The Fornax 3D project: PNe populations and stellar metallicity in edge-on galaxies

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ABSTRACT

Extragalactic planetary nebulae (PNe) are useful distance indicators and are often used to trace the dark-matter content in external galaxies. At the same time, PNe can also help to understand the late stage of stellar evolution. In this study we further explore the importance of stellar metallicity in driving the properties of the PNe population in early-type galaxies, using three edge-on galaxies in the Fornax cluster. Our analysis highlights the importance of ensuring spatial consistency to avoid misleading results when investigating the link between PNe and their parent stellar populations, and suggest that in passively evolving systems variations in the specific number of PNe may pertain to rather extreme metallicity regimes found either in the innermost or outermost regions of galaxies.

Key words. planetary nebulae: general – galaxies: abundances – galaxies: elliptical and lenticular, cD – techniques: imaging spectroscopy – methods: observational

1. Introduction

Planetary nebulae (PNe) can be detected in external galaxies out to great distances thanks to their intense [O III] λ5007 nebular emission, emitting as much as $10^3 - 10^4 L_\odot$ (e.g., O'dell 1963; Paczynski 1970; Rose & Smith 1970; Gesicki et al. 2018). This makes PNe useful tracers for the kinematics of their parent stellar populations in the very outskirts of galaxies allowing one to constrain their dark matter content (e.g., Romanowsky et al. 2003; Douglas et al. 2007; Coccato et al. 2009; Kafle et al. 2018). The PNe populations of external galaxies have also been found to have similar PN luminosity functions (PNLF) with a common bright-end cutoff that in turn makes PNe reliable cosmic distance indicators (Ciardullo et al. 1989; Ciardullo 2012). As tracers of their parent stellar populations, extragalactic PNe can also help to understand the late stage of stellar evolution in galactic environments different from our Milky Way. In fact, both the detailed shape of the PNLF and the fact that the
PNe population in different kinds of galaxies seems to share the same cutoff are still not fully understood. For instance, the actual presence of bright PNe in old, passively evolving systems is a long-standing problem (Marigo et al. 2004; Ciardullo 2005) that only recent theoretical development has started to address (e.g., Gesicki et al. 2018; Valenzuela et al. 2019). Likewise, both the origin of the PNLF bright cut-off (e.g., Ciardullo 2012) and its slope at fainter regimes are not fully understood (e.g., in star-forming regions, as found in the Large Magellanic Cloud by Reid & Parker 2010 or in the outskirts of early-type galaxies, as shown by Hartke et al. 2020).

At a more basic level, the abundance of PNe should also vary across different kinds of galaxies, as proposed by Buzzoni et al. (2006), hereafter B06, and in relation to variations to their overall far-UV flux (the so-called UV-upturn, Burstein et al. 1988). Furthermore, B06 showed the first piece of observational evidence for an anti-correlation between the specific number of PNe per luminosity ($\alpha$) and stellar metallicity, finding at the same time that the presence of a UV-upturn also corresponds to less abundant PNe populations (consistent with previous theoretical work by Greggio & Renzini 1990 as well). It is important to note, however, that the analysis of B06 suffers from a spatial inconsistency in their comparison of PNe and stellar population measurements. Indeed, whereas their $\alpha$ values come from previous halo PNe studies (Ciardullo et al. 1989; Jacoby et al. 1989; Hui et al. 1993), their literature measurements for the Mgb index values (used to trace metallicity) and the UV-upturn pertain to the innermost regions of their sample galaxies.

Nowadays, deep imaging facilities allow us to trace radial variations in $\alpha$ out to the most metal-poor halo regions of galaxies (e.g., Bhattacharya et al. 2019; Hartke et al. 2020). Furthermore, the advent of integral-field spectroscopy can both facilitate the measurement of the stellar metallicity in faint galaxy outskirts (by collecting large aperture spectra, e.g., Weijmans et al. 2009) and detection of PNe deeply embedded in the central bright regions of galaxies (thanks to a detailed spectral modelling, e.g., Sarzi et al. 2011; Pastorello et al. 2013; Spriggs et al. 2020), where they are otherwise inaccessible to narrow-band imaging or counter-dispersed slit-less spectroscopy (e.g., Gerhard et al. 2005; Douglas et al. 2007; Ventimiglia et al. 2011).

