Variation in Star Formation Rate From Galaxy Cluster Center for cl1037

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Introduction

- Data were obtained for this project as a part of a collaboration between the National Optical Astronomy Observatory (NOAO), the Spitzer Science Center, and the ESO Distant Cluster Survey (EDisCS) for student and teacher outreach.
- Infrared data (images and some spectra) of the galaxy cluster, cl1037, were obtained from the Spitzer Space Telescope at 24μm using the MIPS imager.
- Data were also obtained from the Hubble Space Telescope's ACS.
- Cluster members were identified by photometric redshift or spectroscopic redshift, when available.
- Data were reduced by members of the research collaboration.
- Total infrared luminosity (L_{tir}), used for the calculation of SFR, can be extrapolated from the provided Spitzer data using spectral energy distributions (SEDs).

Methods:calculating SFR and Distance

1. Calculate 5 different L_{tir} values for each cluster member based on 5 different SEDs from the rest-frame luminosities at 15μm for the 24μm data provided in Spitzer data.
2. Calculate 5 different SFRs for each galaxy based on the equation: $SFR = 4.5\times10^{-44}\frac{M_\odot/yr}{erg/s}\times L_{tir}(erg/s)$ (Kennicutt, 1998).
3. Calculate average SFR for each galaxy by averaging 5 different SFRs.
4. Calculate distance from center of the cluster using simple distance formula with RA and Dec, result in degrees.
5. Convert degrees to megaparsecs (Mpc) at z=0.58 using the conversion factor 23.7 Mpc/deg and convert to kpc.
6. Classify all members whose regions circles on the IR image (Fig. 1) overlap as potential pairs.
7. Plot galaxies on an xy-scatter and perform a linear regression on isolated galaxies.
8. Compare calculated SFR to SFR predicted by linear regression for potential pairs.
9. Classify potential pairs with SFR less than predicted by linear regression as isolated galaxies and include in a second linear regression.

Discussion of Results

Results of regression in Graph 1 show a positive correlation between SFR and distance from the center of cl1037 with the slope of the regression line being 0.0264$M_\odot$/yr/kpc in the cluster, where the farthest galaxy was roughly 1.37 Mpc from the center, meaning that SFR increases as a function of distance from the center of the cluster in isolated cluster members.

It was noticed that a pair of galaxies had star formation rates that were much higher than those of other galaxies in the cluster, which led to a more detailed analysis of paired galaxies in the cluster. Paired galaxies were selected based on whether their regions circles were overlapping in the IR image (Fig. 1). From the pair analysis it was determined that it is likely neither Pair 11, 12 (Fig. 3) nor Pair 27, 28 (Fig. 5) is a pair undergoing a true merger because of their proximity to expected values from the linear regression in Graph 1. Pair 14, 15 (Fig. 4) had very high SFR values, which would suggest a merger and possibly an active galactic nucleus (AGN) at the center of one or both of the galaxies. Pairs identifiable in the HST image (Fig. 2) were examined to see if they appeared to be merging.

Pairs 11, 12 and 27, 28 were deemed as not true pairs and were included in a second linear regression of isolated cluster members in Graph 2. This linear regression analysis yielded a slope of 0.0293 $M_\odot$/yr/kpc and a correlation coefficient of 0.14. This second linear regression also indicates that SFR increases as a function of distance in this cluster.

There were several sources of error in the data. The most prominent is the use of photometric redshift, which is less accurate than spectroscopy, and the problem of correctly measuring distance from the center in the cluster. There is also the possibility that the 24μm sources are not from star formation in the galaxy, but from AGN or other infrared sources. The use of photometric redshift for determining the membership of the cluster, because it is not as accurate as spectroscopic redshift, could lead to the exclusion of some cluster members in the data or the inclusion of some non-cluster members in the data. To improve on this would require spectroscopic resdshifts for all galaxies in the image. The other large problem in the data is that we only see a cylinder of space when looking at the cluster, so the distances calculated may be wrong for some galaxies (Fig. 6).

Fig. 6: Cylinder of Space

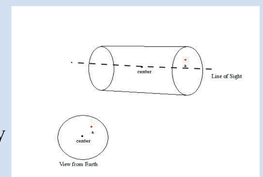


Fig. 6 created by presenter

Abstract

This study investigated how the star formation rates (SFRs) of galaxies in a cluster change as a function of distance from the cluster center. Cl1037 (z=0.58) was studied. It was predicted that SFRs of galaxies in this cluster would decrease as a function of distance from cluster center because of fewer mergers farther out. SFRs were calculated using 24 μm luminosities from Spitzer Space Telescope data. It was found that SFR increases as a function of distance from the cluster's center by 0.026 $M_\odot$/yr/kpc. This observation might be because ram pressure stripping in the cluster would leave central galaxies with fewer materials to form stars. However, the data did not fit the linear regression neatly, with an R^2 correlation co-efficient of 0.11. A detailed analysis of possible pairs in the cluster was also done: one pair was identified in the cluster but two other potential pairs were classified as isolated galaxies. A second linear regression was performed yielding slope=0.0293 $M_\odot$/yr/kpc and R^2=0.14. Learning more about SFRs of low redshift galaxies in clusters can inform us of behavior of clusters at higher redshifts. Further research would include a study of more clusters at low redshifts.

