Search for narrow energy-shifted lines in XMM-Newton AGN spectra

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Abstract. The detection of X-ray narrow spectral features in the 5-7 keV band is becoming increasingly more common in AGN observations, thanks to the capabilities of current X-ray satellites. Such lines, both in emission and in absorption, are mostly interpreted as arising from Iron atoms. When observed with some displacement from their rest frame position, these lines carry the potential to study the motion of circumnuclear gas in AGN, providing a diagnostic of the effects of the gravitational field of the central black hole. These narrow features have been often found with marginal statistical significance. We are carrying on a systematic search for narrow features using spectra of bright type I AGNs available in the XMM-Newton archive. The aim of this work is to characterise the occurrence of the narrow features phenomenon on a large sample of objects and to estimate the significance of the features through Monte Carlo simulations. The project and preliminary results are presented.

1. INTRODUCTION

The presence of Fe K features in the spectra of AGN and the interpretation on their origin are nowadays quite well established. Fe Kα transitions give rise to fluorescence emission lines. The neutral Fe K line at 6.4 keV is usually the most prominent in AGN spectra. An unresolved component of this transition is almost ubiquitous in XMM-Newton AGN spectra (Bianchi et al. 2004, Page et al. 2004, Jiménez-Bailón et al. 2005) and it is generally interpreted as being emitted via X-ray reflection on a distant medium, like the AGN torus (Ghisellini et al. 1994). In some cases it is also possible to observe Fe K lines from ionised Iron atoms emitted at 6.7 and 6.97 keV (see left panel of Fig. 1 for an example of Fe K lines complex in the Sy 1 Mrk 590). The origin of these lines is ascribed to warm gas surrounding the accretion disc. When Fe K emission is produced in the innermost region of the AGN, relativistic effects intervene and they can strongly modify the line profile, giving rise to a broad and skewed Fe K line (Fabian et al. 2000). This was the general picture up to few years ago. In fact the debate on the nature of the inner accretion flow in AGN has been reinforced by the recent discoveries of narrow energy-shifted spectral features in the spectra of several Seyfert 1 Galaxies.

Narrow energy-shifted emission lines have been detected in the hard X-ray spectra of some AGN: NGC 3516 (Turner et al. 2002, Iwasawa et al. 2004), Mrk 766 (Turner et al. 2004, 2006), ESO 198-G24 (Guainazzi 2003), NGC 7314 (Yaqoob et al. 2003), Mrk 841 (Petrucci et al. 2002, Longinotti et al. 2004), ESO 113-G010 (Porquet et al. 2004), UGC 3973, (Gallo et al. 2005). An example of a redshifted emission line detected in NGC 3516 is shown in the right panel of Fig. 1. Theoretical models have
predicted the possibility that Fe K emission lines from the disc can be observed with a narrow profile under some conditions. In fact, the broad Fe line profile arises by integrating the emission from a large area of the disc. But, if the X-ray reflection arises as a result of magnetic flares in localized regions on the disc, energy-shifted narrow lines are instead expected to be observed in the spectrum. Nayakshin et al. (2001) proposed a model in which the accretion disc is illuminated by magnetic flares inducing active regions (hot spots) with limited size. As these regions orbit around the black hole, the emitted line should appear in a range of energies between $\sim 4$–$8$ keV due to the Doppler and gravitational effects. If the emitting region co-rotates with the disc, the flux and the centroid energy of the line vary as a function of the orbital phase. As demonstrated by Dovciak et al. (2004), the line profile computed in time-resolved intervals does show such variations and in theory, it is possible to reconstruct the path of the hotspot on the disc.

Another scenario in which narrow energy-shifted lines can be produced has been proposed by Turner et al. (2002, 2004). Redshifted lines are interpreted as being emitted by material which is either being ejected at relativistic velocity on the far side or falling towards the black hole. The different ranges of energies of the line peaks would then reflect respectively a deceleration or acceleration in the velocity of the gas due to the gravitational force. Remarkably, the “aborted jets” model recently proposed by Ghisellini et al. (2004) to explain the X-ray emission in radio-quiet AGN, predicts the presence of blobs of gas in fast motion close to the black hole.