In this respect, edge-on galaxies can be considered as ideal laboratories to test ideas on the connection between PNe and their parent stellar populations. Indeed, the particular inclination of these galaxies makes it possible to directly compare PNe populations in metal-rich disc regions and their counterparts in the more metal-poor bulge or halo, thus allowing one to start redressing the spatial inconsistencies in the B06 analysis.

Using MUSE integral-field spectroscopic data, we explore the PNe populations for the three edge-on galaxies FCC 153, FCC 170, and FCC 177 in this paper. These targets were observed during the magnitude-limited Fornax3D survey for bright galaxies within the virial radius of the Fornax cluster (Sarzi et al. 2018). We place our findings in the context of the stellar population measurements previously reported by Pinna et al. (2019a,b, hereafter P19). These edge-on galaxies host a range of stellar populations that can be divided into a predominantly metal-rich bulge/thin-disc and metal-poor off-plane populations. In this respect, PNe can be used to trace the kinematics of these parent stellar populations and check whether the abundance of hosted PNe is dependent on different star formation signatures such as the metallicity.

This paper is organised as follows. In Sect. 2, we present a brief summary of the sample galaxies as well as the properties of the observations. In Sect. 3, we explain the methodology and procedures to identify and confirm the detected PNe, as well as to estimate the PNLF, light-weighted metallicity, and luminosity specific PNe number. In Sect. 4, we present and discuss the results of both the PNLF for the three galaxies and the specific PNe number per galaxy as a function of the metallicity of different in-plane and off-plane regions. Lastly, in Sect. 5 we give our conclusions.

2. Observations and data reduction

The MUSE data for FCC 153, FCC 170, and FCC 177 (IC 1963, NGC 1381, and NGC 1380A, respectively) were obtained in the wide-field mode, which ensures a spatial sampling of 0.2′′×0.2′′ on a 1′×1′ field-of-view (FoV). The wavelength range of MUSE cubes ranges between 4650Å and 9300Å with a spectral sampling of 1.25Å pixel$^{-1}$ and an average instrumental spectral resolution of $FWHM_{int} = 2.5\,\AA$ (Sarzi et al. 2018). In the particular case of our three edge-on galaxies, the MUSE data are comprised of a central pointing and offset pointing further covering the outer disc and halo regions, and which from now on we refer to as the halo pointing. Different integration times of 1 h and 1h30 min for a central and halo pointing, respectively, allow one to reach the same limiting surface brightness of $\mu_B = 25\,mag\,arcsec^{-2}$. Central pointings were required to be observed under good seeing conditions ($FWHM < 0.8''$), whereas halo pointings had less stringent image quality constraints ($FWHM < 1.5''$). This is accounted in our PNe analysis (see Sect. 3.2).

The data reduction was performed using the MUSE pipeline (Weilbacher et al. 2012) applying the ESOREXFLEX environment (Freudling et al. 2013) as described in Sarzi et al. (2018) and Iodice et al. (2019). This includes key steps such as sky-subtraction, telluric correction, and both relative and absolute flux calibration. Normally, the single pointings would be aligned through reference stars and further combined to produce final MUSE mosaics, but here this last step was skipped since our PNe analysis will need to be separately applied to our individual, finally reduced central and halo pointings due the aforementioned differences between their imaging quality.

Maps for the stellar kinematics of these objects are presented both in Pinna et al. (2019a,b) and in Iodice et al. (2019), with the former works additionally showing maps for the stellar age and metallicity. These studies also took notice of the absence of diffuse ionised-gas emission in these galaxies, although the presence of PNe in these and other passively evolving objects had already been mentioned in Iodice et al. (2019). This is thanks to a careful spaxel-by-spaxel separation of the stellar continuum and nebular emission using the Gandalf code (e.g., Sarzi et al. 2006) within the novel GIST pipeline of Bittner et al. (2019), as also described in Sarzi et al. (2018).

