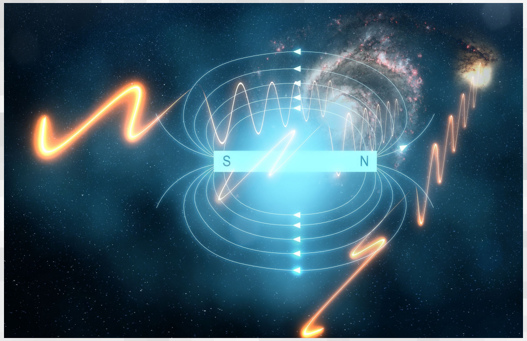
Magnetism and Continuum Surveys Working Together



Federica Govoni

INAF ORA-Cagliari (Italy)

Collaborators:

M. Murgia, A. Bonafede, L. Feretti, C. Ferrari
G. Giovannini, F. Loi, M. Trasatti, V. Vacca

20 - 23 October 2015 Bologna (Italy)
The many facets of extragalactic radio surveys towards new scientific challenges

Magnetism and Continuum Surveys Working Together

Extragalactic magnetic fields:

- Spiral Galaxies (see talks by G. Heald, A. Williams, F. Tabatabaei)
- AGNs (see talks by I. Agudo, R. Laing)
- Galaxy clusters
- Cosmic Web Filaments (see talk by F. Vazza)

Continuum and polarization capability of future surveys will permit to improve our knowledge of the incidence, strength, and morphology of magnetic fields

FARADAY ROTATION

I-part of the talk:
Discrete sources

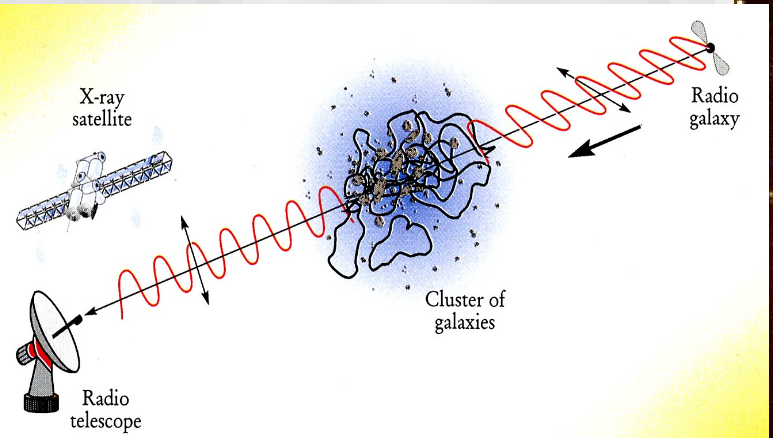
II-part of the talk:
Diffuse Synchrotron Emission

Faraday Rotation

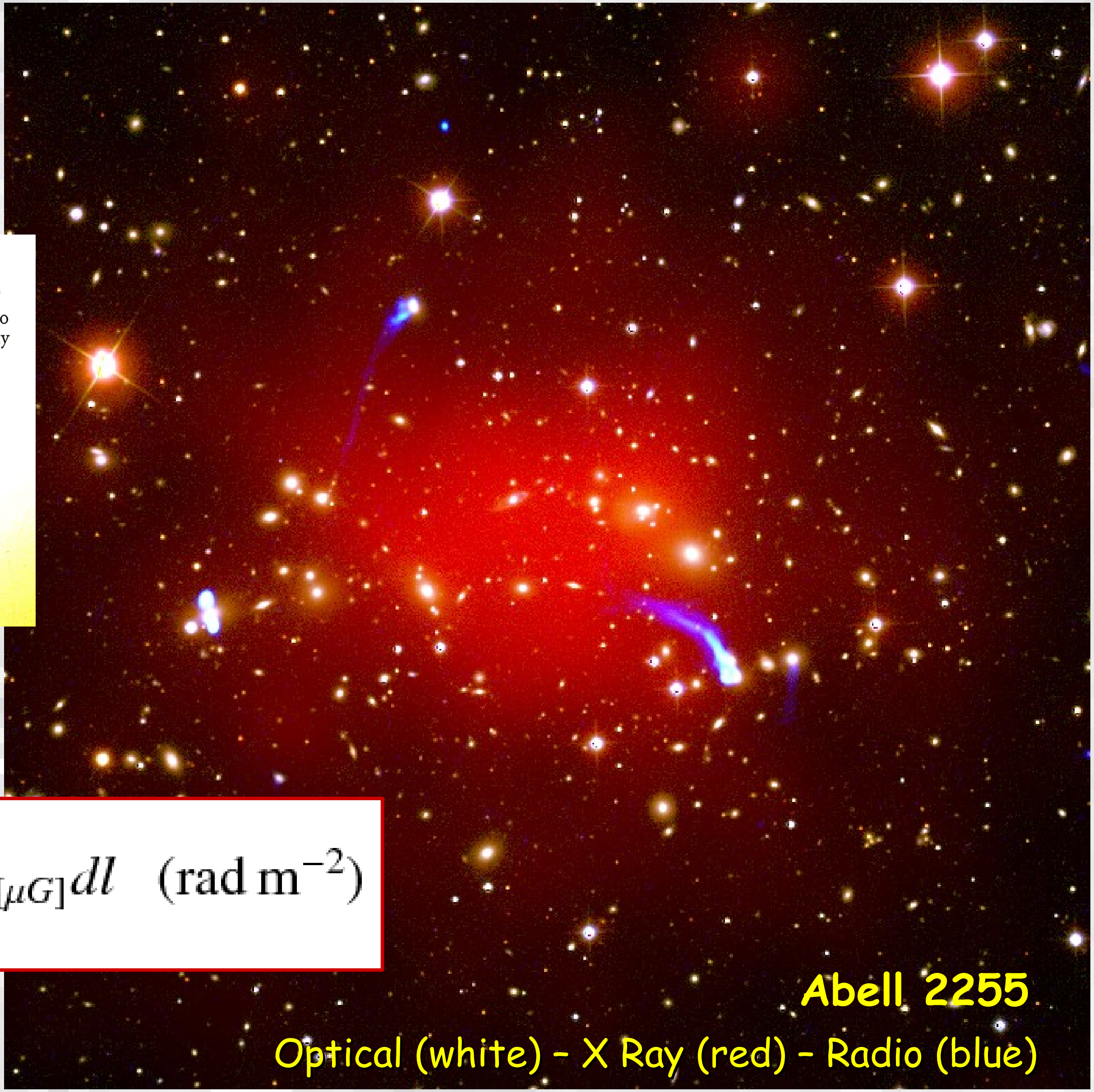
(I-part of the talk)

Rotation Measure of radio galaxies located within or in the background of a galaxy cluster

$$\Delta\chi = \chi_0 + RM \times \left(\frac{c}{\nu}\right)^2$$

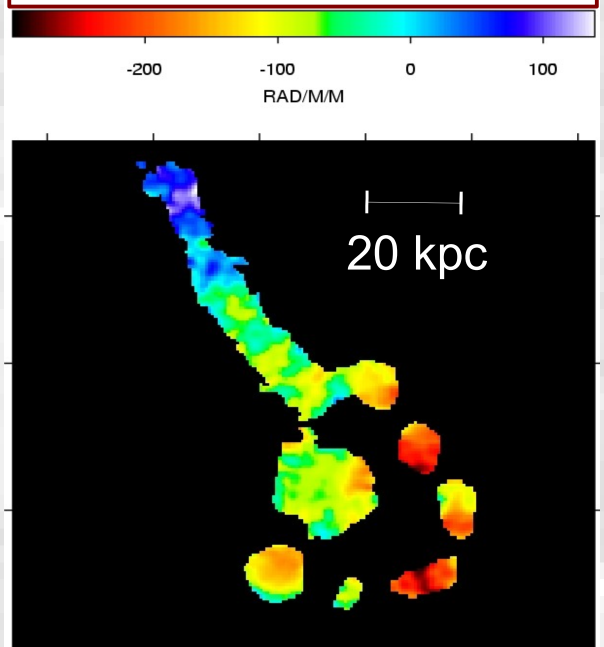


$$RM = 812 \int_0^{L_{[kpc]}} n_{e\,[cm^{-3}]} B_{\|\,[\mu G]} dl \quad (\mathrm{rad\,m^{-2}})$$



Faraday Rotation

$$\Delta\chi = \chi_0 + RM \times \left(\frac{c}{\nu}\right)^2$$



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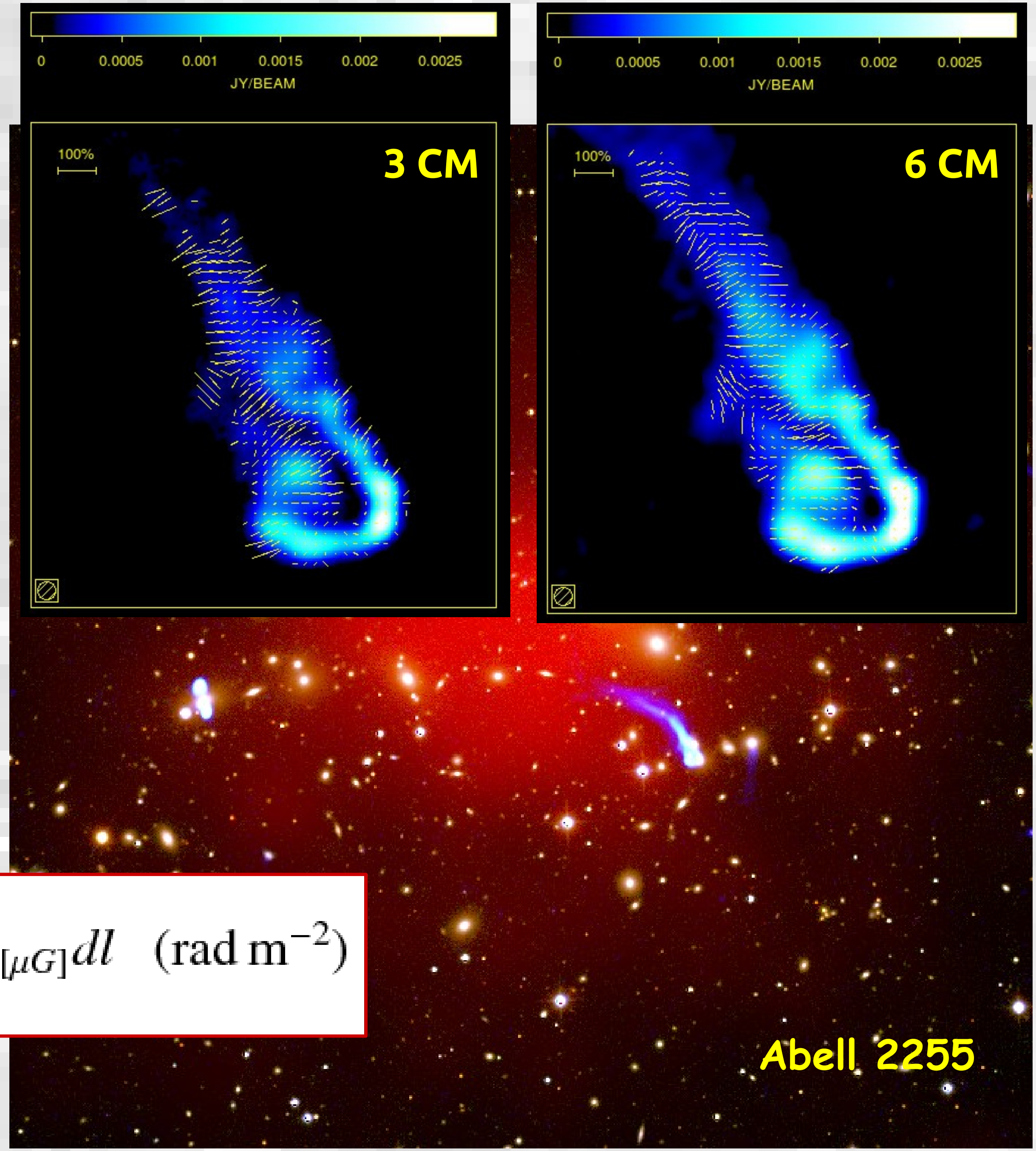
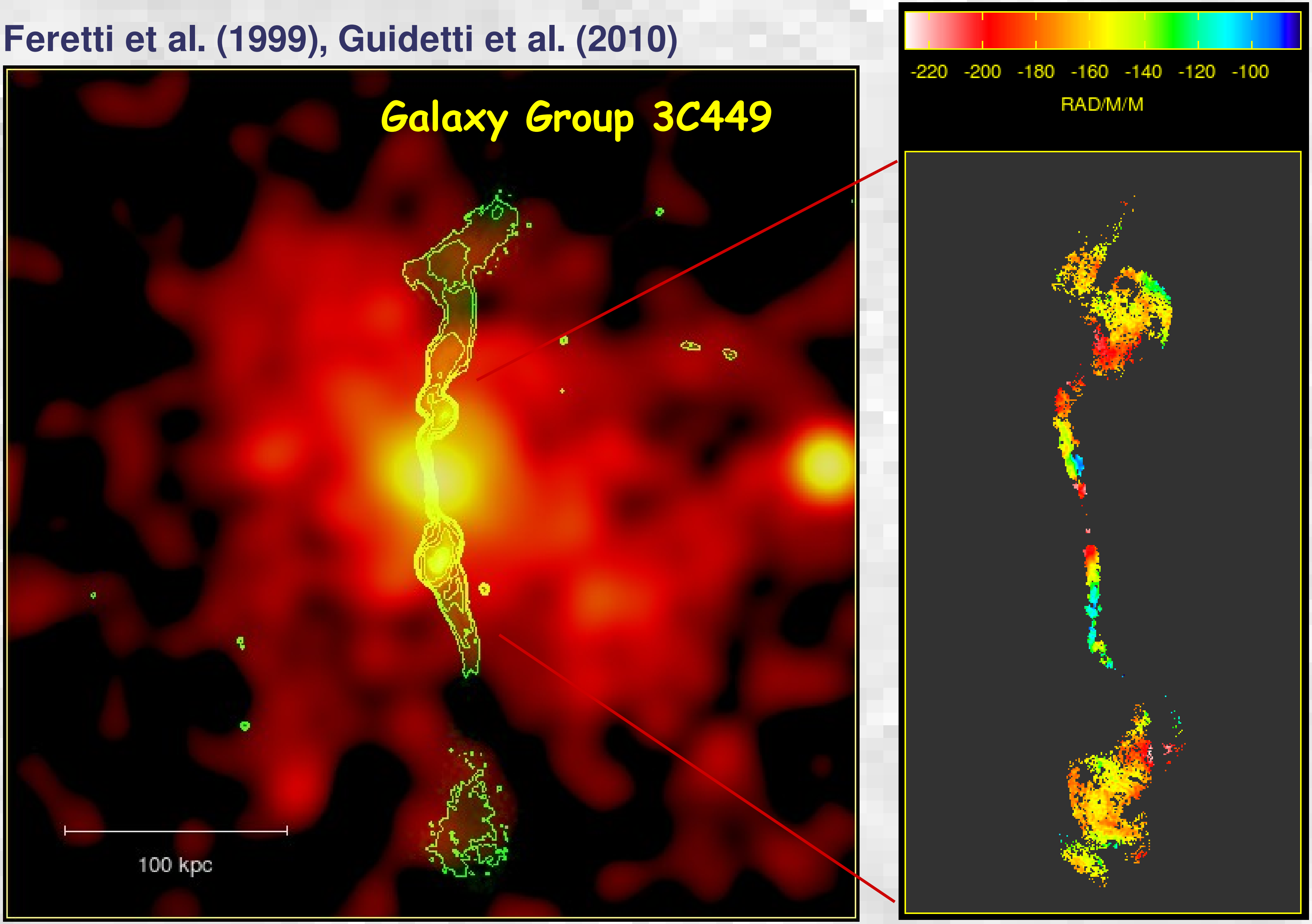


Faraday Rotation: Observations

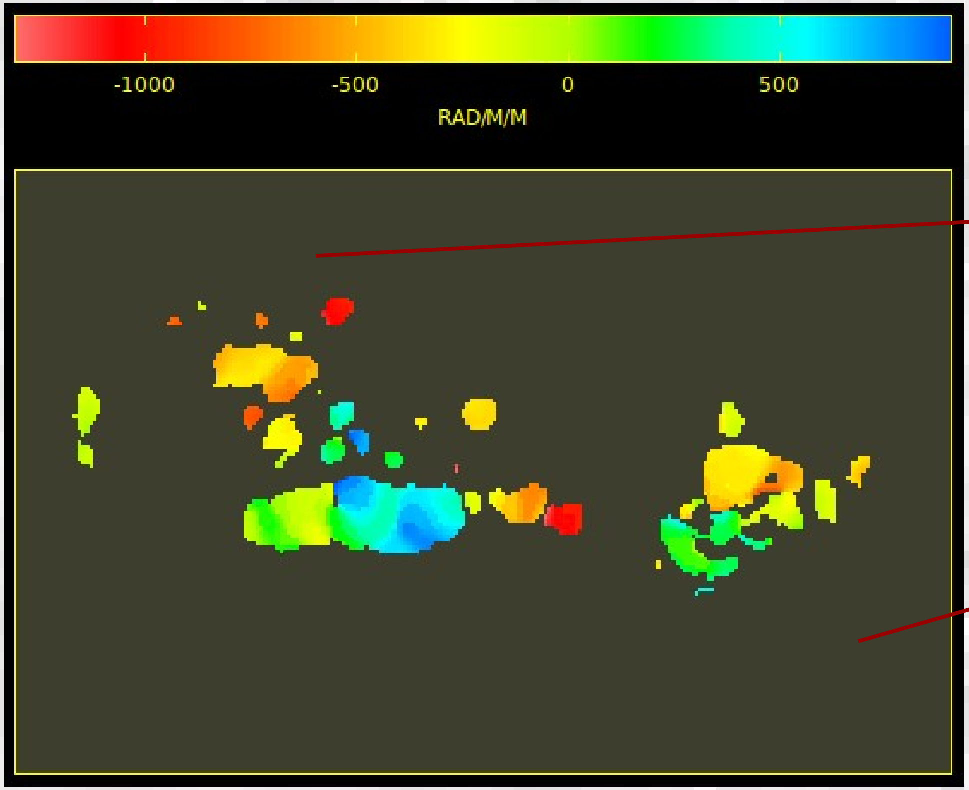
Feretti et al. (1999), Guidetti et al. (2010)

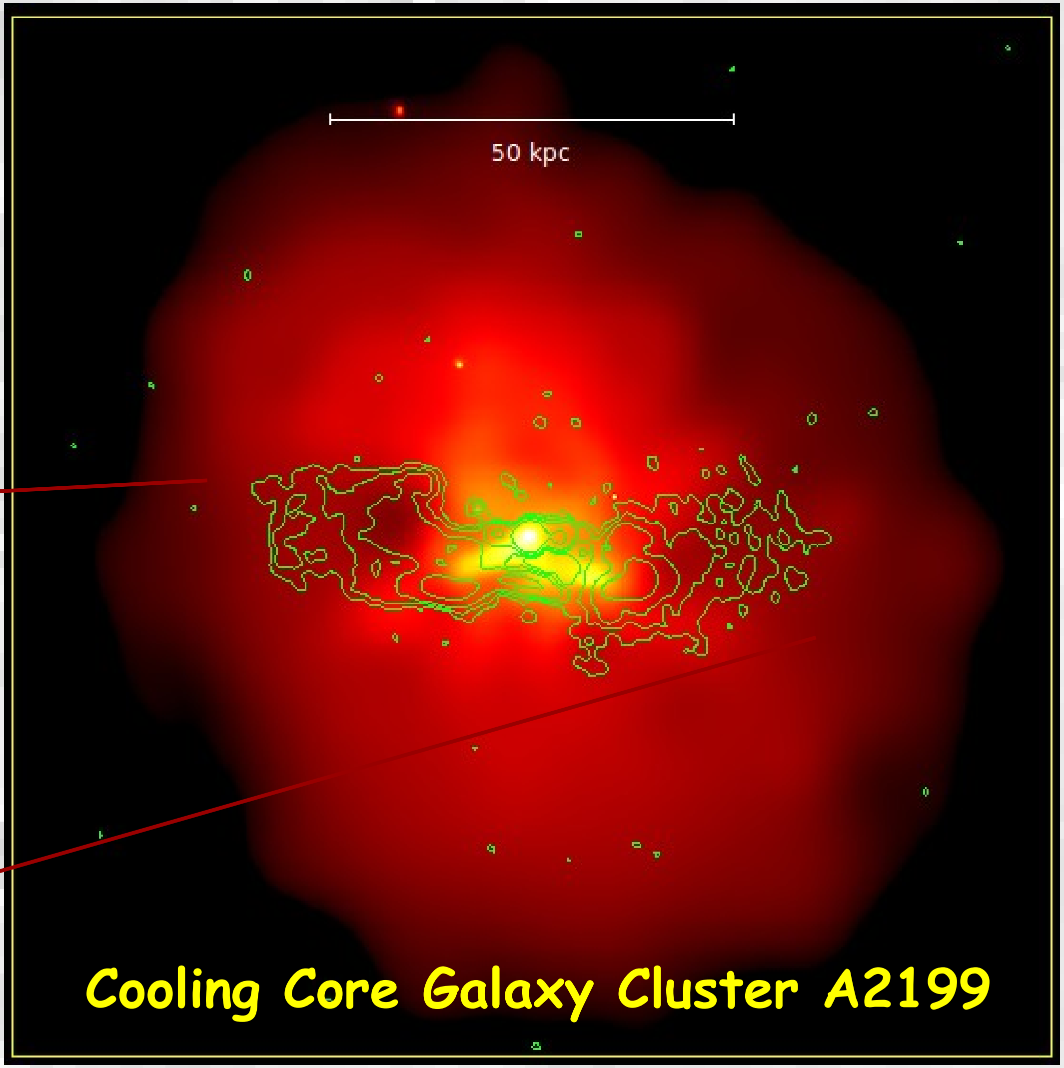


Magnetic field strength of B_0~3.5 μG which fluctuates over scales from 0.2 kpc to 65 kpc

Faraday Rotation: Observations

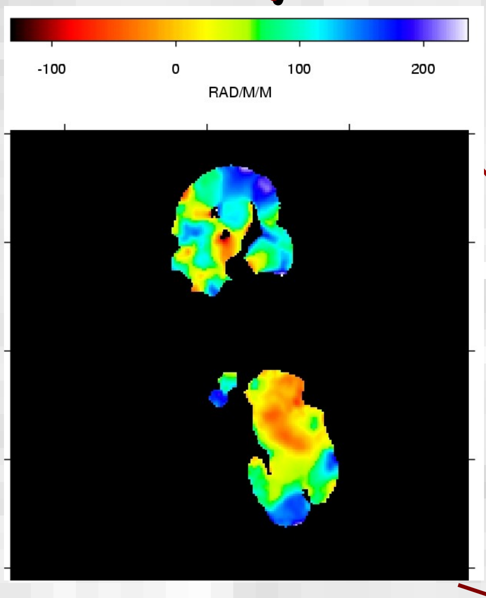
Ge & Owen (1994), Vacca et al. (2012)



