The Dwarf Galaxy-Environment Connection

Dwarf Galaxies: From the Deep Universe to the Present
Proceedings IAU Symposium No. 344, 2019
K. B. W. McQuinn & S. Stierwalt, eds.

doi:10.1017/S1743921318007159

Evolution of star-forming dwarf galaxies in different environments

Marco Grossi

Observatório do Valongo, Universidade Federal do Rio de Janeiro, Ladeira Pedro Antônio 43,
Rio de Janeiro 20080-090, Brazil
email: grossi@astro.ufrj.br

Abstract. The ubiquity of star-forming dwarf galaxies (SFDG) in the local Universe allows us to trace their evolution in all type of environments, from voids to rich clusters. SFDGs in low-density regions are still assembling their mass, they often show peculiar gas morphology and kinematics, likely associated to external gas accretion or galaxy interactions, and they can experience strong bursts of star formation. The most metal-poor SFDGs are found in the field and they are unique laboratories to investigate the star formation process in the low-metallicity regime, at conditions similar to their high-redshift analogues. On the other hand, SFDGs in intermediate- and high-density environments provide a key to understand the processes that remove their interstellar medium (ISM) and suppress star formation, leading to the different types of gas-poor early-type dwarfs. We review the most recent results on the properties of SFDGs at low and high galaxy densities focusing in particular on the impact of a cluster environment on their ISM components (dust, molecular, atomic and ionised gas). We analyse the population of SFDGs in the nearest rich clusters: Virgo, which is still in the process of assembly, and Fornax, which is more dynamically evolved, more compact and denser. We discuss how the different evolutionary stage of the two structures affects the properties of SFDGs.

Keywords. galaxies: dwarf, galaxies: evolution, galaxies: ISM, galaxies: interactions

1. Introduction

More than 70% of all galaxies in the Local Volume are star-forming dwarf galaxies (SFDGs; Karachentsev *et al.* 2004), i.e. low-mass systems rich in atomic gas (HI) and a low metal and dust content. The properties of their interstellar medium (ISM) resemble those of the fundamental building block of galaxies, thus they can be considered *"the initial state of all dwarf galaxies"* (Bergvall 2011). Because they are ubiquitous in the Local Universe they can be studied in different environments, from voids to rich clusters. At low galaxy densities they allow us to study the process of mass assembly unaffected by the interplay with massive galaxies occurring in clusters and groups. At high galaxy densities they can provide a key to understand how different types of dwarf galaxies can emerge due to the interaction with their surroundings.

The Λ cold dark matter (ΛCDM) model (Weinberg *et al.* 2004) predicts that galaxies can grow in two ways: they assemble hierarchically through mergers of smaller dark matter halos, or they accrete gas from the cosmic web. Low-mass systems constitute the dominant population at all redshifts and they play a crucial role in the hierarchical build-up of galaxies. According to simulations dwarf galaxies experience on average three major mergers in their lifetime (Fakhouri *et al.* 2010). Dwarf-dwarf mergers are predicted to be more common at earlier times (Klimentowski *et al.* 2010), however dwarf galaxies in isolated environments are expected to be twice more likely to experience a recent merger at $z < 1$ compared to satellites of a massive host (Deason *et al.* 2014). Therefore, assessing the role of mergers and interactions between dwarfs is extremely important to understand their impact on the evolution of these systems. While massive galaxy mergers have been studied in great detail, dwarf-dwarf interactions have yet to be thoroughly explored, also because such systems are more difficult to be observed.

Diffuse gas accretion is another important process affecting the process of mass assembly in galaxies (Kereš *et al.* 2005). Models of galaxy formation predict that gas accretion from the cosmic web is a primary driver of star formation over cosmic history (Dekel *et al.* 2013), and that at halo masses of $M_h = 10^9 - 10^{10}$ $M_\odot$ cold gas accretion is still expected to occur at $z = 0$ in low-density environments (Kereš *et al.* 2009). Low-mass galaxies should accrete most of their gas through cold flows reaching the central parts of the dark matter halo without being shock heated to the virial temperature (Dekel & Birnboim 2006).

Another issue is the role played by environment on galaxy evolution. Indeed one of the most fundamental correlations between the properties of galaxies in the local Universe is the so-called morphology-density relation (Dressler 1980, Dressler *et al.* 1997). Several studies have shown that early-type, quiescent galaxies are preferentially found in denser environments and such a correlation is observed out to z $\sim$ 1 (Kauffmann *et al.* 2004; Scoville *et al.* 2013; Darvish *et al.* 2016). Environmental effects on galaxy evolution are expected to be stronger in dwarfs. Because of their lower gravitational potentials and less dense ISM (Bolatto *et al.* 2008), SFDGs are more sensitive to their surroundings than more massive galaxies (Boselli & Gavazzim 2006). Ram-pressure stripping (Gunn & Gott 1972), starvation (Larson *et al.* 1980), tidal interactions (Brosch *et al.* 2004), and galaxy harassment (Moore *et al.* 1996) are among the suggested processes that can modify the morphology of a dwarf galaxy in clusters and quench the star formation process through the removal of their ISM, However, the transformation path from star-forming to passive dwarfs is still poorly understood, as well as the nature of the late-type progenitors of today dwarf ellipticals (dEs; Lisker *et al.* 2007, 2013; Mistani *et al.* 2016).

Here we briefly review the most recent results on the properties of SFDGs focusing in particular on two types of environment, the very low density (such as voids) and the very high densities (i.e. the nearest rich clusters to us, Virgo and Fornax), and we discuss how studying SFDGs in the nearby Universe can help clarifying our understanding of galaxy evolution at the low-mass regime.

2. Low-density environments

2.1. *Very isolated star-forming dwarfs: evidence of gas accretion*

Cosmic voids are vast underdense regions with sizes of 20 - 50h^{-1} Mpc and approximately spherical shape (Einasto *et al.* 1980, El-Ad & Piran 1997, Tully *et al.* 2008). Largely unaffected by the processes modifying galaxies in clusters and groups, voids represent an extreme and pristine environment in which to study the accretion history and the process of mass assembly in galaxies.

The advent of the 2 degree field Galaxy Redshift Survey (2dFGRS; Colless *et al.* 2001) and of the Sloan Digital Sky Survey (SDSS; York *et al.* 2000) provided the first large samples of void galaxies that could be used to assess their statistical properties (Hoyle & Vogeley 2004; Pan *et al.* 2012). Observations showed that galaxies in underdense environments are fainter, bluer, and less massive than those in denser regions (Hoyle *et al.* 2005; Moorman *et al.* 2015), and that the centre of voids are mostly populated by dwarf systems (Hoyle *et al.* 2012).

