AGN and Galaxy Clusters (in the radio band)

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INAF – Osservatorio Astronomico di Cagliari

AGN10 2012 Roma
Dall'Orizzonte degli Eventi all'Orizzonte Cosmologico

Overview

1) Radio emission associated with individual galaxies

- Head tail radio galaxies → USED TO INVESTIGATE THE THE PHYSICAL PROPERTIES OF CLUSTERS (magnetic fields)
- Dying radio galaxies

2) Diffuse radio sources in galaxy clusters

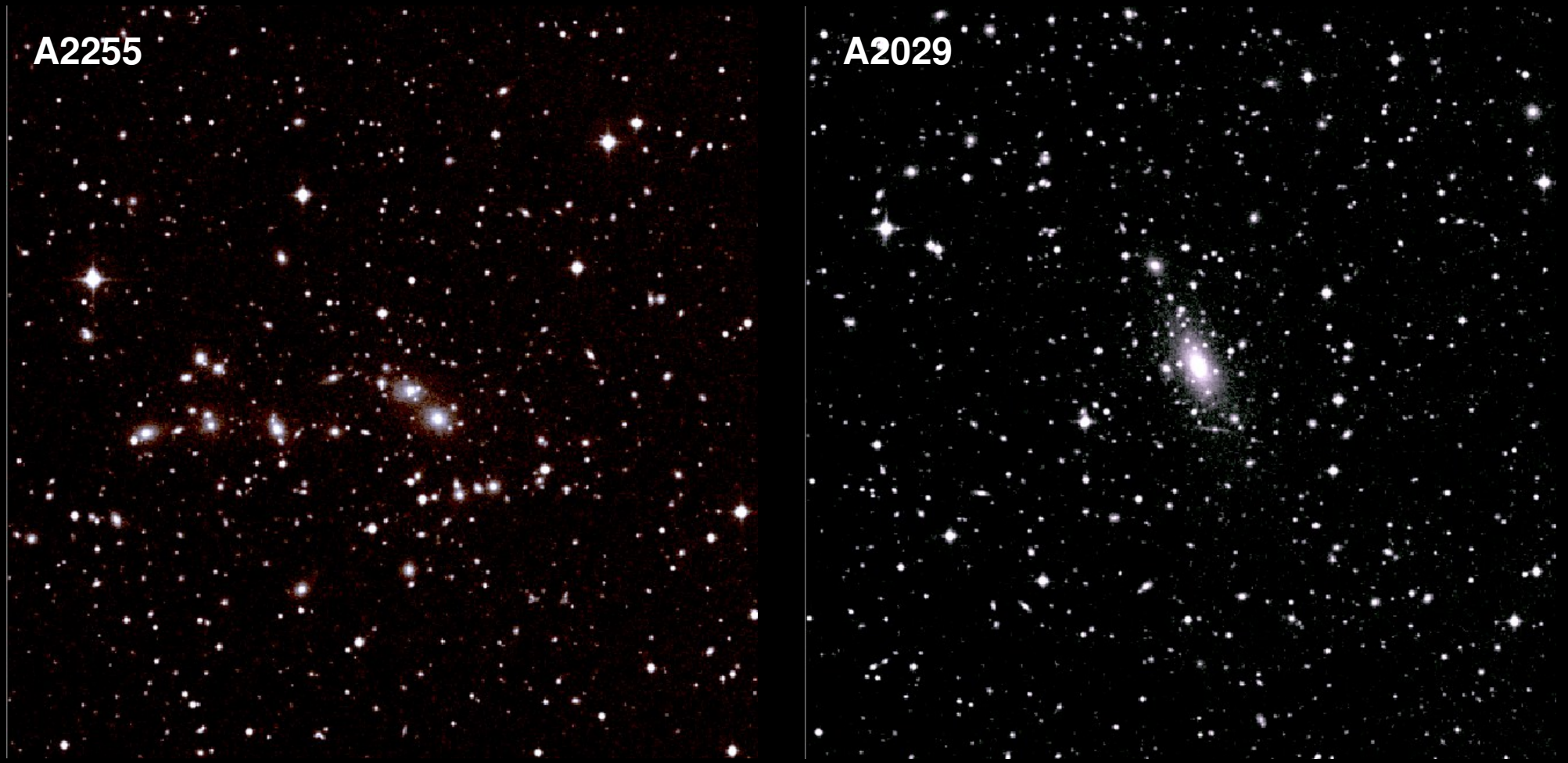
- Halos
- Mini-Halos

→ DEMOSTRATE THE EXISTENCE OF MAGNETIC FIELDS AND RELATIVISTIC ELECTRONS OVER LARGE SCALES

Galaxy Clusters

MERGING CLUSTER

RELAXED CLUSTER

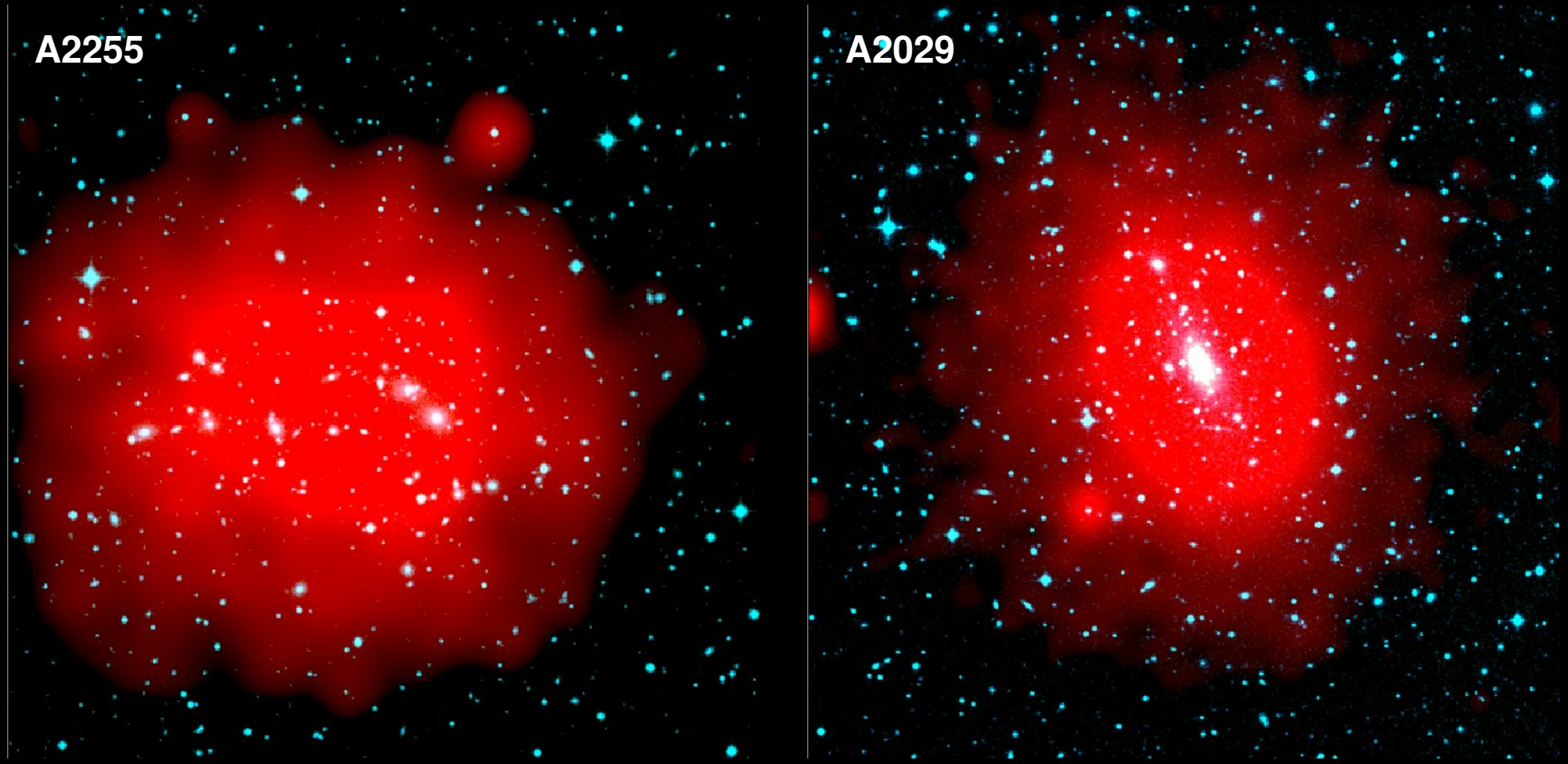


Optical

Galaxy Clusters

MERGING CLUSTER

RELAXED CLUSTER

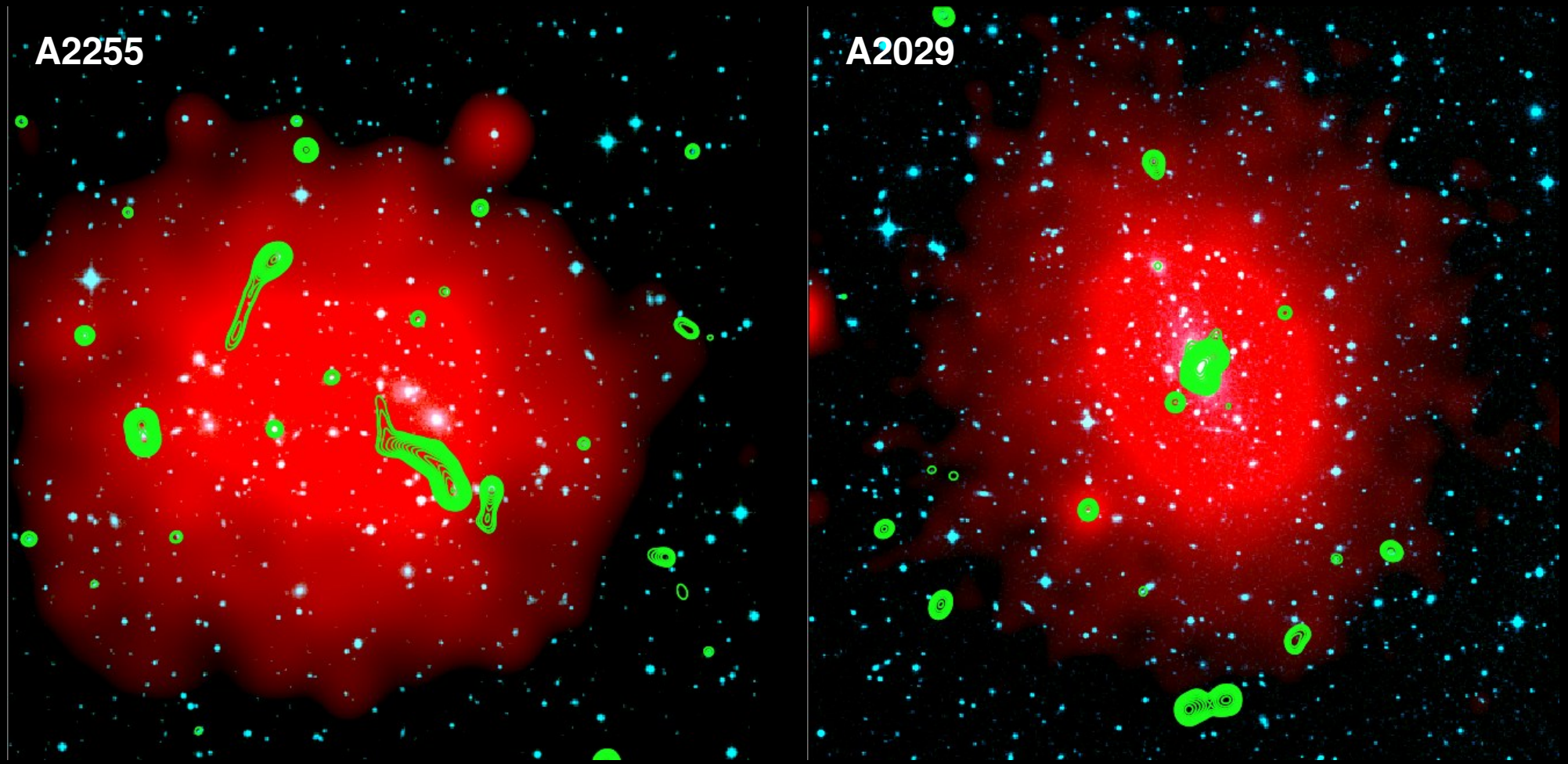


Optical - X-ray

Galaxy Clusters

MERGING CLUSTER

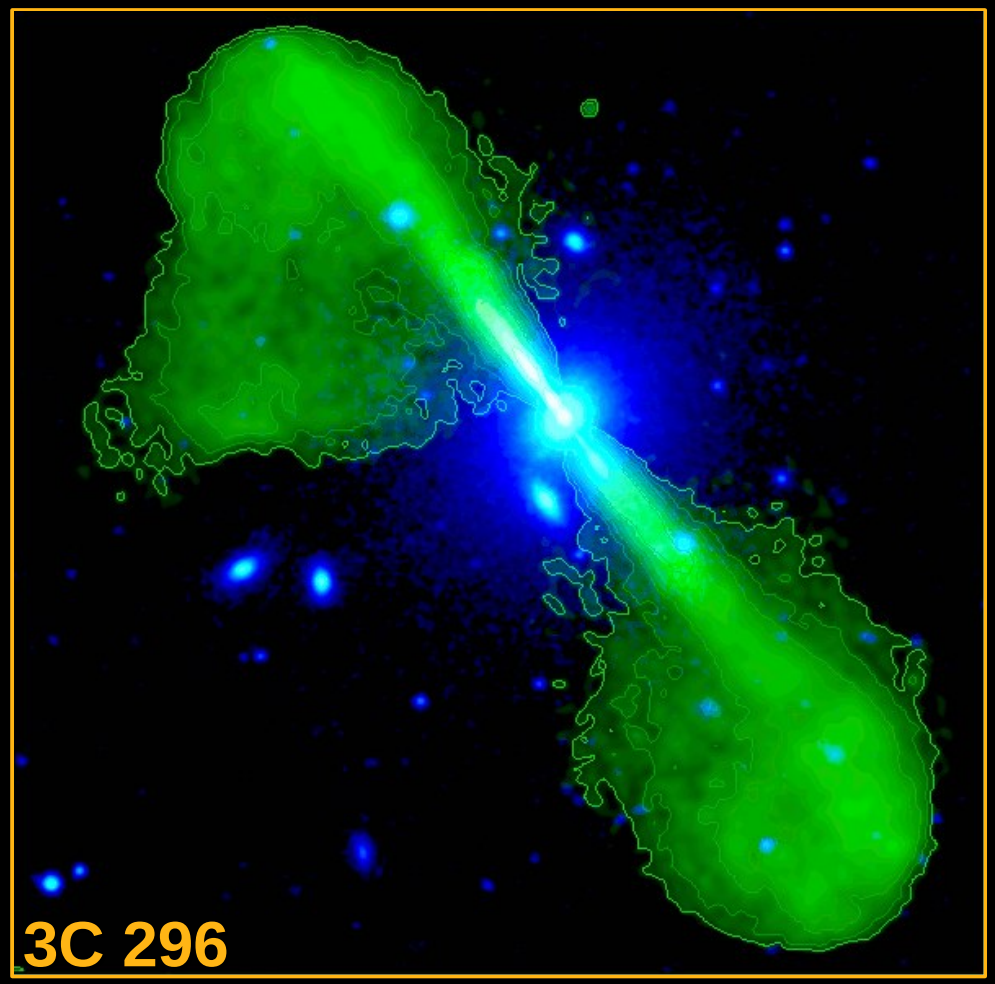
RELAXED CLUSTER

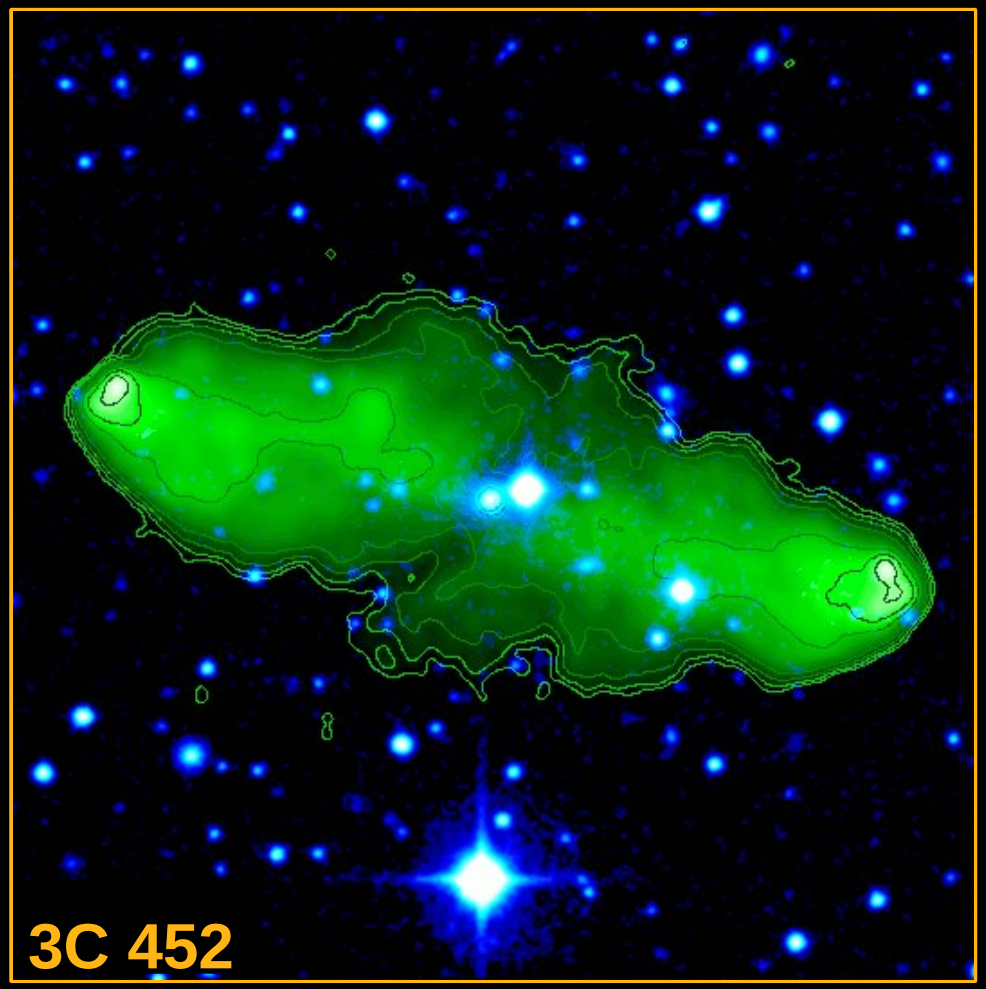


Optical - X-ray - Radio

Radio galaxies

Strong radio sources associated with elliptical galaxies are supplied with energy from active galactic nuclei via plasma beams



