Cosmology and the Early Universe: List of typos, corrections, minor changes (e.g., a few added references)

I wish to thank Hooman Davoudiasl and Sergio Palomares-Ruiz who pointed out some of the typos corrected in this list. I would be certainly grateful to everyone who makes me aware of further typos to be correct (in case you can send me an e-mail to P.Di-Bari@soton.ac.uk).

Chapter 1 Historical breakthroughs

- Page 5, line 7: 'principal' → 'principle'.

Chapter 2 Fundamental observations

- Page 11, after Eq. (2.11): 'The Planck mass is the mass of two identical point-like particles whose absolute value of the gravitational potential energy times their distance is equal to $\hbar\, c$. For larger masses one expects quantum effects to play a role in gravity, since there is a clear violation of the uncertainty principle' to be replaced by:
  'The Planck mass is the mass of two identical point-like particles whose absolute value of the gravitational potential energy at a distance given by the Planck length $\ell_{\rm P} \equiv \hbar c/(M_{\rm P} c^2)$ is equal to the rest energy $M_{\rm P} c^2$ of each particle. For comparable or larger masses one expects quantum effects to play a role in gravity.

Chapter 3 A Newtonian cosmology?

- Page 28, footnote 1: 'So-called luminous flux respects this definition . . . ' → 'So-called luminous flux respects this second definition . . . ' .

Chapter 4 From Classical Mechanics to Relativistic Theories

- Page 41, Eq. (4.11): $F_{i\hat{n}} \to F_{\hat{n}i}$;

– Page 41, after Eq. (4.13):
'...it is more than just a matrix just as a vector is more than ...' →
'...it is more than just a matrix, in the same way as a vector is more than ...';

Chapter 5 Geometry of the Universe

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- Page 72, first line after Eq. (5.20): 'corresponds' → 'correspond'.

Chapter 6 Dynamics of the Universe

Chapter 7 Building a cosmological model

- Page 96, four lines after Eq. (7.14): 'there would be not ...' → 'there would not be ...'.

Chapter 8 The cosmological constant

- Page 110, second line in 8.3: 'It is a flat model with all energy density given by the Λ-like fluid contribution, so that we can specialise ...' → 'It is given by a flat universe containing only a cosmological constant-like fluid. In this case we can specialise ...' ;
- Page 110, 6th line from the end: 'current standard cosmological describing all observations' → 'current standard cosmological model describing all observations' ('model' is missing);

Chapter 9 Age of the universe

Chapter 10 Expansion history of the universe

- Page 129, horizon distance is generalised at any time t. The paragraph: " The latter has a very important implication: in a universe with an origin at time $t_{\rm in}$, corresponding to an initial value of the scale factor $a_{\rm in}$, we cannot receive any light signal from sources located beyond the *horizon distance* (at the present time) defined as

$$d_{H,0}(t_{\rm in}) \equiv \int_{t_{\rm in}}^{t_0} \frac{c\,dt}{a(t)} \,. \qquad " \;,$$

has to be replaced with:

"The latter has a very important implication: in a universe with an origin at time $t_{\rm in}$, corresponding to an initial value of the scale factor $a_{\rm in}$, an observer at time $t > t_{\rm in}$ cannot receive any light signal from sources located beyond the *horizon distance* defined as

$$d_H(t_{\rm in}, t) \equiv a(t) \int_{t_{\rm in}}^{t} \frac{c\,dt'}{a(t')} \,. \tag{1}$$

In particular, at the present time we cannot receive signals beyond the present horizon distance

$$d_{H,0}(t_{\rm in}) \equiv \int_{t_{\rm in}}^{t_0} \frac{c\,dt}{a(t)} \,. \qquad " \tag{2}$$

- Page 130, 11 lines after Eq. (10.2): $d_{H,0}(t_{\rm in}) \to d_H(t_{\rm in}, t_\star)$;
- Page 132: Reference to footnote 4 should be placed before Eq. (10.10), just after ‘at emission by’.

Chapter 11 Matter

- Page 143, first line after Eq. (11.10): ‘Therefore, most of the mass of a galaxy’ → ‘Therefore, most of the visible mass of a galaxy’.

