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Ionized gas outflows vs. “maintenance mode" feedback in MaNGA AGN

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Abstract. We present a study of the ionized gas of 297 Active Galactic Nuclei (AGN) host galaxies and 537 control galaxies observed in the MaNGA-SDSS survey using measurements of the [O III]λ5007Å emission line profiles. Studying the kinematics through the parameter W80 we identified kinematically disturbed regions (KDR) in the AGN, that present higher W80 values than controls. We obtain a median KDR extent of 5.17 kpc, that represents, on average, ≈ 60% of the extent of the region ionized by the AGN. We obtain mass-outflow rates ($\dot{M}_{out}$) and outflow kinetic powers ($\dot{E}_{out}$) for the AGN in the range 1–5.02 $\times 10^{-3}$ $M_\odot$ yr^{-1} and 2.5–10 $\times 10^{37}$ erg s^{-1}.

Resumo. Apresentamos um estudo sobre o gás ionizado de 297 AGNs e 537 galáxias de controle observadas com o MaNGA utilizando a linha de emissão de [O III]λ5007Å. Estudando a cinemática deste gás através do parâmetro W80, observamos que os AGNs possuem regiões cinematicamente perturbadas (KDR) que correspondem a valores maiores de W80 do que nos controles. Encontramos que a extensão mediana do KDR é 5.17 kpc, representando cerca de 60% da extensão de gás ionizada pelo AGN. Com base nos valores de W80, obtivemos taxas de ejeção de massa ($\dot{M}_{out}$) e potência destas ejeções ($\dot{E}_{out}$) nos intervalos 1–5.02 $\times 10^{-3}$ $M_\odot$ yr^{-1} e 2.5–10 $\times 10^{37}$ erg s^{-1}.

Keywords. Galaxies: active – Galaxies: kinematics and dynamics – Galaxies: nuclei

1. Introduction

Active Galaxy Nuclei (AGNs) are the nuclei of galaxies in which the Supermassive Black Hole (SMBH) is “active”, via capture of mass and its feeding to a nuclear SMBH via an accretion disk (1). The accretion process produces energy, and if this energy is efficiently coupled with the gas present in the central region and sometimes up to galactic scales, the AGN could have a significant impact – referred to as feedback, on its host galaxies. Feedback from AGN is believed to play an important role in regulating galaxy growth, in the form of radiation, jets and accretion disk winds that may heat and/or remove gas from the nuclear region of the host galaxy, suppressing star formation and impacting also in the surrounding intergalactic medium.

The goal of this work is to investigate the feedback processes from AGN on galactic scales in the present-day Universe. We use the [O III]λ5007Å (hereafter [O III] emission line to map the kinematics of the ionized gas in a sample of AGN as compared to control galaxies. We use as indicators of outflows the non-parametric measure W_{80} (Wylezalek et al. 2020) of the [O III] emission line, as well as a broad component to this line when present.

2. Data and Measurements

Our sample is drawn from the MaNGA-SDSS survey – Mapping Nearby Galaxies at APO (2) and comprises datacubes of 297 AGNs and 537 control galaxies, the selection following the methodology described in (Rembold et al. 2017).

The fits and resulting properties of the [O III] emission-line profiles were obtained using the code IFSCUBE (Ruschel-Dutra et al. 2020). We fit only the spaxels of the datacubes that have signal-to-noise ratio in the [O III] emission lines higher than 2. In our analysis, 45% of the AGNs showed a broadening in the [O III] line profile that required the use of two Gaussian curves to better fit the emission line, in the central region of the galaxy. The other galaxies did not present this broadening and we used only one component. In order to characterize the kinematic disturbance of the gas we used the parameter W_{80} which is the difference between the velocities V_{90} – the velocity corresponding to 90% of the line flux in the emission-line profile, and V_{10} – the velocity corresponding to 10% of the line flux (Harrison 2014; Wylezalek et al. 2020).

