Re-acceleration of Head-Tail Radio Galaxies in Galaxy Clusters

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Image credit: NASA, ESA, CSA, and STScI

Outline

★ Introduction

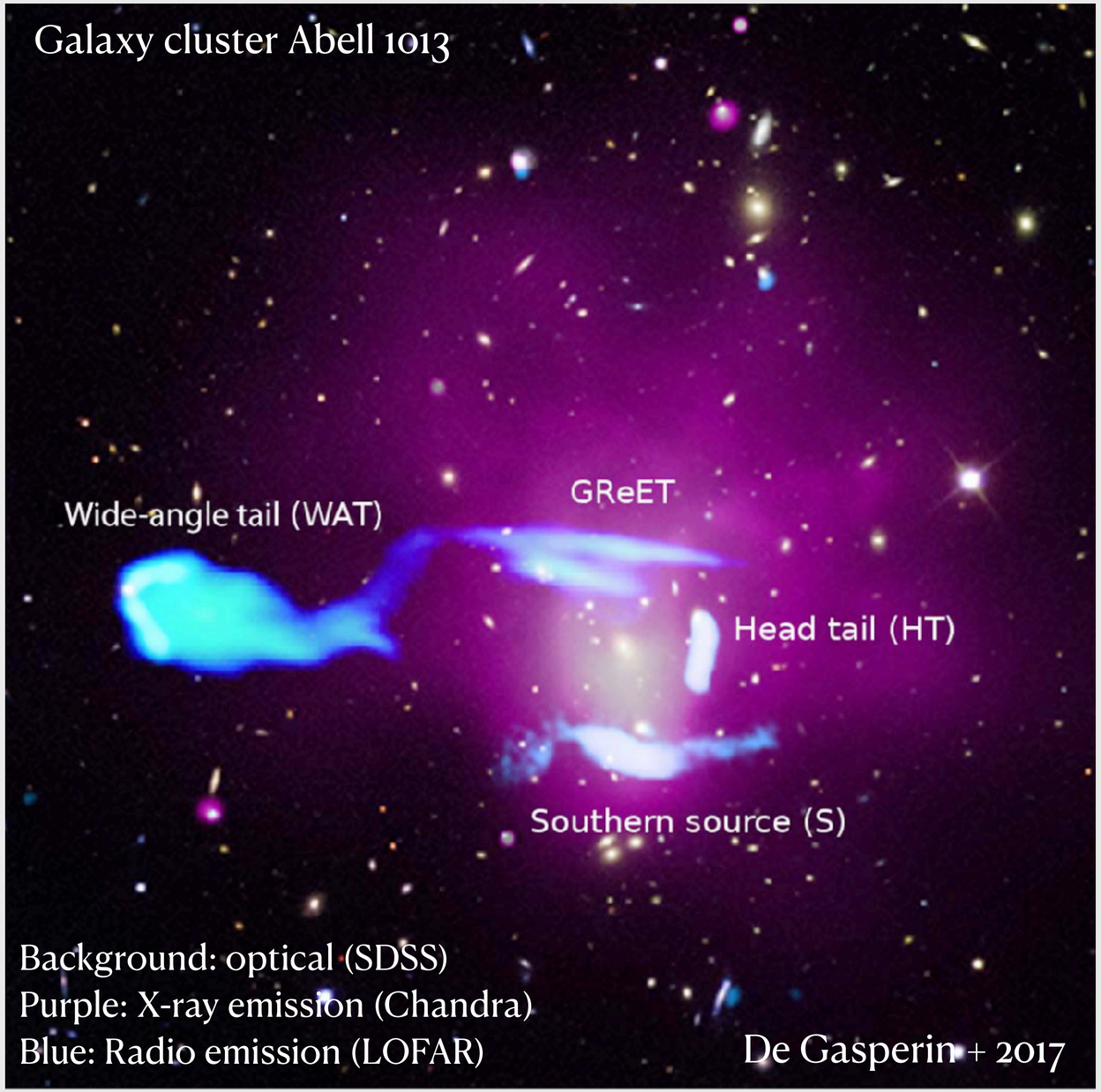
★ Galaxy clusters

★ Head-tail radio galaxy

★ Interactions between head-tail radio galaxy and galaxy cluster medium

Introduction

Introduction



★ Galaxy cluster Abell 1013

★ Redshift: 0.126 (590 Mpc or 1.9 Gly)

★ Dynamical state: highly disturbed, merging system

★ Mass: $3.4 \pm 0.4 \times 10^{14} M_{\mathrm{sun}}$

★ WAT (wide angle tail) galaxy

Galaxy clusters

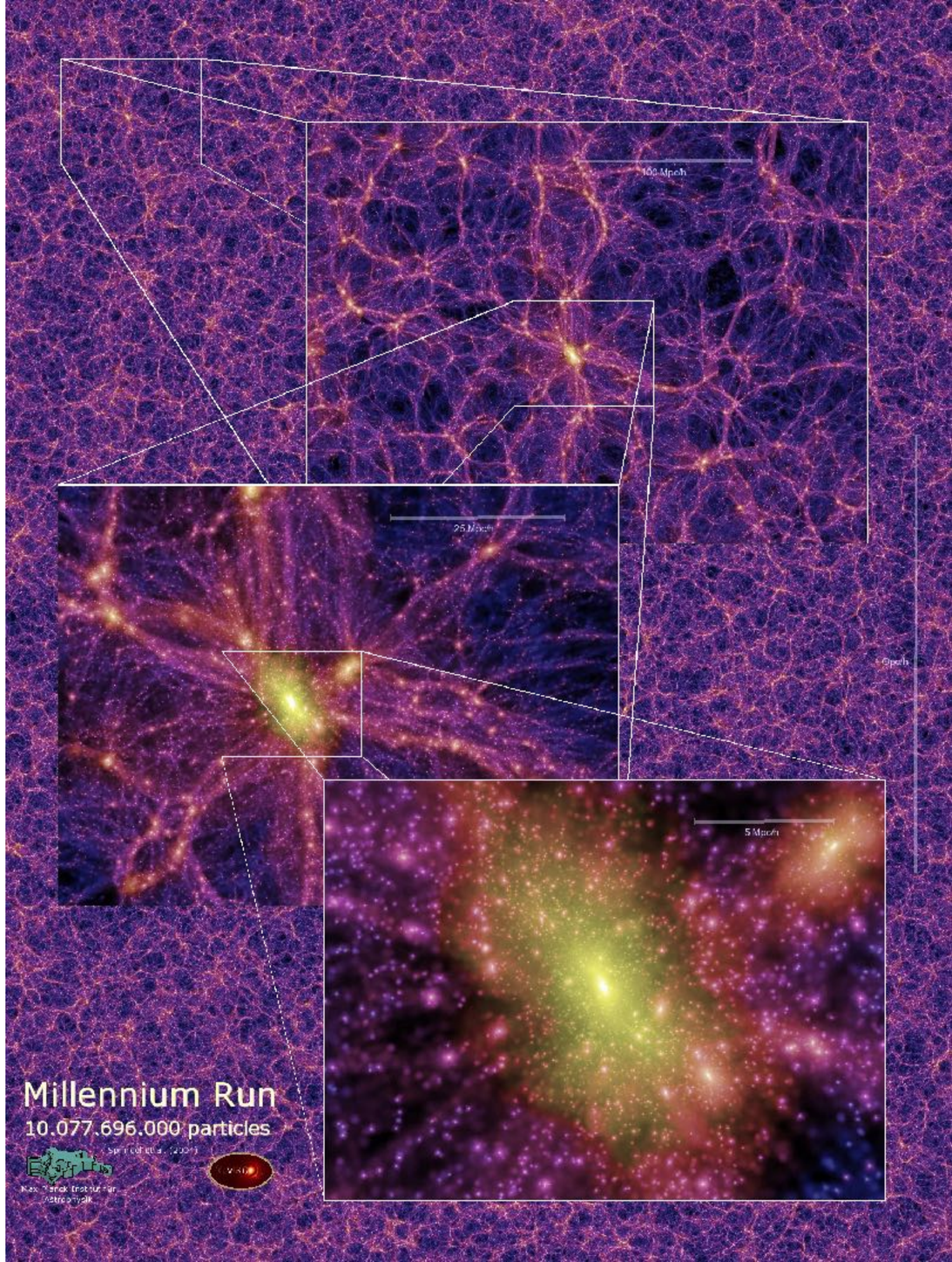
Galaxy clusters

★ Large-scale structure of the Universe:

- filaments, nodes & voids

★ Galaxy clusters:

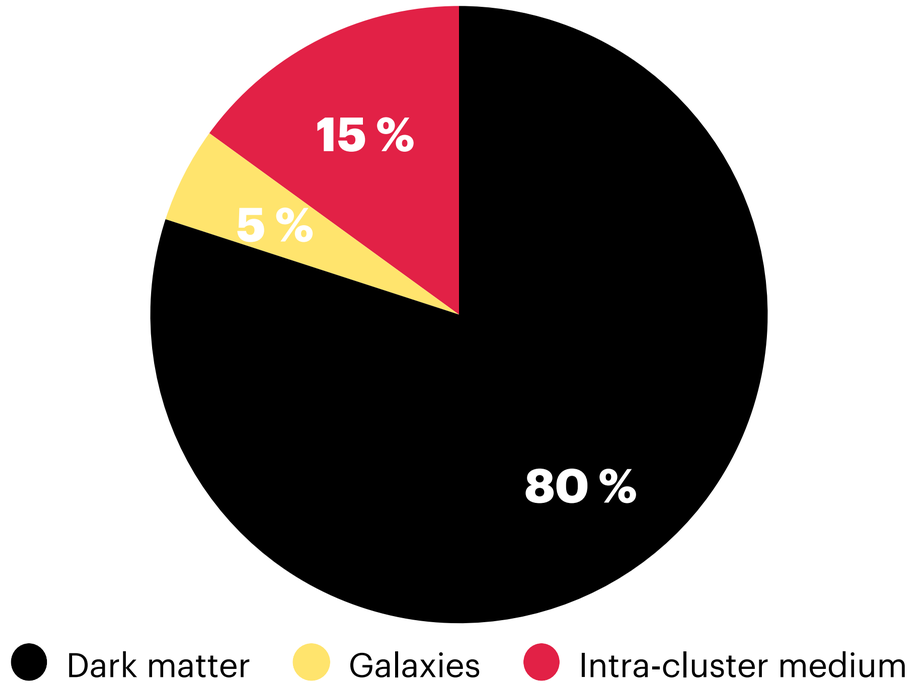
- consist of 100s to 1000s galaxies gravitationally bounded
- located at the nodes of the cosmic web

