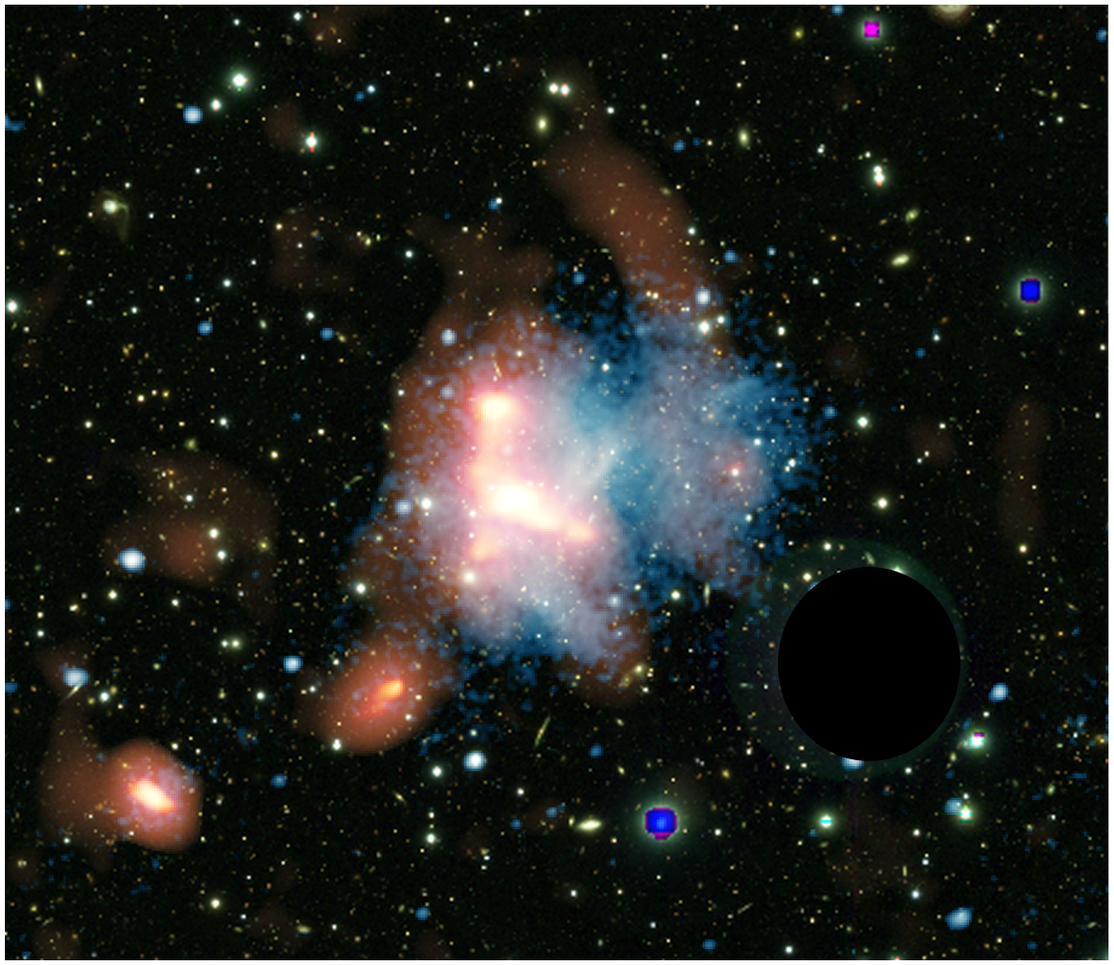
Magnetic fields and radio emission in galaxy clusters: towards the SKA



Annalisa Bonafede

F. Savini, C. Stuardi, F. Vazza

+LOFAR survey KSP

INAF Istituto di Radioastronomia

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

erc European Re

DRANOEL
ERC - Stg16 714245

FARE
RICERCA IN ITALIA
FRAMEWORK PER L'ATTRAZIONE E IL RAFFORZAMENTO DELLE ECCELLENZE PER LA RICERCA IN ITALIA

Galaxy clusters

~100 Galaxies in 9 Mpc^3

Dark matter dominated
~80% of the cluster mass

500 kpc

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Hot Gas
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n ~1e-3 cm^{-3}
—> Brehmsstrahlung
(soft X)

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—> Brehmsstrahlung
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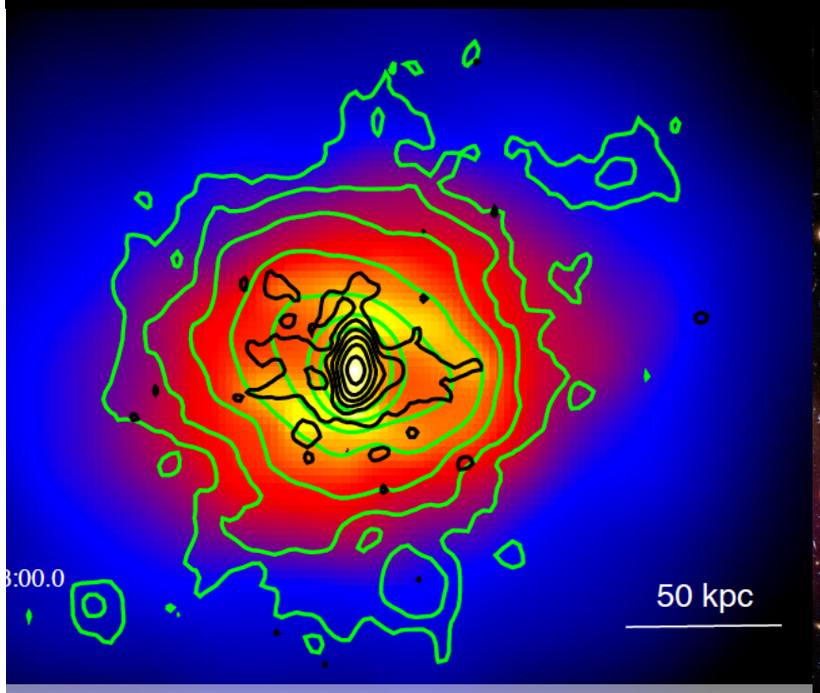
Magnetic field &
Relativistic electrons
—> Synchrotron emission
(radio)
only in some clusters

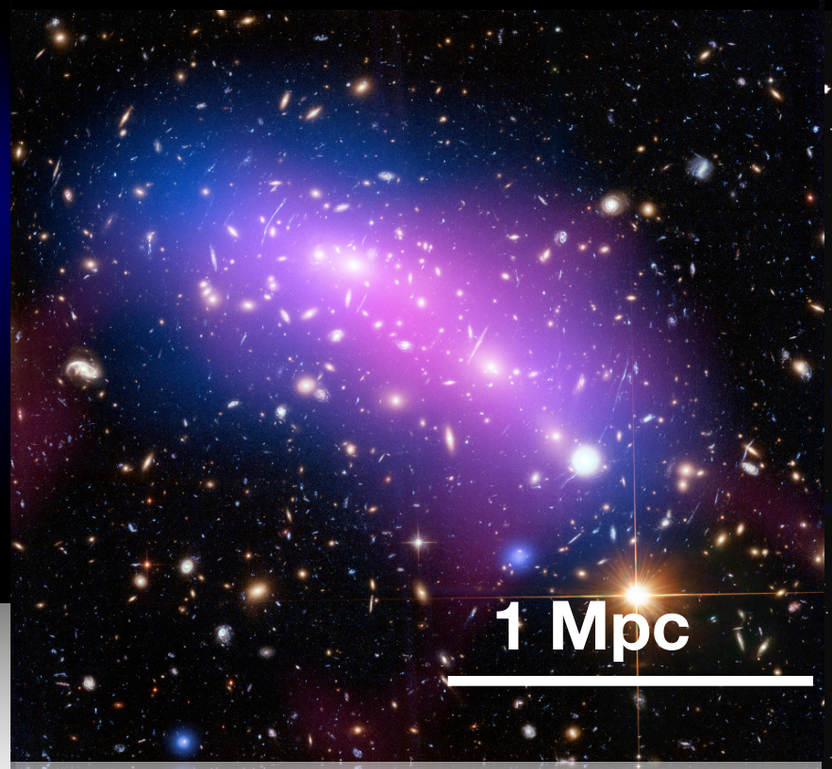
RADIO SOURCES IN CLUSTERS

Radio contours
X-ray (gas) colours



Mini halos
Gitti et al. (2012)

Radio
X-ray (gas)



Radio halos
Ogrean et al. (2015)

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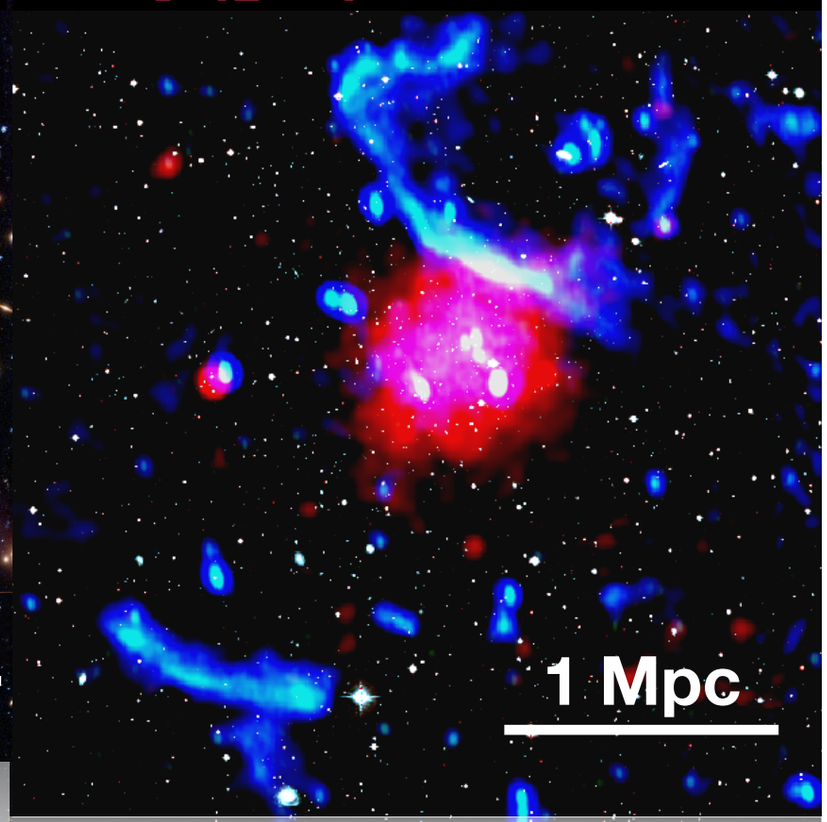
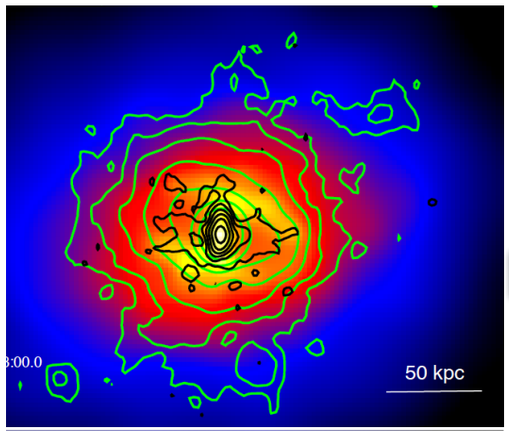


Radio relics
Bonafede et al. (2014)

Virialized systems

Merging systems

CONNECTION WITH DYNAMICAL STATE



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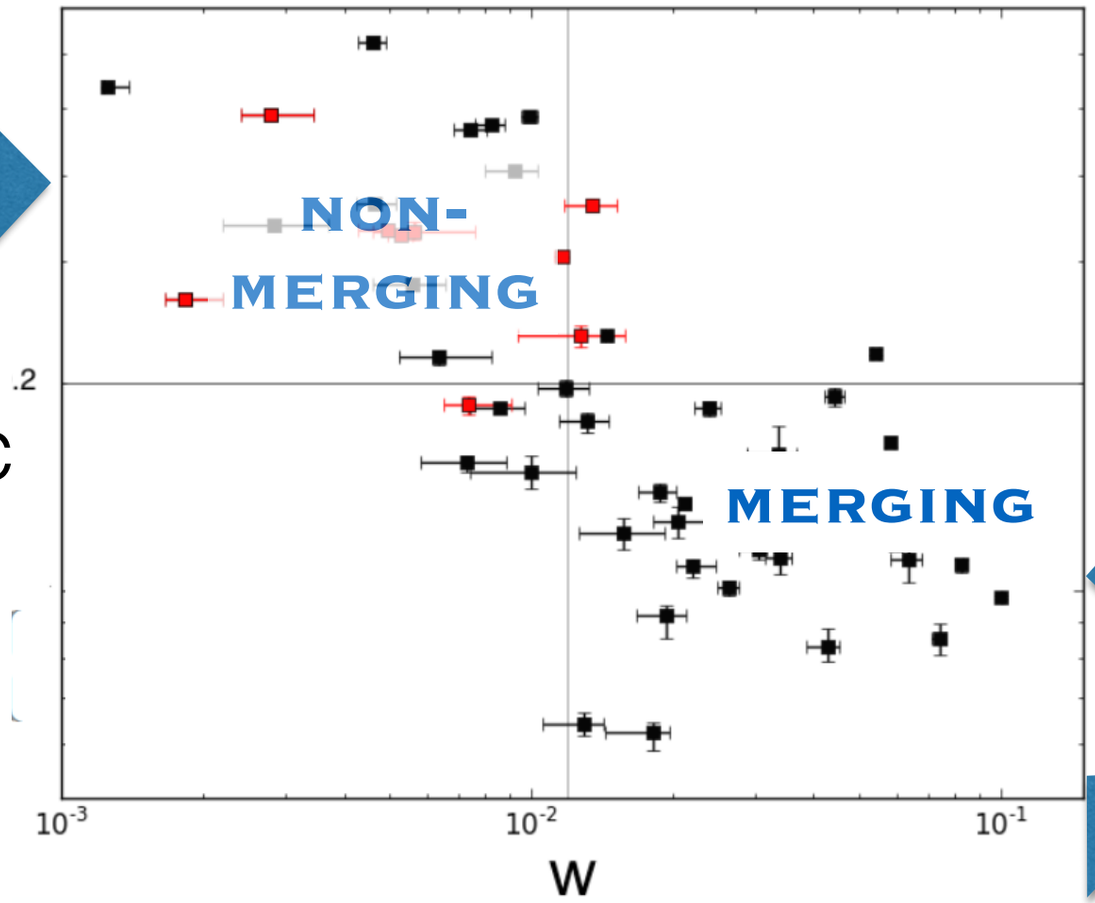

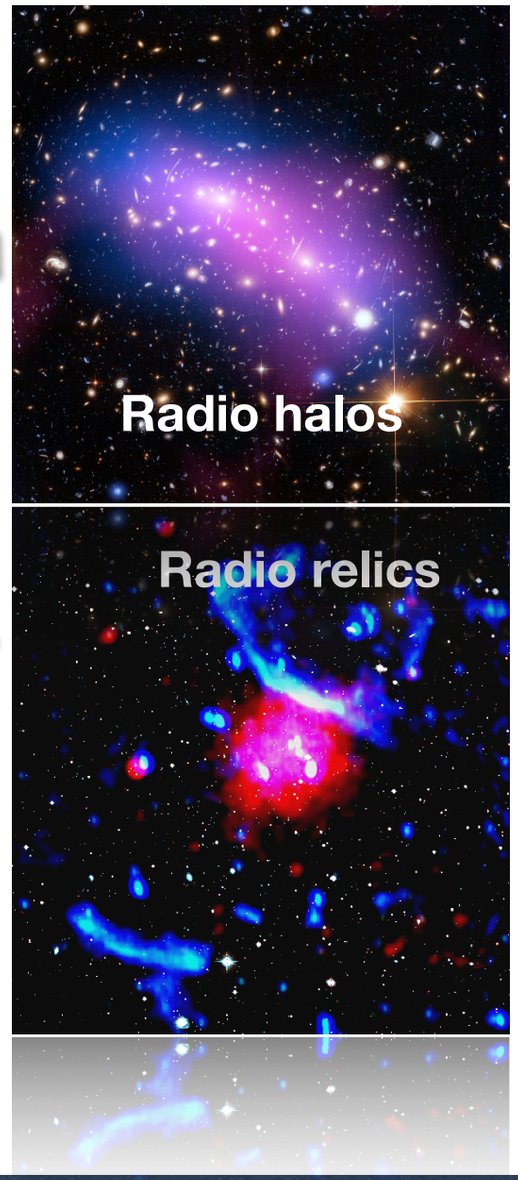

Tracing **co-evolution** of non-thermal component with **cluster dynamics**

WHAT CAN WE LEARN FROM B STUDIES?

(Re)Acceleration processes - Radio sources in the ICM

Microphysics of the ICM

Small-scale instabilities?

Origin of magnetic fields?

B from AGN (e.g Ryu et al. 08, Donnert et al 09)
B amplification from initial seed (e.g. Beresnyak & Miniati 16)
Growth of small-scale instabilities (e.g. Kunz 10)

Can reproduce ~ μG magnetic field in cluster cores

See talk by F. Vazza

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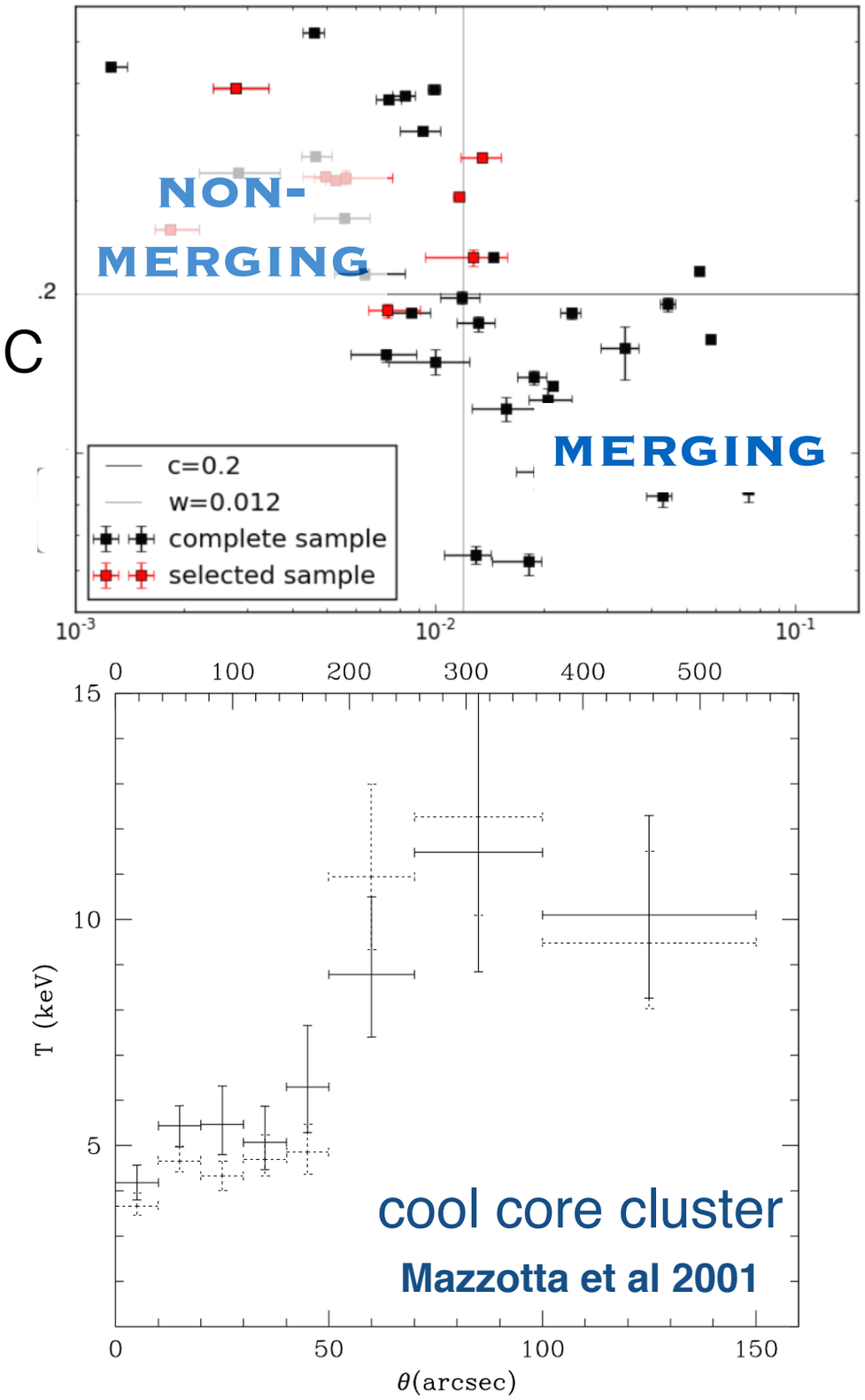
Outline

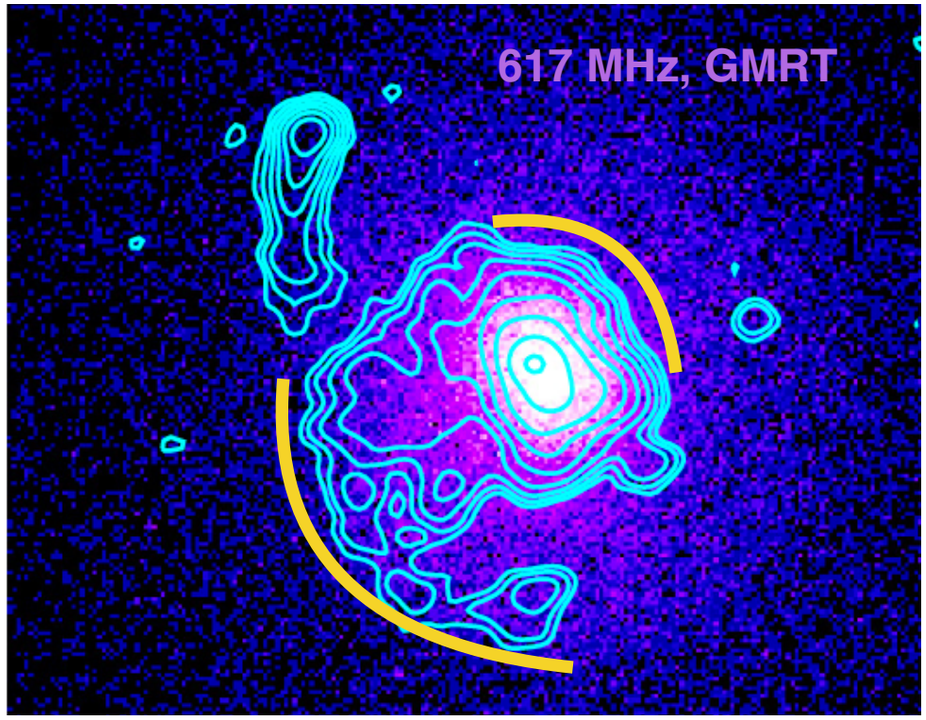
- News from [some] SKA precursors
  LOFAR and JVLA
- New techniques, new challenges
- Forecasts for the SKA

News from LOFAR observations: I



Mini halo confined by cold fronts

[Giacintucci et al 2014]



F. Savini, AB et al. 2018

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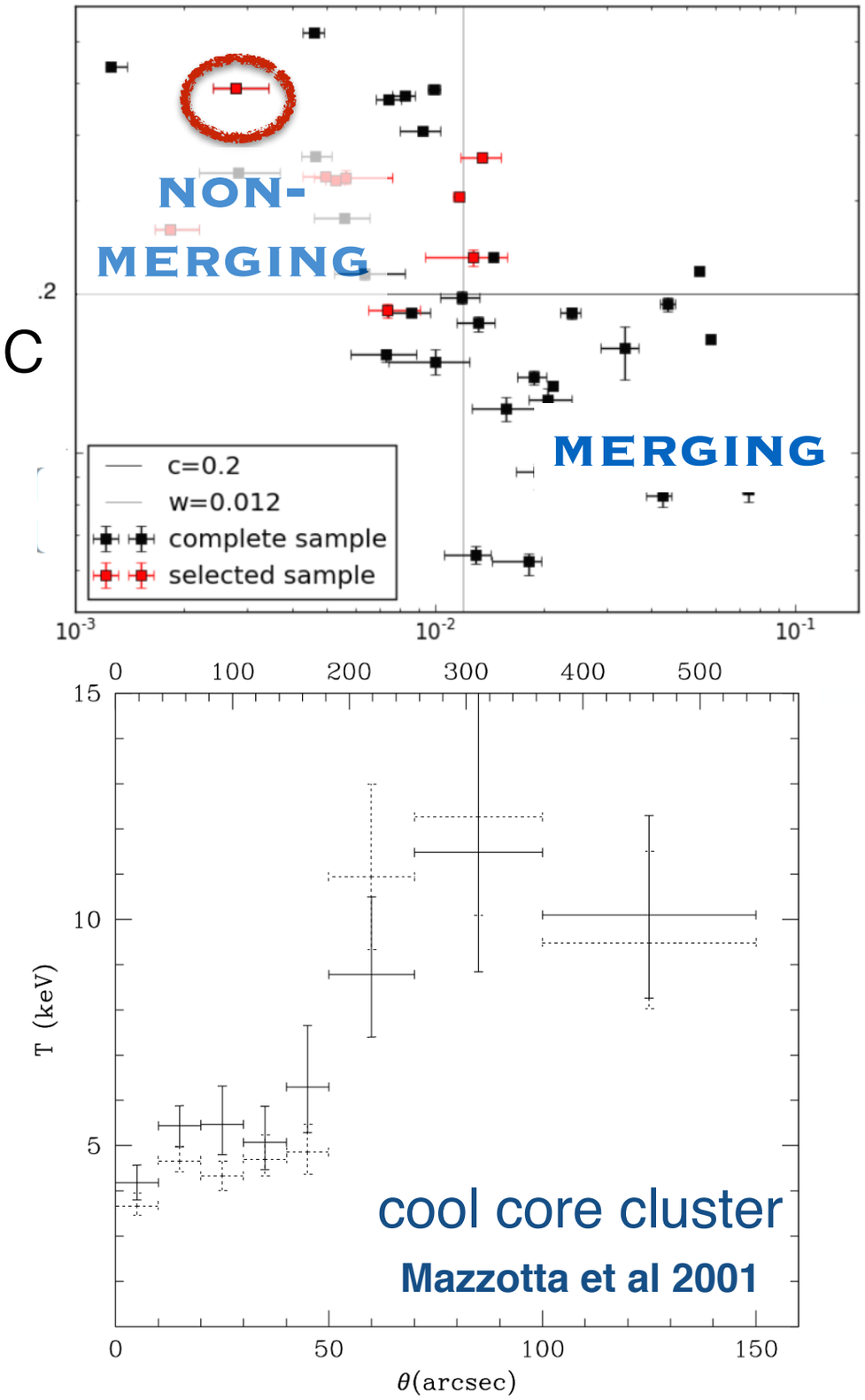

