eROSITA + LOFAR: What it takes to discover radio relics

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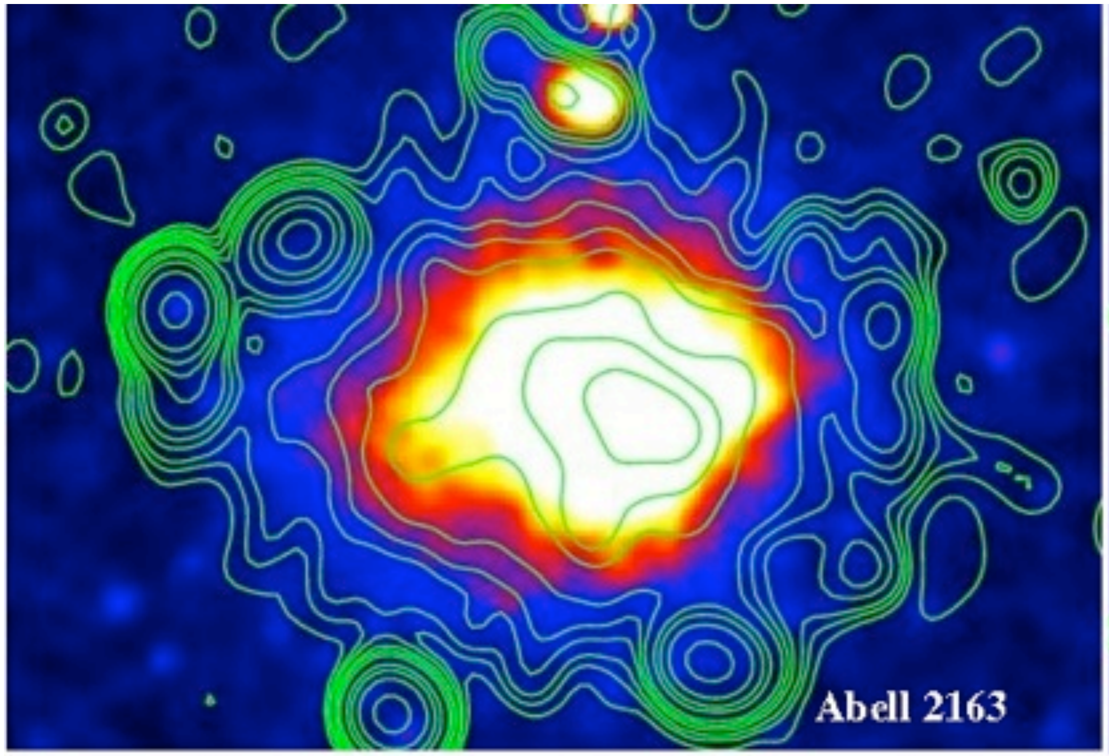
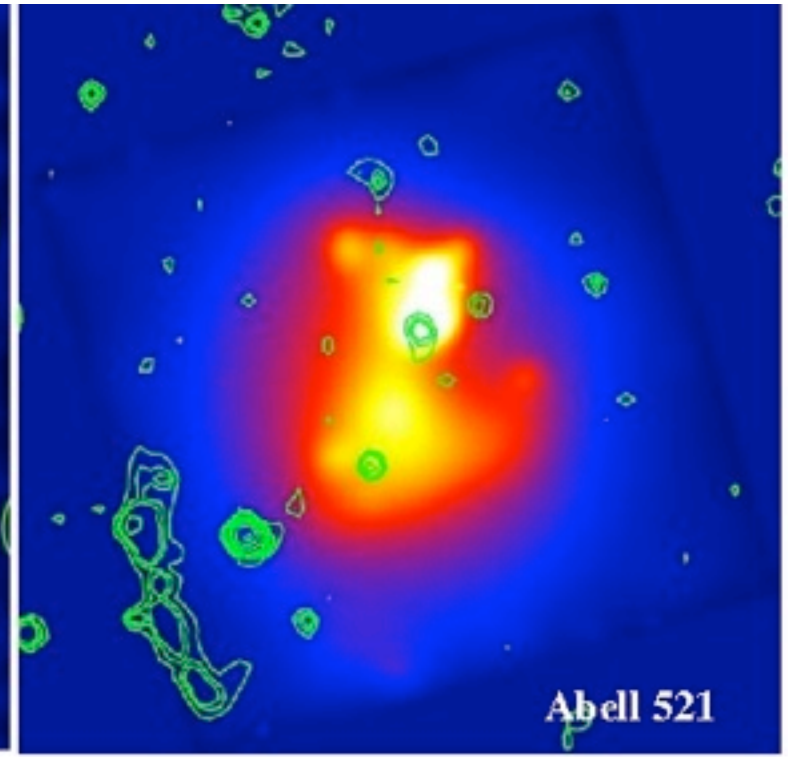
Radio emission in galaxy clusters

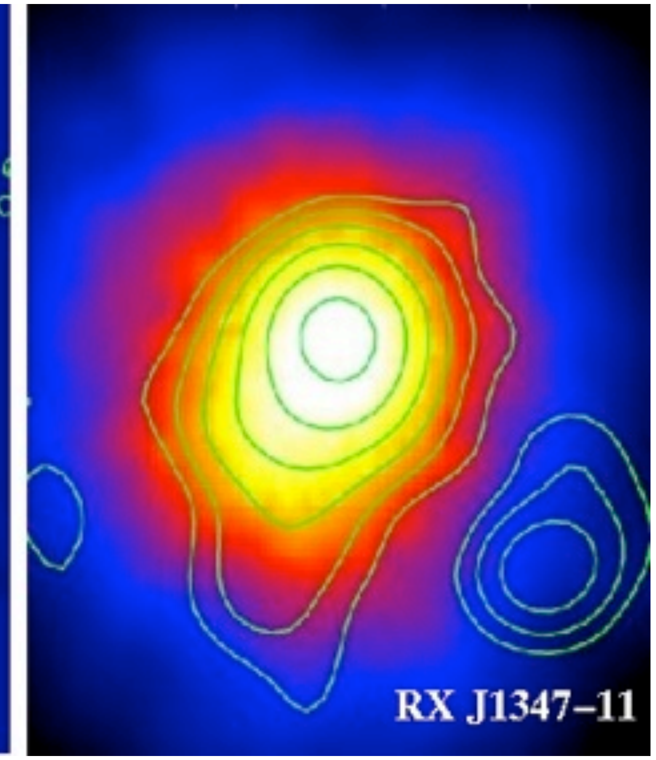
radio halos



radio relics



mini-halos



Color: X-ray, Contours: radio [Ferrari et al. 08]

radio halos

- located in center
- morphology ~ X-ray
- L_x - P relation

? $p_{relativistic}$ + p_{therm} (hadronic)
? turbulent acceleration

radio relics

- located at periphery
- ~100kpc → 'Phoenix'
- ≳1Mpc → 'Gischt'

? Diffusive shock (re)accel?
? Compression of B + n_e

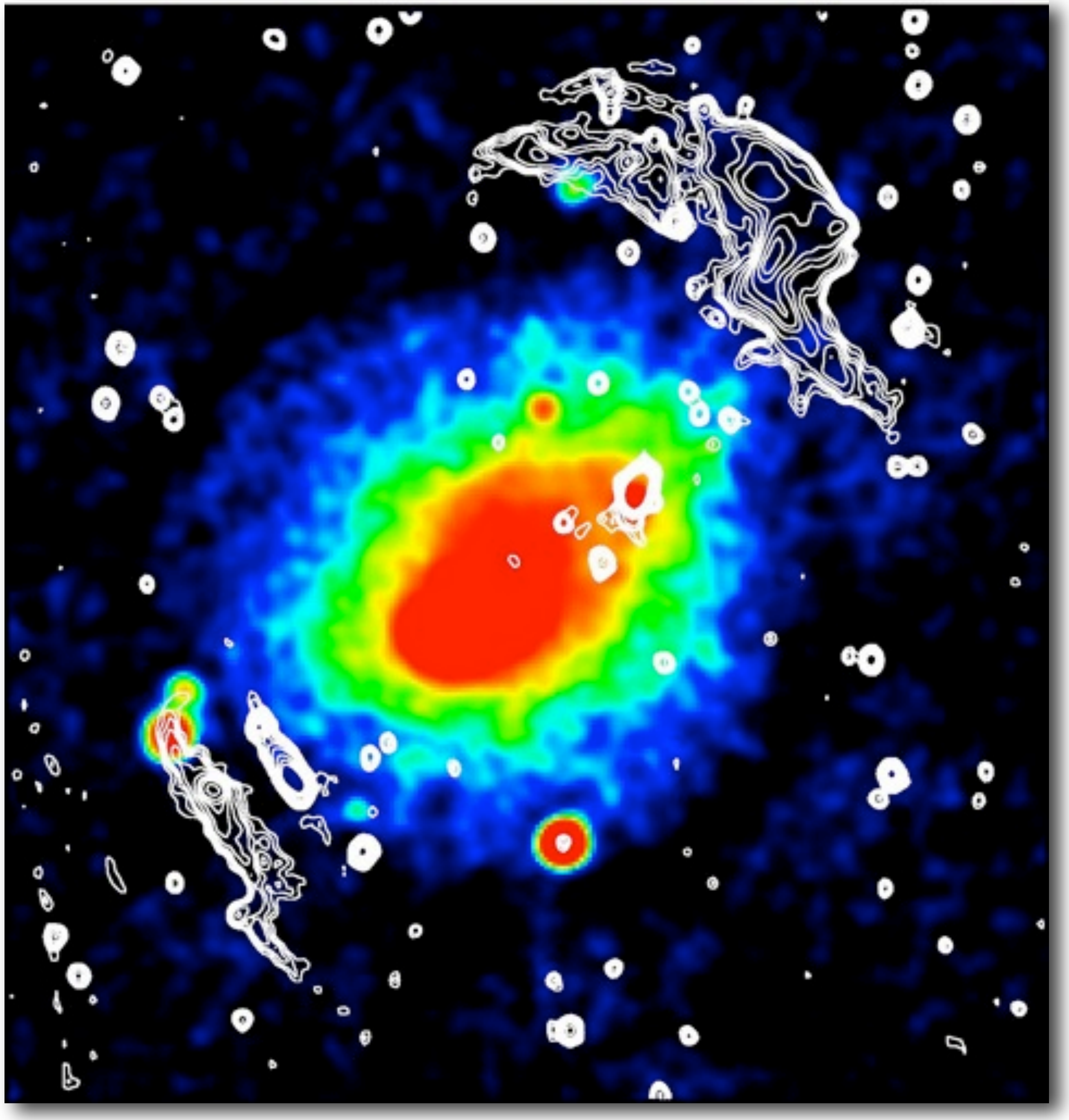
mini-halos

- located in center
- small

? hadronic
? sloshing

The `definition' of radio relics

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



Abell 3667

Color: X-ray, Contours: radio

$S_{1.4GHz} \sim 4$ Jy

$P_x \sim 2\times10^{44}$ erg/s, z=0.055

[Roettgering et al. 97]

Some recently discovered relics

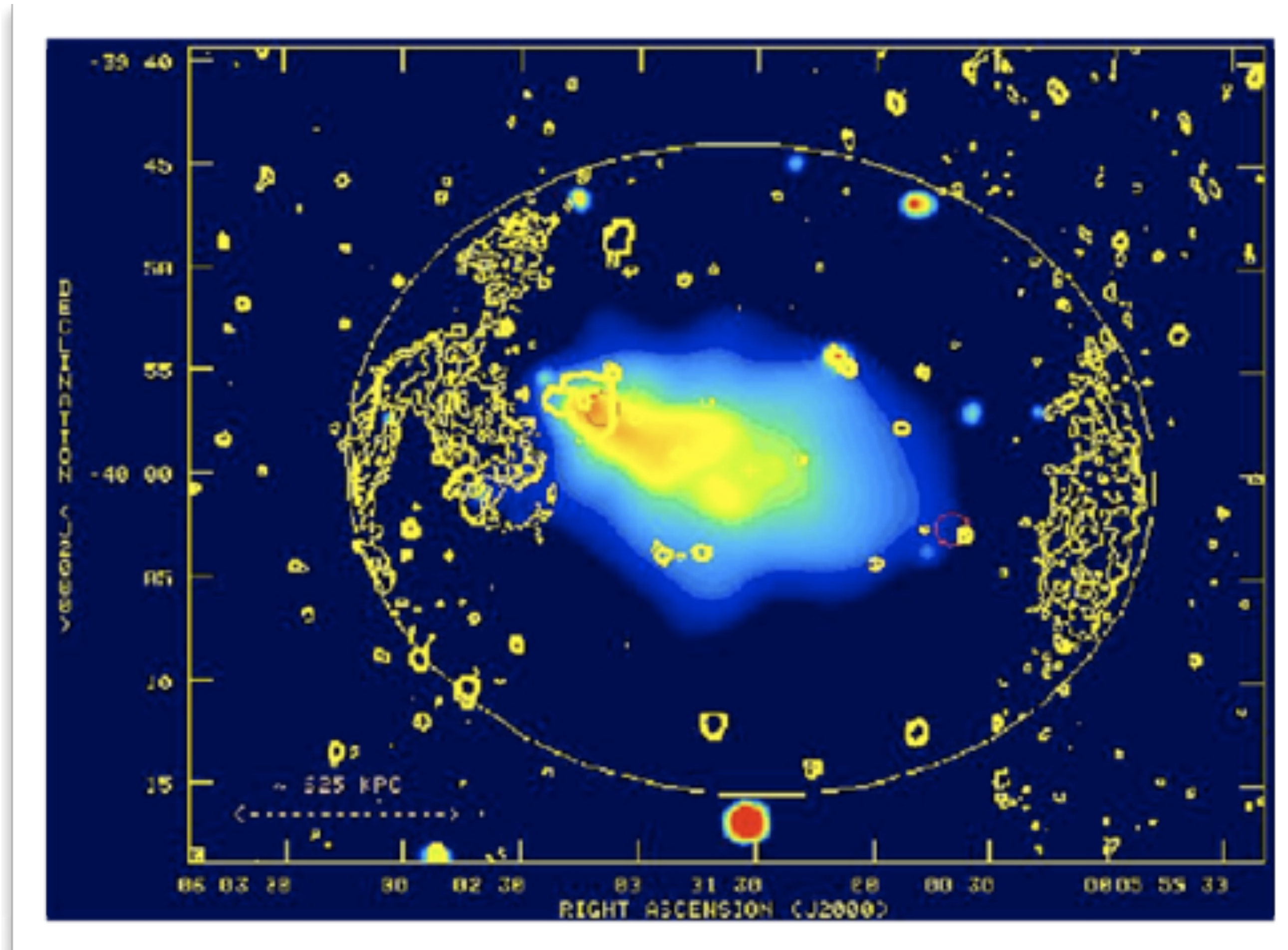
Abell 3376

Color: X-ray, Contours: radio

$S_{1.4GHz} \sim 300$ mJy

$P_x \sim 1\times10^{44}$ erg/s, z=0.047

[Bagchi et al. 06]



