Physics of the Interstellar and Intergalactic Medium: Errata

Updated 2013.04.30

Bruce T. Draine
• preface, p. xvii, typo: reaquaint → reacquaint
  noted 2011.02.13 by B. Hensley.

• §1, p. 2, 1st paragraph, typo:
  nuclear transitions and $\pi^0$ decays. → nuclear transitions, $\pi^0$ decays, and $e^+ - e^-$ annihilations.
  noted 2012.06.26

• §1.1, p. 6, Table 1: change range of densities for H II gas from $0.3 - 10^4$ cm$^{-3}$ to $0.2 - 10^4$ cm$^{-3}$.
  noted 2011.09.22 by B. Ménard.

• §2, p. 11, 3rd paragraph, typo: three basic types → four basic types
  noted 2012.06.22 by F. van der Tak.

• §5.2.2, p. 50, Fig. 5.5: add reference to caption: (Chandra et al. 1984)
  noted 2011.11.03.

• §5.2.2, p. 50: the text should have made clear that the selection rules given were specifically for H$_2$O: change
  The selection rules for electric dipole radiative transitions are $\Delta J = 0, \pm 1$;
  $\Delta K_{-1} = \pm 1, \pm 3$; and $\Delta K_{+1} = \pm 1, \pm 3$.
  to
  The selection rules for electric dipole radiative transitions in H$_2$O are $\Delta J = 0, \pm 1$;
  $\Delta K_{-1} = \pm 1, \pm 3$; and $\Delta K_{+1} = \pm 1, \pm 3$; for less symmetric molecules (e.g., HDO) additional transitions are allowed.
  noted 2011.11.03 by J. M. Shull.

• §6.4, p. 58, Eq. (6.29), typo: replace $7618$ cm s$^{-1}$ → $7616$ cm s$^{-1}$
  and in the following line change $7618$ cm s$^{-1}$ → $7616$ cm s$^{-1}$.
  noted 2011.08.18 by K.-G. Lee.

• §6.4, p. 58, typos: change
  H Lyman $\alpha$ ($\lambda = 1215$ Å) has ... $f_{\ell u} = 0.4162$
  → H Lyman $\alpha$ ($\lambda = 1215.67$ Å) has ... $f_{\ell u} = 0.4164$,
  and in the following sentence, change 0.4162 → 0.4164.
  noted 2011.08.19

• §6.4, p. 60, Eq. (6.41), typo: replace
  \[ \frac{2924}{\gamma_{ut}\lambda_{ut}b_6} \rightarrow \frac{2924}{\gamma_{ut}\lambda_{ut}b_6} \]
  and in Eq. (6.42) change 7618 cm s$^{-1}$ → 7616 cm s$^{-1}$.
  noted 2011.08.18 by K.-G. Lee.

• §8.1, p. 71, 3 places: just before eq. (8.4), just after eq. (8.7), and between eq. (8.8) and (8.9): change “absorption coefficient” → “attenuation coefficient”.
  noted 2011.03.07
• §8.1, p. 71, Eq. (8.9), typo: missing a factor \( n(\text{HI}) \). Should read:

\[
\kappa_V = \frac{3}{32\pi} \frac{1}{\sqrt{2\pi}} \frac{A_{\text{eff}^2}}{\sigma_V} \frac{hc}{kT_{\text{spin}}} n(\text{HI}) e^{-u^2/2\sigma_V^2} \quad (8.9)
\]

noted 2011.03.07 by P. Pattarakijwanich.

• §8.1, p. 71, Eq. (8.10), typo: omit the comma.
noted 2010.02.09

• §8.2, p. 72, Eq. (8.17), typo: change 54.89 \( \rightarrow \) 55.17
noted 2011.07.06 by R. Allen.

• §8.2, p. 73, Eq. (8.21), typo: change \((1 + z) \rightarrow (1 + z)^{-1}\)
noted 2012.06.01 by B. Catinella and N. Evans.

• §8.3, p. 74, Eq. (8.26), typo: \( T_{\text{sky}}(v) \rightarrow T_{\text{sky}}(\text{two occurrences}).\)
noted 2011.02.10

• §8.3, p. 74, Eq. (8.26), typos: \( T_{\text{on}} A(v) \rightarrow T_{\text{off}} A(v) \) (two occurrences).
noted 2013.02.14 by Munan Gong.

• §9.4, p. 79, Eq. (9.21), the second “=“ should be changed to “≈“.
noted 2011.08.18 by K.-G. Lee.

• §10.5, p. 96, Eq. (10.23), typo (extraneous factor of cm\(^5\)):

\[
\ldots \nu_9^{-2.118} \text{ cm}^5 \left( \frac{n_i}{n_p} \right) \frac{EM}{10^{25} \text{ cm}^{-5}} \rightarrow \ldots \nu_9^{-2.118} \left( \frac{n_i}{n_p} \right) \frac{EM}{10^{25} \text{ cm}^{-5}}
\]

noted 2011.03.05 by B. Hensley and P. Pattarakijwanich.

• §10.5, p. 97, footnote 3, typo: \( 5 \times 10^6 \text{ cm}^{-3} \text{ pc} \rightarrow 5 \times 10^6 \text{ cm}^{-6} \text{ pc}.\)
noted 2011.02.15 by C. Petrovich.

• §11.4, p. 110, Eq. (11.35) should read

\[
\nu \ll \frac{e^2(\Delta n_e)_{L,\text{rms}}}{2\pi n_e c} (2LD)^{1/2} = 1 \times 10^3 \text{ GHz} \frac{(\Delta n_e)_{L,\text{rms}}}{10^{-3} \text{ cm}^{-3}} \left( \frac{L}{10^{14} \text{ cm}} \frac{D}{\text{kpc}} \right)^{1/2}.
\]

noted 2013.02.03 by W. Vlemmings.

