A PECULIAR EMISSION-LINE FEATURE IN THE X-RAY SPECTRUM OF THE QUASAR PKS 0637−752

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We report the results from an ASCA observation of the high-luminosity, radio-loud quasar PKS 0637−752 (redshift 0.654), covering the 0.8–15 keV band in the quasar-frame. We find the source to have a luminosity $\sim 10^{46}$ erg s$^{-1}$ in the 2–10 keV band, a factor of $\sim 3$ lower than during a previous Ginga observation. The continuum appears to be well modeled by a simple power-law with $\Gamma = 1.64 \pm 0.07$, with no evidence for absorption by material intrinsic to the quasar, or Fe-K emission (with an equivalent width $\lesssim 80$ eV at 90% confidence). However we do find evidence for a narrow emission line at an energy $1.60 \pm 0.07$ keV and equivalent width $59^{+38}_{-34}$ eV (both in the quasar frame). Line emission at these energies has not been observed in any other active galaxy or quasar to date. We reject the possibility that this line is the result of instrumental artifacts, and briefly explore possible identifications.

*Subject headings:* galaxies: active – quasars: emission lines – quasars: individual: PKS 0637−752 – X-rays: galaxies
1. INTRODUCTION

The picture emerging from many X-ray studies over the last couple of decades of active galactic nuclei (AGNs) is that emission features in the X-ray spectra present in low-luminosity objects (Seyfert 1 galaxies) become scarce in AGNs with 2–10 keV intrinsic luminosity exceeding $\sim 10^{45}$ erg s$^{-1}$ (synonymously, quasars). These trends are discussed at length in Nandra et al. (1997a, 1998) and Reeves et al. (1997; and references therein). The transition to a featureless X-ray power-law continuum (except for possible line-of-sight absorption at low energies) in the high luminosity AGNs, especially radio loud sources, is not fully understood but may be related to the complete ionization of matter responsible for emission-line features and/or beaming of the X-ray continuum swamping out emission-line features.

The radio-loud quasar PKS 0637−752 ($z = 0.654$, Hunstead, Murdoch & Shobbrook 1978) has been observed by the *Einstein* IPC (Wilkes & Elvis 1987; Zamorani et al. 1981, 1984; Elvis and Fabbiano 1984), *EXOSAT* (Lawson et al. 1992; Comastri et al. 1992; Saxton et al. 1993), and *Ginga* (Williams et al. 1992; Lawson and Turner 1997). These X-ray observations had poor energy resolution and yielded only continuum parameters for a simple power-law plus neutral absorber model. The most tightly constrained measurements of the slope were from *Ginga* with a photon index of $\Gamma \sim 1.6 - 1.9$. The column density, $N_H$, has not been well-constrained, although Lawson and Turner (1997) claim a change from $12 \times 10^{21}$ cm$^{-2}$ to $74 \times 10^{21}$ cm$^{-2}$ (intrinsic) between two *Ginga* observations. The *Einstein* observations were under-exposed and so fluxes were uncertain due to the poor spectral constraints. Nevertheless, the non-detection of PKS 0637−752 in one MPC observation and a clear detection in another MPC observation is a clear indicator of a variable continuum (Elvis and Fabbiano 1984). *Ginga* still provided the most reliable 2–10 keV flux, $\sim 9 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ corresponding to a luminosity of $\sim 2.6 \times 10^{46}$ erg s$^{-1}$. 
\( H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1} \) and \( q_0 = 0 \) throughout). In one *Ginga* observation the detection of an Fe-K emission line at \( \sim 6.4 \text{ keV} \) in the quasar frame has been reported with equivalent width \( \sim 100 \text{ eV} \) but the result was marginal (see Williams *et al.* 1992; Lawson and Turner 1997).

In this *Letter* we report on the results of a new X-ray observation of PKS 0637−752 with *ASCA* (*Advanced Satellite for Cosmology and Astrophysics*; see Tanaka, Inoue & Holt, 1994). With some surprise we have discovered an emission-line in the object centered at \( 1.60 \pm 0.07 \text{ keV} \) in the quasar frame. What is even more surprising is that an emission-line at this energy has not been observed in any AGN at all, irrespective of luminosity.

