Detectability of low energy X-ray spectral components in type 1 AGN

A. E. Scott¹ *, G. C. Stewart¹ and S. Mateos¹,²

¹Department of Physics and Astronomy, University of Leicester, University Road, Leicester LE1 7RH, UK
²Instituto de Física de Cantabria (CSIC-UC), Avenida de los Castros, 39005 Santander, Spain

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ABSTRACT
In this paper we examine the percentage of type 1 AGN which require the inclusion of a soft excess component and/or significant cold absorption in the modelling of their X-ray spectra obtained by XMM-Newton. We do this by simulating spectra which mimic typical spectral shapes in order to find the maximum detectability expected at different count levels. We then apply a correction to the observed percentages found for the Scott et al. (2011) sample of 761 sources. We estimate the true percentage of AGN with a soft excess component to be 75 ± 23%, suggesting that soft excesses are ubiquitous in the X-ray spectra of type 1 AGN. By carrying out joint fits on groups of low count spectra in narrow $z$ bins in which additional spectral components were not originally detected, we show that the soft excess feature is recovered with a mean temperature $kT$ and blackbody to power-law normalisation ratio consistent with those of components detected in individual high count spectra. Cold absorption with $N_H$ values broadly consistent with those reported in individual spectra are also recovered. We suggest such intrinsic cold absorption is found in a minimum of ∼5% of type 1 AGN and may be present in up to ∼10%.

Key words: galaxies: active – quasars: general – X-rays: galaxies

1 INTRODUCTION
The X-ray spectral properties of AGN classified optically as type 1 have been recently extensively studied (e.g. Young et al. 2009, Mateos et al. 2010, Corral et al. 2011, Scott et al. 2011). The underlying spectrum in the 0.5–12.0 keV band consists of a power law of photon index $\Gamma \sim 2$ thought to be produced by the inverse Compton scattering of low energy disc photons by a corona of relativistic electrons (Haardt & Maraschi 1993). In higher quality spectra, a soft excess component is detected, rising above the power law at rest-frame energies $\lesssim 1 \text{ keV}$ (Arnaud et al. 1984). This was originally interpreted as the hard tail of the ‘Big Blue Bump’, accretion disc emission seen in the UV, but is now thought perhaps to be an artifact of ionised absorption (Gierliński & Done 2004) or ionised reflection (Ross & Fabian 2005; Crummy et al. 2006). Lower energies are also affected by photoelectric absorption, although the standard orientation based Unified Model (Antonucci 1993) does not predict any intrinsic X-ray absorption to be present in objects which have been classified as type 1 due to the presence of broad lines in their UV/optical spectra.

There have been many studies in which some type 1 objects have shown evidence for intrinsic X-ray absorption. The typical percentage of such objects is ∼ 10%, with many studies quoting this similar value (Page et al. 2003; Perola et al. 2004; Piconcelli et al. 2005; Mateos et al. 2005b; Mainieri et al. 2007; Garcet et al. 2007; Young et al. 2009; Mateos et al. 2011; Corral et al. 2011).

There are a large range of values quoted for the percentage of type 1 sources which include a soft excess. The earliest study with EXOSAT suggested 30–50% of objects included the component (Turner & Pounds 1989) and a study with ASCA found ∼ 40% (Reeves & Turner 2000). It has also been suggested that the soft excess may be a ubiquitous feature in optically selected PG quasars (Porquet et al. 2004; Piconcelli et al. 2005), however these samples are biased towards bright and low redshift sources. The quoted percentage of soft excesses can be very different depending upon the redshift range being considered. For example, Mateos et al. 2011 find a percentage of only 8% when considering their entire sample, but this is increased to 36% when only sources at $z < 0.5$ are considered. Similarly the CAIXA sample of XMM-Newton target sources finds a high percentage of ∼ 80% (Bianchi et al. 2000). This could be because the sample is biased towards low redshift objects and/or good quality spectra in which detecting the spectral component is easier. Clearly, in order to determine whether
the soft excess is present in all sources, the influences of redshift and spectral quality need to be taken into account, using a sample which covers a large range in these properties.

In a recent study of the X-ray spectral properties of 761 type 1 AGN, [Scott et al. (2011); hereafter S11], find ∼ 8% of their sample require a soft excess component and ∼ 4% require intrinsic cold absorption in the modelling of their X-ray spectra. It was noted that these values represent lower limits on the intrinsic percentage of sources which include such components, since their detectability is limited by the quality of the spectra. In this paper we follow on from this analysis and aim to deduce how common these spectral features really are. In the case of the soft excess we do this by simulating typical spectra at different count levels in order to determine the maximum detection rate expected for such an additional spectral feature. This can then be compared to the observed results in order to determine the intrinsic percentage. The original data sample is described in [2] The soft excess simulations and a joint fitting of multiple low count spectra in an attempt to recover the soft excess are described in [3] Section [4] considers the presence of absorption components. We discuss our results in [5] and summarise our conclusions in [6].

