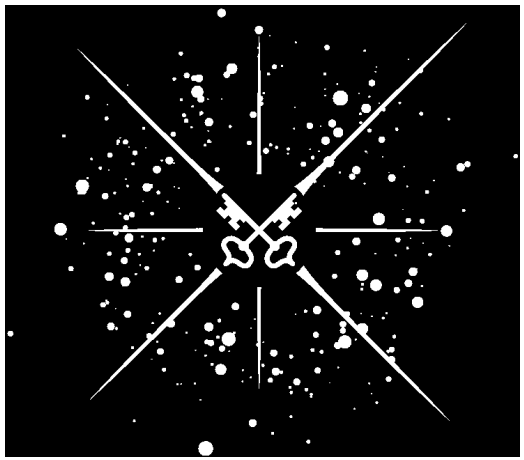
Extragalactic surveys with LOFAR

Huub Röttgering, Leiden



LOFAR

- Core Team
  - Peter Barthel, George Miley, Raffaella Morganti, HR, Ignas Snellen,
- Present Team
  - Rainer Beck, Philip Best, Jim Condon, Alastair Edge, Torsten Ensslin, Heino Falcke,Marijn Franx, Mike Garrett, Huib Intema, Frank Israel, Matt Jarvis, Konrad Kuijken, Rudolf Le Poole, Niruj Mohan,Ronald Nijboer,Amitesh Omar,Tom Oosterloo, Richard Schilizzi, Dominic Schnitzeler, Richard Strom, Cyril Tasse, Alexander Usov, Ed Valentijn, Ilse van Bemmel, Paul van der Werf, Jacco Vink, Willem Jan Vriend, Corina Vogt, Michael Wise
- Future (core-) members
  - Specific expertise, specific access to data/telescopes
  - As a result of more countries joining LOFAR

Why surveys?

- LOFAR is a natural survey instrument
  - Large field of view: 30 MHz : ~10 degrees
- Low radio frequency imaging is all sky imaging
  - Cf Hipparcos, Gaia
  - Need information from a large fraction of the sky for proper calibration of for example the ionosphere
- A natural compliment to other key programs
  - Reionisation
  - Transient surveys
- Data reduction is a real challenge and computer intense: delivering final data products is a real challenge
  - A linux cluster of 1000 pc needed for data reduction

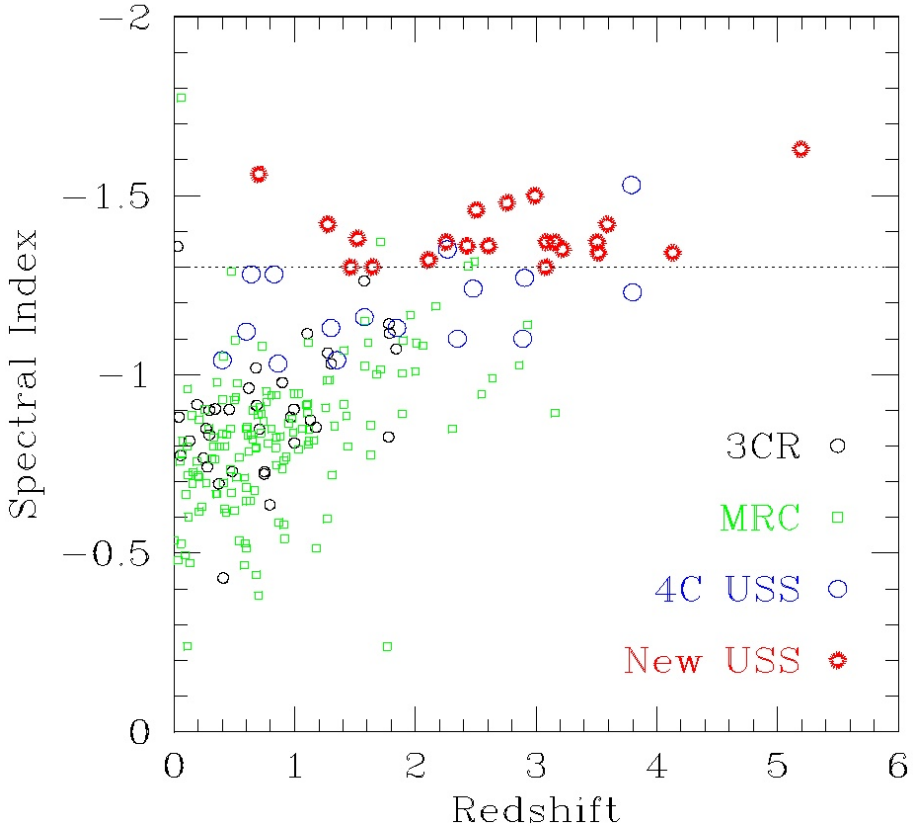
A well defined set of surveys will maximize the scientific usage of LOFAR

