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Identifying the extent of AGN outflows using spatially resolved gas kinematics

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Abstract. We present spatially resolved kinematics of ionized gas in the narrow-line region (NLR) and extended narrow-line region (ENLR) in a sample of nearby active galaxies. Utilizing long-slit spectroscopy from Apache Point Observatory (APO)'s ARC 3.5 m Telescope and *Hubble Space Telescope* (*HST*) we analyzed the strong λ5007 Å [O III] emission line profiles and mapped the radial velocity distribution of gas at increasing radii from the center. We identified the extents of Active Galactic Nuclei (AGN) driven outflows in our sample and determined the distances at which the observed gas kinematics is being dominated by the rotation of the host galaxy. We also measured the effectiveness of radiative driving of the ionized gas using mass distribution profiles calculated with two-dimensional modeling of surface brightness profiles in our targets. Finally, we compared our kinematic results of the outflow sizes with the maximum distances at which the gas is being radiatively driven to investigate whether these outflows are capable of disrupting or evacuating the star-forming gas at these distances.

Keywords. galaxies: active, AGN, NLR, kinematics, feedback, outflows

1. Introduction, Observations & Analysis

The AGN driven outflows observed in the NLRs and ENLRs are thought to play a crucial role in regulating the growth of supermassive black holes and the bulges of the host galaxies. It is important to quantify the significance of these outflows in affecting the star forming gas in the bulge. Our goal is to measure the sizes of AGN driven outflows in a sample of nearby Seyfert galaxies ($z < 0.05$) and determine the fractions of bulges that are being evacuated by these outflows. In this work, we present preliminary results for two of the galaxies in our sample. The long slit observations were taken using the Dual Imaging Spectrograph (DIS) at APO with a resolving power of $\sim$4000−5500. We employed a multiple component gaussian fitting routine (Fischer *et al.* 2017) to determine the wavelength centroids, widths and peak fluxes of the spatially resolved λ5007 Å [O III] emission lines along the slit. The gaussian parameters are used to map the kinematics, velocity dispersion and flux distributions of the ionized gas for different components. The left panel in Figure 1 shows the composite images of NGC 3227 and NGC 4051 with the APO slit positions. The pseudo-IFU diagrams (middle panel) show the velocity maps along the slits for the highest flux components.

2. Results

NGC 3227: We observed high blueshift velocities $\sim$900 km/s to the NE within $1''$ (72 pc) of the nucleus similar to Barbosa *et al.* (2009). There is evidence of faint

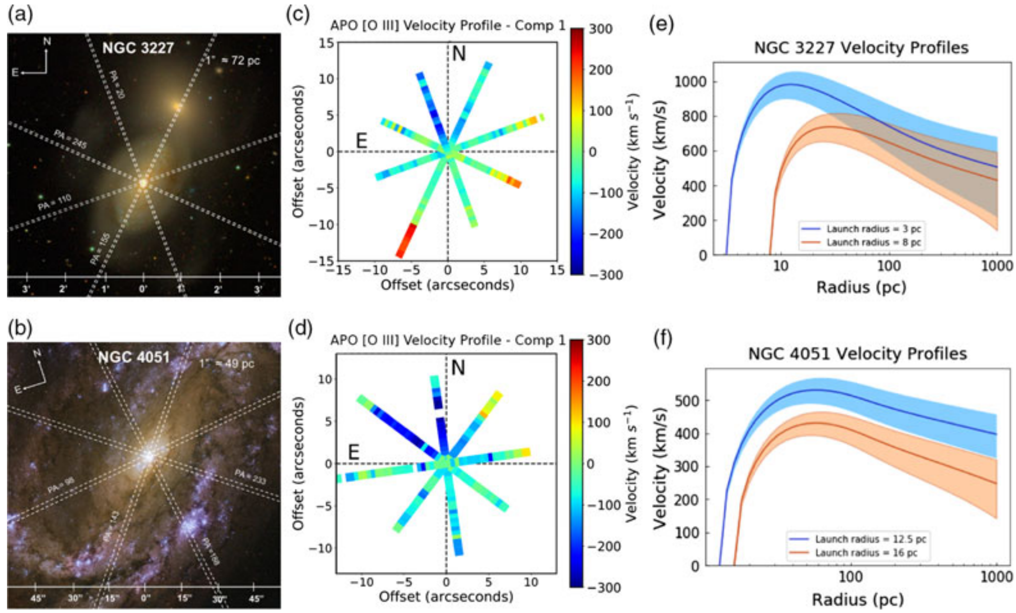

Figure 1. Left panel: (a) NGC 3227 (Sloan Digital Sky Survey) and (b) NGC 4051 (ESA/Hubble & NASA, D. Crenshaw and O. Fox) with the APO-DIS slit positions. Middle panel: Pseudo IFU diagrams for highest flux component. Right Panel: Model outflow velocity profiles calculated using the galaxy mass distribution and radiative driving pressure.

outflows up to $\pm 7''$ ($\sim$500 pc) to the NE and SW sides of the suggested bicone (Fischer *et al.* 2013). The kinematics along position angle (PA) of 155° shows redshift velocity of $\sim$200 km/s to the SW which is similar to stellar and CO velocities shown in Schinnerer *et al.* (1999).

NGC 4051: Blueshift outflows with velocities of $\sim$400 km/s up to $8''$ ($\sim$400 pc) were observed to the NE for PA 188° and PA 233°. That indicates front face of the bicone as seen in STIS (Fischer *et al.* 2013) and GMOS observations (Barbosa *et al.* 2009). Kinematics in PA 143° shows rotational velocity of 100 km/s outside the inner $\pm 5''$ with the NW (receding) and SE (approaching) similar to H_2 kinematics (Riffel *et al.* 2008).

Radiative Driving: We compared the observed velocities with velocities predicted via radiative driving models which was calculated from mass distribution M(r) and radiative acceleration (Das *et al.* 2007). The velocity profiles are plotted in the right panel of Figure 1. The velocities increase with decreasing launch radii and an increasing value of the force multiplier. The uncertainties are propagated considering a range of force multipliers from 2700 to 3300. Mass profiles to calculate the velocities were generated using 2D modeling of surface brightness profiles produced by Bentz *et al.* (2009). The effective radii of the bulges are 1200 pc and 860 pc for NGC 3227 and NGC 4051 respectively.

3. Conclusions

We identified the extents of outflows and found rotational signatures from the observed [O III] gas kinematics in NGC 3227 and NGC 4051. Preliminary velocities derived using radiative acceleration and enclosed mass profiles are consistent with the observed outflow velocities (within a few hundred pc). We observed that radiatively driven outflows terminate inside the bulges of these galaxies. This indicates that only a fraction of the bulges are being affected by AGN driven outflows as seen in Mrk 573 (Fischer *et al.* 2017).

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