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Simultaneous radio and X-ray observations of Galactic Centre low-mass X-ray binaries

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ABSTRACT

We have performed simultaneous X-ray and radio observations of 13 Galactic Centre low-mass X-ray binaries in 1998 April using the Wide Field Cameras on board *BeppoSAX* and the Australia Telescope Compact Array, the latter simultaneously at 4.8 and 8.64 GHz. We detect two Z sources, GX 17+2 and GX 5−1, and the unusual 'hybrid' source GX 13+1. Upper limits, which are significantly deeper than previous non-detections, are placed on the radio emission from two more Z sources and seven atoll sources. Hardness–intensity diagrams constructed from the Wide Field Camera data reveal GX 17+2 and GX 5−1 to have been on the lower part of the horizontal branch and/or the upper part of the normal branch at the time of the observations, and the two non-detected Z sources, GX 340+0 and GX 349+2, to have been on the lower part of the normal branch. This is consistent with the previous empirically determined relation between radio and X-ray emission from Z sources, in which radio emission is strongest on the horizontal branch and weakest on the flaring branch. For the first time we have information on the X-ray state of atoll sources, which are clearly radio-quiet relative to the Z sources, during periods of observed radio upper limits. We place limits on the linear polarization from the three detected sources, and use accurate radio astrometry of GX 17+2 to confirm that it is probably not associated with the optical star NP Ser. Additionally we place strong upper limits on the radio emission from the X-ray binary 2S 0921−630, disagreeing with suggestions that it is a Z-source viewed edge-on.

Key words: polarization – astrometry – binaries: close – radio continuum: stars – X-rays: stars.

1 INTRODUCTION

The Z and atoll sources are thought to be X-ray binaries containing low-magnetic-field (10^8–10^9 G) neutron stars (because many of the atoll sources, and least one of the Z sources, show X-ray bursts) accreting from a low-mass ($M \leqslant M_\odot$) companion star. Use of X-ray 'colour–colour' and/or 'hardness–intensity' diagrams (denoted as CCDs and HIDs respectively) and high-sensitivity X-ray timing have provided a wealth of information on the accretion processes in these sources. Together, the two groups encompass all the brightest low-mass X-ray binaries, and they are clustered in the direction of the Galactic bulge. See e.g. van der Klis (1995, 2000) for reviews of their X-ray properties. All the Z sources, and at least one of the atoll-sources, have been detected at radio wavelengths (see e.g. Penninx 1989; Hjellming & Han 1995; Fender & Hendry 2000). As with all X-ray binaries detected at radio wavelengths, high brightness temperatures appear to preclude thermal emission processes, and synchrotron emission is the favoured emission mechanism. However, other measurements, notably detection of linear polarization, are required to confirm this interpretation. In several cases, high-resolution radio observations have resolved the radio emission into jet-like structures, sometimes with components moving at relativistic velocities (e.g. Hjellming & Han 1995; Fender, Bell Burnell & Waltman 1997; Mirabel & Rodríguez 1999).

The radio emission from the atoll and Z sources shares some common properties with that of the persistent black hole X-ray binaries (Fender & Hendry 2000), which suggests that their low intrinsic magnetic fields (believed to be $\leqslant 10^{11}$ G) have little effect on the accretion/acceleration process (at least for values of the

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Table 1. Total intensity and the fractional polarization of the 14 sources, both with all the baselines and with only baselines >3 km.

		All baselines				Only baselines ⩾3 km			
		Total intensity(mJy)		Fractional polarization		Total intensity(mJy)		Fractional polarization	
Date	Source	6.3 cm	3.5 cm	6.3 cm	3.5 cm	6.3 cm	3.5 cm	6.3 cm	3.5 cm
1998 April 1	2S 0921−630	<0.10	<0.10	–	–	–	–	–	–
(MJD 50 904)	4U 1820−30	<0.14	<0.19	–	–	–	–	–	–
	GX 17+2	0.6 ± 0.04	1.3 ± 0.08	<0.16	<0.14	0.4 ± 0.04	0.9 ± 0.03	<0.28	<0.13
	GX 3+1	<0.18	<0.17	–	–	<0.09	<0.15	–	–
	GX 9+1	<0.16	<0.18	–	–	<0.12	<0.10	–	–
	GX 9+9	<0.21	<0.21	–	–	<0.21	<0.15	–	–
	GX 5−1	<0.23	1.2 ± 0.35	–	<0.68	0.4 ± 0.04	0.6 ± 0.05	<0.33	<0.23
	GX 13+1	<0.80	<0.68	–	–	1.5 ± 0.05	1.2 ± 0.05	<0.08	<0.12
1998 April 4	4U 1636−53	<0.12	<0.15	–	–	<0.17	<0.20	–	–
(MJD 50 907)	GX 340+0	<1.3	<0.20	–	–	<0.30	<0.20	–	–
	GX 339−4	<0.11	<0.13	–	–	<0.18	<0.22	–	–
	4U 1705−44	<0.12	<0.12	–	–	<0.16	<0.20	–	–
	4U 1735−44	<0.13	<0.14	–	–	<0.16	<0.20	–	–
	GX 349+2	<0.11	<0.39	–	–	<0.11	<0.16	–	–

