Astron. Astrophys. 320, 395–398 (1997)

ASTRONOMY AND ASTROPHYSICS

Spectroscopy of narrow emission line X-ray galaxies

Lutz Wisotzki* **and Norbert Bade**

Hamburger Sternwarte, Gojenbergsweg 112, D-21029 Hamburg, Germany (e-mail: lwisotzki@hs.uni-hamburg.de / nbade@hs.uni-hamburg.de)

Received 7 May 1996 / Accepted 11 July 1996

Abstract. We present new X-ray and optical data of six emission line galaxies detected as sources in the ROSAT all-sky survey, of which previous optical spectroscopy had resulted in ambiguous classifications. Our high S/N optical spectra show all targets to be AGN, with five narrow-line Sy 1 galaxies and one of type Sy 1.8. Three objects have permitted lines of FWHM $\lesssim$800 km/s, only slightly broader than the forbidden lines. In all five narrow-line objects, the Fe II line complexes can be detected. The X-ray spectral properties of the sample, however, are consistent with a random AGN sample, and neither particularly soft X-ray spectral slopes, nor significantly enhanced variability can be seen. We briefly discuss the implications for the optical identification of current and future deep X-ray surveys.

Key words: Galaxies: Seyfert – Quasars: emission lines – X-rays: galaxies

1. Introduction

Within the ROSAT all-sky survey, a significant fraction of the detected sources are emission line galaxies (Voges et al. 1996). While the X-ray luminosities of AGN cover a wide range of $< 10^{41}$ erg s^{-1} up to more than 10^{45} erg s^{-1} (all luminosities in this paper refer to the ROSAT band, $h\nu = 0.1 - 2.4$ keV, adopting $H_0 = 50$ km s^{-1} Mpc^{-1}), with no firm lower or upper boundary known, this is generally thought to be different with H II-type galaxies (i.e. starbursts etc.), where the X-ray emission originates largely in stellar debris (X-ray binaries, SNRs). There seems to be a sharp cutoff around $L_X \simeq 10^{42}$ erg s^{-1}. X-ray sources more luminous than that mostly showed clear AGN signatures in their optical spectra (Stocke et al. 1991; Bade et al. 1995, hereafter referenced as Paper I). Also, the ROSAT band X-ray spectra of most AGN tend to be softer than those of starburst galaxies.

However, some observers have recently reported starburst-like optical spectra in objects with luminosities well in excess of the formerly stated limit, often even with $L_X \gtrsim 10^{43}$ erg s^{-1} (Boller et al. 1992, 1994; Ward et al. 1994; Fruscione & Griffiths 1991; Griffiths et al. 1995). If a population of X-ray luminous "super-starbursts" really exists, it may have profound consequences for the origin of the cosmic X-ray background. Alternatively, these objects may be true AGN hidden behind some sort of optically opaque but X-ray transparent screen, with similar implications for the X-ray background. Of course, there remains always the option that objects were misclassification due to inappropriate optical spectra. That the latter is likely to be relevant was demonstrated by Moran et al. (1994) and Halpern et al. (1995) who reclassified many objects as AGN that were previously described as "starburst-like".

Table 1. The observed galaxy sample. Luminosities are given in erg s^{-1} for H_0 = 50 km s^{-1} Mpc^{-1}. The (approximate) optical magnitudes refer to the nuclear components only.

Target	redshift	M_B	log L_X
Mrk 646	0.054	−20.3	43.6
RX J13291+2950	0.047	−19.2	43.5
RX J15088+6814	0.059	−21.6	43.2
RX J16333+4719	0.116	−22.2	44.6
RX J17035+4540	0.061	−21.7	44.5
RX J17260+7431	0.052	−20.4	43.9

We present here the results of a combined X-ray and optical investigation of a sample of X-ray loud galaxies, selected from a large compilation of optically identified ROSAT sources as part of the Hamburg/MPE Garching collaboration (Paper I). There we stated that 14 (out of 283) identified ROSAT sources showed optical spectra suggestive of H II-type activity. However, their X-ray properties, determined from low-quality survey data, seemed to be more indicative of AGN. Five objects were subsequently re-observed with ROSAT in pointed mode to obtain reliable spectral information.

We also secured improved optical spectra of these sources, plus an additional object out of the above 14. Some basic properties of the sample are listed in Table 1.

