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An Hα survey of cluster galaxies – V. Cluster–field comparison for early-type galaxies

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ABSTRACT

We have extended our Hα objective prism survey of eight low-redshift clusters (viz. Abell 262, 347, 400, 426, 569, 779, 1367 and 1656) to include a complete sample of early-type galaxies within 1.5 Abell radii of the cluster centres. Of the 379 galaxies surveyed, 3 per cent of E, E–S0 galaxies, 6 per cent of S0 galaxies, and 9 per cent of S0/a galaxies were detected in emission. From a comparison of cluster and supercluster field galaxies, we conclude that the frequency of emission-line galaxies (ELGs; $W_{\lambda} \geqslant 20$ Å) is similar for field and cluster early-type galaxies. A similar result has previously been obtained for galaxies of types Sa and later. Together, these results confirm the inference of Biviano et al. that the relative frequency of ELGs in clusters and the field can be entirely accounted for by the different mix of morphological types between the differing environments, and that, for galaxies of a given morphological type, the fraction of ELGs is independent of environment. Detected emission is classified as 'compact' or 'diffuse', identified as circumnuclear starburst or active galactic nucleus (AGN) emission and disc emission, respectively. By comparing spectroscopic data for cluster early-type ELGs with data for field galaxies from the Palomar spectroscopic survey of nearby galactic nuclei, we demonstrate that there is modest evidence for an enhancement of compact H II emission relative to AGN emission in the early-type cluster ELGs as compared to the field. For the cluster early-type galaxies, compact H II emission correlates strongly with a disturbed morphology. This suggests that, as for later-type cluster galaxies, this enhanced compact H II emission can readily be explained as an enhancement of circumnuclear starburst emission due to gravitational tidal interactions, most likely caused by subcluster merging and other on-going processes of cluster virialization.

Key words: surveys – galaxies: clusters: general – galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: interactions – galaxies: starburst.

1 INTRODUCTION

Clusters of galaxies are sites of strong morphological evolution of disc galaxies. While the fraction of ellipticals in clusters remains relatively unchanged with redshift, the fraction of spirals is 2–3 times larger in intermediate-redshift clusters as compared to the present, with a corresponding decrease in the S0 population (Dressler 1980; Dressler et al. 1997). This dramatic change in the disc galaxy population since $z \sim 0.5$ suggests that processes associated with cluster virialization cause the transformation of spirals to S0s.

Although a variety of mechanisms have been proposed to explain the morphological change of cluster disc galaxies, there is growing evidence to suggest that gravitational tidal effects are the predominant mechanism for these transformations. Intermediate-redshift clusters have an unexpectedly high proportion of galaxies with unusual morphology, suggestive of merging and tidally interacting systems (e.g. Lavery & Henry 1988; Thompson 1988; Lavery, Pierce & McClure 1992; Dressler et al. 1994; Couch, Ellis & Sharples 1994; Oemler, Dressler & Butcher 1997). Furthermore, the dynamically interacting galaxies seem to be responsible for most of the galaxies that show spectroscopic signs of starbursts (Oemler et al. 1997), as may be expected from the consequences of tidal interactions (e.g. Barton, Geller & Kenyon 2000). These tidal effects and gravitational interactions are able to transform spirals to S0s: by gas stripping (e.g. Valluri & Jog 1991); by the loss of angular momentum of the disc gas, igniting a powerful central starburst, which can assist in the formation of a bulge (e.g. Hernquist & Mihos 1995; Barnes & Hernquist 1996); by tidal heating of the disc, stabilizing it against gravitational instability and suppressing subsequent star formation (e.g. Gnedin 2003b); by truncation of the halo, halting any further infall of cold

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gas (e.g. Merritt 1984; Gnedin 2003b); and by minor merger of two spirals to form an S0 (e.g. Bekki 1998).

The correlation of star formation rate and local projected density that holds for galaxies up to several virial radii from the centres of clusters (e.g. Kodama et al. 2001, 2003; Lewis et al. 2002; Gomez et al. 2003) suggests that preprocessing due to tidal forces in galaxy groups is a significant means to change galaxy morphology (e.g. Zabludoff & Mulchaey 1998). However, recent numerical simulations demonstrate that the tidal forces associated with on-going cluster formation and subcluster merging also play a major role in the morphological transformation of cluster disc galaxies (e.g. Bekki 1999; Gnedin 1999, 2003a,b).

Changes in cluster disc galaxy morphology were dramatic in the past. However, it is important to consider whether such changes are continuing in clusters at the present epoch. If morphological transformations of cluster disc galaxies are occurring at the present, albeit on a reduced scale, the processes involved may be studied in much greater detail than is easily possible at higher redshifts. In fact, there is growing evidence that activity similar to that seen in distant clusters is still on-going at the present epoch. In previous work (Moss & Whittle 1993; Moss, Whittle & Pesce 1998; Moss & Whittle 2000), we have shown that the residual spiral population of low-redshift clusters shares characteristics of the more abundant spiral population in higher-redshift clusters. There is an enhancement of circumnuclear starburst emission in cluster spirals as compared to their counterparts in the field. Moreover, a high proportion of the spirals in low-redshift clusters (e.g. ~40 per cent in Coma) have a distorted morphology, strongly correlated with circumnuclear starburst emission, typical of tidally disturbed systems. Similarly Caldwell & Rose (1997), in a study of five nearby clusters, conclude that 15 per cent of early-type galaxies show signs of on-going or recent star formation, characteristic of starburst or post-starburst galaxies, and that the frequency of such galaxies is enhanced as compared to the field. Further evidence that tides and interactions are not solely the provenance of intermediate-redshift clusters is provided by Conselice & Gallagher (1999), who show that distorted, interacting and fine-scale substructures are common in low-redshift cluster galaxies.

Our previous work was an Hα survey of spirals (types Sa and later) in eight low-redshift clusters, which we used to compare the incidence of star formation in clusters and the field. In the present paper we use the same data set to complete the survey for early-type galaxies, and compare emission for these galaxies between clusters and the field. Such a comparison is of interest for several reasons. First, previous such comparisons have generally concluded that emission is reduced in cluster early-type galaxies as compared to similar galaxies in the field. However, these earlier results have been cast in doubt as a result of the discovery of a previously unrecognized selection effect (cf. Biviano et al. 1997). Our survey data is expected to be free of this selection effect, and we are able to provide an unbiased comparison of emission in cluster and field early-type galaxies (see discussion in Section 3). Secondly, previous results for low-redshift clusters (cf. Caldwell et al. 1993; Caldwell & Rose 1997), lead to an expectation of an enhancement of starbursts in the cluster early-type population as compared to the field. Using the present survey data, we can attempt to confirm this prediction. Finally, data for detected early-type and late-type emission-line galaxies (ELGs) may be combined to gain further insight into processes affecting cluster galaxies particularly from the kinematical properties of the various ELG subgroups. This last investigation is the topic for a subsequent paper (Moss, in preparation).

Identifications of ELGs from combined Hα + [N II] emission for early-type galaxies from the Hα survey data have already been published for Abell 1367 (cf. Moss et al. 1998) In Section 2 we list the early-type galaxies surveyed, and present ELG identifications for the remaining seven clusters. A comparison of emission in field and cluster early-type galaxies is made in Section 3. In Section 4 we investigate possible enhancement of starburst emission in cluster early-type galaxies. Conclusions are given in Section 5.

