Probe of material around the AGN central engine with Suzaku

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Abstract

Material around the AGN central engine is important to understand the evolution of supermassive black hole. We systematically analyzed the Suzakud data of about 70 Seyfert galaxies, about half of which are Compton-thick AGNs, focusing on Fe-K emission/absorption lines, edge, and reflection component. Thanks to well-calibrated data, the center energy and width of the 6.4 keV line is strongly constrained to be 6.395±0.005 keV and <2500 km/s. Fe abundance of the reflector or absorber is also well constrained to be 0.5-1.2 solar, especially for Seyfert 2 galaxies. These support that the reflector is >0.1 pc away from the nucleus. HXD-PIN enables us to determine the absorption and the direct nuclear X-ray luminosity unambiguously. We obtained a clear relation between the absorption column density and the equivalent width of 6.4 keV line, suggesting that the picture of Compton-thick torus is as a whole accepted for both Seyfert 1 and 2 galaxies. Thanks to high quality data with signal-to-noise ratio and accurate continuum determination of Suzaku, ionized Fe-Kα emission or absorption lines are detected from several percents of AGNs. It is found that these features seem to change above several 10^{44} erg/s in such a way that Fe-K features become weak. This extends the previously known X-ray Baldwin effect on the neutral Fe-Kα line to ionized emission or absorption lines. Luminosity-dependence of these properties, regardless of scatter of black hole mass by two orders of magnitudes, indicates that the ionized material is associated with the parent galaxy rather than the outflow and high luminosity nuclear emission would fully ionize the material. This picture matches a trend of lower cold absorption columns for high luminosity AGNs.

Key words: Galaxies: Seyfert — X-ray: Spectroscopy — X-rays: Iron line

1. Introduction

X-ray spectra from Seyfert galaxies are never represented by the simple power-law, but rich of reprocessed features such as absorption, emission and absorption lines, reflection, and so on. Such features are very important to probe the surrounding material around the central supermassive black holes, such as accretion disk or flow, torus, and cloud. Such materials are fuel of the massive black holes, and thus we can obtain information on the evolution of supermassice black holes by studying these materials.

The most prominent feature is a photoelectric absorption of the continuum in the soft X-ray band, and both cold and warm absorbers are found. The cold matter is thought to be associated with the molecular torus, and the absorption column density varies by the viewing angle from the line of sight. For Compton-thin objects with the cold absorption column density of $N_{\rm H} < 10^{23}$ cm^{-2}, $N_{\rm H}$ can be determined by observations below 10 keV. Based on the observations with BeppoSAX, Swift/BAT, and INTEGRAL, a significant fraction of Seyfert galaxies exhibit a Compton-thick cold absorption (Risaliti et al. 1999; Beckmann et al. 2006; Tueller et al. 2008), and a direct nuclear X-ray emission can be observed above 10 keV in that case. Location and geometry of the cold absorber is now extensively studied. Matt (2000) pointed out that the Compton-thin absorber is is different from the Compton-thick molecular torus and it is associated with the interstellar medium in the parent galaxy. Rapid time variation of absorption column density indicates that some of cold absorber exists as a blob-like cloud. Some of Cmpton-thick objects exhibit no optical activity and weak scattering X-ray component, indicating that the torus is geometrically thick than ever thought (Ueda et al. 2007). Warm absorber due to ionized clouds has been often found. It was at first recognied as an ionized absorption edge in the soft X-ray band (Halpern 1984), but lower density absorber has been recently found as absorption lines (e.g. Kaspi et al. 2002). Ionization degree is found to be in a wide range of the ionization parameter. These absorption materials are also observed as a reflector or scatterer. From optical to X-ray band, many emission lines are detected from Seyfert galaxies. Ionization states with a wide range are found; for the iron from the neutral to highly ionized Fe^{+25}.

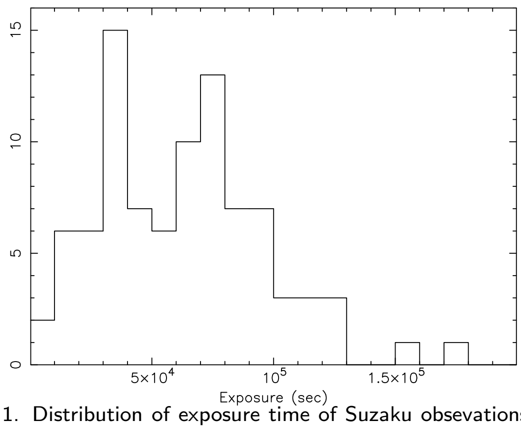

Fig. 1. Distribution of exposure time of Suzaku obsevations for our sample AGNs.