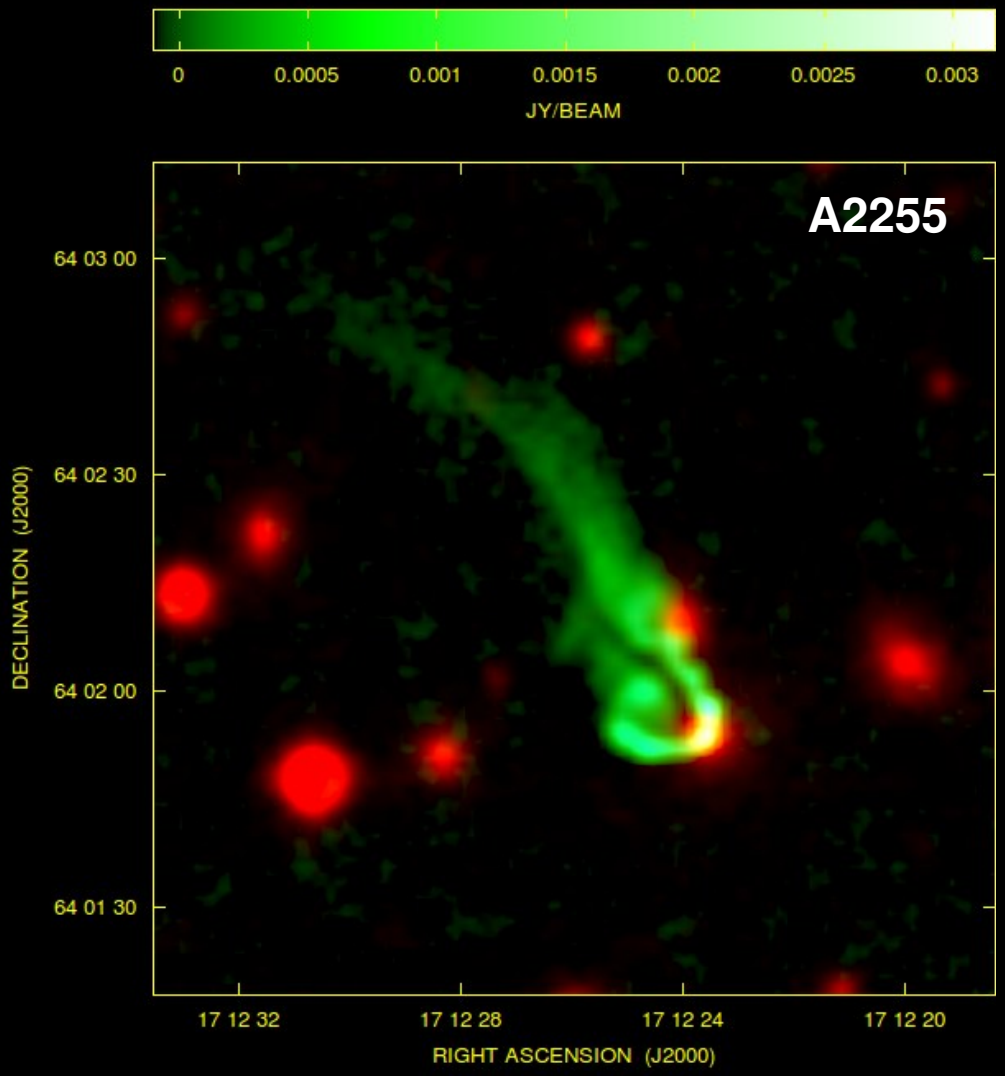


Radio cores, jets, and hot-spots are produced by continuous activity

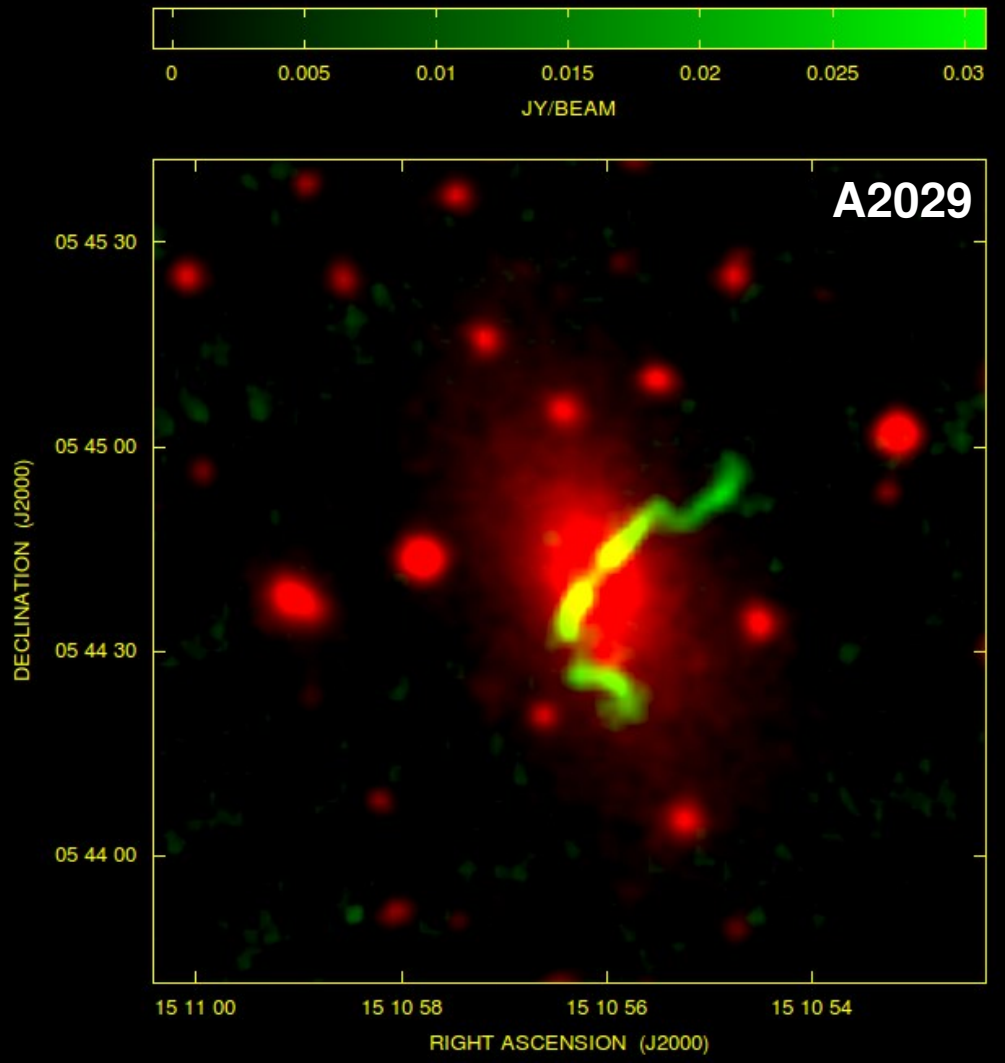
Radio galaxies in Clusters

Radio galaxies located in dense environments often show complex distorted radio structures

NAT Narrow-Angle-Tail



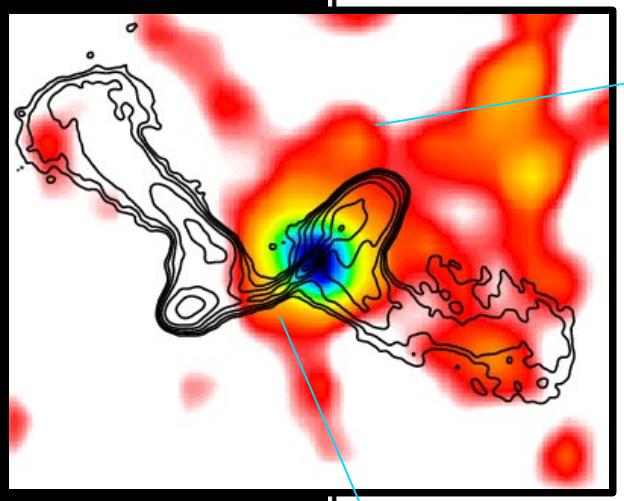
WAT Wide-Angle-Tail

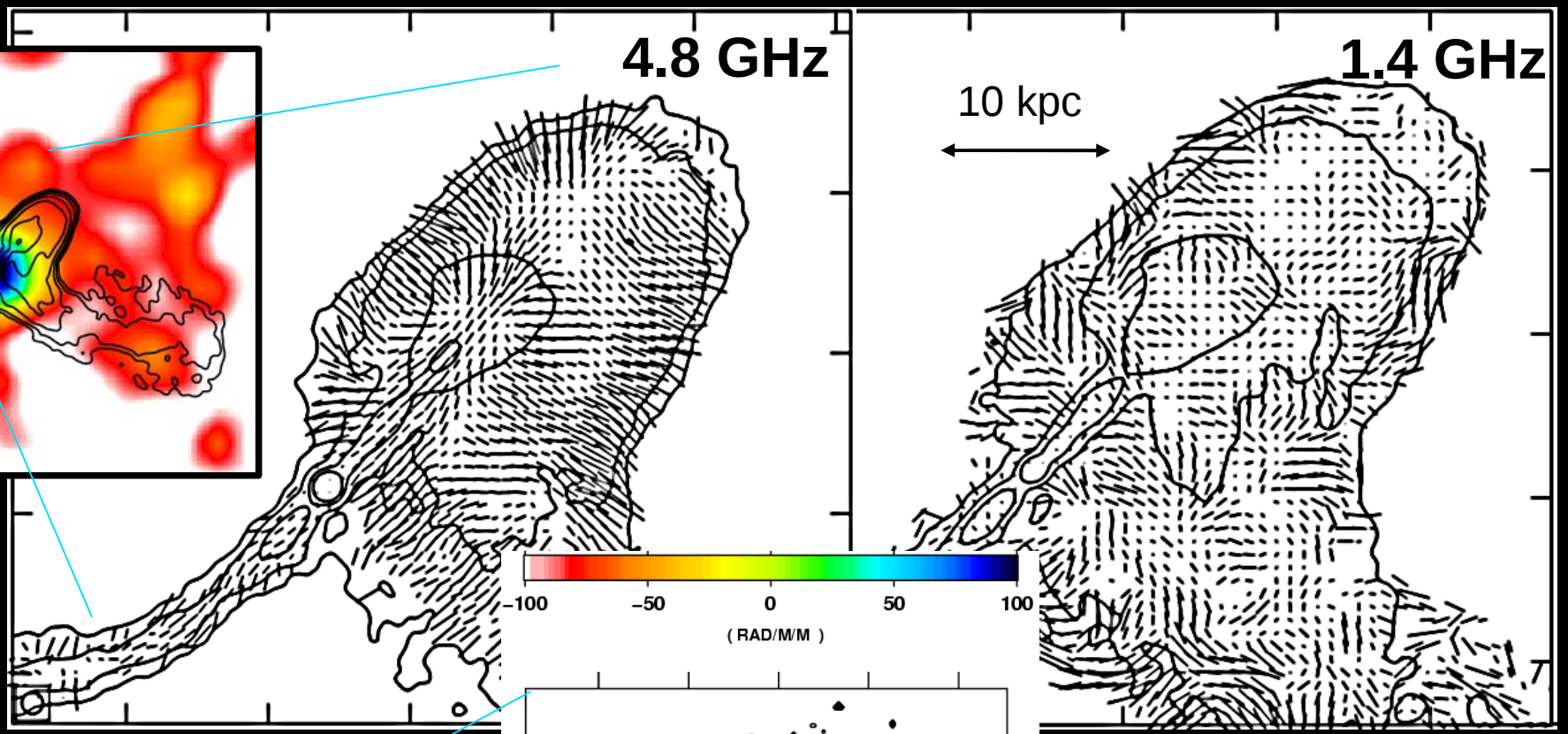


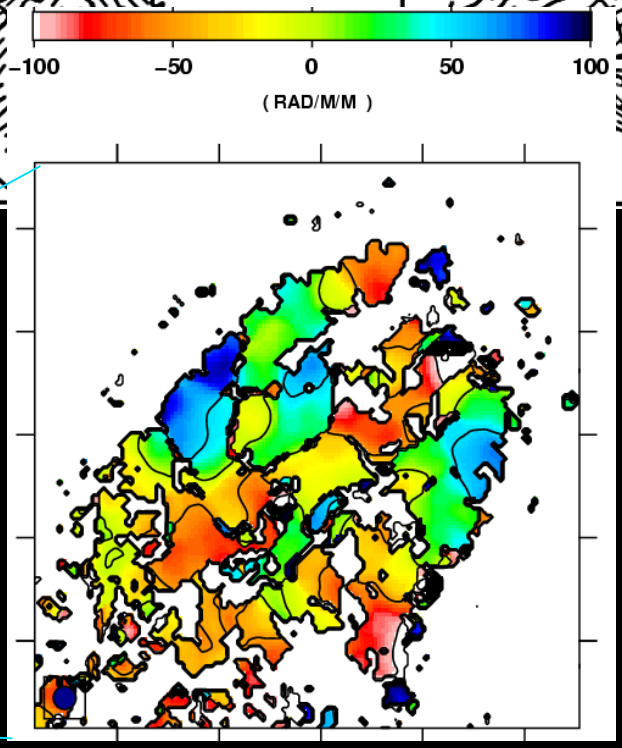
Prototype: NAT 3C465 in A2634 Eilek et al. (1984)

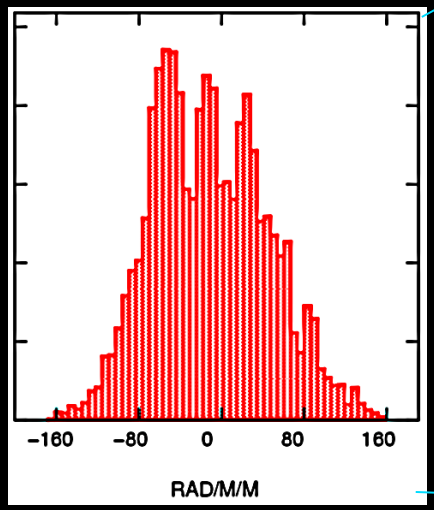
WAT NGC1265 in Perseus O'dea & Owen (1986)

Faraday rotation effect



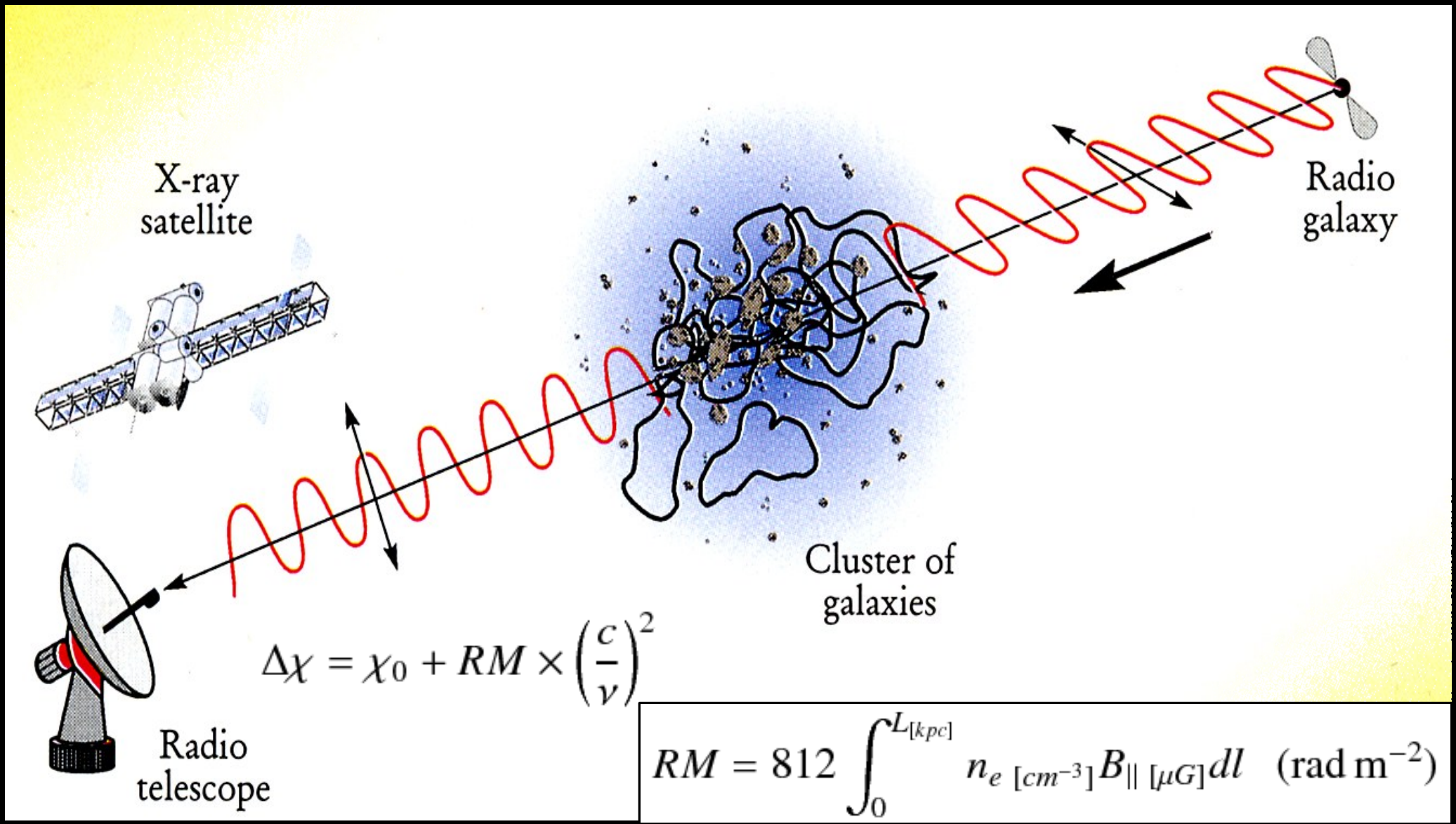






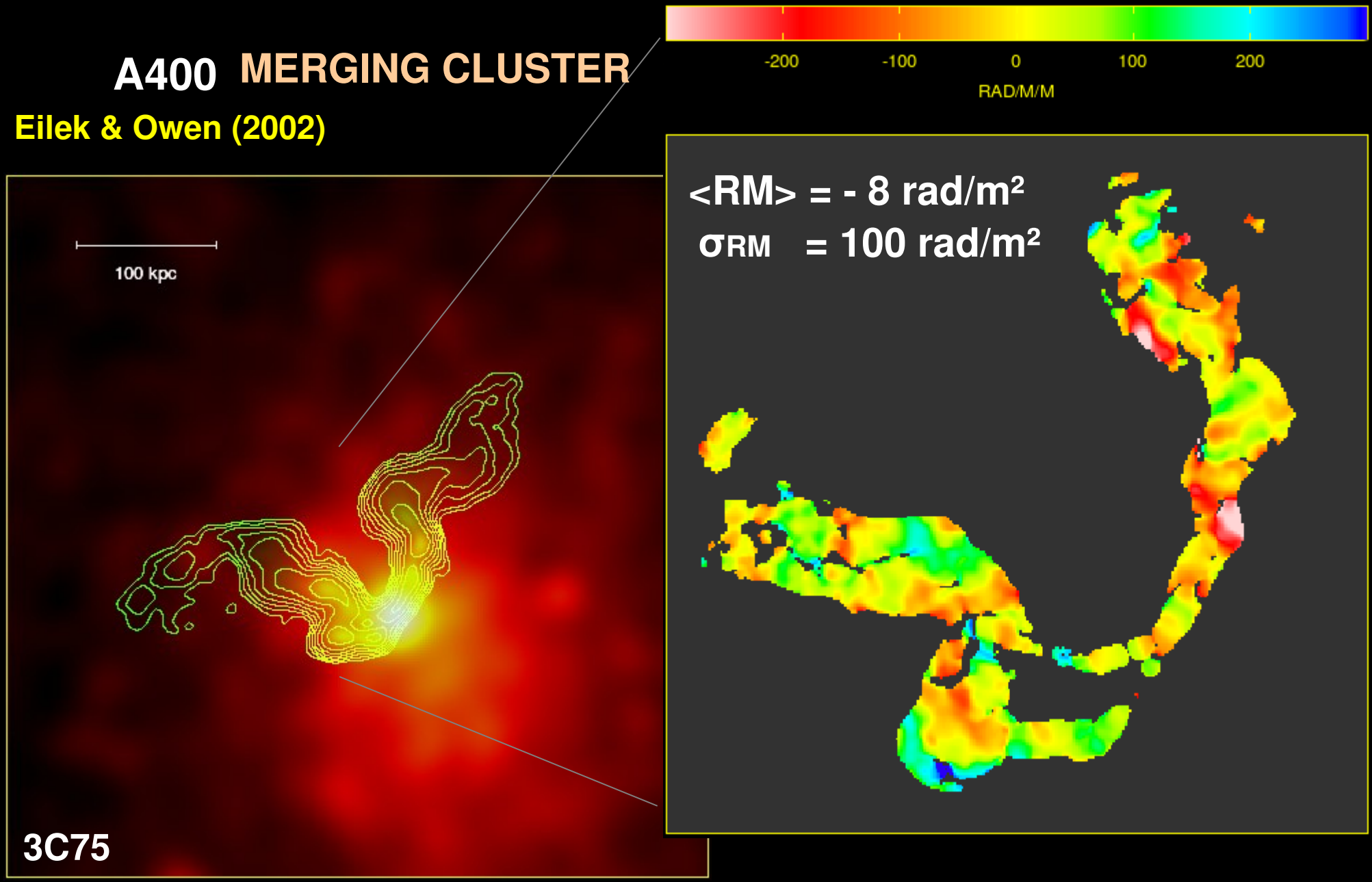
NGC 326
Murgia et al. (2001)

Faraday rotation effect



see e.g. Burn (1966)

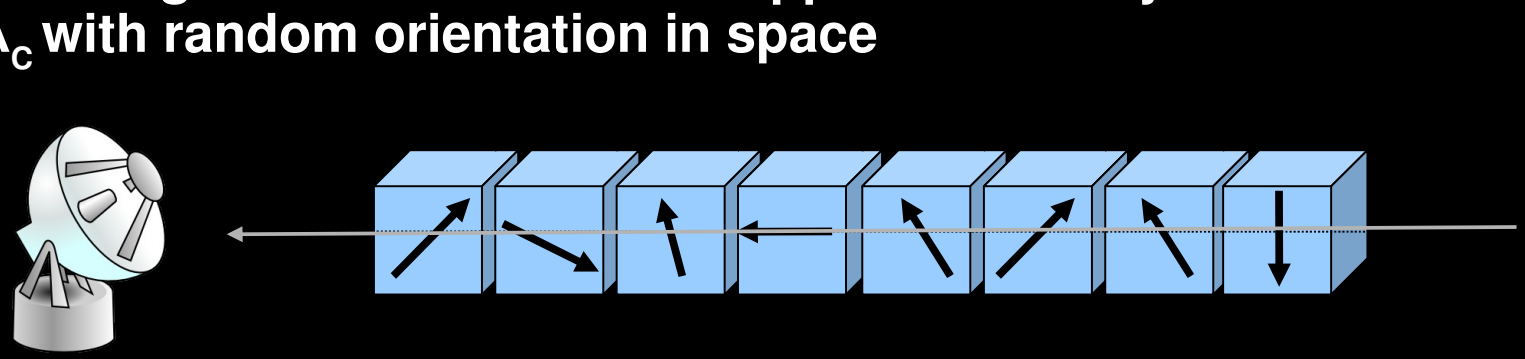
Faraday rotation effect

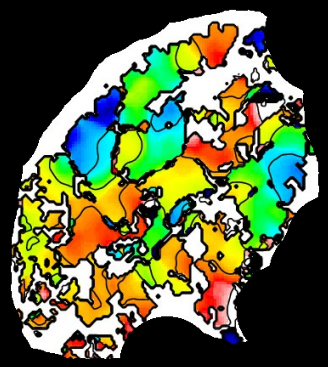


Magnetic field strength of a few μG at the center of merging galaxy clusters.

