GALAXY CLUSTERS

AY 2023-2024

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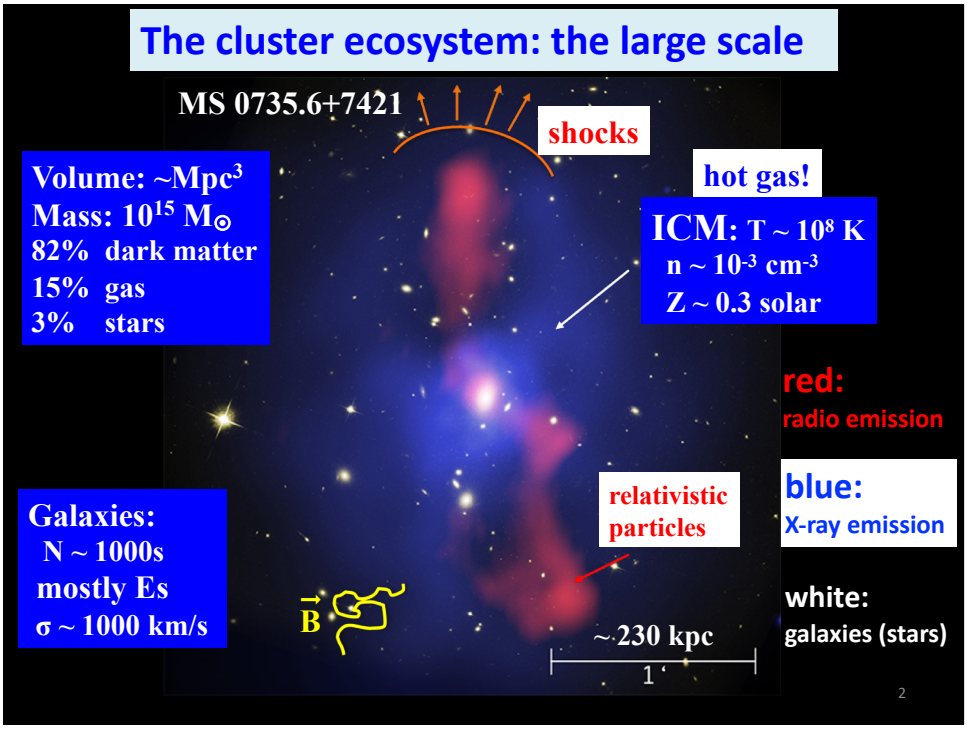
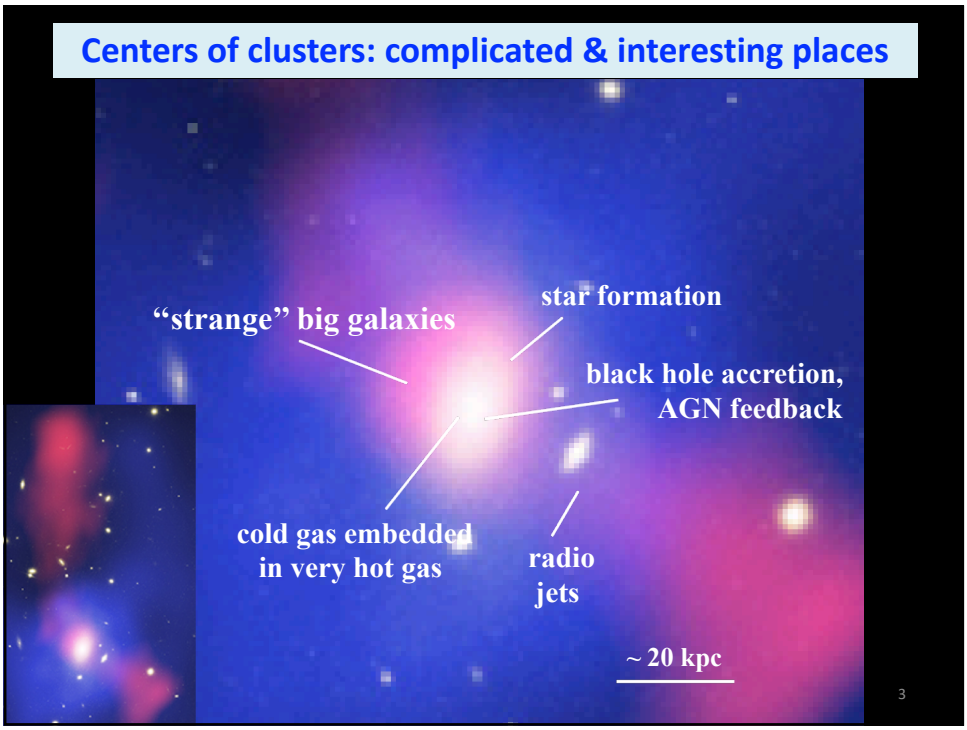
+ Myriam Gitti

