ASCA AND ROSAT X-RAY SPECTRA OF HIGH-REDSHIFT RADIO-LOUD QUASARS
M. CAPPİ,1,7 M. MATSUOKA,1 A. COMASTRI,2 W. BRINKMANN,3 M. ELVIS,4 G. G. C. PALUMBO,5,6 AND C. VIGNALI5

Received 1996 June 20; accepted 1996 October 17

ABSTRACT

Results are presented on the X-ray properties of 9 high-redshift (1.2 < z < 3.4) radio-loud quasars (RLQs) observed by the Advanced Satellite for Cosmology and Astrophysics (ASCA; 10 observations) and ROSAT (11 observations, for a subset of six quasars). New ASCA observations of S5 0014 + 81 (z = 3.38) and S5 0836 + 71 (z = 2.17) and ROSAT observations of PKS 2126 − 158 for which results were never presented elsewhere are included.

A simple model consisting of a power law plus cold, uniform absorption gives acceptable fits to the spectra of all sources. The ASCA spectra of the six brightest objects show evidence for absorption in excess of the Galactic value at a ≥ 99% confidence level. Comparison with the ROSAT data suggests that absorption has significantly varied (∆N_H ≈ 8 × 10^{20} cm^{-2}) in the case of S5 0836 + 71, on a timescale of approximately 0.8 yr in the quasar frame. For the remaining five sources for which ROSAT spectra were available, the two instruments gave consistent results, and the data were combined yielding unprecedented spectral coverage (typically about 0.4–40 keV in the quasar frame) for high-z quasars. This allows us to put severe limits on several different descriptions of the continuum (e.g., broken power law, bremsstrahlung, reflection component). No Fe Kα emission line is detected in any of the ASCA spectra. An absorption edge consistent with Fe Kα at the quasar redshift is marginally detected in S5 0014 + 81. Possible origins for the observed low energy absorption are discussed. In particular, contributions from the molecular clouds and dust present in our Galaxy (usually disregarded) are carefully considered. In light of the new results for S5 0836 + 71 and S5 0014 + 81, absorption intrinsic to the quasars is considered and discussed.

The average slope obtained from the eight ASCA spectra in the observed ∼0.5–10 keV energy band is \( \langle \Gamma_{0.5–10 \text{ keV}} \rangle \approx 1.61 ± 0.04 \), with a dispersion \( \sigma_{0.5–10 \text{ keV}} \approx 0.10 ± 0.03 \). The average photon index in the observed 2–10 keV band, where the effect of absorption is negligible, is \( \langle \Gamma_{2–10 \text{ keV}} \rangle \approx 1.53 ± 0.05 \), with a dispersion \( \sigma_{2–10 \text{ keV}} \approx 0.12 \). Furthermore, the implications of the present results on the calculations of the contribution of quasars to the cosmic X-ray and γ-ray backgrounds are briefly discussed.

Subject headings: galaxies: active — quasars: general — radiation mechanisms: nonthermal — X-rays: galaxies

1. INTRODUCTION

Quasars are the most powerful objects in the whole universe. This is especially true in the X-ray band, where luminosities can reach \( 10^{47}–10^{48} \) ergs s^{-1}. However, how quasars produce such a large amount of energy remains a challenging astrophysical problem. Certainly, because of their extreme conditions, quasars provide a powerful test for models of emission mechanisms of active galactic nuclei (AGNs) (Rees 1984). Quasars show strong continuum emission over the entire electromagnetic spectrum, from radio through the X-ray and even γ-ray region (Sanders et al. 1989; Elvis et al. 1994a; Thompson et al. 1995). Optically selected samples of quasars indicate that approximately 90% of them are radio quiet (RQQs) and approximately 10% are radio-loud (RLQs).

X-ray quasar spectral observations are crucial for two main reasons: first, X-rays carry a large amount of the total quasar luminosity; second, as demonstrated by observations of rapid X-ray variability, X-rays originate from the innermost regions of the quasar (Mushotzky, Done, & Pounds 1993). Most X-ray spectral observations have included mainly low-redshift (z < 1) quasars; the poor energy resolution generally limited the analysis to a simple parameterization of the spectrum with a single power law. In the ∼0.1–4 keV energy range, previous Einstein IPC and ROSAT Position Sensitive Proportional Counter (PSPC) observations have shown that RLQs have significantly flatter X-ray spectra than RQQs (Wilkes & Elvis 1987; Brunner et al. 1992) and that, for a given optical luminosity, RLQs are on average approximately 3 times brighter in X-rays than RQQs (Zamorani et al. 1981). Studies at higher energies (∼2–10 keV) with EXOSAT and Ginga have confirmed the dichotomy, with a clear correlation between spectral index and radio loudness (Williams et al. 1992; Lawson et al. 1992). Whether differences in the observed X-ray properties should be attributed to either intrinsically different properties of the sources or inclination effects and/or host galaxy properties is not yet well understood. Also, selection effects and/or complex spectral structures (e.g., soft-excess emission, ionized absorption) may compli-
cate the correct interpretation of the data (Halpern 1984; Comastri et al. 1992; Fiore et al. 1993).

At high redshifts (≥ 1), spectral information is almost absent for RQQs, and scarce for RLQs, since soft X-ray observations (mainly from the ROSAT PSPC) have allowed only a poor determination of the spectral slopes for only a small number of objects, mostly RLQs (Bechtold et al. 1994; Elvis et al. 1994c, hereafter E94). It is not yet clear whether quasars do exhibit spectral evolution. This is a fundamental question that has a direct impact on quasar formation models. A remarkable result has been the discovery made with the PSPC that at least some of the high-z RLQs have low-energy cutoffs possibly because of absorption along the line of sight (E94). Preliminary results of the Advanced Satellite for Cosmology and Astrophysics (ASCA) observations of high-z RLQs have indeed already confirmed the low-energy cutoff in two of them (Serlemitsos et al. 1994) and discovered a third probable case (Siebert et al. 1996, hereafter S96). Comparison with two high signal-to-noise (S/N) ratio spectra of two RQQs at z ~ 1 (Nandra et al. 1995) indicates that RQQs are steeper than RLQs even at z ≥ 1. However, the number of quasars observed so far is too small to draw any reliable conclusion.

This paper presents a comprehensive and uniform study of ASCA observations of a sample of nine RLQs with 1.2 < z < 3.4. Whenever possible, the ASCA results are compared and combined to ROSAT spectra extracted from the public archive. Extensive search for Fe K emission lines, high-energy excesses ("hard tails"), and alternative models are presented. The possible origin of the apparently common excess absorption found in the data is discussed in the light of two newly discovered RLQs with such a feature. Finally, the impact of these new measurements on the cosmic high-energy background radiation is briefly discussed.

In the following, H₀ = 50 km s⁻¹ Mpc⁻¹ and q₀ = 0 are assumed throughout.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. The Sample

The quasar sample consists of all objects (nine) either from Principal Investigator or archival ASCA observations available before 1996 January 1. The purpose was to analyze data of a reasonably large number of quasars to be able to address for the first time statistically the X-ray properties of the class.

A total of 10 ASCA pointed observations were collected, with S5 0014+81 observed twice. For five quasars, 11 ROSAT PSPC observations were retrieved from the archive and the source spectra were reanalyzed to ensure a uniform and consistent analysis within the sample. A considerable part of our analysis reproduces in part previous work on individual sources (see § 4). The present analysis, however, differs from single object studies as (1) it provides a uniform analysis of the quasar sample, (2) it makes use of the most recent calibrations (particularly important for those observations performed during the performance and veriﬁcation phase of ASCA), and (3) it compares on a uniform basis ASCA and ROSAT spectral results. It is worth pointing out that ASCA results on S5 0014+81 (z = 3.38) and S5 0836+71 (z = 2.17) are new. The relevant data for the whole sample are given in Table 1.

2.2. ROSAT Data Reduction

A subsample of six of the nine quasars were observed on-axis with the PSPC (Pfefferman et al. 1987) on board the ROSAT Observatory (Trümper 1983) between 1991 and 1993.

The relevant data for the observations are listed in Table 2. As indicated in the table, two new PSPC observations of PKS 2126−158 are presented, which almost double the total number of counts available for that source. The PSPC has an energy bandpass in the range 0.1−2 keV with an energy resolution of ΔE/E ~ 0.5 keV at 1 keV. Source spectra were extracted from circles of about 90°−200° centered on the sources, and background spectra were taken from annuli centered on the sources or from circular regions uncontaminated by nearby sources. Source and background counts were corrected for telescope vignetting. Data preparation and analysis were performed using the JAND5 version of the EXSAS/MIDAS software package (Zimmerman et al. 1993). Spectral analysis was performed using the version 8.50 of the XSPEC program (Arnaud, Haberl, & Tennant 1991).

2.3. ASCA Data Reduction

ASCA has two gas imaging spectrometers (GIS) and two solid-state imaging spectrometers (SIS) (Tanaka, Inoue, & Holt 1994). The energy resolution of the GIS and SIS are ΔE/E ~ 0.15 keV and ~0.05 keV at 1 keV, respectively.

| Object       | R.A.* (J2000) | decl.* (J2000) | z* | N_{H_{gal}}^b (10^{20} cm⁻²) | m_{ν}^c (mJy) | f_{S_{GHz}}^c (mJy) | R_{L}^c |
|--------------|---------------|---------------|----|-----------------|--------------|-----------------|-------|
| S5 0014+81   | 00:1708:5     | +81:35:08:1   | 3.38 | 13.9          | 16.5         | 551             | 2.78  |
| PKS 0322−403 | 03:34:13:6     | −40:08:25:4   | 1.44 | 14.3          | 18.5         | 2600            | 4.24  |
| NRAO 140     | 03:36:30:1     | +32:18:29:3   | 1.26 | 14.2*         | 17.5         | 2500            | 3.87  |
| PKS 0438−436 | 04:40:17:2     | +33:08:6:6    | 2.85 | 1.47          | 18.8         | 7580            | 4.84  |
| PKS 0537−286 | 05:39:54:3     | −28:39:56:2   | 3.30 | 1.95*         | 20.0         | 990             | 4.39  |
| S5 0836+71   | 08:41:24:4     | +70:53:42:2   | 2.17 | 2.78          | 16.5         | 2573            | 3.45  |
| PKS 1614+051 | 16:16:37:5     | +04:59:33:2   | 3.21 | 4.90          | 19.5         | 850             | 4.15  |
| PKS 2126−158 | 21:29:12:2     | −15:38:40:8   | 3.27 | 4.85*         | 17.0         | 1240            | 3.33  |
| PKS 2149−306 | 21:51:55:5     | −30:27:53:7   | 2.34 | 1.91          | 17.9         | 1150            | 3.66  |

* Coordinates, redshift, V magnitude, and radio flux at 5 GHz, from Véron-Cetty & Véron 1993.

b Galactic absorption from Dickey & Lockman 1990. The values marked with an asterisk (*) are from Elvis et al. 1989.

c Radio loudness defined as R_{L} = \log(f_{S_{GHz}} / f_{ ν}). We used m_{ν}(0) = 3360 Jy (Wamsteker 1981).
which is about 3 and 10 times better than the ROSAT PSPC. The SIS was operated in 1-CCD, 2-CCD, or 4-CCD modes, depending on the observation (see Table 3). Only chip 1 of SIS0 and chip 3 of SIS1 were used in the analysis of the SIS data, except for the AO1 observation of S5 0014 + 81 where chip 2 of SIS1 was also used because the source photons were spread equally over the two detectors. Following a software-related problem on board ASCA, the data collected from the GIS3 during the observation of PKS 0537—286 were damaged. They could not be recovered and therefore were excluded from the analysis. All observations were performed in FAINT mode and were corrected for dark frame error (DFE) and echo uncertainties. Dotani The data were selected (Otani 1994).

Source counts were extracted from circles centered on the sources of 6' for the GIS and 3' for the SIS. For the SIS instruments, the background spectra were obtained from the edges of the same CCD chip. The use of SIS blank sky files for the background yielded spectral results within the errors reported in the following analysis. For the GIS instruments, we found that the two standard background subtraction methods (backgrounds extracted from the blank sky files or locally) gave systematically different results for the weakest sources. Therefore, a nonstandard background extracted from the blank sky files was adopted. Detailed explanation and justification for this choice is given in Appendix A.