2 OBJECTIVE PRISM SURVEY OF EARLY-TYPE CLUSTER GALAXIES

2.1 Survey sample

An objective prism survey for combined Hα + [N II] emission from cluster galaxies in eight low-redshift clusters (viz. Abell 262, 347, 400, 426, 569, 779, 1367 and 1656) has been undertaken using the 61/94-cm Burrell Schmidt Telescope on Kitt Peak. The survey technique and methods, and the plate material used, have been described in detail in previous papers (Moss, Whittle & Irwin 1988; Moss & Whittle 1993; Moss et al. 1998; Moss & Whittle 2000; Papers I–IV, respectively). For convenience, a brief summary of these details is given here. For each field, two plates were taken using hypersensitized IIIaF emulsion, with an emulsion/filter combination giving a ~350 Å bandpass centred on 6655 Å with a peak sensitivity of ~6717 Å. All plates were taken in conditions of good seeing and good transparency, and an Hα detection was accepted only if the galaxy was independently detected on both plates. Previous work has shown that the approximate detection limit of Hα + [N II] emission is an equivalent width, $W_\lambda \simeq 20$ Å.

The initial survey list comprised all 727 CGCG galaxies (Zwicky et al. 1960–1968) within a radial distance from the cluster centre, $r \leqslant 1.5\,r_A$, where r_A is the Abell radius (Abell 1958). In addition, 79 CGCG galaxies (all except one in Abell 1367, one in Abell 400) that lie in the region $1.5\,r_A < r \leqslant 2.6\,r_A$ were included in the survey. Adopted values of the Abell radius for each cluster, and plate boundaries of the survey plate material, are given in Papers III and IV. Of the 806 CGCG galaxies in the initial list, 37 are double systems. The components of these were surveyed separately, giving a total of 843 galaxies.

Galaxy types according to the revised de Vaucouleurs system (de Vaucouleurs 1959, 1974) were obtained for all galaxies in the initial survey list. Types were either taken from the UGC (Nilson 1973) or determined by inspection from a variety of Schmidt plate material. Details of the type classification procedure are given in Papers III and IV. Types for galaxies in Abell 1367 are given in Paper III, and for galaxies of types Sa and later for the remaining clusters in Paper IV.

Papers III and IV list types and Hα + [N II] emission detection for 460 galaxies, which are mainly of types Sa and later. The present paper completes the survey by listing types and Hα + [N II] emission detection for the remaining 383 galaxies of the survey, which are predominantly of types S0/a and earlier.

Combining the data from this paper with those for Papers III and IV, there are a total of 95 galaxies omitted from the survey as a result of plate defects (68), or a velocity $\geqslant$12 000 km s^{-1} (27). Thus the final total of surveyed galaxies is 748.

2.2 Emission detection

In Table 1 we give galaxy types for the remaining 383 galaxies of the initial survey list, together with the heliocentric velocity taken from the NASA Extragalactic Database (NED). With the exception

Table 1. Cluster galaxy survey sample (see notes at end of table). Column 1: CGCG number (Zwicky et al. 1960–1968). The numbering of CGCG galaxies in field 160 (Abell 1656), which has a subfield covering the dense central region of the cluster, follows that of the listing of the CGCG in the Simbad data base. The enumeration is in strict order of increasing right ascension, with galaxies of lower declination preceding in cases of identical right ascension. Column 2: UGC number (Nilson 1973). Column 3: Galaxy type taken from UGC or estimated from the Palomar Sky Survey. Column 4: Heliocentric velocity taken from the NASA Extragalactic Database (NED).

CGCG	UGC	Type	$v_\odot$ (km s^{-1})	CGCG	UGC	Type	$v_\odot$ (km s^{-1})	CGCG	UGC	Type	$v_\odot$ (km s^{-1})
Abell 262				522-103	...	SB:...	4039	540-048	...	...	6387
521-075	...	SA0/a:	4340	*Abell 347*				540-050	2568	S0	4752
521-077	...	SAB:	5404	538-041	...	S0/a	5819	540-051	...	S0/a	
521-079	1236	S0:	4733	538-044	1790	...	6002	540-053	...	E/S0	4704
522-008	...	S0:	4423	538-055	1837	S0	6582	540-054	2574	SB0/SBa	5015
522-009	1269	E/S0	3855	538-057A	1841	E	6373	540-055	2578	E/S0	5235
522-010	1272	S0	5005	538-057B	1841	E	6595	540-056	...	...	5612
522-011	...	...	4014	538-060	...	S0/a	5659	540-057	2590	...	4719
522-012	...	S...	4041	538-064	1859	S0/a	5917	540-059	...	S0?	5502
522-014	1277	S0/a	4146	538-065	...	S0	5065	540-061	2598	S0?	4504
522-015	1283	E/S0	5049	539-016	1872	E	4978	540-062	...	S0:	5426
522-016	...	...	10936	539-017	1875	E	5201	540-063	2606	E	4888
522-017	1298	S0	5091	539-018	...	S0		540-066	2613	S0	6014
503-033	...	...	5611	539-019	...	S0	5195	540-068	2614	S0/a	5252
522-022	1308	E	5171	539-020	...	E/S0	4407	540-072	...	SA0	4234
522-023	...	SB0:	5048	539-021	1878	E	5766	540-074	...	S0:	4969
503-040	...	E:	10608	539-022	...	...		540-075	2624	S0	5660
522-026	...	SA0:	4877	539-028	...	E/S0	5485	540-077	...	...	5864
522-027	1336	S0	4364	539-031	...	S0/a	5645	540-079	...	S0:	7236
522-030	...	S0:	4690	539-033	...	S0/a		540-080	...	S0:	4983
522-032	1339	SB0	3998	539-034	1979	S0?	5750	540-081	2634	S0/a	5631
522-033	...	S0:	4284	539-035	1987	E?		540-082	...	...	4850
522-034B	1343	S0:	4730	539-037	...	S0/a	5859	540-085	...	E/S0	4370
522-034A	1343	S0:	4618	539-039	...	S0		540-086	2644	E	4978
522-036	...	S0/a	5580	539-042	...	S0	4885	540-087	...	E/S0	6468
522-037	1346	E/S0	5580	539-043	2006	E		540-088	2651	E	7536
522-039	1348	E	4855	539-044	...	pec	4920	540-089	...	S0	3342
522-040	...	S0:	3359	539-050	...	S0	5018	540-092	2657	E?	5059
522-043	1352	S0	5330	539-054	2063	S0	5799	540-095	2660	E	4965
522-044	...	S0:	4928	539-057	2073	S0?	5165	540-096	...	S0	5751
522-045	...	S0:	4788	539-058	2074	S0/a	5601	525-020	2661	S0	5980
522-046	1353	E/S0	5254	*Abell 400*				540-097	...	S0/a:	8194
522-047	1358	S0/a	4458	415-020	2367	S0	7380	540-098	2662	E	3815
522-048	...	E/S0	4151	415-033	...	S0:: pec	8116	540-099	...	E/S0	5387
522-049	...	Sc:	4679	415-034	...	...	7229	540-101	...	E/S0	4500
522-052	1363	S0/a	4968	415-038	...	...	6384	540-102	...	S0	6413
522-053	...	S0/a:	5655	415-040	...	S0:	6861	540-104	...	S0 pec	5066
522-054	...	S...	4387	415-041B	...	E/S0:	7142	540-105	2670	E	6090
522-057	...	SB0/a	4589	415-041A	...	E/S0:	6641	540-107	2673	S0	4266
522-061	...	S0/a:	5033	415-043B	...	S0::	6097	540-108	...	S0:	4300
522-064	1388	E/S0 pec	5359	415-043A	...	S0::	6410	540-109	2675	E	2139
522-065	...	Sb:	5704	415-044	...	S0:	7348	540-110	2676	E/S0	6749
522-068	...	S...	4785	415-046	...	E/S0:	6830	540-111	2682	E	4432
522-072	...	S0:	5371	415-047	...	E/S0:: pec	6333	540-113	...	S0:	4411
522-076	1406	S0	5894	415-049	...	S0:	6770	540-116	...	E/S0	4173
522-080	1415	S0/a	4796	415-050	...	S0:	8215	540-117	2694	S0?	6585
522-083	...	...	4789	415-051	...	...	8581	540-119	2698	E	6421
522-084	1434	S0/a	4540	415-052	...	SA0/a:	6652	540-120	...	S0/a:	4788
522-085	...	S0:	5487	*Abell 426*				540-122	2708	S0	5394
522-087	1440	E	4667	540-035	2528	S0/a	6296	540-123	2717	E	3798
522-089	...	E/S0:	5114	540-038	2533	E/S0	1592	541-004	2725	S0	6192
522-091	...	E/S0	4686	540-040	2536	S0	4792	541-007	2733	E?	5331
522-092	...	S0/a:	4214	540-041	...	S0:	5355	541-012	...	...	4743
522-098	...	S0:	4817	540-044	2554	S0?	2847	541-013	2752	S0	4179
522-099	...	SB:...	5334	540-045	...	...	5830	541-014	...	S0:	5580
522-101	1475	E	4209	540-046	2559	S0	557	541-016A	2756	E/S0	5061
541-016B	2756	S0:		181-028	...	E/S0:	15125	160-052	...	...	8196
541-018	2762	E/S0	5442	181-029	...	S0:	6992	160-053	...	...	7095

