AGN/galaxy separation in the ROSAT Bright Survey

I. Lehmann\textsuperscript{1}, G. Hasinger\textsuperscript{1}, A. D. Schwope\textsuperscript{1}, and Th. Boller\textsuperscript{2}

\textsuperscript{1} Astrophysikalisches Institut Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany
\textsuperscript{2} Max–Planck–Institut für extraterrestrische Physik, Gießenbachstraße, 85740 Garching, Germany

Abstract. The X-ray luminosity function (XLF) of galaxies is dominated by AGN (classified by their optical spectra) above \( L_X = 10^{42} \text{ erg s}^{-1} \), below this value by normal galaxies. The X-ray flux of AGN at low X-ray luminosity therefore contains contributions from stellar processes (winds, supernova explosions etc.). Until now it is not clear which fraction of the observed X-ray flux has to be associated to the underlying stellar emission. We started to investigate a complete luminosity-limited sample of AGN and galaxies with \( \log L_X \leq 42.5 \) to discriminate between the nuclear and galaxy flux. Using the ROSAT HRI data we calculated the radial wobble-corrected profiles of the sources which were compared to a new HRI point spread function (PSF) template derived from 21 X-ray bright stars. The majority of the low-luminosity AGN shows evidence for a significant fraction of extended X-ray emission.

1. Introduction

The soft X-ray background (XRB) is dominated by the integrated emission of discrete sources (Hasinger et al. 1998, Hasinger 1998). Active galactic nuclei (AGN) are dominating the source counts down to the faintest flux limits (Schmidt et al. 1998). However, there are indications, that X-ray active, optically normal galaxies start to dominate the X-ray background at the faintest fluxes (McHardy et al. 1998), which may be obscured AGN.

An X-ray luminosity function has first been determined for AGN, combining the ROSAT Bright Survey (RBS) and the ROSAT Deep Survey (Hasinger et al. 1998) samples with the RIXOS AGN sample (Page et al. 1996) and the Appenzeller AGN Sample (Appenzeller et al. 1998). There is a clear evolution in the AGN luminosity function in the sense that higher redshift AGN are much more abundant or luminous than the local sample. In contrast to Boyle et al. (1994) we cannot fit our data with a pure luminosity evolution, but find a better fit with a density evolution. There is some indication of a slower evolution at luminosities below \( 10^{42} \text{ erg s}^{-1} \) (cf. Schmidt et al. and Miyaji, Hasinger & Schmidt, same issue). However, this takes not into account the known soft X-ray absorption of AGN, which complicates the self-consistent derivation of an XLF model. Additional uncertainties exist at the low-luminosity end of the local AGN luminosity function, where X-rays of non-AGN origin start to play an important role. We have derived an X-ray luminosity function for non-AGN galaxies (hereafter “galaxies”) in the RBS. The data are shown in Fig. 1 with open circles with horizontal error bars. In addition to our flux-limited sample the local galaxy XLF has been derived from a volume-limited sample of galaxies within 7.2 Mpc (Boller, Schmidt & Voges 1998) shown by open circles with horizontal and vertical error bars in Fig. 1.

\begin{figure}[h]
\centering
\includegraphics[scale=0.5]{rosat_agn_de-evolved_xlf.png}
\caption{The new XLF of AGN (solid circles) and normal galaxies (open circles). The solid line gives the AGN luminosity function de-evolved with a \((1+z)^{5}\) density evolution law. The dashed line shows the same function at \( z = 1.6 \), where the thick dashed portion indicates the observed luminosity interval. The dot-dashed line is an extrapolation, which is currently still uncertain. The XLF of AGN and galaxies fit well together in the overlapping region.}
\end{figure}
The two galaxy XLFs fit very nicely together in the overlapping region. From Fig. 1 it becomes obvious that the total XLF is dominated by AGN above and by galaxies below an X-ray luminosity of $\log L_X = 42.5$. The local volume density of AGN is comparable to that of normal galaxies around an X-ray luminosity of $\log L_X = 42.5$. The question therefore arises, whether the soft X-ray luminosity in these objects is contaminated by X-ray photons from the host galaxies (vice versa for galaxies).

