The Coma cluster at LOFAR frequencies

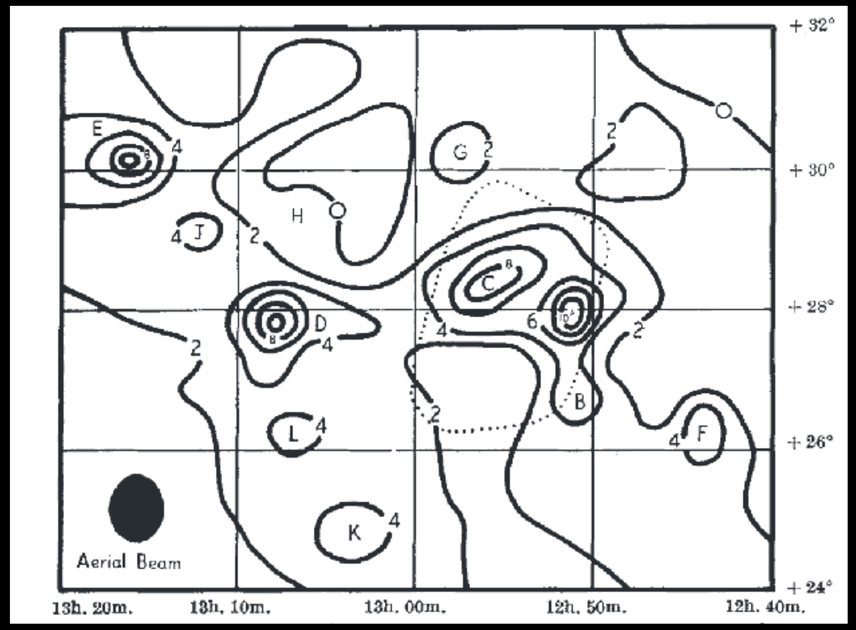
Annalisa Bonafede

LOFAR cluster working group
+ MKSP intergalactic filaments working group

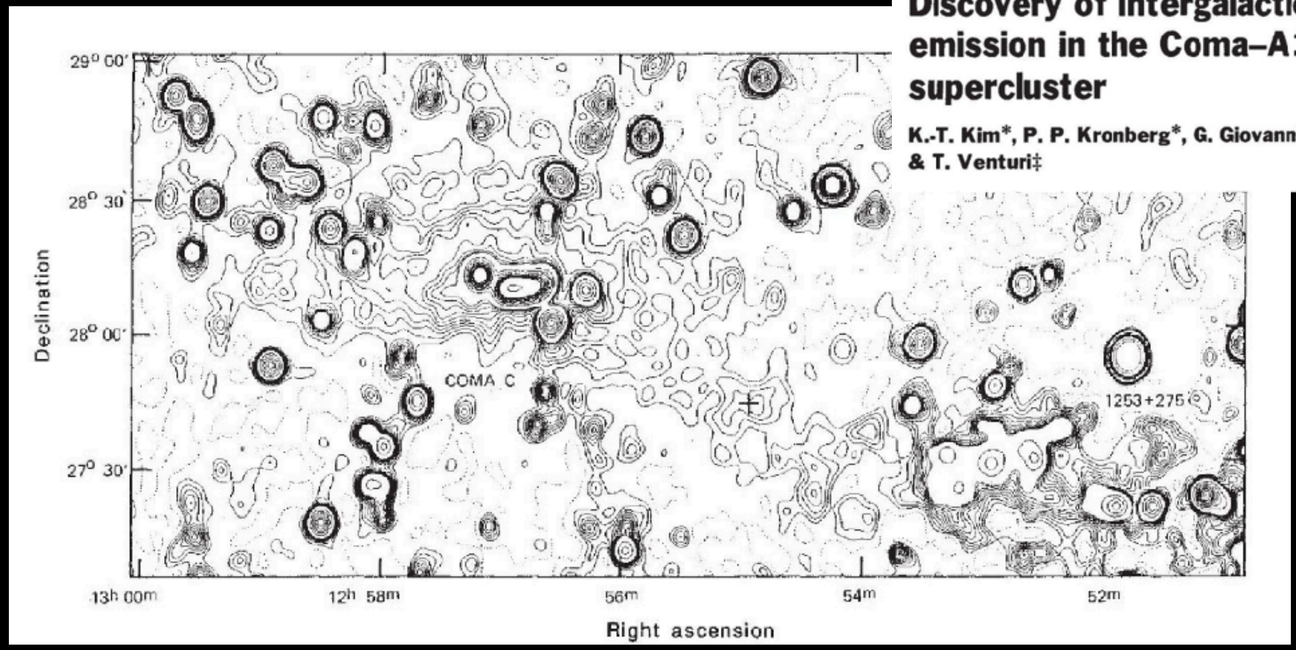
DRANOEL
ERC - Stg16 714245

The Coma cluster from 1956 to now

First radio halo



Large et al. 1956, Nature
408 MHz
~1 deg resolution



Kim et al 1989, Nature
326 MHz WSRT

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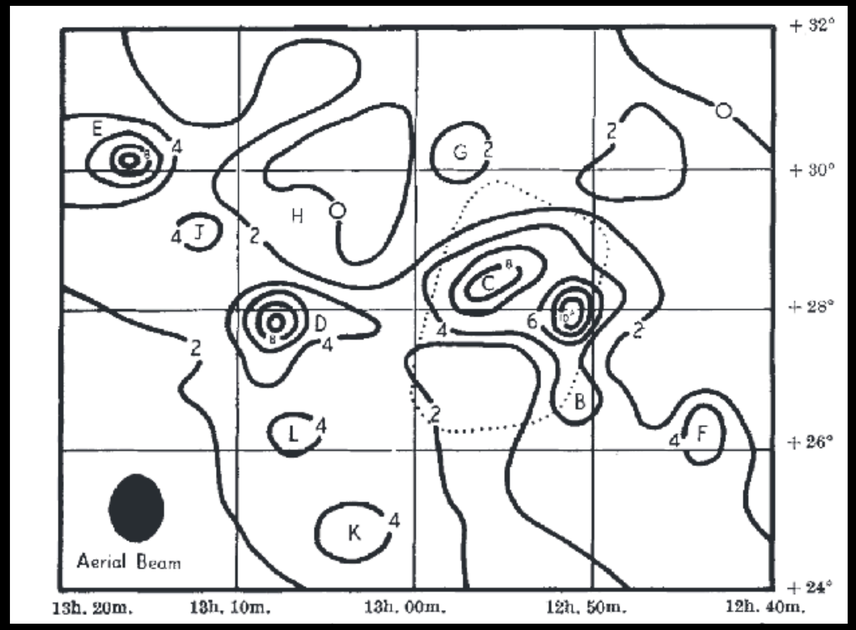

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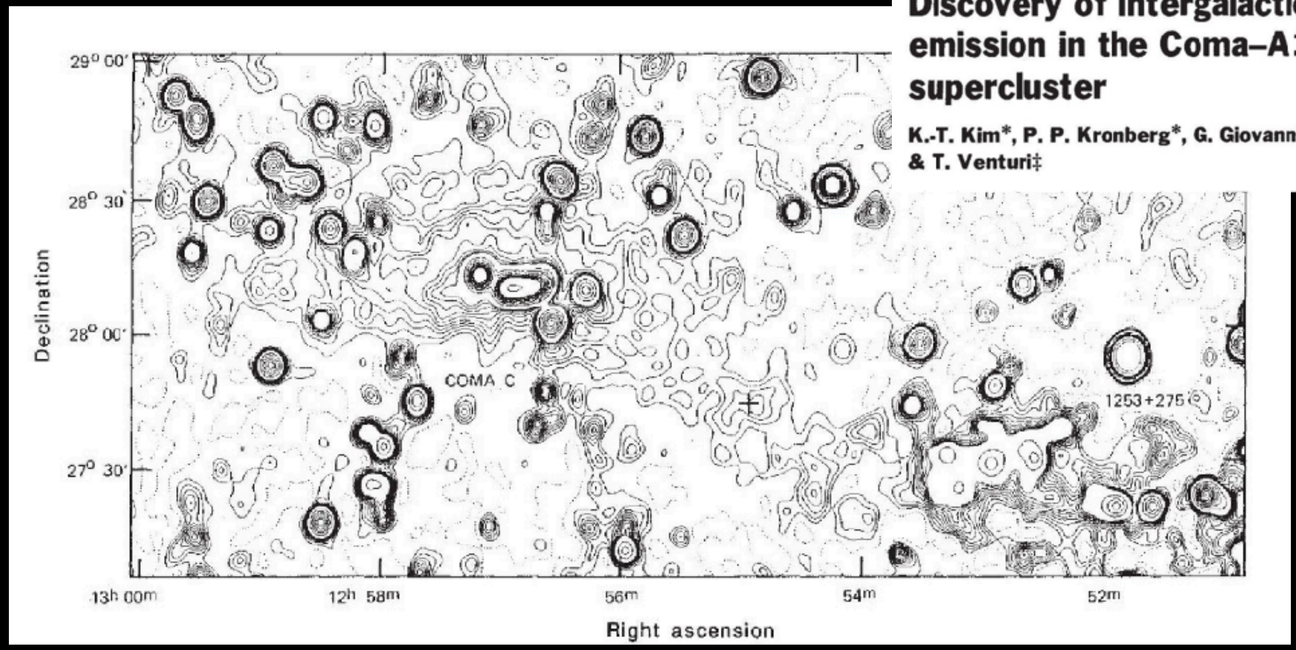


LETTERS TO NATURE

Discovery of intergalactic radio emission in the Coma–A1367 supercluster

K.-T. Kim*, P. P. Kronberg*, G. Giovannini†‡ & T. Venturi‡

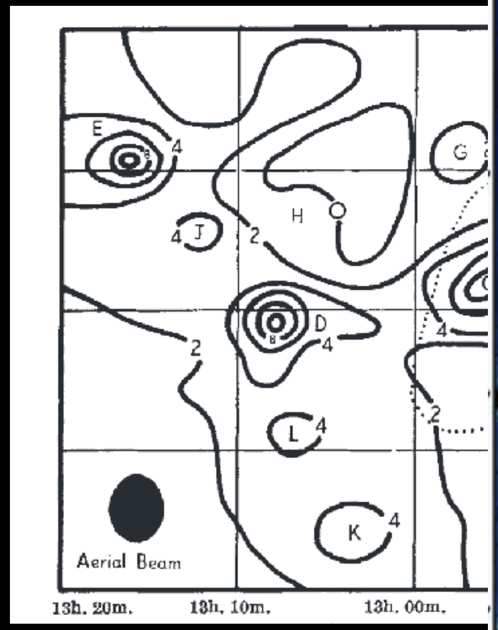
Kim et al 1989, Nature
326 MHz WSRT

Many other observations and studies since then

- **nearby cluster (z=0.0231, 1”=0.5 kpc)**
- **Halo, relic, bridge**

The Coma cluster from 1956 to now

First radio h



Large et al. 195
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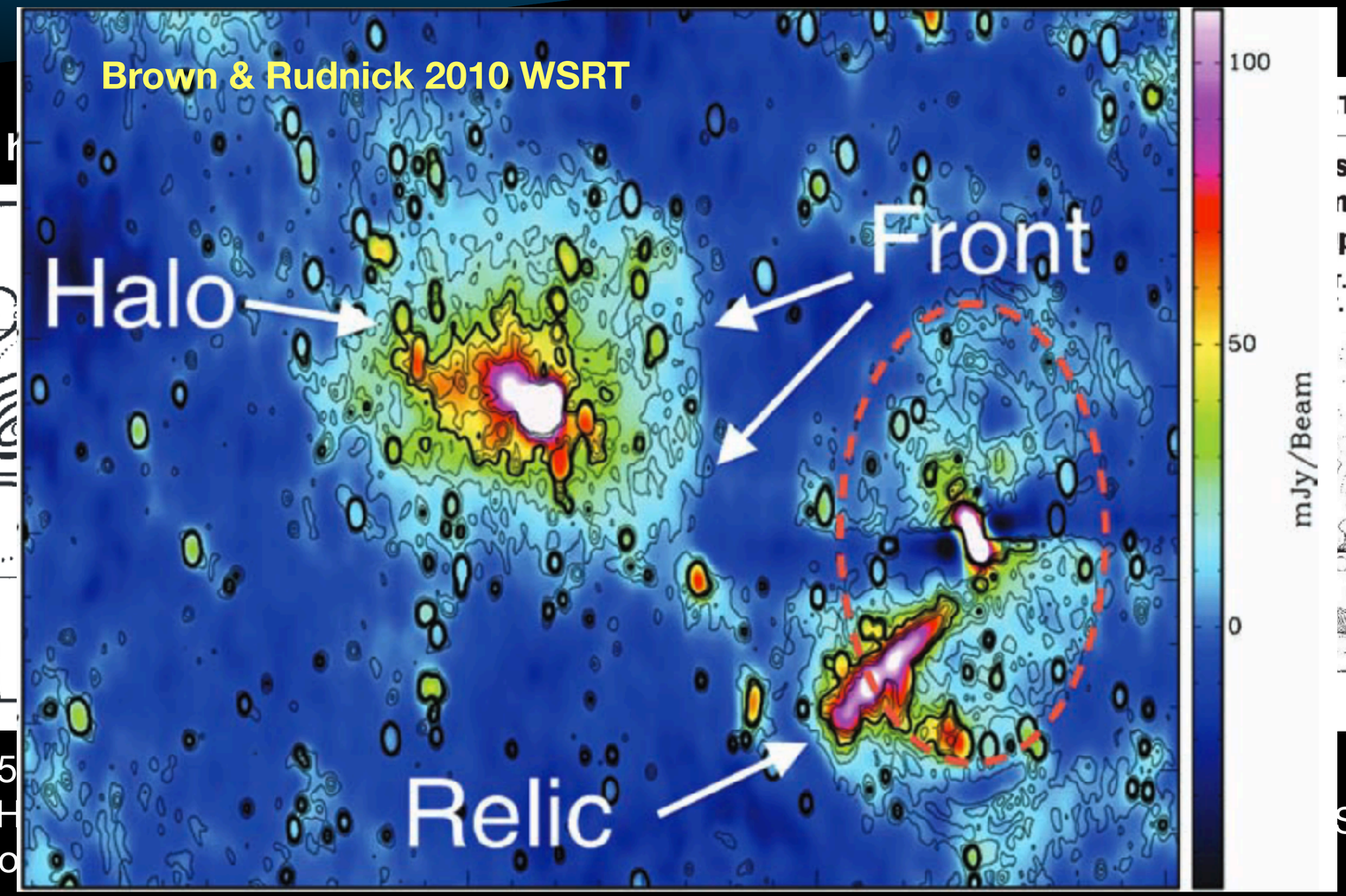

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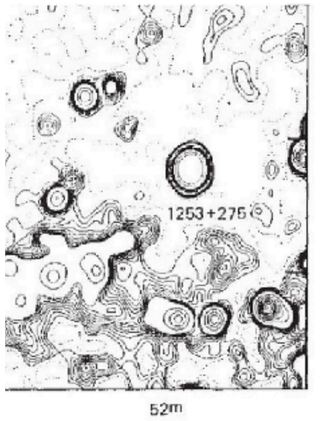

Nature
SRT

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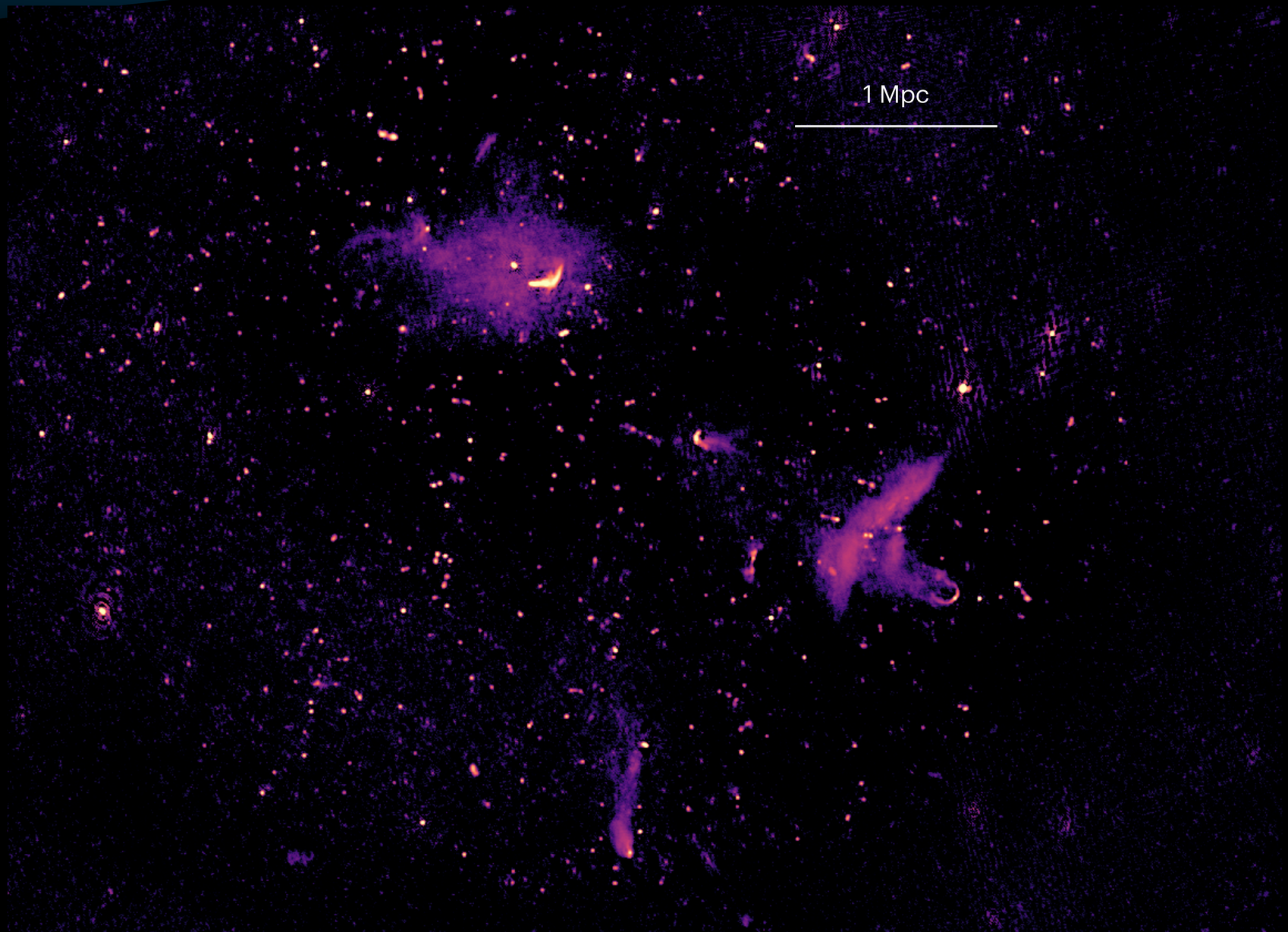
LoTSS
LOFAR 2 meter Sky Survey observations
144 MHz



