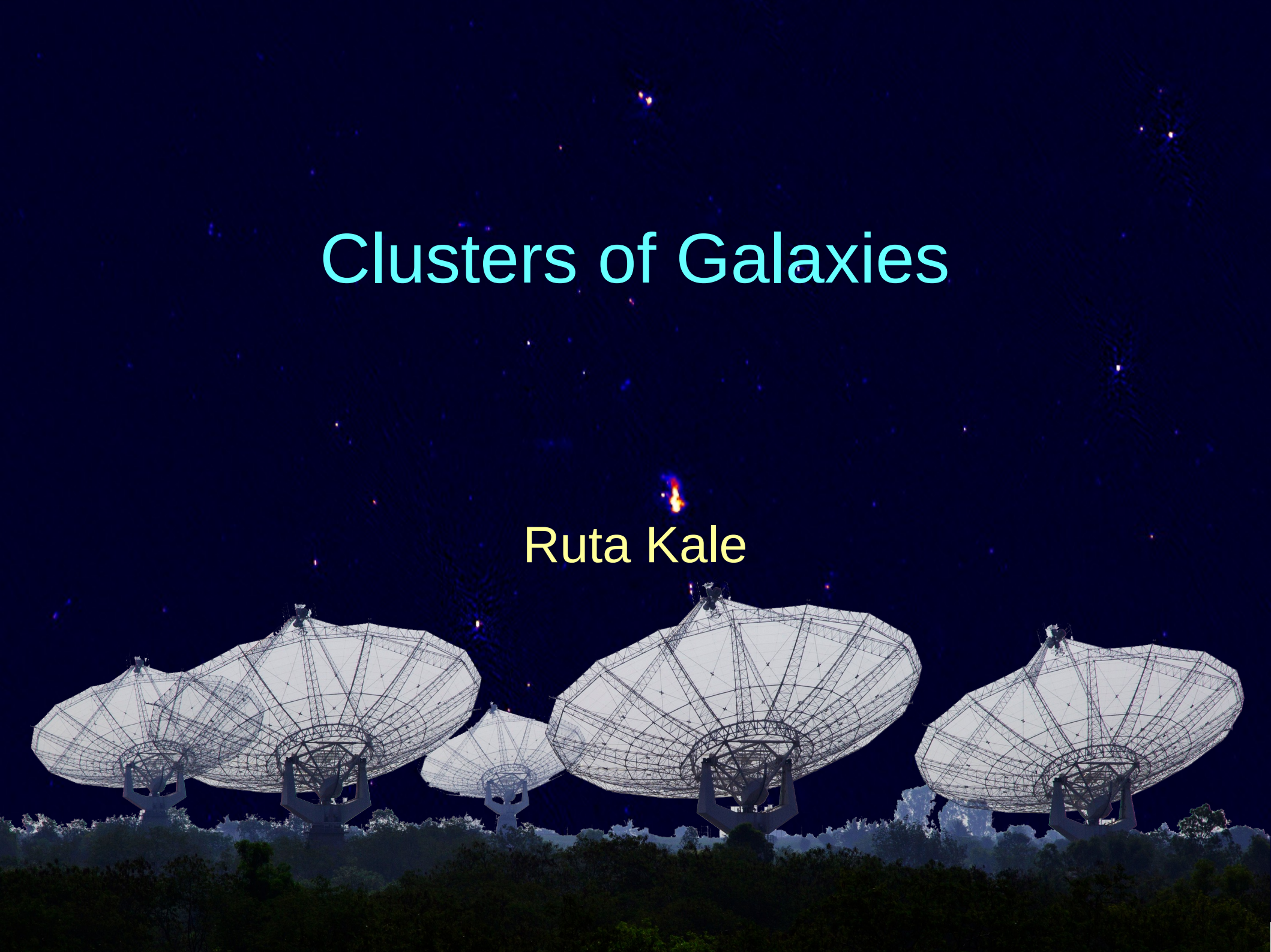
Clusters of Galaxies

Ruta Kale



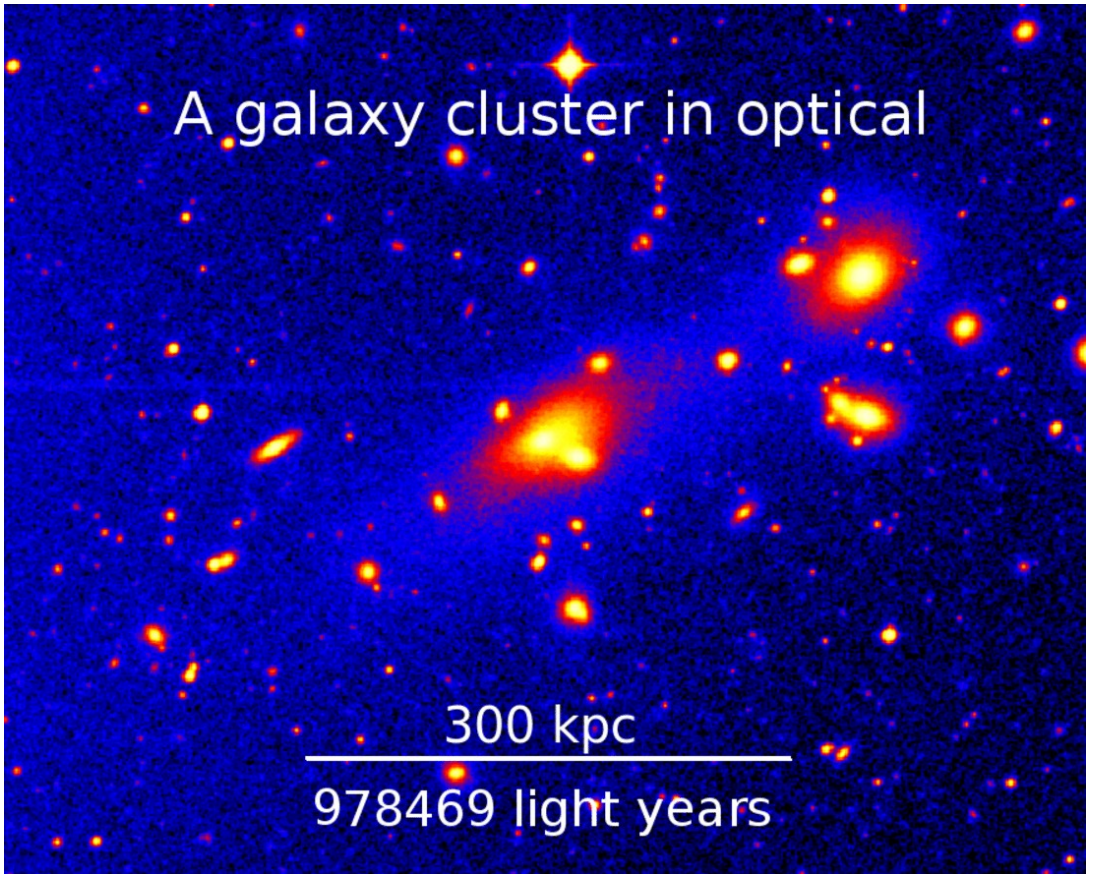
Galaxy clusters

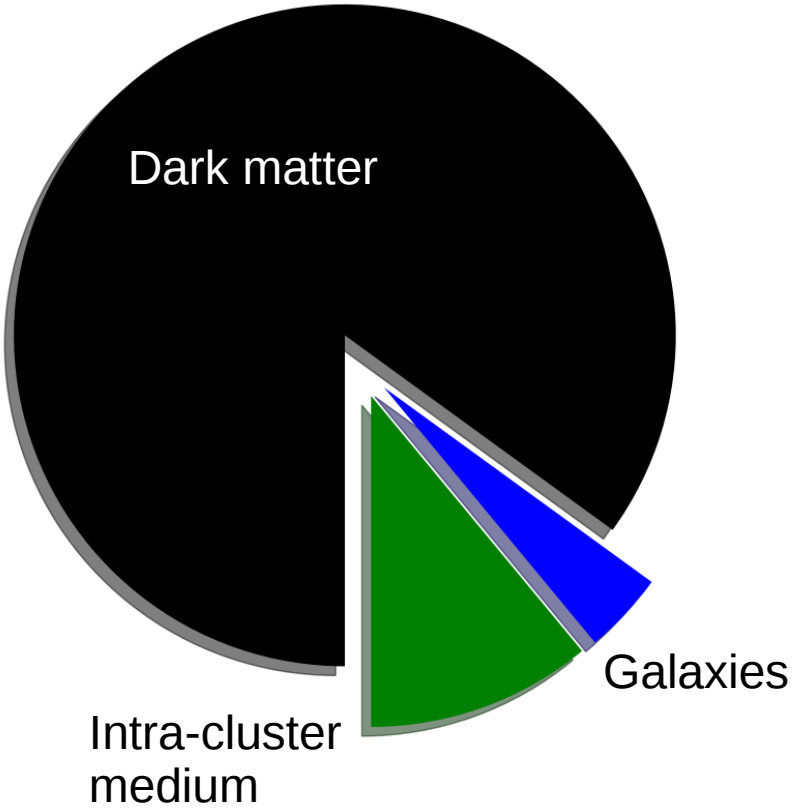
Observationally identified as regions of overdensities in the projected distribution of optically detected galaxies (eg. Zwicky 1938; Abell 1958).