2. The ROSAT HRI observations

We have started to analyse HRI data of all AGN and galaxies in the ROSAT Bright Survey (Fischer et al. 1998, Schwope et al., in prep) which have X-ray luminosities below $\log L_X < 42.5$ (erg/s). The classification of the objects is deduced from optical spectroscopy. Tab. 1 summarizes the information for the statistically complete luminosity-limited sample of 33 RBS objects, including some well-known AGN and galaxies eg. NGC 4051, NGC 4151 and M82. For 27 RBS sources sufficient HRI data were available from the public ROSAT archive to compare their radial profiles with the ROSAT HRI point-spread-function (PSF).

Because the HRI PSF is significantly contaminated by systematic attitude residuals introduced by the spacecraft wobble we developed a new method to correct for these (Harris et al. 1998). The method is based on the following steps:

– Extraction of the HRI data within a constant roll angle interval (using the same guide star configuration)
– Folding the data over the ROSAT 402 sec wobble phase
– Determination of the centroid in phase resolved images
– Shifting the phase resolved images to a single centroid position (shift and add technique)

We checked this new wobble-correction method on a large number of HRI observations of stars, and it works successfully down to HRI countrates of about 0.1 cts/s. The wobble-corrected stellar profiles of 21 RBS stars were used to derive a re-calibrated HRI PSF template, which is available upon request from the authors.

Fig. 2 shows the wobble-corrected radial profile of the RBS star GLIESE 803 normalized to an integrated flux of one in comparison to the theoretical HRI PSF (dashed line) and the re-calibrated HRI PSF (dotted line).

Fig. 3 presents the radial wobble-corrected profile of the Seyfert 1 galaxy NGC 4619 in comparison to the HRI PSF’s. The radial profile indicates an extended soft X-ray emission up to a radius of about 30". The excessive X-ray flux at $r>100"$ is probably due to the uncertainty in background subtraction. The HRI contours of NGC 4619 show a clearly elongated X-ray emission in north-south direction (cf. Fig 4), while the Seyfert 1 galaxy NGC 4151 seems to be only slightly extended in north-east direction (north is on top, east at left).

Elvis et al. (1990) mentioned that such an extended X-ray emission is presumable a common feature in Seyfert galaxies. Using Einstein HRI data they discovered a fraction of 15-30 % extended emission in three (NGC 4151,
NGC 1599, NGC 2992) out of five Seyfert galaxies. There are various possible origins for this emission, e.g. thermal bremsstrahlung, synchrotron radiation, inverse Compton scattering and electron-scattered nuclear radiation. Wilson et al. (1992) favour for the famous Seyfert galaxy NGC 1068 a hot ($10^6 - 7$ K), outflowing wind as the source of the circumnuclear soft X-ray emission.

Most of our studied low-luminosity AGN show an indication of an extended X-ray emission in their radial profiles. Clearly, most of the galaxies reveals extended emission in their radial profiles. On the other hand, we found three examples for point-like X-ray sources in otherwise normal galaxies (cf. Fig. 4). Iyomoto et al. (1998) presented the ASCA results on the S0 galaxy NGC 4203, where they detect hard X-ray emission from a point-like source at the nucleus. A single power-law model with a photon index of $\approx 1.8$, which is a typical value for Seyfert galaxies, fits the spectrum of NGC 4203 well. A point-like soft X-ray emission of the source was already found by Bregman et al. (1995) using ROSAT HRI data.

In order to estimate the fraction of extended soft X-ray emission for each object of our sample we used the simple method by Wilson et al. (1992). We subtracted a suitably scaled re-calibrated HRI PSF from the observed radial profiles. The residuals of the X-ray flux divided by the total flux within a radius of 100″ is regarded as the fraction of extended emission. An outer radius of 100″ was chosen to avoid additional errors due to uncertainties in the background subtraction. The fraction of extended emission is given in the last column of Tab. 1 for the statistically complete RBS AGN/galaxy sample. The classification of the objects in AGN (ID=1) and galaxies (ID=2) was done by their optical spectra. The CR and CH values are the total and hard band (0.5-2.0 keV) ROSAT PSPC coun-

stances. The X-ray luminosity is based on the CH coun-

Fig. 5. The radial profile of the starburst galaxy MRK 202 indicates no extended X-ray emission. The data points are consistent with the re-calibrated HRI PSF.