Results

Fig. 1: Spitzer image of cluster

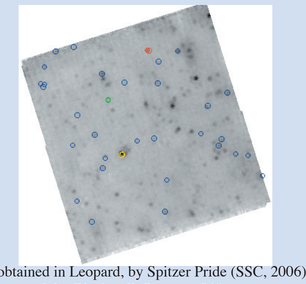


Fig. 1 obtained in Leopard, by Spitzer Pride (SSC, 2006): Query by Observer: John Blackwell, Program 268.

Fig 2: HST image of cluster

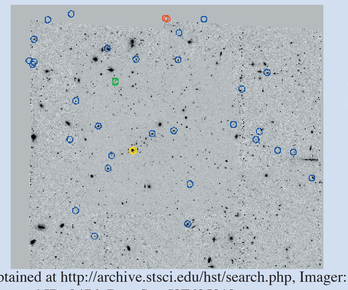


Fig. 2 obtained at http://archive.stsci.edu/hst/search.php, Imager: ACS, Proposal ID: 9476, Data Set: J8F605010

Images of Potential Pairs

Fig. 3: Pair 11, 12

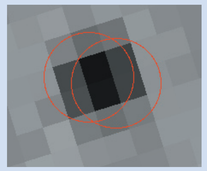


Fig. 4: Pair 14, 15

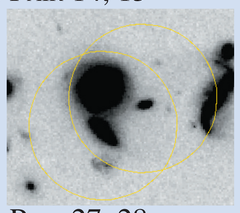
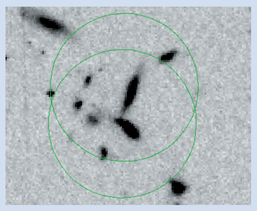
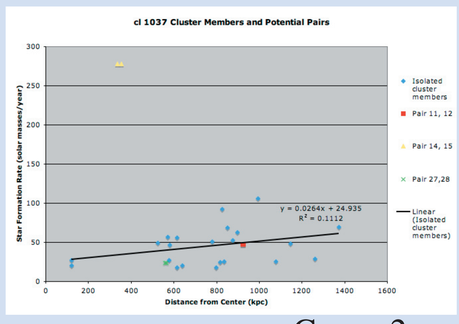


Fig. 5: Pair 27, 28



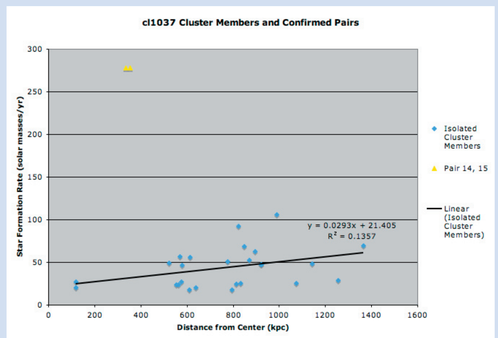
Graph 1



Graph 1 shows the relationship between distance from the center and star formation rate in the galaxy cluster. Each blue point is an isolated galaxy and the points colored red, green, and yellow are all galaxies in a potential pair. Only isolated cluster members were included in the linear regression.

Graph 2

Graph 2 includes all of the isolated galaxies from the cluster but also includes potentially paired galaxies that were identified as isolated cluster members from the separate analysis. Galaxies from previously identified pairs have been colored green or red for identification but were included in the linear regression. Pair 14, 15 (colored yellow) was confirmed as a pair and still not included in linear regression.



Discussion of Conclusions

Through the observations it was found that star formation rate increases as a function of distance from the center of the cluster, which is contradictory to my hypothesis. One possible explanation as to why this is might be that this cluster, cl1037, is cigar-shaped (most visible in the HST image Fig. 2) and is not at equilibrium. This might mean that the star formation rates of individual galaxies in this cluster may be irregularly distributed and a possible way to identify this would be to analyze more clusters that are more neatly spherical and see if the same pattern is found in those clusters.

Another possible explanation for the conclusion might be that ram pressure stripping of the galaxy as it falls in to the center of the cluster takes away much of the raw materials in a galaxy that would be used for star formation. This would mean that even if the galaxy did collide or interact with other galaxies in the center it might not have the necessary materials to form stars, causing a decrease in star formation near the center of the cluster. Some researchers have found that star formation rate does indeed decrease near the center of a galaxy cluster (Fujita & Nagashima, 1999).

Galaxies in the centers of clusters also move very quickly with respect to each other (G. Rudnick, Personal Communication, April 10, 2007). This would mean that galaxies in the center, moving more quickly than galaxies farther out in the cluster, may have a more difficult time merging with other galaxies, resulting in a lower SFR near the center of the cluster.

All of these possible explanations could be further confirmed in a study of several more clusters.

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Future Work

An interesting continuation of this project would be to study several more clusters at similar redshifts to determine whether the results found for cl1037 are also found in other clusters. Another interesting continuation would be to look at this cluster in the radio to analyze the neutral hydrogen content of the galaxies as distance from the center increases to see if there is indeed a lack of raw materials closer to the center which would further validate the conclusion of this study.

A possible continuation for the potential pairs in this study would be to look at the cluster in the X-ray, because one would expect to find strong X-ray sources at the location of a potential pair if indeed it is a true pair of merging galaxies. X-ray analysis of the cluster could also reveal the presence of hot gas in the cluster stripped from cluster galaxies in ram pressure stripping. This would confirm the idea that galaxies near the center might lack necessary star forming materials.

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