STAR FORMATION IN LAS CAMPANAS COMPACT GROUPS

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ABSTRACT

Compact groups (CGs) of galaxies offer an exceptional laboratory for the study of dense galactic environments, where interactions, tidally induced activity, and mergers are expected to be at their highest rate of occurrence. Here we present first results from a new catalog of compact groups, one based on the Las Campanas Redshift Survey (LCRS). Using the equivalent width of [O III] λ3727, we have studied the star formation activity in LCRS CGs: we find strong evidence of depressed star formation in CGs relative to that in loose groups or the field. Although much of this effect can be ascribed to a morphological mix (CGs contain a high fraction of early-type galaxies), there is some evidence that the star formation rate in late-type galaxies is particularly deficient—perhaps only one-half to one-third that of field spiral galaxies. We conclude that gas-stripping mechanisms may play a role in CG environments.

Subject headings: catalogs — galaxies: clusters: general — galaxies: interactions — galaxies: starburst

1. INTRODUCTION

Perhaps over half of all galaxies lie within groups containing 3–20 members (Tully 1987); yet, due to the difficulty of discerning them from the field, groups of galaxies are, as a whole, not as well studied as larger galaxy systems. However, compact groups (CGs), which are defined by their small number of members (<10), their compactness (typical intragroup separations of a galaxy diameter or less), and their relative isolation (intragroup separations much less than group-field separations), are more readily identifiable.

Recently, Tucker et al. (1999) produced a catalog of loose groups (LGs) from the Las Campanas Redshift Survey (LCRS; Shectman et al. 1996), using an adaptive friends-of-friends algorithm (Ramella et al. 1989). Intrigued by the work of Barton et al. (1996), who created a CG catalog from the CFA Redshift Survey and found that most of their CGs were embedded in dense environments, we produced a similar catalog from the much deeper LCRS (Allam & Tucker 1998; Tucker et al. 1999). For extracting group catalogs, redshift surveys have an advantage over sky surveys since redshift adds a third dimension of constraint: group catalogs based on redshift surveys tend to have far fewer chance alignments than do those based on sky surveys (e.g., the Hickson Compact Group [HCG]; see Hickson 1982, 1993). We apply a standard friends-of-friends algorithm to extract a sample of CGs systems in the LCRS. Our definition for these CGs is as follows: (1) greater than or equal to three galaxies, (2) compact (with projected nearest-neighbor intergalaxy separations of $D_t \leq 50 \, h^{-1}$ kpc, or ~1 galaxy diameter), and (3) isolated in redshift (with nearest-neighbor intergalaxy velocity differences of $V_t \leq 1000 \, km \, s^{-1}$).

The LCRS, optimized for efficient observing with a fiber-fed multiobject spectrograph, has a 55" fiber separation limit. This has prevented the observation of spectra for all of the galaxies that were members of close pairs, and therefore many of the galaxies in CG environments are missing from the LCRS redshift catalog. We have partially circumvented this problem by assigning each of the ~1000 "missing" LCRS galaxies the redshift of its nearest neighbor and convolving it with a Gaussian of $\sigma = 200 \, km \, s^{-1}$, a value that is similar to the typical median velocity dispersion of HCGs (Hickson 1982) and of LCRS LGs (Tucker et al. 1999); hence, on the small angular scales necessary for compact group selection, the LCRS falls somewhere between a two-dimensional sky survey and a fully three-dimensional redshift survey. The resulting catalog contains 76 CGs having three or more members, and evidence for interactions in many of these CGs (in the form of tidal tails, bridges, etc.; see Allam & Tucker 1998 and Allam et al. 1999) confirms that, for the most part, they are indeed physical systems. All the CGs contain at least one redshift; 23 contain two or more. (Unfortunately, only one LCRS CG has redshifts for all its members.) The innate physical properties of LCRS CGs—such as typical group richnesses and densities—are similar to those of the Barton et al. catalog, which in turn are similar to those of the HCG catalog, especially for CGs with four or more members. The median redshift for LCRS CGs, however, is ~0.08, which is more than twice that of either of the other two CG catalogs. As with the HCG and Barton et al. samples, LCRS CGs represent some of the densest concentrations of galaxies known and thus provide ideal laboratories for studying the effect of strong interaction on the morphology and stellar content of galaxies. Details of the general properties of these CGs and of how they were extracted from the LCRS will be discussed in Allam et al. (1999); here we will focus on the star formation properties in LCRS CG environments.

