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Detection of an iron K Emission Line from the LINER NGC 4579

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**ABSTRACT**

We present the results of an *ASCA* observation of the LINER NGC 4579. A point-like X-ray source is detected at the nucleus with a 2–10 keV luminosity of \(1.5 \times 10^{41}\) ergs s\(^{-1}\) assuming a distance of 16.8 Mpc. The X-ray spectrum is represented by a combination of a power-law with a photon index of \(\sim 1.7\) and soft thermal component with \(kT \sim 0.9\) keV. An iron K emission line is detected at 6.73 ± 0.13 keV (rest frame) with an equivalent width of \(490^{+180}_{-190}\) eV and is statistically significant at more than 99.9% confidence. The line center energy is consistent with Helium-like iron and is significantly higher than 6.4 keV which is expected from fluorescence by "cold" (or a lower ionization state of) iron. The iron line profile shows no significant red tail in contrast to Seyfert 1 galaxies although the statistics are limited. The line center energy, equivalent width, and profile are consistent with an origin in an ionized accretion disk. However the large mass accretion rate necessary to ionize the accretion disk is not consistent with the observed luminosity and normal accretion models.

*Subject headings:* galaxies: individual(NGC 4579) — galaxies: nuclei — X-rays: galaxies

1. **Introduction**

Recent optical spectroscopic surveys have shown that there are many active galactic nuclei (AGNs) in nearby galaxies and about 40% of bright galaxies are classified as Seyfert galaxies or LINERs (Low Ionization Nuclear Emission-line Regions; *Heckman 1981*) (Ho, Filippenko, &

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Sargent 1997a). The luminosity of these objects are rather low compared to previously known AGN with a median value of the Hα luminosity being only $2 \times 10^{39}$ ergs s$^{-1}$ in the sample of Ho et al (1997a). Such objects (low luminosity AGNs; hereafter LLAGNs) are important for investigating the physics of AGN under an extreme condition, i.e. very low luminosity. X-ray observations probe the innermost regions of AGNs and specifically the iron K line provides information on the ionization state, density, and motion of matter very close to the central energy source.

ASCA observations of Seyfert 1 galaxies revealed that as a class these objects have a broad iron K line with a profile skewed to lower energies, thought to be caused by the reprocessing of the continuum by a relativistic accretion disk (e.g., Tanaka et al. 1993, Nandra et al. 1997a). The center energy of the iron line from Seyfert 1 galaxies is consistent with 6.4 keV, which is expected from fluorescence by neutral or lower ionization states of (Fe XVI) iron in a disk with an inclination of < 30 degrees. In the Seyfert 1.9 galaxy IRAS 18325–5926, a higher peak energy of iron emission is seen, which is compatible with a highly-inclined disk ($i = 40 \rightarrow 50^\circ$) origin (Iwasawa et al. 1996). Highly-ionized iron emission lines are detected from several radio-quiet quasars e.g. E1821+643 (Kii et al. 1991, Yamashita et al. 1997) and PG 1116+215 (Nandra et al. 1996). Nandra et al. (1997b) studied the luminosity dependence of the iron line profile in a large sample of AGN and found that the center energy increases and the red-tail becomes weaker with increasing luminosity. They attributed such behavior to an increasing ionization of the accretion disk with increasing luminosity. Thus X-ray measurements of iron emission lines are powerful diagnostic tools of matter in the vicinity of the nucleus.

There are only a few observations of iron emission lines from low luminosity AGNs ($L_X (2–10 \text{ keV}) \sim 10^{40} \rightarrow 10^{41} \text{ ergs s}^{-1}$). M81 (NGC 3031) with an X-ray luminosity of $L_X (2–10 \text{ keV}) \sim 2 \times 10^{40}$ ergs s$^{-1}$ shows a broad iron line centered at $\sim 6.7 \text{ keV}$ with an equivalent width of $\sim 200$ eV. This line center energy is significantly higher than Seyfert 1 galaxies and similar to luminous quasars. An iron line at 6.4 keV with an equivalent width of $\sim 300$ eV is detected from the low luminosity Seyfert 1 galaxy NGC 5033 ($L_X (2–10 \text{ keV}) = 2 \times 10^{41}$ ergs s$^{-1}$, Terashima et al. 1998b) but only an upper limit on the equivalent width of $\lesssim 300$ eV is obtained for NGC 1097 ($L_X (2–10 \text{ keV}) = 1 \times 10^{41}$ ergs s$^{-1}$, Iyomoto et al. 1996). Although strong iron emission lines are also detected from M51 (= NGC 5194, Terashima et al. 1998a), NGC 1365 and NGC 1386 (Iyomoto et al. 1997), the iron lines in these objects are interpreted as being caused by reprocessed emission from an obscuring tori and/or extended ionized scatterer outside of our line of sight, i.e., these nuclei are heavily obscured. Thus, at present, the number of LLAGNs with small intrinsic absorption from which iron lines are detected is rather limited.

