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Journal Item

A&A 371, 1018–1023 (2001)
DOI: 10.1051/0004-6361:20010417

Astronomy & Astrophysics

The identification of the optical/IR counterpart of the 29.5-s transient X–ray pulsar GS 1843+009*

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Received 21 December 2000 / Accepted 19 March 2001

Abstract. We report on the identification of the optical/IR counterpart of the 29.5-s transient X–ray pulsar GS 1843+009. We re–analysed an archival *ROSAT* HRI observation of GS 1843+009 obtaining a new refined position. The optical and IR follow–up observations carried out for the new error circle allowed us to find a relatively faint ($V = 20.9$) and variable early type reddened star ($V - R = 2.1$). The optical spectra show the Balmer and Paschen series in emission, while the IR observations confirm the presence of a flux excess ($H = 13.2$, $J - H = 0.54$), suggesting that the star is surrounded by a circumstellar envelope. Spectroscopic and photometric data together indicate a B0–B2 IV–Ve spectral–type star located at a distance of ≥ 10 kpc confirming the Be–star/X–ray binary nature of GS 1843+009.

Key words. stars: individual: – GS 1843+009; 1BMW J184536.8+005148 – binaries: general – stars: pulsars: general – stars: emission-line, Be – X-rays: stars

1. Introduction

Be/X–ray binary systems (BeXBs) represent the majority of the known High Mass X–ray Binaries (HMXBs) hosting an accreting rotating magnetic neutron star (White et al. 1995; Coe 2000). Based on the displayed X–ray features, BeXBs can be divided into at least three subclasses: (i) bright transients which display giant X–ray outbursts up to $L_X = 10^{38}$ erg s^{-1} (Type II; Stella et al. 1986) unrelated to the orbital phase, with high spin–up rates, (ii) transients which display periodic outbursts of relatively high luminosity ($L_X \simeq 10^{36}$–10^{37} erg s^{-1}; Type I) generally occurring close to the periastron passage of the neutron star, and (iii) sources displaying no outbursts, but comparatively moderate variations (up to a factor of ~10–100) and low–luminosity ($\leq 10^{36}$ erg s^{-1}) pulsed persistent emission (Negueruela 1998). B–emission (Be) spectral–type stars are characterized by high rotational velocities (up to 70% of their break–up velocity), and by episodes of equatorial mass loss which may produce a ring of gas orbiting around the star at irregular time intervals. At optical wavelengths, Be stars are difficult to classify due to the presence of the circumstellar envelope responsible for the emission lines.

The optical counterparts of the Galactic X–ray transient sources suffer from high absorption columns and reddening, which hampers the possibility of detecting and classifying them. So far only about ~20 optical counterparts of BeXBs have been discovered out of the ~100 known X–ray pulsars (Negueruela 1998). A way around this problem is to observe the field of these X–ray sources in the IR; in fact, the bulk of the emission from matter around the Be peaks at IR wavelengths. Therefore, IR together with optical photometry make it easy to distinguish highly reddened but intrisically bright objects (i.e. late O – early B stars) from nearby (low/no reddening) bright late type stars (such as K or M stars). Over the last three years our group has carried out (mainly by using ESO telescopes) an intensive observational campaign aimed at unveiling the optical/IR counterparts of an X–ray source sample made up by either recently discovered X–ray pulsators or by well-known transient X–ray

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Table 1. Optical/IR observations carried out for the field of GS 1843+009

