THE MEDIUM SENSITIVITY SURVEY AND THE X-RAY SELECTED QUASAR SAMPLE

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ABSTRACT. We find that the inconsistencies discussed by many authors between the expected and observed number of X-ray selected quasars cannot be attributed to incompleteness of the Medium Sensitivity Survey (MSS). We are presently expanding the survey, this effort will produce a very large sample of X-ray selected quasars. Preliminary results are presented.

Quasars were originally discovered through the identification of radio sources. Radio surveys, however, are not a very efficient way to discover new quasars. Only a small fraction, about 10%, of the quasars are in fact radio sources at flux levels detectable in surveys of a large area of sky (e.g. the Bologna, Parkes, and Cambridge surveys) and only about 20% to 40% of the radio sources detected in these surveys (depending on frequency, limiting flux etc.) are identified with quasars. Optical surveys, taking advantage of the particular position of quasars in a multicolor diagram, the quasar UV excess, or the prominence of their emission lines are, by far, the most efficient method of selecting large quasar samples.

In the last few years, as a consequence of the launch of the Einstein Observatory, an X-ray telescope capable of detecting sources as faint as 5×10^{-14} ergs cm^{-2} s^{-1}, X-ray surveys have also become an efficient way of discovering new quasars. X-ray emission is a common feature of quasars and the work of Avni and Tananbaum (1986) has shown that X-ray quiet quasars, if they exist, are limited to a very small fraction (<8%) of the quasar population. In a soft X-ray survey with a limiting sensitivity of 10^{-13} ergs cm^{-2} s^{-1}, slightly more than half of the high galactic latitude sources are Active Galactic Nuclei (quasars and Seyfert galaxies) and they are detected at a rate of about 3 per square degree (cf. Gioia et al. 1984).

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As the samples of X-ray selected quasars grow in number, it is possible to investigate whether they have the same properties of those selected by optical and radio techniques or whether different classes of quasars exist. It is possible, in addition, to test models of quasar evolution derived solely from optical data.

Maccacaro (1984) has pointed out and has briefly discussed the inconsistencies in some of the properties of optically selected and X-ray selected quasars, including their number-counts. More recently, a number of authors have undertaken a quantitative comparison of the properties of optically selected and X-ray selected quasars. We will not summarize here their detailed findings, and we refer the reader to a number of recent publications (Kriss and Canizares, 1985, Franceschini, Gioia and Maccacaro 1986, Schmidt and Green 1986 and Avni and Tananbaum 1986).

The approach followed by these autohrs consists of using the information derived from optical surveys (e.g. a luminosity function plus an evolution model) and combining it with a "description" of the X-ray to optical luminosity ratio to compute expected redshift and luminosity distributions, evolution functions, number counts, etc. for X-ray selected quasars.

The common conclusion is that the current models for the properties of optically selected quasars (luminosity function, evolution, X-ray to optical luminosity ratio) lead to inconsistencies with the observed properties of X-ray selected quasars and, in particular, to the prediction that many more X-ray selected quasars should have been detected than are actually observed.

All the above authors have used the same sample of X-ray selected quasars, the one extracted from the Medium Sensitivity Survey (cf. Maccacaro et al. 1984). This has prompted a detailed examination of possible causes of incompleteness of the MSS quasar sample (Maccacaro and Gioia, 1986).

The published Medium Sensitivity Survey is the result of the analysis of about 350 IPC observations, scattered over the sky, with the restriction that they are at least 20° above or below the galactic plane. These pointing directions are characterized by different values of the hydrogen column density. However, in the survey work, for simplicity, a constant value of 3×10^{20} cm^{-2} has been assumed for the computation of the source X-ray flux and of the image limiting sensitivity. In the soft X-ray band, photoelectric absorption plays an important role and the softer the X-ray band used, the more pronounced are the effects of small changes in the value of the hydrogen column density. The IPC has a significant fraction of its effective area below 0.3 keV. In the MSS however, only the counts recorded in the 0.3 - 3.5 keV band have been used to determine the source parameters. This reduces in part the effects of photoelectric absorption, but does not eliminate them entirely. The rather poor energy resolution of the IPC exacerbates the problem.

