CONFIRMATION OF A CORRELATION BETWEEN THE X-RAY LUMINOSITY AND SPECTRAL SLOPE OF AGNs IN THE CHANDRA DEEP FIELDS.

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We present results from a statistical analysis of 173 bright radio-quiet AGNs selected from the Chandra Deep Field-North and Chandra Deep Field-South surveys (hereafter, CDFs) in the redshift range of 0.1<z <4. We find hat the X-ray power-law photon index of radio-quiet AGNs (RQ AGNs) is correlated with their 2–10 keV rest-frame X-ray luminosity (L_{2-10}) at the >99.5% confidence level in two redshift bins, 0.3<z<0.96, and 1.5<z<3.3 and is slightly less significant in the redshift bin 0.96<z<1.5. The X-ray spectral slope steepens as the X-ray luminosity increases for AGNs in the luminosity range 10^{42} to 10^{45} erg s^{-1}. We investigate the redshift evolution of the correlation between the power-law photon index (G) and the hard X-ray luminosity (L_X) and find that the slope and offset of a linear fit to the correlation change significantly (at the > 99.9% confidence level) between redshift bins of 0.3< z <0.96 and 1.5<z<3.3. We explore physical scenarios explaining the origin of this correlation and its possible evolution with redshift in the context of steady corona models focusing on its dependency on variations of the properties of the hot corona with redshift.

INTRODUCTION

It is important to extend the study of quasars to high redshifts in order to understand their evolution and environments. A relevant conclusion from modern studies is that the quasar luminosity function evolves positively with redshift, having a comoving space density strongly peaked at z~2 (e.g., Schmidt 1968; Boyle et al. 1987; Warren et al. 1994). More recent findings suggest that the evolution of the space density of AGNs is strongly dependent on X-ray luminosity (L_X), with the peak space density of AGNs moving to higher redshifts for more luminous AGNs (e.g., Ueda et al. 2003; Hasinger et al. 2005).

A recent mini-survey of relatively high-redshift (1.5< z <4) gravitationally lensed radio-quiet quasars (RQQs) observed with Chandra and XMM-Newton (Dai et al. 2004) indicated a possible correlation between G and X-ray luminosity. This correlation, characterized by an increase of G whith L_X, was found for RQQs with L_{2-10} in the range 10^{43} to 10^{45} erg s^{-1}. The number of available lensed radio-quiet quasars used by Dai et al. (2004) was limited to a total of 25 sources, of which the brightest 11 had X-ray observations. In order to increase the size of the high-redshift radio-quiet quasar sample, we have compiled a sample of 173 high-redshift AGNs with moderate-to-high S/N spectra available from the Chandra Deep-Field-North and Chandra Deep-Field-South surveys (CDF-N and CDF-S, respectively; jointly CDFs; Giacconi et al. 2002; Alexander et al. 2003).

The main scientific goal of this work is to constrain better the correlation found by Dai et al. (2004). The significant increase in sample size allows us to place tighter constraints on the significance of the correlation. We also test the correlation in narrower redshift bands which will allow us to determine the epoch by which possible changes in the average emission properties of AGNs occurred.
Throughout this work we adopt a flat-dominated universe with H_0=70 km $s^{-1}Mpc^{-1}$, W_L= 0.7, and W_M= 0.3. The Chandra data were reduced using the CIAO version 3.3 software tools provided by the Chandra X-ray Center (CXC), and the spectral analysis was performed using XSPEC version 12.

DATA REDUCTION

Sample Selection: bright radio-quiet (RQ) AGNs from the CDF surveys. This selection corresponds to sources with more than a total of 180 counts in the 0.5-8 keV band and with z>0.1, leading to a sample of about 205 sources. We also restricted this sample to sources with radio-loudness parameter R<10 ($R=f_{5GHz}/f_B$), resulting in a sample size of about 173 RQ AGNs.

Spectral analysis: the default spectral model used was a power-law modified by Galactic and intrinsic absorption. Additional model components were added to the default model in cases where the F-test showed an improvement in the fit at the 95% confidence level when these additional components were used.

Spectral Fitting: two energy ranges.
1)The 0.5-8 keV observed-frame to obtain the maximum S/N.
2)The 2-10 keV rest-frame to reduce absorption effects and high energy reflection.

