ERRATA FOR

# Gravitational-Wave Physics and Astronomy

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## Chapter 1

**Equation (1.21) to Eq. (1.23)**
PAGE 7

The argument here is made clearer by considering a single element of mass $dm$. The text beginning just before Eq. (1.21) through Eq. (1.23) should read:

> An element of the extended body, located at a position $\boldsymbol{x}$ and having mass $dm = \rho(\boldsymbol{x})d^3\boldsymbol{x}$, experiences a tidal force
>
> $$F_i = -\mathcal{E}_{ij}x^j dm. \tag{1.21}$$
>
> If the element is moving through the tidal field with velocity $\boldsymbol{v}$ then there is an amount $F_i v^i$ of work per unit time done on that element. Summing over all elements that comprise the body yields the total amount of work:
>
> $$\begin{aligned} \frac{dW}{dt} &= -\int_{\text{body}} \mathcal{E}_{ij}v^i x^j dm \\ &= -\frac{1}{2}\mathcal{E}_{ij}\frac{d}{dt}\int_{\text{body}} x^i x^j dm \\ &= -\frac{1}{2}\mathcal{E}_{ij}\frac{dI^{ij}}{dt} \end{aligned} \tag{1.22}$$
>
> where, since $dm = \rho(\boldsymbol{x})d^3\boldsymbol{x}$,
>
> $$I^{ij} := \int_{\text{body}} x^i x^j \rho(\boldsymbol{x}) d^3\boldsymbol{x} \tag{1.23}$$
>
> is the *quadrupole tensor*.

*Credit: Nathan Kieran Johnson-McDaniel*

**Before Eq. (1.27)**
PAGE 8

In sentence ending in Eq. (1.27), the term 'quadrupole tensor' should have been used rather than 'moment of inertia tensor'.

*Credit: Leslie Wade*

## Chapter 2

**Equation (2.20)**
PAGE 16

The equation contains an index error; it should read:

$$\mathbf{u}\cdot\mathbf{v} := g_{\mu\nu}u^{\mu}v^{\nu}. \tag{2.20}$$

*Credit: Leslie Wade*

**Equation (2.67)**
PAGE 29

The equation contains an index error; it should read:

$$(\delta a^{\alpha})_{\rm bot} = -\epsilon^2 R_{\mu\nu\rho}{}^{\alpha}(\mathcal{Q})u^{\mu}v^{\nu}a^{\rho}. \tag{2.67}$$

**Equation (2.68)**
PAGE 30

The equation contains an index error; it should read:

$$(\delta a^{\alpha})_{\rm top} = \epsilon^2 R_{\mu\nu\rho}{}^{\alpha}(\mathcal{Q})u^{\mu}v^{\nu}a^{\rho}. \tag{2.68}$$

**Equation (2.102)**
PAGE 36

The equation is missing a factor of 4; it should read:

$$T^{\alpha\beta} = p\left(4\frac{u^{\alpha}u^{\beta}}{c^2} + g^{\alpha\beta}\right) \quad \text{(radiation).} \tag{2.102}$$

**After Eq. (2.148)**
PAGE 44

Equation (2.148) actually contains some post-Newtonian corrections. Text following Eq. (2.148) should read:

In fact, this metric contains some post-Newtonian terms: strictly speaking, to recover Newtonian motion, one needs only $g_{00} = -c^2 - 2\Phi$ and $g_{ij} = \delta_{ij}$ (see Section 4.1).

