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ABSTRACT

We use a sample of 25 QSOs to investigate the average spectrum between the soft X-ray energy band of the *Einstein Observatory* Image Proportional Counter, and the higher energy band of the *HEAO-1* A2 experiment. Assuming a power-law spectrum, we find a 90% confidence range for α ($f_\nu \sim \nu^{-\alpha}$) of 0.83(+0.32,-0.22) for N_H<3 10^{20} atoms cm^{-2}. Higher column densities for QSOs are not anticipated, but if N_H were ~10^{22} atoms cm^{-2}, then α>0.97. Our spectrum is similar to those exhibited by Seyfert galaxies and narrow emission line galaxies above 2 keV. The spectrum is soft enough that, if these objects are typical of the higher redshift more radio-quiet QSOs, then QSOs can be excluded as being the dominant origin of the diffuse X-ray background.

Subject headings: quasars -- X-rays: sources

I INTRODUCTION

X-ray spectroscopy of QSOs and active galactic nuclei (AGN, a class which by our definition comprises BL Lac-type objects, Seyfert galaxies, narrow emission line galaxies, and excludes QSOs) is in its infancy. Work on AGNs is the furthest developed. The 2-30 keV spectra of 5 BL Lac-type objects show variability and tend to require multicomponent fits (see summary of Worrall *et al.* 1981). In contrast, other AGNs fit one-component spectra with spectral indices of small dispersion about $\alpha \simeq 0.7$, $f_\nu \sim \nu^{-\alpha}$ (Mushotzky *et al.* 1980; Mushotzky 1982), and, in the cases where they are measured to ~100 keV, the spectra extrapolate (Rothschild *et al.* 1983). There is at least one example of a Seyfert 1 galaxy, E1615+061, which shows a soft spectral excess characteristic of the BL Lacs (Pravdo *et al.* 1981), but little is known about how widespread this property might be or whether or not it might be more common in the Seyfert galaxies with the highest radio brightness.

The shortage of QSO spectral data results from the limited sensitivity of X-ray instruments of energy resolution better than 25%. The two QSOs with good 2-30 keV spectra are the bright source 3C 273 (Worrall *et al.* 1979) and the X-ray selected radio-quiet quasar 0241+622 (Worrall *et al.* 1980). The latter lies in the galactic plane and thus, despite its X-ray strength, is optically relatively faint due to dust reddening (Margon and Kwitter 1978). The spectrum of 3C 273 is roughly consistent with $\alpha \simeq 0.4$, but it cannot be fitted with a single power law. In contrast, 0241+622 has an index $\alpha \simeq 0.9$.

The Monitor Proportional Counter on the *Einstein Observatory* (MPC) had a lesser capability for accurate background rejection than the *HEAO-1* A2 and *OSO-8* detectors employed in the 3C 273 and 0241+622 measurements. However, long observation times have enabled Halpern and Grindlay (1982) to derive spectral distributions for 14 QSOs and roughly twice as many Seyfert galaxies in the 2-10 keV energy range. They find no difference between the groups which each average $\alpha \simeq 0.7$.

In this paper we report the results of the first investigation of the spectral index of QSOs between the >2 keV region, to which current X-ray spectral information is confined, and the .3-3 keV band of the *Einstein Observatory* Imaging Proportional Counter (IPC). (The median energy of photons detected by the IPC is generally a little below 1 keV, depending on their spectrum and the detector gain). The importance of this analysis becomes clear in the context of the wealth of information which the IPC yields about the X-ray properties of optically, radio and X-ray selected samples of QSOs (Zamorani *et al.* 1981; Ku, Helfand and Lacy 1980; Margon, Chanon and Downes 1982; Reichert *et al.* 1982; Kriss and Canizares 1982; Maccacaro *et al.* 1983; Tananbaum *et al.* 1983). The IPC itself is very limited in its ability to measure spectra. Zamorani *et al.* (1981) use a ratio of counts in high-energy to low-energy PHA channels to show that their QSO sample as a whole is most consistent with $\alpha \simeq 0.4$, although uncertainties are not quoted. No attempt has yet been made to see if some QSOs are consistent with the type of soft X-ray excesses measured for BL Lac objects. Cavaliere *et al.* (1980) show that just such an excess can describe a decrease in the ratio of X-ray to optical luminosity (L_x/L_o) with increasing redshift z, which is a possible fit to the QSO sample of Zamorani *et al.* (1981). (We note however that, contrary to the hypothesis of Cavaliere *et al.*, a correlation of L_x/L_o with optical luminosity rather than z is preferred for radio-quiet QSOs by Reichert *et al.* (1982), for radio-loud QSOs by Tananbaum *et al.* (1983), and for an optically-selected sample of QSOs by Avni and Tananbaum (1982)). Furthermore, a soft spectral excess would cause an overestimate of the QSO contribution to the diffuse background (Cavaliere *et al.* 1980). The selection of QSOs for our test is described in section II. It suffices to mention here that the QSOs are on average more radio bright than a true optically selected sample (e.g. Sramek and Weedman 1978). This is interesting since these are the objects most similar in their radio properties to BL Lac objects and thus perhaps the more likely to show a soft excess.

