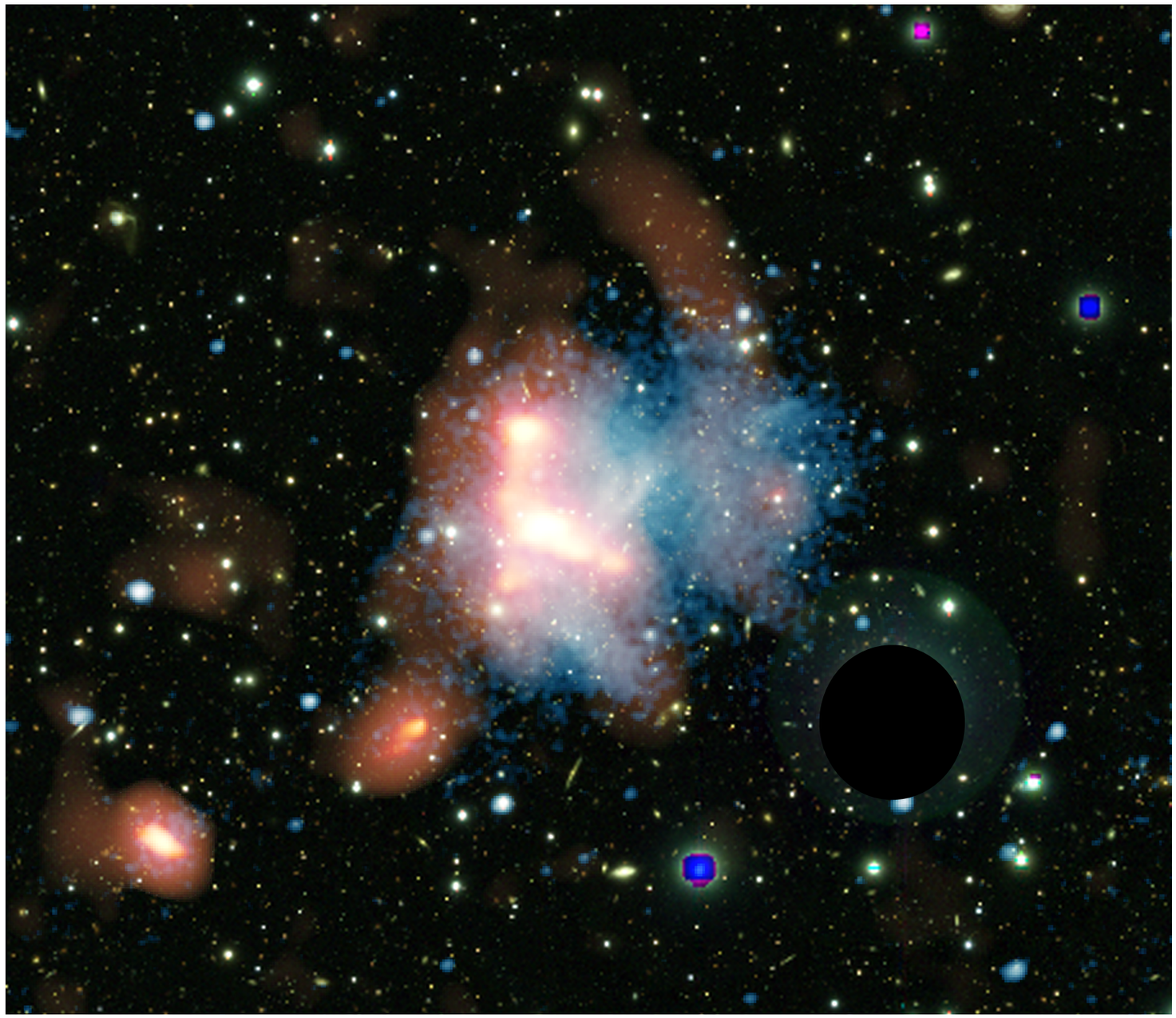
Galaxy clusters at low frequencies



Annalisa Bonafede - held by Marcus Brüggen

G. Brunetti, F. Vazza, C. Stuardi, E. Bonnassieux, N. Biava, & LOFAR cluster working group

Galaxy clusters

~100 Galaxies in 9 Mpc^3

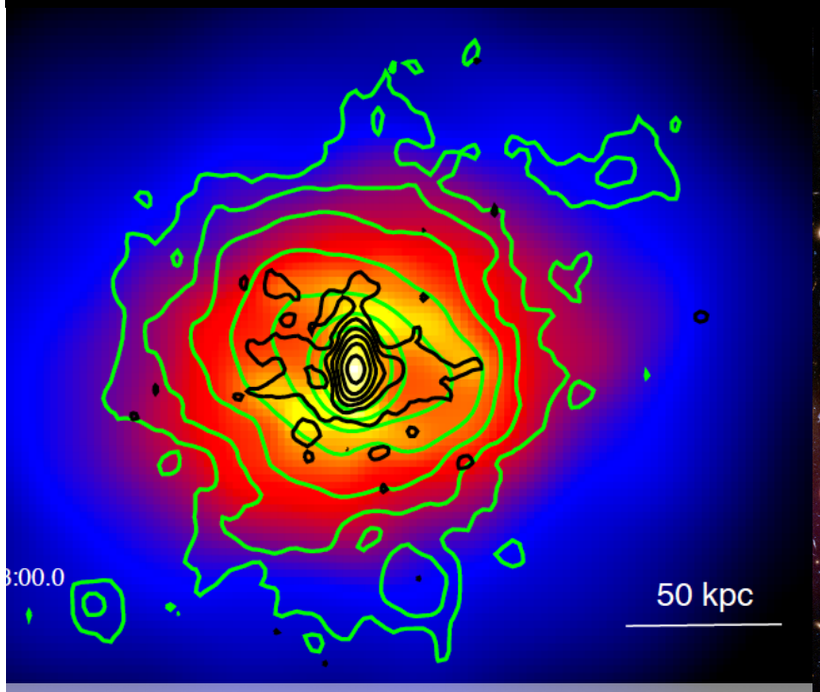
500 kpc

Dark Matter ~80%
of the cluster mass

Hot gas
T ~10^7-10^8 K
n ~1e-3 cm^{-3}
—> bremsstrahlung
(soft X-rays)

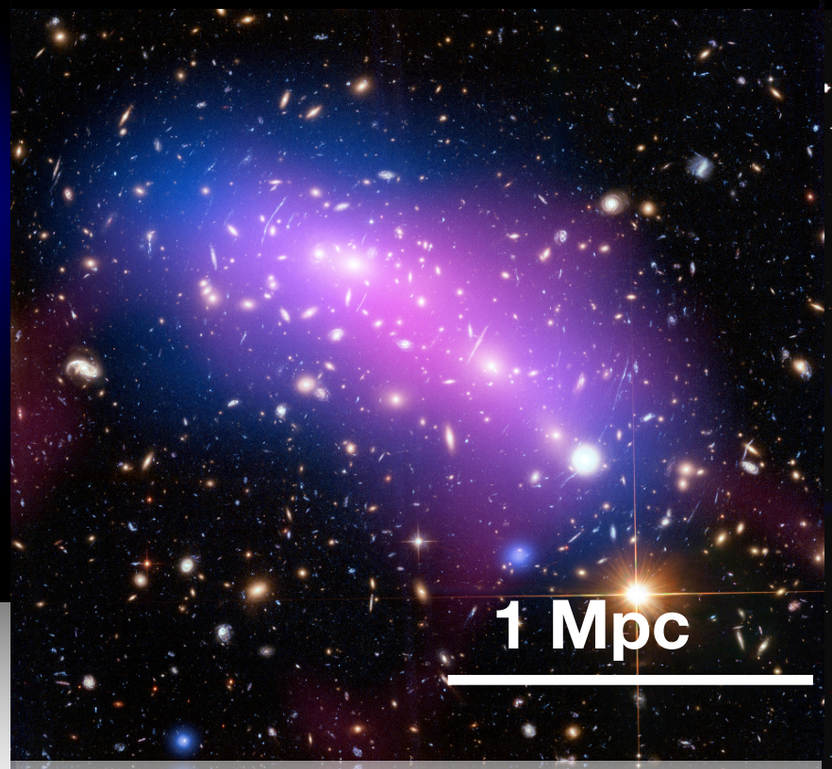
Magnetic fields & relativistic electrons
—> synchrotron emission
(radio)
only in some clusters

Radio contours
X-ray (gas) colours



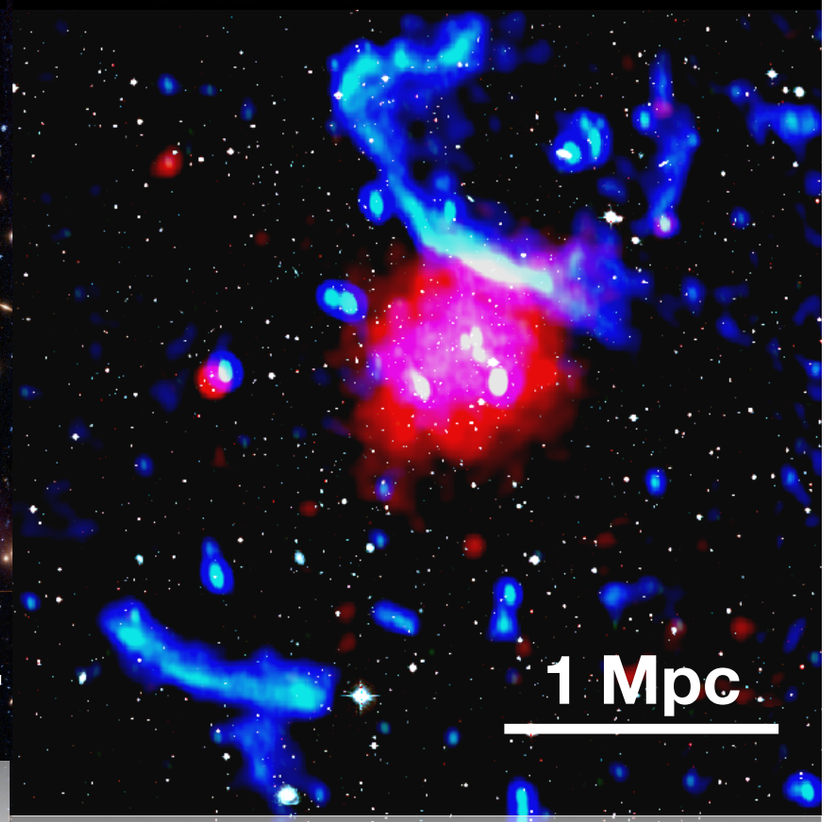
Mini halos
Gitti et al. (2012)

Radio
X-ray (gas)



Radio halos
Ogrean et al. (2015)

Radio
X-ray (gas)



Radio relics
Bonafede et al. (2014)

Virialized systems

Merging systems

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

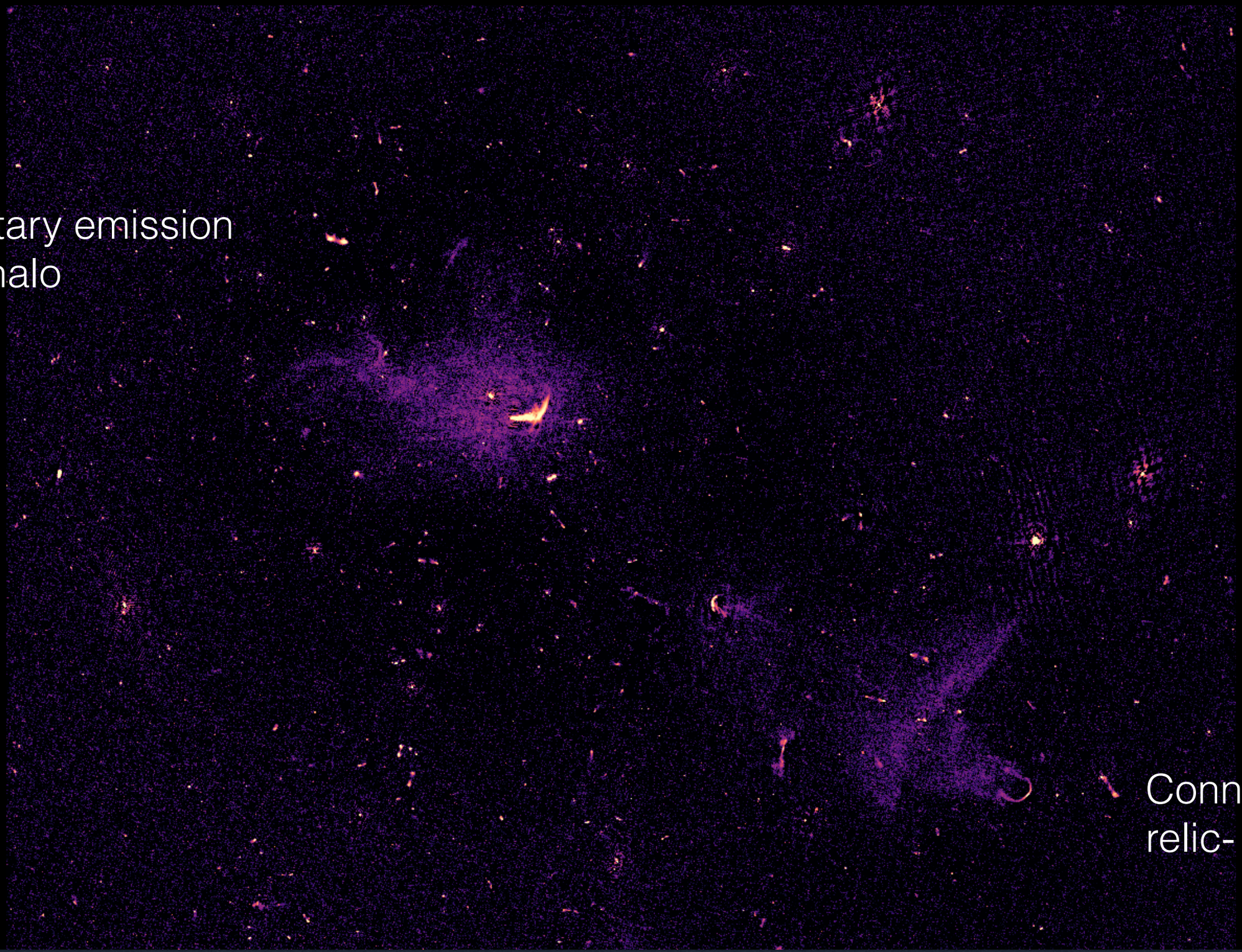
What's new?

