THE EXOSAT SPECTRAL SURVEY OF EMISSION LINE AGN

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ABSTRACT. Results are presented from EXOSAT observations of Seyfert type active galactic nuclei (AGN). The sample chosen for study are 48 hard X-ray selected Seyfert type AGN, including all 30 of the emission line AGN in the Piccinotti sample. Combining EXOSAT LE and ME data has allowed us to obtain broad band X-ray spectra over the range 0.1-10 keV. Spectra in the $\sim$2-10 keV range are found to be well described by a simple power-law. The distribution of spectral indices across the sample can be approximated by a Gaussian distribution of mean energy index α = 0.70 with σ_α = 0.17 although not all individual spectra are consistent with this mean at the 90% confidence level. EXOSAT has also revealed a substantial number of sources with complex soft X-ray spectra. These include spectra with a second spectral component at soft X-ray energies and sources with "leaky" absorbing columns. Evidence that soft excess components occur in at least 50% of Seyfert type AGN together with detection of rapid variability in the soft component provides quantitative support for an accretion disc model for AGN.

1. INTRODUCTION

Ariel 5 first established powerful X-radiation to be a common property of active galaxies, with several bright BL Lac objects and a substantial number of Seyfert-type galaxies being identified with X-ray sources detected by the Sky Survey Instrument (Pounds, 1977; Elvis et al 1978; McHardy et al, 1981). The greater sensitivity of the Einstein Observatory later detected additional Seyferts (Kriss et al, 1980) and a large number of more luminous, but generally fainter, QSO's (Tananbaum et al, 1986), while its companion HEAO-1 spacecraft provided the first useful sample of broad band X-ray spectra of the brighter BL Lac and Seyfert-type sources. A remarkable result of the HEAO-1 spectral survey (Mushotzky, 1984) was the uniformity of the AGN spectra, the great majority being well fitted by a simple power law spectrum of the form F (E) = const. x $E^{-\alpha}$x exp.($-\sigma_E N_H$), with the energy index $\alpha \sim 0.7 \pm 0.2$. In the above, σ_E represents the effective photoelectric cross-section for neutral gas of solar abundance (Morrison and McCammon, 1983). Notable exceptions to the 'canonical' $\alpha \sim 0.7$ power law prior to the launch of EXOSAT were the luminous quasar 3C 273, with $\alpha \sim 0.4$, and the BL Lac objects which were typically steeper with α in the range $\sim$1-2. Spectra of higher resolution from the Solid State Spectrometer (SSS) instrument on the Einstein Observatory covered a narrower energy band (0.8 - 3.5 keV) than the HEAO-1 instruments but were more sensitive to low energy absorption, having an effective limit of $N_H \gtrsim 2 \times 10^{21}$ cm^{-2}. A few sources, mainly of $L_x < 10^{43.5}$ erg sec^{-1} were found to have a low energy cut-off corresponding to an equivalent hydrogen

D. E. Osterbrock and J. S. Miller (eds.), Active Galactic Nuclei, 155–160.

https://doi.org/10.1017/S0074180900140689 Published online by Cambridge University Press

column (N_H) much greater than the line-of-sight interstellar value (N_{gal}) (Reichert et al, (1985). Two especially interesting SSS spectra of Seyfert galaxies were, the report of a 'soft excess' in NGC4151 by Holt et al (1980), who interpreted the soft excess in terms of a partial covering of the hard X-ray source, and the detection of possible thermal emission lines in the spectrum of 3C120 (Petre et al, 1984). Despite the relatively high spectral resolution of the SSS, hindsight suggests that this instrument's narrow bandwidth and its location at low energies, properties shared with the Einstein Observatory IPC, make both less useful for determining AGN power law spectral indices than the proportional counters of HEAO-1 and EXOSAT. The widespread occurrence of soft emission components and of complex low energy absorption, found in the EXOSAT survey, necessitate measurements to be extended over an adequate bandwidth above 2-3 keV, where soft X-ray emission and absorption effects become generally small.

A major programme was carried out with EXOSAT to obtain X-ray spectra of a more complete sample of hard X-ray selected emission line AGN from the Ariel V and HEAO-1 catalogues. This programme of X-ray observations started in August 1983 and continued throughout the 2 1/2 year lifetime of EXOSAT. The sample consists of 48 objects, including all 30 of the emission line AGN in the flux-limited Piccinotti sample (Piccinotti et al, 1981). Observations of our sample of AGN were carried out using the low energy (LE) imaging telescopes (de Korte et al, 1981) and the medium energy (ME) detector array (Turner et al, 1981) on EXOSAT.

