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The X-ray spectrum of the superluminal quasar 1928 + 73

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SUMMARY

EXOSAT observations (0.1–10 keV) of the radio-loud quasar 1928 + 73, which displays superluminal motion, were made at four epochs between 1983/283 and 1984/009, and we obtained spectra of this source from the *EXOSAT* database. The X-ray spectrum (0.1–10 keV) can be explained by a power law and uniform absorption model. No significant low-energy absorption or soft excess were detected. Both soft (0.1–2 keV) and hard (2–10 keV) X-ray flux variations of this quasar were found on a time-scale of one month. Spectral index values obtained from the power-law model suggest that they exceed the 'canonical' value. A thermal bremsstrahlung model also fits well. Uncorrelated variations of the soft and hard fluxes have been found in this source which indicate that they have different origins. A soft excess is apparent when the spectra are fitted with a canonical photon index ~ 1.7. The spectra presented here are the first in the X-ray region for 1928 + 73.

1 INTRODUCTION

1928 + 73 is a radio-loud quasar (Kuhr *et al.* 1981; Ulvestad *et al.* 1981) which looks like a classic radio double source (Johnston *et al.* 1987). It is a core–jet source, with multiple components, which displays apparent superluminal motion (Witzel *et al.* 1988 and references therein). The visual and absolute magnitudes of this quasar are 15.5 and −25.9 (Véron-Cetty & Véron 1987) with a redshift $z = 0.302$ (Lawrence *et al.* 1986).

X-ray observations were made with the *Einstein* satellite using the IPC imaging telescope, and the count rate was $(12.2 \pm 0.9) \times 10^{-2}$ cm^{-2} in the 0.2–3.5 keV range (Biermann *et al.* 1981). However, to the knowledge of the authors, no spectral information is available in the literature about this quasar. When we searched the *EXOSAT* database, we found that this source was observed on four epochs between 1983 and 1984. Here we present the results of an analysis of the four X-ray (0.1–10 keV) spectra obtained from the *EXOSAT* Low (LE) and Medium Energy (ME) detectors.

2 OBSERVATIONS

LE observations of 1928 + 73 were carried out using a Lexan 3000 (LX3) filter – details of the LE detectors are given by de Korte *et al.* (1981). Eight argon-filled proportional counters or detectors were used to obtain the ME spectra – White & Peacock (1988) and Turner, Smith & Zimmermann (1981) have described the *EXOSAT* instrumentation and the ME detectors respectively. These detectors were separated into two groups (detectors 1, 2, 3 and 4 are collectively known as Half 1, and 5, 6, 7, and 8 as Half 2) which can be either aligned to the pointing axis or offset by up to 2° to observe the background emission. Background-subtracted LE count rates with errors were obtained from the *EXOSAT* database and were converted into PHA spectra using the XANADU (X-ray Analysis and Data Utilization) software package.

Background-subtracted ME pulse-height data sets were also obtained from the *EXOSAT* database. A log of observations and LE and ME count rates of 1928 + 73 are given in

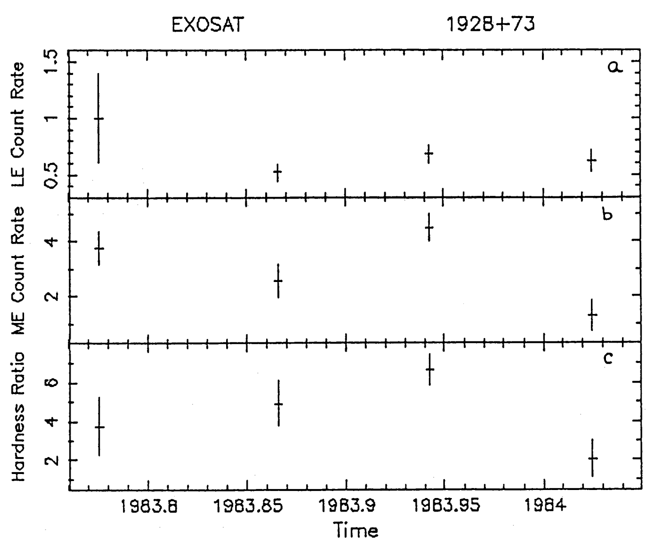

Figure 1. Plot of the (a) LE and (b) ME count rates and (c) the hardness ratio of the source, versus date of observations.