*Credit: Joachim Frieben*

**Equation (2.153)**
PAGE 45

The equation contains a factor of 4 rather than a factor of 2; it should read:

$$\frac{d\boldsymbol{p}}{dt} = \gamma m \left\{ -\boldsymbol{\nabla}\,\Phi - \frac{\partial \boldsymbol{A}}{\partial t} + \boldsymbol{v} \times (\boldsymbol{\nabla} \times \boldsymbol{A}) + \frac{1}{c^2}\left[ 2\frac{\partial \Phi}{\partial t}\,\boldsymbol{v} + 2(\boldsymbol{v}\cdot\boldsymbol{\nabla}\,\Phi)\boldsymbol{v} - v^2\,\boldsymbol{\nabla}\,\Phi \right] \right\}. \tag{2.153}$$

**Equation (2.154)**
PAGE 46

The equation is missing a negative sign; it should read:

$$\Delta\tau = \int_\gamma d\tau = \int_0^1 \sqrt{-g_{\mu\nu}\frac{dx^\mu}{d\sigma}\frac{dx^\nu}{d\sigma}}\, d\sigma, \tag{2.154}$$

**Equation (2.156)**
PAGE 46

The equation is missing a negative sign; it should read:

$$\mathcal{L} = -mc^2\sqrt{-g_{\mu\nu}(\mathbf{x})\frac{dx^\mu}{d\sigma}\frac{dx^\nu}{d\sigma}}, \tag{2.156}$$

**Problem 2.5**
PAGE 47

Part (b) of the problem should read:

b) Compute the equations of motion, $d^2t/d\tau^2$, $d^2r/d\tau^2$, and $d^2\phi/d\tau^2$, ....

## Chapter 3

**Section 3.1**
PAGE 49

The argument made at the beginning of this section is missing a critical step. Following Eq. (3.2) the text should read:

> An important solution is the plane-wave solution, which we choose as travelling in the $z = x^1$-direction. Equation (3.1) implies that the components of the metric perturbation (both the actual perturbation and the trace-reversed version) must all be functions of the retarded time $t - z/c$. Because gauge freedom remains within the Lorenz gauge [cf. Eq. (2.140)], we are free to perform a gauge transformation generated by $\boldsymbol{\xi} = \boldsymbol{\xi}(t - z/c)$ and remain in a Lorenz gauge. We adopt a *synchronous* gauge in which $h_{0i} = 0$ by the choice $\xi_0 = 0$ and $\xi_i = \int \bar{h}_{0i}\, dt$. The Lorenz gauge condition now further requires $\partial\bar{h}^{\mu 0}/\partial x^\mu = \partial\bar{h}^{00}/\partial t = 0$ which implies $\partial\bar{h}^{\mu\alpha}/\partial x^\mu = \partial\bar{h}^{3\alpha}/\partial z = 0$, so $\bar{h}_{00}(t - z/c)$ and $\bar{h}_{3\alpha}(t - z/c)$ are constant, and we are free to choose the constant to be zero. We then have $\bar{h}_{0\alpha} = 0$ and $\bar{h}_{3\alpha} = 0$.

**After Eq. (3.7b)**
PAGE 51

The inline equations of the last sentence of the paragraph are missing factors of $c$. The sentence should read:

> There must be more gauge freedom within the Lorenz gauge that is responsible for the extra (non-physical) degree of freedom (specifically, for $h_{00} = -c^2 h_{33} = \frac{1}{2}c^2(\bar{h}_{11} + \bar{h}_{22})$, which does not appear in the Riemann tensor).

**Equation (3.92)**
PAGE 71

The integrand erroneously has retarded time; the equation should read:

$$I^{ij}(t) = \int x^i x^j \tau^{00}(t, \boldsymbol{x})\, d^3\boldsymbol{x} \tag{3.92}$$

**Equation (3.173)**
PAGE 87

The equations contain the wrong factors of $G$ and $c$ and use $\phi$ rather than $\varphi$; they should read:

$$\dddot{I}_{11} = -\dddot{I}_{22} = 4\frac{c^5}{G}\frac{\mu}{M}\left(\frac{v}{c}\right)^5 \sin 2\varphi \tag{3.173a}$$

$$\dddot{I}_{12} = \dddot{I}_{21} = -4\frac{c^5}{G}\frac{\mu}{M}\left(\frac{v}{c}\right)^5 \cos 2\varphi. \tag{3.173b}$$

**Example 3.15**
PAGE 90

A negative sign is missing in the inline equation near the end of the example; the text should read:

> ...the General Relativity prediction for the orbital decay is $\dot{P} = -2.402 \times 10^{-12}$, ...

