Trienamines in Asymmetric Organocatalysis: Diels-Alder and Tandem Reactions

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Supporting Information

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1. General methods

NMR data were obtained for ^{1}H at 400 MHz, and for ^{13}C at 100 MHz. Chemical shifts were reported in ppm from tetramethylsilane with the solvent resonance as the internal standard in $CDCl_3$ solution. ESI-HRMS was recorded on a Bruker Apex-2. In each case, enantiomeric excess was determined by HPLC analysis on Chiralpak AS, IC, AD and Chiralcel OD columns in comparison with authentic racemic samples. UV detection was monitored at 220 nm or 254 nm. Optical rotation data were examined at 589 nm in $CHCl_3$ or MeOH solution at 20 ºC. Flash chromatography (FC) was performed on silica gel (200-300 mesh) eluting with EtOAc and petroleum ether. TLC was performed on glass-backed silica plates. UV light, K_2MnO_4 and I_2 stains were used to visualize products. All commercially available solvents and reagents were, unless otherwise stated, used as received without further purification. The substrates of 3-substituted oxindoles were prepared from the corresponding isatins (Wittig/N-Boc protection sequence) according to the procedures previously reported.[1] The secondary amine catalysts,[2] ethyl 2-(diethoxyphosphoryl)acrylate[3] and α-cyanoacrylates dienophiles[4] were also synthesized according to the literature procedures.

1. (a) Chen, Z.; Fan, J.; Kende, A. S. *J. Org. Chem*. **2004**, *69*, 79. (b) Petrounia, I. P.; Goldberg, J.; Brush, E. J. *Biochemistry* **1994**, *33*, 2891. (c) Ishimaru, T.; Shibata, N.; Nagai, J.; Nakamura, S.; Toru, T.; Kanemasa, S. *J. Am. Chem. Soc.* **2006**, *128*, 16488.

2. (a) Marigo, M.; Wabnitz, T. C.; Fielenbach, D.; Jørgensen, K. A. *Angew. Chem. Int. Ed.* **2005**, *44*, 794. (b) Liu, Y.-K.; Ma, C.; Jiang, K.; Liu, T.-Y.; Chen, Y.-C. *Org. Lett.* **2009**, *11*, 2848.

3. Semmelhack, M. F.; Tomesch, J. C.; Czarny, M.; Boettger, S. *J. Org. Chem*. **1974**, *43*, 1259.

4. Jadav, S. J.; Reddy, B. S. S.; Basak, A. K.; Visali, B.; Narsaiah, A. V.; Nagaiah, K. *Eur. J. Org. Chem.* **2004**, 546.

2. NMR investigations

NMR samples were prepared by mixing the dienal **1a** (0.1 mmol) with appropriate amounts of the amine **2a** and *o*-fluorobenzoic acid (OFBA) in $CDCl_3$ (see Table 1). At given times, ^1H and ^{13}C NMR spectra of the mixtures were recorded. The ratios of **1a** and **3** were determined by comparison of signals corresponding to the terminal CH_3-groups. We need to define TFB (internal standard) in the procedure (1,3,5-tris(trifluoromethyl)benzene) having a ^1H chemical shift of 8.1 ppm. The chemical shifts for the interesting protons and carbons are for:

heptadienal (**1a**):

