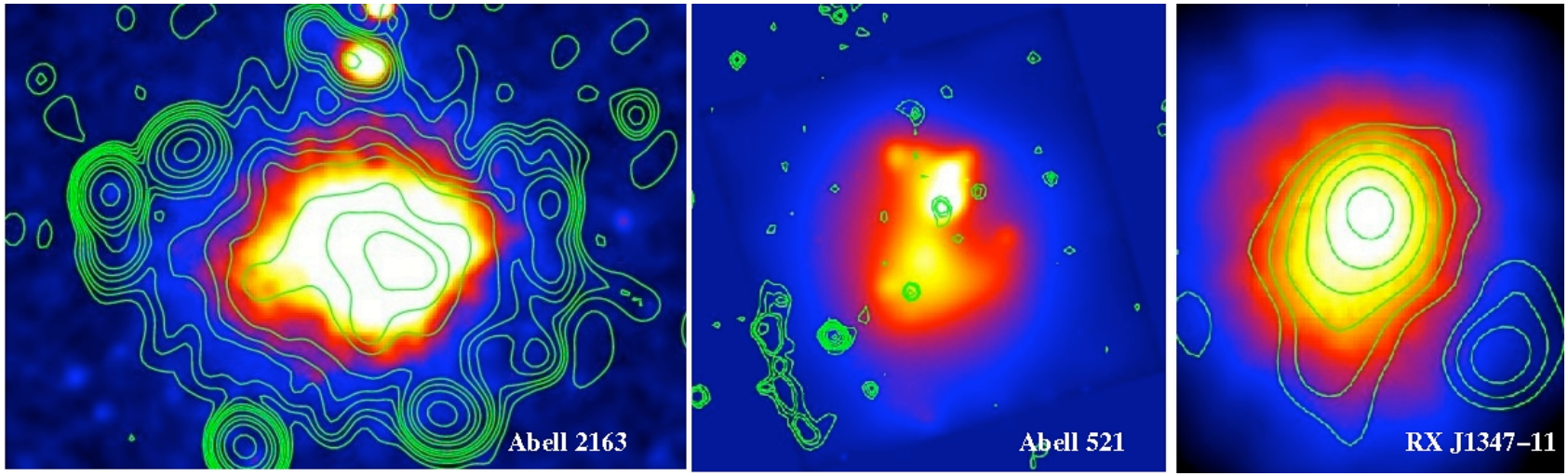
The cosmic radio web: Prospects for LOFAR and SKA

Matthias Hoeft
Thüringer Landessternwarte Tautenburg

Sebastian Nuza, Reinout van Weeren, Marcus Brüggen,
Stefan Gottlöber, Huub Röttgering, Gustavo Yepes

Radio emission in galaxy clusters

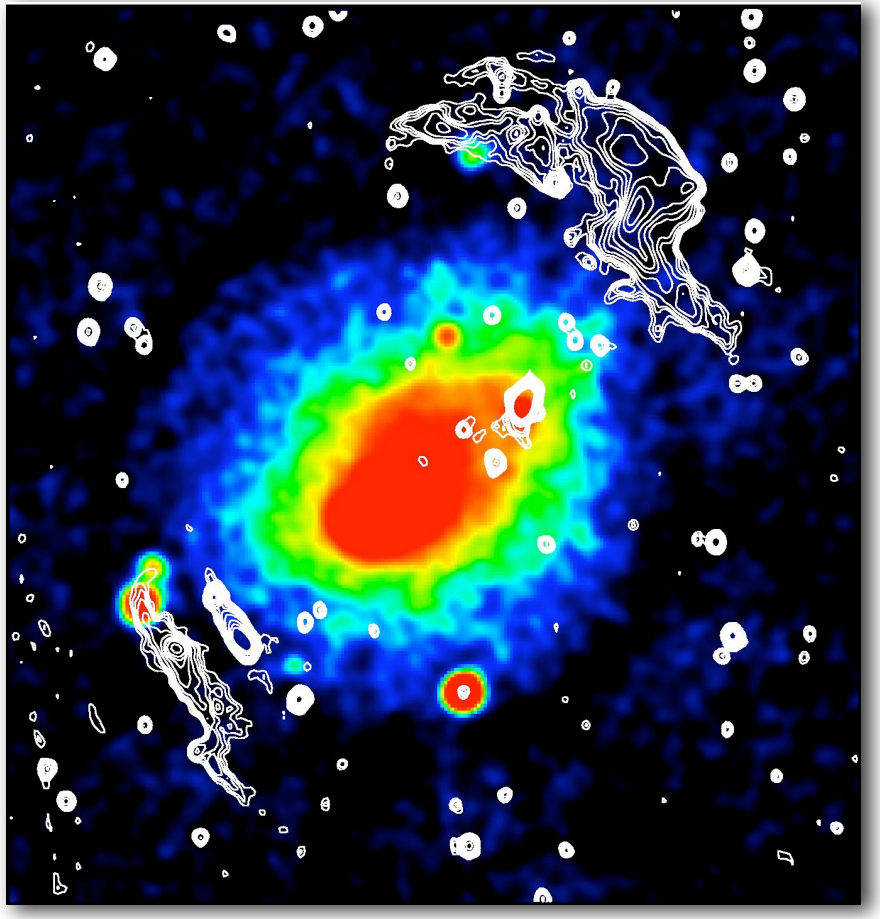


[Ferrari et al. 08]

Halo	Relic	Mini-halo
Turbulence?	Shock fronts?	Sloshing?

The `definition' of radio relics

- extended (about 1Mpc) diffuse emission at the periphery of galaxy clusters
- no optical counterpart
- irregular morphology



Abell 3667

Color: X-ray

Contours: radio

Flux 1.4GHz: ~4 Jy

[Roettgering et al. 97]

Relics are common ...

