Diffuse Radio Emission within or beyond Galaxy Clusters

Brief Introduction

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Galaxy Clusters and Groups

The largest known gravitationally bound structures in the universe;

Typical mass : 10^{13} –10^{15} $M_{\odot}$

Typical diameter : 1 –10 Mpc

- **Composition:**
  - **Galaxies (1% - 3%) :**

    10 – 1000 individual galaxies (poor - massive)
  - **Dark Matter (75% - 90%) :**

    most massive component
  - **Intra-Cluster Medium (ICM, 5% - 15%) :**

    hot gas (10^{7} –10^{8} K) emits X-rays

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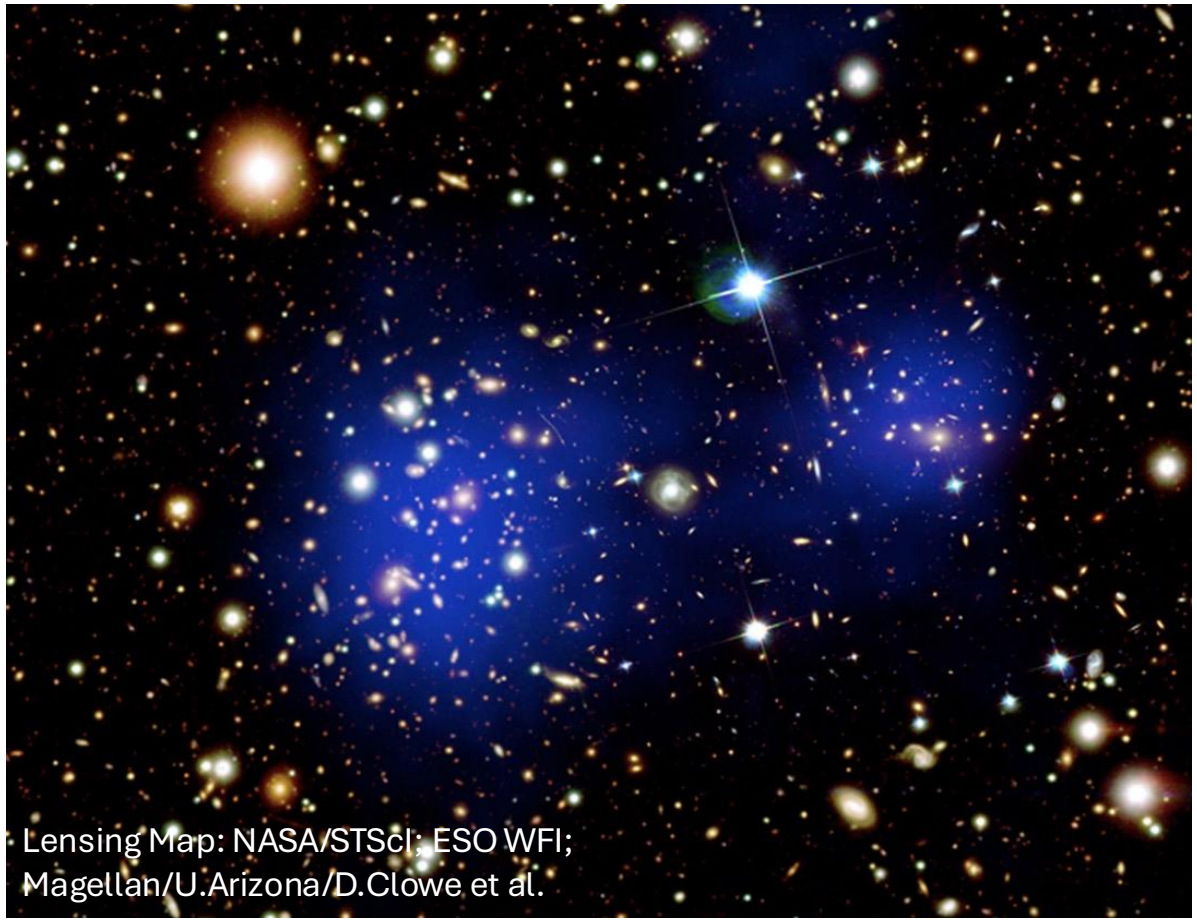

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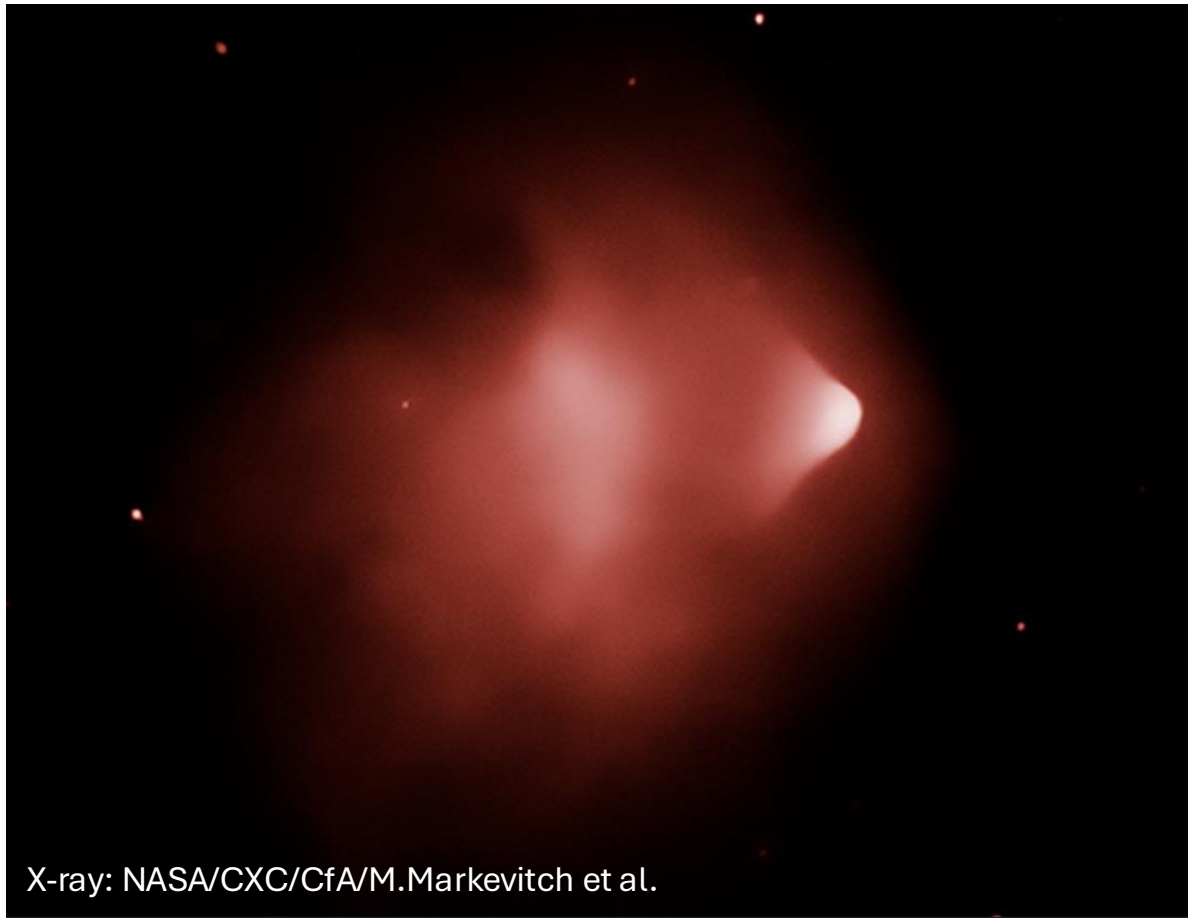

