ASCA observations of two steep soft X-ray quasars

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ABSTRACT

Steep soft X-ray (0.1-2 keV) quasars share several unusual properties: narrow Balmer lines, strong FeII emission, large and fast X-ray variability, rather steep 2-10 keV spectrum. These intriguing objects have been suggested to be the analogs of Galactic black hole candidates in the high, soft state. We present here results from ASCA observations for two of these quasars: NAB0205+024 and PG1244+026.

Both objects show similar variations (factor of $\sim 2$ in 10 ks), despite a factor of about ten difference in the 0.5-10 keV luminosity ($7.3 \times 10^{43}$ erg s$^{-1}$ for PG1244+026 and $6.4 \times 10^{44}$ erg s$^{-1}$ for NAB0205+024, assuming isotropic emission, $H_0 = 50.0$ and $q_0 = 0.0$).

The X-ray continuum of the two quasars flattens by 0.5-1 going from the 0.1-2 keV band toward higher energies, strengthening recent results on another half dozen steep soft X-ray AGN.

PG1244+026 shows a significant feature in the ‘1 keV’ region, which can be described by either as a broad emission line centered at 0.95 keV (quasar frame) or as edge or line absorption at 1.17 (1.22) keV. The line emission could be due to reflection from an highly ionized accretion disk, in line with the view that steep soft X-ray quasars are emitting close to the Eddington luminosity. Photoelectric edge absorption or resonant line absorption could be produced by gas outflowing at a large velocity (0.3-0.6 c).

Key words: Galaxies: Seyfert – Galaxies: individual: PG1244+026, NAB0205+024 — X–rays: galaxies — Line: formation — Line: identification

1 INTRODUCTION

The ROSAT PSPC has found a large spread in the energy spectral indices of low-z quasars\textsuperscript{[4]}: $0.5 < \alpha_{0.1-2keV} < 3.5$. In about 10% of cases $\alpha_{0.1-2keV} > 2$ (e.g. Laor et al. 1994, 1997, Walter & Fink 1993, Fiore et al. 1994). The large spread in $\alpha_{0.1-2keV}$ favoured the discovery of its correlation with other properties. In fact, the steep soft X-ray quasars have then been realized to share a cluster of unusual properties:

- narrow Balmer lines\textsuperscript{[5]} (Laor et al 1994, 1997, Boller et al. 1995);
- strong FeII emission (Laor et al 1994, 1997, Lawrence et al. 1997)
- Rapid, large amplitude variability (factor of 2-50 on

\textsuperscript{[4]} We use “quasars” to describe broad line emission objects, regardless of luminosity.

\textsuperscript{[5]} the permitted lines have FWHM$\leq 2000$ km s$^{-1}$, yet still are clearly broader than the forbidden lines.
timescales from minutes to months, Boller et al., 1995, Brandt et al., 1995, Otani 1995, Boller et al. 1997)

- Somewhat steep hard X-ray spectra (2 > α_{2-10keV} > 0.6, Pounds et al. 1995, Brandt et al., 1997)

Pounds et al. (1995), suggest the latter to be a close physical analogy with the X-ray power-law produced by Comptonization in a hot accretion disk corona in Galactic black hole candidates (BHC) in their ‘soft-high’ state. This is not the only analogy between BHC and steep X-ray spectrum quasars. Laor et al. (1994, 1997) explained the correlation with Hβ FWHM as due to the larger size of a virialized broad emission line region for an AGN in a high L/L_{Edd} state. Ebisawa (1991) found that while the soft component of 6 BHC observed by Ginga is roughly stable on timescales of day or less, the hard component exhibits large variations down to msec time scales. These timescales translates to 10^4 years and 0.1 day for quasars, if they scale with the mass of the compact object. The soft component of BHC extends up to ~ 10 keV in BHC in ‘soft-high’ states, and it is often associated with optically thick emission from an accretion disk. If this is the case, the temperature should scale with the mass of the compact object as M^{-1/4} and the above energy translates to 0.1-0.4 keV for quasars. The rapid large amplitude variability shown by a few narrow line Seyfert 1 galaxies (NLSy1) at about 1 keV on timescales of hours to days (Otani 1995, Brandt et al. 1995, Boller et al. 1997) can then be analogous to the above BHC hard component flickering.

A steep X-ray spectrum quasar with 10-100 times the luminosity of NLSy1s, should be larger and so should vary no more rapidly than several days. Instead Fiore et al. (1998a) find that steep X-ray spectrum PG quasars commonly vary by a factor 2 in 1 day. Variability seems therefore correlated with X-ray spectral slope and Balmer line width (and therefore possibly with the accretion rate) rather than with the luminosity.

Evidence for spectral features in the ‘1 keV’ region in many steep soft X-ray quasars is building up (Turner et al., 1991, Brandt et al., 1994, Otani et al., 1995, Comastri et al., 1995, Leightly et al. 1997, 1998a,b). Instead, ‘normal’ Seyfert 1 galaxies (having broad Balmer lines and flatter soft X-ray spectra) usually have their strongest absorption features at lower energies (in the 0.6-0.9 keV ‘oxygen’ band). An intriguing possibility is that the appearance of these features at different energies also depend on L/L_{Edd}.