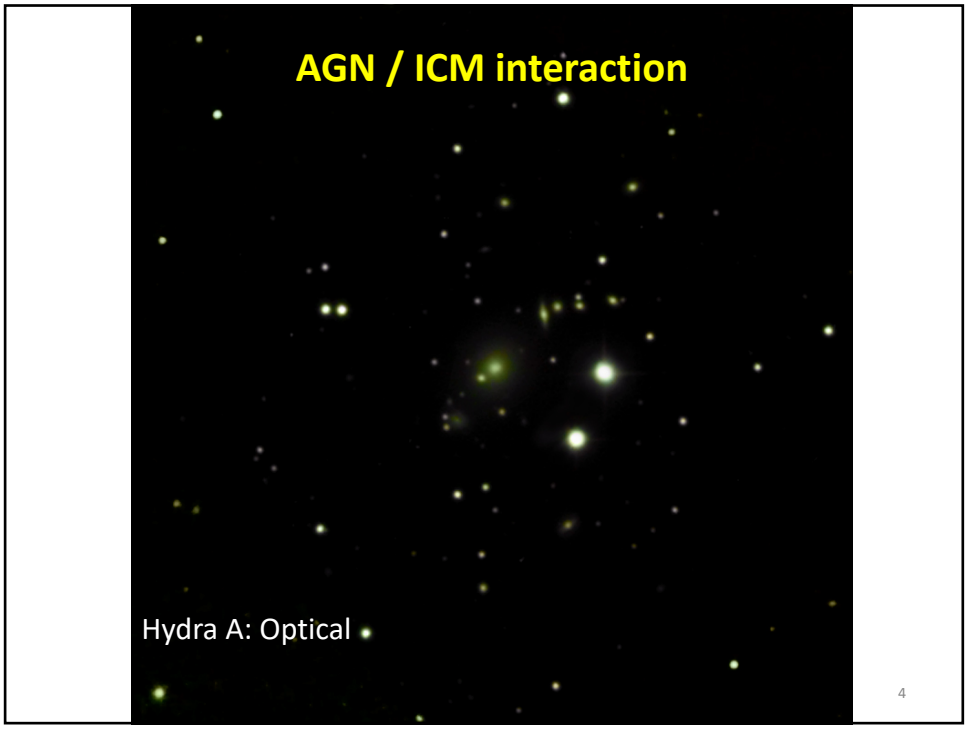
Clusters as an Astrophysical Lab to study:

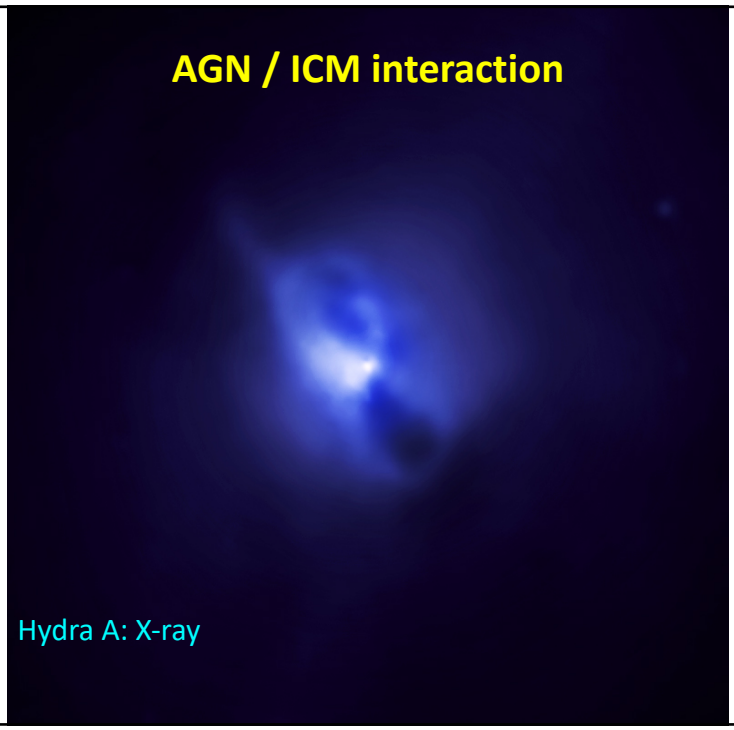
- Galaxies in dense environment
- Gas (hot & cold) astrophysics
- Chemical enrichment (of clusters & Universe)
- BH, AGN, Dark Matter
- Non-thermal phenomena ($\vec{B}$, relativistic particles)

Focus of the class is on current research topics and on (astro)physical processes




Centers of clusters: complicated & interesting places
"strange" big galaxies
star formation
black hole accretion,
AGN feedback
cold gas embedded
in very hot gas
radio
jets
~ 20 kpc
3


