ENVIRONMENTAL EFFECTS ON THE METAL ENRICHMENT OF LOW-MASS GALAXIES IN NEARBY CLUSTERS

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ABSTRACT

In this paper, we study the chemical history of low-mass star-forming (SF) galaxies in the local universe clusters Coma, A1367, A779, and A634. The aim of this work is to search for the imprint of the environment on the chemical evolution of these galaxies. Galaxy chemical evolution is linked to the star formation history, as well as to the gas interchange with the environment, and low-mass galaxies are well known to be vulnerable systems to environmental processes affecting both these parameters. For our study we have used spectra from the SDSS-III DR8. We have examined the spectroscopic properties of SF galaxies of stellar masses $10^8$–$10^{10} M_\odot$, located from the core to the cluster’s outskirts. The gas-phase O/H and N/O chemical abundances have been derived using the latest empirical calibrations. We have examined the mass–metallicity relation of cluster galaxies, finding well-defined sequences. The slope of these sequences, for galaxies in low-mass clusters and galaxies at large cluster-centric distances, follows the predictions of recent hydrodynamic models. A flattening of this slope has been observed for galaxies located in the core of the two more massive clusters of the sample, principally in Coma, suggesting that the imprint of the cluster environment on the chemical evolution of SF galaxies should be sensitive to both the galaxy mass and the host cluster mass. The H I gas content of Coma and A1367 galaxies indicates that low-mass SF galaxies, located at the core of these clusters, have been severely affected by ram-pressure stripping (RPS). The observed mass-dependent enhancement of the metal content of low-mass galaxies in dense environments seems plausible, according to hydrodynamic simulations. This enhanced metal enrichment could be produced by the combination of effects such as wind reaccretion, due to pressure confinement by the intracluster medium (ICM), and the truncation of gas inflow, as a result of the RPS. Thus, the properties of the ICM should play an important role in the chemical evolution of low-mass galaxies in clusters.

Key words: galaxies: abundances – galaxies: clusters: general – galaxies: clusters: individual (Coma, A1367, A634, A779) – galaxies: evolution

Online-only material: color figures

1. INTRODUCTION

The chemical evolution of a galaxy is linked to the star formation history (SFH), as well as to the gas interchange with the environment via inflows or outflows. In this sense, galaxy metallicity could be an observable parameter providing information on the impact of the environment on the galaxy SFH and/or the galaxy gas content.

SFH has been found to be related to the environment that a galaxy inhabits: dense regions, such as galaxy clusters, are mainly populated by red passive spheroids, whereas star-forming (SF) galaxies dominate in the field (Dressler 1980; Balogh et al. 1999, 2004; Poggianti et al. 1999, 2008; Treu et al. 2003; Rines et al. 2005; Finn et al. 2005; Haines et al. 2007). However, intense discussions on the underlying cause of this observational trend are still ongoing. One interpretation has been that this trend could be the mere result of the fact that high-density regions have favored the formation mostly of massive galaxies, which in turn convert their gas in stars faster than dwarf galaxies (Kennicutt 1998) and have already finished forming stars earlier in the past (Merlin & Chiosi 2006). Recent observational evidences support the idea that the stellar mass function can be associated with the environment (Vulcani et al. 2011; Bolzonella et al. 2010).

Another reason could be that the cluster environment causes galaxies to transform their properties, as they move from low-density regions into the cluster core. A number of plausible mechanisms have been proposed, including interactions with the ICM, interactions with the cluster gravitational potential, and small-scale galaxy–galaxy interactions (see Treu et al. 2003, and references therein). Each one of these mechanisms is expected to be effective in different regions of clusters and their outskirts and to affect star formation in different ways and timescales (see, e.g., the review by Boselli & Gavazzi 2006).

For low-mass galaxies, however, the picture appears much clearer. Due to their low-mass surface density and rotation velocity, dwarf galaxies are the most vulnerable systems to environment-related processes that quench star formation, such as the stripping of their halo and/or disk gas. Haines et al. (2007), based on a large sample of dwarf galaxies, have found that passive dwarfs are found only in very dense environments, typical of a cluster virial region, or as satellites of a more massive companion. Studies of three of the richest clusters in the local universe, A2199 (Haines et al. 2006), Coma, and A1367 (Mahajan et al. 2010), suggest that star formation in dwarf galaxies is quenched only in the center of the clusters, in contrast with massive galaxies that can become passive in all environments. All these evidences seem to imply that there exist fundamental differences in the evolution of giant and dwarf galaxies in clusters: while various physical mechanisms could be co-responsible for the evolution of massive galaxies, the evolution of dwarf galaxies seems to be primarily driven by the environment in which they are found.

In accordance with the current cosmological paradigm (e.g., Springel et al. 2005), clusters at $z \sim 0$ have been found to accrete late-type galaxies along the filamentary structures that compose the cosmic web (e.g., Smith et al. 2011). Mahajan et al. (2011) have found that post-starburst dwarfs are preferentially
located in the infall regions of Coma and A1367, suggesting that these galaxies experience a sudden quenching of star formation due to the interaction with the ICM. Moreover, before the gas gets totally stripped off, dwarf galaxies could experience an enhancement of star formation, either during their infall into the cluster along the filaments (Mahajan et al. 2010; Porter et al. 2008) or in the first stages of their encounter with the hot ICM (pressure triggered star formation; Abramson et al. 2011; Sun et al. 2007; Gavazzi et al. 2001). Thus, SF dwarf galaxies are excellent probes to test the influence of the environment on the process of star formation and galaxy evolution.

The gas interchange of a galaxy with the environment is observationally well confirmed. For example, the ram-pressure stripping (RPS; Gunn & Gott 1972) can remove the interstellar medium (ISM) of a galaxy as it moves through the hot intra-cluster gas. Evidences of ongoing gas stripping, in both low- and high-luminosity galaxies, have turned out to be frequent in local universe clusters, such as the Virgo Cluster (Fumagalli et al. 2011; Abramson et al. 2011; Kenney & Koopmann 1999), A1367 (Gavazzi et al. 2001), and A3627 (Sun et al. 2007). In the Coma Cluster core several galaxies have been observed showing clear signs of gas stripping, such as Hα or ultraviolet tails (Yagi et al. 2010; Smith et al. 2010). Additional observational evidence exist confirming the gas stripping in clusters, such as truncated ionized gas disks (Koopmann & Kenney 2004; Koopmann et al. 2006; Cedrés et al. 2009; Jaffé et al. 2011) and disturbed gas kinematics (Jaffé et al. 2011). Moreover, the atomic gas properties of cluster galaxies seem to tell the same story (Haynes et al. 1984; Solanes et al. 2001; Chung et al. 2009; Levy et al. 2007).

Simulations (e.g., Abadi et al. 1999; Mori & Burkert 2000; Tonnesen et al. 2007) suggest that RPS is efficient even up to the cluster virial radius and can remove completely the gas content in timescales of ~10^9 yr, comparable to the cluster crossing time. Additionally, RPS has been found to be a multi-stage process (Roediger & Hensler 2005), and recent simulations indicate that both varying ICM density (Brüggen & De Lucia 2008; Tecce et al. 2010) and inhomogeneities in the ISM (Tonnesen & Bryan 2009) are expected to play an important role in the gas stripping effect. Tecce et al. (2011) report that the gradient of ram pressure becomes steeper with increasing cluster mass; in the massive clusters (M ~ 10^{15} M_☉), the ram pressure at the core is ~100 times higher than at R = R_{200}, whereas in galaxy-group-sized halos the ram pressure at R_{200} is ~10% of the central value. Bekki (2009) simulations suggest that even moderately strong ram pressure, e.g., in clusters of M ~ 10^{14} M_☉ or even in groups, could strip the hot gas halos of galaxies, an effect known as strangulation (see also McCarthy et al. 2008; Kawata & Mulchaey 2008; Feldmann et al. 2011). In Bekki (2009) simulations, the stripping of galactic halo gas seems to be more efficient than that of disk gas, and the efficiency increases with decreasing galaxy mass.

Gas infall has also been proposed to take place in both low-mass irregular and high-mass spiral galaxies, in order to explain broadband colors, gas fractions, SFRs, and metallicities at low and high redshifts (see Dalcanton 2007, and references therein). Additionally, interacting galaxies can undergo nuclear metal dilution due to gas inflows (Kewley et al. 2010; Montuori et al. 2010; Rupke et al. 2010; Michel-Dansac et al. 2008), resulting in the flattening of the gas-phase metallicity gradients and altering their positions on the mass–metallicity relation (MZR).

All these environmental effects described, on both the SFH and the gas content of a galaxy, would be expected to leave their imprint on galaxy metallicity. Even the most recent events of star formation can enrich the gas with metals, so gas metallicities should be very sensitive to trace ongoing changes on the SFH and gas content (Ellison et al. 2009). SF galaxies, through their ionized gas emission, provide this observable information on nebular metallicity. Thus, studying the chemical abundances of SF galaxies in clusters can help appreciate the effect of the environment on the chemical evolution of cluster galaxies.

Previous works (Mouhcine et al. 2007; Cooper et al. 2008; Ellison et al. 2009) on the metallicity of SF galaxies as a function of the environment have not provided conclusive results, as small variations of ~0.05 dex have been derived. These works, however, have been limited to the high stellar mass range, where there are no conclusive evidences whether the cluster environment could change significantly the SFH. Additionally, they have focused on the effect of local galaxy density, which possibly is not the only relevant parameter. Highlighting the cluster environment impact, H I-deficient spirals in Virgo and Pegasus I clusters have been found to be more chemically enriched than normal spirals (Skillman et al. 1996; Robertson et al. 2011), while this correlation between HI deficiency and metallicity has not been observed for field galaxies (Robertson et al. 2011).