2. ENERGY INDEX

All of the sources in our sample were consistent with having a simple power-law X-ray spectrum. Thermal bremsstrahlung models were also tried, but generally provided worse fits to the data than the power-law models.

The best-fit power-law slopes for the full sample are represented in histogram form in Fig 1. Where more complex spectra were required to model the data,only the hard X-ray power-law component has been used and an approximate Gaussian spread was given to each α value appropriate to its statistical precision. A Gaussian fit to the histogram gives α_{mean} = 0.70 and σ_α = 0.17. With allowance for the errors in each individual measurement of α the intrinsic spread of spectral indices is estimated to contribute $\sigma_I \lesssim 0.14$ (at 90% confidence). If there were no intrinsic spread in α then measurement errors alone would result in only 4 or 5 AGN slopes inconsistent with the mean α at the 90% confidence level. However, 18 of the 42 sample sources for which spectra were obtained were found to be inconsistent with the mean power-law spectrum at that confidence level indicating a significant dispersion in intrinsic AGN slopes.

The 18 objects inconsistent with the mean α are distributed across a wide range in luminosity. Four of these objects have well determined spectra either because they were very bright at the time of observation or because they were observed several times. Thus, they can confidently be described as exceptions and provide good evidence that the spread in spectral slopes over the X-ray band is real. These four are:

- NGC3227 had a flat spectrum in four observations. The ME data gave a mean slope of 0.51 ± 0.12, addition of the LE data giving the same mean, 0.51 ± 0.11.
- NGC4151 has been extensively studied by EXOSAT. This Seyfert is one of the brightest in the 2-10 keV band and has revealed a large and

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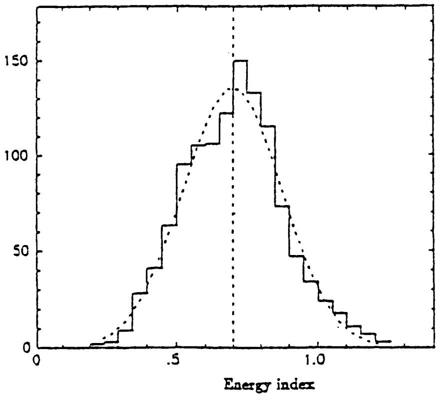

Fig. 1 Weighted distribution of power law indices

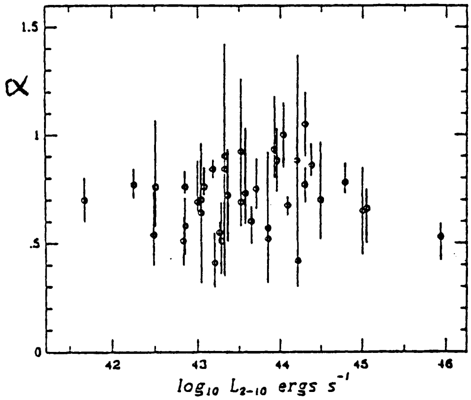

Fig. 2 Power law indices versus luminosity

complex absorbing column. Detailed analysis by Yaqoob et al, (1988) has shown all observations to be consistent with a mean α of ~ 0.59 ± 0.04 for the hard X-ray slope, constant over variations of an order of magnitude in flux.

- 3C273 is by far the most luminous source in our sample and may represent one extreme of the Seyfert phenomenon. Numerous observations with EXOSAT and previous X-ray satellites have shown 3C273 to have a flat spectrum, the observation reanalysed here giving $\alpha = 0.53^{+0.06}_{-0.11}$.
- Akn120 is another bright Seyfert with a well constrained EXOSAT spectrum. The ME data alone gave a slope of $\alpha = 1.10^{+0.23}_{-0.16}$ and addition of the LE data confirmed the steep slope as $\alpha = 1.19 \pm 0.08$. A previous Einstein observation of Akn120 yielded a steep power law consistent with our result (Urry et al. 1987).

Fig. 2 shows α versus log (2-10 keV) luminosity for the ME + LE data where error bars on α cover the 90% confidence range and a typical error on luminosity is ~10%. All luminosities have been absorption corrected so they represent the luminosity at the nucleus, rather than that observed. There is no evidence for any trend in α with luminosity from this data, although a variation of up to $\pm$ 0.2 over 5 decades in luminosity is still consistent with our data.

