SFR in the X-ray Luminous z ~ 0.9 cluster

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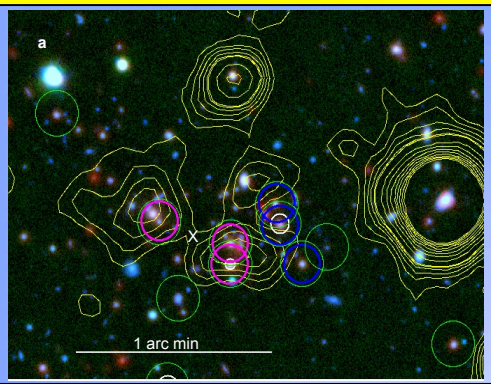
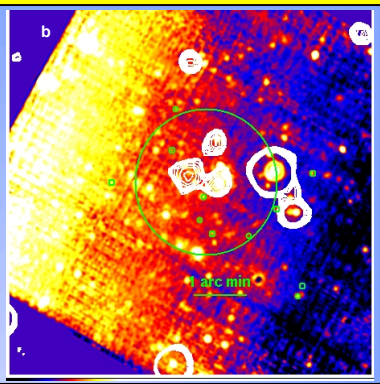
Introduction: The cluster Cl 1257+4738 was found by comparing a ROSAT image with red ground based images to pick out red galaxies from foreground bluer ones. Our study adds another cluster to the handful of clusters with $z \geq 0.9$. Each cluster provides new insights as to the relationship between the evolution of galaxies and the ICM. We acquired *Chandra*, *XMM-Newton*, *Spitzer* IRAC plus MIPS24 data to study this relationship between galaxies and the ICM. In this work we concentrate on using the *Spitzer* data to make a measure of star formation rates (SFRs) and specific star formation rates (SSFRs) as function of distance from the cluster center. The deep *Spitzer* observations of 2,000 seconds in IRAC1-4 plus MIPS24, plus Gemini spectra enabled us to cover a range of SFRs and SSFRs of ~ 100 for spectroscopically confirmed cluster members.





Figs. 1 a, Color image based on Spitzer IRAC 3.6 μm (R), Gemini z (G) and Gemini i (B) image. XMM contours in the 0.3-6 keV interval are superimposed in yellow. Green circles are galaxies that are spectroscopically associated with the cluster. The pink and blue circles indicate galaxies in the two sub-clusters detected by the Serna & Gerbal (1996) method. Big and small white circles indicate the presence or absence of [OII] emission: no white circles = no [OII], small white circles = [OII] smaller than 2 times the noise, large white circles = [OII] stronger than 2 times the noise. North is up and East to the left; a concordant cosmology is assumed, thus 463 kpc = 1 arcmin at the redshift of Cl 1257+4738 z=0.866. The white x marks the approximate cluster center based on the centroid of the X-ray emission. For Fig 1b, the MIPS24 > 5σ detections of cluster members are in the small green circles. The large ~ 1.34 arc min radius circle is the virial radius = 640 kpc.

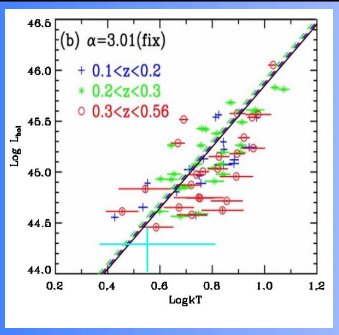


Fig 2. L_X versus kT for low redshift clusters from Ota et al. 2006, plus our data point shown as a light blue cross.

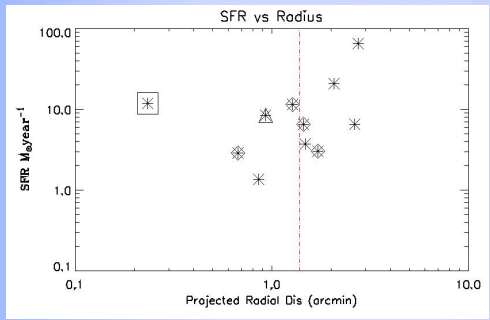


Fig. 3 Star formation rate (SFR) versus distance from the cluster center; diamonds > 2σ OII detected, triangle < 2σ OII; square "outlier." See also Fig 1

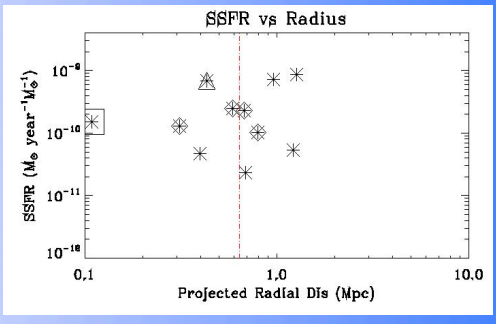


Fig 4 Approximate specific SFR (SSFR) based on IRAC1 and preliminary SED fits versus the distance from the cluster center .