The relevant data for the ASCA observations are given in Table 3. Data preparation and spectral analysis were performed using version 1.0h of the XSELECT package and version 8.50 of the XSPEC program (Arnaud et al. 1991).

### 3. RESULTS

#### 3.1. ROSAT Temporal and Spectral Analysis

The data were first binned in 400 s time intervals, as suggested by the wobble period of the telescope, and light curves were plotted to evidence variability. However, no significant variation was detected. Source spectra were thus accumulated for each observation and binned with an S/N ratio from 4 to 13, depending on the source statistics. Three quasars (PKS 0438—436, S5 0836+71, and PKS 2126—158) had multiple observations. Comparisons between different observations indicate a clear flux varia-

### Table 2

**ROSA T Observation Log**

| Object          | Date          | Wobble | Matrix | Exposure (s) | NC  | References      |
|-----------------|---------------|--------|--------|--------------|-----|-----------------|
| S5 0014 + 81    | 1991 Mar 15   | on     | DRM06  | 5951         | 394 | 1, 2            |
| NRAO 140       | 1992 Aug 08   | off    | DRM36  | 4039         | 992 | 3               |
| PKS 0438—436   | 1992 Sep 19   | on     | DRM36  | 10725        | 645 | 1, 4            |
| PKS 0537—286   | 1992 Sep 28   | on     | DRM36  | 10506        | 547 | 1               |
| S5 0836 + 71   | 1992 Mar 23   | on     | DRM36  | 6993         | 5400| 6               |
| S5 0836 + 71   | 1992 Nov 02   | on     | DRM36  | 5026         | 2008| 6               |
| PKS 2126—158   | 1991 May 08   | on     | DRM06  | 3424         | 613 | 1, 2            |
| PKS 2126—158   | 1992 Nov 12   | on     | DRM36  | 3968         | 729 | 1, 2            |
| PKS 2126—158   | 1993 Apr 27   | on     | DRM36  | 4160         | 741 | This work       |
| PKS 2126—158   | 1993 May 17   | on     | DRM36  | 1610         | 321 | This work       |

* NC denotes net counts.

### Table 3

**ASCA Observation Log**

| OBJECT             | DATE          | EXPOSURE (s) | COUNT RATE (× 10⁻² s⁻¹) |
|--------------------|---------------|--------------|-------------------------|
| S5 0014 + 81 (AOI) | 1993 Oct 29   | 39,004       | 21,750                  |
| S5 0014 + 81 (AOI) | 1994 Oct 07   | 27,494       | 20,703                  |
| PKS 0332—403      | 1994 Aug 12   | 16,646       | 14,153                  |
| NRAO 140          | 1994 Feb 02   | 33,181       | 32,178                  |
| PKS 0438—436      | 1993 Jul 13   | 34,499       | 26,412                  |
| PKS 0537—286      | 1994 Mar 12   | 36,236       | 29,052                  |
| S5 0836 + 71      | 1995 Mar 17   | 16,532       | 10,540                  |
| PKS 1614 + 051    | 1994 Aug 02   | 39,695       | 32,577                  |
| PKS 2126—158      | 1995 Mar 27   | 15,914       | 14,291                  |
| PKS 2149—306      | 1994 Oct 26   | 19,168       | 16,504                  |

* Reported values for the GIS and SIS are averaged over the detectors (GIS2 with GIS3 and SIS0 with SIS1).

### REFERENCES

— (1) Elvis et al. 1994d; (2) S96; (3) Turner et al. 1995; (4) Wilkes et al. 1992; (5) Bühler et al. 1995; (6) Brunner et al. 1994.
PSPC observations of PKS 2126

The weighted mean photon index for the PSPC sample is the total counts from that source. The weighted mean photon index for S5 0836 and possibly for the other two quasars.

Fits were performed using a single absorbed power-law model with absorption cross sections and abundances from Morrison & McCammon (1983). The resulting spectral photon indices $\Gamma$, column densities $N_H$, and normalizations are given in Table 4. The two-dimensional $\chi^2$ contour plots in the parameter space $N_H-\Gamma$ are shown in Figure 1, together with the ASCA contours (see § 3.2). The present reanalysis yielded results consistent with previous measurements (see references in Table 2). It is worth pointing out that the absorption in excess of the Galactic value previously reported for PKS 0438–436 and PKS 2126–158 (Wilkes et al. 1992; E94) is confirmed by the present analysis (see Fig. 1 or Table 4), which makes use of two new PSPC observations of PKS 2126–158, almost doubling the total counts from that source. The weighted mean photon index for the PSPC sample is $(\langle 0.1-2.4\text{ keV} \rangle) \approx 1.53 \pm 0.06$.

More complex models were not attempted since (1) the main purpose of the present analysis of ROSAT observations is to compare and, whenever possible, combine these data with the ASCA data and (2) in all cases, a single absorbed power-law model provides an acceptable description of the spectra. More complex models might, however, be found in the references given in Table 2.

3.2. ASCA Temporal and Spectral Analysis

Source plus background light curves were accumulated for each source, and none of these indicated significant variability. This is not surprising, given the large statistical scatter of the data due to the low counting rates. GIS and SIS spectra were binned with more than 20 counts bin$^{-1}$ between approximately 0.7–10 keV and 0.5–10 keV, respectively. The matrices used were the GIS[23]v4-0.rmf released in 1995 June for the GIS and the “rsp1.1alphaP1” matrices released in 1994 October for the SIS. Since the spectral parameters obtained by separately fitting the four detectors were all consistent at an approximately 90% confidence level, the data were fitted simultaneously from all four instruments with the same model, tying the fit parameters together but allowing the relative normalizations of the four data sets to vary.

The spectra were first fitted using a single absorbed power-law model with all parameters free to vary. The resulting best-fit parameters are given in Table 5, together with the absorbed 2–10 keV flux and intrinsic 2–10 keV luminosity derived from the fits. In each case, a single absorbed power-law model provides an acceptable description of the spectra. The two-dimensional $\chi^2$ contour plots in the parameter space $N_H-\Gamma$ are shown in Figure 1, together with the ROSAT contours. Contours representing the 68%, 90%, and 99% confidence limits for two interesting parameters are indicated for the simultaneous fit of the GIS and SIS data. The 90% confidence contours obtained from separately fitting GIS and SIS are indicated as well. They clearly show that the spectral parameters obtained from the GIS always agree with the SIS results, at least at a 90% confidence level. The elongated shape of the GIS contours in the direction of low column densities is a consequence of the reduction of the GIS effective area at low keV. The much smaller phase space occupied by the GIS around 0.4–0.5 keV is a consequence of the larger energy band and column density (because of the higher statistics).

The contours also clearly show that at least six quasars (S5 0014+81, NRAO 140, PKS 0438–436, S5 0836+71, PKS 2126–158, and PKS 2126–158) have $N_H$ values larger than the Galactic one, at a more than 99% con-

### Table 4

| Object            | Energy Range | $N_H$ (10$^{20}$ cm$^{-2}$) | $\Gamma$ | $A_{ph}$ | $\chi^2_{red}$/dof | $F_{2-10\text{ keV}}$ | $\log L_{2-10\text{ keV}}$ |
|-------------------|--------------|-----------------------------|----------|----------|---------------------|------------------------|--------------------------|
| S5 0014+81        | ~0.4–10      | 20.0$^{+0.30}_{-0.15}$      | 1.89$^{+0.03}_{-0.03}$ | 5.30     | 1.37/17             | 0.73                   | 47.8                     |
| NRAO 140          | ~0.2–5       | 22.5$^{+0.21}_{-0.14}$      | 1.53$^{+0.10}_{-0.16}$ | 20.7     | 1.21/15             | 2.88                   | 46.9                     |
| PKS 0438–436      | ~0.4–9       | 8.13$^{+0.20}_{-0.04}$      | 1.71$^{+0.08}_{-0.04}$ | 3.53     | 0.49/19             | 0.71                   | 47.3                     |
| PKS 0438–436 (Sep)| ~0.4–9       | 5.07$^{+0.09}_{-0.04}$      | 1.57$^{+0.04}_{-0.05}$ | 2.51     | 1.28/25             | 0.57                   | 47.0                     |
| PKS 0438–436 (total)| ~0.4–9     | 6.31$^{+0.39}_{-0.45}$      | 1.62$^{+0.32}_{-0.43}$ | ...      | 0.93/46             | ...                    | ...                      |
| PKS 0537–286      | ~0.4–10      | 3.11$^{+0.64}_{-0.50}$      | 1.50$^{+0.04}_{-0.44}$ | 2.61     | 1.84/7              | 0.65                   | 47.1                     |
| S5 0836+71 (Mar)  | ~0.3–7       | 3.29$^{+0.48}_{-0.46}$      | 1.51$^{+0.13}_{-0.12}$ | 35.0     | 1.27/18             | 8.59                   | 47.8                     |
| S5 0836+71 (Nov)  | ~0.3–7       | 3.45$^{+0.50}_{-0.46}$      | 1.55$^{+0.12}_{-0.22}$ | 17.9     | 1.55/18             | 4.41                   | 47.5                     |
| S5 0836+71 (total)| ~0.3–7       | 3.33$^{+0.42}_{-0.41}$      | 1.52$^{+0.12}_{-0.11}$ | ...      | 1.34/38             | ...                    | ...                      |
| PKS 2126–158 (May)| ~0.4–10      | 8.38$^{+1.37}_{-0.62}$      | 1.44$^{+0.10}_{-0.20}$ | 10.4     | 0.95/18             | 2.08                   | 47.7                     |
| PKS 2126–158 (Nov)| ~0.4–10      | 9.01$^{+2.28}_{-1.15}$      | 1.50$^{+0.22}_{-0.46}$ | 10.9     | 0.93/21             | 2.13                   | 47.8                     |
| PKS 2126–158 (Apr)| ~0.4–10      | 7.23$^{+0.87}_{-0.28}$      | 1.51$^{+0.57}_{-0.42}$ | 10.0     | 0.85/15             | 2.08                   | 47.7                     |
| PKS 2126–158 (Mar)| ~0.4–10      | 11.5$^{+3.00}_{-0.74}$      | 1.91$^{+0.70}_{-0.45}$ | 12.7     | 1.05/15             | 2.23                   | 48.2                     |
| PKS 2126–158 (total)| ~0.4–10   | 8.42$^{+4.88}_{-2.30}$      | 1.53$^{+0.24}_{-0.25}$ | ...      | 0.90/75             | ...                    | ...                      |

**Note:** Intervals are at 90% confidence, for two interesting parameters.

- Approximate energy range, in the quasar rest frame.
- Unabsorbed flux at 1 keV (observed frame) in units of 10$^{-12}$ photons cm$^{-2}$ s$^{-1}$ keV$^{-1}$.
- Absorbed flux between 0.1 and 2 keV (observed frame) in units of 10$^{-12}$ ergs cm$^{-2}$ s$^{-1}$.
- Intrinsic luminosity between 0.1 and 2 keV (quasar frame) in units of ergs s$^{-1}$. 
Fig. 1a

Fig. 1b

Fig. 1. $\chi^2$ contour plots in the $N_H$-$\Gamma$ parameter space. Solid line contours represent 68%, 90%, and 99% confidence limits obtained from ROSAT and ASCA (GIS + SIS). The 90% confidence contours obtained from fitting separately the GIS and SIS are indicated by dashed lines. Best-fit values are indicated by a large plus sign for ROSAT and ASCA (GIS + SIS), and by a small plus sign for GIS and SIS. The vertical lines represent the Galactic absorption obtained from radio measurements at 21 cm with associated errors of $10^{19}$ cm$^{-2}$, if taken from Elvis et al. (1989), or with a conservative 30% error, if taken from Dickey & Lockman (1990).
detected for the first time, at a high (\(S5 \sim 0.014\) ASCA). The present analysis comes from comparing the excess absorption was lost. A striking result from the same analysis column density of approximately 8\(\times 10^{20}\) cm\(^{-2}\) (corrected for the calibration uncertainties estimated below) is real, and the difference between the ASCA and ROSAT results is due to (a) the increased statistic obtained with ASCA or (b) the fact that the absorption is more complex than the adopted one (i.e., a warm absorber). Absorption variability (1) can be disregarded, as there is no reason to expect such increase in all quasars. In order to quantify any systematic instrumental effect (2) of the SIS at low energies, a series of tests described in detail in Appendix B have been applied. Results from this study indicate that part (approximately 2–3 \(\times 10^{20}\) cm\(^{-2}\)) of the excess absorption column density measured in the quasars can indeed be attributed to remaining SIS calibration uncertainties. However, it is very unlikely that the effect is all instrumental, since even after considering a conservative systematic error of approximately (3–4) \(\times 10^{20}\) cm\(^{-2}\) (estimated by us in the Appendix B and, independently, by Hayashida et al. 1995), the measured column densities are still significantly higher than the Galactic values. Also, in light of the fairly good agreement between the ROSAT and ASCA results, in particular for PKS 0438–436 and PKS 2126–158 (see Fig. 1), we are inclined to interpret these excess absorptions as real. Either the improved ASCA S/N ratio or a complex absorber, therefore, is the most plausible and will be further considered below (see § 3.3.2).

