ROSAT HRI observations of nearby galactic nuclei

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ABSTRACT

Pointed observations using the High Resolution Imager (HRI) aboard the *ROSAT* mission have, to date, covered a reasonable fraction ($> 25\%$) of the nearby galactic nuclei classified by Ho, Filippenko & Sargent (1997). Here we present the preliminary results from a statistical study based upon this ROSAT HRI database. Specifically we focus on the discrete X-ray sources associated with the nuclear region of these nearby galaxies (nuclear X-ray sources), which are seen in more than 50% of the galaxies surveyed, and consider the question of whether the soft X-ray luminosities of these sources are correlated with the optical properties of each nucleus.

1. Introduction

The "search for dwarf Seyferts" of Ho, Filippenko and Sargent (1997 and references therein; hereafter HFS) classified the nuclei of a statistically complete sample of bright ($B_T \leq 12.5$ mag), northern galaxies according to their optical emission line ratios. They found that 11% of nearby galaxies harbour a Seyfert-like nucleus, 33% host a Low Ionisation Nuclear Emission-line Region (LINER) and 42% have a nucleus characterised by H II emission. The LINERs may be further split into the subsets of "pure" LINERs (19% of the sample) and "transition" LINERs (14%), with the difference being that the transition objects display a mixture of LINER and H II spectra. In total, 86% of galaxies display emission-line nuclei; the remaining 14% are referred to herein as No Optical Emission Line nuclei (NOELs). These results imply that in excess of 40% of nearby galaxies (*i.e.* those with Seyfert or LINER nuclear spectra) have nuclear activity that may not be explicable by any means other than the presence of a low-luminosity AGN.

This proceedings paper summarises the preliminary results of an analysis of the soft X-ray properties of the HFS nuclei, based on archival *ROSAT* HRI data. The high spatial resolution of this detector makes it an ideal instrument for studying the bright point-like X-ray sources found in the nuclei of nearby galaxies, and specifically for resolving possible low-luminosity AGN from other confusing sources in the galaxy such as luminous X-ray binaries. Thus potentially the HRI can provide improved flux estimates for such sources when compared, for example, to *ROSAT* PSPC observations (*e.g.* Roberts & Warwick 1998).

2. Data analysis

Archival *ROSAT* HRI fields were selected for analysis by cross-correlating their pointing positions with the position of the optical nucleus in each HFS galaxy, using a correlation radius of $15'$ to ensure that each nucleus would be positioned in the field-of-view of the HRI detector. The resulting list was reduced to the highest quality data by introducing an arbitrary exposure time cut-off of ≥ 15 ks, leaving a total of 128 observations covering 81 galaxies. A further 7 of these galaxies were rejected on the basis of being positioned in strong, extended emission associated with the galaxy environment (*e.g.* NGC 1275) or having incomplete galaxy coverage in the HRI image (*e.g.* NGC 598). This latter constraint was adopted to allow a study of all X-ray sources coincident with the optical extent of each galaxy, and is discussed elsewhere (Roberts & Warwick, *in prep.*).

We note that although the parent sample is statistically complete, the subsample of sources with HRI observations may be intrinsically biased, since most galaxies ($> 85\%$) were the actual (selected) target of the observation. The obvious bias towards "known" X-ray bright objects manifests itself as an over-abundance of elliptical galaxies and Seyfert nuclei in the sample (both appearing a factor ~ 2 more frequently than in the HFS sample).

A search was conducted for discrete X-ray sources using the point source search algorithm PSS (Allen 1995), and all the sources detected with a significance of 5σ or above were catalogued for each HRI field. Figure 1 shows an example of this process for M 81. The separation of each source from the optical nucleus of each galaxy in its field was calculated, and all sources within either $20''$ or 0.5 kpc of the optical nucleus were classified as nuclear X-ray sources.

3. Results

A total of 43 nuclear X-ray sources were detected from the 74 galaxies observed (a detection rate of 58%). This left 31 non-detections, for which a 95% upper-limit on the *ROSAT* HRI count rate at the position of each optical nucleus was derived. The count rates of both the detections and upper-limits were converted to fluxes and corrected for the foreground (*i.e.* Galactic) absorption, based upon the assumption that the emission from each nucleus may be described by a power-law continuum spectral form with photon index $\Gamma = 2$. All Galactic columns were interpolated from the measurements of Stark *et al.* (1992). Using the distances provided by HFS we were then able to calculate the Galactic-absorption corrected soft X-ray luminosity of each nuclear X-ray source.