3. Methodology

In order to characterise the PNe populations of our edge-on galaxies, we followed the method of Spriggs et al. (2020). This consists of five separate steps: (i) the identification of PNe candidate using $[O\,III]\lambda5007$ signal-to-noise maps obtained from our dedicated spaxel-by-spaxel GandALF fits; (ii) a dedicated 3D-fitting of such PNe candidates for their kinematics and total $[O\,III]\lambda5007$ flux while imposing a fixed spatial profile for their $[O\,III]\lambda5007$ emission according to the (pre-determined) spatial
Table 1. Point-spread function across the MUSE pointings of the sample galaxies, as characterised using a Moffat function fit to either a foreground star or a selection of bright PNe sources.

| Galaxy    | Method | Pointing | FWHM | β   |
|-----------|--------|----------|------|-----|
| FCC 153   | PNe    | Centre   | 3.6  | 1.9 |
|           |        | Halo     | 3.6  | 4.2 |
| FCC 170   | Star   | Centre   | 4.1  | 2.4 |
|           |        | Halo     | 3.5  | 1.7 |
| FCC 177   | PNe    | Centre   | 3.8  | 1.8 |
|           |        | Halo     | 4.1  | 4.4 |

Notes. (1) Galaxy name. (2) Selected object to estimate the PSF. (3) Selected MUSE pointing. (4) FWHM values are in pixels. (5) β parameter of the Moffat profile. The values FWHM and β are taken from Spriggs et al. (in prep.).

Moffat point-spread function (PSF)\(^1\); (iii) isolating and removing PNe interlopers based on the comparison with the host-galaxy stellar kinematics and unresolved HII-regions or supernovae remnant PNe impostors using line diagnostics; (iv) the construction of the PNLF and of our PNe detection incompleteness function (Sect. 3.1); and (v) finally, the estimation of the total luminosity-specific number of PNe within a given magnitude limit (Sect. 3.2). This last step requires either adopting or deriving the galaxy distance using the PNLF, and it involves re-scaling the incompleteness-corrected model for the PNLF to match the observed number of PNe.

The first three steps of this analysis deliver a catalogue for the PNe contained within the FoV of our MUSE observations. Separate PNe catalogues for each pointing are needed in the first place since the central and halo data were obtained under rather different seeing conditions (Table 1), which has an impact on the shape and extent of the incompleteness functions that we then folded in the PNLF modelling. Our detected PNe are in agreement with those in Spriggs et al. (2021), after that, the only difference is that here we separately applied the last two steps of our PNe analysis to the predominantly metal-rich and metal-poor regions near and off the equatorial plane of our edge-on galaxies, respectively. We obtained separate PNLF and luminosity-specific PNe numbers in order to explore variations in the PNe populations of regions with significantly different parent stellar populations. For this, we applied the stellar population differentiation adopted in Pinna et al. (2019b,a), which is shown by horizontal lines in the top panels of Figs. 1–3. Finally, using two complementary approaches, we proceeded to estimate the stellar metallicity in these regions (Sect. 3.3) in order to place our PNe population results in the context of the B06 relation, which we also re-evaluated using the stellar metallicity measurements from the literature (Sect. 3.4).

3.1. Observed PNLF, completeness corrections, and best-matched PNLF models

Following the procedure outlined in the previous section, we obtained separate catalogues for PNe populations encompassed

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\(^1\) The PSF evaluation assumes a Moffat (1969) profile and is achieved using foreground stars by simultaneously applying our 3D-fitting procedure to the [O\textsc{iii}] 5007 emission of a few bright PNe. The radial extent and kurtosis of the Moffat profile is defined by its parameters \(α\) and \(β\), which relate to the \(FWHM = 2α \sqrt{β} - 1\).
constructed corresponding PNe luminosity functions as shown in the lower panels of Figs. 1–3. To first order, after accounting for the incompleteness of our observations, adjusting for distance and applying an appropriate re-scaling, our observed PNLFs should compare well with the standard form of the PNLF function introduced by Ciardullo et al. (1989). This is given by

\[ N(M) \propto e^{[0.307M_{5007} - 1]} \left[ 1 - e^{[M_{5007} - M_{5007}^*]} \right], \]

where \( M_{5007}^* \approx -4.52 \) mag is the characteristic bright-end cut-off (according to the latest calibration of Ciardullo 2012) that makes the PNLF a useful distance indicator.

