STUDY OF X-RAY REFLECTION FEATURES IN A SAMPLE OF SY 1S OBSERVED BY BEPPOSAX

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Abstract

The ionized disc reflection model of Ross & Fabian is applied to a sample of five Seyfert 1 galaxies observed by BeppoSAX. Good fits were obtained for all the objects in the sample. NGC 4051 and Mkn 335 (usually classified as NLSy 1s) show evidence of a highly ionized accretion disc (\( \xi \approx 350 \) erg cm s\(^{-1} \)) and (\( \xi \approx 800 \) erg cm s\(^{-1} \)). While NGC 3783 seems to be a “pure Sy 1” characterized by a highly ionized accretion disc (\( \xi \approx 500 \) erg cm s\(^{-1} \)). All the sources are consistent with having a face-on disc. The accurate determination of the continuum emission allows us to investigate the spectral variability in the case of Mkn 509.

Key words: galaxies: active – galaxies:Seyfert – X-rays: galaxies

1. Introduction

Evidence for ionized accretion discs in Sy 1s was found in recent observations by XMM and XMM-BeppoSAX (Mkn 509, Pounds et al. 2001, Mkn 205, Reeves et al. 2001, NCG 5506, Matt et al. 2001). This conclusion was reached by considering the energy of the Fe K\( _\alpha \) line. The ionized disc also affects the whole continuum (Ross & Fabian 1993, hereafter RF, Ballantyne et al. 2001b). The wide energy range of BeppoSAX (0.1-200 keV) and its moderate spectral resolution (\( \Delta E/E \), 8% at 6 keV) allow us to measure the intrinsic continuum with good accuracy and to simultaneously observe both the Fe emission line and the Compton reflection hump. We present preliminary results of fitting BeppoSAX spectra of a sample of Seyfert 1 galaxies with the ionized disc model of RF.

2. The selected sources

Details of of BeppoSAX observations and the sources are shown in Table 1. The sample includes observations of sources with F(2-10 keV) greater than \( 10^{-11} \) erg cm\(^{-2} \) s\(^{-1} \) and exposure time greater than 50 ks (with the exception of NGC 4051). This allowed us to obtain a good signal in the PDS band. We search all the sources for spectral variability. We accepted a source as variable if the proba-

3. The Ionized Disc Model

The ionized disc model we used to fit the spectra is described in RF and Ross et al. (1999). The most important quantity in determining the shape of the reflected continuum is the ionization parameter \( \xi = 4\pi F_x/n_H \), where \( F_x \) is the X-ray flux (between 0.01-100 keV) illuminating a slab of gas with solar abundances and constant hydrogen number density \( n_H = 10^{15} \) cm\(^{-3} \). The incident flux is assumed be a power law with spectral photon index \( \Gamma \) and a high energy cut-off at 100 keV. The computed reflected spectrum is multiplied for a factor \( R \) (reflected fraction) and added to the primary continuum. The Fe K\( _\alpha \) emission line is also included in the model. Larger values of \( \xi \) indicate a more ionized disc and this will affect the strength and width of the Fe line (Matt et al. 1993, Matt et al. 1996), and the absorption edges. The soft emission from the accretion disc is not included in the models.

4. Spectral fitting

Each source spectrum was fitted with the RF model described in the preview section (the best fit parameters are listed in Table 2). We fitted LECS (0.15-3 keV), MECS (1.5-10 keV) and PDS (13-200 keV) data simultaneously. The cold absorption is kept fixed to the galactic value. Relativistic smearing was also taken into account by blurring the model with a kernel of Schwarzschild metric. This introduces the following fitting parameters: \( r_{in} \) and \( r_{out} \): inner/outer emitting radius of the annulus, \( \beta \): radial emissivity parameter of the disc and \( i \): inclination angle. We fitted all the spectra also with a standard cold disc reflection model (PEXRAV in XSPEC, Magdziarz & Zdziarski 1995). The best fit parameters listed in Table 2 in order to: (a)
All the SAX data were fitted using the XSPEC package. The relative importance to employ the ionized disc model. α separately determine the Fe K\textsuperscript{\textdollar} parameters and (b) check the relative importance to employ the ionized disc model. All the SAX data were fitted using the XSPEC package 11.1. All the quoted uncertainties correspond to 90% confidence interval for one interesting parameter (\(\Delta \chi^2=2.71\)). Each model tested was multiplied by a normalization constant in order to take into account possible miscalibrations between the different instruments. We allowed the PDS/MECS normalization to vary between 0.77 and 0.95, while the LECS/MECS normalization ratio was running between 0.7 and 1 [Fiore, Guainazzi & Grandi 1998].

