Title
The soft X-ray spectral shape of X-ray-weak Seyfert galaxies

Permalink
https://escholarship.org/uc/item/3xs4d6w2

Journal
ASTROPHYSICAL JOURNAL, 456(2)

ISSN
0004-637X

Authors
Rush, B
Malkan, MA

Publication Date
1996-01-10

DOI
10.1086/176672

Peer reviewed
THE SOFT X-RAY SPECTRAL SHAPE OF X-RAY WEAK SEYFERTS

Brian Rush and Matthew A. Malkan
Department of Physics and Astronomy, University of California, Los Angeles, CA 90095(1562; rush,malkan@bonnie.astro.ucla.edu

ABSTRACT

We present and analyze ROSAT-PSPC observations of eight Seyfert 2 galaxies, two Seyfert 1/QSOs, and one IR-luminous non-Seyfert. These targets were selected from the Extended 12 m Galaxy Sample and, therefore, have different multiwavelength properties from most (optically or X-ray selected) Seyferts previously observed in the soft X-rays. The targets were also selected as having atypical X-ray fluxes among their respective classes, e.g. relatively X-ray strong Seyfert 2s and X-ray weak Seyfert 1/QSOs.

Comparing our observations with those from the ROSAT All-Sky Survey, we found variability (of a factor of 1.5 \pm 2) in both of the Seyfert 1/QSOs, but in none of the Seyfert 2s. Both variable objects have steeper photon indices in the more luminous state, with the softest (\textless 1.0 keV) x-ray varying the most. The time scales indicate that the variable component arises from a region less than a parsec in size.

Fitting the spectra to an absorbed power law model, we found that both the Seyfert 2s and the Seyfert 1/QSOs are best fitted with a photon index of 3.1 \pm 3.2. This is in agreement with the average photon index of a sample of Markarian Seyfert 2s observed by Turner, Urry, & Mushotzky (1993), indicating that most Seyfert 2s, even those displaying a wide variety of multiwavelength characteristics, as well as some Seyfert 1/QSOs, have a photon index much steeper than the canonical (Seyfert 1) value of 1.7. One possible explanation is that these objects have a hotter continuum plus a soft (\textless 1.0 keV) excess in the form of high EW iron and/or oxygen fluorescence lines, a blackbody or even a thermal plasma. Alternatively, the underlying continuum may indeed be steep, powered by a different physical mechanism than that which produces the softer continua in other Seyfert 1s/QSOs.

We imaged one Seyfert 2 (NGC 5005) with the ROSAT HRI, finding about 13\% of the soft X-rays to come from an extended source. This object also has the most evidence from spectral fitting for an extra contribution to the soft X-ray flux in addition to a power-law component, indicating that different components to the soft X-ray spectrum of this object and likely of other X-ray weak Seyferts may come from spatially distinct regions.

Subject headings: Galaxies: Active | Galaxies: Nuclei | Galaxies: Seyfert | X-Rays: Galaxies

\footnote{Accepted for publication in the 10 January 1996 issue of ApJ.}
1. Introduction

Although Seyfert galaxies and quasars have been well studied in the X rays, most previous observational scrutiny has been devoted to the brighter Seyfert 1/QSOs which are more easily detected. There are few observations of those Seyfert 1/QSOs which are relatively X-ray weak or of any Seyfert 2, and not all of those have been measured well enough for detailed spectral analysis. This paper discusses new ROSAT spectra of such objects, broadening the range of types of AGN observed in the soft X-rays. This can provide us with an understanding of the soft X-ray nature of (low luminosity) AGN which is more representative of this entire class of objects, and free from the biases which can result from analyzing only a small subset AGN types.

Previous X-ray missions, in the 2–10 keV energy range, found Seyfert galaxies (mostly Seyfert 1s) to be best by power-law spectra with a photon index of about 1.7–1.9 (e.g., Mushotzky 1984; Turner & Pounds 1989). However, the ROSAT spectra of Seyferts generally have steeper photon indices, of about 2.4 for Seyfert 1s (Turner, George, & Mushotzky 1993, hereafter TGM) and even steeper values 3.2, for Seyfert 2s (Turner, Urry, & Mushotzky 1993, hereafter TUM). There are several possible explanations for these steep observed indices. This could indicate a steeper intrinsic continuum slope, or alternatively adding a “soft” X-ray excess* to an underlying power-law model usually proves the t and attains the best t continuum slope. The nature of this soft excess has been suggested to be one or more of the following: Fe/L and/or Oxygen X-ray lines around 0.8(1.0) keV, a low (tem) perature blackbody, an optically (thin) thermal component, a steep second power-law, or the underlying hard continuum leaking through a partial absorber. It is not evident that a combination of a power-law and a soft excess is necessary in all objects. Perhaps a large amount of absorption ($N_h \leq 10^{23}$) could harden an even softer underlying power-law to give the observed spectrum, or a strong blackbody or optically thin thermal component, could account for all of the observed soft X-ray flux, without an underlying power-law even being necessary.

These large object to object differences in the observed range of $L_x/L_{opt}$ in Seyfert 1s and QSOs of a factor of 300 (e.g., values of $\alpha$ ranging from 1.0/(1.1 to 1.9) Piccinotti et al. 1982; Tananbaum et al. 1986) reflect substantial fundamental differences in the structure of their central engines. A large difference in $X$ (ray properties is also seen in the spectra of Seyfert 2s. For example, NGC 1068, the prototype of a Seyfert 2 which may be a hidden Seyfert 1, is also the brightest and best observed Seyfert 2 in the X-rays. It appears to have a very steep soft X-ray spectrum (Mushotzky & Hapken 1987), but is more like Seyfert 1s at high energies (Koyama et al. 1989), and does not resemble the average spectrum of other Seyfert 2s observed with the IPC, or the spectrum of the Seyfert 2 Mrk 348 observed with Ginga (Marsick et al. 1989).