Masses ~ 10^{14} - 10^{15} $M_{\odot}$

- X- ray luminosities

~ 10^{44} – 10^{45} erg s^{-1c}





Intra-cluster medium

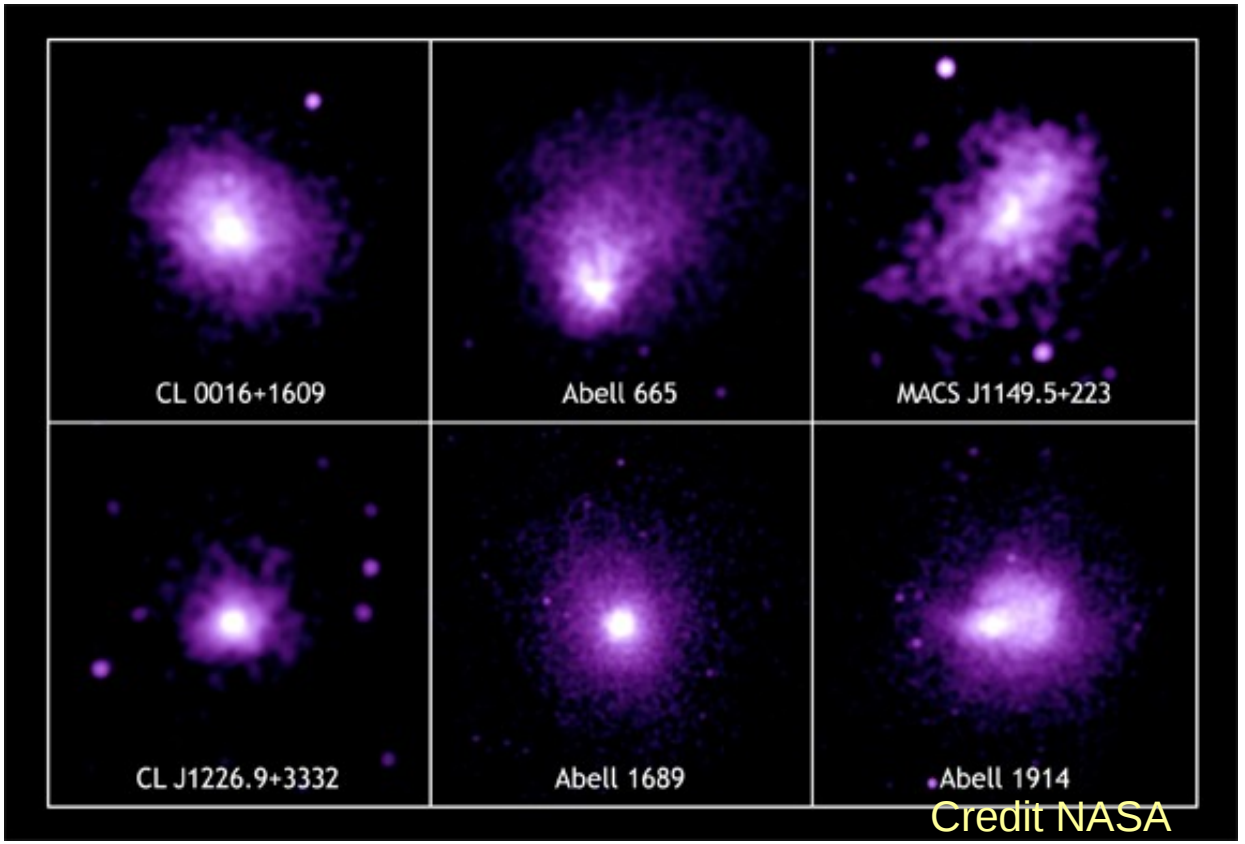
- Thermal plasma

Thermal

Bremsstrahlung

$T \sim 10^8$ K;

Core density, $n_e \sim 10^{-1} - 10^{-3}$ cm^{-3}



- **Relativistic particles (cosmic rays)**
- **Magnetic fields (~ 0.1-a few μG)**

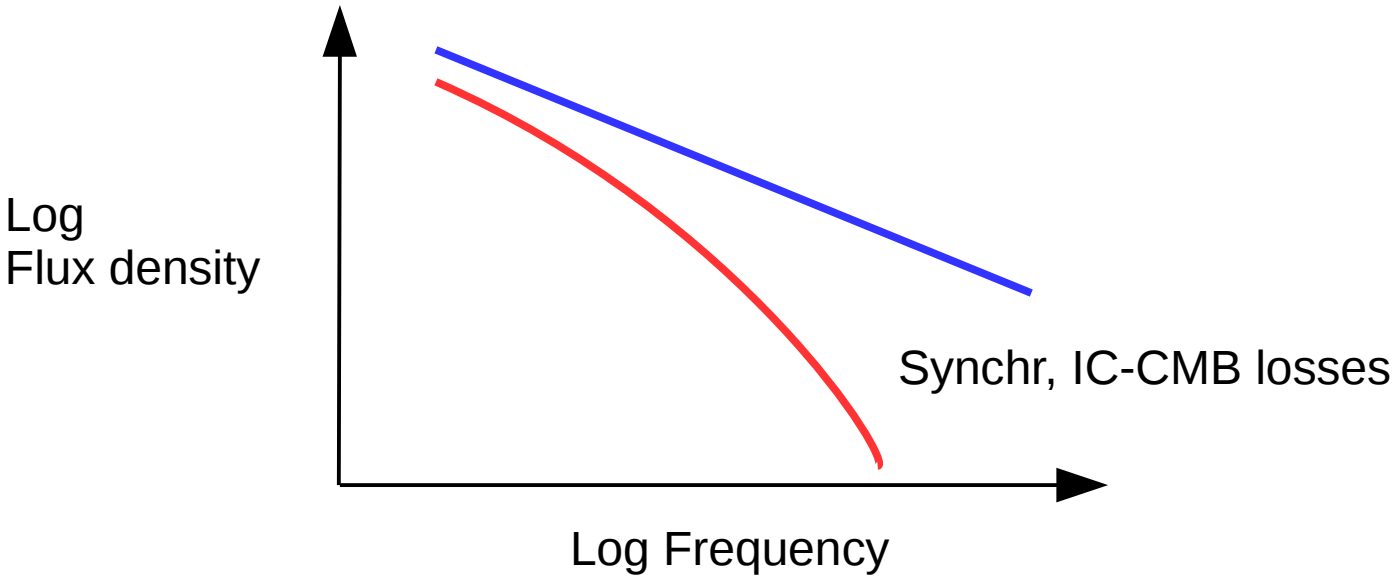
CRe in the ICM

- Relativistic particles
- Magnetic fields

(~ 0.1- a few μG)

Not detectable
in most
observing bands

- **Synchrotron radiation from ~GeV electrons in microGauss magnetic fields: detectable in radio frequency bands.**

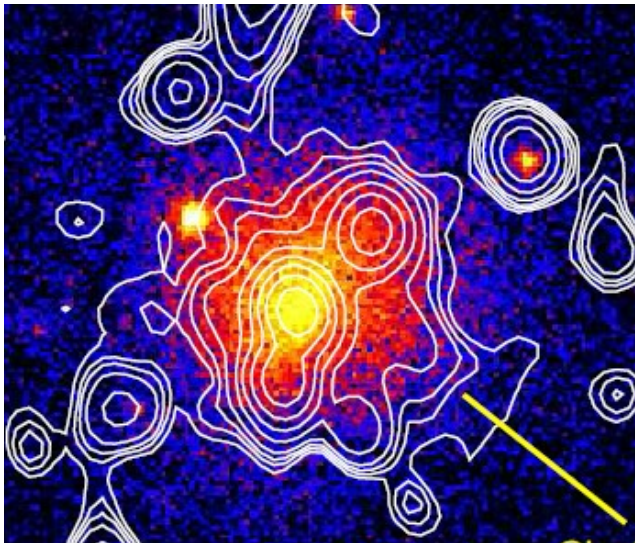


Cluster scale radio sources (~ 100s kpc)

Radio power at 1.4 GHz ~ $10^{24\text{-}26}$ W/Hz
Mpc Extents ~ a few to several tens of arcminutes
Surface brightness < 1 μJy arcsec^{-2}

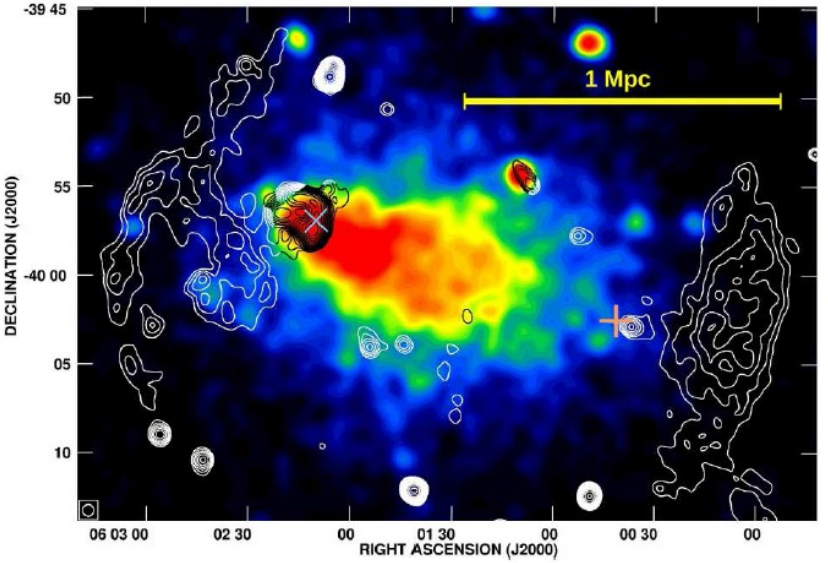
RARE !

