Physics of the Interstellar and Intergalactic Medium

Errata in the first printing.

Updated 2021.02.14

Bruce T. Draine
Which printing of the book you have can be determined from the last line on the copyright page:

- First printing: 1 3 5 7 9 10 8 6 4 2
- Second printing: 3 5 7 9 10 8 6 4 2
- Third printing: 3 5 7 9 10 8 6 4
- Fourth printing: 5 7 9 10 8 6 4
- Fifth printing: 5 7 9 10 8 6
- Sixth printing: 7 9 10 8 6

Errata in the first printing:

- Preface, p. xvii, typo: *reaquaint* → *reacquaint*
  noted 2011.02.13 by B. Hensley.

- Plate 5 caption, typo: *...seen in Plate 6.* → *...seen in Plate 4.*
  noted 2018.04.07 by L. Bouma.

- §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 1.3: change range of densities for H II gas from $0.3 - 10^4 \text{ cm}^{-3}$ to $0.2 - 10^4 \text{ cm}^{-3}$.
  noted 2011.09.22 by B. Ménard.

- §1.2, p. 8, Table 1.4: change abundance of P from $\frac{N_P}{N_H} = 3.23 \times 10^{-7 \pm 0.03}$, $\frac{M_P}{M_H} = 1.00 \times 10^{-5}$ to $\frac{N_P}{N_H} = 2.82 \times 10^{-7 \pm 0.03}$, $\frac{M_P}{M_H} = 8.73 \times 10^{-6}$.
  noted 2013.10.21 by Bon-Chul Koo.

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

- §3.6, p. 28, Eq. (3.31), typo: factor of 2 error. Eq. (3.31) should read
  \[ \sigma_{rr,ul}(E) = \frac{1}{2} \frac{g(X_{\ell})}{g(X_{\ell}^+)} \left( \frac{I_{X,\ell u} + E}{E m_e c^2} \right)^2 \sigma_{\pi,\ell u}(h\nu = I_{X,\ell u} + E), \]  
  noted 2015.06.01 by E. B. Jenkins

- §3.7, p. 28, Eq. (3.33), typo: sign error. Change $e^{-I_n/kT} \rightarrow e^{I_n/kT}$.
  noted 2017.02.09

- §3.8, p. 31, Eq. (3.48), typo: change
  \[ I_{n \alpha} \propto A_{n \alpha} h \nu_{n \alpha} \int n[H(n)] ds \propto n^{-6} b_{n} \int n_e n(H^+) ds \]
\[ \rightarrow I_{n\alpha} \propto A_{n\alpha}h\nu_{n\alpha} \int n[H(n+1)]ds \propto n^{-6}b_{n+1} \int n_e n(H^+)ds \]

noted 2019.02.06

- §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, 3rd paragraph, typos: change
  para-H\textsubscript{2}O must have \( K^-1 + K^+1 \) odd →
  para-H\textsubscript{2}O must have \( K^-1 + K^+1 \) even
  and
  ortho-H\textsubscript{2}O must have \( K^-1 + K^+1 \) even →
  ortho-H\textsubscript{2}O must have \( K^-1 + K^+1 \) odd
  noted 2015.01.15 by Neal Evans.

- §5.2.2, p. 50: the text should have made clear that the selection rules given
  were specifically for H\textsubscript{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\textsubscript{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 \( 7618 \text{ cm s}^{-1} \) → \( 7616 \text{ cm s}^{-1} \)
  and in the following line change \( 7618 \text{ cm s}^{-1} \) → \( 7616 \text{ cm s}^{-1} \).
  noted 2011.08.18 by K.-G. Lee.

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

- §6.4, p. 60, Eq. (6.41), typo: replace
  \[ 2924 \frac{7618 \text{ cm s}^{-1}}{\gamma_{ul}\lambda_{ul}} b_{ul} \] → \[ 2925 \frac{7616 \text{ cm s}^{-1}}{\gamma_{ul}\lambda_{ul}} b_{ul} \]
  and in Eq. (6.42) change \( 7618 \text{ cm s}^{-1} \) → \( 7616 \text{ cm s}^{-1}. \)
  noted 2011.08.18 by K.-G. Lee.

- §5.5, p. 69, Eq. (7.29), typo: missing a factor \( n_{\ell}. \) Should read
  \[ \kappa_{\nu} = n_{\ell} \sigma_{\ell \rightarrow u} \left( 1 - \frac{n_u/g_u}{n_{\ell}/g_{\ell}} \right) < 0 \]
  noted 2020.10.12 by Yan Liang.
• §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:
  \[
  \kappa_\nu = \frac{3}{32 \pi} \frac{1}{\sqrt{2 \pi}} \frac{A_u \lambda_u^2}{\sigma_V} \frac{hc}{k T_{\text{spin}}} n(\text{HI}) e^{-u^2/2\sigma_v^2}
  \] (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 → 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: $T_{\text{sky}}(v) \rightarrow T_{\text{sky}}$ (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.

• §9.8, p. 84, typo in line following Eq. (9.35): change \[
  (v_{\text{FWHM}}/2 \text{ km s}^{-1})^2 / 3 \rightarrow (v_{\text{FWHM}}/2 \text{ km s}^{-1})^{2/3}.
  \]
  noted 2020.09.09 by Roohi Dalal.

• §9.10, Table 9.4, p. 88, typos: for C II and N III, change $^2D_J \rightarrow ^2D_J$ for $J = 3/2$ and $J = 5/2$.
  noted 2015.02.12 by Semyeong Oh.

• §10.2, sentence preceding Eq. (10.5): change ...
  ...the Gaunt factor from quantum-mechanical calculations is approximately
  → ...
  ...the Gaunt factor is approximately (Scheuer 1960)
  noted 2018.11.18 by S. Weinberg.