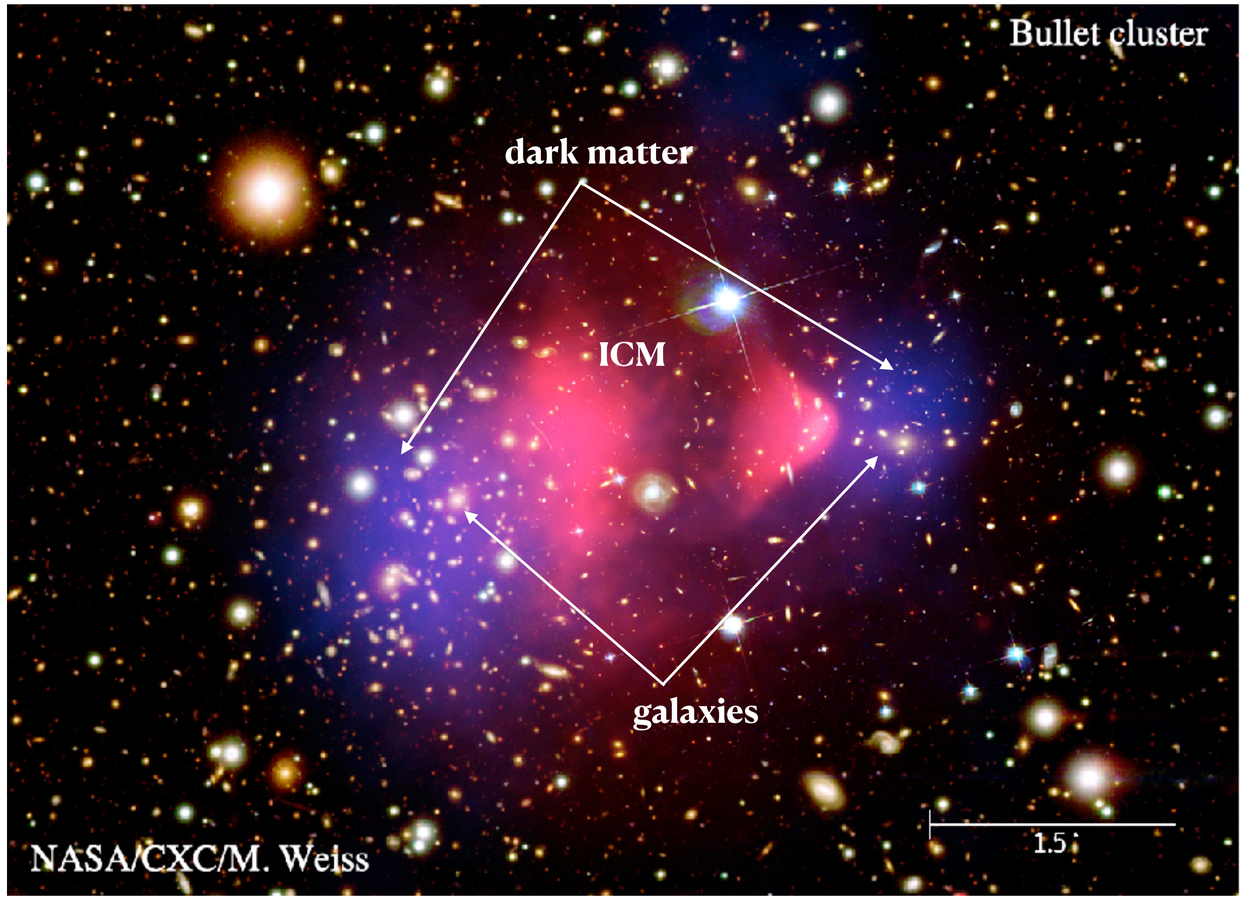


Components of galaxy clusters

★ Total mass (~10^{13} – 10^{15} solar mass):

- galaxies (5 %)
- intra-cluster medium (ICM, 15 %)
- dark matter (80 %)





Intra-cluster medium (ICM)

★ Thermal particles (Temperature *dependence*)

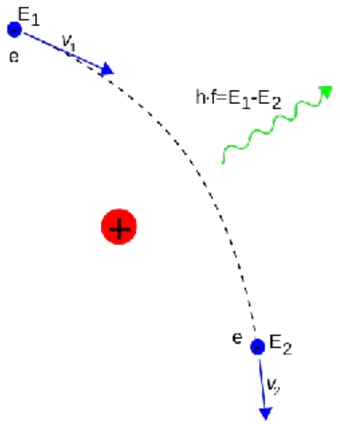
- electrons, protons, helium...
- low particle density: $\sim$ 1000 particles/m^3
- high temperature: $\sim (10 - 100) \times 10^6$ K

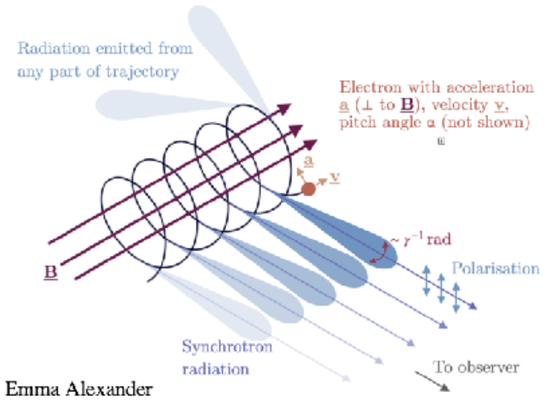
—> emitting X-rays via free-free (bremsstrahlung) mechanism

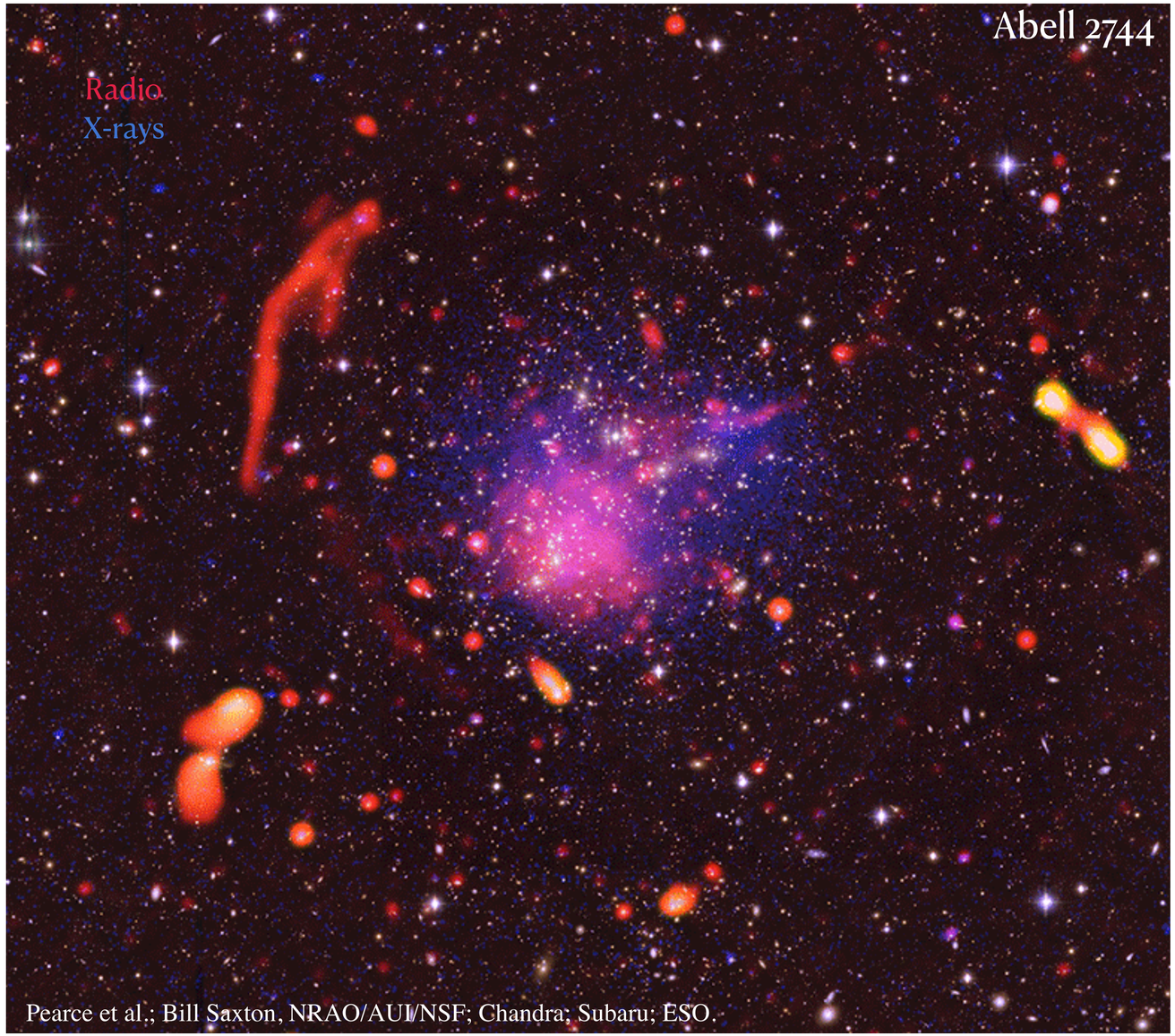
★ Non-thermal components (Temperature *Independence)*

- cosmic ray electrons ($\gamma > 1000 - 5000$), protons.
- magnetic fields ($B = \sim \mu Gauss$)

