Dwarf Galaxies: From the Deep Universe to the Present
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Uncovering dwarf elliptical evolution through spatially resolved spectroscopy

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Abstract. Using spatially resolved spectroscopy from the SDSS-IV Mapping Nearby Galaxies at APO (MaNGA) survey, we identify 69 dwarf elliptical (dE) galaxies in the nearby Universe fainter than $M_r = -19$ ($M_B = -18$), selected independently of morphology and environment. The majority exhibit coherent rotation in their stellar kinematics, consistent with an origin as morphologically transformed disk galaxies. Six galaxies in this dE sample appear to host Active Galactic Nuclei (AGN) that are likely preventing current star formation through maintenance mode feedback. The ionised gas component of these dEs is typically kinematically offset from the stellar component, suggesting the gas is either recently accreted or outflowing. We therefore demonstrate the potential of IFU spectroscopy for understanding the physical properties of dwarf galaxies in detail.

Keywords. galaxies: dwarf, galaxies: evolution, galaxies: active, galaxies: kinematics and dynamics

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1. Introduction

Dwarf elliptical galaxies are the dominant galaxy population by number in the nearby galaxy groups and clusters, yet their origin and formation timescale remains unclear. Cluster dEs exhibit a wide range of star formation histories, with some hosting young, metal rich stellar populations, with others exhibiting ages consistent with them ceasing star formation > 10 Gyr ago (e.g. Penny & Conselice 2008). Recent studies suggest a large fraction of cluster dEs originate as late-type galaxies that have been environmentally quenched and morphologically transformed (e.g. Lisker *et al.* 2006; Toloba *et al.* 2015), however their have been few studies of dEs outside the cluster environment (with the exception of the Local Group). Environment therefore plays a crucial role in driving the evolution of low-mass galaxies.

However, the role of feedback in dwarf galaxy evolution is unclear. While the role of supernova feedback has been shown to be important in regulating star formation in low-mass dwarfs, the importance of AGN feedback is less clear. AGN signatures have been identified in dwarf galaxies (e.g. Reines *et al.* 2013; Moran *et al.* 2014; Sartori *et al.* 2015), though it is not known if AGN can regulate star formation in dwarf galaxies. By using spatially resolved spectroscopy, we can examine the influence of such AGN on their host galaxies through kinematics, emission line diagnostics, and stellar populations.

2. Observations and sample selection

In this work, we identify dE galaxies in the SDSS-IV MaNGA survey (Blanton *et al.* 2017; Bundy *et al.* 2015). MaNGA is a multi-object IFU spectroscopic survey, and will target 10,000 galaxies by 2020. Stellar kinematics, ionised gas kinematics, emission

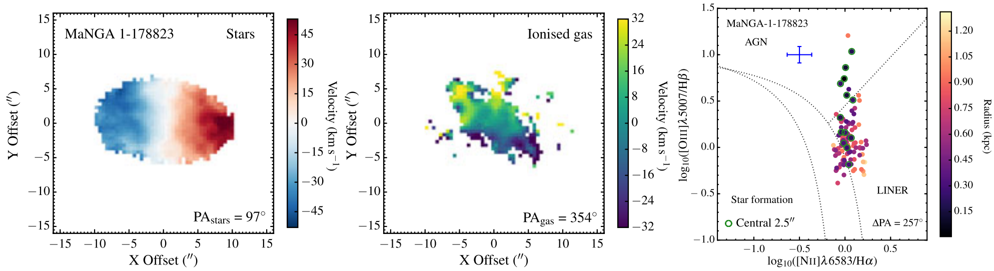

Figure 1. Stellar velocity maps (left panel), ionised gas velocity maps (middle panel) and spatially resolved BPT diagram (right pane) for an example dE AGN host galaxy. Spaxels in the central 2.5″ of each dE are circled in green. An offset in kinematic position angle is seen between the stellar and ionised gas components, and the central emission line ratios are consistent with AGN activity.

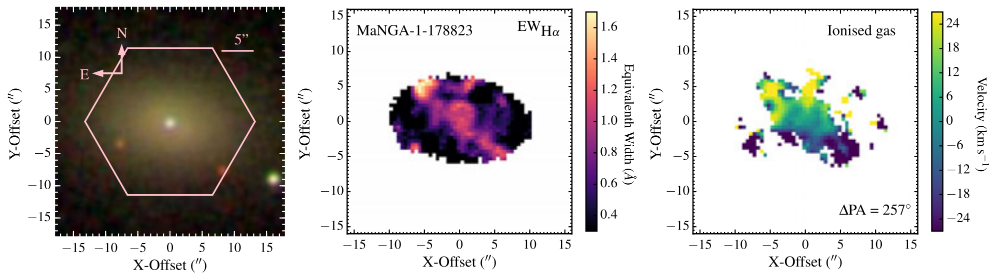

Figure 2. SDSS colour image (right panel), Hα equivalent width (middle panel), and ionised gas velocity map for an example dE AGN host. The MaNGA IFU footprint is shown as a pink hexagon. The bi-symmetric emission line features are similar to those observed in red geyser galaxies (Cheung *et al.* 2016), which maintain quiescence through low-level AGN feedback.

line fluxes, and equivalent widths were provided by the MaNGA data analysis pipeline (Westfall *et al.* in prep). Sixty-nine low-mass ($M_\star < 5 \times 10^9$ M$_\odot$), faint (M$_r > -19$), galaxies with no evidence of ongoing star formation within 1 R_e (Hα equivalent width < 3 Å) were drawn from the first two years of MaNGA data. 85 per cent of these dE galaxies exhibit coherent rotation in their stellar kinematics, suggesting these galaxies are morphologically transformed low-mass disc galaxies. For full details of the sample selection and stellar kinematics, see Penny *et al.* (2016) and Penny *et al.* (2018).