These differences, lead to the question of whether the usual Seyfert 1|Seyfert 2 dichotomy, usually made based on optical spectra, is a physically accurate way to classify these objects in the X-rays. Observations of a wide range of Seyfert galaxies are necessary to determine whether Seyfert 1s and Seyfert 2s represent two primarily distinct classes of objects, or if they are better described as having a continuous range of properties, and whether the observed differences are intrinsic to the nucleus, or represent varying circumnuclear properties, such as the amount and distribution of absorbing material. Our data suggest that a subset of Seyfert 1s (of which we discuss only two objects in this work, but which may include any other objects) are more intrinsically similar (with respect to the source of the soft X-ray emission) to most Seyfert 2s than to other Seyfert 1s. This is most likely explainable if different mechanisms produce the X-rays in the X-ray (quiet) objects. If the standard X-ray emission is mechanism (e.g., inverse Compton scattering of lower energy photons by relativistic electrons, direct synchrotron emission from relativistic electrons produced near the central engine or jet, and/or thermal emission from the hot inner parts of an accretion flow) are in fact virtual "turned off" in these objects, it is quite possible that weaker, more exotic mechanisms (e.g., optically thin thermal emission from the hot intercloud medium) may contribute significantly to the X-rays we actually detect.

2. Target Selection and Observations

2.1. Selection of Objects from the 12 Micron Sample

The objects for which we have obtained pointed PSPC spectra were carefully selected for several reasons. First, they are from (with the exception of
PG 1351+640) from the complete plate and unbiased source of bright AGNs compiled to date by the Extended 12 M icon Galaxy Sample (Rush, Malkan, & Spinoglio 1993). This sample is complete relative to a bolometric \( L_X \) level, and includes those Seyferts which are the brightest at longer wavelengths, including a truly representative number of both X \( (\text{ray}) \) quiet and X \( (\text{ray}) \) loud objects. We selected the IR (brightest Seyfert 2s from this sample which had not previously been observed in any pointed X \( (\text{ray}) \) mission. We also selected two typical examples of relatively X \( (\text{ray}) \) weak Seyfert 1/QSOs. Mkn 1239 has one of the lowest detected X \( (\text{ray}) \) \( \text{ux} \) levels of all 55 Seyfert 1s in the 12 m Sample (20 counts and 0.05 cts/sec in the ROSAT All-Sky Survey; Rush et al. 1996), and PG 1351+640 has the steepest \( \	ext{ux} \) \( (\text{r} = 0.91) \) of the 66 PG QSOs observed by Einstein (Tananbaum et al. 1986).

Second, the 12 m (selected Seyferts are qualitatively different from those observed previously. Halpern & Moran (1993) pointed out that the Seyfert 2s usually observed with polarized X \( (\text{ray}) \) lines are restricted to those with relatively strong X \( (\text{ray}) \) \( \text{ux} \) excesses (found by the Markarian surveys; e.g. those reported in TUM) which are also relatively radio( strong. Compared to these Markarian Seyfert 2s (many of which were observed but not detected by Ginga; Awaki 1993), the targets we observed have redder optical/infrared colors, weaker and smaller radio sources, larger starlight fractions, and steeper Balmer decrement points representative of Seyfert 2s as a general class. Similarly, Mkn 1239 and PG 1351+640 differ from those broad-line AGN usually observed, in that they are specifically chosen to have relatively weak X \( (\text{ray}) \) \( \text{ux} \) levels. The one IR (luminous non-Seyfert we observed was chosen by cross referencing the non-Seyfert in the 12 m Sample with a large sample of IRAS galaxies detected in the ROSAT All-Sky Survey (hereafter RASS; Boller et al. 1992; Boller et al. 1995b) for those non-Seyferts with the highest IR luminosity and X \( (\text{ray}) \) \( \text{ux} \) levels.

### 2.2. Pointed ROSAT PSPC Observations during AO 2|AO 4

The observations were carried out AO 2|AO 4 (from 1991 December to 1993 October) with the ROSAT X \( (\text{ray}) \) telescope, with the Position Sensitive Proportional Counter (PSPC) in the focal plane. The PSPC provides spatial and spectral resolution over the full \( \text{fi} \) eld of view of 2 which vary slightly with photon energy \( E \). The energy resolution is \( E/E = 0.41/\sqrt{E/\text{keV}} \). The on-axis angular resolution is limited by the PSPC to about 0.05, and the on-axis effective collecting area, including the PSPC efficiency, is about 220 \( \text{cm}^2 \) at 1 keV (Brinkmann 1992). See Table 1 for a summary of the observations and count rates for each object, where the objects are listed in decreasing order of total counts obtained.

We have also obtained ROSAT All-Sky Survey data for almost all of the Seyferts in the 12 m and CfA samples. This will be discussed in another paper to be completed shortly after this one (Rush et al. 1996). Those data, on over 100 Seyferts spanning a wide range of characteristics, will complement this work by enabling us to address statistically the scientific issues discussed below for individual objects.

### 3. Data Analysis

For each step of the data analysis discussed below, only those counts in pulse invariant \( \text{P} \) \( \text{I} \) channels \( 12|200 \) inclusive are included. The lower limit is set by the fact that the lower level discriminator lies just below this limit, so any data taken from lower channels cannot be considered as valid events. Furthermore, the analysis of the PSPC PSF has shown that the positions of very soft events cannot be accurately determined because of a ghost imaging effect (J. Turner, p.c.m.). The exact level at which this effect is significant is different for each observation (Wasinger & Snowden 1990), so we conservatively chose to exclude \( \text{P} \) \( \text{I} \) channels below 12. The upper \( \text{P} \) \( \text{I} \) channel included is 200, since the mean effective area falls rapidly at higher energies. We have also defined low, medium, and high energies to refer to \( \text{P} \) \( \text{I} \) channels \( 12 \) to 50, 50 to 100, and 100 to 200, respectively, and \( \text{all} \) energies refers to \( \text{P} \) \( \text{I} \) channels \( 12 \) to 200.