Table 1. The Sample

| Source    | Date          | Redshift (z) | N\textsuperscript{Col} \(_{\text{M}}^\text{H}\) (in 10\textsuperscript{20} cm\textsuperscript{-2}) | cts (2-10 keV) (s\textsuperscript{-1}) | \(t\text{exp}\) (s) (MECS) | \(\chi^2\) (2-10 keV) (erg cm\textsuperscript{2} s\textsuperscript{-1}) | Ref       |
|-----------|---------------|--------------|-------------------------------------------------|--------------------------------------|-----------------------------|----------------|-----------|
| Mkn 335   | 1998-Dec-10   | 0.025        | 3.2                                             | 0.090 ± 0.001                       | 86637                       | 0.8 × 10\textsuperscript{11} | Bianchi et al. 2001 |
| Mkn 841   | 1999-Jul-30   | 0.036        | 2.2                                             | 0.130 ± 0.001                       | 87793                       | 1.3 × 10\textsuperscript{11} | Bianchi et al. 2001 |
| NGC 3783  | 1998-Jun-6    | 0.009        | 9.6                                             | 0.663 ± 0.001                       | 153870                      | 6.0 × 10\textsuperscript{11} | De Rosa et al. 2002 |
| NGC 4051  | 1998-Jun-28   | 0.002        | 1.3                                             | 0.203 ± 0.004                       | 11616                       | 1.9 × 10\textsuperscript{11} | This proceeding |
| Mkn 509   | 1998-May/Oct  | 0.034        | 4.4                                             | 0.603 ± 0.004                       | 87762                       | 5.6 × 10\textsuperscript{11} | Perola et al. 2001 |
| Mkn 509   | 2000-Nov-3/24 | 0.034        | 4.4                                             | 0.278 ± 0.002                       | 152380                      | 2.6 × 10\textsuperscript{11} | This proceeding |

The RF ionized disc reflection model provides an adequate fit for all observations examined. When a cold disc reflection model in employed to fit the spectra the general trend is a higher value of the spectral index and, in addition, a soft X-ray emission component (due to the disc emissivity) in required.

In the case of NGC 3783, Mkn 335 and NGC 4051 the complex low energy spectra (characterized by warm absorber(s) and soft strong excess) require a more detailed study.

The complex structure of the warm gas in NGC 3783 was investigated in the Chandra observation [Kaspi et al. 2001]. The model consisted of two absorption-emission components with the same column density \(\log(N_H) = 22.1\), and differing each other an order of magnitude: \(\log(U) = -0.745\), and \(\log(U) = -1.745\).

With the BeppoSAX-LECS energy resolution the warm absorber is fitted through the detection of the deep OVII and OVIII K-shell absorption edges produced in the low ionization gas. We added to the ionized disc reflection model in NGC 3783 two absorption edges at energies 0.74 keV (\(\tau=0.71\)) and 0.87 keV (\(\tau=0.53\)) respectively, coincident with the OVII, OVIII K-shell absorption edges, and a third absorption feature at 1 keV probably due to a blend of many iron L-shell absorption lines originated in the second more ionized gas [Kaspi et al. 2001]. In the best fit model we included also a narrow Fe line with the intensity fixed to the value observed by Chandra (\(I_{\text{Fe-narrow}}=6.6 \times 10^{-5}\) photons cm\textsuperscript{-2} s\textsuperscript{-1}, [Kaspi et al. 2001]). As shown in Table 2 the fit for the ionized disc reflection model is good (\(\chi^2\)/dof=104.2/101).

In the case of Mkn 335 the best fit model in the whole BeppoSAX energy range includes a warm absorber component characterized by OVII and OVIII absorption edges (\(\tau=0.67\) and \(\tau=0.53\) respectively). The strong soft excess observed in the low energy spectrum can be accounted by the emission from a highly ionized disc (\(\log(\xi)=2.9\), see Table 2).

