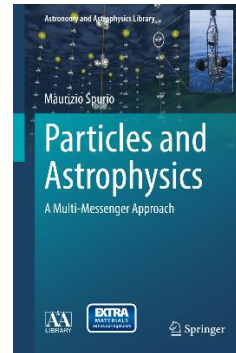


# Comments and errata on “Particles and Astrophysics”

M. Spurio



Despite the effort to be as accurate as possible, many misprints and mistakes were found by colleagues and students. Particularly, I acknowledge the comments of Jim Linnemann (Michigan State University) and James Matthews (Louisiana State University) and their students; Nand Bruynooghe and many colleagues and students who contacted me to improve the book content. In the following list (ordered by the page number) the symbol  $\rightarrow$  means “replace with”.

M. Spurio, January 2017

- p. 2, first line: “As time proceeded, the Universe, Following the the Universe expanded, the energy...”  $\rightarrow$  “As time proceeded, the Universe expanded, the energy...”
- p. 7, line 5: “figure error of the primary mirror had in 1993...”  $\rightarrow$  “figure error of the primary mirror had **been eliminated** in 1993”
- p 17, Line 2: move the sentence “In addition to AMS-02... on the ISS.” at the end of §1.6.1
- p. 29, §2.3.2 , 4th line: losses  $\rightarrow$  loses.
- p. 30, last line. It is: **1 eV = 1.6 x 10<sup>-12</sup> erg**
- p. 32, 4 lines after eq. (2.10): “X<sub>0</sub>~12.9 ... with”  $\rightarrow$  “X<sub>0</sub>~12.9 g cm<sup>-2</sup>. From the Figure, an electron with ...” and replace E=63 with E $\cong$  63
- p. 35. The symbol “ $\varphi$ ” introduced in eq. (2.13) could be confused with “ $\phi$ ” and “ $\Phi$ ” also used in the same section. It is convenient to replace three lines before eq. (2.13) the sentence “Thus the number of CRs arriving” with ““Thus the number of CRs **per unit of area A in a time T, N=A · T**, arriving”. Then, the symbol “ $\varphi$ ” used in eq. (2.13), (2.14) and (2.15) can be replaced with “N/AT”. Thus, for instance:

$$\mathcal{F}(E) = \int \frac{d^2N}{A \cdot T \cdot dE d\Omega} \cos \theta d\Omega \quad \frac{\text{particles}}{\text{cm}^2 \text{s GeV}} \quad (2.16)$$

- p. 35, 5 lines before eq. (2.15): “If the detector ... can be defined, as...”  $\rightarrow$  “If the detector can measure the electric charge Ze of an incoming nucleus of species i, the flux  $\Phi_i$  of that species can be determined, as...
- p. 35, 2 lines before eq. (2.15): trough  $\rightarrow$  through
- p. 37: replace eqs. (2.20a) and (2.20b) with

At energies larger than few GeV (where the contribution of particles coming from the Sun, Sect. 2.8, is negligible) the energy spectrum can be described by a power-law, where  $E_0 = 1$  GeV:

$$\Phi(E) = K \left( \frac{E}{E_0} \right)^{-\alpha} \frac{\text{particles}}{\text{cm}^2 \text{ s sr GeV}} \quad (2.20a)$$

$$\Phi(>E) = \frac{KE_0}{(\alpha-1)} \left( \frac{E}{E_0} \right)^{-\alpha+1} = \frac{KE_0}{(\alpha-1)} \left( \frac{E}{E_0} \right)^{-\gamma} \frac{\text{particles}}{\text{cm}^2 \text{ s sr}}. \quad (2.20b)$$

