X-ray Spectroscopy of a Large Sample of Quasars Observed with ASCA

James Reeves and Martin Turner
Department of Physics and Astronomy, University of Leicester, University Road, Leicester LE1 7RH, e-mail: jnr@star.le.ac.uk

ABSTRACT

The results from X-ray spectral analysis of a large sample of quasars, observed with ASCA, are presented. The X-ray continuum emission is studied, together with the influence of a relativistic jet and quasar spectral evolution with redshift and luminosity. The effects of X-ray reprocessing, in terms of iron Kα line emission and photoelectric absorption are investigated. Finally the role of XMM in exploring the most distant quasars is discussed.

1. The ASCA sample of Quasars

Data have been selected from the ASCA public archives, using mainly quasars that were placed on the ASCA archive up until December 1997. In total 68 quasars have been included in the sample, with the objects selected predominantly broad line (or type I) AGN. This covers a range of redshift (from z=0.06 to z=4.3), and also a wide range of luminosities (M_V=-23 to <-30 and $L_{2-10keV} \sim 10^{43}$ ergs/s to $>10^{47}$ ergs/s). Standard ASCA screening criteria and data selection has been used in analysing the data; the result of this data reduction process gives 62 quasars that have sufficient signal-to-noise for further analysis and interpretation. Of these 62 quasars, 35 are radio-loud and 27 are radio-quiet; according to the definition of radio-loudness (R_L) used by Wilkes & Elvis (1987), where $R_L = \log (F_{5GHz}/F_B)$.

2. The X-ray Continuum Emission from Quasars

It has been found that the X-ray emission properties of the quasars in this sample are strongly dependent upon the properties and orientation of the powerful radio-jet. The radio-loud quasars (RLQ's) tend to be more X-ray luminous and have flatter X-ray spectra compared to the radio-quiet quasars (RQQ's) which are less X-ray luminous and have steeper spectra. The correlation between photon index (,) and radio-loudness (R_L) is illustrated in figure 1; the correlation is significant at >99.99% confidence. Typically the underlying index is , ~ 1.9 in the RQQ's and , ~ 1.6 for the RLQ's (2-10 keV band), although there is significant dispersion within both groups. The fundamental differences between the radio-loud and radio-quiet objects can be explained by the presence of a relativistic jet in the radio-loud quasars. There are probably 2 X-ray emission components in the RLQ's, one originating from (or near to) the central engine

/ accretion disk which is also observed in the radio-quiet quasars, and an additional beamed component associated with the relativistic jet. This can account for the higher luminosity of RLQ's and also the flatter X-ray spectra in the core-dominated radio-loud quasars.

Figure 1: Photon Index against Radio Loudness

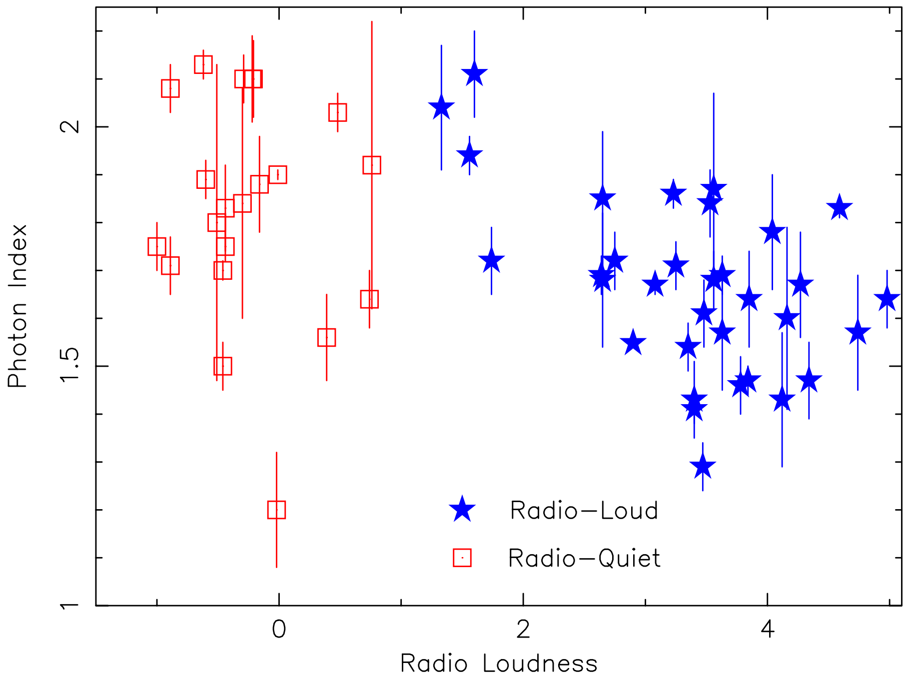

Fig. 1.— Photon Index against Radio-Loudness, plotted for all the quasars in the ASCA sample.