- Fine structure in diffuse sources
- Bridges
- Intermediate objects
- High redshift

The Coma cluster

LOTSS pointing, pipeline calibration,
6” resolution - inner UVcut (0.1 Km) —> suppression of diffuse emission

Hints of
filamentary emission
in the halo



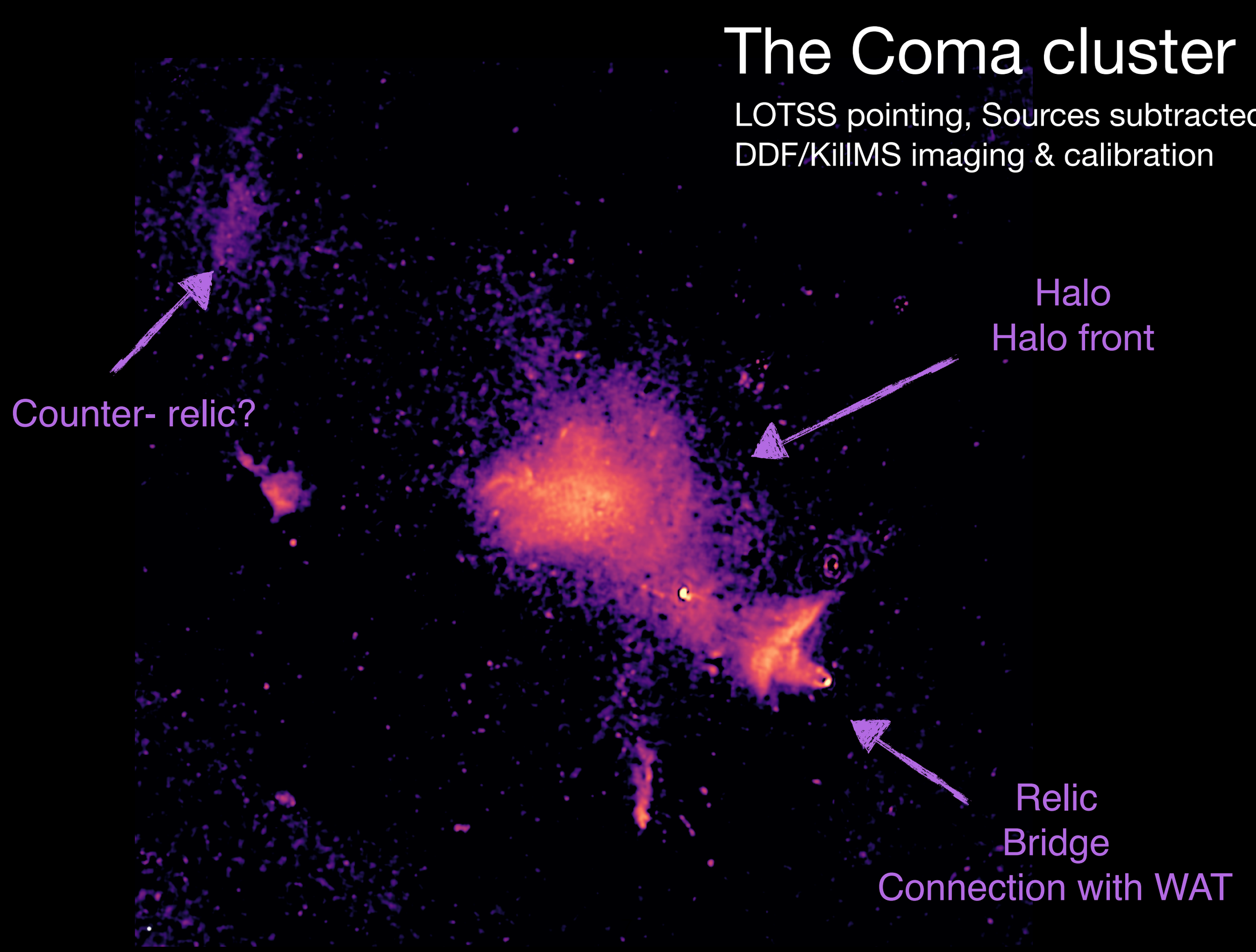
Connection
relic- WAT

The Coma cluster

LOTSS pointing, pipeline calibration,
20” resolution - inner UVcut (0.1 Km) —> suppression of diffuse emission

The Coma cluster

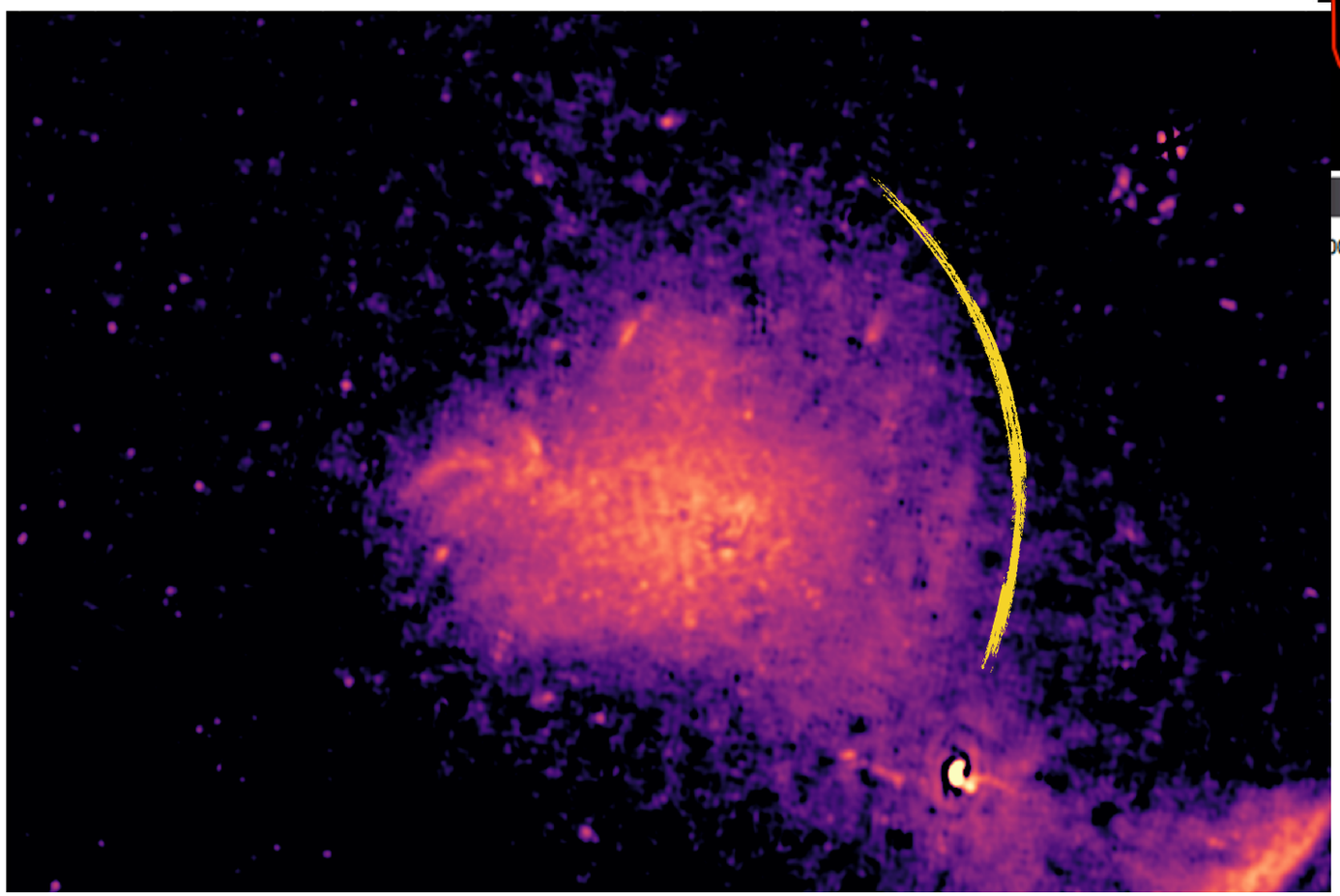
LOTSS pointing, Sources subtracted
DDF/killMS imaging & calibration

