SIGNATURES OF RESONANT ABSORPTION IN X-RAY SPECTRA OF TYPE 1 AGN

F. Nicastro$^{1,2,3}$, F. Fiore$^{1,3}$, G. Matt$^4$

$^1$Harvard-Smithsonian Astrophysical Observatory
60 Garden Street, Cambridge MA 02138, USA
$^2$Istituto di Astrofisica Spaziale – CNR
Via del Fosso del Cavaliere, 00133 Roma, Italy
$^3$Osservatorio Astronomico di Monteporzio
Via Osservatorio 2, 00040 Roma, Italy
$^4$Dipartimento di Fisica, Universitá degli studi “Roma Tre”
Via della Vasca Navale 84, Roma, I00146 Italy

Abstract

We present photoionization models accounting for both photoelectric and resonant absorption. We demonstrate that resonance absorption lines are detectable even in moderate resolution X-ray spectra of type 1 AGN. The spectra transmitted by gas illuminated by the ionizing continua typical of flat X-ray spectrum, broad optical emission line type 1 AGN, and steep X-ray spectrum, narrow optical emission line type 1 AGN (NLSy1) are dramatically different. In particular, we find that both the absorption features seen in many Seyfert 1 galaxies between 0.7 and 1 keV and in several NLSy1 between 1 and 2 keV can be explained by our model, without requiring relativistic outflowing velocities of the gas.

1 Introduction

Soft X-ray spectra of X-ray flat, broad optical emission line type 1 AGN frequently show signatures of reprocessing by ionized matter along the line of sight (Reynolds,
The main features imprinted on these spectra are OVII-OVIII K edges at 0.74 and 0.87 keV. However, as recently pointed out by several authors, photoelectric absorption is not able to entirely account for the complexity of the spectra observed by even moderate resolution instruments. Significant negative residuals between 0.9 and 1 keV, and, in some cases, positive residuals between 0.5 and 0.7 keV, are still present in ASCA-SIS and BeppoSAX LECS spectra of several objects (e.g. NGC 985, Nicastro et al., 1997, 1998a; NGC 3783, George et al., 1998, Piro et al., 1998; MCG-6-30-15, NGC 3516, Reynolds, 1997, Nicastro et al, 1998b).

On the other hand, deep OVII-OVIII K edges have never been observed in the spectra of X-ray steep, narrow optical emission line type 1 AGNs (NLSy1). Nevertheless, the X-ray spectra of several NLSy1 are not featureless, showing broad negative residuals between 1 and 2 keV, after proper modelling of the intrinsic continuum (usually a curved continuum, flattening above 2-3 keV by $\Delta \alpha \sim 0.5 - 1$, Boller et al., 1996, Laor et al., 1997, Brandt et al., 1997). \cite{Leighly1997} interpret these features as blueshifted (by $\sim 0.5c$) OVII-OVIII resonance absorption lines. Fiore et al. (1998) model a similar feature in the ASCA spectrum of PG 1244+026 in terms of either an emission line at 0.92 keV or Fe XVIII and Fe XVII resonant absorption blueshifted by $\sim 0.3$ c.

Here we present photoionization models accounting for both photoelectric and resonant absorption, and compare them to the spectra observed in a broad line Seyfert 1 galaxy and a NLSy1 (see Nicastro et al., 1998a for more details). We show simulations of our models with the moderate resolution ASCA–SIS CCDs, the high spectral resolution gratings AXAF–HETG, and the high collecting area, high spectral resolution baseline Constellation-X calorimeter. We briefly discuss the relevant physics which could be addressed in this field by these instruments.

## 2 Photoelectric+Resonant Absorption Model

We built single-zone photoionization models accounting for both photoelectric and resonant absorption. We consider K$\alpha$ and K$\beta$ resonance absorption lines from H-like and He-like ions of C, O, Ne, Mg, Si, S and Fe, as well as a complex of almost 100 L lines from Si and Fe at $\sim 0.3$ and $\sim 1$ keV respectively (atomic data are from Verner et al. 1996).