Radio halos



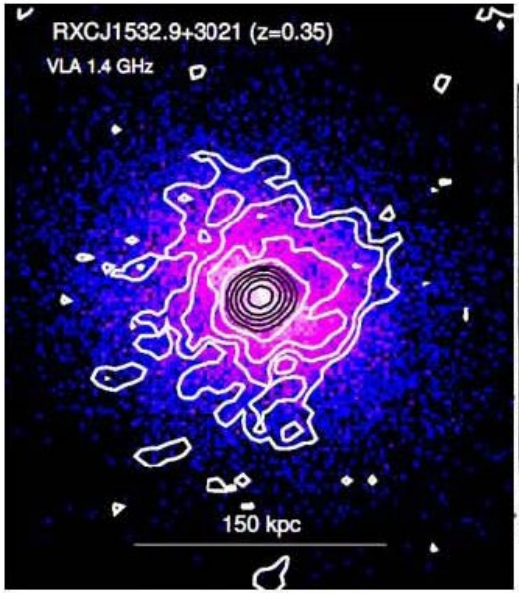
Giacintucci, Kale et al 2013

Radio relics



Abell 3376, Kale et al. 2012, Bagchi et al 2006

Mini-halos



Hlavacek-Larrondo 2013; Kale et al 2013

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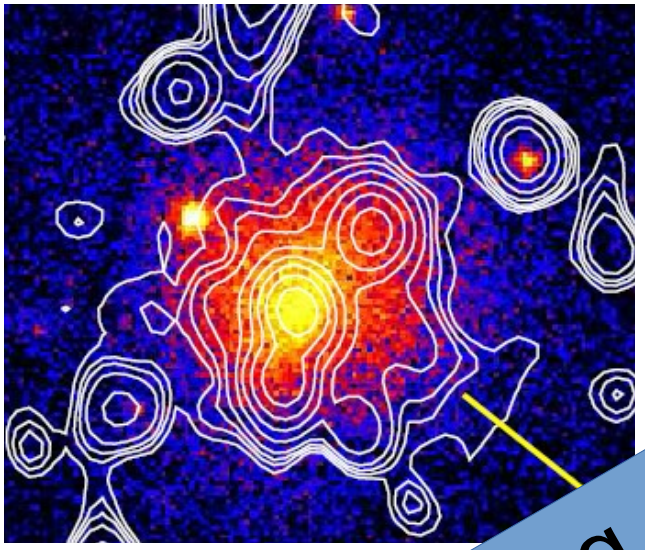
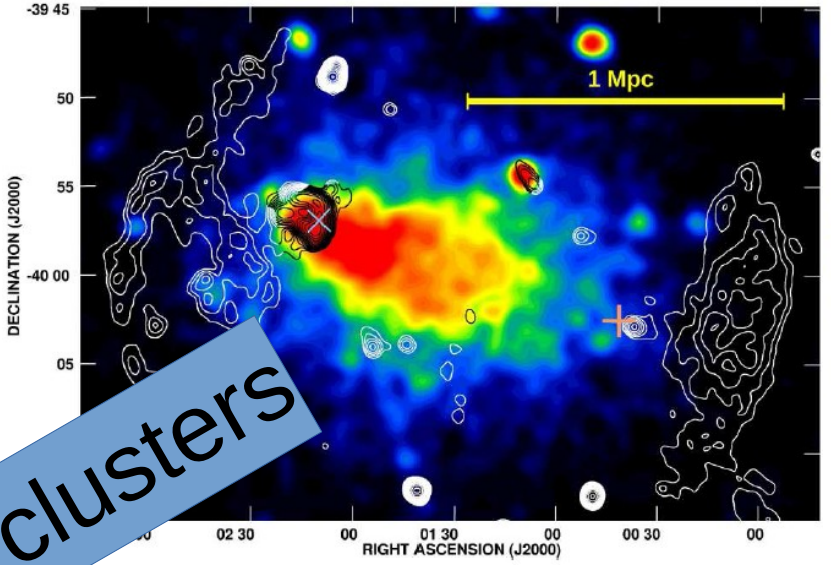
Radio halos



Giacintucci, K[illegible]13

Radio relics



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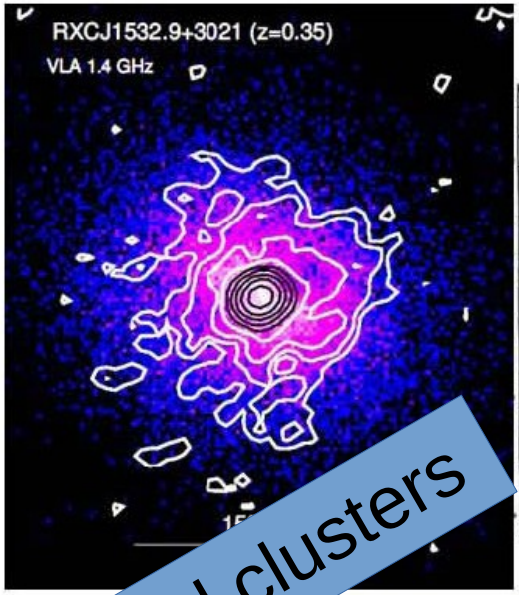
Mini-halos



Hl[illegible]arrondo 2013; [illegible]al 2013

Merging clusters

Relaxed clusters

Open issues

What happens to the radio galaxies in a cluster after their AGNs stop producing jets ?

How does cluster merger affect the different components of the ICM ?

What is the fraction of non-thermal energy in the ICM ?

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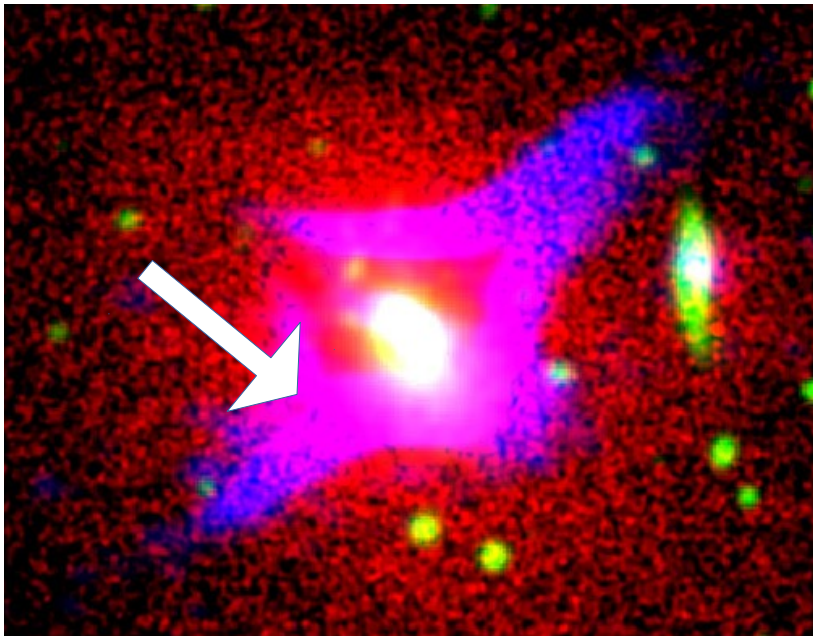
GMRT: Diffuse emission discoveries

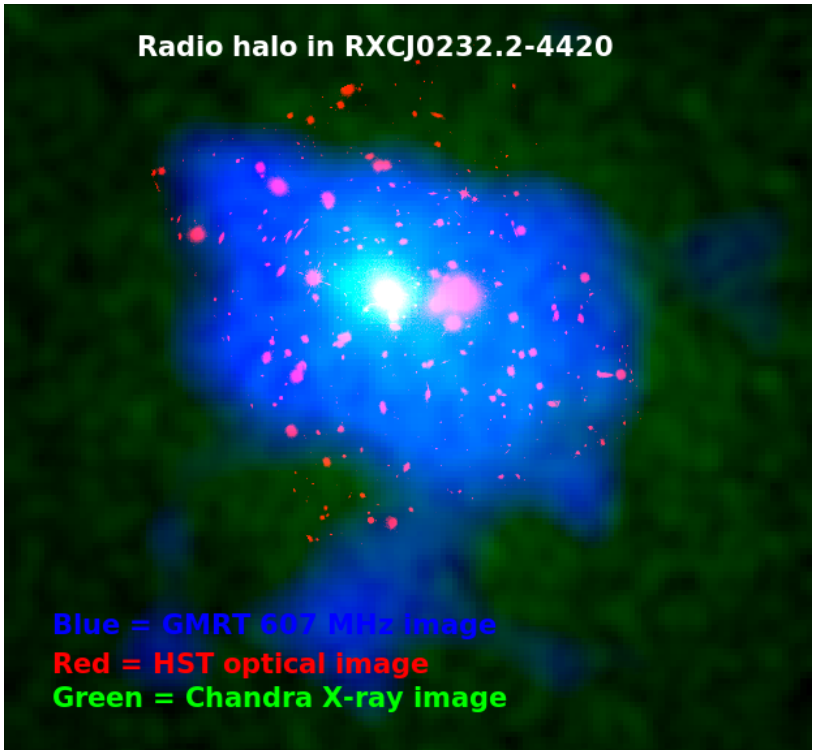
The fourth arc in Abell 2626



Blue : Radio

Origin of the radio arcs ?
- precessing jets ?
- gravitional lensing ?

