OPTICAL IDENTIFICATION OF THE HARDEST X-RAY SOURCE IN THE ASCA LARGE SKY SURVEY

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ABSTRACT

We report the optical identification of the hardest X-ray source (AX J131501 + 3141) detected in an unbiased wide-area survey in the 0.5–10 keV band, the ASCA Large Sky Survey (LSS). The X-ray spectrum of the source is very hard and is well reproduced by a power-law component ($\Gamma = 1.5 \pm 0.2$) with $N\mathrm{H} = 6^{+4}_{-2} \times 10^{22}\,$cm$^{-2}$. We have found a galaxy with $R = 15.62$ mag near the center of the error circle for the X-ray source. The optical spectrum of the galaxy shows only narrow emission lines whose ratios correspond to those of a type 2 Seyfert galaxy at $z = 0.072$, implying an absorption-corrected X-ray luminosity of $2 \times 10^{43}\,$ergs s$^{-1}$ (2–10 keV) and $M_B = -20.93$ mag. A radio point source is also associated with the center of the galaxy. We thus identify the X-ray source with this galaxy as an obscured active galactic nucleus (AGN). The hidden nature of the nucleus of the galaxy in the optical band is consistent with the X-ray spectrum. These results support the idea that the obscured AGNs/QSOs contribute significantly to the cosmic X-ray background in the hard band at the faint flux level.

Subject headings: galaxies: active — galaxies: individual (AX J131501 + 3141) — galaxies: Seyfert — X-rays: galaxies

1. INTRODUCTION

Many efforts have been made to understand the origin of the cosmic X-ray background (CXB). Recently, in the ROSAT deep surveys, ~60% of the CXB in the 0.5–2 keV band has been resolved into discrete sources (Hasinger et al. 1993). On the other hand, in the harder 2–10 keV band, where the bulk of the energy density of the CXB resides, only ~3% of the CXB was resolved into discrete sources (Piccinotti et al. 1982). In the soft X-ray band (0.5–2 keV), type 1 active galactic nuclei (AGNs) are the main contributors to the CXB within a flux level of $1.6 \times 10^{-15}\,$ergs cm$^{-2}$ s$^{-1}$ (McHardy et al. 1998). However, they have X-ray power-law spectra ($\Gamma = 1.7$; Turner & Pounds 1989) significantly softer than that of the CXB in the 2–10 keV band ($\Gamma = 1.4$–1.5; Gendreau et al. 1995; Ishisaki 1996). Therefore, there must be objects that have harder X-ray spectra than type 1 AGNs and contribute significantly to the CXB in this band.

To study the nature of X-ray sources in the hard band, we are now conducting an unbiased large and deep survey with ASCA (Tanaka, Inoue, & Holt 1994) near the north Galactic pole. This is the Large Sky Survey (hereafter LSS; Inoue et al. 1996; Ueda 1996; Ueda et al. 1998). The flux limit of the LSS ($\sim 1 \times 10^{-13}\,$ergs cm$^{-2}$ s$^{-1}$ in the 2–10 keV band) is 100 times deeper than the HEAO 1 A-2 survey, which was the deepest survey in the hard band (Piccinotti et al. 1982). We have surveyed 7.0 deg$^2$ and detected 43 sources above the 4 $\sigma$ level in the 2–10 keV band (Ueda 1996), corresponding to ~30% of the CXB in this band. The average photon index of the X-ray sources detected in the flux range between $1 \times 10^{-13}$ and $5 \times 10^{-13}\,$ergs cm$^{-2}$ s$^{-1}$ is $\Gamma = 1.5 \pm 0.2$ (Ueda et al. 1998), which is significantly harder than the spectra of X-ray sources detected in shallower surveys in the 2–10 keV band and close to that of the CXB. Thus, we are now revealing the presence of the hard sources that are responsible for most of the CXB energy density. Identification of these hard sources is clearly an important next step.