Telescope & Instrument	Date	Exp. (s)	Seeing ($''$)	Range (Band/Å)	Comments
1.0 m JKT & TEK4	1997 July 14	60	$1''.0$	V	
——	"	60	"	R	
——	"	20	"	I	
1.0 m JKT & SITe 2	1999 July 24	500	$1''.1$	V	
——	"	60	"	R	
——	"	20	"	I	
3.5 m NTT & SUSI2	2000 May 5	300	$2''.0$	VRI	
——	"	600	"	B	
1.1 m AZT–24 & SWIRCAM	2000 June 3	30	$2''.1$	JH	
1.5 m Cassini &BFOSC	2000 June 30	5400	$1''.8$	4000–9000	Res. 15 Å
1.5 m Danish & DFOSC	2000 July 27	10800	$0''.9$	4000–9000	Res. 15 Å
——	2000 July 28	3600	$1''.0$	4000–9000	"
4.2 m WHT & ISIS	2000 August 20	3600	$1''.0$	4000–10000	Res. 3.3–6 Å
——	2000 August 21	1800	cloudy	"	"

pulsars with unknown companion. The project, so far, has led us to the unambiguous discovery of the optical counterparts to ∼10 objects (e.g. GS 0834−43, Israel et al. 2000a; XTE J1946+274, Verrecchia et al. 2001; AX J1820.5−1434, Israel et al. 2000b). In some cases V magnitudes in the 20–22 range and $V-R>2$ have been measured in our sample of identified optical/IR counterparts.

The transient X–ray pulsar GS 1843+009 was discovered on 1988 April 3 by *GINGA* intruments during a galactic plane scan observation near the Scutum region (Makino et al. 1988a; 1988b) and later confirmed through pointed observations carried out on 1998 April 19 and 20. Coherent pulsations at a period of $P = 29.5056 \pm 0.0002$ s (pulsed fraction ∼7%) were discovered in its X–ray flux, and a distance of at least 5 kpc was proposed (Koyama et al. 1990a, 1990b). The source was detected again during an outburst on 1997 March 3 by the Burst and Transient Source Experiment (*BATSE*) on board CGRO (Wilson et al. 1997). A new measurement of the pulse period, $P = 29.5631 \pm 0.0003$ s, allowed a period derivative to be inferred of $\dot{P} = (-3.65 \pm 0.11)\ 10^{-8}$ s s^{-1}.

A pointed observation carried out on 1997 March 5 by the *RXTE* Proportional Counter Array (PCA) found the source at a flux level of 60 mCrab (2–60 keV; Takeshima 1997). On 1997 April 4 the *BeppoSAX* Narrow Field Instruments (NFIs) performed a pointed observation of GS 1843+009 (Piraino et al. 1998, 2000). By exploiting the spatial resolution of the *BeppoSAX* imaging instruments, the 90% uncertainty for the position of GS 1843+009 was constrained to be within a $30''$ radius circular error region centered on RA $= 18^{h}45^{m}34^{s} \pm 2^{s}$, Dec $= 0°52'.5 \pm 0'.5$ (equinox 2000; Santangelo et al. 1997). On the same day, the source was also observed with the ROSAT High Resolution Imager (HRI) which inferred a position of RA $= 18^{h}45^{m}36^{s}.9 \pm 0^{s}.6$, Dec $= 0°51'45'' \pm 10''$ (90% confidence level uncertainty, equinox 2000; Dennerl & Greiner 1997).

2. X–ray position

The positions for GS 1843+009 inferred from the *BeppoSAX* and the *ROSAT* observations which were carried out within a few hours of each other, are only marginally consistent (∼$63''$ distance each other). In order to reconcile this difference we re–analysed both observations. The *ROSAT* HRI position was extracted from the Brera Multiscale Wavelet (BMW) catalog obtained by means of a wavelet–based detection technique developed to analyse high energy astronomical images (Lazzati et al. 1999; Campana et al. 1999). Only one source, namely 1BMW 184536.8+005148, was found within the HRI field of view (475 s of effective exposure time). The position of the source, RA $= 18^{h}45^{m}36^{s}.8$, Dec $= 0°51'47.5''$ (90% confidence error radius $9''$, equinox 2000), is nearly coincident to that inferred by Dennerl & Greiner (1997).

