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 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 Γ = 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 ~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/BLR 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 and 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.

<table>
<thead>
<tr>
<th>Nuclear class</th>
<th>Number of galaxies</th>
<th>Number of HRI detections</th>
<th>Median luminosity $\log$ erg s$^{-1}$, 0.1 - 2.4 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seyfert</td>
<td>12</td>
<td>9</td>
<td>39.8</td>
</tr>
<tr>
<td>LINER</td>
<td>17</td>
<td>12</td>
<td>40.1</td>
</tr>
<tr>
<td>Transition</td>
<td>7</td>
<td>5</td>
<td>39.9</td>
</tr>
<tr>
<td>H II</td>
<td>27</td>
<td>13</td>
<td>39.3</td>
</tr>
<tr>
<td>NOEL</td>
<td>11</td>
<td>5</td>
<td>39.4</td>
</tr>
</tbody>
</table>
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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