2. **THE ASCA DATA**

*ASCA* observed PKS 0637−752 in 1996 November 10–11 for a duration of \( \sim 120 \text{ ks} \). Since it is important to demonstrate that our main observational result in this paper, namely the discovery of an unidentified emission line, is not an instrumental artefact, we describe the data analysis in some detail. The reader is referred to Tanaka *et al.* (1994) for details of the instrumentation aboard *ASCA*. The two Solid State Imaging Spectrometers (SIS), hereafter SIS0 and SIS1, with a bandpass of \( \sim 0.5 – 10 \text{ keV} \), were operated in 1-CCD FAINT and BRIGHT modes. The two Gas Imaging Scintillators (GIS), hereafter GIS2 and GIS3, with a bandpass of \( \sim 0.7 – 10 \text{ keV} \), were operated in standard PH mode. The SIS FAINT and BRIGHT mode data were combined and the SIS energy scale was fixed using a prescription based on measurements of Cas A (Dotani *et al.* 1997). This corrects for the continuing decline in the CTI of the CCDs with time and is based on interpolation or extrapolation of the Cas A measurements. The last available Cas A measurements were made just three months before the PKS 0637−752 observation and since the CTI changes very slowly with time, the extrapolation results in a systematic uncertainty in the
gain which is much less than 1% at 1 keV (Dotani et al. 1997). Version 1.1 of the SIS response matrix generator was used in the analysis. However, no corrections were made for any possible offsets, fluctuations and distortion of the CCD dark level distribution (the latter also known as the ‘RDD’ effect). Such corrections (which themselves are subject to uncertainty) can only be applied to FAINT mode data and for 1-CCD mode their effects will only be noticeable for very high statistical quality data. Considering the signal-to-noise of our data these effects can safely be neglected, since there are not enough photons to utilize the full energy resolution of the SIS and the overall uncertainty in the energy scale is less than $\sim 50$ eV (Dotani et al. 1997). More importantly, as a calibration control, we will examine data for two other AGN observed by ASCA shortly before and shortly after PKS 0637−752 (§4).

For the purpose of assessing the spectral results below, we note that spectral fits to GIS data from the Crab have systematics < 3% over the range 0.7–10 keV with the current calibrations (Fukuzawa, Ishida, and Ebisawa 1997). Below $\sim 0.7$ keV the GIS efficiency is greatly reduced and the calibration uncertain. In the analysis below we include the GIS data down to 0.5 keV for the sake of continuity but this does not affect our results because the data are dominated by statistical errors at low energies. From $\sim 0.7$ keV to $\sim 6$ keV the SIS calibration is generally consistent with the GIS, and BeppoSAX LECS and MECS to $\sim 10\%$ or better (see Grandi et al. 1997; Orr et al. 1998). Below $\sim 0.7$ keV the uncertainty is larger, especially between $\sim 0.5 – 0.6$ keV. However, our result is not sensitive to the absolute calibration at these energies and, in any case, we will compare the SIS data for PKS 0637−752 with data from other sources, taken shortly before and after the PKS 0637−752 observation.

Data were screened so that accepted events satisfied the following criteria: (i) data were taken outside the SAA; (ii) the time since or before passage through the SAA or
a satellite day/night transition is $> 50$ s; (iii) the elevation angle to Earth is $> 5^\circ$; (iv) the magnetic cut-off rigidity (COR) is $> 7$ GeV/c; the deviation of the satellite from the nominal pointing position was $< 0.01^\circ$; (v) the SIS parameters measuring active CCD pixels registered $< 100$ active pixels per second, and (vi) the radiation-belt monitor registered $< 500$ ct/s. Hot and flickering pixels in the SIS were removed. Screening resulted in net ‘good’ exposure times in the range $\sim 45.5$–49.1 Ks for the four instruments.

Images were accumulated from the screened data. The ASCA images, as well as a PSPC image obtained from archival data (a 1.3 ks observation made in 1992 May 26), were analysed for possible nearby contaminating sources. No such sources were detected.

Source events were extracted from circular regions with radii of 4’ for the SIS and 6’ for the GIS. Background events were extracted from off-source regions. As a check, background spectra were also made from a 1-CCD blank-sky observation which resulted from the non-detection of the quasar IRAS 15307+3252 (observed 1994 July). These background data were subject to identical selection criteria and used to check the invariance of the spectral results for PKS 0637$-$752 described below.