| Object | Energy Range (keV) | \(N_H\) (10\(^{20}\) cm\(^{-2}\)) | \(\Gamma\) | \(A_b\) | \(Z_{\text{edge}}\) | \(F_{\text{HX}}\) | \(E_{\text{KX}}\) | \(\log L_{\text{HX}}\) | \(\tau_{\text{edge}}\) (Fe K) |
|--------|------------------|------------------|-------|------|----------|-------|-------|----------|------------------|
| S5 0014 + 81 (1993 Oct) | ~2–40 | 28.4\(^{+2.6}_{-1.7}\) | 1.75\(^{+0.09}_{-0.08}\) | 6.66 | 0.82 (31/4) | 24.3 | 47.8 | <75 | <0.23 |
| S5 0014 + 81 (1994 Oct) | ~2–40 | 26.9\(^{+6.9}_{-6.3}\) | 1.66\(^{+0.10}_{-0.12}\) | 6.60 | 0.73 (247) | 47.7 | <131 | 0.21\(^{+0.18}_{-0.17}\) |
| S5 0014 + 81 (total) | ~2–40 | 28.1\(^{+4.5}_{-4.2}\) | 1.72\(^{+0.06}_{-0.07}\) | ... | 102.555 | ... | ... | <70 | 0.15\(^{+0.12}_{-0.11}\) |
| PKS 0332–403 | ~1–20 | 13.9 Fixed | 1.54\(^{+0.03}_{-0.12}\) | ... | 11.3554 | ... | ... | ... | ... |
| NRAO 140 | ~1–20 | 31.8\(^{+3.0}_{-2.8}\) | 1.70\(^{+0.05}_{-0.04}\) | 21.8 | 0.96864 | 9.09 | 2.56 | 47.1 | <36 | <0.10 |
| PKS 0438–436 | ~2–38 | 15.2\(^{+2.7}_{-1.1}\) | 1.63\(^{+0.15}_{-0.14}\) | 3.89 | 0.93236 | 1.75 | 0.63 | 47.3 | <240\(^{b}\) | <0.29\(^{b}\) |
| PKS 0537–286 | ~2–40 | 7.5\(^{+6.5}_{-6.7}\) | 1.46\(^{+0.13}_{-0.05}\) | 3.09 | 0.74197 | 1.85 | 0.63 | 47.4 | <139 | <0.15\(^{b}\) |
| PKS 0836+71 | ~1–30 | 11.4\(^{+3.8}_{-2.8}\) | 1.45\(^{+0.03}_{-0.05}\) | 23.3 | 0.87503 | 14.0 | 4.25 | 47.8 | <110 | <0.11\(^{b}\) |
| PKS 1614+051 | ~2–40 | 4.90 Fixed | 1.6 Fixed | 0.43 | ... | 0.21\(^{i}\) | 0.10\(^{i}\) | 46.4\(^{i}\) | ... | ... |
| PKS 2126–158 | ~2–40 | 13.6\(^{+4.3}_{-4.3}\) | 1.68\(^{+0.09}_{-0.08}\) | 13.1 | 1.01331 | 5.51 | 2.20 | 47.9 | <107 | <0.08 |
| PKS 2149–306 | ~1–30 | 8.3\(^{+2.2}_{-1.2}\) | 1.54\(^{+0.03}_{-0.03}\) | 19.2 | 1.07633 | 9.94 | 3.81 | 47.8 | <85\(^{b}\) | <0.17\(^{b}\) |

Note.—Intervals are at 90% confidence, for two interesting parameters when \(N_H\) is free and for one interesting parameter when \(N_H\) is fixed at the Galactic value.

- Approximate energy range, in the quasar rest frame.
- SIS unabsorbed flux at 1 keV (observed frame) in units of \(10^{-4}\) photons cm\(^{-2}\) s\(^{-1}\) keV\(^{-1}\).
- Absorbed flux between 2–10 keV (observed frame) in units of \(10^{-12}\) ergs cm\(^{-2}\) s\(^{-1}\), calculated with the SIS normalization only.
- Absorbed flux between 0.1–2 keV (observed frame) in units of \(10^{-12}\) ergs cm\(^{-2}\) s\(^{-1}\), extrapolated from the best-fit spectra (i.e., with the SIS normalization).
- Intrinsic luminosity between 2 and 10 keV (quasar frame) in units of ergs s\(^{-1}\), calculated with the SIS only.
- The 90% limit on the equivalent width of the Fe K line measured in the observer frame, with \(\sigma = 0\) eV and \(E = 6.4\) keV (quasar frame), for one interesting parameter (\(\Delta \chi^2 \approx 2.71\)). These values are about a factor of 2 worse if the line widths are as large as 0.5 keV.
- The 90% limit on the absorption edge depth with energy fixed at 7.1 keV (quasar frame).
- Value affected by the calibration uncertainties of the SIS between approximately 1.8 and 2.4 keV. An estimated conservative systematic error of 10 eV (observer frame) for the lines and \(\Delta \chi^2 = 0.05\) for the edge depth have been added to these values.
- Quasar was detected but with too few counts to perform a spectral analysis. Fluxes and luminosity are calculated assuming a photon index of 1.6 (i.e., the average value from the sample) and Galactic absorption.
The weighted mean photon index obtained for the whole sample in the observed \(\sim 0.5-10\) keV band is 
\[\langle \Gamma_{0.5-10\text{ keV}} \rangle \approx 1.59 \pm 0.01\] 
with a dispersion \(\sigma_{0.5-10\text{ keV}} \approx 0.10\) when \(N_H\) is left free to vary, and 
\[1.45 \pm 0.01\] 
with a dispersion of 0.08 when \(N_H\) is fixed at the Galactic value. However, fits with the absorption fixed at the Galactic value of spectral indices. The results obtained in this way are 
\[0.10\] 
and dispersion of 0.08 when is fixed at the Galactic value. 

However, fits with the absorption fixed at the Galactic value of spectral indices. The results obtained in this way are 
\[0.10\] 
and dispersion have also been computed, jointly, using a 
\[\text{residuals of SIS and, in some case, of GIS. The mean slope}
\]

The weighted mean photon index obtained for the 
\[\langle \Gamma_{0.5-10\text{ keV}} \rangle \approx 1.61 \pm 0.04\] 
and \(\sigma_{0.5-10\text{ keV}} = 0.10 \pm 0.03\), where the confidence intervals are the 68% level for two interesting parameters. Fitting the data only between 2–10 keV, where the effect of the absorption is negligible, gives 
\[\langle \Gamma_{2-10\text{ keV}} \rangle \approx 1.53 \pm 0.05\] 
and \(\sigma_{2-10\text{ keV}} \lesssim 0.12\).

The ASCA spectra were also investigated for the presence of Fe Kα emission lines. Given the high redshifts of the quasars, Fe Kα lines are expected at energies between approximately 1.5 and 3 keV, where GIS and SIS effective areas and resolution are highest. No significant Fe Kα emission lines were detected, with upper limits for the equivalent width of a narrow Gaussian line at 6.4 keV ranging between 40 and 415 eV (quasar frame, Table 5). Very similar upper limits were obtained for a line emitted at 6.7 keV in the quasar frame. It is emphasized, however, that since no constraint can be given on the line widths, the upper limits strongly depend on the assumed widths of the lines and become a factor of 2 worse than given here if the widths are as large as 0.5 keV. Next, spectra were searched for neutral Fe K edges at 7.1 keV (quasar frame) and, for ionized Fe K edges, at the mean energy of 7.8 keV observed in Seyfert 1 galaxies (Nandra & Pounds 1994). Whenever these spectral features were expected in the energy range of 1.8–2.4 keV, a conservative systematic error of 10 eV (for the lines) and \(\Delta\tau = 0.05\) (for the edges) were added to take into account the uncertainties of the ASCA response at these energies (Table 5). No absorption edges were detected except for S5 0014+81. For this quasar, the inclusion of an absorption edge at \(E \approx 1.62 \pm 0.1\) keV (\(E \approx 7.1 \pm 0.4\) keV in the quasar frame) with depth \(\tau \approx 0.15^{+0.12}_{-0.11}\) corresponds to a \(\Delta\chi^2 \approx 9\), which is significant at more than 90% confidence. The detection is also supported by the fact that the edge seems to be present in both observations (1993 October and 1994 October) at 68% and 99% confidence level, respectively. The equivalent hydrogen column density derived from the edge is \((4-39) \times 10^{23}\) cm\(^{-2}\) (assuming a spherical distribution of the absorber and an Fe cosmic abundance relative to hydrogen of \(3 \times 10^{-5}\)), which is consistent with \((4-7) \times 10^{23}\) cm\(^{-2}\), measured assuming an intrinsic origin for the absorber (Table 6A). The predicted Fe Kα line equivalent width is in the range of approximately 40–350 eV (Makishima 1986; Leahy & Creighton 1993), consistent with the computed upper limits.

3.3. ROSAT and ASCA Combined Temporal and Spectral Analysis

For five of the nine quasars (S5 0014+81, NRAO 140, PKS 0438–436, PKS 0537–286, and PKS 2126–158), the best-fit spectral parameters derived from ROSAT and ASCA data are consistent with each other at a 90% confidence level. Despite the fact that the ASCA spectra require systematically more absorption than the ROSAT spectra (see Appendix B), the 0.1–2 keV flux extrapolated from the ASCA spectra (Table 5) is in good (within approximately 10%) agreement with the measured ROSAT flux (Table 4). Therefore, the data from the two instruments were combined to the benefit of the higher sensitivity of the ROSAT PSPC at lower energies and of the ASCA instrument higher energy resolution and broadband. The normalizations of the two instruments were left free to vary independently. The unprecedented quality (for high-z quasars) of these combined spectra, covering typically an energy range of approximately 0.4–40 keV in the quasar frame, provides an excellent opportunity to test the data against more complex emission models such as complex absorption, thermal emission, and reflection models, as described in the following.

3.3.1. Single Power-Law Fits

Again, we first fitted the combined spectra with a single absorbed power-law model, with absorption abundances and cross sections from Morrison & McCammon (1983). The results from these fits are given in Table 6A. Spectra, residuals, and contour plots are shown in Figure 2. The weighted mean of the photon indices for the five quasars is 
\[\langle \Gamma_{0.1-10\text{ keV}} \rangle \approx 1.62 \pm 0.02\] 
with a dispersion \(\sigma_{0.1-10\text{ keV}} \approx 0.11\). Note that, when compared with ASCA results alone (Table 5), the addition of ROSAT data for S5 0014+81 and NRAO 140 gives almost unchanged results. However, for the other three sources (PKS 0438–436, PKS 0537–286, and PKS 2126–158), there is indeed a significant improvement combining the data. Note that the column density for PKS 0537–286 turns out to be marginally (>90%) higher than the Galactic value since statistical errors have been reduced, suggesting excess absorption in this source too. However, considering the ASCA SIS systematic uncertainties (Appendix B), conclusions on this issue are unwarranted.

The inclusion of an Fe K emission line or Fe K absorption edge in the model gave results almost identical to the one obtained in §3.2 and given in Table 5.

3.3.2. Absorption Fits

Given sufficient energy resolution, it should, in principle, be possible to constrain the redshift and metal abundances of a neutral absorber through direct spectral fitting. Though such measurements sound difficult with present-generation X-ray telescopes, it might be worth trying them with the best available data.

