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AN *ASCA* GIS SPECTRUM OF S5 0014+813 AT $z = 3.384$

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ABSTRACT

ASCA has detected the $z = 3.384$ quasar S5 0014+813 up to energies of 34 keV in the quasar rest frame using the two GIS instruments. The combined X-ray spectrum has a signal-to-noise ratio of over 50 σ and is consistent with a single power law of energy slope 0.63 ± 0.03 over the 0.8–8 keV (observed) energy range. The spectrum is also well fitted with a simple thermal bremsstrahlung model of $kT = 40 \pm 4$ keV (in the quasar frame), which raises obvious possibilities for contributions to the diffuse X-ray background.

A maximum solid angle of $\Omega_d/2\pi = 0.4$ (90% confidence) can be placed on the strength of a Compton reflection component above the energy of the Fe K-edge. The Fe K 6.4 keV fluorescence line has a rest frame equivalent width <120 eV (90% confidence) at its redshifted energy of 1.46 keV. The weakness of these features differentiates this high-luminosity, high-redshift quasar from the majority of Seyfert galaxies using its X-ray spectrum alone. The GIS slope is consistent with the slope derived by the *ROSAT* PSPC. The normalization at 1 keV in the *ASCA* observation is, however, a factor 30%–40% higher than in the *ROSAT* observation, suggesting a significant increase in the 1 keV (observed) flux over the 31.5 months between the two observations (7.2 months, rest frame).

Subject headings: diffuse radiation — galaxies: active — quasars: general — quasars: individual (S5 0014+813)

1. INTRODUCTION

X-ray observations of AGNs are heavily biased toward X-ray–loud objects of low redshift and moderate luminosity (Elvis 1991). Moreover, these X-ray spectra tend to be taken at low energies, less than ~ 3 keV for *Einstein* (Shastri et al. 1993) and *ROSAT* spectra (Walter & Fink 1993; Fiore et al. 1994; Laor et al. 1994), and less than ~ 10 keV for *Ginga* spectra (Williams et al. 1992; Lawson et al. 1992). Naturally we would like to know the form of AGN spectra at higher energies and how the many features seen in the low-redshift, low-luminosity AGNs extrapolate to extreme examples of the AGN population.

ROSAT PSPC spectra have allowed some determination of spectral slopes for quasars at high redshift and luminosity (Elvis et al. 1994a; Bechtold et al. 1994) in the 1–10 keV emitted range. Unfortunately, the common low-energy cutoff discovered with the PSPC, due possibly to absorption, leads to poorly determined slopes (Elvis et al. 1994a).

ASCA (Tanaka, Holt, & Inoue 1994) now provides the sensitivity to explore higher energies for the brightest quasars at $z \sim 3$. The *ASCA* Gas Imaging Spectrometer (GIS; Makishima et al. 1994) instruments, in particular, are able to determine spectral slopes over the 3–8 keV and 8–30 keV emitted energy ranges to good accuracy. These energy ranges are optimal for setting constraints on Fe K fluorescence emission and on Compton reflection components (Lightman & White 1988; Guilbert & Rees 1988) which begin above 8 keV in the rest frame.

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Accordingly we observed S5 0014+813 with *ASCA*. This is a $z = 3.384$ quasar (Kühr et al. 1983) and is among the highest X-ray flux quasars known with $z \sim 3$. Indeed, it is the only $z \sim 3$ quasar to have a 2–10 keV spectrum reported by *EXOSAT* (Lawson et al. 1992).

2. *ASCA* GIS OBSERVATIONS OF S5 0014+813

The quasar was observed on 1993 October 29 for a total good exposure time of 31.5 ks in both GIS2 and GIS3. We applied the standard conservative data filters: a minimum elevation angle of 15° above Earth's limb, and a minimum cutoff rigidity of 8 GeV c^{-1}. We also excluded data acquired in the first 60 s following each passage through the SAA. The source was readily apparent in the center of the GIS field of view, and the source centroid is 1.'5 from the optical position, an offset typical of *ASCA* data at present. A total of 2904 and 3244 counts were recorded within a 6' radius circle centered on the quasar in GIS2 and GIS3, respectively.

