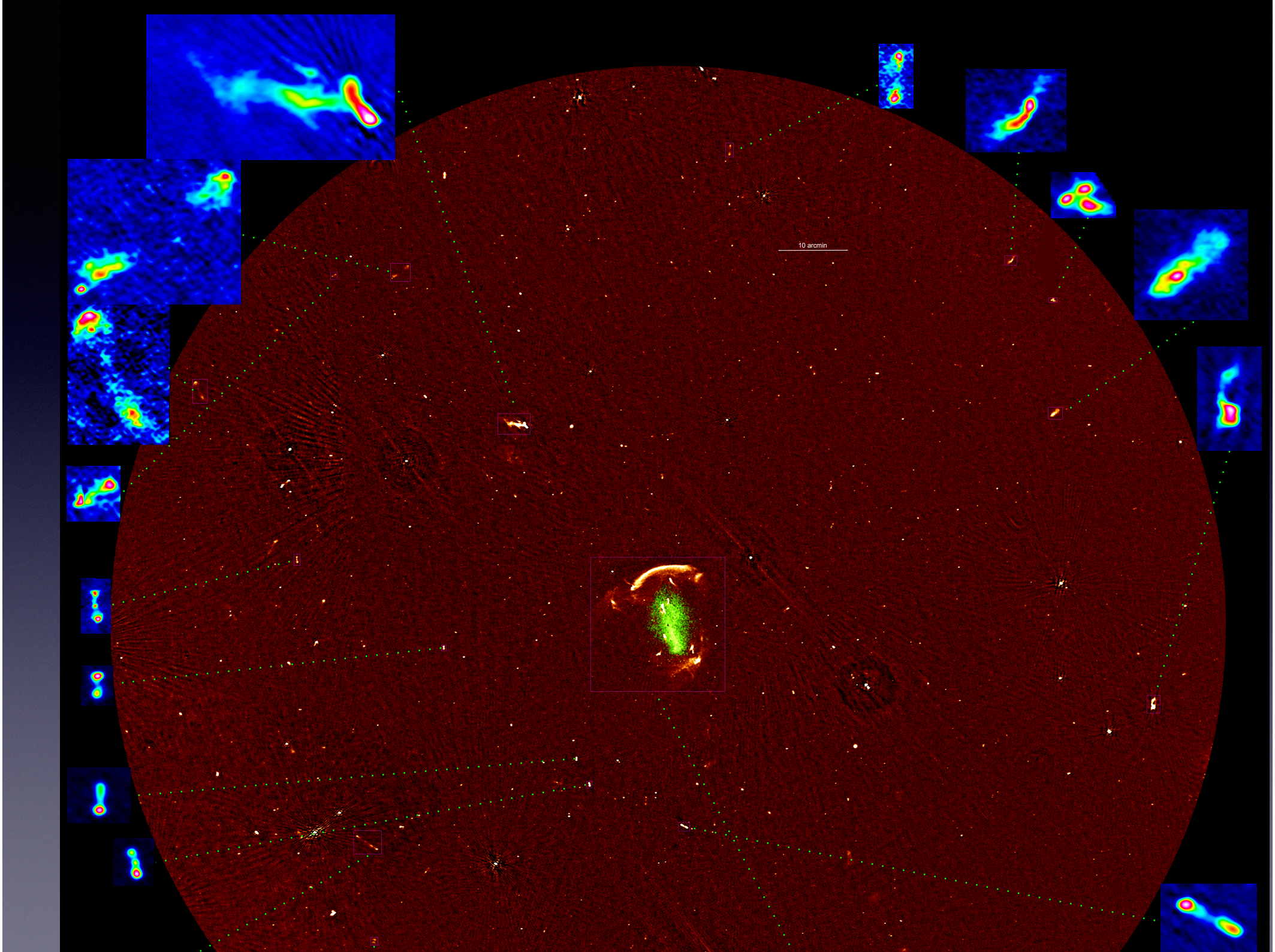
- CasA skymodel: 69MHz, 10” (Reinout van Weeren)
- Data resolution: 64ch, 1s
- Time step: 4s
- Freq. step: 16ch