2 DATA

The S11 sample was created by cross-correlating the SDSS DR5 quasar catalogue (Schneider et al. 2007) and the serendipitous X-ray source catalogue, 2XMMi (Watson et al. 2009). The X-ray spectra were extracted using standard SAS tasks and fit using XSPEC v11.3.2 (Arnaud 1996) over the energy range 0.5–12.0 keV. Histograms showing the redshift and net (i.e. background subtracted) counts distributions of the sources can be found in Fig. [1] All sources have > 75 combined MOS+pn counts, allowing both a simple power law and an absorbed power law to be fit, with the power-law slope, Γ, allowed to vary freely. For 680 sources with > 100 counts, models including a blackbody component were also considered in order to model any soft excess. The best-fitting model was assumed to be a simple power law unless the F-test, used at the 99% significance level, determined that additional components were statistically required. A summary of the different models considered, can be found in Table [1] along with the number of sources best-fit with each. Soft excesses are found in ∼ 8% of the sources in the sample and ∼ 4% require intrinsic absorption. An additional Galactic absorption component was included in each model, fixed at the H1 value determined from the HI map of Dickey & Lockman (1990).

Fig. [2] shows the detected percentages of the soft excess (thick, blue) and absorption (red) components as a function of the number of counts in the spectra. The detected percentage of the additional components is much lower in spectra with low counts where the statistics are poorer and the features are not detected with enough significance. It was suggested in S11 that since at the highest count levels we might expect to be able to detect all soft excess components if they are present, the intrinsic percentage could be as high as the ∼ 80% found in the highest count bin, making soft excesses common in the X-ray spectra of type 1 AGN. Fig. [2] also shows intrinsic absorption detected in up to ∼ 25% of sources in the higher count bins. Since the sample is drawn from a population of type 1 AGN, such a component is not expected to be required in the modelling of their X-ray spectra. The F-test was used at 99% significance when choosing the best-fitting model for a particular source, therefore 1% of the detections of a specific spectral component can be considered spurious. This 1% level is shown by the dashed line in Fig. [2].

The sample contains 62 sources which were the target of an XMM-Newton observation and therefore generally contain more counts in their X-ray spectra than the serendipitously detected sources. The percentage of targets in each count bin is shown in Fig. [2] and increases towards the higher count bins as expected, with the top bin including almost only target sources. These sources could bias the detection percentages if they were selected for observation due to a previously known soft excess or intrinsic absorption. We therefore exclude the target sources from our subsequent analysis, leaving 699 sources in the sample.

For sources at increasing redshifts, the contribution of a soft excess component or absorption in the spectra will gradually decrease as a larger contribution is redshifted outside of the XMM-Newton EPIC instrument bandpass (Turner 2001; Strüder et al. 2003). Therefore the detected percentages of these components are expected to be higher in bins containing mostly low redshift sources, which tend to be the bins with higher numbers of counts, hence the higher detection rate may be due to this redshift bias. The average redshift of the sources in each count bin is plotted in Fig. [2].

| Model | Spectral Components | Sources |
|-------|---------------------|---------|
| po | Power Law | 672 |
| apo | PL + absorption | 29 |
| po+b | PL + soft excess | 55 |
| apo+b | PL + absorption + soft excess | 5 |

Table 1. The different models used to fit the X-ray spectra of the sources in the S11 sample.

1 The description and documentation are available online at http://xmm.esac.esa.int/sas/

2 699 sources have > 75 counts and 619 have > 100 counts which we fit with models including a soft excess.
Detectability of spectral components

Figure 2. The top plot shows how the percentage of sources which require an absorption or soft excess component varies depending on the number of counts (MOS+pn) that are available in the spectra. The lowest count bin includes sources with between 75–320 total counts for absorption and 100–320 total counts for the soft excess, since these were the minimum numbers of counts required for fitting that particular spectral component. The sample includes 62 sources which were the target of an XMM-Newton observation, rather than a serendipitous detection. The middle plot shows the percentage of sources within each count bin which are target sources. The errors in the top two plots have been calculated from Poissonian statistics. The bottom plot shows how the average redshift of the sources in each count bin varies and includes standard errors on the mean.

and does decrease with increasing counts as expected. However we note that within each count bin the sources do cover a large range in redshifts.

