RECENT STAR FORMATION IN CLUSTERS OF GALAXIES: EXTREMELY COMPACT STARBURSTS IN A539 AND A634

D. Reverte, J. M. Vilchez, J. D. Hernández-Fernández, and J. Iglesias-Páramo
Instituto de Astrofísica de Andalucía, CSIC, Granada, Spain
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ABSTRACT

We report on the detection of two Hα-emitting extremely compact objects from deep images of the A634 and A539 clusters of galaxies at z ~ 0.03. Follow-up long-slit spectroscopy of these two unresolved sources revealed that they are members of their respective clusters, showing Hα-type spectra. The luminosity and the extreme equivalent width of Hα + [N II] measured for these sources, together with their very compact appearance, has raised a question about the origin of these intense starbursts in the cluster environment. We propose that the compact starburst in A539 resulted from the compression of the interstellar gas of a dwarf galaxy when entering the cluster core, while the starburst galaxy in A634 is likely to be the result of a galaxy-galaxy interaction, illustrating the preprocessing of galaxies during their infall toward the central regions of clusters. The contribution of these compact star-forming dwarf galaxies to the star formation history of galaxy clusters is discussed, as well as a possible link with the recently discovered early-type ultracompact dwarf galaxies. We note that these extreme objects will rarely be detected in normal magnitude-limited optical or NIR surveys, mainly due to their low stellar masses (on the order of 10⁶ M☉), whereas they will easily show up in dedicated Hα surveys given the high equivalent width of their emission lines.

Key words: galaxies: abundances — galaxies: clusters: general — galaxies: starburst — galaxies: stellar content — intergalactic medium

1. INTRODUCTION

The understanding of the role played by the environment on galaxy evolution still remains a major issue. A key aspect to understanding the evolution of galaxies in clusters is the knowledge of their star formation (SF) history, intimately related to their morphology and gas content. Indeed, it has been reported that the global star formation rates (SFRs) of spiral galaxies located in the innermost regions of nearby and intermediate-redshift clusters appear strongly depressed as compared to the results found for similar galaxies at larger clustercentric radii (e.g., Balogh et al. 1998, 2004; Gavazzi et al. 2002; Lewis et al. 2002). Less information is available in the literature with respect to the evolution of the SF activity of the population of dwarf galaxies in clusters. To date, only a handful of works have dealt with the study of the SF activity in the population of star-forming dwarf and irregular galaxies in nearby clusters (e.g., Gallagher & Hunter 1989; Drinkwater & Hardy 1991; Vilchez & Monte 1995; Duc et al. 2001; Boselli et al. 2002; Iglesias-Páramo et al. 2003; Lee et al. 2003; Vilchez & Iglesias-Páramo 2003).

Several physical mechanisms have been invoked to explain the influence of the cluster environment on the evolution of star-forming galaxies (see Boselli & Gavazzi 2006). Gas-rich late-type galaxies falling for the first time into the intracluster medium (ICM) of a rich cluster can suffer compression of their interstellar medium by ram pressure, triggering SF bursts; this process can be followed by the stripping of their external gaseous component, thus inducing a quenching of their SF activity. In addition, gravitational interactions could give rise to different kinds of tidal interactions: interactions with other galaxies, interactions with the cluster potential, and “harassment” (Moore et al. 2000). Other important processes include the “starvation” of the galactic gas component and the “preprocessing” of galaxies in falling groups into clusters (Poggianti 2004). Overall, SF activity is expected to be more efficient in high-velocity objects at the periphery of the clusters, as shown by numerical simulations (Fujita & Nagashima 1999; Mori & Burkert 2000). From the observational point of view, it is not yet clear whether the SF activity of cluster dwarf irregulars may vary along the clustercentric radius. It seems clear that dwarf galaxies and large spirals should show different responses to the action of cluster tidal fields as a physical consequence of their different mass concentrations (Moore et al. 1999). To date, there is not enough observational information available on the evolution of star-forming dwarf galaxies (SFDGs) in clusters, which is mostly a consequence of the magnitude-limited searches.

Isolated intergalactic H II regions have recently been found in the vicinity of cluster spirals, thus providing evidence for their origin in tidal interactions and from previously processed material (Gerhard et al. 2002; Cortese et al. 2004). Furthermore, a population of intergalactic planetary nebulae (PNe) has been reported to exist in the Virgo (Freeman et al. 2000; Arnaboldi et al. 2003) and Coma (Gerhard et al. 2002; Cortese et al. 2004) Clusters. Obviously, the luminosity contrast of the emission lines of H II regions and PNe and their relative compactness has allowed them to be detected in nearby clusters, but not in more distant ones given their low luminosities.

A new class of ultracompact dwarf galaxies (UCDGs) in the nearby clusters Fornax (Drinkwater et al. 2000) and Virgo (Jones et al. 2006) has recently been discovered. These galaxies show extremely compact surface brightness profiles and sizes slightly larger than those of stellar clusters, a few tens of parsecs, with absolute B magnitude −13 ≤ MB ≤ −11 (Drinkwater et al. 2004), and typically also present spectra lacking emission lines. Two explanations for the nature of these galaxies have been proposed: either they are the successors of tidally stripped dwarf ellipticals, or they have originated from merged young massive clusters of tidal origin (Mieske et al. 2006). Up to now, the typical UCDGs reported in clusters do not appear to show recent SF activity; thus, the possibility of analogous star-forming UCDGs in the cluster environment could shed light on the nature and evolution of dwarf galaxies.

