A BLR origin for the iron Kα line in NGC 7213

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ABSTRACT

The X-ray spectrum of NGC 7213 is known to present no evidence for Compton reflection, a unique result among bright Seyfert 1s. The observed neutral iron Kα line, therefore, cannot be associated with a Compton-thick material, like the disc or the torus, but is due to Compton-thin gas, with the Broad Line Region (BLR) as the most likely candidate. To check this hypothesis, a long Chandra HETG observation, together with a quasi-simultaneous optical spectroscopic observation at the ESO NTT EMMI were performed. We found that the iron line is resolved with a FWHM=2 400+1 100−600 km s^{-1}, in perfect agreement with the value measured for the broad component of the Hα, 2640+110−90 km s^{-1}. Therefore, NGC 7213 is the only Seyfert 1 galaxy whose iron Kα line is unambiguously produced in the BLR. We also confirmed the presence of two ionised iron lines and studied them in greater detail than before. The resonant line is the dominant component in the Fe xxv triplet, therefore suggesting an origin in collisionally ionised gas. If this is the case, the blueshift of around 1 000 km s^{-1} of the two ionised iron lines could be the first measure of the velocity of a starburst wind from its X-ray emission.

Key words: galaxies: active - galaxies: Seyfert - X-rays: individual: NGC7213

1 INTRODUCTION

A narrow component of the iron Kα line is almost invariably present in Chandra high energy gratings and XMM-Newton CCD spectra of Active Galactic Nuclei (e.g. Bianchi et al. 2007; Yaqoob & Padmanabhan 2004, and references therein). The line, typically unresolved with upper limits of several thousands km s^{-1} for the Full Width at Half Maximum (FWHM), must be produced far from the nucleus, either in the torus envisaged in the Unification Model (Antonucci 1993) or in the Broad Line Region (BLR). In the former case, and if the torus is Compton-thick, a Compton reflection component should also be present. In the latter case, a much fainter Compton reflection component is expected, and the intrinsic width of the iron line should be the same as that of the optical broad lines. The torus hypothesis seems to be preferred for the majority of sources (e.g. Bianchi et al. 2004; Nandra 2006), but to unambiguously distinguish between these hypotheses high energy resolution observations are required, which at present only Chandra can provide.

The Seyfert 1/LINER NGC 7213 (z=0.005839) presents a negligible amount of Compton reflection (R=ΔΩ/2π < 0.19: Bianchi et al. 2003, 2004). This result, confirmed by three other BeppoSAX observations, is unique among bright Seyfert 1s observed by BeppoSAX (Perola et al. 2002; Risaliti 2002; Dadina 2008). Therefore, the observed neutral iron line, whose equivalent width is ≃ 80 eV, cannot be associated with a Compton-thick material, like the disc or the torus, but is due to Compton-thin gas, like the BLR. The line width is unresolved by XMM-Newton EPIC pn, giving only an upper limit of about 8 000 km s^{-1}. In this Letter, we present a long Chandra grating observation of the iron line width, which turns out to be resolved and fully consistent with the FWHM of the broad component of the Hα line, as measured in a quasi-simultaneous optical observation.
2 DATA REDUCTION

2.1 X-ray observation

NGC 7213 was observed in two consecutive Chandra Advanced CCD Imaging Spectrometer (ACIS; Garnire et al. 2003) observations, with the High Energy Transmission Grating Spectrometer (HETGS; Canizares et al. 2005) in the focal plane. The first observation (obsid 7742) was performed on 2007, August 6th, for 115 ks, while the second one (obsid 8590) on 2007, August 9th, for 35 ks. Data were reduced with the Chandra Interactive Analysis of Observations (CIAO; Fruscione et al. 2006) 4.0.1 and the Chandra Calibration Data Base (CALDB) 3.4.2 software, adopting standard procedures. First order High Energy Grating (HEG) and Medium Energy Grating (MEG) spectra were extracted for the source and the background. After having verified that there is no significant variability neither within any single observation nor between the two, we co-added them with the tool ADD_GATING_SPECTRA, in order to have a single HEG spectrum and a single MEG spectrum, for a total exposure time of 148 ks each.

