Disc–jet coupling in an atoll-type neutron star X-ray binary: 4U 1728–34 (GX 354–0)

S. Migliari,1⋆ R. P. Fender,1⋆ M. Rupen,2 P. G. Jonker,3 M. Klein-Wolt,1 R. M. Hjellming2 and M. van der Klis1

1 Astronomical Institute ‘Anton Pannekoek’, University of Amsterdam, and Centre for High Energy Astrophysics, Kruislaan 403, 1098 SJ, Amsterdam, the Netherlands
2 National Radio Astronomy Observatory, Socorro, NM 87801, USA
3 Institute of Astronomy, Madingley Road, Cambridge CB3 0HA

Accepted 2003 May 12. Received 2003 May 9; in original form 2003 March 20

ABSTRACT
We have analysed 12 simultaneous radio (Very Large Array) and X-ray (RXTE) observations of the atoll-type X-ray binary 4U 1728–34, performed in two blocks in 2000 and 2001. We have found that the strongest and most variable emission seems to be associated with repeated transitions between hard (island) and softer (lower banana) X-ray states, while weaker, persistent radio emission is observed when the source is steadily in the hard X-ray state. There is a significant positive ranking correlation between the radio flux density at 8.46 GHz and the 2–10 keV X-ray flux. Moreover, significant positive ranking correlations between radio flux density and X-ray timing features (i.e. break and low-frequency Lorentzian frequencies) have been found. These correlations represent the first evidence for a coupling between disc and jet in an atoll-type X-ray binary. Furthermore, drawing an analogy between the hard (island) state and the low/hard state of black hole binaries, we confirm previous findings that accreting neutron stars are a factor of ∼30 less ‘radio loud’ than black holes.

Key words: binaries: close – stars: individual: 4U 1728–34 – stars: neutron – ISM: jets and outflows – radio continuum: stars.

1 INTRODUCTION
In black hole candidates (BHCs) and in Z-type neutron star (NS) X-ray binaries, connections between inflow (disc) and outflow (jet) have been established. Many works (e.g. Hjellming & Han 1995 and references therein; Falcke & Biermann 1996; Dhawan, Mirabel & Rodríguez 2000; Fomalont, Geldzahler & Bradshaw 2001) suggest that all the radio emission from such systems (including weak spatially unresolved emission) originates in jet-like outflows. In persistent BHCs, steady jet outflows are associated with the ‘low/hard’ X-ray state, while they are not detected in the ‘high/soft’ state (Fender et al. 1999; Fender 2001a,b). In Z-type NSs the radio emission seems to be strongest in the ‘horizontal’ branch and weakest in the ‘flaring’ branch (Penninx et al. 1988; Hjellming & Han 1995, and references therein). Atoll-type NS X-ray binaries share many X-ray spectral and timing properties with BHCs (especially in the low/hard state; van der Klis 1994). However, only a few atolls are detected in radio band because of their lower radio luminosity (Fender & Hendry 2000). Hence, although they represent the largest class of X-ray binaries (∼45 per cent, using the ‘broader’ definition of Fender & Hendry 2000), no information on a possible radio:X-ray coupling has been available until now.

4U 1728–34 (GX 354–0; Forman, Tananbaum & Jones 1976) is a low-mass X-ray binary and a type I X-ray burster (Lewin, Clark & Doty 1976; Hoffman et al. 1976). From X-ray burst properties, a distance to the source (accurate to within 15 per cent: Kuulkers et al. 2003) of 5.2 kpc, for a 1.4-M⊙ mass NS, was obtained (Galloway et al. 2002; see also Basinska et al. 1984). Hasinger & van der Klis (1989) classified 4U 1728–34 as an atoll-type X-ray binary. A multi-Lorentzian timing study of the power spectrum shows well-defined and correlated features in both the low- and high-frequency ranges (for details see e.g. van Straaten et al. 2002, and references therein). Timing properties are related to the position of the source in the colour–colour diagram (CD; e.g. Méndez & van der Klis 1999; Di Salvo et al. 2001; van Straaten et al. 2002), and therefore to the changing mass accretion rate M (which probably increases from the island to the banana state: e.g., Hasinger & van der Klis 1989; although there are secular changes on time-scales of a few days or longer that cause shifts in the CD: e.g. van der Klis 2001). The continuum of the broadband 0.1–100 keV energy spectrum of the persistent emission of 4U 1728–34 in the soft state is well fit by a soft thermal (blackbody or multitemperature disc blackbody) plus a Comptonized component (Di Salvo et al. 2000).

