XMM-Newton RGS OBSERVATIONS OF WARM ABSORBERS IN SEYFERT 1 GALAXIES

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We present results from the analysis of *XMM-Newton* RGS spectra of the Seyfert 1 galaxies NGC 3783 and NGC 7469. Both galaxies have multi-phase warm absorbers, as shown by the presence of narrow absorption and emission lines in their soft X-ray spectra, with a wide range of ionisation levels. The absorbing medium is blueshifted throughout the ionisation range. The overall column of the warm absorber in NGC 7469 is perhaps 100 times lower than that in NGC 3783, but we have been able to show that the ionisation parameters of its high-ionisation phase warm absorber and its warm emitter are consistent.

1. Introduction

The advent of high-resolution X-ray spectroscopy of extragalactic sources with the launch of *XMM-Newton* and *Chandra* has enabled the warm absorber/emitters of Seyfert galaxies to be investigated in unprecedented detail. The warm absorber in a Seyfert 1 galaxy is highly ionised (photoionised) gas, intrinsic to the AGN, which is in our line of sight to the central engine. In a Seyfert 2 we apparently see the emission from this gas as the central engine itself is obscured from our line of sight [1]. his emission is also visible, though much less prominently, in Seyfert 1s. This paper summarises the results, to date, of the analysis of *XMM-Newton* RGS [2] spectra from observations of two Seyfert 1 galaxies: NGC 3783 and NGC 7469.

The ionisation state of the photoionised warm absorber gas is parametrised by the ionisation parameter

$$\xi = \frac{L}{nr^2}\,, \qquad (1)$$

where L is the source luminosity (in erg s^{-1}), n the gas density (in cm^{-3}) and r the source distance in cm, so ξ has the units erg cm s^{-1} [3] which are used throughout this paper.

Our RGS data are processed under the *XMM-Newton* SAS (Science Analysis System) and analysed using SPEX 2.00, a development version of SPEX [4], which provides two possibilities for warm absorber modelling. One model (*slab*) applies absorption by individual ions to a spectral continuum, and the other (*xabs*) applies photoionised absorption by a given column of gas, at a given ionisation parameter and elemental composition.

2. NGC 3783

The first high resolution X-ray spectrum of NGC 3783 (z=0.00973), a Seyfert 1 galaxy, was obtained using the *Chandra* HETGS by Kaspi *et al.* [5]. It showed narrow absorption (and a few emission) lines from the warm absorber. There is now a spectacular 900 ks *Chandra* HETGS observation [6], showing the warm absorber spectrum with unprecedented statistical quality.

There have also been two *XMM-Newton* RGS observations of this source. The first (of duration $\sim$ 40 ks) is already published by Blustin *et al.* [7], and was used for extensive modelling of the warm absorber. The second observation, of 280 ks, provides equivalent data quality to the 900 ks *Chandra* observation and is currently under study. In this paper we will discuss some results from both of the RGS observations of NGC 3783.

Fig. 1 shows the 40 ks RGS spectrum, as published in Blustin *et al.* [7], with a two-phase warm absorber model (red line) and the assumed underlying continuum (blue) superimposed. Ranges where absorption (or emission) by various species becomes important are marked. Notable features include the Unresolved Transition Array (UTA) of M-shell iron, strong absorption by L-shell iron, narrow absorption lines from various states of O, N, C, Si, S, Ar and Ne and the O VII emission line triplet. We found that there are two main ionisation phases in this warm absorber: a low-ionisation phase associated with the UTA (log $\xi \sim 0.3$), and a high-ionisation phase which probably extends over a range of ionisation parameters from log $\xi \sim 2.4$ upwards. Both phases are blueshifted by about 800 km s^{-1}.

In the past, with lower-resolution spectrometers, such a spectrum would have been interpreted in terms of O VII and O VIII absorption edges. This approach is no longer realistic with an RGS observation - whilst NGC 3783 has a very strong warm absorber, and there may well be some edge opacity in O VIII in particular (although the exact amount of O VIII is hard to estimate from this spectrum), any edge absorption is so heavily cut into by the many states of L-shell iron present that it is not useful any more as a diagnostic. Instead, we use the iron transitions themselves to provide a far more sensitive parametrisation of the overall ionisation structure of the warm absorber. This is demonstrated in Fig. 2, in which the columns of individual iron states from Fe VI to Fe XXIV are plotted against the log ξ of maximum abundance of that state. This shows the increased columns of the iron states corresponding to the high-ionisation and low-ionisation phases.