Detailed high energy X-ray spectra of luminous quasars with steep soft X-ray spectra are essential to understand the ‘narrow-broad line’ phenomenon in AGN, in particular whether the peculiar X-ray properties depend on optical luminosity, optical-to-X-ray ratio (α_{OX}), or on their Eddington ratio. To this end we selected two bright quasars with α_{0.1-2keV} > 2.0 (Fiore et al. 1994) at the extreme values of optical luminosity, both with low Galactic N_H (Table 1) of 1.9×10^{20} cm^{-2} for PG 1244+026, and of 3.0×10^{20} cm^{-2} for NAB0205+024, Elvis et al. 1989) and observed them with ASCA. We report the results in this paper.

2 OBSERVATION AND DATA REDUCTION

Table 1 gives the redshift, M_V, the 0.2-2 keV luminosity, α_{OX}, the average PSPC count rate and spectral index and the Galactic N_H for the two quasars. Table 2 gives the ASCA observation log, the SIS and GIS exposure times and count rates.

Both observations were performed in two CCD mode with the source at the ‘1CCD mode’ position. Data reduction was performed using ftools 3.6. We used “bright” mode SIS data, combining LOW, MEDIUM and HIGH bit rates. Conservative cleaning criteria were applied (minimum Earth occultation = 7 degrees, minimum magnetic rigidity = 6 GeV/c, minimum bright Earth angle = 20 degrees, and excluding data collected in the first 32 seconds after the satellite passage in the SAA and through the day-night terminator). Counts, light curves and spectra from the two quasars were accumulated in circular regions of 3 and 4 arcmin radius for SIS and GIS respectively.

We are interested in the high energy spectrum of these sources and since they are rather faint, and possibly very steep, background subtraction plays a crucial role. Background counts were accumulated from regions surrounding the sources and compared with counts accumulated from the same regions from ‘blanksky’ observations. The ‘local’ and ‘blanksky’ background counts were always within 10 % of each other for the four ASCA instruments. To obtain the best possible signal to noise in the background subtracted spectra we therefore used the ‘blanksky’ background in our spectral analysis. We extracted background spectra from ‘blanksky’ event files using the same regions as for source extraction. The count rates of the two sources become that of the background at about 7 keV (observer frame). After background subtraction PG1244+026 is observed in the GIS up to 10 keV and NAB0205+024 up to 8 keV (9.3 keV quasar frame), both at the > 3 σ level.

Spectral fits were made separately to the spectra from the four ASCA instruments and to the spectra obtained combining together the data from the two SIS and GIS detectors. The results were consistent with each other. In the following we present the results obtained following the second approach. In some cases χ^2 are smaller than 1. This is due to the prescription adopted in adding the spectra, for the propagation of the errors (the Gehrels, 1986, algorithm; error = 1.0 + SQRT(N + 0.75)). Spectra were always rebinned following 2 criteria: a) to sample the energy resolution of the detectors with four channels at all energies where possible, and b) to obtain at least 20 counts per energy channel. In the spectral fits we limited ourselves to the 0.6-10 keV energy band, to minimize the systematic effect due to the uncertainty in the SIS calibration below 0.6 keV. N_H was always constrained to be greater than or equal to the Galactic value along the line of sight.

In all cases the quoted errors represent the 90 % confidence interval for 1 interesting parameter.

3 VARIABILITY

ASCA observed the two quasars for a total elapsed time of 105 ks (PG1244+026) and 119 ks (NAB0205+024). We can therefore study the variability of these sources on time scales from a few hundred seconds to about 1.5 days.

Figure 1 and 2 show the SIS light curves of the two sources. Following Ptak et al. (1994) the values were com-
Table 1. Steep soft X-ray quasars

| name            | z   | $M_V^{0}$ | $L_{0.2-2keV}$ | $\alpha_{OXS}$ | PSC | $\alpha_{0.1-2keV}$ | $N_{H(Gal)}$ |
|-----------------|-----|-----------|----------------|----------------|-----|---------------------|--------------|
| PG1244+026     | 0.048 | -21.1     | 0.14           | 1.4            | 1.0 | 2.3 $\pm$ 0.1       | 1.9$^b$      |
| NAB0205+024    | 0.155 | -25.0     | 1.8            | 1.6            | 0.7 | 2.3 $\pm$ 0.1       | 3.0$^b$      |

$^a$ $H_0 = 50$, $q_0 = 0$; $^b$ Elvis et al. 1989

Table 2. ASCA observations

| name            | Dates       | Exposure | SIS-GIS 2 | SIS count rate | GIS count rate |
|-----------------|-------------|----------|-----------|----------------|----------------|
| PG1244+026      | 1-3 Jul 1996 | 37-39   | 0.442$^+$/$^-0.004$ | 0.241$^+$/$^-0.004$ |
| NAB0205+024     | 18-20 Jan 1996 | 50-54 | 0.150$^+$/$^-0.001$ | 0.153$^+$/$^-0.002$ |

A drop of a factor of about 2 is present at the beginning of the light curve of NAB0205+024 on a ~ 15 ks timescale. In this paper we limit ourselves to pointing out that roughly similar variability is observed in two sources which differs in luminosity by a factor ~ 10. Significant, although rather small, spectral variability is also present in the ASCA observations of the two sources. A systematic analysis of the variability in different energy bands and of the spectral variability is in progress and will be presented, together with a similar analysis on a sample of about 20 Seyfert 1 galaxies and quasars observed by ASCA and BeppoSAX, in a paper in preparation. In the following sections we present the average properties of the spectra. We anticipate that the spectral variability will not modify the results presented here.