• §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, Eq. (10.25), typo (missing factor of 2): should read

\[ j_{b,\nu} = \frac{2h^3}{g_i g_f} \frac{2}{(2\pi m_e kT)^{3/2} c^2} \exp\left(\frac{-(h\nu)}{kT}\right) \sigma_{b,\nu}(\nu)n_e n_i \]

noted 2021.02.14 by Shigenobu Hirose.

- §10.5, p. 97, footnote 3, typo: 50 × 10^6 cm\(^{-3}\) pc → 5 × 10^6 cm\(^{-6}\) pc.

noted 2011.02.15 by C. Petrovich.

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

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

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:

<table>
<thead>
<tr>
<th></th>
<th>CMB, ( T = 2.725 \text{ K} )</th>
<th>( T_2 = 4000 \text{ K} ), ( W_2 = 1.65 \times 10^{-13} )</th>
<th>( T_3 = 7500 \text{ K} ), ( W_3 = 1 \times 10^{-14} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starlight total</td>
<td>( \approx 1.05 \times 10^{-12} )</td>
<td>( \approx 1.06 \times 10^{-12} )</td>
<td>( \approx 1.06 \times 10^{-12} )</td>
</tr>
<tr>
<td>ISRF total</td>
<td>( \approx 2.19 \times 10^{-12} )</td>
<td>( \approx 1.98 \times 10^{-12} )</td>
<td>( \approx 1.98 \times 10^{-12} )</td>
</tr>
</tbody>
</table>

noted 2012.11.08

- §12.5, p. 123, below eq. (12.4): change

...\( W_1 \) by 40%, from \( W_1 = 5 \times 10^{-13} \) to \( 7 \times 10^{-13} \).

...\( W_1 \) by 75%, from \( W_1 = 4 \times 10^{-13} \) to \( 7 \times 10^{-13} \), and raised \( W_2 \) from \( 1.0 \times 10^{-13} \) to \( 1.65 \times 10^{-13} \).

noted 2014.11.11 by S. Bianchi.

- §13.1, pp. 128, eq. (13.1), (13.3), (13.4): for notational consistency with the rest of the chapter, change \( \sigma_{pe} \to \sigma_{pi} \)

noted 2018.01.07 by L. Bouma.

- §13.1, p. 128, typo:

\[ \sigma_{pe}(H_2) = 2.8 \sigma_{p,i}(H) \to \sigma_{pe}(H_2) = 2.8 \sigma_{pe}(H) \]

noted 2011.03.06

- §13.1, p. 129, clarification:

...photoionization cross sections for O...

...photoionization cross sections \( \sigma_{pi} \) for O...

noted 2011.03.06

- §13.1, p. 130, Eq. (13.5), clarification:

\( \zeta_{p,i} \to \zeta_{pi}, \quad \sigma_{pe} \to \sigma_{pi} \)

noted 2011.03.06
• §13.1, p. 130, second paragraph, typo:
  ...to $3 \times 10^{-10} \text{s}^{-1}$ for Si  $\rightarrow$  ...to $3 \times 10^{-9} \text{s}^{-1}$ for Si
  noted 2017.03.05

• §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:
  $\sigma_{\text{e.i.}}  \rightarrow  \sigma_{\text{ci}}$ (4 places),  $k_{\text{e.i.}}  \rightarrow  k_{\text{ci}}$ (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>$\alpha_{\text{in}}(L)$</th>
<th>$\alpha_{\text{in}}(5 \times 10^3 \text{ K})$</th>
<th>$\alpha_{\text{in}}(1 \times 10^4 \text{ K})$</th>
<th>$\alpha_{\text{in}}(2 \times 10^4 \text{ K})$</th>
<th>$\alpha_{\text{in}}(\text{approximation})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{1s}$</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 $\times 10^{-13}$</td>
<td>$T_{4}^{-0.540 - 0.017 \ln T_{4}}$</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 $\times 10^{-14}$</td>
<td>$T_{4}^{-0.537 - 0.019 \ln T_{4}}$</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>5.36 $\times 10^{-14}$</td>
<td>$T_{4}^{-0.681 - 0.061 \ln T_{4}}$</td>
</tr>
<tr>
<td>$\alpha_{2}$</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 $\times 10^{-14}$</td>
<td>$T_{4}^{-0.636 - 0.046 \ln T_{4}}$</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 $\times 10^{-15}$</td>
<td>$T_{4}^{-0.547 - 0.024 \ln T_{4}}$</td>
</tr>
<tr>
<td>$\alpha_{3p}$</td>
<td>3.03 $\times 10^{-14}$</td>
<td>1.73 $\times 10^{-14}$</td>
<td>1.19 $\times 10^{-14}$</td>
<td>1.73 $\times 10^{-14}$</td>
<td>$T_{4}^{-0.868 - 0.093 \ln T_{4}}$</td>
</tr>
<tr>
<td>$\alpha_{3}$</td>
<td>3.33 $\times 10^{-14}$</td>
<td>4.55 $\times 10^{-14}$</td>
<td>2.67 $\times 10^{-14}$</td>
<td>4.55 $\times 10^{-14}$</td>
<td>$T_{4}^{-0.729 - 0.060 \ln T_{4}}$</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>3.59 $\times 10^{-15}$</td>
<td>$T_{4}^{-0.562 - 0.026 \ln T_{4}}$</td>
</tr>
<tr>
<td>$\alpha_{4p}$</td>
<td>1.51 $\times 10^{-14}$</td>
<td>9.66 $\times 10^{-15}$</td>
<td>6.90 $\times 10^{-15}$</td>
<td>9.66 $\times 10^{-15}$</td>
<td>$T_{4}^{-0.691 - 0.064 \ln T_{4}}$</td>
</tr>
<tr>
<td>$\alpha_{4}$</td>
<td>1.90 $\times 10^{-14}$</td>
<td>1.08 $\times 10^{-14}$</td>
<td>8.07 $\times 10^{-15}$</td>
<td>1.08 $\times 10^{-14}$</td>
<td>$T_{4}^{-0.870 - 0.094 \ln T_{4}}$</td>
</tr>
<tr>
<td>$\alpha_{4f}$</td>
<td>1.09 $\times 10^{-14}$</td>
<td>5.54 $\times 10^{-15}$</td>
<td>3.57 $\times 10^{-15}$</td>
<td>5.54 $\times 10^{-15}$</td>
<td>$T_{4}^{-1.041 - 0.100 \ln T_{4}}$</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 $\times 10^{-14}$</td>
<td>$T_{4}^{-0.805 - 0.065 \ln T_{4}}$</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 $\times 10^{-13}$</td>
<td>$T_{4}^{-0.721 - 0.018 \ln T_{4}}$</td>
</tr>
<tr>
<td>$\alpha_{B}$</td>
<td>4.53 $\times 10^{-13}$</td>
<td>2.50 $\times 10^{-13}$</td>
<td>1.43 $\times 10^{-13}$</td>
<td>2.50 $\times 10^{-13}$</td>
<td>$T_{4}^{-0.833 - 0.035 \ln T_{4}}$</td>
</tr>
</tbody>
</table>

