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RBS 1032: a dwarf-nucleated spheroidal galaxy with an intermediate-mass black hole hosted in a globular cluster

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ABSTRACT

We report here the multiwavelength observations of the bright supersoft X-ray source, RBS 1032. Most likely, its optical counterpart is a non-emission-line dwarf galaxy with a prominent nucleus. Line and band indices of this nucleus, clearly suggest that its optical spectrum is dominated by the nuclear supermassive globular clusters. No radio and infrared (*IRAS*) emissions are detected from this dwarf galaxy. Weak near-infrared (2MASS) emissions have been detected. The optical-to-near-infrared colours are consistent with the globular clusters than those of active galactic nuclei. We have shown here that RBS 1032 is not a foreground object. However, with the available data the possibility of RBS 1032 being a classical nova cannot be completely ruled out. We have demonstrated that RBS 1032 is not a X-ray-bright optically normal galaxy. In contrast, we have illustrated that the super-soft X-ray emissions of RBS 1032 may be from a binary system, consisting of an intermediate-mass ($\sim 5 \times 10^4$ M$_\odot$) black hole with a white dwarf companion. Most likely this system is hosted by one of the nuclear globular clusters of the dwarf galaxy.

Key words: accretion, accretion discs – black hole physics – galaxies: dwarf – X-rays: galaxies – X-rays: individual: RBS 1032.

1 INTRODUCTION

The detection of intermediate-mass black holes (IMBHs) in the 10^2–10^4 M$_\odot$ range is extremely important both from the viewpoint of black hole formation and for our understanding of galaxy evolution. IMBHs could fill in the black hole mass function between stellar mass black holes ($\lesssim 20$ M$_\odot$) and the supermassive (10^6–10^9 M$_\odot$) black holes in active galactic nuclei (AGNs). Similarly, they could also fill the gap in the X-ray luminosities between X-ray binaries ($\lesssim 10^{38}$ erg s^{-1}) and AGNs ($\gtrsim 10^{42}$ erg s^{-1}). Thus, accreting IMBHs are perhaps the most intriguing scenario because they describe a possible link between stellar collapse and the formation of AGNs and galactic bulge formation.

Now the question arises: which are the ideal hosts of IMBHs. It has been suggested that the centres of super-massive star clusters may produce IMBHs (Portegies Zwart & McMillan 2000, 2002; Miller & Hamilton 2002; Gurkan, Freitage & Rasio 2004). Observationally, the presence of IMBHs in some star clusters has been suggested (Gebhardt et al. 2000; Gebhardt, Rich & Ho 2002; Gerssen et al. 2002; Gebhardt, Rich & Ho 2005). Supermassive star clusters are dominantly present in the nuclear region of dwarf galaxies. In general, there are three types of dwarf galaxies: spheroidals, ellipticals and irregulars and of these dwarf ellipticals form the most common type of galaxies in the local Universe (Ferguson & Binggeli 1994; Kormendy & Bender 1994). In this paper, following the nomenclature of Kormendy & Bender (1994), we will call the dwarf ellipsoidal galaxies as spheroidals. Most bright spheroidals display a clear enhancement of the surface brightness in the nuclear region. These nuclei are not resolvable beyond the distance of the Local Group. However, the resolved nuclei of local spheroidals (say NGC 205 or M 33) clearly demonstrate that they are dynamically separate supermassive star clusters (Monaco et al. 2004, and references therein). Thus, spheroidals with bright ultrasoft X-rays from their nuclei are the potential hosts of IMBHs.

RBS 1032 is a bright ($\sim 0.41 \pm 0.04$ count s^{-1}) ultrasoft X-ray source (1RXS J114727.1+494302), which was detected in the *ROSAT* All Sky Survey (RASS, Fischer et al. 1998; Schwope et al. 2000). The optical counterpart of this X-ray source was originally suggested to be a star (RA 11$^{\rm h}$47$^{\rm m}$27.1$^{\rm s}$, Dec. +49$^{\rm d}$43$^{\rm m}$02$^{\rm s}$; Zickgraf et al. 2003). Here, we present multiwavelength observations to determine the nature of the optical counterpart and the origin

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Table 1. *ROSAT* spectral parameters of RBS 1032.

Spectrum	Count rate (cts s^{-1})	Power-law model $N_H{}^a$	Γ	χ^2/dof	Diskbb model $N_H{}^a$	kT_{in}(eV)	χ^2/dof	$L_X{}^b$
1992 December	0.151 ± 0.008	$2.6^{+1.9}_{-0.9}$	$4.39^{+2.7}_{-0.9}$	20.4/14	$2.2^{+0.9}_{-1.2}$	$72.5^{+30.4}_{-18.1}$	21.2/14	3.3 ± 1.9
1994 June	0.077 ± 0.005	$4.4^{+5.2}_{-3.2}$	$5.1^{+4.9}_{-0.5}$	7.6/6	$3.8^{+1.2}_{-1.1}$	$64.9^{+12.2}_{-11.2}$	7.0/6	1.6 ± 0.9

^{a}In units of 10^{20} cm^{-2}; ^{b}in units of 10^{42} erg s^{-1}, PIMMS computed with 55-eV blackbody temperature and Galactic N_H.

of X-ray emission from RBS 1032. Observations, data analysis and the results are presented in Section 2. Discussion and conclusions are given in Sections 3 and 4, respectively.