Main survey science

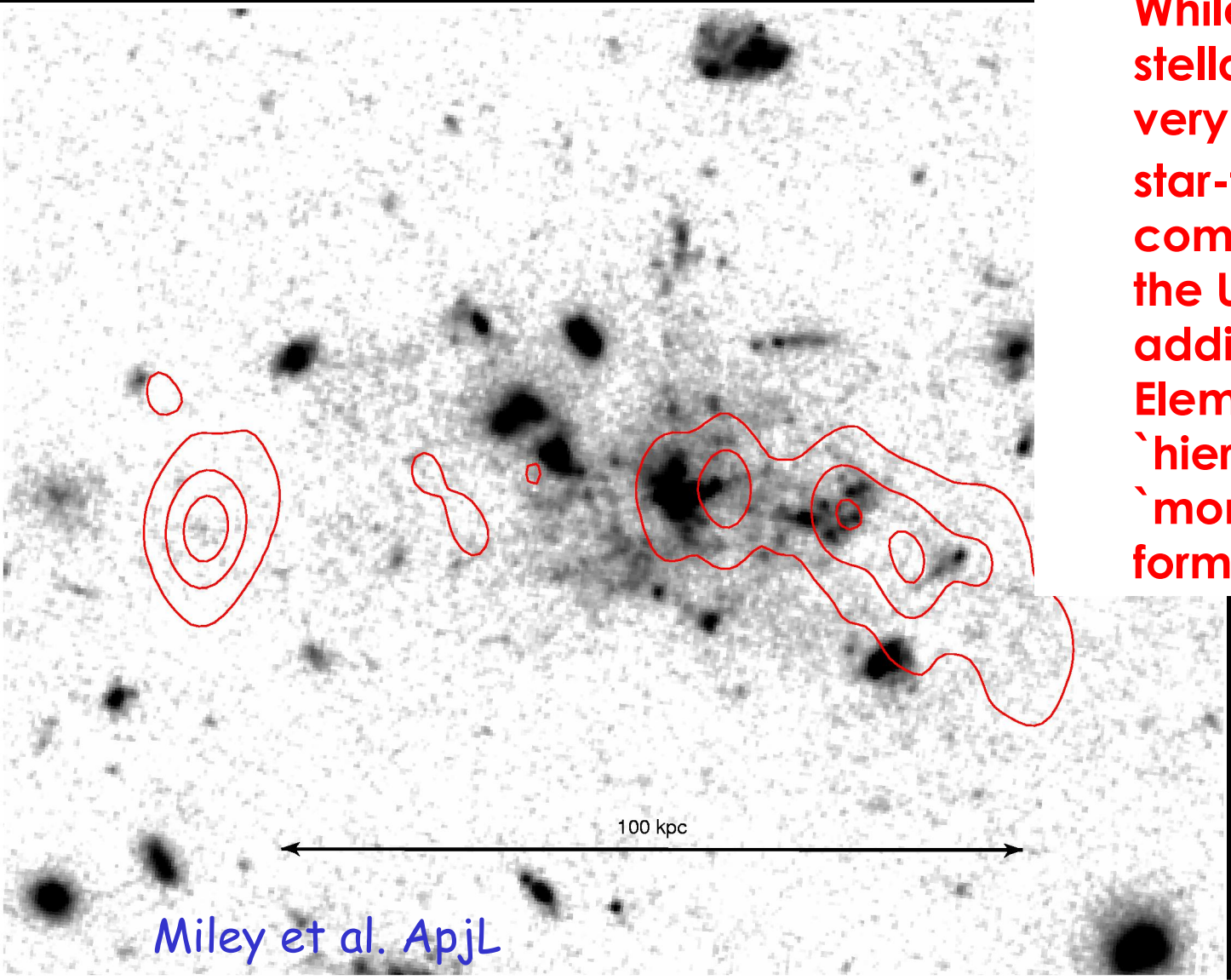
- Distant radio galaxies
- Diffuse radio emission from clusters
- Starburst galaxies