- p. 40, 6 lines before §2.7: corresponds → correspond
- p. 44, first line of §2.7.2: “distance between stars and their diameter” → “distances between stars and the star diameters”
- p. 51, line after eq. (2.34): I.S. → SI
- p. 52, before eq. (2.37): “Using ... radiation:” → “Using the number density of the CMB radiation, derived from the measurement of the temperature T and the Planck’s law of black-body radiation”
- p. 52, 5 lines after eq. (2.38): “galactic CRs have started very long ..” → “galactic CRs started a very long time ago”
- p. 55, line 9: “their mass cannot easily derived” → “their mass cannot easily **be** derived”
- p. 57, in the TRD paragraph: “and heavy particle, as...” → “and heavy particles, as...”
- p. 57, §3.1, last line: “Higher is the charge, higher is the number of...” → “The higher the charge, the higher the number of ...”
- p. 58, 3 lines after §3.2.1: remove “, the Neper’s constant.” (unnecessary)
- p. 58. Replace from eq. 3.3 to the end of the page with:

In the simplest model, the nuclear cross-sections are assumed energy-independent and proportional to the geometrical area of the interacting nuclei:

$$\sigma = \pi R^2 \quad \text{with} \quad R \simeq R_T + R_P \quad (3.3)$$

where  $R_P$  and  $R_T$  are the projectile ( $P$ ) and target ( $T$ ) radii. From nuclear models, the radius of a nucleus with mass  $A$  is:

$$R_A = r_o A^{1/3} \quad \text{with} \quad r_o \simeq 1.2 \times 10^{-13} \text{ cm} \quad (3.4)$$

where  $r_o$  is a parameter whose numerical value is close to the charge radius of the proton,  $\sim 0.85 \times 10^{-13}$  cm. This model is confirmed by the experimental fact that the proton-proton cross-section ( $\sigma_{pp}$ ) outside the region of the resonances is almost constant in a wide energy range [see Sects. 7.3 and 7.4 of Braibant et al. (2011)] at the value given by the geometrical cross-section,  $\sigma_{pp} \simeq \pi r_o^2 \simeq 45$  mb. The p-p cross section increases very slowly with the center-of-mass energy  $\sqrt{s}$  of the interaction. The  $\sigma_{pp}$  reaches  $\sim 70$  mb at LHC energies ( $\sqrt{s} \sim 10$  TeV), corresponding to primary CR protons with kinetic energy of  $\sim 10^5$  TeV.

- p. 60, last lines: replace “...  $A_{\text{atm}} = 14.5$  we obtain: ... (3.7). ” with: “...  $A_{\text{atm}} = 14.5$  with our approximated formula, Eq. 3.5, we obtain ... (3.7) .. that is in agreement with measurement of p-air cross section for CR protons in the GeV-TeV energy range.”
- p. 61: Replace eq. (3.8c) and the two lines before with

Finally, for a heavy CR nucleus (e.g. Iron, with  $A_{Fe} = 56$ ) using Eq. (3.3) we obtain a ration between the Fe-air and p-air cross-section of

$$\frac{\sigma_{Fe,air}}{\sigma_{p,air}} \simeq \frac{(A_{Fe}^{1/3} + A_{Atm}^{1/3})^2}{A_{Atm}^{2/3}} = 6.5 \quad \text{and thus} \quad \lambda_I^{Fe} \simeq \frac{85}{6.5} = 13 \text{ g cm}^{-2}. \quad (3.8c)$$

This value is in agreement with dedicated measurements [3Cr83].

Where the new reference is

3Cr83. J. H. Crane, D.D. Guo, M. H. Israel and J. Klarmann, Interaction mean-free-path of cosmic-ray Fe in air. *Astrophysics and Space Science* 94, no. 1 (1983) 201-209.