X-ray absorption lines in the Fe K band may also provide insights on the central region of AGN. The first detection of an absorption redshifted Fe K line was found in ASCA data of NGC3516 (Nandra et al. 1999). With the advent of XMM–Newton and Chandra, the number of absorption features in active galaxies spectra have considerably increased: Q0056-363 (Matt et al. 2005), E 1821 + 643 (Yaqoob & Serlemitsos 2005, but see also Jiménez-Bailón et al. 2006), Mrk 509 (Dadina et al. 2005), PG1211 + 143 (Reeves et al. 2005), Mrk 335 (Longinotti et al. 2006b). One of the
best example of variable absorption structures from Kα and Kβ transitions of ionised Iron is the XMM-Newton spectrum of NGC 1365 (Risaliti et al. 2005) displayed in the left panel Fig. 2, whereas on the right side of the same figure is plotted the redshifted absorption line detected in Mrk 335 (see caption for details). Several cases of X-ray blueshifted absorption lines have been interpreted as evidence for high velocity outflows: APM 08279+5255 and PG1115+080 (Chartas et al. 2002, 2003), PG1211+143 (Pounds et al. 2003), PDS 456 (Reeves et al. 2003), although few of them somewhat questionable (McKernan et al. 2004). The outflows interpretation is also supported by theoretical models where synthetic spectra produced through radiative transfer calculations are found in good agreement with the observations on a qualitative level (Sim 2005). According to accretion models, high velocity gas should be present in the surroundings of the central region of AGN and the presence of such gas is in principle observable in the form of absorption features imprinted on the X-ray spectra (Crenshaw et al. 2003). Depending on the kinematic structure and dynamical state of the gas, the absorption lines would be observed with different widths and with some displacement from their rest frame energy. This gas is likely to be highly ionised due to the nuclear continuum irradiation and therefore is bound to produce absorption mainly in the Fe K shell band. Resonance transitions from FeXXV and FeXXVI produce absorption features at the energy of 6.7 and 6.97 keV. Taking into account the source redshift, these features should be observed in the 5–8 keV range for most objects. To be observed with considerable energy-shift, the lines must be forming in a plasma infalling on the accretion disc or or outflowing at high velocity. Although the exact nature of the energy shift of such lines is as yet unclear, the most likely scenario for producing the observed features would involve a combination of gas orbiting in highly relativistic motion and/or gravitational shifts of the photons (Ruszkowski et al. 2000).
TABLE 1. Object type in our sample

| Object type      | Number |
|------------------|--------|
| Seyfert 1        | 31     |
| Radio Quiet QSO  | 39     |
| Narrow Line Sy1  | 15     |

2. SYSTEMATIC SEARCH FOR NARROW FEATURES

Emission and absorption energy-shifted lines are clearly two distinct phenomena, but they share some common properties:

- They are detected with marginal significance (2–3 σ)
- They have been found in individual objects, by individual authors and therefore with various methods of data reduction and analysis, and with heterogeneous calibrations
- They are probably of transient nature, since most detections have been found in time-resolved spectra.
- High confidence detections of such features would be of crucial importance in testing the black hole paradigm for AGN and would provide a new additional tool to be used alongside the broad Fe Kα line.

The project described in the following aims to perform a systematic search on narrow energy-shifted lines in the *XMM-Newton* archive and to characterise the significance of the detections with Monte Carlo simulations.

The data have been collected from the *XMM-Newton* archive. The spectra are part of a larger sample of AGN including all the observations flagged as “AGN” in the *XMM-Newton* archive and public up to March 2006 (Bianchi et al. in preparation). We have selected only the sources with number of counts in the hard X-ray band higher than 1000 counts, obtaining a list of 124 spectra extracted from 85 type-1 AGNs (multiple observations are available for many sources). Table 1 reports the optical classification of the objects. The data have been processed with SAS version 6.5.0 and analysed with XSPEC 12.2.1ao.

2.1. Methodology

The procedure described hereafter is adapted from Longinotti et al. (2006b), where it was used to test the significance of the redshifted absorption line in Mrk 335. For the present work, each spectrum in the sample has been fitted in the 2-10 keV range with a baseline model defined by a power law + 3 Gaussian emission lines with energies at 6.4, 6.7, 6.97 keV and width fixed to 1 eV. Then, the presence of additional narrow lines is tested by adding \(n\) narrow Gaussian lines to the baseline model, allowing positive and negative deviations for the line intensity and excluding the range 6.4-7 keV. The energy
of these lines is free to vary between 4 and 9 keV. In this way a best fit model made by a power law + 3 Fe K lines + \( n \) Gaussian lines is found. The significance of these additional Gaussian lines with respect to the best fit model is checked through the F-test. Only those lines that are found significant at more than 99% for the F-test are included in the best fit (this conservative threshold has been arbitrarily chosen).

In the next step we test the significance of the \( n \) Gaussian lines in the best fit. A line detected in this way could be due to random deviations originated by Poisson noise in the data. Thus, the question is “what is the probability that a deviation in \( \chi^2 \) this large or larger is obtained by chance?”. To answer it, we run Monte Carlo simulations on each spectrum where a shifted line has been detected at more than 99% for the F-test. The algorithm for the simulations is as follows. We produce \( 10^4 \) realisations of the spectrum fitted with an input model made by the best fit model without the line that is being tested. In this way we obtain 10000 fake background-subtracted data sets with photon statistics and spectral shape corresponding to the original spectrum. Each of the simulated spectra is fitted with the input baseline model. Then, the Gaussian line to be tested is added back to the baseline model, a new spectral fit is performed and the improvement in \( \chi^2 \) for adding that line is recorded for each of the simulated spectra. The number of \( \Delta \chi^2 \) larger than the one found in the real spectrum will be used to estimate the significance of the line in the real spectrum.