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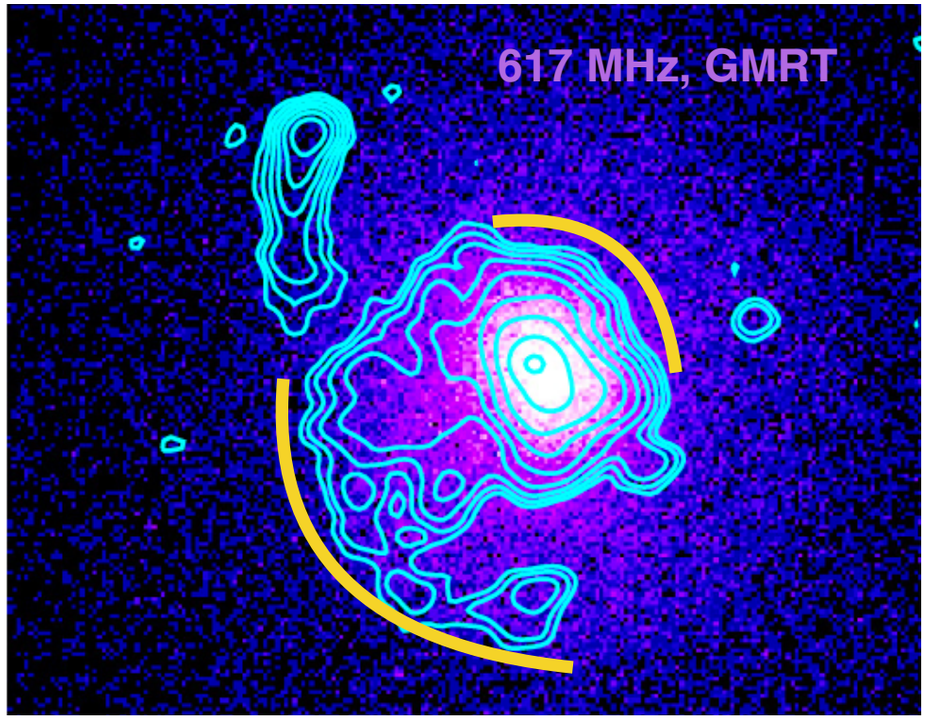

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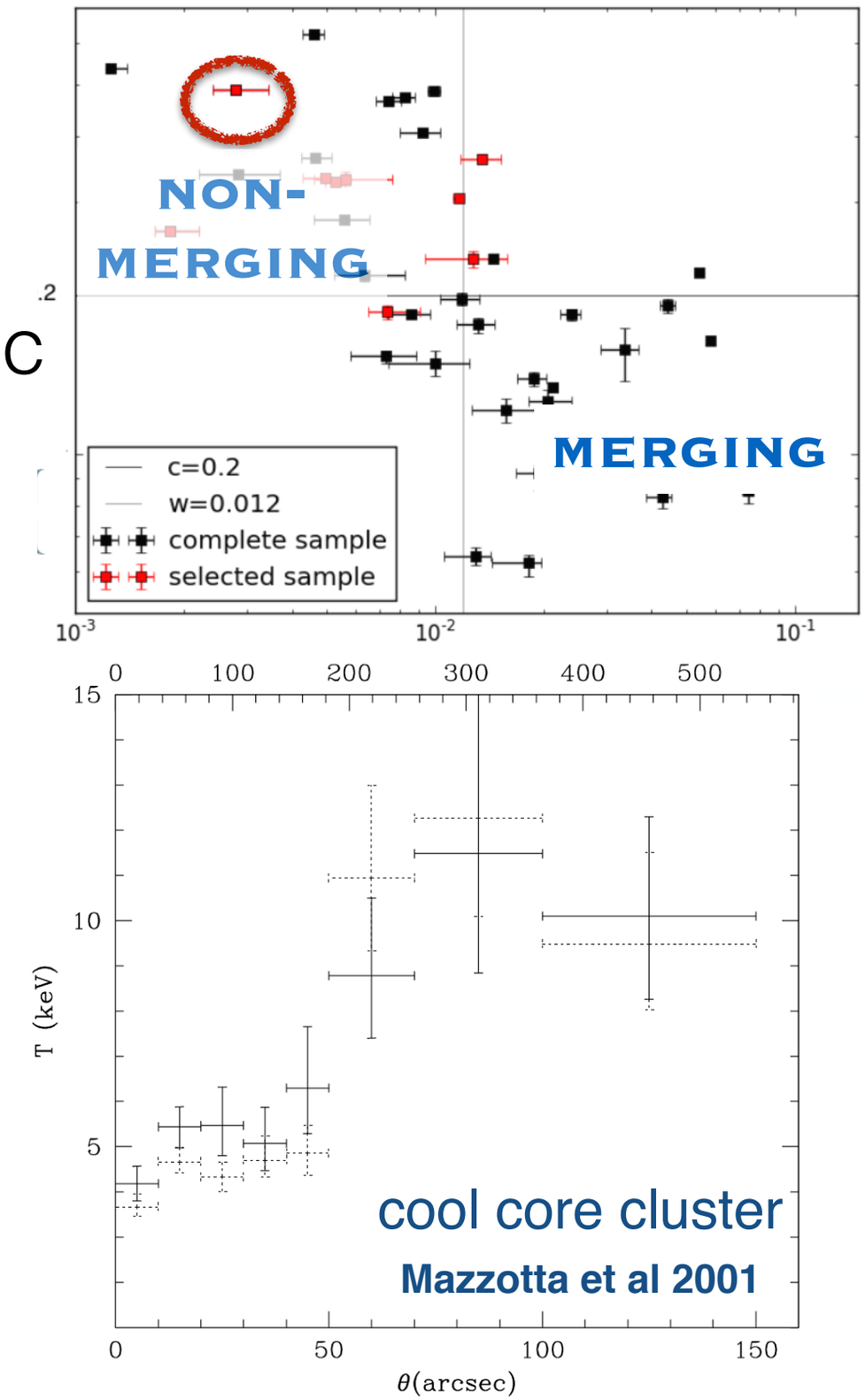
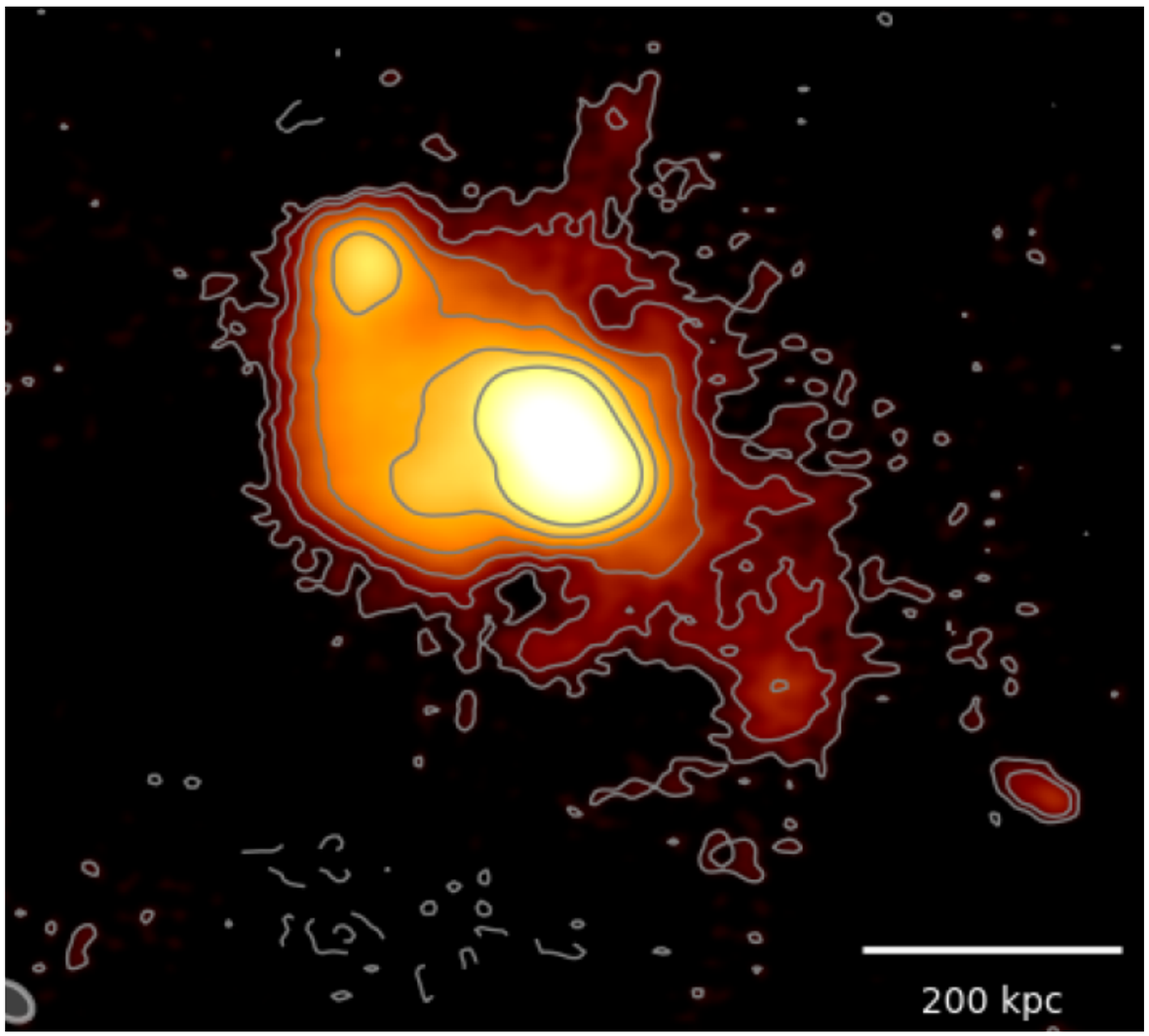


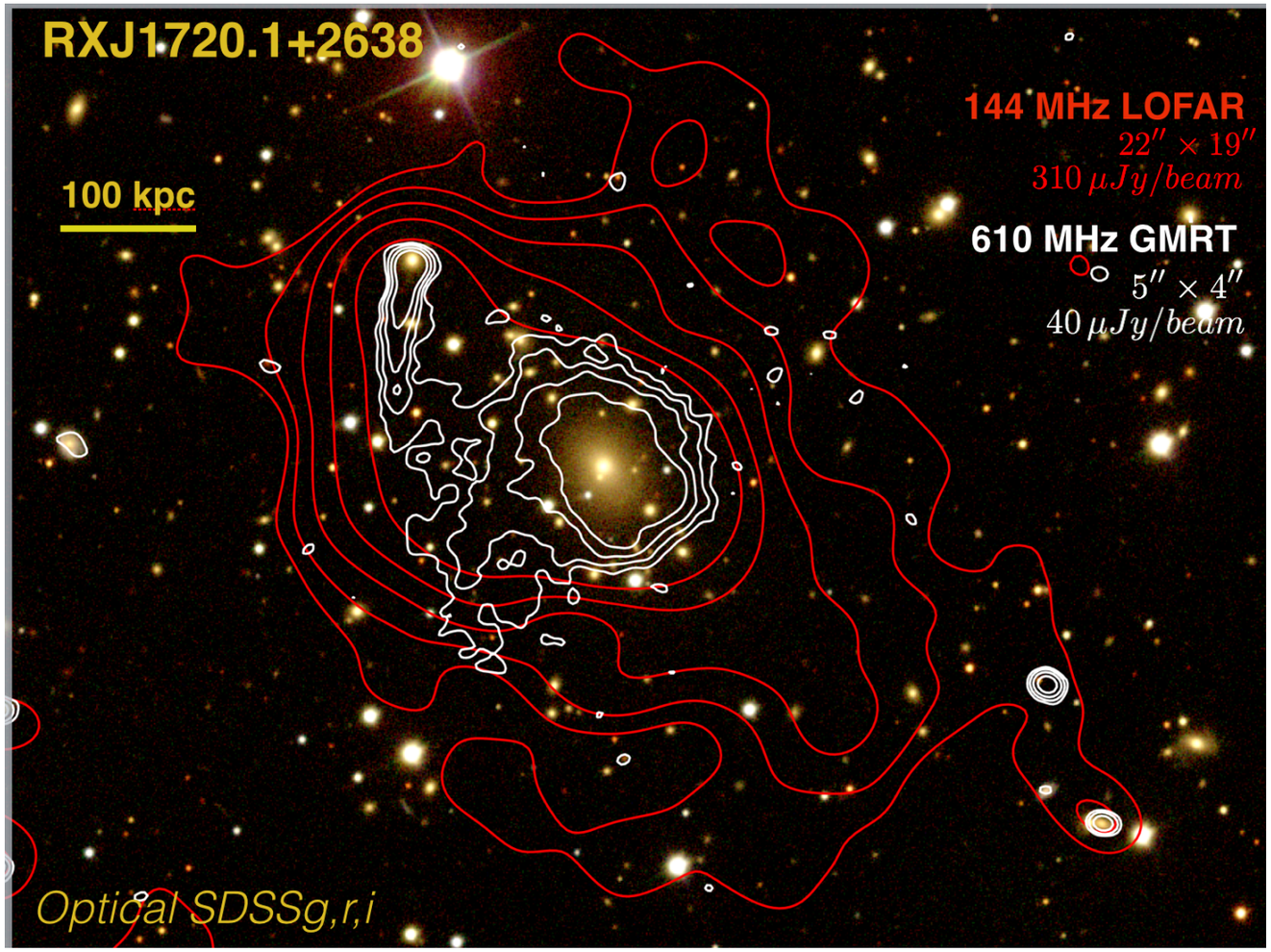


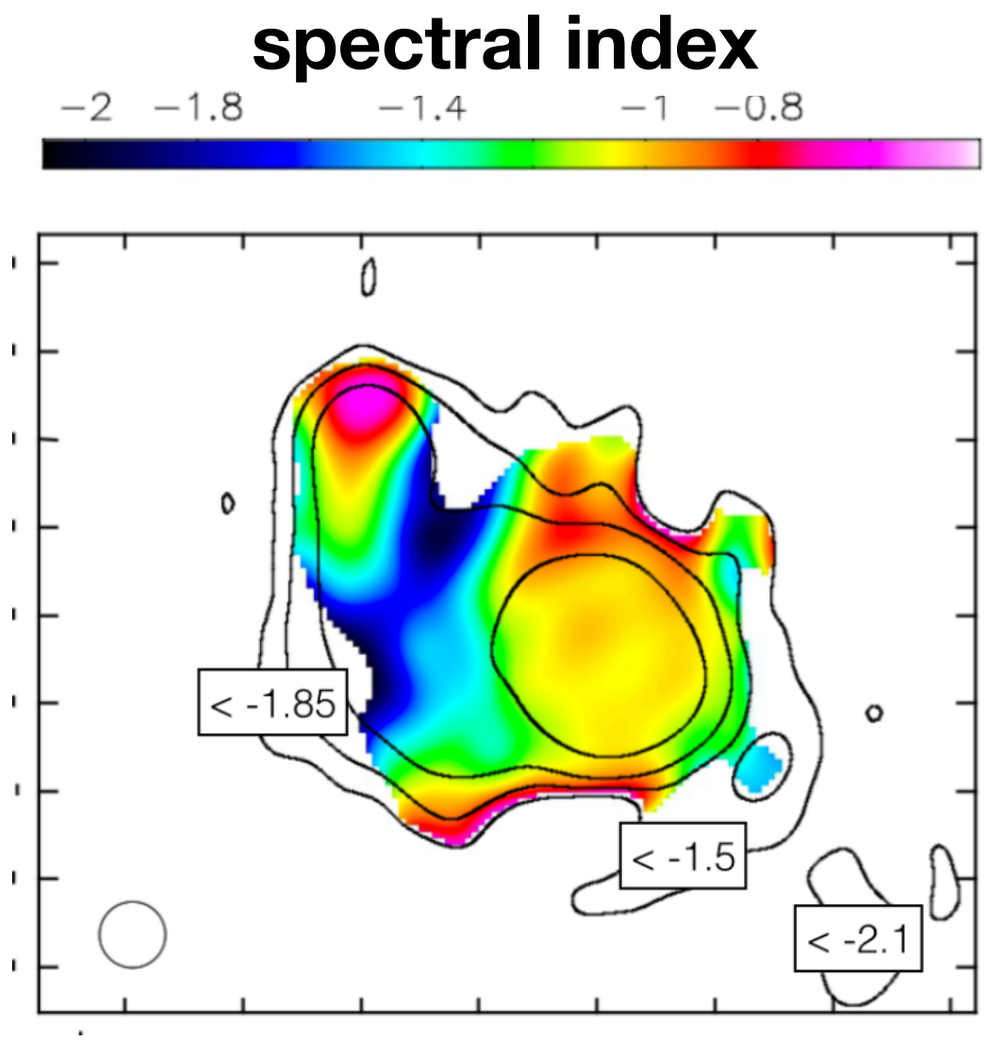
LOFAR observations (144 MHz)
14”x9” resolution, noise ~200 μJy/beam

Emission well beyond the cold fronts!

F. Savini, AB et al. 2018

News from LOFAR observations: I





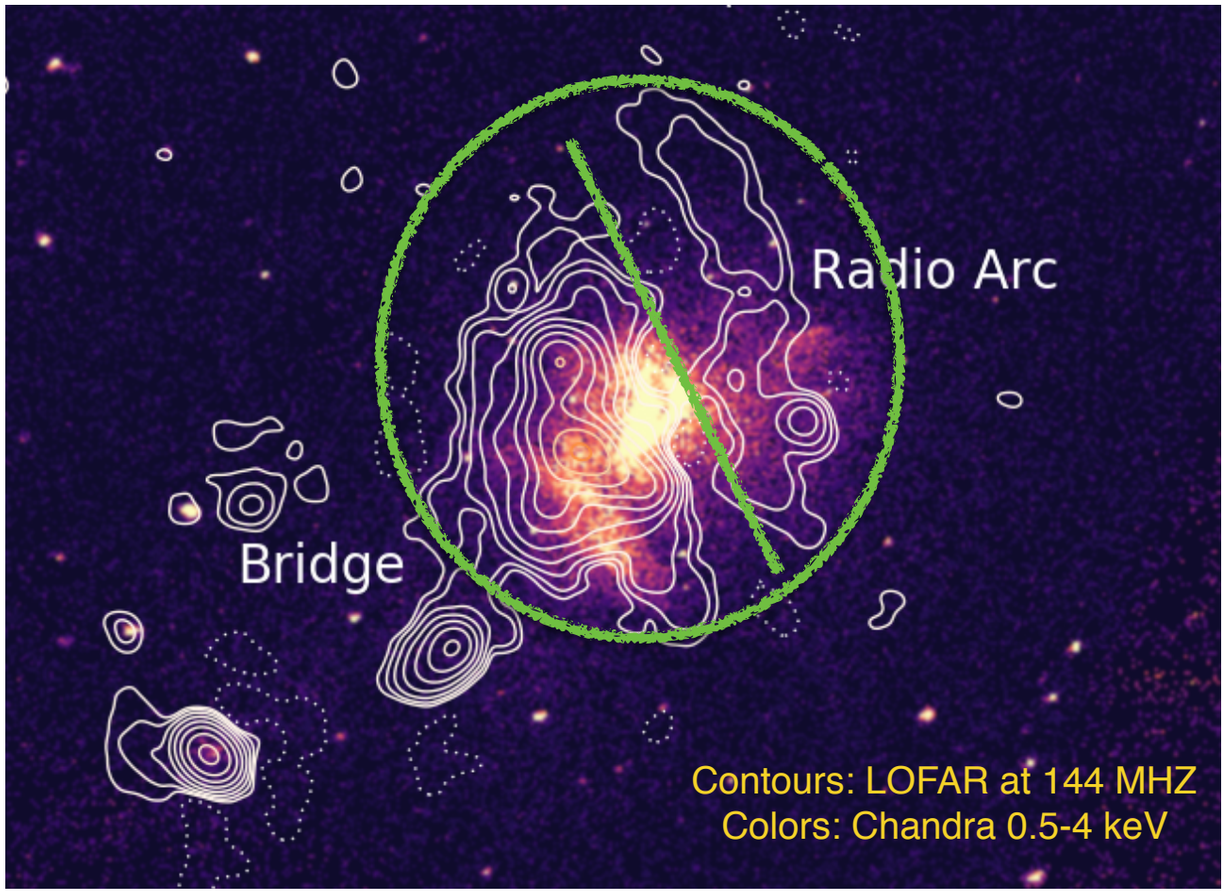
- Flat, uniform spectrum in the core
- Steep emission SW and NE regions

New mechanism of particle acceleration?
Core-sloshing accelerating particles on cluster scale?

F. Savini, AB et al. 2018

News from LOFAR observations: II

Interplay thermal - non-thermal emission



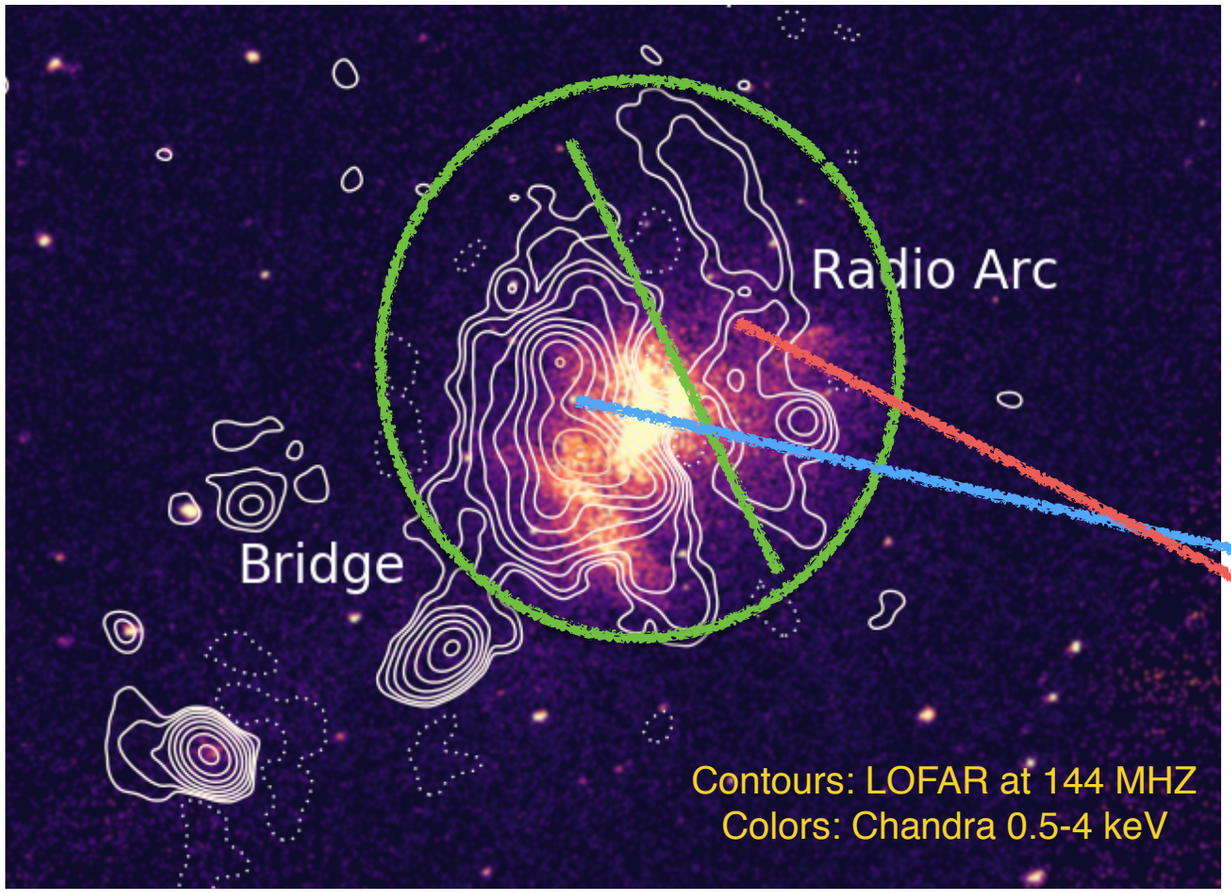
Gas density fluctuations

$$\frac{\delta\rho_k}{\rho} = \eta\frac{V_k}{c_s}$$

Zhuravleva et al. 2014, Gaspari et al 2014

News from LOFAR observations: II

Interplay thermal - non-thermal emission



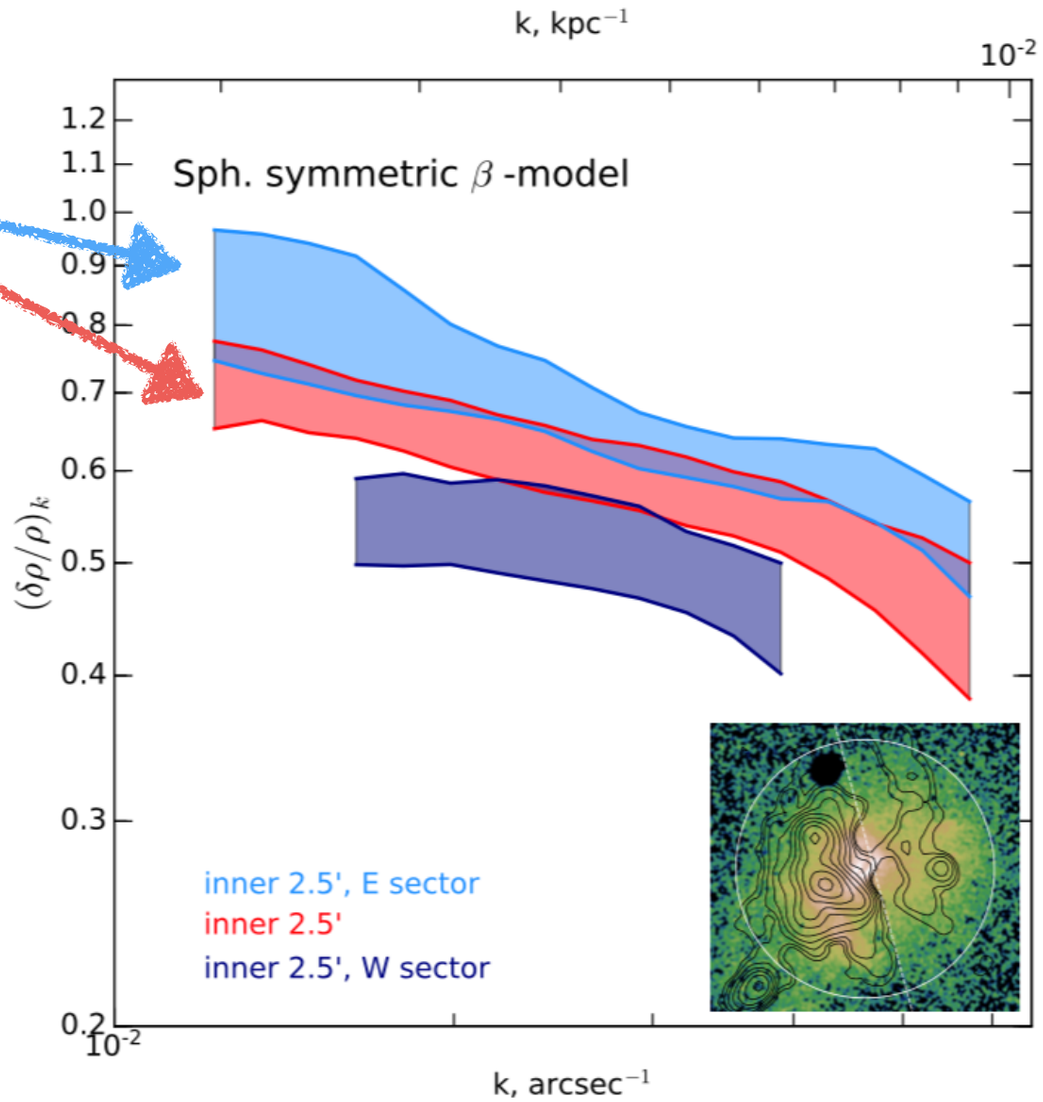
E_kin/E_therm twice larger in the left region