The separations of the nuclear X-ray sources from the optical nuclei are shown in Figure 2. At the median distance of the detected nuclei (16.8 Mpc) the typical error in each HRI position of $\sim 10''$ corresponds to a linear separation at the galaxy of ~ 0.8 kpc.

The derived soft X-ray luminosities are compared to the optical classification of each nucleus in Figure 3, and the median luminosities (including the 95% upper-limits) are given in Table 1.

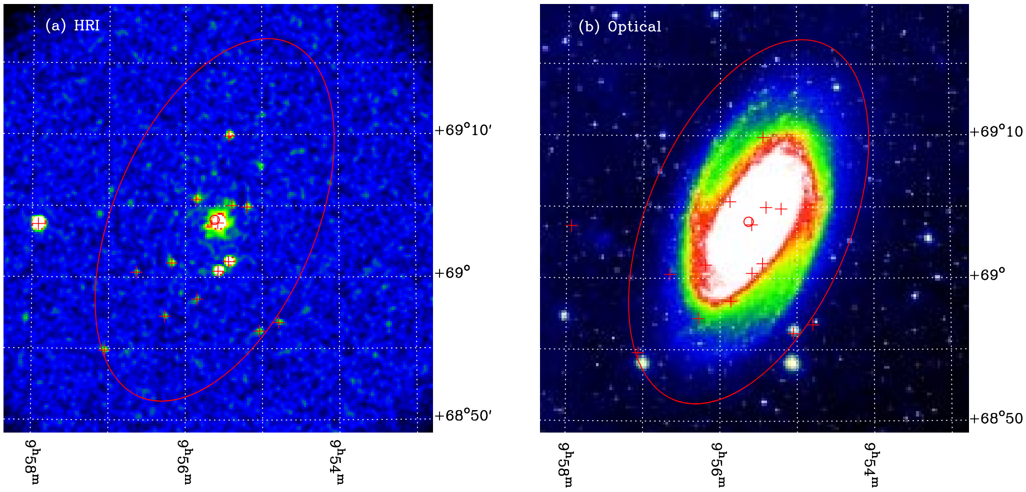

Fig. 1.— Data analysis results for a 21 ks observation of NGC 3031 (M 81), showing the HRI data (left) and an optical image of the same field taken from the Digitised Sky Survey (right). The detected X-ray sources are marked with crosses. A circle of radius 20″ identifies the optical nucleus.

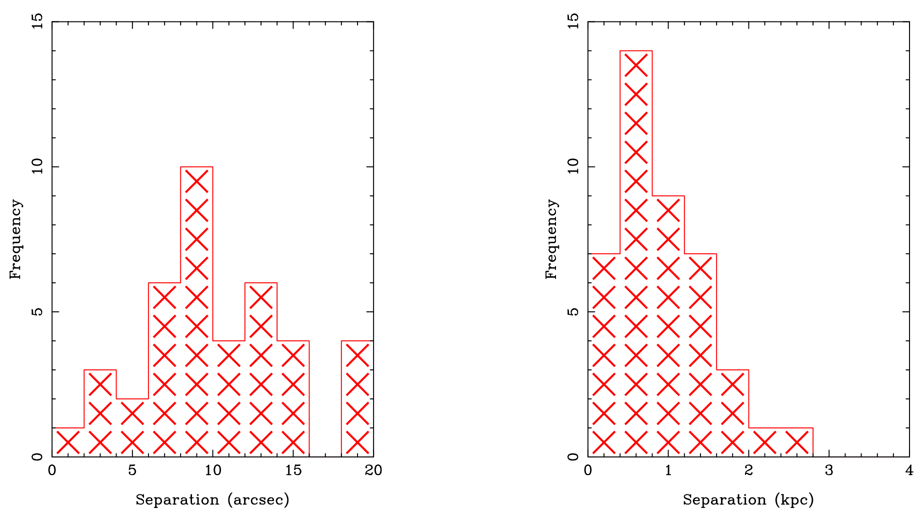

Fig. 2.— The separation between the optical nucleus and detected nuclear X-ray source for the HRI sample, in arcseconds (left) and kpc (right).

