X-ray Continuum Slope and X-ray Spectral Features in NLS1 Galaxies

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Abstract

The idea that some of the unusual features in the X-ray spectra of Narrow-Line Seyfert 1 galaxies (NLS1s) are due to the steep X-ray continuum is tested by comparing photoionization model calculations with various observed properties of Seyfert 1 galaxies. A meaningful comparison must involve the careful use of the “right” X-ray ionization parameter, designated here \( U(\text{oxygen}) \). When this is done, it is found that the strength of the continuum absorption features is insensitive to the exact slope of the 0.1–50 keV continuum. It is also shown that the complex of iron L-shell lines near 1 keV can produce strong absorption and emission features, depending on the gas distribution and line widths. While this may explain some unusual X-ray features in AGN, the predicted intensity of the features do not distinguish NLS1s from broader line sources. Finally, acceleration of highly ionized gas, by X-ray radiation pressure, is also not sensitive to the exact slope of the X-ray continuum.

Key words: galaxies: active; quasars: general; quasars: absorption lines; X-rays: galaxies

1 Introduction

The steep X-ray spectrum of Narrow Line Seyfert 1 galaxies (NLS1s) has been shown to be highly correlated with many of the unusual properties of these sources (e.g. Boller, Leighly and Wills’ articles in this volume). It is therefore important to study the consequences of this continuum shape and its influence on the highly ionized gas (hereafter HIG) in such sources. In particular, it is interesting to test the idea that steep slope active galactic nuclei (AGN) contain HIG which is either significantly more ionized or significantly more neutral than the same component in broad line Seyfert 1 galaxies (BLS1s). If correct, this would have significant influence on the observed X-ray features and, perhaps, also on the properties of the associated UV absorption lines.
This paper presents the results of new model calculations pertaining to the strength (i.e. the optical depth) of the continuum absorption features around 0.7-0.9 keV, the absorption and emission lines in the two sub-classes of Seyfert 1 galaxies, and the motion of the HIG in NLS1s. In what follows, the dividing line between NLS1s and BLS1s is defined at X-ray continuum photon slope of $\Gamma = 2.3$.

2 Unusual spectral features in NLS1s

2.1 A comparison of the X-ray spectrum of NLS1s and BLS1s

A large number of BLS1s have been observed by ASCA, allowing a detailed investigation of the X-ray absorption features and some statistical analysis of these properties (e.g. Reynolds 1997; George et al. 1998). This, however, is not the case for NLS1s. The objects studied so far from this group are few and the signal-to-noise of most of the ASCA spectra is far inferior to the high quality spectra of the brightest BLS1s. The information available in the literature, as well as the new data presented in this meeting, allow however, a superficial comparison of the X-ray spectral properties of the two groups. In particular, it was claimed that:

- Some NLS1 galaxies show a strong absorption feature at around 1 keV which is different in shape and in energy from the commonly observed O VII and O VIII continuum absorption features in BLS1s. This was interpreted as due to O VII and O VIII resonance absorption lines in a gas moving at a relativistic speed away from the central object (Leighly et al. 1997).
- Other NLS1s (e.g. Akn 564, see Turner, Netzer & George 1999) show strong emission near 1 keV and no sign of X-ray absorption over the ASCA energy range. The strength and energy of this emission feature is still a source of discussion. Turner et al. (1999) have suggested that it may be produced by a large number of iron L-shell lines indicating, perhaps, iron over-abundance.
- The 1 keV absorption feature observed in some NLS1s is the result of a large number of iron absorption lines close to this energy (Nicastro, Fiore & Matt 1999). The strength of this feature and the relative weakness of the bound-free to O VII and O VIII absorption, are related to the unusually steep continuum in NLS1s.