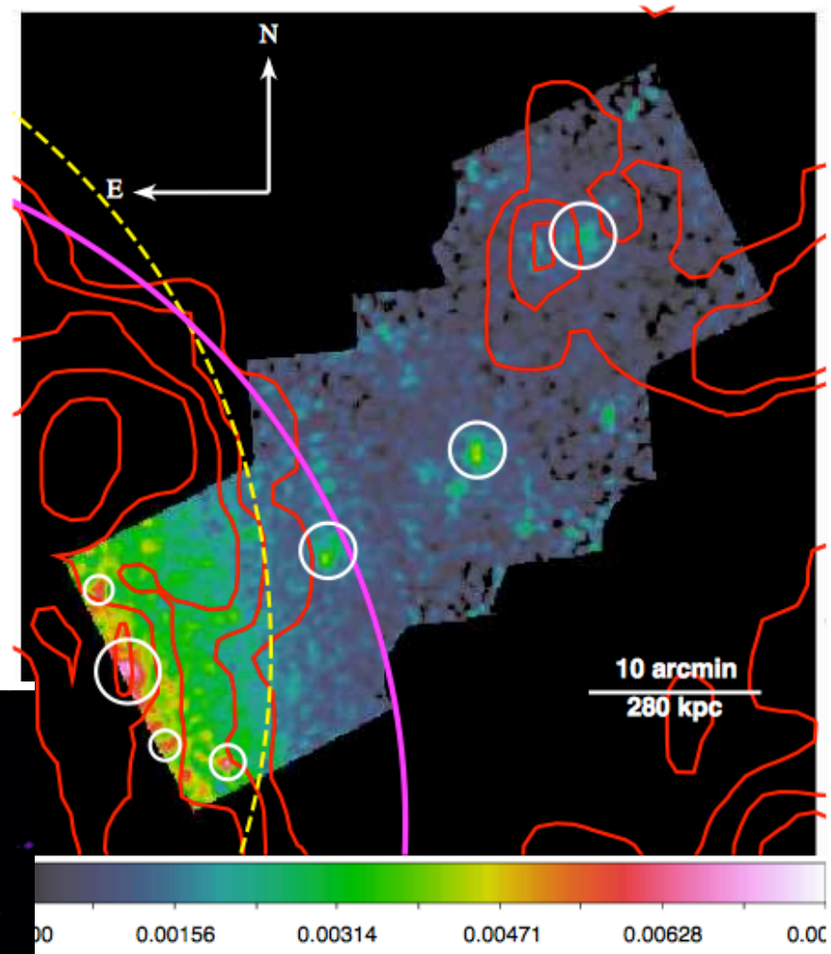


A closer look: the halo front

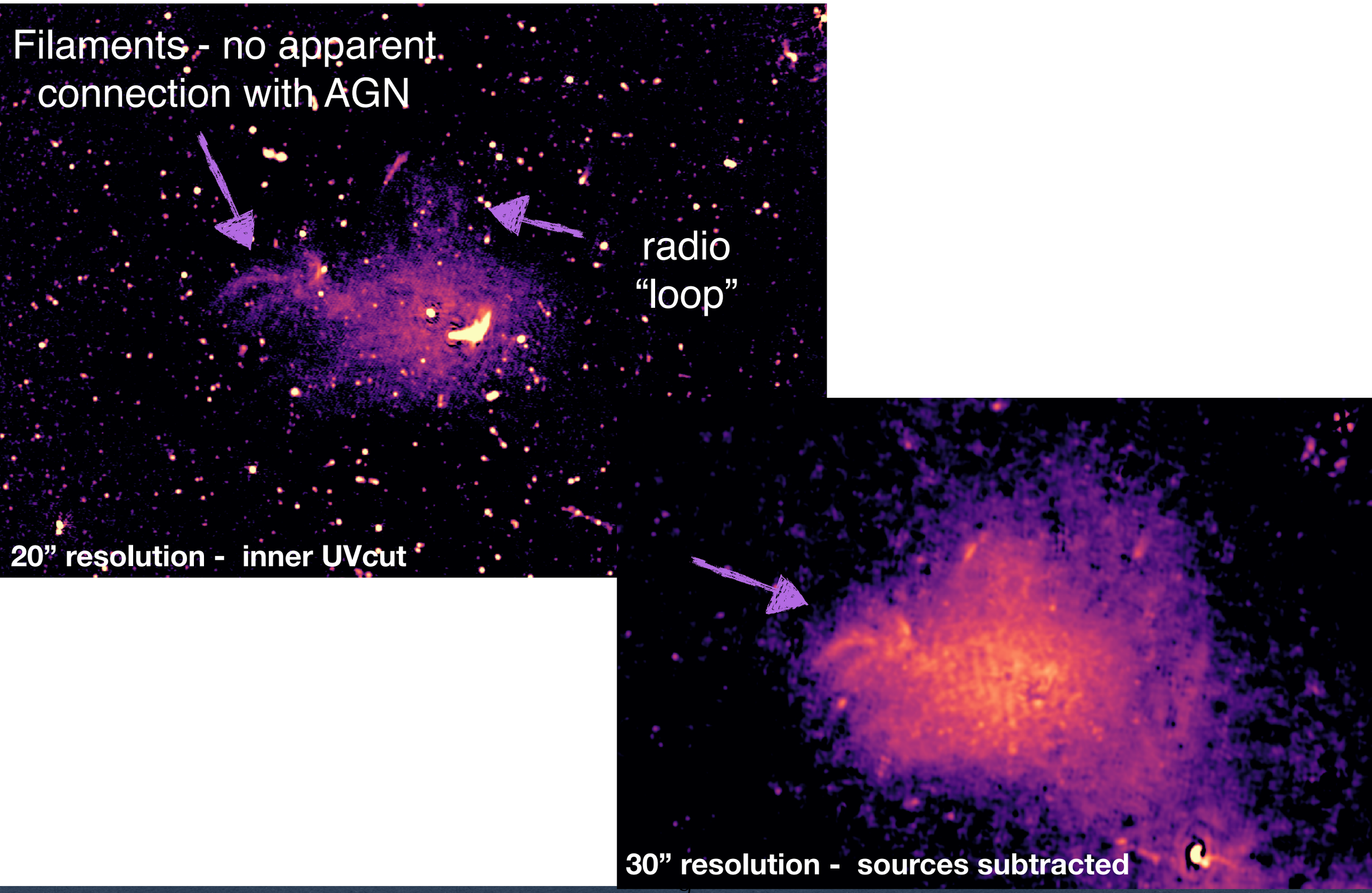
Suzaku observations of a shock front tracing the western edge of the giant radio halo in the Coma Cluster

Yuusuke UCHIDA[1,2], Aurora SIMIONESCU[1], Tadayuki TAKAHASHI[1,2], Norbert WERNER[3,4], Yuto ICHINOHE[1,2], Steven W. ALLEN[3,4,5], Ondrej URBAN[3,4,5] and Kyoko MATSUSHITA[6]



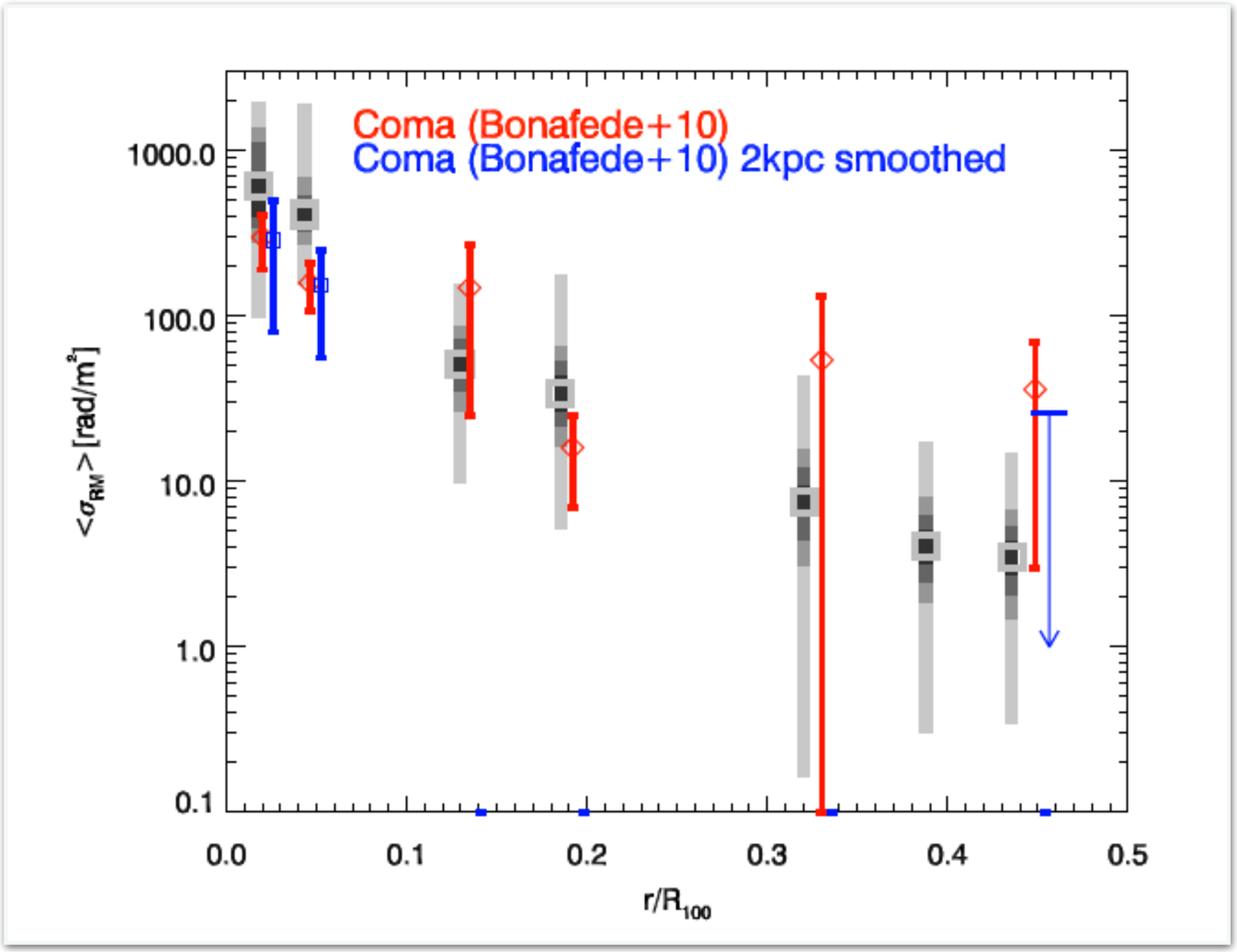


A closer look: filaments in the halo



Filaments in the halo - simulations

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



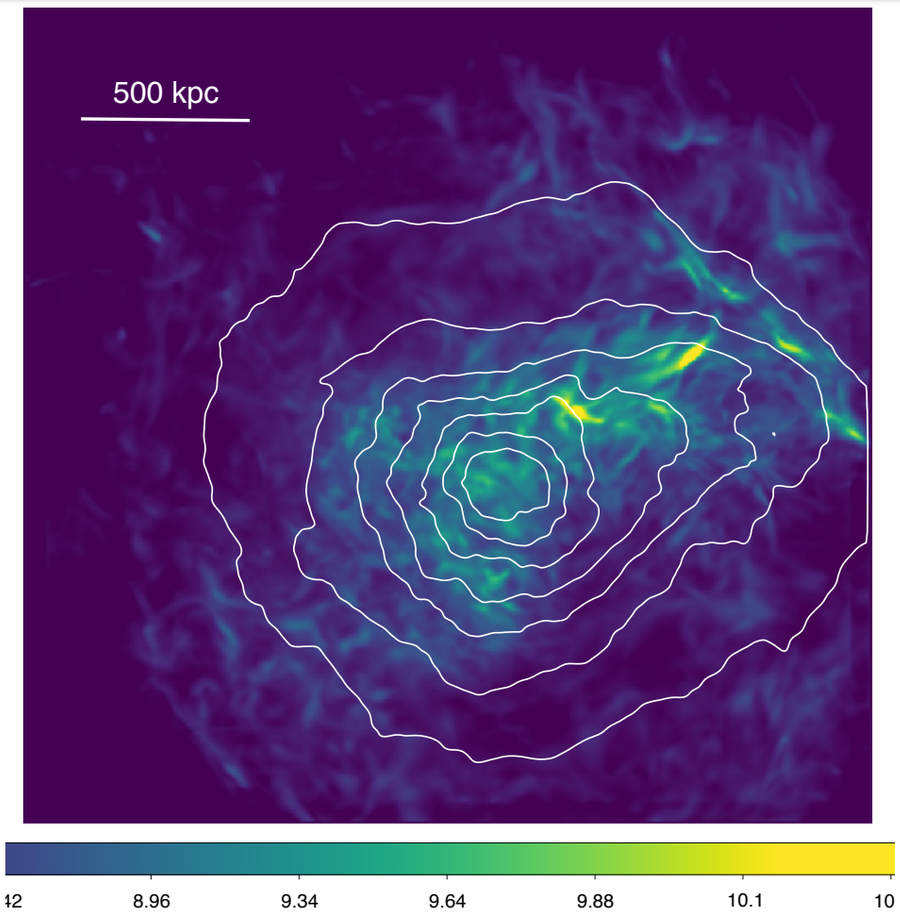
Simulation

data

Good match with RM observations

Vazza et al. (2018)

Filaments in the halo - simulations



Turbulent energy flux
(compressive component)

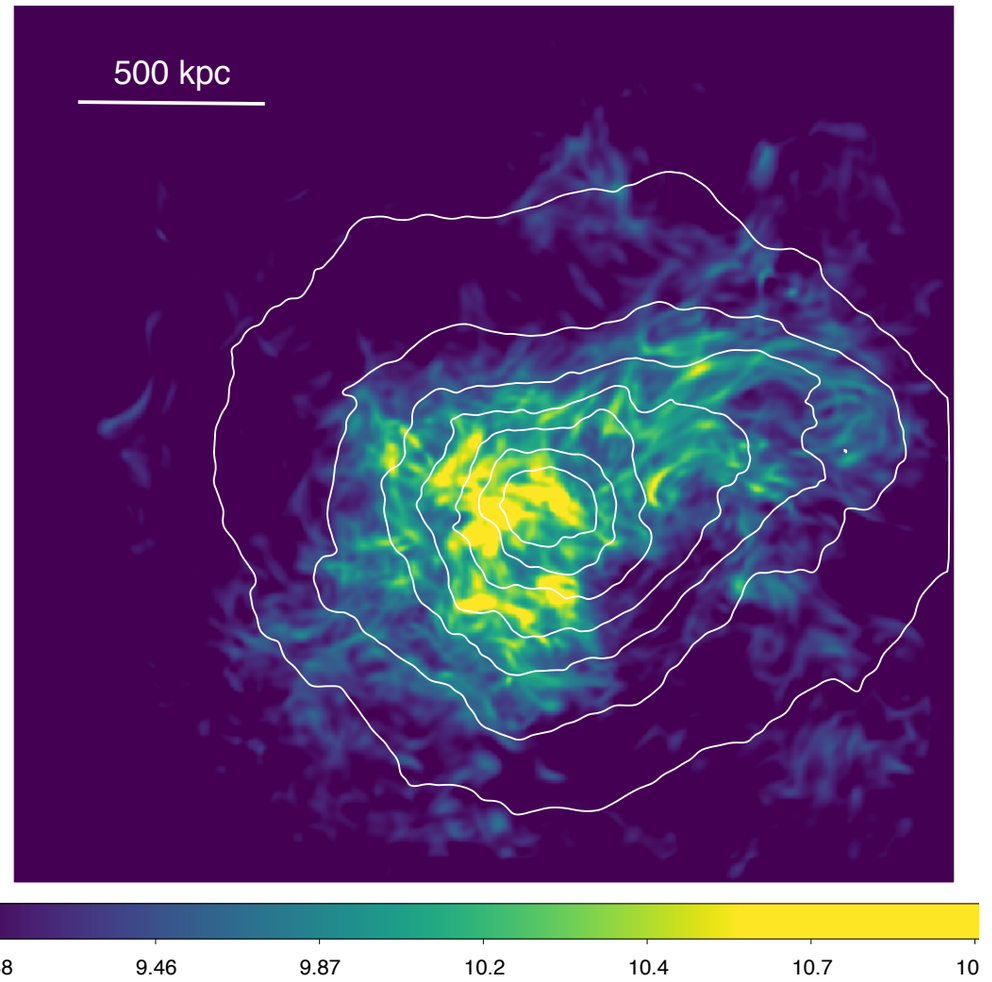
$$E_t \propto \rho \frac{\sigma_{v_c}^3}{l} \times \frac{B^2}{(B^2 + B_{CMB}^2)}$$

