**ASCA observations of Deep ROSAT fields - III. The Discovery of an Obscured Type 2 AGN at \( z = 0.67 \)**

B.J.Boyle\(^1\), O.Almaini\(^2\), I.Georgantopoulos\(^3\), A.J.Blair\(^4\), G.C.Stewart\(^4\), R.E.Griffiths\(^5\), T.Shanks\(^6\), K.F.Gunn\(^6\)

\(^1\) Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia  
\(^2\) Institute for Astronomy, University of Edinburgh, Blackford Hill, Edinburgh, EH9 3HJ  
\(^3\) National Observatory of Athens, Lofos Koufou, Palaia Penteli, 15236, Athens, Greece  
\(^4\) Department of Physics & Astronomy, The University of Leicester, Leicester LE1 7RH  
\(^5\) Department of Physics, Carnegie Mellon University, Wean Hall, 5000 Forbes Ave., Pittsburgh, PA 15213, USA  
\(^6\) Physics Department, University of Durham, South Road, Durham DH1 3LE

**ABSTRACT**

We report on the discovery of a narrow-emission-line object at \( z = 0.672 \) detected in a deep ASCA survey. The object, AXJ0341.4–4453, has a flux in the 2–10 keV band of \( 1.1 \pm 0.27 \times 10^{-13} \text{erg s}^{-1} \text{cm}^{-2} \), corresponding to a luminosity of \( 1.8 \times 10^{44} \text{erg s}^{-1} \) (\( q_0 = 0.5, H_0 = 50 \text{km s}^{-1} \text{Mpc}^{-1} \)). It is also marginally detected in the ROSAT 0.5–2 keV band with a flux \( 5.8 \times 10^{-15} \text{erg s}^{-1} \text{cm}^{-2} \). Both the ASCA data alone and the combined ROSAT/ASCA data show a very hard X-ray spectrum, consistent with either a flat power law (\( \alpha < 0.1 \)) or photoelectric absorption with a column of \( n_H > 4 \times 10^{22} \text{cm}^{-2} \) (\( \alpha = 1 \)). The optical spectrum shows the high-ionisation, narrow emission lines typical of a Seyfert 2 galaxy. We suggest that this object may be typical of the hard sources required to explain the remainder of the X-ray background at hard energies.

**Key words:** X-rays: general – galaxies: active – quasars: general

1 INTRODUCTION

The high-redshift analogues to Seyfert 2 galaxies, the so-called Type 2 or obscured active galactic nuclei (AGN), have been increasingly postulated as a major contributor to the X-ray background (XRB) in recent years (see e.g. Comastri et al. 1995). Interest in these objects has centred on their X-ray spectra, which are likely to be significantly harder than those observed in normal QSOs or Type 1 AGN. Ordinary QSOs are known to comprise the bulk of the soft (0.5 – 2 keV) source population identified to date (Shanks et al. 1991, Schmidt et al. 1998) but their spectra are too soft to explain the remainder of the XRB at harder energies. Even relatively modest amounts of gas and dust \( (n_H > 10^{21} \text{cm}^{-2}) \) in the central regions would readily absorb soft X-ray photons \( (< 2 \text{keV}) \) and significantly harden the X-ray spectrum. A population of objects with X-ray spectra of this type can readily reproduce the spectrum of the X-ray background (Madau et al. 1994, Comastri et al. 1995). The discovery of at least one obscured QSO at high redshift \( (z = 2.35) \) lends some weight to this hypothesis (Almaini et al. 1995), although the unambiguous identification of large numbers of such objects remains elusive.

A number of groups (Boyle et al. 1995a, Griffiths et al. 1996) have detected increasing numbers of low redshift \( (z < 0.5) \) galaxies with narrow emission lines (NELGs) as the optical counterparts to faint ROSAT sources. The precise nature of these objects is unclear (Boyle et al. 1995b); optical classification based on standard emission-line-ratio diagnostics reveals them to be borderline starburst/Seyfert 2 galaxies. A hybrid explanation consisting of both phenomena is a strong possibility (Boyle et al. 1995b, Fabian et al. 1998). The mean X-ray spectra of these objects appear to be significantly harder than that of QSOs (Almaini et al. 1996, Romero-Colmenero et al. 1996). Recently, Schmidt et al. (1998) have argued that confusion plays a significant role in the optical identification of some of the faintest X-ray sources, and that some of the emission-line galaxies identified previously are not the true optical counterparts of the X-ray source. Nevertheless, the hardness of their X-ray spectra suggests that the true identifications will not be standard broad emission-line QSOs. Indeed, Roche et al. (1995) have cross-correlated faint galaxy positions with the unresolved ROSAT X-ray background to demonstrate statistically that a large fraction of the soft X-ray background must be due to faint \( B \sim 23 \text{mag} \) galaxies.