Table 1 – *continued*

CGCG	UGC	Type	$v_\odot$ (km s^{-1})	CGCG	UGC	Type	$v_\odot$ (km s^{-1})	CGCG	UGC	Type	$v_\odot$ (km s^{-1})
Abell 569				181-031	...	E/S0	8252	160-056	8086	S0	5844
234-031	...	...	5792	181-033	4972	S0?	7075	160-057	...	...	7506
234-040	...	...	6047	181-034	...	...	6310	160-059	...	...	7675
234-047	3659	E	5944	181-035	4974	S0?	7023	160-061A	...	...	7907
234-048	...	S0/a:	5661	181-038	...	...	6657	160-061B	...	...	6697
234-053	...	S0:	5895	181-040	5001	SB0	1687	160-063	...	S0:	6023
234-054	...	...	6003	181-041	...	E/S0:	12742	160-065	...	E/S0	7145
234-058	...	...		*Abell 1656*				160-066	...	...	8004
234-059	...	S0:	5341	159-098	...	E/S0:	8010	160-068	8092	...	7660
234-064	...	...	5748	159-101	...	...	7745	160-069	...	...	6704
234-068	...	S0/a:	6156	159-102	8017	...	7061	160-070	...	E/S0	8430
234-070	3695	E/S0	5795	159-104	...	S0/a:	6159	160-071	...	...	5682
234-073	3696	E/S0	6150	159-106	...	...	7945	160-072	...	S0/a	5916
234-074	...	S0:	4820	159-111	8026	S0/a	7627	160-074	8097	S0/a	7164
234-075	3699	S0	5836	159-112	...	...	6413	160-076	...	S0:	7972
234-077	...	S0:	6108	159-113	8028	E/S0	8365	160-078	...	E/S0:	5554
234-078	...	E/S0:	5472	159-114	...	SB0/a:	7033	160-079	...	...	6336
234-080	...	SB:0/a:	6174	159-115	...	...	6202	160-080	...	...	7088
234-081	3713	E/S0	6500	159-118	8038	...	7863	160-081	...	...	6650
234-082	...	E/S0:	5648	159-119	...	...	7495	160-082	...	...	7678
234-083	...	E/S0:	5747	160-015	...	S0:	7356	160-083	...	E/S0	7980
234-084	...	E/S0:	6310	160-016	...	...	7177	160-084	...	...	5675
234-085	...	...	6158	160-017	8049	...	6989	160-085	...	...	6812
234-086	...	E/S0	6393	160-018	...	...	7049	160-086	...	...	4859
234-087	...	S0:	4820	160-019	...	...	7115	160-087	...	E/S0 pec	6841
234-088B	3719	...		160-020	...	...	4968	160-088	...	E/S0	7780
234-089	...	...	5894	160-021	8057	E/S0	6915	160-089	8100	E?	4670
234-091	3720	E	5925	160-022	...	S0:	6486	160-090	...	E/S0	6875
234-095	...	E/S0	6102	160-023	...	...	6883	160-091	...	...	6790
234-096	...	E/S0	5824	160-024	...	...	7506	160-092	...	E/S0:	4755
234-097	3725	E/S0	6171	160-026	...	S0/a:	7525	160-093	...	...	7209
234-098	...	S0/a:	5132	160-027	...	...	6297	160-094	...	E/S0:	6717
234-101	...	E/S0:	5487	160-028	8065	S0	7630	160-095	...	E/S0:	5848
234-105	...	S0:	6229	160-029	...	S0/a:	6296	160-097	...	...	8045
234-108	...	E/S0	5823	160-031	...	...	6849	160-098	8103	S0	7224
234-110	...	S0/a:		160-032	...	S0/a:	7581	160-100	...	...	6148
234-111	3758	E/S0 pec	5678	160-033	...	...	6273	160-101	...	...	5978
234-113	...	...	9988	160-034	...	...	8064	160-102	...	...	8342
234-115	...	...		160-035	...	S0/a:	7495	160-103	...	...	8009
235-006	...	S0:	5861	160-037	...	...	7463	160-104	...	...	6678
Abell 779				160-039	8070	E	7362	160-105	...	...	6900
181-005	...	E/S0:	14974	160-040	...	...	5475	160-106	...	E/S0:	9401
181-008	...	SB0/a	7171	160-041	...	...	7230	160-108	...	...	8071
181-009	...	S0:	6634	160-042	...	...	6087	160-109	8106	E	6740
181-011	...	E/S0	7213	160-044A	8072	E	6775	160-111	...	E/S0	6392
181-014	...	...	6781	160-044B	8072	E	6302	160-112	...	...	6568
181-015	...	...	7036	160-045	...	...	6356	160-113B	...	...	9902
181-018	4939	S0/a	6379	160-046A	...	...	7343	160-114	8110	E	6494
181-020	...	...	6465	160-046B	...	...	7234	160-115	...	...	7268
181-021	...	S0:	6394	160-047	...	...	6118	160-116	...	...	7268
181-022	...	S0/a:	7062	160-048A	...	E/S0:	5861	160-117	...	...	6781
181-024A	4942	E	6948	160-048B	...	...	6990	160-118	...	...	11114
181-024B	...	E/S0	5180	160-049	...	...	7237	160-119	...	...	5737
181-027	...	...	7321	160-051	8080	S0/a	7410	160-120	...	E/S0:	7365

of eight galaxies in Abell 262 typed as spirals and one galaxy in Abell 347 typed as 'peculiar', accidentally overlooked in previous work, the remaining 374 galaxies are all of types S0/a and earlier, or are untyped (type class '. . .'). Of the galaxies listed in Table 1, 30 could not be surveyed because of plate defects (these galaxies are listed in the 'Notes to the table'), or a velocity $\geqslant$12 000 km s^{-1}, since in the latter case any Hα emission is redshifted beyond the sensitivity limit of the plate. Thus there is a total of 353 surveyed galaxies.

