RevMexAA (Serie de Conferencias), **16**, 229–232 (2003)

GALAXY STAR FORMATION AS A FUNCTION OF ENVIRONMENT

F. J. Castander,[1,2,3], M. L. Balogh,[4] M. Bernardi,[5,6] R. G. Bower,[4] A. J. Connolly,[6] D. G. Gilbank,[4] P. L. Gómez,[5] T. Goto,[5] A. M. Hopkins,[6] C. J. Miller,[5] R. C. Nichol,[5] D. P. Schneider,[7] R. Seth,[6] and A. I. Zabludoff[8]

RESUMEN

Presentamos un estudio de la tasa de formación estelar (SFR) en función del medio ambiente utilizando datos del SDSS EDR. Encontarmos que la SFR es menor en medios densos (cúmulos y grupos) que en el campo. La disminución en la SFR empieza a notarse a una distancia de unos 4 radios viriales. No encontramos ninguna evidencia de brotes de formación estelar cuando las galaxias caen en los cúmulos. También presentamos un proyecto para estudiar estos efectos en pares de cúmulos donde los efectos de los filamentos y la estructura a gran escala se podrían detectar.

ABSTRACT

We study the galaxy star formation rate (SFR) as a function of environment using the SDSS EDR data. We find that the SFR is depressed in dense environments (clusters and groups) compared to the field. We find that the suppression of the SFR starts to be noticeable at around 4 virial radii. We find no evidence for SF triggering as galaxies fall into the clusters. We also present a project to study these effects in cluster pairs systems where the effects of filaments and large scale structure may be noticeable.

Key Words: **GALAXIES: CLUSTERS: GENERAL — GALAXIES: EVOLUTION — STARS: FORMATION — GALAXIES: STELLAR CONTENT — SURVEYS**

1. INTRODUCTION

The rate at which galaxies form stars is observed to depend on the environment. There have been several spectroscopic studies investigating the connection between the star formation rate in galaxies and the environment at redshifts $z > 0.2$ (e.g., Balogh et al. 1997; Poggianti et al. 1999; Couch et al. 2001; Postman, Lubin, & Oke 2001), in which it has been found that galaxies form fewer stars in denser environments than in sparser media and therefore the star formation in clusters of galaxies is lower than that in the field at the same redshift. Galaxies in clusters are thought to have extinguished (or considerably diminished) their gas reservoirs to fuel further star formation. Several mechanisms have been put forward to explain the loss of such gas and therefore the reduction of the star formation rate (SFR) of galaxies in clusters. These include ram-pressure stripping (e.g., Gunn & Gott 1972); galaxy harassment (e.g., Moore et al. 1999); tidal disruption (e.g., Byrd & Valtonen 1990), and galaxy interactions and mergers (e.g., Zabludoff & Mulchaey 1998). However, the main physical mechanism responsible for the trend observed is unclear. The CNOC group performed a spectroscopic survey of fifteen X-ray selected clusters. They interpreted their findings by proposing that star formation is quenched as galaxies fall into the clusters (Balogh et al. 1999). In contrast, the MORPHS group, studying a heterogeneous, mainly optically-selected sample, suggested that star formation is triggered as galaxies fall into clusters (Poggianti et al. 1999).

Theoretically, within the framework of hierarchical structure formation, semi-analytical models, in which the amount of star formation is determined by a simple prescription governed by the amount of cold gas and the time since the last interaction with a halo, are able to reproduce the basic trends of star formation rate with environment (e.g., Balogh, Navarro, & Morris 2000; Diaferio et al. 2001). However, the physical mechanisms driving the gas mass loss still remain to be properly determined.