Fourteen dEs in this sample retain an ionised gas component, despite having red colours ($u - r > 1.9$) and low Hα equivalent widths (EW$_{H\alpha} < 3$ Å) consistent with no ongoing star formation. The ionised gas components for five of these are kinematically offset by $> 30°$ from their stellar component (Fig.1, left and middle panels). The ionised gas is co-rotating with the stars for 8 galaxies, and a kinematic offset could not be determined for one dE in our sample, as it does not exhibit rotation in its stellar component.

Using spatially resolved BPT (Baldwin *et al.* 1981) diagrams, we can identify the ionising source within these galaxies through their emission line flux ratios. Six galaxies have clear AGN-like emission line ratios at their centres (Fig.1, right panel), while the remaining 8 galaxies have line ratios consistent with composite AGN/star formation activity. For five of the AGN host galaxies, the kinematic position angle of the ionised gas is offset from that of the stars, indicating the two components are not in dynamical equilibrium. This kinematic offset is consistent with either gas accretion, or an outflow. Just one AGN host dE in our sample, MaNGA 1-230177, has stellar and ionised gas components that

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Table 1. Observed properties of the dwarf galaxy AGN hosts

MaNGA-ID	RA J2000.0	Dec J2000.0	z	M_r mag	$PA_{\star}$ $\circ$	PA_{gas} $\circ$
1-38618	03:30:29.42	−00:29:19.6	0.022	−18.84	45 ± 6.5	116 ± 9.4
1-379255	07:53:03.98	+52:44:35.5	0.018	−18.36	134 ± 18.4	22 ± 9.2
1-230177	08:19:35.49	+26:21:45.6	0.020	−18.82	37 ± 2.2	52 ± 5.0
1-178823	20:47:03.31	+00:26:12.4	0.013	−18.92	97 ± 1.7	354 ± 6.7
1-113520	21:10:00.53	+11:30:38.3	0.017	−18.98	65 ± 4.5	182 ± 1.8
1-29809	23:53:52.52	−00:05:55.4	0.022	−18.72	21 ± 4.4	232 ± 8.9

are co-rotating. For full details of the dE AGN hosts and sample selection, see Penny *et al.* (2018).

The AGN-host dEs also exhibit bi-symmetric emission line features (Fig.2), and resemble the red geysers identified in Cheung *et al.* (2016). Such galaxies maintain their quiescence through gentle AGN heating, and we suggest such a feedback process operates in these dE galaxies. Basic details for the six AGN host galaxies are given in Table 1.

3. Discussion and Conclusions

The presence of disk-like rotation in the majority of our sample of 69 dEs is consistent with the kinematics of dEs in the outskirts of the Virgo Cluster (e.g. Toloba *et al.* 2015). This rotation, along with faint spiral or disc-like structure (e.g. Lisker *et al.* 2006), is interpreted as evidence of a disc galaxy origin for dEs. Given the dEs in our sample are located in the galaxy group environment at small projected separation from giant galaxies brighter than $M_K = -23$ (Penny *et al.* 2016, 2018), we conclude most of our sample are quenched spiral galaxies that have been stripped of their star forming material.

Despite exhibiting optically red colours ($u - r > 1.9$) and weak Hα emission ($EW_{H\alpha} <$ 3 Å) inside $1\,R_e$ consistent with no ongoing star formation, 14 dEs in our sample retain an ionised gas component. Line strength diagnostics reveal 8 of these galaxies exhibit line ratios consistent with composite star formation/AGN activity, while the ionisation source for the remaining 6 dEs is likely due to AGN activity. Given their lack of current star formation activity, we suggest these six dEs are maintaining quiescence through AGN heating. This result implies maintenance-mode AGN feedback may play a role in suppressing star formation in dwarf galaxies, though environmental processes are likely the dominant quenching mechanisms for dE progenitors. Multi-wavelength follow-up observations are required to understand the role of AGN feedback in dE evolution.

Acknowledgements

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Discussion

Q1: How would you expect AGN to trigger in these cluster dwarfs?

A1: This would not be in clusters, but rather in outskirts where gas can be accreted. This would also help explain the bursty star formation we see in these.

Q2: Does the linear-like extended emission also play a role in quenching low mass galaxies in low density environments?

A2: Probably a consequence of the "red geyser" winds from AGN, not independent quenching effects from stellar feedback.

Q3: Given that it is believed that quiescent dwarfs evolve from star forming dwarfs, have you looked at rotation in your blue dwarf sample?

A3: We have IFU data for such galaxies, so this would definitely be an interesting follow up paper, and a good test of such a formation mechanism.

Q4: How far away are the galaxies in your sample, approximately?

A4: They are within about 100 Mpc

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