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Cataclysmic variables as sources of gravitational waves

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Abstract. General relativity predicts that binary systems of stars produce gravitational waves of significant intensity. Here we are particularly interested in the cataclysmic variable binaries (CVs). These systems emit low frequency gravitational waves, $f < 10^{-3} Hz$. We present here a catalog of CVs and argue that part of them are capable of being detected by the Laser Interferometer Space Antenna (LISA).

Key words: gravitational waves – stars: novae, cataclysmic variables

1. Introduction

Detection of gravitational radiation from astrophysical sources will mark a breakthrough in the history of astronomy (see, e.g., Thorne 1987 and Schutz 1996). Experimental efforts to search for these space-time wrinkles have been under development for the past twenty years (Thorne 1995, 1996). With the advent of technological improvements in several crucial aspects of the detection process we will soon be ready to turn them a physical reality (Schutz 1996, Thorne 1995, Finn & Chernoff 1993).

In particular, the Laser Interferometric Space Antenna (LISA) is designed to detect low frequency gravitational waves in the frequency range $10^{-4} - 1$ Hz, which are not possible to detect on the Earth because of seismic noise. There is a lot of very interesting astrophysical phenomena which are believed to generate GWs in the frequency band detectable by LISA, namely: formation of supermassive black holes (SMBHs), SMBH-SMBH binary coalescence, compact stars orbiting around SMBHs (in, e.g., galactic nuclei), a wide variety of binaries, such as pairs of close white dwarfs (WDs), pairs of neutron stars, neutron star and black hole binaries, pairs of contacting normal stars, normal stars and white dwarfs (cataclysmic) binaries, and pairs of stellar black holes.

Due to the fact the GWs are produced by a large variety of astrophysical sources and cosmological phenomena it is quite probable that the Universe is pervaded by a background of such waves. Binary stars of a variety of stars (ordinary, compact or combinations of them), Population III stars, phase transitions in the early Universe, cosmic strings are examples of sources able to produce a background of GWs.

As the GWs possess a very weak interaction with matter passing through it unharmed, relic radiation (spectral properties for example) once detected can provide information on the physical conditions from the era in which they were produced. In principle it will be possible, for example, to get information from the epoch when the galaxies and stars started to form and evolve.

Concerning our galaxy, it presents a large number of binary systems, which produce a GW background named binary confusion noise (see Hils et al. 1990, Bender & Hils 1997). Some of the galactic binary sources are: close white dwarfs binaries (CWDBs), neutron star binaries (NSBs), unevolved binaries, WUMs binaries and cataclysmic binaries.

The binary systems are the most understood of all sources of GWs (see, e.g., Thorne 1987). Knowing the masses of the stars, the orbital parameters and their estimated distances, one can calculate the details of the GW produced.

The LISA's sensitivity as well as the binary confusion noise will determine in the end if one is able to discriminate the signal of a particular astrophysical source.

The first papers concerning the gravitational radiation from binaries systems were written by Mironowskii (1966), who studied in particular the W UMa stars, and by Forward & Berman (1967), approximately 30 years ago. After that many other studies concerning the evaluation of GWs background produced by various types of binary stars in the Galaxy followed (see, e.g., Douglass & Braginsky 1979; Lipunov & Postnov 1987; Lipunov et al. 1987; Evans et al. 1987; Hils et al. 1990; Bender & Hils 1997; Webbink & Han 1998; Hils 1998)

Here we are particularly interested in the cataclysmic variable binaries as sources of GWs, such a system is formed by a white dwarf and a low mass secondary star. The total number of such a kind of binary is estimated to amount 10^6 in the Galaxy (see, e.g. Hils et al. 1990). These systems produce low frequency GWs, namely, $f_{gw} < 10^{-3}$, which could be detected by LISA.

We are not concerned here with the calculation of a confusion noise produced by such binaries, our aim is similar to the study by Douglass & Braginsky (1979) who evaluate the dimensionless amplitude h for a series of specific low frequency GW

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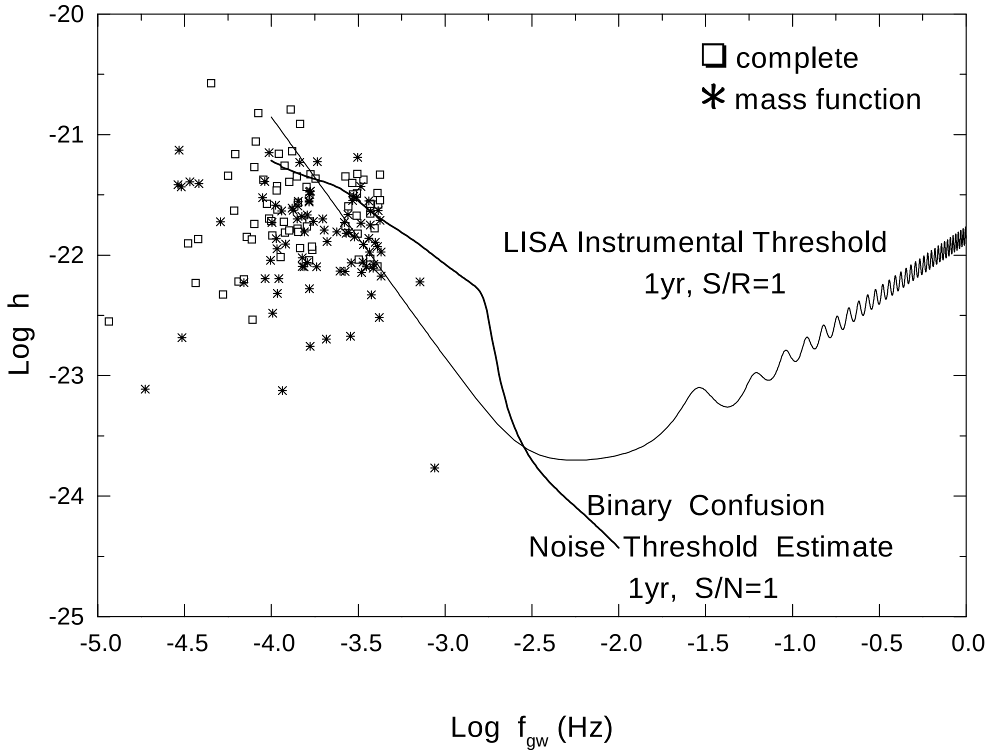

