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Broadband X-ray emission from radio-quiet Active Galactic Nuclei

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Abstract. The broadband X-ray emission from radio-quiet active galactic nuclei (AGNs) is the only probe of their central engines available at present. Deep broadband X-ray observations are providing a wealth of information on AGNs. Here I discuss *XMM-Newton* and *Suzaku* observations of two AGNs with particular emphasis on the broad Iron Kα line, Compton reflection, and new inferences from the observations of partial covering X-ray absorption.

Keywords : galaxies: active – galaxies: nuclei – galaxies: Seyfert – X-rays: galaxies

1. Introduction

X-ray emission from radio-quiet active galactic nuclei (AGNs) is complex, consisting of several components and modified by multiple absorbing, both neutral and ionized, material. The broadband (0.1 − 100 keV) emission is dominated by the 'primary' X-ray emission, generally thought to arise from the accretion disk-corona through the Comptonization of soft disk photons by the hot electrons ($kT_e \sim 100$ keV) in the corona. The primary X-ray emission is partially reprocessed by the accretion disk, the putative cold torus and the circumnuclear matter e.g., disk/torus winds and the broad and narrow-line regions. The disk and the torus give rise to the Compton reflection emission as a result of the two competing processes - photoelectric absorption and Compton scattering. At low energies below 10 keV, the photoelectric absorption dominates and most of the incident primary emission is absorbed by the disk or the torus with reemission in fluorescent emission lines, the iron Kα line at 6.4 keV being the most prominent one. At higher energies, the Compton down scattering dominates. The combination of photoelectric absorption and Compton scattering gives rise to a

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hump called as the 'Compton reflection hump' in the 10 – 40 keV range. In case of reprocessing in the accretion disk, the iron line is broad and skewed by kinematic and relativistic effects. If the reflection occurs in the torus, the iron line is narrow and unresolved. In type 2 AGNs where our line of sight is thought to pass through the cold torus as envisaged in the unification schemes, the primary emission including the disk reflection emission is absorbed at low energies by the torus and often observed are the scattered continuum and photoionized line emission from far away partially ionized regions such as the optical narrow line region. In type 1 AGNs where our line of sight is not intercepted by the torus, a soft X-ray excess emission below $\sim$ 2 keV is often observed. This soft excess emission is a smooth continuum component, not a blend of emission and/or absorption lines. The origin of the soft excess emission is not clearly known but likely arises from relativistically blurred reflection from partially ionized material or optically thick thermal Comptonization in the outer layers of a disk. The soft excess could also be an artifact of absorption from partially ionized smeared wind. In type 1 AGNs, the low energy X-ray emission is generally affected with warm absorption that is detected as numerous absorption lines and edges in the high resolution grating spectra.

At present, the main objectives of X-ray study of radio-quiet AGNs include (i) the origin of the soft X-ray excess emission, (ii) reality of the broad iron Kα line, (iii) iron line and its relation to Compton reflection, (iv) precision measurement of broad iron Kα line parameters and thereby inferring black hole spin, (v) measuring high energy cut-offs and thus inferring about the temperature of the Comptonizing plasma, (vi) time variability of different spectral components and their relationship, (vii) warm absorbers and high velocity outflows, and (viii) partial covering absorption. Below I discuss some of these issues using the *Suzaku* observations of two AGNs.

2. X-ray emission from MCG-5-23-16

The first *XMM-Newton* observation of MCG-5-23-16 revealed a broad and nearly symmetric Fe Kα emission line (Dewangan et al. 2003). The Fe Kα line has two distinct components – a narrow unresolved component with an equivalent width of $\sim$ 40 eV and a broad component with an FWHM of $\sim 40,000$ km s^{-1} and an equivalent width of $\sim$ 120 eV. An absorption feature at $\sim$ 7.1 keV was also detected. The energies of the emission and absorption features are consistent with those arising from neutral iron. The broad component is consistent with an iron Kα line expected from a relativistic accretion disk around a Schwarzschild or Kerr black hole. The second and long look *XMM-Newton* observation confirmed the results of the first observation and additionally detected photoionized emission lines in the soft X-ray band and a possible sporadic absorption line at 7.7 keV (Braito et al. 2006, 2007)

The broadband X-ray observation with *Suzaku* revealed the high energy emission from MCG-5-23-16 with little ambiguity (Reeves et al. 2007). The broadband

X-ray continuum consists of a cutoff power-law with photon index, $\Gamma = 1.9$ and cut-off energy > 170 keV. This power-law is absorbed through a Compton-thin matter of column density $N_H = 1.6 \times 10^{22}$ cm^{-2}. A soft excess is observed below 1 keV and is likely a combination of scattered continuum and emission lines from distant photoionized gas. *Suzaku* confirmed the complex and broad iron line from MCG-5-23-16. The iron K line profile showed narrow neutral iron Kα and Kβ emission lines, as well as a broad line which can be modeled by a moderately inclined accretion disk. The line profile suggested that either the disk is truncated at a few tens of gravitational radii, or the emissivity profile of the disk is relatively flat. A strong Compton reflection component accompanying the iron K line complex is detected above 10 keV, which is best modeled by a combination of Compton reflection from the accretion disk and distant matter such as the putative cold torus. The reflection component does not seem to vary. The overall picture is that this Seyfert 1.9 galaxy is viewed at moderate inclination $\sim 50^\circ$ through Compton-thin matter at the edge of a Compton-thick torus covering 2π steradians. This picture is consistent with the unification model.

