Effects of X-ray Emitting Hot Plasmas on the Galaxy Evolution

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X-ray emitting plasma (ICM=Intra Cluster Medium), more massive than galaxies, may provide a major origin of the environmental effects

(1) Makishima+01, *PASJ* 53, 401 (2) Takahashi+09, *ApJ* 701, 377
(3) Gu+13 *ApJ* 767, id. 157 (4) Gu+16 *ApJ* 826, id. 72
(5) Gu, Makishima, & Kawaharada, *in prep.*

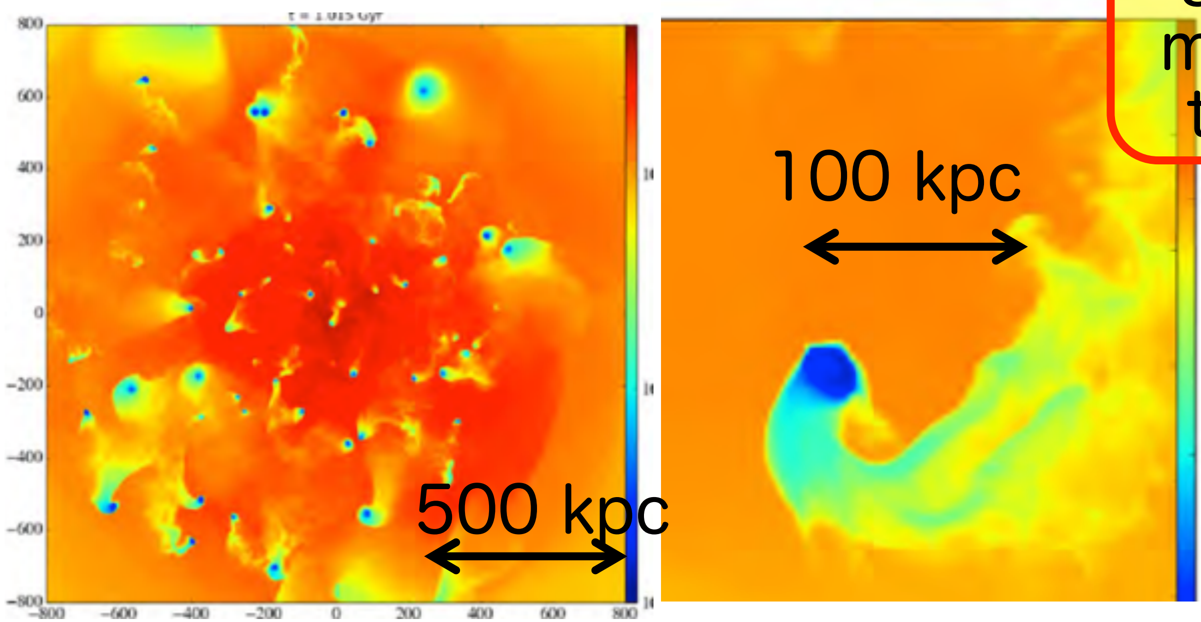
1. Introduction

Hereafter CLG

PhD Thesis, Rukumani Vijayaraghavan *(2015 U. Illinois)*

"Clusters of galaxies are harsh environments for their constituent galaxies. A variety of physical processes effective in these dense environments transform gas-rich, spiral, star-forming galaxies to elliptical or spheroidal galaxies with very little gas."

Over t_H, a galaxy "sweeps" an ICM mass comparable to its own mass



Temperature maps of ICM in a simulated young CLG (Vijayaraghavan +Ricker 2017)

2. *There are no Cooling Flows!*

- ✧ *ASCA* (1993~2001) : The worlds' first X-ray imaging spectroscopy mission in a broad (0.3~10 keV) band.
- ✧ Contrary to the *group hypnosis* (集団催眠) of Cooling Flow picture, ICM at the CLG center was not cooling below kT~1 keV (Makishima+01, *PASJ*)
- ✧ The ICM is heated by some mechanism.

