AN ASCA GIS SPECTRUM OF S5 0014+813 AT Z=3.384

Martin Elvis[1], M. Matsuoka[2], A. Siemiginowska[1], F. Fiore[1,3], T. Mihara[2] and W. Brinkmann[4]

[1] Harvard-Smithsonian Center for Astrophysics
60 Garden Street Cambridge MA 02138
e-mail: elvis@cfa.harvard.edu
[2] RIKEN, the Institute of Physical and Chemical Research
Wako, Saitama, Japan
[3] Osservatorio Astronomico di Roma
via dell'Osservatorio 5, Monteporzio-Catone (RM), I00040 Italy
[4] Max Planck Institut für Extraterrestrische Physik
D-85740 Garching b. München, Germany

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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 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 fit with a simple thermal bremsstrahlung model of kT=40±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 % to 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: galaxies: active, quasars: general, quasars: individual: S5 0014+813, diffuse radiation.

1. Introduction

X-ray observations of AGN 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 AGN 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 cut-off discovered with the PSPC and due possibly to absorption, leads to poorly determined slopes (Elvis et al 1994a).

ASCA (Tanaka et al 1994) now provides the sensitivity to explore higher energies for the brightest quasars at z~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.

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~3. Indeed it is the only z~ 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 29 October 1993 for a total good exposure time of 31.5 ksec in both GIS2 and GIS3. We applied the standard conservative data filters: a minimum elevation angle of 15 degrees above the Earth's limb, and a minimum cut-off rigidity of 8 GeV/c. We also excluded data acquired in the first 60 seconds 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 arcmin from the optical position, an offset typical of ASCA data at present. 2904 and 3244 counts were recorded within a 6 arcmin 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 arcmin and 17 arcmin.

(2) Background events were extracted from the same region as the source events in blank sky background event files, provided by the ASCA GOF (the files being a superposition of 15 blank sky fields observed during the ASCA PV phase (May 93 - Mar 94) with a total exposure time of 350 ksec), for the same values of cut-off rigidity ($>$ 8GeV/c) 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 shape of the spectra obtained with the two methods agree to within $\sim 3\%$. The total background is $\sim 40\%$ 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 $\sim 10\%$ of the flux of a point source with a spectrum similar to that of S5 0014+813 outside the 6 arcmin 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 sigma 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 arcmin 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), five arcminutes from the quasar, is probably identified with a V=8.8 K0 star (HD1165, SAO 44, PSPC offset = 9 arcsec). The fainter source (10% of S5 0014+813), only 1.5 arcmin 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. HD1165 is detected in the ASCA SIS0 image of the field (Elvis et al 1994b, in preparation). 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" and "g3v3_1_4c" (1994 April 20) provided by the ASCA GOF. 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 GIS 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 to 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 (1σ). 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 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 Ω=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 10keV [1] 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±5keV, Marshall et al 1980) is remarkable. Superficially it suggests that AGN produce the X-ray background. Radio-loud, z=3 quasars such as those observed with ASCA, cannot themselves produce the XRB, being too rare and redshifted down to kT∼10 keV. However OSSE also give a temperature of ∼45 keV (Johnson et al 1994) for low z AGN. That AGN from opposite ends of the luminosity, redshift and radio-loudness scales give 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 AGN.

A power law fit gives a slope α_E=0.63±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 galaxy NGC4151 (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 AGN. S5 0014+813 strengthens this trend. Zdziarski, Życki, & Krolik (1993) use a strong reflection component in AGN 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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[1] The only other quasar with a high S/N spectrum above 10 keV (emitted) was 3C273 (Turner et al 1990). However, an observation of a transient source of equal or greater strength to 3C273 at 60 keV only 15 arcmin from 3C273 (GRS1227+025, Bassani et al 1991) puts in doubt the reliability of the large beam Ginga measurement.

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Figure Captions

Figure 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.

Figure 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.

Table 1: **ASCA Observations of S5 0014+813**

Instrument	Counts	exposure (s)	background (cts)	net ct/s
GIS2	2904	31635	800	0.066
GIS3	3244	31500	860	0.075

Table 2: **GIS ASCA Power-law spectral fits for S5 0014+813**

Instruments	energy range[a]	N_H^b	α_E, or kT^c	norm.[d]	χ^2(dof)
			$[\Omega_d/2\pi]$		
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	0.63±0.05	–	149.8 (147)
		0+2.0[e]			
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	–	149.8 (147)
			[0.0 + 0.3]		
GIS2+3	0.2-8	0.144FIX	0.62±0.03	–	129.5 (127)
			[0.0 + 0.4]		

[a] in keV; [b] in units of 10^{22} atoms cm^{-2}; [c] in keV, in quasar rest frame, for thermal Bremsstrahlung fits; [d] in units of 10^{-4} keV s^{-1} cm^{-2} keV^{-1}; [e] column at z=3.38.