Faraday rotation effect

The magneto-ionic medium is approximated by uniform cells of size Λ_c with random orientation in space





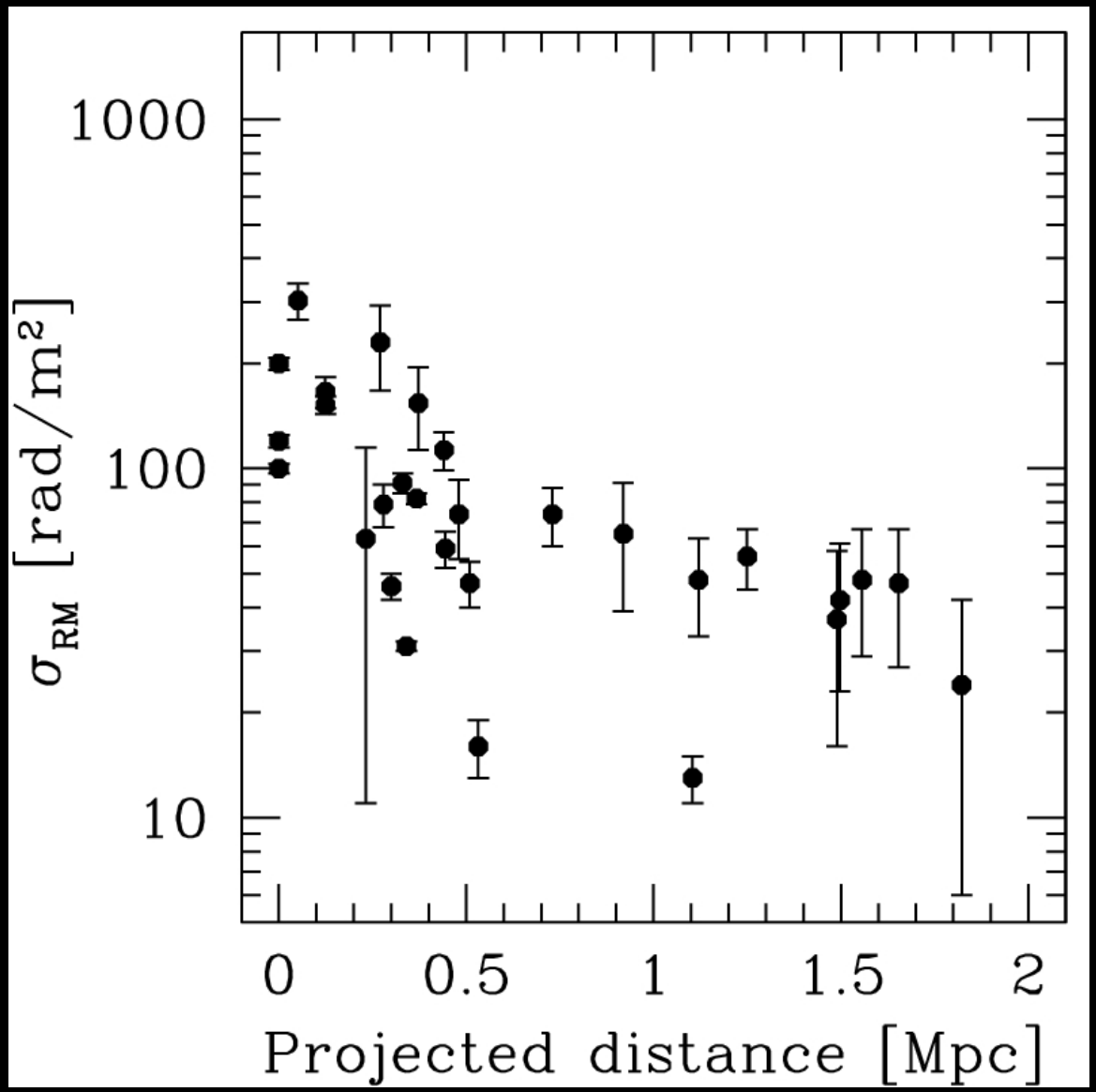
The Faraday rotation from a physical depth L (>>Λ_c) is expected to be a Gaussian with zero mean and dispersion given by:

$$\sigma_{RM}^2 = \langle RM^2 \rangle = 812^2 \Lambda_c \int_L (n_e B_{\|})^2 dl \quad (\mathrm{rad^2 m^{-4}})$$

$$\sigma_{RM} = 812 \sqrt{\Lambda_c}\ \sqrt{L}\, n_e\, \sigma_{B_{\|}}$$

See e.g. Lawler & Dennison (1982), Tribble (1991), Feretti et al. (1995), Felten (1996), Sokoloff et al. (1998)

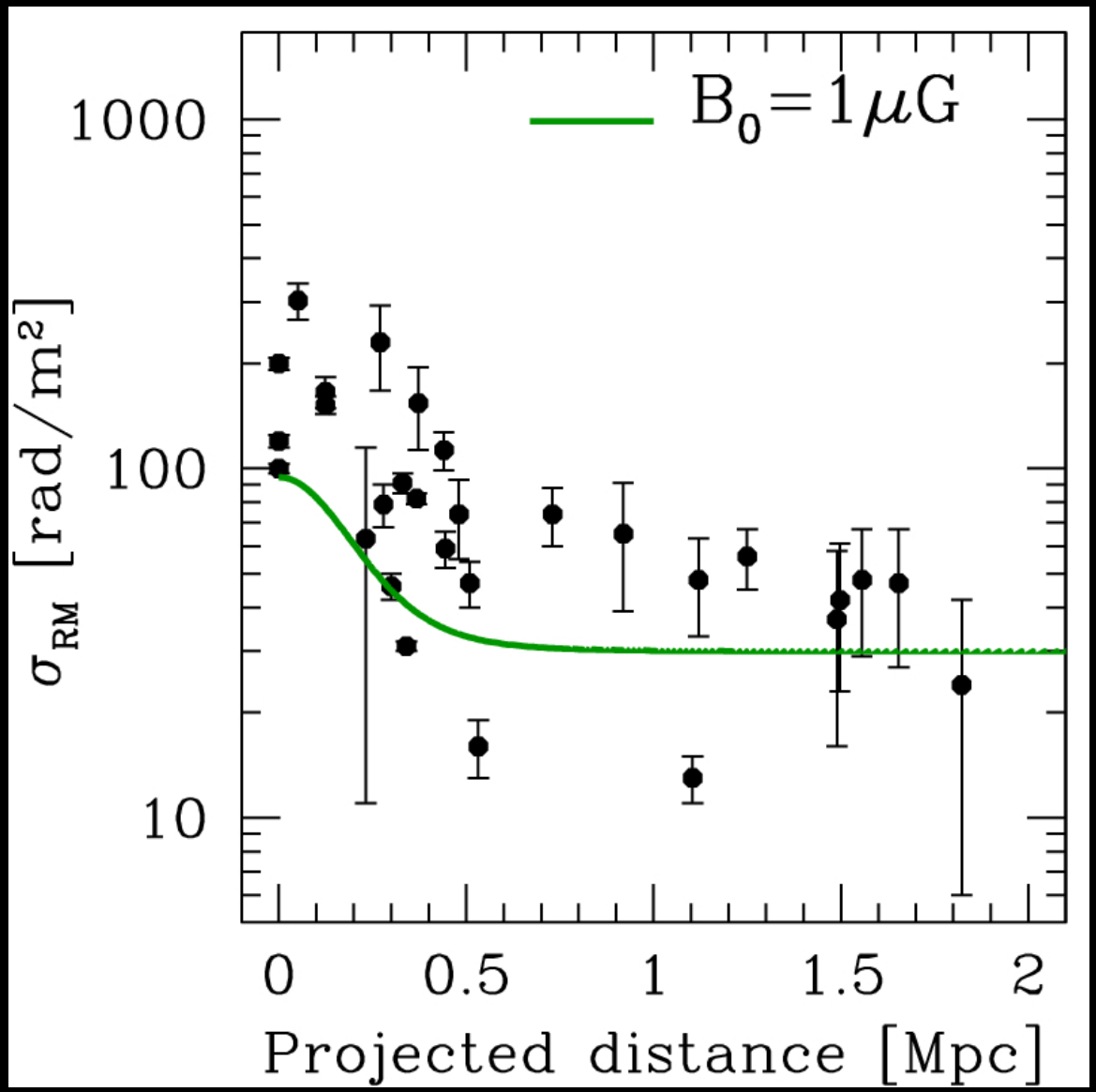
Faraday rotation effect



Bonafede et al. (2010)
Eilek & Owen (2002)
Feretti et al. (1999)
Govoni et al. (2001, 2006, 2010)
Guidetti et al. (2008)
Taylor et al. (2001)

These trends indicate that magnetic fields are common in galaxy clusters, in agreement with the results by Clarke et al. (2004) and Johnston-Hollitt & Ekers (2004) who analyzed the <RM> of sources located behind and within clusters.

Faraday rotation effect



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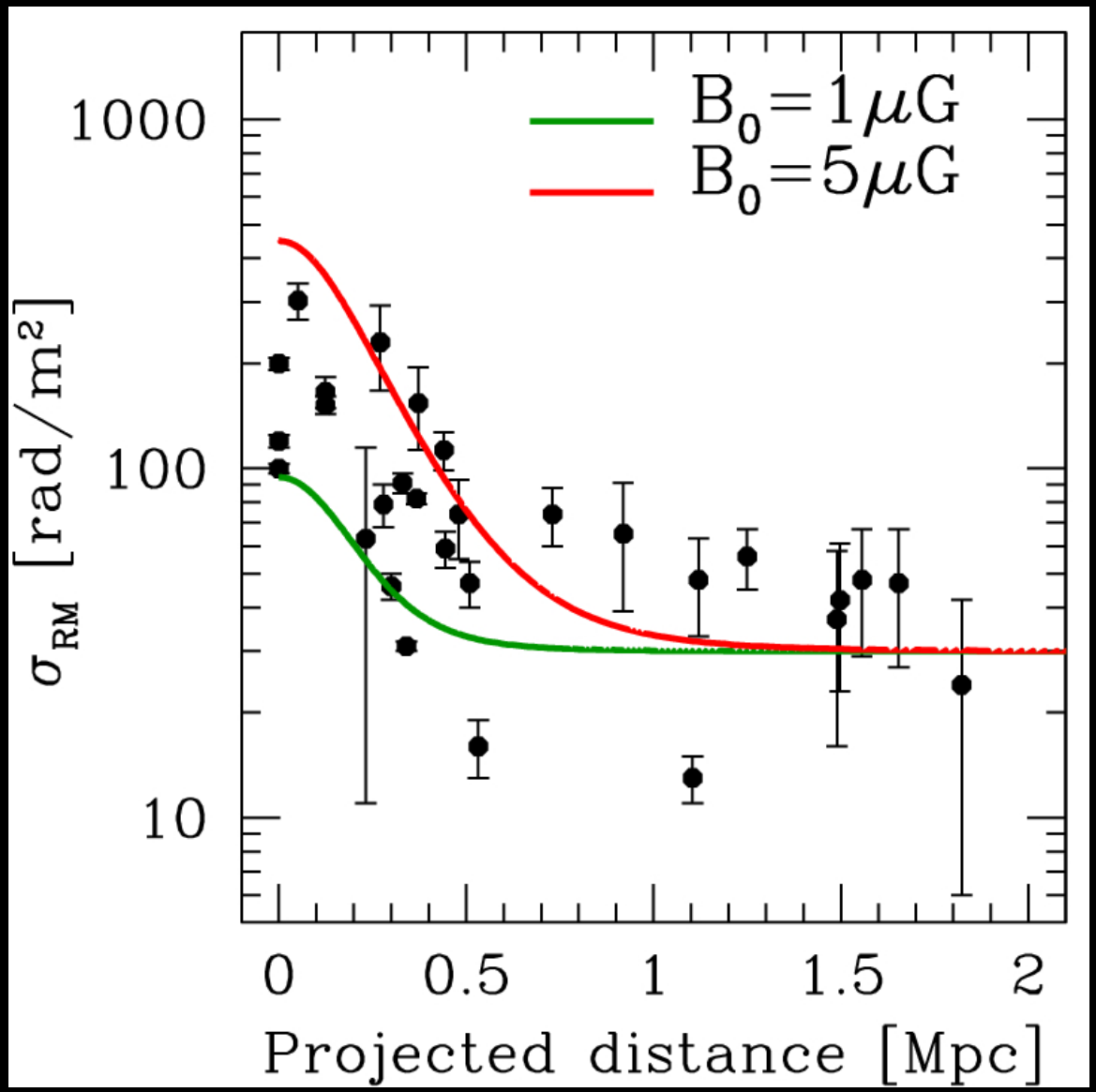
Auto-correlation length ΛB=25 kpc

$$\langle \mathbf{B} \rangle (r) = \langle B_0 \rangle \left[\frac{n_e(r)}{n_0} \right]^{\eta}$$

η≃0.5

Faraday rotation effect



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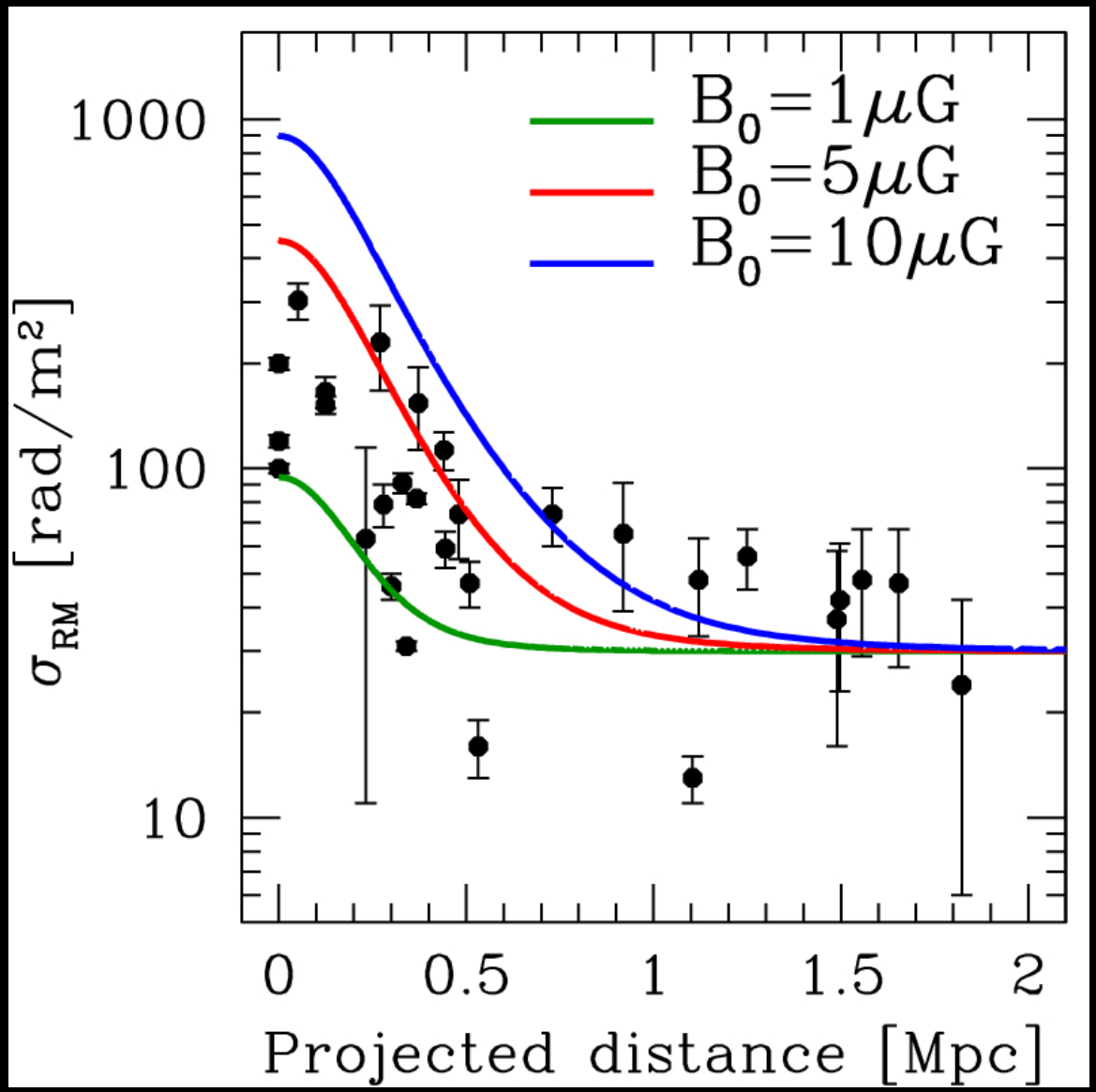

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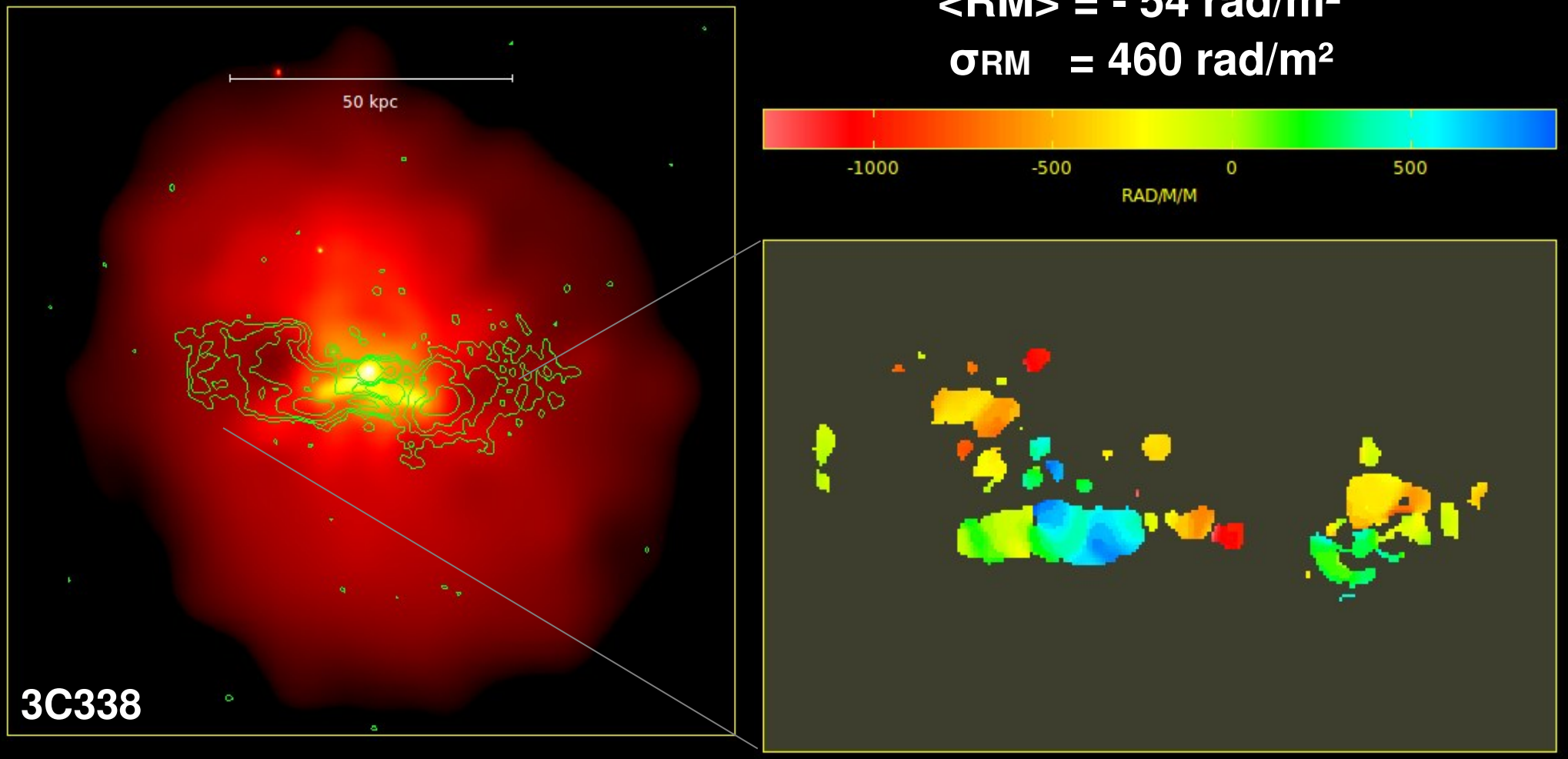
Faraday rotation effect

A2199 RELAXED CLUSTER

Vacca et al. (2012)

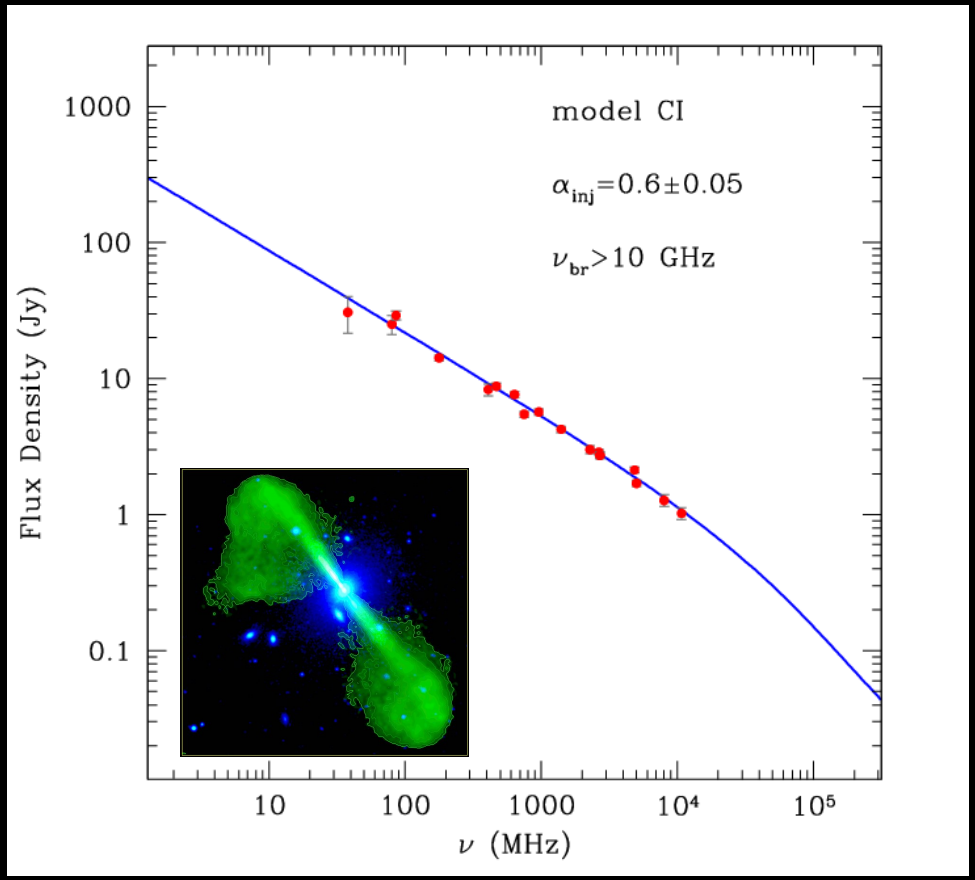


Magnetic field strength larger than 10 μG at the center of cool-core clusters.

