X-ray Observations of AGN at Intermediate to High Redshift

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Abstract.

The cores of active galactic nuclei (AGN) harbor some of the most extreme conditions of matter and energy in the Universe. One of the major goals of high-energy astrophysics is to probe these extreme environments in the vicinity of supermassive black holes, which are intimately linked to the mechanisms that produce the continuum emission in AGN. X-ray studies seek to understand the physics responsible for the continuum emission, its point of origin, how nuclear activity is fueled, and how supermassive black holes evolve. The key to finding answers to these questions lies in measuring the intrinsic luminosities and spectral shapes, the relation of these properties to other wavebands, and how the source properties change with redshift. This article reviews X-ray observations of AGN from redshifts of \( \sim 0.1 - 3 \) with the goal of summarizing our current knowledge of their X-ray spectral characteristics. Results are evaluated in terms of their robustness and are examined in the light of current theoretical predictions of energy release via processes associated with the accretion mechanism. A possible evolutionary scenario is discussed, along with the importance of AGN studies at high redshift as they relate to the total energetics of the Universe.

INTRODUCTION

Since their discovery, active galactic nuclei (AGN) have stood out as uniquely luminous objects in the Universe. We are fairly confident that their ultimate power source is the release of gravitational energy sustained by an accretion disk, which feeds matter directly onto a supermassive black hole. Evidence for the accretion mechanism is found in X-ray-bright Seyfert galaxies, which have broad Fe K\( \alpha \) lines indicative of radiatively efficient, geometrically thin accretion disks extending down to the radius of marginal stability [1,2]. However, the mechanisms to produce electromagnetic radiation from the accreting material and the manner in which this material actually reaches the black hole are still unclear. Understanding the accretion mechanism is important because nuclear activity in galaxies is common (perhaps more common than previously thought) and therefore accretion is likely to play a fundamental role in the energetics of the Universe.

The Universe is populated with many classes of AGN, the most powerful of which
are QSOs ($L_X \sim 10^{46-48}$ erg s$^{-1}$). Their high luminosities make them observable at great distances, thereby providing ways to obtain fundamental information about the formation and subsequent evolution of galaxies. As we look toward the early Universe, studies of QSOs can help answer these important questions:

- Do all galaxies contain massive black holes and what roles do AGN play in the formation and evolution of galaxies?

- How does the accreting material make its way into the surroundings of the black hole, and how is this material fed directly into the black hole?

- Is there a change in the accretion efficiency or accretion rate with $z$?

- Are we seeing the flaring of short lived QSO events in many nuclei or a slow decline in a few nuclei that have been QSOs from the start?

Or, in observational terms: In what ways do AGN exhibit spectral evolution?

X-ray observations are of particular value because they provide a powerful diagnostic of the environs of the accretion flow and a powerful means for tracing evolution. Variability studies show that the X-ray continuum emission in AGN originates on the spatial scales we are most interested in – close to the black hole. X-rays can also penetrate large amounts of gas and dust in which some active nuclei are embedded. Moreover, X-ray emission appears to be a universal property of QSOs [3], which allows us to trace their properties out to high redshift. The major limitation of X-ray studies is the need for different instruments to cover the entire X-ray continuum range. Unbiased and statistically valid X-ray samples of QSOs have been difficult to obtain, but this will change with the next generation of X-ray observatories, beginning with the launch of Chandra and XMM in 1999. This article evaluates the current status of X-ray spectroscopy studies of QSOs, with emphasis on objects whose spectra appear to be dominated by accretion mechanisms rather than jet/beaming mechanisms.

