Soft X-ray Spectra of Seyfert Galaxies

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I. Introduction

The first X-ray (2-10 keV) spectral surveys of active galactic nuclei (AGN) were remarkably uniform, with spectral indices narrowly distributed about $\alpha = 0.65$, independent of radio-emitting properties or X-ray luminosity (Mushotzky 1984). In the few AGN detected above 20 keV, this canonical power law extended to at least 50 keV (Rothschild *et al.* 1983, Pounds 1985, Worrall *et al.* 1980; Halpern 1982; Worrall and Marshall 1984). In practice these surveys were dominated by low luminosity Seyfert 1 galaxies.

The Wilkes and Elvis (1987) IPC survey of 33 quasars was distinctly at odds with these previous, higher energy, spectral surveys: the power-law indices were steeper and broadly distributed. Further, the spectral shape depended on radio loudness, in the sense that radio-loud quasars were flat, $< \alpha_{RL} > \sim 0.5$ while radio-quiet quasars were steep, $< \alpha_{RQ} > \sim 0.9$. This clearly suggested the "canonical" picture was "wrong" in some way. However, since the "canonical" picture was derived from higher energy observations of lower luminosity, lower redshift AGN, the Wilkes and Elvis quasars could be different because of X-ray band, X-ray luminosity, redshift, or AGN type.

Fortunately, a large number of Seyfert galaxies were also observed with the *Einstein Observatory* IPC. In this paper we report the spectral results for IPC observations of 75 optically-selected Seyfert galaxies, the largest such sample studied in X-rays, and the first with information about the soft X-ray spectra of optically-selected Seyfert 2 galaxies. This survey can be compared dircctly to the Wilkes and Elvis quasar survey and to 2-10 keV surveys of Seyfert 1s to unravel the effects of AGN type, observing band, redshift, and luminosity.

2. Results

The well-determined spectra in our sample (mostly high luminosity Seyfert 1s) are generally consistent with their weighted mean power-law index, $<\alpha> = 0.81$. However, the lower luminosity Seyfert 2s in our sample have, as a group, significantly flatter power-law indices, $\alpha \sim 0.5$. The well-studied Seyfert 2 galaxy NGC 1068 has a very steep soft X-ray spectrum (Monier and Halpern 1987) and is distinctly different from almost every other Seyfert (1 or 2) in the sample. This may be difficult to reconcile with the obscured torus model (Antonucci and Miller 1985, Krolik 1988), which was based on NGC 1068.

The number of radio-loud objects in our sample is small; nevertheless we extend to Seyfert galaxies the correlation seen in quasars between radio-loudness and flatness of the soft X-ray spectrum. Our data are also consistent with the correlation between the strength of optical FeII lines and the soft X-ray spectral index observed in quasars (Wilkes, Elvis, and McHardy 1987).

Ten of the 43 Seyfert 1s for which we have well-determined spectra also have 2-20 keV spectra measured with HEAO1-A2 (Mushotzky *et al.* 1980, Mushotzky 1984). A comparison shows that our spectra are systematically softer, by $\Delta\alpha \sim 0.1$-0.2. The difference between the IPC and HEAO1-A2 spectra of Seyferts must be due to the difference in bandpass.

Selection effects are probably very important in our sample. Sub-samples of low luminosity galaxies and of Seyfert 2s are nearly the same, and their properties are indistinguishable. The Seyfert 2s tend to be relatively brighter in the radio compared to the Seyfert 1s — since they are

D. E. Osterbrock and J. S. Miller (eds.), Active Galactic Nuclei, 173–174.

https://doi.org/10.1017/S0074180900140719 Published online by Cambridge University Press

optically selected this is not surprising (Ulvestad and Wilson 1984a,b; Edelson 1987). Therefore the fact that they appear flatter than the Seyfert 1s could be due to (1)their AGN type, (2)their low luminosity, or (3)their higher radio flux. This too may be selected for, in that few Seyfert 2s are detected, and since X-ray flux correlates with radio flux (Zamorani *et al.* 1981, Worrall 1987), the radio-bright ones will be preferentially detected.

However, independent of AGN type, there is a significant correlation between spectral index and emitted X-ray luminosity, in the sense that lower luminosity spectra are flatter. When we remove possible causes like Seyfert type, radio loudness, and fits with large uncertainties, the correlation persists (99.97% confidence). While the spectral index distribution for our sample is formally consistent (according to a KS test) with the Wilkes and Elvis distribution for quasars, combining the two data sets strengthens the α-L_x correlation. (It is not significant in the radio-quiet quasar sample alone, however.) The weighted mean spectral indices are $< \alpha_{IPC}^{S1} > = 0.83$ for radio-quiet Seyfert 1s and $< \alpha_{IPC}^{Q} > = 0.91$ for quasars, a small but significant difference.

Most of our Seyferts have IPC spectra consistent with no intrinsic absorption by cold gas, to within a few times 10^{20} cm^{-2} for the brighter spectra, below the limits expected for a normal face-on spiral galaxy. These low intrinsic absorbing columns observed in our sample have important ramifications reddening studies. Also, among unabsorbed sources there is actually an [unphysical] negative intrinsic absorbing column density (as was found by Wilkes and Elvis for quasars), which probably indicates soft excesses at low energies. In some cases Seyfert spectra do show significant positive intrinsic absorption, more commonly among low luminosity objects ($L_x < 10^{43.5}$ ergs s^{-1}; Reichert *et al.* 1985), but the amount of absorption is not correlated with X-ray luminosity. Finally, there is a dearth of absorbing column densities in the range 10^{21}-10^{22} cm^{-2}, as is expected if absorption occurs in the broad-line clouds.

Acknowledgement — We would like to thank Chris Papineau for help with the data analysis.

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