The results on NGC 4203 strongly suggest that this object hosts a low-luminosity AGN. In addition to MRK 202, the example shown in Fig. 3 the point-like X-ray emission of NGC 1313 seems to indicate an optically hidden AGN (cf Tab. 1). Recently, Ptak et al. (1998) have investigated a low-luminosity sample of AGN and starburst galaxies, including NGC 253, NGC 3147, NGC 3998 and M82, which belong to our sample. For all sources they found evidence in the ASCA hard X-ray spectra for a hard component, which can be explained either with an absorbed power-law or with thermal bremsstrahlung of $T \approx 10^8$ K. Future hard X-ray spectroscopy of MRK 202 and NGC 1313 is necessary to confirm the AGN nature of these objects.

3. AGN/galaxy separation in X-rays

In contrast, eight out of thirteen galaxies exhibit a clear spatially resolved source extension (between 75% and 100%) in the HRI band. The contribution of a possible hidden AGN to the total X-ray luminosity is very limited. As already mentioned, only a small number of galaxies are only slightly extended in soft X-rays (cf Fig. 4).
Table 1. The RBS low-luminosity sample of AGN (ID=1) and galaxies (ID=2). CR and CH are the total and hard band (0.5−2.0 keV) ROSAT PSPC countrates, the X-ray luminosity \( L_X \), the redshift and the fraction of extended X-ray emission. A horizontal bar indicates cases without sufficient HRI data. Bold numbers mark AGN with a significant extended X-ray emission.

| Name           | Type     | ID | CR  | CH  | \( L_X \) | \( z \) | Fraction of extended X-ray emission [%] |
|----------------|----------|----|-----|-----|-----------|-------|----------------------------------------|
| Holmberg II    | Gal/HII  | 2  | 0.223 | 0.207 | 39.44 | 0.0005 | 27±5                                    |
| M 81           | Sy1.8    | 1  | 0.998 | 0.933 | 39.66 | 0.0003 | 12±3                                    |
| M 94           | Gal      | 2  | 0.255 | 0.125 | 39.80 | 0.0010 | 79±3                                    |
| NGC 0253       | Gal/Starburst | 2  | 0.298 | 0.256 | 39.91 | 0.0008 | 92±1                                    |
| NGC 5905       | Sy1      | 1  | 0.310 | 0.002 | 40.00 | 0.0113 | −                                       |
| M 33           | Gal      | 2  | 0.556 | 0.539 | 40.04 | 0.0006 | 33±3                                    |
| M82            | Gal/Starburst | 2  | 0.897 | 0.897 | 40.38 | 0.0007 | 97±4                                    |
| NGC 1313       | Gal      | 2  | 0.227 | 0.227 | 40.50 | 0.0016 | 18±5                                    |
| M 83           | Gal      | 2  | 0.261 | 0.223 | 40.54 | 0.0017 | 90±7                                    |
| NGC 4151       | Sy1      | 1  | 0.224 | 0.139 | 40.89 | 0.0033 | 32±2                                    |
| NGC 5033       | Sy1.9    | 1  | 0.338 | 0.193 | 40.93 | 0.0030 | 13±8                                    |
| NGC 4203       | Gal      | 2  | 0.521 | 0.326 | 41.32 | 0.0036 | 11±5                                    |
| NGC 1566       | Sy1      | 1  | 0.425 | 0.185 | 41.37 | 0.0050 | 21±5                                    |
| NGC 3998       | Sy1/Liner| 1  | 0.629 | 0.487 | 41.48 | 0.0035 | 6±4                                     |
| NGC 4051       | Sy1      | 1  | 3.918 | 1.077 | 41.49 | 0.0024 | 10±2                                    |
| NGC 1404       | Gal      | 2  | 0.305 | 0.201 | 41.63 | 0.0065 | 87±7                                    |
| RXS J1447+1145 | Gal      | 2  | 0.261 | 0.010 | 41.68 | 0.0300 | −                                       |
| NGC 4636       | Gal      | 2  | 0.936 | 0.800 | 41.75 | 0.0037 | 100±27                                  |
| NGC 3147       | Sy2      | 2  | 0.205 | 0.130 | 41.79 | 0.0094 | 25±6                                    |
| WPVS 07        | Sy1/NL   | 1  | 0.959 | 0.014 | 41.80 | 0.0288 | −                                       |
| NGC 1068       | Sy2      | 1  | 1.785 | 0.866 | 41.82 | 0.0038 | 55±8                                    |
| UGC 06728      | Sy1/NL   | 1  | 0.375 | 0.336 | 41.82 | 0.0060 | 7±6                                     |
| ESO 568-21     | Sy1/NL   | 1  | 0.241 | 0.117 | 41.92 | 0.0114 | 17±14                                   |
| NGC 5846       | Gal/E    | 2  | 0.467 | 0.460 | 41.97 | 0.0061 | 98±5                                    |
| NGC 5813       | Gal/E    | 2  | 0.545 | 0.520 | 42.06 | 0.0064 | 97±11                                   |
| MRK 1126       | Sy1.5    | 1  | 0.350 | 0.199 | 42.08 | 0.0106 | −                                       |
| MRK 1502       | Sy1      | 1  | 0.818 | 0.609 | 42.09 | 0.0060 | 5±5                                     |
| IRAS 22146-5955| AGN      | 1  | 0.798 | 0.132 | 42.21 | 0.0153 | −                                       |
| RXS J0439-5311 | Sy1/NL   | 1  | 0.759 | 0.061 | 42.26 | 0.0243 | −                                       |
| MRK 202        | Gal/Starburst | 2  | 0.213 | 0.085 | 42.28 | 0.0210 | 6±4                                     |
| ESO 548-81     | AGN      | 1  | 0.258 | 0.172 | 42.28 | 0.0145 | −                                       |
| NGC 3035       | Sy1      | 1  | 0.263 | 0.226 | 42.41 | 0.0144 | 7±7                                     |
| NGC 4619       | Sy1      | 1  | 0.222 | 0.100 | 42.43 | 0.0231 | 17±7                                    |