*E-mail: migliari@science.uva.nl (SM); rpf@science.uva.nl (RPF)
The optical counterpart of 4U 1728–34 cannot be detected due to the high extinction in the galactic centre direction. In 1997 Martí et al. (1998) observed 4U 1728–34 in the radio band (at 4.86 GHz) with the VLA, and after a few non-detections (with upper limits up to 0.32 mJy) successfully detected its radio counterpart with a variable flux density ranging between ∼0.3 and ∼0.6 mJy. They also detected a J and K-band infrared source ($J = 19.6 ± 0.4$ and $K = 15.1 ± 0.2$) within 1 arcsec of the radio source.

2 OBSERVATIONS AND DATA ANALYSIS

4U 1728–34 was observed on 13 occasions between 2000 and 2001 with the VLA, 12 times simultaneously with RXTE observations. In Table 1 we show the MJDs of the observations in 2000 (a to f) and in 2001 (g to l) and the non-simultaneous with RXTE at MJD 52056.37. The array was in configuration C during the observations in 2000, B during the non-simultaneous observation and g, and CnB during h to l. Observation durations ranged from 5 min to a few hours; flux densities measured at both 4.86 and 8.46 GHz are reported in Table 1. Flux calibration was achieved using J1331+305 or J0137+331; phase calibration was performed using J1744–312 and data reduction using AIPS. Absolute calibration of the flux density scale is estimated to be accurate to ∼3 per cent. No significant flux density variations were found within each data set. Combining the data, the best-fitting coordinates for the radio counterpart are J2000 RA 17°31′57.687 ±0.0013 Dec −33°30′01.11 ±0.18′; this is consistent with the position reported in Martí et al. (1998) within 1.5′. There is no evidence for any spatial extension during these observations.

For the RXTE observations we have used data from the Proportional Counter Array (PCA; for spectral and timing analyses) and the High Energy X-ray Timing Experiment (HEXTE; only for spectral analysis). The durations of the X-ray observations range between half an hour to a few hours. We have used the PCA STANDARD2 data to produce the CD of the RXTE observations (Fig. 1). The soft colour and the hard colour are defined as the count rate ratio $(3.5–6)/(2–3.5)$ keV and $(9.7–16)/(6–9.7)$ keV, respectively. We have normalized the colours of 4U 1728–34 to the colours of the Crab calculated with the closest observation available to each 4U 1728–34 observation. The identification of the X-ray states as island (IS) and lower banana (LB) are confirmed by timing properties (see below; Di Salvo et al. 2001; van Straaten et al. 2002).

For the spectral analysis of PCA STANDARD2 data we subtracted the background, estimated using PCASEXTRACT v3.0, produced the detector response matrix with PCARSP v8.0 and analysed the energy spectra in the range 3–20 keV. We extracted HEXTE energy spectra (channels 15–61) from both clusters A and B, subtracted the background, corrected for dead-time using FTOOLS v5.2 and analysed the spectra between 20 and 60 keV, except the observation a in which the source was not detected above 40 keV. A systematic error of 0.75 per cent was added to the PCA data. Four observations (see Table 1) show one X-ray burst in the PCA light curve. We excluded the burst from the data and analysed only the spectra of the steady persistent emission averaged over each observation. The spectra of d to l are well fitted by an absorbed power law with a high-energy cutoff (in the range ∼19–30 keV) and a blackbody, plus a 6.4–6.7 keV Gaussian emission line. No high-energy cutoff is necessary for a, b and c. The equivalent hydrogen column density $N_H$ was fixed to 2.5 × 10$^{22}$ cm$^{-2}$ (Hoffman et al. 1979; Grindlay & Hertz 1981; Foster, Ross & Fabian 1986; Di Salvo et al. 2000).

