**TITLE**

AGN Population at 10^{-13} erg s^{-1} cm^{-2} : Results from Optical Identification of ASCA Surveys

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Abstract. In this paper, results of optical identification of ASCA surveys are summarized. To understand luminous AGNs in the z ≤ 1 universe, the ASCA AGN sample is still better than samples of AGNs from deep Chandra or XMM-Newton surveys. Combining the identified sample of AGNs from ASCA Large Sky Survey and Medium Sensitivity Survey, the sample of hard X-ray selected AGNs have been expanded up to ∼80 AGNs above the flux limit of 10^{-13} erg s^{-1} cm^{-2} in the 2–10 keV band. One fifth of the ASCA AGNs are absorbed narrow-line AGNs. The luminosity distribution of the absorbed AGNs is limited below 10^{45} erg s^{-1}, though there are 14 non-absorbed broad-line AGNs are detected above the luminosity. The result suggests lack of absorbed luminous AGNs (deficiency of type 2 QSO).

1. Introduction

A hard X-ray selection is one of good selection methods that can sample AGNs without bias against heavy absorption to the nucleus. ASCA is the first satellite that is sensitive enough to detect AGNs beyond nearby universe in the hard X-ray band. Many optical spectroscopic-follow-up observations have been and being done for X-ray sources detected in ASCA surveys that range from wide-area medium sensitivity surveys (e.g., Della Ceca et al. 2000) to deep surveys with a few pointings (e.g., Georgantopoulos et al. 1997). To understand luminous AGNs in the z ≤ 1 universe, the ASCA AGN sample is still better than samples of AGNs from deep Chandra or XMM-Newton surveys (Figure 1).

Here, the results of optical identification of the ASCA Large Sky Survey (hereafter LSS; Ueda et al. 1999a; Akiyama et al. 2000a) and the ASCA Medium Sensitivity Survey (hereafter MSS; Ueda et al. 1999b) are summarized. An advantage of the two surveys is high completeness of the optical identification (33/34 for ASCA LSS and 51/55 for ASCA MSS, so far). The ASCA LSS covers 5 degree^2 area near the north galactic pole down to 2 × 10^{-13} erg^{-1} cm^{-2} s^{-1}. The optical identification is done for 34 X-ray sources detected by SIS detector and 30 AGNs are identified. On the other hand, the ASCA MSS is a serendipitous survey of GIS pointing observations from 1993 to 1996. The original sample consists of 55 X-ray sources with flux more than 3 × 10^{-13} erg^{-1} cm^{-2} s^{-1} in the northern sky selected from 15 arcmin radius areas of 176 GIS field of views. The sample contains 48 AGNs so far. The optical identification of the ASCA MSS is now being extended to X-ray sources detected in outer area
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Figure 1. Redshift-luminosity distributions of hard X-ray selected AGNs. Small circles, large squares, large circles, and triangles represent sample of AGNs from the \textit{HEAO1 A2}, \textit{ASCA} LSS, \textit{ASCA} MSS, and \textit{Chandra} Surveys (in detail see text). Open symbols represent AGNs with X-ray absorption column densities less than $N_H$ of $10^{22}$ cm$^{-2}$ (for \textit{ASCA} LSS and \textit{HEAO1 A2} samples) and AGNs with a strong broad-line(s) (for \textit{ASCA} MSS and \textit{Chandra} samples).

of GIS and in southern sky observations. Finally the \textit{ASCA} MSS sample will contain more than 100 identified sources.

2. Deficiency of Type-2 QSOs

A sample of hard X-ray selected AGNs enables us to estimate the fraction of absorbed AGNs. The redshift vs. luminosity distribution of the identified AGNs is shown in Figure 1. Squares and large circles represent \textit{ASCA} LSS and MSS AGNs respectively. One fifth of identified AGNs are narrow-line (broad-line-weak) and absorbed AGNs. In the luminosity range below $10^{44}$ erg s$^{-1}$, one third of AGNs are absorbed narrow-line AGNs. Considering the fact that objects with absorption column densities of up to $N_H$ of $10^{22.5}$ cm$^{-2}$ can be detected without bias using 2–10 keV emission, the fraction of absorbed narrow-line AGNs is consistent with the absorption column density distribution of nearby Seyfert galaxies (Risaliti et al. 1999). On the other hand, in the luminosity range above $10^{45}$ erg s$^{-1}$, 14 broad-line AGNs are detected in total, but no narrow-line AGN is found. The result suggests lack of absorbed luminous AGNs (deficiency of type 2 QSOs). Similar tendencies also appear in the \textit{HEAO1 A2} sample (small circles in Figure 1; Piccinotti et al. 1982) and recent results of \textit{Chandra} optical
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Figure 2. Fitted column density versus 2–10 keV luminosity diagram of the ASCA LSS AGNs. The X-ray luminosities are not corrected for the absorption. Narrow-line AGNs with X-ray absorption with hydrogen column density larger than $10^{22}$ cm$^{-2}$ are marked with dots. Upper limits for column densities are indicated with downward arrows.

identification (small triangles in Figure 1; Hornschemeier et al. 2000; Mushotzky et al. 2000; Brandt et al. 2000; Fiore et al. 2000). Chandra AGNs with a strong broad-line(s) in their optical spectra or listed as a QSO are plotted with open symbols, and filled symbols represent other AGNs or galaxies. It should be noted that the optical identification of Chandra sources is not complete at this moment and unidentified X-ray sources with red optical counterparts may be a missing population of type 2 QSOs.