The spectral analysis was done by first extracting spectra from the events \( 1 \) \( \text{using the QP SPEC} \) command in the PROS package in IRAF. We made sure that the output of PROS were properly compatible with XSPEC, in particular with regards to the manner in which these two packages deal with binning and calculating statistical errors. We then simple models using the XSPEC software, with the events in \( \text{P} \) \( \text{I} \) channels \( 12 \) to 200 binned so as to include at least 20 counts in each bin, allowing 2 techniques to be applied.

\[ \text{http://heasarc.gsfc.nasa.gov/docs/rosat/qspect.htm} \]
app eled. We use the most recent response matrix available, released from MPE in 1993 January. We first set the data to the standard absorbed power (law model), both with all parameters ($N_{\text{Hi}}$, and normalization) free and with $N_{\text{Hi}}$ fixed at the Galactic value (see Table 2). We use the photon index, $\gamma$, defined such that $N = (N = \text{number of photons})$, which is output by the fitting routines in XSPEC. This relates to the spectral slope, $\gamma$, defined by $F / \nu$, as $\gamma = 1$. We also perform several other tasks, either adding a thermal component to the power (law or tting only a thermal component). These are discussed in §4.2.

The quoted uncertainties are at the 90\% confidence level, assuming one free parameter of interest (Lampton, Margon, & Bowyer 1976), when available (i.e., when the chi-square minimum to determine these uncertainties properly converged; these are denoted as separate upper and lower uncertainties). Otherwise, the 1\% uncertainty on each parameter is given (denoted as a single value).

Hardness ratios provided a simple approximation to the spectral shape, even for those objects which didn’t have enough counts to accurately fit a spectral model to (see Table 3). The hardness ratio is defined as $HR = (A/B)/(A+B)$, where $A = \text{cctt}(0.02(1.00 \text{ keV})$ and $B = \text{cctt}(1.01(2.00 \text{ keV})$. Also given is the ratio $A/(A+B)$, which we refer to as $F_{\text{soft}}$.

The spatial analysis was done using the SAO im age display in IRAF/PROS. Each of the sources was observed at the center of the PSPC field, with the exception of NGC 1144, which was about 20° south of the field center. This object was partially occulted by the telescope support structure and we thus corrected the exposure time accordingly. The accumulated PSPC counts for each object were calculated using the IM-CNTS task in IRAF/PROS and are listed in Table 1. All counts in a circular region surrounding the source are given, after subtracting the background, as calculated in a source (free annular region) just outside the circle.

Finally, using the TIM SORT and LIT CURV tasks in PROS, we extracted light curves for each object. This was done individually for low, medium, and high energies and for all energies. All of the objects were observed over periods of no more than 8 days, except for NGC 3982 and PG 1351+640, which were observed in several segments, spanning 5 and 11 months, respectively, allowing us to test for variations on a half-year to year time scale.

4. Results

4.1. Variability

4.1.1. Seyfert 2s

Any variation in the spectra of our Seyfert 2s would have been considered an important result, as there are only a couple reports to date of X-ray variability in Seyfert 2 galaxies (e.g., in NGC 1365) TUM and possibly in M82 (Canizares et al. 1986), and none of these are conclusive (e.g., the variation in NGC 1365 may be due to the serendipitous sources). However, no significant short-term variation was found for any Seyfert 2 in our sample. The one object which was observed over a 5 month period, NGC 3982, showed no significant variation over this time scale either (see, for example, the count rates in Table 1).

We also compared the count rates of our pointed observations to those obtained during the ROSAT All-Sky Survey for the same objects (Rush et al. 1996), as shown in Figure 1. Point sizes in Figure 1 are proportional to the square of the total count rate in our pointed observation and error bars are statistical uncertainties in the count rates. The RASS was taken during 1990 July 1-1991 February, thus this comparison provides time delays of 1-3 years for the various objects. As can be seen, the 5 Seyfert 2s with the most counts in our observations show no sign of variability since the RASS. That the count rates for two of the fainter Seyfert 2s and for the one IR luminous non-Seyfert are different is probably not an indication of variability, since we have extremely low counts for those objects (in both our observations and the RASS), and it is unlikely that only the objects with the fewest observed count rates would be the only ones to vary.
4.1.2. Seyfert 1/Q SO s

However, there is evidence for variation in both of our Seyfert 1/Q SO s. From Table 1 and Figure 1, we can see that M kn 1239 increased its count rate by about a factor of two between the RASS and our observation (over 21–28 months, depending on when this object was observed during the RASS). The spectral slope steepened slightly during this period, from \( = 2.69 \) to \( = 2.94 \) (for a power-law \( t \) with \( \gamma \) constrained to \( N_H \); gal, which is the only spectral parameter we have from the RASS).

We don’t have RASS data for PG 1351+ 640, but we can see that it varied during our observations, which spanned the 11 months from 1992 November to 1993 October, increasing its total counts and \( \times \) by factors of 1.5 and 1.4, respectively (a 10 result). The spectral shape varied, becoming steeper as this object became more luminous, as with M kn 1239. The 0.12–1.00 keV count rate increased by \( 59\% \), whereas the 1.00–2.00 count rate only increased by \( 14\% \), as indicated by the counts and hardness ratios of Table 3. The best( t photon index steepened slightly, from 2.54 to 2.73 (see Table 2).

That the spectra of both of these objects steepened during the more luminous state indicates that most of the variability was at the lowest energies (i.e., below 1 keV). The time scale of the variability puts an upper limit on the size of the emitting region for this soft component, of much less than a light-year for PG 1351+ 640, and less than two light-years for M kn 1239, restricting the sources to the area not much larger than the broad line region.

4.2. Spectral Fitting

4.2.1. Power (Law M) models

We test each of our spectra to a simple absorbed power-law model, both with \( N_H \) held constant at the Galactic value, and allowing it to vary. As an example, we show in Figure 2 the data and folded model for our highest SNR object, PG 1351+ 640. Below we discuss how the spectra for the other objects differ. We also show, in Figure 3, the 2 contour plot which results from minimizing \( \gamma \) as a function of \( N_H \) and for this object. The contours represent the 68%, 90%, and 99% confidence limits (1, 1.6, and 2.6, respectively) and the plus marks the best( t value. The contour plots for our strongest 6 objects (in terms of total counts) PG 1351+ 640; NGC 5055; M kn 1239; NGC 424; NGC 4388; and NGC 5135) look roughly the same as this one, and those for the other objects look increasingly \( \beta \) bent", with less well-defined maxima as the total number of photons decreases.