The gas metallicity of SF dwarf galaxies in local universe clusters has also been addressed. In Virgo dIrr, the gas metallicity has not been found to show a clear trend with the environment (Vilchez 1995; Lee et al. 2003; Vaduvescu et al. 2007); however, Lee et al. (2003) have found that five of these dIrr are gas deficient with respect to field dIrr at comparable oxygen abundances, and this gas deficiency correlates with the X-ray surface brightness of the ICM. Some SF dwarfs in the Hydra Cluster (Duc et al. 2001) have been found to be metal-rich for their luminosities, and Vaduvescu et al. (2011), comparing the MZR of SF dwarfs in Hydra, Fornax, and Virgo, have suggested that differences in the MZR seem to exist for galaxies in such different environments. Going to a more massive cluster (A2151), Petropoulou et al. (2011) have been able to observe dwarf galaxies, located in the cluster core, showing higher metallicities for their mass.

In the present study we extend these previous works, investigating the chemical history of SF dwarf galaxies in four clusters in the local universe: Coma (A1656), A1367, A779, and A634. Coma and A1367 are among the nearest very rich galaxy clusters, and both belong to the large structure called the Coma supercluster. Recent insightful evidences on the assembly history and the SFH of the low-mass galaxy population in the Coma supercluster (Smith et al. 2011; Mahajan et al. 2010, 2011) seem to indicate that it provides exemplary conditions for searching the potential imprints of the cluster environment on galaxy chemical enrichment. To investigate whether the mass of the host cluster could play a significant role in the chemical evolution of SF dwarf galaxies, we include in our sample two lower-mass clusters: A779 and A634. In total, these clusters are the four Abell clusters with Sloan Digital Sky Survey (SDSS) spectroscopic data that fulfill the following criteria: (1) to be visible from the northern hemisphere (δ ≥ −25 deg) and (2) to be located at the same distance at ~100 Mpc (0.02 < z < 0.03). Thus, the sample of clusters studied in the present work belong
to a semi-spheric shell of the local universe\textsuperscript{4} and span a wide range of halo masses from $10^{13}$ to $10^{15} \, M_\odot$.

We have used the latest spectroscopic release SDSS-III DR8, where new emission-line measures have been provided, after correcting the spectra for the underlying stellar population. This is an important issue when deriving gas-phase metallicities, reducing biases that previous works could have been suffering. Additionally, three out of four of the present sample clusters were not included in previous releases than DR7. Anyway, they would have been excluded by the previous studies on the gas-phase metallicity of SDSS cluster galaxies (Ellison et al. 2009; Cooper et al. 2008; Mouchine et al. 2007), due to the redshift cutoff implemented in these works. Moreover, our analysis includes, apart from oxygen abundance, the N/O ratio, a relevant observable to appreciate the effects on cluster galaxies (see also Petropoulou et al. 2011).

This paper is organized as follows. In Section 2 we describe the selection of the sample of SF dwarf galaxies in four nearby clusters, in Section 3 we derive the spectroscopic properties of our galaxy sample, and in Section 4 their gas-phase metal abundances. In Section 5 we discuss the MZR of our sample clusters and in Section 6 the chemical enrichment of the SF dwarf galaxies relative to their H\textsc{i} mass content. In Section 7 we discuss the environmental effects that could affect the chemical evolution of cluster galaxies, and finally in Section 8 we briefly summarize the findings of the present work. In this work we adopt the cosmological parameters $H_0 = 73 \, \text{km s}^{-1} \, \text{Mpc}^{-1}$, $\Omega_M = 0.73$, and $\Omega_{\Lambda} = 0.27$.

\textsuperscript{4} In this semi-spheric shell are found three additional Abell clusters, A400, A539, and A2666, but they do not have SDSS spectroscopic data. Multifiber spectroscopic observations for these clusters will be presented in a forthcoming work (V. Petropoulou et al. 2012, in preparation).

2. THE GALAXY SAMPLE

In this paper, we study the chemical properties of SF dwarf galaxies in the central region (up to $\sim 3 \, R_{200}$) of four nearby clusters (Coma, A1367, A779, and A634), using spectroscopic data of SDSS-III DR8. In Table 1 we give details on the cluster properties, and in Table 2 we give details on the regions studied in this work (see the captions of both tables).

Coma is a very massive cluster, with very high velocity dispersion and X-ray luminosity (Ledlow et al. 2003). There are two central cD galaxies, NGC 4874 and 4889, and a subcluster, projected to $\sim 1.5$ Mpc to the southwest of the core and centered on NGC 4839, appears to be merging with the main cluster (Briel et al. 1992; Neumann et al. 2003). A1367 reveals a complex dynamical state (Cortese et al. 2004), with an elongated X-ray emission, showing multiple clumps, supporting a multiple merger scenario (Donnelly et al. 1998; Sun & Murray 2002). Additionally, substructures falling into the cluster core (Cortese et al. 2006; Gavazzi et al. 2003) suggest an early stage of formation of the cluster. Cortese et al. (2008a), based on UV photometry, have found that star formation in Coma is substantially suppressed compared to that in the field, while A1367 has an abundance of bright SF galaxies (see Iglesias-Páramo et al. 2002). The optical luminosity function of galaxies has a much steeper faint-end slope in Coma than in A1367 (Iglesias-Páramo et al. 2003). On the other hand, A779 and A634 are two clusters of very low velocity dispersion. A634 X-ray luminosity is at the ROSAT detection limits, while A779 presents a nearly circular X-ray emission around the cD galaxy NGC 2832.

Cluster galaxies were selected using spectroscopic redshift information. In Figure 1, we plot the velocity histograms of all galaxies with SDSS spectroscopic data in the areas considered.

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### Table 1

| Cluster      | R.A. J2000 | Decl. J2000 | $z$   | $\sigma_v$ (km s$^{-1}$) | $m-M$ (mag) | Scale (Mpc deg$^{-1}$) | $R_{200}$ (Mpc) | $M_M$ ($M_\odot$) | $L_X$ (10$^{42}$ erg s$^{-1}$) |
|--------------|------------|-------------|-------|--------------------------|-------------|-------------------------|----------------|----------------|-------------------------|
| A1656        | 12 59 48.7 | 27 58 50    | 0.0231| 1008                     | 35.06       | 1.79                    | 1.73           | $1.2 \times 10^{14}$ | 9.30 ± 0.14             |
| A1367        | 11 44 29.5 | 19 50 21    | 0.0222| 879                      | 34.95       | 1.71                    | 1.51           | $8.1 \times 10^{14}$ | 2.30 ± 0.08             |
| A779         | 09 19 50.8 | 33 46 17    | 0.0225| 339                      | 34.92       | 1.68                    | 0.58           | 4.6 $\times 10^{13}$ | 0.29 ± 0.04             |
| A634         | 08 14 33.7 | 58 02 52    | 0.0265| 391                      | 35.23       | 1.94                    | 0.67           | $7.1 \times 10^{13}$ | <0.08                   |

**Notes.** Column 1: cluster; Column 2: right ascension in hours, minutes, and seconds of cluster center as given in NED; Column 3: declination, in degrees, arcminutes, and arcseconds of cluster center (NED); Column 4: cluster mean redshift (NED); Column 5: cluster velocity dispersion in km s$^{-1}$; Column 6: cluster redshift in magnitudes (NED); Column 7: cluster scale in Mpc deg$^{-1}$; Column 8: cluster $R_{200}$ in Mpc as derived using Equation (8) of Finn et al. (2005); Column 9: cluster mass in $M_\odot$, as derived using Equation (10) of Finn et al. (2005); Column 10: ROSAT X-ray luminosity $L_X$ in units 10$^{42}$ erg s$^{-1}$ (Ledlow et al. 2003).

### Table 2

| Cluster | Area (deg$^2$) | $z$ | Total Dwarf SF Dwarf SF Dwarf SF $R_{200}$ Dwarf SF $R_{200}$ |
|---------|---------------|----|-----------------|-----------------|-----------------|
| A1656   | 5.7 × 5.7     | 0.015–0.0323 | 1017 616 194 | 148 | 293 | 25 |
| A1367   | 5.2 × 5.2     | 0.015–0.0323 | 564 356 238 | 191 | 107 | 41 |
| A779    | 2 × 2         | 0.0189–0.0275 | 106 66 32 | 31 | 26 | 7 |
| A634    | 2 × 2         | 0.0246–0.0293 | 97 60 34 | 26 | 24 | 10 |

**Notes.** Column 1: cluster; Column 2: square area studied in deg$^2$; Column 3: the redshift range considered for each cluster; Column 4: total number of galaxies in the considered area and velocity range; Column 5: number of dwarf ($m_{mag} > 15$) galaxies; Column 6: number of SF galaxies; Column 7: number of SF dwarf galaxies; Column 8: number of dwarf galaxies at distances $R \leq R_{200}$ from the cluster center; Column 9: number of SF dwarf galaxies at distances $R \leq R_{200}$ from the cluster center.
We perform a Gauss fit to the velocity distribution of each cluster. The central velocity obtained by the fit is in good agreement with the mean cluster velocity given by NED, indicated in Figure 1. We consider as cluster galaxies all the galaxies with velocities \( v_{\text{clus}} \pm 3\sigma_v \), where \( v_{\text{clus}} \) is the mean cluster velocity and \( \sigma_v \) is the dispersion given by the fit. In Table 2 we give the velocity range considered for each cluster and the total number of galaxies with SDSS spectroscopic data found within the area considered and within the respective velocity range.