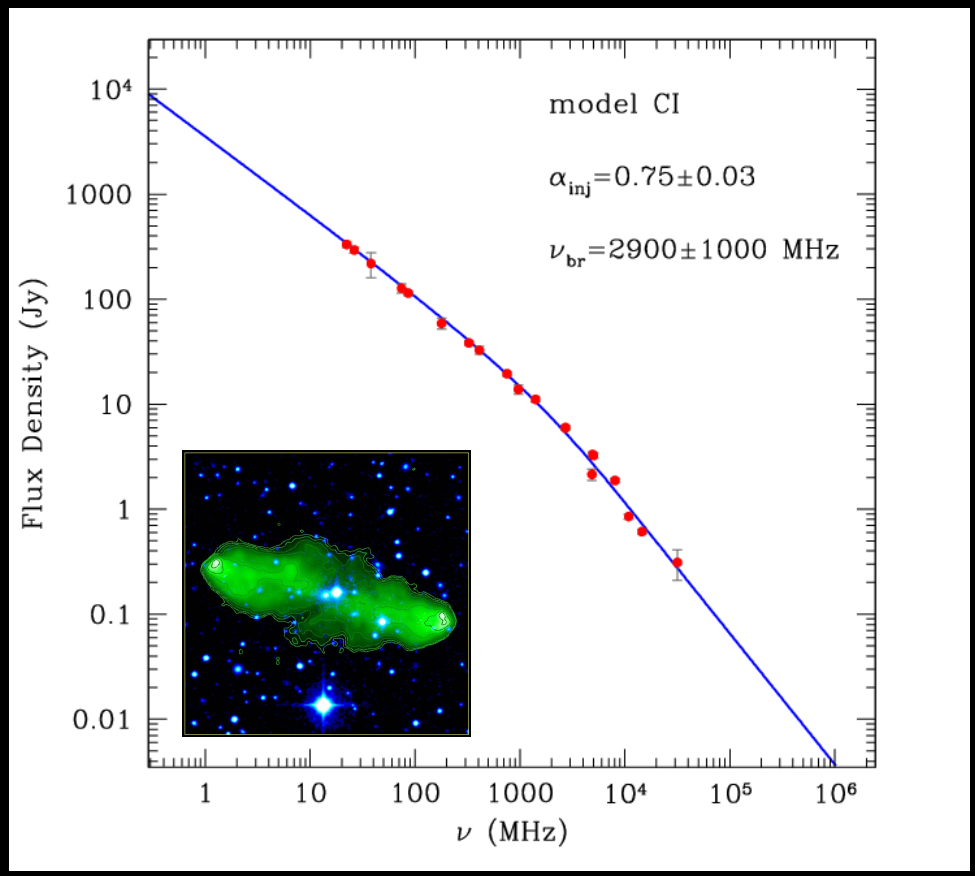
Radio galaxies

The total spectra of active radio sources are usually well-approximated by a power law over a wide range of frequencies. Spectral breaks at high-frequency with a moderate steepening are also observed.

3C296



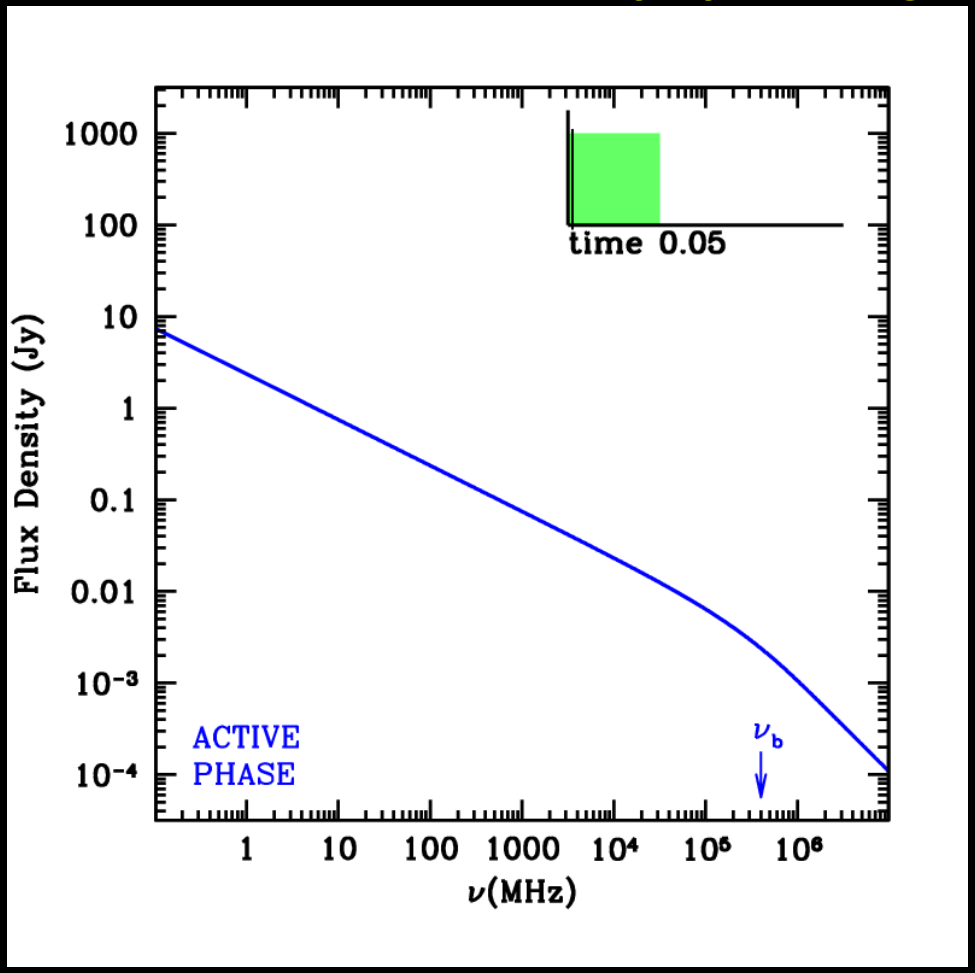
3C452



Radio galaxies: spectral evolution

During the active phase the source is continuously replenished of fresh particles. However, due to the radiative losses, the high-frequency spectrum steepen beyond a time-dependent break frequency

Courtesy by M. Murgia



$$\nu_b \propto B^{-3} t_s^{-2}$$

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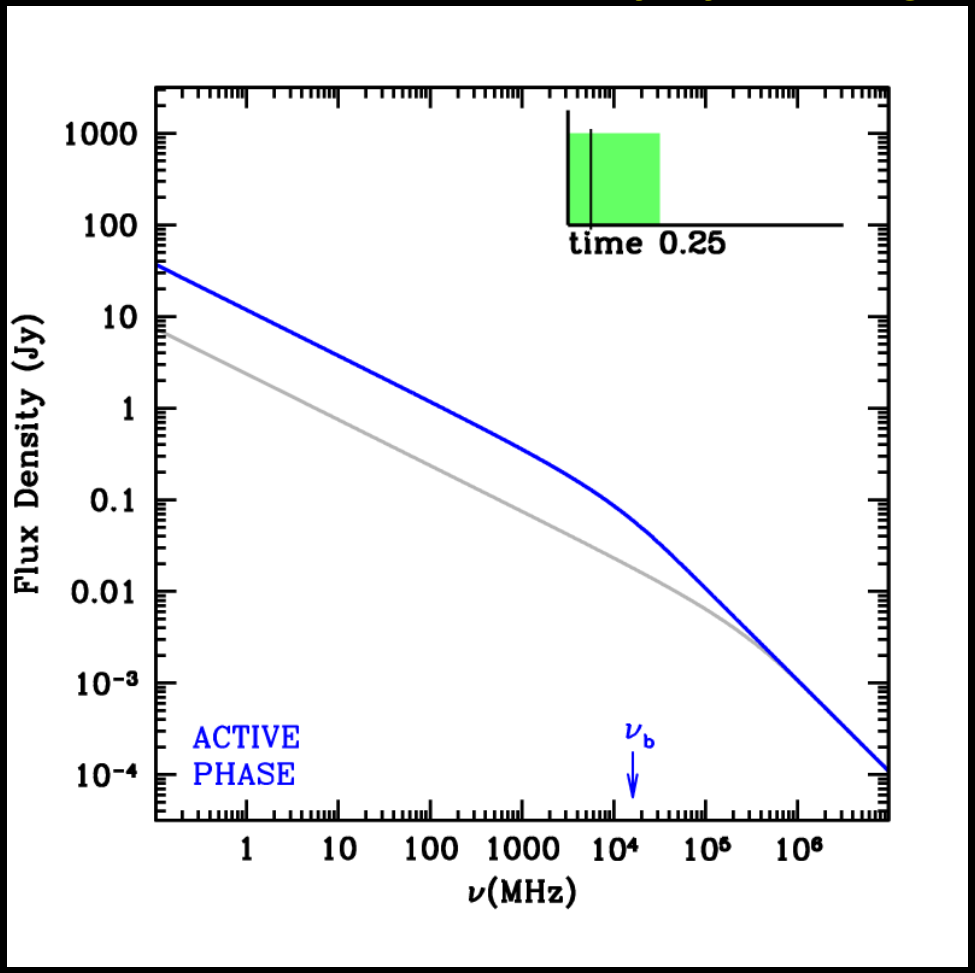

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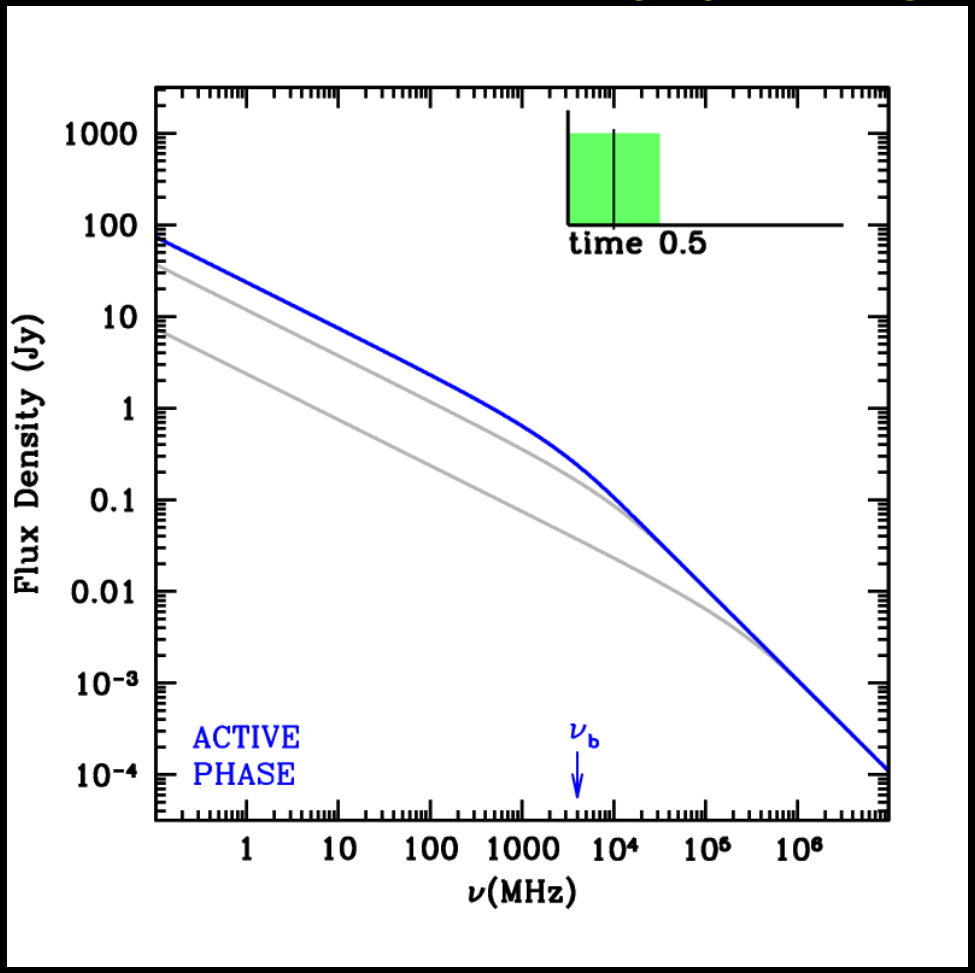

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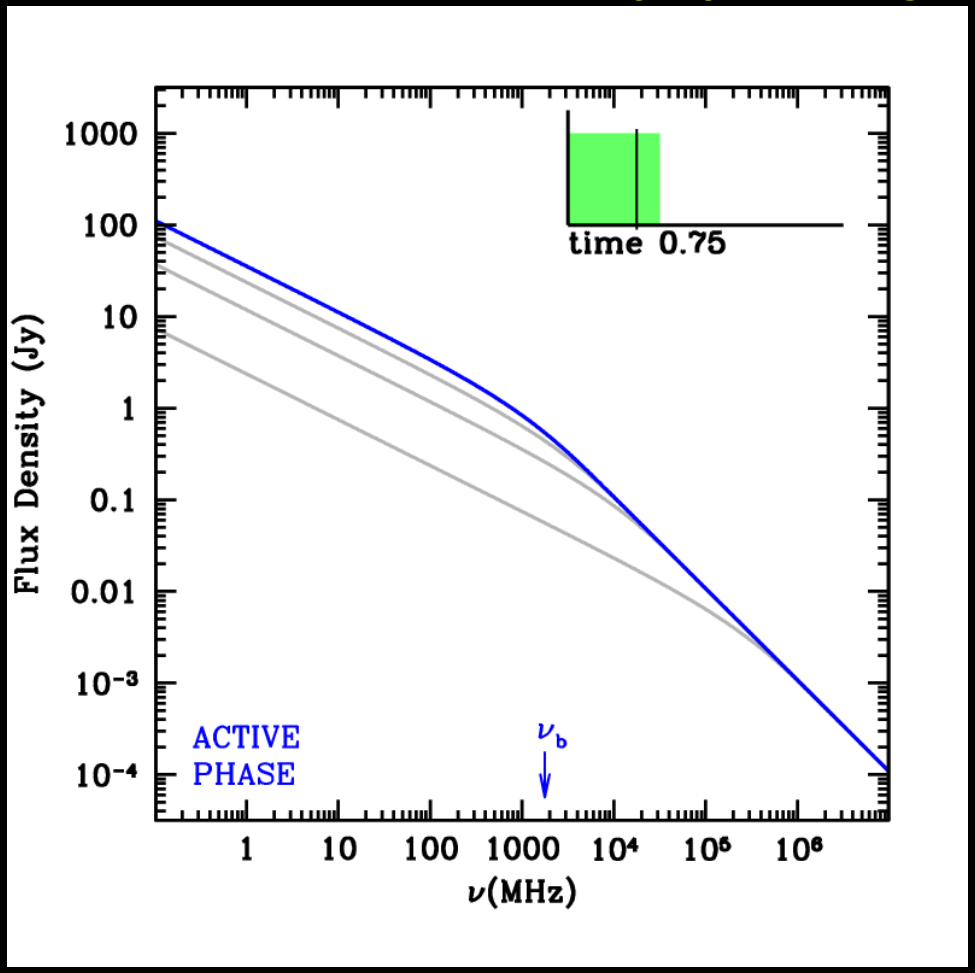

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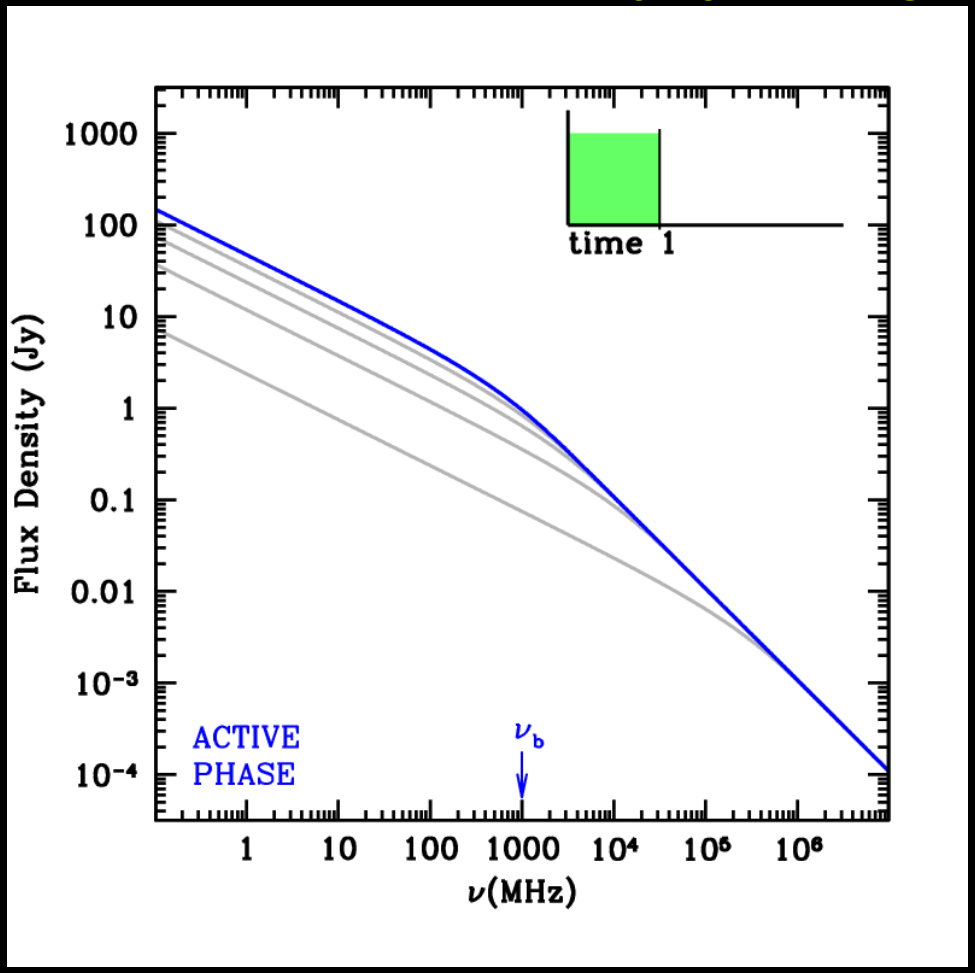

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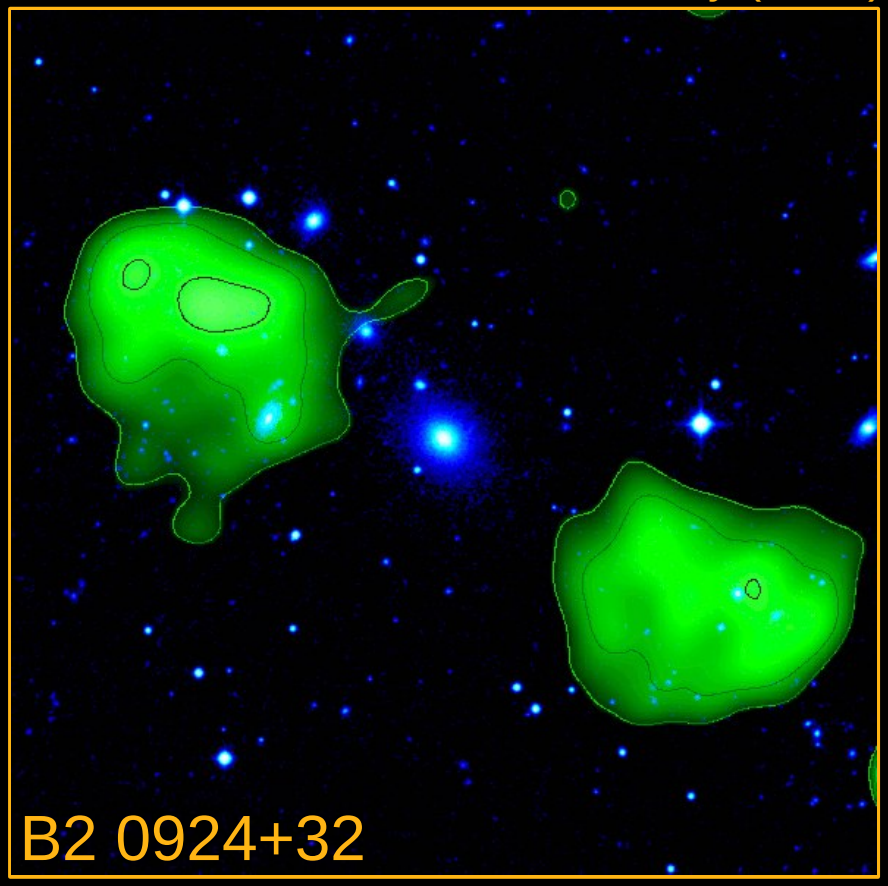
Dying radio galaxies

When the activity in the nucleus stops or fall to such a low level that the plasma outflow can no longer be sustained, the radio source is expected to undergo a period of fading (the dying phase).