Locating z>6 radio galaxies

- Basis
  - Redshift ~ spectral index
  - Most distant radio sources luminous at low frequencies
- Science
  - Formation and evolution of massive blackholes, galaxies and clusters
  - As probes of epoch before reionisation to study HI absorption

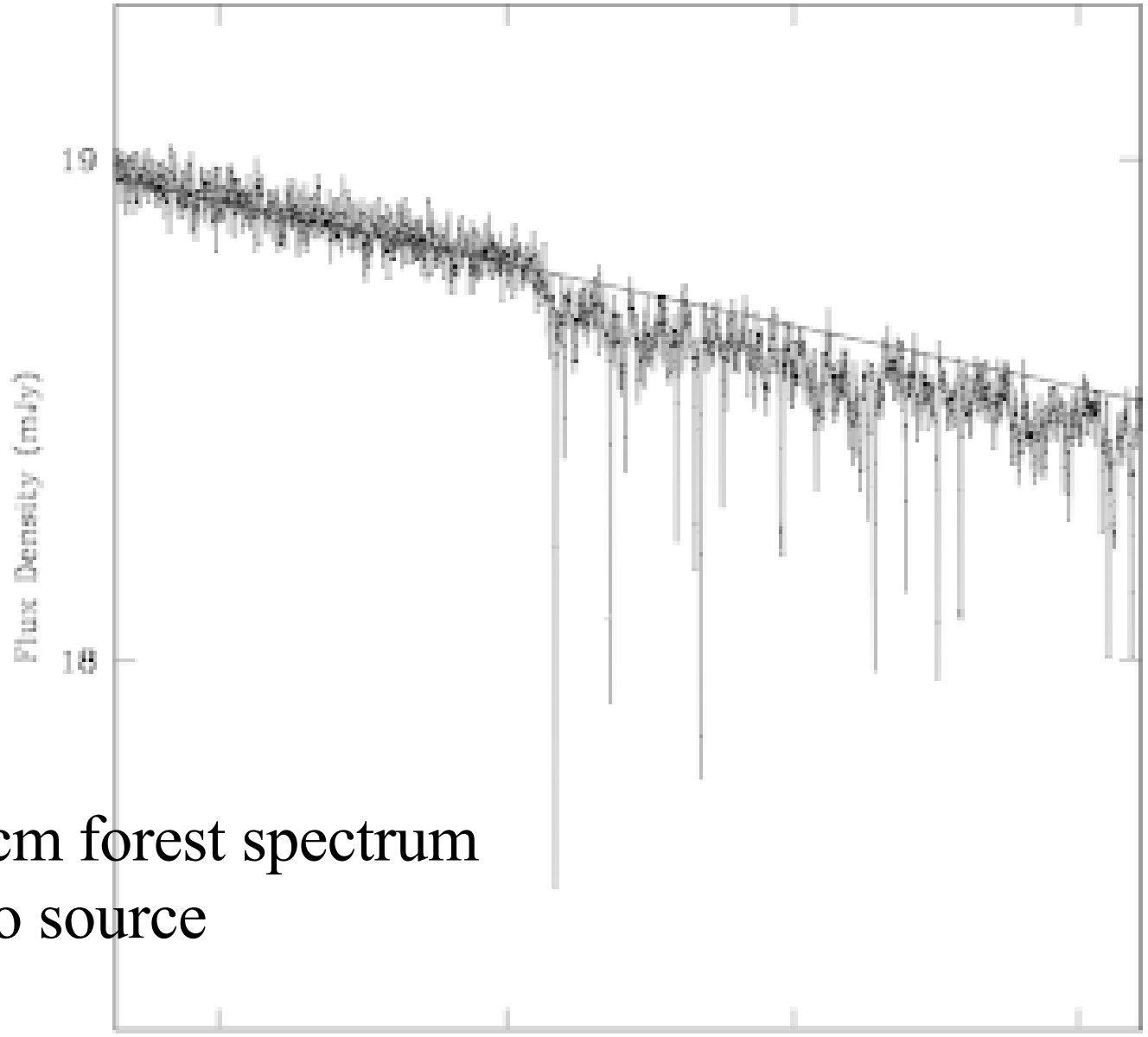