**X-RAY CONTINUUM PROPERTIES OF QSOS**

The X-ray spectral characteristics of QSOs for redshifts up to $z \sim 3$ are summarized in Table 1. All results derive from spectral modeling techniques, which assume that the QSO spectrum in a given energy band can be modeled with an absorbed power law having a photon index $\Gamma (N(E) \propto E^{-\Gamma})$. For cases where the line-of-sight absorption is consistent with that due to our Galaxy ($N_{\text{Hgal}}$), the fits have $N_H$ fixed at $N_{\text{Hgal}}$. For cases where $N_H$ is significantly larger than $N_{\text{Hgal}}$, $N_H$ is left as a free parameter. In this article, the term “soft X-ray” is loosely applied to photon energies between 0.1 and 2.4 keV and the term “hard X-ray” is loosely
applied to photon energies between 2 and 10 keV. The energy bands of the experiments listed in Table 1 overlap and so only the photon indices that are strongly weighted toward soft or hard energies are discussed.

When photon index is plotted against redshift (Figure 1), it is apparent that $\Gamma$ decreases with increasing $z$. For RQQs, $\Gamma$(soft) ranges from $\sim 2.6$ at low $z$ to $\sim 2.2$ at high $z$ ($\Delta \Gamma = 0.4$ from $z = 0.1 \rightarrow 2$) while $\Gamma$(hard) changes only slightly with $z$, from $\sim 1.9$ to $\sim 1.7$. For RLQs, $\Gamma$(soft) decreases by a larger amount from $\sim 2.5$ at low $z$ to $\sim 1.7$ at high $z$ ($\Delta \Gamma = 0.8$ from $z = 0.1 \rightarrow 3$), while $\Gamma$(hard) remains fairly constant with $z$. In addition, the soft X-ray index is related to radio loudness in the sense that RLQs have systematically smaller values of $\Gamma$(soft) than RQQs. At high energies, the spectral shapes are similar implying a common emission mechanism and minimal spectral evolution.

What about possible selection biases? The set of observations that most likely contain a selection bias is the ASCA sample of high-z RQQs [4]. For a given optical luminosity, RQQs are $\sim 3$ times less luminous in X-rays than RLQs [5] and so only the most luminous RQQs have reliable hard X-ray data, especially at high $z$. For a given distribution of $\Gamma$(hard), ASCA may be biased towards detecting objects

| Radio class | Sample size | $z^a$ | Energy [keV] | Instr. | $< \Gamma_X >$ | Intrinsic$^b$ $N_H$? | Comments$^c$ | Ref. |
|-------------|-------------|-------|-------------|--------|---------------|----------------|-------------|-----|
| RQQ 42      | 0.12 ± 0.05 | 0.1 – 2.4 | Rosat | 2.56$^{+0.10}_{-0.11}$ | no | d | [6] |
| 9           | 0.3 ± 0.03  | 0.1 – 2.4 | Rosat | 2.47 ± 0.33 | no | d | [6] |
| 19          | 0.19 ± 0.08 | 0.1 – 2.4 | Rosat | 2.72 ± 0.09 | no | d | [7] |
| 390         | 0 → 2.5     | 0.1 – 2.4 | Rosat | 2.58 → 2.22 | — | d | [8] |
| 16          | 0.18 ± 0.21 | 0.3 – 3.5 | Einstein | 1.91$^{+0.67}_{-0.36}$ | no | s. excess (7) | [9] |
| 12          | 0.076 ± 0.04 | 0.1 – 10 | Exosat | 2.18 ± 0.35 | no | s. excess (5) | [10] |
| 9           | 0.54 ± 0.47 | 0.5 – 10 | ASCA | 1.93 ± 0.06 | yes (3) | Fe K (5) | d | [11] |
| 5           | 2.1 ± 0.13  | 2 – 10  | ASCA | 1.68 ± 0.09 | no | FeK (1) | d | [4] |
| 7           | 0.13 ± 0.08 | 2 → 20  | Ginga | 1.90 ± 0.38 | — | | [12] |
| RLQ 65      | 0.08 → 2.3  | 0.1 – 2.4 | Rosat | 2.52 → 1.87 | no | d | [6] |
| 4           | 0.27 ± 0.11 | 0.1 – 2.4 | Rosat | 2.15 ± 0.14 | no | d | [7] |
| 4           | 3.16 ± 0.23 | 0.1 – 2.4 | Rosat | 1.71 ± 0.08 | yes (3) | d | [13] |
| 9           | 2.56 ± 0.8  | 0.1 – 2.4 | Rosat | 1.53 ± 0.06 | yes (2) | d | [14] |
| 17          | 0.34 ± 0.19 | 0.3 – 4.5 | Einstein | 1.48$^{+0.63}_{-0.36}$ | no | | [9] |
| 5           | 0.27 ± 0.22 | 0.1 – 10 | Exosat | 1.79 ± 0.19 | no | s. excess (1) | [10] |
| 3           | 2.3 ± 0.83  | 0.5 – 10 | ASCA | 1.67 ± 0.20 | yes (1) | d | [15] |
| 15          | 2.42 ± 1.29 | 0.5 – 10 | ASCA | 1.63 ± 0.04 | yes (9) | Fe K (2) | d | [11] |
| 9           | 2.56 ± 0.8  | 0.5 – 10 | ASCA | 1.61 ± 0.04 | yes (6) | d | [14] |
| 6           | 0.38 ± 0.3  | 2 → 20  | Ginga | 1.71 ± 0.16 | — | d | [12] |