The ASCA mission has now yielded information on the nature of the X-ray background at harder energies (2 – 10 keV), albeit at a poorer spatial resolution \( (\sim 1 \text{arcmin}) \) than the ROSAT mission. Although attempts to carry out optical identification programs have been frustrated by the large ASCA point-spread-function (PSF), Ohta et al. (1996)
were able to identify a high redshift, $z = 0.9$, Type 2 AGN as a counterpart to a faint ASCA source. This source has an X-ray luminosity of $1 \times 10^{44}$ erg s$^{-1}$, and was, until the observations reported on in this paper, the only Type 2 AGN at high redshift ($z > 0.1$) to be identified on the basis of its hard $2 - 10$ keV flux.

Many ASCA source identification programmes now rely on the cross-correlation of the positions of sources detected in deep ASCA data with those in deep ROSAT data obtained over the same fields. This was the method we chose to employ in our programme of faint ASCA source identifications. Paper I in this series (Georgantopoulos et al. 1997) reported on the source population and the $2 - 10$ keV log $N - \log S$ in three deep ASCA fields which had been cross-correlated with ROSAT data. Paper II (Boyle et al. 1998) presented the AGN $2 - 10$ keV X-ray luminosity function and the extrapolated AGN contribution to the $2 - 10$ keV XRB. We have since obtained data for a further two deep ASCA fields and, in the course of the optical follow-up, identified an object with narrow emission lines as the counterpart to one of the hardest ASCA X-ray detections in our source list.

In Section 2 we present the optical and X-ray observations and in Section 3 we discuss the properties of the object and present our conclusions.

2 OBSERVATIONS

2.1 X-ray

We have obtained deep (100–200 ksec) ASCA data in five fields in which we had already carried out a deep ($S_{0.5-2 keV} > 3 \times 10^{-15}$ erg s$^{-1}$ cm$^{-2}$) ROSAT survey (Georgantopoulos et al. 1996). The deep fields surveyed to date are centred in three locations; two pointings in the South Galactic Pole (SGP) regions ($00^h 53^m - 28^\circ$), two in the UKST 249 field ($03^h 44^m - 45^\circ$) and one in the UKST F585 field ($10^h 46^m + 00^\circ$). The X-ray images used for source detection were obtained by a mosaic of the data from both Gas Imaging Spectrometer (GIS) detectors, thus maximising the effective exposure time. X-ray sources were then located using the Point Source Search (PSS) algorithm of Allen (1992). Full details of the X-ray analysis (source detection, flux calculation) can be found in Paper I.

One source, centred at RA(2000) = 03$^h$41$^m$24.7$^s$, Dec(2000) = $-44^\circ$53’01”, was found to exhibit extreme X-ray properties, with an exceptionally hard X-ray spectrum. The ASCA count rate for the source (named AXJ0341.4–4453) based on the ‘cleaned’ image is $1.7 \pm 0.46 \times 10^{-3}$ count s$^{-1}$. For an intrinsic energy spectral index of $\alpha = 1$ and $n_H = 4 \times 10^{22}$ cm$^{-2}$ (see below), we obtain a flux of $S_{2-10 keV} = 1.1 \pm 0.27 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$.

AXJ0341.4–4453 is one of the brightest detections on the ASCA field above 2 keV, but remains undetected in the softer $1 - 2$ keV band. Although too faint to enable detailed spectral fitting, we note however that the source shows an unusually large ASCA hardness ratio $HR = 0.91 \pm 0.24$, defined by: $HR = \frac{H - S}{H + S}$ where $H$ and $S$ are the ASCA count rates in the ASCA hard ($2 - 10$ keV) and soft ($1 - 2$ keV) bands respectively. This immediately suggests a hard, inverted X-ray spectrum or heavy photo-electric absorption. Given that there is no detection in the soft band, it is more appropriate to give the lower limit on the hardness ratio corresponding to the upper limit on the soft count rate. We therefore estimated a lower bound on the hardness ratio using the method of Kraft et al. (1991). This gives a 99 per cent lower limit of $HR > 0.34$, which still corresponds to a very hard power law index of $\alpha < 0.1$.

