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LETTER

Letter to the Editor

X-ray detections of weak Seyfert 2's with BeppoSAX

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Abstract. We report the detection in the X rays of two weak Seyfert 2's (NGC3393 and NGC4941) with the Italian–Dutch satellite BeppoSAX. These are among the first sources observed in a sample of 12 Seyfert 2's which are being studied within the BeppoSAX core program, in an effort to probe the putative torus at high X-ray energies, calibrate an isotropic luminosity indicator for absorbed nuclei, and determine the distribution of torus thicknesses, N_H.

Both a Compton thick spectrum, with a reflected power law and a large equivalent width iron line, and a Compton thin spectrum, with the intrinsic power law transmitted through a large column density absorber, provide acceptable fits to both sources, with some preference for the latter model in the case of NGC4941. The high initial detection rate in our program points to a large final X-ray sample.

Key words: X-rays: galaxies – Galaxies: Seyfert – Galaxies: individual: NGC3393 – Galaxies: individual: NGC4941

1. Introduction

A variety of observations have provided evidence that Seyfert 2 galaxies host a nuclear active source which is similar to that observed in Seyfert 1's, but is obscured along our line of sight by a pc-scale gaseous torus (see Antonucci 1993 for a review). The most elementary version of such a "unified model" assumes Seyfert 2's and Seyfert 1's to be identical physical objects, while the orientation of the line of sight with respect to the obscuring torus accounts for all the observed differences between the two classes. X-ray data have played a major role among the observations supporting this model. EXOSAT first, and Ginga later clearly proved that the X-ray emission of several Sy2's is characterized by a power law spectrum similar to that observed in Sy1's (photon index ~ 1.7), with a cutoff at low energies due to photoelectric absorption by gas of column density between 10^{22} and 10^{24} cm^{-2} (e.g. Awaki et al. 1991; Koyama 1992; Nandra & Pounds 1994). Such a dense absorbing column has been identified with the torus.

Hard X-ray spectra were recognized as a powerful potential tool to test and probe various issues on active nuclei. The direct component of the Sy2 X-ray emission (i.e. the emission at energies above the absorption cutoff) provides direct information on the intrinsic luminosity of the active nucleus; more specifically, it can be regarded as the only isotropic indicator of the luminosity of Sy2 nuclei. The knowledge of the intrinsic luminosity should allow to test whether Sy2 and Sy1 nuclei indeed have the same average power ("strong" version of the unified model), or there is some systematic luminosity difference (Barcons et al. 1995; Falcke et al. 1995). The distribution of absorbing column densities N_H should provide information on the geometry and physics of the obscuring material. Eventually, by assessing the distribution of luminosities, spectral indices, and column densities among Sy2's, the origin of the X-ray background should be tightly constrained without assuming any specific model for the spectra of Sy2's (Setti & Woltjer 1989; Comastri et al. 1995; Zdziarski et al. 1995; Barcons et al. 1995).

However, such goals have not been fully addressed yet. The available hard X-ray spectra of Sy2's are affected by selection effects towards X-ray bright sources, or sources known to be bright in either UV or IR. Ginga surveys on Sy2's, such as Awaki et al. (1991), Koyama (1992) and Mulchaey et al. (1992), contain a large fraction of Markarian galaxies and/or sources bright in the HEAO1 survey. Therefore, such studies are not representative of the full Sy2 population, but they rather sample the high luminosity tail and/or the Sy2's absorbed by low column

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densities. More recently, ASCA observations have improved the Sy2 census by providing hard X-ray spectra of a larger number of sources. As a result, Sy2's with lower luminosities and larger absorbing column densities have been detected (e.g. Ueno et al. 1996; Awaki et al. 1996; Makishima et al. 1994). Yet, bias effects are still significant and the statistics very limited. Also the paucity of highly absorbed ($N_H > 10^{25}$cm^{-2}), Compton thick Sy2's (only four candidates were known at the beginning of our program, see e.g. Matt 1997 and references therein) probably does not reflect the real abundance of such objects, but is rather a consequence of a selection effect, as the X-ray spectrum of these sources is seen only in reflection and, therefore, it is orders of magnitude fainter than in other Seyferts.

2. The weak Seyfert 2 core program

We have undertaken a program of observations with BeppoSAX, the Italian–Dutch X-ray satellite, aimed at properly assessing the distribution of luminosities and absorbing column densities in a sample of Sy2's as little biased as possible with respect to orientation effects. Objects suitable for such a survey were drawn from the Seyfert sample of Maiolino & Rieke (1995). This sample is extracted from the Revised Shapley Ames catalogue of galaxies, limited in total blue magnitude ($B_T <$ 13.2), and Seyfert nuclei are identified according to the properties of their (narrow) emission line spectrum. Although, as discussed in Maiolino & Rieke, the narrow line spectrum is not a completely isotropic indicator of the nuclear activity, this Seyfert sample is much less biased than others, both in terms of luminosity of the nuclear source and of properties of the host galaxy.