All the fits were performed with XSPEC 12.4.0 (Arnaud 1996), taking into account the instrumental resolution with the response matrix computed with standard procedures. Local fits were performed around the iron Kα band with the unbinned spectra, using the Cash (1979) statistic, in order to take advantage of the high spectral resolution of the gratings. Broad band (0.4-10 keV) fits were instead performed on the binned spectra, where the large number of counts in each bin (250) allowed the use of the χ² statistic. We did not analyse the 6th order data in this paper, since the count-rate per frame (≥0.5 s⁻¹ in the inner 2-pixel region) is larger than the one suggested for pileup-free spectra (see The Chandra ABC Guide to Pileup), as confirmed by the resulting very flat spectrum.

2.2 Optical observation

In order to measure the physical width of the Hα line, we asked for director discretionary time (ID: 279.B-5054.A) to obtain a quasi-simultaneous observation of NGC 7213 at the ESO NTT telescope (La Silla, Chile). The observation was carried out in service mode on 2007, September 22th with the EMMI spectrograph equipped with grating #7 and a 1-arcsec width slit. The wavelength resolution was 2.49 Å (the pixel scale was 0.82 Å) in the range 5650-7140 Å. Four spectra, with 30 sec long integrations each, were obtained with 15 arcsec offsetted positions (pattern A B A B). The reduction process used standard MIDAS and IRAF facilities. The raw data were bias-subtracted, corrected for pixel-to-pixel variations (flat field) and eventually sky-subtracted. Wavelength calibrations were carried out by comparison with exposures of He and Ar lamps, with an accuracy of 0.17 Å (1σ). Relative flux calibration was carried out by observations of the spectrophotometric standard star LTT9239 (Hanuy et al. 1992, 1994). The final S/N ratio was about 22.

3 SPECTRAL ANALYSIS

In the following, errors correspond to the 90% confidence level for one interesting parameter (Δχ² = 2.71), while error bars in the plots correspond to 1 σ. Energies and wavelength-weights are reported in the rest-frame of the source. The Galactic column density along the line of sight to NGC 7213 is included (2.04 × 10²⁰ cm⁻²; Dickey & Lockman 1990).

3.1 The Fe complex

Figure 1 shows the HEG spectrum in the 6.-7.5 keV band. Three significant emission lines are apparent. The strongest is the neutral Kα line at 6.397±0.006 keV, consistent with iron less ionised than Fe XII (House 1969). The observed flux (2.9±0.9 ph cm⁻² s⁻¹) and the EW (120±40 eV) are in agreement, within errors, with those found by XMM-Newton (Bianchi et al. 2003). The iron Kα line is actually composed of a doublet, Kα₁ at 6.404 keV and Kα₂ at 6.391 keV, with a flux ratio 2:1 (Bearden 1967). Although the separation of this doublet cannot be resolved by the Chandra HEG, we adopted a rigorous approach fitting two Gaussians, separated by 13 eV, the flux ratio fixed to the expected one and the width free to vary, but forced to be the same for the two lines. The width of the lines is resolved: σ = 22±10 eV. Forcing the lines to be narrow (σ = 0) leaves large residuals and a significantly worse fit (∆C = +15). We note here that the measure of the width is completely unaffected by this modelling with respect to a single Gaussian, as already observed by Vagnozzi et al. (2001) for other sources.

Let us investigate the origin of the observed broadening. A possible origin for the observed width may be the presence of a Compton Shoulder (CS). If the CS is modelled with a Gaussian line with centroid energy at 6.3 keV and σ = 40 eV (Matt 2002), while the iron line width is fixed to 0, the fit is significantly worse (∆C = +14) and only an upper limit on the CS flux is found. This is not surprising, given the absence of a Compton reflection component associated to the CS. Another explanation for the width of the iron line can be blending with iron lines from higher ionisation states, but this would imply a larger value for the centroid energy of the resulting line and a clear asymmetric profile. Therefore, Doppler broadening is left as the most likely explanation for the width of the iron line, which would correspond to a FWHM=2.400±1.000 km s⁻¹ (see Fig. 2).