3. X-ray Spectra of Hard X-ray Selected QSOs

Some of broad-line z~1 QSOs have harder X-ray spectra than typical X-ray spectra of QSOs (power-law with photon index of 1.7), although their optical colors, optical spectra, and X-ray to optical flux ratios are same as normal QSOs. In the ASCA LSS AGNs, four high-redshift broad-line QSOs show hard X-ray spectra with apparent photon indices of 1.3±0.3. The hard X-ray spectra may also be explained by absorption with log $N_H$(cm$^{-2}$)=22~23 at the object’s redshift, if we assume an intrinsic photon index of 1.7 (Figure 2, it should be noted that redshifts and hard X-ray luminosities correlate each other in the ASCA LSS sample. Therefore, the hard X-ray luminosity of $L_{2-10}$ keV $\sim 10^{45}$ erg s$^{-1}$ corresponds to the redshift of $z \sim 1$). Similar hardenings of X-ray spectra of high-redshift broad-line QSOs are also reported in other ASCA surveys (Della Ceca et al. 2000) and Beppo-SAX surveys (La Franca et al. 2000). The origin of the hardness is not clear yet. The hardness of the X-ray spectra of high-redshift
QSOs may be explained by the existence of the reflection component. Because of a bump of the reflection component, observed photon indices of type 1 Seyferts in the 0.7–10 keV band is expected to get harder to $z \sim 2$.

4. A Case of an Absorbed QSO at $z=0.65$

A few candidates of narrow-line-strong absorbed QSOs were found in the ASCA surveys, though the fraction of absorbed AGNs in the high luminosity range is not as high as that in the low luminosity range. AX J131831+3341 is a moderately absorbed ($N_H$ of $10^{22}$ cm$^{-2}$) QSO at $z=0.65$ found in the ASCA LSS (Akiyama et al. 2000b, Akiyama et al. 2001). Its optical spectrum shows strong emission lines, such as broad Mg $\text{II}$ 2800 Å, narrow [O $\text{II}$] 3727 Å, and narrow [O $\text{III}$] 5007 Å, but no broad H$\beta$ emission line. Its small H$\beta$-to-[O $\text{III}$] 5007 Å equivalent width ratio $\log$(H$\beta$/[O $\text{III}$])= −0.54 is comparable to those of Seyfert 1.8–2 galaxies (Winkler 1992). The X-ray luminosity is estimated to be $10^{45}$ erg s$^{-1}$, which is as large as the luminosity of the knee of the AGN luminosity function in the 2–10 keV band at $z \sim 0.6$ (e.g., Boyle et al. 1998), and corresponds to the luminosities of QSOs.

The optical and near-infrared images show a nucleus and an extended host galaxy around the QSO (left panel in Figure 3). In the right panel of Figure 3, the $R-I$ and $I-K$ colors of nuclear and host galaxy components are shown. The nuclear component have blue $R-I$ colors but red $I-K$ color. The $I-K$ color of the nuclear component is much redder than optically-selected QSOs at similar redshifts (open squares; Elvis et al. 1994). A possible explanation of these colors is that, in the $K$ band, heavily absorbed ($A_V \sim 3$ mag) nucleus emerges, while optical light originates from scattered blue nuclear light. The estimated fraction of scattered light is 2%, which is similar to that observed in narrow-line radio galaxies (Alighieri et al. 1994). Such a red optical to near-infrared color and a blue optical color may be common characteristics of X-ray selected absorbed QSOs at intermediate redshifts. Recent observations reveal that another absorbed QSO at a redshift of 0.9, AX J08494+4454, also has a blue optical color and a red optical to near-infrared color ($R-I = 0.67$ mag and $I-K = 3.4$ mag; Nakanishi et al. 2000; Akiyama et al. in preparation). Also, a significant fraction of the optical and near-infrared counterparts of Chandra hard X-ray sources show similar red near-infrared colors ($I-HK' = 4 \sim 5$ mag) and blue optical colors ($B-I = 1 \sim 2$ mag) (Mushotzky et al. 2000).

The host galaxy extends 62 kpc away from the nucleus. The asymmetric and extended structure of the component suggests a galaxy interaction or merging in the host galaxy. The $V-R$, $R-I$, and $I-K$ colors of the host galaxy are consistent with a stellar population with age of 1 Gyr. Thus, AX J131831+3341 may have a post-starburst galaxy as the host galaxy like a "post-starburst quasar", UN J1025-0040 (Brotherton et al. 1999).

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Figure 3. Right) Optical $R$ band image of AX J131831+3341 taken with the 8.2m Subaru telescope with integration time of 1800 s. Left) The $R - I$ and $I - K$ color-color diagram of the nuclear (filled square) and the host galaxy (filled circle) components of AX J131831+3341. The open squares represents colors of optically-selected QSOs at redshifts between 0.2 and 1.5 from Elvis et al. (1994). Pentagons show colors of power-law model with indices ($f_\nu = \nu^{\alpha}$) of $-1.0$ (top) and $0.0$ (bottom). The tracks of passively evolving stellar population models with ages from 0.01 Gyr to 12 Gyr are indicated with thick solid line. The arrow represents the effect of reddening with $A_V$ of 1 mag.
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