NGC 4579 (M58) is a Sab galaxy in the Virgo cluster of galaxies and classified as a LINER or Seyfert 1.9 galaxy based on the optical emission lines (Ho et al. 1997a, Keel 1983, Stauffer 1982) and the broad Hα component, detected with a FWHM $\sim 2300$ km s$^{-1}$ (Ho et al. 1997b). There exists a flat-spectrum radio core (Hummel et al. 1987). An Einstein HRI observation showed the presence of an unresolved X-ray nucleus and the X-ray flux was measured to be
\[ F_X = 7.9 \times 10^{-12} \text{ ergs s}^{-1} \text{ cm}^{-1} \] in the 0.2–4.0 keV band with the Einstein IPC (Fabbiano, Kim, & Trinchieri 1992; Halpern & Steiner 1983) which corresponds to the X-ray luminosity of \[ 2.7 \times 10^{41} \text{ ergs s}^{-1} \] (we assume a distance of 16.8 Mpc (Tully 1988) throughout this paper). These facts indicate the presence of a LLAGN in this galaxy. A recent ultraviolet imaging observation by Hubble Space Telescope (HST) Faint Object Camera (FOC) detected a point source at the nucleus (Maoz et al. 1995). Its UV spectra were taken by HST Faint Object Spectrograph (FOS) and a featureless UV continuum is detected as well as various emission lines. Comparison of the FOC and FOS data also indicate a factor of 3.3 decrease of UV flux in 19 months. The narrow UV emission lines are incompatible with shock excitation model and a photoionization model is preferred (Barth et al. 1996). Several broad UV emission lines are also detected. These UV results provide further support for the presence of a LLAGN in NGC 4579. On the other hand, Maoz et al. (1998) estimated the ionizing photon number by extrapolating the UV luminosity at 1300 Å towards higher energies and argued that the observed UV continuum is not sufficient to explain the Hα luminosity. They also suggest that emission from AGNs is most prominent at energies higher than the UV. Measurements of an X-ray flux and continuum slope provide information on the ionization source in this LINER. In this paper we report the detection of an Iron K emission line centered at 6.7 keV and discuss X-ray properties of the LLAGN in NGC 4579 and origin of the iron emission line.

2. Observation

NGC 4579 was observed on 1995 June 25 with the ASCA satellite (Tanaka, Inoue, & Holt 1994). The solid state imaging spectrometers (SIS0 and SIS1) were operated in the 2 CCD Faint and Bright mode. Effective exposure time was 32 ksec and 3 ksec for Faint and Bright mode data, respectively, after the standard data screening. As we can correct echo and dark frame errors (DFE), more reliable determination of absolute energy is possible for Faint mode data than Bright mode (Otani & Dotani 1994). Since the SIS sensors were operated in Faint mode during most of the observation time we used only Faint mode data for the following analyses. The gas imaging spectrometers (GIS2 and GIS3) were operated in the pulse-height (PH) nominal mode. We obtained a useful exposure of 31 ksec after the standard data screening and rejection of high background time intervals. X-ray light curves and spectra were extracted from circular regions centered on NGC 4579 with a radius of 4’ for SIS and 6’ for GIS. The spectra from SIS0 and SIS1 were added together after gain corrections. Spectra from GIS2 and GIS3 were also combined. Background data were accumulated from a source free region in the same field. The mean counting rates of SIS and GIS were 0.15 counts s\(^{-1}\) in 0.5–10 keV and 0.09 counts s\(^{-1}\) in 0.7–10 keV per detector, respectively, after background subtraction. No significant variability was detected during the observation. A constant model fit to the light curve with a bin size of 5760 sec (one orbit of the ASCA satellite) in the 2-10 keV band yields reduced chi-square of 1.29 for 16 degrees of freedom. The upper limit on the variability amplitude is 7% (r.m.s.) or 26% (peak-to-peak) for this light curve. Therefore we summed all useful data together.
3. Results