Notes: $^a$Mean redshift and standard deviation except for cases with arrows, which indicate the range of $z$. $^b$Indicates whether absorption in excess of the Galactic value is present. Parenthesis contain the number of objects. $^c$Indicates cases for which excess soft X-ray emission or Fe K$\alpha$ emission is detected. Parenthesis contain the number of objects. $^d$Denotes data that are plotted in Figure 1.
with small $\Gamma$(hard). On the other hand, these objects still possess fairly steep soft X-ray slopes [8]. Since these objects have both steep low-energy spectra and flat high-energy spectra, the trend seen with ASCA probably does represent RQQs at high $z$.

The dichotomy of spectral indices is robust and provides strong evidence for two distinct emission mechanisms, one at low energies that dominates the spectra up to $z = 1 - 2$, and one at high energies that is approximately independent of $z$. A distinct energy for this spectral “break” toward low energies (obviously a larger effect in RQQs than in RLQs) has not been found, but it is probably somewhere between 0.5 and 1 keV for low-$z$ objects [10]. To explain the spectral changes with $z$, RLQs must have their soft component shifted out of the Rosat band by $z = 2$, beyond which $\Gamma$ reaches its redshift-independent value [16]. RQQs, on the other hand, have not yet displayed the point at which the soft component is shifted out of the Rosat band, and so the spectral break must occur at a higher energy compared to RLQs (Figure 1). Depending on how the soft and hard X-ray components are normalized, either the soft X-ray emission is enhanced in RQQs relative to RLQs or the hard component is enhanced in RLQs relative to RQQs. The fact that RLQs are the stronger X-ray sources implies the latter.

PHOTOELECTRIC ABSORPTION

Characteristics for QSOs at $z > 2$ that have high-quality X-ray data are listed in Table 2. More than 1/2 of the RLQs possess absorption in excess of the Galactic value. In contrast, RQQs and low $z$ quasars lack significant amounts of intrinsic absorption, with a handful of RQQs, such as PG 1114+445 [18] showing evidence for ionized absorption. The absorption in RLQs can be as much as $\sim 5 \times 10^{22}$ cm$^{-2}$ in the quasar frame, which is similar to that seen in intermediate-type Seyfert galaxies such as NGC 4151. However, the physical properties of the absorbers are not well known because the X-ray data are ambiguous. In some cases, data at other wavebands support the contention that the absorption is physically associated with the quasar [19], while in other cases, the data favor absorption at low $z$ [20]. If the absorber is intrinsic to the quasar, it could be nuclear material as in low-$z$, low-$L_x$ objects or it could exist on a larger scale such as the host galaxy (or protogalaxy).