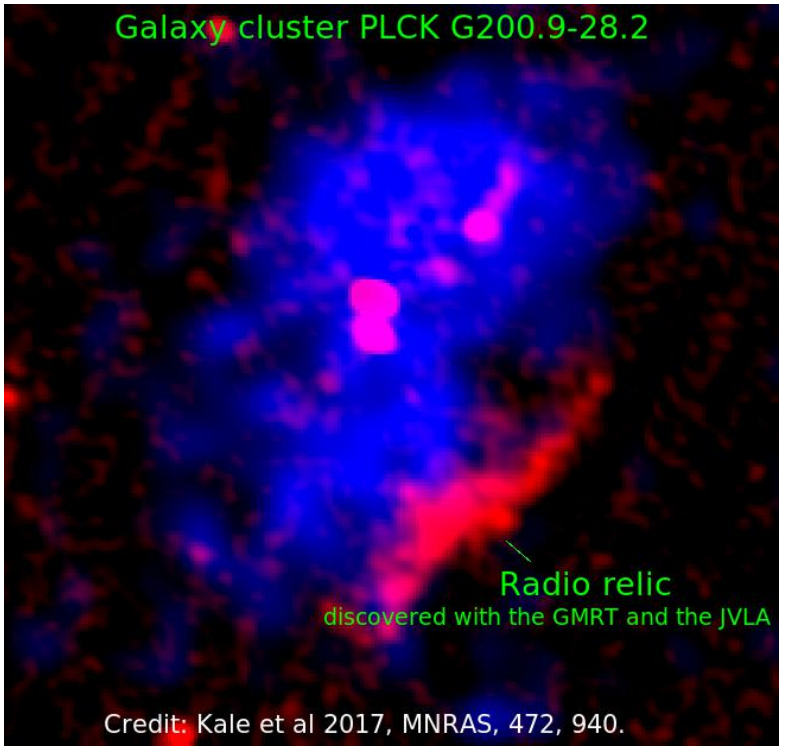
Kale and Gitti 2017



A mini-halo to radio halo transition system

Kale et al 2019

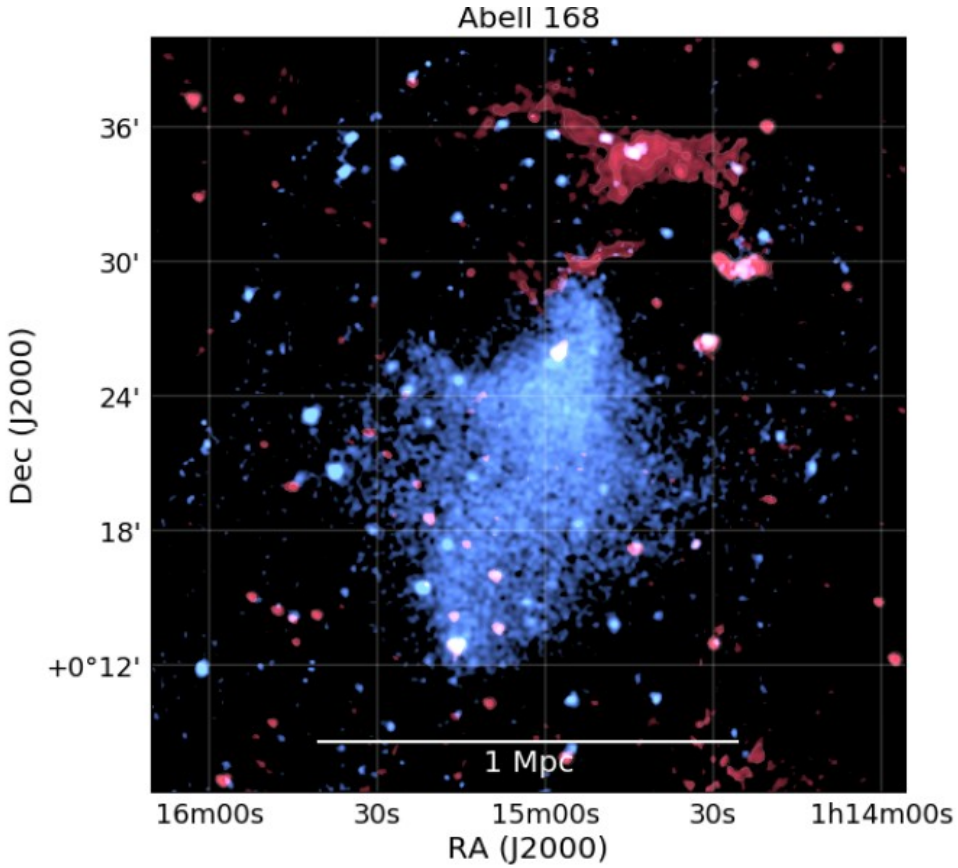
GMRT: Shock relics in low mass galaxy clusters



Mach number~ 3

Kale et al 2017

Red: Radio
Blue: X-rays



Even lower mass cluster with shock relics !