Cordey (1987)

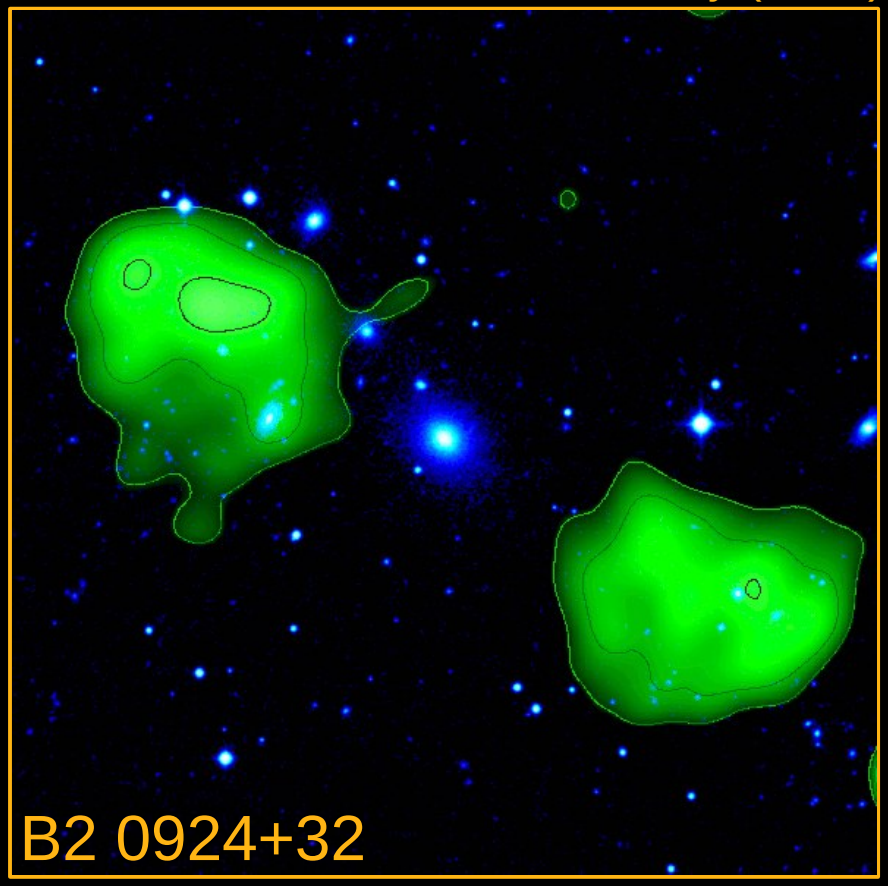


Radio core, well-defined jets, and compact hot-spots will disappear because they have to be sustained by continuing injection. The radio lobes may remain detectable longer if subject only to radiative losses.

Dying radio galaxies

Given the comparatively short duration of the active stage (~10^7 yr) we could expect a large number of dying radio sources.

Cordey (1987)



ONLY A HANDFUL OF DYING-RADIO SOURCES ARE KNOWN!

Only a few percent of the radio sources in the 3C and B2 samples have the characteristic of a dying radio galaxies Giovannini et al. (1988). A possible explanation is their relatively fast spectral evolution during the fading fase.

Dying radio galaxies: spectral evolution

The switch-off of the injection of energetic electrons leads to a second high-frequency break followed by an exponential cut off of the radio spectrum (e.g. Komissarov & Gubanov 1994)

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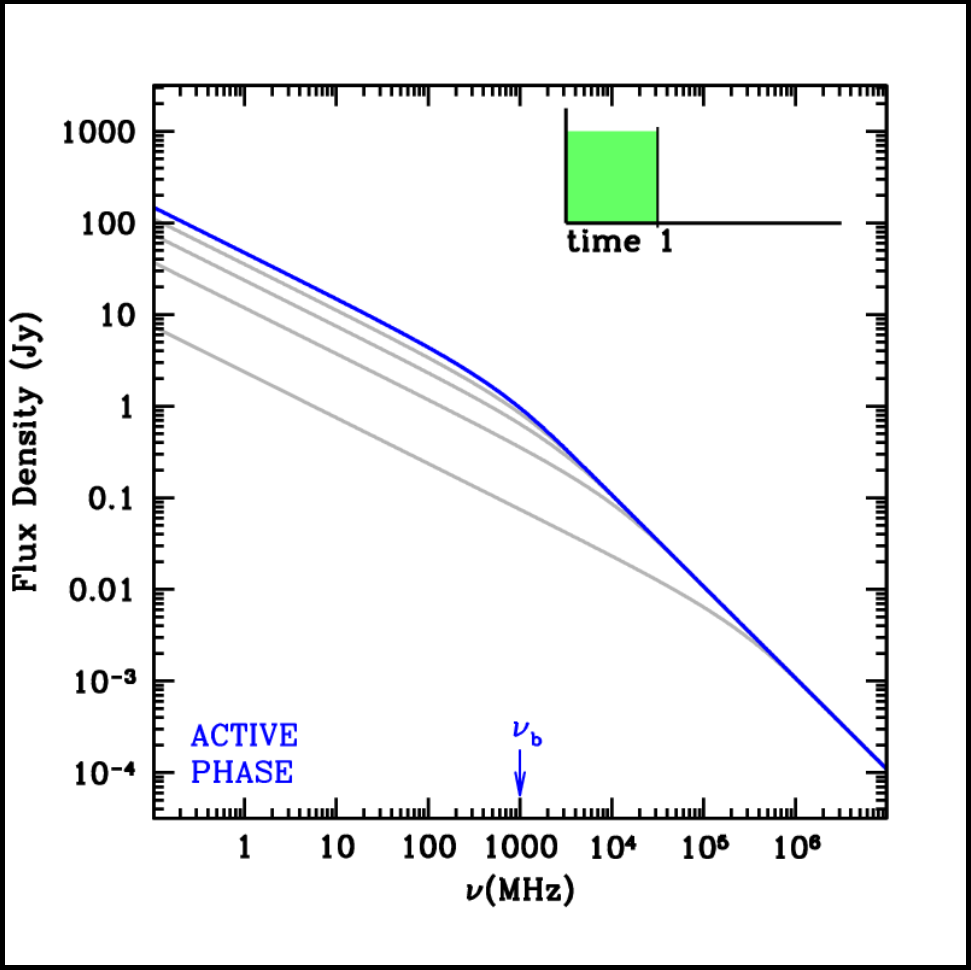

$$\nu_{b\,high} = \nu_{b\,low}\left(\frac{t_s}{t_{OFF}}\right)^2$$

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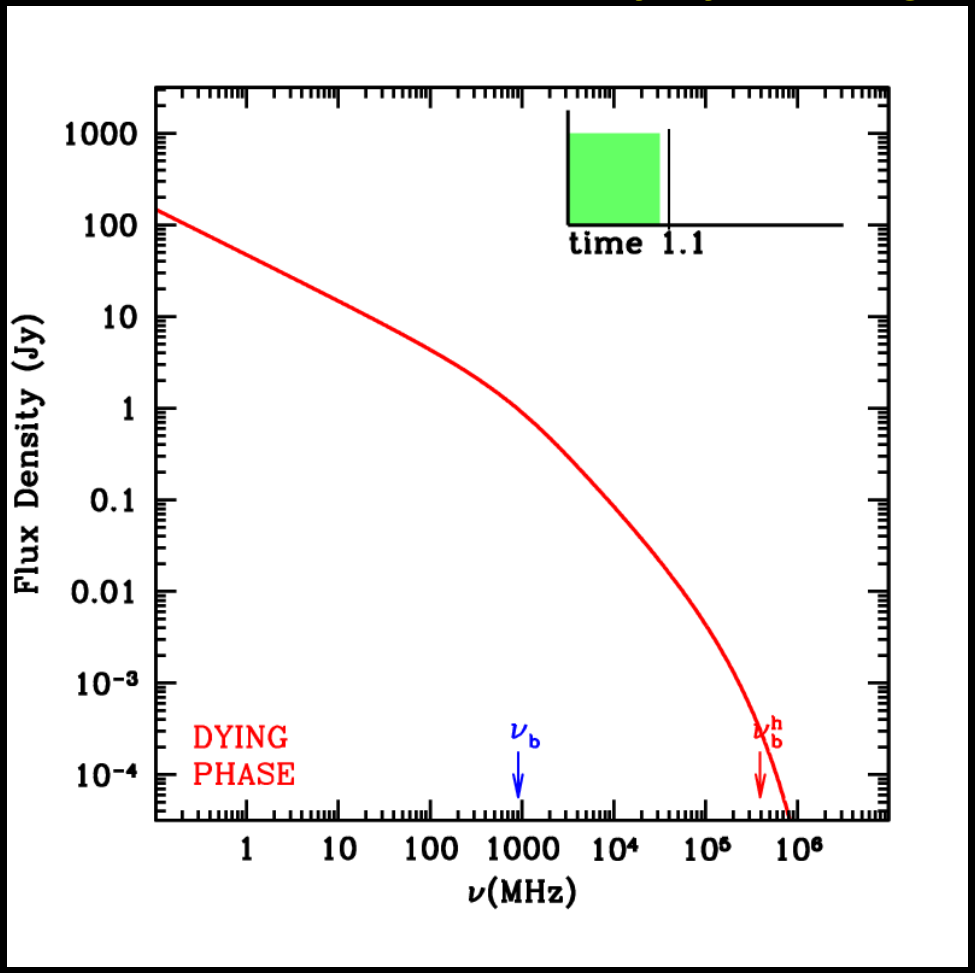

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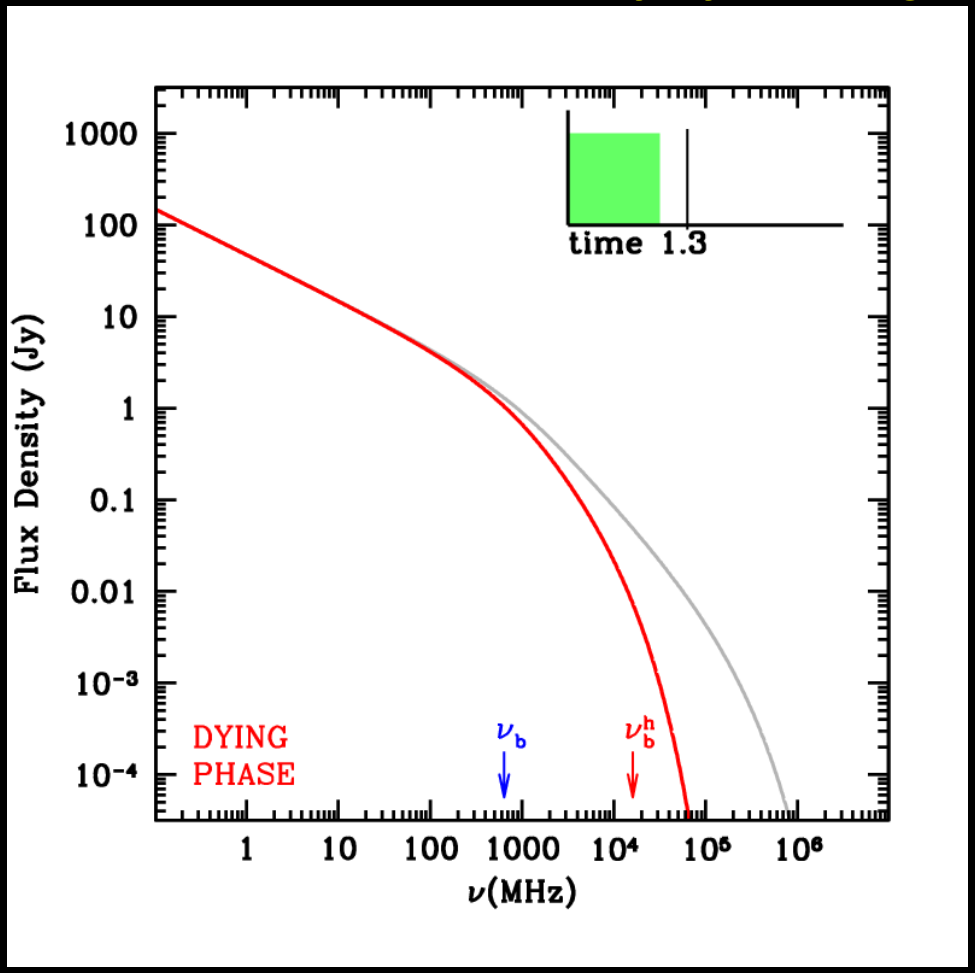

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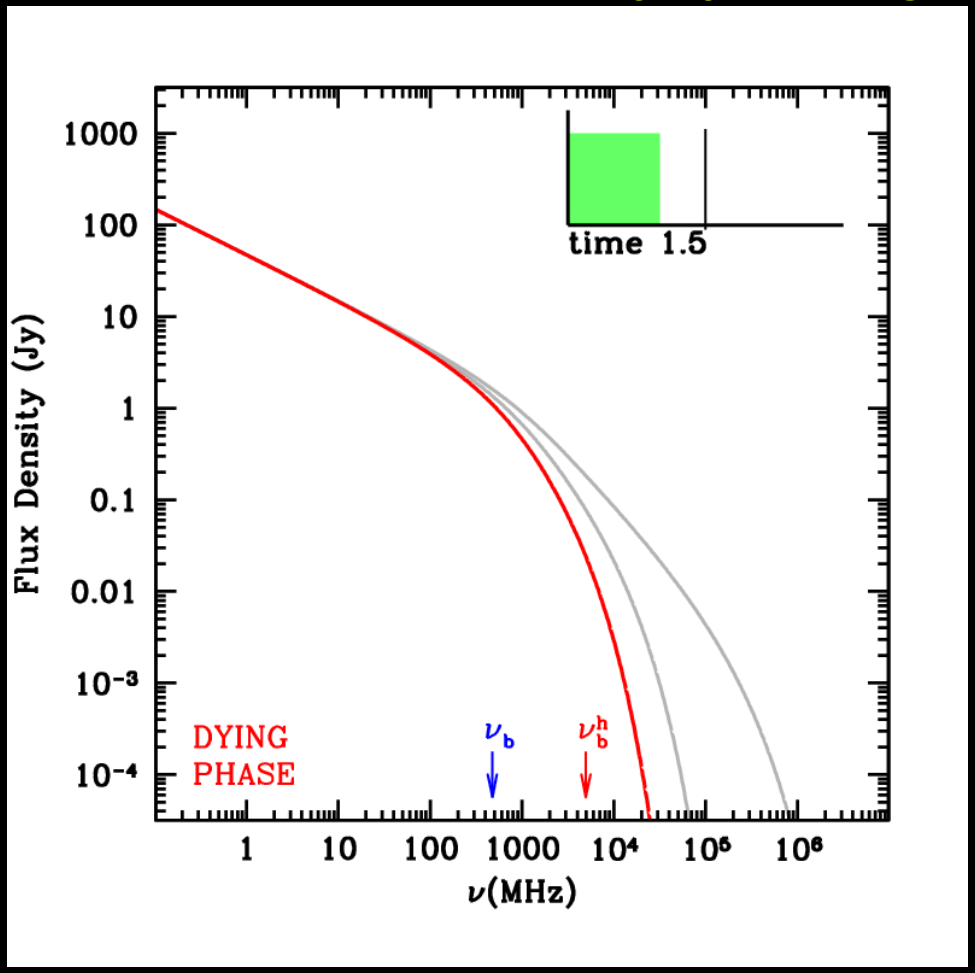

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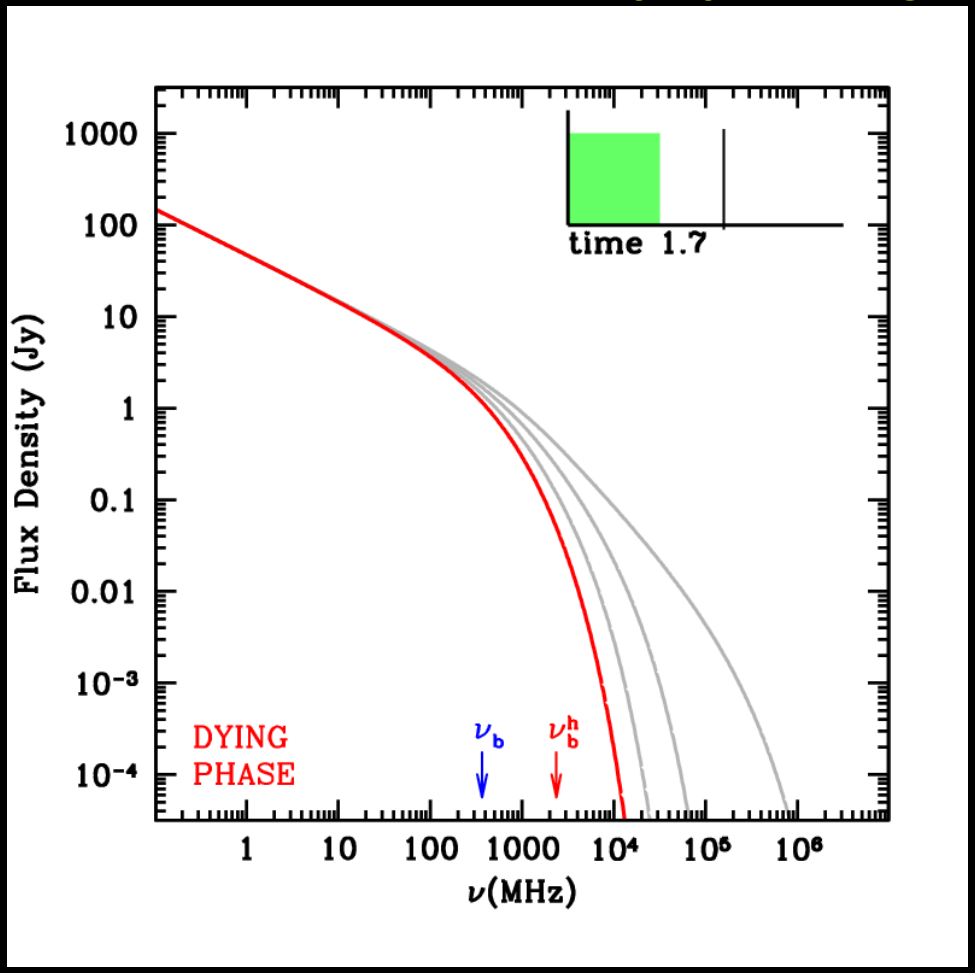

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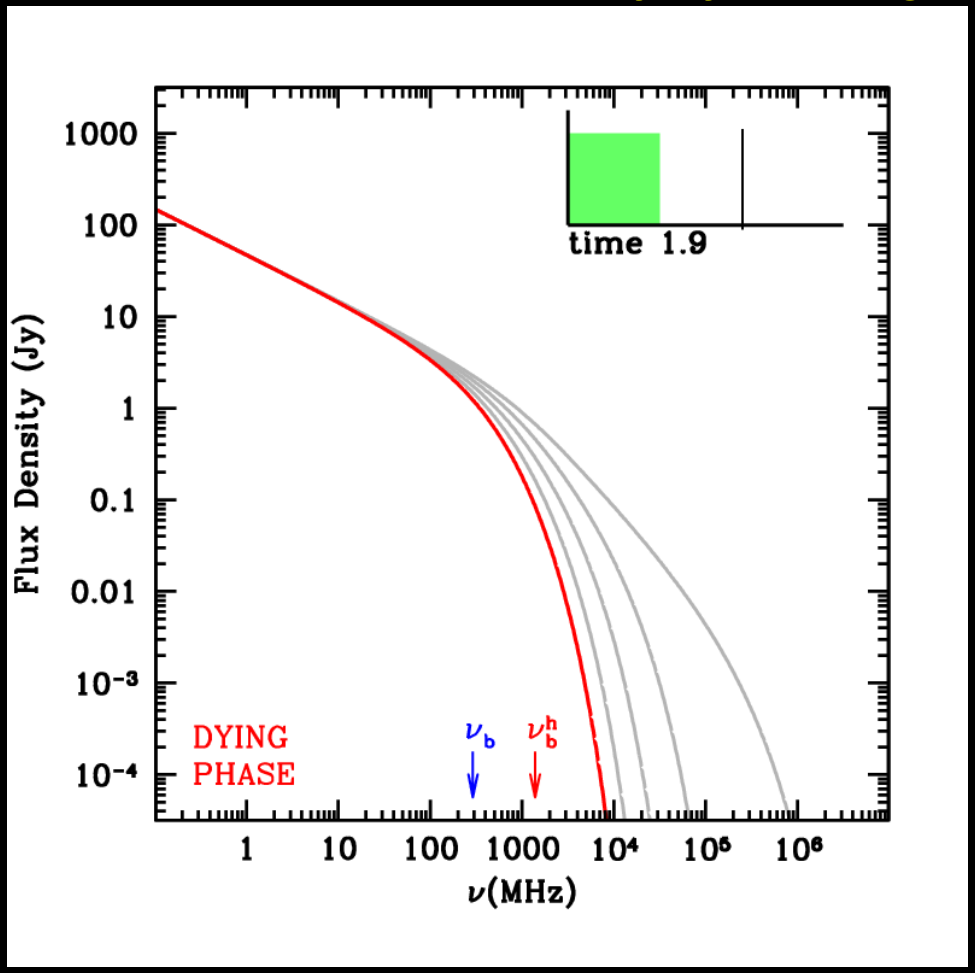