Radio Power > 40 times higher

Gas density fluctuations

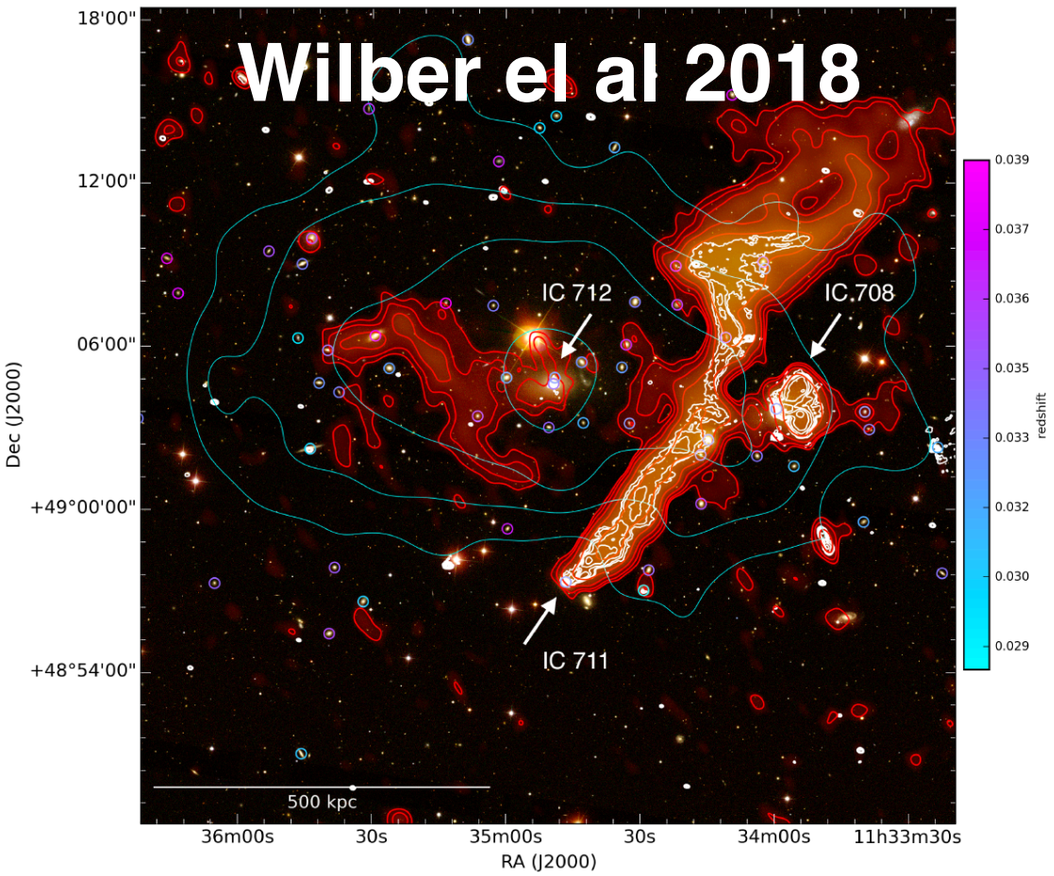
$$\frac{\delta\rho_k}{\rho} = \eta\frac{V_k}{c_s}$$

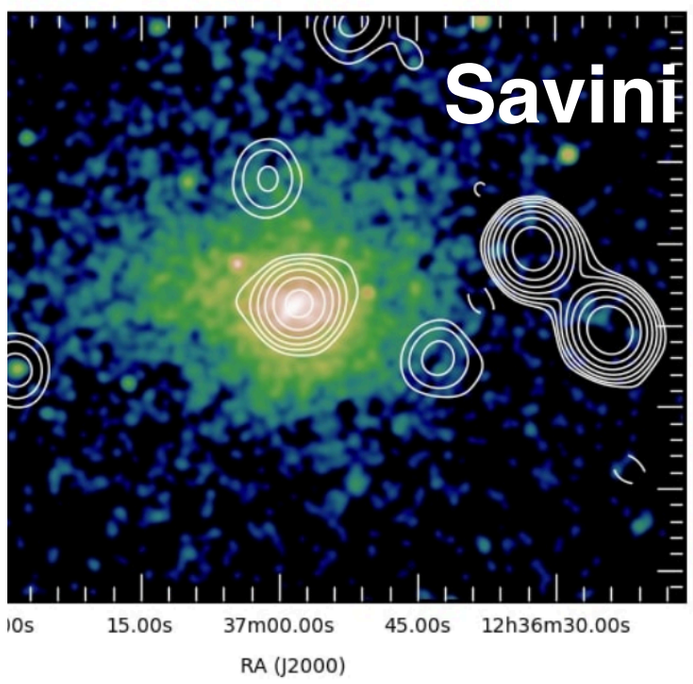
Zhuravleva et al. 2014, Gaspari et al 2014

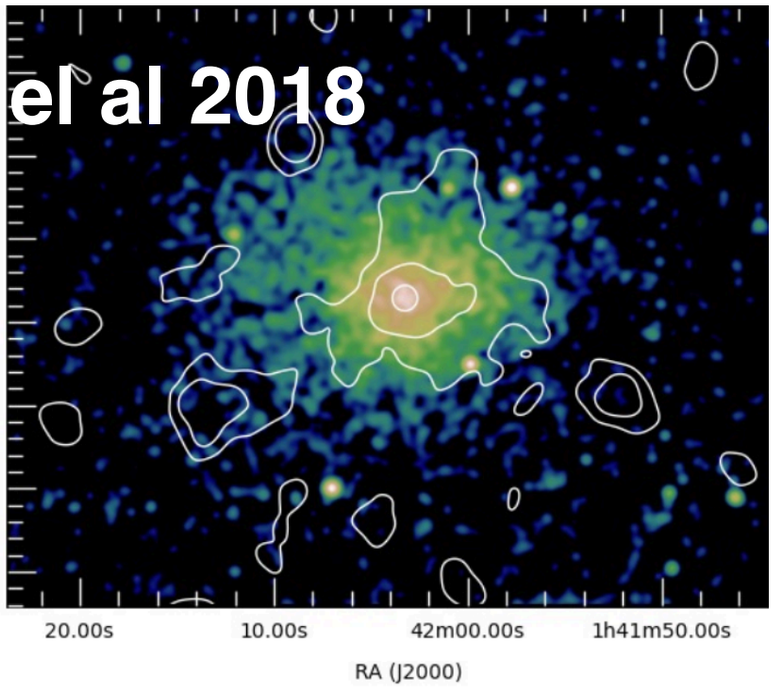


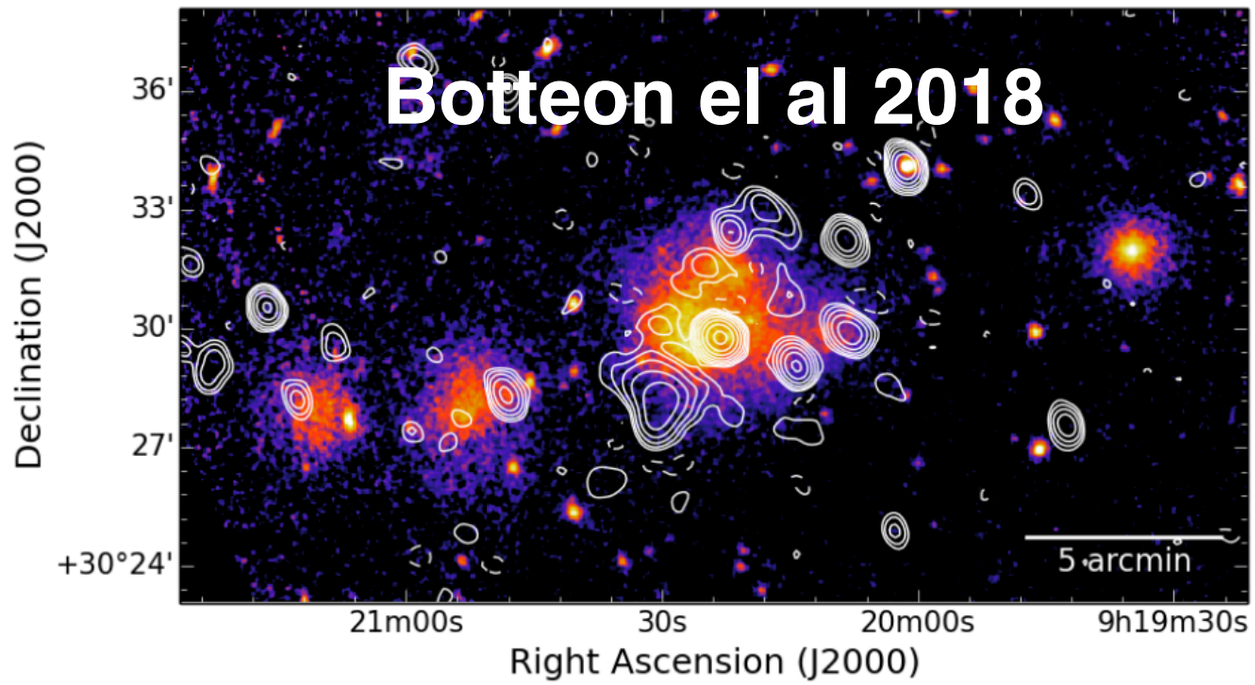
Bonafede et al. 2018

More LOFAR results









A&A Special Issue: LOFAR survey

Authors in the Italian community:
Bonafede, Botteon, Brienza, Brunetti, Cassano, Murgia, Prandoni, Vacca, Vazza, Wittor

Conclusions so far

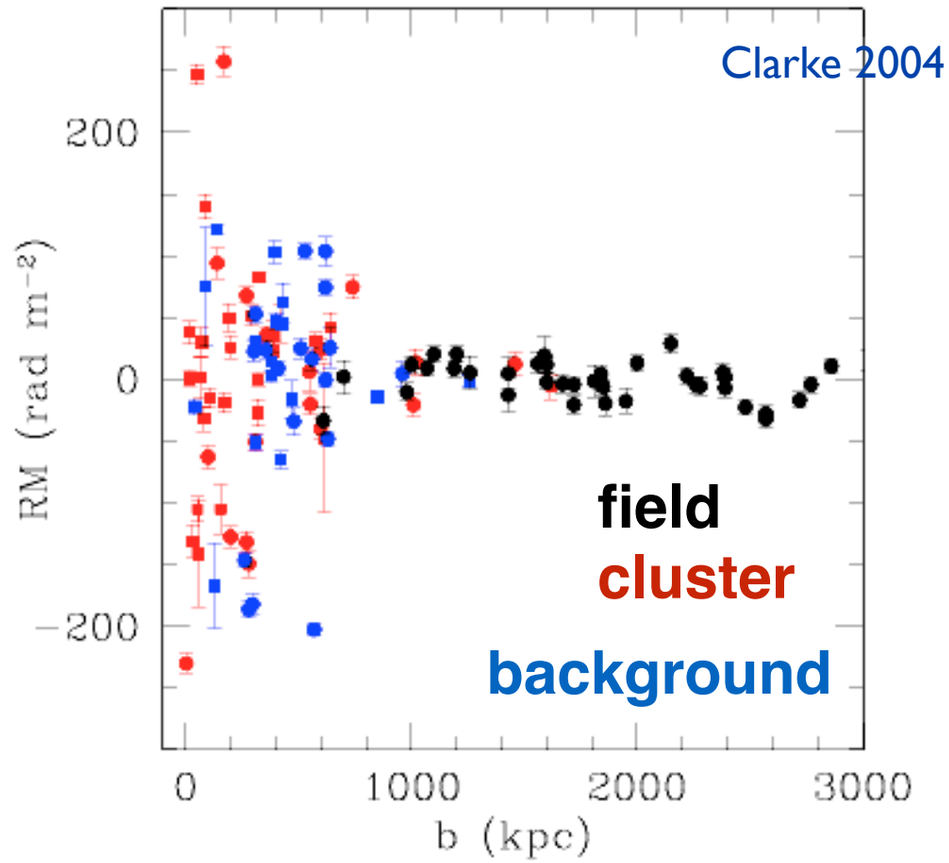
- New emission in galaxy clusters
- $P \propto \gamma_L^2 B^2$

  Independent measurement of B needed

HOW CAN WE CONSTRAINT MAGNETIC FIELDS?

Rotation Measure λ^2 fit

$$\Psi_{obs} = \Psi_{int} + K \underbrace{\int_{los} B_{los} n dl}_{\mathbf{RM}} \lambda^2$$



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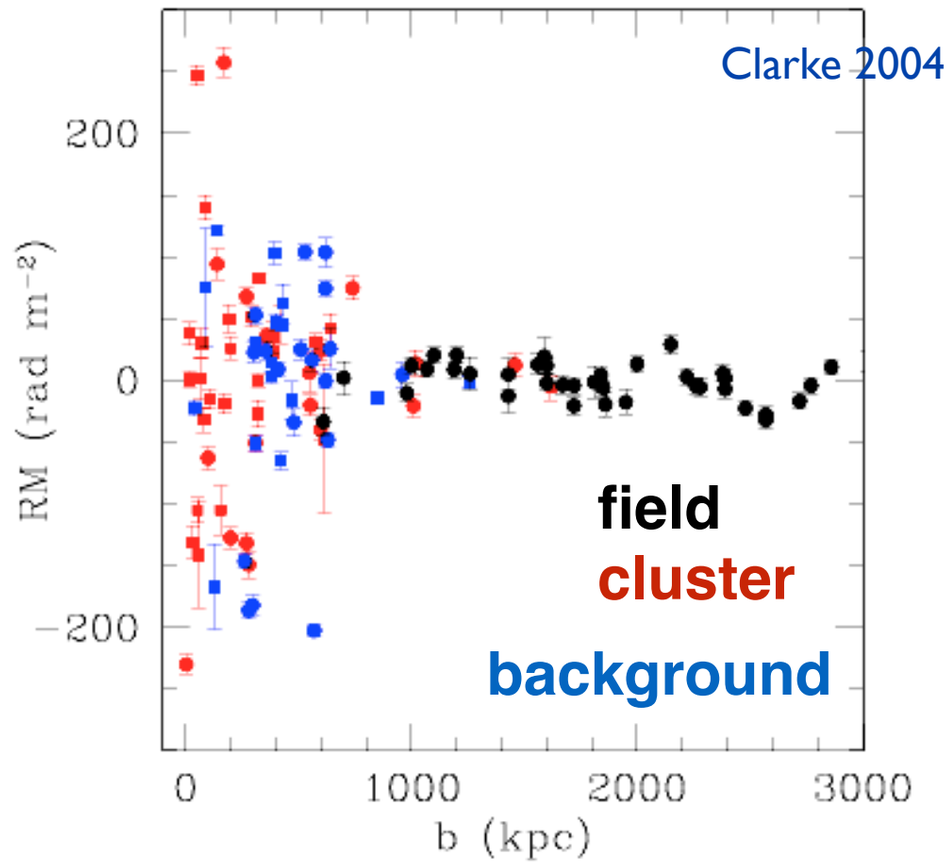
$$P(\lambda^2) = \int_{-\infty}^{+\infty} F(\phi) e^{2i\phi\lambda^2} d\phi$$



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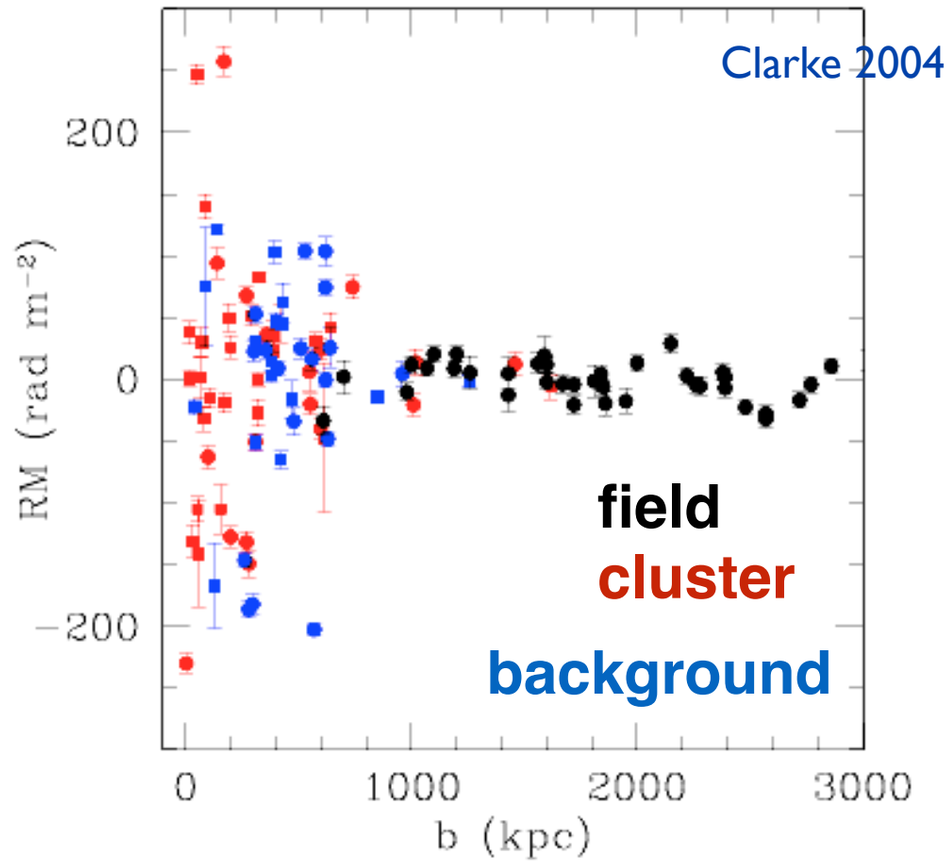

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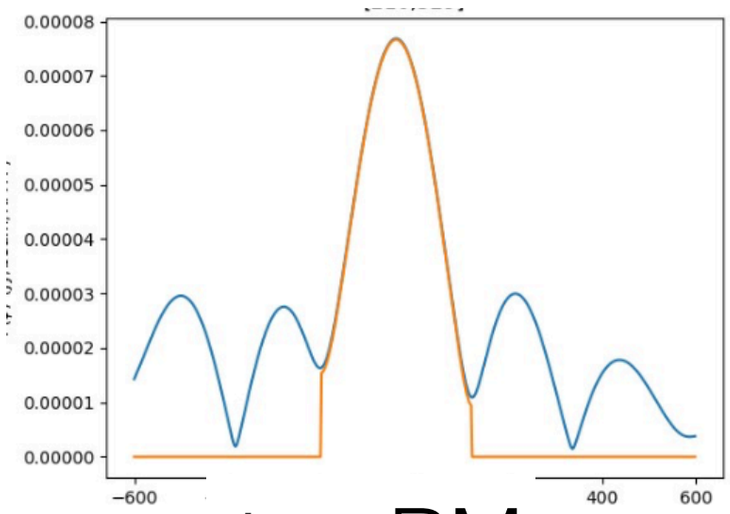
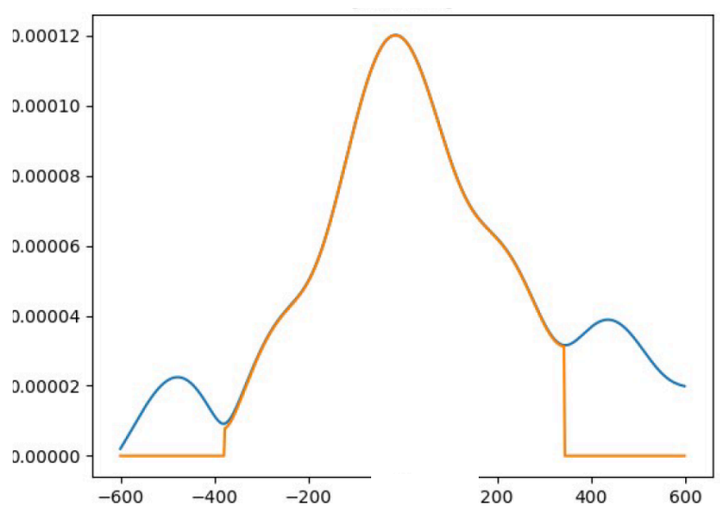
F(ϕ)



ϕ = RM

F(ϕ)



ϕ

credits: Stuardi

MODELING OF THE MAGNETIC FIELD

Obtaining mock RM images

observed $RM = \int_0^d B_{los} n dl$

MODELING OF THE MAGNETIC FIELD

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model for gas distribution From X-ray emission/ cosmological simulations

MODELING OF THE MAGNETIC FIELD

Obtaining mock RM images

observed $RM = \int_0^d B_{los} n dl$

model for gas distribution From X-ray emission/ cosmological simulations

3D model for B

B components: Gaussian distribution

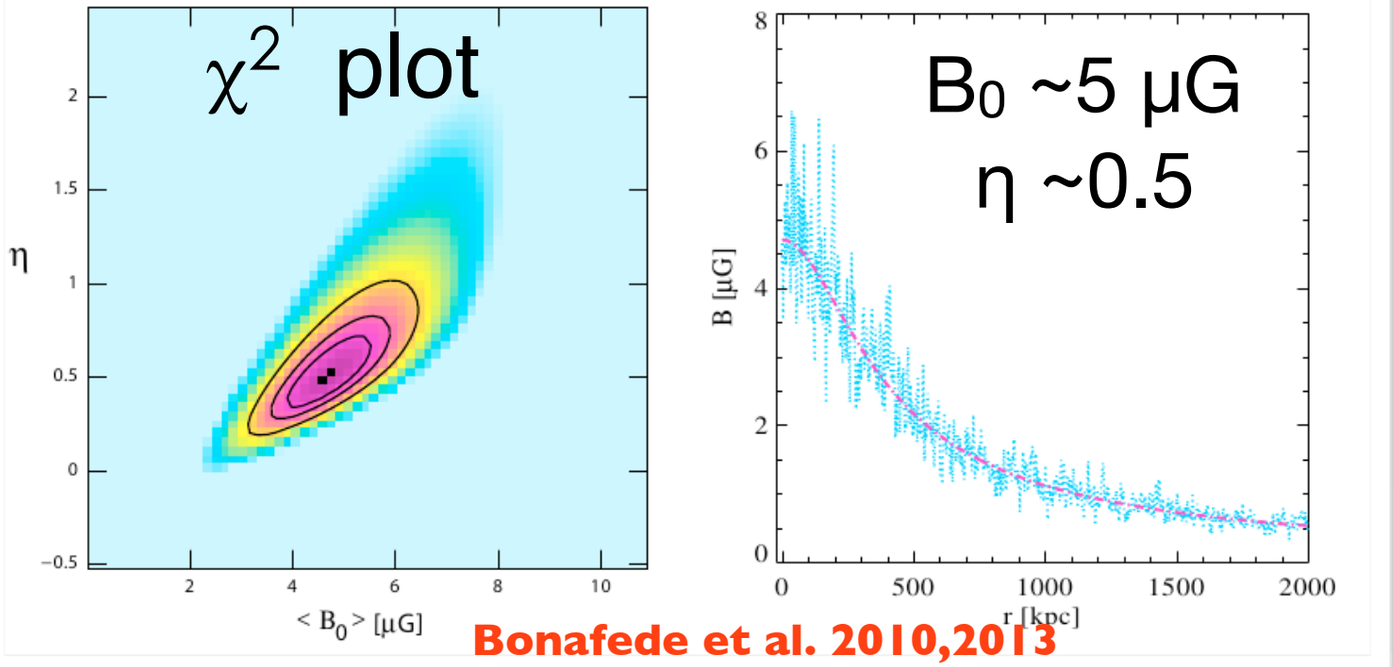
B spectrum: power law $|B_k|^2 \propto k^{-n}$

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

CONSTRAINTS ON THE MAGNETIC FIELD

Obtaining mock RM images

$$B \propto B_0 n_{gas}^{\eta}$$



Bonafede et al. 2010,2013

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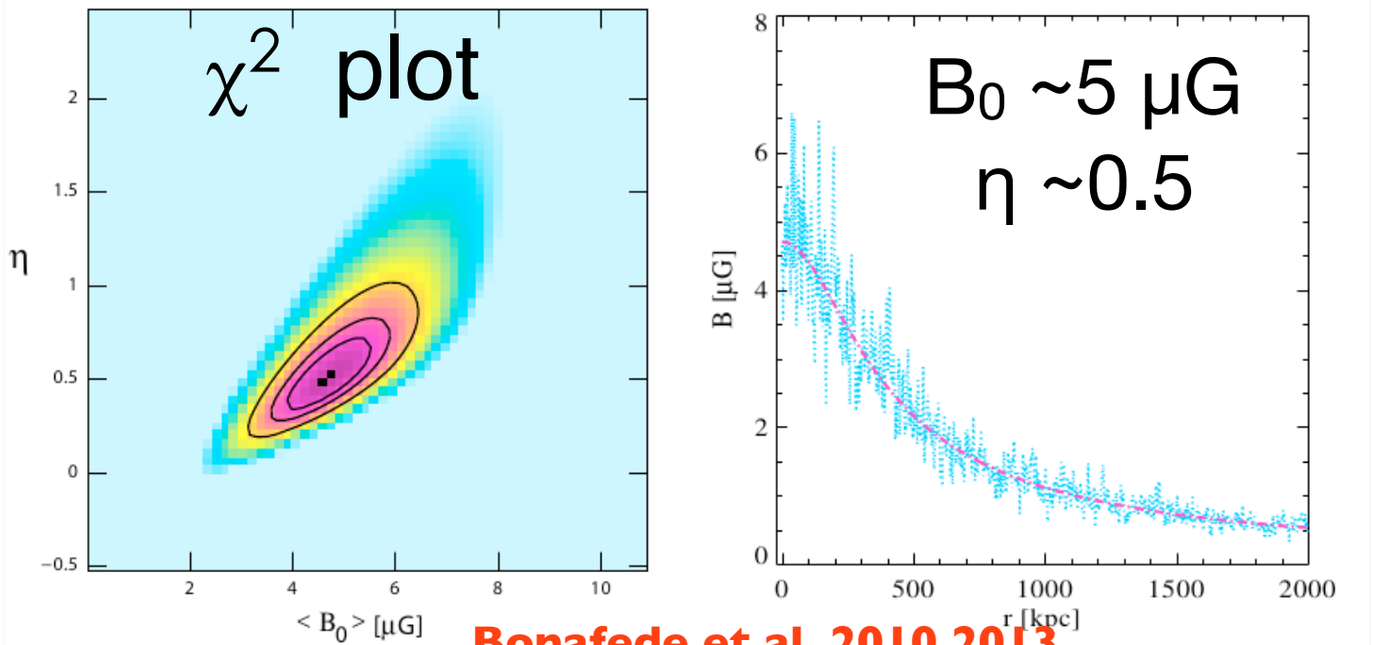

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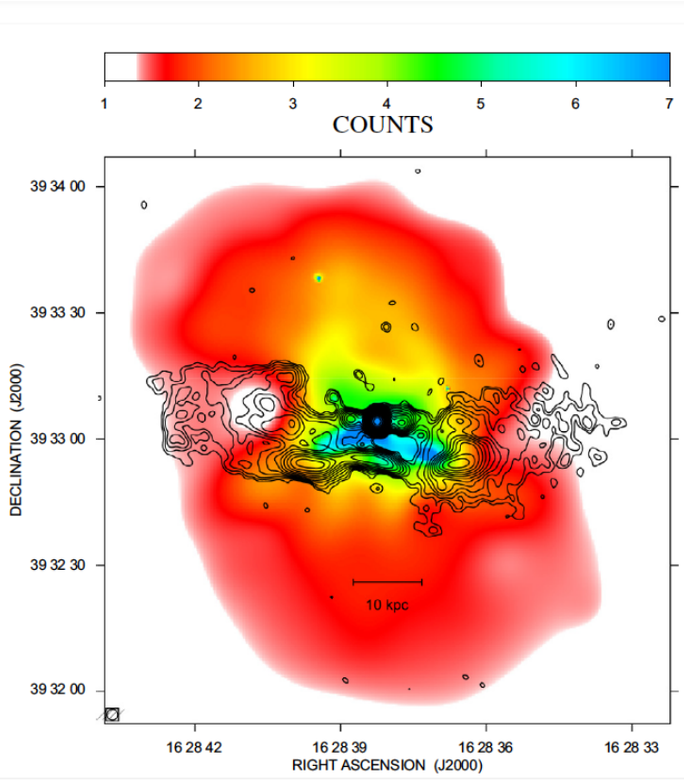