Dwarakanath, Parekh and Kale 2018

Extended GMRT Radio Halo Survey

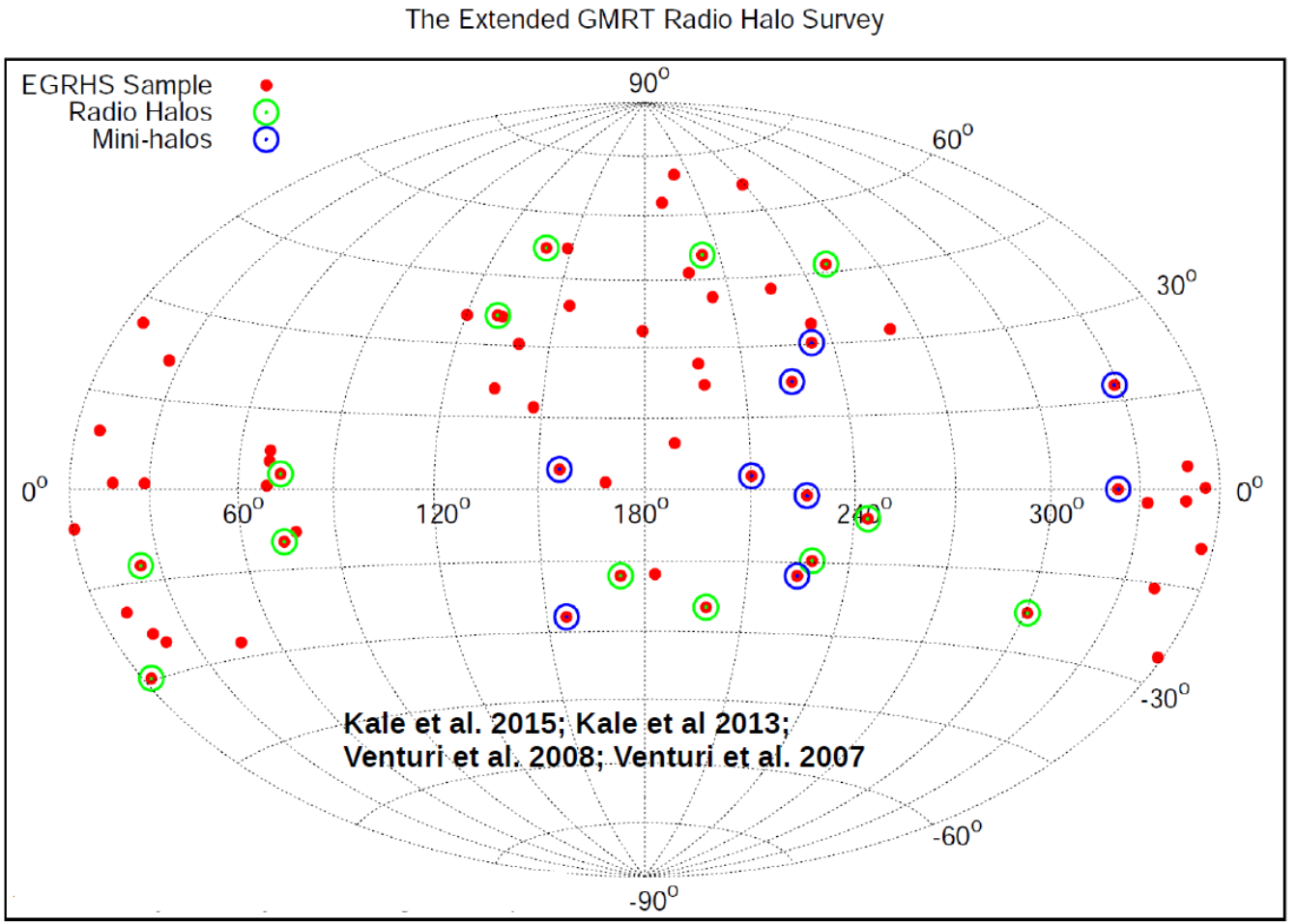
Sample:
REFLEX + eBCS X-ray catalogues

Bohringer et al 2004;
Ebeling et al. 1998, 2000

$L_{x(0.1\text{-}2.4\ keV)} > 5x10^{44}$ erg/s

$0.2 < z < 0.4$

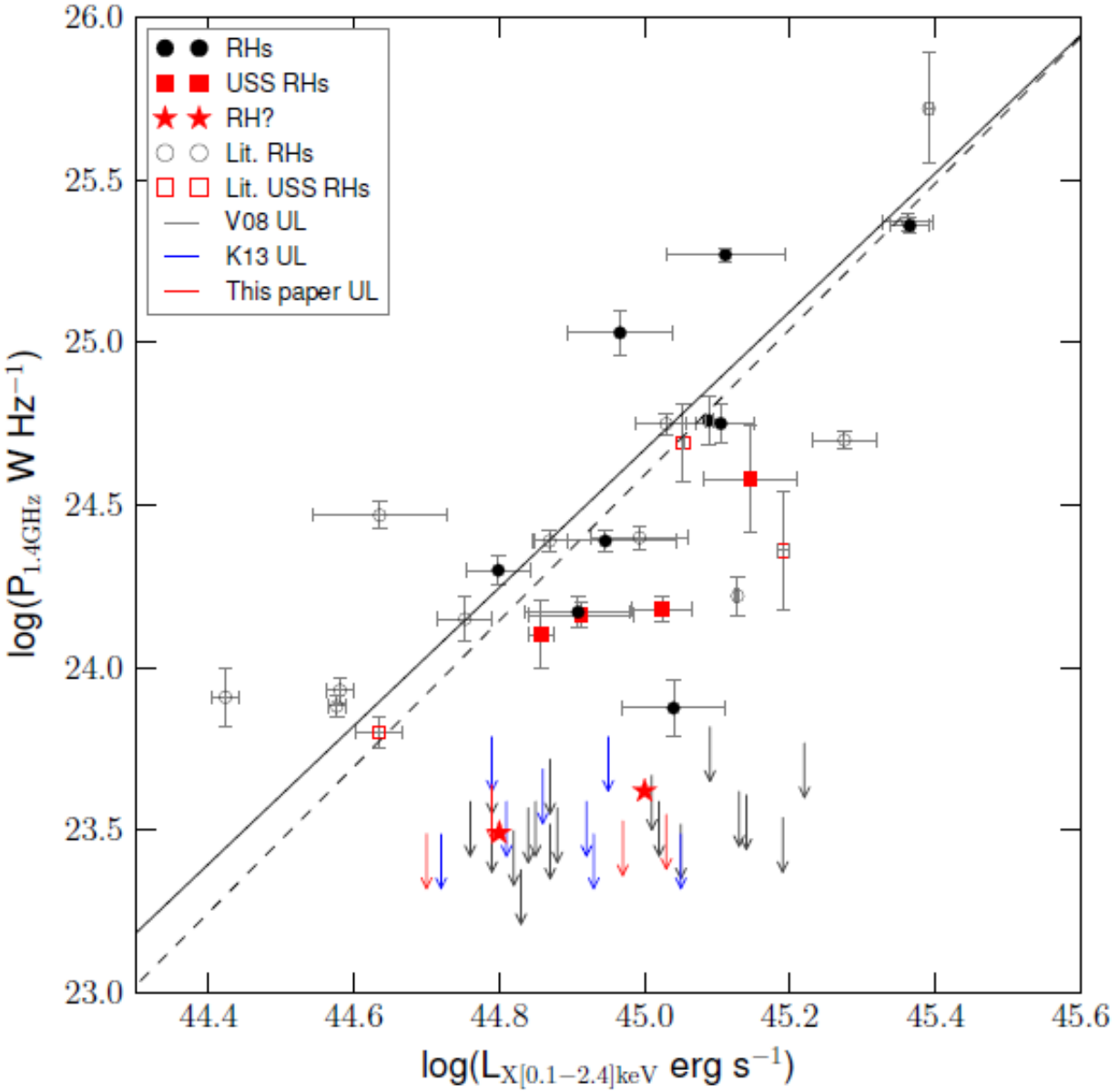
Declination > -30°



64 clusters

Venturi et al 2007, 2008; Kale et al 2013, 2015a,b

Venturi et al 2007, 2008; Kale et al 2013, 2015a,b



Life-time of radio halos
~0.1 Gyr

Brunetti et al. 2009

$$P_{1.4GHz} \propto L_x^{2.13+/-0.26}$$

Even non-detections if quantified as upper limits are results !

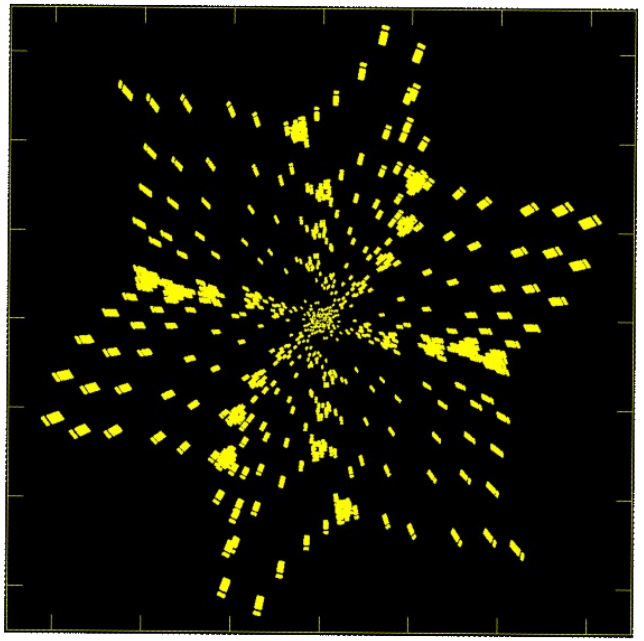
With the Upgraded GMRT ?

Wide-band system

- Improved uv-coverage
- implies better imaging of extended sources

Deo and Kale 2017, ExA

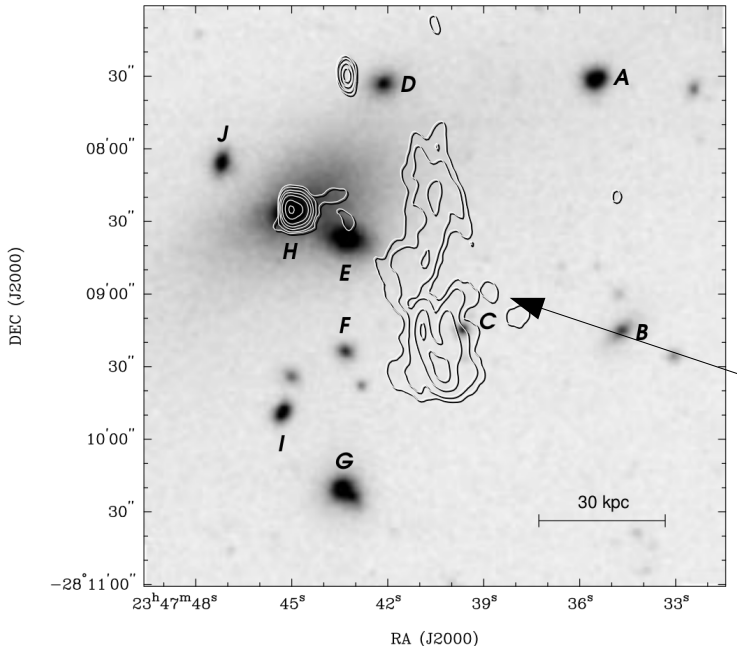
- Contiguous frequency coverage for spectral studies



Abell 4038

RA_{J2000}	23h47m43.2s
DEC_{J2000}	-28°08′29″
Redshift†	0.02819 ± 0.00055
kT†	2.69 ± 0.43 keV
$L_{[0.01-40]keV}$ ++	$(1.900 \pm 0.025) \times 10^{44}$ erg s^{-1}
M‡	$1.5 \pm 0.1 \times 10^{14}$ $M_\odot$

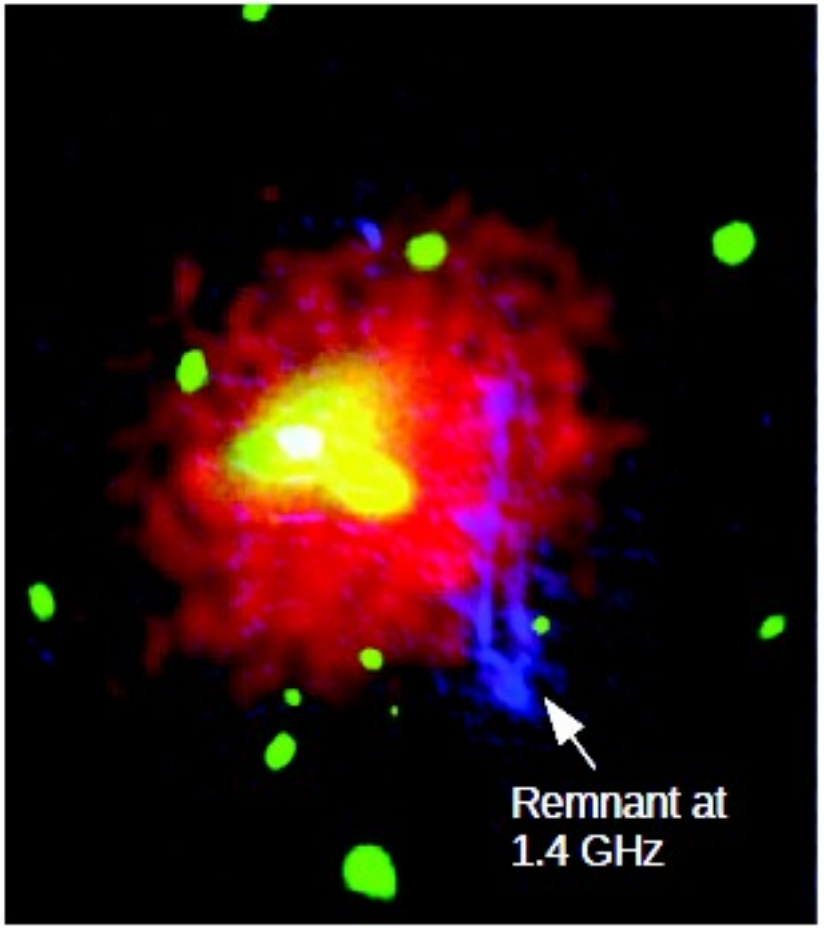
† Sanders et al. (2011) ++ Mittal et al. (2011) ‡ Planck Collaboration et al. (2016)