ACS / HST imaging of MRC1138: a brightest cluster galaxy assembly at z=2.2



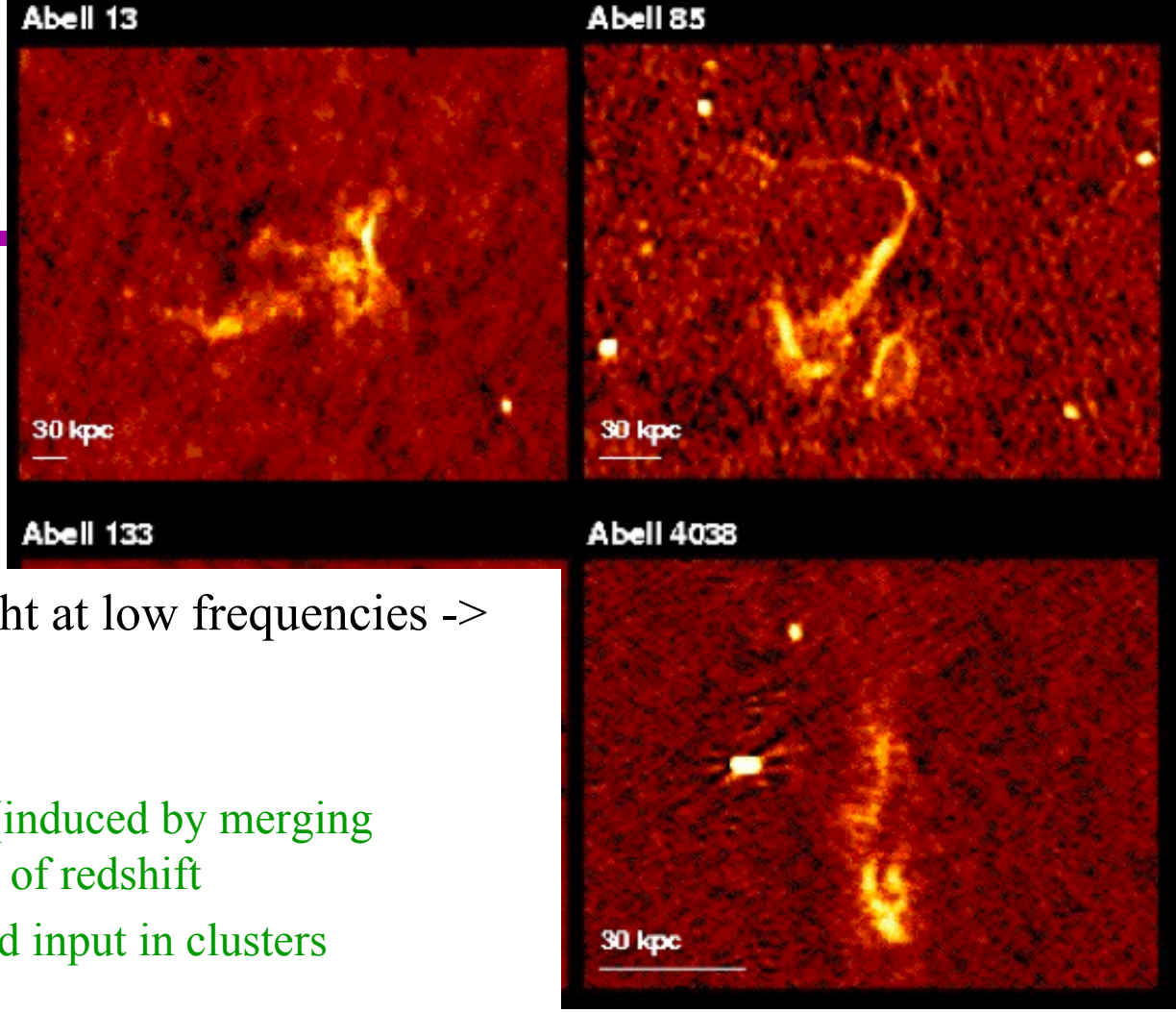
Miley et al. ApjL

While mass of central stellar component is very high (>10^{11} M_0), star-forming companions seen in the UV add little additional mass: Elements of both `hierarchical' and `monolithical' formation processes



