Perseus in Sicily: From Black Hole to Cluster Outskirts
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X-ray probing of NGC 1275 nuclear region with Hitomi, Swift, and Suzaku

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Abstract. NGC 1275 has been known as a ppint-like X-ray source with a continuum and a Fe-K line. Unlike radio and GeV/TeV gamma-ray emissions, origin of X-ray emission is not yet understood; is it a jet emission like blazars or an accretion corona emission like Seyfert galaxies. X-ray emission is important to determine the SED of jet emission to constrain jet parameters and also understand the relation between accretion and jet. Here we report a recent X-ray probing of NGC 1275 nuclear region with Hitomi/SXS, Swift/XRT, and Suzaku/XIS. Hitomi/SXS gave the first opportunity to measure a Fe-K line of AGNs with several eV resolution. The line center is consistent with the neutral iron emission, and the width is constrained to be 500-1600 km/s (FWHM). This ruled out the origin of broad line region and inner accretion disk. A low-covering-fraction molecular torus or a rotating molecular disk around pc scales, illuminated by accretion corona emission, is suggested as a possible origin. For the continuum emission, Suzaku/XIS monitor observations revealed that the X-ray flux has gradually increased as the GeV gamma-ray flux. Swift/XRT showed a several-days flux increase, associated with the GeV gamma-ray flare. These results on the continuum emission suggests a contribution of jet emission to the X-ray emission. Based on the combined results of Fe-K line and continuum, we discuss some scenarios for X-ray emitting region.

1. Results and discussion

NGC 1275 is an interesting AGN since it shows a sign of emissions from jet and disl/corona in the multi-wavelength band. Radio and GeV/TeV gamma-rays have been detected from NGC 1275 (Abdo *et al.* 2009), while emission from disk/corona are suggested in the X-ray and optical band (Yamazaki *et al.* 2013). Here we reported a brief summary of recent X-ray studies of NGC 1275, based on the Hitomi/SXS (Hitomi collaboration 2018), Suzaku and Swift/XRT (Fukazawa *et al.* 2018), and discussed the origin of X-ray emission, refering to Fukazawa *et al.* (2016).

In the X-ray band, a point-like source has been detected from Einstein/HRI, ROSAT/HRI, Chandra, and XMM-Newton (Fabian *et al.* 2015). XMM-Newton detected a Fe-K (6.4 keV) line (Churazov *et al.* 2003). Fe-K 6.4 keV line is typical for Seyfert galaxies, while a low Eddington luminosity ratio of 10^{-4} to 10^{-3} gives a doubt whether a normal stanrard accretion disk and torus exists or not. What is an origin of Fe-K line; does it come from torus or others? Precise spectroscopy of Fe-K 6.4 keV line is very important to constrain the origin by measuring doppler shift, width, ionization, and so on. X-ray CCD cannot distinguish between 2000 km s^{-1} and several 100 km s −1. Grating spectroscopy with Chandra/HETG gave a hint of BLR origin of Fe-K 6.4 keV line (Shu *et al.* (2011)). On the other hand, Fe-K variability time scale of a few years suggests a torus origin (Fukazawa *et al.* 2016).

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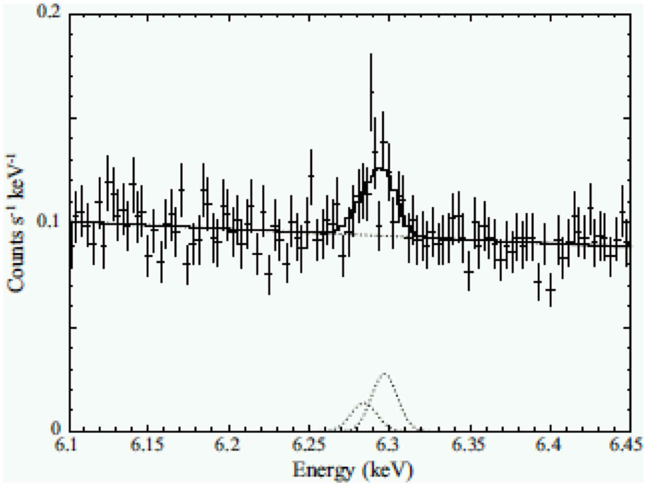

Figure 1. Fe-Kα line of NGC 1275 detected with Hitomi/SXS (Hitomi Collaboration 2018).

Hitomi/SXS observed NGC 1275 during an initial operation observing the Perseus cluster on Feb. 25–27th and Mar. 4–6th, 2016, with an exposure of 240 ks. SXI (CCD) took only a small amount of data, and HXI and SGD have not yet operated. Hitomi/SXS results on Fe-K 6.4 keV line of NGC 1275 has been reported by Hitomi Collaboration (2018).

Hitomi/SXS gave us the first fine spectroscopy of AGN Fe-K line with an energy resolution of 4.9 eV. A resolved line is simple; just Kα_1 and Kα_2, indicating a neutral iron as origin. The center energy is well determined to be 0.01700$\pm$0.00063 in redshift for the neutral Fe-K line, consistent with the latest optical redshift (0.017284) of parent galaxy. The line width is for the first time constrained to be 500–1600 km s^{-1} (FWHM), ruling out the BLR (2750 km s^{-1}) origin. Equivalent width (EW) is just 10 eV for the observed continuum which includes both of AGN and cluster emissions. By PSF photometry technique, we extracted an AGN continuum flux, and an EW of 25 eV was obtained against the AGN conitnuum.

