OVIII Recombination Features in AGN Spectra

R. S. Warwick & R. G. Griffiths
X-ray Astronomy Group, Dept. of Physics & Astronomy, University of Leicester, University Road, Leicester LE1 7RH, U.K.

ABSTRACT

Seyfert galaxies have been shown to exhibit a rich variety in terms of their X-ray spectra. One process which contributes in the soft X-ray band is the scattering of the continuum flux by highly ionized gas in the vicinity of the nucleus. In those galaxies where the direct view of the continuum source is blocked below a few keV by line-of-sight absorption, the scattered component is often apparent as a soft X-ray excess. A spectral feature observed near 0.9 keV in the X-ray spectra of several such Seyfert galaxies can be interpreted as due to OVIII recombination radiation produced in the scattering medium. If confirmed, such features will provide a new diagnostic of the state of strongly photoionized gas in Seyfert nuclei.

1. Introduction

As a result of missions such as *Ginga*, *ROSAT* and *ASCA* and, more recently, *RXTE* and *SAX*, Seyfert galaxies have been shown to exhibit a rich phenomenology in terms of their X-ray spectra. A topic of particular recent interest has been the study of gas in the vicinity of the active nucleus which is strongly photoionized by the ultraviolet and X-ray flux emanating from the central source. Recent observations provide clear evidence for ionized absorption systems, more commonly known as warm absorbers, in many Seyfert 1 galaxies (e.g. Reynolds 1997; George et al. 1998). The presence of highly ionized gas has also been inferred in Seyfert 2 nuclei as the medium responsible for the scattering of the nuclear flux into our line of sight, even when our direct view of the nucleus is heavily obscured (e.g. Antonucci 1993).

Unless the scattering medium is completely photoionized by the incident nuclear flux, it will imprint absorption features on the emergent flux. There is also the possibility that the radiation processes intrinsic to the scatterer will be revealed through the superposition of sharp emission features. In a recent paper (Griffiths et al. 1998) we have suggested that a feature observed near 0.9 keV in the X-ray spectrum of the Seyfert 2 galaxy Mrk 3, could be due to OVIII recombination (the energy of the OVIII edge being 0.87 keV) originating in the relatively hot, photoionized medium which electron scatters a few percent of nuclear continuum of Mrk 3 into our line of sight. Here we extend our discussion of this model and consider its application to NGC 4151 and also several other Seyfert 2 galaxies.

2. The X-ray Spectra of Strongly Photoionized Plasmas

We use the photoionization code XSTAR (Kallman & Krolik 1997) to calculate the emission and absorption spectrum of a gas cloud subject to an intense photoionizing continuum flux. Briefly, the state of the gas cloud is described by the ionization parameter $\xi = \mathrm{L}/nr^2$ where L is the source luminosity in the 0.0136 – 13.6 keV bandpass in erg s^{-1}, n is number of hydrogen atoms/ions in the gas per cm^3 and r is the distance of the inner edge of the cloud to the central source in cm. In our current XSTAR models we assume a gas density of $n = 10^6$ cm^{-3} and also impose the requirement of both ionization and radiative equilibrium. Further details of our use of XSTAR are given in Griffiths et al. (1998).

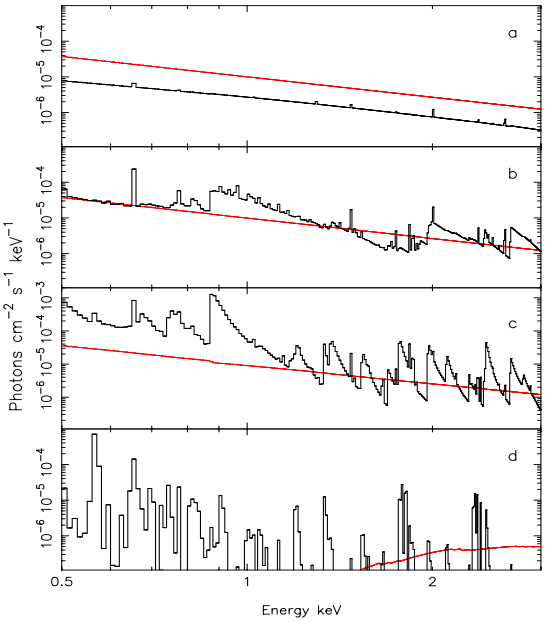

Fig. 1.— The scattered and intrinsic emission from a highly photoionized gas (shown respectively as the red and black components). The four panels correspond to log ξ values of (a) 4.0; (b) 3.0; (c) 2.5; (d) 2.0.