At magnitudes brighter than $M_{B,r} \sim -16$, probed in most of the surveys of rather distant voids extracted from the SDSS (D $\sim$ 100-200 Mpc), there is not a clear difference between SFDGs in very isolated environments or in denser regions in terms of specific

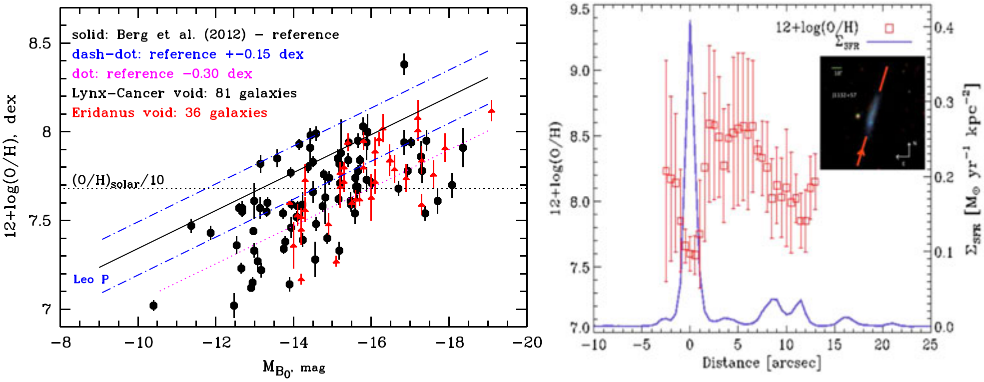

Figure 1. Left: Luminosity-metallicity relation for galaxies in the Eridanus (triangles) and Lynx-Cancer (filled-dots) voids. The solid line shows the linear regression obtained for the control sample of galaxies in the Local Volume (Berg *et al.* 2012). The dotted line (offset by −0.30 dex from the reference sample) indicates the region where the most metal-poor dwarfs are located. Adapted from Kniazev *et al.* (2018). Right: Variation of oxygen abundance (squares with error bars) and surface SFR (solid line) along the major axis of the XMP galaxy SDSS J1132+57. The metallicity drop coincides with the brightest knot and the peak of the surface SFR. The SDSS cut-out image of the galaxy is shown in the upper-right corner of the panel. Adapted from Sánchez-Almeida *et al.* 2015.

star formation rates (sSFR) and gas fractions (Kreckel *et al.* 2011a, 2012; Moorman *et al.* 2016). On the other hand, studies of the nearest voids such as the Lynx-Cancer or Eridanus, allowed to inspect the faintest isolated dwarfs ($M_r > -14$ mag, Pustilnik & Tepliakova 2011a; Kniazev *et al.* 2018), revealing a population of extremely gas-rich, very metal-poor objects ($Z < Z_{\odot}/20$), with low-surface brightness (LSB) optical counterparts (Pustilnik *et al.* 2011b, 2013). They show metallicities lower by at least 0.2 dex compared to galaxies of similar luminosity. The faintest objects have oxygen abundances 2 to 4 times lower than the galaxies in the Local Volume (Fig 1, left panel; Pustilnik *et al.* 2016; Kniazev *et al.* 2018). This suggests that low-luminosity SFDGs in voids evolve slower, likely due to the much reduced rate of galaxy interactions, and that the main star formation episode occurred rather recently (between one and a few Gyrs ago; Pustilnik *et al.* 2013).

Recent surveys have found several unusual objects in voids. VGS12 is an isolated low-mass system showing a HI polar disc with no optical counterpart; the absence of a companion makes it unlikely that the substantial neutral hydrogen content ($M_{HI} = 3 \times 10^9$ $M_{\odot}$, $f_{gas} \sim 0.8$) is the result of a close encounter (Stanonik *et al.* 2009). KK246 is another very isolated dwarf galaxy in the Tully void; the extended HI disc shows anomalous kinematics associated to a gas cloud whose velocity is inconsistent with the disc rotation (Kreckel *et al.* 2011a). These works suggest that the presence of extended and disturbed HI morphologies around these objects may arise from material flow inside the voids and that SFDGs in underdense environments are still assembling their mass through gas accretion from the intergalactic medium (IGM).

Another evidence of ongoing intergalactic gas accretion in SFDGs is provided by metallicity measurements of their HII regions. Extremely metal-poor star-forming dwarfs (XMPs), with oxygen abundances 12 + log O/H $\lesssim$ 7.7 (< 0.1 $Z_{\odot}$), constitute a rare class of isolated galaxies in the nearby Universe (Sánchez-Almeida *et al.* 2016). They are considered to be the best local analogues of the population of dwarf galaxies at high redshifts. XMPs are predominantly low-mass systems, with large amounts of HI (M_{HI}/M_* ~ 20), and they do not follow the mass-metallicity relation (Sánchez-Almeida *et al.* 2016).

Usually they show an off-center star-forming region of lower metallicity compared to the rest of the disc (Fig. 1, right panel). The decrease of the metal abundance in these regions is found to be of the order of 0.3 dex or larger and it is associated to the peak of the surface star formation rate (SFR; Sánchez-Almeida *et al.* 2015). The metallicity drops may give evidence of pristine gas accretion from the IGM. The infall of metal-poor gas triggers star formation and mixes with the more metal-rich, pre-existing gas component (Sánchez-Almeida *et al.* 2016). If the gas accretion and the starburst occur in a time scale similar to or shorter than the mixing time scale, the mass of the star-forming clumps is expected to be dominated by the metal-poor gas component (van de Voort & Schaye 2012).

One of the most intriguing properties of XMPs is the existence of a lower metallicity threshold detected in their star-forming regions, usually of the order of 2% the solar metallicity. If the star formation activity is fed by the infall of gas from the IGM, the observed minimum metallicity could be related to the current abundance of the local intergalactic gas. Indeed simulations predict that the metal abundance of the IGM has been raising with time, enriched by galactic winds and outflows, and its current value is expected to be of the order of 1% of the solar value (van de Voort & Schaye 2012, Rahmati *et al.* 2016).

