# Radio relis (and halos) in galaxy clusters

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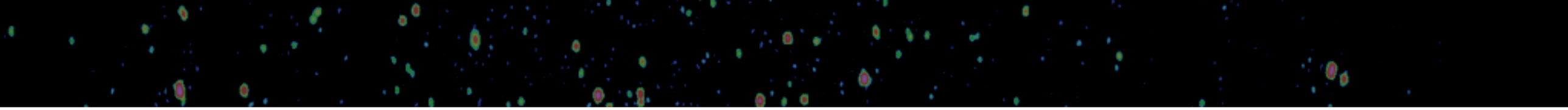
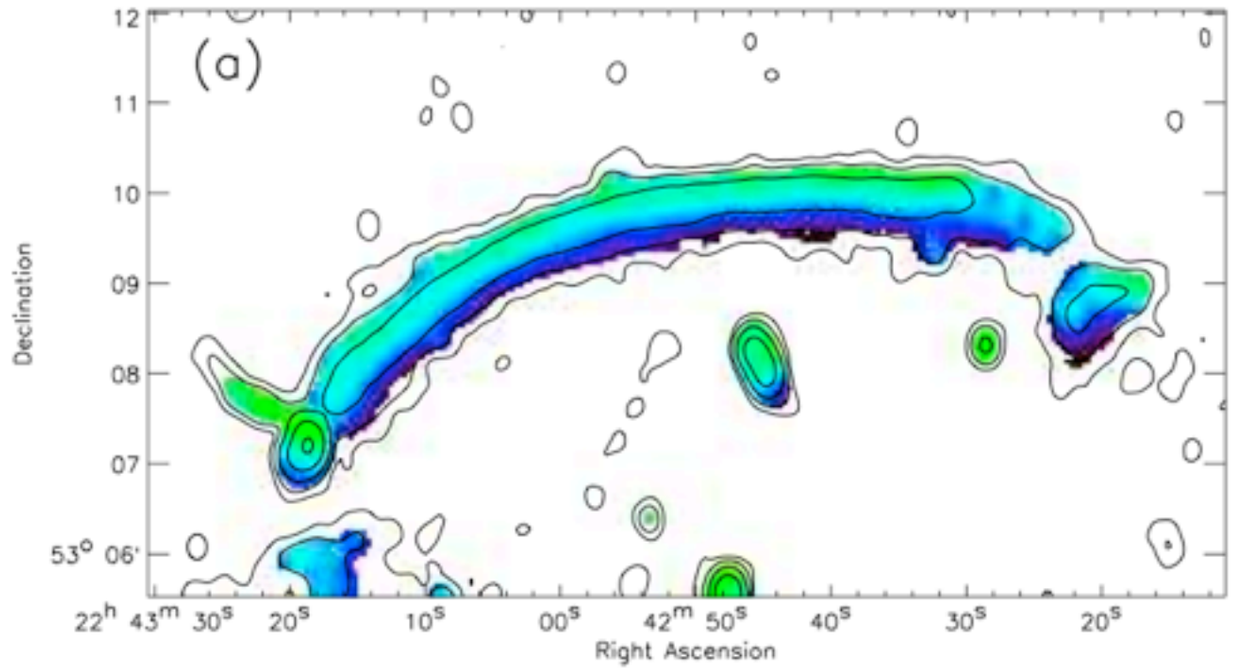


- overall spectrum of relics
- relic statistics
- an unusual radio halo

# Radio relic: the textbook example

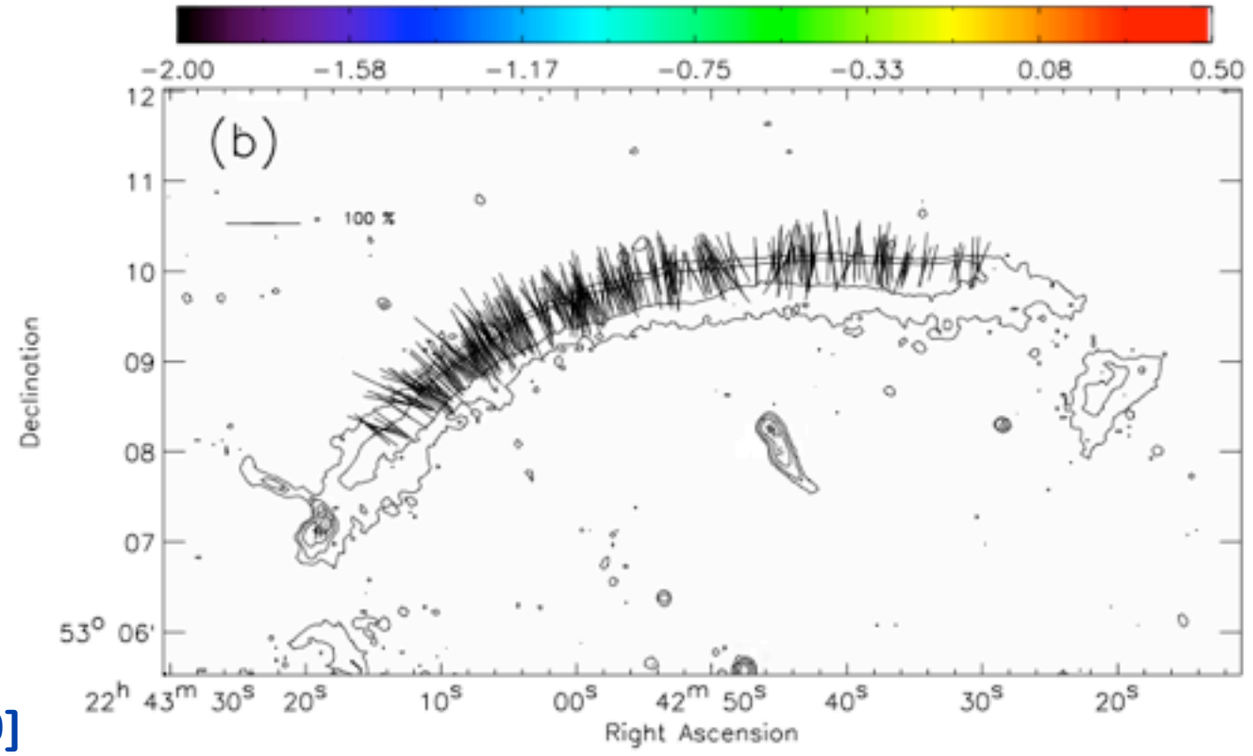
## CIZA2242, the “sausage”

- perfect aging profile
- intrinsic width ~ 55 kpc
- homogenous along relic
- perfect magnetic field alignment




## but:

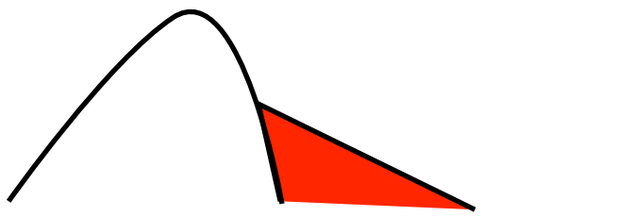
- no projection effects?




[van Weeren+ 2010]

# The canonical(?) model for radio relics

- trace merger shock fronts [Ensslin+ 1998]
- diffusive shock acceleration:
  power-law electron spec. (observed $\gamma \sim 10^4$ )
- injection or seed electrons:
  thermal? accretion shocks? fossil AGN? shock drift accel?
- downstream advection and cooling (synchr. + IC)



fraction of diss. energy

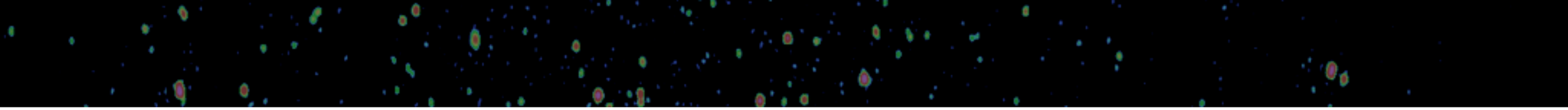
$$\frac{\mathrm{d}P(\nu_{\rm obs})}{\mathrm{d}\nu} = 6.4\times10^{34}\,\frac{\rm erg}{\rm s\,Hz}\,\frac{A}{\rm Mpc^2}\,\frac{n_{\rm e}}{10^{-4}{\rm cm}^{-3}}\,\frac{\xi_{\rm e}}{0.05}\left(\frac{\nu_{\rm obs}}{1.4\,\rm GHz}\right)^{-\frac{s}{2}} \times\left(\frac{T_{\rm d}}{7\,\rm keV}\right)^{\frac{3}{2}}\frac{\left(\frac{B}{\mu\rm G}\right)^{1+\frac{s}{2}}}{\left(\frac{B_{\rm CMB}}{\mu\rm G}\right)^2+\left(\frac{B}{\mu\rm G}\right)^2}\,\Psi(\mathcal{M},T)$$

injection+efficiency

DSA

cooling+synch

[Hoeft & Brüggen 07]

