A Chandra observation of the distant radio galaxy B2 0902+343: a powerful obscured active galaxy

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1 INTRODUCTION

B2 0902+343 at $z = 3.395$ was the highest redshift radio galaxy known at the time of its discovery (Lilly 1988). Its radio source structure consists primarily of a knotted jet extending a short way from a flat-spectrum nucleus out to the north-west, before being deflected left through 90° in a hotspot (Carilli et al., 1994; Carilli 1995). Further diffuse, very steep-spectrum emission continues to the north, and two faint hotspots lie symmetrically to the south, lending the overall structure an inverted-S shape. The source is compact, with the radio emission lying all within 7 arcsec, or 50 kpc at the redshift of the galaxy (assuming a cosmology of $H_{0}=70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega=1.0$ and $\omega=0.7$). The radio source is exceptional for its very large Faraday rotation measures (in excess of 1000 rad m$^{-2}$) and steep rotation measure gradients across the northern hotspot (Carilli et al. 1994; Carilli 1995).

The optical continuum from the host galaxy is visible only from two clumps to either side of the radio jet (Eisenhardt & Dickinson 1992), with extended faint diffuse emission spreading from two clumps to either side of the radio jet (Eisenhardt & Dickinson 1992). Associated neutral hydrogen 21cm absorption has been detected against the (extended) radio continuum (Uson, Bagri & Cornwell, 1991; Briggs, Sorar & Taramopoulos, 1993; de Bruyn, 1996).

0902+343 was detected in a 33 ksec-long exposure with the ROSAT PSPC, but only above 0.7 keV (corresponding to $> 3$ keV in the rest frame), which could indicate intrinsic absorption of around $10^{23}$ cm$^{-2}$ (Crawford, 1998). However, the lack of counts in the ROSAT spectrum meant that the low-energy deficit (and thus the interpretation of the X-ray spectrum as an absorbed power-law) was significant only at the $2\sigma$ level.

2 OBSERVATION AND RESULTS

B2 0902+343 was observed by the Chandra satellite on 2000 Oct 26 for 9.78 ksec with the ACIS-S (sequence number 700212). There were no background flares during the observation so we extracted data from the full exposure. An X-ray source is detected at the position of 0902+343 with 94 10 counts (Fig. 1). Background was estimated from a neighbouring, source-free region. The counts are almost evenly divided between the 0.5–2 keV and 2–7 keV energy bands, with 52, 7 and 42, 6 counts respectively. The centroid of the X-ray source (at RA 09 05 30.14, Dec +34 07 56.0) is exactly aligned with the flat spectrum knot at the southern end of the radio jet (RA 09 05 30.13, Dec +34 07 56.1), supporting its identification as the active nucleus. (We have confirmed the accuracy of the Chandra coordinates by checking the positions of serendipitous sources in the field of view that are clearly identified with optical sources; we find the agreement to be good to within 0.3 arcsec.) The detection is consistent with being a point source at this position, although we note that a visual inspection suggests a slight (but not significant) elongation to the source along the same direction as the radio source axis.

We extract a spectrum for the source, binning it into 12 counts per bin (Fig. 2). If only Galactic absorption (of column density $2.6 \times 10^{21}$ cm$^{-2}$; Stark et al. 1992) is assumed, then the spectrum is fit by a power law of improbable photon index of $\Gamma = 0.68 \pm 0.23$ (uncertainties are 90 per cent for one interesting parameter). It is much flatter than the spectrum of most quasars and radio galaxies (e.g. Sambruna, Eracleous & Mushotzky, 1999). If we allow for...
intrinsic absorption at the redshift of the object we find a good fit for $kT = 3.2 \pm 0.2$ keV and an inferred intrinsic column density of $N_H = 1.8 \times 10^{22}$ cm$^{-2}$. The reduced chi-squared is 0.363 for five degrees of freedom (acceptable at the 15 per cent level), and the intrinsic 2–10 keV luminosity, (after correction for absorption) is $3 \pm 10^{45}$ erg s$^{-1}$. Due to the low number of photons this spectrum can only be an approximate guide to the intrinsic properties of the source. The upper limit to the equivalent width of any redshifted 6.4 keV iron line is 840 eV.

The flat power law of photon index $\Gamma = 1.4$ could be due to the emission being dominated by the jet and similar to that in high redshift blazars (e.g. Fabian et al 2001a,b). Reeves et al (2001) find $\Gamma = 1.27$ for a radio-loud quasar at $z = 3.2$ and attribute it to a face-on jet. However, Carilli (1995) argues that the jet in 0902 is pointed out of the Sky plane at an angle of 45–60 degrees so it should not appear as a blazar.

