

## Discovery of Five Narrow-Line Seyfert 1 Galaxies and Implications on the NLS1 Model

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**Abstract** We report the discovery of five Narrow-Line Seyfert 1 galaxies (NLS1s) identified from the ROSAT All-Sky Survey bright sources. One of them has a quasar-like luminosity and two, including the quasar-like one, have close companions and/or show interacting features. We calculate the central black hole masses and Eddington ratios for the five NLS1s. In combination with the objects of Kaspi et al., we find that NLS1s have smaller central black hole masses and higher accretion rate than normal Seyfert 1s.

**Key words:** black hole physics – galaxy: active – galaxy: Seyfert – X-ray: galaxy

### 1 INTRODUCTION

Narrow-Line Seyfert 1 galaxies (hereafter NLS1s) are defined as Seyfert 1 galaxies with  $H\beta$  FWHM  $\leq 2000 \text{ km s}^{-1}$  (Osterbrock & Pogge 1985). While having narrower emission lines, they share all other spectral features with the typical Seyfert 1s, such as strong Fe II lines and line ratio  $[OIII]/H\beta < 3.0$ . In X-ray, they usually show rapid variability and a steep X-ray spectrum with soft X-ray excess (Boller et al. 1996; Leighly 1996).

Although some authors have argued that the differences between NLS1s and normal Seyfert 1s really represent a continuum of properties (Goodrich 1989), distinct NLS1 models have been proposed, such as smaller inclination of a disk-like Broad-Line Region (hereafter BLR) to the line of sight, or smaller black hole (hereafter BH) mass with higher (close to Eddington limit, in fact) accretion rate compared to normal Seyfert 1s (see a review by Boller et al. 1996). Currently, only  $\sim 200$  (While this paper was being written, Williams, Pogge, & Mathur (2002) published 150 NLS1s detected in the Sloan Digital Sky Survey) NLS1s have been found (Véron-Cetty & Véron 2001) and obviously more NLS1s are needed to understand their nature.

NLS1s are efficiently found in soft X-ray selected Seyfert 1 samples, in which they represent  $\sim 16\%$ – $50\%$  of all objects (Stephens 1989; Puchnarewicz et al. 1992), compared to  $\sim 10\%$  in optically-selected samples (Giannuzzo et al. 1998). Xu et al. (1999) have reported the discovery

of 18 NLS1s selected from ROSAT All-Sky Survey (hereafter RASS) bright sources. From the RASS Bright Source Catalog (hereafter RASS-BSC) we have now identified five NLS1s. We have calculated their BH masses and Eddington ratios, and, in combination with the objects reported in Kaspi et al . (2000), we have constrained the model of NLS1s.

**Table 1** Journal of Observations

ROSAT Name	Obs. Date <sup>†</sup>	Start Time <sup>†</sup>	Exposure(s)
1RXS J053353.0+704158	1999-11-04	19:58:40	3600
1RXS J102012.6+342837	1999-12-12	18:20:16	3600
1RXS J133209.8+842412	2000-06-27	13:23:25	1800
1RXS J150017.7+104424	2000-06-30	12:59:47	1600
1RXS J161323.5-091742	2000-06-30	14:53:18	1300

<sup>†</sup> The observation date and start time have been converted to the universal time.

**Table 2** Optical and X-ray Data

ROSAT Name (1RXS J)	R.A. (J2000)	DEC	$B$	$z$	$M_B$	Count Rate (cts s <sup>-1</sup> )	HR1	HR2	$f_x$ (erg s <sup>-1</sup> cm <sup>-2</sup> )
J053353.0+704158	05:33:53.82	+70:41:54.3	15.9	0.052	-21.16	0.0841	0.76	-0.24	$6.14 \times 10^{-12}$
J102012.6+342837	10:20:12.74	+34:28:39.3	17.7	0.111	-20.60	0.0920	-0.47	0.21	$1.17 \times 10^{-12}$
J133209.8+842412	13:32:11.37	+84:24:15.7	16.3	0.170	-23.47	0.1266	0.72	0.13	$7.88 \times 10^{-12}$
J150017.7+104424	15:00:17.80	+10:44:40.8	17.7	0.114	-20.73	0.0832	-0.17	-0.63	$1.74 \times 10^{-12}$
J161323.5-091742	16:13:24.18	-09:17:37.4	18.1	0.130	-21.48	0.0874	1.00	0.09	$8.41 \times 10^{-12}$