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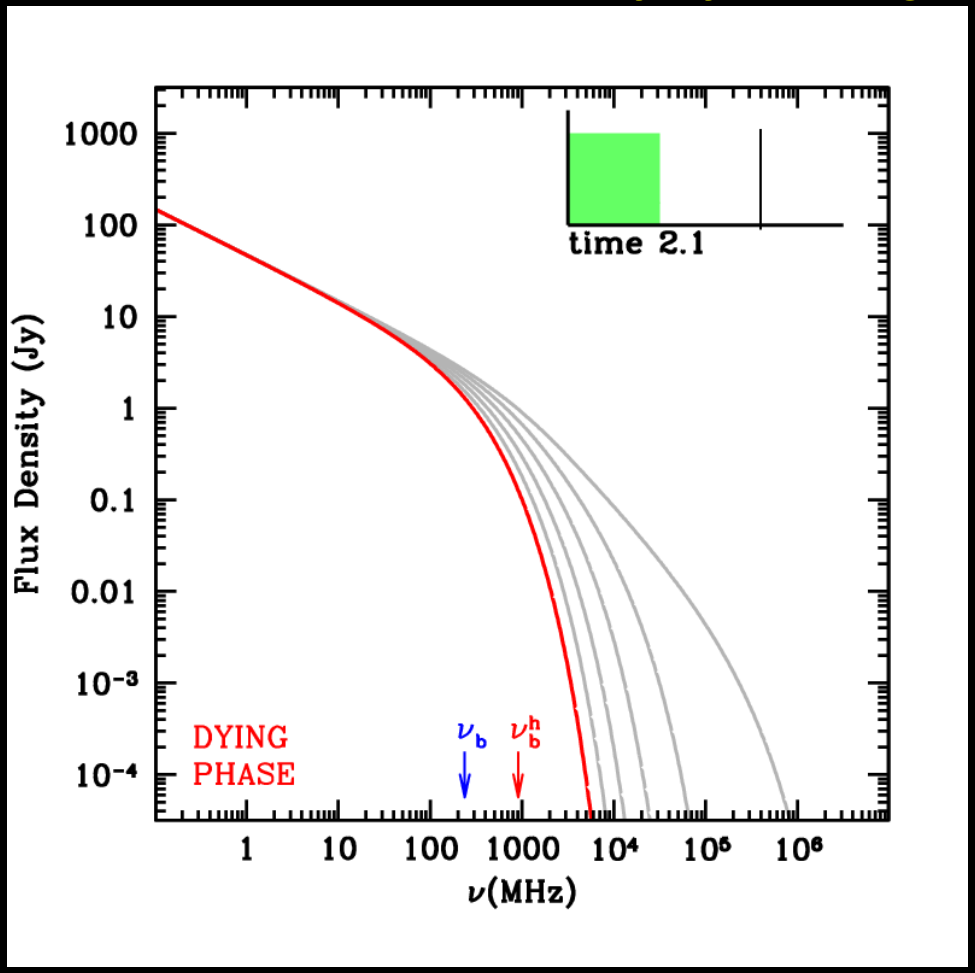

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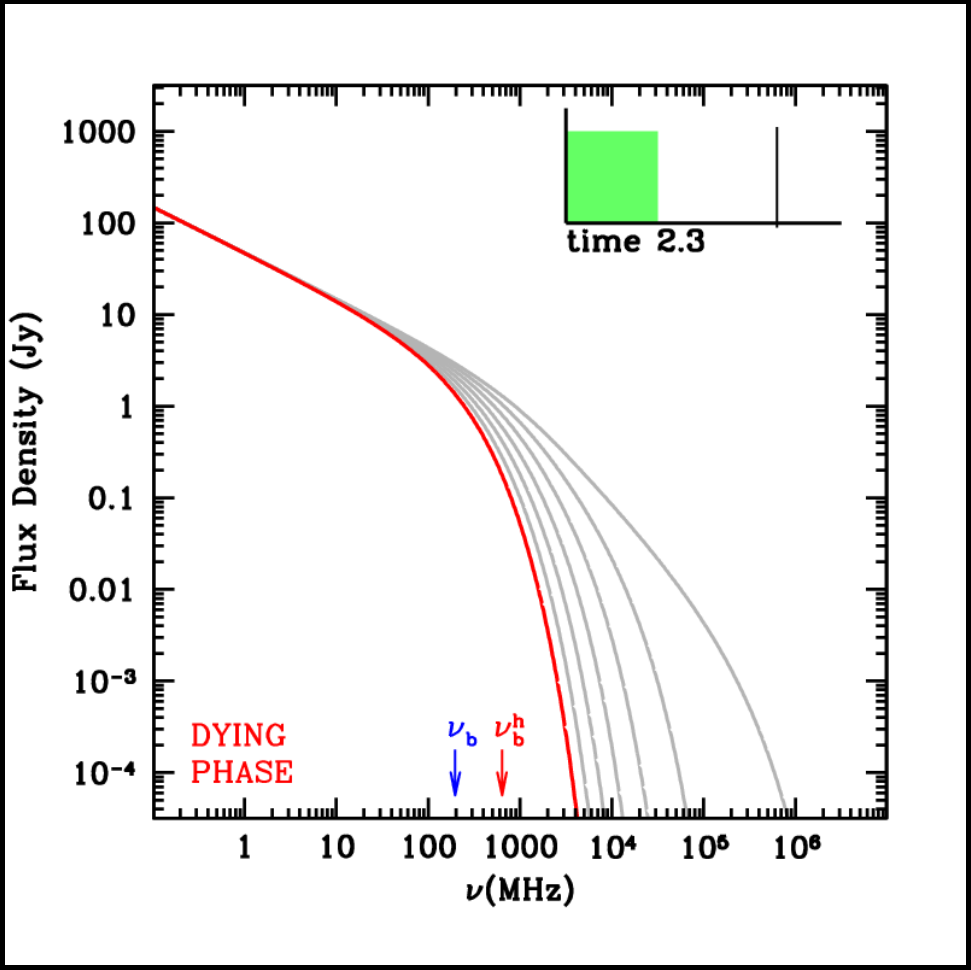

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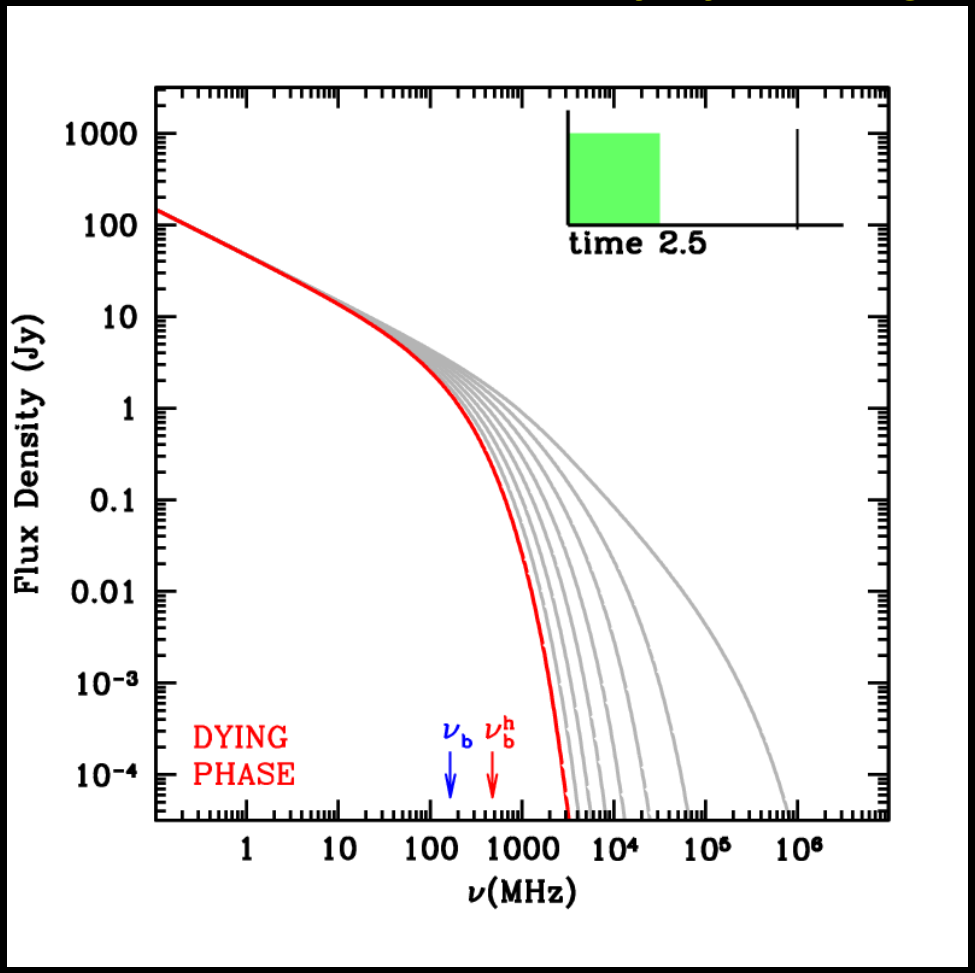

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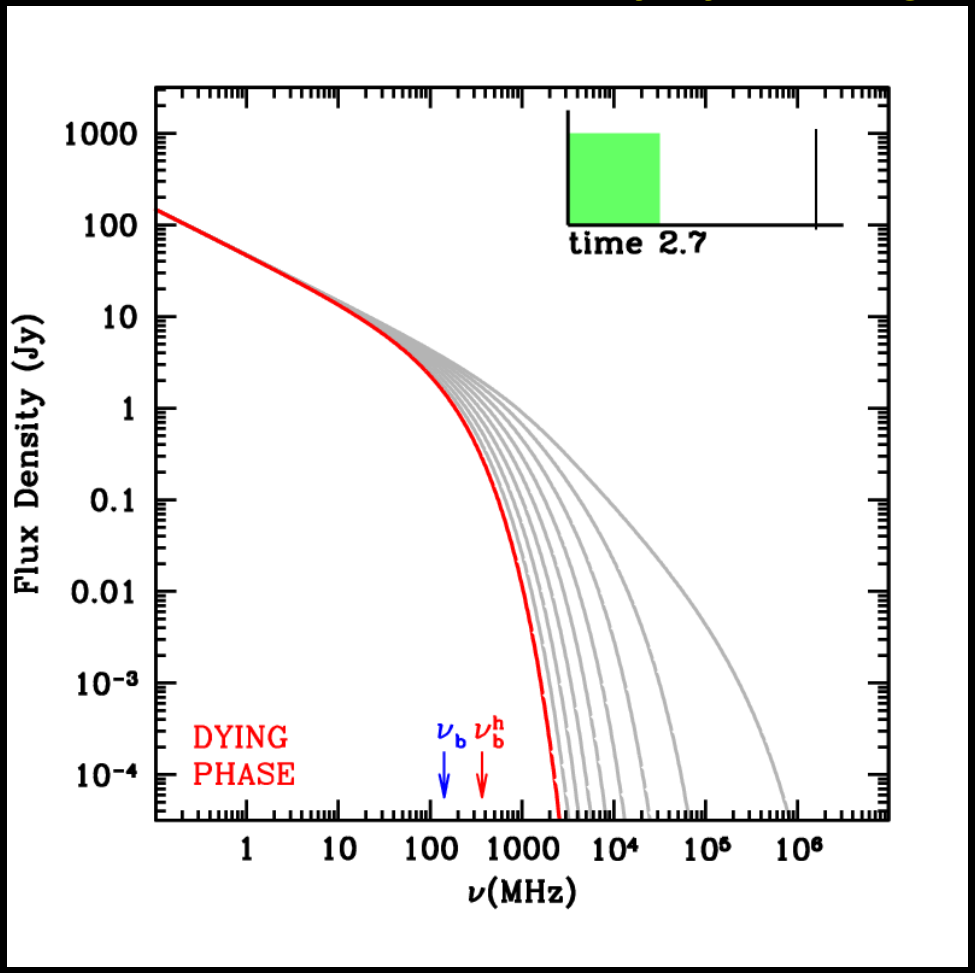

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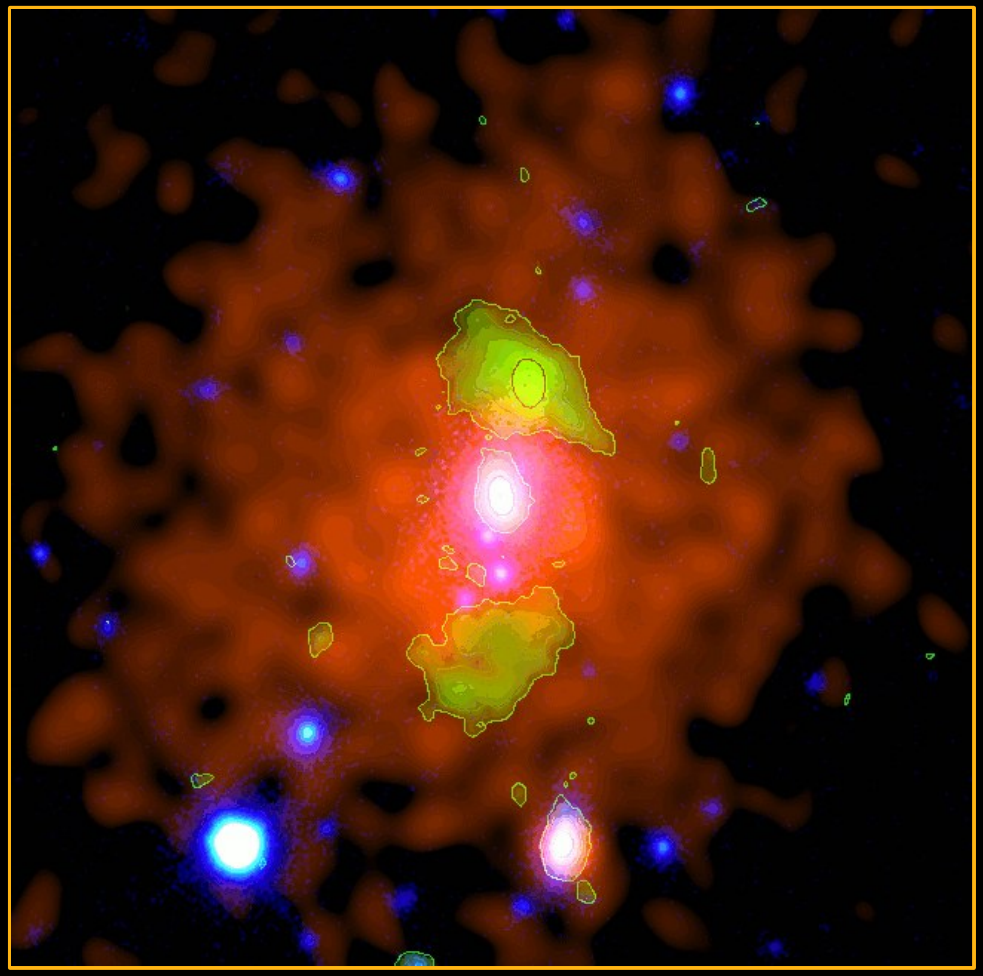
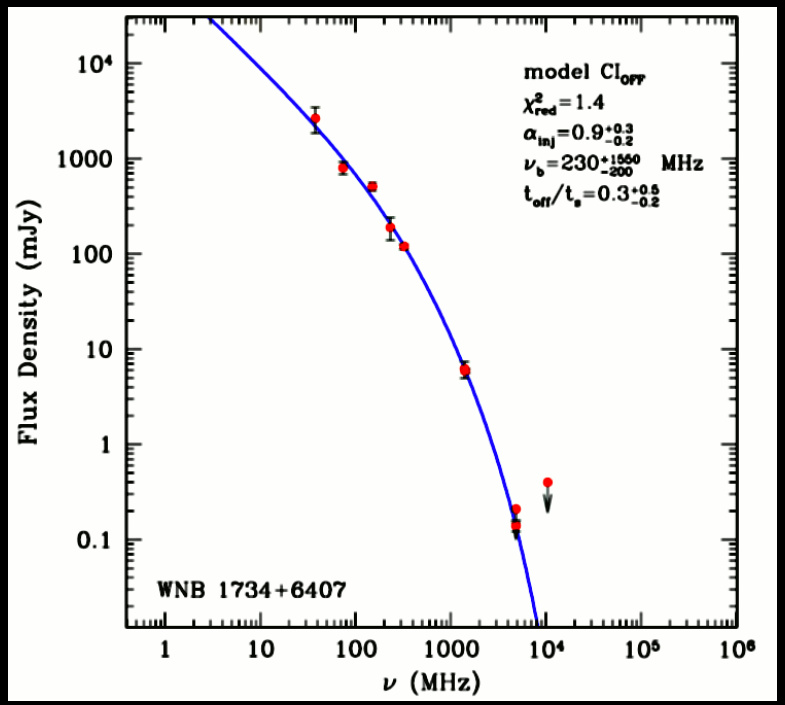
In search of dying radio sources in the local Universe

Dying radio galaxies are more easily detected at low radio frequencies, therefore low frequency ~300 MHz surveys, are particularly well-suited to search for these elusive objects
(e.g. Parma et al. 2007, Giacintucci et al. 2007, Murgia et al. 2011)



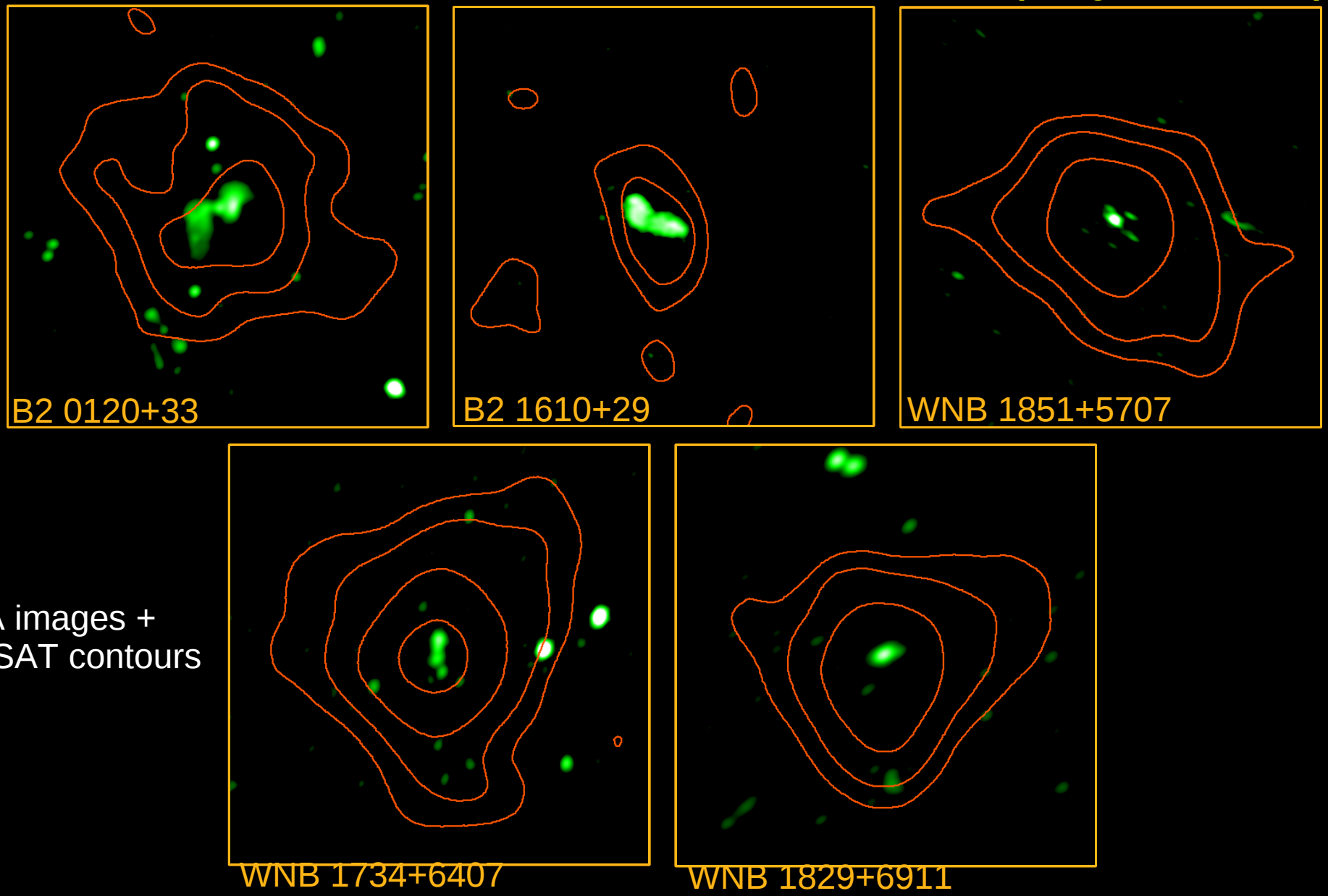


CHANDRA ACIS-I 0.5-7 keV image of the dying radio source WNB 1734+6407 at the center of Abell 2276 (Murgia et al. submitted)

The X-ray environment of dying sources

Tendency for dying sources to reside in dense environments, at the center of an X-ray emitting cluster or group of galaxies.