We have also investigated more complex emission models. Since we are observing up to about 30 keV in the rest frame of the source, reflection may be flattening the spectrum. We have therefore refit the data including a pexrav model (Magdziarz & Zdziarski 1995). This yields $kT = 1.4 \pm 0.1$ keV and $N_H = 9.7^{+3.4}_{-2.6} \times 10^{22}$ cm$^{-2}$ ($\chi^2$/dof = 2.3; p=5) when the reflection fraction is assumed to be unity (reflection from a flat surface). We have also examined partial-covering models and find acceptable fits for $kT = 1.4 \pm 0.1$ keV with an 80 per cent covering fraction and column density of $N_H = 3.4 \pm 0.2 \times 10^{23}$ cm$^{-2}$.

The lack of spatial extent and the good fit of a highly absorbed power-law to the X-ray spectrum clearly show that the emission that Chandra observes is dominated by the central nucleus. The large column density reinforces the idea that we are not detecting a very extended structure, or the mass of absorbing gas would be impossibly large. The very high Faraday rotation measures seen in the radio source are comparable to those seen locally in cluster cooling flows, and do suggest the presence of a surrounding hot magnetized medium (Carilli et al 1994; Carilli 1995). We attempt to constrain the presence of a thermal component by adding thermal emission to the absorbed power-law model in the fit to the spectrum. Assuming a (rest-frame) temperature $kT = 3$ keV for any thermal component, we find, assuming $\Gamma = 1.8$; a thermal gas luminosity of $7.5 \times 10^{44}$ erg s$^{-1}$; it increases to $10^{45}$ erg s$^{-1}$ if a higher temperature of $kT = 5$ keV is assumed. Again the column density and intrinsic luminosity of the nucleus are increased. The X-ray data cannot rule out the additional presence of a sizeable mass of hot, thermal gas, but do not require it. If the central galaxy of a massive subcluster is forming here then it should be embedded in hot cooling gas with a temperature of 1-5 keV. Given the high redshift of the source, clear evidence for a low-energy spectral upturn is difficult given the declining sensitivity of the ACIS-S detector below 0.5 keV. Further observations with X-ray missions with better sensitivity at low energies – such as XMM-Newton – are required to test for the presence of any extended component of soft X-ray emission.

3 DISCUSSION

The nucleus of 0902+343 is both powerful and highly absorbed. No object in the sample of Sambruna et al (1999) has a similar combination of extreme power and column density. Some objects in the sample of high redshift radio-loud quasars of Cappi et al (1999) do approach this combination, but the lack of absorption in one of their absorbed objects, PKS 0537-286, when observed at much higher signal-to-noise with XMM-Newton by Reeves et al (2001) raises uncertainties. The 2–10 keV intrinsic luminosity of 0902+343 is an order of magnitude more than that from the nucleus in Cygnus A (Young et al 2002). If we assume, following the spectral energy distributions of Elvis et al (1994), that the 2–10 keV luminosity is about 3 per cent of the total then the bolometric power of the nucleus is about $10^{47}$ erg s$^{-1}$. Much of it is absorbed and presumably re-radiated in the far infrared (FIR) bands. Hughes, Dunlop & Rawlings (1997) estimate a value of $10^{44.8}$ L$_\odot$ for the far infrared luminosity of the source which, after a small correction for the difference in cosmology used, is $8 \times 10^{43.7}$ erg s$^{-1}$ and comparable with that deduced above. This assumes thermal dust emission. They have since shown (Archibald et al 2001) that the submm spectrum is dominated by synchrotron emission, so the above FIR luminosity should be seen as an upper limit, unless the radiating dust is warm (> 100K). Pentericci et al (1999) suggest that the optical morphology of 0902+343 may be due to obscuration by large amounts of dust; such dust, and associated gas, may account for the X-ray absorption.

There is little room for any strong starburst emission and we conclude that the active nucleus dominates the luminosity. The central black hole, if the Eddington limit is not to be exceeded and beaming is unimportant, should have a mass greater than about $10^7 M_\odot$. This implies that a full-grown active nucleus resides at the centre of what has been inferred to be a proto-galaxy from its appearance at optical and infrared wavelengths.
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Figure 2. The best-fitting Chandra spectrum of the X-ray source associated with the radio galaxy B2 0902+343, folded through the instrument response (top) and the contours of confidence for the excess absorption $N_{\text{H}}$ and photon index (lower plot). The contours are for $\chi^2 = 2.3, 4.61$ and $9.21$ (corresponding to the 68, 90 and 99 per cent confidence regions for two interesting parameters). The best fit marked by the cross in the confidence plot is shown against the spectrum as a solid line.

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