Table 1. Log of observations of the LE and ME spectra and count rates of 1928 + 73.

Start time (D H M)	End time (D H M)	LE Count rate (Lexan) (10^{-4} cm^{-2} s^{-1})	ME Count rate* (10^{-4} cm^{-2} s^{-1})	Hardness ratio
1983/283 03 52	1983/283 11 59	1.00 ± 0.39	3.76 ± 0.60	3.76 ± 1.46
1983/316 21 49	1983/317 05 27	0.52 ± 0.07	2.56 ± 0.60	4.92 ± 1.15
1983/344 04 07	1983/344 11 29	0.68 ± 0.08	4.50 ± 0.50	6.62 ± 0.78
1984/009 23 00	1984/010 06 30	0.62 ± 0.10	1.28 ± 0.57	2.06 ± 0.92

*The count rates are for PHA channels 6 to 35 corresponding to the energy range 2 to 10 keV with the best signal-to-noise ratio.

Table 2. Power law + absorption fits to the spectra of 1928 + 73.

Date	Γ[a]	N[b]	N_H[c]	Flux 0.1–2 (keV)	Flux 2–10 (keV)	L_x[e] 0.1–2 (keV)	L_x[e] 2–10 (keV)	Reduced χ^2 (d.o.f)
1983/283	$2.25^{+0.50}_{-0.45}$	$2.84^{+2.30}_{-1.24}$	$0.13^{+0.75}_{-0.10}$	4.72±1.84	5.01±0.80	1.85±0.72	1.97±0.31	0.97 (29)
1983/316	$2.25^{+0.39}_{-0.29}$	$1.56^{+0.31}_{-0.30}$	$0.13^{+0.75}_{-0.10}$	2.60±0.35	2.75±0.64	1.02±0.14	1.08±0.25	0.72 (31)
1983/344	$2.11^{+0.40}_{-0.41}$	$2.38^{+1.70}_{-1.00}$	$0.15^{+0.14}_{-0.10}$	3.71±0.44	5.14±0.57	1.46±0.17	2.02±0.22	0.53 (31)
1984/009	$4.2^{+1.90}_{-1.47}$	$11.10^{+57.0}_{-9.00}$	$0.63^{+0.67}_{-0.46}$	4.15±0.67	1.49±0.66	1.63±0.26	0.59±0.26	1.01 (19)

[a]Photon index. [b]Normalization in 10^{-3} photons cm^{-2} s^{-1} keV^{-1} at 1 keV. [c]Column density in 10^{22} cm^{-2}. [d]Flux in 10^{-12} erg cm^{-2} s^{-1}. [e]Luminosity in 10^{45} erg s^{-1}.

Table 1. Figs 1(a) and (b) display the plot of the LE and ME count rates, and the corresponding plot of the hardness ratio (ME count rate/LE count rate) of this source is shown in Fig. 1(c).

3 SPECTRAL ANALYSIS AND RESULTS

A spectral analysis has been carried out for the combined LE and ME data sets using the XSPEC (X-ray Spectral Fitting) software package. A power-law model with uniform absorption, using the effective photoelectric cross-section given by Morrison & McCammon (1983), was fitted to the spectra. The best-fitting parameters with 90 per cent confidence limits, which were computed for each parameter by the procedure detailed by Lampton, Margon & Bowyer (1976) ($\chi^2_{min} + 4.61$ for two free parameters), are presented in Table 2. It is evident from the reduced χ^2 values that this model provides a good fit to all of the data sets. From the fitted parameters it can be seen that the spectral index, $\alpha = \Gamma - 1$ where Γ is the photon index, changed between 1.25 ± 0.4 and 3.2 ± 1.6 during the *EXOSAT* observations. Table 2 also shows that the value of the hydrogen column density (N_H) is of the order of 10^{21} cm^{-2} which suggests that there is very weak absorption intrinsic to the source. Fig. 2 displays the LE and ME fluxes and shows that these varied between 1983/283 and 1984/009. Figs 3(a) and (b) show the observed LE + ME spectra of 1928 + 73 with the best-fitting power law and a uniform absorption model convolved through the detector response. Residuals between the model and spectra are