Fig. 1. Dimensionless amplitude h versus GW frequency f_{gw} of all CVs of our catalogue and the LISA instrumental threshold and the binary confusion noise threshold estimate curves for 1 year of observations and S/N=1.

binaries. Based mainly on the 6th edition of the catalogue of cataclysmic binaries, low mass X-ray binaries and related objects (Ritter & Kolb 1998) we have catalogued almost 160 CV systems for which it is possible to evaluate the GW amplitude. We have catalogued firstly those CVs with known distances, orbital period and masses, quantities necessary to evaluate the GW amplitude produced by such objects; secondly we have catalogued those systems for which the distances and the orbital periods are known, the masses being obtained from a mass-period relationships.

The remainder of the paper is as follows: Sect. 2 deals with the cataclysmic variables. Sect. 3 addresses the gravitational waves from cataclysmic variables. The discussion and conclusions are summarized in Sect. 4.

2. The cataclysmic variables

A Cataclysmic Variable (CV) is a semi-detached binary system of low mass and very short orbital period. The primary star is an accreting degenerate white dwarf and the secondary one is usually, but not always, a late-type star that fills its critical Roche lobe and transfers matter to the companion. There are 1020 cataclysmic variables classified (Downes et al. 1997) and more than 300 of them have known periods (Ritter & Kolb 1998, hereafter RK98). From a period histogram Patterson (1998, his Fig. 1) shows, with data taken from RK98 (see also Kolb et al. 1998, Fig. 4, to orbital periods below 5 hours), that the majority of these systems have periods ranging from 1.2 to 15.0 h.

We have catalogued, in Tables 1 and 2, 156 CV systems. In Table 1 we have catalogued 68 CVs, where in Column 1 we present their names, in Column 2 the distances in parsecs, in Column 3 the periods in days, in Column 4 the primary mass in solar masses, in Column 5 the secondary mass in solar masses, in Column 6 the gravitational wave amplitude h (see Sect. 3 for its calculation), and finally in Column 7 we present the references used to obtain the data of each CV system. In Table 2 we have catalogued 88 CVs for which only the distances and periods are known; the label of the columns are the same as in Table 1.

For the systems with orbital periods of up to 10 hours it is possible to make use of a mass function to compute the masses of the secondary stars. We have computed the mass of the secondary star using an equation obtained by Smith and Dhillon (1998, hereafter SD98). Their mass-period relationship has the following best fit (Eq. 9 of SD98):

$$M_2/M_\odot = 0.126P - 0.11, \text{ with period in hours.} \tag{1}$$

To calculate the mass of the primary star we have used the unweighted average for all systems (see, Table 4a of SD98):

$$\begin{aligned} M_1 &= 0.69M_\odot \ \text{ below period gap} \\ M_1 &= 0.80M_\odot \ \text{ above period gap} \end{aligned} \tag{2}$$

The period gap, namely, $2 < P < 3$ hours, a failure in the distribution of cataclysmic variables, has been discussed in the literature recently by, for example, Clemens et al. (1998) and Kolb et al. (1998). For stars in the gap period we have considered the mean value $M_1 = 0.74M_\odot$.

It is worth noting that Eqs. 1 and 2 (SD98) were obtained from 14 reliable CV mass determination. In our sample there are 68 CVs with known masses, whose values were obtained by various methods. A fit with 62 CVs gives a relationship consistent with SD98. Five do not fit the $M_2 \times$ orbital period distribution,

Table 1. Catalogue of 68 CVs for which the distances, the periods and the masses are known. In the columns we see, respectively, CV names, distances in parsecs, periods in days, primary mass (in solar masses), secondary mass (in solar masses), gravitational wave amplitude h (see Sect. 3 for its calculation), and references used to obtain the data of each CV system.