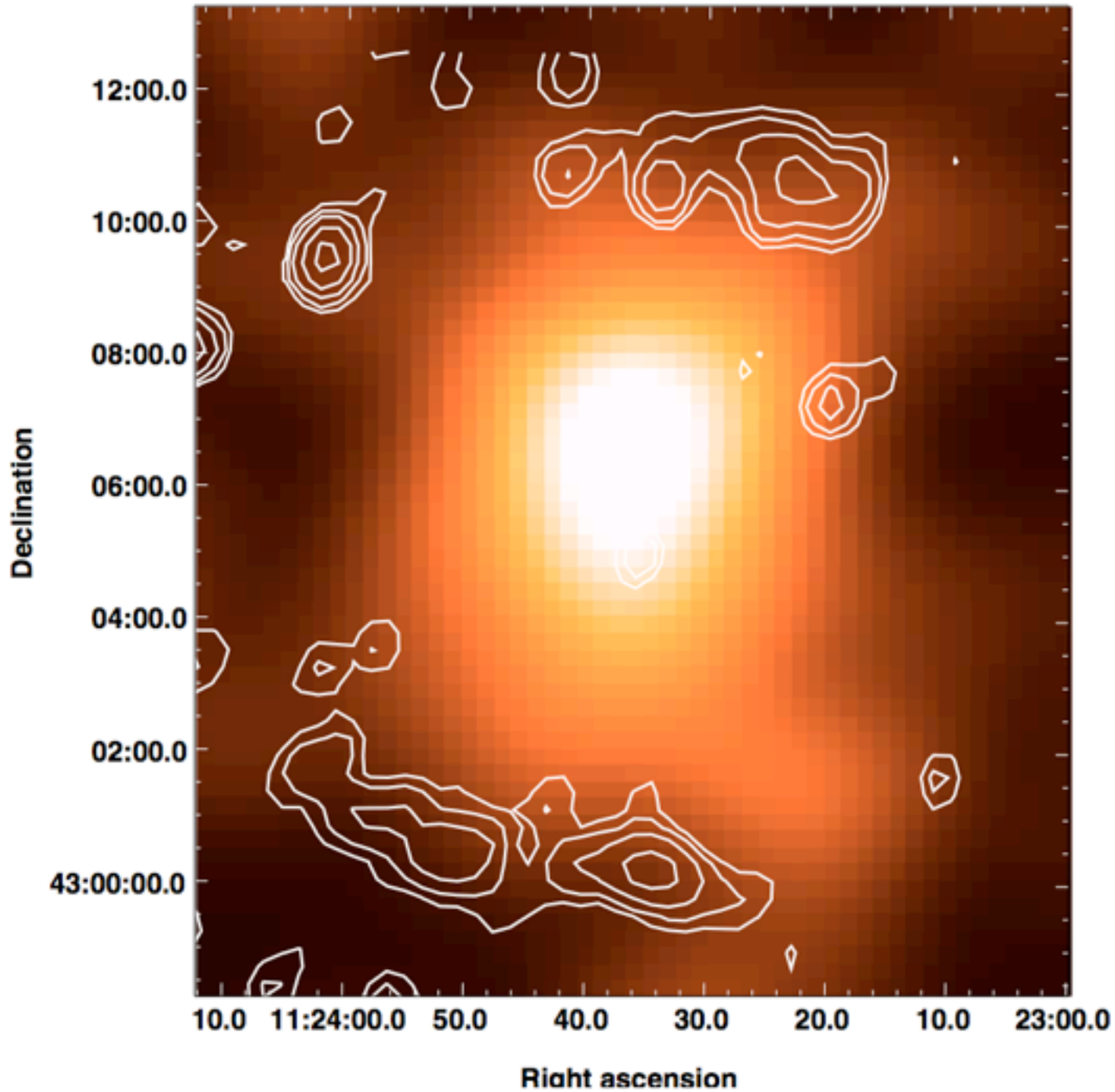


# Does this work for any relic?

# Example: Double relic in Abell 1240

a typical, low lum double relic

- relic north
  - 6.0 +/- 0.2 mJy (20cm)
  - LSS 650 kpc
- relic south
  - 10.1 +/- 0.4 mJy (20cm)
  - LSS 1250 kpc
- polarized

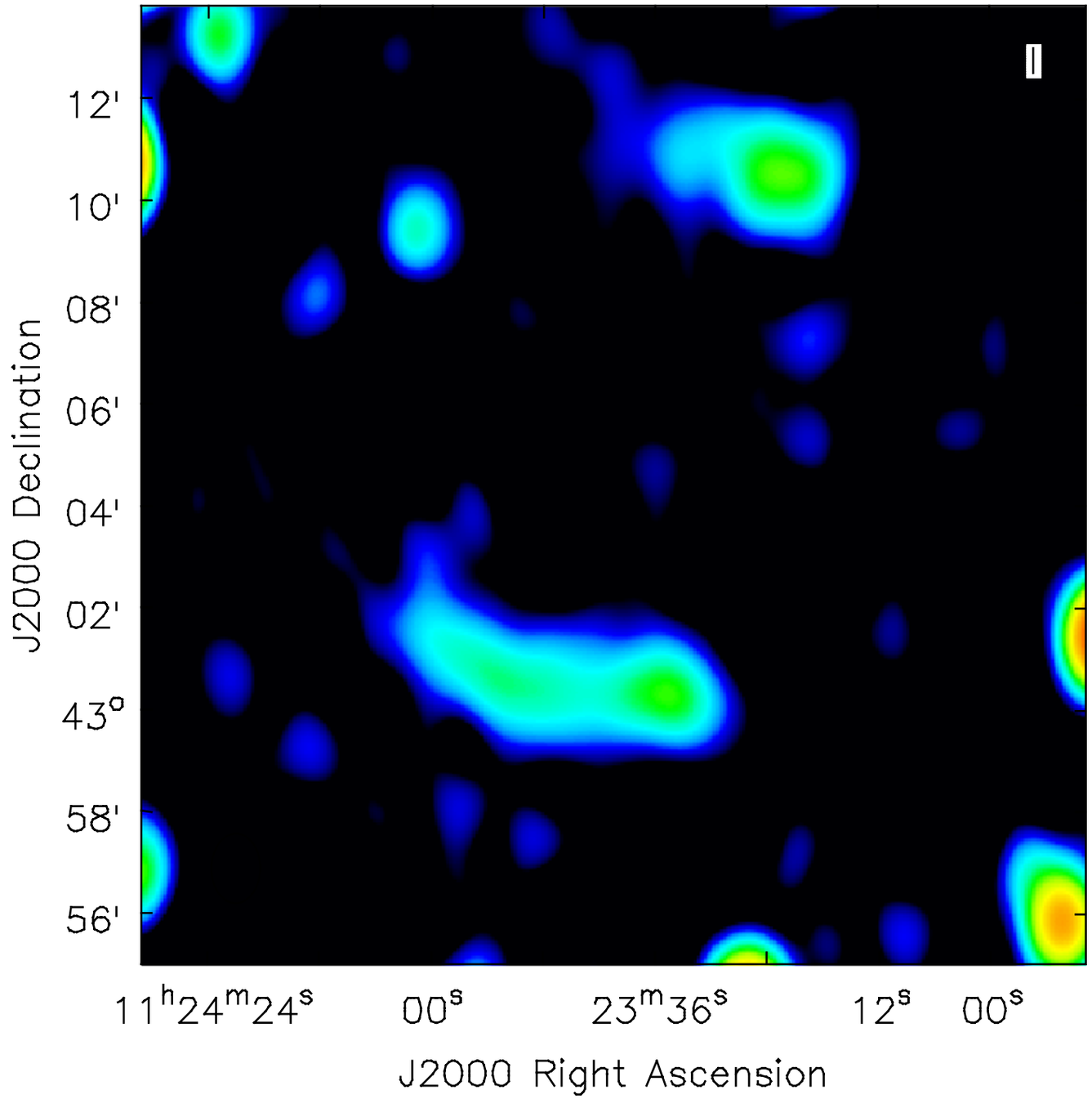



VLA + ROSAT, Lx ~$10^{44}$ erg/s

[Bonafede+ 2009]

# Low frequency follow up: WSRT

- relic north
  - 35 mJy (90cm)
  - alpha = - 1.2
- relic south
  - 10.1 +/- 0.4 mJy (20cm)
  - alpha = - 1.1
- no surprises




[Drabent+ in prep.]

