Multi-wavelength Properties of X-ray Selected Buried AGNs

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Abstract

We construct a new sample of obscured AGNs and investigate their X-ray spectra and multi-wavelength properties. Our sample is consisting of 38 AGNs selected from the XMM-Newton serendipitous source catalogue, and covers a broad range of scattering fractions (∼0.1−10%), which is the fraction of scattered emission with respect to direct emission. Their spectra obtained with XMM-Newton and/or Suzaku are analyzed to calculate scattering fractions and we find eight objects with a very small scattering fraction (<0.5%). They are strong candidates for *buried* AGNs. Their multi-wavelength properties are also discussed.

Key words: X-rays: galaxies, galaxies: active, galaxies: Seyfert

1. Introduction

It is known that cold matter (torus) is surrounding the supermassive black hole in AGNs, and warm gas photoionized by an AGN is located in the opening part of the torus (e.g., Antonucci 1993). If an AGN is observed from the torus side, absorbed direct emission and emission scattered by the warm gas are observed. A fraction of scattered emission with respect to direct emission (scattering fraction; $f_{\rm scat}$) can be used to estimate the opening angle of the torus. Ueda et al (2007) found AGNs with an extremely small $f_{\rm scat}$ (<0.5%), whereas a typical value is ∼ 3% (Turner et al. 1997; Bianchi and Guainazzi 2007). More examples are then reported by several authors (Eguchi et al. 2009; Winter et al. 2008, 2009; Noguchi et al. 2009). They would be buried in a geometrically thick torus with a very small opening angle assuming that the scattering fraction reflects the solid angle of the opening part of the torus. In an early stage of the evolution of galaxies and their central black holes, a large amount of gas responsible for active star formation may be closely related to obscuration of the nucleus. Therefore, AGNs almost fully covered by an absorber are an important class of objects in studying evolution of AGNs and their hosts.

2. Sample

In order to construct a new sample of obscured AGNs that covers a broad range of $f_{\rm scat}$, we used hardness ratios (HRs) as used in Noguchi et al. (2009). First, we selected 4627 objects with count rates > 0.05 in 0.2-12 keV from the Second XMM-Newton Serendipitous Source Catalogue (Watson et al. 2008), and plotted their HRs defined as

$$\mathrm{HR3} = \frac{\mathrm{CR}(2-4.5\ \mathrm{keV}) - \mathrm{CR}(1-2\ \mathrm{keV})}{\mathrm{CR}(2-4.5\ \mathrm{keV}) + \mathrm{CR}(1-2\ \mathrm{keV})}$$

and

$$\mathrm{HR4} = \frac{\mathrm{CR}(4.5-12\ \mathrm{keV}) - \mathrm{CR}(2-4.5\ \mathrm{keV})}{\mathrm{CR}(4.5-12\ \mathrm{keV}) + \mathrm{CR}(2-4.5\ \mathrm{keV})},$$

where CR(1−2 keV), CR(2−4.5 keV), and CR(4.5−12 keV) are count rates in 1−2, 2−4.5, and 4.5−12 keV, respectively (crosses in Fig.1). Then, we calculated the hardness ratios expected for an obscured AGN using a model consisting of absorbed and unabsorbed power laws corresponding to direct and scattered emission, respectively, with $N_{\rm H} = 10^{21-25}$ cm^{-2} and $f_{\rm scat} = 0.5$−10% (lines in Fig.1). As shown in Fig.1, objects with a small $f_{\rm scat}$ are located in the upper right portion. 38 objects were selected as a new sample of obscured AGNs covering a broad range of $f_{\rm scat}$ with $N_{\rm H} = 10^{23-24}$ cm^{-2} and $f_{\rm scat} < 10\%$ (circles in Fig.1). This sample allows us to investigate correlations between geometrical structure around a nucleus and multi-wavelength properties.

3. Results

We performed spectral fits for our sample to estimate $f_{\rm scat}$ more quantitatively. For Compton thick AGNs, Suzaku spectra covering a broad energy band were used to determine direct and reflection components more accurately. Assuming their soft X-ray emission is dominated by scattered emission, we can calculate $f_{\rm scat}$ using the best-fit models with the equation

$$f_{\rm scat} = \frac{L^{\rm soft}_{0.5-2}}{L^{\rm int}_{0.5-2}},$$

where $L^{\rm int}_{0.5-2}$ and $L^{\rm soft}_{0.5-2}$ are absorption corrected fluxes in the 0.5−2 keV band for the power law corresponding to the direct emission and all the components except for the direct power law, respectively.

From the spectral analysis, we found that $f_{\rm scat}$ for our sample are in the range of ∼0.1−10%. In particular, those of eight objects were very small (<0.5%). They would be the same population as the new type of AGN buried in a very geometrically thick torus with a small opening angle found by Ueda et al. (2007).