The background within the source extraction region was estimated in two ways:

1. The backgrounds were taken from annuli of inner and outer radii between 10' and 17'.
2. Background events were extracted from the same region as the source events in blank sky background event files, provided by the *ASCA* Guest Observer Facility (the files being a superposition of 15 blank sky fields observed during the *ASCA* PV phase [1993 May–1994 March] with a total exposure time of 350 ksec), for the same values of cutoff rigidity (>8 GeV c^{-1}) used for the source events.

The former background was significantly smaller than the latter (by a factor ~ 0.75) as expected due to the vignetting of the XRT. In the following we present the results obtained with the second background subtraction method. We point out, however, that the shapes of the spectra obtained with the two

TABLE 1

ASCA OBSERVATIONS OF S5 0014+813

Instrument	Counts	Exposure (s)	Background (counts)	Net Counts s^{-1}
GIS2	2904	31635	800	0.066
GIS3	3244	31500	860	0.075

methods agree to within ~3%. The total background is ~40% of the source counts, leading to a total of about 2200 net counts and a 40 σ spectrum of S5 0014+813 in each GIS (Table 1). The *ASCA* point-spread function (PSF) in the GIS puts ~10% of the flux of a point source with a spectrum similar to that of S5 0014+813 outside the 6′ radius used here. All reported fluxes are corrected for this. Fluxes are not corrected for dead-time effects. The highest energy at which the quasar is detected at the 3 σ level is 7.7 keV (bin width of 0.3 keV), which corresponds to 34 keV in the emitted frame.

A complication is the presence of two sources in the *ROSAT* PSPC image within 6′ of the quasar. In the *ROSAT* band, the count rate of these sources represents 90% of that of the quasar. The brighter source (80% of S5 0014+813), 5′ from the quasar, is probably identified with a $V = 8.8$ K0 star (HD 1165, SAO 44, PSPC offset = 9″). The fainter source (10% of S5 0014+813), only 1.′5 from the quasar, is unidentified. It has a PSPC hardness ratio $[R = (H-S)/(H+S) = 0.76 \pm 0.36$, where S is the 0.1–0.4 keV band and H is the 0.4–2.4 keV band] similar to the quasar, suggesting that it is outside the substantial Galactic N_H (14.4×10^{20} atoms cm^{-2}; Stark et al. 1989) in this direction. HD 1165 is detected in the *ASCA* SIS0 image of the field (Elvis et al. 1994b). Its count rate is about 10% of that of the quasar in the 0.8–2 keV band and is only 2% in the 2–8 keV band. We shall assume the contribution from these two sources is negligible, but this caveat should be borne in mind.

3. SPECTRAL FITS

In all spectral fits we used the response matrices "g2v3_1_4c" (1994 April 20) provided by the *ASCA* Guest Observer Facility. Note that, because of the small count rates, statistical errors dominate over systematic errors from the two instrumental responses. The results of all fits are given in Table 2.

A single power-law fit gave no significant evidence of excess absorption in either GIS, so we fixed N_H to the Galactic value. The GISs are not sensitive to column densities smaller than 10^{21} atoms cm^{-2} in any case. For a power law, the two instruments agree well (to 20% in normalization, 2% in slope), and both give good χ^2, so we made a simultaneous joint fit (letting the normalization in the two instruments be free to vary). This gave an energy slope of 0.63 ± 0.05, consistent with the *ROSAT* PSPC slope of 0.8 ± 0.2 (assuming Galactic N_H). Adding the PSPC spectra simultaneously gives the same results. Allowing an extra absorption component at the quasar redshift gives a 90% upper limit to the intrinsic absorption is 2.6×10^{22} atoms cm^{-2}. Figures 1 and 2 show the fit and residuals to all three data sets.

A thermal bremsstrahlung spectrum fitted the joint GIS data just as well as a power law. Such a fit is constrained on both sides and gives a rest frame temperature of 39 ± 4 keV. This is a temperature of some interest.