We use CLOUDY (Ferland, 1996, vs. 90.01) to calculate the physical structure of a given cloud of gas photoionized by a given ionizing continuum shape. Intensities, equivalent widths and profiles of the considered resonance absorption lines are then consistently computed considering both Doppler and natural broadening mechanisms. Doppler broadening includes a term accounting for turbulence of the gas along the line of sight:

$$\Delta \nu_D = \frac{\nu_0}{c} \left( \frac{2kT}{M} + \sigma_v^2 \right)^{0.5}.$$  \hspace{1cm} (1)

In order to evaluate the relative contribution of these two terms to the total optical depth, we report the ratio between the central optical depth in the two extreme cases:

\footnote{IRAS 13224-3809, PG 1404+226, 1H 0707-495, Leighly et al, 1997; PG 1244+026, Fiore et al., 1998, Ark 564, Comastri et al., 1997.}
\[ \sigma_v = 0 \text{ (thermal motion only: } \tau_0^{\text{therm}}) \text{ and } \sigma_v \gg \sqrt{kT/M}. \] 
This quantity does not depend on the particular considered transition, the distribution of the ionic abundances in the gas, and its column density, and is therefore a good estimator of the relative contribution of the two Doppler broadening mechanisms to the core optical depth:

\[
\frac{\tau_0^{\text{therm}}}{\tau_0^{\text{turb}}} = 2.3 A^{0.5} (\alpha - 0.5) \beta \sigma_v^{-3}. \tag{2}
\]

In eq. (2) \( A \) is the atomic weight of the given element, and \( \beta \sigma_v = \sigma_v / c \). A given column of non-turbulent highly ionized gas in photoionization equilibrium can therefore be more than a factor 10 thicker to the resonant absorption process (at the energy of the transition) than an identical column of gas undergoing strong turbulence (\( \sigma_v \geq 300 \text{ km s}^{-1} \), i.e. (\( \beta \sigma_v \)) \(-3 \geq 1 \).

### 2.1 Transmitted Spectra

As an example we present two spectra transmitted by gas photoionized by two drastically different ionizing continua: a flat X-ray continuum with \( \alpha_E = 0.9 \), and a double component X-ray continuum including a low energy component, parameterized by a black-body with \( kT=0.15 \text{ keV} \), and a power law component with \( \alpha_E = 0.9 \). Similar continua are typically observed in broad line type 1 AGN and NLSy1 respectively. Fig. 1a and 1b show these spectra. The 2-10 keV flux of these spectra is of \( 10^{-11} \text{ erg s}^{-1} \text{ cm}^{-2} \). In both cases we include a cut-off due to neutral absorption from a column of \( N_H = 3 \times 10^{20} \) (to simulate Galactic absorption). The dispersion and outflowing gas velocities are \( \sigma_v = 500 \text{ km s}^{-1} \), and \( v=1000 \text{ km s}^{-1} \) respectively, typical of the UV/X-ray ionized absorbers (Mathur et al., 1994, 1995, 1998).

The spectrum in Fig. 1a (Ionization Parameter \( U=1, N_H = 10^{22} \text{ cm}^{-1} \)) shows a complex absorption structure between 0.3 and 2 keV whose strongest features are CVI, OVII-OVIII and NeIX-NeX K-edges, at 0.49 keV, 0.74-0.87 keV and 1.20-1.36 keV respectively. These features have been observed in moderate resolution spectra of almost half of the flat X-ray spectrum, broad optical emission lines Seyfert 1 galaxies observed by ASCA (Reynolds et al., 1997). However other relevant features are clearly visible in this spectrum. In particular we note the presence of strong K\&K\( \alpha \)-K\( \beta \) resonance absorption lines from H-like and He-like ions of O and Ne, and two systems of L resonance absorption lines from Si (\( \sim 0.3 - 0.4 \text{ keV} \)) and Fe (\( \sim 1 - 2 \text{ keV} \)). These lines could well be present in the spectra of many known warm absorber AGNs. The energy of several of the Fe-L and Ne lines is close to that of the OVIII K-edge, and their integrated equivalent width can be as high as \( \sim 20 \text{ eV} \) for turbulence velocities of \( \sim 500 \text{ km s}^{-1} \). Not including them in the modeling of even moderate resolution spectra could lead to a significant overestimate of the OVIII K-edge optical depth.