Because of the uncertainties associated with the properties of the absorbing material in high-$z$ RLQs, some general spectral trends are not clear. For example, does the shape of the intrinsic spectrum depend on the luminosity of the source? Other QSO studies have not found a significant correlation between $\Gamma$ and $L_X$ except for the general trend that RLQs have smaller X-ray indices than RQQs [11,12,14]. Table 2 also shows no correlation between $\Gamma$ and $L_X$, but $\Gamma$ depends on how the

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1) Not necessarily a complete sample.

2) A strong case for absorption is made by Fiore et al. (1998) [17]. An alternative but less favored explanation is downward curvature in the intrinsic spectrum, such as that resulting from emission dominated by synchrotron losses.
absorption is handled in the spectral modeling. Having $N_H$ “wrong” can make $\Gamma$ artificially large or small and so the true values of $\Gamma$ are somewhat uncertain.

The data also do not require that only high-z RLQs possess intrinsic absorption. Indeed, if only the hard X-ray component is absorbed, this underlying absorption could remain “hidden” in other QSOs. In RQQs, the stronger soft component might easily swamp the underlying absorption, regardless of $z$. For RLQs, where the soft component is not as prominent, column densities of a few $\times 10^{22}$ cm$^{-2}$ would flatten the observed spectrum at $\sim 1 – 2$ keV in the quasar frame. Such flattening could go undetected in low-z quasars in the following ways. For *Rosat*, the flattening falls too near the upper energy range of the detector. For *ASCA*, which covers a larger bandpass, flux from the soft component may average out the flattening so

### Table 2. X-ray Properties of a Representative Sample of QSOs at $z > 2$

| Quasar            | $z$    | $\Gamma_x$ | $N_H^{\alpha}$ [10$^{20}$ cm$^{-2}$] | $N_{H\text{gas}}$ [10$^{20}$ cm$^{-2}$] | log $L_x$ [erg s$^{-1}$] | Radio Class | Fe K$\alpha$ EW$^b$ [eV] | Ref. |
|-------------------|--------|------------|-------------------------------------|----------------------------------------|--------------------------|-------------|------------------------|------|
| S5 0014 + 81      | 3.38   | 1.7 ± 0.07 | 27.4 ± 4                           | 13.9                                   | 47.8                     | RLQ         | < 70                   | 14   |
| 0040 + 0034       | 2.00   | 1.79$^{+0.15}_{-0.14}$ | 9.7$^{+5.5}_{-5.2}$              | 2.45                                  | 46.4                     | RQQ         | —                     | 4    |
| PKS 0237 – 233    | 2.22   | 1.68 ± 0.06 | 122$^{+62}_{-34}$ (qf)            | 2.39                                  | 46.8                     | RLQ < 32.2  | —                     | 11   |
| 0300 – 4342       | 2.30   | 1.69$^{+0.24}_{-0.10}$ | < 6.8                           | 1.83                                  | 46.0                     | RQQ         | —                     | 13   |
| Q 0420 – 388      | 3.12   | 2.24 ± 0.48 | 34 ± 33 (qf)                      | 1.91                                  | 46.9                     | RLQ         | —                     | 13   |
| PKS 0438 – 436    | 2.85   | 1.5 ± 0.1   | 5.8$^{+2.6}_{-1.4}$              | 1.47                                  | 47.0                     | RLQ < 240   | —                     | 14   |
| PKS 0528 + 134    | 2.07   | 2.64 ± 0.07 | 420 ± 90 (qf)                    | 23.0                                  | 47.1                     | RLQ 119 ± 58 | —                     | 11   |
| PKS 0537 – 286    | 3.11   | 1.4 ± 0.1   | 2.8$^{+1.0}_{-0.7}$              | 1.95                                  | 47.3                     | RLQ < 139   | —                     | 14   |
| S5 0836 + 71$^c$  | 2.17   | $\sim 1.5$ | $\sim 3.3 ± 0.7$                  | 2.78                                  | 47.5                     | RLQ < 110   | —                     | 14   |
| 1101 – 264        | 2.15   | 2.19$^{+0.58}_{-0.47}$ | 19.5$^{+19.5}_{-15.5}$          | 5.68                                  | 45.8                     | RQQ 690 ± 560 | — | 4 |
| 1255 + 3536       | 2.04   | 1.59$^{+0.12}_{-0.11}$ | < 6.6                           | 1.22                                  | 46.3                     | RQQ         | —                     | 4    |
| 1352 – 2242       | 2.00   | 1.66$^{+0.25}_{-0.23}$ | < 17.9                         | 5.88                                  | 46.0                     | RQQ         | —                     | 4    |
| 1422 + 231        | 3.62   | 1.68 ± 0.14 | < 151 (qf)                      | 2.9                                   | 47.0                     | RLQ < 263   | —                     | 11   |
| RXJ 1430.3 + 4203 | 4.72   | 1.29 ± 0.05 | < 5.3                          | 1.4                                   | 47.1                     | RLQ < 100   | —                     | 21   |
| Q 1508 + 571      | 4.30   | 1.43 ± 0.08 | < 477 (qf)                      | 1.34                                  | 47.2                     | RLQ < 156   | —                     | 11   |
| PKS 1614 + 051    | 3.21   | 1.43 ± 0.14 | < 250 (qf)                      | 5.0                                   | 46.6                     | RLQ < 132   | —                     | 11   |
| Q 1745 + 624      | 3.89   | 1.68 ± 0.25 | 21$^{+15}_{-14}$                 | 3.4                                   | 47.0                     | RLQ < 180   | —                     | 22   |
| PKS 2126 – 158    | 3.28   | $\sim 1.6 ± 0.1$ | 10.4$^{+1.3}_{-2.3}$            | 4.85                                  | 48.0                     | RLQ < 107   | —                     | 14   |
| PKS 2149 – 306    | 2.35   | 1.54 ± 0.05 | 8.3$^{+1.8}_{-2.3}$              | 1.91                                  | 47.8                     | RLQ < 85    | —                     | 14   |
| PKS 2351 – 154$^d$| 2.67   | 1.92(fixed) | 12.7$^{+3.7}_{-2.9}$            | 2.18                                  | —                       | RLQ         | —                     | 23   |

