GB1508+5714, the First z>4 Radio Selected Quasar in X-rays

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ABSTRACT

We report the detection in X-ray of a high redshift (z=4.30) radio-loud quasar, GB1508+5714, the first radio-selected z>4 quasar seen in X-rays. The quasar was observed serendipitously with the *Einstein* observatory IPC at 0.02±0.003 cts s^{-1}. It is 10 times brighter than the other two z>4 X-ray detected quasars. The X-ray source is unusually hard, implying either $\alpha_E < -0.2$, or $N_H > 10^{22}$ atoms cm^{-2} (1σ limits) for a simple power-law plus intrinsic (z=4.3) absorption. Intrinsic absorption would make GB1508+5714 similar to a large fraction of z∼3 radio-loud quasars.

Subject headings: Quasars, X-rays general

1. Introduction

The highest redshift quasars are of interest not only for their 'record setting' quality, but also because they can tell us about the formation of quasars and about conditions in the first few percent of the age of the universe. Their number density can tell us about the number of sites with deep potential wells ≈1 Gyr after the big bang (Turner 1991), and their emission lines can tell us about abundances at the same epoch (Hamman & Ferland 1992). In principle we should also be able to learn about the quasar emission processes, by comparing the continua of quasars at low z with those of their cousins at an epoch before the rapid decline in mean quasar luminosity that occurs at z≈2 (Boyle et al. 1987).

However, although there are now several tens of quasars known at z>4 (NED, 1995), only a few have the broad band radio-to-X-ray continuum coverage now common at low z (e.g. Elvis et al. 1994). There are only two reported X-ray detections of quasars at z>4. One is X-ray selected (RX J1759.4+6638 at z=4.32, Henry et al., 1994), and one is optically selected (0000-263 at z=4.11, Bechtold et al., 1994), while other deep searches have been unsuccessful (PC0953+4749 at z=4.5, Molthagen, Wendker & Briel, 1994). Deep X-ray surveys (e.g. Boyle et al. 1993) have only a few percent of the many quasars they uncover at redshifts above 2.5.

In this paper we report the third X-ray detection of a z>4 quasar. GB1508+5714 is a newly discovered z=4.30 quasar (Hook et al. 1995). Since GB1508+5714 was first detected as a 5GHz radio source (Patnaik et al., 1992) it is the first z>4 radio-selected quasar to be detected in X-rays.

2. The X-ray Source

We searched the ROSAT and *Einstein* X-ray data bases to find out whether GB1508+5714 had been observed by a sensitive X-ray satellite. No ROSAT pointing included the quasar position, but a short (2580 seconds) *Einstein* Imaging Proportional Counter (IPC, Giacconi et al., 1979, Gorenstein et al., 1984) exposure contained the quasar (Table 1). We extracted the dataset from the *Einstein* CD-ROMS (SAO HEAD CD-ROM Series 1 (Einstein), Nos. 10-13), and analyzed it using IRAF PROS software. [1]

The *Einstein* observatory target was the galaxy NGC5879 which was not detected (Fabbiano et al.. 1992). However a point source is seen some 3 arcmin from the galaxy.

[1] IRAF is distributed by NOAO which is operated by AURA, Inc., under contract to the NSF.

The source is also clearly seen in 'The Einstein Observatory Catalog of IPC X-ray Sources' image (Harris et al. 1990), however it is not listed as a detected source in the catalog, being marginally below their threshold. In neither case is the point source identified. Using the `detect` algorithm in PROS we find a 4.2σ detection of the source, and an IPC count rate of 0.02 ct s^{-1}. This is the only source detected in the 60×60 arcmin field.

In table 1 we list the properties of the X-ray source. The IPC position is offset by 22 arcsec from the optical coordinates of GB1508+5714 (15:08:45.19, +57:14:02.6 (1950), Hook et al. 1995), within the $\sim$50 arcsec errors on IPC positions (Gioia et al., 1990). We conclude that GB1508+5714 has been detected by the *Einstein* IPC.

Source counts were extracted within a standard 3 arcmin radius centered on the X-ray source. This size of circle allows proper correction for mirror scattering (Harnden et al. 1984). The background was estimated from an annulus of $1.5'$ width beginning at a $3.5'$ radius centered on the source. All the errors quoted in this paper are 1σ errors.