As a first step, therefore, elemental abundances were fixed at the cosmic value, given by Morrison & McCammon (1983), and spectral fittings with two separate absorbers, one at \(z = 0\) fixed at the Galactic value and one at the quasar redshift with \(N_H\) free, were repeated. The resulting parameters are given in Table 6A. Accordingly, the column densities obtained for an absorber intrinsic to the quasar are larger, ranging between approximately \((1.7-55) \times 10^{21}\) cm\(^{-2}\). If the redshift of the absorber is left free to vary, no preferential solution is found for any of the quasars, indicating that the present data do not allow us to distinguish between a local absorber (at \(z = 0\)) or any other absorber placed between us and the quasars. Fixing the absorber at the quasar redshifts, if the abundances of the metals (C, N, O, Ne, Mg, Si, S, Ar, Ca, and Fe) were tied together and left
is expected below 0.2 keV, where the PSPC response drops down rapidly. Moreover, since the present spectra indicate that the ROSAT spectra were typically less absorbed than the ASCA spectra (§ 3.2), this may be somehow the signature of a warm absorber. In order to test this hypothesis, a warm absorber model ("absor") in the XSPEC package) placed at the redshift of the quasars has, therefore, been directly fitted to the data. Free parameters were the ionization parameter \( \xi = L/nR^2 \) ergs s\(^{-1}\) cm, where \( L \) is the warm gas density and \( R \) is the distance of the absorber from the source) and the warm column density \( N_w \) (cm\(^{-2}\)). A temperature of \( 3 \times 10^4 \) K (Reynolds & Fabian 1995) and Fe cosmic abundances were assumed. Results are reported in Table 6B. Although the fits are generally statistically worse than with a single absorbed power-law model, the data accumulated to date do not rule out this model and are consistent with ionization parameters of the order of approximately a few tens up to a few hundreds of ergs cm\(^{-2}\), with warm column densities ranging between approximately \( (2-7) \times 10^{22} \) cm\(^{-2}\).

3.3.3. Alternative Continuum Models

The possibility that other continuum models could be applied to the data was considered in the attempt to explain the low-energy cutoff with Galactic absorption only and/or provide an alternative description of the higher energy power-law spectrum.

A model consisting of a broken power-law with the absorption column density fixed at the Galactic value was first applied in order to check whether a flat power law is able to describe the observed low-energy cutoff. The spectral curvature may indeed be a property of the intrinsic emission of the quasars, as a break in the continuum is expected if the emission is due to the synchrotron mechanism, in which radiative losses are likely to steepen the spectra at higher energies. Similar arguments are often used to explain the convex shape of the X-ray spectra of BL Lac objects (e.g., Barr, Giommi, & Maccagni 1988). The results of these fits are shown in Table 6B. In order to obtain acceptable fits, the soft component is required to be very flat, with typical values of the photon index of less than 1, while the photon index of the hard component is basically identical to the values found with a single power-law model. In the four cases where the break energies are constrained, they are found to be in the \( \sim 0.7-1.5 \) keV energy range in the observer frame. These fits are statistically acceptable, and, in principle, very flat spectra could be explained, for example, in the framework of inverse Compton models, assuming a particular energy distribution of the electron

### Table 6A

**ASCAS and ROSAT Combined Spectral Fits: Single Power Law**

| Object     | Energy Range (keV) | \( N_H \) (10\(^{20}\) cm\(^{-2}\)) | \( \Gamma \) | \( \chi^2_{\text{red}}/\text{dof} \) |
|------------|--------------------|--------------------------------------|--------------|---------------------------------|
| S5 0014 + 81 | ~0.4-4.0           | 27.4\(^{+4.0}_{-3.9}\) 1.71\(^{+0.7}_{-0.7}\) | 1.03/572     |                                 |
| NRAO 140   | ~0.2-2.0           | 31.1\(^{+3.0}_{-2.7}\) 1.70\(^{+0.4}_{-0.4}\) | 0.97/881     |                                 |
| PKS 0438-436 | ~0.4-3.8          | 5.81\(^{+2.6}_{-2.4}\) 1.48\(^{+0.1}_{-0.1}\) | 0.77/204     |                                 |
| PKS 2126-158 | ~0.4-4.0           | 10.4\(^{+3.1}_{-2.3}\) 1.63\(^{+0.7}_{-0.7}\) | 0.99/411     |                                 |

**Note:** Intervals are at 90% confidence, for two interesting parameters.

**Table 6B**

**Complex Models for the Absorption**

| Object     | \( N_w \) (10\(^{20}\) cm\(^{-2}\)) | \( \xi \) (ergs cm\(^{-1}\) s\(^{-1}\)) | \( \chi^2_{\text{red}}/\text{dof} \) | \( \Gamma_{\text{soft}} \) | \( E_{\text{break}} \) (keV) | \( \Gamma_{\text{hard}} \) | \( \chi^2_{\text{red}}/\text{dof} \) |
|------------|--------------------------------------|--------------------------------------|---------------------------------|--------------|-----------------|-----------------|---------------------------------|
| S5 0014 + 81 | 741\(^{+647}_{-286}\) 1.79\(^{+0.9}_{-0.7}\)               | <191                                 | 1.03/571                         | ~0.05/0.70   | 1.04/0.16       | 1.60/0.04       | 1.03/571                         |
| NRAO 140   | 305\(^{+346}_{-129}\) 1.73\(^{+0.5}_{-0.4}\)               | 93\(^{+11.1}_{-10.0}\)               | 0.98/880                         | 0.85/0.12    | 1.57/0.11       | 1.64/0.05       | 0.96/880                         |
| PKS 0438-436 | 210\(^{+297}_{-82}\) 1.49\(^{+0.11}_{-0.09}\)             | <120                                 | 0.97/280                         | ~0.5         | 0.68/0.37       | 1.41/0.08       | 0.99/280                         |
| PKS 2126-158 | 210\(^{+399}_{-190}\) 1.40\(^{+0.12}_{-0.10}\)             | <4350                                | 0.77/203                         | <1.3         | <3.8            | 1.47/0.37       | 0.81/203                         |

**Note:** Intervals are at 90% confidence, for two interesting parameters.
Fig. 2a

Fig. 2.—Best-fit spectra and $\chi^2$ contour plots of the combined ROSAT and ASCA data. The data are fitted with a single absorbed power-law model and have been binned to an S/N ratio higher than 4 for display purposes. Note that the ROSAT counts (lower spectra) have been normalized by the PSPC geometric area of 1141 cm$^2$. Therefore, the ROSAT counts should be read as "normalized counts s$^{-1}$ keV cm$^{-2}$." The contours represent the 68%, 90%, and 99% confidence limits, and the vertical lines are, as in Fig. 1, the Galactic absorption and associated errors. For S5 0014+81, the energy of the Fe K edge has been indicated.
population (i.e., with a convex shape produced by the effect of radiative cooling at high energy and escape at low energies; G. Ghisellini, private communication). This model therefore cannot be directly ruled out. However, considering that the broken power-law model requires an extra free parameter and that statistically it is never significantly better than the single absorbed power-law model, using this model is unjustified with the present data.

The data were then fitted with a thermal bremsstrahlung model. With the absorption fixed at the Galactic value, this model is also not acceptable because there are significant and systematic deviations in the residuals at low \((E \lesssim 1 \text{ keV}, \text{observer frame})\) energies. With free absorption, we find that the spectra can also be described by a very high temperature \((kT \sim 20\text{–}90 \text{ keV in the source frame})\) thermal model and an absorption slightly reduced, but still significantly \((\gtrsim 99\%\) higher than the Galactic column, when compared to the single absorbed power-law model (Table 6C). The fits are, however, in all cases worse than with a single power-law model. Note, moreover, that at these temperatures, a bremsstrahlung emission model is virtually indistinguishable from a flat power law in the \textit{ASCA} energy range, and, as already noted by S96, these temperatures correspond to approximately 10–15 \text{ keV in the observer frame, which is suspiciously similar to the \textit{ASCA} higher energy limit. Since the temperature of bremsstrahlung emission is primarily determined by its high-energy cutoff, only relatively poor constraints can be set with \textit{ASCA} on this parameter (errors of about 25\%–90\%; see Table 6C). As a result, the description given with the power-law model is preferable, and the thermal model will not be considered any further.

Previous \textit{Ginga} results (Nandra \\& Pounds 1994) have shown that the canonical X-ray slope \((\Gamma \sim 1.7)\) of Seyfert 1 galaxies can be interpreted as the sum of an intrinsic steep power law with \((\Gamma_{2-20 \text{ keV}} \sim 1.8\text{–}2.1)\) plus a reflection component (e.g., Lightman \\& White 1988). Prompted by these results and the fact that the present sample of quasars exhibit fairly flat \((\Gamma \sim 1.5\text{–}1.7)\) spectra up to approximately 30–40 \text{ keV (rest frame)}, we searched for evidence of high-energy flattening. A reflection component was included in the absorbed power-law model, leaving the absorption and photon index free to vary.

In its simplest form, this model (plrefl in XSPEC) adds only one free parameter, the relative normalization, \(R (= A_{\text{refl}}/A_{\text{pl}})\), between the reflected component \((A_{\text{refl}})\) and the incident power law \((A_{\text{pl}})\) (see, e.g., Cappi et al. 1996 for more details on this model). The reflected component was inte-
graduated over all viewing angles. Present results give no evidence for a reflection component, with upper limits of \( R \) ranging from approximately 0.3 to 0.7 at a 90% confidence limit for two interesting parameters (Table 6C). The lack of Fe K emission lines further supports this conclusion, although it should be noted that broad lines cannot be excluded from the data.

In order to test the consistency of the present results with what is commonly found in Seyfert 1 galaxies, we forced the intrinsic power law to be steep, with a photon index fixed at \( \Gamma = 1.9 \), and fitted the data again. As a result, the model spectra required a substantial amount of reflection, \( R \approx 1.1 \) to 3.1, in order to explain the observed flat spectra. However, since all the fits became significantly worse (\( \Delta \chi^2 \sim 10-20 \)), the presence of such a reflection component can be ruled out on a statistical basis.

On the other hand, a high-energy cutoff has been discovered with GRO OSSE in the intrinsic spectrum of Seyfert galaxies that can be described by an exponential law of the form \( E^{-\Gamma} \exp \left(-E/E_c\right) \) (Jourdain et al. 1992), but where the precise value of the e-folding energy, \( E_c \), is still uncertain (\( \sim 40-300 \) keV). A hard X-ray cutoff was therefore added to the model and fitted to the data, but no constraint was obtained for the e-folding energy, with lower limits on \( E_c \) ranging between 15 and 40 keV in the quasar frame.

4. COMMENTS ON INDIVIDUAL OBJECTS

4.1. S5 0014+81

S5 0014+81 is the farthest and optically brightest quasar in this sample. It was observed in X-rays by EXOSAT in 1984 (Lawson et al. 1992), by the ROSAT PSPC in 1991 (E94; Bechtold et al. 1994), and by ASCA in 1993 and 1994. The GIS data obtained from the first of the two ASCA observations are discussed by Elvis et al. (1994d). Their results are in very good agreement with the present GIS results. The ROSAT image indicates that there are two X-ray sources within approximately 6' of the quasar. One source at about 1.8 from the quasar was excluded from the ROSAT analysis and was estimated to be negligible in the ASCA energy band. The other source, a \( V = 8.8 \) K0 star at approximately 5' from the quasar was neglected for both instruments. The photon index and column density derived here (Table 5) are consistent with previous measurements. Considering the instrumental uncertainties and different instrumental bandpasses, the EXOSAT and ROSAT PSPC spectra are consistent in both spectral index and flux to the ASCA results. However, it is the first time that the column density is clearly constrained at a value higher than the Galactic column at a high (>99.99%) significance level (Fig. 2). The absolute amount of excess absorption is approximately \( 13.4 \times 10^{20} \) cm\(^{-2} \). It should be noted that S5 0014+81 is well known for its Lyman limit absorbers, which have been the object of extensive studies (e.g., Steigman 1994 and references therein), but that no damped Ly\( \alpha \) system is known along the line of sight to this quasar (Lanzetta, Wolfe, & Turnshek 1995).

4.2. PKS 0332–403

This object was observed in the ROSAT All-Sky Survey (RASS) with a flux between 0.1–2.4 keV of \( (1.75 \pm 0.6) \times 10^{-12} \) ergs cm\(^{-2} \) s\(^{-1} \) (Brinkmann, Siebert, & Boller 1994). This is in reasonable agreement with the ASCA flux of approximately \( (0.96 \pm 0.1) \times 10^{-12} \) ergs cm\(^{-2} \) s\(^{-1} \) extrapolated between 0.1–2.4 keV and corrected for absorption. The ASCA observations were studied by S96, who derived spectral parameters consistent with our results.