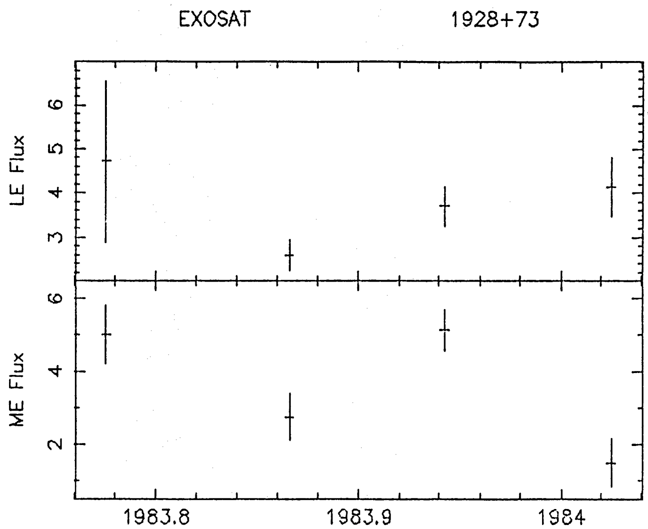

Figure 2. As Fig. 1 but for LE and ME fluxes.

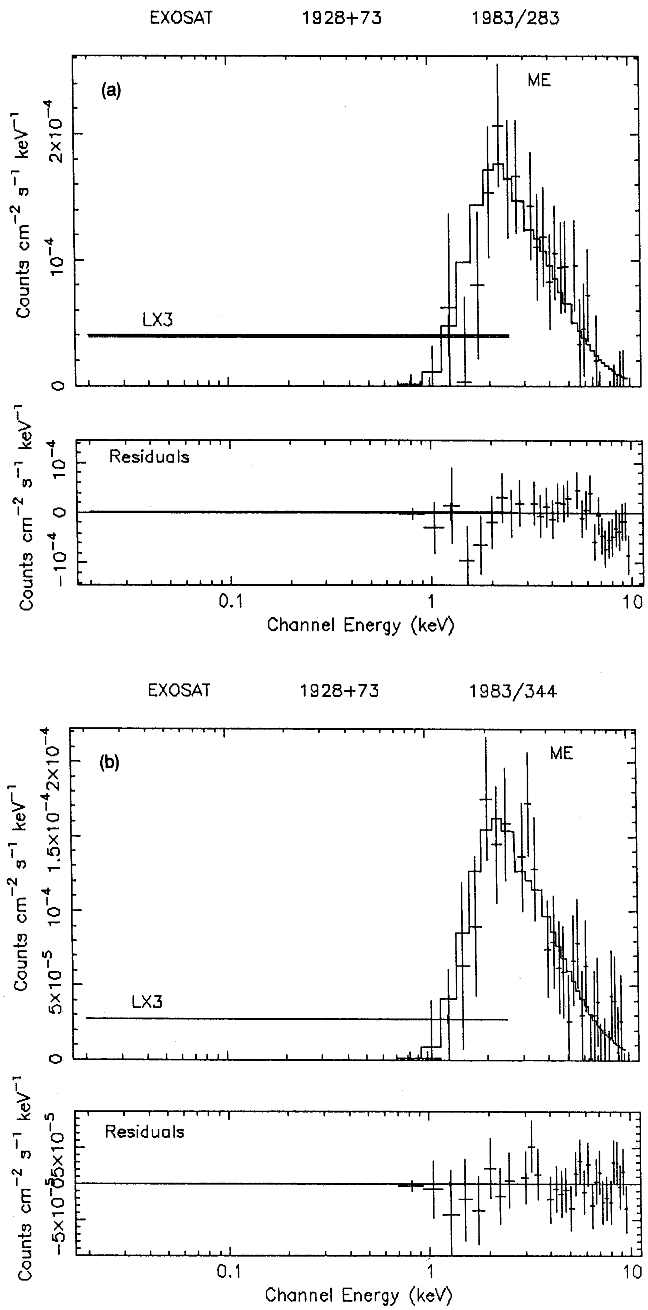

Figure 3. (a) Observed spectrum of 1928 + 73 for 1983/283 fitted with a simple power law and uniform absorption model. The lower panel of the figure shows the residuals between the spectrum and the model in units of counts. (b) As (a) but for 1983/344.

shown in the lower panel of these figures. There is no soft excess apparent.