AGN / ICM interaction
Hydra A: Optical
4


AGN / ICM interaction
Hydra A: X-ray
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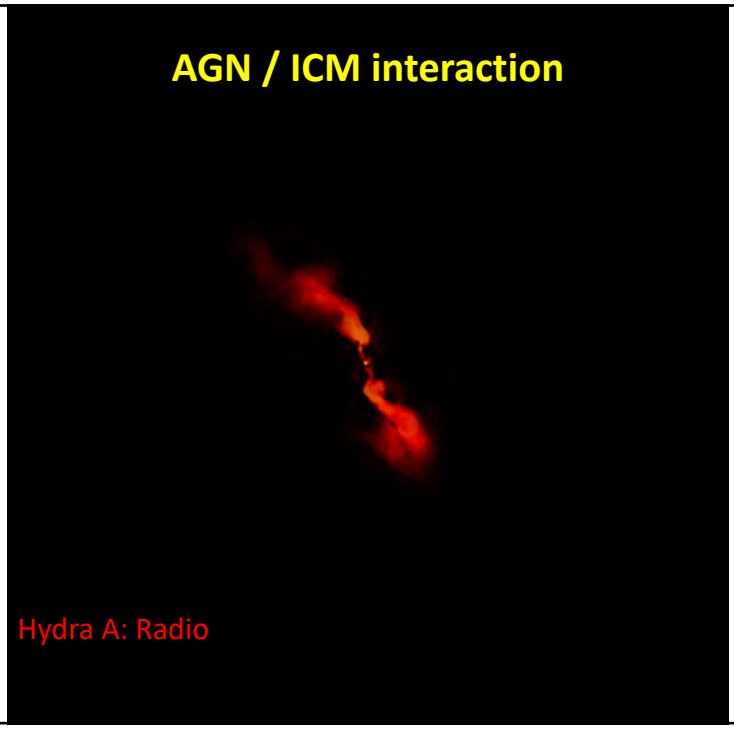
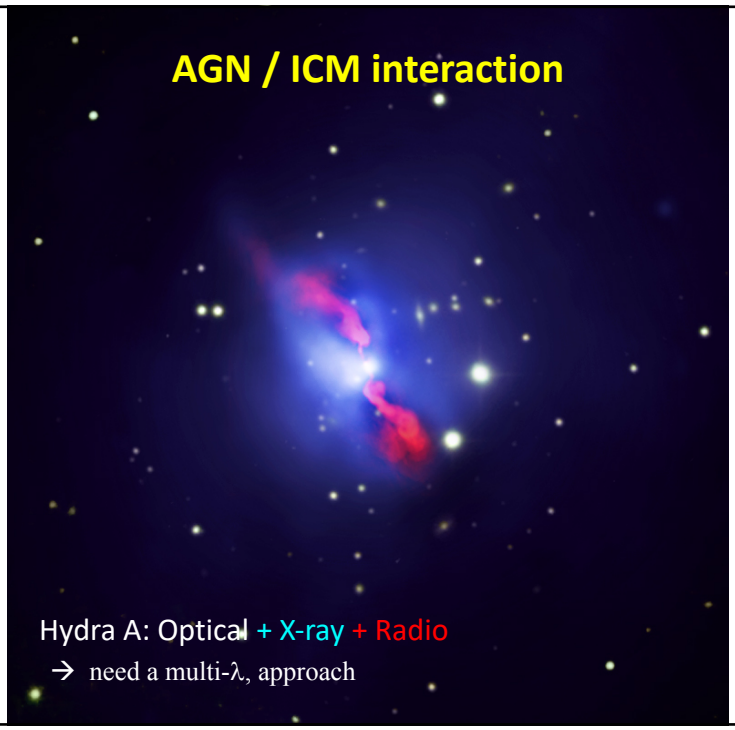

AGN / ICM interaction
Hydra A: Radio
6



Main topics (obs + theo)

Intracluster/interstellar medium (hot and old)
- Many physical processes
- Heating and cooling, AGN feedback
- Turbulence

Chemical evolution: origin of metals, their distribution
- SN astrophysics
- Star formation history

Galaxy evolution in clusters
- galaxy-galaxy interactions
- interaction with the ICM