4.3. NRAO 140

NRAO 140 has a long history of X-ray observations. Previous HEAO-1, Einstein, EXOSAT, and Ginga observations have shown that its X-ray spectrum is well described by a single absorbed power law with \( \Gamma \sim 1.5–1.8 \) (Marscher 1988; Ohashi et al. 1992). This source is known for showing a large and variable X-ray absorption column (\( N_H \sim 3–20 \times 10^{21} \) cm\(^{-2} \)), which has been interpreted as the passage of Galactic dense clouds across the line of sight (Bania, Marscher, & Barvainis 1991). ROSAT and ASCA observations are discussed in Turner et al. (1995). Their combined fit yields \( \Gamma \approx 1.73 \pm 0.03 \) and \( N_H \approx (3 \pm 0.2) \times 10^{21} \) cm\(^{-2} \), which is nearly identical to the present results (Table 6A). The X-ray absorption column is significantly larger than the Galactic H\( \alpha \) column density (\( N_H \approx 14.2 \times 10^{20} \) cm\(^{-2} \); see Elvis, Lockman, & Wilkes 1989) derived from measurements at 21 cm. However, \(^{12}\)CO emission measurement toward NRAO 140 implies a molecular hydrogen column density of \( N_H \approx 17 \times 10^{20} \) cm\(^{-2} \), which, when added to the H I column density, is in excellent agreement with the observed X-ray column (Bania et al. 1991; Turner et al. 1995). These results confirm that the excess and variable absorption in NRAO 140 plausibly originates from Galactic molecular clouds passing across the quasar line of sight. It should be noted, however, that these results are based on the assumption that the CO-to-H\( \alpha \) conversion factor is approximately \( 3 \times 10^{20} \) cm\(^{-2} \) K\(^{-1}\) km\(^{-1}\) s, as commonly found for clouds in the Galactic plane. But this
value is rather uncertain in the case of high-latitude molecular clouds, such as those toward NRAO 140. Assuming the much lower conversion factor of approximately $0.5 \times 10^{20}$ cm$^{-2}$ K$^{-1}$ km s$^{-1}$ s obtained by de Vries, Heithausen, & Thaddeus (1987) or Heithausen et al. (1993), the molecular hydrogen column density is reduced by a factor of approximately 6 and implies, again, excess absorption. It should also be noted that absorption intrinsic to the quasar is not ruled out by the current data.

4.4. PKS 0438–436

The ROSAT observations of this object were discussed in great detail by Wilkes et al. (1992) and E94, and its spectral energy distribution is shown in Bechtold et al. (1994). As E94 noted, the apparent flux decrease by approximately 30% between the two ROSAT observations (Table 4) can be explained if one takes into account the different wobble mode between the observations. Preliminary results of the ASCA observation were given in Serlemitsos et al. (1994) and are consistent with those presented here.

4.5. PKS 0537–286

The ROSAT and ASCA observations of PKS 0537–286 were previously discussed by Bührler et al. (1995) and S96, yielding results consistent with the present analysis. As shown in § 3.3.1, combining the ROSAT and ASCA spectra, there is marginal evidence for excess absorption also in this quasar, however, within the uncertainties in the low-energy response of the SIS. Note, however, that even after removing all the SIS data below 1.5 keV, the excess absorption remains statistically significant at the greater than 90% confidence level.

4.6. S5 0836+71

As Brunner et al. (1994) noted, S5 0836+71 underwent a flux decrease by a factor of approximately 2 between the two ROSAT observations (Table 4), with no evidence of spectral variation. The timescale of the variation corresponds to approximately 0.2 yr in the quasar frame. The present analysis shows that the ASCA flux is consistent with the ROSAT flux in the lower state. Compared with the ROSAT spectra, the ASCA results provide strong evidence for variable absorption ($\Delta N_H \sim 8 \times 10^{20}$ cm$^{-2}$) in the direction of S5 0836+71 on a timescale of less than 2.6 yr. Including in the model the Galactic absorption and assuming that the extra absorption is intrinsic to the quasar, the ASCA fit gives an intrinsic $N_H \sim 1.18^{+0.42}_{-0.37} \times 10^{22}$ cm$^{-2}$. The change in absorption then corresponds to a $\Delta N_H \sim 1 \times 10^{22}$ cm$^{-2}$ on a timescale of $\leq 0.8$ yr in the quasar frame. It should be emphasized that fitting the ASCA spectra with a broken power-law model absorbed by the Galactic column gives $I_{\text{soft}} \lesssim 0.65$, $E_{\text{break}} \lesssim 0.96_{-0.10}$ keV, and $I_{\text{hard}} \approx 1.37^{+0.04}_{-0.03}$, with a fit formally acceptable ($\chi^2_{\text{red}}/\text{dof} \approx 0.87/502$). However, as in the other cases in which this model was applied (§ 3.3.3), this model is unlikely (but not ruled out), since it requires the soft component to be extremely flat. The ROSAT and ASCA spectra were also fitted simultaneously with a single warm absorber model (§ 3.3.2). The fits were, however, not acceptable because of large residuals in the ASCA data between 0.5–1.5 keV. Even a complex model could not, therefore, explain the spectra from the two instruments simultaneously. Variable absorption (neutral or ionized) is therefore required by the present data. It is interesting to note that S5 0836+71 has also been observed several times with EGRET in the high-energy $\gamma$-ray band (Nolan et al. 1996). The reported spectrum is very steep ($\Gamma \approx 2.5 \pm 0.5$) regardless of the (variable) $\gamma$-ray intensity.

4.7. PKS 1614+051

PKS 1614+051 was marginally detected with the Einstein IPC (Wilkes et al. 1994) and in the RASS (S96). The source is very faint also in the ASCA observation, with a 2–10 keV flux of approximately $2 \times 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$.

4.8. PKS 2126–158

PKS 2126–158 was first detected in X-rays with the Einstein IPC (Zamorani et al. 1981). The ROSAT spectrum is discussed in E94, and the spectral energy distribution is given in Bechtold et al. (1994). Note that two additional ROSAT observations have been analyzed in the present work that almost doubled the total number of ROSAT counts. The ASCA observations were discussed by Serlemitsos et al. (1994), who tentatively constrained the redshift of the absorber at $z < 0.4$. However, we cannot reproduce such contours, neither with nor without the addition of the ROSAT data. No redshift is preferred from our analysis. This discrepancy might be attributed to the fact that Serlemitsos et al. (1994) use older response matrices obtained from the preliminary calibrations of the GIS and SIS instruments.

4.9. PKS 2149–306

RASS and ASCA observations of PKS 2149–306 were discussed in S96. The comparison of the spectra obtained from the two instruments indicates spectral variability in this source, most likely interpreted in terms of variable absorption (see Fig. 2 of S96). The column density found in the present analysis is consistent with, but slightly higher than, the value obtained by S96. However, it should be noted that, unlike the S5 0836+71 case, the extra-absorption is not very large in this source ($\Delta N_H \sim 4 \times 10^{20}$ cm$^{-2}$ in S96; $\Delta N_H \sim 6 \times 10^{20}$ cm$^{-2}$ in the present analysis) and could therefore be affected significantly by the SIS calibration uncertainties discussed in § 3.2 and Appendix B.

5. DISCUSSION

5.1. Excess Absorption

The most striking result obtained from the present analysis is that the X-ray spectra of six high-$z$ RLQs examined here are absorbed by column densities significantly higher than the Galactic value. Moreover, since these measurements correspond to the higher S/N ratio data, they suggest that absorption is common (maybe ubiquitous) in high-$z$ RLQs. In this section, we discuss the possible origin of such absorption.

5.1.1. Line-of-Sight Absorption

1. Galactic.—Assuming that the extra absorption originates somewhere between the observer and the quasars, the first thing to examine is whether all of it could be produced in our Galaxy. This evaluation is commonly done through
radio measurements at 21 cm, which have been found to trace reasonably well the total amount of gas in the Galaxy (Dickey & Lockman 1990). However, the column densities are derived from measurements averaged over fairly large areas (several tens of arcmin²). Moreover, radio observations only detect interstellar atomic hydrogen and neither molecular gas (e.g., H₂, CO, OH, etc.) nor dust. So it may happen that, for a given path, the total effective absorbing column is significantly higher than that indicated by 21 cm measurements. If one also considers the proper motion of molecular clouds, it could well be possible to explain strong and variable absorption by means of special conditions in our Galaxy alone. A remarkable example is the case of NRAO 140, which is located at the edge of a molecular cloud (the IC 348 cloud in the Perseus-Taurus region; see Ungerechts & Thaddeus 1987). As discussed above (§ 4.3), when the molecular content along the line of sight is properly taken into account through ¹²CO measurements to calculate the total effective absorption column, it is possible to account for the large X-ray absorption column measured for this quasar. Under this hypothesis, the absorption variability may plausibly be due to the passage of absorbing clouds across the line of sight. Given this possibility, we checked for Galactic CO emission in the direction of all quasars of the present sample (Table 7). Surveys of local CO emission toward extragalactic sources did not detect CO emission in the direction of S5 0836+71 and PKS 2149−306 (Liszt & Wilson 1993; Liszt 1994). A deep (rms ~ 0.04 K) observation in the direction of PKS 2126−158 puts another limit on any contribution from Galactic absorption in this source (D. Hartmann, private communication). From Table 7, note that S5 0014+81 is the source with the lowest Galactic latitude after NRAO 140 that increases the probability for a contamination from Galactic molecular clouds. Furthermore, S5 0014+81 is located at the edge of a large molecular cloud complex (the Polaris Flare), and CO emission is detected from positions near the quasar (e.g., from a point of local maximum at \( l = 120.50 \) and \( b = 18.63 \)) over an area of more than 1 deg² (Heithausen et al. 1993). It is difficult to quantify precisely the contribution of the cloud to the total column density along the line of sight to S5 0014+81. However, we believe it is probably negligible in this case, because from the CO emission map shown in Figure 5 of Heithausen et al. (1993), the CO line intensity should be \( \lesssim 0.4 \) K km s⁻¹ in the direction of S5 0014+81. A rather conservative assumption for the CO-to-H₂ conversion factor of \( (2-3) \times 10^{20} \) molecules cm⁻² K⁻¹ km⁻¹ s (Strong et al. 1988) would therefore yield a column density \( N_{\text{H}_2} \approx 1.6 \times 10^{20} \) atoms cm⁻², which is in any case negligible if compared to the atomic hydrogen column density of \( N_{\text{H}} \approx 13.9 \times 10^{20} \) atoms cm⁻² derived from 21 cm observations (Dickey & Lockman 1990).

Another indirect tracer of the total column of gas along a given path is the emission in the infrared band, in particular at 100 μm. The IRAS survey has shown that the Galactic IR emission is composed of a diffuse background emission plus several large, filamentary "cirrus" features (Low et al. 1984), predominantly associated with dust in clouds with column densities of a few times \( 10^{20} \) cm⁻² and located even at high Galactic latitudes. Using the IRAS Faint Source Survey catalog provided on-line (Moshir 1989) the IR emission within a radius of 6' of each quasar was investigated (Table 7). There is no evidence for contamination from cirrus clouds in these quasars, except for PKS 2126−158, for which the IRAS Faint Source Survey maps indicate a probable contamination (Wheelock et al. 1994). From the IRAS maps, the 100 μm flux in the direction of PKS 2126−158 is estimated to be \( \lesssim 1.9 \) Jy (the maximum value in that region), which corresponds to a brightness \( \lesssim 1.5 \) MJy sr⁻¹ for a typical IRAS source covering 3' × 5'. Adopting a conservative range of \( dS_{100}/dN_{\text{H}} \approx (0.5-2.0) \) MJy sr⁻¹/10² cm⁻² (Reach, Heiles, & Koo 1993; Heiles, Reach, & Koo 1988; de Vries et al. 1987) as typical dust-to-gas ratios, this implies a total \( (H_2 + H \, \, \text{H})_\odot \) hydrogen column density of \( (0.7-3) \times 10^{20} \) cm⁻². These values are close to the 21 cm estimate of \( N_{\text{H}} \approx 4.85 \times 10^{20} \) cm⁻² (Elvis et al. 1989), thus ensuring that there is no significant excess IR emission and that, therefore, cirrus contamination is likely to be negligible for the present discussion even in this case.