II MEASUREMENTS

a). Sample selection.

The limitation to our method of investigation is the relatively poor sensitivity of experiments in the energy range above that of the IPC. But, using data from the *HEAO-1* A2 experiment, we can measure an average flux for a sample of QSOs, even though the members are at fluxes below the limiting sensitivity of our detectors. This method has been used by Worrall, Marshall and Boldt

(1979) to study normal galaxies, although there the sample provided upper limits only. Since we needed to bias our sample selection to X-ray brighter QSOs, we considered the correlation between X-ray and optical flux established by Ku, Helfand and Lucy (1980). In the absence of a complete catalogue of optically selected QSOs, we chose to select those objects which are of visual magnitude brighter than 16 in the compilation of Burbidge, Crowne and Smith (1977). Only data from the *HEAO-1* A2 detectors with $1^{\circ}.5\times3^{\circ}$ field of view were used in this analysis (see Rothschild *et al.* (1979) for an experiment description). We excluded QSOs which were not well resolved spatially by the *HEAO-1* A2 detectors from known bright X-ray sources in the 2-10 keV band. The list of bright sources was compiled from pre-*HEAO* results and was augmented with new sources discovered with *HEAO-1* A2 (Marshall *et al.* 1979). Such sources must have been brighter than $\sim 2\ 10^{-11}$ ergs cm^{-2} s^{-1} (2-10 keV) to have been detected. Of the 31 QSOs which satisfied our requirements, 25 were observed with the IPC. These constitute our sample and are listed in Table 1.

b). *HEAO-1* A2 Flux Average.

The *HEAO-1* A2 experiment completed two six-month scans of the sky during the satellite mission, beginning in August 1977. For each coverage we found counting rates for the 25 QSOs in the manner described by Worrall, Marshall and Boldt (1979). Negative QSO rates were allowed. The detector field of view and layer combination we have chosen for this analysis, defined by Marshall *et al.* (1979), has a quantum efficiency that exceeds 50% of its peak value between ~3 and ~17 keV and gives rates in units of R15 counts s^{-1}. The two sky scans are consistent with the QSO fluxes remaining constant.

As a check, we repeated the procedure for a subset of a grid of approximately uniformly spaced directions at high (>25°) galactic latitude (since only 3 of the QSOs are at lower latitudes). A total of 437 directions satisfied our criteria. The calculated fluxes had an approximately Gaussian distribution with a standard deviation of 0.3 R15 counts s^{-1} and a mean of 0.022 ± 0.015 R15 counts s^{-1}. (The small offset from zero is due to differences in the automatic source-finding algorithm between sources within one collimator size of the target direction and those away from the target. These differences are needed in order to avoid having the program simultaneously fit a source at the target position as well as a source it found very nearby. If this were not done, the target source intensities would be very uncertain). The width of the distribution indicates that for directions with nominal exposure we can measure fluxes with a combined 1σ error due to counting statistics and an excess variance (presumably due to source count fluctuations) of about 0.3 R15 counts s^{-1}. Since the average error due to counting statistics alone for this sample is 0.22 R15 counts s^{-1}, we deduce the error due to the excess variance to be about 0.21 R15 counts s^{-1}. Our best estimate of each R15 QSO flux is therefore calculated by taking the weighted mean of the two observations using errors due only to counting statistics, and then subtracting

0.022. (The counting statistics are poorer for scan 2 than scan 1 since an increasing proportion of time was spent pointing at sources, rather than scanning, as the mission progressed). The statistical uncertainty in the mean R15 flux is then added in quadrature to the excess variance of 0.21 to give a final error estimate. This method assumes temporal variations in the excess variance to be negligible. If there were temporal variations, our uncertainty in R15 for a given source would be reduced. The flux and error for each QSO are presented in column 3 of Table 1. Column 2 of the table gives the dates of the middle of the two ~4 day scanning periods for each QSO. The mean of the 25 fluxes is 0.19±0.05 counts s^{-1}.