A rather unexplored possibility is the search for very compact, actively star-forming dwarf galaxies in clusters. These galaxies...
should show emission lines with high equivalent widths, as shown by PNe and H\(\beta\) regions, although their expected intrinsic luminosity would be much larger than in the cases of PNe and H\(\beta\) regions, thus favoring their detection in clusters. Besides the work on Virgo (Gerhard et al. 2002) and Fornax (Drinkwater et al. 2001), there is recent evidence for “missing” compact galaxies in the local field, i.e., galaxies that have been misclassified as stars due to their compactness by standard star-galaxy separation techniques in the Millennium Galaxy Catalogue (MGC; Liske et al. 2006).

In this work we report on the detection and properties of two very compact strong starbursts that have been found associated to the clusters of galaxies A539 and A634. These two objects were discovered by visual inspection of some H\(\alpha\) frames covering approximately \(1'' \times 1''\) on the basis of their compactness and strong H\(\alpha\) emission. The parent clusters are at approximately the same distance (\(z \approx 0.03\)) and show rather different properties: whereas A539 is a rich X-ray-luminous cluster, A634 is a poor, disperse cluster, for which only an upper limit in X-ray by ROSAT is available, probably indicating an ongoing galaxy assembling from the cluster outskirts. The adopted heliocentric velocities (velocity dispersions) for A539 and A634 are 8514 km s\(^{-1}\) (\(\sigma_{A539} = 629 \text{ km s}^{-1}\)) and 7945 km s\(^{-1}\) (\(\sigma_{A634} = 391 \text{ km s}^{-1}\)), respectively (Struble & Rood 1999). Thus, assuming a standard cosmology with \(H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}\), \(\Omega_M = 0.3\), and \(\Omega_{\Lambda} = 0.7\), the distances to the clusters adopted throughout this paper are 124.2 Mpc (A539) and 115.7 Mpc (A634).

This paper is organized as follows: § 2 describes the observations and data handling. Section 3 enumerates the main observational properties of the two galaxies, and in § 4 we discuss their main properties, origin, and evolutionary stage. Finally, in § 5 we present our conclusions and final remarks about the relative importance of these kinds of objects for the SFR budget of nearby clusters of galaxies.

2. OBSERVATIONS

2.1. Imaging

H\(\alpha\) + continuum imaging of the two starburst sources DRP A539a and DRP A634a, were obtained with the Wide Field Camera (WFC) attached to the Prime Focus of the 2.5 m Isaac Newton Telescope at the Observatorio del Roque de los Muchachos (ORM), La Palma, Spain, in 2002 and 2003 December and 2003 February. The WFC consists of an array of four thinned AR-coated EEV 4K \(\times\) 2K devices, plus a fifth used for autoguiding. The pixel scale is 0.33'' pixel\(^{-1}\), which gives a total field of view of about 34'' \(\times\) 34''. Given the particular arrangement of the detectors, a squared area of about 11'' \(\times\) 11'' is lost in the top right corner of the field. Given the redshift of these objects, an ON-band narrow filter (\(\lambda_0 = 6725 \text{ Å}, \Delta \lambda_{\text{FWHM}} = 85 \text{ Å}\)) to isolate the H\(\alpha\) emission and an OFF-band narrow filter (\(\lambda_0 = 6563 \text{ Å}, \Delta \lambda_{\text{FWHM}} = 95 \text{ Å}\)) to measure the continuum emission corresponding to the redshifted H\(\alpha\) line were used. At least four different exposures, slightly dithered to remove cosmic rays, were obtained for each position with each filter. The typical seeing of our frames was between 0.8'' and 1.5'', except for a few nights of the 2002 run that were around 2''. Table 1 shows a log of the imaging observations.

Data reduction was performed using the standard software package IRAF\(^1\) following the standard procedure of bias correction, flat-fielding, and flux calibration. In order to properly subtract the continuum from the H\(\alpha\) emission, the counts of the OFF-band frames were scaled so that the counts of (nonsaturated) field stars were the same in ON-band and OFF-band frames.

ON-band observations of the spectrophotometric standard stars G191-B2B, PG 0934+554, PG 0834+546, BD +33 2642, Feige 56, and Feige 67 were taken to perform the flux calibration of our objects. The accuracy of the zero point was 0.05 mag. The photometry of the ON-band and OFF-band sources was performed with the IRAF task aphot, and consisted of circular aperture photometry until convergence of the growth curve was achieved.

Both objects, DRP A539a and DRP A634a, appear very compact and much brighter in ON-band than in OFF-band, as shown in Figures 1 and 2. While DRP A539a appears to be an isolated source, a diffuse low surface brightness structure has been detected extending northeast from DRP A634a. Hereafter, the compact source is referred to as DRP A634a, whereas the diffuse low surface brightness structure is named LSB A634a. Some knotty faint H\(\alpha\) emission can be seen at the northern tip of LSB A634a, which is referred to as LSB A634a...knot. Table 2 shows the relevant photometric properties of these objects, as measured from our H\(\alpha\) and continuum frames. The luminosities have been corrected for Galactic extinction following Schlegel et al. (1998) and the Cardelli et al. (1989) extinction curve. The H\(\alpha\) + [N \(\alpha\)] luminosity of LSB A634a...knot has been estimated assuming that it is located at the same distance as DRP A634a.\(^2\)

2.2. Spectroscopy

Long-slit spectroscopy of DRP A539a, DRP A634a, and LSB A634a was obtained with the Alhambra Faint Object Spectrograph and Camera attached to the 2.5 m Nordic Optical Telescope at the ORM on 2004 November 19 and 2004 December 9. Grisms 8 and 14 were used, giving useful spectral ranges of 5825–8350 and 3275–6125 Å, respectively. The spatial resolution across the slit was 0.19'' pixel\(^{-1}\). During the first night, the slit width was set to 1.2'', resulting in an effective spectral resolution of 7.1 Å, and an 1800 s exposure for each spectral range was obtained for DRP A634a. The second night was devoted to DRP A539a and LSB A634a. Due to an improvement in the weather conditions, the slit width was set to 0.4'', yielding a spectral resolution of 2.8 Å. A total of 3 \(\times\) 1800 s exposures for each spectral range of DRP A539a were taken with the slit oriented along the parallactic direction.

