Average Iron line emission from distant AGN

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Abstract We have developed a new method to construct a high SNR X-ray average spectrum for type 1 and type 2 AGN in order to measure the main properties of the Fe Kα emission line. Our method takes into account all the possible contributions to the continuum around the emission line, and an estimate of the significance of any excursion above this continuum can be obtained from it. We applied this method to the identified AGN within AXIS and XWAS, 606 type 1 and 117 type 2 AGN, and obtained average spectra for both AGN types. We found an unresolved emission line on the final average spectrum of type 1 and 2 AGN with an EW $\sim$ 100 eV, corresponding to neutral or low-ionization Fe Kα emission, thus emitted far from the central source. We also found that the EW of this narrow line becomes weaker as the luminosity increases, the so-called Iwasawa-Taniguchi effect. A clear relativistic component in the Fe Kα line is not present in the average spectra and the continuum is best represented by a mixture of absorbed power laws plus a moderate reflection component for type 1 AGN. In the case of type 2 AGN, the statistics turned out to be insufficient to distinguish between a reflection component and a relativistic line. We estimated the EW of any relativistic contribution to be $<$ 400 eV and $<$ 300 eV at 3σ confidence level for type 1 and type 2 AGN, respectively. Our results are in excellent agreement with studies of local AGN, whereas we obtain a much lower value for the relativistic line EW than studies at higher redshifs.

1 Introduction

The Fe Kα line is the most common emission feature in X-ray spectra. Its central energy varies from 6.4 to 6.9 keV depending on the level of ionization of the emitting material and it displays a relativistic profile when emitted from the innermost

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parts of the acretion disk in AGN (*Active Galactic Nuclei*).

Several recent studies have tried to measure the average Fe Kα emission line properties in AGN obtaining very different results. Individual studies over local samples of AGN ([5], [3]) found that a narrow line with an EW (*equivalent width*) of the order $\sim$ 100 eV seems to be a common charateristic in AGN. On the other hand, a relativistic line is only detected in around 50 % of the sources with an EW spanning a wide range of values and with an average value of $\sim$ 100-200 eV.

For distant AGN, a direct individual X-ray spectral analysis is not possible due to the low number of counts collected, so the best solution is to average or stack as many X-ray spectra as possible. Results from this kind of analysis are presented in [6] and [1]. Results from the former shows a strong relativistic Fe Kα line in the average spectrum of type 1 and type 2 AGN with EW $\sim$ 600 and 400 eV for type 1 and type 2 AGN, respectively. A similar result, within errors, is also found in [1].

Given this differing results at low and high redshifts, is clear that a careful revision of the stacking or averaging method applied to faint object spectra is needed. To this end, we developed a new X-ray spectral averaging method and applied it to a large sample of type 1 and type 2 AGN. Our method takes into account the effects of the continuum emission around the emisison line and the counting statistics, without needing to fit complex models to the data but modelling the underlying continuum using simulations. We have extensively tested this method and a significance for the emission line detection can be derived from it.

2 X-ray data

We compiled all the identified type 1 and 2 AGN from the XMS (*XMM-Newton Medium Survey*) fields within AXIS (*An XMM-Newton International Survey*) and XWAS (*XMM-Newton Wide Angle Survey*). After selecting those spectra with more than 80 counts in the total band (0.2-12 keV), we obtained a sample of 606 type 1 and 117 type 2 AGN corresponding to more than 1000 and 200 individual spectra, respectively. The redshift, counts and hard(2-10 keV) flux distributions of our sample are shown in Fig. 1.

3 Averaging procedure

After spectral extraction, we fit an absorbed power law modified by intrinsic absorption to each individual spectrum and used this model to unfold the spectrum, i.e., to recover the input spectrum in physical units (keV cm^{-2} s^{-1} keV^{-1}). We then corrected for Galactic absorption, via a table model constructed from the `XSPEC`