More complex spectra are not required. To investigate the presence of curvature we fitted a power law to the PSPC-GIS data above and below 2 keV (8.8 keV in the quasar frame) separately. No slope change is seen greater than 0.2 (1 σ). A complete Compton reflection model fit to the GIS data using a cold flat disk for the reflector gave a 90% upper limit (for two

TABLE 2

GIS *ASCA* POWER-LAW SPECTRAL FITS FOR S5 0014+813

Instruments	Energy range (keV)	N_H (10^{22} atoms cm^{-2})	α_E, or kT[a] $[\Omega_d/2\pi]$	Normalization (10^{-4} keV s^{-1} cm^{-2} keV^{-1})	χ^2(dof)
		Power-Law			
GIS2	0.8–8	0.22 ± 0.12	0.69 ± 0.14	6.1 ± 1.0	78.1 (58)
GIS2	0.8–8	0.144FIX	0.62 ± 0.05	5.5 ± 0.3	79.1 (59)
GIS3	0.8–8	0.23 ± 0.12	0.72 ± 0.13	7.3 ± 1.2	49.2 (67)
GIS3	0.8–8	0.144FIX	0.63 ± 0.05	6.5 ± 0.3	50.4 (68)
GIS2+3	0.8–8	0.22 ± 0.09	0.70 ± 0.09	...	127.5 (127)
GIS2+3	0.8–8	0.144FIX	0.63 ± 0.03	...	129.5 (128)
PSPC+GIS2+3......	0.2–8	0.144FIX 0+2.0[b]	0.63 ± 0.05	...	149.8 (147)
PSPC+GIS2+3......	0.2–2	0.144FIX	0.67 ± 0.17	...	65.0 (55)
GIS2+3	2–8	0.144FIX	0.68 ± 0.05	...	81.9 (88)
		Thermal Bremsstrahlung			
PSPC+GIS2+3......	0.2–8	0.144FIX	$38.9^{+4.1}_{-3.5}$	...	149.6 (148)
GIS2+3	0.8–8	0.144FIX	$39.6^{+4.3}_{-3.6}$	...	125.6 (128)
		Reflection			
PSPC+GIS2+3......	0.8–8	0.144FIX	0.63 ± 0.03 [0.0 +0.3]	...	149.8 (147)
GIS2+3	0.2–8	0.144FIX	0.62 ± 0.03 [0.0 +0.4]	...	129.5 (127)

[a] In keV, in quasar rest frame, for thermal Bremsstrahlung fits.
[b] Column at $z = 3.38$.

