Restless Quasar Activity: From *BeppoSAX* to *Chandra* and XMM-Newton

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We briefly review some of the progress made in the last decade in the study of the X-ray properties of the quasar population from the luminous, local objects observed by *BeppoSAX* to the large, rapidly increasing population of $z > 4$ quasars detected by *Chandra* and XMM-Newton in recent years.

1. Introduction

Over the last decade *ASCA* and *BeppoSAX* have significantly improved our knowledge of the X-ray properties of Active Galactic Nuclei (AGNs), especially at low redshifts, thanks to their broad-band coverage and relatively large effective areas above 2 keV. Moreover, the unique X-ray coverage above $\approx 10$ keV (up to $\approx 100$–200 keV) provided by the Phoswich Detector System (PDS) onboard *BeppoSAX* has allowed proper definition of intrinsic X-ray continuum shapes of local Seyfert galaxies (e.g., [1,2,3,4]; see also [5], this Volume) and quasars (e.g., [6]).

In Section 2 we will briefly recall the most important *BeppoSAX* results obtained for a peculiar AGN: the luminous, nearby radio-quiet quasar (RQQ) PDS 456.

Although a few X-ray spectral studies of quasars at $z \approx 2$–3 have been carried out with *ASCA* (e.g., [7,8]) and *BeppoSAX* (e.g., [9]), the properties of luminous RQQs at higher redshifts ($z > 4$) were poorly known before the launches of *Chandra* and XMM-Newton. In Section 3 we will discuss the large improvements that have occurred in this field in the last few years.

2. One “intriguing” *BeppoSAX* observation: Warm and cold absorption in the luminous, nearby RQQ PDS 456

Unfortunately, high-luminosity quasars are usually found at relatively high redshifts, thus appearing rather weak and difficult to study in X-rays before the launches of *Chandra* and XMM-Newton. In this context, PDS 456, at $z = 0.184$ and with $L_{\text{bol}} \approx 10^{47} \text{ erg s}^{-1}$, can be considered an exceptional case, thus allowing an accurate modeling of the X-ray continuum and reprocessing features with both *BeppoSAX* and *ASCA* ([10] and, recently, with XMM-Newton ([11]). The X-ray spectrum of PDS 456 is characterized by a prominent ionized Fe K edge [clearly visible in the data-to-model residuals shown in Fig. 1, panel (a), when a single power-law fit is adopted]; the edge corresponds to Fe XXIV–XXVI at $\approx 8.8$ keV [see Fig. 1, panel (b)]. The lack of iron emission lines suggests that the ionized edge is due to matter along the line-of-sight rather than reflection from a highly ionized accretion disk. Indeed, the hard X-ray continuum is due to transmission through a very ionized medium, best fitted by a column density $N_{H_{\text{warm}}} \approx 4.5 \times 10^{24} \text{ cm}^{-2}$, coupled with absorption by cold matter having $N_{H_{\text{cold}}} \approx 2.7 \times 10^{22} \text{ cm}^{-2}$ ([13]; see Fig. 2 for the best-fit spectrum).

The X-ray properties of PDS 456 appear quite different from those of the majority of the local...
Palomar-Green quasars (e.g., [6,12]); its photon index is rather flat ($\Gamma = 1.4 - 1.6$; see [10]) and the absorber ionization parameter $U = \frac{n_{\text{phot}}}{n_e}$, defined as the ratio of the ionizing photon density at the surface of the cloud to the electron density of the gas, is extremely high ($\approx 7900$; see [10]). This overall X-ray picture for PDS 456 has been confirmed recently by XMM-Newton, whose spectral resolution has allowed three high-ionization iron K edges ([11]) to be distinguished instead of the one observed by BeppoSAX (likely due to the different spectral resolution and effective area). XMM-Newton has also discovered an extreme gas outflow velocity of $\approx 50,000$ km s$^{-1}$ ([11]), thus supporting the idea that the ionized matter is close to the active nucleus of PDS 456. Furthermore, the source showed repeated X-ray flaring episodes, with an X-ray flux doubling time of $\approx 30$ ks and a total energy output of the flaring events as high as $10^{51}$ erg ([13]). This extreme X-ray variability and the presumably high accretion rate make this source more similar to the Narrow-Line Seyfert 1 galaxies. High-resolution X-ray spectroscopy of such objects can provide further details on the accretion mechanisms responsible for the X-ray emission in high-luminosity objects (e.g., [11,14]).

3. The realm of the ancient quasars

The last few years evidenced an increasing interest in the study of $z \gtrsim 4$ AGNs (mainly quasars), including in the X-ray band. Prior to 2000 there were only six quasars at $z > 4$ with X-ray detections. The number of X-ray detected quasars at $z > 4$ doubled when the first systematic X-ray study of these objects was carried out using archival ROSAT data ([10]). Since then,
the progress made in this field has been substantial. This has been possible due to the availability of increasing numbers of $z > 4$ quasars from ground-based optical surveys (e.g., the Sloan Digital Sky Survey – SDSS, [16], the Digital Palomar Sky Survey – PSS, [17], and the Automatic Plate Measuring facility survey – APM, [18]), and the excellent capabilities of Chandra and XMM-Newton for detecting faint sources.

To define the basic individual X-ray properties (i.e., X-ray fluxes, luminosities, and optical-to-X-ray spectral indices) of $z > 4$ quasars, we started a program to observe with Chandra and XMM-Newton both the optically brightest $z \approx 4-4.6$ PSS/APM quasars and the higher redshift, optically fainter SDSS quasars ([19,20,21,22,23]; see also the recent review by [24]). Since the pioneering work with ROSAT ([15]), the number of AGNs with X-ray detections has therefore increased significantly to more than 80 (see Fig. 3). In the redshift range $z \approx 4-6.3$ (also see [25,26,27,28]), the number of AGNs with X-ray detections has therefore increased significantly to more than 80 (see Fig. 3). Due to the extremely low background in typical Chandra snapshot ($\approx 4-10$ ks) observations, it has also been possible to derive average spectral constraints for subsamples of high-redshift quasars using joint spectral fitting with $\approx 120-340$ X-ray counts ([22,23]). At $z > 4$, optically selected RQQs have a photon index of $\Gamma \approx 1.8-2.0$, similar to the results found at low and intermediate redshifts (e.g., [12]). Furthermore, no spectral evolution of the X-ray continuum shape over cosmic time has been found (see [23] and Fig. 4). At high redshift, this result has been supported recently by direct X-ray spectroscopy of QSO 0000 $-263$ at $z = 4.10$ with XMM-Newton ([33]).

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