It is well known that direct interactions between galaxies
tend to increase their star formation rate (SFR) (Larson &

Compact groups (solid line), loose groups (dashed line), and the field (dotted line). A formal $\chi^2$ test indicates that the distribution for compact groups differs from that for loose groups at the 99.99965% confidence level and from that for field galaxies at the 99.99951% confidence level.

Variables affecting SFR in high-density environments, such as interactions, are expected to increase the SFR in galaxies, as indicated by Bershady et al. (1998). LCRS galaxies in CGs represent an environment where interactions, tidally triggered activity, and galaxy mergers are expected to be at their highest rate of occurrence. Therefore, if no other factors dominate, we may expect a global enhancement in the SFR of LCRS CG galaxies. In order to test this hypothesis, we use the equivalent width (EW) of the emission line [O II] $\lambda$3727 as a star formation indicator. We have used automatically measured rest-frame LCRS EW([O II])'s, which have a mean error of 2.2 Å (Hashimoto et al. 1998). Figure 1 shows the distribution of the EW([O II]) in CGs, in LGs, and in the field. A formal $\chi^2$ test indicates that the distribution for CGs differs from that for LGs at the 99.99965% confidence level and from that for field galaxies at the 99.99951% confidence level. (These very high formal confidence levels are due partly to the large samples involved and partly to the large differences among these samples for the smallest bin.)

Following Hashimoto et al. (1998), we classify the emission-line strength as follows: NEM (no emission), for which $EW < 5 \text{ Å}$; WEM (weak emission), for which $5 \text{ Å} \leq EW < 20 \text{ Å}$; and SEM (strong emission), for which $EW \geq 20 \text{ Å}$. The WEM class contains mostly normal galaxies, where star formation is governed by internal factors such as gas content and disk kinematics. The SEM class contains mainly starburst galaxies, where star formation is due to interaction. Table 1 represents the frequency of EW([O II]) for galaxies in different environments. The variations in the frequency of the SEM class may reflect environmental variations in galaxy-galaxy interaction rates.

Note that the fraction of LG galaxies showing a normal (WEM) SFR is only three-quarters that for the field galaxies and that the fraction of LG galaxies showing starburst (SEM) activity is only two-thirds that in the field. For CG galaxies, the ratios are more severe: the fraction of CG galaxies with a normal SFR is only two-thirds that for the field galaxies, and the fraction of CG galaxies that are starbursting is only half that of the field, indicating that the SFR in high-density environments is generally weaker than in the field.

### 4. THE DISTRIBUTION OF [O II] EQUIVALENT WIDTHS

Several works have used EW([O II]) $\lambda$3727 as a star formation index for distant galaxies (Colless et al. 1990; Kennicutt 1992). We have used automatically measured rest-frame LCRS EW([O II])'s, which have a mean error of 2.2 Å (Hashimoto et al. 1998). Figure 1 shows the distribution of the EW([O II]) in CGs, in LGs, and in the field. A formal $\chi^2$ test indicates that the distribution for CGs differs from that for LGs at the 99.99965% confidence level and from that for field galaxies at the 99.99951% confidence level. (These very high formal confidence levels are due partly to the large samples involved and partly to the large differences among these samples for the smallest bin.)

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### 4. THE CONCENTRATION INDEX C OF LCRS GALAXIES

Although the SFR in high-density environments is, on average, depressed relative to that in the field, much of this effect

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**Table 1**: The EW(O II) of LCRS Galaxies in Different Environments

| Environment     | Total Number | NEM ($EW < 5 \text{ Å}$) | WEM ($5 \text{ Å} \leq EW < 20 \text{ Å}$) | SEM ($EW \geq 20 \text{ Å}$) |
|-----------------|--------------|-------------------------|------------------------------------------|--------------------------|
| Compact group   | 104          | 72 (69.2% ± 8.2%)        | 27 (26.0% ± 5.0%)                       | 5 (4.8% ± 2.2%)          |
| Loose group     | 6612         | 4312 (65.2% ± 1.0%)      | 1892 (28.6% ± 0.7%)                     | 408 (6.2% ± 0.3%)        |
| Field           | 12915        | 6804 (52.7% ± 0.6%)      | 4905 (38.0% ± 0.5%)                     | 1206 (9.3% ± 0.3%)       |
The Concentration Index $C$ of LCRS Galaxies