2.2. *Dwarf-dwarf interactions*

Mergers of massive gas-rich galaxies are associated with bursts of star formation and they play an important role in the growth and evolution of galaxies (Mihos & Hernquist 1994; Bournaud *et al.* 2011). However, the mechanisms that trigger the enhancement of the star-formation activity in low-mass systems are poorly understood. Mergers and interactions between dwarf galaxies have been proposed to explain the properties of starbursting blue compact dwarfs (BCDs; Noeske *et al.* 2001, Bekki 2008) and of actively star-forming dwarfs without no clear optical companion (Telles & Terlevich 1995). Several SFDGs show extended and filamentary HI structures, which may indicate a recent interaction or a merger event (Stil & Israel 2002; Lelli *et al.* 2014). High resolution 21-cm observations of IZw18, the prototypical BCD, unvealed large amounts of HI around the galaxy with a spectacular HI plume extending for over 13.5 kpc, probably originated in a tidal interaction between the main complex (IZw18A) and the lower-mass companion IZw18C (Lelli *et al.* 2017).

The first stellar stream discovered around a dwarf irregular galaxy – NGC 4449, one of the most intensely star-forming systems in the Local Volume – showed that satellite accretion occurs also in SFDGs (Martínez-Delgado *et al.* 2012). The stream is associated to the tidal disruption of a dwarf spheroidal – NGC 4449B, with a stellar mass of at least 1/50 of the primary galaxy – and the merger is probably responsible for the enhanced star formation activity of NGC 4449. Examples of mergers/interactions of dwarf galaxies are also being found in voids. The very metal-poor SFDG DDO 68 (Ekta *et al.* 2008) shows extended stellar features (a tail and an arc) that give evidence of a multiple merging event (Annibali *et al.* 2016), while a much fainter companion, DDO 68C at ∼42 kpc, is connected to the primary galaxy by a LSB HI bridge (Cannon *et al.* 2014).

Discoveries of dwarf galaxy pairs are increasing (Stierwalt *et al.* 2015, Paudel *et al.* 2018). The TiNy Titans (TNT) Survey (Stierwalt *et al.* 2015) provided a first systematic study of 104 dwarf galaxy pairs in different interaction stages and environments, selected from the SDSS. The survey, which includes pairs with masses between $7 < \log(M/M_\odot) < 9.7$, mass ratios of $M_{*,1}/M_{*,2} < 10$ and a projected separation smaller than 50 kpc, showed that interactions between low mass galaxies do affect the structure and star formation activity of SFDGs. The SFR increases in more compact isolated pairs, similarly

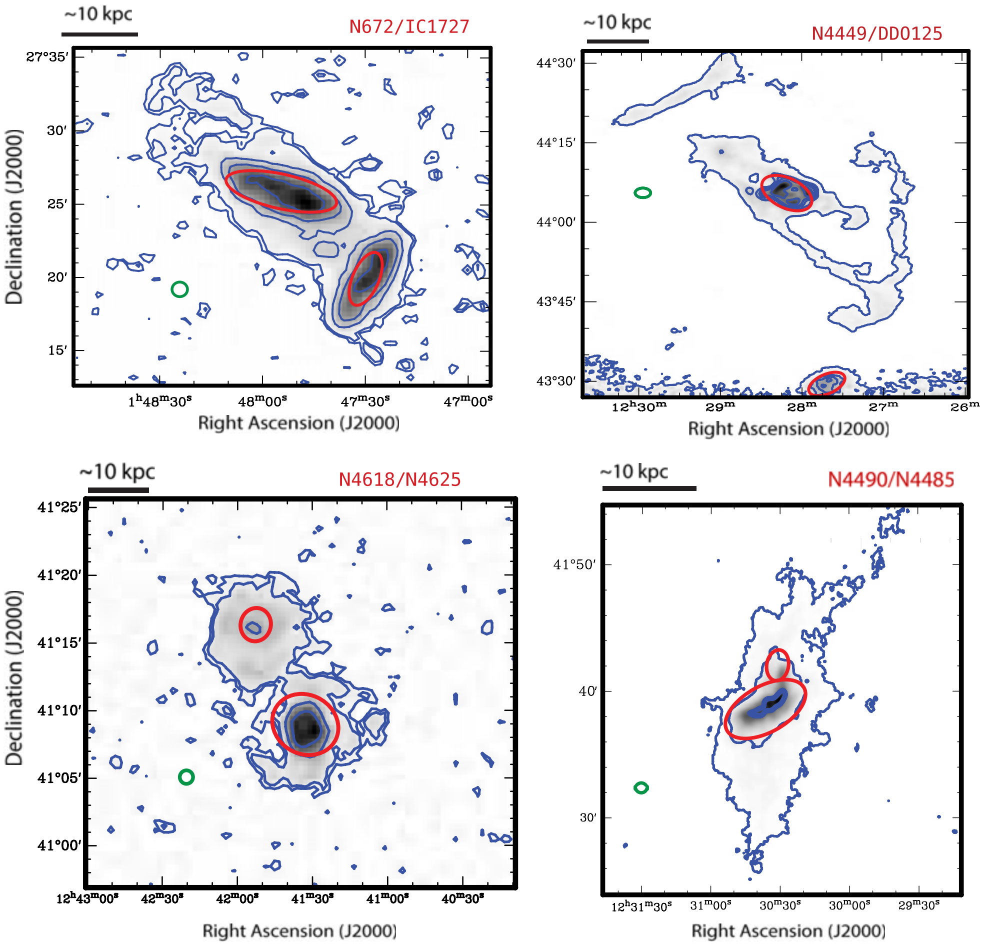

Figure 2. HI maps of a subset of dwarf galaxy pairs taken from the LV-TNT survey. The ellipses indicate the size of the stellar disc of each galaxy. Adapted from Pearson *et al.* (2016).

to what found in massive galaxies (Patton *et al.* 2013), confirming the role of close encounters in enhancing star formation activity in low-mass systems.

HI maps of dwarf galaxy pairs, (the Local Volume TiNy Titans survey, LV-TNT; Pearson *et al.* 2016) pointed out that large amounts of gas are present in their outskirts compared to non-paired analogues (more than 50 per cent of the total gas mass is beyond their stellar extents). This suggests that dwarf-dwarf interactions can move gas out to large distances from the pair (Fig. 2). However, simulations of the dwarf system NGC 4490 - NGC 4485, an isolated pair surrounded by a HI envelope of $\sim$ 50 kpc size (Pearson *et al.* 2018; Fig. 2, bottom-right panel), predict that the gas structure remains bound to the system after the interaction and it will be re-accreted in a few Gyrs, providing a long-lasting gas supply for future star formation episodes (Pearson *et al.* 2018). On the other hand, if the pairs are non-isolated, the interaction with the hot halo of the nearby massive galaxy will prevent gas from being re-accreted, as in the case of the Magellanic Clouds (Pearson *et al.* 2016).