Although also for the *BeppoSAX* observation we obtained nearly the same position reported by Santangelo et al. (1997), we note that in this case the uncertainty radius at 90% cannot be set to $30''$ due to the relatively poor aspect spacecraft solution during this observation (the `STR_CONF` star traker flag in the house–keeping data ≤ 3) and, therefore, a more realistic value in the $50''$–$70''$ range must be considered. In the following we will refer to the ROSAT HRI position obtained from the BMW catalog and by Dennerl & Greiner (1997) as the correct one.

3. Optical/IR observations

We observed the field including the ROSAT HRI error circle several times during 1997–2000 both in the optical and IR band (see Table 1). The field was first imaged at optical wavelengths (VRI filters) on 1997 July 14 with the 1.0-m Jacobus Kapteyn Telescope (JKT; La Palma) equipped with the TEK4 CCD ($5'.6 \times 5'.6$ field of view and $0''.33$/pixel resolution). A further set of VRI images was obtained at the JKT on 1999 July 24 with the SITe2 CCD ($10' \times 10'$ field of view and $0''.33$/pixel resolution).

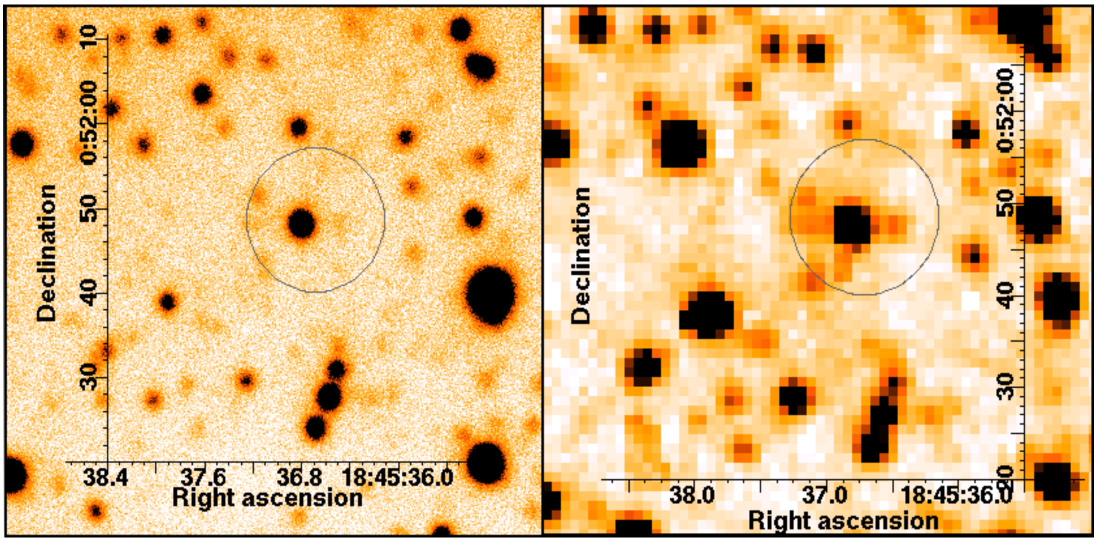

Fig. 1. Optical R–filter (left panel; NTT) and IR H–filter (right panel; AZT–24) images of the field of GS 1843+009 together with the new X–ray position uncertainty region (9″ radius) derived from the 1997 April 4 *ROSAT* HRI observation. North is top, east is left. The relatively bright star within the circle is the proposed optical counterpart of GS 1843+009

In both cases Starlink's *CCDPACK* (Draper 2000) was used to perform the bias subtraction and flat–field correction, while GAIA (Draper & Gray 2000) was employed for the photometry.

