The MACRO galaxy cluster project: What can we suggest?

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The mass- and volume-completed MACRO galaxy cluster sample

The Aim

We expect to make some suggestions to observations using simulated galaxy clusters with mock observation softwares in both optical and X-ray bands.

The Cosmological Simulations

- Standard ΛCDM cosmology parameters: $\Omega_m = 0.24; \Omega_b = 0.04; h = 0.72; \sigma_8 = 0.8; n_s = 0.96$.
- Simulation resolution: 2×1024^3 particles; Boxsize $410h^{-1}Mpc$ on each side; softening length $7.5h^{-1}kpc$. Particle masses: $\sim 7 \times 10^8, \sim 4 \times 10^9 h^{-1} M_\odot$.
- Simulation details: The DM run treats all particles as dark matter particles; The CSF run includes gas cooling (C), star forming (S), and SuperNova feedback (F); The AGN run also takes the AGN feedback into account.

More details of these simulations can also be found in Cui et al. 2012, 2014.

The MACRO galaxy cluster catalogue

- Halos are identified with the spherical overdensity (SO) package – PIAO (Cui et al. 2014).
- From DM run, we select out ~180 halos, which have $M_{200} \geq 2.0 \times 10^{14} h^{-1} M_\odot$.
- Using the unique dark matter particle ID, all the halos from the CSF and AGN runs are matched to these selected halos from the DM run.

Mock observation images

- Optical: star particles are treated as a simple stellar population. Based on the synthetic code (Cui et al. 2011), we produced the SDSS u, g, r band images of these clusters.
- X-ray: PHOX is used to generate X-ray photons (Biffi et al. 2012). The realistic image is convolved with the response matrices of Chandra detector with 50ks exposure time.