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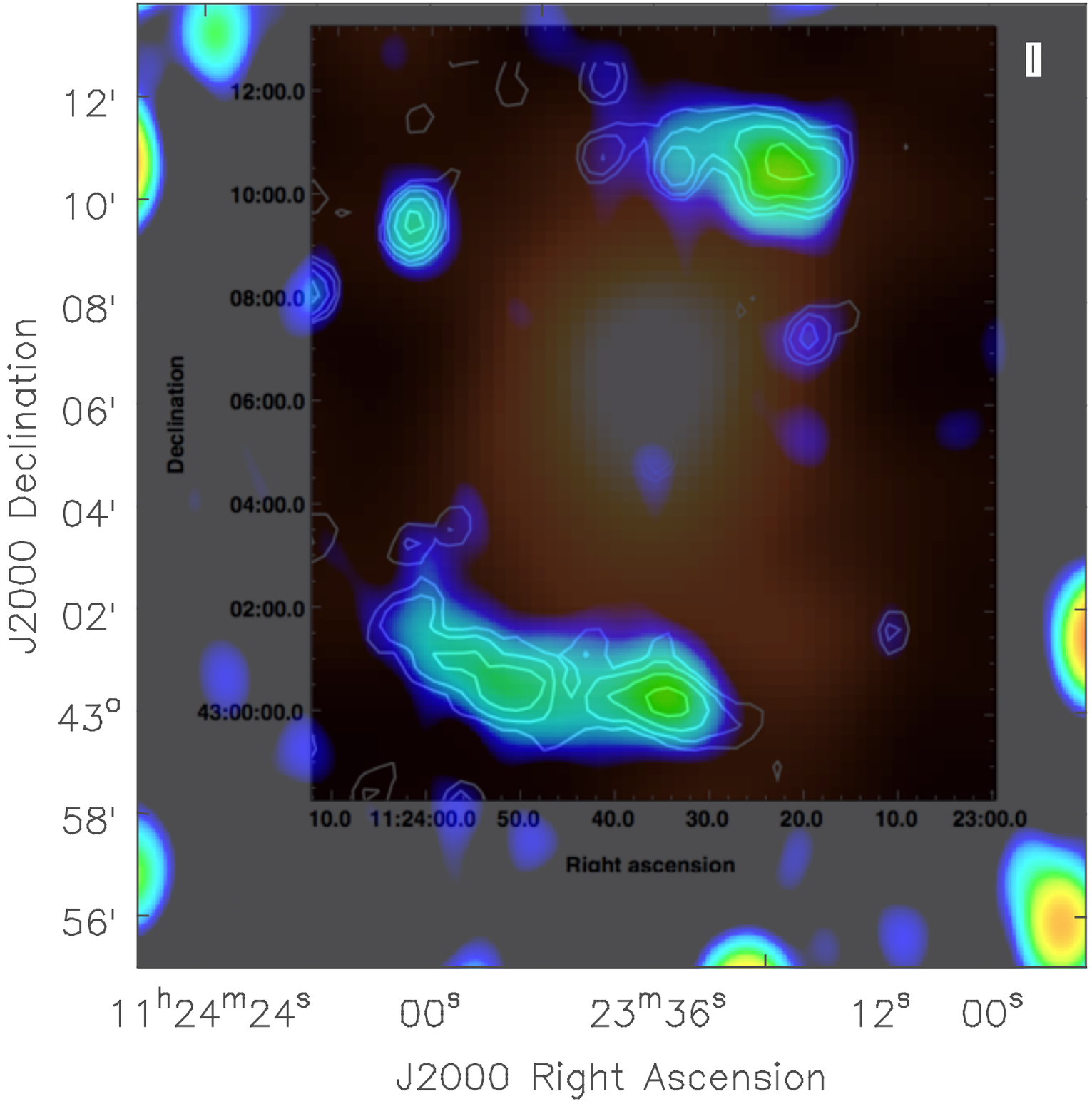


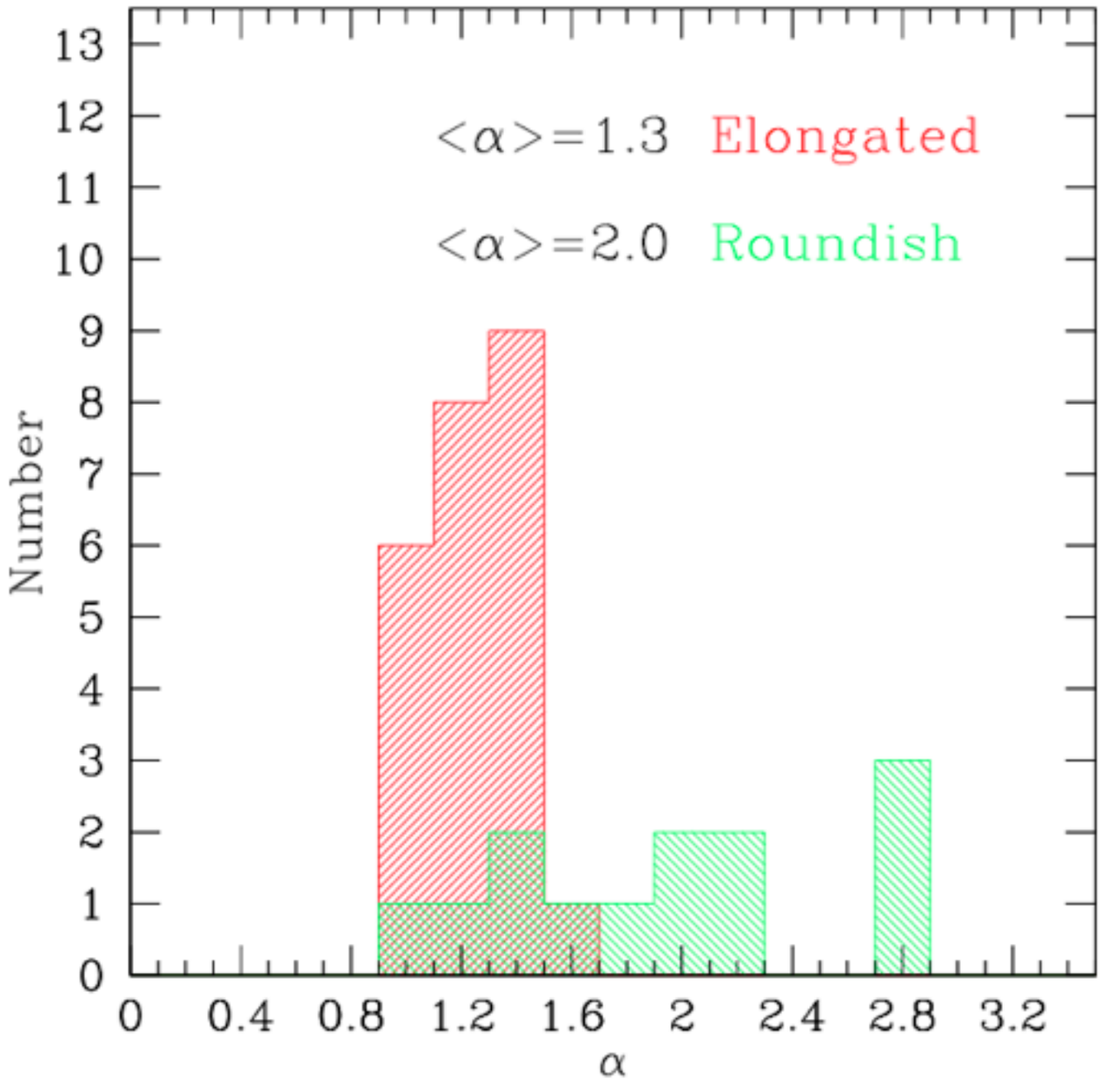
# Radio relic ‘compilation’

- most of ‘proper’ relics have a power-law spectrum with spectral index 1-1.6
- consistent with DSA+cooling
- counter examples:

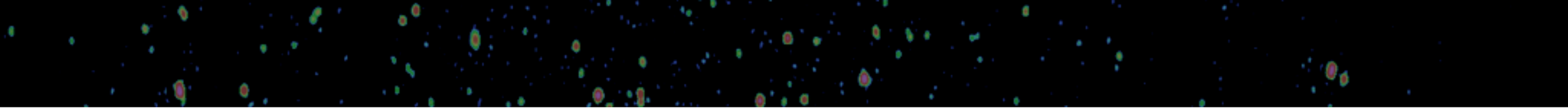
  A2256: too flat

  A2146: shock but no radio

  …



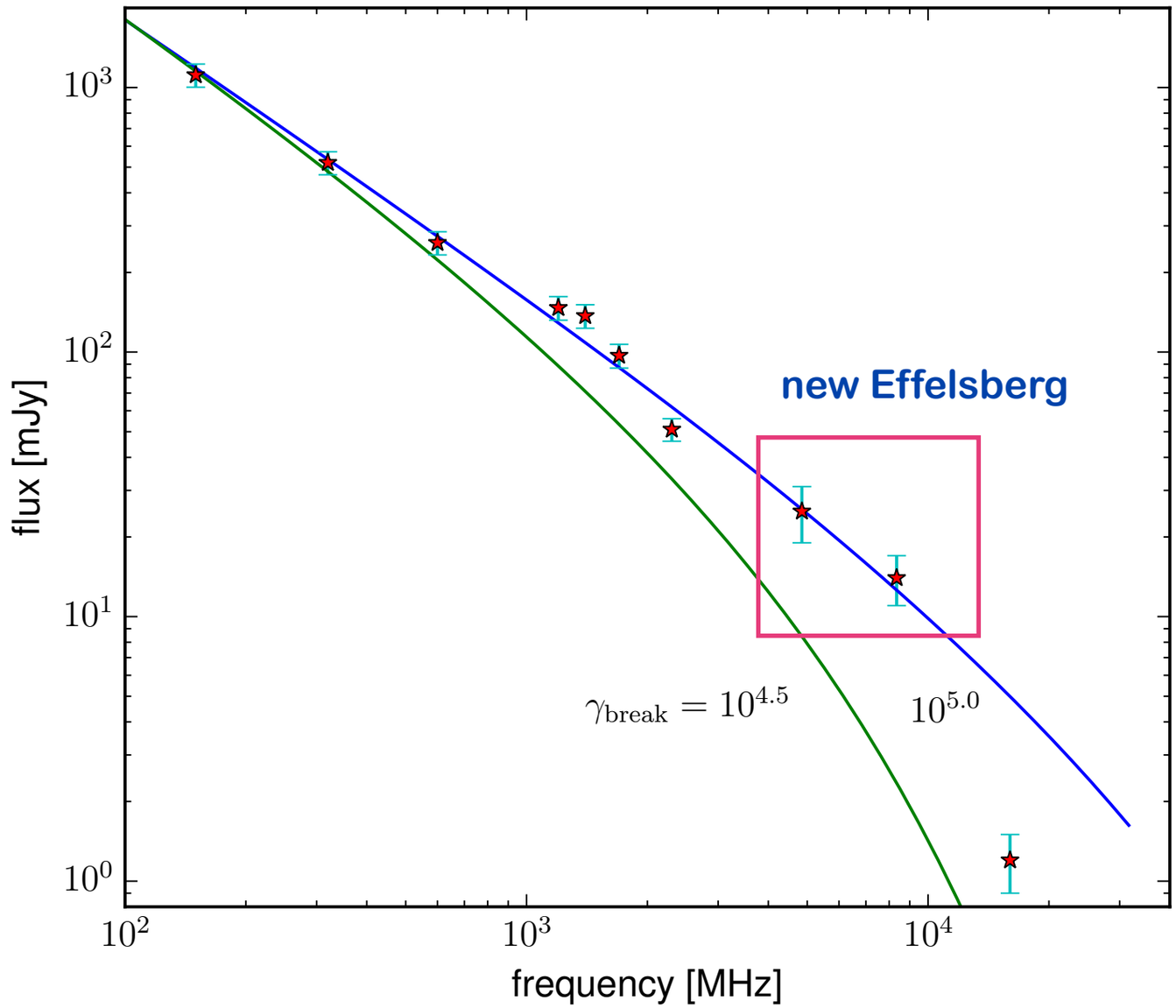

[Feretti+ in 2012]



# Is there a high frequency cut-off?

# The “sausage” spectrum

- indication for break >10 GHz
- but
  - not seen by lower single dish obs
  - SZ?

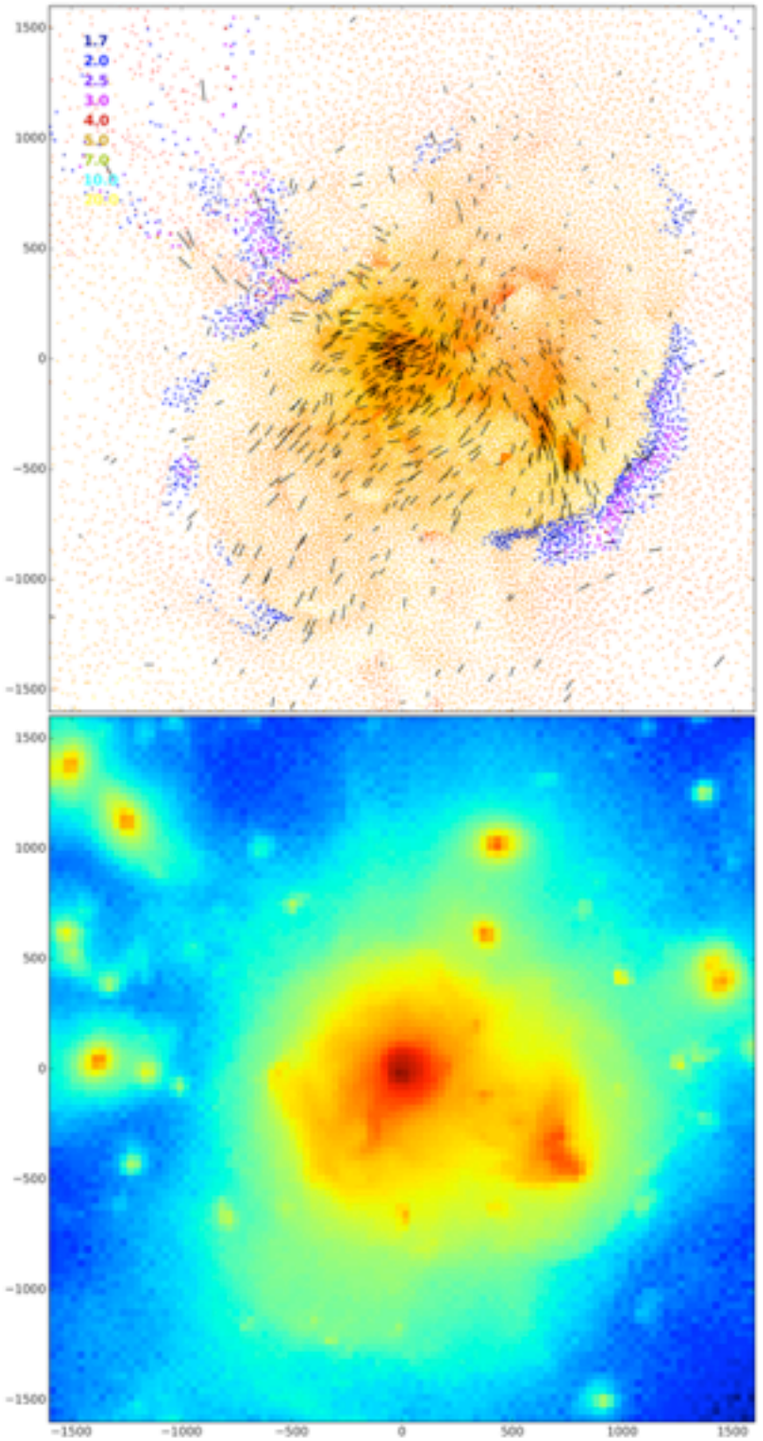



[Stroe+ 2013]

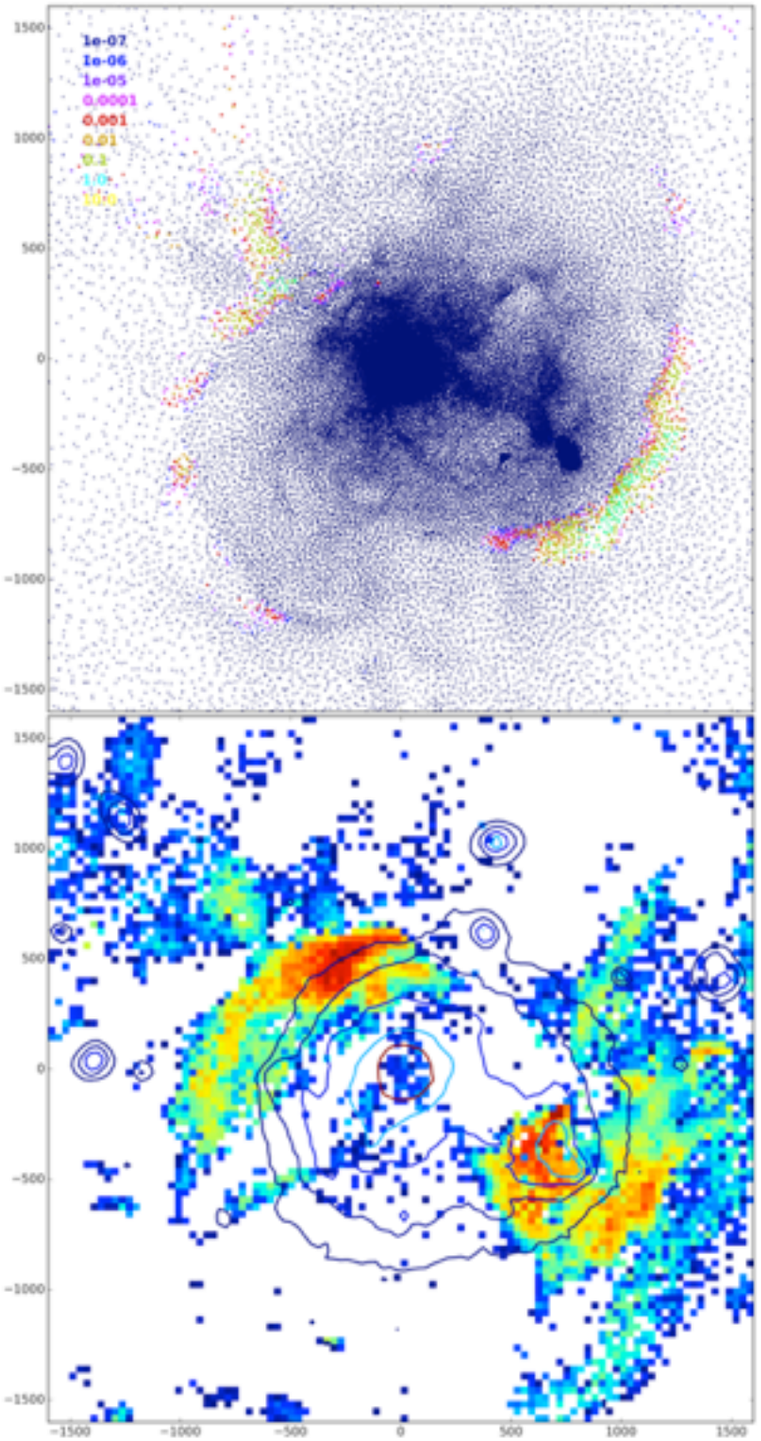
# Does any shock-front hosts a relic?