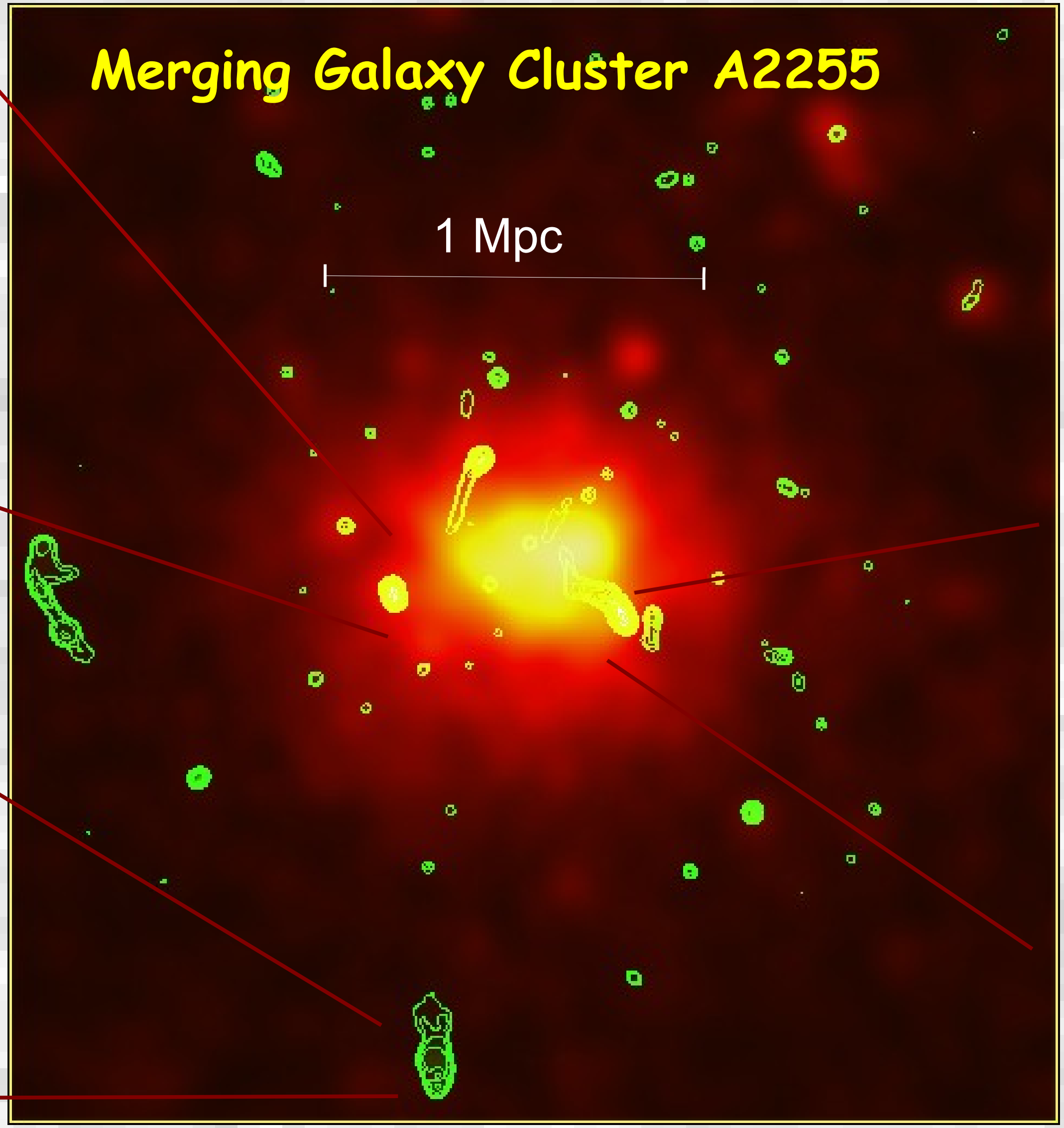


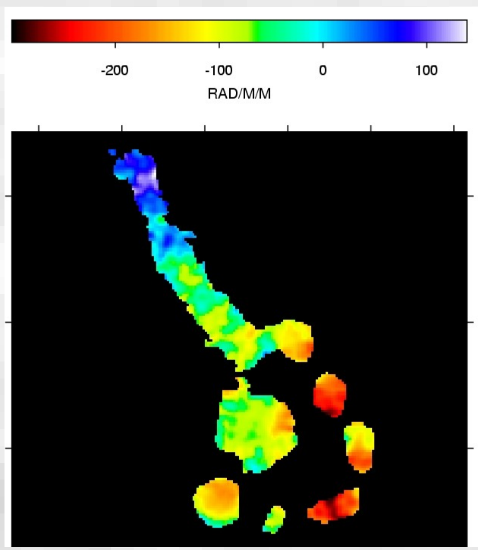
Magnetic field strength of $B_0 \sim 12$ μG which fluctuates over scales from 0.7 kpc to 35 kpc

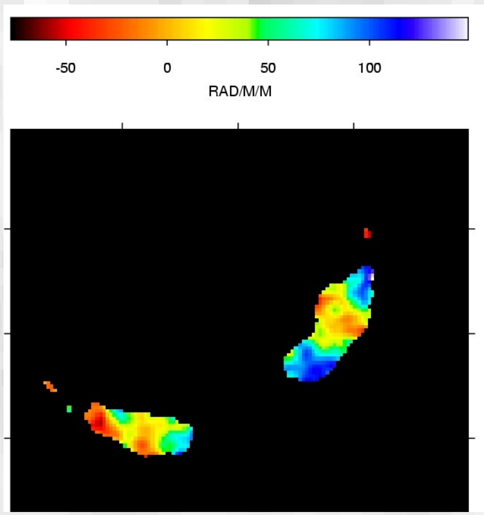
Faraday Rotation: Observations



Govoni et al. (2006), Pizzo et al. (2011)



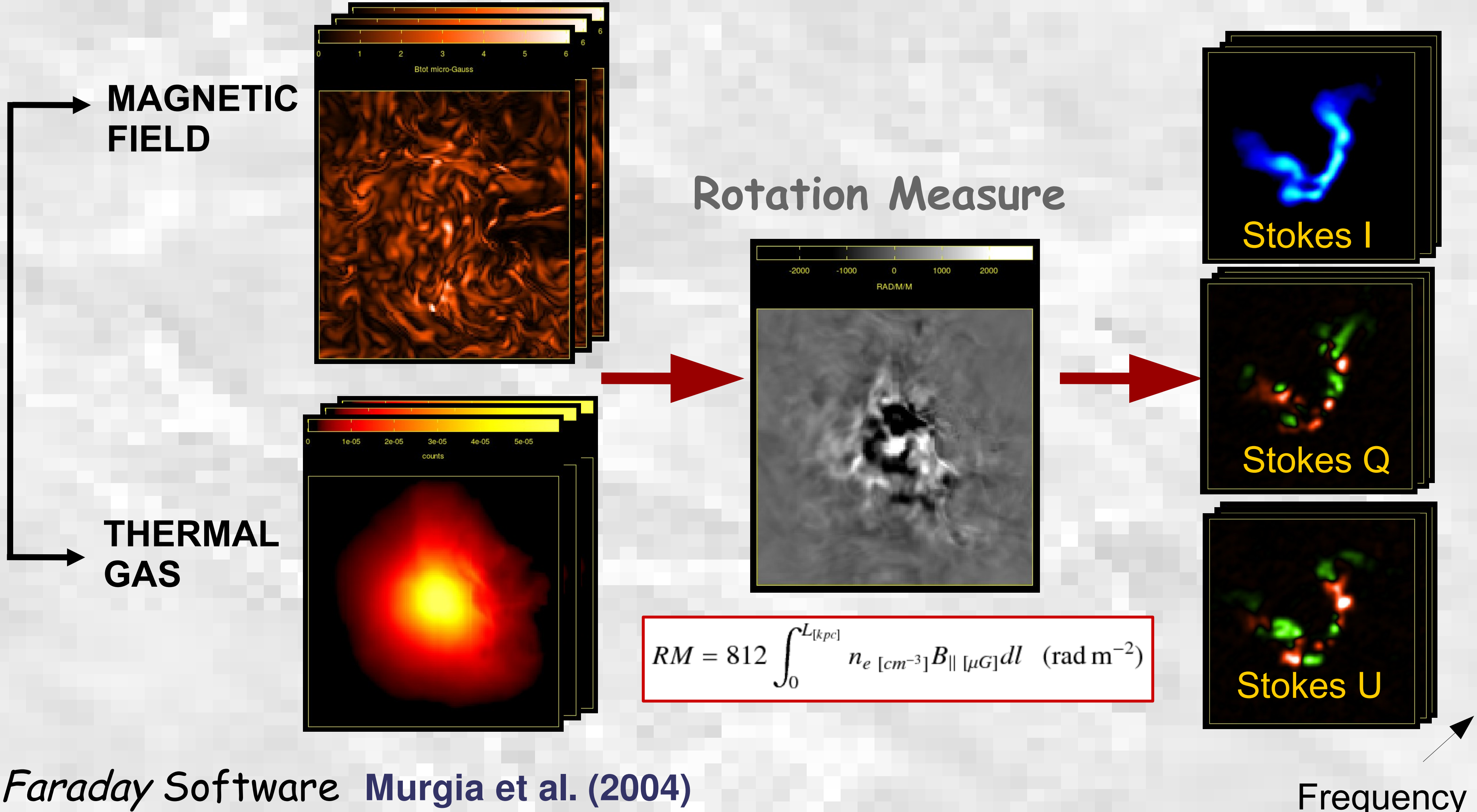




By sampling the Rotation Measure with radio galaxies located at different projected distance from the cluster center it is possible to investigate the behaviour of the fluctuations of the magnetic field on large scale

Faraday Rotation: Simulations

Dedicated software tools and Bayesian approaches have been proposed to interpret the Faraday Rotation effect and constraint the magnetic field parameters **Ensslin & Vogt (2003), Murgia et al. (2004), Laing et al. (2008), Kuchart & Ensslin (2011), Bonafede et al. (2013)**



$$RM = 812 \int_0^{L_{[kpc]}} n_{e\ [cm^{-3}]} B_{\|\ [\mu G]} dl \quad (\mathrm{rad\ m^{-2}})$$

Faraday Software **Murgia et al. (2004)**
Cosmological MHD simulations **Xu et al. (2012)**

Faraday Rotation: Simulations

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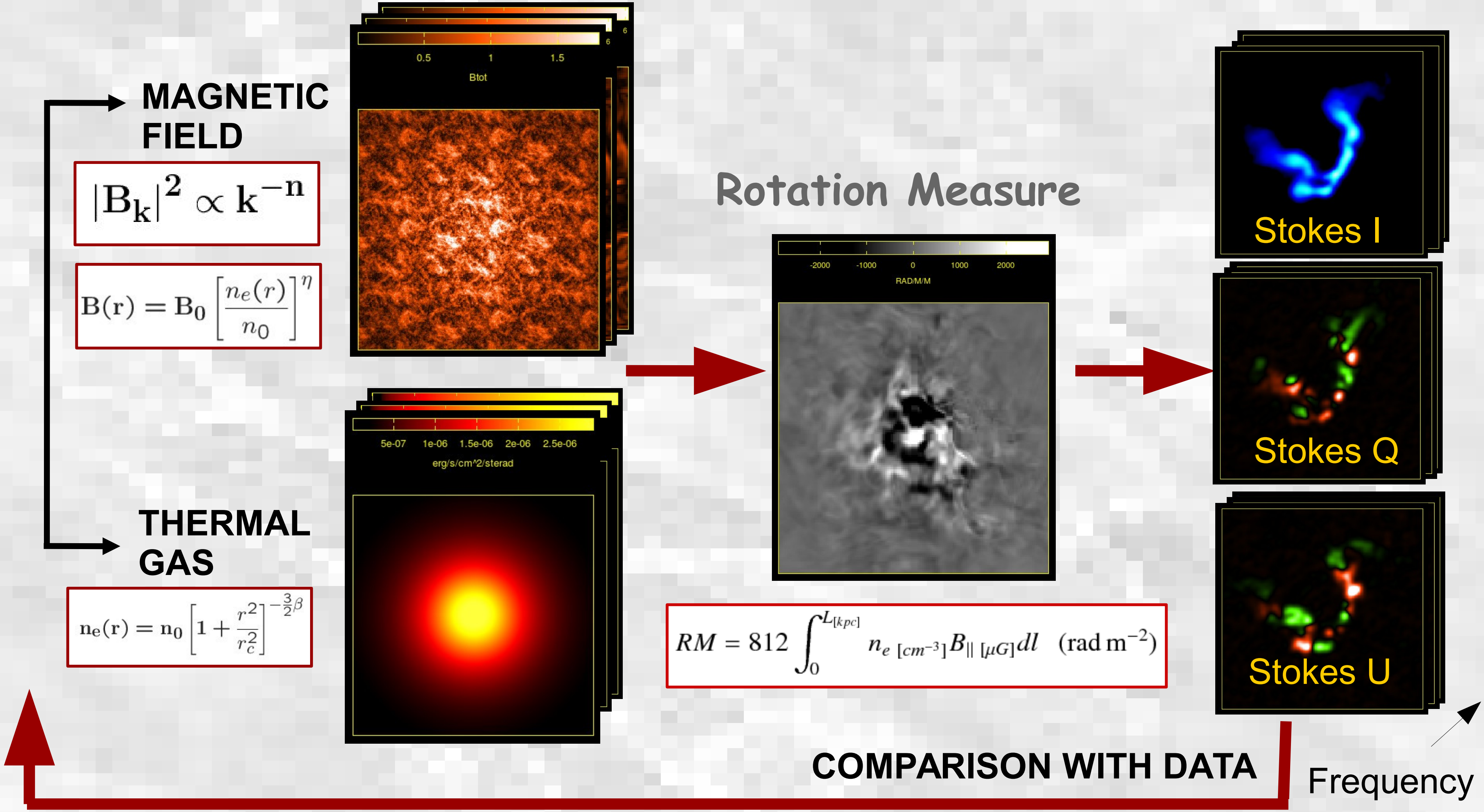
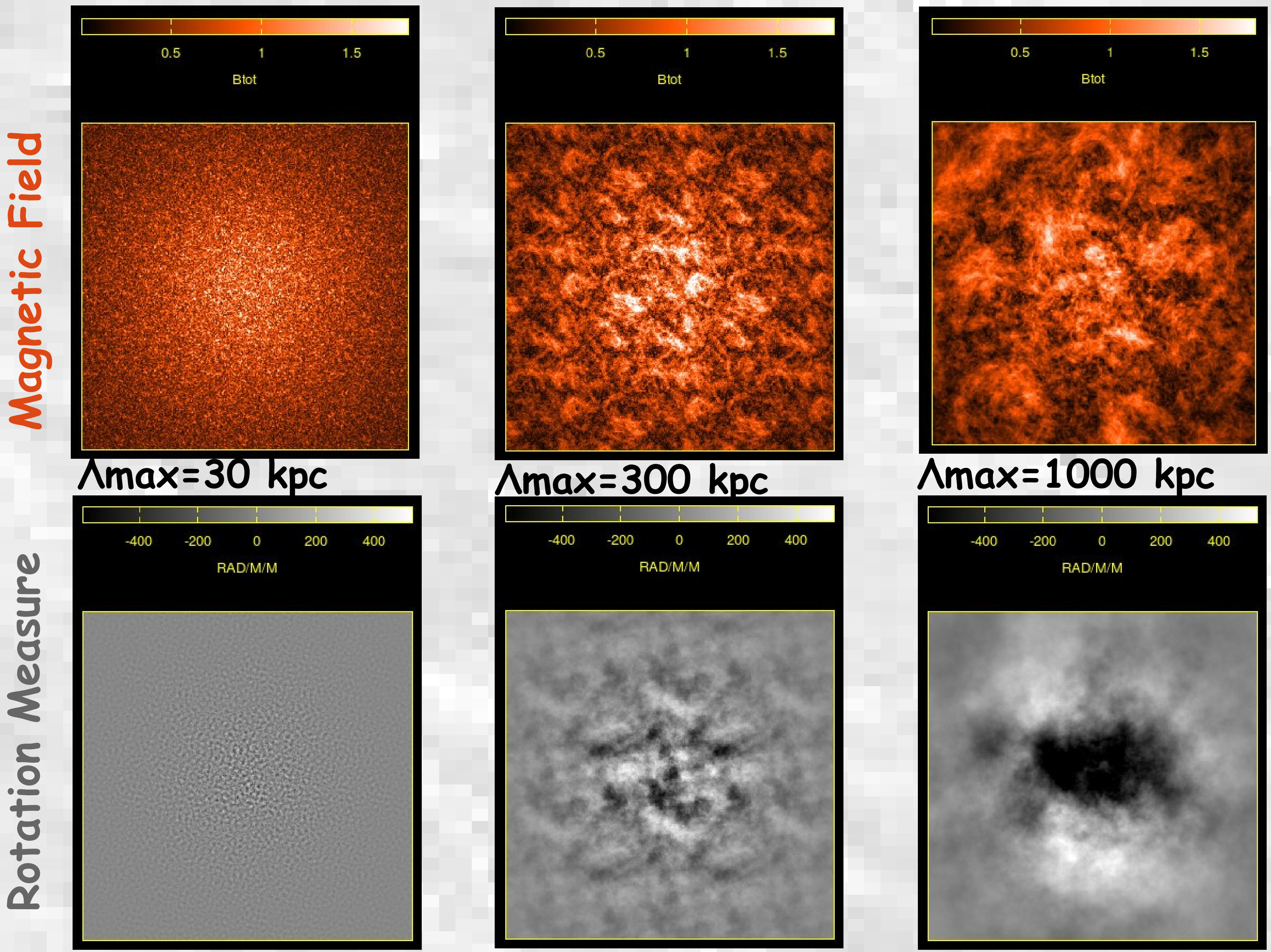