**Problem 3.1**
PAGE 91

The first equation in the problem should read:

$$T^{\mathrm{GW}}_{\alpha\beta} = -\frac{c^4}{8\pi G}\langle \overset{2}{G}_{\alpha\beta} \rangle + O(h^3),$$

## Chapter 4

**Equation 4.11**
PAGE 101

The equation contains an index error; it should read:

$$\begin{aligned} 16\pi t_{\alpha\beta} = &-4\frac{\partial\Phi}{\partial x^\alpha}\frac{\partial\Phi}{\partial x^\beta} - 8\frac{\partial^2\Phi}{\partial x^\alpha \partial x^\beta} \\ &+ \eta_{\alpha\beta}(8\Phi\nabla^2\Phi + 6(\boldsymbol{\nabla}\Phi)\cdot(\boldsymbol{\nabla}\Phi)) \end{aligned} \tag{4.11}$$

**Equation 4.35a**
PAGE 105

The equation contains a factor of $1/c^2$ error; the first line should read:

$$g_{00} = -c^2 + h_{00} = -c^2 - 2\Phi - 2\frac{\Phi^2}{c^2} + 4\Psi - \frac{1}{c^2}\frac{\partial^2\chi}{\partial t^2} + O(\epsilon^6)$$

**Equation 4.50**
PAGE 108

There is a missing subscript in this equation; the second to last line should read:

$$+\hat{\boldsymbol{n}} \cdot \boldsymbol{x}_A \frac{(v^i_A x^j_A + v^j_A x^i_A)}{c} + (\hat{\boldsymbol{n}} \cdot \boldsymbol{x}_A)^2 \frac{v^i_A}{c} \frac{v^j_A}{c}$$

**Equation 4.52**
PAGE 109

There is a subscript error on the last line of this equation; the last line should read:

$$\left. -\frac{1}{2} \frac{(\boldsymbol{v}_1 \cdot \boldsymbol{r}_{12})(\boldsymbol{v}_2 \cdot \boldsymbol{r}_{12})}{c^2 r_{12}^2} \right] \tag{4.52}$$

*Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel*

**Equation 4.53**
PAGE 109

There is a subscript error on the last line of this equation; the last line should read:

$$\left. +\frac{1}{2} \frac{(\boldsymbol{v}_1 \cdot \boldsymbol{r}_{12})(\boldsymbol{v}_2 \cdot \boldsymbol{r}_{12})}{c^2 r_{12}^2} \right], \tag{4.53}$$

*Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel*

**Equation. (4.63)**
PAGE 110

There are factors of $c$ errors after the last equality; the equation should read:

$$x^{3/2} = \frac{GM\omega}{c^3} = \frac{GM}{c^2 a} \frac{v}{c} = \frac{v^3}{c^3} \left[ 1 + (3 - \eta) \frac{v^2}{c^2} \right] \tag{4.110}$$

*Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel*

**Before Eq. (4.65)**
PAGE 111

The energy function should be defined as:

$$\mathcal{E} := (E - Mc^2)/Mc^2$$

*Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel*

**Equation (4.104)** PAGE 118

The equation contains index errors; it should read:

$$\bar{h}_{\alpha\beta} = h_{\alpha\beta} - \frac{1}{2}\overset{0}{g}_{\alpha\beta}h, \tag{4.104}$$