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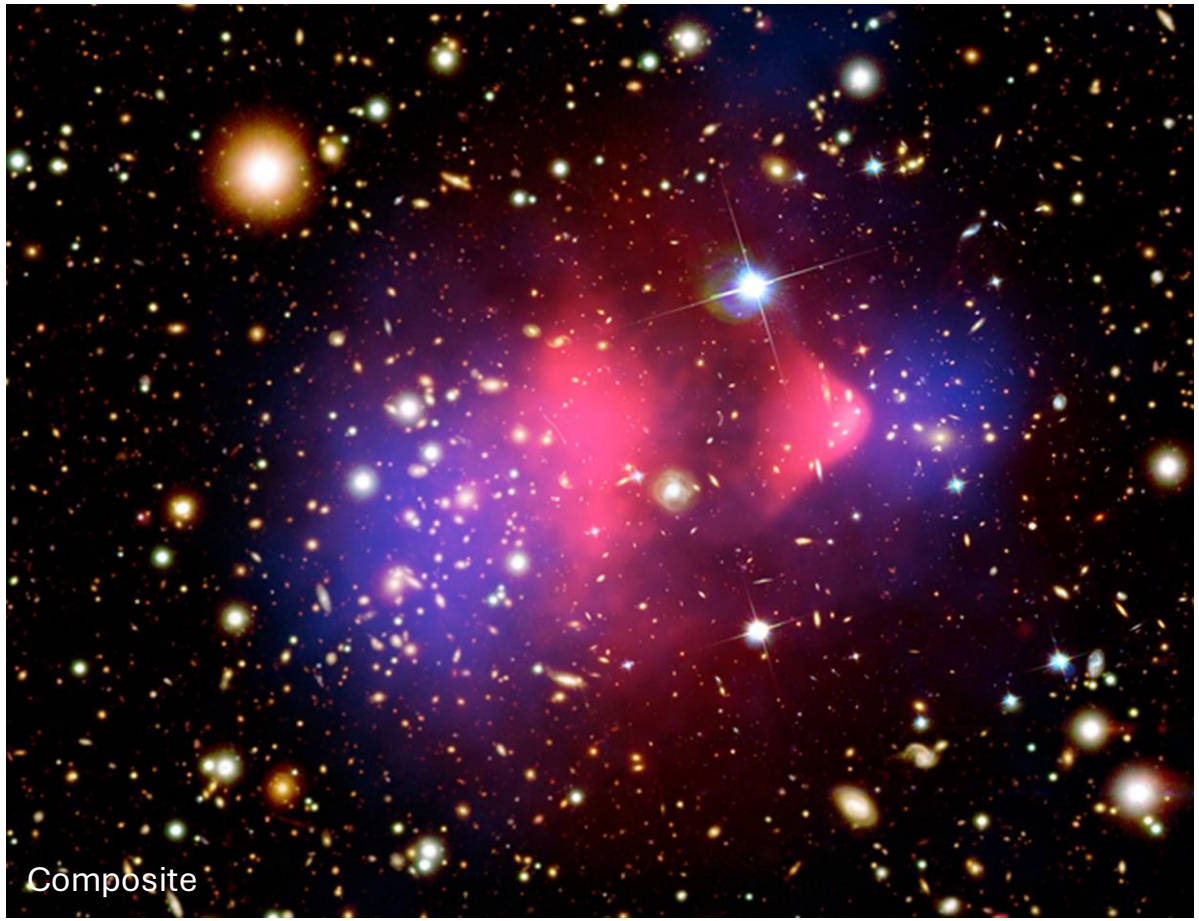
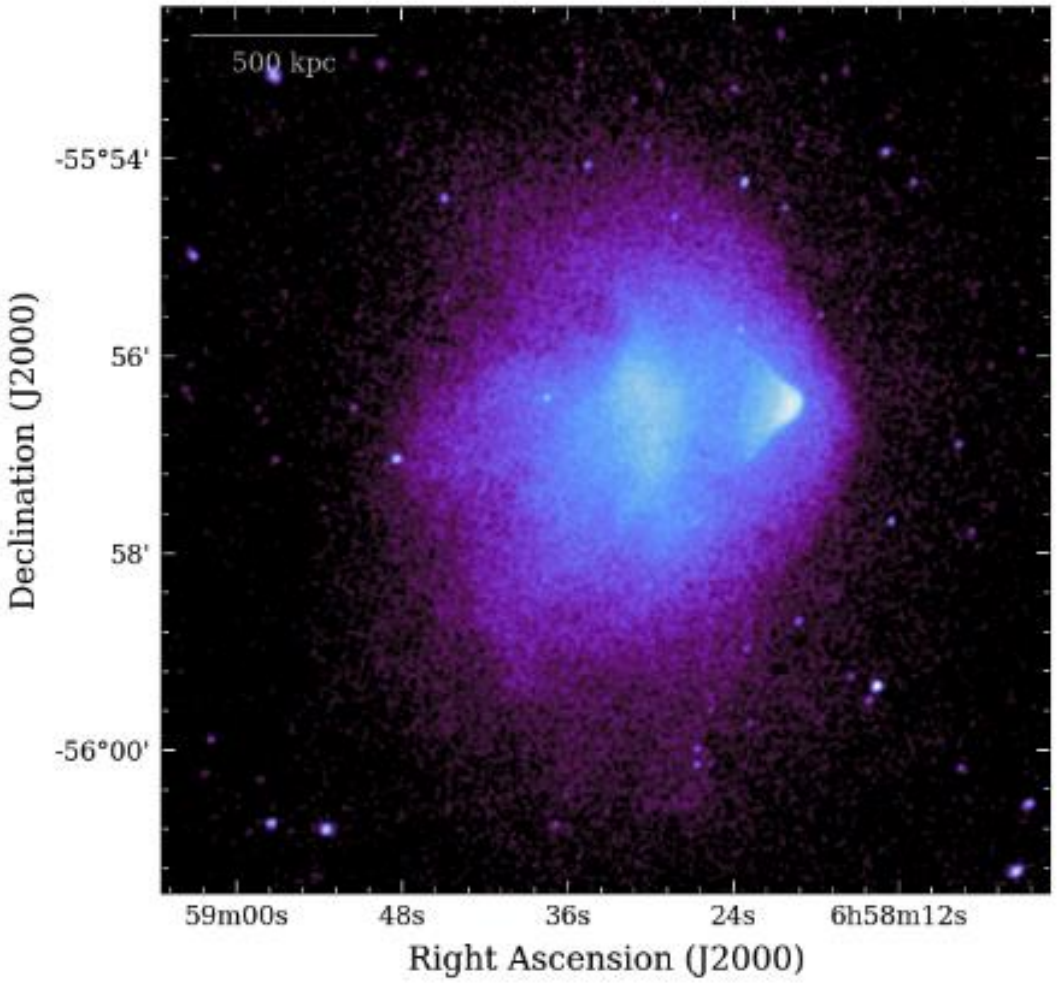


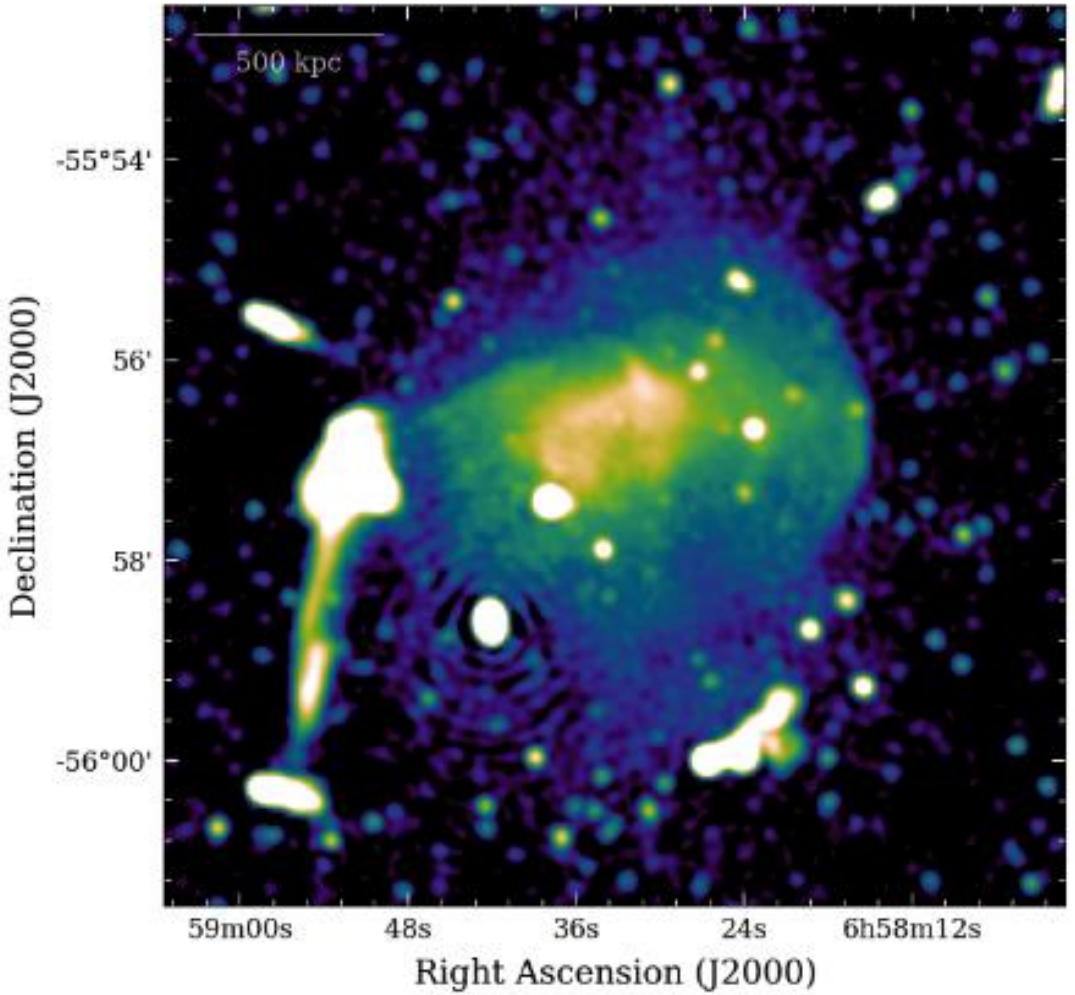
Bullet Cluster -- Head-on merger

Botteon et al. (2023)

0.5 – 2.0 keV Chandra image



MeerKAT image at 1.28 GHz



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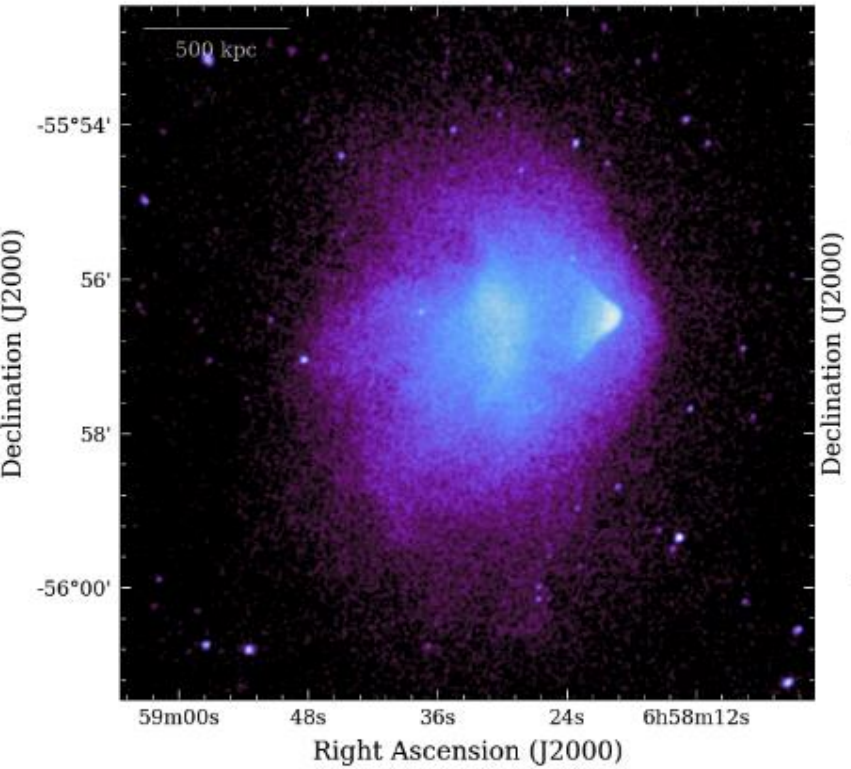