Figure 1 shows the predicted spectral form of the electron scattered continuum and the intrinsic emission from a medium which is heated and strongly photoionized by the direct radiation from a Seyfert nucleus.

3. Application to NGC 4151

The X-ray spectrum of NGC 4151 is characterised by hard continuum radiation, heavy and complex absorption, a prominent and possibly broad iron Kα line and a soft X-ray excess which dominates the spectrum below $\sim$ 2 keV. Here we identify the soft excess as scattered nuclear continuum radiation, amounting to roughly one percent of the direct flux.

We have analysed the SIS spectra obtained from a deep *ASCA* observation performed in May, 1995. We adopt a largely empirical model for the X-ray spectrum above 2 keV involving multiple partial covering of the continuum source in NGC 4151. The soft excess is formed by the scattering of the nuclear continuum in a highly photoionized medium (situated within a few parsecs of the nucleus) with the intrinsic emission of the scatterer co-added (see Fig. 2). This approach gives a significantly better fit to the *ASCA* spectrum of NGC 4151 than does either a model based on pure electron scattering or one combining pure electron scattering with emission from a thermal (coronal equilibrium) plasma.

The best-fitting model shown in Fig. 2 has $\log \xi \approx 2.5$ and a corresponding plasma temperature of $kT \approx 10^{5.5}$ K. The spectral peak apparent near 0.9 keV in the *ASCA* SIS spectrum of NGC 4151 is attributed to recombination directly into the K-shell of fully stripped oxygen ions in the scattering medium. We find that in order to avoid an over-prediction of the OVIII recombination flux we require a significant fraction of the scattered flux to be produced in plasma with at least a factor ten higher ionization parameter, at which point the temperature will have risen to close to the Compton temperature of $\sim 10^{7.5}$ K. A consistent picture is thus one in which very hot, fully ionized plasma, perhaps in the form of an outflow or wind from the nucleus of NGC 4151 (e.g. Krolik & Kriss 1995), is responsible for most of the scattering. However, embedded regions of cooler and denser gas give rise to the discernable OVIII recombination feature.

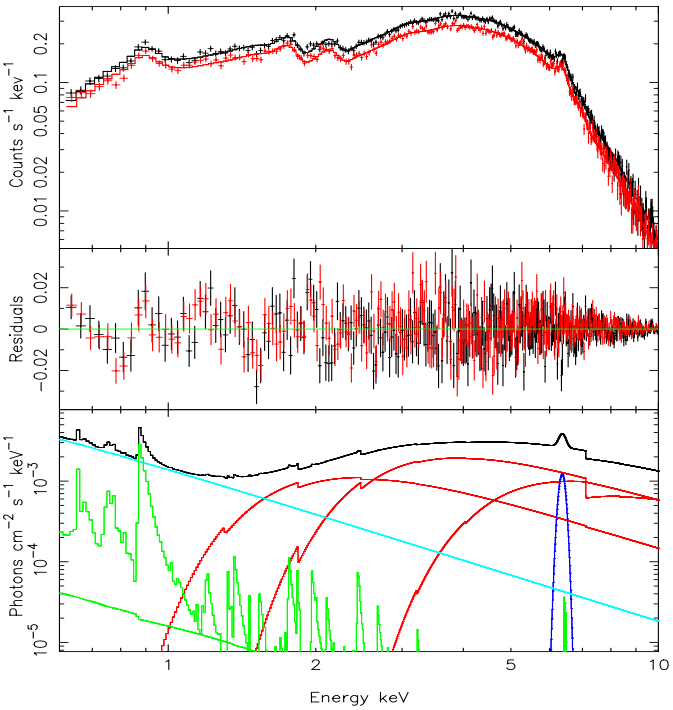

Fig. 2.— *Top panel:* The *ASCA* SIS (S0 and S1) count-rate spectra of NGC 4151 with the best fitting model shown as the solid lines. *Mid-panel:* The residuals to the fit. *Bottom panel:* The best-fitting model with OVIII recombination a prominent feature near 0.9 keV.

