X-ray observations of high-redshift quasars: Current status and XMM prospects

Joachim Siebert and Wolfgang Brinkmann
Max-Planck-Institut für extraterrestrische Physik, Postfach 1603, 85740 Garching, Germany

ABSTRACT

High-redshift quasars are the most luminous and most distant, compact objects in the observable Universe. Their radiation was emitted at a time when the Universe had only about 10% of its present age. Therefore these objects serve as tracers of the physical conditions in the early Universe. Further, high-redshift quasars can be used as background light sources to study the intervening intergalactic medium.

ROSAT and ASCA observations have significantly increased our knowledge of the X-ray properties of high-redshift quasars. About 30 quasars with $z > 3$ are detected in X-rays at present, most of them, however, with low quality spectral data. The most important results are the apparent lack of spectral evolution and the frequent occurrence of intrinsic absorption in radio-loud quasars.

However, many questions remain unanswered. In particular, the X-ray spectra of high-redshift *radio-quiet* quasars are basically unknown. Do radio-quiet quasars also show excess absorption? What do their spectra look like and do they evolve with cosmic epoch? Finally, XMM will provide the sensitivity to allow us to derive limits on the basic physical parameters of intervening matter like the intergalactic medium or damped Lyα systems via their imprint on the X-ray spectrum of the background quasar.

1. Introduction

1.1. Why are high-redshift quasars interesting?

Quasars are the most powerful, continuously emitting sources of electromagnetic radiation in the observable Universe. Their continuum emission spans all wavelengths from the radio to the hard X-ray and even to the γ-ray region. Because of their enormous luminosities, quasars are visible out to very large distances. This has important implications:

1. The radiation of distant (e.g. $z{\sim}3$) quasars was emitted at a time, when the Universe had only about 10% of its present age. Thus, they can be used as tracers of the physical conditions in the early Universe.

2. Because quasars are visible over a very large range of redshifts, it is possible to study their evolution with cosmic epoch.

3. The observed electromagnetic spectrum can be used to study intervening systems along the line-of-sight to the distant quasar. Well-known examples at optical wavelengths are the Lyα forest and the Lyα Gunn–Peterson test.

1.2. What can we learn from the X-ray emission of high-redshift quasars?

The X-ray range is important for at least two main reasons: the X-ray luminosity represents a large fraction of the bolometric luminosity of quasars (Elvis et al. 1994a) and it is known from variability and spectral studies (e.g. Mushotzky, Done & Pounds 1993; Tanaka et al. 1995) that the X-rays are emitted very close to the "central engine" – a region which is not accessible at any other wavelength with current instrumentation.

By investigating the X-ray properties we thus can hope to learn something about the basic physical conditions in the innermost region of active galactic nuclei and to understand how quasars form, how they evolve and how the enormous amounts of electromagnetic radiation are generated.

Finally, the soft X-ray photons represent an independent tool for the study of intervening systems via their imprint on the observed spectrum.

2. Current status

While the number of high-redshift ($z > 3$) quasars known from optical surveys rapidly increased during the last two decades, the investigation of their X-ray properties had to await the launch of sensitive X-ray observatories like ROSAT and ASCA. About 30 quasars with redshifts greater than three have been detected with the ROSAT PSPC. Roughly two-thirds are radio-loud. A number of these quasars were studied in follow-up observations with ASCA, to obtain high resolution, broad band X-ray spectra. However, most quasars with reasonable spectral information are radio-loud, because they are more luminous in X-rays compared with radio-quiet quasars for a given optical luminosity.

The main results can be summarized as follows:

- The X-ray spectra in the intrinsic 0.5-40 keV energy range can be described with a simple, absorbed power law model with photon indices , of about 1.6 to 1.7 (Siebert et al. 1996; Cappi et al. 1997). There is no evidence for additional spectral features like a reflection component or a fluorescent Fe-Kα emission line in high-redshift quasars. However, the signal-to-noise ratio of the spectra at higher energies is insufficient to draw definite conclusions.