accretion rate near to the Eddington limit). The major influence on the acceleration of radio-emitting relativistic electrons must be the state of the accretion disc, itself determined by the accretion rate. Thus at all times we should expect to see some relation between behaviour in X-ray timing and spectra and radio timing and spectra.

Apart from the unusual source GX 13+1 (and probably also GX 354+0 – Martí et al. 1998), no atoll source has been reliably detected at more than one epoch. Previous upper limits can be found in Grindlay & Seaquist (1986); Nelson & Spencer (1988); Cooke & Ponman (1991); see Hjellming & Han (1995) for more details.

2 OBSERVATIONS

On 1998 April 1 and 4 we observed several low-mass X-ray binaries in the direction of the Galactic Centre with the Australia Telescope Compact Array (ATCA), contemporaneously with X-ray observations of the region with the *SAX* Wide Field Camera (WFC). In addition we have used *RXTE* All Sky Monitor (ASM) data to judge the longer term trend in the X-ray behaviour of the sources around the times of our observations.

2.1 ATCA

On 1998 April 1 and 4 we observed the Galactic Centre X-ray binary sources with ATCA, in a high-resolution 6-km configuration. The observations were made simultaneously at 6.3 cm (4800 MHz) and 3.5 cm (8640 MHz). Observations were from 13:00–02:00 UT and 11:00–02:00 UT on April 1–2 and 4–5 respectively. Primary flux calibration was achieved using PKS 1934−638. Observations consisted of 15-min snapshots of the targets interleaved with 5-min observations of a phase calibrator (VLA calibrator B1748-253/J1751-253 and ATCA calibrator 1646−50 on April 1 and 4 respectively). This resulted in four or five 15-min observations of each source over the observing run. The MIRIAD software package (Sault, Teuben & Wright 1995) was used to reduce the data. Flux densities and upper limits were measured from maps formed by combining all the snapshots for each source; for those targets clearly detected, point-source fits in the image plane were used to estimate the flux density.

In addition, on April 1 we observed the low-mass X-ray binary 2S 0921−630 between 06:15 and 13:00 UT. As with the snapshots of the Galactic Centre sources, observations involved 15 of every 20 min on the target, with 5 min on the phase calibrator (ATCA calibrator 0843−54). Primary flux calibration was achieved using PKS 0823−500.

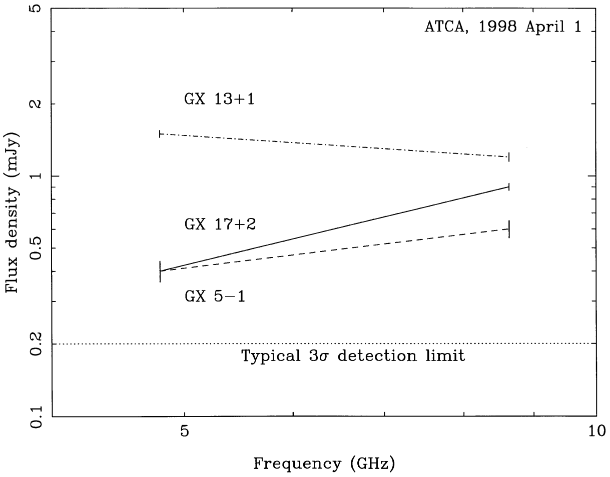

Figure 1. 4–9 GHz radio spectra of the three sources detected using flux densities measured from point-source fits to long-baseline (⩾3 km) data only (see text).

Table 1 lists the targets and summarizes the detections and upper limits at 6.3 and 3.5 cm. We list measurements for maps made using all baselines and also for those made using only baselines ⩾3 km (47 000 kλ and 85 000 kλ at 6.3 and 3.5 cm respectively). By selecting only long baselines, we avoid problems with the sidelobes of emission of very extended objects typically found near the Galactic Plane. This emission is problematic for observations of this kind, as the emission is very poorly imaged (see discussion in Burgess & Hunstead 1995). In nearly all cases the flux density measured on the shortest (⩽ few 100 m) baselines was much greater than the flux density we were trying to measure for the point-source target. In particular, the sources GX 5−1 and GX 13+1 were clearly detected at both frequencies only when using the longer baselines (GX13+1 is in a field of bright, extended emission which was measured at ~0.8 Jy at 6.3 cm on the shortest baselines and is not well imaged by five 15-min snapshots). In almost half of all the maps made there were confusing sources which were brighter than the target. Fig. 1 plots the radio spectra of the three sources that were unambiguously detected at both frequencies.