Of these 353 predominantly early-type galaxies, 28 galaxies were detected in emission. The emission-line galaxies (ELGs) are listed in Table 2. For galaxies in Table 2 that are untyped (type class '. . .'),

Table 1 – *continued*

CGCG	UGC	Type	$v_{\odot}$ (km s^{-1})	CGCG	UGC	Type	$v_{\odot}$ (km s^{-1})	CGCG	UGC	Type	$v_{\odot}$ (km s^{-1})
160-121B	...	...	6371	160-143	...	...	6828	160-167	...	...	8210
160-122	...	...	4634	160-144	...	...	5965	160-168	...	S0:	7759
160-121A	...	...	6811	160-145	...	...	6664	160-169	...	...	5965
160-123	...	...	8220	160-146	8133	S0	7334	160-170	8154	S0	5443
160-124	...	S0	8492	160-149	...	E/S0:	5484	160-171	...	S0/a	6917
160-125	...	SB:0/a:	7208	160-151	8137	S0	7387	160-174	...	...	5602
160-126	...	E/S0	6812	160-152	...	...	7556	160-175	...	E/S0:	6358
160-128	8117	E/S0	6012	160-153	...	...	5807	160-176B	8167	...	
160-129	...	E/S0:	7521	160-155	8142	E/S0	7887	160-177	...	E/S0:	5939
160-131	...	...	5441	160-156	...	...	7072	160-181	8175	E	5968
160-133	...	S0:	6363	160-157	...	E/S0	7764	160-182	8178	E	6909
160-134	...	...	7112	160-158	...	...	7188	160-184	...	...	7075
160-135	...	...	7997	160-161	...	E/S0:	7572	160-187	...	...	7944
160-136	8122	S0/a	6925	160-162	...	S0/a:	5580	160-189B	8194	...	7163
160-137	...	E/S0:	8793	160-163	...	...	6872	160-190	...	...	7851
160-138	...	E/S0:	6940	160-164B	...	...		160-192	...	S0/a:	6307
160-141	...	E	5012	160-165	...	E/S0	6211	160-193	...	...	7304
160-142	...	...	7665	160-166	...	...	7406	160-195	8206	S0/a	6655

Notes. *Galaxies not surveyed.* A total of 24 galaxies were not surveyed because of plate defects: nine galaxies on a defocused region of plate 15270 for Abell 1656 (CGCG Nos 159-106, 159-114, 159-119, 160-016, 160-029, 160-034, 160-035, 160-044A and 160-044B); 12 galaxies whose spectra were overlapped by adjacent stellar or galaxy spectra (CGCG Nos 159-113, 522-027, 538-041, 538-057A, 538-057B, 538-060, 539-043, 415-034, 415-041A, 415-041B, 540-089 and 541-016A); and three galaxies that lay outside the overlap region of the survey plate pair (CGCG Nos 503-033, 503-040 and 540-035).
Double systems. CGCG 522-034A and B: N and S components, $m_p \sim 14.7$ and 15.1, respectively. CGCG 415-043A and B: NW and SE components, $m_p \sim 16.3$ and 16.3, respectively. CGCG 541-016A and B: S and N components, $m_p \sim 15.8$ and 15.8, respectively. CGCG 234-088A and B: S and N components, $m_p \sim 15.4$ and 16.6, respectively. CGCG 181-024A and B: NE and SW components, $m_p \sim 13.7$ and 14.5, respectively. CGCG 160-046A and B: N and S components, $m_p \sim 15.5$ and 15.9, respectively. CGCG 160-048A and B: W and E components, $m_p \sim 15.9$ and 16.2, respectively. CGCG 160-061A and B: S and N components, $m_p \sim 15.8$ and 16.1, respectively. CGCG 160-113A and B: W and E components, $m_p \sim 16.0$ and 16.8, respectively. CGCG 160-121A and B: S and N components, $m_p \sim 15.3$ and 15.7, respectively. CGCG 160-164A and B: E and W components, $m_p \sim 16.3$ and 16.3, respectively. CGCG 160-176A and B: W and E components, $m_p \sim 13.5$ and 15.2, respectively. CGCG 160-189A and B: E and W components, $m_p \sim 14.0$ and 16.5, respectively.

we list additional type information from NED, where available. The visual classification of the detected emission according to visibility (S = strong; MS = medium strong; M = medium; MW = medium weak; and W = weak) and concentration (VC = very concentrated; C = concentrated; N = normal; D = diffuse; and VD = very diffuse) is given according to the scheme used in previous work (cf. Papers I–IV). Similarly, for the subsequent analysis, we choose binary ranks for the Hα appearance, yielding two parameters: *compact* emission (concentration classes VC, C or N); and *diffuse* emission (concentration classes D or VD). Notes on individual objects are appended to the table.

In Table 3 we summarize emission detection frequency with morphological type. In order to approximate a volume-limited sample (cluster galaxies and galaxies proximate to the cluster in the supercluster field), we restricted the sample to galaxies with velocities within 3σ of the cluster mean. For each morphological type class, the table lists the total sample number (n_t), the numbers of detected galaxies with compact and diffuse emission ($n_{e,c}$ and $n_{e,d}$, respectively), and the overall percentage of galaxies detected in emission (p_e). Corresponding values are also given when NED types, where available, have been included for galaxies with undetermined types (n'_t, $n'_{e,c}$, $n'_{e,d}$ and n'_e).

Similar results have been given and discussed previously (cf. Paper IV). The present work provides a greatly increased sample for early-type galaxies (S0/a and earlier) and confirms, as expected, a much lower detection frequency for early-type galaxies as compared to spirals and later types. Moreover, the detected emission for early-type galaxies is seen to be predominantly compact emission. The likely origin for this emission is discussed in Section 4.

3 EMISSION IN CLUSTER AND FIELD GALAXIES

The earliest studies that compared the frequency of emission between field and cluster galaxies were in agreement in finding, *for a given galaxy morphological type*, a lower frequency of ELGs in clusters (e.g. Osterbrock 1960; Gisler 1978; Dressler, Thompson & Shectman 1985; Hill & Oegerle 1993). However, Biviano et al. (1997) identified a hitherto unsuspected systematic effect that causes an overestimate in the fraction of ELGs at fainter magnitudes, due to the bias that operates against the successful determination of redshifts for faint galaxies without emission lines. When field galaxies are on average fainter than the cluster galaxy sample and redshift data are incomplete, this systematic effect works to overestimate the frequency of emission in field as compared to cluster galaxies.

Based on the ESO Nearby Abell Cluster Survey spectral data (5634 galaxies in the directions of 107 cluster candidates), Biviano et al. (1997) concluded that the observed difference in frequency of ELGs between field and cluster galaxies could be entirely accounted for by the variation in this frequency with galaxy morphological type, and the differing morphological mix between field and cluster galaxies. By inference, there is expected to be no difference in the ELG frequency for galaxies of a given morphological type between cluster and field environments, in disagreement with all earlier studies.