**Equation (4.105)** PAGE 118

Some Ricci terms were omitted; the equation should read:

$$G_{\alpha\beta} = \overset{0}{G}_{\alpha\beta} + \frac{1}{2}\Big(-\overset{0}{g}{}^{\mu\nu}\overset{0}{\nabla}_\mu\overset{0}{\nabla}_\nu\bar{h}_{\alpha\beta} - \overset{0}{g}_{\alpha\beta}\overset{0}{\nabla}_\mu\overset{0}{\nabla}_\nu\bar{h}^{\mu\nu} + \overset{0}{\nabla}_\mu\overset{0}{\nabla}_\alpha\bar{h}^\mu{}_\beta + \overset{0}{\nabla}_\mu\overset{0}{\nabla}_\beta\bar{h}_\alpha{}^\mu - \bar{h}_{\alpha\beta}\,\overset{0}{g}{}^{\mu\nu}\overset{0}{R}_{\mu\nu} + \overset{0}{g}_{\alpha\beta}\,\bar{h}^{\mu\nu}\overset{0}{R}_{\mu\nu}\Big) + O(h^2). \tag{4.105}$$

*Credit: John Friedman*

**Equation (4.107)** PAGE 118

The error in Eq. (4.105) propagates to this equation; it should read:

$$\overset{0}{g}{}^{\mu\nu}\overset{0}{\nabla}_\mu\overset{0}{\nabla}_\nu\bar{h}_{\alpha\beta} - \overset{0}{\nabla}_\mu\overset{0}{\nabla}_\alpha\bar{h}_\beta{}^\mu - \overset{0}{\nabla}_\mu\overset{0}{\nabla}_\beta\bar{h}^\mu{}_\alpha + \bar{h}_{\alpha\beta}\,\overset{0}{g}{}^{\mu\nu}\overset{0}{R}_{\mu\nu} - \overset{0}{g}_{\alpha\beta}\,\bar{h}^{\mu\nu}\overset{0}{R}_{\mu\nu} = -\frac{16\pi G}{c^4}\delta T_{\alpha\beta} \quad \text{(Lorenz gauge).} \tag{4.107}$$

*Credit: John Friedman*

**Equation (4.109)** PAGE 118

The error in Eq. (4.107) propagates to this equation; it should read:

$$\overset{0}{g}{}^{\mu\nu}\overset{0}{\nabla}_\mu\overset{0}{\nabla}_\nu\bar{h}_{\alpha\beta} + 2\overset{0}{R}_\alpha{}^\mu{}_\beta{}^\nu\bar{h}_{\mu\nu} - \overset{0}{R}_\alpha{}^\mu\bar{h}_{\beta\mu} - \overset{0}{R}_\beta{}^\mu\bar{h}_{\alpha\mu} + \bar{h}_{\alpha\beta}\,\overset{0}{g}{}^{\mu\nu}\overset{0}{R}_{\mu\nu} - \overset{0}{g}_{\alpha\beta}\,\bar{h}^{\mu\nu}\overset{0}{R}_{\mu\nu} = -\frac{16\pi G}{c^4}\delta T_{\alpha\beta} \quad \text{(Lorenz gauge).} \tag{4.109}$$

*Credit: John Friedman*

## Chapter 5

**Problem 5.4**
PAGE 195

The last sentence of the problem should read:

> Compute the gravitational waveform seen by an observer at a distance $r = 10\,\text{kpc}$ off the axis of the collapsing spheroid.

## Chapter 6

**Before Eq. (6.99)**
PAGE 224

The inline equation in the sentence beginning before Eq. (6.99) is missing a superscript 2; it should read:

$$S_I = 2\hbar c k I_0 G_{\text{prc}} G_{\text{arm}}^2 (k\Delta L_0)^2$$

**Equation (6.112)**
PAGE 228

The equation is missing a superscript 2; it should read:

$$I_{0,\text{opt}} = \frac{\pi^2 M c}{2k} \frac{1}{G_{\text{prc}} G_{\text{arm}}^2} \frac{f_{\text{opt}}^2}{|\hat{C}_{\text{FP}}(f_{\text{opt}})|^2} \tag{6.112}$$