—> emitting radio emission via synchrotron mechanism



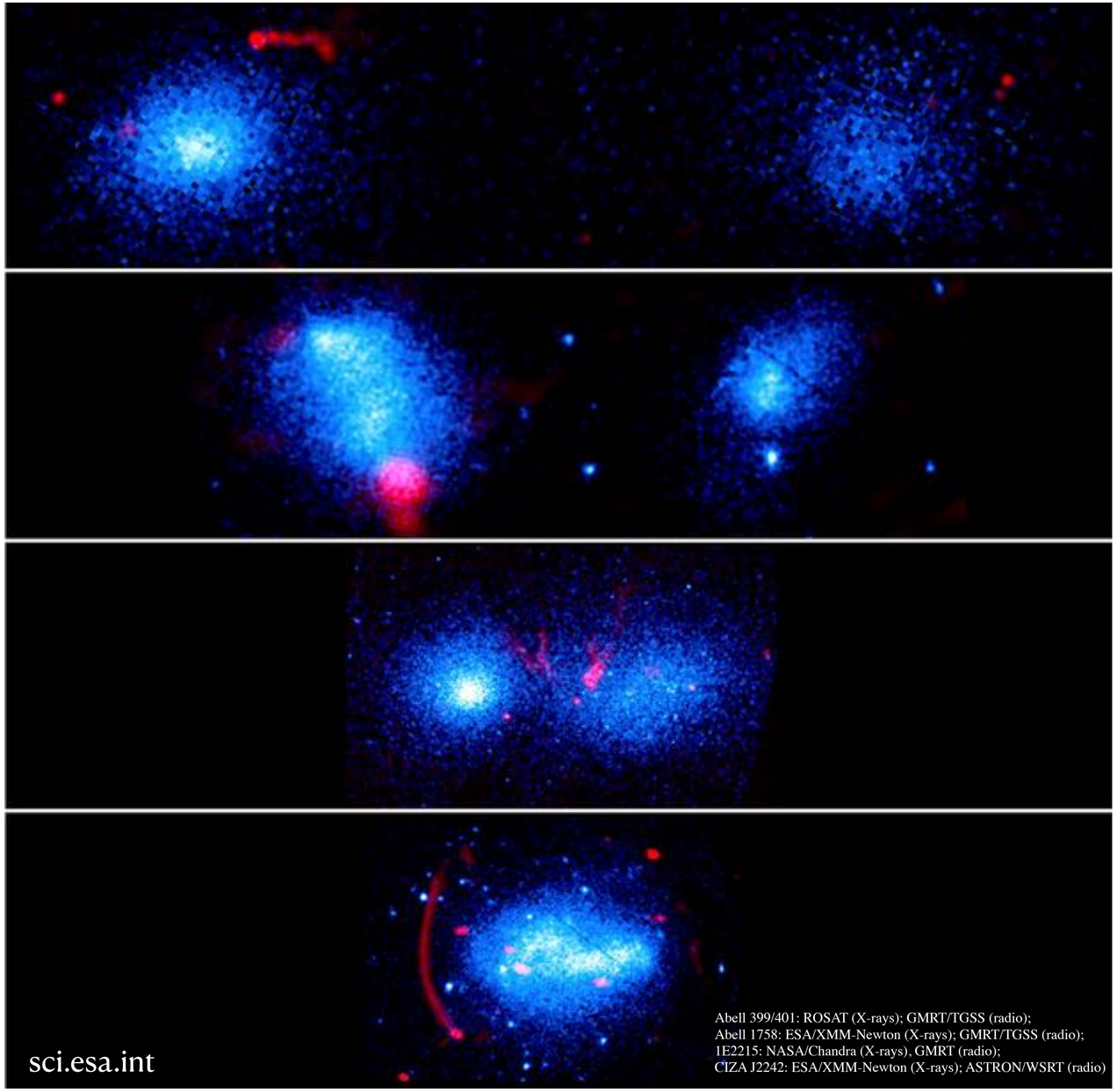




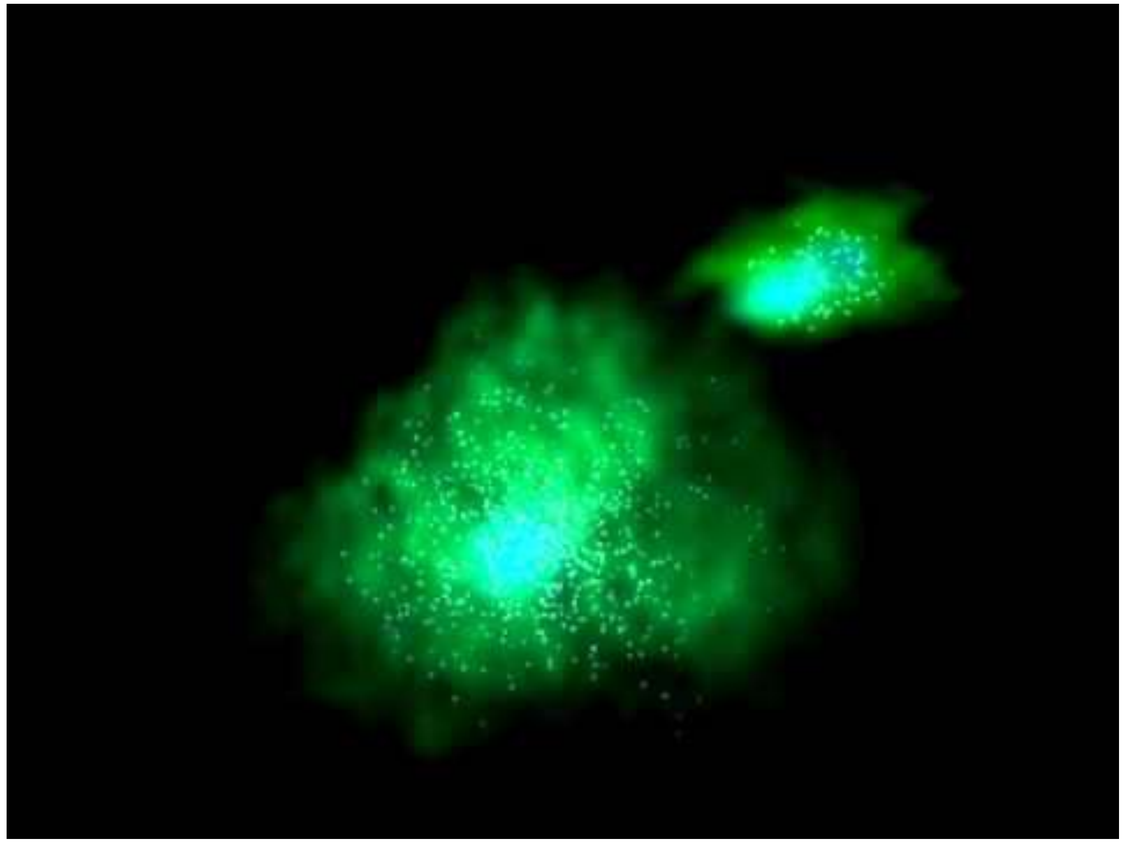
Free-free (bremsstrahlung) emission

Synchrotron emission (→ distribution of B and CRe)

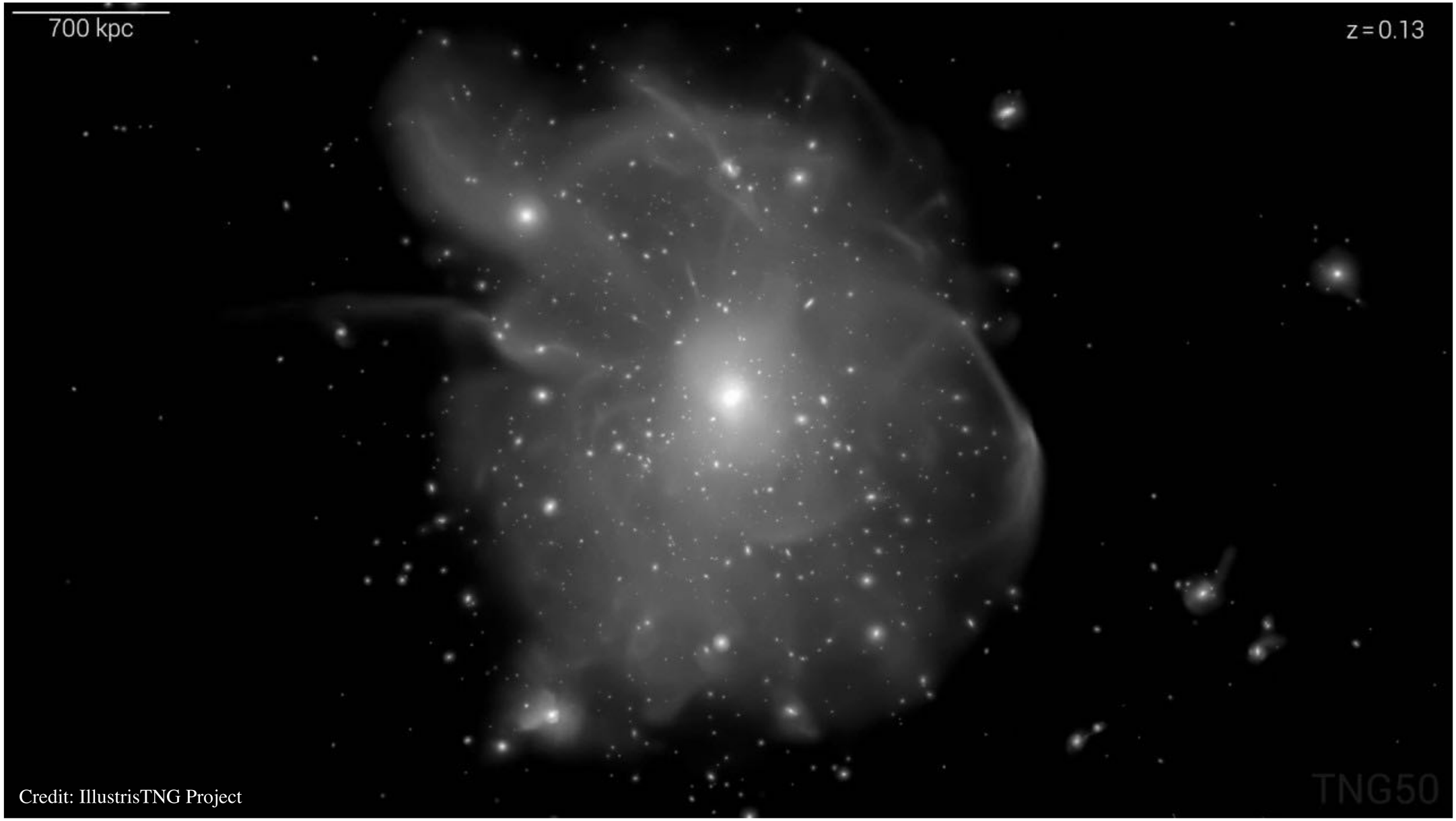
Massive galaxy clusters



★ Massive galaxy clusters form through a sequence of merger of sub-clusters. Shocks & turbulence are generated.



Galaxy cluster formation: Simulation TNG50



Credit: IllustrisTNG Project

Radio Galaxy

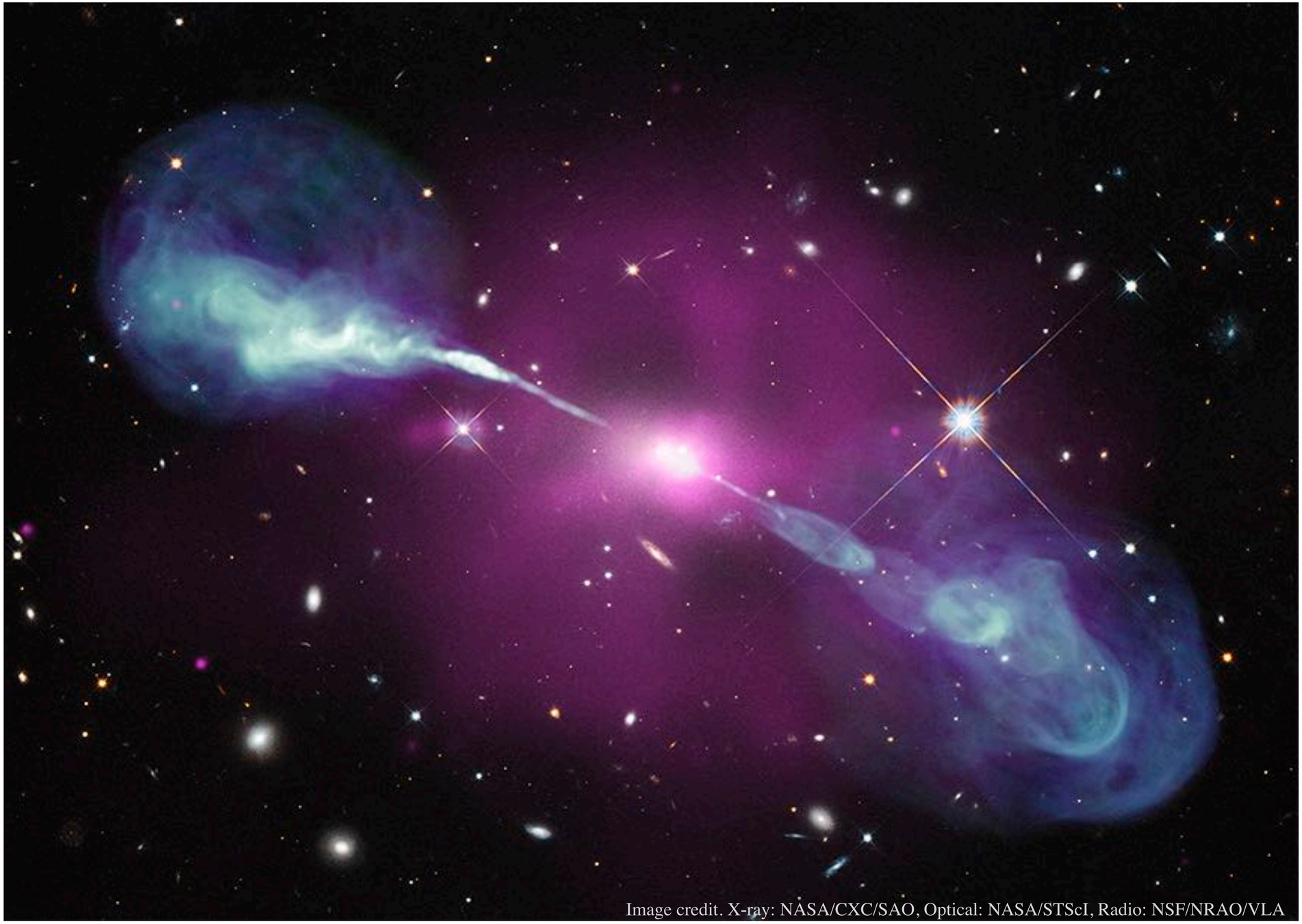
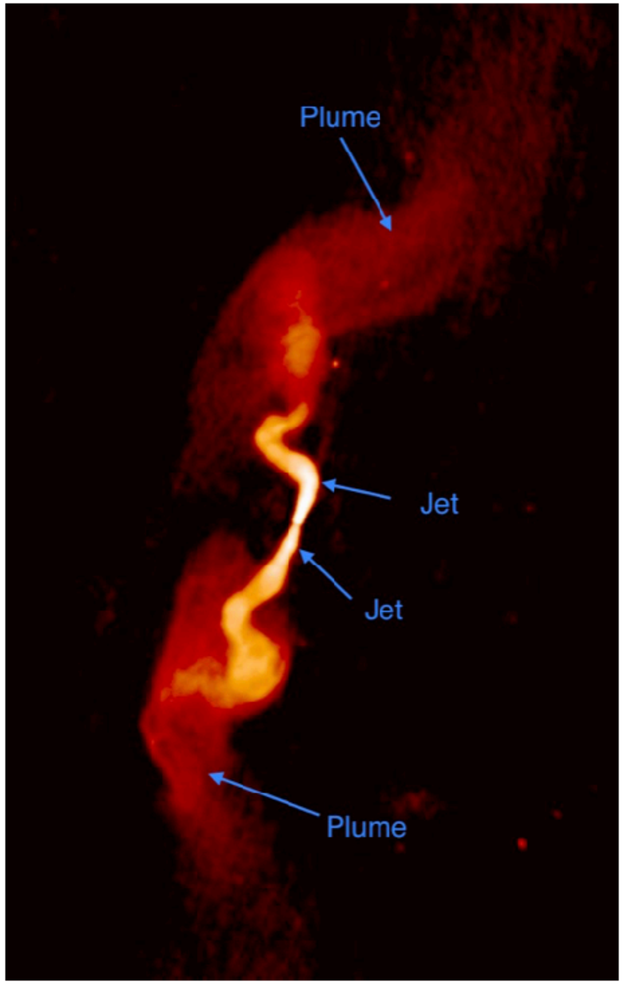