• §12.1, p. 120, Eq. (12.1), add: where \( \nu_9 \equiv \nu / \text{GHz} \)
noted 2012.06.22 by F. van der Tak.

• §12, p. 121, Table 12.1, typos:

| \text{CMB, } T_1 = 2.725 \text{ K} | \quad : & \quad 4.19 \times 10^{-13} \rightarrow 4.17 \times 10^{-13} \\
| \text{CMB, } T_2 = 4000 \text{ K, } W_2 = 1.65 \times 10^{-13} | \quad : & \quad 3.19 \times 10^{-13} \rightarrow 3.20 \times 10^{-13} \\
| \text{CMB, } T_3 = 7500 \text{ K, } W_3 = 1 \times 10^{-14} | \quad : & \quad 2.29 \times 10^{-13} \rightarrow 2.39 \times 10^{-13} \\
| \text{Starlight total} | \quad : & \quad 1.05 \times 10^{-12} \rightarrow 1.06 \times 10^{-12} \\
| \text{ISRF total} | \quad : & \quad 2.19 \times 10^{-12} \rightarrow 1.98 \times 10^{-12}.

noted 2012.11.08
• §13.1, p. 128, typo:
  \[ \sigma_{\text{pe}}(\text{H}_2) = 2.8\sigma_{\text{p,i}}(\text{H}) \rightarrow \sigma_{\text{pe}}(\text{H}_2) = 2.8\sigma_{\text{p,i}}(\text{H}) \]
  noted 2011.03.06

• §13.1, p. 129, clarification:
  ...photoionization cross sections for O... \rightarrow ...photoionization cross sections \sigma_{\text{pi}} for O...
  noted 2011.03.06

• §13.1, p. 130, Eq. (13.5), clarification:
  \[ \zeta_{\text{p,i}} \rightarrow \zeta_{\text{pi}}, \sigma_{\text{pe}} \rightarrow \sigma_{\text{pi}} \]
  noted 2011.03.06

• §13.1, p. 131, Table 13.1, typo: \( \zeta_{\text{p,i}} \rightarrow \zeta_{\text{pi}}, \sigma_{\text{p,i}} \rightarrow \sigma_{\text{pi}} \)
  noted 2011.03.06

• §13.4, p. 134, typos:
  \[ \sigma_{\text{e,i}} \rightarrow \sigma_{\text{e}} \text{ (4 places)}, \ k_{\text{e,i}} \rightarrow k_{\text{e}} \text{ (2 places).} \]
  noted 2011.03.06

• §14.2, p. 138, Table 14.1. A reference to Burgess (1965; Mem. Royal Astr. Soc., 69, 1) [the source of the hydrogenic radiative recombination rates] has been added in the table footnote. Upon recomputing the rates from Burgess, a few of the table entries had the last digit change by 1. Some of the coefficients in the approximate fitting formulae have also changed slightly. Here is the revised version:

<table>
<thead>
<tr>
<th>Temperature ( T )</th>
<th>( 5 \times 10^4 ) K</th>
<th>( 1 \times 10^4 ) K</th>
<th>( 2 \times 10^4 ) K</th>
<th>approximation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_{\text{e}} )</td>
<td>( 2.28 \times 10^{-13} )</td>
<td>( 1.58 \times 10^{-13} )</td>
<td>( 1.08 \times 10^{-13} )</td>
<td>( 1.58 \times 10^{-13} T_4^{-0.540} - 0.017 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{2s} )</td>
<td>( 3.37 \times 10^{-14} )</td>
<td>( 2.34 \times 10^{-14} )</td>
<td>( 1.60 \times 10^{-14} )</td>
<td>( 2.34 \times 10^{-14} T_4^{-0.537} - 0.019 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{2p} )</td>
<td>( 8.33 \times 10^{-14} )</td>
<td>( 5.36 \times 10^{-14} )</td>
<td>( 3.24 \times 10^{-14} )</td>
<td>( 4.36 \times 10^{-14} T_4^{-0.687} - 0.014 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_3 )</td>
<td>( 1.17 \times 10^{-13} )</td>
<td>( 7.70 \times 10^{-14} )</td>
<td>( 4.84 \times 10^{-14} )</td>
<td>( 7.70 \times 10^{-14} T_4^{-0.636} - 0.046 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{3s} )</td>
<td>( 1.13 \times 10^{-14} )</td>
<td>( 7.82 \times 10^{-15} )</td>
<td>( 5.29 \times 10^{-15} )</td>
<td>( 7.82 \times 10^{-15} T_4^{-0.547} - 0.024 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{3p} )</td>
<td>( 3.17 \times 10^{-14} )</td>
<td>( 2.04 \times 10^{-14} )</td>
<td>( 1.24 \times 10^{-14} )</td>
<td>( 2.04 \times 10^{-15} T_4^{-0.683} - 0.062 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{3d} )</td>
<td>( 3.03 \times 10^{-14} )</td>
<td>( 1.73 \times 10^{-14} )</td>
<td>( 9.09 \times 10^{-15} )</td>
<td>( 9.09 \times 10^{-15} T_4^{-0.868} - 0.093 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{3} )</td>
<td>( 7.33 \times 10^{-14} )</td>
<td>( 4.55 \times 10^{-14} )</td>
<td>( 2.67 \times 10^{-14} )</td>
<td>( 4.55 \times 10^{-14} T_4^{-0.729} - 0.060 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{4s} )</td>
<td>( 5.23 \times 10^{-15} )</td>
<td>( 3.59 \times 10^{-15} )</td>
<td>( 2.40 \times 10^{-15} )</td>
<td>( 4.55 \times 10^{-15} T_4^{-0.562} - 0.026 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{4p} )</td>
<td>( 1.51 \times 10^{-14} )</td>
<td>( 9.66 \times 10^{-15} )</td>
<td>( 5.60 \times 10^{-15} )</td>
<td>( 9.66 \times 10^{-15} T_4^{-0.691} - 0.064 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{4d} )</td>
<td>( 1.90 \times 10^{-14} )</td>
<td>( 1.08 \times 10^{-14} )</td>
<td>( 5.67 \times 10^{-15} )</td>
<td>( 1.08 \times 10^{-14} T_4^{-0.870} - 0.094 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{4f} )</td>
<td>( 1.09 \times 10^{-14} )</td>
<td>( 5.54 \times 10^{-15} )</td>
<td>( 2.57 \times 10^{-15} )</td>
<td>( 5.11 \times 10^{-15} T_4^{-0.314} - 0.010 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{4} )</td>
<td>( 5.02 \times 10^{-14} )</td>
<td>( 2.96 \times 10^{-14} )</td>
<td>( 1.64 \times 10^{-14} )</td>
<td>( 2.96 \times 10^{-14} T_4^{-0.805} - 0.065 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{A} )</td>
<td>( 6.81 \times 10^{-13} )</td>
<td>( 4.17 \times 10^{-13} )</td>
<td>( 2.51 \times 10^{-13} )</td>
<td>( 4.17 \times 10^{-13} T_4^{-0.721} - 0.018 \ln T_4 )</td>
</tr>
<tr>
<td>( \alpha_{B} )</td>
<td>( 4.53 \times 10^{-13} )</td>
<td>( 2.59 \times 10^{-13} )</td>
<td>( 1.43 \times 10^{-13} )</td>
<td>( 2.59 \times 10^{-13} T_4^{-0.833} - 0.035 \ln T_4 )</td>
</tr>
</tbody>
</table>