**Equation (6.123)**
PAGE 230

A factor is missing from the equation; it should read:

$$-4\pi^2 f^2 \ell \tilde{x} = -g(\tilde{x} - \tilde{X}) \tag{6.123}$$

**Equation (6.187)**
PAGE 243

Arguments to the $D$ function are given in reverse order; the equation should read:

$$\begin{aligned} \tilde{\phi}_{\text{ext}}(f) &:= \tilde{\phi}_{\text{ext},1}(f) - \tilde{\phi}_{\text{ext},2}(f) \\ &= kL\tilde{h}_{ij}(f)[\hat{p}^i \hat{p}^j D(\hat{\boldsymbol{p}} \cdot \hat{\boldsymbol{n}}, fL/c) - \hat{q}^i \hat{q}^j D(\hat{\boldsymbol{q}} \cdot \hat{\boldsymbol{n}}, fL/c)] \\ &= 2kL\tilde{h}(f), \end{aligned} \tag{6.187}$$

**Equation (6.202)** PAGE 247

There is an extra factor of $i$; the equation should read:

$$\hat{C}_{\rm SR}(f) = \frac{t_{\rm SRM} e^{-i(2\pi f \ell_{\rm SRC}/c+\phi_{\rm SRC})}}{1 - r_{\rm SRM}\left(\frac{r_{\rm ITM}-e^{-4\pi i f L/c}}{1-r_{\rm ITM}e^{-4\pi i f L/c}}\right) e^{-2i(2\pi f \ell_{\rm SRC}/c+\phi_{\rm SRC})}}. \qquad (6.202)$$

**Before Eq. (6.210)** PAGE 254

Correct spelling is *Sagnac interferometer*.

*Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel*

## Chapter 7

**After Eq. (7.1)** PAGE 269

A stationary process is not necessarily ergodic. The second sentence after Eq. (7.1) should read:

If the process is also *ergodic* then the ensemble average is equivalent to a long time average. . . .

*Credit: Kipp Cannon*

**Equation (7.5)** PAGE 270

There are extraneous superscript 2s; the equation should read:

$$\begin{aligned} \langle x^2 \rangle &= \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{\infty} x_T^2(t)dt \\ &= \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{\infty} |\tilde{x}_T(f)|^2 df \\ &= \lim_{T\to\infty} \frac{2}{T} \int_{0}^{\infty} |\tilde{x}_T(f)|^2 df \\ &= \int_0^\infty S_x(f) df, \end{aligned} \qquad (7.5)$$

*Credit: Benjamin Lackey*

**Equation (7.65)** PAGE 283

The equation should read:

$$\begin{aligned} \mathcal{O}(\boldsymbol{\mu}; \boldsymbol{\mu}+\Delta\boldsymbol{\mu}) &:= \max_{\Delta t} \mathcal{A}(t_0, \boldsymbol{\mu}; t_0+\Delta t, \boldsymbol{\mu}+\Delta\boldsymbol{\mu}) \\ &= \max_{\Delta t} \left( u(t_0,\boldsymbol{\mu}), u(t_0+\Delta t, \boldsymbol{\mu}+\Delta\boldsymbol{\mu}) \right) \end{aligned} \qquad (7.65)$$

*Credit: Joseph Romano*

**Equation (7.67)** PAGE 283

The equation should read:

$$\gamma^{ij}(\boldsymbol{\mu}) = -\frac{1}{2} \max_{\Delta t} \left( u(t_0, \boldsymbol{\mu}) \, , \frac{\partial^2 u}{\partial \mu_i \partial \mu_j} (t_0 + \Delta t, \boldsymbol{\mu} + \Delta \boldsymbol{\mu}) \right) \\ = g^{ij} - g^{i0} g^{0j} / g^{00} \qquad (i, j > 0). \tag{7.67}$$