To further investigate the redshift issue, the sources are split into broad redshift bins of $z < 1$ and $z > 1$. Separate detection curves are created and are shown in Fig. 3. In the case of the absorbed sources (top), the detected percentages for the low and high redshift sources appear to be consistent within the error ranges. This is likely due to the large range of $N_H$ values found in the sample, which means that we are able to detect absorption in sources at a range of redshifts. The percentage of sources detected with a soft excess component is higher in the low redshift sample than in the high redshift sample as expected. The curve for the $z > 1$ sources shows gaps where the detected fraction falls to zero, due to the low numbers of sources; although soft excesses are detected in the sample up to $z = 2$, the majority (82%) are found in sources with $z \lesssim 1$ as expected.

Figure 3. These figures show how the detected fraction of absorption (top) and soft excess (bottom) components varies with the numbers of counts in the spectra, considered in broad redshift bins of $z < 1$ and $z > 1$. There is a notable difference between the two curves in the bottom panel indicating a strong redshift dependence on the detectability of soft excess components.

3 SOFT EXCESS COMPONENTS

3.1 Intrinsic Percentage

In order to determine the intrinsic percentage of sources with a soft excess component, we carry out multiple sets of simulations in order to quantify their detectability. This is done by finding the maximum percentage of components that are expected to be detected in spectra with different numbers of counts.

At each of 5 redshifts and between 7 and 11 different count levels, we simulate 1000 spectra which include a soft excess. Each spectrum is fit over the energy range 0.5–12.0 keV with the ‘po’ and ‘po+bb’ models, and the F-test is used at 99% significance to determine whether the component is statistically required. The percentage of sources in which we significantly detect the component is then determined. By repeating this procedure with sets of spectra at different count levels and redshifts we construct synthetic detectability curves from which we can determine the maximum detection percentage at any count level.

We create our spectra, using the fakeit command in XSPEC which distributes a given number of counts, controlled by varying the exposure time, around a defined model with statistical fluctuations and assigns them Poissonian errors. We define the model such that it mimics the shape of a typical source in the S11 sample, both in terms of the shape of the components i.e. the $\Gamma$ and kT values and the size of the components, particularly the ratio of the blackbody normalisation to that of the power-law normalisation since this will also determine how easy the blackbody is to detect over the power-law continuum. 55 sources required the ‘po+bb’ model in the original S11 analysis. The distribution of power-law slopes and kT values for these
As each bin includes sources at a range of redshifts, we calculate a corrected percentage using all five of the detectability curves and determine a weighted average value according to the equation:

\[ \text{Result} = \sum (\text{weight} \times \text{corrected percentage}) \]  

where the ‘weight’ is the fraction of sources for which each particular redshift curve is appropriate for within that count bin. For sources at \( z > 2 \), the maximum percentage is fixed at 1%, since no real soft excesses are expected, but spurious detections may occur. Since the count bins are broad and the sources are not distributed evenly within them, they are further divided into sub-bins. The redshift-corrected percentage is calculated for each as outlined above, and an overall corrected percentage is reconstructed for the full count bin using equation 1, where ‘weight’ in this case is the fraction of sources within the particular count sub-bin.

The dashed blue line in Fig. 5 shows the corrected percentage. The values are roughly constant after the effect of spectral quality has been removed. In order to determine a value for the intrinsic percentage, \( \chi^2 \) is calculated for constant percentages between 0 and 100%. The minimum \( \chi^2 \) occurs for a constant percentage of 75 \( \pm 23\% \), for which the fit has a null hypothesis probability of \( p = 91\% \). This method produces a corrected percentage greater than 100% in the 3rd bin. Whilst this has no physical meaning, its large error bar makes it entirely consistent with the corrected percentages obtained for the other bins. Capping this bin at 100% reduces our intrinsic percentage estimate by only 1%.

To test whether a 1% spurious level is appropriate we simulated spectra which did not include a soft excess, and determined how many times we incorrectly detected this component with > 99% significance. For the majority of count levels this percentage was consistent with, or lower than 1%. However, for the lowest and highest count levels (\( \lesssim 100 \) and \( \sim 50,000 \)) the spurious level was somewhat higher (up to \( \sim 5\% \)), suggesting that both the usual statistical problems affecting simulated fits and some small systematic calibration errors exist. The count bin most affected by the spurious level is the lowest, as the simulated curve for \( z = 1.5 \) sources falls below 1%. If the maximum percentage from the simulated curve is fixed at 1%, the spurious level, the correction factor is under-estimated. Excluding this bin from the intrinsic percentage determination gives \( 71^{+26}_{-24}\% \), which is consistent with the value obtained when the bin is included.

