X-RAY EMISSION FROM LINERs OBSERVED WITH ASCA

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ABSTRACT

We searched for evidence of the presence of AGN in LINERs using X-ray images and spectra up to 10 keV obtained with *ASCA*. We detected hard point-like nuclear sources with X-ray luminosities of $10^{40} - 10^{41}$ ergs s^{-1} from LINER 1s. Their Hα luminosities are positively correlated with the X-ray luminosities. These facts strongly support that these LINER 1s are ionized by low luminosity AGN. LINER 2s in the present sample have systematically lower X-ray to Hα luminosity ratio ($L_{\rm X}/L_{\rm H\alpha}$) suggesting that there exist other ionizing source or that the AGN is heavily obscured even at energies above 2 keV. X-ray properties of low luminosity AGNs are also discussed.

INTRODUCTION

Optical spectroscopic surveys have shown that low level activity is common in nearby galaxies. In particular, low ionization nuclear emission-line regions (LINERs; Heckman 1980) are detected in 40% of nearby bright galaxies (Ho et al. 1997a). Excitation mechanisms of LINERs are still under debate and there are several mechanisms, which can explain LINER type optical emission lines, such as (1) photoionization by low luminosity AGNs (LLAGNs), (2) photoionization by very hot stars (3) shocks, and so on (see Filippenko 1996 for a review). The presence of an X-ray nucleus is one of the most convincing evidence for an AGN. We present X-ray observations of LINERs obtained with *ASCA* and compare their X-ray properties with low luminosity Seyfert galaxies and luminous AGNs. We also discuss the X-ray properties of LLAGNs.

OBSERVATIONS AND RESULTS

X-ray Results

We analyzed X-ray data of 17 LINERs obtained with *ASCA*. We also analyzed 10 low luminosity Seyfert galaxies (hereafter LLSeyferts) for comparison. The sample is shown in Table 1. These data are taken from proprietary and archival data selected based on optical emission line classifications and note that the present sample is not complete. Optical emission line classifications are taken from Ho et al. (1997a, b), but for NGC 4594 (Kormendy et al. 1995), NGC 1097 (Storchi-Bergman et al. 1993), and IC 1459 (Phillipps et al. 1986). The objects with and without a broad Hα component in their optical spectra are referred as type 1 objects (LINER 1s and Seyfert 1s) and type 2 objects (LINER 2s and Seyfert 2s), respectively.

We detected hard X-ray emission above 2 keV from all the objects except for one object (NGC 404). The X-ray spectra are represented by a two component model: a power-law modified by photo electric

Table 1: Observed galaxies

classification	name
LINER 1	NGC315, NGC1052, NGC1097, NGC3998, NGC4203, NGC4438 NGC4450, NGC4579, NGC4594, NGC5005, IC1459
LINER 2	NGC 404, NGC 4111, NGC 4569, NGC 4736, NGC 5195, NGC 7217
Seyfert 1	NGC2639, NGC3031, NGC4258, NGC4565, NGC4639, NGC5033
Seyfert 2	NGC2273, NGC3079, NGC3147, NGC4941

absorption (hard component) plus an optically thin thermal plasma (soft component). The photon indices of the power-law component are $\Gamma \sim 1.7 - 2.0$ and the temperatures of the soft component are $kT \sim 0.5 - 0.7$ keV (Terashima 1998). The X-ray luminosities of the hard component range from 4×10^{39} ergs s^{-1} to 6×10^{41} ergs s^{-1} in the 2–10 keV band.

Ionizing source of LINERs

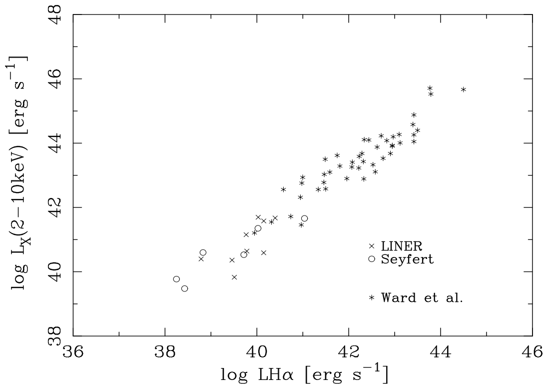
The hard X-ray emission from galaxies can be produced by various origins such as AGN, X-ray binaries distributed in a galaxy, and starburst activity. If the dominant excitation mechanism of LINERs is photoionization by LLAGNs, the Hα luminosity $L_{\mathrm{H}\alpha}$ is expected to be proportional to the X-ray luminosity L_{X} as is observed in Seyfert galaxies (e.g. Ward et al. 1988; Koratkar et al. 1995). Figure 1. shows the correlation between L_{X} and $L_{\mathrm{H}\alpha}$ for LINER 1s and Seyfert 1s. A plot of $F_{\mathrm{H}\alpha}/F_{\mathrm{X}}$ vs F_{X} is also shown in Figure 2. We used LINER 1s for which broad Hα luminosities are available in the literature, and $L_{\mathrm{H}\alpha}$ is the sum of the narrow and broad components. Data for luminous Seyfert 1s and QSOs are taken from Ward et al. (1988). The correlation observed for luminous AGNs extends to lower luminosity and strongly support that the primary ionizing source in our sample of LINER 1s is LLAGNs. Note that the $L_{\mathrm{X}}/L_{\mathrm{H}\alpha}$ for starburst galaxies are about two orders of magnitude smaller than Seyfert galaxies (Pérez-Olea & Colina 1996).