Along with the neutral iron line, two other significant emission lines are observed in the HEG spectrum of NGC 7213, at 6.721±0.016 and 6.987±0.019 keV (see Fig. 1 and Table 1). The latter can be interpreted as emission from Fe XXVI, but its energy is blueshifted by a velocity of 900±500 km s⁻¹ with respect to the theoretical value of 6.966 keV. If the other emission line is identified with the forbidden component of Fe XXV Kα (6.637 keV), the blueshift must be 3000±200 km s⁻¹. If instead it is identified with the resonant component (6.700 keV), its corresponding blueshift would be 900±500 km s⁻¹, i.e. consistent with the one found for the Fe XXVI line. The fluxes and EWs of the two lines (see Table 1) are consistent with those found by XMM-Newton (Bianchi et al. 2003). Finally, no neutral Kβ is found. The 90% confidence level upper limit on its flux (4 × 10⁻⁶ ph cm⁻² s⁻¹) leads to an upper limit on the ratio against Kα.

1 http://chandra.ledas.ac.uk/ciao4.0/download/doc/pileup_abc.ps
The spectrum is re-binned for clarity and the positions of the most important transitions are marked.

Figure 1. Chandra HEG spectrum of NGC 7213 around the iron line, along with the best fit with three Gaussian emission lines. The spectrum is re-binned for clarity and the positions of the most important transitions are marked.

Figure 2. Flux vs. FWHM contour plot for the neutral iron line in NGC 7213. The curves refer to $\Delta C = 2.30$, 4.61 and 9.21, i.e. confidence levels of 68, 90 and 99% for two interesting parameters.

Table 1. NGC 7213: the iron line complex in the Chandra HEG spectrum.

| Line       | $E_T$ (1) | $\Delta E$ (2) | FWHM (3) | Flux (4) | EW (5) |
|------------|-----------|----------------|----------|----------|--------|
| Fe i-XII   | 6.400$^*$ | $-3^{+6}_{-11}$ | 2400$^{+1100}_{-600}$ | 2.9$^{+0.9}_{-0.7}$ | 120$^{+40}_{-30}$ |
| Fe XXV     | 6.700     | $+21^{+10}_{-16}$ | $< 5500$  | 0.7$^{+0.5}_{-0.5}$ | 24$^{+17}_{-17}$ |
| Fe XXVI    | 6.966$^*$ | $+21^{+19}_{-10}$ | $< 2700$  | 1.3$^{+0.6}_{-0.6}$ | 60$^{+30}_{-30}$ |

Notes: (1) Identification. (2) Theoretical energy in keV (NIST, [Balchenko et al. 2004]). (3) $E_{\text{obs}} - E_T$ in eV, after correction for $z=0.005839$. (4) km s$^{-1}$ Col. (5) $10^{-5}$ ph cm$^{-2}$ s$^{-1}$. Col. (6) eV.

Table 2. NGC 7213: optical emission lines in the ESO NTT EMMI spectrum.

| Line | $\lambda$ (1) | $\Delta \lambda$ (2) | FWHM (3) | Flux (4) |
|------|---------------|-----------------------|----------|----------|
| [O i] | 6300.32       | -0.3                  | 620$^{+60}_{-70}$ | 3.38$^{+0.01}_{-0.01}$ |
| [O i] | 6363.81       | +2.8                  | 620$^{+60}_{-70}$ | 0.94$^{+0.01}_{-0.01}$ |
| H$\alpha$ | 6562.79         | -1.1                  | 280$^{+30}_{-30}$ | 1.33$^{+0.13}_{-0.15}$ |
| H$\alpha$ | 6562.79         | +2.6                  | 2640$^{+110}_{-900}$ | 14.75$^{+0.18}_{-0.60}$ |
| [N ii] | 6548.06        | -0.1                  | 370$^{+30}_{-30}$ | 1.15$^{+0.07}_{-0.07}$ |
| [N ii] | 6583.39        | -0.1                  | 370$^{+30}_{-30}$ | 3.45$^{+0.21}_{-0.21}$ |
| [S ii] | 6716.42        | -0.2                  | 350$^{+30}_{-30}$ | 1.78$^{+0.012}_{-0.015}$ |
| [S ii] | 6730.78        | -0.3                  | 350$^{+30}_{-30}$ | 1.77$^{+0.011}_{-0.016}$ |