\( \alpha_{\text{e}} \) from Burgess (1965); \( \alpha_{B} \) from Hummer & Storey (1987) (for \( n_\text{e} = 10^8 \text{ cm}^{-3} \))
• §14.2, p. 139, typos: In Equations (14.3) and (14.4), the leading factor of $Z$ should be to the first power, rather than $Z^2$: the equations should read

$$\alpha_A(T) \approx 4.13 \times 10^{-13} \, Z \, (T_4/Z^2)^{-0.7131-0.0115 \ln(T_4/Z^2)} \, \text{cm}^3 \, \text{s}^{-1},$$  \hspace{0.5cm} (14.3)

$$\alpha_B(T) \approx 2.54 \times 10^{-13} \, Z \, (T_4/Z^2)^{-0.8163-0.0208 \ln(T_4/Z^2)} \, \text{cm}^3 \, \text{s}^{-1}. $$  \hspace{0.5cm} (14.4)

noted 2012.01.04 by E. Jenkins.

• Fig. 14.1, p. 140, typos: the quantities plotted should be labelled $Z^{-2}T_4^{1/2}\alpha_A$ and $Z^{-2}T_4^{1/2}\alpha_B$ (rather than $Z^{-3}T_4^{1/2}\alpha_A$ and $Z^{-3}T_4^{1/2}\alpha_B$):

![Figure 14.1 Case A and Case B rate coefficients $\alpha_A$ and $\alpha_B$ for radiative recombination of hydrogen, multiplied by $T_4^{1/2}$ (equations 14.5, 14.6). Note that no single power-law fit can reproduce the $T$-dependence over a wide range in $T$.](image)

noted 2012.01.04 by E. B. Jenkins.

• Table 14.2, p. 143, typo: Pfundt → Pfund

noted 2011.03.05 by B. Hensley.

• §14.2.4, p. 144, Eq. (14.11), typo: $1880 \, \text{cm}^{-3} \rightarrow 1.55 \times 10^4 \, \text{cm}^{-3}$

noted 2011.03.17

• §14.5, p. 151, typo: [OIII]4959,5007 → [OIII]4960,5008

noted 2012.06.22 by F. van der Tak.

• §14.6, p. 153, typo:

...from the wave function of $AB$... → ...from the wave function of $AB^+$...

noted 2011.03.05 by P. Pattarakijwanich.

• §14.6, p. 154, Table 14.8 update: replace

$$H_3^+ + e^- \rightarrow H_2 + H \quad 1.1 \times 10^{-7}T_2^{-0.56} \quad \text{McCall et al. (2004)}$$

with
\[ \begin{align*}
H_2^+ + e^- & \rightarrow H + H + H \quad 8.9 \times 10^{-8} T_2^{0.48} \quad \text{McCall et al. (2004)} \\
H_3^+ + e^- & \rightarrow H_2 + H \quad 5.0 \times 10^{-8} T_2^{0.48} \quad \text{McCall et al. (2004)}
\end{align*} \]

noted 2013.04.03

- §14.7.1, p. 155, typo: \( I_{\text{O}(3P_0)} = 13.6181 \text{ eV}, \) \( \rightarrow \ I_{\text{O}(3P_2)} = 13.6181 \text{ eV}, \) noted 2011.02.22 by Xu Huang.

- §14.7.1, p. 156, Eq. (14.31), for notational consistency: \( n(H) \rightarrow n(H^0) \) noted 2011.05.15 by E. B. Jenkins.

- §14.7.1, p. 156, just before Eq. (14.35), typo:
  In the low density limit... \( \rightarrow \) In the high density limit...
  noted 2011.05.15 by E. B. Jenkins.

- §14.7.1, p. 157, Figure 14.5: plotted curves were numerically incorrect. Corrected Figure 14.5:

![Figure 14.5](image)

**Figure 14.5** Dependence of oxygen ionization fraction on hydrogen ionization fraction due to charge exchange. The low-density limit applies for \( n_H \lesssim 10^4 \text{ cm}^{-3}. \)

noted 2011.05.18 by E. B. Jenkins.