As indicated in Table 2, when \( N_H \) is allowed to vary, the best( t value is always higher than the Galactic value, by a factor of 2|3 (again, for the 6 well(determined spectra), the one exception being PG 1351+ 640 which shows no increase. The fact that \( 2 \) (reduced \( 2 \)) decreases by \( 35-50\% \) when allowing \( N_H \) to vary indicates that these values are more accurate than the Galactic ones. This indicates that there is indeed some internal absorption of one form or another in these objects, and that the underlying slope is steeper than that which is obtained when requiring \( N_H = N_H \); gal. We illustrate this in Figure 4, where we plot the photon indices obtained with \( N_H \) free versus with \( N_H \) fixed. Most of our Seyfert 2s, as well as those from TUM, have the former steeper by \( 1 \).

The average values of which we obtain with \( N_H \) free are \( = 3 \) for our 4 Seyfert 2s with significant counts, and \( = 3 \) for our two Seyfert 1/Q SO s. These values are similar to the six Seyfert 2s observed by TUM, which have \( = 3 \), but differ from the six Seyfert 1/Q SO s observed by TGM which have \( = 2.4 \).

In Figure 5, we plot the photon index versus count rates for the pointed observations of this work, TUM, and TGM. We see that most of the objects have significantly steeper values of than the old canonical value of 1.7 (dotted line). All of our well( observed Seyfert 2s (dotted triangles), and most of TUM’s Seyfert 2s (open triangles), and both of our Seyfert 1/Q SO s have values of 3. The one exception is M kn 372 which has a value of \( = 2.2 \). However this object is now known to be a Seyfert 1, and, as expected lies close to the average value of the Seyfert 1/Q SO s from TGM at \( = 2.4 \).

What these data show us, and, not only do most Seyfert 2s have a best( t photon index around 3, but also that Seyfert 1s are divided between objects which have similar spectral slopes as Seyfert 2s and those which have softer spectra with 2. Physical explanations for this are discussed further in x[5] and x[7].
4.2.2. Internal Absorption

For each of our targets, we looked at the best-fit hydrogen column density as compared to the Galactic value, and compared this to the photon indices and hardness ratios, to try to determine the significance of internal absorption and how this affects the observed count rates and spectral shape. Figure 5 seems to indicate that a few of the faintest objects also have the hardest spectra. This is tentative, however, since these objects are the ones with the fewest photons and the data are not very trustworthy. However, we do note that, if real, this is consistent with these faint objects being the most heavily absorbed (i.e., with low signal-to-noise, a heavily absorbed, intrinsically steep spectrum would appear similar to a relatively unabsorbed at spectrum). We investigate this trend further by plotting the spectra of our 8 brightest objects in Figure 6 (in order of brightness, from the upper left, down to the lower right), to a power law with $N_\text{H}$ free. The general trend is for the fainter objects to have harder spectra (as also indicated by the hardness ratios in Table 3), with the 4 highest hardness ratios belonging to 4 of the 5 lowest-count objects (the exception being NGC 3982 which actually has one of the lowest hardness ratios).

To determine whether these harder spectra objects may be more heavily obscured by dust, we have compared their ROSAT hardness ratios to their IRAS colors (see Figure 7). Six of our objects are very dusty in the far IR, having values of $\log F_{10} = F_{25} < 0.8$ 16$, which is among the reddest (which probably means the dust is enshrouded) third of even Seyfert 2s (Rush et al. 1993). This includes the four lowest-count objects in our sample. Conversely, both PG 1351 and Mkn 1239 have values of $\log F_{10} = F_{25} < 0.15$, which is among the hottest 20% of even Seyfert 1s. However, there is no strong relation of the IRAS color to the hardness ratio other than that of the three hardest objects are also among the reddest.

Taken together, these results indicate that there is a trend for the fainter objects to have harder ROSAT spectra, indicating that absorption is partially responsible for steepening the spectra. However, there is less evidence that the amount of absorption is correlated with redness/dustiness in the galaxy, as determined from IRAS colors.

4.2.3. Additional Models

We also tried some of our spectra to other models. These include a power law plus an emission line or them all component. Raymond (Smith et al. plasm allowing a blackbody), or them all component alone. As discussed in X-ray for individual objects, there are several cases where the $t$'s in Table 3 indicate that the $t$ more than a simple power law may be necessary to explain the soft X-rays.

First, we added an additional component to the underlying powerlaw. The $t$'s to neither of our Seyfert 1/QSOs were improved by adding another component. This is as expected, as the powerlaw to both objects were quite good ($^2_0$ of 0.79 and 0.67 for PG 1351+640 and Mkn 1239, respectively). The $t$ did improve, however, when we added an emission line to some of our Seyfert 2s. See, for example, Figure 8 which shows the model for a power law plus gaussian emission line to NGC 5005. The best $t$ energy for this line is at 0.8 keV, around the energy expected for Fe(L and/or Oxygen K emission lines.

Adding this component also has the effect of attenuating the underlying powerlaw slope from 3.0 to 2.4. Similar results are obtained for the $t$s to NGC 5135 and NGC 4388, which are slightly improved by adding emission lines at 0.5, and 0.6 keV, respectively.

We also tried fitting each object to a thermal model only. Again, both Seyfert 1/QSOs were not a good fit at all well in this way. However, several Seyfert 2s with PG 5005, NGC 5135, NGC 5929, and NGC 1144, were better (i.e., lower $^2_0$ for the same number of free parameters) by a $0.2$ keV blackbody plus an absorbed powerlaw (see, for example Figure 9 for the blackbody to NGC 5135). This is significant in that it prevents us from saying conclusively that the soft X-rays from these objects are associated with the AGN at all, and that they may simply be due to stellar processes. It is not likely that ROSAT data alone will be able to definitively distinguish between stellar and nonstellar explanations for the X-ray emission from Seyfert 2s, as the most definitive tests to discriminate between such models are best done in the hard X-rays (e.g., Ina wasawa 1995).

