EUV and Soft X-ray Evidence for Partially Ionized Gas in Active Galactic Nuclei

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We present a synoptic study of active galactic nuclei (AGN) detected by *EUVE*. We also present complementary *ROSAT* PSPC spectra for these sources and for other AGN in directions of low galactic absorption. It is found that the best-fit power-law photon indices of the X-ray spectra at 0.1–2.4 keV are anti-correlated with their galactic hydrogen columns. The indices for the 0.9–2.4 keV range do not show such a correlation, and are considerably smaller (i.e. flatter). We discuss a number of possible interpretations of this correlation but only one of these, the presence of a partially ionized absorbing gas in the AGN, explains the observations satisfactorily. The ubiquity of this effect suggests that this component be may very common in AGN.

Studies of the behavior of AGN in the EUV and soft X-rays have recently begun with the launch of *EUVE* and *ROSAT*. We report a collective effect which emerged from an examination of a sample of AGN observed by the two satellites. Our original sample was a set of 8 objects which are part of the much larger catalog of AGN detected in the Lex/B (65 – 190 eV) filter passband by *EUVE* during the survey and pointed phases of the mission. This subset is formed by selecting only objects for which we have well defined soft X-ray spectra from the *ROSAT* public archive. Moreover we have excluded BL Lac objects as they are special cases where a significant fraction of their emission comes from relativistic jets. Spectral models have been obtained by fitting the power-law parameters with galactic absorption to the PSPC data. Predicted Lex/B count rates using these best-fit parameters are found to be in reasonable agreement with the observed values (Lieu et al. 1995), indicating that the sources have not varied significantly and that we are not severely affected by any uncertainty in the soft response of the PSPC. In Table 1 we list the sources and their properties.

In this work we explore the relationship between intrinsic source absorption in the soft X-ray/EUV and absorption within our own galaxy, using the cross sections of Morrison and McCammon (1983). In Figure 1 we plot galactic H I column density (N_H, obtained from one of the following sources: Stark et al. 1987; Elvis et al. 1989; Dickey et al. 1990) against the best-fit photon indices. A striking anti-correlation exists between these two independently measured quantities. We do not believe that this is due to the method of fitting as in that case one would expect there to be a positive correlation between index and N_H. Further, in order to demonstrate that this is not an EUV selection effect, we have included in Figure 1 those non-BL Lac objects detected by the *ROSAT* sky survey (Walter & Fink 1993, Brinkmann & Siebert 1994) in directions of $N_H < 2.3 \times 10^{20}$ cm^{-2}, also detailed in Table 1. It is clear that these separately acquired data follow a very similar trend to that of the EUV data.

One possible explanation of the anti-correlation is that the spectra of AGN located in directions of high N_H are dominated by their > 1 keV photons since galactic absorption is removing the lower energy photons. A fit to the entire 0.1–2.4 keV band would then be biased by the spectral shape in the > 1 keV band. The spectrum from this higher energy band is known to be flatter and in Figure 2 we plotted the best-fit indices for

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TABLE 1. AGN observed by EUVE and ROSAT

Name	RA			DEC			Type	Lex/B (c/ks)	Photon Index 0.11–2.4 keV	χ^2_{red}	Galactic N_H (10^{20} cm^{-2})	Fitted N_H (10^{20} cm^{-2})
PG 1415+451	14	17	0.6	+44	56	00	QSO	5.2±1.5	3.01±0.15	1.23	1.16	$1.61^{+0.30}_{-0.35}$
Mrk 478	14	42	6.5	+35	26	4	Sy1/QSO	62±10	3.38±0.15	1.24	1.11	$1.44^{+0.20}_{-0.20}$
NGC 4051	12	03	11.0	+44	32	24	Sy1	17±8	3.00±0.15	1.53	1.31	$1.95^{+0.28}_{-0.23}$
PG1116+215	11	19	8.0	+21	19	36	QSO	17±13	2.77±0.20	1.16	1.44	$1.62^{+0.20}_{-0.20}$
Ton 180	00	57	20	−22	22	36	Sy1.2	53±8	3.06±0.05	0.80	1.47	$1.46^{+0.10}_{-0.10}$
CG 0912	14	21	29.6	+47	47	00	AGN	3.4±1.0	2.12±0.30	1.02	1.74	$1.69^{+0.55}_{-0.55}$
3C 273	12	29	6.7	+02	03	00	QSO	79.2±0.8	2.18±0.30	1.09	1.8	$1.49^{+0.10}_{-0.10}$
NGC 7213	22	09	17.0	−47	09	36	Sy1	23±7	2.06±0.10	0.98	1.92	$1.68^{+0.32}_{-0.28}$
IR13349+2438	13	37	18.7	24	23	3	QSO	—	3.61±0.34	1.16	1.00	1.6 ± 0.6
CG 1043	12	42	10.5	33	17	4	Sy1	—	3.10±0.47	1.41	1.30	3.2 ± 1.7
3C279	12	56	11.2	−5	47	22	QSO	—	1.65±0.38	0.76	2.22	2.3 ± 1.1
NGC1566	04	19	00	−55	03	00	AGN	—	1.79 ± 0.41	0.35	1.55	0.7 ± 1.1
Mkn110	09	22	00	52	30	00	AGN	—	2.17 ± 0.27	0.25	1.57	1.3 ± 0.6
PG0953+451	09	54	41	30	30	00	AGN	—	2.93 ± 0.33	1.48	1.18	1.7 ± 0.8
Mkn142	10	22	00	51	55	00	AGN	—	3.12 ± 0.23	1.10	1.18	1.6 ± 0.5
3C263	11	37	00	66	04	00	AGN	—	2.66 ± 0.51	0.66	0.82	1.5 ± 1.2
Mkn766	12	16	00	30	06	00	AGN	—	2.75 ± 0.13	0.74	1.76	3.3 ± 0.5
NGC4593	12	37	00	−05	04	00	AGN	—	2.49 ± 0.42	1.07	1.97	2.0 ± 1.3
Mkn279	13	52	00	69	33	00	AGN	—	2.15 ± 0.17	1.27	1.64	1.8 ± 0.5
NGC5548	14	16	00	25	22	00	AGN	—	2.21 ± 0.15	1.00	1.93	1.7 ± 0.4
PG1444+407	14	45	00	40	48	00	AGN	—	3.41 ± 0.53	0.97	1.31	2.2 ± 1.5