For the three sources detected, GX 17+2, GX 5−1 and GX 13+1, we were additionally able to place limits on the linear polarization of the emission of a few tens of per cent (see Table 1).

2.2 *SAX* WFC

The Wide Field Cameras (WFCs, Jager et al. 1997) onboard the *BeppoSAX* satellite (Boella et al. 1997) are identical coded mask telescopes pointing in different directions. Each camera has a 40 × 40° field of view and covers the 2–27 keV energy range. The imaging capability (angular resolution is about 5 arcmin) and the good sensitivity (~5–10 mCrab in 10^4 s) allow an accurate monitoring of complex sky regions, like the Galactic bulge. The *BeppoSAX* WFCs are carrying out a programme of monitoring observations of the field around the Galactic Centre. The purpose is to detect X-ray transient activity, particularly from low-mass X-ray binaries (LMXBs), the Galactic population of which exhibits a strong concentration in this field, and to monitor the behaviour of persistently bright X-ray sources (see e.g. Heise 1999). This programme consists of campaigns during the (northern) spring and autumn of each year. Each campaign lasts about two months and typically comprises weekly observations.

In this paper we report on part of the X-ray monitoring programme during spring 1998, i.e. April 1–5. These observations were performed with WFC unit 1. In order to investigate the state of the X-ray sources we observed in the radio, we created hardness versus intensity diagrams, where hardness is defined as the ratio of the count rates in the 5–20 keV and 2–5 keV bands, and intensity as the total count rate per cm^2 in the 2–20 keV band. All X-ray measurements are corrected for dead time and background. Depending on the brightness of the source, we determined average hardness and intensity values ranging from 2 to 40 min.

Some hardness–intensity diagrams for the brightest of the Galactic Centre X-ray binaries at the time of our observations are shown in Figs 2 (Z sources) and 3 (atoll sources).

2.3 *RXTE* ASM

The *Rossi X-ray Timing Explorer* (*RXTE*) All-Sky Monitor (ASM) monitors bright X-ray sources up to several times daily in the 2–12 keV band. In this paper we have utilized the total 2–12 keV intensity data to judge the state of the X-ray sources on