Non-thermal processes
- magnetic field, relativistic particles

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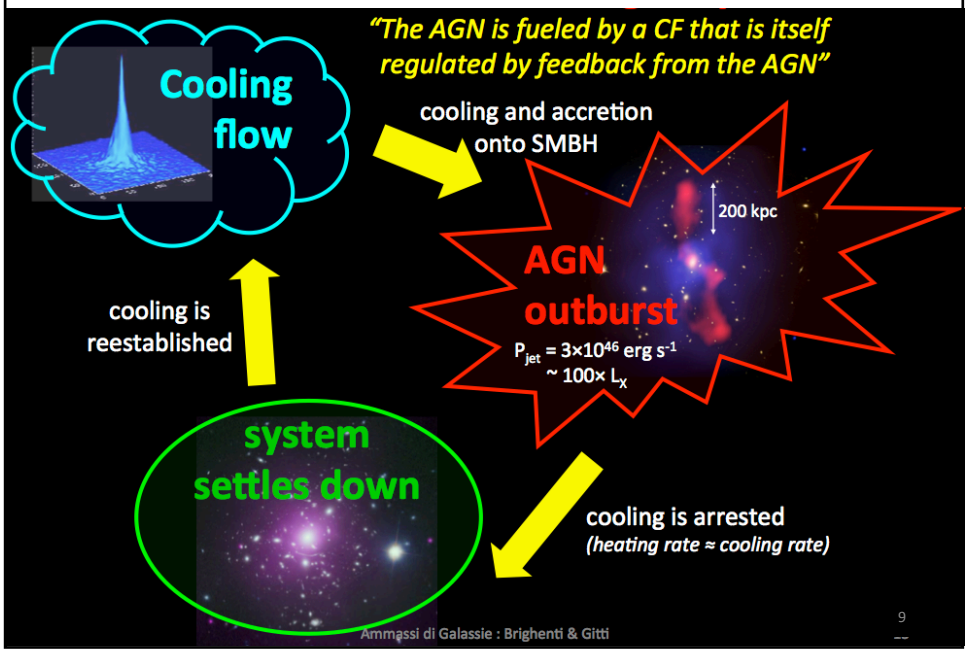
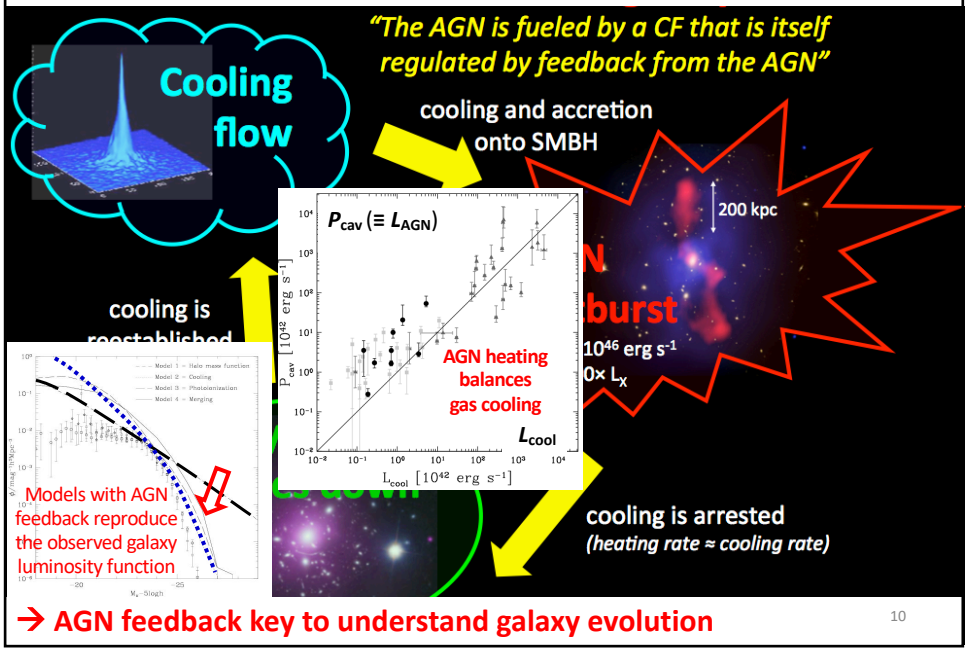
AGN feedback cycle