In the LSS, we have discovered the very hard X-ray source AX J131501 + 3141, whose power-law index is by far...
the hardest among the LSS sources. This object provides a good opportunity to examine the nature of the hard X-ray sources found in our systematic survey, and the result will be a key for the understanding of the origin of the CXB in the hard band. In this paper, we report on the optical identification and properties of AX J131501 + 3141 and their implications for the origins of the CXB. Results of the X-ray observations are presented in detail in a separate paper (Sakano et al. 1998). Throughout this paper, we use $q_0 = 0.5$ and $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

2. IDENTIFICATION OF AX J131501 + 3141

2.1. X-Ray Properties

AX J131501 + 3141 is the hardest X-ray source detected in the LSS. The apparent X-ray spectrum from its initial observation can be fitted by a single power-law model with a photon index $\Gamma = -0.18 \pm 0.31$ (for $E \propto E^{-\Gamma+1}$) in the 0.7–10 keV band. Since the photon indices of the other X-ray sources detected in the LSS are distributed between 0.4 and 4.0, in the flux range from $1 \times 10^{-13}$ to $1 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$ (2–10 keV), the photon index of AX J131501 + 3141 is outstandingly hard.

Subsequently, deeper X-ray observations of this object, totaling 100 ks, were made to learn more details of its X-ray properties (Sakano et al. 1998). The results, given in Sakano et al. (1998), are as follows: The flux of AX J131501 + 3141 in the 2–10 keV band is $\sim 5 \times 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$, while in the 0.5–2 keV band no X-ray flux is detected above a 3 $\sigma$ level, and the corresponding upper limit is $1.2 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$. The X-ray spectral shape seems to be a power law with a low energy cutoff at $\sim 2$–3 keV; the best-fitted parameters are $\Gamma = 1.5^{+0.7}_{-0.6}$ and absorbing column density $N_H = 6.5^{+4.1}_{-2.2}$ cm$^{-2}$ in the observed frame. The Galactic column density of neutral hydrogen in this direction is $N_{HI} = 1.1 \times 10^{20}$ cm$^{-2}$ (Stark et al. 1992). The deep observations were made at two epochs (1995 December and 1996 June), and 30% variability was detected. From the deep X-ray observations, the position of AX J131501 + 3141 is accurately determined to be $\alpha = 13^h 15^m 00.8^s$, $\delta = 31^\circ 41' 28''$ (J2000), with an error radius of 30' (95% confidence).

2.2. Optical Imaging Observations of AX J131501 + 3141

To identify the optical counterpart of AX J131501 + 3141, we made imaging observations with a Tektronix 2048 $\times$ 2048 CCD on the University of Hawaii 88" telescope in 1996 April. Images were obtained in two bands, $B$ and $R$, with a spatial sampling of 0.22 pixels$^{-1}$. The exposure times were 20 and 15 minutes for the $B$ and $R$ bands, respectively. The FWHM of the seeing in the images was 1$''$.1 in $B$ and 1$''$.0 in $R$.

Figure 1 shows the $R$-band image centered on the position of AX J131501 + 3141 with its error circle of radius 30'. In the error circle, there are one bright galaxy and a few faint objects. The coordinates of the bright galaxy are $\alpha = 13^h 15^m 01:15$, $\delta = 31^\circ 41' 28''$ (J2000), which is only 3'2 from the best position of the X-ray source. Hence, this is the most promising candidate for the optical counterpart. The galaxy has total magnitudes $R = 15.62 \pm 0.02$ and $B = 17.25 \pm 0.02$ and is cataloged as an S0 galaxy with $B = 17.2$ in Slezak et al. (1988). We hereafter call this bright galaxy "galaxy A."

The other objects in the error circle are fainter than $B = 22.4$. Since type 1 AGNs are the most X-ray–loud objects among the known extragalactic X-ray sources, we expect that the optical counterpart of AX J131501 + 3141 must be brighter than $B = 19.9$ on the basis of its 2–10 keV X-ray flux, assuming $\Gamma = 1.7$ together with the X-ray–to–optical flux ratio of type 1 AGNs identified in the Cambridge–Cambridge ROSAT Serendipity Survey (Boyle & di Matteo 1995). Since $B = 22.4$ is more than 1 order of magnitude fainter, none of these other objects are likely to be the optical counterpart.