In summary, on the basis of the above local CO properties and IR emission in the direction of these quasars, it is unlikely that all the extra absorption measured in X-rays is attributable to absorption by molecular clouds in our Galaxy, except possibly for NRAO 140. However, some contamination from molecular clouds and cirrus clouds may be present in S5 0014+81 and PKS 2126−158 respectively, but at a low level.

2. Extragalactic.—It has been known for decades that the space density of quasars decreases above \( z \sim 3 \) (see Shaver 1995 for a review). Although one plausible explanation for this decrease may be related to the way quasars evolve, it has also been argued that dust and gas in intervening galaxies could explain or at least contribute to the apparent

| Table 7 |

**Local Interstellar CO and Infrared Emission toward the Quasars**

| Object     | \( l \)   | \( b \)   | CO Emission | References | IR\(100\)σm Emission | References |
|------------|---------|---------|-------------|------------|----------------------|------------|
| S5 0014+81 | 121.6113| 18.8020 | Possible    | 1          | No                   | 6          |
| PKS 0332−403 | 247.7640| −54.0749|              | ...        | No                   | 6          |
| NRAO 140   | 158.9997| −18.7650| Yes         | 2          | No                   | 6          |
| PKS 0438−436 | 248.4109| −41.5654|              | ...        | No                   | 6          |
| PKS 0537−286 | 232.9400| −27.2924|            | ...        | No                   | 6          |
| S5 0836+71 | 143.5408| 34.4257 | No          | 3          | Yes                  | 6          |
| PKS 2126−158 | 35.9295| −41.8679| No          | 4          | Yes                  | 6          |
| PKS 2149−306 | 17.0770| −50.7845| No          | 5          | No                   | 6          |

* An entry of "Yes"/"No" indicates that \( ^{12}\text{CO} \) \( J = 1-0 \) line Galactic emission has/not been detected in the direction of the quasar (see § 5.1.1.2).

* An entry of "Yes"/"No" indicates that there is/is not contamination by cirrus (see § 5.1.1).

**References.** — (1) Heithausen et al. 1993; (2) Bania et al. 1991; (3) Liszt & Wilson 1993; (4) D. Hartmann, private communication; (5) Liszt 1994; (6) Moshir 1989.
turnover in space density (Ostriker & Heisler 1984). Examples of probable intervening galaxies have already been found in several high-z BL Lac objects (PKS 1413+135; Stocke et al. 1992; AO 0235+164; Madejski 1994; PKS 0537−44 and W1 0846+561, Narayan & Schneider 1990; MS 0205.7+3509, Stocke, Wurtz, & Perlman 1995). Interestingly, soft X-ray absorption is often present at a level of approximately a few times $10^{21}$ cm$^{-2}$, which is similar to our findings.

A related possibility is absorption by gas and/or dust in damped Ly$\alpha$ systems (e.g., Fall & Pei 1993, 1995), which are plausibly associated to galaxy progenitors along the line of sight (Wolfe 1995). As extensively discussed by Elvis and collaborators in a variety of papers (E94 and references therein) that included three of the present quasars (PKS 0438−436, PKS 2126−158, and S5 0014+81), the numbers and column densities of intervening damped Ly$\alpha$ systems (Lanzetta et al. 1995) could possibly explain the measured X-ray absorption. It should be noted, however, that if the hypothesis of the intervening absorber is correct, whether it is a galaxy or a damped Ly$\alpha$ system, then it predicts that the absorption should remain constant over long timescales. This is in apparent contrast with our findings, in which significant absorption variability has been detected in S5 0836+71 ($\delta$ 4.69, although this “blazar-type” object may be intrinsically different from the other quasars. Moreover, an absorption edge has been marginally detected in S5 0014+81 at the energy expected if the absorber is at the quasar redshift. These results suggest that the absorption is more likely intrinsic to the quasars, as discussed in the following.

5.1.2. Intrinsic Absorption

1. Absorption by dust and/or neutral gas.—Recent observations are reviving the long-standing idea (Rieke, Lebofsky, & Kinman 1979; Sanders et al. 1989) that quasars themselves may be embedded in large quantities of dust or thick gas. Webster et al. (1995) have recently claimed that a large population of radio-loud quasars are so red that they may have been missed by optical searches. This reddening is interpreted as arising from dust that is most likely located within the quasar host galaxy since the effect appears to be independent of redshift. Other evidence for obscuration have been found in several type 2 AGNs, including several narrow line radio galaxies of low and high luminosities (e.g., Centaurus A, Bailey et al. 1986; 3C 109, Goodrich & Cohen 1992; Allen & Fabian 1992; Cygnus A, Ueno et al. 1994; 3C 265, Dey & Spinrad 1996). In these objects, the absorption is thought to arise in a nuclear torus, with a wide range of column densities (up to $N_H \sim 10^{24} - 10^{25}$ cm$^{-2}$). These arguments argue in favor of the presence of large quantities of obscuring material, possibly in the form of dust. Other indirect evidence for large quantities of matter in high-z objects comes from the recent measurement by Ohta et al. (1996) of a strong CO (5−4) emission line from a $z = 4.69$ radio-loud quasar. Assuming a Galactic CO-to-H$_2$ ratio, they infer a total mass of cold gas of approximately $10^{11} M_\odot$.

Another possibility for the site of neutral absorbing material is in a cluster of galaxies. Since RLQs at $z > 0.5$ are sometimes located in rich clusters of galaxies (Yee & Ellingson 1993), cluster cooling flows may provide the necessary cold material to produce the observed X-ray absorption (White et al. 1991; E94). The radio galaxy Cygnus A is a remarkable example of such a scenario (Reynolds & Fabian 1996). However, again, if the variable absorption observed in S5 0836+71 and possibly PKS 2149−306 is real, this could not be explained either by an absorption torus or by a cooling flow model. Thus, an alternative explanation must be found, at least for these cases. One possible explanation could be the passage of neutral material (e.g., dense absorbing clouds) across the radiation field (possibly anisotropic). On one hand, cold clouds or “blobs” are expected to survive the intense radiation field close to the central regions of AGNs (Guilbert & Rees 1988; Celotti, Fabian, & Rees 1992) and may well imprint reflection features (iron line and hard tail) commonly seen in the X-ray spectra of AGNs (Nandra & George 1994). On the other hand, anisotropic radiation, possibly with beaming of the radiation, may be expected in these objects on the basis of the extremely high luminosity ($L_{2−10\, keV} \sim 10^{47}−48$ ergs s$^{-1}$, in the quasar frame) observed and on the basis of general arguments on the unification of radio-loud quasars (Urry & Padovani 1995). As far as S5 0836+71 is concerned, superluminal radio components (Krichbaum et al. 1990), a rapid $\gamma$-ray flare observed by $EGRET$ (von Linde et al. 1993), and theoretical arguments (Dondi & Ghisellini 1995) support the hypothesis that, at least in this object, the radiation source is relativistically beamed. Optically thin clouds with column densities of $N_H \sim 10^{21−22}$ cm$^{-2}$ covering the continuum radiation or, alternatively, optically thick ($N_H > 10^{25}$ cm$^{-2}$) clouds covering quite a large fraction of it could plausibly reproduce the observed X-ray absorption. The variability could arise from the passage of the clouds across the radiation field line of sight.

2. Absorption by ionized gas.—The absorption may also be produced by partially ionized “warm” material. Warm absorbers have been previously invoked to explain the complex X-ray absorption observed in several active galaxies (Nandra & Pounds 1994; Cappi et al. 1996) and quasars (MR 2251−178, Halpern 1984, Otani 1996; 3C 351, Fiore et al. 1993, Mathur et al. 1994; 3C 212, Elvis et al. 1994b, Mathur 1994). The state of a warm absorber depends only, though critically, on the ionization parameter, $\xi = L/nR^2$ (Kallman & McCray 1982). Since warm absorbers have been unambiguously detected in low-luminosity AGNs, they may survive also at higher luminosities since, for a given density, the gas may just be at a larger distance from the central source. As shown in § 3.3.2, the present data are consistent with a warm absorber model as a possible explanation of the low-energy absorption. However, the quality of the data coupled with the high redshifts do not allow us to distinguish between a cold and ionized absorber. It is interesting to note that if the $ASCA$ X-ray spectrum of MR 2251−178 ($z \approx 0.068$; $L_{2−10\, keV} \sim 10^{45}$ ergs s$^{-1}$), which clearly indicates the presence of a warm absorber ($\xi \approx 28$, $N_{\rm warm} \approx 2.6 \times 10^{21}$ cm$^{-2}$), is redshifted to $z = 2$ (i.e., the data are cut at $E \gtrsim 1.2$ keV), then it could be equally well fitted with a neutral absorption column density of approximately ($6−12 \times 10^{20}$ cm$^{-2}$ (C. Otani, private communication), similar to what we find in our sample. This implies that the data accumulated to date for high-z quasars can hardly be used to distinguish between a cold or ionized absorber. A warm absorber cannot, therefore, be ruled out.

If the warm absorber hypothesis is correct, variable absorption could be interpreted as variation in the ionization state of the absorber (e.g., MCG −6–30−15; see Otani et al. 1996). An ionized absorber also predicts an
absorption edge at $E > 7.1$ keV that seems to be at variance with our findings for S5 0014 + 81, in which the fitted energy of the absorption edge is centered at approximately 7.1 keV. The quality of the data, however, does not exclude mildly ionized absorption either.

5.2. Statistical Properties

Correlations among the following parameters: photon index, column densities, 2–10 keV luminosity, radio loudness, and source redshift have been searched for in the whole ASCA sample. The analysis shows no significant correlation, which is not surprising given the small size of the sample. Though not adequate for statistical correlations between the X-ray emission parameters, the sample is large enough to be representative of the entire class of “X-ray–selected” high-z RLQs. But because the sources were selected among the brightest and farthest ones detected by previous satellites, the sample is clearly biased toward the most luminous objects in the universe.

Earlier X-ray spectra of RLQs, mostly at low redshift, showed mean photon indices between approximately 1.4 and 1.8 both in the soft ($\sim$0.1–4 keV; Einstein IPC, Wilkes & Elvis 1987; ROSAT PSPC, Brunner et al. 1994) and hard ($\sim$2–10 keV; EXOSAT, Comastri et al. 1992; Ginga, Lawson & Turner 1996) energy bands. In some works, significant dispersion around the mean has been found (Brunner et al. 1994; Lawson & Turner 1996). If real, this indicates that either RLQs have an intrinsic dispersion of slopes or the intrinsic X-ray spectrum is more complex than a single absorbed power law (e.g., soft-excess or complex absorption). Previous X-ray spectra of high-z RLQs taken with ROSAT (E94, Bechtold et al. 1994) and ASCA (Serlemitsos et al. 1994; S96) are consistent with an average photon index between approximately 1.5 and 1.8 up to 30 keV in the source frame.

The mean photon index derived for the whole sample over the full ASCA energy band is $\langle \Gamma_{0.5-10\,\text{keV}} \rangle \approx 1.61 \pm 0.04$ with a dispersion $\sigma_{0.5-10\,\text{keV}} \approx 0.10 \pm 0.03$. This average value is in agreement with most of the findings described above for low-z and high-z RLQs derived in both the soft and hard band, and it indicates that there is no X-ray spectral evolution with redshift or luminosity over a broad ($\sim$1–40 keV) energy band (source frame). This is further illustrated in Figure 3, which shows the X-ray spectral slopes observed with ASCA between approximately 0.5 and 10 keV as a function of redshift and 2–10 keV luminosity (quasar frame) together with the photon indices obtained with Ginga for 18 low-z RLQs as reported by Lawson & Turner (1996). It is interesting to note that the dispersion is significantly different from zero also at high-z, although it is somewhat smaller than the Ginga value $\sigma \approx 0.19^{+0.06}_{-0.04}$ (Lawson & Turner 1996). However, the mean photon index obtained with ASCA in the 2–10 keV energy band, in which the present measurements are not affected by the absorption, is $\langle \Gamma_{2-10\,\text{keV}} \rangle \approx 1.53 \pm 0.05$, with a dispersion $\sigma_{2-10\,\text{keV}} \approx 0.12$. The intrinsic dispersion is, in this case, consistent with zero within 1 $\sigma$. This result implies that the above nonzero dispersion is probably a consequence of the heterogeneous absorption measured in the data and that the intrinsic distribution of photon indices is well characterized by a single slope.