## 2 OBSERVATIONS AND RESULTS

The five objects are all ‘blank field’ sources in the RASS-BSC, i.e., they have no counterparts in any other catalog within a search radius of  $300''$  around them. Their high X-ray fluxes make them good AGN candidates. The optical spectroscopic observations were carried out at the Xinglong Station, National Astronomical Observatories in 1999 and 2000. Table 1 lists the observational parameters. We used the 2.16 m telescope and OMR spectrograph with a grating of  $195\text{\AA}/\text{mm}$ . The spectral coverage is  $4000 \sim 8500\text{\AA}$  with a resolution of about  $10\text{\AA}$ . Data reduction and line measurements were done with IRAF. All the five spectra are displayed in Fig. 1. The emission lines are labeled in the first spectrum.

The optical and X-ray data on these five NLS1s are presented in Table 2. The X-ray fluxes are calculated by assuming power spectra  $F_{\text{photon}} \propto E^{-\Gamma}$  with an average X-ray photon index  $\Gamma = 3.0$  for NLS1s (Karl 1999). The optical positions and  $B$  magnitudes are taken from the on-line APM catalog<sup>1</sup>. The accuracy of the magnitude varies from 0.1 magnitude for most objects to 0.3 magnitude for the objects near the faint end of the plate. The absolute magnitudes are calculated for  $H_0 = 75.0 \text{ km s}^{-1} \text{ Mpc}^{-1}$  and  $q_0 = 0.5$ , and with Galactic extinction correction. The line fluxes and line widths (FWHMs) are measured using SPECTOOL and checked with SPLOT within IRAF environment. The  $H\beta$  line is fitted with a Lorentz profile, which is typical of the NLS1 class (e.g., Moran, Halpern & Helfand 1998).