The following is a closer examination of these claims. The underlying assumption is that photoionization by the X-ray continuum is the sole excitation and heating source of the HIG in both classes of AGN.
2.2 X-ray continuum absorption in NLS1 galaxies

The idea that a steeper X-ray continuum results in a different level of ionization of the surrounding gas can be tested by photoionization models. However, we must make sure that the comparison is meaningful and the calculations reflect, indeed, the influence of the X-ray continuum. In particular, it is important to use the “correct” ionization parameter,

\[ U = \frac{\int_{E_1}^{E_2} (L_E/E) dE}{4\pi r^2 n_H c} \]  

i.e. to carefully choose the most appropriate energy range \( E_1 - E_2 \).

Several different ionization parameters are currently in use, e.g. the UV ionization parameter designated here \( U(\text{hydrogen}) \) \( (E_1 = 13.6 \text{ eV}) \), and the X-ray ionization parameter (Netzer 1996) with \( E_1 = 0.1 \text{ keV} \) and \( E_2 = 10 \text{ keV} \). The fractional ionization of O VII and O VIII, the ions contributing most to the bound-free absorption by the HIG, are determined, almost exclusively, by \( E > 0.5 \text{ keV} \) photons. Hence, it is useful to define a new ionization parameter, \( U(\text{oxygen}) \), over the energy range corresponding to oxygen ionization, \( E_1 = 0.538 \text{ keV} \) and \( E_2 = 10 \text{ keV} \). Extensive tests show that HIG clouds, similar in their properties to those observed in BLS1s, are hardly affected by X-ray photons with energy below \( E_1 \). Hence, a meaningful comparison of the effect of the continuum slope is through comparing models with the same \( U(\text{oxygen}) \). It can also be shown that some combinations of different \( U(\text{hydrogen}) \) and spectral energy distribution (SED) can produce conflicting results regarding the influence of the X-ray continuum slope.

Figure 1 shows a comparison of the spectra of two HIG clouds that are exposed to (a) a typical BLS1 continuum with \( \Gamma = 2 \) and (b) an extremely steep X-ray continuum of \( \Gamma = 2.8 \). \( U(\text{oxygen}) \) is the same in both cases (0.02). This is about the average value measured by George et al. (1998) for their sample of BLS1s. The softer part of this continuum is a combination of a power-law IR continuum and a weak UV bump. This corresponds, for the case of \( \Gamma = 2.8 \), to \( U(\text{hydrogen}) = 28 \) and \( U_X = 0.4 \). The column density is typical of strong absorption HIG (10\(^{22}\) cm\(^{-2}\)), the hydrogen number density, \( n_h \), is 10\(^8\) cm\(^{-3}\) (the model is insensitive to this parameter provided it is below about 10\(^{13}\) cm\(^{-3}\)) and the composition close to solar. As evident from the diagram, “standard slope” and “steep slope” continua produce roughly the same strength absorption features when normalized to the same \( U(\text{oxygen}) \). Thus, the X-ray continuum slope by itself is not the cause of the apparent difference in continuum absorption properties between NLS1s and BLS1s.
2.3 X-ray absorption lines in NLS1s

Next we test the idea that the mysterious 1 keV absorption feature is due to the conglomeration of a large number of iron L-shell lines combined with an unusually steep continuum. The absorption spectrum of such gas has been calculated allowing for various slope continua and various width lines (e.g. various values of the micro-turbulent velocity). The results indicate that the optical depths and equivalent widths (EWs) of the absorption lines are very insensitive to the continuum slope, when normalized to the same value of $U(\text{oxygen})$. Both BLS1 continua and NLS1 continua produce strong absorption lines over the range of interest. The observed EWs depend on the line widths, the covering factor and the turbulent velocity. For more discussion see Netzer (2000).

The examples shown in Fig. 2 and 3 are for a HIG illuminated by a $\Gamma = 2.5$ X-ray continuum with $U(\text{oxygen}) = 0.2$ ($U(\text{hydrogen}) = 143$ and $U_X = 2.5$). Fig. 2 is a pure absorption case, i.e. the $4\pi$ covering factor is very small but the line-of-sight covering factor is 1.0. The softer part of the continuum, and the other model parameters, are identical to the ones used for the previous case. As seen in the diagram, strong absorption features are indeed present.
This confirms the Nicastro et al. (1999) suggestion about the origin of the 1 keV absorption feature, especially for gas clouds with large micro-turbulent velocity (200 km/sec in the case shown here). Pure thermal profiles do not produce strong enough absorption lines to explain the 1 keV feature reported by Leighly et al. (1997).