4 SPECTRAL ANALYSIS

Figures 3 and 4 show the SIS+GIS spectra of PG1244+026 and NAB0205+024 fitted with a simple power law absorbed at low energy by a column of cold gas equal to or higher than the Galactic column along the line of sight. Table 3 gives the best fit parameters and the $\chi^2$. It is clear that this simple model is inadequate to describe the 0.6-10 keV spectrum of both quasars. A hard tail, larger than the 5-10% systematic uncertainties at these energies (Gendreau & Yaqoob 1997), is evident in both cases. In the spectrum of PG1244+026 there is also a significant excess with respect to the model about 1 keV. The feature is visible in both SIS and GIS detectors. We discuss these two findings in turn in the next two sections.

4.1 0.6-10 keV continuum

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4.1 0.6-10 keV continuum

The ASCA SIS and GIS responses are peaked at 1-2 keV and decrease sharply at higher energies. Therefore the ASCA ‘2-10 keV’ slopes are strongly biased toward the lowest energy boundary. This means that some caution should be used when comparing ASCA ‘2-10 keV’ slopes with those of experiments whose responses peak around 6 keV such as EXOSAT, GINGA, BeppoSAX and XTE. To address this, we fitted the SIS+GIS spectra of PG1244+026 and NAB0205+024 with a simple power law in the observed 0.6-
Table 3. PG1244+026 & NAB0205+024 spectral fits

| Model               | $N_H^a$ | $\alpha_E$ or $T^b$ | $E_{\text{break}}$ or $\Omega/2\pi$ | $E_{\text{break}}$ or $\Lambda^c$ | $\chi^2$ (dof) |
|---------------------|---------|---------------------|-------------------------------------|-----------------------------------|----------------|
| PG1244+026          |         |                     |                                     |                                   |                |
| PL 0.6-10 keV       | 1.9±0.6 | 1.67±0.04           | –                                   | –                                 | 177.9 (148)    |
| PL 2-10 keV         | 1.9FIXED| 1.35±0.12           | –                                   | –                                 | 48.4 (82)      |
| PL 3-10 keV         | 1.9FIXED| 1.03±0.30           | –                                   | –                                 | 29.1 (58)      |
| PL 4-10 keV         | 1.9FIXED| 0.67±0.55           | –                                   | –                                 | 14.4 (38)      |
| Broken PL 0.6-10 keV| 3.6±1.7 | 1.80±1.1            | 1.06±0.24                          | 2.8±0.6                           | 149.1 (145)    |
| PL+Raym 0.6-10 keV  | 1.9±0.7 | 0.88±0.05           | 1.54±0.06                          | > 0.5                             | 135.3 (145)    |
| PL+BB 0.6-10 keV    | 5.3±1.8 | 0.16±0.03           | 1.40±0.15                          | –                                 | 139.2 (145)    |
| PL+Comp.Refl 0.6-10 keV | 2.6±1.7 | 2.78±0.06          | > 8                                | –                                 | 150.5 (146)    |
| NAB0205+024         |         |                     |                                     |                                   |                |
| PL 0.6-10 keV       | 3.0±0.1 | 1.38±0.02           | –                                   | –                                 | 126.2 (147)    |
| PL 2-10 keV         | 3.0FIXED| 1.09±0.10           | –                                   | –                                 | 42.4 (86)      |
| PL 3-10 keV         | 3.0FIXED| 0.94±0.20           | –                                   | –                                 | 23.3 (58)      |
| PL 4-10 keV         | 3.0FIXED| 0.62±0.45           | –                                   | –                                 | 9.5 (38)       |
| Broken PL 0.6-10 keV| 3.0±1.4 | 1.50±0.3            | 0.98±0.10                          | 2.4±0.5                           | 85.2 (145)     |
| PL+Raym 0.6-10 keV  | 3.0±0.7 | 0.49±0.05           | 1.02±0.25                          | < 0.01                            | 82.8 (144)     |
| PL+BB 0.6-10 keV    | 3.0±0.2 | 0.16±0.02           | 1.15±0.07                          | –                                 | 86.2 (145)     |
| PL+Comp.Refl 0.6-10 keV | 3.0±0.2 | 1.44±0.04          | > 4.2                              | –                                 | 95.2 (146)     |

In Table 3 and show in Figure 5.

In the last three series of fits the $N_H$ was fixed to the Galactic value. The best fit slopes flatten by 0.5–1 going from the low energy dominated to the higher energy range. (We note that for NAB0205+024 the quasar redshift implies that these slopes refer to slightly harder energy ranges: 10 keV in the observer frame corresponds to 11.6 keV in the quasar frame).

The PSPC spectral index for both quasars is 2.3(±0.1, Fiore et al., 1994), steeper than any of the values in table 3. For NAB0205+024 the ASCA low energy index is flatter than the PSPC by 0.4–0.8, and the ASCA best fit $N_H$ coincides with the Galactic value, suggesting that the spectrum continues to steepen below ASCA X-ray energies.

To parameterize a curved spectrum we have also fitted the 0.6-10 keV spectra of the two quasars with: a broken power law model; a power law + optically thin plasma emission (Raymond & Smith 1977) model; a power law + black body model; a power law + Compton reflection model. The results are again in Table 3 and confirm the presence of significant curvature in the spectra of these quasars.