<sup>1</sup> <http://www.ast.cam.ac.uk/~mike/apmcat/>

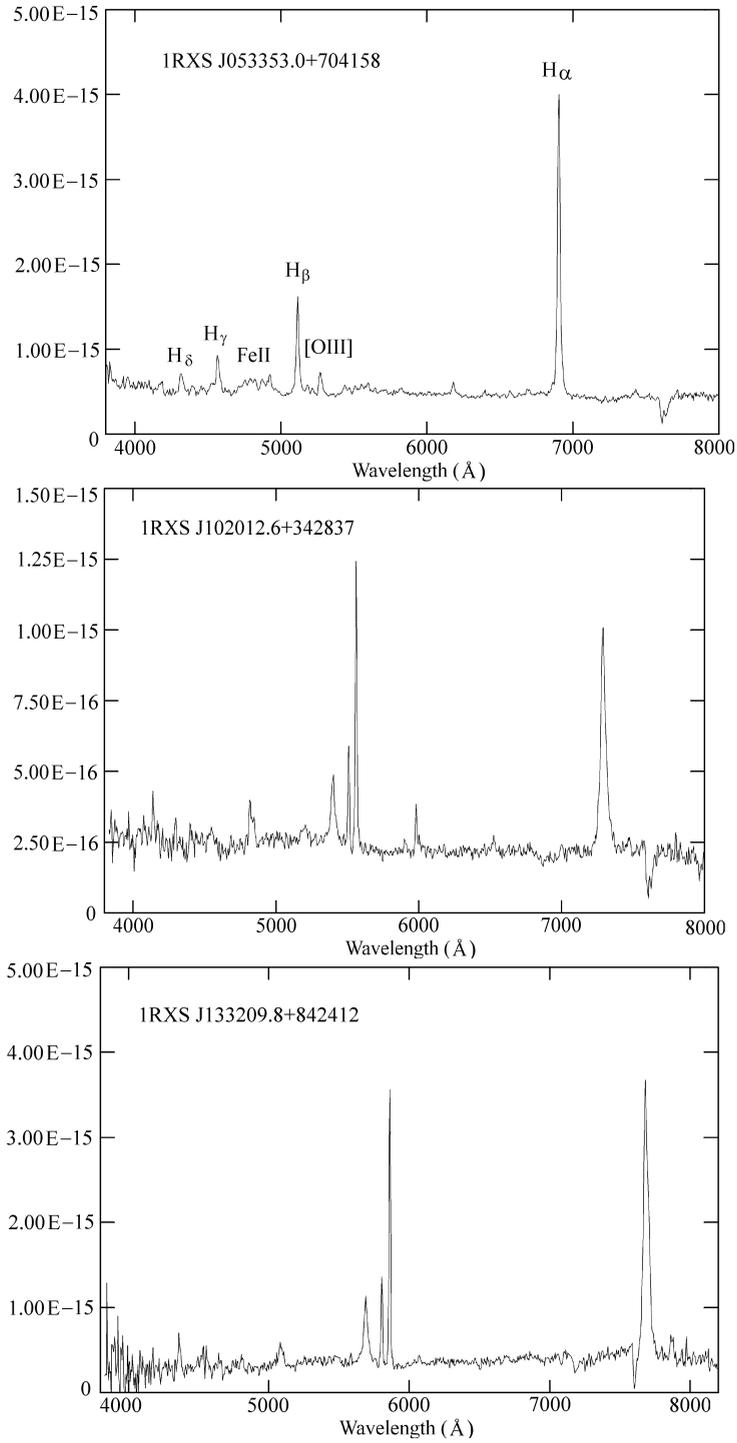


Fig. 1 Spectra of the identified five NLS1s. The spectral flux ( $F_\lambda$ ) is in  $\text{erg cm}^{-2} \text{s}^{-1} \text{Å}^{-1}$ .

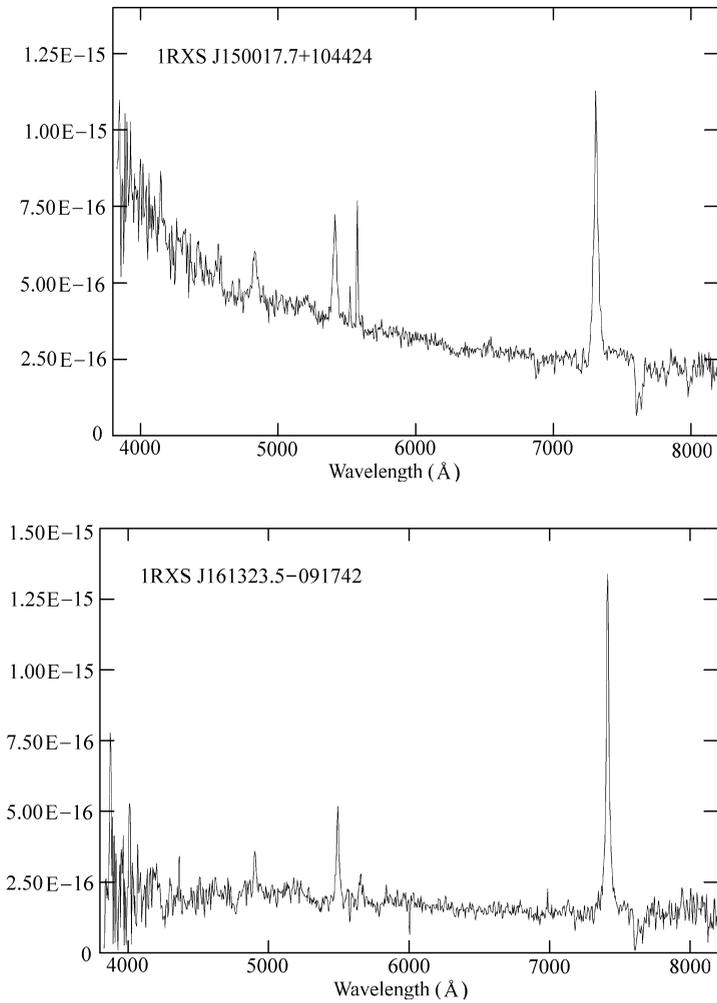


Fig. 1 Continued.