The chance probability of one galaxy brighter than 16.0 mag falling in the error circle of the X-ray source is only $8 \times 10^{-3}$. This is obtained by adopting a surface density of such galaxies of 38 deg$^{-2}$ (e.g., Stevenson, Shanks, & Fong 1986). This low probability reinforces the conclusion that galaxy A is the optical counterpart of AX J131501 + 3141.

2.3. A Radio Source in the Error Circle of AX J131501 + 3141

In the error circle of AX J131501 + 3141, a radio source is detected in the FIRST Survey. The FIRST Survey is a radio source survey conducted with the Very Large Array in the 1.4 GHz band with a 5$\sigma$ limiting flux of 1 mJy (Becker, White, & Helfand 1995). The coordinates of the radio source are $\alpha = 13^h 15^m 01:19$, $\delta = 31^\circ 41' 29''$ (J2000), which is very close (1') to the center of galaxy A (Table 1). The radio source is pointlike, and no structure can be seen. Considering the positional accuracy of the radio source (1') and that of the optical galaxy center (0'8), we regard the radio source as being associated with the center of galaxy A.

In the course of the optical follow-up program of the LSS, we examined the distribution of FIRST radio sources around LSS X-ray sources to evaluate the cross-correlation between radio and X-ray sources and found a 3.5 $\sigma$ correlation within a radius of 0'6 from the X-ray sources (Akiyama et al. 1998). This radius corresponds to the error radius of the X-ray source positions. The presence of a significant correlation between the radio and X-ray sources implies that a FIRST radio source within 0'6 of an LSS X-ray source is the radio counterpart of the X-ray source, with a probability of more than 80%. This is an additional

| Band          | Name                  | Coordinates (J2000) | Uncertainty (arcsec) | Distance (arcsec) |
|---------------|-----------------------|---------------------|----------------------|--------------------|
| X-ray         | AX J131501 + 3141      | 13 15 00.9          | 31 41 28             | 30                 |
| Radio         | FIRST source          | 13 15 01.19         | 31 41 29.1           | 1                  |
| Optical       | Galaxy A              | 13 15 01.15         | 31 41 28.1           | 0.8                |

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

* Distance from the optical center of galaxy A.
reason why galaxy A, which is also the radio source detected near the center of the error circle of AX J131501 + 3141, is very likely to be the optical counterpart of the X-ray source.

In summary, considering all the results discussed in § 2, we conclude that galaxy A and its central radio source are to be identified with AX J131501 + 3141. In the next section, we will present further evidence on the nature of galaxy A.

3. Nature of AX J131501 + 3141

3.1. Type 2 Seyfert at $z = 0.072$

We made a spectroscopic observation of AX J131501 + 3141 (galaxy A) with the multislit spectrograph (CryoCam) on the KPNO Mayall 4 m telescope on 1996 April 9. We used grism 730 and covered the spectral range from 6000 to 9000 Å with a resolution of 22 Å. We used a 2.5 wide slit. The spectral sampling was 4.3 Å pixels$^{-1}$, and the spatial resolution was 0.84 pixels$^{-1}$. The FWHM of the seeing was $\sim 1'$. The exposure time was 30 minutes. The spectrum was summed within a 4" width along the slit direction (P.A. 62.5°) centered on the nucleus of the galaxy.

We detected emission lines of Hα, [N II] $\lambda\lambda$6548, 6583 and [S II] $\lambda\lambda$6717, 6731 clearly, but no broad Hα emission line. The logarithmic line ratios are log ([N II] $\lambda$6583/Hα) = 0.28 and log ([S II] $\lambda\lambda$6717, 6731/Hα) = −0.07, which imply that this object is classified as a type 2 Seyfert galaxy or a LINER (Veilleux & Osterbrock 1987). To be more definitive in the classification, a spectrum in the blue wavelength region is needed. The redshift of this object turned out to be $z = 0.072$, and the resulting luminosities...
are $L_X = 2 \times 10^{43}$ ergs s$^{-1}$ in the 2–10 keV band after absorption correction and $M_B = -20.93$ mag without K-correction. The power of the nuclear activity in the hard X-ray band is as large as that of a typical Seyfert galaxy (the knee of the luminosity function of type 1 AGNs is $L_X \sim 3 \times 10^{43}$ ergs s$^{-1}$ in the 0.5–3.5 keV band, according to Jones et al. 1997).