3. LOW ENERGY ABSORPTION

The combined ME+LE instruments aboard EXOSAT were sensitive to absorbing columns down to ~ 10^{20} cm^{-2}, a factor of ~ 10 lower than the previous limit provided by the SSS instrument on Einstein. Fig. 3(a) shows the measured X-ray columns for each source (less the galactic column), compared with the galactic line-of-sight values derived from 21 cm measurements (Heiles, 1975); ~50% of these sources show a measured X-ray column significantly above the galactic value at the 90% confidence level (18 out of 35 sources for which such data are available). Allowing for a small error on the measured galactic column (~10^{20} cm^{-2}), 3 points lie significantly below the 1-1 line: Akn120, NGC7213 and NGC7469, probably due

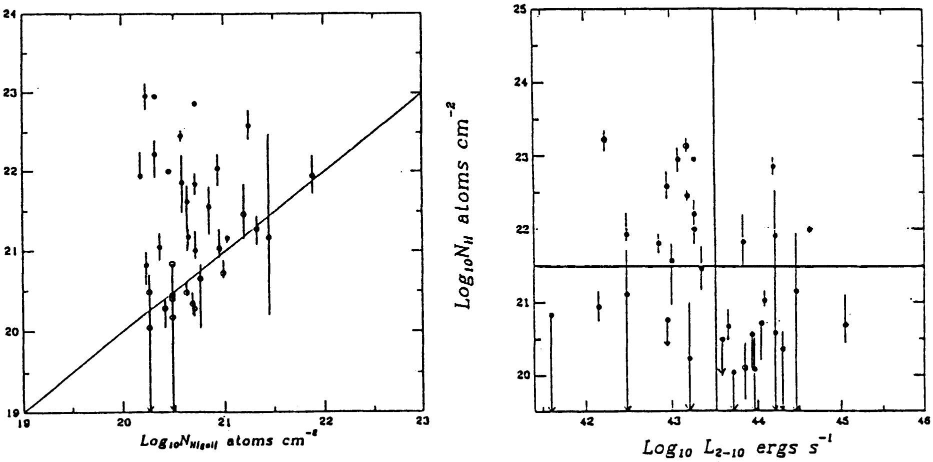

Fig. 3 X-ray absorbing column versus (a) galactic column and (b) nuclear luminosity

to the presence of a soft emission component in these cases.

Next, the X-ray columns were compared to X-ray nuclear luminosity (ie. corrected for absorption). Taking $10^{43.5}$ erg s^{-1} as a crude dividing line between low and high luminosity AGN (to provide a direct comparison with Reichert et al 1985) and considering $\sim 10^{21.5}$ cm^{-2} to be a 'substantial' column, Fig.3(b) shows that eleven low luminosity objects and four high luminosity objects possess a substantial column. One of the high luminosity objects is MR2251 which exhibits a variable column, indicating that the absorbing material is situated close to the nucleus (Pan et al, 1988). Thus, the EXOSAT data confirm that high X-ray absorption is more common in low luminosity AGN, although the distinction is less clear than that found by Reichert et al (1985).

4. SOFT EXCESS EMISSION

X-ray observations performed with previous satellites and supported by EXOSAT results have shown that above $\sim$2 keV Seyfert galaxies are generally well described by a simple power-law of index $\alpha \sim 0.7$. However, the flux of the UV continuum generally lies above the extrapolation of the X-ray spectrum and a turn-up of the latter between 1 keV and 10 eV is required to meet it. Observations of the line ratios from the BLR have also shown that a larger X-ray-ultra violet (XUV) flux is required to ionize this region than is provided by a simple extrapolation of the $\alpha = 0.7$ power-law into the extreme ultraviolet.

Prior to EXOSAT there were only a few objects which showed evidence for the predicted spectral turn-up. HEAO-1's low energy detctor (LED) observations of the Seyfert galaxy E1615+061 (Pravdo et al, 1984) showed it to have a very steep single power-law slope, whilst Mkn509 (Singh et al, 1985) required a two component spectrum (assuming a galactic N_H) in the 0.18-2.8 keV band. EXOSAT observations have made clear the need to distinguish between two types of 'soft excess'. These are:

- emission from a distinct soft X-ray spectral component;
- leakage of soft X-rays through a patchy or partially ionized absorber