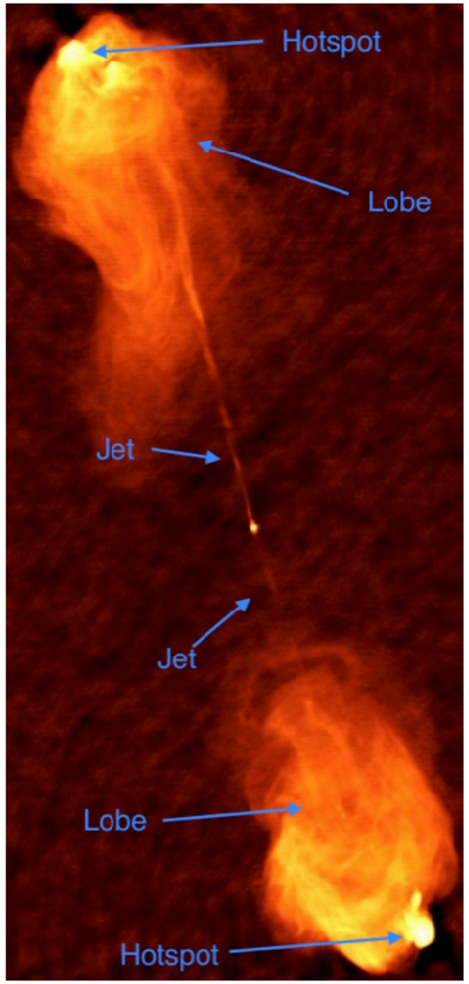
Image credit. X-ray: NASA/CXC/SAO, Optical: NASA/STScI, Radio: NSF/NRAO/VLA

- Hercules A
- Active galaxy
- Redshift: 0.155

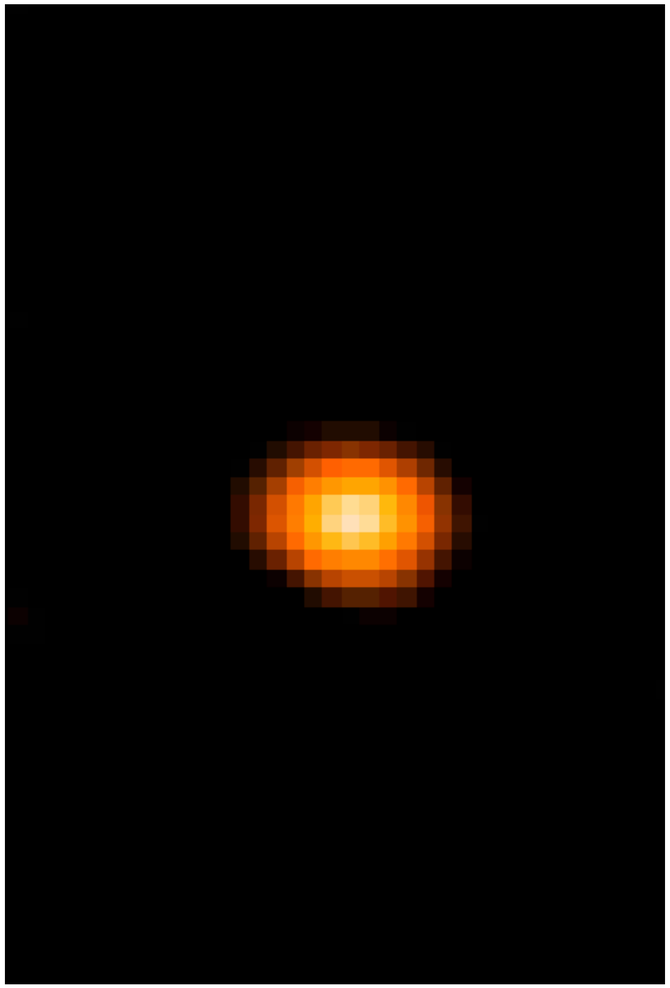
Radio galaxy classification



Fanaroff-Riley I (FR-I)



Fanaroff-Riley II (FR-II)



Compact

Bent galaxy

X-shaped radio galaxies

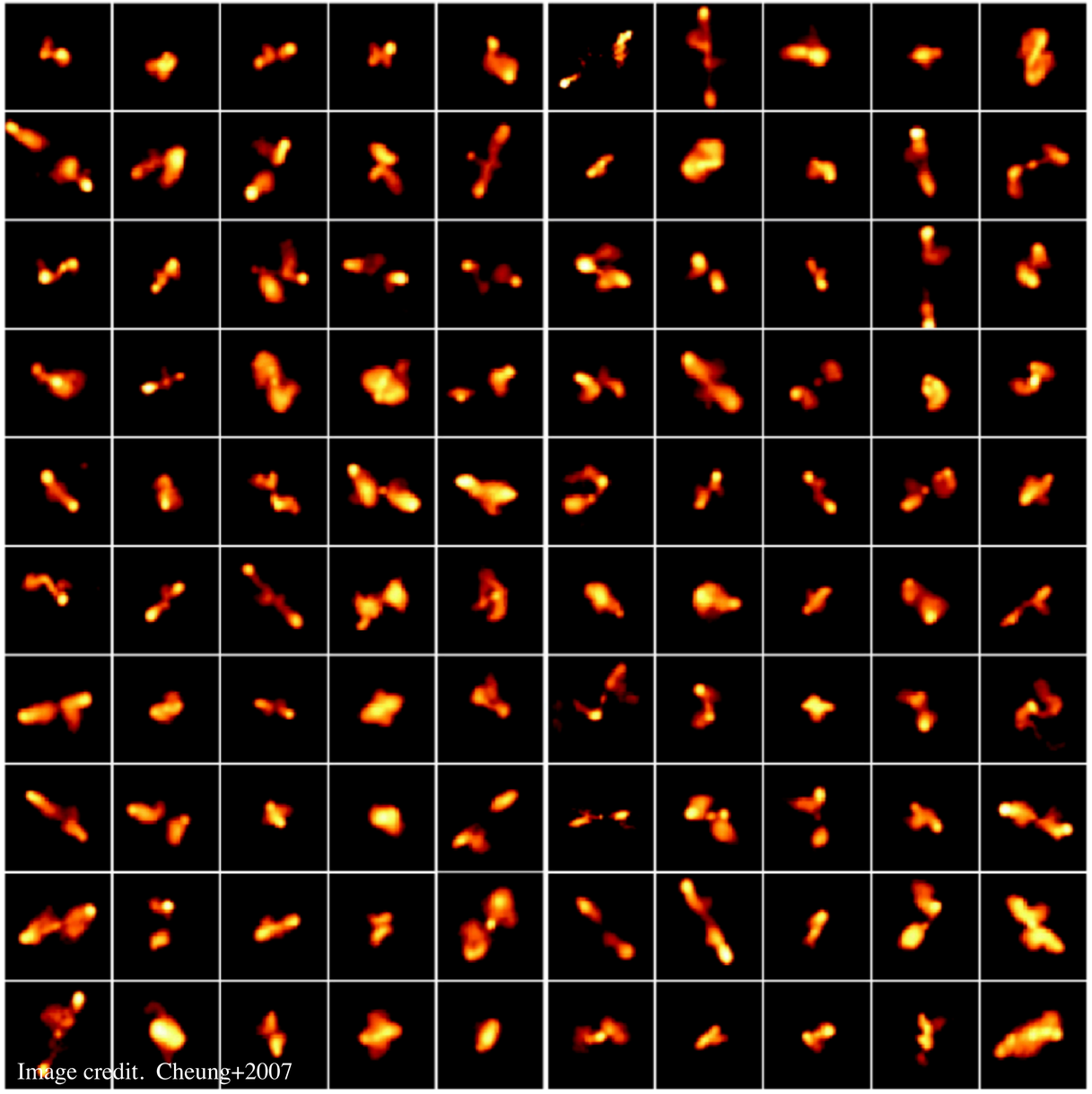
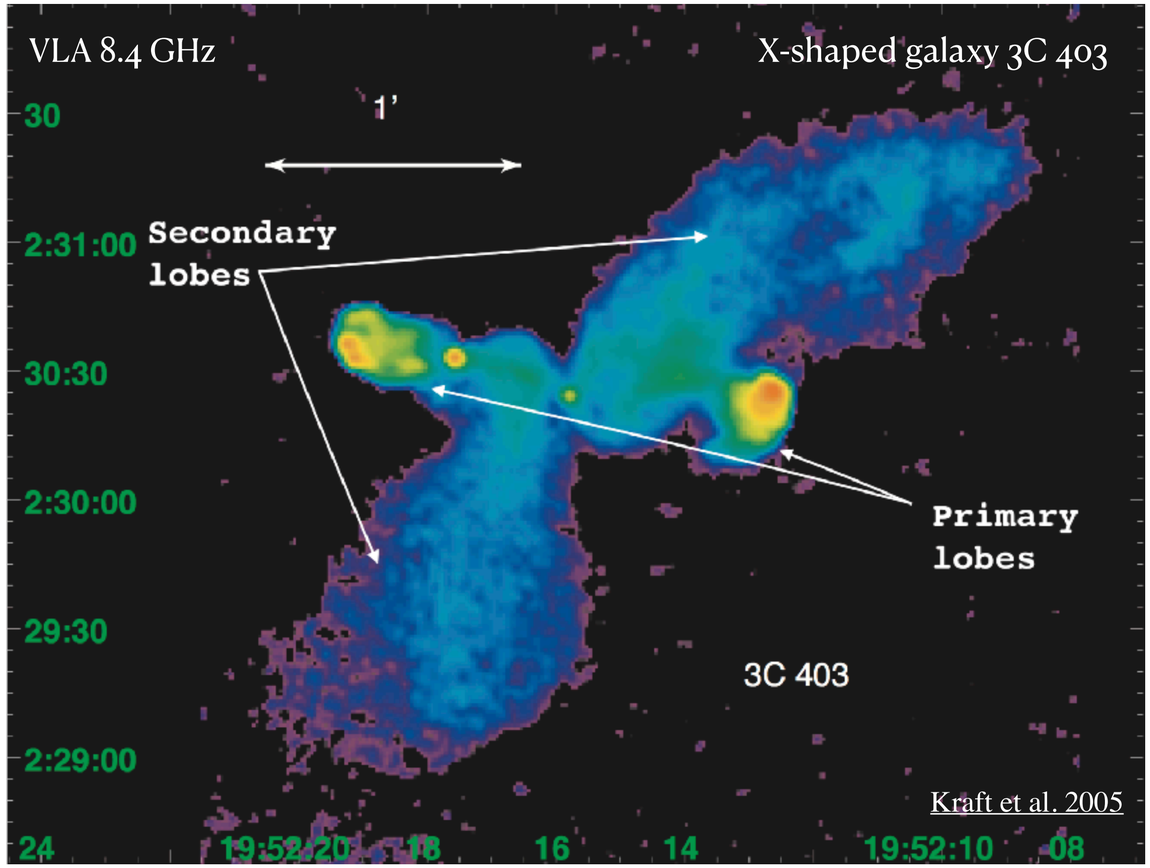
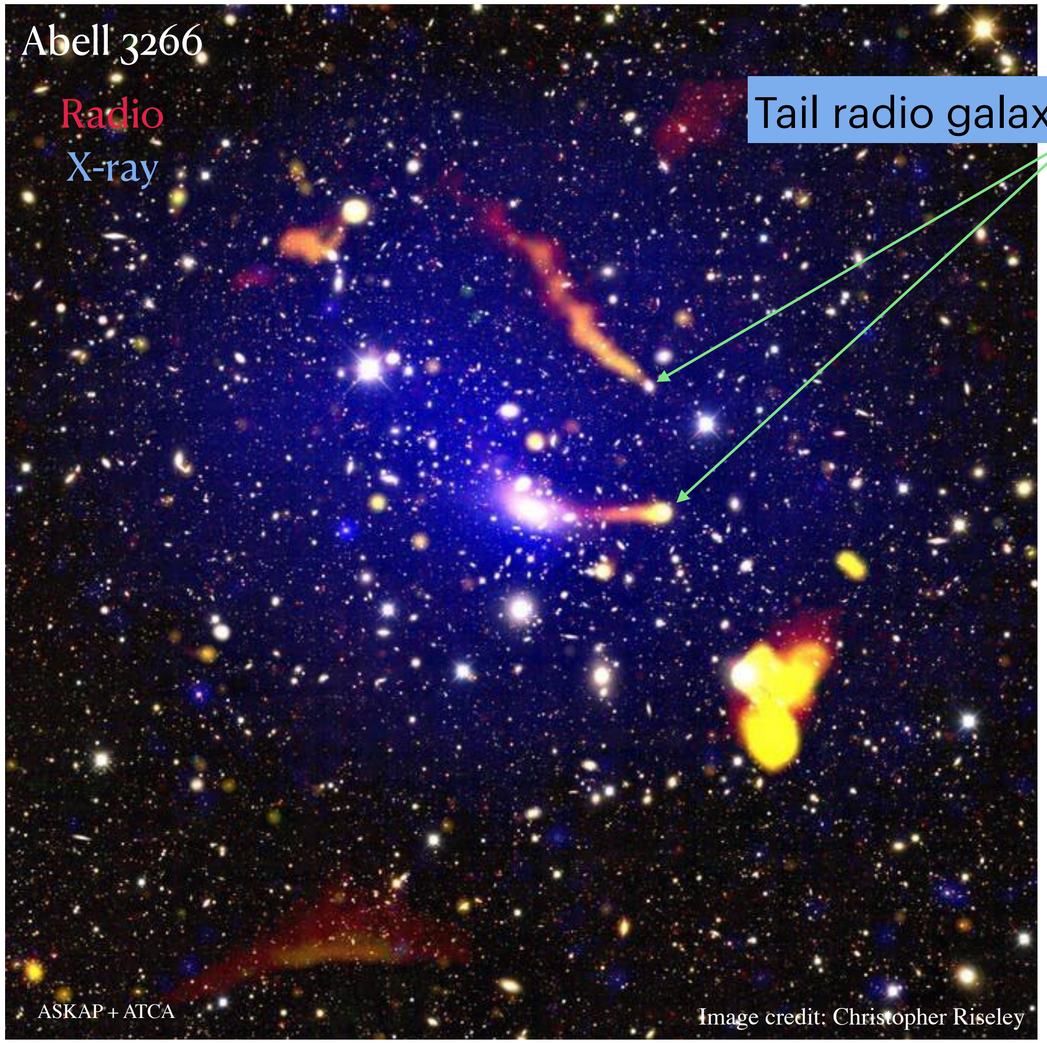