Close encounters among gas-rich dwarf galaxies can have a considerable impact on the star formation history and dynamical state of these systems, however they are rare in the local Universe. According to Stierwalt *et al.* (2017), within the completeness limits of the

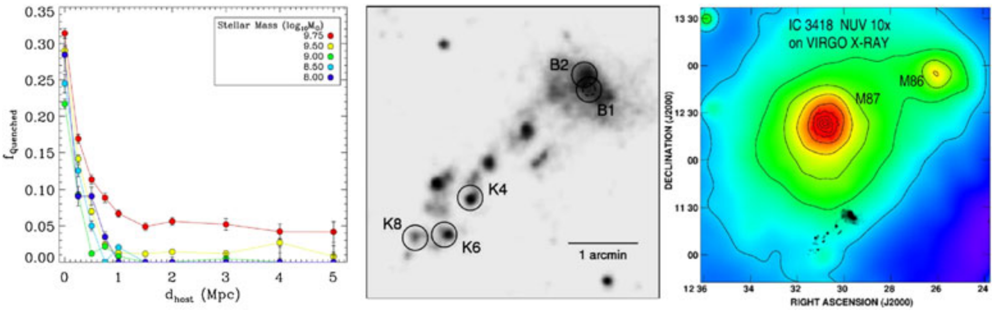

Figure 3. Left panel: Fraction of quenched dwarf galaxies as a function of distance to the nearest massive host in different stellar mass bins. Adapted from Geha *et al.* (2012). Central panel: GALEX image of the dwarf irregular galaxy IC 3418 showing the main stellar body and the star-forming regions in the extended tail. Adapted from Jáchym *et al.* (2013). Right panel: Location of IC 3418 with respect to M87, the massive elliptical at the core of the Virgo cluster. Contours represent X-ray emission measured by ROSAT. The size of IC 3418 is increased by a factor 10. Adapted from Kenney *et al.* (2014).

SDSS, only ∼4% of dwarf galaxies at $z < 0.015$ have close companions (i.e. a separation smaller than 50 kpc) with a stellar mass ratio of at least 1:10.

3. High density environments

Morphological segregation is the clearest evidence of the processes that determine the evolution of galaxies in high-density environments and it applies to both high- and low-mass systems. Early-type dwarfs (dEs and dwarf spheroidals, dSphs) represent the dominant population in clusters, but they are very rarely found in the field. According to Geha *et al.* (2012) the fraction of quenched dwarfs in low-density environments† (i.e. beyond 1.5 Mpc from a massive host) is less than 0.06%. On the other hand, they represent ∼ 30% of the dwarf galaxy population in dense environments, i.e. when they are found at a distance of 250 kpc or less from a massive host (Fig. 3, left panel).

It is well established that late-type galaxies in rich clusters tend to have a lower HI content than their more isolated counterparts and that there is an anti-correlation between HI deficiency and the distance to the cluster center (Giovanardi *et al.* 1983; Haynes & Giovanelli 1984; Chung *et al.* 2009; Deason *et al.* 2014). HI removal is the first step to quench the SF activity, and it usually corresponds to a truncation of the Hα emission in the outer regions of galaxy discs (Koopmann & Kenney 2004; Boselli & Gavazzim 2006).

It was long debated whether this also applies to the other components of the ISM such as molecular gas, which is generally more concentrated in the center of galaxies than HI (Kenney & Young 1986; Fumagalli *et al.* 2009) and dust (Popescu *et al.* 2002; Tuffs *et al.* 2002). Spiral galaxies in the Virgo cluster show that lower-density atomic gas is preferentially removed from the outskirts and that HI-deficient spirals have dust discs significantly less extended than gas-rich ones (Cortese *et al.* 2010, 2012; Corbelli *et al.* 2012). On the other hand, the molecular gas component appears to be removed less efficiently than HI in cluster galaxies (Boselli *et al.* 2014, Chung *et al.* 2017).

An example of the dramatic effects of a dense environment on the transformation of SFDGs is given by IC 3418, a HI- and H$_2$-deficient dwarf in the Virgo cluster (Jáchym *et al.* 2013). The galaxy is at ∼ 280 kpc in projection from the massive elliptical M87 at the core of the cluster, with less than 1% of the expected HI and H$_2$ mass. All the atomic gas has been stripped from its main body, and CO is only marginally detected in the

---

† The study analysed dwarf galaxies in the mass range $10^7 < M_* < 10^9$ M$_\odot$

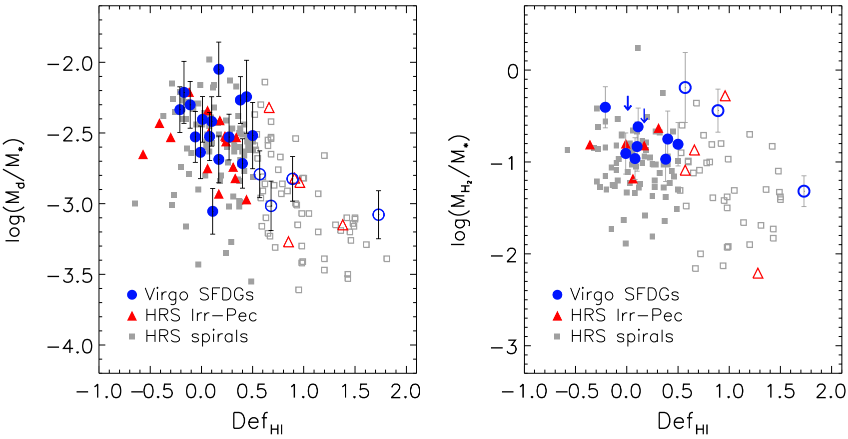

Figure 4. Environmental effects on the different components of the interstellar medium of Virgo SFDGs (dots) compared to the Herschel Reference Survey spiral (squares) and irregular-peculiar (triangles) galaxies. HI-deficient galaxies are indicated with empty symbols, and arrows indicate Virgo dwarf upper limits. Left: Ratio of dust-to-stellar mass against HI deficiency. Right: Ratio of H_2-to-stellar mass against HI deficiency. Adapted from Grossi *et al.* (2016).

center. The star formation is quenched in the disc of this galaxy, but it shows a tail of star-forming regions originated from ram-pressure stripped gas (Fig. 3, central and right panels; Jáchym *et al.* 2013; Kenney *et al.* 2014).