3.1. The X-ray Image

NGC 4579 is detected at the position of the optical nucleus within position determination uncertainties and the X-ray image looks point-like. We compared X-ray images in the 0.5–2 keV and 2–10 keV band with the point spread function (PSF) of ASCA XRT + SIS to evaluate the spatial extent. We fit the azimuthally averaged surface brightness profiles with those of a model PSF + constant background, where we left two parameters free; the normalization of PSF and the background level. We obtained good fits with reduced chi-square $\chi^2_\nu = 0.64$ and 0.70 (11 dof) for the soft and hard energy bands, respectively. Thus the images in these energy bands are consistent with a point source. In order to set an upper limit to the spatial extent we fit the radial brightness profiles with those of a two-dimensional Gaussian convolved through the PSF (see Ptak 1997 for the technique). In this fitting, the free parameters are the Gaussian $\sigma$, the normalization of the Gaussian, and the background level. The upper limits of the Gaussian width are 0.25 arcmin for both soft and hard band (0.25 arcmin corresponds to 1.2 kpc at 16.8 Mpc).

The fitted background level is $\sim 2.5$ times higher than that of the blank sky observations released by NASA Guest Observer Facility in the 0.5–2 keV band, while the 2–10 keV background is consistent with the blank sky fields. NGC 4579 is located at $\sim 1.8^\circ$ away from M87 in the Virgo cluster of galaxies and soft diffuse emission due to the intracluster gas is present in this region (Böhringer et al. 1994). Thus the high background level in the soft band is most likely due to Virgo cluster emission. In the soft band image, no significant structure is seen.

3.2. The X-ray Spectrum

The X-ray spectra obtained with the SIS and GIS are shown in Fig. 1. The X-ray spectra could not be fitted with simple power-law or thermal bremsstrahlung model and residuals were clearly seen around 1 keV and 6.7 keV, which can be identified with iron L line complex and an iron K emission line, respectively. An acceptable fit is obtained with the sum of a power-law, a Raymond-Smith (R-S) thermal plasma model (Raymond & Smith 1977) and a Gaussian at 6.7 keV. In the fitting, the absorption column density is assumed to be the Galactic value ($3.1 \times 10^{20}$ cm$^{-2}$; Murphy et al. 1996) for the R-S component and left free for the power-law component. The best fit parameters of the X-ray continuum are summarized in Table 1 and the best fit model are also shown in Fig. 1 as a histogram. The photon index of the power-law component is $1.72 \pm 0.05$ (hereafter quoted errors are 90% confidence for one interesting parameter), and the X-ray luminosity of this component is $1.5 \times 10^{41}$ ergs s$^{-1}$ in the 2–10 keV band. Although a small excess absorption $N_H = (4 \pm 3) \times 10^{20}$ cm$^{-2}$ is necessary to fit the data in addition to the Galactic absorption, $N_H$ is still consistent with the Galactic value if the calibration uncertainties of the SIS at low energies are taken into account. Since the power-law component dominates the
X-ray flux even in the soft energy band, the abundance of the metals in the R-S component is poorly constrained. Therefore we fixed the abundance at 0.5 solar, which is typical for hot gas in spiral galaxies (e.g. Ptak 1997). Then the soft component is represented by the R-S model with $kT = 0.90^{+0.11}_{-0.05}$ keV. The addition of the R-S component to the power-law + Gaussian model improved chi-square significantly ($\Delta \chi^2 = 33.4$) and this decomposition of the spectrum is very similar to that of many other low luminosity objects observed by ASCA [Serlemitsos, Ptak and Yaqoob 1996]. The X-ray luminosity of the R-S component is $1.2 \times 10^{40}$ ergs s$^{-1}$ in the 0.5–4 keV band. The luminosity of the R-S component depends on the assumed abundance value, and $0.88 \times 10^{40}$ and $1.7 \times 10^{40}$ ergs s$^{-1}$ are obtained for assumed abundance values 1.0 and 0.1 solar, respectively. The hard band spectrum can be also represented by a Raymond-Smith thermal plasma with $kT = 7.9^{+1.3}_{-0.9}$ keV and abundance of $0.55^{+0.18}_{-0.16}$ instead of a power-law plus Gaussian (Table 1).