C*H*O = 9.59 (d, *J* = 8.0 Hz) and 9.52 (d, *J* = 8.0 Hz),

CH_2CH_3 = 1.07 (t, *J* = 7.5 Hz),

CH_2CH_3 = 12.7,

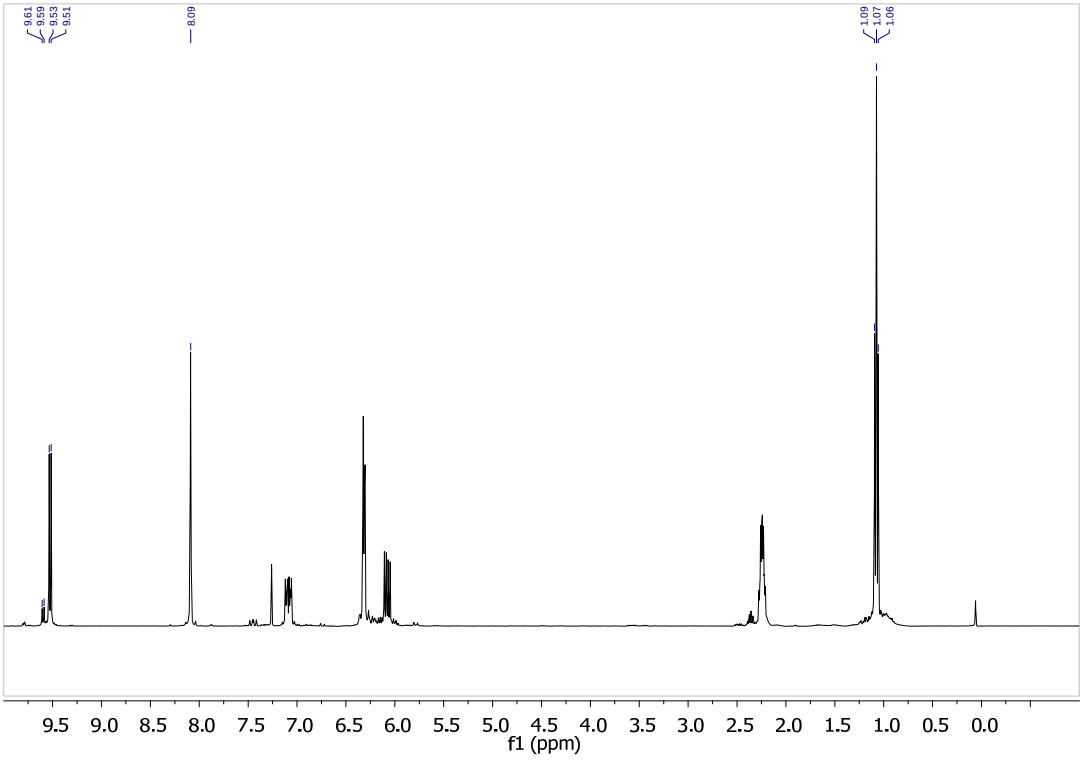
CH_2CH_3 = 26.2,

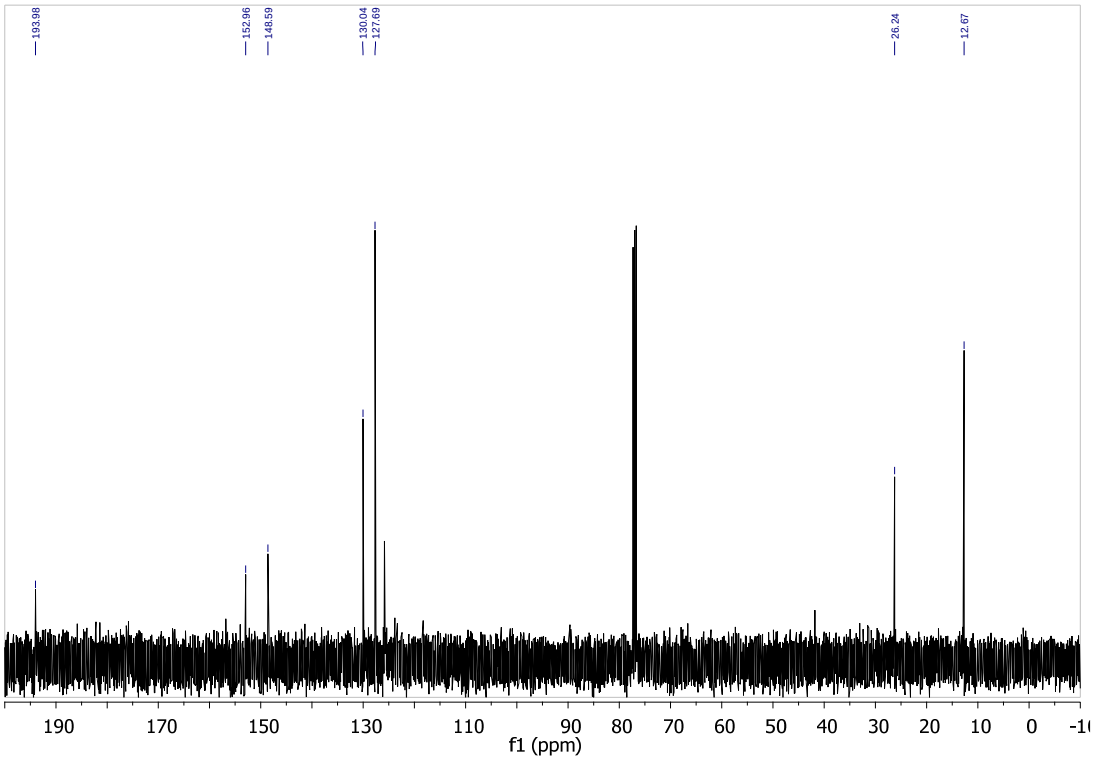
and for the corresponding trienamine (**3**):