Maccacaro and Gioia (1986) have therefore determined, interpolating HI measurements from the recent survey of Stark et al. (1986), the best estimate for the hydrogen column density along the line of sight for the individual IPC images used in the MSS. The distribution of the values of the hydrogen column density has a mean of $\log N_H = 20.5$ or $N_H = 3.16 \times 10^{20}$. This confirms the correctness of the choice of $N_H = 3 \times 10^{20}$ cm^{-2} as a value representative of all the MSS fields. The distribution is slightly asymmetric with respect to the sharp peak, with more fields being characterized by a hydrogen column density smaller than the peak value. The smallest value of N_H seen is 6.1×10^{19}, the largest is 1.4×10^{21}.

The survey has then been divided into two independent subsets, depending on the value of the hydrogen column density pertinent to each observation. The first subset ("HI") is comprised of all the fields for which N_H is larger than 3.37×10^{20} cm^{-2}, and by the X-ray sources detected in these fields. Images of the regions of sky characterized by N_H smaller than 3.37×10^{20} cm^{-2}, and the corresponding sources, define the second subset ("LO"). The value 3.37×10^{20} has been chosen so that the two subsets contain the same number of IPC images.

The possible effects of the neglected non-uniformity of the hydrogen column density on the number of sources detected, has been checked by testing whether X-ray sources are detected in different proportions in the two subsets, and in particular whether the HI subset is characterized by fewer sources than the LO subset.

This analysis has been restricted to the fields for which the neutral hydrogen data are available ($\delta > -40^{\circ}$). Of the 79 extragalactic sources detected in these images, 41 (52%) belong to the HI subsample and 38 (48%) belong to the LO subsample. These fractions are identical (within the statistical uncertainties due to the limited statistics) to what is expected from the sky coverage of the two subsets. The flux distributions for the sources in the two subsets are also identical.

Maccacaro and Gioia (1986) therefore concluded that there is no evidence of a loss of sources due to the fact that a number (~50%) of IPC images are characterized by values of the hydrogen column density higher than assumed. Consequently, the extragalactic MSS sample, and thus the quasar sample, can be considered statistically complete. Therefore the inconsistency between the expected and the observed number of X-ray selected quasars cannot be attributed to incompleteness of the X-ray selected quasar sample.

Kriss and Canizares (1985) pointed out that some of the discrepancies between the properties of X-ray selected and optically selected quasars must be attributed to the presence of numerous low luminosity, partially reddened and X-ray absorbed objects in the X-ray selected sample. These quasars are not represented in the optically selected samples. These authors have thus restricted their analysis to the MSS quasars characterized by B-V > 0.65. They have shown that when the apparently red objects are excluded the agreement with the optical sample improves considerably. This, however, does exacerbate the discrepancy between the observed and predicted number counts.

Franceschini, Gioia and Maccacaro (1986) have explored a different possibility. These authors have found that the properties of X-ray selected quasars predicted from those of optically selected quasars critically depend on the shape of the distribution of the residuals in the X-ray to optical luminosity correlation. Franceschini, Gioia and Maccacaro have suggested that the observed dispersion σ of the α_{OX} distribution ($\alpha_{OX} = -\log[Lx/Lo]/2.605$) of optically selected quasars suffers from a systematic bias, such that values substantially higher than expected are observed. They interpret this as due to the presence of "noise" which adds to the intrinsic variance of the distribution. When a narrower, "intrinsic" α_{OX} distribution is used, most of the discrepancies, including the number-counts inconsistency, are eliminated.

Clearly there is the need for a larger sample of X-ray selected quasars.

A major expansion of the Medium Survey has begun. As of this writing about 1200 IPC images have been analyzed, yielding a useful area of 600 square degrees. We have detected a total number of about 700 serendipitous sources with fluxes in the range $\sim 7 \times 10^{-14}$ to $\sim 10^{-11}$ ergs cm^{-2} s^{-1}. The extension of the Medium Sensitivity Survey will be completed early next year. It is expected to contain approximately 900 X-ray sources. Of these, at least 400 are expected to be identified with quasars and Seyfert galaxies (AGN). The present status of the expanded Medium Survey is summarized in Table 1.