An iron K line is clearly detected in the X-ray spectra: the addition of a Gaussian line improved $\chi^2$ by 20.0 for three additional parameters (line center energy, line width, and normalization). Therefore the iron line is statistically significant at more than 99.9% confidence according to the F-test. The line center energy is $6.73^{+0.13}_{-0.12}$ keV (rest frame), which is higher than the 6.4 keV typically observed from Seyfert 1 galaxies. The equivalent width is $490^{+180}_{-190}$ eV. The iron line profile is shown in Figure 2 as the ratio of the data to the best fit continuum component of the above fits. Figure 3 shows the confidence contours for the line energy and intensity. The best fit energy agrees with He-like iron and the 90% confidence range corresponds to the ionization state from Fe XX to Fe XXV (He-like). A line center energy of 6.4 keV, which is expected from cold or low-ionization iron, is excluded at more than the 99% confidence level. The confidence contours for the line width $\sigma$ and intensity are shown in Figure 4. The emission line is marginally broad. Although the best fit width is $\sigma = 170$ eV, a narrow line cannot be excluded at 90% confidence level for two interesting parameters. If we fix the line width at $\sigma = 0$, a line center energy of $6.82^{+0.10}_{-0.26}$ keV and equivalent width of $360^{+175}_{-135}$ eV are obtained.

A combination of multiple narrow lines instead of a single broad Gaussian also provides a good fit ($\chi^2 = 0.958$ for 201 dof), where the line center energies are fixed at 6.4 keV, 6.7 keV, and 7.0 keV, which represent cold, He-like, and H-like iron, respectively. The obtained equivalent widths are $110^{+130}_{-110}$, $240^{+170}_{-160}$, and $160^{+190}_{-160}$ eV, respectively (Table 2). The 6.7 keV line is the dominant component also in this model.

Many Seyfert 1 galaxies show broad iron lines with a significant red tail and they are interpreted as originating from the inner part of a relativistic accretion disk (e.g. Tanaka et al. 1995). We examined the disk-line model by Fabian et al. (1989) instead of the Gaussian model. Since the statistics are limited, only two parameters, the inclination angle of the disk and normalization, were left free. The inclination angle is defined such that $i = 0$ corresponds to a face-on disk. The line emissivity is assumed to be proportional to $r^{-q}$ and $q$ is fixed at 2.5, which is the typical value for Seyfert 1 galaxies (Nandra et al. 1997a). The line center energy is fixed at 6.4 keV or 6.7 keV. The inner radius of the line-emitting region was fixed at 6$r_g$, where
\( r_g = GM/c^2 \) is the gravitational radius. The outer radius is fixed at the \( \chi^2 \) local minima for the fits, 16.6\( r_g \) and 10.5\( r_g \) for 6.4 keV and 6.7 keV case, respectively. The disk-line model fits provided worse reduced \( \chi^2 \) values \( \Delta \chi^2 \sim 8 \) than the Gaussian modeling of the line. The best fit parameters are summarized in Table 3. Although the fit is acceptable, systematic positive residuals are seen around 6.7 keV. This is probably due to absence of significant red asymmetry in the observed profile. The obtained equivalent width \( \sim 900 \) eV is extremely large compared to the value expected from a X-ray irradiated disk (e.g. George & Fabian 1991) and observed in Seyfert 1 galaxies (Nandra et al. 1997a).

4. Discussion

4.1. X-ray emission from a low luminosity AGN

We obtained X-ray images and spectra in the 0.5–10 keV band and a point-like X-ray source with a photon index of \( \Gamma = 1.72 \pm 0.05 \) is detected. An iron line is also detected at 6.7 keV. In the soft energy band, a broad line like feature identified with iron-L line complex indicates the presence of thin-thermal plasmas of temperature \( kT \sim 0.9 \) keV.