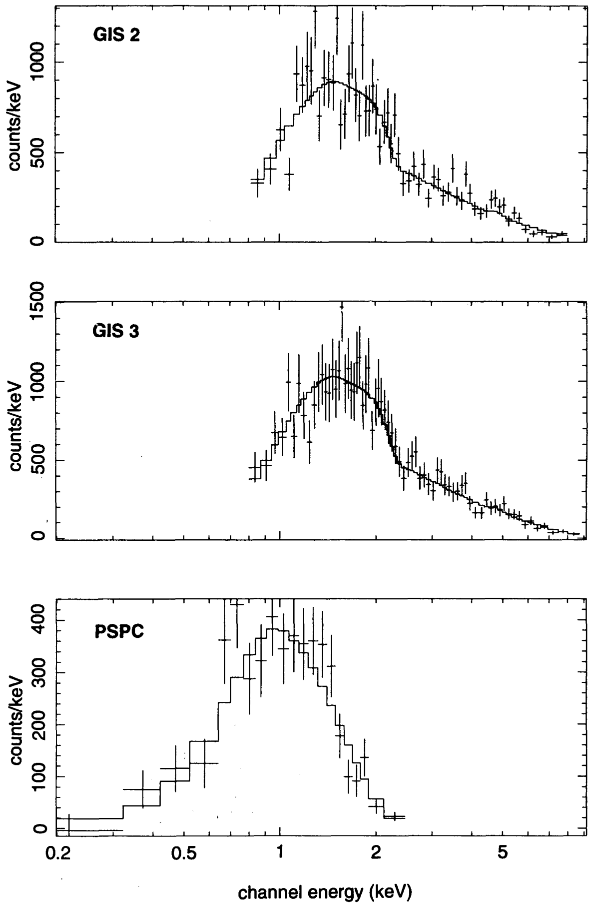

FIG. 1.—*ASCA* GIS + PSPC X-ray spectra of S5 0014+813. The solid line shows the best-fit single power-law model fitted from 0.2 to 8 keV. Energies are in the observed frame.

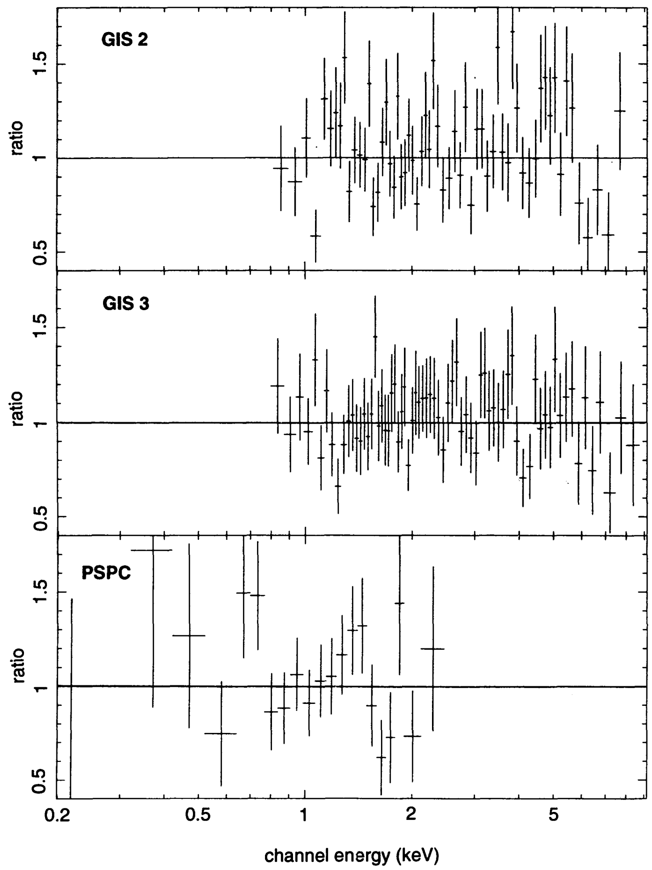

FIG. 2.—Residuals after subtracting the best-fitting 0.2–8 keV power law from the *ASCA* GIS and PSPC spectra of S5 0014+813. Energies are in the observed frame.

interesting parameters) of $\Omega_d/2\pi = 0.4$ to the solid angle subtended by the disk. (Adding the PSPC data tightened this limit slightly to 0.3.) None of the fits is improved by an Fe K fluorescence line at 6.4 or 6.7 keV (emitted, 1.46 keV; 1.53 keV, observed, respectively; $\Delta\chi^2 < 1$). A 90% upper limit to the equivalent width for an intrinsically narrow line at 1.46 keV is 27 eV (observed frame, 120 eV emitted). The 90% limit for a narrow line at 1.53 keV is EW = 31 eV (EW = 140 eV, quasar frame).

The mean GIS normalization for a power-law fit, when corrected for the PSF loss, is a factor 1.4 above that of the *ROSAT* data and suggests variability in the 31.5 months between the two observations (7.2 months in the quasar frame). If this light-travel time radius corresponds to 10 Schwarzschild radii, then $M < 4 \times 10^{11}\ M_\odot$. The *EXOSAT* 1 keV normalization is close to the PSPC value and the *EXOSAT* slope (0.9 ± 0.4) is fully consistent with both the *ASCA* GIS and PSPC values (see Bechtold et al. 1994).