In order to obtain a spectrum in a blue region, we made another spectroscopic observation of galaxy A with the KPNO 2.1 m telescope and the Goldcam spectrograph on 1997 June 8. Three 30 minute exposures were taken through a 1.9 slit at P.A. $= 90^\circ$. The spectra covered the wavelength range 3866–7511 Å, with a spectral resolution of 5.1 Å. The uncertainty in the wavelength scale is 0.1 Å. The flux from the nuclear region dominates the optical spectrum, and it is only slightly resolved spatially in this observation. Therefore, we summed the spectrum using an optimal extraction only slightly resolved spatially in this observation. There-

The continuum contains a great deal of starlight, as evidenced by the Ca II absorption lines. Also, the H and K, H and Mg I b, and Na I D absorption lines. Also, the H/β line shows an absorption plus emission structure. In order to obtain more accurate measurements of the weak emission lines, we must subtract the stellar continuum spectrum. The model spectrum consists of an elliptical galaxy stellar template (NGC 5332) and a featureless power-law continuum, with the relative strengths of the two components adjusted to provide the smoothest fit to the continuum in the neighborhood of the emission lines. The spectrum obtained is also shown in Figure 2. Using the subtracted spectrum (Fig. 2b, dashed line), fluxes of the emission lines can be measured more accurately, although there are still obvious residuals due to the mismatch between the stellar populations of the two galaxies.

The resulting logarithmic line ratios turn out to be log ([N II]/Hα) = 0.06, log ([S II]/Hβ) = 0.17, log ([O III]/Hβ) = 0.29, and log ([O IV]/Hβ) = 0.31 (see Table 2). The ratio [O III]/Hα typically implies that galaxy A is a Seyfert galaxy rather than a LINER (Veilleux & Osterbrock 1987). These emission lines were resolved in the spectrum, with the widths all approximately the same and consistent with FWHM = 325 ± 25 km s$^{-1}$. There is no hint of the presence of a broad-line component of Hα or H/β, even after subtraction of the continuum. Therefore we conclude that galaxy A is classified as a type 2 Seyfert.

One interesting feature in the spectrum is that the intensity of the [O II] λ3727 emission line is strong in galaxy A. In the [O II] λ3727/[O III] λ5007 versus [O III] λ5007/Hβ plane (Ferland & Netzer 1983), galaxy A is located between typical type 2 Seyferts and LINERs because of its large log ([O II] λ3727/[O III] λ5007) values (0.004). After correcting for reddening, using the large Balmer decrement (H/β = 7.58), galaxy A falls among typical LINERs in this diagram, because of the resulting larger value of log ([O II] λ3727/[O III] λ5007) = 0.36. There are two possible explanations for the ratio of the oxygen emission lines: (1) a small ionization parameter ($U \sim 10^{-3}$) in the nucleus, similar to LINERs, and (2) contamination by star-forming regions in the disk of the galaxy, which would enhance [O II] λ3727 relative to [O III] λ5007. We favor the second explanation, because a LINER classification is not supported by the other defining line ratio, [O I] λ6300/[O III] λ5007, which is less than 3 in this spectrum, and also because the distribution of the Hα emission along the slit in the spectra taken with the 2.1 m telescope is slightly more extended than that of [N II] λ6583. The spatial extent of the Hα line is 4.2 pixels FWHM (3.3), while that of [N II] λ6583 is 3.7 pixels (2.9).

Unfortunately, we cannot separate the nuclear component from an extended component in [O II] λ3727 and H/β, because the signal-to-noise ratios of the lines are low and the focus of the spectrum at the blue end is poor. The difference between the Hα and [N II] λ6583 region is also confirmed in the spectrum taken with the 4 m telescope. In addition, the color of the disk of galaxy A is $B - R = 1.3$, which is bluer than the bulge of the galaxy. These results suggest there is some contamination in the nuclear emission lines by star formation in the disk of the galaxy.