If the opening angle of the torus is small, they would have a small amount of narrow line region gas. We investigated the relation between $f_{\rm scat}$ and a ratio of [O III]λ5007 to intrinsic 2−10 keV luminosities ($L_{\rm [O\ III]}/L_{2-10}$) to test our prediction. [O III] luminosities were corrected for the extinction using Balmer decrements. We found that $L_{\rm [O\ III]}/L_{2-10}$ for AGNs with a small $f_{\rm scat}$ tend to be smaller than those with a large $f_{\rm scat}$ (Fig.2). This result is in agreement with the above prediction and indicates that surveys that rely on optical emission lines would have a bias against AGNs with a very small $f_{\rm scat}$ (i.e., almost completely buried AGNs).

We compared $f_{\rm scat}$ with black hole masses calculated from stellar velocity dispersion (Tremaine et al. 2002), and found no significant correlation between them. We also investigated the relation between $f_{\rm scat}$ and Eddington ratios ($L_{\rm bol}/L_{\rm Edd}$). $L_{\rm bol}$ were calculated from $L_{\rm bol} \sim 30 \times L_{2-10}$, where 30 is a typical bolometric correction factor for luminous AGNs (Elvis et al. 1994). In Fig.3, $L_{\rm bol}/L_{\rm Edd}$ are plotted against $f_{\rm scat}$ and anticorrelation is found between them. This correlation suggests that a buried AGN is rapidly growing compared with an AGN with the torus of a large opening part. $f_{\rm scat}$ might be an indicator of the activity growing phase of black holes and a useful parameter to understand the evolution of active nuclei.

References

Antonucci R. 1993, ARA&A 31 473

Bianchi S. & Guainazzi M. 2007 in "The Multicolored Landscape of Compact Objects and Their Explosive Origins", ed. T. di Salvo et al. (New York: AIP)., 822

Eguchi S. et al. 2009 ApJ., 696, 1657

Elvis M. et al. 1994 ApJS., 95, 1

Noguchi K. et al. 2009 ApJ., in press

Tremaine S. et al. 2002 ApJ., 574, 740

Turner T.J. et al. 1997 ApJS., 113, 23

Ueda Y. et al. 2007 ApJ., 664, L79

Watson M.G. et al. 2009 A&A., 493, 339

Winter L.M. et al. 2008 ApJ., 674, 686

Winter L.M. et al. 2009 ApJ., 690, 1322

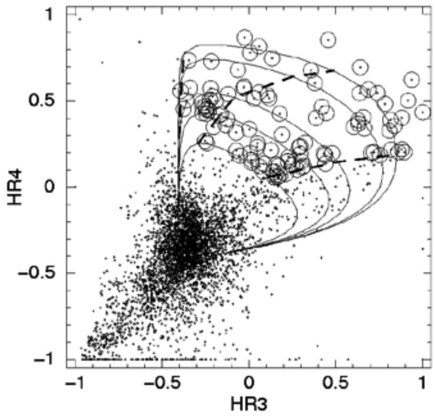

Fig. 1. Distribution of hardness ratio (HR) for bright 2XMM catalogue sources (Crosses). Our sample is shown as circles. Solid lines show the HRs expected for the scattering fraction of 10, 5, 3, 1, and 0.5 % from inside to outside. Dashed lines correspond to log$N_{\rm H}$ of 23, 23.5, and 24 cm^{-2} from lower right to upper left.

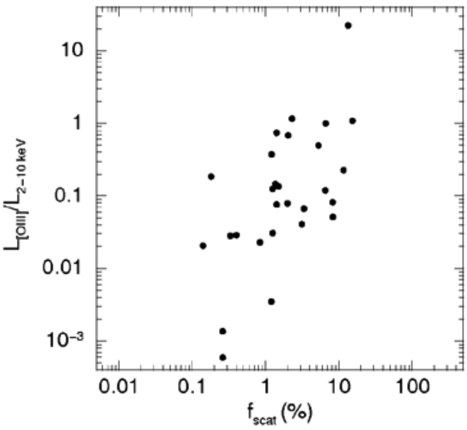

Fig. 2. Correlation between scattering fraction and ratio of intrinsic luminosity in the 2−10 keV band and reddening corrected [O III]λ5007 luminosity.

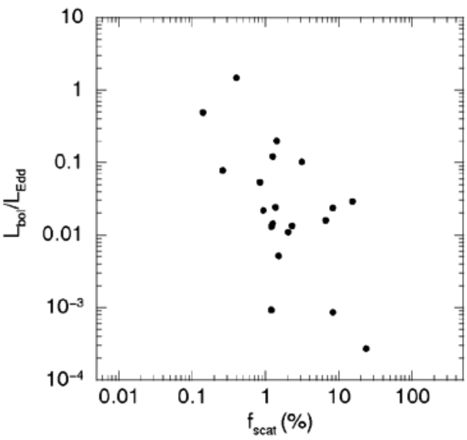

Fig. 3. Correlation between scattering fraction and Eddington ratio.