Optical images in the B (600 s) and VRI (300 s each) filters were taken on 2000 May 5 with the ESO 3.5-m New Technology Telescope (NTT) at La Silla equipped with the Superb Seeing Imager – 2 (SUSI2; 5.′5 × 5.′5 field of view and 0.″16/pixel resolution). The data were reduced using standard ESO–MIDAS and IRAF procedures for bias subtraction and flat–field correction. Photometry for each stellar object in the image was derived with the DAOPHOT II program (Stetson 1987). Astrometry of the images was performed by using the USNO star catalog which provides an absolute positional accuracy of ∼0.″5 (Monet 1998). The GS 1843+009 field was further observed in the J (30 s) and H (30 s) filters on 2000 June 3 from the 1.1-m AZT–24 telescope at Campo Imperatore (Italy) equipped with the Supernova Watchdogging IR Camera (SWIRCAM; 4.′4 × 4.′4 field of view and 1.″04/pixel resolution). Data analysis procedures similar to those described above were applied. Within the X–ray positional uncertainty circle we detected only one highly reddened ($V - R = 2.09$) and relatively bright ($H = 13.2$) IR object (see Fig. 1) as expected for a distant and instrinsically blue early–type star. Moreover the star is the only variable object in the error circle Table 2 lists the results of the optical and IR photometry for the proposed optical counterpart of GS 1843+009.

Spectroscopic observations of the candidate optical counterpart were obtained on 2000 June 30 with the 1.52 m "Cassini" telescope (Loiano Observatory) equipped with the Bologna Faint Objects Spectrometer and Camera (BFOSC; Bregoli et al. 1987; Merighi et al. 1994; 12.′2 × 12.′2 field of view and 0.″58/pixel resolution). We performed low–resolution (15 Å) spectroscopy for a total exposure time of 5 400 s (3 × 1800 s). After applying standard corrections, cosmic rays were removed from each spectrum and the sky–subtracted stellar spectra were obtained, corrected for atmospheric extinction. The signal to noise (S/N) ratio was extremely low and object counts were only detected above 5500 Å. A strong emission line (equivalent width, EW, of -14 ± 2 Å and Full Width Half Maximum, $FWHM$, consistent with the instrumental resolution) was detected, its wavelength corresponding to that of Hα. This result strongly suggested that the optical source was associated with GS 1843+009. In order to achieve better statistics we further observed the candidate optical counterpart to GS 1843+009 on 2000 July 26 and 27 from the ESO 1.5-m Danish telescope (La Silla, Chile) equipped with the Danish Faint Object Spectrometer Camera (DFOSC; 15′ × 15′ field of view and 0.″4/pixel resolution). Five low–resolution (15 Å) spectra were obtained for a total effective exposure time of 14 400 s. Reduction procedures similar to those described above were applied to each spectrum. The resulting summed spectrum (flux uncalibrated) is shown in Fig. 2. Also in this case the Hα emission line was evident (EW of -14 ± 1 Å), while no other emission lines were detected.

Finally on 2000 August 20 and 21 two medium–resolution spectra (total on–source integrations of 3600 s and 1800 s respectively) were taken with the Intermediate Dispersion Spectroscopic and Imaging System (ISIS) mounted on the 4.2 m William Herschel Telescope (WHT), located at the Observatorio del Roque de los Muchachos, (La Palma, Spain). The blue arm was equipped with the R158B grating and the EEV#10 CCD, which gives a nominal dispersion of ∼1.6 Å/pixel. The resolution at ∼6000 Å, estimated from the $FWHM$ of arc lines, is ∼6 Å. The red arm was equipped with the R316R grating and the Tek4 CCD, which gives a nominal dispersion of ∼1.5 Å/pixel (the resolution is ∼3.3 Å at ∼8000 Å).

Table 2. Optical and IR results for the proposed counterpart.

Date	B	V	R	I	$V-R$	J	H	$J-H$
July 1997	–	20.6 ± 0.5	18.6 ± 0.2	16.5 ± 0.2	2.0	–	–	–
July 1999	–	20.2 ± 0.3	18.5 ± 0.3	17.1 ± 0.3	1.7	–	–	–
May 2000	>24.1	20.89 ± 0.05	18.80 ± 0.05	16.79 ± 0.05	2.09	–	–	–
June 2000	–	–	–	–	–	13.75 ± 0.05	13.21 ± 0.05	0.54

RA(J2000) =	$18^{\rm h}45^{\rm m}36\overset{\rm s}{.}8$
Dec(J2000) =	$+00°51'48\overset{''}{.}3$
Spectral type:	B0–B2 IV–V e
E_{B-V}:	$2.3 \rightarrow 2.9$
Distance:	$\geq$10 kpc

Note – B magnitude upper limit is at 90% confidence level. Position uncertainty is $0\overset{''}{.}5$.