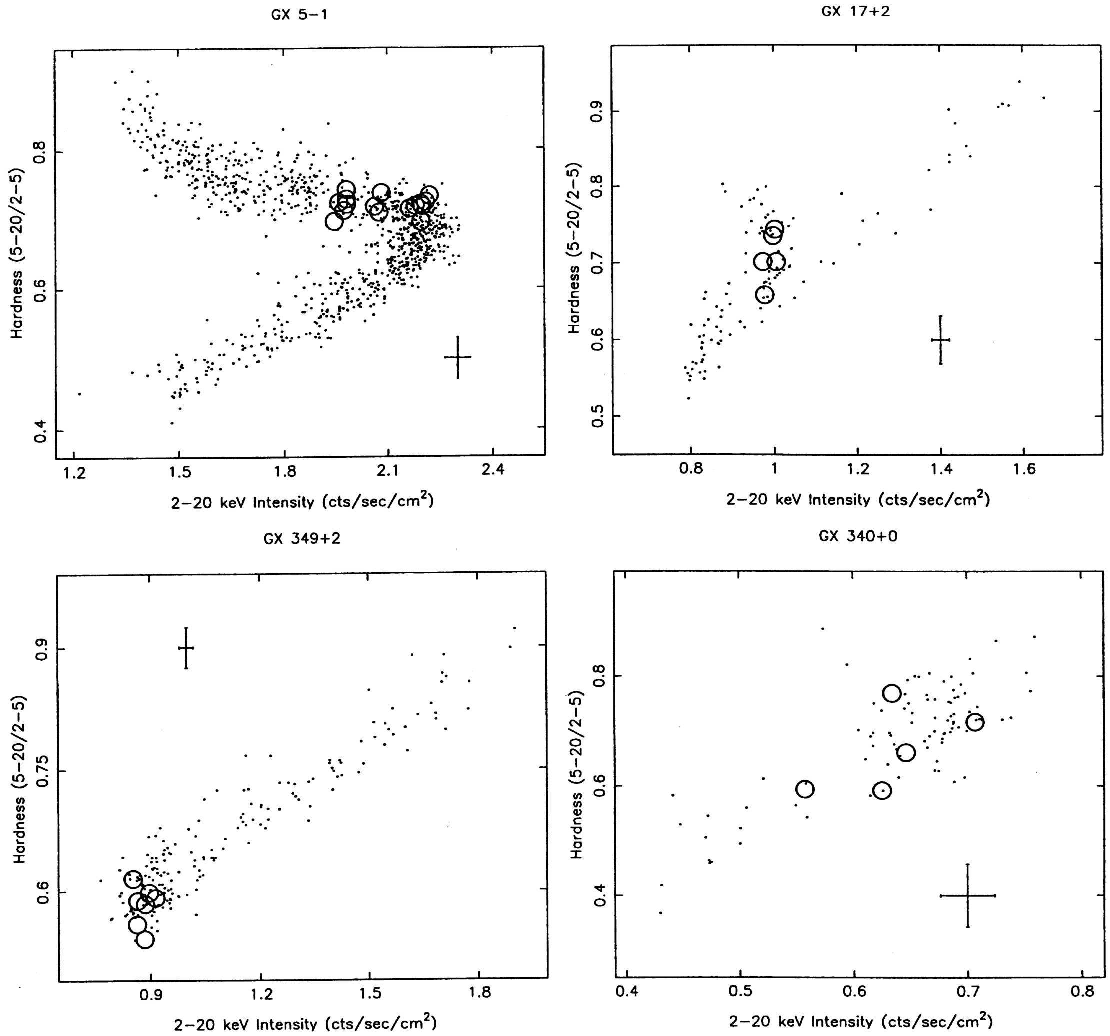

Figure 2. Hardness–intensity plot of the *SAX* WFC data for the Z sources during the period of the ATCA radio observations. All data from the 1998 April 1–5 *SAX* WFC observations are plotted; open circles indicates those observations strictly simultaneous with the radio observations. Typical uncertainties are indicated on each plot. The integration times are 2, 10, 16 and 20 min for GX 5−1, 349+2, 17+2 and 340+0, respectively.

