X-RAY STUDIES OF SEYFERT GALAXIES AND QUASARS

Claude R. Canizares, Gerard A. Kriss[1], John Kruper and
C. Megan Urry
Department of Physics and Center for Space Research
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139 U.S.A.

ABSTRACT. We present results of studies carried out with the imaging instruments on the Einstein Observatory. We summarize a statistical analysis of the X-ray properties of optically selected, radio quiet quasars including nine new high redshift quasars detected in two deep X-ray surveys. We find that the X-ray to optical luminosity ratio of optically selected quasars decreases with increasing optical luminosity. It depends only weakly, if at all, on redshift. However, the distribution function does not properly account for the properties of the X-ray selected Medium Sensitivity Survey sample (MSS). We note that part of the discrepancy could be due to the presence of red, low luminosity quasars in the MSS but not in the optically selected samples. We also summarize some results from a detailed study of the X-ray properties of 64 Seyfert galaxies. None of the spectral fits performed for the brightest 20 required unusually steep spectra, although in many cases the spectral indices were not well constrained. Of the ten objects with good measurements of the absorbing column density, three showed excesses above the galactic value while the remaining seven gave excess columns generally less than 2×10^{20} cm^{-2} and consistent with zero. Variability studies of the full Seyfert sample showed three objects to be variable on timescales of a few hours. One of these is the Seyfert II Mkn 78.

1. X-RAY PROPERTIES OF OPTICALLY SELECTED RADIO QUIET QUASARS

We have recently published the results of a study of optically selected, radio quiet quasars (Kriss and Canizares 1985). Our data set of 77 quasars and Seyferts and 101 upper limits includes objects from the literature (through 1984) and new data from our Einstein Observatory exposures of fields that had been surveyed optically for quasars using grism techniques (Hoag and Smith 1977, Sramek and Weedman 1978). We detected 9 of the 23 optically selected quasars; this 40% detection rate is high compared to that of earlier surveys and merely reflects the long

[1]Present address: Johns Hopkins University

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(~ 50 ksec) exposure times. Inclusion of these objects nearly doubles the number of high redshift quasars in the sample, which is very important in defining the possible z dependence of their X-ray properties (see Margon's contribution to this meeting).

Figures 1 and 2 show the X-ray to optical fluxes and luminosities for the sample. There is a strong correlation in both flux and luminosity: the ratio of X-ray to optical luminosities scatters by less

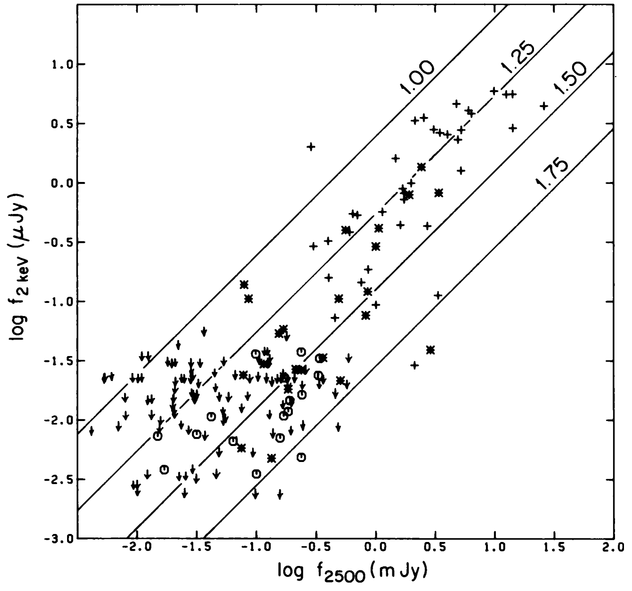

Figure 1. X-ray vs. optical flux for optically selected, radio quiet quasars from Kriss and Canizares (1985). The solid lines are the loci of constant α_{ox} as indicated. The arrows indicate upper limits and the symbols represent Seyfert galaxies (+), UV selected objects (*) and grism selected objects (circles).

