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Destroying Degeneracy: Chandra Observations of Faint Radio-Quiet Quasars at $z > 4$

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Abstract. The existing sample of high redshift quasars with X-ray data suffers from selection such that luminosity is artificially correlated with redshift. In our Chandra+XMM survey of radio-quiet $z > 4$ quasars (Bechtold et al. 2003), we found α_{ox} and Γ_X are strong functions of redshift but also weak function of luminosity, whereas other studies suggest that these X-ray parameters depend most strongly on luminosity. So far, only the brightest $z > 4$ quasars have been targeted with Chandra, so that exposure times would be short (5 ksec); this strategy only strengthens the L–z correlation in the available X-ray sample. To remedy this situation, we observed 5 faint, radio-quiet, non-BAL quasars at $z > 4$. We have supplemented our observations with Chandra data from the literature, creating a sample of 48 $z > 4$ radio-quiet non-BAL quasars. A partial correlation analysis did not reveal any significant correlations of α_{ox} and Γ_X with either luminosity or redshift for $z > 4$; however, on average, these high redshift quasars have higher α_{ox} and lower Γ_X than low-redshift quasars.

1. Observations and Sample

We obtained new Chandra observations of the faint, radio-quiet, non-BAL sources Q0910+564, SDSS 1444-0123, SDSS 2357+0043, PC 1450+3404, and SDSS 1413+000. These sources had 14, 11, 14, 22, and 22 counts in the range 0.3-6.5 keV, respectively. We supplemented these observations with sources from the literature, giving us a sample of 48 quasars with $z > 3.7$. For those sources with more than 10 counts we fit a power-law of the form

$$f(E) = f_0 E^{-\Gamma_X} \quad (1)$$

We also computed a ratio of optical to X-ray flux, α_{ox}, defined as

$$\alpha_{ox} = -0.384 \log(f_{2keV}/f_{2500}) \quad (2)$$

For those sources with less than five counts we took the values of α_{ox} from the literature. The flux at 2500Å was calculated from the AB magnitude at 1450Å, assuming the optical continuum is a power-law with frequency spectral index $\alpha = -0.79$. We adopted the WMAP best-fit parameters when calculating luminosities :

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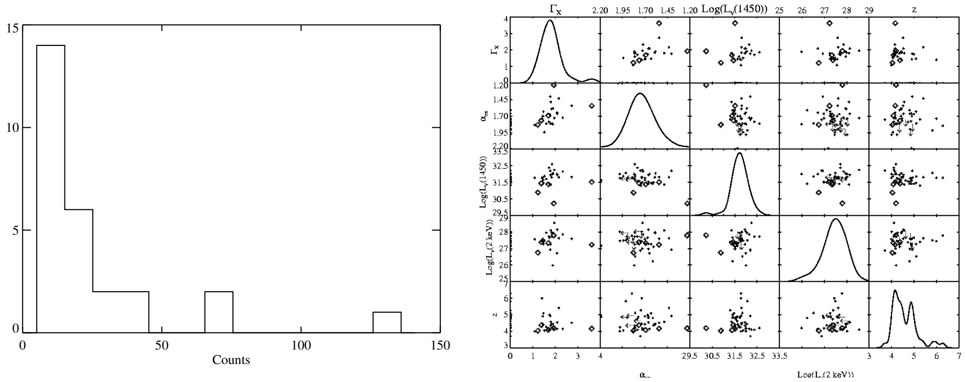

Fig. 1. *Left:* Histogram showing the number of counts for those source with more than 10 counts. *Right:* Scatterplot matrix summarizing our results. The diagonals show the quasar densities in that parameter space, and the off-diagonals compare the relationships between the different parameters.

$q_0 = 0.5, h = 0.71, \Omega_m = 0.27$, and $\Omega_\lambda = 0.73$. Figure 1a shows the number of counts for the sources with more than 10 counts.

2. Results

Our results our summarized in the scatterplot matrix, shown in Figure 1b. The diagonal plots show the parameter densities, estimated via kernel density estimation, and the off-diagonal plots show the 2-D scatter plots of the parameters. Our five new observations are shown as diamonds, and arrows denote 3σ upper limits. We computed the Kendall partial correlation coefficient for α_{ox}, Γ_X, and $\log L_\nu(2keV)$, each as a function of redshift and $\log L_\nu(1450\text{Å})$. We did not find any significant correlations among these parameters, however if we remove the source with $\Gamma_X = 3.6$ a significant correlation does exist between Γ_X and optical luminosity (2.5σ). However, there are only 27 sources with more than 10 counts so it is difficult to assign a signficance to this correlation. These results are in agreement with previous studies that have failed to find evidence for a correlation between α_{ox}, Γ_X, and $\log L_\nu(2keV)$ with optical luminosity at $z > 4$ (e.g., Vignali et al. 2003). In all three cases the correlation with optical luminosity was significantly stronger than that with redshift. It should be noted that the uncertainties in the X-ray parameters are large, so the probability densities of the uncertainties may have broadened the densities of these parameters, attenuating the correlation coefficients. Although we did not find any significant correlations among the $z > 4$ quasars, their values of α_{ox} and Γ_X are on average different than those of low redshift quasars, consistent with previous studies (e.g., Bechtold et al. 2003). High redshift quasars have higher values of α_{ox} and lower values of Γ_X.

References

Bechtold, J., et al. 2003, ApJ, 588, 119
Vignali, C., et al. 2003, AJ, 125, 2876