CH=CHCH_3 = 1.71 (d, *J* = 7.0 Hz),

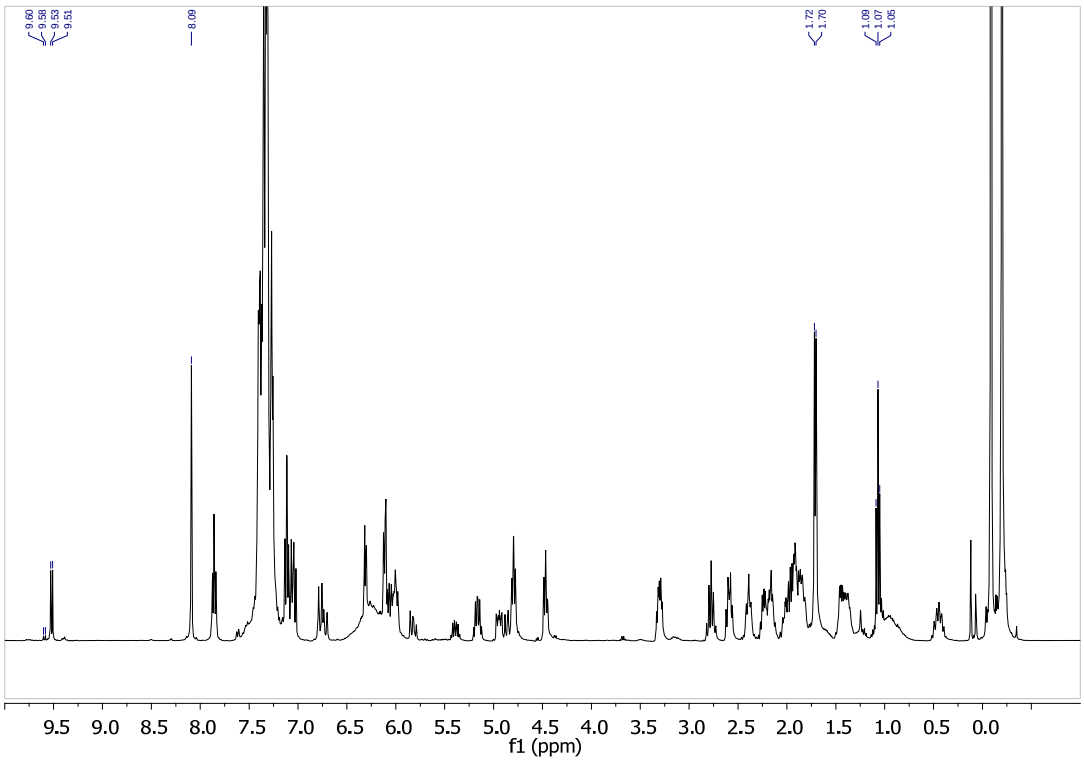
CH=CHCH_3 = 18.1

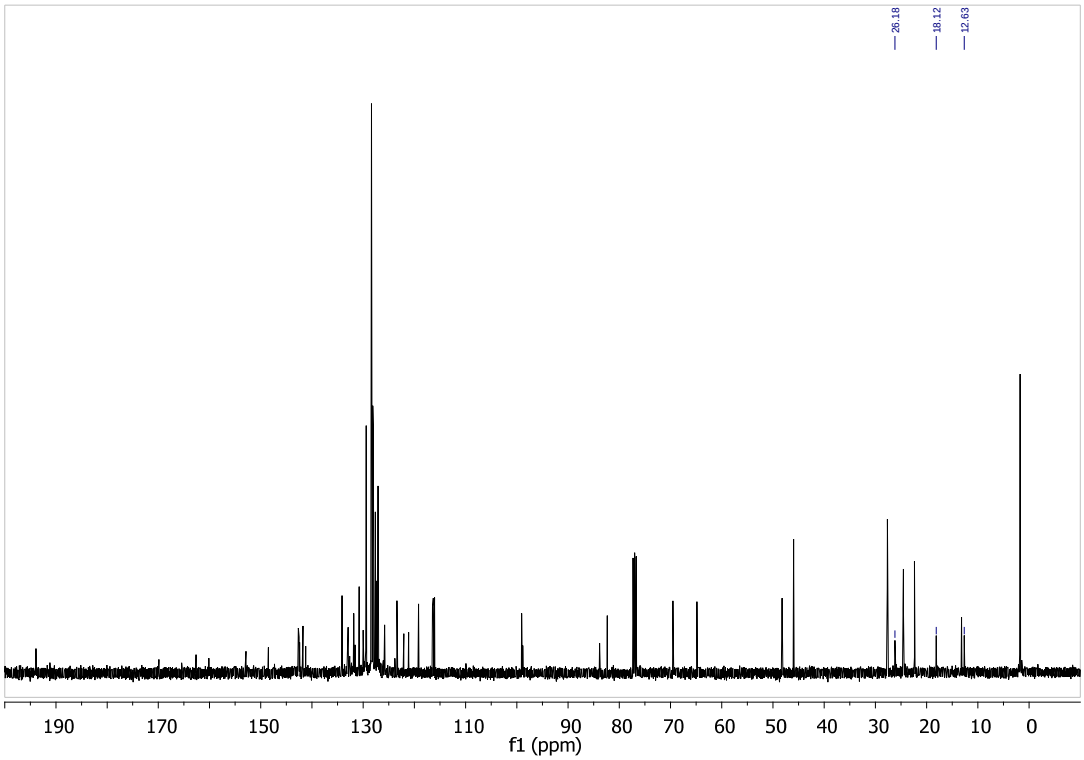
2,4-Heptadienal (1 equiv.), TFB (0.3 equiv.)



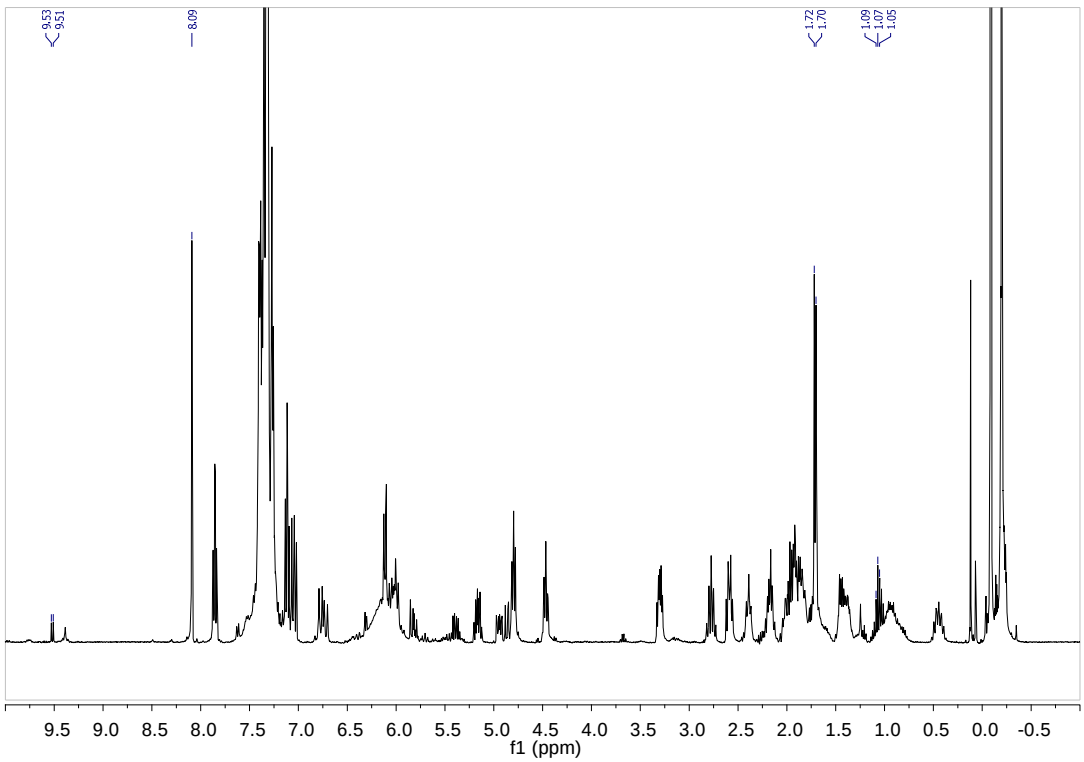


2,4-Heptadienal (1 equiv.), TFB (0.3 equiv.), **2a** (1 equiv.), OFBA (0.5 equiv.) in $CDCl_3$ (0.5 mL)after 1h