- In a few radio-loud quasars significant X-ray absorption in excess of the Galactic N_H value was found (Elvis et al. 1994; Siebert et al. 1996; Cappi et al. 1997). No intrinsically absorbed radio-quiet quasar is currently known. This clearly favors an interpretation in terms of *intrinsic* absorption, which is particularly exciting, because it points towards intrinsic differences between the central regions of radio-loud and radio-quiet quasars and thus has the potential to shed light on the still enigmatic radio-loud/radio-quiet dichotomy.

- From a comparison of EXOSAT and Ginga spectra of *local* quasars (in order to cover the same intrinsic energy range) it is tentatively concluded that radio-loud quasars do not show spectral evolution, which may indicate that quasars are short-live phenomena.
- Spectral information for radio-quiet quasars is scarce. ROSAT measurements seem to indicate that high-redshift radio-quiet quasars have steeper X-ray spectra than radio-loud quasars, as it is already known for their low-redshift counterparts. However, from recent ASCA observations of $z \sim 2$ radio-quiet quasars (Vignali et al. 1998) it seems that there is no significant spectral difference to radio-loud quasars, but the uncertainties are rather large.

3. Prospects for XMM observations

Compared to previous X-ray missions, XMM provides a much larger effective area and the capability to measure X-ray spectra up to 15 keV with high energy resolution. These characteristics offer unique possibilities for the study of high-redshift quasars.

1. XMM observations are the first and presumably only possibility in the foreseeable future to measure the X-ray spectra of z>3 radio-quiet quasars with a reasonable signal-to-noise ratio. This allows us to address a number of unsolved problems in quasar physics:
   - Do radio-quiet quasars show intrinsic absorption as it is observed in radio-loud quasars?
   - Does the difference in the X-ray spectra between radio-loud and radio-quiet quasars persist to high redshifts?
   - Does the X-ray spectrum of radio-quiet quasars evolve with cosmic epoch?

   An answer to these questions is of outmost relevance for our understanding of the radio-loud/radio-quiet dichotomy and the formation and evolution of the quasar population.
2. The hard X-ray spectra of high-redshift quasars can be determined with unprecedented accuracy. It will be possible to derive tight constraints on any additional spectral features, such as iron lines or a reflection hump. To illustrate the improvement in the quality of the obtained X-ray spectra we compare in Figure 1 a simulated 30 ksec ASCA observation with a simulated XMM observation of equal duration. In both cases we show the ratio of the simulated data to a simple power law model. The simulations are based on a real ASCA observation of the z = 3.11 quasar PKS 0537-286. However, the input power law model was modified by two additional spectral features in both simulations, namely *intrinsic* absorption