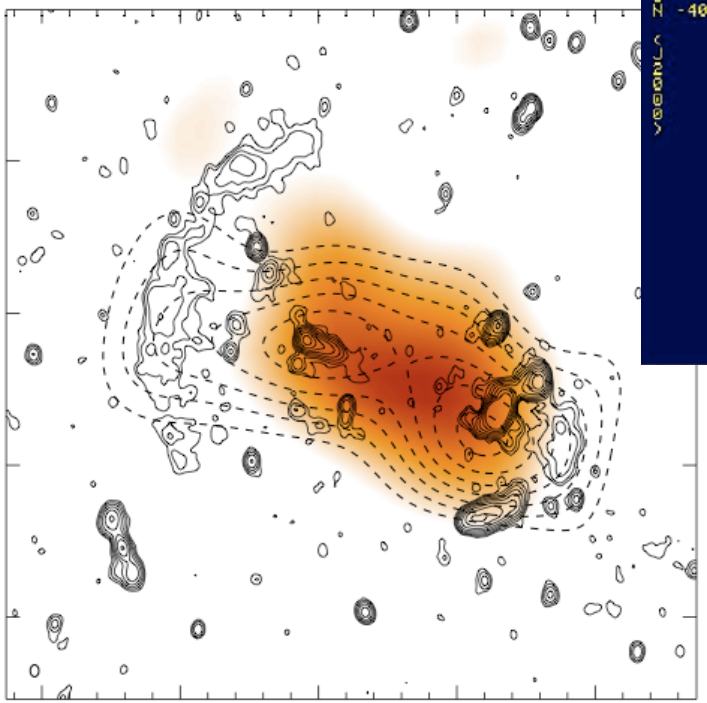
Abell 3667

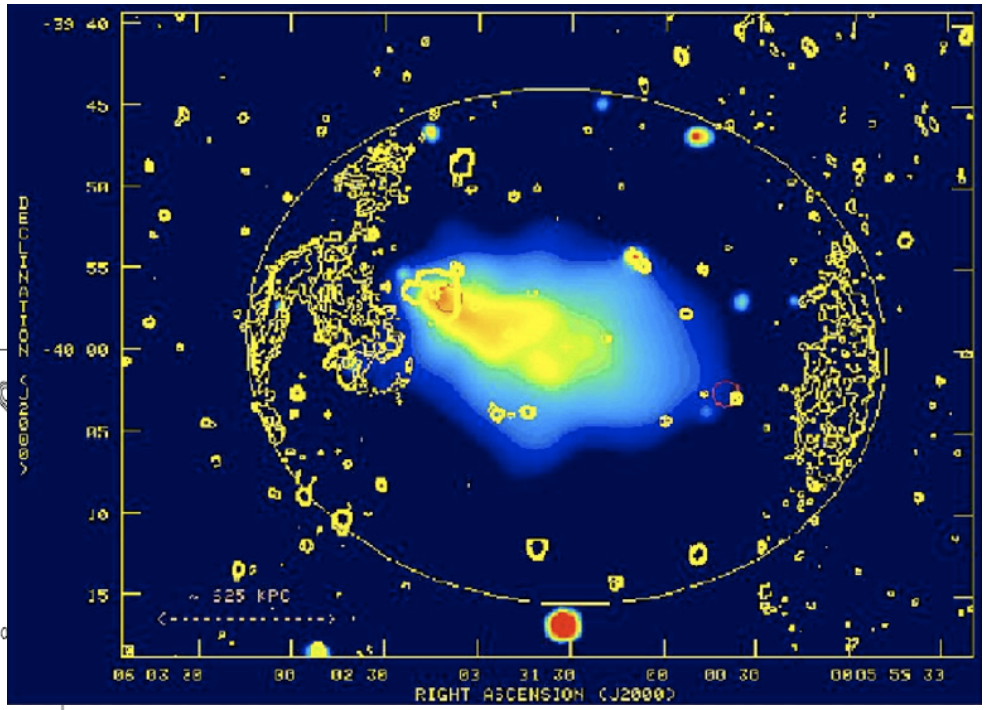
Color: X-ray

Contours: radio

Flux 1.4GHz: 300 mJy

[Bagchi et al. 06]





ZwCl 0008

Color: X-ray

Contours: radio, dashed contours galaxies

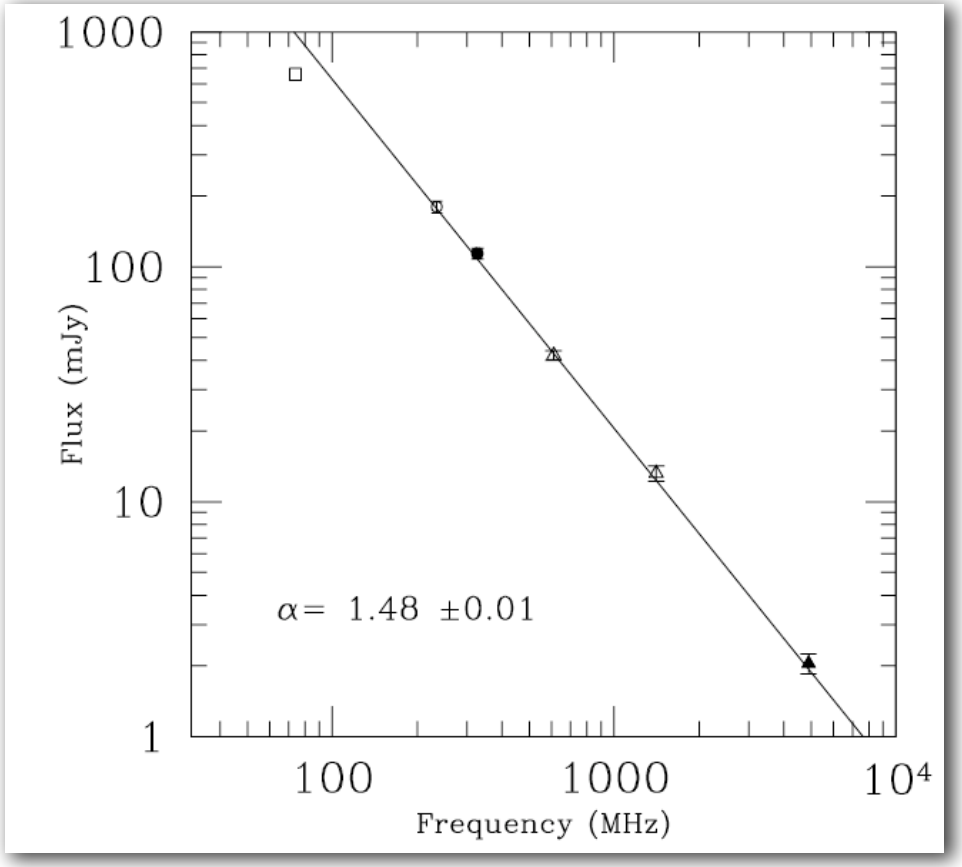
Flux 1.4GHz: 67 mJy

[van Weeren, MH, et al. 11]

The overall radio spectrum

- perfect power-law in radio spectrum
- fits very well 'simple' DSA predictions:

  s = (r+2)/(r-1)

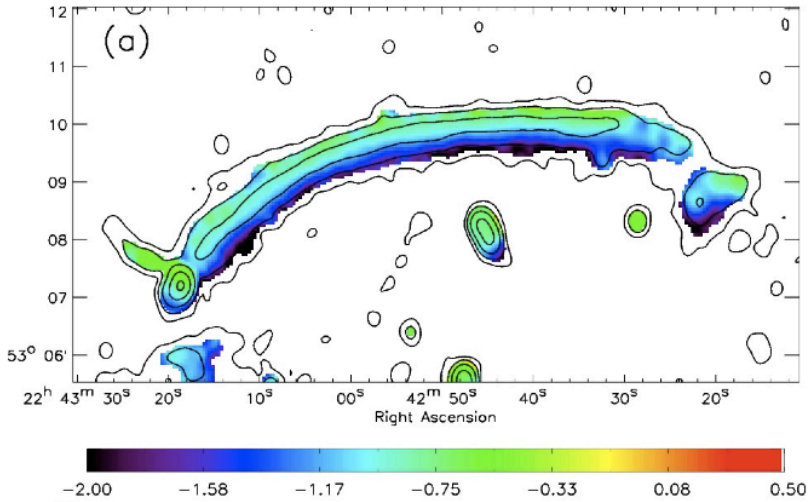


Abell 521

[Giacintucci et al. 08]

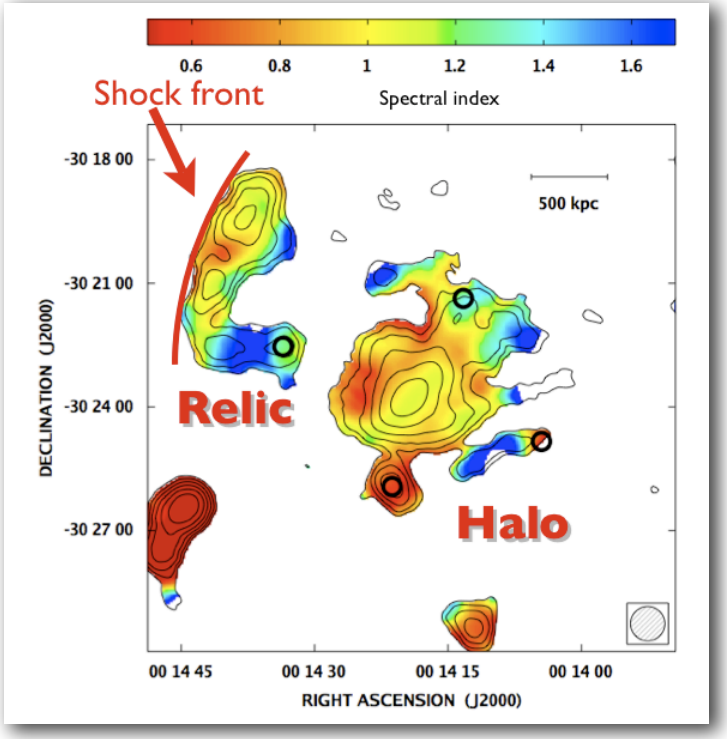
Spectral index map - aging

- systematic trend perpendicular to the long extend of the relic
- indicates motion of the shock front and aging of electrons