|$\alpha_{\text{ref}}$ from Burgess (1965); $\alpha_{B}$ from Hummer & Storey (1987) (for $n_{e} = 10^{6} \text{ cm}^{-3}$)

• §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

$$\alpha_{A}(T) \approx 4.13 \times 10^{-13} \frac{T}{T_{4}} \langle Z / Z^2 \rangle^{0.7131 - 0.0115 \ln(T_{4}/Z^2)} \text{cm}^3 \text{s}^{-1} \text{),(14.3)}$$

$$\alpha_{B}(T) \approx 2.54 \times 10^{-13} Z \langle T_{4}/Z^2 \rangle^{-0.8163 - 0.0208 \ln(T_{4}/Z^2)} \text{cm}^3 \text{s}^{-1} \text{),(14.4)}$$

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](image_url)

**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 $T$.

noted 2012.01.04 by E. B. Jenkins.

- Table 14.2, p. 143, typo: Pfundt $\rightarrow$ 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: $[\text{OIII}]4959,5007 \rightarrow [\text{OIII}]4960,5008$
  noted 2012.06.22 by F. van der Tak.

- §14.6, p. 153, typo:
  ...from the wave function of $AB$... $\rightarrow$ ...from the wave function of $AB^+$...
  noted 2011.03.05 by P. Pattarakijwanich.

- §14.6, p. 154, Table 14.8 update: replace
  
  $\text{H}_3^+ + e^- \rightarrow \text{H}_2 + \text{H} \quad 1.1 \times 10^{-7}T_2^{-0.56}$
  \text{McCall et al. (2004)}
  
  with
  
  $\text{H}_3^+ + e^- \rightarrow \text{H} + \text{H} + \text{H} \quad 8.9 \times 10^{-8}T_2^{-0.48}$
  \text{McCall et al. (2004)}
  
  $\text{H}_5^+ + e^- \rightarrow \text{H}_2 + \text{H} \quad 5.0 \times 10^{-8}T_2^{-0.48}$
  \text{McCall et al. (2004)}
  
  noted 2013.04.03

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

- §14.7.1, p. 156, Eq. (14.31), for notational consistency: $n(\text{H}) \rightarrow n(\text{H}^0)$
  noted 2011.05.15 by E. B. Jenkins.
• §14.7.1, p. 156, just before Eq. (14.35), typo:
In the low density limit... → 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:

![Dependence of oxygen ionization fraction on hydrogen ionization fraction due to charge exchange. The low-density limit applies for $n_{H} \lesssim 10^{4} \text{cm}^{-3}$.](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.

• §14.9, p. 159, typo: factor of 2 error. Eq. (14.41) should read

$$\sigma_{rr}(E) = \frac{g_{\ell}}{2g_{\nu}} \frac{(I+E)^2}{E m_{e} c^{2}} \sigma_{pi}(h\nu = I+E) .$$

(14.41)

noted 2015.06.01 by E. B. Jenkins.

• §14.9, p. 160, typo: factor of 2 error. Eq. (14.43) should read

$$\frac{\langle \sigma v \rangle_{rr}}{\langle \sigma v \rangle_{ci}} \approx 2\pi \alpha^{3} f_{pi}^{2} \frac{I}{C kT} e^{I/kT} ,$$

(14.43)

noted 2015.06.01 by E. B. Jenkins.

• §14.9, p. 160, typo: factor of 2 error. Eq. (14.44) and following should read

$$\frac{I}{kT} e^{I/kT} = \frac{C}{2\pi f_{pi}^{2}} \frac{1}{\alpha^{3}} .$$

(14.44)

If $C \approx 1$ and $f_{pi} \approx 1$, this has solution $I/kT \approx 10.6$. ...
noted 2015.06.01 by E. B. Jenkins.
• §15.1, p. 163, typo: $\sigma_{p,i} \rightarrow \sigma_{pi}$ (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 $h\nu > 24.6$ eV photons that are absorbed by H.
  noted 2011.03.17

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

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

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

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

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

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

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

• §15.3, p. 167, Eq. (15.13), typo:
  $$3360 \left(\frac{Q_{0,49}}{49}\right)^{1/3} n_2^{1/3} \rightarrow 2880 \left(\frac{Q_{0,49}}{49}\right)^{1/3} n_2^{1/3} T_4^{0.28}$$
  where we have taken $\sigma_{pi} = 2.95 \times 10^{-18} \text{ cm}^2$.
  noted 2011.03.17
• §15.4, p. 169, Eq. (15.27) (twice) and following paragraph (twice): typo:
\[ \sigma_d \rightarrow \sigma_{\text{dust}} \]
noted 2011.03.05 by B. Hensley.