Faraday Rotation: Simulations

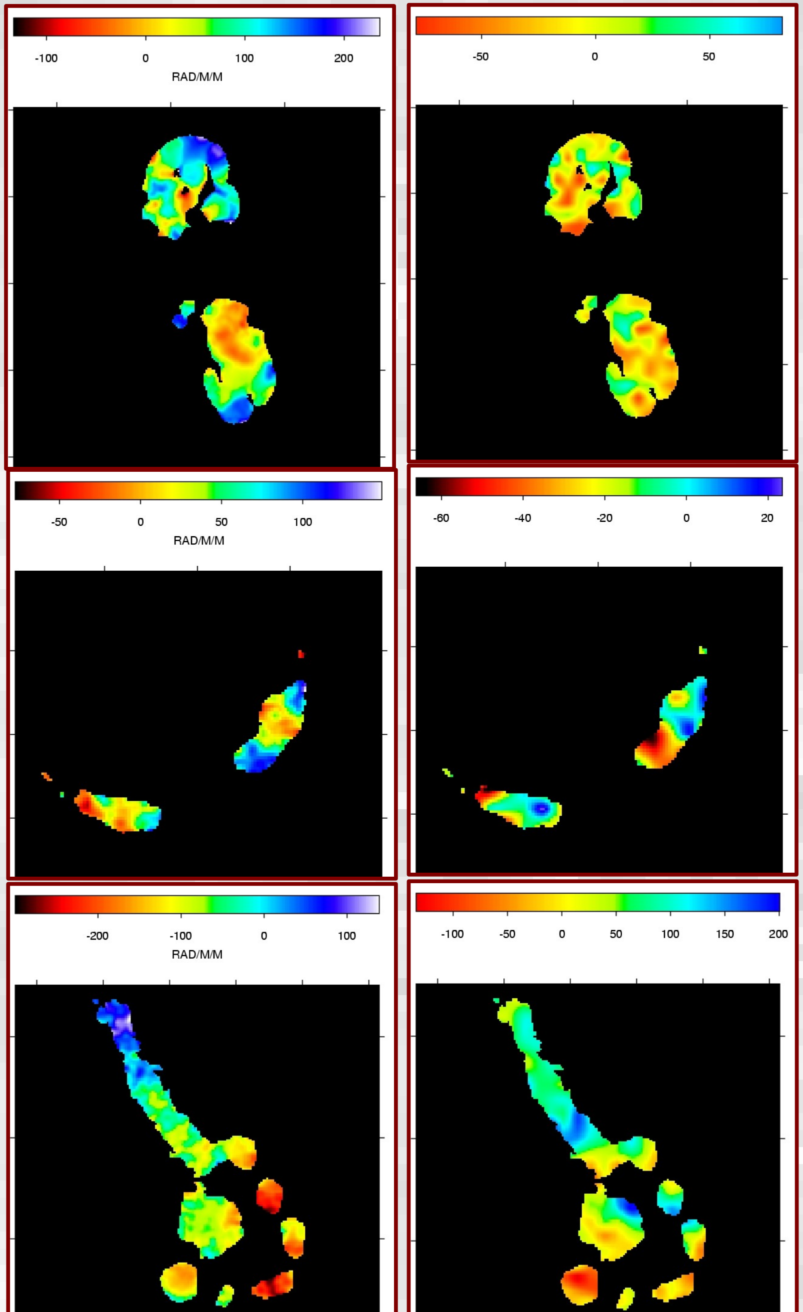
B0=1 μG
Kolmogorov n=11/3
Λmin=2 kpc



Faraday Software **Murgia et al. (2004)**

Faraday Rotation

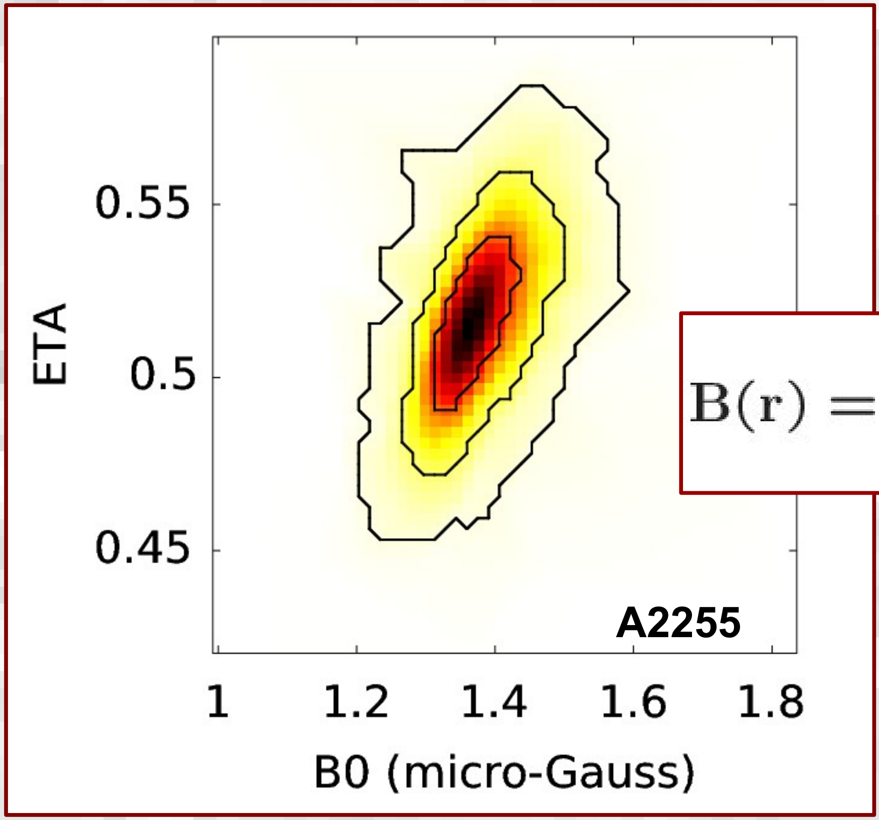
OBSERVED **SIMULATED**



B0 ~1-3 μG in merging galaxy clusters
B0 ~10 μG in cooling core galaxy clusters

Magnetic fields fluctuate over a wide range of spatial scales

Magnetic fields decreases following the thermal gas density



$$\mathbf{B(r)} = \mathbf{B}_0 \left[\frac{n_e(r)}{n_0} \right]^{\eta}$$

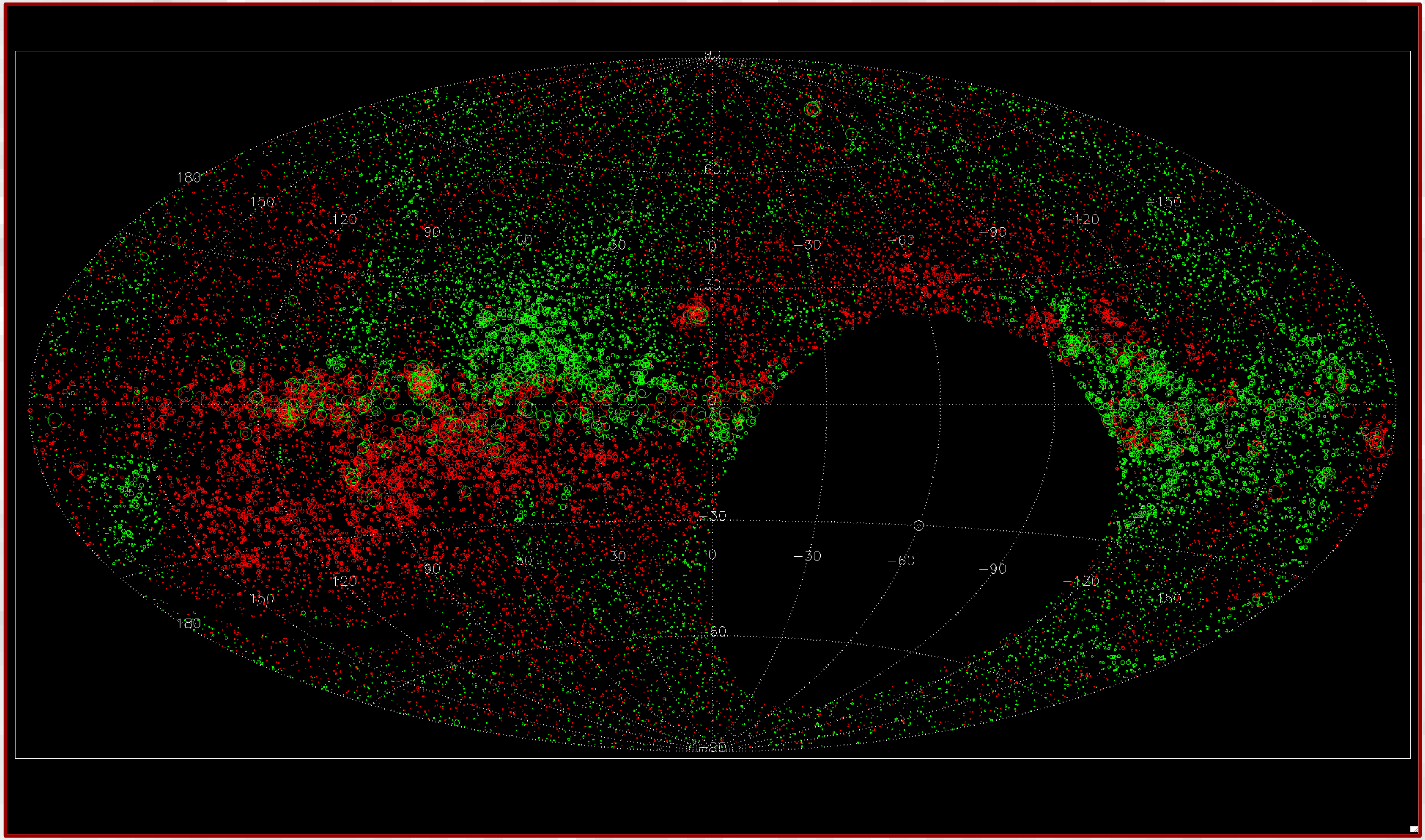
The sensitivity of current radio facilities limits RM studies to a few radio galaxies per cluster and a few galaxy clusters have been studied in detail.

Faraday Rotation

NRAO VLA Sky Survey **Condon et al. (1998)**

Frequency=1.4GHz
Beam=45''
σI~0.45 mJy/beam
σU,Q~0.30mJy/beam

Rotation Measures **Taylor et al. (2009)**



≈40000 Rotation Measures (≈1 RM per deg^2)

SKA Cosmic Magnetism All-Sky Survey

Gaensler et al. (2004), Feretti & Johnston-Hollitt (2004), Beck & Gaensler (2004)
proposed a 1.4 GHz polarization survey with the SKA, resulting
in a closely spaced FARADAY ROTATION MEASURE GRID.
10 years later, the importance of the RM grid has only increased.

Polarization Survey
Stokes I,Q,U

INSTRUMENT	SKA1-Mid
FREQUENCY	Band2 (950-1760 MHz)
SENSITIVITY	4 μJy/beam
RESOLUTION	2”
FIELD OF VIEW	All-Sky 30.000 deg²

HIGHEST PRIORITY
OF THE SKA MAGNETISM
COMMUNITY

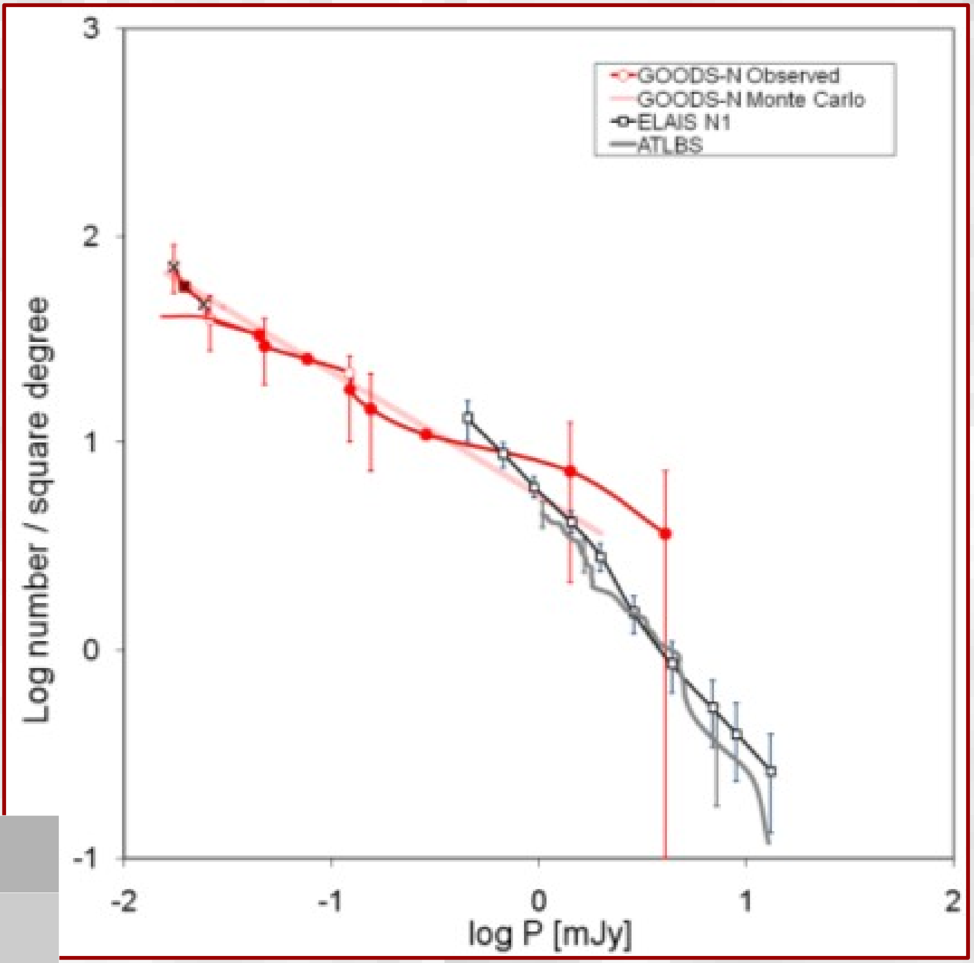
Johnston-Hollitt et al. (2015)

- All-Sky RM grid
- Broadband polarimetry of diffuse synchrotron emission
- Continnum science

SKA Cosmic Magnetism All-Sky Survey

Extrapolating the current polarization counts (**Rudnick & Owen 2014, Stil et al. 2014, Hales et al. 2014**) to 4μJy levels, we expect a ~200-500x denser Rotation Measure Grid than the most accurate All-Sky map actually available.

Rudnick & Owen (2014)



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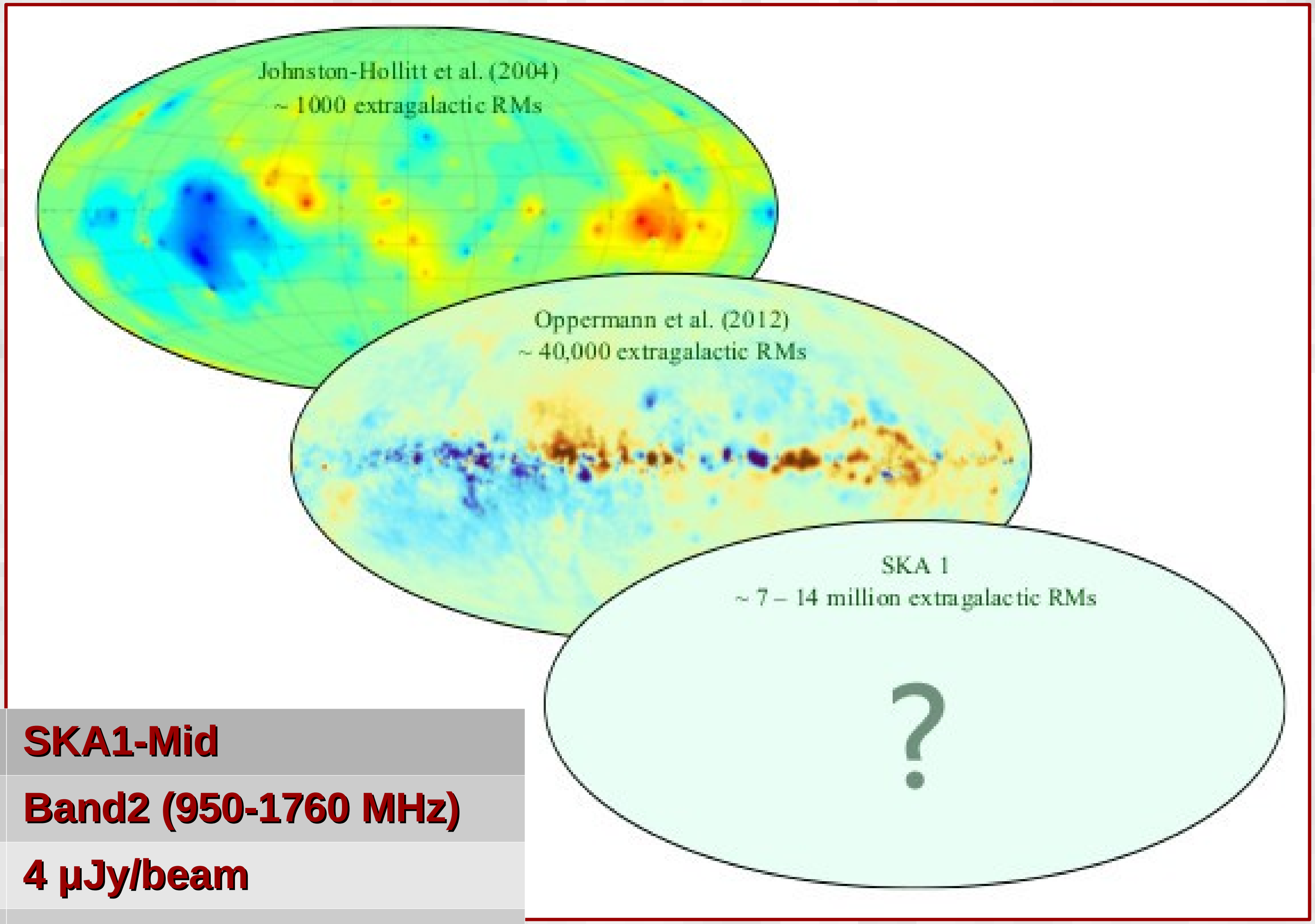

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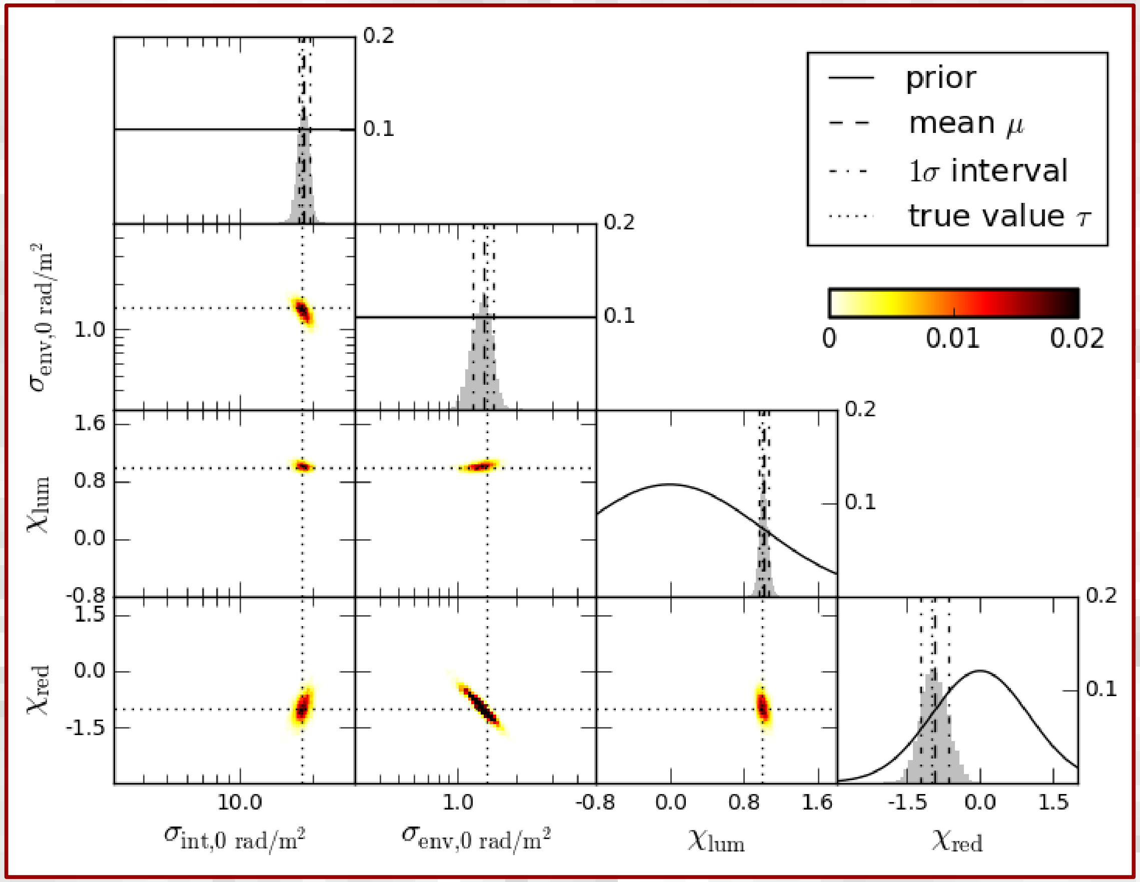
SKA Cosmic Magnetism All-Sky Survey

Bayesian algorithms have been developed to exploit the information from the incoming polarization surveys and RM grids and to separate between the extragalactic contribution intrinsic to the emitting sources from that due to the overall large-scale environment (galaxy clusters, filaments, voids).

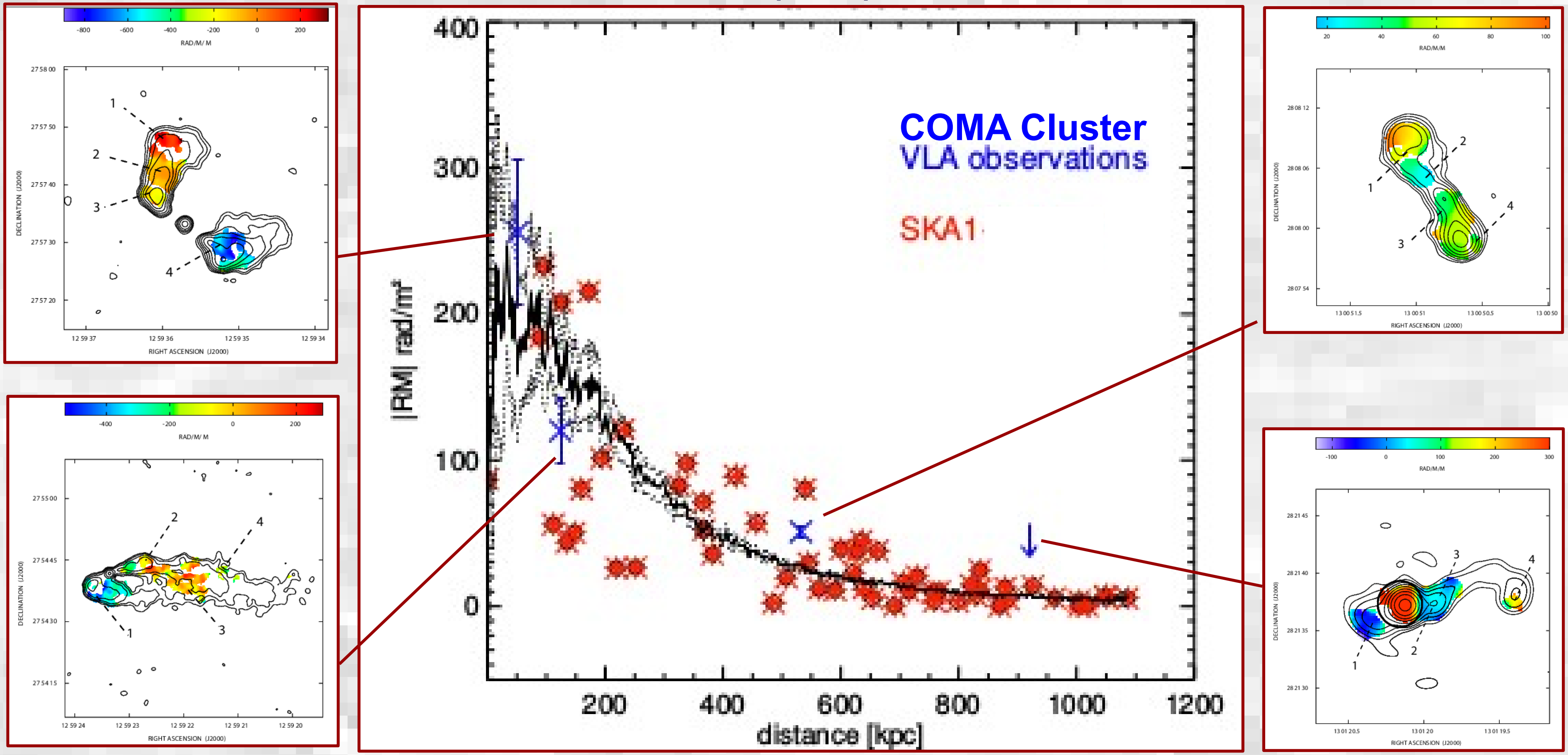
Vacca et al. (2015), Vacca et al. (submitted)



Application to mock data from SKA1-Mid Band 2
3500 sources

SKA Cosmic Magnetism All-Sky Survey

Bonafede et al. (2015)



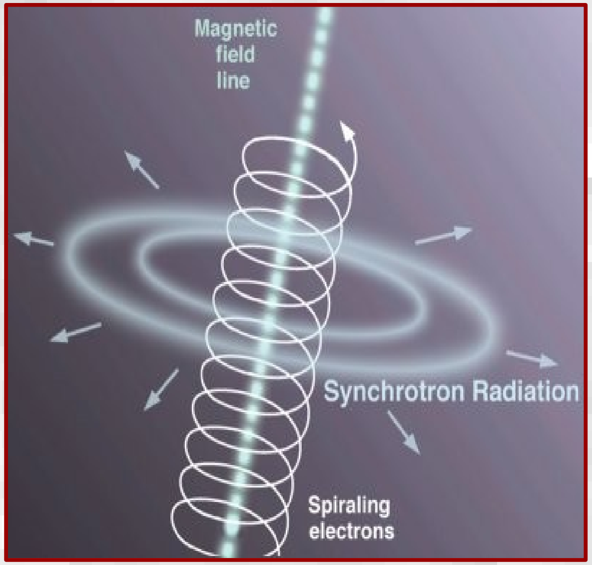
Bonafede et al. (2010)

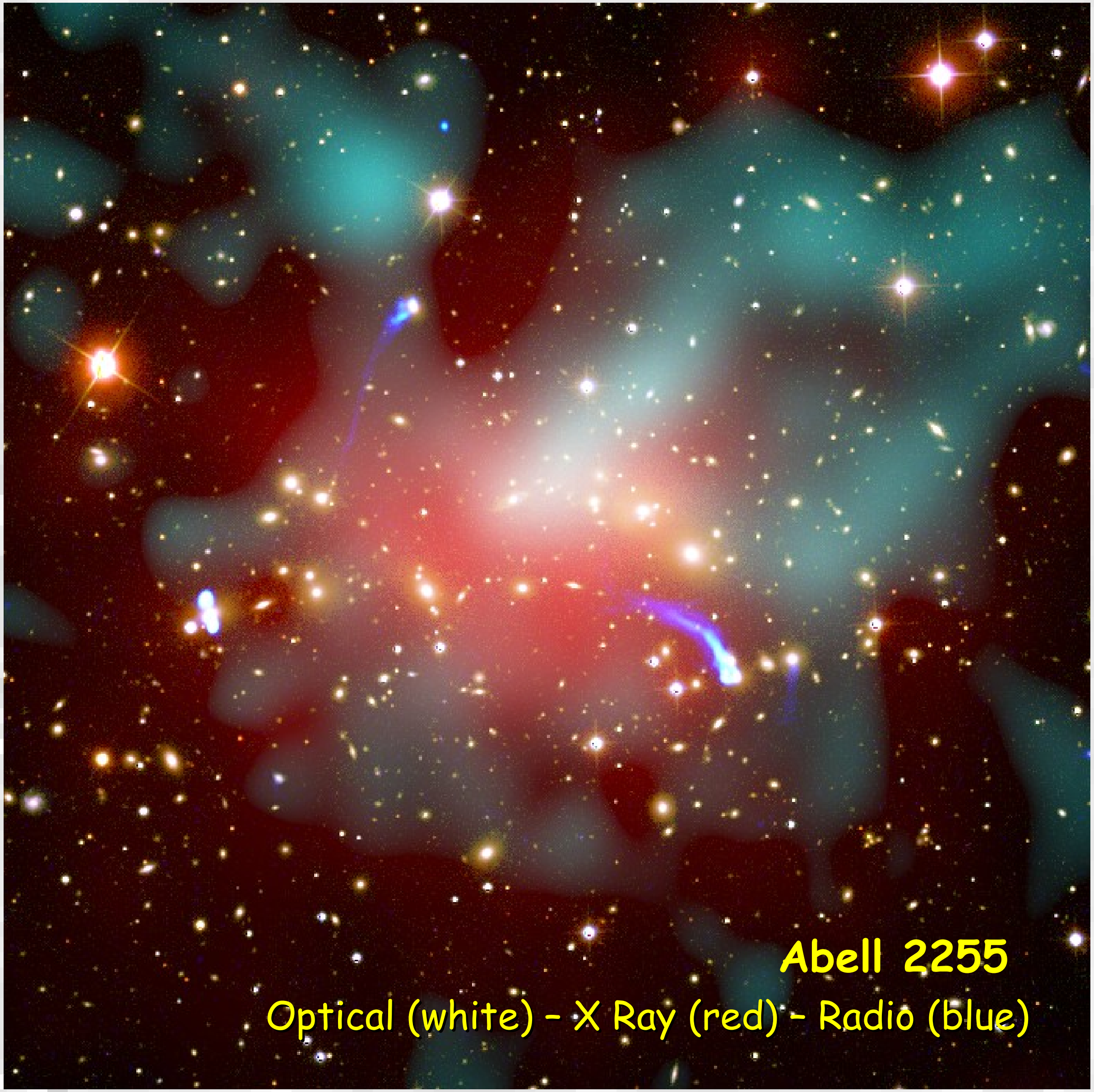
SKA1 will have the potential of measuring the RM toward a large number of sources by deriving a detailed description of the strength, structure, and radial decrease of cluster magnetic fields.