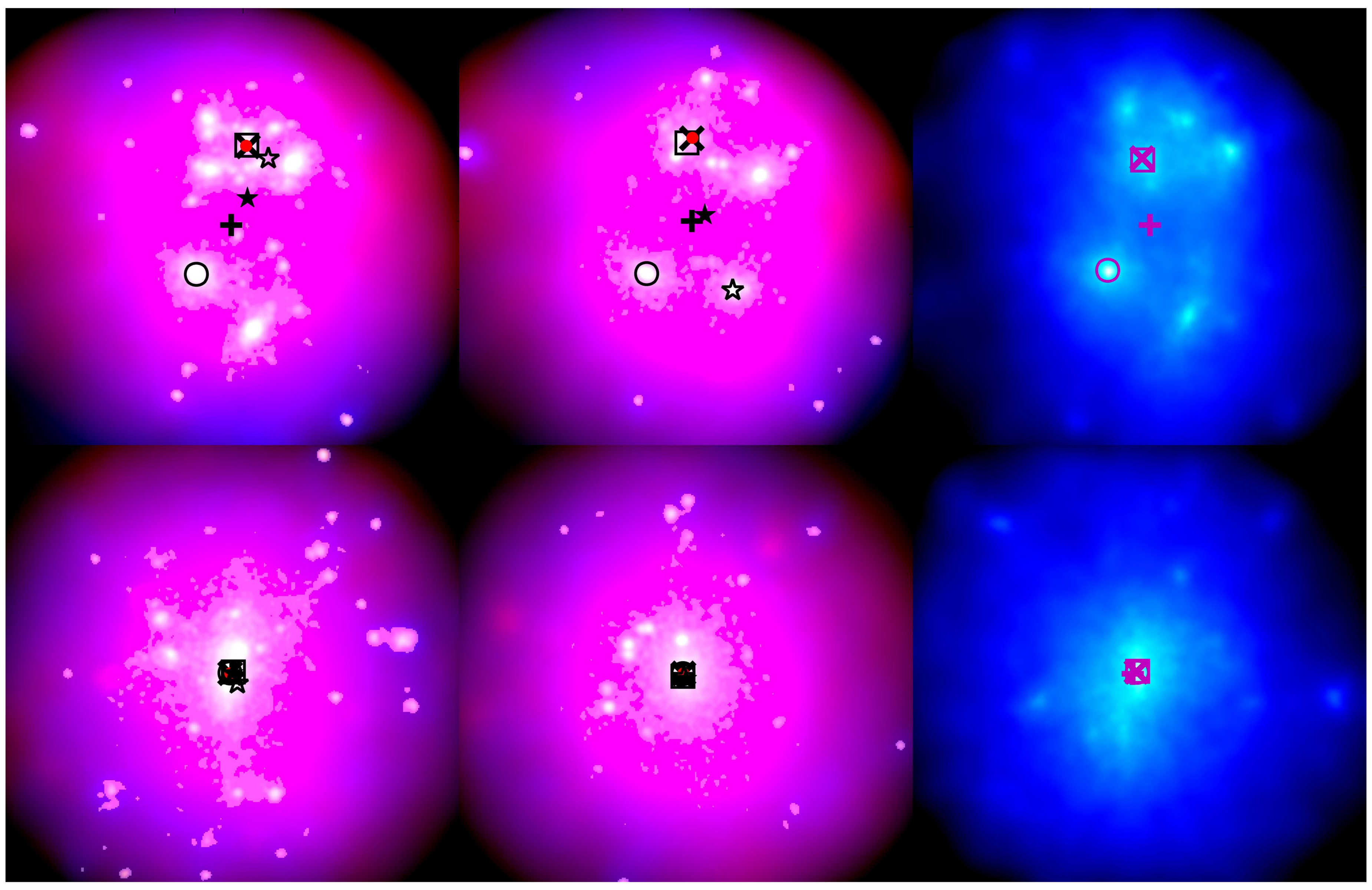

Figure : Two galaxy cluster examples with different versions of simulations. Upper row shows an unrelaxed galaxy cluster, while the lower row is for a relaxed one. From left to right panels, the galaxy clusters are from the AGN, CSF, and DM runs. Blue color is coding to the dark matte density; while red color is for the gas density. White regions are the stellar luminosity map in SDSS r-band.

The galaxy cluster centers (Cui et al. 2016a)

The definitions of the galaxy cluster center

- Theoretical definitions: minimum potential position, maximum density position (estimation methods: SPH, Voronoi tessellation, etc.).
- Optical centre: the position of the BCG.
- X-ray centre: Centroid, X-ray peak.

The offsets between different definitions

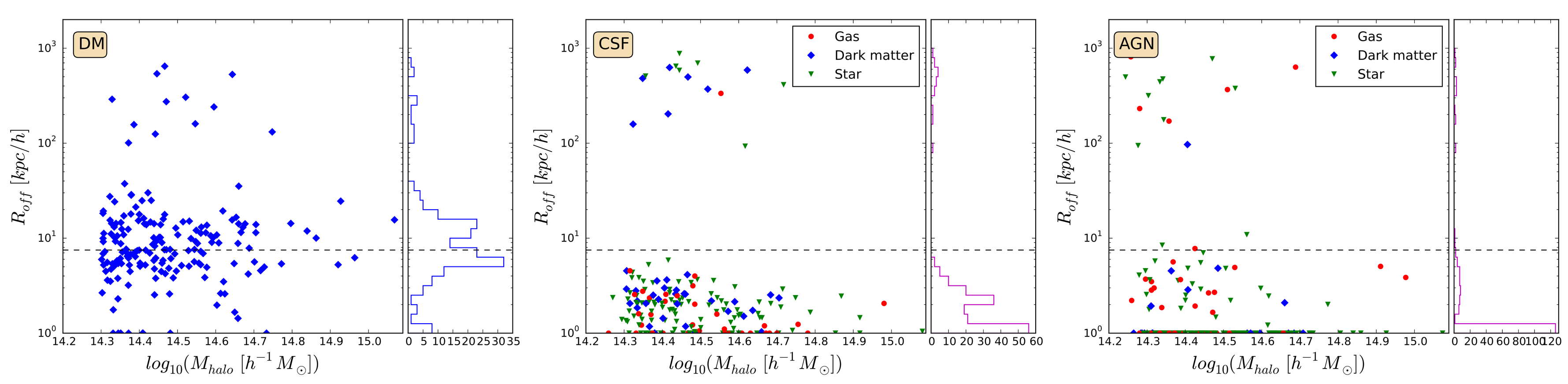

Figure : The offsets between potential center and density center. There is a good consistency between the minimum potential center and the maximum density center. The large offsets for some clusters are simply caused by large in-falling substructures.