Simulated 21 cm forest spectrum
For a z=8 radio source
Carilli 2005

Cluster radio sources



- Diffuse, extended and bright at low frequencies -> LOFAR
- Issues
  - Dynamics of cluster gas (induced by merging subclusters) as a function of redshift
  - Energy and magnetic field input in clusters
  - AGN feedback processes
- Simpel modeling: > few thousand halos up to z=1 (Ensslin and Rottgering 2002, also see also Cassano, this conference)

Distant starburst galaxies

- Dominant population at low flux densities
- in few years observing: 10^8 galaxies
  - Star formation rate of 10 M/yr up to z=3

    100 z=8

    (factor of 10 deeper than present radio surveys)
- Important complement
  - Scuba-2,Spitzer, Herschel, Omegacam, NGST, VISTA, ALMA
- Star formation history, nature of starbursts, clustering

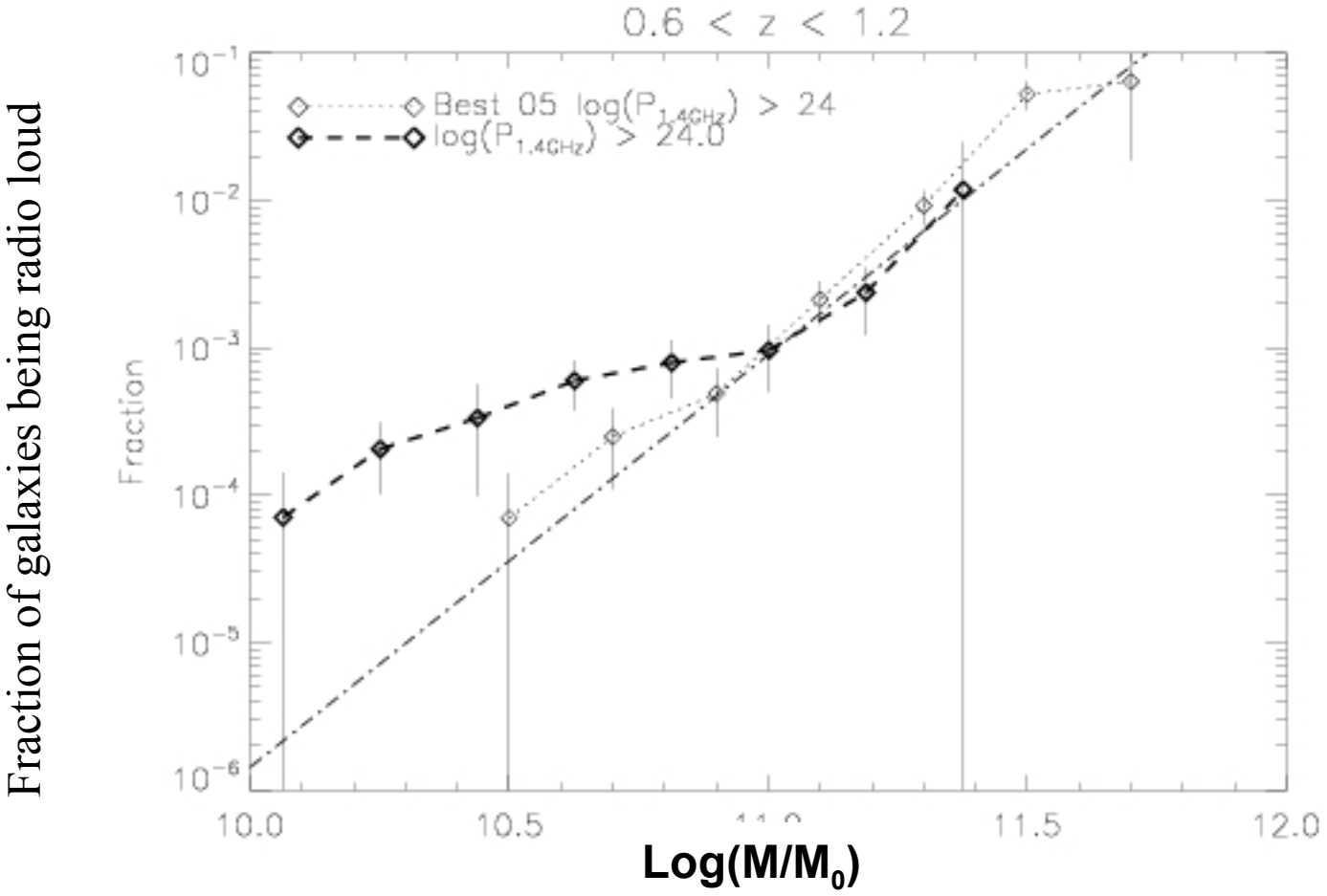
Main Drivers

- 100 z ~ 6 radio galaxies
  - Formation and evolution of massive galaxies, black holes and clusters