### 3.2. Hidden Nucleus of the Galaxy

The optical image (Fig. 1) of AX J131501 + 3141 shows no pointlike structure at the center of the galaxy, suggesting that the majority of the optical continuum photons in the central region of the galaxy originate in stars in the bulge. The column density to the nuclear X-ray source, $N_H = 6 \times 10^{22}$ cm$^{-2}$ (Sakano et al. 1998), corresponds to $A_V \approx 33$ mag, according to the relations $N_H = 8 \times 10^{23}$ cm$^{-2}$ mag$^{-1}$ (Bohlin, Savage, & Drake 1978) and $A_V$ = $E(B - V)$ = 3.14 (Seaton 1979), which is large enough to hide the optical nuclear source. Thus, the absence of a blue, pointlike nuclear source in the optical light is consistent with the large column density derived from the X-ray spectrum.

The large Balmer decrement (H/β = 7.58) could be the result of extinction by a material distributed within or around the narrow-line region, rather than on the scale of the galaxy (e.g. the disk of the edge-on galaxy). If the large

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### TABLE 2

RESULTS OF THE SPECTROSCOPIC OBSERVATIONS

| Number       | Redshift | $B^*$ | $R^*$ | log ([N II]/Hα) | log ([S II]/Hβ) | log ([O III]/Hβ) |
|--------------|-----------|-------|-------|----------------|----------------|------------------|
| Galaxy A ....| 0.07203 ± 0.00009 | 17.25 | 15.62 | 0.06*          | −0.31*         | 0.65*            |
| Galaxy B ....| 0.072     | 18.08 | 16.90 | −0.39*         | ...            | ...              |
| Galaxy C ....| 0.189     | 18.75 | 17.03 | 0.0*           | ...            | ...              |

* Total magnitude.
* [N II] λ6583.
* [S II] λ6717, 6731.
* [O III] λ5007.
* Line ratio after subtraction of stellar continuum.
* Line ratio from multislit spectroscopy without subtraction of stellar continuum.
Fig. 2a

Optical spectrum of the nuclear region of galaxy A. The abscissa shows observed wavelength in angstroms, and the ordinates shows flux density in $10^{-16}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$. Identified emission and absorption lines are marked at the top of the figure. (b) Closeup view of the optical spectra. The abscissa and ordinate are same as in (a). Left panel shows the H$\beta$ region; right panel shows the H$\alpha$ region. The dashed line in each panel shows the spectra after subtracting the model stellar continuum (see § 3.1).
Balmer decrement is the result of reddening and we assume that the intrinsic ratio of Hα to Hβ is 3.1, the color excess $E(B - V)_{\text{Hamer}}$ is required to be 0.82. This value corresponds to the column density of the narrow-line region of $N_{H1+H2} = 4.8 \times 10^{21} \text{ cm}^{-2}$. On the other hand, the $B - R$ color in a 5" aperture centered on galaxy A is 1.96 ± 0.03 mag, which is redder than those of normal elliptical galaxies ($B - R = 1.47 ± 0.05$ mag; Buta et al. 1994; Buta & Williams 1995). If the intrinsic bulge color is the same as a typical color of an elliptical galaxy, the color excess of the bulge, $E(B - V)_{\text{bulge}}$, is 0.28, if we adopt the relation $E(B - V) = E(B - R)/1.76$ (Seaton 1979). This value is smaller than that of the narrow-line region. Thus, the difference between $E(B - V)_{\text{Hamer}}$ and $E(B - V)_{\text{bulge}}$ suggests that dust could be distributed on the scale of the narrow-line region and smaller than that of the bulge.