We recently studied a population of SFDGs in Virgo and addressed their dust, atomic, and molecular gas properties (Grossi *et al.* 2015, Grossi *et al.* 2016). We found that the interaction with a cluster environment is removing their atomic gas and dust components, as suggested by the decrease of the dust -to-stellar mass ratio with increasing HI deficiency (Fig. 4, left panel). Regardings the molecular gas component, because of the small number statistics of CO detections at high HI-deficiencies (empty circles in the right panel of Fig. 4), it is difficult to draw strong conclusions. Nonetheless, comparing our sample and the late-type galaxies in the Herschel Reference Survey (Boselli *et al.* 2014) it appears that the molecular gas is less affected than dust and atomic gas. Moreover, it results that H_2 becomes the dominant gaseous component in HI-deficient galaxies (Grossi *et al.* 2016, Mok *et al.* 2017).

The ionised phase is also a good tracer of stripped gas in dense regions: late-type galaxies in nearby clusters show extended ($\sim$ 50 kpc) tails of ionised gas (Boselli *et al.* 2014) or truncated Hα discs (Koopmann & Kenney 2004). We are carrying out a pilot survey with integral field unit spectroscopy observations of a subset of far-infrared-detected dwarfs with different levels of HI deficiencies (i.e. from none to high, $0.1 < Def_{HI} < 1.7$) using the PMAS/PPAK instrument at the 3.5m Calar Alto telescope (Grossi *et al.*, in prep.). The dwarfs are at different stages of interaction with the cluster environment, thus they can give different snapshots of the evolutionary path from star-forming to more passive systems. Our observations clearly show that the extension of the Hα emission in galaxies with higher HI-deficiency is truncated compared to those with a normal HI content (Fig. 5, top panels). Interestingly, two galaxies in the sample show an inverted metallicity gradient (Fig. 5, bottom panels) which are usually observed in isolated dwarf galaxies (see §2.1) or at high redshift (Cresci *et al.* 2010).

Ram-pressure stripping can efficiently remove the ISM of low-mass star-forming systems on very short time scales ($\sim$ few hundreds Myrs), and it can transform gas-rich star-forming systems into gas-poor quiescent objects on time scales of the order of 0.8 -

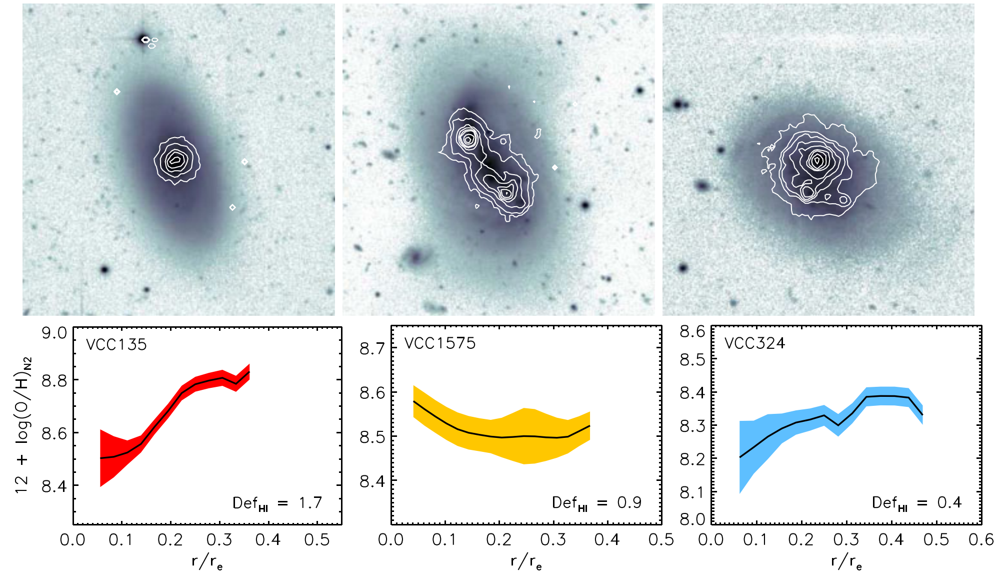

Figure 5. Top panels: Hα emission contours of three Virgo SFDGs overlaid on the optical images (g-band). The galaxies have three different levels of HI deficiency. VCC 135 (to the left) is the most HI-deficient of the sample, while VCC 324 (to the right) is moderately HI-deficient. The Hα emission is more centrally concentrated in the galaxies with a lower HI content. Bottom panels: Oxygen abundance radial profiles of the three galaxies. VCC 135 and VCC 324 show a peculiar inverted metallicity gradient.

1.7 Gyr (Boselli & Gavazzim 2006; Boselli *et al.* 2014). However, ram pressure stripping is not the only mechanism responsible for producing dEs in clusters and gravitational interactions must also play a role (Mastropietro *et al.* 2005, Mistani *et al.* 2016).

Structurally, dEs are more complex than they might seem. Beneath their regular and smooth appearance some dEs present late-type features such as discs, spiral arms, or blue centers (Jerjen *et al.* 2000; Lisker *et al.* 2006, 2007, 2009; Janz *et al.* 2012), and in some cases they can host an atomic gas or dust component (di Serego Alighieri *et al.* 2007, 2013; Hallenbeck *et al.* 2017). They also have a wide range of kinematic properties, including clear signs of rotation (Pedraz *et al.* 2002, Toloba *et al.* 2009), with rotation curves comparable to those of late-type spiral galaxies of similar luminosity (Toloba *et al.* 2011). Rotationally supported dEs in Virgo are mainly located at the periphery of the cluster and they host younger stellar populations, while pressure-supported systems have predominantly-old stellar populations and they are found in the inner regions (Toloba *et al.* 2009). These properties suggest a formation scenario where more than one process may determine their final evolution. The transformation from a star-forming to a passive dwarf could involve an initial phase of ram-pressure stripping as the galaxy enters a dense environment for the first time, where most of its ISM is removed (Conselice *et al.* 2003; Boselli & Gavazzim 2006; Boselli *et al.* 2014), followed by tidal interactions that kinematically heat the stellar disc modifying the galaxy morphology (Gnedin 2003; Lisker *et al.* 2009; Toloba *et al.* 2015).