- 100 cluster radio sources at z ~ 1
  - Dynamics of cluster gas, evolution of cluster wide magnetic fields
- 100 clusters of starbursts at z>2
  - SFR ~ 10 M_0/yr at z=2-3
- Serendipity
  - << 30 MHz

Other important topics

- AGN and radio source physics
  - Giant radio sources
  - Young radio sources
- Nearby normal galaxies
  - Warm ism
  - Halos
- Large scale structure
  - Radio emission from filaments
  - Strong Lensing
  - Weak lensing
  - Clustering of radio sources
- Galactic
  - Supernova Remnants
  - HII regions
  - Recombination line
  - Exo-planets
  - Pulsars

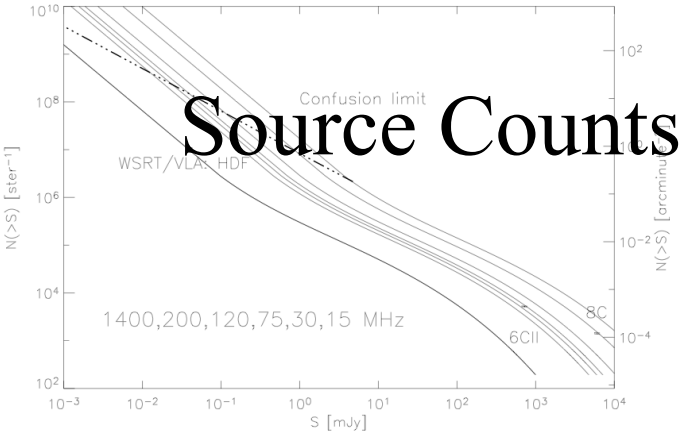
Results combining GMRT (500 radio sources) and CFHTL surveys (5 million galaxies)



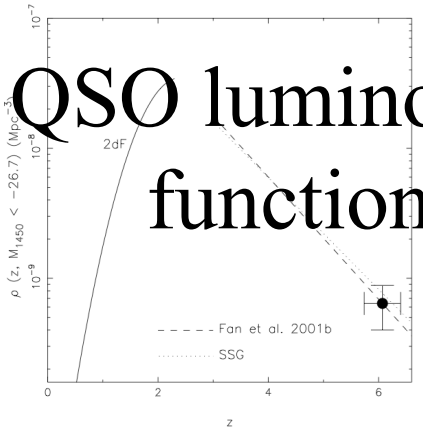
→ Low mass radio sources evolve more than high mass

Thesis : Cyril Tasse

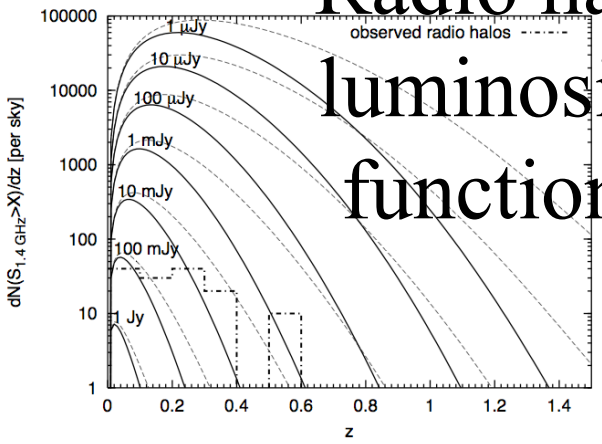
Compromising area, depth, frequency range