Next we tried to fit the LE + ME spectra using a thermal bremsstrahlung model, and the best-fitting parameters with 90 per cent error bars are presented in Table 3. It can be seen that all of the spectra except that of 1983/316 fit well with the thermal bremsstrahlung model, and the plasma temperature varies between $1.08^{+1.12}_{-0.47}$ and $4.69^{+5.10}_{-1.79}$ keV.

4 DISCUSSSION

The quasar 1928 + 73 was observed with *EXOSAT* on four occasions between 1983 and 1984 (1983/283 to 1984/009) and during this period both the LE (0.1–2 keV) and ME (2–10 keV) fluxes varied. Figs 1–2 and Tables 1–2 show that the variations of the LE count rates or fluxes were in concert with the variations of the ME count rates or fluxes, but the relative variations of the LE count rates or fluxes differ from those of the ME count rates or fluxes. The LE and ME variations are therefore uncorrelated, with a correlation coefficent between LE and ME fluxes of 0.30 for four observations, which means that the probability of the fit being random is > 70 per cent. Also, no clear correlation between the hardness ratio and the LE or ME fluxes was found. From the existing observations it should be noted that 1928 + 73 displayed both soft (0.1–2 keV) and hard (2–10 keV) X-ray flux variations on a time-scale of a month, and the average luminosity of this quasar was $\sim 10^{45}$ erg s^{-1}, both in the soft and hard X-ray bands.

From Figs 1 and 2 it is evident that the ME count rate or flux falls by a factor of ~4 between 1983/344 and 1984/009, while the LE count rate or flux remains unchanged. This type of uncorrelated variations of the LE and ME fluxes has also been found in *EXOSAT* and *Ginga* observations of 3C 273 (Turner *et al.* 1990). These results indicate that the LE and ME fluxes have different origins. A soft excess for such sources may not stand above the extrapolation of the hard power law, but the distribution of their fluxes indicates a separate component. This can be seen from Figs 4(a) and (b) which show the presence of soft excesses in 1928 + 73 when the ME data were fitted with a canonical $\Gamma \sim 1.7$. Thus it is suggested that the differential variability of the soft and hard fluxes of an Active Galactic Nucleus (AGN) may provide indirect evidence for the presence of soft excess, as has been found in 1928 + 73.

There are differences between radio-loud and radio-quiet quasars in their X-ray properties, in that the radio-loud quasars are usually more luminous in the X-ray region than the radio-quiet quasars (Zamorani *et al.* 1981; Kembhavi, Feigelson & Singh 1985). 1928 + 73 is a radio-loud quasar with multiple component structures and superluminal

Table 3. Thermal bremsstrahlung + absorption fits to the spectra of 1928 + 73.

Date	kT^{f}	N^{b}	N_{H}^{g}	Reduced χ^2 (d.o.f)
1983/283	$3.88^{+3.10}_{-1.38}$	$1.20^{+0.96}_{-0.55}$	$3.84^{+33.1}_{-2.74}$	0.86 (29)
1983/316	2.28	1.40	9.3	0.71 (31)
1983/344	$4.69^{+5.10}_{-1.79}$	$0.95^{+0.75}_{-0.46}$	$5.64^{+5.90}_{-3.10}$	0.52 (29)
1984/009	$1.08^{+1.12}_{-0.47}$	$5.98^{+33.1}_{-4.86}$	$22.0^{+34.0}_{-17.0}$	0.94 (19)

[b]Normalization in 10^{-3} photons cm^{-2} s^{-1} keV^{-1} at 1 keV. [f]Plasma temperature in keV. [g]Column density in 10^{20} cm^{-2}.