3.1. *The Fornax cluster*

It is important to study other nearby galaxy clusters and verify if these trends apply also to dense environments with different characteristics than Virgo. Fornax is the second

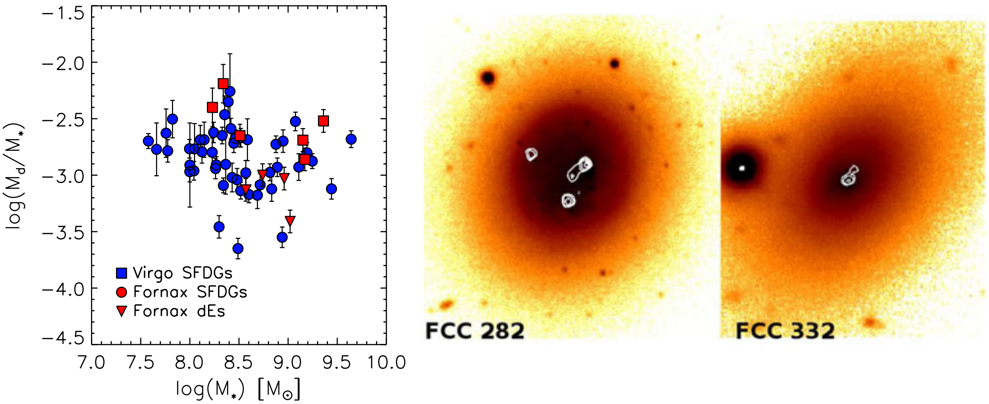

Figure 6. Left panel: Comparison between the dust-to-mass ratio of Virgo and Fornax dwarfs detected in the *Herschel* surveys of the clusters. Central and right panels: Example of two Fornax dEs (FCC 282, FCC 332) showing residual star formation activity. Hα + [NII] emission (contours) overlaid on the r-band image obtained with Gemini/GMOS-S.

largest galaxy cluster within a distance of 20 Mpc (Blakeslee *et al.* 2009). The main structure is very compact ($r_{vir} \simeq 750$ kpc, Drinkwater *et al.* 2001) and consists of 22 galaxies brighter than $M_B < -18$ mag and around 200 fainter galaxies (Ferguson 1989). Fornax is a factor of seven less massive than Virgo (Jordán *et al.* 2007), thus it bridges the gap between evolved groups and more massive clusters. It has a more regular shape and it is more dynamically evolved than Virgo, as indicated by the high early-type galaxy fraction within the virial radius (87% including massive and dwarf ETGs; Ferguson 1989). However, it shows evidence of a substructure at about 3° southwest from the cluster centre, characterized by a predominant late-type population of galaxies that are infalling towards the main structure (Drinkwater *et al.* 2001). Previous HI surveys found that Fornax galaxies present a moderate HI deficiency, and that there is a considerable deficit of HI-rich galaxies in the centre of the cluster (Schröder *et al.* 2001, Waugh *et al.* 2002).

Fornax has not been studied as well as Virgo yet, however different multi-wavelength surveys have been recently completed or are currently ongoing. The central region of the cluster out to the virial radius has been observed with *Herschel* (Davies *et al.* 2013, Fuller *et al.* 2014); members with a stellar mass $\gtrsim 10^8$ M$_\odot$ have been targeted with ALMA to search for CO(1-0) emission (Zabel *et al.* 2018); a region of 12 square degrees that covers the main cluster and the infalling substructure centred on NGC 1316 will be studied at 21-cm with the MEERKAT telescope (Serra *et al.* 2016); two deep optical surveys of approximately 30 square degrees around the cluster have been recently completed, the Fornax Deep Survey (FDS, Venhola *et al.* 2018) and the Next Generation Fornax Cluster Survey (NGFCS, Ordenes-Briceño *et al.* 2018).

The population of dwarf galaxies in Fornax is dominated by early-type dwarfs as in Virgo (Ferguson 1989), and the late-to-early-type ratio increases with radius (de Rijcke *et al.* 2010). The larger velocity dispersion of Fornax SFDGs and their more extended spatial distribution compared to the giant members indicate that they are an infalling population recently accreted from the cluster (Drinkwater *et al.* 2001). The fraction of Fornax SFDGs detected by the *Herschel* within the virial radius is lower compared to Virgo (31% against 47%, Fuller *et al.* 2014), but both populations appear to have similar dust properties (Fig. 6, left panel). On the other hand, Fornax early-type dwarfs present a higher rate of star formation than expected by their morphological classification; 30% of the dE population studied by Drinkwater *et al.* (2001) present a significant

Hα emission (EW $>$ 3 Å; Fig. 6). Some of these dEs also host a dust (Fuller *et al.* 2014) and a molecular gas component (Zabel *et al.* 2018). Thus they could represent a link between more vigorously star-forming dwarfs and quenched dEs in Fornax, and the ongoing surveys of the cluster will allow to shed light on the evolutionary history of these systems.