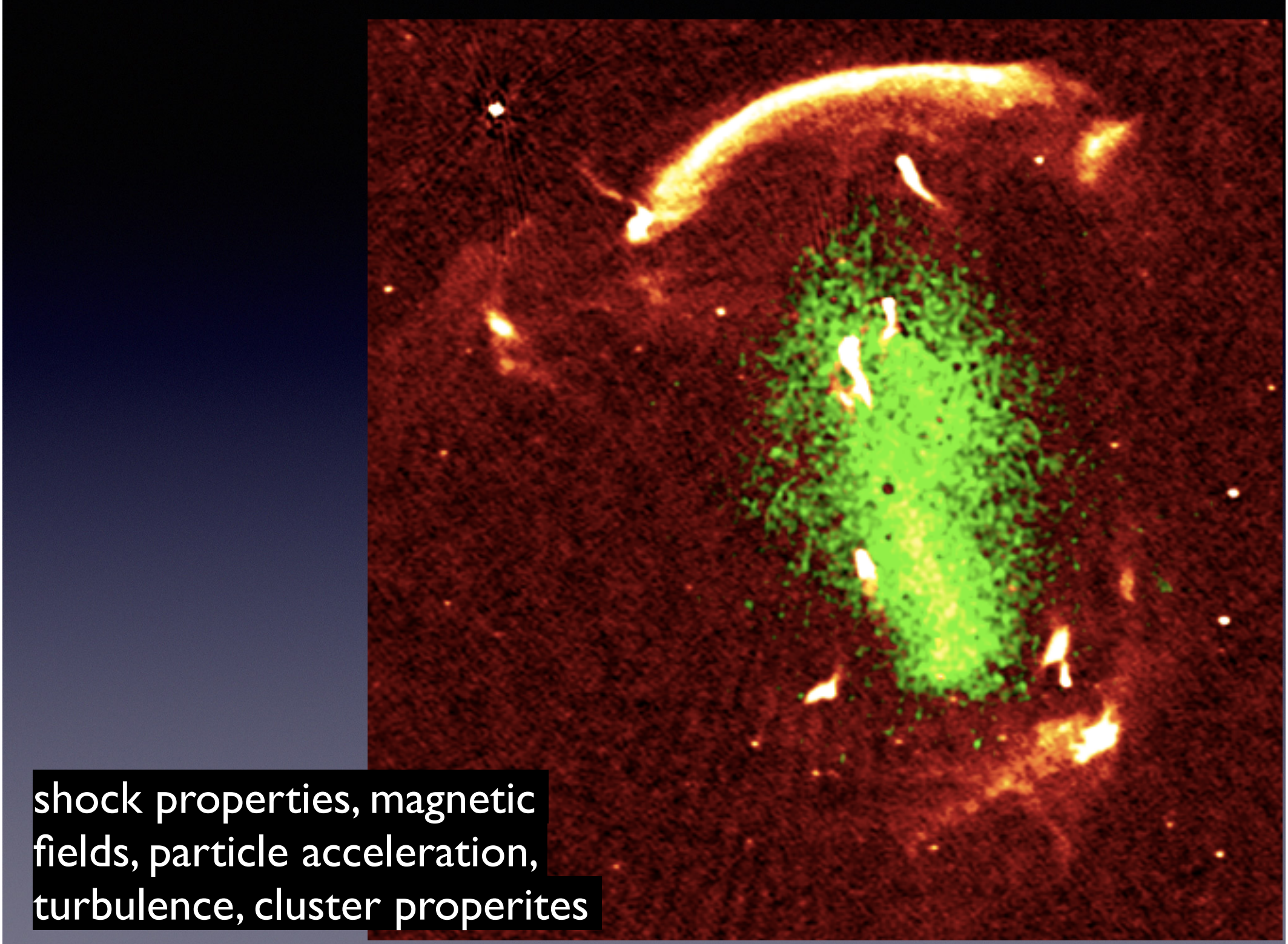


CygA




Sausage
cluster


10 arcmin



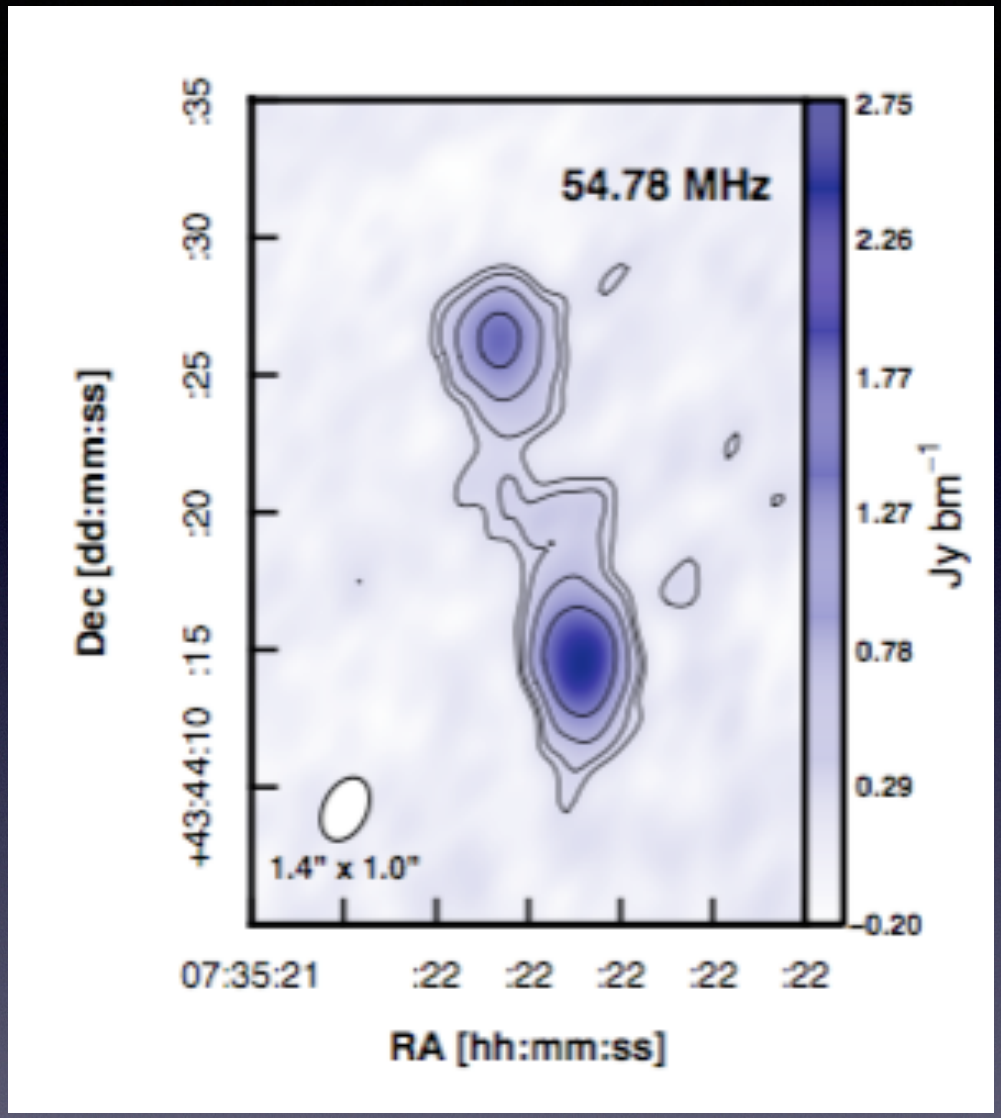
shock properties, magnetic fields, particle acceleration, turbulence, cluster properites