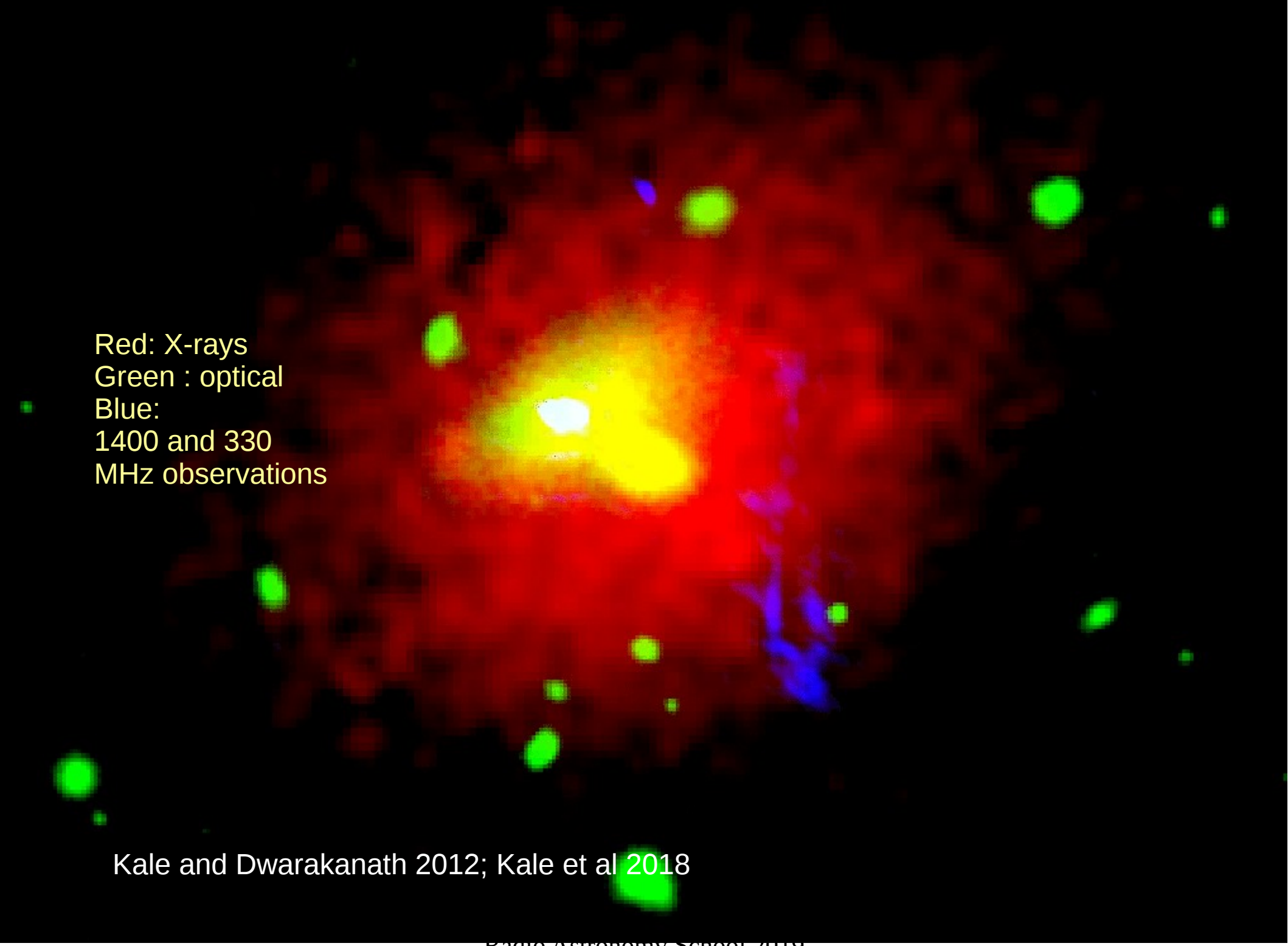
Slee et al 2001

Radio relic or a dead radio galaxy
A steep spectrum diffuse source of size ~56 kpc with no obvious optical counterpart.