3.3. Spectral Energy Distribution

Using the photometric results from the radio to X-ray wavelength regions, we can compare the spectral energy distribution (SED) of galaxy A with other type 2 Seyferts. Photometric results on the galaxy are summarized in Table 3. (In the infrared we use an upper limit from the IRAS Faint Source Catalog [Moshir et al. 1992] in the region containing galaxy A.) Figure 3 shows the SED of galaxy A, as well as those of type 2 Seyferts taken from Mas-Hesse et al. (1995). The SEDs are normalized such that they have the same flux density as galaxy A at the optical wavelength (~B band). Since the logarithmic flux density ratio between radio (1.4 GHz) and optical (B band) is −4.83, similar to the other radio-quiet type 2 Seyferts, galaxy A is a radio-quiet object. The flux density in the hard X-ray band is located within a scatter of other type 2 Seyferts; galaxy A has the typical value of the flux density ratio of the hard X-ray to the optical region as type 2 Seyferts.

3.4. An Interacting Galaxy?

In Figure 4 we show a wide image of AX J131501 + 3141. Around AX J131501 + 3141, we can see two other bright galaxies of similar size, one (galaxy B) located at 67” east, and the other (galaxy C) located at 55” south-southeast of AX J131501 + 3141. In course of the multislit spectroscopy, we also observed these galaxies. The results are shown in Table 2. Since galaxy C has $z = 0.189$, its closeness to galaxy A is just a chance projection. Galaxy B has almost the same redshift (0.072) as galaxy A. The velocity difference between galaxy A and galaxy B is 90 km s⁻¹, and their projected separation is 67", which corresponds to 124 kpc at $z = 0.072$. The magnitudes of galaxy B are $B = 18.08$ and $R = 16.90$, and its morphology is that of a normal spiral galaxy without any clear distortion. However, the spectrum of galaxy B has emission lines which are H ii region-like (Veilleux & Osterbrock 1987). The $B - R$ color of its disk is 1.0 mag, which is bluer than the disk of galaxy A. Thus, these results would indicate enhanced star formation in the disk of galaxy B. There is a possibility that the interaction is a driver of both the nuclear activity in galaxy A and the enhanced star formation in the disk of galaxy B.

4. IMPLICATIONS FOR THE NATURE OF HARD X-RAY SOURCES

The hardest X-ray source detected in the continuous 7.0 deg² area of the LSS has been identified with a type 2 Seyfert, having a column density to the nucleus of $N_H = 10^{22.8} \text{ cm}^{-2}$ in the local universe ($z < 0.1$). Surface density of such an object is consistent with recent models of the origin of the CXB by, e.g., Madau, Ghisellini, & Fabian (1994) and Comastri et al. (1995), described below. They propose that type 2 AGNs are hard X-ray sources that need to exist to account for the hardness of the spectrum of the CXB, because type 2 AGNs have harder X-ray spectra than type 1 AGNs, resulting from the absorption of their soft X-ray photons. In the surveyed area, we have estimated the number density of type 2 AGNs that have a column density of $N_H = 10^{22} - 10^{23.5} \text{ cm}^{-2}$ and X-ray flux larger than $5 \times 10^{-13} \text{ ergs cm}^{-2} \text{ s}^{-1}$ in the 2–10 keV band, i.e., the flux of AX J131501 + 3141. According to the model of Comastri et al. (1995), the expected number is 1.2. The observed

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TABLE 3

PHOTOMETRY OF AX J131501 + 3141

| Name     | Band   | Log Frequency (Hz) | Observed Flux Density | log (\(\nu L_\nu\)) |
|----------|--------|--------------------|-----------------------|---------------------|
| FIRST    | 1.4 GHz| 9.15               | 3.83 mJy              | 39.08               |
| IRAS     | 60 μm  | 12.70              | <0.1 Jy               | <44.08              |
| Optical  | R band | 14.66              | 15.62 mag             | 44.21               |
|          | B band | 14.83              | 17.25 mag             | 43.91               |
| ASCA     | 2.0 keV| 17.68              | 9.6 \times 10^{-13}sb | 41.7                |
|          | 10.0 keV| 18.38              | 6.4 \times 10^{-14}sb | 43.2                |

* Unit in ergs s⁻¹.
* Flux density in ergs s⁻¹ cm⁻² keV⁻¹ without absorption correction.