Some recently discovered relics

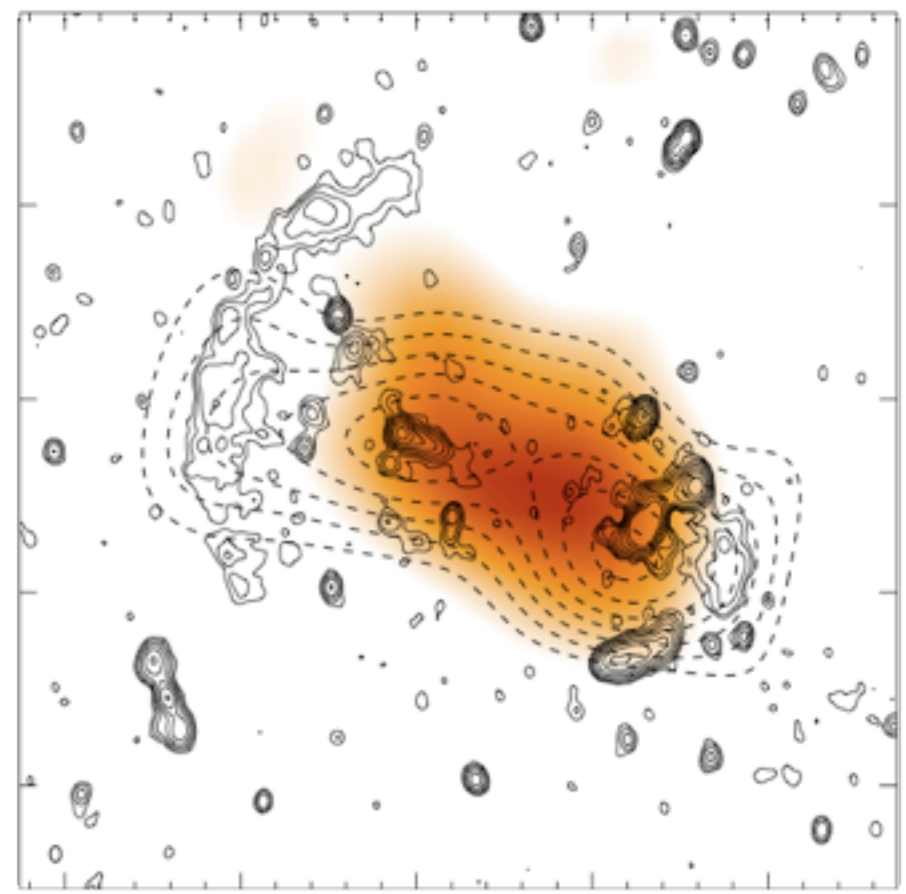
ZwCl 0008

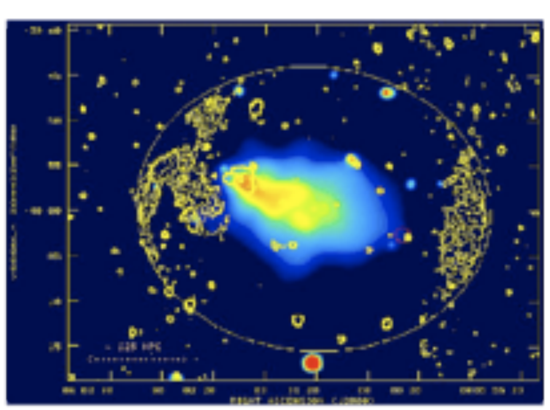
Color: X-ray, Contours: radio

$S_{1.4GHz} \sim 67$ mJy

$P_x \sim 0.5\times10^{44}$ erg/s, z=0.1

[van Weeren, MH, et al. 11]





Some recently discovered relics

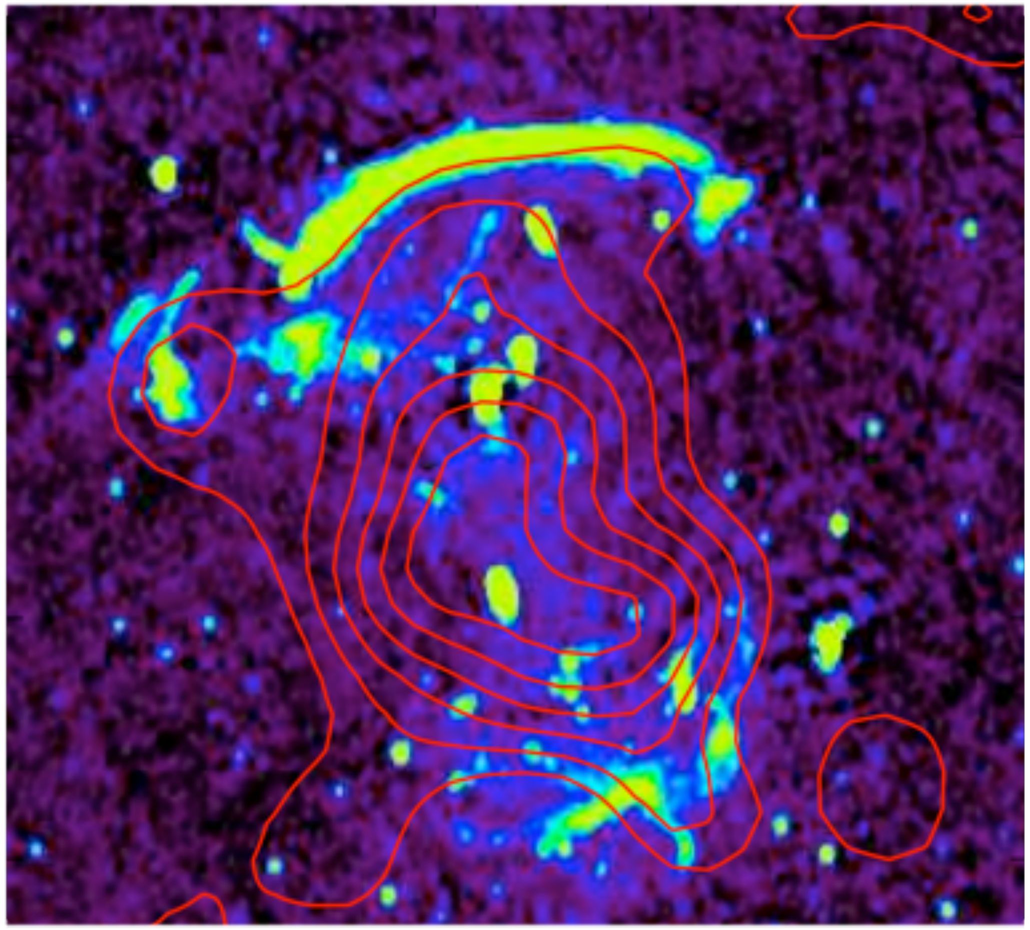
CIZA 2242 ('Sausage')

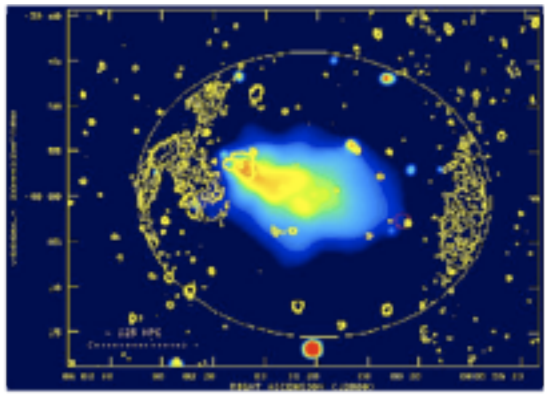
Color: radio, Contours: ROSAT

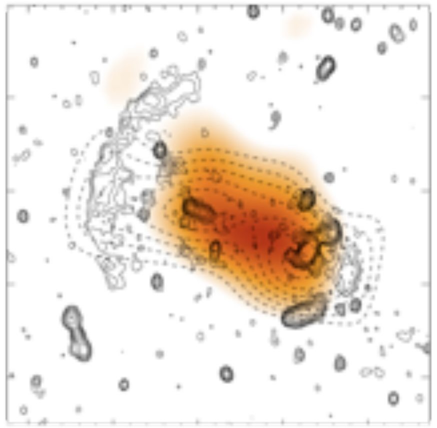
$S_{1.4GHz}$ ~ 240 mJy

P_x ~ 6.8×10^{44} erg/s, z=0.19

[van Weeren, et al. 11]







Some recently discovered relics

PLCK G287.0

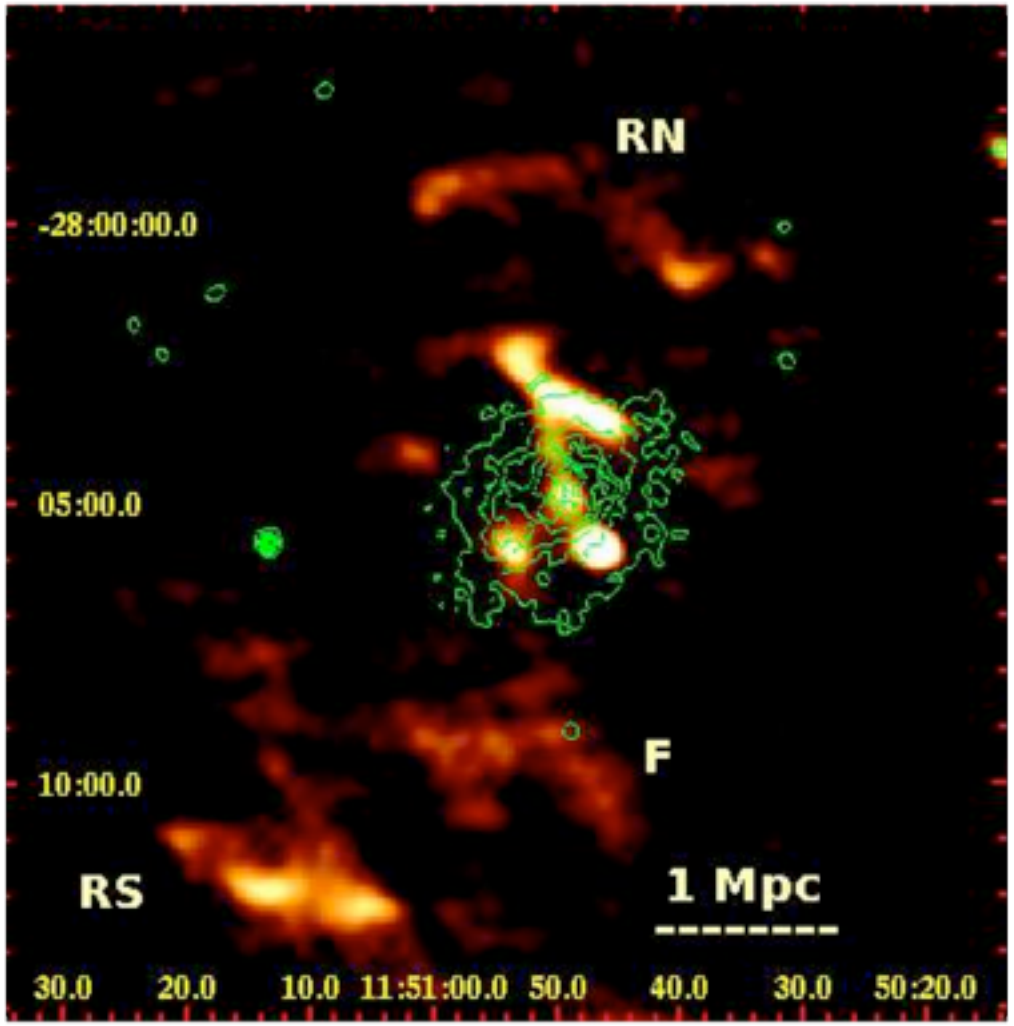
Color: radio, Contours: XMM (short exposure)