Four of our QSO sample show $>2.5\sigma$ detections (see column 8 of Table 1). Of these, 2251-179 is an already catalogued 2-10 keV X-ray source (Ricker *et al.* 1978), but, due to its low flux and unknown spectrum, we have chosen to keep it in our sample. Without these four, the QSO sample average is 0.08±0.05.

The R15 cts s^{-1} can be converted to flux values assuming certain spectral parameters. For our derivation of the power-law normalizations, the statistical errors in our R15 values outweigh uncertainties in N_H, for $N_H<3\ 10^{21}$ atoms cm^{-2}. Column 4 of Table 1 gives normalization values, numerically equal to the extrapolated 1 keV flux values, and 1σ errors, for $\alpha=0.8$ and $N_H=3\ 10^{20}$ atoms cm^{-2}.

c). IPC Flux Values.

Although IPC flux values for some of the 25 QSOs are already published (see column 8 of Table 1), we have reanalysed each object using a consistent procedure. More than one IPC measurement was made for about one third of our sample. We chose the available observation of longest duration. Column 6 of Table 1 gives power-law normalization values, numerically equal to the 1 keV fluxes, assuming $\alpha=0.8$ and $N_H<3\ 10^{20}$ atoms cm^{-2}. The 1σ error includes this range of uncertainty in N_H, but the error is dominated by the uncertainty in the precise detector gain for the observation. Three of the QSOs were not detected.

III RESULTS

We compare the IPC 1 keV fluxes and the extrapolated estimates from *HEAO-1* A2 under the assumption that a power law of fixed spectral index between ~1 keV and ~7 keV is an appropriate model for each source. The contribution to χ^2 from each source is $(K_1(\alpha)-K_2(\alpha))^2/\sigma(\alpha)^2$, where K_1 and K_2 are defined as the numerical values of the 1 keV fluxes from *HEAO-1* A2 and the IPC respectively, and σ is the corresponding standard deviation due to combined uncertainties in the two measurements. We find that the summed χ^2 is a minimum when $\alpha\simeq0.83$. Its value of 23.5 for 24 degrees of freedom implies that our model is a satisfactory description of the data. The 90% confidence range of α, i.e. that for which the χ^2 is $<(\chi_{min}{}^2+2.7)$, gives $\alpha=0.83(+0.32,-0.22)$.

Two sources alone give a relatively large contribution to the total χ^2, and these may be candidates for variable X-ray emission.

The source 1100+772 contributes 6.3, with the *HEAO-1* A2 flux being too low to agree with the IPC measurement. In contrast, 2201+315, while contributing 4.4 to the total χ^2, is a significant *HEAO-1* A2 source which would not have been expected based on its IPC counting rate. An alternative explanation for this case might be that a source lies outside the IPC field but still within the field of view of the *HEAO-1* A2 detectors. It could also be an example of enhanced low energy absorption, although this explanation is not supported by an atypically large IPC hardness ratio.

A large value of N_H intrinsic to the QSOs would cause our IPC flux values to be underestimated relative to the *HEAO-1* A2 extrapolations. If the average intrinsic absorption is 10^{22} atoms cm^{-2}, then we estimate that α is >0.97. Currently, there are not the data to constrain QSO column densities. For the two QSOs with good measured spectra, 3C 273 gives $N_H < 4.5\ 10^{21}$ atoms cm^{-2} (Worrall *et al.* 1979) and 0241+622 suffers too much absorption in the galactic plane for a useful limit to be placed on an intrinsic column density. For AGNs, it is only the less luminous for which column densities are large enough to have been detected so far. Mushotzky(1982) found that the 10 AGNs with measurable column densities >6 10^{21} atoms cm^{-2}, from a sample of 19, all have 2-10 keV X-ray luminosities <5 10^{43} ergs s^{-1}. However, our QSOs are not low in X-ray emission compared with a typical X-ray selected sample of similar redshift. The 18 identified QSOs in table 5 of Reichert *et al.* (1982) have a mean redshift of 0.48 and IPC X-ray luminosity of 1.2 10^{45} ergs s^{-1}. In comparison, the 22 IPC-detected QSOs of our sample have a mean redshift of 0.37 and luminosity in the same energy band of 3.3 10^{45} ergs s^{-1}.