For the production of the power spectra we used EVENT data with a time resolution of 125 µs. We rebinned the data in time to obtain a Nyquist frequency of 4096 Hz. For each observation we created power spectra segments of 128 s length, cutting the first five energy channels to avoid possible fake high frequency features of instrumental origin (Klein-Wolt, Homan & van der Klis, in preparation), and we removed X-ray bursts from the data, but no background and dead-time corrections were performed. We averaged the power spectra and subtracted the Poisson noise estimated between 3000 and 4000 Hz applying the standard method by Zhang et al. (1995). We applied the Leahy et al. (1983) normalization and then converted the power spectra to squared fractional rms. For the fitting procedures the multi-Lorentzian model was used in the power times frequency representation (for details see Belloni, Psaltis & van der Klis 2002 and references therein).

The power spectra are fitted using one broad Lorentzian to represent the low-frequency noise and the break frequency, one or two narrower Lorentzians ($L_b$ and $L_d$; see van Straaten, van der Klis & Méndez 2003 for details on nomenclature), a broad Lorentzian around 100 Hz ($L_{b,h}$) and narrow Lorentzians to fit the kHz QPOs.

### Table 1

| MJD   | $F_{(2–60)} \times 10^{-9}$ (erg s$^{-1}$ cm$^{-2}$) | $F_{(2–10)} \times 10^{-9}$ (erg s$^{-1}$ cm$^{-2}$) | $F_{8.46}$ (mJy) | $F_{4.86}$ (mJy) | break (Hz) | $L_b$ (Hz) | $L_d$ (Hz) | $L_u$ (Hz) |
|-------|-----------------------------------------------|-----------------------------------------------|-----------------|-----------------|-------------|-----------|-----------|-----------|
| 51638.53 | 1.46 ± 0.07 | 1.03 ± 0.05 | 0.50 ± 0.08 | ... | 4.84 ± 0.45 | 15.36 ± 0.64 | 28.59 ± 1.63 | ... |
| 51649.58$^a$ | 0.88 ± 0.10 | 0.44 ± 0.05 | < 0.9 | ... | 12.70 ± 2.64 | 21.95 ± 0.68 | 51.49 ± 3.55 | 870 ± 3 |
| 51669.51 | 3.51 ± 0.23 | 2.25 ± 0.15 | 0.6 ± 0.2 | ... | 12.77 ± 2.63 | 21.97 ± 0.67 | 51.47 ± 3.53 | 870 ± 4 |
| 51677.32 | 2.75 ± 0.18 | 1.54 ± 0.10 | 0.33 ± 0.15 | ... | 4.85 ± 0.45 | 15.36 ± 0.64 | 28.57 ± 1.62 | 563 ± 23 |
| 51685.47 | 3.55 ± 0.22 | 1.81 ± 0.11 | 0.62 ± 0.2 | ... | 6.43 ± 0.46 | 18.09 ± 0.42 | 29.17 ± 2.07 | 610 ± 13 |
| 51695.34$^a$ | 3.83 ± 0.50 | 1.84 ± 0.24 | < 1.2 | ... | 2.37 ± 0.19 | 15.40 ± 0.58 | ... | ... |
| 52056.37$^a$ | ... | ... | 0.18 ± 0.02 | 0.19 ± 0.05 | ... | ... | ... | ... |
| 52058.36$^a$ | 4.66 ± 0.31 | 2.42 ± 0.16 | 0.11 ± 0.02 | < 0.15 | 2.50 ± 0.22 | 15.94 ± 0.61 | 616 ± 19 | ... |
| 52061.35$^a$ | 1.20 ± 0.14 | 0.60 ± 0.07 | 0.09 ± 0.02 | < 0.14 | 2.19 ± 0.35 | 13.75 ± 1.13 | ... | ... |
| 52063.31 | 1.31 ± 0.13 | 0.61 ± 0.06 | 0.11 ± 0.02 | < 0.13 | 1.29 ± 0.18 | 15.31 ± 1.75 | ... | ... |
| 52065.34 | 1.36 ± 0.13 | 0.62 ± 0.06 | 0.15 ± 0.02 | 0.20 ± 0.02 | 1.53 ± 0.14 | 10.98 ± 0.59 | ... | ... |
| 52067.30 | 1.43 ± 0.25 | 0.69 ± 0.12 | 0.16 ± 0.02 | < 0.15 | 1.75 ± 0.20 | 12.19 ± 0.74 | ... | ... |
| 52069.29 | 1.48 ± 0.11 | 0.70 ± 0.05 | 0.09 ± 0.02 | < 0.14 | 1.18 ± 0.08 | 9.83 ± 0.41 | 399 ± 37 | ... |