Following Spriggs et al. (2020), we defined the PNe detection completeness at a given apparent magnitude \( M_{5007} \) as the fraction of galaxy stellar light within the MUSE FoV where a PNe of that particular magnitude can be detected. For this, we applied our PNe detection criteria on a spaxel-by-spaxel basis by first computing the peak \([\text{O} \text{III}]\) \( \lambda 5007 \) flux for PNe of apparent magnitude \( M_{5007} \) (given our PSF model) and subsequently checking if the corresponding peak \( A_{\text{OIII}} \lambda 5007 \) spectral amplitude (given the MUSE spectral resolution and the typical PNe intrinsic \( \sigma \) of \( \sim 40 \text{ km s}^{-1} \)) exceeds three times the local residual-noise level from our previous spaxel-by-spaxel GandALF spectral fitting.

This procedure is equivalent to randomly populating the MUSE FoV with simulated PNe of magnitude \( M_{5007} \), while considering that larger numbers would be expected in brighter regions, and then simply evaluating the completeness as the fraction of galaxy stellar light within the MUSE FoV where a PNe of that particular magnitude can be detected. For this, we applied our PNe detection criteria on a spaxel-by-spaxel basis by first computing the peak \([\text{O} \text{III}]\) \( \lambda 5007 \) flux for PNe of apparent magnitude \( M_{5007} \) (given our PSF model) and subsequently checking if the corresponding peak \( A_{\text{OIII}} \lambda 5007 \) spectral amplitude (given the MUSE spectral resolution and the typical PNe intrinsic \( \sigma \) of \( \sim 40 \text{ km s}^{-1} \)) exceeds three times the local residual-noise level from our previous spaxel-by-spaxel GandALF spectral fitting.

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3.2. Total and luminosity-specific PNe numbers

Once the Ciardullo et al. (1989) PNLF had been matched to the observed PNLF in the in- and off-plane regions of our edge-on galaxies, we could estimate the total number of PNe from the bright cut-off down to a chosen magnitude limit by simply integrating the shifted and re-scaled model PNLF as it is. Following Buzzoni et al. (2006), in this way we estimated the true number \( N_{2.5} \) of PNe 2.5 magnitude from the PNLF bright cut-off. To this extrapolated total, we associated errors obtained by appropriately rescaling the Poisson uncertainty on the actual number of PNe that we observed within a given region, computed following the prescription of Gehrels (1986).

From this number, we can estimate the so-called luminosity specific number of PNe

\[ \alpha_{2.5} = \frac{N_{2.5}}{L_{\text{bol}}}, \]

where \( L_{\text{bol}} \) is the bolometric luminosity for the region where we have been looking for PNe. In turn, this is given by

\[ L_{\text{bol}}(L_\odot) = 10^{-0.4(M_1 - M_{1,\odot})} \times 10^{-0.4(BC_{\text{g}} - BC_{\text{g,\odot}})}, \]

where \( M_1 \) and \( M_{1,\odot} \) are the absolute magnitude for the region of interest within the galaxy and the Sun within a chosen broadband filter, while \( BC_{\text{g}} \) and \( BC_{\text{g,\odot}} \) are the corresponding bolometric magnitude corrections from the given broadband filter. See also Torres (2010, Eq. (9)) and Hartke et al. (2020, Eq. (14)).