- §15.1, p. 163, typo: \( \sigma_{p_i} \) (two places) \( \rightarrow \) \( \sigma_{pi} \) (two places) noted 2011.03.05

- §15.1.2, p. 163, change
  the Case B radiative recombination rate for \( \text{He}^+ + e^- \rightarrow \text{He}^0 \) is \( \sim 1.9 \) times larger than for hydrogen.

\( \rightarrow \)

\[ \alpha_{\text{eff}}(\text{He})/\alpha_B(\text{H}) \approx 1.1 - 1.7, \] depending on the fraction \( y \) of \( h\nu > 24.6 \text{ eV} \) photons that are absorbed by H.

noted 2011.03.17
• Table 15.1, p. 164, typo: $M/\dot{M}_\odot$ for O6.5V star: 38.0 → 28.0
noted 2013.01.31

• §15.1.2, p. 165, change
will be $\sim 18\%$ → will be $\sim 14\%$
noted 2011.03.17

• §15.1.2, p. 165, change
if $Q_1 < 0.18Q_0$, → if $Q_1 \leq 0.14Q_0$,
noted 2011.03.17

• §15.1.2, p. 165, change
$Q_1/Q_0 \geq 0.18$, → $Q_1/Q_0 \geq 0.14$,
noted 2011.03.17

• §15.1.2, p. 165, change
O6.1 V and earlier, O5.3 III and earlier, and O4 I and earlier – have $Q_1/Q_0 \geq 0.18$.
→ O6.9 V and earlier, O6.5 III and earlier, and O6 I and earlier – have $Q_1/Q_0 \geq 0.14$.
noted 2011.03.17

• §15.4, p. 168, Eq. (15.19), typo: $\sigma_d$ → $\sigma_{\text{dust}}$
noted 2011.02.24 by Xu Huang.

• §15.3, p. 166, Eqs. (15.10, 15.11), typo: $\sigma_{p,i}$ → $\sigma_{pi}$
noted 2011.03.06

• §15.3, p. 167, Eq. (15.12), typo: $\sigma_{p,i}$ → $\sigma_{pi}$
noted 2011.03.06

• §15.3, p. 167, Eq. (15.13), typo:

\[
3360 \left( Q_{0.49} \right)^{1/3} n_2^{1/3} \rightarrow 2880 \left( Q_{0.49} \right)^{1/3} n_2^{1/3} f_4^{0.28}
\]

where we have taken $\sigma_{pi} = 2.95 \times 10^{-18}$ cm$^2$.
noted 2011.03.17

• §15.4, p. 169, Eq. (15.27) (twice) and following paragraph (twice): typo:
$\sigma_d$ → $\sigma_{\text{dust}}$
noted 2011.03.05 by B. Hensley.

• §15.4, p. 170, Eq. (15.30), typo: $\sigma_d$ → $\sigma_{\text{dust}}$
noted 2011.03.05 by B. Hensley.

• §15.4, p. 170, following Eq. (15.30), add:
where $\sigma_{d, -21} \equiv \sigma_{\text{dust}}/10^{-21}$ cm$^2$.
noted 2011.03.05

• §15.5, p. 172, line 4, typo: ... about the He ... → ... above the He ... noted 2011.03.06 by S. Ferraro
- § 15.7.1, p. 179, Eq. (15.53), typo: $\sigma \rightarrow \sigma_{\text{dust}}$
  noted 2011.03.05

- § 15.7, p. 180, typo: substantially reduced $\rightarrow$ substantially increased
  noted 2011.02.24

- § 15.8, p. 180, Eq. (15.59), typo: there is a spurious factor of $c$ in the denominator. It should read

$$U \equiv \frac{1}{n_H} \int_{v_0}^{\infty} \frac{u_\nu d\nu}{h\nu}$$

  noted 2011.03.06 by S. Ferraro.

- § 16.4, p. 186, Eq. (16.9, 16.10), update: change

$$H_3^+ + e^- \rightarrow H_2 + H \ , \ k_{16.9} = 4.1 \times 10^{-8} T_2^{-0.52} \text{ cm}^3 \text{ s}^{-1} ,$$

$$H_3^+ + e^- \rightarrow H + H + H \ , \ k_{16.10} = 7.7 \times 10^{-8} T_2^{-0.52} \text{ cm}^3 \text{ s}^{-1} ,$$

to

$$H_3^+ + e^- \rightarrow H_2 + H \ , \ k_{16.9} = 5.0 \times 10^{-8} T_2^{-0.48} \text{ cm}^3 \text{ s}^{-1} ,$$

$$H_3^+ + e^- \rightarrow H + H + H \ , \ k_{16.10} = 8.9 \times 10^{-8} T_2^{-0.48} \text{ cm}^3 \text{ s}^{-1} ,$$

and cite McCall et al. (2004) for $k_{16.9}$ and $k_{16.10}$.

- § 16.4, p. 187, typo: in paragraph below eq. (16.15), change

$$x_e \approx x_M \approx 1.9 \times 10^{-4} \rightarrow x_e \approx x_M \approx 1.1 \times 10^{-4} \text{ (see eq. 16.3)}$$

  noted 2013.04.04

- § 16.4, p. 186, Eq. (16.18), added information:

$$H_3^+ + M \rightarrow MH^+ + H_2 : \ k_{16.18} \approx 2 \times 10^{-9} \text{ cm}^3 \text{ s}^{-1} \quad (16.18)$$

  noted 2011.04.03

- § 16.5, p. 189, Eq. (16.25), typo: in numerator of RHS, replace $k_{16.19} \rightarrow A$, so that it reads

$$\frac{n_e}{n_H} = \frac{[B^2 + 4A\zeta_{\text{CR}}(1 + \phi_s)/n_H]^{1/2} - B}{2k_{16.19}} , \quad (16.25)$$

  noted 2011.03.30 by C. Hill.

