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# TIDALLY-INDUCED STAR FORMATION IN CLUSTER GALAXIES

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## RESUMEN

Se ha hecho un relevamiento, con prisma objetivo, de la emisión global en H$\alpha$ en 433 galaxias de 8 cúmulos. Se encuentra evidencia de brotes de formación estelar, debidas a interacciones con otras galaxias, en galaxias de tipo Sa y más tardías. La frecuencia de las interacciones aumenta con la riqueza de los cúmulos y afecta a más del 40% de dichas galaxias en el cúmulo de Coma. La frecuencia de interacciones en galaxias de tipo tardío en los cúmulos más ricos es comparable a la frecuencia observada en cúmulos distantes ($z \geq 0.2$).

## ABSTRACT

An objective prism survey of global H$\alpha$ emission has been undertaken of 433 galaxies in 8 nearby clusters. Evidence is found of central bursts of star formation in galaxies of type Sa and later, triggered by galaxy-galaxy interactions. The frequency of such interactions appears to increase with increasing cluster mean central galaxy density, and may affect more than 40% of these galaxies in the Coma cluster. The frequency of galaxy interactions among late-type galaxies in the richest nearby clusters may thus be comparable to the corresponding frequency observed in distant ($z \geq 0.2$) clusters.


*Key words:* **GALAXIES: CLUSTERS — H II REGIONS — STARS: FORMATION**

## 1. INTRODUCTION

There is mounting evidence for significant evolution in rich cluster galaxies over the past ~ 5 Gyr. Butcher & Oemler (1978) first discovered a significantly higher fraction of blue galaxies in distant clusters as compared to nearby examples. This effect was subsequently confirmed to be widespread in rich clusters at $z \geq 0.2$, and can be attributed to a subset of cluster members either undergoing or having just recently completed a vigorous short-lived burst of star formation. Significant factors in the triggering of such star formation are galaxy interactions and mergers (Lavery et al. 1992; Couch et al. 1994).

It may be asked whether there is evidence of such interaction and merger-induced star formation in nearby clusters. A convenient method of searching for evidence of such star formation is to survey global H$\alpha$ + [N II] emission which has been shown to be a good indicator of the current rate of massive star formation in spiral galaxies (Kennicutt & Kent 1983). This paper reports on a survey of nearby cluster galaxies for such emission and discusses the implications of the results for an understanding of cluster galaxy evolution.

## 2. CLUSTER SURVEY

### *2.1. Survey Material*

An objective prism survey of global combined H$\alpha$ + [N II] ($\lambda\lambda$ 6548, 6583 Å) emission has been undertaken for a total of 247 CGCG galaxies of types Sa and later within 1.5 $r_A$ (where $r_A$ is the Abell radius) of the centres of 7 nearby clusters (Abell 262, 347, 400, 426, 569, 779 and 1656), and of 186 CGCG galaxies of all types within 2.5 $r_A$ of the cluster centre of Abell 1367. The survey method has been described in detail by Moss et al. (1988).

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### *2.2. Emission and Galaxy Properties*

The approximate detection threshold of the prism survey is a global H$\alpha$ equivalent width, $W_\lambda$ = 20 Å. Galaxies detected in emission and those not detected have similar distributions of absolute magnitude. As may be expected, few galaxies of types earlier than Sa are detected, while some 36% of spirals are detected. However fewer late-type spirals (Sc, Sc-Irr) are detected in emission than expected. This agrees with an earlier result of Kennicutt (1983) for Sc galaxies in the Virgo cluster, and it may be related to the depletion of the gas content of late-type spirals. On the other hand, it is also possible that our prism survey is less sensitive than a photoelectric study to extended emission of late-type spirals.

By visual inspection of the prism spectra, both *diffuse* and *compact* emission may be distinguished (Moss et al. 1988; Moss & Whittle 1993). Compact emission is much brighter than the underlying continuum and is sharply delineated from it. It is almost always centred on the nucleus in a small region (median diameter 3.9 kpc)[3]. Diffuse emission is only slightly brighter than the continuum and has an indistinct appearance spanning a larger region (median diameter 10.3 kpc).

Approximately 58% of the galaxies detected have diffuse emission, which is interpreted as due to normal star formation in the galactic disks. By contrast, compact emission correlates with a barred structure (significant at the $3\sigma$ level) or with a disturbed appearance (significant at the $7\sigma$ level) of the galaxy. Furthermore a disturbed appearance of a galaxy is strongly correlated with the presence of a nearby companion (significant at the $6\sigma$ level), and compact emission in unbarred spirals is similarly correlated with the presence of a companion (significant at the $3.7\sigma$ level). It appears that a central burst of star formation in the spirals is triggered by either a barred structure or from tidal effects due to galaxy-galaxy interactions (Moss & Whittle 1993; Moss et al. 1995).

Measurements of H$\alpha$ equivalent widths are available for the majority of detected galaxies in three of the clusters (Abell 347, 1367 and 1656). These measurements permit a more sensitive comparison of the numbers of galaxies detected in emission with the expected numbers based on the magnitude-limited field galaxy sample of Kennicutt & Kent (1983). This comparison confirms a deficiency of late-type spirals (Sc, Sc-Irr) detected in emission compared to the number expected, and shows, furthermore, there to be a subsample of early-type cluster spirals (Sa, Sab) with unusually strong emission which are not found in the field. The emission in these galaxies may be due to a central burst of star formation triggered by galaxy-galaxy interactions (Moss & Whittle 1993).

