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Radio-loud narrow-line Seyfert 1 galaxies with high-velocity outflows

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Abstract. We have studied four radio-loud Narrow-line Seyfert 1 (NLS1) galaxies with extreme optical emission-line shifts, indicating radial outflow velocities of up $2450\,\mathrm{km\,s^{-1}}$. The shifts are accompanied by strong line broadening, up to $2270\,\mathrm{km\,s^{-1}}$ in [NeV]. A significant ionization stratification (higher line shift at higher ionization potential) of most ions implies that we see a large-scale wind rather than single, localized jet-cloud interactions. The observations are consistent with a scenario, where the signatures of outflows are maximized because of a pole-on view into the central engine of these radio-loud NLS1 galaxies.

Keywords. Black holes, galaxies, emission lines, outflows, jets

1. Introduction

Powerful gaseous outflows in Active Galactic Nuclei (AGN) deposit mass, energy and metals in the interstellar medium of the host galaxy or on even larger scales (review by Fabian 2012). They therefore shape the structure and composition of the core environment, and may play an important role in unified models. The most powerful jets and outflows may significantly affect the co-evolution of galaxies and black holes by feedback processes, by regulating star formation, and possibly clearing the host galaxy off large fractions of its interstellar medium.

There is ample observational evidence for gaseous winds and outflows in AGN, which often manifest as kinematic shifts of optical emission lines. These are typically on the order of $100\,\mathrm{km\,s^{-1}}$ or less, but may be much higher especially in some high-redshift radio galaxies.

There are indications, that winds are especially strong in NLS1 galaxies, where accretion near the Eddington limit likely implies the presence of strong, radiation-pressure driven outflows (e.g. Komossa *et al.* 2008). Narrow-line Seyfert 1 galaxies are a subclass of AGN with extreme multi-wavelength properties. As a class, they are characterized by the narrow widths of their broad Balmer lines, super-strong FeII emission, ultra-steep X-ray spectra and enhanced variability. While NLS1 galaxies are on average more radio-quiet than broad-line AGN (Komossa *et al.* 2006), a small fraction of them is beamed and radio-loud (e.g. Komossa *et al.* 2006, Yuan *et al.* 2008).

2. Sample selection and results

In order to explore the presence and properties of powerful outflows in radio-loud NLS1 galaxies, we have analyzed four very radio-loud NLS1s from the sample of Yuan *et al.* (2008) which were initially noted for their shifted [OIII] emission lines, placing them in the class of "blue outliers". All four show extreme line shifts, among the highest measured so far. This is the first dedicated study of ionized gas outflows in a mini-sample

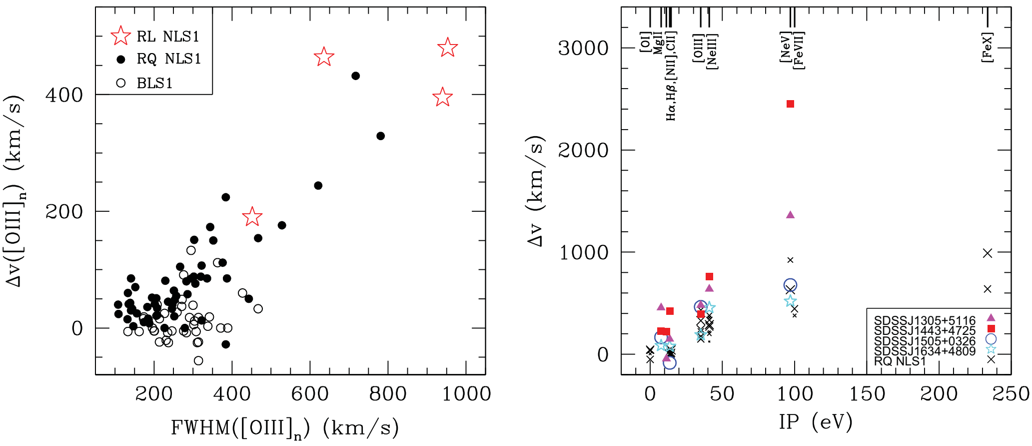

Figure 1. Left: Velocity shift – line width correlation of [OIII]λ5007. For comparison, the sample of Broad-line Seyfert 1 galaxies (open circles) and NLS1 galaxies (filled circles) of Komossa *et al.* (2008) is plotted. Right: Radial velocity as a function of ionization potential IP. The NLS1 galaxies of this study are marked by large grey symbols. For comparison, the nine "blue outliers" of Komossa *et al.* (2008) are shown (small black crosses).

of radio-loud NLS1 galaxies. In order to measure emission-line shifts and widths, we have analyzed the optical spectra of the four NLS1 galaxies, taken in the course of the Sloan Digital Sky Survey (SDSS DR7; Abazajian *et al.* 2009). Emission line shifts and widths were measured by fitting Gaussians to the lines (for details of the data preparation and analysis, see Komossa *et al.* 2015, in prep.).

Extreme emission-line blueshifts are present in all four galaxies (Fig. 1). In [OIII]λ5007, we measure a line width of FWHM($[\mathrm{OIII}]_{\mathrm{n}}$) = 950 km s^{-1} and a shift of $\Delta v([\mathrm{OIII}]_{\mathrm{n}})$ = 480 km s^{-1} (SDSSJ130522.75+511640.3), and $\Delta v([\mathrm{OIII}]_{\mathrm{n}})$ = 460 km s^{-1} (SDSSJ150506.48+032630.8). High-ionization lines of [NeV]λ3426 are present in all spectra, and show even higher shifts, with Δv([NeV]) = 2450 km s^{-1} (SDSSJ144318.56+472556.7) and Δv([NeV]) = 1360 km s^{-1} (SDSSJ130522.75+511640.3). The [OIII] emission lines follow a width-shift correlation, in the sense that more highly shifted lines are much broader (Fig. 1). Further, there is an overall trend among the observed emission lines of higher blueshift with higher ionization potential (Fig. 1). This finding implies that we see a large-scale flow rather than single, localized jet-cloud interactions.

Accreting close to the Eddington limit, NLS1 galaxies likely drive strong outflows. If high radio loudness in NLS1 galaxies is generally due to beaming, we expect a pole on view onto these galaxies, and so the effects of polar outflows are maximized, consistent with the findings presented in this work.

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