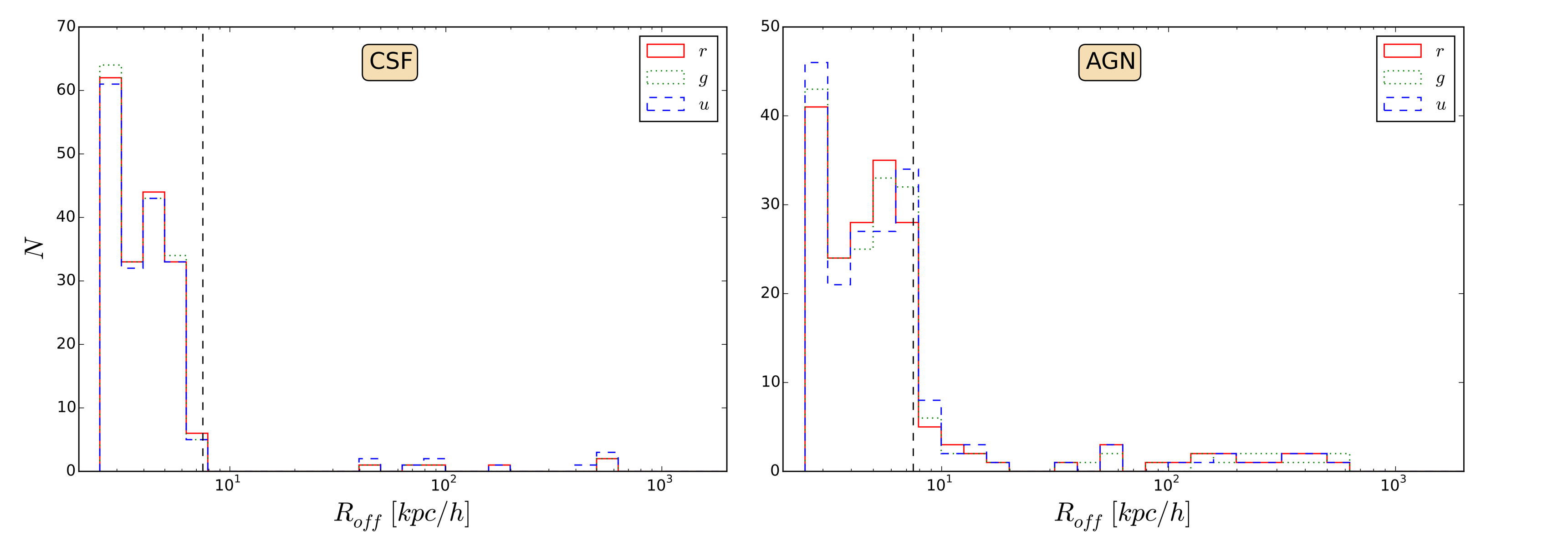

Figure : Offsets between potential center and optical center. Similar to the upper plot, the optical center is in good agreement with the potential center for both hydro-dynamcial runs.