Fig. 3.—Spectral energy distribution of AX J131501 + 3141. Large filled rectangles are data points of AX J131501 + 3141. Large filled triangle is the upper limit to the infrared emission. Other smaller marks represent SEDs of type 2 Seyferts from Mas-Hesse et al. (1995): open rectangles, Mrk 348; crosses, NGC 1068; filled rectangles, NGC 2110; open pentagons, Mrk 3; open hexagons, NGC 4388; filled hexagons, NGC 4507; open triangles, NGC 5506; arrows, NGC 5674; open circles, NGC 7582.
surface number density is 1 (AX J131501 + 3141), if there are no more such objects in the LSS region. In fact, we cannot expect the presence of more such objects for the following two reasons:

1. The AGNs with \( N_H = 10^{22} - 10^{23} \text{ cm}^{-2} \) in the local universe should have very hard X-ray spectra, like the hardest source, but no such hard source is found in the LSS region above \( 5 \times 10^{-13} \text{ ergs cm}^{-2} \text{ s}^{-1} \) (Ueda 1996).

2. High-redshift AGNs with \( N_H = 10^{22} - 10^{23} \text{ cm}^{-2} \) have softer X-ray spectra than the hardest source in the observed frame, because of K-correction, and may exist in the LSS region. However, the probability that such a high-z object exists is very low, because the predicted redshift distribution of absorbed AGNs above \( 5 \times 10^{-13} \text{ ergs cm}^{-2} \text{ s}^{-1} \) (2–10 keV) is peaked in \( z \leq 0.1 \) and declining with \( z \geq 0.1 \), if we adopt the evolution of X-ray luminosity function for type 1 AGNs (Jones et al. 1997) and assume the number ratio of type 1 to type 2 AGNs is constant with \( z \).

In other surveys some hard X-ray sources have also been identified with absorbed AGNs. In Iwasawa et al. (1997), a hard X-ray source (AX J1749 + 684) detected serendipitously was identified with a nearby (\( z = 0.05 \)) obscured AGN. The hard X-ray flux of the object is \( 9.6 \times 10^{-13} \text{ ergs cm}^{-2} \text{ s}^{-1} \), 2 times brighter than AX J131501 + 3141. A fainter hard X-ray source (AX J08494 + 4454) with \( f_X = 9.0 \times 10^{-14} \text{ ergs cm}^{-2} \text{ s}^{-1} \) in the 2–10 keV band was identified with a type 2 QSO at \( z = 0.9 \) in the course of optical follow-up observations of the ASCA Lynx Deep Survey (Ohta et al. 1996). A common feature of these three type 2 AGNs is that they are hard X-ray sources with radio detections. The \( \alpha_{XX} (f \propto v^{-\alpha}) \) values of these three objects are 0.67 (AX J131501 + 3141), 0.67 (AX J1749 + 684), and 0.60 (AX J08494 + 4454). The agreement of these indices suggests that a hard X-ray survey together with a radio survey is a fairly efficient way to select obscured type 2 AGNs.

Recently, in some optical follow-up programs for the ROSAT deep fields, faint X-ray sources have been identified with narrow emission-line galaxies (NELGs), such as type 2 Seyferts, star-forming galaxies, and LINERs (Boyle et al. 1995; Griffiths et al. 1996; McHardy et al. 1998). These objects are thought to be possible candidates for hard sources, but their X-ray spectra in the hard band have not been established. With respect to their soft X-rays, their ratios of 0.5–2 keV to optical flux are 1 order of magnitude larger than those of normal galaxies and 1 order of magni-
tude smaller than those of QSOs (Griffiths et al. 1996). If we use the upper limit of AX J131501 + 3141 in the 0.5–2 keV band, we find that its X-ray to optical flux ratio is more than 10 times smaller than those of typical NELGs and closer to the normal galaxies \((\log \left[ \frac{f_X(0.5-2 \text{ keV})}{f_B} \right] = -1.52)\). Thus, AX J131501 + 3141 may be different from the NELGs detected in the \(ROSAT\) surveys. However, it is possible that we are seeing the same population of objects at lower redshifts. To establish the nature of the hard X-ray sources, identification of all the X-ray sources detected in the LSS is clearly necessary.

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