- p. 65, 3<sup>rd</sup> line: left size → left **side**
- p. 66, last line before §3.4.2 : This allow the measurement → This **allows** the measurement...
- p. 68, 9 lines before end: 1.5 kG (capital kG for “kiloGauss”, not kg)
- p. 69, line 16: composed by → composed of
- p. 69, line 26: ... is made by many layers... → ...is made **of** many layers...
- p. 71, Table 3.3: Fe(16) → Fe (26)
- p. 72, legend of Fig. 3.7: “Sypmson” → “Simpson”
- p. 75, last paragraph: binging energies → **binding** energies
- p. 91, last line. Add at the end: “36,000 g cm<sup>-2</sup>. **This value does not arise from the flat Earth approximation.**”
- p. 94, 2 lines above (4.13) : the process show down → the process **slows** down
- p. 94, the line after (4.14): ...where the cascade starts. → ... where the secondary photons or electrons start an electromagnetic cascade.
- p. 95, first line: The Heitler’s model → Heitler’s model
- p. 106, caption of fig. 4.7: “They are... (4.48).” → “Iron nuclei are uniformly shifted by ~150 g cm<sup>-2</sup> w.r.t. protons according to Eq. (4.48)”.
- p. 114, line 5 of the text: spurius → **spurious**
- p. 119, line 9 : ...to concentrates the light... → ...to concentrate the light...
- p. 120, 7th line from the bottom: increases as increasing → increases **with** increasing
- p. 136, 2 lines before (5.3): nuclei on protons → nuclei **by** protons
- p. 139, eq. (5.13):  $10^{25} \text{ cm} = 3 \text{ Mpc} \rightarrow 3 \times 10^{24} \text{ cm} = 1 \text{ Mpc}$
- p. 139, eq. (5.14) becomes:

$$\tau_{esc} = \frac{x_{esc}}{c} = \frac{3 \times 10^{24} \text{ cm}}{3 \times 10^{10} \text{ cm/s}} \simeq 10^{14} \text{ s} = 3 \times 10^6 \text{ y}. \quad (5.14)$$

- p. 141, two lines after the second equation: “The statistical ...50%. “→ “The error on this quantity is quite large, mainly due to the statistical error on  $r_{mea}$ .”
- p. 151, 1<sup>st</sup> line: the rigidity is equal → the rigidity is **proportional**
- p. 151, eq. (5.43) and following line: replace “ $\tau_{esc}$  “ with “ $\rho \tau_{esc}$  “

$$\mathcal{N}_P(E) = \frac{Q_P(E) \cdot \tau_{esc}(E)}{1 + c\rho \tau_{esc}(E)/\lambda_I} \quad (5.43)$$

- p. 153, 2 lines below (5.49): ...to an increases of ..-> ... to an increase of...
- p. 156 to 159: In section 5.8.1 a problem arises due to the fact that the symbol used for the frequency ( $\nu$ , the greek “nu”) and for the speed ( $v$ , lower case) are identical in the Springer typo. This produces confusion, in particular in eq. (5.66). The solution is to replace the symbol used for the speed with the capital letter,  $V$ . This is first introduced two lines after eq. (5.53) in the centripetal acceleration:  $v^2/R$ . →  $V^2/R$ . Equations (5.54), (5.55), (5.61), (5.62), (5.64), (5.65) and (5.66) are affected by the change of  $v$  with  $V$ . For instance eq. (5.66) is now:

$$v \sim (\Delta t)^{-1} \sim \Gamma^2 v_g = \Gamma^3 v_r = \frac{\Gamma^3 V}{2\pi R} \quad (5.66)$$

- p. 160, end of the first paragraph: whit → with
- p. 170-171: remove the last paragraph and eq. (6.11) and replace with:

the interstellar medium (5.34), i.e.  $\ell \sim 0.1$  pc. The constant

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<sup>2</sup> The coefficient 8 in Eqs. (6.9) and (6.10) is due to the uni-dimensional discussion. In the three-dimensional case, the correct coefficient is 2.