\(^{1}\) Image Reduction and Analysis Facility, written and supported at the National Optical Astronomy Observatory.

\(^{2}\) The possible origins of these objects and their environment are discussed in § 3.
angle. Finally, a 600 s exposure using grism 8 was performed in order to observe the extended emission of LSB A634a; in this case, the slit was centered on DRP A634a and was carefully oriented at an angle of 54° (from north to east). Due to an increase in the humidity, this exposure was stopped after 600 s. Table 3 shows the log of spectroscopic observations.

Data reduction was performed using IRAF, following the standard procedure of bias correction, flat-fielding, and wavelength and flux calibration. One-dimensional spectra of DRP A539a and DRP A634a were extracted by adding the flux in the spatial sections along the slit, which maximizes their signal-to-noise ratios. A total of 10 and 7 pixels were added for DRP A539a and DRP A634a, respectively. The same procedure was followed to extract a one-dimensional spectrum for LSB A634a. As a consequence of its low surface brightness only a faint emission line, spatially corresponding to LSB A634a_knot, was obtained after adding a total of 21 pixels. As indicated below, this emission line was identified as Hα.

Both nights were only partially photometric, so an absolute spectrophotometric flux calibration was not attempted. However, the spectrophotometric standard star Hiltner 600 was observed before and after each object with each grism, and thus a relative calibration of the spectra in physical units was performed. The spectra corresponding to the red grism were scaled to the blue ones by using the continuum level and the flux of the [He i] λ5876 line, present in the blue and red spectra. The scaling factors were found to be ~1 within an error bar of ~20%. Beyond 7600 Å fringing effects begin to be noticeable, and data at longer wavelengths are ineffective. Figures 3 and 4 show the combined (red grism + blue grism) spectra of DRP A539a and DRP A634a, respectively. Both spectra are dominated by narrow emission lines and show a very faint underlying continuum.

![Figure 1](https://example.com/fig1.png)

**Fig. 1.**—ON-band (Hα; left) and OFF-band (red continuum; right) images of the DRP A539a region. The arrow indicates the position of the object.

![Figure 2](https://example.com/fig2.png)

**Fig. 2.**—ON-band (Hα; left) and OFF-band (red continuum; right) images of the DRP A634a region. The downward arrow indicates the position of DRP A634a. The upward arrow points to LSB A634a_knot. The low surface brightness structure apparent in the right panel is LSB A634a.
The emission lines were measured with the IRAF task `splot`. The errors of the line fluxes were estimated from the standard deviation of a series of independent repeated measurements, sampling the adjacent continuum for each line. In order to calculate the extinction, the Balmer decrement was computed using the H\alpha, H\beta, H\gamma, and H\delta line fluxes and compared to its theoretical values (Hummer & Storey 1987). Given the low continuum shown by both objects, no correction for underlying absorption was performed.

Radial velocities were computed from a \(\sigma\)-weighted average of the redshifts corresponding to the individual emission lines. After applying the heliocentric corrections, values of \(v_{\text{rad}} = 8940 \pm 40\) and 8470 \(\pm 30\) km s\(^{-1}\) were found for DRP A539a and DRP A634a, respectively. The quoted errors correspond to the standard deviations of the velocities derived from individual lines. The measured velocities are offset by about 500 km s\(^{-1}\) from the mean heliocentric velocities adopted for the parent clusters. As is discussed in §§ 4.1 and 4.2, the projected positions of our two objects with respect to the centers of the clusters, together with their redshifts, are consistent with their corresponding cluster memberships.

In the spectrum of LSB A634a_knot, shown in Figure 5, despite the low signal-to-noise ratio an emission line was detected at the 3.5 \(\sigma\) level. This line, centered at \(\lambda = 6747\) Å, is almost coincident with the wavelength of the H\alpha line of DRP A634a. Assuming that this line effectively corresponds to H\alpha, a radial velocity of 8390 km s\(^{-1}\) is inferred for LSB A634a_knot, after correcting for heliocentric relative motions.

In Tables 4 and 5 we present the spectroscopic properties of DRP A539a and DRP A634a: reddening-corrected line fluxes, reddening coefficients \(C(\text{H}\beta)\), equivalent widths of H\beta, H\alpha, and [O\text{ ii}], H\beta flux, and the fluxes of the most prominent emission lines relative to H\beta. As can be seen, the values reported for the H\alpha equivalent width, although slightly larger than the ones derived from H\alpha imaging, are consistent within the errors.

Table 5 also shows the electron temperatures and oxygen abundances derived using the `temden` and `ionic` tasks in the IRAF `nebular` package in STSDAS. Oxygen abundances were derived directly from spectral lines of [O\text{ ii}] \(\lambda\lambda 3727\) and [O\text{ iii}] \(\lambda\lambda 4959, 5007\) and using their electron temperatures from measurements of [O\text{ iii}] \(\lambda 4363\).