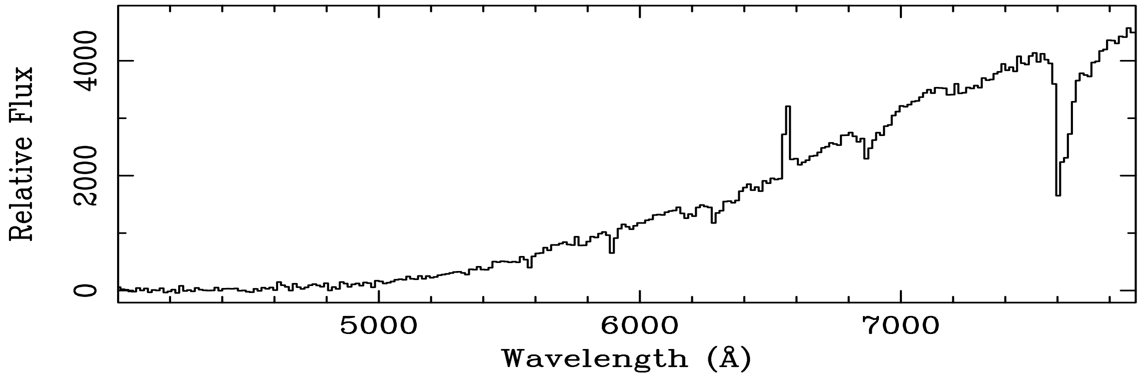

Fig. 2. The 14 400-s low resolution (15 Å) spectrum of GS 1843+009 obtained on 2000 July 27–28 from the 1.5 m Danish telescope at La Silla (Chile)

The I–band spectrum of the optical counterpart to GS 1843+009 displays the wealth of emission lines typical of early–type Be stars, which is generally seen in Be/X-ray binary counterparts (Negueruela & Torrejón 2001; see Fig. 3). The Paschen series appears strongly in emission from Pa11 down to Pa22 (though the last members of the series are difficult to measure due to increasing atmospheric contamination). Parameters of several emission lines are displayed in Table 3. Pa18 is clearly double–peaked, indicating blend with O I λ8446 Å. The larger $FWHM$s and EWs of Pa15 and Pa16 indicate that they are also blended with the Ca II $\lambda\lambda$ 8498, 8542 Å lines, though there is nothing in the parameters of Pa13 to make us suspect its blending with the third member of the Ca II triplet, at λ8662 Å. The N I band at $\lambda\lambda$ 8680 − 8686 Å, sometimes seen in emission in Be stars (Andrillat et al. 1988) could be on the red wing of Pa13, but the S/N ratio is not enough to ascertain it.

Apart from Hα, no other lines are observed in the blue part of the optical spectrum. The flux shortwards of λ6000 Å is too weak for any line to be detected. The O I $\lambda\lambda$ 7772 − 7775 Å band, which is sometimes seen in emission in Be stars, falls in the region affected by the dichroic. The lack of any spectral absorption features prevents us from an accurate spectral classification. However, the presence of strong emission in the Paschen series identifies the star as earlier than B2 (Andrillat et al. 1988), i.e., in the spectral range occupied by known Galactic Be/X–ray binary counterparts (Negueruela 1998).

Due to the difficulty in determining the local continuum, the values of EWs have large uncertainties, typically $\sim$15%, but as high as 30% for Pa11 (uncertainties have been estimated by considering different continuum levels). The narrowness of all the unblended lines as well as their shape, clearly shows that this Be star is close to pole–on. Be stars with larger inclinations to the line–of–sight generally display double–peaked Paschen emission lines with $\Delta v_{\rm peak} > 200\,{\rm km\,s^{-1}}$, i.e., clearly separable at this resolution.