2. X-ray observations

For three of the investigated objects (Mrk 646, RX J13291 + 2950 and RX J16333+4719) we obtained pointed ROSAT

Send offprint requests to: L. Wisotzki

* Visiting Astronomer at the German-Spanish Astronomial Center, Calar Alto, operated by the Max-Planck-Institut für Astronomie, Heidelberg, jointly with the Spanish National Commission for Astronomy

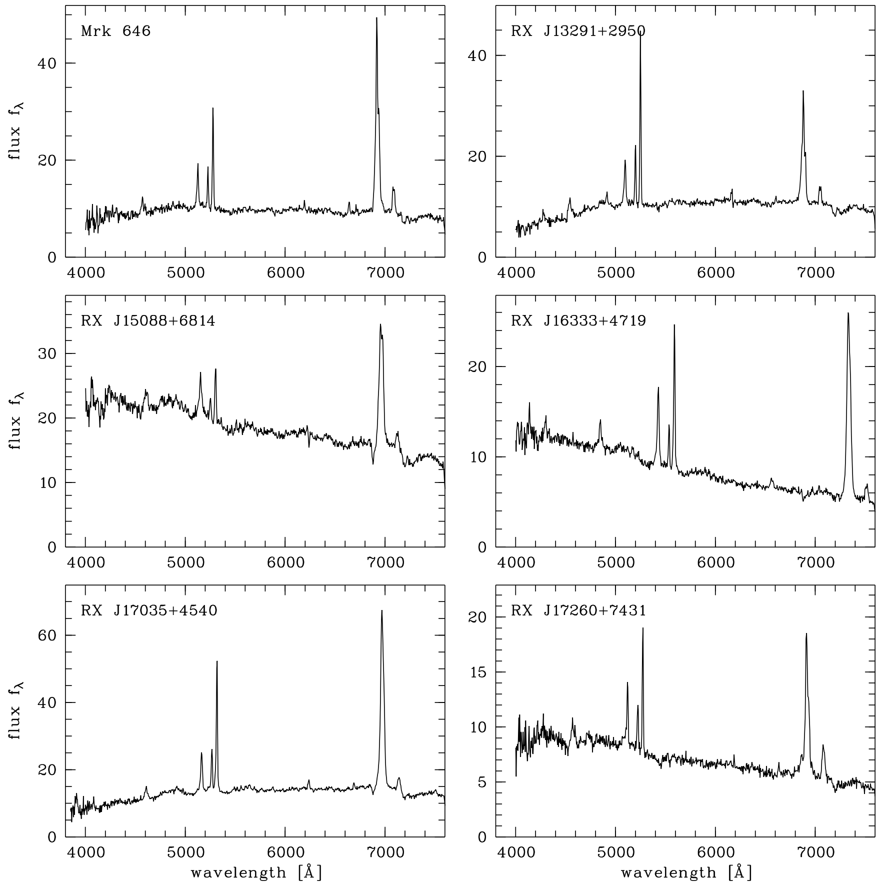

Fig. 1. Optical spectra of the six target galaxies. Fluxes are given as f_λ in arbitrary units

PSPC observations. For another two (RX J17035+4540 and RX J17260+7431), PSPC pointed observations were extracted from the ROSAT public archive. For RX J15088+6814 only the ROSAT all-sky survey (RASS) data already presented in Paper I were available. Source extraction, background reduction and data preparation were performed with the EXSAS software package. For the spectral analysis, simple power law descriptions were used to ease comparisons with other published objects. The results of the spectral fits are given in Table 2.

The simple power-law model gives an adequate description of the spectra of all analysed objects, only RX J16333+4719 revealed a more complex spectral behaviour. For this source, the description with a power law is statistically acceptable, but there are systematic deviations. A broken power law (with a steep energy index of α_E = 3.1 below 0.52 keV and a flat α_E = 0.2 for energies up to 2.4 keV) significantly improves the fit. More physical models (additional black body or bremsstrahlung component) fail to remove the deviations.

If the Galactic hydrogen column N_H is left as a free fit parameter in the simple power law fit to the pointed observation of RX J17035+4540, $N_H = 3.34 \pm 0.56 \times 10^{20}\,cm^{-2}$ is calculated. This is significantly higher than the Galactic value $N_H = 1.15 \times 10^2\,cm^{-2}$ (Stark et al. 1992). A fit with N_H fixed to that value must be statistically rejected with $\chi^2/\nu == 4.63$. RX J17035+4540 therefore belongs to the rare AGN with intrinsic absorption. This result was already found in the RASS data on a lower significance level (Paper I), where only one other such example was found in a sample of 75 objects.

