A WISE-Chandra view of baryon content evolution in clusters

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abstract

We study the relationship between two major baryonic components in galaxy clusters, namely the galaxies and the intracluster medium (ICM), using 94 clusters that span the redshift range 0-0.6. Accurately measured total and ICM masses from *Chandra* observations, and stellar masses derived from *Wide-Field Infrared Survey Explorer* (WISE) and *Two-Micron All-Sky Survey* (2MASS) allow us to trace the evolution of cluster baryon content in a self-consistent and self-contained fashion. We find that the evolution of the ICM mass–total mass relation is consistent with the expectation of self-similar model, while there is no evidence for redshift evolution in the stellar mass–total mass relation. This suggests that the clusters acquire their gas and galaxy contents in different ways.

introduction

There have been many studies of cluster baryon content at z~0. Such studies using large cluster samples at higher redshifts are in short supply. The first attempt has been made with the X-ray selected groups at z=0.1-1 detected in COSMOS field (Giodini et al. 09). Our analysis is complementary in the sense that we probe the high mass end, with accurate X-ray measurements.

Our analysis relies on the X-ray measurements to provide the cluster center, size, and the mass of the ICM. For each cluster, we use the background-subtracted total flux to estimate the total cluster luminosity and stellar mass. We then examine correlations among the mass components and their evolution.

data

cluster samples

- low-z sample: 49 z<0.1 clusters from Lin et al. (04)
- intermediate-z sample (z=0.1-0.6): 16 from Chandra subsample of ROSAT 400d survey (Vikhlinin et al. 09) and 29 from Maughan et al. (08)
- total mass M_{500}, ICM mass M_{ICM}, and stellar mass M_{star} are all measured within r_{500}
- total mass derived from Y_X–M_{500} relation
- this is the largest cluster sample used for this purpose to date

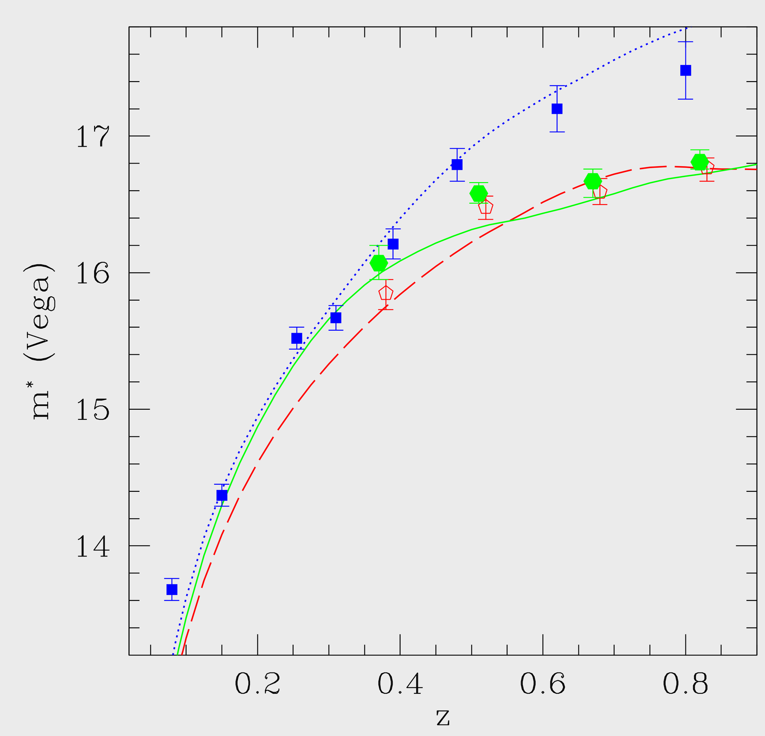
WISE data

We use the preliminary data release from WISE, which covers 57% of the sky. For each cluster we obtain data out to 5-10 r_{200}, so that we can determine the local background well.