NGC 4051 has a warm absorber well known for its spectral complexity [Guainazzi et al. 1996]. Nevertheless the BeppoSAX low energy spectrum was well fitted adding to the RF model an absorption edge at energy \(E=2.71\).
The Fe line profile is modelled adding to the relativistic disc line a second narrow gaussian component at E=6.4 keV.

\[ \star \] Parameter fixed at that value in the fit.

Table 3. Results II: The iron line.

| Source          | \( \Gamma \) | \( E_{\text{Fe}} \) (keV) | \( \sigma \) or \( \tau_{\text{out}} \) (keV or (r_a)) | EW (eV) | \( \chi^2 / \text{dof} \) |
|-----------------|-------------|--------------------------|---------------------------|---------|-------------------|
| Mkn 335        | 2.04±0.17   | \( \star \) 6.4         | 6.1±0.2                   | 660±150 | 126/123 |
| Mkn 841        | 2.12±0.10   | \( \star \) 6.4         | 9.0±0.3                   | 260±120 | 120.8/119 |
| NGC 3783       | 1.87±0.06   | \( \star \) 6.39±0.09   | 0.36±0.09                 | 190±47  | 100.7/102 |
| NGC 4051       | 1.65±0.10   | \( \star \) 6.2±0.2     | <1                       | 135±200 | 102.3/106 |
| Mkn 509 (1998) | 1.97±0.03   | \( \star \) 6.88±0.01   | ^0.4                      | 115±65  | 101.3/141 |
| Mkn 509 (2000) | 1.75±0.06   | \( \star \) 6.57±0.28   | 0.55±0.18                 | 140±100 | 106/126 |

\* Parameter fixed at that value in the fit.

0.88 keV (\( \tau=0.74 \)). Also in this case the strong soft excess can be accounted from the emission by a highly ionized disc (\( \log(\xi)=2.65 \), see Table 2).

We stress here that Mkn 335 and NGC 4051 are classified as a Narrow Line Seyfert 1 galaxies, and in this class of sources high ionized disc are often observed (Ballantyne et al. 2001a).

The RF model applied on a sample of NLSy 1s observed by ASCA (Ballantyne et al. 2001a), shows that these sources might possess an ionized disc. Most of the Sy 1s we analysed observed by BeppoSAX show evidence of an ionized disc. The ionization parameters are anyway much less that that observed in NLSy 1s, not surprisingly as in latter class of objects are commonly believed to accrete at high rates. NGC 3783 is the “pure Sy 1” in our sample that seems to be characterized from a highly ionized accretion disc (\( \log(\xi)=2.73 \)).

The RF model allows a rich variety of anisotropic thermal emission components (\( 0<i<40^\circ \)) and with a radial emissivity parameter \( \beta=-3 \).

The flux variation of a factor of 2 detected between the two observations of Mkn 509 (taken 2 years apart), can be completely explained with a change of the intrinsic slope \( \Delta \Gamma \sim 0.2 \). This behaviour is fully consistent with that observed in other Sy 1s (NGC 5548, Nicolato et al. 2001; NGC 4151, Piro et al. 2002; IC 4329a, Done et al. 2001; NGC 7469, Nandra et al. 2000; MCG-6-30-15, Vaughan & Edelson 2001; NGC 3783, De Rosa et al. 2001), and with the map of the \( F_x \) vs \( \alpha \) relationship expected in a Comptonization model for the intrinsic continuum emission (Pettucci et al. 2000 and references therein).

We are extending this analysis to a wider sample (20 objects) of sources observed by BeppoSAX.

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Acknowledgements

The BeppoSAX satellite is a joint Italian-Dutch program. We thank the BeppoSAX SDC for assistance. ADR acknowledges G. Matt for useful discussions and financial support from the European Association for Research in Astronomy (EARA) Marie Curie fellowships.
Figure 1. In each plot we show LECS (black), MECS (red) and PDS (green) data (upper panels) and data/model ratio (lower panels) for the ionized disc reflection model (the best fit parameters are listed in Table 2). In the case of NGC 3783, Mkn 335 and NGC 4051 the spectral analysis must take into account the complex soft X-rays spectra characterized by warm absorber(s). These features are included in the best fit model (see discussion in Section 5). The soft excess observed at $E < 2$ keV (particularly strong in the two NLSy 1s NGC 4051 and Mkn 335), can be accounted by the disc emissivity.