Notes: (1) Identification. (2) Laboratory wavelength ($\AA$), in air ([Bowen 1960]). (3) $\lambda_{\text{obs}} - \lambda_{\text{true}}$ after correction for $z=0.005839$. Typical error $\pm 0.5 \AA$. Col. (4) km s$^{-1}$ (instrumental resolution not removed). Col. (5) $10^{-14}$ erg cm$^{-2}$ s$^{-1}$.

3.2 The optical spectrum

The optical spectrum of NGC 7213 was analysed between 6300 and 6800 Å. The most important atomic transitions expected in this wavelength range are clearly observed in the spectrum (see Fig. 3), so no attempt was made to remove the (unknown) contribution from the stellar continuum. Note that the optical spectrum analysed by [Filippenko & Halpern 1984], to whom we will refer, was not galaxy-subtracted longward of 5500 Å, either.

Fig. 1 shows the H$\alpha$ blended with the [N ii] doublet. In order to disentangle any broad component of the H$\alpha$, we assumed that (i) $F([\text{N ii}]) \lambda 6583/3F([\text{N ii}]) \lambda 6548)=3$, as required by the ratio of the respective Einstein coefficients, (ii) $\lambda_2/\lambda_1 = 6583.39/6548.06$ and (iii) the [N ii] lines are Gaussians with the same width. With these physical assumptions, a fit with three narrow emission lines (H$\alpha$ plus the [N ii] doublet) is very poor and strongly suggests the presence of a broad component. The addition of this further component leads to a very good fit; see Table 2 and Fig. 4 for the 4 Gaussian lines included in the fit and their convolution which nicely matches the observed profile.

The widths of the narrow H$\alpha$ and the [N ii] doublet are similar (see Table 2), while the FWHM of the broad component of H$\alpha$ ($2640^{+110}_{-900}$ km s$^{-1}$) clearly requires a different origin, i.e. the BLR. Our results are qualitatively in
agreement with those of Filippenko & Halpern (1984), in the sense that at least a broad component for the Hα is required by the data (they actually fit a total of seven components, but with the warning that the physical significance of all these lines is questionable). Moreover, the FWHM we derive for the Hα is close to the width of the broad component of the Hβ as measured by Filippenko & Halpern (1984) and Winkler (1992), around 4 000 and 3 200 km s^{-1}, respectively.

Finally, the [S ii] doublet has a FWHM consistent with that of the [N ii] doublet and the narrow Hα component, while the [O i] doublet is broader, but all in agreement with an origin in the Narrow Line Region.

4 DISCUSSION

Differently from all the other Seyfert 1s with broadband X-ray observations, NGC 7213 lacks a Compton reflection component, the clearest signature for the presence of a Compton-thick material. Therefore, the observed neutral iron line must originate in a Compton-thin material, be it the BLR or a Compton-thin torus.

The Chandra HEG spectrum of NGC 7213 allowed us to resolve, for the first time, the iron line width at 2.400^{+110}_{-90} km s^{-1} (FWHM). The analysis of a quasi-simultaneous optical observation confirmed the presence of a broad component of the Hα line, for which we measured a FWHM=2640^{+110}_{-90} km s^{-1}. The widths of the two lines are in very good agreement, which suggests that they are likely to be produced in the same material.