For a given IPC detection, the corresponding value of $K_2(\alpha)$ is only weakly dependent on α. This is because photons detected by the IPC all have energies close to 1 keV. However, photons detected by the *HEAO-1* A2 detectors are at energies above 1 keV, and $K_1(\alpha)$ increases with α with a dependence which is slightly stronger than linear. If we adopt a model in which α is allowed to have a Gaussian distribution of values of some standard deviation σ, then,

$$K_1(\bar{\alpha})=\sigma^{-1}(2\pi)^{-1/2}\int K_1(\alpha)\exp(-0.5((\alpha-\bar{\alpha})/\sigma)^2)d\alpha$$

and, for any given QSO, $K_1(\bar{\alpha})$ will slightly exceed its value determined using the δ-function model. We thus expect the best fit range for $\bar{\alpha}$ to have lower values. We have evaluated the above integral for $\sigma=0.2$, approximating $K_1(\alpha)$ with discrete values determined at intervals of 0.1 in α. We find that the 90% confidence level lower limit for $\bar{\alpha}$ reduces from 0.61 to 0.58. This is therefore a small effect.

We have constructed the IPC hardness ratio histogram for our sample, as defined by Zamorani *et al.* (1981). The mean value is 1.04±0.07, which is not inconsistent with their value of 1.14±0.06. Zamorani *et al.* state that their hardness ratio is most consistent with $\alpha\simeq0.4$. However, there is currently no general calibration between α and hardness ratio. We thus cannot say whether or not the IPC spectrum of our sample implied by the measured hardness ratio is consistent with our range of α (0.61-1.15) found for the energy band between the IPC and *HEAO-1* A2 experiments.

IV CONCLUSIONS

We have found that, assuming a power law spectrum, this sample of QSOs is most consistent with a flux density spectral index of 0.83(+0.32,-0.22) (90% errors), $N_H<3\ 10^{20}$ atoms cm^{-2}, between the *HEAO-1* A2 experiment energy range and that of the *Einstein Observatory* IPC, where sensitivities are highest to photons of ~7 keV and ~1 keV respectively. This index is in agreement with that found above 2 keV for Seyfert galaxies and narrow emission line galaxies by Mushotzky *et al.* (1980) and Mushotzky (1982), and samples of AGNs and QSOs investigated by Halpern and Grindlay (1982).

It has been suggested that QSOs make up a substantial fraction of the unresolved XRB in the 1-3 keV energy band (Tananbaum *et al.* 1979) and thus could reasonably be expected to contribute significantly to the 3-50 keV band where the XRB spectrum has been most accurately measured. An important test of this hypothesis is that the aggregate spectrum of contributors to the XRB must equal the observed XRB spectrum. De Zotti *et al.* (1982) have investigated this question quantatatively by assuming that each contributor has a power-law spectrum with a high energy cutoff. They conclude that, if Seyfert 1 galaxies contribute 30% of the XRB, then the remaining contributors must have a spectral index of <0.4. Thus, if QSOs are the only other substantial contributors, their average spectral index must be <0.4.

We have examined in a relatively crude way the constraints on the percentage contribution to the 3-10 keV XRB of a population with the spectral index we derive from our sample. The XRB spectral data is from the *HEAO-1* A2 experiment (Marshall *et al.* 1980), from the upper layers of the HED1 and MED detectors. We have restricted the energy band to less than 10 keV. At higher energies, the XRB spectrum gradually softens in a manner consistent with a 40 keV thermal bremsstrahlung spectrum. This softening can be produced by a variety of power-law models with cutoffs, but for simplicity we have chosen to avoid this energy band. We have assumed that Seyfert 1 galaxies contribute 30% of the XRB energy flux between 3 and 10 keV and that they have a spectral index α=0.7. The correct contribution (assuming no evolution) probably lies between 20% and 40% depending on the shape of the Seyfert galaxy luminosity function below luminosities of 3×10^{42} ergs s^{-1} (Piccinotti *et al.* 1982; Elvis, Soltan and Keel 1982). Clusters of galaxies probably contribute about 4%; the exact number again depends on poorly sampled regions of the luminosity function (Piccinotti *et al.* 1982) as well as possible evolutionary effects. We have made the extreme assumption that the contribution from clusters is negligible. Since clusters have relatively soft spectra, subtracting a cluster contribution from the XRB spectrum makes the residual spectrum harder and in general less amenable to contributions of sources with soft spectra.