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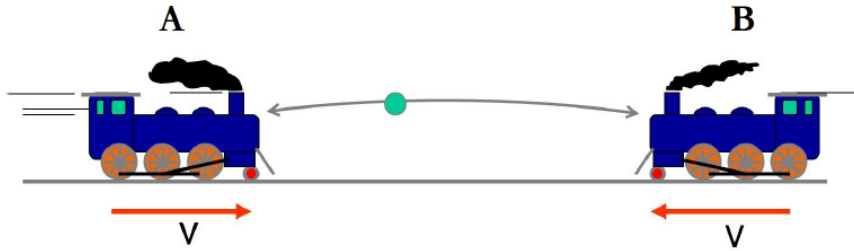


Fig. 6.4 Toy-model of a possible first-order Fermi acceleration mechanism

$$\tau_F'' = \frac{\ell v}{2U^2} \sim 10^7 \text{ years} \quad (6.11)$$

corresponds to the fact that a sizeable energy increase of a CR particle could only be reached on very large timescales.

- p. 173: in the discussion after (6.21) the spherical definition of the solid angle is incorrect and eq. (6.22) must be corrected:

Here,  $x = \cos \theta$ ,  $d\Omega = d\phi \sin \theta d\theta = d\phi dx$  is the differential solid angle and  $f(x)$  is given by (6.20). The average over all directions with  $\cos \theta > 0$  gives:

$$\langle \cos \theta \rangle = \frac{\int_0^1 \cos \theta \cdot \cos \theta \cdot d\cos \theta}{\int_0^1 \cos \theta \cdot d\cos \theta} = \frac{2}{3}. \quad (6.22)$$

- p. 175, fig. 6.5: **labels (b) and (c) are swapped**
- p. 176, last line of 6.2 : ... many collisions is necessary → ...many collisions **are** necessary
- p. 179, eq. (6.36b): In the denominator, it is  $U=5 \times 10^8$  cm/s (according to eq. 6.33)
- p. 181, lines after eq. (6.39): “Referring to Fig. 6.5c,d, the typical time ...is” → “Following the discussion of Drury (1983) and referring to Fig. 6.5b), the typical time between successive encounters in the rest frame of a shock front moving at velocity  $v_s \equiv U$  is”
- p. 182, 1st line of §6.4 : of accelerate particles → of **accelerated** particles
- p. 184, three lines after (6.48): (Fig. 6.5b) → **(Fig. 6.5c)**
- p. 185: replace eq. (6.54) with:

$$-\alpha_s = -1 + \Lambda = -2 \quad (6.54)$$

- p. 191, line after (6.67): During the permanence of a star in the... → During the time a star is in the...

- p. 192, two lines after (6.71): we ca use → we can use
- p. 192, last line: we done → was done
- p. 193, second line: adimensional → dimensionless
- p. 218, footnote: add after  $v/c$ , “**when  $v \ll c$** ”
- p. 223, 8 lines above (7.26): ... lies in such plane → ... lies in such **a** plane ...
- p. 224, 3rd line: if more tha one → if more than one
- p. 225, 1st line: Different experiment → ... experiments
- p. 245, eq. (8.4) missing differential symbol “d” before  $N_\gamma$
- p. 246, eq. (8.6a): the symbol  $\epsilon$  in a wrong position. Read “ $\gamma_\epsilon$ ”
- p. 246, line after (8.6b): 0.250 mb. → 0.250 mb **for each individual channel**.
- p. 248, line after (8.12): remove “valid in the high energy limit” (always valid!).
- p. 248, line after (8.13): are very close to → **approach**
- p. 252, two lines before §8.4.1: simply → simple
- p. 253, eq. (8.24) and two lines after equation; eq. (8.26): replace “J(v)” with “F(v)”

$$F(v)dv = -\left(\frac{dE}{dt}\right)\left(\frac{dN}{dE}dE\right) = -\left(\frac{dE}{dt}\right)\kappa E^{-\alpha_e}dE. \quad (8.24)$$

$$F(v) = (\text{constants}) \cdot \kappa \cdot B^{(\alpha_e+1)/2} \cdot v^{-(\alpha_e-1)/2}. \quad (8.26)$$