### 3 INDIVIDUAL COMMENTS

Objects 1RXS J102012.6+342837 and 1RXS J133209.8+842412 both have a companion object and show interacting features (see the DSS finding charts in Fig. 2). The former has a fainter companion in its southwest. Spectroscopic observation revealed an AGN with the same redshift and the results will be reported in another paper. The latter shows a very disturbed morphology. The nucleus is in the east and its host galaxy extends to the west and then curves to the north and points to a very faint companion at the northwest. It is worthwhile to dedicate further observations on this system.

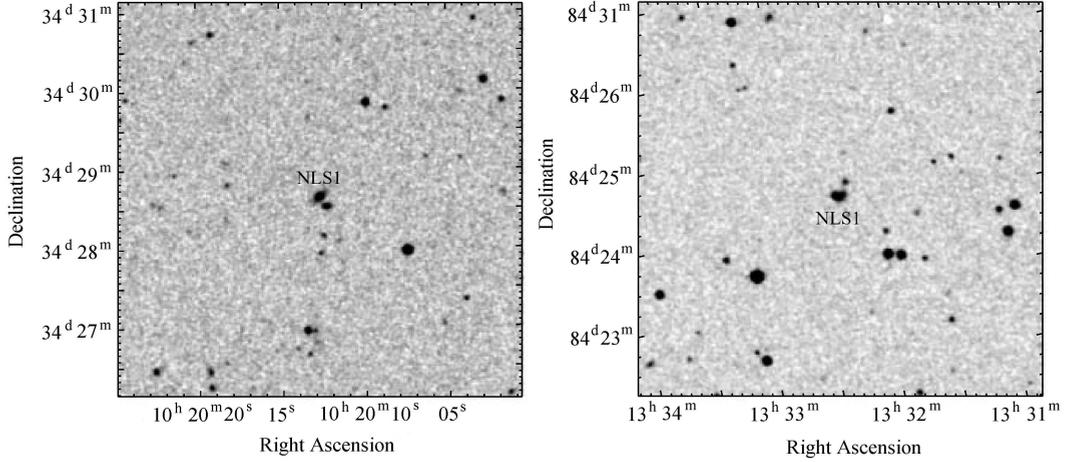


Fig. 2 Finding charts of 1RXS J102012.6+342837 and 1RXS J133209.8+842412, both are in possible interacting systems. Each chart covers an area of  $5' \times 5'$  and is centered on the X-ray position.

Object 1RXS J133209.8+842412 has a quasar-like luminosity ( $M_B = -23.47$ ). It is much brighter than the other four NLS1s. Véron-Cetty and Véron (2001, 10th edition) have listed 55 NLS1s with quasar-like luminosities, 27 of which were identified from ROSAT X-ray sources. Our discovery adds one more to this class of objects. The questions are still open whether they represent a distinct population of AGNs, or are correlated with typical quasars and represent the long-sought type 2 quasars (e.g. Norman et al. 2002).