SELECTION EFFECTS

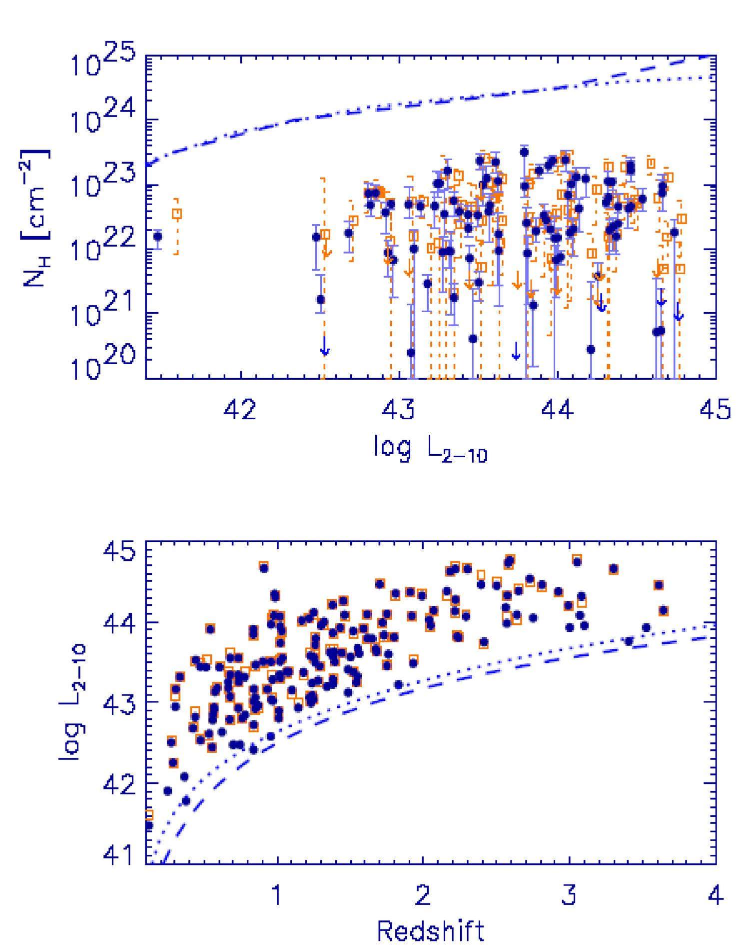

Figure 1.-- Estimated best-fit column densities versus 2-10 keV luminosities (upper panel), and 2-10 keV luminosities versus redshifts (lower panel) of the z>0.1 RQ AGNs. Blue-filled circles represent sources with fits performed in the 0.5-8 keV observed-frame band and orange-open squares represent sources with fits performed in the 2-10 keV rest-frame band. In the upper panel, the two lines indicate the maximum column density that can be detected for a source with 0.1<z<4.0, and a total of 170 counts in the 0.5-8 keV observed-frame (dashed) and 2-10 keV rest-frame (dotted). In the lower panel the lines indicate the minimum luminosity required for the detection of a source as a function of redshift. A total of 170 counts in the 0.5-8 keV observed-frame band (dashed) or a total of 170 counts in the 2-10 keV rest-frame band (dotted) is assumed. For the limits shown in this figure it is assumed that the source is detected at the ACIS-I aim-point with an exposure time of ~2Ms.