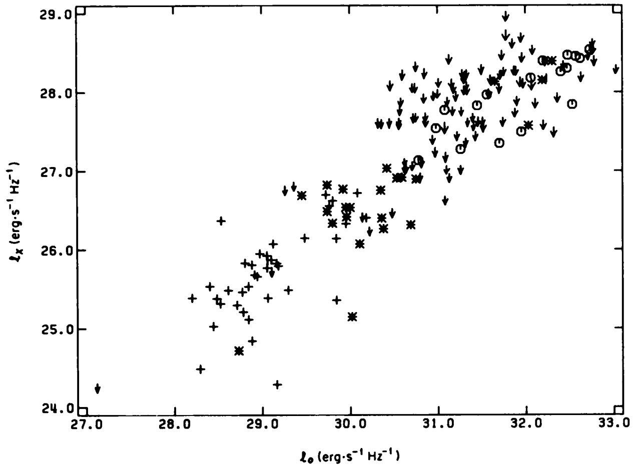

Figure 2. X-ray vs. optical luminosities for the objects shown in Fig. 1.

than two orders of magnitude over five orders of magnitude of luminosity -- from Seyferts to the most luminous quasars. One thing that these plots show is that the term "X-ray quiet quasar" is simply inappropriate. Our statistical analysis of the upper limits indicates that they are fully consistent with the detections (i.e. the undetected objects can be drawn from the same parent distribution as the detected objects with high probability). Thus few, if any, quasars lack significant X-ray emission (see also Avni and Tananbaum 1986).

There has been great interest in looking beyond the evident $L_x - L_o$ correlations to see if L_x/L_o, or equivalently $\alpha^x_{ox} = - [\log L_x/L_o]/2.605$, depends on luminosity or redshift; that is, to see if there is any curvature in Fig. 2 (we take L_x and L_o to be monochromatic luminosities at 2 keV and 2500 Å, respectively, in the quasar rest frame). In Kriss and Canizares (1985) we describe the various parametric and non-parametric statistical analyses that we applied to the data (using the methods of Avni et al. 1980). The specific parameters we derive are consistent with those found earlier by Avni and Tananbaum (1982), although our uncertainties are considerably smaller because of our larger sample.

There is now remarkable agreement among all workers in this field about the amount of X-ray emission from optically selected quasars (see Zamorani's and Margon's papers at this meeting and the recent work by Avni and Tananbaum 1986 and Schmidt and Green 1986). All agree that α_{ox} has a strong dependence on L_o corresponding to the relation $L_x \sim L_o^{0.7}$; we are able to rule out independence of the two variables with high significance. On the other hand there is at most only a weak dependence of α_{ox} on redshift, and independence is permitted by our data.

It must be stressed that these relationships are purely phenomenological; their physical meaning is not at all clear. In particular, the recent work on the IR to X-ray spectra of quasars being performed by Elvis and colleagues (see Elvis et al. 1985 and the contributions by Elvis, Fabbiano and Wilkes in this volume) shows that one must be exceedingly cautious in interpreting anything as primitive as a two-point power law index that spans 2.6 decades of frequency. One clear problem is that by choosing to measure L_o at 2500 Å we are very sensitive to the relative contributions of both the "big bump" and "little bump" in the optical/UV spectrum. If these change with L_o and/or z it could cause an apparent α_{ox} dependence even if the underlying power law continuum were fixed. We are now trying to obtain better measures of the underlying optical-to-X-ray spectrum in hopes of refining the analysis.