For an X-ray timing analysis the data were binned into time intervals of 400 s, or integer multiples of 400 s, necessary to avoid artificial flux variations caused by the satellite wobble motion of 400 s period. No significant flux variability was detected for five of the six objects, while RX J13291+2950 showed to be strongly variable. The count rate changed nearly a factor of 10 between minimum and maximum. The background did not change significantly over the observing period and accompanying bright X-ray sources on the PSPC image did not follow the variability behaviour of RX J13291+2950, thus supporting the reality of this high flux variability amplitude. Further quantitative estimations about short time variability are limited by the fact that the pointed observation of RX J13291+2950 is split into many short intervals, so that often the intervals are shorter than the wobble period. If the restriction to the wobble period is loosened, an event with a doubling period shortly below 800 s is observed. We found no significant variations in spectral properties for this object.

3. Optical spectroscopy

Medium-resolution spectra were obtained during two nights (1 and 3 July, 1994) at the Calar Alto 2.2 m telescope using the then new focal reducer & spectrograph CAFOS, equipped with a Tek-

Table 2. X-ray spectral properties. Listed are the parameters from free power law fits for the five targets with pointed PSPC observations. T is the integration time, χ^2/ν the reduced goodness-of-fit parameter. For RX J15088+6814, only the parameters from the power law fit with N_H fixed to the Galactic value based on RASS data (Paper I) was available.

Target	T [s]	count rate [s^{-1}]	N_H [10^{20} cm^{-2}]	α_E	f_X [erg cm^{-2} s^{-1}]	χ^2/ν
Mrk 646	1874	0.397 ± 0.015	1.2 ± 0.6	1.23 ± 0.16	5.6 ± 1.4	0.76
RX JI3291+2950	7037	$0.080 + 0.004$	1.0 ± 0.7	1.49 ± 0.14	1.0 ± 0.1	1.13
RX J15088+6814		0.04 ± 0.01		1.93 ± 0.87	0.9	
RX JI6333+4719	3880	0.223 ± 0.008	0.4 ± 0.3	1.20 ± 0.36	1.9 ± 0.3	1.15
RX J17035+4540	2758	0.595 ± 0.016	3.3 ± 0.6	1.39 ± 0.23	19.5 ± 4.2	0.51
RX J17260+7431	10578	0.107 ± 0.004	2.9 ± 0.6	0.90 ± 0.26	3.0 ± 0.5	1.05

tronix CCD of 1024×1024 pixels. Using the B-400 grism and a slit of $2''$, a spectral resolution (FWHM) of 12Åwas reached, with spectra covering the range from 3800–8100Å. Unfortunately, the spectrograph suffered from coma aberration due to incorrectly manufactured optics, and full resolution could only be maintained in the central parts of the spectra, i.e. between $\sim$ 5000 and 6500Å, while unresolved spectral lines outside this range assumed a triangular shape.

As we were mainly interested in the Hβ/[O III] and Hα/[N II] complexes and other lines within the such defined interval, the aberration problem did not seriously compromise the usefulness of our spectra. Somewhat more affected were a few higher resolved spectra obtained with the R-200 grism. Although the nominal resolution was $\sim$ 5 Å, the instrumental profile near Hα was already considerably distorted, and the effective resolution was only $\sim$ 8 Å.

Exposure times ranged between 20 and 60 min per target. An approximate relative flux scale was established by observing a few spectrophotometric standard stars; as the observing conditions were not photometric, no absolute calibration was attempted. Wavelength calibration was performed with the internal Mercury/Cadmium/Helium/Rubidium lamp. The data were reduced with standard procedures, and the resulting spectra are shown in Fig. 1. The continuum signal-to-noise ratio in the relevant parts of the spectra is always > 30.

4. Notes on the individual objects

Mrk 646 Our new spectrum shows that the permitted emission lines are slightly broader than the forbidden lines: While [O III] is unresolved, the FWHM of Hβ, corrected for the instrumental profile, is only 750 km/s, which is more than in a normal starburst but very narrow indeed for a Sy 1 galaxy. This is confirmed by a higher resolved spectrum of the Hα/[N II] complex, which shows distinctively the different line widths of forbidden and permitted lines. Thus, from its optical spectrum Mrk 646 has to be classified as an extreme example of a narrow-line Sy 1 galaxy.