In this paper, we present new observational data to help understand the connection between star formation rate and environment. In Section 2, we de-

[1]Yale University, New Haven, USA.
[2]Universidad de Chile, Santiago, Chile.
[3]Andes Prize Fellow.
[4]Department of Physics, University of Durham, , Durham, UK.
[5]Department of Physics, Carnegie Mellon University, Pittsburgh, USA.
[6]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, USA.
[7]Department of Astronomy and Astrophysics, Pennsylvania State University, USA.
[8]Steward Observatory, University of Arizona, Tucson, USA.

scribe and briefly analyze data at low redshift obtained with the Sloan Digital Sky Survey. In Section 3, we present new projects at intermediate redshift. In Section 4, we present our conclusions and discuss future prospects with large telescopes such as the GTC.

2. STUDIES AT LOW REDSHIFT: SDSS

The Sloan Digital Sky Survey (SDSS[9]) is a joint, 5 passband ($ugriz$) imaging and medium resolution ($R \simeq 1800$) spectroscopic survey of 10 000 deg^2 (York et al. 2000). In 2001 June, the SDSS, as part of their Early Data Release (EDR), released spectra of nearly 50 000 galaxies, stars and QSOs over 460 deg^2 (Stoughton et al. 2002). Given the large area coverage, which properly samples the field population and also includes clusters of galaxies of different masses, and the quality and quantity of the spectra, the SDSS is ideally suited to determining the environmental dependences of galaxy star formation at low redshift. We have therefore used the SDSS EDR to study this problem (see Gómez et al. 2002 for full details).

We have selected our sample from the SDSS EDR spectra applying the following criteria. We have chosen all galaxies spectroscopically confirmed galaxies high confidence. Among those, we have rejected objects that had warning flags set and also those that had no line measurements for Hα or [O II]. We are left with approximately 36 000 galaxies. We define a volume-limited survey by choosing galaxies only in the redshift range $0.050 \leq z \leq 0.105$ and more luminous than $M(r^\star) = -20$ ($H_0 = 75$ km s^{-1} Mpc^{-1}). For these galaxies, we use the line parameters measured by the SDSS spectroscopic pipeline (Frieman et al. 2002). We derive the star formation rate of each galaxy using its measured Hα flux and the theoretical relation of Kennicutt (1998). We then correct this SFR for SFR-dependent reddening using the prescription of Hopkins et al. (2001).

In order to study the SFR environmental dependence, we have searched for virialized groups and clusters in our EDR sample. We have used the C4 algorithm described in Nichol et al. (2001) and Miller et al. (2002). In brief, this algorithm selects structures of similar properties in a seven-dimensional space of four colors, position on the sky, and redshift. Taking into account the selection criteria mentioned above, we have selected nineteen groups and clusters of galaxies for which we have measured velocity dispersions using a 3σ clipping algorithm (Miller et al. 2002). The velocity dispersions range between 200 and 1000 km s^{-1}, with typically 40 members measured.

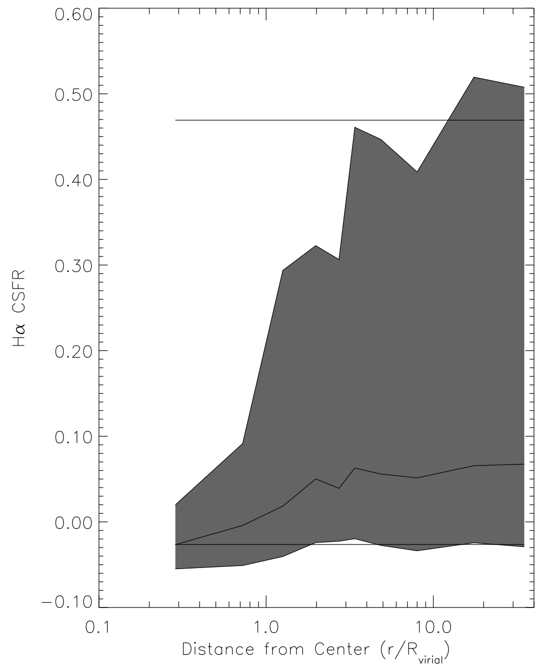

Fig. 1. Distribution of the corrected SFR (see text) as a function of projected clustercentric radius. The projected radii are scaled to the virial radius of each cluster. The shaded regions shows the distribution between the 75th and 25th percentiles. The line in between represents the median of the distribution. The horizontal lines are the 75t and 25th percentiles of the field population.