Diffuse Synchrotron Emission

(II-part of the talk)

(see talks by G. Bernardi, A. Bonafede, R. Cassano, V. Cuciti, R. Kale, R. VanWeeren, T. Venturi)

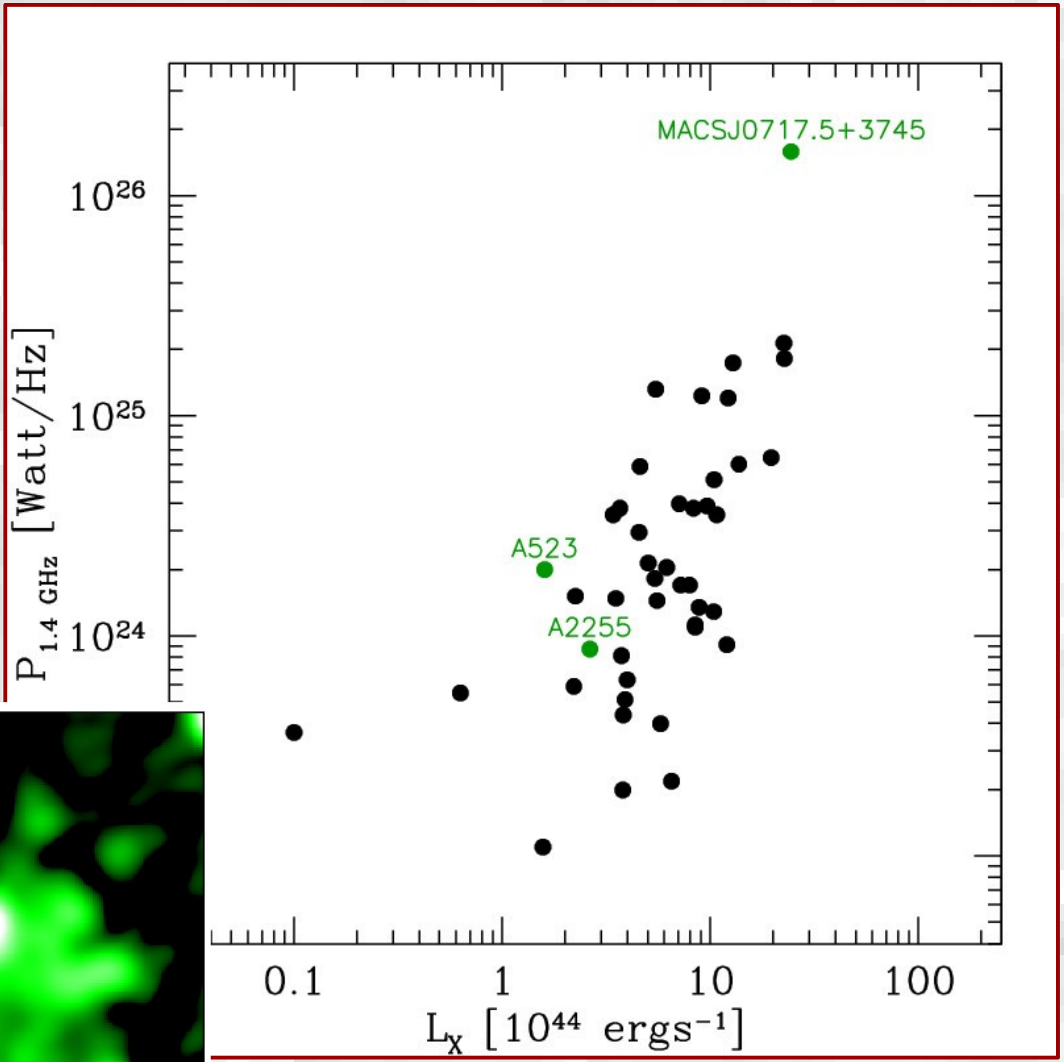


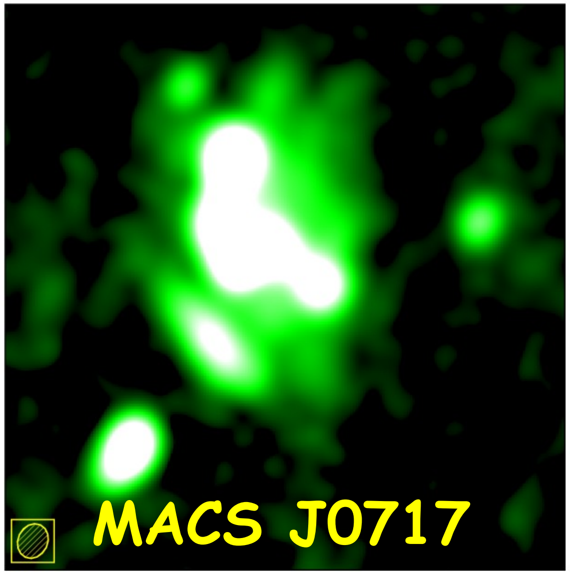


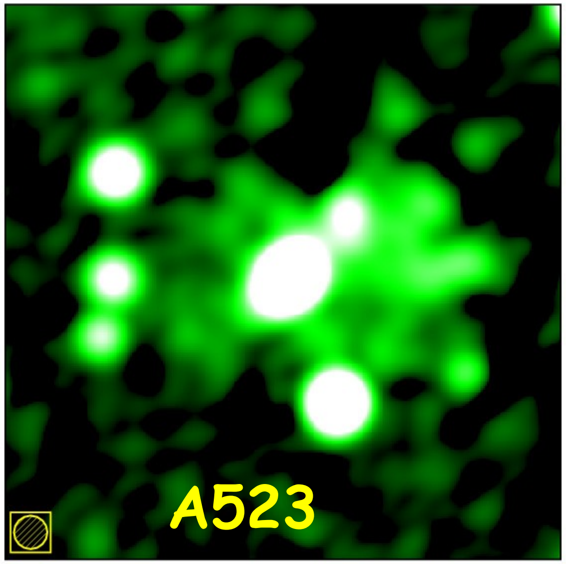
Radio halos are ideal sources for magnetic field studies in galaxy clusters.

Diffuse Synchrotron Emission : Observations

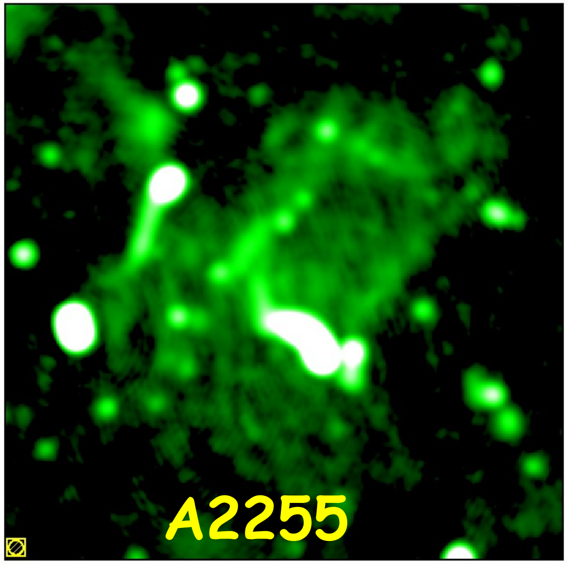
Feretti et al. (2012)





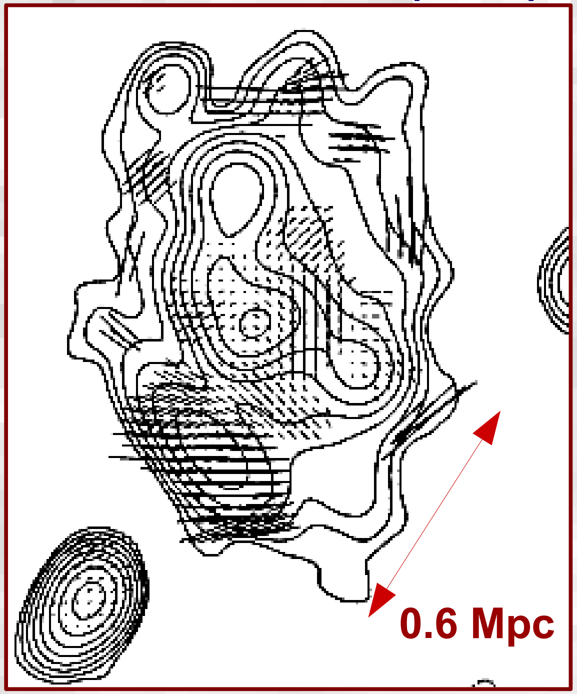


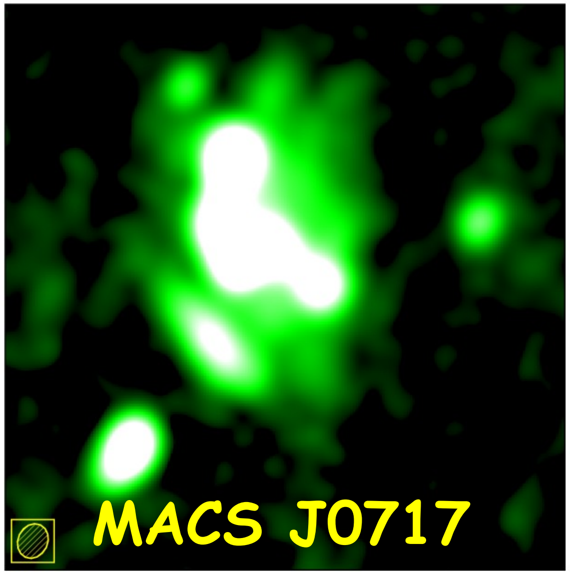
Radio X-ray Relation



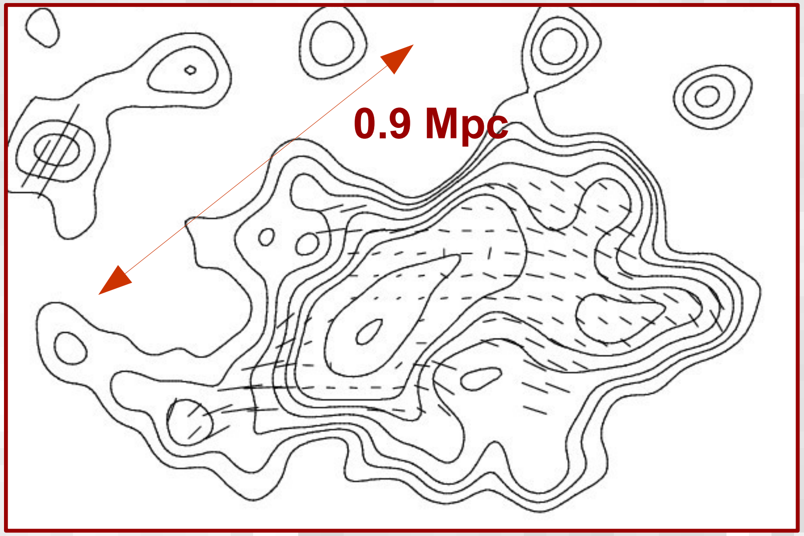
Diffuse Synchrotron Emission : Observations

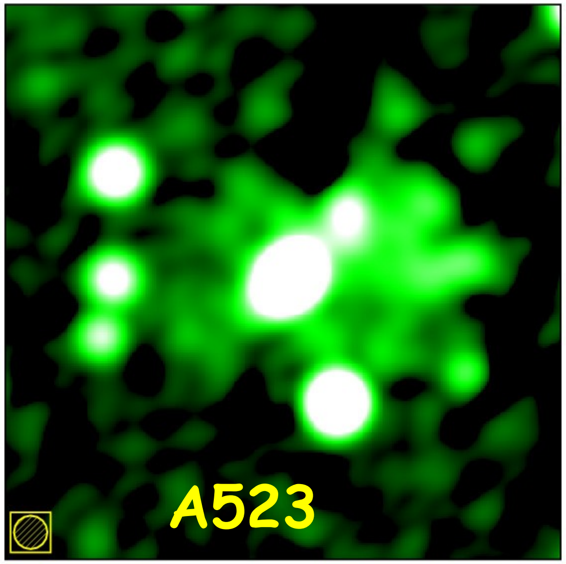
Bonafede et al. (2009)



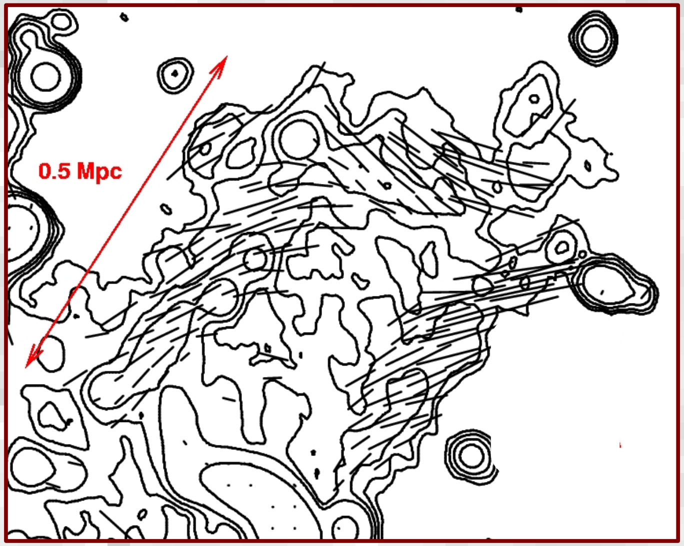


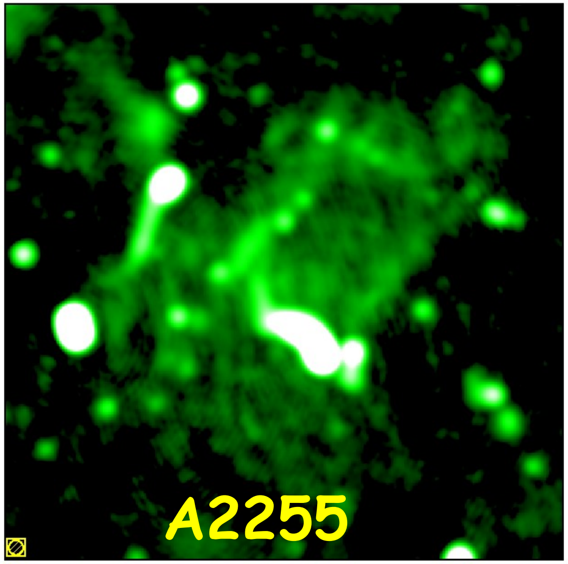
Girardi et al., (submitted)





Govoni et al. (2005), see also Pizzo et al. (2011)





Diffuse Synchrotron Emission : Simulations

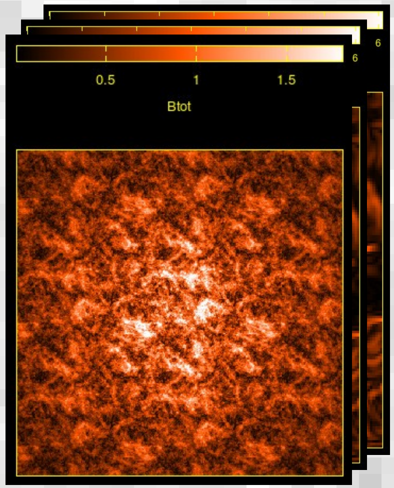
RELATIVISTIC ELECTRONS

$$N(\gamma)d\gamma = N_0\gamma^{-\delta}d\gamma$$

MAGNETIC FIELD

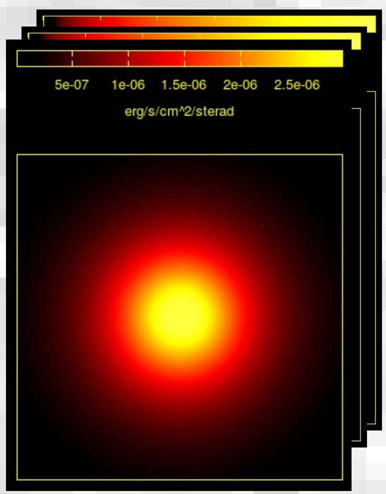
$$|B_k|^2 \propto k^{-n}$$

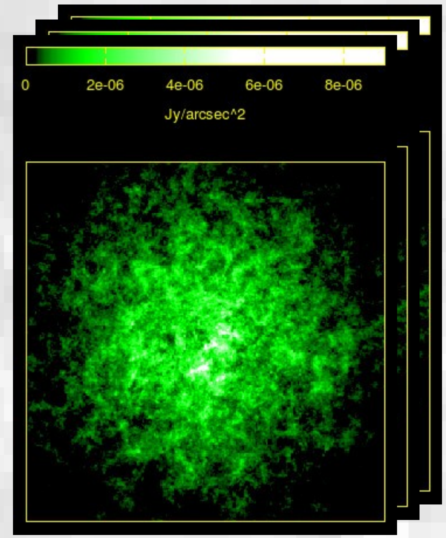
$$B(r) = B_0\left[\frac{n_e(r)}{n_0}\right]^{\eta}$$



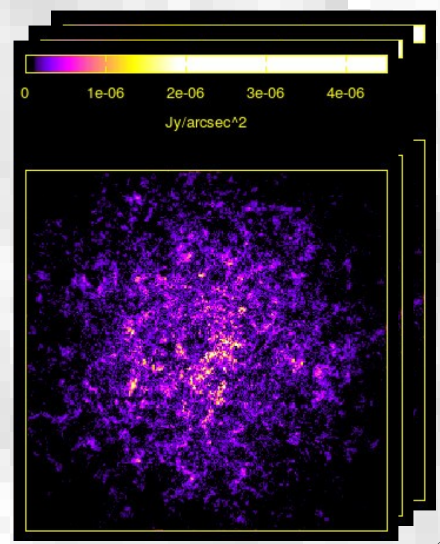
THERMAL GAS

$$n_e(r) = n_0\left[1+\frac{r^2}{r_c^2}\right]^{-\frac{3}{2}\beta}$$





TOTAL INTENSITY



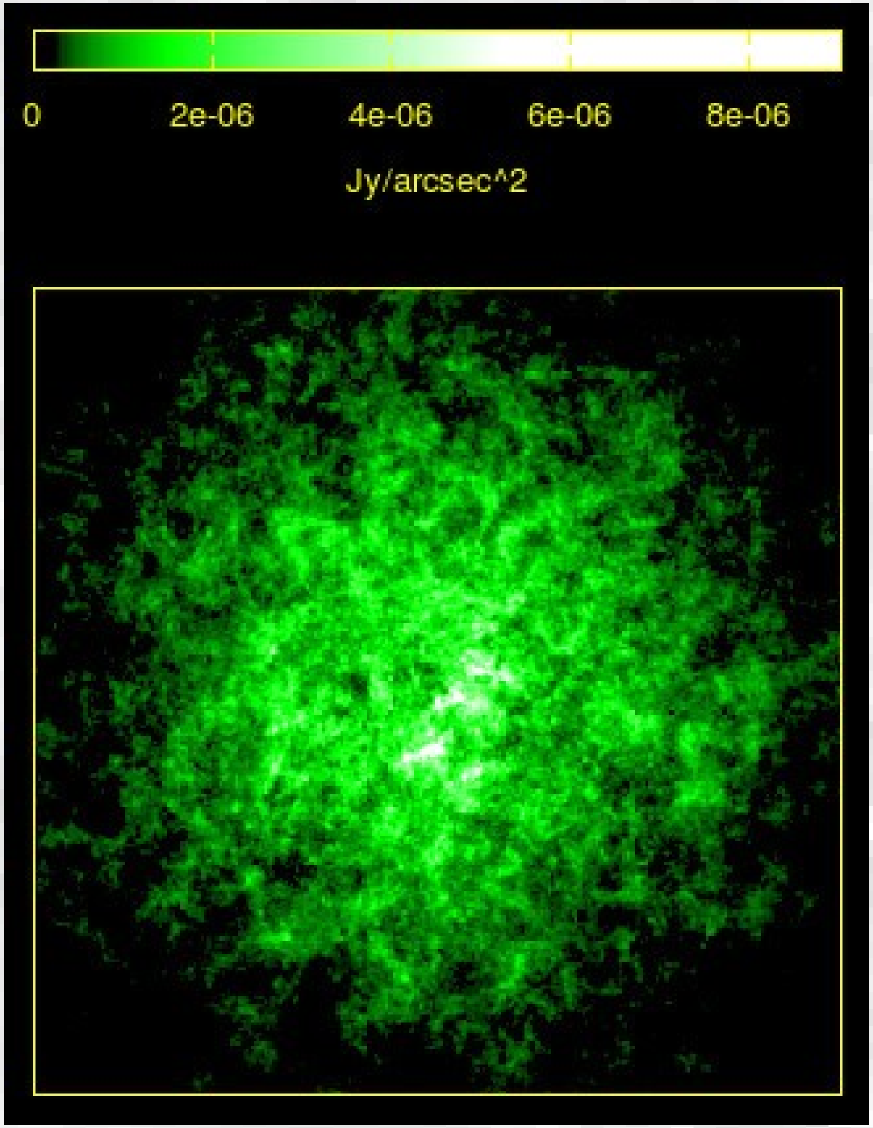
POLARIZED INTENSITY

Frequency

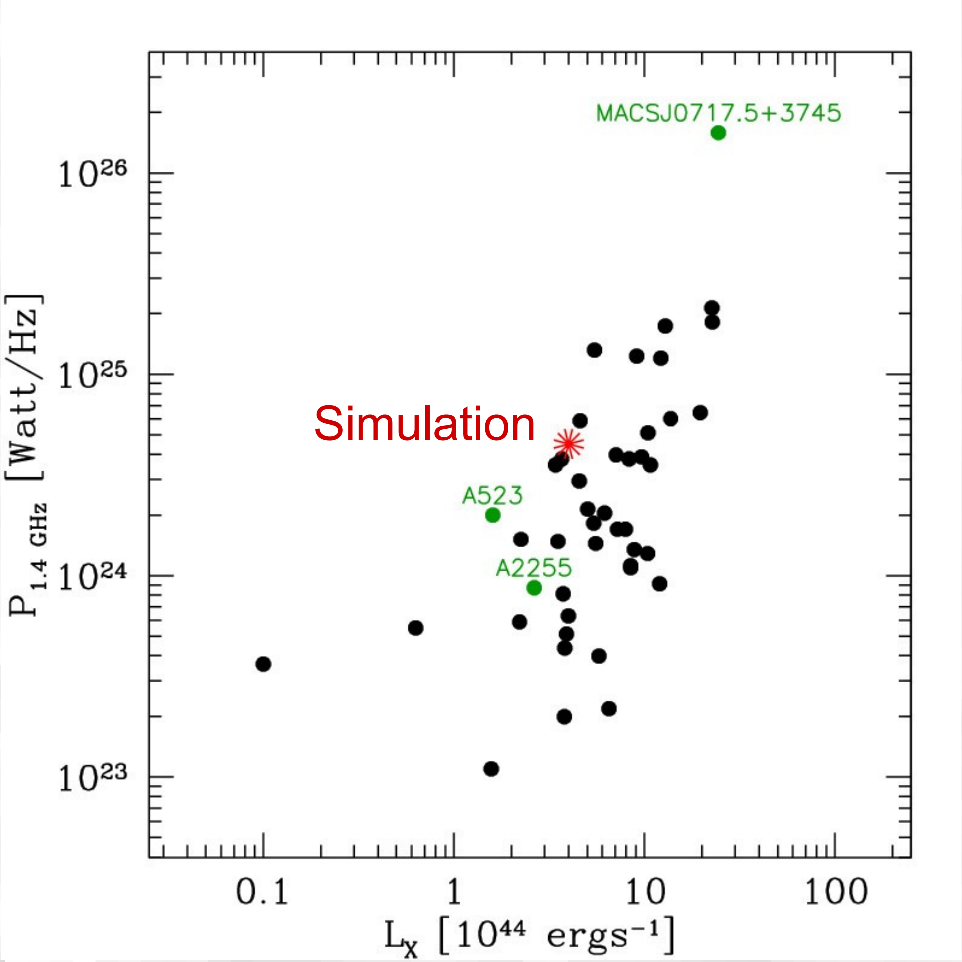
Faraday Software **Murgia et al. (2004)**