- LoTSS data
with ad-hoc reprocessing

- 2 x 8h pointings
jointly deconvolved

- resolution of 20″
noise of 0.1 μJy-beam

20 arcsec resolution

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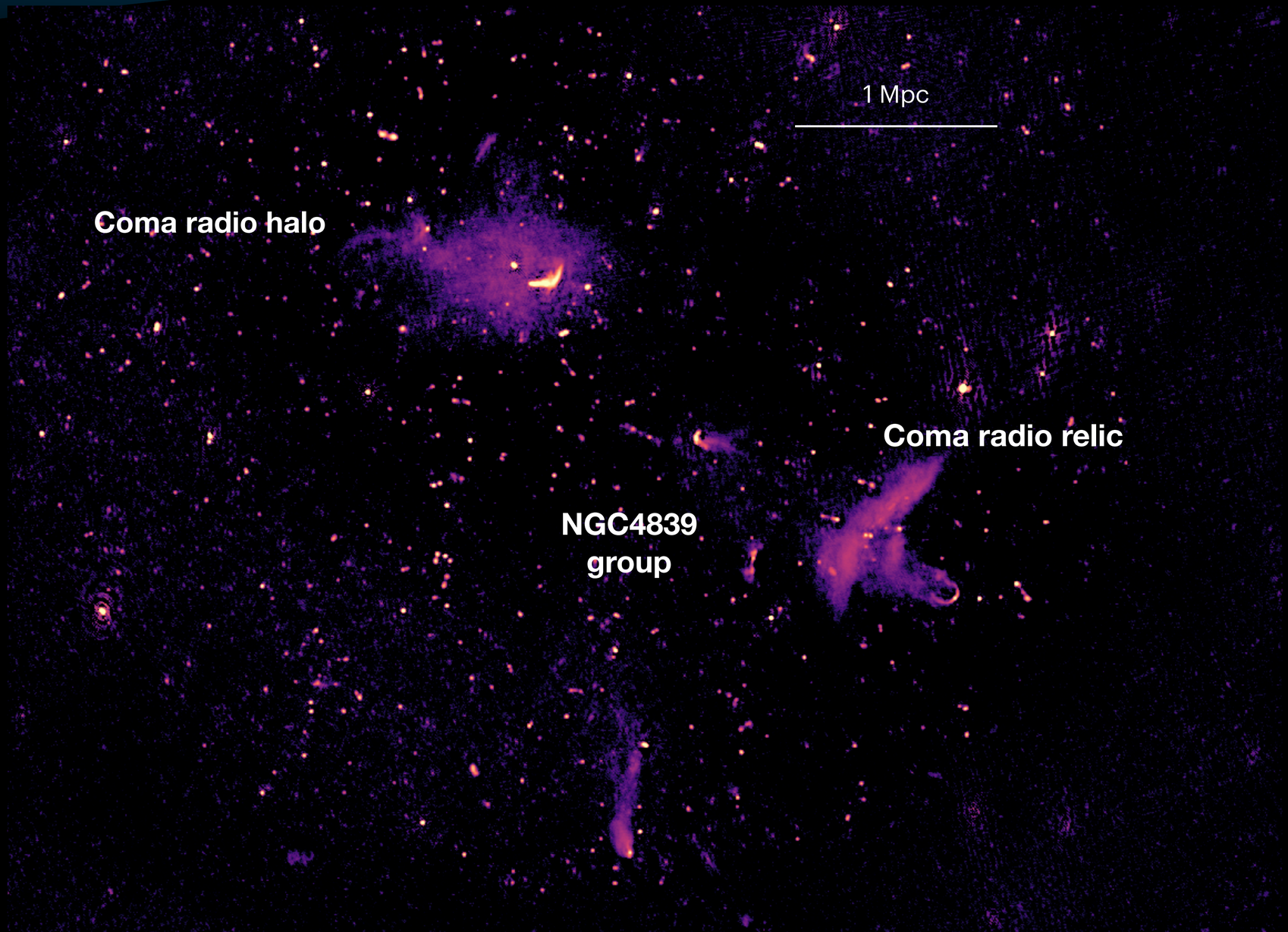

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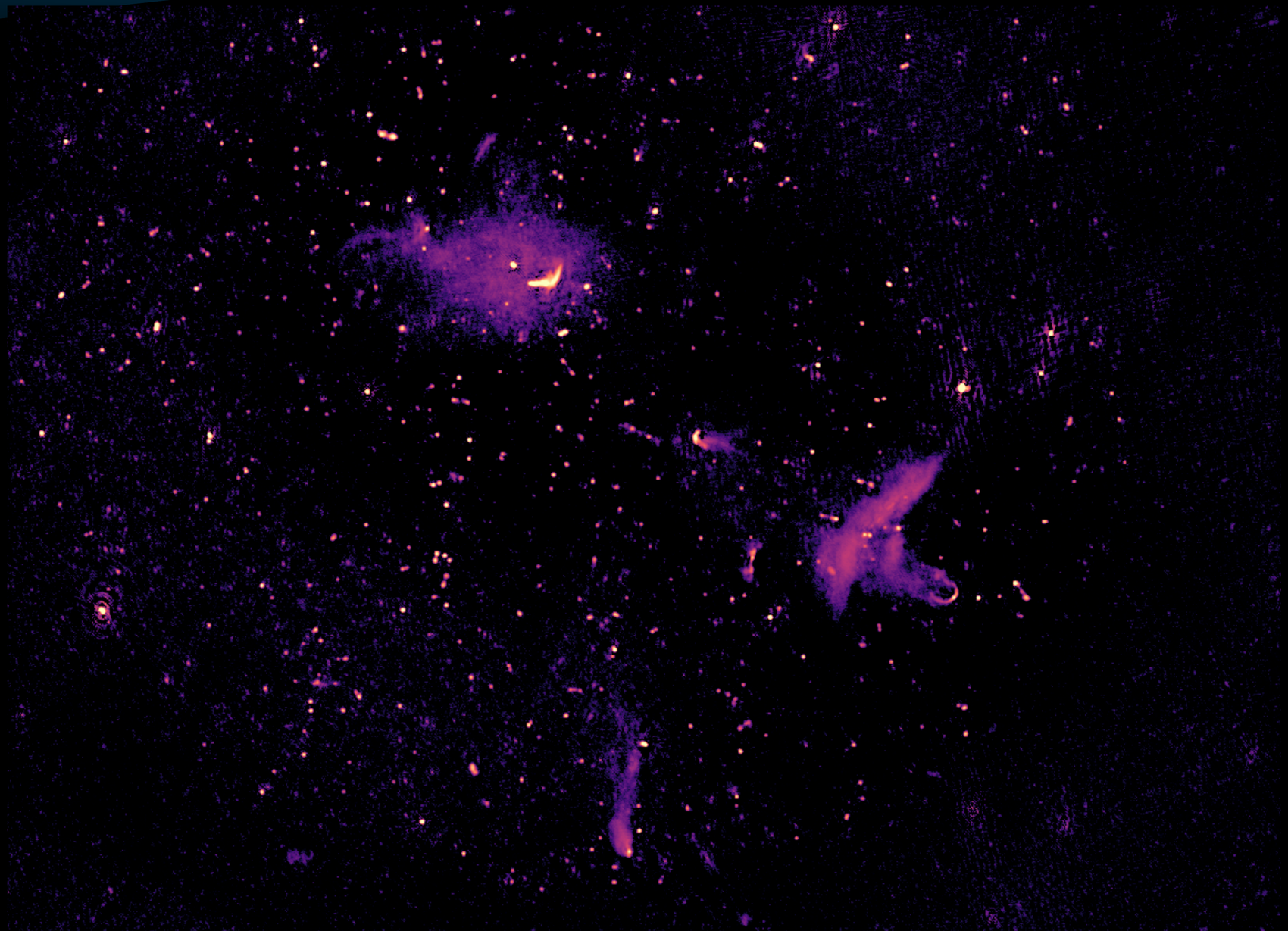

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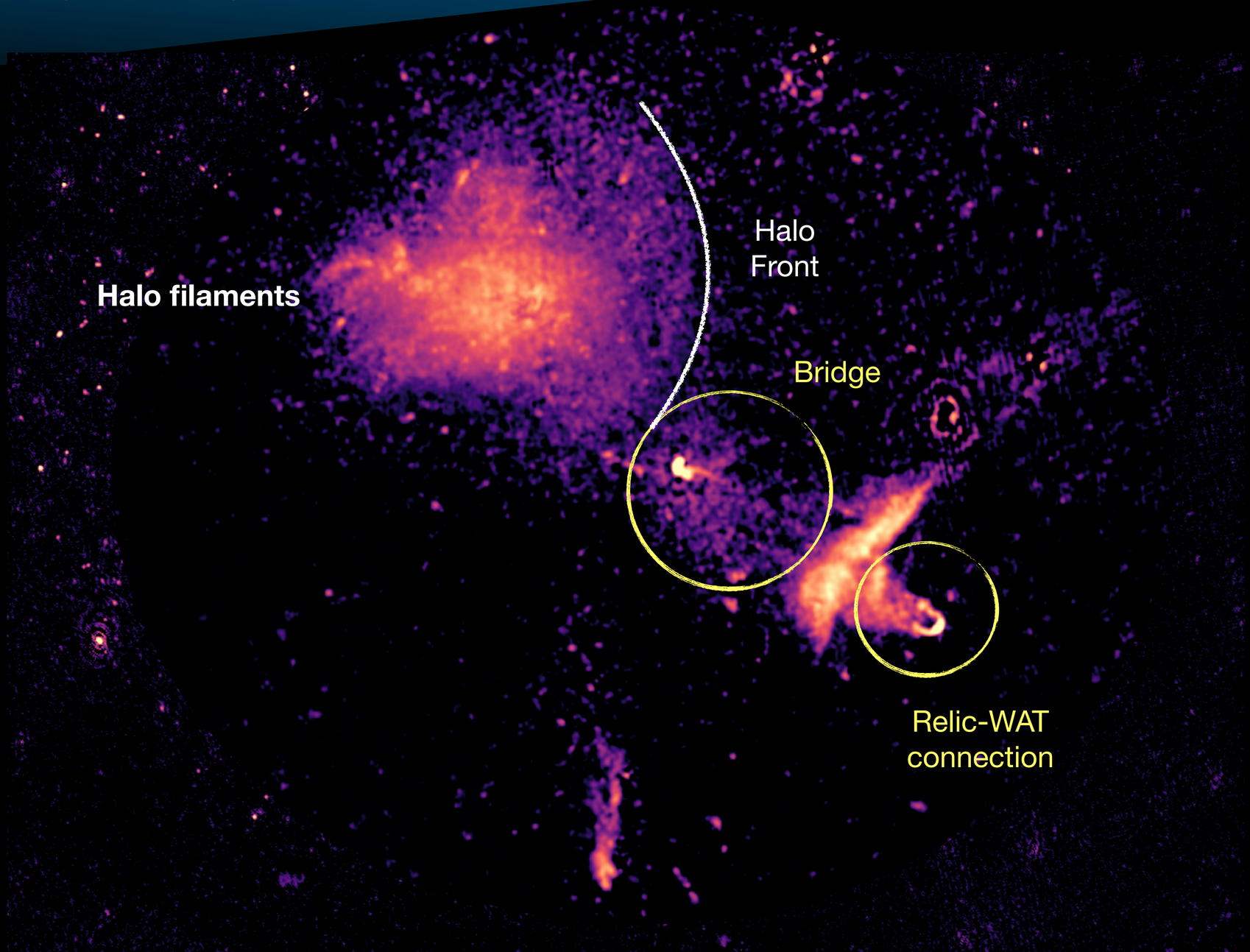
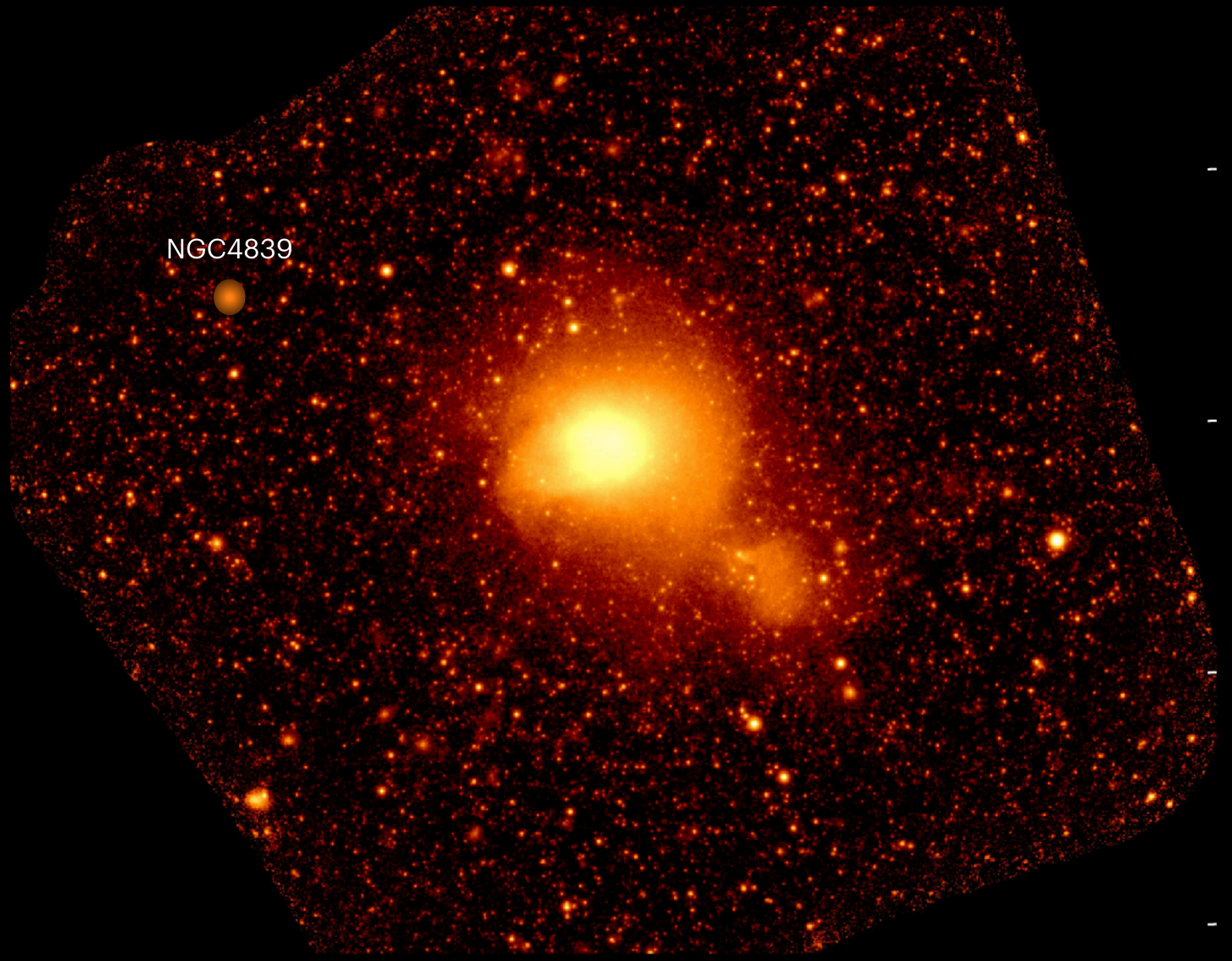


Radio emission and dynamical status

eROSITA
Churazov et al (2021)

Lyskova et al (2019)