CIZA 2242

[van Weeren et al. 10]

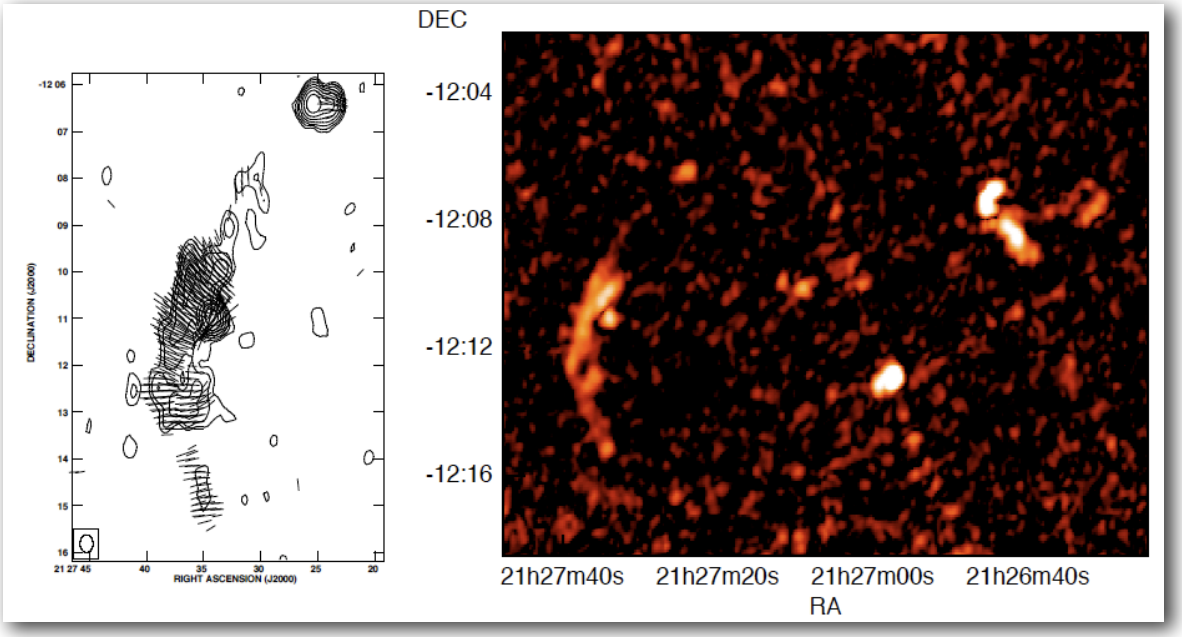


Abell 2744

[Orrù et al. 04]

Polarization of the diffuse emission

- for A2345: average polarization 22%
  maximal polarization 50%
- other examples
  Abell 786, CIZA 2242: average polarization ~50%
  [Harris et al. 93, van Weeren et al. 11]

