Errata for Gravity: An Introduction to Einstein's General Relativity, *1st and 2nd Printing*

Updated 3/24/2004

Thanks are due to Richard Cook, Scott Fraser, Peter Milonni, John North, and Rolf Riklund who supplied many of these corrections.

xv, 2l: "At its core.." instead of "At is core.."

xvi: Insert Max Tegmark in between Tuck Stebbins and Dave Tytler.

xvi: Replace "individual figure captions" with "individual figure credits".

xx, Credit for Fig 13.3: Herrnstein not Hernstein.

26, last line Box: "America" instead of "Americal".

27: Horizontal bar after Example 2.1.

29, Problem 9: Replace R with a for consistency with eq. (2.21).

31, 2l: "and" is repeated.

33, 3l from bottom: "origin of the frame" rather than "origin the frame".

35, Box 3.1, last par.: Replace "with mass .... about 11 orders of magnitude smaller than the wavelength of visible light." with the following:

"with mass m is $h/(mv)$ which for the velocities of the atoms in these experiments is very much smaller than the wavelength of visible light."

(note it's h in the above formula not $\hbar$.)

45, Problem 1: Replace "What are the ... " to the end with the following (clearer): "Consider a rectangular frame (x',y',z') rotating with respect to the inertial frame with an angular velocity ω about a common z-axis ($z' = z$). What are the equations of motion obeyed by $x'(t)$, $y'(t)$ and $z'(t)$ in the rotating frame? Sketch the trajectory of the particle in the $x'y'$-plane and show explicitly that it satisfies these equations of motion."

57, Figure 4.8: In the left hand part of this picture the point B' should be 3 units from $A'C'$ not 3.5 units as shown. For the figure as presented the relevant equation in (c) in the inverted footnote would be changed to $|A'B'| = (-3^2 + 3.5^2)^{1/2} = 1.80$. But don't make both of these changes! It would be cleaner to fix the figure.

62, 1l after Example 4.2: "did not refer to" instead of "did not to refer to".

63, Figure 4.12: Would be more consistent with other figures in this section if t, t_1, t_2 are replaced with ct, ct_1, and ct_2.

84, Figure 5.7: If there is space in the caption, add the sentences: "This is a two-dimensional plot. But it is both evocative and conventional to draw three-dimensional light cones even though there is only two-dimensional information."

100, Problem 5: The reference should be to Figure 5.6.

111, caption of Figure 6.3: Replace "over short" with "over a short".

122, Figure 6.9: The brighter and darker halves of the orbits are a printer artifact which would be nice to fix.

124, 5l: "applied to the rate" instead of "applied to rate".

133, Problem 13: Add a clarifying clause to the fourth sentence so it reads: " Calculate the total elapsed time measured on each clock assuming that the maximum height is much smaller than the radius of the Earth." Delete the last sentence. The question could be confusing.

137, Equation (c): The discussion in this Box is is ok as is, but it would more upwardly compatible (e.g. with Hawking and Ellis) if t' and r' were defined as:

$$\begin{aligned} u' &\equiv \tan^{-1} u \equiv (t' - r')/2 \\ v' &\equiv \tan^{-1} v \equiv (t' + r')/2 \end{aligned}$$

143, eq (7.43): $T = A\tau$ should be $T = \tau/A$.

148, 5l: "surface in three-dimensional flat space" instead of "surface in flat three-dimensional flat space."

150, just below (7.47): hyphenate axisymmetric as axi-symmetric.

155, Equation (7.56): If there is a dot hovering over this equation, as there is in the author's copy, it shouldn't be there.

155, last sentence of Ex 7.8: "is a unit vector" instead of "is unit vector".

157, Equation (i): The superscript A should be the same weight as in (a) or (b).

162, Eq. (7.78): Delete the "*a*'s" in this equation (so it is a *unit* normal as advertised.)

166, Problem 16, 2l: "is" is repeated.

173, 3l from bottom: "can be thought of" instead of "can be though of".

175, line above (8.23): The equation in the text should be $u^r \equiv dr/d\tau = U$, not $= 0$.

178, l above (8.35): Replace (8.6a) with (8.33).

180, 4l par. 3: "that the coordinate basis" instead of "that coordinate basis".

181, line below (8.48) "constructing Riemann normal coordinates at" not "constructing Riemann normal at".