There are 54 objects classified as Seyfert 2's in the Maiolino & Rieke sample; intermediate Seyferts could arise from a peculiar geometry (see below), and we have not considered them. Out of the 54, 22 have already been observed by ASCA, and for almost all of them hard X-ray information has been published (see Polletta et al. 1996 and references therein; see also the HEASARC online database). We have prioritized the remaining targets in terms of their [OIII] flux, under the assumption that the [OIII] emission is a sufficient approximation to an isotropic measure of the nuclear luminosity. If the [OIII] emission were not completely isotropic, our initial sample would be biased in favour of objects with lower optical absorption and, perhaps, lower values of N_H. The initial sample includes 12 objects, to be observed during the first year of BeppoSAX; we aim at the completion of the sample within the satellite lifetime; we are also collecting optical data both from archives and from new observations.

According to the "two–tori" picture of Maiolino & Rieke (1995), the Seyfert nuclei are surrounded by a pc-scale torus, oriented at random with respect to the host galaxy, and responsible for the obscuration of the X rays and of the broad lines, and by a larger and less opaque screen ($N_H \sim 10^{22}$ cm^{-2}), coplanar with the galaxy, and responsible for the intermediate Seyfert types. Within this scenario our initial sample might be somewhat biased in favour of face-on Seyfert 2's, but would be free from biases with respect to the inner, thicker torus. In any case, our data would allow us to detect a possible bias by looking for an inverse correlation between N_H and [OIII] at constant nuclear luminosity, i.e., at constant intrinsic L_X. Such a correlation would be important *per se*, since it would give information on the height of the torus; and could be corrected for in order to restore the usefulness of our results for the goals of the program.

3. Data collection, analysis and results of spectral fitting

The X-ray astronomy satellite BeppoSAX is a joint project of the Italian Space Agency (ASI) and the Netherlands Agency for Aerospace Programs (NIVR) developed by a consortium of institutes in Italy and The Netherlands, including the Space Science Department of ESA (SSD). The scientific payload comprises four Narrow Field Instruments [NFI: Low Energy Concentrator Spectrometer (LECS), Medium Energy Concentrator Spectrometer (MECS), High Pressure Gas Scintillation Proportional Counter (HPGSPC), and Phoswich Detector System (PDS)], all pointing in the same direction, and two Wide Field Cameras (WFC), pointing in diametrically opposed directions perpendicular to the NFI common axis. A detailed description of the entire BeppoSAX mission can be found in Butler & Scarsi (1990) and Boella et al. (1997a). The MECS (see below) consists of three equal units, with a field of view of 28 arcmin radius, working range 1.3–10 keV, energy resolution $\sim$8% and angular resolution $\sim$0.7 arcmin (FWHM) at 6 keV. The effective area at 6 keV is 155 cm^2 (Boella et al. 1997b).

Our targets were observed with the NFI for $\sim$15 ksec starting on January 8.92 UT, 1997 (NGC3393), and for $\sim$29 ksec starting on January 22.18 UT, 1997 (NGC4941). In both cases, only the MECS provided useful data, since the LECS exposure was much shorter due to the switching off of the instrument over the illuminated Earth, and the HPGSPC and PDS were not sensitive enough for such low fluxes. For each source, the three MECS were aligned, equalized, and summed; the extraction radius was chosen equal to the suggested value of 4 arcmin; the background was taken from much longer exposures of the empty sky, and again extracted in a 4 arcmin radius centered approximately on the same detector coordinates as the source. The net source counts are 104$\pm$16 (6.7 σ) and 307$\pm$24 (13 σ) for NGC3393 and NGC4941, respectively. After grouping the total counts in energy bins with a minimum of 20 counts each, and discarding any event outside the 2–10 keV interval because of poor calibrations, we carried out the spectral analysis with XSPEC, complemented with the release 97.1 of the BeppoSAX response matrices.

We have tried three spectral models, all including a gaussian line plus, respectively: a power law, a fraction of which is transmitted through cold matter (transmission model), a power law with zero absorption (scattering model), and a reflected spectrum due to the reprocessing of a power law by cold matter (reflection model). The torus surrounding the nucleus is assumed to be Compton thin in the transmission scenario, Compton thick in the remaining cases; in these latter cases a mirror is required, which can be either grey (scattering) or energy dependent (reflection).