Name	d(pc)	P(days)	$M_1/M_\odot$	$M_2/M_\odot$	log h	Ref.
RX And	135	0.209893	1.14	0.48	-21.16	W87, RK98
V603 Aql	110	0.1381	0.66	0.29	-21.32	B96, RK98
V1315 Aql	300	0.139690	0.73	0.30	-21.72	RvPT92, RK98
AE Aqr	102	0.411656	0.79	0.50	-21.34	TK98, RK98
HU Aqr	111	0.086820	0.95	0.15	-21.35	SHM96, RK98
UU Aqr	200	0.163580	0.67	0.20	-21.78	BSH96, RK98
T Aur	830	0.204378	0.68	0.63	-22.02	P84, RK98
QZ Aur	2000	0.357496	1.05	1.05	-22.22	CS95, RK98
SS Aur	200	0.1828	1.08	0.39	-21.39	W87, RK98
V363 Aur	600	0.321242	0.86	0.77	-21.85	RvPT92, RK98
Z Cam	175	0.289841	0.99	0.70	-21.27	W87, RK98
OY Car	86	0.63121	0.685	0.070	-22.23	BBB96, RK98
HT Cas	165	0.073647	0.61	0.09	-21.82	W87, RK98
BV Cen	450	0.610108	0.83	0.90	-21.87	P84, RK98
V436 Cen	210	0.062501	0.7	0.17	-21.57	W87, RK98
WW Cet	100	0.1758	0.85	0.41	-21.14	W87, RK98
Z Cha	130	0.074499	0.84	0.125	-21.49	W87, RK98
HL CMa	210	0.2145	1.0	0.45	-21.43	W87, RK98
BG CMi	700	0.134749	0.8	0.38	-21.96	W95, RK98
AC Cnc	800	0.300478	0.82	1.02	-21.87	W87, RK98
SY Cnc	450	0.380	0.89	1.10	-21.63	W87, RK98
YZ Cnc	290	0.0868	0.82	0.17	-21.76	W87, RK98
TV Col	500	0.228599	0.75	0.56	-21.84	W95, RK98
TX Col	550	0.2383	1.3	0.57	-21.70	W95, RK98
TV Crv	350	0.06250	0.52	0.12	-22.03	HRAH96
EM Cyg	350	0.290909	0.57	0.76	-21.74	W87, RK98
SS Cyg	75	0.275130	1.19	0.704	-20.82	W87, RK98
CM Del	280	0.162	0.48	0.36	-21.81	W87, RK98
HR Del	285	0.214165	0.67	0.55	-21.62	W87, RK98
DO Dra[a]	155	0.165374	0.83	0.38	-21.35	W95, RK98
SW Sex[b]	450	0.134938	0.58	0.33	-21.93	RvPT92, RK98
EP Dra	300	0.072656	0.43	0.13	-22.04	W95, RK98
U Gem	81	0.179606	1.26	0.57	-20.79	W87, RK98
AH Her	250	0.258116	0.95	0.76	-21.37	W87, RK98
AM Her	75	0.128927	0.39	0.26	-21.36	W95, RK98
DQ Her	330	0.193621	0.60	0.40	-21.81	W87, RK98
V838 Her	3000	0.2976635	0.87	0.74	-22.54	VSWS96, RK98
EX Hya	105	0.068234	0.78	0.13	-21.37	W95, RK98
VW Hyi	65	0.074271	0.63	0.11	-21.33	W87, RK98
WX Hyi	265	0.074813	0.90	0.16	-21.67	W87, RK98
DP Leo	450	0.062363	0.71	0.11	-22.08	W95, RK98
T Leo	76	0.05882	0.16	0.11	-21.77	SHM96, RK98
ST LMi	128	0.079089	0.76	0.17	-21.40	W95, RK98
BT Mon	1700	0.333814	1.04	0.87	-22.20	SDM98, RK98
V426 Oph	100	0.2853	0.90	0.70	-21.05	W87, RK98
V2951 Oph	140	0.062428	0.44	0.13	-21.65	P84, RK98
CN Ori	295	0.163199	0.74	0.49	-21.57	W87, RK98
EF Peg	172	0.0837	0.65	0.17	-21.59	SHM96, RK98
IP Peg	124	0.158206	1.15	0.67	-20.91	W87, RK98
RU Peg	174	0.3746	1.21	0.94	-21.16	W87, RK98
GK Per	340	1.996803	0.90	0.25	-22.55	W95, RK98
RR Pic	240	0.145025	0.95	0.4	-21.43	B96, RK98
VZ Scl	530	0.144622	1.0	0.4	-21.76	W87, RK98

[a] Also known as YY Dra

[b] Also known as PG 1012-03

Table 1. (continued)

Name	d(pc)	P(days)	$M_1/M_\odot$	$M_2/M_\odot$	log h	Ref.
LX Ser	340	0.158432	0.41	0.36	-21.94	RvPT92, RK98
RW Sex	290	0.24507	0.8	0.6	-21.57	W87, RK98
V Sge	56	0.514197	0.74	2.8	-20.57	B96, RK98
WZ Sge[c]	194	0.056688	0.45	0.058	-22.09	B96, RK98
V1223 Sgr	600	0.140244	0.5	0.4	-22.04	W95, RK98
V3885 Sgr	280	0.2163	0.8	0.7	-21.46	W87, RK98
RW Tri	270	0.231883	0.45	0.63	-21.72	RvPT92, RK98
SW UMa	140	0.05618	0.71	0.10	-21.58	W87, RK98
UX UMa	250	0.196671	0.47	0.47	-21.72	RvPT92, RK98
CU Vel	200	0.0785	1.23	0.15	-21.49	W87, RK98
IX Vel[d]	150	0.193929	0.82	0.53	-21.26	W87, RK98
TW Vir	455	0.18267	0.91	0.40	-21.79	W87, RK98
J1015.5+0904	100	0.054777	0.56-1.12	0.09	-21.54	BRSH98
DX And	660	0.440502	0.51	0.50	-22.33	SD98, SHM96, RK98
VV Pup	145	0.69749	1.1	0.2	-21.90	RK98, KB99