4.3. Spatial Extent

4.3.1. HRI Image of NGC 5005

If multiple components are responsible for the soft X-rays in these objects, it is quite possible that
are from spatially distinct regions, as is already known to be the case for some brighter Seyfert galaxies. For example, the brightest and best observed Seyfert 2 in the X (rays) is NGC 1068, the prototype of a Seyfert 2 which may be a hidden Seyfert 1. HRI Imaging (Wilson 1994; Halpern 1992; Wilson et al. 1992) of this object reveals at least three components to the soft (X (ray emission): (a) a compact nuclear source, coincident with the optical nucleus, (b) an asymmetric emission extending 10/-20 kpc with the radio jet and narrow [O III] emission, and (c) large-scale (60/-20 kpc) emission with similar morphology to the starburst disk. These three components comprise 55%, 23%, and 22% of the X (ray uX, respectively.

To investigate whether similar structures may be responsible for part of the soft X (rays from our much fainter) objects, we obtained a 27 ksec HRI exposure of our brightest Seyfert 2 galaxy, NGC 5005, shown in the contour plot in Figure 10 (the contour values range from 0.05 to 0.6 photons/pixel and the spatial resolution is 0'/2/pixel). The central source spans 20/-20 kpc, and is significantly extended (FW HM 10'/2) as compared to the HRI on (axis PSF FW HM 5'/2). The position of the peak of this central component agrees within error to the optical position, and is roughly 3'/2 south of the radio (interferometer position given by Villa et al. 1990).

In addition to this central component, there is an extended wing from about 10/-20 to 25/-20 kpc to the south-west of the central source (from 0.6/-1 kpc to 1.4/-1 kpc). This feature contains about 13% of the total counts (subtracted counts as does the central source). It is not observed by TUM, which are Marakarian objects (optically) identified X (ray sources about / from each of the six Seyfert 2s observed in their program. In some cases (e.g., NGC 1365) these sources are likely bright X (ray sources in the host galaxy, and in others (e.g., Mkn 78) they are likely low luminosity AGNs. We looked for such sources in the HRI image of our 12 m Seyfert 2s, and found none. The number of Seyfert 2s observed between these two samples makes it unlikely that this difference could be explained simply by chance. One possible explanation is that the objects in TUM are galaxies previously known to be relatively bright in the X (rays from Einstein IPC observations, and that these extended sources could have contributed to the Einstein uX.

4.3.2. PSCP Images

None of targets show extended emission in the PSCP image. However, not being primarily an imaging instrument, the resolution does not show structure on much larger scales than the HRI, and cannot be used to rule out subarcminute scales, as exemplified by the fact that our HRI image of NGC 5005 clearly shows structure not apparent in the PSCP image of ages (up to 25 kpc) of the object.) Several of the images contain extended objects 10/-20 from the target, clearly distinguished by the resolution of the PSCP. The only exception is NGC 1144, which is not separated from NGC 1143. Since the latter is a non-active galaxy the X (rays are likely to be mostly from NGC 1144, however we note the PSCP spectrum is a combination of these two sources. It is interesting to note that TUM found serendipitous (optically) unidentified X (ray sources about / from each of the six Seyfert 2s observed in their program. In some cases (e.g., NGC 1365) these sources are likely bright X (ray sources in the host galaxy, and in others (e.g., Mkn 78) they are likely low luminosity AGNs. We looked for such sources in the HRI image of our 12 m Seyfert 2s, and found none. The number of Seyfert 2s observed between these two samples makes it highly unlikely that this difference could be explained simply by chance. One possible explanation is that the objects in TUM are galaxies previously known to be relatively bright in the X (rays from Einstein IPC observations, and these extended sources could have contributed to the Einstein uX.

5. Discussion

5.1. The Standard Soft X (Ray Slope for X (Ray Weak Seyferts

Considering both our data and that of TUM, it appears that a steep spectral slope, around = 3, should be considered the standard slope for X (ray) weak Seyferts. This includes virtually all Seyfert 2s, as indicated by the results that have been derived for Seyfert 2s displaying a wide range in multiwavelength characteristics. As discussed in Section 5.1, our objects were chosen from the 12 m sample and thus have redder optical/infrared colors than the objects observed by TUM, which are Marakarian objects of
selected as having a strong UV excess.

Even the prototypical Seyfert 2 galaxy, NGC 1068, resembles these objects. Monier & Halpern (1987) observed this object with Einstein, finding a 0.1| 3.8 keV photon index of $3.9$, and $N_H$ consistent with the Galactic value. Our data from the RASS give a 0.1| 2.0 keV value of $= 2.78$ for this object (Rush et al. 1996), which is slightly harder, but consistent when considering that our RASS data was taken with $N_H$ constrained to $N_H_{gal}$.

This category of X-ray/soft AGN not only includes most Seyfert 2s, but also X-ray/weak Seyfert 1|Q SOs, such as PG 1351+ 640 and Mkn 1239. That the soft X-ray source in these objects may be the same as in most Seyfert 2s is consistent with their selection as being X-ray/weak for Seyfert 1/Q SOs. In contrast, other Seyfert 1/Q SOs, e.g., those observed by TGM, were known to be relatively strong in the soft X-rays, and thus one would expect those objects to have X-ray spectra more similar to conventional Seyfert 1s. Thus, it seems that the standard Seyfert 2|Seyfert 1 dichotomy in not the simplest way to categorize these AGN in the soft X-rays. Rather, we could refer to (relatively) steep, X-ray/weak objects and at, X-ray/strong objects, whose soft X-rays are probably dominated by different components.

We also found steep average spectral slopes in our RASS data (to be analyzed thoroughly in Rush et al. 1996), of $\gamma_{S1} = 2.24 \pm 0.49$ and $\gamma_{S2} = 2.86 \pm 0.48$ for 39 Seyfert 1s and 5 Seyfert 2s, respectively (uncertainties quoted are 1 individual scatter). These were done with $N_H$ constrained to $N_H_{gal}$, and thus the best-fit slopes are likely a little steeper, depending mainly on the amount of internal obscuration. This could place the average slope of the Seyfert 2s over 3 and that of the Seyfert 1s around 2.4| 2.5. This and the fact that there is a wide range of slopes for the Seyfert 1s, with over 1/3 being steeper than $= 2.5$ assuming no internal absorption, makes these results consistent with those for our pointed observations (namely that all Seyfert 2s and some Seyfert 1s have slopes much closer to 3 than to 2. Similar results have been found in other works, for example Boller, Brandt, & Fink (1995a), who surveyed 46 narrow-line Seyfert 1s with ROSAT and found them all to have extremely steep spectra (some with as high as 5).

