Optical, near-infrared and hard X–ray observations of SAXJ 1353.9+1820: a red quasar *

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ABSTRACT

We present the results of a follow–up ASCA observation and multicolour optical and near-infrared photometry carried out at the 3.5-m Italian National Telescope Galileo of SAXJ 1353.9+1820. This object, serendipitously discovered by BeppoSAX in the 5–10 keV band, has been spectroscopically identified as a red quasar at z =0.217. The combined X–ray and optical–infrared data reveal the presence of a moderately luminous X–ray source (∼ 1044 erg s−1) obscured by a column density of the order of 1022 cm−2 in a otherwise optically passive early-type galaxy. The implications for the nature of red quasars and their possible contribution to the hard X–ray background are briefly outlined.

Key words: galaxies: active – quasars: individual: SAXJ 1353.9+1820 – X–rays: galaxies

1 INTRODUCTION

The BeppoSAX High Energy Large Area Survey (HELLAS) has discovered a large population of hard X–ray sources, which account for about 20–30 per cent of the cosmic X–ray background (XRB) in the 5–10 keV energy range (Fiore et al. 1999). This band provides an efficient tool to discriminate between accretion-powered sources, like the Active Galactic Nuclei (AGN) are generally thought to be, and sources dominated by the starlight component. Moreover, hard X–ray selection is less affected by obscuration with respect to other bands, making possible the study of the nuclear continuum without any relevant contamination by reprocessed radiation. Indeed the optical identification process indicates that the large majority of the HELLAS sources are AGN (La Franca et al., in preparation). Among these, SAXJ 1353.9+1820 can be considered one of the most intriguing sources. After its discovery in the context of the HELLAS survey, it was spectroscopically identified as a radio-quiet AGN at a redshift of 0.2166 (Fiore et al. 1999). Its optical spectrum is dominated by starlight, as the presence of H and K plus Mg I absorption lines clearly indicates. The Hα equivalent width (about 90 Å), the absence of the Hβ and the BeppoSAX hardness ratio are suggestive of significant reddening of the nuclear radiation. The hard X–ray luminosity, L5–10 keV ∼ 1.4 × 1044 erg s−1, the presence of a broad Balmer line and the optical spectrum properties allow to classify this object as a fairly low-luminosity, red quasar.

This class of objects, originally discovered in radio–selected samples (Smith & Spinrad 1980), is characterized by red optical colours (B–K up to 8, Webster et al. 1995). On the basis of ROSAT PSPC observations and optical spectroscopy Kim & Elvis (1999) pointed out that a significant fraction (from a few percent up to 20 per cent) of soft X–ray selected radio–quiet quasars belong to this class. The origin of the observed ‘redness’ may be ascribed to dust absorption, to intrinsic red colours (> 70 per cent of the red sources of the Parkes sample has < 30 per cent of contribution to B–K by their host galaxies, Masci et al. 1998) or to an excess of light in K band rather than a dust-induced deficit in B (Benn et al. 1998). Whatever is the origin of the red colours, it is likely...
that a large fraction of quasars could have been missed by the usual selection techniques in the optical band (Webster et al. 1995). If this is the case, red quasars could constitute a sizeable fraction of the absorbed AGN population needed to explain the hard X-ray background spectrum (i.e. Comastri et al. 1995) especially if the optical reddening is associated with X-ray absorption. Hard X-ray observations provide the most effective way to select these objects; indeed already two candidates have been found among the first optical identifications of HELLIAS sources (Fiore et al. 1999). In order to better understand the spectral properties of these objects we have started a program of multwavelength follow-up observations of a sub-sample of HELLIAS sources. Here we present the first results obtained in the X-ray band with ASCA and at optical-infrared wavelengths with the 3.5-m Italian National Telescope Galileo (TNG) at La Palma (OIG and ARNICA photometric cameras). Throughout the paper we have used a luminosity distance of 500 Mpc and at redshift z = 0.