In the case of NGC3393 the small number of bins does not allow an elaborate modeling. In order to cope with the low statistics we have frozen to standard values as many parameters as possible; in particular, we have kept the intrinsic spectral index at 1.7, which is the "universal" value outside a few Schwarzschild radii. The scattering model gives an acceptable χ^2 (6.1 with 8 d.o.f.), but requires a hot, ionized plasma for the mirror; if we assume that all iron is H–like or He–like, we find that the equivalent width of the line, EW, is larger than 4.5 keV at the 90% level; such a value is incompatible with cosmic abundances for all but the lowest column densities (Matt et al. 1996). The best fit parameters of the remaining models (χ^2 of 2.1 and 3.8 with 6 and 7 d.o.f., respectively) are shown in Table 1. Both models are acceptable, from a statistical and an astrophysical point of view, and indeed they overinterpret the data. If the reflection scenario is correct, the intrinsic luminosity of the source should be at least an order of magnitude greater than the observed one, 4.1×10^{41} erg s^{-1}, more in line with the [OIII] luminosity.

Table 1. Spectral fit parameters for NGC3393, for transmission and reflection models, respectively. Frozen parameters are: photon indices (1.7), line energy (6.4 keV), line width (0.1 keV). Normalizations are in photons/cm^2/s/keV at 1 keV for power laws, and in photons/cm^2/s for lines; line EW are in keV, and are calculated with respect to the observed continuum; column densities are in units of 10^{22} atoms/cm^2; model fluxes are in units of 10^{-13} erg/cm^2/s in the 2–10 keV range; luminosities in 10^{41} erg/s in the 2–10 keV range, after correction for absorption and assuming H_0=50 km/s/Mpc; the confidence intervals are 90% with one interesting parameter.

Model	Parameter Name	Value and Range
Transmission	Normalization #1	5.05 (0.43–213) $\times10^{-4}$
	Column Density	77.5 (> 17.0)
	Normalization #2	4.65 (1.61–7.19) $\times10^{-5}$
	Line Normalization	9.07 (0.89–17.1) $\times10^{-6}$
	Line EW	1.18 (0.08-3.35)
	Model Flux	5.57 $\pm$ 0.83
	Luminosity	16.8 $\pm$ 2.5
Reflection	Normalization	1.75 (0.04–3.73) $\times10^{-3}$
	Escape fraction	0.02 (0.00–1.00)
	Line Normalization	1.18 (0.32–1.88) $\times10^{-5}$
	Line EW	2.08 (0.42–5.03)
	Model Flux	4.99 $\pm$ 0.75
	Luminosity	4.05 $\pm$ 0.60

In the case of NGC4941, a scattering model gives a χ^2 of 25.5 with 21 d.o.f., and a *negative* photon index, which is obviously an artifact of a strongly absorbed component. If the photon index is frozen at 1.7, the model can be rejected with a χ^2 of 47.8 for 22 d.o.f. The remaining models are both formally acceptable (χ^2 of 16.6 and 23.5 with 20 and 21 d.o.f. for the transmission and the reflection scenario, respectively), but the latter does not reproduce adequately the lowest energy points. We have thus tried to ignore this low energy excess (which could be due to a different source, say a starburst), and to fit the remaining points on their own. The transmission scenario is still marginally better than the reflection one, in that it reduces the χ^2 by more than 2.71 (the 90% confidence limit) at the expense of one additional parameter; the difference lies in the roll over observed below $\sim$5 keV, which is difficult to fit with a reflected power law of intrinsic slope 1.7. Table 2 gives the best fit parameters of the two models; in particular, the iron line EW is within the expected ranges in both cases (Ghisellini et al. 1994; Matt et al. 1996). In the transmission scenario the luminosity (after correction for absorption) is 2.1×10^{41} erg s^{-1}, which places NGC4941 at the lower end of the Seyfert luminosity function.

Table 2. The same as Table 1 for NGC4941.

Model	Parameter Name	Value and Range
Transmission	Normalization #1	8.37 (4.18–20.5) $\times10^{-4}$
	Column Density	69.1 (> 40.6)
	Normalization #2	4.85 (2.78–6.51) $\times10^{-5}$
	Line Normalization	1.27 (0.64–1.83) $\times10^{-5}$
	Line EW	0.98 (0.43–1.53)
	Model Flux	8.54 $\pm$ 0.67
	Luminosity	2.06 $\pm$ 0.16
Reflection (> 3 keV)	Normalization	4.27 (3.34–5.20) $\times10^{-3}$
	Escape fraction	0.00 (frozen)
	Line Normalization	1.49 (0.87–2.00) $\times10^{-5}$
	Line EW	1.41 (0.77–2.07)
	Model Flux	7.54 $\pm$ 0.59
	Luminosity	0.453 $\pm$ 0.036

The observed spectra of the two galaxies with the best fitting models superposed on them are given in Figs. 1 and 2 for NGC3393 (reflection scenario) and NGC4941 (transmission scenario), respectively.