Correlations have also been investigated between the quasar photon index and X-ray luminosity (L_X) or redshift (z). The luminosity range covered extends from $L_X \sim 10^{41}$ ergs/s for the least luminous AGN (including Seyfert 1's) to $L_X \sim 10^{47}$ ergs/s for the most luminous quasars. Only the radio-quiet AGN were considered in order to eliminate the effects of the relativistic jet. It is found that there is no significant correlation between the X-ray photon index with either luminosity or redshift. This suggests that there is little evolution in the *underlying* X-ray emission from quasars with either luminosity or redshift; which covers a wide range of luminosities, accretion rates and black hole masses.

3. The Iron Kα Fluorescence Line

An iron Kα fluorescence line has been systematically fitted to the spectra of all the 62 quasars. In 21 of these quasars there is significant (>90% confidence) evidence for an iron line at rest energies (QSO frame) between 6-7 keV. The lines tend to be found mainly in the radio-quiet quasars, with correlations showing that the line equivalent width (EW) decreases towards the more radio-loud quasars. Thus a beamed component in the radio-loud quasars may 'dilute' the strength of the iron line.

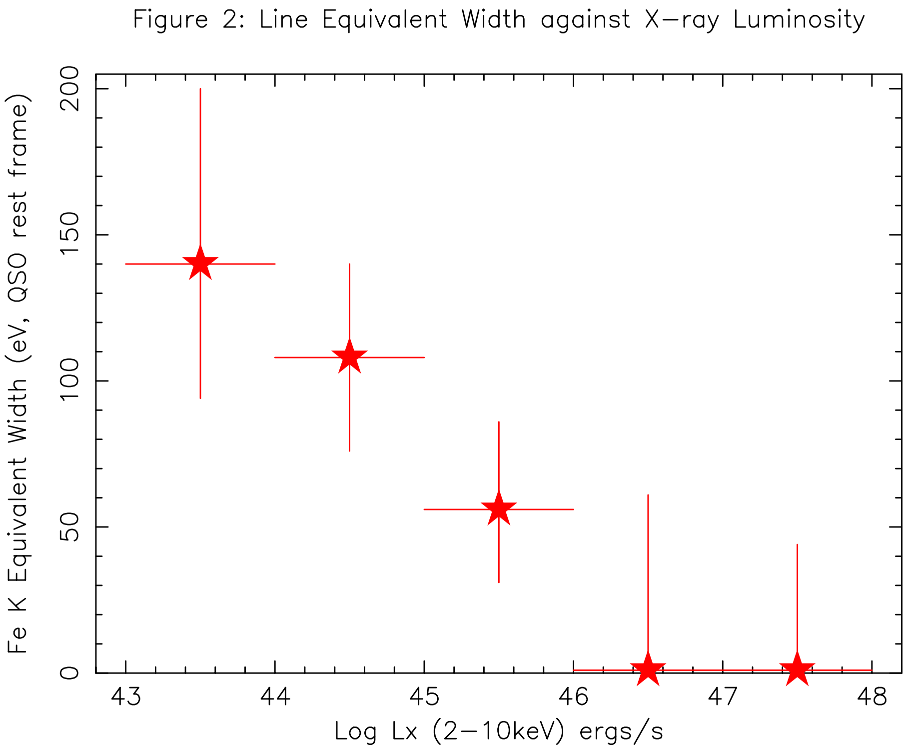

Fig. 2.— Mean iron Kα line equivalent width plotted against (log) 2-10 keV X-ray luminosity. The trend for the line strength to diminish with increasing luminosity is clearly seen.

In addition it is found that the iron line EW diminishes with X-ray luminosity (see figure 2), i.e. similar to an 'X-ray Baldwin effect' (Iwasawa & Taniguchi 1993). This correlation is significant (at $>$99.9% confidence) even when only the radio-quiet quasars are considered; i.e. the correlation occurs over and above the trend with quasar radio-loudness. The iron line emission in many of the quasars originates from partially ionised material, that is the lines are emitted at energies significantly $>$6.4 keV (figure 3). This is in contrast to the situation in Seyfert1's where the iron lines are emitted at $\sim$ 6.4keV (i.e. from neutral material).

