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Erratum: Black holes and gravitational waves in models of minicharged dark matter

Vitor Cardoso,[a,b] **Caio F.B. Macedo,**[c] **Paolo Pani**[d] **and Valeria Ferrari**[d]

[a]CENTRA, Departamento de Física, Instituto Superior Técnico – IST, Universidade de Lisboa – UL, Avenida Rovisco Pais 1, 1049 Lisboa, Portugal
[b]Waseda Institute for Advanced Study (WIAS), Waseda University, Shinjuku, Tokyo 169-8050, Japan
[c]Faculdade de Física, Universidade Federal do Pará, Salinópolis, Pará, 68721-000 Brazil
[d]Dipartimento di Fisica, "Sapienza" Università di Roma & Sezione INFN Roma1, P.A. Moro 5, 00185, Roma, Italy

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List of corrected errors

The published work has a couple of typos, and incorrect factors of two in the EM fluxes, as well as incorrect combinations of Newton's constant and its effective version, G and $G_{\rm eff}$. In particular, eqs. (3.2)-(3.5) should read

$$\frac{dE_{\rm em}}{dt} \sim \frac{2}{3}\left(\frac{\epsilon_1 e}{m_1} - \frac{\epsilon_2 e}{m_2}\right)^2 \frac{G_{\rm eff}^2 m_1^2 m_2^2}{c^3 R^4}\,, \tag{1}$$

$$\frac{dE_h}{dt} \sim \frac{2}{3}\left(\frac{\epsilon_{h,1} e}{m_1} - \frac{\epsilon_{h,2} e}{m_2}\right)^2 \frac{G_{\rm eff}^2 m_1^2 m_2^2}{c^3 R^4}\,, \tag{2}$$

$$\frac{dE_{\rm GW}}{dt} \sim \frac{32}{5c^5}\eta^2 \frac{G G_{\rm eff}^3 M^5}{R^5}\,, \tag{3}$$

$$\frac{dE_{\rm dip}}{dt} := \frac{2}{3}\zeta^2 \frac{G_{\rm eff}^3 m_1^2 m_2^2}{c^3 R^4}\,. \tag{4}$$

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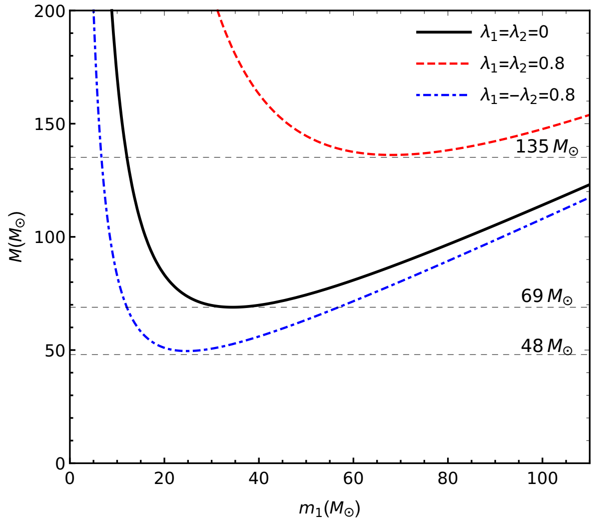

Figure 1. Total mass $M = m_1 + m_2$ of a binary system as a function of m_1 obtained from eq. (7) for fixed $\mathcal{M}_{\rm measured} \approx 30M_\odot$ and for different values of λ_i. The black curve corresponds to the uncharged case [1]. Note that when $\lambda_1\lambda_2 < 0$ the total mass of the system can be significantly smaller than in the uncharged case.

Equation (3.7) should read as

$$R \ll 480\frac{GM}{c^2}\left(\frac{0.1}{\zeta}\right)^2 , \quad \Omega \gg 0.3\text{Hz}\sqrt{\frac{G_{\rm eff}}{G}}\left(\frac{60M_\odot}{M}\right)\left(\frac{\zeta}{0.1}\right)^3 , \tag{5}$$

and eq. (3.8), the most important object of the work, along with the definition of chirp mass should read as

$$\begin{aligned}\Psi_+(f) = 2\pi f t_c - \Phi_c + \frac{3}{128}\frac{G_{\rm eff}}{G}\left(\frac{G_{\rm eff}\mathcal{M}}{c^3}\pi f\right)^{-5/3}\Bigg[1 - \frac{5}{84}\eta^{2/5}\zeta^2\frac{G_{\rm eff}}{G}\left(\frac{G_{\rm eff}\mathcal{M}}{c^3}\pi f\right)^{-2/3} \\ + \left(\frac{3715}{756} + \frac{55}{9}\eta\right)\eta^{-2/5}\left(\frac{G_{\rm eff}\mathcal{M}}{c^3}\pi f\right)^{2/3}\Bigg] ,\end{aligned} \tag{6}$$

where t_c and Φ_c are the time and phase at coalescence, f is the GW frequency and $\mathcal{M} := M\eta^{3/5}$ is the chirp mass.