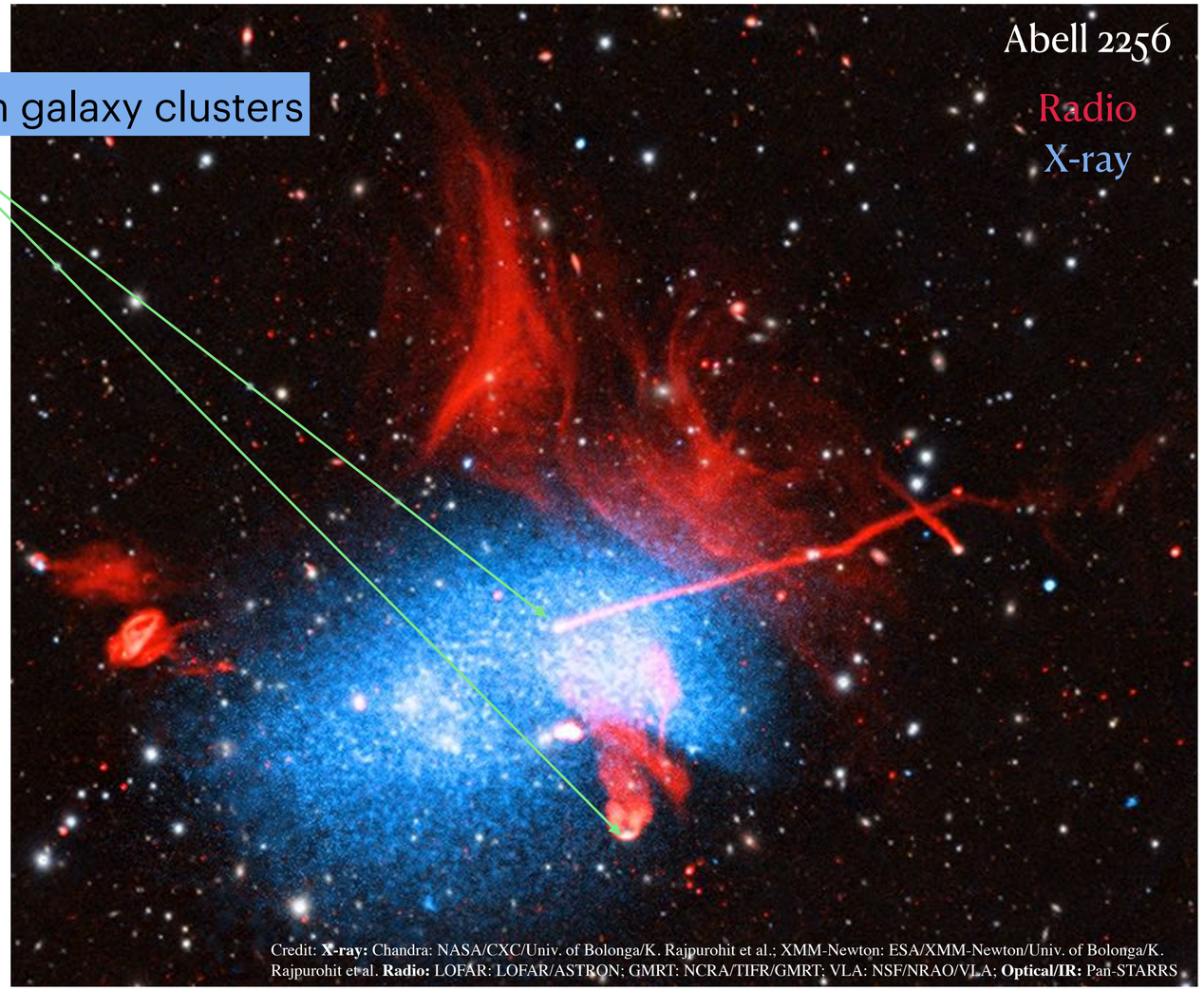
Image credit. Cheung+2007



Bent radio galaxy in galaxy cluster environment



Tail radio galaxies in galaxy clusters

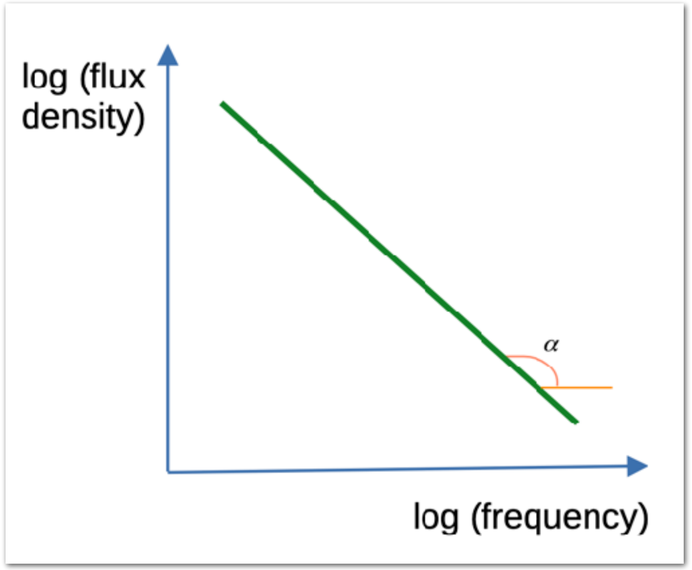


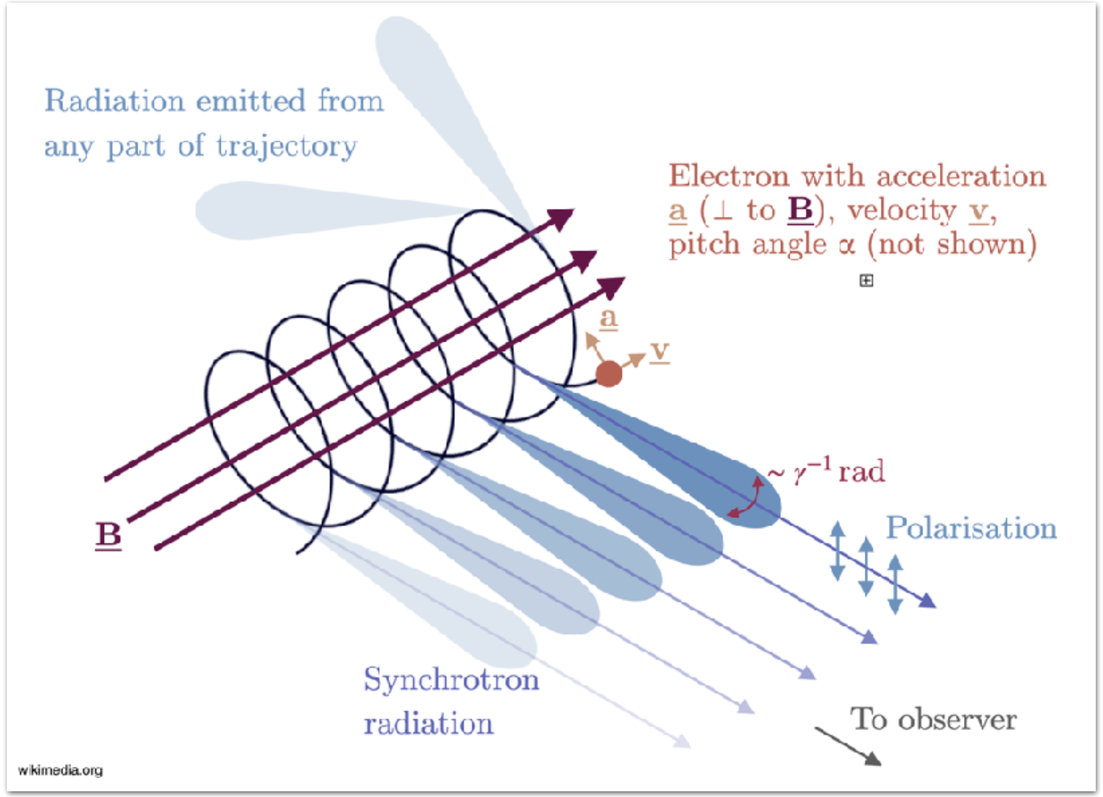
Synchrotron spectrum

★ Synchrotron radiation (Magnetobremsstrahlung) caused by charged particles spiralling along B field.