Brunetti et al (2006)

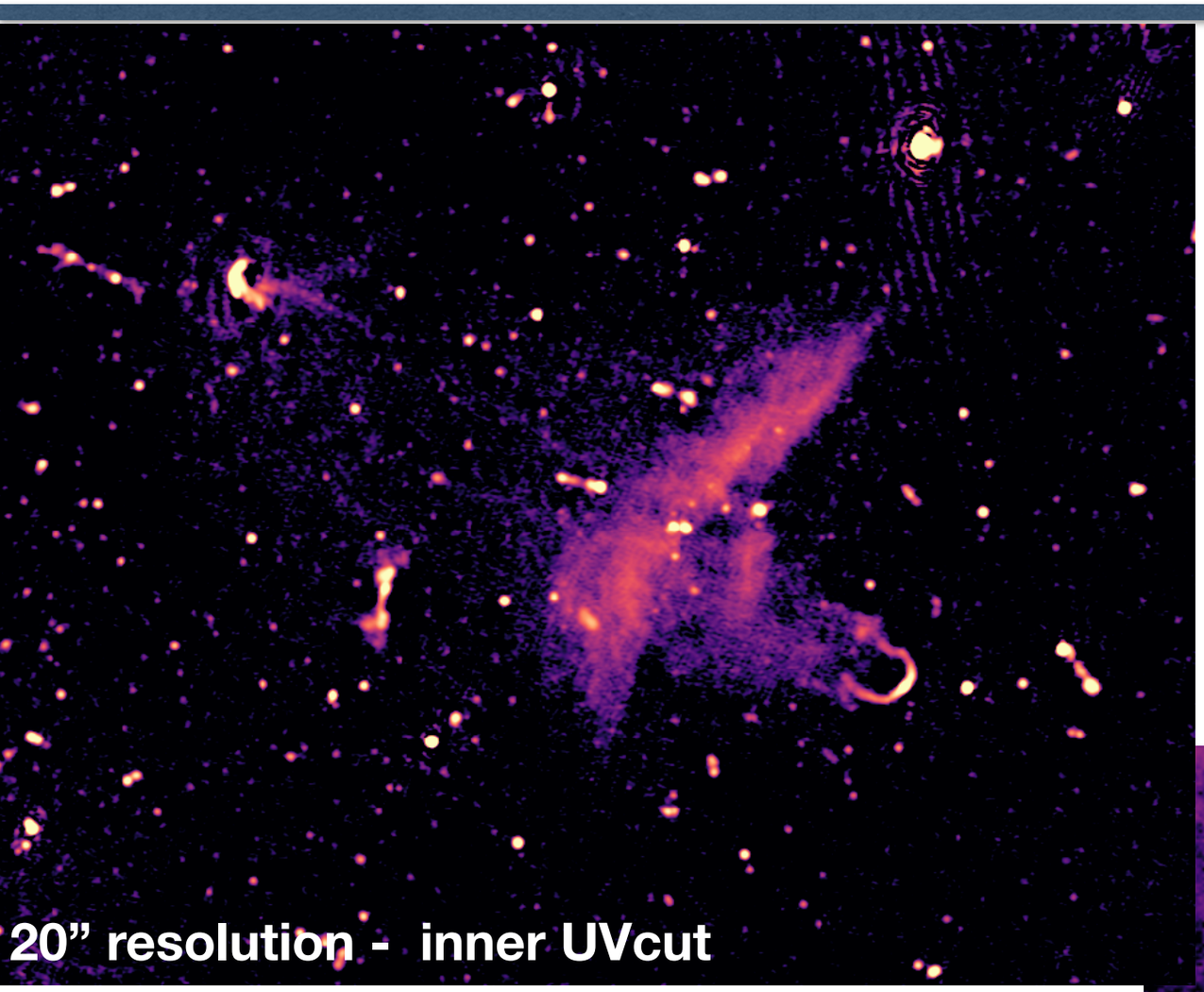
Turbulent energy flux
(solenoidal component)

$$E_t \propto \rho \frac{\sigma_{v_s}^3}{l} \times \frac{B^2}{(B^2 + B_{CMB}^2)}$$

—> Origin of the observed filaments?

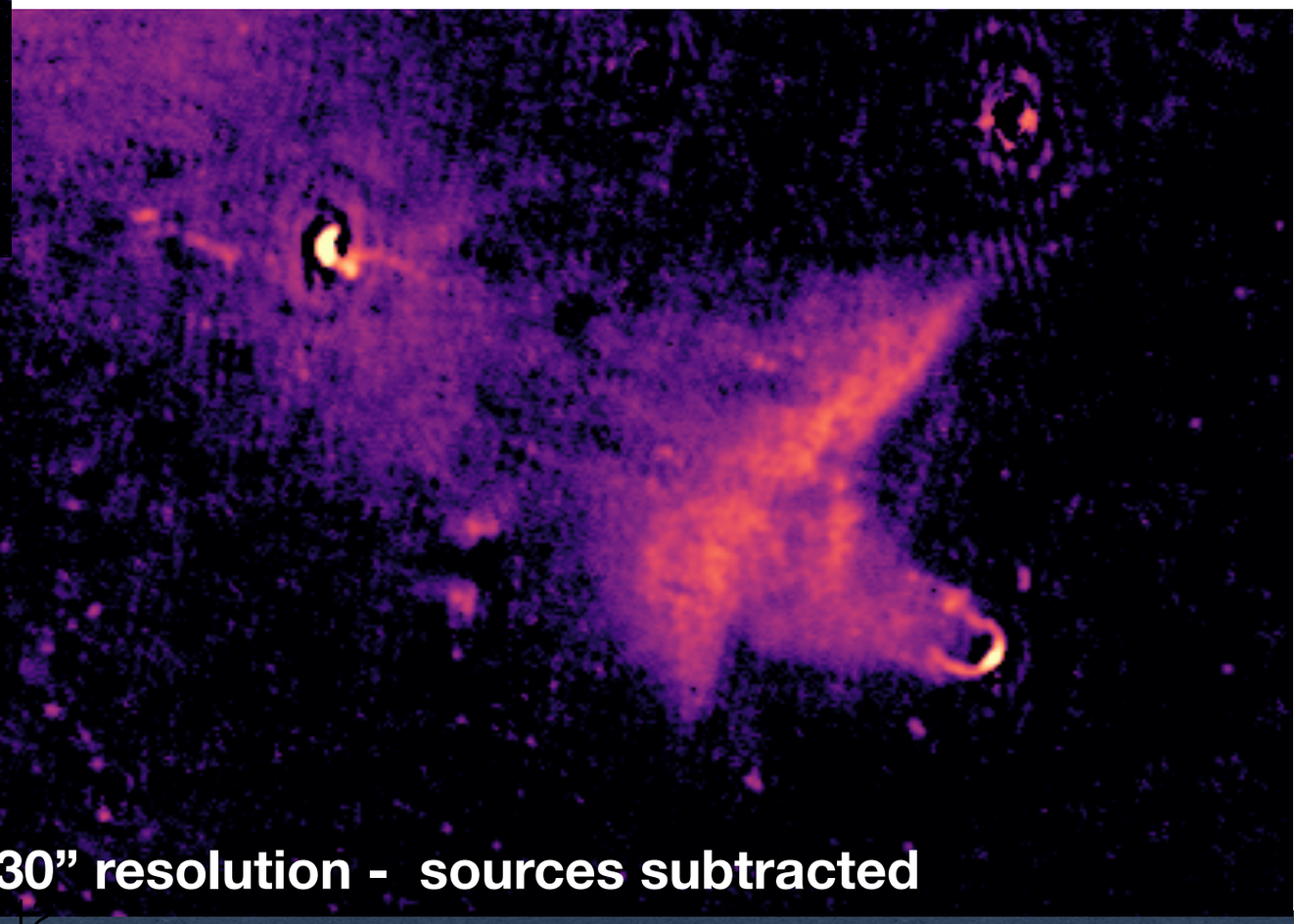


A closer look: The relic region



20” resolution - inner UVcut

WAT feeding the relic?