2 ASCA DATA REDUCTION AND SPECTRAL ANALYSIS

SAXJ 1353.9+1820 (RA: 13h 53m 54s.4, DEC: 18° 20′ 16″) was observed with the ASCA satellite (Tanaka, Inoue & Holt 1994) in January 1999 for about 60 ks. The observation was performed in Faint mode and then corrected for dark frame error and echo uncertainties (Otani & Dotani 1996). The data were screened with the XSELECT package (version 1.4b) with standard criteria. Spectral analysis on the resulting cleaned data was performed with XSPEC version 10 (Arnaud et al. 1996).

The background-subtracted count rates are 6.0±0.4 × 10⁻³ counts s⁻¹ for SIS (Solid-State Spectrometers, Gendreau 1995) and 7.4±0.4 × 10⁻³ counts s⁻¹ for GIS (Gas-Scintillation Spectrometers, Makishima et. al. 1996). Both SIS and GIS spectra were grouped with almost 20 photons for each spectral bin in order to apply χ² statistics. Calibration uncertainties in the soft X-ray band have been avoided by selecting only data at energies higher than 0.5 keV. No discrepancies have been found between SIS and GIS spectral analysis, therefore all the data have been fitted together allowing the relative normalizations to be free of varying. The uncertainties introduced by background subtraction have been carefully checked using both local and blank-sky background spectra and also varying their normalizations by ± 10 per cent. The lack of significant variations for the source count rate and spectral shape makes us confident on the robustness of the results.

A simple power law model plus Galactic absorption (N_H ≈ 2.05 × 10¹⁰ cm⁻², Dickey & Lockman 1990) leaves some residuals in the fit (χ²=174/158) and gives a very flat slope (Γ < 0.9). The addition of an extra cold absorber at the redshift of the source (model (a) in Table 1) improves the fit and the continuum X-ray spectral slope is now Γ = 1.28±0.23 (errors are at 90 per cent for one interesting parameter, or Δχ²=2.71, Avni 1976), attenuated by a column density N_H = 6.14±2.10 × 10²¹ cm⁻², assuming cosmic abundances (Anders & Grevesse 1989) and cross sections derived by Balucinska-Church & McCammon (1992). The best-fitting spectrum and the confidence contours for the absorbed power law model are presented in Fig. 1 and Fig. 2, respectively. The unabsorbed 2–10 keV flux and luminosity are ~ 6.2 × 10⁻¹³ erg cm⁻² s⁻¹ and ~ 1.3 × 10⁴⁴ erg s⁻¹. The 5–10 keV ASCA flux is about 40 per cent lower than in BeppoSAX. X-ray variability and/or cross-calibration uncertainties could provide a likely explanation.

Table 1. ASCA SIS+GIS spectral fits (0.9–10 keV energy range)

| Model | Γ    | N_H (10²¹ cm⁻²) | CvrFract (%) | χ²/dof |
|-------|------|----------------|--------------|--------|
| (a)   | 1.9  | 15.4±2.70      |              | 181/158|
| (b)   | 1.9  | 15.4±2.70      |              | 181/158|
| (c)   | 1.9  | 15.4±2.70      |              | 181/158|
| (d)   | 1.9  | 15.4±2.70      |              | 181/158|

SAXJ 1353.9+1820 does not show any particular feature or any other indication of reprocessed radiation. Neither the iron Kα emission line (the 90 per cent upper limit on the equivalent width being 330 eV) nor the reflection component (which is basically unconstrained by the present data) do improve the fit. The N_H value (which has been fixed at the quasar redshift but which could lie along the line of sight to the QSO) is in agreement with the value found by the hardness ratio analysis of BeppoSAX data.

The best-fitting slope is extremely hard and significantly flatter than the average slope of Seyfert Galaxies and quasars with similar luminosities and redshifts (Nandra & Pounds 1994; Reeves et al. 1997; George et al. 1999). Indeed assuming a ‘canonical’ Γ = 1.9 value we were not able to obtain a good fit as relatively large residuals are present at high energies (model (b)). The underlying continuum spectrum could be either intrinsically flat or flattened by a complex (multicolumn and/or leaky) absorber (Hayashi et al. 1996; Vignali et al. 1998). To test this last hypothesis we have fitted a partial covering model (models (c) and (d) in Table 1), where part of the direct component escapes without being absorbed. While the best-fitting model still requires a flat slope, a steeper continuum partially absorbed by a column density of ~ 3 × 10²² cm⁻² does provide a good fit to
3 OPTICAL AND NIR PHOTOMETRY