Diffuse Synchrotron Emission : Simulations

SIMULATION AT FULL RESOLUTION



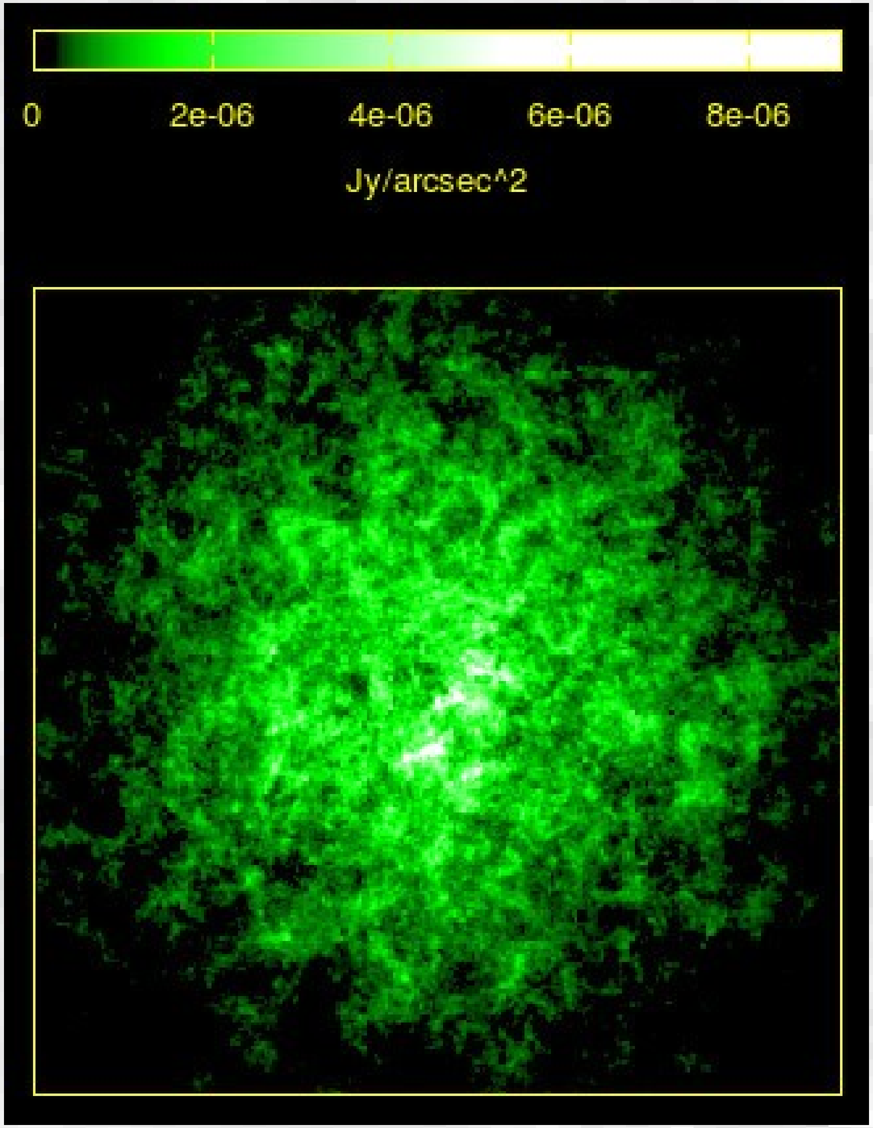
TOTAL INTENSITY

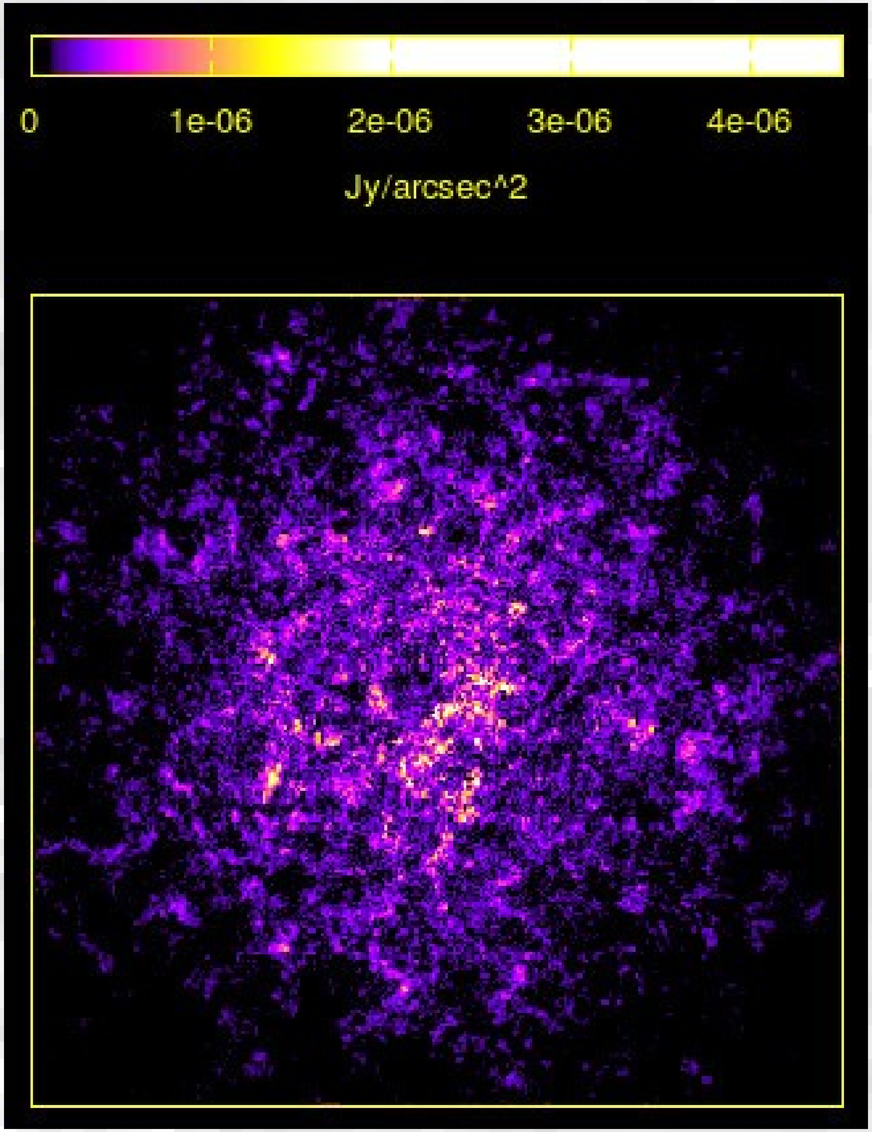


Diffuse Synchrotron Emission : Simulations

SIMULATION AT
FULL RESOLUTION

Fractional Polarizazion
P/I=22%





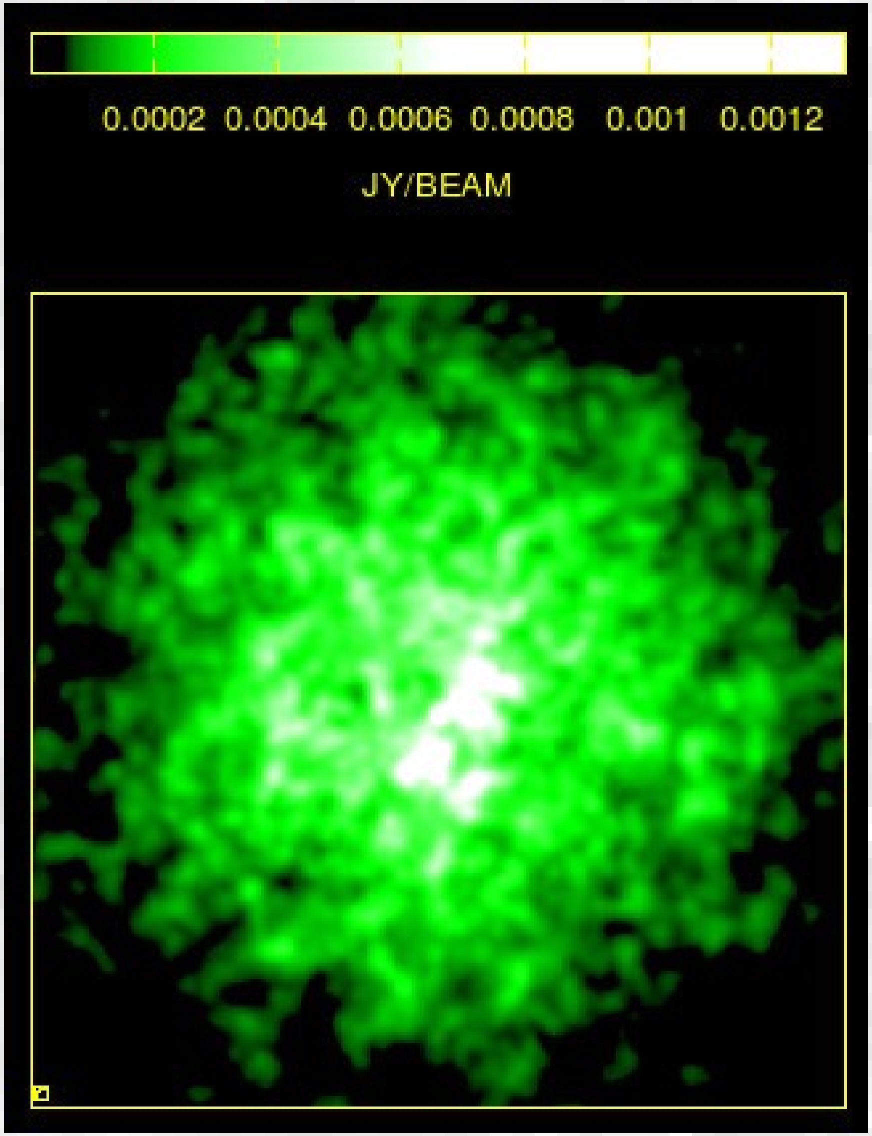
TOTAL INTENSITY

POLARIZED INTENSITY

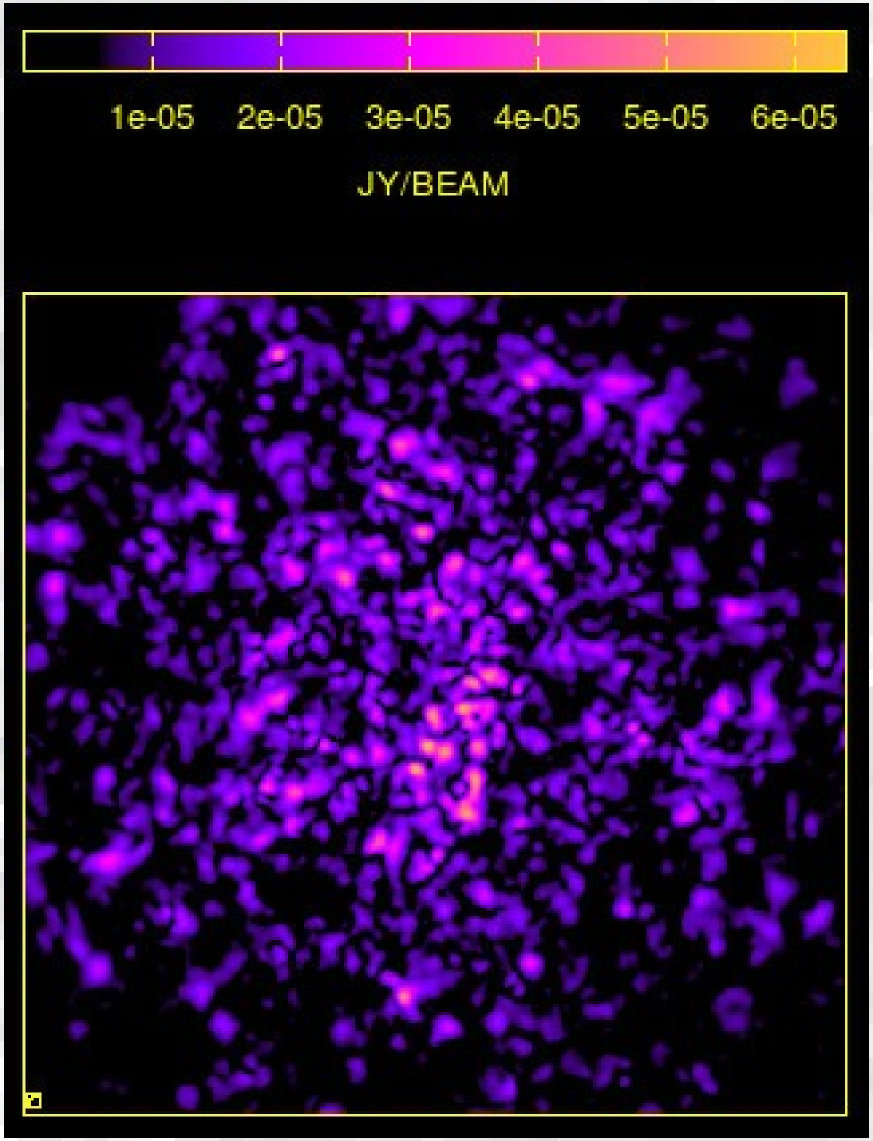
Diffuse Synchrotron Emission : Simulations

SIMULATION AT
15" RESOLUTION

Fractional Polarizazion
P/I=6%
BEAM DEPOLARIZATION



TOTAL INTENSITY

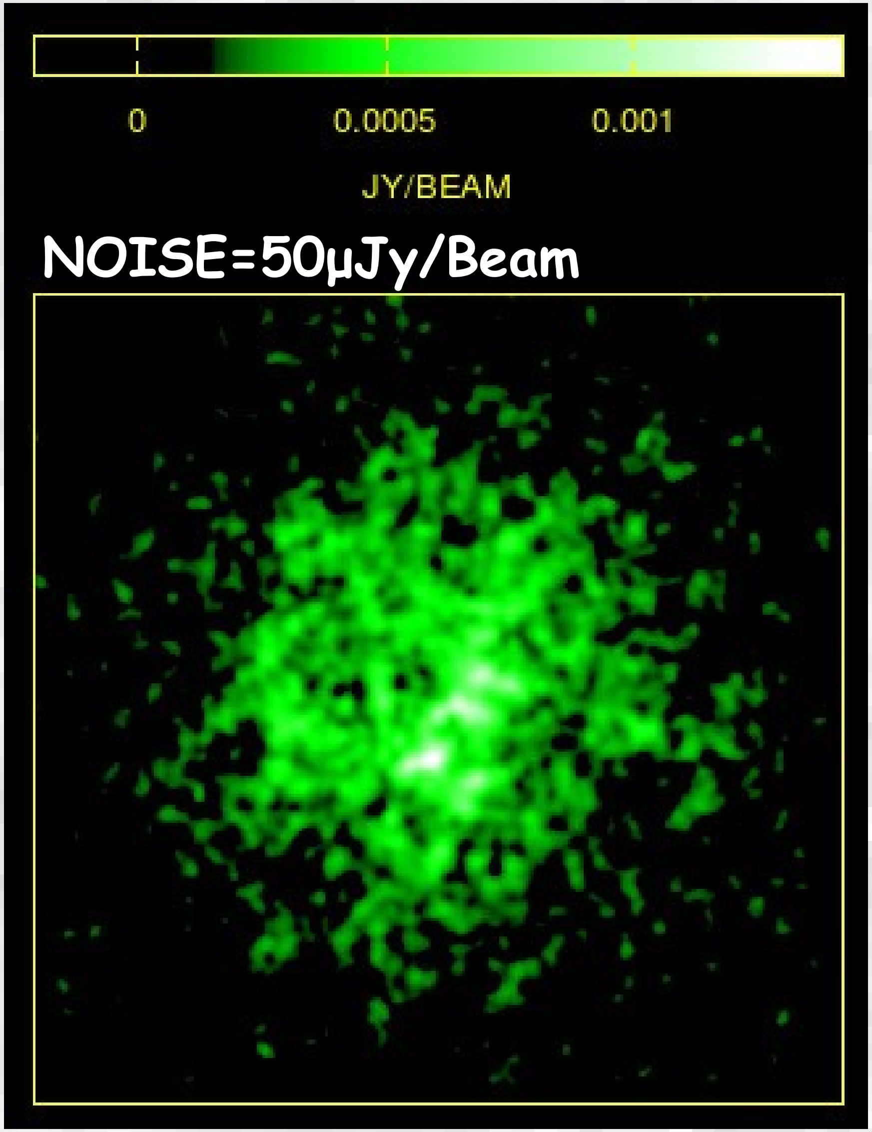


POLARIZED INTENSITY

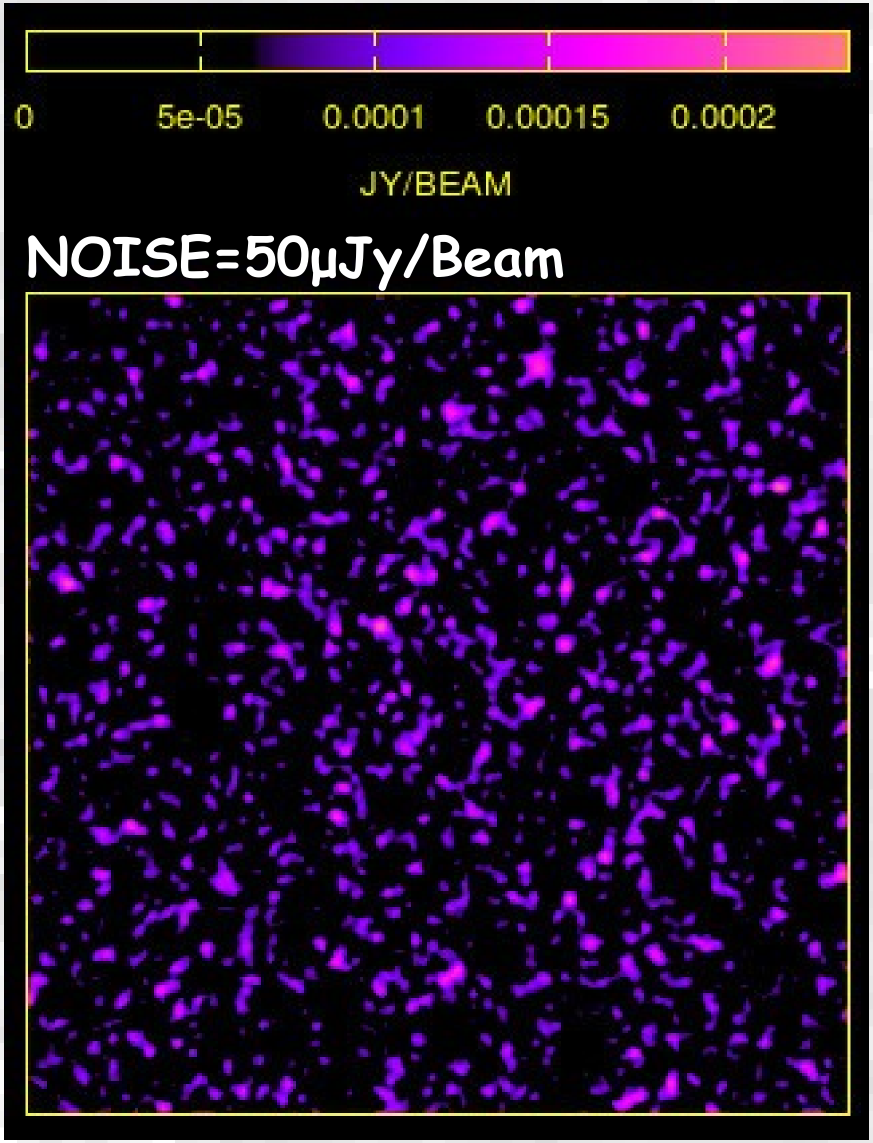
Diffuse Synchrotron Emission : Simulations