the 0.9–2.4 keV band against N_H. For the fifteen objects where we have sufficient data to fit the 0.9–2.4 keV band it is clear that the high energy indices do not correlate with N_H and that the average 0.9–2.4 keV index is 2.20±0.10, considerably flatter than the average 0.1–2.4 keV index of 2.72±0.07, applicable to the data in Figure 1. However, in going from a column of 1×10^{20} cm^{-2} to 2×10^{20} cm^{-2} only half the photons below 0.5 keV are absorbed, and as an index of 2.2 is still quite steep it is difficult to see how a fit at 2×10^{20} cm^{-2} could be dominated solely by the higher energy photons.

We therefore must look for another explanation. In Figure 3 we display the best fit total absorption against the galactic absorption associated with a hydrogen column derived from 21 cm measurements. The best fit columns are larger than the galactic value for the low N_H sources, providing evidence for intrinsic absorption in the AGN. Recent evidence from *GINGA* showed that up to ~ 50% of bright Seyferts may have partially ionized absorbers (Nandra & Pounds 1994) and such absorbers can significantly alter the observed spectrum (Reynolds & Fabian 1995). Indeed, three of our sources (NGC4051, NGC7213, NGC4593) show evidence for a partially ionized absorber. Since we only have PSPC spectra it is not possible to exclude either the possibility of the AGN having a complex intrinsic spectrum giving rise to the observed shape in the PSPC spectrum, or the presence of a partial covering of the source by cold gas. Our correlation, however, is

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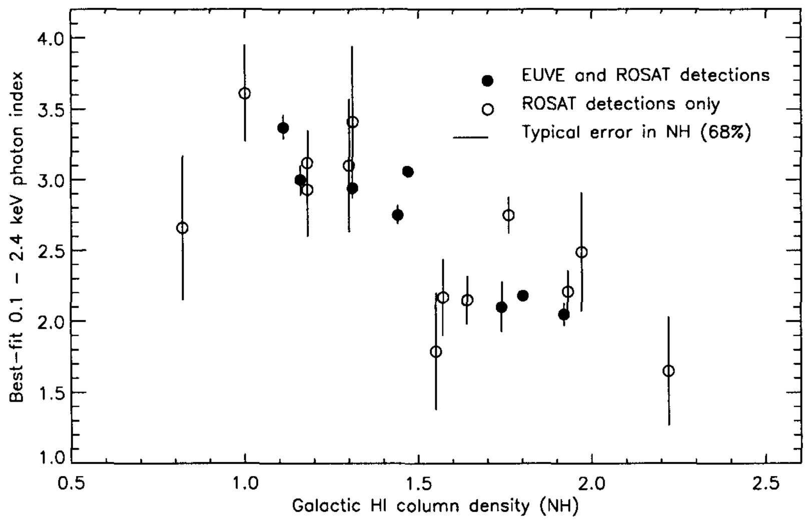

FIGURE 1. Galactic (21 cm) H I column density plotted against best-fit power-law indices for the PSPC spectra in the 0.11–2.4 keV range, for the 21 AGN shown in Table 1. The photon index is simultaneously fitted with a variable total absorption, so that the results are independent of galactic absorption from a measurement viewpoint. The errors in N_H are determined from the dispersion of results in the immediate vicinity of the sky location concerned; directional variations of the column within the radio beam size represents the dominant source of uncertainty.

unlikely to be caused by either of these two effects since in neither case can one introduce a distortion of the spectrum as a function of galactic N_H.