3. RESULTS

Figure 6 shows the radial profiles\(^3\) of DRP A539a and DRP A634a, derived from our sharpest images. The first is marginally different from the typical stellar profile, showing a radius at half-maximum \(r_{\text{FWHM}} = 0.44''\) (\(r_{\text{FWHM}} = 0.39''\)). The second is almost indistinguishable from the stellar profile, with \(r_{\text{FWHM}} = 0.39''\) (\(r_{\text{FWHM}} = 0.38''\)). After correcting these profiles for the effect of seeing under the assumption of a Gaussian point-spread function\(^4\) (PSF), effective (half-light) radii of 0.14'' and 0.09'' are derived, which correspond to 84 and 32 pc for DRP A539a and DRP A634a, respectively. These effective radii are lower than most values presented for misclassified compact galaxies in the MGC (Liske et al. 2006) and resemble the values typically shown by UCDGs in nearby clusters (Drinkwater et al. 2004).

As concerns LSB A634a, the length of its major axis from our continuum image was estimated to be \(\approx 28''\). At the distance of DRP A634a this length corresponds to 1.6 kpc. This value is in good agreement with the dimensions of edge-on disk galaxies. The angular size of the system argues against it being a high-redshift object. If, for example, the emission line reported in § 2.2 were one of the [O\text{ ii}] lines, the redshift would be \(z \approx 0.35\), and the corresponding diameter of the system at such a distance would be 138 kpc, which is highly unlikely for an edge-on galaxy. For the same reason, we can discard the possibility of this system being located at larger distances.

\(^3\) We derived the radial profiles using the IRAF task `radprof`. This task fits a PSF on each star and selects objects in the field through an input coordinate file, deriving a FWHM of the fitted profile.

\(^4\) Driver et al. (2005) have reported a slight deviation from Gaussian behavior when correcting the effective radii of galaxies for the effect of seeing in the MGC. For the scope of this work, Gaussian behavior of the PSF is assumed.

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**Table 2**

| Object | R.A. (J2000.0) | Decl. (J2000.0) | \(E(\text{H}\alpha + [\text{N}\text{ ii}])\ (10^3\ \text{ergs s}^{-1})\) | \(\text{EW}([\text{O}\text{ ii}] + [\text{N}\text{ ii}])\) (Å) |
|--------|---------------|---------------|-------------------------|------------------|
| DRP A539a | 05 16 51.7 | +06 19 32.1 | 1.27 \(\pm\) 0.03 | 430 \(\pm\) 60 |
| DRP A634a | 08 13 55.6 | +58 02 32.4 | 2.38 \(\pm\) 0.21 | 1010 \(\pm\) 230 |
| LSB A634a_knot | 08 13 57.0 | +58 02 42.5 | 1.03 \(\pm\) 0.25 | 65 \(\pm\) 23 |
| LSB A634a + DRP A634a | | | 3.4 \(\pm\) 0.4 | 190 \(\pm\) 40 |

Notes.—Col. (1): Object ID. Cols. (2) and (3): Right ascension and declination; units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Col. (4): H\alpha + [N\text{ ii}] luminosity corrected for Galactic extinction. Col. (5): H\alpha + [N\text{ ii}] equivalent width.

**Table 3**

| Object | Date | Spectral Range (Å) | Exp. Time (s) | Slit Width (arcsec) | Position Angle\(^a\) (deg) |
|--------|------|-------------------|--------------|-------------------|-------------------|
| DRP A634a | 2004 Nov 19 | 3700–6100 | 1 \(\times\) 1800 | 1.2 | 245.5 |
| DRP A634a | 2004 Nov 19 | 6000–8000 | 1 \(\times\) 1800 | 1.2 | 235.5 |
| DRP A539a | 2004 Dec 9 | 3700–6100 | 3 \(\times\) 1800 | 0.4 | 336.4, 356.4, 15.4 |
| DRP A539a | 2004 Dec 9 | 6000–8000 | 3 \(\times\) 1800 | 0.4 | 312.7, 323.1, 30.4 |
| LSB A634a + DRP A634a | 2004 Dec 9 | 6000–8000 | 1 \(\times\) 600 | 0.4 | 54.0 |

\(^a\) Position angle (measured from north to east) corresponds for every value on the table to the parallactic angle, except for the last exposure.
Broadband magnitudes can be derived for DRP A634a, since Sloan Digital Sky Survey frames are available. Aperture photometry corrected for Galactic extinction of DRP A634a yields $M_V = -15.81$ mag and $M_r = -14.50$ mag. The broadband magnitudes of the composite system LSB A634a + DRP A634a were also derived, obtaining $M_V = -17.38$ mag and $M_r = -17.30$ mag. Since DRP A539a was observed with the Gunn $r'$ filter, a value of $M_r \approx -16.07$ mag was estimated for this galaxy. By applying the average $g'-r' = -0.02$ mag of the sample of ultracompact blue dwarf galaxies (UCBDs) of Corbin et al. (2006), a value of $M_r \approx -16.09$ is obtained for DRP A539a. The magnitudes derived for DRP A539a and DRP A634a are brighter than those typical of early-type UCDGs in clusters (Mieske et al. 2006). Nevertheless, the Starburst99 model (Leitherer et al. 1999) predicts that the optical magnitudes of an instantaneous burst of SF can fade by more than 3 mag in about 10$^8$ yr. These results, together with the limits to the sizes of DRP A539a and DRP A634a, open the possibility of them being the progenitors of early-type UCDGs like those recently found in nearby clusters.