The 280 ks (2 orbit) *XMM-Newton* RGS observation of NGC 3783 will enable this modelling to be taken a lot further. It has equivalent data quality to the 900 ks *Chandra* HETGS observation, but extends the coverage to longer wavelengths. We present here some preliminary results from this observation (Behar *et al.* [8]). The overall 280 ks RGS spectrum agrees well with the previous 40 ks RGS spectrum and the models developed for it, and also with the 900 ks Chandra observation. Fig. 3 is a close-up of the O VII emission triplet region of the spectrum; narrow absorption lines from all the states of oxygen from neutral right up to He-like are also visible

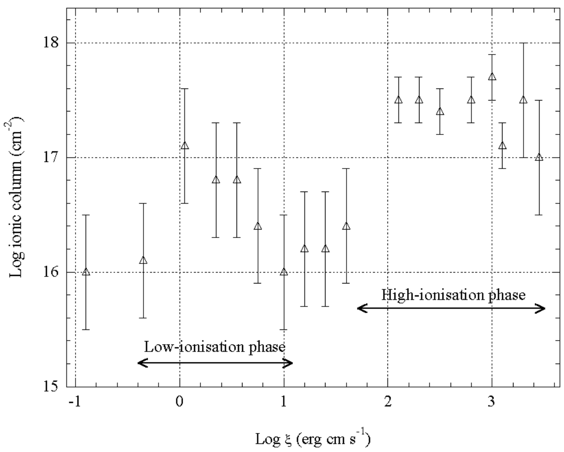

Figure 2. Logarithmic columns of iron states from Fe VI to Fe XXIV (except Fe XV, for which only an upper limit was obtained) plotted against log ξ of maximum abundance for each ionisation state; this is an indicator of the overall ionisation structure of the warm absorber (from [7]).

in this plot, with O VIII absorption present at shorter wavelengths. An absorption line from O VII in our own Galaxy is also visible. A similar range of ionisation is seen in other ions and this will enable a very detailed picture of the overall ionisation structure to be established, alongside any possible variation in elemental composition and outflow speed with ionisation state.

Fig. 4 shows the EPIC-pn [9] spectrum of NGC 3783 from the long *XMM-Newton* observation, accumulated over two orbits, with a Galactic absorbed power-law continuum model and their ratio for illustrative purposes. All the iron absorption from the warm absorber in the soft band will have implications for the form of the spectrum in the hard band; we must now take into account line and edge absorption from highly-ionised iron in our modelling of the iron Kα region consistently with that observed in the soft band. Both iron Kα and iron Kβ emission lines are clearly observed (Fig. 4). The intensity of the higher energy line is probably too high to originate purely from Kβ, given the strength of Kα, so it may also contain emission from Fe XXVI, as suggested for the shorter *XMM-Newton* observation [7].