The correlations of line EW and energy (with luminosity) cannot be explained in terms of a relativistic jet. Therefore the evolution of the iron line must be due to the properties of the quasar central engine. If the lines are interpreted in terms of reflection of X-rays off the accretion disk, then as the ionisation state of matter in the inner disk increases with AGN luminosity, the iron line energy may also increase with luminosity. When most of the inner disk becomes fully ionised (in high luminosity and high accretion rate AGN), then the observed line strength (or EW) can decrease considerably (Matt, Fabian & Ross 1993). This interpretation may explain the lack of line and Compton reflection features in the X-ray spectra of high luminosity quasars. (Reeves *et al.* 1997, Nandra *et al.* 1997)

Figure 3: Line Energy against X−ray Luminosity (narrow lines)

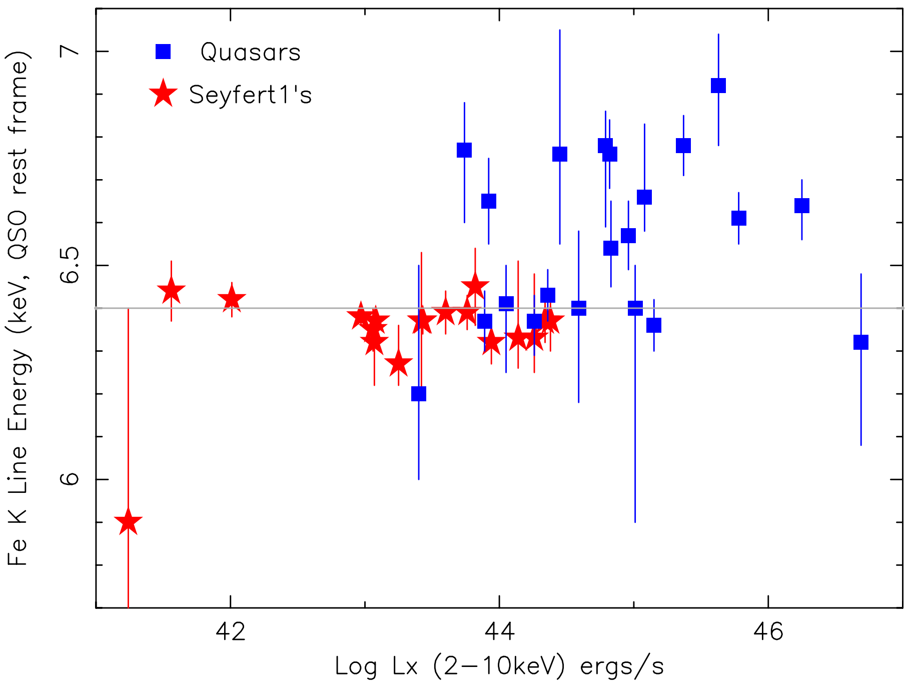

Fig. 3.— Iron line energy against X-ray luminosity, plotted for both quasars (blue) and Seyfert 1's (red). It is clearly seen that the iron line energy (and hence ionisation state) increases with luminosity; many of the quasars have energies significantly >6.4 keV.

4. Soft X-ray Photoelectric absorption

The amount of intrinsic absorption N_H observed in the quasar spectra has been found to increase with quasar redshift. Typically columns in high redshift (z>2) quasars are of the order (10^{22}cm^{-2}, QSO rest frame), whereas at low redshift N_H is only of the order few $\times$ 10^{20}cm^{-2}. The positive correlation between N_H and z is illustrated in figure 3; in addition the correlation is still significant even when uncertainties in the low energy calibration of ASCA and the Galactic column density are taken into account. There is evidence in some of the low z quasars for absorption from warm or partially ionised material, although at high redshifts the ionisation-state of the absorbers is not constrained.

The most striking observation here is the discovery of moderately large absorption columns in several of the high z quasars. As these high z quasars are predominantly type I AGN, obscuration in terms of the molecular torus (as observed in Seyfert 2's) seems unlikely. The physical origins of this absorption can then either be local to the rest frame of the quasars at high z, or it may even be associated with matter at intermediate redshifts (i.e. from intervening line of sight material) not physically connected with the quasars. It is possible that the if the absorbing material is intrinsic to these quasars, then it could be similar in nature to the high ionisation absorbers observed in more nearby quasars and Seyfert 1's. The most substantial source of soft X-ray absorption from intervening matter would probably be from damped Lyman-α absorption systems, however in most cases this might not contribute significantly towards the amount of absorption that is seen. A more detailed review on the origins of this X-ray absorption can be found in the literature (e.g. Elvis *et al.* 1998, Cappi *et al.* 1997).