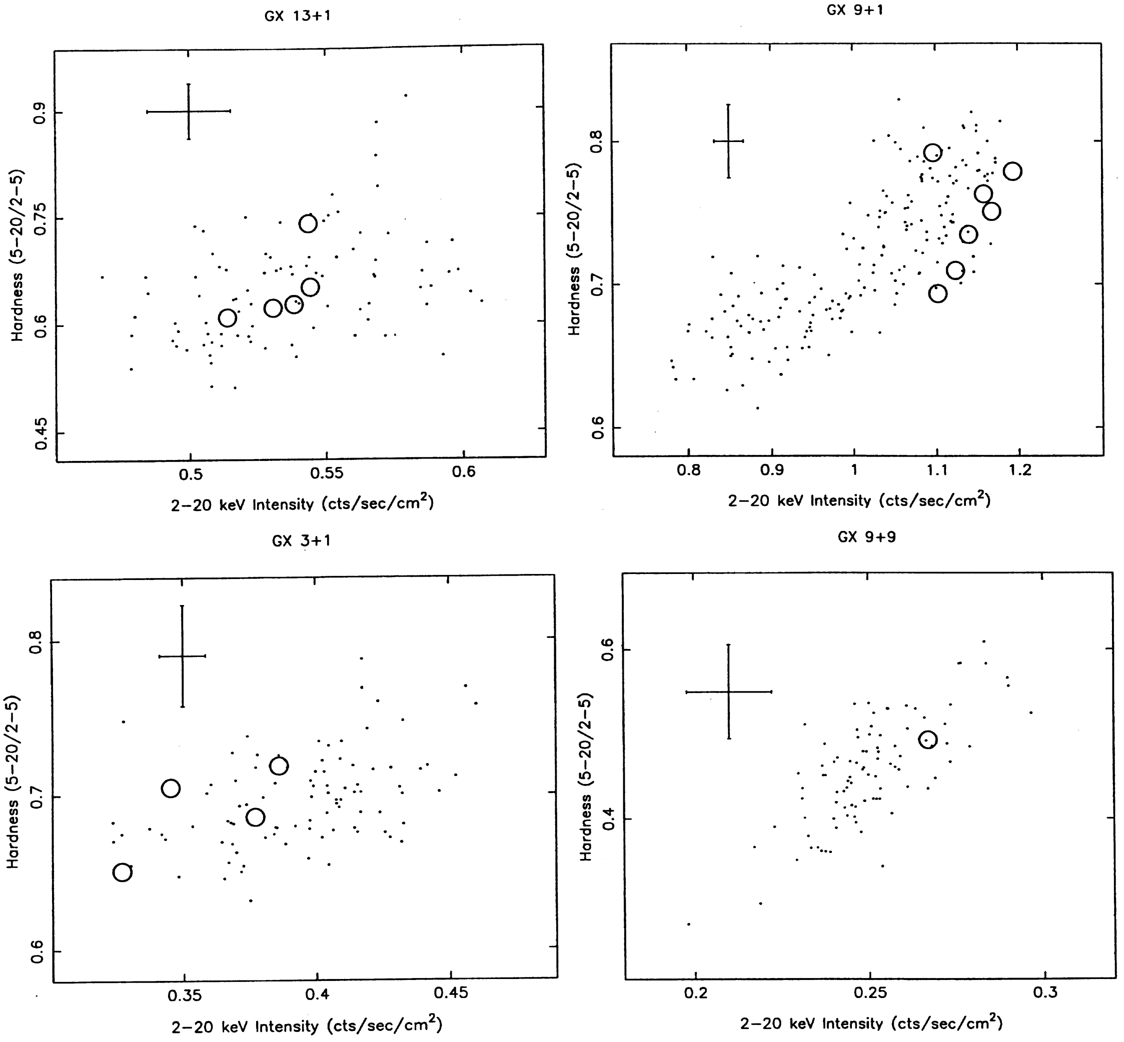

Figure 3. As Fig. 2, but for the four atoll sources that were strongest during the contemporaneous *SAX*:ATCA observations. The integration times are 10 min for GX 9+1 and 20 min for GX 13+1, 3+1 and 9+9.

Table 2. Comparison of radio and X-ray properties of the X-ray binaries at the time of observation.

Source	Class	*RXTE* ASM (count s^{-1})	*SAX* WFC (state[a])	Radio?	Comments
GX 17+2	Z	41	Upper NB/Lower HB (see Fig. 2)	Yes	
GX 5−1	Z	65	Upper NB/Lower HB (Fig. 2)	Yes	
GX 340+0	Z	30	Upper NB (Fig. 2)	No	Previously reliably detected
GX 349+2	Z	53	Lower NB (Fig. 2)	No	Previously reliably detected
GX 13+1	atoll/Z ?	23	Quite stable (see Fig. 3)	Yes	Radio properties like Z sources
2S 0921−630	?		Not in f.o.v.	No	Unlikely to be a Z source
4U 1820−30	atoll	12	Mean hardness[b] ∼0.78	No	Reported detection at ∼0.5 mJy level
GX 3+1	atoll	17	B (see Fig. 3)	No	Improved radio limit
GX 9+1	atoll	16	UB (Fig. 3)	No	Improved radio limit
GX 9+9	atoll	16	UB? (Fig. 3)	No	Improved radio limit
4U 1636−53	atoll	12	Not in f.o.v.	No	First reported radio limit
4U 1705−44	atoll	8	Mean hardness ∼0.51	No	First reported radio limit
4U 1735−44	atoll	9	Mean hardness ∼0.43	No	Improved radio limit
GX 339−4	BHC	20		No	Radio quenched in X-ray high state[c]

[a] Z sources: horizontal branch (HB), normal branch (NB); atoll sources: banana (B), upper banana (UB).
[b] Hardness ≡ (5–20/2–5) keV count rate.
[c] See Fender et al. (1999b).

time-scales longer than the relatively short (~1 d) *SAX* WFC observations. See e.g. Levine et al. (1996) for more details.

3 DISCUSSION

3.1 Radio detections and upper limits

Table 2 summarizes the classification (Z, atoll or black hole candidate) of the targets, and their X-ray and radio state at the time of the observations. It is clear from the *RXTE* ASM count rates that the Z sources are systematically brighter than the atoll sources, and that the 'hybrid' source, GX 13+1, is somewhere between the two groups. Below we discuss each of the source classes in general, as well as the X-ray:radio connection and the accurate relative astrometry available from our data.

3.1.1 The Z sources

Two of the four Z sources have been detected, as well as the unusual 'hybrid' atoll/Z source GX 13+1. This is not surprising as all of these sources have been previously detected (e.g. Hjellming & Han 1995). We note that these are the same three sources detected in a previous survey of the same region published by Grindlay & Seaquist (1986), although for the non-detections our upper limits are in general significantly more stringent. Fig. 1 displays the radio spectra of the three detected sources, and Table 3 lists the spectral indices from these data. It is reassuring to note that for GX 17+2, the only source clearly detected with all baselines *and* using only baselines ⩾3 km, while the flux densities measured vary by ~50 per cent, the spectral index remains about the same. The spectral indices of GX 17+2 and GX 5−1 are inverted, probably as a result of the superposition of ejected components, which peak earliest at higher frequencies as they expand. Some variant of the very flat radio–mm spectral component observed from Cyg X-1 (Fender et al. 2000) cannot however be ruled out.