The X-ray luminosity (\( 1.5 \times 10^{41} \) ergs s\(^{-1} \) in 2–10 keV ) is 1–3 orders of magnitude smaller than typical Seyfert galaxies and falls in the classes of LINERs and "low luminosity" Seyfert galaxies (Serlemitsos et al. 1996, Iyomoto et al. 1996, Ishisaki et al. 1996, Terashima et al. 1998b). In normal spiral galaxies, the X-ray emission is dominated by discrete sources, specifically low mass X-ray binaries (LMXBs) (e.g. Fabbiano 1989, Makishima et al. 1989). The X-ray luminosity from LMXBs are roughly proportional to B-band luminosity \( L_B \) and their X-ray spectra can be approximated by a thermal bremsstrahlung of a temperature of several keV. The ASCA X-ray spectrum of NGC 4579 is also fitted by \( kT \sim 8 \) keV thermal plasma model. However the strong iron line at 6.7 keV is not compatible with the X-ray spectra of LMXBs, since the equivalent width of iron emission lines from LMXBs are small (several tens of eV, Hirano et al. 1987). Additionally, the \( L_X/L_B \) value \( 1.3 \times 10^{-3} \) is more than an order of magnitude higher than normal spiral galaxies (e.g. \( L_X/L_B = 3.5 \times 10^{-5} \) for M31; Makishima et al. 1989). Additionally an upper limit on the size of an archival ROSAT PSPC image is 14” (Gaussian \( \sigma \)), which corresponds to 1.1 kpc at 16.8 Mpc. This upper limit is significantly lower than the size of the galaxy. Therefore we conclude that contribution from LMXBs to X-ray emission of NGC 4579 is negligible.

Hot plasmas with temperatures on the order of \( \sim 10 \) keV are present in the Galactic center region and their X-ray spectra show prominent, ionized iron K emission (e.g. Koyama et al. 1996). The X-ray spectral shape of NGC 4579 in the hard X-ray band is similar to such hot gas. However, the X-ray luminosity of NGC 4579 is three orders of magnitude higher than the Galactic ridge emission (\( L_X \sim 2 \times 10^{38} \) ergs s\(^{-1} \); Kaneda et al. 1997, Yamasaki 1996, Warwick et al. 1985). Starburst galaxies also show a hard spectral component with a temperature of \( \sim 10 \) keV and their X-ray luminosities are around \( 10^{40} \) ergs s\(^{-1} \) (e.g. 3.4 \( \times \) 10\(^{40} \) ergs s\(^{-1} \) in 2–10 keV for M82; Ptak et
al. 1997). However the starburst activity in NGC 4579 is weaker than M82, since the far-infrared luminosity of NGC 4579 is about an order of magnitude lower than that of M82. Furthermore, starburst galaxies show weak or no iron emission contrary to NGC 4579. Therefore hot plasma is unlikely as the origin of the hard component and iron emission line in NGC 4579 and we conclude that the AGN emission dominates the ASCA spectra and that other components such as a hot gas contribution is small, if any.

We note that errors in background subtraction of the Virgo cluster hot gas do not affect the detection of the iron emission line at 6.7 keV, since the cluster gas is very dim in this region and temperature is low \( (kT \sim 2 \text{ keV}) \) (Matsumoto 1998, Böhringer et al. 1994). Actually no significant iron emission is detected from the GIS field around NGC 4579.

If the primary ionizing mechanism of LINER optical emission lines in this galaxy is photoionization by a LLAGN, \( L_X/L_{\text{H}\alpha} \) might be expected to be similar to Seyfert 1 galaxies, for which there is a good positive correlation between \( L_X \) and \( L_{\text{H}\alpha} \) (e.g. Ward et al. 1988, Serlemitsos et al. 1996). Using the \( \text{H}\alpha \) luminosity of broad plus narrow component \( L_{\text{H}\alpha} = 5.9 \times 10^{39} \text{ ergs s}^{-1} \) (Ho et al. 1997b) and the observed X-ray luminosity in the 2–10 keV band, we obtain \( L_X/L_{\text{H}\alpha} \approx 26 \) for NGC 4579. This value is in excellent agreement with those of Seyfert 1 galaxies (Ward et al. 1988) and strongly supports a low luminosity AGN as the ionizing source of the LINER in NGC 4579.

Less luminous Seyfert 1 galaxies tend to show rapid and large amplitude variability (Mushotzky, Done, & Pounds 1993 and references therein). However NGC 4579 shows no significant short term variability. Lack of variability on short time scales seems to be a common property of LLAGNs (Mushotzky 1992, Petre et al. 1993), for example the LLAGN in NGC 1097 (Iyomoto et al. 1996) and NGC 3998 (Awaki et al. 1991) also show no significant variability on timescales less than a day. Direct comparison of ROSAT PSPC and ASCA flux in the 0.5–2 keV band show a factor of two increase in \( \sim 3.5 \) years.