### 2.2. Preliminary results and considerations on the method

At the time of the writing, only few test-runs have been performed, setting the threshold of significance at 99 and 95%, in order to understand how the method works. This allows us to identify some drawbacks of the method and improve it before reporting unclear or incomplete results. Some of these problems are highlighted in the following: the method does not take into account the complexity of many AGN spectra, particularly in Seyfert Galaxies. For example, if a broad line or spectral curvature is present, the automatic procedure would mimic the broad feature with many adjacent narrow lines. The transient nature of the shifted features constitutes another issue to be taken into account and solved: in a systematic search on the integrated spectra, some of the transient feature would be lost, as it happens in our sample for NGC 3516. However, a preliminary check on the well known objects PG1211+143 and Mrk 509 where detections of narrow lines have been claimed, confirms the presence of shifted lines and therefore we are confident that our procedure provides a good basis to search for shifted lines systematically.

Among the many future developments of this work, we foresee to test the detection procedure varying the baseline models for the simulated spectra. We would like to run it in samples of different objects in the XMM-Newton archive (e.g. Blazars) to be used as a control sample and to take into account the transient nature of the features performing the search in time-resolved spectra.
REFERENCES

1. Bianchi S., Matt G., Balestra I., Guainazzi M., Perola G. C., 2004, A&A, 422, 65
2. Bianchi S., Guainazzi M., et al. in preparation
3. Chartas G., Brandt W. N., Gallagher S. C., Garmire G. P., 2002, ApJ, 579, 169
4. Chartas G., Brandt W. N., Gallagher S. C., 2003, ApJ, 595, 85
5. Crenshaw D. M., Kraemer S. B., George I. M., 2003, ARA&A, 41, 117
6. Dadina M., Cappi M., Malaguti G., Ponti G., de Rosa A., 2005, A&A, 442, 461
7. Dovčiak M., Bianchi S., Guainazzi M., Karas V., Matt G., 2004, MNRAS, 350, 745
8. Fabian A. C., Iwasawa K., Reynolds C. S., Young A. J., 2000, PASP, 112, 1145
9. Gallo L. C., Fabian A. C., Boller T., Pietsch W., 2005, MNRAS, 363, 64
10. Ghisellini, G., Haardt, F., & Matt, G. 1994, MNRAS, 267, 743
11. Ghisellini, G., Haardt, F., & Matt, G. 2004, A&A, 413, 535
12. Guainazzi M., 2003, A&A, 401, 903
13. Iwasawa K., Miniutti G., Fabian A. C., 2004, MNRAS, 355, 1073
14. Jiménez-Bailón, E., Piconcelli, E., Guainazzi, M., Schartel, N., Rodríguez-Pascual, P. M., & Santos-Lleó, M. 2005, A&A, 435, 449
15. Jiménez-Bailón, E., Santos-Lleó, M., Piconcelli, E., Matt, G., Guainazzi, M., Rodríguez-Pascual, P., astro-ph/0610233, A&A in press
16. Longinotti A. L., Nandra K., Petrucci P. O., O’Neill P. M., 2004, MNRAS, 355, 929
17. Longinotti A.L., Bianchi S., Santos-Lleo M. et al., 2006a, accepted for publication on A&A
18. Longinotti A.L., Sim S., Nandra K., Cappi M., 2006b, astro-ph/0609414, MNRAS in press
19. McKernan B., Yaqoob T., Reynolds C. S., 2005, MNRAS, 658
20. Nandra K., George I. M., Mushotzky R. F., Turner T. J., Yaqoob T., 1999, ApJ, 523, L17
21. Nayakshin S., Kazanas D., 2001, ApJ, 553, L141
22. Page, K. L., O’Brien, P. T., Reeves, J. N., & Turner, M. J. L. 2004, MNRAS, 347, 316
23. Petrucci P. O., et al., 2002, A&A, 388, L5
24. Porquet D., Reeves J. N., Uttley P., Turner T. J., 2004, A&A, 427, 101
25. Pounds K. A., Reeves J. N., King A. R., Page K. L., O’Brien P. T., Turner M. J. L., 2003, MNRAS, 345, 705
26. Reeves J. N., Pounds K., Uttley P., Kraemer S., Mushotzky R., Yaqoob T., George I. M., Turner T. J., 2005, ApJ, 633, L81
27. Risaliti, G., Bianchi, S., Matt, G., Baldi, A., Elvis, M., Fabbiano, G., & Zezas, A. 2005, ApJL, 630, L129
28. Ruszkowski M., Fabian A. C., 2000, MNRAS, 315, 223
29. Sim S. A., 2005, MNRAS, 356, 531
30. Turner T. J., et al., 2002, ApJ, 574, L123
31. Turner T. J., Kraemer S. B., Reeves J. N., 2004, ApJ, 603, 62
32. Turner, T. J., Miller, L., George, I. M., & Reeves, J. N. 2006, A&A, 445, 59
33. Yaqoob T., Padmanabhan U., 2004, ApJ, 604, 63
34. Yaqoob T., Serlemitsos P., 2005, ApJ, 623, 112