- § 16.5, p. 189, Fig. 16.3. The original figure was evaluated with a too-large rate for $k_{16.19}$. The figure has been redone, now also showing the result if $\zeta_{\text{CR}} = 1 \times 10^{-17} \text{ s}^{-1}$.
Figure 16.3 Fractional ionization in a dark cloud, estimated using Eq. (16.25), with the grain recombination rate coefficients set to $k_{16,20} = k_{16,22} = 10^{-14} \text{cm}^3 \text{s}^{-1}$ (see Fig. 14.6). The dashed line is a simple power-law approximation $x_e \approx 2 \times 10^{-5} (n_H/\text{cm}^{-3})^{-1/2}$.

noted 2013.03.05.

- §17.2, p. 192, Table 17.1. This has been revised to include critical densities for both $H$ and $e^-$:  

<table>
<thead>
<tr>
<th>Ion</th>
<th>$E_{\ell}/k$ (K)</th>
<th>$E_u/k$ (K)</th>
<th>$\lambda_{ud}$ (\mu m)</th>
<th>$T = 100$ K (cm$^{-3}$)</th>
<th>$T = 5000$ K (cm$^{-3}$)</th>
<th>$n_{\text{crit, } u}(H)$</th>
<th>$n_{\text{crit, } u}(e^-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CII</td>
<td>$2^3 P_{1/2}$</td>
<td>$2^3 P_{3/2}$</td>
<td>0</td>
<td>157.74</td>
<td>2.7$\times 10^5$</td>
<td>1.5$\times 10^3$</td>
<td>68.13</td>
</tr>
<tr>
<td>CII</td>
<td>$3^3 P_0$</td>
<td>$3^3 P_1$</td>
<td>23.60</td>
<td>609.7</td>
<td>620</td>
<td>170</td>
<td>76.95</td>
</tr>
<tr>
<td>CII</td>
<td>$3^3 P_1$</td>
<td>$3^3 P_2$</td>
<td>23.60</td>
<td>62.44</td>
<td>720</td>
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<td>75.95</td>
</tr>
<tr>
<td>OI</td>
<td>$3^3 P_2$</td>
<td>$3^3 P_0$</td>
<td>0</td>
<td>63.185</td>
<td>2.5$\times 10^5$</td>
<td>4.9$\times 10^4$</td>
<td>1.8$\times 10^5$</td>
</tr>
<tr>
<td>OI</td>
<td>$3^3 P_1$</td>
<td>$3^3 P_0$</td>
<td>227.71</td>
<td>145.53</td>
<td>2.4$\times 10^4$</td>
<td>8.6$\times 10^3$</td>
<td>2.3$\times 10^4$</td>
</tr>
<tr>
<td>SiII</td>
<td>$2^3 P_{1/2}$</td>
<td>$2^3 P_{3/2}$</td>
<td>0</td>
<td>413.28</td>
<td>2.5$\times 10^5$</td>
<td>1.2$\times 10^3$</td>
<td>140.53</td>
</tr>
<tr>
<td>SiII</td>
<td>$3^3 P_0$</td>
<td>$3^3 P_1$</td>
<td>0</td>
<td>129.68</td>
<td>4.8$\times 10^4$</td>
<td>2.8$\times 10^4$</td>
<td>2.9$\times 10^4$</td>
</tr>
<tr>
<td>SiII</td>
<td>$3^3 P_1$</td>
<td>$3^3 P_2$</td>
<td>110.95</td>
<td>321.07</td>
<td>4.8$\times 10^4$</td>
<td>3.6$\times 10^4$</td>
<td>4.4$\times 10^4$</td>
</tr>
</tbody>
</table>

noted 2013.03.05.

- §17.5, p. 197, Eq. (17.27) should read 

$$R_{12} = (g_2/g_1) \left[ C_{21} e^{-E_{21}/kT} + n_{\gamma, 21} A_{21} \right].$$  

(17.27)

noted 2010.11.27
• §17.7, p. 199, top line, typo: \( n_{\text{H, crit}} \to n_{\text{crit}}(\text{H}) \)
  noted 2011.03.10

• §18.1.2, Fig. 18.3, p. 208, two typos: The ground states of S II and Ar IV should both have degeneracy \( g_0 = 4 \)
  noted 2012.11.12 by A. Natta

• §18.4.1, p. 212: Replace wavelength in air with wavelength \textit{in vacuo}:
  “Balmer jump” at \( \lambda = 3645.1 \) Å \( \to \) “Balmer jump” at \( \lambda = 3647.0 \) Å
  noted 2011.03.11

• §18.4.1, p. 212: Refine wavelength midway between H 20 and H 21 lines:
  \( \lambda_{\text{BJ, red}} = 3682.6 \) Å \( \to \) \( \lambda_{\text{BJ, red}} = 3682.1 \) Å
  noted 2011.03.11

• §19.3, p. 222: revise value for \( A_{10} \): replace
  \( A_{10} = 6.78 \times 10^{-8} \) s\(^{-1} \) \( \to \) \( A_{10} = 7.16 \times 10^{-8} \) s\(^{-1} \) (see eq. 5.7).
  noted 2013.04.17

• §19.3, p. 223: revised numbers according to revised value for \( A_{10} \):
  eq. (19.15): 281 \( \to \) 297 , eq. (19.17): 281 \( \to \) 297 , eq. (19.19): 46 \( \to \) 50
  noted 2013.04.17

• §19.4, p. 224, typo: function \( \to \) function
  noted 2011.03.11 by C. Petrovich

• §21.3, p. 242, typo: ...into the UV. whereas... \( \to \) ...into the UV, whereas...
  noted 2011.03.21

• §21.6.1, p. 244, typo: \( k^2 = \epsilon_{\text{ISM}} \omega^2 c^2 \to k^2 = \epsilon_{\text{ISM}} \omega^2 / c^2 \)
  noted 2011.03.28