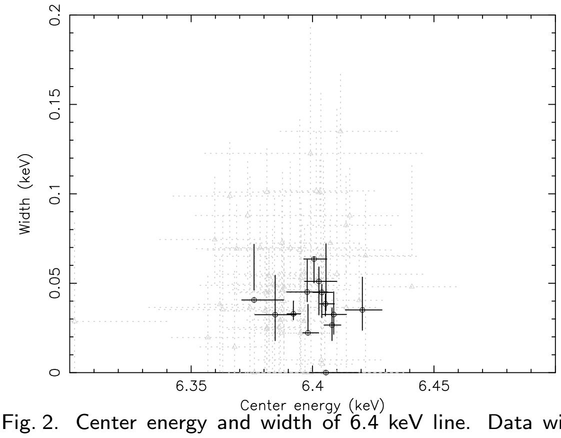

Fig. 2. Center energy and width of 6.4 keV line. Data with small errors are denoted as solid error bars.

These materials are considered to be related with the evolution of the central black hole or engine. Recent X-ray survey revealed that heavily absorbed AGNs are deficit at the high luminosity (e.g. Ueda et al. 2003). In addition, blue-shifted absorption lines are sometimes found in high luminosity AGNs (Pounds et al. 2003; Reeves et al. 2003), indicating the relativistic massive outflow, which is promissing of feedback to the parent galaxy evolution. Therefore, it is important to obtain a general view of materials around the supermassive black hole in order to understand the coevolution of the black hole and galaxy. It is also important to understand the complex X-ray spectra of Seyfert galaxies and derive the intrinsic spectral shape of the central engine. Physical properties of environmental materials are subject to the luminosity of the central engine. However, the absorption column density and intrinsic luminosity of Compton-thick Seyfert galaxies cannot be measured below 10 keV. In addition, constraint of thereflection component is avaible with a wide X-ray band spectroscopy. BeppoSAX and/or XMM-Newton has given opportunities of such studies, but the energy resolution of BeppoSAX around Fe-K lines is too poor to resolve the broad/narrow lines, neutral/ionized lines, or absorption lines. Variability of Seyfert galaxies does not ensure the relation of spectral properties below and above 10 keV. Then, Suzaku XIS/HXD combination (Mitsuda et al. 2007; Koyama et al. 2007; Takahashi et al. 2007; Kokubun et al. 2007) is quite powerful for such studies, thanks to its wide X-ray band, good signal-to-noise ratio, and well-calibrated response. Since a typical exposure time of AGNs with Suzaku is long as shown in figure 1, a signal-to-noise ratio of data is very high. Here, we report the systematic studies of Fe-K line features of Seyfert galaxies and its dependence on the intrinsic luminosity and cold absorber.

2. Data Sample

We selected the Seyfert galaxies from the archival Suzaku data as of March 2009. Furthermore, We looked at the XIS and HXD spectrum, and chose the objects which are detected with HXD-PIN. The detection of HXD-PIN is important to constrain the Compton-thick absorption column density and measure the intrinsic luminosity free from the absorption. This condition leads to selecting objects which are not so faint as to analyze the Fe-K line feature with a good signal-to-noise ratio. As a result, we analyzed about 70 objects, about 40% are Seyfert 1 galaixes, about 20% are Compton-thin Seyfert 2 galaxies, and about 40% are Compton-thick Seyfert 2 galaxies. All the objects were observed with the XIS 5x5 or 3x3 mode and the normal HXD mode. We screened the data with standard selection criteria. We accumulated the XIS photons within 4 arcmin of the object, and coadded the XIS- 0, 2, and 3 data to derive the spectrum. We created the XIS rmf and arf files with `xisrmfgen` and `xisarfgen` (Ishisaki et al. 2008), respectively. The XIS detector background is estimated with `xisnxbgen` (Tawa et al. 2008) and the CXB is added to the thus-obtained background spectrum. For the HXD, we utilized the "tuned" PIN and GSO background (Fukazawa et al. 2009). The good time interval (GTi) is determined by taking the logical-and of GTI among XIS data, HXD data, and HXD background data.

3. Analysis of Fe-K line features

In order to study the Fe-K line features, we first determined the baseline continuum modeling. Since Suzaku spectra of most Seyfert 1 objects cannot be expressed by simple power-law model plus absorption, we added the reflection component and a Fe-K line and fitted the spectra above 3 keV. After obtaining the spectral parameters, we restricted the energy band in 5–9 keV and

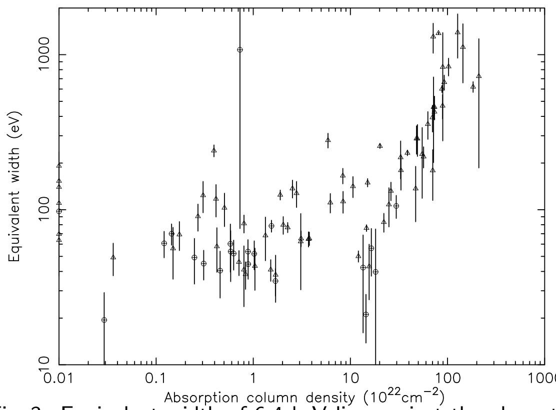

Fig. 3. Equivalent width of 6.4 keV line against the absorption column density. Triangles or circles are AGNs with the luminosity of $< 10^{44}$ erg/s and $> 10^{44}$ erg/s, respectively.