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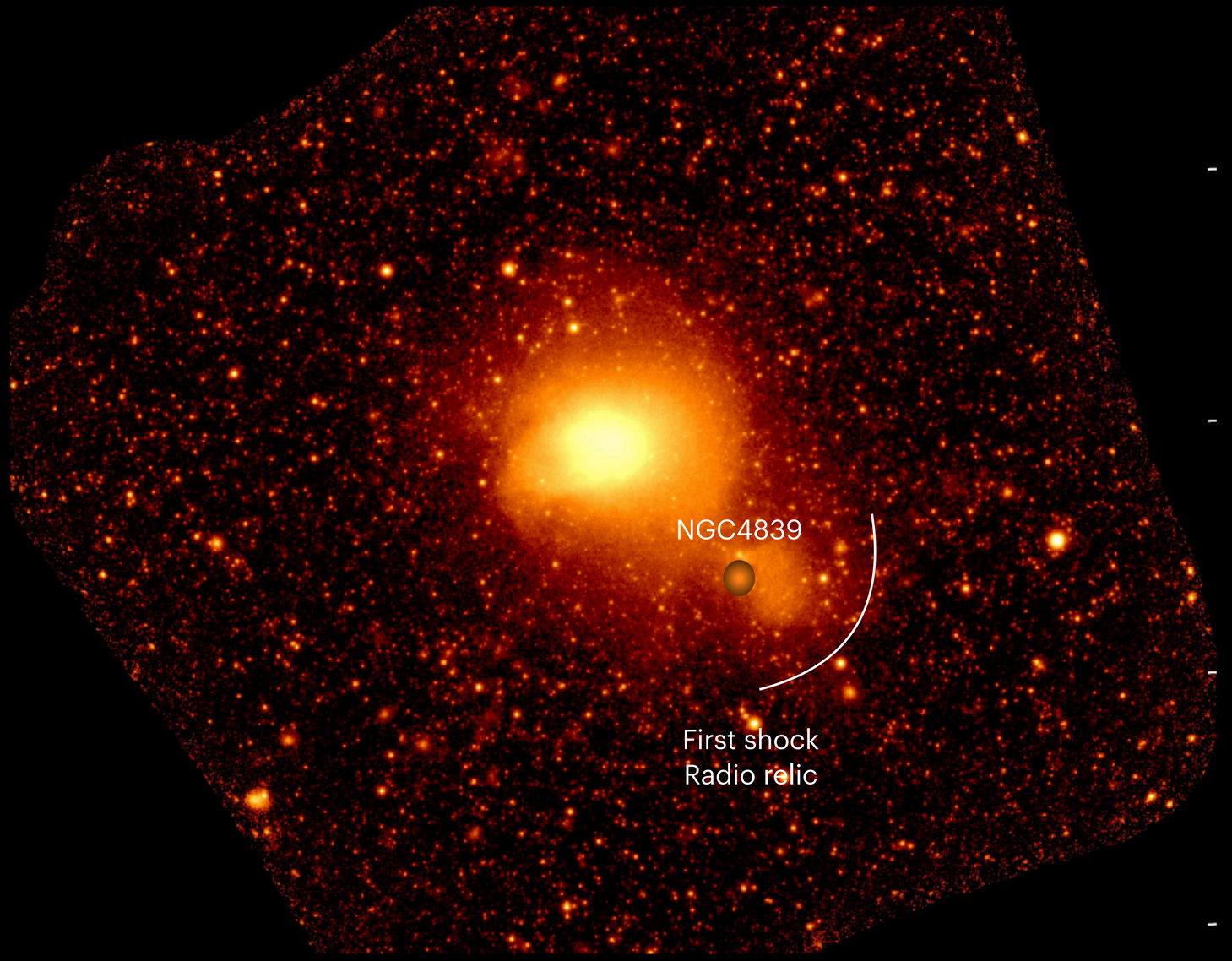

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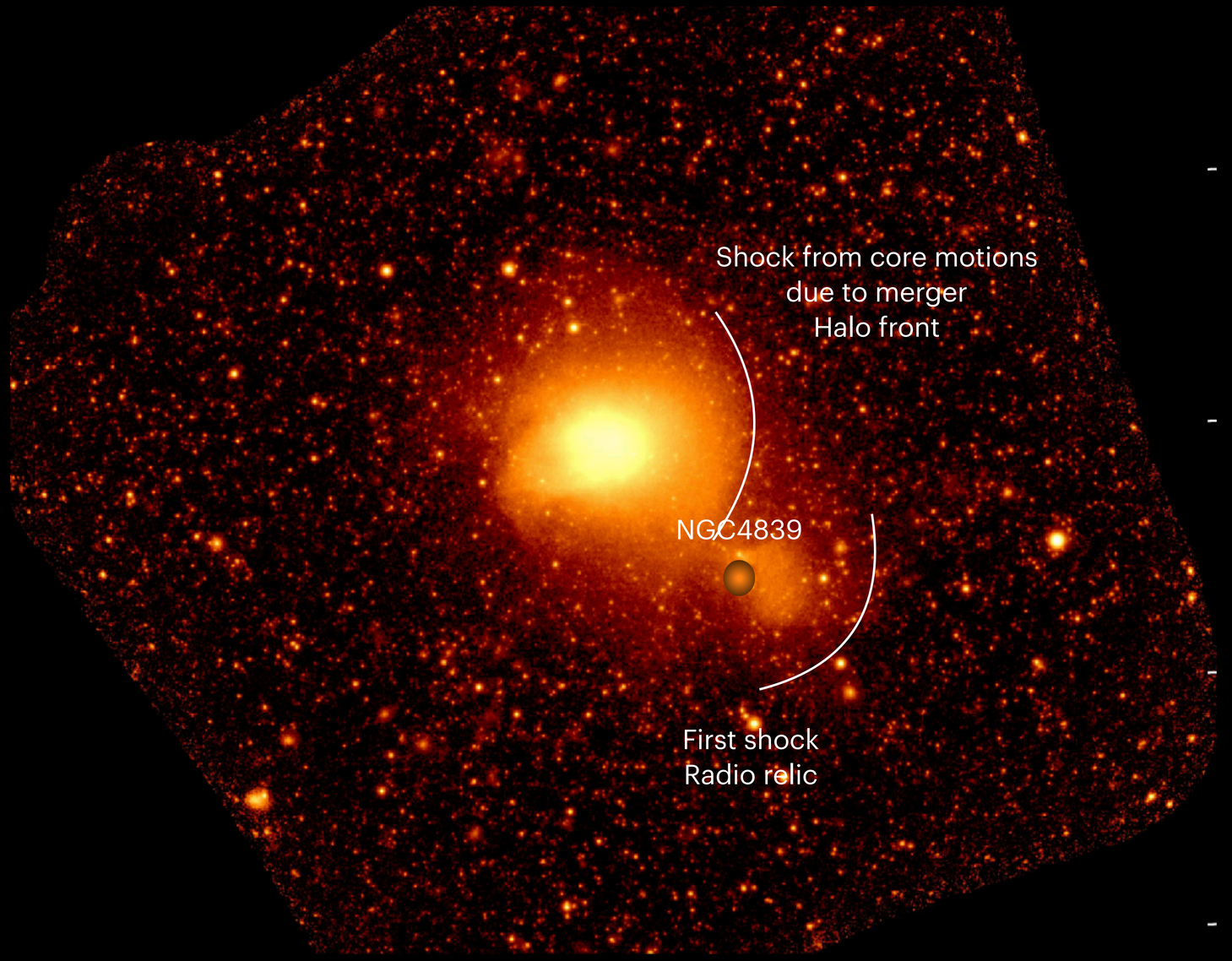

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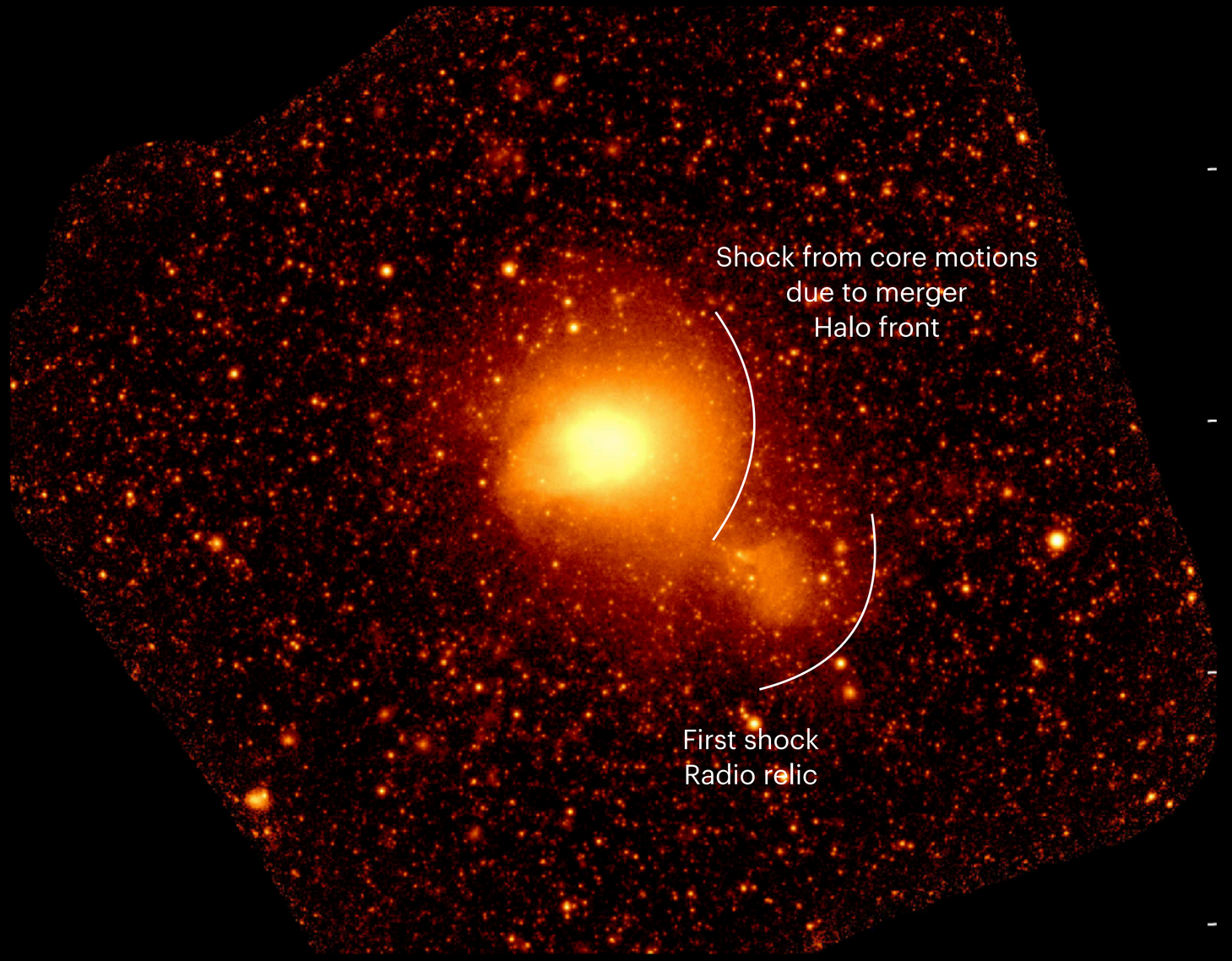


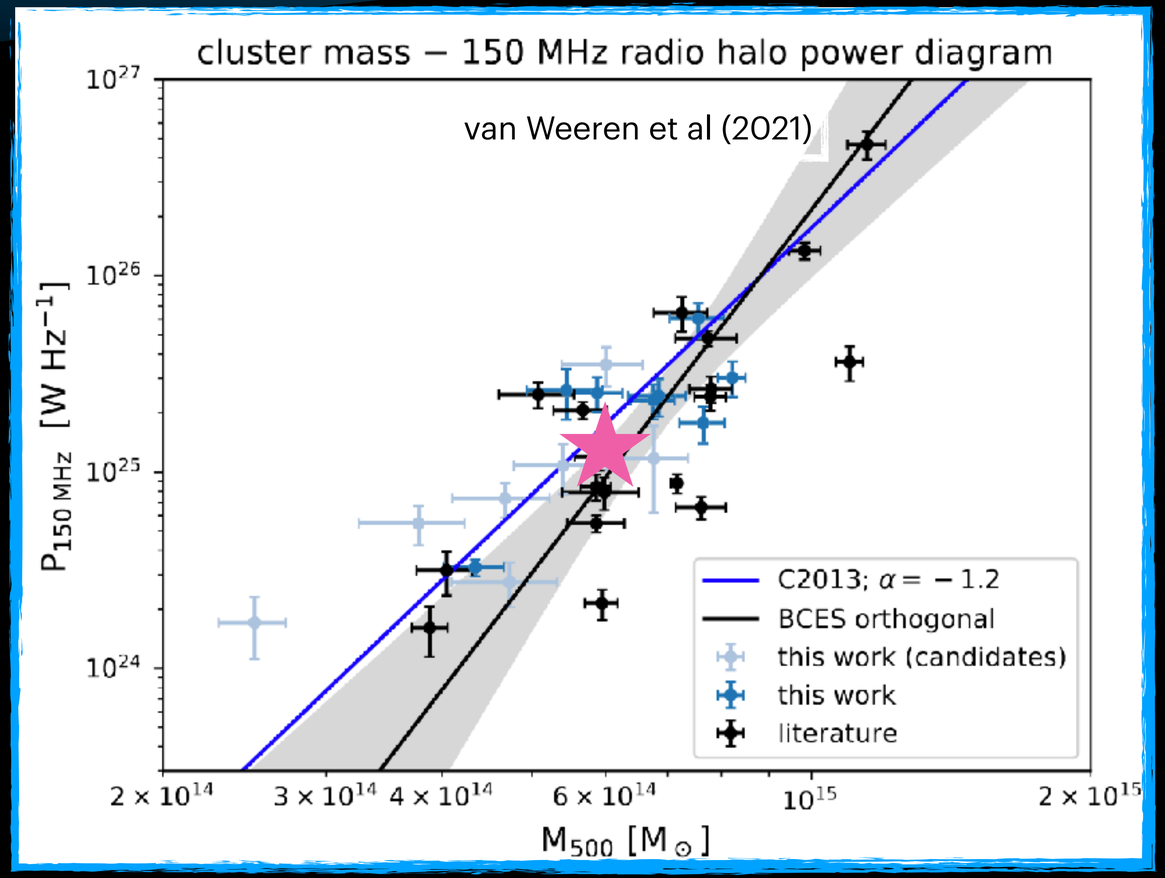
The Coma radio halo

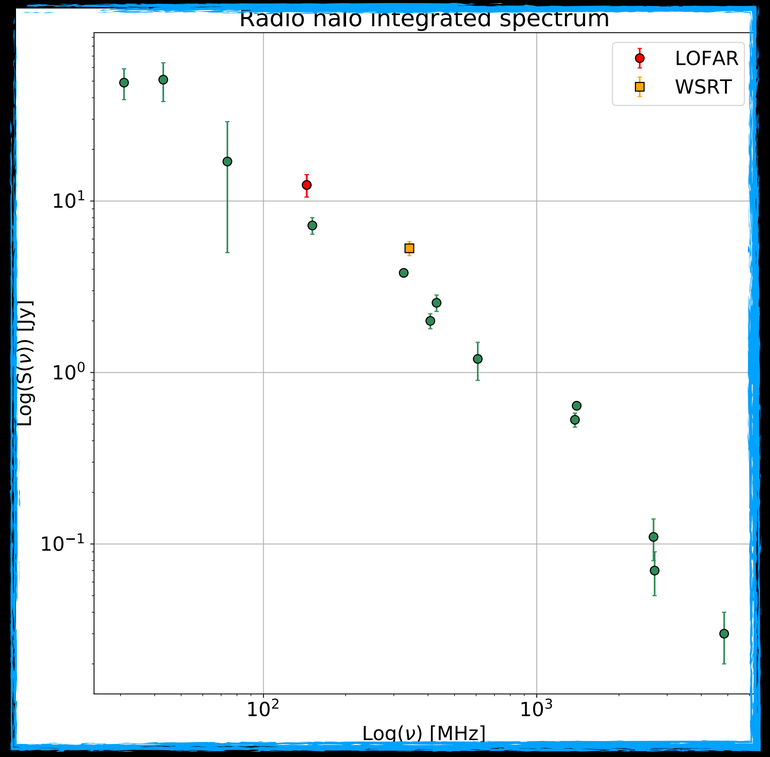
Radio halo profile:
Ellipsoidal exponential fit