For the present prism survey, field and cluster galaxies have been surveyed in an identical manner to the same magnitude limit. Redshift data are available for most (∼96 per cent) of the galaxy sample, and field and cluster samples have both been limited to galaxies with

Table 2. Galaxies detected in Hα emission (see notes at end of table). Columns 1 and 2: As columns 1 and 2 of Table 1. Columns 3 and 4: Right ascension and declination (1950.0) of the galaxy centre taken from the CGCG. Column 5: Radial distance in Abell radii (Abell 1958) of the galaxy with respect to the cluster centre. Adopted positions for the cluster centres and values of the Abell radii are given in Paper IV. Column 6: CGCG photographic magnitude. For double galaxies, magnitude estimates for individual components obtained by eye from PSSN are given in parentheses. Columns 7 and 8: As columns 3 and 4 of Table 1. The † in column 7 indicates that types were taken from NED. Column 9: A visibility parameter describing how readily the Hα emission is seen on the plates according to a five-point scale (S = strong, MS = medium strong, M = medium, MW = medium weak, W = weak). Column 10: A concentration parameter describing the spatial distribution of the emission and contrast with the underlying continuum, on a five-point scale (VD = very diffuse, D = diffuse, N = normal, C = concentrated, VC = very concentrated). Column 11: The number in this column indicates the note on this galaxy that appears below.

CGCG	UGC	RA		Dec.		r (r_A)	m_p	Type	$v_\odot$ (km s^{-1})	Hα emission Vis.	Conc.	Notes
Abell 262												
522-011	...	1	46.4	34	43	0.8	15.4	S0†	4014	MS	C	1
522-039	1348	1	49.9	35	55	0.0	14.8	E	4855	W	N	2
522-053	...	1	51.0	36	23	0.3	15.4	S0/a:	5655	W	D	
522-072	...	1	53.4	35	20	0.5	15.2	S0:	5371	M	D	3
Abell 347												
539-031	...	2	24.4	41	47	0.2	15.0	S0/a	5645	S	VC	4
539-044	...	2	30.5	41	8	1.0	15.3	pec	4920	MS	VD	
Abell 400												
415-020	2367	2	51.0	6	4	0.9	15.3	S0	7380	W:	VD	
415-033	...	2	53.8	4	25	1.2	15.2	S0:: pec	8116	M	N	
415-038	...	2	54.3	6	0	0.2	15.3	S0†	6384	S	N	
415-043B	...	2	55.3	5	35	0.2	(16.3)	S0::	6097	W:	D	
415-050	...	2	56.6	5	56	0.3	15.0	S0:	8215	S	N	
415-052	...	2	57.5	5	36	0.6	15.3	SA0/a:	6652	W:	N	
Abell 569												
234-085	...	7	7.0	48	16	0.3	15.5	...	6158	MW	N	
234-096	...	7	7.9	47	1	1.2	15.3	E/S0	5824	M	C	
234-113	...	7	11.9	49	42	1.0	15.7	Sc†	9988	W	D	
234-115	...	7	13.0	49	58	1.2	15.7	...		W	N	
Abell 1656												
159-101	...	12	50.3	27	40	1.4	15.3	Irr†	7745	S	N	
159-102	8017	12	50.4	28	39	1.3	14.5	Sab†	7061	M	D	
160-020	...	12	53.7	27	57	0.7	15.5	Sa†	4968	S	C	
160-026	...	12	54.1	27	33	0.8	15.5	S0/a:	7525	MW	N	
160-033	...	12	54.5	27	10	1.0	15.1	E†	6273	MW	N	5
160-068	8092	12	56.2	27	51	0.4	14.2	(R′)SA0−?†	7660	W	N	
160-078	...	12	56.7	27	55	0.3	15.1	E/S0:	5554	S	N	6
160-156	...	12	59.6	28	3	0.4	15.4	SA0†	7072	W	N	
160-158	...	12	59.7	27	55	0.5	15.1	S0pec?†	7188	S	N	
160-169	...	13	0.6	26	47	1.3	15.7	S†	5965	M	N	
160-189B	8194	13	3.9	29	20	1.5	(16.5)	S	7163	W	D	
160-193	...	13	4.8	28	18	1.3	15.5	Sc +†	7304	S	N	

Notes. *Individual objects.* 1. CGCG 522-011 = Ark 59 (Arakalian 1975). This high surface brightness elliptical blue object is a component of a triple system and is likely to be interacting with another component, CGCG 522-013 = V Zw 113 ('distorted blue Sc', cf. Zwicky 1971; $v_\odot$ = 4019 km s^{-1}). 2. CGCG 522-039 = NGC 708, the brightest galaxy in Abell 262. It has a radio jet (Bridle & Perley 1984), and also a doubly ionized gas component, one aligned with the stars of the galaxy and the other strongly decoupled, suggesting an external origin (Plana et al. 1998). Nuclear emission ratio, [N II]/Hα ∼ 2 (Miller & Owen 2002). 3. CGCG 522-072 = V Zw 144 ('blue fuzzy elliptical disc compact'; cf. Zwicky 1971). 4. CGCG 539-031 = Mrk 1176. Markarian starburst galaxy paired with companion (Keel & van Soest 1992; Miller & Owen 2002). 5. CGCG 160-033 = Ark 395 ('compact symmetrical blue object with envelope'; cf. Arakalian 1975) 6. CGCG 160-078 = Mrk 58. A blue disc galaxy which shows a very asymmetric gas distribution (cf. Bravo-Alfaro et al. 2000). Type given by NED is SBa.

velocities within 3σ of the cluster mean. Field galaxies thus comprise an approximately volume-limited sample, and both field and cluster galaxies are expected to have similar distributions in both apparent and absolute magnitude. Accordingly, we expect comparative frequencies of cluster and field ELGs determined from this survey to be free of the bias identified by Biviano et al. (1997) as well as systematic effects due to any dependence of the Hα emission on absolute magnitude.

Using data from the prism survey, we have previously shown that, for galaxies of types Sa and later, there is indeed no difference in the ELG frequency between field and cluster environments, in accord with the conclusions of Biviano et al. (1997) (cf. Paper IV, and references therein). A similar result has been obtained by Gavazzi et al. (1998) for galaxies of types Sa and later. These authors compared Hα equivalent widths for volume-limited samples of cluster and supercluster field galaxies to the same magnitude limits in the Coma supercluster, and concluded that there was no significant difference between the two samples.

Using the prism survey data in this paper, we now compare ELG frequencies for E, S0, S0/a galaxies between field and cluster environments. We adopt the definitions of projected radial distance from the cluster centre (R), local surface density (Σ) and cluster type (CT) given in Paper IV. For the latter parameter, CT, cluster galaxies were taken as those surveyed galaxies with $r \leqslant 1.0\, r_A$; field galaxies were

Table 3. Galaxies detected in emission for different type classes.