The emperor's new clothes

劇団四季「はだかの王様」
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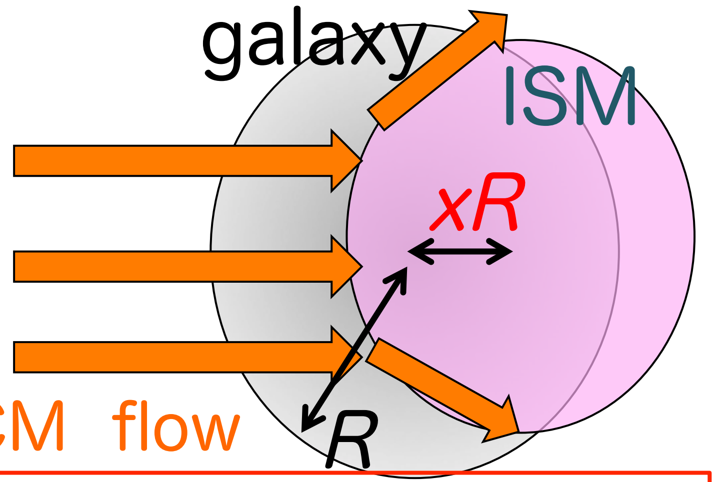
- ✧ Moving gal's strongly interact with the ICM, and create turbulence.
- ✧ The turbulence is dissipated as ICM entropy, which stops CFs.
- ✧ Gal's thus loose dynamical energy, and fall to the CLG bottom on ~t_H.

3. How Galaxies interacts with ICM

- ICM, in-flowing with velocity v, exerts ram pressure to ISM.
- If it is mild, ISM is displaced by xR (Roediger +2015).
- By gravity, the displaced ISM pulls the whole galaxy.



$$x \sim 0.5\ (\gamma/0.01)^{-1}\ (R/10\mathrm{kpc})^{4}\ (n_e/10^{-3})\ (M_g/10^{11} M_0)^{-2}\ (v/10^{8})^{2}$$

fractional ISM mass (γ) | ICM density (n_e) | galaxy mass (M_g) | in-flow velocity (v)

- When x<1, ISM is bound, and keep interacting.
- Even an elliptical galaxy (γ~0.01) can interact with the in-flowing ICM and create ICM turbulence.
- Dynamical friction provides additional interaction.

4. Cosmological Galaxy Infall

Using two samples, the optical/X-ray angular extent ratios of CLGs were studied for its evolution.

