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Hard X-ray Emission and the Ionizing Source in LINERs

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ABSTRACT

We report X-ray fluxes in the 2–10 keV band from LINERs (low-ionization nuclear emission-line regions) and low-luminosity Seyfert galaxies obtained with the *ASCA* satellite. Observed X-ray luminosities are in the range between 4×10^{39} and 5×10^{41} ergs s^{-1}, which are significantly smaller than that of the "classical" low-luminosity Seyfert 1 galaxy NGC 4051. We found that X-ray luminosities in 2–10 keV of LINERs with broad Hα emission in their optical spectra (LINER 1s) are proportional to their Hα luminosities. This correlation strongly supports the hypothesis that the dominant ionizing source in LINER 1s is photoionization by hard photons from low-luminosity AGNs. On the other hand, the X-ray luminosities of most LINERs without broad Hα emission (LINER 2s) in our sample are lower than LINER 1s at a given Hα luminosity. The observed X-ray luminosities in these objects are insufficient to power their Hα luminosities, suggesting that their primary ionizing source is other than an AGN, or that an AGN, if present, is obscured even at energies above 2 keV.

Subject headings: galaxies: active — galaxies: nuclei — galaxies: Seyfert — X-rays: galaxies

1. Introduction

LINERs (low-ionization nuclear emission-line regions; Heckman 1980) are fairly common in nearby galaxies. A recent optical spectroscopic survey of nearby galactic nuclei has shown that ~30% of bright galaxies have LINERs (Ho, Filippenko, & Sargent 1997a, 1997b; Ho et al. 1997c). The ionization mechanism of LINERs is still controversial (see Filippenko 1996 for a review). There are several ionization mechanisms, which can explain LINER type optical emission lines, such as (1) photoionization by low-luminosity AGNs (LLAGNs), (2) photoionization by very hot Wolf-Rayet stars or O-stars, (3) shocks, (4) cooling flows, and so on.

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LLSeyfert 2s), respectively, by analogy with Seyfert 1s and Seyfert 2s. Two objects (NGC 4192 and NGC 4569) are classified as a transition object between a LINER and an H II nucleus. Although NGC 1097 was a LINER 2 historically (Phillips et al. 1984), we adopt a classification of Seyfert 1.5 based on Storchi-Bergmann, Baldwin, & Wilson (1993) since the *ASCA* observation was performed after the appearance of double-peaked broad Hα. Hα luminosities are taken from Ho et al. (1997a, c) except for several objects (see Table 1 for references). We estimated the amount of reddening by the Balmer decrement for narrow lines and corrected for reddening using the reddening curve of Cardelli et al. (1989), where we assumed the theoretical value of Hα/Hβ=3.1. In the case that the observed Hα/Hβ is less than 3.1, no correction was made. The reddening corrections for broad Hα lines were made by same amount as narrow lines.

X-ray emission is detected from all the objects except for NGC 404. The X-ray spectra of most of the objects are represented by a two-component model consisting of an optically-thin thermal plasma with a temperature of $\sim$0.7 keV and a hard component. Spectra of a few objects do not require a soft thermal component. The hard component is well represented by a power law with a photon index of $\sim$ 1.5–2.0. Detailed results of spectral fits are given in Terashima et al. (2000b). The absorption column density for the hard component ranges from 10^{20} to 10^{24} cm^{-2}. We will make use of the intrinsic luminosities of the hard component corrected for the absorption in the 2–10 keV band. If the absorption column is greater than 10^{24} cm^{-2} and a transmitted hard X-ray continuum is not seen, corrections for the absorption cannot be made. In such a case, we utilize the observed luminosities corrected for only the Galactic absorption. These luminosities are summarized in Table 1. The X-ray luminosities range from 4×10^{39} ergs s^{-1} to 5×10^{41} ergs s^{-1}. Results of *ASCA* observations for several objects have been already published, and references for them are also shown in Table 1.