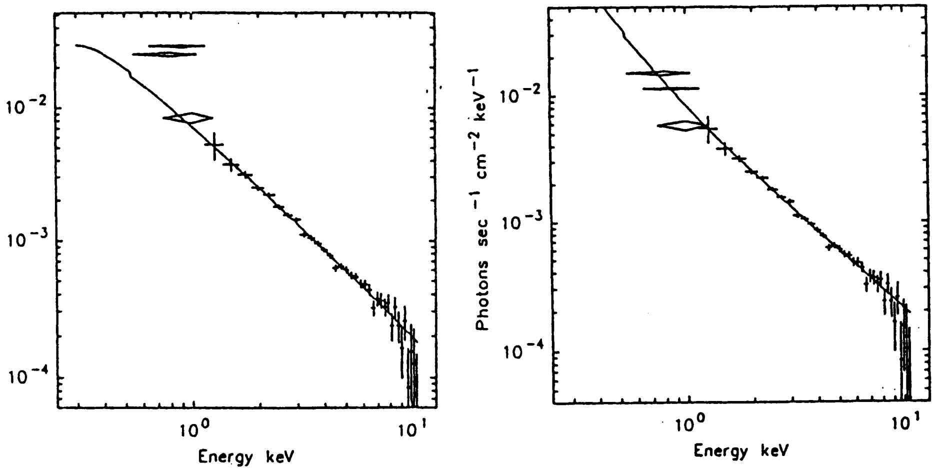

Fig. 4 (a) Single and (b) double power law fits to NGC5548

The first 'soft excess' observed with EXOSAT was in NGC 4151. This Seyfert galaxy is one of the brightest AGN in the 2-10 keV range and has been extensively studied throughout the EXOSAT mission (Pounds et al, 1986a, Yaqoob et al, 1988), showing both a non-varying soft emission component below ~1 keV and a soft excess due to leakage in the 1.5-3.5 keV band. The first soft X-ray component discovered with EXOSAT and identified with the active nucleus (on grounds of rapid variability) was in the luminous Seyfert Mkn841 (Arnaud et al, 1985). The second example was found in one of the Leicester spectral survey sources, Mkn335 (Pounds et al, 1986 b). A third, NGC5548, is illustrated in Fig. 4 where an extrapolation of the hard power law is seen to fall well short of the LE spectral points.

Excess soft X-rays were found in 8 of the Leicester spectral survey sources: Mkn335, NGC2110, NGC4051, NGC4151, NGC5548, 3C273, MCG-6-30-15, and MR2251. Soft excesses were also implied in a further 7 objects, namely NGC526A, Fairall-9, Akn120, NGC4593, NGC7213, NGC7314 and NGC7469 on the basis of uncorrelated variability observed in the ME and LE bands and/or by the fact that derived absorbing columns were significantly lower than the measured galactic values. Analysis of other EXOSAT observations, of Fairall-9 (Morini et al, 1986) and NGC7469 (Barr, 1987) confirmed the need for a soft excess in those sources too.

In all cases where there was evidence for a soft excess, both partial covering models and two power-law models were tried. In all but three cases the two power-law model was preferred. The exceptions were NGC4151, NGC2110 and MR2251 where the partial covering model was a better fit.

5. DISCUSSION

The remarkable constancy of spectral slope, over such a wide luminosity range, places strong constraints on models of emission and secondary processing (eg. in a pair plasma) of the hard power law component (Guilbert et al, 1983; Zdziarski and Lightman, 1985). Its origin very close to the central black hole seems in little doubt, given the frequent detection of rapid variability in the EXOSAT sample. The discrepancy between the canonical α and the flatter 2-10 keV slope of the X-ray

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background radiation suggests that if low luminosity AGN are indeed a major component of the X-ray background, strong spectral evolution must occur beyond the limits of the EXOSAT sample.

Our finding that a separate, soft nuclear component frequently occurs may be the strongest evidence to date of the existence of stable accretion discs feeding the central black hole in Seyfert nuclei. The implied inner disc temperatures of kT~0.1 keV support the view that, in these objects, at least, the central black holes cannot have masses much greater than $\sim 10^7 M_\odot$, a result consistent with that derived from variability data (see McHardy, 1988). The prospects for learning a great deal about the central engine and its environment in AGN offered by the various X-ray spectroscopic missions of the next decade are exciting indeed.

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DISCUSSION

CANIZARES Did you look for a possible correlation between X-ray spectral index and the radio properties of the object?

POUNDS No, but there were only a few (~ 5) radio bright sources in the EXOSAT sample.

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