The equivalent widths of the most conspicuous Balmer emission lines of our two objects are relatively high: EW(H$\beta$) values (77 and 280 Å for DRP A539a and DRP A634a, respectively) are in fact above the median value (~40 Å) reported for the sample of H ii galaxies of Terlevich et al. (1991) and also for the sample of H i-rich dwarf galaxies in the Hydra Cluster of

**TABLE 4**

| Line       | $\lambda$ (Å) | $f_i$  | DRP A539a | DRP A634a |
|------------|---------------|--------|-----------|-----------|
| [O ii]      | 3727          | 0.28   | 1058 ± 7  | 375 ± 17  |
| [Ne iii]    | 3868          | 0.24   | 522 ± 14  | 419 ± 80  |
| H$\alpha$   | 3889          | 0.24   | 210 ± 19  | 112 ± 15  |
| H$\gamma$   | 3970          | 0.22   | 320 ± 30  | 258 ± 17  |
| [S ii]      | 4068          | 0.20   | 77 ± 15   | ...       |
| H$\beta$    | 4101          | 0.19   | 268 ± 15  | 171 ± 22  |
| H$\delta$   | 4340          | 0.13   | 513 ± 10  | 473 ± 21  |
| [O iii]     | 4363          | 0.13   | 70 ± 20   | 202 ± 16  |
| He $\lambda$| 4471          | 0.10   | ...       | 53 ± 13   |
| [Ar iv]     | 4711          | 0.04   | ...       | 59 ± 14   |
| H$\beta$/H$\alpha$ | 4861 | 0.00  | 1000 ± 16 | 1000 ± 10 |
| [O iii]     | 4959          | -0.04  | 1869 ± 7  | 2740 ± 14 |
| [O ii]      | 5007          | -0.05  | 5280 ± 40 | 8272 ± 10 |
| He $\lambda$| 5876          | -0.26  | 73 ± 8    | 105 ± 10  |
| H$\alpha$   | 6563          | -0.37  | 2827 ± 5  | 2789 ± 5  |
| [N ii]      | 6584          | -0.37  | 47 ± 5    | 27 ± 5    |
| He $\lambda$| 6678          | -0.38  | ...       | 29 ± 5    |
| [S ii]      | 6717          | -0.39  | 112 ± 10  | 46 ± 5    |
| He $\lambda$| 6731          | -0.39  | 130:       | 29 ± 5    |
| [Ar iii]    | 7065          | -0.43  | ...       | 58 ± 7    |
| [Ar iv]     | 7135          | -0.44  | ...       | 85 ± 9    |
an extreme case. The high equivalent widths shown by our two galaxies reveal very strong and young SF activity. The ages and stellar masses of the recent SF episodes can be estimated from the luminosities and equivalent widths of the Balmer lines. By assuming an instantaneous burst of SF, and using Starburst99 (Leitherer et al. 1999) for a Kroupa initial mass function with luminosities and equivalent widths of the Balmer lines. By assum-

**TABLE 5**

| Parameter                  | DRP A539a       | DRP A634a       |
|----------------------------|-----------------|-----------------|
| C(Hβ)                      | 0.27            | 0.47            |
| [O ii] (λ3727)              | 12800 ± 1500    | 16800 ± 700     |
| (O ii)] (λ3727)             | 11900 ± 1000    | 14800 ± 500     |
| 12 + log ([O ii]/Hα)        | 7.65 ± 0.14     | 6.75 ± 0.06     |
| 12 + log ([O iii]/Hβ)       | 7.93 ± 0.14     | 7.83 ± 0.05     |
| 12 + log ([O iii]/Hα)       | 8.12 ± 0.14     | 7.87 ± 0.06     |
| F(Hβ) (10^{-15} ergs cm^{-2} s^{-1}) | 4.21 ± 0.09 | 8.75 ± 0.08 |
| EW(Hα) (Å)                  | 77 ± 17         | 280 ± 90        |
| EW(O III) (Å)               | 510 ± 90        | 1290 ± 120      |
| EW(O II) (Å)                | 70 ± 15         | 110 ± 40        |

Notes.—The reddening coefficient C(Hβ), electron temperatures, and oxygen abundances, as well as the Hβ flux and the equivalent width for Hβ, Hα, and [O ii], are quoted. The Hβ flux has been corrected for Galactic and intrinsic extinction using the extinction law R = 3.1 and the objects' C(Hβ).

tracks, we find that the ages predicted are 5.8 and 4.5 Myr (5 and 4 Myr using Geneva High tracks) for DRPA539a and DRPA634a, respectively. The corresponding masses that are being converted into stars are 2.0 × 10^6 and 2.2 × 10^6 M_☉, respectively, with an uncertainty of 15%. This computation assumes the approximation that all Lyman continuum photons are absorbed by the gas.

Figure 7 shows the luminosity-metallicity relation for dwarf galaxies (after Pilyugin et al. 2004), including the points for DRPA539a and DRPA634a, with M_B = −15.60 and −15.89 mag, respectively. Absolute magnitudes in B have been obtained from M_B after applying the correction term q = −0.21, as reported by Fukugita et al. (1995) for late-type dwarf galaxies. The two points follow the mean relation reported for nearby dwarf galaxies and remain far from the locus occupied by typical tidal dwarf galaxies (TDGs; see the review by Kuntz & Östlin 2000 and references therein). In Figure 7 the point corresponding to the integrated system LSB A634a + DRP A634a appears to separate from the luminosity-metallicity relation by more than 1 mag, being too luminous for the metallicity derived for DRP A634a (Table 5).

4. DISCUSSION

4.1. DRP A539a

Figure 8 shows the optical DSS (Palomar Digitalized Sky Survey) frame of the inner region of the cluster A539. Contours corresponding to the X-ray emission and to the surface density of galaxies (from the Two Micron All Sky Survey [2MASS]) of A539 are overlaid. It can be seen that the maxima of the surface density of galaxies and X-ray emission are coincident. The X-ray luminosity of A539 is 6.7 × 10^{44} ergs s^{-1} (White et al. 1997). Its velocity dispersion was estimated to be 629 km s^{-1}, thus giving a total dynamical mass for the cluster of 32 × 10^{13} M_☉ (Struble & Rood 1999). The projected distance of DRPA539a from the center of A539 is 300 kpc, which corresponds to 0.2r_200. This short distance, together with the measured radial velocity of DRP

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5 The derived values for the age and stellar mass of the burst are the nominal values obtained from the measured imaging Hα flux and corresponding error (dereddening error is included).