2. X-RAY SELECTED ACTIVE NUCLEI

A glaring reminder of our lack of understanding about the X-ray properties of quasars is our inability to use the models derived for optically selected objects to account for the observed properties of X-ray selected objects. This was addressed by Kriss and Canizares (1985) as it has been by others (Zamorani and Maccacaro, this meeting, Zamorani 1982, 1985, Maccacaro 1984, Franceschini, Gioia and Maccacaro 1986, Avni and Tananbaum 1986, Schmidt and Green 1986). Briefly, the data of the *Einstein Observatory* Medium Sensitivity Survey (MSS; Gioia et al. 1984) are not commensurate with the optically selected samples in α_{ox} dependence, z distribution, luminosity function slope and number counts. In Kriss and Canizares (1985), we point out that part of the discrepancy could arise from the presence in the MSS of a large number of low luminosity red objects (with B - V > 0.65) which are not represented in optically selected samples. These tend to lower the redshift distribution of the MSS. Some of the objects may be intrinsically red, but there are also likely to be effects of reddening, X-ray absorption and contamination by galaxy light all of which can distort the α_{ox} distribution. We stress, however, that the red objects cannot explain all the incommensurability of the optical and X-ray samples; the low number counts of the MSS, for example, are exacerbated when the red objects are excluded.

Therefore, we conclude that reconciliation of the optically selected and X-ray selected samples is still a serious problem, and one must approach all discussions of the contribution of radio quiet quasars to the X-ray background with extreme caution. The MSS objects are themselves one small part of the X-ray background. If our models have trouble accounting for this part that is already directly resolved, then we should be exceedingly wary about extrapolations that attempt to explain the part that remains unresolved.

3. X-RAY PROPERTIES OF SEYFERT GALAXIES

We will now switch emphasis entirely and focus on detailed properties of a sample of Seyfert galaxies studied with the Einstein Observatory Imaging Proportional Counter (IPC). This is a continuation of the work of Kriss, Canizares and Ricker (1980). To date we have analyzed data on 50 Seyferts: 37 type I, 10 type II and 3 of ambiguous classification (we have in addition 14 X-ray upper limits).

3.1 X-ray Spectra

We were able to fit spectral models to the data of the twenty brightest objects in the sample. We used a power law modified by absorption in cold material. The mean power law index (defined as $-d[\log f_\nu]/d[\log \nu]$) is 0.86 ± 0.06 (rms), which is slightly larger than the "canonical" value of 0.7 seen in the 2-10 keV range for brighter Seyferts (e.g. see Mushotzky 1984). Although many of our indices are not well constrained, none of our fits requires the very steep spectra (spectral indices as large as 2) found by Elvis et al. (1985) for several quasars.

One interesting result involves the very low absorbing columns that we are finding for some Seyferts. Figure 3 shows the 90% confidence limits on neutral hydrogen column density along the line of sight after subtraction of the Galactic column taken from the 21 cm survey of Stark et al. (1985). Of the ten objects with good N_H determinations, all of which are Seyfert I's, three show significant excesses over the Galactic values. But the remaining seven objects have extremely low excess columns, 2×10^{20} cm^{-2} (which would correspond, for example, to a density of less than 0.06 cm^{-3} over 1 kpc). This shows that we have very clear lines-of-sight to the central engines of at least some Seyfert galaxies, which is encouraging for future studies of their intrinsic properties.

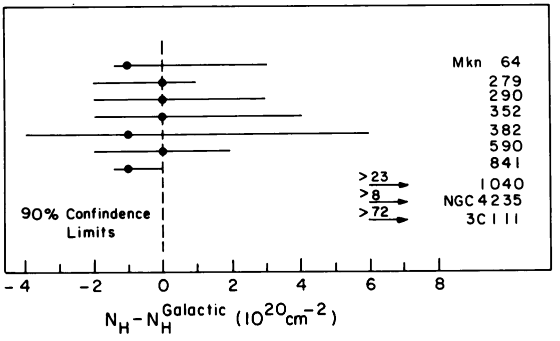

Figure 3. Residual column density after subtraction of the Galactic column for the ten Seyfert I galaxies listed.

3.2 Short Timescale Variability

The full sample of Seyferts was used to search for variability on timescales comparable to the observation time, which was typically about an hour. We used both chi squared and Kolmogorov-Smirnov (KS) tests for departures from constant flux. For all but three objects, the tests were negative, indicating limits of between 7 and 60% on the amplitude of any short timescale variability. There are three Seyferts for which the data are not consistent with a constant source intensity. These are listed in Table 1. The variability timescale is a few hours, which corresponds to a size scale of $\sim 10^{14}$ cm.