184, Problem 5: The reference to the wormhole metric should be to (7.39) not (8.14).

186, 11l from top: "concentrate on predicting" rather than "concentrate on the predicting".

188, last sentence under Schwarzschild Radius bullet: "face up to these radii" instead of "face up these radii".

188, 3l above (9.8): "$c = 1$ and both space and time" instead of "$c = 1$ and both and space and time".

200, 1l above (9.44): Change "for any orbit" to "for any equatorial orbit" if possible (clearer).

202, Figure 9.5: The label ℓ should be ℓ/M.

203, 4l above (9.54): "last term in the denominator" instead of "last term the denominator".

213, 3l from top of text: "radii of the orbits of the Earth and the reflector" rather than "radii of the Earth and reflector" (clearer).

214, 6l above (9.91): "depends crucially on the use" rather than "depends crucially the use".

215, Problem 6: replace "(exterior geometry the Schwarzschild geometry)," with "whose exterior geometry is the Schwarzschild geometry, "

223, 3l from bottom: "when the Sun is in the field" instead of "when the Sun in the field".

226, Equation 10.13 The formula is in Gaussian units and the sign of the second term is wrong. Replace "... can be modeled by" and the equation by "can be modeled by (SI units)" and this equation

$$n(r) = 1 - \frac{e^2 N(r)}{2\varepsilon_0 m\omega^2}$$

228, Figure 10.6: Change sentence beginning "The bottom part..." to "The bottom part shows the experimental data for the deflection in the angular position of 0116+08 measured relative to the other two sources."

232, 1l last paragraph: "The Sun has a quadrupole moment" instead of "The Sun has quadrupole moment".

233, Problem 5: The problem would be easier to do if there was one more column in the table, viz.

	Semimajor axis 10^6 (km)	Eccentricity	Mass/$M_\oplus$	Period (yr)
Mercury	57.91	.2056	.054	.241
Venus	108.21	.0068	.815	.615
Earth	149.60	.0167	1.000	1.000

235, footnote: add (See Figure 17.7 for the origin of the unit.) or (See also Figure 17.7.) if that won't fit.

236, 4l in caption: "The heavy dashed line shows" instead of "The solid line shows".

237, 2l: "take place in a plane normal" instead of "take place in plane normal".

244, 2l above end of 1st par.: "can naturally fall onto" instead of "can naturally can fall onto".

245, Equation (a): The formula for the Thomson cross section is given in Gaussian units. Add to the preceding sentence "(SI units)" and replace eq. (a) by

$$\sigma_T = \frac{8\pi}{3}\left(\frac{e^2}{4\pi\varepsilon_0 m_e c^2}\right)^2 = 0.665\times 10^{-24}\ \mathrm{cm}^2.$$

252, 4l of paragraph 2: "half the maximum distance between the stars" instead of "the maximum distance between the stars".

252, 8l of second full paragraph: "motion of the binary system" instead of "motion of binary system".

256, 7l of second paragraph: "matter above nuclear" instead of "matter at above nuclear".

259, 3l from bottom: "than inside it" rather than "and inside it".

261, 4l above (b) in Box: The text equation should be $f^r = mM/R^2$, ie there is a factor of m missing.

262, 7l from top: Replace "Schwarzschild" with "Schwarzschild geometry"

271, caption for Figure 12.6: Replace "and $\pm 3.25M$." by "$\pm 3.25M$, and $\pm\infty$. Also 2l above end replace $r = M$ with $r = 2M$. (The left hand figure would be helped by a few indications of constant r hyperbolae, and constant t straight lines.)

274, 4l above end of text: "distant observer, leading to the increasing" rather than "distant observer leading the increasing".

278, Problem 13: Replace "Does she see her feet..." with "Does she ever see her feet ..."

295, Problem 3: The figure in the text shows two jets and the problem should be amended to reflect that as follows:

"In the image of the radio source Cygnus A in Figure 13.5 one jet is much brighter than the other. Rotating black hole models of the source suggest that the two jets emerge in opposite directions along the rotation axis. What famous effect of special relativity could contribute to an explanation of the difference in brightness. Assuming the intensities differ by a factor of 100, and that the axis makes an angle of 45° with respect to the line of sight, what can you say about the velocity of the sources of the visible radiation in the jets?"