#### 4 BLACK HOLE MASSES OF NLS1s

The virial mass of a BH at the center of an AGN can be calculated by

$$M_{\text{BH}} = v_{\text{BLR}}^2 R_{\text{BLR}} / G. \quad (1)$$

The velocity of the BLR clouds can be estimated from the FWHM of the H $\beta$  line,  $v_{\text{BLR}} = f \times v_{\text{FWHM}}$ , where  $f$  is a factor depending on the BLR geometry and kinematics. Although there are still some uncertainties, the most commonly used value is  $f = \sqrt{3.0}/2.0$ , to account for the velocities in three dimensions and for using half of the FWHM. The size of the BLR can be estimated from the empirical  $R_{\text{BLR}} - \lambda L_{\lambda}(5100 \text{ \AA})$  relation obtained by Kaspi et al. (2000),

$$R_{\text{BLR}} = (32.9^{+2.0}_{-1.9}) \left[ \frac{\lambda L_{\lambda}(5100 \text{ \AA})}{10^{44} \text{ erg s}^{-1}} \right]^{0.700 \pm 0.033} \text{ lt-days}. \quad (2)$$

The virial mass is then (Kaspi et al. 2000)

$$M = 1.464 \times 10^5 \left( \frac{R_{\text{BLR}}}{\text{lt-days}} \right) \left( \frac{v_{\text{FWHM}}}{10^3 \text{ km s}^{-1}} \right)^2 M_{\odot}. \quad (3)$$

The physical properties of the five NLS1s are summarized in Table 3. The monochromatic luminosities at 5100  $\text{\AA}$  are calculated from the APM  $B$  magnitude with an adopted optical

spectral index of  $\alpha = -0.5$  ( $f_\nu \sim \nu^\alpha$ ) and an uncertainty of 0.2 mag. The Eddington luminosities are computed from the obtained BH masses with  $L_{\text{Edd}} = 1.3 \times 10^{38} \times M_{\text{BH}}$  (Lang 1999). The bolometric luminosities are roughly estimated as  $L_{\text{bol}} \approx 9\lambda L_\lambda(5100 \text{ \AA})$  (Kaspi et al. 2000).

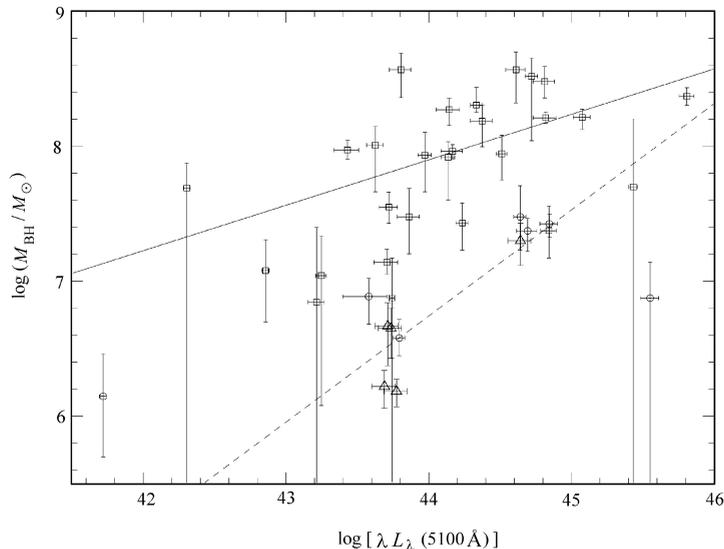


Fig. 3 Distribution of the five NLS1s (denoted in triangles) in the luminosity-mass plane. Also plotted are 34 objects presented in Kaspi et al. (2000), among which 27 are broad-line objects (quasars and normal Seyfert 1s) (squares), and seven are NLS1s (circles). The solid and dashed lines are best fits to the 27 broad-line AGNs and 12 NLS1s, respectively.

In the BH mass vs. luminosity plot of Fig. 3, the triangles are the five NLS1s reported here, the squares are the 27 broad-line AGNs (quasars and normal Seyfert 1s) in the list of 34 objects of Kaspi et al. (2000), and the circles are the seven NLS1s in the same list.