2 OBSERVATIONS, DATA ANALYSIS AND RESULTS

2.1 X-ray observations

RBS 1032 was originally detected in the RASS at a count rate of 0.41 ± 0.04 (Fischer et al. 1998; Schwope et al. 2000) and subsequently, two *ROSAT*/PSPCB pointed observations of this source were carried out on 1992 December 7 and 1994 June 05. The LEXTRCT software package was used to analyse these observations (Tennant 2006). The source flux was found to be roughly constant within observations, but to vary by a factor of two between two observations (see Table 1) and a factor of 5.5 between November 05, 1990 (RASS) and June 05, 1994. For analysis, the PSPCB spectra of RBS 1032 were binned to give at least 20 counts per bin. The XSPEC absorption-corrected (zphabs), zpowerlw, zbbody, mekal and diskbb models were used to fit these two spectra. Fit statistics are almost similar for all the models. In Table 1, we list the spectral parameters of the zpowerlw and the diskbb models. The normalization parameters of these models are not tightly constrained, so we have used the PIMMS with a blackbody model of temperature 55 eV and the Galactic hydrogen column density ($N_H \sim 1.98 \times 10^{20}$ cm^{-2}), to compute the conservative unabsorbed luminosities of RBS 1032. These are listed in Table 1. The X-ray spectrum, disc blackbody model and residuals are shown in Fig. 1. The 1–2.4 keV unabsorbed flux varied between 1.1×10^{-12} and 6.0×10^{-12} erg cm^{-2} s^{-1} giving a peak luminosity of $\sim 10^{43}$ erg s^{-1} during the RASS observation.

The inferred mass of the accretor, derived from the disc blackbody model, is around 5×10^4 M$_\odot$. Its extremely soft disc blackbody temperature also suggests that the observed X-rays are from an IMBH system. From the present data, we are unable to distinguish between the 'extremely steep power law' (very high state) and 'pure thermal' (high/soft state) models (McClintock & Remillard 2006). However, it may be suggested that the X-ray emitting source in RBS 1032 was in the soft thermal-dominant state during the *ROSAT* observations, which indicates that the accreting system of RBS 1032 was in a radiatively efficient accretion state (Jester 2005). During this state the radio emission will be quenched, which is analogous to the jetless black hole X-ray binaries in the thermal-dominant state (Gallo, Fender & Pooley 2003). Non-detection of radio emissions from RBS 1032 and its observed X-ray properties also support this scenario.

2.2 Optical Observations

V-band photometry of an 8×8 arcmin^2 field centred on RBS 1032 was carried out with the Russian–Turkish 1.5-m optical telescope (Antalya, Turkey) on 2004 April 16. A thermo-electrically

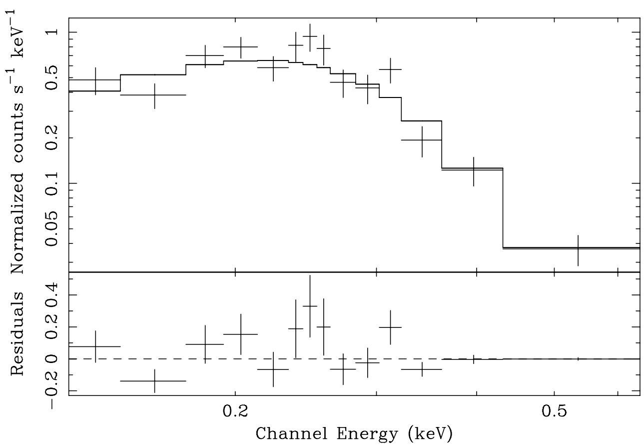

Figure 1. The *ROSAT*/PSPC spectrum of RBS 1032 together with the disc blackbody model (solid line). The lower panel shows the residuals between the data and the model.

cooled (−60°C) ANDOR CCD (~0.48 arcsec per binned pixel) was used as the detector. In total five exposures, 300 s each, were obtained between 22:15 and 22:43 UT (seeing ~1.8 arcsec). Standard CCD photometric reduction procedures were carried out using the PC-based MAXIM software. The median average of five exposures and two nearby USNO stars were used for photometry. Positionally, RBS 1032 coincides with a dwarf galaxy of 17.06 ± 0.1 mag in the *V* band. A radial profile of this dwarf galaxy is compared with that of two nearby USNO stars and is shown in Fig. 2. It is evident from this figure that this galaxy is an extended object. In addition, the excess nuclear emission of this dwarf galaxy, compared to the stellar radial profiles, suggests the presence of a bright nucleus.

Spectroscopic observations of this dwarf galaxy were carried out on 2004 April 26, at the prime focus of the 6-m telescope of the

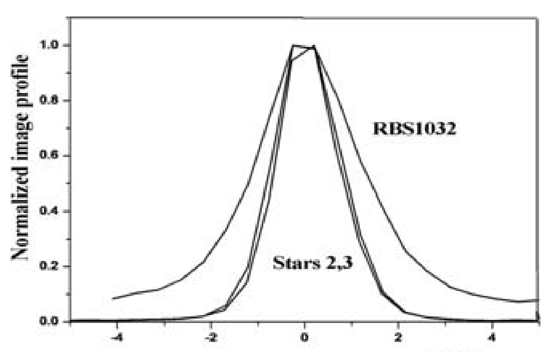

Figure 2. Radial profiles of the dwarf galaxy and two USNO stars in its field. The profiles have been normalized to unity, for comparison. Excess emissions, right from the centre to the outer part of the dwarf galaxy are evident when compared with the stellar radial profiles. This indicates that it has a bright nucleus and it is extended.