$$I(r) = I_0 e^{-(\frac{x^2}{r_1^2}+\frac{y^2}{r_2^2})^{1/2}}$$

r_1 ~355 kpc
r_2~ 268 kpc

P(144 MHz) ~1.47 10^{25} W/Hz

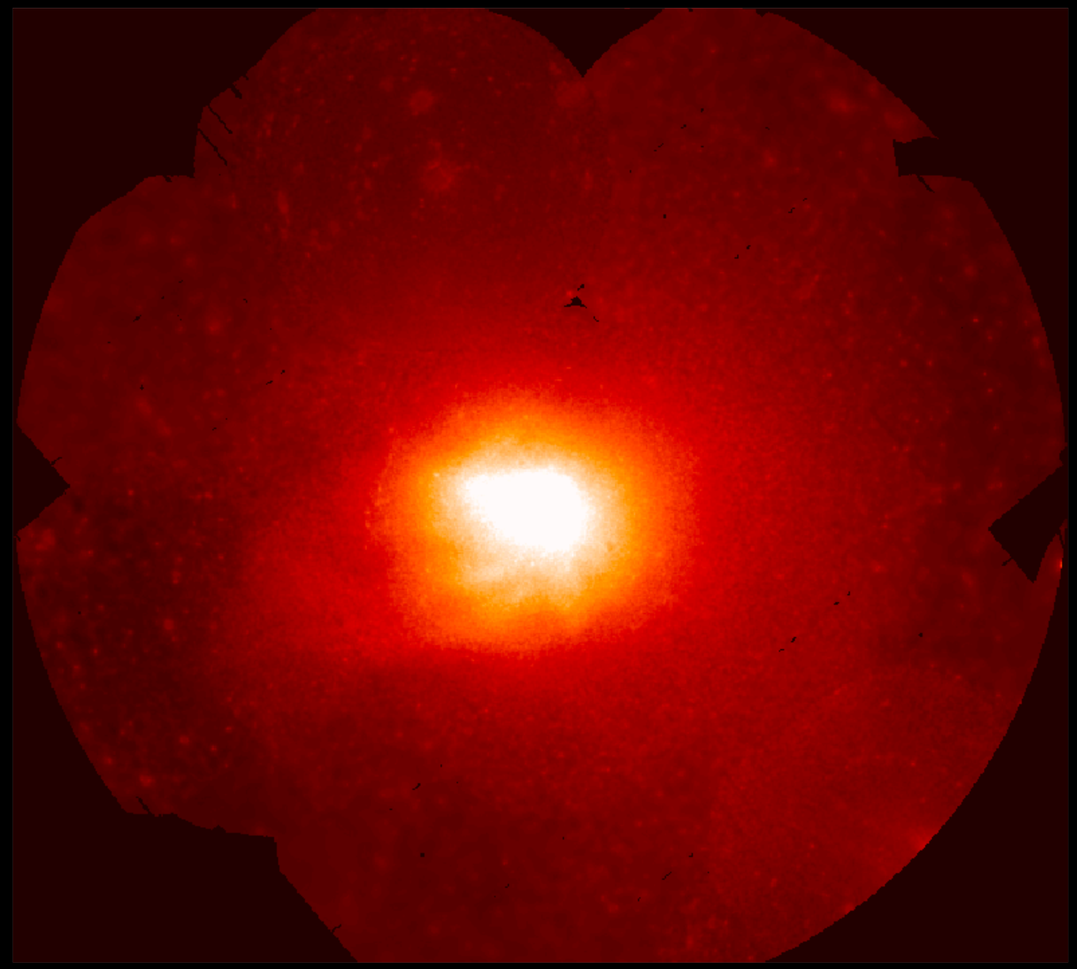




The Coma radio halo: thermal- non thermal correlation

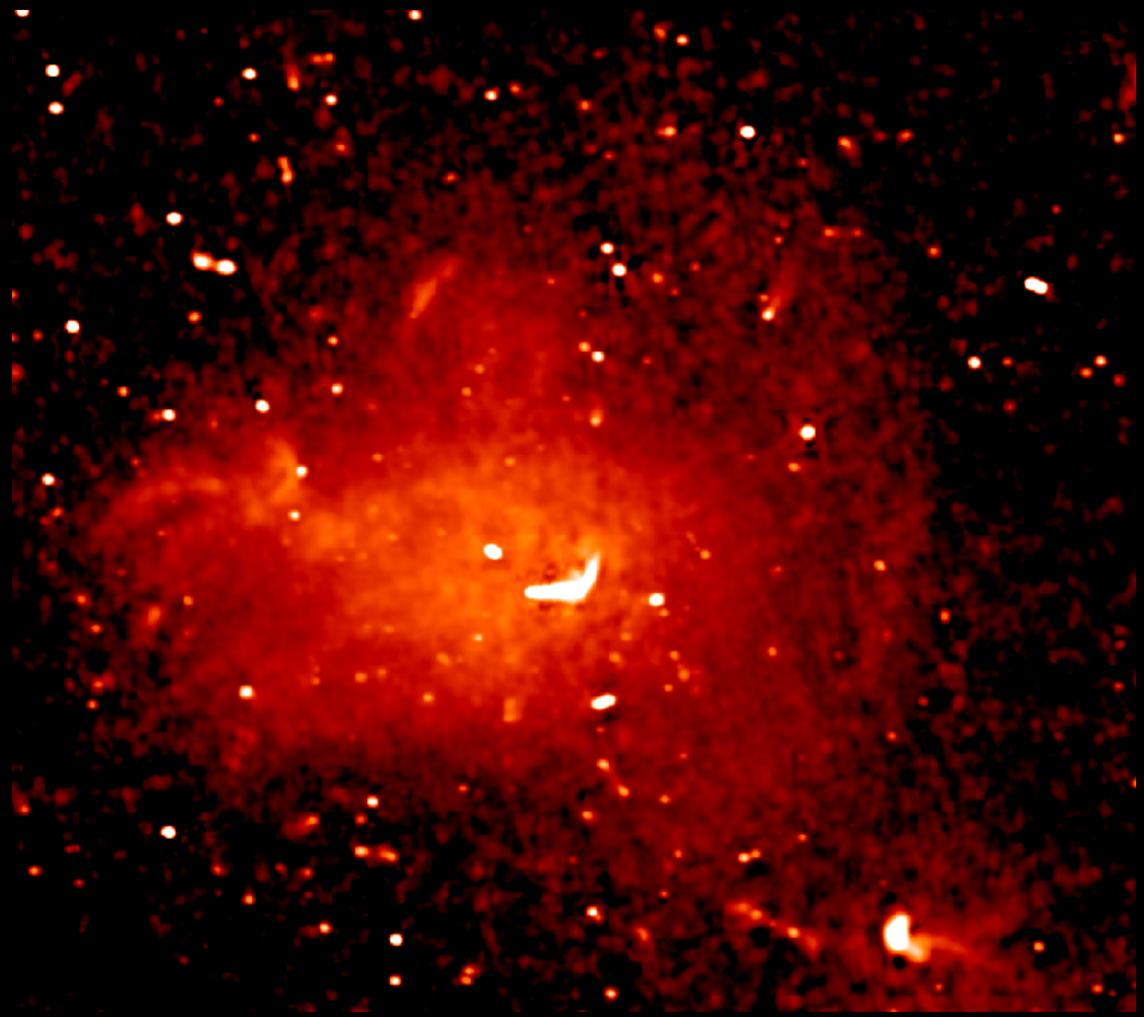
XMM-Newton mosaic
all 54 archival obsid re-processed (credits Zhang & Simionescu)

$$j_X \propto n_e^2 (kT)^{1/2}$$



LOFAR 144 MHz observations

$$j_R \propto N_0 B^{(\delta+1)/2}$$

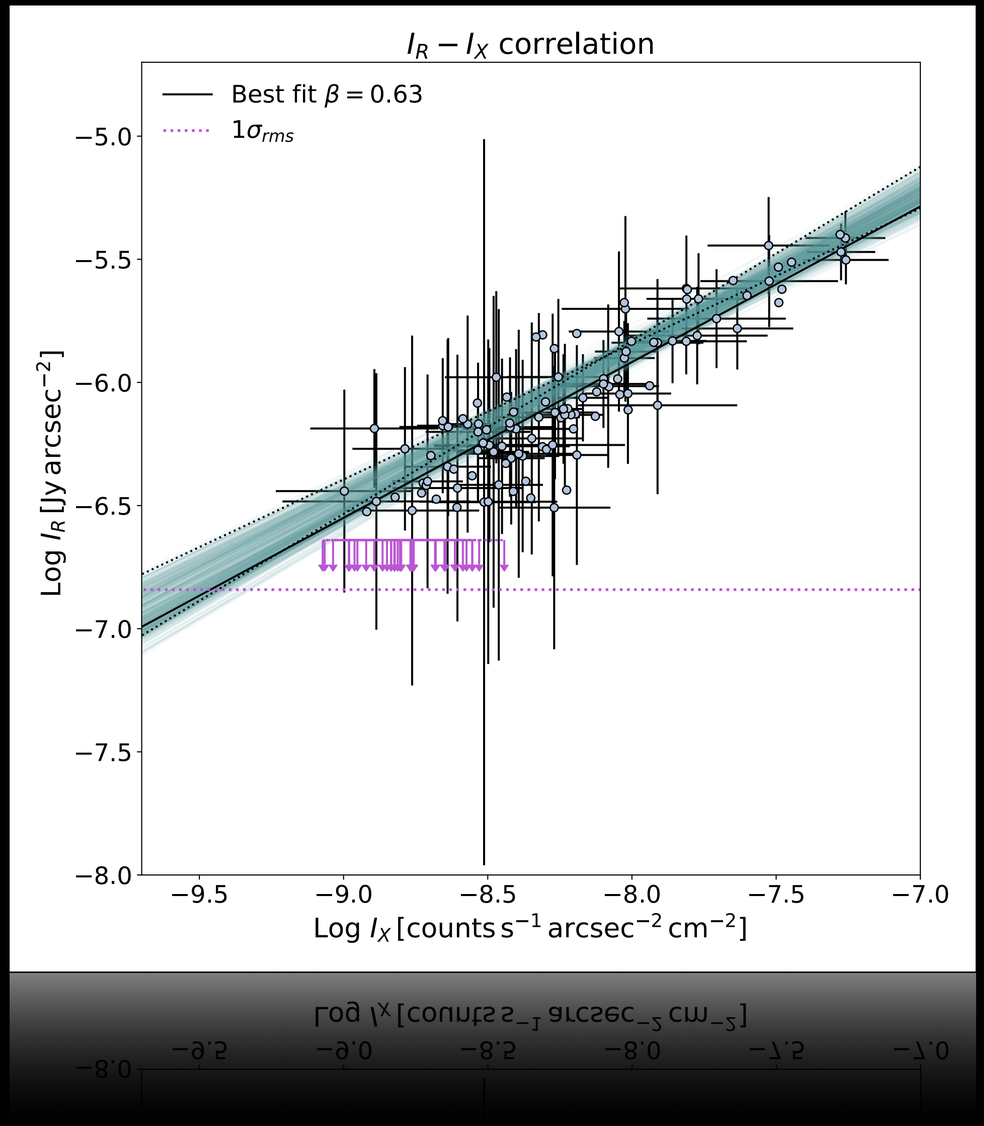


The Coma radio halo: thermal- non thermal correlation

Sub- linear Scaling between radio and X-ray

$$I_R \propto I_X^{0.63}$$

Computed on the 35” image
consistent with Govoni et al 2001



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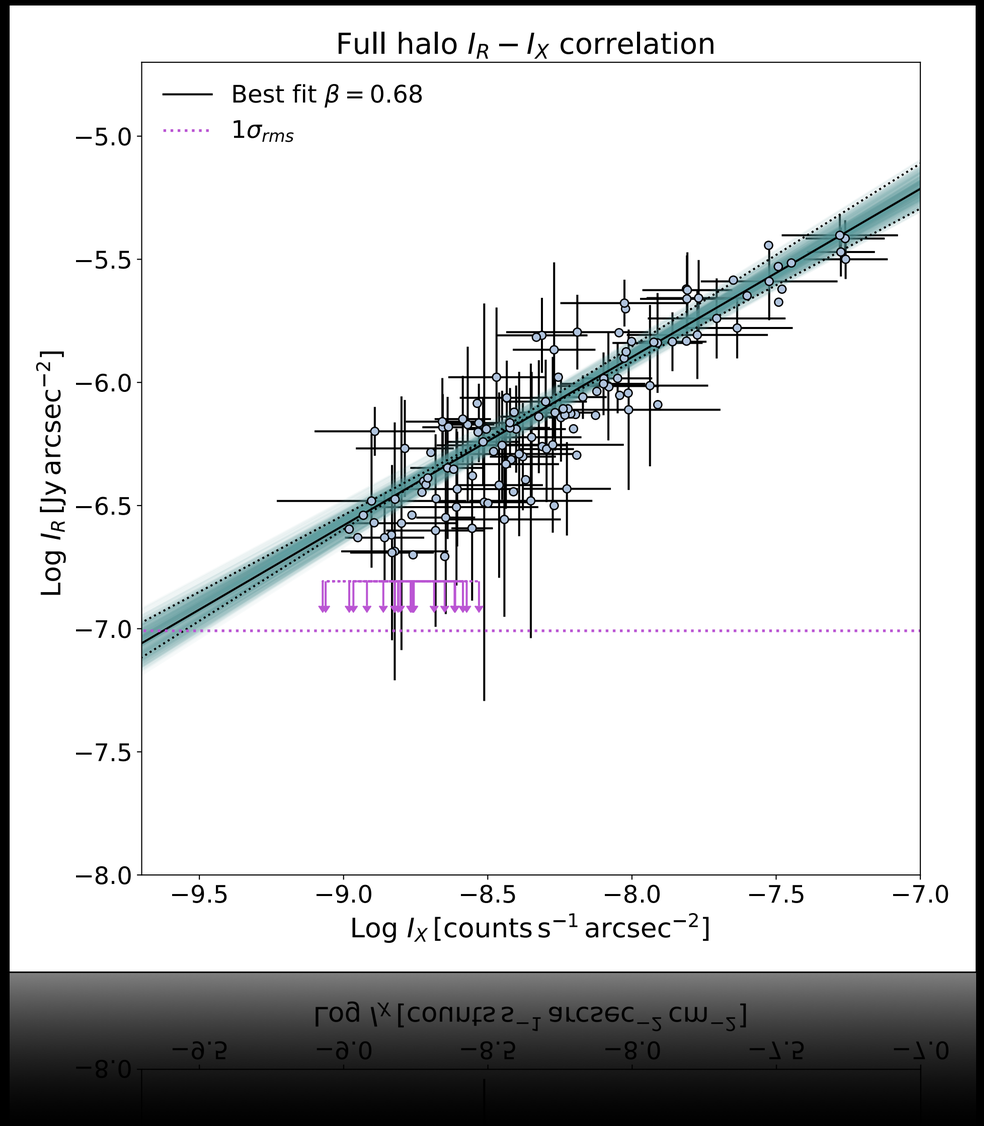

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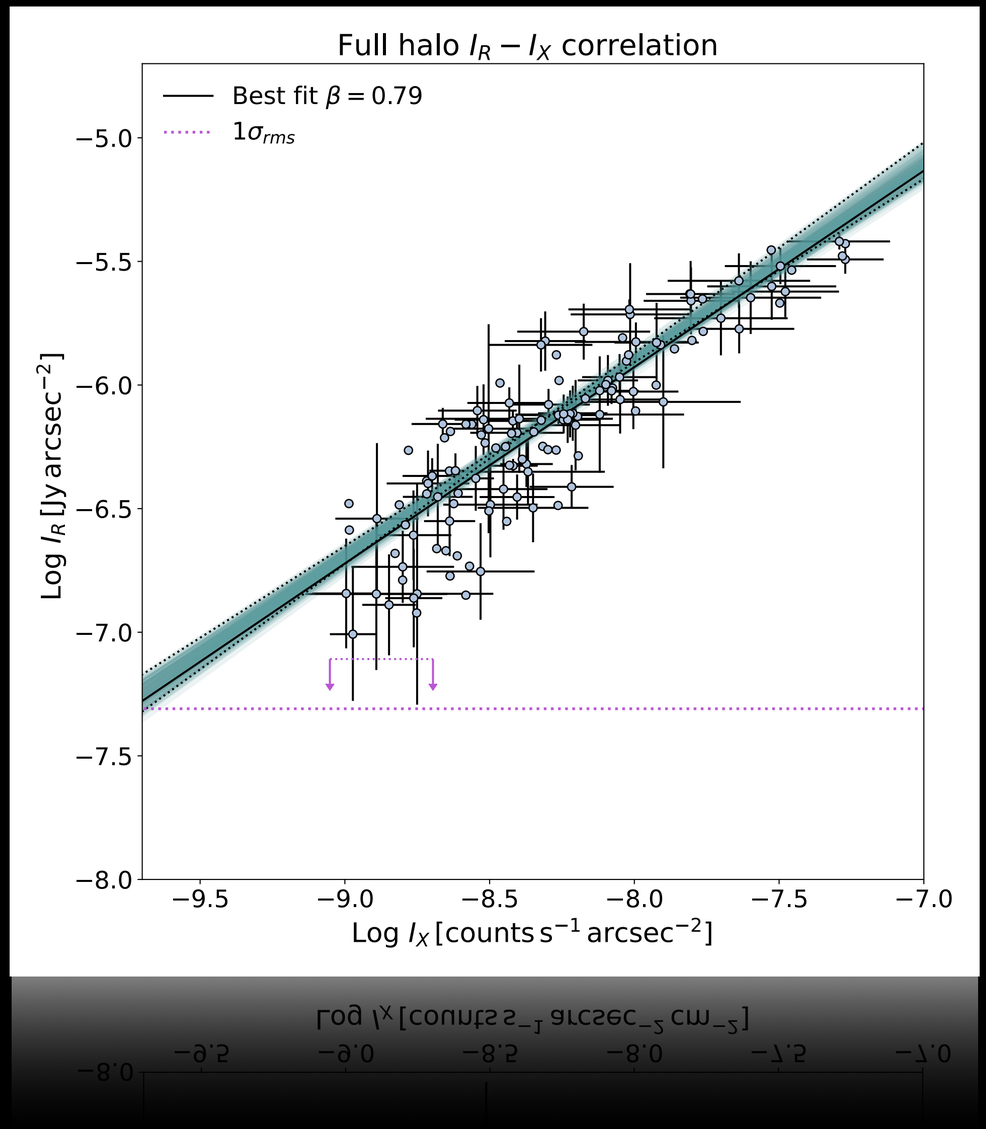