5.2. Physical Interpretation

There are several competing explanations for the steep slopes observed in many X-ray/weak Seyferts, as compared to the steeper slopes observed in conventional X-ray/strong Seyferts. The physical models which may be able to explain all or part of the observed differences between steep and at slope Seyferts include:

1) A separate, hard power-law present in steep objects which is very weak, such as a scattered component. Although we see no evidence of such a component in our ts, we cannot rule out this possibility, as observations in a larger wavelength baseline of X-ray/weak Seyferts may detect such a component if it is extremely faint.

2) Much of the soft spectrum of steep objects being produced by the same physical mechanism, located in the same place, as the soft excess observed in many at objects. In this model, steep objects have relatively more soft excess and less of the hard power-law.

The evidence for this type of spectrum would be that to a power-law (only a model would give a very steep slope, but that adding the soft excess would attenuate the underlying slope while in proving the t. As discussed in x4,2,3, and x6, we have evidence for this in several of our objects, and even a pure blackbody with no underlying power-law cannot be ruled out in some cases. This is even more evident in TUM, as most of their objects are tted significantly better when either an emission line or Raymond-Smith plasma are added to the power-law. If we do assume that a very soft excess exists in these objects, a physical model for this excess still remains to be determined. For example, it could be their emission from the galaxy, hot gas near the nucleus, iron and/or oxygen emission line(s), or the UV bump shifted into the ultra-soft X-rays as suggested in Boller et al. (1995a). But, again, we stress that such evidence is not universal, as several of our objects show no definite preference for anything other than a power-law.

3) That the soft spectrum we see in X-ray/weak Seyferts represents a component present in most or all Seyferts, but which is much weaker in X-ray strong objects and is thus suppressed by the hard spectrum in those objects. If so, this universal component non-nuclear, i.e. similar to the soft X-ray observed in normal starburst galaxies (from, e.g., X-ray binaries and SNRs)?
(4) That the soft spectra arise from the same physical process (and from the same location) as the at power laws in some Seyfert 1s, but with a higher value for , caused by variance of one or more intrinsic physical parameters? For example, of several explanations Boyle et al. (1995a) suggest for their steep spectra, one of the more promising ones is that the central engine in these objects is at a lower mass than other Seyfert 1s, and would thus have an accretion disk emitting at a higher temperature, shifting the UV bump into the low (energy end of the ROSAT band, steepening the X-rays. This idea is also one possible explanation for the steep spectra we found in PG 1351+ 640 and MKN 1239, as well as other X-ray weak Seyfert 1/QSO s. To test the idea thoroughly, one would need to observe the spread in for many X-ray weak and X-ray strong Seyferts and see if there is a continuous range of observed values, as opposed to a more-or-less bimodal distribution. If such a range is observed, then detecting any X-ray or multiwavelength parameter which is correlated with would provide information about the fundamental cause of its variance.

Finally, an important caveat in this distinction between X-ray weak and strong Seyferts is that our X-ray weak and strong Seyfert 2s in the soft X-rays, which is seen in several ways: (1) even though the former have the same steep slope when fitted to a power law, they are more often fitted only by this steep power law, as opposed to a power law plus an additional component (and PG 1351+ 640 cannot be fitted at all by any model other than a pure power law); (2) they are also more luminous in the soft X-rays than all but the very strongest Seyfert 2s; and (3) they show less indication of internal absorption (above the Galactic value): of all our objects, PG 1351+ 640 is the only one not to have even the slightest evidence for internal absorption in a power law, and several of our Seyfert 2s show much stronger evidence for internal absorption than does MKN 1239. This last difference is of particular importance because it can affect the measured parameters in each of the models listed above. These differences imply that, although the observed soft X-ray emission from these Seyfert 1/QSO s is similar to that from Seyfert 2s, the underlying physical processes are probably at least partially different. Perhaps, for example, the X-ray weak Seyfert 1/QSO s are best explained by one or more of the models listed above, but the Seyfert 2s by another. Thus, whereas is seen s as though these relatively X-ray weak Seyfert 1/QSO s should not be strictly grouped with the more luminous (at slope) Seyfert 1/QSO s with regards to the soft X-ray properties, they still appear somewhat distinct from even the relatively X-ray strong Seyfert 2s and perhaps represent an intermediate or mixed class.

6. Notes on Spectral Fits to Individual Objects

6.1. PG 1351+ 640 and MKN 1239

These two Seyfert 1/QSO s were relatively well observed, with 990 and 595 counts obtained, respectively. Both were well fitted with a simple power law. For our strongest object, PG 1351+ 640, no improvement is obtained by allowing to vary, giving no indication of internal absorption. For MKN 1239, an increase of about a factor of 1.5 in over the Galactic value reduces from 0.95 to 0.77, perhaps indicating some internal absorption.

We tried to fit each object to the other models listed in Table 2. For PG 1351+ 640, the parameters returned each time indicated that a single power law was preferred (i.e., the normalization for other components was at or near zero). MKN 1239, on the other hand, well to a power law model with the addition of a Gaussian emission line around 0.7 keV. This t was not, however better than those with a Rayleigh profile or a blackbody replacing the emission line. Thus, if there is a second component to the soft X-rays spectrum, we cannot distinguish among several possibilities for its shape.

For PG 1351+ 640, we also separately fit the spectrum which were taken during 1992 November and 1993 October to a power law model. A slight increase in the best t is found in the more luminous state.

6.2. NGC 424, NGC 4388, NGC 5005, and NGC 5135

These four Seyfert 2s each yielded at least 400 counts (see Table 1), sufficient for accurate spectral fitting. For these objects, an average photon index of = 3.13 (3.0, 3.2, 3.2, and 3.2, respectively) was obtained when was allowed to vary, and of = 2.90 (1.7, 2.1, 1.9, and 2.3) when was constrained to the Galactic value.