295, Problem 4: Add code [E] and replace the sentence beginning "Calculate the predicted...." with "Make a rough *estimate* of the predicted linear orbital velocities as a function of angular separation from the center by assuming that the stars are in circular orbits whose plane is perpendicular to the line of sight."

301, 1l after (14.11): "using (14.8)" instead of "using (14.9) and (14.10)".

304, Figure 14.3: Something has gone wrong with the figure since the original. The spinning object at the center of the laboratory is supposed to be a sphere. There isn't any "O" near the $\vec{J}$.

304, 5l from bottom: "solve for the precession" rather than "solve the for the precession".

305, Box 14.1, 1l: Replace "In late 2002, NASA expects" with "In the near future, NASA expects". (2002 has long gone and the future of this is uncertain.)

305, 6l from bottom: After the sentence ending "... Cartesian coordinates." insert. "(We won't need its explicit form.)"

308, Problem 2: replace "... for a circular orbit." with "... for a circular orbit lying in that plane". (clearer).

309, Problem 8: replace "if the spin starts..." with "if the spatial part of the spin starts ..." (clearer).

313, 2l from top: Replace "the the" by "the".

313, 9l from top: Replace "inside inside" by "inside".

315, Equation 15.12: might be clearer if ρ_+ is replaced by $\rho_+(\theta)$ and ρ_+^2 is replaced by $\rho_+^2(\theta)$.

319, 2l from bottom: Replace $r = 2M$ with $r = M$.

321, 3l from start of last par.: "moving in that orbit" rather than "moving the orbit".

322, (15.27): The second term should be $g_{tt}(u^t_{obs})^2$.

328, Problem 1: Italics for "Estimate" to be consistent with usage in other problems.

341, 6l from bottom of text: "But the various" rather than "But the the various".

345, 3l of Problem 11: "of" is repeated.

348, 3l from top of text: "If the visible..." rather than "If the the visible...".

353, Box 17.1 Before the sentence beginning "However..." insert "(For the origin of the unit see Figure 17.7.)" if it will fit.

353, Figure 17.6: Replace "approximately 20%." with "approximately 20%, keeping the size of the dots the same."

354, 3rd par: Replace the one long sentence beginning "Distances to nearby stars..." with the following two: "Distances to nearby stars can be determined precisely. However the cosmological redshift can be measured accurately only for galaxies sufficiently far away that the recession velocity dominates their local motions due to the attraction of other galaxies that may be nearby." (clearer).

356, 2l: "apparent magnitude" should be italicized just like absolute magnitude.

362, Figure 17.12: Replace " at a temperature resolution of resolution well" with "at a temperature resolution well..."

365, Problem 6: After the sentence ending "at 20% expansion." insert "(Real galaxies won't expand in size, so ignore the copier's expansion of the dots.)"

382, 10l from top: Replace "speed of light since the the time of ..." with "speed of light since the time of ...".

382, 12l from bottom of text: Replace the two sentences beginning "The past light cone of an observer... " with "Past light cones of an observer at two different times are shown. (One of these could be our past light cone were the time t_0.) " (there are two cones in the figure not one.)

384, 3l of Closed FRW Model subsection: "described by the scale factor" instead of "described in the scale factor."

389, 11l from bottom: Replace "matter has been the dominant density driving ..." with "matter has made the dominant contribution to the energy density driving..." or if that doesn't fit "matter has dominated the energy density driving ...".

392, 4l below (18.79): Replace $t_0 = H_0\tilde{t}_0$ with $t_0 = \tilde{t}_0/H_0$.

394, Figure 18.9: Replace $\Omega_m = 1.5$ with $\Omega_m = 2$.

395, Problem 1: replace "How would $a(t)$ it look..." with "How would $a(t)$ look ..."; replace "at all times assuming the ... isotropic." with "assuming the ... isotropic at all times."

397, Problem 18: Change label to "Radiation Dominated FRW Models". (De-Sitter space should be on problem 19.)

398, Problem 19: Add the label "de Sitter Space".

398, Problem 22: "for" is repeated.

400, 3l: "introduced in this chapter" instead of "introduced this chapter".

406, Figure 19.2: The distinction between the dotted, dashed and solid lines is much clearer on the original from A. Riess — check figure.

411, 2nd line of last par. "shows their relation to to ..." should be "shows their relation to ...".

434, bottom of text: Replace "Rocket thrust is need..." with "Rocket thrust is needed...".