Because to leading order the GW phase depends on the combination $(G_{\rm eff}/G)^{-2/3}(G\mathcal{M})^{-5/3}$, a rescaling of Newton's constant is degenerate with the measurement of the chirp mass. Extracting the latter from the Newtonian GW phase obtained by neglecting charge effects would yield a result that is rescaled by a factor $(G_{\rm eff}/G)^{2/3}$ relative to the real chirp mass of the system, namely

$$\mathcal{M} := M\eta^{3/5} = \frac{\mathcal{M}_{\rm measured}}{(1-\lambda_1\lambda_2)^{2/3}} , \tag{7}$$

Accordingly, figure 2 in the published version is affected, but the correction is small. The correct numbers are shown in figure 1.

Equation (3.10) should read as

$$r_\Psi := -\frac{18\eta^{4/5}}{743 + 924\eta}\zeta^2\frac{G_{\rm eff}}{G}\left(\frac{G_{\rm eff}\mathcal{M}}{c^3}\pi f\right)^{-4/3} , \tag{8}$$

JCAP04(2020)E01

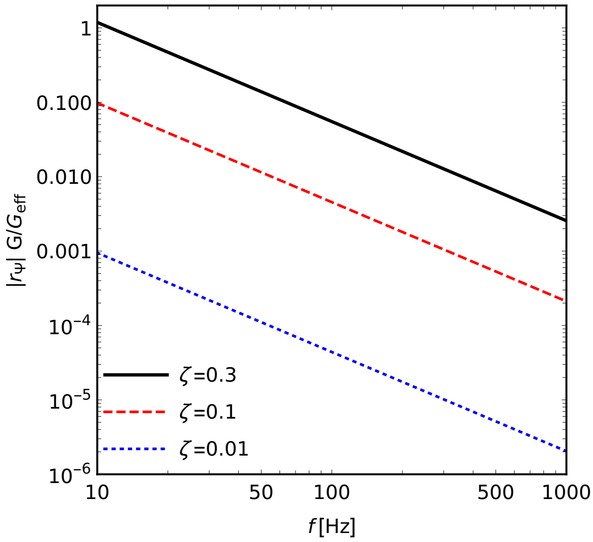

Figure 2. Ratio r_Ψ (normalized by $G_{\rm eff}/G$) between the hidden-charge-induced GW phase and the first post-Netwonian correction [cf. eq. (8)] for the quasicircular inspiral of two charged masses with $m_1 = m_2 = 30M_\odot$ and different values of the coupling ζ as a function of the GW frequency. Note that $\zeta \approx 0.3$ saturates the bound presented in eq. (11).

and is shown in figure 2 as a function of the GW frequency for a typical inspiral. The only difference with respect to the published version is that the y-axis is now normalized by $G_{\rm eff}/G$.

The number of cycles should read as

$$\mathcal{N} = \frac{1}{32\pi^{8/3}}\frac{G_{\rm eff}}{G}\left(\frac{G_{\rm eff}\mathcal{M}}{c^3}\right)^{-5/3}\left(f_{\rm min}^{-5/3} - f_{\rm max}^{-5/3}\right)\left[1-\delta_{\mathcal{N}}\right] \,,$$

where

$$\delta_{\mathcal{N}} = \frac{25}{336}\eta^{2/5}\zeta^2\frac{G_{\rm eff}}{G}\left(1+\frac{f_{\rm min}^{5/3}}{f_{\rm max}^{5/3}}\right)\left(\frac{G_{\rm eff}\mathcal{M}}{c^3}\pi f_{\rm min}\right)^{-2/3} \,, \tag{9}$$

and we have also expanded for $f_{\rm max} \gg f_{\rm min}$ to simplify the final expression. In the small-charge limit, for $f_{\rm max} \sim 100\,{\rm Hz}$ and $f_{\rm min} \sim 30\,{\rm Hz}$, we obtain

$$\delta_{\mathcal{N}} \approx 0.01\left(\frac{\zeta}{0.1}\right)^2 \,. \tag{10}$$

Therefore, dipolar effects change the number of cycles relative to the Newtonian case by a few percent when $\zeta \approx 0.1$ and by less than 0.01% when $\zeta < 0.01$. On the other hand, these corrections become important at smaller frequencies and might produce detectable effects for space-based interferometers such as eLISA [2].

Ref. [3] performed a detailed analysis to derive GW-based constraints on generic dipolar emissions in compact-binary inspirals (see also ref. [4]). It is straightforward to map eq. (4) into this generic parametrization. In our case the parameter B defined in refs. [3, 4] reads $B = \frac{5}{48}\zeta^2$. The analysis of ref. [3] shows that GW150914 sets the upper bound $|B| \lesssim 2\times10^{-2}$, whereas a putative eLISA detection of a GW150914-like event with an optimal detector

JCAP04(2020)E01

configuration or a combined eLISA-aLIGO detection set the projected bound as stringent as $|B| \lesssim 3 \times 10^{-9}$. In our case these bounds translate into

$$|\zeta| \lesssim 0.4 \qquad \text{aLIGO} \tag{11}$$

$$|\zeta| \lesssim 10^{-4} \qquad \text{eLISA-aLIGO (projected)} \tag{12}$$

Acknowledgments

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