6 From the 0.4–2.4 keV ROSAT map.
A539a, ensures that this object is well within the region defined by the caustic of the cluster (see Fig. 2 of Rines et al. 2003).7

The existence of such an active star-forming object at such a short distance from the center of a cluster is unusual and opens several questions about its nature and origin. One possibility is that this object could be a TDG, resulting from a galaxy-galaxy interaction. These kinds of objects have been previously reported in different environments such as clusters (Duc et al. 1999, 2000; Iglesias-Páramo et al. 2003), groups (Iglesias-Páramo & Vílchez 2001; Mendes de Oliveira et al. 2004), or just pairs of interacting galaxies (Mirabel et al. 1992; Duc et al. 2000). TDGs originate out of the tidal features resulting during the interaction, and under certain conditions they can escape the potential well of the parent galaxy and evolve independently (Elmegreen et al. 1993). A visual inspection of the ON-band and OFF-band frames shows no signatures of galaxy-galaxy interactions around DRP A539a. The closest galaxy is 2MASX J05165377+0619216, an S0 galaxy whose radial velocity is \( v = 8063 \text{ km s}^{-1} \), located at a projected distance of 32" (about 18 kpc). We analyzed the isophotes of this galaxy and did not find any distortion or abnormal twist of the isophotes that could be taken as a signature of interaction. Moreover, no diffuse emission was detected around this galaxy in the direction of DRP A539a. In addition, as shown in Figure 7, DRP A539a follows the mean luminosity-metallicity relation derived for a large sample of dwarf galaxies. Based on these arguments, we can discard DRP A539a as being a TDG.

Another possibility is that DRP A539a is the product of ICM-induced efficient SF in gas clouds drifting into the cluster (Bekki & Couch 2003). In this scenario the SF activity results from the compression of molecular clouds stripped from spiral galaxies through galaxy-galaxy or galaxy tidal field interactions. Isolated intracluster H\( \text{ii} \) regions have already been reported in the Virgo Cluster (Gerhard et al. 2002; Cortese et al. 2004). However, these H\( \text{ii} \) regions are more than 1 order of magnitude less luminous than DRP A539a. It should be noted that the objects studied in Cortese et al. (2004) are located close to the two bright spirals VCC 836 and VCC 873, which are probably their progenitors. Nonetheless, DRP A539a does not appear to be associated with any gas-rich bright galaxy, suggesting that either the parent molecular cloud is the result of an ancient episode of gas stripping, where the stripped galaxy is already far away, or we are facing a SFDG falling for the first time into the cluster core. Theoretical

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7 In the particular case of A539, the caustic appears well defined, and any possible contamination is low. However, these authors remark that although the caustic separates cluster members from foreground and background galaxies in a more efficient way than the velocity \( \sigma \)-clipping, some interlopers may still lie within the caustics.
models predict that SFDGs lose their external gas very rapidly when they enter the cluster potential well, due to the ram pressure exerted by the ICM (Mori & Burkert 2000); also, according to Bekki & Couch (2003) the timescale for the transformation of gas into stars due to ICM pressure is on the order of 10 Myr; for this reason we argue that DRPA539a is in the very early stages of the infall process.

4.2. DRPA634a

Figure 9 shows the optical DSS frame of the cluster A634, with the overlaid contours corresponding to the surface density of galaxies derived from 2MASS. This cluster is not detected in X-rays by the ROSAT mission, so an upper limit of $6 \times 10^{41}$ ergs s$^{-1}$ is adopted for its X-ray luminosity. The nondetection of X-ray emission means that this cluster is probably in the process of formation, and therefore a virialized core is not yet in place. Nevertheless, the smoothed surface density contours from 2MASS show a dense central aggregate of galaxies showing the galaxy cluster location and shape. We must note that the cluster center as indicated by the 2MASS contours, $\alpha = 08^h15^m08^s$, $\delta = +58^\circ14'58''$ (J2000.0), is about 12' away from the center quoted in Struble & Rood (1999). Hereafter, for our dynamical considerations and being conservative, we have adopted the center of the cluster inferred by the 2MASS contours. The heliocentric velocity measured for DRPA634a differs from the cluster heliocentric velocity by $1.34\sigma_{A634}$ km s$^{-1}$, and this object is located at a projected distance of 398 kpc from the cluster center. Both values, heliocentric velocity and projected distance, would place DRPA634a within the caustic of every galaxy cluster presented in Rines et al. (2003) at the $2\sigma$ confidence level, especially in the case of A194, a cluster presenting velocity dispersion and extension in the sky very similar to those of A634. The nondetection in X-ray of A634, together with the substantial distance of DRPA634a from the cluster center, may weaken the hypothesis that the strong SF activity shown by this object could be the result of the compression of molecular clouds due to pressure exerted by the ICM. Nonetheless, we must bear in mind that the lack of detection of X-ray emission in A634 does not necessarily mean it is devoid of a significant ICM.