3. Results

In order to compare the values of W_{80} for the AGN with those for the control galaxies, we have built an histogram of the values from all spaxels of all galaxies, shown in the left panel of Fig.1: the distribution has a median at $\sim$ 321 km s^{-1} and $\sim$ 260 km s^{-1} for the AGN and control galaxies, respectively. The KS-test shows a very low p-value ($< 10^{-116}$) when comparing the AGN distribution to that of the control sample, revealing that the kinematic properties in these sources are distinct. The central panel shows the distribution of the median $\langle W_{80} \rangle$ values for each galaxy, that has a median value of 361 km s^{-1} for the AGN and 280 km s^{-1} for the controls. AGNs have a broader distribution of $\langle W_{80} \rangle$, reaching up to 600 km s^{-1}.

The right panel of Fig.1 shows a comparison of the median $\langle W_{80} \rangle$ values separately for the narrow and broad components with those of the control galaxies. The KS-test shows low p-values of about 10^{-5} when comparing the distribution of the AGN narrow component to the controls and of about 10^{-77} when comparing the distribution for the broad component to the controls. Thus, even the narrow component shows a distinct distribution from that of the controls, towards lower values of $\langle W_{80} \rangle$. We also find a significant positive correlation between $\langle W_{80} \rangle$ and the total [O III] luminosity (L [O III]). This correlation confirms previous results that the AGN luminosity plays a dominant role in introducing kinematic disturbances and outflows in the host galaxies.

We define a *kinematically disturbed region* (KDR) as the region where the AGN significantly affects the gas kinematics. We

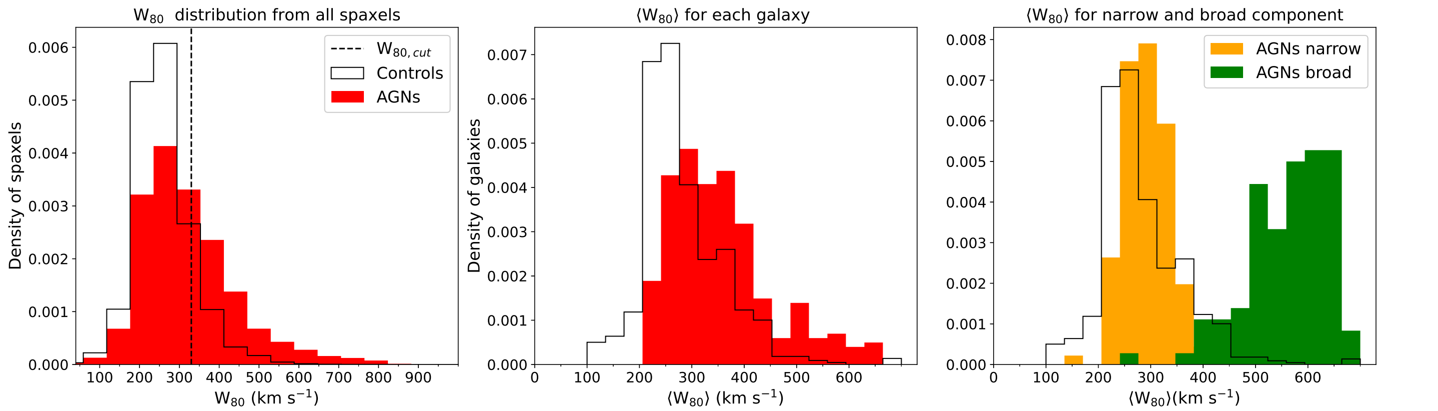

Figure 1. *Left panel:* Distribution of W_{80} measurements for each spaxel of the AGN and control samples. AGNs are shown in red and controls in gray. The dashed line shows the adopted cut value $W_{80,cut} \approx 330\,\mathrm{km\,s^{-1}}$ (see text). *Central panel:* The median value of W_{80} for each galaxy. *Right panel:* Median values of W_{80} from the narrow and broad component compared with control galaxies.

use the AGN and control samples W_{80} distribution to look for this “threshold" value $W_{80,cut}$ that characterizes the KDR. We define $W_{80,cut}$=260 + 71=330 km s^{-1}, where 260 km s^{-1} is the median and the α =71 km s^{-1} is the standard deviation of the W_{80} distribution for the controls.