439, line below (20.73): Replace "means the the spin..." with "means the spin..."

443, Problem 14: In the text and displayed equation the nablas (∇) should be bold faced.

444, Problem 25: Add code [A].

449: Example 21.2 is incorrect. Replace the text beginning "In this basis..." to the end of the example with the following (designed just to fit in the space):

An observer falling freely and radially might employ just such a basis where the components of the deviation equation (21.5) become

$$\frac{d^2\chi^{\hat{r}}}{dt^2} = +\frac{2M}{r^3}\chi^{\hat{r}} \ , \quad \frac{d^2\chi^{\hat{\theta}}}{dt^2} = -\frac{M}{r^3}\chi^{\hat{\theta}} \ , \quad \frac{d^2\chi^{\hat{\phi}}}{dt^2} = -\frac{M}{r^3}\chi^{\hat{\phi}} \ . \tag{21.9}$$

An object falling towards the central mass is stretched in the radial direction and compressed in the transverse directions by tidal gravitational forces.

Example 21.2. Detecting the Earth's Gravitational Field from inside the space shuttle. A space shuttle falls freely and radially towards the Earth. Astronauts inside use Newtonian physics to analyze the relative motion of two ping pong balls to detect the Earth's gravitational field as in Example 6.3. The balls start at relative rest at $t = 0$, when radius R is crossed, separated radially by a small distance s. The separation vector is thus $\vec{\chi} = s\vec{e}_{\hat{r}}$ initially and its time derivative is zero then. The subsequent evolution of $\vec{\chi}$ is determined by the deviation equations (21.9). Over a short period of time t after $t = 0$ the solution to (21.9) is

$$\vec{\chi}(t) \approx s\left[1 + (M/R^3)t^2\right] \ \vec{e}_{\hat{r}} \ . \tag{21.10}$$

This is only valid over times t small enough that $|\vec{\chi}(t)|$ remains small and r changes little. For such times, the change $\delta s(t)$ in separation between the balls is

$$\delta s(t)/s \approx (2\pi t/P)^2 \tag{21.11}$$

where P is the period of a circular orbit at radius R. This coincides with the estimate (6.15) in Example 6.3. The Earth's gravitational field can be detected through the deviation of the balls.

453, 4l from top: "Since the $\mathbf{e}^{\hat{\alpha}}$ ... ie the in text equation needs a hat over the alpha.

453, 1l below (21.26): Replace "when calculated (21.25)." with "when calculated using (21.25)."

467, Problem 4: replace "of geodesic deviation." with "of geodesic deviation (21.19)." (clearer).

469, Problem 24: Replace "to the test particles the gravitational" with "to the test particles when the gravitational.."

473, eq. 22.10: The first N in this equation should be a $\mathcal{N}$. Only the first! There are four more that are ok so the equation should start $\Delta\mathcal{N} = \cdots$. Then in the immediately preceding line the same thing. "... particles $\Delta\mathcal{N}$ in the three-volume ..."

489, Problem 12: replace "... *A*, *B*, and *C* are functions..." with "... *A*, *B*, *C*, and *D* are functions...".

496, eq. (22.23): Delete the $= 0$ at the end.

512, Problem 11: replace the sentences beginning "Calculate ..." with "Calculate the gravitational wave metric perturbations at a large distance L along the positive $z-$axis." (The problem involved calculating energy flux for non-harmonically varying sources for which the energy flux expression was only covered in a Web supplement.)

515, 1l of third paragraph: "can be" is repeated.

535, 2nd sentence in 2nd bullet point: "helium to uranium have nearly.." instead of "helium to uranium have have nearly ..".

538, Problem 10: Add to the end of the first sentence as follows: "... of area $4\pi R^2$ and negligible mass. (The shell is not made of realistic matter.)"

541, l19: Replace "the meter is *defined* to be 299,792,458 of those seconds" with "the meter is *defined* to be 1/(299,792,458) of one of those seconds"

541, l9 from bottom: The last two digits of π are interchanged. Should be "...265" rather than '...256'.

578, entry for Parsec: add "355 (fig)".

last endpaper: “Astronomical Constants” was intended to be in the same font and size as “Conversion Factors” and “Physical Constants”. However, it would work probably better as a separate section in the same style as “Useful Numbers”.

Supplement to Ch. 23 The factor of 4 in eq.(1) should be 2.