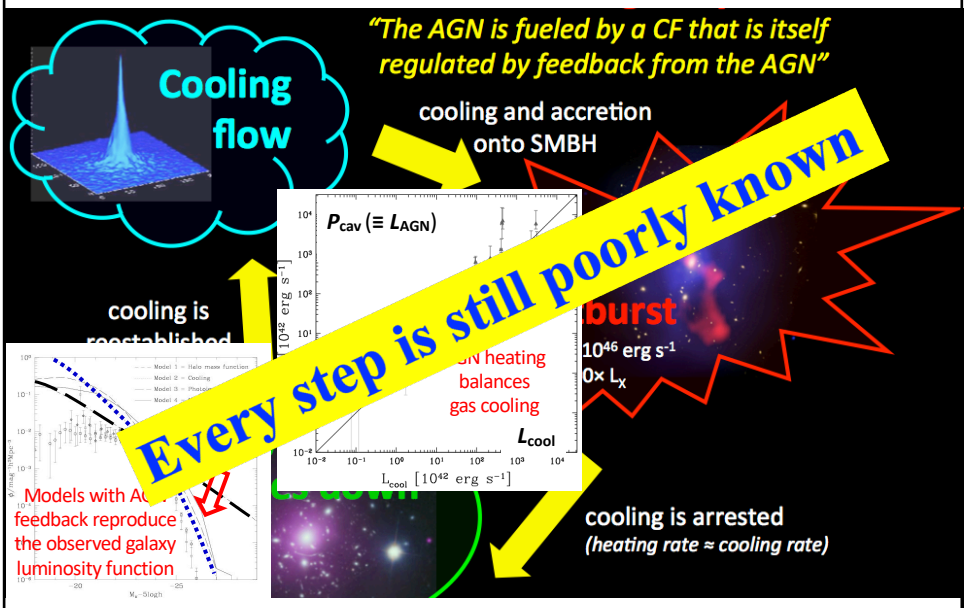


AGN feedback cycle



→ AGN feedback key to understand galaxy evolution

AGN feedback cycle



→ AGN feedback key to understand galaxy evolution

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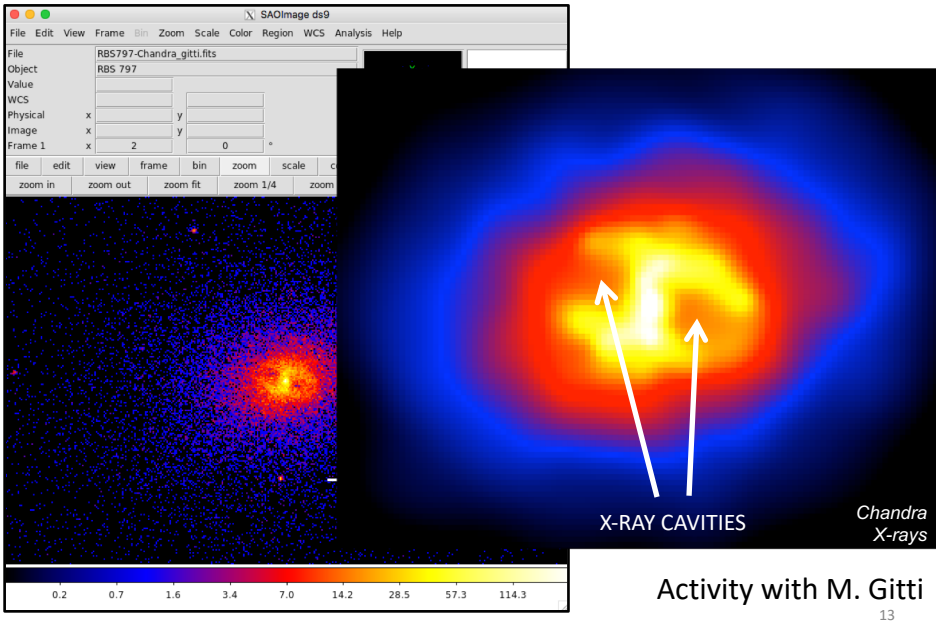
Play with real data!



Activity with M. Gitti

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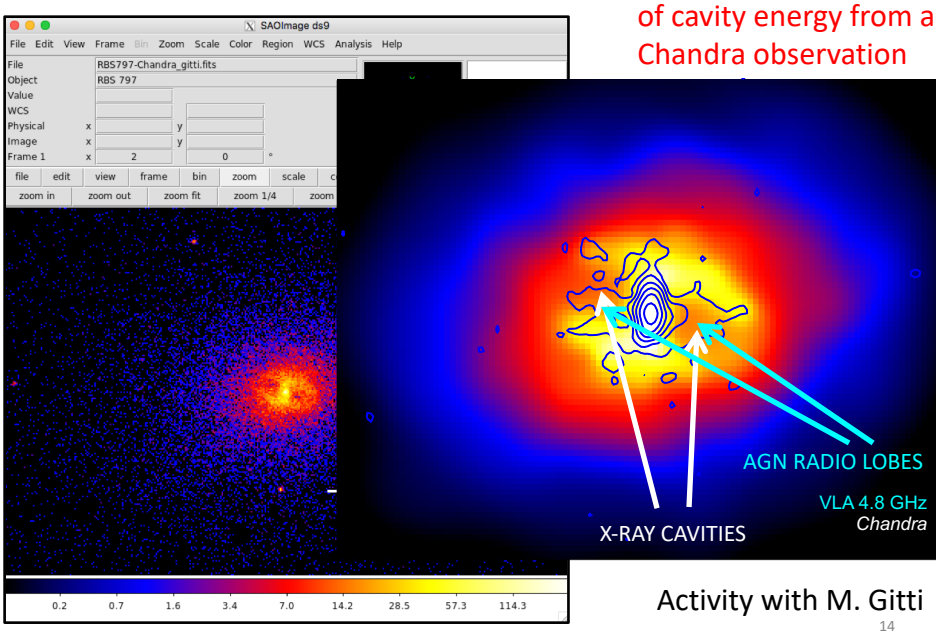
Play with real data!