GB1508+5714 has a flat radio spectrum at 150–250 mJy from 0.365 to 8.4 GHz, with no sign of a low frequency cut-off (Becker et al., 1991, Patnaik et al., 1992). It should thus be compared with other flat radio spectrum sources.

For a power-law with $\alpha_E = 0.5$, which is appropriate for a flat spectrum radio source (Worrall & Wilkes 1990) plus Galactic absorption, the observed 0.3–3.5 keV flux is 1.0×10^{-12} ergs s^{-1} cm^{-2}. The large redshift of the source brings the rest frame energy range observed by *Einstein* to $\sim$1–18 keV. It is most appropriate then to quote a rest frame luminosity in the standard 2–10 keV band (Table 1). The X-ray luminosity of GB1508+5714 is similar to the brightest z$\sim$3 quasars, PKS 2126$-$158 and S5 0014+813 (Elvis et al. 1994).

There are too few counts to fit a spectrum. However, a standard X-ray color ('hardness ratio' HR, Maccacaro et al. 1988) shows that the source is hard with HR=$+0.7^{+0.4}_{-0.3}$. Figure 1 shows how this hardness ratio converts into constraints on the parameters of a simple power-law plus intrinsic (z=4.3) absorption model. For only Galactic absorption an energy slope $\alpha_E < -0.2$ is implied. Of order 90% of the sources in the *Einstein* Extended Medium Survey have steeper implied slopes (Maccacaro et al. 1988).

Alternatively, we can constrain the column density if we assume a power-law slope. Flat spectrum radio-loud quasars (but not BL Lacs) have a remarkably tight distribution of slopes around a mean α_E=0.5 (Worrall & Wilkes 1990). The maximum allowed 1σ range of slopes is $0.25 < \alpha_E < 0.75$, at 90% confidence (Worrall & Wilkes 1990). For these slopes any column density at the quasar redshift must be larger than 10^{22} atoms cm^{-2}, with values of $\sim10^{23}$ atoms cm^{-2} being preferred. These column densities assume cold material at cosmic abundances. Neither of these conditions need apply around a quasar or at high redshift (Mathur et al. 1994, Hamman & Ferland 1992, Elvis et al. 1994), as we discuss below. However, at the 2σ uncertainty level of the HR, α_E=0.5 and Galactic N_H are consistent with the data.

3. Discussion

Only two other quasars with z>4 are known X-ray sources. In the soft X-ray band GB1508+5714 is by far the brightest, with an X-ray flux 80 times greater than RX J1759.4+6638, and 10 times greater than 0000-263. This makes it the only z> 4 quasar for which X-ray spectra can be obtained with current instrumentation. If the source is indeed heavily obscured, then it will appear even brighter above 2 keV.

The brightness of GB1508+5714 is reflected in its two-point optical to X-ray slope, α_{ox}. Wilkes et al. (1994) find a relation between α_{ox} and optical luminosity that predicts an α_{ox}=1.5 for a radio loud quasar at the optical luminosity of GB1508+5714 (logl_{opt}=32.68, assuming α_{opt}=0.5). The observed α_{ox}=1.1 (again for α_{opt}=0.5). This $\Delta\alpha_{ox}$ of 0.4 is a large fraction of the observed range of α_{ox} ~1.0-2.0 (Zamorani et al., 1981), and corresponds to GB1508+5714 being overbright in X-rays by a factor of 10.

Blazars often have smaller α_{ox} than unbeamed quasars. The GB1508+5714 radio source is unresolved at 0.2 arcsec (Patnaik et al. 1994). No variability or polarization data are available in the literature, so that these standard classification criteria are not available. The α_{ro} and α_{ox} 'colors' can pick out Blazars (Stocke et al., 1991, Schachter et al. 1993). For GB1508+5714 α_{ro}=0.44, which places it inside the blazar region, thus beaming is likely in GB1508+5714.

If there is strong intrinsic X-ray absorption in GB1508+5714 this would be similar to the situation in many other radio-loud quasars (Elvis et al. 1994, Fiore & Elvis 1995). An ionized absorber has been seen in the BL Lac object PKS 2155-305 (Canizares & Kruper 1984). The column density in GB1508+5714 would be particularly large ($\sim 10^{23}$cm^{-2}). This creates a problem due to the absence of an associated Lyman limit absorber (Storri-Lombardi et al. 1994), which implies $N_H(HI) \lesssim 10^{17}$. A highly ionized absorber, which would reduce the HI column density without affecting the X-ray absorption, would then be needed (Mathur et al. 1994). A neutral fraction, HI/H(total)< 10^{-6} is implied. There is a hint of OVI self-absorption in ultraviolet (rest) spectrum (Hook et al., 1995) which would be expected in this case. This level of ionization is similar to the situation in 3C 351 where an ionized absorber is found with HI/H(total)~ 10^{-4} to 10^{-6} (Mathur et al. 1994). The quasar would be capable of ionizing material at $n_e=10^5$ cm^{-3}, similar to 3C351) to this level out to quite large radii, $\sim$3 kpc (using CLOUDY, Ferland 1991).