Vacca et al 2012

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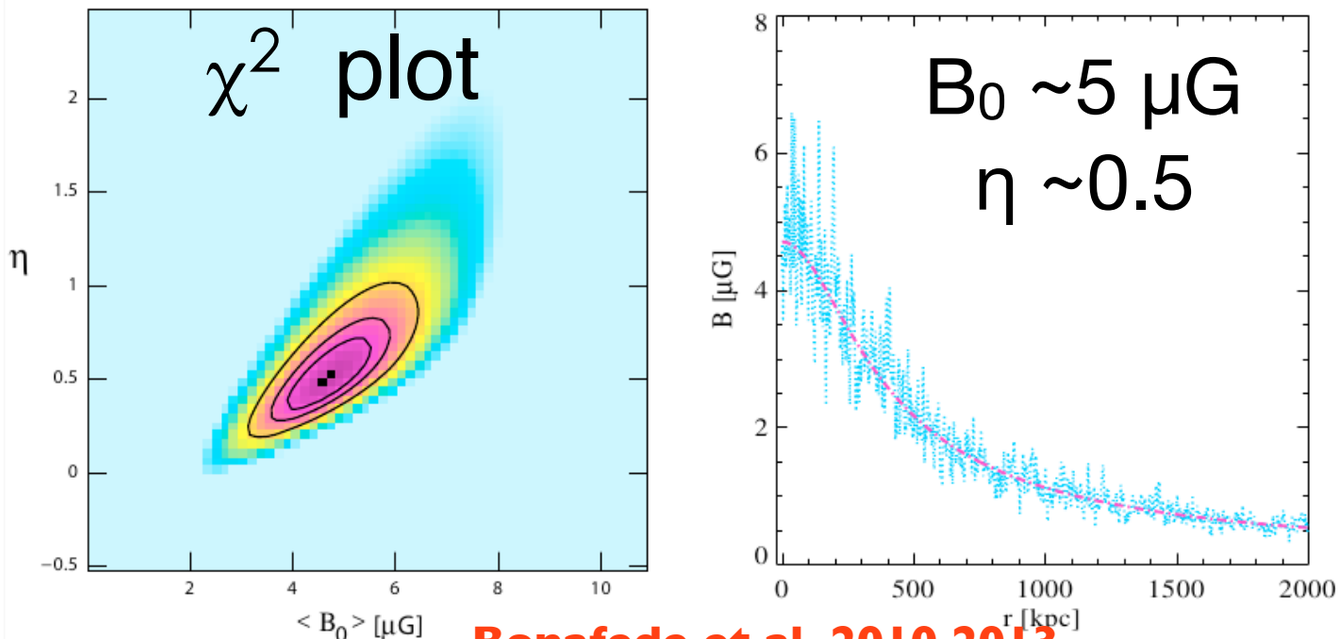

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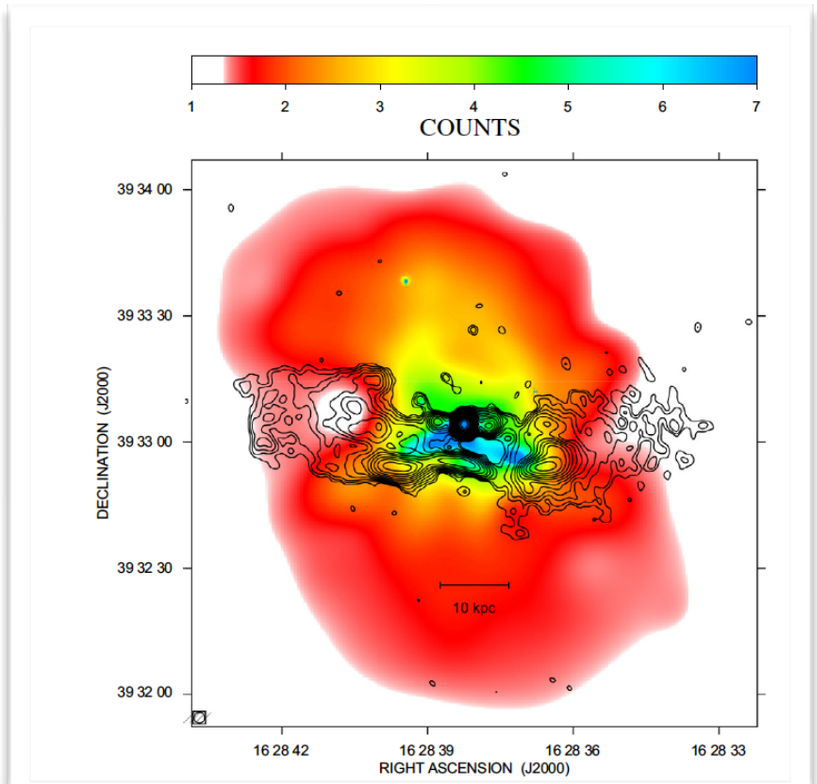

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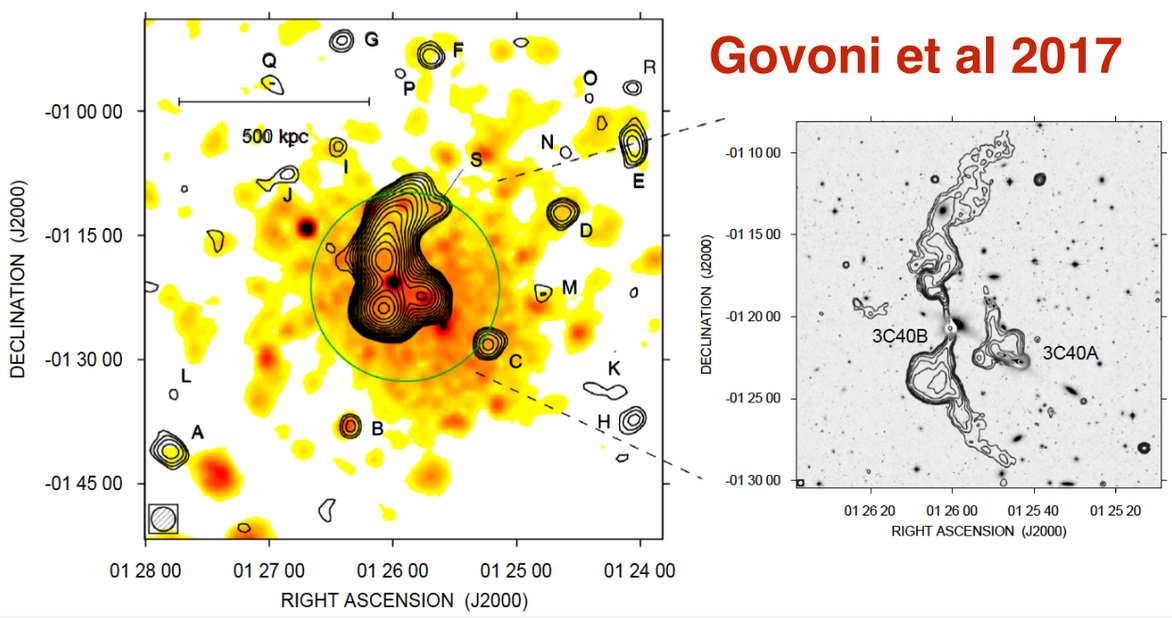

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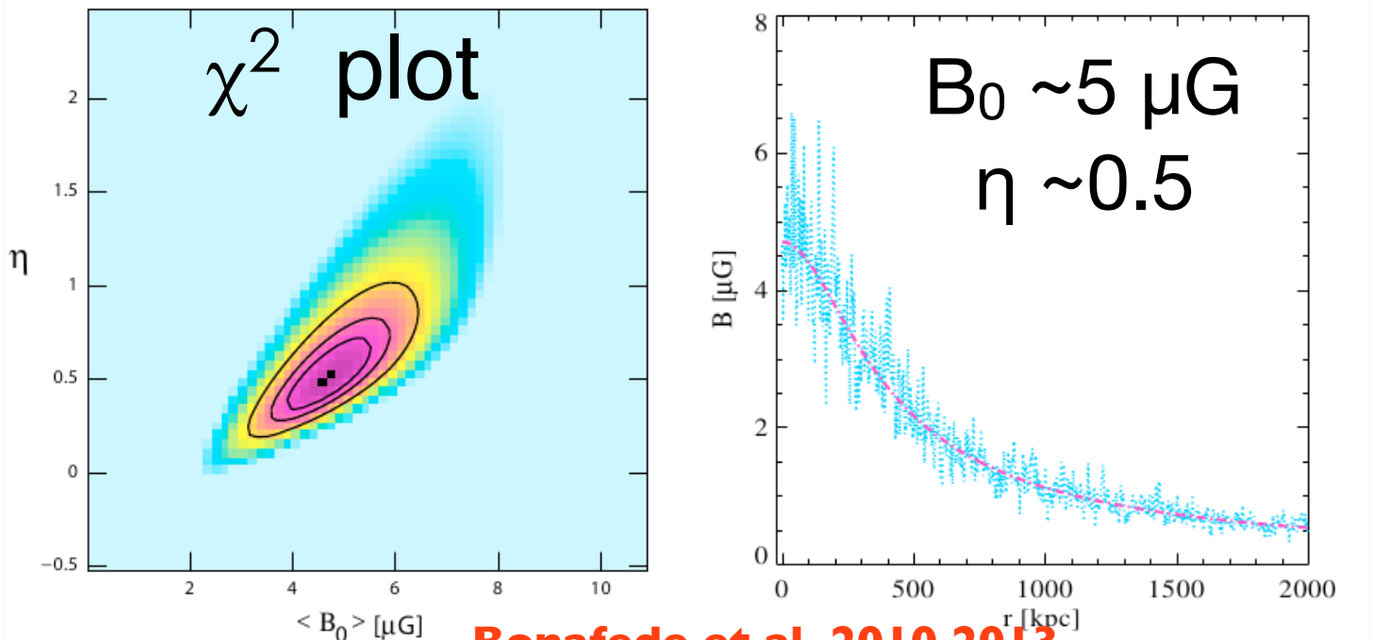

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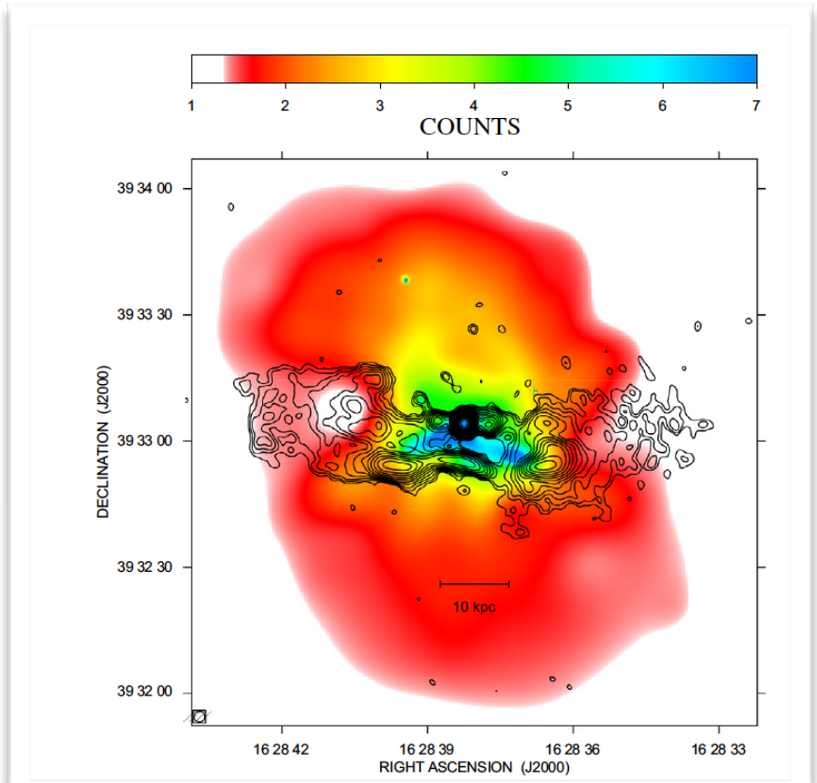

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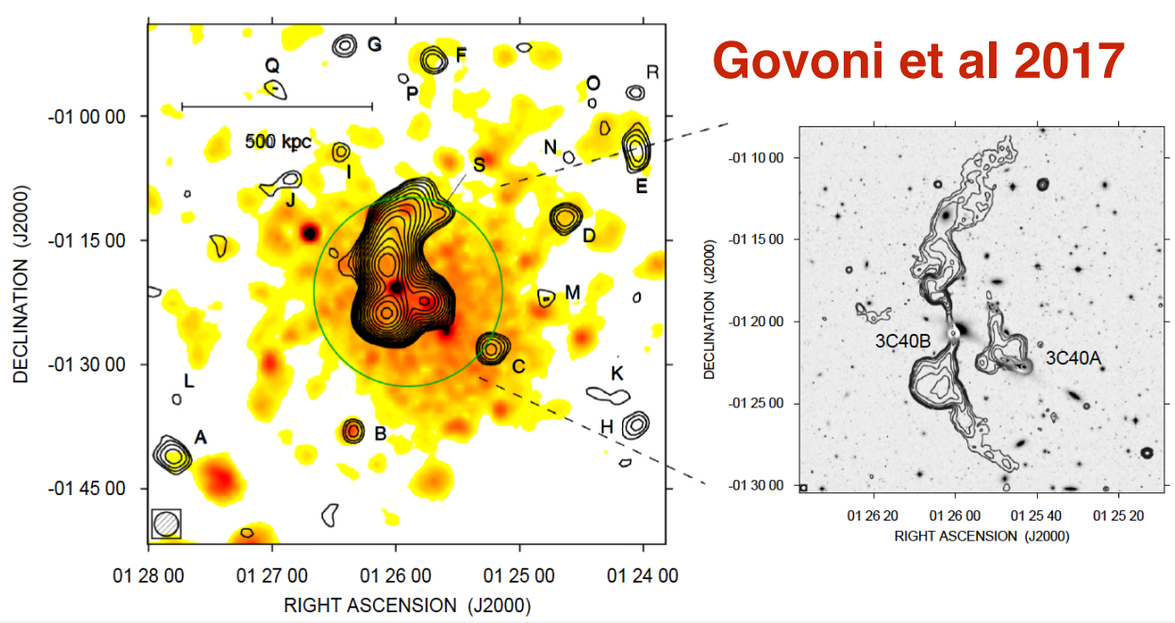
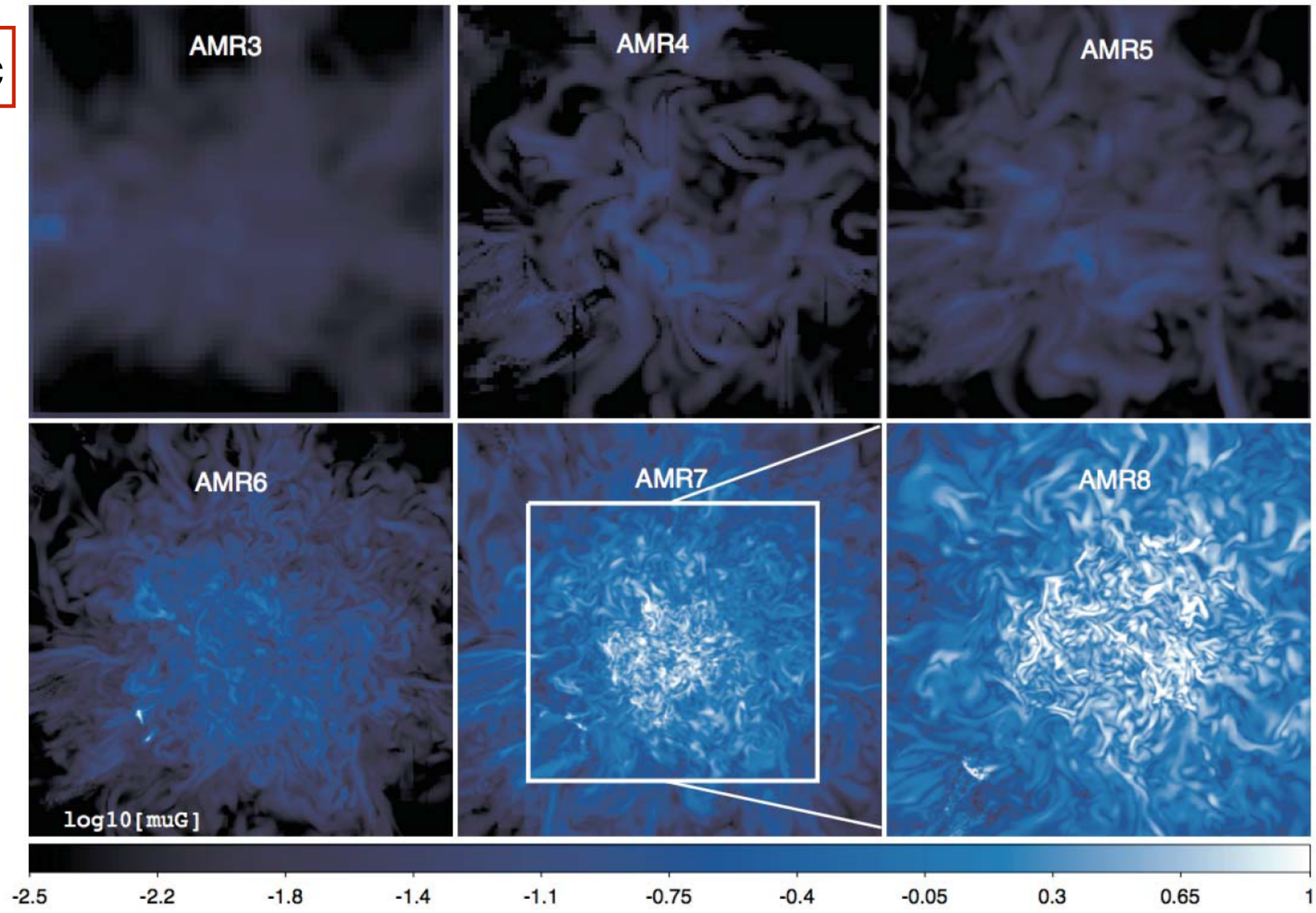


B_0 ~1-5 μG
η ~0.5 - 1

NON-GAUSSIAN COMPONENTS

Primordial magnetic field B_0=0.1nG at z=30
cluster “Coma-like” M ~10^{15} Msun
Dedner formulation MHD 256^3 cells + 8 levels

Δx~126 kpc



Δx~4 kpc

Vazza et al. (2018)

Figure 4. Map of projected mean magnetic field strength for resimulations of our cluster at an increasing resolution, for regions of 8.1×8.1 Mpc^2 around the cluster centre at $z = 0$. Each panel shows the mass-weighted magnetic field strength (in units of $\log_{10}[\mu G]$ for a slice of $\approx$ 250 kpc along the line of sight.

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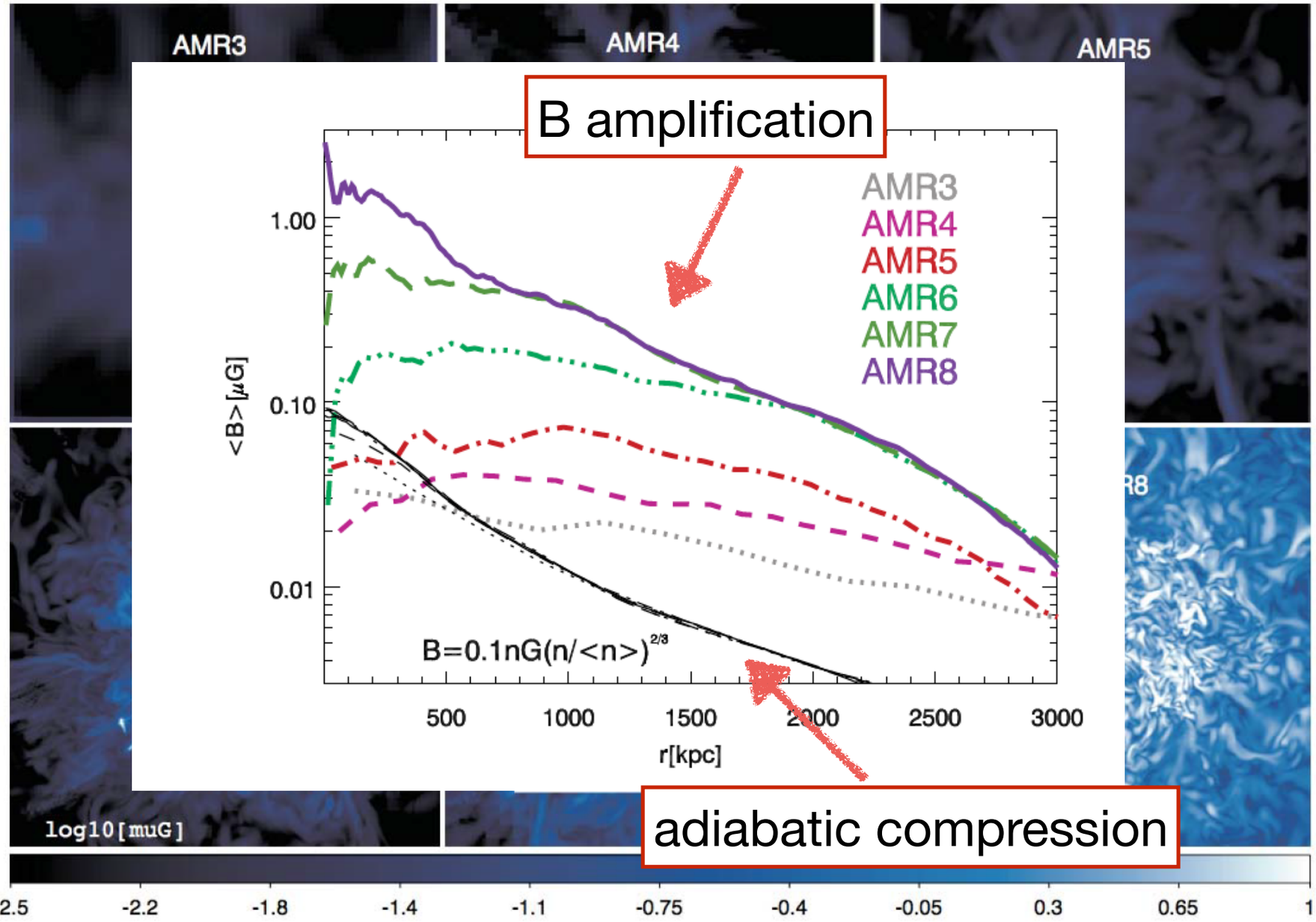

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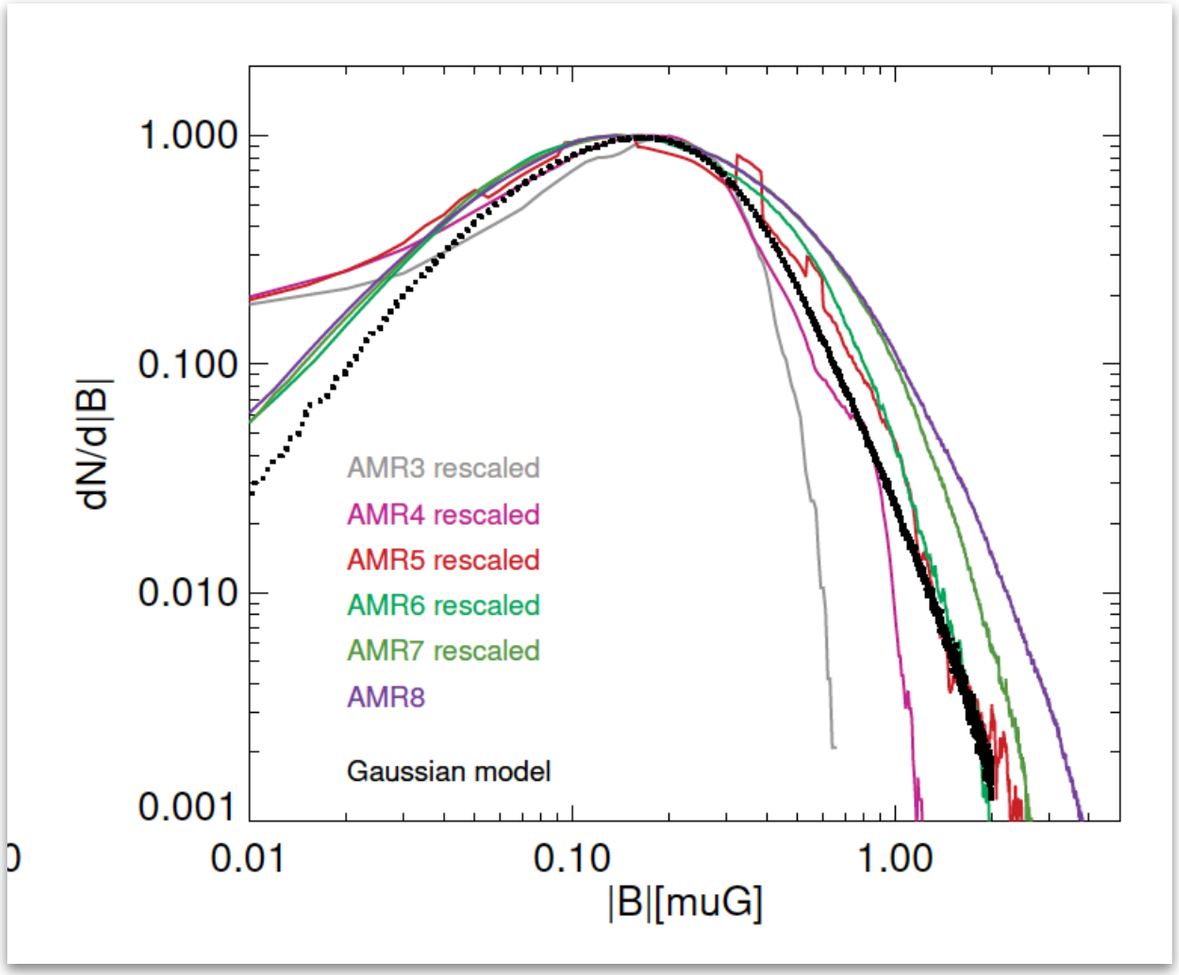
MAGNETIC FIELD DISTRIBUTION

Δx~126 kpc

Δx~4 kpc

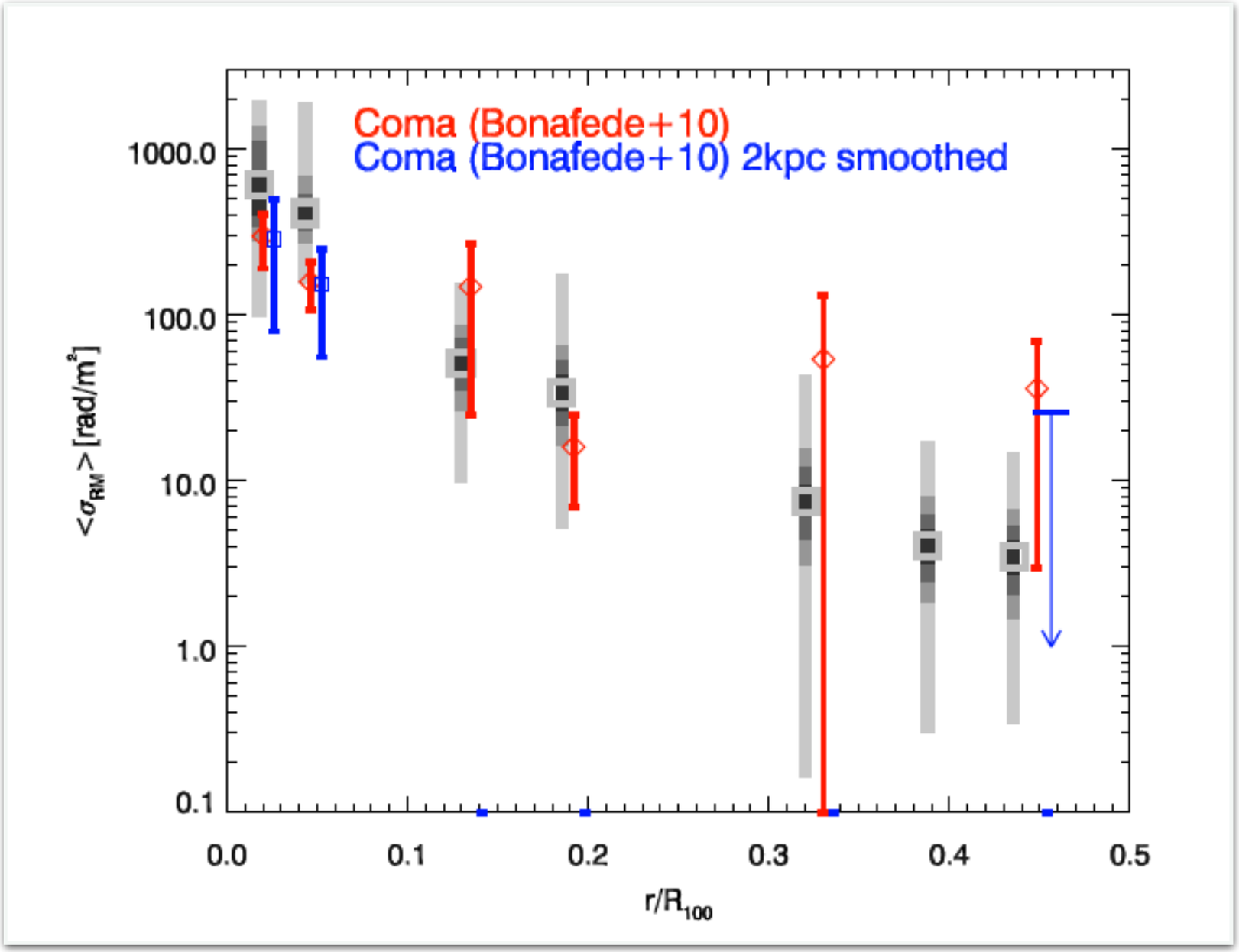
Normalised to highest resolution



Departure from Gaussian distribution
Amplitude of non-Gaussian tail depends on time and cluster dynamics