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

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

• §15.5, p. 172, line 4, typo: ... about the He ... \( \rightarrow \) ... above the He ... 
noted 2011.03.06 by S. Ferraro

• §15.5, p. 174, sentence preceding Eq. (15.36), typo:
\[ N(\text{He}^+)/N(\text{H}^+) < n_{\text{He}}/n_{\text{H}} \rightarrow N(\text{He}^+)/N(\text{H}^+) < n_{\text{He}}/n_{\text{H}} \]
noted 2020.09.29 by H. Jia

• §15.5, p. 179, Eq. (15.53), typo: \( \sigma_d \rightarrow \sigma_{\text{dust}} \)
noted 2011.03.05

• §15.7, p. 180, typo: substantially reduced \( \rightarrow \) substantially increased
noted 2011.02.24

• §15.7, p. 180, Eq. (15.59), typo: there is a spurious factor of \( c \) in the denominator. It should read
\[ U \equiv \frac{1}{n_{\text{H}}} \int_{x_0}^{\infty} \frac{n_e d\nu}{h\nu} \]
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 \( k_{16.10} \).
noted 2013.04.03

• §16.4, p. 187, typo: in paragraph below Eq. (16.15), change
\[ x_c \approx x_M \approx 1.9 \times 10^{-4} \rightarrow x_c \approx x_M \approx 1.1 \times 10^{-4} \] (see Eq. 16.3)
noted 2013.04.04
• §16.5, p. 188, Eq. (16.16), typo: should read
\[ H_2 + \text{CR} \rightarrow H_2^+ + e^- + \text{CR} \]

noted 2020.09.29 by R. Córdova

• §16.5, p. 188, Eq. (16.18), added information:
\[ H_3^+ + M \rightarrow MH^+ + H_2 : \quad k_{16.18} \approx 2 \times 10^{-9} \text{ cm}^3 \text{s}^{-1} \quad (16.18) \]

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 \( x_e \propto n_H^{1/2} \).

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>ℓ</th>
<th>u</th>
<th>$E_{\ell}/k$ (K)</th>
<th>$E_u/k$ (K)</th>
<th>$\lambda_{ul}$ (µm)</th>
<th>$n_{\text{crit, } u(H)}$ (cm$^{-3}$)</th>
<th>$T = 100$ K</th>
<th>$T = 5000$ K</th>
<th>$n_{\text{crit, } u(e^-)}$ (cm$^{-3}$)</th>
<th>$T = 100$ K</th>
<th>$T = 5000$ K</th>
</tr>
</thead>
<tbody>
<tr>
<td>C II</td>
<td>2P$^{3/2}_1$</td>
<td>2P$^{3/2}_3/2$</td>
<td>0</td>
<td>91.21</td>
<td>157.74</td>
<td>$2.7 \times 10^3$</td>
<td>$1.5 \times 10^3$</td>
<td>6.8</td>
<td>40.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C I</td>
<td>3P$^0_0$</td>
<td>3P$^1_1$</td>
<td>0</td>
<td>23.60</td>
<td>609.7</td>
<td>620</td>
<td>170</td>
<td>76.</td>
<td>6.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3P$^1_1$</td>
<td>3P$^2_2$</td>
<td>23.60</td>
<td>62.44</td>
<td>370.37</td>
<td>720</td>
<td>150</td>
<td>75.</td>
<td>6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O I</td>
<td>3P$^0_2$</td>
<td>3P$^1_1$</td>
<td>0</td>
<td>227.71</td>
<td>63.185</td>
<td>$2.5 \times 10^5$</td>
<td>$4.9 \times 10^4$</td>
<td>1.8</td>
<td>$4.8 \times 10^4$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3P$^1_1$</td>
<td>3P$^0_0$</td>
<td>227.71</td>
<td>326.57</td>
<td>145.53</td>
<td>$2.4 \times 10^4$</td>
<td>$8.6 \times 10^3$</td>
<td>2.3</td>
<td>$4.8 \times 10^3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si II</td>
<td>2P$^{1/2}_1$</td>
<td>2P$^{3/2}_3/2$</td>
<td>0</td>
<td>413.28</td>
<td>34.814</td>
<td>$2.5 \times 10^5$</td>
<td>$1.2 \times 10^5$</td>
<td>140.</td>
<td>$1.5 \times 10^5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si I</td>
<td>3P$^0_0$</td>
<td>3P$^1_1$</td>
<td>0</td>
<td>110.95</td>
<td>129.68</td>
<td>$4.8 \times 10^4$</td>
<td>$2.8 \times 10^4$</td>
<td>2.9</td>
<td>$10^4$</td>
<td>830.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3P$^1_1$</td>
<td>3P$^2_2$</td>
<td>110.95</td>
<td>321.07</td>
<td>68.473</td>
<td>$9.9 \times 10^4$</td>
<td>$3.6 \times 10^4$</td>
<td>4.4</td>
<td>$10^4$</td>
<td>1.9</td>
<td>$10^4$</td>
</tr>
</tbody>
</table>

noted 2011.03.06

• §17.3. p. 195, footnote 3. typos:
  ... frequency $\sim 8 \times 10^{10}$ Hz... → ... frequency $\sim 1.1 \times 10^{10}$ Hz...
  ... $\sim 10^9$ precession periods. → ... $\sim 18$ precession periods.
noted 2020.10.02

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

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

noted 2010.11.27

• §17.7, p. 199, top line, typo: $n_{H, \text{crit}} \rightarrow n_{\text{crit}}(H)$
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 $y_0 = 4$
noted 2012.11.12 by A. Natta

• §18.4.1, p. 212: Replace wavelength in air with wavelength in vacuo:
  “Balmer jump” at $\lambda = 3645.1$ Å → “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 → $\lambda_{\text{BJ, red}} = 3682.1$ Å
noted 2011.03.11