In PG1244+026 the power law + Raymond-Smith model gives a $\chi^2$ significantly better than the broken power law model because it fits also the $\sim 1$ keV feature (see next section). However, the best fit energy index is still very steep and positive residuals are evident above 4 keV (Figure 6).
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In NAB0205+024 the power law + Raymond-Smith model gives an acceptable $\chi^2$ only for low metal abundances, given the absence of significant features in the spectrum, similar to the ROSAT results of Fiore et al. (1994). Above 4 keV the best fit is similar to that in the broken power law model. Fits with a power law + black body models give acceptable $\chi^2$ in both cases. The power law indices in this case are slightly steeper than in the broken power law model. Inspection of the residuals shows again a slight excess of counts at high energy. In PG1244+026 the power law + black body model again gives a $\chi^2$ significantly better than the broken power law model because it partly fits also the feature around $\sim 1$ keV (see next section). Fits with a Compton reflection model (plrefl in xspec) give $\chi^2$ significantly higher than the previous models and push the parameter $\Omega/2\pi$ to high and implausible values.

We do not see any significant line emission at the energies of the iron Kα lines. The 90 % upper limits to the equivalent width of a narrow line at 6.4 (and 6.7 keV), rest frame, in PG1244+026 and NAB0205+024 are 400 eV and 230 eV (640 eV, 314 eV) respectively.

The $\chi^2$ for the fits to the PG1244+026 spectra are much higher than those for the similar fits to the NAB0205+024 spectra because of the presence of the ‘1 keV’ feature in the former quasar. We discuss this feature next.

4.2 Low energy features

We have already noted that a ‘1 keV’ feature seems to be present only in PG1244+026, the quasar with the lower luminosity. Figure 7 shows the results of a simple power law model fit to the 0.6-4 keV spectrum of PG1244+026: the ‘1 keV’ feature is clearly visible.

It has been recently realized that Residual Dark Distribution (RDD, the error in ASCA’s onboard correction for CCD dark current) can affect the low energy ASCA SIS spectra. The symptom of the RDD problem is a sudden decrease in the SIS effective area towards lower energies from about 1 keV. We are however confident that this has little effect on the ‘1 keV’ feature for the following reasons: a) SIS data of PG1244+026 and NAB0205+024 have similar RDD value but the ‘1 keV’ feature is visible in the spectrum of...
PG1244+026 only, the 90% upper limit to any unresolved gaussian line emission at about 1 keV in NAB0205+024 is of 20 eV; b) the feature is present also in the GIS spectrum; the feature is present at the same level in SIS0 and SIS1, while the RDD tends to be greater for SIS1 than for SIS0.

To investigate the physical origin of the ‘1 keV’ feature and to quantify its strength we performed a series of spectral fits to the SIS and GIS spectra of PG1244+026 using only the 0.6-4 keV range, to avoid the complications of the hard tail (see previous section). The results are reported in Table 4, along with those of the other fits in this section.

### 4.2.1 Emission Line model

The fit with a power law model plus a gaussian line gives a small $\chi^2$ (90.1 for 101 degrees of freedom). The equivalent width of the 1 keV feature, in the power law plus gaussian line fit, is similar in the SIS and GIS detectors. In Table 4 we report the SIS determination of $64\pm15$ eV. The line width is well constrained and cleanly resolved in the SIS spectrum to $\sigma = 0.11\pm0.03$ keV.

A fit with a power law plus a thermal plasma model (Raymond-Smith 1977) gives an acceptable $\chi^2$ (93.1, 100 dof). The best fit temperature (1 keV) implies that the ‘1 keV’ emission is dominated by a blend of iron-L and neon emission lines.

An emission line feature can be mimicked by fitting a spectrum with a strong absorption feature at slightly higher energies. We have then fitted the SIS and GIS spectra with models including absorption structures.

### 4.2.2 Absorption Edge Fits

Fits with one absorption edges gives $\chi^2$ significantly higher than the previous case (102.5, 102 dof). The edge energy (1.17 keV, quasar frame) is consistent with that of NeIX and/or iron L FeXVI and FeXVII. The best fit neutral $N_H$ is significantly higher than the Galactic value. This is reasonable, since if there is highly ionized Ne and Fe L absorption it is likely to have also highly ionized oxygen absorption at 0.74-0.87 keV. We then refitted the SIS and GIS spectra with a model including three absorption edges, at the energies of the most abundant ions in highly ionized gas with high NeIX abundance: OVII, OVIII and NeIX-FeXVI-FeXVII (Nicastro et al. 1998), fixing the cold $N_H$ to the galactic value. The results were not satisfactory. The depth of the oxygen edges is zero with small upper limits and the $\chi^2$ is significantly higher than in the previous case: 114.7. Leaving $N_H$ free improves the $\chi^2$, but the oxygen edge depths are still zero and the fit resembles completely the single edge fit. Fixing $N_H$ to the Galactic value but leaving free the energies of two edges produces again a good fit ($\chi^2 = 94.8$, 101 dof). The best fit energy of one edge is again 1.12 keV, but that of the other edge is < 0.64 keV (observer frame), close to the lower boundary of the observed range. So, if the cold absorption is fixed to the Galactic value, then there must be additional absorption edge(s) at energies lower than the observed range, corresponding to oxygen less ionized than OVI. We note however that this conclusion is weakened by the unknown contribution of the SIS RDD, which pushes low energy events below the detection threshold.