Vazza et al (2018)

COMPARISON WITH FARADAY ROTATION MEASURES



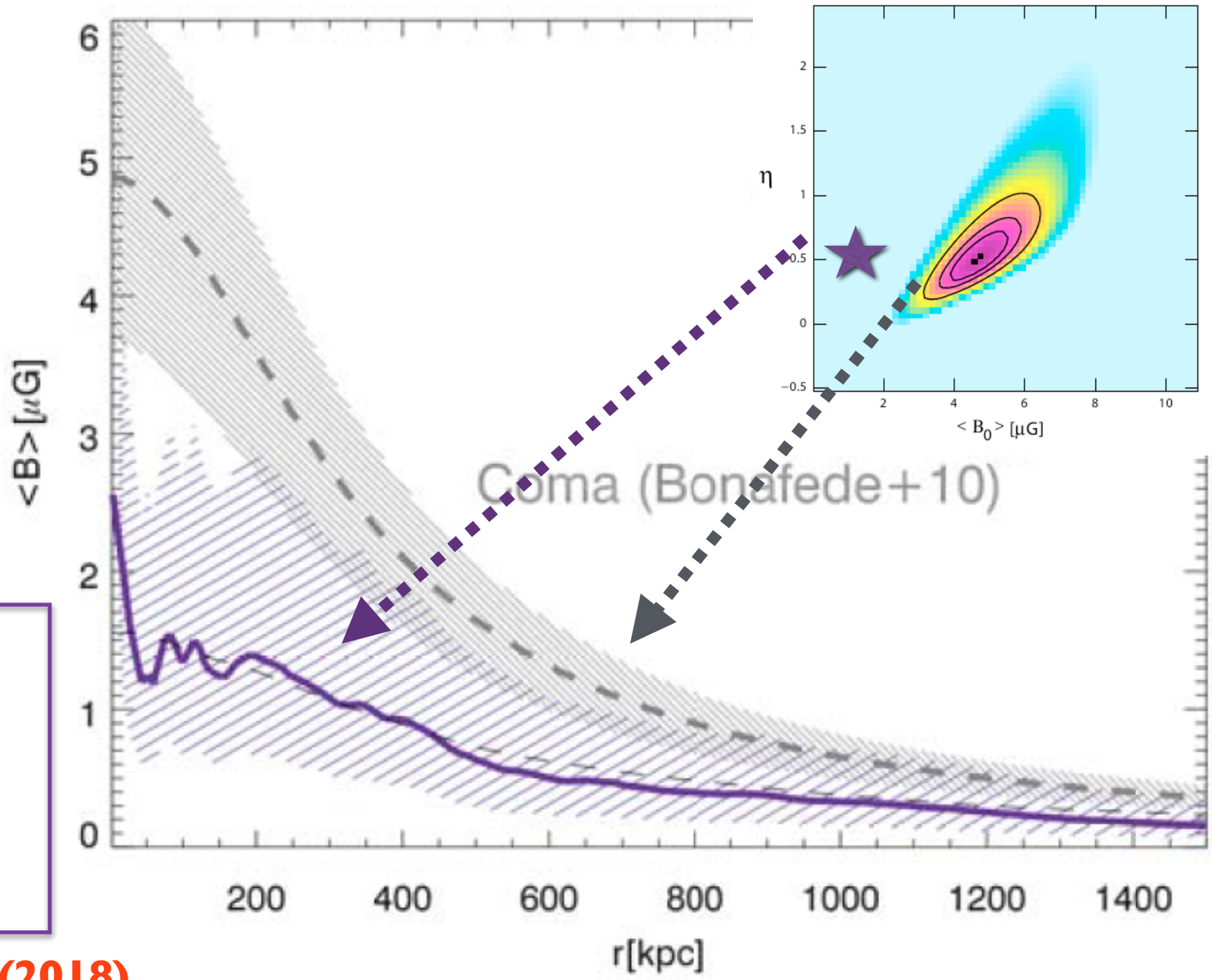
Simulation

data

Vazza et al (2018)

B LOWER THAN DERIVED WITH GAUSSIAN FIELDS

$$B \propto B_0 n_{gas}^{\eta}$$



B_0 ~5 μG
η ~0.5

Bonafede et al 2010

Central B (core) ~1.5 μG

Vazza et al (2018)

Conclusions so far

- New emission in galaxy clusters

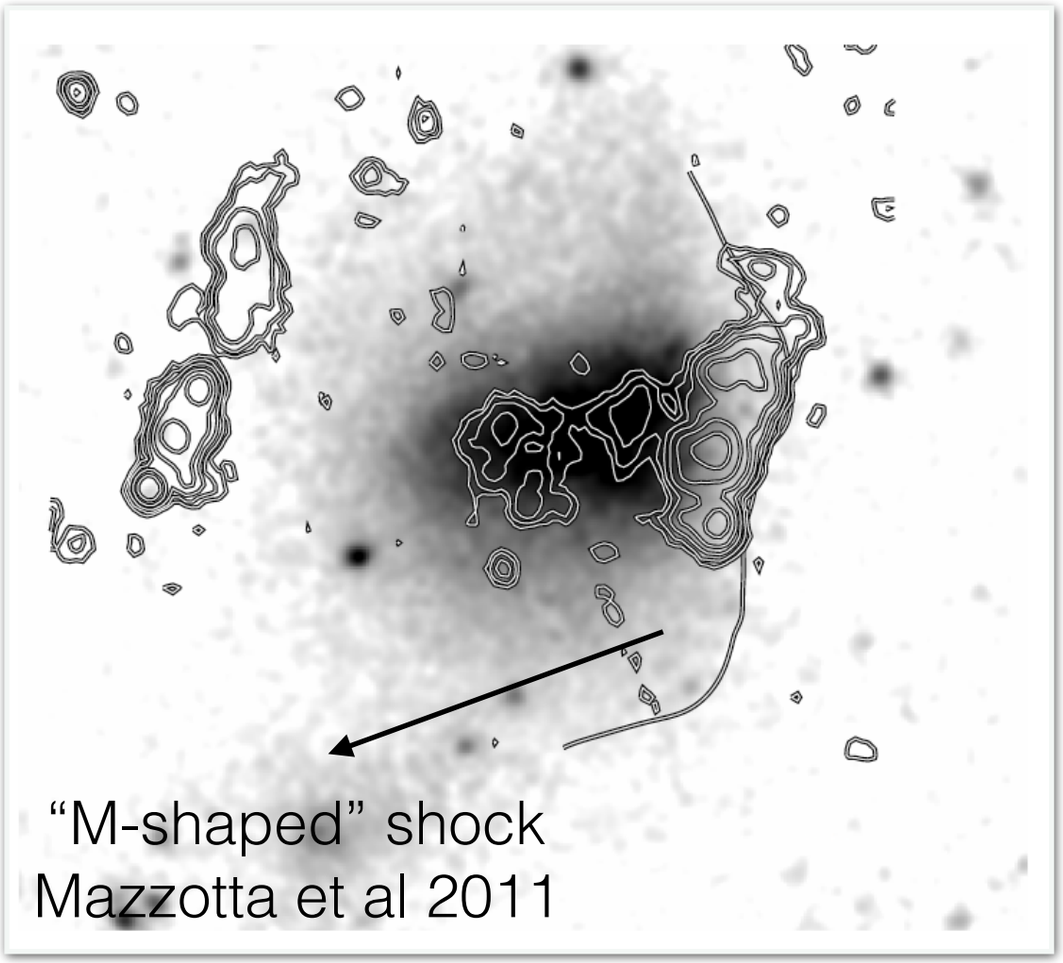
- $P \propto \gamma_L^2 B^2$

  Independent measurement of B needed

→ Emission from background sources to constrain B —> not enough!

News from JVLA: I

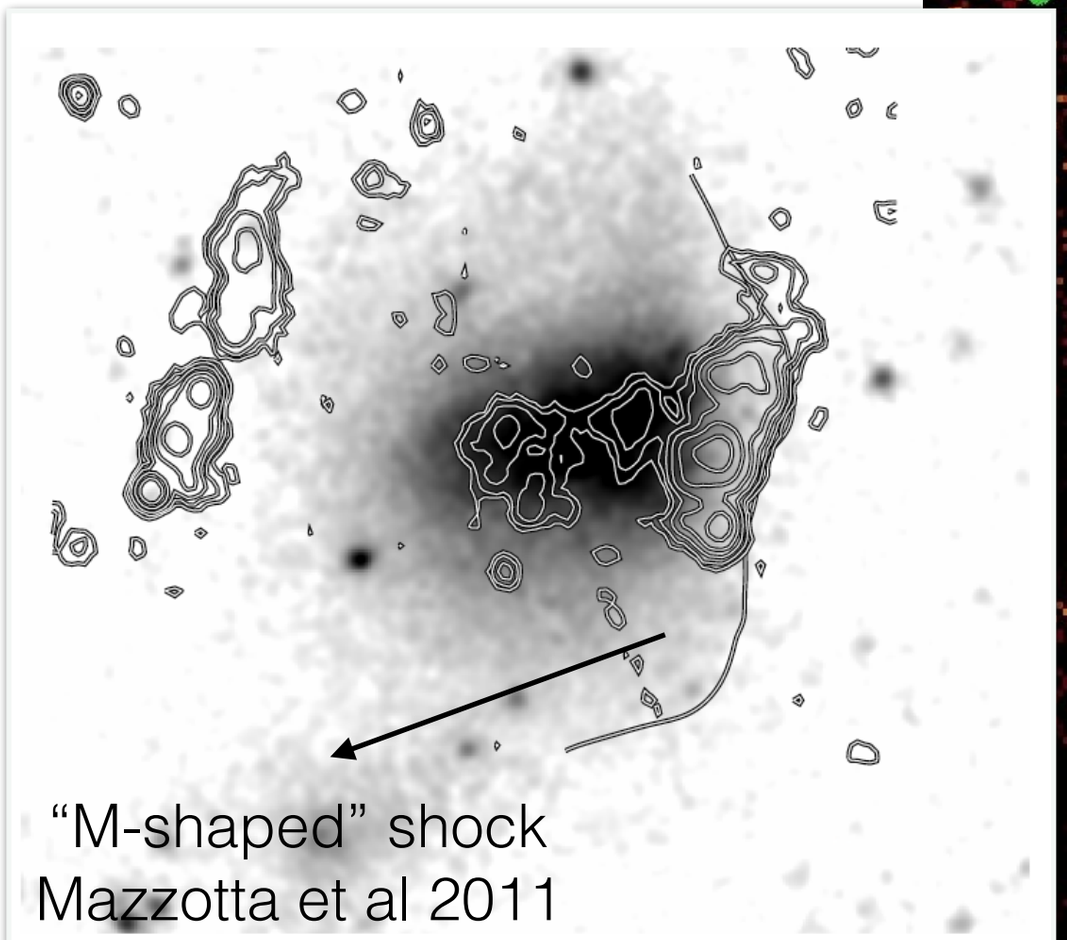
Statistical approach: 80 h JVLA L band, to sample RM through all clusters with double relics



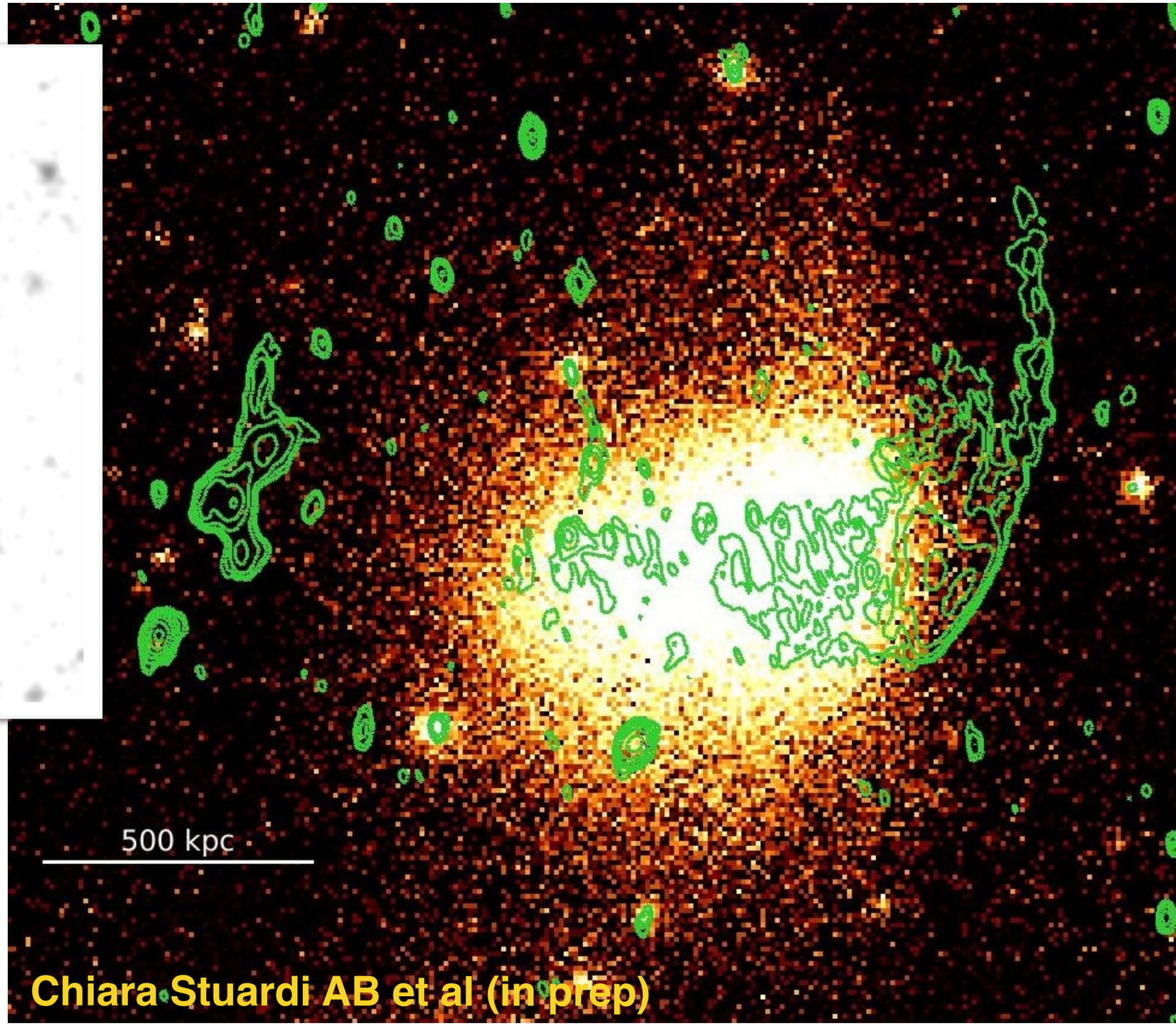
"M-shaped" shock
Mazzotta et al 2011

News from JVLA: I

Statistical approach: 80 h JVLA L band, to sample RM through all clusters with double relics



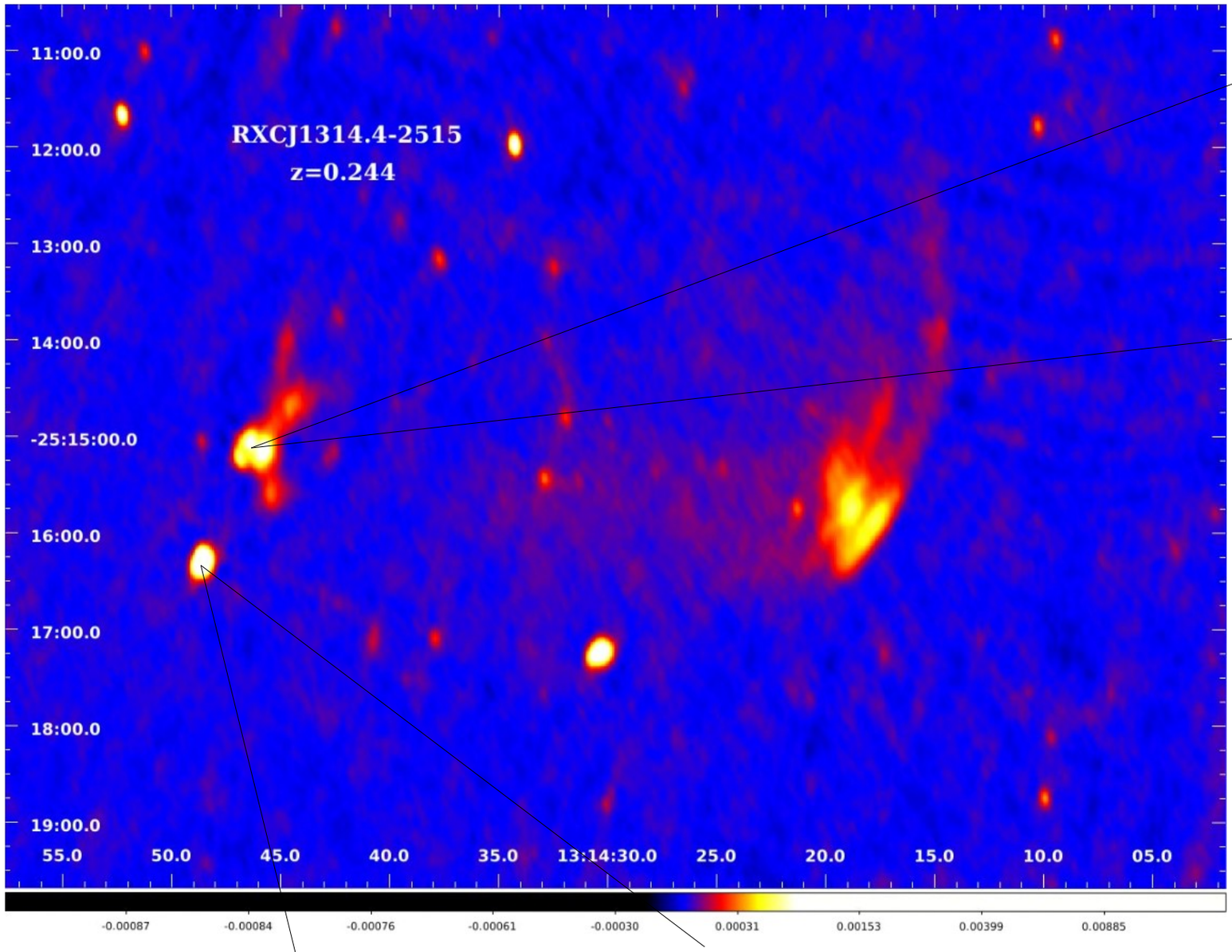
“M-shaped” shock
Mazzotta et al 2011

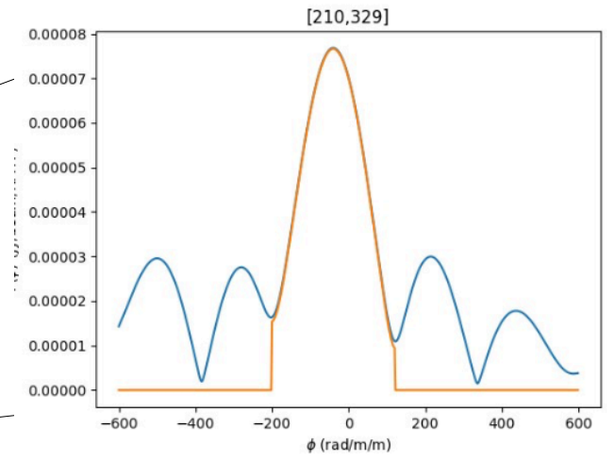


RXCJ1314.4-2515
Colors: XMM-Newton
Contours: JVLA L band B+C array

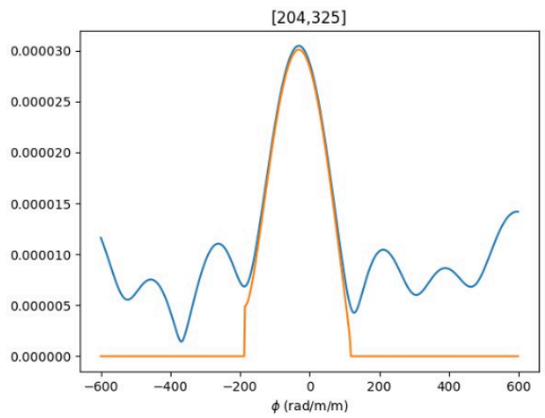
Chiara Stuardi AB et al (in prep)

News from JVLA: I





Φ_{max} = -30±2 rad/m²



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$\langle RM \rangle_{Gal}$ = -30 rad/m²

Stuardi, AB et al. (in prep)

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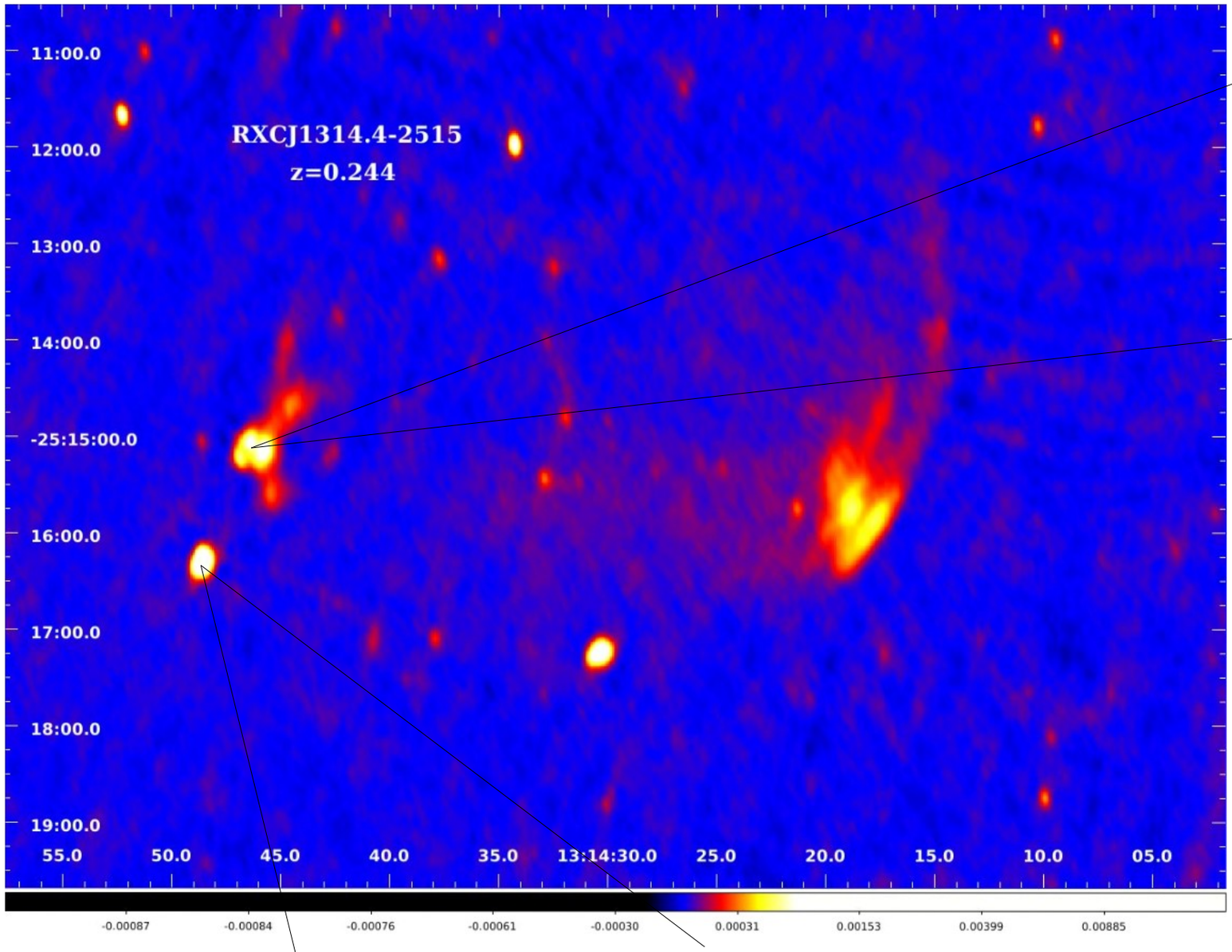

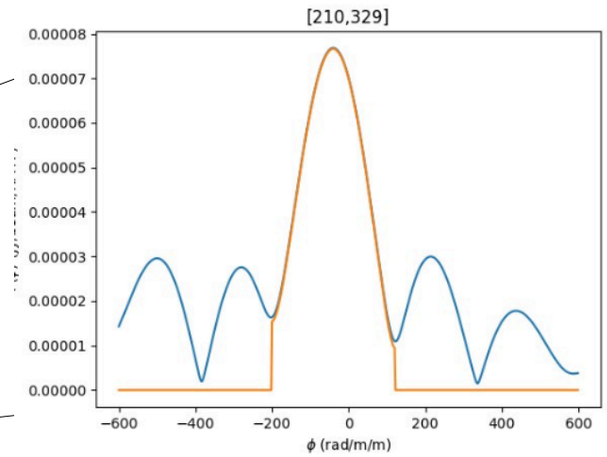

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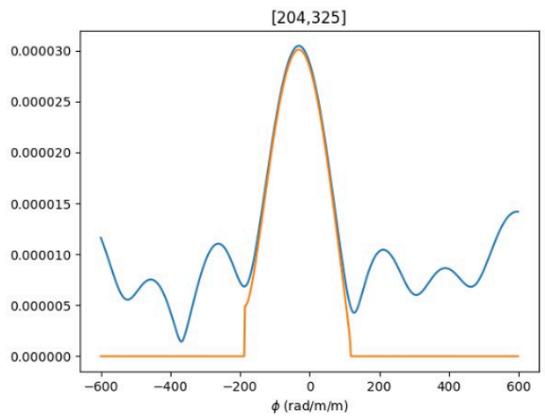