Sample I: selected 34 relaxed CLGs

✧ Over z=0.08 ～0.89

✧ Optical: Own data with UH88 multi-band photo

✧ X-ray: Archives from *Chandra* & *XMM-Newton*

✧ Gu,..Kodama, Shimasaku, KM+13, *ApJ* **767**, 157

Sample II: 340 relaxed CLGs

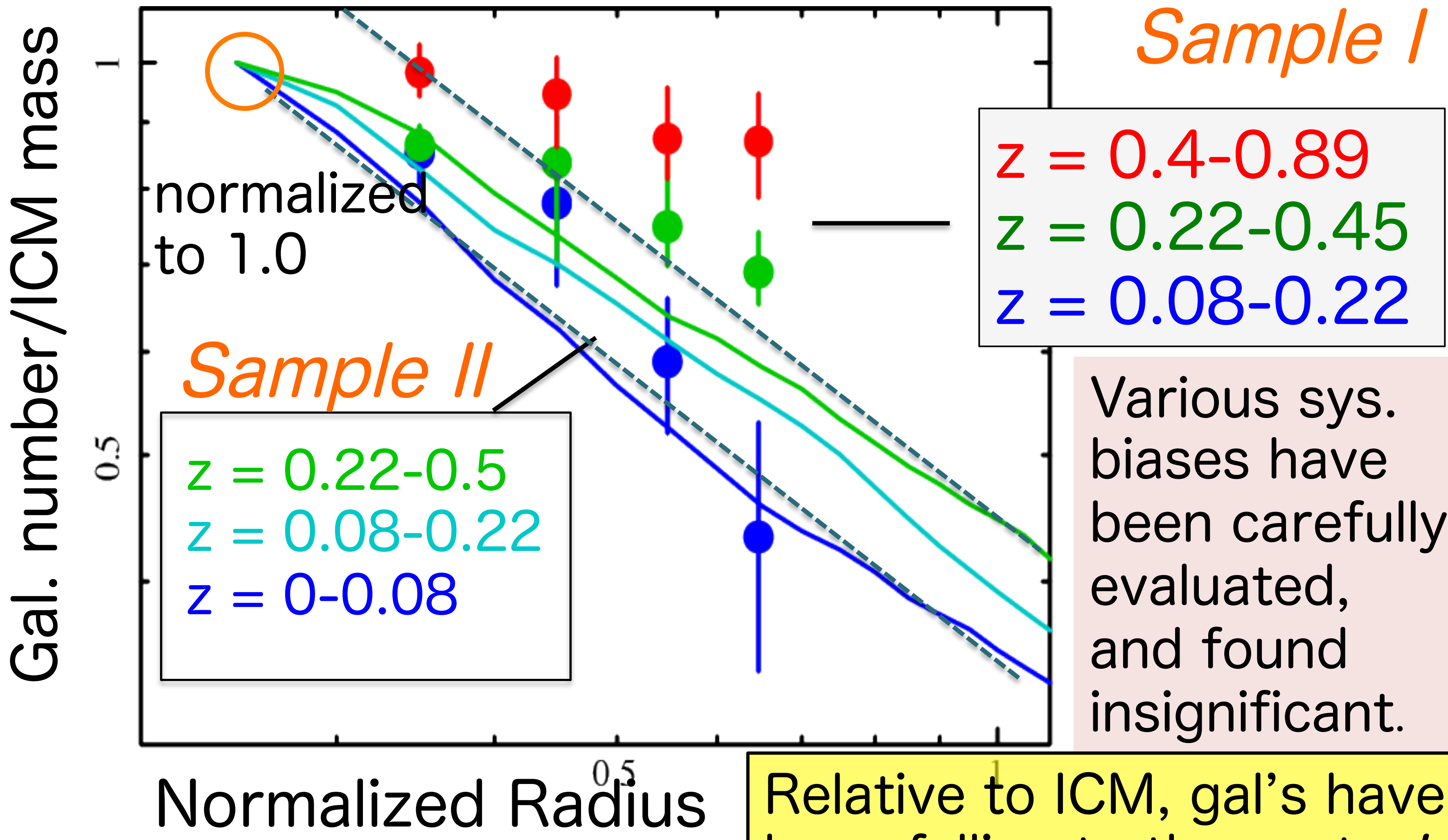
✧ over z=0.01 ～ 0.50

✧ Optical: SDSS, partially spectroscopic

✧ X-ray: the same as above

✧ Gu, Makishima +16, *ApJ*, **826**, id 72

2D integ. gal. num./ 2D integ. ICM mass

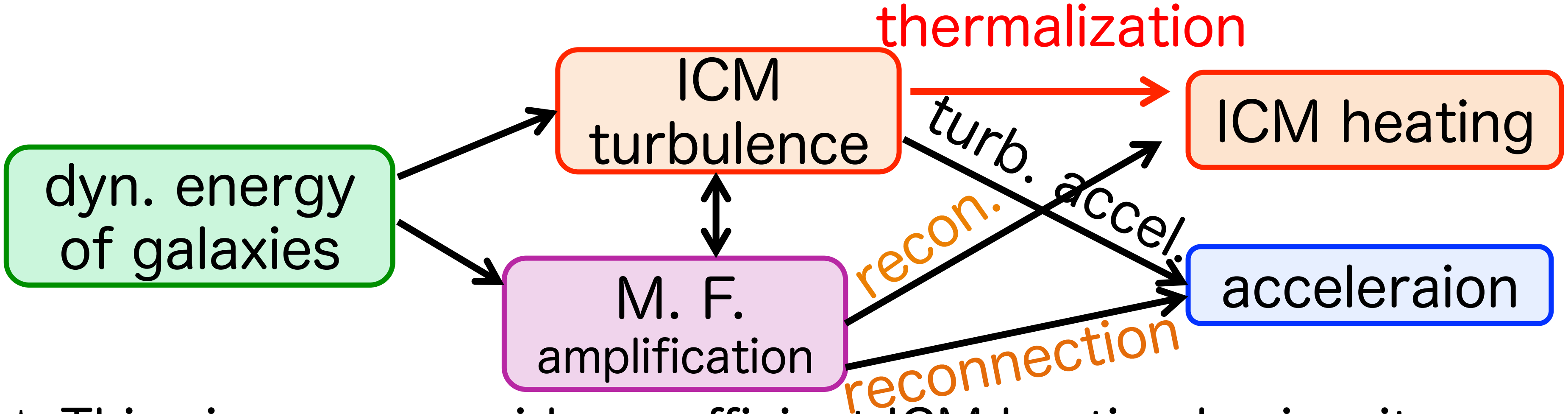


Various sys. biases have been carefully evaluated, and found insignificant.

Relative to ICM, gal's have been falling to the center*!*

5. Mild ICM Turbulence

Hitomi results on the Perseus CLG: The ICM turbulence is subsonic, σ=160 km/s ~s/5, and rather uniform over the central ~100 kpc (Hitomi collaboration 2017).



✧ This view can provide a sufficient ICM heating luminosity over t_H, and explain the *Hitomi* results (Gu, KM+*in prep.*).

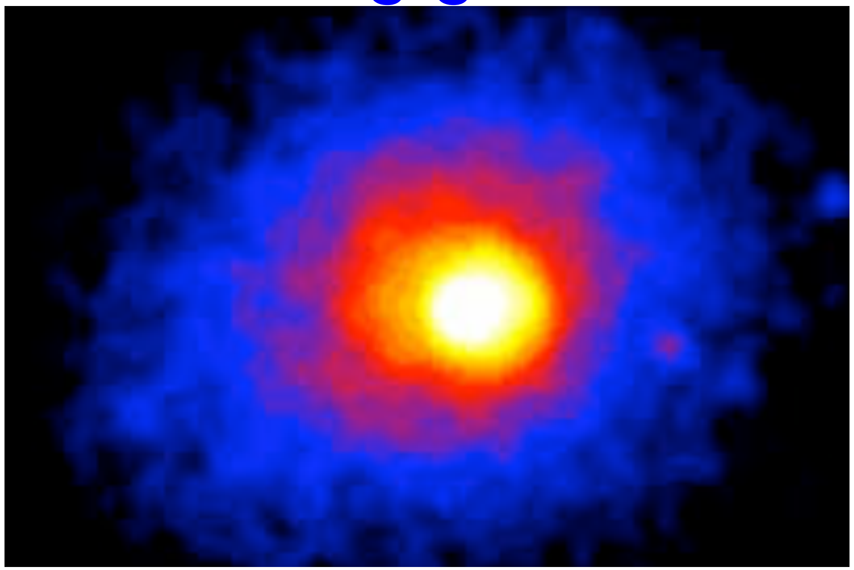
✧ A contrasting view of "turbulence/heating due to AGN jets" fails to explain the *Hitomi* results.

✧ The overall process should significantly affect the galaxy evolution, and drive the environmental effects !

6. A Lesson (教訓)

Optical astronomers considered only galaxies, neglecting the dense plasma environment.

X-ray astrophysicists considered only ICM, neglecting the role of moving galaxies.



Because of insufficient interactions between the two communities, the important subject of galaxy vs. ICM interaction remained unexplored.

7. Conclusion

The galaxy-ICM interaction scenario can explain:

1. The ICM heating mechanism to stop Cooling Flows.
2. The observed cosmological (z~1 to 0) galaxy in-fall.
3. Distributions in z~0 clusters: Gals<DM<ICM~metals.
4. The subsonic and uniform turbulence in Perseus.

The scenario will also explain the environmental effects, via gas removal and "quenching".

In order to explore this novel possibility, enhanced interactions are highly encouraged between the optical and X-ray communities.