★ Radio emissivity: $j_{\mathrm{radio}} \propto B^{(\alpha+1)}\nu^{\alpha}$

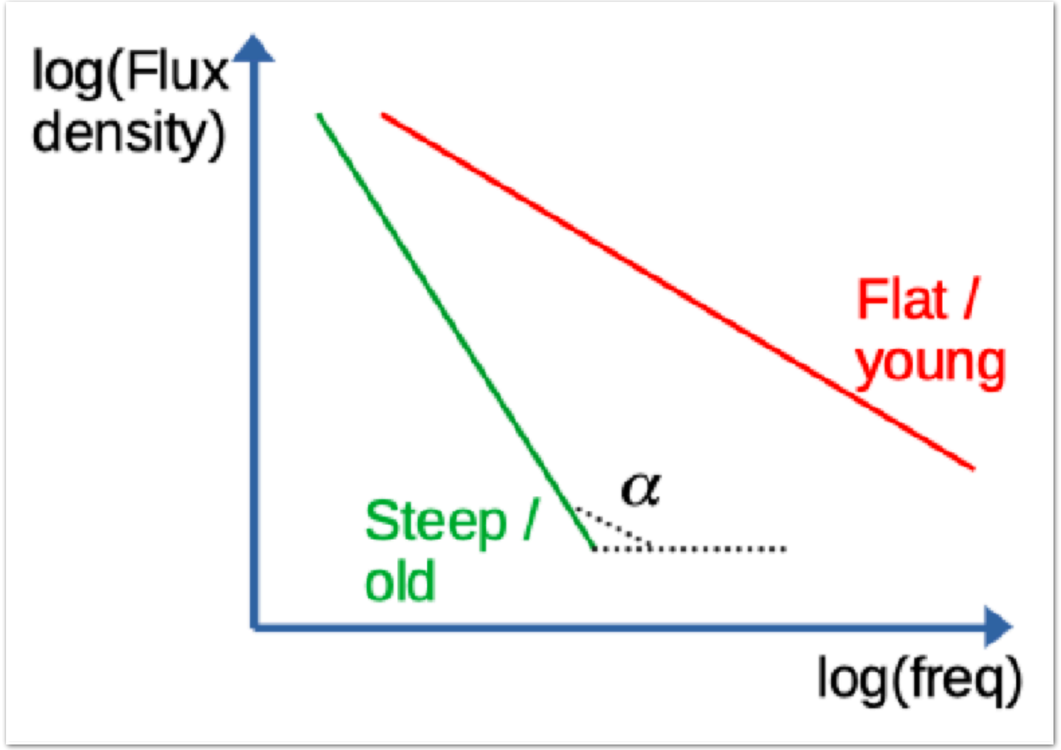
(B: magnetic field, ν: frequency, α: spectral index)

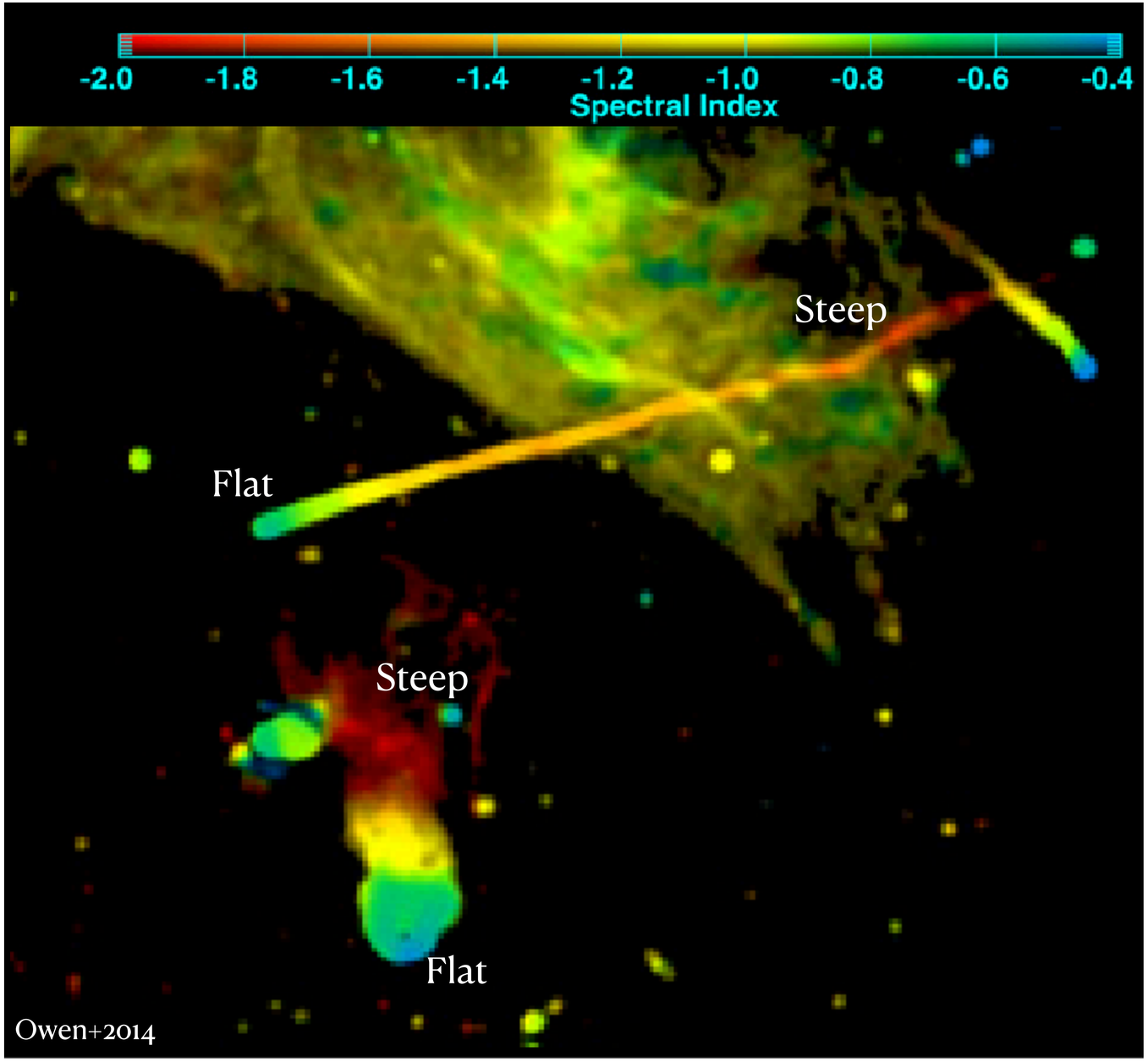




Spectral ageing

★ Radio emitting particles lose energy and radio spectrum steepens.