The X-ray spectral slope \( \Gamma = 1.72 \pm 0.05 \) is identical to the average value found for hard X-ray selected Seyfert 1 galaxies (Mushotzky et al. 1993) but the luminosity is lower than that of any Seyfert 1 galaxy but NGC 4051. Based on the FW01 (full width at 0 intensity) of a broad emission line and an estimate of the size of the broad line region, mass of the central black hole is roughly estimated to be \( M_\bullet \sim 4 \times 10^6 M_\odot \). Then the Eddington ratio \( L/L_{\text{Edd}} \) is \( \sim 10^{-3} \) for the observed luminosity of \( \sim 5 \times 10^{41} \text{ ergs s}^{-1} \) (Barth et al. 1996), although their blackhole mass estimation is crude. Therefore the X-ray spectral slope does not seem to be drastically changed even at a very low Eddington ratio. This is also true for M81, for which \( L/L_{\text{Edd}} \) is estimated to be \( \sim (2 - 10) \times 10^{-4} \) (Ho, Filippenko, & Sargent 1996) and the photon index is \( 1.85 \pm 0.04 \) (Ishisaki et al. 1996).

Soft thermal emission of \( kT \sim 0.5 - 1 \) keV is often observed from low luminosity AGNs (Terashima 1997, Ptak 1997, Serlemitsos et al. 1996). In some cases, such emission is associated with starburst activity (e.g. Iyomoto et al. 1996, Terashima et al. 1998a). Since the far-infrared
luminosity of NGC 4579 is $1.5 \times 10^{43}$ ergs s$^{-1}$ some star formation activity may be present which may explain the thermal emission. The soft thermal X-ray to far infrared luminosity ratio $L_X/L_{\text{FIR}} = 6 \times 10^{-4} - 1.1 \times 10^{-3}$ is consistent with starburst galaxies (e.g. David, Jones, & Forman 1992) within the scatter.

### 4.2. Iron-K line

A marginally broad ($\sigma \approx 0.17$ keV) iron emission line is clearly detected at $6.73^{+0.13}_{-0.12}$ keV and the equivalent width is $490^{+180}_{-190}$ eV for the broad Gaussian model fit. The line center energy is significantly higher than 6.4 keV, which is typically observed from Seyfert 1 galaxies, and consistent with He-like iron. A similar broad iron line centered at $\sim 6.7$ keV is detected from the low luminosity Seyfert galaxy M81 (Ishisaki et al. 1996, Serlemitsos et al. 1996). The line can also be represented by line blending of neutral, He-like, and H-like iron and dominated by He-like iron. The disk-line profile (Fabian et al. 1989) is probably inconsistent with the data for 6.4 keV or 6.7 keV intrinsic line energy because of following reasons. The $\chi^2$ value is worse than a single broad Gaussian fit and systematic residuals remain in the disk-line fit, since a significant red tail is not clearly seen in the data. Furthermore, the disk-line model provides the very large equivalent width $\sim 900$ eV, which is about 4 times larger than the results of the disk-line fit to Seyfert 1 galaxies ($<\text{EW}> = (230 \pm 60)$ eV, Nandra et al. 1997a). Therefore our data prefer a symmetric Gaussian-shape profile with intrinsic line center energy of 6.7 keV (He-like) rather than 6.4 keV ($<\text{Fe XVI}$). Thus the ionization state of the iron line emitter may be different from that of higher luminosity Seyfert 1 galaxies in at least some LLAGNs (NGC 4579 and M81)

Strong ionized iron emission lines are observed in heavily obscured Seyfert 2 galaxies (NGC 1068, Ţen et al. 1994, Iwasawa, Fabian, & Matt 1997; NGC 1365, Iwamoto et al. 1997; see also Turner et al. 1997a). In these objects continuum emission from the nucleus is completely blocked and only scattered radiation is observed. Ionized iron lines are interpreted as originating from a photoionized scattering medium. If the continuum of NGC 4579 is scattered radiation, then the observed X-ray luminosity is only a fraction of its intrinsic luminosity. Since the scattering fraction is typically less than 10 % for Seyfert 2 galaxies (Ţen 1993), the $L_X/L_{[\text{OIII}]}$ should be less than 10 % of those of Seyfert 1 galaxies as is the case for NGC 1068 (Mulchaey et al. 1994). However the observed X-ray to $[\text{OIII}]$ λ5007 luminosity ratio $L_X/L_{[\text{OIII}]}$ is very similar to Seyfert 1 galaxies. Therefore the observed X-ray continuum is not likely to be due to a scattered component. Then the observed iron line should be emitted from the matter close to the nucleus in order to be ionized and/or broadened due to the Doppler effect.