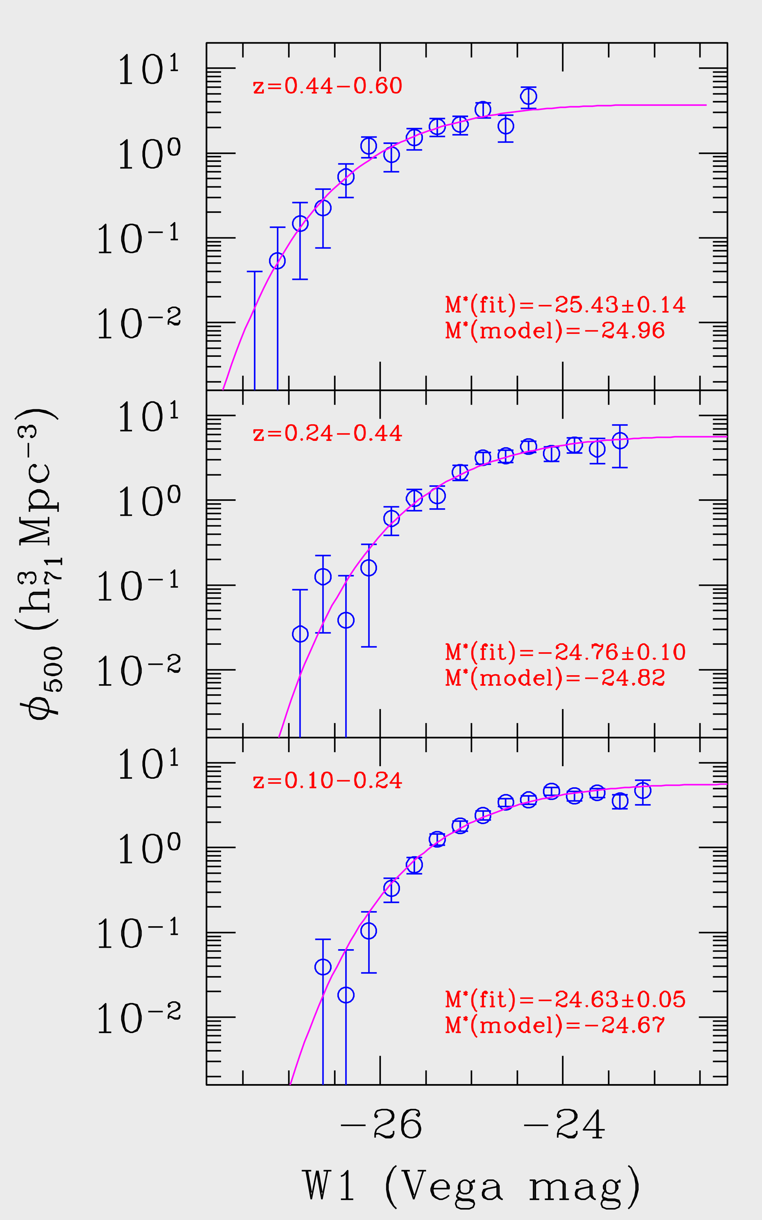
Stellar contamination is removed by using 2MASS data. We discard all WISE sources located within 2" of a 2MASS point source from the WISE catalog. Based on comparisons to deep optical and near-IR data, we find that this effectively removes 93% of the stars from our catalogs. The remaining stars would be subtracted statistically.

stellar mass

For k-correction, we use the updated version of Bruzual & Charlot (03) model to obtain predictions for a single population formed in a burst at z=3, with Kroupa initial mass function (IMF). The model is normalized such that it gives adequate description for the evolution of m* (characteristic magnitude in luminosity function, LF) at 2.2, 3.6, and 4.5 microns (blue, green, and red points below; data from Mancone et al. 10).



The composite LFs below show that the BC model provides a decent description of the cluster galaxy evolution.



The BC model provides a way to infer the luminosity evolution of cluster galaxies, as well as the stellar mass-to-light ratio Υ.

For each cluster, we sum up fluxes in WISE channel 1 (W1) down to m*(z)+1.5 within r_{500}, subtract expected background flux from an annulus of width 4-5 r_{200}. The flux is then converted into luminosity [by integrating the LF down to M*(z)+2], L_{500}, and stellar mass is obtained as $M_{star}=L_{500}\,\Upsilon$.