So far several candidates of origin of Fe-K line has been suggested; accretion disk, BLR, and torus. For NGC 1275, molecular disk and molecular clouds have been found (Salomé *et al.* 2006; Scharwächter *et al.* 2013) and they are also a candidate of Fe-K emitter. Hitomi/SXS spectoscopy ruled out an accretion disk and a BLR as origon. Hitomi/SXS also could constrain an extent of Fe-K line emission to be $<$ 42 arcsec ($<$ 17 kpc), and Chandra X-ray data did not show a Fe-K line at 4–30 arcsrc region (1.6–12 kpc) from the center. Based on the Monte Carlo simulation, a Fe-K line flux from the molecular clouds is estimated to be too weak to explain the observed flux. So, torus or molecular disk remains as an origon. A Fe-K line width is consistent with [Fe II] line width of 380–1000 km s^{-1} from the molecular disk (Scharwächter *et al.* 2013), and this prefers an origin of molecular disk. A small EW of Fe-K against 100–200 eV of typical Seyfert galaxies (Fukazawa *et al.* (2011)) indicates a small column density of torus if the torus is an origin.

Then, how about other radio galaxies are on the X-ray properties? Fukazawa *et al.* (2014) reported Suzaku obseravtions of GeV gamma-ray emitting radio galaxies. Some radio galaxies show a Fe-K line; Cen A, 3C 120, 3C 111, and NGC 1275, while other galaxies do not; M87, NGC 6251, PKS 0625-354, and 3C 78. Jet emission is likely to be dominant in the X-ray band for the latter galaxies. Fe-K line of NGC 1275 suggests a disk/corona emission in the X-ray band, since jet emission is so beamed that only a

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Table 1. Summary of evidence for disk/corona versus jet origin for X-ray emission (Fukazawa *et al.* 2015)

Source	Fe-K line	X-ray spectral index	X-ray variability	[O III] line	T ype [ref.]
3C 78	jet	jet	inconclusive	jet	LERG
NGC 1275	disk/corona	inconclusive	jet	disk/corona	HERG/LERG
3C 111	disk/corona	inconclusive	inconclusive	disk/corona	HERG
3C 120	disk/corona	inconclusive	inconclusive	disk/corona	HERG
PKS 0625-354	jet	jet	inconclusive	jet	LERG
M 87	jet	jet	jet	jet	LERG
Cen A	disk/corona	inconclusive	jet	inconclusive	HERG
NGC 6251	jet	inconclusive	inconclusive	jet	LERG

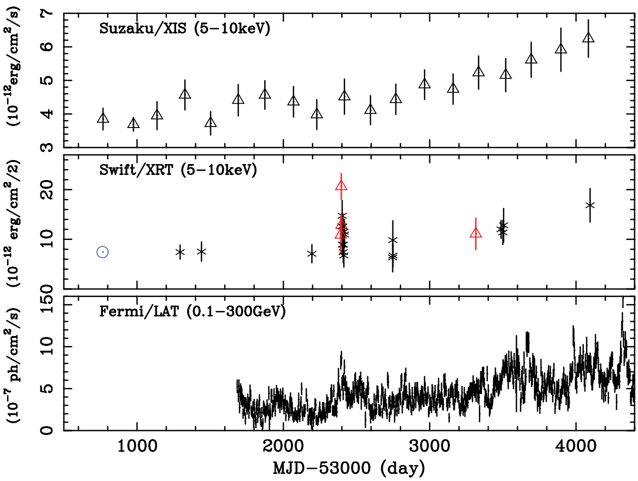

Figure 2. Fermi GeV gamma-ray, Suzaku X-ray, and Swift/XRT X-ray light curves of NGC 1275 (Fukazawa *et al.* 2018).

small fraction of Fe-K emission is predicted. On ther other hand, GeV/TeV gamma-ray emission has been detected and broad-band SED including X-ray band can be represented by jet SSC model. Then, does X-ray continuum come from disk/corona or jet?

Fukazawa *et al.* (2018) reported that Suzaku X-ray monitoring observations every half year shows a recent gradual flux increase as well as GeV gamma-ray, and X-ray and GeV flux correlate well with each other. This long-term gradual X-ray and GeV gamam-ray flux increase is likely to come from the radio C3 spot (Nagai *et al.* (2016)), without any change of SED shape. Swift/XRT observed this galaxy several times, and a short-term flare was detected at the GeV gamma-ray flare in 2010, where the GeV spectrum became hard, suggesting a freshly accelerated electrons. This indicates that a jet emission also exists in the X-ray band of NGC 1275.

Fukazawa et al. (2014) discussed about X-ray emission properties of radio galaxies in terms of Fe-K line, X-ray spectral index, X-ray variability, [O III] line, and optical type. For low excitation radio galaxies (LERG), which has a low accretion rate, X-ray emission is likely to be a jet-origin. For high excitation radio galaxies (HERG), X-ray emission is likely to be a disk/corona-origin. NGC 1275 is an intermediate type between LERG and HERG, and this is consistent with that X-ray emission is contributed from both disk/corona and jet.

In the near future, XARM observations will give us opportunity to measure a variability of Fe-K line and 10–20 keV continuum. Also Athena can provide more on Fe-K line spectroscopy with a good S/N and a large EW avoiding a cluster emission. These are important to constrain the Fe-K origin and also probe a central engine of NGC 1275.

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