The spectrum in Fig. 1b (\( U=10, N_H = 10^{23} \text{ cm}^{-1} \)) does not show any absorption K-edges in the 0.1-3 keV range, despite of the large column density used. This is a direct consequence of the much steeper soft X-ray ionizing continuum (compared to the one used to produce the spectrum in Fig. 1a). This continuum, in fact, contains enough photons to fully ionize all the elements lighter than Ne-Mg. Iron ions instead are still distributed in medium-high ionization states. This gives rise to a complex system of resonant absorption lines and edges from the Iron L shells, all between 1 and
Figure 1: Spectra emerging from clouds of gas photoionized by (a) a typical Seyfert 1 continuum, and (b) a typical NLS1 continuum (see details in the text).

These absorption features may therefore be responsible for the deficit of counts seen by ASCA in several NLSy1 at these energies. If this is the case, the gas outflowing velocity would not need to be relativistic. The ionization parameter adopted (U = 10) is expected for sources of the luminosity of the NLSy1 of the Leighly et al. (1997) sample provided that: (a) the physical properties of the absorber are similar to those of the absorbers usually seen in broad line type 1 AGN; and (b) the radial distance of the gas from the ionizing sources, in units of gravitational radii, scales approximatively with the square root of the luminosity (as in fact observed in the Reynolds, 1997, sample).

2.2 Simulated Spectra

For both the transmitted spectra of Fig. 1a and 1b we carried out 100 ksec ASCA-SIS, 100 ksec AXAF-HETG and 20 ksec Constellation-X calorimeter simulations. We performed the AXAF-HETG simulations with the MARX simulator (“MARX User Guide”, vs 1.0, 1997), while, to simulate the ASCA-SIS and the Constellation-X calorimeter spectra, we wrote a simple program to fold the emerging spectra of Fig. 1a and 1b through the instrument responses, and add background (for the ASCA-SIS) and statistical noise.

In the upper panels of Fig. 2 and 3 we show the ratios between the two ASCA-SIS simulated spectra and the continuum used in the simulations (i.e. without the resonance absorption lines). Clear negative residuals at 0.6-1 keV and 1-2 keV respectively are present in both the panels, so indicating the capability of even moderate resolution...
Figure 2: Ratio between a 100 ksec ASCA-SIS simulation of the model in Fig. 1a and the best fit warm absorber model accounting for photoelectric absorption only (a). 100 ksec AXAF-MEG and 20 ksec Constellation-X simulations of the emerging spectrum in Fig. 1a (b and c respectively).

instruments to detect resonance absorption lines.

Fig. 3bc and 4bc show the AXAF-HETG and Constellation-X simulations of the models in Fig 1a and 1b respectively. The high resolution AXAF-HETG resolves most of the lines and edges present in the emerging spectra of Fig. 1a and 1b, so allowing a stringent test of our “ionized absorber+resonant absorption” models. Despite of the low signal to noise of the first order HETG spectra, outflowing or inflowing velocity of the gas can be accurately determined, as well as turbulence velocity along the line of sight. The much higher (factor of 100) effective area of the baseline Constellation-X calorimeter, will permit to accumulate very good quality spectra of these (and at least one order of magnitude lower luminosity) AGNs with much shorter (factor of 5) exposure time, so allowing for: a) detailed variability studies of the ionization state of the gas; b) an accurate measure of absorption line ratios, which in turn would allow the use of powerful plasma diagnostic; c) the high resolution observation of a large sample of AGN, which would be useful for the determination of the distribution of the absorber density, ionization state, chemical composition and distance from the ionizing source and for the study of the evolution of these distributions with redshift and luminosity.