In the case of our MUSE observations, we chose the SDSS \( g \)-band to compute the observed \( m_g \) and absolute \( M_g \) magnitudes of the in- and off-plane regions in our edge-on galaxies. As for deriving the bolometric correction, we followed the procedure described by Spriggs et al. (2020), whereby \( BC_g \) was derived using the optimal combination of EMILES stellar templates (Vazdekis et al. 2016) that best matches the MUSE integrated spectrum observed within the region of interest (i.e., our in- and off-plane region in both a central and halo pointing). Adopting a bolometric correction for the Sun in the \( g \)-band of \( BC_{g,\odot} = -1.78 \) mag and a \( g \)-band absolute magnitude of \( M_{g,\odot} = 5.23 \) mag (Willmer 2018), as well as using Eq. (3), we estimated the bolometric luminosity of our in- and off-plane regions, which are reported in Table 2. Errors in \( L_{\text{bol}} \) are dominated by \( M_g \) errors from distance uncertainties.
Table 2. Results of the analysis for the MUSE central and halo pointings of the sample galaxies.

| Galaxy (1) | Region (2) | PNe detected per region | $N_{25}$ (4) | $L_{bol}$ (5) | $\sigma_{25}$ (6) | [Z/H]$_{SSP}$ (dex) (7) | [Z/H]$_{BFH}$ (dex) (8) |
|-----------|------------|-------------------------|-------------|---------------|----------------|---------------------|---------------------|
| FCC 153   | in-plane   | 29                      | 99$^{+22}_{-18}$ | (4.7$^{+0.7}_{-0.5}$) x 10$^6$ | (2.1$^{+0.3}_{-0.2}$) x 10$^{-8}$ | -0.13               | 0.008               |
|           | off-plane  | 16                      | 24$^{+8}_{-5}$  | (1.2$^{+0.1}_{-0.2}$) x 10$^6$ | (2.0$^{+0.2}_{-0.2}$) x 10$^{-8}$ | -0.645              | -0.617              |
| FCC 170   | in-plane   | 38                      | 116$^{+22}_{-19}$ | (5.7$^{+0.6}_{-0.7}$) x 10$^6$ | (2.0$^{+0.4}_{-0.3}$) x 10$^{-8}$ | -0.188              | -0.11               |
|           | off-plane  | 4                       | 7$^{+6}_{-5}$   | (6.3$^{+0.7}_{-0.8}$) x 10$^6$ | (1.1$^{+0.3}_{-0.4}$) x 10$^{-8}$ | -0.595              | -0.63               |
| FCC 177   | in-plane   | 46                      | 6$^{+4}_{-3}$   | (2.6$^{+0.5}_{-0.4}$) x 10$^6$ | (2.4$^{+0.3}_{-0.4}$) x 10$^{-8}$ | -0.173              | -0.057              |
|           | off-plane  | 10                      | 9$^{+4}_{-3}$   | (5.8$^{+1.1}_{-0.9}$) x 10$^6$ | (1.5$^{+0.3}_{-0.4}$) x 10$^{-8}$ | -0.135              | -0.556              |
| FCC 153   | in-plane   | 24                      | 4$^{+11}_{-7}$  | (1.9$^{+0.3}_{-0.2}$) x 10$^6$ | (2.3$^{+0.3}_{-0.2}$) x 10$^{-8}$ | -0.049              | 0.016               |
|           | off-plane  | 14                      | 15$^{+5}_{-4}$  | (5.7$^{+0.6}_{-0.8}$) x 10$^6$ | (2.6$^{+0.2}_{-0.3}$) x 10$^{-8}$ | -0.554              | -0.483              |
| FCC 170   | in-plane   | 35                      | 7$^{+13}_{-12}$ | (2.6$^{+0.3}_{-0.4}$) x 10$^6$ | (2.9$^{+0.3}_{-0.4}$) x 10$^{-8}$ | -0.51               | -0.07               |
|           | off-plane  | 4                       | 5$^{+4}_{-3}$   | (2.0$^{+0.2}_{-0.3}$) x 10$^6$ | (2.5$^{+0.4}_{-0.3}$) x 10$^{-8}$ | -0.048              | 0.32                |
| FCC 177   | in-plane   | 12                      | 7$^{+6}_{-4}$   | (5.8$^{+1.1}_{-0.9}$) x 10$^6$ | (2.6$^{+0.2}_{-0.3}$) x 10$^{-8}$ | -0.158              | -0.168              |
|           | off-plane  | 7                       | 7$^{+3}_{-2}$   | (1.8$^{+0.3}_{-0.3}$) x 10$^6$ | (3.9$^{+1.4}_{-1.2}$) x 10$^{-8}$ | -0.47               | -0.894              |

Notes. (1) Target galaxy. (2) Studied region. (3) Number of observed PNe. (4) Theoretical expected number of PNe down to 2.5 magnitudes. (5) Bolometric luminosity. (6) Luminosity specific PNe number. (7) Light-weighted metallicity derived from SSP index measurements. (8) Light-weighted metallicity obtained from the analysis of full spectral fitting.