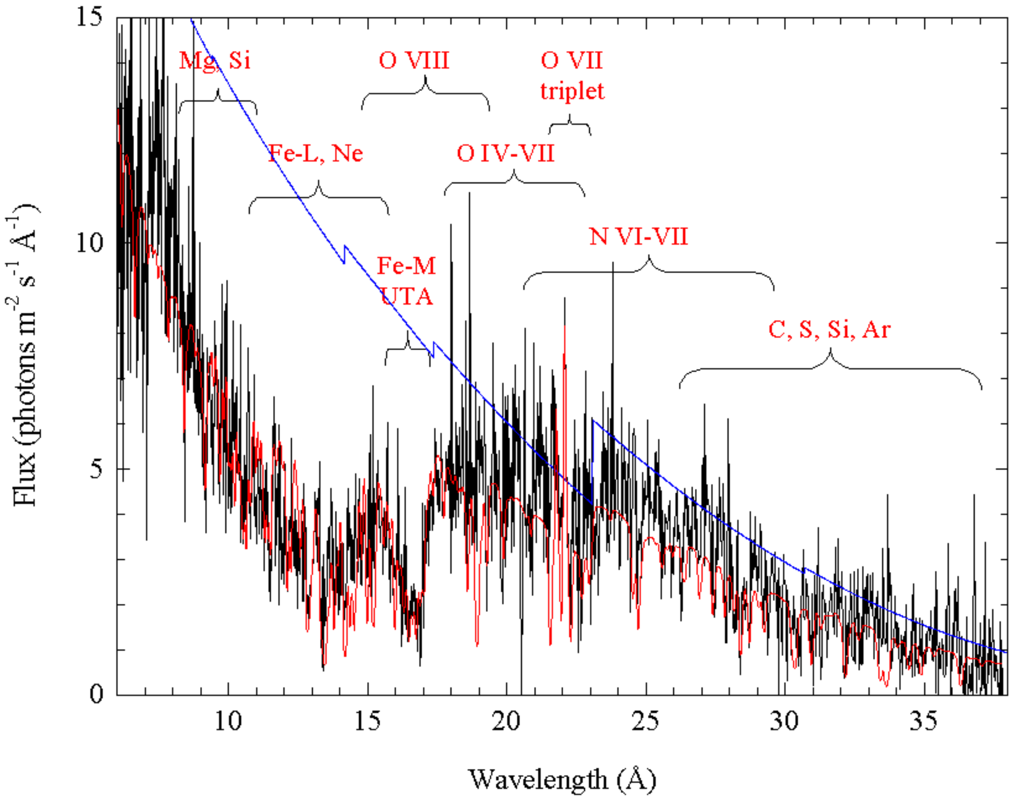

Figure 1. The 40 ks RGS spectrum of NGC 3783 (black) with, superimposed, the underlying power-law continuum (blue) and two-phase warm absorber model. Ranges where absorption or emission by certain species is important are marked (plotted in the source rest frame; from [7]).

3. NGC 7469

The first high-resolution X-ray spectrum of the Seyfert 1.2 galaxy NGC 7469 ($z = 0.00164$; [10]) was taken during a 40 ks *XMM-Newton* observation in December 2000. This is soon to be followed (at the time of writing) by a *Chandra* HETGS observation. We present here some preliminary results from the analysis of the *XMM-Newton* dataset (described in detail in Blustin *et al.* [11] and Blustin *et al.* [12]).

The EPIC-pn spectrum was modelled with a power-law and two blackbodies to reproduce the prominent soft excess; this continuum model was also used for the RGS spectrum. Fig. 5 shows the RGS spectrum, in which the warm absorber is far less visible than in NGC 3783. There are, though, a few narrow absorption and emission lines (but no trace of absorption edges); the positions of the most important ones are marked on the spectrum. Below the spectrum is a plot of their statistical significance. This was produced by fitting a gaussian to the features against a smoothed continuum. Most prominent in the spectrum are the C VI Lyα emission and absorption lines (33.736 Å in the rest frame), and the O VII forbidden emission line (22.101 Å in the rest frame). There is little evidence for iron emission or absorption in the spectrum.

Fig. 6 is a plot of ionisation parameter of maximum abundance versus blueshift for the most important absorption lines in the spectrum. There are far fewer measurable ionisation states than