[c] Smack (1993) obtained a distance of $48pc$, which gives $\log \mathrm{h} = -21.49$, a factor of 4 greater
[d] Not always classified as CV

namely: AE Aqr, OY Car, BV Cen, GK Per, V Sge. Our fit is given by:

$$M_2/M_\odot \;=\; (0.121 \pm 0.004)P - 0.070 \pm 0.020, \quad \text{with period in hours.} \tag{3}$$

In our catalogue 9 systems have periods above 9 hours, namely: QU Car, V394 CrA, V841 Oph, TY PsC, VV Pup, U Sco, MR Ser, NA UMa and SU UMa. From RK98 we have obtained the spectral type only for VV Pup (M4-5), U Sco (F6-G0-5) and MR Ser (M5-6/5). The secondary mass is then obtained from the spectral type versus M_2 diagram of Kolb & Baraffe (1999). For VV Pup RK98 give a mass ratio $M_1/M_2 = 5.5$, giving in this way $M_2 = 0.2M_\odot$ and $M_1 = 1.1M_\odot$; for U Sco $1.0 < M_2 < 1.3M_\odot$; and for MR Ser $M_2 < 0.1M_\odot$. For all these systems with the exception of VV Pup, we have also to make use of the mass function. We have considered these values as upper limits to the secondary mass.

3. Gravitational waves from cataclysmic variables

We proceed now calculating the gravitational wave amplitude (h) and frequency (f_{gw}) for the CVs presented in our catalogue. As already mentioned the binary systems are the most understood of all sources of GWs (see, e.g., Thorne 1987). Knowing the masses of the stars, the orbital parameters and their estimated distances, one can calculate the details of the GW produced. In our catalogue for 68 of the CVs the necessary parameters for the calculation of h and f_{gw} are known, for the other 88 CVs we needed to obtain their masses through the Eqs. 1 and 2, as discussed in preceding section.

The CVs emit GWs at twice the orbital frequency and harmonics thereof (see, e.g., Thorne 1987). For eccentricity $\epsilon < 0.2$ the line at $f_{gw} = 2f_{orb}$ is the dominant; for $\epsilon \simeq 0.5$ the lines at $f_{gw}/f_{orb} \simeq 2$ through 8 are all strong; for $\epsilon \simeq 0.7$ the lines at $f_{gw}/f_{orb} \simeq 4$ through 20 are all strong (see, e.g., Thorne 1987). Following Thorne (1987), the characteristic amplitude, in the low eccentricity case with $f_{gw} = 2f_{orb}$, is given by

$$h \;=\; 8.7 \times 10^{-21}\left(\frac{\mu}{M_\odot}\right)\left(\frac{M}{M_\odot}\right)^{2/3} \times \left(\frac{100\,pc}{r}\right)\left(\frac{f_{gw}}{10^{-3}\,Hz}\right)^{2/3} \tag{4}$$

The above equation takes into account both polarizations, h_+ and $h_\times$, and it is averaged over the orientation angles of the source (Thorne 1987). The amplitude given by this equation is thus a factor of $\simeq 2$ smaller than the maximum amplitude.

We are also considering that all CVs of our catalogue have low eccentricity, and therefore Eq. 4 can be applied to them.

The LISA curves, as discussed by the LISA Study Team (1998) are calculated realistically, and in some sense somewhat conservative, due to the fact that the sensitivity could in principle be improved in many aspects.

The LISA mission is planned to last 2 years, but it could last up to 10 years, as a result: a) its sensitivity to long-lived sources is improved; b) the noise, the threshold curves and the GW noise from white-dwarf binaries would lower, as a result it would be possible to resolve more sources and remove them from the binary confusion noise background.

Although the three LISA arms are not independent, LISA could in some sense act as two interferometers, improving its capability of detection and sensitivity. A third arm allows LISA to detect two different GW observable, which can be thought of as being formed from the signals of two different interferometers, with one arm common to both. As a result, besides an improvement in sensitivity, LISA's ability to measure, for example, the polarization of the GWs is improved. It is worth mentioning that the LISA curves usually presented elsewhere only consider a single interferometer.

Table 2. Catalogue of 88 CVs for which only the distances and the periods are known. In the columns we see, respectively, CV names, distances in parsecs, periods in days, gravitational wave amplitude h (see Sect. 3 for its calculation), and references used to obtain the data of each CV system.