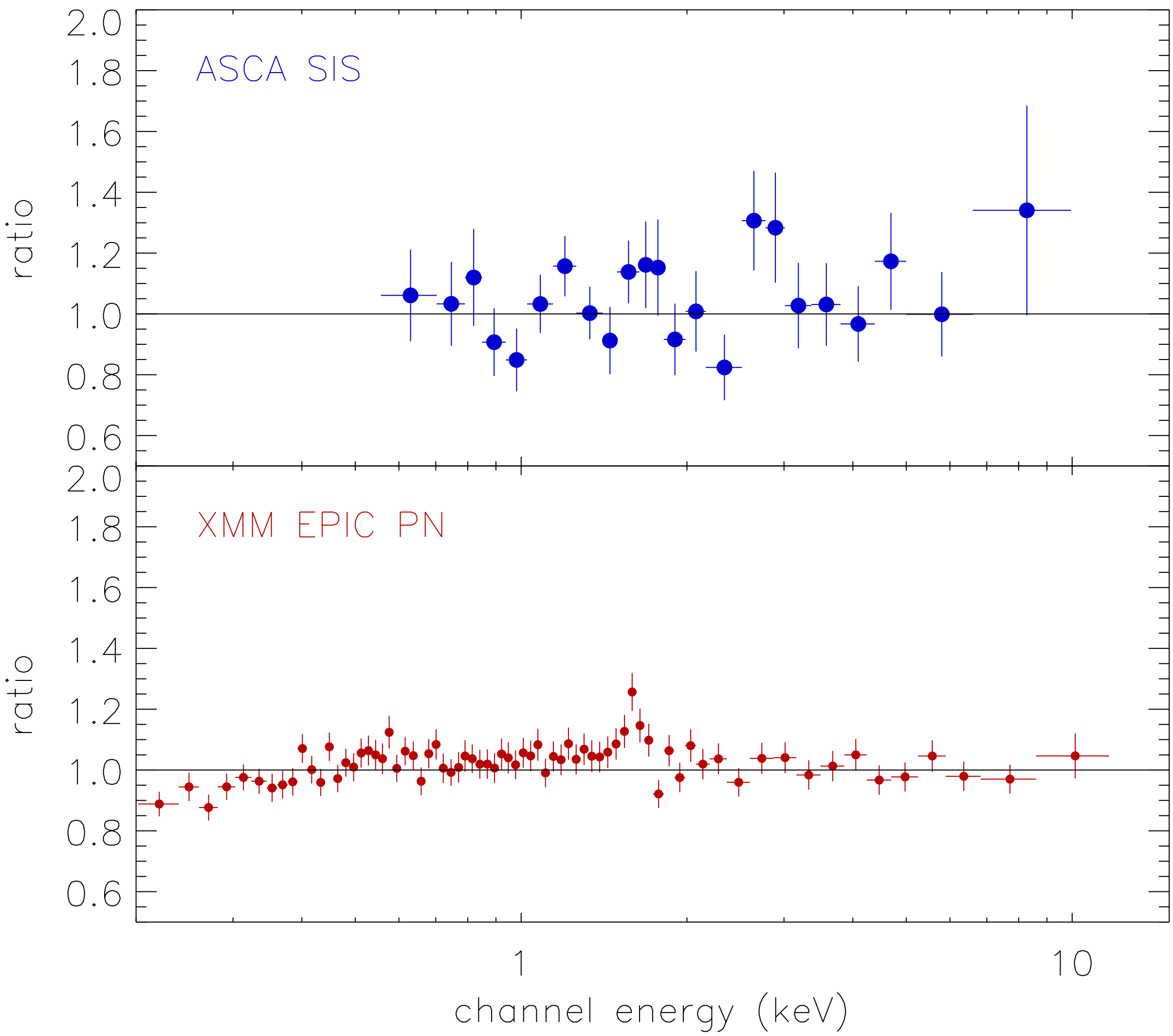

Fig. 1.— Comparison of simulated 30 ksec ASCA and XMM observations based on the real ASCA data of the z = 3.11 quasar PKS 0537-286. Two spectral features were added to a simple power law model, namely *intrinsic* absorption of the order of 10^{21} cm^{-2} and a EW = 100 eV Fe Kα emission line. Both features are recovered in the XMM observation only.

of the order of 10^{21} cm^{-2} and a narrow Fe Kα fluorescence line with an equivalent width of about 100 eV. Both features clearly show up in the XMM observation.

3. XMM observations likely provide sufficient sensitivity to apply an “X-ray Gunn-Peterson test” (Aldcroft et al. 1994): if no absorption towards a high-redshift quasar is detected in excess of the Galactic value, a lower limit on the temperature and an upper limit on the density of the intergalactic medium can be derived. Further, if damped Lyα systems are located in the line-of-sight to a high-redshift quasar, it is possible to constrain the ionization state of these systems and thus to derive limits on their size, temperature and density (Elvis et al. 1994).

REFERENCES

Aldcroft T., Elvis M., McDowell J., Fiore F., 1994, ApJ 437, 584

Cappi M., Matsuoka M., Comastri A., Brinkmann W., Elvis M., Palumbo G.G.C., Vignali C., 1997, ApJ 478, 492

Elvis M., Wilkes B.J., McDowell J.C., et al., 1994a, ApJS 95, 1

Elvis M., Fiore F., Wilkes B., McDowell J., 1994b, ApJ 422, 60

Mushotzky R.F., Done C., Pounds K.A., 1993, ARA&A 31, 717

Siebert J., Matsuoka M., Brinkmann W., Cappi M., Mihara T., Takahashi T., 1996, A&A 307, 8

Tanaka Y., Nandra K., Fabian A.C., et al., 1995, Nature 375, 659

Vignali C., Comastri A., Cappi M., Palumbo G.G.C., Matsuoka M., 1998, astro-ph/9809076

This preprint was prepared with the AAS LaTeX macros v4.0.