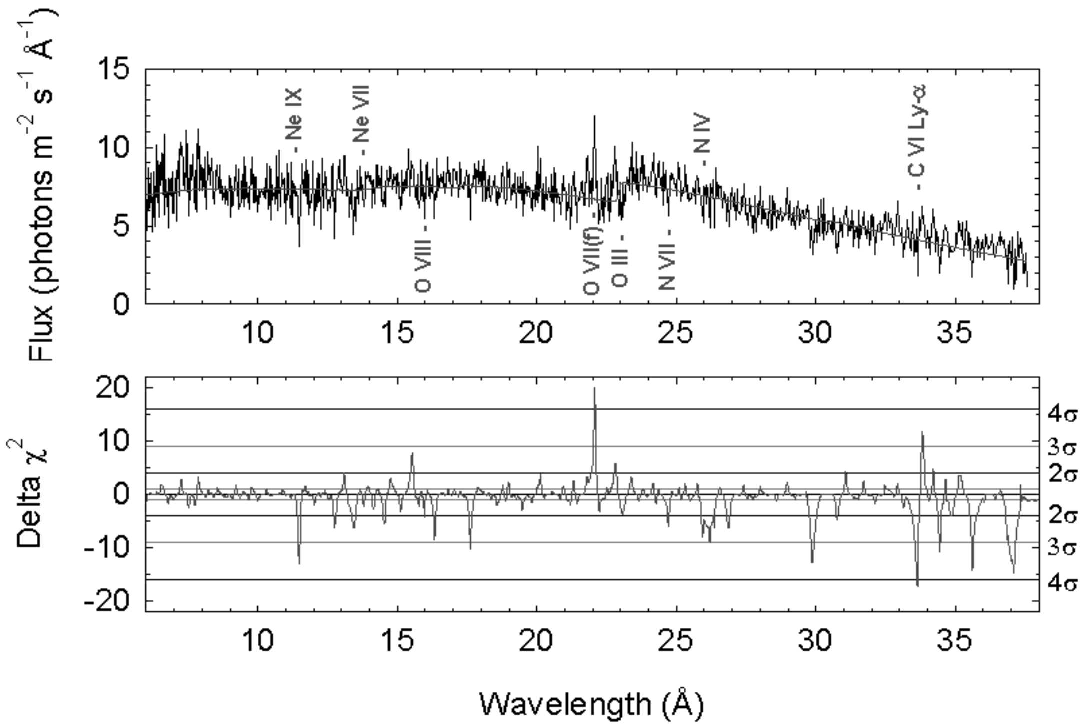

Figure 5. The RGS spectrum of NGC 7469 (plotted in the source rest frame; top panel), with the positions of the most important spectral features marked, and (bottom panel) the statistical significance of the features in terms of σ (from [12]).

in NGC 3783, although we can see that there is a large range of ionisation parameter in the absorber, and that all ionisation levels seem to be blueshifted.

The ions from the high-ionisation phase of this warm absorber cluster somewhere above log ξ of 1. If we assume that log ξ of this phase is 1.6 (as estimated from the ratio of the absorbed fluxes of O VIII Lyβ and O VII Heβ; these particular lines are used since the α transitions in each case are partially filled in by emission), and take the blueshift of this phase to be -900 km s^{-1} (the value obtained when the blueshifts of O VII Heβ, O VII Heγ and O VIII Lyβ are fitted together), then the overall column of this high-ionisation phase can be estimated to be of order 2 x 10^{20} cm^{-2} (using *xabs* in SPEX 2.00). This is far lower than the equivalent hydrogen column of the high-ionisation phase of NGC 3783 ($\sim$ 3 x 10^{22} cm^{-2}), and such a low overall column probably explains the lack of any significant iron absorption in the warm absorber of NGC 7469. It is also possible to estimate the ionisation parameter of the warm emitter from the fluxes of the O VIII Lyα and O VII Heα emission lines, taking into account the effect of absorption on these lines; the value so obtained (log ξ = 2.1 $\pm$ 0.2 if the emitter is seen through the warm absorber or 1.7 $^{+0.3}_{-0.2}$ if it is not) for the emitter is consistent with that of the high-ionisation phase of the warm absorber (further details in [12]).

4. Conclusions

In summary, both NGC 3783 and NGC 7469 have a multi-phase warm absorber with a wide range of ionisation parameters. NGC 3783 has a far deeper warm absorber (in our line of sight) than NGC 7469. The warm absorbers of both galaxies are outflowing at several hundred km