Notes. $^a$The observation shows an X-ray burst; $^b$not simultaneous with RXTE.
Disc–jet coupling in 4U 1728–34

1.2 1.4 1.6 1.8 2.0 1.2 1.4 1.8 1.6 2.0

Figure 1. X-ray colour–colour diagrams (CDs) of the 12 RXTE/PCA observations of 4U 1728–34 simultaneous with VLA: Soft Colour \(= (3.5–6) \text{ keV}/(2–3.5) \text{ keV} \), Hard Colour \(= (9.7–16) \text{ keV}/(6–9.7) \text{ keV} \). All the 12 simultaneous radio/X-ray observations are shown in each panel (the small points represent 16 s os data). Marked with filled squares are the individual observations in chronological order (a-to-f are the observations in 2000 and g-to-l are the observations in 2001; see Table 1). The corresponding radio flux densities in \(\mu\text{Jy} \) at 8.46 GHz and, when available, at 4.86 GHz (upper limits are 3\(\sigma \)) are also indicated.

3 OVERALL PATTERN OF BEHAVIOUR

Fig. 1 shows the position in the CD of the 12 observations and the corresponding radio flux density (the upper limits are 3\(\sigma \)) at 8.46 GHz and, where available, at 4.86 GHz. We see that the observations in 2000 (taken every \(\sim 10 \text{ d} \)) are mainly in the IS with two excursions to the LB. It seems that during this period the source was repeatedly transiting between IS and LB. These observations show the highest radio flux density values up to 0.6 \(\text{mJy} \) with variations of \(\sim 0.3 \text{ mJy} \) between observations, and two non-detections (both non-detections have 3\(\sigma \) limits above the other measurements in IS, so are consistent with the other observations). In 2001 the observations (taken every 2–3 d) are steady in the IS, the radio flux density is lower (around 0.1 \(\text{mJy} \)) and the variations are smaller (\(\ll 0.06 \text{ mJy} \)) than in 2000. This indicates a possible association of radio flaring with transitions between hard (i.e. IS) and softer (i.e. LB) X-ray states, and ‘quiescent/steady’ radio emission with the hard (IS) state. We cannot find any measurable effect of type-I X-ray bursts on radio emission, although we notice that the bursts are detected when the radio flux seems to be low: in two observations of 2001 and in the two observations of 2000 with no radio detections (see Table 1).

The dual-frequency radio measurements are not good enough to seriously constrain the radio spectrum (see Table 1). They are in most cases consistent with both flat \( (\alpha \sim 0, \text{ where} \ S_{\nu} \propto \nu^{\alpha} \text{ and} \ S_{\nu} \text{ is the radio flux density at a certain frequency} \nu \text{ spectrum radio emission as observed from low/hard state black holes}, \) or the optically thin emission \( (\alpha \sim -0.6) \) observed from X-ray transients (i.e. non-simultaneous observation: \(\alpha = -0.14 \pm 0.36; \)

Figure 2. Power spectrum of the observation c. The break, \(L_b\), \(L_h\), \(L_{\text{Hz}}\) and \(L_u\) are shown.