The ASCA lightcurves do not show significant variability, the highest excess variance (e.g. see Nandra et al. 1997b) we obtain is from SIS0 and has the value $(6.9 \pm 5.8) \times 10^{-3}$ for 128 s bins. This is to be compared with $0.111 \pm 0.005$ we obtain for the highly variable Seyfert 1 MCG $-6-30-15$ from a 4 day ASCA observation. The count rates in the accumulated background-subtracted spectra ranged from $\sim 0.22$–0.41 ct/s. Spectra were binned to have a minimum of 20 counts per bin in order to utilize $\chi^2$ as the fit statistic.
3. SPECTRAL FITTING RESULTS

We fitted spectra from the four ASCA instruments simultaneously in the range 0.5–9.5 keV with a simple power-law plus cold, neutral absorber model. A total of two interesting parameters were involved (the photon index, $\Gamma$, and column density, $N_H$), plus four independent instrument normalizations. (The deviation of any of the four normalizations from their mean was less than 7%). The results are shown in Table 1. The best-fitting photon index, $\Gamma = 1.64 \pm 0.07$, is consistent with typical historical values ($\S 1$). The column density, $N_H$, is consistent with the Galactic value of $9.1 \times 10^{20}$ cm$^{-2}$ obtained from Dickey and Lockman (1990). The instrument-averaged observed 0.5-2 keV and 2–10 keV fluxes are $1.3$ and $3.3 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ respectively. The 0.5–10 keV luminosity in the source frame is $1.1 \times 10^{46}$ erg s$^{-1}$. Thus the source has dimmed by almost a factor of 3 relative to the Ginga observations made in 1998 July 4 and 1990 August 23 (Lawson and Turner 1997). However, the flux is consistent (within systematic uncertainty) with an EXOSAT observation made in 1984 September 8 (Comastri et al. 1992).

Although the above simple continuum model provides an adequate fit, inspection of the ratios of data to model (Figure 1) reveal a statistically significant ‘hump’ at $\sim 1$ keV (observed frame) in both SIS0 and SIS1. The GIS data are ambiguous since the effective area is falling rapidly and the energy resolution is worse than the SIS.

We repeated the four-instrument fits with the addition of a simple Gaussian to model the apparent emission-line feature. Three extra parameters were involved, namely the line center energy, $E_c$; the Gaussian intrinsic width, $\sigma$, and the line intensity, $I$. Note that we will refer to all three parameters, plus the equivalent width (EW), in the quasar frame. Initially we allowed all three parameters to float and the results are shown in Table 1. The effect on the continuum parameters is negligible ($< 1\%$ in both $\Gamma$ and $N_H$). It can be seen that the line is not resolved. The results from repeating the fit with $\sigma$ fixed at 0.01 keV
(narrow line) are also given; the difference in $\chi^2$ is completely negligible (0.1) so we use this fit to derive bounds on $E_c$ and EW. Note that the decrease in $\chi^2$ compared to the model without an emission line is $> 14$ for the addition of two free parameters so the line feature is detected at a confidence level much greater than 99%. It is appropriate here to use a $\Delta \chi^2 = 4.61$ criterion to derive 90% confidence errors on the best-fitting line parameters since we want to know the bounds on $E_c$ and EW, independently of $\Gamma$ and $N_H$ (e.g. see Yaqoob 1998). We obtain $E_c = 1.60 \pm 0.07$ keV and EW = $59^{+38}_{-34}$ eV.

We also searched for Fe-K line emission by adding a Gaussian with center energy fixed at various values in the range 6.4–6.97 keV (with the low-energy line removed). Neither a narrow ($\sigma = 0$) or broad ($\sigma = 0.5$) Gaussian component was statistically required, the 90% one-parameter upper limits on the EW being 41 and 82 eV respectively.

All the above spectral results were repeated with the alternative background spectra made from a blank field, as described in §2, and the results were confirmed to be robust to the background used.

4. THE REALITY OF THE EMISSION-LINE FEATURE

Since an emission-line feature like that reported above has never before been observed in a quasar (or indeed any active galaxy), we sought explanations which did not require the line to be intrinsic to the quasar.

To check whether the SIS calibration is responsible we examined SIS data for 3C 371 (a quasar with $z = 0.051$, observed five days before PKS 0637–752 ) and for Pictor A (a radio galaxy with $z = 0.034$, observed fifteen days after PKS0637 − 752 see also Eracleous and Halpern, 1998). Figure 2 shows the ratios of data to a simple power-law plus absorber model (both SIS0 and SIS1) for all three sources fitted over the 0.5–9.5 keV range, but
zoomed in the range 0.5–1.5 keV (observed frame). It can be seen that the emission-line feature in PKS 0637–752 is not present in 3C 371 or Pictor A.