POSSIBLE EVOLUTION IN THE STRENGTH OF THE G - L_X CORRELATION

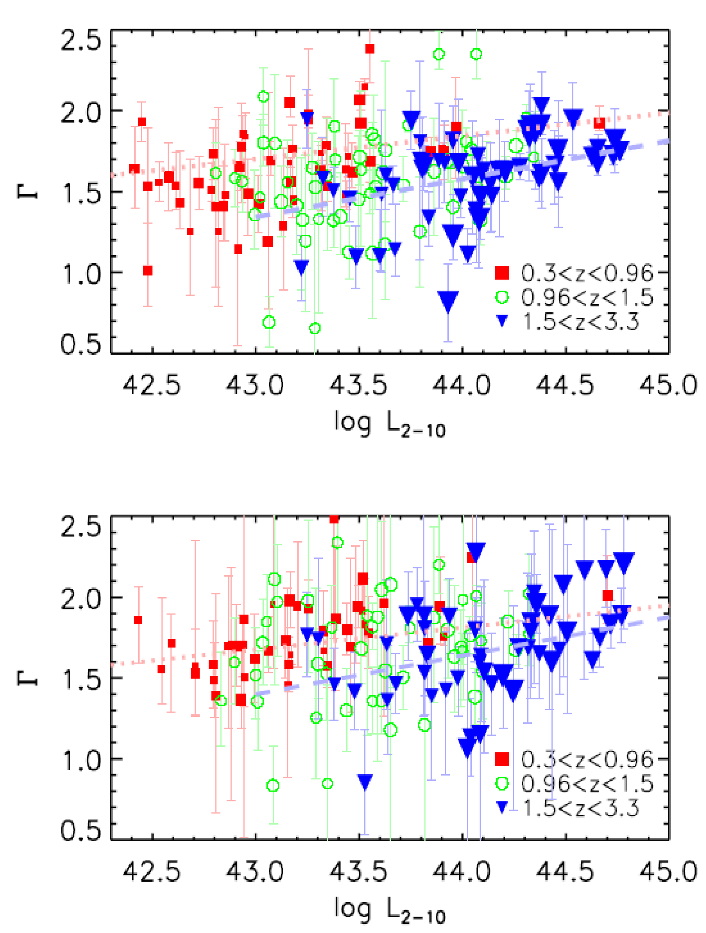

Figure 2.-- G versus 2–10 keV luminosity of RQ AGNs in the redshift range of 0.3<z<3.3. In the upper panel we show sources with fits performed in the 0.5–8 keV observed-frame band. In the lower panel we show sources with fits performed in the 2–10 keV rest-frame band. The symbol size increases with redshift. Red-filled squares are sources with 0.3<z<0.96, green-open circles are sources with 0.96<z<1.5, and blue-filled triangles are sources with 1.5<z<3.3. The dotted line indicates the least-squares fit to sources having 0.3<z<0.96. The dashed line shows the least-squares fit to sources having 1.5<z<3.3.

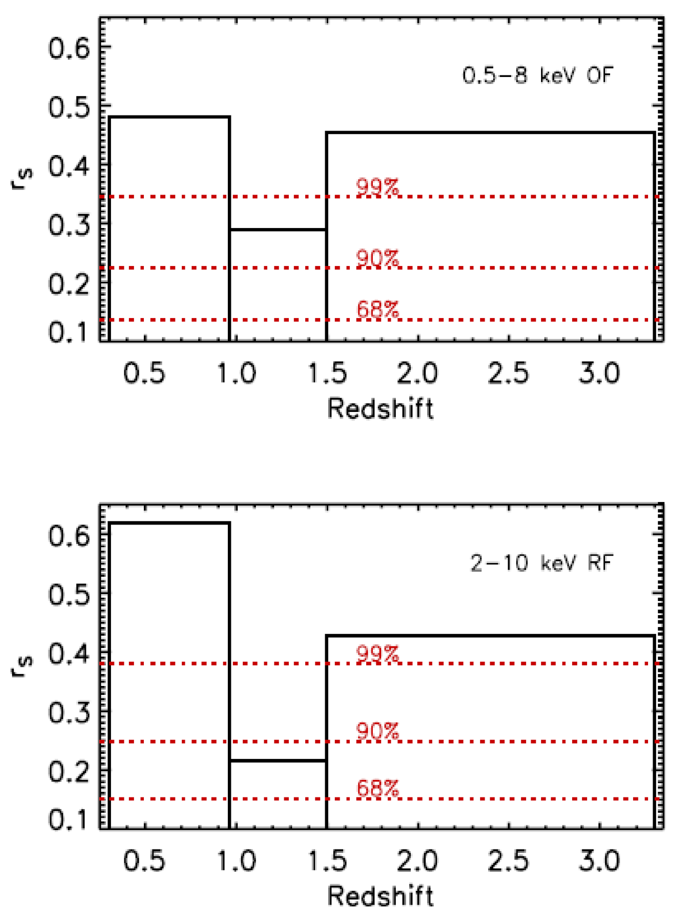

Figure 3.-- Spearman correlation coefficients of the G - L_{2-10} relation as a function of redshift for the RQ AGNs within each independent redshift bin. In the upper panel each redshift bin contains ~55 RQ AGNs and the fits were performed in the 0.5-8 keV observed-frame band. In the lower panel each redshift bin contains ~45 RQ AGNs, and the fits were performed in the 2-10 keV rest-frame band. The dotted lines correspond to three different levels of significance (68%, 90% and 99%); these are obtained assuming 55 sources in the upper panel and 45 sources in the lower panel.