SIMULATION AT
15" RESOLUTION

BEAM DEPOLARIZATION + NOISE
POLARIZATION NOT DETECTED



TOTAL INTENSITY

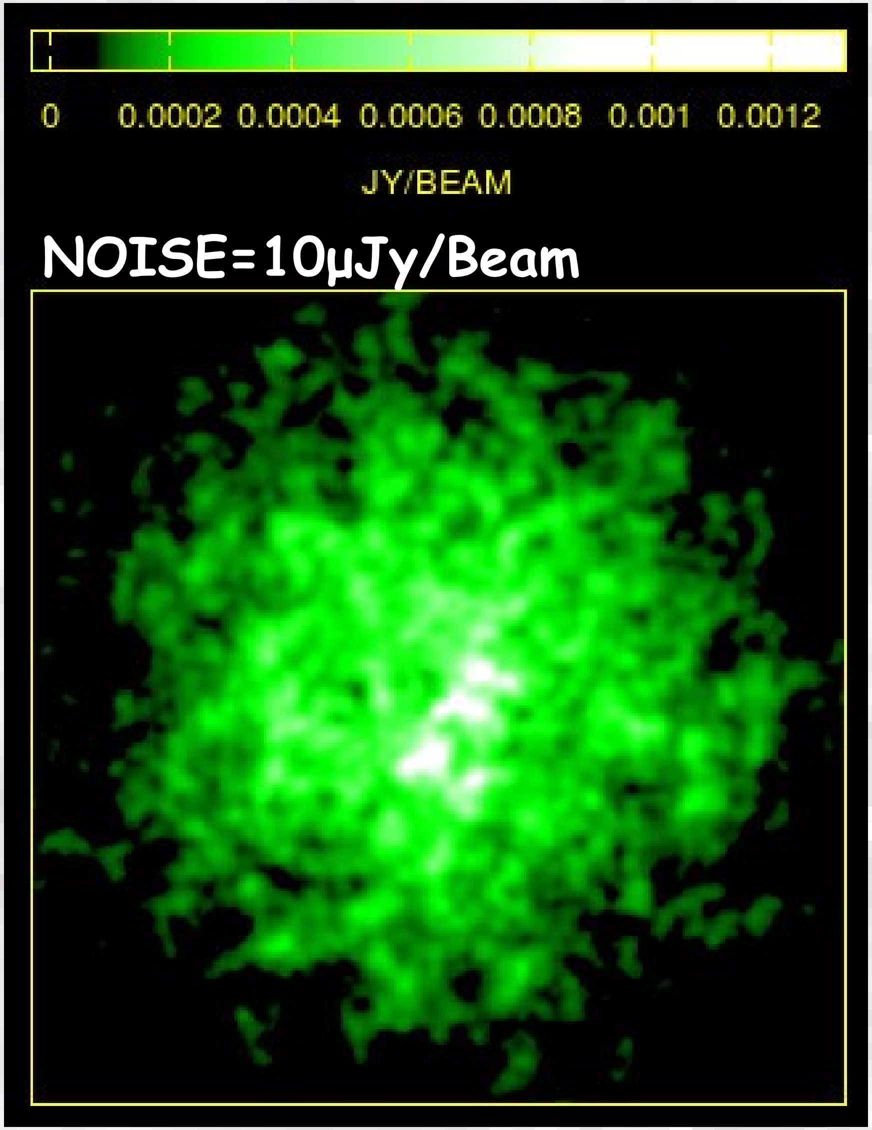


POLARIZED INTENSITY

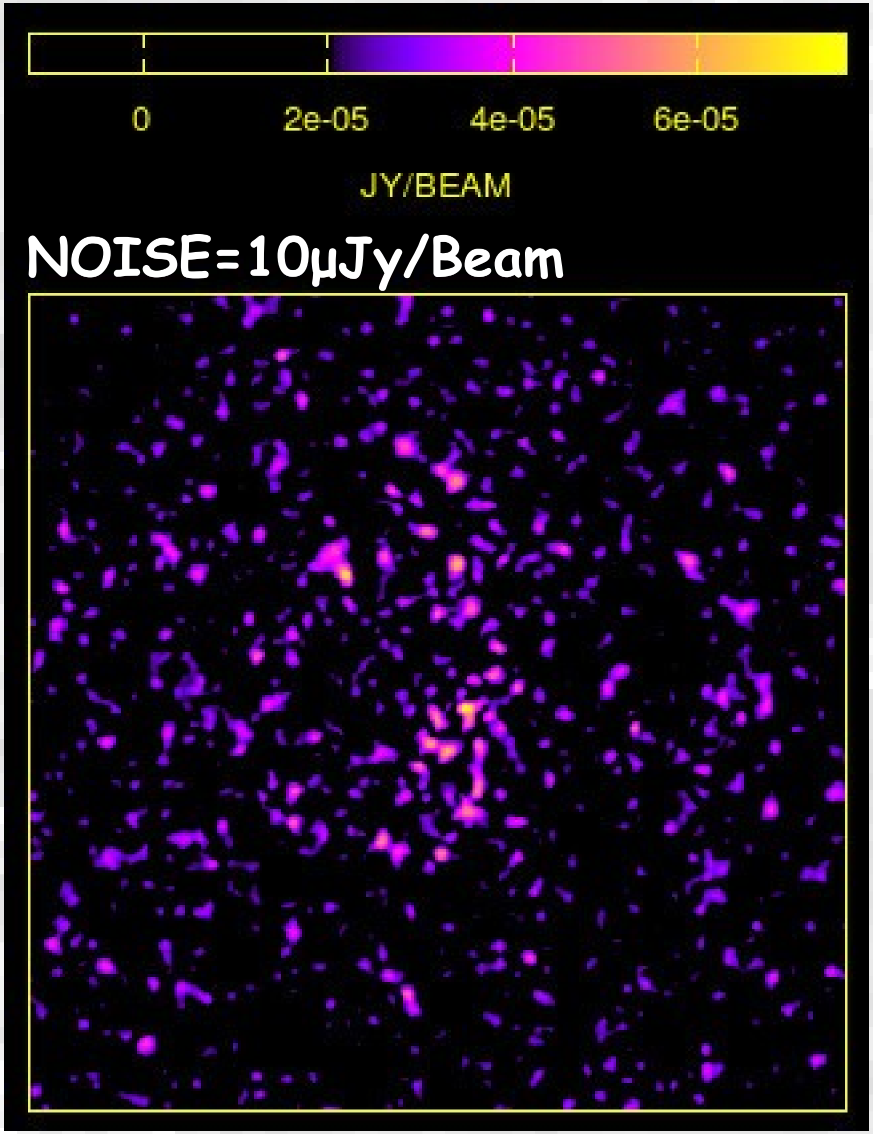
Diffuse Synchrotron Emission : Simulations

SIMULATION AT
15" RESOLUTION

BEAM DEPOLARIZATION + NOISE
POLARIZATION NOT DETECTED



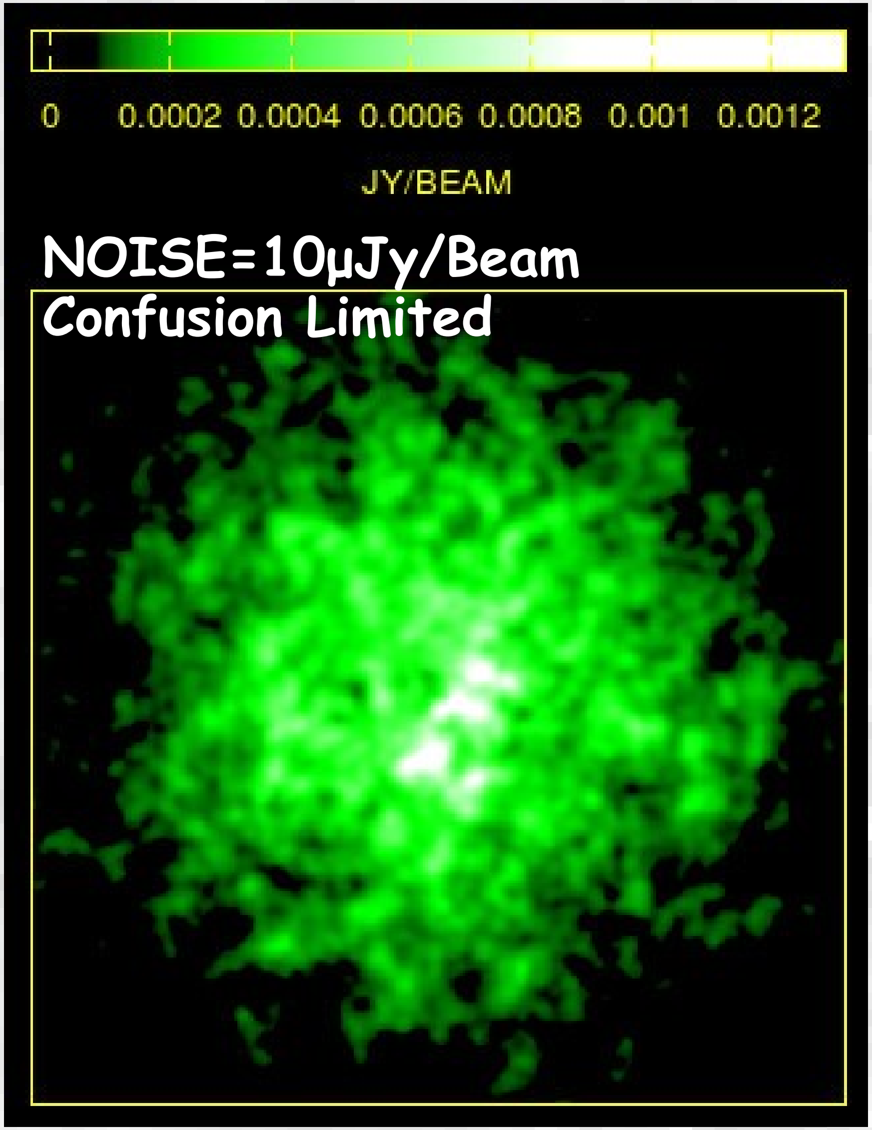
TOTAL INTENSITY



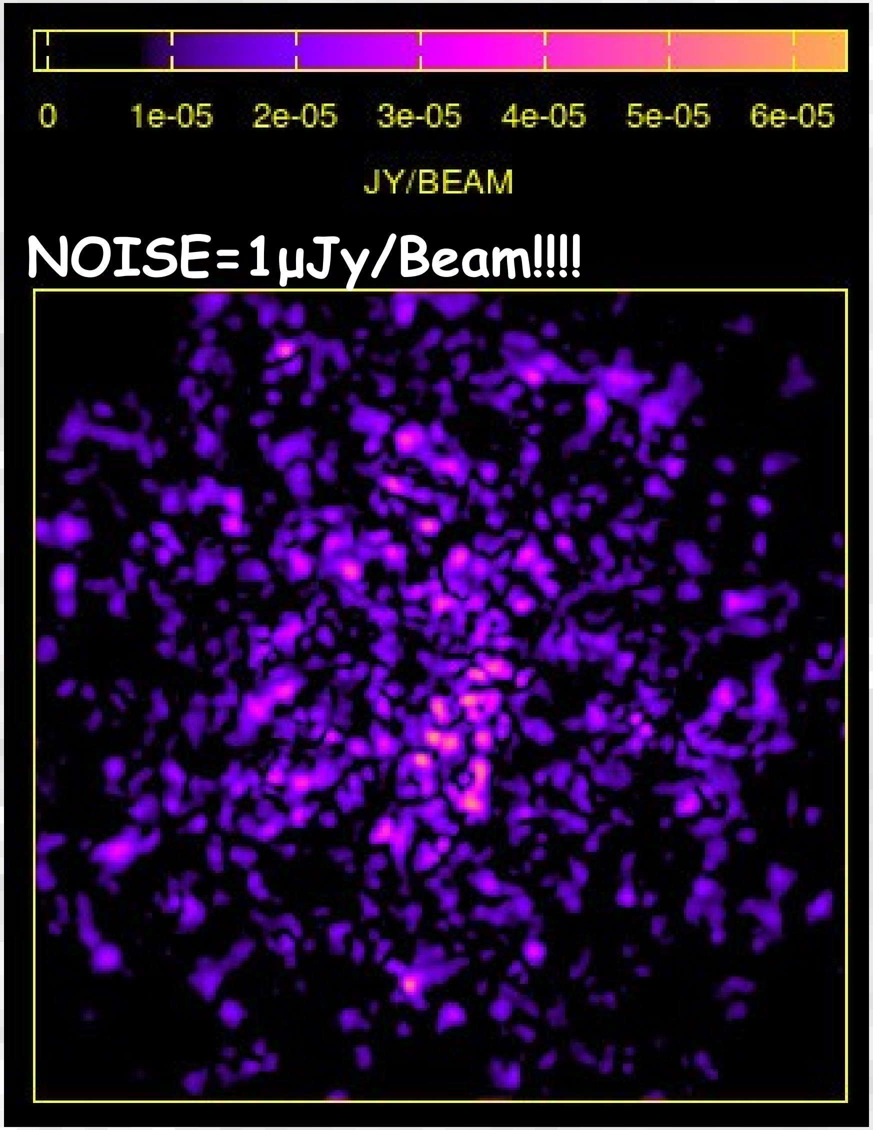
POLARIZED INTENSITY

Diffuse Synchrotron Emission : Simulations

SIMULATION AT
15″ RESOLUTION



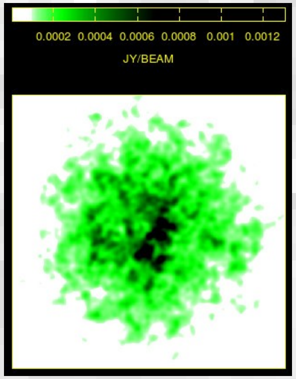
BEAM DEPOLARIZATION + NOISE



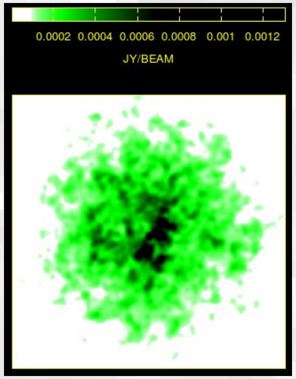
The detection of polarized signal in radio halos is a very hard task!!

Synchrotron Emission:

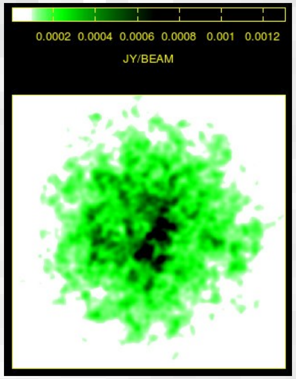
TOTAL INTENSITY



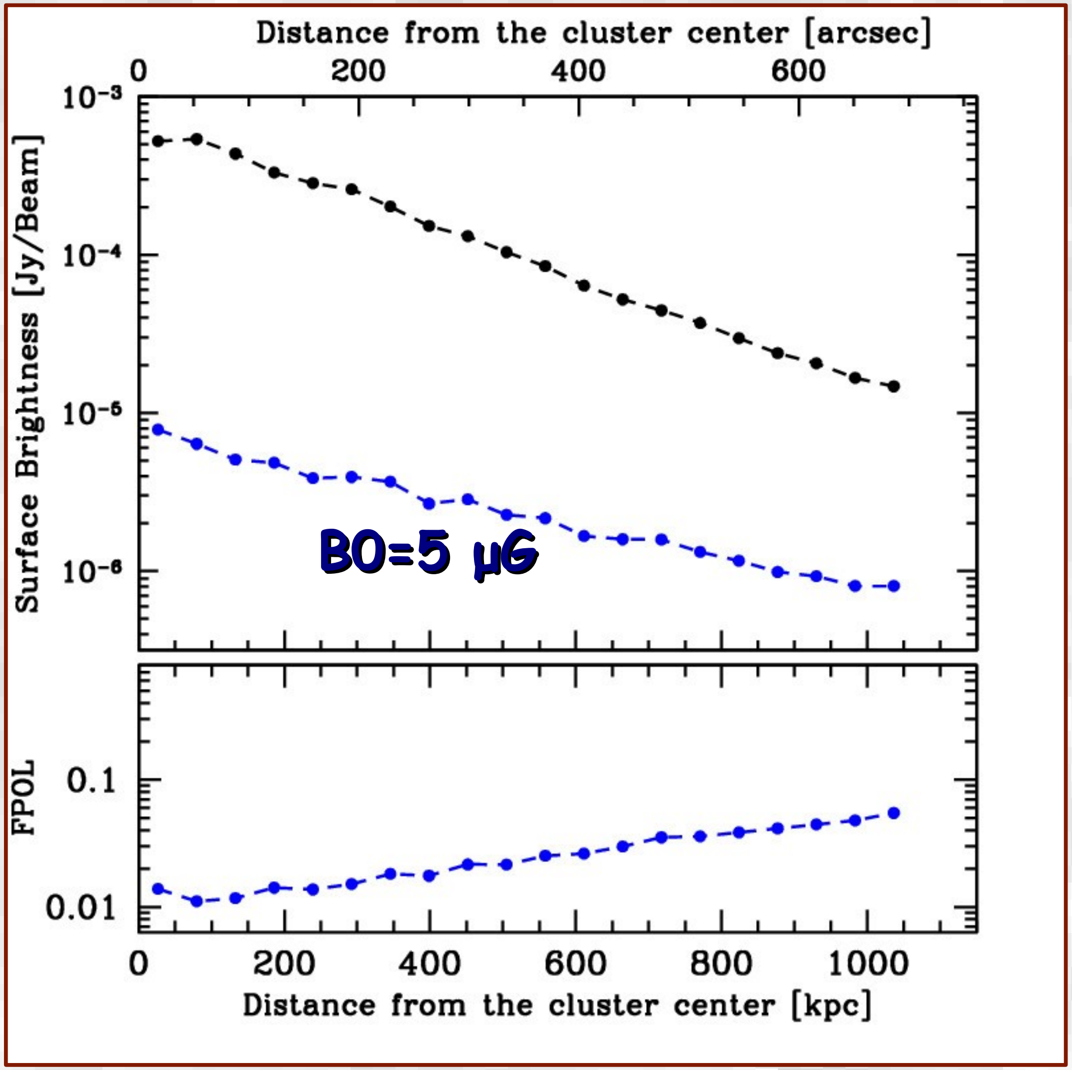
B0=0.5 μG

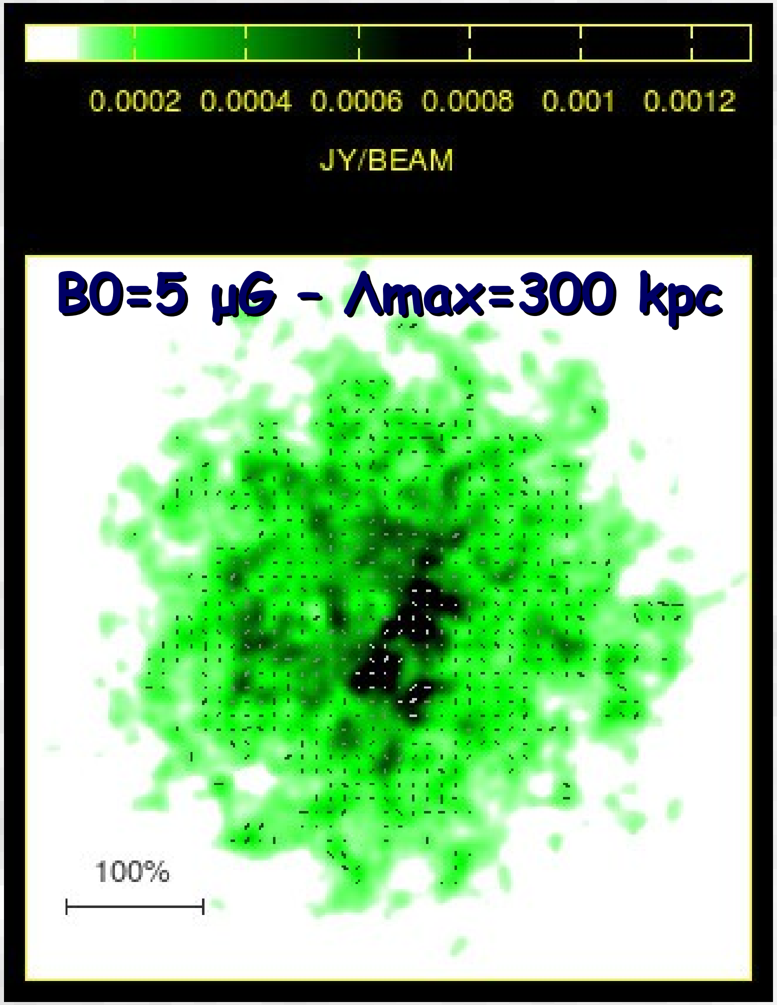


B0=1 μG



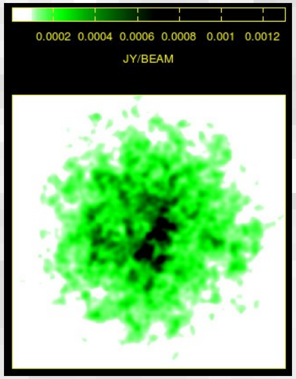
B0=5 μG



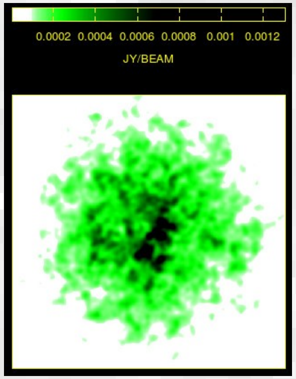


Synchrotron Emission:

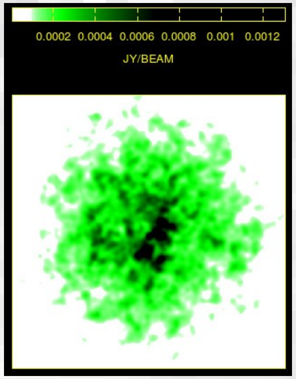
TOTAL INTENSITY



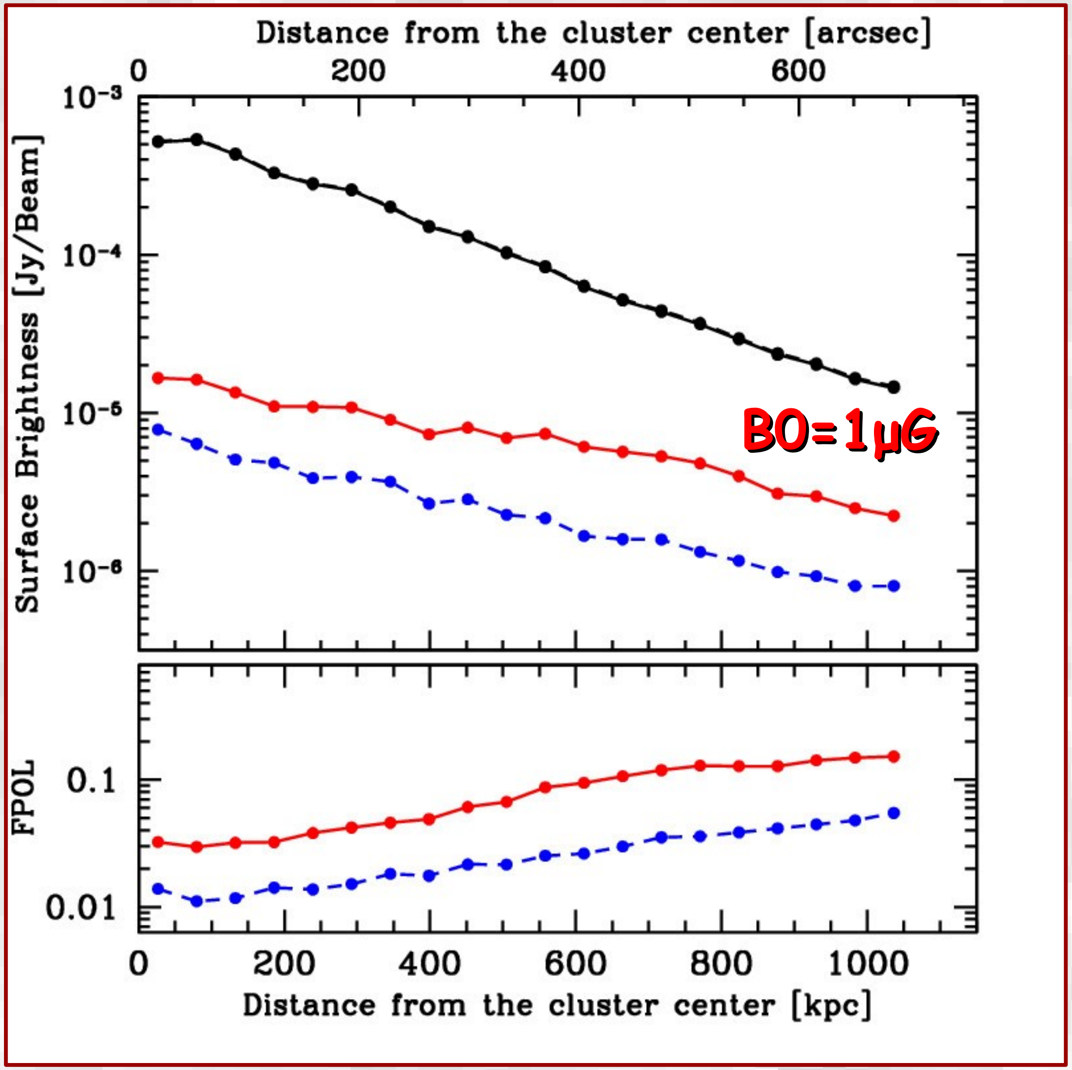
B0=0.5 μG

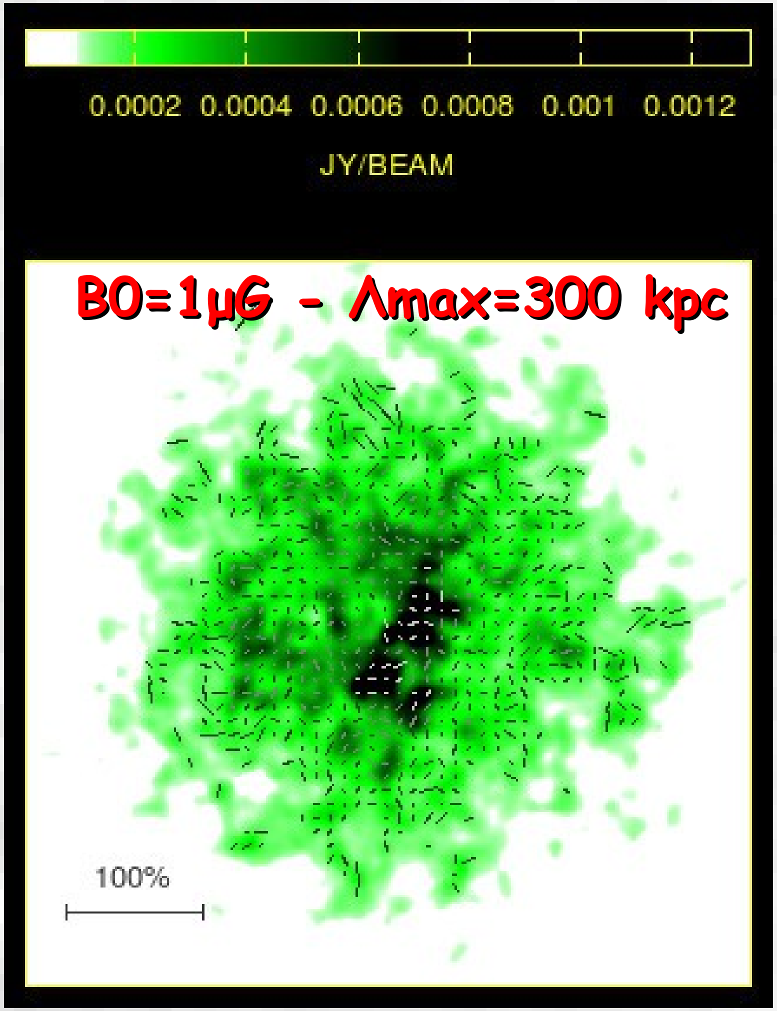


B0=1 μG



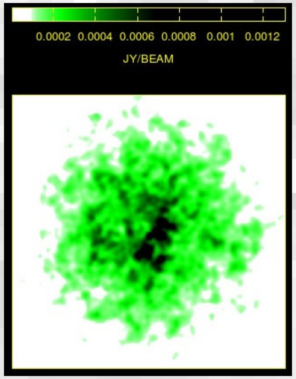
B0=5 μG



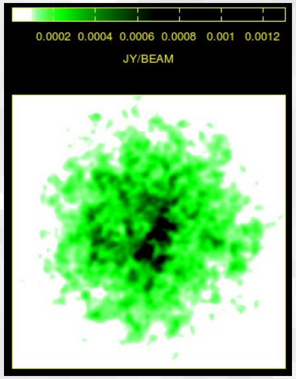


Synchrotron Emission:

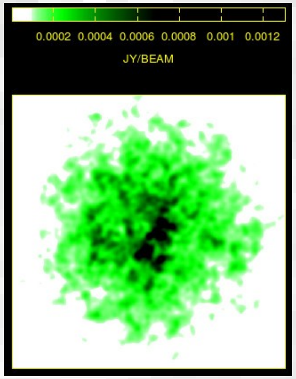
TOTAL INTENSITY



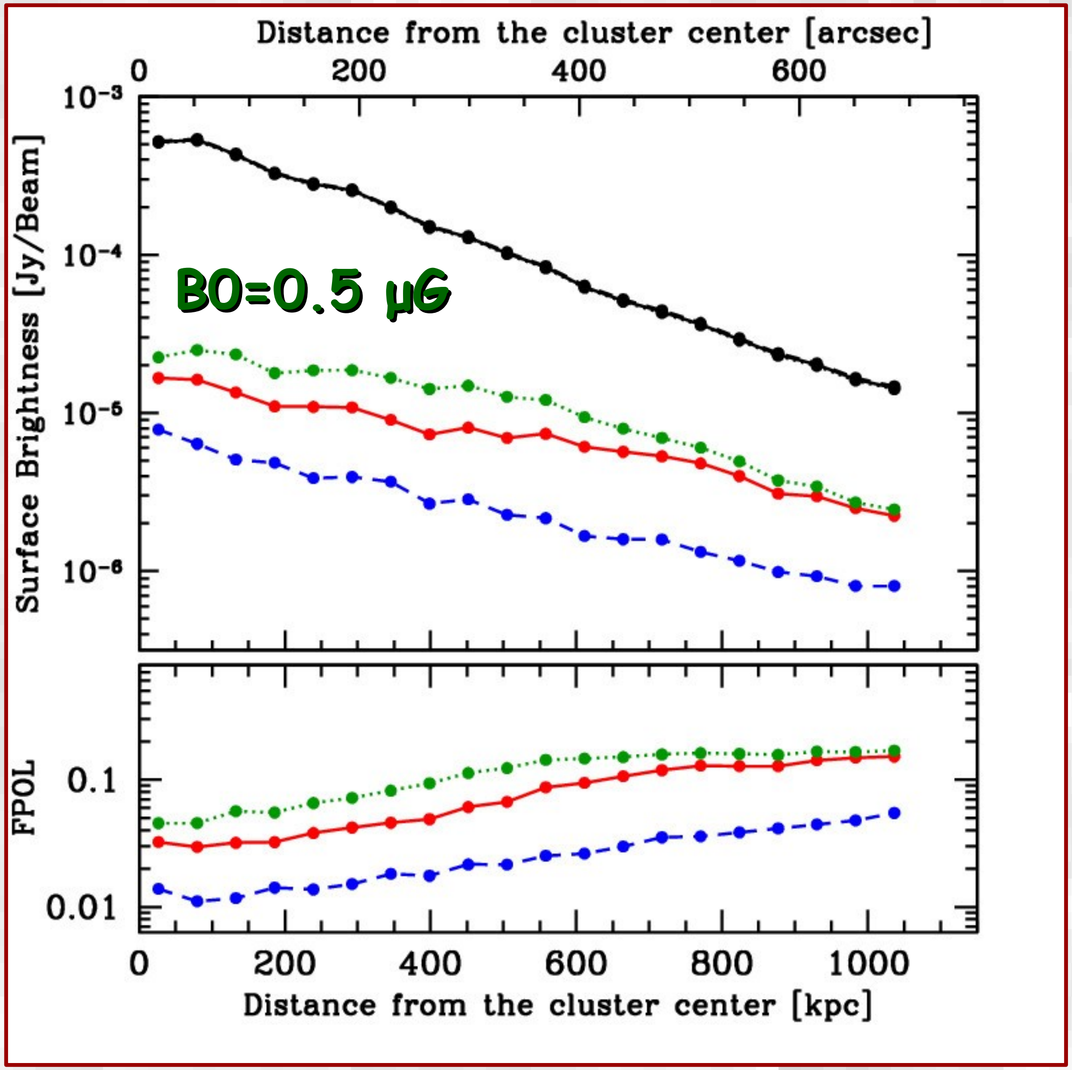
B0=0.5 μG

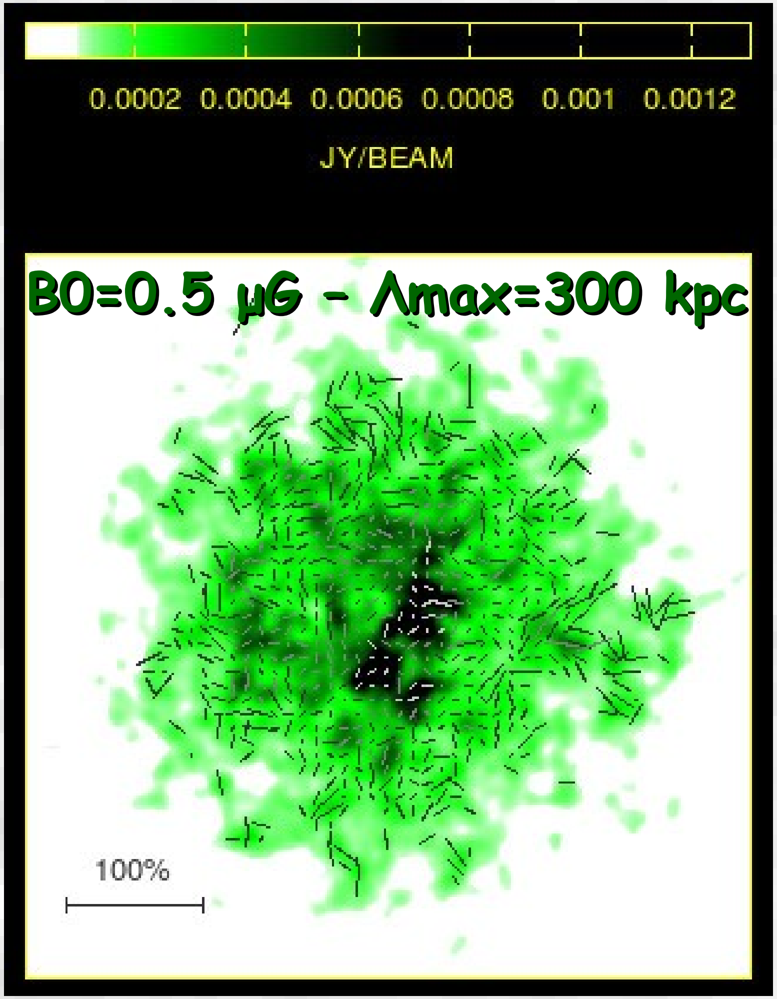


B0=1 μG



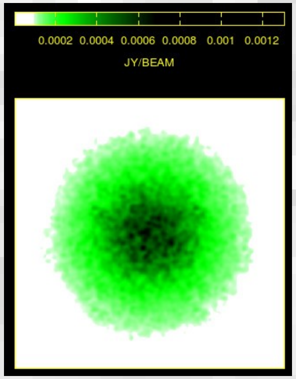
B0=5 μG



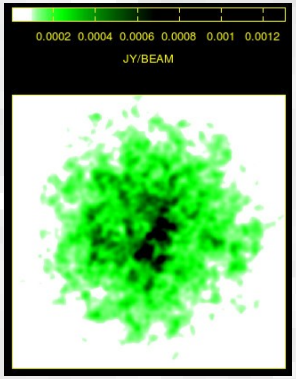


Synchrotron Emission:

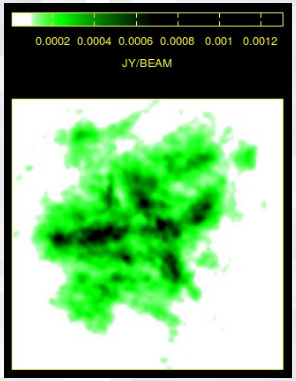
TOTAL INTENSITY



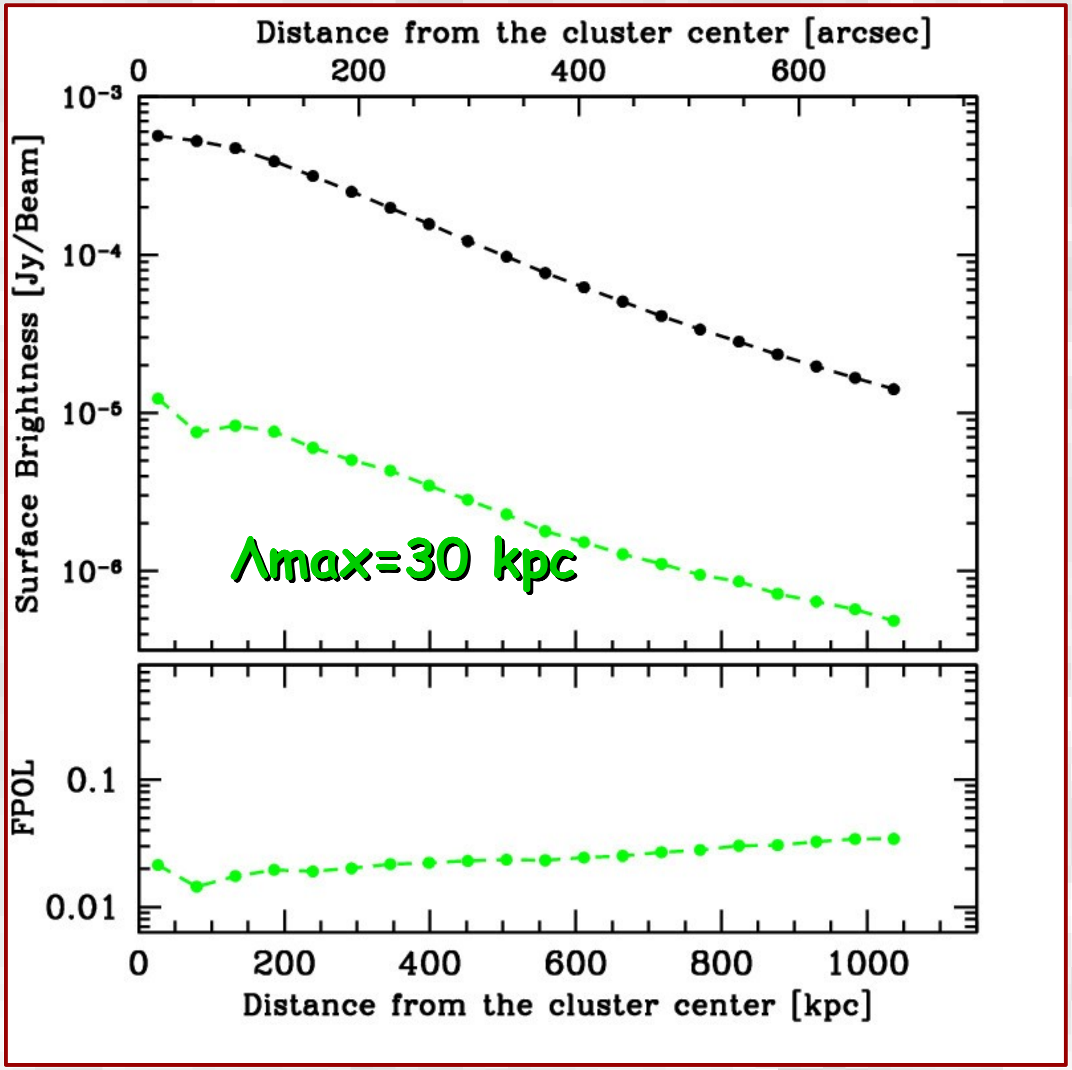
Λmax=30 kpc

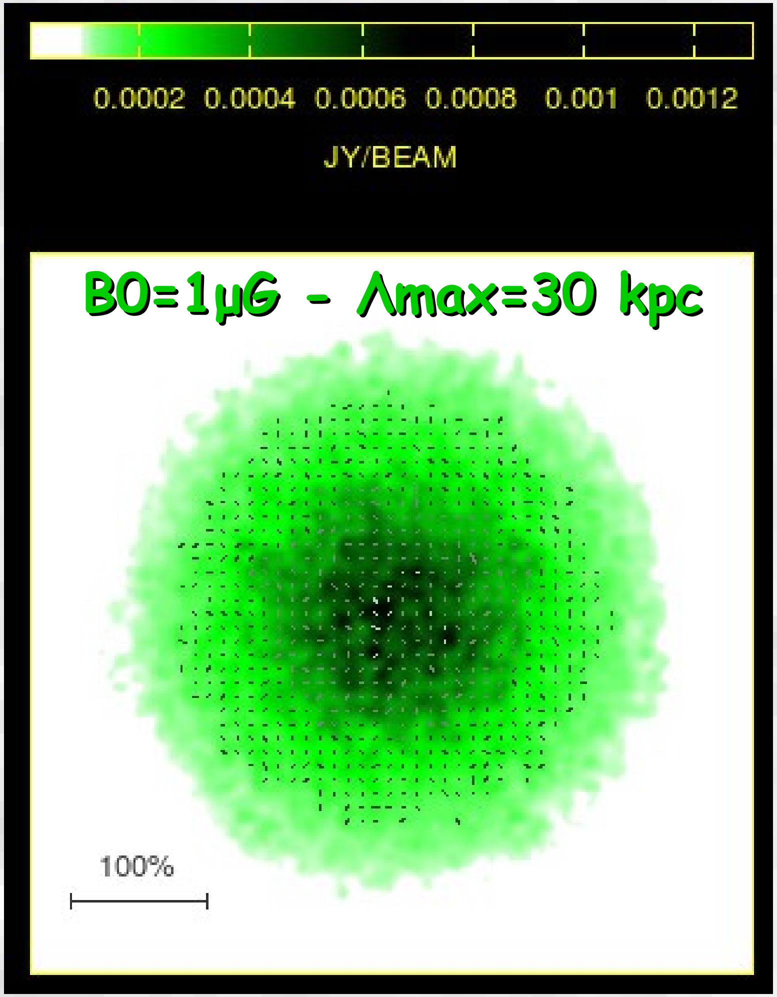


Λmax=300 kpc



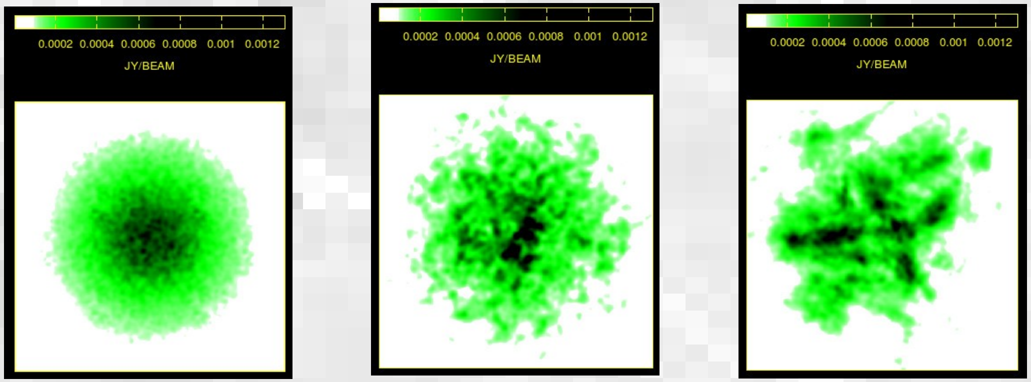
Λmax=1000 kpc



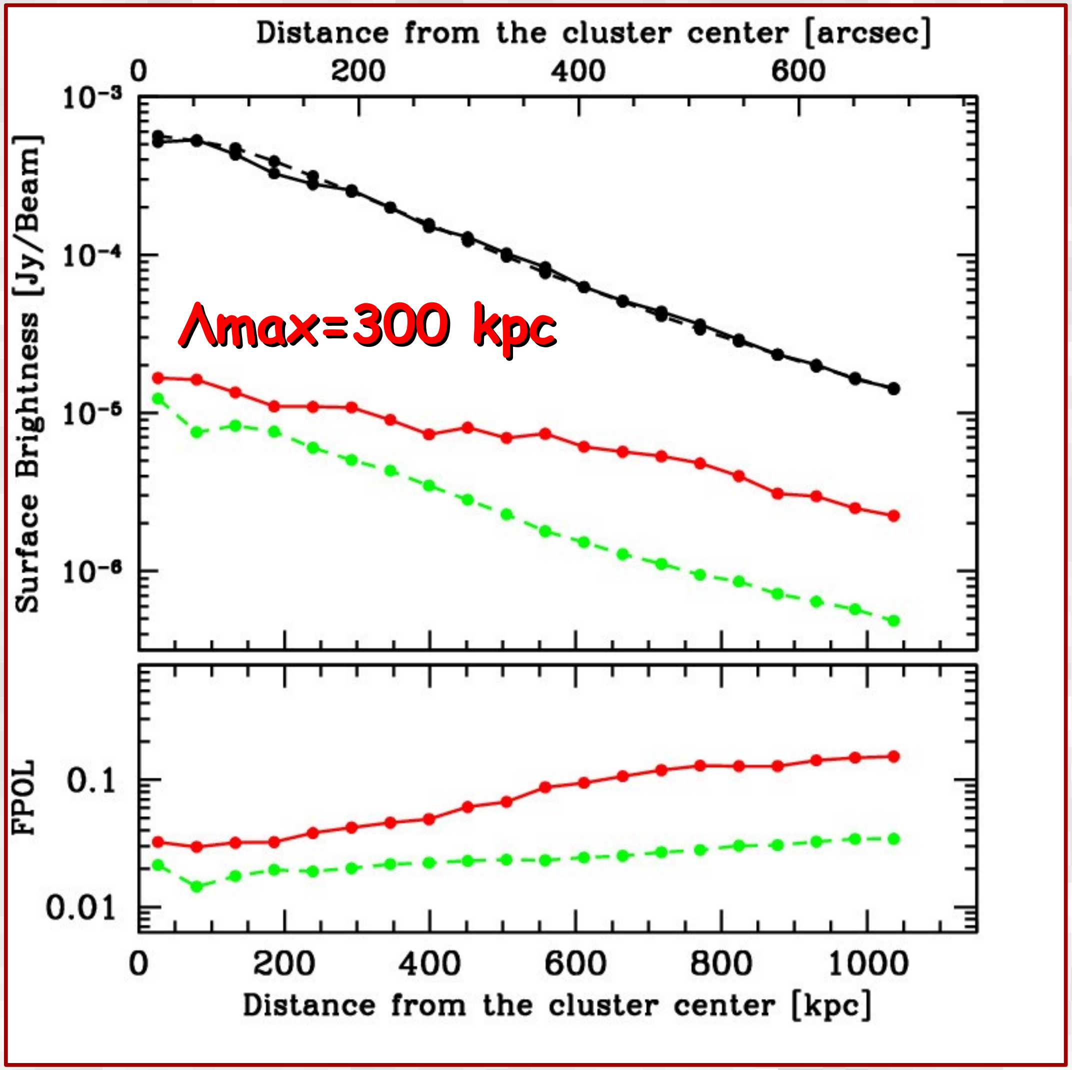


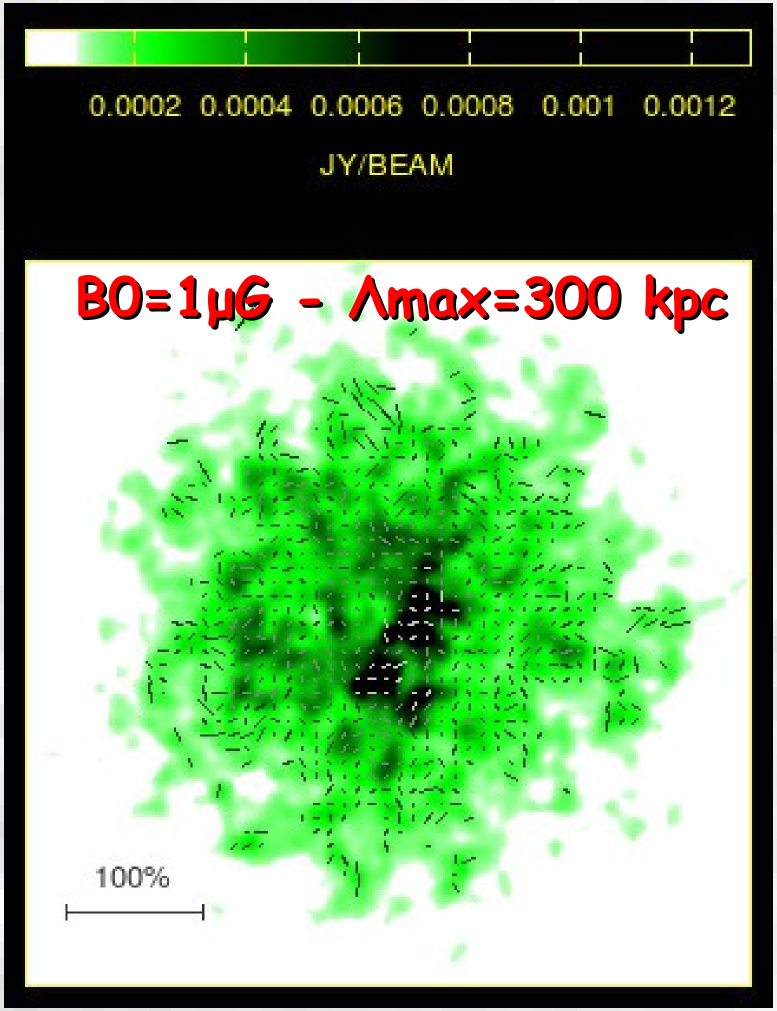
Synchrotron Emission:

TOTAL INTENSITY



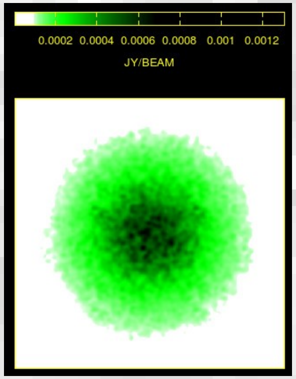
Λmax=30 kpc Λmax=300 kpc Λmax=1000 kpc



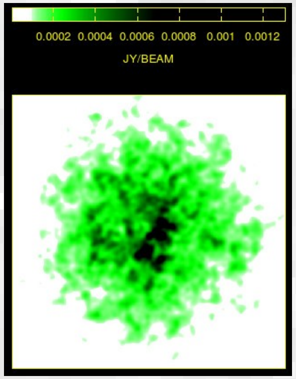


Synchrotron Emission:

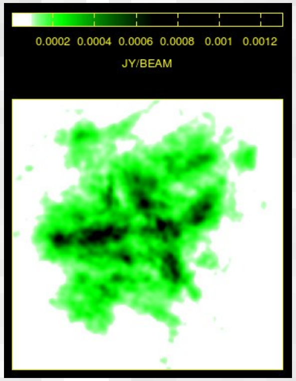
TOTAL INTENSITY



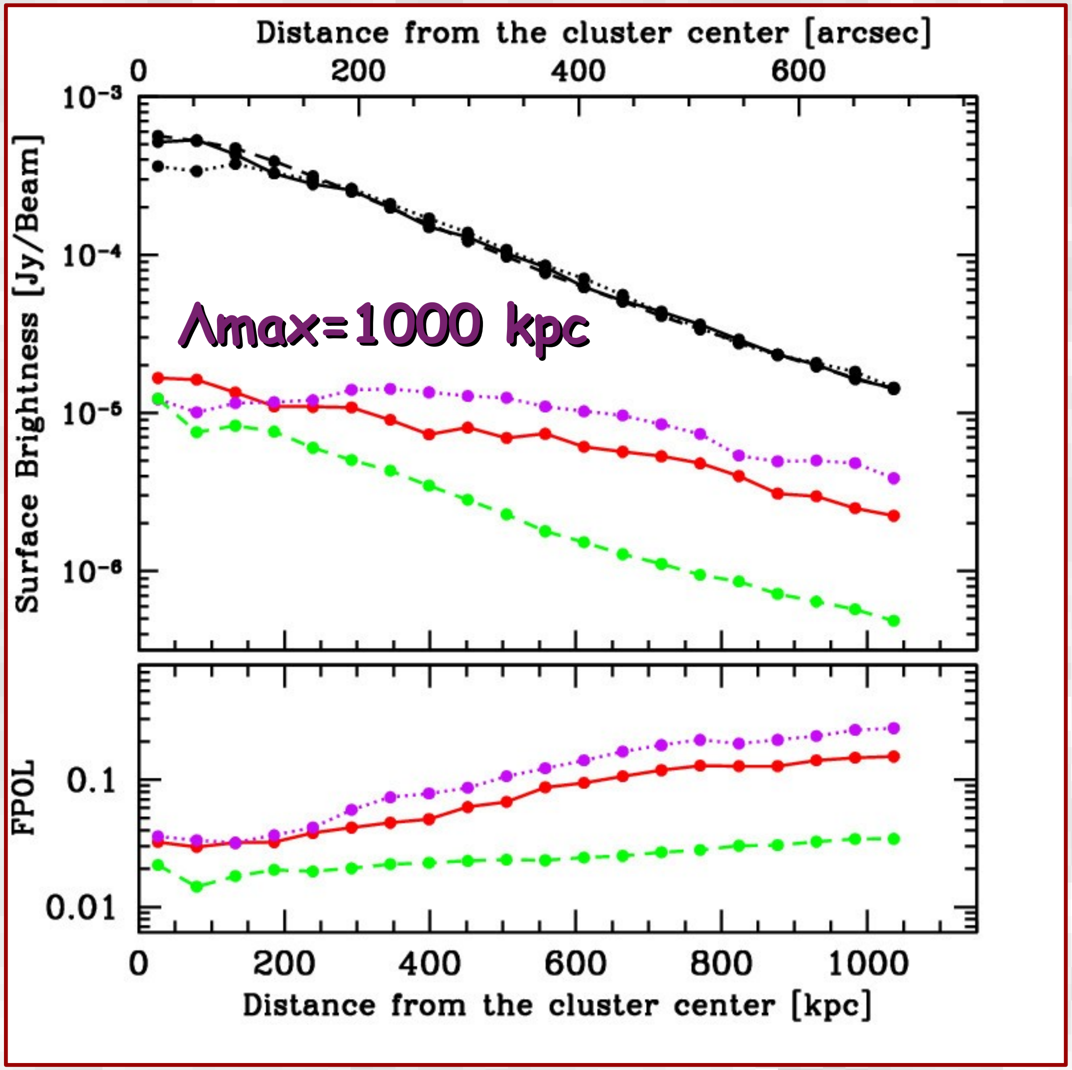
Λmax=30 kpc

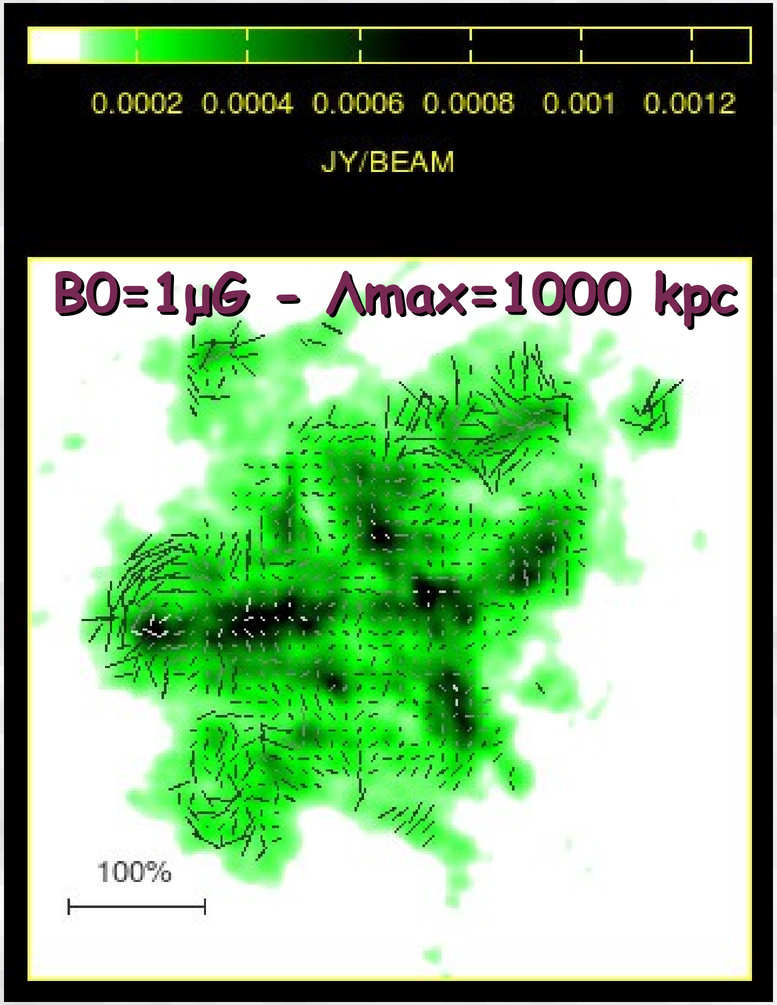


Λmax=300 kpc



Λmax=1000 kpc

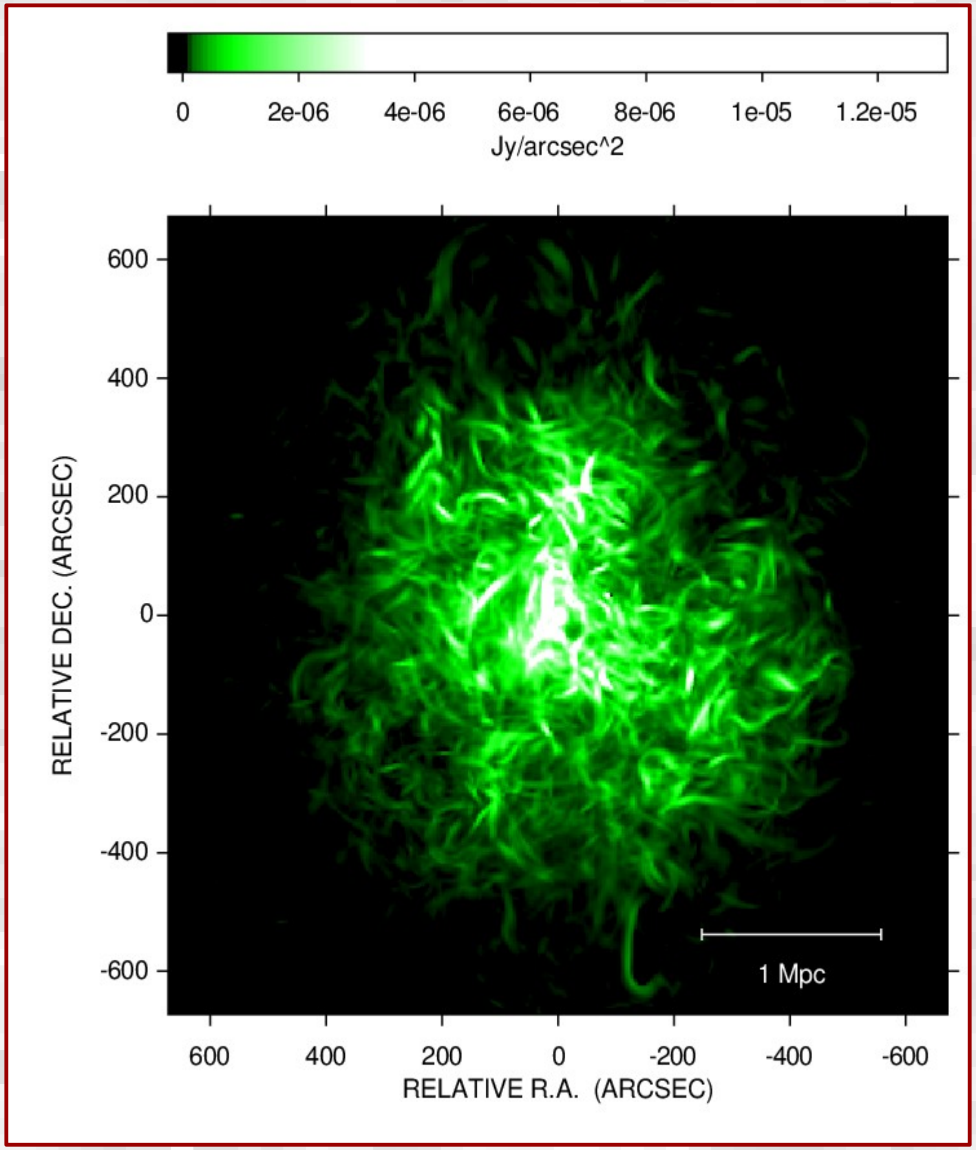




Synchrotron Emission:

Cosmological MHD simulations expect filamentary structures in radio halos

Xu et al. (2012)

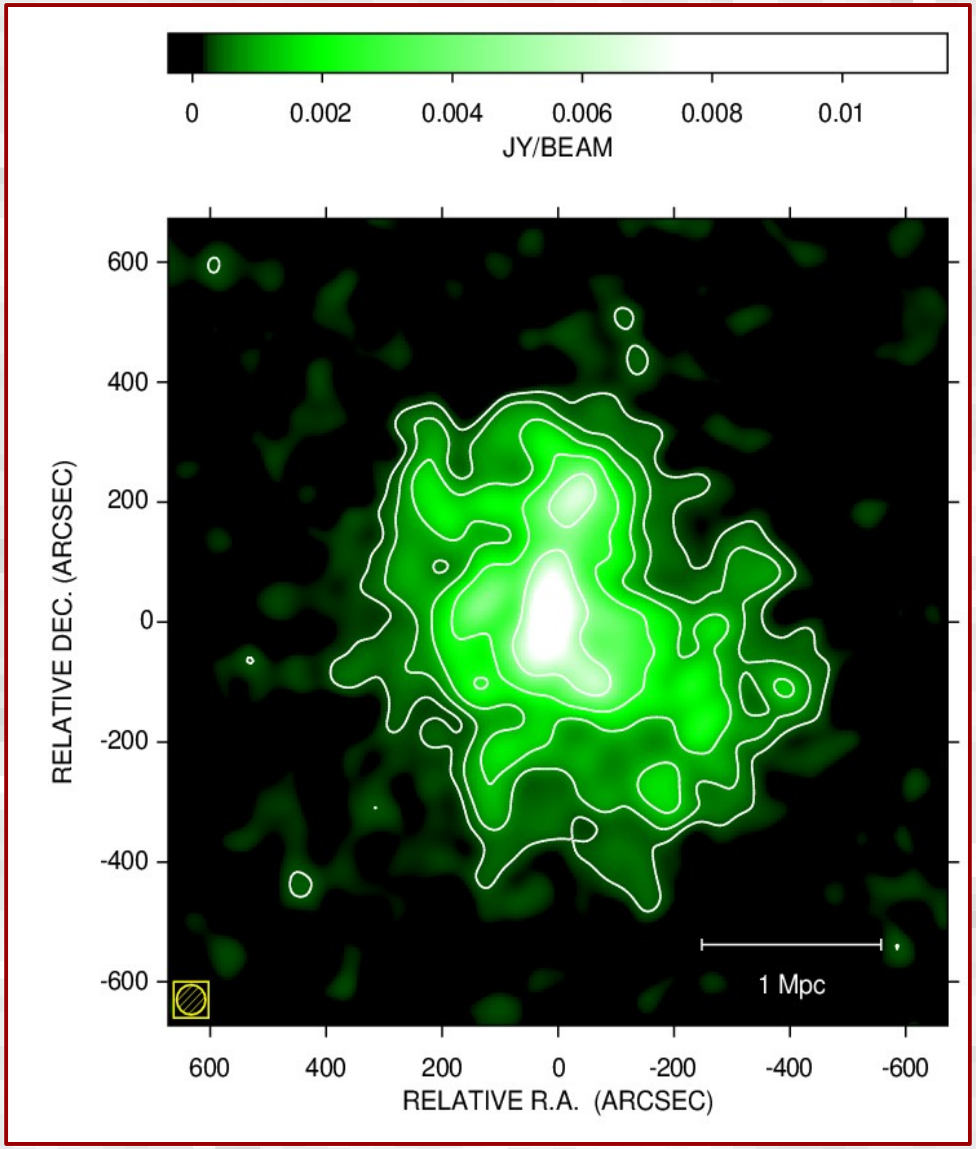


Full resolution emission at 1.4 GHz

Synchrotron Emission:

These filamentary structures are not visible when observed with the resolution and sensitivity of the current facilities

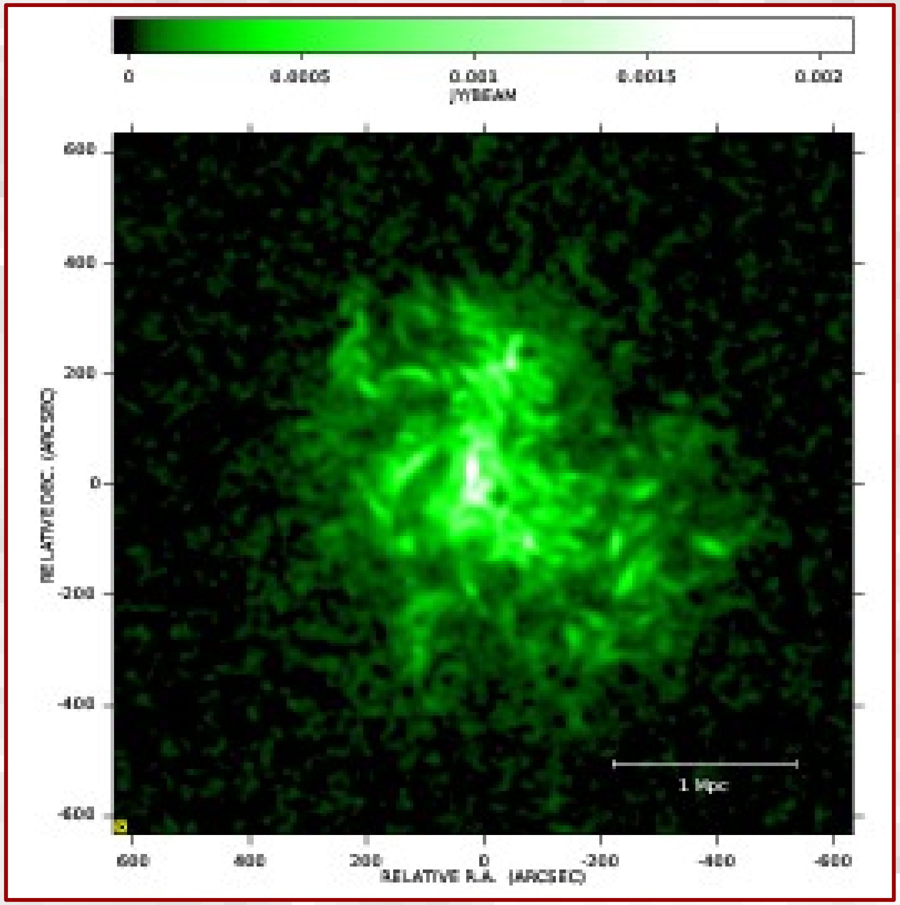
Xu et al. (2012)



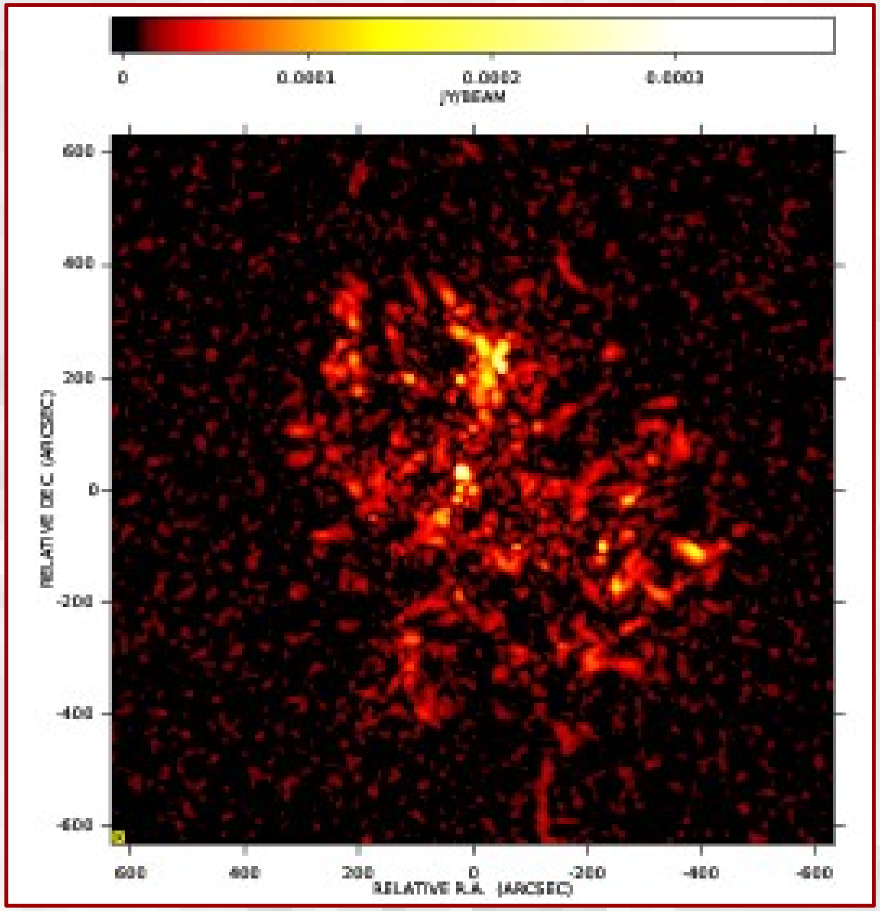
Frequency 1.4 GHz, Resolution 50''
σI=0.1 mJy/beam

Synchrotron Emission:

These filamentary structures may be visible when observed with the resolution and sensitivity of the future facilities **Govoni et al. (2013), Govoni et al. (2015)**



Total Intensity



Polarized Intensity

1.4 GHz - Bandwidth 300 MHz - Resolution 10'' – Sensitivity 10μJy/beam

Survey WODAN with APERTIF
Survey EMU with ASKAP (**see talk by R. Norris**)
Survey POSSUM with ASKAP

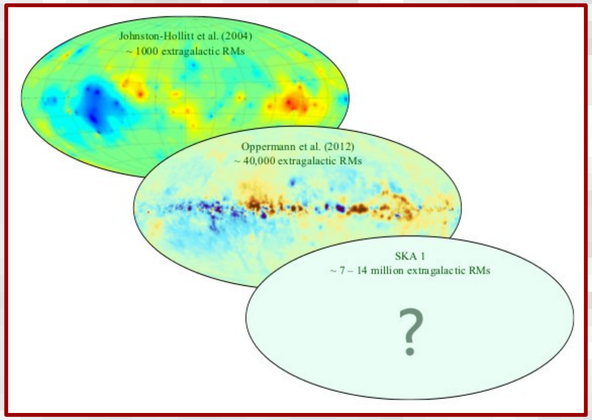
Conclusion:

Despite of their importance, our knowledge about strength, structure, evolution and origin of magnetic fields is still poor and numerous open questions remain unanswered.

The full-Stokes capability of the future high sensitivity and resolution spectro-polarimetric surveys, promise a transformational advance in our understanding of cosmic magnetism.

I have shown how these surveys combined with innovative approaches incorporating theoretical, and numerical techniques, will permit to improve our knowledge of the incidence, strength and morphology of magnetic fields in Galaxy Clusters

Faraday Rotation



Continuum and Polarized Diffuse Synchrotron Emission