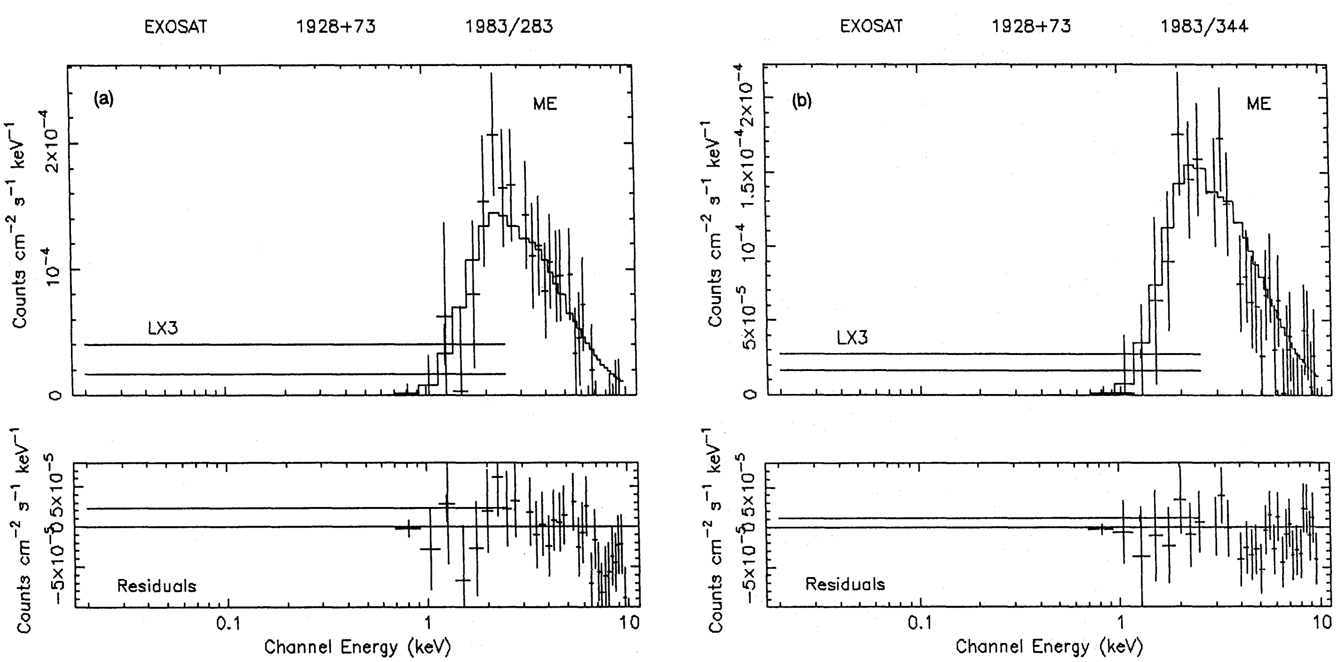

Figure 4. (a) As Fig. 3(a) but with the photon index value fixed at the canonical value ~1.7. (b) As (a) but for 1983/344.

motion (Witzel *et al.* 1988 and references therein). It is also a luminous X-ray source ($\sim 10^{45}$ erg s^{-1} in the 0.1–10 keV range, using Friedman cosmology with $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$). Wilkes & Elvis (1987) have found another difference between the two types of quasar, namely that the radio-loud ones have flat X-ray spectra and the radio-quiet ones steep X-ray spectra. But 1928 + 73, although radio-loud, has an X-ray spectrum steeper than the 'canonical' value (Turner & Pounds 1989) for AGNs. The same type of steepening was also found in the X-ray spectrum of the radio-loud quasar PKS 1217 + 023 observed with *EXOSAT* and *Ginga* (Ghosh & Soundararajaperumal 1991 and references therein). These results imply that the X-ray spectral index may not be a good indicator to differentiate between radio-loud and radio-quiet quasars.

From the best-fitting parameters of the thermal bremsstrahlung and absorption model (see Table 3), it is evident that the plasma temperature is a minimum (1984/009) when the hardness ratio of the source is also a minimum (during the *EXOSAT* observations) and vice versa: the correlation coefficient between the plasma temperature and the hardness ratio of the source is 0.90 for three observations (excluding the observation of 1983/316) which suggests that these two parameters are correlated. On the basis of this result, it may be suggested that the hardness ratio of this quasar depends on the plasma temperature of the source, although it is not clear which physical process is responsible for variations of the plasma temperature.

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