4. Discussion and conclusion

The X–ray, optical and IR observations of the field of GS 1843+009 presented here led to the identification of the optical counterpart of this 29.5 s transient X–ray pulsar discovered in 1988. The measurement of the distance to GS 1843+009 based on the optical data is hampered by the uncertainties in the spectral classification.

However some information can be inferred based on our optical and IR photometric measurements. The intrinsic $(V-R)$ color for GS 1843+009 is $\sim -0.1 \rightarrow -0.15$ (assuming a main sequence or sub–giant star with spectral

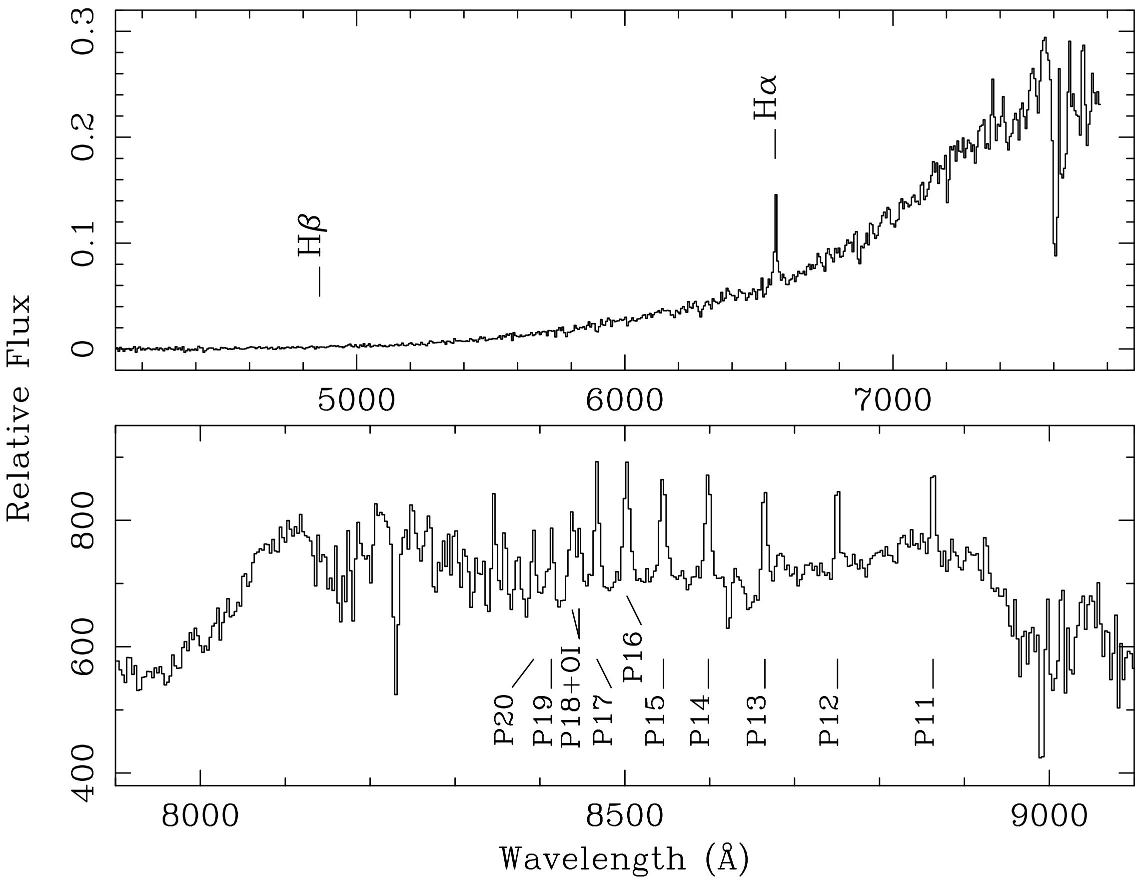

Fig. 3. The medium resolution spectra of GS 1843+009 obtained on 2000 August 20 and 21 at the WHT at La Palma (Spain)