Figure 3. SDSS composite image (12 × 12 arcsec^2) of a dwarf galaxy, which is the optical counterpart of RBS 1032. The bright nucleus of this galaxy can be clearly seen.

Special Astrophysical Observatory with a long-slit spectrograph (Afanas'ev et al. 1995) and a liquid-nitrogen-cooled CCD system. We used a 1302 lines mm^{-1} grating which gives a $\Delta\lambda = 2.6$ Å resolution in the 3860–5100 Å region. Two spectra with 600 and 1200 s exposures were obtained with a signal-to-noise ratio of 10–11. Ar–Ne–He lamp spectra were used for the wavelength calibration and the spectrum of the spectrophotometric standard star, BD+28 2106 (Bohlin 1996), was used for flux calibration. The MIDAS software package was used for the data reductions (Ballester 1992). The Balmer, He I and Ca II lines were used to determine the redshift of this dwarf galaxy, which was measured to be 0.0260 ± 0.0001.

The Sloan Digital Sky Survey (SDSS) is an excellent tool for spectroscopic studies of objects brighter than 17.8 mag with a spectral resolution, $\lambda/\Delta\lambda = 1800$, using a pair of spectrographs fed by a total of 640 fibres (Lupton, Gunn & Szalay 1999; Smith et al. 2002; Stoughton et al. 2002; Abazajian et al. 2003; Pier et al. 2003). Both the photometric (SDSS J114726.69+494257.8) and spectroscopic (SpecObjId=272412374814687232) observations of RBS 1032 were carried out by the SDSS on 2002 December 28. The SDSS composite image and the nuclear spectrum of the dwarf galaxy are shown in Figs 3 and 4, respectively. The photometric magnitudes of this object and its neighbours (within 30 arcsec) in u, g, r, i and z bands are presented in Table 2. Standard U, B, V, R and I magnitudes of the dwarf galaxy are 18.19, 17.86, 17.09, 16.52 and 15.98 mag, respectively. The measured B-band absolute magnitude of the dwarf galaxy is $M_B = -17.39$ mag, which is consistent with those of bright spheroidal galaxies detected in Virgo cluster (Gorgas et al. 1997). Most bright spheroidals ($M_B < -16$) clearly show the presence of enhanced central nuclei, which are due to the presence of supermassive star clusters (Sandage, Binggeli & Tammann 1985; van den Bergh 2000). Such a bright nucleus is also present in this dwarf galaxy as is evident from Figs 2 to 4. Its surface brightness profile of the SDSS/r-band image, was fitted with a King model plus a constant representing the background. This model fits better than the exponential model [$\chi^2 \sim 547$ for 49 degrees of freedom (d.o.f.)], but still not acceptable ($\chi^2 = 147$ for 49 d.o.f.) due to the

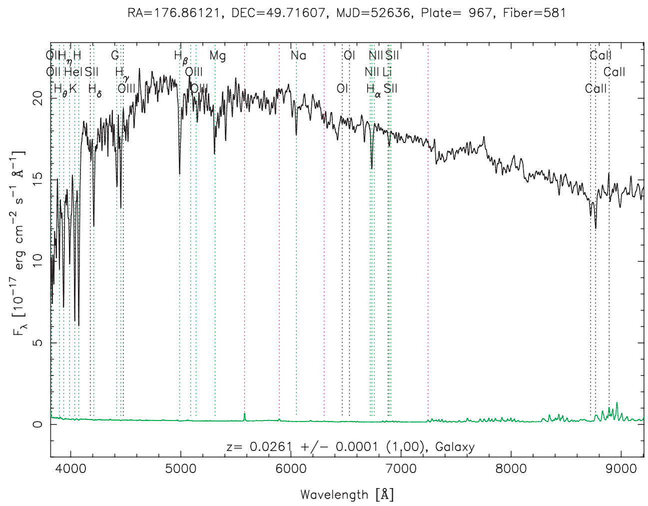

Figure 4. The nuclear spectrum of a dwarf spheroidal galaxy at a redshift of 0.0261 ± 0.0001 observed with the SDSS.

Table 2. Photometric magnitudes^a of RBS 1032 and its neighbours within a circle of 30.0 arcsec radius.

Source name (SDSS J)	SDSS colours (mag) u	g	r	i	z	Remarks
114726.69+494257.8	18.86	17.40	16.82	16.52	16.33	Dwarf galaxy
114724.97+494308.1	24.98	24.51	23.01	21.55	21.64	Galaxy
114726.88+494250.5	22.95	22.79	21.93	21.92	20.53	Galaxy
114726.91+494324.7	22.64	21.06	20.32	19.99	19.86	Galaxy
114727.76+494247.7	21.21	21.42	21.38	21.72	22.27	Galaxy
114727.94+494303.2	24.52	24.47	23.58	23.13	20.93	Stellar-like
114728.62+494315.7	21.42	20.47	19.72	19.19	19.18	Galaxy
114729.06+494248.9	22.83	23.19	23.53	22.94	22.41	Galaxy

^{a}SDSS photometry is accurate to 0.03 mag. (Smith et al. 2002; Ivezic 2004).

presence of excess emission below 1 arcsec. This model is equivalent to a standard beta model, $\propto [1 + (r/r_c)^2]^{-3\beta+1/2}$. From the fit parameters, the derived values of the core radius and β are 2.7 kpc and 0.87, respectively. These results, also suggest the presence of a cusp at the centre of the dwarf galaxy.