To select the dwarf galaxies, we adopt the following criteria: SDSS BPT class \( > 3 \) (classification as SF, based on the BPT diagram; Baldwin et al. 1981), and signal-to-noise ratio \( S/N > 3 \) for the lines \([\text{O III}]\lambda 5007, [\text{N II}]\lambda 6584, \text{H}\alpha, \text{H}\beta, [\text{S II}]\lambda 6717, \) and \([\text{S II}]\lambda 6731\). Finally, we have taken special care to include in our final sample of SF dwarf galaxies one spectrum per galaxy (a few galaxies have multiple observations), as well as to exclude spectra that correspond to distinct H\( \Pi \) regions of some parts of galaxies, because these spectra provide substantially underestimated mass values (see Section 3). The number of SF dwarf galaxies for each cluster is given in Table 2. For these galaxies we calculate the distance \( R \) from the cluster center given in units of \( R_{200} \). In Table 2 we also give the number of SF dwarf galaxies located in the cluster core, at distance \( R \leq R_{200} \), and the total number of dwarf galaxies at \( R \leq R_{200} \) for each cluster.

We note that there are more SF dwarf galaxies, showing low \( S/N \) emission lines (the galaxies with BPT class \( = 2 \) in SDSS), in the areas of the clusters of our sample, especially of Coma. These galaxies could be suffering the quenching effect of the cluster environment, illustrated well in studies based on the H\( \alpha \) equivalent widths (EWs) of SF galaxies (e.g., Balogh et al. 2004; Rines et al. 2005). In the present work, given that a high-S/N emission-line spectrum is required to derive properly spectroscopic properties (e.g., reddening coefficients) and gas metallicities, we do not include in our galaxy sample the low-S/N SF population (we call them class 2 population). By doing this, we probably consider the more recently accreted galaxies to the cluster environment, and as a consequence the potential suppressing of their star formation could be observed in an early stage. As we will discuss in Section 5, the behavior of class 2 population would not change the conclusions of this work.

Poggianti et al. (2006), based on a large sample of clusters, sampling the whole mass range from groups to massive clusters, have been able to show that the fraction of SF galaxies depends on galaxy mass, for clusters at both high-\( z \) and low-\( z \). These authors found that about 20% of the galaxies in clusters at \( z \approx 0 \) with \( \sigma > 500 \) km s\(^{-1}\) are SF. Due to the SN restrictions and the SDSS spectroscopic data incompleteness (especially in clusters, due to constraints in the fiber placement; see Blanton et al. 2005a, 2005b), our galaxy sample is not a complete sample of the SF galaxies in these clusters. Thus, we should not compare our data with the rates found by Poggianti et al. (2006). However, the goal of this work is to investigate the imprint of the cluster environment on the chemical evolution of SF galaxies in clusters, the general quenching effect in clusters being well established by several previous works.

Figure 2 shows the color g – i histogram of dwarf galaxies (green line), SF dwarf galaxies (blue line), and SF dwarf galaxies to \( R \leq R_{200} \) for each cluster (note that logarithmic scale has been used for Coma). It is well illustrated that the dwarf galaxy population in these clusters is composed by two main

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**Figure 1.** Radial velocity histogram for all galaxies with SDSS-DR8 spectroscopic data within \( 3R_{200} \) from the center of each cluster. The velocity bin is 100 km s\(^{-1}\). The dashed line represents the mean cluster radial velocity as given in NED (Coma: \( c_z = 6930 \) km s\(^{-1}\); A1367: \( c_z = 6600 \) km s\(^{-1}\); A779: 6750 km s\(^{-1}\); A634: 7950 km s\(^{-1}\)). The dashed region indicates the adopted velocity range at \( \pm 3\sigma_v \) around the mean cluster velocity.
populations, red and blue, producing two maxima in the color histogram at $g - i \sim 0.6$ and $g - i \sim 1.1$, following the general bimodal distribution of the galaxy population (Strateva et al. 2001; Baldry et al. 2004). Coma has a larger fraction of red bimodal distribution of the galaxy population (Strateva et al. 2001). We note that in all findings on the color–magnitude diagrams of these clusters (e.g., Kewley et al. 2005; Magrini et al. 2007; Bresolin et al. 2009). However, in this work we focus our attention on dwarf/irregular galaxies, where spatial metallicity gradients are not expected to be important (Kobulnicky & Skillman 1997; van Zee et al. 2006; van Zee & Haynes 2006). Thus, taking into account the smaller diameter of dwarfs, we do not expect aperture biases to be important for the galaxies of the present sample.

3. SPECTROSCOPIC PROPERTIES

SDSS-III DR8 provides new emission-line measures (Tremonti et al. 2004; Brinchmann et al. 2004), derived after correcting the spectra for the underlying stellar continuum, using the high-resolution population synthesis models of Bruzual & Charlot (2003). The Balmer emission lines can be severely affected by the absorption of the underlying stellar component (Martín-Manjón et al. 2008, 2010), and this would affect the derived values of the reddening coefficient, the line indices, and, as a consequence, the gas-phase metallicity (see Section 4). This effect is expected to be negligible here, allowing a reliable study of the galaxies’ gas metallicity. We find that DR8 measures of Balmer emission lines such as $H\gamma$ and $H\delta$ are significantly improved as compared to DR7 spectroscopic data.

We use the Balmer emission lines $H\alpha$, $H\beta$, $H\gamma$ (and where the S/N permits also $H\delta$) to derive the reddening coefficients $c(H\beta)$ for our sample of SF galaxies, using Case B approximation (Osterbrock 1989), adopting the Cardelli et al. (1989) extinction law, and taking into account the line measurements’ error. Mahajan et al. (2010) provide Spitzer MIPS 24 μm flux for a sample of Coma Cluster galaxies. From this sample, 25 galaxies belong to our sample of SF dwarfs. For these 25 galaxies we find that the derived reddening coefficient $c(H\beta)$ shows a tight correlation with their flux at 24 μm, in the line of Relaño et al. (2010), who suggest that the dust responsible for the Balmer extinction should be emitting at 24 μm.

The presence of both singly and doubly ionized oxygen line transitions in the optical wavelengths has permitted us to develop an efficient metallicity calibration (Pagel et al. 1979) based on the indicator $R_{23} = \lambda 3727/[O\text{~ii}]\lambda 3727 + [O\text{~ii}]\lambda 4959 + [O\text{~iii}]\lambda 5007)/H\beta$. Obtaining the $[O\text{~ii}]\lambda 3727$ line measures from DR8, however, was problematic. Although some spectra present high-S/N $[O\text{~ii}]\lambda 3727$ line, no measure is provided by DR8. For the galaxies that SDSS does not provide $[O\text{~ii}]\lambda 3727$, 3729 measures with $S/N > 3$, but $[O\text{~ii}]\lambda 3727$ is detectable in the spectrum with $S/N > 3$, we measure the $[O\text{~ii}]\lambda 3727$ integrated flux. We have verified that our measures and DR8 give consistent emission-line fluxes for several emission lines (e.g., $[N\text{~ii}]/H\alpha$ and $[N\text{~ii}]/[O\text{~ii}]$, when there is $[O\text{~ii}]$). Table 3 presents the number of galaxies for which we have SDSS $[O\text{~ii}]\lambda 3727$, 3729 measures, the number of galaxies for which we measure integrated $[O\text{~ii}]\lambda 3727$, the total number of galaxies with $[O\text{~ii}]$ measure, and the total number of SF dwarf galaxies for A1656 and A1367.

Despite this effort, we could not obtain $[O\text{~ii}]\lambda 3727$ for all galaxies belonging to the four clusters of $z \sim 0.23$. This is be-

| Cluster | DR8 | New | Total | All |
|---------|-----|-----|-------|-----|
| A1656   | 35  | 52  | 87    | 149 |
| A1367   | 42  | 48  | 90    | 194 |

Table 3: Galaxies with $[O\text{~ii}]\lambda 3727$ Measures
diagrams for SF dwarf galaxies in Coma (triangles), A1367 (stars), A779 (circles). Filled symbols represent galaxies to distances \( R \leq R_{200} \), and again we see that the galaxies in the cluster core are not different from the rest regarding excitation.

We have also obtained the median estimate of the total stellar mass of the galaxies from the MPA-JHU spectroscopic catalog (Kauffmann et al. 2003). We have found that this galaxy mass estimate is consistent with the mass we derived using the k-correct algorithm (Blanton & Roweis 2007). We have also found a good agreement between the MPA-JHU mass estimates and Mouhcine et al. (2011) galaxy masses, derived by K-band imaging, for seven galaxies of our sample that belong also to the sample of Mouhcine et al. (2011).

4. OXYGEN ABUNDANCES

Accurate abundance measurements require the determination of the electron temperature, which is usually obtained from the ratios of auroral to nebular line intensities such as \([\text{O} \text{ III}]\) over \([\text{O} \text{ II}]\) \( \lambda 5007 \). This is often referred to as the “direct” method. When auroral lines are not detected, empirical methods are generally used, based on the ratios of bright forbidden lines to hydrogen recombination lines. Among these, the most widely used abundance indicator is the \( R_{23} \) index (although still carrying significant hazards; e.g., see Pérez-Montero & Díaz 2005). Another extensively used parameter to derive gas-phase metallicities is \( N_{2} \) (Storchi-Bergmann et al. 1994; PMC09). The use of this parameter has two important advantages: the relation between \( N_{2} \) and the oxygen abundance is single-valued and the emission lines involved are very close in wavelength, so the \( N_{2} \) parameter is almost free of uncertainties introduced by reddening correction or flux calibration. A third very useful index is \( O3N2 \) (Alloin et al. 1979), which shows a relatively tight and linear relationship with \( 12 + \log(O/H) \) (Pettini & Pagel 2004, hereafter PP04) for \( O3N2 \leq 2 \).