• §21.6.1, p. 244, Eq. (21.12), typo:
  \( n_{\text{gr}} C_{\text{ext}}(\omega) = 2 \text{Im}(k) = 2 \omega \epsilon_{\text{ISM}} \approx \omega (\text{Im}(\epsilon_{\text{ISM}})) \approx \omega \epsilon_{\text{ISM}} \) \( (21.12) \)
  \( \to \)
  \( n_{\text{gr}} C_{\text{ext}}(\omega) = 2 \text{Im}(k) = 2(\omega/c) \text{Im}(\sqrt{\epsilon_{\text{ISM}}}) \approx (\omega/c) \text{Im}(\epsilon_{\text{ISM}}) \) \( (21.12) \)
  noted 2011.03.28

• §22.4.2, p. 252, Eq. (22.27), typo: \( 4\pi \to 9\pi \).
  noted 2012.06.26

• §23.1, p. 265, typo:
  lower oscillator strength \( f(\text{C II}[2325] \text{ Å}) = 1.0 \times 10^{-7} \)
  \( \to \)
  larger oscillator strength \( f(\text{C II}[2325] \text{ Å}) = 1.0 \times 10^{-7} \)
  noted 2012.12.27

• §23.1, p. 266, typo: \( \text{Mg}_{2+a} \text{Fe}_{2-a} \text{SiO}_4 \to \text{Mg}_{2+a} \text{Fe}_{2-a} \text{SiO}_4 \)
  noted 2011.03.24 by C. Petrovich
• §23.3, p. 269, typo: ...that the *at most*... → *that at most*... noted 2011.03.23

• §23.4, p. 272, Fig. 23.5 caption, typo: Lowe panels:... → Lower panels:... noted 2011.03.23

• §23.10, p. 280, typo: varies → varies noted 2011.03.23

• §23.10, p. 283, typo: totally → total noted 2011.03.23

• §24.2, p. 293, typo: ...does not extend below ∼23K. → ...does not extend below ∼35K. noted 2011.03.24

• §24.2, p. 293, typo: ...corresponds the grain... → ...corresponds to the grain... noted 2011.03.25

• §26.2.2, p. 309, Fig. 26.2: the rightmost abscissa label should read “100”, not “10”. noted 2011.03.29 by B. Hensley.

• §26.3.1, p. 311, Eq. (26.24), typo:

\[ \mu = \frac{Qa^2 \omega}{3} \rightarrow \mu = \frac{Qa^2 \omega}{3c} \]

noted 2011.05.01 by P. Pattarakijwanich.

• §26.3.1, p. 311, Eq. (26.25), typos: The equation should read

\[ \Omega_L = \frac{5UB}{8\pi \rho a^2 c} = 3.7 \times 10^{-10} \left( \frac{3 \text{ g cm}^{-3}}{\rho} \right) \left( \frac{U}{\text{Volt}} \right) \left( \frac{B}{5 \mu G} \right) \left( \frac{0.1 \mu m}{a} \right)^2 \text{s}^{-1}. \] (26.25)

noted 2011.05.01 by P. Pattarakijwanich.

• §26.3.1, p. 311, after Eq. (26.25), typo: \( 2\pi/\Omega_L \approx 10 \text{ yr} \) → \( 2\pi/\Omega_L \approx 500 \text{ yr} \) noted 2011.05.01 by P. Pattarakijwanich.

• §27.1, p. 315, 2nd paragraph, typo: ...resulting photoelectron will... → ...resulting photoelectrons will... noted 2011.03.31

• §27.1, p. 317, typo: ...injection of photoelectron energy rate... → ...injection of photoelectron energy... noted 2012.06.22 by F. van der Tak.

• §27.1, p. 317, typo: ...nebulae dust are dusty,... → ...nebulae are dusty,... noted 2011.03.31
• §28.1, p. 326, 2nd paragraph, typo: ...form the the... → ...form the...
   noted 2011.03.31

• §28.2, p. 327, 2nd paragraph, typo:
  $EM \approx 5 \times 10^6 \text{ cm}^{-3} \text{ pc} \rightarrow EM \approx 5 \times 10^6 \text{ cm}^{-6} \text{ pc}$
  noted 2011.03.31 by C. Petrovich.

• §29.1, p. 332, 1st paragraph, typo: $b = 0 \rightarrow b = 90^\circ$, so that the 2nd sentence reads
  ...vary as $N(\text{H I}, b) = N(\text{H I}, b = 90^\circ)/\sin|b| = N_0 \csc|b|$.
  noted 2012.11.04 by R. Simons.

• §29.4, p. 335, typo:
  ...found $nT \approx 2800 \text{ cm}^{-3} \text{ K}$... → ...found $nT \approx 3800 \text{ cm}^{-3} \text{ K}$...
  noted 2011.04.05

• §29.4, p. 335, typo: ...implies $n_H \approx 35 \text{ cm}^{-3}$. → ...implies $n_H \approx 50 \text{ cm}^{-3}$.
  noted 2011.04.05

• §30.2, p. 339, typo: ...near threshold are... → near-threshold yields are...
  noted 2011.04.05 by B. Hensley.

• §31.4, p. 349, Eq. (31.24), typo: on RHS, change
  \[
  \frac{\pi e^2}{m_e c^2 h} \sum_u f_{\ell u} \lambda_{\ell u}^3 u \lambda f_{\text{shield},\ell u} \rightarrow \frac{\pi e^2}{m_e c^2 h} \sum_u f_{\ell u} \lambda_{\ell u}^3 u \lambda f_{\text{shield},\ell u} \rho_{\text{diss},u}
  \]
  noted 2013.04.12 by Ai-Lei Sun.

• §31.4, p. 349, Eq. (31.25), typo: $\tau_{1000} \rightarrow \tau_{d,1000}$
  noted 2012.07.10

• §32.1, p. 357, 1st paragraph, typo: ...a their... → ...their...
  noted 2012.06.22 by F. van der Tak.