We determined the line parameters of different absorption features present in the nuclear spectrum of RBS 1032, using the IRAF software package. Our measured values are similar to those listed in the SDSS DR4 data release (http://cas.sdss.org/dr4/en/tools/explore/obj.asp?id=588295841785446534). We adopted the equivalent widths and the Lick system line and band indices from the SDSS DR4 (SpecLineIndex) and these are listed in Table 3. These line (Fe, Mg$_1$, Mg$_2$ and Mg b) and band (CN, G4300 and TiO) indices of the dwarf galaxy are consistent with those of the globular clusters of our Galaxy and M 31 (Burstein et al. 1984), see Fig. 5. These globular clusters dominantly contribute to the nuclear spectrum of the dwarf galaxy and their presence makes its nucleus bright; this will be discussed in more detail in Section 3.3.

2.3 Infrared and radio observations

An infrared counterpart of the dwarf galaxy was not present in the searched *IRAS* images. However, weak counterparts were detected

Table 3. Equivalent widths and Lick system line and band indices of RBS 1032.

Line/ band	Equivalent width (Å)	Line index (mag)	λ_{min} (Å)	λ_{max} (Å)
CN1	−2.43 ± 0.33	−0.073 ± 0.009	4143.3	4178.3
CN2	−0.73 ± 0.32	−0.022 ± 0.009	4143.3	4178.3
Ca4227Å	1.01 ± 0.17	0.092 ± 0.016	4223.4	4235.9
G4300Å	2.95 ± 0.29	0.096 ± 0.009	4282.6	4317.6
Fe4383Å	2.77 ± 0.33	0.060 ± 0.007	4370.3	4421.6
Ca4455Å	1.00 ± 0.20	0.049 ± 0.010	4453.4	4475.9
Fe4531Å	3.20 ± 0.27	0.080 ± 0.007	4515.5	4560.5
C4668Å	2.18 ± 0.38	0.028 ± 0.005	4635.3	4721.6
H_β	3.79 ± 0.21	0.153 ± 0.009	4849.2	4878.0
Fe5015Å	4.03 ± 0.34	0.059 ± 0.005	4979.1	5055.4
Mg1	1.50 ± 0.31	0.025 ± 0.005	5070.5	5135.6
Mg2	4.21 ± 0.24	0.113 ± 0.007	5155.6	5198.1
Mgb	2.04 ± 0.23	0.070 ± 0.008	5161.6	5194.1
Fe5270Å	2.54 ± 0.24	0.071 ± 0.007	5247.1	5287.1
Fe5335Å	2.25 ± 0.26	0.063 ± 0.007	5313.6	5353.6
Fe5406Å	1.52 ± 0.21	0.062 ± 0.008	5389.0	5416.5
Fe5709Å	0.29 ± 0.22	0.013 ± 0.010	5698.2	5722.0
Fe5782Å	0.49 ± 0.18	0.027 ± 0.010	5778.2	5798.2
NaD	1.45 ± 0.20	0.049 ± 0.007	5878.5	5911.0
TiO	10.95 ± 0.27	0.018 ± 0.005	5938.3	5995.9
TiO	22.78 ± 0.32	0.037 ± 0.004	6191.3	6273.9

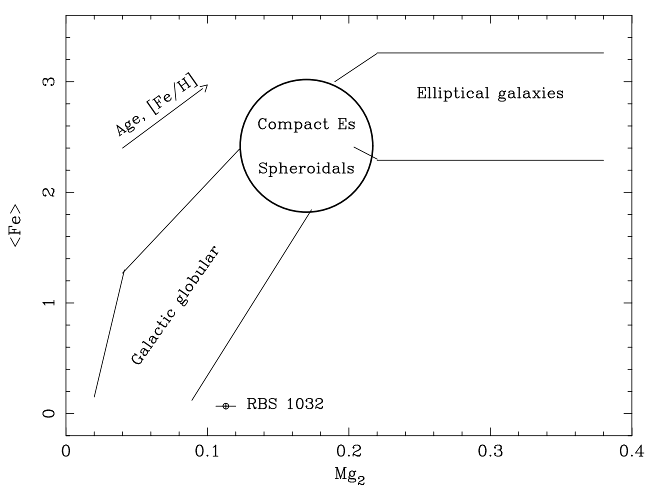

Figure 5. Line strength diagram of a dwarf spheroidal galaxy. Also, shown are the positions for globular clusters, compact elliptical galaxies, spheroidal galaxies and elliptical galaxies, taken from Gorgas et al. (1997). The arrow shows the direction for the old populations and the high-metalicity objects.

in 2MASS data (J, H and K_s bands). Photometry of these images was performed using the LEXTRCT software package (Tennant 2006). Derived J-, H- and K_s-band magnitudes of the counterpart are (15.2 ± 0.5), (14.8 ± 1.0) and (14.8 ± 1.0) mag, respectively. These results suggest that this dwarf galaxy is a weak infrared emitter ($V - K \sim 2.0 \pm 1.0$) compared to AGNs (Cutri et al. 2002). However, the optical and infrared colours of the dwarf galaxy are consistent with those of nuclear globular cluster systems of spheroidal galaxies (Mobasher & Trentham 1998; Lotz, Miller & Ferguson 2004). NRAO/VLA FIRST and NRAO/VLA Sky Survey data archives were searched, but we did not find any radio source within a circle of 30 arcsec radius, centred on RBS 1032.

