Systematic study of a large sample of NLS1 galaxies from SDSS: first results

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Abstract. This proceedings contribution summarizes first results obtained from a systematic study of 2011 NLS1 galaxies, as presented in Zhou et al. (2006, ApJS 166, 128). The sample was compiled by examining the spectral parameters of galaxies and QSOs derived from SDSS DR3 data. We discuss some preliminary results on the statistic properties of the sample, such as the fraction of NLS1, the properties of broad and narrow emission lines, and emission in other wavebands. The black hole mass – velocity dispersion relation for NLS1s was re-examined using the velocity dispersion values estimated from the stellar absorption spectra of the host galaxies. Preliminary result from an X-ray study for a small subset using data obtained by XMM-Newton is briefly discussed.

1. Introduction

Narrow line Seyfert 1 galaxies (NLS1s) are a special type of active galactic nuclei (AGN) whose optical spectra are similar to Seyfert 1 type, but with much narrower Balmer line width; they also show weak [OIII] lines and strong FeII emission in optical and UV (Osterbrock & Pogge 1985). The importance of NLS1s lies in that their properties are at the extremity among Seyfert 1 family, including steep soft X-ray spectra ($E < 2\text{keV}$) and rapid X-ray variability, strong blue wings of emission lines (e.g. Boroson & Green 1992; Laor et al. 1994; Wang 1996, Boller et al. 1996, Grupe et al. 1999, 2001, Xu, et al. 2003). Observational data show that NLS1 tend to have small black hole masses and the high Eddington ratios $L/L_{\text{Edd}}$ (e.g. Boroson 2002). In fact, they were found to locate at one extreme end of eigenvector 1 of the correlation matrix (Boroson & Green 1992, Sulentic et al. 2000), which is believed to be driven primarily by $L/L_{\text{Edd}}$. Radio-loud NLS1s were also found to exist, though their number is still small (e.g. Komossa et al. 2006).

Yet there are quite a few aspects about NLS1s where controversies remain or little study has been given to. The reasons can be ascribed partly to the relatively small number of NLS1 known (a few hundreds) before this work, as well as the heterogeneity of the objects as a whole. For example, little work has been done regarding broad band SED, associated outflows, radio-loud NLS1s

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and their jets, host galaxies, optical variability, mean spectrum and dispersion, the $M_{\text{BH}} - \sigma$ relation, as well as their cosmic evolution. A much larger and homogeneously selected NLS1 sample is required. With its large sky coverage and unprecedented sensitivity and uniformity, the spectroscopic survey of the Sloan Digital Sky Survey (SDSS; York et al. 2000) provides us with the most suitable database for discovering NLS1s. As a pioneer work, Williams et al. (2002) have compiled a sample of 150 NLS1 from the SDSS Early Data Release.

We carried out an extensive and systematic search for NLS1s by making use of the SDSS DR3 data, which yielded 2011 NLS1s, mostly previously unknown. The sample and preliminary statistical results are presented in Zhou et al. (2006). In this proceedings contribution, we summarize the sample properties and some of the significant results, with some new, preliminary development.

2. Sample and statistical results

2.1. Sample

Our NLS1s were drawn from the SDSS DR3 spectroscopic databases of both galaxies and QSOs. The data reduction procedure, as described in detail in Zhou et al. (2006), consists of mainly two steps. Firstly, star light contribution to fiber spectra from host galaxies is carefully removed by performing starlight-nuclear spectral decomposition using our algorithm (Lu et al. 2006) developed at University of Science of Technology of China. Our technique has proved to be accurate and robust when performing extensive testing against results from independent observations and measurement, including HST spectroscopic measurements (Wang T., et al. in prep.). Secondly, nuclear emission-line spectra—with the star-spectrum and continuum subtracted—are fitted to derive spectral parameters using the code as described in Dong et al. (2005). In this process, the Balmer emission lines are de-blended into a broad and a narrow component—this is essential as by doing so we could really measure the physical parameters of the broad line region. This process accounts for the difference in the results for some of the objects between our work and that of Williams et al. (2002).

We selected NLS1s as those having FWHM of the broad component of $\text{H}\beta$ or $\text{H}\alpha$ (detected at the $> 10\sigma$ confidence level) narrower than 2200 km s$^{-1}$. The 10% relaxed margin in the linewidth cutoff compared to the conventional 2000 km s$^{-1}$ (Goodrich 1989) is to recover those NLS1s dropped out due to the uncertainty in linewidth measurement. Our criteria resulted in 2011 NLS1 candidates. Using a stricter criterion of 2000 km s$^{-1}$ would reduce the sample to 1885 objects. All but one fulfill $\text{[OIII]}/\text{H}\beta < 3$—the second item of the conventional definition. We gave, along with the source list, measured spectral parameters and their error estimates. Below we summarize some of the preliminary results directly based on statistical analysis of observed and derived parameters; for details of these analysis please refer to Zhou et al. (2006).