Type	Total		Compact ELGs		Diffuse ELGs		Percentage ELGs	
	n_t	n'_t	$n_{e,c}$	$n'_{e,c}$	$n_{e,d}$	$n'_{e,d}$	p_e	p'_e
E	39	(55)	1	(2)	0	(0)	2.6	(3.6)
E-S0	82	(84)	2	(2)	0	(0)	2.4	(2.4)
S0	127	(173)	3	(8)	2	(2)	3.9	(5.8)
S0/a	60	(67)	5	(5)	1	(1)	10.0	(9.0)
Sa	55	(58)	8	(9)	8	(8)	29.1	(29.3)
Sab	25	(27)	3	(3)	7	(8)	40.0	(40.7)
Sb	40	(40)	10	(10)	8	(8)	45.0	(45.0)
Sbc, Sc	44	(45)	7	(8)	11	(11)	40.9	(42.2)
Sc–Irr, Irr	11	(13)	1	(2)	3	(3)	36.4	(38.5)
pec	21	(21)	14	(14)	2	(2)	76.2	(76.2)
S…	61	(69)	12	(13)	13	(13)	41.0	(37.7)
…	105	(18)	12	(2)	1	(0)	12.4	(11.1)

Note. n'_t, $n'_{e,c}$, $n'_{e,d}$ and p'_e for the various samples are obtained by including NED types, where available, for galaxies with indeterminate type.

those surveyed galaxies with either $r > 1.5\,r_A$ or (for Abell 262, 347, 400 and 779) $r > 1.0\,r_A$. Clusters were ranked according to increasing mean space density of galaxies in the central regions of the cluster ($r \leqslant 0.5\,r_A$) with the first rank for field galaxies. (For further discussion, cf. Paper IV.)

If the frequency of ELGs varies systematically from field to cluster, we expect this frequency to show a dependence on one or more of the three parameters, R, Σ and CT. A Kendall rank test shows no significant correlation between the fraction of E, S0, S0/a galaxies detected in emission and each of R, Σ and CT (significance levels of 0.0σ, -1.1σ and -0.8σ, respectively). Thus we confirm that there is no dependence of the frequency of ELGs among early-type galaxies on either local surface density or cluster environment in accord with the results of Biviano et al. (1997).

A Kendall rank test also shows no significant correlation between the fraction of E, S0, S0/a galaxies detected in *compact* emission and each of R, Σ and CT (significance levels of -0.3σ, -0.3σ and 0.1σ, respectively). This result is expected from the previous one, because most ELGs in the E, S0, S0/a sample have compact emission. However, this result is in contrast to the previous finding (cf. Paper IV) of an enhancement of compact emission for cluster spirals.

In previous work, we have suggested that the enhancement of compact emission in cluster galaxies of types Sa and later is due to circumnuclear starbursts triggered by tidal interactions associated with subcluster merging and on-going processes of virialization. With this scenario, one expects an enhancement of compact emission in the non-virialized later-type galaxy population. The degree of enhancement is likely to be related to the strengths of the varying gravitational fields in clusters of differing galaxy density and stage of relaxation.

If this scenario is correct, any corresponding enhancement of compact emission in early-type cluster galaxies may be less evident. As a cluster continues to form, and spirals are transformed into earlier type galaxies, any enhancement of circumnuclear starburst emission in early-type galaxies is likely to be masked by the increasing number of these galaxies in the cluster.

Accordingly, we attempt to test whether there is an enhancement of starburst emission in early-type galaxies in the clusters surveyed, using an alternative method described in the next section.

4 ENHANCEMENT OF STARBURST EMISSION IN CLUSTER EARLY-TYPE GALAXIES

In previous work, restricted to a sample of the surveyed cluster galaxies of types Sa and later, we have shown that compact emission can convincingly be identified as due to circumnuclear starburst emission, whereas diffuse emission originates from more normal star formation in the discs of the spiral galaxies. The compact emission was shown to be associated both with a tidal disturbance of the galaxy and with the presence of a bar. For spirals in this sample, a strong association was also found between compact emission and the presence of a tidal companion, which suggests that much of this emission is caused by circumnuclear starbursts associated with local galaxy–galaxy interactions. However, galaxies classified as peculiar show no tendency to have tidal companions, although a very high percentage (∼76 per cent) of these galaxies show compact emission (see Table 3). As discussed in Paper IV, a natural explanation of this latter result is that peculiars are predominantly on-going mergers, in which the companion is already indistinguishable from its merger partner, and the compact emission arises from the starburst induced by the merger.

However, for early-type galaxies, the association between compact emission and star formation appears less likely. For example, in the Palomar spectroscopic survey of nearby galactic nuclei (PSSN; Ho, Filippenko & Sargent 1997), not a single elliptical galaxy shows emission attributable to star formation.

The above suggests that we might detect any enhancement of starburst emission in the early-type cluster galaxies by comparison of the fraction of detected early-type cluster ELGs that show H II emission, with the same fraction for a comparable field sample. We proceed to make this comparison as follows. First, we determine the *expected* fraction of early-type ELGs with H II emission from data for the field from the PSSN. This is done in Section 4.1. Then, in Section 4.2, we make a comparison between this expected fraction and the *observed* fraction for cluster early-type ELGs, using a compendium of published data. As will be seen, this comparison gives a modest indication of an enhancement of starburst emission in cluster early-type galaxies. Furthermore, we show how this enhancement of emission can readily be explained by the effect of gravitational tidal interactions.

4.1 Expected emission from field data

The PSSN is based on high-quality optical spectra of moderate resolution for the nuclei ($r \lesssim 200$ pc) of almost every bright galaxy ($B_T \leqslant 12.5$) in the northern sky ($\delta > 0°$). Using standard nebular diagnostics, the probable ionization mechanisms of the emission-line objects in the survey have been identified. These spectral classifications can be used to infer the likely origin of the compact emission detected in early-type galaxies by the present objective prism survey in the following way.

First, we select a subsample of the PSSN sample whose distribution in absolute magnitude approximately matches that of the CGCG galaxies in the prism survey. This match is important because the ionization mechanism for emission-line objects in the PSSN has a strong dependence on absolute magnitude. In Fig. 1, we show the distributions of absolute asymptotic B magnitudes corrected for internal and Galactic extinction, M_B^0, for galaxies in the prism survey, and for a subsample of the PSSN restricted to $M_B^0 \leqslant -18.5$. Values of M_B^0 for the prism survey galaxies were derived from CGCG magnitudes, m_p, converted to the B_T system following Paturel, Bottinelli & Gouguenheim (1994) and corrected for galactic and internal absorption following Sandage & Tammann (1987). Values

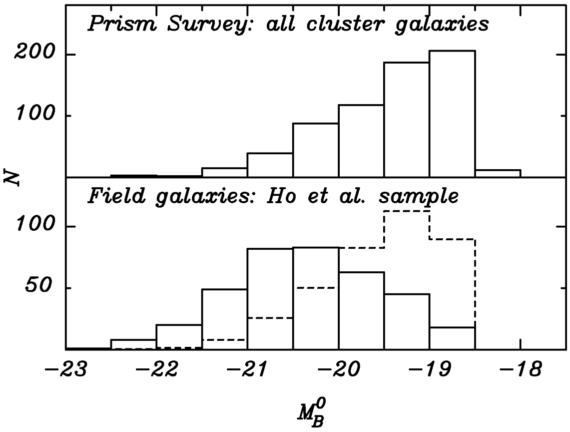

Figure 1. Distribution in absolute magnitude, M_B^0, for galaxies in the prism survey (top) and in a subsample of the Palomar spectroscopic survey of nearby galactic nuclei (PSSN) restricted to $M_B^0 \leqslant -18.5$ (bottom). The dashed histogram shows the volume-weighted distribution for the PSSN subsample.

of M_B^0 for the PSSN subsample were taken from Ho et al. (1997).[1] In both cases, absolute magnitudes were derived assuming $H_0 = 75$ km s^{-1} Mpc^{-1}.