4. Discussion and conclusions

While a firmer basis for discussion will be provided only by the completion of the program, it is tempting to put forward a few comments. First of all, for the first targets we have a detection rate of 100% (at the time of writing five further observations were performed, and they too resulted in detections): this is at least a suggestion that at the level of a few $\times10^{-13}$ erg/cm^2/s nearby Seyfert 2's are frequently visible at medium–hard X-ray energies.

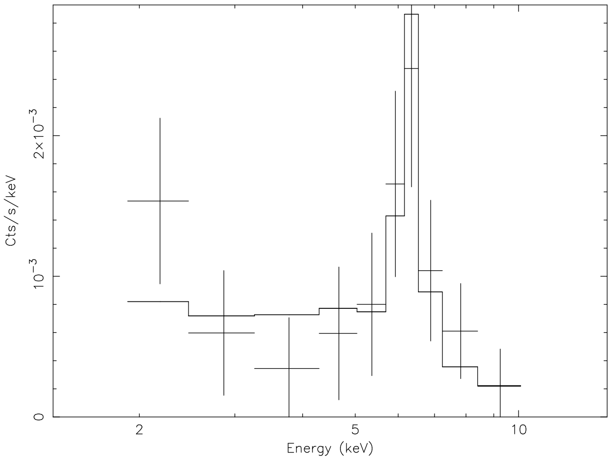

Fig. 1. The observed BeppoSAX spectrum of NGC3393 with the reflection best fit model. The fit parameters are given in Table 1.

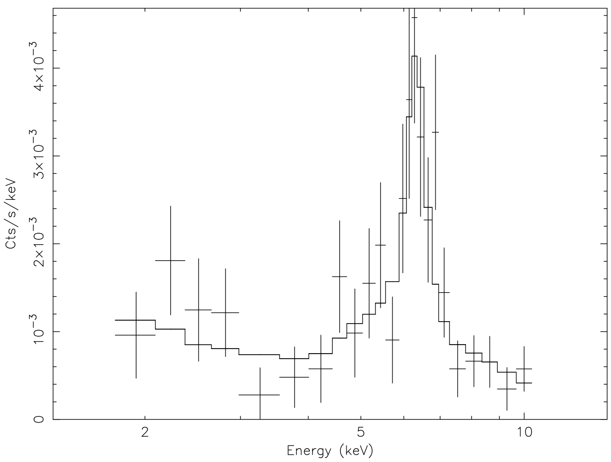

Fig. 2. The observed BeppoSAX spectrum of NGC4941 with the transmission best fit model. The fit parameters are given in Table 2.

More troublesome appear the prospects of measuring the column density N_H with a reasonable precision; while we are certain that NGC3393 and NGC4941 both have N_H larger than several times 10^{23} cm^{-2}, with the X-ray data alone and with the available statistics we cannot discriminate between a Compton thin or a Compton thick torus. This uncertainty entails a large uncertainty on the intrinsic X-ray luminosity. Previous studies have pointed to the far infrared luminosity (FIR) or to the [OIII] luminosity as isotropic indicators of the "true" luminosity of the nucleus (e.g. Mulchaey et al. 1994; Awaki 1997). In our case, assuming that Sy1's and Sy2's are intrinsically identical, assuming that L_X/L_{FIR} = 0.2 and $L_X/L_{[OIII]}$ = 100 for Sy1's (Mulchaey et al. 1994), and –finally– assuming that both galaxies have Compton thin tori, we find that NGC4941 is underluminous in X rays by a factor of $\sim$ 10, and NGC3393 by $\geq$ 40. On the other hand, assuming that both galaxies have Compton thick tori, and we see only 1% of the intrinsic flux as reflected flux, we find reasonable agreement with the Sy1 normalization.

With many more data points of similar quality we will be able to check the self–consistency of the unified model. For an independent test of it, however, we would have to measure N_H and the intrinsic L_X without a priori assumptions; this would require longer exposures, in order to acquire better statistics in the 2–10 keV range with the MECS, and to obtain detections or significant upper limits at energies $\geq$ 20 keV with the PDS, where in the reflection scenario a Compton hump would be expected.

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