### 4.2.3 Ionized absorber models Fits

We fitted the data with a detailed ionized absorber model (not including resonant scattering absorption lines). We first generated a grid of photoionization equilibrium models using CLOUDY (Ferland 1996), and fitted the spectrum interpolating by this grid, using the method of Fiore et al. (1993). To calculate the models we have assumed the observed spectral energy distribution (Fiore et al. 1995, Elvis et al. 1994). This is important, since the soft X-ray spectrum of this source strongly differs from that of ‘normal’ Seyfert 1 galaxies, where warm absorbers are usually found (Reynolds 1997). A steep soft X-ray spectrum can completely ionize oxygen and neon but not iron, and so can produce edges in the 1-2 keV (Fe-L) and 7-9 keV (Fe-K) ranges, but not in the ‘oxygen’ 0.6-0.9 keV band. A fit with this model produces an acceptable $\chi^2$ (see Table 4, ionized absorber model 1).

In Figure 8 we show the best fit steep SED model (thick line), and a photoionization model obtained using a standard, much flatter AGN SED (a power law of $\alpha = 1.2$ from UV to X-rays, thin line), which, above 1 keV, gives a comparably good fit to the data. While iron in the flat SED model has a ionization structure similar to that of the model obtained using the right SED, oxygen is much less ionized: note the deep OVIII edge present in the flat SED model.

In this fit the redshift of the absorber is significantly higher than that of the quasar, because the main feature in the transmitted spectrum is the FeXVIII edge at 1.36 keV, while the deepest edge in the quasar spectrum is at 1.17 keV (quasar frame). However, a good fit can be also obtained for a different absorber redshift ($z = -0.33$, Table 4, ionized absorber model 2). In this case the 1.17 feature is interpreted in terms of OVII and OVIII absorption. We cannot discriminate between these two solutions on statistical grounds.

We have also tried fits with a collisional equilibrium model (Nicastro et al. 1998). The results were very similar to those obtained in the case of photoionization equilibrium (see Table 4, ionized absorber model 3).

In all fits with detailed warm absorber models the column of cold gas is significantly higher than the Galactic value, similar to the values found using single edges to parameterize the absorber (Table 4).

### 4.2.4 Absorption Line Fits

Fits with a single gaussian absorption line do not give acceptable $\chi^2$. Fits with two or more absorption gaussian lines can produce $\chi^2$ of 96 or smaller. These models are indistinguishable for the SIS from models with a broad absorption notch, which we discuss in the following. Physical models including resonant absorption lines, as well as absorption edges from ionized plasma will be discussed in a paper in preparation (Nicastro et al. 1998b).
Table 4. PG1244+026: spectral fits in the band 0.6-4 keV

| Continuum models          | α   | N_H | T   | A  | χ² (dof) |
|---------------------------|-----|-----|-----|----|---------|
| PL                        | 1.70±0.02 | 1.9+1.0 | –   | –   | 131.8 (104) |
| PL + BB                   | 1.50±0.11 | 9.5±5.0 | 0.14±0.02 | – | 109.5 (101) |
| PL + Raym                 | 1.61±0.03 | 1.9+0.3 | 1.00±0.06 >0.5 | –   | 93.1 (100) |

| emission line            | line E       | line EW | χ² (dof) |
|--------------------------|--------------|---------|---------|
| PL + Gauss               | 1.60±0.04    | 1.9+0.5 | 0.91±0.03 | 64±15 | 90.1 (101) |

| absorption edge models   | edge E | τ   | χ² (dof) |
|--------------------------|--------|-----|---------|
| PL + 1 edge              | 1.88±0.11 | 8.2±3.0 | 1.12±0.03 | 0.25±0.07 | – | 102.5 (102) |
| PL + 2 edges             | 1.88±0.11 | 1.9FIXED | 1.12±0.10 | 0.26±0.08 | – | 94.8 (101) |

| ionized absorber models  | logN_H ionized | U or logT | z abs. | χ² (dof) |
|--------------------------|----------------|-----------|--------|---------|
| 1 – Phot. ion.           | 1.92±0.10      | 11.1±3.5  | 22.59±0.15 | 2.00±0.12 | 0.25±0.07 | 93.2 (101) |
| 2 – Phot. ion.           | 1.94±0.10      | 11.0±3.5  | 21.56±0.10 | 1.20±0.10 | -0.33±0.10 | 95.7 (101) |
| 3 – Coll. ion.           | 1.90±0.10      | 11.3±3.5  | 22.62±0.14 | 6.92±0.07 | 0.24±0.06 | 90.7 (101) |

| absorption notch models  | T | notch E | notch width | Cov. frac. | χ² (dof) |
|--------------------------|---|---------|-------------|-----------|---------|
| PL + notch               | 1.93±0.08 | 9.3±3.3 | 1.44±0.05 | 680±70 | 0.14±0.04 | 97.5 (100) |
| PL + BB + notch          | 1.48±0.20 | 7.8±4.4 | T = 0.16±0.03 | 1.16±0.03 | 14±7 | 1FIXED |

\( a \) in \( 10^{20} \text{ cm}^{-2} \); \( b \) in keV; \( c \) metal abundances; \( d \) in eV

4.2.5 Absorption Notch Fits

Fits with an absorption notch give \( \chi^2 \) higher than those with an emission line by \( \Delta \chi^2 \approx 7 \). While the power law + notch fit is formally acceptable, the best fit value of the notch width is implausibly large (almost 1 keV), forced by the very low value of the covering fraction required by the fit. However, the best fit parameters are strongly dependent on the proper modeling of the continuum. For example, using a power law + a black body to parameterize the continuum gives an acceptable fit fixing the notch covering fraction to 1, which in turn results in a much more reasonable value for the notch width of 14±7 eV. The ASCA band width in not wide enough and its spectral resolution is not good enough to constrain adequately both a complex continuum and the notch parameters.