The calibration of these parameters can be empirical (e.g., PP04; Pilyugin & Thuan 2005; Pilyugin et al. 2010, from now P10), that is, using direct measurements of the oxygen abundance of \( H \) II regions in the local universe, or theoretical (e.g., McGaugh 1991; Kewley & Dopita 2002; Tremonti et al. 2004; Nagao et al. 2006; Dors et al. 2011), that is, using photoionization models covering different ranges of physical parameters. Though, it has long been reported (e.g., Kewley & Ellison 2008) that there exist systematic differences that can reach up to \( \sim 0.5 \) dex between most model and empirical calibrations, especially in the higher metallicity regime (but see Dors et al. 2011).

A strong hint that the direct measures and the empirical calibrations should yield metallicities closer to reality was given by Bresolin et al. (2009). These authors derived the metallicities of \( 28 \) \( H \) II regions in the galaxy NGC 300 using the direct method and found that these metallicities agree with the abundances derived from young massive stars, with stellar and nebular abundances giving virtually coincident slopes and intercepts of radial gradients. An important quantity that should be taken into account [\text{O} \text{ II}] \( \lambda 3727 \), redshifted to this velocity, lies at the edge of the wavelength range covered by SDSS spectroscopy. We have performed K-S tests and have verified that the subsample of galaxies with [\text{O} \text{ II}] measured (by DR8 or this work) and the whole sample of SF dwarf galaxies are statistically indistinguishable in their properties: \( M_{z} \), metallicity (by Pérez-Montero & Contini 2009, hereafter PMC09; see Section 4), and mass. We conclude that the lack of [\text{O} \text{ II}] measures is a random effect, due to the radial velocity of each galaxy for the cluster velocity dispersion, and does not correlate with any of the fundamental galaxy properties.

We have used the reddening-corrected line fluxes for our sample of galaxies to compute five standard optical line ratios, which we show in Figure 3, combined into three commonly used diagnostic diagrams. Our sample galaxies show typical line ratios of normal SF dwarf galaxies. Additionally, the galaxies located at \( R \leq R_{200} \) span the whole range of values in all [\text{O} \text{ II}] and [\text{N} \text{ II}] ratio measurements.

(\text{A color version of this figure is available in the online journal.})
Figure 4. [O III] / Hβ vs. EW(Hα) for SF dwarf galaxies in Coma (A1656, triangles) and A1367 (stars). Filled symbols represent galaxies at $R \leq R_{200}$.

(A color version of this figure is available in the online journal.)

Figure 5. Left: the difference of $12 + \log(O/H)$ derived using PMC09 and PP04 calibrations. A1656: continuous, A1367: dashed line. Middle: the same between PMC09 and PIL10 calibrations, for galaxies with [O II] measured. Right: the same using Dors et al. (2011) models and PIL10 calibration (for galaxies with [O II] measured and $12 + \log(O/H)_{\text{DORS11}}>8.2$).

(A color version of this figure is available in the online journal.)

account when comparing stellar and nebular oxygen abundances is the amount of oxygen depleted onto dust grains in ionized nebulae. According to Peimbert & Peimbert (2010), this fraction amounts to about 0.10 dex for low-mass galaxies. Bresolin et al. (2009) discussed this effect and found that, even considering a gas depletion factor of $-0.1$ dex, the intercepts of the nebular and stellar abundance gradients would be consistent. Then they compared their direct estimates of the metallicity of the ionized gas with the most widely used model calibrations, and they report that model calibrations yield higher metallicities of about a factor of two in the O/H range derived. On the contrary, the abundances derived using empirical calibrations use to be in good agreement with their direct measurements.

Another strong hint was given recently by Dors et al. (2011). These authors produced models that reproduce O/H estimates consistently with the values derived using the direct method, for the upper range of O/H values, where all previous models showed systematic discrepancies.

Simón-Díaz & Stasińska (2011) derived the O/H abundance ratio using 13 B-type stars from the Orion star-forming region and obtained an excellent agreement with the O/H recombination line abundances derived for the Orion nebula by Esteban et al. (2004). For the Orion nebula Simón-Díaz & Stasińska (2011) considered a correction of $\sim0.12$ dex due to the dust grain depletion, which is in excellent agreement with the value estimated by Mesa-Delgado et al. (2009). Since recombination lines are generally very weak, they are not observed in our sample of galaxies. In any case, this analysis is based on the relative comparison of galaxy metallicities; thus, no relevant effect is expected from the derivation of absolute abundances.

In this work we use the empirical calibrations of P10, N2 calibration of PMC09, and O3N2 calibration of PP04 to derive the oxygen abundances. We note that for our sample of galaxies always $O3N2 < 2$, lying in the valid range of PP04 calibration. In Figure 5 (left), we compare the oxygen abundances derived using the PMC09 and PP04 calibrations for the galaxies in the two most populated clusters of our sample, and we can see a very good agreement. The use of the P10 empirical calibration requires the measure of [O II] $\lambda3727$ line, which we do not have for all our sample galaxies; see Section 3. In Figure 5 (middle), we compare the oxygen abundances derived using the P10 and PMC09 calibration, for those galaxies with [O II] measured. We see that the PMC09 calibration yields slightly higher metallicities ($\sim0.1$ dex) than P10 calibration, in
agreement with our previous considerations in Petropoulou et al. (2011). We also derive the oxygen abundance of galaxies with agreement with our previous considerations in Petropoulou et al. (2011). We also derive the oxygen abundance of galaxies with agreement with our previous considerations in Petropoulou et al. (2011). We also derive the oxygen abundance of galaxies with agreement with our previous considerations in Petropoulou et al. (2011). We also derive the oxygen abundance of galaxies with agreement with our previous considerations in Petropoulou et al. (2011). We also derive the oxygen abundance of galaxies with agreement with our previous considerations in Petropoulou et al. (2011). We also derive the oxygen abundance of galaxies with agreement with our previous considerations in Petropoulou et al. (2011). We also derive the oxygen abundance of galaxies with agreement with our previous considerations in Petropoulou et al. (2011).

In order to limit our sample only to galaxies with [O ii] measures in the following we use the PM09 calibration of the galaxy oxygen abundance. We are aware that PM09 could slightly overestimate (~0.1 dex) the galaxy O/H abundance, but as discussed later on, we do not expect this to affect our discussion, as we always perform careful comparison of metallicities derived using the same method. We also use the N2S2 calibration of PM09 to derive N/O ratios for our SF dwarf galaxies as in Petropoulou et al. (2011).

In order to illustrate the properties of our galaxies, in Figure 6 we plot the Hα flux of the SF region covered by the SDSS fiber, for the SF dwarf galaxies in Coma (triangles) and A1367 (diamonds), versus the EW(Hα). The Hα fluxes have been corrected for extinction (from the derived c(Hβ); see Section 3) and have been transformed to an equivalent number of ionizing photons Q(H), under the assumption that no ionizing photons escape the galaxies (Osterbrock 1989). The points are color coded to the derived galaxy metallicity. Then we add the loci of Starburst99 models (Leitherer et al. 1999) for instantaneous bursts of total mass Ms = 10^7 M⊙ (continuous) and Ms = 10^8 M⊙ (dashed) lines in massive stars for metallicities Z = 0.02 (in red), Z = 0.008 (green), and Z = 0.004 (black). According to these models, and assuming single bursts, the SF regions studied would span a mass range of ~10^6–10^7 M⊙.

In Figure 7 we plot the galaxy metallicity, as measured by 12+log(O/H), versus galaxy stellar mass, for the SF dwarf galaxies in Coma (A1656, triangles), A1367 (stars), A779 (squares), and A634 (circles). Filled symbols correspond to galaxies at a distance R < R200 from the cluster center. We see that the SF dwarf galaxies follow well-defined sequences on these plots. Having a look at the MZR of A1656 and A1367, we observe that at low galaxy masses (10^8 M⊙ < M* < 10^9 M⊙), the derived metallicities cover a range of ~0.4 dex, while at higher masses (10^9 M⊙ < M* < 10^10 M⊙) the relation becomes tighter, appearing to shape a triangle instead of a simple linear correlation. Additionally, we observe that, for the same bin of mass, galaxies at R < R200 are preferentially located at the upper part of the global sequences. For the two clusters (A779, A634) of lower mass, we do not verify either of these two features, as we discuss in the following.

We first note that the behavior observed seems independent of the abundance calibration used. When we use the PP04 calibration of O3N2, we obtain the same mass–metallicity sequences and the SF dwarf galaxies in the core of A1656 and A1367 still crowd the upper part of the MZR (we cannot do the same using P10 calibration because we do not have enough galaxies with measured [O ii] inside R200). As a consequence, the effect observed seems to be significant, despite the intrinsic errors of the N2 and O3N2 calibrations.

Second, in Section 3 we have verified that our sample galaxies do not show any systematic differences regarding excitation, as a function of their location in the cluster (in or out R200). Thus, the higher metallicities derived for galaxies at R < R200, with higher [N ii]/Hα, are not biased by excitation effects (see Berg et al. 2011, for a thorough discussion on this effect).

The third sanity check has been to test whether the position of the SF dwarfs at R < R200 on the MZR is the result of some bias in the mass estimate. We have found that galaxy stellar mass, versus other galaxy properties, such as broadband colors and excitation, does not show any correlated dependence on the cluster-centric distance of the galaxies. After all these tests, we assume that the shift observed toward higher metallicities, for galaxies at R < R200, mainly in Coma, should not be the result of some bias in the abundance and/or mass estimates.