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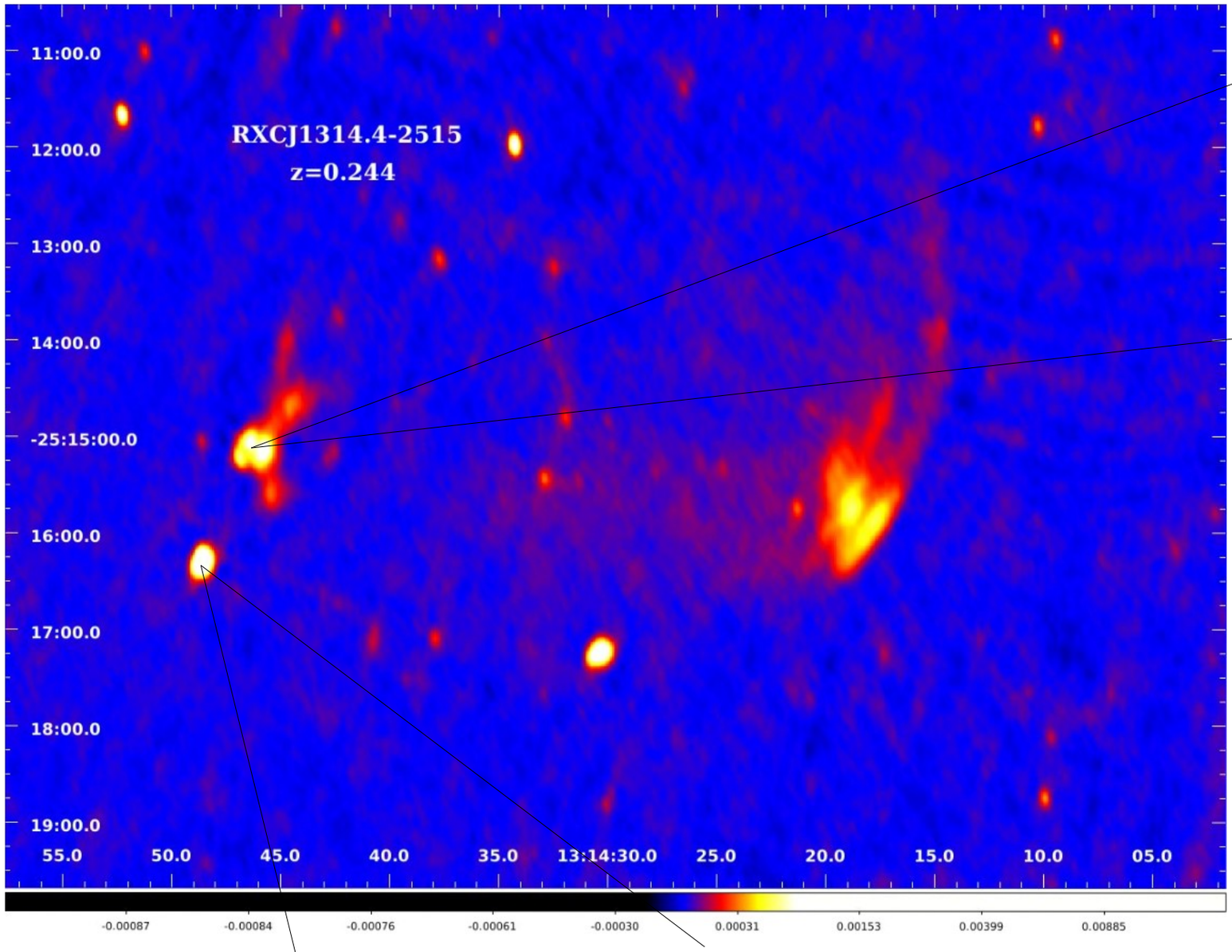

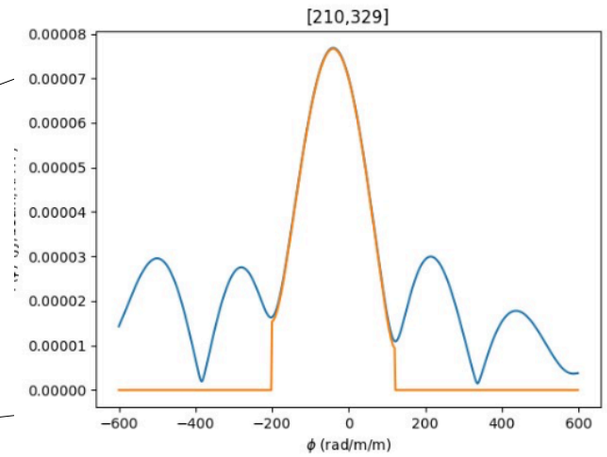

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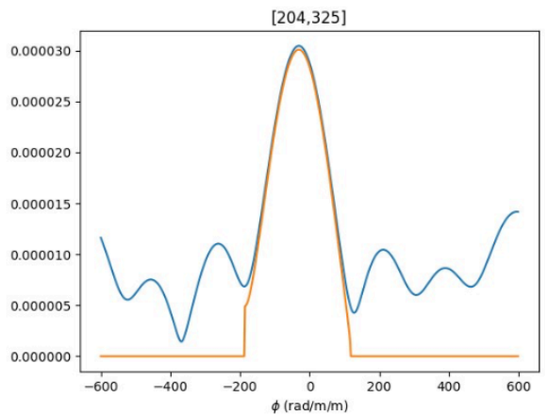

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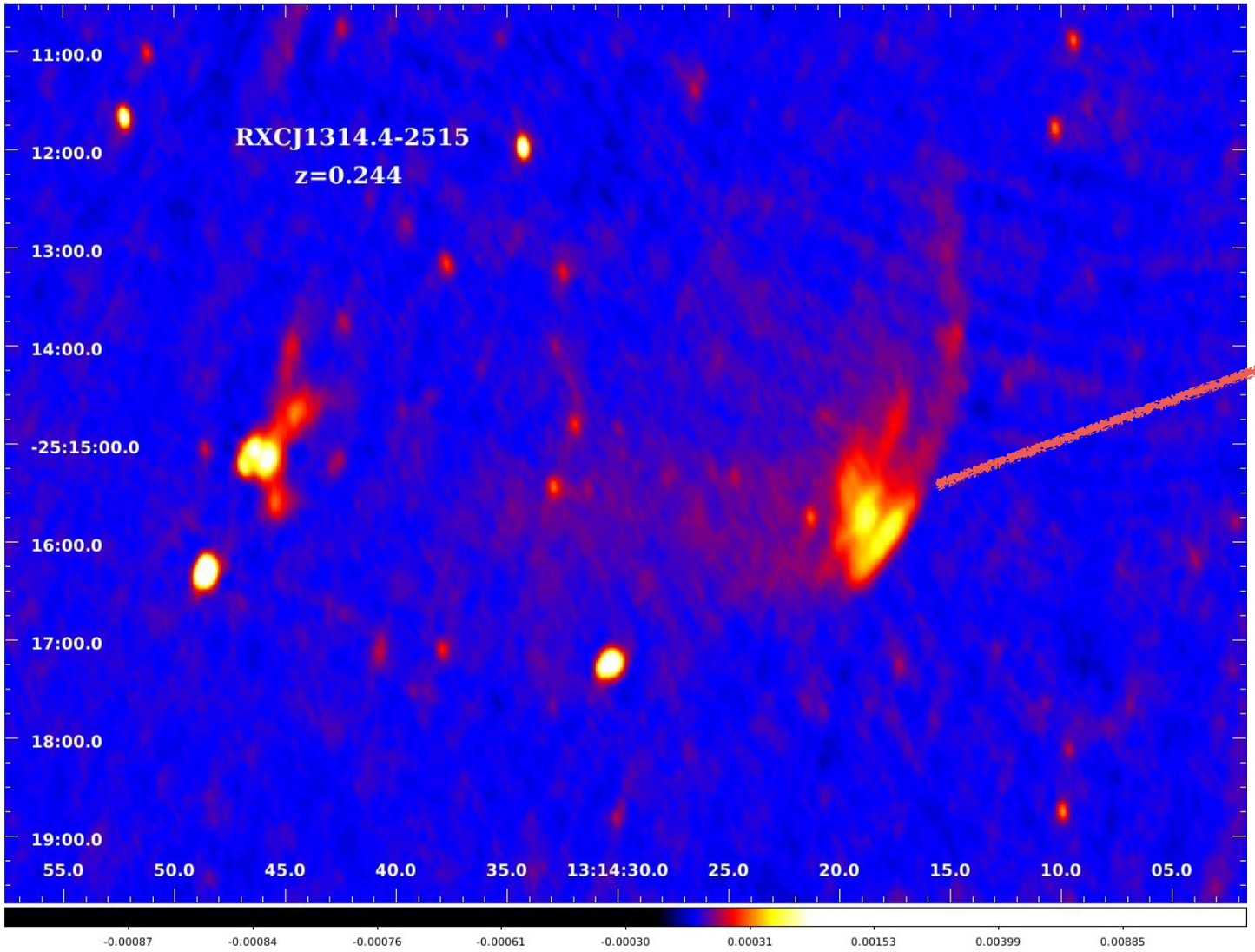
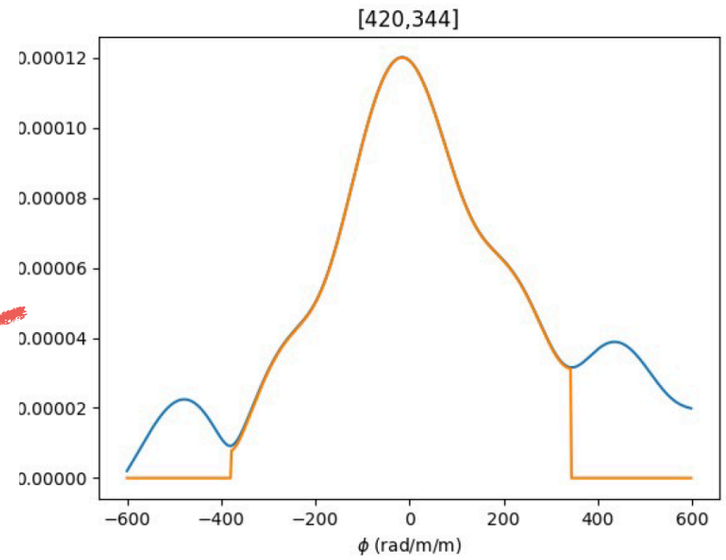
B in cluster outskirts: probes from radio relics





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+

ϕ ~-100 - 200 rad/m²

Rotation of the polarisation plane from/within the relic!

Stuardi, AB et al. (in prep)

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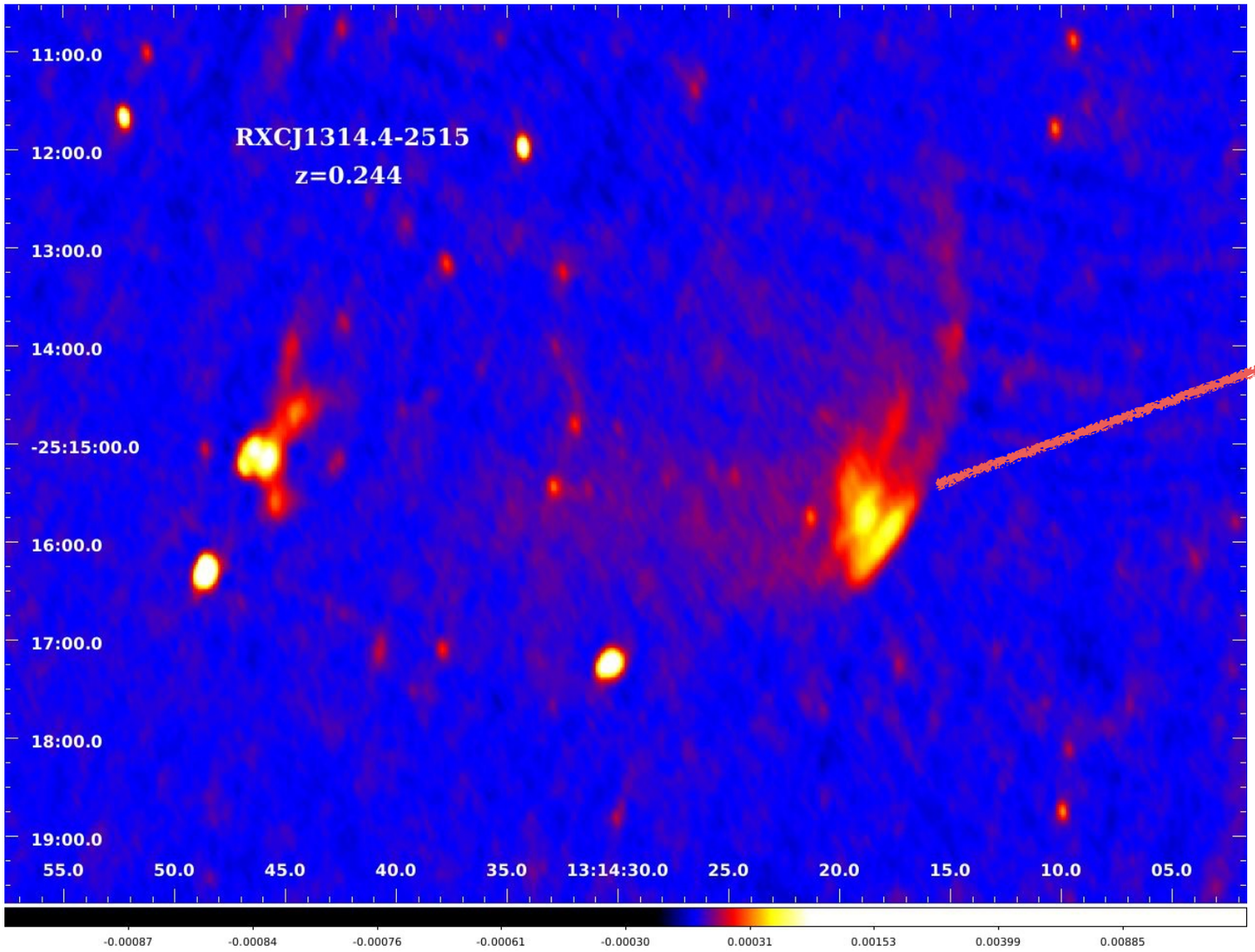

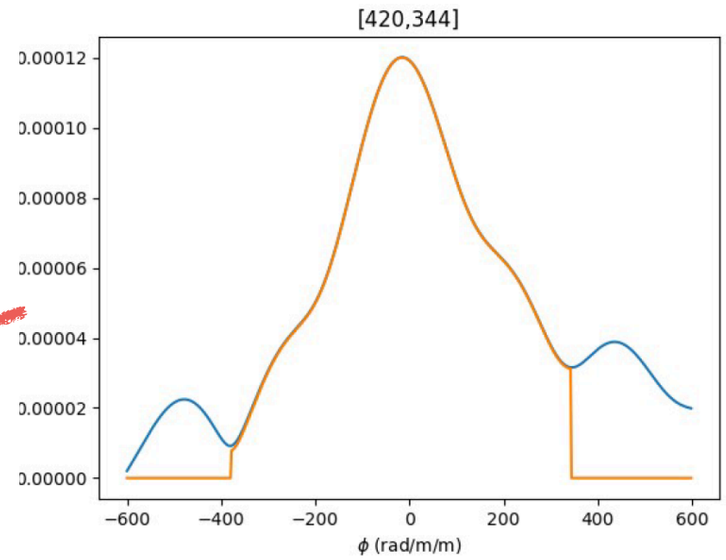

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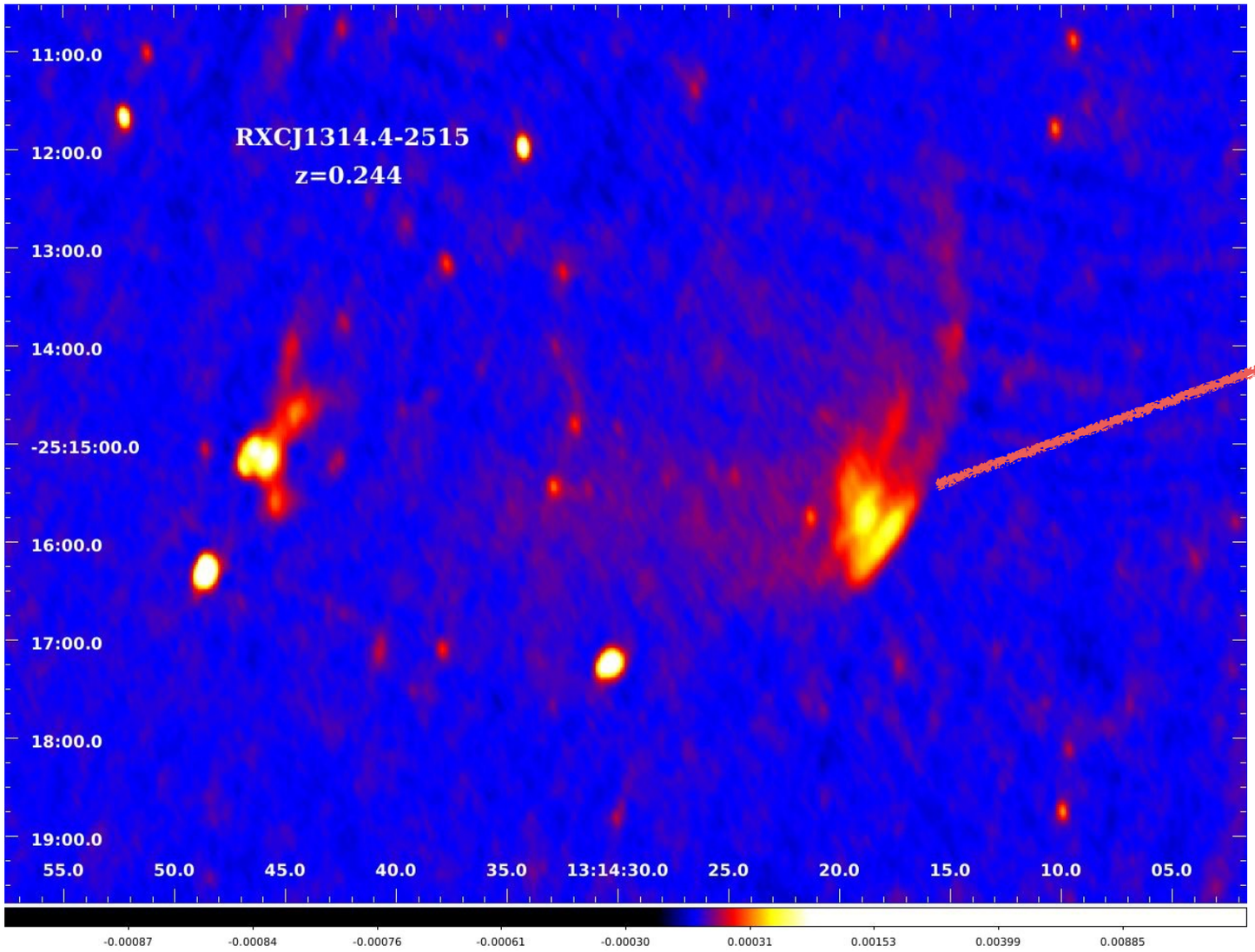

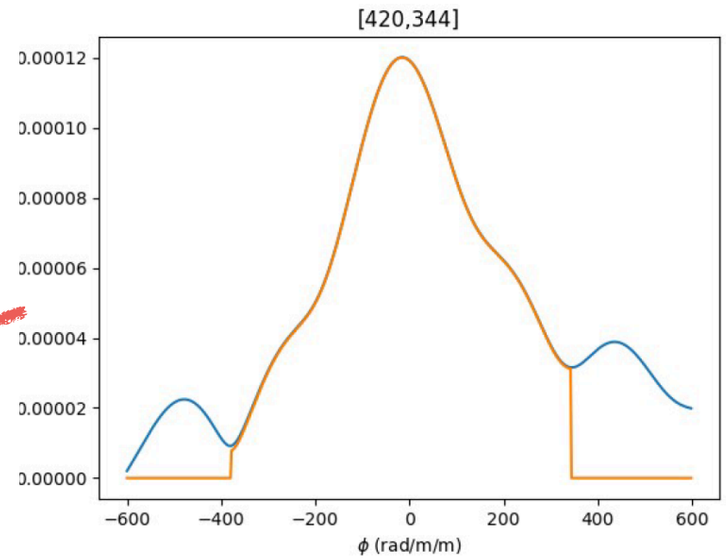

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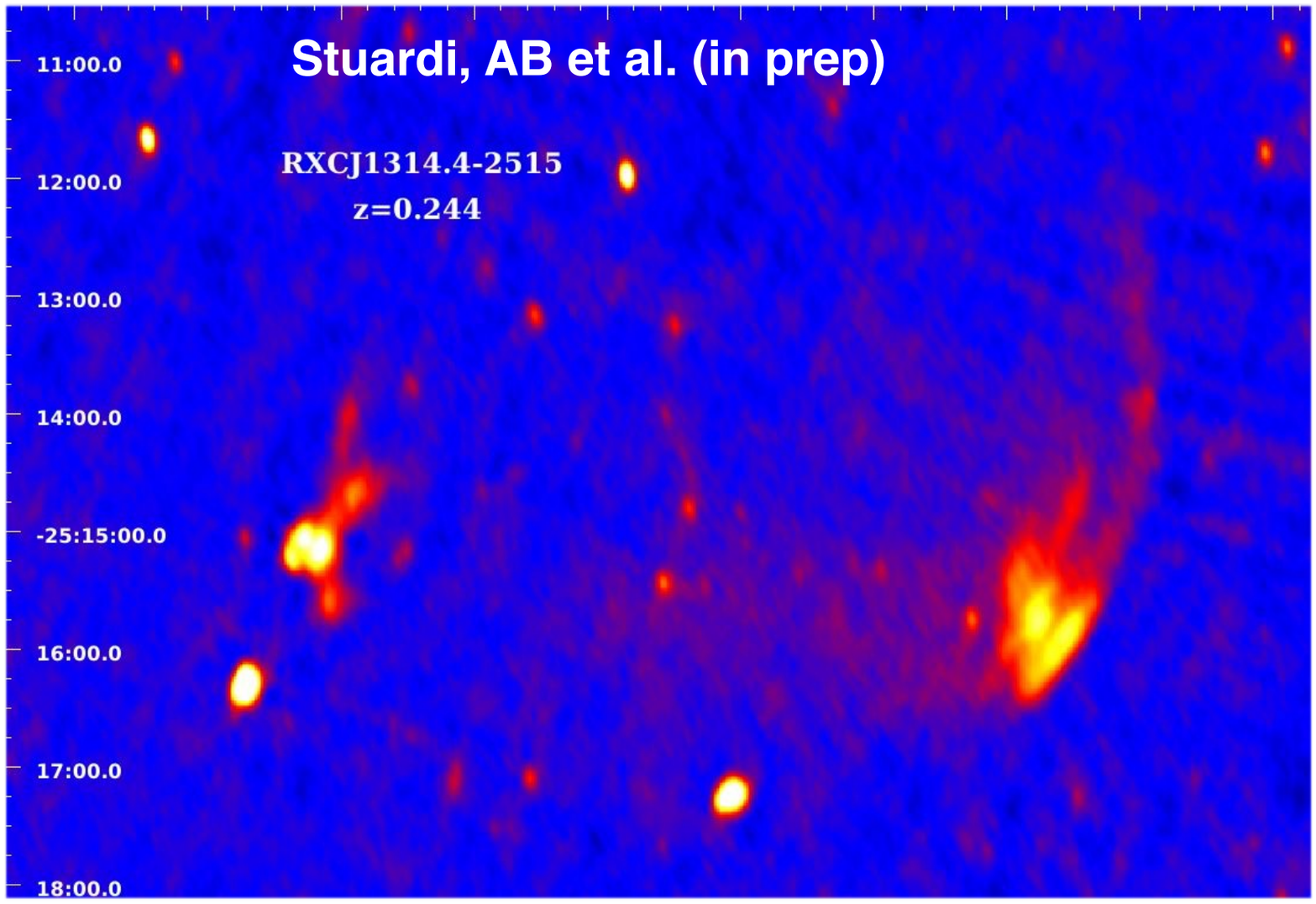
News from JVLA: II



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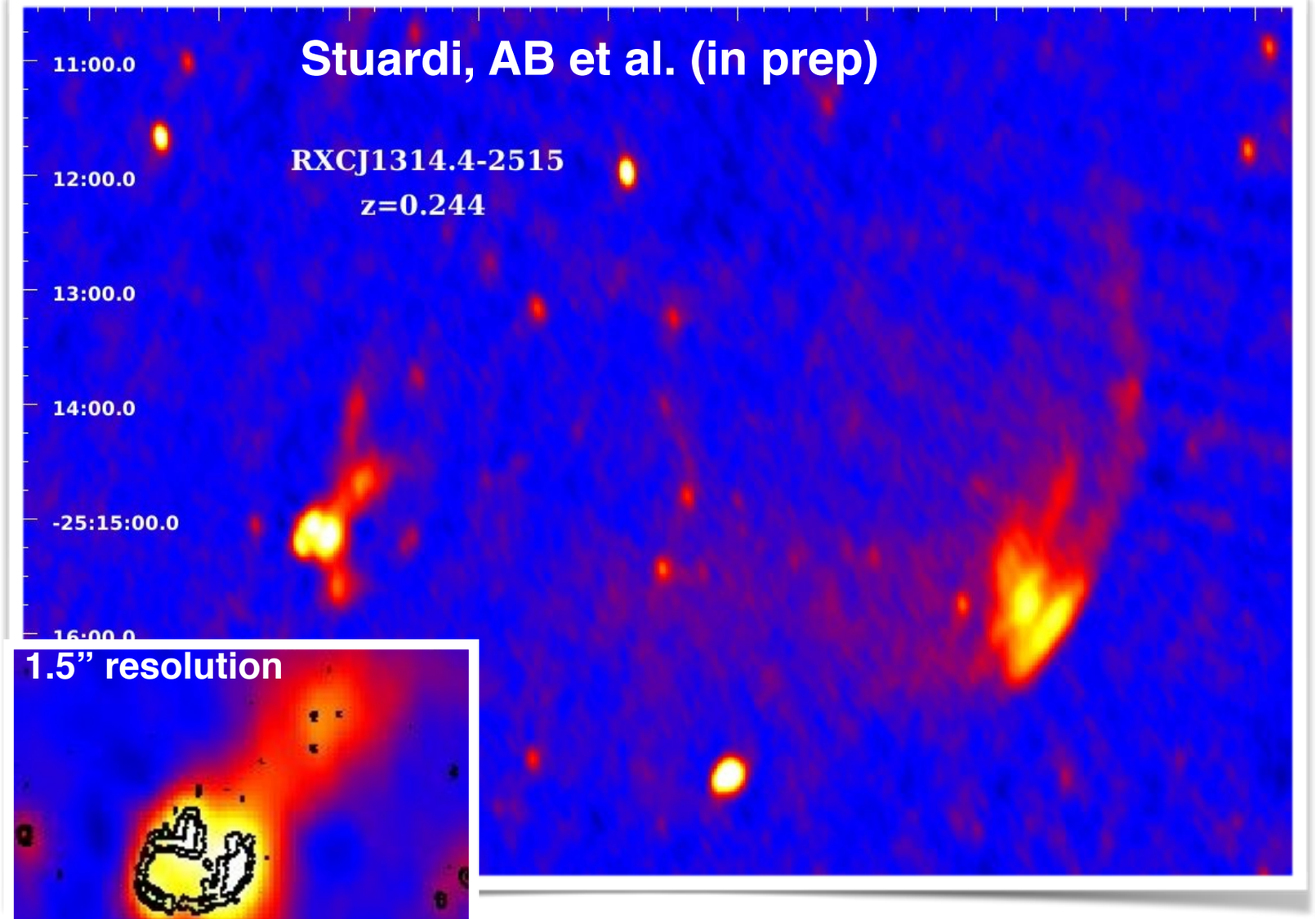