3.3. Stellar metallicity measurements from integrated MUSE spectra

In order to place our PNe findings in relation to the properties of their parent stellar population and in particular to check on any dependence of $\alpha_{25}$ with stellar metallicity, we proceeded to measure the latter in both the in- and off-plane regions in and above the disc of our edge-on galaxies, both in MUSE central and halo pointings. For this, we integrated our MUSE spectra in these regions (as defined by P19; Sect. 3) over a minimum signal-to-noise of 1, obtaining four different spectra for each galaxy, and we derived the stellar metallicity according to the following two approaches: (i) based on full spectral fitting using the pPXF code (Cappellari & Emsellem 2004; Cappellari 2017) in the 4750–5500 Å wavelength range as done in P19, using a set of single-age stellar population models from the MILES library (Falcón-Barroso et al. 2011) to estimate an average value for the stellar metallicity; (ii) spectral fitting focused on the wavelength regions around a specific absorption-line features particularly sensitive to either age (e.g., $H\beta$), metallicity (e.g., Fe 5270 and Fe 5335), or $\alpha$-element abundance (e.g., Mg 5177) as done in Martín-Navarro et al. (2019), using also the single-age stellar population models from the MILES library to derive a single, best-fitting value for the metallicity [Z/H]$_{SSP}$.

These two methods are complementary. The spectral-fitting approach of P19 allows one to account for an extended star-formation and metal-enrichment history through a combination of single-age models of varying age and metallicity instead of adopting only the values corresponding to the best matching single-age stellar population model as in Martín-Navarro et al. (2019). The latter approach, however, also accounts for more subtle variations in $\alpha$-element abundances (and in fact, also in the slope at the low-mass-end of the stellar initial-mass function), to which a full-spectral fitting can be rather insensitive.2

3.4. Revising the Buzzoni et al. relation

The evidence for the anti-correlation between the specific number of PNe $\alpha_{25}$ and stellar metallicity of B06 was based on literature measurements for the strength of the Mg$_2$ absorption-line index rather than an actual metallicity measurement. To quantify the $\alpha_{25}$ variations that they would have found with actual metallicity measurements, we took all the objects in the B06 sample that were also observed over the course of the ATLAS$3D$ survey (Cappellari et al. 2011). Using the measurements of McDermid et al. (2015), we revisited the $\alpha_{25}$-metallicity relation of B06. As in the case of our two adopted approaches to estimate the stellar metallicity, McDermid et al. (2015) provide average (light-weighted) values based on full-spectral fitting [Z/H]$_{SSP}$ and single-age values from the best stellar-population model [Z/H]$_{BFH}$ that best matched the observed strength of a set of absorption line-strength indices, while accounting for [α/Fe] variations.

Figure 4 shows that such a revised $\alpha_{25}$ – metallicity relation remains in place only when considering [Z/H]$_{BFH}$ values, indicating at best a factor ~6 variation in the specific number of PNe per 0.4 dex variation in metallicity. No visible trend is present when considering [Z/H]$_{SSP}$ values. This suggests that either [α/Fe] may also play a part in the original trend with the Mg$_2$ line-strength index, which also subsists when looking at the ATLAS$3D$ Mg$_2$ values, or caution is needed when considering the widely different spatial scales probed by B06.

4. Results and discussion

We give our final estimates for the specific number of PNe 2.5 magnitudes from the PNLF bright cut-off and stellar metallicity in the regions near or above and below the equatorial plane of our sample galaxies summarised in Table 2. Figure 5 finally shows how these quantities fare against each other across such different regions and as observed both in our central and halo MUSE pointings.