Notes: $^a$(qf) absorption in the QSO frame as opposed to the observer’s frame (all others).

$^b$Assumes a narrow Gaussian line at 6.4 keV in the QSO rest frame.

$^c$Absorption changes by $\Delta N_H$ $\sim 8 \times 10^{20}$ in 0.8 yr.

$^d$Absorption changes on timescale of $< 0.41$ yr in the QSO frame.
that it is not detected. On the other hand, for $z = 1 - 2$ the contaminating soft component is shifted out of the ASCA/Rosat band and the absorption cutoff is shifted to around $\sim 0.3 - 0.6$ keV in the observer’s frame, into a region where it is more easily detectable. Higher quality spectra at low X-ray energies are needed to address this question.

It is interesting that QSOs do not show the same evidence for spectral flattening at energies $> 10$ keV [4,14] that is common in Seyfert galaxies [24] and is the signature of Compton reflection. Fe Kα emission is also weaker and/or much less common in quasars and QSOs than in Seyfert galaxies and nearby radio-loud objects like 3C 120 [25]. The equivalent width of the Fe Kα line decreases with increasing luminosity from $\log L_X = 41.7 - 47.2$ [26]. This trend continues to $z = 2$ [27] with RLQs at high $z$ rarely showing Fe Kα emission [14,11].

The lack of reflection and Fe Kα emission in QSOs suggests that they possess a different structure in their accretion flow compared to lower-luminosity galaxies. The difference may relate to the high luminosities and high degree of ionization in the their inner regions. A lack of Fe Kα emission may signify complete ionization of iron atoms in the accretion disk or that the inner parts of the disk have been completely blown away. High ionization would also allow the Compton reflection to suffer much less absorption in the disk. In this case, reflection is still present but it would have a shape almost indistinguishable from the continuum source. For RLQs, the X-ray emission associated with the jet may simply dominate the spectrum, rendering spectral features from the accretion flow undetectable.