The flux of S5 0014+813 in the 1–8 keV observed band is 3.2×10^{-12} ergs s^{-1} cm^{-2}, which corresponds to a 4–30 keV luminosity of 1.1×10^{48} ergs s^{-1}, about 2.5 times greater than the inferred *ROSAT* rest frame luminosity of 4.4×10^{47} ergs s^{-1}, (the GIS 2–10 keV luminosity is 6.2×10^{47} ergs s^{-1}) for $H_0 = 50$ km s^{-1} Mpc^{-1}, and $\Omega = 0$. The GIS X-ray luminosity requires a central black hole mass $\sim 10^{10}\ M_\odot$ in order not to violate the Eddington limit, which does not conflict with the variability limit. If the bolometric luminosity could be used, then the two limits would become very close.

4. DISCUSSION AND CONCLUSIONS

We have detected a $z = 3.384$ quasar up to 34 keV in the quasar frame with the *ASCA* GIS. With a S/N of $\sim 50\ \sigma$ the GIS measurements of high-redshift quasars currently give us, paradoxically, our best measurements of quasar spectra above 10 keV[5] and approach the quality of spectra for bright Seyfert galaxies from *Ginga*.

A thermal bremsstrahlung fit gives a temperature of 39 ± 4 keV (quasar frame). Similar temperatures were reported to two other high-z quasars by Serlemitsos et al. (1994), unfortunately without quoted uncertainties. The closeness of these three temperatures to the X-ray background temperature (40 ± 5 keV; Marshall et al. 1980) is remarkable. Superficially it suggests that AGNs produce the X-ray background. Radio-loud, $z = 3$

[5] The only other quasar with a high S/N spectrum above 10 keV (emitted) was 3C 273 (Turner et al. 1990). However, an observation of a transient source of equal or greater strength to 3C 273 at 60 keV only 15′ from 3C 273 (GRS 1227+025; Bassani et al. 1991) puts in doubt the reliability of the large-beam *Ginga* measurement.

quasars such as those observed with *ASCA* cannot themselves produce the XRB, being too rare and redshifted down to $kT \sim 10$ keV. However, *OSSE* also gives a temperature of ~ 45 keV (Johnson et al. 1994) for low-z AGNs. That AGNs from opposite ends of the luminosity, redshift, and radio-loudness scales gives the same temperature suggests a remarkably uniform process at work, such as the Klein-Nishina cross section, and may allow the background spectrum to be produced by AGNs.

A power-law fit gives a slope $\alpha_E = 0.63 \pm 0.03$ and needs no additional components down to quite tight limits: a Lightman & White (1988) Compton reflection component is not required and the 90% limit to the solid angle subtended by the disk is $\Omega_d/2\pi = 0.4$; a narrow 6.4 keV (rest frame) iron line is not required by the fit either, and the 90% limit on its rest frame equivalent width is 120 eV. This is strikingly similar to the unusual Seyfert NGC 4151 (Yaqoob et al. 1993) and differentiates S5 0014+813 from typical low-redshift Seyfert galaxies which have strong iron K-lines (EW = 100–300 eV), and a strong Compton hump ($\Omega_d/2\pi \approx 1$; Nandra & Pounds 1994 and references therein). Williams et al. (1992) found these features to be weak in high-luminosity, radio-loud AGNs. S5 0014+813 strengthens this trend. Zdziarski, Życki, & Krolik (1993) use a strong reflection component in AGNs to integrate over redshift to produce the X-ray background. Not seeing a reflection hump in S5 0014+813 detracts from this model.

ASCA has demonstrated an ability to produce good spectra of quite faint quasars. This should be exploited for more high-redshift quasars, particularly radio-quiet quasars and quasars at redshifts more likely to dominate the X-ray background. We also note that even in the lower (rest frame) energy range of 2–10 keV there are only about 20 good S/N quasar spectra, all from *Ginga* (Williams et al. 1992). Here *ASCA* is ideally placed to obtain high-quality spectra. Even short *ASCA* observations of bright low-redshift quasars will dramatically improve our basic knowledge of quasars.

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