In order to explore further the trends that appear in Figure 7, we have performed a bisector linear fit to the MZR of each cluster, considering first the galaxies at R < R200, second the galaxies at R > R200, and third all the galaxies together. In Table 4, we present the obtained slopes and the corresponding errors from the dispersion around the linear fit. We observe that the MZR fits for galaxies at R > R200 have slopes ~0.3 for all the clusters of our sample. Lee et al. (2006) have derived the MZR for 25 nearby dwarf irregular (dI) galaxies (10^8 M⊙ < M* < 10^9 M⊙), extending the well-known SDSS MZR (Tremonti et al. 2004) to the lower mass range. Lee et al. (2006) have found a very tight correlation, over the whole

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**Table 4**

| Cluster | R ≤ R200 | R > R200 | All |
|---------|----------|----------|-----|
| A1656   | 0.19 ± 0.03 | 0.33 ± 0.03 | 0.30 ± 0.02 |
| A1367   | 0.28 ± 0.03 | 0.36 ± 0.02 | 0.32 ± 0.02 |
| A779    | 0.30 ± 0.11 | 0.28 ± 0.05 | 0.29 ± 0.04 |
| A634    | 0.37 ± 0.15 | 0.29 ± 0.07 | 0.32 ± 0.05 |

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8 We here adopt the value 12 + log(O/H)_⊙ = 8.69 for the solar oxygen abundance (Asplund et al. 2009).

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**Figure 6.** Number of ionized photons Q(H), as measured by the Hα flux of the SF region covered by the SDSS fiber, for our sample of SF dwarf galaxies in Coma (triangles) and A1367 (diamonds), vs. the EW(Hα), color coded to the derived galaxy metallicity. Lines represent the Starbursts99 models (Leitherer et al. 1999) for instantaneous bursts of total mass in massive stars M* = 10^7 M⊙ (continuous) and M* = 10^8 M⊙ (dashed) and metallicities Z = 0.02 (in red), Z = 0.008 (green), and Z = 0.004 (black). (A color version of this figure is available in the online journal.)

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5. THE MASS–METALLICITY RELATION

In Figure 7 we plot the galaxy metallicity, as measured by 12+log(O/H), versus galaxy stellar mass, for the SF dwarf galaxies in Coma (A1656, triangles), A1367 (stars), A779 (squares), and A634 (circles). Filled symbols correspond to galaxies at a distance R < R200 from the cluster center. We see that the SF dwarf galaxies follow well-defined sequences on these plots. Having a look at the MZR of A1656 and A1367, we observe that at low galaxy masses (10^8 M⊙ < M* < 10^9 M⊙), the derived metallicities cover a range of ~0.4 dex, while at higher masses (10^9 M⊙ < M* < 10^10 M⊙) the relation becomes tighter, appearing to shape a triangle instead of a simple linear correlation. Additionally, we observe that, for the same bin of mass, galaxies at R < R200 are preferentially located at the upper part of the global sequences. For the two clusters (A779, A634) of lower mass, we do not verify either of these two features, as we discuss in the following.

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stellar mass range, with slope $\sim 0.3$; thus, the slopes derived here are in very good agreement with their results. As we discuss further in Section 7, this value of the slope is supported by the semi-analytic models and hydrodynamic simulations of Finlator & Davé (2008) and Davé et al. (2011), where momentum-driven wind scalings are introduced to explain the MZR.

For Coma, and to a less extent for A1367, a flattening of the MZR is observed when considering galaxies inside $R_{200}$, with the fits showing clearly smaller slopes, within the quoted errors (see Table 4). This is made evident in Figure 7, where we plot with a continuous line the linear fit for galaxies at $R \leq R_{200}$ and with dashed line the fit corresponding to galaxies at $R > R_{200}$. For A779 and A634, considering the large errors (due to the reduced number of SF dwarf galaxies in these clusters), we do not appreciate any difference in the slope inside and outside the cluster core. In Figure 7, we plot the overall fit to the MZR for A779 and A634.

In Figure 8, we plot the N/O ratio versus galaxy stellar mass, and again we find a good correlation, even tighter than the MZR, for all our clusters. Again, filled symbols correspond to galaxies to a distance $R \leq R_{200}$ from the cluster center. As before, galaxies in the cluster core of Coma and A1367 tend to crowd the upper part of the global sequence. Oxygen, produced in Type II SNe, is typically released after $\sim 10$ Myr, while the bulk of nitrogen is produced and released over a substantially longer period, $\gtrsim 250$ Myr. This is an important piece of information to take into account when one attempts to identify the mechanisms relevant for the chemical evolution of cluster galaxies. As we will discuss further in Section 7, this chemical “clock” seems to imply that if there is an environmental effect driving the observed difference in the abundance ratio, this should be acting since at least $10^8$ yr ago.

Observing the triangular shape of the MZR of A1656 and A1367 in Figure 7, we investigate whether there could be a physical cause for the galaxies showing lower metallicity for the same bin of mass. The MZR has been found to show a second parameter dependence on SFR (Ellison et al. 2008; Amorín et al. 2010; Mannucci et al. 2010; Lara-López et al. 2010; Cresci et al. 2011; Yates et al. 2011). This can easily be understood by the correlated behavior of gas-phase metallicity and SFR after a gas infall event: when a galaxy accretes metal-poor gas, its metallicity is diluted to values typical of lower mass galaxies, while its final mass increases, and consequently the galaxy moves below the MZR. In the same time, the presence of a large amount of gas stimulates star formation, and this is the reason why galaxies with higher SFR have lower metallicities at

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9 We note here that the class 2 population referred to in Section 2 spans the higher mass range, where we have seen that the MZR becomes tighter, and had it been included, would not have significantly changed the derived slopes.
a given stellar mass. This should be a transient phase, and when the galaxy consumes the gas, producing the new metals, it will return to the mean MZR (Davé et al. 2011; Dalcanton 2007).

Mannucci et al. (2010) claimed that the MZR is the projection of the two-dimensional (2D) space of a more fundamental 3D relation between stellar mass, gas metallicity, and SFR and proposed the quantity $\mu = \log M_\star - 0.32 \log (\text{SFR})$, which defines a projection of the MZR that minimizes the scatter of local galaxies. We have used the median estimate of the total SFR provided by DR8 (Brinchmann et al. 2004) to explore whether the quantity $\mu$ could decrease the scatter observed in Figure 7. The SDSS SFR estimates have been derived by combining emission-line measurements of the fiber spectrum and applying aperture corrections by fitting models to the photometry outside the fiber (as in Gallazzi et al. 2005; Salim et al. 2007). In Figure 9 we plot the oxygen abundance $^{12}\log (\text{O}/\text{H})$ versus $\mu$ for the SF dwarfs in A1656 and A1367, and we see that the scatter drops for the galaxies at lower metallicities for the same bin of mass (the Spearman’s correlation coefficient increases from 0.73 in Figure 7 to 0.77 in Figure 9 for A1656, and from 0.80 to 0.83 for A1367). However, the separation we observe in the MZR between galaxies inside and outside $R_{200}$ is kept equally.

Moreover, in this metal dilution scenario, the N/O ratio should not be affected (e.g., the “green pea” galaxies show normal N/O ratios for their mass; Amorín et al. 2010), and the relation between N/O versus stellar mass should not show correlated scatter. However, as Figure 8 shows, the N/O ratio segregates galaxies inside $R_{200}$, with these galaxies also showing higher N/O ratios for the same bin of mass. The effect of infalling gas is expected to be more relevant for galaxies at high redshift (e.g., Cresci et al. 2010; Tacconi et al. 2010; Dekel et al. 2009); thus, the fundamental metallicity relation introduced by Mannucci et al. (2010) considerably accounts for the evolution of the MZR with redshift (Erb et al. 2006; Maiolino et al. 2008; Mannucci et al. 2009). But in the local universe, where our sample of clusters is located, different mechanisms should be invoked to explain the trends observed.

The question arises now as to whether the galaxies inside $R_{200}$ have evolved in a different way than the other cluster galaxies, rendering them chemically more enriched than the galaxies at $R > R_{200}$, or alternatively whether less metallic galaxies, for the same bin of mass, are more vulnerable to the quenching effect of the cluster environment, and this could be the reason we do not observe them preferentially in the cluster core. To investigate the second idea, we searched whether there is any observable trend with the distance from the cluster center of the morphological type of our sample of SF galaxies.

We have calculated the standard concentration index $C = R_{90}/R_{50}$, where $R_{90}$ and $R_{50}$ are the radii enclosing 90% and 50% of the Petrosian r-band luminosity of the galaxy. We have found that our sample galaxies show typical
Figure 9. Oxygen abundance 12+log(O/H) vs. the quantity \( \mu = \log M_\star - 0.32 \log(SFR) \) for SF dwarf galaxies in Coma (A1656, triangles) and A1367 (stars). Filled symbols correspond to galaxies at \( R \leq R_{200} \). The continuous line is the linear fit for galaxies at \( R \leq R_{200} \) and the dashed line the fit for galaxies at \( R > R_{200} \). (A color version of this figure is available in the online journal.)

Figure 10. Upper panel: the difference of the derived oxygen abundance 12+log(O/H), for each galaxy, with the oxygen abundance given by the bisector linear fit 12+log(O/H)_{fit}, as a function of the cluster-centric radial distance \( R/R_{200,i} \). Lower panel: the same for log(N/O). The blue points correspond to A1565 and the red points to A1367. (A color version of this figure is available in the online journal.)