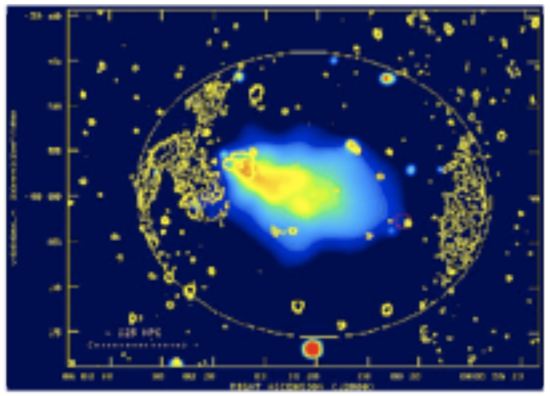
$S_{1.4GHz} \sim 58$ mJy

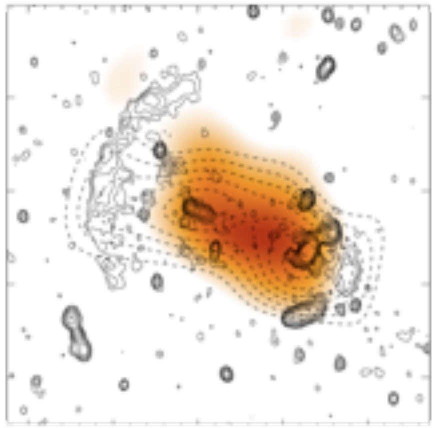
$P_X \sim 17\times10^{44}$ erg/s, z=0.39

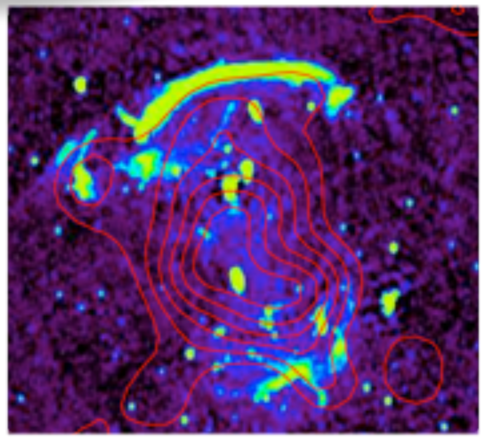
[Bagchi et al. 11]

First Planck radio relic









Some recently discovered relics

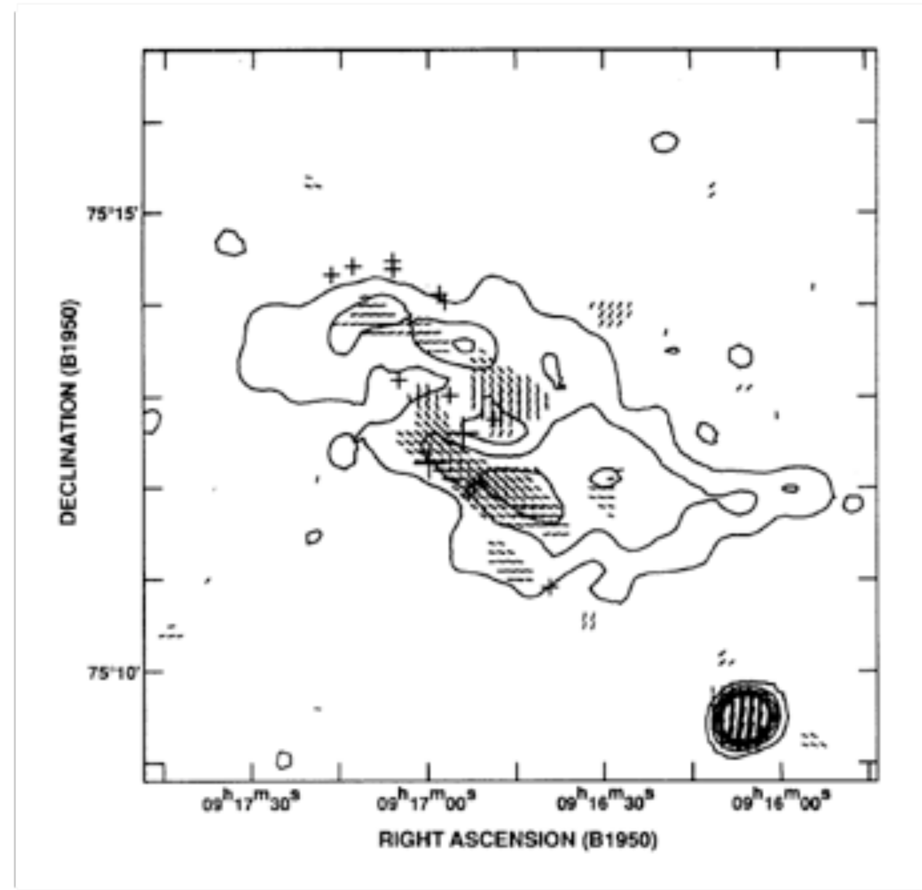
A 786

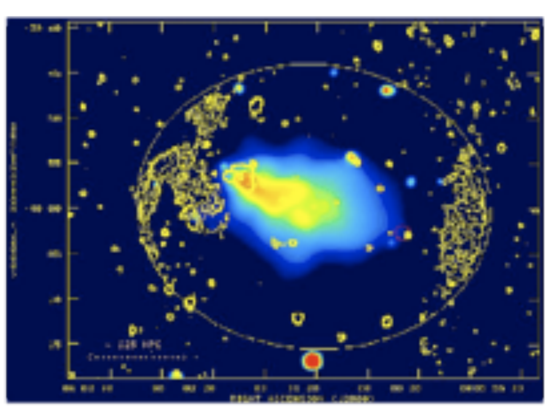
Contours: radio

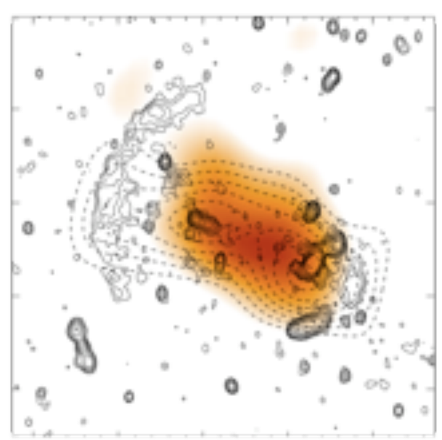
$S_{1.4GHz}$ ~ 120 mJy

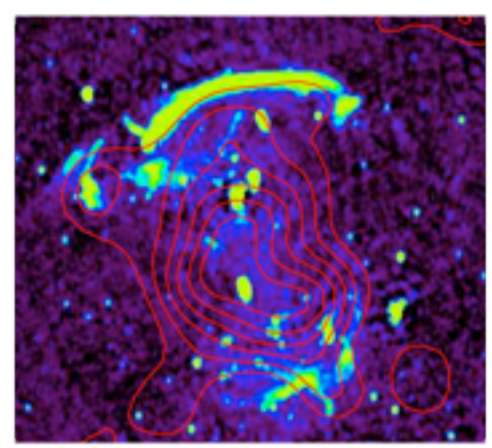
P_x ~ 1.5×10^{44} erg/s, z=0.12

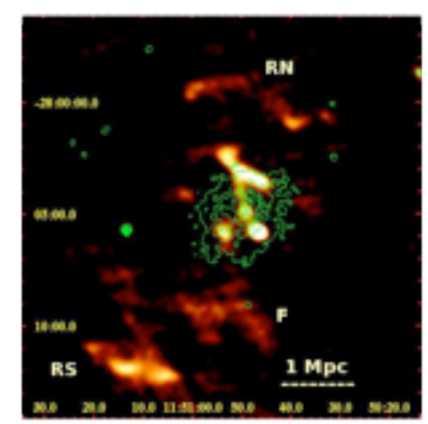
[Harris et al. 93]











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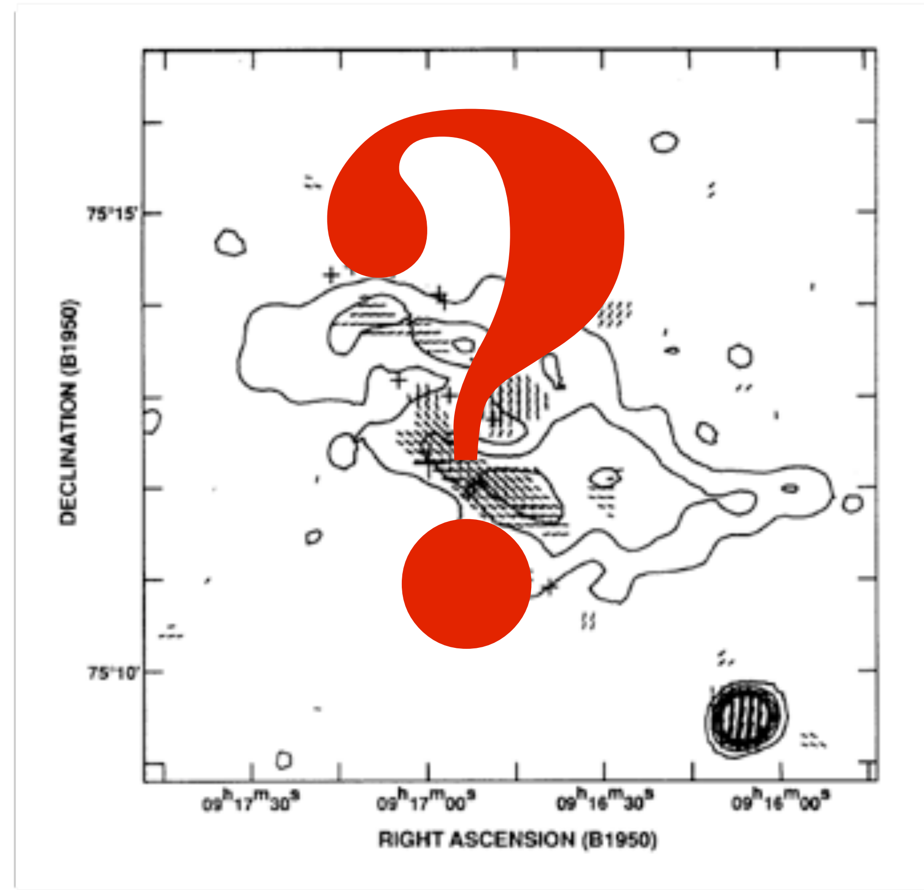