We observe no significant difference in $\alpha_{25}$ between in- and off-plane regions, irrespective of the methodology used to

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2 Whereas P19 derived mass-weighted values here, we instead used light-weighted averages [Z/H]$_{BFH}$ in order to be more consistent with the approach of Martín-Navarro et al. Our conclusions are not affected by this choice.
estimate the stellar metallicity, finding at most a factor \(\sim 2.6\) increase in \(\alpha_{2.5}\) between the off-plane measurements of FCC 177 where there is a 0.33 dex difference. This lack of a trend appears to contradict the results of B06. Indeed, even though the metallicity estimates for the predominantly metal-poor off-plane regions can span a wide range of values, on average they are \(\sim 0.4\) dex lower than their counterparts closer to the equatorial plane and therefore ought to show up to \(\sim 6\) times higher values for \(\alpha_{2.5}\) according to our most optimistic revision of the B06 analysis (Sect. 3.4). Despite the large uncertainties in the \(\alpha_{2.5}\) values for such fainter off-plane regions, there is simply no room to accommodate a factor 6 (i.e., \(\sim 0.8\) dex) increase in \(\log(\alpha_{2.5})\). This result is at odds with the recent work of Hartke et al. (2020), who find a clear increase in the specific PNe number in the outskirts of the closer Leo Group early-type galaxy NGC 3379 (M105), based on deep narrow-band on-off imaging extending out to nearly 23 effective radii \((R_e)\). This study reveals, however, that such an enhancement in \(\alpha\) values begins from \(8R_e\), onwards, deep in the outer stellar halo or even in the intra-group light medium and at a metallicity regime most likely below the one found in the metal-poor extra-planar regions of our edge-on galaxies. On the other hand, at smaller radii, Hartke et al. (2020) find no \(\alpha\) variation despite the presence of large stellar population gradients (e.g., within \(3-4R_e\), Weijmans et al. 2009) and this is consistent with our findings. Changing perspective, the lack of a trend between \(\alpha\) and metallicity also contrasts with the observations in three edge-on galaxies in the Fornax cluster, or the tentative evidence for a decrease in the number of bright PNe (Pastorello et al. 2013). Although edge-on systems are not particularly suited to explore the innermost and crowded PNe populations of galaxies, future MUSE studies assisted by adaptive optics have the potential to shed more light in this respect.

5. Conclusions

Using MUSE observations, we have explored the PNe populations in three edge-on galaxies in the Fornax cluster, offering an unique benchmark for testing the presence of systematic differences in the PNe content between predominantly metal-rich regions near the equatorial plane and generally metal-poor off-plane populations. We have found no significant evidence of a change in the specific number of PNe between the metal-poor and metal-rich regions of our edge-on galaxies, despite us probing a range in stellar metallicity values (0.5 dex) similar to that of previous investigations which were, however, comparing the properties of PNe and their parent stellar population on rather different spatial scales. Presently, our results further suggest that variations in the specific number of PNe in passively evolving systems may pertain to extreme metallicity regimes and to either the innermost or outermost regions of galaxies.

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Fig. 4. PNe specific number vs stellar metallicity for Buzzoni et al. (2006) sample galaxies covered also by the Atlas\(^5\) integral-field spectroscopic survey (see McDermid et al. 2015), for two different star formation history measurements: full spectral fitting from a single-age stellar population (left panel) and full-index-fitting based on a focused set of absorption lines (right panel).

Fig. 5. Luminosity specific PNe number \(\alpha\) as a function of metallicity for the best-fitting single-age stellar population to selected spectral regions (top panel) following Martin-Navarro et al. (2019) and for the light-weighted metallicity resulting from a full spectral fitting (bottom panel) following P19. Circles and triangles show values from in-plane and off-plane regions, respectively whereas filled and open symbols denote whether these were found within our central or halo MUSE pointings. The colour of the symbols indicate measurements from each galaxy, with dashed lines showing linear fits to all values for each object.
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