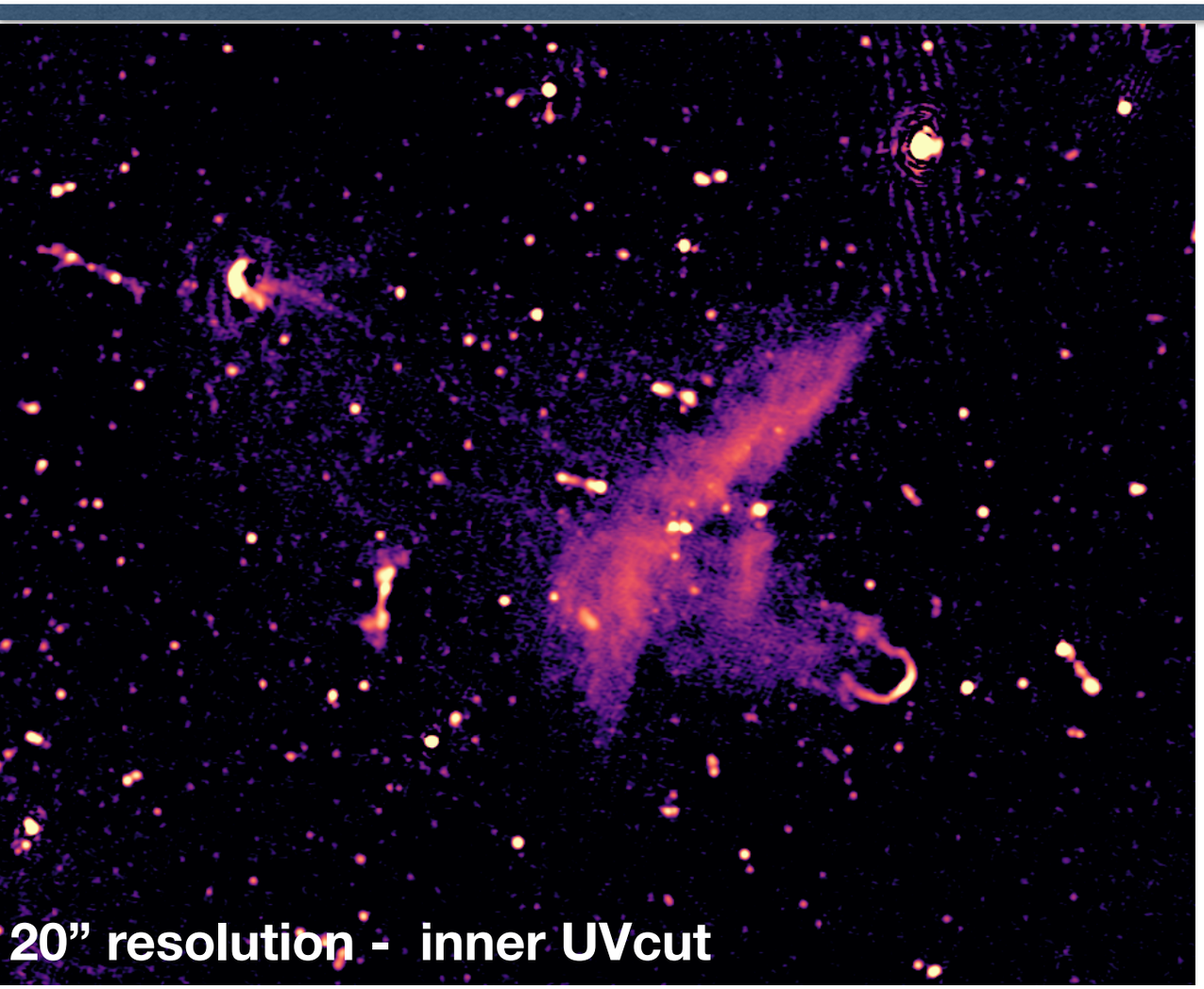
30” resolution - sources subtracted

Bridge connecting halo and relic

- shock re-acceleration?
- Turbulence? **(Brunetti & Vazza in prep.)**

Preliminary estimate α ~-1.5

A closer look: The relic region



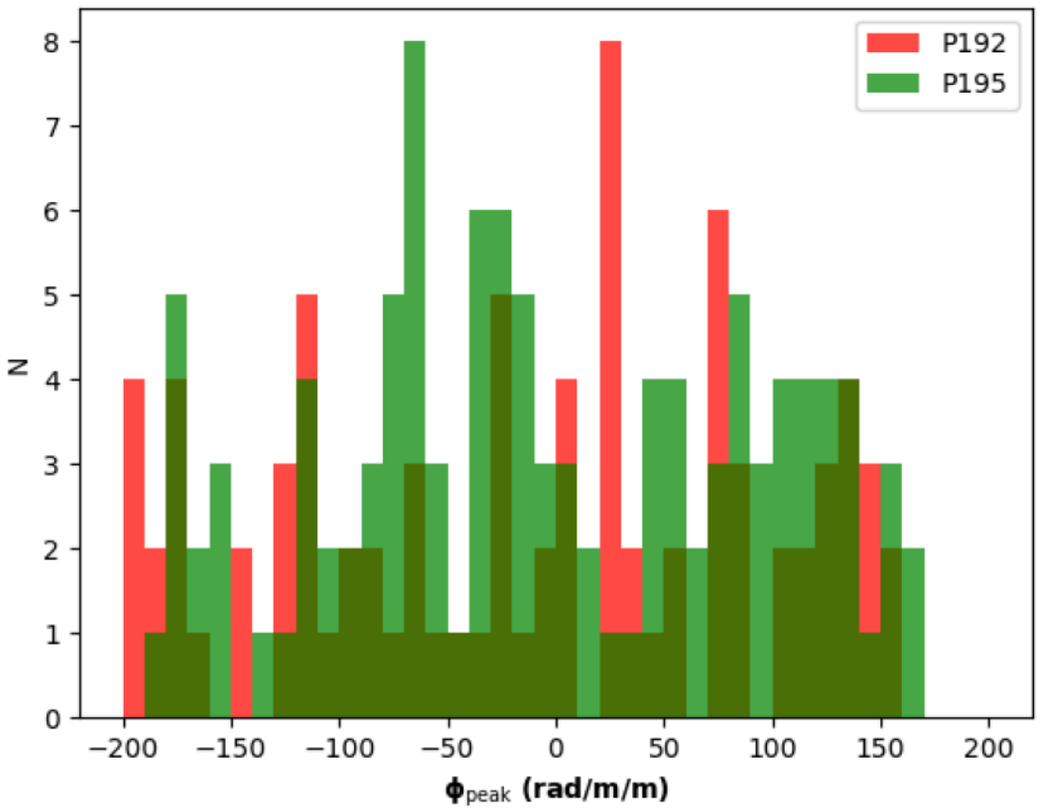


Figure 2: Distribution of RM values in the two pointings.

Polarisation?
No consistent detection above 8 σ
in both LOTSS pointings

Credits: Stuardi, O’Sullivan

The interacting pair A399- A401

Clusters at 3 Mpc distance

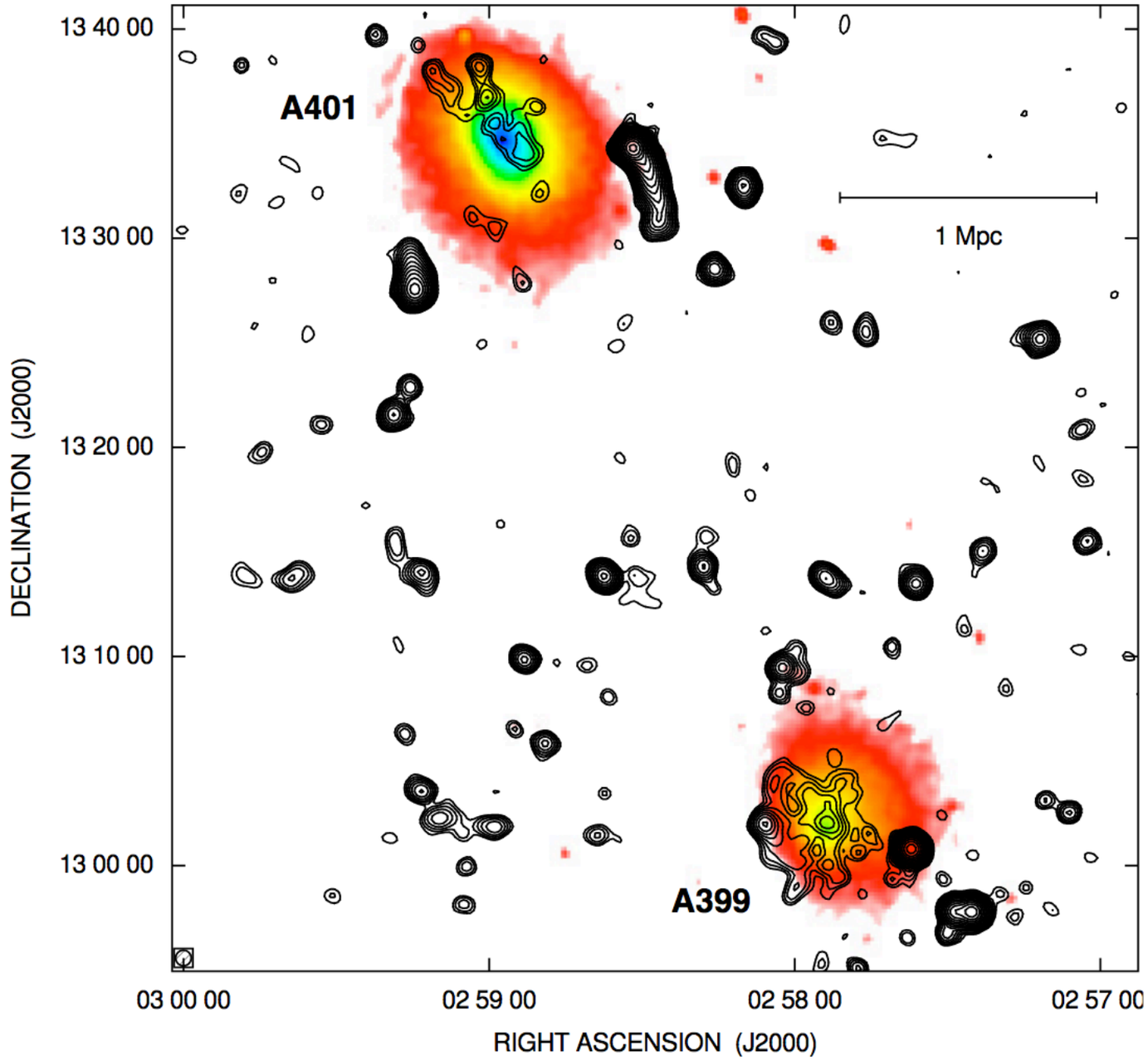
Double radio halo discovered with VLA

(Murgia et al 2010)