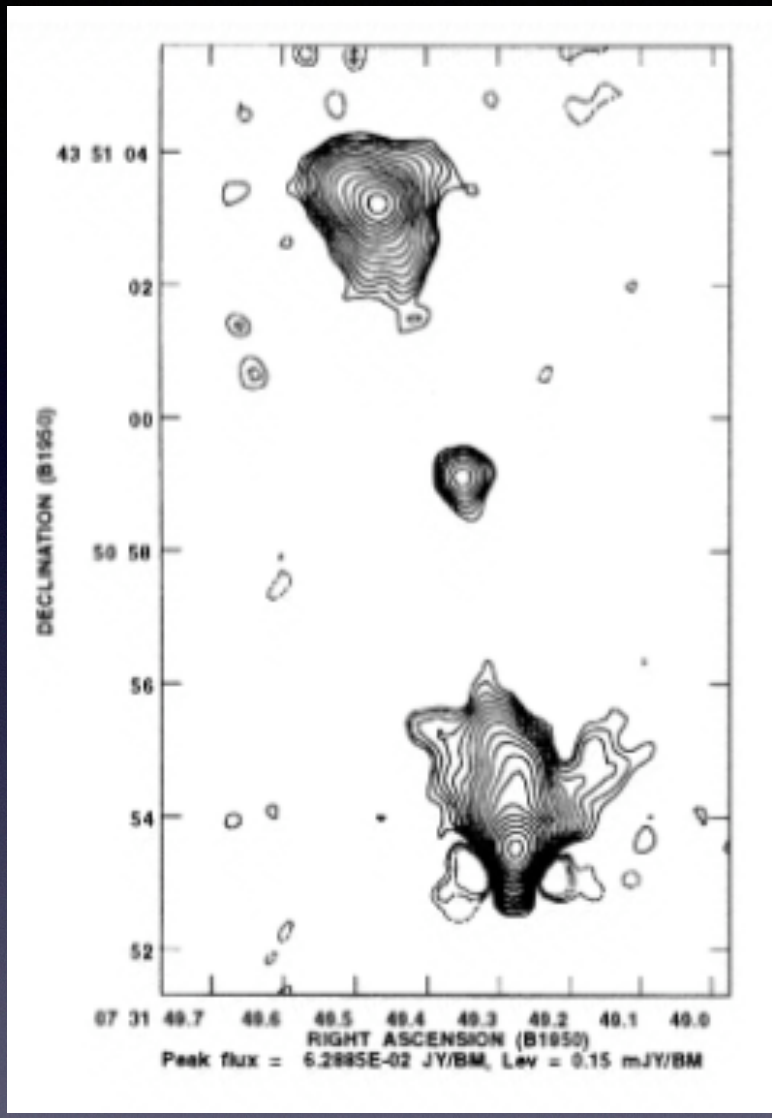
Donnert et al. 2016

Name	Value	
$d_{\rm center}$	1.3 Mpc	Distance to center
z	0.188	Redshift
Length	2 Mpc	Longest Extent on the sky
Width	200 kpc	Extent of the brightness profile
Ψ	< 10 deg	Angle into plane of sky
M	4.6	Mach number
$T_{\rm up}$	3.0 keV	Upstream temperature
$n_{\rm th,up}$	1.6×10^{-4} cm^{-3}	Upstream thermal number density
s	2.1	Injection spectral index of CRe
$v_{\rm dw}$	1184 km/s	Downwind speed
$c_{\rm s,up}$	902 km/s	Sound speed of upstream medium
$v_{\rm shock}$	4144 km/s	Shock speed in upstream medium
σ	3.5	Compression ratio
$\sigma_{\rm Temp}$	7.5	Thermal compression ratio
$n_{\rm th,dw}$	5.6×10^{-4} cm^{-3}	Downwind thermal number density
$T_{\rm th,dw}$	22.4 keV	Downwind temperature
$B_{\rm IC}$	4.6 μG	$B_{\rm CMB}$ at z=0.188

Plus merger geometry (2:1 mass ratio, zero impact parameter and time since core passage ~1Gyr