© 2003 RAS, MNRAS 342, L67–L71

Downloaded from https://academic.oup.com/mnras/article-abstract/342/4/L67/958941
by guest on 30 July 2018
respectively. The squares mark the observations in 2001. The lines are the upper limits and the observation g (star) (fl line) respectively; in Fig. 4 the fitting power-laws \( R \propto \nu^\alpha \) where \( R \) is the radio flux density and \( \nu \) is the frequency, have \( \Gamma = 0.9 \pm 0.1 \) and \( \Gamma = 1.4 \pm 0.2 \) for break and \( L_h \) respectively. There is also a hint (with only four points, treating with caution the observation g; see also Section 5) of a correlation between \( L_h \) frequencies and radio flux density \( \sim 20 \) mJy at 15.2 GHz. A possible (qualitative) behaviour was found by Muno et al. (2001) for the BHC GRS 1915+105; they found that the radio plateau' observations (i.e. radio flux densities \( \sim 100 \) mJy at 15.2 GHz) show lower 0.5–10 Hz QPO frequencies than ‘radio faint’ observations (i.e. radio flux densities \( \lesssim 20 \) mJy at 15.2 GHz).

The QPO frequencies are generally interpreted as being related to the motion of matter in the accretion disc at a certain radius. In particular, in low magnetic field NS systems, the kHz QPOs are thought to be related to motion of matter a few stellar radii from the star (see van der Klis 2000, for a review), and, as in e.g. Miller, Lamb & Psaltis (1998), correspond to the inner radius of the Keplerian disc. According to most models (see e.g. van der Klis 2001, and references therein) the kHz QPOs (and also other timing features like the break and \( L_h \) that generally correlate with

---

4 RADIO:X-RAY CORRELATIONS

Fig. 3 shows the radio flux density as a function of the soft spectral component (i.e. blackbody), the hard spectral component (i.e. power law) and the total unabsorbed 2–10 keV X-ray flux (this range is chosen to allow a direct comparison with the radio:X-ray flux correlation in BHCs; e.g. Gallo, Fender & Pooley 2003; see Section 5) of the 12 observations. Excluding the observation g (the star; we will discuss this point in Section 5), there are significant positive ranking correlations between the radio flux density and the X-ray fluxes (99, 97 and 98 per cent significance with blackbody, power-law and total respectively). The fitting power-laws \( F_R \propto F_X^\Gamma \), where \( F_R \) is the radio flux density and \( F_X \) is the X-ray flux, shown in Fig. 3 have \( \Gamma \) of 1.4 ± 0.2 and 1.5 ± 0.2 for blackbody, power-law and total X-ray flux respectively. This indicates that the jet power is correlated to the accretion rate as inferred from X-ray flux density.

In Fig. 4 we show the frequency of the break and \( L_h \) as a function of the radio flux density. There is a significant positive ranking correlation between break, \( L_h \) frequencies and radio flux density (99 per cent and 98 per cent significance respectively; in Fig. 4 the fitting power laws \( F_R \propto \nu^\alpha \), where \( F_R \) is the radio flux density and \( \nu \) is the frequency, have \( \Gamma = 0.9 \pm 0.1 \) and \( \Gamma = 1.4 \pm 0.2 \) for break and \( L_h \) respectively). There is also a hint (with only four points, treating with caution the observation g; see also Section 5) of a correlation between \( L_h \) frequency and the radio flux density. An opposite (qualitative) behaviour was found by Muno et al. (2001) for the BHC GRS 1915+105; they found that the ‘radio plateau’ observations (i.e. radio flux densities \( \sim 100 \) mJy at 15.2 GHz) show lower 0.5–10 Hz QPO frequencies than ‘radio faint’ observations (i.e. radio flux densities \( \lesssim 20 \) mJy at 15.2 GHz).

The QPO frequencies are generally interpreted as being related to the motion of matter in the accretion disc at a certain radius. In particular, in low magnetic field NS systems, the kHz QPOs are thought to be related to motion of matter a few stellar radii from the star (see van der Klis 2000, for a review), and, as in e.g. Miller, Lamb & Psaltis (1998), correspond to the inner radius of the Keplerian disc. According to most models (see e.g. van der Klis 2001, and references therein) the kHz QPOs (and also other timing features like the break and \( L_h \) that generally correlate with

---

`L70  S. Migliari et al.