Excluding S5 0836 + 71 from the sample because of its blazar-like properties, the results are as follows: 

$\langle \Gamma_{0.5-10\,\text{keV}} \rangle \approx 1.64 \pm 0.06$ with $\sigma_{0.5-10\,\text{keV}} \approx 0.07^{+0.07}_{-0.03}$,

and $\langle \Gamma_{2-10\,\text{keV}} \rangle \approx 1.57 \pm 0.09$ with $\sigma_{2-10\,\text{keV}} \lesssim 0.14$. These are consistent with the above results.

5.3. Implications for the X-Ray and $\gamma$-Ray Backgrounds

It is by now widely accepted that AGNs could supply the bulk of the X-ray background (XRB) emission above a few keV. Detailed modeling, based on the unified scheme and assuming the existence of a large population of absorbed AGNs, provides a good fit to the observed XRB spectrum up to approximately 100 keV (Madau, Ghisellini, & Fabian 1994; Comastri et al. 1995). If the absorption discovered in some of the objects in our sample turns out to be a common property of high-z, high-luminosity RQQs, then this would give strong support to the above models.

It should be noted that RLQs constitute only a small fraction of the quasar population, so that their contribution to the XRB is of the order of a few percent. This point is also reinforced by our findings that the observed X-ray spectra of RLQs have $\Gamma \sim 1.5$–1.6 up to approximately 40 keV in the source frame, steeper than the XRB, as illustrated in Figure 3. But the derived mean slope for the present sample has interesting implications for the $\gamma$-ray background (GRB). In fact, it has been recently pointed out (Comastri, Di Girolamo, & Setti 1996) that flat-spectrum radio quasars
(FSRQs) may provide a significant fraction (~70%–80%) of the GRB above several tens of MeV. This result has been achieved assuming that the X-ray spectra of FSRQ in the X-ray band (from approximately 1 keV up to several hundreds of keV) are characterized by a slope with $\Gamma = 1.5$. Our findings therefore provide further support for this model, suggesting that RLQs are likely to provide an important contribution to the hard XRB and GRB.

6. CONCLUSIONS

The present analysis of ASCA and ROSAT observations of high-z RLQs confirms that excess absorption is common in these objects. It is indeed detected significantly in the six brightest quasars of our sample. Unfortunately, even combining the two instruments, it is not possible to constrain the redshift of the absorber through direct spectral fitting. However, new results for S5 0836 + 71, and possibly S5 0014 + 81, favor the hypothesis that, at least in these two cases, the absorption is intrinsic to the quasars. Indeed, a comparison of ASCA and ROSAT spectra indicates that the absorption has varied ($\Delta N_H \sim 8 \times 10^{20} \text{ cm}^{-2}$) in S5 0836 + 71 on a timescale of approximately 2.4 yr (observer frame), and an Fe K absorption edge is marginally detected in the ASCA observations of S5 0014 + 81, at the energy expected if the absorber is at the redshift of the quasar. If we assume that the absorption is intrinsic for all objects in the sample, the column densities imply a range of approximately (1.7–55) $\times 10^{21} \text{ cm}^{-2}$.

Since the data do not allow us to constrain unambiguously the redshift of the absorption, several possible origins have been considered. A careful search for Galactic CO and/or IR (100 $\mu$m) emission in the direction of the quasars indicates that the contribution to the total X-ray absorption column from molecular gas and dust present in our Galaxy is negligible for the majority of the quasars. It is, however, likely to be significant in the case of NRAO 140. Extragalactic absorption from intervening galaxies and/or damped Ly$\alpha$ systems may be relevant for some of the objects, but it is not consistent with the new findings for S5 0836 + 71 and S5 0014 + 81. Intrinsic absorption from an absorption torus or intracluster gas is also unlikely in light of the absorption variability. It is therefore argued that the preferable explanation is intrinsic absorption by cold gas, possibly in the form of clouds, near the central source. A warm absorber would be a plausible candidate as well.

The accumulated counts allowed us to put, for most objects, stringent limits on the presence of an Fe K emission line, with upper limits on the EW ranging between approximately 40 and 400 eV in the quasar frame. There is, however, more uncertainty about the strength of the line if the width is left free to vary. Alternative continuum models have also been fitted to the data. The upper limits on the intensity of Compton reflection range between $R \sim 0.1$–0.7. A broken power-law model, tested as an alternative explanation for the low-energy cutoff, would require unreasonably flat ($\Gamma < 1$) slopes at low energies, although it cannot be ruled out by the data. It is also argued that a thermal bremsstrahlung origin for the observed continuum is unlikely.

The average photon index ($\langle \Gamma \rangle \sim 1.5$–1.6) is consistent with previous measurements at high and low-z, therefore suggesting that RLQs do not show spectral changes over about two decades in energy ($\sim 0.4$–40 keV) with either redshift or luminosity. This average slope, which is steeper than the spectrum of the XRB but flatter than the average slopes of RQQs and low-luminosity AGNs, also suggests that RLQs do not contribute significantly to the XRB but instead are likely to provide a significant fraction of the GRB flux.

The authors would like to thank all the ASCA team members for making these observations possible. M. C. thanks T. Dotani, Y. Ikebe, T. Kotani, K. Leighly, C. Otani, and T. Yaqoob for helpful discussions on the calibration of the SIS and Dap Hartmann for measuring the Galactic CO emission in the direction of PKS 2126 – 158. M. C. also acknowledges financial support from the Science and Technology Agency of Japan (STA fellowship), hospitality from the RIKEN Institute, and support from the European Union. G. G. C. P. acknowledges partial financial support from MURST and ASI. A. C. acknowledges financial support from the Italian Space Agency under the contracts ASI-94-RS-96 and ASI-95-RS-152. This work has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration.

APPENDIX A

GIS BACKGROUNDS

In the standard way of analyzing ASCA GIS spectra, there are two possible choices for the background subtraction: either from a source-free part of the observation field of view (hereafter “local background”) or from the available blank sky observations with the same region filter as used for the source spectrum (see The ABC Guide to ASCA Data Reduction [Day et al. 1995]). Both methods should, in principle, give similar results. However, slight but significant differences in the source spectral slopes were found in the present analysis and forced us to choose a nonstandard background region.

The problem is that background regions extracted from the source field of view almost inevitably fall at a substantial off-axis distance because sources are usually pointed nearly on-axis. But as the distance from the X-ray telescope optical axis increases, reduction of the contribution from the cosmic XRB (due to the vignetting) and softening of the non-XRB (Kubo et al. 1994) change in a complex and position-dependent manner the spectrum of the background, which cannot be corrected in the current analysis procedure. On the other hand, standard background regions extracted from the blank sky files from the same area as that used for the source almost always include the regions contaminated by the Seyfert 2 galaxy NGC 6552 (Ebisawa 1994). Because of the very strong Fe K emission line of this source at approximately 6.4 keV (Fukazawa et al. 1994), the source spectra obtained with blank sky backgrounds tend to be steeper than those obtained with local background
subtractions. As a result, in the analysis of the weakest sources (typically those with intensity \( \leq 0.1 \) counts s\(^{-1}\)), different backgrounds often yielded significantly different source slopes, with deviations up to \( \Delta \Gamma \sim 0.2 \). Therefore, we adopted a nonstandard background extracted from the GIS standard blank sky files from a region noncontaminated by NGC 6552 and at the same or, if not possible, similar off-axis distance of the source region. This choice of background has the advantage of avoiding the above problems of the off-axis position with the local background and of the contamination by NGC 6552 with the blank sky background. However, it has the disadvantage of the screening criteria of the blank sky background never matching exactly those of the source observation (similarly to any other choice of blank sky background). However, we estimate that this is a minor problem when standard screening criteria are adopted because the GIS background reproducibility (in time) is achieved with systematic errors less than a few percent (Ikebe et al. 1995).

**APPENDIX B**

ON THE ASCA SIS RESPONSE UNCERTAINTIES AT LOW ENERGIES

Although the results obtained with ASCA and ROSAT always agree within their statistical errors (except for S5 0836+71), the present analysis indicates that the ASCA spectra require systematically more absorption than the ROSAT spectra (Fig. 1). This suggests that the SIS responses may suffer from a systematic excess absorption, although ROSAT PSPC calibration uncertainties (e.g., nonlinear gain variations) may play a role as well. This confirms previous, more detailed, studies on the SIS calibration uncertainties at low energies (e.g., Hayashida et al. 1995). Indeed, it is widely recognized that there are local features around 0.5–0.6 keV that show up, preferentially in strong sources, in the form of absorption edges around 0.5 keV and/or emission lines at approximately 0.6 keV (e.g., Guainazzi & Piro 1994; Cappi et al. 1996; Dotani et al. 1996). The origin of the problem is not clear, although it is probably related to the presence of the oxygen K edge (produced in the CCD dead layer) at \( E \sim 0.54 \) keV in the SIS response. Because of this edge, a small offset and/or variations of a few eV in the exact response energy scale could easily be responsible for such features. Though no clear feature is evident in the low-energy residuals of the quasar spectra (Fig. 2), it is possible that it could have somehow affected our measurements. Other uncertainties concern the absolute SIS efficiency at low energies, which is currently being quantified in terms of a systematic error of approximately \( 3 \times 10^{20} \) cm\(^{-2}\) for SISO and approximately \( 2 \times 10^{20} \) cm\(^{-2}\) for SIS1 in the absorption column (Hayashida et al. 1995; Dotani et al. 1996). This problem is probably related to the correct calibration of the SIS quantum efficiency, i.e., the thickness of the CCD dead layer. It is not clear, however, how much the above local features at \( E \sim 0.5 \) keV are responsible for and/or related to such excess absorption, but, in principle, both effects (local features and excess absorption) should be already taken into account in the systematic error of approximately \( 3 \times 10^{20} \) cm\(^{-2}\).

In light of the above considerations, we have performed a series of checks in order to establish the reliability of the measured excess absorption for all ASCA spectra.

1. **Test 1: Artificial gain shifts.**—Using the “gain” command in XSPEC, we shifted the energy scales of the SISO and SIS1 responses between \( \pm 20 \) eV, i.e., within the typical systematic 2 \( \sigma \) uncertainties in the energy scale (Otani & Dotani 1994). The observed changes in the column densities were, in every case, lower than \( 2 \times 10^{20} \) cm\(^{-2}\), which is smaller than the typical statistical errors found in the present work.

2. **Test 2: Cut of the data below 0.65 keV.**—When, more drastically, all data below 0.65 keV were ignored, the fits yielded even larger best-fit absorption columns for the quasars NRAO 140, PKS 0438–436, PKS 0537–286, and PKS 2126–158. For S5 0014+81 and S5 0836+71, the columns were lowered by approximately \( 1 \times 10^{20} \) cm\(^{-2}\) (~5\%\) and \( 2.5 \times 10^{20} \) cm\(^{-2}\) (~20\%), respectively. In every case, the absorption columns remained significantly higher than the Galactic value at more than 99\% confidence level. From (1) and (2) we conclude that the measured SIS excess absorption cannot be attributed to the local detector features commonly reported around 0.5–0.6 keV. The problem is more likely related to the SIS efficiency as a whole at low energies.

3. **Test 3: Comparison with the calibration source 3C 273.**—The SIS response matrices were calibrated on the ground and then cross-calibrated with the GIS in-flight using the observations of the quasar 3C 273. In particular, the response matrices of SISO chip 1 and SIS1 chip 3 (the chips used in the present analysis) were calibrated using an observation performed in 1993 December 20. The calibrations were performed taking the slopes from the GIS spectra and assuming Galactic absorption. The quasar 3C 273 was observed 8 more times by ASCA. Results obtained from the overall observations (Cappi & Matsuoka 1996) do not modify the conclusions presented below. For the purpose of investigating the efficiency of the SIS, only the results from the 1993 December 20 calibration observation are reported below. The observation was analyzed using the same criteria (same screening criteria, extraction regions, etc.) used for the quasars to allow a direct comparison. About 82,000 counts per SIS were collected in the 0.4–10 keV energy range, for a total exposure time of approximately 15,500 s. The spectra extracted for SISO and SIS1 were then fitted with a single absorbed power-law, first separately and then simultaneously. Confidence contours obtained from each fit are shown in Figure 4. The best-fit column density is larger than the Galactic column in both SISO and SIS1, yielding an excess column density of approximately \( 2 \times 10^{20} \) cm\(^{-2}\) in the fit with both detectors. This value gives a direct estimate of the systematic error we must take into account when interpreting the results from the present analysis. This estimate is in good agreement with the measurements obtained by Hayashida et al. (1995). Also, it should be noted that independent analysis of the SIS data extracted from the central regions of Coma cluster also show excess absorption of approximately \( 3 \times 10^{20} \) cm\(^{-2}\) (K. Hashimoto, private communication).
Therefore, we conclude that the total systematic error of the absorption column density should be conservatively smaller than approximately \((3-4) \times 10^{20} \text{ cm}^{-2}\) as reported by Dotani et al. (1996). In the analysis presented in § 3 and when discussing the results, only deviations larger than this value have been considered.