Table 1

Variable Seyfert Galaxies

Name	Type	Probability Source is Constant	Timescale (hrs)
IIIZw2	I	$<<10^{-3}$	~ 10
Mkn 766	I	10^{-5}	~ 2
Mkn 78	II	$<10^{-3}$	~ 2

This brings the number of Seyferts with observed short timescale variability to about a half dozen (Pounds 1985). Two of these are Seyfert type II's (Mkn 78 reported here, and NGC 5506) which strengthens the conclusion that at least some members of this heterogeneous class have compact active nuclei similar to those in Seyfert I's and quasars (see Elvis and Lawrence 1985). Our data fit into the rough correlation between variability timescale and luminosity presented by Barr at this meeting. Barr and Mushotzky (1986) use this correlation to suggest that the emitting regions of all Seyferts and quasars are marginally in the regime in which electron-positron pair production begins to dominate the energetics.

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DISCUSSION

Veron : Do Seyfert 2 galaxies have on average a larger column density than the Seyfert 1 galaxies ?

Canizares : None of the twenty cases we have studied is a Seyfert 2. This is because Seyfert 2's are generally lower luminosity and have insufficient flux to allow us to measure their spectra. Also, I should note that by selecting objects with sufficient signal we are also biasing ourselves against heavily absorbed objects, because these will have few counts in the IPC band.

Malkan : Your tight upper limits on the internal absorption column densities in Seyfert 1's are very nice. It's gratifying that they also imply rather strict upper limits on the reddening of the continuum (say $E_{B-V} < 0.07$ mag), which we are also deducing from the optical/UV observations of many AGN's.

Margon : With regard to your comment that the fractional contribution of QSOs to the X-ray background is highly uncertain, I want to stress that the 70% fraction quoted in our own work is most certainly an upper limit. There are very significant uncertainties, in particular the effect stressed at this meeting by Elvis and Wilkes: the tremendous uncertainty in the appropriate X-ray spectral index implies that even the measured X-ray fluxes from individual QSOs may be highly uncertain !

Canizares : I agree.

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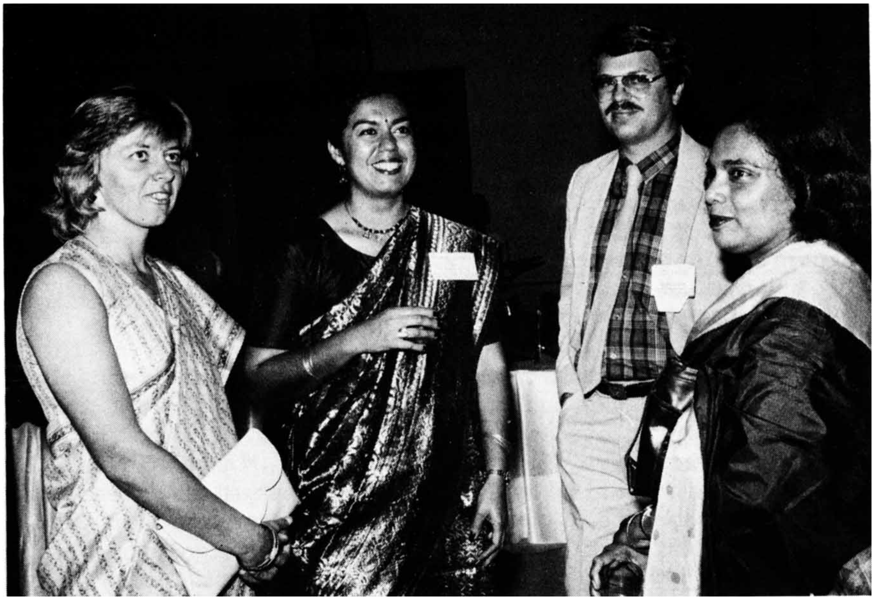

Belinda Wilkes, Rosalinda and Richard Puetter and Ranu Kundu

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