C values as related to late-type galaxies (~2.3–2.5; see, e.g., Shimasaku et al. 2001; Strateva et al. 2001), and we see no trend of the C value in and outside of \( R_{200} \). We have additionally checked that galaxies in the same bin of mass do not show any concentration–metallicity correlation. A more detailed morphological study could be of interest here; Penny & Conselice (2011) found remarkably smooth structures of dwarf galaxies in the Perseus cluster and suggest that dwarfs in cluster cores should be highly dark matter dominated to prevent their tidal disruption by the cluster potential. In the present study we cannot verify the hypothesis that SF galaxies inside \( R_{200} \) are more concentrated/compact and consequently more resistant to the hostile cluster environment. Thus, morphology does not seem to explain their relative position in the upper part of the MZR; this should be the result of some different evolution.

To investigate whether the scatter observed in the MZR could be related to differences in the underlying stellar population, we have obtained for all our cluster galaxies the spectral index \( D_n(4000) \) (Balogh et al. 1999), after correction for emission lines, as given by SDSS DR8. All our SF dwarfs show \( D_n(4000) < 1.4 \), which corresponds to typical ages <1 Gyr. Additionally, we have seen that the gas-phase metallicity does not show any correlated behavior with the age of the underlying population. In Section 3, we have shown that SF dwarfs at \( R \leq R_{200} \) in Coma do not show any observable difference in the g − i color distribution as compared to the galaxies at \( R > R_{200} \). Thus, the more metallic SF dwarf galaxies found in the cluster core, especially of Coma, are neither older nor redder than the rest of SF galaxies.

To quantify the effect observed in the MZR for Coma and A1367, in the upper panel of Figure 10 we plot the mean difference of the derived 12+log(O/H) abundance for each galaxy with respect to the 12+log(O/H)_{fit}, as a function of the cluster-centric radial distance sampled in a bin of 0.5\( R_{200} \). In the lower panel we plot the same for log(N/O). We observe that in Coma, the mean difference in 12+log(O/H), in the closest bin to the cluster core, is positive and above the rms error (i.e., positive for all objects) and can reach above \( \sim 0.15 \) dex. The same is found for the log(N/O) ratio, which can get up to \( \sim 0.27 \) dex difference in the cluster core. In A1367 smaller differences are obtained of \( \sim 0.05 \) dex in log(O/H) and \( \sim 0.1 \) dex in log(N/O). This divergence, combined with the fact that for the low-mass clusters of our sample this trend has not been revealed at all, seems to indicate that the cluster mass is a most relevant parameter. As will be discussed in Section 7, what seems to drive the disparate evolution of SF dwarf galaxies in Coma appears to be related to the properties of the forceful ICM of this cluster.
We explore the dependence of the trend observed for our cluster galaxies as a function of the local galaxy density, using the density estimator $\Sigma_{4.5}$. In the left panel of Figure 11 we plot the mean difference of the derived $12+\log(O/H)$ for each galaxy with respect to the $12+\log(O/H)$ given by the bisector linear fit, as a function of $\Sigma_{4.5}$, in a bin of 0.5 dex. The errors correspond to the standard deviation from the mean value of $\log(O/H) - \log(O/H)_{\text{bin}}$. In the right panel we plot the same difference for the $\log(N/O)$ ratio. In the highest local density bin we find a mean difference in $\log(O/H)$ of $\sim 0.05$ dex for both Coma and A1367, in agreement with the previous findings (e.g., Ellison et al. 2009). $\log(N/O)$ presents a measured difference of $\sim 0.15$ dex for both clusters.

We note here that estimating the local galaxy density for clusters with large velocity dispersions as in Coma ($\sigma_V \sim 1000$ km s$^{-1}$) and A1367 bears significant hazards. Allowing neighbors to have velocity differences of the order of $\sigma_V$ could result in counting out galaxies in the cluster core and thus underestimating density. Conversely, allowing velocity differences of $2\sigma_V$ or $3\sigma_V$ could introduce a severe bias to relatively isolated objects, overestimating their density. In Figure 11, we use $\Sigma_{4.5}$ derived permitting neighbors to have velocity differences of 2000 km s$^{-1}$, but we have checked that the behavior does not change using velocity differences of $\sigma_V$, $2\sigma_V$, and $3\sigma_V$.

Previous works have pointed out the effect of the environment on the gas-phase metallicity of galaxies (Mouchine et al. 2007; Cooper et al. 2008; Ellison et al. 2009) and have found that galaxies within dense environments show statistically higher metallicities of $\sim 0.05$ dex at the same bin of galaxy mass. These works, however, have related this behavior to local galaxy density. In particular, Ellison et al. (2009) have discussed the importance of cluster membership, and although they have found that enhanced metallicities are present at distances $R < R_{200}$ from the cluster center, they have concluded that the enhancement observed is driven by local overdensity and does not depend on cluster properties such as $R_{200}$, $\sigma_V$, or cluster mass.

Figure 11. Same as in Figure 10, as a function of the local galaxy density $\Sigma_{4.5}$ in a bin of 0.5 dex. (A color version of this figure is available in the online journal.)

There is a general good relation between the cluster-centric distance and the local galaxy density, within the cluster virial radius (e.g., Rines et al. 2005), so the metallicity enhancement of the cluster core galaxies is expected to appear as a function of the local galaxy density as well. However, in the present work we find that the enhancement of the gas-phase metallicity is sensitive to the cluster mass and appears to be more prominent if we consider the $R_{200}$ region of a massive cluster such as Coma. This evidence points toward a possible connection of the chemical enrichment of cluster galaxies with their ICM properties.

6. CHEMICAL ENRICHMENT VERSUS H$\text{I}$ MASS

In clusters, the gas interchange of a galaxy with its environment is expected to be very relevant. Observable gas tails give evidence of ongoing gas stripping, and a significant fraction of spirals have been found to have truncated ionized gas disks compared to their stellar disks (see Section 1). Recently, Jaffé et al. (2011), based on a large sample of emission-line galaxies from the EDisCS sample at intermediate redshifts (0.4 < $z$ < 1), found that the fraction of kinematically disturbed galaxies increases with cluster velocity dispersion and decreases with distance from the cluster center but remains constant with projected galaxy density. In addition, disturbed gas kinematics does not co-occur with morphological distortions as traced by optical (Hubble Space Telescope) imaging, suggesting that the mechanism that affects most the gas of cluster galaxies has to be linked with the ICM.

The atomic gas is expected to be the first to suffer the RPS in the cluster environment. Indeed, cluster spiral galaxies are more H$\text{I}$ deficient than similar galaxies in the field, and this deficiency appears to be increasing toward the cluster center (Haynes et al. 1984). Additionally, because of the shallower gravitational potentials, dwarfs can be extremely fragile to RPS (Solanes et al. 2001). In the Virgo Cluster core, Chung et al. (2009) found many H$\text{I}$-deficient galaxies, and at intermediate distances, at $\sim 1$ Mpc from the center, they found a remarkable number of galaxies with long, one-sided H$\text{I}$ tails pointing away from M87. Truncated H$\text{I}$ disks were found even in the Pegasus I Cluster (Levy et al. 2007), a cluster with a low level of X-ray emission.

An interesting method to check for modulations of the H$\text{I}$ content of SF galaxies is through comparing the galaxy chemical enrichment with the theoretical values predicted by the “closed-box” model (Edmonds 1990). According to this model, the mass fraction of metals should be a direct function of the gas mass fraction:

$$\mu = \frac{M_{\text{gas}}}{M_{\text{gas}} + M_*}.$$

Here, the gas mass is considered to be the mass of H$\text{I}$ ($M_{\text{H1}}$) with a correction for neutral helium $M_{\text{gas}} = 1.32 M_{\text{H1}}$. We neglect
We have derived the small and difficult to evaluate. According to Israel (1997), for the contribution due to molecular hydrogen, as this seems to be small and difficult to evaluate. According to Israel (1997), for the contribution due to molecular hydrogen, as this seems to be small and difficult to evaluate. According to Israel (1997), for the contribution due to molecular hydrogen, as this seems to be small and difficult to evaluate. However, the CO-to-H$_2$ conversion relation is not well known for low-metallicity systems and the H$_2$ fraction might be even higher (e.g., Keres et al. 2003). Comparing with chemical evolution models is actually possible only when information on the H$_1$ mass of a galaxy is available. Two of our sample clusters have recently published H$_1$ data. Cortese et al. (2008b) have presented 21 cm H$_1$ line observations of the central part of A1367, as part of the Arecibo Galaxy Environment Survey (AGES). This sample covers $\sim$20% of the total region covered by our sample and $\sim$70% of the region with $R \leq R_{200}$, and their H$_1$ mass limit, at A1367 distance, is $6 \times 10^8 M_\odot$. They have detected 57 galaxies that belong to the A1367 Cluster, out of which 17 also belong to our sample of SF dwarf galaxies. Haynes et al. (2011) have recently released a catalog with 21 cm H$_1$ line sources, covering $\sim$40% of the final ALFALFA survey area. This release includes $\sim$50% of the area of A1656 covered by the present work and also $\sim$50% of the area with $R \leq R_{200}$, and their low H$_1$ mass limit at the Coma Cluster distance is $\sim 4 \times 10^8 M_\odot \,(M_{H_1} > 10^7 M_\odot$ at the Virgo Cluster distance; Giovanelli et al. 2005). We have found 31 objects in common with our sample of SF dwarf galaxies.\footnote{Arecibo Legacy Fast Arecibo L-band Feed Array (ALFALFA).}

In Figure 12 (left), we plot the oxygen abundance versus the gas mass fraction (in the form log ln (1/$\mu$)) for A1656 (triangles) and A1367 (stars) and A1656 (triangles) and A1367 (stars) for the galaxies for which we have H$_1$ data (filled symbols mean $R \leq R_{200}$). In Figure 12 (right), we plot the gas mass fraction $\mu$ versus the stellar mass. We add (with smaller points) all the SF dwarf galaxies of our sample that do not have H$_1$ measurements, but they are located within the regions mapped by AGES and ALFALFA (up to the present release). We assign to these galaxies the H$_1$ mass detection limit of each survey, this being an upper limit of the H$_1$ mass of these galaxies (the arrows indicate the direction to which these upper limits could be displaced). Again, open and filled small symbols mean outside and inside the cluster $R_{200}$, respectively.