As a next step, we examine whether LINER 2s are also ionized by LLAGNs or not. Since the X-ray properties (X-ray images, spectra) and L_{X}-$L_{\mathrm{H}\alpha}$ correlation indicate that the hard X-ray emission of most of the LINER 1s and LLSeyferts are dominated by AGN, we compare LINER 2s with LINER 1s and LLSeyferts. We use only the narrow Hα component for the comparison. Histograms of $L_{\mathrm{X}}/L_{\mathrm{H}\alpha}$ ratios for LINER 1s + LLSeyferts and LINER 2s shown in Figure 3 clearly show that the $L_{\mathrm{X}}/L_{\mathrm{H}\alpha}$ values for LINER 2s are systematically lower than LINER 1s + LLSeyferts except for NGC 4736 (the largest $L_{\mathrm{X}}/L_{\mathrm{H}\alpha}$ among LINER 2s). If we assume case B recombination, 100% covering fraction, and the spectrum of the ionizing continuum of $\propto \nu^{-1}$, the X-ray luminosities of LINER 2s in low $L_{\mathrm{X}}/L_{\mathrm{H}\alpha}$ bins are not enough to drive the Hα luminosities. These facts suggest that the dominant ionizing source of LINER 2s in the present sample is not an AGN or the AGN is heavily obscured even at energies above 2 keV.

X-ray Properties of Low Luminosity AGNs

Using LINERs and LLSeyferts in which X-ray emission is dominated by AGN, we investigate the X-ray properties of LLAGNs. In this subsection, we use data of (1)NGC 315, 1097, 3031, 3079, 3147, 3998, 4203, 4450, 4579, 4594, 4639, 4736, 5033, IC 1459 and (2)NGC 1052, 2273, 2639, 4258, 4941. The absorption column densities for galaxies in the group (1) and group (2) are $N_{\mathrm{H}} < 10^{23}$ cm^{-2} and $N_{\mathrm{H}} > 10^{23}$ cm^{-2}, respectively. We classify these subclasses as Type 1 and Type 2 LLAGNs, respectively.

The luminosity dependence of photon indices for Type 1 AGNs is shown in Figure 4. The data for



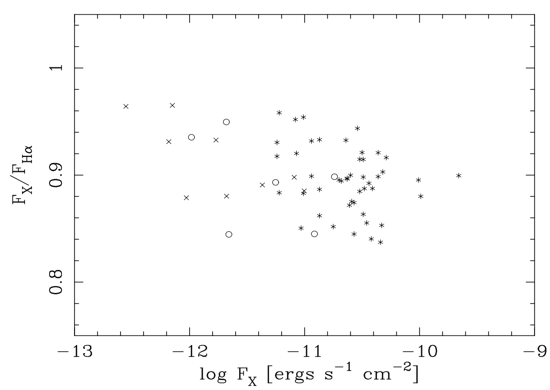


Fig. 1 (*Left*). Correlation between X-ray and Hα luminosity for LINER 1s and Seyfert 1 galaxies.
Fig. 2 (*Right*). X-ray flux dependence of Hα flux to X-ray flux ratio.