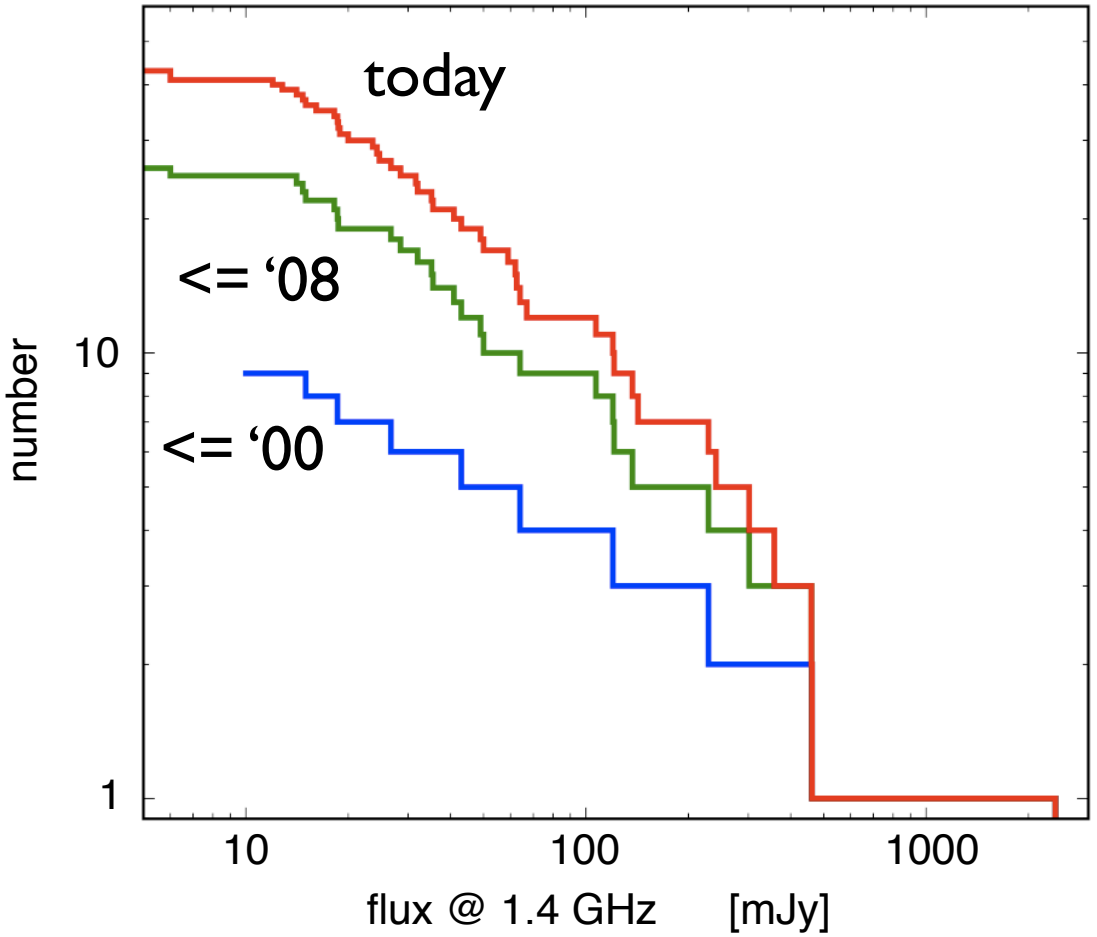


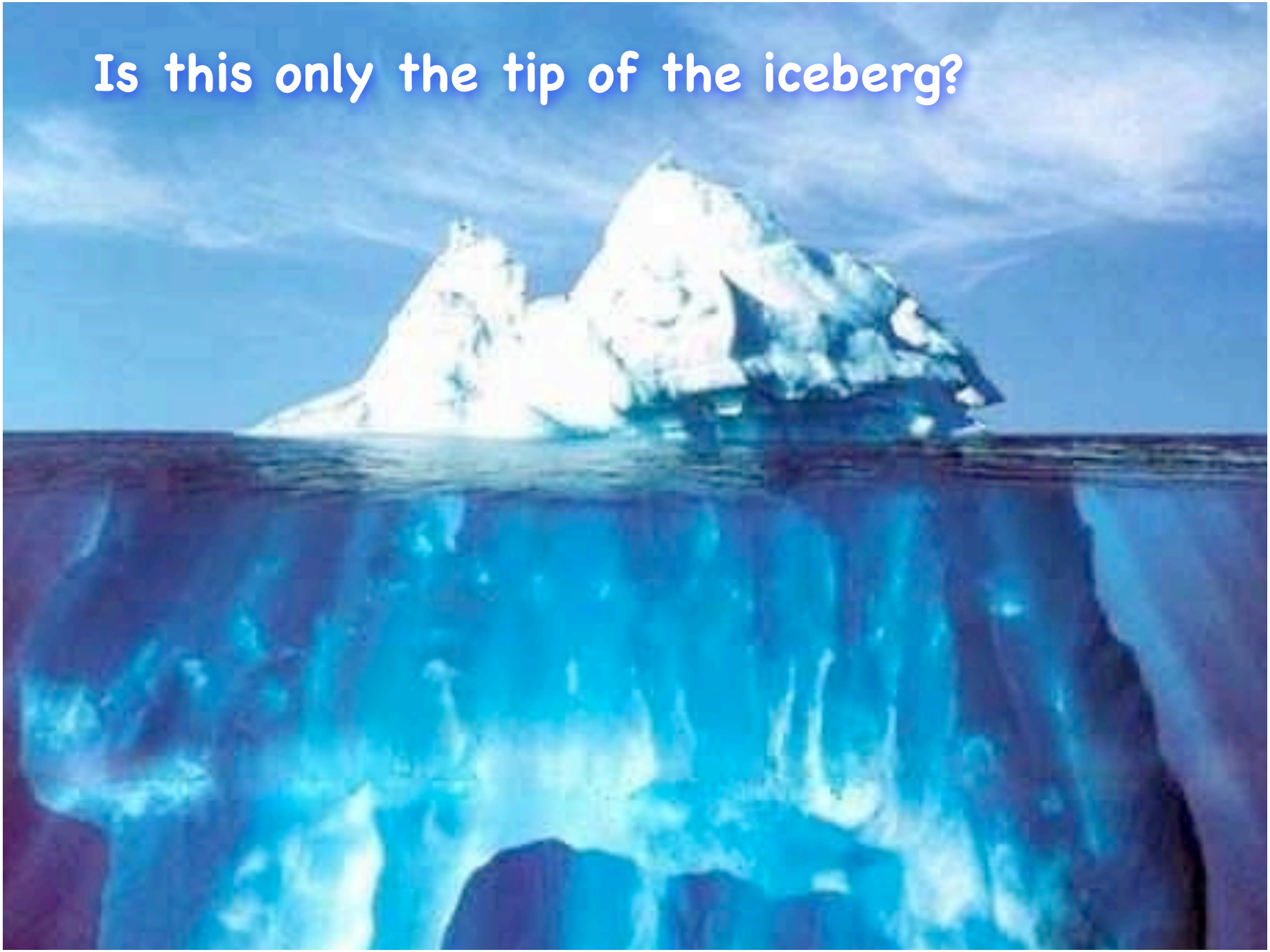
Abell 2345
VLA 1.4 GHz
Color: polarized emission
[Bonafede et al. 2009]

Estimates for the magnetic field strength

	Abell 3667 NW relic
• Rotation measure of background sources	3-5 μG [Johnston-Hollitt 04]
• Inverse Compton emission would directly measure the electron density $\frac{F^{\mathrm{sync}}}{F^{\mathrm{IC}}} = \frac{U_{\mathrm{B}}}{U_{\mathrm{CMB}}}$	> 1.6 μG Suzaku 10-40 keV upper limit [Nakazawa et al. 08]
• Equipartition	~2 μG

Total number of known relics

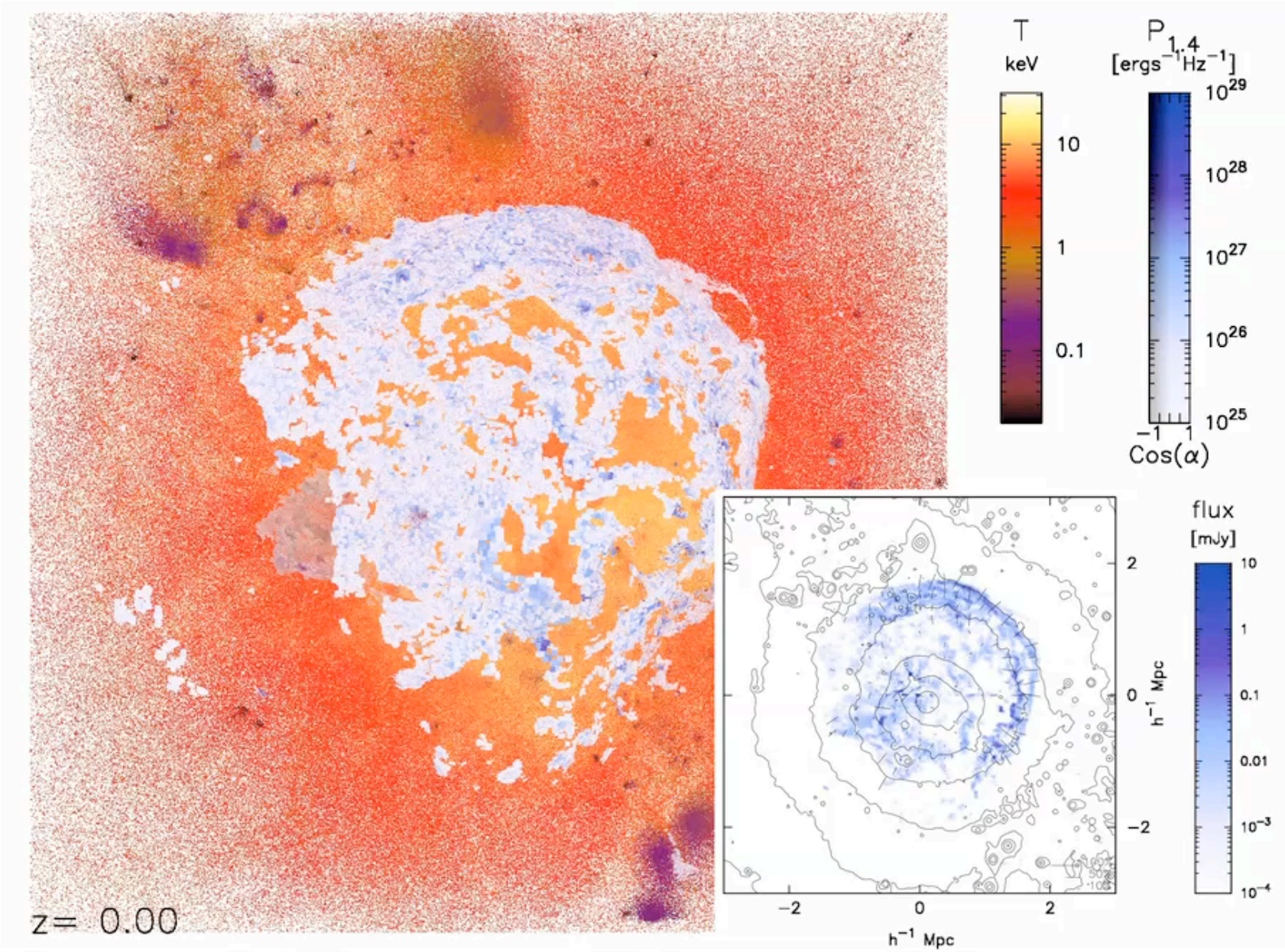



Is this only the tip of the iceberg?