POSSIBLE EVOLUTION IN THE SHAPE OF THE G - L_X RELATION

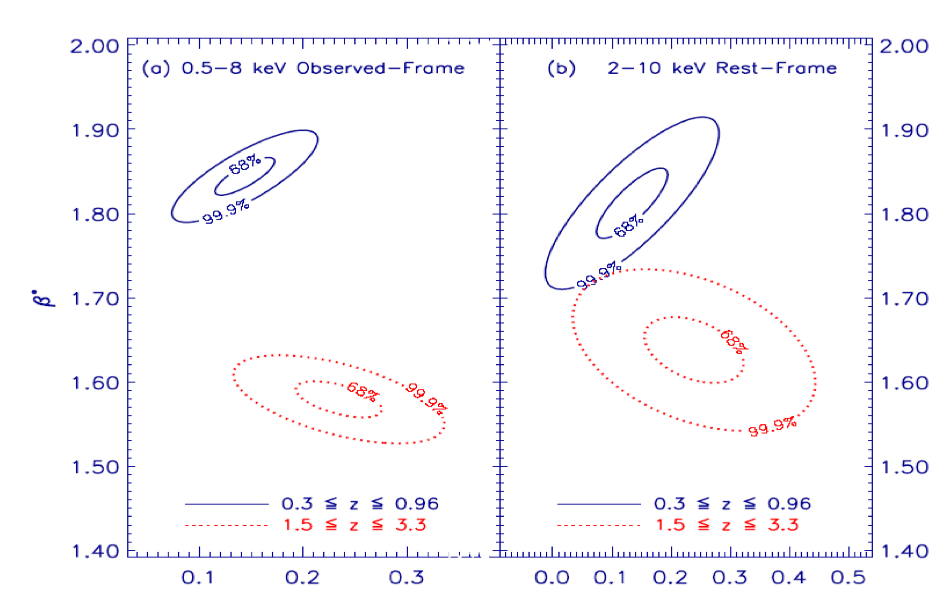

Figure 4.-- 68% and 99.9% confidence contours of the slope a and offset b*. of the G - L_X correlation for AGNs in the 0.3<z<0.96 (solid contours) and 1.5<z<3.3 (dotted contours) redshift ranges. The parameters a and b* were derived from fits of the linear model G=log(L_{2-10}/L_{44})+b* where L_{44} = 10^{44} erg s^{-1}. The fits were performed in the 0.5–8 keV observed-frame band (a) and in the 2–10 keV rest-frame band (b). The confidence contours indicate that the parameters of the linear fit to the G - L_X correlation differ at the >99.9% confidence level between the 0.3<z<0.96 and 1.5<z<3.3 redshift ranges.

DISCUSSION AND CONCLUSIONS

In this paper we have selected a sample of radio-quiet AGNs (173) from the CDF surveys with moderate-to-high S/N, and have found strong evidence of a correlation between the X-ray spectral parameters G and L_X. We found that the slope and offset of a linear fit to the G - L_X relation possibly evolves for sources with z>0.1. Analyzing this relation in three different redshift bins that contain a similar number of sources (~50) we conclude that this correlation is highly significant in two redshift bins, 0.3<z<0.96, and 1.5<z<3.3 and slightly less significant in the redshift bin 0.96<z<1.5. We note that the possible weakness of this correlation for sources with 0.96<z<1.5 appears to be driven by the absorbed sources in this redshift range. The G - L_X correlations in 0.3<z<0.96 and 1.5<z<3.3 are significant at the >99.9% confidence level for fits performed in the 0.5–8 keV observed-frame and at the >99.5% confidence level in the 2–10 keV rest-frame. The relation results in a softening of the X-ray spectra as the luminosity of the AGNs increases. The G - L_X correlation found in the redshift range of 1.5<z<3.3 is of special interest because it confirms a previous independent study of RQQ at z>1.5 (Dai et al. 2004).

The fact that this correlation is also present when we estimate the luminosities in the 2–10 keV rest-frame, and also holds for sources with low column densities, suggests that this correlation is not artificially driven by any un-modeled complexity in the intrinsic absorption (N_H). We performed several tests to investigate whether the G - L_X correlation found in this study is produced by a change with luminosity of the Compton-reflection component. We found that the strengths and slopes of the G - L_X correlation for sources within 1.5<z<3.3 are similar for fits performed in the 0.5–8 keV observed-frame and 2–10 keV rest-frame bands. Our analysis indicates that the strengths and slopes would be significantly different if the correlation was driven by a Compton-reflection component. The difference between the observed weighted mean values of G obtained from fits performed in the 0.5–8 keV observed-frame and 2–10 keV rest-frame bands is less than 0.03. Our simulations indicate that if an un-modeled Compton-reflection component was producing the observed correlation a difference of of about 0.2 would be expected. We conclude that a Compton-reflection component is unlikely driving the G - L_X correlation found in this study.

We presented two steady-corona models (Haardt et al. 1997; Merloni & Fabian 2001) that can explain both the G - L_X correlation found in this work and the saturation observed in the L_{2-10} vs. G relation using the surveys analyzed in Dai et al. 2004. Based on these models, we proposed two different interpretations to explain the correlation and its possible evolution with z. The first interpretation posits that this relation is driven by changes in the Eddington ratio (e) for a population of AGNs of similar mass. The second interpretation posits that the relation is driven by changes in the black-hole mass of the AGNs. To explain the detected possible evolution of the slope and offset of the linear fit to the G - L_X correlation we have proposed a simple model that posits that the mean properties of the hot coronae of AGN at z~2.2 differ significantly from those of AGN at z~0.7. This model also assumes that within each redshift bin the optical depths of the hot coronae of the AGNs are similar.

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