| Galaxies’ Environment | Total Number | Mean     | Median  |
|-----------------------|--------------|----------|---------|
| Compact group ..........| 86           | 0.324 ± 0.009 | 0.302   |
| Loose group ........... | 4528         | 0.303 ± 0.001 | 0.298   |
| Field ..................| 8287         | 0.287 ± 0.008 | 0.28    |

might be due merely to differences in the average morphological mix. After all, spiral galaxies, which are more prevalent in the field, tend to have higher average SFRs than do elliptical galaxies. To test this possibility, we have made use of the measurement by Hashimoto et al. (1998) of the concentration index, $C$, for LCRS galaxies as a measure of the morphological types of galaxies in our sample. The $C$ index represents the intensity-weighted second moment of a galaxy; it compares the flux between specified inner and outer isophotes of a galaxy in order to indicate the degree of light concentration. As such, the $C$ index is related to the Hubble type (Abraham et al. 1994), where late/irregular-type galaxies have smaller $C$ values. The total number of galaxies in our sample with a measured $C$ index is 12,901. The mean and median $C$ indexes are given for each of the different galaxy environments in Table 2.

The $C$ distribution of CGs galaxies is shown in Figures 2 and 3. A Kolmogorov-Smirnov (K-S) test indicates that the CG galaxies are drawn from the same morphological parent population as the LG galaxies at a probability of 20%; the probability that CG and the field galaxies have the same morphological mix is only 0.2%. Clearly, the distribution of CG galaxies is skewed toward early types (large $C$’s).

In Figure 4, the distribution of EW(O II) versus the $C$ index is shown for LCRS galaxies in the different environments. The relation between the mean $C$ index, $\langle C \rangle$, and the mean EW(O II), $\langle$EW(O II)$\rangle$, is presented in Figure 5. Note that $\langle$EW(O II)$\rangle$ increases smoothly with decreasing $\langle C \rangle$ for LG and field galaxies, which parallels the relation between Hubble type and EW(O II) (Kennicutt 1992). Although much noisier, the same relation basically holds true for CG galaxies too. We must note, however, that the latest type (the smallest $C$ bin) CG galaxies show a significant deficit of star formation—perhaps only one-half to one-third that of field galaxies of this morphology. Therefore, it appears that not all the differences between the average star formation properties of CGs, LGs, and the field are due merely to the morphological mix. Some appear to be due to the dampening of star formation within late-type CG galaxies.

5. CONCLUSION

The star formation histories of galaxies in CGs can provide insight into the environmental factors that influence the evolution of galaxies. One approach is to examine the spectra of galaxies for evidence of ongoing star formation or of a young stellar population. We can then compare the fraction of compact group galaxies with recent star formation with the fraction from loose groups and the field.

We have done this by making use of a new catalog of CGs, based on the LCRS, that contains 253 galaxies in 76 CGs. To clarify whether or not interaction produces enhanced star formation in LCRS CGs, they have been compared to carefully selected samples of LCRS LG and field galaxies. In all, a sample of 21,326 LCRS galaxies in the three different environments was employed.

We compared the SFR based on the strength of the emission-line EW(O II) for LCRS CGs, LGs, and field galaxies: we found that the fraction of starbursts for CG members is roughly
half that for the field, whereas for LG galaxies it is roughly
two-thirds that for the field. Also, we found that a normal
galaxy SFR occurs for LCRS CG galaxies at roughly two-thirds
the rate for the field, whereas for LG galaxies this rate is three-
fourths that for the field. This means that, on average, the star
formation in high-density environments is depressed with re-
spect to the field.

Much of this effect can be attributed to the different mor-
phological mixes associated with low- and high-density envi-
ronments: when we compared the distribution of CG galaxies to be definitely
skewed toward early morphological types (large C index),
which generally tend to have relatively low SFRs. Nonetheless,
when we then compared the SFR versus the C index for CG,
for LG, and for field galaxies, we found that the SFR for CGs
appears to be deficient for very late morphological types (small
C index); in fact, the SFR for these late-type CG galaxies is
only one-half to one-third the SFR for field spiral galaxies.