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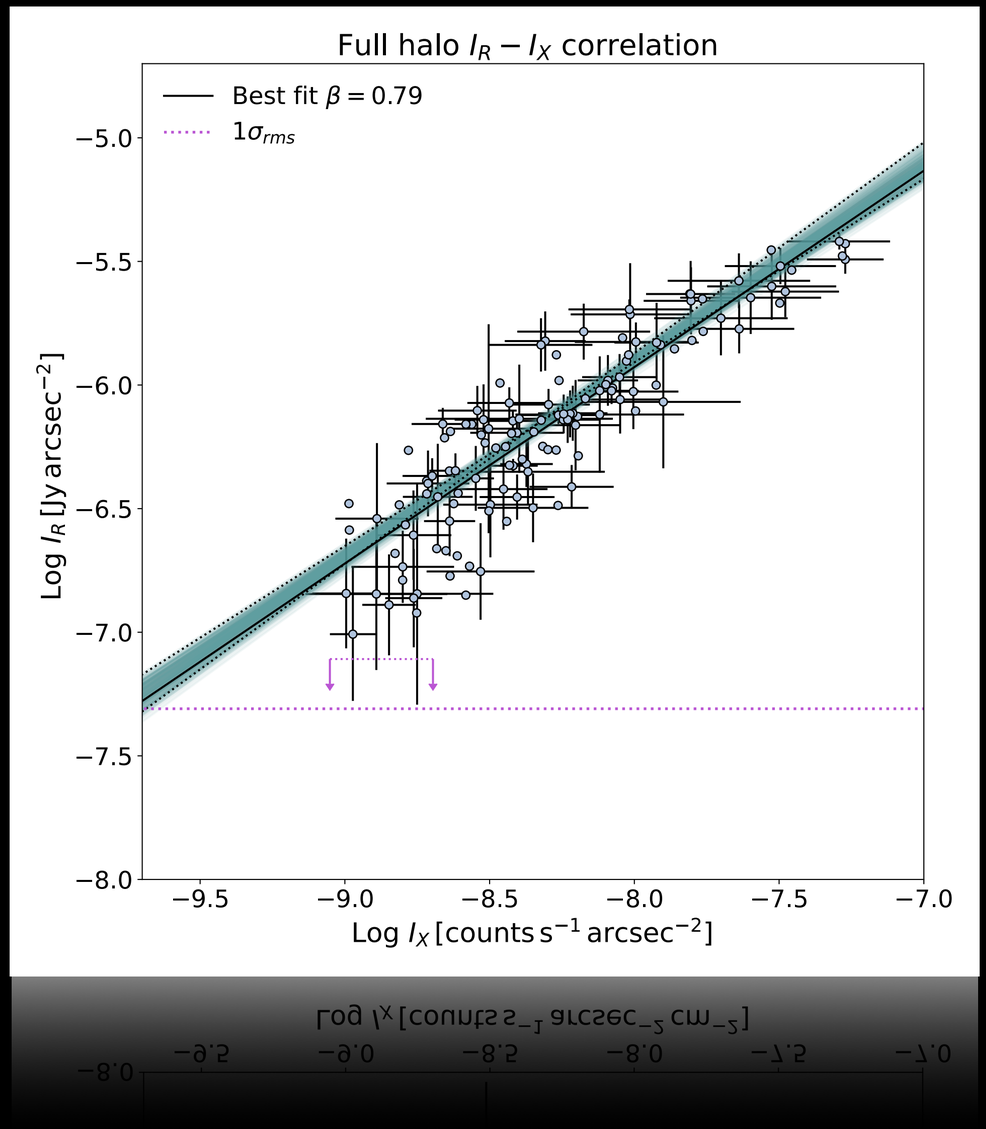

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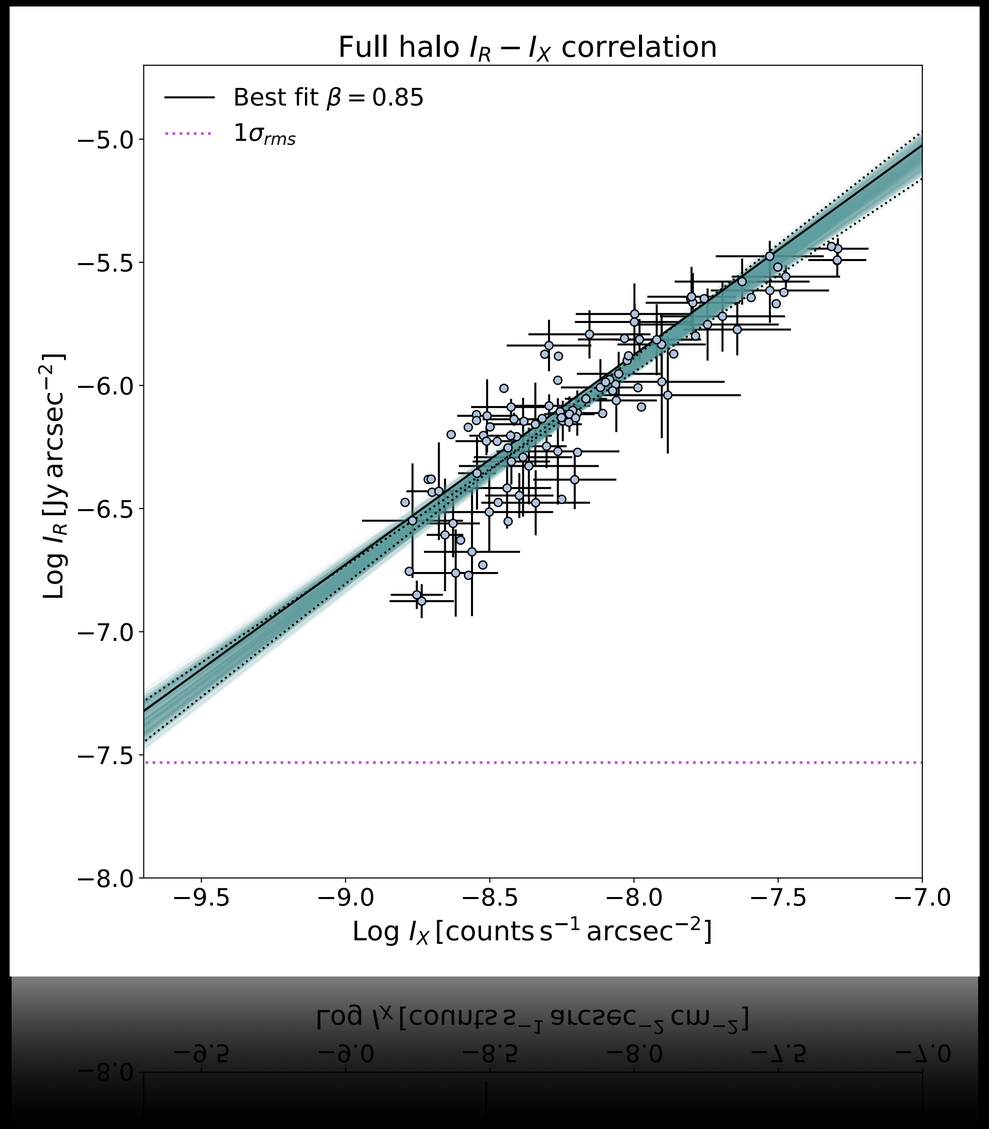

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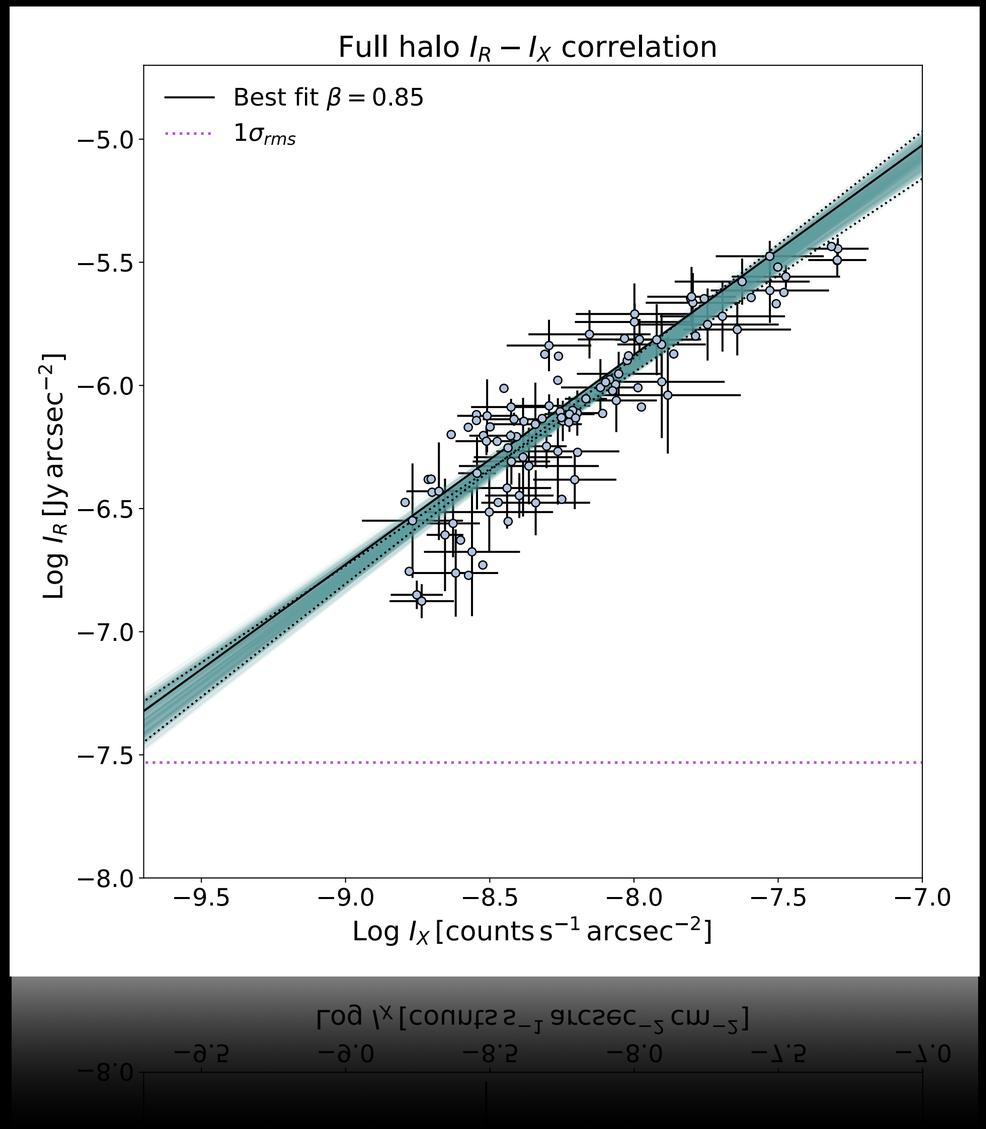
The correlation becomes steeper
as we smooth radio and X-ray

$$I_R \propto I_X^{0.85}$$

Computed on the 5’ image



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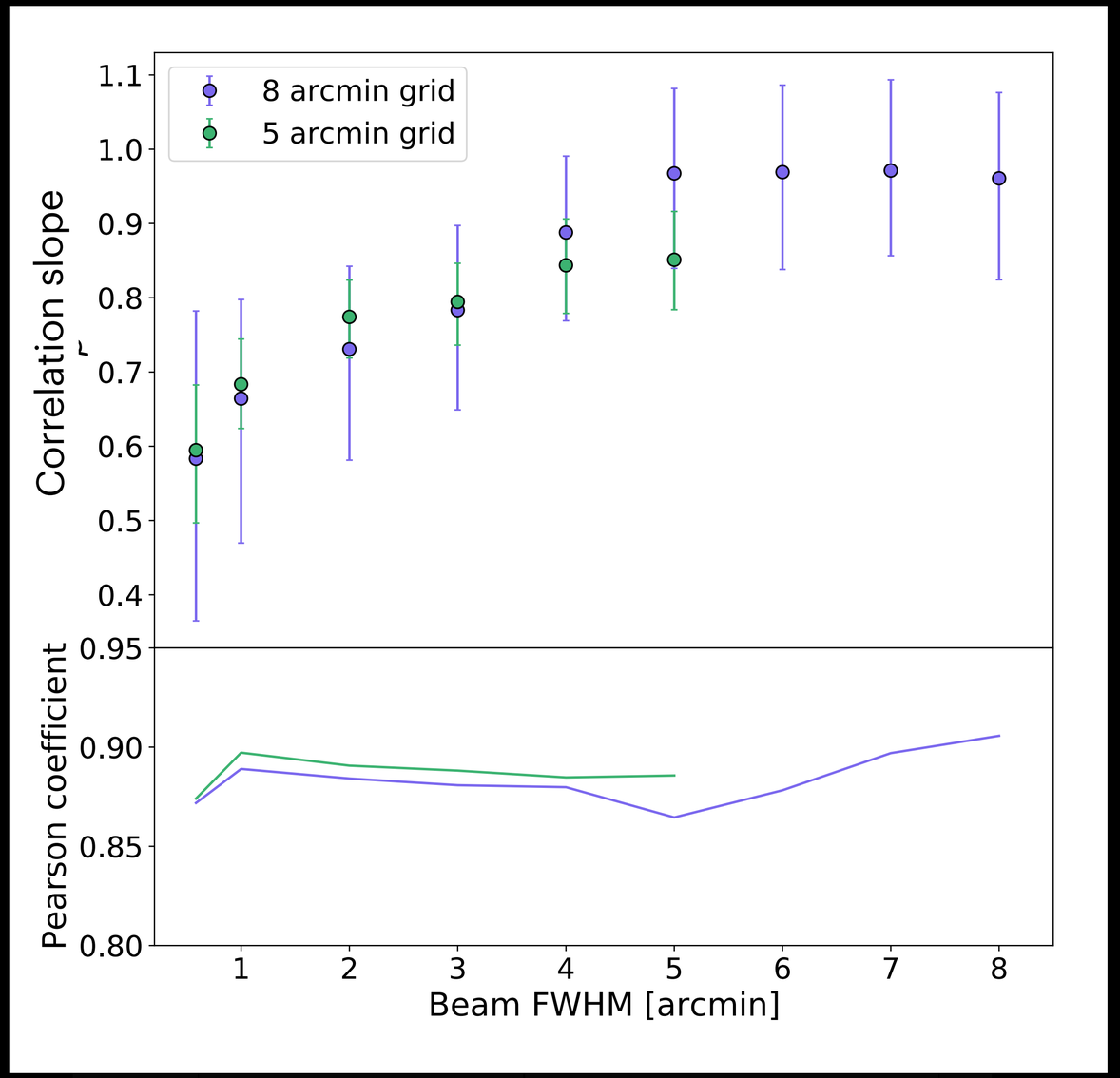
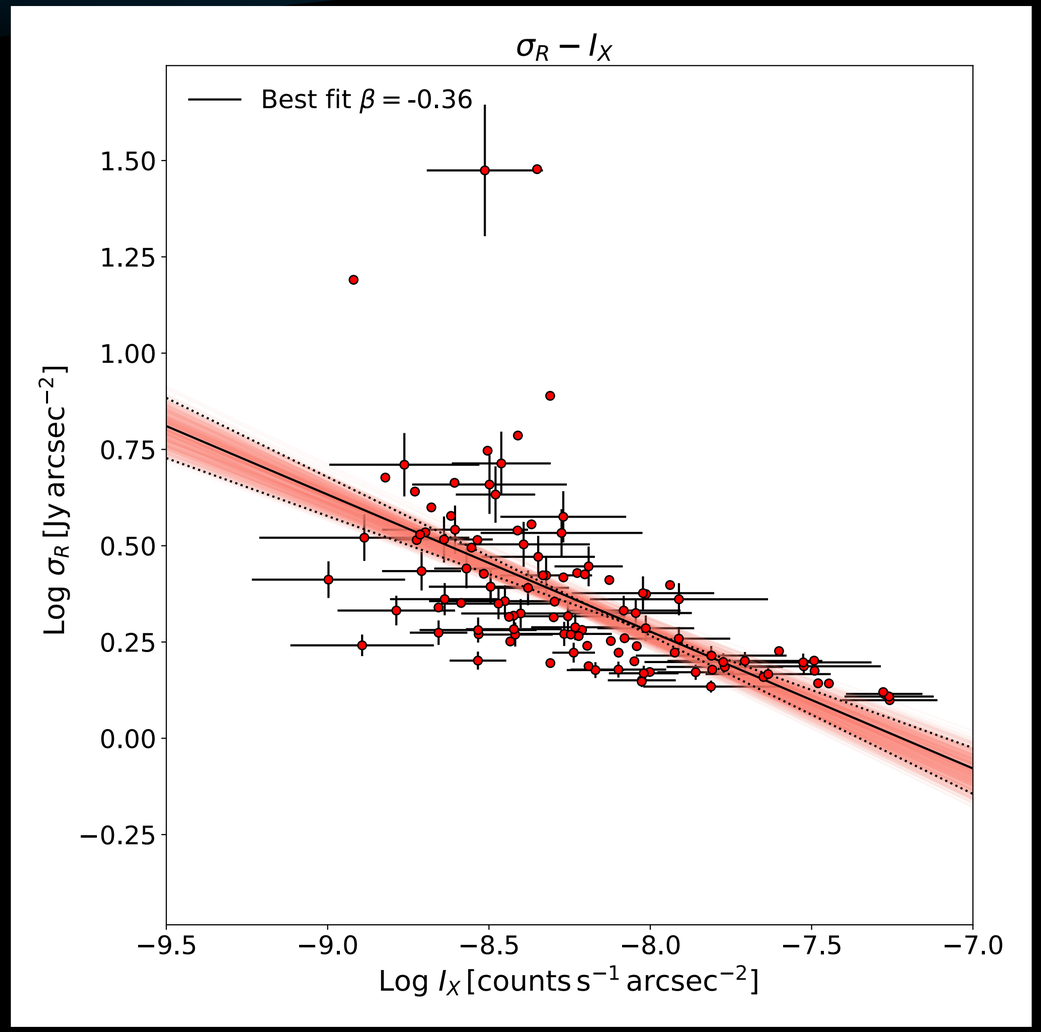
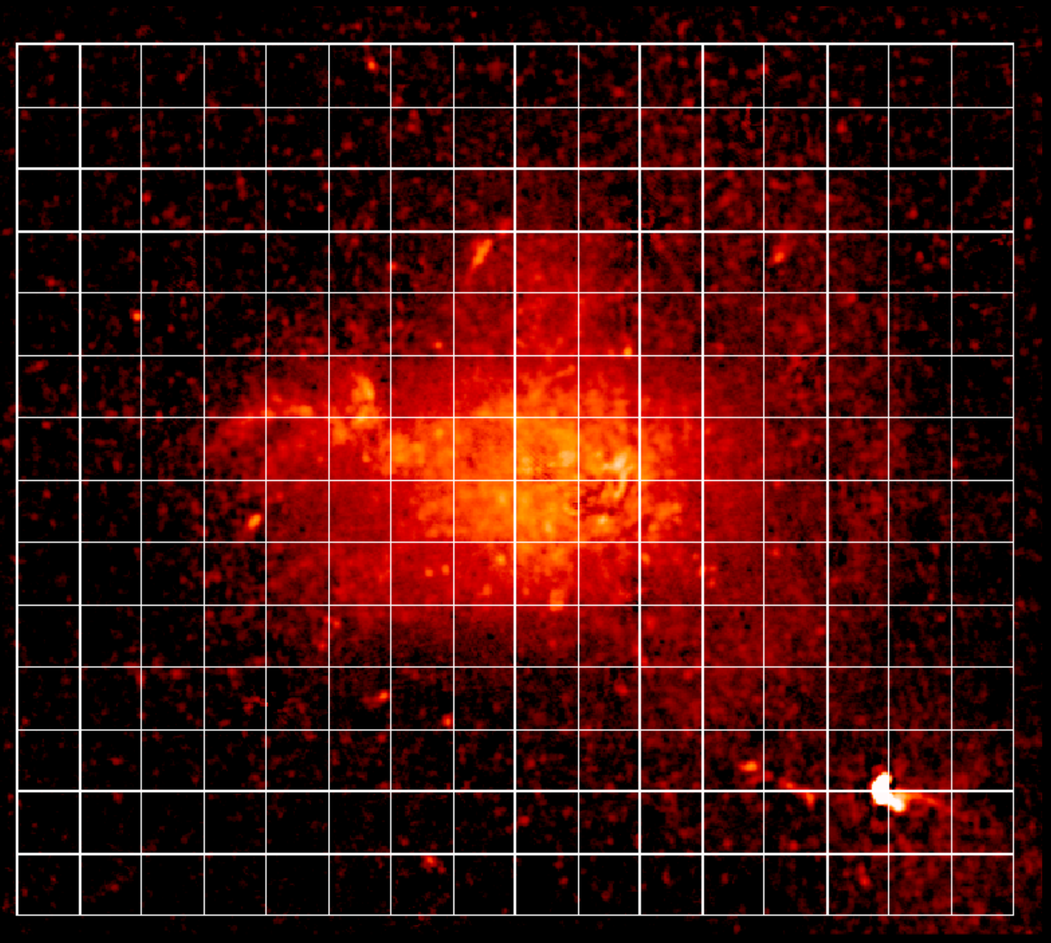