### 3.2 Joint Spectral Fitting

We have shown that after correcting for spectral quality, a soft excess component may be ubiquitous in the S11 sample. We now re-analyse spectra with low numbers of counts

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in a joint fitting to see if the soft excess feature can be recovered in a combination of spectra where it was previously undetected.

The S11 sample includes 436 sources which were originally fit with a simple power-law model i.e. the soft excess feature was not detected in their spectra with > 99% significance, and which have < 500 counts. This limit is imposed so that the joint fitting is not dominated by a single object with high numbers of counts. Samples of ∼ 30 sources (∼ 50 MOS and/or pn spectra) are created which cover a narrow range in redshift. The resulting groups of spectra include a total of ∼ 7000 counts, a level at which a soft excess in a z < 1 source is expected to be detected 100% of the time if it is present. This is shown in Fig. 4 where the detectability curves for z = 0.4 and z = 0.75 sources are at 100% at a 7000 count level.

The groups of spectra are jointly fit with the simple power law model, ‘po’, in which Γ is free to vary. In each case we find a best-fitting result of Γ ∼ 2. In the case of the lowest two redshift bins the fit is significantly improved by using the ‘po+bb’ model, both in terms of a lower χ²/ν, as listed in Table 2 and an F-test comparing the two models which equal 100% in both cases. However the Γ values are lower than 1.8, the value used in the simulations of the previous section. For all except the 5th bin the kT values are consistent with those found in individual sources with high count spectra.

Each group of spectra is also fit with the ‘po+bb’ model in which Γ is fixed at 1.8, kT is tied to a common value for each of the spectra and the normalisations of both the blackbody and power-law components are left free to vary. The results are listed in Table 2 as the model ‘po+bb fix B’, and include the median value of the blackbody to power-law normalisation ratios and the percentage of spectra for which the ratio is > 0.01, which is interpreted as a blackbody component being present. For the three lower redshift bins (z < 1) the inclusion of a blackbody component in the spectral fit results in a better fit and the blackbody temperatures are consistent with the previous values obtained from the individual high count spectra. The normalisation ratios of the blackbody to power-law components are also consistent, both in terms of the median value and a Kolmogorov–Smirnov (KS) test which finds the full distribution of ratios to be not significantly different from those found in single object spectra in S11. The median normalisation ratio of ∼ 0.04 is consistent with the value used in the simulations of the previous section and corresponds to a luminosity ratio of ∼ 0.2. In addition, the percentage of spectra which do include a blackbody component (since the fit allows a blackbody normalisation of zero for individual spectra) is consistent with the intrinsic percentage calculated in §4. This model also gives a better fit for the highest of the redshift bins. However, the kT value is too high to be consistent with the temperatures observed in individual spectra.

It has been suggested that the soft excess feature is ubiquitous in high accretion rate AGN and that it is this parameter which may determine its presence in the spectra, or the size of the component (e.g. Done et al. 2012). We use the Eddington ratio as a proxy for mass accretion rate defined as $\lambda_{\text{Edd}} = \log(L_{\text{bol}}/L_{\text{Edd}})$. The bolometric luminosity was estimated from the observed X-ray luminosity in the 2–10 keV band, measured from the best-fitting spectral model, by applying the luminosity-dependent correction of Marconi et al. (2004). The Eddington luminosity was estimated using virially determined black hole mass estimates from the Shen et al. (2008) catalogue. As before, we use only sources with < 500 total counts and those best-fit with the model ‘po’. In addition, we also further restrict the sources to those at z < 1 and we split the remaining sources into 3 sub-samples containing roughly equal numbers of sources. The samples are fit with both the ‘po+bb fix A’ and ‘po+bb fix B’ models, the results of which are listed in Table 3 along with the properties of each sample. The ‘po+bb fix A’ model finds that a best-fitting normalisation ratio is consistent with the 0.04 found in single spectra for the top 2 bins. In the case of the lowest $\lambda_{\text{Edd}}$ bin this value is considerably lower, although it has a large associated error. A KS test finds the distributions of the normalisation ratios determined from the ‘po+bb fix B’ model to be consistent, however the median values do vary from a lower value than expected in the low $\lambda_{\text{Edd}}$ bin to a higher value than expected in the high $\lambda_{\text{Edd}}$ bin. In addition, the percentage of spectra for which allow each data set to vary is 100% at a 1σ error boundary.
Table 2. The samples used for the joint fitting and the results from fitting the spectra with the simple power law model ‘po’ in which $\Gamma$ is allowed to vary freely and the ‘po+bb’ model in which $\Gamma$ is both fixed at 1.8 and free to vary. ‘po+bb fix A’ refers to the model in which the blackbody to power-law normalisation ratio is kept the same for each spectrum and ‘po+bb fix B’ is the model in which both the blackbody and power-law normalisations are free to vary. In the case of model A, the normalisation ratio quoted is the best-fitting value with a 68% error and for model B it is median value. The errors on the $kT$ and $\Gamma$ parameters are 90%. Notes: *Not all sources have both a MOS and a pn spectrum available. For this sample we are unable to estimate reliable errors from the fit.