4.2.6 Comparison with the PSPC results

PG1244+026 was observed with the PSPC in December 1991 and the results of this observation have been reported by Fiore et al. (1994). The 0.6-2 keV flux level during the PSPC observation was about 50% lower than the mean flux in the ASCA observation. The fit of an absorbed power law to the PSPC spectrum gives an acceptable \( \chi^2 \) (22.8 for 25 dof), \( \alpha_{0.1-2keV} = 2.3±0.1 \) and \( N_H = 2.9±0.3 \times 10^{20} \text{ cm}^{-2} \), slightly higher than the Galactic value. Most of the PSPC counts were detected below 0.3 keV, in the ‘Carbon’ band. The quality of the spectrum between 0.3 and 2 keV is not very high and emission or absorption features fainter than \( \sim 20\% \) cannot be excluded in this energy band. No evidence of spectral variability is present in the ROSAT data despite a factor of 2 flux variability.

The PSPC data strongly constrain the level of any cold or warm absorption affecting the ‘Carbon’ band. Best fitting models to the ASCA data including absorption features in the 1-2 keV band (Table 4) require a rather large absorption in addition to the Galactic one below 1 keV. Therefore, it is important to study whether the ASCA best fit models are consistent with the PSPC ones. Rather than performing joint fits to the ASCA and PSPC data, which are complicated by the large uncertainty in the relative PSPC/ASCA SIS calibration, and by the detailed shape of the continuum over the broad 0.1-4 keV band, we fitted the PSPC data with a power law model including the emission or absorption features found in the previous section (see Table 4). The results are in Table 5, where we also report (in brackets) the 99% parameter upper limits, or confidence intervals, when appropriate.

We see that the presence of an emission line at 0.91 keV is not required by the PSPC spectrum, but an equivalent width of 65 eV is not excluded (10% probability). However, the presence of a cold absorber of thickness 8.2±3.0 \( \times 10^{20} \text{ cm}^{-2} \) is inconsistent with the PSPC spectrum (probability < 1%), while the presence of an edge at 0.62 keV with \( \tau = 0.51 \pm 0.14 \) is only marginally consistent with the PSPC result.
Table 5. PG1244+026: spectral fits to the PSPC

| model     | $N_H^a$ (10^{20} cm^{-2}) | $\alpha_E$ | line or edge E\(_b^c\) | line EW\(_c^c\) or $\tau$ | $\chi^2$ (dof) |
|-----------|---------------------------|------------|-----------------------|------------------------|---------------|
| PL        | 2.9±0.3                   | 2.3±0.1    | 0.91FIXED             | 0±68 (+100)            | 22.8 (25)     |
| PL + gauss| 2.9±0.3                   | 2.3±0.1    | 0.3±0.4               | 0.3±0.3                | 20.9 (24)     |
| PL + 1 edge| 2.7±0.4 (0.6)            | 2.2±0.2    | 1.12FIXED             | 0.3±0.3                | 20.9 (23)     |
| PL + 2 edges| 2.7±0.4                 | 2.2±0.2    | 1.12FIXED             | 0.3±0.3                | 20.9 (23)     |

\(a\) in $10^{20}$ cm\(^{-2}\); \(b\) in keV; \(c\) in eV

Figure 8. The thick line shows the best fit photoionized absorber model for PG1244+026 using the observed steep spectrum (note that the absorber has z=0.25, while the quasar has z=0.048). The thin line shows a photoionization model obtained using a much flatter SED (see text). Both models produce Fe-L absorption features around 1 keV. The flat SED also produces deep OVIII edge, which is not observed.

5 DISCUSSION

5.1 Continuum

The ASCA observations of PG1244+026 and NAB0205+024 have shown that the X-ray continuum of these two quasars flattens by 0.5-1 passing from the 0.1-2 keV (PSPC) to the 2-10 keV band. Similar results were obtained by Brandt, Mathur & Elvis (1997); and by Comastri et al. (1998) and Leighly et al. (1998a) on TONS180, Pounds et al. (1995) and Fiore et al. (1998a) on REJ1034+390, Leighly et al. (1998b) on AKN564. It appears that the X-ray spectrum of a sizeable number of steep PSPC and narrow Balmer line quasars has significant curvature, being flatter at higher energies.

This could be due to different components influencing the spectrum at different energies, as might happen in ‘normal’ broad lines Seyfert 1 galaxies and quasars, where a soft component is often present. The relative intensity of the two components would be quite different from ‘normal’ quasars. Laor et al. (1997) suggested a fainter hard component relative to the optical in the majority of low redshift PG quasars (assuming a two component model). However, Grupe (1996) found evidence for a stronger soft excess in a sample of soft X-ray selected Seyferts dominated by narrow-line objects.