If the iron line is emitted by an accretion disk, a line profile with significant red tail is expected (Fabian et al. 1989). On the other hand, the observed profile seems to be symmetric in shape although the statistics are limited. Broad lines with weaker red tails than Seyfert 1s are observed in AGNs with much higher luminosity; $L_X > 10^{44}$ ergs s$^{-1}$ (Nandra et al. 1997b). If the inner-most part of the accretion disk is almost fully ionized, the red component is expected to
be very weak or absent. Thus the observed profile is consistent with the interpretation that the observed iron K emission is from an ionized disk.

The obtained equivalent width (∼ 500 eV for the Gaussian model) is rather large compared to that seen in most Seyfert 1 galaxies. If the disk is highly ionized, the fluorescence yield of iron increases and absorption by lighter elements decreases as light elements are almost completely ionized. In such a situation the equivalent width of an iron line can increase by a factor of two (Matt et al. 1993, Zycki & Czerny 1994). Therefore the large equivalent width is also naturally explained by an ionization effect.

The ionization state of photoionized matter is determined by an ionization parameter ξ = L/nR² (Kallman & McCray 1982), where L, n, and R is the luminosity of ionizing photons, the number density of photoionized matter, and the distance from light source to photoionized matter, respectively. The X-ray luminosity of NGC 4579 is only 1.5 × 10⁴¹ ergs s⁻¹, which is 1–3 orders of magnitude smaller than for Seyfert 1 galaxies, and the X-ray luminosity of M81, from which an iron line centered at ∼ 6.7 keV is detected, is even lower (∼ 2 × 10⁴⁰ ergs s⁻¹). In order to photoionize iron atoms to be He-like, ξ should be at least ∼ 500, while ξ < 100 is required for less ionized species (< Fe XVI) which is probably appropriate for usual Seyfert 1 galaxies. Therefore nR² in the iron line emitting region should be more than two orders of magnitude smaller than that of luminous Seyfert 1 galaxies. An expected ionization parameter under an assumption of standard α disk is calculated by Matt et al. (1993). According to their results, the ionization parameter has a strong dependence on the mass accretion rate ξ ∝ ̇m³ (equations (5) and (6) in Matt et al. 1993), where ̇m is denoted in units of the critical accretion rate ̇m = L/L_Edd. In order to ionize iron to He-like, ̇m should be at least 0.2 (Figs. 2 and 5 in Matt et al. 1993). However the order-of-magnitude estimate of the central black hole mass by Barth et al. (1996) combined with the observed luminosity gives a significantly smaller value of ̇m ∼ 1 × 10⁻³. Then we cannot explain the very low luminosity and the ionized iron line at the same time in the standard disk model. This may suggest that the accretion processes in AGN is different in a very low luminosity situations with very small ̇m.

An advection dominated accretion flow (ADAF) model is proposed for AGNs specifically for objects radiating at very low Eddington ratio (e.g. ̇m ∼ 10⁻⁴ for NGC 4258, Lasota et al. 1996). In the model by Lasota et al. (1996), a standard disk is assumed outside of r_in and an ADAF inside of r_in. In an ADAF, accreting matter is heated up to very high temperatures (T_i ∼ 10¹²K, T_e ∼ 10⁹K). However our detection of an iron line indicates the presence of highly ionized (but not fully ionized) matter surrounding a large solid angle viewed from the light source. This means that r_in should be small and a geometrically thin disk is appropriate. Therefore the iron line in NGC 4579 cannot be explained solely by an ADAF model and the real situation in NGC 4579 may correspond to a condition near the transition from the α disk to an ADAF.

Future sophisticated modeling of accretion in LLAGNs and calculation of expected iron emission as well as precise measurements of an iron K line and mass determination by HST Space
Telescope Imaging Spectrograph will be important to understand physical processes in extremely low luminosity AGNs.