| $z$ range | No. of sources | Total Counts | Model | $\chi^2/\nu$ | $\Gamma$ | $kT$ (keV) | Normalisation Ratio | Percentage with SE |
|-----------|----------------|--------------|-------|--------------|--------|------------|---------------------|-------------------|
| 0.21–0.55 | 34 (51)        | 8078         | po    | 859/636 (1.351) | 2.10$^{+0.04}_{-0.05}$ | 0.07 | 78 ± 17 |
|           |                |              | po+bb | 664/584 (1.137) | 1.55$^{+0.08}_{-0.06}$ | 0.024 ± 0.002 | 74 ± 16 |
|           |                |              | po+bb fix A | 873/635 (1.375) | 1.8 (fixed) | 0.04 |
|           |                |              | po+bb fix B | 675/585 (1.154) | 1.8 (fixed) | 0.04 |
| 0.56–0.77 | 30 (50)        | 7661         | po    | 861/615 (1.400) | 2.07$^{+0.05}_{-0.02}$ | 0.07 | 84 ± 18 |
|           |                |              | po+bb | 682/564 (1.209) | 1.63$^{+0.08}_{-0.13}$ | 0.040 ± 0.010 | 72 ± 16 |
|           |                |              | po+bb fix A | 854/614 (1.391) | 1.8 (fixed) | 0.05 |
|           |                |              | po+bb fix B | 693/565 (1.227) | 1.8 (fixed) | 0.05 |
| 0.77–0.98 | 33 (51)        | 7367         | po    | 683/611 (1.118) | 2.03$^{+0.05}_{-0.04}$ | 0.036 ± 0.005 | 63 ± 14 |
|           |                |              | po+bb | 624/559 (1.116) | 1.98$^{+0.04}_{-0.05}$ | 0.02b |
|           |                |              | po+bb fix A | 681/610 (1.116) | 1.8 (fixed) | 0.02 |
|           |                |              | po+bb fix B | 579/569 (1.034) | 1.8 (fixed) | 0.02 |
| 0.98–1.12 | 31 (51)        | 7583         | po    | 632/629 (1.005) | 2.02$^{+0.05}_{-0.04}$ | 0.048 ± 0.008 | 63 ± 14 |
|           |                |              | po+bb | 576/577 (0.998) | 1.99$^{+0.04}_{-0.06}$ | 0.02 |
|           |                |              | po+bb fix A | 616/628 (0.981) | 1.8 (fixed) | 0.04 |
|           |                |              | po+bb fix B | 629/578 (1.088) | 1.8 (fixed) | 0.04 |
| 1.12–1.19 | 30 (50)        | 6749         | po    | 604/578 (1.045) | 2.03$^{+0.04}_{-0.05}$ | 0.045 ± 0.005 | 63 ± 14 |
|           |                |              | po+bb | 571/527 (1.083) | 1.96$^{+0.04}_{-0.06}$ | 0.02 |
|           |                |              | po+bb fix A | 597/577 (1.035) | 1.8 (fixed) | 0.04 |
|           |                |              | po+bb fix B | 606/528 (1.148) | 1.8 (fixed) | 0.04 |
| 1.19–1.28 | 29 (50)        | 5614         | po    | 485/509 (0.953) | 1.97$^{+0.05}_{-0.03}$ | 0.062 ± 0.002 | 63 ± 14 |
|           |                |              | po+bb | 450/458 (0.983) | 1.89$^{+0.05}_{-0.06}$ | 0.02 |
|           |                |              | po+bb fix A | 471/508 (0.927) | 1.8 (fixed) | 0.04 |
|           |                |              | po+bb fix B | 416/459 (0.906) | 1.8 (fixed) | 0.04 |