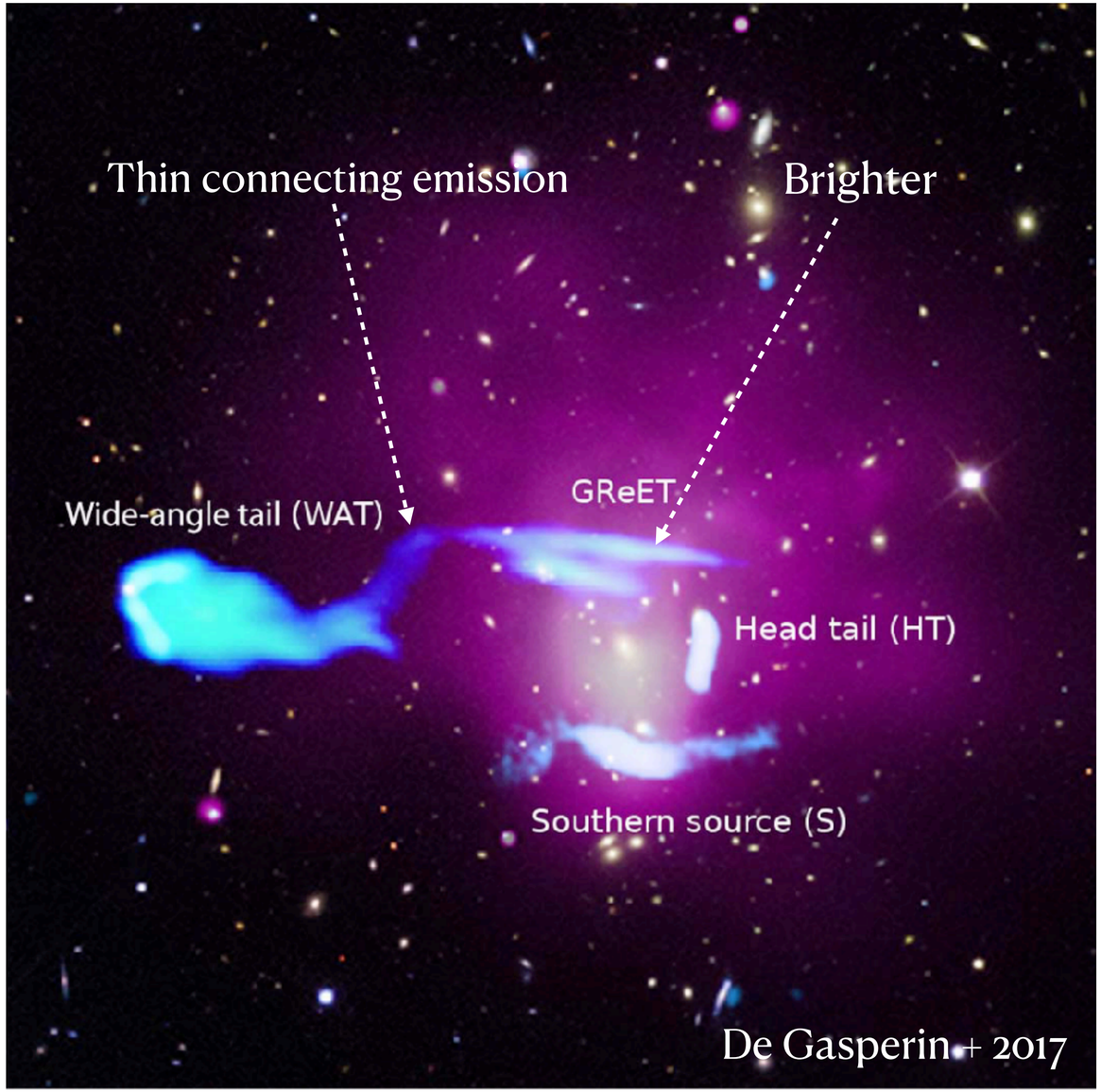


The WAT galaxy in Abell 1033

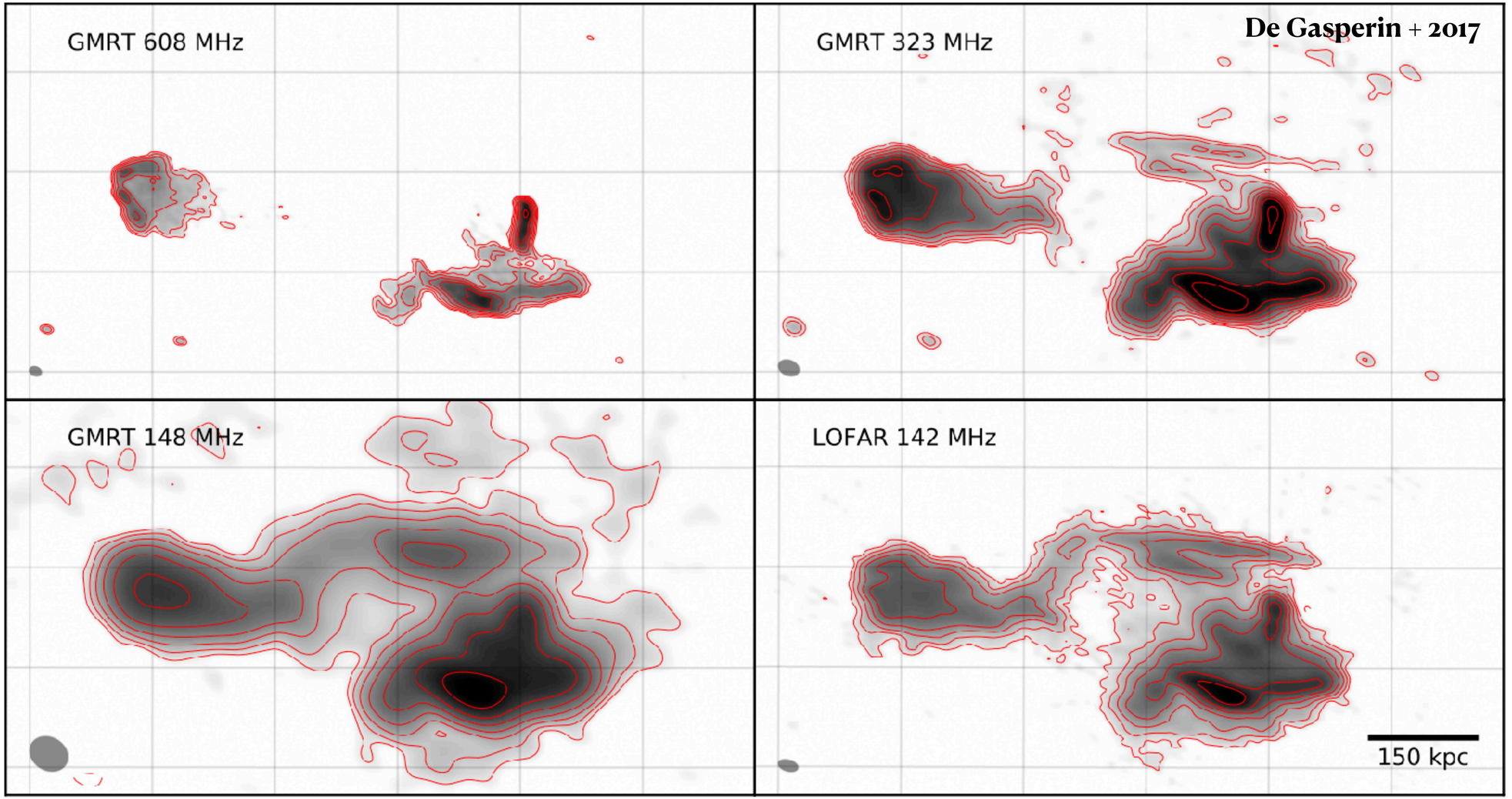
★ Connection between WAT and central double elongated sources?

- Thin emission connecting the two sources
- Orientation
- More evidence?

★ If so, why tail is brighter? More high relativistic electrons?



Multi-frequency radio observations



★ Brighter emission at lower frequencies due to synchrotron nature ($S = A \times \nu^{\alpha}$)

★ More emission in the connecting region (at ~150 MHz)

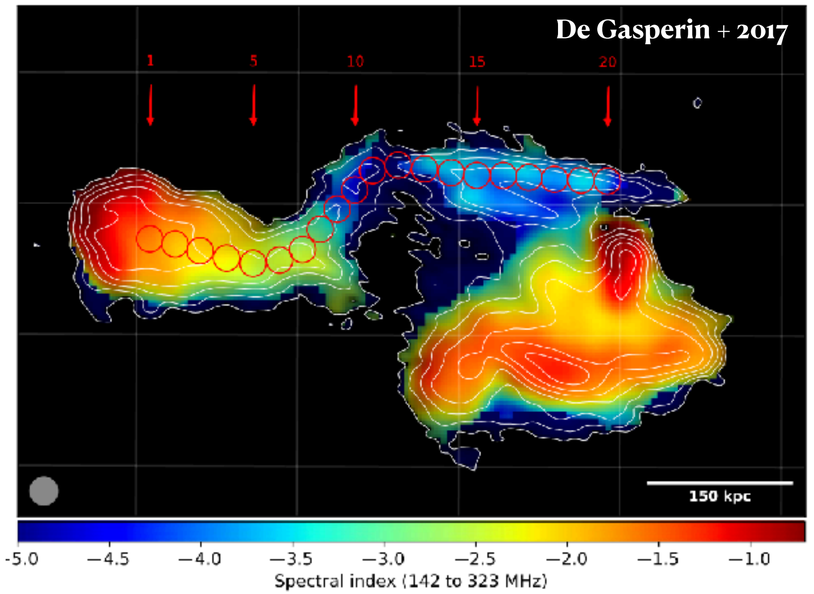
Spectral index distribution

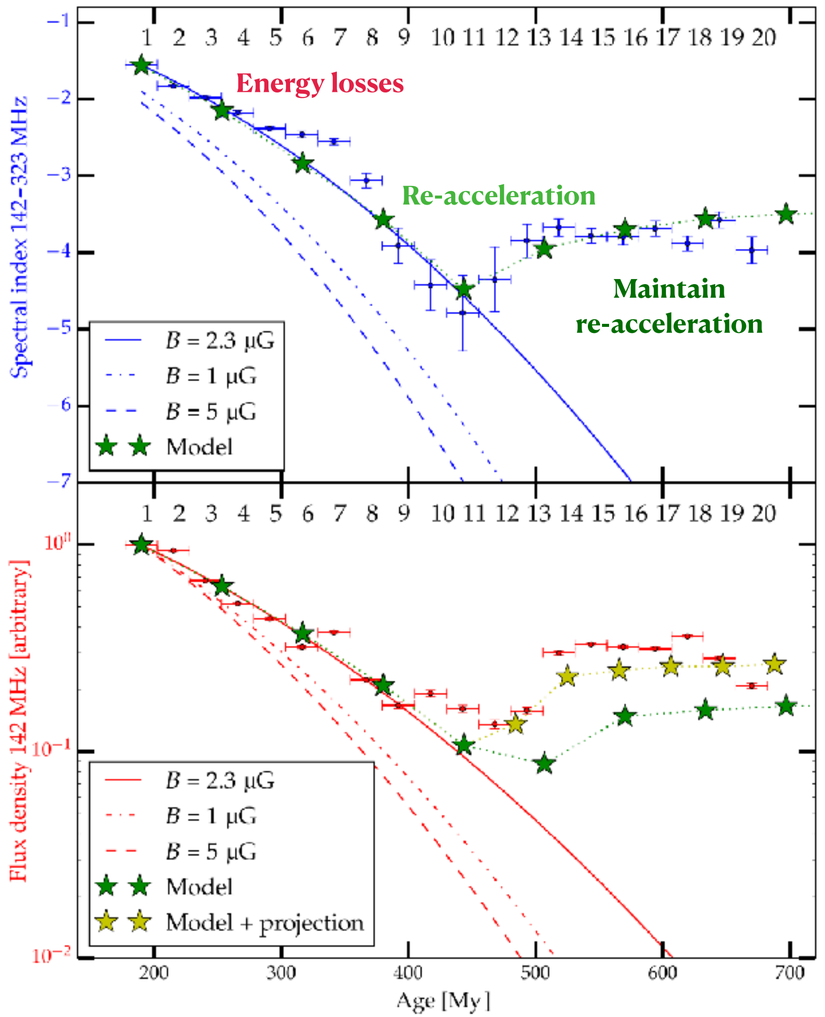
★ Spectral index relates to the age after the particles are injected/ accelerated from the galaxy.

★ Spectral steepening behind the WAT galaxy (region 0-10)
—> energy losses

★ Then spectral flattening (region 10-13)
—> starting acceleration

★ Then remains constant, increases brightness (region 13-20)
—> additional acceleration/B strength.





Sources of particle acceleration: shock or turbulence?

The galaxy cluster Abell 3411 - 3412

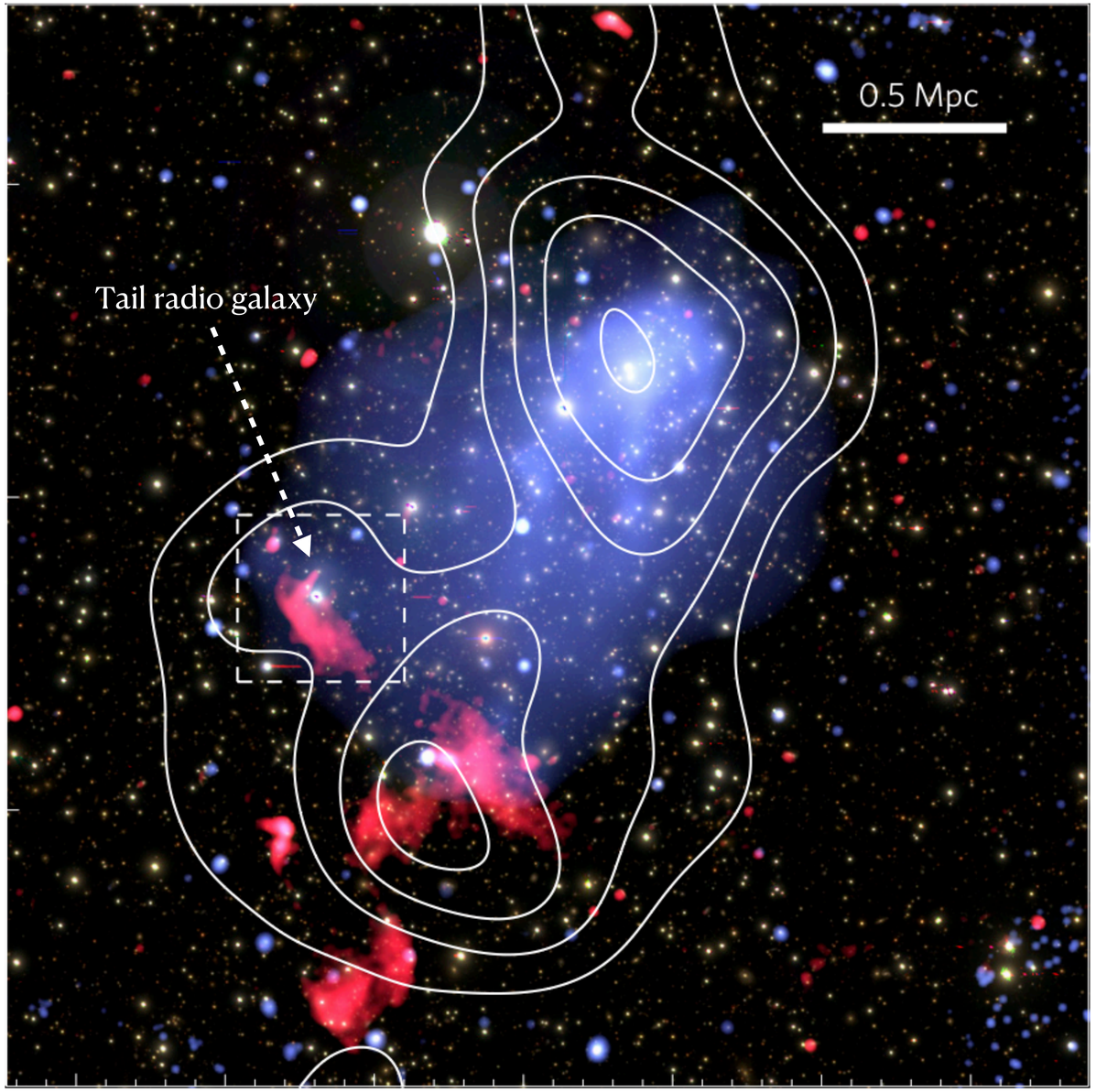
★ Galaxy cluster Abell 3411 - 3412

★ Redshift: 0.16 (2.5 Gly)