A more natural explanation would be the presence of a partially ionized intrinsic absorber in all of these objects. Such an absorber, with a temperature $\sim$ 50,000 to 500,000 K, transmits photons with lower energy than $\sim$ 0.4 keV with very little absorption, but the O VII and O VIII edges give rise to a significant absorption at energies of 0.8 keV and above. Therefore, a partially ionized absorber intrinsic to the source will contribute a significant fraction of the total absorption above 0.8 keV but not below it. Any model based on a simple power-law spectrum combined with galactic absorption will be forced to steepen the fit to take into account the increased absorption of the hard X-ray photons relative to the $<$ 0.8 keV photons. Indeed, by looking at the transmission curve of a typical warm partially ionized absorber (Reynolds & Fabian 1995), the ratio of absorption between the $<$ 0.4 keV and $>$ 0.8 keV photons can be as large as a factor of 10. This scenario then yields, at least qualitatively, a natural explanation for the anti-correlation between spectral index and N_H. At very low columns the effect of the partially ionized absorber will be significant, therefore steepening the observed spectrum. At higher column densities, however, the fraction of the absorption due to the partially ionized gas will decrease and therefore the spectrum will flatten. This therefore predicts an anti-correlation of observed spectral slope with N_H, exactly what we observe. The

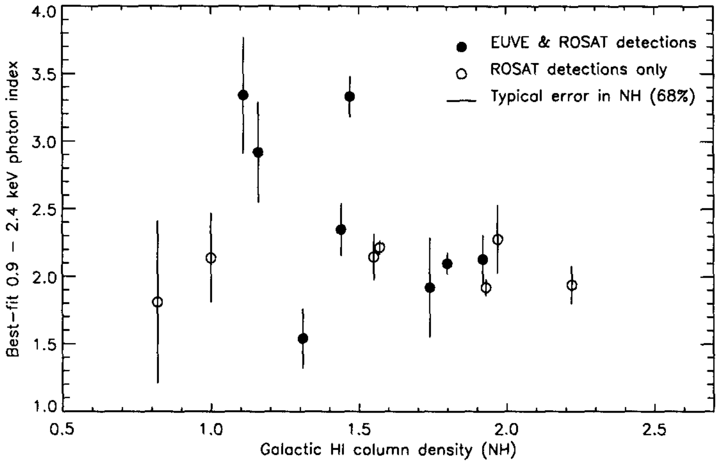

FIGURE 2. Galactic (21 cm) H I column density plotted against best-fit power-law indices for the *ROSAT* spectra in the 0.9–2.4 keV range, for 15 of the AGN shown in Table 1. No correlation between the power law indices and galactic absorption is seen.

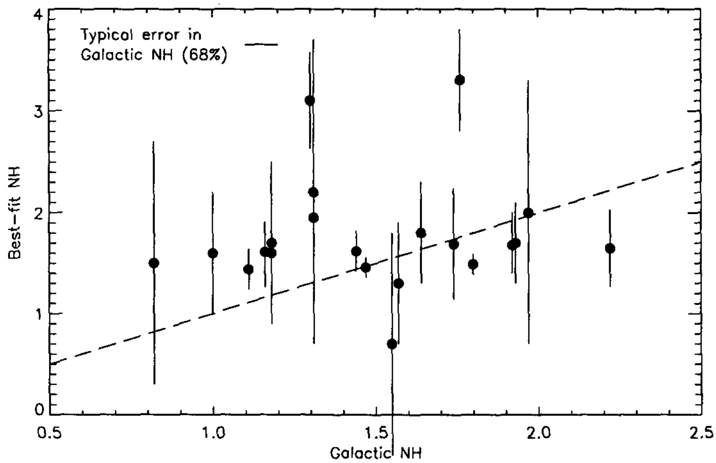

FIGURE 3. Galactic (21 cm) versus best-fit column densities for the AGNs listed in Table 1. The dashed line shows where the two sets of column densities agree. At low galactic hydrogen columns power-law models with absorption yield higher best-fit columns than the corresponding galactic values. This is indicative of intrinsic absorption which will be increasingly masked in AGNs observed through larger amounts of galactic absorption.

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fact that we see such a good correlation for a sample of bright AGN selected purely on the value of the galactic absorption implies that partially ionized absorbers are commonplace, and indeed that such absorbers may exist in all AGN. The reason why they are not seen in all AGN is that the effect of this absorber is overwhelmed by the galactic absorption for many objects with large N_H.

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