→ Try your own estimate of cavity energy from a Chandra observation



Activity with M. Gitti

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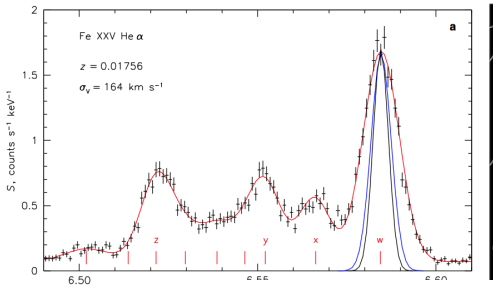
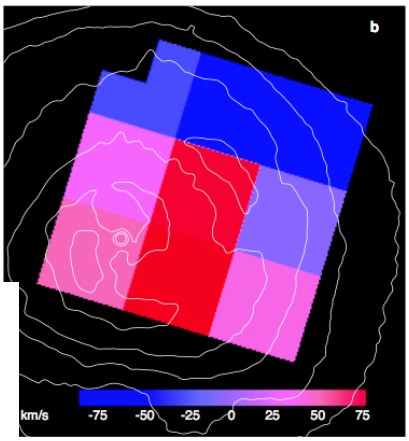
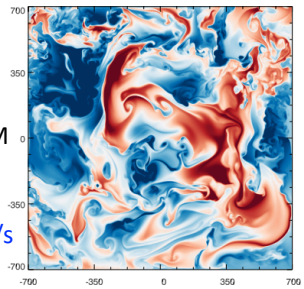
A hot topic: turbulence

Observations: Hitomi, 2016





Simulations: mergers generate strong fluid turbulence in the ICM



$E_{turb} \approx$ 10-30% E_{therm}

$\delta v_{turb} \approx$ 300-1000 km/s

more instruments to come: important in the near future

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Metals (Fe, Si, O, Mg…)

Fe

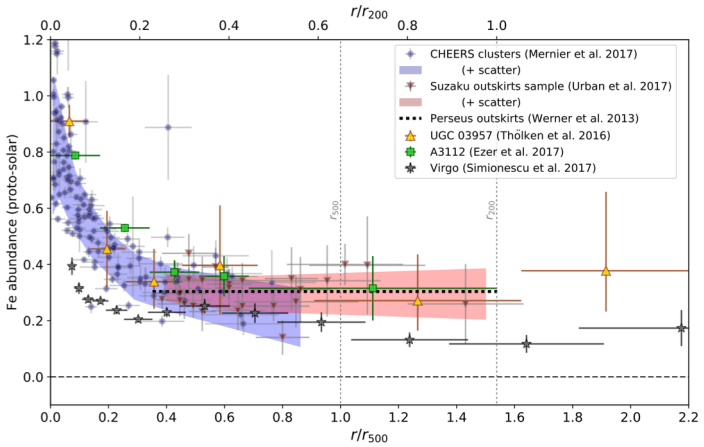

Fig. 3 Measured radial Fe abundance profile in cool-core clusters compiled from recent works. The conversion $r_{500} \simeq 0.65\, r_{200}$ is adopted from Reiprich et al. (2013). The blue cir-

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Galaxies are also strange, and so do strange things