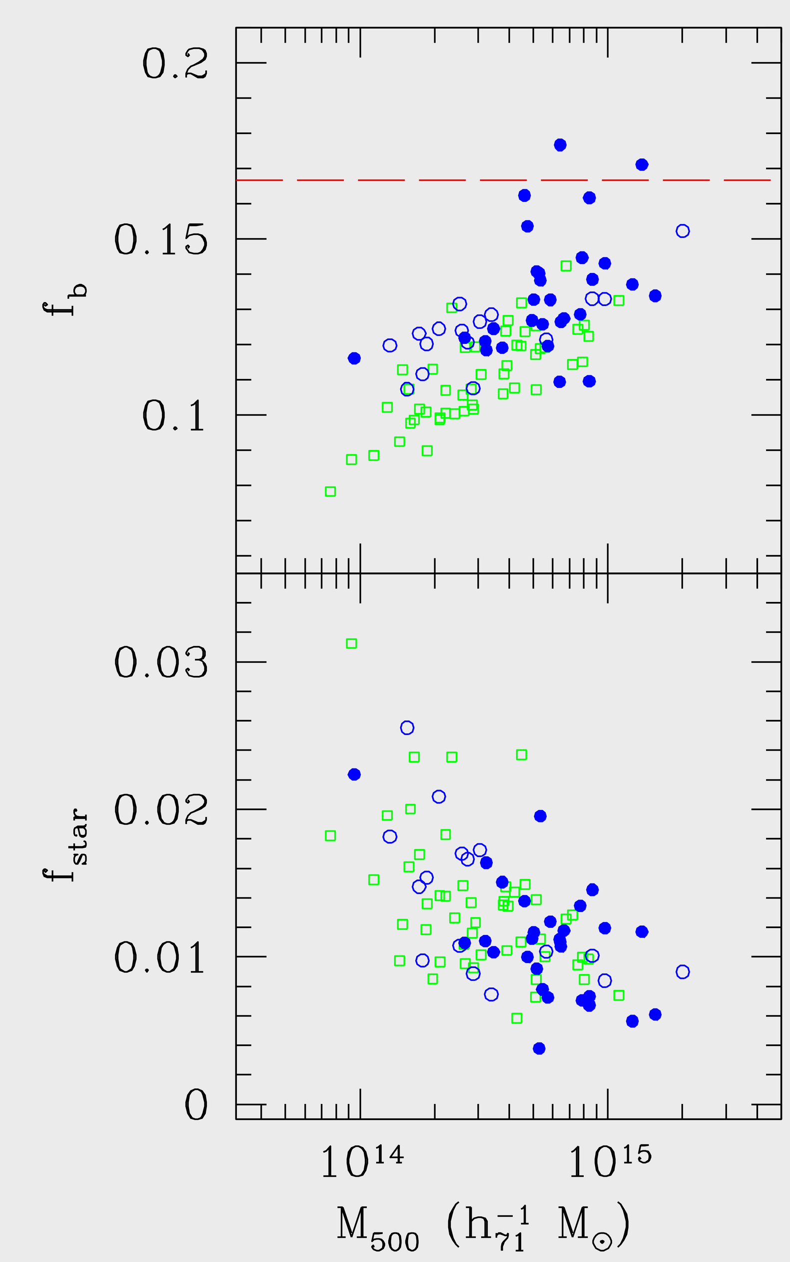
For our z<0.1 clusters, we take the total luminosity measurements from Lin et al. (04), which is based on 2MASS K-band data. We multiply the total light with the K-band mass-to-light ratio from the BC model to estimate the stellar mass.