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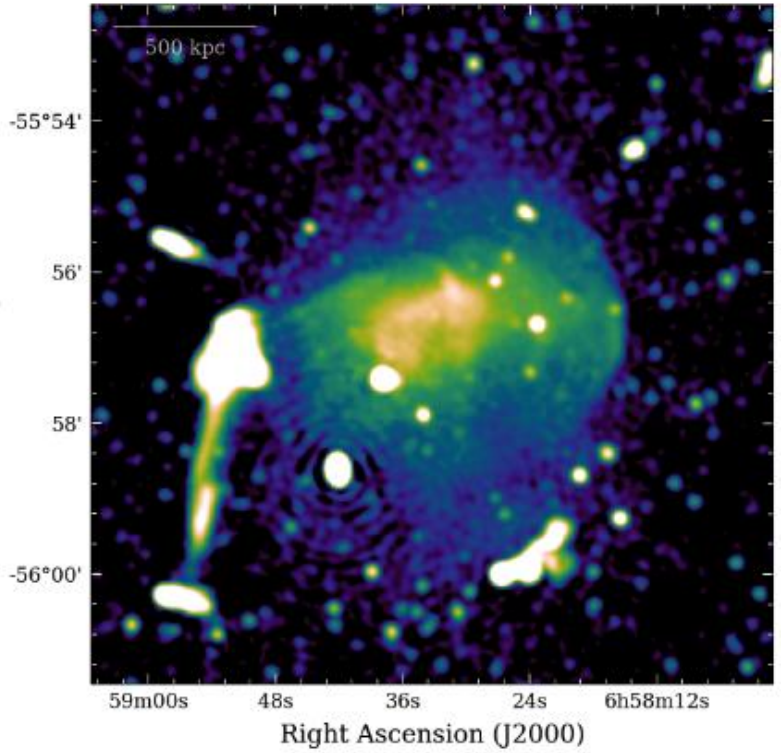


- Relativistic electrons

  --- shocked-heated, AGN, SF

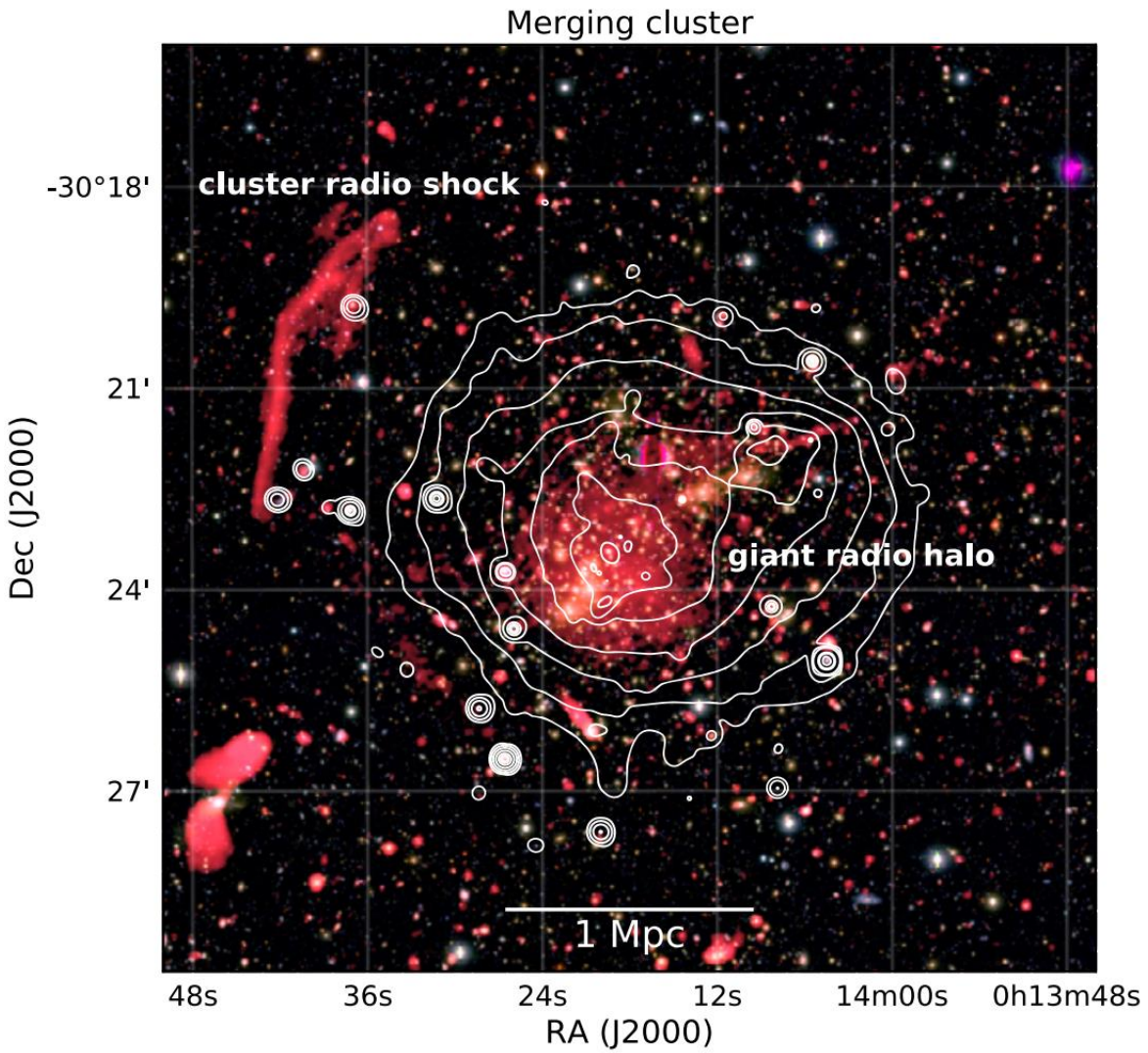
- (Re-)accelerated mechanism

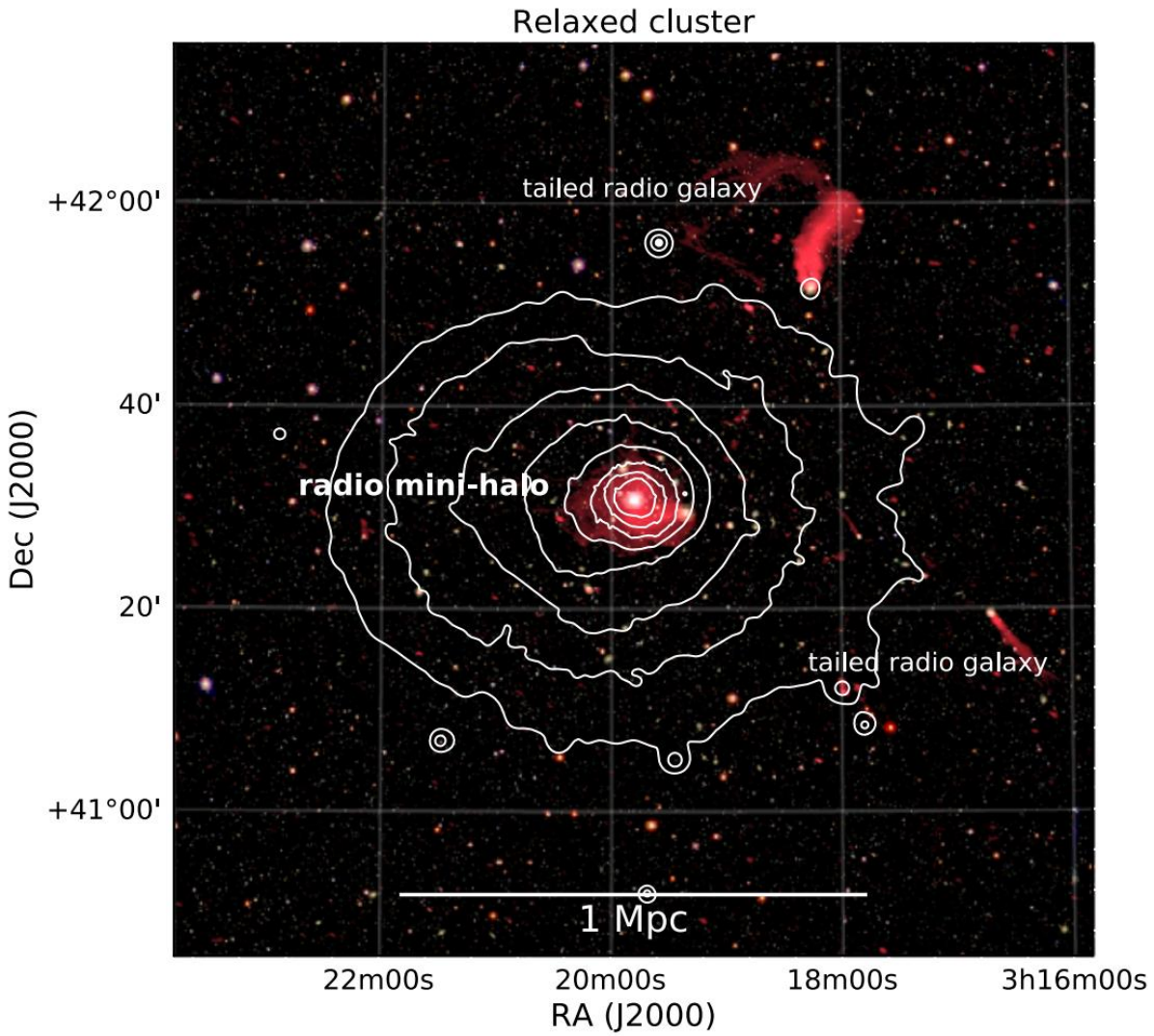
  --- shock, turbulence

- Magnetic field

Energy loss time scale: $\sim 10^7$ yr at 1 GHz, $\sim 10^8$ yr at 0.1 GHz

Radio halo, radio relic, and radio mini-halo





Contours represent X-ray morphology

Taken form van Weeren et al. (2019)