The lack of detection of GX 349+2 and GX 340+0, given their previous reliable detections (Hjellming & Han 1995 and references therein), may be a result of our having unluckily caught them in radio-'low' states. This is presumably related to their not having been on the horizontal branch or upper part of the normal branch in the X-ray HID – see Section 3.2 below.

The upper limits to the linear polarization of the radio emission from GX 17+2 and GX 5−1, of the order of 20 per cent (Table 1), do not seriously constrain the emissive mechanism or optical depth of the ejecta. While the brightest radio transients may show very high linear polarization (e.g. Fender et al. 1999a; Hjellming et al. 1999), the total radio flux (i.e. not resolving individual components) from X-ray binaries is generally polarized at less than the 20 per cent level.

3.1.2 The atoll sources

Excluding 2S 0921−630 (see discussion below), we have observed several bona fide atoll-type X-ray binaries and not detected any of them. Significantly, this group includes GX 9+1 and GX 9+9, amongst the most luminous (in X-rays) of the class. In particular we do *not* detect the atoll source 4U 1820−30 in the globular cluster NGC 6624. All the limits presented in Table 1 are either improvements on previous limits (typically by a factor of ~2) or the first limits presented for the sources. These upper limits are further evidence that the atoll sources as a class are significantly fainter at radio (as well as X-ray) wavelengths than the Z sources, a point explored further in Fender & Hendry (2000).

Table 3. Spectral indices for the three sources detected.

Source	Spectral index $\alpha = \Delta \log S_\nu / \Delta \log \nu$ (all baselines)	(baselines ⩾3 km)
GX 17+2	1.3 ± 0.1	+1.4 ± 0.1
GX 5−1	–	+0.7 ± 0.1
GX 13+1	–	−0.4 ± 0.1

3.1.3 GX 13+1

While originally classified as an atoll source, the bright X-ray binary GX 13+1 shares several of the properties of the Z sources (Homan et al. 1998 and references therein). In particular, the system is known to be a relatively bright and persistent radio source, supported by our strong detection at a level ⩾1 mJy. The radio spectrum from this source, unlike that of GX 17+2 and GX 5−1, was negative during our observations and consistent with optically thin synchrotron emission. Combined with the relatively bright state, this suggests the recent ejection of a radio-emitting component, which has expanded to an optically thin state.

The limits on linearly polarized emission, of 8 per cent and 12 per cent at 6.3 and 3.5 cm respectively, are fairly constraining as this level of linear polarization is sometimes achieved by brighter radio transients associated with X-ray binaries, particularly when the emission is optically thin (as suggested in this case by the spectral index of −0.4 ± 0.1). Probably there is still a large contribution from a depolarized core and/or Faraday depolarization in the ejecta.

3.1.4 2S 0921−690: an edge-on Z source ?

It has been suggested that 2S 0921−630 (V395 Car) is a Z source viewed nearly edge-on (Zwarthoed et al. 1993 and references therein; see also Shahbaz et al. 1999). As the Z sources have all been detected at one time or another as radio sources (Hjellming & Han 1995 and references therein), it is expected that 2S 0921−630 should also be a radio source if it is one of these systems. Zwarthoed et al. (1993) placed upper limits on the radio flux density from this source of ~0.5 mJy at 4.8 GHz. Fender & Hendry (2000) have shown that the mean radio flux density of the Z sources at cm wavelengths, when on the Horizontal Branch, is $55 \pm 13/d^2$ mJy (where d is the distance to the source in kpc). Our significantly stronger upper limits of ⩽0.1 mJy further constrain the nature of 2S 0921−630. It is possible, given the variability in the radio emission from the Z sources, that both ourselves and Zwarthoed et al. (1993) have been unlucky enough to catch 2S 0921−630 in a radio 'off' state (corresponding to the lower NB or FB). However, if this is not the case, the stronger upper limits on the radio flux density imply one of the following.

(i) 2S 0921−630 is not a Z-source and only produces the much weaker and more transient radio emission associated with atoll-type sources.

(ii) 2S 0921−630 is a Z source, at a distance of ⩾20 kpc.

(iii) Radio emission from Z sources is strongly beamed and perpendicular to the orbital plane, so that the observed flux from 2S 0921−630 is severely reduced. This would however imply that the other six Galactic Z sources all have very similar inclinations, and we consider it unlikely.

We consider the most likely conclusion of this result to be that 2S 0921 − 630 is not a Z source.