AXJ0341.4–4453 was also found to have a faint 4.5$\sigma$ ($S_{0.5-2 keV} = 6 \times 10^{-15}$ erg s$^{-1}$ cm$^{-2}$) ROSAT source only $8$ arcsec distant, well within the 90-arcsec correlation length for ASCA/ROSAT positional coincidences (Paper I). Assuming no X-ray variability between the ROSAT and ASCA observation epochs, combining the ROSAT and ASCA data yields a hardness ratio (as defined above) of $HR = 0.70 \pm 0.20$ or a spectral index of $\alpha = -0.8$ over the range $1 - 10$ keV.

2.2 Optical

The optical source closest to the ROSAT counterpart of AXJ0341.4–4453 was a $B = 21.4$ object only $11$ arcsec from the ROSAT position (see Fig. 1) and only $3$ arcsec from the ASCA source position. The optical position of the source is RA(2000) = 03$^h$41$^m$24.4$^s$, Dec(2000) = $-44^\circ$53’02”. Although a spectroscopic identification already exists for many of the ROSAT sources on this field (QSF1, Griffiths et al. 1995), the optical counterpart to AXJ0341.4–4453 had not been observed previously, because the ROSAT source was below the nominal X-ray detection limit ($5\sigma$) adopted for completeness in the original ROSAT survey.

The optical source was observed with the Low Dispersion Survey Spectrograph (LDSS) at the Cassegrain focus of the Anglo-Australian Telescope (AAT) on the night of 1997 September 6. The total integration time was 2400 seconds. LDSS was operated with a single ‘long-slit’ aperture mask (1.7-arcsec slit width) and medium resolution grism.
A Tektronix CCD was used as the detector to give an overall spectral resolution of 13 Å. Conditions were poor; 2 arcsec seeing and the observations were made through light cirrus. Wavelength calibration was achieved using a copper-argon arc lamp.

The resulting optical spectrum is shown in Fig. 2. The five strong emission lines identified in the spectrum are listed in Table 1. The mean emission line redshift obtained from these lines (excluding Hδ, see below) is $z = 0.6724 \pm 0.0002$.

Based on this redshift, the 2–10 keV X-ray luminosity for AXJ0341.4–4453 is $1.8 \times 10^{44}$ erg s$^{-1}$ ($q_0 = 0.5$, $H_0 = 50 \text{ km s}^{-1} \text{Mpc}^{-1}$).

The mean rest full width half maxima (FWHM) for the emission lines is $900 \pm 150$ km s$^{-1}$; marginally greater than the instrumental profile of $\sim 650$ km s$^{-1}$. The Hδ emission line appears to be cut on its red side by an absorption feature. This is consistent with the lower value of the emission line redshift obtained for this line. This absorption feature is also seen in the spectrum of AXJ0849+4454, the $z = 0.9$ Type 2 AGN at discovered by Ohta et al. (1996).

### 3 DISCUSSION

The strong [NeV] emission in the optical spectrum of AXJ0341.4–4453 indicates that this object is likely to be an AGN. The lack of any broad emission lines, particularly the broad MgII$\lambda$2798 line at 4673 Å further implies that this is an example of a high redshift Seyfert 2 galaxy or Type 2 AGN. This is confirmed by its high X-ray luminosity ($1.8 \times 10^{44}$ erg s$^{-1}$), unlikely to originate from a star-forming galaxy. The optical spectrum bears many similarities to that obtained for the $z = 0.9$ Type 2 AGN observed by Ohta et al. (1996), and other Type 2 AGN identified by ROSAT in Lockman hole field (Schmidt et al. 1998).

The identification of such sources as bona fide Type 2 AGN has recently been called into question by Halpern and co-workers in a series of papers, see Halpern, Eracleous & Forster (1998) and references therein. They have demonstrated that many of the sources initially identified as Type 2 AGN either exhibit broad Balmer lines and are better clas-

### Table 1. Emission Line Parameters for AXJ0341.4–4453

| Line       | $\lambda_{\text{obs}}$ (Å) | $z$ | $W_0$ (Å) | FWHM$_{0}$ (km s$^{-1}$) |
|------------|---------------------------|-----|------------|--------------------------|
| [NeV]$\lambda$3426 | 5729                      | 0.6722 | 6.6        | 1140                     |
| [OII]$\lambda$3727  | 6234                      | 0.6727 | 14.7       | 740                      |
| [NeIII]$\lambda$3869 | 6470                      | 0.6723 | 5.7        | 830                      |
| [NeIII]$\lambda$3968 | 6636                      | 0.6724 | 2.4        | 900                      |
| Hδ          | 6853                      | 0.6706 | 3.6        | 870                      |
sified as high-redshift Seyfert 1.8 or Seyfert 1.9 galaxies, or are members of the class of narrow-line Seyfert 1 galaxies (Brandt et al. 1994), with steep (soft) X-ray spectral indices. Given its hard X-ray spectrum, we can immediately rule out AXJ0341.4–4453 as a narrow-line Seyfert 1.