3. Results and Discussion

3.1. LINER 1s

In order to examine whether optical emission lines in LINER 1s are photonionized by high-energy photons from an AGN, we search for a correlation between X-ray luminosities in the 2–10 keV band ($L_{\rm X}$) and Hα luminosities ($L_{\rm H\alpha}$) for objects with broad Hα in their optical spectra. It is known that a significant positive correlation between these two quantities exists for luminous AGNs (e.g., Ward et al. 1988). If photoionization by an LLAGN is the dominant ionization mechanism in LINER 1s, a $L_{\rm X}$-$L_{\rm H\alpha}$ correlation is expected. Figure 1a shows the correlation between $L_{\rm X}$ and $L_{\rm H\alpha}$ for LINER 1s and LLSeyfert 1s in our sample and luminous Seyfert 1s and QSOs taken from Ward et al. (1988); the Hα luminosities shown represent the sum of the narrow and broad components of the line. It is clear that the correlation extends to lower luminosities. The same correlation using fluxes is shown in Figure 1b. The correlation is still significant in this plot. This correlation strongly suggests that the dominant ionization source in LINER 1s is photoionization by LLAGNs photoionization under Case B recombination and a covering fraction of unity (Osterbrock 1989). Since X-ray luminosities of most LINER 2s are small ($L_X < 2 \times 10^{40}$ ergs s^{-1}), X-ray binaries in the host galaxy might also contribute to observed X-ray fluxes. Actually some objects such as NGC 3607, NGC 4111, NGC 4374, and NGC 4569 have hard band (>2 keV) images extended to several kpc (Terashima et al. 2000a, b), which implies a lower value of $L_X/L_{H\alpha}$ for the nuclear component. Therefore the objects with low log $L_X/L_{H\alpha}$ (<1) are too X-ray weak to ionize optical emission lines, even if X-ray variability of a factor of a few is also taken into account. If an AGN is present and is the dominant ionizing source in these objects, it should be obscured even at energies above 2 keV. Although no clear evidence for the presence of heavily obscured AGN (e.g. heavily absorbed X-ray continuum and/or strong Fe-K emission line) has been obtained so far, the current data cannot rule out such a possibility. Alternatively, there might be other ionization sources. The *Hubble Space Telescope* UV spectra of NGC 404 and NGC 4569 actually show large number of hot stars concentrated in pc-scale nuclear regions (Maoz et al. 1998), and these objects could be examples of LINERs ionized by stellar sources (Terashima et al. 2000a).

3.3. Fraction of AGNs in Bright Galaxies

According to the optical spectroscopic survey by Ho et al. (1997a, b), Seyferts, LINER 1s and LINER 2s are detected in 11%, 5%, 28% of northern ($\delta > 0°$) bright ($B_T \leq 12.5$ mag) galaxies. If we assume an extreme case that all Seyferts and LINER 1s are AGNs and all LINER 2s are not AGNs, the fraction of AGN is estimated to be 16% of bright galaxies. This percentage, however, should be regarded as a lower limit because extremely weak broad Hα is difficult to detect unambiguously (Ho et al. 1997c). Furthermore, some LINER 2s clearly indicate AGN-like activity. For example, NGC 4261 has prominent radio jets and kinematic evidence for a massive black hole (Ferrarese, Ford, & Jaffe 1996). Other examples include the "Sombrero" galaxy (NGC 4594) and NGC 4736. The $L_X/L_{H\alpha}$ values for these object are similar to LINER 1s and LLSeyferts. This fact also indicates that the $L_X/L_{H\alpha}$ ratio is a good indicator of the presence of AGNs. Hard X-ray surveys conducted at high angular resolution, such as afforded by *Chandra*, would be crucial to refine the true AGN fraction in nearby galaxies.

