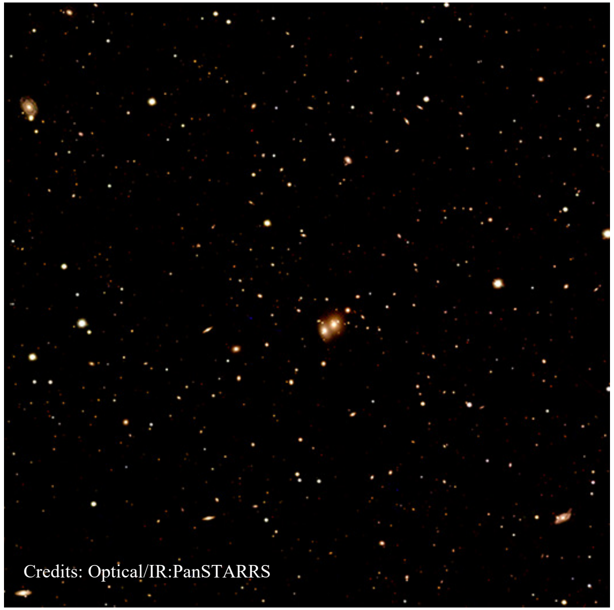
The Merger Dynamics of Galaxy Cluster Abell 1775 and The Interplay Between the ICM and Tailed Radio Galaxies

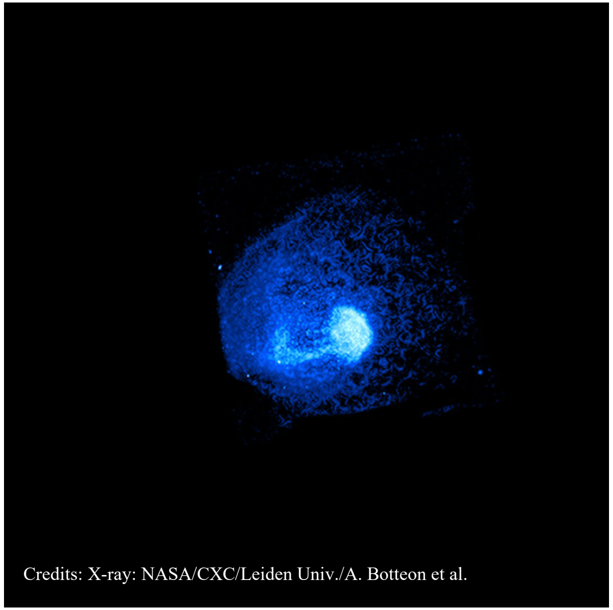
Dan Hu

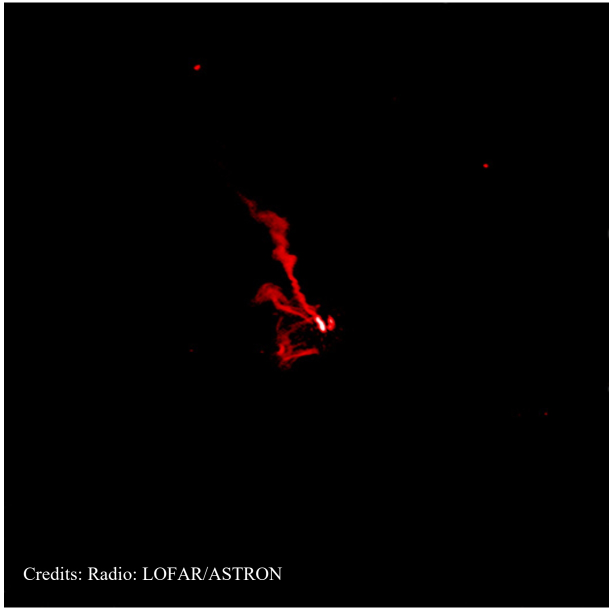
High-Energy Astrophysics Group @ Masaryk University

hudan.bazhaoyu@gmail.com

Abell 1775 (z = 0.0717)







Optical/IR data from the Pan-STARRS telescope in Hawaii (blue, yellow, and white)