3 DISCUSSION

The optical counterpart of RBS 1032 (1WGA J1147.4+4942, RA: $11^h47^m26.7^s$ and Dec: $+49^d42^m$ 58^s) was originally identified as a star of 17.2 mag (Zickgraf et al. 2003). From our observations (see Section 2.1), we have identified the probable counterpart as a 17.1 ± 0.1 mag dwarf galaxy at $11^h47^m26.8^s$ $+49^d42^m59^s$ and a redshift of 0.0260 ± 0.0001, which has been confirmed with the SDSS results presented in Section 2.1. We have also found that there is no object brighter than 17.1 mag, within a circle of 2.6 arcmin radius at the position of RBS 1032.

3.1 Possible optical counterparts of RBS 1032

The on-axis angular resolution of the *ROSAT*/PSPC is ∼30.0 arcsec. In Table 2, we list all the SDSS-detected objects within a circle of 30.0 arcsec radius at the position of RBS 1032. It can be seen from this table that this circle contains six galaxies, one stellar-like object and the bright dwarf galaxy. The X-ray-to-optical flux ratios (F_X/F_O) of these six galaxies are in the range of 80–3000. This result suggests that these six galaxies cannot be the optical counterpart of RBS 1032 (Maccacaro et al. 1988). Only, if the brightest of these six galaxies hosts a BL Lac object, then that could be the possible counterpart of RBS 1032. However, the BL Lac objects are almost always unresolved. In addition, the absence of radio emission from RBS 1032 with its extremely soft thermal X-ray spectra, does not support the BL Lac hypothesis. It may be possible that the stellar-like object may be the foreground optical counterpart of RBS 1032. We analysed the five-band *SDSS*-images of this object. It was detected only in the z-band with 20.98 ± 0.15 mag. This value is consistent with the SDSS measurement (Table 3). Non-detection in other bands indicates that it is a red object and could be a late-type star. However, its F_X/F_O value is >3000, which suggests that it is neither a X-ray emitting star (Maccacaro et al. 1988), nor a cataclysmic variable (Bradt & McClintock 1983; Ritter & Kolb 1998), nor a supersoft source (Kahabka & van den Heuvel 1997; Ritter & Kolb 1998). Similarly, the colour index between the X-ray and the optical fluxes of RBS 1032 and this stellar-like object (B fainter than 25.06 mag), respectively, is at least 25.3, which is beyond the range for X-ray binaries (van Paradijs & McClintock 1995). The observed strong variability of RBS 1032 suggests that it cannot be an isolated neutron star, also.

It is important to mention here that the optical observation (SDSS) was carried out on 2002 December and the last *ROSAT* observation was obtained on 1994 June. Thus, it may be possible that RBS 1032 was a classical nova, which would have been optically much fainter during the SDSS observations. We have searched all known optical data bases and also enquired to many astronomers and amateur astronomer's organizations, regarding the availability of optical data on RBS 1032, observed between 1990 and 1994. Unfortunately, the only additional data that we have found were taken with the former Hamburg Schmidt Telescope between 1980 and 1984. Thus, presently, we are unable to confirm or reject the classical nova origin of RBS 1032. However, it may be mentioned that the supersoft phase of classical novae may last, at the most, for two and a half years (Orio 2004, and references therein). RBS 1032 was detected as an ultrasoft X-ray source during the RASS observations in 1992 December 7 (Fischer et al. 1998; Schwope et al. 2000) and it remained as an ultrasoft X-ray source at least until 1994 June 5 (Table 1). This duration is longer than the longest supersoft phase of classical novae (Orio 2004, and references therein).

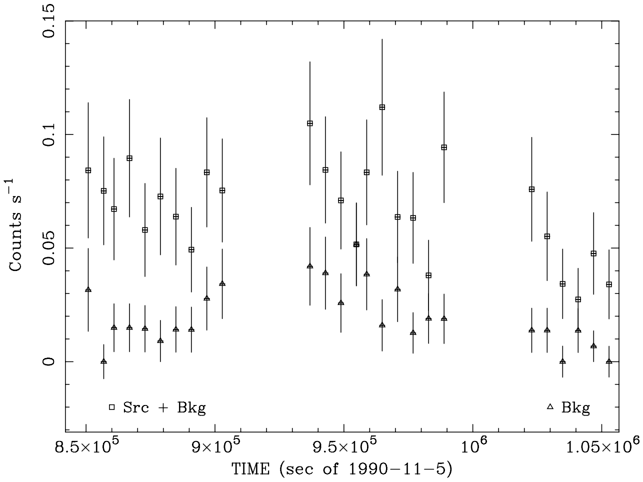

Figure 6. *ROSAT* light curve of RBS 1032 observed during the RASS observations. Source plus background and background count rates are shown with square and triangle symbols. Background-subtracted light curve was fitted with a constant flux model and shows no variability ($\chi^2 = 22.1$ for 25 d.o.f.).