In all cases, we tried adding another component to the t. In the case of NGC 5135 the t was improved
at a significance level of > 90%. This object has the hardest spectrum of these four Seyfert 2s. Considering that it is also the largest \(N_\text{H}\), the hard spectrum and the good fit to a second component above 0.5 keV both probably indicate significant absorption of the softest X rays below 0.5 keV. Adding emission lines also improved the fit to NGC 5005 (> 99% significance level) and NGC 4388 (> 90%). Only in the case of NGC 5005 was the emission line at the energy expected for Fe L and/or O Kx detected by the large X-ray spectrum of the four Seyfert 2s. Considerably lower significance levels were obtained, allowing only 12 and 9 points (bins) above 0.5 keV both probably indicate significant absorption and the good fit to a second component, respectively.

Interestingly, we also observed the NGC 5005 and NGC 5135 to a black-body model and obtained better fits than to a power-law model, further indicating that we don't know the source of the soft X rays whether they are from the non-stellar active nucleus or from stellar processes such as X-ray binaries or supernova. In the latter case, we have some evidence that a small contribution of the soft X rays may come from an extended component, as discussed in the spectral analysis of NGC 5005.

6.3. IRAS F01475+0740 and NGC 5929

For these two objects, only 276 and 200 counts were obtained, allowing only 12 and 9 points (bins) for the spectral fitting, respectively. Interestingly, relatively to the 0.5–2.0 keV range, F01475+0740 has almost no counts below 0.5 keV, and NGC 5929 has very few. In fact, F01475+0740 has the hardest spectrum of any object we observed, indicated both by the hardness ratios in Table 3 and by the very high uncertainty of the 0.5 keV count rate. NGC 5929 also has a harder spectrum than any of the objects discussed above, but not nearly as hard as F01475+0740. This may indicate that these objects are very heavily absorbed, which would explain both the low overall flux and the hard spectrum.

When adding another component to the power-law fit for F01475+0740, the slope tended towards zero (as at least we would allow) with only a small contribution from the other component, indicating nothing more than the very hard spectrum of the simple power-law. For NGC 5929, a slight improvement in the fit was obtained by adding a second component, similar to some of the brighter four Seyfert 2s discussed above, but with much less statistical significance.

6.4. NGC 3982 and NGC 1144

These two objects yielded so few counts that can only give a very rough estimate of the best-fit photon index, which is 2.12 and 1.90 for NGC 3982 and NGC 1144, respectively with \(N_\text{H}\) set to zero. Only NGC 3982 had enough photons to allow a fit with \(N_\text{H}\) variable, which yielded = 3.4. Although this slope is similar to the values for our bright Seyfert 2s, the spectra do not look similar. NGC 3982 has the softest and NGC 1144 the second hardest count rates of any of our Seyfert 2s. There were not enough counts to fit to a composite model, but we did try to fit these spectra to a simple black-body, to estimate whether or not a power-law is even the most descriptive of the soft X rays. For NGC 3982 there was only marginal improvement in the fit, but for NGC 1144 it did drop by almost a factor of two for the black-body fit as compared to a power-law.

6.5. CGCG 022 (021)

In addition to the 10 Seyfert galaxies discussed above, we also observed one IR luminous non-Seyfert which had been detected by the ROSAT All-Sky Survey. We would expect the ROSAT spectra of this type of object to be similar to those from Seyfert 2s, both of which emit strongly in the thermal, but relatively weakly in the X-rays, if the X-ray emission in the latter are produced by the normal processes of stellar evolution, as in classic starburst nuclei like NGC 7714 (Wiedemann et al. 1981).

Unfortunately, the observation of CGCG 022 (021) yielded only 81counts, and a count rate of 0.010 0.003 cts/s, which is not sufficient for a detailed spectral analysis. There may be some indication of variability, since the RASS count rate was 0.064 0.018 cts/s, indicating a >2 change. However, this is very tentative as the background subtracted counts obtained in the pointed and RASS observations are only 81 and 26, respectively.

We do see, though, that this non-Seyfert has a hard spectrum quite similar to that of several of the weaker Seyfert 2s F01475+0740, NGC 5929, and NGC 1144. This indicates that heavy internal absorption is probably present. To describe the spectrum further, we attempted to fit a simple power-law and a black-body model to the X-ray flux, although with high uncertainties. A simple power-law and a black-body model provided similar accurate fits (2 of 1.2 and 1.3, respectively), however the error bars are high.
7. Summary and Conclusions

We have analyzed pointed ROSAT PSPC spectra of 11 objects selected as having atypical soft X-ray emissions. These include 8 Seyfert 2s and one IR (luminous non-Seyfert) selected from the Extended 12 m Galaxy Sample, which all have relatively strong detections in the ROSAT All-Sky Survey, as compared to other objects in their class. We also observed on X-ray weak Seyfert 1/QSOs from this sample and a similar object selected from the PG Bright Qasar Survey.

We found both Seyfert 1/QSOs, Mkn 1239 and PG 1351+640, to vary in flux by a factor of 2 and 1.5, over periods of less than 2 and 1 year, respectively. Both objects had steeper spectra in their more luminous state, indicating that the variability was mainly due to the softest X-rays, which are connected to a size of less than a parsec.

All of our Seyfert 2s, which had acceptable counts for accurate spectral fitting, as well as both Seyfert 1/QSOs, have soft X-ray photon indices of 3, similar to the Seyfert 2s observed by TUM. The wide spread occurrence of such steep slopes suggests that this value of 3 is the norm for a wide variety of AGN, namely Seyfert 2s and many Seyfert 1/QSOs. Therefore, discussing relatively steep (3), X-ray weak objects versus at (2), X-ray (strong objects may be a more fundamental way to separate Seyferts with respect to the soft X-rays than the usual type 1 (type 2) dichotomy (derived primarily from optical spectra).

There are several possible explanations for these steep slopes. One is the presence of a very soft (<1 keV) excess in addition to a harder underlying continuum. We see strong evidence in the spectra to some of our objects for such a component, but a physical model for this excess still needs to be determined. It could be strong iron and/or oxygen line emission, a blackbody, or even a thermal plasma. However, several of our objects show no definite preference for anything other than a steep powerlaw. Alternatively, both at and steep components could be present in some Seyferts, with one or the other dominating depending on internal physical conditions. Or the steep and at spectra observed in different objects may have the same basic origin, but with variance of one or more parameters affecting the measured slope. Distinguishing between these and other models for the X-ray emission from Seyferts can best be done by testing multiple component models over the entire 0.1-10 keV range, where the distinguishing spectral signatures of competing models can be most clearly identified. Thus, obtaining high SNR spectra of X-ray weak Seyferts, with several thousand of counts both in the soft and hard X-rays, should prove a profitable pursuit of current and future X-ray missions.