REFERENCES

Allen, S. W., & Fabian, A. C. 1992, MNRAS, 258, 29P
Anders, E., & Grevesse, N. 1989, Geochim. Cosmochim. Acta, 53, 197
Arnaud, K. A., Haberl, F., & Tennant, A. 1991, XSPEC User’s Guide (ESATM-09).
Bailey, J., Sparks, W. B., Hough, J. H., & Asaro, D. J. 1986, Nature, 322, 150
Bania, T. M., Marscher, A. P., & Barvainis, R. 1991, AJ, 101, 2147
Barr, P., Giommi, P., & Maccagni, D. 1988, ApJ, 324, L11
Bechtold, J., et al. 1994, AJ, 108, 374
Brinkmann, W., Siebert, J., & Boller, T. 1994, A&A, 281, 355
Brunner, H., Friedrich, P., Zimmermann, H., & Stauffert, R. 1992, MPE Rep. 235, 198
Brunner, H., Lamer, G., Worrall, D. M., & Stauffert, R. 1994, A&A, 287, 436
Bühler, P., Courvoisier, T. J.-L., Stauffert, R., Brunner, H., & Lamer, G. 1995, A&A, 295, 309
Cappi, M., & Matsuoka, M. 1996, in Proc. X-Ray Imaging and Spectroscopy of Cosmic Hot Plasmas, in press.
Cappi, M., Mihara, T., Matsuoka, M., Hayashida, K., Weaver, K. A., & Otani, C. 1996, ApJ, 458, 149
Celotti, A., Fabian, A. C., & Reeves, M. J. 1992, MNRAS, 255, 419
Comastri, A., Cappi, M., & Matsuoka, M. 1996, MPE Rep. 263, in press
Comastri, A., Di Girolamo, T., & Setti, G. 1996, A&AS, in press
Comastri, A., Setti, G., Zamorani, G., Elvis, M., Giommi, P., Wilkes, B. J., & McDowell, J. C. 1992, ApJ, 384, 62
Comastri, A., Setti, G., Zamorani, G., & Hasinger, G. 1995, A&A, 296, 1 de Vries, H. W., Heithecker, A., & Thaddeus, P. 1987, ApJ, 319, 723
Day, R. F., et al. 1995, The ABC Guide to ASCA Data Reduction (NASA/GSFC
Dey, A., & Spinrad, H. 1996, ApJ, 459, 133
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Donahue, R. M., & Ghisellini, G. 1995, MNRAS, 273, 583
Dotani, T., et al. 1996, ASCA Newsl. 4, 3
Ebisawa, K. 1994, GOF Report (NASA/GSFC
Elvis, M., et al. 1994a, ApJS, 95, 1
Elvis, M., Fiore, F., Mathur, S., & Wilkes, B. 1994b, ApJ, 425, 103
Elvis, M., Fiore, F., Wilkes, B., McDowell, J. C., & Bechtold, J. 1994c, ApJ, 422, 60 (E94)
Elvis, M., Lockman, F. J., & Wilkes, B. J. 1989, AJ, 97, 777
Elvis, M., Matsuoka, M., Mihara, T., & Brickmann, W. 1994d, ApJ, 436, L55
Fall, S. M., & Pei, Y. C. 1993, ApJ, 402, 479
Gendreau, K. C., et al. 1993, PASJ, 46, L141
Gendreau, K. C., et al. 1995, PASJ, 47, L5
Goodrich, R. W., & Cohen, M. H. 1992, ApJ, 391, 623
Guainazzi, M., & Piro, L. 1994, RIKEN report
Guilbert, P. W., & Rees, M. J. 1988, MNRAS, 233, 475
Halpern, J. P. 1984, ApJ, 281, 90
Hayashida, K., Miura, N., Hashimoto, K., & Murakami, S. 1995, ISAS Internal Report
Heiles, C., Reach, W. T., & Koo, B.-C. 1988, ApJ, 332, 313
Heithausen, A., Stacy, J. G., de Vries, H. W., Mebold, U., & Thaddeus, P. 1993, A&A, 268, 265
Ikebe, Y., Ishisaki, Y., Kubo, H., Ieda, E., Takahashi, T., & Makishima, K. 1995, ASCA Newsl. 3, 13
Jourdain, E., et al. 1992, A&A, 256, L38
Kallman, T. R., & McCray, R. 1982, ApJS, 50, 263
Krichbaum, T. P., Hummel, C. A., Quirrenbach, A., Schalinski, C. J., & Witzel, A. 1990, A&A, 230, 271
Krolik, J. H., & Kallman, T. R. 1984, ApJ, 286, 366
Kubo, H., et al. 1994, ASCA News. 2, 14
Lanzetta, K. M., Wolfe, A. M., & Turnshek, D. A. 1995, ApJ, 440, 435
Lawson, A. J., & Turner, M. J. L. 1996, MNRAS, submitted
Lawson, A. J., Turner, M. J. L., Williams, O. R., Stewart, G. C., & Saxton, R. D. 1992, MNRAS, 259, 743
Leahy, D. A., & Cottingham, J. 1993, MNRAS, 263, 314
Lightman, A. P., & White, T. R. 1988, ApJ, 335, 57
Liszt, H. S. 1994, ApJ, 429, 638
Lizet, H. S., & Wilson, R. W. 1993, ApJ, 403, 663
Low, F. J., et al. 1984, ApJ, 278, L19
Maccacaro, T., Gioia, I. M., Wolter, A., Zamorani, G., & Stocke, J. T. 1988, ApJ, 326, 680
Madau, P., Ghisellini, G., & Fabian, A. C. 1994, MNRAS, 270, L17
Madojoki, R., & George, I. M. 1994, MNRAS, 263, 974
Manohar, J. P., & Heisler, J. 1984, ApJ, 278, Ostriker, 1
Makishima, K. 1986, in Lecture Notes in Physics, 266, ed. K. O. Mason, J. M. Watson, & N. E. White (Berlin: Springer), 249
Maraschi, A. P. 1988, ApJ, 334, 552
Mathur, S., Wilkes, B., Elvis, M., & Fiore, F. 1994, ApJ, 434, 493
Mathur, S. 1994, ApJ, 431, L75
Morrison, R., & McCammon, D. 1983, ApJ, 270, 119
Mosher, M. 1995, preprint
Mushotzky, R. F., Done, C., & Pounds, K. A. 1993, ARA&A, 31, 717
Nandra, K., Fabian, A. C., Brandt, W. N., Kunieda, H., Matsuoka, M., Mihara, T., Ogasaka, Y., & Terashima, Y. 1995, MNRAS, 276, 1
Nandra, K., & George, I. M. 1995, MNRAS, 272, 974
Nandra, K., & Pounds, K. A. 1994, MNRAS, 268, 405
Narayan, R., & Schneider, P. 1990, MNRAS, 243, 192
Nolan, P. L., et al. 1996, ApJ, 459, 100
Ohashi, T., Tashiro, M., Makishima, K., Kii, T., Makino, F., Turner, M. J. L., & Williams, O. R. 1992, ApJ, 398, 87
Ohta, K., et al. 1996, Nature, submitted
Ostrikov, I. P., & Heister, J. 1984, ApJ, 278, 1
Otani, C. 1995, Ph.D. thesis, Univ. of Tokyo
—. 1996, MPE Rep. 263, in press

FIG. 4. — $\chi^2$ contour plots in the $N_{H} - \Gamma$ parameter space for 3C 273. Solid line contours represent 68%, 90%, and 99% confidence limits for SIS0 + SIS1. Dashed lines indicate the 90% confidence contours for SIS0 chip number 1 (SIS1) and SIS1 chip number 3 (SIS3), fitted separately. Best-fit values are indicated with plus signs. The vertical lines represent the Galactic absorption (solid line) and associated 30% errors (dotted line) from Dickey & Lockman 1990.
Otani, C., & Dotani, T. 1994, ASC A Newsl. 2, 25
Otani, C., et al. 1996, PASA, 48, 211
Pfefferman, E., et al. 1987, Proc. SPIE, 733, 519
Reach, W. T., Heiles, C., & Koo, B.-C. 1993, ApJ, 412, 127
Rees, M. J. 1984, ARA&A, 22, 471
Reynolds, C. S., & Fabian, A. C. 1995, MNRAS, 273, 1167
———. 1996, MNRAS, 278, 479
Rieke, G. H., Lebofsky, M. J., & Kinman, T. D. 1979, ApJ, 232, L151
Sanders, D. B., Phinney, E. S., Neugebauer, G., Soifer, B. T., & Matthews, K. 1989, ApJ, 347, 29
Serlemitsos, P., Yaqoob, T., Ricker, G., Woo, J., Kunieda, H., Terashima, Y., & Iwasawa, K. 1994, PASJ, 46, L43
Shaver, P. A. 1995, in Proc. 17th Texas Symp. on Relativistic Astrophysics and Cosmology, 759, 87
Siebert, J., Matsuoka, M., Brinkmann, W., Cappi, M., Mihara, T., & Takahashi, T. 1996, A&A, 307, 8 (S96)
Steigman, G. 1994, MNRAS, 269, L53
Stocke, J. T., Wurtz, R. E., & Perlman, E. S. 1995, ApJ, 454, 55
Stocke, J. T., Wurtz, R. E., Wang, Q., Elston, R., & Jannuzzi, B. 1992, ApJ, 400, L17
Strong, A. W., Bloemen, J. B. G. M., Dame, T. M., Grenier, I. A., & Hermen, W. 1988, A&A, 207, 1
Tanaka, Y., Inoue, H., & Holt, S. S. 1994, PASJ, 46, 37
Thompson, D. J., et al. 1995, ApJS, 101, 259
Trümper, J. 1983, Adv. Space Res., 2, 241
Turner, T. J., George, I. M., Madejski, G. M., Kitamoto, S., & Suzuki, T. 1995, ApJ, 445, 660
Ueno, S., Koyama, K., Nishida, M., Yamauchi, S., & Ward, M. J. 1994, ApJ, 431, L1
Ungerechts, H., & Thaddeus, P. 1987, ApJS, 63, 645
Urry, C. M., & Padovani, P. 1995, PASP, 107, 803
Véron-Cetty, M.-P., & Véron, P. 1993, ESO Sci. Rep. 13
von Linde, J., et al. 1993, A&A, 267, L23
Wamsteker, W. 1981, A&A, 97, 329
Webster, R. I., Francis, P. J., Peterson, B. A., Drinkwater, M. J., & Masci, F. J. 1995, Nature, 375, 469
Wheelock, S. L., et al. 1994, IRAS Sky Survey Atlas: Explanatory Supplement (NASA/STI)
White, D. A., Fabian, A. C., Forman, W., Jones, C., & Stern, C. 1991, ApJ, 375, 35
Wilkes, B. J., & Elvis, M. 1987, ApJ, 323, 243
Wilkes, B. J., Elvis, M., Fiore, F., McDowell, J. C., Tananbaum, H., & Lawrence, A. 1992, ApJ, 393, L1
Wilkes, B. J., Tananbaum, H., Worrall, D. M., Avni, Y., Oey, M. S., & Flanagan, J. 1994, ApJS, 95, 1
Williams, O. R., et al. 1992, ApJ, 389, 157
Wolfe, A. M. 1995, in QSO Absorption Lines, ed. G. Meylan (Heidelberg: Springer), 13
Yee, H. K. C., & Ellingson, E. 1993, ApJ, 411, 43
Zamorani, G., et al. 1981, ApJ, 245, 357
Zimmerman, H. U., Belloni, T., Izzo, C., Kahabka, P., & Schwentker, O. 1993, MPE Rep. 244