# Shock fronts in the “Music” cluster sample

**Mach number (slice)**




**radio emission (slice)**



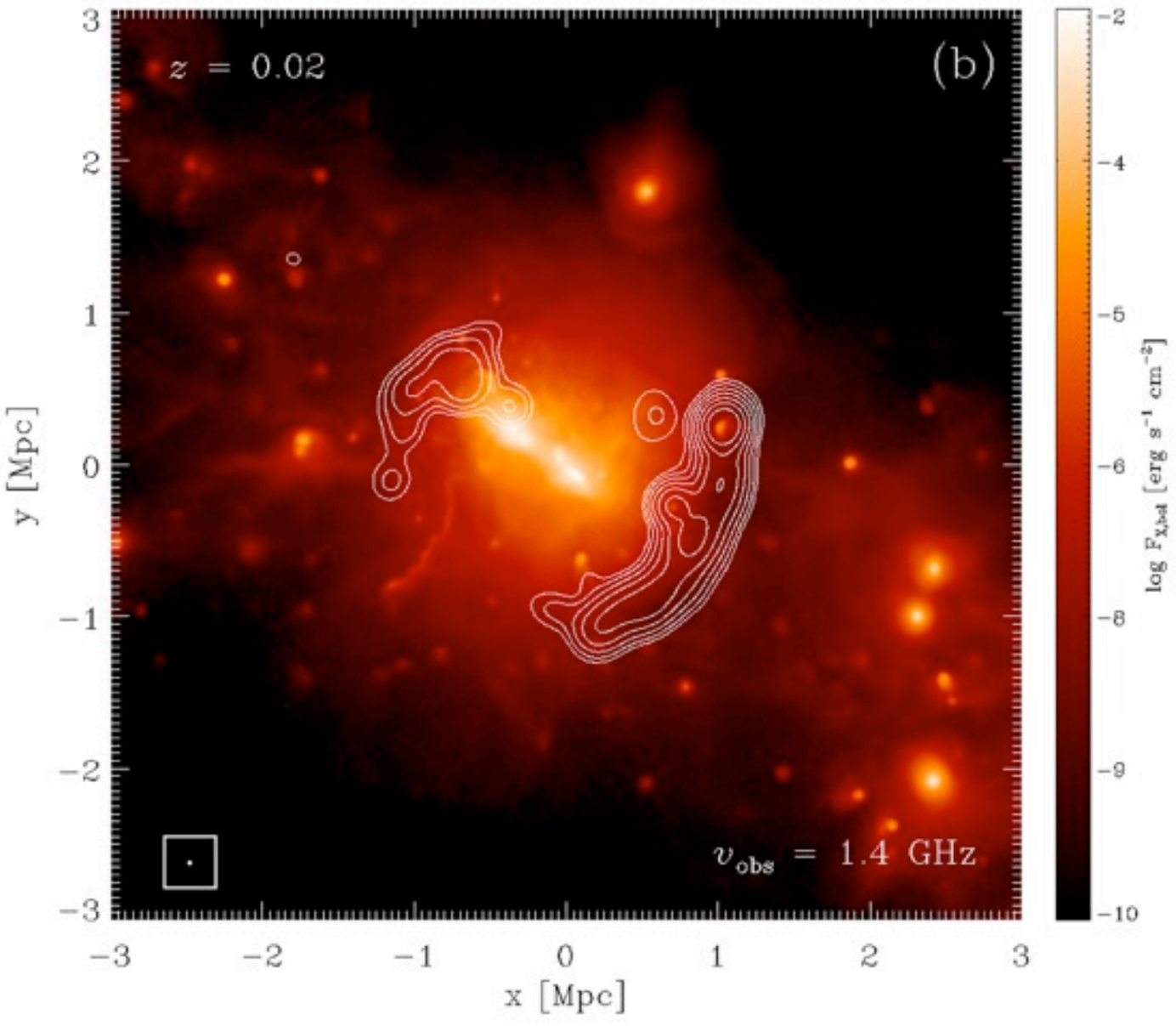

**X-ray**




**radio (projected)**

# Simulat radio relic sample

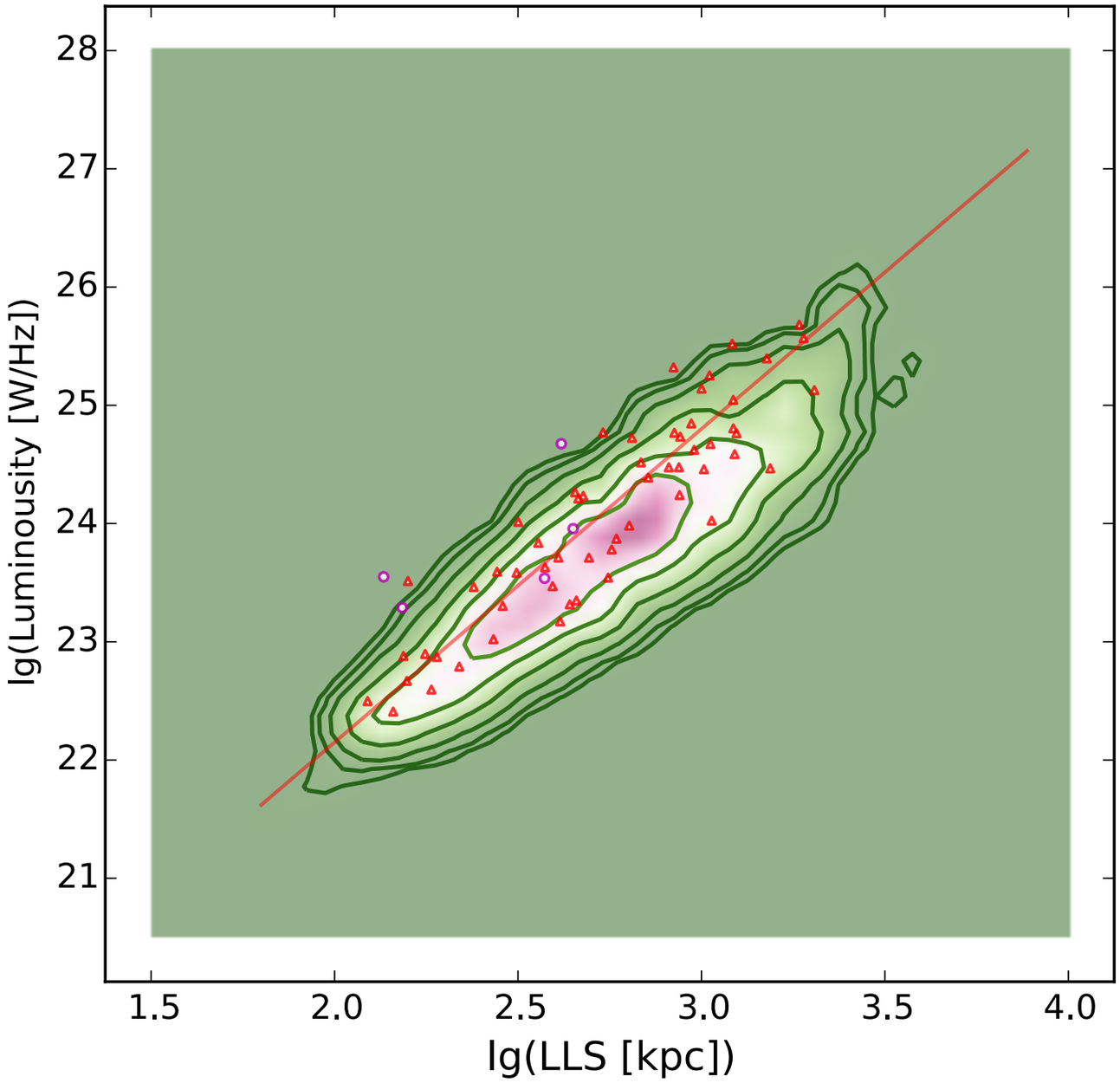
- aim: mimic NVSS appearance
  beam 45arcsec
  surface bright: ~ 1mJy/beam
- difficult: what is one relic? depends on surface brightness threshold
- measure flux and LLS




[Nuza, Gelszinnis in prep]

# Statistics: Luminosity - LLS relations

- measure relics in NVSS in the same way
- reproduces Lum - LSS corr
- but: we habe introduced a detection bias for small relics