Figure 12. Left: the oxygen abundance vs. the gas mass fraction for A1656 (triangles) and A1367 (stars, filled symbols mean $R \leq R_{200}$), for the galaxies within the covered regions by AGES and ALFALFA. The green continuous line indicates the theoretical yield $y_o = 0.0074$, and the blue dashed line corresponds to a lower yield $y_o = 0.002$. Right: the gas mass fraction $\mu$ vs. the stellar mass. Small points in both plots represent H$_1$ mass upper limits for the galaxies included in the surveyed regions but not having H$_1$ measurements. The arrows indicate the direction to which these upper limits could be displaced.

(A color version of this figure is available in the online journal.)
Section 4). These galaxies in the core of A1367 could be “newcomers” (see also Petropoulou et al. 2011), observed before the action of RPS lowers significantly their atomic gas content, shifting them toward lower effective yield values.

We also observe a tendency to lower effective yields as metallicity increases, suggesting that these galaxies host lower H\textsubscript{i} mass than expected by the closed-box model (a similar behavior was found for A2151 SF galaxies; see Petropoulou et al. 2011, Figure 14). The atomic gas deficiency is confirmed when we compare the H\textsubscript{i} content of our sample galaxies (measurements or upper limits) with the M\textsubscript{H\textsubscript{i}} of field counterparts of the same absolute magnitude, as calculated following Toribio et al. (2011). Two representative examples are the dwarf galaxies CGCG 97-073 and CGCG 97-079 (marked on the plot) that have been investigated before (Iglesias-Páramo et al. 2002; Gavazzi et al. 2001), showing long (H\alpha) tails that reveal their recent interaction with the ICM. The H\textsubscript{i} content of CGCG 97-079 appears to be severely affected: this galaxy has the lower H\textsubscript{i} mass detected and lays below y = 0.002 in the left panel of Figure 12. CGCG 97-073 in turn does not appear to have lost a large amount of H\textsubscript{i} yet.

We conclude that, to the distance of Coma and A1367, given the detection limit of the H\textsubscript{i} data, we observe the atomic gas of galaxies that still contain a substantial fraction of their H\textsubscript{i} mass. The almost absolute lack of detections in the central part of A1656 indicates that galaxies there have been severely affected by the cluster environment, and the RPS has partly or completely removed their atomic gas content, rendering them undetectable in 21 cm H\textsubscript{i} line. In turn, in the central part of A1367 there are some SF dwarf galaxies still with detectable H\textsubscript{i} mass (i.e., possible “newcomers”).

7. DISCUSSION

It is well established that dense environments, such as cluster cores, present larger fractions of passive galaxies than the field (e.g., Dressler 1980; Poggianti et al. 1999, 2006; Treu et al. 2003; Finn et al. 2005). This confirms the important influence of the environment on galaxy evolution. Although the big debate on nature versus nurture remains open, accumulated evidence seems to indicate that, in the particular case of dwarf galaxies, environment is a fundamental driver of their evolution (Mahajan et al. 2010; Haines et al. 2006, 2007). It has been found (Smith et al. 2011; Porter et al. 2008) that significant infall of low-mass SF galaxies exists along the filamentary structures onto the densest clusters. Reaching cluster cores, dwarf galaxies can experience a starburst event, induced by their first interaction with the ICM (Gavazzi et al. 2001; Sun et al. 2007; Levy et al. 2007; Petropoulou et al. 2011). Then, RPS is expected to be very efficient (e.g., Tonnesen et al. 2007) and could strip the gas of a dwarf galaxy in very short timescales (∼10⁸ yr), converting a large fraction of dwarf galaxies, first into post-starburst as those observed in Coma (Mahajan et al. 2011; Poggianti et al. 2004), and finally into passive galaxies.

Despite the fateful “switching off” of star formation predicted by the models of RPS, we have found quite a number of SF dwarf galaxies in our clusters. The selection of our galaxy sample to have strong emission lines means that they do still contain ionized gas. However, as we show in Section 6, a large fraction of these galaxies do not contain the amount of H\textsubscript{i} mass expected by the closed-box model, indicating that they should be suffering RPS, which has first affected their neutral gas content. Tecce et al. (2010) simulations seem to indicate that at z ∼ 0, 50% of galaxies inside the virial radius (R\textsubscript{vir}) have experienced important ram-pressure effects. These pressures appear to have a strong effect on the cold gas content: 70% of the simulated galaxies within R\textsubscript{vir} have been found to be completely depleted of cold gas. Additionally, Tecce et al. (2010) models have suggested that the rate at which the cold gas of a galaxy is stripped depends on the halo virial mass of the host cluster; thus, less massive galaxies within massive clusters are the most affected.

In order to investigate the chemical evolution of the SF dwarf galaxies in the present sample of clusters, we have derived their MZR. The MZR of galaxies is well established (e.g., Tremonti et al. 2004; Lee et al. 2006). There exist a variety of chemical evolution models and hydrodynamical simulations advocating different physical mechanisms to explain this relation. For example, the ejection of metal-enriched gas by galactic outflows, triggered by, e.g., (multiple) supernova explosions, could be more efficient in systems with shallower potential wells (e.g., Larson 1974; Marconi et al. 1994; De Lucia et al. 2004). A variable efficiency of star formation, increasing with galactic mass (often named “downsizing”), could also be invoked to reproduce the MZR (e.g., Matteucci 1994; Tissera et al. 2005; de Rossi et al. 2007; Calura et al. 2009). For dwarf galaxies, where supernova winds are expected to be more important, a combination of downsizing and winds could affect the shape and slope of the MZR (Tassis et al. 2008; Spitoni et al. 2010). Other mechanisms, such as dilution caused by infall and variations in the IMF, have also been proposed; however, they show problems reconciling dwarf SFRs and metallicities (see the review by Tolstoy et al. 2009).

Recently it has been found that hydrodynamic simulations that incorporate momentum-driven wind scalings provide among the most successful overall fits to a wide range of observed galaxy properties (Finlator & Davé 2008; Oppenheimer et al. 2010; Davé et al. 2011). Finlator & Davé (2008) developed a simple analytic model to understand the MZR, where the gas-phase metallicity of a galaxy is set by a balance between infall and outflow, plus star formation. In this “equilibrium” model the mass outflow rate (\eta, i.e., the balance between infall and outflow) scales inversely with circular velocity, and this naturally reproduces a slope of the MZR Z \propto M_{⋆}^{1/3} at M_{⋆} < 10^{10.5} M_{\odot}. Lee et al. (2006) observationally obtained this slope of the MZR for a sample of nearby dIrr galaxies, with a remarkably small dispersion. This value of the slope is in agreement with the slope given by the linear fit of our sample galaxies, located either in the low-mass clusters A779 and A634 or at the outer regions of Coma and A1367.

Davé et al. (2011) discuss the effect of SFR and of environment on the MZR and find that the overall trends are consistent with the expectations from the “equilibrium” model. The scatter observed in the MZR for our sample galaxies does not correlate with SFR (Section 5); thus, it does not seem to be related to metal dilution suffered by the galaxies showing lower metallicities at the same bin of mass. Regarding environment, Davé et al. (2011) hydrodynamic simulations reproduce low-mass galaxies in dense environments showing higher metallicities for the same bin of mass than galaxies at lower densities. The authors suggest that this should not be the result of galaxies processing more gas into stars, but rather the consequence of the environmental dependence of wind recycling. Much of the material entering into the galaxies’ ISM at z = 0 is recycled winds (Oppenheimer et al. 2010), that is, the reaccretion of the wind material when the wind velocity does not exceed the galaxy escape velocity.
(see also Bekki et al. 2009). This mechanism accounts for the fact that metallicity differences seem to disappear for high-mass galaxies: at high galaxy mass, wind recycling is so effective that metallicity approaches the theoretical yield regardless of environment. Instead, at low masses, most ejected material could normally escape the galaxy (Oppenheimer et al. 2010), unless the galaxy resides in a dense environment, with a hot gaseous halo that could significantly slow winds.

In Section 5 we have seen that SF dwarf galaxies in the Coma Cluster core, and to a less extent in A1367, show higher metallicities for the same bin of mass than galaxies outside $R_{200}$. This results in the flattening of the MZR for dwarfs to distances $R < R_{200}$. The amount of this flattening appears to be related to cluster mass, with the less massive clusters of our sample not showing this behavior at all. This observed trend matches well the above wind recycling scenario. Models suggest that in high-density environments (i.e., in cluster cores) galactic winds can be suppressed by the high pressure of the ICM (Schindler et al. 2005; Kapferer et al. 2006, 2009). Accordingly, this could cause faster recycling and thus prevent galaxies from losing their metals. The suppression to take place needs ICM pressures $\gtrsim 10^{-12}$ dyn cm$^{-2}$ (Schindler & Diaferio 2008). Teyce et al. (2011) have found that on the outskirts of clusters as (or more) massive as Coma ($> 10^{15} M_{\odot}$) the ram pressure reaches $\sim 5 \times 10^{-12} h^2$ dyn cm$^{-2}$, the same order of magnitude as in the core of clusters of virial mass $\sim 10^{15} M_{\odot}$. In turn, the ram pressure in the core of massive clusters is expected to be $\sim 100$ times higher. Consequently, as we go to clusters of higher X-ray luminosity, higher would be the pressure exerted and the wind suppression is expected to be more effective. The wind suppression in the cluster cores could approximate the no-wind case depicted in Davé et al. (2011) hydrodynamic simulations, where the slope of the MZR is found to be flatter than when considering wind scalings.