• §18.5, p. 214, Eq. (18.11): Change
  ... $\Omega_{i3}$ is approximately independent of $T_e$, we have
  $$\frac{n(\text{O III})}{n(H^+)} = C \frac{I(\text{O III}5008)}{I(H\beta)} T_4^{-0.37} e^{2.917/T_4} ,$$
  to
  ... $\Omega_{i3} \propto T_4^{0.12}$ (see Appendix F), we have
  $$\frac{n(\text{O III})}{n(H^+)} = C \frac{I(\text{O III}5008)}{I(H\beta)} T_4^{-0.49} e^{2.917/T_4} ,$$

(18.11)
noted 2015.02.27

▪ §19.3, p. 222: revise value for $A_{10}$: replace
$A_{10} = 6.78 \times 10^{-8} s^{-1} \rightarrow A_{10} = 7.16 \times 10^{-8} s^{-1}$ (see Eq. 5.7).

noted 2013.04.17

▪ §19.3, p. 223: revised numbers according to revised value for $A_{10}$:

noted 2013.04.17

▪ §19.4, p. 224, typo: functon $\rightarrow$ function

noted 2011.03.11 by C. Petrovich

▪ §20.1, p. 229, typo just below Eq. (20.2): replace
...unit time that level $x$ will... $\rightarrow$ ...unit time the level $u$ will...

noted 2020.10.12 by Yan Liang

▪ §21.3, p. 242, typo: ...into the UV. whereas... $\rightarrow$ ...into the UV, whereas...

noted 2011.03.21

▪ §21.6.1, p. 244, typo: $k^2 = \epsilon_{ISM} \omega^2 c^2 \rightarrow k^2 = \epsilon_{ISM} \omega^2 / c^2$

noted 2011.03.28

▪ §21.6.1, p. 244, Eq. (21.12), typo:

\[
\begin{align*}
n_{gr} C_{ext}(\omega) &= 2\text{Im}(k) = 2\omega \text{Im}(\sqrt{\epsilon_{ISM}}) \approx \omega c \text{Im}(\epsilon_{ISM}) \\
&\rightarrow \\
n_{gr} C_{ext}(\omega) &= 2\text{Im}(k) = 2(\omega/c) \text{Im}(\sqrt{\epsilon_{ISM}}) \approx (\omega/c) \text{Im}(\epsilon_{ISM})
\end{align*}
\]

(21.12)

noted 2011.03.28

▪ §22.4.2, p. 252, Eq. (22.27), typo: $4\pi \rightarrow 9\pi$.

noted 2012.06.26

▪ §22.6, p. 256, footnote 6: the DDSCAT website has moved. Change

noted 2019.03.25

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

$\rightarrow$

larger oscillator strength $f(\text{C II}[2325 \text{Å}]) = 1.0 \times 10^{-7}$

noted 2012.12.27

▪ §23.1, p. 266, typo: $\text{Mg}_{2x}\text{Fe}_{2-2x}\text{SiO}_4 \rightarrow \text{Mg}_{2x}\text{Fe}_{2-2x}\text{SiO}_4$

noted 2011.03.24 by C. Petrovich

▪ §23.3.2, p. 268, typo: Si-O-Si bending mode $\rightarrow$ O-Si-O bending mode

noted 2020.10.12
• §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: totaly → 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, p. 308, Eq. (26.23), numerical error: should read

$$\frac{\omega}{2\pi} = 4.6 \text{ GHz} \left(\frac{T_{\text{rot}}}{100 \text{ K}}\right)^{1/2} \left(\frac{0.001 \mu \text{m}}{a}\right)^{5/2}$$

(26.23)

noted 2014.06.27 by B. Jiang.

• §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:

$$\mu = \frac{Q a^2 \omega}{3} \rightarrow \mu = \frac{Q a^2 \omega}{3c}$$

noted 2011.05.01 by P. Pattarakijwanich.

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

$$\Omega_L = \frac{5UB}{8\pi \rho a^2 c} = 3.7 \times 10^{-10} \left(\frac{3 \text{ g cm}^{-3}}{\rho}\right)\left(\frac{U}{\text{Volt}}\right)\left(\frac{B}{5 \mu \text{G}}\right)\left(\frac{0.1 \mu \text{m}}{a}\right)^2 \text{ s}^{-1}.$$  (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: $EM \approx 5 \times 10^6 \text{ cm}^{-3} \text{ pc} → EM \approx 5 \times 10^6 \text{ cm}^{-6} \text{ pc}$
  noted 2011.03.31 by C. Petrovich.

• §28.3, p. 328, 4th paragraph, typo: change distance from $\Theta_1$Ori C to the Orion Bar ionization front: $\sim 7.8 \times 10^{18} \text{ cm} → \sim 7.8 \times 10^{17} \text{ cm}$
  noted 2020.10.26

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

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

• §31.4, p. 349, Eq. (31.25), typo: $\tau_{1000} → \tau_{d,1000}$
  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: magnetic → magnetic
  noted 2011.04.11
• §32.9, p. 368, just before eq. (32.11), typo: change
  \[ A_V/N_H = 1.87 \times 10^{21} \text{ cm}^2 \rightarrow A_V/N_H = 5.3 \times 10^{-22} \text{ mag cm}^2. \]
  noted 2016.03.04 by Ilsang Yoon.

• §32.11, p. 372, prepenultimate paragraph: terminological correction. Change “core” to “clump” (three occurrences).
  noted 2015.04.16

• §33.1, p. 375, typo: photodisociation \( \rightarrow \) photodissociation
  noted 2011.04.11

• §33.1, p. 375, typo: occurring \( \rightarrow \) 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. 386, Eq. (34.10): sign mistake on RHS; change
  \[ -4\pi r^2 \kappa \frac{dT}{dr} \rightarrow 4\pi r^2 \kappa \frac{dT}{dr} \]
  noted 2019.04.18 by G. Halevi.