Figure 4: Column Density against Redshift

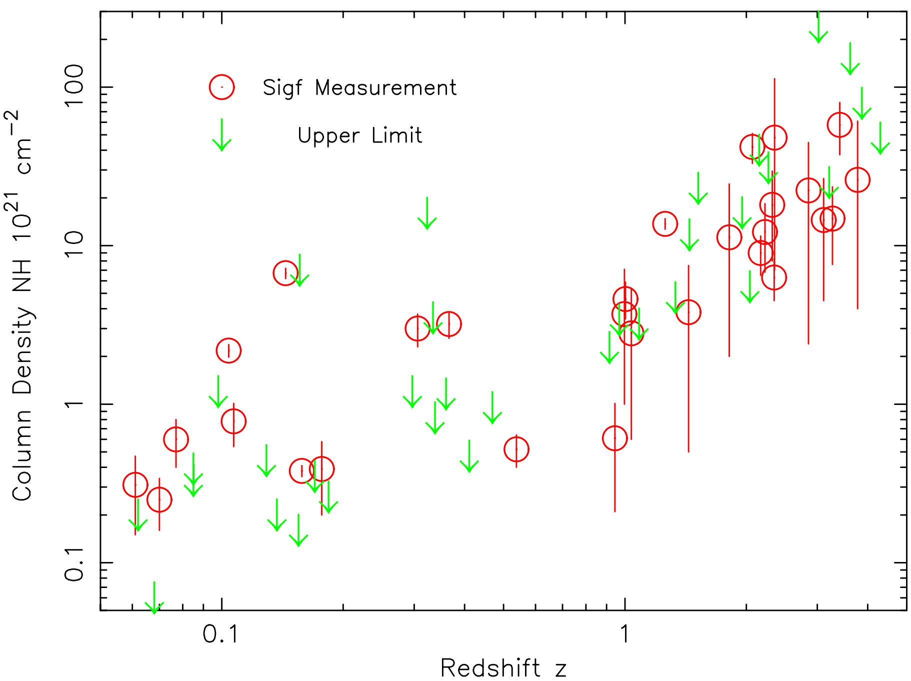

Fig. 4.— Quasar intrinsic column density (or N_H) plotted against redshift. The N_H shown is corrected for Galactic absorption and is plotted in the QSO rest frame. Significant measurements are in red, upper-limits in green.

5. Future Observations with XMM

A summary of possible future observations that could be conducted with XMM is shown below, both by following-on the results of the ASCA observations presented earlier and also from performing a feasibility analysis (i.e. from spectral simulations).

- **The origins of the soft X-ray absorption in high z quasars.**

  - Determination of absorber ionisation state and location and hence constrain the origin of this excess absorption at high z.
  - Dependence on radio-loudness. Is the origin of the X-ray absorption in the high redshift quasars just limited to radio-loud quasars?
  - Provide clues to the nature of intervening line of sight matter in the Universe and the material environment in distant quasars.

- **The study of high redshift, high luminosity radio-quiet quasars.**

  - Is there any spectral evolution in the quasar phenomenon at the earlier epochs in the Universe? The results so far with ASCA suggest there is little spectral evolution of the primary X-ray emission (up to z$\sim$3).
  - The nature of the accretion disk and the central engine. Would we expect to see ionised lines from luminous quasars or are there no reflection features and a bare power-law continuum?
  - Evidence for a SMBH (Super-Massive Black Hole) in quasars; would we expect to see the disk-line profiles that are observed in Seyfert 1's? - XMM EPIC is the ideal instrument to perform spectroscopy on the most distant (and therefore faint) quasars.
  - The existence of type II/obscured AGN and quasars at high z.

- **High resolution soft X-ray spectra (using XMM RGS)**

  - Particularly suitable for studying soft X-ray features from warm absorbers and AGN with strong soft X-ray excess emission.

REFERENCES

Cappi M., et al. 1997, ApJ, 478, 492

Elvis M., et al. 1998, ApJ, 492, 91

Iwasawa K., & Taniguchi Y., 1993, ApJ, 413, L15

Matt G., Fabian A.C., Ross R., 1993, MNRAS, 262, 179

Nandra K., et al. 1997, 488, L91

Reeves J.N., et al. 1997, MNRAS, 292, 468.

Wilkes B.J., & Elvis M., 1987, ApJ, 323, 243

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