4C+43.15: a powerful radio galaxy at z=2.5

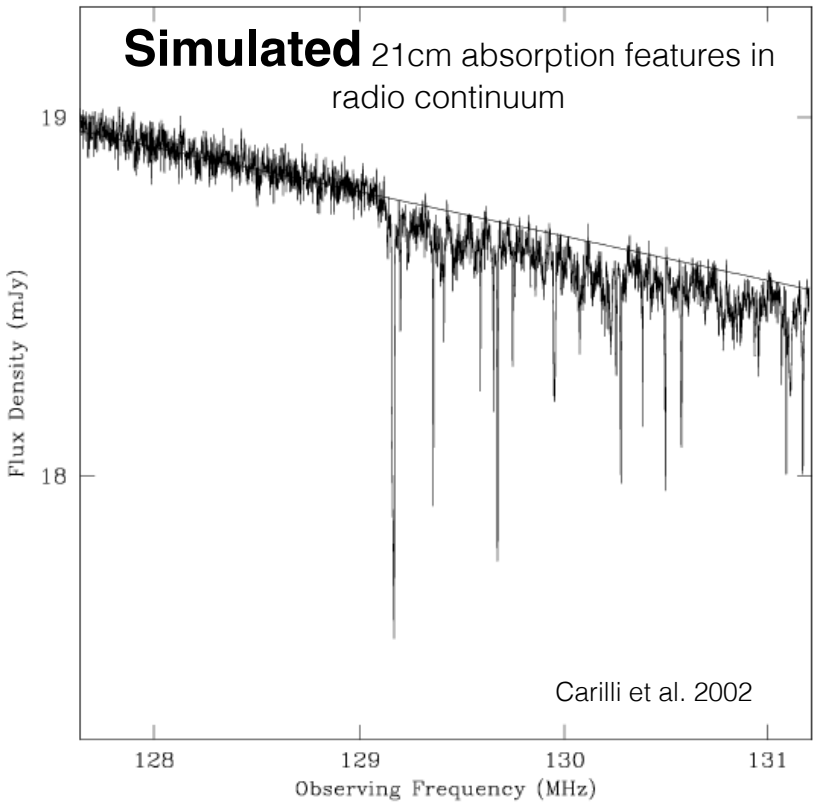


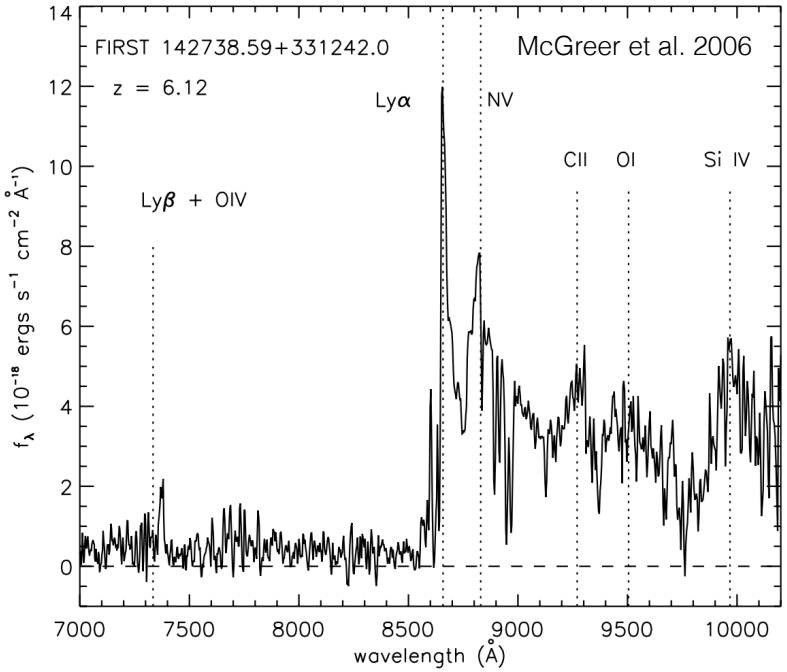


LOFAR 58 MHz, 40 mJy
(2 times thermal noise, 4.5 hrs obs.)
Resolution: 0.9 * 0.6 arcsec
Morabito et al. in prep

VLA 4.6 GHz
Carilli et al. 1997

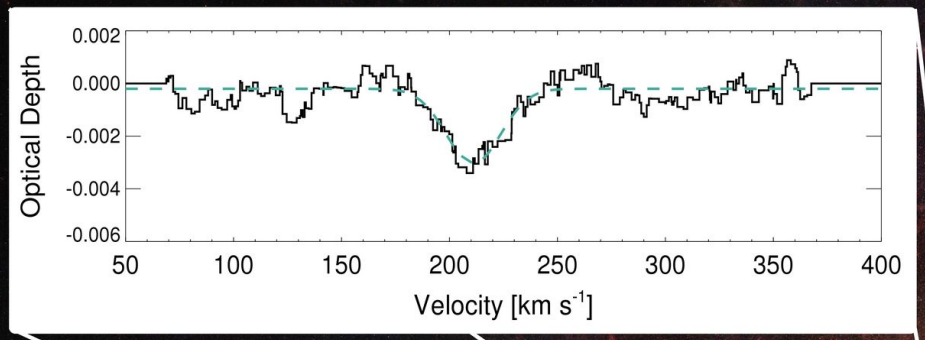
z = 6.12 Radio Loud QSO as seen in Bootes field