In addition, classical novae have displayed intense variability on short time-scales (Orio et al. 2002; Krautter et al. 2004). Fig. 6 displays the *ROSAT* light curve of RBS 1032. We performed a χ^2 test against a constant flux hypothesis of this light curve and the results show that the light curve did not vary during the interval of RASS observations. Similarly, the *ROSAT* light curves of two pointed observations (see Table 1) did not vary on the time-scales of hours to days. Thus, most likely, RBS 1032 may not be a classical nova. This can be confirmed from future simultaneous optical and X-ray observations of RBS 1032.

3.2 Is RBS 1032 an X-ray bright optically normal dwarf galaxy?

RBS 1032 coincides spatially with a dwarf galaxy, which has a bright nucleus. However, the absence of emission lines in the optical spectrum of this nucleus suggests that it is not an active nucleus. Recently, a few X-ray bright but optically normal galaxies have been discovered (XBONGs, Elvis et al. 1981; Griffiths et al. 1995; Comastri et al. 2002; Maiolino et al. 2003; Page et al. 2003; Severgnini et al. 2003). Thus, RBS 1032 being an X-ray bright normal dwarf galaxy could be similar to the XBONGs. It has been suggested that XBONGs are either (1) heavily obscured luminous AGNs (Marconi et al. 2000) or (2) BL Lac–like objects (Comastri et al. 2002) or (3) starlight-dominated galaxies (Moran, Filippenko & Chormock 2002) or (4) AGNs with radiatively inefficient accretion discs (Yuan & Narayan 2005). In contrast to these suggestions, we find from the multiwavelength results of RBS 1032 that (1) $N_{\rm H}$ is almost consistent with the Galactic value, (2) there is a lack of detectable radio and infrared (*IRAS*) emissions, (3) the optical continuum emission of RBS 1032 is weaker than those in the luminous AGNs at similar redshifts and (4) the X-ray power-law index is extremely steep. All these results argue that RBS 1032 is not an XBONG.

Finally, we conclude that the optical counterpart of RBS 1032 is a dwarf galaxy at a redshift of 0.0261 ± 0.0001, whose X-ray emissions are not due to the nuclear activity of this dwarf galaxy.

3.3 Optical counterpart of the IMBH system of RBS 1032

In Section 2.1, we have shown that the bright nucleus of this nucleated dwarf spheroidal galaxy is due to the presence of globular clusters in its central region. From our visual inspection, we find that the size of this bright nucleus will be around 1.5 arcsec (700–800 pc). From 1.5-arcsec aperture photometry, we estimate that the apparent and absolute magnitudes in the V band of the unresolved nucleus are 19.03 and -16.27 mag, respectively. The maximum number of globular clusters detected in the nuclear region of nucleated spheroidal galaxies is around 50 (Lotz et al. 2004). Thus, assuming that there are 50 globular clusters in the nuclear region of RBS 1032, we could determine the lower limit of cluster brightness, which will be $\sim M_V = -12.02 \pm 0.1$ mag ($m_V = 23.2$ mag). Similarly, by assuming that there may be only a few clusters (Lotz et al. 2004), then the brightest clusters in the nuclear region will have $\sim M_V = -14.5 \pm 0.2$ mag ($m_V = 20.8$ mag). Thus, we expect a distribution of star clusters with the values of M_V between -12.02 ± 0.1 and -14.5 ± 0.2 mag or the values of M_V will be between 23.2 and 20.8 mag.

Our measured $(V - I)$ colour for RBS 1032 is 1.11, but if we use equation (2) of Lotz et al. (2004), then this colour for the globular clusters in RBS 1032 will be, $\langle V - I\rangle_{\rm GC} = 0.92$ and their average metalicity [Fe/H] ~ -1.49, using equation (3) of Lotz et al. (2004) is similar to the measured metalicity range for the globular clusters in Local Group spheroidals ($-2.5 <$ [Fe/H] < -1.0; Lotz et al. 2004, and references therein). When these results are compared, we also find that the globular clusters in RBS 1032 are as metal-poor as the globular clusters in the Milky Way ([Fe/H] < -1.0, Burstein et al. 1984). In fact, the line and band indices of RBS 1032 (Fig. 5) clearly suggest that its nuclear globular clusters are different in age and metalicity compared to those of the spheroidals and elliptical galaxies (Gorgas et al. 1997). Thus, the bright nucleus of RBS 1032 is a collection of bright young, metal-poor and massive globular clusters, which have also been detected in other bright spheroidals (Sandage et al. 1985; van den Bergh 2000). These supermassive clusters are the potential objects to host IMBH systems (Portegies Zwart & McMillan 2000, 2002; Miller & Hamilton 2002; Gurkan, Freitage & Rasio 2004; Maccarone 2004; Maccarone, Fender & Tzioumis 2005).