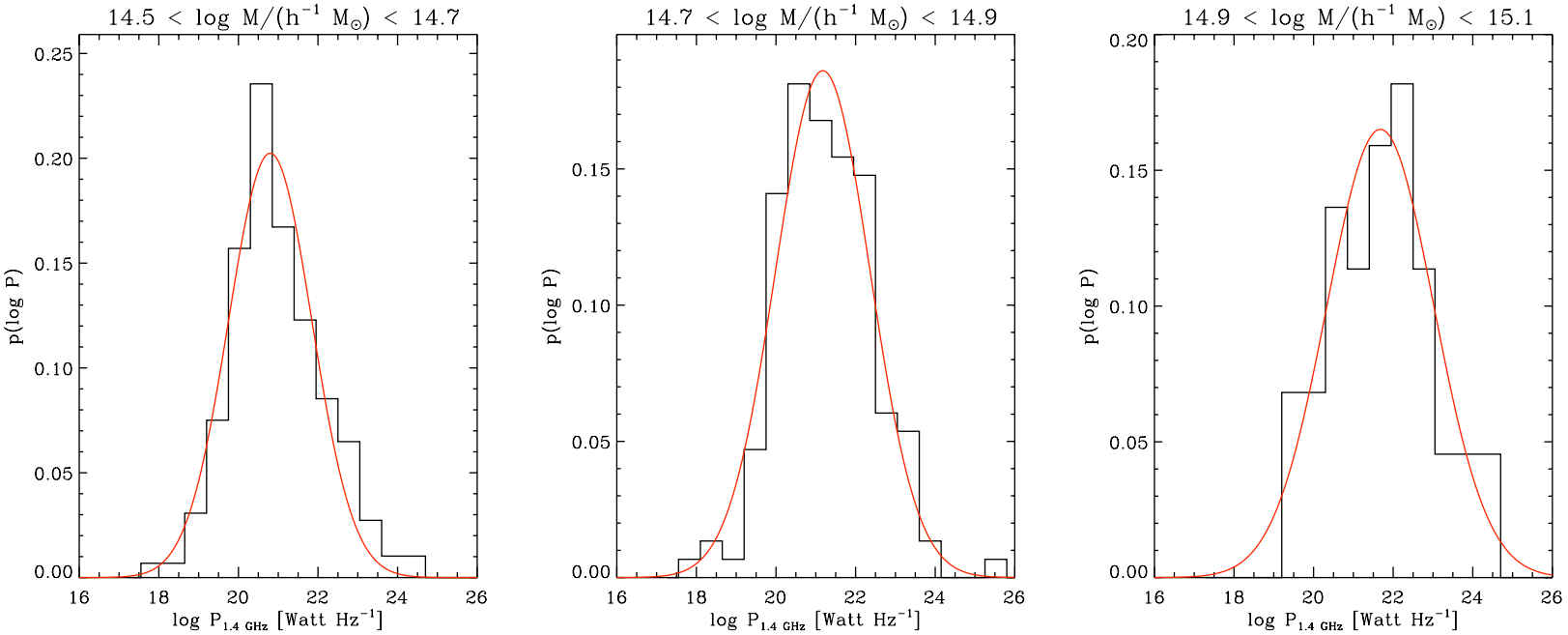
Radio emission in a cosmological simulation

Mare Nostrum Universe:

- 500 Mpc/h
- gas and dark matter particles, 1024^3 each
- Gadget (SPH), no radiative cooling


T
keV
10
1
0.1
P1.4
[ergs−1Hz−1]
10^29
10^28
10^27
10^26
10^25
−1
1
Cos(α)
flux
[mJy]
10
1
0.1
0.01
10^−3
10^−4
2
0
−2
h^−1 Mpc
−2
0
2
h^−1 Mpc
z= 0.00

Radio power distribution



[Nuza, MH et al. submitted]

- relic luminosity probability function

$p(P_\nu, M)$: log-normal

Distribution function: Scaling laws

- distribution function

$$p(P_\nu, M, z, \nu_{obs}) \propto \exp\left(-(\log P - \log P_{mean})^2/\sigma^2\right)$$

- Model fits to Mare Nostrum simulation

mass	$P_{mean} \propto M^{2.6}$
redshift	$P_{mean} \propto z^{3.4}$
observing frequency	$P_{mean} \propto \nu_{obs}^{-1.2}$

Abundance of radio relics

- Convolve halo mass function and radio relic luminosity probability

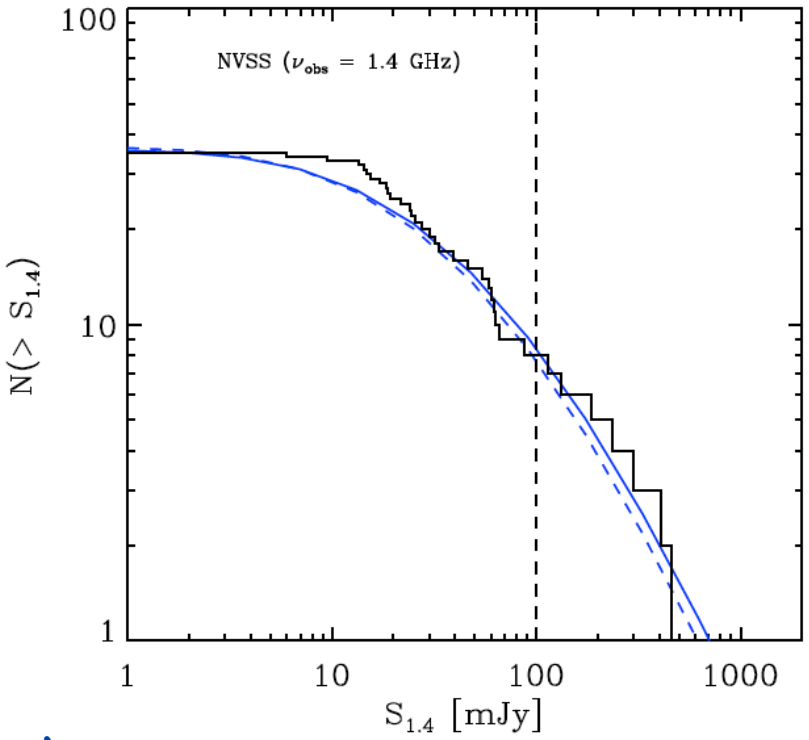
$$\int \mathrm{d}V \; \frac{\mathrm{d}n}{\mathrm{d}M} \; p(P, M, z, \nu_{\mathrm{obs}})$$

- Introduce 'detection probability'

$$p_{\mathrm{detect}} = \frac{1}{2}\left\{1 + \mathrm{erf}\left(\frac{\log S - \log S_{\mathrm{thres}}}{\sigma_{\mathrm{detect}}}\right)\right\}$$