The KDR is defined as the region with $W_{80} \geq W_{80,cut}$ and that contains only spaxels that are classified as AGN or composite in the BPT diagrams and obtain their extent R_{KDR}. We also define the region ionized by the AGN as that corresponding to the regions classified as AGN or composite in the BPT diagrams and obtain their extent R_{AGN}. We find medians of R_{KDR}=5.17 kpc and R_{AGN}=8.43 kpc, respectively, for these regions, showing that, typically, the extent of the KDR is about 60% that of the region ionized by the AGN.

Assuming that the KDR is due to an AGN outflow, we have adopted a spherical geometry to estimate the mass outflow rate and power of the outflow. We estimated the mass in outflow using the L [O III] emission line. The gas density was obtained from the [S II] 6718,31 emission lines ratio. We adopted two values for the outflow velocity: (i) W_{80} of the composite profile; (ii) the velocity of the broad component (for galaxies that have two components in the fit). The radius of the outflow is adopted to be R_{KDR}.

We find the following median values for the AGN: $\dot{M}_{out,W_{80}}$ = 5.02 $\times10^{-3}$ $M_\odot$ yr^{-1} and $\dot{M}_{out,W_{broad}}$ = 1 $\times10^{-3}$ $M_\odot$ yr^{-1}. These yield a mean kinetic power of the outflow $\dot{E}_{kin,W_{80}} = 2.67 \times 10^{37}$ $erg\ s^{-1}$ and $\dot{E}_{kin,broad} = 1.52 \times 10^{38}$ $erg\ s^{-1}$. In order to compare our results with previous ones from the literature, as well as to obtain the coupling efficiency of the AGN ($\epsilon_f = \dot{E}_{out}/L_{bol}$) we plot in Fig. 2 the individual values for $\dot{M}$ and $\dot{(E)}$ for our data and from the literature. We find that our data defines a locus in the plot filling the low luminosity end, approximately along the lowest sequence defined by previous studies, corresponding to a coupling efficiency of ≈ 0.01%.

4. Conclusions

The main conclusions of this work are:

– W_{80} [O III] are, on average higher in the AGN than in controls; we attribute this difference to kinematic disturbance due to an AGN outflow;
– The kinematic disturbance reaches large distances in the host galaxies, corresponding to ≈,60% of the extent of the region ionized by the AGN;

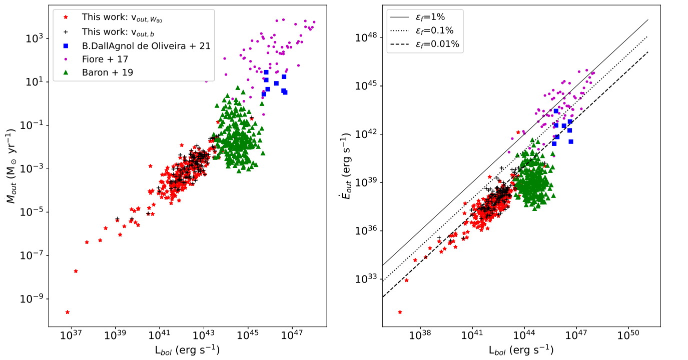

Figure 2. Mass outflow rate ($\dot{M}_{out}$, left) and outflow power ($\dot{E}_{out}$, right) as a function of the AGN bolometric luminosity (L_{bol}). Our data are presented as filled red stars, and black crosses. We added some data from literature: blue squares from ionized outflows of QSOs from (Dall'Agnol de Oliveira et al. 2021); the purple dots, for the ionized outflows from (Fiore et al. 2017); and the green triangle for (Baron & Netzer 2019). The solid, dotted and dashed black lines in left panel correspond to kinetic coupling efficiencies ϵ_f of 1%, 0.1% and 0.01%, respectively.

– The power of the outflow is proportional to the AGN luminosity, but its coupling efficiency is of the order of 0.01%, not enough to expel the gas from the galaxy, but can heat;
– The combination of low power and large distances (several kpc) reached by the disturbance configure what can be described as a “maintainance mode feedback".

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