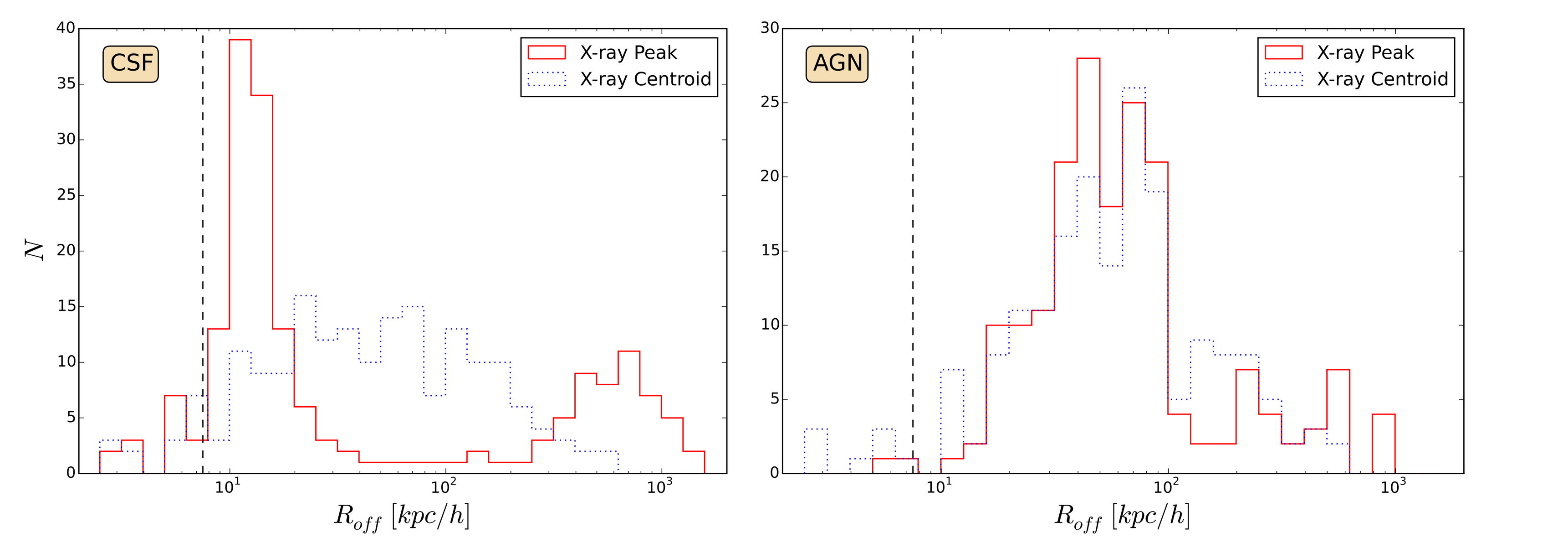

Figure : Offsets between potential center and X-ray center. **Compared to the optical center, the X-ray center tends to have a larger offset to the potential center.**

The galaxy cluster dynamical state: theoretical investigation (Cui et al. 2016b)

The relaxed and un-relaxed the galaxy clusters: the theoretical classification

- Virial ratio: $\eta = (2T - E_s)/W$, here T is total kinetic energy, W is total potential energy, E_s is the energy from surface pressure.
- Center of mass offset: $\Delta_r = |R_{cm} - R_c|/R_{vir}$.
- Substructure mass fraction: $f_s = M_{sub}/M_{total}$.
- Velocity dispersion deviation: $\zeta = \sigma/\sigma_t$, here $\sigma_t = \sqrt{GM_{total}/R}$.