References

Annibali, F., Nipoti, C., Ciotti, L., *et al.* 2016, *ApJ*, 826, L27
Berg, D. A., Skillman, E. D., Marble, A. R., *et al.* 2012, *ApJ*, 754, 98
Bergvall, N. 2012, Dwarf Galaxies: Keys to Galaxy Formation and Evolution, Astrophysics and Space Science Proceedings, *Springer-Verlag Berlin Heidelberg*, 2012, p. 175
Bekki K. 2008, *MNRAS*, 388, L10
Blakeslee, J. P., Jordn, A., Mei, S., *et al.* 2009, *ApJ*, 694, 556
Bolatto, Alberto D., Leroy, A. K., Rosolowsky, E., *et al.* 2008, *ApJ*, 686, 948
Boselli, A. & Gavazzi, G. 2006, *PASP*, 118, 517
Boselli, A., & Gavazzi, G. 2014, *A&AR*, 22, 74
Boselli, A., Cortese, L., Boquien, M., *et al.* 2014, *A&A*, 564, A66
Bournaud, F., Chapon, D., Teyssier, R., *et al.* 2011, *ApJ*, 730, 4
Brosch, N., Almoznino, E., & Heller, A. B. 2004, *MNRAS*, 349, 357
Cannon, J. M., Johnson, M., McQuinn, K. B., *et al.* 2014, *ApJ*, 787, L1
Chung, A., van Gorkom, J. H., Kenney, J. D. P., *et al.* 2009, *AJ*, 138, 1741
Chung, E. J., Yun, M. S., Verheijen, M. A. W., & Chung, A. 2017, *ApJ*, 843, 50
Colless, M., Dalton, G., Maddox, S., *et al.* 2001, *MNRAS*, 328, 1039
Conselice, C. J., O'Neil, K., Gallagher, J. S., *et al.* 2003, *ApJ*, 591, 167
Corbelli, E., Bianchi, S., Cortese, L., *et al.* 2012, *A&A*, 542, A32
Cortese, L., Davies, J. I., Pohlen, M., *et al.* 2010, *A&A*, 518, L49
Cortese, L., Ciesla, L., Boselli, A., *et al.* 2012, *A&A*, 540, A52
Cresci, G., Mannucci, F., Maiolino, R., *et al.* 2010, *Nature*, 467, 7317
Darvish B., Mobasher B., Sobral D., *et al.* 2016, *ApJ*, 825, 113
Davies, J. I., Bianchi, S., Baes, M., *et al.* 2013, *MNRAS*, 428, 834
Deason, A., Wetzel, A., & Garrison-Kimmel, S. 2014, *ApJ*, 794, 115
Dekel, A., & Birnboim, Y. 2006, *MNRAS*, 368, 2
Dekel, A., Zolotov, A., Tweed, D., *et al.* 2013, *MNRAS*, 435, 999
Dénes, H., Kilborn, V. A., & Koribalski, B. S. 2014, *MNRAS*, 444, 667
di Serego Alighieri, S., Gavazzi, G., Giovanardi, C., *et al.* 2007, *A&A*, 474, 851
di Serego Alighieri, S., Bianchi, S., Pappalardo, C., *et al.* 2013, *A&A*, 552, A8
Dressler, A. 1980, *ApJ*, 236, 351
Dressler, A., Oemler, A. Jr., Couch, W. J., *et al.* 1997, *ApJ*, 490, 577
Drinkwater M. J., Gregg M. D., Holman, B. A., *et al.* 2001, *MNRAS*, 326, 1076
Einasto, J., Joeveer, M., & Saar, E. 1980, *MNRAS*, 193, 353
El-Ad, H., & Piran, T. 1997, *ApJ*, 491, 421
Ekta B., Chengalur, J. N., & Pustilnik, S. A. 2008, *MNRAS*, 391, 881
Fakhouri, O., Ma, C.-P., & Boylan-Kolchin, M. 2010, *MNRAS*, 406, 2267
Ferguson, H. C. 1989, *AJ*, 98, 367
Fuller, C., Davies, J. I., Auld, R., *et al.* 2014, *MNRAS*, 440, 1571
Fumagalli, M., Krumholz, M. R., Prochaska, J. X., *et al.* 2009, *ApJ*, 697, 1811
Geha M., Blanton M. R., Yan R., *et al.* 2012, *ApJ*, 757, 85
Giovanardi, C., Helou, G., Salpeter, E. E., *et al.* 1983, *ApJ*, 267, 35
Gnedin, O. Y. 2003, *ApJ*, 589, 752
Grossi, M., Hunt, L. K., Madden, S. C., *et al.* 2015, *A&A*, 574, A126
Grossi, M., Corbelli, E., Bizzocchi, L., *et al.* 2016, *A&A*, 590, A27
Gunn, J. E., & Gott, III, J. R. 1972, *ApJ*, 176, 1
Hallenbeck, G., Koopmann, R., Giovanelli, R., *et al.* 2017, *AJ*, 154, 58
Haynes, M. P., & Giovanelli, R. 1984, *AJ*, 89, 758