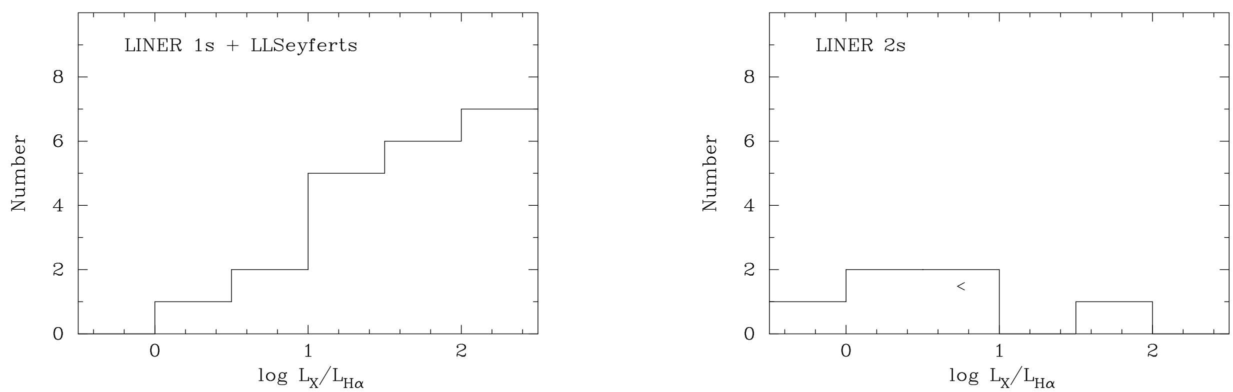
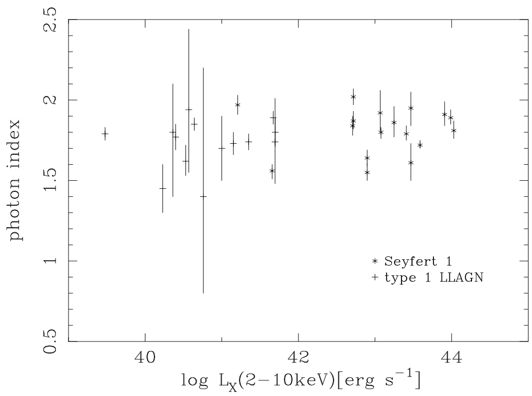


Fig. 3 X-ray to Hα luminosity ratio for LINER 1s + low luminosity Seyfert galaxies (*left*) and LINER 2s (*right*).

luminous Seyfert 1 galaxies are taken from Nandra et al. (1997b). The histogram of absorption column densities is shown in Figure 5. Figure 4 indicates that X-ray spectra of Type 1 LLAGNs show quite similar photon indices to luminous AGNs. The photon indices of Type 2 AGNs also show no luminosity dependence, although errors are large for both luminous and low luminosity Type 2 AGNs. The absorption column densities range from 10^{20} cm^{-2} to 10^{24} cm^{-2} and there exists LLAGNs both with heavy absorption and small absorption as in Seyfert galaxies. Note that the present sample is not complete and that the distribution of absorption column densities does not reflect the optical depths or geometry of the obscuring matter around LLAGNs.

Thus the X-ray continuum shape of LLAGNs are quite similar to luminous AGNs. On the other hand, iron K emission line properties and the variability in Type 1 LLAGNs are different from luminous AGNs. No significant iron K emission is detected from our Type 1 LLAGN sample except for NGC 3031, NGC 4579, and NGC 5033, in contrast to usual Seyfert 1s which generally show iron K emission at 6.4 keV. The center energy of the iron K lines in NGC 3031 and NGC 4579 are 6.7 keV (Ishisaki et al. 1996; Serlemitsos et al. 1996; Terashima et al. 1998a), which is significantly higher than Seyfert 1s, while that of NGC 5033 is 6.4 keV (Terashima et al. 1998b). These iron line properties are possibly due to difference of physical states of accretion disks between LLAGNs and luminous AGNs.

It is well known that Seyfert 1 galaxies with lower luminosities (down to $L_X \sim 10^{42}$ ergs s^{-1}) show larger amplitude and shorter time scale variability than higher luminosity objects (e.g. Nandra et al. 1997a). However type 1 LLAGNs indicate no detectable time variability within one day except for NGC 3031 (Ishisaki et al. 1996) and NGC 5033 (Terashima et al. 1998b), and longer time scale seems to be common (Ptak et al. 1998). A variability time scale provides upper limit of the size



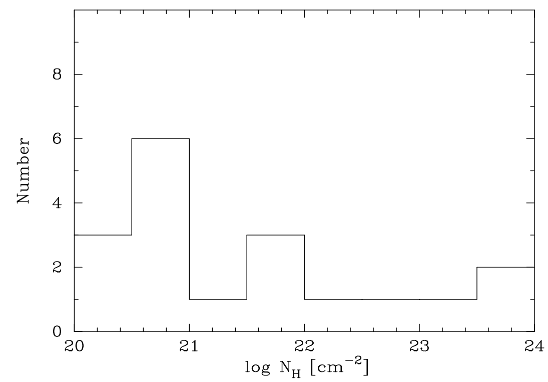


Fig. 4 (*Left*). Luminosity dependence of photon indices for type 1 AGNs.

Fig. 5 (*Right*). Absorption column dendities for low luminosity AGNs.

of the X-ray emitting region and longer time scale would suggest the presence of the large central engine, i.e. a central black hole with a huge mass (Awaki 1998 in these proceedings).

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