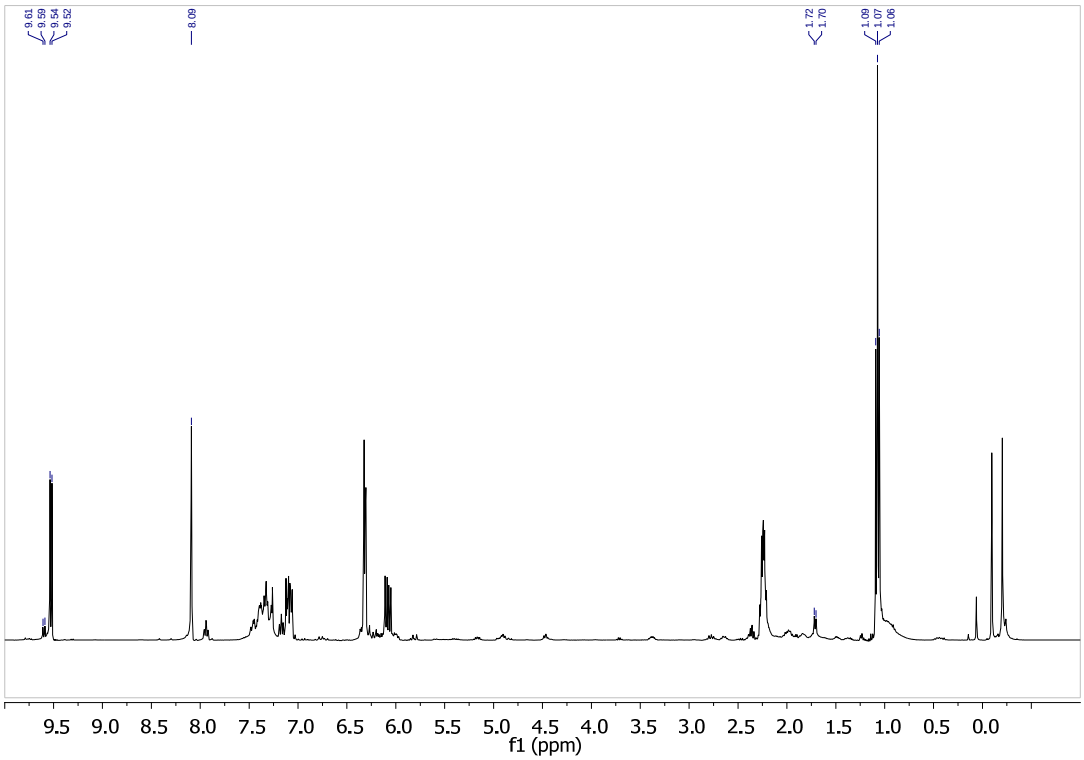




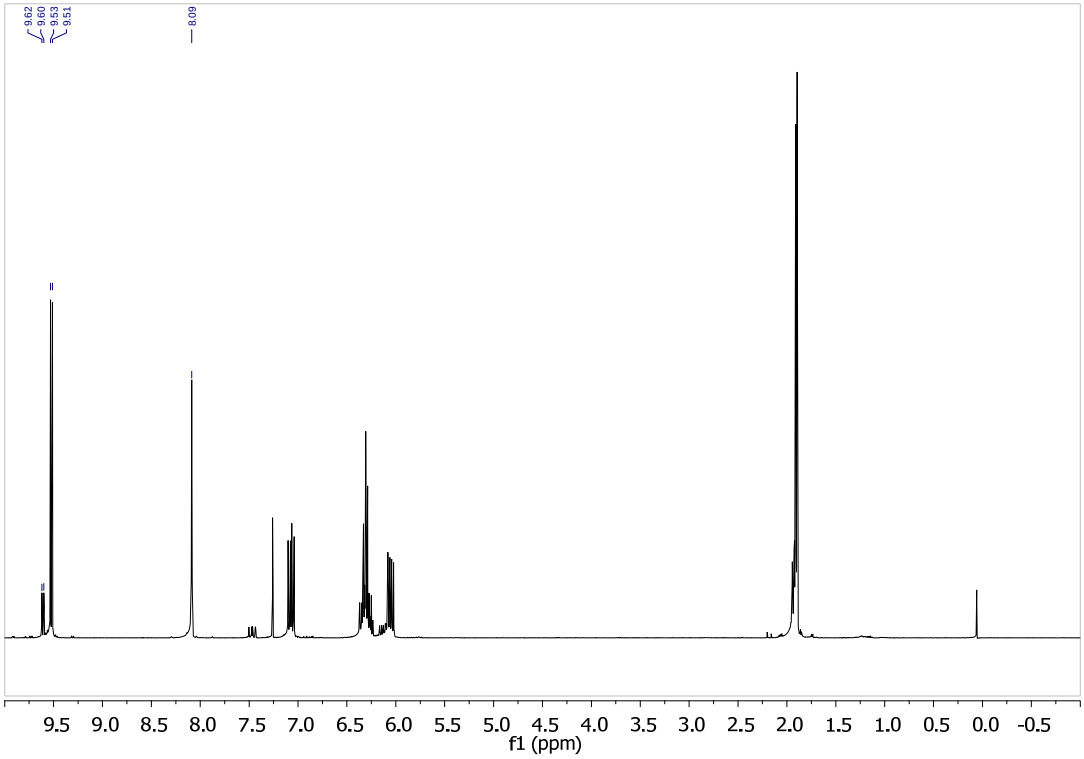
2,4-Heptadienal (1 equiv.), TFB (0.3 equiv.), **2a** (1 equiv.), OFBA (0.5 equiv.) in $CDCl_3$ (0.5 mL) after 6h