Radio halo brightness fluctuations





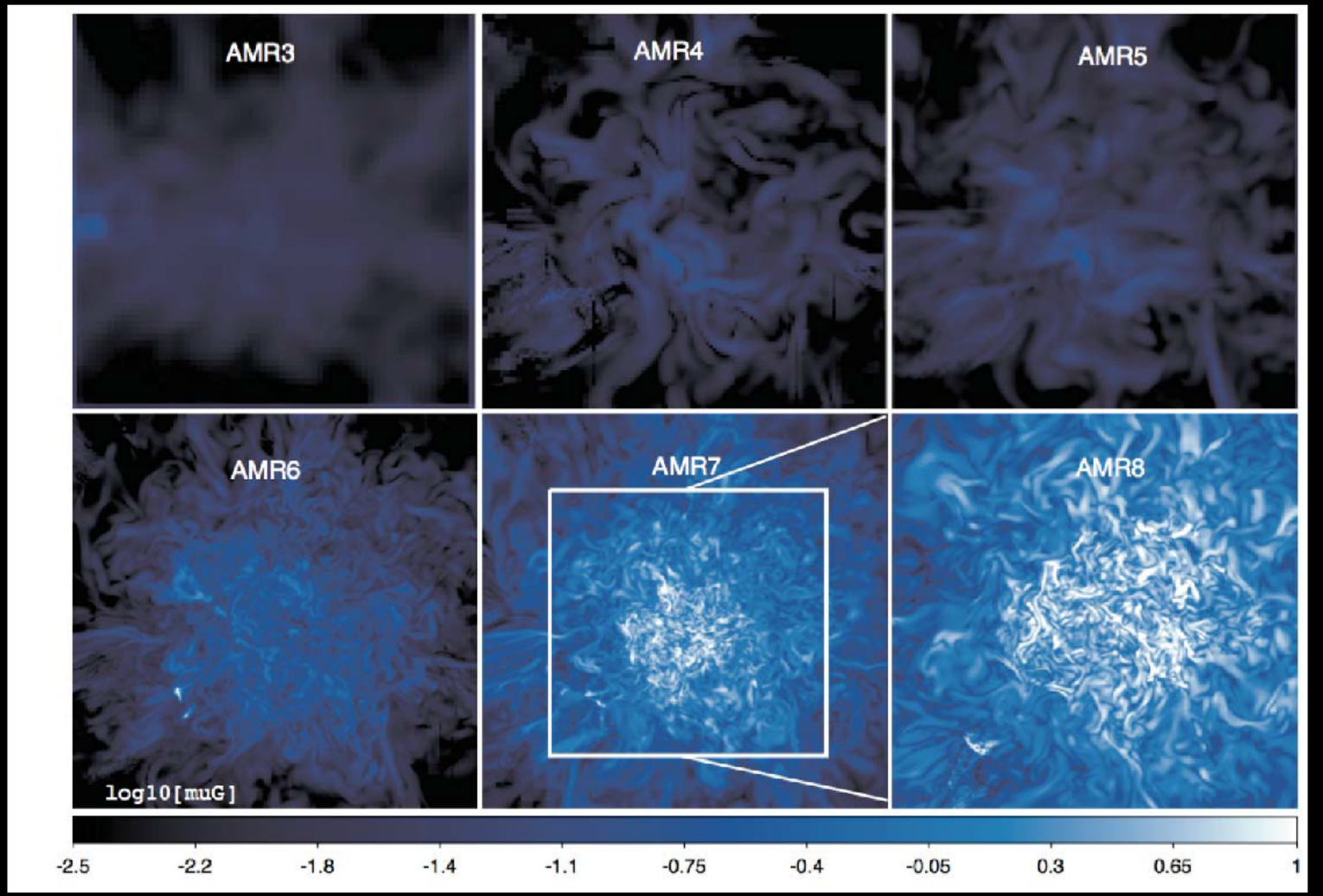
Scatter of radio brightness
higher at the cluster periphery

Trying to decipher the re-acceleration mechanism

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

Projected mean magnetic field at increasing resolution, up to 4 kpc

Good match with RM data on Coma



Vazza et al. (2018)

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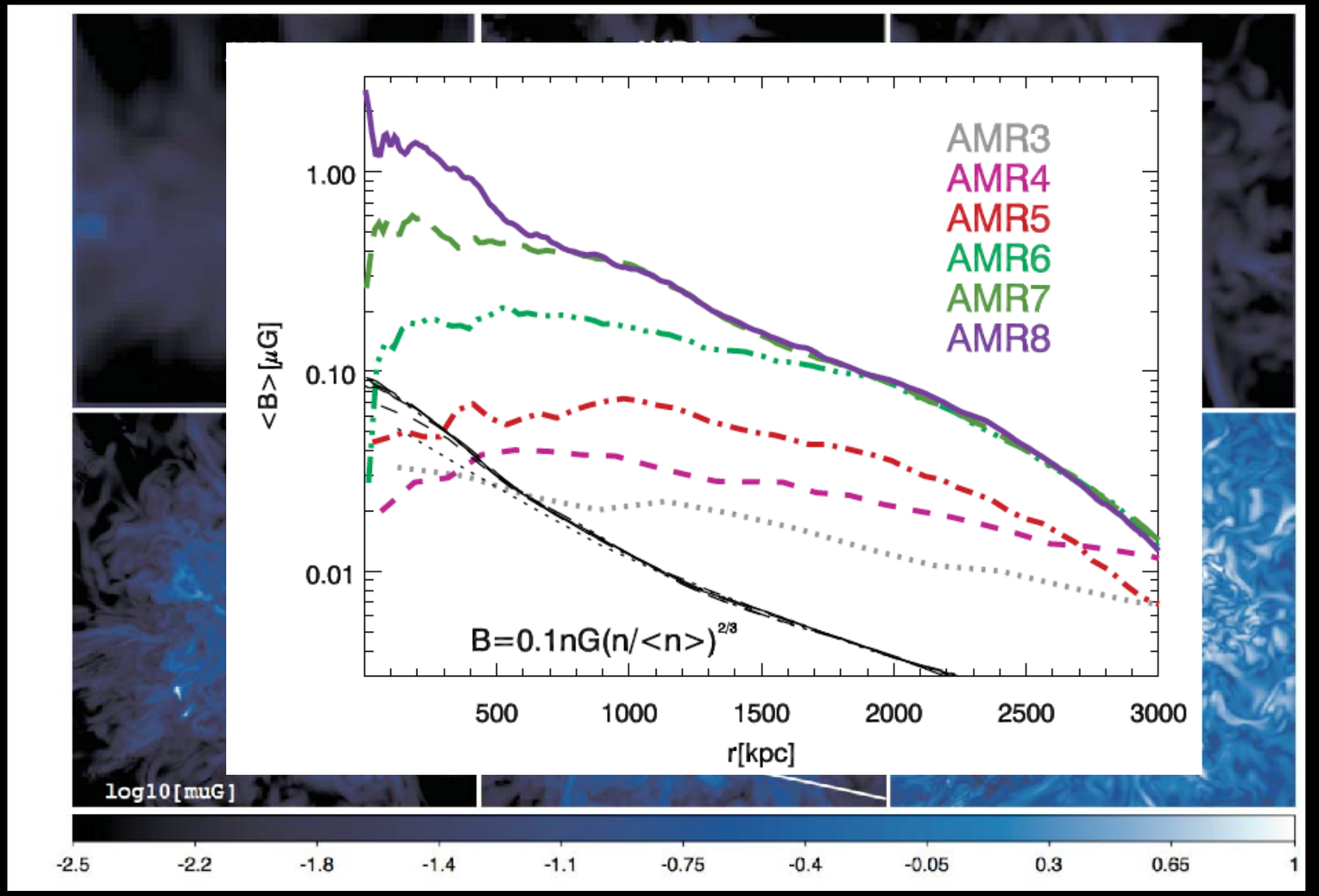

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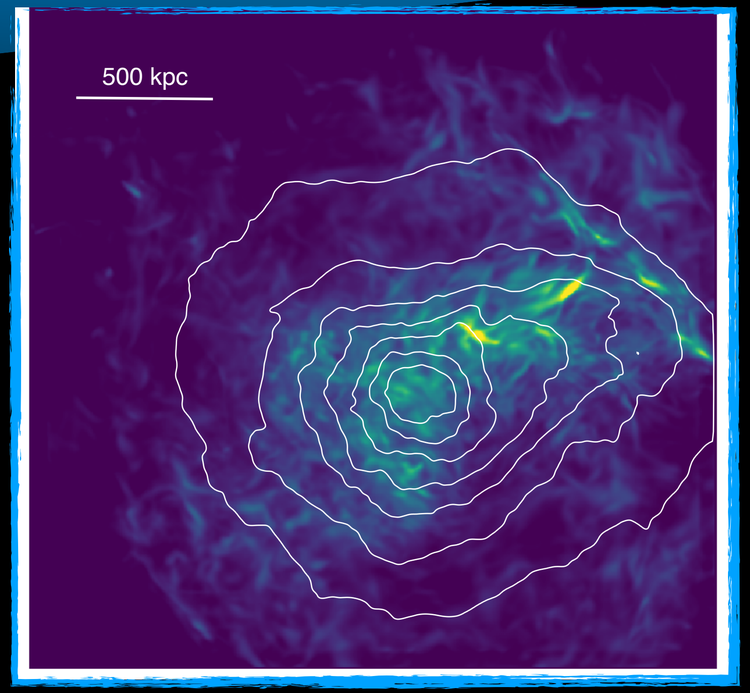
Trying to decipher the re-acceleration mechanism

Turbulent energy flux
(compressive component)

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



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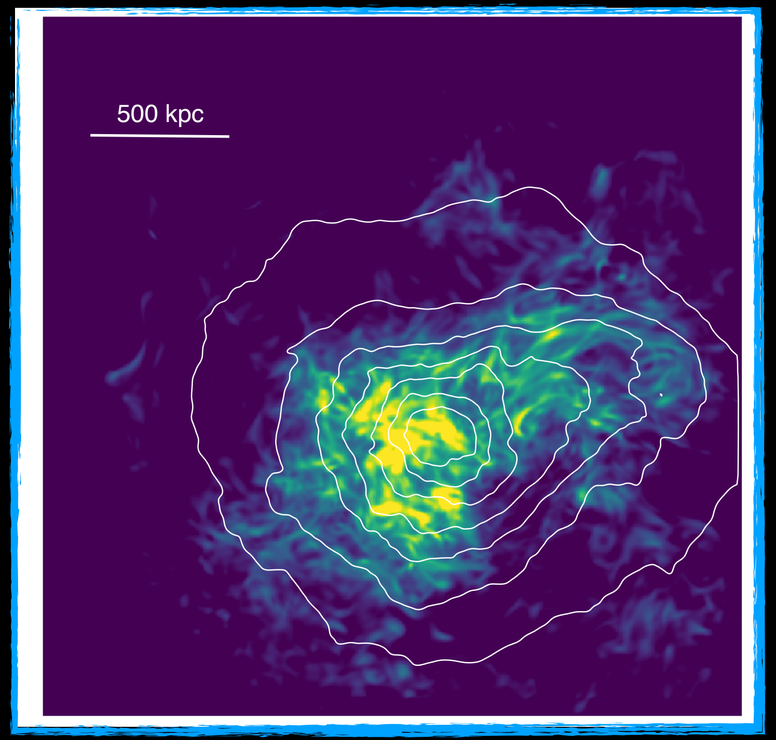

Both quantities have a similar trend with respect to X-ray
but
different normalisations

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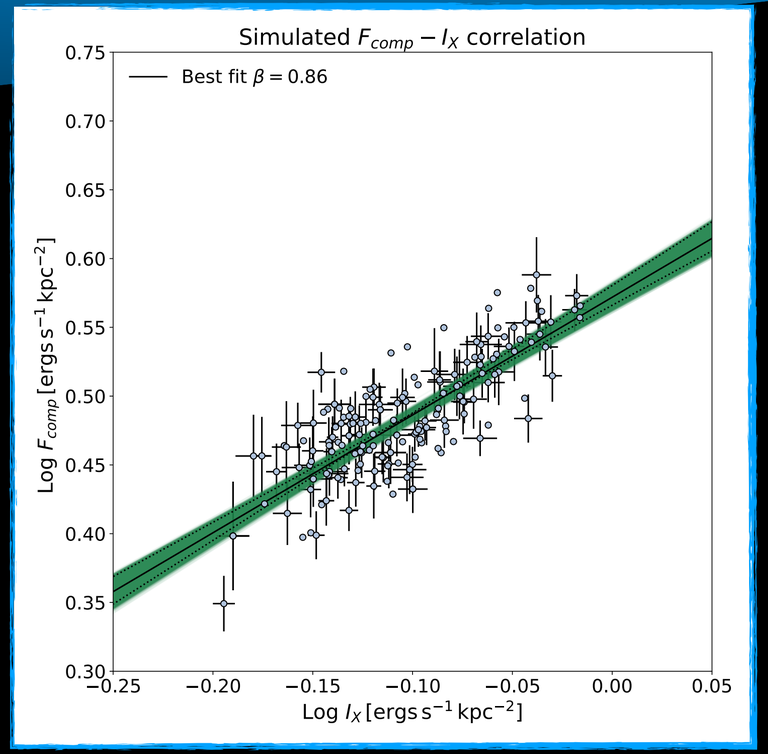

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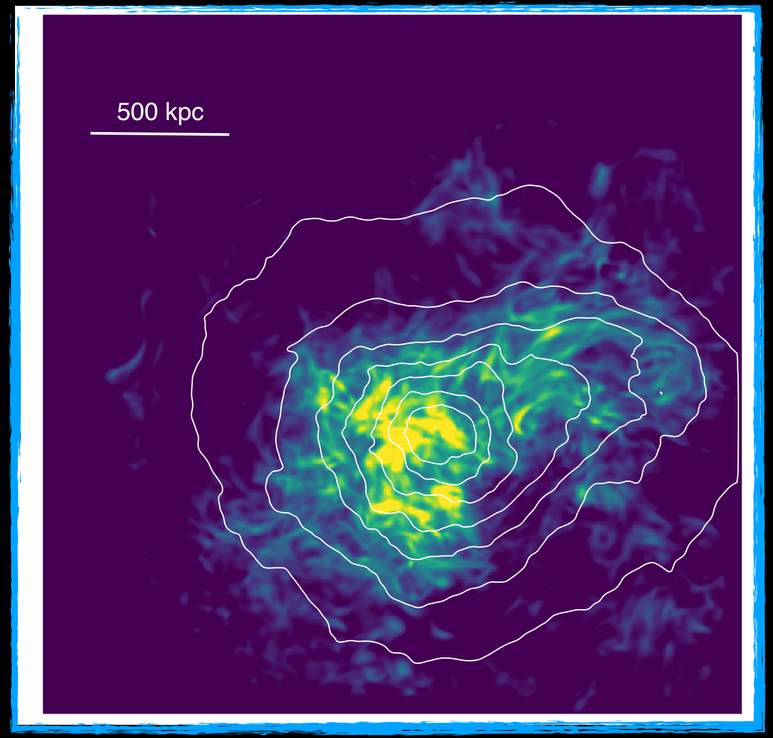