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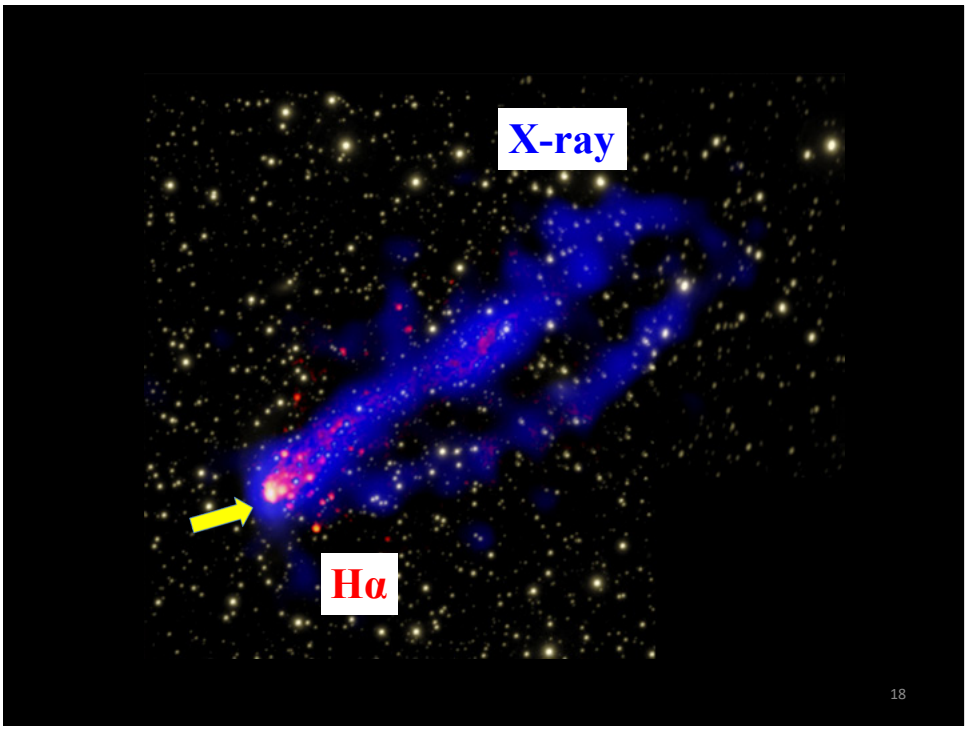
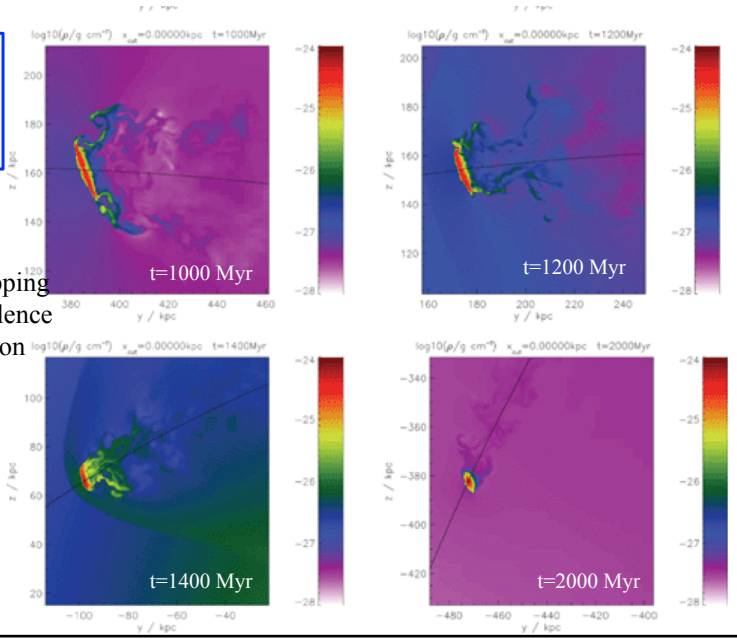


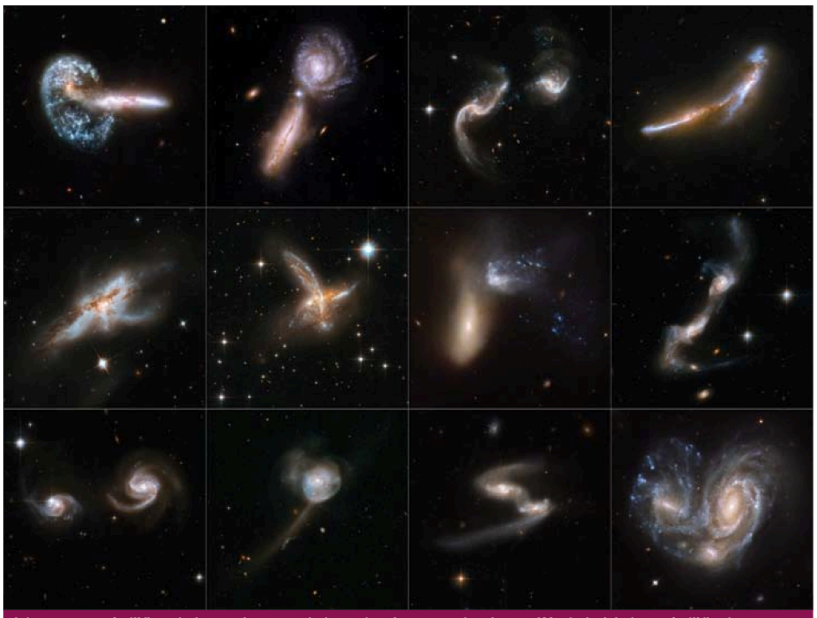
Galaxy-cluster interaction: ram pressure

Theory
⇓
Simulations

- galaxy orbit
- ram pressure stripping
- viscosity & turbulence
- thermal evaporation