Chapter 12 The cosmic microwave background

- Page 151: ‘. . . by the thermal equilibrium expressions, (2.34) and (2.36).’ → ‘. . . by the thermal equilibrium expressions, Eq. (2.34) and Eq. (2.36) respectively.’
- In Eq. (12.7) replace $T(t) = T(t_{\rm eq}^{M\Lambda})$ with $T(t) \simeq T(t_{\rm eq}^{M\Lambda})$;
- ‘is valid also before the decoupling between the matter and radiation’ → ‘is valid also before the decoupling between matter and radiation’;
- At the end of paragraph after Eq. (12.9), add the following sentence: ‘As we will see, from the observations of CMB anisotropies one finds $\Omega_{B,0}\, h^2 \simeq 0.022$ corresponding to $\eta_{B,0} \simeq 6.1 \times 10^{-10}$.’
- Page 157, second line: after ‘mass of the hydrogen-1 atom’, add the following footnote: ‘The hydrogen-1 atom (symbol ^{1}H) is also called ‘protium’ and it is the most common of the hydrogen isotopes. The other two isotopes found in nature are hydrogen-2 (commonly called deuterium and indicated either with symbol ^{2}H or more usually with D) and hydrogen-3 (commonly called tritium and indicated with symbol ^{3}H or more usually with T)’;
- Page 158, after Eq. (12.16) replace period with comma and add: ‘where in the last numerical expression we have used the numerical value in Eq. (2.34) for $n_{\gamma,0}$ and $\eta_{B,0} \simeq 6.1 \times 10^{-10}$’;
- Eq. (12.24): $\eta_B \to \eta_{B,0}$;
- Page 161, footnote 7: Add at the end: ‘As noticed in the previous footnote, the redshift or reionisation corresponds to a temperature $T_{\rm re} \simeq 0.002\,{\rm eV}$ fortunately well below $0.01\,{\rm eV}$, the temperature of decoupling of Thomson scatterings that we calculated assuming all electrons to be free. This is why $\tau(t_\star)$ remains much less than unity despite reionisation, otherwise we would not observe the CMB today.’
- Page 162, line 5: ‘It can be indeed shown that one has also to require a condition $\eta_B^{\rm rec} \ll 1$’ →
  ‘It can be indeed shown that one has also to require a condition $\eta_B^{\rm dec} \equiv \eta_B(t_{\rm dec}) \ll 1$’
- Page 162, line 7: ‘finding $\eta_B^{\rm rec} \sim 6 \times 10^{-10}$’ → ‘finding, as we have seen, $\eta_B^{\rm dec} = \eta_{B,0} \sim 6 \times 10^{-10}$’;

- Page 163, at the end of footnote 10 add: 'We just mention that while E-mode polarisation and its anisotropies have been well measured, B-mode polarisation, of cosmological origin, has so far escaped detection. This can be produced only by tensor primordial perturbations, that would be the imprint on CMB of primordial gravitational waves. Inflationary models predict some positive signal but its size is strongly model dependent. Observations have so far placed an upper bound on the tensor-to-scalar ratio of primordial perturbations (see discussion at page 207). This translates into important constraints on models of inflation.'
- Page 165, table 12.1 caption: 'third column' → 'last column';
- Page 166, 8 lines after Eq. (12.41): delete 'coming from cosmology';
- Page 166, 10 lines from the end: 'third column' → 'last column';
- Page 166, 6 lines from the end: '...combined with external information.' → '...combined with external information such as BAO, type Ia supernovae and a prior $H_0 = (70.6 \pm 3.3)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ from astrophysical measurements ('ext' in the last column of Tables 12.1 and 12.2) ';
- Page 166, 4 lines from the end: '...for the same datasets of Table 12.1' → '...for the same datasets of Table 12.1 in the case of 1-parameter extensions to the ΛCDM model';
- Page 167, line 6: '...information is combined (third column): the most stringent ... ' → '...information is combined (last column): this is the most stringent ...';
- Page 168, footnote 18: Replace everywhere $\Omega_{B,0} \rightarrow \Omega_{B,0}h^2$ and Eq. (12.39) → Eq. (12.38).

Chapter 13 Radiation-dominated regime

- Page 176, line before Eq. (13.11): 'the upper bound' → 'the upper bound (at 95% C.L.)';
- Page 176, line before Eq. (13.11): add the footnote: 'We have seen that from CMB anisotropies combined with external information a stringent one derives a stringent upper bound on the sum of neutrino masses $\sum_i m_{\nu_i} \lesssim 0.194\,\mathrm{eV}$ (at 95% C.L.). When this is combined with the information from neutrino mixing experiments, it translates into an upper bound $m_{\nu_i} \lesssim 0.065\,\mathrm{eV}$ on each neutrino mass that is of course much more stringent than (13.11). However, the upper bound from Tritium β-decay experiments is model independent and in any case it is sufficient for our considerations.';
- Page 177, 2 lines after (13.17): 'until $T \simeq m_e\, c^2$ ' → 'down to $T \simeq m_e\, c^2$'.

Chapter 14 Big Bang nucleosynthesis

- Page 187, line 7: 'abundance' → 'abundances';
- Page 188, footnote 9: 'However, ^{7}Be decays' → 'However, ^{7}Be later decays';
- Page 191, 2 lines before Eq. (14.32): 'We can extend the definition given at the time of recombination,' → 'We can extend its definition, given at the time of decoupling in Eq. (13.21),';
- Page 191, Eq. (14.32): $7/8 \rightarrow 7/4$;
- Page 191, 2 lines after Eq. (14.32): 'at freeze-out is provided by' → 'at the n/p freeze-out is provided by';
- Page 191, 4 lines from the end: 'at the freeze-out' → 'at the n/p freeze-out'.

Chapter 15 Inflation

- Page 195, line 4: 'usually called the *inflationary stage*' → 'usually referred to as '*inflation*'.
- Page 196, footnote 2: '. . . the considered quantity is a dynamical variable' → '. . . the considered quantity has to be a dynamical variable';
- Page 204, line 10: 'on CMB B-mode polarisation anisotropies,' → 'on CMB B-mode polarisation anisotropies (see footnote 10 in Chapter 12),'.