4. Application to Seyfert 2 galaxies

Griffiths et al. (1998) report a spectral feature near 0.9 keV in the X-ray spectrum of Mrk 3. Similarly, in a recent paper, Comastri et al. (1998) considered the *ASCA* spectrum of the Seyfert 2 galaxy NGC 4507 in which a line-like feature is again observed near 0.9 keV; however these authors attribute the feature to a helium-like Neon line at a rest energy of 0.92 keV.

In Fig. 3 we show results of fitting a cut-off continuum plus scattered power-law model to the X-ray spectra of Mrk 3, NGC 4507 and two other Seyfert 2 galaxies. In each case there is evidence for an emission peak near 0.9 keV. Table 1 details the results of fitting a narrow Gaussian line to the observed feature in these galaxies and NGC 4151. The measured line energies are consistent with the hypothesis that the 0.9 keV feature originates from the same physical process in all of the sources, namely OVIII recombination. The observed spread of equivalent width can be readily accommodated in the photoionized scatter model discussed above.

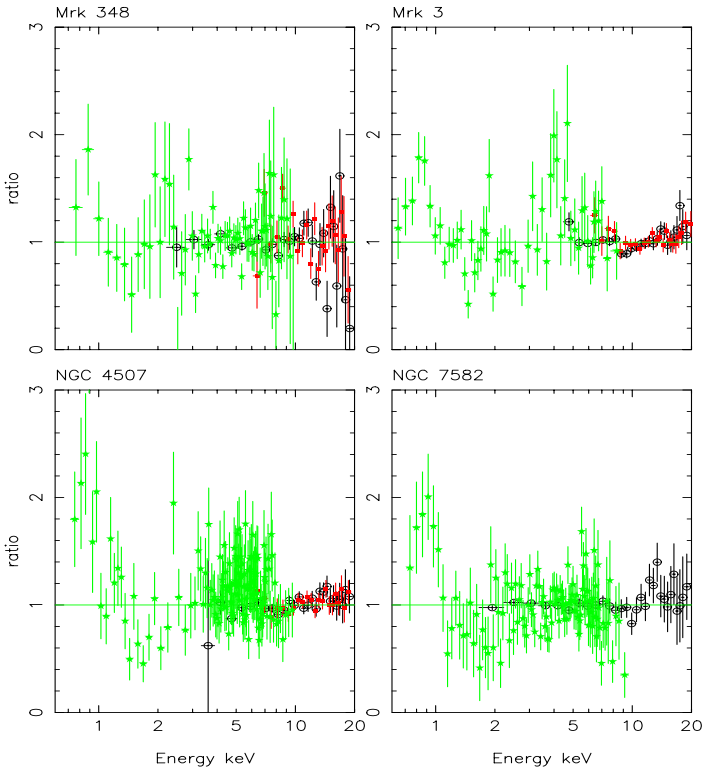

Fig. 3.— The ratio of the measured *ASCA* SIS (green) plus Ginga LAC X-ray spectra (red and black) to the best-fitting cut-off continuum plus scattered power-law spectral model for four Seyfert 2 galaxies.

Table 1: Fits of a narrow Gaussian line to the 0.9 keV feature.