Whereas the PSSN is an apparent magnitude-limited sample, the prism survey sample is approximately volume-limited and thus has a relative preponderance of fainter galaxies. To match the samples more closely, the PSSN subsample was weighted according to the volume surveyed. The volume-weighted distribution is shown by the dashed histogram in Fig. 1.

Next, we have used the PSSN volume-weighted sample to determine the percentages of galaxies that have H II emission for each of the three type groups: E, S0, S0/a; Sa, Sab, Sb; and Sbc, Sc, Sc–Irr. These percentages are shown in Fig. 2. In this figure, the percentage of galaxies with H II emission is plotted against the combined equivalent width of Hα + [N II] (λ6584), W_λ(Hα + [N II]). The percentage plotted is a cumulative percentage for all galaxies with equivalent width $\geqslant W_\lambda$.

Values of W_λ plotted in Fig. 2 from the PSSN are for nuclear emission from slit spectroscopy. By contrast, ELG detections for the prism survey are based on integrated global emission. However, for strong emission ($W_\lambda \geqslant 10$ Å), we expect equivalent widths determined by slit spectroscopy and integrated global emission to be well correlated (cf. Kennicutt & Kent 1983). Accordingly, for $W_\lambda \geqslant 10$ Å, we can assume that percentages of galaxies with H II emission in Fig. 2 are representative of emission galaxies detected in the prism survey.

Arrows in Fig. 2 indicate the values of W_λ at which the fraction of galaxies with equivalent width $\geqslant W_\lambda$ equals the fraction of galaxies detected in compact emission by the prism survey. Percentage values for each type group at these points thus indicate the percentages of prism survey compact ELGs that are expected to have H II emission.

It is seen that a majority of late-type compact ELGs are expected to have H II emission (~75 per cent for types Sa, Sab, Sb; and ~100 per cent for types Sbc, Sc, Sc–Irr). This is in agreement with previous work, where it is assumed that compact emission from

[1] Although the details of the derivations of M_B^0 for the two samples differ, the resulting magnitude differences are not considered significant in the present context.

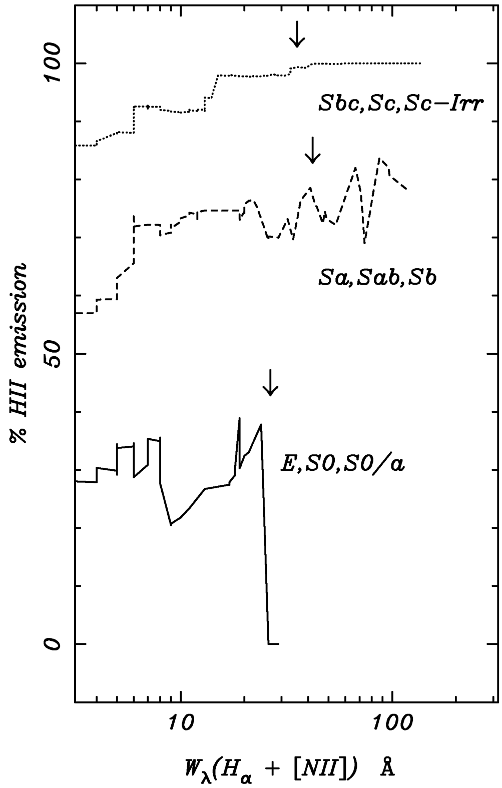

Figure 2. Cumulative percentages of the volume-weighted PSSN field galaxy sample (Ho et al. 1997) with H II emission, plotted against the combined equivalent width, W_λ(Hα + [N II]). The cumulative percentages (with the integrated number of galaxies, n, increasing from right to left) are for all galaxies with equivalent width $\geqslant W_\lambda$. Plots are given for each of the type groups: E, S0, S0/a ($n \geqslant 3$); Sa, Sab, Sb ($n \geqslant 3$); and Sbc, Sc, Sc–Irr ($n \geqslant 10$). Arrows indicate the values of W_λ at which the fraction of galaxies with equivalent width $\geqslant W_\lambda$ equals the fraction of galaxies detected in compact emission by the cluster prism survey.

galaxy types Sa and later is predominantly due to star formation (cf. Papers II–IV). By contrast, only ~30 per cent of compact ELGs of early type (E, S0, S0/a) are expected to have H II emission. The remaining early-type compact ELGs are expected to have AGN or LINER (low-ionization nuclear emission region) emission.

4.2 Comparison of expected and observed H II emission for early-type cluster galaxies

The above expected percentages of compact ELGs of different galaxy types with H II emission may be compared with actual percentages from spectroscopic data. In Table 4, we list spectral classifications for 54 compact ELGs in the eight clusters surveyed. These represent 69 per cent of the total of 78 compact ELGs that have a velocity within 3σ of the cluster mean. Spectral classifications were taken from Miller & Owen (2002) or derived from data given in NED. For these latter, either the galaxy classification was taken from NED, or, when not available, classification of the emission as either H II or AGN was made using emission-line ratios in the UZC Spectral Archive (Falco et al. 1999), following the method of Veillieux & Osterbrock (1987).

For the three type groups (E, S0, S0/a; Sa, Sab, Sb; and Sbc, Sc, Sc–Irr), restricted to galaxies within one Abell radius of the cluster centres (or within 0.5 Abell radii of each of the two subcluster

Table 4. Spectral classifications for galaxies with compact emission (see notes at end of table). Column 2: CGCG number (Zwicky et al. 1960–1968); see Table 1. Column 3: Galaxy type taken from Papers III and IV, and this paper. The † indicates that types were taken from NED. Columns 4 and 5: Spectral classification and its reference.

Cluster	CGCG	Type	Spectral type	Ref.
Abell 262	521-074	S: pec	H II	2
	522-003	pec	H II	2
	522-011	S0†	H II	2
	522-020	SBb	Sbrst	2
	522-039	E	Sy2	2
	522-058	SBa	Sbrst	2
	522-077	SBb: pec	H II	2
Abell 347	538-043	pec	SF	1
	539-024	SBb	H II	3
	539-025	SB pec	SF	1
	539-031	S0/a	SF	1
Abell 400	415-050	S0:	Mix	1
Abell 426	540-064	SBb	Sy2	2
	540-094	Sbc	H II:	2
	540-103	pec:	Sy2	2
	541-009	SBc	AGN	2
Abell 569	234-056	S pec	H II	2
	234-057	pec	SF	1
	234-066	pec:	SF	1
	234-071	SB: pec	AGN	2
	234-079A	S: pec	AGN	2
	234-115	...	SF	1
Abell 779	181-023	S	Ab+	1
	181-030	SB:b	AGN:	2
Abell 1367	97-026	SBa pec	SF	1
	97-068	SBc pec	SF	1
	97-079	S:...pec	SF	1
	97-087	Sd pec	SF	1
	97-114	S0/a: pec	H II	2
	97-125	Sa: pec:	SF	1
	126-110	Sab pec	Sy1	2
	127-049	SBab	SF	1
	127-052	SA0	Lin	1
	127-055	SAa	SF	1
	127-071	S... pec	H II	2
	127-095	SBb	H II	2

Table 4 – *continued*

Cluster	CGCG	Type	Spectral type	Ref.
Abell 1656	159-101	Irr†	H II	2
	160-020	Sa†	H II	2
	160-026	S0/a:	H II	2
	160-055	SB:ab	SF	1
	160-064	pec	Sbrst	2
	160-067	pec	SF	1
	160-068	(R′)SA0−?†	SF	1
	160-075	pec	Sbrst	2
	160-078	E/S0:	Sbrst	2
	160-127	pec	SF	1
	160-130	pec:	SF	1
	160-148A	S pec	Mix	1
	160-156	SA0†	Sy	2
	160-158	S0 pec?†	Sbrst	2
	160-160	pec	H II	2
	160-179	S: pec	H II	2
	160-180	pec	H II	2
	160-193	S:...	Sbrst	2

Notes. *References and abbreviations.* 1. Miller & Owen (2002), SF = star-forming galaxy; Ab+ = predominantly absorption-line spectrum, although with slight emission of [N II] and sometimes [S II]; Sey = Seyfert; Lin = LINER; Mix = nuclear spectrum that of a Seyfert or LINER, with off-nuclear spectrum showing star formation. 2. NED, either NED galaxy classification (Sbrst, Sy, Sy1, Sy2) or classification as H II or AGN emission from the line ratios of emission lines in the UZC Spectral Archive (Falco et al. 1999).