*Credit: Joseph Romano*

**Equation (7.234)** PAGE 328

The equation should read:

$$\Delta t_0 = \sqrt{(\Gamma^{-1})_{00}} = \frac{1}{\varrho} \frac{|B^{00}|^{1/2}}{2\pi f_0}, \tag{7.234a}$$

$$\Delta \varphi_0 = \sqrt{(\Gamma^{-1})_{11}} = \frac{1}{\varrho} \frac{|B^{11}|^{1/2}}{2}, \tag{7.234b}$$

$$\frac{\Delta \mathcal{M}}{\mathcal{M}} = \sqrt{(\Gamma^{-1})_{22}} = \frac{1}{\varrho} \frac{128}{5} \left( \frac{\pi G \mathcal{M} f_0}{c^3} \right)^{5/3} |B^{22}|^{1/2}. \tag{7.234c}$$

**Equation (7.282)** PAGE 340

The summations over $j$ are different for the two terms in the integrand; the equation should read:

$$\mathcal{N}^2 := \sum_{i=1}^{N} 4 \int_0^\infty \left\{ -T \sum_{\substack{j=1 \\ j<i}}^{N} \frac{\hat{S}_{ij}(f) \hat{S}_{ji}(f)}{S_i(f) S_j(f)} \right. \\ \left. + 2 \,\mathrm{Re} \sum_{\substack{j=1 \\ j \le i}}^{N} \sum_{\substack{k=1 \\ k \ne i,j}}^{N} \frac{\tilde{s}_i^*(f) \hat{S}_{ik}(f) \hat{S}_{kj}(f) \tilde{s}_j(f)}{S_i(f) S_k(f) S_j(f)} \right\} df \tag{7.282}$$

**Equation (7.298)** PAGE 343

The equation should read:

$$\Omega_0 = \varrho T^{-1/2}\left(\frac{3H_0}{10\pi^2}\right)^{-1}\left(2\int_0^\infty \frac{\gamma_{\rm HL}^2(f)}{f^6 S_{\rm H1}(f) S_{\rm L1}(f)}\,df\right)^{-1/2} \sim 2\times 10^{-6} \tag{7.298}$$

## Chapter 8

(No errors reported so far. . . .)

## Appendix A

(No errors reported so far. . . .)

## Appendix B

**Equation (B.4)**
PAGE 364

There are errors in a few factors; the equation should read:

$$
\begin{aligned}
h_{22} = &- 8\sqrt{\frac{\pi}{5}}\frac{G\mu}{c^2 r}\mathrm{e}^{-2i\varphi}x\left\{1 - \left(\frac{107}{42} - \frac{55}{42}\eta\right)x\right. \\
&+ \left[2\pi + 6i\ln\left(\frac{x}{x_0}\right)\right]x^{3/2} \\
&- \left(\frac{2173}{1512} + \frac{1069}{216}\eta - \frac{2047}{1512}\eta^2\right)x^2 \\
&- \left[\left(\frac{107}{21} - \frac{34}{21}\eta\right)\pi + 24i\eta\right. \\
&\quad \left. + i\left(\frac{107}{7} - \frac{34}{7}\eta\right)\ln\left(\frac{x}{x_0}\right)\right]x^{5/2} \\
&+ \left[\frac{27\,027\,409}{646\,800} - \frac{856}{105}\gamma_\mathrm{E} + \frac{2}{3}\pi^2\right. \\
&\quad - \frac{1712}{105}\ln 2 - \frac{428}{105}\ln x - 18\left[\ln\left(\frac{x}{x_0}\right)\right]^2 \\
&\quad - \left(\frac{278\,185}{33\,264} - \frac{41}{96}\pi^2\right)\eta - \frac{20\,261}{2772}\eta^2 \\
&\quad \left.\left. + \frac{114\,635}{99\,792}\eta^3 + i\frac{428}{105}\pi + 12i\pi\ln\left(\frac{x}{x_0}\right)\right]x^3\right\};
\end{aligned}
\qquad \text{(B.4)}
$$

*Credit: Benjamin Lackey*