SAXJ 1353.9+1820 has been observed at the 3.5-m National Telescope Galileo with the Optical Imager (OIG) during the night of 1999 June 18. We carried out optical broad band imaging in the Johnson–Kron–Cousins U, B, V, R and I filters. The exposure times were respectively 900, 480, 180, 120 and 120 seconds while the seeing ranges from 0.9 arcsec (FWHM) in the reddest band to 1.3 arcsec in the ultraviolet, with a steady increase through the optical bands giving evidence that the blurring is mainly due to atmospheric causes. During the same night we observed the standard fields PG 1323−086, PG 1633+099 and SA 110 in order to obtain accurate photometric calibrations and to determine the colour terms of the relatively new OIG system. All the frames were acquired at airmass \( \leq 1.5 \). The data reduction and analysis has been performed in a standard way using IRAF\footnote{IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Associated Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation} routines. Bias exposures taken at the beginning and at the end of the night were stacked, checked for consistency with the overscan region of the scientific images and subtracted out. The bias-subtracted frames were then flat-fielded using sky flats. The cosmic rays of the CCD region around the target have been interactively identified and removed by fitting of the neighbouring pixels.

The photometry has been performed using \texttt{apphot}, the Aperture Photometry Package available in IRAF. The object is clearly extended, and we used a quite large aperture radius (~ 8 arcsec) for all the bands, corresponding to a projected distance of about 15 \( h_{70}^{-1} \) kpc at the redshift of SAXJ 1353.9+1820. Measurements in the J and K-short bands were also made with the ARNICA instrument at the same telescope within the framework of a wider near-IR follow-up of the HELIAS sources. The data reduction and analysis of the near–IR data will be discussed in detail in Maiolino et al. (in preparation), here we simply report the resulting photometry. The results of the combined aperture photometry are presented in Table 2.

The surface brightness (SB) profiles in the U, B, V, R and I filters have been estimated computing a curve of growth for each passband with increasing circular apertures (Fig. 3). An effective radius of \( \sim 1.5 \) arcsec was independently derived from all but one fits (for the I-band we obtained a slightly more concentrated profile). The dashed line in figure represents the \( r^{1/4} \) law, which fits very well the observed profiles outside of the seeing-dominated region down to the faintest flux levels. The SB profiles are typical for elliptical galaxies suggesting that at optical wavelengths there is no evidence of an unresolved nucleus in SAXJ 1353.9+1820.

4 DISCUSSION AND CONCLUSIONS

The \textit{ASCA} observation confirms the presence of a bright and moderately absorbed (\( N_H \sim 6 \times 10^{21} \text{ cm}^{-2} \)) nucleus with a flat hard X-ray spectrum, in agreement with the BeppoSAX hardness ratio analysis. Assuming for the underlying contin-
uum slope the average value of quasars in the same energy range, the absorption column density could be as high as $N_H \sim 3 \times 10^{22}$ cm$^{-2}$ if some 20 per cent of the nuclear radiation is not absorbed. Even if the X-ray data alone does not allow to distinguish between the two possibilities, we can safely conclude that SAXJ 1353.9+1820 harbours a mildly obscured, luminous ($L_\text{2-10keV} \simeq 1.3 \times 10^{44}$ erg s$^{-1}$) active nucleus.

Not surprisingly high energy observations of quasars characterized by similar dust reddened optical continua do reveal the presence of absorption by cold (IRAS 23060+0505, Brandt et al. 1997a) and/or warm (IRAS 13349+2438, Brandt et al. 1997b) gas.

A basic step forward in understanding the nature of this red quasar and of red quasars as a whole, is provided by optical plus near-IR studies (see Maiolino et al., in preparation, for further details). The surface brightness profiles are consistent with those of an elliptical galaxy, and the optical colours ($U-B=0.43$, $B-V=1.40$, $V-R=0.83$ and $R-I=0.70$) agree with the properties of a early-type galaxy at $z=0.2$ (Fukugita et al. 1995).