### *2.3. Emission and Cluster Properties*

The eight clusters surveyed range from low density spiral-rich clusters to the higher density spiral-poor Coma cluster. The clusters were ranked according to mean central galaxy density using the following procedure. The number of galaxies with absolute magnitude, $M_{T,0} \leq -20.4$, within 0.5 $r_A$ of the cluster centre was determined. Known foreground and background galaxies were subtracted from the total, and the final count was corrected for cluster galaxies projected onto the central region and used to determine a central mean galaxy density. The cluster sample was divided into four cluster types according to this central mean galaxy density: type 1, $\sim$ 1 galaxy Mpc$^{-3}$ (Abell 262, 347, 400 and 779); type 2, $\sim$ 2 galaxies Mpc$^{-3}$ (Abell 426); type 3, $\sim$ 3 galaxies Mpc$^{-3}$ (Abell 1367); and type 4, $\sim$ 5 galaxies Mpc$^{-3}$ (Abell 1656). (The cluster Abell 569 which has a double structure was omitted from the ranking.)

While the decrease in percentage of late-type galaxies with increasing cluster richness is well known, what is of more interest in the present context is the effect on the late-type galaxy population (types Sa and later) of the increasing galaxy density of richer cluster environments. This environment indeed appears to have a significant effect on the late-type galaxy population as the following results indicate.

Firstly there is a strong correlation (significant at the $4.7\sigma$ level) between a disturbed appearance of a spiral in the sample and the mean central galaxy density of the cluster environment. Similarly there is a strong correlation (significant at the $5\sigma$ level) between the occurrence of compact emission and the cluster mean central galaxy density. This latter correlation is almost wholly due to an increasing fraction of galaxies classified as 'peculiar' with increasing cluster mean central galaxy density. This increase in the fraction of galaxies classified as 'peculiar' is significant at the $4.4\sigma$ level. By contrast there is no significant correlation between the occurrence

[3]A value for the Hubble constant, $H_0$ = 50 km s$^{-1}$ Mpc$^{-1}$, is assumed throughout this paper.

TABLE 1

VARIATION OF GALAXY PROPERTIES WITH CLUSTER MEAN CENTRAL GALAXY DENSITY

| | Cluster Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | |
| | $\rho \sim 1\ Mpc^{-3}$ | | $\rho \sim 2\ Mpc^{-3}$ | | $\rho \sim 3\ Mpc^{-3}$ | | $\rho \sim 5\ Mpc^{-3}$ | |
| Disturbed galaxies (% spirals) | 6 | (7%) | 4 | (8%) | 8 | (29%) | 6 | (43%) |
| *Compact* emission (% types Sa and later) | 12 | (12%) | 14 | (22%) | 11 | (28%) | 12 | (44%) |
| 'Peculiar' (% types Sa and later) | 4 | (4%) | 4 | (12%) | 2 | (6%) | 8 | (29%) |

of a barred spiral structure and the cluster mean central galaxy density, or between the occurrence of diffuse emission and the cluster mean central galaxy density.

The numbers and percentages of the galaxy sample for disturbed galaxies, galaxies with compact emission, and galaxies classified as 'peculiar' in the four cluster types defined above, are presented in Table 1. It is seen that the percentage of spirals which are disturbed varies from only 7% in the poorest clusters to 43% in the Coma cluster. The percentage of galaxies (Sa and later) detected with compact emission shows a similarly marked increase from 12% to 44% respectively, and the percentage of galaxies classified as 'peculiar' rises from only 4% in the poorest clusters to almost 30% in the Coma cluster.

## 3. DISCUSSION

Evidence has been given above for central bursts of star formation in cluster spirals induced by galaxy-galaxy interactions. In the richest clusters it is to be expected that cluster-galaxy interactions will also cause a tidal distortion of spirals and perhaps trigger central bursts of star formation (e.g., Byrd & Valtonen 1990). However, this effect is only expected to be significant close to the centres ($r \leq 0.25 r_A$) of the richest clusters. The fact that a disturbed appearance of a galaxy is strongly correlated with the presence of a nearby companion, and it is not correlated with radial distance from the cluster centre (out to a distance of 1.5 $r_A$) seems to indicate that cluster-galaxy interaction is not the dominant effect causing either galaxy tidal disturbance or the associated central burst of star formation, although this interaction may be a significant effect in the centres of the richest clusters.

Since, as has been shown, the proportion of late-type galaxies, which are disturbed and have central bursts of star formation, increases with increasing cluster mean central galaxy density, this may imply a corresponding increase in galaxy-galaxy interactions for these galaxy types. Galaxies which are classified as 'peculiar' may be on-going mergers resulting from some fraction of these galaxy-galaxy interactions. If this is the case, then it is to be expected that the proportion of galaxies of this type would also increase with increasing cluster mean central galaxy density, and, as previously noted, this is indeed found to be the case. These results suggest that the stronger cluster gravitational fields of the richer clusters might be more efficient in promoting galaxy-galaxy interactions. A surprisingly high proportion ($> 40\%$) of the late-type galaxies surveyed in the Coma cluster are disturbed or have a central burst of star formation. This proportion is comparable to the proportion of late-type galaxies in clusters at earlier epochs which are similarly disturbed or interacting with companion galaxies with associated strong star formation, and suggests that similar processes may be at work to cause these effects in the nearby and more distant cluster, although, of course, the fraction of cluster galaxies which are late-type galaxies is much higher for the more distant clusters.

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