Finally, we obtained a ROSAT HRI image of one Seyfert 2 (NGC 5005) and found about 13% of the flux to come from an extended component. This implies that multiple components of the soft X-ray spectra of Seyferts may arise in spatially distinct regions, as has been previously observed primarily in brighter objects. Further, deeper in ages of X-ray weak Seyferts will be necessary to determine the physical processes giving rise to these components, as well as how common such phenomena are in Seyfert galaxies.

We thank Jane Turner for much help in understanding the PROS and XSPEC software, the ROSAT data, and the specifications of the PSPC, and for providing us with the results of TUM and TGM before publication. This work was supported by NASA grants NAG 5(1358) and NAG 5(1719).
REFERENCES

Awaki, H. 1993, in Proc. of Nagoya Conference on X-Ray Astronomy, in press

Boleli, T., Brandt, W. N., & Fink, H. 1995a, A&A accepted.

Boleli, T., Dennefeld, M., Fink, H., M. eurs, E. J. A., & Molendi, S. 1995b, submitted to A&A

Boleli, T., M. eurs, E. J. A., Brinkmann, W., Fink, H., Zimmermann, U., & A dorf, H.-M. 1992, A&A 261, 57

Brikman, W. 1992, in Physics of Active Galactic Nuclei, Eds. Duschl, W. J. & Wagner, S. J. (Berlin: Springer-Verlag), p. 19

Canizares, C. R., Kess, G. A., Kuiper, J., & Urry, C. M. 1986, in Proceedings of the IAU Symposium, Bangalore, India, Dec. 2–6 1985. (Dordrecht: D. Reidel Publishing Co.), p. 253

Halepem, J. P. 1992, in Testing the AGN Paradigm, AIP Conference Proceedings 254, Eds. S. S. Holt, S. G. Ne, & C. M. Urry, p. 524 (American Institute of Physics)

Halepem, J. P. & Moran, E. C. 1993, in Cambridge AGN Conference, in press

Hasinger, G. & Snowden, S. 1990, MPE note entitled "Calibration Corrections to Individual Events."

Iwasawa, K. 1995, preprint

Koyama, K., Inoue, H., Tanaka, Y., Awaki, H., Takano, S., Ohashi, T., & Matsuoka, M. 1989, PASJ 41, 731

Lampton, M., Margon, B., & Bowyer, S. 1976, ApJ 208, 177

Monier, R. & Halepem, J. P. 1987, ApJ 315, L17

Mushotzky, R. F. 1984, Adv. Space Res. 3, 157

Piccinotti, G. P., Mushotzky, R. F., Borkin, E. A., Holt, S. S., Marshall, F. E., Serlemitsos, P. J., & Shafer, R. A. 1982, ApJ 253, 485

Rush, B. M., A Ikan, M. A., & Spinoglio, L. 1993, ApJ 89, 1

Rush, B. M., A Ikan, M. A., Fink, H., & Voges, W. 1996, in prep.

Tananbaum, H., Avni, Y., Goren, R. F., Schmitt, M., & Zamorani, G. 1986, ApJ 305, 57

Turner, T. J., George, IM., & Mushotzky, R. F. 1993, ApJ 412, 72 (TGM)

Wilson, A. S., Elvis, M., Lawrence, A., & Bland-Hawthorn, J. 1992, ApJ 391 L75.

Wilson, A. S. 1994, STScI preprint No. 813, to be published in the proceedings of the ROSAT Symposium, held 8–10 Nov. 1993 in College Park, MD.
**FIGURE LEGENDS**

**Figure 1** | Our pointed PSPC count rates versus count rates from the ROSAT All-Sky Survey. Squares are Seyfert 1/QSOs, triangles are Seyfert 2s, and the star is our IR luminous non-Seyfert. Point sizes / total counts. Error bars are statistical uncertainties. The solid line represents CTR_{Pointed} = CTR_{RASS}.

**Figure 2** | PSPC Spectrum of PG 1351+640, fit to an absorbed power law with \( N_H \) free.

**Figure 3** | Contour plot of \( N_H \) vs. for the fit shown in Figure 2. Contours represent confidence limits of 68, 90, and 99% and the plus marks the best fit value.

**Figure 4** | Photon Index for power law fits with \( N_H \) free versus \( N_H \) constrained to \( N_H \) _gal_. The solid lines represent \( N_H \) _gal_ = \( N_H \) _free_ = \( N_H \) _gal_ + 1. Symbols are the same as in Figure 1, with open triangles representing Seyfert 2s from TGM.

**Figure 5** | Photon Index for power law fits with \( N_H \) free, versus log count rate. Symbols are the same as in Figure 1, with the addition of open squares and open triangles for the Seyfert 1/QSOs in TGM and the Seyfert 2s in TGM, respectively. Point sizes / total counts. The dotted line shows the canonical value of \( \gamma = 1.7 \). For the Seyfert 1/QSOs from TGM, there was little spread in 5 of 6 objects between 2.11 - 2.50 and the other 5 at 3.10), and thus only the average value is shown here.

**Figure 6** | PSPC spectra of all of our 8 brightest objects, each fit to an absorbed power law with \( N_H \) free. The objects are placed in order of total counts obtained, starting with PG 1351+640 in the upper left, going down each column, to NGC 1144 in the lower right. (Figure 6 is placed last among the figures.)

**Figure 7** | IRAS 25\( \mu \)m color versus hardness ratio. Symbols are proportional to total counts.

**Figure 8** | Model of the total power law plus emission line to our PSPC spectrum of NGC 5005, where the individual components are shown. The dotted line is a gaussian emission line at 0.8 keV, the long dashed line is the absorbed power law, and the solid line is the total model.

**Figure 9** | PSPC Spectrum of NGC 5135, fit to a black body model.

**Figure 10** | Contour plot made from our 27 ks HRI image of NGC 5005. Contours range from 0.05 to 0.60 photons/pixel. The spatial resolution is 0.25 per pixel.