The comparable radial velocities measured for DRPA634a and LSB A634a, and their close position in the sky, could be indicative of those objects being physically related. The optical morphology of the LSB A634a + DRPA634a system may suggest

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8 In the case in which the cluster center quoted by Struble & Rood (1999) is adopted, the corresponding projected distance would amount to 16 kpc, and DRPA634a would be a cluster member at a higher confidence level.
an edge-on, late-type, low surface brightness galaxy, with an off-center, very bright knot accounting for most of the optical light. In this scenario, would this system be anywhere close to the Tully-Fisher (TF) relation? To answer this question, first we have assumed that the difference between the radial velocities of DRP A634a and LSB A634a...knot provides an estimation of the internal velocity of the system, giving $v_{\text{max}} \approx 80$ km s$^{-1}$. Second, we have applied the results of Pierini & Tuffs (1999), who derived the TF relation for a sample including dwarf star-forming galaxies from the Virgo Cluster Catalogue in the $K^\prime$ band. The $M_K^\prime$ magnitude of the system was derived from the $M_B$ magnitude (see §3) making use of (1) the average ($B - K$) color for the Virgo sample of 57 (Sdm –Sd/Sm to Im/BCD) galaxies: $-(B - K) \approx 2.85$, and (2) the mean color, $(B - K_j) \approx 2.20$, obtained for the sample of blue compact dwarfs from Noeske et al. (2003). Taking the average value of both results, $(B - K) = 2.53 \pm 0.33$, we found $M_K^\prime = -19.70 \pm 0.35$ mag for the system LSB A634a + DRP A634a. Applying the fit of Pierini & Tuffs (1999; see their Fig. 6) to our value of $v_{\text{max}}$, their TF relation predicts $M_K^\prime = -16.89$ mag, nearly 3 mag fainter than the value of $M_K^\prime$ estimated above for the whole system. In the optical, several papers on the TF relation for low-luminosity galaxies have appeared recently. The TF relation for local disks and irregular galaxies from Ziegler et al. (2002) would predict a value of $M_B \approx -15$ mag for our $v_{\text{max}} \approx 40$ km s$^{-1}$, about 2 mag fainter than the value measured for our system. According to Swaters (1999, Fig. 13, p. 117), galaxies with absolute magnitudes fainter than $M_V \approx -18$ systematically fall below a straight-line TF relation. This fact has been highlighted by McGaugh (2000) pointing out the different evolutionary stage of gas-rich dwarfs with respect to spiral disks. More recently, Schombert (2006) concluded that dwarf galaxies form a distinct sequence, being more diffuse than disk galaxies. To summarize, the predictions of the TF relation for galaxies with an internal velocity of order $v_{\text{max}} \approx 40$ km s$^{-1}$ yield luminosity values much fainter than that determined here for this system. On the other hand, as mentioned in §3 this integrated system deviates the luminosity-metallicity relation, being too luminous for its metallicity. According to these findings, the object formed by LSB A634a + DRP A634a is not proven to be a single galaxy.

Even though the LSB A634a + DRP A634a system is not likely to be a single galaxy, those objects could still be physically related. Under this assumption, we propose that the strong SF activity shown by DRP A634a is the result of an encounter between these objects. In fact, examples of recent SF bursts associated with small groups of galaxies that are falling into a cluster have already been reported in the literature (Sakai et al. 2002; Gavazzi et al. 2003b; Cortese et al. 2006), and are thought to be associated with the so-called preprocessing of galaxies before entering the cluster environment. This mechanism could account for a nonnegligible fraction of the evolution of galaxies in dense environments. Further observations of this intriguing system are needed in order to fully understand its nature and evolutionary state.

5. CONCLUSIONS

We have reported two examples of extreme star-forming objects in nearby clusters with different properties and at different evolutionary phases. The observations show that, although they do not share the same origin, both compact and young starbursts show a very intense SF activity, even when compared to similar objects in other nearby clusters or in less dense environments.

The origins of the two starbursts reported in this paper are probably associated with different physical mechanisms: DRP A539a is directly associated with the dense and hot ICM that compresses intergalactic clouds and induces SF episodes in a short timescale, before ram pressure is able to sweep the external gas. The case of DRP A634a can be related to the preprocessing of galaxies before they enter the cluster environment. In this case, the aggregates of galaxies whose final fate is to fall into the cluster inner regions are the environments in which secondary evolution is taking place.

Two questions arise from these considerations: What is the relative importance of such compact and extreme starbursts with respect to the global SFR of nearby clusters? And is there any evolutionary link between them and the early-type UCDGs already reported in the literature (Drinkwater et al. 2004)? To answer the first question, a detailed search based on H$_\alpha$ surveys is required. We note that an extensive spectroscopic survey of A539 devoted to studying the SF in cluster galaxies has been carried out by Rines et al. (2005), but DRP A539a was not selected there because their sample of galaxies was NIR-magnitude limited. The same would have happened with DRP A634a if the cluster A634 had been surveyed under the same conditions. These nondetections are naturally explained by the fact that these objects are dwarfs and very young. However, they show up very easily in wide-field H$_\alpha$ imaging surveys despite their size and small stellar content. These kinds of surveys are required to carry out a detailed census of compact starbursts in clusters of galaxies. In this way, their relative contribution to the total SFR budget of nearby clusters will definitely be determined. As concerns the second question, several explanations have already been proposed for the origin of UCDGs (see Jones et al. 2006 for an interesting review), although the discussion remains open. We propose that compact and strong starbursts like the ones presented in this paper could evolve to early-type dwarf galaxies after the cessation of SF and, if stripping is efficient as the galaxy approaches the innermost regions of the cluster, become UCDGs like the ones reported in the Virgo and Fornax Clusters. A complete census of compact starbursts in clusters, with accurate projected positions and surface densities, will also help to answer this question.