Table 1

PRESENT STATUS OF EXPANDED MEDIUM SURVEY

IPC images analyzed	1160	(345)
Total area of sky (sq.deg.)	590	(90)
Sources detected	680	(112)
Area for IPC field (sq.deg.)	0.5	(0.2)
Sources identified	287	(112)
Sources with radio data	260	(102)
Identifications with Active Galactic Nuclei:	135	(56)

The numbers in parentheses refer to the published MSS samples (Maccacaro et al. 1982, Stocke et al. 1983, Gioia et al. 1984). A program aimed at the identification of all these sources is in progress. Radio measurements are also being obtained for the AGN in the sample which are easily visible from the VLA. The AGN sample has already grown to 135 objects, more than twice the number in the published sample (cf. Maccacaro, Gioia and Stocke 1984). The basic properties of the X-ray selected quasars are shown in Figures 1 through 3.

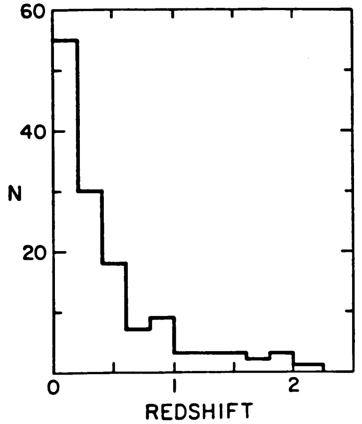

Fig. 1 Redshift distribution.

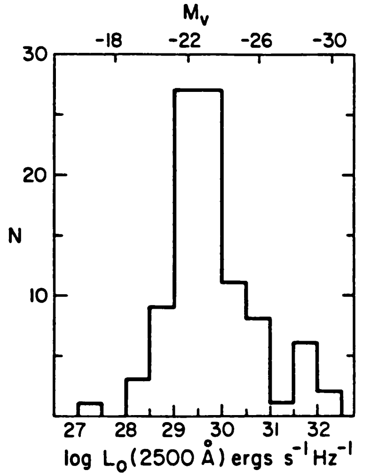

Fig. 2 Optical luminosity distribution

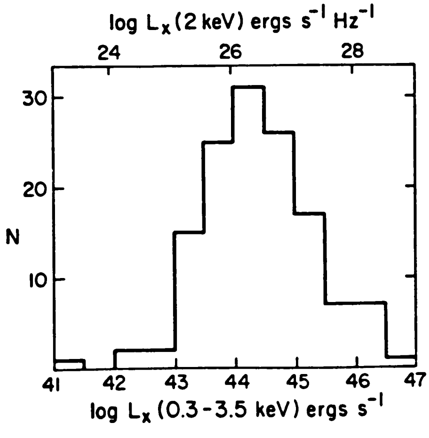

Fig. 3 X-ray luminosity distribution.

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Because of the present incompleteness of the optical identification program, the properties of this enlarged AGN sample may be (and probably are) biased in favor of the apparently brighter objects. We therefore caution the reader to keep this bias in mind.

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DISCUSSION

Margon : I will describe later in this meeting a program that obtained X-ray information on a large, uniformly selected group of high redshift QSOs. We observe a narrower α_{ox} distribution than reported by Avni and Tananbaum, and this would agree with your speculation that a narrow distribution could help to reconcile the optical and X-ray counts.

Schmidt : Richard Green and I have derived X-ray quasar counts based on Einstein observations of the bright PG quasars. We find agreement with the quasar content of the Medium Sensitivity Survey after introduction of mild X-ray luminosity evolution, approximately $(1+z)^{1.5}$.

Maccacaro : There are several ways to reconcile predicted and observed X-ray number counts. I believe we need larger X-ray selected samples of quasars before reaching definite conclusions.