Name	d(pc)	P(days)	log h	Ref.
AR And	269	0.1630	-21.59	SHM96, VBRP97,RK98
DH Aql	116	0.0778	-21.51	SHM96,RK98
UU Aql	225	0.14049	-21.55	SHM96, RK98
V1101 Aql	300	0.1441667	-21.67	MdV98
V1432 Aql[a]	230	0.140235	-21.57	W95, RK98
FO Aqr	325	0.202060	-21.63	W95, RK98
VY Aqr	97	0.0635	-21.55	SHM96, RK98
TT Ari	185	0.137551	-21.47	W87, RK98
XY Ari	200	0.2526697	-21.39	W95, RK98
WX Ari	198	0.13934	-21.50	SHM96, RK98
RS Cae	440	0.07	-22.14	BRSB96
AF Cam	425	0.23	-21.73	SHM96, RK98
BY Cam	190	0.13979	-21.48	W95, RK98,DM98
BZ Cam	830	0.153693	-22.09	RN98, RK98
QU Car	500	0.454	-21.72	W87, RK98
V592 Cas	330	0.115063	-21.79	TTPF98
V705 Cas	2400	0.2280	-22.48	MGWS98, RK98
V834 Cen	86	0.070498	-21.43	W95, RK98
WX Cet	185	0.05829	-21.89	SHM96, RK98
AR Cnc	681	0.2146	-21.95	SHM96, RK98
EG Cnc	320	0.05997	-22.11	PKS98
UU Col	740	0.143750	-22.06	BRBT96
AL Com	190	0.056668	-21.93	SHM96, RK98
GO Com	361	0.0658	-22.10	SHM96, RK98
GP Com	90	0.03231	-22.22	P84
V394 CrA	5000	0.7577	-22.69	W95, RK98
V1500 Cyg	1200	0.139513	-22.28	W95, RK98
V1521 Cyg	10000	0.1997	-23.12	P84
V1668 Cyg	3600	0.1384	-22.76	P84, RK98
V1974 Cyg	1770	0.081259	-22.67	CGPK97, RK98
DM Dra	580	0.087	-22.13	SHM96, RK98
CQ DraBC	100	0.1256	-21.23	RGB88, RK98
AH Eri	113	0.2391	-21.15	SHM96, T97
EF Eri	94	0.056266	-21.63	W95, RK98
V1309 Ori[b]	1500	0.332613	-22.23	HCPD97, RK98
V349 Pav[c]	400	0.1109	-21.89	W95, RK98
AO Psc	420	0.149626	-21.81	W95, RK98
AY Psc	565	0.217321	-21.86	SHM96, RK98
TY Psc	250	0.6833	-21.39	W87, RK98
BX Pup	750	0.127	-22.10	W87, RK98
CP Pup	556	0.06143	-22.33	B96, RK98
U Sco	14000	1.23056	-23.11	W95
DI UMa	107	0.0548	-21.71	SHM96, RK98
MR Ser	139	0.78798	-21.13	W95, RK98
UZ Ser	300	0.1730	-21.63	W87, RK98
WY Sge	700	0.153635	-22.02	SMN96, RK98
QS Tel	300	0.097187	-21.81	W95, RK98
EK Tra	200	0.0636	-21.86	W87, RK98
AN UMa	270	0.79753	-21.41	W95, RK98, BMSS96
BC UMa	255	0.063	-21.97	SHM96, RK98
DV UMa[d]	277	0.08597	-21.82	SHM96, RK98
EV UMa	700	0.055338	-22.52	W95, RK98
SU UMa	280	0.7635	-21.43	W87, RK98
PW Vul[e]	1600	0.2137	-22.32	RN96, RK98
QQ Vul	320	0.154520	-21.68	W95, RK98
QU Vul	2600	0.111765	-22.70	dVGB97, RK98
E2259+586	3600	0.0266	-23.77	P84
J0132.7-6554	300	0.0540499	-22.17	BRBT97
J0203.8+2959	600	0.191667	-21.91	SSB98, RK98
J0744-52	820	0.15	-22.10	RBC98
J1016.9-4103	615	0.093055	-22.13	GS98
J1724.0+4114	250	0.0832639	-21.81	GSW98
J1957.1-5738[f]	350	0.068625	-22.06	TBSB96, RK98
J2022.6-3954	190	0.05417889	-21.97	BRBT97
J2115.7-5840[g]	250	0.07691	-21.85	SBOH97, RK98
KT Per	245	0.162500	-21.55	TR97
TZ Per	275	0.2605	-21.52	W87, RK98
UV Per	115	0.0622	-21.64	W87, RK98
TY PsA	190	0.0841	-21.66	W87, RK98
UZ For	230	0.087865	-21.73	W95, RK98, SMB97
IR Gem	250	0.0684	-21.91	W87, RK98
V533 Her	1200	0.2098	-22.20	P84, RK98
WW Hor	430	0.080199	-22.06	W95, RK98
BL Hyi	128	0.078915	-21.55	W95, RK98
DO Leo	878	0.234515	-22.04	SHM96, RK98
RZ Leo	174	0.0708	-21.73	SHM96, RK98
X Leo	345	0.1644	-21.70	W87, RK98
RU LMi	1273	0.251	-22.19	SHM96, RK98
SX LMi	150	0.0625	-21.75	SHM96, RK98
BK Lyn	114	0.07498	-21.52	SHM96, RK98
AY Lyr	52	0.07370	-21.19	SHM96, RK98
CY Lyr	115	0.1591	-21.23	W87, TTK98
MV Lyr	322	0.1329	-21.72	W87, RK98
TU Men	270	0.1172	-21.70	W87, RK98
CW Mon	290	0.1762	-21.61	W87, RK98
CQ Mus	290	0.059365	-22.07	VBRP97, RK98
V841 Oph	255	0.60423	-21.41	W87, RK98
CZ Ori	300	0.2189	-21.59	W87, RK98

[a] Also known as J1940.2-1025
[b] Also known as J0515.6+0105
[c] Also known as V2008-65.5
[d] Not always classified as CV
[e] Not always classified as CV
[f] Also known as Pav4
[g] Also known as Ind1

In Fig. 1 we show the dimensionless amplitude h (using Eq. 4), for all the CVs presented in Tables 1 and 2, as a function of the GW frequency; also plotted are the curves for the LISA instrumental threshold and the binary confusion noise threshold estimate curves for 1 year of observations and S/N=1. The values for h for all CVs of our catalogue, calculated via Eq. 4, are also presented in Tables 1 and 2.