• §34.4, p. 387, typo: Eq. (34.17) is off by a factor 3, and should read
  \[ t_{\text{evap}} = \frac{3M}{2\dot{M}} = \frac{25 \times 2.3(n_{\text{H}},_c)R_c^2m_e^{1/2}e^4 \ln \Lambda}{8 \times 0.87(kT_h)^{2.5}} \]  \hspace{1cm} (34.17)
  Eq. (34.18) is numerically correct, but should have shown the dependence on \( \ln \Lambda \):
  \[ = 5.1 \times 10^4 \text{ yr} \left( \frac{n_{\text{H},_c}}{30 \text{ cm}^{-3}} \right) \left( \frac{R_c}{\text{ pc}} \right)^2 \left( \frac{T_h}{10^7 \text{ K}} \right)^{-2.5} \left( \frac{\ln \Lambda}{30} \right). \]  \hspace{1cm} (34.18)
  noted 2013.01.05 by B. Hensley.

• §35.3, p. 392, typo: rate-of-change v of... \( \rightarrow \) rate-of-change of v...
  noted 2011.04.14

• §36.1, p. 397, typo: occurring \( \rightarrow \) occurring
  noted 2011.04.26

• §36.2.2, p. 399, Eq. (36.8), two corrections: \( 8\pi \rightarrow 4\pi \) and \( B_xB_zv_x \rightarrow B_xB_zv_x. \) The equation should read
  \[ \frac{\partial}{\partial x} \left[ \frac{1}{2} \rho v_x v_x^2 + U v_x + \rho v_x v_x + \frac{(B_y^2 + B_z^2)}{4\pi} v_x - \frac{B_x B_y v_y}{4\pi} - \frac{B_x B_z v_z}{4\pi} \right] - \frac{\kappa}{d-x} + \rho v_x \Phi_{\text{grav}} = \Gamma - \Lambda. \]  \hspace{1cm} (36.8)
  noted 2011.04.19
• §36.2.3, p. 400, Eq. (36.10): $8\pi \to 4\pi$ (twice)
  noted 2011.04.19
  $v_x$ multiplying $B_yB_x$ should be $v_y$, and $v_x$ multiplying $B_zB_x$ should be $v_z$.
  noted 2015.12.17 by J. Miralda-Escudé.
  The equation should read
  \[
  \left\{ \frac{\rho v^2}{2} + \frac{\gamma p}{\gamma - 1} \right\} v_x + \frac{(B_y^2 + B_z^2)}{4\pi} v_x - \frac{(B_yB_yv_y + B_zB_zv_z)}{4\pi} - \kappa \frac{dT}{dx} \right\}_1 = \left\{ \frac{\rho v^2}{2} + \frac{\gamma p}{\gamma - 1} \right\} v_x + \frac{(B_y^2 + B_z^2)}{4\pi} v_x - \frac{(B_yB_yv_y + B_zB_zv_z)}{4\pi} - \kappa \frac{dT}{dx} \right\}_2. \tag{36.10}
  \]

• §36.2.5, p. 401, Eq. (36.16): $8\pi \to 4\pi$ (twice). The equation should read
  \[
  \frac{\rho_1 u_1^3}{2} + \gamma \frac{p_1}{\gamma - 1} + \frac{u_1 B_1^2}{4\pi} = \frac{\rho_2 u_2^3}{2} + \gamma \frac{p_2}{\gamma - 1} + \frac{u_2 B_2^2}{4\pi}, \tag{36.16}
  \]
  noted 2011.04.19

• §36.2.5, p. 401, Eq. (36.19): $8\pi \to 4\pi$ (twice). The equation should read
  \[
  \frac{1}{2} \rho_1 v_s^3 + \gamma \frac{p_1}{\gamma - 1} + \frac{B_1^2}{4\pi} v_s = \frac{1}{2} \rho_1 v_s^3 + \gamma \frac{p_2}{\gamma - 1} + \frac{B_2^2}{4\pi} v_s. \tag{1}
  \]
  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.

• §37.1, p. 413, 2nd paragraph: Change
  Cases of astrophysical interest will normally have...
  $\rightarrow$
  Many cases of astrophysical interest will have...
  noted 2018.04.09.

• §37.1, p. 413, typo just above Eq. (37.3):
  \[
  Jh\nu/c = \rho_1 u_1 h\nu/\mu c \ll \rho_1 (u_1^2 + c_1^2 + B_1^2)/8\pi).
  \]
  $\rightarrow$
  \[
  Jh\nu/c = \rho_1 u_1 h\nu/\mu c \ll \rho_1 (u_1^2 + c_1^2) + B_1^2/8\pi.
  \]
  noted 2016.12.08 by Ryohei Nakatani.
• §37.1, Eq. (37.8): The correction terms for \( u_R \), \( x_R \), \( u_D \), and \( x_D \) can be improved by analyzing the full cubic equation (37.3): change

\[
\begin{align*}
  u_R &\approx 2c_2 \quad \rightarrow \quad u_R \approx 2c_2 \left[ 1 - \frac{2c_1^2 - 3v_{A1}}{8c_2^2} \right] \\
  x_R &\approx \frac{1}{2} + \frac{2c_1^2 + v_{A1}^2}{16c_2^2} \quad \rightarrow \quad x_R \approx \frac{1}{2} \\
  u_D &\approx \frac{2c_1^2 + v_{A1}^2}{4c_2} \quad \rightarrow \quad u_D \approx \frac{2c_1^2 + v_{A1}^2}{4c_2} \left[ 1 + \frac{2c_1^2 + v_{A1}^2}{8c_2^2} \right] \\
  x_D &\approx \frac{4c_2^2}{2c_1^2 + v_{A1}^2} \quad \rightarrow \quad x_D \approx \frac{4c_2^2}{2c_1^2 + v_{A1}^2} \left[ 1 - \frac{c_1^2}{8c_2^2} \right]
\end{align*}
\]

noted 2018.02.19 by Woong-Tae Kim.