A large relative intensity of the soft component has important consequences on various competing models for the soft component. Disc reprocessing models (Matt et al. 1993, Fiore et al. 1997) would require highly anisotropic emission to account for the discrepancy between the observed soft and hard fluxes. Optically thin free-free emission (e.g. Barvainis 1993) is ruled out by these observations because the best fit power law slope is still too steep to fit the spectrum above 4 keV, because variability rules out optically thin plasma (Elvis et al. 1991) and because of the implausibly low metal abundances (<1% solar, see Table 3) required in NAB0205+024 (see Sect. 3.2.1). The most likely origin for the steep component is Comptonized disc emission (e.g. Czerny & Elvis 1987, Fiore et al. 1995, Pounds et al. 1995).

The high energy spectral index of the two quasars $\alpha_H$ ~ 1.0 (see Table 3) is consistent with that of ‘normal’ Seyfert 1 galaxies (e.g. Nandra & Pounds 1994, Nandra et al. 1997). The error on $\alpha_H$ is however large and so no strong conclusion can be drawn on the origin of the hard emission. An answer to this question must await the large area and high energy sensitivity of AXAF, XMM and Spectrum X-gamma.

5.2 Origin of the ~ 1 keV feature in PG1244+026

The ~ 1 keV feature in PG1244+026 could be explained in terms of either a broad ($\sigma = 0.1$ keV) emission line at 0.91 keV (0.95 keV quasar frame) of about 60 eV equivalent width or a $\tau = 0.25$ absorption edge at 1.17 keV (or an absorption notch at 1.22 keV). These possibilities cannot be discriminated between on statistical grounds.

An absorption interpretation requires additional low energy absorption, either cold (with a column density higher than Galactic by ~ $7 \times 10^{20}$ cm\(^{-2}\)) or a $\tau = 0.25$ absorption edge at 1.17 keV (or an absorption notch at 1.22 keV). These possibilities cannot be discriminated between on statistical grounds.

The observed spectrum can be interpreted in terms of either an inflowing ($v/c=0.25$) or an outflowing ($v/c=-0.33$) absorber. In the first case the ion contributing most to the absorption is FeXVIII, in the second case it is OVIII. The two cases cannot be discriminated on statistical grounds. While an outflowing absorber has been suggested in several other cases (see e.g. Mathur et al. 1994), this would be the first case for an inflowing highly ionized absorber.

A similar situation is found in IRAS 13224-3809 by...
Otani et al. (1995), in AKN564 by Brandt et al. (1994) and by Leighly et al. (1998a). Otani et al. (1995) and Leighly et al. (1997) interpret the features in the 1–2 keV band in terms of blueshifted absorption from relativistically \((v=0.2-0.6 \, c)\) outflowing material. If the 1.17 keV feature in PG1244+026 is due to a blueshifted OVIII photoelectric absorption, then the absorption seen below 0.64 keV may be due to CVI photoelectric absorption from the same gas. This distribution is far from an equilibrium distribution (see eg. Nicastro et al. 1998), not an impossible situation considering the large variability observed in this source.

The absorption features seen between 1 and 2 keV may also be interpreted in terms of resonant lines (e.g. Leighly et al. 1997). If the ion producing the absorption is oxygen OVIII (resonant line at 0.65 keV), the best fit notch energy of 1.22 keV (quasar frame) implies a very high gas velocity: \(-0.56c\). Fe XVIII (\(E=0.87\) keV) or Fe XVII (\(E=0.81\) keV) can also contribute to the absorption, because of their high oscillator strengths, 1.7, 0.6 respectively (Kato et al. 1976), and abundances. If the 1.22 keV absorption notch is due to these ions then the velocity of the outflowing gas will be smaller, \(-0.33c\).

In any case, in the blueshifted absorption scenario the gas is outflowing at velocities which are a sizeable fraction of \(c\), reminiscent of blobs of gas in jets. It is interesting to note that similar absorption features have been observed in Blazars (e.g. PKS2155-304, Canizares & Kruper, 1984, other BlLacs, Madejski et al. 1991, 3C273, Grandi et al. 1997), but usually below 1 keV. Somewhat surprisingly this implies less extreme conditions in these radio-loud objects than in our radio-quiet quasars. High redshift radio loud quasars may have similar jet-related absorption too (Elvis et al., 1997).

An alternative interpretation of the 1 keV feature is in terms of an emission line due to highly ionized oxygen, neon (NeIX) and/or to Iron L. There are two possible origin for this line: recombination in an optically thin thermal plasma, or “reflection” in photoionized matter.

5.2.1 Thermal plasma

A thermal plasma is highly implausible on physical grounds (Elvis et al. 1991, Fiore et al. 1995). Emission measure is \(\sim 2.5 \times 10^{56} \text{ cm}^{-3}\). For a spherical source (with radius \(R\)) and constant electron density \(n_e\), \(n_e = 2.43 \times 10^{32} R^{-2/3} \text{ cm}^{-3}\). If \(R < 10^{14} \text{ cm}\) from the observed X-ray variability, \(n_e < 1.5 \times 10^{12} \text{ cm}^{-3}\). This implies an electron scattering optical depth \(\tau_T \gtrsim 30\). With such values a thermal plasma is no longer optically thin. The situation is even worse if the matter is clumpy, as the density of each cloud must be greater.