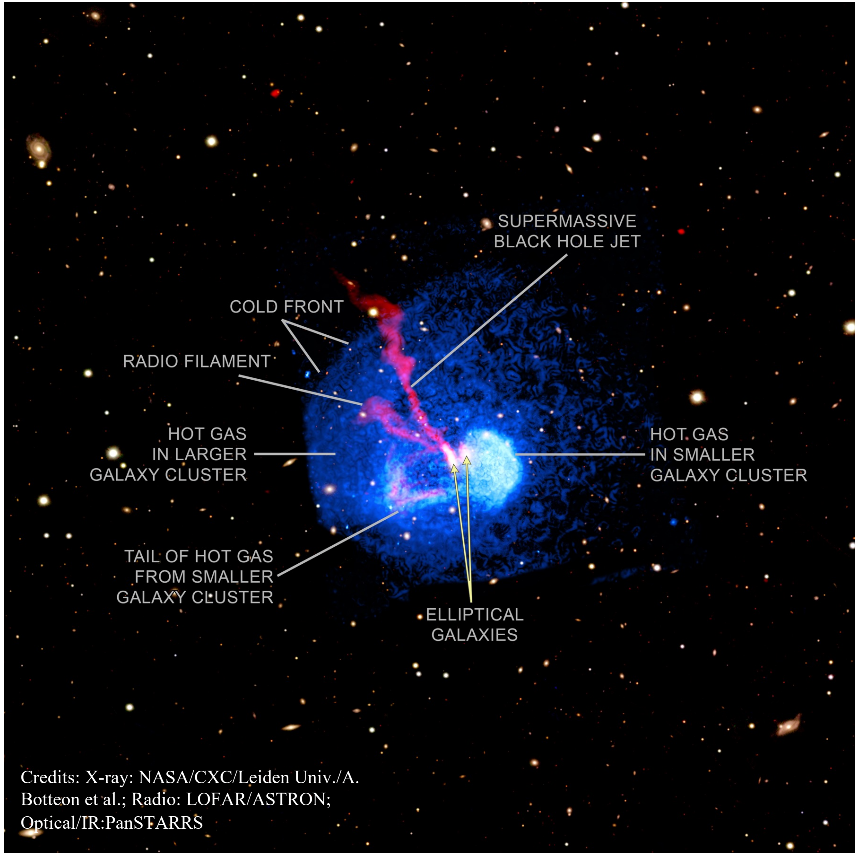
X-rays from Chandra (blue)

Radio data from the LOw Frequency ARray (LOFAR; red)

Abell 1775 (z = 0.0717)

Onging merger?

Properties of radio tail of head-tail radio galaxy?

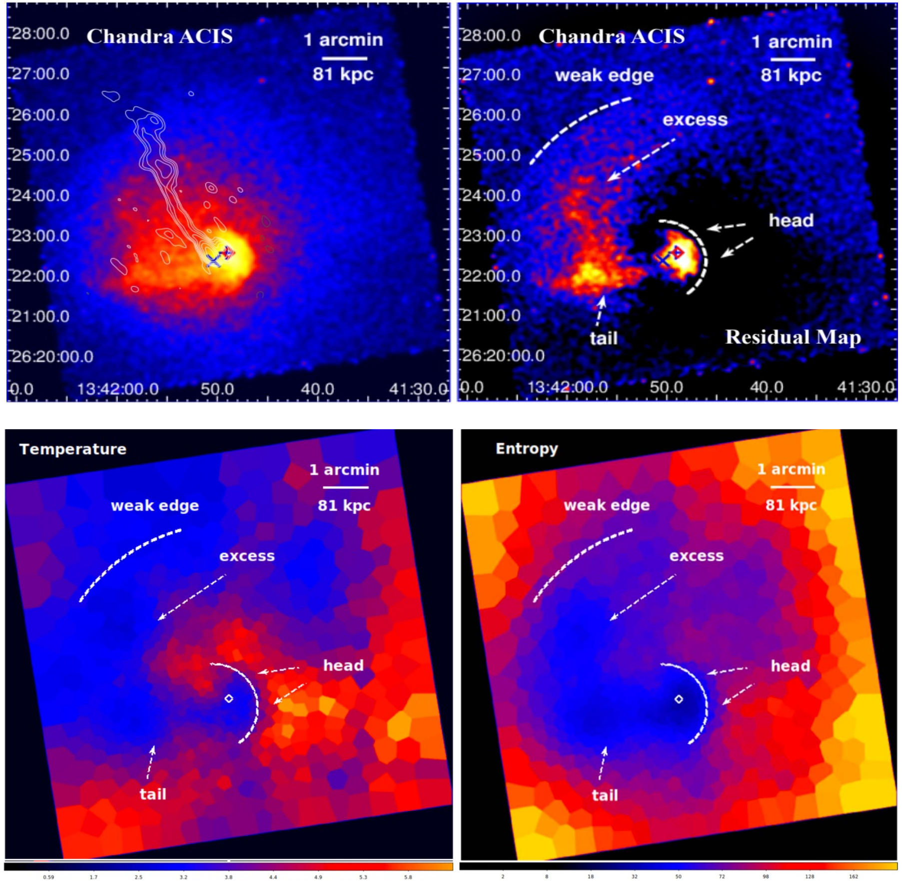


X-rays from Chandra (blue), optical data from the Pan-STARRS telescope in Hawaii (blue, yellow, and white), & radio data from the LOw Frequency ARray (LOFAR; red).