Pre-merging system at z ~0.07

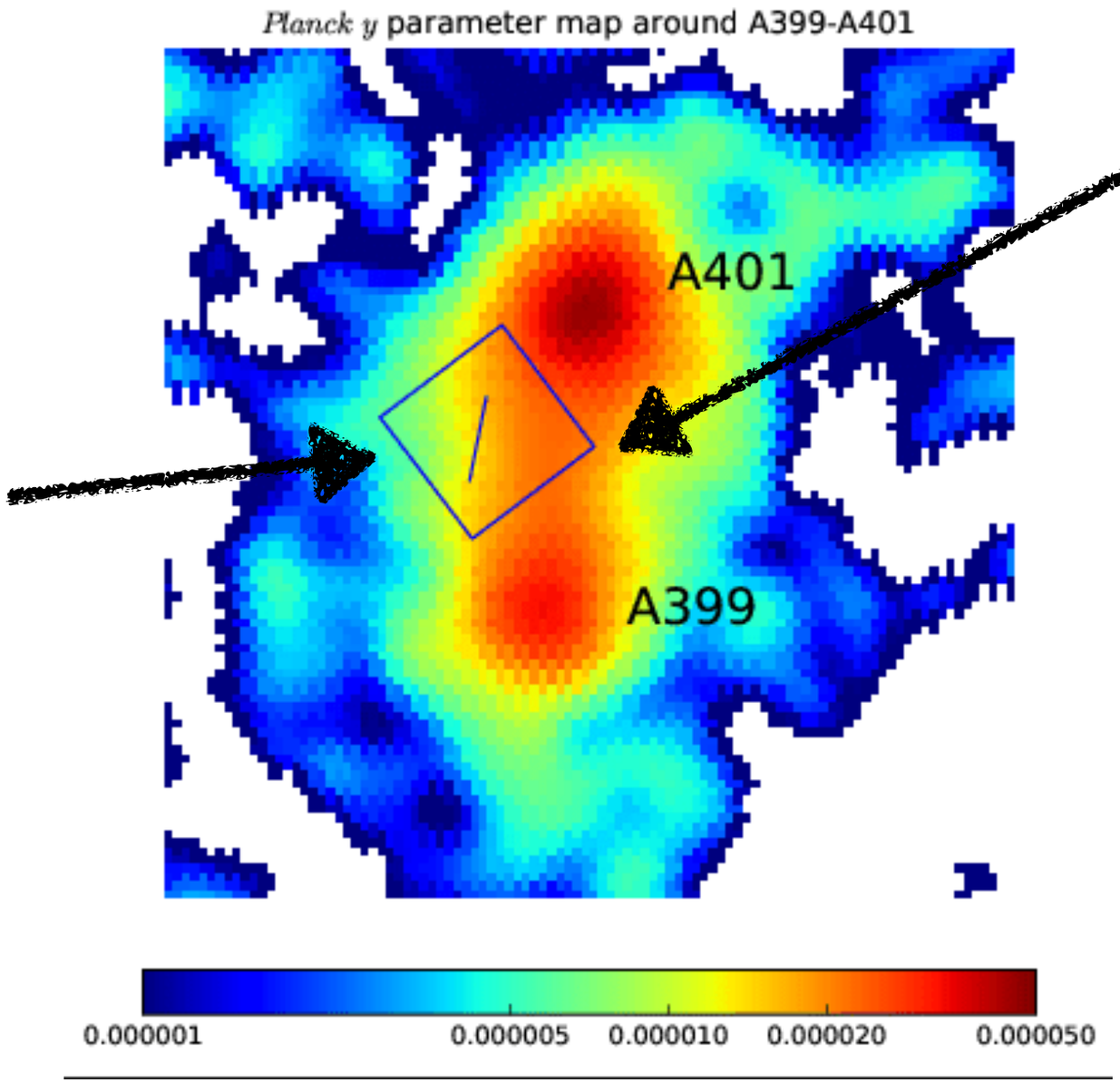
M ~ 9.3e14 Msun

M ~ 5.7e14 Msun



XMM-Newton colours VLA 1.4 GHz contours

The interacting pair A399- A401



Isothermal filament
weak plasma

Weak shock (M~2)
detected by Suzaku

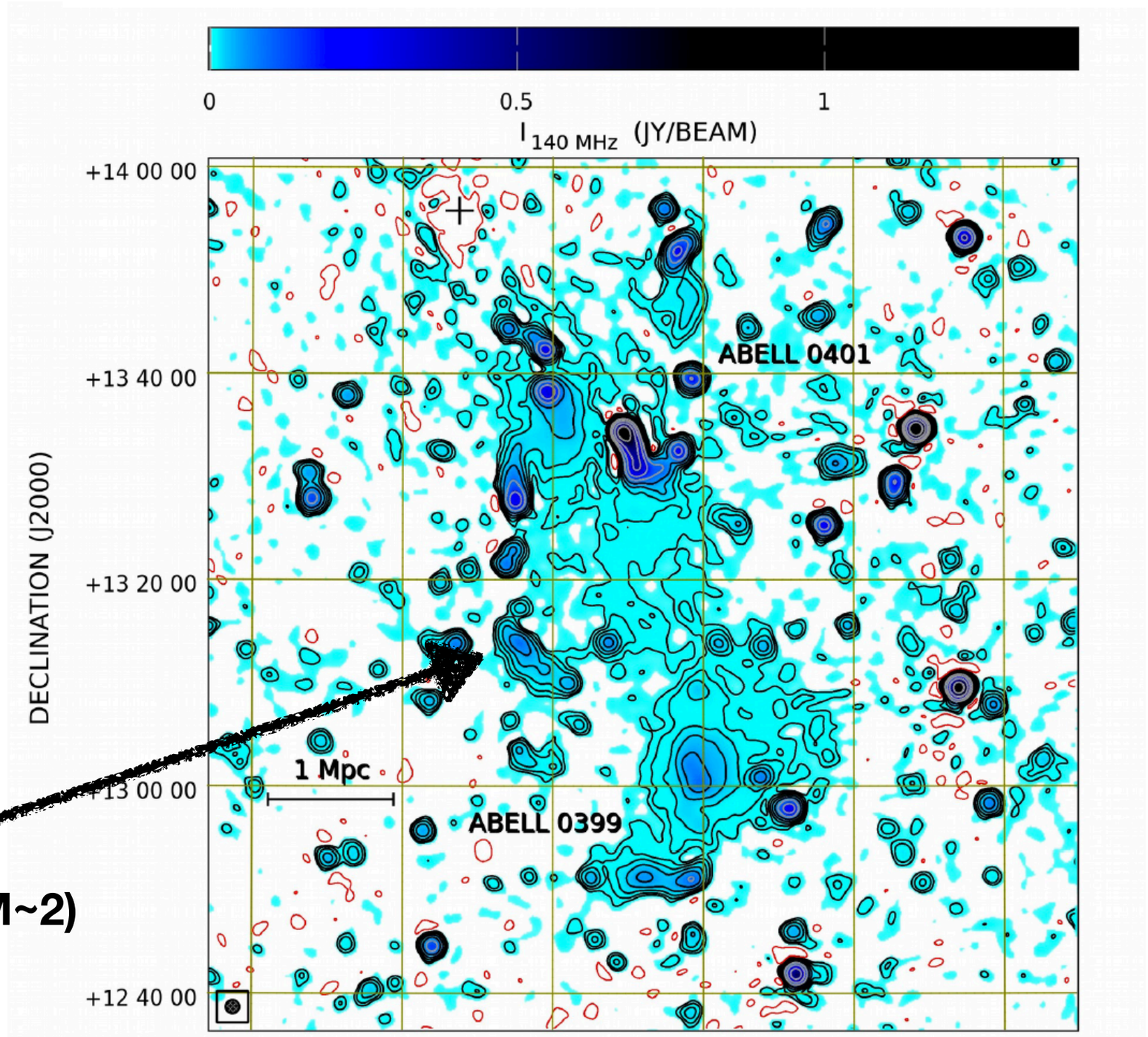
LOFAR cycle 2 observations
10h in HBA dual mode

Credit: Planck collaboration

Science
AAAS

A radio ridge connecting two galaxy clusters in a filament of the cosmic web

Authors: F. Govoni[1*], E. Orrù[2], A. Bonafede[3,4], M. Iacobelli[2], R. Paladino[3], F. Vazza[4,3,11], M. Murgia[1] ,V. Vacca[1] , G. Giovannini[3,4], L. Feretti[3], F. Loi[1,4], G. Bernardi[3,5,6], C. Ferrari[7], R.F. Pizzo[2], C. Gheller[8], S. Manti[9], M. Brüggen[10], G. Brunetti[3], R. Cassano[3], F. de Gasperin[10,11], T.A. Enßlin[12,13], M. Hoeft[14], C. Horellou[15], H. Junklewitz[16], H.J.A. Röttgering[11], A.M.M Scaife[17], T.W. Shimwell[2,11], R.J. van Weeren[11] , M. Wise[2].



Accepted!

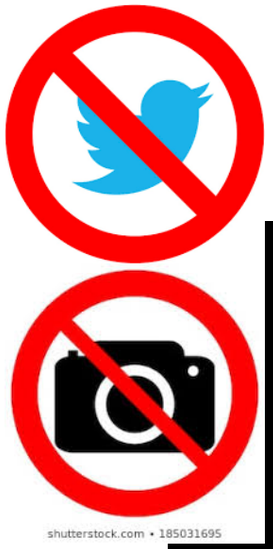
Weak shock (M~2)

80″ resolution
rms noise 1 mJy/beam

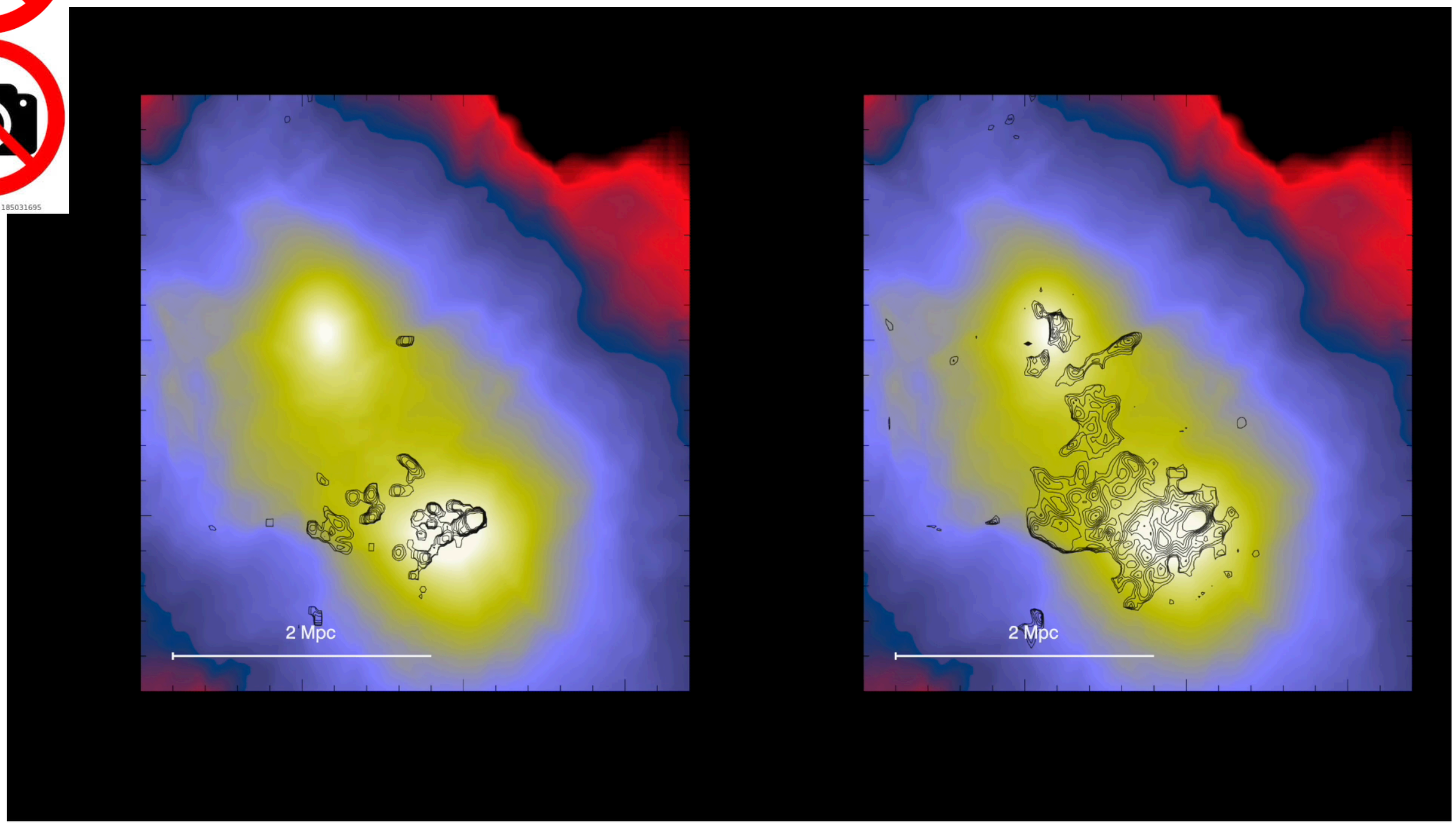
Science
AAAS

A radio ridge connecting two galaxy clusters in a filament of the cosmic web

Accepted!



Origin of the radio emission: shock re-acceleration of fossil electrons?



Pre-merging cluster

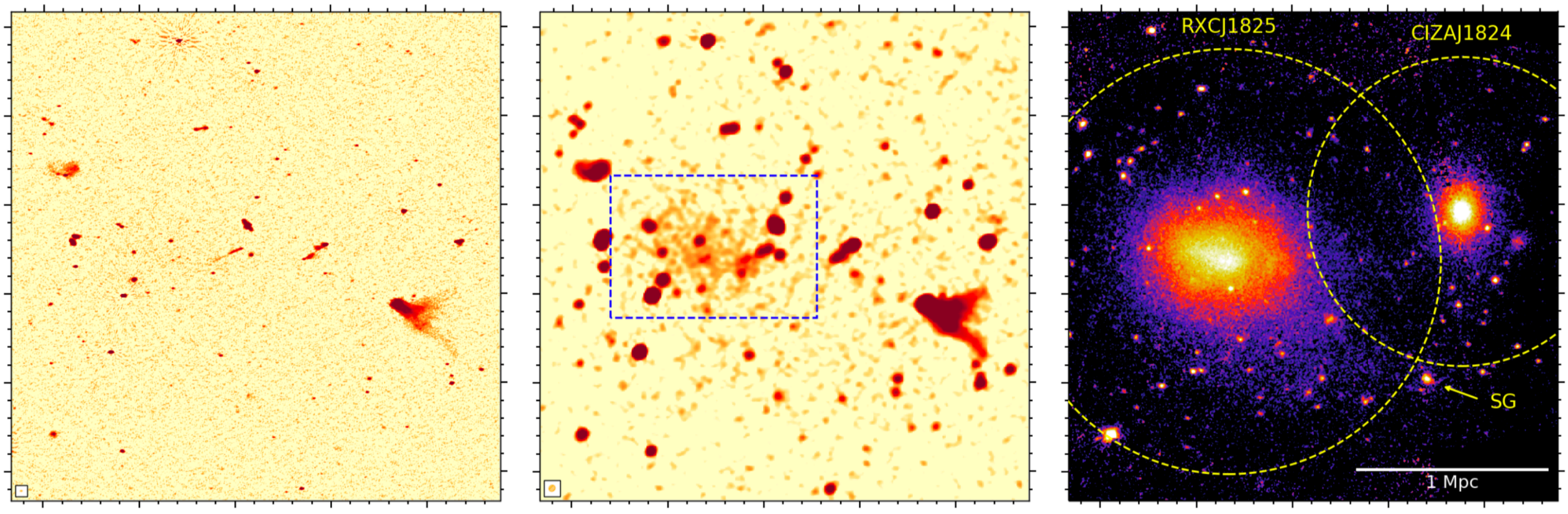


Fig. 1. The cluster pair RXCJ1825/CIZAJ1824 as observed with LOFAR HBA at high (*left*) and medium (*center*) resolution, and with *XMM-Newton* in the 0.5 − 2.0 keV band (*right*). The resolution and rms noise of the LOFAR images are $8.5'' \times 4.7''$ and $\sigma = 110\ \mu$Jy beam^{-1} (high), and $27.1'' \times 24.4''$ and $\sigma = 220\ \mu$Jy beam^{-1} (medium). The beam sizes are shown in the bottom left corners. The blue box in the LOFAR medium resolution image shows the region where we evaluate the flux density of the halo. Yellow circles in the *XMM-Newton* image denote the approximate location of r_{500} for each cluster (cf. Tab. 1) while the arrow indicates the Southern Group (SG). The displayed images have matched coordinates and cover a FoV of $33' \times 33'$.