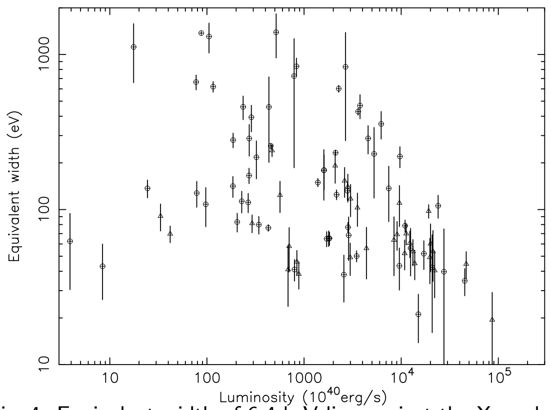

Fig. 4. Equivalent width of 6.4 keV line against the X-ray luminosity (10–50 keV). Triangles or circles are Seyfert 1 and 2 galaxies, respectively.

fixed the absorption, reflection fraction, and powerlaw photon index. We included four gaussians, considering lines of 6.4 keV, 6.7 keV (He-like), 7.0 keV (H-like), and 7.09 keV (neutral Fe-Kβ). The line energy and width of 6.4 keV is let free, but others are fixed; the center energy is fixed to the value in the rest frame, and their line width is to be 0 keV. We allow a negative value for the normalization of ionized Fe-K lines; 6.7 keV and 7.0 keV.

Figure 2 shows the plots of center energy and width of the 6.4 keV line. The center energy is well constrained within 6.35–6.45 keV, and well-determined objects give an average of 6.395$\pm$0.005 keV. The width is constrained to be $<$ 2500 km/s for well-determined objects. These indicate that the 6.4 keV line likely comes from the neutral matter at $>$ 0.1 pc away from the nucleus. Less time variability of 6.4 keV line (Hiragi et al. in this proceeding) is also consistent with this picture. Figure 3

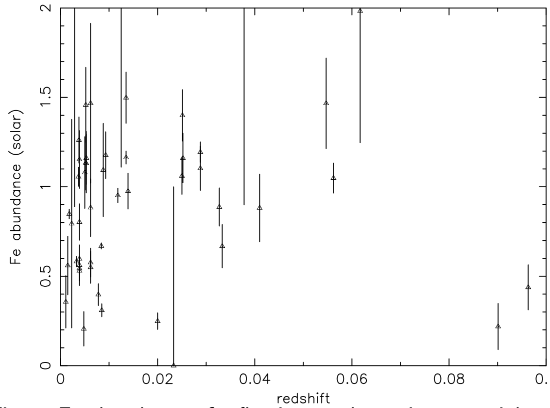

Fig. 5. Fe abundance of reflection or absorption material against the redshift.

shows the equivalent width of the 6.4 keV line against the absorption column density; the latter is determined by wide-band spectral fitting of the Suzaku spectrum. Thanks to well-constraint of absorption by the HXD data, we obtained the clearest correlation than ever between the equivalent width and absorption; positive correlation above $N_{\rm H} = 10^{22}$ cm^{-2}, and almost constant equivalent around 40–120 eV width below $N_{\rm H} = 10^{22}$ cm^{-2}. The positive correlation is in good agreement with the prediction of flueoresent line by the Compoton-thick torus with various column density (Ikeda et al. 2009). The latter trend indicates that the Compton-thick reflector also exists around the nucleus at the off line of sight even for Seyfert 1 galaxies. It is also some hints of smaller equivalent width for higher X-ray luminosity, implying the ionization of reflectors for high luminosity AGNs. This trend of the Baldwin effect (Iwasawa and Taniguchi 1993) is clearly seen in figure 4, and Suzaku for the first time found a clear trend for Seyfert 2 galaxies by measuring the luminosity of direct component accurately above 10 keV band. Thanks to good signal-to-noise ratio around Fe-K lines and reflection humps, Suzaku can constrain the Fe abundance of absorber and reflector. We thus obtained the Fe abundance by assuming that the absorber and reflector have the same metal abundance and the metallicity is one solar abundance except Fe. Figure 5 shows the Fe abundance against the redshift. It can be seen that the Fe abundance is around 0.5–1.2 solar, and rules out the supersolar value which was suggested for some cases by the previous X-ray measurements.