Origin of other radio substructures?

Interplay between intra-cluster medium (ICM) and radio galaxies?

1. Merger Scenario of Abell 1775



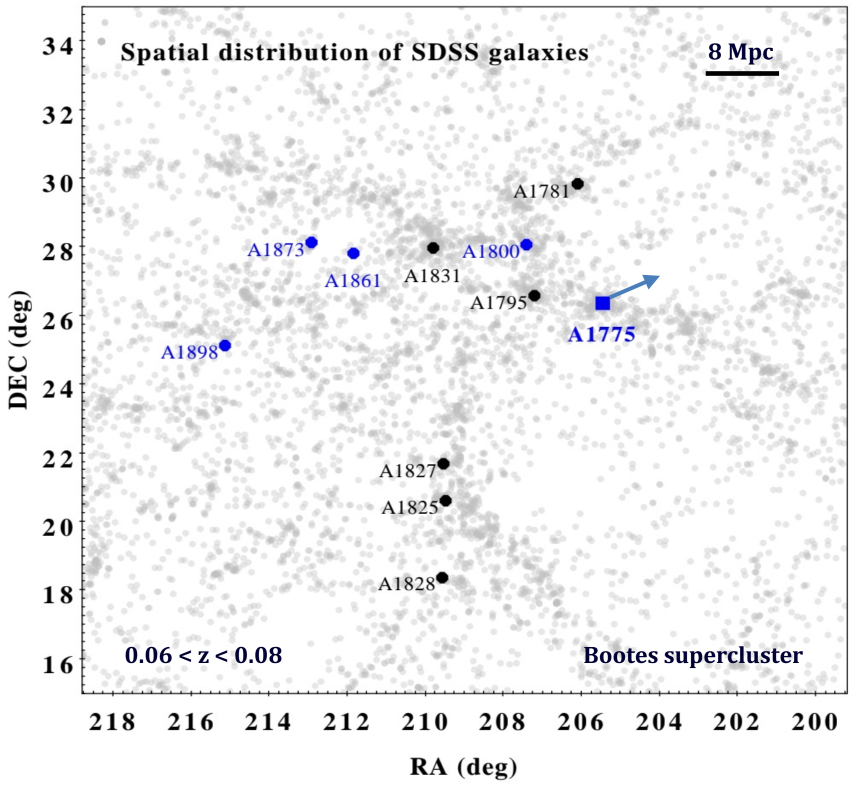
X-ray discontinuities in the ICM and gas motions

- Arc-shaped edge (i.e., head):
  - ~ 48 kpc west of the X-ray peak
- Cold gas tail:
  - Extends eastward to ~163 kpc
- Spiral-like X-ray excess:
  - Within ~ 81- 324 kpc northeast of the core
  - Connects with the end of the tail
- Head, weak edge → cold front:

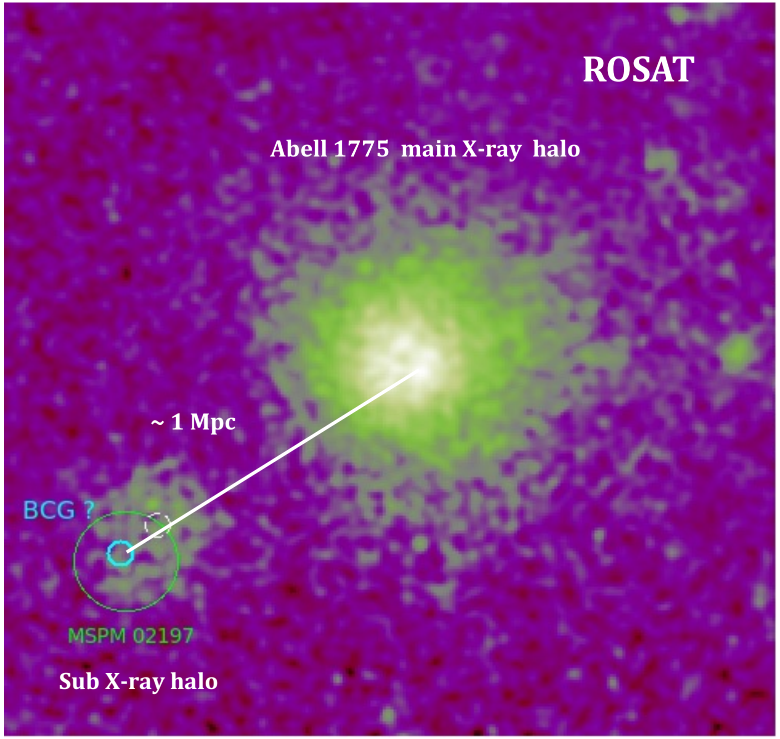
Spiral pattern → gas sloshing process → merger-induced?