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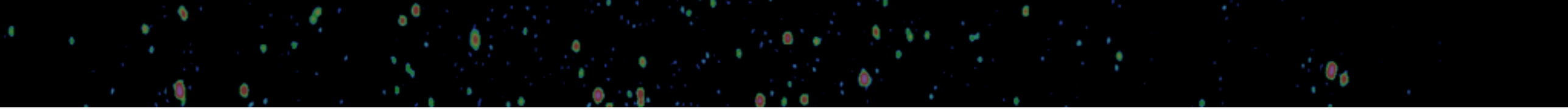
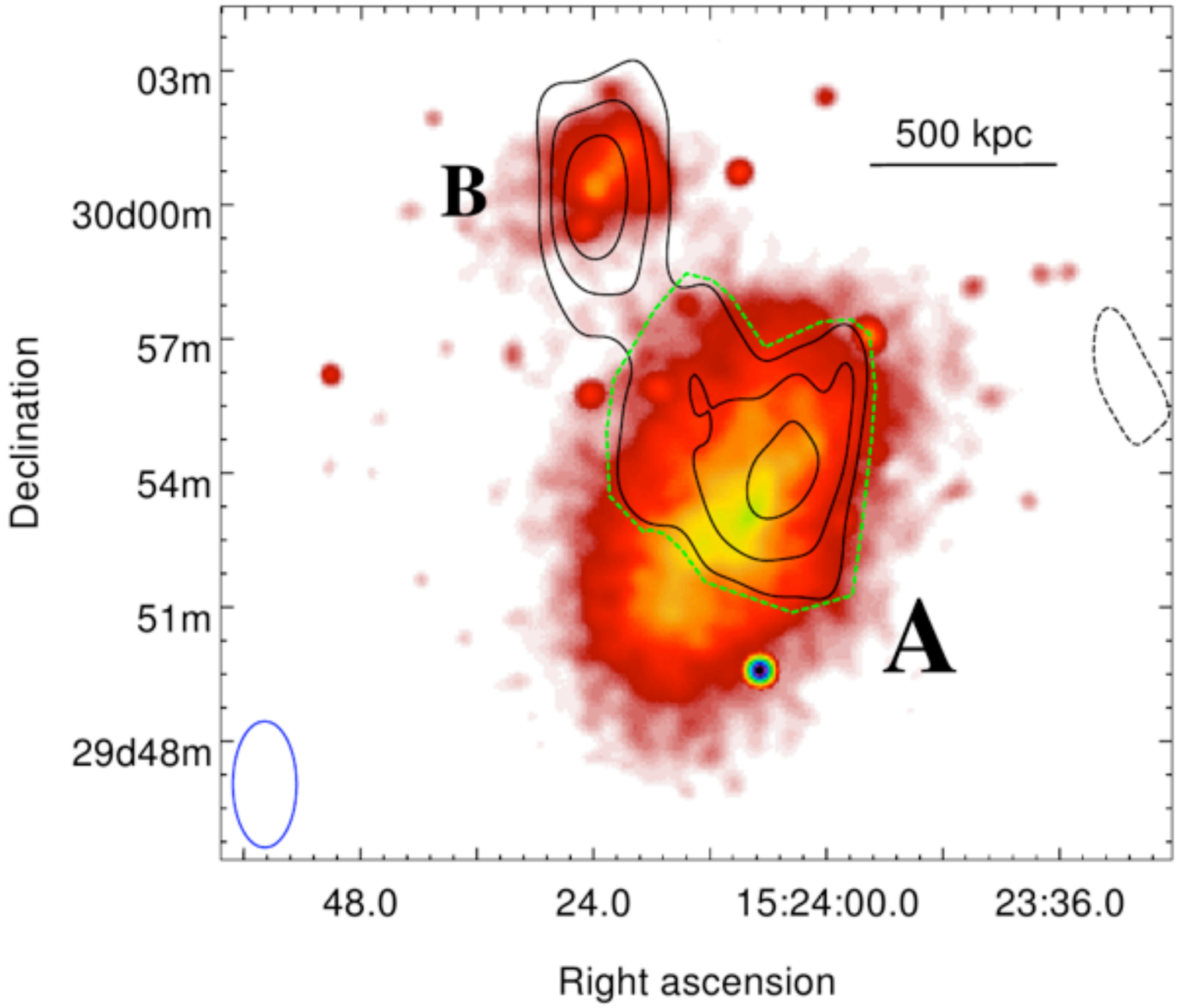


# Future prospects?

# LOFAR observations: Abell 2069

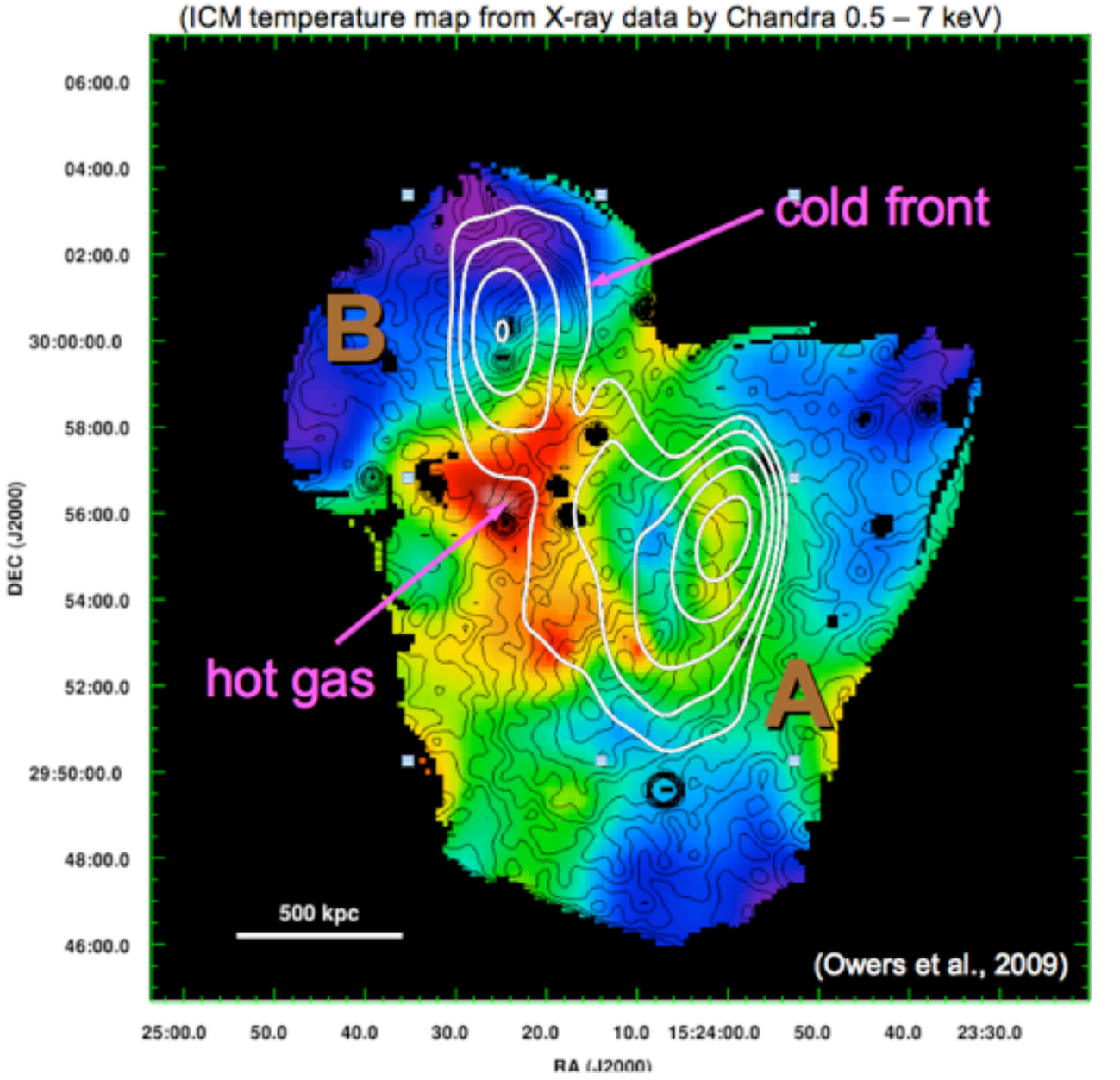
- Lx ~ 5 x $10^{44}$ erg/s
- WSRT 350 MHz
- contains a halo in A
- contains diffuse emission in B