4 ABSORPTION COMPONENTS

Intrinsic cold absorption may also be present in type 1 AGN, suppressing the lower energy emission. The percentage of sources with detected absorption is shown in Fig. 2 and appears to be limited by the spectral quality in a similar way to that of the soft excess. However, the effect is not as strong, with the detected percentage decreasing by approximately 20% from the higher to lower count bins rather than ~ 80% in the case of the soft excess. It was suggested in S11 that the true percentage of absorbed sources could be as high as the ~ 25% found in the highest count range, where we might expect the spectra to be of good enough quality to detect any significant absorption if present. However, the highest count bins are heavily contaminated by target sources, resulting in a lower detected percentage of absorption components once they are removed from consideration. Fig. 2 shows the detected percentage after target removal. The highest count bin in this plot now suggests that 5.6 ± 3.9% of type 1 AGN may include an intrinsic absorption component. In the lower count bins (< 3200), the detected percentage of absorbed sources does not vary significantly suggesting that the detectability is not as heavily dependent on spectral quality as it is for the soft excess feature.

The detectability of absorption in the spectra is highly dependent on the $N_H$ value and the range of rest-frame column densities found in the absorbed sources is very broad, $10^{21}$ to $10^{23}$cm$^{-2}$. Therefore we cannot choose a single model to simulate which is representative of all the absorbed sources we detect, unlike in the case of the soft excess, and we do not have enough statistics in order to weight detectability curves by both $N_H$ and $z$. We do attempt to quantify the detectability of absorption components with different column densities by simulating absorbed spectra at $z = 1$. These detectability curves are shown in Fig. 6 by the black curves of different line style. They show that a column of $10^{23}$cm$^{-2}$ (equivalent to $2 \times 10^{22}$cm$^{-2}$ at $z = 0$) would be detected in most spectra with > 200 counts, whereas a col-
umn of \(\sim 3 \times 10^{22} \text{ cm}^{-2}\) (equivalent to \(5 \times 10^{20} \text{ cm}^{-2}\) at \(z = 0\)) is not strong enough to be detected in spectra of this quality at \(z = 1\). For the highest count bin (\(\gtrsim 3200\) counts), the detectability curves for all but the lowest level of \(N_H\) shown in Fig. 2 are at 100%. This means that we expect to be sensitive to all reasonable levels of \(N_H\) and therefore our intrinsic percentage estimate is robust. The fraction of sources with particular \(N_H\) levels is roughly constant in both different \(z\) and count bins (the 2 properties being correlated), and hence the slight decrease in the detected percentage between the top bin where we expect to detect all levels of \(N_H\) and the bottom bins is what is expected when objects with lower \(N_H\) and/or higher redshifts are no longer detectable.

These simulations do not include a soft excess component which could also reduce the detectability of any absorption present. We investigate this by simulating sources with both the standard soft excess parameters and 2 values of \(N_H\) (shown by the lines of open circles in Fig. 2). For log \(N_H = 22\) our sensitivity drops by approximately 10\% at low count levels (\(~ 200\) counts), increasing to \(~ 25\%\) at higher count levels (\(~ 1000\) counts), making little difference to our conclusions. In the case of log \(N_H = 21.5\), at low count levels (\(\gtrsim 1000\)) we are mostly insensitive to the absorption anyway, such that the inclusion of a soft excess makes little difference to its detectability. At higher counts levels (\(\sim 10,000\)) where the statistics are better, including the soft excess can reduce our sensitivity to the absorption component by \(~ 65\%).

In Fig. 4 a joint fitting was carried out on groups of low count spectra to see if the soft excess feature could be recovered. Similarly, we fit the ‘apo+bb’ model to the same samples to see if an absorption component can be recovered in addition to the soft excess already found to be present. We implement the model with \(\Gamma\) fixed to 1.8, kT fixed at 0.2 keV and leave both the power law and blackbody normalisations free to vary. The best-fitting \(N_H\) values are listed in Table 4. We find that an absorption component can be recovered in the low count spectra, but only in the lower redshift bins is this component constrained. Although the \(N_H\) values are of the order of those seen in single object fits in the S11 sample, the range in column densities means that the values we obtain here merely represent an ‘average’ \(N_H\) value, the exact value of which should be treated with caution.