- p. 253, eq. (8.27): The exponent on the r.h.s. must be “-(a-1)”

$$E_\gamma^2 \frac{dN_\gamma}{dE_\gamma} \propto E_\gamma^{-(a-1)} \quad \text{where} \quad a = (\alpha_e - 1)/2. \quad (8.27)$$

- p. 254, two lines after (8.28):  $E_\gamma^{-1/2} \rightarrow E_\gamma^{-3/2}$
- p. 255, one line before and two after (8.34): replace “J(v)” with “F(v)” and modify eq. (8.34)

$$E_\gamma^2 \frac{dN_\gamma}{dE_\gamma} = v F(v) \propto E_\gamma^{7/2} \quad (8.34)$$

- p. 257, last line: we ca use → we can use
- p. 265, second •, 2nd line: The inverse Compton scattering boost some ... → ... boosts ...
- p. 278, first line: at the two poles → along the rotation axis
- p. 287, Fig. 9.5: the magic observatory = the **MAGIC** observatory
- p. 303, §9.8, 2nd paragraph, 3rd line: trough → through
- p. 313, first line of the second paragraph: a part interferometer → apart **from** interferometer
- p. 328, 3rd line of the text under 2. : energy is – released → energy is released (no -)
- p. 336, sentence under (10.18): we expect that a break in the neutrino spectrum ... is expected → we expect a break in the neutrino spectrum around ... .
- p. 364, line after (11.15): as the analogous of (11.6). → **because it does not factorize as eq. (11.6) did.**
- p. 381, one line after and one before (11.44): eigen states → eigenstates
- p. 383, 4 lines away from the bottom: a Cherenkov ringthat = ...ring that... (+ space)
- p. 397, second paragraph: “Probe useful ... emitted.” → “The neutrinos emitted from various thermonuclear processes in the Sun are extremely useful in testing theoretical predictions.”
- p. 397, third paragraph: remove “at these days” after “on particle physics”.
- p. 398, third line: Few neutrino → **A** few neutrino
- p. 401, before first •, and p. 439, second reference: Bachall → **Bahcall**
- p. 406, last line: trough → through
- p. 408: 1st line of final paragraph: trough reaction (12.12) ... → through reaction (12.12) ...
- p. 418, §12.7, 4th line: This induce → This induces

- p. 419: 1st line: “Here, it is derived a resonant condition for the neutrino energy” → “Here, a resonant condition for the neutrino energy is derived”
- p. 422, 1st line under (12.34): Vacuum neutrino mixing modify the ... → .. **modifies** ..
- p. 424, last sentence of §12.8.1: “Also high-energy .... on Earth.” → “Propagation effects change the flavor composition ratio also for high-energy neutrinos arriving on Earth from astrophysical sources.”
- p. 424, fig. 12.9, in the brown quadrant:  $^{26}\text{Si} \rightarrow ^{28}\text{Si}$
- p. 425, §12.10, 2nd paragraph, 1st line: Thyco Brahe → Tycho Brahe
- p. 426, three lines before §12.11: “However, some experimental aspects do completely fit in the model” → “Hence, some experimental aspects do not completely fit the model”
- p. 427, final paragraph, 1st line: Near the end of its live → .. **life** ...
- p. 448, 8<sup>th</sup> line of §13.4: have performed → have **been** performed
- p. 449, 4<sup>th</sup> line: do not reproduces → do not reproduce
- p. 467, last paragraph of §13.8.4, 1st line: ... detectors able of measure the ... → ... detectors capable of measuring the ...
- p. 468, 5 lines under (13.26): balance due thermonuclear... → balance due **to** thermonuclear ...
- p. 471, 13.9.3 , line 6: the searche → the search
- p. 472, last line of the 1st paragraph: “We can argue about what are the requirements on the age” → “We can argue what the requirements are on the age”

Particles and Astrophysics

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