3. Partial covering X-ray absorption & binary SMBHs

If the central X-ray source in an active galactic nucleus is partially obscured by an absorbing cloud such that only a part of the X-ray emission is modified by absorption while the other part is unabsorbed, then the resulting X-ray spectrum is said to be affected with the partial covering absorption. There are observations that have been interpreted as partial covering absorption in active galactic nuclei (Holt et al. 1980; Reeves et al. 2008; Dewangan et al. 2008; Turner et al. 2009; Winter et al. 2009). In the case of a single supermassive black hole (SMBH), it is difficult to have thick column of gas which is close enough so that it does not cover the central, compact source fully and is also sufficiently far so that the gas is weakly ionized causing photoelectric absorption. One possibility is the clumpy winds from an accretion disk around an SMBH. These winds located within or near the optical/UV broad line region provide partial covering obscuration of a single active nucleus (Turner et al. 2009). If this interpretation is correct, we must observe correlated variability between the direct low energy X-ray emission and the absorbed high energy continuum since both the bands are part of the same continuum arising from a single active nucleus. If the direct continuum at low energies and absorbed continuum at high energies are not correlated, this would mean that the two continuum components are not part of the same continuum source. Such situations may occur if one active nucleus is hiding behind the putative torus belonging to any of the nuclei or the accretion disk of the other nucleus. X-ray emission from the unresolved pair of absorbed and unabsorbed active nuclei would result in the partial covering absorption in the X-ray spectrum. Thus, close pair of active nuclei can, in principle, be inferred if the X-ray emission from one of the nuclei suffers significantly more absorption than that of the other nucleus.

4. Binary SMBHs in PDS 456

PDS 456 is a radio-quiet quasar. It is the most luminous quasar ($L_{bol} \sim 10^{47}$ ergs s^{-1}, z = 0.184) in the nearby universe. The high luminosity of PDS 456 implies a black hole mass $M_{BH} \sim 10^9 M_{\odot}$ from the Eddington limit (Reeves et al. 2000). We have performed variability and spectral analysis of the broadband X-ray data obtained with the *Suzaku* observation of PDS 456 (Dewangan & Misra 2011). PDS 456 was highly variable during the *Suzaku* observations on scales of 20 ks. Cross-correlation analysis using lightcurves in different energy bands showed that there is string correlation at zero lag between the $0.5 - 2$ keV and $2 - 5$ keV bands but no such correlation is seen between the $0.5 - 2$ keV band and $5 - 10$ keV or the PIN $10 - 70$ keV bands. However, the correlation at zero lag is again seen between the two hard bands XIS $5 - 10$ keV and PIN $10 - 70$ keV. The absence of any correlation between the soft and intermediate bands and the appearance of strong correlation between the two hard band strongly suggests that two physically distinct continuum components dominate the soft and hard bands.

Spectral modeling of the broadband *Suzaku* data revealed that the data are actually consistent with two distinct continuum components. The *Suzaku* and *XMM-Newton* spectra are consistent with a double continuum model - (i) BB ($kT \sim 100$ eV + PL ($\Gamma \sim 2.5 - 2.9$) modified by the Galactic column, and (ii) intrinsically absorbed PL ($\Gamma \sim 1.4 - 2$). The first continuum model is similar to that observed from PG quasars. The second continuum is similar to that observed from type 2 AGNs such as Seyfert 2s. The lightcurves in different energy bands reveal that the two continua are variable but not correlated.

The most appropriate interpretation of the observation of two independent continua from PDS 456 is that the quasar hosts a binary system of active nuclei which vary independently with average $0.5 - 10$ keV luminosities $\sim 2 \times 10^{45}$ ergs s^{-1} and 2.5×10^{44} ergs s^{-1}. If both the nuclei are accreting at the similar rates relative to their Eddington rates, the black hole masses can be estimated to be $\sim 9 \times 10^8 M_{\odot}$ and $\sim 10^8 M_{\odot}$. The absence of double set of narrow or broad emission lines in the optical spectrum suggests that the broad line region (size ~ 0.7 pc) is common to the two SMBHs and hence should be larger than their separation. The X-ray evidence for binary SMBHs in PDS 456 with a separation less than ~ 0.7 pc makes it the most compact system of SMBHs and it may be a possible source of gravitational waves from merging SMBHs.

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