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1A table of the sample including measured spectral parameters is available as on-line data associated with the paper Zhou et al. (2006, ApJS 166, 128).
2.2. Summary of statistical results

1) NLS1 fraction
We found a strong dependence of the NLS1 fraction among all Seyfert 1 AGNs. With increasing optical luminosity, the fraction of NLS1s first increases and peaks at \( M_g \sim -22 \), and then drops again rapidly. The NLS1 fraction also depends on radio-loudness, dropping from \( \sim 15\% \) in radio-quiet to only 5% in radio-loud objects. The NLS1 fraction in optically selected AGN sample is much lower than that in soft X-ray (ROSAT) selected AGN samples.

2) Emission line properties
On average the relative F\( \text{e}^{\text{II}} \) emission, \( R_{4570} = \frac{\text{Fe}^{\text{II}}(4434-4684)}{H\beta} \), in NLS1s is about twice that in normal AGNs, and is anti-correlated with the broad component width of the Balmer emission lines. The equivalent width of H\( \beta \) and Fe\( \text{II} \) emission lines are strongly positively correlated with the H\( \beta \) and continuum luminosities (the 'inverse' Baldwin effect). We do not find any difference between NLS1s and normal AGNs in regard to the Narrow Line Region.

3) \( M_{\text{BH}}-\sigma \) relation
We have examined the black hole mass vs. stellar velocity dispersion (\( \sigma \)) relation for a subsample of 308 NLS1s for which \( \sigma \) could be measured directly from fitting the starlight in the SDSS spectra with our stellar spectral templates. A significant correlation between \( M_{\text{BH}} \) and \( \sigma \) is found, but with the bulk of black hole masses falling below the values expected from the \( M_{\text{BH}} - \sigma \) relation for normal galaxies and normal AGNs (Figure 1, left panel). This result indicates that NLS1s are underage AGNs, where the growth of the SMBH lags behind the formation of the galactic bulge (see also, e.g. Mathur et al. 2001, Grupe et al. 2004, Bian & Zhao 2004, Botte et al. 2004). We also find that the width of [NII] is well correlated with \( \sigma \).

4) X-ray properties
635 NLS1s in the sample have X-ray counterparts detected in the RASS. The well-known anti-correlation between the width of broad low-ionization lines and the soft X-ray spectral slope for broad line AGNs extends down to \( \text{FWHM} \sim 1000 \text{ km s}^{-1} \) in NLS1s, but the trend appears to reverse at still smaller line widths. There are 28 NLS1s being observed by XMM-Newton either as targets or serendipitously, for which their spectra were analyzed. For most of the objects the 0.3–10 keV X-ray continuum can be fitted with a power law plus a soft X-ray excess, mostly well parameterized by a blackbody component. No significant Fe K\( \alpha \) line was detected. In Figure 1 (right panel) we plot the distribution of the photon indices of the underlying continuum derived from XMM-Newton data. The spectral slopes are systematically steeper than those for broad line Seyfert 1 galaxies, confirming previous results (e.g. Leighly 2000).

5) Radio-loud NLS1s
Of the sample 142 (7%) NLS1s were detected in radio in the FIRST survey. About two dozen are very radio loud (radio-loudness >100; Zhou et al. in prep.). Of particular interest, some objects show hybrid properties of NLS1 and blazar—with 2MASX J0324+3410 being an extreme example (Zhou et al. 2007, ApJ in press). A detailed investigation of radio-loud fraction of NLS1s is underway, by taking into account various selection effects in the SDSS spectroscopic survey.
Figure 1. Upper panel: The $M_{\text{BH}}-\sigma$ relation for 308 NLS1s for which $\sigma_*$ is reliably measured, with the dash line as the Tremaine et al. (2002) relation for normal galaxies. Lower panel: Distribution of the photon indices of the underlying 0.3–10keV X-ray continuum for those having XMM-Newton data
2.3. On-going and future work

We are currently working on updating the NLS1 AGN sample using the latest SDSS DR5 data. Other work currently undertaken includes: analyzing the X-ray spectral and temporal data for those having XMM-Newton and ROSAT observations, examining optical variability of NLS1 using the SDSS supernovae survey data (Ai et al. this proceedings), radio-loud NLS1s, broad-band SED. As for the future, we also plan to work on, as example, NLS1s’ host galaxies and their stellar populations and comparisons with those of broad line Seyfert AGNs, high-redshift NLS1s.

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