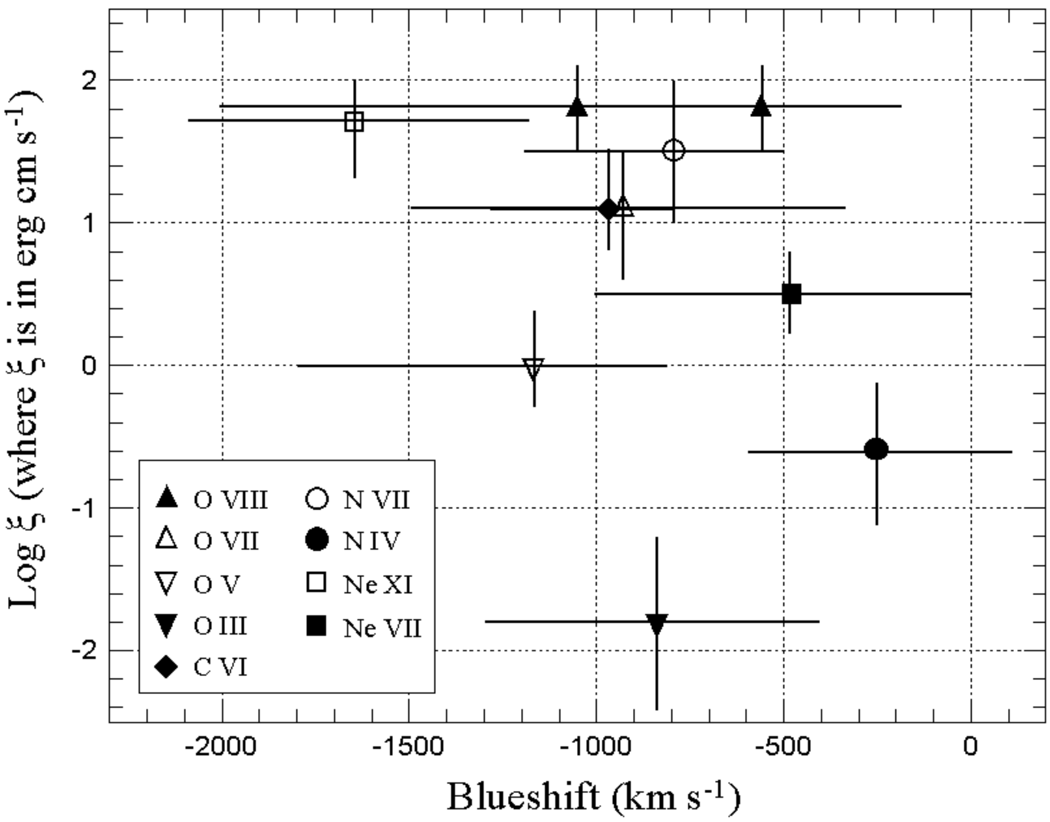

Figure 6. The ionisation parameter of maximum abundance versus blueshift for the most important absorption lines in the RGS spectrum of NGC 7469 (from [12]).

s^{-1}, with the high-ionisation and low-ionisation phases apparently moving at the same speed, within the uncertainties. Unlike NGC 3783 (and unusually for an AGN), NGC 7469 shows very little evidence of iron absorption or emission in its spectrum, which may well be due to the low overall column in the warm absorber. The ionisation level of the warm emitter in NGC 7469 is consistent with that of the high-ionisation phase of its warm absorber.

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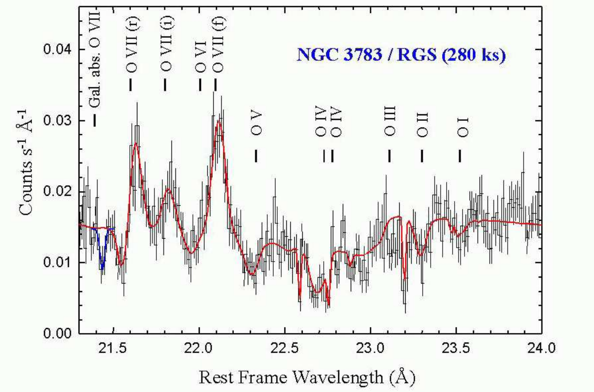

Figure 3. Plot of the O VII emission triplet region of the RGS spectrum from the 280 ks *XMM-Newton* observation of NGC 3783, showing also absorption by oxygen states from neutral to He-like as well as O VII absorption from our own galaxy (rest-frame wavelengths).

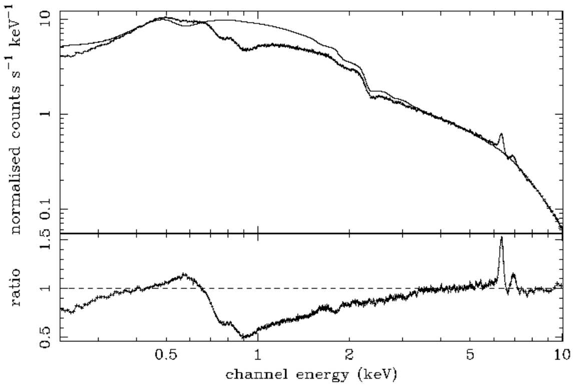

Figure 4. The EPIC-pn 0.2–10 keV spectrum of NGC 3783, compiled from data taken over two orbits of *XMM-Newton* with a Galactic absorbed power-law overplotted for illustrative purposes (top panel) and the ratio of the data to this model (bottom panel), clearly showing the warm absorption in the soft X-rays and the Fe emission line complex around 6–7 keV.

ACKNOWLEDGEMENTS

This work is based on observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA Member States and the USA (NASA). The MSSL authors acknowledge the support of PPARC. SRON is supported financially by NWO, the Netherlands Organization for Scientific Research.