### INTRINSIC X-RAY EMISSION MECHANISMS

The source of the continuum emission in AGN is thought to be ultimately linked to an accreting supermassive black hole. Within the vicinity of the black hole, X-rays can be produced via Compton upscattering of soft photons off either electron-positron pairs [28], a population of hot electrons [29], or bulk motion in the accretion flow [30,31]. The lack of annihilation lines in Seyfert spectra causes some problems for pair models [32] and so this discussion focuses on the latter two mechanisms for X-ray production. The emitting region is envisioned as lying somewhere just above the accretion disk, often represented as a smooth extended corona above the disk or small-scale flaring regions on the disk surface.

Thermal Comptonization or bulk-motion Comptonization predict that the distinct observational signature of a black hole is an emergent power law with a spectral turnover between $50 - 500$ keV. If both processes are occurring, then the changes/differences in photon index can be explained as a trade-off between the two. If conditions are such that bulk motion Comptonization dominates, then for an accretion disk that orbits a Schwarzschild black hole with an inner radius extending to the innermost stable orbit, $\Gamma$ approaches 2.5 for mass accretion rates $m_\odot >> 1$, where $m_\odot = M_\odot/(M_\odot)$ and $(M_\odot)$ is the Eddington rate. If thermal Comptonization dominates, the spectra are harder, with $\Gamma \geq 1.5$. This model has
been successfully used to explain the spectra of Galactic black-hole candidates, which show $\Gamma = 1.3 - 1.9$ in their low (hard) state and $\Gamma = 2.5$ in their high (soft) state [33].

For RQQs, where we think accretion mechanisms dominate the X-ray spectrum, those with $\Gamma \geq 2$ may be cases where we see X-rays from bulk motion Comptonization without modifications by ionized absorbers or reflection, i.e., the raw emergent spectrum from the accreting black hole. Within the context of the accretion model, the hard X-ray component in RQQs can result from thermal Comptonization.

Different mechanisms dominate the spectra of RLQs. RLQs show a significant correlation between their $0.1 - 2.4$ X-ray and total radio luminosity at 5 GHz [34] and $\Gamma$ decreases with increasing radio loudness [9] in the sense that flat spectrum radio quasars (FSRQs), which are core-dominated, have flatter X-ray spectra than their steep spectrum radio quasar (SSRQ) counterparts [16,35]. This implies the presence of two emission mechanisms and has led to the two-component beaming model, which explains the difference in observed properties as caused by the relative orientation of the source axis to our line of sight [36]. In FSRQs, the highly beamed component points toward us and we see mostly upscattering of low-energy photons off relativistic electrons in the jet, while in SSRQs we see mostly the isotropic emission.

**UNIFICATION AND EVOLUTION**

Unified schemes explain the diversity of AGN classes as resulting from inclination plus obscuration effects, e.g., Seyfert type 2 (narrow-line) galaxies are edge-on Seyfert 1 (broad-line) galaxies. These models succeed when applied to specific subsamples of AGN, but a global unification scheme has proved elusive. For radio-loud objects, two schemes seem to be required, one for low luminosity objects and one for high luminosity objects [37]. For RQQs, broad absorption line (BAL) QSOs can be unified with nonBAL QSOs through axis orientation, but there are many arguments against RQQs being edge-on RLQs, including differences in their radio morphologies and underlying galaxy hosts [38]. What we are left with is a fragmented “unification” scheme.

It may be more promising to examine evolution scenarios, i.e., are low luminosity Seyferts connected to distant and more powerful AGN? Seyfert galaxies have composite X-ray spectra that consist of an underlying power law with $\Gamma \sim 1.9$, a Compton reflection tail above $\sim 10$ keV, Fe Kα emission [24], and significant photoelectric absorption from neutral and/or ionized gas [39]. High luminosity AGN lack significant evidence of X-ray reprocessing and many lack significant absorption. An evolutionary scenario that accounts for the difference requires QSOs to have much less cold material in their cores or for the material to be very highly ionized. As the source becomes less luminous with time, the ionization decreases and/or more cold material collects in the galaxy core.

