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Searching and Understanding the Presence of AGNs in Dwarf Galaxy Nuclei

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Abstract. Active Galactic Nuclei (AGNs) are compact and highly luminous regions located at the center of some galaxies that emit across the entire electromagnetic spectrum. In general, this extreme luminosity results from a mass accretion process driven by a supermassive black hole (SMBH). In the case of low-mass galaxies - those with stellar mass $M_* < 5 \times 10^9$ $M_\odot$ - the presence of AGNs is uncommon. If they occur, it is expected that the central black holes have masses less than 10^5 $M_\odot$, known as intermediate-mass black holes (IMBH). We used the Mapping Nearest Galaxies at Apache Point Observatory (MaNGA) survey to study a sample of low-mass galaxies posibly hosting an AGN, according to their excess emission at radio, infrared or X-ray wavelengths. We started analyzing the galaxies that exhibit optical emission line ratios typical of AGN as classified by the BPT diagram. The spectra of the central regions, show broad profiles of the Hα line emission. From these profiles we estimate black hole masses that range between 10^6 $M_\odot$ and 10^7 $M_\odot$.

Resumo. Os Núcleos Ativos de Galáxias (AGNs) são regiões compactas e altamente luminosas localizadas no centro de algumas galáxias que emitem em todo o espectro eletromagnético. Em geral, essa luminosidade extrema resulta de um processo de acreção de massa impulsionado por um buraco negro supermassivo (SMBH). No caso de galáxias de baixa massa - aquelas com massa estelar $M_* < 5 \times 10^9$ $M_\odot$ - a presença de AGNs é incomum. Se ocorrerem, espera-se que os buracos negros centrais tenham massas inferiores a 10^5 $M_\odot$, conhecidos como buracos negros de massa intermediária (IMBH). Utilizamos o levantamento de Mapeamento de Galáxias Mais Próximas no Observatório Apache Point (MaNGA) para estudar uma amostra de galáxias de baixa massa possivelmente hospedam um AGN, de acordo com seu excesso de emissão em comprimentos de onda de rádio, infravermelho ou raio-X. Iniciamos analisando as galáxias que exibem razões de linhas de emissão ópticas típicas de AGNs, conforme classificado pelo diagrama BPT. Os espectros das regiões centrais mostram perfis largos da linha de emissão Hα. À partir desses perfis, estimamos massas de buracos negros que variam entre 10^6 $M_\odot$ e 10^7 $M_\odot$.

Keywords. Galaxies: dwarf – Galaxies: active – Galaxies: nucleus

1. Introduction

It is a well-established fact that every massive galaxy harbors a supermassive black hole (SMBH) in its core (Kormendy & Ho 2013). The observed correlations between SMBH mass and galaxy bulge properties, such as velocity dispersion, luminosity, and mass, have led to the belief that the evolution of SMBHs is intimately connected to the evolution of host galaxies (Ferrarese & Merritt 2000). However, despite these correlations and understanding their relation to galaxy evolution, the proper formation and evolution of SMBHs is not yet fully understood. Intermediate mass black holes (IMBHs) found in local dwarf galaxies can play a crucial role in advancing our understanding of SMBH seed formation. The study of dwarf galaxies that host IMBHs offers valuable insights into the formation and evolution of SMBHs, shedding light on their interaction with their host galaxies. Additionally, comprehending the role of black holes (BHs) in less massive galaxies may hold the key to addressing various cosmological and galaxy evolution challenges, including active galactic nuclei (AGN) feedback, outflows, and the suppression of star formation in dwarfs. In general, the identification of IMBHs often involves the detection of AGNs. To achieve this, emission line diagnostic diagrams, commonly known as BPT diagrams (Baldwin, Phillips & Terlevich 1981), are employed. These diagrams play a crucial role in segregating line-emitting galaxies based on their primary excitation source, facilitating the distinction between gas ionization caused by AGNs and that originating from stars. Additionally, the utilization of broad Hα emission has proven effective in identifying low-mass AGNs (e.g., Greene & Ho (2007); Reines et al (2013)).

In this study, we use SDSS/MaNGA (Mapping Nearby Galaxies at APO; Bundy K., et al. (2015)) data to study a sample of candidate AGN in nearby low-mass galaxies ($M_* < 10^{9.6}$ $M_\odot$). First we want to check whether the AGN activity is confirmed at optical wavelengths using the BPT diagram, then we want to estimate the central BH masses using the approach outlined in Greene & Ho (2005). Lastly we want to analyze the properties of the host galaxies to understand the effect of the AGN on the evolution of low-mass galaxies.

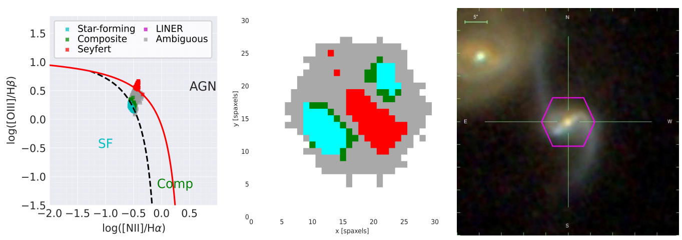

Figure 1: MaNGA analysis for object 9889-1902. Left: Location of each MaNGA spaxel on the BPT diagram. Middle: Spatial distribution of the BPT classified spaxels (color-coded as in the left panel). Right: SDSS composite image. The pink hexagon shows the IFU coverage of this object.