In Fig. 2 we zoom Fig. 1 for the frequency band $1-5\times10^{-4}$ Hz, and also plot the curves labeled L1 (L5) and CN1 (CN5) which are the LISA instrumental threshold and the binary con-

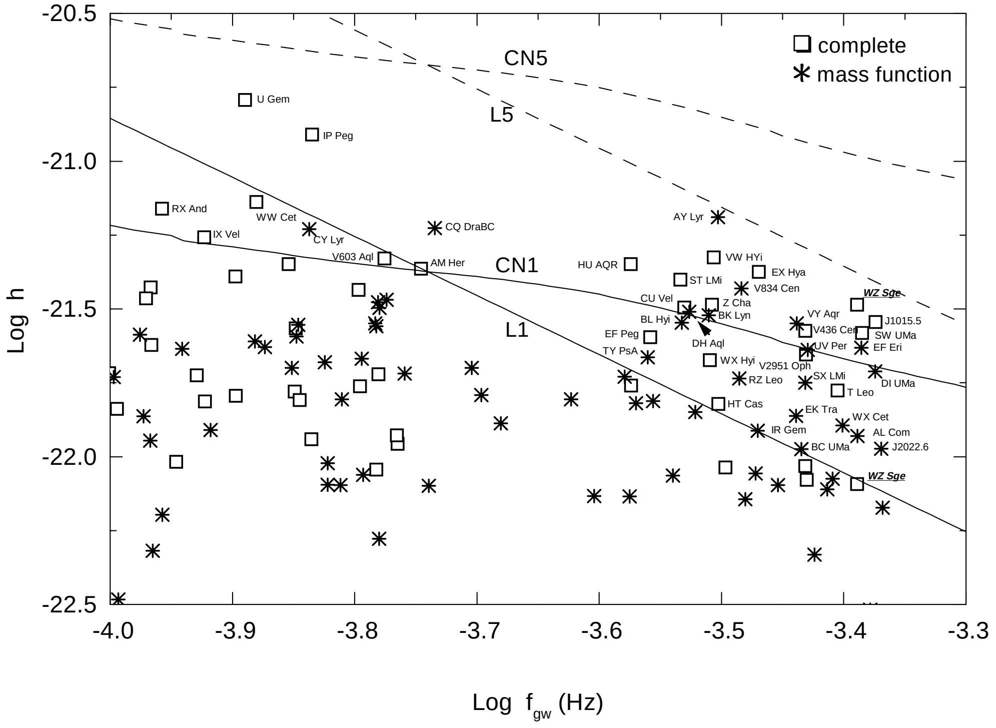

Fig. 2. Dimensionless amplitude h versus GW frequency f_{gw} for some CVs of our catalogue. The curves labeled L1 (L5) and CN1 (CN5) are the LISA instrumental threshold and the binary confusion noise threshold estimate curves for 1 year of observations and S/N=1 (S/N=5), respectively.

fusion noise threshold estimate curves for 1 year of observations and S/N=1 (S/N=5), respectively.

Among the CVs presented in our catalogue no one has $S/N > 5$, and therefore at this signal-to-noise ratio it is not possible to detected them.

It is worth mentioning at this point that even the CV named WZ Sge, which is usually considered to be one of the most promising CVs capable of being detected by LISA, cannot be detected at $S/N > 5$. We have used here new data presented mainly in the 6th edition of the catalogue of cataclysmic binaries, low mass X-ray binaries and related objects (Ritter & Kolb 1998), and in particular for the WZ Sge the masses presented are smaller than thought before (see, e.g., Douglass & Braginsky 1979). This explains why WZ Sge appears here in our study with a dimensionless amplitude h much smaller than presented by the LISA Study Team (1998).

The parameters for WZ Sge used by Douglass & Braginsky (1979) were obtained from Warner (1976), namely, $M_1 = 1.5 M_\odot$ and $M_2 = 0.12 M_\odot$ (the masses), and from Kraft (1962), namely, $d = 75 pc$ (the distance). Barret (1996), on the other hand, obtained a distance of 194 pc (this is the distance that appears in Table 1) with the linear polarimetric technique. Smack (1993), instead, obtained the masses $M_1 = 0.45 M_\odot$, $M_2 = 0.058 M_\odot$ and a distance of $d = 48 pc$, from visual and ultraviolet observations. Even considering a distance of $d = 48 pc$, WZ Sge would appear below $S/R = 5$ curves. For comparison we plot WZ Sge for a distance of $d = 48 pc$ (see, Fig. 2).

As usual in astrophysics the distance plays a key role here. The case for WZ Sge is an example that we have addressed to call attention to an issue that could occur with almost all other CVs of our catalogue. As a result this uncertainty in the distance could move the points plotted in Figs. 1 and 2 upwards or downwards.