• §32.1, p. 357, 2nd paragraph, typo: (see Plate 15). → (see Plate 11).
  noted 2011.06.07 by S. Lorenz Martins.

• §32.9, p. 368, typo: magntic → magnetic
  noted 2011.04.11

• §33.1, p. 375, typo: photodisociation → photodissociation
  noted 2011.04.11

• §33.1, p. 375, typo: occuring → occurring
  noted 2011.04.25 by B. Hensley.

• §33.2.2, p. 378, typo: reaction products should be $\text{OH}^+ + \text{H}_2$
  noted 2011.04.12
• §34.4, p. 387, typo: eq. (34.17) is off by a factor 3, and should read
\[ t_{\text{evap}} = \frac{3M}{2M} = \frac{25 \times 2.3(n_{\text{H}})_{e}R_{e}^{2}m_{e}^{1/2}e^{4} \ln \Lambda}{8 \times 0.87(kT_{r})^{2.5}} \] (34.17)

Eq. (34.18) is numerically correct, but should have shown the dependence on \( \ln \Lambda \):
\[ = 5.1 \times 10^{4} \gamma T \left( \frac{n_{\text{H}}}{30 \text{ cm}^{-3}} \right) \left( \frac{R_{e}}{\text{pc}} \right)^{2} \left( \frac{T_{r}}{10^{7} \text{ K}} \right)^{-2.5} \left( \frac{\ln \Lambda}{30} \right). \] (34.18)

noted 2013.01.05 by B. Hensley.

• §35.3, p. 392, typo: rate-of-change \( v \) of...
\[ \rightarrow \text{rate-of-change of } v \ldots \] noted 2011.04.14

• §36.1, p. 397, typo: occuring \[ \rightarrow \] occurring
noted 2011.04.26

• §36.2.2, p. 399, Eq. (36.8), two corrections: \( 8\pi \rightarrow 4\pi \) and \( B_{y}B_{y}v_{y} \rightarrow B_{x}B_{y}v_{y} \). The equation should read
\[ \frac{\partial}{\partial x} \left[ \frac{1}{2} \rho v^{2} + U_{v} + p_{v}v + \frac{(B_{y}^{2} + B_{z}^{2})}{4\pi}v_{x} - \frac{B_{y}B_{y}v_{y}}{4\pi} - \frac{B_{x}B_{y}v_{y}}{4\pi} \right. \\
\left. - v_{j}\sigma_{jx} - \kappa \frac{dT}{dx} + \rho v_{x} \Phi_{\text{grav}} \right] = \Gamma - \Lambda. \] (36.8)

noted 2011.04.19

• §36.2.3, p. 400, Eq. (36.10): \( 8\pi \rightarrow 4\pi \) (twice). The equation should read
\[ \left\{ \left[ \frac{\rho v^{2}}{2} + \frac{\gamma p}{\gamma - 1} \right] v_{x} + \frac{(B_{y}^{2} + B_{z}^{2})}{4\pi}v_{x} - \frac{(B_{y}B_{y} + B_{x}B_{y})}{4\pi}v_{y} - \kappa \frac{dT}{dx} \right\}_{1} = \\
\left\{ \left[ \frac{\rho v^{2}}{2} + \frac{\gamma p}{\gamma - 1} \right] v_{x} + \frac{(B_{y}^{2} + B_{z}^{2})}{4\pi}v_{x} - \frac{(B_{y}B_{y} + B_{x}B_{y})}{4\pi}v_{y} - \kappa \frac{dT}{dx} \right\}_{2}. \] (36.10)

noted 2011.04.19

• §36.2.5, p. 401, Eq. (36.16): \( 8\pi \rightarrow 4\pi \) (twice). The equation should read
\[ \frac{\rho_{1}u_{1}^{3}}{2} + \frac{\gamma}{\gamma - 1}u_{1}p_{1} + \frac{u_{1}B_{1}^{2}}{4\pi} = \frac{\rho_{2}u_{2}^{3}}{2} + \frac{\gamma}{\gamma - 1}u_{2}p_{2} + \frac{u_{2}B_{2}^{2}}{4\pi}, \] (36.16)

noted 2011.04.19
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• §36.2.5, p. 401, Eq. (36.19): $8\pi \rightarrow 4\pi$ (twice). The equation should read
\[
\frac{1}{2} \rho_1 v_s^3 \frac{\gamma}{\gamma - 1} p_1 v_s + \frac{B_1^2}{4\pi} v_s = \frac{1}{2} \rho_1 v_s^3 + \frac{\gamma}{\gamma - 1} p_2 v_s + \frac{B_1^2}{4\pi} v_s x . \tag{1}
\]

noted 2011.04.19

• §36.2.5, p. 402, Eq. (36.27), typo:
\[
\frac{3}{16} \mu v_s^2 \rightarrow \frac{3}{16} \frac{\mu v_s^2}{k}
\]

noted 2011.05.17 by P. Pattarakijwanich.

• §36.6, p. 409, typo: occuring $\rightarrow$ occurring
noted 2011.04.25 by B. Hensley.

• §39.1.1, p. 430, typo: case of Type II supernova $\rightarrow$ case of Type II supernovae
noted 2011.04.21

• §39.1.1, p. 430, typo: relative dense $\rightarrow$ relatively dense
noted 2011.04.21

• §39.1.1, p. 430, typo: Plate 11 $\rightarrow$ Plate 12
noted 2011.04.21 by C. Petrovich.