The important role of the density of the ICM can be supported by Poggianti et al. (2009a, 2009b) findings. These authors have found that the fraction of post-starburst galaxies depends on cluster mass, and the fraction of spiral galaxies in clusters in the local universe is anticorrelated with $L_X$ (whereas no trend is observed with cluster velocity dispersion). Now it seems to turn up that it is not only to the quenching efficiency but also to the chemical evolution of low-mass cluster galaxies that the properties of the ICM could play an important role.

Another possibility that emerges from the “equilibrium” model scenario is that galaxies in denser regions could result, having higher metallicities as a consequence of curtailed inflow, due to gas stripping and/or strangulation. The relation $Z \propto M_{\ast}^{0.3}$ is the result of the balance between inflow and outflow processes. If gas accretion is truncated by some sort of environmental suppression, then the galaxy consumes its gas to form metals along the locus of $Z \propto M_{\ast}$ and will move above the mean MZR (Davé et al. 2011). If accretion does not restart, the galaxy will end up exhausting all the available gas for star formation and finally be transformed to a passive galaxy. Accordingly, our SF dwarf galaxies that lie above the MZR could be in this particular phase of environmental quenching, where enhanced metal enrichment precedes the switching off of star formation. As we show in Section 6, the majority of galaxies inside $R_{200}$ seem to have suffered important gas removal, especially in A1656.

The above picture could describe well what is happening to the galaxies in the Coma Cluster core, where SF dwarfs show on average $\sim 0.15$ dex higher metallicities than the overall MZR.

By reaching the outskirts of this massive cluster, the ISM–ICM interaction can produce starburst events that accelerate gas depletion in cluster dwarf galaxies, as compared to their isolated counterparts. In the same time, galactic winds should have started to get suppressed, preventing metal lost from the low-mass galaxies, which otherwise would have been expected to be very efficient. As RPS starts taking away the gas content (starting from the halo gas reservoir and the H$^i$ disk), the infall of pristine gas gets truncated, and the chemical enrichment follows a steeper path on the mass–metallicity plane. By the end of their star formation, the low-mass galaxies could have experienced a significant metallicity enhancement. Considering that this shutting-off in Coma could take $\sim 10^9$ yr (the crossing time of this cluster), there is enough time also for nitrogen to get delivered to the ISM, yielding the observed trend in the N/O ratio. In Figure 13 we give a schematic representation of this scenario.

Moreover, low-mass galaxies could reach clusters already chemically enhanced up to some degree. Recent works (Mahajan et al. 2010; Porter et al. 2008) have found an increased star formation in galaxies falling into clusters along supercluster-scale filaments. Additionally, simulations (e.g., Bekki 2009) suggest that even moderately strong ram pressure, such as in group-like environments, could strip the hot gas halos of galaxies, with efficiency increasing at the low-mass regimes. Consequently, low-mass galaxies could suffer gas exhaustion by both gas depletion through star formation and some stripping process such as strangulation, also in their ways toward clusters. Both mechanisms would lead to chemical enhancement (product of the increased star formation as compared to isolated dwarf galaxies in the first case, and of the lulled infall in the second). This scenario could explain the trends observed for the oxygen abundance and N/O ratio even in A1367 (a cluster of $M \sim 10^{14} M_{\odot}$), as well as the elevated metallicities observed for some galaxies at $R > R_{200}$ in both Coma and A1367.

Carter et al. (2002) have invoked pressure confinement by the intracluster medium (ICM) to explain the cluster-centric radial gradient of the stellar metallicity for a sample of passive
galaxies in Coma. Smith et al. (2009), however, have argued that the observed gradient should be interpreted as a trend in age rather than metallicity. Younger passively evolving dwarfs could have arisen by the transformation of infalling field late-type galaxies, indicating that the buildup of the passive population is an ongoing process in the outskirts of the cluster, related to environment-driven processes (regarding the infalling galaxy population in Coma; see also Aguerrí et al. 2004).

In a subsequent work, Smith et al. (2011) have found that the cluster-centric age gradient for the red-sequence dwarfs in Coma is a global trend and is not driven by the ongoing merger of the NGC 4839 group to the southwest of Coma. These authors have compared their results with the predictions from simulated cluster assembly histories (the Millennium Simulation; Springel et al. 2005) and have argued that in order to reproduce the strength of the age gradient observed for the red-sequence dwarfs in Coma, either a dominant burst or a gradual decline in the star formation rate has to be invoked; models with very abrupt quenching would lead to shallower age trends. These findings support the scenario proposed here: recent star formation, within a massive cluster like Coma, could yield the chemical enrichment of dwarf cluster galaxies.

Finally, a mechanism for the chemical enrichment of cluster galaxies to be considered could be the presence of enriched inflows. Historically it has been thought that there was a remarkable uniformity in the metal abundance of the ICM (\(\sim 0.5 Z_{\odot}\)) as a function of cluster mass, ranging from cooling-core to noncooling-core clusters (see Werner et al. 2008 for a review on the chemical enrichment in the ICM, and Schindler & Diaferio 2008 for a review on the processes proposed to explain this enrichment). However, recently, the spatially resolved analysis of the chemical composition of the ICM has revealed that this is not uniformly enriched in metals. ICM abundance gradients are common in clusters, showing a peak in the central region and a decline outward (e.g., De Grandi et al. 2004; Leccardi & Molendi 2008; Lovisari et al. 2011). The central metallicity of the ICM can reach even over solar values, associated with the presence of the brightest cluster galaxy (RPS could also play a role in the metallicity enhancement in cluster centers). The question arises as to whether infall of enriched material of the ICM could affect the metallicity of cluster galaxies. However, detailed modeling would be needed, regarding the cooling of the ICM and the accretion mechanisms, which is beyond the scope of the present work.

8. SUMMARY AND CONCLUSIONS

In this work we have studied the chemical history of low-mass SF galaxies in four clusters in the local universe. The sample clusters belong to a semi-spheric shell of the local universe (\(\delta \gtrsim -25\) deg and 0.02 \(< z < 0.03\)) and span a mass range from \(10^{13}\) to \(10^{15} M_{\odot}\). The regions studied cover the clusters’ core up to 3\(R_{200}\). We have been searching for the potential imprints of the cluster environment on the galaxy chemical enrichment.

We have used the latest SDSS spectroscopic release DR8. SF galaxies have been selected on the basis of their SDSS emission-line fluxes, and a limit in magnitude has been applied to select dwarf galaxies. Considering low-mass galaxies, aperture biases are not expected to be important. We note that DR8 spectroscopic data have been corrected for the underlying stellar continuum, this being an important improvement when studying nebular gas properties. We have found that our SF dwarf galaxies show typical line ratios of normal H\(\text{II}\) galaxies.

Gas-phase metallicities of the O/H and N/O ratio have been derived carefully using different empirical and model calibrations. The accurate mass estimates provided by SDSS DR8 have been used, to derive the MZR of the cluster galaxies. Well-defined sequences have been found in the MZ plane, and we have observed a decrease of the scatter when the correction for the SFR has been applied. The value derived for the slope of the MZR is in agreement with the predictions of hydrodynamic models, which use momentum-driven winds to reproduce the MZR. Well-defined sequences have also been derived in the N/O versus mass plane.

For the more massive clusters of this sample, Coma and A1367, the galaxies located at cluster-centric distances \(R < R_{200}\), are preferentially located at the upper part of the global sequences of O/H and N/O versus mass. This increase in metallicity is mass dependent, being higher at the lower mass bins, and in the core of Coma reaches on average \(\sim 0.15\) dex in O/H. This effect yields the flattening of the MZR for SF dwarf galaxies within the core of these massive clusters.

The metal enhancement of SF dwarfs in the cluster core has been found to be more important when considering the \(R_{200}\) region of the most massive cluster Coma (\(M \simeq 10^{15} M_{\odot}\)). Despite the general good relation of local galaxy density with cluster-centric distance, this effect appears diluted in terms of local galaxy density, suggesting that the relevant parameter able to affect the chemical evolution of SF dwarf galaxies should be the presence of a dense ICM.

Finally, we have related the metallicity of our SF dwarf galaxies with their H\(\text{I}\) mass content, derived using available 21 cm data. We then compared with the predictions of the so-called closed-box model and the normal H\(\text{I}\) content of isolated counterparts and found that SF dwarf galaxies in the cores of A1367 and Coma should be suffering an important RPS.

We discuss that the properties of the ICM could be a key parameter to the chemical evolution of low-mass cluster galaxies. Efficient gas stripping (ram pressure or/and strangulation) and effective metal retention, due to the suppression of galactic winds, could lead to a different chemical enrichment scenario for cluster galaxies.

The present sample consists of four clusters, and although the trends observed could be insightful, meaningful conclusions could be taken out only by improving statistics considerably. In a future work we will investigate further the connection of the chemical enrichment of cluster galaxies with the properties of the ICM, for a larger set of clusters, sampling a wide range of X-ray luminosities.

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