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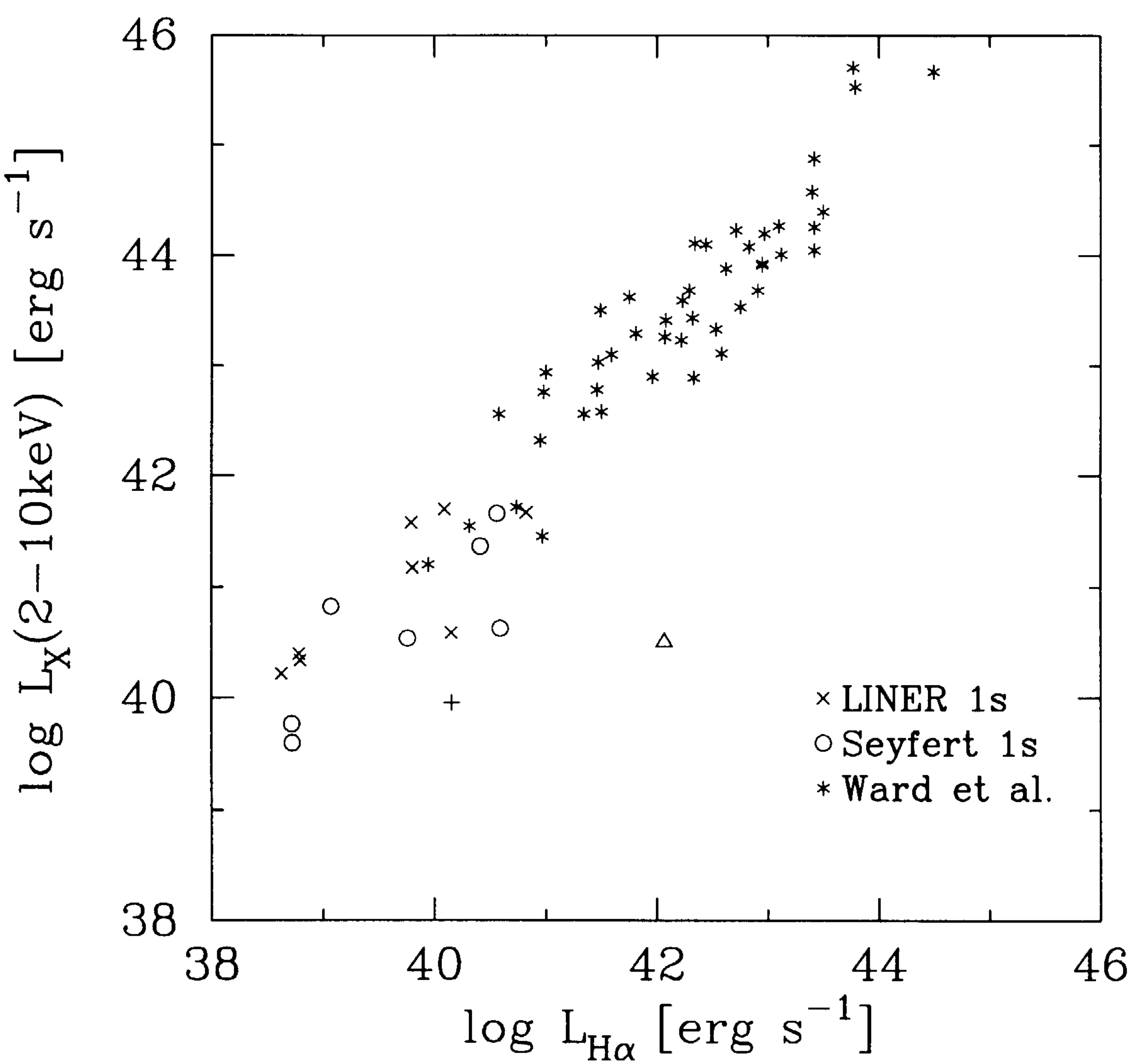
Table 1. X-ray and Hα luminosities for observed galaxies