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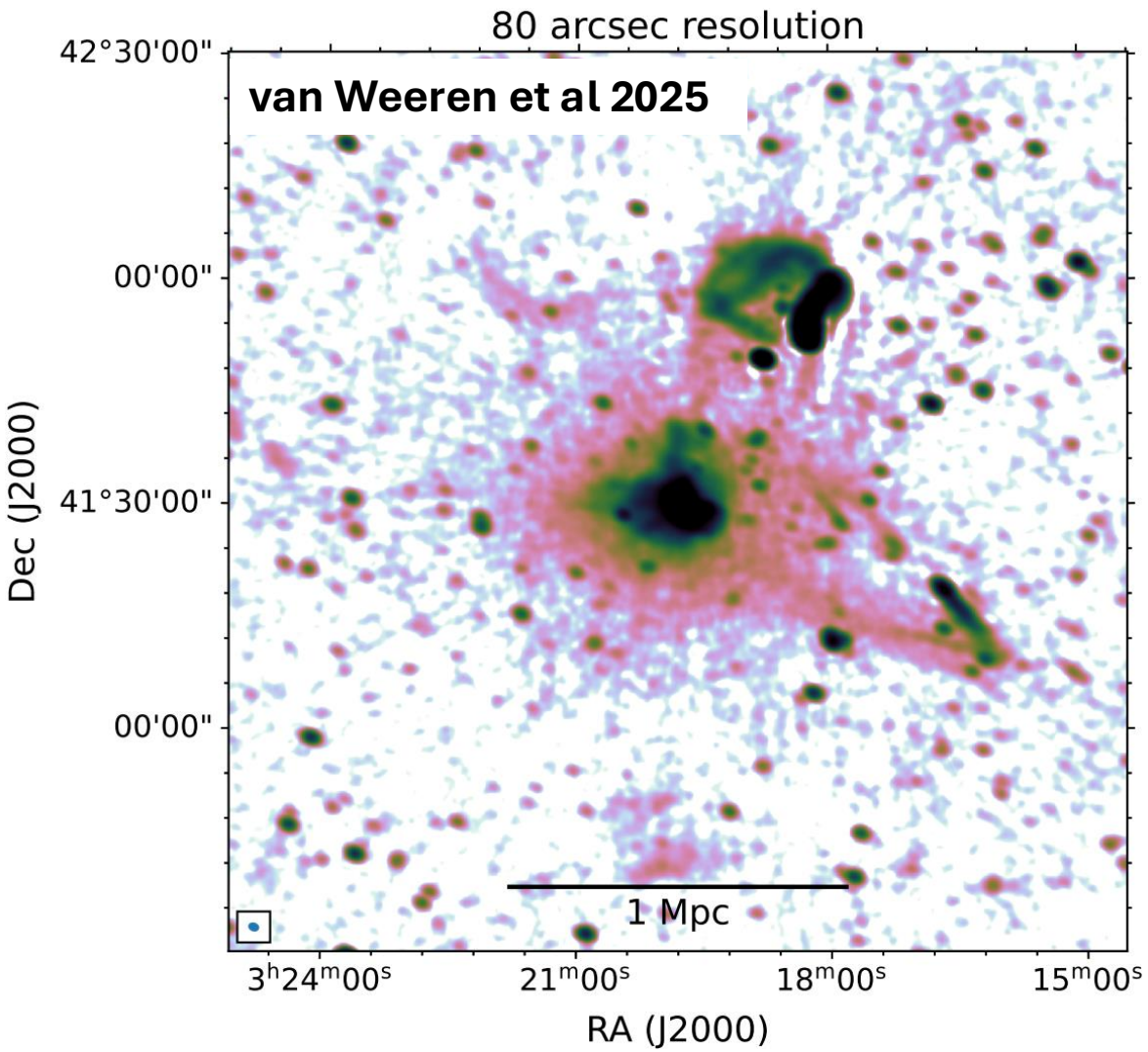