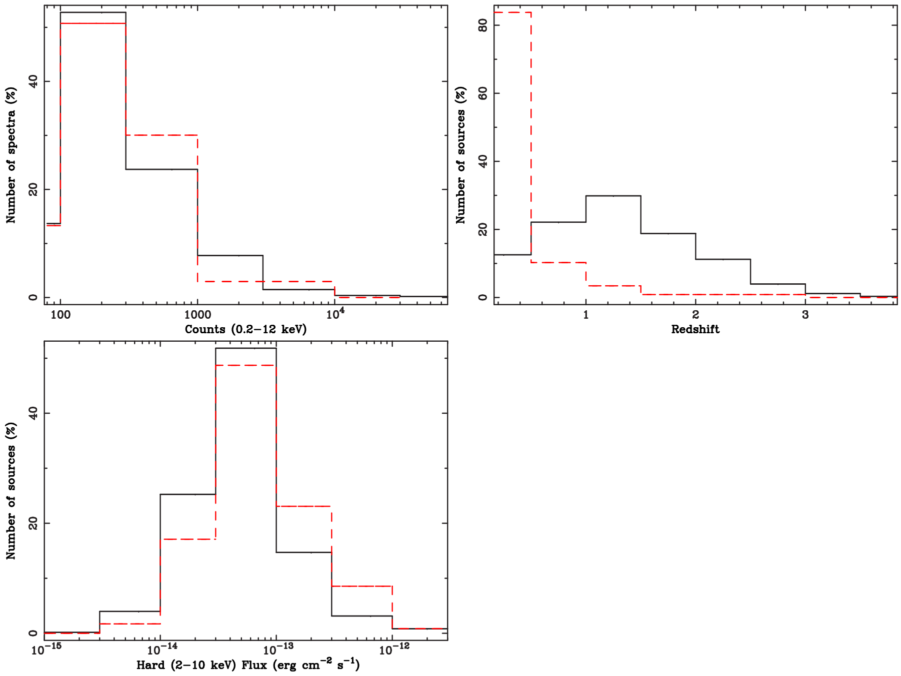

Fig. 1 **Top-left:** Counts distribution corresponding to the type 1 (solid line) and type 2 (dashed line) AGN samples. **Top-right:** Redshift distribution. **Bottom:** Flux distribution.

phabs model, and shifted each spectrum to rest-frame.

Since we want all the spectra to contribute to the final average with the same weight, we need to rescale them. We achived that by computing the flux in the 2-5 keV rest-frame band and dividing each spectrum by this value. In this way, every now rescaled spectrum has the same 2-5 keV rest-frame flux. We finally re-binned the spectra to a common energy grid and average all of them using a simple mean.

To take into account any possible contribution to the final average spectra from counting statitistics, individual spectral shape or the method itself, we decided not to simply fit a model to the average spectrum but to estimate the effects of all these possible contributions by using simulations. We simulated 100 times each individual spectrum using the best-fit models from the real data, and keeping the same quality as in the real data. Then we applied to the simulated data exactly the same process as to the real data. From these 100 simulations, we constructed a 100-simulations average continuum, that should account for the mixture of absorbed power laws, and also 100 simulated continua from which we obtained confidence limits by removing the extreme values.

The average spectra for type 1 and type 2 AGN along with the simulated continuum and the 1σ and 2σ confidence limits are shown in Fig. 2. We obtain a power law slope of Γ = 1.92 $\pm$ 0.02 and Γ = 1.44 $\pm$ 0.02 for type 1 and type 2 AGN, respectively. The lower value for type 2 AGN is likely due to the larger intrinsic absorption for this kind of sources. We can see that a narrow peak centered around 6.4 keV is present in both average spectra along with some deviations from the power law shape between 4 and 9 keV. However, these deviations are also present as large dispersions in the simulated spectra.

4 Results

We performed the spectral fit to the average spectra assuming a base-line model composed of the 100-simulations continuum – accounting for a mixture of absorbed power laws – and a narrow gaussian emission line. We did not obtain a good fit using only this model so we added several aditional components such as absorption (neutral and ionized), reflection (neutral and ionized) and a relativistic line.

For type 1 AGN, we found that the best model corresponds to the base-line model plus moderate reflection (R$\sim$0.5, i$\sim$60 degrees, in agreement with often measured values for type 1 AGN and reflection from cold matter in the distant torus), and we computed an upper limit of any relativisic line contribution to be $<$ 400 eV at 3σ confidence level. This value is in excellent agreement with recent resuts from local samples of AGN ([5], [3]). However, this value is much lower than the one obtained from studies of AGN at high redshifs ([6], [1]). For type 2 AGN, the poor statistics does not allow us to distinguish between a reflection component or a relativistic line. In any case, the relativistic contribution is $<$ 300 eV at 3σ confidence level.

The better statistics for the type 1 AGN sample allowed us to divide this sample into different sub-samples in order to search for any dependence of the line emission on flux, redhsift or luminosity. We did not find any dependence on flux nor on redhift, but we did find a marginal dependence on the narrow Fe Kα EW on luminosity, becoming larger as the luminosity decreases. This behavior have been previously reported as the Iwasawa-Tanigichi effect ([4]). However, this result is not conclusive due to the poor statistics of the luminosity sub-samples.