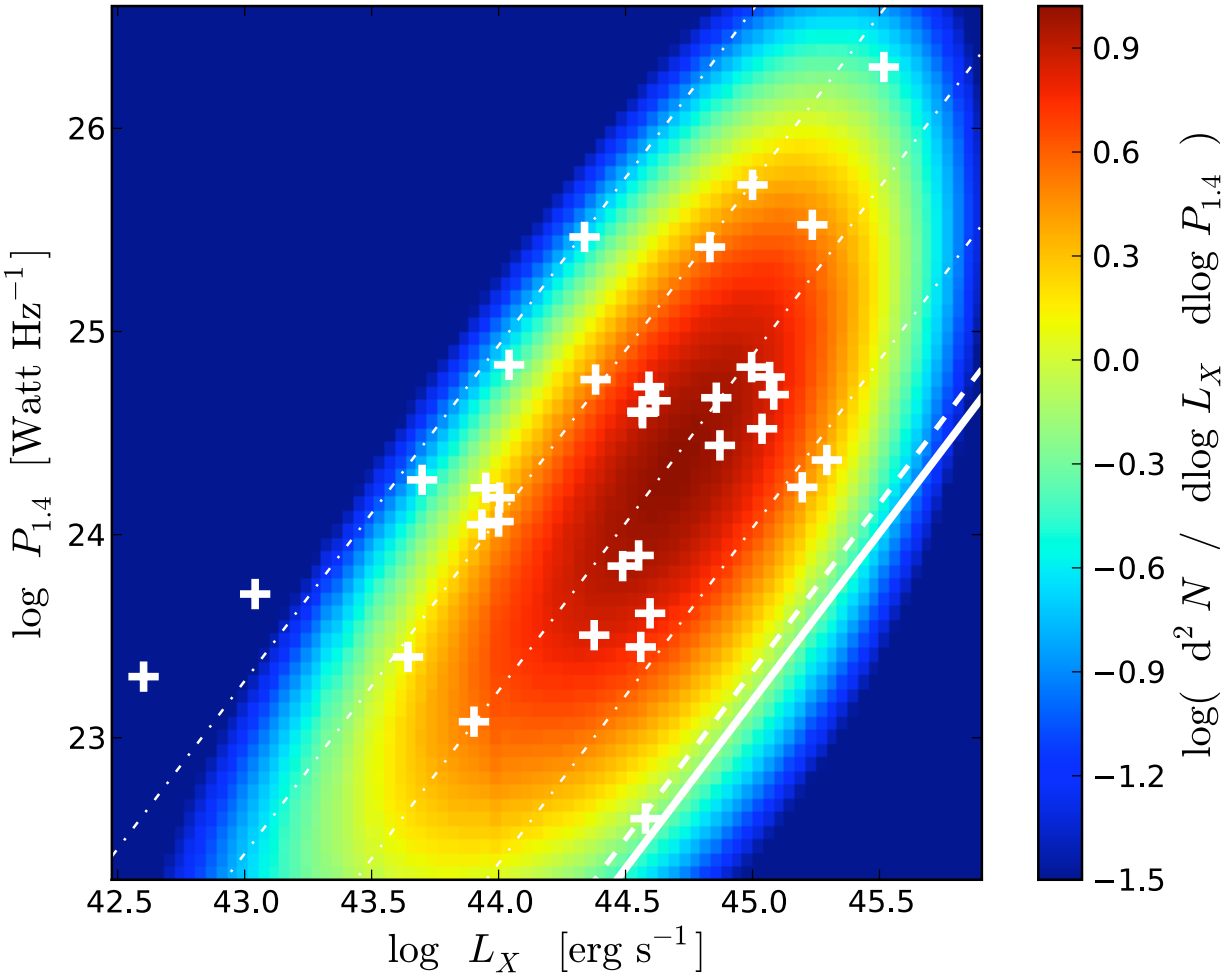
Normalize probability distribution by number of observed relics