Further support for this classification comes from the detection of permitted Fe II emission lines, unambiguous indicators of an active nucleus. Although these lines are weak in terms of peak-to-continuum contrast (the maximum contrast is $\sim 3\sigma$), the integrated fluxes of both "Fe II bumps" around λ4600 and λ5400 (rest wavelengths) are comparable to that of Hβ, which is typical for such objects (e.g., Boller et al. 1996).

RX J13291+2950 The optical spectrum is very similar to that of Mrk 646, with the additional feature of a H II λ4686 line which is almost never observed in H II-type galaxies, certainly not with this strength. The corrected Hβ FWHM is 830 km/s, while forbidden lines are unresolved. This and again weak but significant traces of Fe II lines make clear that the object is another narrow-line Sy 1.

The continuum flux level drops quickly shortward of 5000Å. Probably the AGN radiation is significantly diluted by stellar light from the host galaxy, as indicated by the presence of stellar absorption features such as Na λ5890, Mg λ5168–75, and the G band. There is no evidence that the AGN continuum might be reddened by dust absorption.

RX JI5088+6814 This object is clearly a Sy 1, with FWHM(Hβ) = 1500 km/s and a strong Fe II λ4600 bump. Note that although the previous assignment in Paper I as a 'narrow-line' galaxy is a misclassification based on a too low S/N spectrum, the object falls still in the category of 'narrow-line Sy 1' galaxies.

RX J16333+4719 We found this galaxy to contain two nuclei, only $\sim 4''$ apart. One has a starburst spectrum, and it seems that this spectrum has been recorded in Paper I. The other is a narrow-line Sy 1 with quite canonical properties, as shown in Fig. 1. The intrinsic FWHM of Hβ is 1000 km/s.

RX J17035+4540 Our high S/N spectrum shows also this galaxy to be a genuine (again narrow-lined) Sy 1, with properties very similar to those of Mrk 646. The measured intrinsic FWHM of Hβ is 800 km/s, and Fe II lines are unambiguously present.

The overall continuum shape is uncommonly red, but without indication of stellar absorption features; hence, it appears possible that the nuclear continuum of this galaxy suffers from intrinsic dust reddening. We noted above that the X-ray spectral analysis gives rise to a similar suspicion. However, turning the tentative internal X-ray absorption of $N_H \simeq 2 \times 10^{20}$ cm^{-2} into a colour excess, we get $E(B-V) \simeq 0.03$, hardly enough to significantly redden the optical spectrum. Just to "flatten" the spectrum ($f_\lambda \approx$ const.), already an $E(B-V)$ ten times higher is required. As the standard Balmer decrement diagnostic is not applicable for broad AGN lines and therefore no independent evidence about optical reddening is available, we must at present concede that the magnitude of absorption in RX J17035+4540 is unclear.

RX J17260+ 7431 Although in this target the permitted and forbidden emission lines are equally narrow and not resolved in our spectra, there is a broad component of Hα and also (quite faint) of Hβ with a FWHM of $\sim$ 3000 km/s, leading to a classification as Sy 1.8.

5. Discussion and conclusions

The results of our optical spectroscopy so far confirm our suspicion: In five of the investigated six cases, the Balmer lines showed up to be slightly broader than the forbidden lines; in one case a weak broad Hα component was detected. In all of the former cases, we were also able to trace emission lines of Fe II, an unambiguous indicator for nuclear activity. All of the investigated.sources have therefore to be reclassified as AGN.

Although the observed sample is in no sense complete, it is worth noting that its X-ray properties are not inconsistent with those of a random AGN sample (as produced, e.g., in Paper I). Neither are the X-ray spectra exceptionally soft, nor is there a discernible trend towards enhanced variability (with the exception of RX J13291+2950). This can be contrasted with the recent claim by Boller et al. (1996) that narrow-line Sy 1 galaxies (NLS1) have, on average, softer spectral slopes than AGN with broader lines. Little of such a correlation is seen in our data. While most of the known ultra-soft AGN may be in fact NLS1, the reverse apparently needs not be true. The same authors have stated that NLS1 tend to be more variable than other AGN; again, this is not reflected in our results.