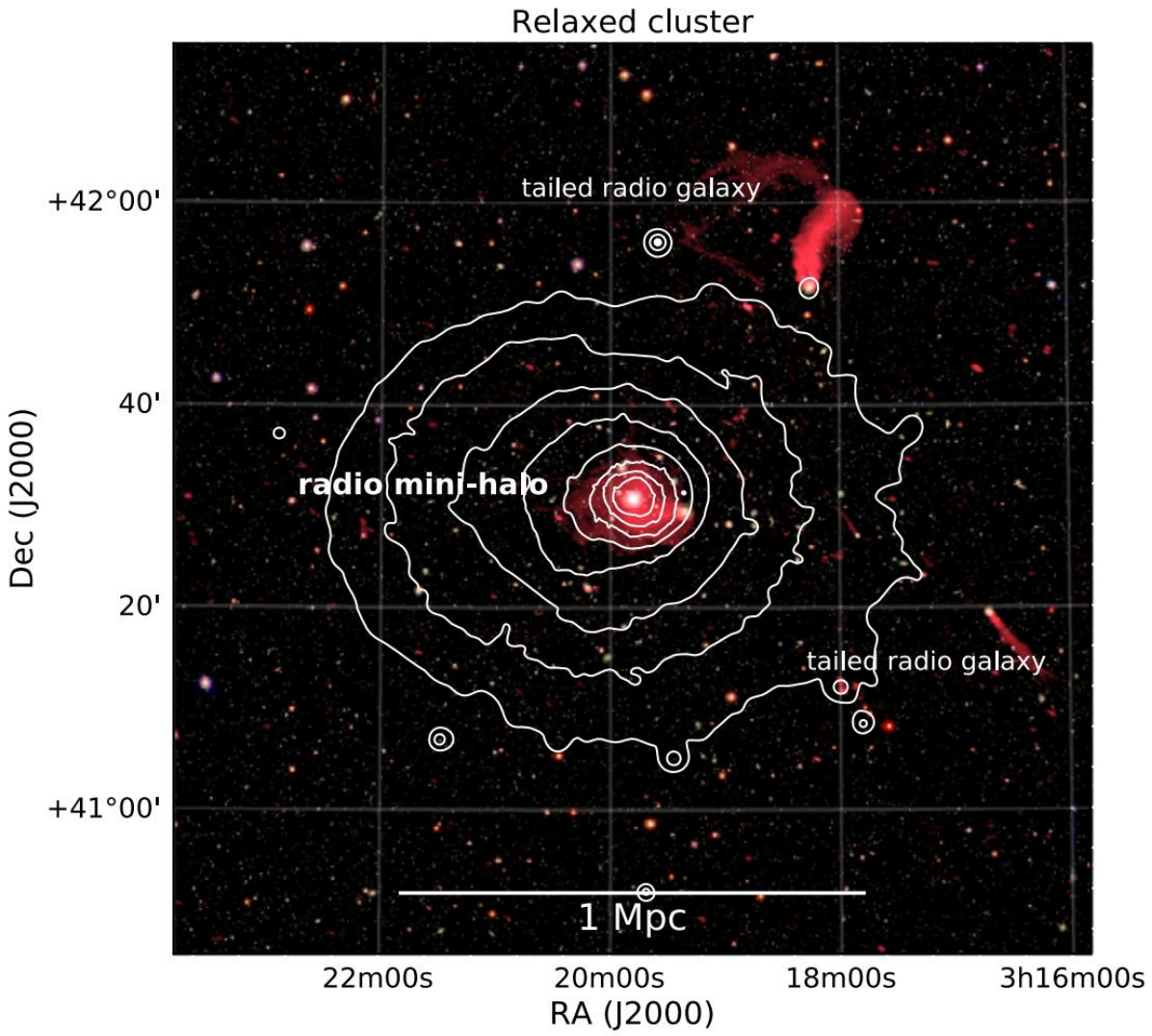

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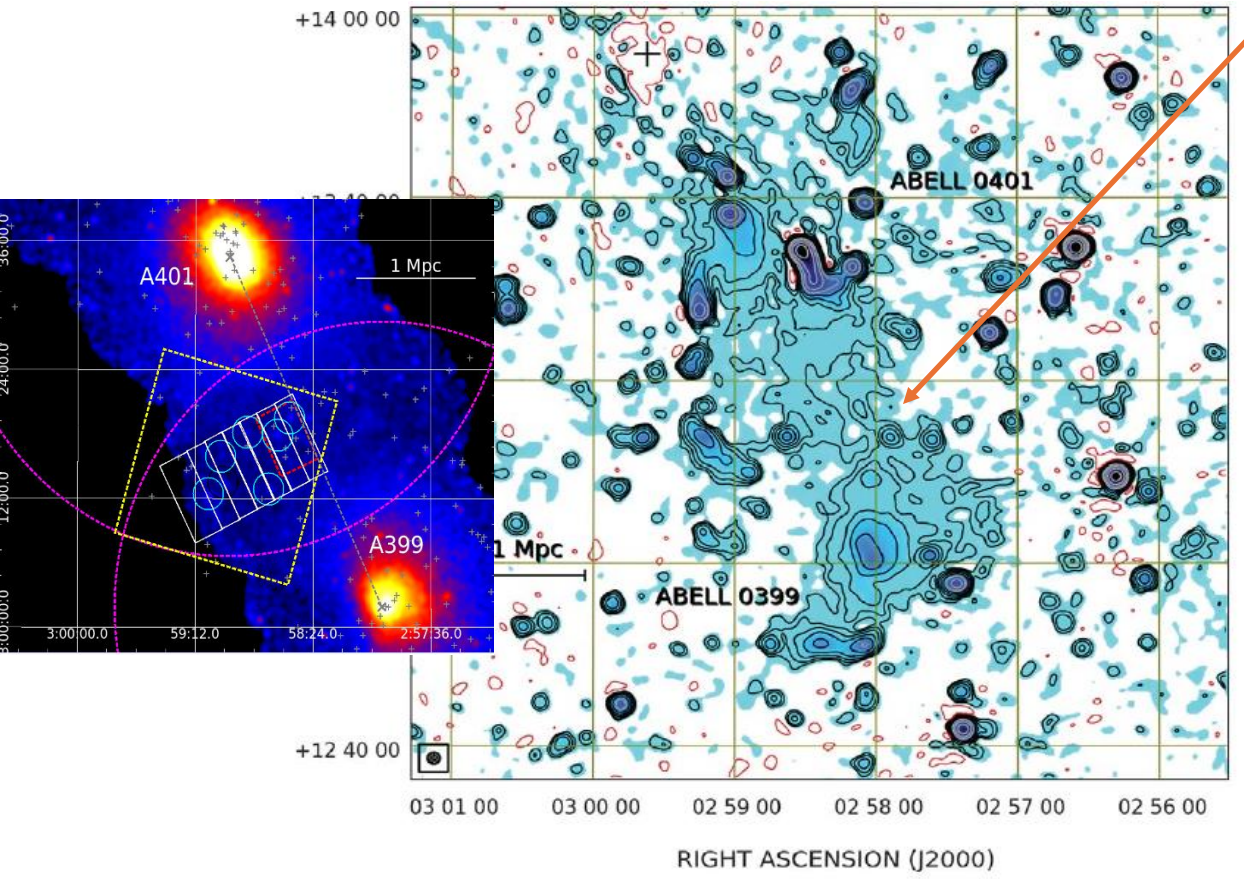
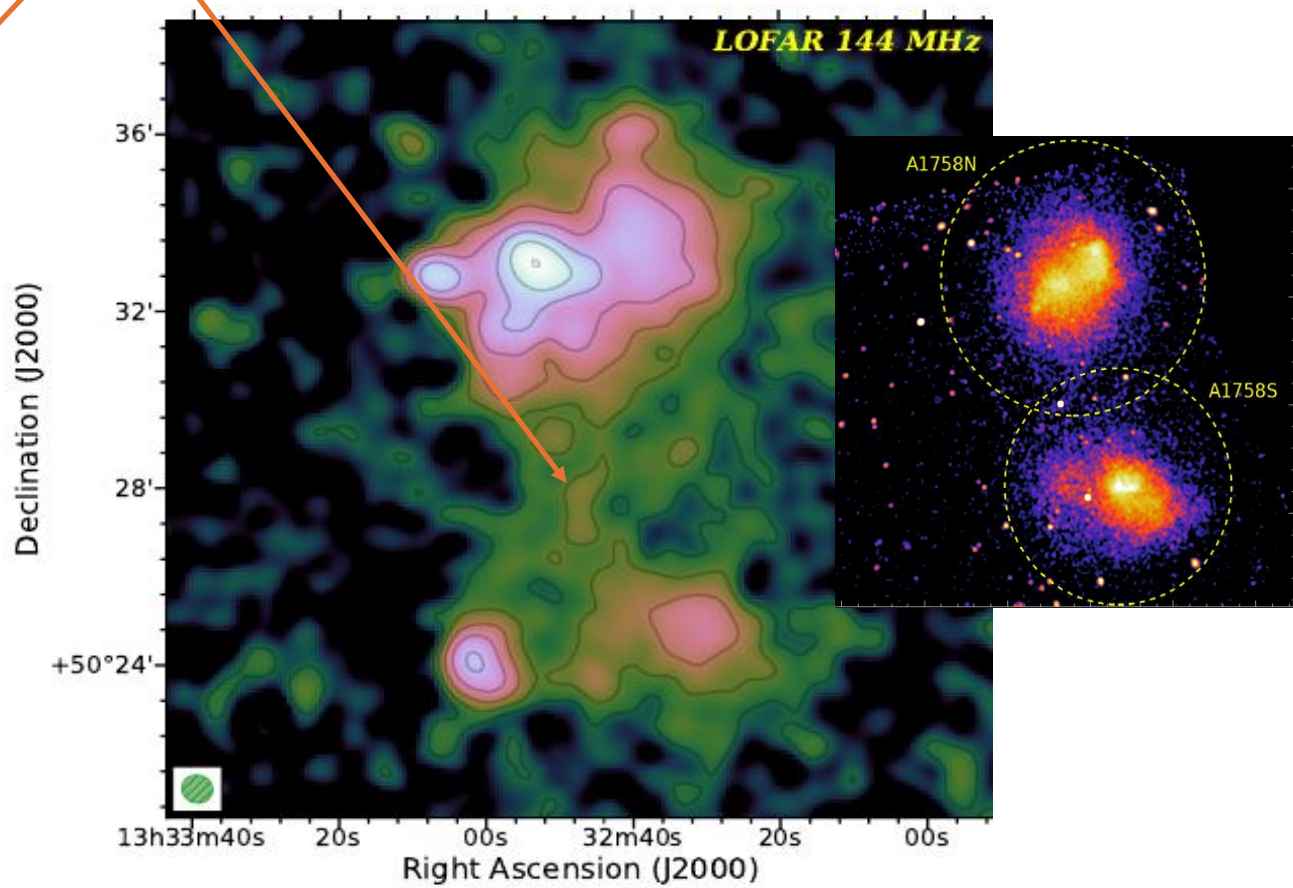
Radio Bridge connecting pre-merging galaxy clusters

A399-A401
Govoni+19, Science

Radio bridge: above 3 σ

A1758N-S
Botteon+ 20





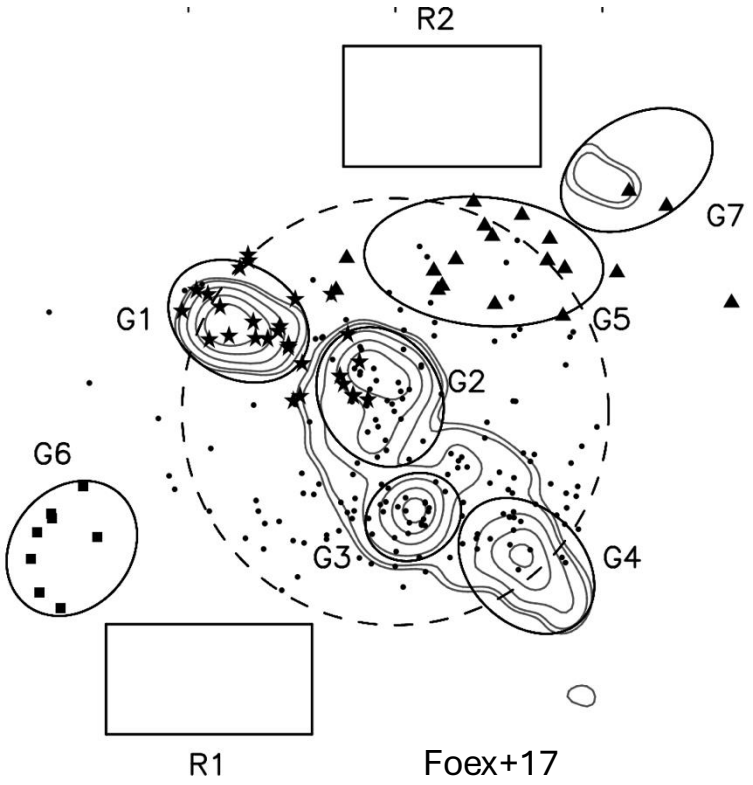
- A population of relativistic electrons exist at the bridge region + re-accelerated by shocks or turbulence.

Pre-merger cluster pair A3016 - A3017 (z = 0.2195)

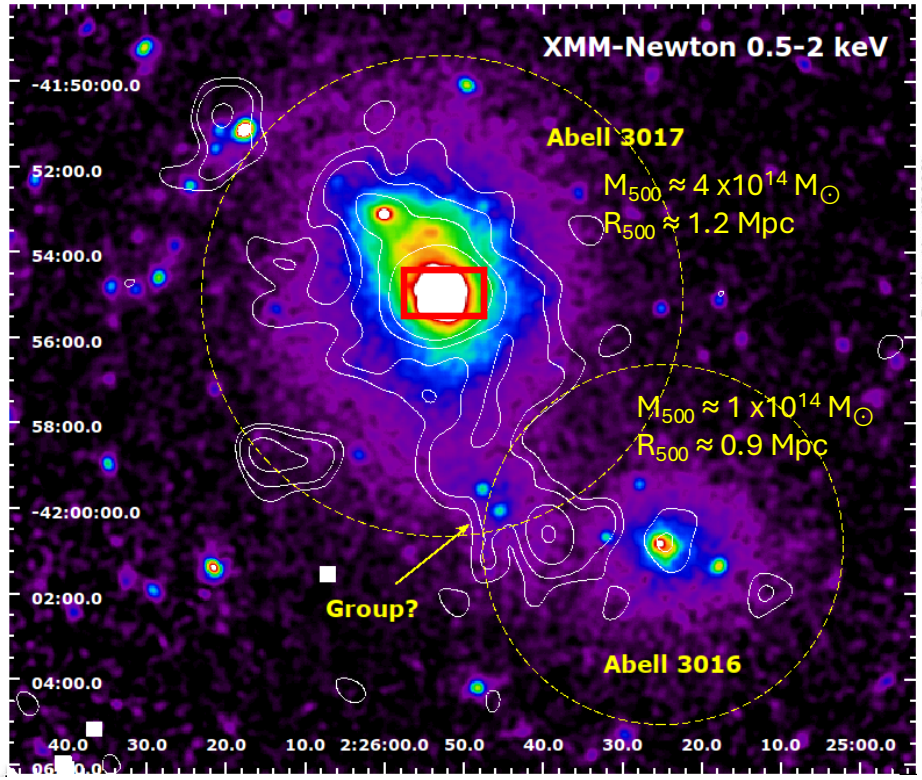
Optical: Four galaxy concentrations form a ~4 Mpc filament extending SW–NE.
A3016 and the group are likely bound to A3017 and lie nearly in the plane of the sky (Foex+17).