We have already stated in §2 that there are no contaminating sources in the ASCA or PSPC images. The emission line cannot be a background feature (for example from Galactic diffuse emission) because the background from nearby regions in the same field and at the observed energy of the emission line in the SIS lies at least a factor 12 below the on-source spectrum. It is unlikely that the emission line is produced in the intervening galaxy at $z = 0.469$ (Elvis and Fabbiano 1984) since the galaxy would have to be extremely luminous (almost as luminous as the quasar is thought to be). We also examined the PSPC spectra. These data show residuals to a power-law model which suggest the presence of a line like that observed by ASCA. However, the PSPC data do not allow the presence of the line to be statistically confirmed, as the energy resolution is extremely poor and signal-to-noise is very low because the exposure time is only 1.3 ks.

We conclude that the emission line at an energy of 1.60 keV in the rest-frame of PKS 0637–752 is not an instrumental artifact and is almost certainly associated with the quasar itself.

5. DISCUSSION AND CONCLUSIONS

We have reported the results of a new X-ray observation of PKS 0637–752 with ASCA. Although the luminosity had diminished by a factor of $\sim 3$ compared to previous Ginga observations (six and eight years earlier), the ASCA data are the most sensitive to date in the 0.5–10 keV band ($\sim 0.8–15$ keV in the quasar frame). However, the ASCA luminosity is consistent with an EXOSAT observation made twelve years earlier. It is possible that the larger field of view of Ginga was confused with another source which may have contributed
to the higher luminosity so the apparent variability should be treated with caution. We find the continuum to be well modeled by a simple power-law with $\Gamma = 1.64 \pm 0.07$ and Galactic absorption. We find no evidence for Fe-K emission although the data allow a line with moderate equivalent width (90% confidence quasar-frame upper limits in the range $41–82$ eV, corresponding to line intrinsic widths in the range $0–0.5$ keV respectively).

Our most important result from the *ASCA* observation is the discovery of a narrow emission line at an energy $1.60 \pm 0.07$ keV. We have presented strong evidence that this is not an instrumental artefact and is likely to be associated with PKS 0637–752 itself. With conservative assumptions for systematic errors, we find the line center to lie in the range $1.48–1.72$ keV and to have an EW of $59^{+38}_{-34}$ eV in the quasar frame. Line emission in this energy band has not been observed in any other AGN to date, and its identification is not at all obvious. The allowed range of energies encompasses transitions from MgXI–XII, FeXXII–XXVI and NiIXIX–XXVIII (assuming no bulk motion). Highly ionized gas is commonly seen in absorption in low luminosity Seyfert 1 galaxies (e.g. Reynolds 1997; George *et al.* 1998) and in emission in some Seyfert 1 (below) and many Seyfert 2 galaxies (e.g. Turner *et al.* 1997). However theoretical models of both optically-thick and optically-thin gas predict the stronger lines elsewhere in the spectrum, particularly due to a blend of O, Ne and Fe lines $\lesssim 1.5$ keV (e.g. see Zycki *et al.* 1994; Kallman *et al.* 1996; Netzer 1996, and references therein). Indeed the presence of emission lines at such energies was suggested in *Einstein* SSS observations (e.g. Turner *et al.* 1991) and have been detected in the *ASCA* spectra of NGC 4151 (Figure 1 in Yaqoob *et al.* 1995), PG 1244+026 (blend at $\sim 1$ keV, Fiore *et al.* 1998), and Ton S 180 (blend at $\lesssim 1$ keV, Turner, George, Nandra 1998). The detection of OVI(0.57 keV) emission has been claimed in the case the *ASCA* data from NGC 3783 (George, Turner, Netzer 1995), Mkn 290 (Turner *et al.* 1996), and IC 4329A (Cappi *et al.* 1996), although uncertainties in the calibration $< 0.6$ keV make their reality less compelling. However, none of these lines are consistent with the observational result
for PKS 0637−752 without an assumption of bulk in/outflow. The emission feature closest in energy to that reported in PKS 0637−752 and which has also been observed in ASCA data from both Seyfert 2 galaxies (Turner et al. 1997) and starburst galaxies (e.g. Ptak et al. 1997) is the SiXIII(1.84–1.86 keV) blend. However, the identification of the line observed in PKS 0637−752 with such emission not only requires an anomalous Si abundance relative to O, Ne, S and Fe, but redshifting of the new emission-line energy by ∆z ∼ 0.05−0.30 (i.e. the line-emitting matter must be infalling at velocities ≥ 0.05c) with respect to the optical emission line gas which has z = 0.654 (Hunstead et al. 1978). Future observations of this intriguing X-ray emission-line feature at high spectral resolution with AXAF, XMM and Astro-E, will clearly help to shed light on its identity and origin.

