# ERRATA FOR Gravitational-Wave Physics and Astronomy

Jolien D. E. Creighton, Warren G. Anderson

2014-06-26

## **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 *x* and having mass  $\frac{dm}{dm} = \rho(x) d^3 x$ , experiences a tidal force

$$F_i = -\mathcal{E}_{ij} x^j \frac{dm}{dm}. \tag{1.21}$$

If the element is moving through the tidal field with velocity 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:

$$\frac{dW}{dt} = -\int_{\text{body}} \mathcal{E}_{ij} v^{i} x^{j} dm$$

$$= -\frac{1}{2} \mathcal{E}_{ij} \frac{d}{dt} \int_{\text{body}} x^{i} x^{j} dm$$

$$= -\frac{1}{2} \mathcal{E}_{ij} \frac{dI^{ij}}{dt}$$
(1.22)

where, since  $dm = \rho(x)d^3x$ ,

$$I^{ij} \coloneqq \int_{\text{body}} x^i x^j \rho(\mathbf{x}) d^3 \mathbf{x}$$
(1.23)

is the quadrupole tensor.

Credit: Nathan Kieran Johnson-McDaniel

Before Eq. (1.27) In sentence ending in Eq. (1.27), the term 'quadrupole tensor' PAGE 8 should have been used rather than 'moment of inertia tensor'. Credit: Leslie Wade

## **Chapter 2**

Equation (2.20) The equation contains an index error; it should read: PAGE 16

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

Credit: Leslie Wade

Equation (2.67) PAGE 29

The equation contains an index error; it should read:

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

Equation (2.68)

quation contains an index error: it should read.

PAGE 30

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

Equation (2.102) The equation is missing a factor of 4; it should read:

PAGE 36

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

After Eq. (2.148) Equation (2.148) actually contains some post-Newtonian correc-PAGE 44 tions. 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) The equation contains a factor of 4 rather than a factor of 2; it should PAGE 45 read:

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

# PAGE 46

Equation (2.154) The equation is missing a negative sign; it should read:

$$\Delta \tau = \int_{\gamma} d\tau = \int_{0}^{1} \sqrt{-g_{\mu\nu}} \frac{dx^{\mu}}{d\sigma} \frac{dx^{\nu}}{d\sigma} d\sigma, \qquad (2.154)$$

Equation (2.156) The equation is missing a negative sign; it should read:

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

Problem 2.5 PAGE 47

Part (b) of the problem should read:

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

## **Chapter 3**

```
Section 3.1
                     The argument made at the beginning of this section is missing a
PAGE 49
                     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. Equa-
                       tion (3.1) implies that the components of the met-
                       ric perturbation (both the actual perturbation and the
                       trace-reversed version) must all be functions of the
                       retarded time t - z/c. Because gauge freedom re-
                       mains within the Lorenz gauge [cf. Eq. (2.140)], we
                       are free to perform a gauge transformation generated
                       by \xi = \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)The inline equations of the last sentence of the paragraph are miss-<br/>ing 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) The in PAGE 71 read:

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

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

# **Equation (3.173)** The equations contain the wrong factors of *G* and *c* and use $\phi$ rather PAGE 87 than $\phi$ ; they should read:

$$\ddot{I}_{11} = -\ddot{I}_{22} = 4 \frac{c^5}{G} \frac{\mu}{M} \left(\frac{v}{c}\right)^5 \sin 2\varphi \qquad (3.173a)$$
$$\ddot{I}_{12} = \ddot{I}_{21} = -4 \frac{c^5}{G} \frac{\mu}{M} \left(\frac{v}{c}\right)^5 \cos 2\varphi. \qquad (3.173b)$$

Example 3.15A negative sign is missing in the inline equation near the end of the<br/>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:

 $T^{\mathrm{GW}}_{lphaeta} = -rac{c^4}{8\pi G} ig\langle rac{2}{\mathbf{G}_{lphaeta}} ig
angle + O(h^3),$ 

## **Chapter 4**

Equation 4.11 PAGE 101 The equation contains an index error; it should read:

 $16\pi t_{\alpha\beta} = -4 \frac{\partial\Phi}{\partial x^{\alpha}} \frac{\partial\Phi}{\partial x^{\beta}} - 8 \frac{\partial^{2}\Phi}{\partial x^{\alpha}\partial x^{\beta}} + \eta_{\alpha\beta} (8\Phi\nabla^{2}\Phi + 6(\nabla\Phi) \cdot (\nabla\Phi))$  (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 There is a missing subscript in this equation; the second to last line PAGE 108 should read:

$$+\,\hat{\boldsymbol{n}}\cdot\boldsymbol{x}_{A}\frac{(v_{A}^{i}x_{A}^{j}+v_{A}^{j}x_{A}^{i})}{c}+(\hat{\boldsymbol{n}}\cdot\boldsymbol{x}_{\underline{A}})^{2}\frac{v_{A}^{i}}{c}\frac{v_{A}^{j}}{c}$$

Equation 4.52 PAGE 109

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

$$-\frac{1}{2} \frac{(v_1 \cdot r_{12})(v_2 \cdot r_{12})}{c^2 r_{12}^2} \right]$$
(4.52)

Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel

#### Equation 4.53 There is a subscript error on the last line of this equation; the last PAGE 109 line should read:

$$+\frac{1}{2}\frac{(v_1 \cdot r_{12})(v_2 \cdot r_{12})}{c^2 r_{12}^2} \bigg], \qquad (4.53)$$

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:

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

Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel

Before Eq. (4.65) The energy function should be defined as:

PAGE 111

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

Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel

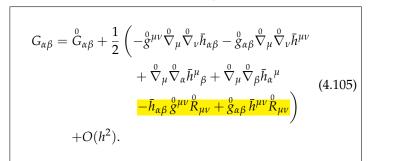
Equation (4.104) The equation contains index errors; it should read:

PAGE 118

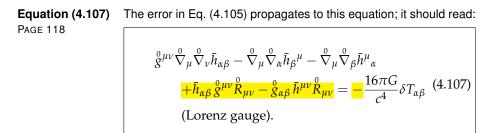
$$\bar{h}_{\alpha\beta} = h_{\alpha\beta} - \frac{1}{2} g_{\alpha\beta}^{0} h, \qquad (4.104)$$

Equation (4.105) PAGE 118

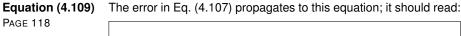
Some Ricci terms were omitted; the equation should read:



Credit: John Friedman



Credit: John Friedman



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

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 kpc off the axis of the collapsing spheroid.

# **Chapter 6**

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

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

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

**Equation (6.112)** The equation is missing a superscript 2; it should read:

PAGE 228