While it is impossible to rule out a Seyfert 1.8/1.9 classification on the basis of the only Balmer line (Hδ) seen in the spectrum of AXJ0341.4–4453, we can place a useful 3σ upper limit of 10A on the rest equivalent width of any broad (5000km s$^{-1}$ FWHM) MgIIa2798 emission line. This is well below the typical equivalent width of broad MgII seen in the objects observed to date by Halpern et al. (e.g. $W_0$ of 47Å for 1E0449.4–1823). Note there may be a weak ($W_0 \sim 5Å$), narrow (FWHM< 2000 km s$^{-1}$) emission feature at $\lambda \sim 4690Å$ in the spectrum of AXJ0341.4–4453. However, the association of this weak feature with MgIIa2798 is uncertain given that it is redshifted 650 km s$^{-1}$ with respect to the narrow emission lines of [OII], [NeII] and [NeV], and by over 1000 km s$^{-1}$ from the Hδ emission line.

Indeed, the classification of these objects as Seyfert 1.8/1.9 or Seyfert 2 may well be a largely taxonomic issue. More fundamental to the nature of the AXJ0341.4–4453 is the fact that it exhibits a hard X-ray spectrum. If we assume that absorption causes the flattening of the hardness ratios, the ASCA 1–10 keV hardness ratio ($HH > 0.34$) yields a 99 per cent confidence lower limit on the photo-electric absorption of $n_H > 4 \times 10^{22} cm^{-2}$, for an intrinsic energy spectral index $\alpha = 1$. The combined ROSAT/ASCA hardness ratio ($HH = 0.70$) yields an absorption of $n_H \sim 10^{23} cm^{-2}$, for $\alpha = 1$. The dust associated with such a column would be more than enough to extinguish the broad line region in the optical waveband. We conclude that this is an example of an AGN obscured by gas and dust, of the type widely postulated to account for the hard X-ray background (Madau et al. 1994, Comastri et al. 1995).

AXJ0341.4–4453 also exhibits the highest value $\alpha_{OX}$ in any object in our survey, $\alpha_{OX} = 1.8$ ($\alpha_{OX} = -\log(L_{2keV}/L_{2500Å})/2.605$). This may be compared to mean value of $\alpha_{OX} = 1.45 \pm 0.10$ for the survey sources as a whole. This is consistent with significant absorption of the 2keV X-ray flux by a large HI column and is typical of the values obtained for Seyfert 2 galaxies at low redshift (see e.g. Rush et al. 1996).

Examples of obscured AGN have also been found at low redshift ($z < 0.1$) from ASCA observations. Akiyama et al. (1998) report on the discovery of a type 2 Seyfert galaxy, AX J131501+3411, at $z = 0.072$. This object exhibits a similar absorption column to that obtained for AXJ0341.4–4453 ($n_H \sim 6 \times 10^{22} cm^{-2}$) and is the hardest X-ray source in the ASCA large sky survey. Another source AX J1749+684, identified by Iwasawa et al. (1997), may also be an example of a low redshift obscured AGN, but with a lower absorbing column $n_H \sim 8 \times 10^{21} cm^{-2}$.

If obscured AGN such as AXJ0341.4–4453 are to explain the hard XRB then they should emerge in significant numbers in forthcoming, deeper X-ray surveys (e.g. with AXAF or XMM). They should also turn up in the latest mid- and far-infrared deep surveys, where the energy absorbed by the obscuring gas and dust will be re-radiated (Granato et al. 1997). At mid-infrared wavelengths the European Large Area Infrared Space Observatory Survey (ELAIS, Oliver et al. 1997) will reach unprecedented sensitivities, and large numbers of obscured AGN should be identified (Barcons et al. 1995). For obscured QSOs at high redshift, the expected dust emission peak at $\lambda \sim 60 – 100\mu$m is redshifted into the sub-millimetre region. Deep surveys with the new Sub-mm Common User Bolometer Array (SCUBA) at the James Clerk Maxwell Telescope in Hawaii therefore present an ideal opportunity to detect these obscured objects, if they are truly the explanation for the origin of the hard XRB.

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