Botteon et al (in prep)

Radio vs X-rays

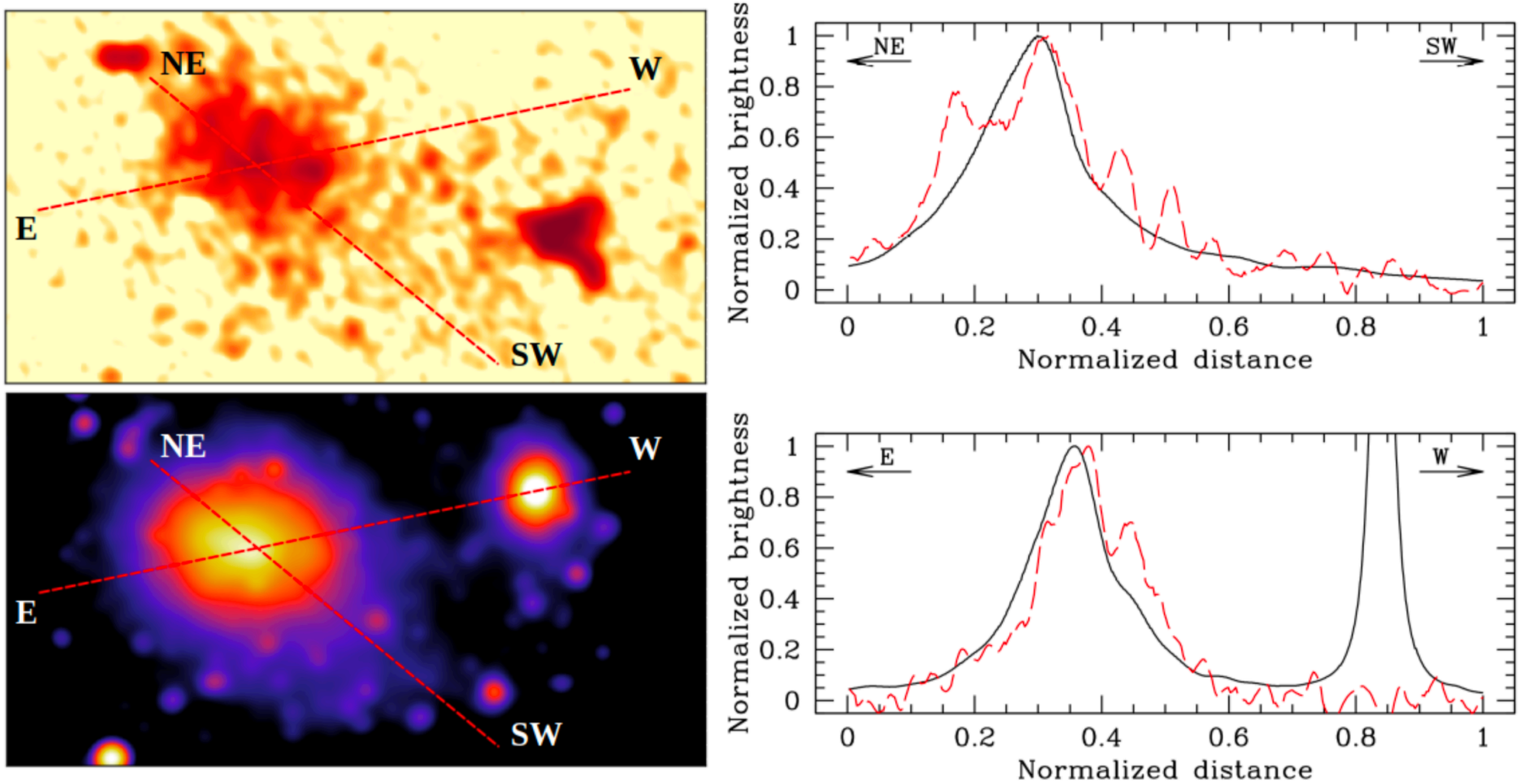


Fig. 4. One-dimensional brightness profiles of the X-ray (black lines) and radio emission (red dashed lines) extracted in the dashed lines reported in the left panels. The profiles are normalized at the brightness peak of RXCJ1825.

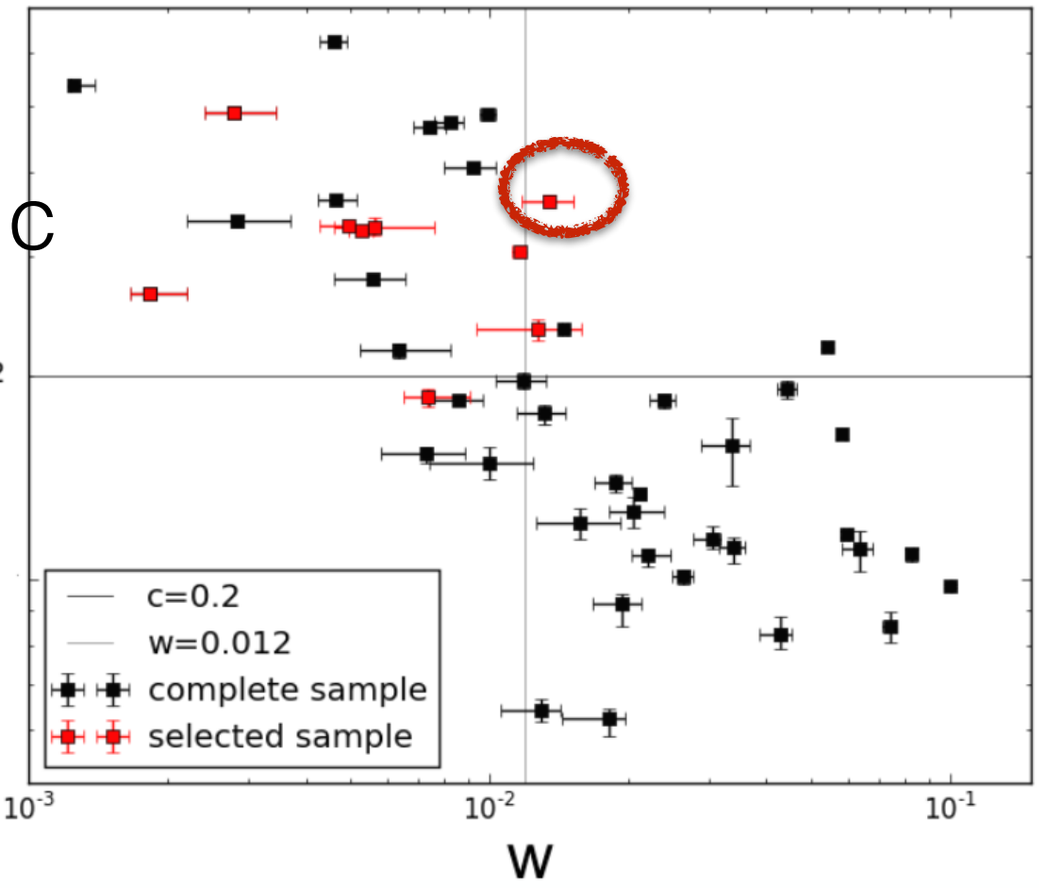
Botteon et al (in prep)

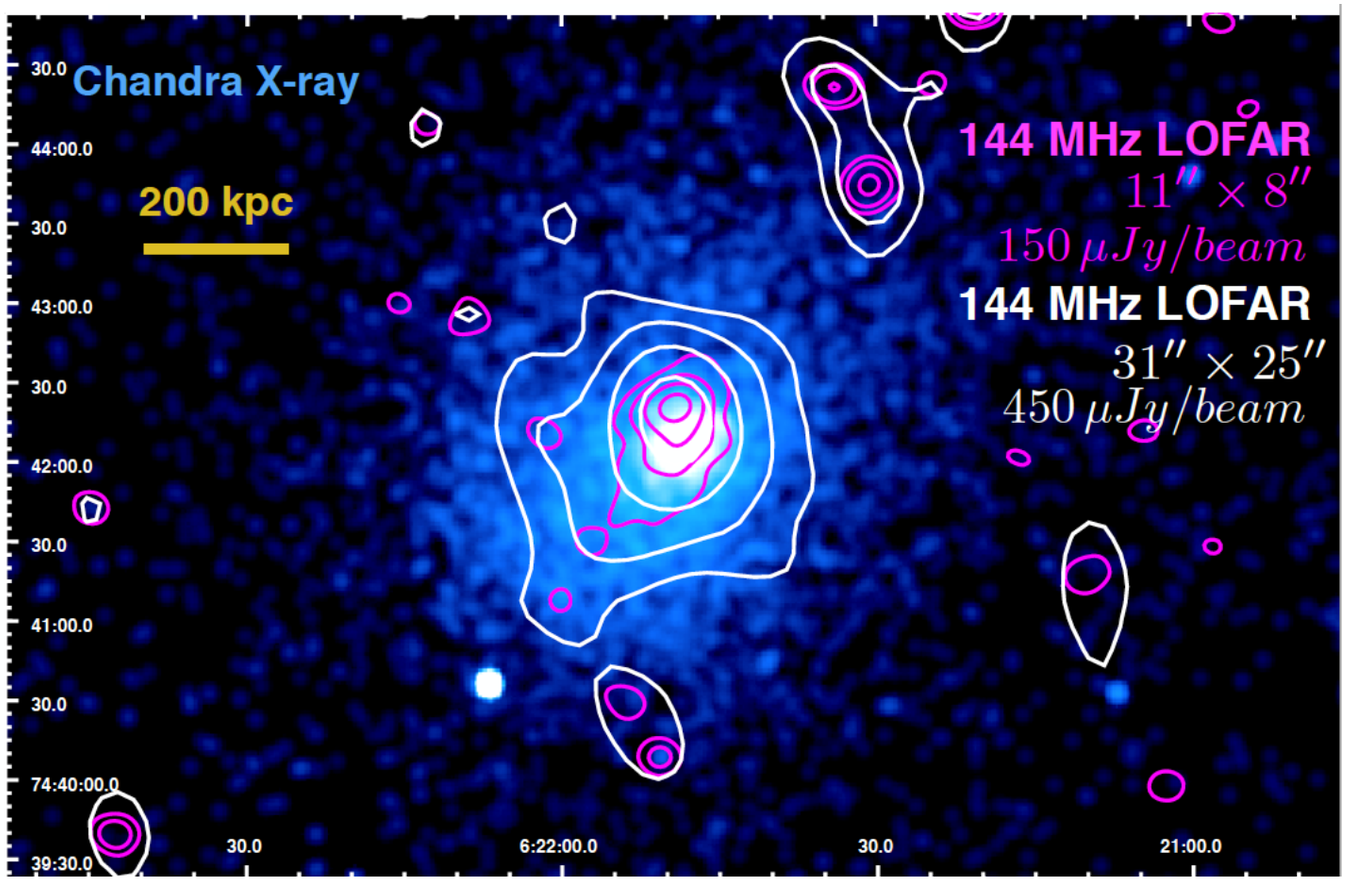
Minihalos may not be so mini.

Intermediate halo

Candidate Mini-halo (50 kpc scale)

[Giacintucci et al 2017]





Steep spectrum on large scale α <-1.7

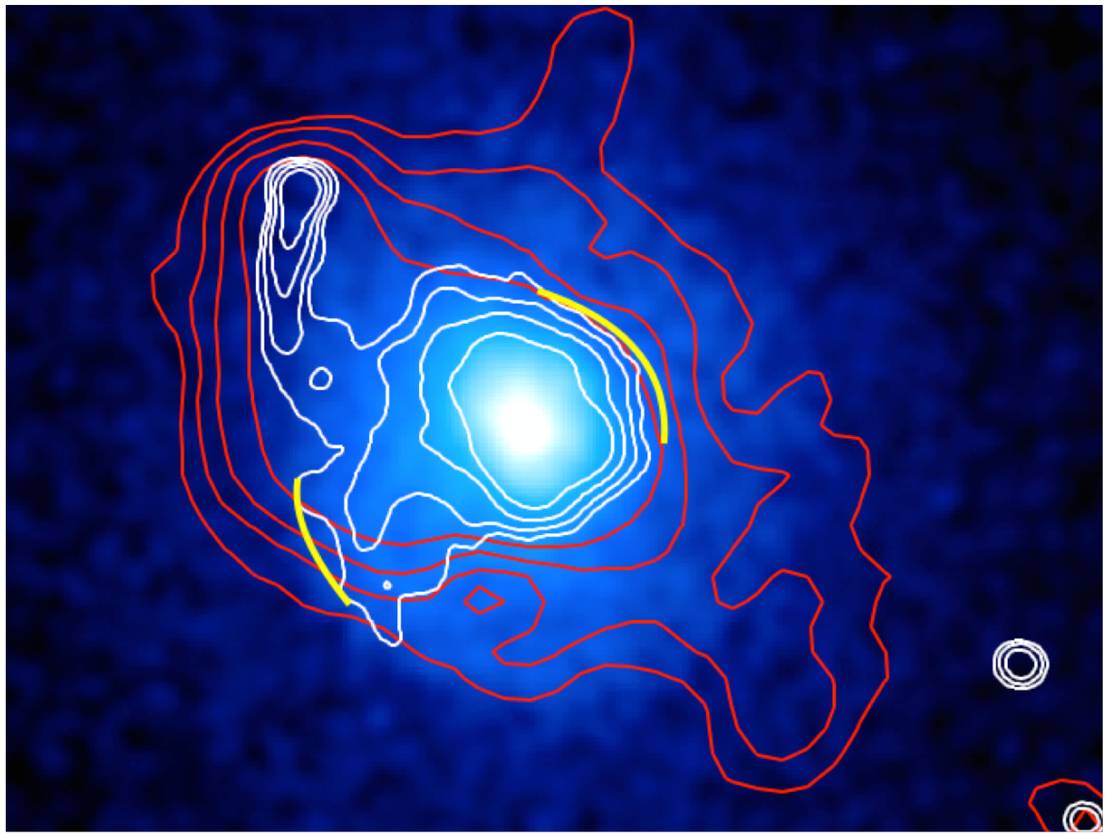
Possible flatter spectrum in the core α ~ 1.3