Red: Chandra X-ray image
Green: DSS R-band optical
Blue: Radio 1.4 GHz

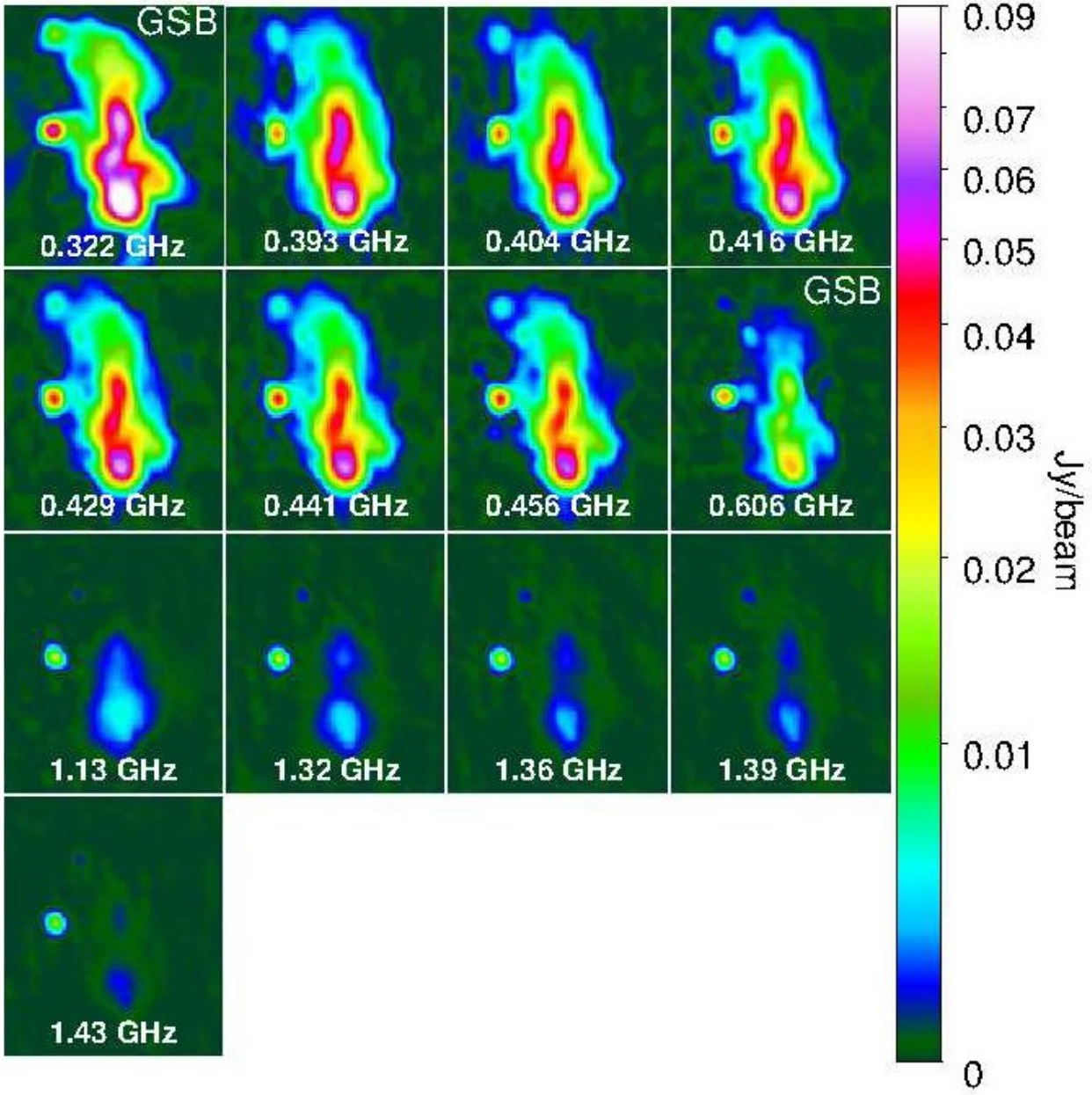


Kale and Dwarakanath 2012

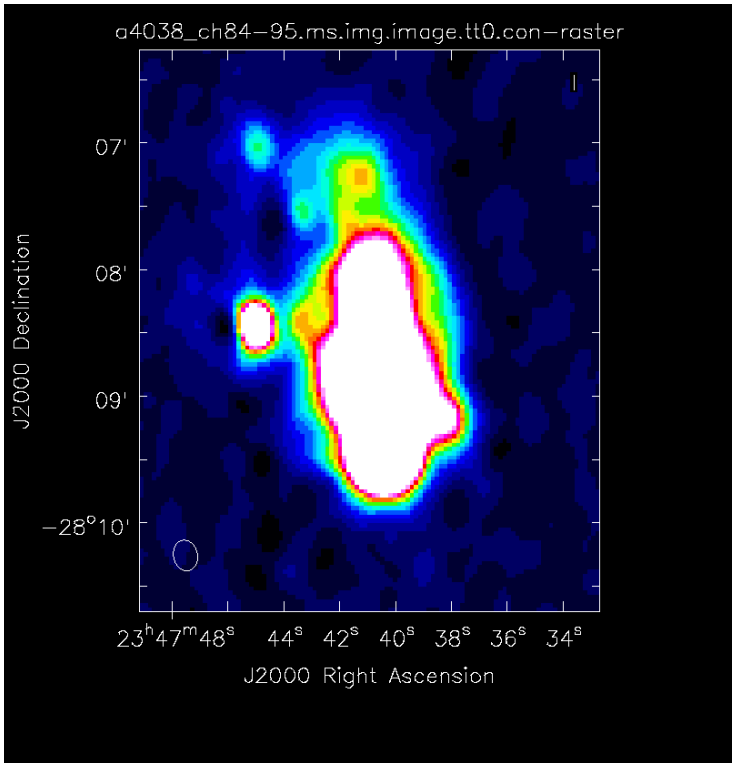


Kale and Dwarakanath 2012; Kale et al 2018

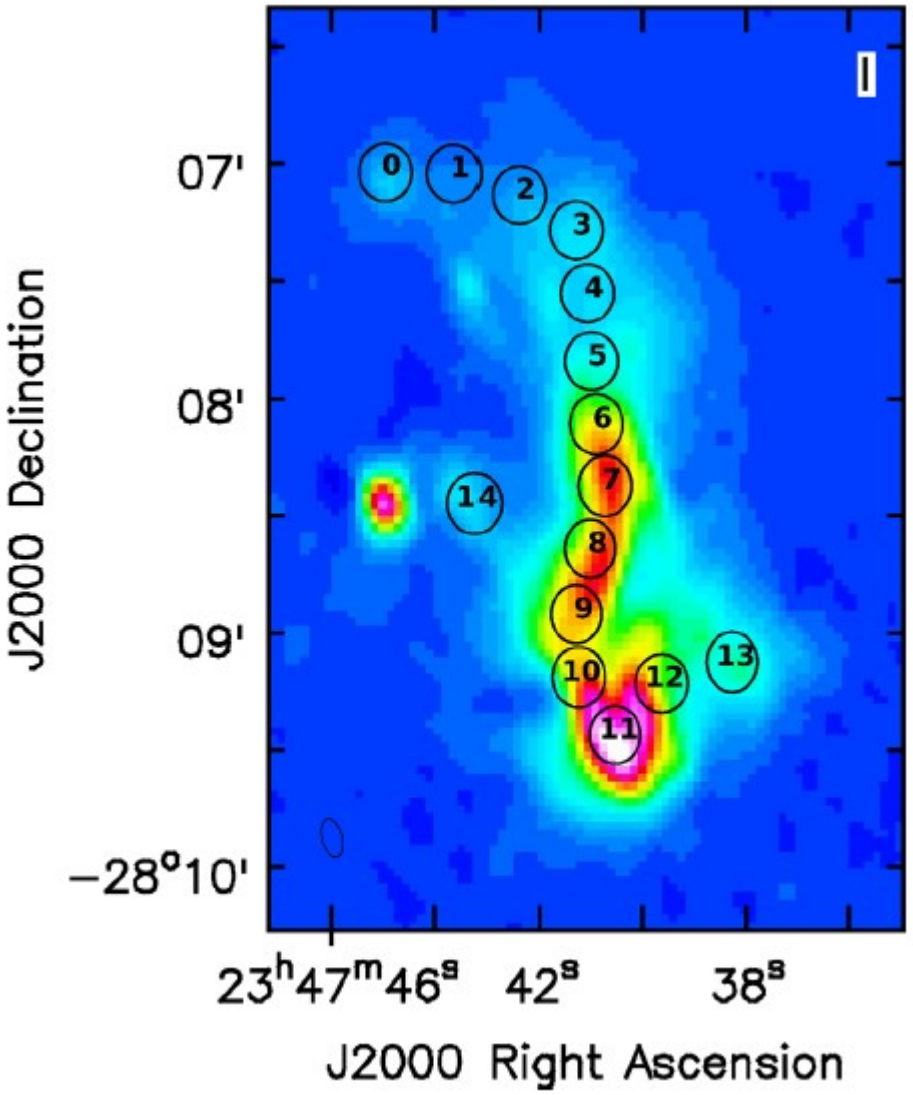
Sub-band- images

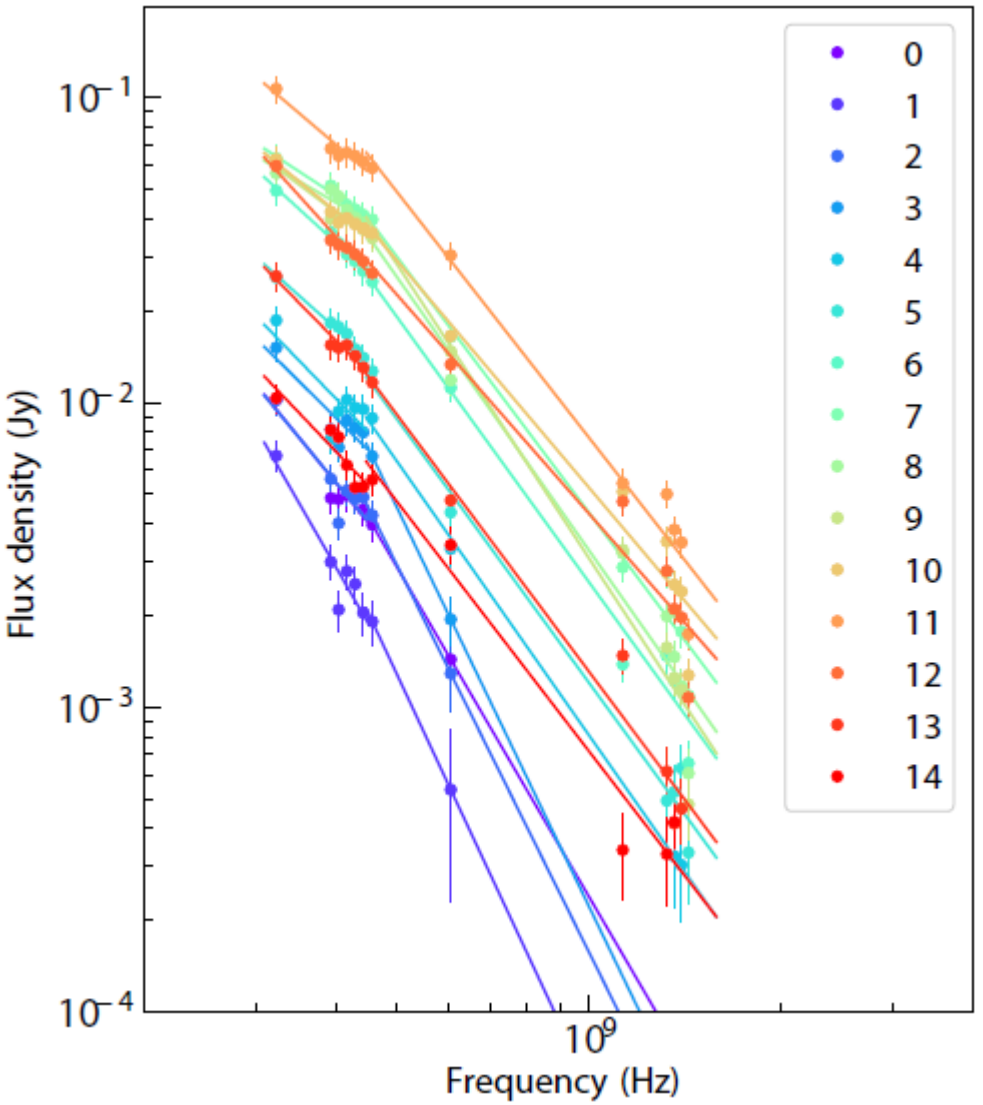


The uv-coverage being closely matched, the limitation is only the rms sensitivity.



