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: neutron

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 1992, 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, Bender & Webbink 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 was 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, Postnov & Prokhorov 1987, Evans, Iben & Smarr 1987, Hils, Bender & Webbink 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. Hills, Bender & Webbink 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 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: Section 2 deals with the cataclysmic variables. Section 3 addresses the gravitational waves from cataclysmic variables. The discussion and conclusions are summarized in Section 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, Webbink & Shara, 1997) and more than 300 of them have known periods (Ritter & Kolb, 1998, hereafter RK98). From a period histogram Patterson (1998, his Figure 1) shows, with data taken from RK98 (see also Kolb, King and Ritter, 1998, figure 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 section 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 (equation 9 of SD98):

$$\frac{M_2}{M_\odot} = 0.126P - 0.11,$$ with period in hours. \hspace{1cm} (1)

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

$$M_1 = \begin{cases} 0.69M_\odot & \text{below period gap} \\ 0.80M_\odot & \text{above period gap} \end{cases}$$ \hspace{1cm} (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, King and Ritter (1998). For stars in the gap period we have considered the mean value $M_1 = 0.74M_\odot$.

It is worth noting that Equations 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, namely: AE Aqr, OY Car, BV Cen, GK Per, V Sge. Our fit is given by:

$$\frac{M_2}{M_\odot} = (0.121 \pm 0.004)P - 0.070 \pm 0.020,$$ with period in hours. \hspace{1cm} (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
| 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  | SMH96, RK98|
| UU Aqr  | 200   | 0.163580| 0.67          | 0.20          | -21.78  | BS96, 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   | 0.298941| 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          | 0.99          | -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| 0.61          | 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   | 0.290999| 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* | 155   | 0.165374| 0.83          | 0.38          | -21.35  | W95, 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  | 0.297635| 0.87          | 0.74          | -22.54  | VSWS96, RK98|
| EX Hya  | 105   | 0.068234| 0.78          | 0.13          | -21.37  | W95, RK98  |
| VW Hya  | 65    | 0.074271| 0.63          | 0.11          | -21.33  | W87, RK98  |
| WX Hya  | 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  | SMH96, 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  | SMH96, 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   | 1.096803| 0.90          | 0.25          | -22.55  | W95, RK98  |
| SW Sexb | 450   | 0.134938| 0.58          | 0.33          | -21.93  | RVPT92, RK98|

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*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.   |
|------------|-------|---------|---------------|---------------|---------|--------|
| 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 |
| 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          | 0.058         | -22.09  | B96, RK98 |
| V3885 Sgr  | 200   | 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     | 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 |

a Smack (1993) obtained a distance of 48 pc, which gives log $h = -21.49$, a factor of 4 greater.

b Not always classified as CV

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 equations 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 $\epsilon \approx 0.5$ the lines at $f_{gw}/f_{orb} \approx 2$ through 8 are all strong; for $\epsilon \approx 0.7$ the lines at $f_{gw}/f_{orb} \approx 4$ 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

$$h = 8.7 \times 10^{-21} \times \left( \frac{\mu}{M_\odot} \right) \left( \frac{M}{M_\odot} \right)^{2/3} \left( \frac{100 \text{pc}}{r} \right)^{2/3} \left( \frac{f}{10^{-3} \text{Hz}} \right)^{2/3}$$

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 $\approx 2$ smaller than the maximum amplitude.

We are also considering that all CVs of our catalogue have low eccentricity, and therefore equation 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.

In Figure 1 we show the dimensionless amplitude $h$ (using equation 3), 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 equation 4, are also presented in Tables 1 and 2.

In Figure 2 we zoom Figure 1 for the frequency band $1 - 5 \times 10^{-4}$ Hz, and also plot the curves labeled L1 (L5) and CN1 (CN5) which 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.
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 section 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   | 0.144167| -21.67  | Mdv98          |
| V1432 Aql$^b$| 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      |
| VX 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   | 0.153963| -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  | SHM6, 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  | RGB98, RK98    |
| AH Eri       | 113   | 0.2391  | -21.15  | SHM96, T97     |
| EF Eri       | 94    | 0.056266| -21.63  | W95, 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   |

$^a$ Also known as J1940.2-1025
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 explain 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, $M_1 = 1.5 M_⊙$ and $M_2 = 0.12 M_⊙$ (the masses), and from Kraft (1962), namely, $d = 75 pc$ (the distance). Barret (1996), on the other hand, obtained a distance of

Table 2. Continued

| Name        | d(pc) | P(days) | log h | Ref.      |
|-------------|-------|---------|-------|-----------|
| V841 Oph    | 255   | 0.60423 | -21.41| W87, RK98 |
| CZ Ori      | 300   | 0.2189  | -21.59| W87, RK98 |
| V1309 Ori$^a$ | 1500  | 0.332613| -22.23| HCPD97, RK98 |
| V340 Pav$^b$ | 400   | 0.1109  | -21.89| W95, 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 |
| 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       |
| 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   | 0.6636  | -21.86| W87, RK98 |
| AN UMa      | 270   | 0.79753 | -21.41| W95, RK98, BMSS96 |
| BC UMa      | 255   | 0.063   | -21.97| SHM96, RK98 |
| DI UMa      | 107   | 0.0548  | -21.71| SHM96, RK98 |
| DV UMa$^c$  | 277   | 0.08597 | -21.82| SHM96, RK98 |
| EV UMa      | 700   | 0.055338| -22.52| W95, RK98 |
| SU UMa      | 280   | 0.7035  | -21.43| W87, RK98 |
| PW Vul$^d$  | 1600  | 0.2137  | -22.32| RN96, RK98 |
| QQ Vul      | 320   | 0.154520| -21.68| W95, RK98 |
| QU Vul      | 2600  | 0.111765| -22.70| dVG897, 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| G98       |
| J1724.0+4114| 250   | 0.0832639| -21.81| GSW98     |
| J1957.1-5738| 350   | 0.068625| -22.06| TBSB96, RK98 |
| J2022.6-3954| 190   | 0.05417889| -21.97| BRBT97    |
| J2115.7-5840| 250   | 0.07691 | -21.85| SBOH97, RK98 |

$^a$ Also known as J0515.6+0105
$^b$ Also known as V2008-65.5
$^c$ Not always classified as CV
$^d$ Not always classified as CV
$^e$ Also known as Pav4
$^f$ Also known as Ind1
194 pc (this is the distance that appears in Table 1) with the linear polarimetric technique. Smack (1993), instead, obtained the masses $M_1 = 0.45M_\odot$, $M_2 = 0.058M_\odot$ 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, Figure 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 Figures 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.

**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 $S/N=1$. 
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.

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

$$h_{CV} > \left(f_{gw} \cdot t\right)^{-1/2} h_{\text{confusion noise}}$$

(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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