Overall, our sample has a median X-ray luminosity of only $10^{39.7}$ erg s^{-1}; the median luminosities for Seyfert, LINER and transition nuclei (the putative low-luminosity AGN hosts of HFS) all lie

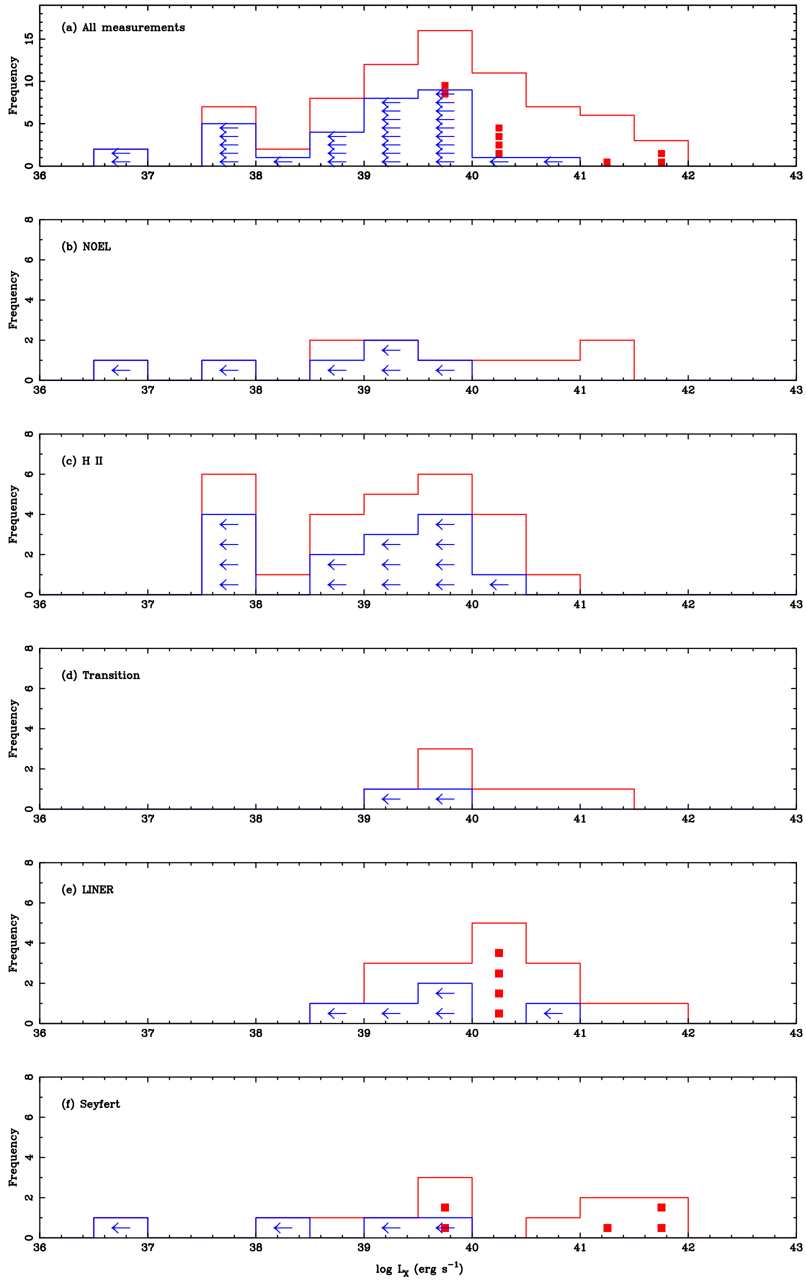

Fig. 3.— The X-ray luminosity distributions for the nuclear X-ray sources, shown for each class of optical nucleus. Non-detections are shown in blue with the left-pointing arrow, broad line nuclei are shown as filled red squares.

above this value, with the H II and NOEL nuclei lying below. It is also revealing to split Seyfert and LINER nuclei into their broad- and narrow-line classes; this demonstrates that the broad-line objects are substantially more X-ray luminous ($10^{40.5}$ erg s^{-1} as opposed to $10^{39.8}$ erg s^{-1}).