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9 The GOLDMine database (Gavazzi et al. 2003a) was used to derive these data (see http://goldmine.mib.infn.it).
REFERENCES

Arnaboldi, M., et al. 2003, AJ, 125, 514
Balogh, M. L., Baldry, Ivan, K., Nichol, R., Miller, C., Bower, R., & Glazebrook, K. 2004, ApJ, 615, L101
Balogh, M. L., Schade, D., Morris, S. L., Yee, H. K. C., Carlberg, R. G., & Ellingson, E. 1998, ApJ, 504, L75
Bekki, K., & Couch, W. J. 2003, ApJ, 596, L13
Boselli, A., & Gavazzi, G. 2002, A&A, 386, 124
———. 2006, PASP, 118, 517
Boselli, A., Iglesias-Páramo, J., Vilchez, J. M., & Gavazzi, G. 2002, A&A, 386, 134
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Cortese, L., Gavazzi, G., Boselli, A., & Iglesias-Páramo, J. 2004, A&A, 416, 119
Cortese, L., et al. 2006, ApJ, 637, 242
Drinkwater, M. J., Gregg, M. D., Couch, W. J., Ferguson, H. C., Hilker, M., Jones, J. B., Karick, A., & Phillipps, S. 2004, Publ. Astron. Soc. Australia, 2, 375
Drinkwater, M. J., Gregg, M. D., Holman, B. A., & Brown, M. J. I. 2001, MNRAS, 326, 1076
Drinkwater, M., & Hardy, E. 1991, AJ, 101, 94
Drucker, D. H., Yan, F., & Bouchard, L. 1999, ApJ, 525, 63
Duc, P. A., Papaderos, P., Balkowski, C., Thuan, T. X., & De Propris, R. 2006, PASP, 118, 517
Duc, P. A., Cayette, V., Balkowski, C., Thuan, T. X., Papaderos, P., & van Driel, W. 2001, A&A, 376, 763
Duc, P. A., Papaderos, P., Balkowski, C., Cayatte, V., Thuan, T. X., & van Driel, W. 1999, A&AS, 136, 539
Elmegreen, B. G., Kaufman, M., & Thomas, M. 1993, ApJ, 412, 90
Freeman, K. C., et al. 2000, in ASP Conf. Ser. 197, Dynamics of Galaxies: From the Early Universe to the Present, ed. F. Combes, G. A. Mamon, & V. Charmandaris (San Francisco: ASP), 363
Gerhard, O., Arnaboldi, M., Freeman, K. C., Kashikawa, N., Okamura, S., & Yasuda, N. 2005, ApJ, 621, L93
Gerhard, O., Arnaboldi, M., Freeman, K. C., & Okamura, S. 2002, ApJ, 580, L121
Hummel, D. G., & Storey, P. J. 1987, MNRAS, 224, 801
Iglesias-Páramo, J., Boselli, A., Cortese, L., Vilchez, J. M., & Gavazzi, G. 2002, A&A, 384, 383
Iglesias-Páramo, J., & Vilchez, J. M. 2001, ApJ, 550, 204
Iglesias-Páramo, J., et al. 2003, A&A, 406, 453
Jones, B. J., et al. 2006, AJ, 131, 312
Kunth, D., & Östlin, G. 2000, A&A Rev., 10, 1
Lee, H., McCall, M. L., & Riecher, M. G. 2003, AJ, 125, 2975
Leitherer, C., et al. 1999, ApJS, 123, 3
Lewis, I., et al. 2002, MNRAS, 334, 673
Liske, J., Driver, S. P., Allen, P. D., Cross, N. J. G., & De Propris, R. 2006, MNRAS, 369, 1547
McGaugh, S. 2002, BAAS, 32, 1496
Mendes de Oliveira, C., Cypraiano, E. S., Sodré, L., Jr., & Balkowski, C. 2004, ApJ, 605, L17
Mieske, S., Hilker, M., Infante, L., & Jordán, A. 2006, AJ, 131, 2442
Mirabel, I., F. Dormiti, H., & Lutz, D. 1992, A&A, 256, L19
Moore, B., Lake, G., Quinn, T., & Stadel, I. 1999, MNRAS, 304, 465
Moore, B., Quilis, V., & Bower, R. 2000, in ASP Conf. Ser. 197, Dynamics of Galaxies: From the Early Universe to the Present, ed. F. Combes, G. A. Mamon, & V. Charmandaris (San Francisco: ASP), 363
Mori, M., & Burkert, A. 2000, ApJ, 538, 559
Moresco, K. E., Papaderos, P., Cairós, L. M., & Fricke, K. J. 2003, A&A, 410, 481
Pierini, D., & Tuffs, R. J. 1999, A&A, 343, 751
Pilyugin, L. S., Vilchez, J. M., & Contini, T. 2004, A&A, 425, 849
Poggianti, B. 2004, in Baryons in Dark Matter Halos, ed. R.-J. Dettmar, P. Salucci, & U. Klein (Trieste: SISSA), 104
Rines, K., Keller, M., Kurtz, M., & Diaferio, A. 2003, AJ, 126, 2152
———. 2005, AJ, 130, 1482
Sakai, S., Kennicutt, R. C., Jr., van der Hulst, J. M., & Moss, C. 2002, ApJ, 578, 842
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Schombert, J. M. 2006, AJ, 131, 296
Strobe, M. F., & Rood, H. J. 1999, ApJS, 125, 35
Swaters, R. A. 1999, Ph.D. thesis, Gröningen Univ.
Terlevich, R., Melnick, J., Masegosa, J., Mole, M., & Copetti, M. V. F. 1991, A&AS, 91, 285
Vilchez, J. M. 1995, AJ, 110, 1090
Vilchez, J. M., & Iglesias-Páramo, J. 2003, ApJS, 145, 225
White, D. A., Jones, C., & Forman, W. 1997, MNRAS, 292, 419
Ziegler, B. L., et al. 2002, ApJ, 564, L69