4. Conclusions

We have found evidence for a significant contribution of the host galaxy to the X-ray luminosity of AGN in a statistically complete RBS sample of low-luminosity AGN. Future spatially resolved hard X-ray spectroscopy is necessary in order to uncover the nature of this extended X-ray emission.

Acknowledgements. We made use of the ROSAT HRI public data archive at the MPE. The work has been supported in part by the DLR (former DARA GmbH) under grant 50 OR 9403 5.

References

Appenzeller I., Thiering I., Zickgraf F.–J., et al, 1998, ApJS 117, 319
Boller Th., Schmidt K.–H., Voges W., 1998, A&A submitted
Boyle B.J., Shanks T., Georgantopoulos I., et al., 1994, MNRAS 260, 49
Bregman J.N., Hogg D.E., Roberts M.S., 1995, ApJ 441, 561
Elvis M., Fassnacht C., Wilson A.S., et al., 1990, ApJ 361, 459
Fischer J.-U., Hasinger G., Schwpe A.D., et al., 1998, AN, in press
Harris D.E., Silverman J.D., Hasinger G., et al., 1998, A&A submitted
Hasinger G., Burg R., Giacconi R., et al., 1998, A&A 329, 482
Hasinger G., 1998, AN 319, 37
Iwamoto N., Makishima K., Matsushita K., et al., 1998, astro-ph/9806158
McHardy I.M., Jones L.R., Merrifield M.R., et al., 1998, MNRAS 295, 641
Page M.J., Carrera F.J., Hasinger G., et al., 1996, MNRAS 281, 579
Ptak A., Serlemitsos P., Yaqoob T., et al., 1998 astro-ph/9808159
Schmidt M., Hasinger G., Gunn J., et al., 1998, A&A 329, 495
Schwope A.D., et al, in prep.
Wilson A.S., Elvis M., Lawrence A., et al., 1992, ApJ 391, L75