In Figure 1 we present the observed distribution of corrected SFR derived from Hα, as quantified by the median, and the 25th and 75th percentiles, as a function of projected clustercentric radius. We have scaled all radial distances by the virial radius of each cluster using the formula $R_{\rm V} \simeq 0.002\sigma h_{100}^{-1}$ Mpc from Girardi et al. (1998).

Figure 1 shows a clear decrease in the star formation activity as a function of clustercentric radius. Two effects are readily visible: First, the whole distribution of SFR decreases as one enters the cluster. Second, the skewness of the distributions decreases; that is, the tail of strong star forming galaxies rapidly diminishes as one enters the cluster environment. These results are in qualitative agreements with the finding of the CNOC group (Balogh et al. 1999; Ellingson et al. 2001). Statistically, the cluster and field SFR distribution start to differ at $\sim 4R_{\rm V}$. At no clustercentric radius does there appear to be an enhancement in the SFR compared to the field; this suggests that the infall of galaxies

[9]See http://www.sdss.org.

into the cluster does not trigger strong bursts of star formation.

3. STUDIES AT INTERMEDIATE REDSHIFTS: DOUBLE CLUSTERS

We have also started a program to study the star formation activity in clusters at intermediate redshifts ($z \sim 0.4$). At these redshifts, the CNOC and MORPHS groups have already carried out extensive spectroscopic studies of X-ray and optically selected clusters. We aim to complement their data by targeting double clusters, systems where not only the cluster effects can be studied but also the effects due to the filaments. For this purpose we have started using large telescope facilities with which high signal-to-noise spectra can be obtained in reasonable exposure times. The good quality spectra will help us to better determine the star formation histories and star formation activities of the galaxies studied.

So far, we have obtained extensive spectroscopic data at the VLT and Magellan telescopes for a complex system at redshift $z = 0.42$ in an area of approximately ($7\ h^{-1}$ Mpc)^2. This system was selected from an optical survey of *ROSAT* X-ray fields (Gilbank et al. 2002) and is composed of at least three cluster/groups. Unfortunately, our analysis is still in progress and no results can be presented at this time.

4. DISCUSSION AND FUTURE PROSPECTS

We are carrying out a detailed investigation of the effects of environment on galaxy star formation. At low redshift, the SDSS provides an ideal sample to tackle this problem. Using the SDSS EDR, we manage to trace the SFR out to the field. As already known, we find that the SFR is lower in clusters than in the field. We find that the SFR starts to decrease at approximately 4 virial radii or the turn-around radius. The decrease in the SFR is mainly due to a reduction in the number of the stronger star forming galaxies. No triggering of star formation is found as galaxies fall into the cluster. Our results are in qualitative agreement with those found at intermediate redshift by the CNOC group (Balogh et al. 1999; Ellingson et al. 2001) and with expectations from semi-analytical models (Kauffmann et al. 1999; Diaferio et al. 2001; Balogh et al. 2002).

In order to understand the causes of the observed trends, we will complement our current investigations with other observables. We will measure of the gas density and correlate the gas density and the velocity dispersion of the system with the SFR rate. We will estimate the galaxy masses and compare the galaxies' binding energy to their measured SFRs. We will measure the galaxies' morphologies and investigate the density–morphology–SFR relation. We will also investigate the star formation histories of the galaxies, paying special attention to poststarburst galaxies. We will increase the size of our sample as the SDSS acquires more and more data.

We will also investigate the evolution in these environmental trends. By relaxing our sample selection constraints we will be able to study evolution within the SDSS database itself, but to extend the evolutionary studies beyond $z \sim 0.2$ large observing facilities with large multiplexing capabilities, such as those rendered by VLT + VIMOS or GTC + OSIRIS, are needed.