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

Equation (6.123) A factor is missing from the equation; it should read:

PAGE 230

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

**Equation (6.187)** Arguments to the *D* function are given in reverse order; the equation should read:

$$\begin{split} \tilde{\phi}_{\text{ext}}(f) &\coloneqq \tilde{\phi}_{\text{ext},1}(f) - \tilde{\phi}_{\text{ext},2}(f) \\ &= k L \tilde{h}_{ij}(f) [\hat{p}^i \hat{p}^j D(\frac{\hat{p} \cdot \hat{n}, fL/c}{\hat{p} \cdot \hat{n}, fL/c}) - \hat{q}^i \hat{q}^j D(\frac{\hat{q} \cdot \hat{n}, fL/c}{\hat{q} \cdot \hat{n}, fL/c})] \\ &= 2k L \tilde{h}(f), \end{split}$$
(6.187)

There is an extra factor of *i*: the equation should read: Equation (6.202)

PAGE 247

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

Before Eq. (6.210) Correct spelling is Sagnac interferometer.

PAGE 254 Credit: Charalampos Markakis and Nathan Kieran Johnson-McDaniel

# **Chapter 7**

<b>After Eq. (7.1)</b> Page 269	A stationary process is not necessarily ergodic. The second sentence after Eq. (7.1) should read:
	To the second is the second in the second labor to the second labo

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

Credit: Kipp Cannon

Equation (7.5)	There are extraneous superscript 2s; the equation should read:
----------------	--

PAGE 270

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

Credit: Benjamin Lackey

# Equation (7.65)

PAGE 283

$$\mathcal{O}(\boldsymbol{\mu}; \boldsymbol{\mu} + \Delta \boldsymbol{\mu}) \coloneqq \max_{\Delta t} \mathcal{A}(t_0, \boldsymbol{\mu}; t_0 + \Delta t, \boldsymbol{\mu} + \Delta \boldsymbol{\mu})$$
  
= 
$$\max_{\Delta t} \left( u(t_0, \boldsymbol{\mu}), u(t_0 + \Delta t, \boldsymbol{\mu} + \Delta \boldsymbol{\mu}) \right)$$
(7.65)

Credit: Joseph Romano

.

Equation (7.67) PAGE 283 The equation should read:  $\gamma^{ij}(\mu) = -\frac{1}{2} \max_{\Delta t} \left( u(t_0, \mu), \frac{\partial^2 u}{\partial \mu_i \partial \mu_j} (t_0 + \Delta t, \mu + \Delta \mu) \right)$   $= g^{ij} - g^{i0} g^{0j} / g^{00} \qquad (i, j > 0).$ (7.67)

Credit: Joseph Romano

### Equation (7.234) The equation should read:

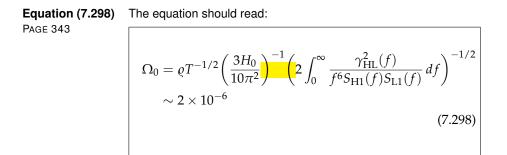
PAGE 328

# $\Delta t_{0} = \sqrt{(\Gamma^{-1})_{00}} = \frac{1}{\varrho} \frac{|B^{00}|^{1/2}}{2\pi f_{0}}, \qquad (7.234a)$ $\Delta \varphi_{0} = \sqrt{(\Gamma^{-1})_{11}} = \frac{1}{\varrho} \frac{|B^{11}|^{1/2}}{2}, \qquad (7.234b)$ $\frac{\Delta \mathcal{M}}{\mathcal{M}} = \sqrt{(\Gamma^{-1})_{22}} = \frac{1}{\varrho} \frac{128}{5} \left(\frac{\pi G \mathcal{M} f_{0}}{c^{3}}\right)^{5/3} |B^{22}|^{1/2}. \qquad (7.234c)$

Equation (7.282) PAGE 340

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

$$\mathcal{N}^{2} \coloneqq \sum_{i=1}^{N} 4 \int_{0}^{\infty} \left\{ -T \sum_{\substack{j=1\\j < i}}^{N} \frac{\hat{S}_{ij}(f)\hat{S}_{ji}(f)}{S_{i}(f)S_{j}(f)} + 2 \operatorname{Re} \sum_{\substack{j=1\\j \le i}}^{N} \sum_{\substack{k=1\\k \neq i,j}}^{N} \frac{\tilde{S}_{i}^{*}(f)\hat{S}_{ik}(f)\hat{S}_{kj}(f)\hat{S}_{j}(f)}{S_{i}(f)S_{k}(f)S_{j}(f)} \right\} df$$
(7.282)



# **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:

$$\begin{aligned} h_{22} &= -8\sqrt{\frac{\pi}{5}}\frac{G\mu}{c^2r}e^{-2i\varphi}x\left\{1 - \left(\frac{107}{42} - \frac{55}{42}\eta\right)x\right.\\ &+ \left[2\pi + 6i\ln\left(\frac{x}{x_0}\right)\right]x^{3/2} \\ &- \left(\frac{2173}{1512} + \frac{1069}{216}\eta - \frac{2047}{1512}\eta^2\right)x^2 \\ &- \left[\left(\frac{107}{21} - \frac{34}{21}\eta\right)\pi + 24i\eta\right.\\ &+ i\left(\frac{107}{7} - \frac{34}{7}\eta\right)\ln\left(\frac{x}{x_0}\right)\right]x^{5/2} \\ &+ \left[\frac{27\,027\,409}{646\,800} - \frac{856}{105}\gamma_{\rm E} + \frac{2}{3}\pi^2\right.\\ &- \frac{1712}{105}\ln2 - \frac{428}{105}\ln x - 18\left[\ln\left(\frac{x}{x_0}\right)\right]^2 \\ &- \left(\frac{278\,185}{33\,264} - \frac{41}{96}\pi^2\right)\eta - \frac{20\,261}{2772}\eta^2 \\ &+ \frac{114\,635}{99\,792}\eta^3 + i\frac{428}{105}\pi + 12i\pi\ln\left(\frac{x}{x_0}\right)\right]x^3 \right\}; \end{aligned}$$
(B.4)

Credit: Benjamin Lackey