GB1508+571 is a remarkably bright X-ray source with an unusually hard spectrum. It will prove valuable in many follow-up studies.

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Figure Captions

Figure 1: Values of IPC hardness ratio (HR) as a function of energy spectral index (α_E) for various values of assumed column density (N_H). Curves for the Galactic N_H for GB1508+5714, and for two values of intrinsic (z=4.3) absorption are given (10^{22} atoms cm^{-2}, 10^{23} atoms cm^{-2}). Also shown are the measured value of HR for GB1508+5714, and the range of spectral index found in flat radio spectrum quasars (FRS α_E range).

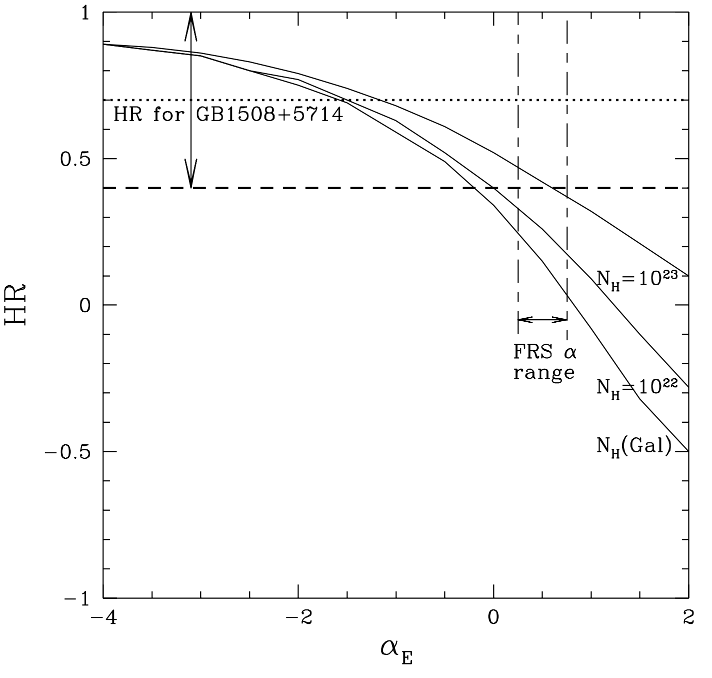
HR for GB1508+5714
FRS α
range
N_H=10^23
N_H=10^22
N_H(Gal)
HR
α_E
1
0.5
0
−0.5
−1
−4
−2
0
2

Table 1: GB1508+5714

redshift, z	4.30
m (POSS, E)	19
Position (optical, 1950)	15:08:45.19
	+57:14:02.6
N_H (Galactic)	1.55×10^{20} cm^{-2}
(Stark et al. 1989)	
Einstein IPC:	
date	1980 Dec. 22
sequence no.	I9143
exposure time	2850 sec.
count rate	0.017 ± 0.003 ct s^{-1}
net counts	44 ± 17
soft counts	8 ± 10
hard counts	40 ± 10
Position (X-ray, 1950)	15:08:47.9
	+57:14:00.2
Hardness ratio	$0.7^{+0.4}_{-0.3}$
Flux^a (0.3–3.5 keV)	
($\alpha_E = 0.5$, N_H=N_H(Gal))	7.0×10^{-13}
($\alpha_E = 1$, N_H=N_H(Gal))	5.9×10^{-13}
α_{ox}	1.1
Luminosity(2-10 keV)^b	
($\alpha_E = 0.5$, N_H=N_H(Gal))	8.0×10^{47}erg s^{-1}
($\alpha_E = 1.0$, N_H=N_H(Gal))	3.8×10^{47}erg s^{-1}

a. correcting for Galactic absorption, in units of ergs s^{-1} cm^{-2}; b. in quasar rest frame, for H_0=50 km s^{-1} Mpc^{-1}, Ω=0