Table 5. Percentages of galaxies with compact H II emission in clusters and the field.

Type	Cluster			Field		
	Total	Percentage compact H II emission		Total	Percentage compact H II emission	
	n_c	$p_{ce,c}$	$p^d_{ce,c}$	n_f	$p_{ce,f}$	$p^d_{ce,f}$
E, S0, S0/a	302	3.6	1.3	28	7.1	0.0
Sa + later	177	19.2	7.3	45	8.9	0.0

Note. $p_{ce,c}$, $p^d_{ce,c}$, $p_{ce,f}$ and $p^d_{ce,f}$ are the percentages of galaxies with compact H II emission and which both have compact H II emission and are disturbed, for cluster and field galaxies, respectively. NED types for galaxies with otherwise indeterminate type have been included where available.

centres in Abell 569), the observed percentages of galaxies with H II emission are 68 per cent ($n = 11$), 80 per cent ($n = 10$) and 100 per cent ($n = 3$), respectively. For the two later-type groups, these values are in good agreement with the expected percentages of galaxies with H II emission. For galaxies classified as peculiar, the observed percentage is 90 per cent ($n = 10$), in accord with the suggestion above that these galaxies are predominantly on-going mergers. However, for early-type galaxies, the observed percentage is higher than expected (significance level $\sim 2.8\sigma$), and suggests an enhancement of H II emission for the early-type cluster galaxies with compact emission.

If this enhancement of H II emission in early-type cluster galaxies is real, what is its likely cause? Obviously, the simplest explanation is that previously suggested for cluster later types, viz. the effects of gravitational tidal interactions on the galaxies. For the present sample of cluster early-type galaxies (types E, S0 and S0/a), restricted to galaxies within one Abell radius of the cluster centres, there is a very strong correlation between the incidence of compact H II emission and a disturbed morphology for the galaxy (significance level of 8.2σ). Four out of nine disturbed galaxies show compact H II emission, while only six out of 270 undisturbed galaxies show this emission. This is a similar result to that found previously for cluster galaxies of types Sa and later, and indeed suggests that any enhancement of H II emission in cluster early-type spirals is due to gravitational tidal effects as is the case for later-type cluster galaxies.

In Table 5 we compare the fractions of galaxies in the field and in clusters that have compact H II emission ($p_{ce,f}$ and $p_{ce,c}$, respectively) and the fractions that have compact H II emission and in addition are tidally disturbed ($p^d_{ce,f}$ and $p^d_{ce,c}$, respectively). Cluster galaxies are defined to be those within $1.0\, r_A$ of the cluster centres (or within $0.5\, r_A$ of each of the two subcluster centres in Abell 569), while field galaxies are defined to be those outside $1.0\, r_A$ for the clusters Abell 262, 347, 400, 569 and 779, and outside $1.5\, r_A$ for

Abell 426, 1367 and 1656 (cf. Paper IV). We make the comparison for E, S0, S0/a and Sa and later galaxies separately.

First consider the later types. We find that the increase in the percentage of galaxies with compact H II emission in clusters is largely accounted for by an additional population of *disturbed* galaxies with compact H II emission – indeed there are *no* such galaxies in the field. This restates our earlier findings in Paper IV, which focused specifically on the later types.

For the early-type galaxies, again there is a population of *disturbed* galaxies with compact H II emission that have no counterparts in the field. The number of these galaxies ($n = 4$) is exactly that required to explain the observed excess of H II emission in cluster early-type ELGs as determined from a comparison with the PSSN spectroscopic data for field galaxies (cf. Section 4 above). Thus for early types as well as later types, an enhancement of compact H II emission in cluster galaxies is readily explained by gravitational tidal interactions associated with cluster virialization.[2]

5 CONCLUSIONS

In a series of papers (cf. Moss et al. 1988; Moss & Whittle 1993; Moss et al. 1998; Moss & Whittle 2000), we have undertaken an Hα survey of an essentially complete sample of 748 CGCG galaxies in eight low-redshift clusters (viz. Abell 262, 347, 400, 426, 569, 779, 1367 and 1656). This paper has presented previously unpublished data for 383 mainly early-type galaxies and completes publication of data for the survey. The combined survey data show that emission detection increases as expected from earlier to later galaxy types (3 per cent for E, E–S0; 6 per cent for S0; 9 per cent for S0/a; and 41 per cent for types Sa and later).

A comparison of cluster and field early-type galaxies shows a similar frequency of emission detection. Together with the same result obtained for cluster and field galaxies of types Sa and later, these data confirm the inference of Biviano et al. (1997) that differences between the frequency of ELGs between clusters and the field can be entirely accounted for by the differing mix of galaxy morphological types in the two environments, while *for a given morphological type* there is no difference in the frequency of ELGs between clusters and the field. As noted by Biviano et al., this result is in disagreement with all or most previous studies. It is to be noted that this result has been obtained for galaxies with relatively strong emission ($W_\lambda \geqslant$ 20 Å). Work is in progress to extend these results to fainter limits in equivalent width (cf. Sakai, Kennicutt & Moss 2001).

Although the incidence of emission does not vary between cluster and field environments, the survey has shown that the type of emission does vary. Detected emission is classified as ‘compact’ or ‘diffuse’, identified as circumnuclear starburst or AGN emission and disc emission, respectively. In previous work, we have shown that for galaxies of types Sa and later, there is an enhancement of compact H II emission in cluster galaxies as compared to the field. This type of emission has been shown to be strongly correlated with a tidally disturbed morphology of the galaxy.

In the present work, a comparison of spectroscopic data for the cluster early-type ELGs with that for field galaxies from the PSSN (Ho et al. 1997) gives a modest indication (significance level $\sim 2.8\sigma$) for enhanced compact H II emission in early-type cluster ELGs as compared to the field. Moreover, the compact H II emission in the early-type cluster galaxies is strongly correlated with a disturbed galaxy morphology (significance level of 8.2σ).

For both early type and later types, there is a population of disturbed galaxies with compact H II emission that have no counterparts in the field. This suggests that, for cluster galaxies of all types, enhancement of compact H II emission can readily be explained as an enhancement of circumnuclear starburst emission due to gravitational tidal effects. As discussed previously (cf. Moss & Whittle 2000), these gravitational tidal effects are most likely to be associated with subcluster merging and other processes of on-going cluster virialization.

[2] In Table 5, the percentage of early-type galaxies with compact H II emission in the field is numerically greater than in the cluster. However, as discussed above in Section 3, this cluster–field difference is not statistically significant.

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