The relations and the relaxation fraction

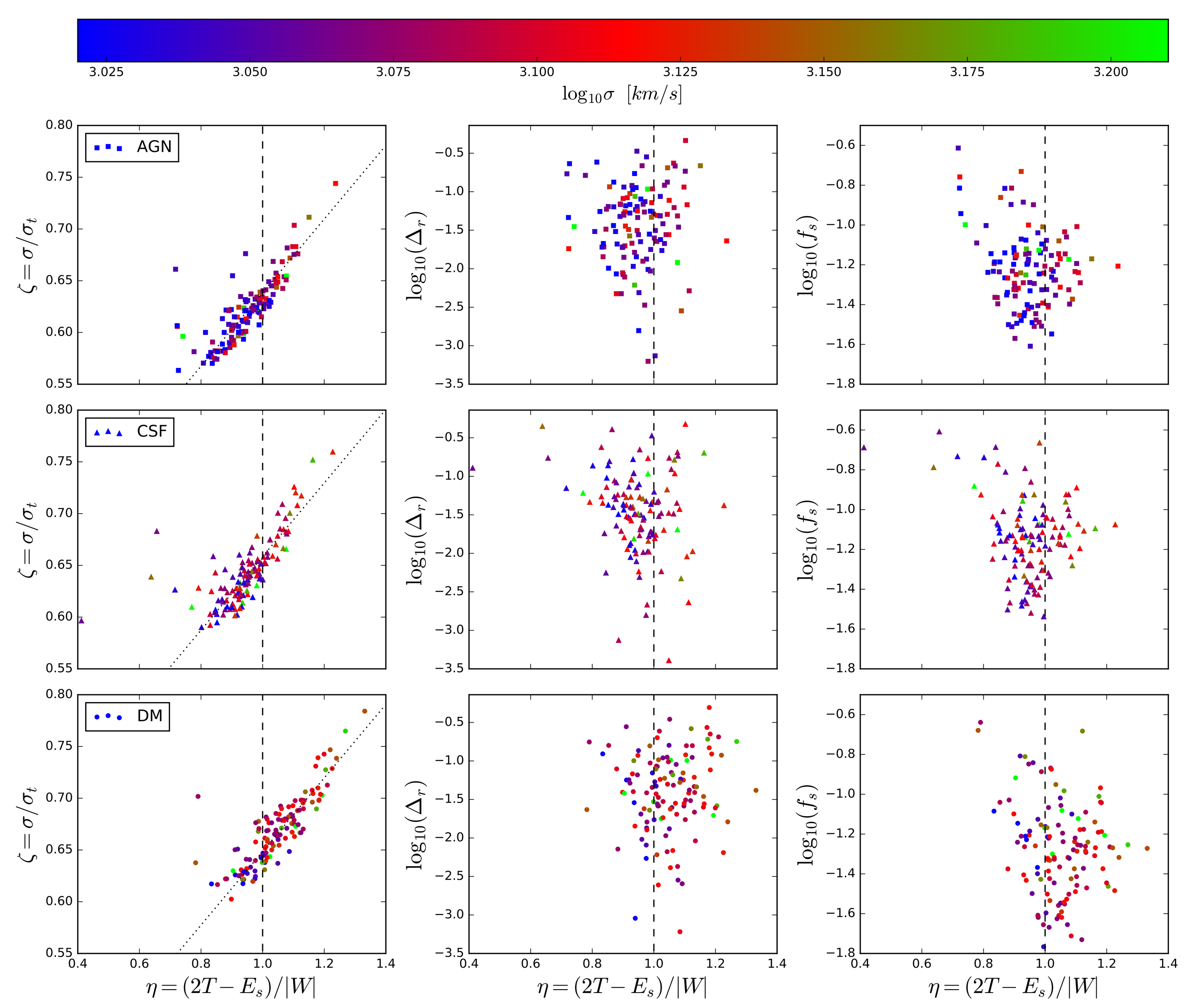

Figure : The relations between ζ (left column), Δ_r (middle column), f_s (right column) parameters and the virial ratio parameter η. From top to bottom panels, we show the results from AGN, CSF and DM runs. The symbol color is coding to its velocity dispersion indicated in the colorbar on the top of the plot. **1) There is no clear bimodal distribution between the relaxed and un-relaxed clusters from these parameters. 2) Dotted lines in the left column are the fitting results to the data points with a fix slope of 0.355. There is a good correlation between η and ζ, which also shows no dependence on baryon models. 3) Applying a restricted cut for these parameters, $\sim$ 37% are the relaxed clusters.**

References

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What can we suggest?

- Optical selected center (BCG center) is a better tracer of minimum potential than the X-ray selected center.
- There is no clear bimodal distribution between the relaxed and un-relaxed clusters. The correlation between η and ζ suggests a new way in observation of calculating η parameter for the cluster dynamical state. In addition, baryon effect is not strong, the η parameter from the CSF/AGN runs is $\sim$ 10% lower than from the DM run. However, the relaxation fraction is less affected (see our paper Cui et al. 2016b for the detail).
- We will tell you more about the differences between the classification methods (in all theoretical, optical and X-ray aspects) on cluster dynamics. Please keep eye on it, which will come out soon.