1. Merger Scenario of Abell 1775

- **As an infalling subcluster?**



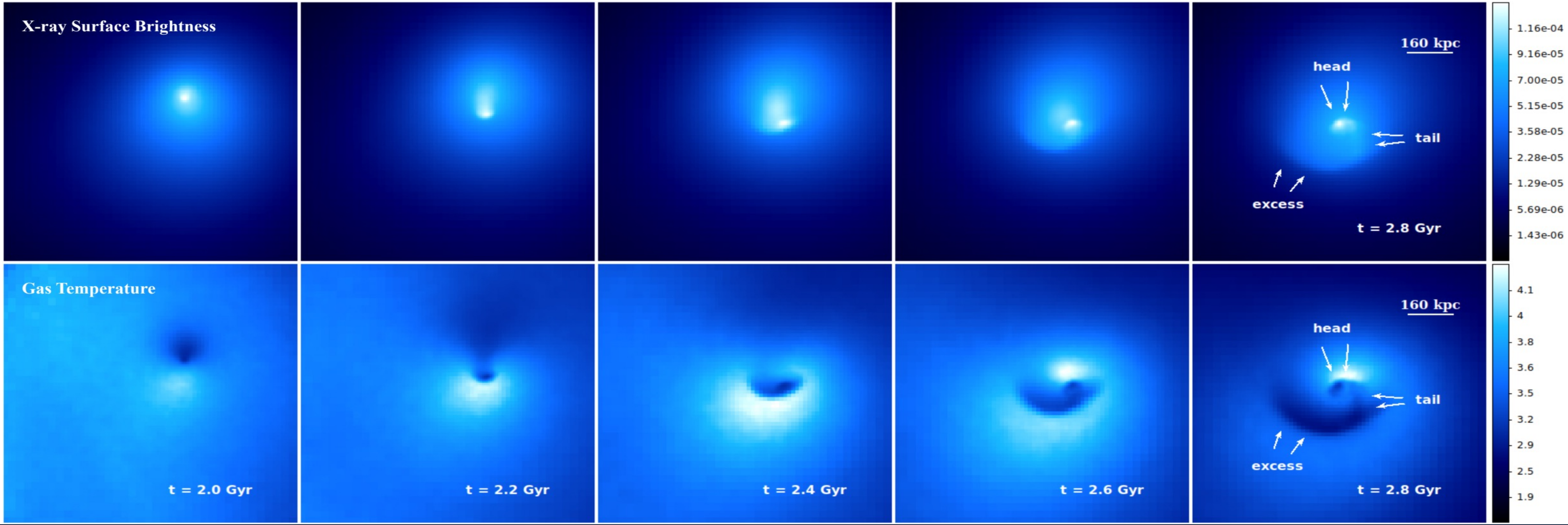
- **As a primary cluster?**



1. Merger Scenario of Abell 1775

➢ As a primary cluster? ← SPH simulations (GADGET-3)

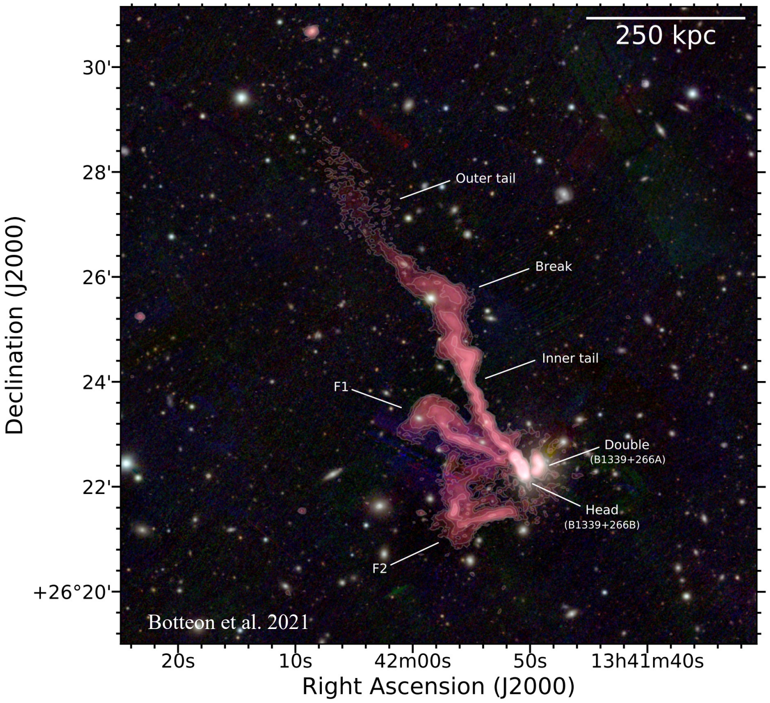
- ✓ Observed X-ray morphology, gas temperature, DM mass distribution can be reproduced → gas sloshing;
- ✓ NAT radio galaxy is likely to be a single galaxy falling into the cluster center, rather than a centrally dominated galaxy of sub-cluster