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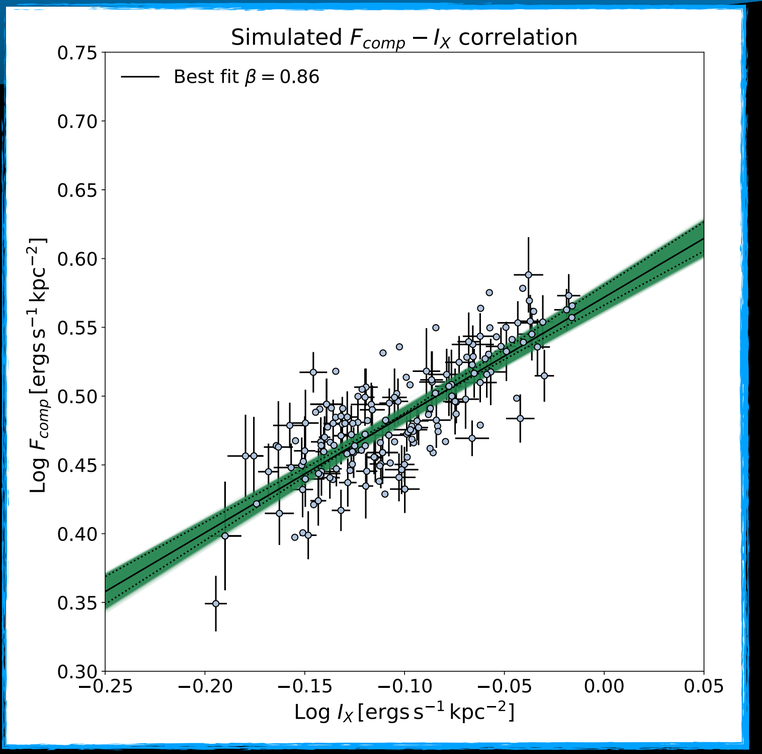

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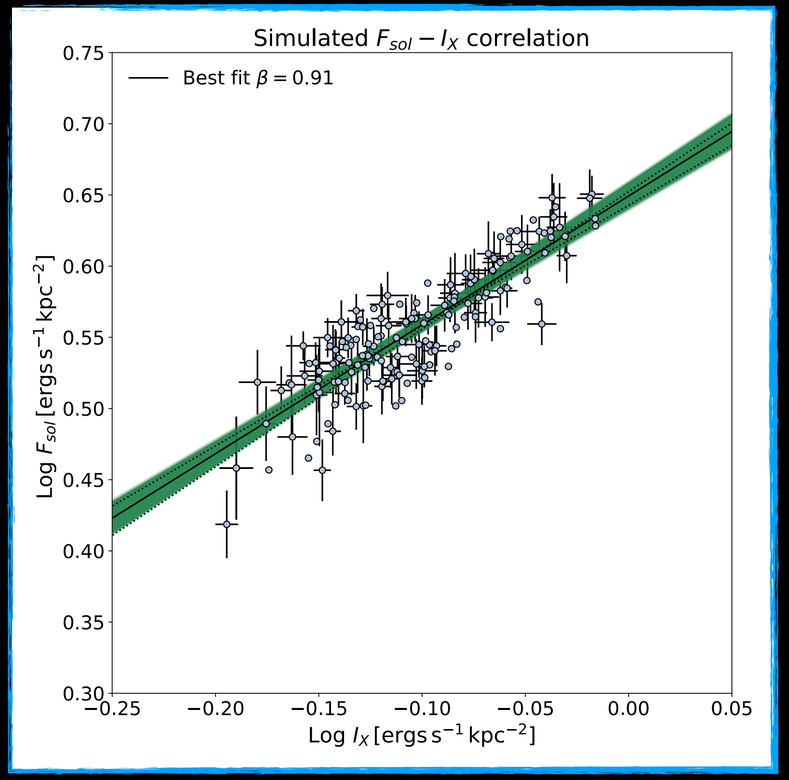

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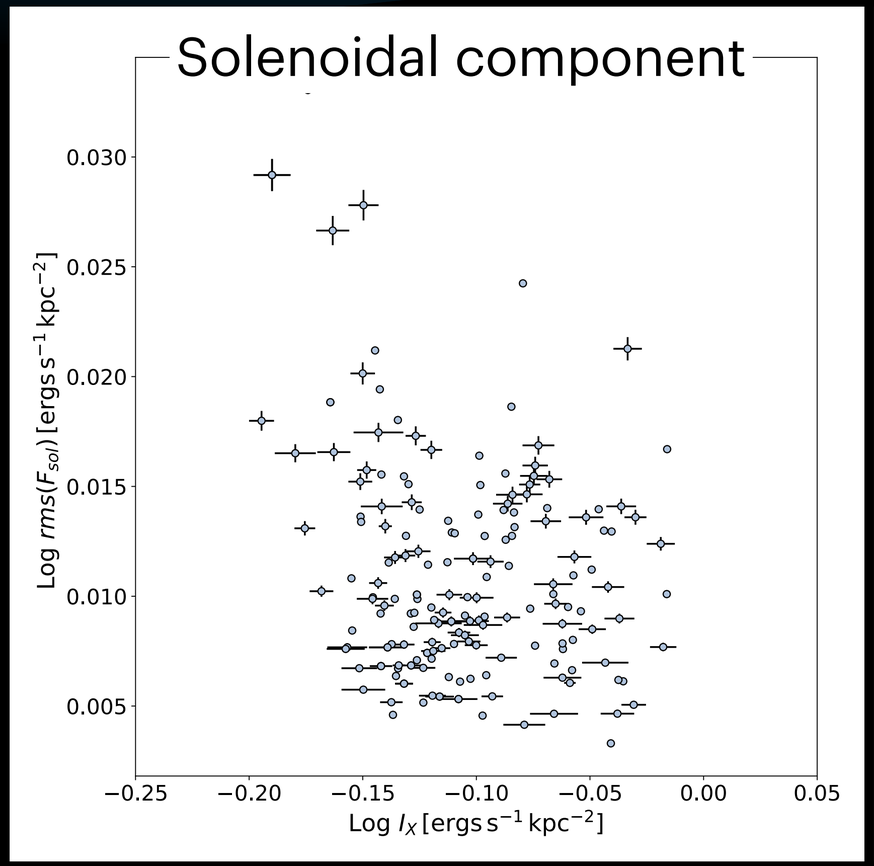
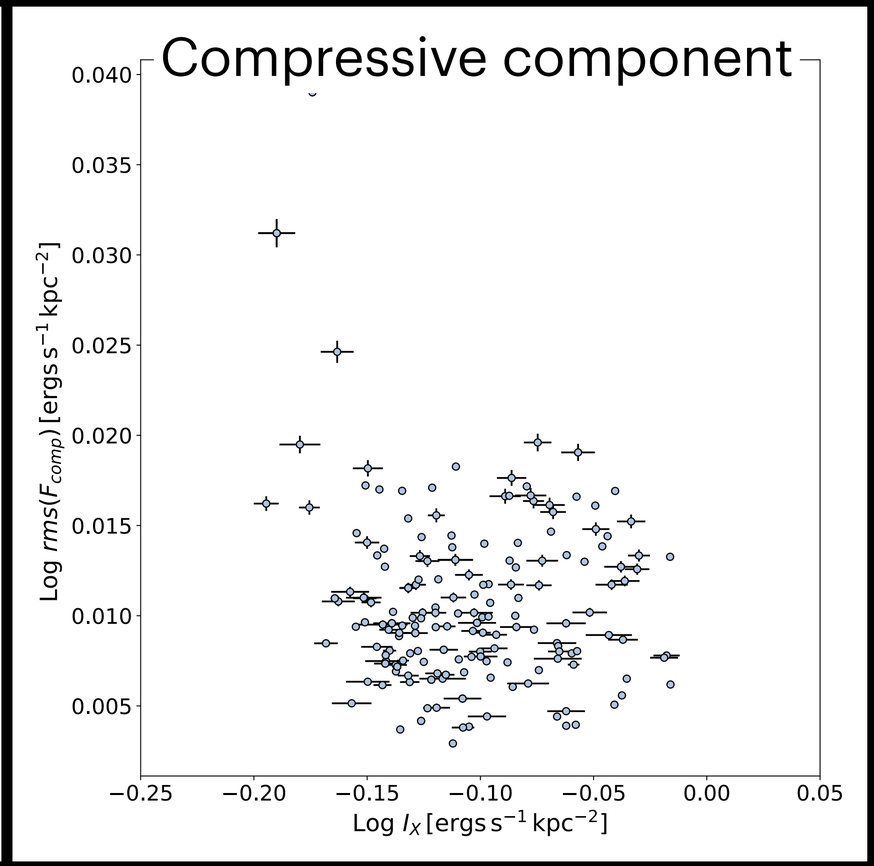
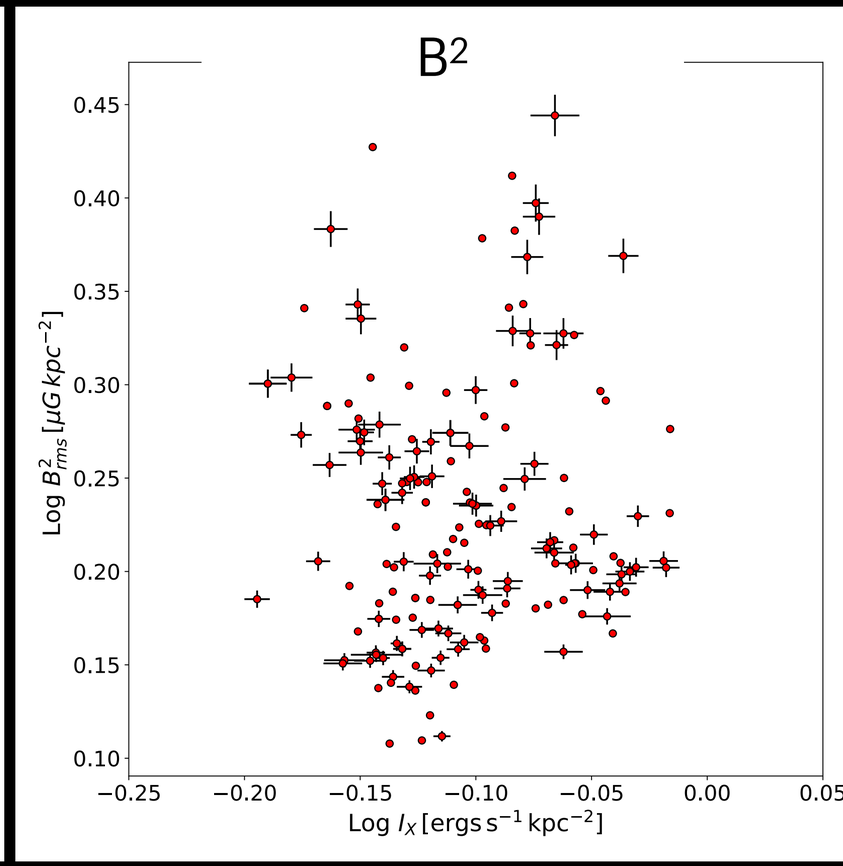
Can we reproduce the observed scatter of radio vs X ray?

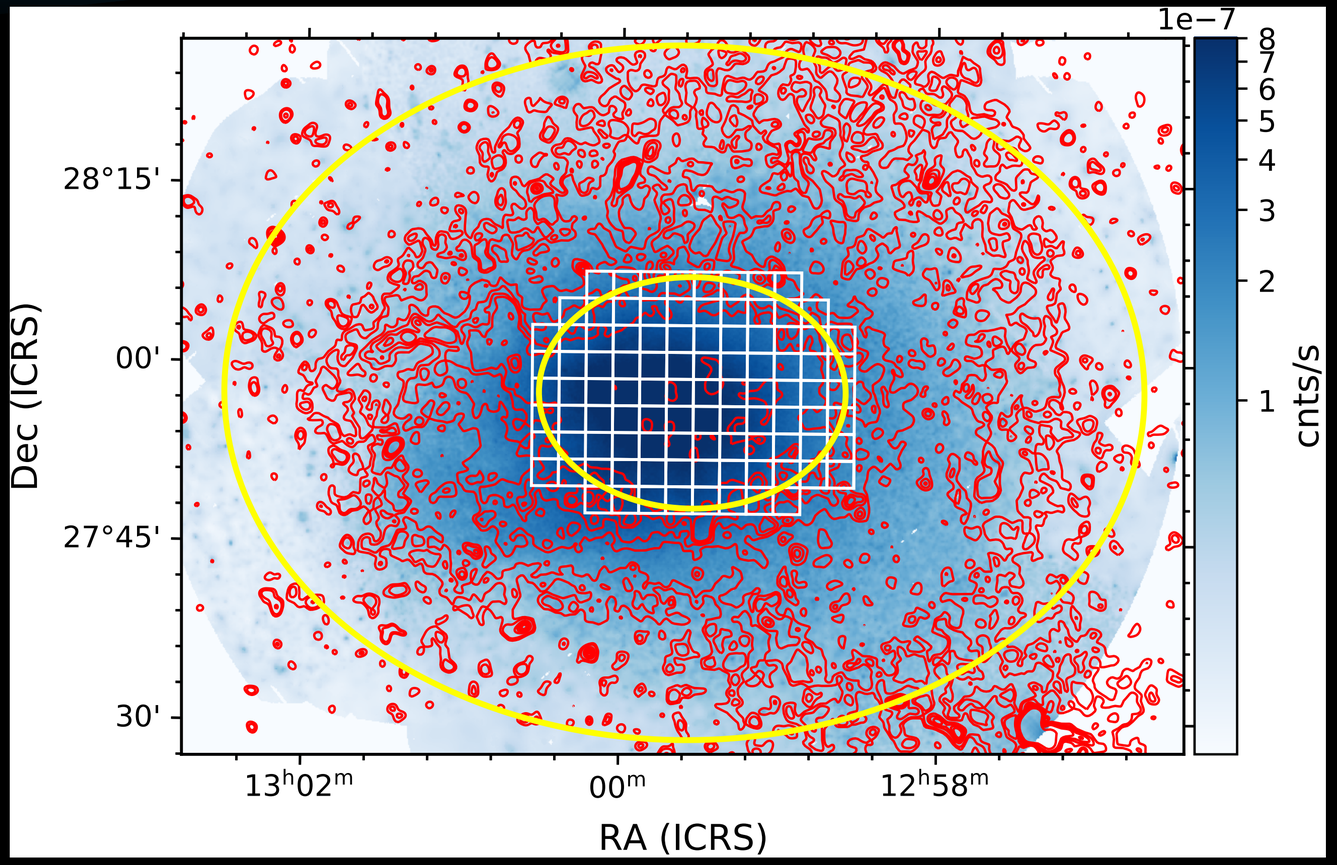






The observed scatter is due to the distribution of particles, spatial and/or energetic

Different trends in the centre and periphery?



In the inner halo core

$$I_R \propto I_X^{0.43\pm0.8}$$

In the halo outskirts

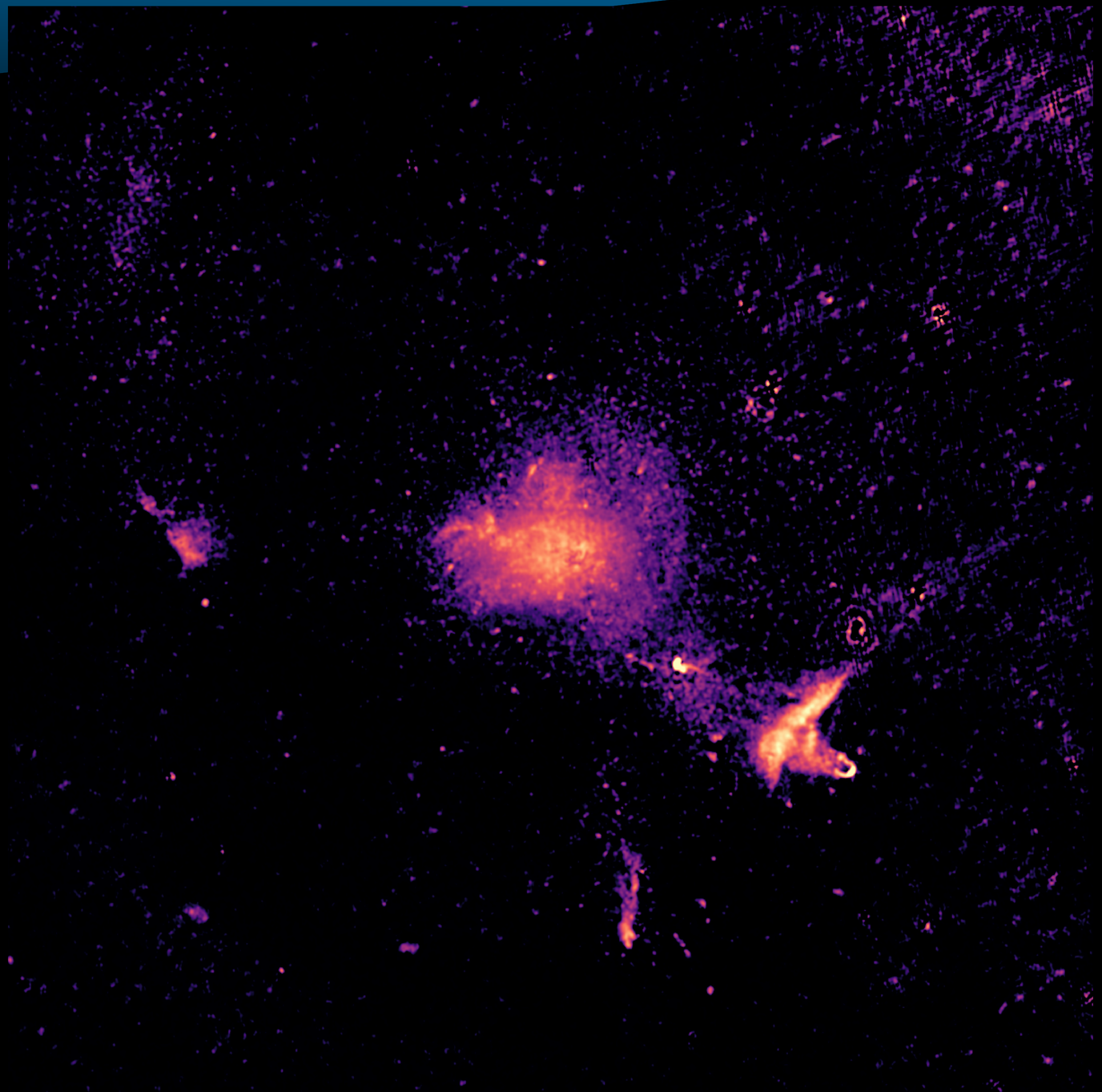
$$I_R \propto I_X^{0.57\pm0.3}$$

Halo powered by different turbulent modes in the core and in the outskirts?

