RADIO EMITTING X-RAY BINARY STARS

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1. Introduction

Some of the most astrophysically interesting objects are found among the radio-emitting X-ray binary stars (REXRB). The class includes the well-studied objects such as SS 433, Cyg X–3 and Sco X–1. The recent discoveries of relativistic ejection of radio knots in the X-ray transients 1915+105 (Mirabel & Rodriguez 1994) and 1655–40 (Hjellming & Rupen 1995) well illustrate the extreme nature of some of these objects.

X-ray binaries are semi-detached binary stars in which matter is transfered from a more or less normal star onto a neutron star or black hole. X-ray satellites have detected large numbers of these objects (193 in a recent catalogue by van Paradijs 1995). However only a small fraction of these are known to have radio emission (e.g. Hjellming 1988).

2. Radio properties

The radio emission mechanism is almost certainly non-thermal and due to synchrotron radiation, since the sources have high brightness temperatures and in some cases show polarized emission. Energetic electrons and magnetic fields are therefore required. The relationship between the radio and X-ray emission remains unclear, though some sources with Z–shaped X-ray colour-colour diagrams have stronger radio emission in the radio when in the horizontal branch (e.g. GX 5+1, Tan et al. 1992).

The REXRBs found to date contain a wide range of different types of source, although all obtain their energy as a result of accretion onto a compact object. There is as yet no clear demarcation in the radio behaviour

A. Evans and J. H. Wood (eds.), Cataclysmic Variables and Related Objects, 371–374.

between high mass XRBs (Table 1), low mass XRBs (Table 2) and black hole candidates. Flux densities vary from a barely detectable 0.1 mJy to 20 Jy, giving radio luminosities which are $\sim 10^6$ times smaller than those at X-ray wavelengths, so at first sight the radio emission is insignificant.

TABLE 1. The High Mass REXRB

Object		Orbital Period	Radio Flux mJy	Dist. kpc	Radio Lum. erg s^{-1}	X-ray Lum. erg s^{-1}
γ Cass.	0053+604	2.3 h	0.3	0.22	10^{27}	10^{33}
LSI+61°303	0236+610	26.5 d	25..240	2.3	$10^{31}..10^{32}$	10^{33}
V725 Tau	0535+262	111 d	0.2	1.8	10^{28}	$10^{34}..10^{37}$
SS 433	1909+048	13.1 d	200..2000	4.9	$10^{32}..10^{33}$	10^{35}
GRS	1915+105	?	<0.2..700	12.5	$10^{31}..10^{34}$	10^{38}
Cyg X-1	1956+350	5.6 d	7..20	2.5	$10^{30}..10^{31}$	10^{37}
Cyg X-3	2030+407	4.8 h	50..20000	10	$10^{32}..10^{35}$	10^{37}

However this ignores the contribution to the energetics made by the relativistic electrons and magnetic fields necessary for the production of the radio emission. Estimates for the minimum energy in these components can be made (see e.g Pacholczyk 1970) using $E_{\rm min} = (B^2/8\pi)(7/3)$Volume, where B is the magnetic field calculated assuming equipartition. The ratio of proton to electron energy, and the filling factor, have both been assumed to be unity in the calculations. Thus the minimum energy, and hence the power required, can be found if the time-scale for the generation of an extended component is known. The time-scale can be easily determined from the radio flux variability when components are seen to be formed and to evolve.

Only a very few REXRBs turn out to have known radio structures, due to most being unresolved by the VLA and too weak to be studied by VLBI. Most objects which have known structures are listed in Table 3, the only exception being Cir X-1. It is striking that all these objects have collimated flows in their radio structure and that three (J1655−40, SS 433 and 1915+105) have well developed jets.

Using data given by the papers in Table 3, we can work out the equipartition magnetic fields (mostly around 30 mG) and minimum energies of the electrons and magnetic fields required to give the observed radio emission. Using the rise times of the radio flares we can then find the minimum power required as shown in Table 3.

TABLE 2. The Low Mass REXRB

Object		Orbital Period	Radio Flux mJy	Dist. kpc	Radio Lum. erg s^{-1}	X-ray Lum. erg s^{-1}
J0422+32	0422+327	5.1 h	4..8	1..6	$\sim 10^{30}$	$10^{36}..10^{37}$
V1055 Ori	0614+091	5 d	3..40	2.5	$10^{30}..10^{31}$	10^{36}
Nova Mon	0620-003	7.8 h	5..300	0.6	$10^{28}..10^{30}$	$10^{32}..10^{38}$
Nova Mus	1124-684	10.4 h	2..170			
Cen X-4	1455-314	15.1 h	1..8			
Sco X-1	1617-155	0.79 d	1..10	2	$10^{29}..10^{30}$	$10^{37}..10^{38}$
GRO	J1655-40	2.62 d	2..7000	3.2	$10^{30}..10^{33}$	10^{37}
GX9+9	1728-169	4.2 h	0.4	10	10^{30}	10^{38}
GX9+1	1758-205		0.4			10^{38}
GX13+1	1811-171		0.1..1	7	$10^{29}..10^{30}$	10^{38}
GX17+2	1813-140		0.5..13	8.5	$10^{29}..10^{31}$	10^{38}
Ser X-1	1837+049		1	10	10^{30}	10^{38}
Aql X-1	1908+005	19 h	0.1..0.4			10^{36}
QZ Vul	2000+251	8.3 h	0.4..8	2	$10^{29}..10^{30}$	10^{38}
V404 Cyg	2023+338	6.5 d	0.3..1640	3.	$10^{29}..10^{33}$	10^{38}
Cyg X-2	2142+380	9.8 d	0.6..12	8	$10^{31}..10^{32}$	10^{38}
GT2318+620	2318+620		6..40	3..6	$10^{31}..10^{32}$	$10^{34}..10^{35}$

TABLE 3. Energetics of REXRB

Object	Type	Refs. for radio	Radio Rise-time	X-ray Lum. erg s^{-1}	Min. Radio Power erg s^{-1}
LSI+61°303	ns + Be	1	4 d	10^{33}	10^{34}
GRO J1655-40	BH?	2	< 10 d	10^{37}	10^{37}
SS 433	ns + WN	3	1 d	10^{35}	10^{37}
GRS 1915+105	not known	4	< 2 d	10^{38}	10^{39}
Cyg X-3	ns+WR	5	~ 6 h	10^{37}	10^{39}

1 - Massi et al. 1993; 2 - Tingay et al. 1995; 3 - Jowett 1995; 4 - Mirabel & Rodriguez 1995; 5 - Spencer et al. 1986.

3. Conclusion

We can see that the minimum powers required for the radio emission are comparable or even in excess of the X-ray luminosity, and much greater than the observed radio luminosity. Therefore the radio emission, contrary to common belief, is energetically important and may even dominate the system. Note that SS 433 also has a high kinetic energy in thermal material responsible for the moving optical lines of $\sim 10^{41}$ erg s^{-1} and suggests that even higher powers are required. The extraction of such large luminosity from the binary system should therefore be considered when accretion models are being discussed.

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