• §39.1.2, p. 433, eq. (39.22, 39.23, 39.24), typos: the factor $(E_{51}/n_0^2)$ should be $(E_{51} n_0^2)$, so that the equations should read
\[
v_s(t_{rad}) = 188 \text{ km s}^{-1} (E_{51} n_0^2)^{0.07} , \tag{39.22}
\]
\[
T_s(t_{rad}) = 4.86 \times 10^5 \text{ K} (E_{51} n_0^2)^{0.13} , \tag{39.23}
\]
\[
kT_s(t_{rad}) = 41 \text{ eV} (E_{51} n_0^2)^{0.13} . \tag{39.24}
\]

noted 2012.10.02 by G.B. Field.

• §39.2, p. 435, footnote 1, typo (twice): occuring $\rightarrow$ occurring
noted 2011.04.12 by B. Hensley.

• §39.4, p. 439, typo: neighboorhood $\rightarrow$ neighborhood
noted 2011.04.14

• §40.2, p. 442, typo: with a increased energy $\rightarrow$ with an increased energy
noted 2011.04.26

• §40.5, p. 447, typo: protons with $E \gtrsim 10^5 \text{ GeV}$ have $R_{\text{gyro}} < 10^{-4} \text{ pc}$ $\rightarrow$ protons with $E \lesssim 10^5 \text{ GeV}$ have $R_{\text{gyro}} < 10^{-4} \text{ pc}$
noted 2011.04.26

• §40.9, p. 450, typo: $e^+ H \rightarrow H^+ + 2\gamma$ $\rightarrow$ $e^+ + H \rightarrow H^+ + 2\gamma$
noted 2011.04.27
• §41.3.2, p. 457, Eq. (41.46), typo: replace

\[ E_{\text{mag}} = \frac{B_{\text{rms}}^2 - B_0^2}{8\pi} V \quad \rightarrow \quad E_{\text{mag}} = \frac{B_{\text{rms}}^2}{8\pi} V \]

noted 2011.04.28

• §41.3.2, p. 457, Eq. (41.46), typo: replace

\[ E_{\text{mag}} = \frac{B_{\text{rms}}^2 - B_0^2}{8\pi} V \quad \rightarrow \quad E_{\text{mag}} = \frac{B_{\text{rms}}^2}{8\pi} V \]

noted 2011.04.28

• §41.4, p. 460, Eq. (41.55), typo: \( \langle \sigma v \rangle \rightarrow \langle \sigma v \rangle_{\text{int}} \)

noted 2012.04.16

• §41.4, p. 460, Eq. (41.55), typo: \( m_m \rightarrow m_n \)

noted 2013.04.30 by K. Silsbee

• §41.4, p. 461, Eq. (41.56), typo: \( \langle \sigma v \rangle \rightarrow \langle \sigma v \rangle_{\text{int}} \)

noted 2012.04.16

• §41.6, p. 463, typo: ... the allows the \( \rightarrow \) ... this allows the

noted 2011.04.28 by B. Hensley

• §41.6, p. 463, typo: magenetic \( \rightarrow \) magnetic

noted 2011.01.10


(Also corrected in Bibliography)

noted 2012.06.22 by F. van der Tak.

• §42.2, p. 467, last paragraph, typo: ...face-on it, may... \( \rightarrow \) ...face-on, it may...

noted 2012.06.22 by F. van der Tak.

• §42.4, p. 470, 3rd paragraph should read

... to be \( Q_{0,\text{MW}} = (3.2 \pm 0.5) \times 10^{53} \text{s}^{-1} \), after...

noted 2011.01.04

• §42.5, p. 471, Eq. (42.9) typo: dsik \( \rightarrow \) disk

noted 2011.01.04

• Plate 5 caption: 2nd sentence should read

... synchrotron emission seen in Plate 4.

noted 2011.01.12

• Appendix A, p. 473, typo: entry for \( a_0 \) should read

...Bohr radius \( \equiv \hbar^2/m_e e^2 = \ldots \)

noted 2013.03.05 by Wenhua Ju.
• Appendix A, p. 475: entry for RM should read
  \[ RM \ldots \text{see Eq. (11.23)} \]
  noted 2011.01.05

• Appendix E, p. 483, typo: Pfundt \rightarrow Pfund
  noted 2011.04.28 by B. Hensley.

• Appendix E, p. 484: diagram for C IV: the wavelength labels 1548.2 and 1550.8 should be interchanged.
  noted 2011.03.11

• Appendix E, p. 486: labelling of the fine-structure excited state for C II, N III, and O IV should have \( J = \frac{3}{2} \) (not \( J = \frac{1}{2} \)).
  noted 2012.01.29 by E.B. Jenkins.

• Appendix F, p. 501, Table F.6: incorrect powers of 10 in lines 5 and 6:
  \[ k_{uf} \text{ for } \ell - u = 3P_0 - 3P_1 \text{ should read } 1.26 \times 10^{-10} T_2^{0.115+0.057 \ln T_2} \]
  \[ k_{u\ell} \text{ for } \ell - u = 3P_0 - 3P_2 \text{ should read } 2.64 \times 10^{-10} T_2^{0.231+0.046 \ln T_2} \]
  noted 2012.05.02 by M.J. Wolfire

• Appendix I, p. 506, typo: \( \sim E_{uf}/h \rightarrow \sim h/E_{uf} \)
  noted 2013.02.07 by Munan Gong.

• Appendix I, p. 507, typo (missing \( \frac{1}{2} \)): Eq. (I.4) should read
  \[ b_{\text{crit}}(v) = W a_0 \left[ 1 + \frac{Ze^2}{W a_0 m_e v^2 / 2} \right]^{1/2} \]  
  noted 2011.02.08 by B. Hensley.

• Appendix J, p. 508, Eq. (J.3), typo in line 3:
  \[ ... + \int dV \frac{\partial}{\partial x} (v_j \rho v_i x_i) \rightarrow ... + \int dV \frac{\partial}{\partial x_j} (v_j \rho v_i x_i) \]
  noted 2011.02.14 by Xu Huang.