3.1.5 GX 339−4

This black hole candidate is commonly detected at a level of ~5 mJy at cm wavelengths when in the low/hard X-ray state (Hannikainen et al. 1998 and references therein). However, at the time of these observations the source was in the high/soft X-ray state, and the radio emission was suppressed; see Fender et al. (1999b) for a fuller discussion.

3.2 The radio: X-ray relation

Penninx et al. (1988) showed that for the Z source GX 17+2 there appeared to be a strong coupling between X-ray state and radio emission. This was in the sense that radio emission was strongest on the horizontal branch (HB), weak on the normal branch (NB) and absent on the flaring branch (FB). This relation was found to be consistent with simultaneous radio and X-ray observations of the Z sources Cyg X-2 (Hjellming et al. 1990a) and Sco X-1 (Hjellming et al. 1990b). The relation did not appear to hold in simultaneous radio and X-ray observations of the Z source GX 5−1 (Tan et al. 1992), but, given the uncertainty in our knowledge of time delays before onset of the radio emission (presumably as some component of the ejecta expands and increases in radio flux above our detection threshold), more study is required to investigate this.

We observed four Z sources simultaneously with ATCA and the *BeppoSAX* WFC. Inspection of Fig. 2 and Table 2 shows that the two sources that were detected, GX 17+2 and GX 5−1, were in the upper NB/HB and HB respectively. The two Z sources that were not detected, GX 340+0 and GX 349+2, were in the NB and at the NB/FB vertex respectively, at the time of observation. Thus our observations are in agreement with the relation observed from GX 17+2, Cyg X-2 and Sco X-1, in which radio emission is significantly stronger on the HB than on the NB, which itself is stronger than on the FB.

Fig. 3 shows the HIDs for the brightest of the atoll sources at the time of our observations. GX 9+1 appears to be in the UB; while for GX 3+1 and GX 9+9 the X-ray ‘state’ is less well defined. GX 13+1 was relatively stable during the course of these observations; it will be of interest to see whether recent simultaneous *RXTE* PCA/VLA observations (Homan et al., in preparation) reveal it to be in a similar region of the HID when radio-bright.

3.3 Relative astrometry

Reynolds et al. (1995) have shown that the coordinates measured with ATCA are accurate to ~17 mas per degree of separation of the target from the phase calibrator, plus some systematic error resulting from uncertainty in the absolute position of the calibrator itself. Table 4 lists the positions derived from point-source fits at 3.5 cm to each of the three detected sources. As all three sources were observed with the same phase calibrator, J 1751−253 (B1748−253), the relative separations can be measured to a few tens of mas. The uncertainty in the absolute position of J 1751−253 is no more than 10 mas (it is a VLA ‘B’ quality calibrator), and so the relative uncertainties arising from ATCA will dominate. It is the improvement in the accurate coordinates of this calibrator that allows us to improve on the coordinates of GX 5−1 presented in Grindlay & Seaquist (1986).

Table 4. Accurate positions of the three sources detected, based upon point-source fits at 3.5 cm. The dominant positional uncertainty scales as 17 mas per degree of separation ($\Delta\theta$) of the target from the phase calibrator J 1751−253. The error in each ordinate is $\sqrt{2}$ of the total uncertainty.

Name	$\Delta\theta$ (deg)	Coordinates (J2000) RA	Dec.	σ (mas)
J 1751−253	–	17:51:51.263	−25:24:0.063	≤10
GX 17+2	11.4	18:16:01.388	−14:02:10.425	~190
GX 13+1	8.3	18:14:31.083	−17:09:25.859	~140
GX 5−1	2.3	18:01:08.233	−25:04:42.044	~40

The importance of these relative astrometric measurements is twofold. Firstly, given the crowded nature of the Galactic Centre region at optical and infrared wavelengths, very accurate coordinates are required to identify confidently the counterpart to the X-ray and radio source. This is well illustrated by the recent discussion about the true infrared counterpart to GX 17+2 (Deutsch et al. 1999). Our best position for this source is consistent with the weighted J2000 position presented in Deutsch et al. (1999), and supports their assertion that NP Ser is *not* the optical/IR counterpart to the X-ray source. The infrared counterpart to GX 13+1 is more confidently determined (Naylor, Charles & Longmore 1991; Bandyopadhyay et al. 1999). Our new very accurate coordinates for GX 5−1 have recently been utilized to identify finally the probable infrared counterpart to this source (Jonker et al. 2000).

Secondly, there is a large uncertainty in the distance to most of these sources. Future accurate relative astrometry will allow measurements of relative proper motions of the sources to be made to see whether they agree with the Galactic rotation curve for the Galactic Centre distance, and/or possess high peculiar velocities, as inferred recently for the unusual X-ray binary Cir X-1 (Johnston, Fender & Wu 1999).