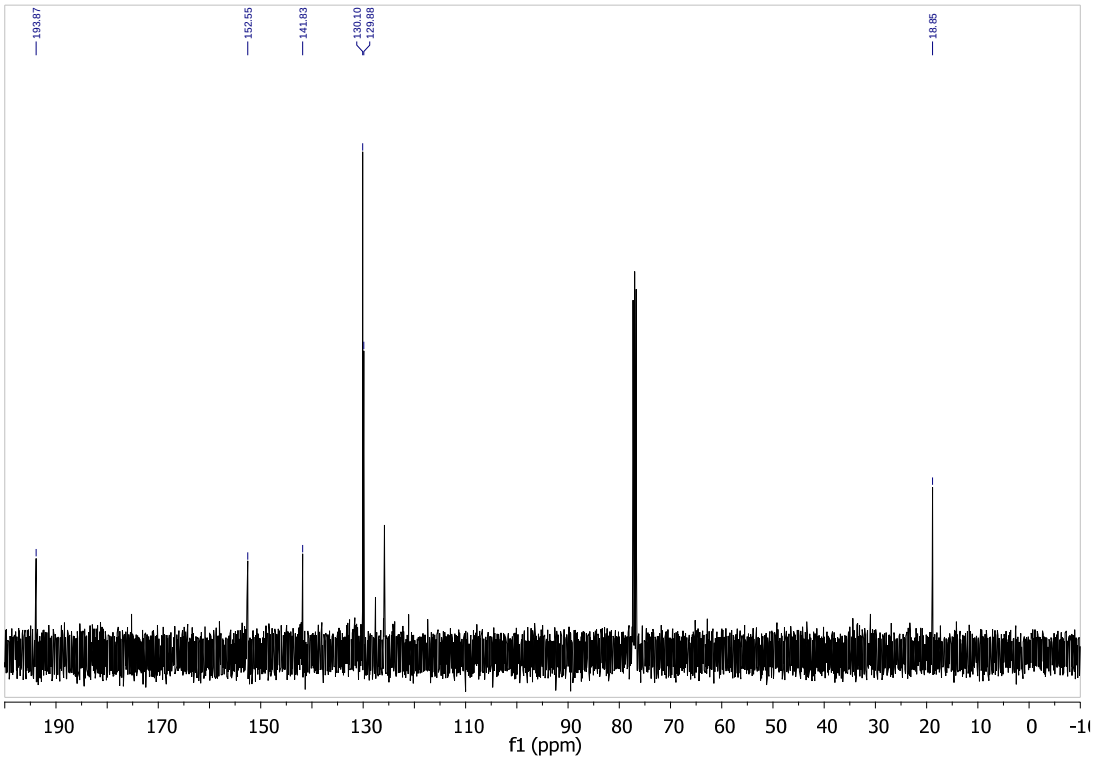


2,4-Heptadienal (1 equiv.), TFB (0.3 equiv.), **2a** (0.1 equiv.), OFBA (0.1 equiv.) in $CDCl_3$ (0.5 mL)after 1h

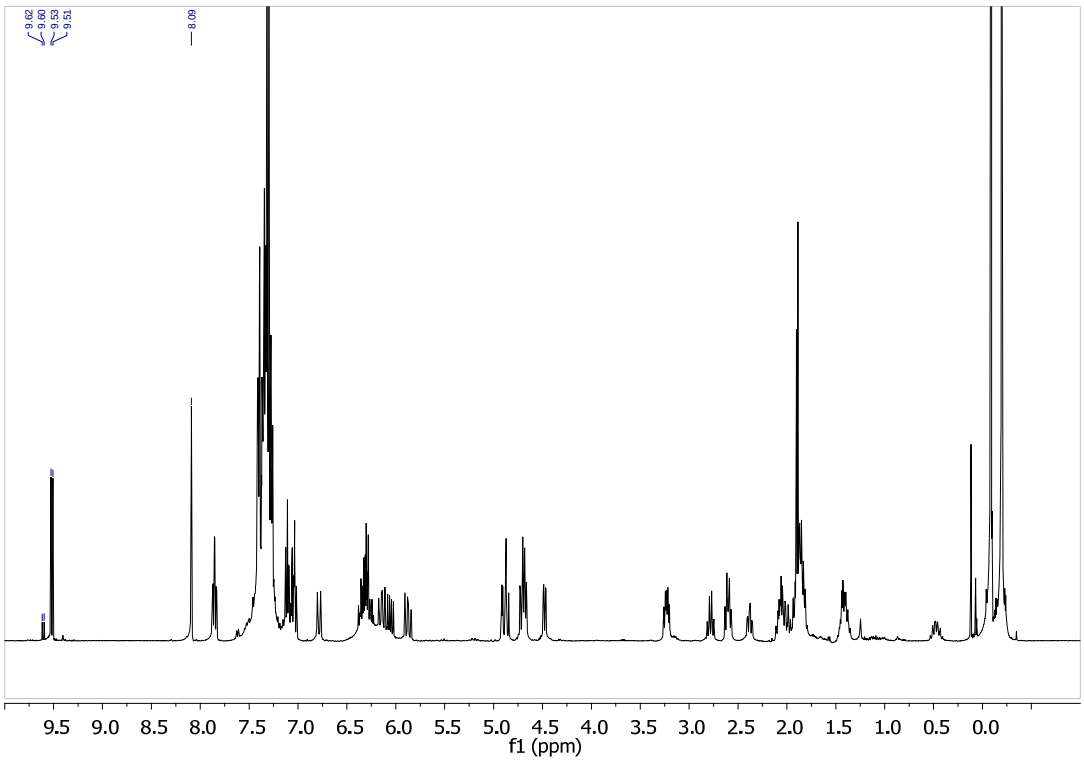


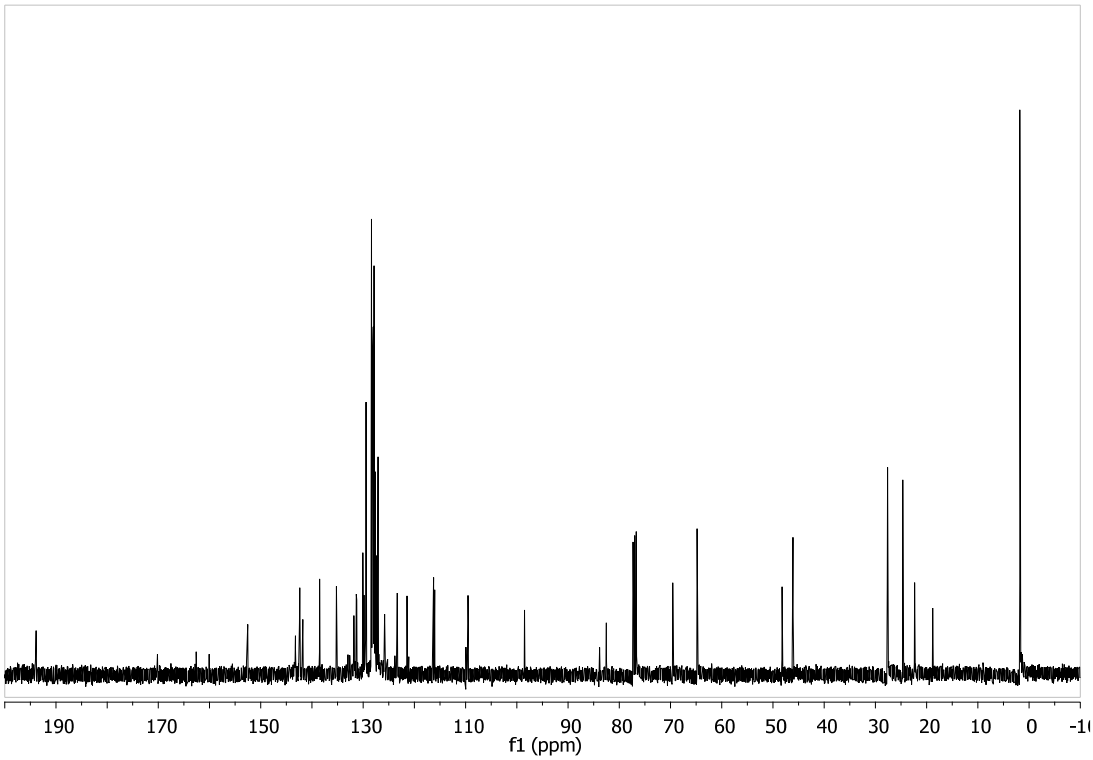
2,4-Hexadienal (1 equiv.), TFB (0.3 equiv.)