We used equation (3) of Maccarone (2004), to compute the brightness of the optical counterpart of the IMBH system of RBS 1032. Values of $L_{\rm X}$, $M_{\rm BH}$ and d (distance of RBS 1032) were assumed to be 3×10^{42} erg s^{-1} (Table 1), 10^4 M$_\odot$ ($M_{\rm BH}$ could be between a few hundreds to a few thousands solar mass) and 114 Mpc, respectively. The computed value of the V-band brightness of the optical counterpart of the IMBH system of RBS 1032 is 22.9 mag. Thus, one of the bright nuclear star clusters ($m_V \sim 20.8$ mag) of the dwarf galaxy, will easily host the IMBH system. In addition, our measured values of the optical colours of the nucleus ($V - K = 2.0 \pm 1.0$) are consistent with the suggested optical colours of the IMBH system ($V - K = 1.2$; Maccarone 2004).

3.4 Origin of X-ray emissions

Both thermal and non-thermal models can describe the *ROSAT*/PSPCB spectra of RBS 1032. The power-law model shows very steep photon indices ($\Gamma > 5$). The normalization of the disc blackbody model, which is not tightly constrained, indicates that the mass of the accretor can be in the range of a few hundreds to several tens of thousands of solar mass. It has been suggested that Population III stars could lead to the formation of IMBHs (mass

$\sim$50–300 $M_{\odot}$) and they will be present at the nuclear region of a galaxy (Madau & Rees 2001). If such a single IMBH accreted from the surrounding interstellar medium at the Bondi rate, then it will display extremely flat power law with a steady luminosity of the order of 10^{31}–10^{33} erg s^{-1}. On the other hand, if such an IMBH forms a low-mass binary system, then its maximum peak X-ray luminosity could reach up to $\sim 2 \times 10^{41}$ erg s^{-1}, which will be at least a factor of 50 fainter than the observed peak luminosity of RBS 1032.

An IMBH ($\sim 5 \times 10^4\ M_{\odot}$) formed in a star cluster will most likely encounter a white dwarf of the same cluster and can form a binary through gravitational bremsstrahlung or tidal capture (Colpi et al. 2005; Mapelli et al. 2005). Such a system through Roche lobe overflow will produce a thermal-dominant soft X-ray spectrum, similar to the observed spectra of RBS 1032, which was in very-high or high state (Miller, Fabian & Miller 2004). Temperature of the accretion disc of this IMBH-binary system will be low. This is due to the fact that the temperature of the inner edge of the disc scales with the mass of the accretor. Thus, low-temperature disc with high X-ray luminosity means that its optical-to-X-ray flux ratio will be low (see fig. 5 of Winter, Mushotzky & Reynolds 2005). This explains the bright X-ray luminosity and very weak optical emission seen from RBS 1032, which has been discussed in the previous section. At the low-mass transfer rate, the IMBH system will be in low/hard (flat power law) state or it may display transient character (Miller et al. 2004). During the low/hard state of RBS 1032, weak radio emission ($\sim$70 μJy) could be detected (Merloni, Heinz & di Matteo 2003; Maccarone 2004; Maccarone, Fender & Tzioumis 2005). Future radio and X-ray observations of RBS 1032 will be useful to determine the nature of this IMBH system.

4 CONCLUSIONS

In summary, RBS 1032 is an ultrasoft X-ray source that varied by a factor of 6 between the two *ROSAT* observations. Its X-ray spectrum is dominated by a thermal component or a very steep power law. The temperature and the normalization parameter of the disc blackbody model, suggest that the X-rays are emitted from an IMBH system of mass $\sim 5 \times 10^4\ M_{\odot}$. Multiwavelength results suggest that the optical counterpart of RBS 1032 is a nucleated, non-emission line, dwarf spheroidal galaxy. The bright nucleus of this dwarf galaxy is not due to its nuclear activity, but due to the presence of supermassive globular clusters at its nucleus. Most likely, one of these star clusters hosts the IMBH system, which emits bright ultrasoft X-rays and weak optical emission with no detectable radio and infrared emissions. This could be tested using simultaneous *Chandra* and *HST* observation of RBS 1032 to determine the offset between the optical centre and the X-ray source position. In addition, we expect to detect radio emission ($\sim$70 μJy) during its low/hard state with correlated variability between the X-ray spectral and temporal parameters.