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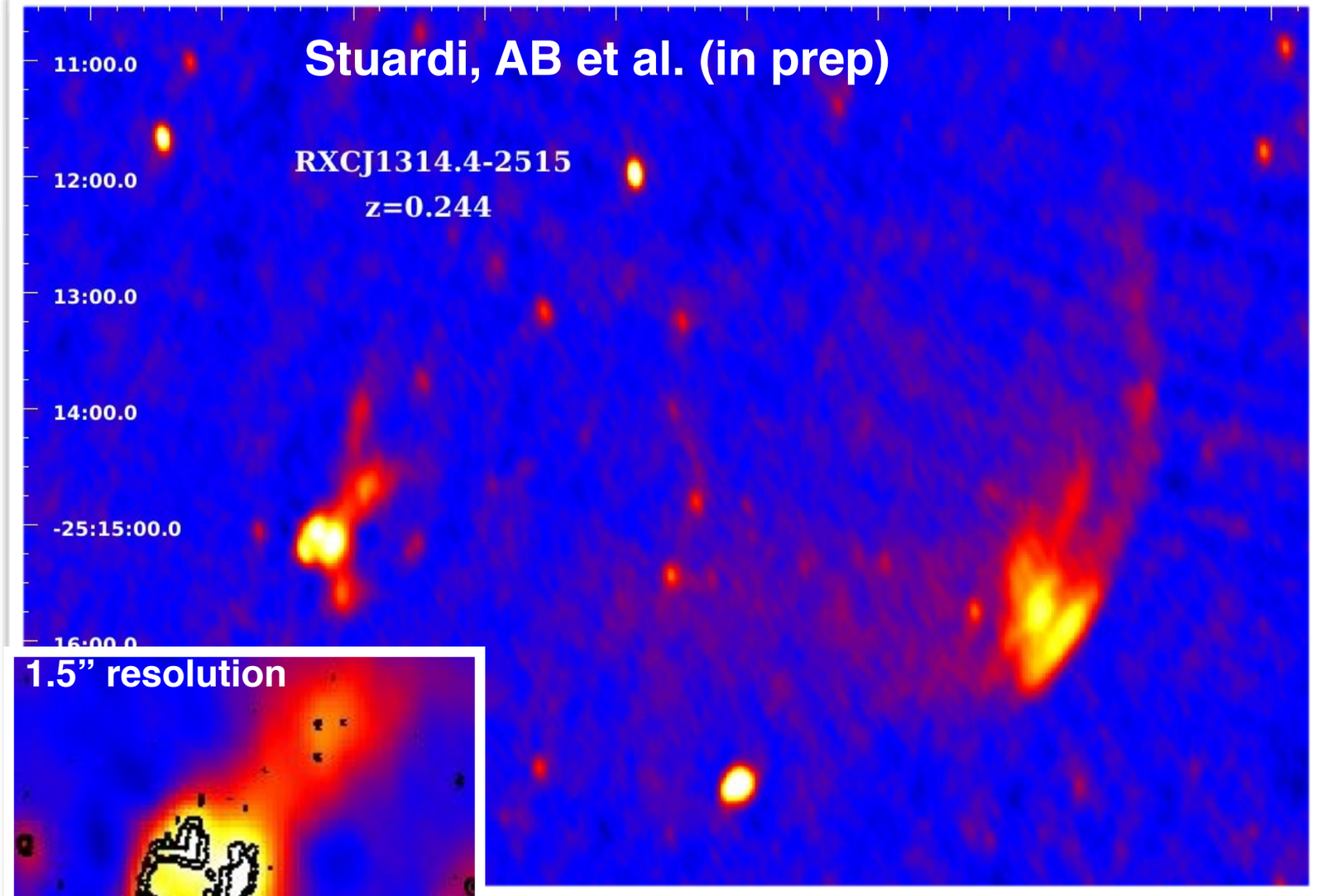

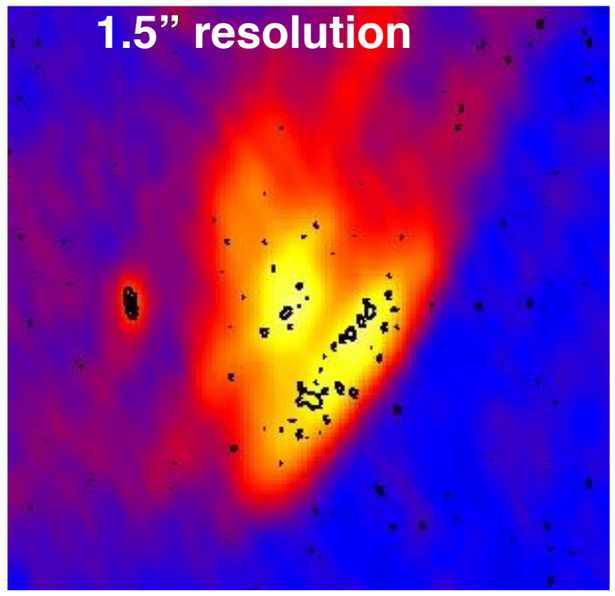

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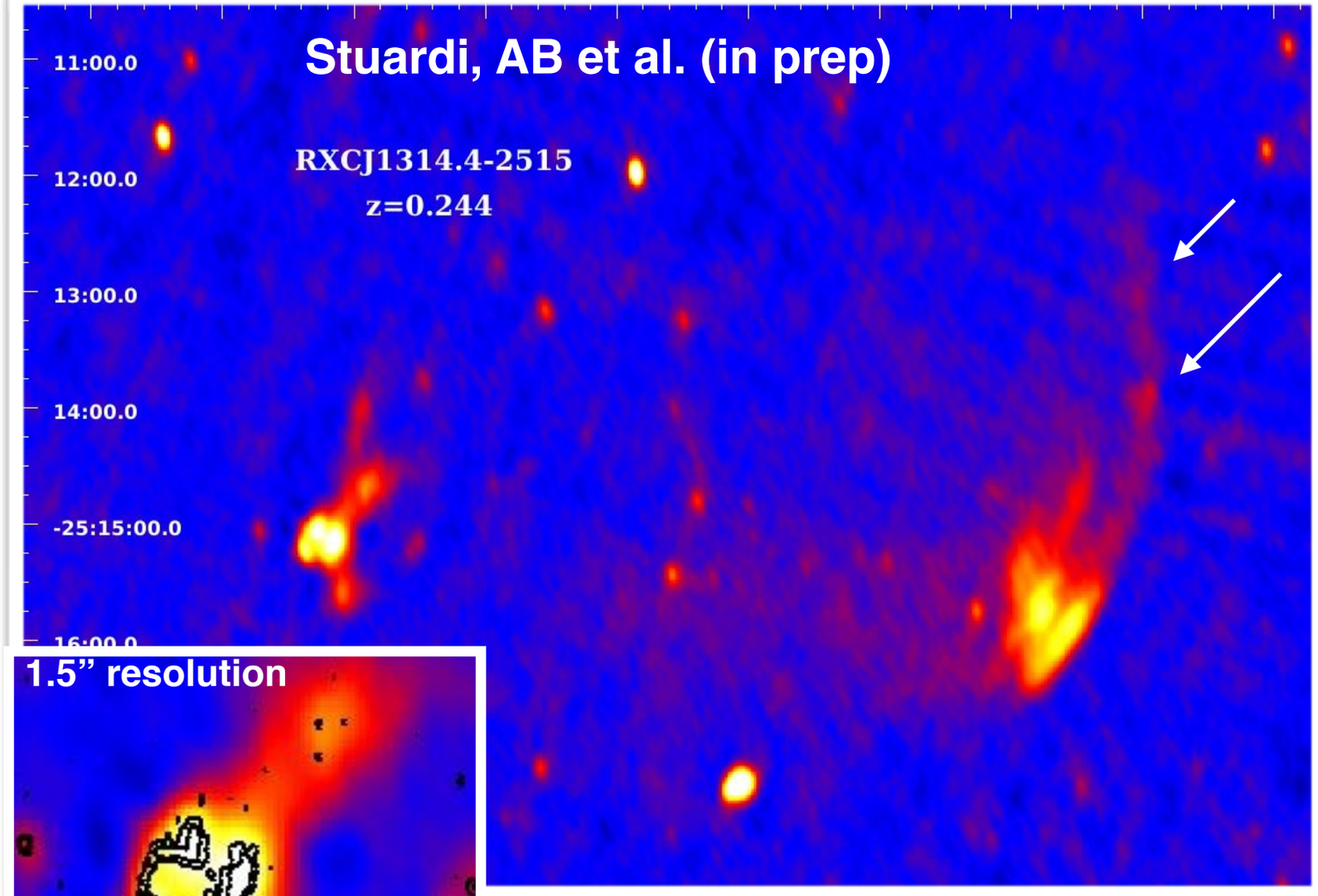

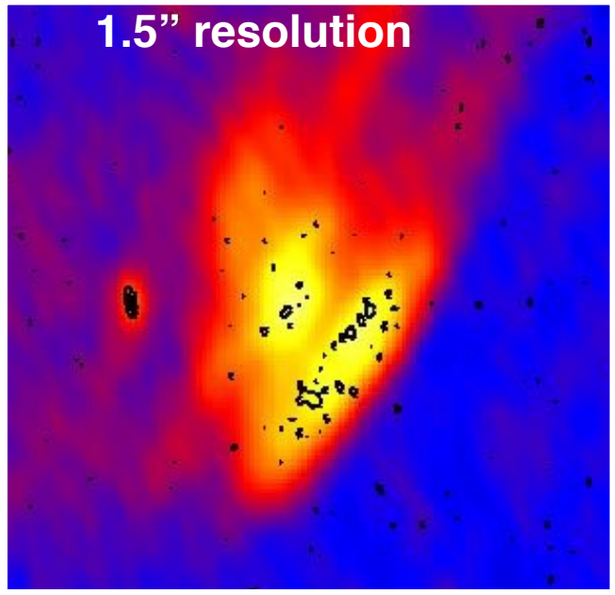

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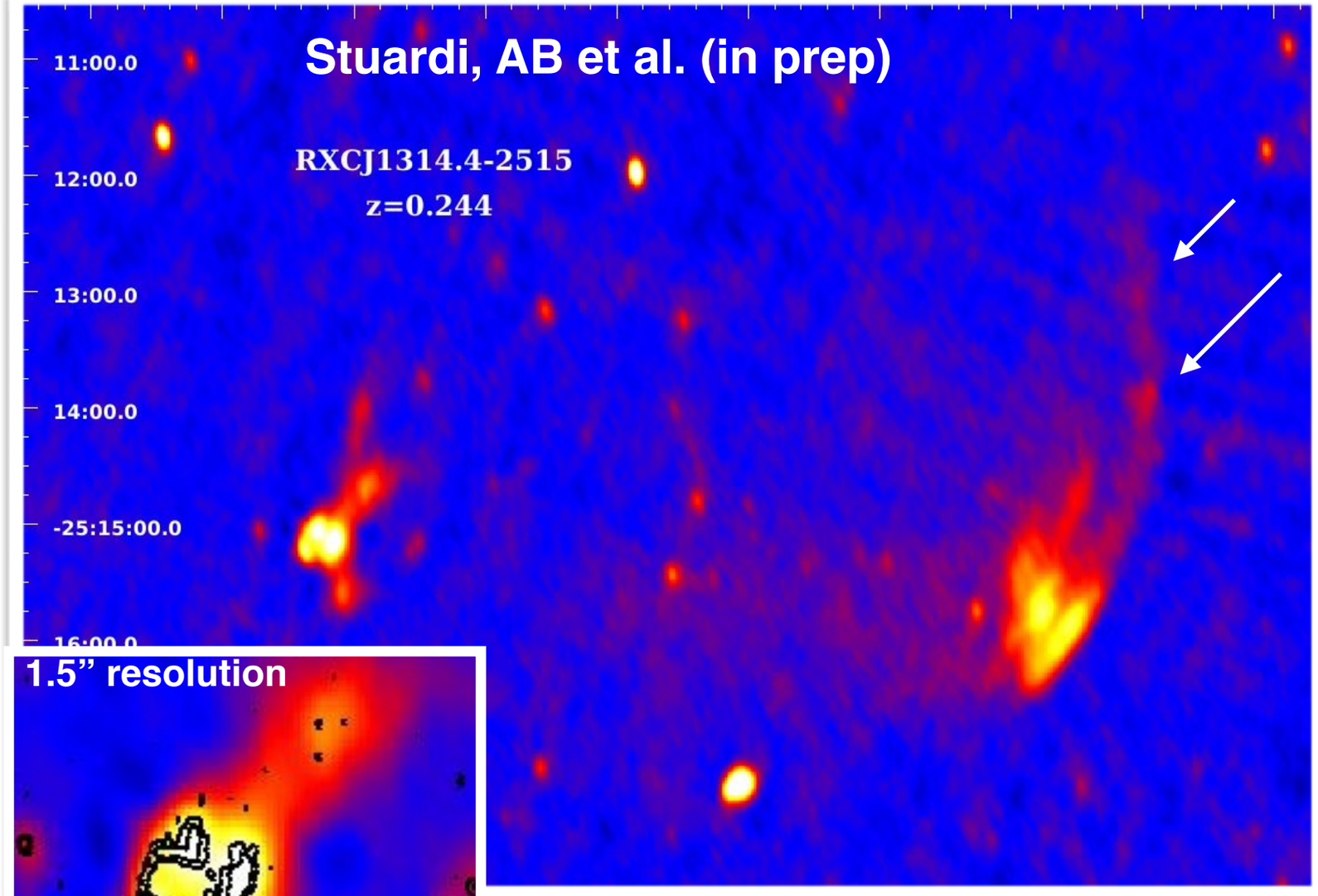
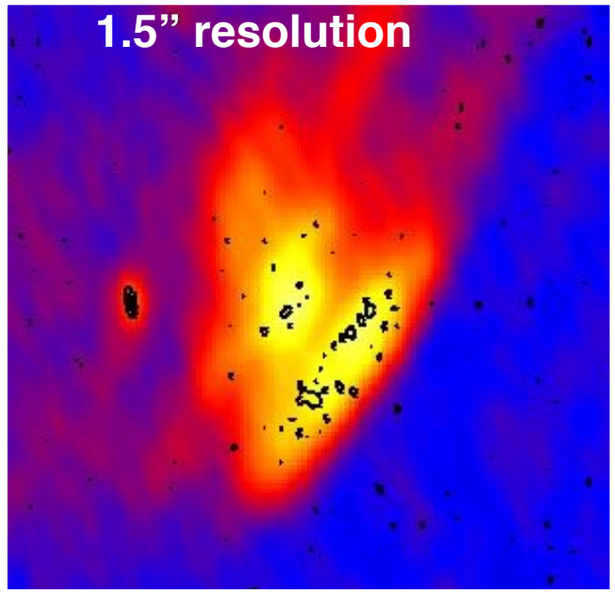
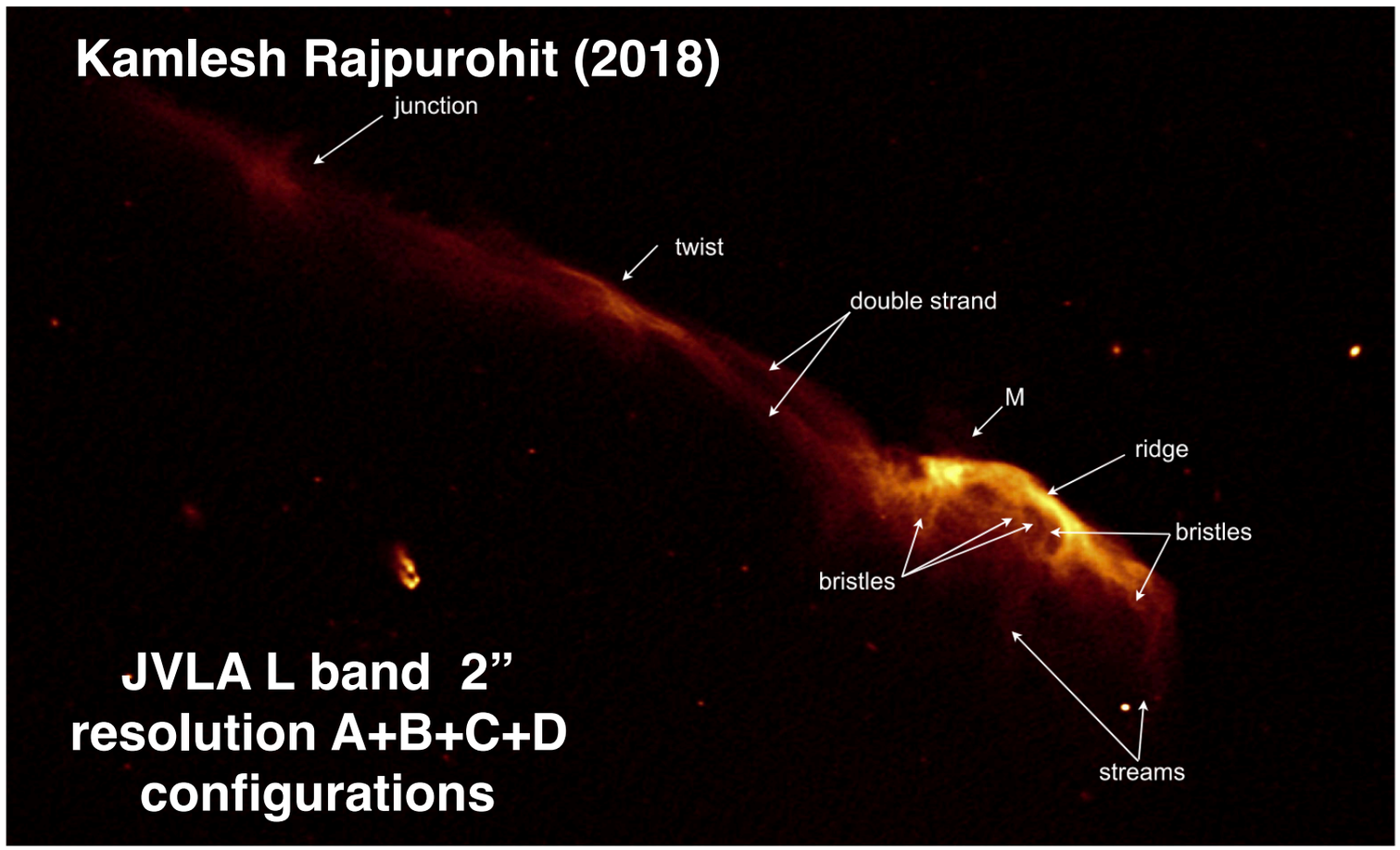




Connection with radiogalaxies ?

Filamentary structure in relics

News from JVLA: II



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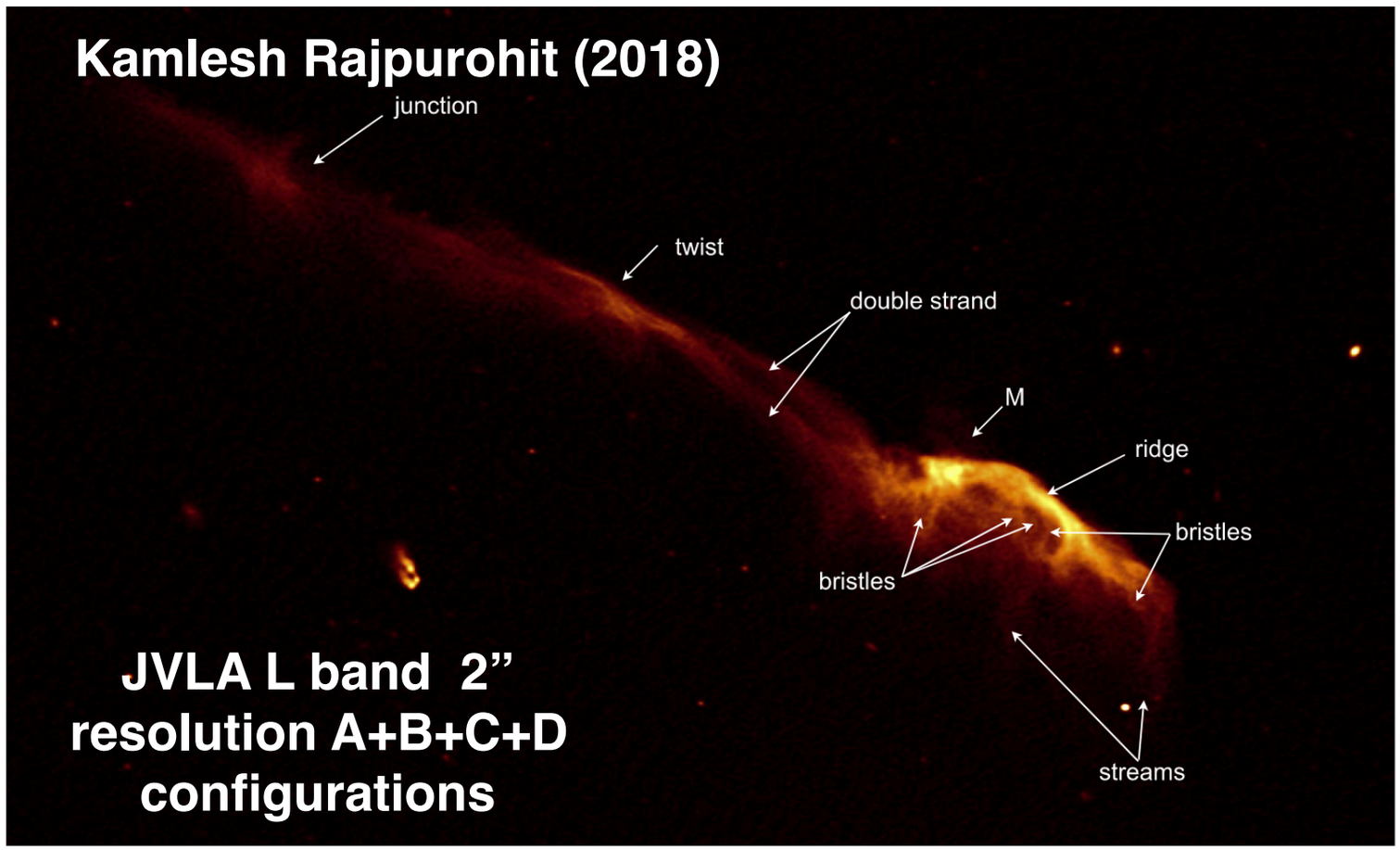

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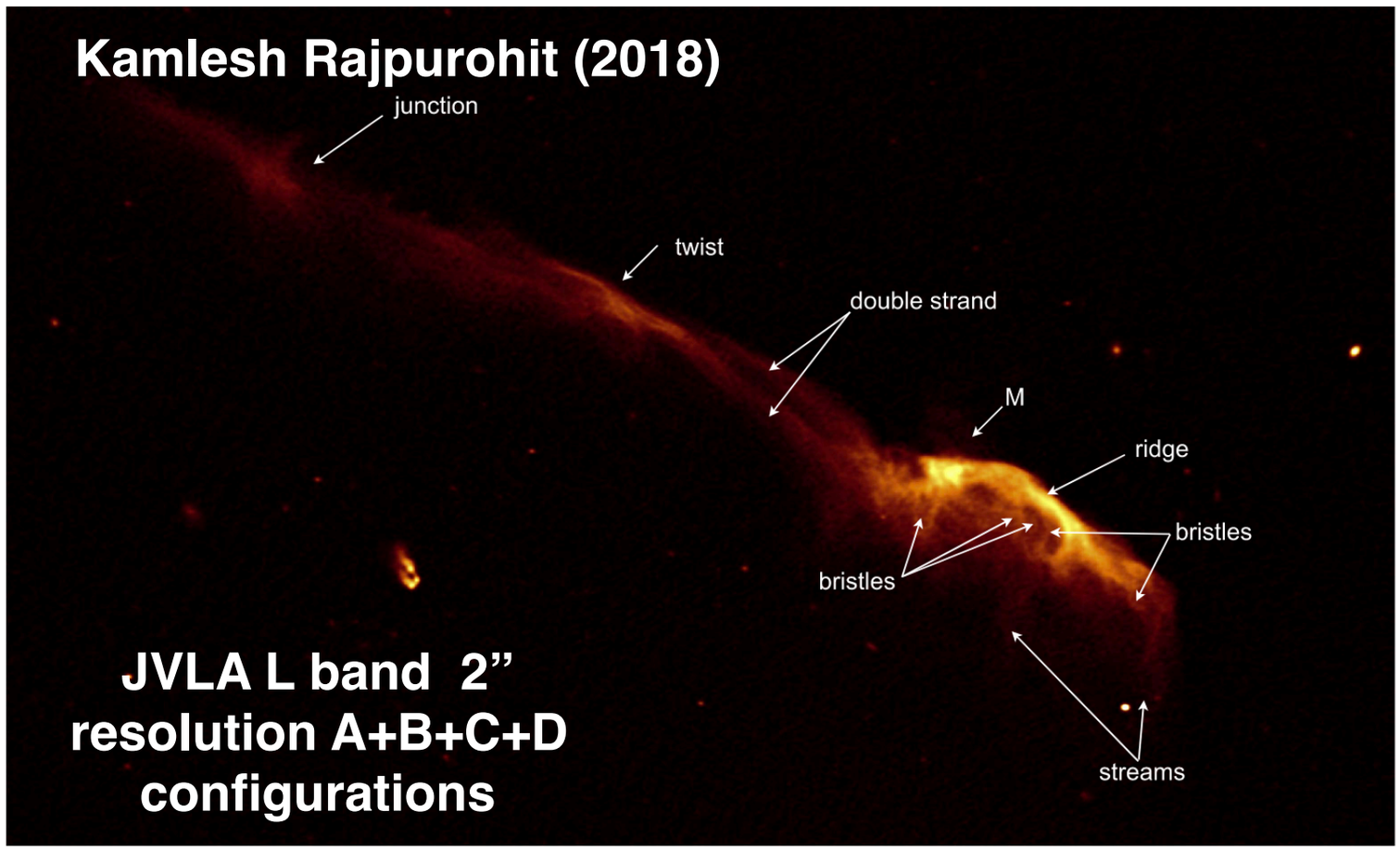

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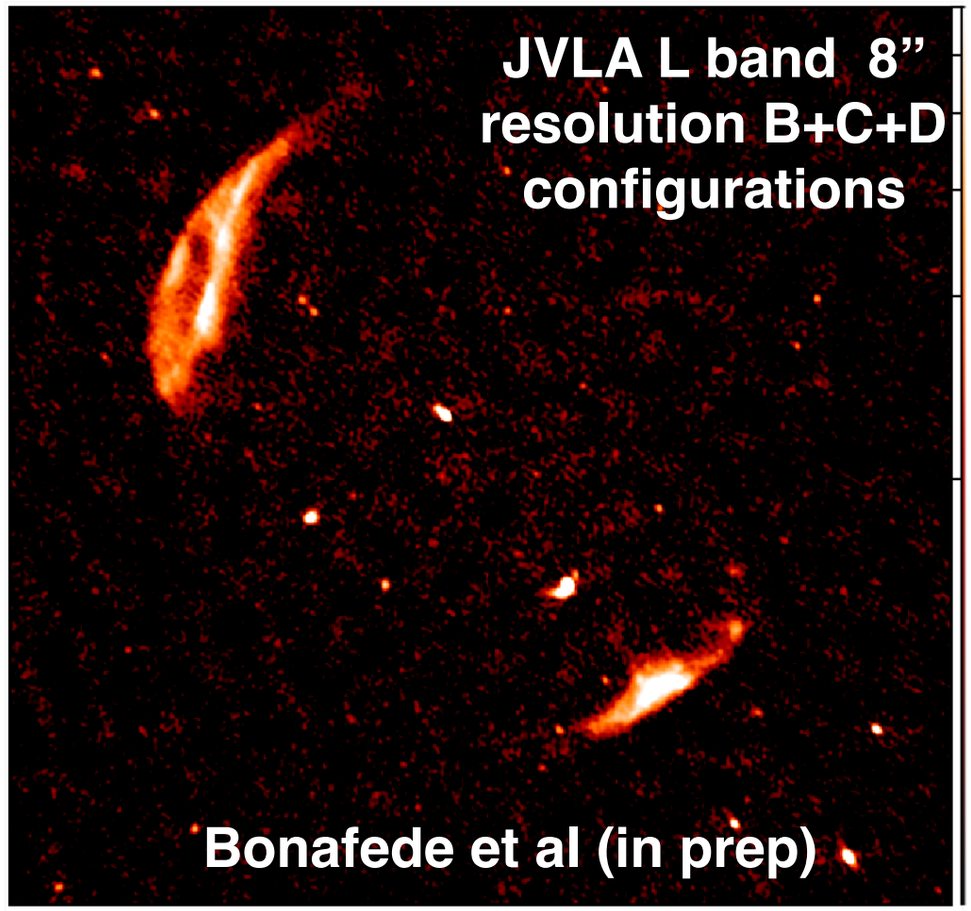