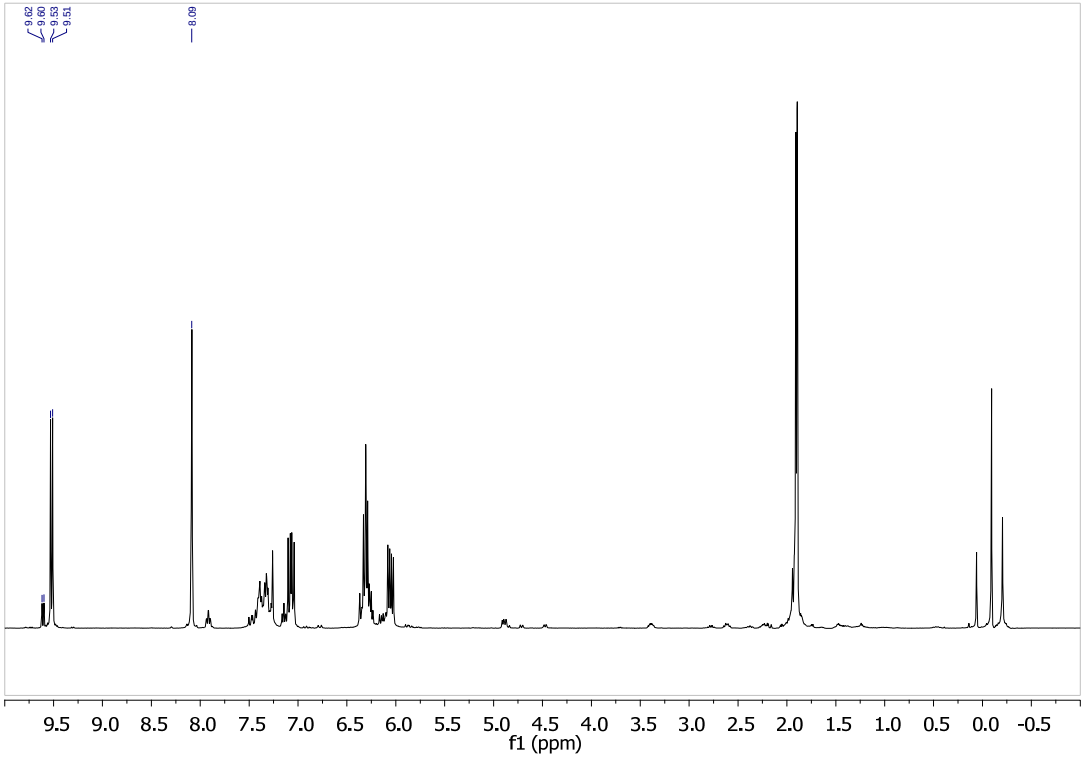


2,4-Hexadienal (1 equiv.), TFB (0.3 equiv.), **X** (1 equiv.), OFB (0.5 equiv.) in $CDCl_3$ (0.5 mL)after 1h





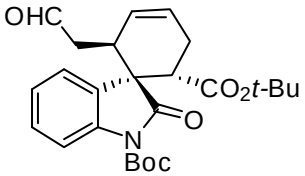
2,4-Hexadienal (1 equiv.), TFB (0.3 equiv.), **X** (0.1 equiv.), OFB (0.1 equiv.) in $CDCl_3$ (0.5 mL)after 1h



3. General procedure for the Diels-Alder reaction of 2,4-dienals

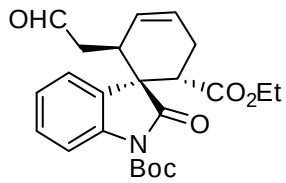
Procedure A: The reactions were performed with **1** (0.15 mmol), **4** (0.1 mmol), **2b** (0.02 mmol) and OFBA (0.02 mmol) in $CHCl_3$ (1 mL) at room temperature for the specified reaction time. After the reaction was finished, the mixture was concentrated and the residue was purified by FC on silica gel (petroleum ether/ EtOAc) to afford the Diels-Alder adducts **5a-f** and **5l-p**.

Procedure B: The reactions were performed with **1b** (0.2 mmol), **4** (0.1 mmol), **2b** (0.02 mmol) and OFBA (0.02 mmol) in $CHCl_3$ (0.5 mL) at 50 °C for the specified reaction time. After the reaction was finished, the mixture was concentrated and the residue was purified by FC on silica gel (petroleum ether/ EtOAc) to afford the Diels-Alder adducts **5g-k**.