We can fit the data with the assumed Seyfert contribution and a second power-law component (figure 1a). This second power law has an index of α=0.29 (+0.03,-0.02) (90% confidence limits) and is thus incompatible with that of the QSO sample studied in this work, where $\alpha > 0.58$. Figure 1b illustrates how poorly the data fit the model, even when the index of the second power law is taken to be the smallest consistent with our observations (0.58). As discussed above, the fit worsens if a contribution due to clusters of galaxies is included or if our best fit spectral index for QSOs of 0.83 is used.

Acceptable fits can be made to the data if an additional very hard component is included. We note that the contribution of this component must decrease rapidly at energies greater than 10 keV in order to avoid exceeding the XRB spectrum. Table 2 gives the parameters of the additional component required for various amounts of contributions from sources with $\alpha = 0.83$ (and 0.58). We note that, for QSOs with the spectra preferred by our observations to contribute more than 30% of the 3-10 keV XRB, there must exist X-ray sources with very intriguing spectra, making a significant contribution to the XRB.

Our final conclusions are that at least one of the following must be true.

1). Our assumption of a single power-law spectrum is incorrect and our QSOs have a hard spectrum in the *HEAO-1* A2 energy band ($\alpha \simeq 0.4$) and a soft excess in the IPC. This seems unlikely since the QSO spectral index above 2 keV found by Grindlay and Halpern (1982) is more in agreement with our result than with $\alpha \simeq 0.4$, and the hardness ratio we observe in the IPC does not suggest a soft excess.

2). A typical QSO member of the hypothesised X-ray emitting population which dominates the XRB has a harder spectrum than that measured for our sample. This might be the case if, for example, radio-quiet QSOs exhibit harder X-ray spectra than the radio-loud ones, possibly due to different X-ray emission mechanisms. Our sample is biassed towards radio-loud QSOs (see column 7 of table 1). Although the X-ray to optical luminosity ratio favours radio-loud objects (Zamorani *et al.* 1981), the density of this subset alone is too small to dominate the XRB, and a typical member of the hypothesised X-ray emitting population must be radio-quiet. Another possibility is that higher redshift QSOs exhibit harder X-ray spectra than those of our sample.

3). QSOs are not the dominant contributors to the XRB in the 3-10 keV energy range in which the XRB is most precisely measured, and there exists another, as yet unidentified, $\alpha<0.4$ component in this energy band.

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Table 1

HEAO-1 A2 and IPC fluxes for the 25 QSOs.

(1) QSO	(2) HEAO-1 A2 Dates[(a)] m/d/y	(3) HEAO-1 A2 R15 ct/s	(4) HEAO 1 A2 K_1[(b)] (α=0.8)	(5) IPC Seq # date	(6) IPC K_2[(b)] (α=0.8)	(7) Radio[(c)]	(8) Notes
0026+129 PG 0026 z=0.142	01/02/78 07/04/78	.75±.28	48±18	5417 01/04/81	19.0±2.7	Q	d,i,k
0205+024 NAB 0205 z=0.155	01/21/78 07/24/78	.18±.29	12±19	3978 07/20/79	9.5±2.9	Q	
0414-060 3C 110 z=0.781	02/20/78 08/24/78	-.10±.28	-6±18	521 02/25/79	4.8±0.6	L	i
0537-441 z=0.894	09/12/77 03/13/78	.25±.24	16±15	7499 04/08/80	2.7±0.4	L	i
0837-120 3C 206 z=0.2	11/08/77 05/06/78	.34±.26	22±17	8933 04/21/81	26.2±3.9	L	
0955+326 3C 232 z=0.533	11/12/77 05/11/78	-.35±.26	-22±17	2712 05/25/79	0.5±0.6	L	h
0959-443 z=0.84	12/18/77 06/17/78	-.03±.23	-2±15	5405 01/10/80	2.9±.6	L	
1004+130 4C 13.41 z=0.24	11/27/77 05/20/78	.01±.28	6±18	563 05/21/79	0.2±.2	L	h,k
1011+250 TON 490 z=1.631	11/19/77 05/17/78	.22±.28	14±18	2031 05/23/79	2.9±.5	L	j
1100+772 3C 249.1 z=0.311	10/19/77 04/17/78	-.47±.23	-30±15	478 04/27/79	10.2±1.9	L	i