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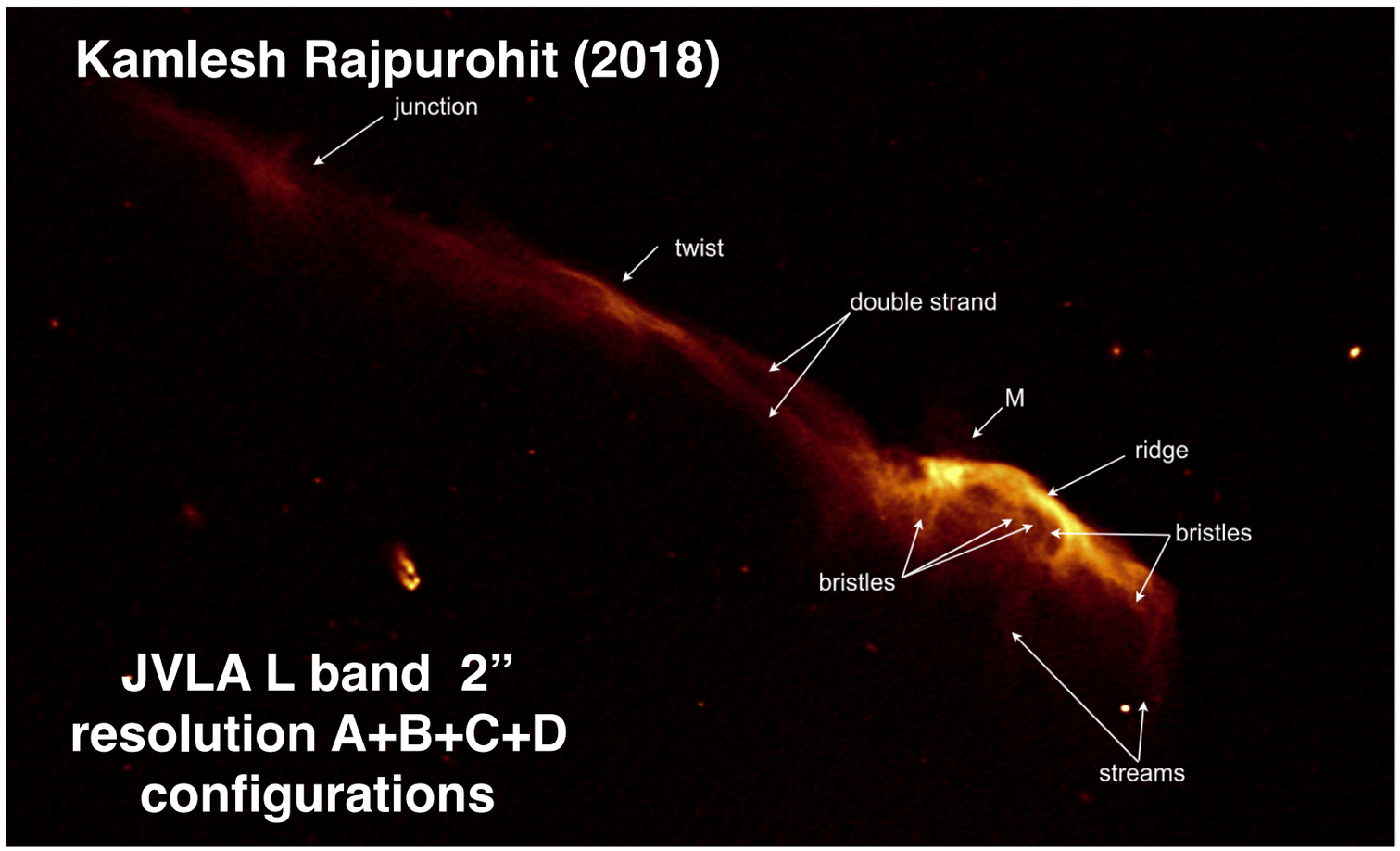

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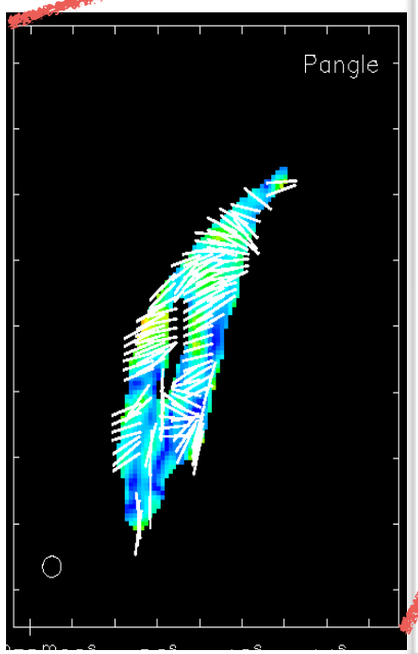
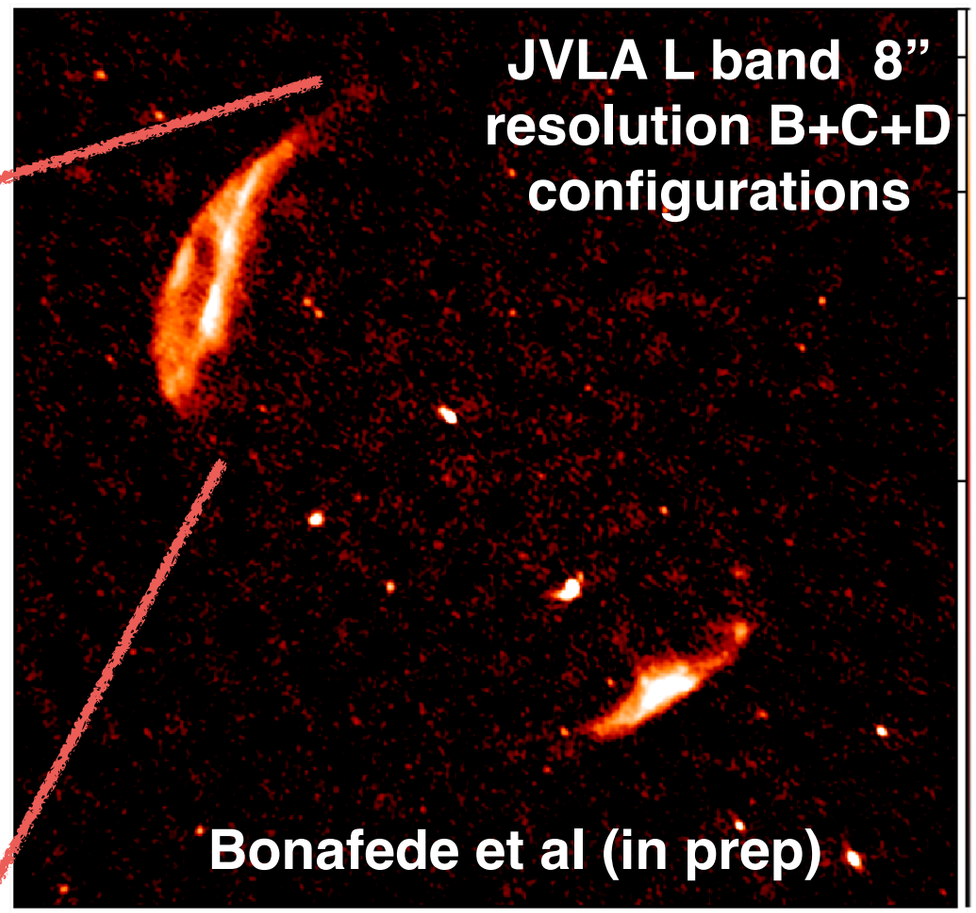
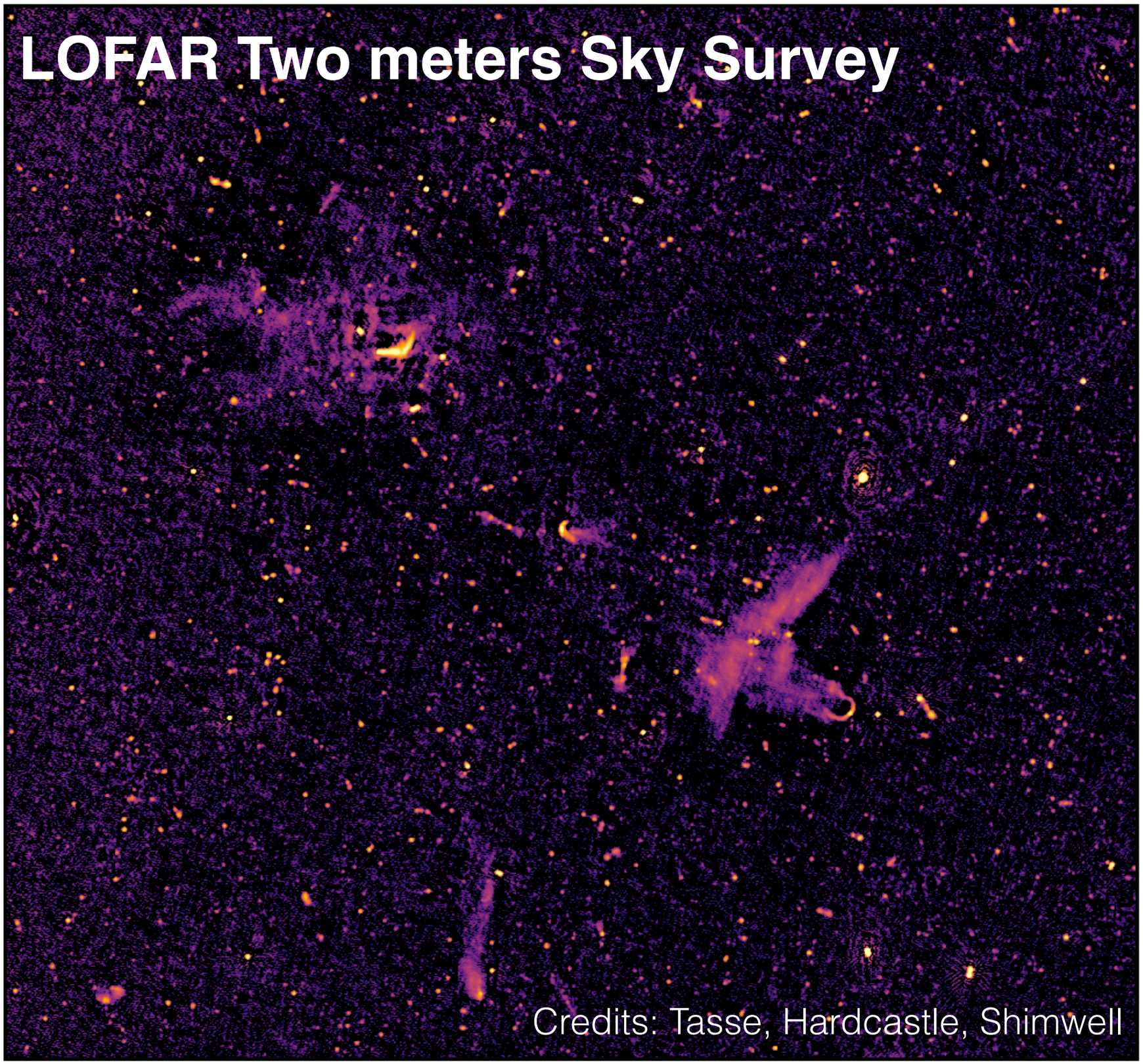




More new from LOFAR in polarisation!



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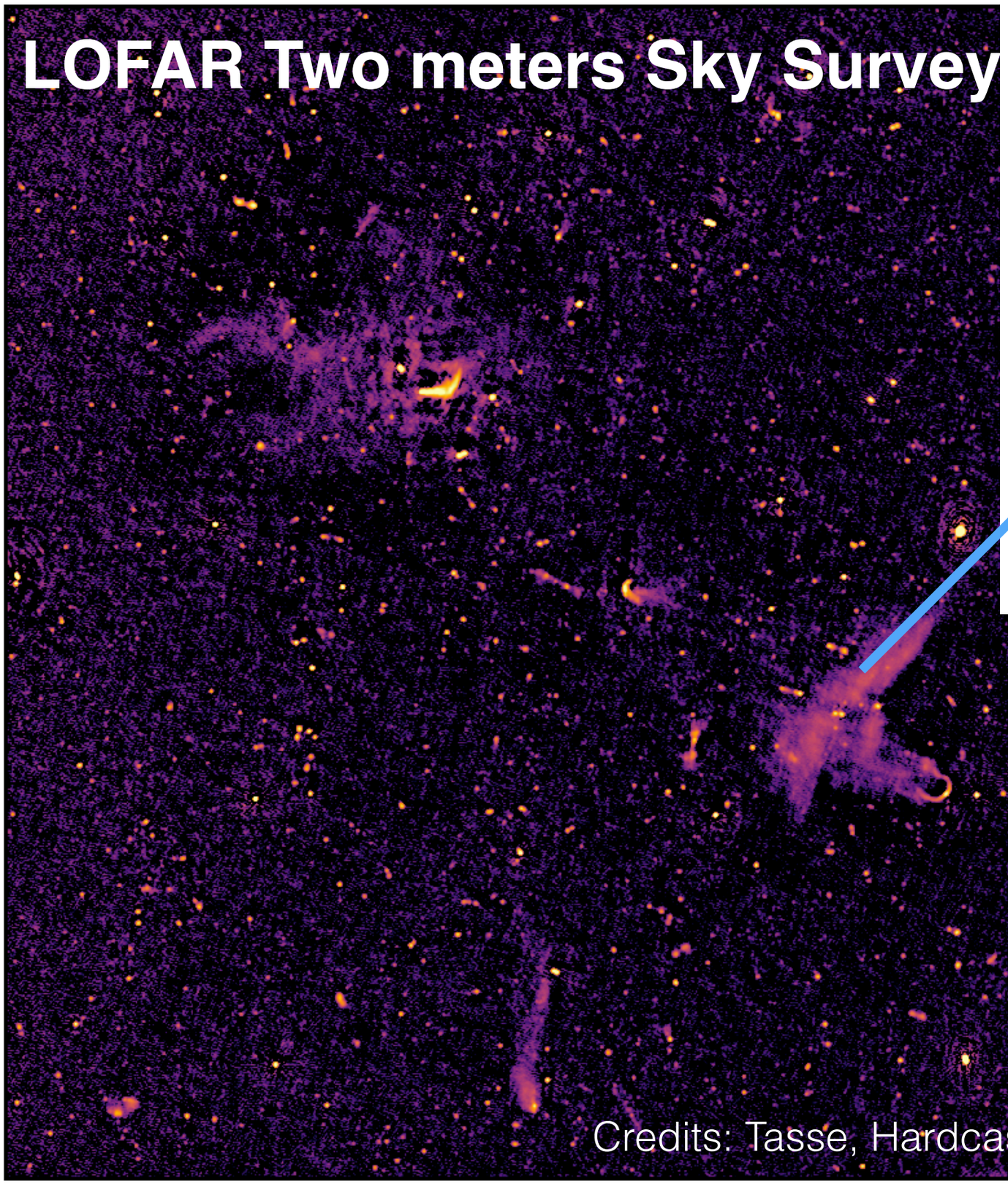
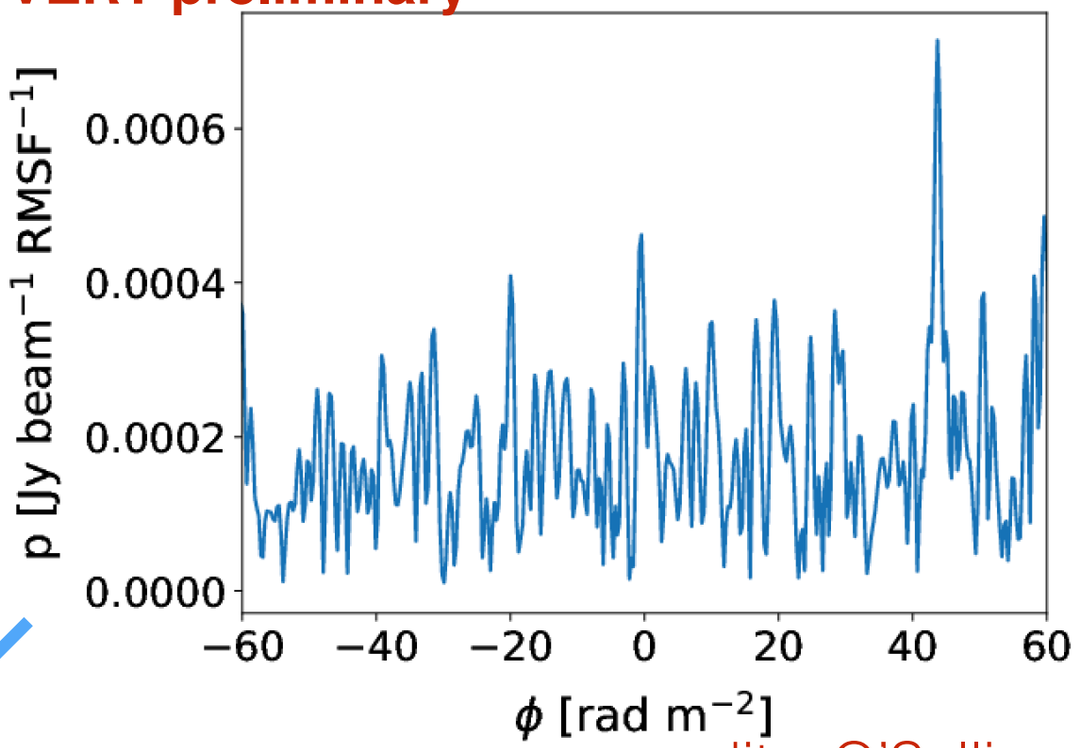


VERY preliminary



credits: O'Sullivan

Low frequency
—> low B

Conclusions so far

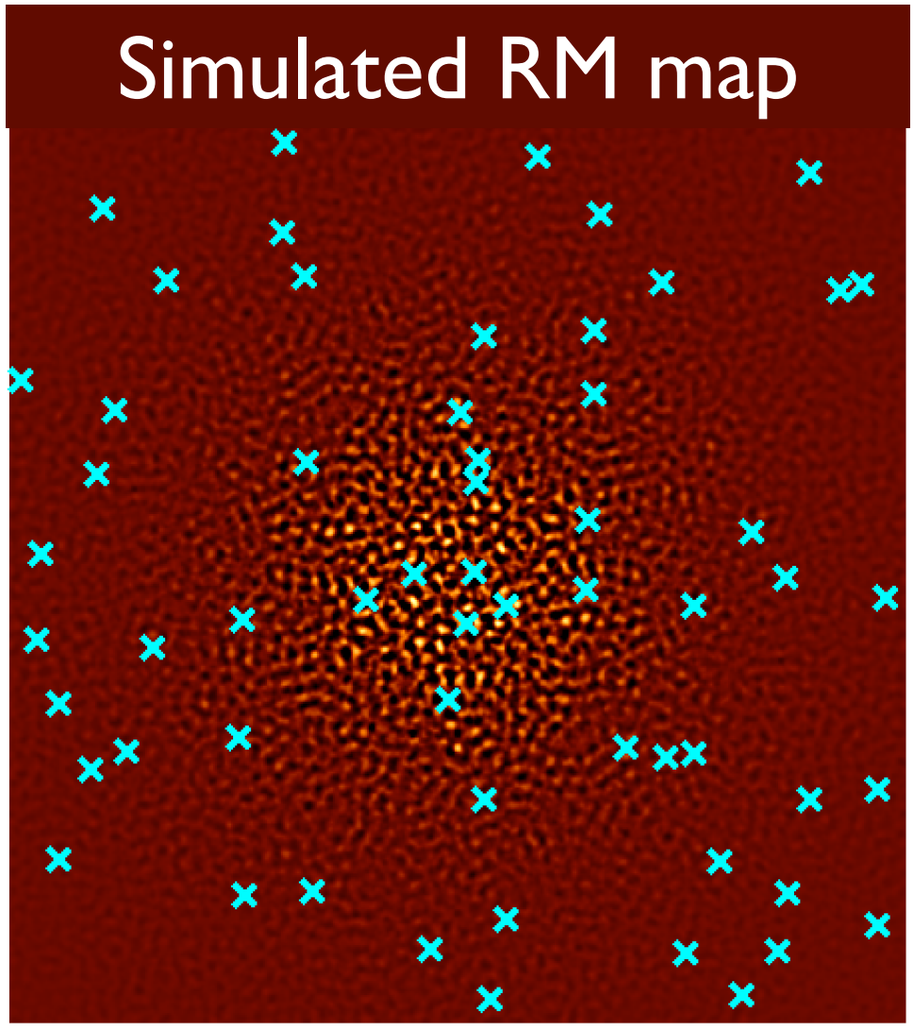
- New emission in galaxy clusters
- $P \propto \gamma_L^2 B^2$

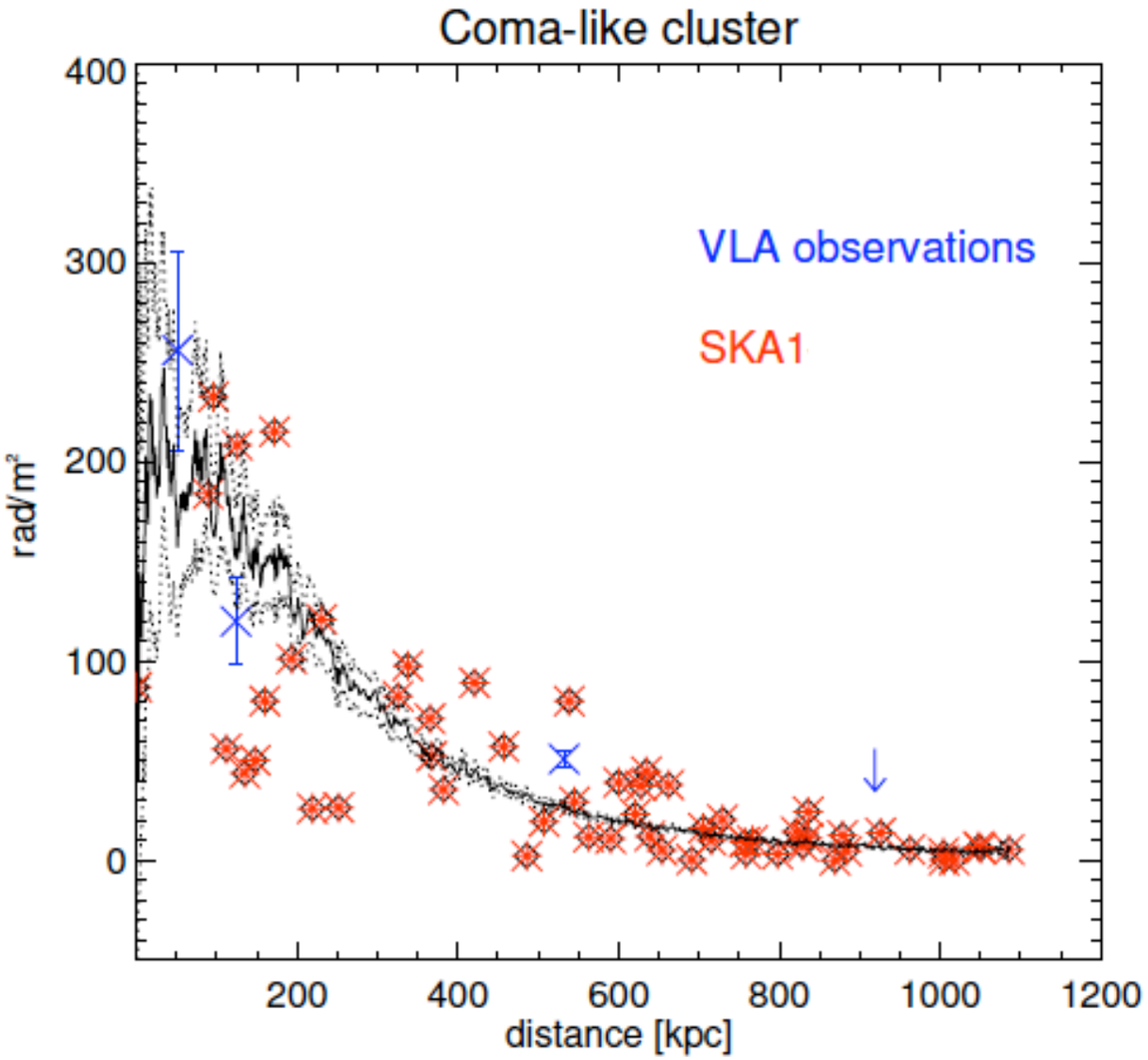
  Independent measurement of B needed
- Emission from background sources to constrain B —> not enough!

Emission from extended sources detected! Not trivial interpretation

F. Loi talk!

SKA: RM grid from a single cluster

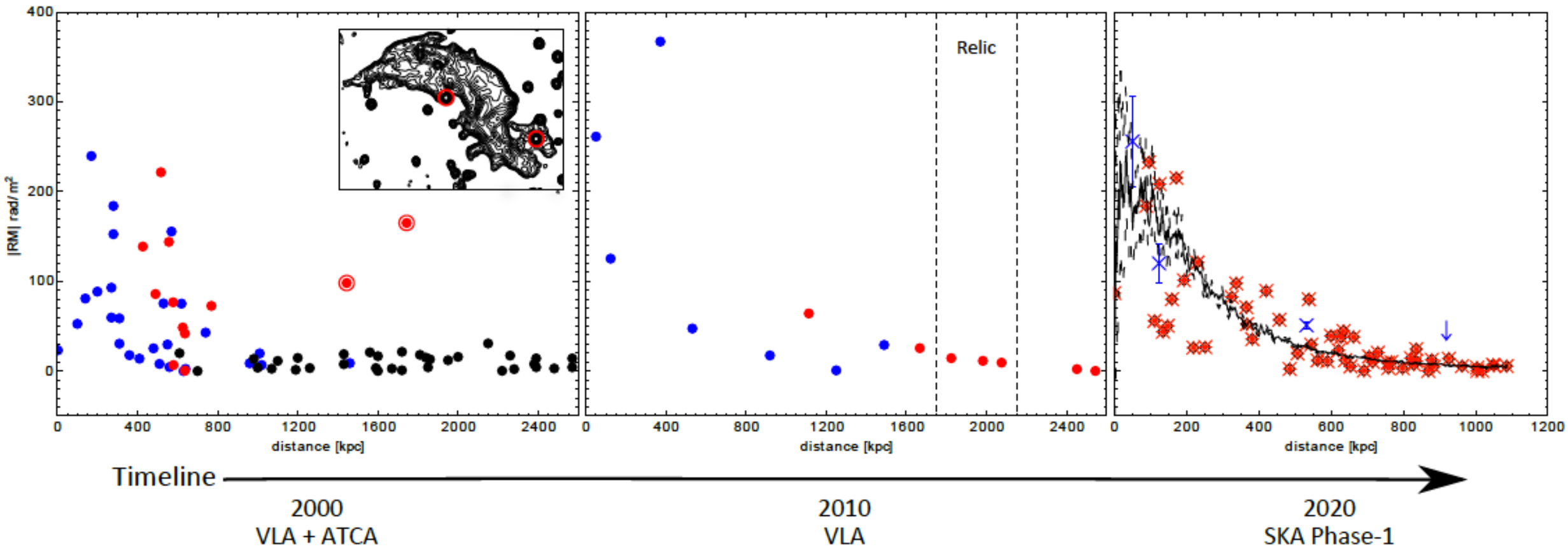




315 polarised sources / sq degree at 1 μJy at
1.6 arcsec resolution (Rudnick & Owen 2014)

Bonafede et al (2015)

RM grid - a Coma-like cluster with SKA



Johnston-Hollitt et al 15

Conclusions

- New emission in galaxy clusters
- $P \propto \gamma_L^2 B^2$

  Independent measurement of B needed
- Emission from background sources to constrain B —> not enough!
- Emission from extended sources detected! Not trivial interpretation
- Great potential of SKA for B studies BUT need new techniques to fully exploit its capabilities