XMM-Newton/SDSS: star formation efficiency and constraints on the matter density parameter

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Abstract

It is believed that the global baryon content of clusters of galaxies is representative of the matter distribution of the universe, and can, therefore, be used to reliably determine the matter density parameter Ω_m. The basic assumption of these methods is that that the global baryon fraction and the mass-to-light ratio are constant in cluster scales and they fairly represent the matter and light distribution of the Universe. This hypothesis is challenged by the growing evidence from optical and X-ray observations that the total baryon mass fraction and mass-to-light ratio increases towards rich clusters. In this context, we investigate the dependence of stellar, and total baryon mass fractions as a function of mass. To do so, we used a subsample of 19 clusters extracted from the X-ray flux limited sample HIFLUGCS that have available DR-7 SDSS data. From the optical analysis we derived the stellar masses. Using XMM-*Newton* we derived the gas masses. Then, adopting a scaling relation we estimate the total masses. Adding the gas and the stellar mass fractions we obtain the total baryonic content that was found to increase with cluster mass, reaching WMAP-7 prediction for clusters with $M_{500} \sim 10^{15}\ M_{sun}$. The stellar mass fraction diminishes as cluster mass increases, suggesting a difference in the amount of stars formed per unit of halo mass. That is, the efficiency of star formation varies on cluster scales that lower mass systems are likely to have higher star formation efficiencies. It follows immediately that, the dependence of the stellar mass fraction on total mass results in an increase of the mass-to-light ratio from lower to higher mass systems. We also discuss the consequences of these results in the context of determining the cosmic matter density parameter Ω_m.

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SAMPLE AND DATA ANALYSIS

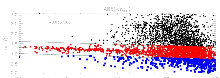
Sample: 19 HIFLUGCS clusters have DR-7 SDSS optical data available and are unbiased with respect to the original sample;

To analyze the matter distribution in galaxy clusters through the baryon mass fraction, the fundamental step relies on total, gas and stellar masses estimates. We derived all quantities within r_{500} and each determination is explained below:

1- Gas mass estimates

We determined the gas masses through the XMM-Newton X-ray data analysis.

2- *Stellar mass estimates*



DR-7 SDSS photometric data
For all galaxies within r_{500}

→

- Constrain red-sequence (RS);
- Define red and blue galaxies within r_{500};
- Histogram of the number of galaxies per bin of 0.5mag = luminosity function (LF).

BACKGROUND GALAXIES
in an outer annulus
beyond 8 x r_{500}

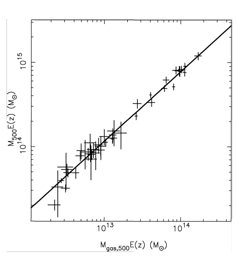
→

- Use cluster RS;
- Define red and blue galaxies within r_{500};
- Fit the background LF with a power-law;
- Statistical subtraction.

- The power-law fit to the background galaxies is then subtracted from the overall LF;
- Integrating the LF we have the total luminosity;
- Adopting a different mass-to-light ratio for red and blue galaxies (taken form Kauffmann et al. (2003) we derive the stellar masses.

3- Total mass estimates using gas mass as a proxy:

We derived the total masses from the X-ray data, using a scaling relation. We adopted this procedure instead of using the standard measurement from X-ray data under the assumption of hydrostatic equilibrium (HE) because the present sample contains relaxed and non relaxed clusters where the HE assumption may not be valid.



$$\left(\frac{M_{500}}{10^{14}M_\odot}\right) = (0.891 \pm 0.017) + \log\left(\frac{M_{gas}}{10^{14}M_\odot}\right) \times (0.83 \pm 0.22)$$

Fig.1: Total mass as a function of gas mass for 41 clustersand groups taken from Arnaud et al. (2007), Böringer et al. (2007), Sun et al. (2009), and Vikhlinin et al. (2006),. The continuous line is the power-law best fit for the data.

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RESULTS

In the panel below we show the results derived for the **gas-mass fraction (red circles)**, **stellar mass fraction (green stars)**, and **baryon-mass fraction (black triangles)** as a function of the total mass within r_{500}. For comparison, we show some of the **results in the literature from Lin et al. (2003) and Giodini et al. (2009).** The horizontal lines on the top of the figure represent the WMAP-7 result for the cosmic baryon fraction (f_b=0.171 ± 0.009; Jarosik et al. 2011).

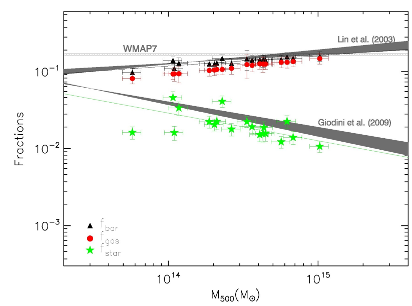

Fig. 2: baryon, stellar and gas mass fraction as a function of cluster mass. We present the results using the XMM-*Newton* X-ray data for the gas mass determination, photometric optical DR-7 SDSS for stellar mass measurements, and the scaling relation (presented in Fig.1) to derive the total mass using the gas mass as a proxy.

Baryon fraction dependence on cluster mass

The power-law fit for the total baryon mass fraction is $f_b = 10^{(-1.54 \pm 0.10)} \times [M_{500}/10^{14}\ M_{sun}]^{(-0.359 \pm 0.170)}$, and for the stellar-mass fraction is $f_{star} = 10^{(-0.93 \pm 0.018)} \times [M_{500}/10^{14}\ M_{sun}]^{(0.136 \pm 0.028)}$. Toward more massive clusters the value gradually approaches the WMAP-7 prediction, reaching it at $M_{500} = 1.6 \times 10^{15}\ M_{sun}$.

Mass-to-light ratio

The total mass-to-optical light ratio decreases toward low-mass systems, following the relation $M_{tot}/L = 10^{(2.02 \pm 0.10)} \times [M_{500}/10^{14} M_{sun}]^{(0.361 \pm 0.169)}$. This result is a direct consequence of the varying star formation efficiency on cluster scales. In this work the M/L varies from 60 M/L up to almost 300 M/L. Total mass-to-optical light ratio does not show evidence of a flattening, and the best-fit leads to a M/L = 241M/L for clusters with a total mass of $10^{15}\ M_{sun}$.

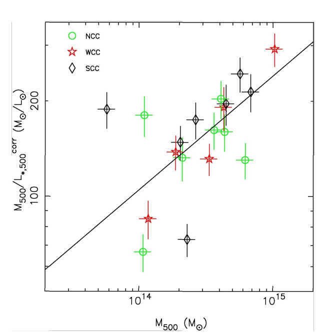

Fig. 3: mass-to-light ratio as a function of cluster mass. The green, red and black points denotes non cool-core, weak cool-core and strong cool-core clusters, respectively.

Constraints on Ω_m

We derived the matter density parameter using the Oort (1958) technique and also from the baryon-to-total mass ratio. Using these two approaches, we obtained $0.07 < \Omega_m < 0.3$ and $0.15 < \Omega_m < 0.27$, respectively. Using the baryon-to-total mass ratio to compute Ω_m seems to give narrower and more accurate range.