\[ \alpha = -0.55; h: \alpha = -0.69; i: \alpha = -0.31; j: \alpha = -0.56 \pm 0.14; k: \alpha = -0.21; l: \alpha = -0.81. \]`
them; Di Salvo et al. 2000; Méndez et al. 2001; van Straaten et al. 2002) are related to the disc mass accretion rate. Therefore our radio flux/X-ray timing correlations represent independent (i.e. different from radio/X-ray flux correlations) evidence for a coupling between accretion and outflow rates. As a caveat, we note that the correlations discussed above are dominated by the difference between the two blocks of data, in 2000 and 2001, respectively. While the correlations themselves are not in doubt, further observations are required to establish if there is a smooth relation between the blocks or a more bimodal form of behaviour.

5 DISCUSSION

We know that the X-ray flux does not trivially trace the disc mass accretion rate; ‘parallel tracks’ are observed between kHz QPO frequencies and X-ray luminosity (e.g. Méndez et al. 1999; Ford et al. 2000; Méndez et al. 2001). The strong coupling between spectral and timing properties in X-ray binaries, suggests that the QPOs are actually a more straightforward indicator, rather than luminosity, of not of the absolute value of Φ at least of variations of the disc mass accretion rate and maybe of the inner radius of the accretion disc (see van der Klis 2001). Therefore, the radio/X-ray flux and even more the radio flux/X-ray timing correlations translate into the first evidence for a coupling between the accretion disc inflow and the jet outflow in an atoll source.

4U 1728–34 shows a correlation between radio flux density and X-ray flux qualitatively similar to that found for BHCs in the low/hard state (Hannikainen et al. 1998; Corbel et al. 2000, 2003; Gallo et al. 2003), although the index Γ of the coupling (see Fig. 3) is rather steeper. The observation g (star in Fig. 3, has the highest X-ray flux in our sample and a low (compared to what ‘expected’ from the radio/X-ray flux correlation we have found for the other observations) radio flux density. Because g shows the same low-frequency timing properties of the other observations in 2001, this high X-ray flux can be interpreted as due to a ‘parallel track’ effect (see e.g. Méndez et al. 2001). Furthermore, in the power spectrum, although the low frequency features are in agreement with previous observations at the same position in the CD, the relative strengths of the kHz QPOs we find (the ‘lower’ kHz QPO is stronger than the ‘upper’) are usually observed in softer observations, i.e. in the banana state rather than in the IS (e.g. van Straaten et al. 2002). A comparison with BHCs (see e.g. Gallo et al. 2003) also show that g is almost at the same X-ray luminosity (using a distance of 5.2 kpc: Galloway et al. 2002) as the ‘radio quenching’ in BHCs; this suggests (nothing more than this, as it is only one point) that suppression (‘quenching’) of the radio jet may occur above some luminosity, as in BHCs. It is interesting to note that 4U 1728–34 shows a strong correlation as e.g. Cyg X-1 (Gallo et al. 2003), show a radio luminosity ∼30 times less than Cyg X-1 (i.e. scaled to 1 kpc; the radio flux densities are $F_{\text{radio}} \sim 2.5 \text{ mJy}$ and $F_{\text{Cyg X-1}} \sim 75 \text{ mJy}$). This confirms (also quantitatively) the Fender & Hjellming (2000) finding of radio ‘loudness’ difference between atoll-type NSs and BHCs.

X-ray (i.e. mainly accretion) properties in atoll sources and in BHCs (in low/hard state) seem to be qualitatively the same (e.g. van der Klis 1994). This suggests that the same physical processes take place in both type of sources. What about the physical processes that connect inflow (disc) and outflow (jet) matter in X-ray binaries? The key to answering this question lies in the study of atoll versus BHCs disc–jet coupling. The results presented in this paper may be a first step in that direction.

ACKNOWLEDGMENTS

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. We would like to thank Steve van Straaten and Tiziana Di Salvo for useful discussions.