5 Conclusions

We have developed a new method to construct a high SNR (*signal to noise ratio*) average spectrum and applied it to a large sample of type 1 and type 2 AGN up to redshift 3.5. We found that a narrow Fe Kα line with an EW $\sim$ 100 eV is an universal feature of AGN at high redshifts, as it has also been found in local samples. The

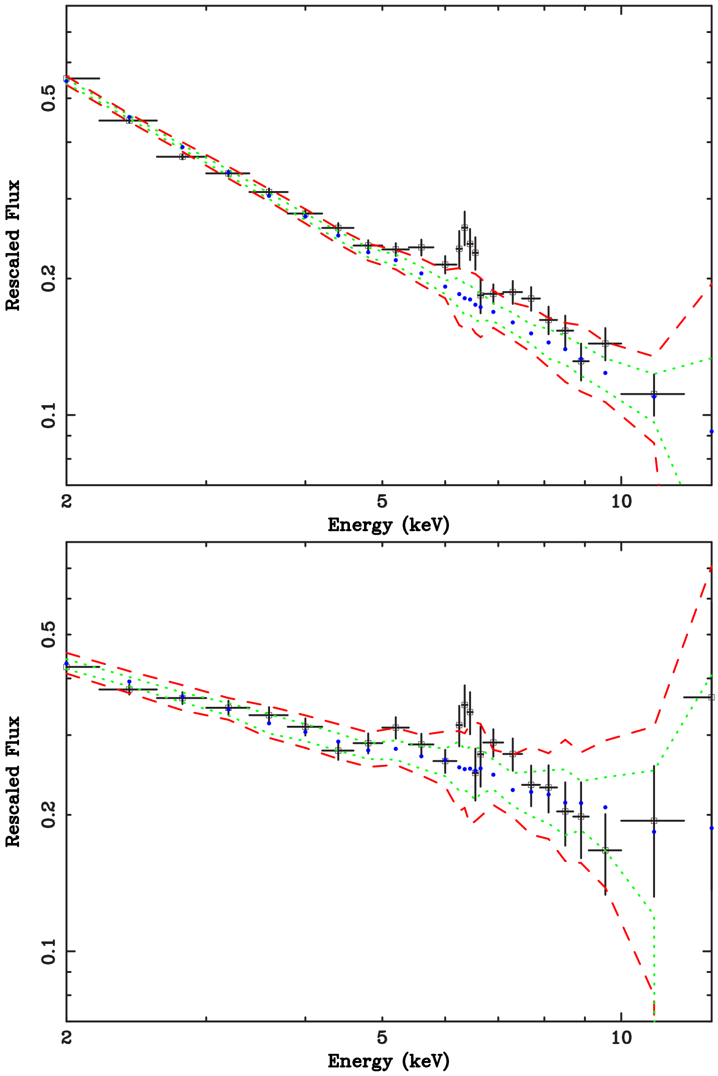

Fig. 2 **Left:** Type 1 AGN average spectrum (squares) and simulated continuum (circles) along with the 1σ (dotted line) and 2σ (dashed line) confidence limits. **Right:** Type 2 AGN average spectrum, simulated continuum and confidence limits.

remaining deviations from a power law in the final type 1 AGN average spectrum are better represented by a reflection component than by a relativistic line, and we estimated an upper limit for the relativistic contribution EW of 400 eV at 3σ confidennce level. Poorer statistics in the type 2 sample does not allow to distinguish between reflection and relativistic emission, but we measured an upper limit for the later of 300 eV also at 3σ confidence level. These limits are well below the values reported from similar analyses of high redshift AGN ([6], [1]). The possible explanations for these diverging results could be as follows:

1. **Differences in the method:** our method takes into account more carefully all the possible contributions to the underlying continuum that the previous ones. We have tested that broad features, such as a broad red wing for an intrinsically narrow line, can appear if the dispersion of the continuum, and other effects due to the averaging method, are not taken into account very carefully.

2. **Different samples:** differences in the sources luminosity or in the data quality could affect our results since we are using low to medium quality X-ray data whereas, for example, the spectra on [6] are of better quality on average. However, the larger size of our sample, compared to the one presented in [6], should compensate that.

In order to test both scenarios, we are compiling an even larger sample from both deeper and shallower samples, including the one presented in [6]. Preliminary results appear to favour option 1 above, thus confirming the weakness of relativistic line components in distant AGN. An extensive description of our averaging method can be found in [2].

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