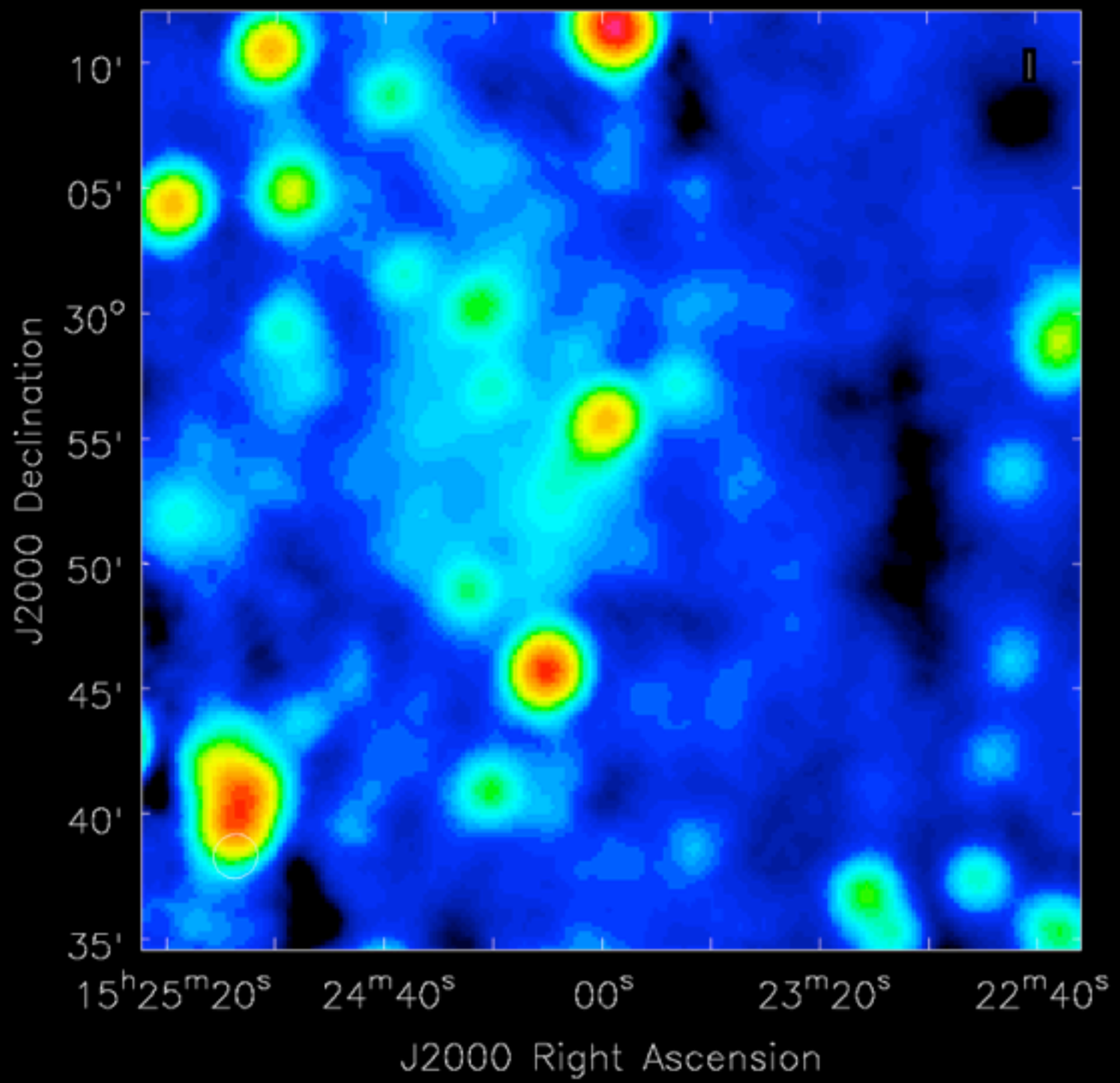

[Drabent+ 2015]

# Abell 2069: a pre-merger?

- a pre-merger system?
- cold front in B

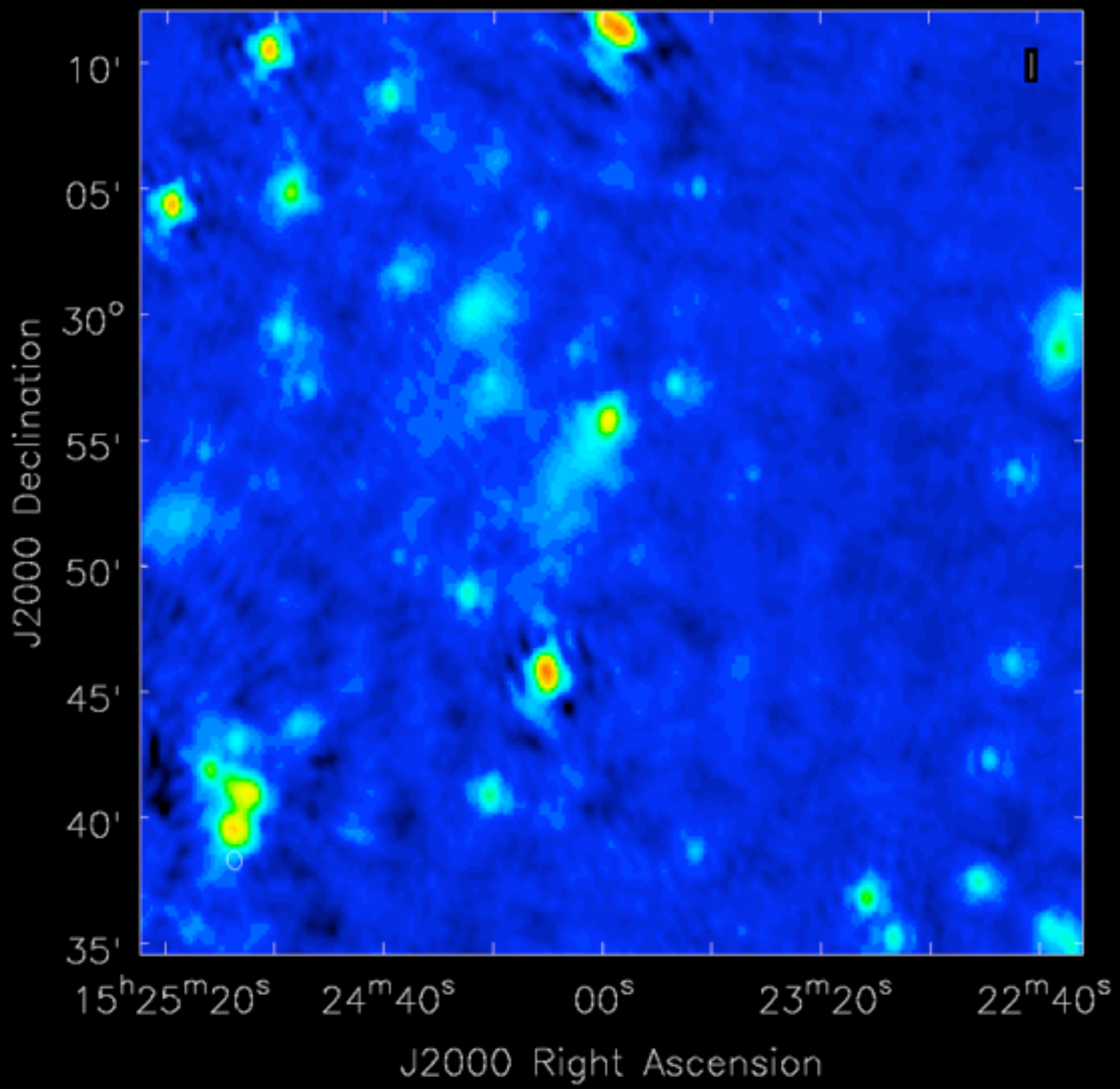



**23 Core** Stations and **14 Remote** Stations
Total observation **time**: **10 hours**
**Frequency** band: **120-180 MHz**