5.2.2 Photoionized matter

The second possibility is that the ‘1 keV’ emitting matter is photoionized by the central nucleus. We can assume that the gas is not covering the source because there is not significant OVII and/or OVIII absorption. We therefore assume that we are not observing a “warm absorber”, but rather a “warm reflector”. This could either be a warm absorber viewed from its side, in which case the matter would be optically thin to Thomson scattering; or the accretion disc, and the matter would be thick. Since both the “reflector” and the primary emission (which provides most of the continuum) are observed, the optically thick case gives the highest values of the equivalent width. However, even in the optically thick case the expected EWs can barely account for the observed values (see below); hence we neglect the optically thin case altogether.

The observed line (which is significantly broad) may be a blend of several lines (see for instance Życki et al. 1994, Netzer 1997). The observed energy suggests the 0.92 keV Ne ix and 1.02 keV Ne x recombination lines, the 0.87 keV Oxygen viii (to ground state) line and the iron L (around 0.8 keV) lines being the most important. None of these lines alone can account for the observed EW; for instance, the maximum value (i.e. for a face-on disk with an intervening ion fraction \(\sim 0.6\)) for the Ne ix line is about 10 eV, while that of the oxygen recombination line is about 15 eV (note that a O viii Kα recombination line at 0.65 keV with a similar EW should also be present; the 90% upper limit on such a line is 30 eV). These values have been calculated using the formulae of Basko (1978), and assuming a reasonable ionization structure. (In the disc hypothesis an iron Kα line at 6.5-6.9 keV is also expected, but the upper limit of 300-400 eV does not exclude the presence of such a line.) Allowing for a possible factor of 2 neon and/or iron overabundance (an oxygen overabundance would decrease the Ne line while not increasing the O line) and/or anisotropy of the illuminating radiation, the observed equivalent width could be explained (note that in many Seyfert 1 galaxies the iron Kα line is also stronger than expected, suggesting iron overabundance or anisotropic illumination).

In this scenario the ‘1 keV’ feature may arise from an highly ionized accretion disk. In the Matt et al. (1993) models high ionization is mainly due to a high accretion rates (the ionization parameter depends on \(\dot{m}\)). The detection of these emission lines in steep soft X-ray quasars would then be further evidence of high \(L/L_{\text{Edd}}\). We note that since recombination can occur only in highly ionized atoms, we would not expect features of this kind in ‘normal’ quasars, as their disc should be much less ionized, as in fact observed.

The strong dependence of the ionization parameter on \(\dot{m}\) allows for large differences in the ionization structure against small differences in \(\dot{m}\) and therefore that the ‘1 keV’ feature may not be ubiquitous in NLSy1s. Indeed, a similar feature is not present in NAB0205-024. A line with the same equivalent width as in PG1244+026 (60 eV) would have been detected in the NAB0205+024 SIS spectrum (the 90 % upper limit is only 20 eV). In the accretion disc scenario this would imply a different ionization state (higher or lower) of the matter or a significant metal underabundance in NAB0205+024.

5.3 Variability

The mean 0.5-10 keV luminosity measured by ASCA in PG1244+026 and NAB0205+024 differs by an order of magnitude: \(7.3 \times 10^{43}\) and \(6.4 \times 10^{44} \text{ erg s}^{-1}\) respectively (assuming isotropic emission, \(H_0 = 50.0\) and \(q_0 = 0.0\)). The optical (3000 Å) monochromatic luminosities differs even more: \(4 \times 10^{43}\) and \(9.4 \times 10^{44} \text{ erg s}^{-1}\) respectively. The variations seen in the NAB0205+024 light curve imply an efficiency in the conversion of matter into radiation greater than 1.6 %
(e.g. Fabian 1984). Taken at face value, this excludes thermonuclear reactions as the origin of the observed X-ray luminosity for which the upper limit on the efficiency is in this case about 0.7%.

The similar variability observed in the two quasars agrees with the Fiore et al. (1998a) finding that the variability properties of (PG) quasars are correlated with the shape of the soft X-ray spectrum and the width of the Balmer lines, and so possibly then with the accretion rate, in the scheme of Pounds et al. (1995), and Laor et al. (1994), (1997).

6 CONCLUSIONS

ASCA observations of two steep soft X-ray quasars have shown that:

(i) The X-ray continuum of the two quasars flattens by $\Delta$α = 0.5 – 1 going toward high energies. Similar results were obtained by authors on some half dozen steep soft X-ray quasars.

(ii) PG1244+026 shows a significant feature in the ‘1 keV’ region. Similar features were again reported in other steep soft X-ray quasars. The data are not good enough to discriminate between a broad emission line centered at 0.95 keV (quasar frame) or an absorption edge at 1.17 keV, or an absorption notch at 1.22 keV.

Line emission could be due to reflection from an highly ionized accretion disk, in line with the view that steep soft X-ray quasars are emitting close to the Eddington luminosity. Photoelectric edge absorption or resonant line absorption could be produced by gas outflowing at a large velocity (0.3-0.6 c). In these absorption models significant cold (i.e. oxygen less ionized than OVI) absorption in excess of the Galactic is required. This would imply an increase by (i.e. oxygen less ionized than OVI) absorption in excess of the Galactic is required. This would imply an increase by (i.e. oxygen less ionized than OVI) absorption.

(iii) The two quasars show similar variability properties (flux variations up to a factor of 2 in 10 ks) despite a factor of ten difference in the X-ray observed luminosity. This agrees with the Fiore et al (1998a) finding that the variability properties of radio-quiet quasars are correlated with the shape of the X-ray spectrum, the width of the Balmer lines and so possibly with the accretion rate.

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