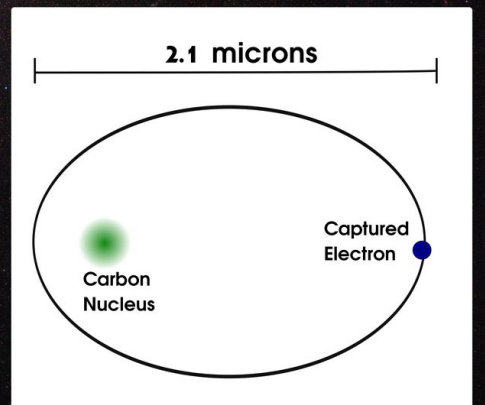


Williams, Retana, Saxena, Duncan

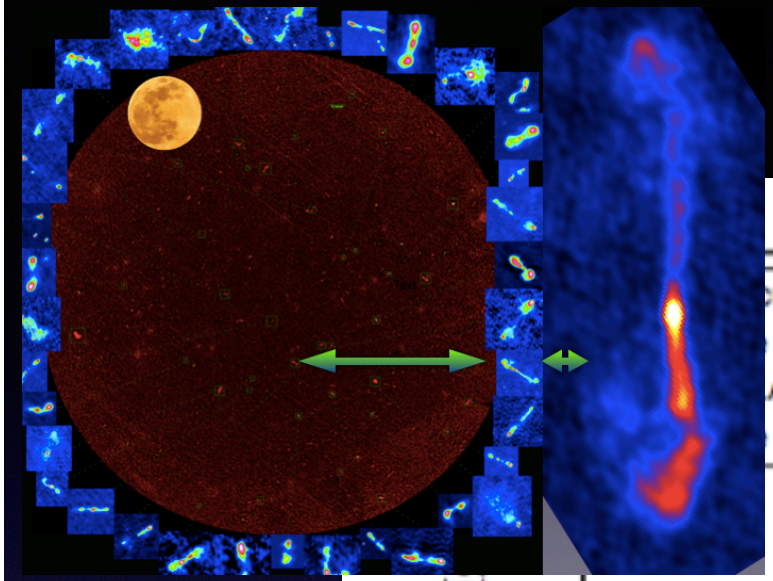
LOFAR discovers largest carbon atoms outside our Milky Way