We note that the present calculations are rather different from the ones presented by Nicastro et al. (1999) for the same parameters. This is true for the H-like and He-like lines as well as the the iron L-shell lines (Netzer 2000). As for the influence of the X-ray slope, a comparison of various slope continua, with the same value of $U(oxygen)$, clearly show that this behavior is typical of both NLS1s and BLS1s. Thus the strong absorption lines and large absorption EWs are typical of the two groups of sources.

![Graph showing X-ray absorption features](image)

**Fig. 2.** X-ray absorption features for $U(oxygen)=0.2$ $\Gamma = 2.5$ and different spectral resolution: $E/\Delta E = 1000$ and $E/\Delta E = 20$. The low resolution is similar to what is provided by CCD type detectors at around 2 keV. It produces strong and broad absorption features around 1 keV that can be confused with blueshifted components.

### 2.4 X-ray emission lines in NLS1s

Finally, the idea of an unusually strong emission feature near 1 keV in NLS1 spectra, was also tested. Typical X-ray lines in photoionized gas are weak with small EWs (1-10 eV for the strongest lines assuming typical HIG, see Netzer
1996). This is well below the EW observed by Turner et al. (1999) in the ASCA spectrum of Akn 564 (about 70 eV). However, the inner geometry of the source may be such that the $4\pi$ covering factor is large yet the line-of-sight is relatively clear. In this case, continuum absorption is negligible and the scattered continuum photons will be seen on top of the unabsorbed powerlaw continuum. Such an unusual geometry can appear, for example, in flat HIG systems with extreme inclination to the line-of-sight.

Fig. 3 shows the theoretical spectrum resulting from such a special geometry. The cloud is identical to the one shown in Fig. 2 but the $4\pi$ covering factor is large (0.8) and the line-of-sight is clear of absorbing material. The emission around 0.9-1.0 keV is, indeed, very strong. This is especially noticeable when plotted with the low ASCA resolution (solid line). Note again that the turbulent velocity is the key factor and clouds with pure thermal profiles produce much weaker emission lines.

![Theoretical spectrum resulting from such a special geometry.](image)

Fig. 3. The same gas as in Fig. 2 shown for the case of no absorption along the line of sight. The total equivalent width of the strong and broad emission features near 0.9 keV, relative to the incident continuum, is about 60 eV

3 Motion of the ionized gas

The ionized nuclear gas in Seyfert galaxies is subjected to the intense radiation field of the central source which can produce strong radiation pressure forces.
Such forces, due to the UV continuum, and their influence on the ionized gas dynamics, have been studied in detail for BALQSOs (e.g. Arav, Lee & Begelman, 1994 and references therein). Yet, little has been done so far on the acceleration of the HIG by the intense X-ray source.

In a recent paper, Chelouche and Netzer (2000) investigated the physics and dynamics of HIG clouds exposed to typical AGN X-ray continua. The results confirm that such gas can be accelerated to high velocities depending on the origin of the flow relative to the center, its column density, the confining pressure and the absorption line widths. Typical velocities of 500-1000 km/sec have been obtained for gas clouds that originate just outside the broad line region (BLR); a likely location of HIG clouds.

The Chelouche and Netzer (2000) calculations have also been applied to steep spectrum sources, in an attempt to check whether the gas dynamics can provide another distinguishing factor between BLS1s and NLS1s. The detailed calculations, that will be presented elsewhere, show that the less luminous steeper X-ray continua of NLS1s are as efficient as the shallower and more luminous BLS1 continua in accelerating the HIG to high velocities. Thus, the dynamics of the HIG is not likely to provide a clear distinction between NLS1s and BLS1s.

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