REFERENCES

Basinska E. M., Lewin W. H. G., Szyajno M., Cominsky L. R., Marshall F. J., 1984, ApJ, 281, 337
Belloni T., Psaltis D., van der Klis M., 2002, ApJ, 572, 392
Corbel S., Fender R. P., Tzioumis A. K., Nowak M. A., McIntyre V., Durouchoux P., Sood R., 2000, A&A, 359, 251
Corbel S., Nowak M. A., Fender R. P., Tzioumis A. K., Markoff S., 2003, A&A, 400, 1007
Dhawan V., Mirabel I. F., Rodríguez L. F., 2000, ApJ, 543, 373
Di Salvo T., Iaria R., Burderi L., Robba N. R., 2000, ApJ, 542, 1034
Di Salvo T., Méndez M., van der Klis M., Ford E., Robba N. R., 2001, ApJ, 546, 1107
Falcke H., Biermann P. L., 1996, A&A, 308, 321
Fender R. P., 2001a, MNRAS, 322, 31
Fender R. P., 2001b, Astrophys. Space Sci. Supp., 276, 69
Fender R. P., Hendry M. A., 2000, MNRAS, 317, 1
Fender R. P. et al., 1999, ApJ, 519, L165
Fomalont E. B., Geldzahler B. J., Bridhash C. F., 2001, ApJ, 558, 283
Ford E. C., van der Klis M., Méndez M., Wijnands R., Homan J., Jonker P. J., van Paradijs J., 2000, ApJ, 537, 368
Forman W., Tananbaum H., Jones C., 1976, ApJ, 206, L29
Foster A. J., Ross R. R., Fabian A. C., 1986, MNRAS, 221, 409
Gallo E., Fender R. P., Pooley G. G., 2003, MNRAS, in press
Galloway D. K., Psaltis D., Chakrabarty D., Muno M. P., 2001, ApJ, in press (astro-ph/0208464)
Grindlay J. E., Hertz P., 1981, ApJ, 233, L51
Hannikainen D. C., Heuvel P. J. E., van Paradijs J., 1998, A&A, 337, 460
Hasinger G., van der Klis M., 1989, A&A, 225, 79
Hjellming R. M., Han X. H., 1995, in Lewin W. H. G., van Paradijs J., van den Heuvel E. P. J., eds, X-ray Binaries. Cambridge Univ. Press, Cambridge, p. 308
Hoffman J. A., Lewin W. H. G., Doty J., Hearn D. R., Clark G. W., Jernigan G., Li F. K., 1976, ApJ, 210, L13
Hoffman J. A. et al., 1979, ApJ, 233, L51
Kuulkers E., den Hartog P. R., in ’t Zand J. J. M., Verbunt F. W. H., Harris W. E., Cocchi M., 2003, A&A, 399, 663
Leahy D. A., Darbro W., Ekers R. F., Weisskopf M. C., Kahn S., Sutherland P. G., Grindlay J. E., 1983, ApJ, 266, 160
Lewin W. H. G., Clark G. W., Doty J., 1976, IAU Circ., 2922
Miller M. C., Lamb F. K., Psaltis D., 1998, ApJ, 508, 791
Marit J., Mirabel I. F., Rodríguez L. F., Chaty S., 1998, A&A, 332, L45
Méndez M., van der Klis M., 1999, ApJ, 517, L51
Méndez M., van der Klis M., Ford E. C., 2001, ApJ, 561, 1016
Méndez M., van der Klis M., Ford E. C., Wijnands R., van Paradijs J., 1999, ApJ, 511, L49
Muno M. P., Remillard R. A., Morgan E. H., Waltman E. B., Dhawan V., Hjellming R. M., Pooley G., 2001, ApJ, 556, 515
Penninx W., Lewin W. H. G., Zijlstra A. A., Mitsuda K., van Paradijs J., 1988, Nat, 336, 146
van der Klis M., 1994, ApJS, 92, 511
van der Klis M., 2000, ARA&A, 38, 717
van der Klis M., 2001, ApJ, 561, 943
van Straaten S., van der Klis M., Di Salvo T., Belloni T., 2002, ApJ, 568, 912
van Straaten S., van der Klis M., Méndez M., 2003, ApJ, submitted
Zhang W., Jahoda K., Swank J. H., Morgan E. H., Giles A. B., 1995, ApJ, 449, 930

This paper has been typeset from a TeX/LaTeX file prepared by the author.