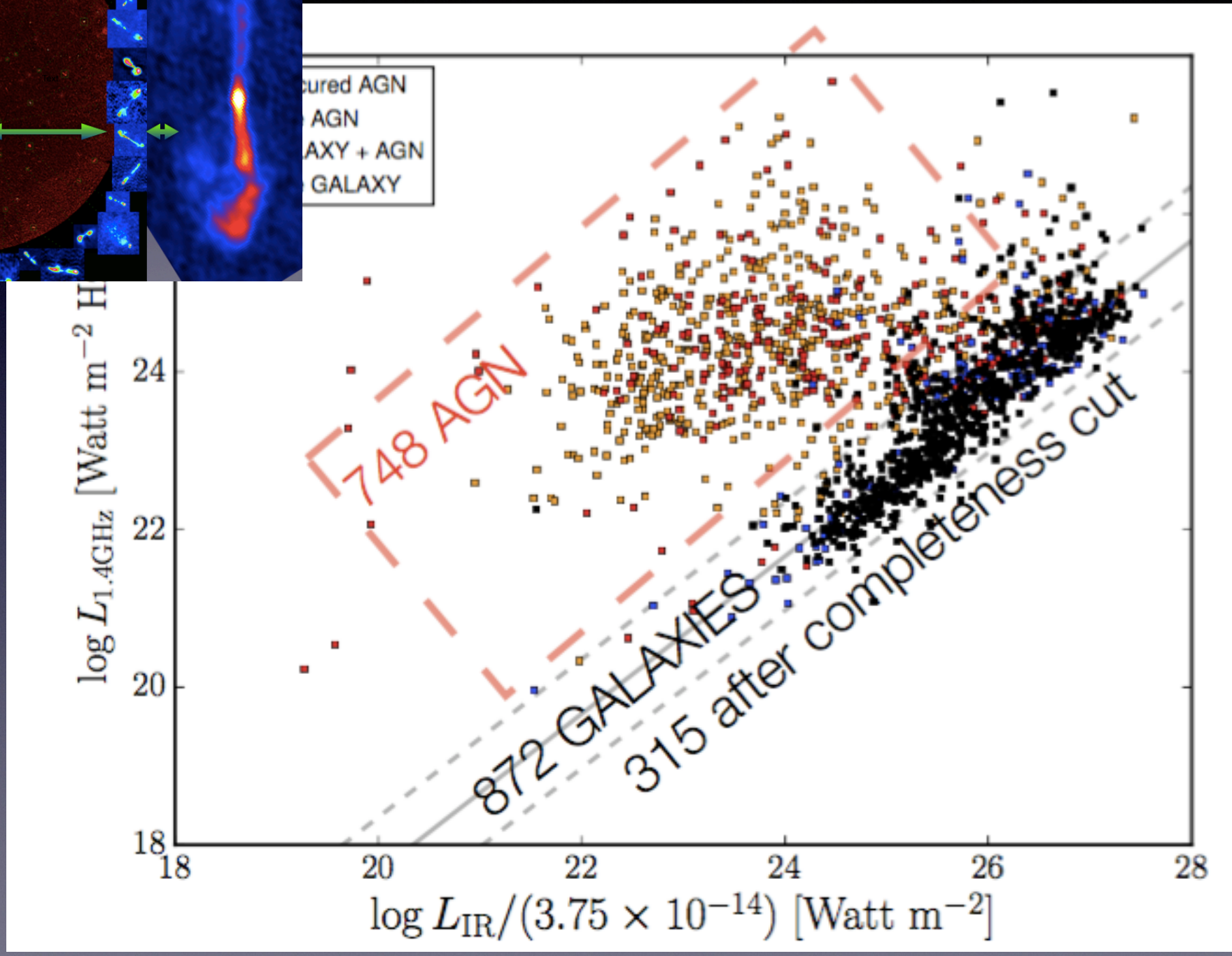


Carbon radio recombination lines (n~400-500): tracing the cold (~100 K), diffuse (n< 1 cm^3) medium

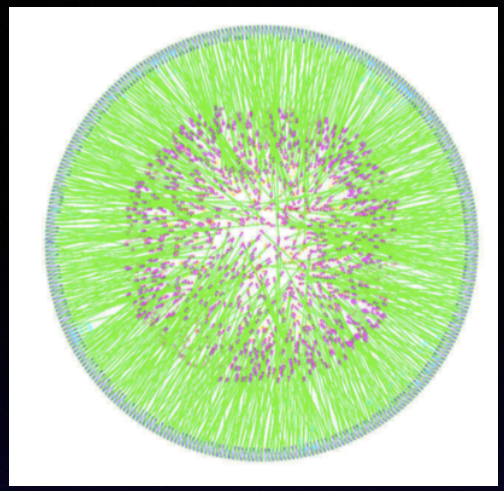


AGN/starburst studies

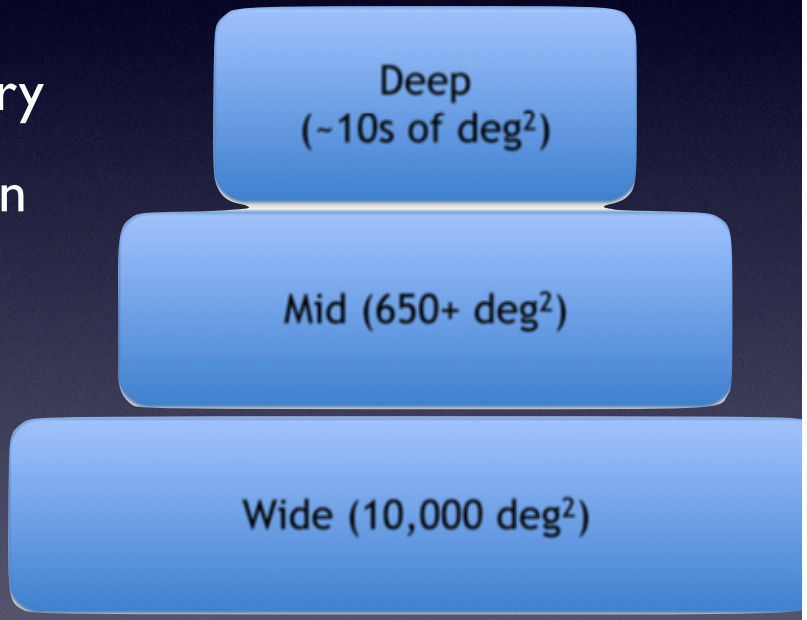




WEAVE 1000 fibre spectrograph on WHT



- 1 million fibre projects for LOFAR follow-up starting in 2018
- Science
  - Star-formation evolution across cosmic history
  - Co-evolution of black-hole and star formation - physics of AGN feedback
  - Finding radio galaxies in the Epoch of Reionisation at z > 6
- Three tier survey design



Euclid map 15,000 degrees^2 in o and IR for weak lensing and BAOs
Launch 2020