(Murgia et al. 2011)

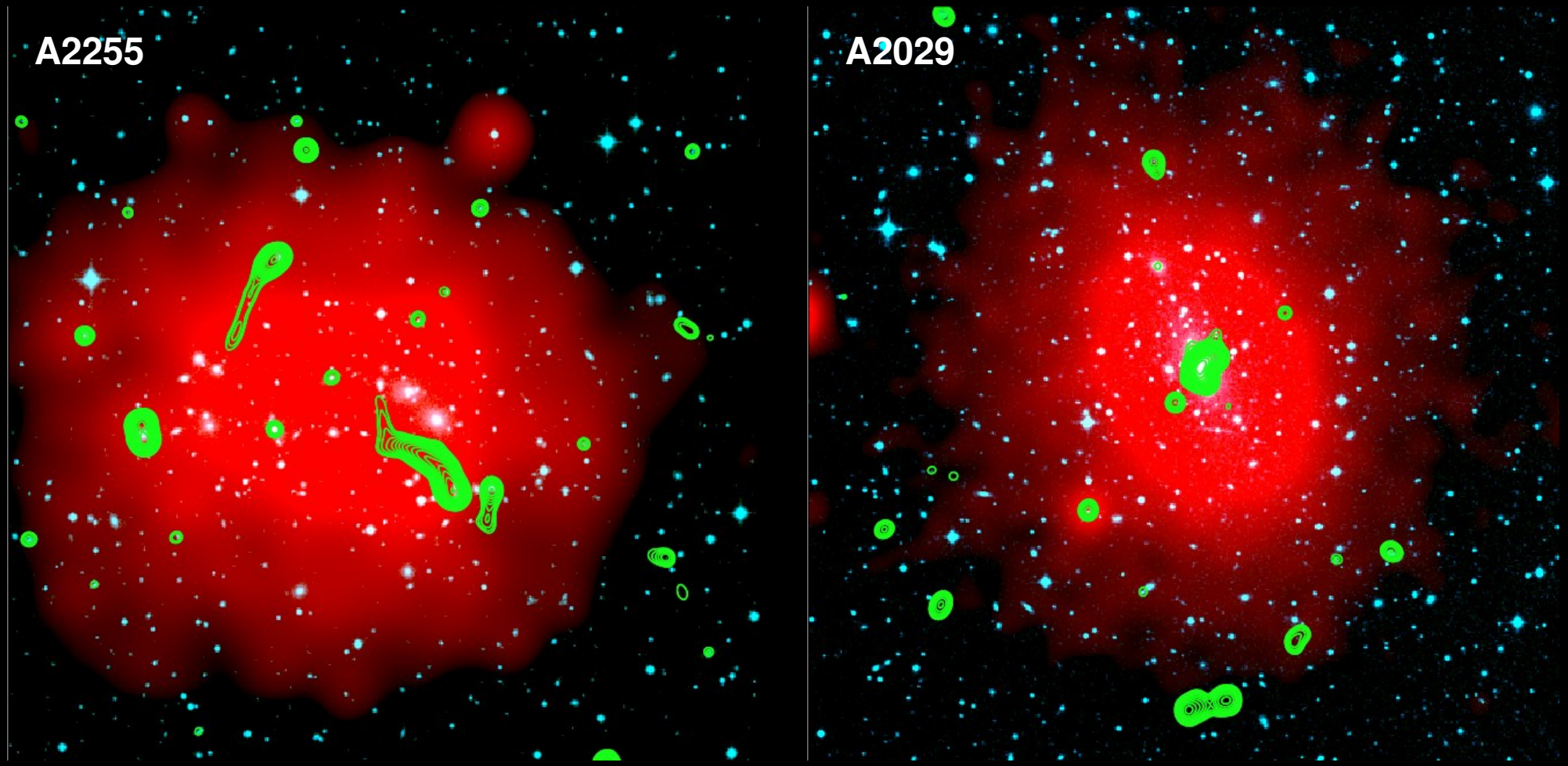


VLA images +
ROSAT contours

Galaxy Clusters

MERGING CLUSTER

RELAXED CLUSTER

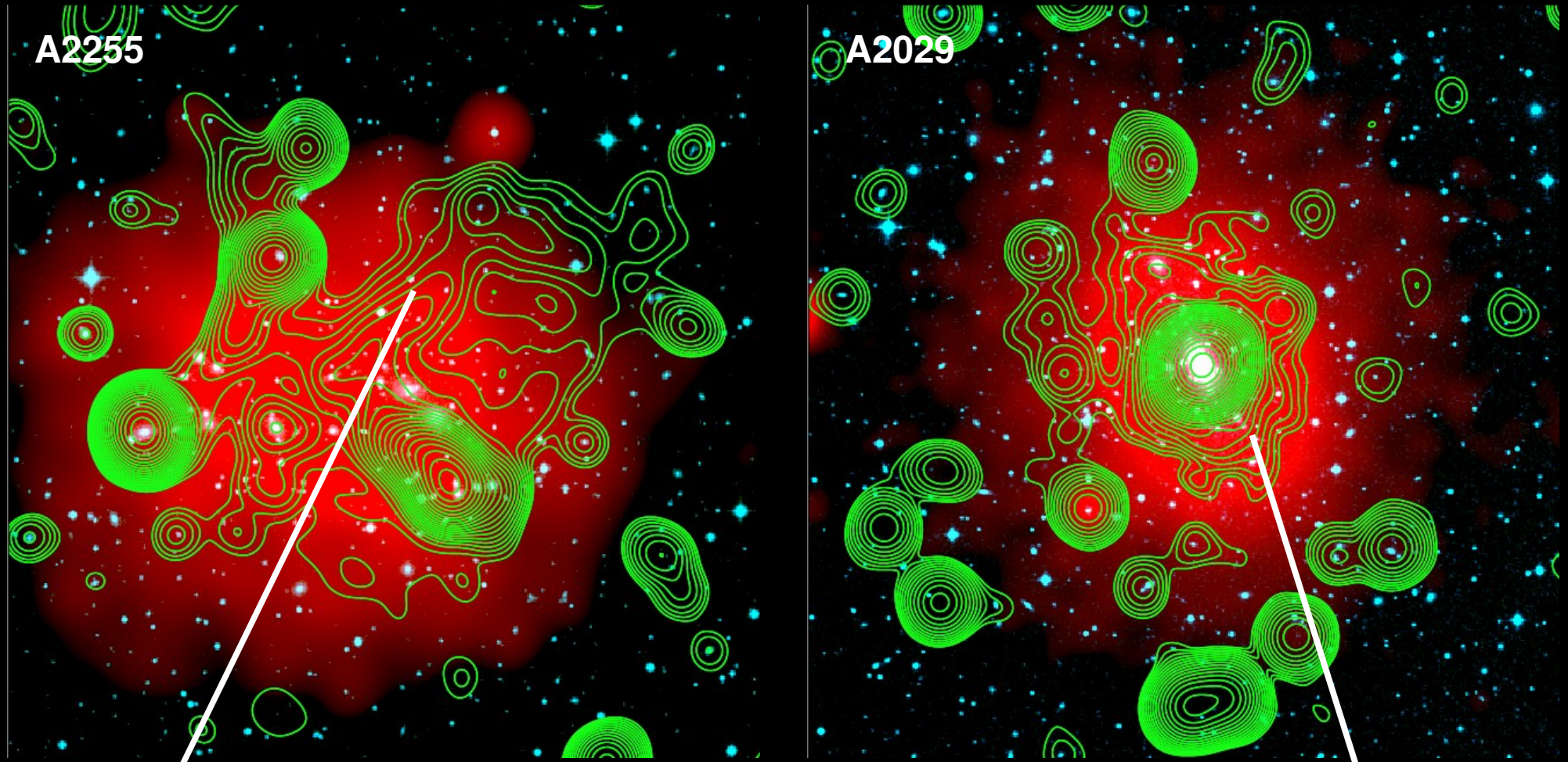


Optical - X-ray - Radio

Diffuse radio sources in Clusters

MERGING CLUSTER

RELAXED CLUSTER



Optical - X-ray - Radio

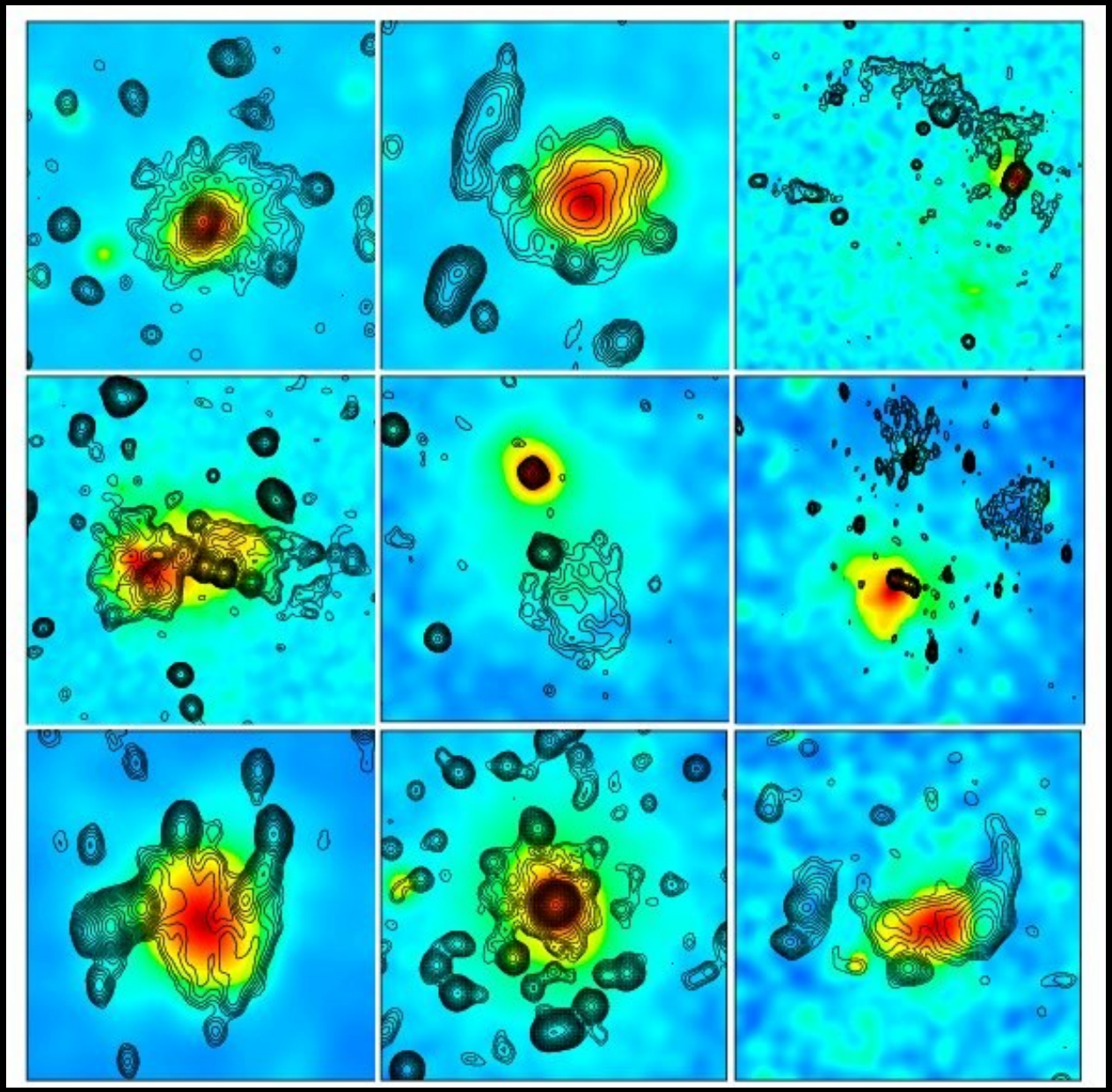
Halos

Mini-Halos

Low surface brightness synchrotron sources not connected to the galaxies but diffuse in the intra-cluster medium.

Diffuse radio sources in Clusters

Direct evidence of the presence of μG cluster magnetic fields.



(Feretti et al. 2012)

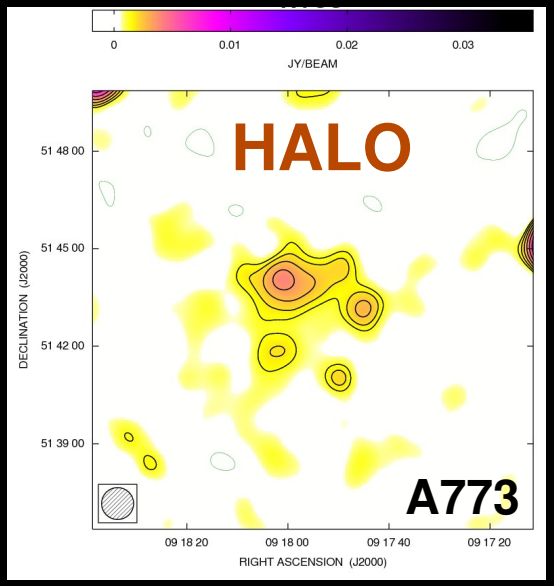
~40 HALOS
~50 RELICS
~10 MINI-HALOS

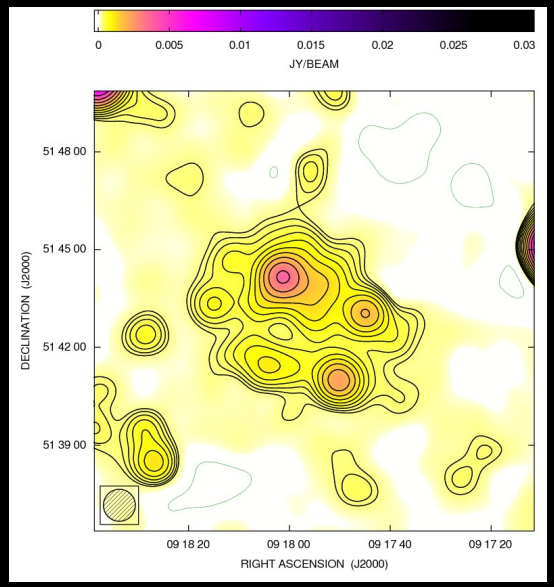
Diffuse radio sources in Clusters

Search of diffuse radio sources in all-sky surveys with VLA and WSRT

(Giovannini et al. 1999, Kempner & Sarazin 2001, Rudnick & Lemmerman 2009)

NVSS

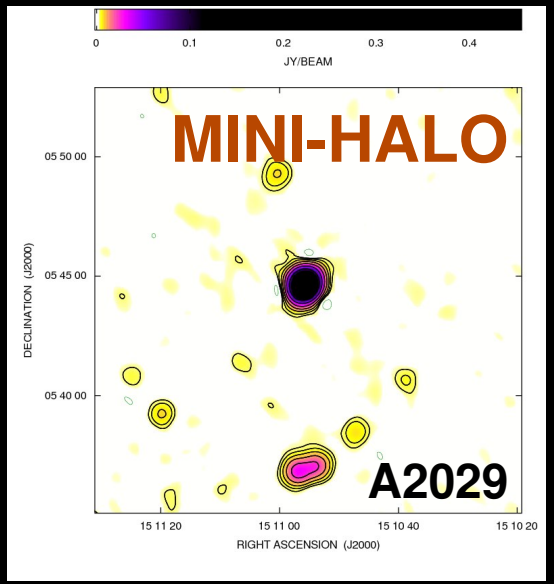


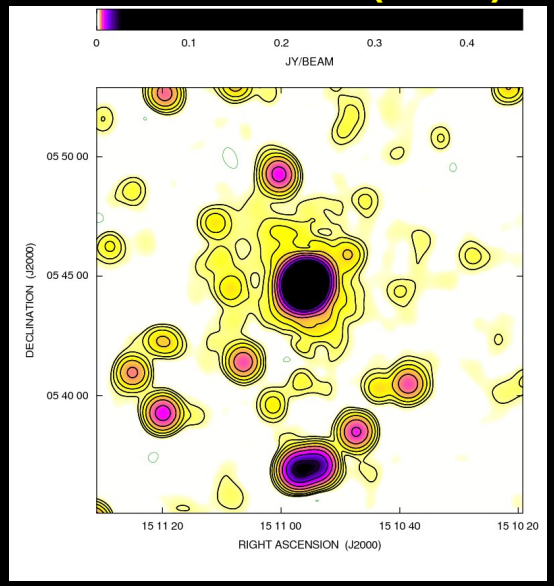


VLA Obs.

Govoni et al. (2001)

NVSS





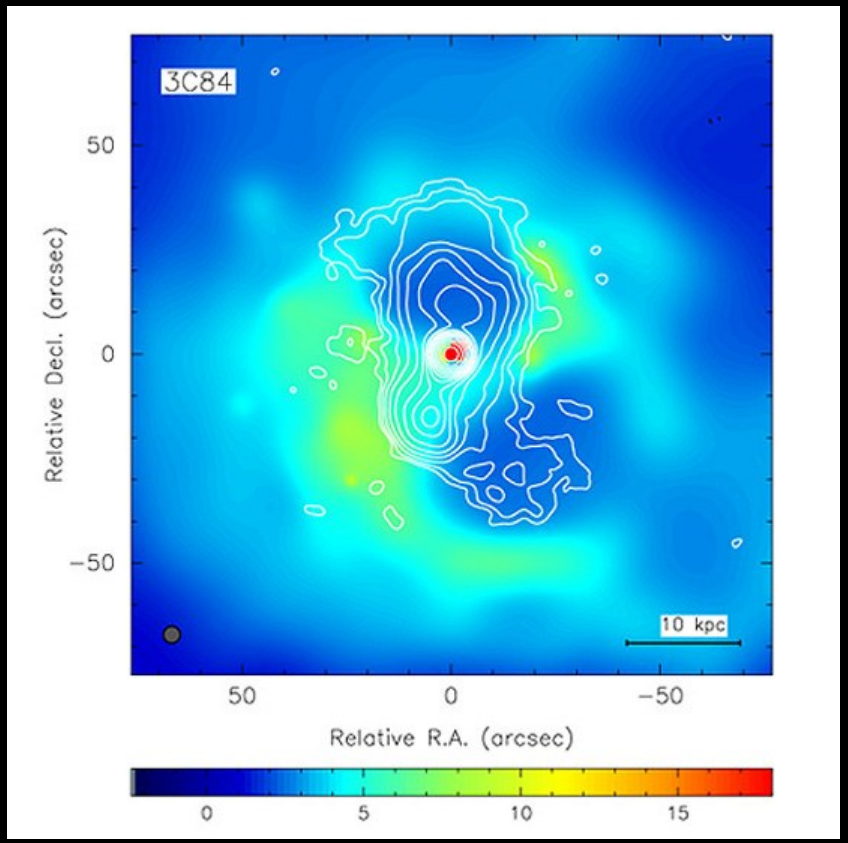
VLA Obs.

Govoni et al. (2009)

Diffuse radio sources in Clusters

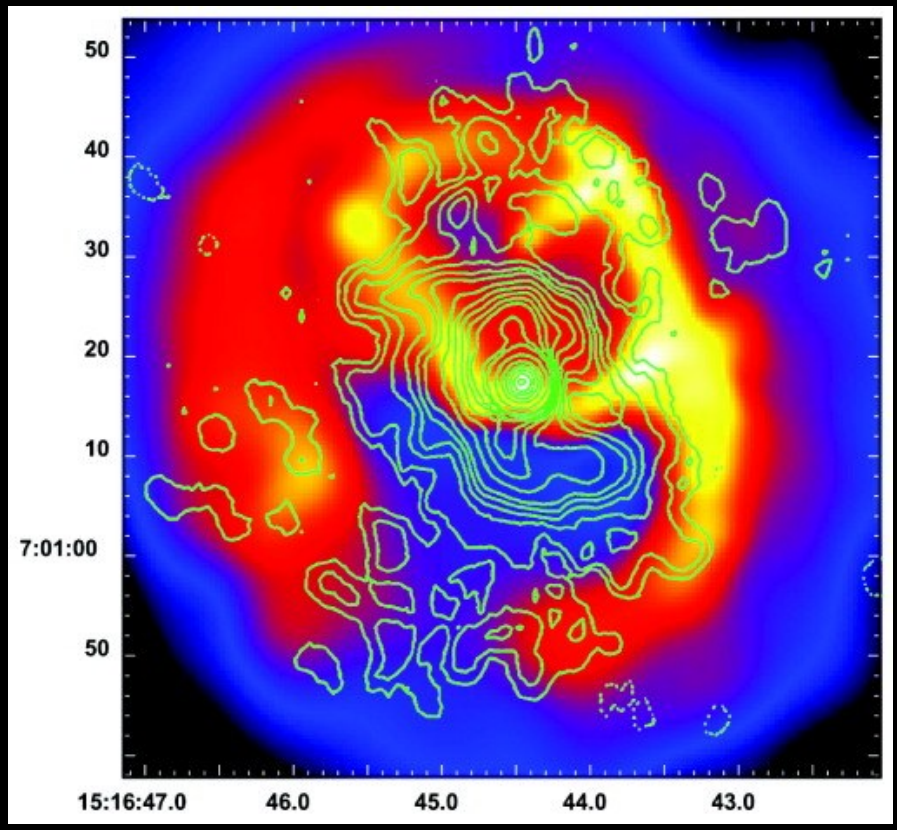
Mini-halos are not those steep radio sources in which the ambient thermal gas is clearly separated by the non-thermal plasma, as in the case of AGN radio lobes whose expansion has created cavities or holes in the intra-cluster X-ray emission.