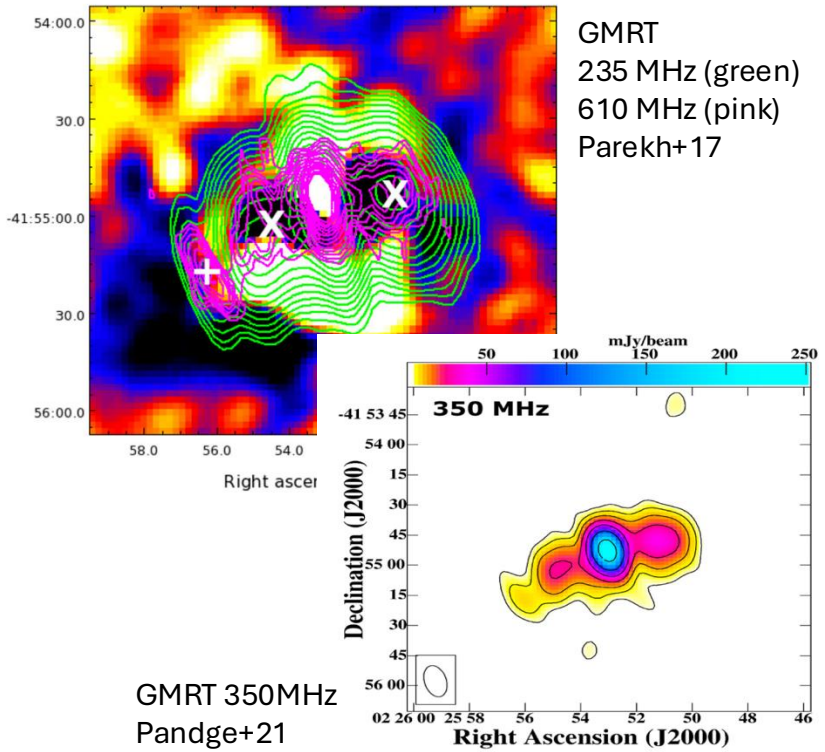
X-ray: The X-ray bridge between A3016 and A3017 contains hot gas primary from an embedded group, likely shock-heated due to pre-merger interaction (Chon+19).

Radio: A3017 hosts a central AGN with lobes aligned with X-ray cavities, a radio phoenix ~150 kpc from the center ($\alpha \leq -1.8$) (Parekh+17, Pandge21, knowles22).



Foex+17



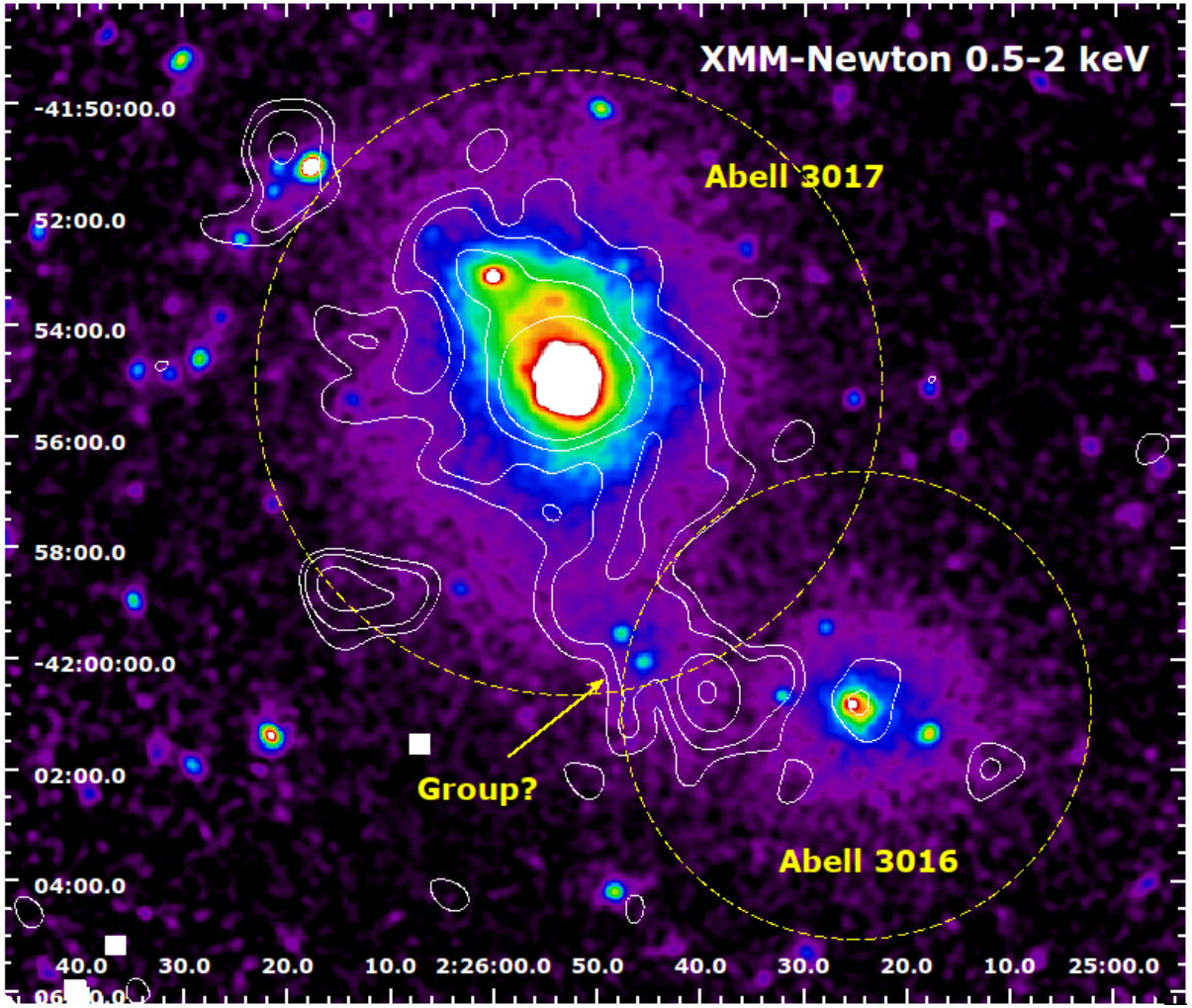


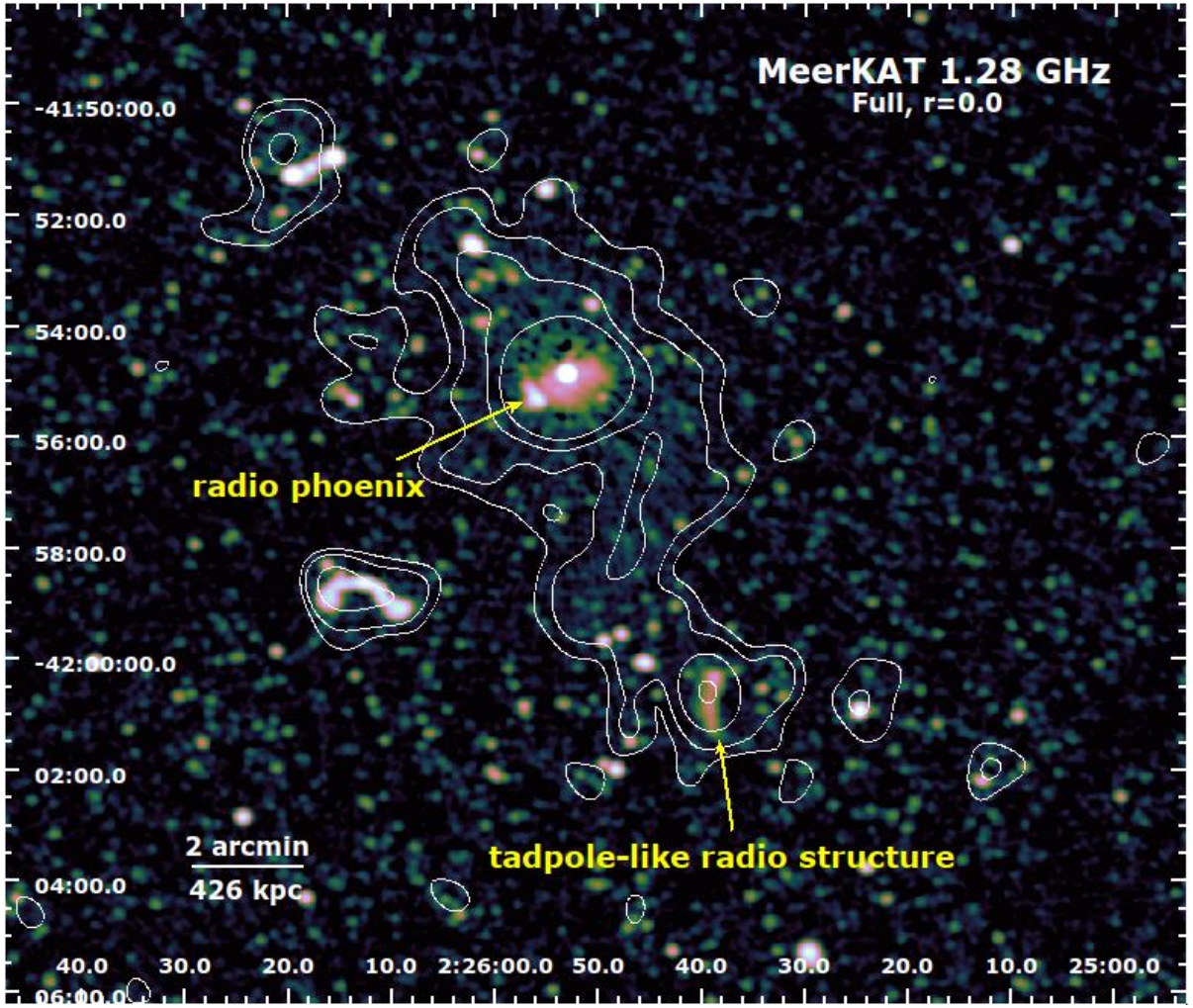
GMRT
235 MHz (green)
610 MHz (pink)
Parekh+17