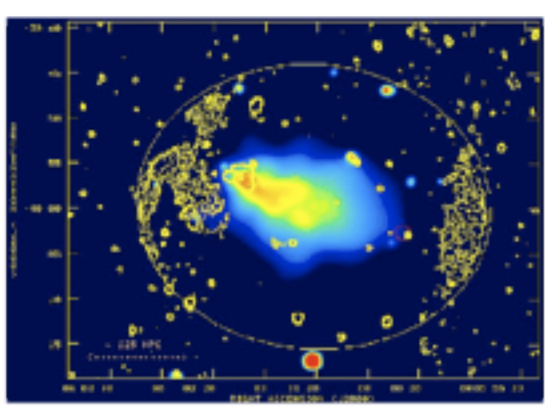

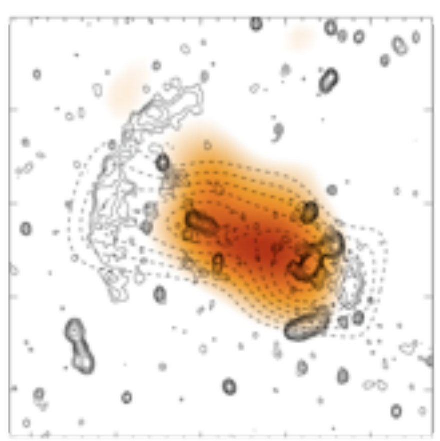

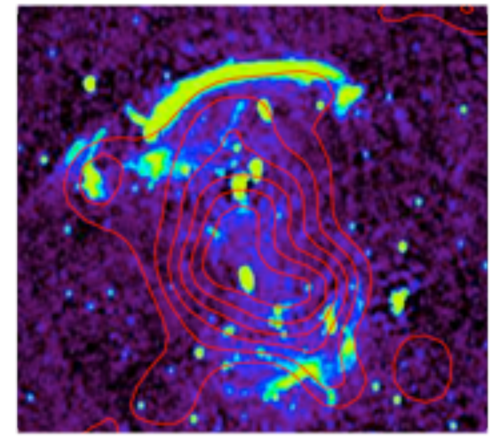

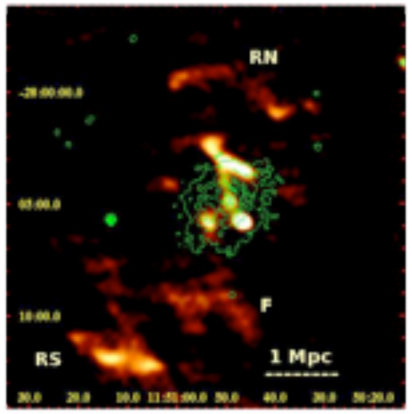

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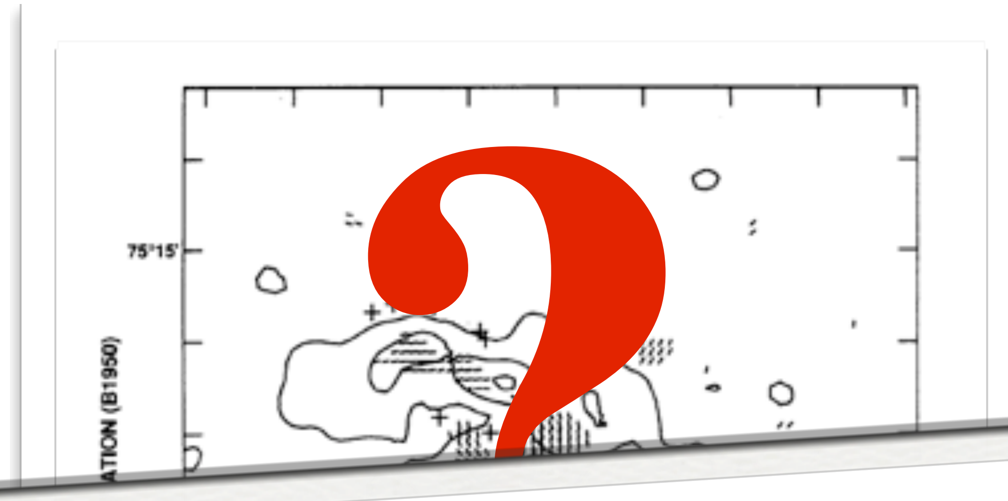
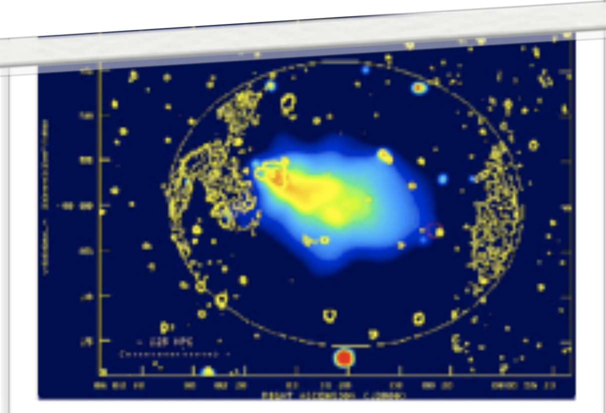
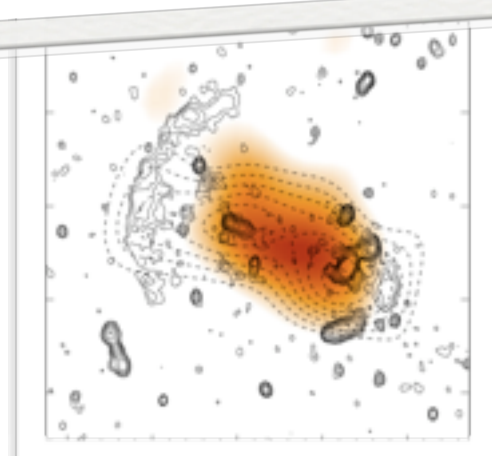


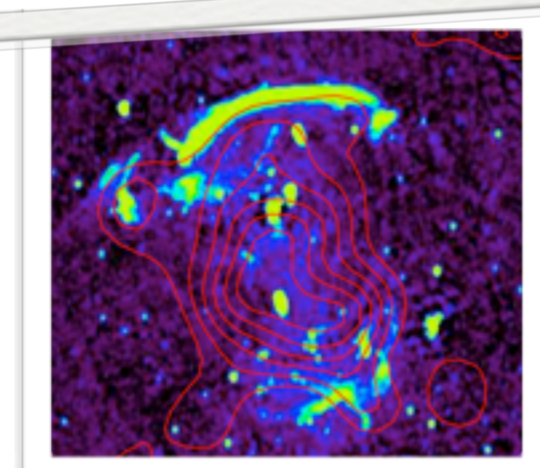
Relic identification is not straight forward

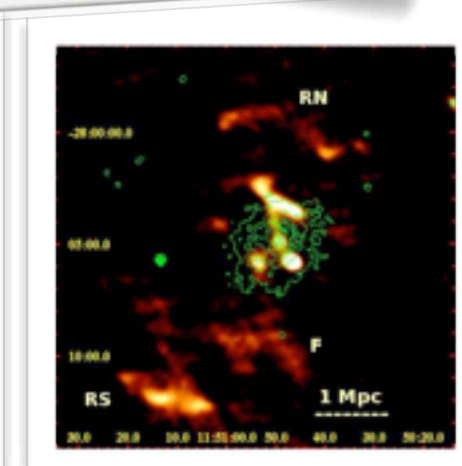
candidate → confirm cluster → deep radio obs

cluster X-ray contours are crucial



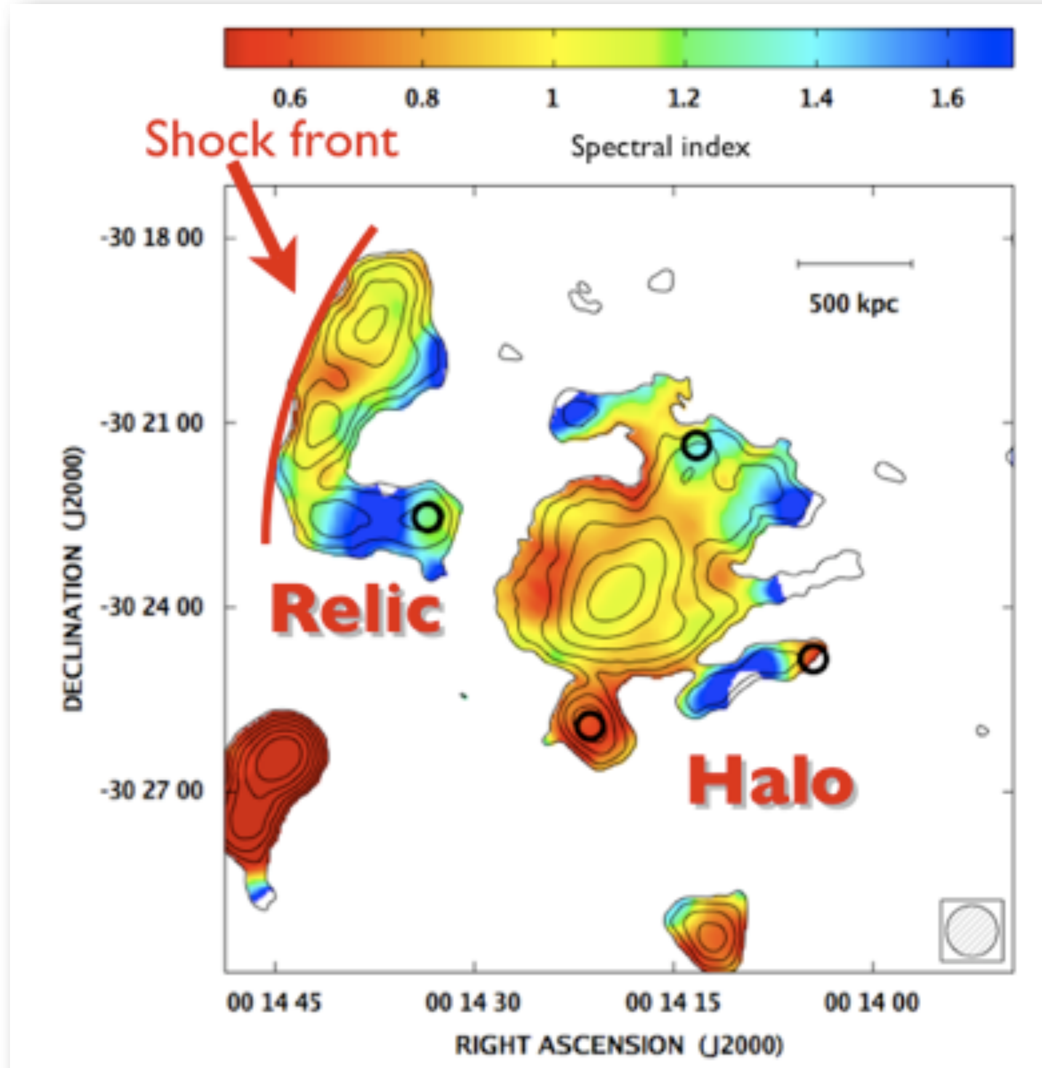




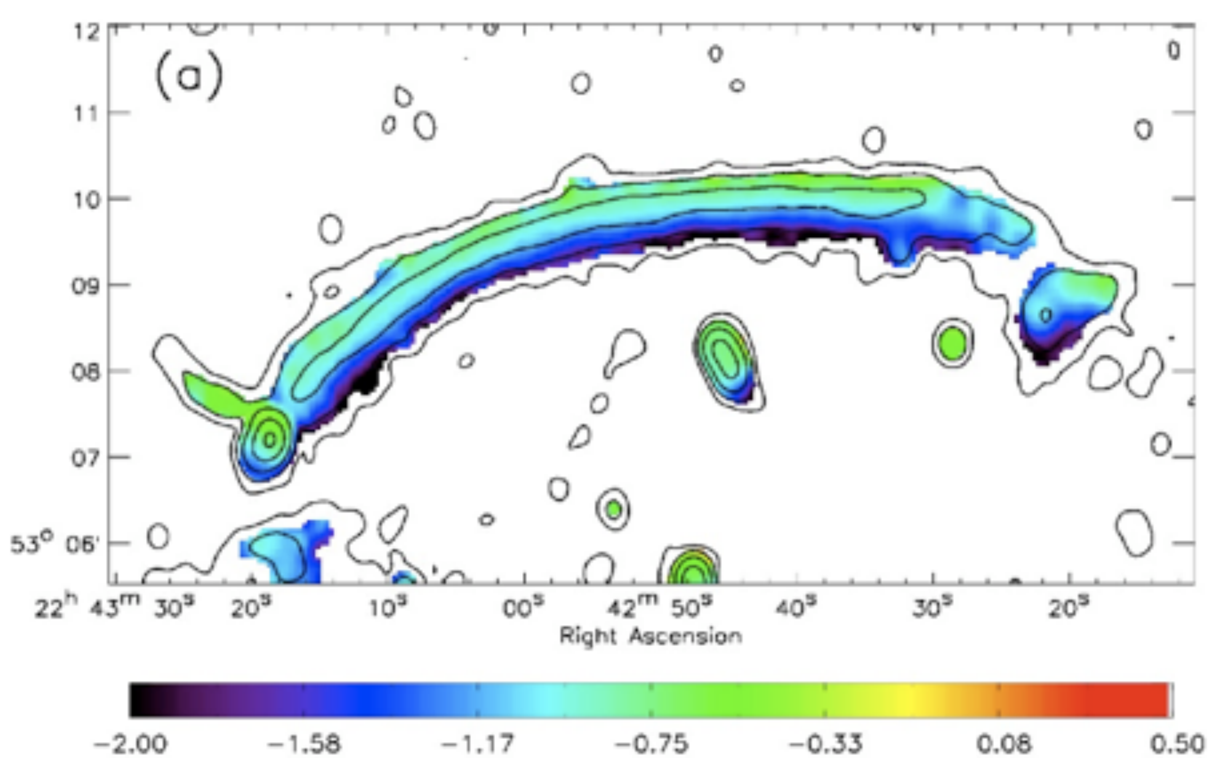


Spectral index map - aging

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



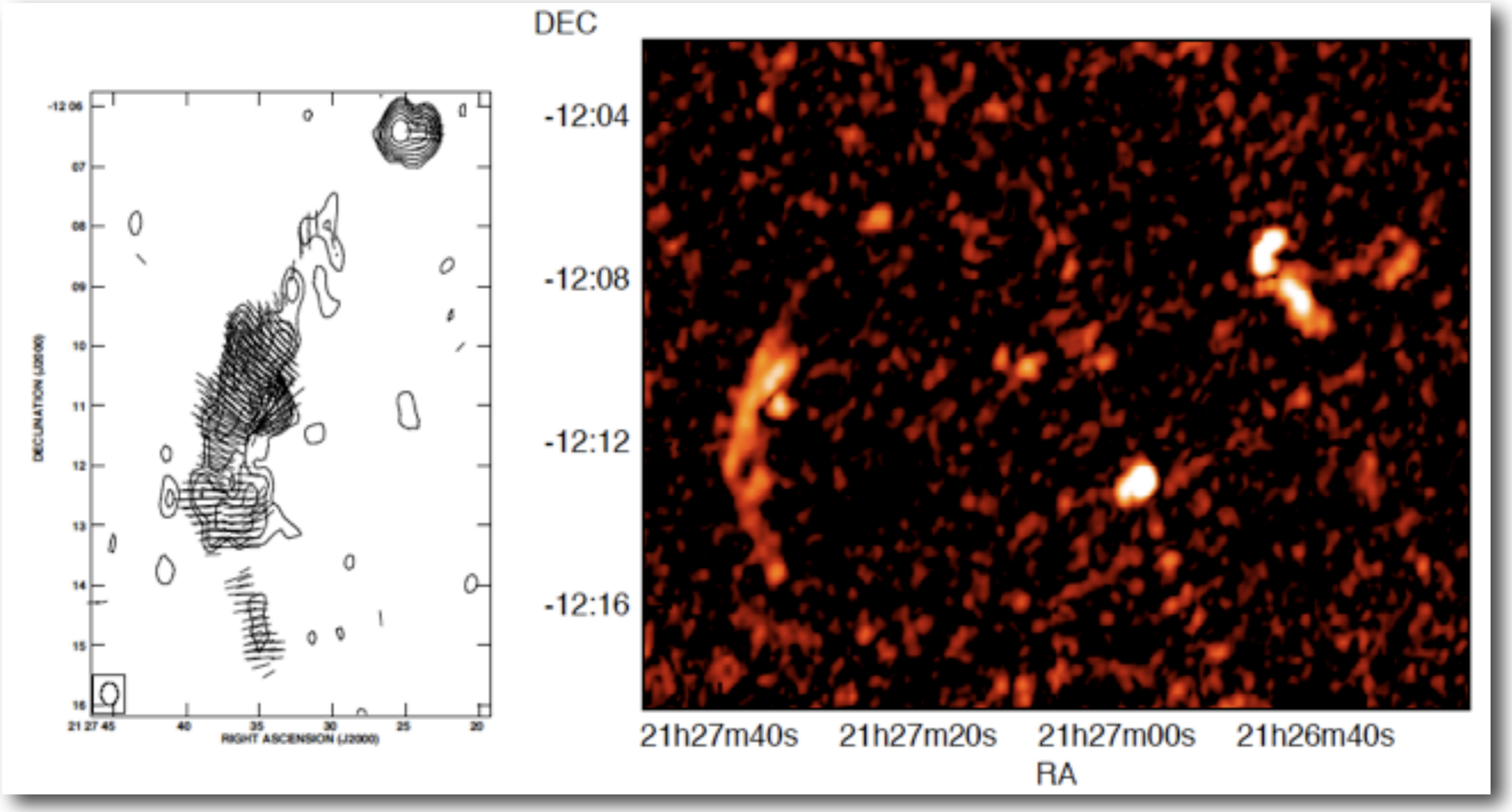
Abell 2744
[Orrù et al. 04]