### Table 3

| \(\lambda_{\text{Edd}}\) range | No. of sources (spectra) | Total Counts | Model | \(\chi^2/\nu\) | \(\Gamma\) | kT (keV) | Normalisation | Percentage with SE |
|-----------------------------|--------------------------|--------------|-------|----------------|--------|----------|---------------|-------------------|
| \(-2.3\) to \(-1.3\)       | 28 (47)                  | 5613         | po+bb fix A | 685/498 (1.376) | 1.8 (fixed) | 0.15±0.16 | 0.008±0.7 | 45 ± 12          |
|                             |                          |              | po+bb fix B | 570/452 (1.261) | 1.8 (fixed) | 0.18±0.02 | 0.005        |                  |
| \(-1.3\) to \(-1.0\)       | 32 (52)                  | 8383         | po+bb fix A | 821/660 (1.244) | 1.8 (fixed) | 0.25±0.03 | 0.048±0.004 | 75 ± 16          |
|                             |                          |              | po+bb fix B | 657/609 (1.079) | 1.8 (fixed) | 0.23±0.02 | 0.004        |                  |
| \(-1.0\) to \(+0.2\)       | 26 (36)                  | 6536         | po+bb fix A | 546/500 (1.092) | 1.8 (fixed) | 0.18±0.04 | 0.05±0.01  | 83 ± 21          |
|                             |                          |              | po+bb fix B | 472/465 (1.015) | 1.8 (fixed) | 0.16±0.03 | 0.084        |                  |

\(a\) \(\lambda_{\text{Edd}} = \log (L_{\text{bol}}/L_{\text{Edd}})\)

### Table 4

| \(z\) range | \(N_H\) (\(\times 10^{22}\) cm\(^{-2}\)) |
|-------------|-----------------------------------------|
| 0.21–0.55   | 0.57±0.27                               |
| 0.56–0.77   | 0.83±0.19                               |
| 0.77–0.98   | < 0.43                                  |
| 0.98–1.12   | < 0.17                                  |
| 1.12–1.19   | < 0.53                                  |
| 1.19–1.28   | < 0.61                                  |

Figure 6. This figure shows how the detected percentage of an intrinsic cold absorption component varies with the number of counts in the X-ray spectra (red, solid line). It reproduces Fig. 2 but the sources which were the target of an \(XMM-Newton\) observation have been removed. As a result of the reduced number of sources this leaves, the original top three bins are combined. The percentage appears to remain constant at \(~ 3\%\) for spectra with \(75–32,000\) counts, suggesting the detectability is not as heavily dependent on the spectral quality as is the case for the soft excess. The black lines represent simulated detectability curves for the detection of absorption components with different column densities (shown by the different line styles) in simulated spectra at \(z = 1\). The equivalent \(N_H\) value at \(z = 0\) is quoted in brackets on the figure. The open circles show the detectability of absorption of log \(N_H = 22\) and log \(N_H = 21.5\), when a soft excess of typical shape and size is also included in the spectra.
5 DISCUSSION

The origin of the soft excess emission is still a matter of debate. Since this feature has been shown to be ubiquitous in the X-ray spectra of type 1 AGN, any models to explain its origin must be applicable to all sources. Some theories of the soft excess describe it as an ‘apparent’ feature, rather than an additional component in the spectrum. A strong jump in opacity at ~ 0.7 keV is created by lines and edges of ionised O\textsc{vii} and O\textsc{viii} which are smeared by the high velocities or gravitational redshifts found close to a black hole. This can appear from absorption through optically thin material in the line of sight (Gierliński & Done [2004]) or via reflection from optically thick material out of the line of sight (Ross & Fabian [2003], Crummy et al. [2006]). More recently, Done et al. [2012] have suggested that the soft excess may be intrinsic emission from the disc, which is shifted into soft X-ray energies due to the required colour-temperature correction, and further Compton upscattering produces the full components observed. However, this only applies to the lowest mass/highest accretion rate AGN and since we find the soft excess to be present not only in high accretion rate sources, this suggests two separate interpretations for the soft excess are required. An alternative theory, is that part of the soft X-ray emission may be due to cooling outflows which are now thought to be reasonably common in AGN (Tombesi et al. 2010). During Eddington accretion episodes, high velocity (v ∼ 0.1c) and highly ionised (ξ ∼ 10^4) winds are produced and when these interact with the interstellar medium of the host galaxy, the gas is strongly shocked (King 2010). Subsequent Compton cooling of this gas may be observable as a soft X-ray component, as suggested in the case of NGC 4051 (Pounds & Vaughan [2011]).