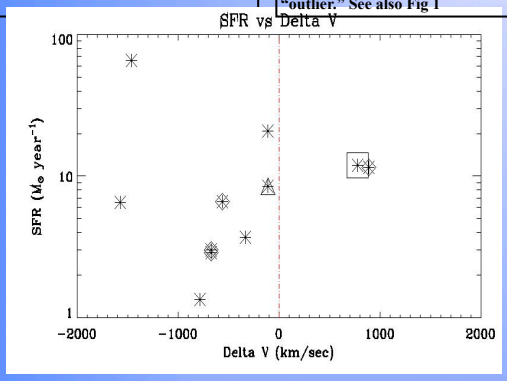


Fig. 5 SFR versus line of sight velocity, symbols mean the same as in Fig 3

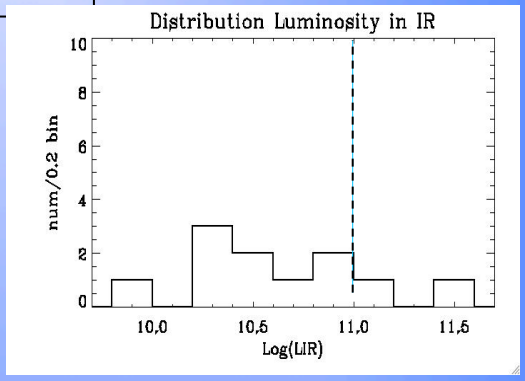


Fig. 6 Histogram of total L_{IR} (1-1000 Microns) in $L_{\odot}$ Note that 10^{11} and above is classified as a LIRG.

Discussion:

- **Cl157+47 at z = 0.866 is one of the highest redshift clusters with a richness of multi-wavelength data spanning the X-ray to the mid IR.**
- **The cluster is dynamically young based on the X-ray emission contours and the position kT vs L_X. And the bi-modal galaxy distribution.**
- **OII is detected in only a handful of the the lower SFR members, which leads us to *speculate* that the higher SFR (higher MIPS24 flux) galaxies have the OII attenuated by dust. Thus, OII is not a good tracer of SFR at redshifts near 0.9 where the galaxies are likely red but not dead.**
- **The SFR tends to increases with increasing cluster centric distance, but the SSFR shows no clear trend. Perhaps the total stellar mass is reduced (via ram pressure stripping or galaxy-galaxy interactions) such that the SFR will be higher in lower density regions versus the SSRF, which depends on the total galaxy stellar mass as well as the SFR.**
- **Many of the higher SFR galaxies have line of sight velocities of 1,000 km s^{-1}. The property of a higher SFR suggests these galaxies have not yet passed through the cluster core, but then their relatively high velocity must be explained. We *suggest* that the cluster is so young that galaxies are just infalling along several different cold dark matter filaments whose crossings form the cluster center .**

Summary and Conclusions: We have found a 6E14 $M_{\odot}$ X-ray bright cluster of galaxies at $z = 0.866$ that is still in the process of formation due to its bi-modal structure and X-ray emission properties. The cluster is spectroscopically confirmed with the mass determined through the velocity dispersion of the cluster members. Star-forming galaxies appear to be offset in velocity from the cluster redshift by up to 1,000 km/s indicating that the cluster is being built up by galaxies infalling along filaments. Although the SFR in the cluster members increases with increasing projected distance, the SSFR approximately constant as a function of distance. Thus, it is likely that the cluster is a newly (less that one galaxy crossing time of ~ 1 Gyr) formed mass concentration located at the crossing of dark matter filaments. Therefore models of hierarchical CDM large scale structure formation should accommodate cluster formation as late as about z ~0. 9 with massive (≥1E11$M_{\odot}$) galaxies that are red but not dead.

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References: Ota, N 2006, ApJ, 640, 673, Patel et al, 2009, ApJL, 705 L67. Serna A. & Gerbal D., 1996, A&A 309, 65, Temporin et al, 2009 Astro Nach, 330,915