CIZA 2242
[van Weeren et al. 10]

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. 10]



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 $$\frac{F^{\rm sync}}{F^{\rm IC}} = \frac{U_{\rm B}}{U_{\rm CMB}}$$	> 1.6 μG Suzaku 10-40 keV upper limit [Nakazawa et al. 08]
Equipartition	$\sim$2 μG

What do we learn from radio relics?

Magnetic fields

- strength
- correlation length
- origin

Cosmic rays

- shock (re)accleration
- population of non-therm electrons
- shocks in the ICM

High resolution studies | Statistical samples

What do we learn from radio relics?

Magnetic fields
- strength
- correlation length
- origin

Cosmic rays
- shock (re)accleration
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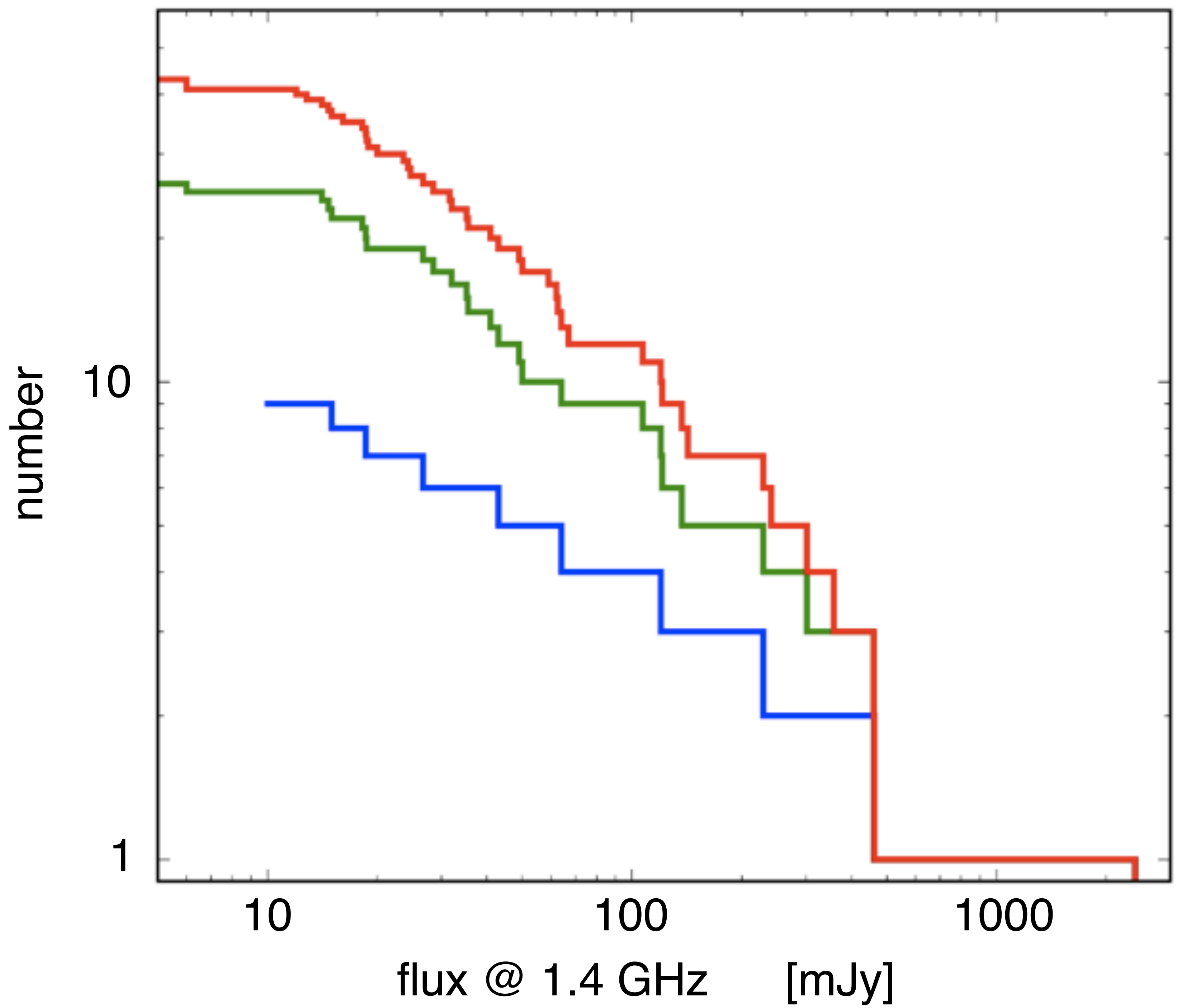
High resolution studies | Statistical samples + Cosmological simulations

Total number of known relics



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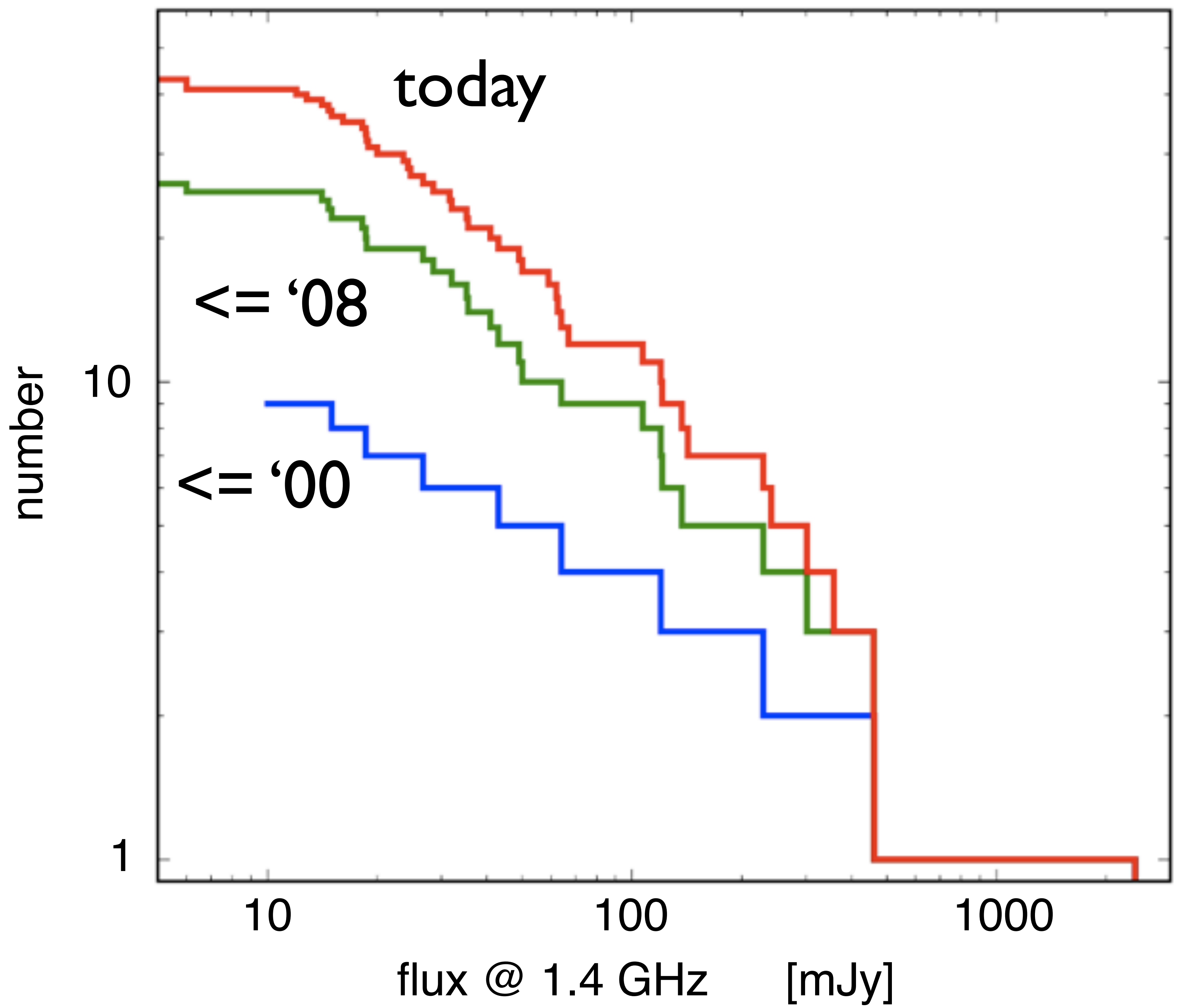
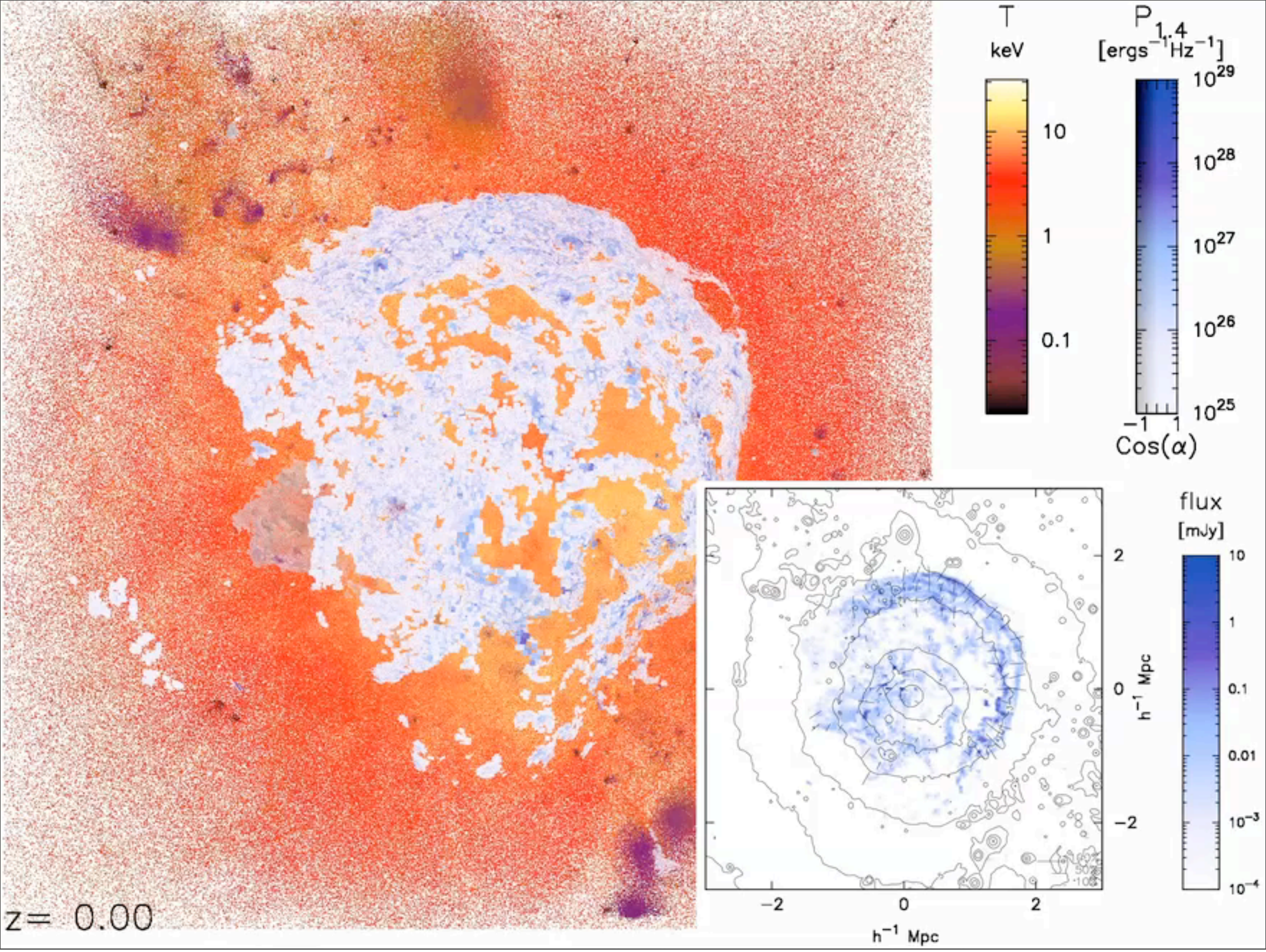


Is there more to discover?