It is clear from these findings that CG environments tend to
depress star formation, partly because of a relative overabun-
dance of early-type galaxies and partly because of some mecha-

nism that damps star formation within late-type CG spiral
galaxies. Note that results from other sources—in particular,
the HCG catalog and from the sample of poor groups by
Zabludoff & Mulchaey (1998)—lend support to this view. For
example, both of these other samples have been shown to have
galaxy populations skewed toward early types (Hickson 1982;
Zabludoff & Mulchaey 1998). More interesting, however, is
the growing body of evidence, both in the far-infrared (Allam
1998) and in Hα (Iglesias-Páramo & Vilchez 1999), that the

global star formation rates within HCGs are, on average, not
enhanced relative to field samples of similar morphological
mix. Indeed, Iglesias-Páramo & Vilchez even note a marginally
significant locus of HCG spiral galaxies of particularly low Hα
emission in their Figure 4; these HCG spiral galaxies may
 correspond to our LCRS CG sample of low-SFR late-type
galaxies.

Therefore, our initial hypothesis—that interaction-induced
starbursts dominate the global SFR in LCRS CGs—fails. Al-
though starbursts are no doubt important, other factors prevail
to yield a net depression in the SFR in CG environments. Much
of this effect is merely due to the high fraction of early-type
galaxies in CGs, but at least some of it is likely due to dampered
activity in late-type galaxies; this second mechanism indicates
that gas-stripping mechanisms may play a role in CG envi-
ronments.

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REFERENCES

Abraham, R. G., Valdes, F., Yee, H. K., & van den Bergh, S. 1994, ApJ, 432, 75
Allam, S. 1998, Ph.D. thesis, Univ. Potsdam
Allam, S., & Tucker, D. 1998, BAAS, 30, 1244
Allam, S. S., Tucker, D. L., Hashimoto, Y., & Lin, H. 1999, in preparation
Barton, E., Geller, M. J., Ramella, M., Marzke, R. O., & da Costa, L. N. 1996,
AJ, 112, 871
Bushouse, H. A. 1987, ApJ, 320, 49
Colless, M., Ellis, R. S., Taylor, K., & Hook, R. N. 1990, MNRAS, 244, 408
Hashimoto, Y., Oemler, A., Lin, H., & Tucker, D. L. 1998, ApJ, 499, 589
Hickson, P. 1982, ApJ, 255, 382
Iglesias-Páramo, J., & Vilchez, J. M. 1999, ApJ, 518, 94
Kennicutt, R. C. 1992, ApJ, 388, 310
Kennicutt, R. C., Roettiger, K. A., Keel, W. C., van der Hulst, J. M., & Hummel, E. 1987, AJ, 93, 1011
Larson, R. B., & Tinsley, B. M. 1978, ApJ, 219, 46
Ramella, M., Geller, M. J., & Huchra, J. P. 1989, ApJ, 344, 57
Shectman, S. A., Landy, S. D., Kirshner, R. P., Lin, H., Oemler, A., Tucker, D. L., & Schechter, P. L. 1996, ApJ, 470, 172
Tucker, D. L., Oemler, A., Hashimoto, Y., Shectman, S. A., Kirshner, R. P., Lin, H., Landy, S. D., & Schechter, P. L. 1999, ApJS, submitted
Tully, B. 1987, ApJ, 321, 280
Zabludoff, A. I., & Mulchaey, J. S. 1998, ApJ, 496, 39

Fig. 4.—EW(O ii) λ3727 vs. C index for LCRS galaxies in compact groups
(filled circles), in loose groups (open circles), and in the field (points).

Fig. 5.—The relation between the mean concentration index, ⟨C⟩, and the
mean EW(O ii), ⟨EW(O ii)⟩, for compact group galaxies (filled circles), for
loose group galaxies (open circles), and for field galaxies (open triangles).

L92
STAR FORMATION IN LAS CAMPANAS COMPACT GROUPS
Vol. 522

ii

A

EW(O II) \quad \lambda

0.1

10

100

0

0.1

0.2

0.4

0.6

C

0

5

10

15

<EW(O II) \quad \lambda>

0

0.2

0.4

0.6

⟨C⟩