- S_{thres} = 100 mJy σ_{detect} = 0.75

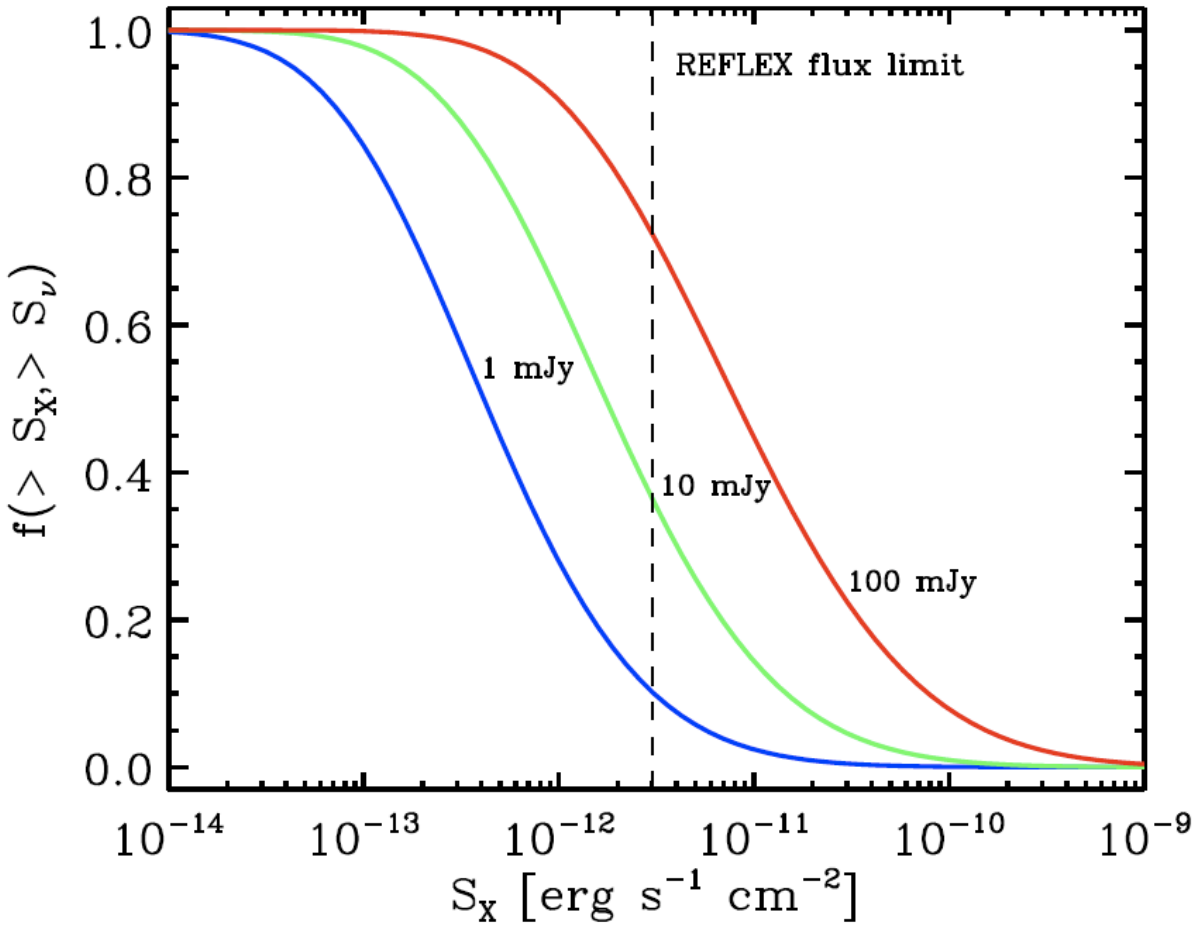


- σ_{rms} (NVSS) = 0.45 mJy

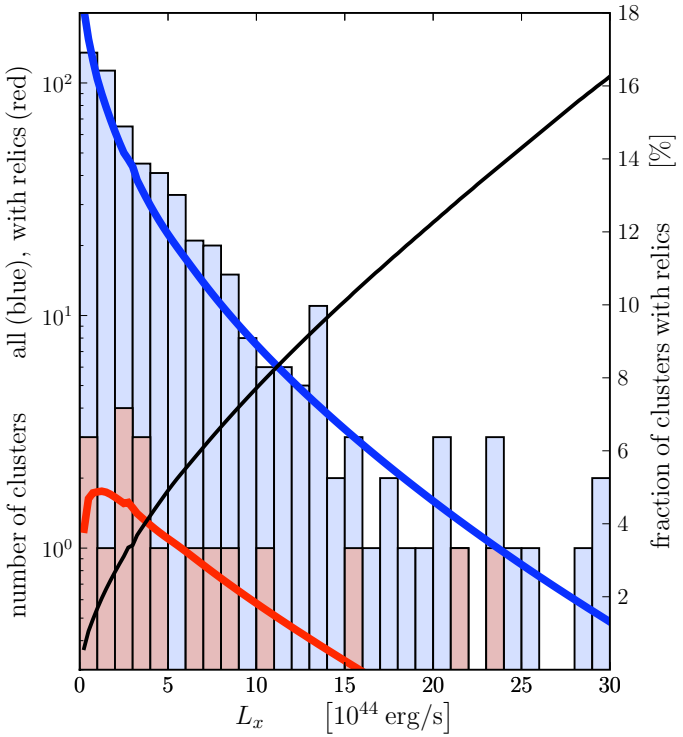
L_X - $P_{1.4}$ distribution

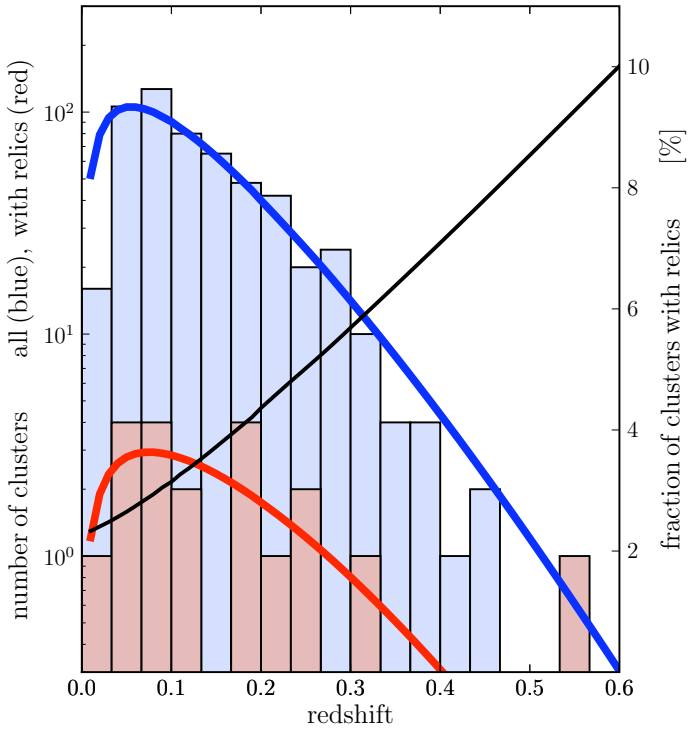


The need for deep cluster surveys



X-ray limited cluster sample





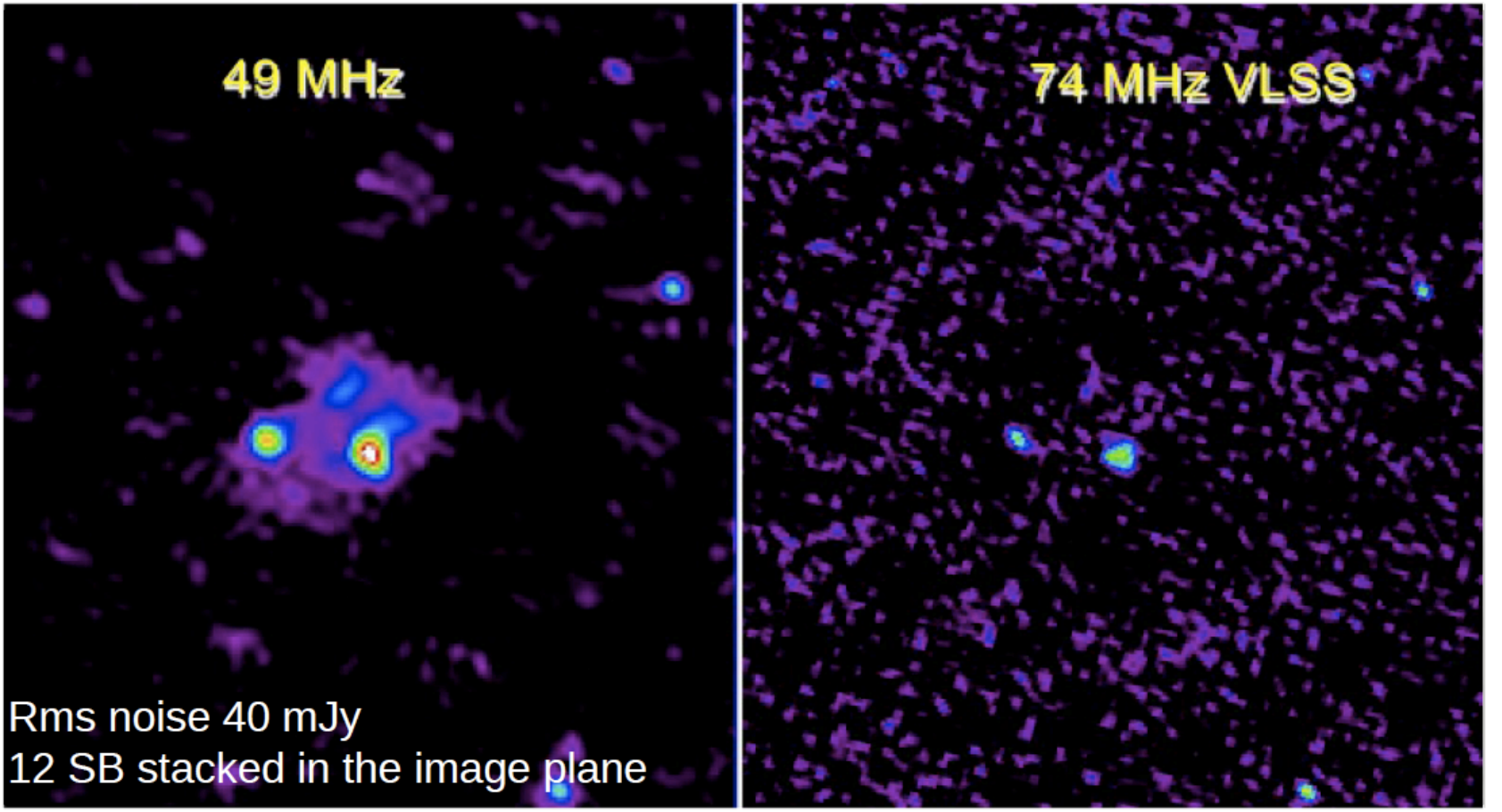
- NORAS + REFLEX sample
- fraction of clusters with relic: 3.6%
- S_{thres} = 15 mJy