Chapter 16 ΛCDM model and cosmological puzzles

- Page 209, line 20: '. . . for the matter-antimatter asymmetry of the universe is in general also accompanied by *CP* violation in neutrino mixing' → '. . . for the matter-antimatter asymmetry of the universe is expected in general, though not necessarily, also to be accompanied by *CP* violation in low energy neutrino mixing';
- Page 209, line 26: after the end of paragraph ('. . . testing leptogenesis.') add footnote: 'However, the discovery of a positive signal in neutrinoless double beta decay experiments could legitimately be regarded as a strong positive test, since it would imply lepton number violation and the Majorana nature of neutrinos. It would be that strong, that one could legitimately start considering leptogenesis as an established model of baryogenesis. The information from low energy neutrino experiments, combined with leptogenesis, would then provide a powerful phenomenological way to single out a realistic model of new physics, maybe even without needing new physics at colliders. This would be in particular true if some additional evidence of new physics emerges, like for example discovery of primordial gravitational waves or of a non-astrophysical component in very high energy neutrinos.'

Chapter 17 Dark matter

- Page 213, line 18: 'The EROS-2 survey places an upper bound . . . ' → 'The EROS-2 survey places a lower bound . . . ';
- Page 215: Right-hand side of Equation (17.4): 0.60 eV → 0.06 eV;
- Page 216, footnote 7: Add: 'In this respect, it is quite encouraging that leptogenesis strongly favours neutrino masses, $m_{\nu_i} \lesssim 0.1\,\mathrm{eV}$ [1], an upper bound now fully positively tested by the upper bound on the sum of neutrino masses from CMB anisotropies, implying, for each neutrino mass, $m_{\nu_i} \lesssim 0.065\,\mathrm{eV}$.' Add new reference:

  BIBLIOGRAPHY

  [1] W. Buchmuller, P. Di Bari and M. Plumacher, Annals Phys. **315** (2005) 305 [hep-ph/0401240].
- Page 223, line 27: 'completed processes' → 'complicated processes';
- Page 224, line 15: 'In 2012 the IceCube collaboration reported the discovery of very high energy neutrino events.' → 'In April 2013 the IceCube collaboration reported the discovery of two very high energy neutrino events [16].' (year corrected, specified 'two' and reference [16] moved here);
- Page 224, line 16: 'The latest data include about 60 reported events, with energies in the range ∼ (10–1000) TeV [16].' → 'A further analysis has then reported twenty-six additional high energy neutrino events, with energies in the range ∼ (10–1000) TeV [1].' Add new reference:

  BIBLIOGRAPHY

  [1] M. G. Aartsen *et al.* [IceCube Collaboration], Science **342** (2013) 1242856 [arXiv:1311.5238 [astro-ph.HE]].
- Page 224, line 22: 'for example active galactic nuclei . . . are most plausible sources.' → 'for example active galactic nuclei . . . are most plausible sources, though they are not sufficient to reproduce the whole observed flux and this might indicate the presence of an unknown astrophysical contribution.';
- Page 224, line 23: 'However, there is currently an excess . . . with canonical cosmic rays predictions' → 'However, there is currently an excess . . . with canonical cosmic predictions for a generic astrophysical component';
- Page 224, line 25: 'This excess can be interpreted either . . . to be more favoured.' → 'This excess might be interpreted in terms of a non-canonical new astrophysical component. However, quite intriguingly, it might also be interpreted in terms either . . . more favoured.';
- Page 225, line 4: 'if the discovery WIMPs' → 'if the discovery of WIMPs' ('of' missing);

- Page 227, line 2: ‘instead of inversely proportional’ → ‘instead of being inversely proportional’;
- Page 228, line 15: ‘. . . violation problem in QCD’ → ‘. . . violation problem in QCD [1]’. Add new reference:

BIBLIOGRAPHY

[1] R. D. Peccei and H. R. Quinn, *CP Conservation in the Presence of Instantons*, Phys. Rev. Lett. **38** (1977) 1440.

- Page 229, three lines from the end: ‘RH neutrinos’ → ‘right-handed neutrinos’;
- Page 230, 4 lines after Eq. (17.19): ‘by neutrino oscillations’ → ‘by neutrino oscillation experiments’.
- Page 230, 23 lines after Eq. (17.19): ‘of the order of $\tau \gtrsim 10^{27}$ s, nine orders . . . ’ → ‘of the order of $\tau \gtrsim 10^{28}$ s, ten orders . . . ’;
- Page 230, 25 lines after Eq. (17.19): ‘As mentioned, in 2012 . . . ’ → ‘As mentioned, in 2013 . . . ’;
- Page 231, line 6: ‘a dark matter contribution should show manifest . . . ’ → ‘a dark matter contribution should manifest . . . ’.

Chapter 18 Ad libitum?

Chapter 19 Summary of numerical values of constants and parameters