• §37.1 and §37.2, pp. 414-416: the mathematics is correct, but the “weak-type”, and “strong-type” terminology was unfortunately inverted: all occurrences of “weak-type” should be changed to “strong-type”, and vice-versa:
• §37.1.1, p. 414, first paragraph:
  ...are called strong R-type. Strong R-type solutions...
  \rightarrow
  ...are called weak R-type. Weak R-type solutions...
• §37.1.1, p. 414, second paragraph:
  ...referred to as weak R-type,... \rightarrow ...referred to as strong R-type,...
• §37.1.1, p. 414, second paragraph:
  Hence, only strong R-type I-fronts are physically relevant.
  \rightarrow
  Hence, only weak R-type I-fronts are physically relevant.
• §37.1.2, p. 414, first paragraph:
  ...is termed weak D-type. \rightarrow ...is termed strong D-type.
• §37.1.2, p. 414, second paragraph:
  ...is termed strong D-type. \rightarrow ...is termed weak D-type.
• Fig. 37.1 and caption should be:
Figure 37.1 $u_2/u_1 = \rho_1/\rho_2$, as a function of the velocity $u_1$ of the I-front relative to the neutral gas just ahead of the I-front, for D-type and R-type ionization front solutions (see text) for an example with $c_1 = 1 \text{ km s}^{-1}$, $v_{A1} = 2 \text{ km s}^{-1}$, and $c_2 = 11.4 \text{ km s}^{-1}$. The astrophysically relevant solutions are the strong D-type and weak R-type cases, shown as heavy curves. There are no solutions with $u_1$ between $u_D$ and $u_R$.

- §37.1, p. 416, first paragraph:
  ...

- §37.1, p. 417, fourth line:
  ...

noted 2016.12.06 by Ryohei Nakatani.

- §37.2, p. 418, typos:
  ...

noted 2016.12.08 by Ryohei Nakatani.

- §38.3, p. 428, last paragraph, typo:
  $\dot{M}_w \approx 2 \times 10^{-5} \text{ km s}^{-1} \rightarrow \dot{M}_w \approx 2 \times 10^{-5} \text{ M}_\odot \text{ yr}^{-1}$

noted 2015.12.17 by J. Miralda-Escudé.

- §39.1.1, p. 430, typo: case of Type II supernova → case of Type II supernovae

noted 2011.04.21
• §39.1.1, p. 430, typo: relative dense → relatively dense
  noted 2011.04.21

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

• §39.1.2, p. 433, Eqs. (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

\[
\begin{align*}
v_s(t_{\text{rad}}) &= 188 \text{ km s}^{-1} (E_{51}n_0^2)^{0.07}, \\
T_s(t_{\text{rad}}) &= 4.86 \times 10^5 \text{ K} (E_{51}n_0^2)^{0.13}, \\
kT_s(t_{\text{rad}}) &= 41 \text{ eV} (E_{51}n_0^2)^{0.13}.
\end{align*}
\]

(39.22) (39.23) (39.24)

noted 2012.10.02 by G.B. Field.

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

• §39.4, p. 438, Eqs. (39.35) and (39.36), typos: they should read

\[
\begin{align*}
N_{\text{SN}} &= 0.24 S_{-13} E_{51}^{1.26} n_0^{-1.47} c_{s,6}^{-13/5} \\
&= 0.48 S_{-13} E_{51}^{1.26} n_0^{-0.17} p_4^{-1.30}, \\
p_4 &= \frac{p/k}{10^4 \text{ cm}^{-3} \text{ K}}
\end{align*}
\]

(39.35) (39.36)

noted 2014.06.27 by B. Jiang.

• §39.4, p. 438, Eq. (39.37), typos: Eq. (39.37) should read

\[
\begin{align*}
\frac{p}{k} &= S_{-13} E_{51}^{0.97} n_0^{-0.13} \times 5700 \text{ cm}^{-3} \text{ K}
\end{align*}
\]

(39.37)

noted 2014.06.27 by B. Jiang.

• §39.4, p. 439, typo: neighborhood → neighborhood
  noted 2011.04.14

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

• §40.5, p. 447, typo: protons with \( E \lesssim 10^5 \text{ GeV} \) have \( R_{\text{gyro}} < 10^{-4} \text{ pc} \) →
  protons with \( E \lesssim 10^3 \text{ GeV} \) have \( R_{\text{gyro}} < 10^{-4} \text{ pc} \)
  noted 2011.04.26

• §40.9, p. 450, typo: \( e^+ H \rightarrow H^++2\gamma \) → \( e^+ + H \rightarrow H^+ + 2\gamma \)
  noted 2011.04.27
• §41.3, p. 456, typo: missing factor of $G$. Eq. (41.36) should read
\[ E_{\text{grav}} = -\frac{G}{2} \int dV_1 \int dV_2 \frac{\rho(r_1)\rho(r_2)}{|r_1 - r_2|} \] 

(41.36)

noted 2015.04.30 by J. Greco.

• §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: $\langle \sigma v \rangle \rightarrow \langle \sigma v \rangle_{\text{nt}}$

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: $\langle \sigma v \rangle \rightarrow \langle \sigma v \rangle_{\text{nt}}$

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: magnetic $\rightarrow$ 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: $d_{\text{sk}} \rightarrow$ 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 $\equiv \hbar^2/m_e e^2 = ...$

noted 2013.03.05 by Wenhua Ju.
Appendix A, p. 475: entry for RM should read
RM ... see Eq. (11.23)
noted 2011.01.05

Appendix B, p. 476: typo: incorrect units for Stefan-Boltzmann constant \(\sigma\):
\[
5.67040 \times 10^{-5} \text{erg s}^{-1} \text{cm}^{-3} \text{K}^{-4} \rightarrow 5.67040 \times 10^{-5} \text{erg s}^{-1} \text{cm}^{-2} \text{K}^{-4}
\]
noted 2019.05.14 by Aaron Tran.