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1202+281 GQ COMAE z=0.165	12/11/77 06/10/78	.33±.27	21±17	4258	18±4.5 05/23/79	Q	i
1219+755 MK 205 z=0.07	10/28/77 04/27/78	.25±.23	16±15	5424	37.5±7.5 04/21/80	Q	e,i,k
1229+204 TON 1542 z=0.064	12/20/77 06/21/78	.05±.27	3±17	3967	15.2±2.0 12/14/79	Q	
1351+640 PG 1351 z=0.088	11/28/77 05/29/78	.15±.25	10±16	520	0.5±.2 04/27/79	L	i,k
1425+267 TON 202 z=0.366	01/14/78 07/16/78	.01±.26	1±17	3971	1.7±.5 01/23/80	L	
1512+370 z=0.371	01/20/78 07/24/78	.07±.25	5±16	3973	8.1±1.5 01/23/80	L	
1525+227 z=0.253	02/01/78 08/04/78	-.23±.27	-15±17	10368	0.5±.2 03/06/81	L	g
1612+262 TON 256 z=0.131	02/13/78 08/18/78	.75±.28	48±18	2056	13±3 01/29/79	L	d,f,j
1704+608 3C 351 z=0.371	01/27/78 07/29/78	.24±.22	15±14	510	3.8±.5 01/05/79	L	i,j,k
2128-123 z=0.501	11/13/77 05/12/78	.22±.28	14±18	8413	7.2±.9 05/11/80	L	
2135-147 OX-158 z=0.2	11/14/77 05/12/78	.15±.28	10±18	5426	16.3±2.1 05/11/80	L	i
2141+174 OX 169 z=0.213	11/27/77 05/26/78	.15±.27	10±17	9667	4.0±7. 12/23/80	L	i,k
2201+315 4C 31.63 z=0.297	12/08/77 06/07/78	.77±.26	49±17	7182	9.5±1.6 06/16/80	L	d,f

2251-179 z=0.064	11/30/77 05/29/78	.80±.28	51±18	2074	40.7±9.0 05/23/79	Q	d,j
2251+113 4C 11.72 z=0.323	12/11/77 06/09/78	.28±.28	18±18	2073	0.5±.4 06/16/80	L	h

a. Fluxes are derived from ~4 days of scanning centered on this date.

b. Flux=10^{-4} $K^{-(\alpha+1)}$ cm^{-2} s^{-1} keV^{-1}.

c. L= Radio-loud. Q=Radio-quiet.

d. HEAO-A2 detction of $>2.5\sigma$.

e. IPC detection at significantly higher flux than HEAO-A2 value would predict.

f. IPC detection at significantly lower flux than HEAO-A2 value would predict.

g. During a shorter IPC observation the flux was three times brighter and showed possible short time scale variability with a very soft energy spectrum (Matilsky, Shrader and Tananbaum (1982)).

h. IPC non-detection.

i. IPC or HRI flux previously published by Zamorani *et al.* (1981).

j. IPC flux previously published by Ku, Helfand and Lucy (1980).

k. IPC or HRI flux previously published by Tananbaum *et al.* (1979).

Table 2

Characteristics of the 3rd power law required to fit the 3-10 keV XRB data, assuming a 30% Seyfert contribution (α=0.7), for various QSO contributions.