4 CONCLUSIONS

We have demonstrated the usefulness of coordinating X-ray and radio observations of low-mass X-ray binaries. In the absence of large-scale programmes and/or the next generation of radio telescopes, we believe that such snapshots of the X-ray and radio state of these systems are the best way to build up a comprehensive (empirical) understanding of the X-ray:radio relation and hence the accretion disc:jet coupling in these systems.

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REFERENCES

Bandyopadhyay R. M., Shahbaz T., Charles P. A., Naylor T., 1999, MNRAS, 306, 417

Boella G., Butler R. C., Perola G. C., Piro L., Scarsi L., Bleeker J. A. M., 1997, A&A, 122, 299

Burgess A. M., Hunstead R. W., 1995, Pub. Astron. Soc. Aust., 12, 227

Cooke B. A., Ponman T. J., 1991, A&A, 244, 358

Deutsch E. W., Margon B., Anderson S. F., Wachter S., Goss W. M., 1999, ApJ, 524, 406

Fender R. P., Hendry M. A., 2000, MNRAS, 317, 1

Fender R. P., Bell Burnell S. J., Waltman E. B., 1997, Vistas Astron., 41, 3

Fender R. P., Garrington S. T., McKay D. J., Muxlow T. W. B., Pooley G. G., Spencer R. E., Stirling A. M., Waltman E. B., 1999a, MNRAS, 304, 865

Fender R. P. et al., 1999b, ApJ, 519, L165

Fender R. P., Pooley G. G., Durouchoux P., Tilanus R. P. J., Brocksopp C., 2000, MNRAS, 312, 853

Grindlay J. E., Seaquist E. R., 1986, ApJ, 310, 172

Hannikainen D. C., Hunstead R. W., Campbell-Wilson D., Sood R. K., 1998, A&A, 337, 460

Heise J., 1999, Nucl. Phys. B – Proc. Suppl., 69, 186

Hjellming R. M., Han X., 1995, in Lewin W. H. G., van Paradijs J., van der Heuvel E. P. J., eds, X-ray binaries. Camridge Univ. Press, Cambridge, p. 308

Hjellming R. M., Han X., Cordova F. A., Hasinger G., 1990a, A&A, 235, 147

Hjellming R. M. et al., 1990b, ApJ, 365, 681

Hjellming R. M.,et al., 1999, ApJ, 514, 383

Homan J., van der Klis M., Wijnands R., Vaughan B., Kuulkers E., 1998, ApJ, 499, L41

Jager R. et al., 1997, A&AS, 125, 557

Johnston H. M., Fender R. P., Wu K., 1999, MNRAS, 308, 415

Jonker P. G., Fender R. P., van der Klis M., Hambly N., 2000, MNRAS, 315, L57

Martí J., Mirabel I. F., Rodríguez L. F., Chaty S., 1998, A&A, 332, L45

Mirabel I. F., Rodríguez L. F., 1999, ARA&A, 37, 409

Naylor T., Charles P. A., Longmore A. J., 1991, MNRAS, 252, 203

Nelson R. F., Spencer R. E., 1988, MNRAS, 234, 1105

Penninx W., 1989, in Hunt J., Battrick B., eds, 23rd ESLAB symposium on ‘Two Topics in X-ray Astronomy’, ESA SP-296, p. 185

Penninx W., Lewin W. H. G., Zijlstra A. A., Mitsuda K., van Paradijs J., van der Klis M., 1988, Nat, 336, 146

Reynolds J. E. et al., 1995, A&A, 304, 116

Sault R. J., Teuben P. J., Wright M. C. H., 1995, in Shaw R., Payne H. E., Hayes J. J. E., eds, ASP Conf. Ser. Vol. 77, Astronomical Data Analysis Software and Systems IV. Astron. Soc. Pac., San Francisco, p. 433

Shahbaz T., Kuulkers E., Charles P. A., van der Hooft F., Casares J., van Paradijs J., 1999, A&A, 344, 101

Tan J., Lewin W. H. G., Hejllming R. M., Penninx W., van Paradijs J., van der Klis M., Mitsuda K., 1992, ApJ, 385, 314

van der Klis M., 1995, in Lewin W. H. G., van Paradijs J., van den Heuvel E. P. J., eds, X-ray binaries. Cambridge Univ. Press, Cambridge, p. 252

van der Klis M., 2000, ARA&A, in press (astro-ph/0001107)

Zwarthoed G. A. A., Stewart R., Penninx W., van Paradijs J., van der Klis M., Roy A. L., Amy S. W., 1993, A&A, 267, 101

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