Name	Distance [Mpc]	Class	log $L(\mathrm{H}\alpha)$ (Broad) [ergs s^{-1}]	log $L(\mathrm{H}\alpha)$ (Narrow) [ergs s^{-1}]	log L_X (2–10 keV) [ergs s^{-1}]	$L_X/L_{\mathrm{H}\alpha}$	reference X	reference Hα
NGC 315	65.8	L1.9	39.92	39.61	41.70	2.09	1	
NGC 1052	17.8	L1.9	39.54	39.45	41.58	2.13	2,3	1,2
NGC 3998	21.6	L1.9	40.59	40.43	41.67	1.24	4	
NGC 4203	9.7	L1.9	38.59	38.34	40.40	2.06	5	
NGC 4438	16.8	L1.9	39.54	40.04	39.96	−0.08		
NGC 4450	16.8	L1.9	38.48	38.51	40.34	1.83		1,2
NGC 4579	16.8	S1.9/L1.9	39.49	39.53	41.18	1.65	4,6	
NGC 4636	17.0	L1.9	38.37	38.27	40.22	1.95	7–11	
NGC 5005	21.3	L1.9	40.05	39.48	40.59	1.11		
NGC 404	2.4	L2	...	37.82	<37.66	< −0.16	12	
NGC 3507	19.8	L2	...	39.60	39.92	0.32		
NGC 3607	19.9	L2	...	39.53	40.16	0.63		
NGC 4111	17.0	L2	...	39.85	39.94	0.09	12	
NGC 4192	16.8	T2	...	40.49	39.58	−0.91	12	
NGC 4261	35.1	L2	...	39.82	41.18	1.36	1, 13	
NGC 4374	16.8	L2	...	39.35	40.33	0.98	8–10	
NGC 4457	17.4	L2	...	39.79	39.98	0.20	12	
NGC 4569	16.8	T2	...	40.66	40.08	−0.58	12	3
NGC 4594	20.0	L2	...	39.82	41.00	1.18	4,14	
NGC 4736	4.3	L2	...	38.12	39.64	1.52	15	4
NGC 7217	16.0	L2	...	39.78	39.86	0.08		
NGC 1097	14.5	S1.5	40.55	39.53	40.63	1.10	16	5
NGC 1365	16.9	S1.8	42.02	41.08	40.50	−0.58	17	6
NGC 2639	42.6	S1.9	39.79	40.48	41.66	1.18	18	1,2
NGC 3031	1.4	S1.5	38.41	38.44	39.60	1.16	19	
NGC 4258	6.8	S1.9	38.90	38.60	40.83	2.23	4,20	
NGC 4565	9.7	S1.9	38.38	38.46	39.77	1.31	21	
NGC 4639	16.8	S1.0	39.75	38.39	40.54	2.15	22	
NGC 5033	18.7	S1.5	40.32	39.70	41.37	1.67	23	
NGC 1386	16.9	S2	...	40.94	40.34	−0.60	17	7
NGC 2273	28.4	S2	...	41.00	41.93	0.93		

Figure Captions

Fig. 1.— (*a*) Correlation between X-ray and Hα luminosities for LINER 1s, low-luminosity Seyfert 1s, and luminous type 1 AGNs taken from Ward et al. (1998)., (*b*) Correlation between X-ray and Hα fluxes for the same sample as (*a*). The triangle and the cross correspond to NGC 1365 and NGC 4438, respectively.

Fig. 2.— log $L_{\rm X}/L_{\rm H\alpha}$ for low-luminosity Seyfert 1s, low-luminosity Seyfert 2s, LINER 1s, and LINER 2s. The symbol "<" denotes an upper limit.