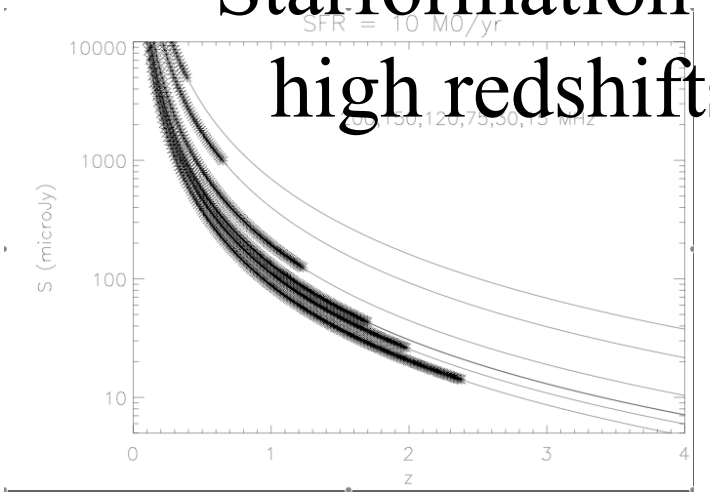
Source Counts



QSO luminosity function



Radio halo luminosity functions



Starformation at high redshifts

Draft survey plan for 100 km LOFAR

ν MHz (1)	Flux density mJy (2)	Area	Source density arcmin^{-2} (3)	Number Sources (4)	Int. time 1 beam hour (5)	Total 4 beam years (6)	Main aim
15	4.7	2π sr	0.2	1.3×10^7	48	0.07	Serendipity
30	1.0	2π sr	0.7	5.4×10^7	38	0.22	$z \sim 6$ radio galaxies
60	1.0	2π sr	0.3	2.2×10^7	24	0.56	Spectral information
120	0.043	2π sr	11.6	8.6×10^8	23	2.17	Distant halos in clusters $z \sim 6$ radio galaxies
200	0.014	250 deg^2	32.2	3.0×10^7	191	0.61	Distant starbursts

Notes:
The flux limit given is at the 3 sigma level, indicating that the vast majority of the sources brighter than this limit should be detected.

- Commissioning surveys / Local sky model
  - Testing calibration procedures
  - Nice low frequency compliment for NVSS
  - Low frequency spectra for nearby galaxies

ν	λ	Sensitivity	Resolution	Primary beam	Number beams
MHz	m	mJy/beam	arcsec	degree	
(1)	(2)	(3)	(4)	(5)	(6)
15	20.0	33	335	23	50
30	10.0	6	167	11.5	200
60	5.0	5	84	5.7	800
75	4.0	4	67	4.6	1250
120	2.5	0.2	42	2.9	3200
150	2.0	0.2	34	2.3	5000
200	1.5	0.2	25	1.7	8888
240	1.2	0.2	21	1.4	12800