From our sample we note that 37 CVs have h values greater than the S/N =1 LISA curve and also appear above the binary confusion noise curve, such CVs, therefore, could in principle be detected at this signal-to-noise ratio; Of these 37 CVs, 33 are below the period gap ($1.25 < P < 2.16$ hours). We also note that the maximum distance of these CVs to the Earth is approximately 300 pc. Patterson (1998) estimates that the space density of active CVs is $d = 10^{-5} pc^{-3}$, with 75% of them below the period gap. So, the expected number of active CVs up to a radius of 300 pc would amount to approximately 850 systems with periods below the gap. We have therefore only a part of them in our catalogue. This means that the prospect of detection of CVs is improved.

It is worth mentioning that even if the sources are not detectable after 1 year of observation they can be detected after an additional integration time t, namely

$$h_{\rm CV} > (f_{gw} \cdot t)^{-1/2} \, h_{\rm confusion\ noise} \tag{5}$$

(see, e.g., Thorne 1987). It is important to have in mind, however, that below 1 mHz there could exist many binaries per frequency bin that could be hard to resolve individual sources (see, e.g., Hils 1998), unless we know their position in sky like those in Tables 1 and 2.

It is worth mentioning also that due to the fact that the LISA curves presented here are only for single interferometers, and that LISA could work as two independent interferometers, this improves the possibilities of detection of CVs by LISA, since LISA curves as well as the binary confusion noise curves go down.

4. Discussion and conclusions

The CVs produce GWs which could in principle be detected by the LISA antenna, since CVs produce low frequency GWs in the frequency band where LISA is sensitive. Due to the fact that a positive detection of a CV by the LISA antenna might be improved once we know the sources beforehand we compile in the present study a catalogue of CVs, for which we know at least their orbital periods and distances.

We argue that the present study is of interest since in the literature one has not found a systematic identification of possible detectable GW CVs, since an early study made by Douglass & Braginsky (1979) twenty years ago, and also a preliminary study by Aguiar et al. (1998). We have been able to catalogue approximately 160 CVs, from which a reasonable part of them could be detected once the LISA antenna become operative.

We argue that it would be of interest whether other groups performed a similar study for the other binary systems which produce low frequency GWs in the frequency band where the LISA antenna is sensitive.

It is worth mentioning that a positive detection of a binary system through its gravitational emission, with some help of electromagnetic data observations, could lead one to know all the parameters related to the binary system, namely, the masses of the stars, their distances to the earth, the period of the system and their orientation angles.

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References

Aguiar O.D., de Araujo J.C.N., Meliani M.T., Jablonski F.J., Araújo M.E., 1998, In: Folkner W.M. (ed.) AIP Conference Proceedings: Second International LISA Symposium on the Detection and Observation of Gravitational Waves in Space. Woodbury, New York, Vol. 456, p. 87

Baptista R., Steiner J.E., Horne K., 1996, MNRAS 282, 99 (BSH96)

Barret P., 1996, PASP 108, 412 (B96)

Bender P.L., Hils D., 1997, Class. Quantum Grav. 14, 1

Bonnet-Bidaud J.M., Mouchet M., Somova T.A., Somov N.N., 1996, A&A 306, 199 (BMSS96)

Bruch A., Beele D., Baptista R., 1996, A&A 306, 151 (BBB96)

Burwitz V., Reinsch K., Beuermann K., Thomas H.-C., 1996, A&A 310, L25 (BRBT96)

Burwitz V., Reinsch K., Schwope A.D., et al., 1996, A&A 305, 507 (BRSB96)

Burwitz V., Reinsch K., Beuermann K., Thomas H.-C., 1997, A&A 327, 183 (BRBT97)

Burwitz V., Reinsch K., Schwope A.D., et al., 1998, A&A 331, 262 (BRSH98)

Campbell R.D., Shafter A.W., 1995, ApJ 440, 336 (CS95)

Chochol D., Grigar J., Pribulla T., et 1997, A&A 318, 908 (CGPK97)

Clemens J.C., Reid I.N., Gizis J.E., O'Brian M.S., 1998, ApJ 496, 352

della Valle M., Gilmozzi R., Bianchini A., Esenoglu A., 1997, A&A 325, 1151 (dVGB97)

Done C., Magdziarz P., 1998, MNRAS 298, 737 (DM98)

Douglass D.H., Braginsky V.B., 1979, In: Hawking S.W., Israel W. (eds.) General Relativity, an Einstein Centenary Survey. Cambridge University Press, Cambridge

Downes R.A., Webbink R.F., Shara M.M., 1997, PASP 109, 345

Evans C.R., Iben I., Smarr L., 1987, ApJ 323, 129

Finn L.S., Chernoff D.F., 1993, Phys. Rev. D 47, 2198

Forward R. L., Berman D., 1967, Phys. Rev. Lett. 18, 1071

Kraft R., 1962, ApJ 136, 312

Greiner J., Schwarz R., 1998, A&A 340, 129 (GS98)

Greiner J., Schwarz R., Wenzel W., 1998, MNRAS 296, 437 (GSW98)

Harrop-Allin M.K., Cropper M., Potter S.B., Dhillon V.S., Howell S.B., 1997, MNRAS 288, 1033 (HCPD97)