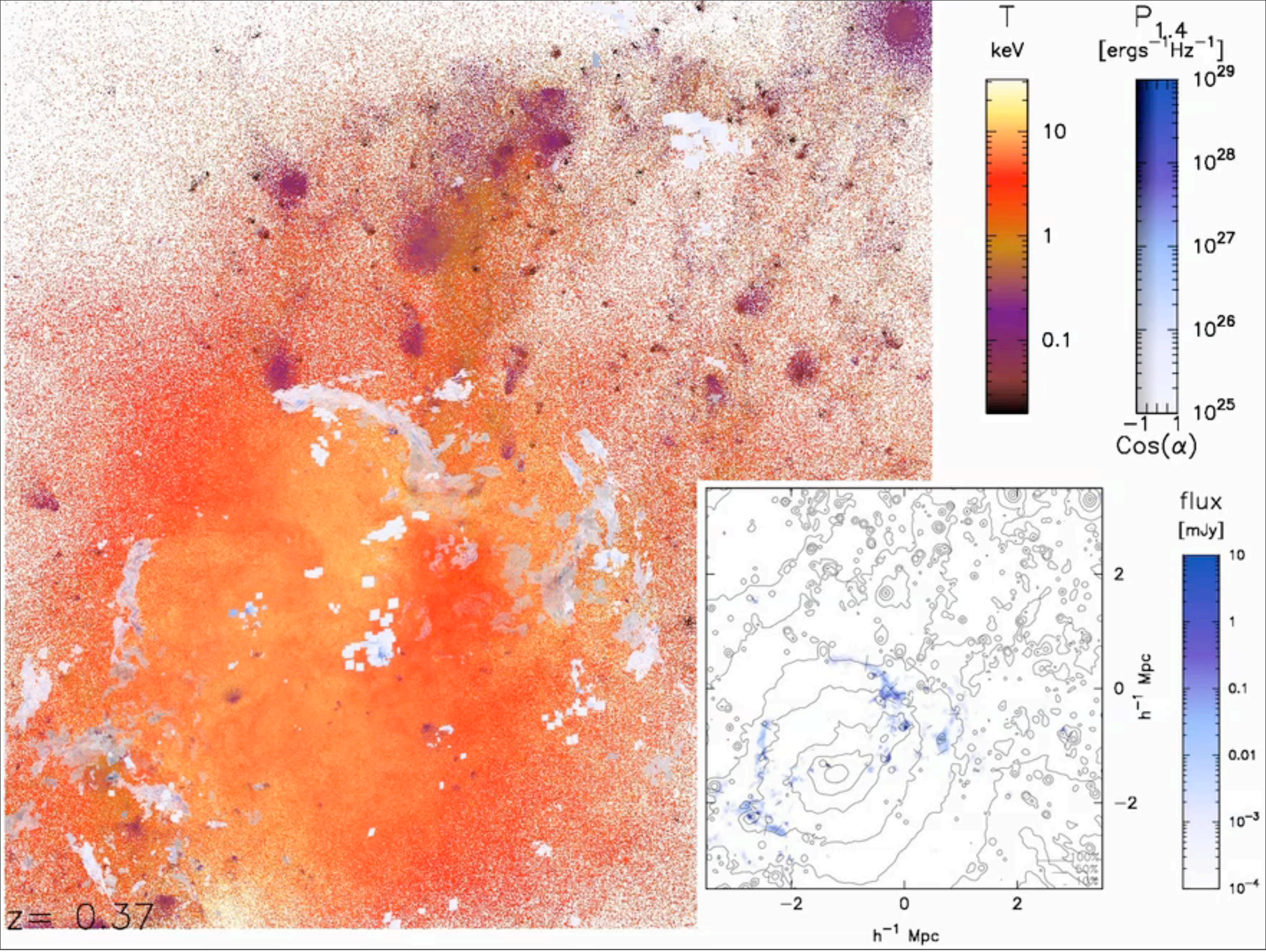
Radio emission in a cosmological simulation

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
$P_{1.4}$
[erg s^{-1} Hz^{-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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flux
[mJy]
10
1
0.1
0.01
10^{-3}
10^{-4}
2
0
−2
−2
0
2
h^{-1} Mpc
h^{-1} Mpc
z= 0.37

Relic luminosity probability

[Nuza, MH et al. sub, see poster downstairs]

- Relic luminosity probability

$$p(P, M, z, \nu_{\rm obs}) = \exp\left\{\frac{(\log P - \log P_{\rm mean})^2}{2\sigma^2}\right\}$$

- Scaling relations from the Mare Nostrum simulation

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

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Interface: Simulations - Observations

Abundance of radio relics

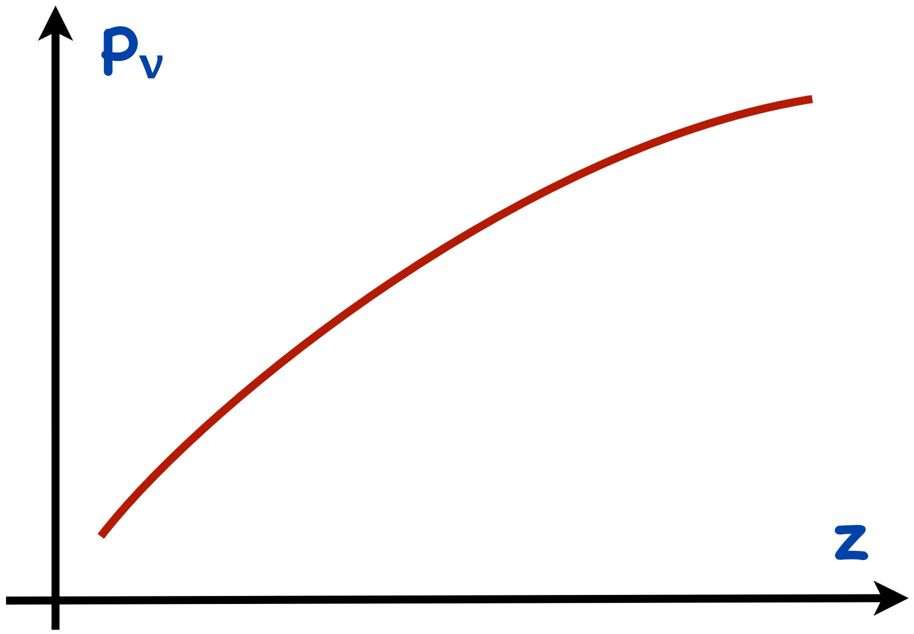
- Halo mass function + radio relic luminosity probability

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

- Survey sensitivity → discovery probability

$$f\left(S - S_{\mathrm{thres}}\right)$$

(Surface brightness, cluster known?, dynamic range, ...)



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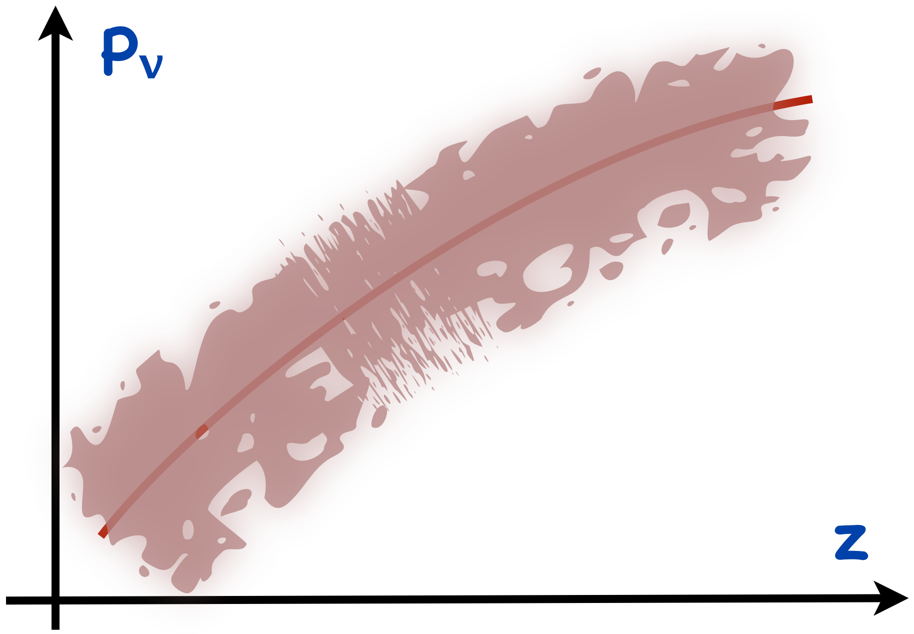
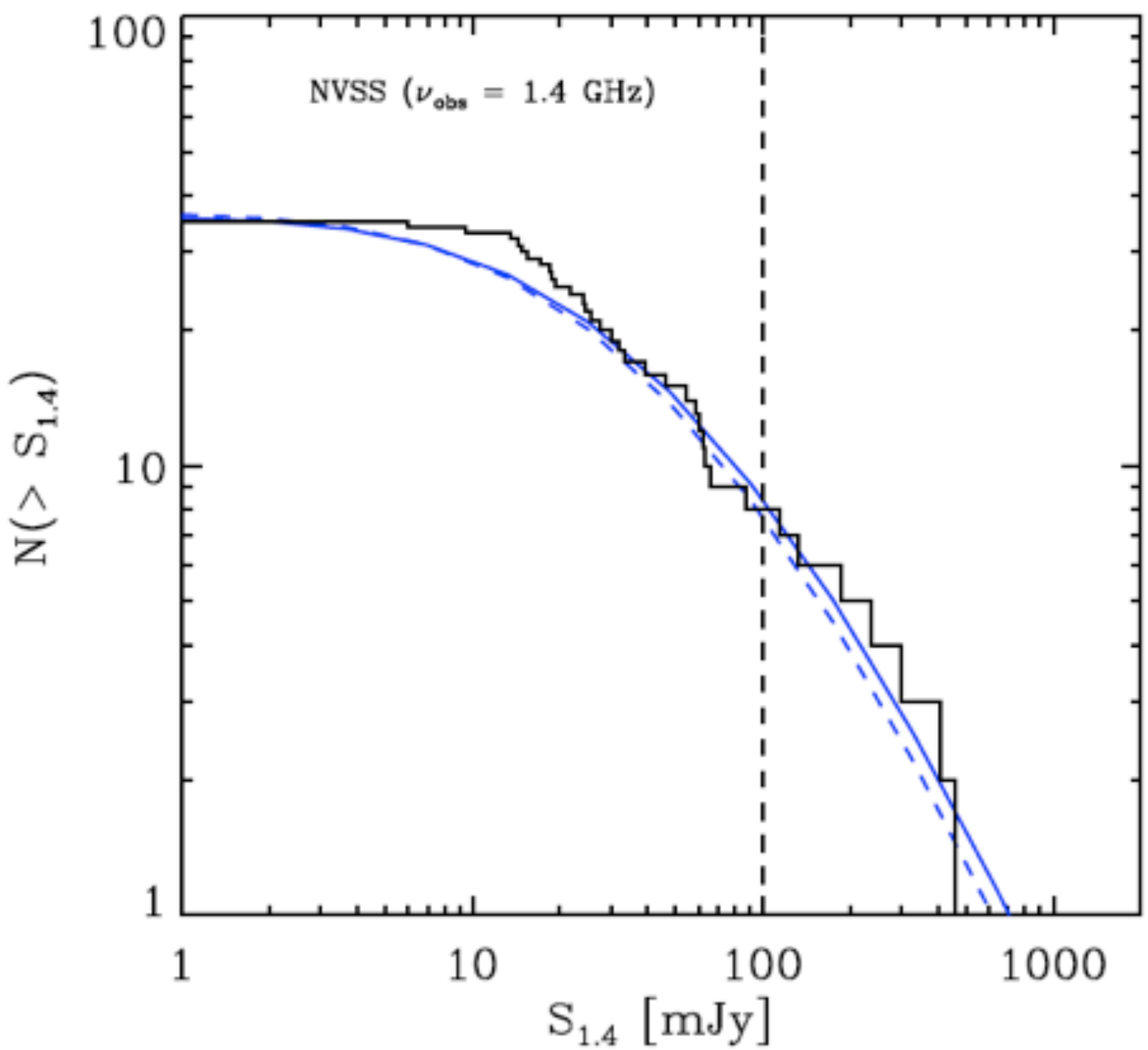