Figure 4 (top) shows the observed X-ray luminosity plotted against the predicted X-ray luminosity of a starburst component in each galaxy, taken from the far-infrared luminosity - starburst X-ray luminosity relationship given as Equation 2 of David *et al.* (1992), and corrected to the HRI band. Though this relationship has a large intrinsic scatter, a substantial number of nuclei are more X-ray luminous by a factor $\sim 10 - 1000$ than the prediction. While this may be expected in "known" active nuclei such as Seyferts and LINERs, this is an interesting result for the H II nuclei showing large excesses, whose X-ray luminosity should nominally originate in starburst activity. In Figure 4 we also plot the X-ray luminosity of each nucleus against the absolute magnitude of the bulge region of each galaxy (calculated statistically from the absolute magnitude of each galaxy and its Hubble type; see HFS). The rather tight correlation so revealed suggests that the bulge of a galaxy does strongly influence the rate of accretion onto the putative super-massive black hole at its core.

4. Conclusions

Nuclear X-ray sources are present in 58% of the optical galactic nuclei that we have examined. This finding is in broad agreement with other similar recent work (*e.g.* Colbert & Mushotzky 1998). However, the nature of these X-ray sources remains somewhat unclear as the *ROSAT* HRI offers little or no spectral information. Many of these sources may be *bona fide* low-luminosity AGN; this seems very likely in broad-line Seyfert and LINER objects, and is also probably the case in such nuclei with narrow-line classifications. However the relatively low luminosity of the objects in this sample implies a high probability that some of the sources may be other types of X-ray luminous objects, for example luminous Supernovae or a number of spatially unresolved X-ray binaries. XMM, of course, has the capability to sort the *bona fide* low luminosity AGN from the imposters. Its combination of spatial resolution, broad band spectroscopy and large collecting area will be ideal for detecting and studying the X-ray counterparts to optical nuclei in nearby galaxies, thereby revealing their incidence and nature.

Table 1: The median X-ray luminosities for the optical nuclear classes.

Nuclear class	Number of galaxies	Number of HRI detections	Median luminosity (log erg s^{-1}, 0.1 - 2.4 keV)
Seyfert	12	9	39.8
LINER	17	12	40.1
Transition	7	5	39.9
H II	27	13	39.3
NOEL	11	5	39.4

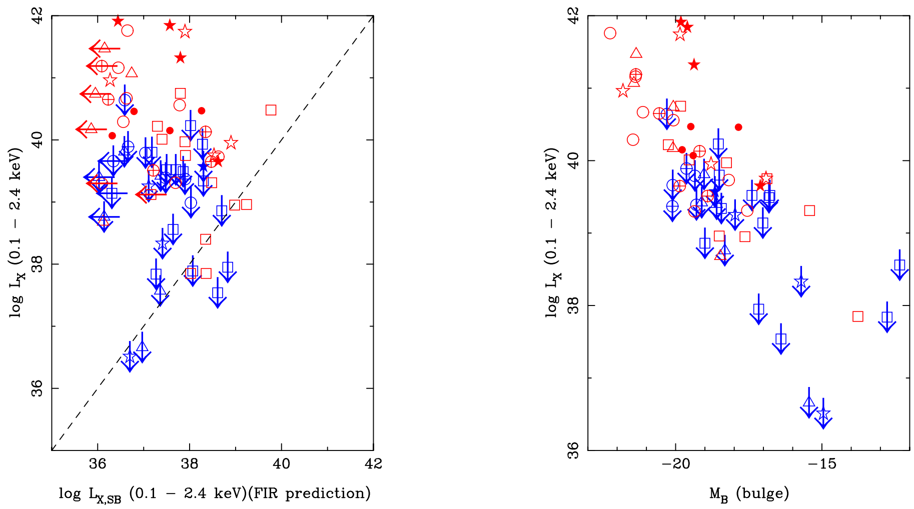

Fig. 4.— (left) X-ray luminosity versus predicted starburst X-ray luminosity. The symbols are: star - Seyfert; circle - LINER (with the broad-line objects of either type filled-in); crossed circle - transition; square - H II ; triangle - NOEL. The arrows represent upper limits on the measurements, and non-detections are shown in blue. (right) X-ray luminosity versus bulge absolute magnitude, using the same symbols. The typical error on the X-ray luminosity is ±0.2 in log units.

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