GMRT 350MHz
Pandge+21

Radio image of A3016 - A3017

Hu et al. (2025)





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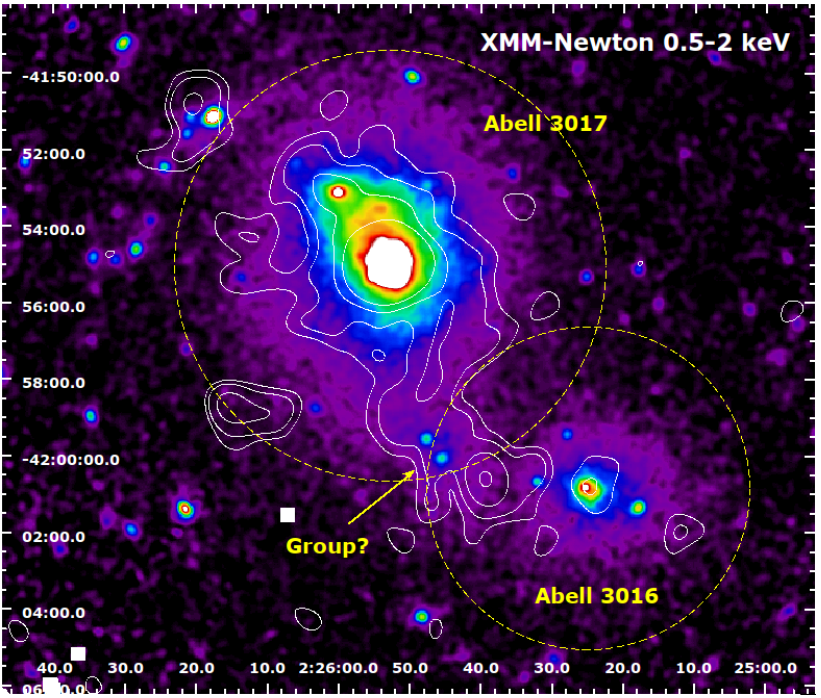

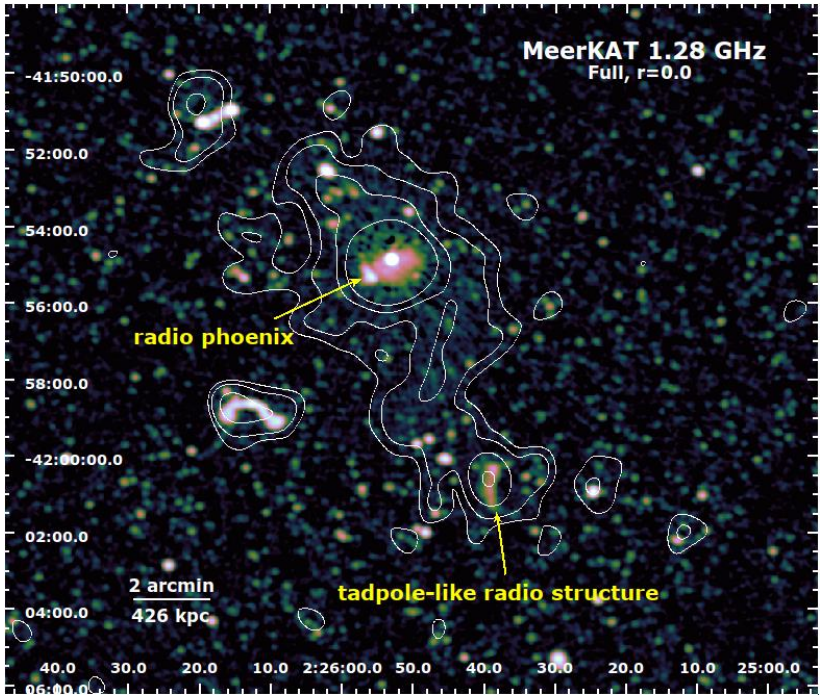

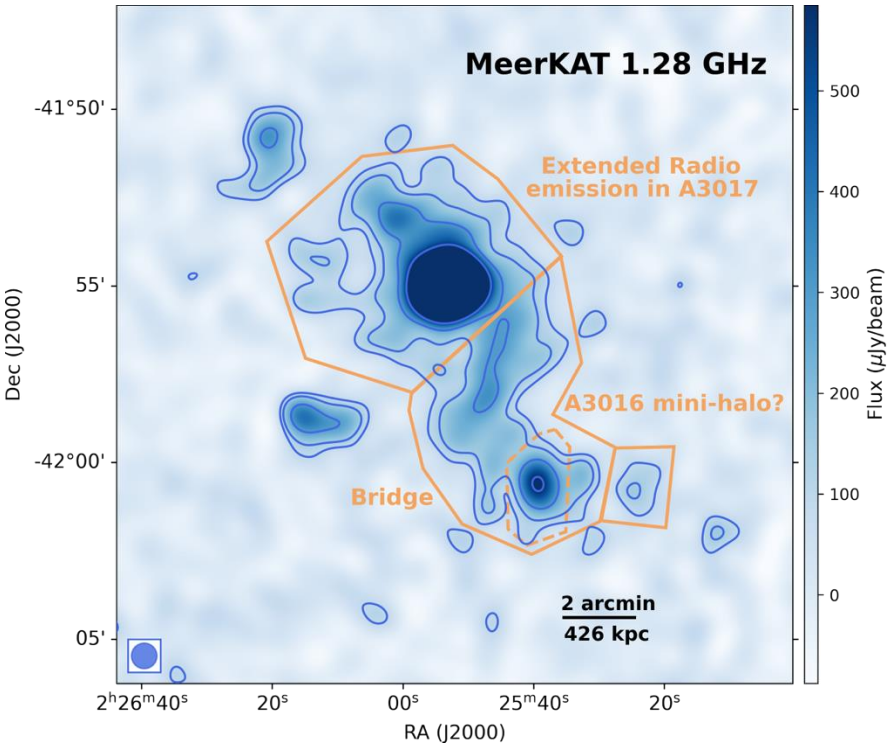

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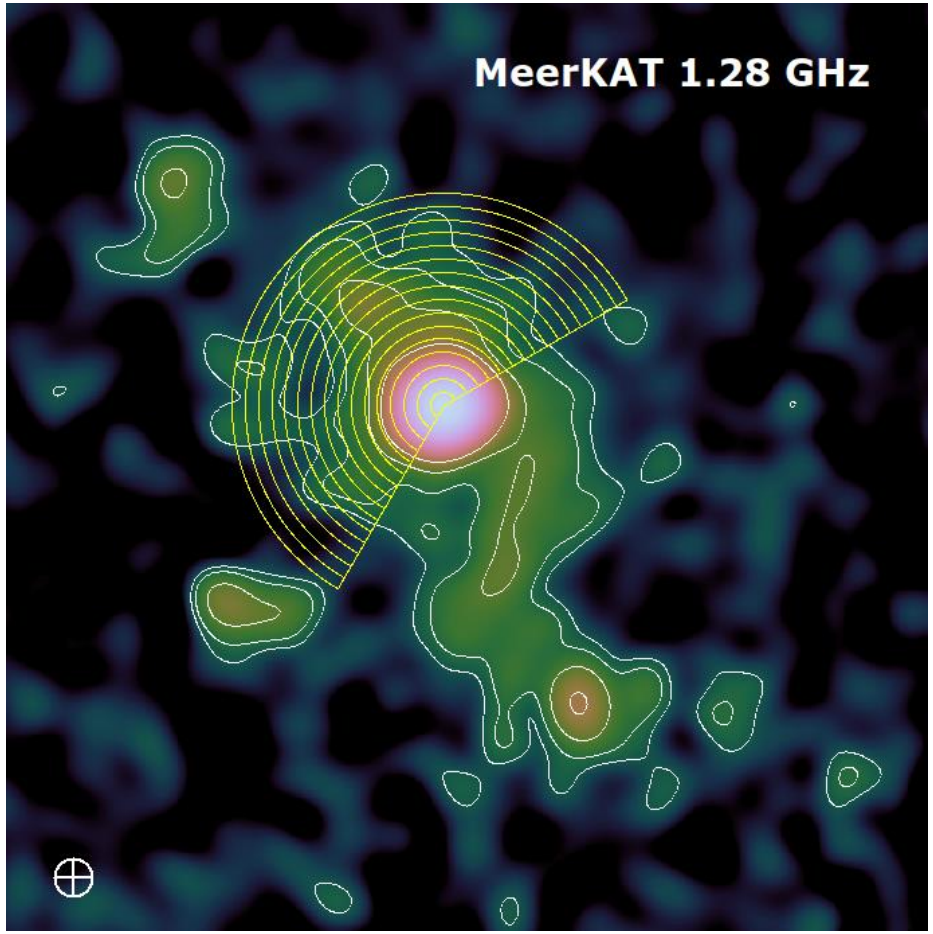
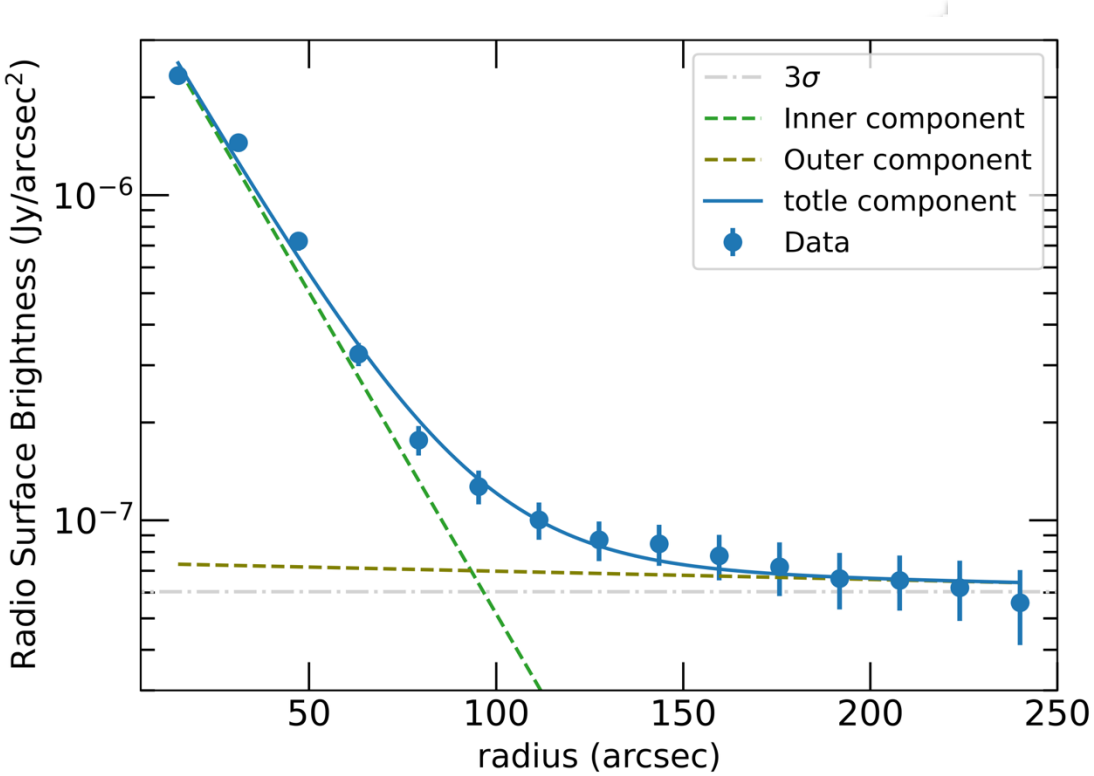