3 Conclusion

We have calculated spectra emerging from ionized gas illuminated by flat and steep ionizing continua, typical of Seyfert galaxies and NLSy1 respectively, taking into account both photoelectric and resonant absorption. We have convolved these spectra
Figure 3: Ratio between a 100 ksec ASCA-SIS simulation of the model in Fig. 1b and the best fit continuum model (a). 100 ksec AXAF-MEG and 20 ksec Constellation-X simulations of the emerging spectrum in Fig. 1b (b and c respectively).

with the responses of the moderate resolution ASCA-SIS CCDs, the high resolution high energy transmission gratings on board AXAF (AXAF-HETG), and the high collecting area, good resolution baseline Constellation-X calorimeter. Our major findings are:

1. The distribution of relative ionic abundances in photoionized gas dramatically depends on the exact shape of the ionizing continuum.

2. Strong Kα and Kβ resonance absorption lines from He-like and H-like ions of C, O, and Ne, along with deep CVI, OVII-OVIII, NeIX-X K edges, and FeXV-XVII L edges, are expected to be present in the 0.1-3 keV spectra of flat X-ray spectrum quasars emerging from photoionized gas along the line of sight. When fitting low and medium resolution X-ray data with phenomenological multi-edge models, these resonance absorption lines may produce the effect of overestimating the optical depth of the OVIII K edge.

3. Conversely, no strong absorption edge is expected to be imprinted on spectra emerging from gas illuminated by steep ionizing continua and with physical and geometrical properties similar to those found in broad line type 1 AGN. However, a large number of strong Fe L and Mg, Si, and S Kα and Kβ resonance absorption lines (almost 70) are predicted between 1 and 2 keV. Fitting low and medium energy resolution data with continuum models may then result in deep smooth negative residuals at these energies. We then suggest that the ∼1 keV absorption feature observed by ASCA in several Narrow Line Seyfert 1 galaxies can be explained in terms of resonance absorption lines, without requiring relativistic outflowing velocities of the gas.
4. Future observations with the high resolution gratings on board AXAF will allow to unambiguously detect the most important resonance absorption lines and then measure the gas dispersion velocity.

5. The observations possible with the Constellation calorimeter will allow the application of powerful plasma diagnostics to the brightest AGN and the study of a large sample of AGN for statistical purposes.

4 References

Boller, Th., Brandt, W.N & Hink, H.: 1996, Astron. Astrophys. 305, 53.
Brandt, W.N., Mathur, S., Elvis, M.: 1997, Mon. Not. R. Astr. Soc. 285, 25.
Comastri, A., et al.: 1997, Proceedings of the Symposium “The active X-ray sky”, in press, astro-ph/9712278.
George, I.M., Turner, T.J., Mushotzky, R., Nandra, K., Netzer, H.: 1998, Astrophys. J. 503, 174.
Ferland G.J., 1996 CLOUDY vs. 90.01
Fiore, F., et al.: 1998, Mon. Not. R. Astr. Soc. 298, 103.
Laor, A., Fiore, F., Elvis, E., Wilkes, B.J., McDowell, J.C.: 1997, Astrophys. J. 477, 93.
Leighly, K.M., Mushotzky, R.F., Nandra, K. & Forster, K.: 1997, Astrophys. J. Lett. 489, L25.
Mathur S., Wilkes B.J., Elvis M., Fiore F.: 1994, Astrophys. J. 434, 493
Mathur S., Elvis M., Wilkes B.J.: 1995, Astrophys. J. 452, 230
Mathur S., Wilkes B.J., Aldcroft T.: 1998, Astrophys. J in press.
Nicastro, F., Fiore, F., Brandt, W.N., Reynolds, C.S.: 1997, Proceedings of the Symposium “The active X-ray sky”, in press.
Nicastro, F., Fiore, F. & Matt G.: 1998a, Astrophys. J. submitted.
Nicastro, F. & Fiore, F.: 1998b, in preparation.
Piro, L., Nicastro, F., et al.: 1998, in preparation.
Reynolds, C.S.: 1997, Mon. Not. R. Astr. Soc. 287, 513
Verner, D. A., Verner, E. M., and Ferland, G. J., 1996, Atomic Data Nucl. Data Tables