2. *Radio emission in Abell 1775*

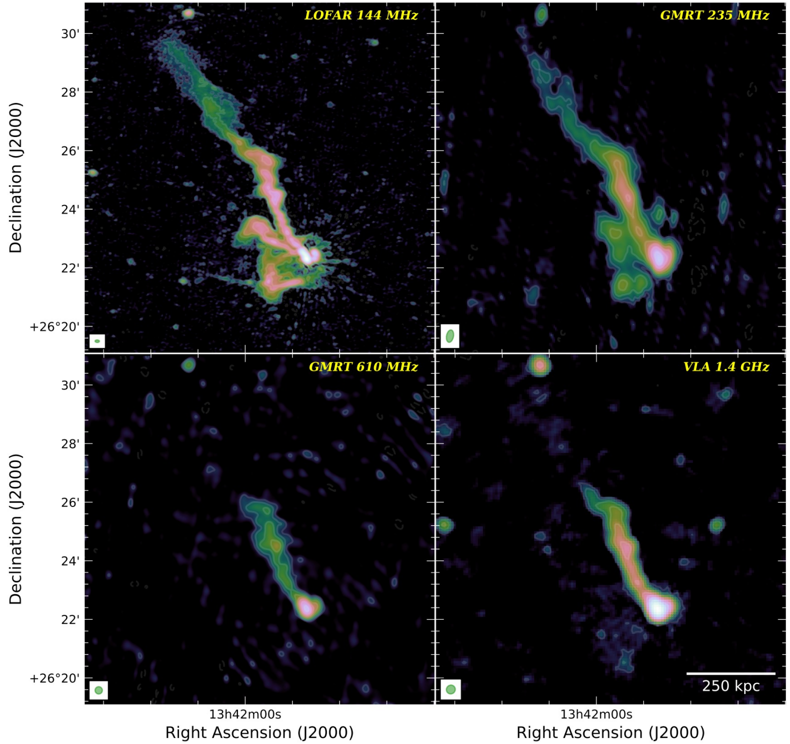
Botteon et al. 2021; A&A 649, A37

- **Radio tail in NAT radio galaxy:**
  - Bright head ($S_{144\ MHz} \approx 1.2$ Jy)
  - Inner 400 kpc-tail ($S_{144\ MHz} \approx 1.3$ Jy)
  - Outer 400 kpc-tail ($S_{144\ MHz} \approx 0.3$ Jy)
- **Diffuse radio emission:**
  - Filamentary emission F1 ($S_{144\ MHz} \approx 0.6$ Jy)
  - Filamentary emission F2 ($S_{144\ MHz} \approx 1.5$ Jy)
  - Central diffuse emission ($S_{144\ MHz} \approx 0.2$ Jy)



LOFAR 144 MHz high-resolution (5'' × 3'') data. Radio contours start from 3σ, where σ = 148 μJy beam⁻¹, and they are spaced by a factor of 2. Botton et al. 2021

2.1 Head-tailed radio galaxy



LOFAR 144 MHz (9'' × 5''), GMRT 235 MHz (26'' × 14''), GMRT 610 MHz (15'' × 15''), and VLA 1.4 GHz (19'' × 18''). Botton et al. 2021

- **Outer tail emission can only be observed at low-frequency**

  More diffuse and wider, constant surface brightness

  → oldest population of electrons has been disturbed and reenergized

- **Tail breaks and change direction at the position of cold front**

  Dynamics of the ICM impacts the morphology and spectral properties of tailed cluster radio galaxy

  → interplay between the head-tail radio galaxy and the thermal gas

- **Integrated flux density**

  Inner tail:

  $\alpha_{144\,MHz}^{610\,MHz} = 1.06 \pm 0.02,$

  $\alpha_{610\,MHz}^{1.4\,GHz} = 1.69 \pm 0.14$

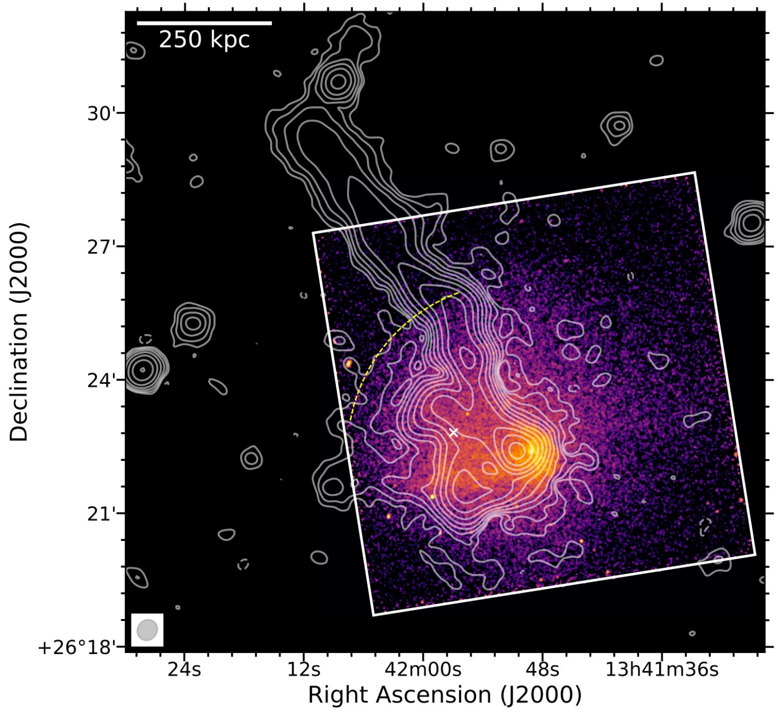
  Outer tail:

  $\alpha_{144\,MHz}^{235\,MHz} = 1.23 \pm 0.52$

- **Spectral index map:**

  α = 0.6-0.7 in the core, spectral steepens along the tail

2.1 Head-tailed radio galaxy



LOFAR 144 MHz low-resolution (29'' × 26'') contours overlaid on the Chandra image. Radio contours start from 3σ, where σ = 255 μJy beam^{-1}, and they are spaced by a factor of 2. Botton et al. 2021

- **Outer tail emission can only be observed at low-frequency**

  More diffuse and wider, constant surface brightness

  → oldest population of electrons has been disturbed and reenergized

- **Tail breaks and change direction at the position of cold front**

  Dynamics of the ICM impacts the morphology and spectral properties of tailed cluster radio galaxy

  → interplay between the head-tail radio galaxy and the thermal gas

- **Integrated flux density**

  Inner tail:

  $$\alpha_{144\,MHz}^{610\,MHz} = 1.06 \pm 0.02,$$

  $$\alpha_{610\,MHz}^{1.4\,GHz} = 1.69 \pm 0.14$$

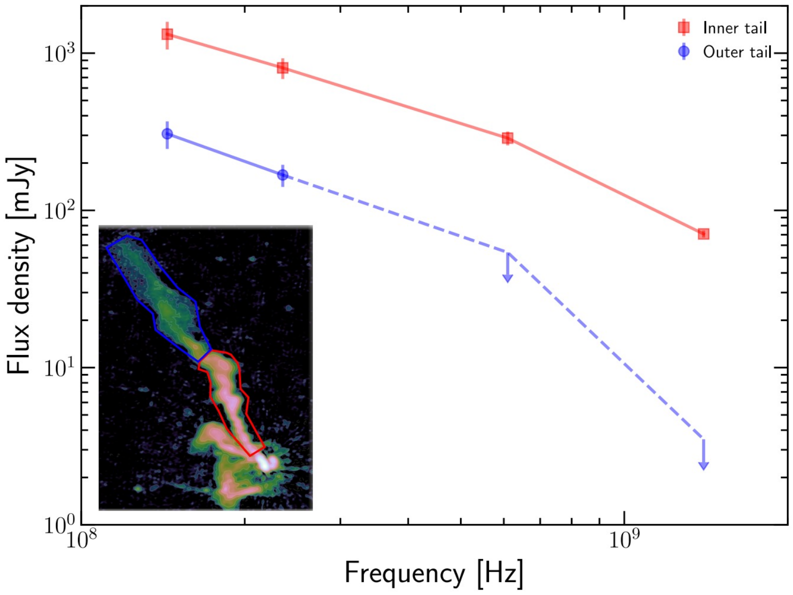
  Outer tail:

  $$\alpha_{144\,MHz}^{235\,MHz} = 1.23 \pm 0.52$$

- **Spectral index map:**

  α = 0.6-0.7 in the core, spectral steepens along the tail

2.1 Head-tailed radio galaxy



Integrated spectra of the "inner" and "outer" regions (shown in the inset panel) of the head-tail radio galaxy. Botton et al. 2021