Appendix D, p. 481: corrected typos:
F VI \(\rightarrow\) VII: \( I = 147.163 \rightarrow 157.163 \)
Ne VI \(\rightarrow\) VII: \( I = 154.214 \rightarrow 157.934 \)
Ti III \(\rightarrow\) IV: \( I = 24.492 \rightarrow 27.492 \)
Ti V \(\rightarrow\) VI: \( I = 123.7 \rightarrow 99.299 \)
Zn VI \(\rightarrow\) VII: \( I = 133.903 \rightarrow 108.0 \)
noted 2015.07.10 by Guangtun Ben Zhu.

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 \(J = 3/2\) (not \(J = 1/2\)).
noted 2012.01.29 by E.B. Jenkins.

Appendix E, p. 495: \(^2\text{D}_{3/2,1/2}\) energy levels were misplotted for S II and Ar IV.
noted 2013.10.21 by Bon-Chul Koo.
Corrected figure [Opportunity taken to update energy Ar IV energy levels]
using latest values from NIST Atomic Spectra Database (ver. 5.1 [Online]):

- Appendix F, Table F.2, p. 497, typo: the first transition listed for S III: change $^3P_0 \rightarrow ^3P_0$ to $^3P_0 \rightarrow ^3P_1$.
- Appendix F, Table F.3, p. 498: updated electron collision strengths for O I:

<table>
<thead>
<tr>
<th>Ion</th>
<th>$\ell - u$</th>
<th>$\Omega_{u\ell}$</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>O I</td>
<td>$^3P_2 \rightarrow ^3P_1$</td>
<td>$0.0105 T_4^{0.4861+0.0054 \ln T_4}$</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>$^3P_2 \rightarrow ^3P_0$</td>
<td>$0.00459 T_4^{0.4507-0.0066 \ln T_4}$</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>$^3P_1 \rightarrow ^3P_0$</td>
<td>$0.00015 T_4^{0.4709-0.1396 \ln T_4}$</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>$^3P_1 \rightarrow ^1D_2$</td>
<td>$0.0312(2J+1) T_4^{0.945-0.001 \ln T_4}$</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>$^3P_1 \rightarrow ^1S_0$</td>
<td>$0.00353(2J+1) T_4^{0.000-0.135 \ln T_4}$</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>$^1D_2 \rightarrow ^1S_0$</td>
<td>$0.0893 T_4^{0.662-0.089 \ln T_4}$</td>
<td>b</td>
</tr>
</tbody>
</table>

- Appendix F, Table F.6, p. 501: The table title should be “Rate Coefficients for ... Deexcitation...” rather than “... Excitation...”.
- Appendix F, Table F.6, p. 501: incorrect powers of 10 in lines 5 and 6: $k_{u\ell}$ for $\ell - u = ^3P_0 \rightarrow ^3P_1$ should read $1.26 \times 10^{-10} T_2^{0.115+0.057 \ln T_2}$.
$k_{\ell-u} = ^3P_0-^3P_2$ should read $2.64 \times 10^{-10} T_2^{0.231+0.046 \ln T_2}$

NB!: See also erratum below on inadvertent interchange of $^3P_0-^3P_2$ and $^3P_1-^3P_2$ deexcitation rates.

noted 2012.05.02 by M.J. Wolfire

- Appendix F, Table F.6, p. 501: the rates for entries 5 and 6 should be interchanged, so that entries 4-6 read

<table>
<thead>
<tr>
<th>Entry</th>
<th>Species</th>
<th>Reaction</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>H</td>
<td>$^3P_0 - ^3P_1$</td>
<td>$1.26 \times 10^{-10} T_2^{0.115+0.057 \ln T_2}$</td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>$^3P_0 - ^3P_2$</td>
<td>$2.64 \times 10^{-10} T_2^{231+0.046 \ln T_2}$</td>
</tr>
<tr>
<td>6</td>
<td>H</td>
<td>$^3P_1 - ^3P_2$</td>
<td>$3.64 \times 10^{-10} T_2^{231+0.046 \ln T_2}$</td>
</tr>
</tbody>
</table>

noted 2015.07.03 by Munan Gong.

- Appendix F, Table F.6, p. 501: the rates for entries 23-28 should be changed to

<table>
<thead>
<tr>
<th>Entry</th>
<th>Species</th>
<th>Reaction</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>H$_2$</td>
<td>$^3P_1 - ^3P_0$</td>
<td>$2.49 \times 10^{-10} T_2^{31.56} Z/T_4$</td>
</tr>
<tr>
<td>24</td>
<td>H$_2$</td>
<td>$^3P_1 - ^3P_0$</td>
<td>$2.49 \times 10^{-10} T_2^{31.56} Z/T_4$</td>
</tr>
</tbody>
</table>

noted 2019.01.14.

- Appendix I, p. 507, typo in line 3:

$$... + \int dV \frac{\partial}{\partial j} (v_j \rho v_i x_i) \rightarrow ... + \int dV \frac{\partial}{\partial x_j} (v_j \rho v_i x_i)$$

noted 2011.02.14 by Xu Huang.
• Appendix J, p. 510, Eq. (J.8): missing sign:

\[ Y_3 = E_{grav} = \frac{1}{2} \int dV_1 \int dV_2 \ G \frac{\rho(r_1)\rho(r_2)}{|r_1 - r_2|} \]

→

\[ Y_3 = E_{grav} = -\frac{1}{2} \int dV_1 \int dV_2 \ G \frac{\rho(r_1)\rho(r_2)}{|r_1 - r_2|} \]

noted 2020.11.13

• Appendix J, p. 510, Eq. (J.13), typo:

\[ \Pi_0 \equiv \oint dS \cdot rp \quad \rightarrow \quad \Pi_0 \equiv \frac{1}{3} \oint dS \cdot rp \]

noted 2017.03.08.