Unprecedented signal-to-noise ratio of the Suzaku data for many AGNs revealed that ionized emission and absorption lines with an equivalent width of 10–50 eV are very common for Seyfert galaxies, regardless of type 1 or 2 objects. The strongest emission lines are seen for Compton-thick Seyfert 2 galaxies such as NGC 4945, while the strongest absorption lines are seen for NGC

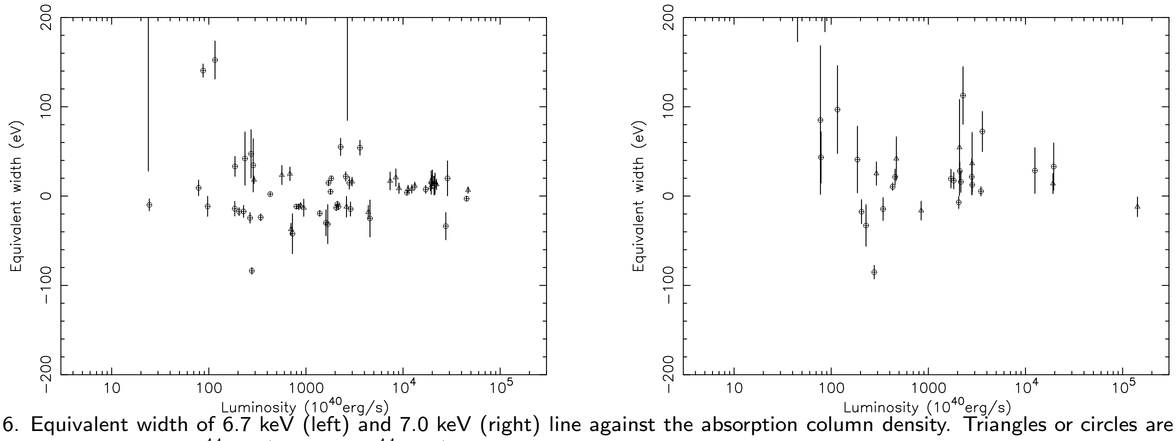

Fig. 6. Equivalent width of 6.7 keV (left) and 7.0 keV (right) line against the absorption column density. Triangles or circles are AGNs with the luminosity of $< 10^{44}$ erg/s and $> 10^{44}$ erg/s, respectively.

1365. No clear correlation with the absorption column density indicates that the ionized material exists as blob-like clouds, independently of the Compton-thick torus. We observe absorption or emission line, when the ionized blob exists toward the line of sight or does not. Absorption lines are not seen for Compton-thick Seyfert 2 galaxies with $N_{\rm H} > 10^{24}$ cm^{-2}, indicating that the viewing angle along the disk prevents the emission from transimitting the ionized material which is considered to exist above the disk. Figure 6 shows the relation of equivalent width of 6.7 and 7.0 keV lines against the X-ray luminosity, where the absorption line is expressed as a negative value. There is a trend of smaller equivalent width for higher X-ray luminosity, the first hint of Baldwin effect for ionized Fe-K lines.

Although time variation of 6.4 keV line is very small (Hiragi et al., in this proceeding), it is observed for 6.7 and 7.0 keV emission and absorption lines for some objects. Suzaku data of NGC 5548 show an example of such variability in such a way that absorption line at 6.7 keV appeared when the flux became higher with a variability time scale of $\sim$ 10 days. Similar trend is also seen in the Suzaku data of NGC 3227.

These observational features for ionized Fe-K lines can be compared with the inner radius of dust torus against the AGN optical luminosity (Suganuma et al. 2006), where light travel time δt of inner radii of torus is propotional to the square of luminosity as $\propto L^{0.5}$. For luminosity of 10^{44} erg/s, the inner radius of torus is around 100 light days, and thus within such a radius the irradiation from the AGN central engine is significant. From the variability time scale of ionized Fe-K lines, highly ionized material is considered to locate around 0.1 pc or so from the central engine. When the luminosity becomes higher than several 10^{44} erg/s, an inner region of the dust torus become evaporated and also highly ionized material are fully ionized and emission or absorption lines cannot be observed. This picture matches that the cold absorption column tends to be lower for high luminosity AGNs (e.g. Ueda et al. 2003). Futhermore higher luminosity the radiation becomes, massive outflow might occur as observed in some high luminosity AGNs. Luminosity-dependence of these properties, regardless of scatter of black hole mass by two orders of magnitudes, indicates that the ionized material is associated with the parent galaxy rather than the supercritical-accretion-induced outflow.

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