5. Summary

We observed the LINER NGC 4579 with ASCA and detected X-ray emission with a luminosity $1.5 \times 10^{41}$ ergs s$^{-1}$ probably from a LLAGN. The X-ray spectral slope ($\Gamma = 1.72 \pm 0.05$) is quite similar to Seyfert 1 galaxies. Iron K emission is detected at 6.7 keV, which is consistent with He-like iron, with an equivalent width of 500 eV. Although the statistics are limited, the observed iron line profile shows no significant red tail and a symmetrically-shaped He-like iron line is preferred rather than a blueshifted component of the disk-line profile from neutral or low-ionization iron as seen in Seyfert 1 galaxies. The observed center energy, profile, and equivalent width of iron emission are well explained in terms of an ionized disk origin. However the ionization parameter cannot be large enough to ionize the disk with the inferred low Eddington ratio (Matt et al. 1993). The detection of iron emission indicates that a large solid angle seen from the X-ray source is surrounded by ionized material. This is inconsistent with an advection dominated accretion flow model for LLAGNs (Lasota et al. 1996).

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Table 1: Results of spectral fitting to the SIS and GIS spectra of NGC4579

| model        | $N_H$(galactic) [10^{20} \text{ cm}^{-2}] | $kT$ [keV] | abundance [solar] | $N_H$ [10^{20} \text{ cm}^{-2}] | $\Gamma$ or $kT$ [keV] | abundance [solar] | $\chi^2$/dof |
|--------------|-----------------------------------------|-----------|-----------------|---------------------------------|-------------------------|-----------------|-------------|
| (1)          | 3.1(f)                                   | 0.90^{+0.11}_{-0.05} | 0.50(f) | 4.1 $\pm$ 2.7 | 1.72 $\pm$ 0.05 | —              | 192.4/201   |
| (2)          | 3.1(f)                                   | 0.88^{+0.11}_{-0.05} | 0.50(f) | 0(f)             | 7.9^{+1.3}_{-0.9}     | 0.55^{+0.18}_{-0.16} | 198.2/204   |

Note. — The fitting models are (1)Raymond-Smith + Power-law and (2)Raymond-Smith + Raymond-Smith. (f) in the table denotes frozen parameter. The quoted errors in parenthesis are at the 90% confidence level for one interesting parameter.

Table 2: Gaussian fits to the iron K line.

| model                  | $E_L$ [keV] | $\sigma$ [keV] | EW [eV] | $\chi^2$/dof |
|------------------------|-------------|----------------|---------|--------------|
| narrow Gaussian        | 6.82^{+0.10}_{-0.26} | 0(f)           | 360^{+175}_{-135} | 195.5/202   |
| broad Gaussian         | 6.73^{+0.13}_{-0.12} | 0.17^{+0.11}_{-0.12} | 490^{+180}_{-190} | 192.4/201   |
| three narrow Gaussians | 6.4(f)      | 0(f)           | 110^{+130}_{-110} | 192.6/201   |
|                        | 6.7(f)      | 0(f)           | 240^{+170}_{-160} |              |
|                        | 7.0(f)      | 0(f)           | 160^{+190}_{-160} |              |

Table 3: Disk-line model fits to the iron K line.

| $E_L$ [keV] | $R_{in}$ [R_g] | $R_{out}$ [R_g] | $i$ [degree] | EW [eV] | $\chi^2$/dof |
|-------------|----------------|----------------|--------------|---------|--------------|
| 6.4(f)      | 6(f)           | 16.6(f)        | 42 $\pm$ 4   | 880^{+570}_{-360} | 200.7/202   |
| 6.7(f)      | 6(f)           | 10.5(f)        | 36 $\pm$ 3   | 920^{+530}_{-320} | 201.5/202   |
Fig. 1.— *ASCA* SIS and GIS spectra of NGC 4579. The best fit model consist of a Raymond-Smith thermal plasma, power-law, and Gaussian is shown as histograms. SIS(a) and GIS(b) data are plotted separately for clarity.

Fig. 2.— Data/model ratio for the best fit continuum model around an iron K emission line. The crosses with and without filled circle represent SIS and GIS data, respectively. Energy scale is not redshift corrected.

Fig. 3.— Confidence contours for the line energy and intensity. Energy scale is redshift corrected. The contours correspond to 68%, 90%, and 99% confidence level for two interesting parameters ($\Delta \chi^2 = 2.3$, 4.6, and 9.2, respectively).

Fig. 4.— Confidence contours for the line width (Gaussian $\sigma$) and intensity. The contours correspond to 68%, 90%, and 99% confidence level for two interesting parameters.