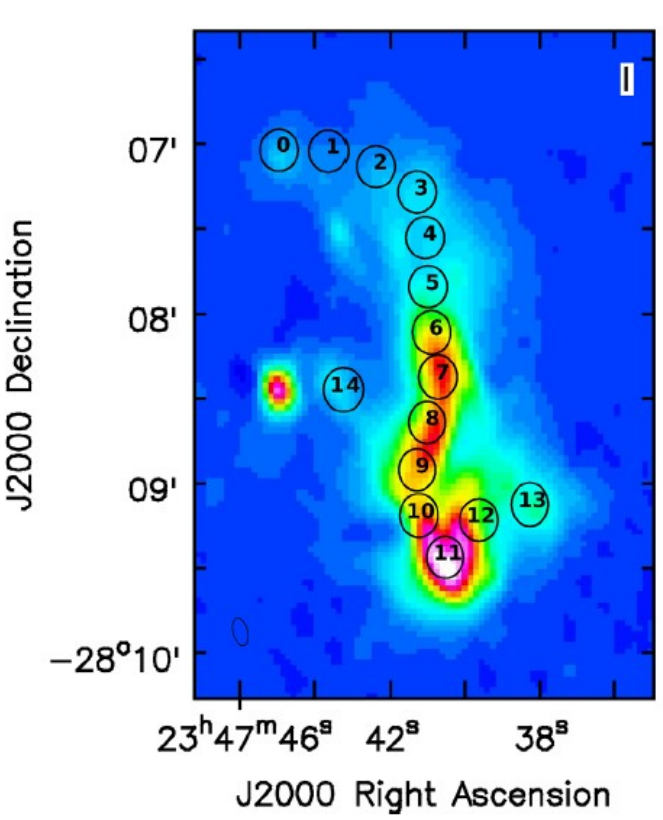
Spectra in 15 regions across the relic

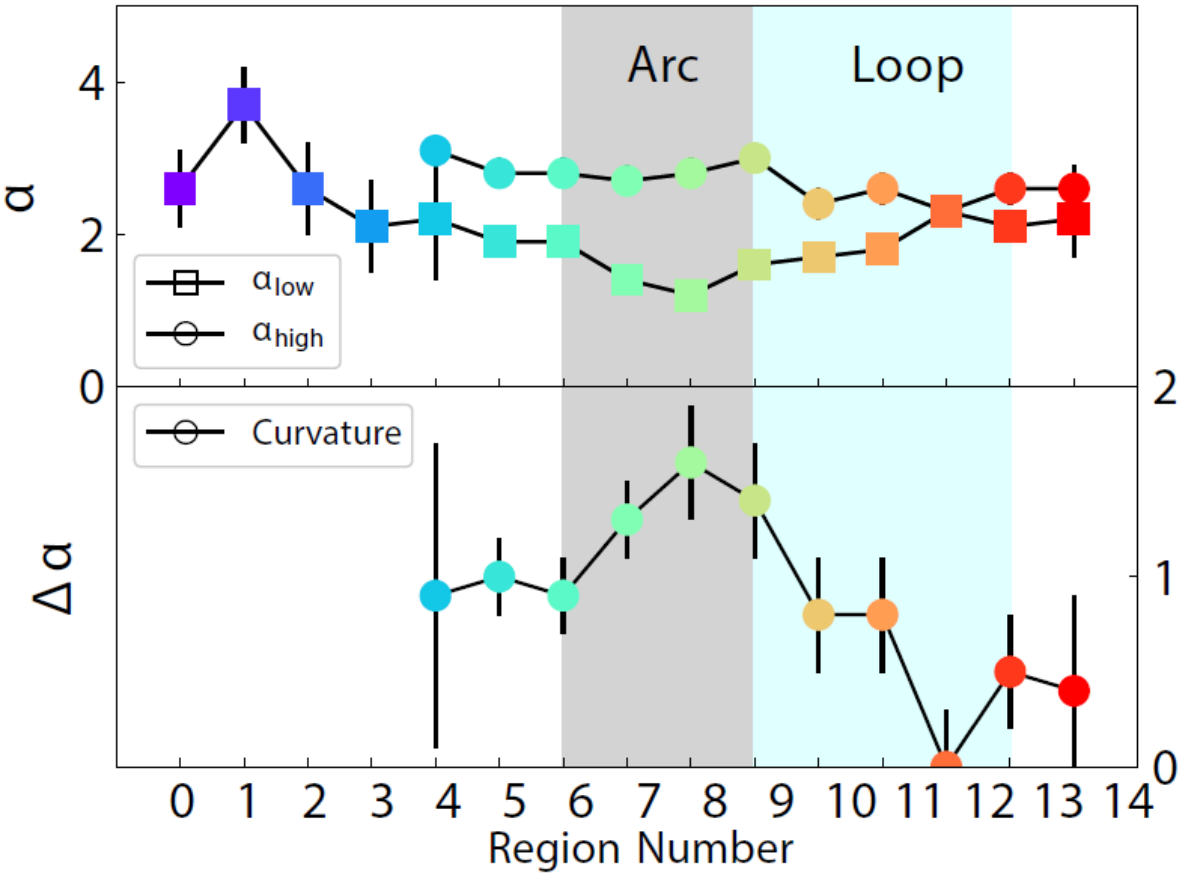




Curvature

$$\Delta\alpha = \alpha_{\text{high}} - \alpha_{\text{low}}$$





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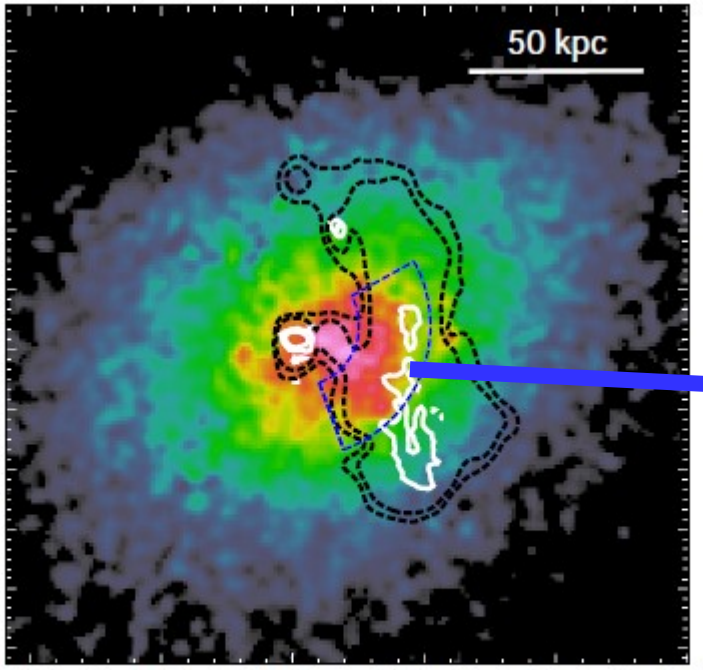

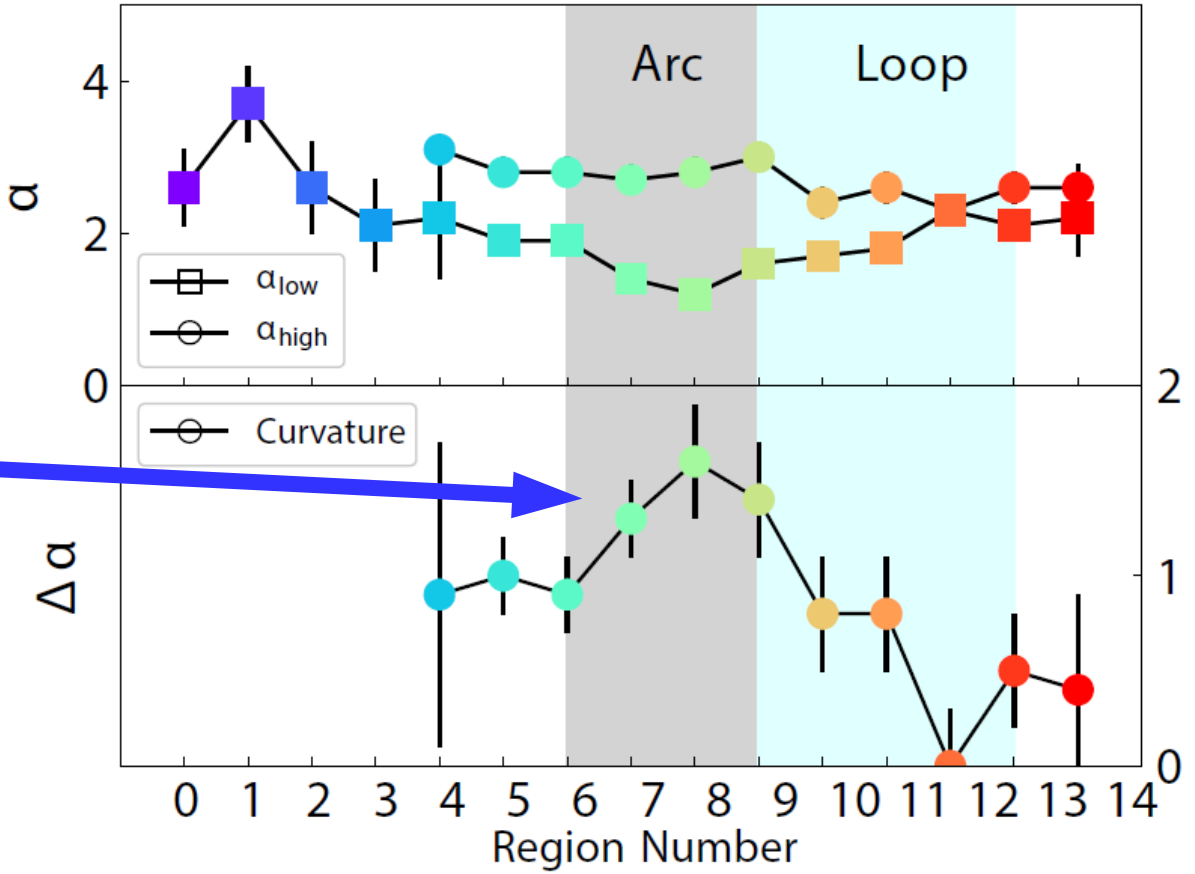

Summary

Radio bands offer direct probes of magnetic fields and cosmic rays in galaxy clusters.

A large range of possibilities opened for study by sensitive new radio telescopes such as the uGMRT and LOFAR.