Table 3. Measured parameters of emission lines detected in the WHT spectra of the proposed optical counterpart to GS 1843+009. The *FWHM*s have been corrected for instrumental effects. See text for details

Line	*EW* (Å)	*FWHM* (km s^{-1})
Pa 11	−1.0	135
Pa 12	−1.3	115
Pa 13	−1.2	140
Pa 14	−1.8	220
Pa 15	−2.0	300
Pa 16	−2.2	285
Pa 17	−2.1	160
Pa 18 + O I λ8446 Å	−2.5	blend
Pa 19	−1.3	–
Pa 20	−1.2	170
Hα	−18	280

type in the B0–B2 range). Since the observed $(V-R)$ is $\sim 1.7 \rightarrow 2.1$ the reddening should amount to $E_{V-R} \sim 1.8 \rightarrow 2.3$, and assuming a standard reddening law (Fitzpatrick 1999) this converts to $A_R \sim 5.6 \rightarrow 7$, $A_V \sim 7 \rightarrow 9$ and $E_{B-V} \sim 2.3 \rightarrow 2.9$ (regardless of whether the reddening medium is uniformly distributed along the line of sight or is intrinsic to the source). However from the X–ray spectral fits (Piraino et al. 2000) a $N_{\rm H}$ of 2–3 10^{22} cm^{-2} was derived, corresponding to an $E_{B-V} \sim 3.2 \rightarrow 5$ (Bohlin et al. 1978), which is not consistent with the above results. Considering the total Galaxy $N_{\rm H}$ column in the direction of GS 1843+009, 1–2 10^{22} cm^{-2}, a value of $E_{B-V} \sim 2.7 \rightarrow 3.2$ was inferred. This result suggests that at least part of the inferred X–ray $N_{\rm H}$ is local to the system and obscures the neutron star during outbursts and that the binary system is quite far from us. A good agreement with the V, R and I measurements is obtained for a B1IV–V star at a distance larger than 10 kpc (note that in the direction to GS 1843+009 the Galaxy edge is located at ∼15 kpc) and an $E_{B-V} \sim 2.8$. However, according to Hayakawa et al. (1977), the interstellar extinction to the direction of GS 1843+009 is somewhat larger than the average Galactic plane value, which might imply a smaller distance (in the 5–8 kpc range) to the source. We can reasonably discard the possibility of a luminosity class III which would imply an $E_{B-V} \sim 3.2$ and an IR–deficiency. For a reference B1V–IV star ($M_V \sim -3.5$) at a distance of 10–15 kpc and based on the IR photometry we infer an excess ≥ 1.5 and ≥ 1.2 magnitudes in J and H filters, respectively, suggesting the presence of a circumstellar envelope. We also note that the proposed counterpart is the only object displaying flux variability in the field of GS 1843+009 ($\sim 2\sigma$ confidence level in the V and I band) as expected for Be/X–ray binaries, further suggesting the correctness of the identification.

Based on both photometric and spectroscopic findings we conclude that the proposed optical counterpart of GS 1843+009 is most likely a B0–2 V–IVe variable star at a distance larger than 10 kpc. A more accurate distance and spectral classification would require more detailed optical spectroscopic observations in the blue end of the spectrum with a larger telescope.

For a distance of 10–15 kpc and a 1–10 keV flux of $\sim$6 10^{-10} erg s^{-1} cm^{-2} as measured by BeppoSAX during the 1997 April outburst (Piraino et al. 2000) we obtain an X–ray luminosity of L_X (1–10 keV) $\simeq$ 5–20 10^{36} erg s^{-1}. Such a luminosity is a typical value shown by X–ray pulsars in binary systems during Type I outbursts (Stella et al. 1986; Negueruela 1998) occurring close to the time of periastron passage and with a periodic recurrence at the orbital period of the system.