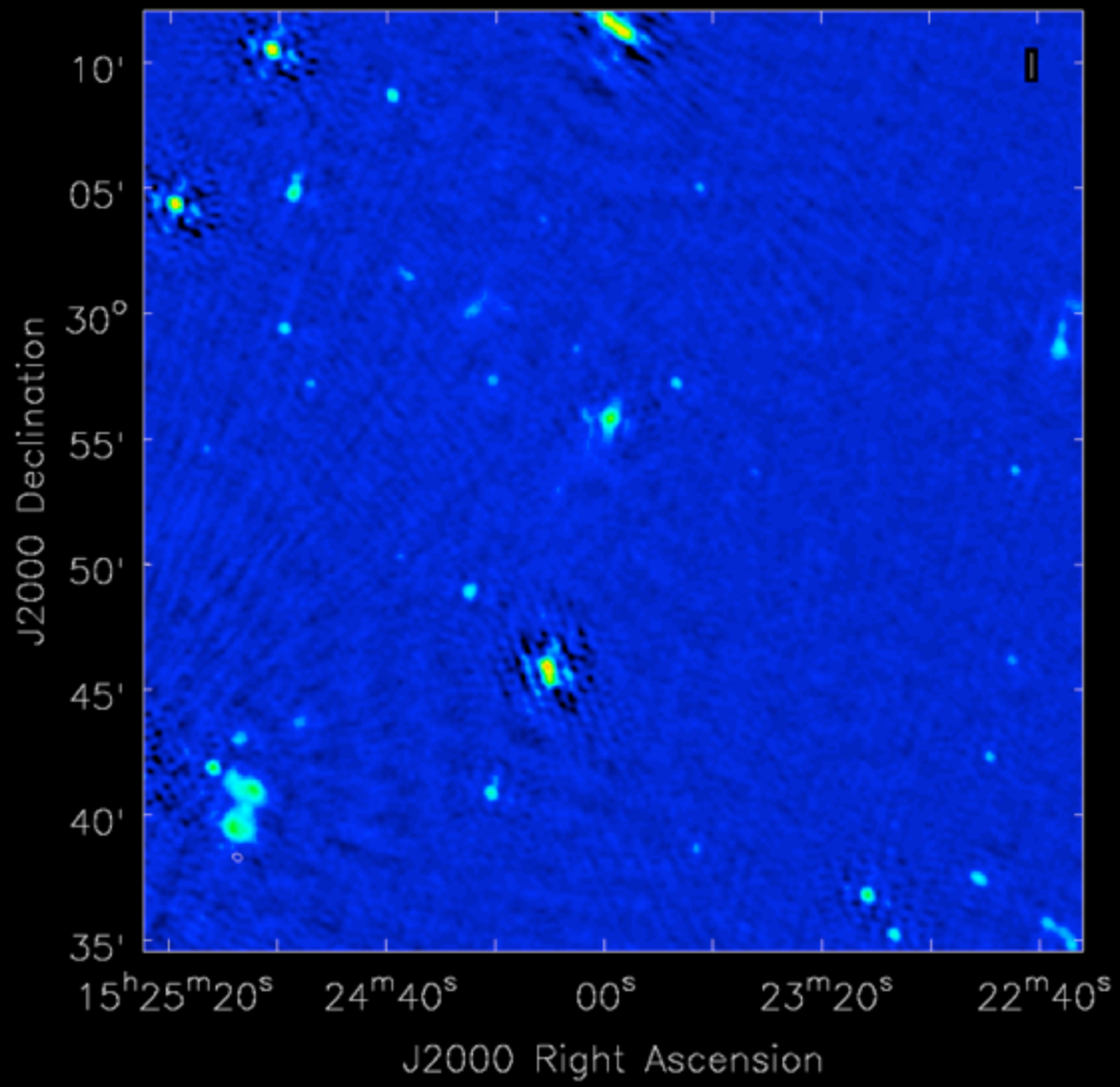

**100/370 subbands used (27%)**

**beam: 106" × 103"**
**r.m.s.: 1.5 mJy/beam**




**100/370 subbands used (27%)**

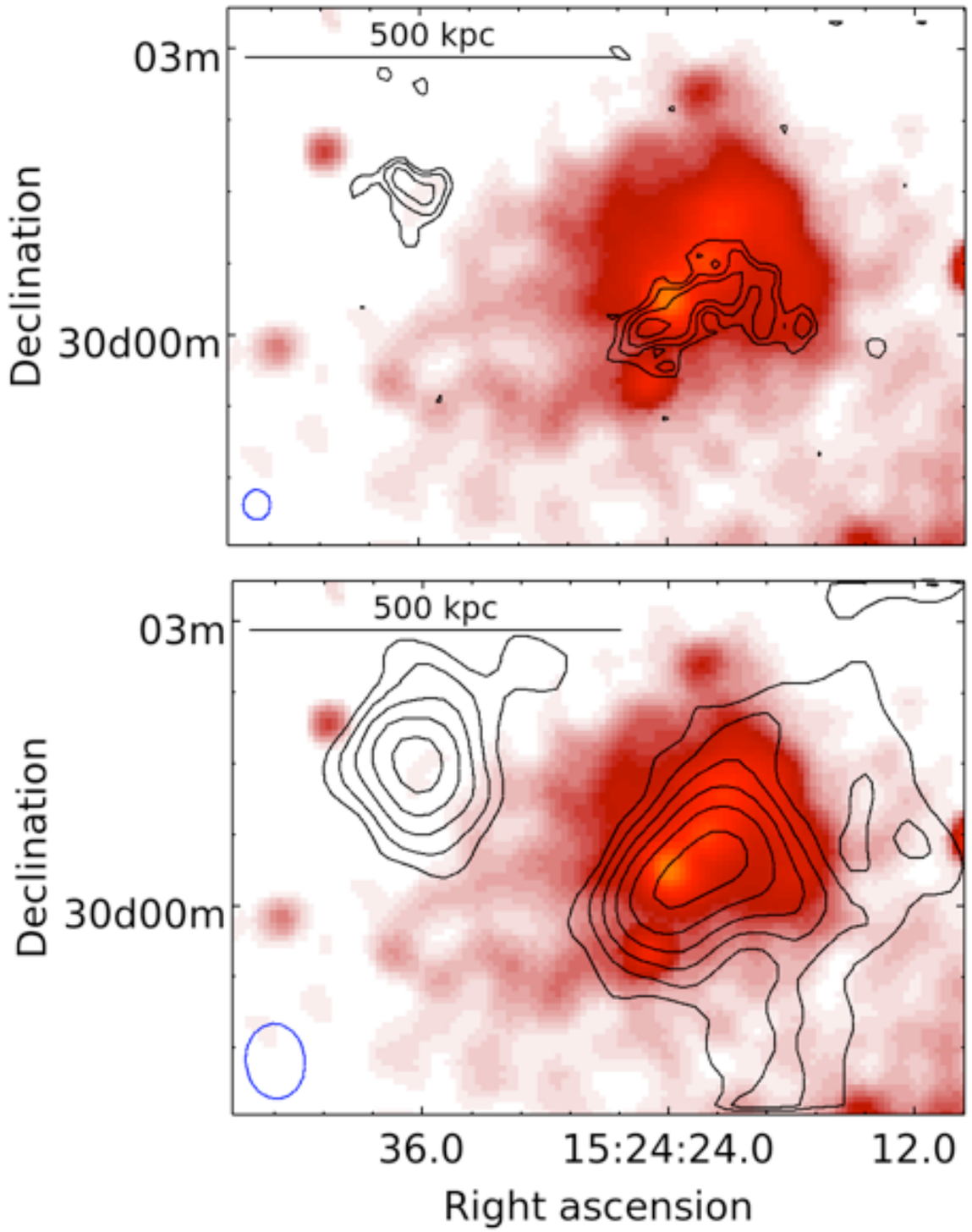
**beam: 45" × 35"**
**r.m.s.: 760 μJy/beam**




**100/370 subbands used (27%)**

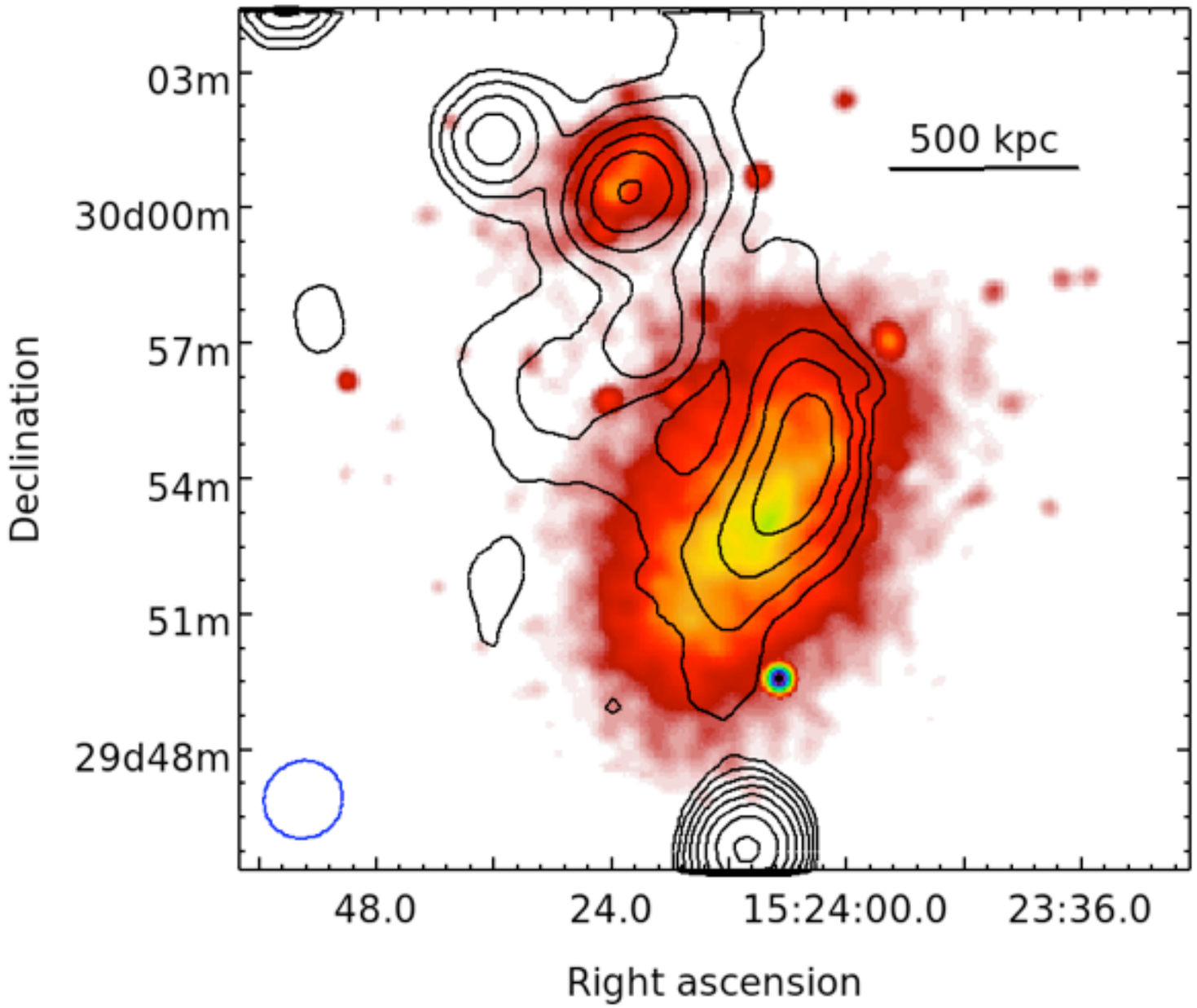
**beam: 22" × 18"**
**r.m.s.: 380 μJy/beam**

- in B:
  diffuse emission with similar morphology as X-ray
- ‘radio rim’ to South




[Drabent in prep.]

- **extended emission coincides with hot ICM**




[Drabent in prep.]

# Summary

- overall spectrum of sausage
  - power-law
  - possible high frequency cut-off
- relic statistics
  - consistent with populating merger shocks uniformly
- Prospects with LOFAR
  - very well suited to identify diffuse emission
  - Abell 2069
    - Halo in main component
    - Minihalo in subcomponent (?)
    - diffuse emission in compressed gas