Hils D., 1998, In: Folkner W.M. (ed.) AIP Conference Proceedings: Second International LISA Symposium on the Detection and Observation of Gravitational Waves in Space. Woodbury, New York, Vol. 456, p. 68

Hils D., Bender P.L., Webbink R.F., 1990, ApJ 360, 75

Howell S.B., Reys A.L., Ashley R., Harrop-Allin M.K., Warner B., 1996, MNRAS 282, 623 (HRAH96)

Kolb U., Baraffe I., 1999, In: Charles P.A., King A.R., O'Donoghue D. (eds.) Proceedings of the Warner Symposium on Cataclysmic Variables, New Astronomy Reviews (in press) (KB99)

Kolb U., King A.R., Ritter H., 1998, MNRAS 298, L29

LISA Study Team, 1998, In: LISA Pre-Phase A Report. 2nd Edition, Publication MPQ-233, Max-Plank Institute for Quantum Optics, Garching, chapter 1, p. 7

Lipunov V.M., Postnov K.A., 1987, SvA 31, 228

Lipunov V.M., Postnov K.A., Prokhorov M.E., 1987, A&A 176, L1

Masetti N., della Valle M., 1998, A&A 331, 187 (MdV98)

Mason C.G., Gelrz R.D., Woodward C.E., et al., 1998, ApJ 494, 783 (MGWS98)

Mironowskii V.N., 1966, SvA 9, 752

Patterson J., 1984, ApJS 54, 443 (P84)

Patterson J., 1998, PASP 110, 1132

Patterson J., Kemp J., Skillman D.R., et al., 1998, PASP 110, 1290 (PKS98)

Ramsay G., Buckley D.A.H., Cropper M., 1998, MNRAS 294, 187 (RBC98)

Reimers D., Griffin R., Brown A., 1988, A&A 193, 180 (RGB88)

Ringwald F.A., Naylor T., 1996, MNRAS 278, 808 (RN96)

Ringwald F.A., Naylor T., 1998, AJ 115, 286 (RN98)

Ritter H., Kolb U., 1998, A&AS 129, 83 (RK98)

Rutten R.G.M., van Paradijs J., Tinbergen J., 1992, A&A 260, 213 (RvPT92)

Schutz B.F., 1996, In: Lasota J.-P., Marck J.-A. (eds.) Proceedings of the Les Houches School on Astrophysical Sources of Gravitational Radiation, Cambridge University Press, Cambridge

Schwarz R., Schwope A.D., Beuermann K., et al., 1998, A&A 338, 465 (SSB98)

Schwope A.D., Buckley D.A.H., O'Donoghue D., et al., 1997, A&A 326, 195 (SBOH97)

Schwope A.D., Mengel S., Beuermann K., 1997, A&A 320, 181 (SMB97)

Smack J., 1993, A&A 43, 101

Smith D.A., Dhillon V.S., 1998, MNRAS 301, 767 (SD98)

Smith D.A., Dhillon V.S., Marsh T.R., 1998, MNRAS 296, 465 (SDM98)

Somers M.W., Mukai K., Naylor T., 1996, MNRAS 278, 845 (SMN96)

Sproats L.N., Howell S.B., Mason K.O., 1996, MNRAS 282, 1211 (SHM96)

Taylor C.J., Thorstensen J.R., Patterson J., et al., 1998, PASP 110, 1148 (TTPF98)

Thomas H.-C., Beuermann K., Schwope A.D., Burwitz V., 1996, A&A 313, 833 (TBSB96)

Thorne K.S., 1987, In: Hawking S., Israel W. (eds.) Three Hundredth Years of Gravitation. Cambridge University Press, Cambridge

Thorne K.S., 1995, In: Van Paradijs J., Van del Heuvel E., Kuulkers E. (eds.) Proceedings of the International Astronomical Union Symposium: Compact Stars in Binaries. Vol. 165, Kluwer, Dordrecht

Thorne K.S., 1996, In: Wald R. (ed.) Proceedings of the Chandrasekhar Symposium, Chicago University Press, Chicago

Thorstensen J.R., 1997, PASP 109, 1241 (T97)

Thorstensen J.R., Ringwald F.A., 1997, PASP 109, 483 (TR97)

Thorstensen J.R., Taylor C.J., Kemp J., 1998, PASP 110, 1405 (TTK98)

Trimble V., Kundu A., 1998, AJ 115, 358 (TK98)

Vanlandingham K.M., Starrfield S., Wagner R.M., Shore S.N., Sonneborn G., 1996, MNRAS 282, 563 (VSWS96)

Verbunt F., Bunk W.H., Ritter H., Pferffermann E., 1997, A&A 327, 602 (VBRP97)

Warner B., 1976, In: Eggleton D., Mitton S., Whelan J.A.J. (eds.) Proceedings of the International Astronomical Union Symposium: Structure and Evolution of Close Binary Systems. Vol. 73, Kluwer, Dordrecht

Warner B., 1987, MNRAS 227, 23 (W87)

Warner B., 1995, Cataclysmics Variable Stars. Cambridge University Press, Cambridge (W95)

Webbink R.F., Han Z., 1998, In: Folkner W.M. (ed.) AIP Conference Proceedings: Second International LISA Symposium on the Detection and Observation of Gravitational Waves in Space. Woodbury, New York, Vol. 456, p. 61