To test if this scenario is possible, we have to verify if the observed EW of the iron line is in agreement with an origin in the BLR. Following the detailed procedure described by Yaqoob et al. (2001), derived from Krolik & Kallman (1987) adopting updated atomic data, the expected EW for the BLR in NGC 7213 can be written as:

\[ \text{EW}_{\text{Fe}} \simeq 34 \left( \frac{f_c}{0.35} \right) \left( \frac{N_H}{10^{23} \text{ cm}^{-2}} \right) \text{ eV} \]  

This estimate assumes a spherically symmetric cloud distribution for the BLR, with a covering factor of \( f_c \), a column density of \( N_H \) for each cloud and an iron abundance relative to hydrogen of \( \log A_{\text{Fe}} = 4.68 \times 10^{-5} \) (Anders & Grevesse 1989). The powerlaw index of \( \Gamma = 1.69 \) derived from the Chandra and the XMM-Newton observations was further adopted in the derivation of (1). Assuming \( f_c = 0.35 \), a column density around 3 \times 10^{23} cm^{-2} can reproduce an \( \text{EW} \simeq 100 \) eV, which is the order of magnitude found by Chandra and XMM-Newton. These values for \( f_c \) and \( N_H \) are within the ranges usually assumed in photoionization models of BLRs (Netzer 1990). In particular, \( f_c = 0.35 \) is the value derived by Goad & Koratkar (1998) from observational constraints in the Seyfert 1 NGC 5548, even if more ‘canonical’ values around 0.1 and 0.25 are generally found. The large covering factor needed to account for the iron line EW may be at odds with the regular intensity of the observed broad optical lines, but the weakness or absence of an UV bump in NGC 7213 (e.g. Starling et al. 2005) may result in a deficit of UV photoionizing photons and compensate the geometrical factor. In any case, \( f_c \) and \( N_H \) can be lower, provided that \( A_{\text{Fe}} \) is larger than solar and/or the X-ray illumination of the BLR is anisotropic (see e.g. Yaqoob et al. 2001, and references therein). On the other hand, we cannot exclude a further contribution to the iron line EW from a Compton-thin torus, located on a pc-scale, but we stress here that we do not have any other piece of evidence to support its presence.

The presence of emission lines from highly ionised iron in the Chandra HEG spectrum of NGC 7213 confirms the XMM-Newton results by Bianchi et al. (2003). As suggested...
by these authors, their origin may be in gas photoionised by the AGN, as found in many Seyfert 1s and 2s (e.g. Bianchi & Matt 2002; Bianchi et al. 2003). However, the gratings data presented here revealed that the resonant line is the dominant component in the Fe xxv triplet (unless its blueshift is significantly larger than the one measured for the Fe xxvi line), which is suggestive of an origin in gas in collisional equilibrium. This is in agreement with the results found by Starling et al. (2005) using diagnostic tools based on the O vii triplet observed in the XMM-Newton RGS spectrum of NGC 7213. It is interesting to note that the Fe xxv-xxvi lines’ blueshift of around 1.000 km s$^{-1}$ (consistent with the centroid energies of the O vii lines as measured by Starling et al. 2005), together with the evidence that the gas producing such lines is in collisional ionization equilibrium, suggest that the hot, line emitting, gas be in the form of a starburst driven wind (see e.g. Heckman 2003 and references therein), rather than an intrinsic (typically photoionized) AGN wind.

The H$\alpha$ morphology of NGC 7213 was studied in detail by Storchi-Bergmann et al. (1996) and Hameed et al. (2001). A circumnuclear ring of star formation is located at 20-30 arcsec from the nucleus (corresponding to a few kpc) and a giant H$\alpha$ filaments is present at 2.9 arcmin in distance (around 19 kpc). Neither of these structures is observed in the Chandra X-ray image, which only shows an unresolved (within few arcsec) nucleus. However, Storchi-Bergmann et al. (1996) reported the possible presence of a collimated outflow within 14 arcsec from the nucleus, with a velocity around 100 km s$^{-1}$ The gas producing the ionised iron lines reported in this Letter may be the inner, hotter and faster phase of this superwind. If this is the case, this could be the first measure of the velocity of a starburst wind from its X-ray emission.

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