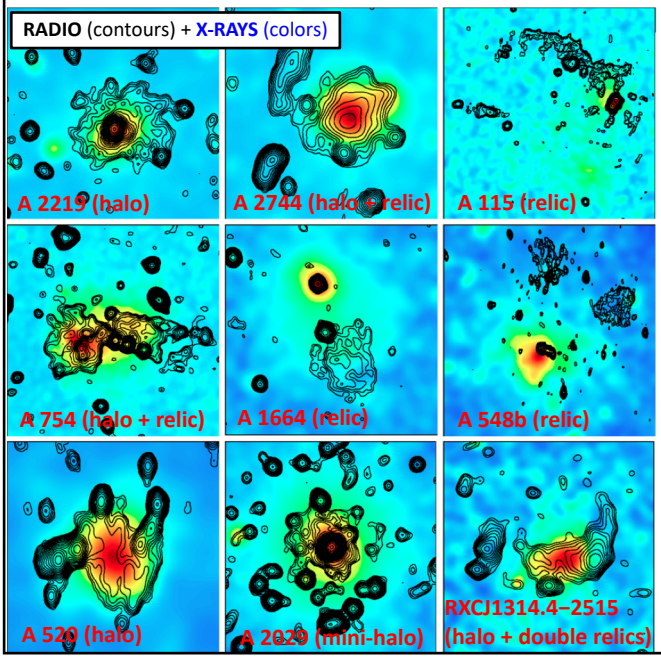


Dynamical interaction



4: An assortment of colliding galaxies at various stages. In the nearby universe around one in every 100 galaxies is in the act of colliding, but mergers were more common long ago when galaxies were closer together. (NASA, ESA, the Hubble Heritage [STScI/AURA]-ESA/Hubble Collaboration, and A Evans [Univ. of Virginia, Charlottesville/NRAO/Stony Brook Univ.])

Diffuse radio emission



- Halos
- Relics
- Mini-halos

✓ Not associated with any individual galaxy
✓ No optical counterpart
✓ Large size (~100s kpc- 1 Mpc)
✓ Low surface brightness (~μJy/arcsec^2 at 1.4 GHz)
✓ Steep spectral index

Origin: re-acceleration

(mini-) halos ↔ Turbulence
relics ↔ Shocks

Lecture by M. Gitti

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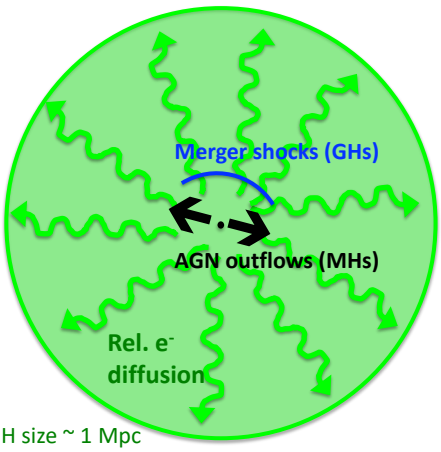
Origin of the diffuse radio emission of (mini)-halos

Diffusion time ≫ Radiative lifetime → ***Slow diffusion problem***

($\gg 10^9$ yr) ($\approx 10^8$ yr)



GH size ~ 1 Mpc
MH size ~100s kpc

- ***Hadronic* models** :

  Secondary electrons generated by p-p collisions in cluster volume

*(**GHs**: Dennison 80; Blasi & Colafrancesco 99, Miniati et al. 01; Keshet & Loeb 10, Ensslin 11,..*
__MHs__: Pfrommer & Enßlin 04, Zandanel et al. 13)

- ***Leptonic* models** :

  Re-acceleration of rel. electrons by MHD turbulence in the ICM

*(**GHs**: Petrosian 01; Brunetti et al. 02, 04, 07; Cassano & Brunetti 05, Petrosian & Bykov 08, ..*
__MHs__: Gitti et al. 02, 04; ZuHone et al. 13)

Lecture by M. Gitti

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Recap

- Learn about **AGN feedback physics** (from black hole accretion to 100s kpc-scale shocks. For galaxies too…)
- Learn how **cluster environment modifies the evolution of galaxies**
- Learn the **thermal, dynamical & chemical evolution of the ICM**
- Learn about **magnetic field** & **relativistic particles**
- Learn about **plasma microphysics**
- Learn how to use clusters for **cosmology** (just a little)

✓ **Theory and observations**

✓ **Emphasis on current, debated "hot topics"**

(this means we'll learn to read **research papers**)

✓ **strong connection with GFE, AGN, Cosmology, Gas Dynamics…**

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Cluster people @ DIFA

Lots of local researchers works on Galaxy Clusters

Theory: Hydro or MHD simulations

Observations: X-ray, AGN feedback, galaxy stripping, ..
Radio: **B**, relativist particles, plasma physics, jets, ..

Strong collaboration with scientists at INAF (for both theory & observations)

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The aftermath: Laurea & PhD thesis on this subject

Theoretical projects (Fabrizio Brighenti et al.):

hydro simulations of AGN feedback
hydro simulations of gas cooling in clusters
hydro simulations of turbulence in galaxy clusters
hydro simulations of mixing/evaporation of cold clouds

Observational projects (Myriam Gitti et al.):

X-ray observations (Chandra) of shocks, X-ray cavities
X-ray observations of sloshing gas
Hot and cold gas observations of ICM (cooling/heating cycle)
Radio observations (JVLA/LOFAR) of jets, lobes, diffuse emission

Close collaboration with other Institutions: INAF-Bo, Padova, CfA-Harvard, HST, NASA, and more

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Exam (Brighenti + Gitti)

Oral: discussion, physical understanding, ability to deal with an astrophysical problem

When? Talk to us

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