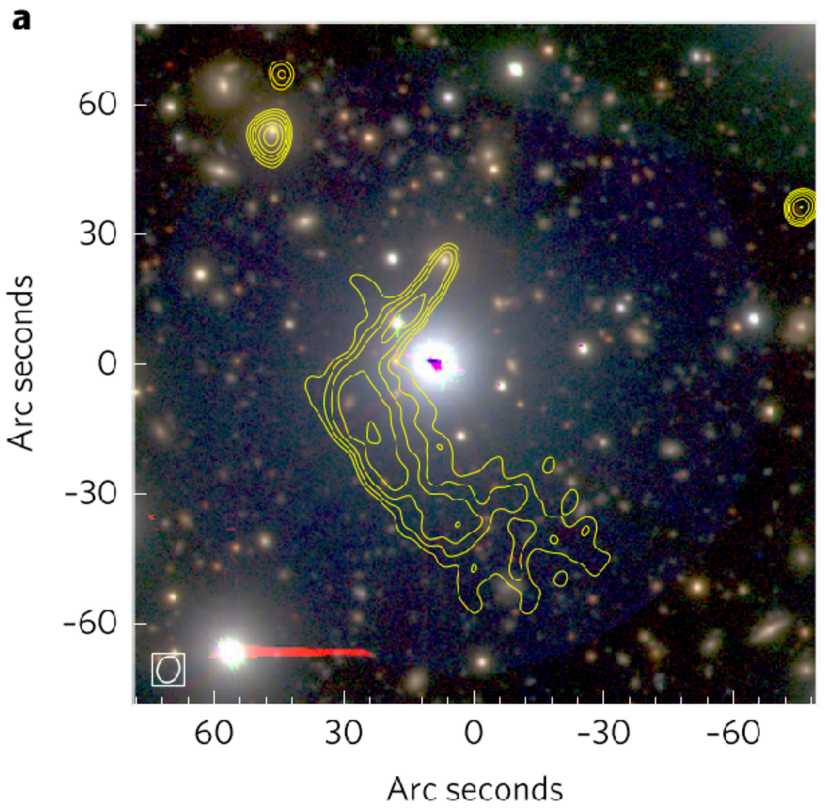
★ Dynamical state: highly disturbed, merging system

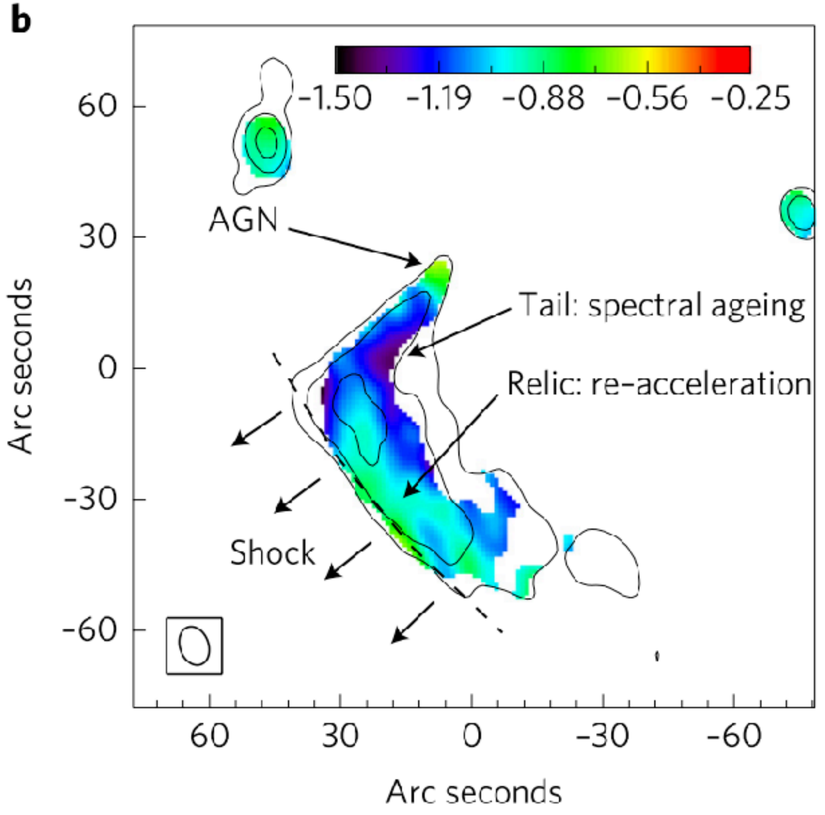
★ Mass: $\sim 2 \times 10^{15} M_{\mathrm{sun}}$

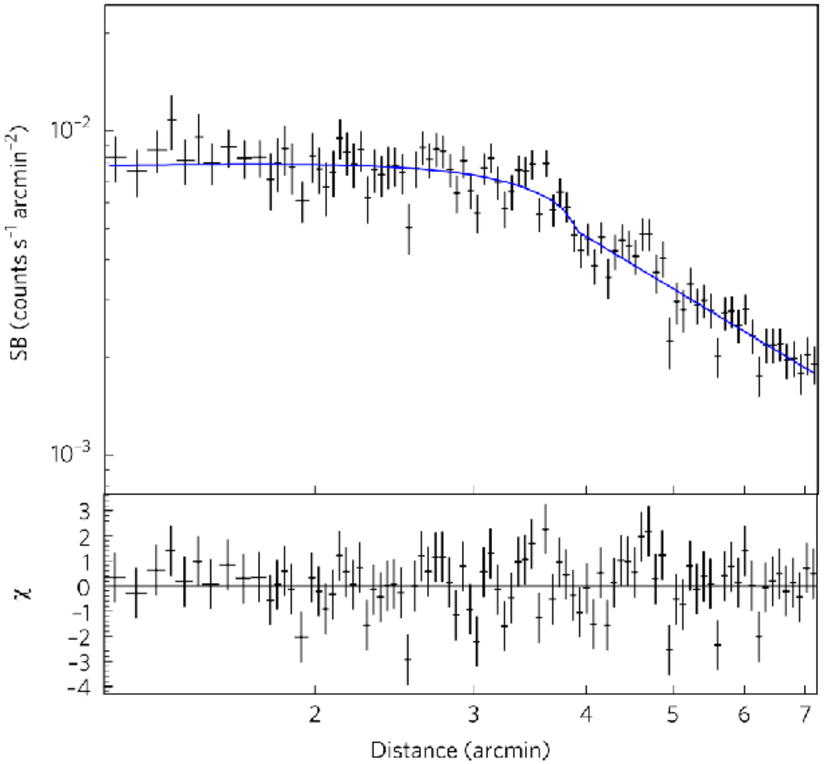
★ A radio galaxy with disturbed tail



Properties of the tail radio galaxy







★ Unusual disturbed tail of a galaxy.

★ Normal spectral steepening behind the galaxy, then flattening of the spectrum.

★ Shock is detected at the location of the disturbed tail.

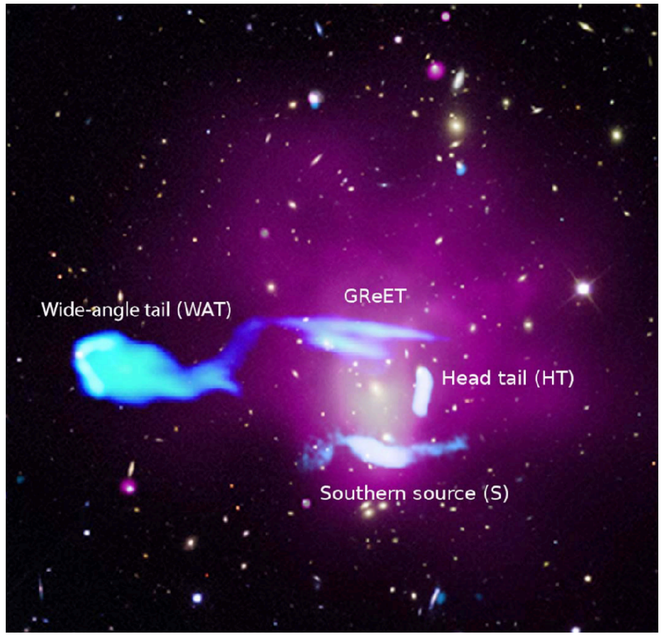
Take-away messages

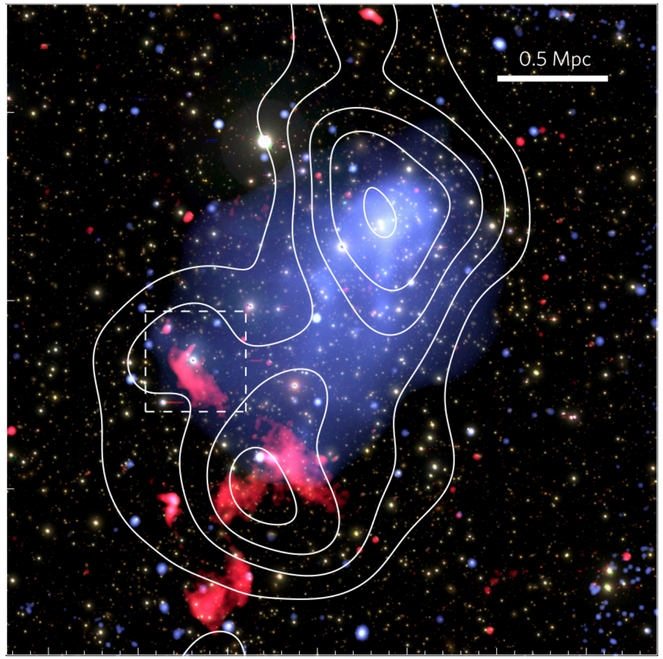
★ During the formation of galaxy clusters, turbulence and shocks are generated in the intra-cluster medium (ICM).

★ Head-tail radio galaxy indicates the effect of the environment on the galaxy jets/lobes.

★ Re-energised tails can be seen in highly-disturbed ICM environment (via turbulence/shock).

★ The interaction can be used to understand the physics of the particle acceleration (e.g. in shock/turbulence)





Thanks very much for your attention!