Hoyle, F., & Vogeley, M. S. 2004, *ApJ*, 607, 751
Hoyle, F., Rojas, R. R., Vogeley, M. S., *et al.* 2005, *ApJ*, 620, 618
Hoyle, F., Vogeley, M. S., & Pan, D. 2012, *MNRAS*, 426, 3041
Jáchym, P., Kenney, J. D. P., & Ržuička, A. 2013, *A&A*, 556, A99
Janz, J., Laurikainen, E., Lisker, T., *et al.* 2012, *ApJ*, 745, L24
Jerjen, H., Kalnajs, A., & Binggeli, B. 2000, *A&A*, 358, 845
Jordán, A., Blakeslee, J. P., Côté, P., *et al.* 2007, *ApJS*, 169, 213
Karachentsev, I. D., Karachentseva, V. E., Huchtmeier, W. K., *et al.* 2004, *AJ*, 127, 2031
Kauffmann G., White S. D. M., Heckman T. M., *et al.* 2004, *MNRAS*, 353, 713
Kenney, J. D., & Young, J. S. 1986, *ApJ*, 301, L13
Kenney, J. D. P., Geha, M., Jáchym, P., *et al.* 2014, *ApJ*, 780, 119
Kereš, D., Katz, N., Weinberg, D. H., *et al.* 2005, *MNRAS*, 363, 2
Kereš, D., Katz, N., Fardal, M., *et al.* 2009, *MNRAS*, 395, 160
Klimentowski, J., Lokas, E. L., Knebe, A., *et al.* 2010, *MNRAS*, 402, 1899
Kniazev, A. Y., Egorova, E. S., & Pustilnik, S. A. 2018, *MNRAS*, 479, 3842
Koopmann, R. A., & Kenney, J. D. P. 2004, *ApJ*, 613, 866
Kreckel, K., Platen, E., Aragón-Calvo, M. A., *et al.* 2011a, *AJ*, 141, 4
Kreckel, K., Peebles, P. J. E., van Gorkom, J. H., *et al.* 2011b, *AJ*, 141, 204
Kreckel, K., Platen, E., Aragón-Calvo, M. A., *et al.* 2012, *AJ*, 144, 16
Larson, R. B., Tinsley, B. M., & Caldwell, C. N. 1980, *ApJ*, 237, 692
Lelli F., Verheijen M., Fraternali F., et. al 2012, *A&A*, 537, A72
Lelli, F., Verheijen, M., & Fraternali, F. 2014, *MNRAS*, 445, 1694
Lisker, T., Grebel, E. K., & Binggeli, B. 2006, *AJ*, 132, 497
Lisker, T., Grebel, E. K., & Binggeli, B., *et al.* 2007, *ApJ*, 660, L1186
Lisker, T., Janz, J., Hensler, G., *et al.* 2009, *ApJ*, 706, L124
Lisker, T., Weinmann, S. M., & Janz, J., *et al.* 2013, *MNRAS*, 432, 1162
Martínez-Delgado D., Romanowsky, A. J., Gabany, R. J., *et al.* 2012, *ApJ*, 748, L24
Mastropietro, C., Moore, B., Mayer, L., *et al.* 2005, *MNRAS*, 364, 697
Mihos, J. C., & Hernquist, L. 1994, *ApJ*, 431, L9
Mistani, P. A., Sales, L. V., Pillepich, A., *et al.* 2016, *MNRAS*, 455, 2323
Mok, A., Wilson, C. D., Knapen, J. H., *et al.* 2017, *MNRAS*, 467, 4282
Moore, B., Katz, N., Lake, G., *et al.* 1996, *Nature*, 379, 613
Moorman, C. M., Vogeley, M. S., Hoyle, F., *et al.* 2015, *ApJ*, 810, 108
Moorman, C. M., Moreno, J., White, A., *et al.* 2016, *ApJ*, 831, 118
Noeske K. G., Iglesias-Paramo J., Vílchez J. M., *et al.* 2001, *A&A*, 371, 806
Ordenes-Briceño, Y., Eigenthaler, P., & Taylor, M. A.; 2018, *ApJ*, 859, 52
Pan, D. C., Vogeley, M. S., Hoyle, *et al.* 2012, *MNRAS*, 421, 926
Patton D. R., Torrey P., Ellison S. L., *et al.* 2013, *MNRAS*, 433, L59
Paudel, S., Smith, R., Yoon, S. J., *et al.* 2018, *ApJ*, 237, 36
Pearson, S., Besla, G., Putman, M. E., *et al.* 2016, *MNRAS*, 459, 1827
Pearson, S., Privon, G. C., Besla, G., *et al.* 2018, *MNRAS*, 480, 3069
Pedraz, S., Gorgas, J., Cardiel, N., *et al.* 2002, *MNRAS*, 32, L59
Popescu, C. C., Tuffs, R. J., Völk, H. J., *et al.* 2002, *ApJ*, 567, 221
Pustilnik S. A., & Tepliakova A. L. 2011a, *MNRAS*, 415, 1188
Pustilnik S. A., Martin J.-M., Tepliakova A. L., *et al.* 2011b, *MNRAS*, 417, 1335
Pustilnik S. A., Martin J.-M., Lyamina Y. A., *et al.* 2013, *MNRAS*, 432, 2224
Pustilnik, S. A., Perepelitsyna, Y. A., Kniazev, A. Y. 2016, *MNRAS*, 463, 670
Rahmati, A., Schaye, J., Crain, R. A., *et al.* 2016, *MNRAS*, 459, 310
Sánchez-Almeida J., Elmegreen, B. G., Muñoz-Tuñón, C., *et al.* 2015, *ApJ*, 810, L15
Sánchez-Almeida J., Pérez-Montero E., Morales-Luis A. B., *et al.* 2016, *ApJ*, 819, 110
Schröder, A., Drinkwater, M. J., & Richter, O.-G. 2001, *A&A*, 376, 98
Scoville, N., Arnouts, S., Aussel, H., *et al.* 2013, *ApJS*, 206, 3
Serra, P., de Blok, W. J. G., Bryan, G. L., *et al.* 2016, Proceedings of MeerKAT Science: On the Pathway to the SKA. 25-27 May, 2016 Stellenbosch, South Africa

Stanonik, K., Platen, E., Aragon-Calvo, M. A., *et al.* 2009, *ApJ*, 696, L6
Stierwalt S., Besla G., Patton D., *et al.* 2015, *ApJ*, 805, 2
Stierwalt, S., Liss, S. E., Johnson, K. E., *et al.* 2017, *Nature Asronomy*, 1, 25
Stil J. M., & Israel F. P. 2002, *A&A*, 392, 473
Telles E., & Terlevich R. 1995, *MNRAS*, 275, 1
Toloba, E., Boselli, A., Gorgas, J., *et al.* 2009, *ApJ*, 707, L17
Toloba, E., Boselli, A., Cenarro, A. J., *et al.* 2011, *A&A*, 526, A114
Toloba, E., Guhathakurta, P., Boselli, A., *et al.* 2015, *ApJ*, 799, 172
Tuffs, R. J., Popescu, C. C., Pierini, D., *et al.* 2002, *ApJS*, 139, 37
Tully, R. B., Shaya, E. J., & Karachentsev, I. D. 2008, *ApJ*, 676, 184
van de Voort, & F., Schaye, J. 2012, *MNRAS*, 423, 2991
Venhola, A., Peletier, R., Laurikainen, E., *et al.* 2018, *A&A*, in press
Waugh, M., Drinkwater, M. J., Webster, R. L., *et al.* 2002, *MNRAS*, 337, 641
Weinberg, D. H., Davé, R., Katz, N. *et al.* 2004, *ApJ*, 601, 1
York, D. G., Adelman, J., Anderson, Jr., J. E., *et al.* 2000, *AJ*, 120, 1579
Zabel, N., Davis, T. A., Smith, M. W. L., *et al.* 2018, *MNRAS*, submitted

Discussion

Q1: For star-forming dwarfs in voids, which process is more responsible for the low oxygen abundances in the ionised gas, inflow from the IGM low Z gas or that there hasn't been many galaxy-galaxy mergers (i.e. generations of massive stars)?

A1: It is difficult to answer which process is dominating without a systematic study of either the HI morphology or the radial metallicity variation in void dwarf galaxies, which could provide evidence of ongoing gas accretion. So far, it seems that both mechanisms can be responsible for the observed low metallicities.

Q2: Speaking of HI deficiencies requires to normalize the HI content to "normal" galaxies. How is this feasible for the inhomogeneous samples of dIrrs?

A2: Blind HI surveys like ALFALFA are providing large samples of field late-type dwarfs that can be used as reference to assess the HI content of normal unperturbed dwarf systems. The HI-deficiency parameter for late-type dwarf galaxies has been recently recalibrated by Gavazzi *et al.*(2013).

Q3: Given that very few dwarfs in Fornax have been detected with *Herschel*, can you tell us whether the optical image scan give us some clues about when a galaxy contains dust?

A3: This kind of analysis can be performed with the deep multi-imaging optical surveys of Fornax (i.e. the FDS and the NGFCS). We don't have access to these data sets, thus we cannot say much about the dust content of galaxies not detected with *Herschel*.