Discrimination between active galactic nuclei and H II-type or starburst galaxies is mostly done by measuring the properties of optical emission lines. Three criteria are commonly employed: line widths, detection of characteristic lines, and emission line ratios. Application of the first two criteria to our data yield consistent results as shown. It is important that, by demonstrating that the relatively narrow permitted lines in the spectra of our galaxies are really 'broad', we have effectively lost the option to use the third (and very popular) method of classifying emission line ratios into diagnostic diagrams like those elaborated by Veilleux & Osterbrock (1987). 'Broad' and 'narrow'-line regions in AGN are spatially distinct regions with vastly different physical conditions, and a "diagnostic" ratio such as, e.g., $F(\mathrm{H}\beta)/F([\mathrm{O\,III}])$ becomes meaningless if lines emerging from different regions are combined.

However, the poor quality of typical follow-up spectra in X-ray sources identification work often inhibits an unambiguous distinction between AGN-and H II-type spectra from line widths alone. In such cases, researchers have sometimes based their classifications entirely on emission line ratios (Fruscione & Griffiths 1991), or in combination with the condition that the FWHM of Hβ or Hα for AGN had to be $\gtrsim$1000 km/s (Griffiths et al. 1995). In view of the extremely small line widths found during our investigation, this seems too strict – all our objects except RX J15088+6814 match this condition, yet all are AGN. This sheds some doubt on the justification of claims by the above authors to have found galaxies with apparent H II-type spectra, but $L_X \simeq 10^{43}$ erg s^{-1}. We also remark that there might be less need for a "hidden AGN" scenario, at least for this type of sources.

Many similar objects doubtlessly exist, particularly at larger redshifts and at fainter flux levels. It is to be expected that optical identification programmes will, for many of these, yield only spectra of poor quality, with little chances to detect the subtle features shown here to decide about the objects' nature. As a general strategy to deal with such data, we cordially agree with and recommend the conclusions forwarded by Halpern et al. (1995) that for a galaxy with X-ray luminosity in excess of 10^{42} erg s^{-1}, an AGN should be assumed *per default* as cause of the X-ray emission unless proven otherwise.

The main difference between the Moran et al. (1994) and Halpern et al. (1995) samples and ours is the dominance of Sy 1.9 type objects in their, and of narrow-line Sy 1 in our sample (this could be related to the average X-ray luminosities, which is almost an order of magnitude higher in our sample). The misclassifications corrected by Moran et al. and Halpern et al. were mostly based on non-detections of veritably *broad* emission components, while the narrow lines consistently reflected only the conditions in the host galaxies. In contrast, the extreme examples of narrow-line Sy 1 galaxies shown in this paper demand that the above rule be supplemented by another note of caution: Until spectral data of sufficient quality have established beyond doubt that no broad emission lines are visible, the applicability of diagnostic diagrams to classify emission line spectra is highly questionable.

Acknowledgements. We acknowledge support from a DFG travel grant (Wi 1369/1-1).

References

Bade N., Fink H.H., Engels D., Voges W., Hagen H.-J., Wisotzki L., Reamers D., 1995, A&A 110, 469 (Paper I)
Boller T., Meurs E.J.A., Brinkmann W., Fink H., Zimmermann U., Adorf H.-M., 1992, A&A 261, 57
Boller T., Fink H., Schaeidt S., 1994, A&A 291, 403
Boller T., Brandt W.N., Fink H., 1996, A&A 305, 53
Fruscione A., Griffiths R.E., 1991, ApJ 330, L13
Griffiths R.E., Georgantopoulos I., Boyle B.J., et al., 1995, MNRAS 275, 77
Halpern J.P., Helfand D.J., Moran E.C., 1995, ApJ 453, 611
Moran E.C., Halpern J.P., Helfand D.J., 1994, ApJ 433, L65
Stark A.A., et al., 1992, ApJS 78, 77 Stocke J.T., et al., 1991, ApJS 76, 813
Veilleux S., Osterbrock D.E., 1987, ApJS 63, 295
Voges W., et al., 1996, in: Röntgenstrahlung from the Universe, MPE Report 263, 637
Ward M.J., Hughes D.H., Dunlop J.S., Appleton P.N., 1994, IAU Symp. 159, 311