Acknowledgements. This work is supported through CNAA, ASI and Ministero dell'Università e Ricerca Scientifica e Tecnologica (MURST) grants. IN and GLI thank the service observing programme at the WHT in La Palma. AJN and DHM thank the service observing programme at the JKT in La Palma. During part of this work, IN was supported by an ESA external fellowship. The WHT and JKT are operated on the island of La Palma by the Royal Greenwich Observatory in the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofísica de Canarias.

References

Andrillat, Y., Jaschek, M., & Jaschek, C. 1988, A&AS, 72, 129
Bohlin, R. C., Savage, B. D., & Drake, J. F. 1978, ApJ, 224, 132
Bregoli, G., Federici, L., Merighi, R., et al. 1987, in ESO–OHP Workshop on the Optimization of the Use of CCD Detectors in Astronomy, Saint–Michel–l'Observatoire, France, June 17–19, 1986, Proceedings (A88–13301 03–89), Garching, ESO, Germany, 177
Campana, S., Lazzati, D., Panzera, M. R., et al. 1999, ApJ, 524, 423
Coe, M. J. 2000, Proceedings of the 175th IAU Colloq., ed. M. A. Smith, H. F. Henrichs, & J. Fabregat, ASP Conf. Ser. 214, 656
Dennerl, K., & Greiner, J. 1997, IAU Circ., 6645
Draper, P. W., Taylor, M., & Allan, A. 2000, Starlink User Note 139.12, R.A.L.
Draper, P. W., & Gray, N. 2000, Starlink User Note 214.7, R.A.L.
Hayakawa, S., Ito, K, Matsumoto, T., et al. 1977, A&A, 56, 325
Fitzpatrick, E. L. 1999, PASP, 111, 63
Israel, G. L., Covino, S., Campana, S., et al. 2000a, MNRAS, 314, 87
Israel, G. L., Covino, S., Polcaro, V. F., et al. 2000b, Proceedings of the 175th IAU Colloq., ed. M. A. Smith, H. F. Henrichs, & J. Fabregat, ASP Conf. Ser. 214, 739
Koyama, K., Kawada, M., Kunieda, H., et al. 1990a, Nature, 343, 146
Koyama, K., Kawada, M., Takeuchi, Y., et al. 1990b, ApJ, 356, L47
Lazzati, D., Campana, S., Rosati, P., et al. 1999, ApJ, 524, 414
Makino, F., and the ASTRO–C Team 1987, Ap. Letters Comm., 25, 223
Makino, F., and *GINGA* Team 1988a, IAU Circ., 4583
Makino, F., and *GINGA* Team 1988b, IAU Circ., 4587
Merighi, R., Mignoli, M., Ciattaglia, C., et al. 1994, Bologna Technical Reports 09,-1994,-05
Monet, D. G. 1998, AAS Meeting #193, #120.03
Negueruela, I. 1998, A&A, 338, 505
Negueruela, I., & Torrejón, J. M. 2001, in prep.
Piraino, S., Santangelo, A., Giarrusso, S., et al. 1998, Nucl. Phys. B (proc. Suppl.), 69/1–3, 220
Piraino, S., Santangelo, A., Segreto, A., et al. 2000, A&A, 357, 501
Santangelo, A., Giarrusso, S., Del Sordo, S., et al. 1997, IAU Circ., 6659
Stella, L., White, N. E., & Rosner, R. 1986, ApJ, 208, 669
Stetson, P. B. 1987, PASP, 99, 191
Takeshima, T. 1997, IAU Circ., 6595
Verrecchia, F., Israel, G. L., & Negueruela, I. 2001, in prep.
Wilson, R. B., Harmon, B. A., Scott, D. M., et al. 1997, IAU Circ., 6586
White, N. E., Nagase, F., & Parmar, A. N. 1995, in X–ray Binaries, ed. W. H. G. Lewin, J. van Paradijs, & E. P. J. van den Heuvel (Cambridge University Press), 1