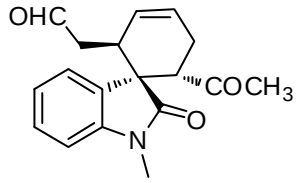


5a, 6 h ; 98% yield; $[\alpha]_D^{20}$ = +14.1 (*c* = 1.85 in $CHCl_3$); 98% ee, determined by HPLC analysis after **5a** was converted to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2tBu$ in THF, 25 °C) [Daicel Chiralpak IC, *n*-hexane/ *i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 12.30 min, t (minor) = 14.29 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.68 (s, 1H), 7.88 (d, *J* = 8.0 Hz, 1H), 7.32-7.22 (m, 2H), 7.09-7.05 (m, 1H), 5.99-5.97 (m, 1H), 5.75-5.71 (m, 1H), 3.28-3.17 (m, 2H), 2.95-2.92 (m, 1H), 2.75-2.56 (m, 2H), 2.39 (dd, *J* = 18.4, 5.2 Hz, 1H), 1.63 (s, 9H), 1.15 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.5, 177.1, 170.9, 149.1, 139.2, 131.4, 128.1, 128.0, 126.1, 124.1, 123.6, 114.7, 83.9, 81.7, 49.3, 45.7, 41.5, 37.5, 28.0, 27.4, 25.4 ppm; ESI-HRMS: calcd. for $C_{25}H_{31}NO_6$+H 442.2230, found 442.2231.

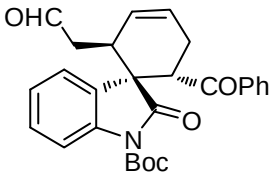
Preparative scale (l.5 mmol) catalyzed by 10 mol% of **2b** in the presence of 10 mol% OFBA for 20 h.



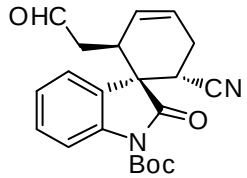
5b, 4 h; 92% yield; $[\alpha]_D^{20}$ = +28.5 (*c* = 1.35 in MeOH); 98% ee, determined by HPLC analysis after **5b** was converted to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2tBu$ in THF, 25 °C) [Daicel Chiralpak AD, *n*-hexane/ *i*-PrOH = 95:5, 1.0 mL/min, λ = 254 nm, t (major) = 7.79 min, t (minor) = 6.21 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.68 (s, 1H), 7.88 (d, *J* = 8.0 Hz, 1H), 7.32-7.22 (m, 2H), 7.08-7.04 (m, 1H), 5.99-5.97 (m, 1H), 5.77-5.73 (m, 1H), 3.93 (q, *J* = 7.2 Hz, 2H), 3.30-3.21 (m, 2H), 2.98-2.96 (m, 1H), 2.84-2.76 (m, 1H), 2.61-2.53 (m, 1H), 2.41 (dd, *J* = 18.4, 4.8 Hz, 1H), 1.63 (s, 9H), 1.04 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.5, 177.4, 171.8, 149.0, 139.4, 131.2, 128.4, 128.2, 125.9, 124.1, 123.5, 114.8, 84.0, 60.9, 49.1, 45.6, 41.3, 37.4, 28.0, 25.6, 13.7 ppm; ESI-HRMS: calcd. for $C_{23}H_{27}NO_6$+Na 436.1736, found 436.1731.



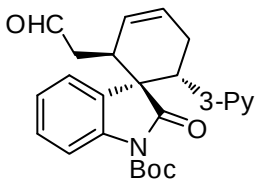
5c, 4 h; 99% yield; $[\alpha]_D^{20}$ = +24.8 (*c* = 1.95 in MeOH); 97% ee, determined by HPLC analysis after **5c** was converted to the corresponding α,β-unsaturated ester (Ph_3P=$CHCO_2$*t*Bu in THF, 25 °C) [Daicel Chiralpak AD, *n*-hexane/ *i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 16.76 min, t (minor) = 22.38 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.67 (s, 1H), 7.29-7.25 (m, 1H), 7.17 (d, *J* = 7.6 Hz, 1H), 6.97-6.93 (m, 1H), 6.88 (d, *J* = 8.0 Hz, 1H), 6.01-5.98 (m, 1H), 5.81-5.77 (m, 1H), 3.34-3.26 (m, 2H), 3.18 (s, 3H), 2.88-2.86 (m, 1H), 2.79-2.72 (m, 1H), 2.51-2.43 (m, 1H), 2.36 (dd, *J* = 18.4, 4.8 Hz, 1H), 2.05 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 207.2, 199.7, 178.7, 143.5, 132.5, 129.6, 127.9, 125.6, 123.6, 122.2, 108.2, 48.6, 48.5, 45.3, 37.2, 28.7, 26.3, 25.5 ppm; ESI-HRMS: calcd. for $C_{18}H_{19}NO_3$+H 298.1443, found 298.1447.



5d, 3 h; 97% yield; $[\alpha]_D^{20}$ = +24.3 (*c* = 2.25 in $CHCl_3$); 98% ee, determined by HPLC analysis after **5d** was converted to the corresponding α,β-unsaturated ester (Ph_3P=$CHCO_2$*t*Bu in THF, 25 °C) [Daicel Chiralpak AD, *n*-hexane/*i*-PrOH = 95:5, 1.0 mL/min, λ = 254 nm, t (major) = 10.35 min, t (minor) = 11.89 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.70 (s, 1H), 7.96 (d, *J* = 8.0 Hz, 1H), 7.80-7.78 (m, 2H), 7.54-7.50 (m, 1H), 7.43-7.39 (m, 2H), 7.34-7.30 (m, 1H), 7.23-7.22 (m, 1H), 7.08-7.04 (m, 1H), 6.00-5.98 (m, 1H), 5.83-5.80 (m, 1H), 4.17 (dd, *J* = 11.2, 6.0 Hz, 1H), 3.24 (dd, *J* = 18.4, 8.0 Hz, 1H), 3.11-3.09 (m, 1H), 2.83-2.77 (m, 1H), 2.55-2.42 (m, 2H), 1.60 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.0, 199.4, 177.5, 149.0, 139.3, 136.1, 133.1, 132.0, 129.0, 128.6, 128.4, 128.0, 126.0, 124.1, 123.4, 114.9, 84.0, 49.6, 45.4, 44.5, 37.9, 28.0, 27.2 ppm; ESI-HRMS: calcd. for $C_{27}H_{27}NO_5$+Na 468.1787, found 468.1785.
Preparative scale (l.5 mmol) catalyzed by 10 mol% of **2b** in the presence of 10 mol% OFBA for 6 h.