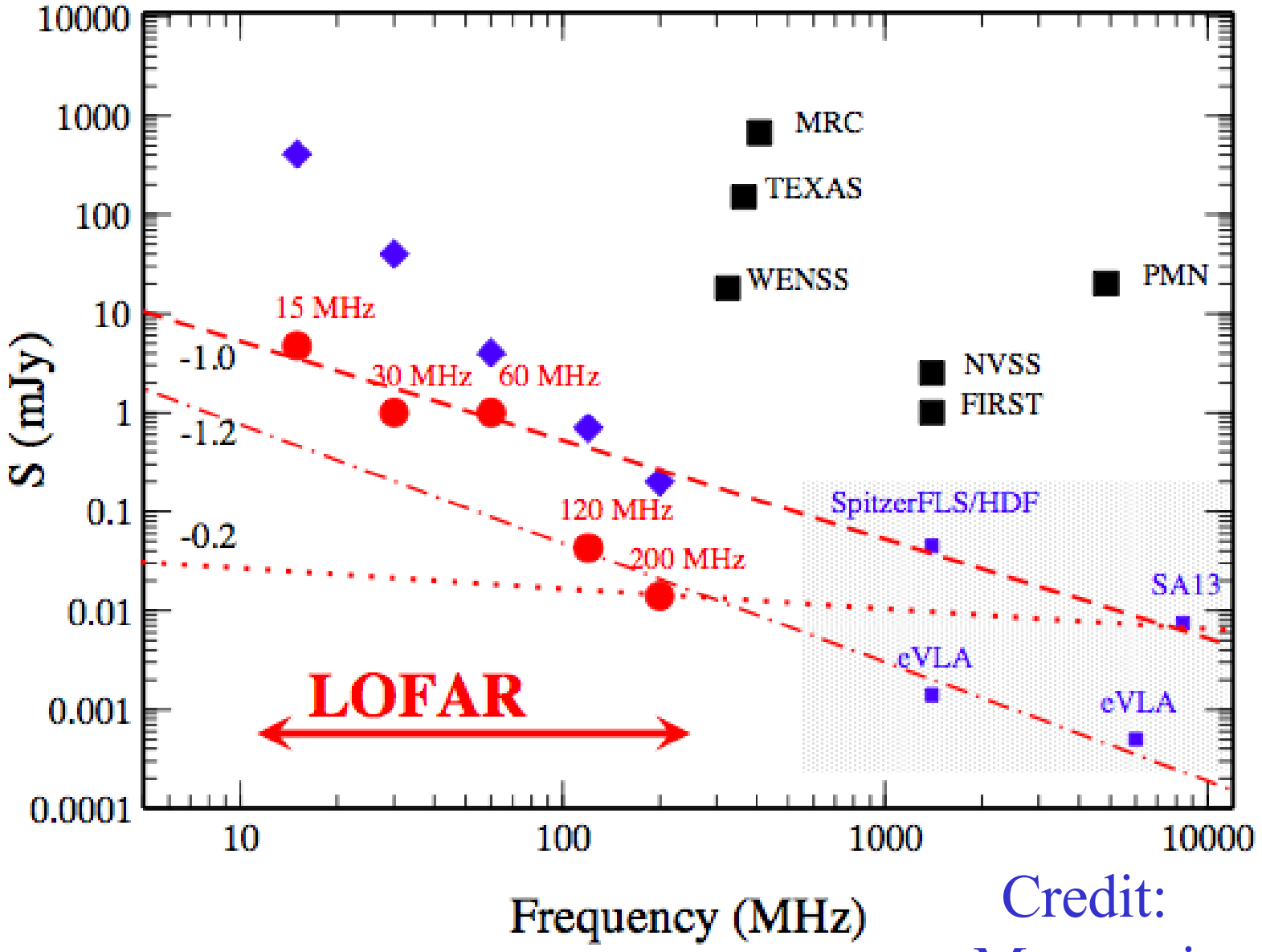
Table 3.2: *Main scientific capabilities of the 15 km LOFAR array. Notes for columns: (3) Point source sensitivity given as the rms map noise for 1 hour integration time, 2 polarizations and 4 MHz bandwidth, (5) (Primary) beam size calculated for a 50 meter station, (6) Number of independent beams covering 2π sterradian. The sensitivity numbers for 15, 60, 150, 240 MHz have been provided by Robert Braun (priv. com.).*

Table 1.1: *Proposed surveys with the 15 km LOFAR*

ν MHz (1)	Flux† density mJy (2)	Area (3)	Source density arcmin^{-2} (4)	Number Sources (5)	Int. time 1 beam hour (6)	Total 1 beam week (7)
15	410	2π sr	0.004	3.0e+05	0.1	0.02
30	40	2π sr	0.02	1.2e+06	0.2	0.26
60	4	2π sr	0.07	~1e+06	13.0	6
120	0.7	2π sr	0.3	1.9e+07	0.9	17
200	0.2	250 deg^2	0.7	6.8e+05	7.1	5

Notes:
† The specified flux limits given are 3-sigma values.

Radio Surveys



Credit: Morganti