Source	E^a_{line}	A^b_{line}	EW[c]
NGC 4151	$0.898^{+0.006}_{-0.006}$	8.6±1.3	44±7
Mrk 348	$0.86^{+0.03}_{-0.04}$	3.7±0.7	237±45
Mrk 3	$0.88^{+0.03}_{-0.01}$	3.2±1.0	81±25
NGC 4507	$0.90^{+0.01}_{-0.02}$	2.6 ±0.7	129±35
NGC 7582	$0.92^{+0.04}_{-0.05}$	3.7±1.5	228±92

[a] Rest-frame line energy in keV.
[b] Line intensity in units of 10^{-5} photon cm^{-2} s^{-1}.
[c] Line equivalent width in eV (wrt the scattered continuum).

5. The Promise of XMM

The launch of XMM will provide a tremendous opportunity for the advancement of our knowledge in the field of astrophysical X-ray spectroscopy. Specifically, the good spatial resolution combined with the excellent sensitivity, band-width coverage and spectral resolution of the XMM instrumentation should enable the complex set of processes which give rise to the observed spectra of cosmic X-ray sources to be unravelled. In this context, we will certainly need to harness a wide range of diagnostic techniques in order to investigate the hot plasmas present in the nuclei of Seyfert galaxies. The OVIII recombination feature discussed here, if confirmed, may well provide one such diagnostic. To illustrate the possibilities we have produced simulated XMM EPIC and RGS spectra for NGC 4151 on the basis of our best fit photoionized scatterer model. The recombination feature is prominent in both the EPIC and RGS spectra at a high signal to noise ratio (Fig. 4). From such data it should be possible, for example, to determine the precise temperature of the scattering medium and whether this material is in the process of outflow from (or conceivably in-fall towards) the central nuclear source.

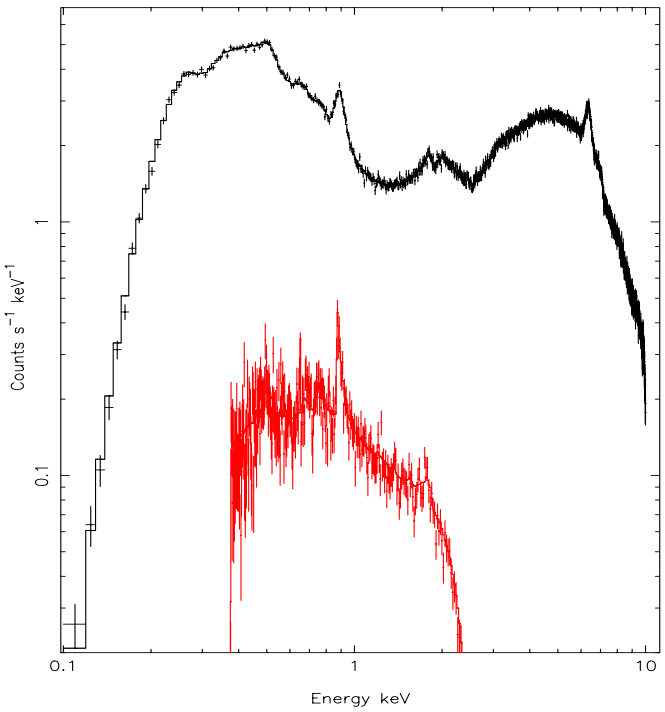

Fig. 4.— Simulated XMM EPIC and RGS spectra for NGC 4151. An observation duration of 50 ks is assumed.

REFERENCES

Antonucci R.R.J., 1993, ARA&A, 31, 473

Comastri A., Vignali C., Cappi M., Matt G., Audano R., Awaki H., Ueno S., 1998, MNRAS, 295, 443

George I.M., Turner T.J., Netzer N., Nandra K., Mushotzky R.F., Yaqoob T., 1998, ApJS, 114, 73

Griffiths, R.G., Warwick, R.s., Georgantopoulos,I., Done, C., Smith, D.A., 1998, MNRAS, 298, 1159

Kallman T.R., Krolik J.H., 1997, XSTAR: A Spectral Analysis Tool. Version 1.40 of the User's Guide

Krolik J.H., Kriss G.A., 1995, ApJ, 447, 512

Reynolds C.S., 1997, MNRAS, 286, 513

This preprint was prepared with the AAS LaTeX macros v4.0.