- **Outer tail emission can only be observed at low-frequency**

  More diffuse and wider, constant surface brightness

  → oldest population of electrons has been disturbed and reenergized

- **Tail breaks and change direction at the position of cold front**

  Dynamics of the ICM impacts the morphology and spectral properties of tailed cluster radio galaxy

  → interplay between the head-tail radio galaxy and the thermal gas

- **Integrated flux density**

  Inner tail:

  $\alpha_{144\,MHz}^{610\,MHz} = 1.06 \pm 0.02,$

  $\alpha_{610\,MHz}^{1.4\,GHz} = 1.69 \pm 0.14$

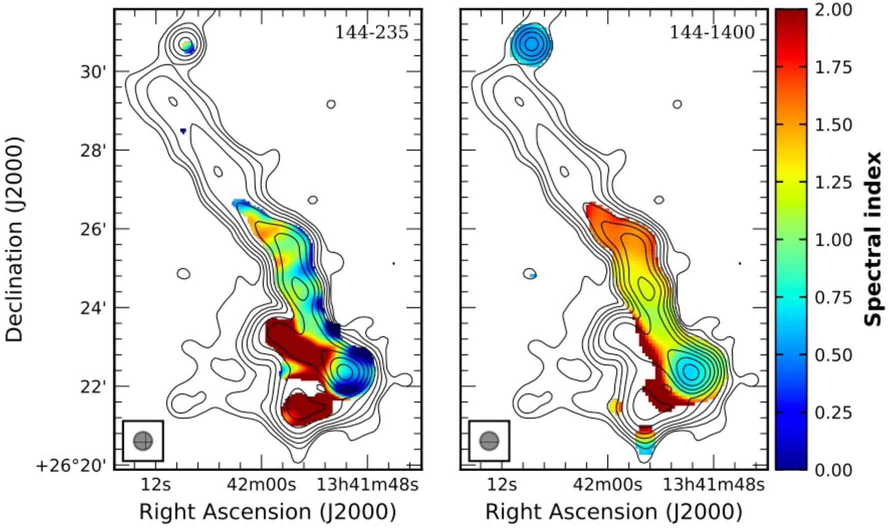
  Outer tail:

  $\alpha_{144\,MHz}^{235\,MHz} = 1.23 \pm 0.52$

- **Spectral index map:**

  α = 0.6-0.7 in the core, spectral steepens along the tail

2.1 Head-tailed radio galaxy



Low (144−235 MHz) and high (144−1400 MHz) frequency spectral index maps at a resolution of 28’’ × 28’’ with LOFAR contours at the same resolution overlaid. Botton et al. 2021

- **Outer tail emission can only be observed at low-frequency**

  More diffuse and wider, constant surface brightness

  → oldest population of electrons has been disturbed and reenergized

- **Tail breaks and change direction at the position of cold front**

  Dynamics of the ICM impacts the morphology and spectral properties of tailed cluster radio galaxy

  → interplay between the head-tail radio galaxy and the thermal gas

- **Integrated flux density**

  Inner tail:

  $$\alpha_{144\,MHz}^{610\,MHz} = 1.06 \pm 0.02,$$

  $$\alpha_{610\,MHz}^{1.4\,GHz} = 1.69 \pm 0.14$$

  Outer tail:

  $$\alpha_{144\,MHz}^{235\,MHz} = 1.23 \pm 0.52$$

- **Spectral index map:**

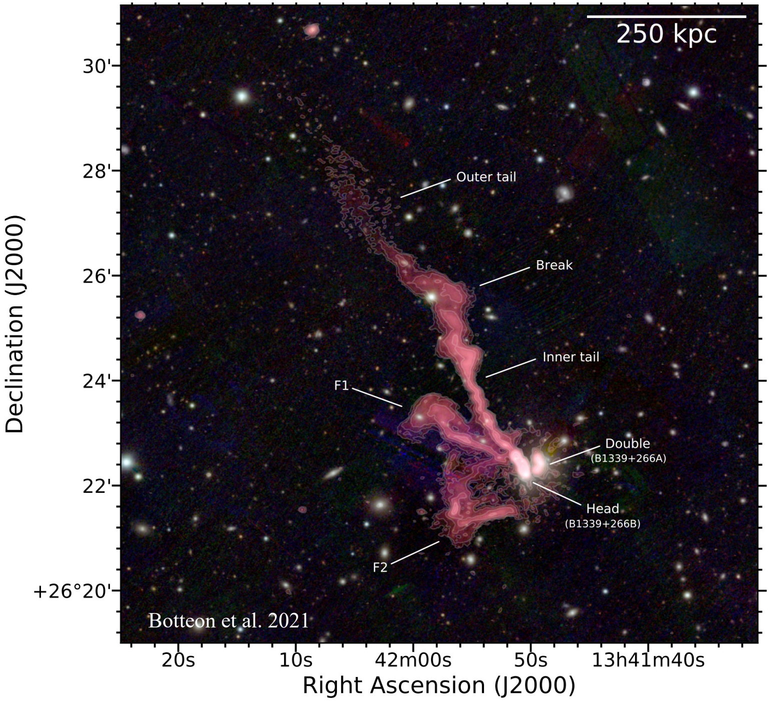
  α = 0.6-0.7 in the core, spectral steepens along the tail

2.2. Diffuse radio emission

- **Filamentary radio emission:**
  - Ultra steep spectrum, $\alpha = 2.4$
  - Lack of clear optical counterpart
  - Corresponding to compression region in ICM

  → revived fossil plasma emission

- **Origin of revived fossil plasma emission:**
  - Relativistic plasma injected by two tailed-radio galaxies
  - Revived by the adiabatic compression due to gas motion in the cluster core



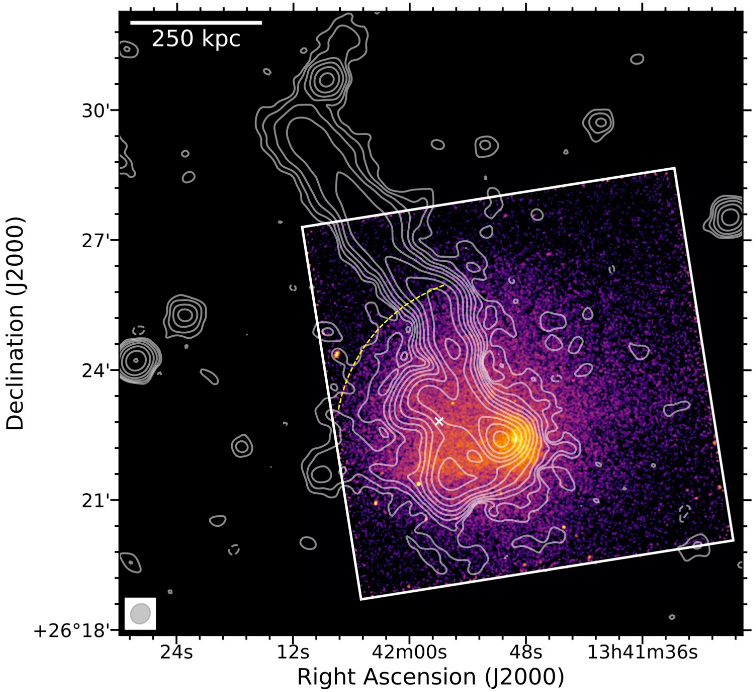
LOFAR 144 MHz high-resolution (5’’ × 3’’) data. Radio contours start from 3σ, where σ = 148 μJy beam^{-1}, and they are spaced by a factor of 2. Botton et al. 2021

2.2. *Diffuse radio emission*

- **Roundish diffuse radio emission:**
  - Located at the cluster center
  - Radio emission size ~ 300 kpc
  - Confined by the cold front in the NE
  - Radio power $P_{144\ \mathrm{MHz}} \approx 3.1\times10^{24}$ W Hz^{-1}

  → radio mini-halo

- **Origin of radio mini-halo:**
  - Pre-existing population of seed relativistic electrons were injected by cluster AGN
  - Re-accelerated by the turbulence triggered by merger-induced gas sloshing



LOFAR 144 MHz low-resolution (29’’ × 26’’) contours overlaid on the Chandra image. Radio contours start from 3σ, where σ = 255 μJy beam⁻¹, and they are spaced by a factor of 2. Botton et al. 2021

3. Conclusion

1. **Abell 1775 is the primary cluster undergoing merger-induced gas sloshing;**
2. **The transition between inner and outer tail of NAT occurs at the cold front; Outer tail might originate from the re-acceleration of the oldest electrons in the tail;**
3. **Filamentary and diffuse radio emission with ultra-steep spectrum can be classified as revived fossil plasma;**
4. **Central diffuse radio emission can be speculated as radio min-halo, re-accelerated by the turbulence generated by the merger-induced gas sloshing.**

THANKS!

THANKS!

Questions & Comments