FJC acknowledges the Organizing Committee for the financial support received to attend the conference.

Funding for the creation and distribution of the SDSS Archive has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the US Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The participating institutions are the University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, Johns Hopkins University, Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy, the Max-Planck-Institute for Astrophysics, New Mexico State University, Princeton University, the United States Naval Observatory, and the University of Washington.

REFERENCES

Balogh, M. L., Morris, S. L., Yee, H. K. C., Carlberg, R. G., & Ellingson, E. 1997, ApJ, 488, L75
Balogh, M. L., Morris, S. L., Yee, H. K. C., Carlberg, R. G., & Ellingson, E. 1999, ApJ, 527, 54
Balogh, M. L., Navarro, J. F., & Morris, S. L. 2000, ApJ, 540, 113
Byrd, G., & Valtonen, M. 1990, ApJ, 350, 89
Couch, W. J., Balogh, M. L., Bower, R. G., Smail, I., Glazebrook, K., & Taylor, K. 2001, ApJ, 549, 820
Diaferio, A., Kauffmann, G., Balogh, M. L., White, S. D. M., Schade, D., & Ellingson, E. 2001, MNRAS, 323, 999
Ellingson, E., Lin, H., Yee, H. K. C., & Carlberg, R. G. 2001, ApJ, 547, 609
Frieman, J., et al. 2002, in preparation
Gilbank, D. G., Bower, R. G., Castander, F. J.,

& Bell, E. 2002, in preparation
Girardi, M., Giuricin, G., Mardirossian, F., Mezzetti, M., & Boschin, W. 1998, ApJ, 505, 74
Gómez, P. L., et a., 2002, in preparation
Gunn, J. E., & Gott, J. R. I. 1972, ApJ, 176, 1
Hopkins, A. M., Connolly, A. J., Haarsma, D. B., & Cram, L. E. 2001, AJ, 122, 288
Kauffmann, G., Colberg, J. M., Diaferio, A., & White, S. M. D. 1999, MNRAS, 303, 188
Kennicutt, R. C. 1998, ApJ, 498, 541
Miller, C. J., et al. 2002, in preparation
Moore, B., Lake, G., Quinn, T., & Stadel, J. 1999, MNRAS, 304, 465
Nichol, R. C., Connolly, A. J., Moore, A. W., Schneider, J., Genovese, C., & Wasserman, L., 2001, ASP Conf. Proc., 225, Virtual Observatories of the Future, ed. R. J. Brunner, S. G. Djorgovski, and A. S. Szalay (San Francisco: ASP), 265
Poggianti, B. M., et al. 1999, ApJ, 518, 576
Postman, M., Lubin, L. M., & Oke, J. B. 2001, AJ, 122, 1125
Stoughton, C., et al. 2002, AJ, 123, 485
York, D. G., et al. 2000, AJ, 120, 1579
Zabludoff, A. I., & Mulchaey, J. S. 1998, ApJ, 496, 39

F. J. Castander: Yale University, P.O.Box 208101, New Haven, CT 06520-8101, USA and Universidad de Chile, Casilla 36-D, Santiago, Chile (fjc@astro.yale.edu and fjc@das.uchile.cl)
M. L. Balogh, R. G. Bower and D. G. Gilbank: Department of Physics, University of Durham, South Road, Durham, DH1 3LE, UK (M.L.Balogh, R.G.Bower, D.G.Gilbank@durham.ac.uk)
M. Bernardi, P. Gómez, T. Goto, C. J. Miller, R. C. Nichol: Department of Physics, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15217, USA (bernardi, pgomez, tomo, chism, nichol@cmu.edu)
A. J. Connolly, A. M. Hopkins: Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 14217, USA (ajc, ahopkins@phyast.pitt.edu)
D. P. Schneider: Department of Astronomy and Astrophysics, Pennsylvania State University, University Park, PA 16802, USA (dps@miffy2.astro.psu.edu)
A. I. Zabludoff: Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721, USA (azabludoff@as.arizona.edu)