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REFERENCES

Abazajian K. et al., 2003, AJ, 126, 2081
Afanas'ev V. L., Courtes G., Dodonov S. N., Plana H., 1995, in Comte G., Marcelin M., eds, ASP Conf. Ser. Vol. 71, Tridimensional Optical Spectroscopic Methods in Astrophysics. Astron. Soc. Pac., San Francisco, p. 278
Ballester P., 1992, ESO Conf. &Workshop Proc., 41, 177
Baumgardt H. P., Hut P., Makino J., McMillan S., Portegies Zwart S., 2003, ApJ, 582, L21
Bohlin R. C., 1996, AJ, 111, 1743
Bradt H. V. D., McClintock J. E., 1983, ARA&A, 21, 13
Burstein D., Faber S. M., Gaskell C. M., Krumm N., 1984, ApJ, 287, 586
Colpi M., Devecchi B., Mapelli M., Patruno A., Possenti A., 2005, in Burderi A. L., Antonelli L. A., D'Antona F., Di Salvo T., Israel G. L., Piersanti L., Tornambè A., Straniera O., eds, AIP Conf. Proc. Vol. 727, Interacting Binaries: Accretion, Evolution, and Outcomes. Am. Inst. Phys., New York, p. 205
Comastri A. et al., 2002, ApJ, 571, 771
Cutri R. M., Nelson B. O., Francis P. J., Smith P. S., 2002, in Green R. F., Khachikian E. Y., Sanders D. B., eds, ASP Conf. Ser. Vol. 284, AGN Surveys. Astron. Soc. Pac., San Francisco, p. 127
Elvis M., Schreier E. J., Tonry J., Davis M., Huchra J. P., 1981, ApJ, 246, 20
Ferguson H. C., Binggeli B., 1994, A&AR, 6, 67
Fischer J.-U., Hasinger G., Schwope A. D., Brunner H., Boller T., Trumper J., Voges W., Neizvestny S., 1998, Astron. Nachr., 319, 347
Gallo E., Fender R. P., Pooley G. G., 2003, MNRAS, 344, 60
Gebhardt K. et al., 2000, AJ, 119, 1268
Gebhardt K., Rich R. M., Ho L. C., 2002, ApJ, 578, L41
Gebhardt K., Rich R. M., Ho L. C., 2005, ApJ, 634, 1093
Gerssen J., van der Marel R. P., Gebhardt K., Guhathakurta P., Peterson R. C., Pryor C., 2002, AJ, 124, 3270
Gorgas J., Pedraz S., Guzman R., Cardiel N., Gonzalez J. J., 1997, ApJ, 481, L19
Griffiths R. E., Georgantopoulos I., Boyle B. J., Stewart G. C., Shanks T., della Ceca R., 1995, MNRAS, 275, 77
Gurkan M. A., Freitage M., Rasio F. A., 2004, ApJ, 604, 632
Ivezic Z., 2004, Astron. Nachr., 325, 583
Jester S., 2005, ApJ, 625, 667
Kahabka P., van den Heuvel E. P. J., 1997, ARA&A, 35, 69
Kormendy J., Bender R., 1994, ESO Conf., Workshop Proc., 49, 161
Krautter J., Ness J.-U., Starrfield S., Burwitz V., Drake J. J., Orio M., 2004, Rev. Mex. Astron. Astrofís., 20, 275
Lotz J. M., Miller B. W., Ferguson H. C., 2004, ApJ, 613, 262
Lupton R. H., Gunn J. E., Szalay A. S., 1999, AJ, 118, 1406
Maccarone T. J., 2004, MNRAS, 351, 1049
Maccacaro T., Gioia I. M., Wolter A., Zamorani G., Stocke J. T., 1988, ApJ, 326, 680

Maccarone T. J., Fender R. P., Tzioumis A. K., 2005, Ap&SS, 300, 239
Madau P., Rees M. J., 2001, ApJ, 551, L27
Maiolino R. et al., 2003, MNRAS, 344, L59
Mapelli M., Colpi M., Possenti A., Sigurdsson S., 2005, MNRAS, 364, 1315
Marconi A., Oliva E., van der Werf P. P., Maiolino R., Schreier E. J., Macchetto F., Moorwood A. F. M., 2000, A&A, 357, 24
McClintock J. E., Remillard R. A., 2006, in Lewin W. H. G., van der Klis M., eds, Compact Stellar X-ray Sources. Cambridge Univ. Press, Cambridge, p. 157
Merloni A., Heinz S., di Matteo T., 2003, MNRAS, 345, 1057
Miller M. C., Hamilton D. P., 2002, MNRAS, 330, 232
Miller J. M., Fabian A. C., Miller M. C., 2004, ApJ, 607, 931
Mobasher B., Trentham N., 1998, MNRAS, 293, 315
Monaco L., Bellazzini M., Ferraro F. R., Pancino E., 2005, MNRAS, 356, 1396
Moran E. C., Filippenko A. V., Chormock R., 2002, ApJ, 579, L71
Orio M., Parmar A. N., Greiner J., Ögelman H., Starrfield S., Trussoni E., 2002, MNRAS, 333, L11
Orio M., 2004, Rev. Mex. Astron. Astrofís., 20, 182
Page M. J. et al., 2003, Astron. Nachr., 324, 101
Pier J. R., Munn J. A., Hindsley R. B., Hennessy G. S., Kent S. M., Lupton R. H., Ivezić Ž., 2003, AJ, 125, 1559
Portegies Zwart S. F., McMillan S. L. W., 2000, ApJ, 528, L17
Portegies Zwart S. F., McMillan S. L. W., 2002, ApJ, 576, 899
Ritter H., Kolb U., 1998, A&AS, 129, 83
Sandage A., Binggeli B., Tammann G. A., 1985, AJ, 90, 1681
Schwope A. D. et al., 2000, Astron. Nachr., 321, 1
Severgnini P. et al., 2003, A&A, 406, 483
Smith J. A. et al., 2002, AJ, 123, 2121
Stoughton C. et al., 2002, AJ, 123, 485
Tennant A. F., 2006, AJ, 132, 1372
van den Bergh S., 2000, PASP, 112, 932
van Paradijs J., McClintock J. E., 1995, in Lewin W. H. G., van Paradijs J., van den Heuvel E. P. J., eds, X-ray Binaries. Cambridge Univ. Press, Cambridge, p. 58
Yuan F., Narayan R., 2005, ApJ, 612, 724
Winter L. M., Mushotzky R. F., Reynolds C. S., 2005, ApJ, in press (astro-ph/0512480)
Zickgraf F.-J., Engels D., Hagen H.-J., Reimers D., Voges W., 2003, A&A, 406, 535

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