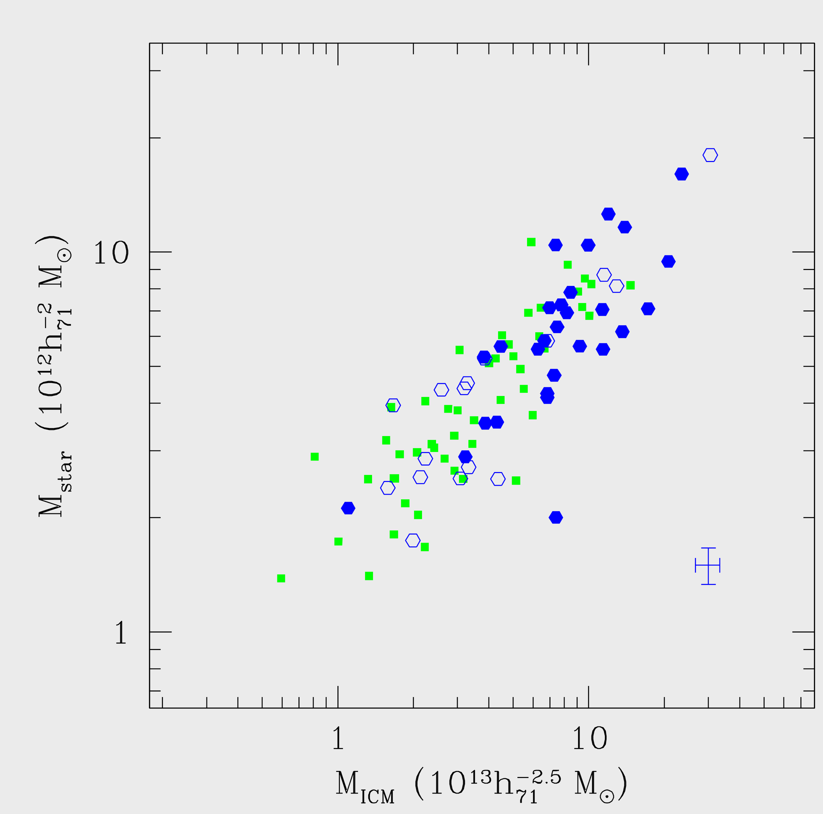
scaling relations

Our dataset allows us to examine three scaling relations with a large cluster sample across a wide redshift range:

- stellar mass vs total mass
- ICM mass vs total mass
- stellar mass vs ICM mass

We show below the total baryon fraction, stellar mass fraction, and the M_{star}–M_{ICM} correlation. In these figures, green points are z<0.1 clusters, while blue ones are at z=0.1-0.6 (solid: Maughan sample; open: Vikhlinin sample).





To examine any redshift evolution, we fit the data with the form

$$M_{\rm star} \propto M_{\rm ICM}^{s_1}(1+z)^{\gamma_1}$$

$$M_{\rm star} \propto M_{500}^{s_2}(1+z)^{\gamma_2}$$

$$M_{\rm ICM} \propto M_{500}^{s_3}(1+z)^{\gamma_3}$$

and find that

$(s_1,\gamma_1)=(0.62\pm0.04,-0.41\pm0.22)$,
$(s_2,\gamma_2)=(0.70\pm0.05,-0.13\pm0.21)$,
$(s_3,\gamma_3)=(1.14\pm0.01,0.46\pm0.06)$,
based on bootstrap resampling.

discussion

evolution of baryons in clusters

The evolution of ICM mass–total mass relation can be understood in the context of self-similar evolution (SSE, see Vikhlinin et al. 09). Let us denote $M_{ICM} \propto M^{1+\kappa}$, where $\kappa \approx 0.14$ based on our data. Introducing the nonlinear mass scale M_{NL}, at which the rms fluctuation of linear power spectrum equals to $\delta/D(z)$, where $\delta \approx 1.68$ and D(z) is the growth factor, we expect the ICM mass fraction f_{ICM} to be the same for systems of the same M_{500}/M_{NL} at different redshifts, under SSE. We then have $f_{ICM} \propto (M_{500}/M_{NL})^{\kappa}$. Note that $M_{NL}(z)^{-\kappa}$ is consistent with $(1+z)^{\gamma_3}$ scaling up to z~0.5.

We have thus shown that the two main baryonic components in clusters appear to evolve differently: while the ICM evolve according to self-similar expectation, the stellar mass–total mass relation remains similar up to z~0.6 (that is, γ_2 is consistent with zero). The latter behavior is consistent with the finding of Giodini et al (09).

On the face value, this may indicate that clusters acquire their gas and galaxy content in different ways. Or, it implies strong dynamical evolution (e.g., tidal stripping) of galaxies once they become cluster members. It is thus critical for future studies to include the contribution from intracluster stars (e.g., Gonzalez et al. 07). Unfortunately, with the depth of WISE all-sky survey, we would not be sensitive to this stellar population. Dedicated observations with HST WFC3, or with the upcoming Subaru HyperSuprime Cam survey should be able to address this issue.

systematics

The greatest systematic uncertainty in our analysis is the choice of IMF. For example, using the Chabrier IMF would result in stellar mass-to-light ratio that is 40% lower, thus affecting the total stellar mass fraction measurements. Any systematic variation of IMF with galaxy mass or morphology would also affect the slope of the M_{star}–M_{500} correlation.

references

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