QSOs also differ from Seyferts by (apparently) having spectral components from
two physically distinct emission mechanisms. One component is associated with a relativistic jet while the other is most likely related to the accretion mechanism. Since processes associated with accretion are also thought to produce the continuum emission in Seyfert galaxies, an evolutionary connection between RQQs and Seyferts is plausible. The soft X-ray spectra of RQQs are significantly steeper than Seyfert galaxies, but are also more consistent with the predictions of bulk-motion Comptonization. This would suggest that bulk motion Comptonization is the more important physical mechanism in RQQs while thermal Comptonization of soft photons by a hot corona is the more important physical mechanism in Seyfert galaxies.

THE TOTAL ENERGY OUTPUT OF THE UNIVERSE

Until recently, little attention has been given to sources of energy in the universe that are not directly visible at optical-UV wavelengths. It now seems probable that most AGN are heavily absorbed, and that their central engines are primarily visible via hard X-rays. The energy density of the X-ray background peaks at \( \sim 30 \) keV. Less than 15% of this total energy density can be accounted for by the Rosat AGN, which dominate the soft X-ray background. If AGN comprise the hard X-ray background, then most must have huge absorbing columns \( (N_H \sim 10^{22} - 10^{25} \text{ cm}^{-2}) \) [40]. The importance of the hard (> 10 keV) X-ray band for studying the total energy output for these objects cannot be overemphasized. A significant fraction of the energy in the Universe may reside in absorbed AGN [41] and the total accretion energy released by these AGN may be comparable to the energy generated by nuclear burning by the total stellar population. If most of the accretion in the Universe is highly obscured, then the emitted power per galaxy based on optical, UV, or soft X-ray quasar luminosity functions will be underestimated.

SUMMARY AND FUTURE PROSPECTS

This article summarizes our current knowledge of the X-ray spectral properties of QSOs. X-ray observations from \( z = 0.1 \) to \( \sim 3 \) keV indicate two distinct X-ray components in their spectra. One component is soft with \( \Gamma \sim 2.0 - 2.5 \) and the other is hard with \( \Gamma \sim 1.5 - 1.9 \). In the soft X-ray band the spectra flatten with increasing \( z \) while in the hard X-ray band the spectra show little change with \( z \). RLQs have flatter X-ray spectra than RQQs with the exception of high energies at high \( z \), where both have similar spectral shapes. Accretion mechanisms such as thermal Comptonization or bulk-motion Comptonization are the most likely source of the continuum in RQQs while jet/beaming mechanisms dominate RLQs. Significant absorption is observed in RLQs at high \( z \) but the physical properties of the absorbing material are uncertain. More sensitive data will place stringent limits on the absorption cutoffs and properties of the absorbing gas, the spectral breaks
between the soft and hard X-ray continuum components, and the signatures of X-ray reprocessing. Considering an evolutionary scenario, RQQs and Seyfert galaxies are possibly connected, with a different accretion mechanism dominating in each.

Results from X-ray experiments such as ASCA for low-z AGN suggest that much of the accretion in the Universe is highly obscured. So far, X-ray observations at intermediate to high z have shed little light on this question. Surveys by XMM, ABRIXAS, and Chandra (limited to $E < 10$ keV) will probe columns up to a few times $10^{23}$ cm$^{-2}$; while future missions such as Constellation – X (Valinia, this volume) will probe columns up to $10^{25}$ cm$^{-2}$ for fluxes as low as $\sim 1 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$ in reasonable exposure times.

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FIGURE 1. Observed photon index in the soft X-ray band (0.1 – 2.4 keV; Rosat) and hard X-ray band (~ 0.5 – 20 keV; Ginga and ASCA) vs. redshift.

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