46
44
42
40
38
log L_X(2−10keV) [erg s^{-1}]
38
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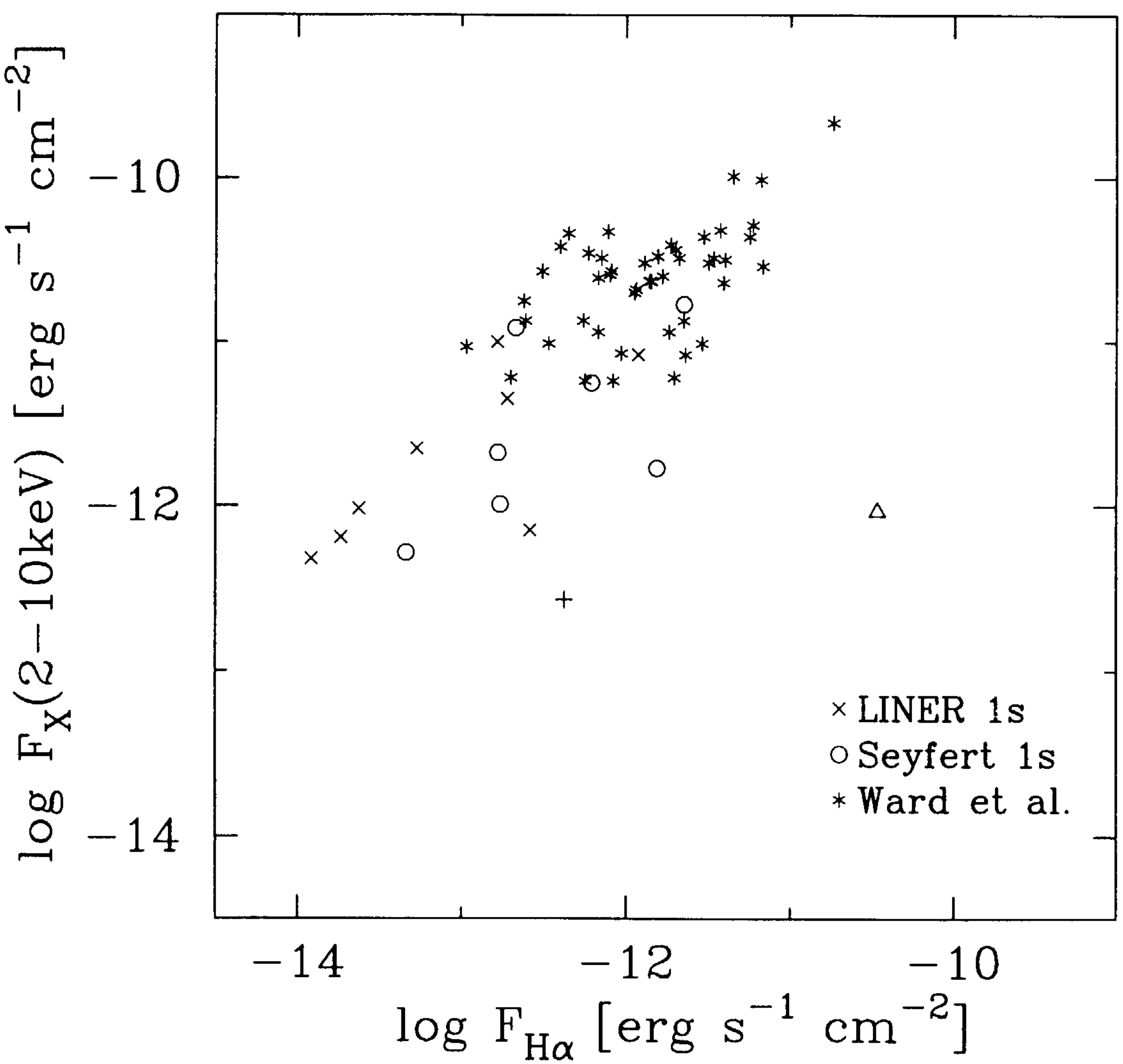
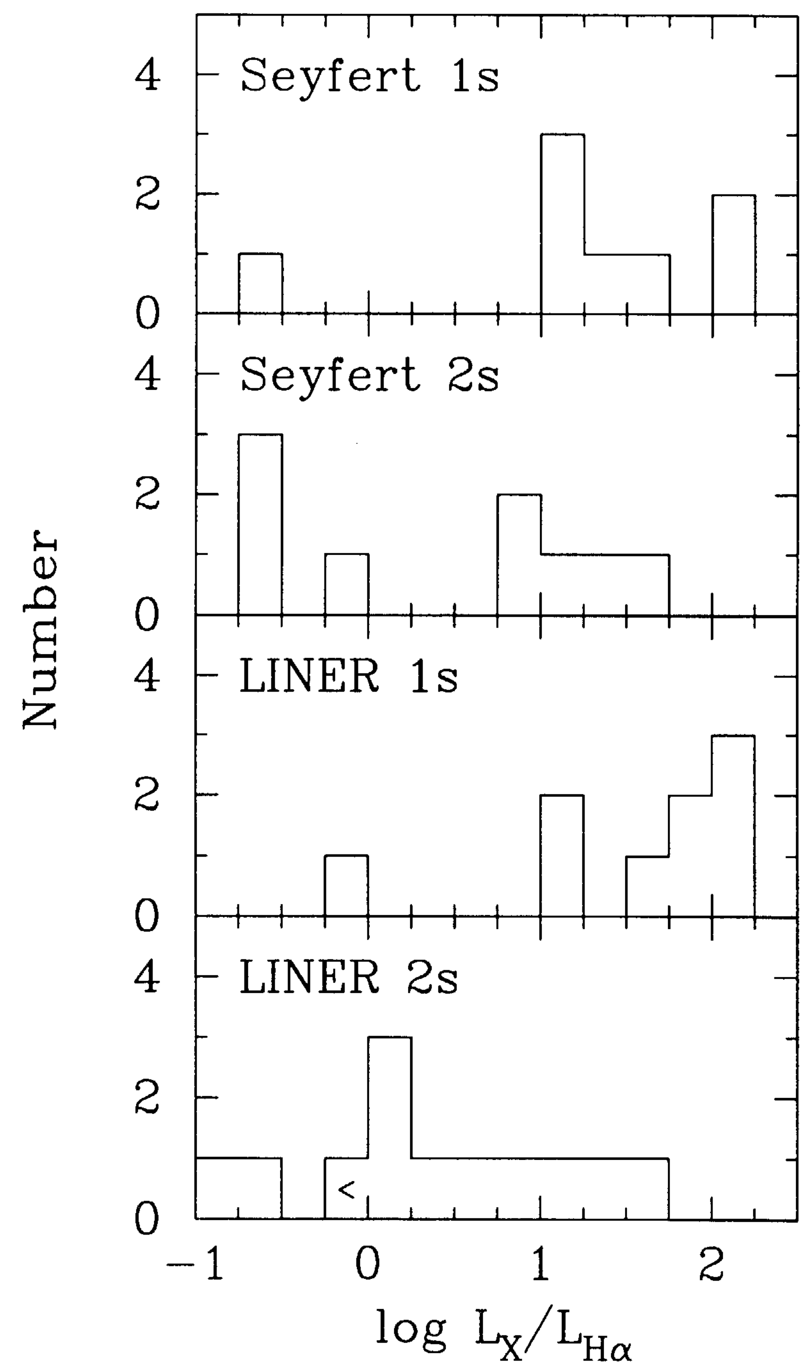
44
46
log $L_{H\alpha}$ [erg s^{-1}]
LINER 1s
Seyfert 1s
Ward et al.


log F_X(2−10keV) [erg s^{-1} cm^{-2}]
−10
−12
−14
−14
−12
−10
log $F_{H\alpha}$ [erg s^{-1} cm^{-2}]
× LINER 1s
○ Seyfert 1s
∗ Ward et al.



Seyfert 1s
Seyfert 2s
LINER 1s
LINER 2s
Number
log $L_X/L_{H\alpha}$