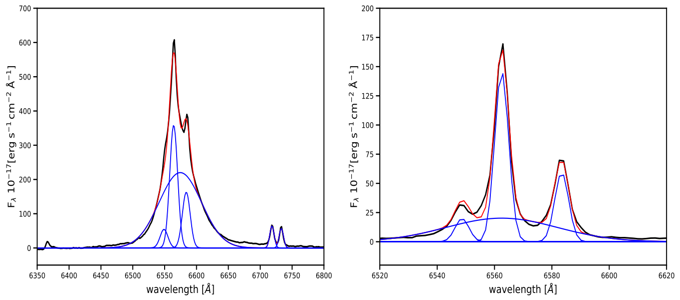

FIGURE 2: Best-fit results from the nuclear emission spectra of MaNGA 9000-1901 on the left and 8982-3703 on the right, both showing the broad Gaussian component in the $H\alpha$ profiles.

2. Data

Our sample is derived from the SDSS/MaNGA , which is an IFU spectroscopic survey of approximately 10,000 nearby galaxies (z < 0.1). The MaNGA AGN catalog Comerford et al. (2020), provides robust identifications of 406 AGN from the MaNGA sample, based on mid-infrared Wide-field Infrared Survey Explorer colors, Swift/BAT ultrahard X-ray detections, NVSS and FIRST radio observations. After applying a cut in stellar mass, $M_* < 10^{9.6}$ $M_\odot$, we obtained 16 low-mass galaxies hosting a candidate AGN.

3. Methodology

Our goal is to investigate whether the presence of an AGN can be also identified using MaNGA spectra, considering that optical observations provide valuable tools for estimating black hole masses. First we analyzed the BPT diagrams of the individual spaxels of the 16 candidates and we found that only 3 galaxies exhibit emission line ratios in their central regions consistent with the presence of an AGN (Fig. 1). This suggests that the BPT diagnostic may not be suitable to identify low-luminosity AGN in star-forming low mass galaxies as it has been found in previous studies (Birchall, Watson & Aird 2020). Two targets of the samples, MaNGA-9876-3702 and MaNGA-10220-12701, show LINER-like spectra in spaxels that are either at the border of the MaNGA FOV or well offset from the galaxy disk, and they have been excluded from this analysis. Here we focus on the galaxies that show clear evidence of AGN-like spectra in their central regions (Table 1). These three targets show broad emission line profiles, thus we fit the $H\alpha$ + [N II] doublets with a broad and narrow $H\alpha$ component, using the [S II] doublet to constrain the width of the narrow component (Fig. 2, Reines et al 2013).

4. Results

The FWHM of the broad components range between ~1600 and ~3600 km s^{-1}. We estimate the BH masses using Reines et al (2013), assuming that the kinematics of the gas in the broad-line region is dominated by the BH gravitational field:

$$\log\left(\frac{M_{\rm BH}}{M_\odot}\right) = 6.57{+}0.47\log\left(\frac{L_{H\alpha}}{10^{42}\ {\rm ergs}^{-1}}\right){+}2.06\log\left(\frac{{\rm FWHM}_{H\alpha}}{10^{3}\ {\rm kms}^{-1}}\right) \tag{1}$$

This equation was derived following the approach outlined in Greene & Ho (2005), but includes the updated radius–luminosity relationship from Bentz et al (2013).

We find black hole masses that range between 10^6 $M_\odot$ and 10^7 $M_\odot$, therefore, despite the small masses of these galaxies, their black holes are not IMBH, but rather appear to be SMBH.

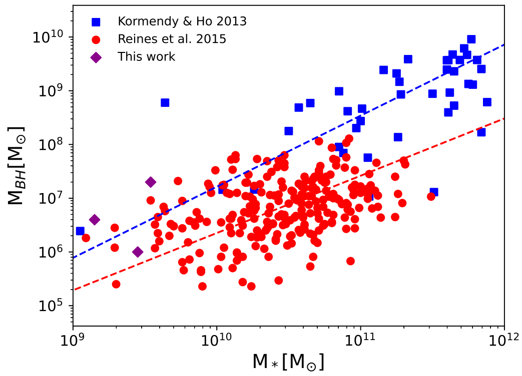

FIGURE 3: Comparison between black hole mass vs. total host galaxy stellar mass results obtained by Kormendy & Ho (2013) in bulge-dominated galaxies, Reines & Volonteri (2015) in late-type galaxies and this work

Table 1: Main properties of the AGN candidates

MaNGA-ID	$\log_{10}(M_\star/M_\odot)$	$\log_{10}(M_{BH}/M_\odot)$	FWHM [km/s]
9000-1901	9.54	7.3 ± 0.2	3572 ± 286
9889-1902	9.45	6.0 ± 0.2	1598 ± 128
8982-3703	9.15	6.6 ± 0.1	2101 ± 168

The scaling relation between masses in bulge-dominated galaxies Kormendy & Ho (2013) suggests that the evolution of massive BHs is linked to that of the bulge of their host galaxies and it provides important information on the assembly of galaxy structures. Furthermore, studies comparing BH and total stellar mass in late-type galaxies find shallower scaling relations, suggesting that the evolution of the black hole mass is not tightly linked to that of the disk mass (Fig.3, Reines & Volonteri 2015, hereafter RV15).

Our galaxies fall above the scaling relation expected for late-type galaxies, despite the significant amount of scatter observed in the sample of RV15. Our intention is to estimate the BH mass for the rest of the galaxies in the sample, looking for evidence of broad-line AGN in the MaNGA spectra and also employing additional methods to measure the BH masses (Guimarães et al., in prep). Lastly we will explore the impact of the AGN on the overall evolution of their host galaxy.

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