LOFAR: Commissioning observations

Abell 2256

van Weeren, Bonafede, Pizzo

the LOFAR Consortium

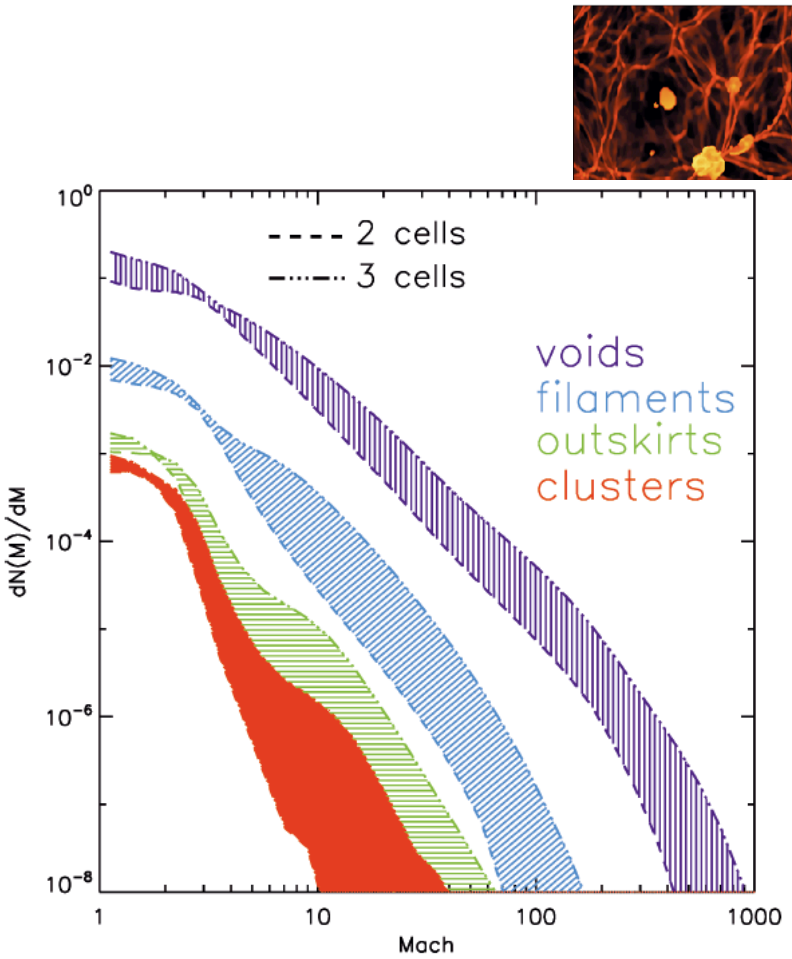


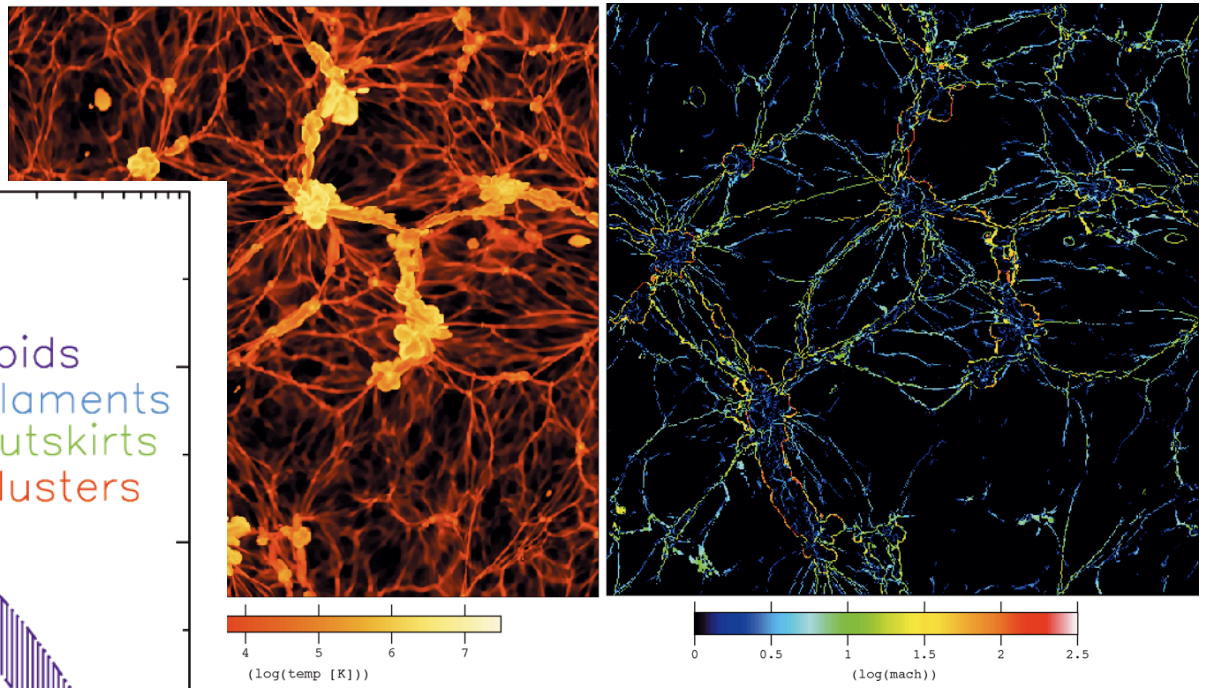
Predictions for LOFAR surveys

- Assumption: blind survey -> $S_{thres} \sim 200 \times \sigma_{rms}$

Tier	Frequency	σ_{rms}	area	N_{tot}
	[MHz]	[μJy]	[deg^2]	
1	120	100	20 k	1000
2	120	25	240	90
3	150	6.2	30	20

The cosmic web: Shock fronts

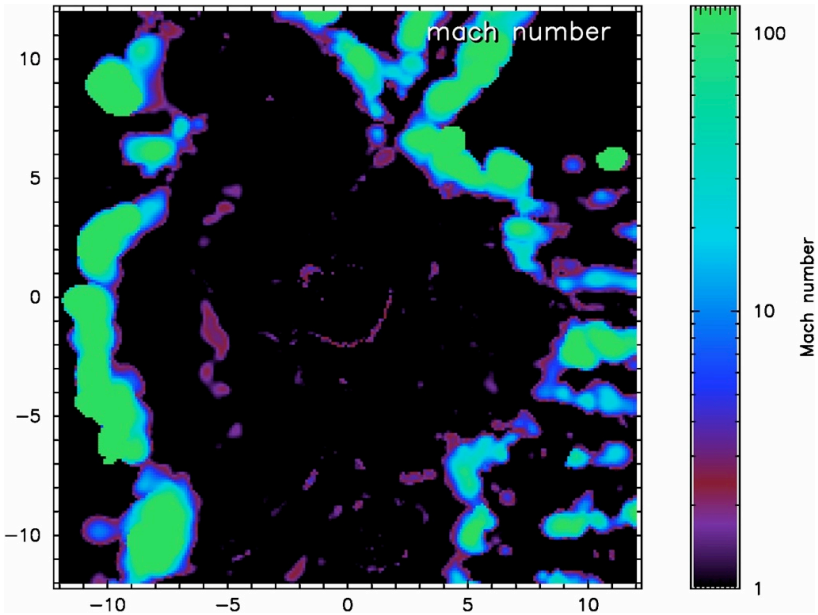




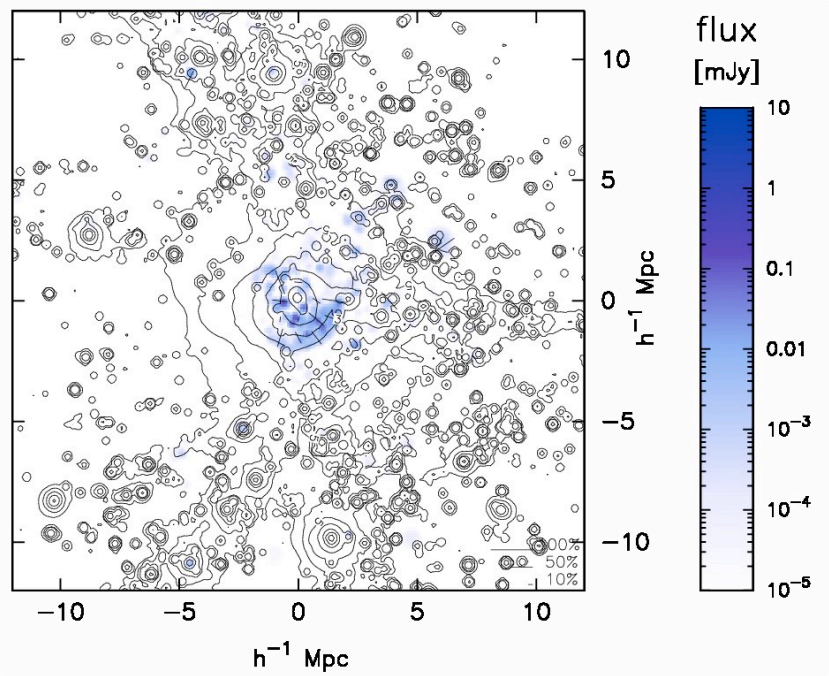
[Vazza et al. 2009]

Radio emission from accretion shocks?

Mach number (slice)



X-ray and radio lumin (project.)



- high efficiency of high Mach number shocks and self-generated B-field may boost radio emission of accretion shocks

Prospects for LOFAR and SKA

High sensitivity:

many relics await discovery, > 1000

Cosmic web ?

+ high resolution:

relics show small scale structure

due to Mach number, B variations

Polarization

Relics are polarized at high frequency -> SKA