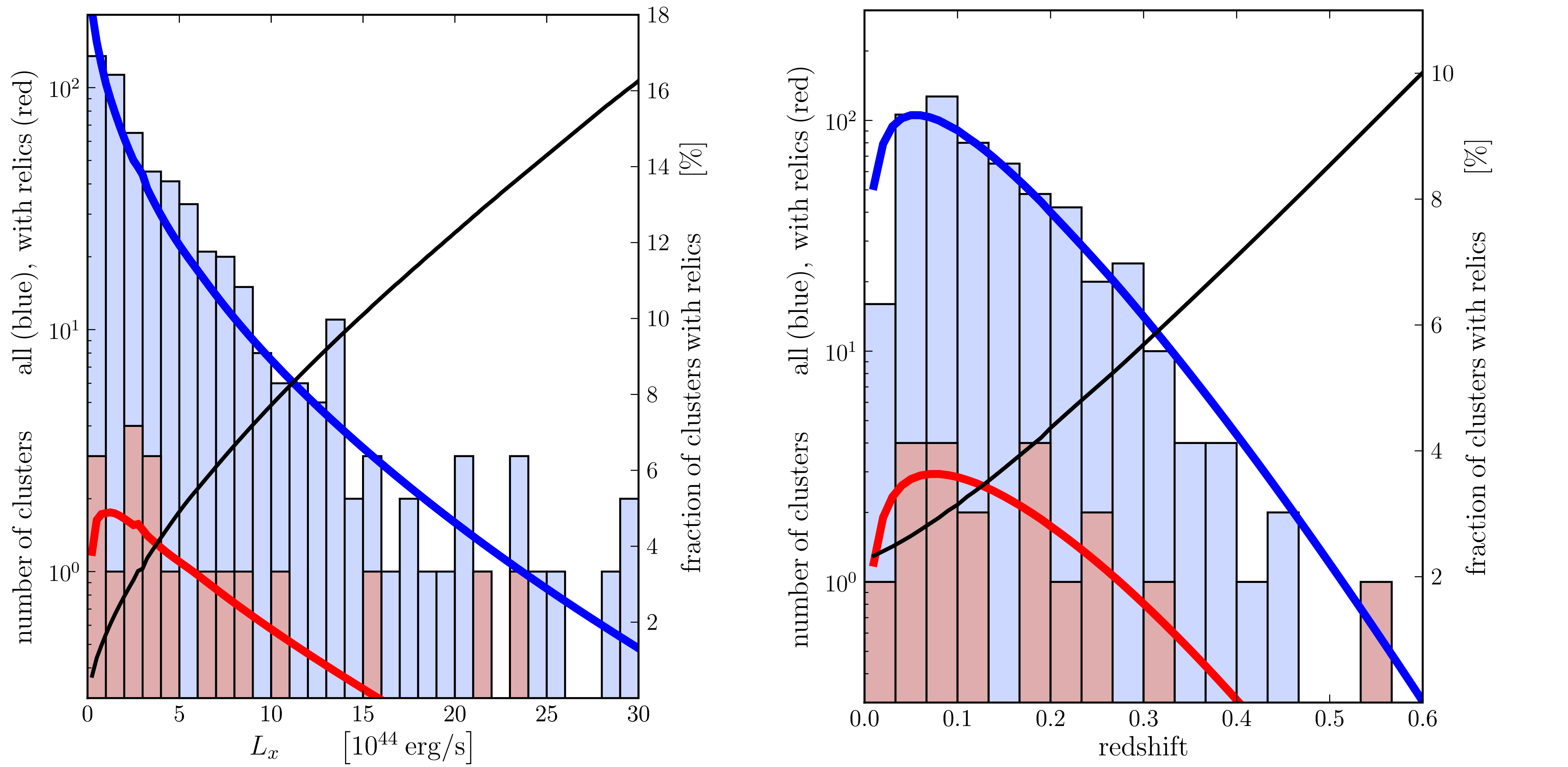
Normalize probability distribution by number of observed relics

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



- σ_{rms} (NVSS) = 0.45 mJy

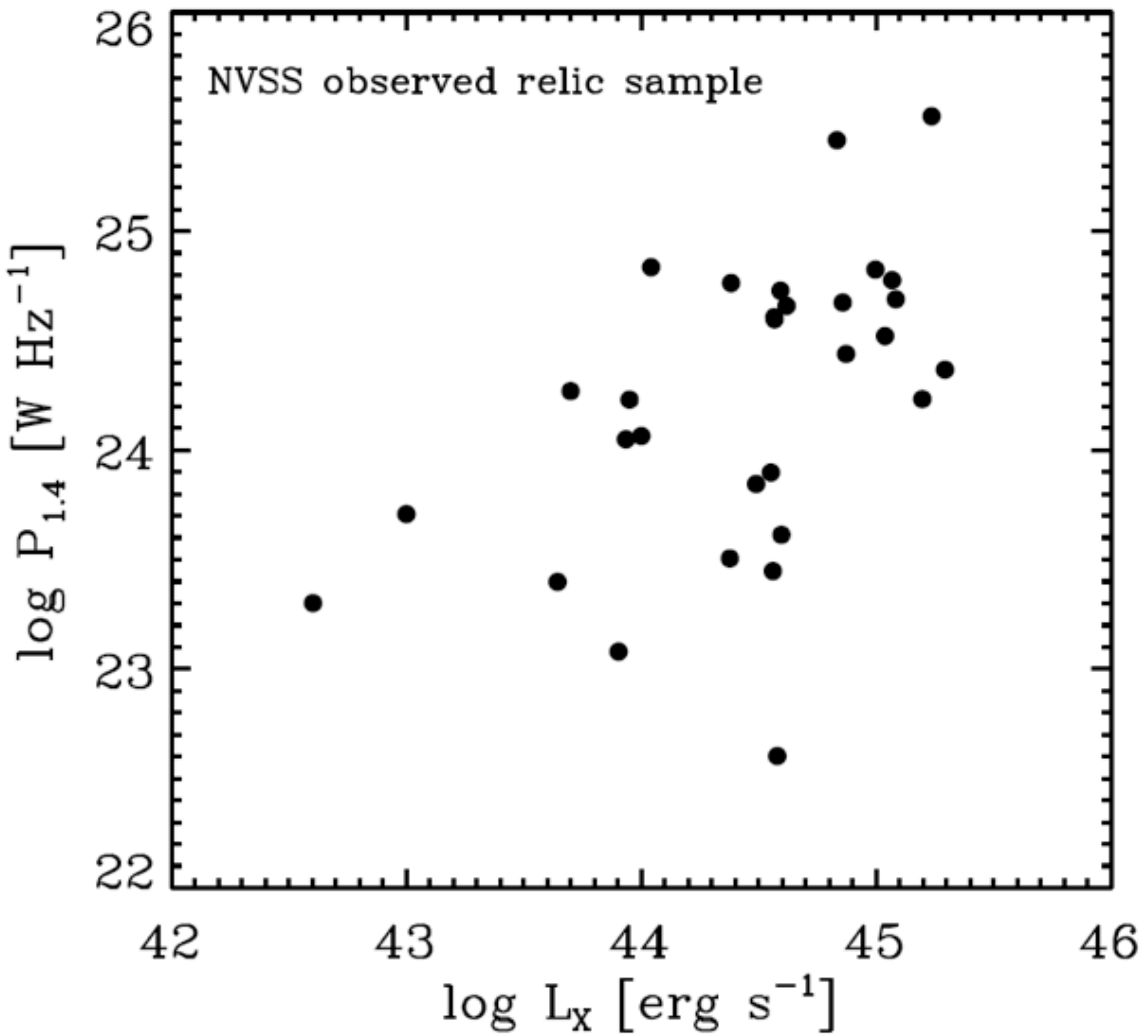
X-ray limited cluster sample



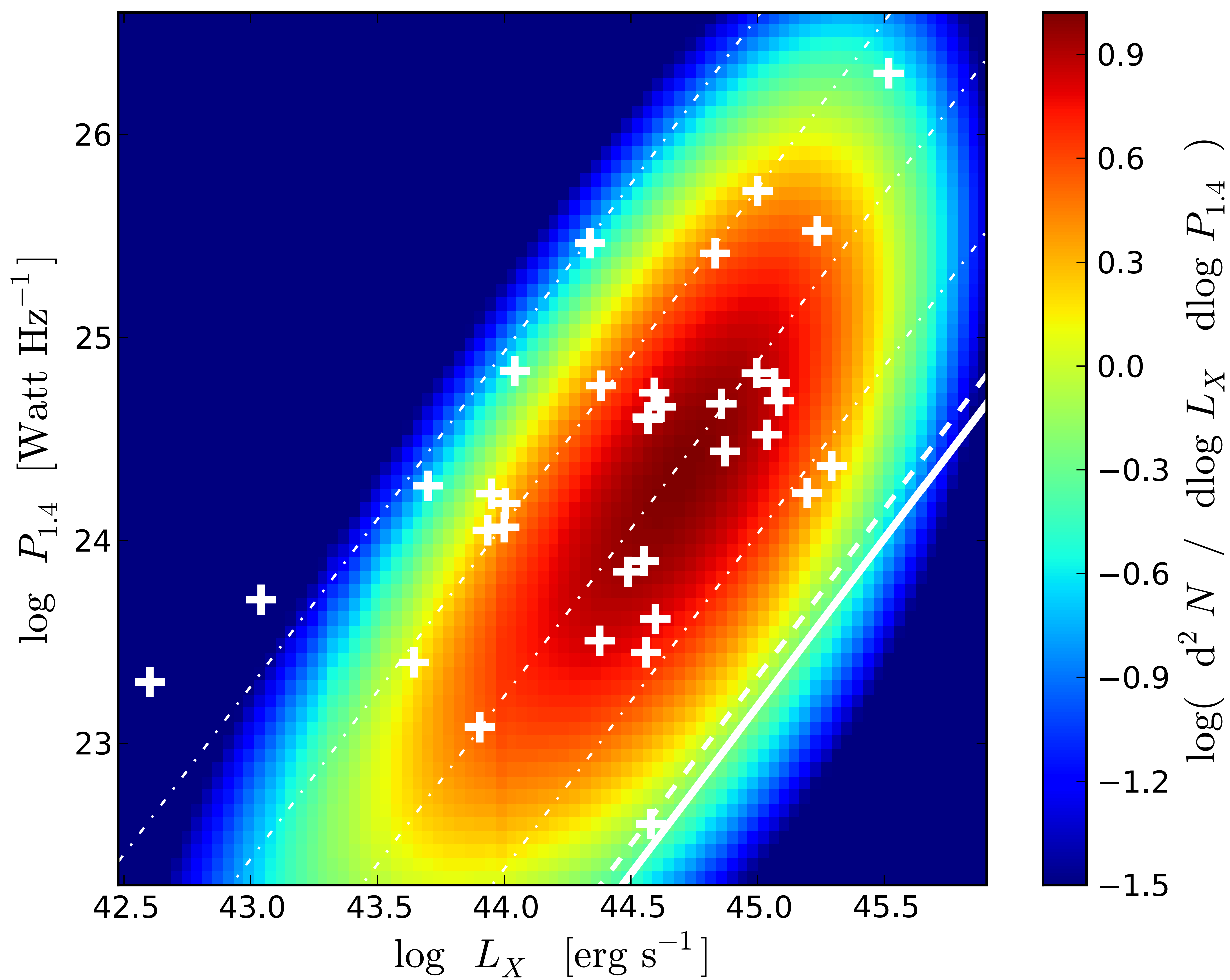
[van Weeren et al, 2011]

- NORAS + REFLEX sample
- fraction of clusters with relic: 3.6%
- S_{thres} ~ 30 mJy