F. Savini et al. (2019)

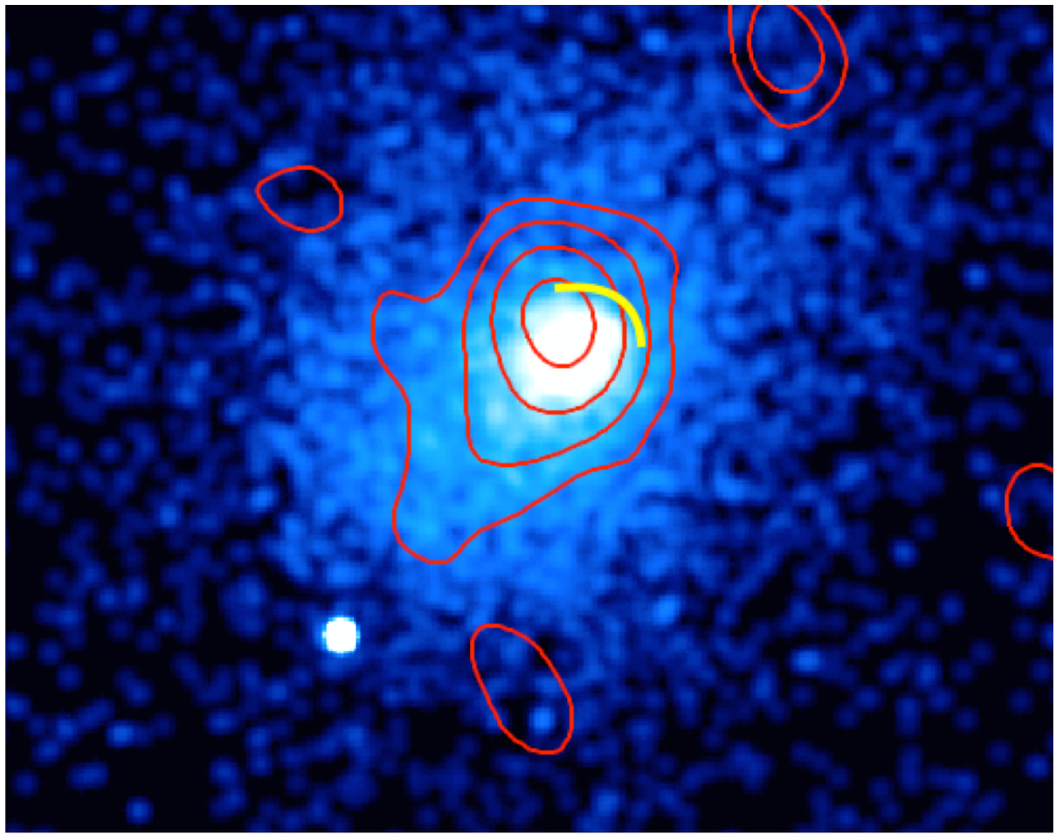
X-ray cold fronts

Gas sloshing & minor mergers

RXJ1720.1+2638



PSZ1G139.61+24.20



Savini et al. (subm.)

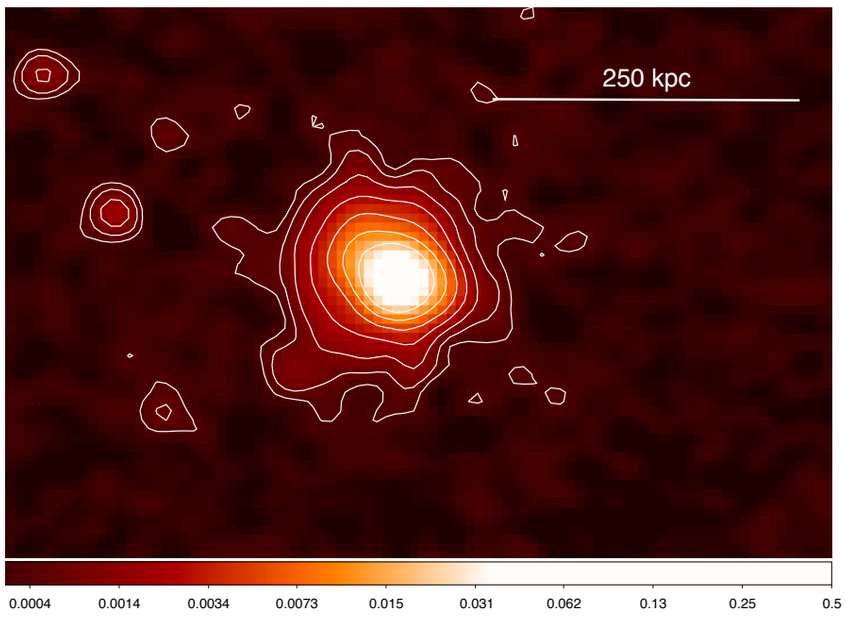
Occurrence of halo & mini-halo emission

8 more clusters observed - LOFAR cycle 10 observations

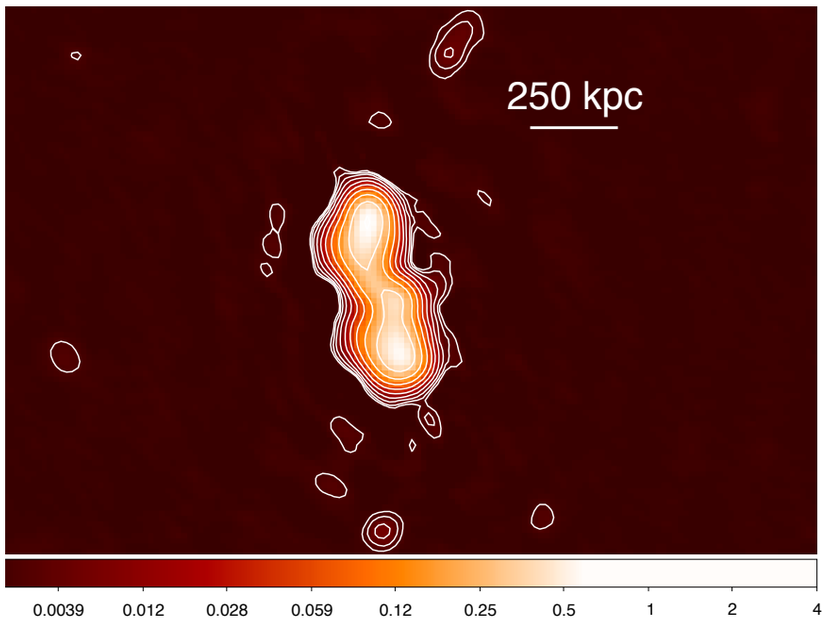
Selection criteria:

- dense and cool core
- minor merger signatures (from X-ray morphological analysis)

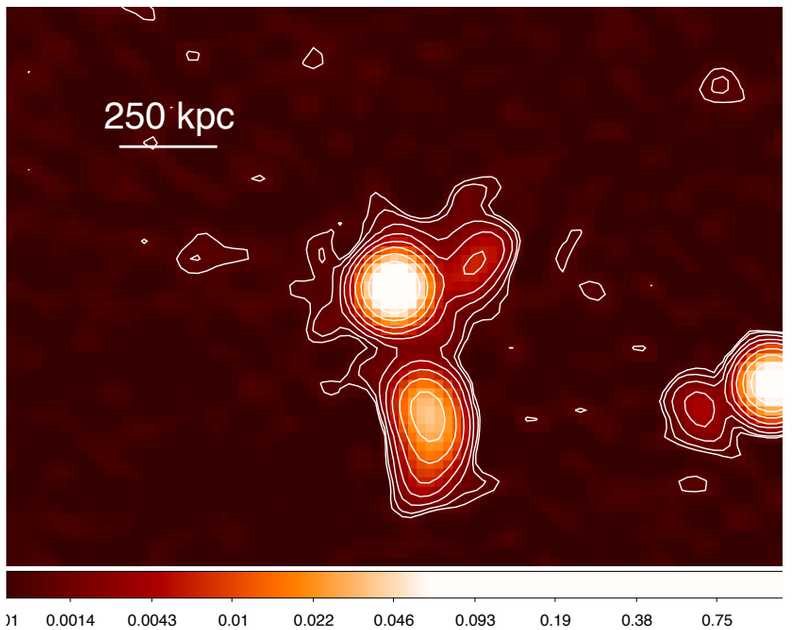
Preliminary results



mini halo in RBS797



no diffuse emission
MS0735.6 +7421



mini halo (?)
RXCJ1720.2

N. Biava PhD project

Radio halos @ z=0.616

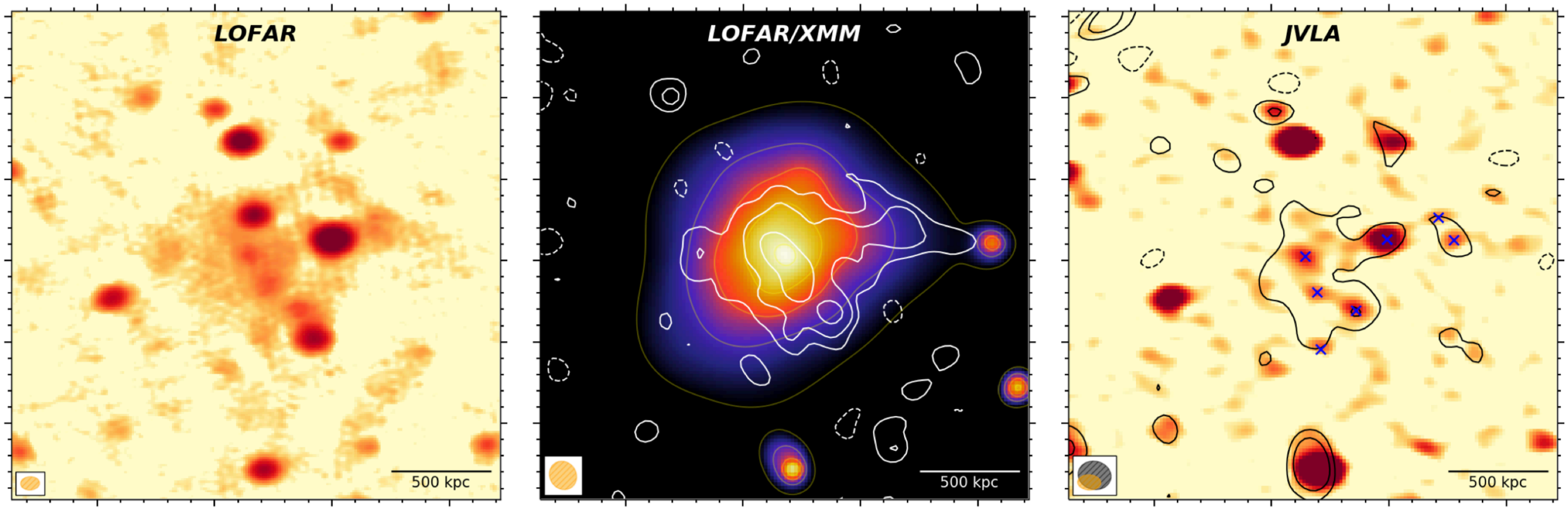


FIG. 2.— Left: LOFAR 144 MHz medium resolution ($13.9'' \times 9.7''$) image with a noise of $\sigma = 90$ μJy beam^{-1}. Center: *XMM-Newton* adaptively smoothed image in the $0.5 - 2.0$ keV band with contours overlaid in yellow. The LOFAR 144 MHz low resolution contours ($21.6'' \times 19.4''$) obtained after the source subtraction are reported in white starting from 2σ, where $\sigma = 200$ μJy beam^{-1}. In both the panels the negative -2σ contours are displayed in dashed while the beams are reported in the bottom left corners. Right: 1–2 GHz high-resolution ($17'' \times 11''$, $\sigma = 20\mu$Jy beam^{-1}) JVLA image with 2.5σ low-resolution ($24.5'' \times 20.8''$, $\sigma = 36$ μJy beam^{-1}) source-subtracted JVLA radio contours.

On $P_{1.4}$ – M_{500} correlation → magnetic field strength similar to low-z clusters of same mass

Cassano et al (in prep)

What's new?

- Fine structure in diffuse sources
- Bridges
- Intermediate objects
- High redshift

Many more interesting results from LOTSS