**Table 3** Physical Properties

ROSAT Name (1RXS J)	[OIII]/H $\beta$	H $\beta$ FWHM (km s $^{-1}$ )	$\lambda L_\lambda$ (5100 $\text{\AA}$ ) ( $10^{43}$ erg s $^{-1}$ )	$M_{\text{BH}}$ ( $10^6 M_\odot$ )	$L_{\text{Edd}}$ ( $10^{44}$ erg s $^{-1}$ )	$L_{\text{bol}}/L_{\text{Edd}}$
053353.0+704158	0.19	780 $\pm$ 40	5.95 $\pm$ 1.10	1.53 $\pm$ 0.35	1.99 $\pm$ 0.46	2.70 $\pm$ 0.13
102012.6+342837	1.25	1430 $\pm$ 260	5.16 $\pm$ 0.95	4.65 $\pm$ 2.29	6.04 $\pm$ 2.98	0.77 $\pm$ 0.24
133209.8+842412	1.26	1400 $\pm$ 150	43.9 $\pm$ 8.09	20.0 $\pm$ 6.85	25.9 $\pm$ 8.90	1.52 $\pm$ 0.24
150017.7+104424	0.34	1380 $\pm$ 190	5.44 $\pm$ 1.00	4.49 $\pm$ 1.82	5.84 $\pm$ 2.36	0.84 $\pm$ 0.19
161323.5-091742	0.23	870 $\pm$ 80	4.90 $\pm$ 0.90	1.66 $\pm$ 0.52	2.16 $\pm$ 0.67	2.04 $\pm$ 0.26

The solid and dashed lines are the best fits to the 27 broad-line AGNs and 12 NLS1s, respectively. Measurement errors in both variables are taken into account in the fitting (Press et al. 1992). It is clear that the BH masses of NLS1s are one order of magnitude smaller than those of broad-line AGNs. At high luminosity, however, NLS1s approach the broad-line objects in BH mass.

The Eddington ratio ( $L_{\text{bol}}/L_{\text{Edd}}$ ) distributions are plotted in Fig. 4 for the broad- and narrow-line objects. The NLS1s in general have higher Eddington ratios than broad-line objects.

After excluding two outliers (the lower-left object NGC 4051 and the lower-right object PG 1704, both are far away from the regression line mentioned above (Peterson et al. 2000; Vestergaard 2002)), the remaining 10 NLS1 objects have an average Eddington ratio of 1.36, while the 27 broad-line AGNs, one of 0.30. The higher Eddington ratio implies a higher accretion rate in NLS1s.

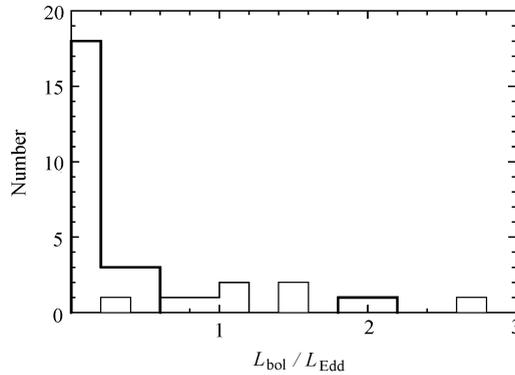


Fig. 4 Distribution of the Eddington ratios of 26 broad-line AGNs (thick line) and 10 NLS1s (thin line). NGC 4051 and other two objects with Eddington ratios larger than 3.0 have been excluded.

Thus, our statistics suggests that NLS1s have smaller mass BHs and higher accretion rates as compared to normal Seyfert 1s. In fact, smaller mass BHs have also been reported for NLS1s by Oshlack et al. (2001) and Puchnarewicz et al. (2001). By using the tight correlation between BH mass and bulge velocity dispersion, Wu & Han (2001) estimated the BH masses and inclination angles for a sample of 11 Seyfert 1s. Their results indicate that NLS1s have smaller mass BHs than normal Seyfert 1s but do not have significantly different inclination angles. Smaller BH mass also helps to explain the rapid X-ray variability found in NLS1s since the light crossing time and dynamical timescale of the central engine would be smaller.

## 5 CONCLUSIONS

We report the discovery of five NLS1s identified from the RASS bright sources. Two of them have close companions and/or show interacting features. We calculate their central BH masses and Eddington ratios and the results show that NLS1s have smaller mass BHs and higher accretion rates than normal Seyfert 1s.

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