New emission in the field

Arc-like patch of diffuse emission
at r ~ 3.6 Mpc from cluster centre
(i.e. 1.2 Rvir)

Accretion shock?



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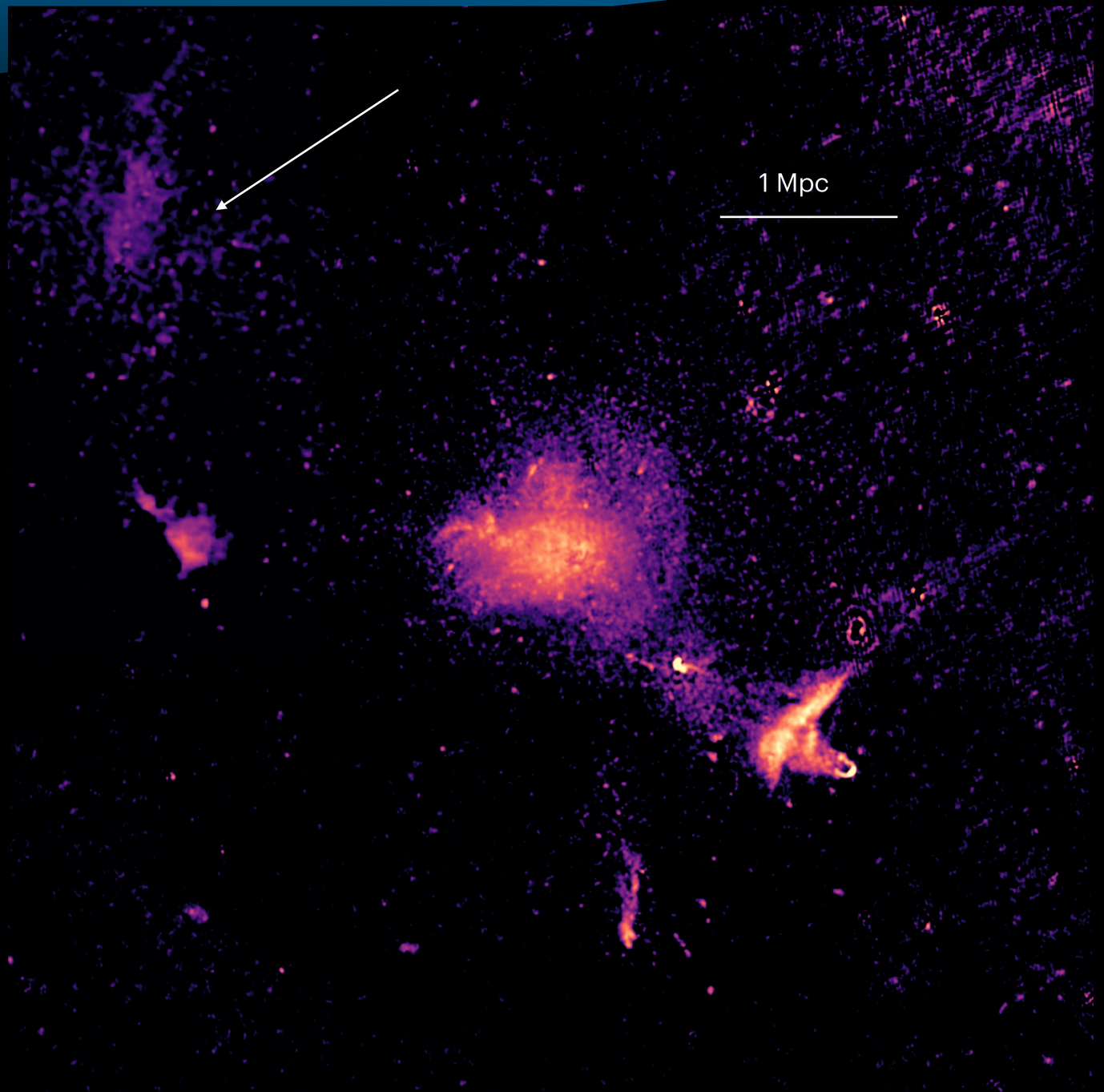

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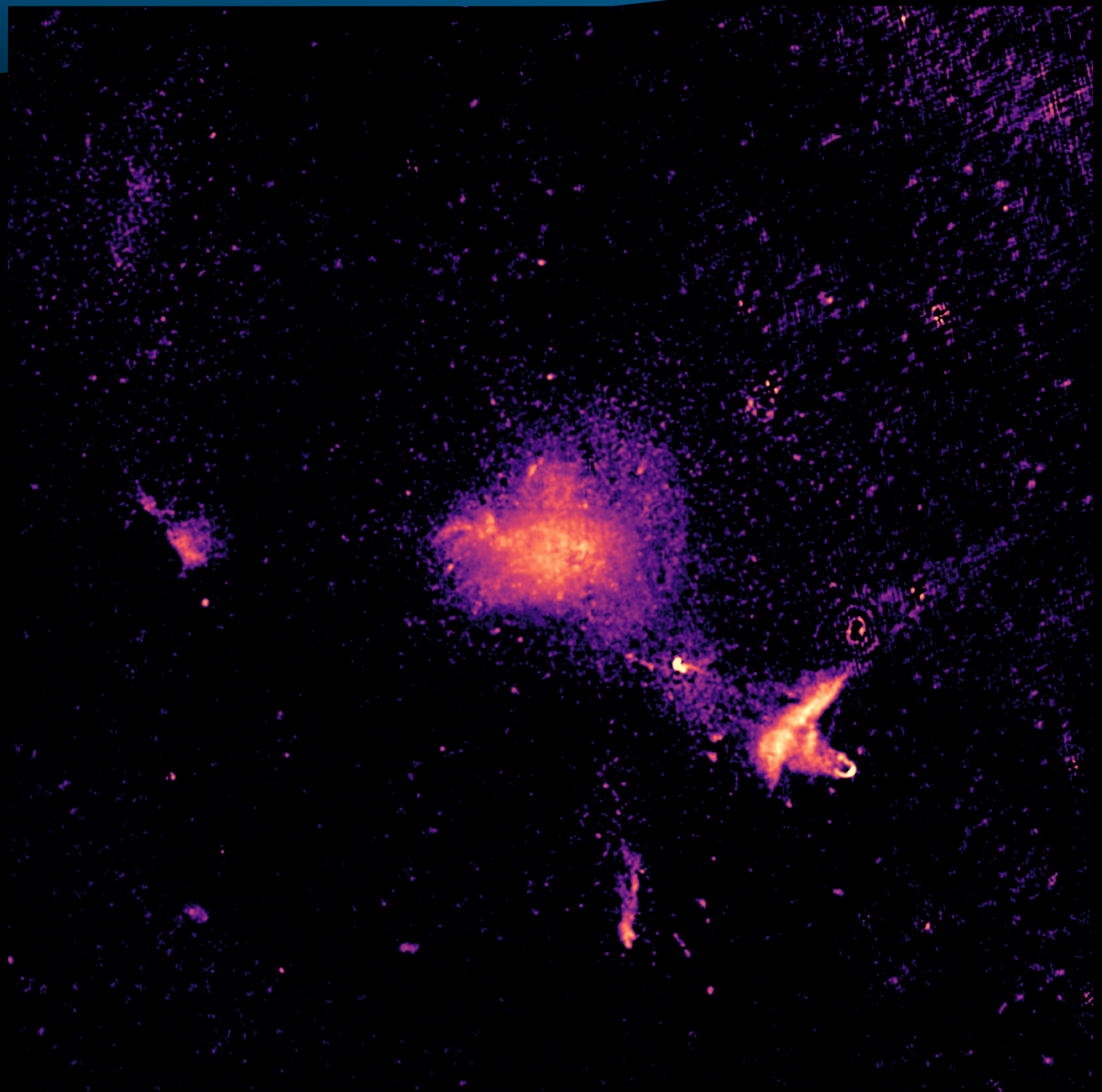

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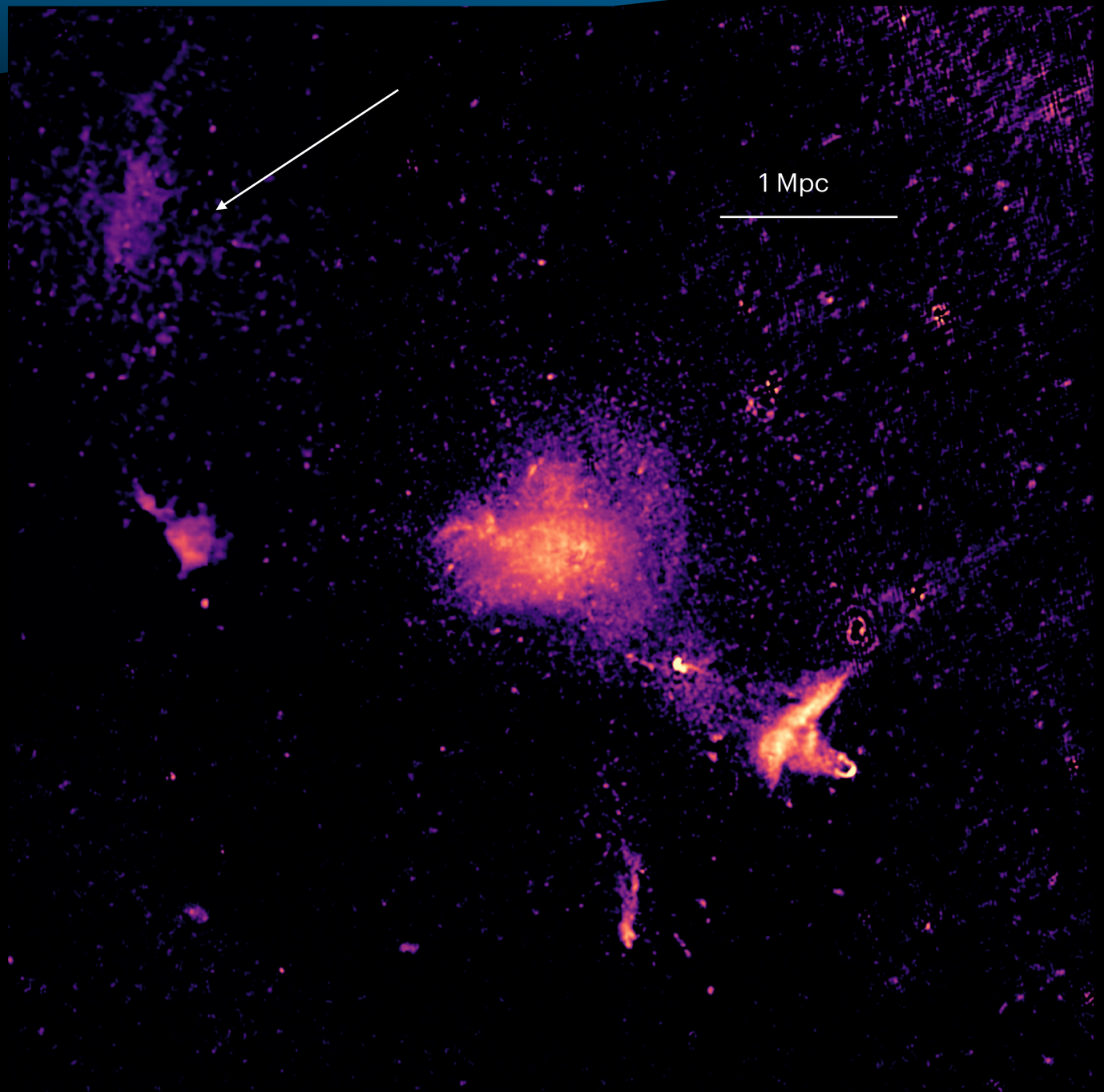
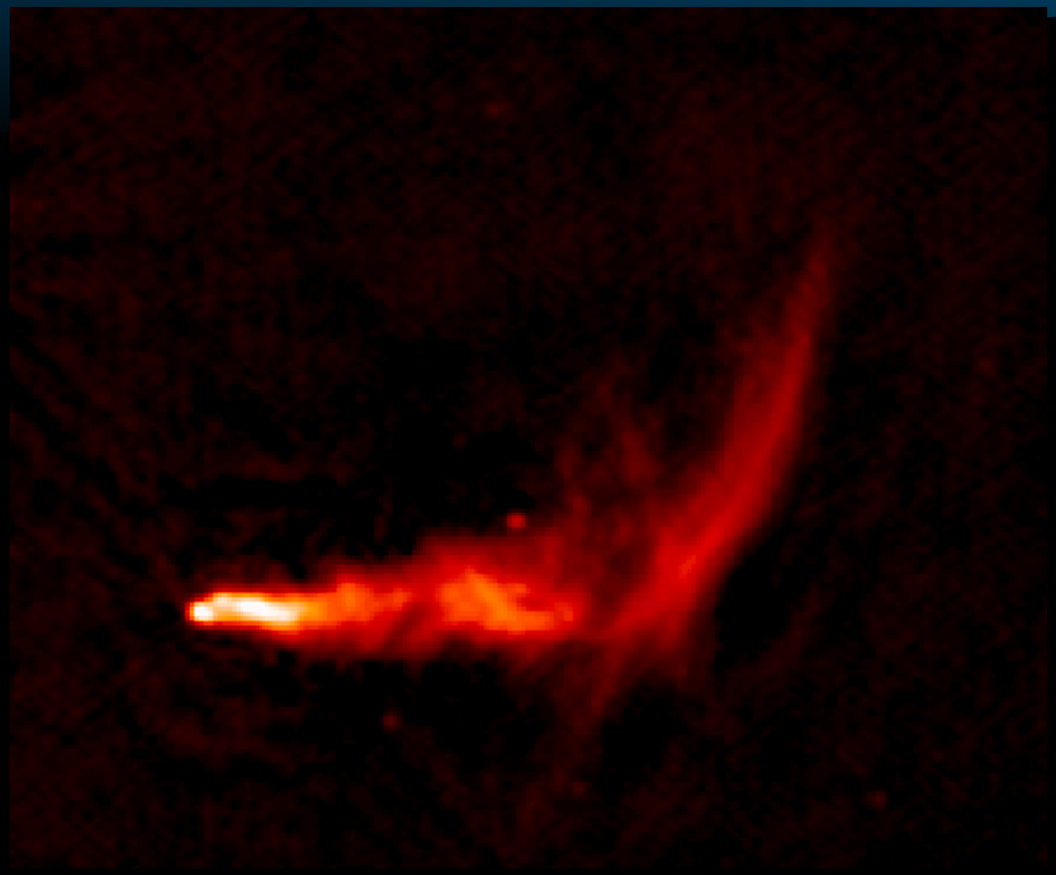
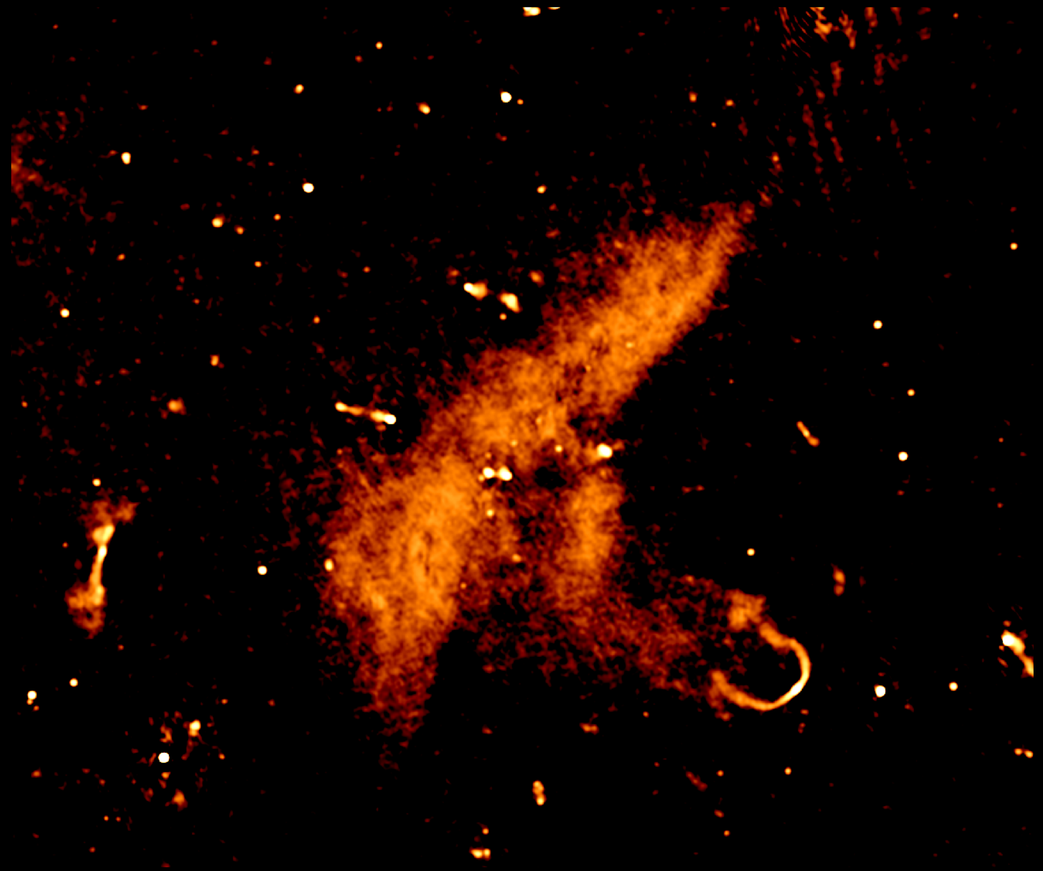
Accretion shock?



Coma AGN





Conclusions

- Stepping into new territory to decipher particle acceleration mechanisms

- Large field of view: a lot of physics to be learnt (AGN, halos, relic, new sources!)