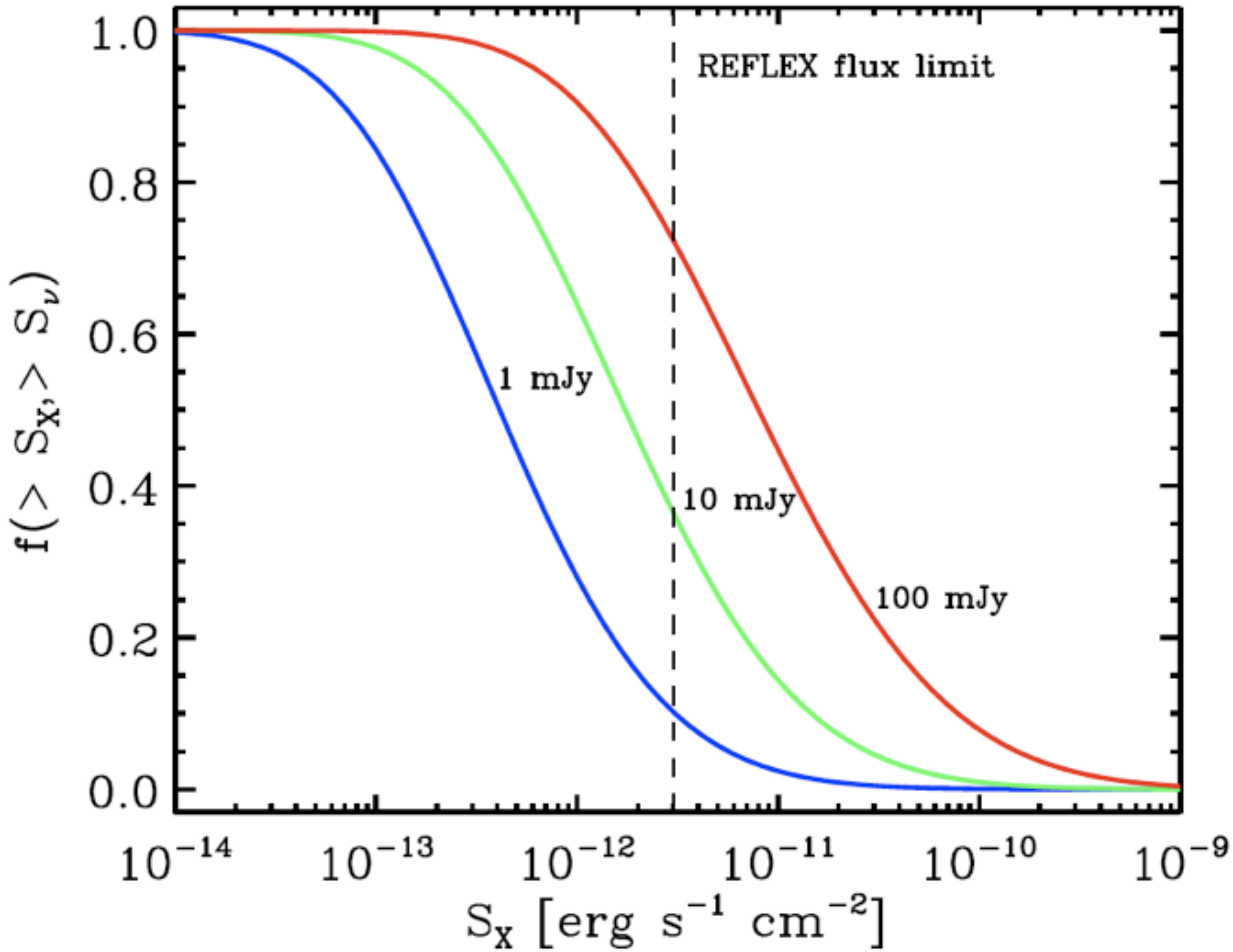
L_X - $P_{1.4}$ distribution



L_X - $P_{1.4}$ distribution



The need for deep cluster surveys



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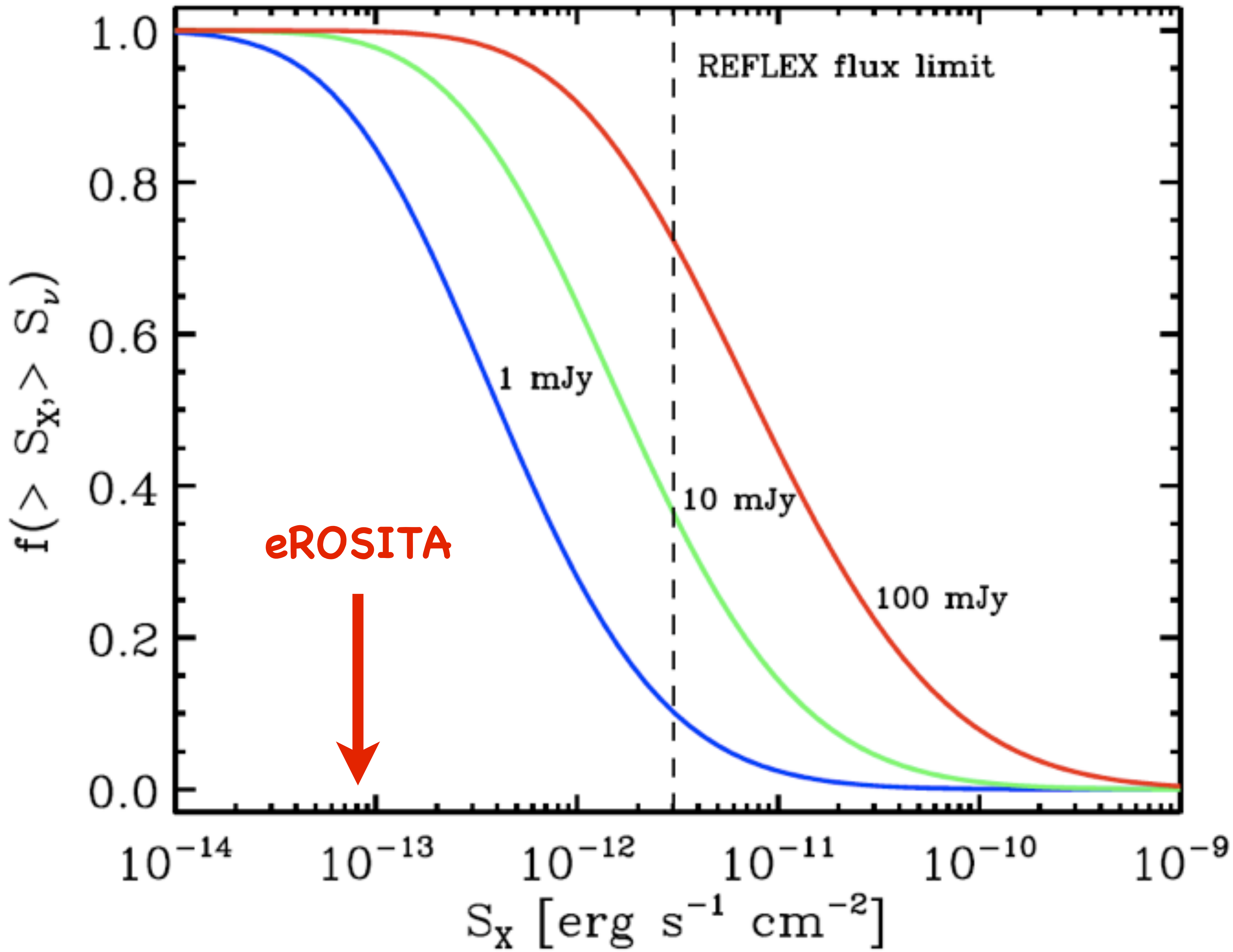
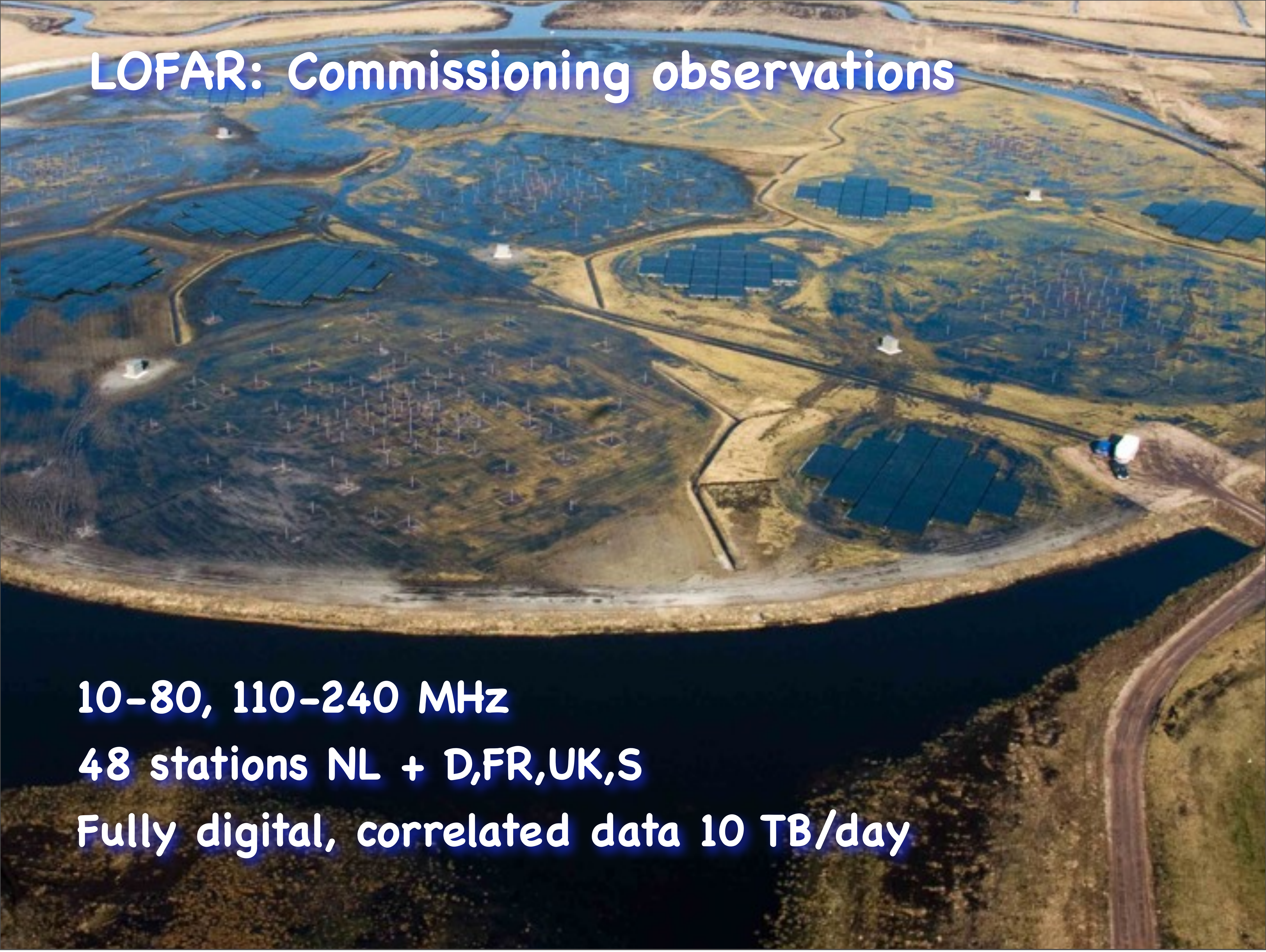


LOFAR: Commissioning observations



10-80, 110-240 MHz

48 stations NL + D,FR,UK,S

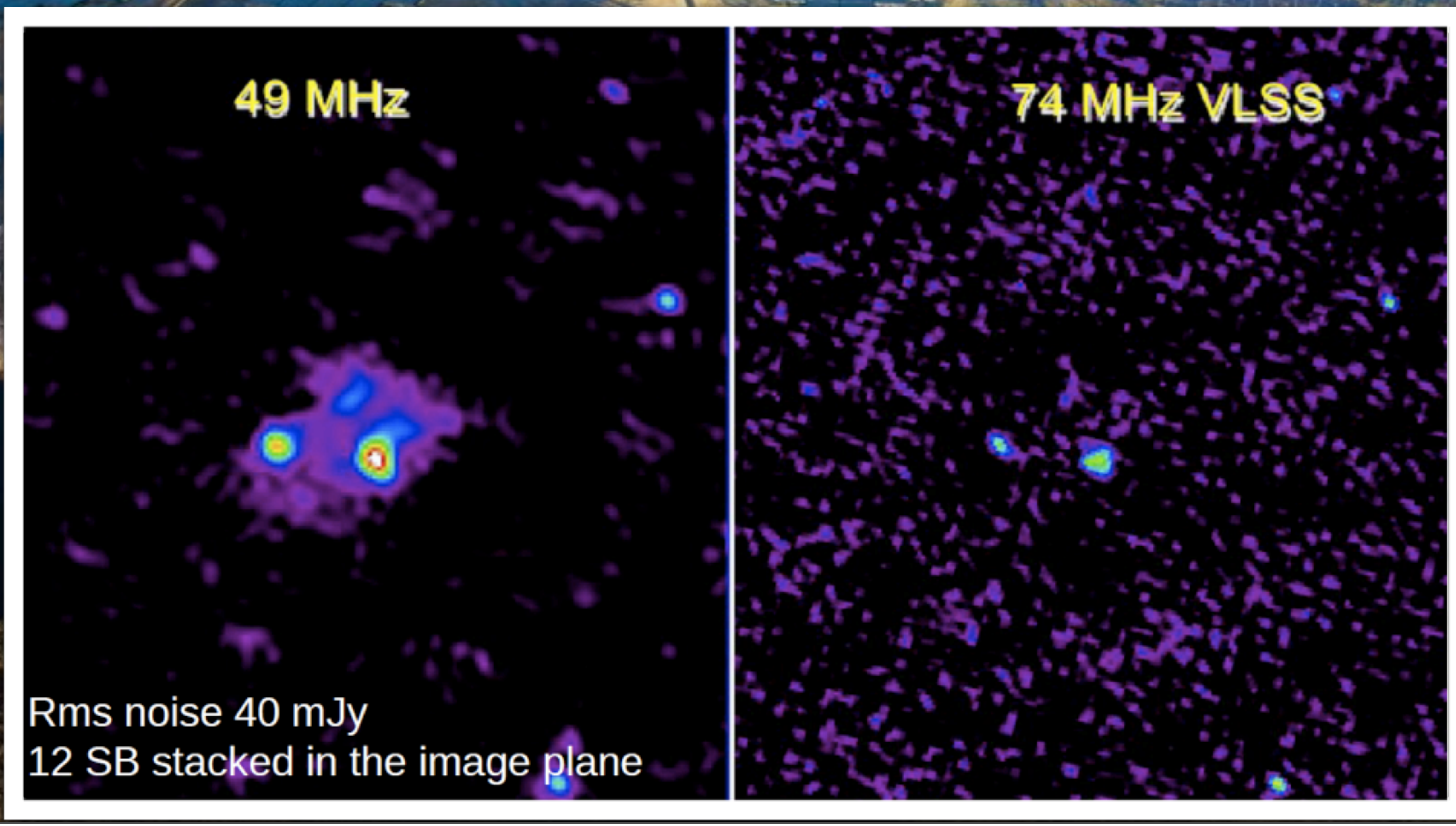
Fully digital, correlated data 10 TB/day

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	2000
2	120	25	240	130
3	150	6.2	30	30

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	[MHz]	[illegible]	[deg^2]	
1	[illegible]	[illegible]	k	2000
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Thanks!