$$I_R(r) = I_{0,\mathrm{inner}} e^{-r/r_{e,\mathrm{inner}}} + I_{0,\mathrm{outer}} e^{-r/r_{e,\mathrm{outer}}}$$



- Fitted with a double exponential model:
  Inner component: $r_{e,\mathrm{inner}} = 78 \pm 4$ kpc
  Outer component: faint, extended, flatter profile
- Indicates coexistence of mini-halo and outer radio halo.

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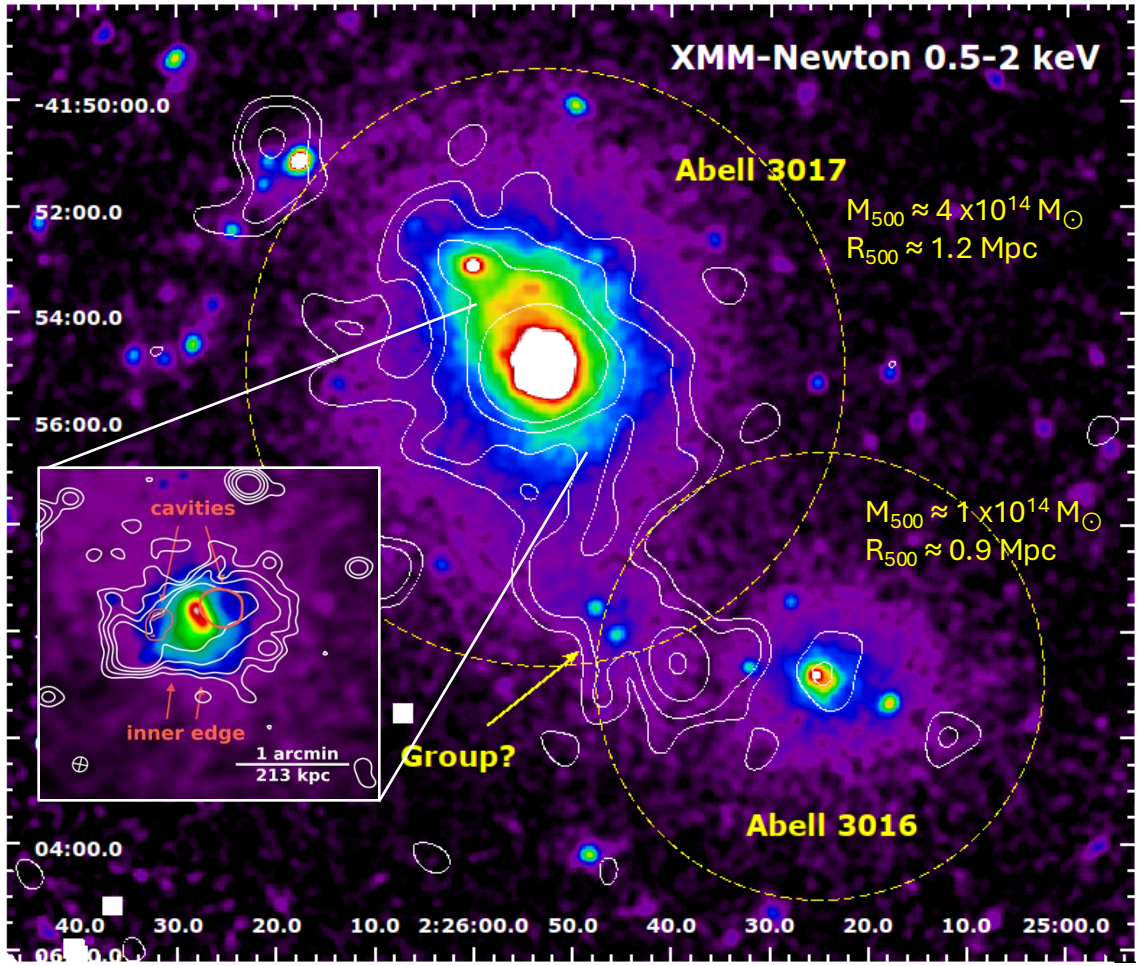

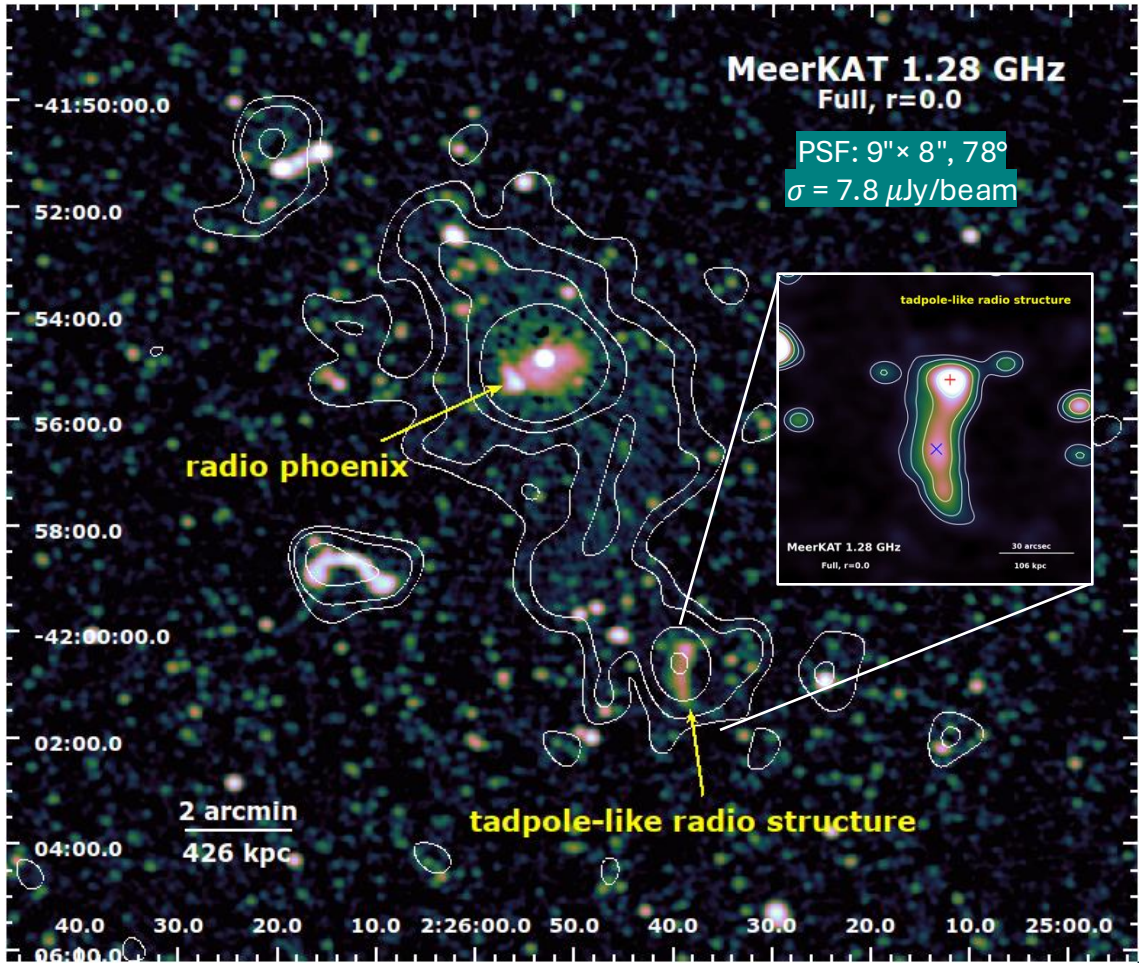

Thanks for Your Attention!