3C84 in Perseus cluster



Fabian et al. (2000)

3C317 in A2052 cluster

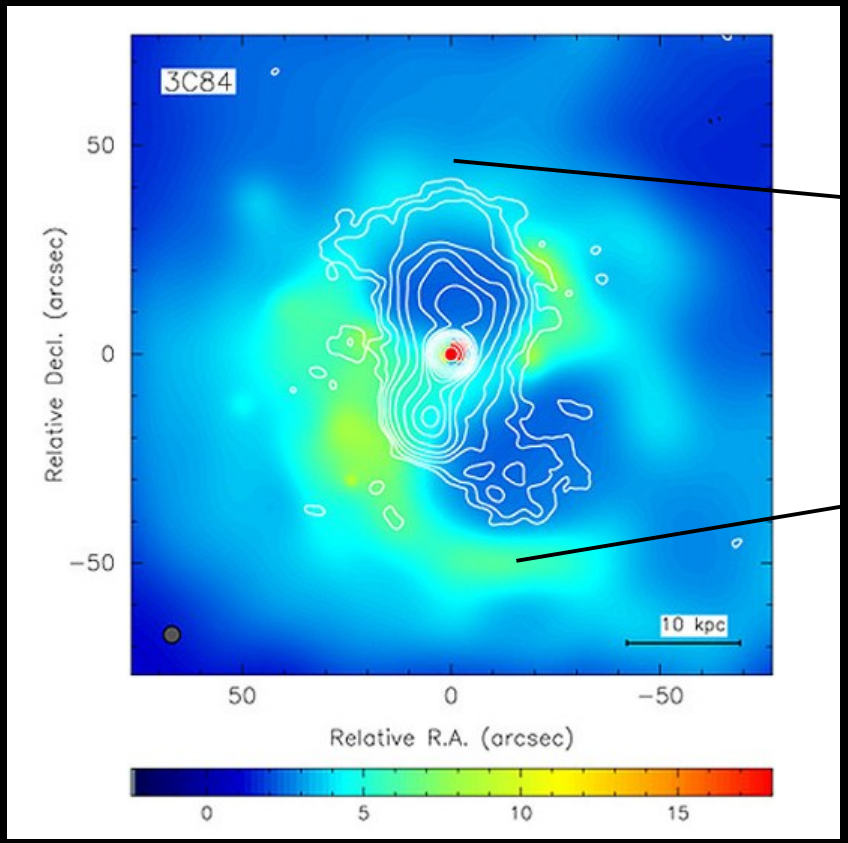


Blanton et al. (2002)

Diffuse radio sources in Clusters

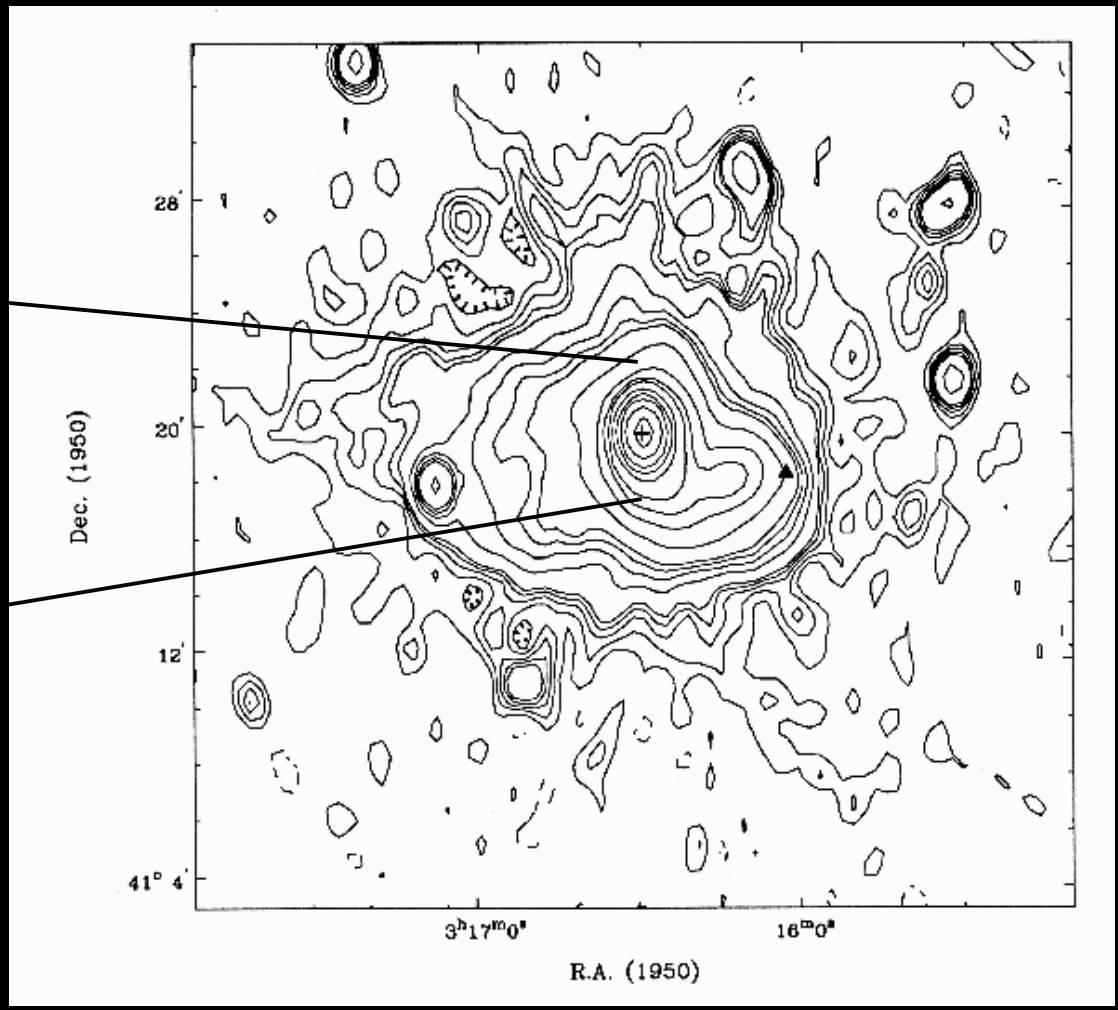
The radio source 3C84 at the center of Perseus shows X-ray cavities in the inner region, but on larger scale the cluster exhibits a diffuse radio emission mixed with the thermal intra-cluster gas.

3C84 in Perseus cluster



Fabian et al. (2000)

Burns et al. (1992), Sijbring (1993)



PROTOTYPE EXAMPLE OF MINI-HALO

Galaxy Clusters

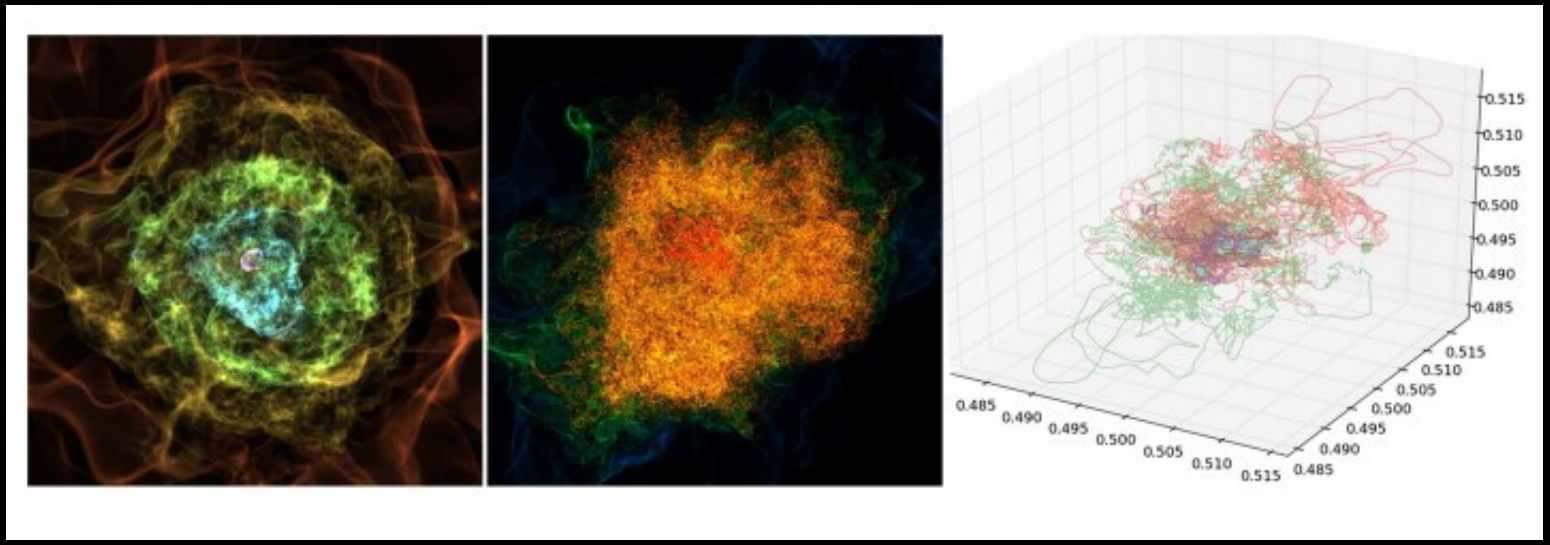
Although the existence of cluster-wide magnetic fields is well accepted, their origin is still unclear. MHD cluster formation simulations have been performed with different initial magnetic fields, including:

- Random or uniform fields from high redshift (Dolaget al. 2002, Dubois & Teyssier 2009)

- Outflows of normal galaxies (Donnert et al. 2009)

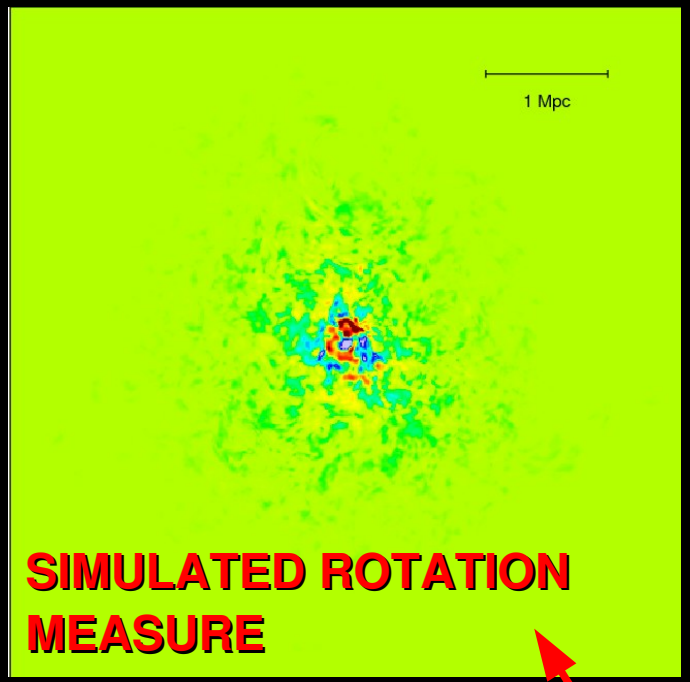
- AGN (Xu et al. 2010, Xu et al. 2011)

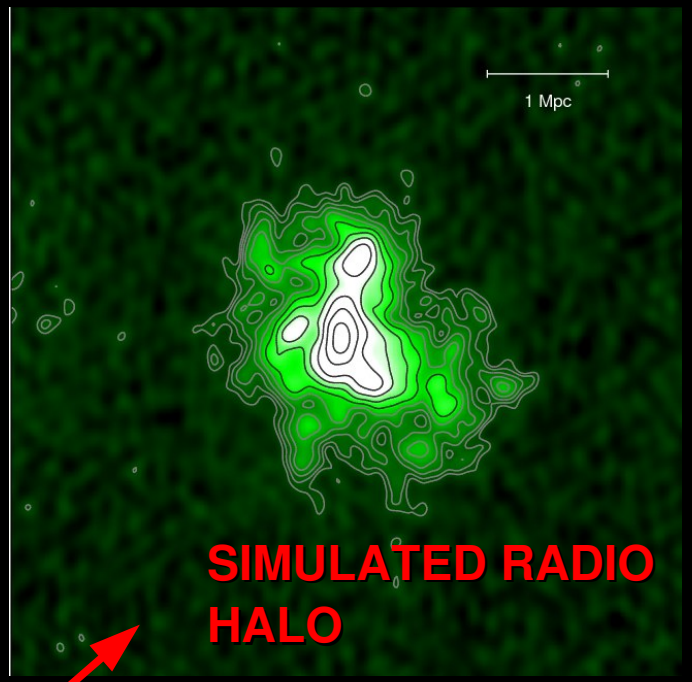
Large scale magnetized radio jets and lobes from AGNs serve as a very intriguing source of cluster magnetic fields, because they could carry large amounts of magnetic energy and fluxes and distribute them to large scales.

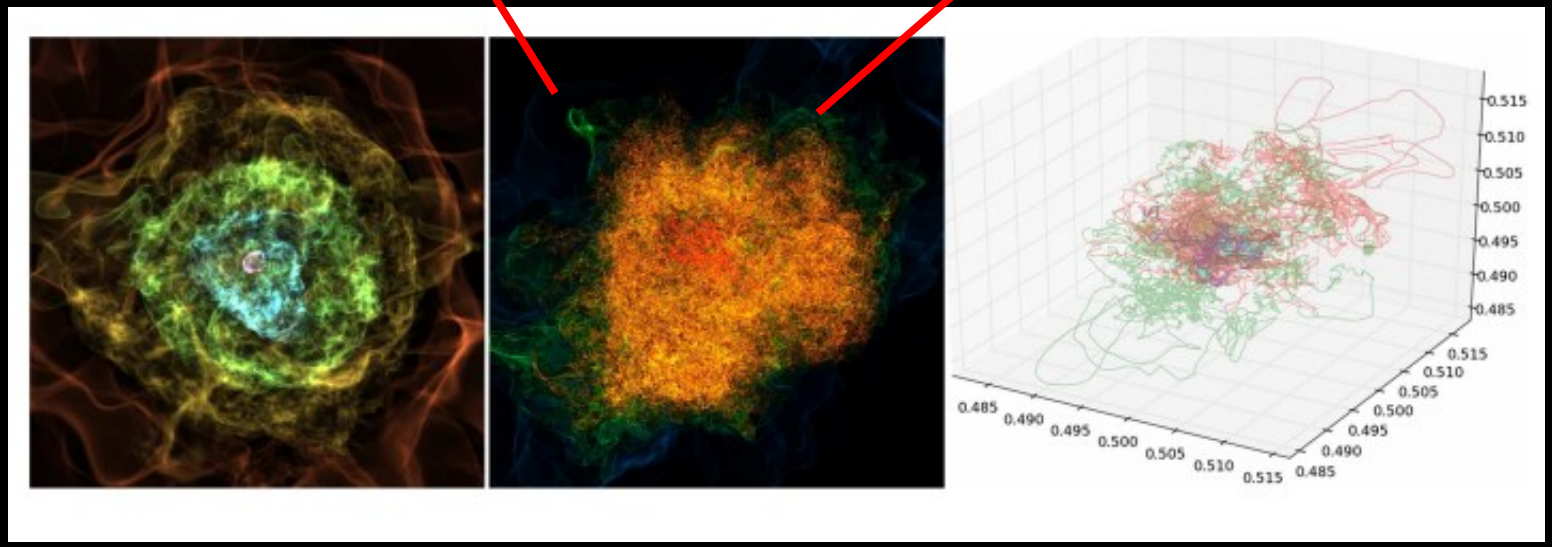


Xu et al. ApJ in press

Galaxy Clusters





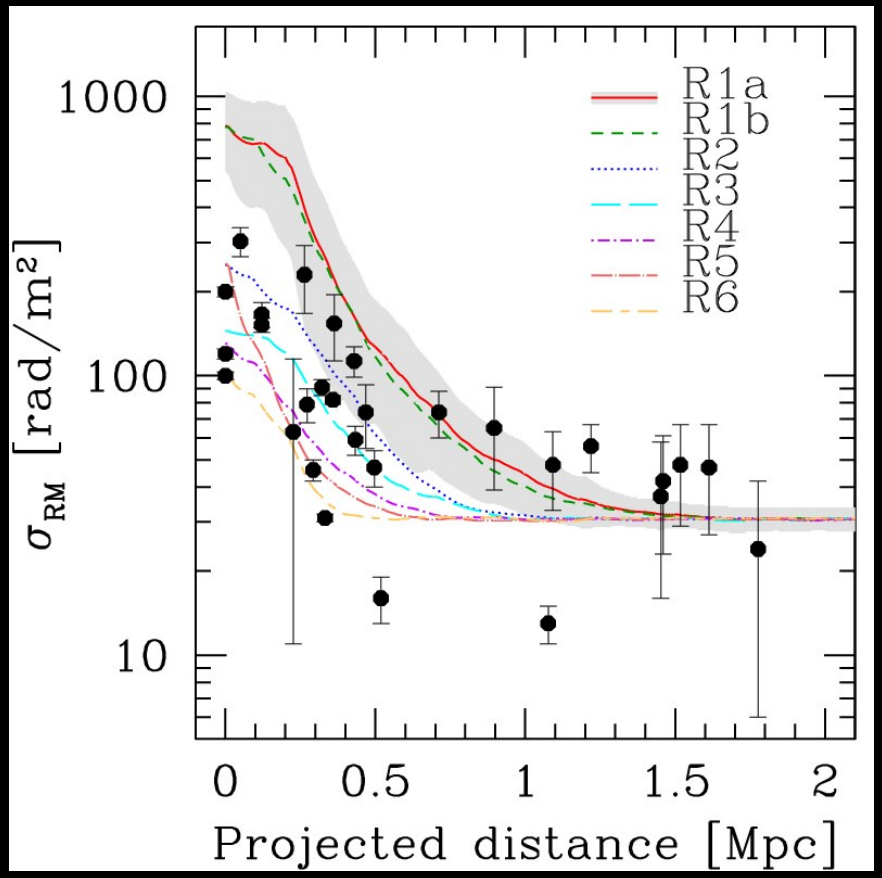


Xu et al. ApJ in press

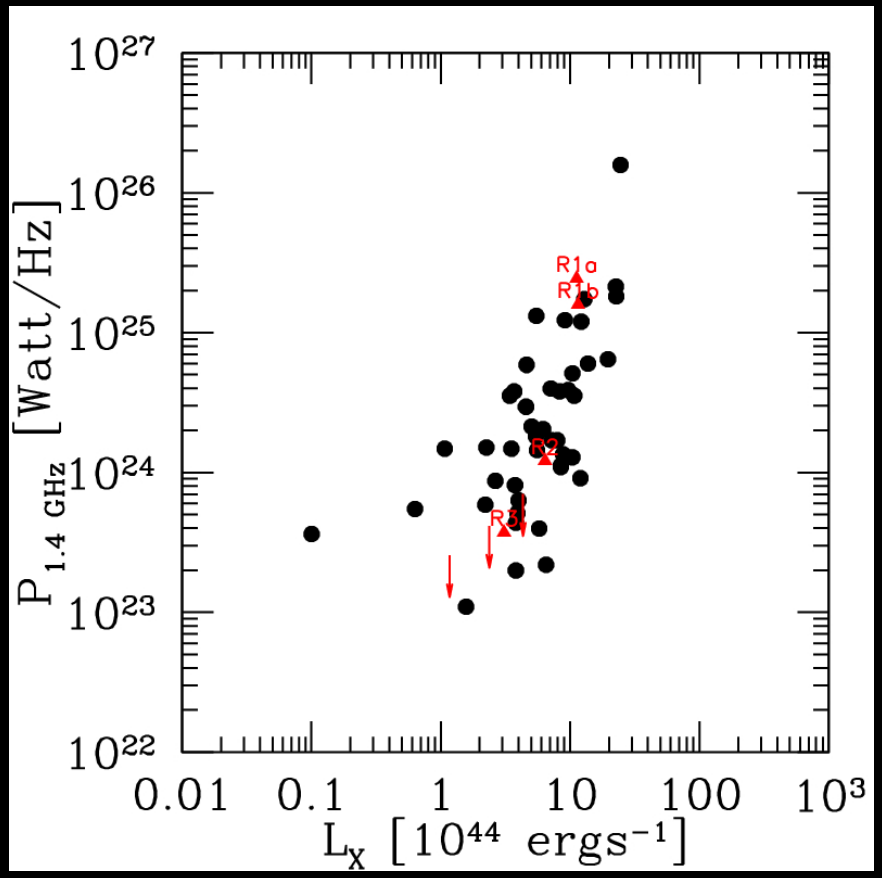
Galaxy Clusters

SIMULATIONS – DATA COMPARISON

ROTATION MEASURE



Lx-Lradio relation in HALOS



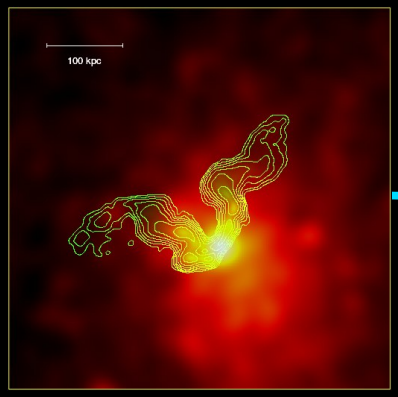
Xu et al. ApJ in press

Conclusions

RADIO EMISSION IN GALAXY CLUSTERS TAKES A VARIETY OF FORMS

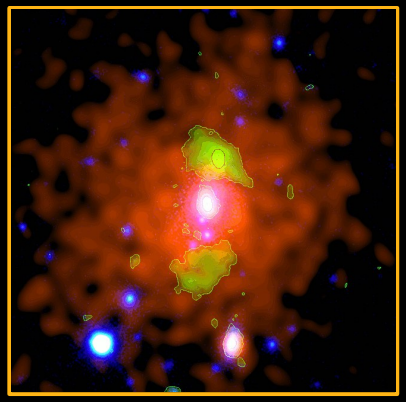
1) Radio emission associated with individual galaxies

- Head tail radio galaxies



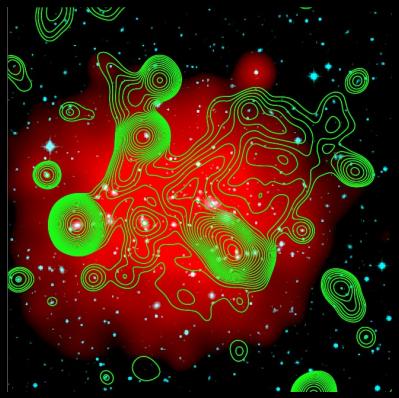
USED TO INVESTIGATE THE CLUSTER MAGNETIC FIELDS

- Dying radio galaxies



2) Diffuse radio sources in galaxy clusters

DEMOSTRATE THE EXISTENCE OF MAGNETIC FIELDS AND RELATIVISTIC ELECTRONS OVER LARGE SCALES



- Halos

- Mini-halos