The ubiquity of the soft excess means that any X-ray spectral fitting of type 1 AGN must take this feature into account. It has been shown that leaving this component unmodelled can lead to a Γ value ∼ 0.1 too steep. In addition, any attempt to constrain an intrinsic η\textsubscript{H} value must also include the blackbody component in the fit since they appear in the spectra at a similar energy range. It was found in S11 that the average η\textsubscript{H} values for sources fit with the ‘po+bb’ model were significantly flatter than those fit with the ‘po’ model (Γ\textsubscript{po} = 1.98 ± 0.01, Γ\textsubscript{po+bb} = 1.87 ± 0.05, KS significance = 0.0003) suggesting that the underlying power-law slope in sources with a soft excess is different. However, our modelling uses a blackbody at low energies to model the soft excess component and this is purely phenomenological - it provides a good representation of the feature seen in spectra of our quality. If the soft excess is actually a broad spectral feature as suggested by reflection models, our modelling may not be fully accounting for the spectral complexity and the power-law slope at higher energies could still contain some of this component.

This work and many in the literature, have confirmed the presence of a population of AGN which are classified as type 1 due to the presence of broad emission lines in their UV/optical spectra, but also show significant X-ray absorption. Conversely there are also objects optically classified as type 2 which are unabsorbed in X-rays (e.g. Panessa & Bassani [2002], Mateos et al. [2005]). These objects are not reconciled by the standard orientation based Unified Model which invokes an obscuring torus to both block the line of sight to the broad line region and give X-ray absorption in the case of type 2 AGN, but not type 1. Constraining the fraction of absorbed type 1 sources may aid in interpreting these objects in terms of a correction to the Unified Model. Such a correction may include invoking the ‘clumpy torus’ model (Nenkova et al. 2008a,b) in which the torus consists of individual clouds. Observations of AGN which showed large amplitude and rapid variability of the X-ray column density were interpreted as occultations by clouds in the broad-line region, suggesting clumpy absorbers may be present at a range of different scales. In this model observing a given source as absorbed depends upon the covering factor of the clouds and is a probability issue rather than one of just orientation (Risaliti et al. 2002). It has also been suggested that obscuration of AGN could occur due to the presence of a warped accretion disc (Greenhill et al. 2003; Nayakshin 2005; Lawrence & Elvis 2010). In this scenario there is no need for an obscuring torus; the type 2 objects tend to be the ones with larger misalignments, giving larger covering factors.

Whilst it would be interesting to compare how the detection of the low energy spectral components varies with radio loudness\textsuperscript{4}, we lack the statistics to do this. However we do note that 6/75 radio loud quasars (RLQ) have a detected soft excess and a joint fit of 29 sources with a total of ∼ 7000 counts gives similar soft excess parameters to those found for the radio-quiet objects. The prevalence and magnitude of soft-excesses thus appears very similar for RQQ and RLQ, contrary to previous suggestions that RLQ do not include this component, (e.g. Sulentic et al. 2011).

6 CONCLUSIONS

In this paper we have simulated X-ray spectra consisting of a power law and a soft excess, in which the shape of the later component represents a typical example of those found in the S11 sample. The spectra were fit in xspec over the energy range 0.5–12.0 keV and an F-test was used at 99% significance to test whether the component was statistically required in the fit. By repeating this procedure for spectra with different numbers of counts, maximum detection curves were generated and compared to the observed results from the real data sample presented in S11. The effect of redshift on the detectability was also taken into account. Despite the raw percentage of sources with a soft excess being ∼ 8%, we showed that after correcting for the spectral quality, the intrinsic percentage is 75 ± 23%. This suggests that within the S11 sample, almost all of the sources could include a soft excess component with a shape and size typical of that seen in the highest count spectra, and it is merely the quality of the spectra that is limiting our ability to detect them. The detectability of a soft excess component is dependent on both the blackbody temperature and the size of its normalisation with respect to the underlying power law used in the modelling, but we find that using slightly different values for either does not change our overall conclusion.

\textsuperscript{4} The determination of the radio loudness of the sources is described in S11.
If soft excesses are ubiquitous, then the feature should be recovered in a combination of low count spectra. Groups of $\sim 50$ spectra ($\sim 7000$ counts) were created in narrow $z$ bins, including spectra with $< 500$ counts and which had no previous evidence for additional spectral features. The groups at $z < 1$ were shown to be better fit with a model including a soft excess, and the temperature and normalisation with respect to the underlying power law of the components required were consistent with those found in individual high count spectra.

We are unable to conduct a simulation procedure in order to determine the percentage of type 1 AGN which require an intrinsic cold absorption component. However, we suggest that its detectability may not be as dependent upon spectral quality as the soft excess. We stress that a non-negligible percentage, $\sim 5\%$, of type 1 AGN may include such an absorption feature and therefore any spectral modelling must take the possibility of this feature into account.

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