2nd (QSO) Power Law		3rd Power Law		χ^2(16 dof)
α_2	% Contribution	α_3	% Contribution	
+0.83	60	-2.52	10	340.7
	40	-0.46	30	36.0
	20	+0.07	50	17.4
+0.58	60	-1.53	10	45.6
	40	-0.11	30	17.0
	20	+0.17	50	16.6

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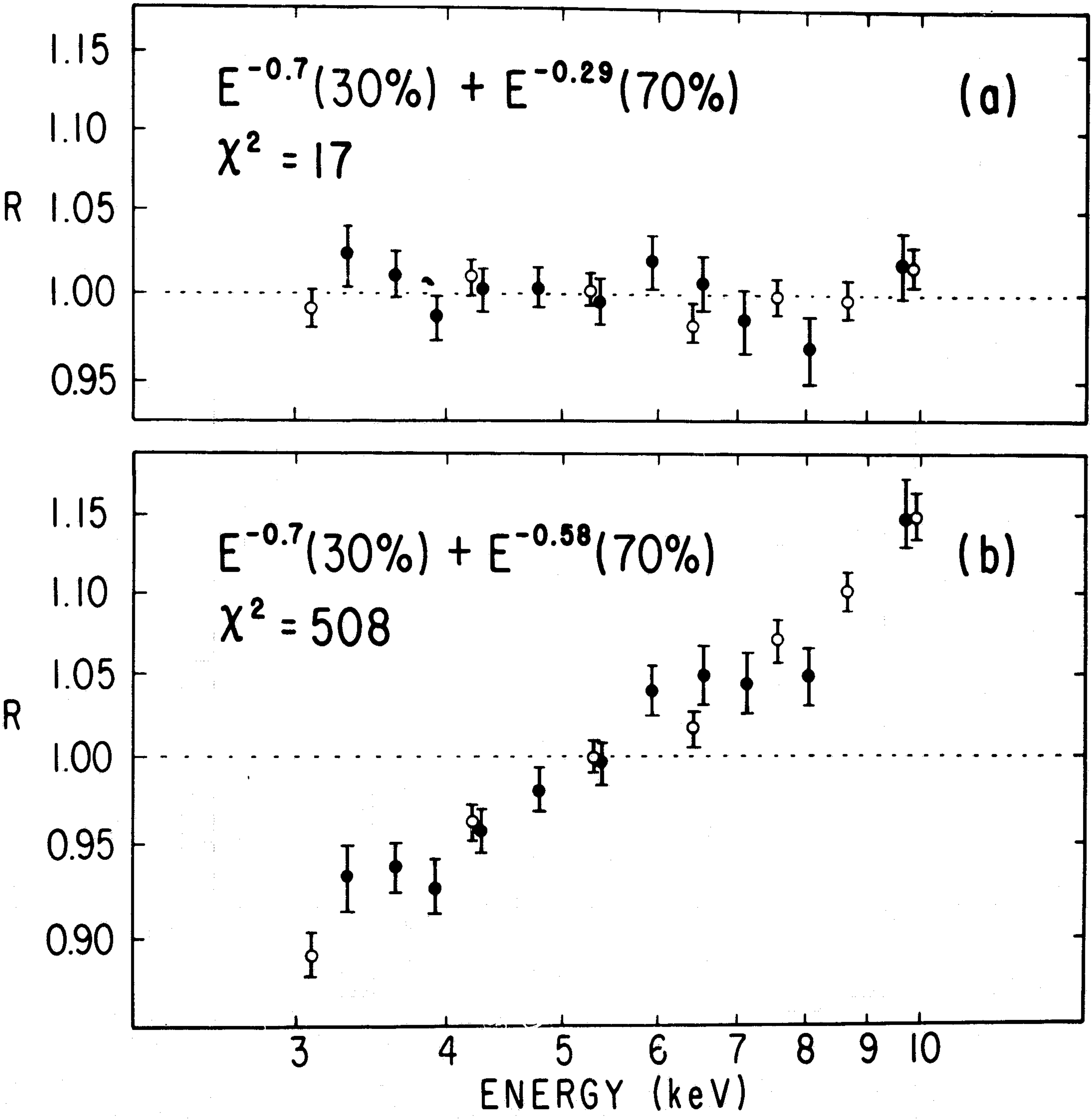
FIGURE CAPTION

Figure 1.

The ratio of observed counts for the X-ray background (Marshall *et al.* 1980) to those predicted for combinations of incident power-law spectra. Open circles are measurements with the *HEAO-1* A2 MED detector. Closed circles are with the HED1.


$E^{-0.7}(30\%) + E^{-0.29}(70\%)$
$\chi^2 = 17$
(a)
$E^{-0.7}(30\%) + E^{-0.58}(70\%)$
$\chi^2 = 508$
(b)
R
1.15
1.10
1.05
1.00
0.95
0.90
3
4
5
6
7
8
9
10
ENERGY (keV)