The authors thank the ASCA mission operations team at ISAS, Japan, and all the instrument teams for their dedication and hard work in making these ASCA observations possible. This research made use of the HEASARC archives at the Laboratory for High Energy Astrophysics, NASA/GSFC.
Table 1. Spectral Fits to PKS 0637–752

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<th>Parameter</th>
<th>No line</th>
<th>broad line</th>
<th>narrow line</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma$</td>
<td>$1.64^{+0.07}_{-0.07}$</td>
<td>$1.63^{+0.08}_{-0.07}$</td>
<td>$1.63^{+0.08}_{-0.07}$</td>
</tr>
<tr>
<td>$N_H$ ($10^{20}$ cm$^{-2}$)</td>
<td>$8.9^{+3.2}_{-3.1}$</td>
<td>$10.2^{+3.8}_{-3.2}$</td>
<td>$10.1^{+3.6}_{-3.1}$</td>
</tr>
<tr>
<td>$\sigma$ (keV)</td>
<td>$0.07^{+0.24}_{-0.07}$</td>
<td>$0.01$ (FIXED)</td>
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</tr>
<tr>
<td>$E_c$ (keV)</td>
<td>$1.60^{+0.12}_{-0.14}$</td>
<td>$1.60^{+0.07}_{-0.07}$</td>
<td></td>
</tr>
<tr>
<td>$I$</td>
<td>$4.9^{+7.0}_{-3.5}$</td>
<td>$4.3^{+2.9}_{-2.5}$</td>
<td></td>
</tr>
<tr>
<td>EW (eV)</td>
<td>$66^{+94}_{-47}$</td>
<td>$58^{+39}_{-34}$</td>
<td></td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>568.5</td>
<td>553.8</td>
<td>553.9</td>
</tr>
<tr>
<td>degrees of freedom</td>
<td>530</td>
<td>527</td>
<td>528</td>
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Note. — The continuum model used is a simple power law plus absorber with the photon index, $\Gamma$, and column density, $N_H$, floating. The absorber is placed at $z = 0$. The emission line parameters are all referred to in the quasar frame ($z = 0.654$); these are the intrinsic width, $\sigma$, the center energy, $E_c$, the intensity ($10^{-5}$ photons cm$^{-2}$ s$^{-1}$), and the equivalent width (EW). Errors are 90% confidence for two interesting parameters ($\Delta \chi^2 = 4.61$) for the continuum and for the line when it is narrow. Otherwise the errors are 90% confidence for three interesting parameters ($\Delta \chi^2 = 6.251$) for the line parameters when the intrinsic line width is floating.
REFERENCES


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This manuscript was prepared with the AAS TeX macros v4.0.
Figure Captions

Figure 1
Ratio of the ASCA data for PKS 0637−752 (z = 0.654) to the best-fitting power-law plus absorber model. Notice the significant residuals in the SIS0 and SIS1 data, corresponding to ∼ 1.6 keV in the quasar frame (see text).

Figure 2
Ratio of SIS data to best-fitting power-law plus absorber models for 3C 371 (z = 0.051), PKS 0637−752 (z = 0.654) and Pictor A (z = 0.034). The 3C 371 were taken only five days before the observation of PKS 0637−752 while the Pictor A data were taken fifteen days after PKS 0637−752. Thus calibration uncertainties in the SIS cannot account for the emission-line feature seen in PKS 0637−752. Note that the best-fitting parameters for 3C 371 are $\Gamma = 1.76^{+0.06}_{-0.07}$ and $N_H = 5.1^{+2.5}_{-2.3} \times 10^{20}$ cm$^{-2}$ and for Pictor A they are $\Gamma = 1.84^{+0.02}_{-0.03}$ and $N_H = 11.1 \pm 1.0 \times 10^{20}$ cm$^{-2}$ (errors correspond to $\Delta \chi^2 = 4.61$).