In order to obtain a self-consistent description of the optical-IR properties we fitted the photometric points with a two-components model consisting of an old stellar population template ($10^{10}$ yr, Bruzual & Charlot 1993) and a moderately absorbed ($A_V \simeq 2$ mag, corresponding to $N_H \simeq 4 \times 10^{21}$ cm$^{-2}$ for Galactic dust-to-gas ratio, i.e. Bohlin, Savage & Drake 1978) quasar spectrum template (Elvis et al. 1994; Francis et al. 1991). As shown in Fig. 4, the combination of these two spectra provides a good description of the observed data (possibly with the exception of the J photometry, which deviates by 1.4 sigma). The quality of the fit is acceptable ($\chi^2 \simeq 1.3$ when both the uncertainties in the photometric data and in the template spectra are taken into account) indicating that most of the optical and near-IR flux is dominated by star-light.

The present results add further evidence on the hypothesis of substantial dust and gas absorption as an explanation of the observed properties of this red quasar. Even more interesting is that the active nucleus peers only at X-ray energies and possibly at wavelengths longward of 2 $\mu$m (see Fig. 4), while at optical wavelengths SAXJ 1353.9+1820 looks like a normal evolved elliptical galaxy. If this behaviour applies also to other objects it may well be that a significant fraction of obscured AGNs resides in otherwise normal passive galaxies. These nuclei would have been completely missed in optical quasar surveys because of their extended morphology and galaxy-like colours. If the column density is of the order of $10^{22}$ cm$^{-2}$ or higher, their fraction could be underestimated also in soft X-ray surveys. If this is the case, the fraction of red objects among radio quiet quasars ($\sim 3$–20 per cent, Kim & Elvis 1999) should be considered as a lower limit. This may have strong implications for the XRB synthesis models, which in their simplest version (i.e. Madau, Ghisellini & Fabian 1994; Comastri et al. 1995) predict a large number of high-luminosity absorbed quasars (called type 2 QSO). Despite intensive optical searches, these objects appears to be elusive indicating a much lower space density than that of lower luminosity Seyfert 2 galaxies (Halpern, Eracleous & Forster 1998) and calling for a substantial revision of AGN synthesis models for the XRB (Gilli, Risaliti & Salvati 1999).

An alternative possibility (see Comastri 2000) is that X-ray obscured AGN show a large variety of optical properties including those of SAXJ 1353.9+1820. It is worth noticing that column densities as high as $10^{23.5}$ cm$^{-2}$ have been detected in Broad Absorption Line QSO (Gallagher et al. 1999), in some UV bright soft X-ray weak QSO (Brandt et al. 1999), and in a few HELLAS sources optically identified with broad line blue quasars (Fiore et al. 1999). It is thus possible that the sources responsible for a large fraction of the XRB energy density are characterized by a large spread in their optical to X-ray properties. The $\alpha_{ox}$ spectral index, defined as the slope joining the 2500 $\AA$ and the 2 keV flux densities, is usually employed to measure the optical to X-ray ratio. Not surprisingly, absorbed objects are characterized by values of $\alpha_{ox}$ (> 1.8) much steeper than the average value of bright unabsorbed quasars and Seyfert galaxies, $\alpha_{ox} \simeq 1.5$ (Laor et al. 1997; Yuan et al. 1998), while the faint nuclear UV flux density and the relatively bright 2 keV flux of SAXJ 1353.9+1820 correspond to $\alpha_{ox} \simeq 1$, which is quite flat but not unusual for red quasars (Kim & Elvis 1999).

A detailed discussion on the quasars contribution to the XRB is beyond the purposes of this Letter. Here we note that as far as the X-ray spectral properties and the bolometric luminosity of $\sim 10^{45}$ erg s$^{-1}$ (estimated using the average SED of Elvis et al. 1994 with the measured $\alpha_{ox}$) are concerned, SAXJ 1353+1820 can be classified as a high-luminosity absorbed AGN.

Future sensitive X-ray observations with Chandra and XMM coupled with optical spectropolarimetry data would be extremely helpful to better understand the nature of red quasars and to estimate their contribution to the XRB.
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