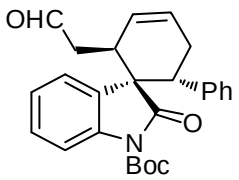


5e, 4 h; 90% yield; $[\alpha]_D^{20}$ = +86.5 (*c* = 2.35 in $CHCl_3$); 98% ee, determined by HPLC analysis after **5e** was converted to the corresponding α,β-unsaturated ester (Ph_3P=$CHCO_2$*t*Bu in THF, 25 °C) [Daicel Chiralcel OD, *n*-hexane/*i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 9.40 min, t (minor) = 11.53 min]; dr 93:7, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.61 (s, 1H), 7.87 (d, *J* = 8.0 Hz, 1H), 7.55 (d, *J* = 7.6 Hz, 1H), 7.42-7.38 (m, 1H), 7.23-7.20 (m, 1H), 5.95-5.91 (m, 1H), 5.77-5.73 (m, 1H), 3.42-3.34 (m, 1H), 3.14-3.11 (m, 1H), 2.95-2.87 (m, 1H), 2.63-2.41 (m, 3H), 1.63 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.0, 173.8, 148.6, 139.3, 129.8, 127.7, 127.6, 125.1, 124.0, 122.0, 119.0, 115.1, 85.1, 48.9, 44.0, 37.2, 31.3, 28.1, 25.8 ppm; ESI-HRMS: calcd. for $C_{21}H_{22}N_2O_4$+Na 389.1477, found 389.1475.

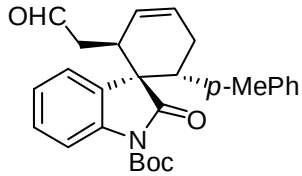


5f, 10 h, 96% yield; $[\alpha]_D^{20}$ = -23.8 (*c* = 1.25 in $CHCl_3$); 97% ee, determined by HPLC analysis after **5f** was converted to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2C_2H_5$ in THF, 40 °C) [Daicel Chiralpak AS, *n*-hexane/*i*-PrOH = 90:10, 1.0 mL/min, λ = 254 nm, t (major) = 7.65 min, t (minor) = 9.17 min]; dr 85:15, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.74 (s, 1H), 8.38-8.36 (m, 1H), 8.02-8.01 (m, 1H), 7.65 (d, *J* = 8.4 Hz, 1H), 7.37-7.30 (m, 2H), 7.19-7.15 (m, 1H), 6.99-6.95 (m, 1H), 6.90-6.88 (m, 1H), 6.10-6.06 (m, 1H), 5.90-5.86 (m, 1H), 3.50 (dd, *J* = 18.4, 8.0 Hz, 1H), 3.33 (dd, *J* = 10.4, 6.4 Hz, 1H), 3.18-3.17 (m, 1H), 2.58-2.52 (m, 3H), 1.47 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.9, 176.2, 150.2, 148.3, 139.1, 135.9, 134.7, 133.4, 129.6, 129.0, 128.8, 126.9, 124.5, 124.2, 122.7, 114.9, 84.1, 52.6, 45.3, 40.8, 36.5, 29.1, 27.8 ppm; ESI-HRMS: calcd. for $C_{25}H_{26}N_2O_4$+Na 441.1790, found 441.1796.

The minor diastereomer could be isolated in quite low yield. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.59 (s, 1H), 8.27-8.26 (m, 1H), 8.04-8.03 (m, 1H), 7.43-7.42 (m, 1H), 7.37-7.34 (m, 1H), 7.29-7.26 (m, 1H), 7.16-7.12 (m, 2H), 6.99-6.93 (m, 1H), 6.07-6.03 (m, 1H), 5.69-5.66 (m, 1H), 3.52-3.50 (m, 1H), 3.38 (dd, *J* = 7.6, 5.2 Hz, 1H), 3.13-3.05 (m, 1H), 2.57-2.50 (m, 1H), 2.42-2.35 (m, 1H), 2.08-1.99 (m, 1H), 1.66 (s, 9H) ppm.

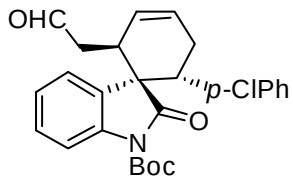


5g, 60 h, 67% yield; $[\alpha]_D^{20}$ = +26.8 (*c* = 2.65 in MeOH); 97% ee, determined by HPLC analysis after **5g** was converted to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2tBu$ in THF, 25 °C) [Daicel Chiralcel OD, *n*-hexane/*i*-PrOH = 98:2, 1.0 mL/min, λ = 220 nm, t (major) = 6.38 min, t (minor) = 8.50 min]; dr 92:8, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.74 (s, 1H), 7.61 (d, *J* = 8.0 Hz, 1H), 7.58-7.21 (m, 2H), 7.20-6.96 (m, 4H), 6.66 (d, *J* = 7.2 Hz, 2H), 6.10-6.06 (m, 1H), 5.87-5.83 (m, 1H), 3.48 (dd, *J* = 18.4, 8.0 Hz, 1H), 3.29 (dd, *J* = 10.0, 6.0 Hz, 1H), 3.17-3.16 (m, 1H), 2.58-2.50 (m, 3H), 1.45 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.2, 176.4, 148.4, 139.3, 139.0, 130.4, 128.8, 128.7, 128.4, 127.7, 127.5, 127.1, 124.3, 124.2, 114.6, 83.6, 52.8, 45.4, 43.4, 36.6, 29.4, 27.9 ppm; ESI-HRMS: calcd. for $C_{26}H_{27}NO_4$+Na 440.1838, found 440.1831.

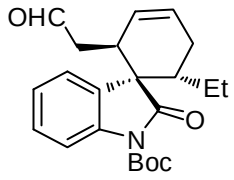


5h, 60 h, 58% yield; $[\alpha]_D^{20}$ = +18.1 (*c* = 3.25 in MeOH); 98% ee, determined by HPLC analysis after **5h** was converted to the corresponding α,β-unsaturated ketone ($Ph_3P{=}CHCOPh$ in THF, 40 °C) [Daicel Chiralcel OD, *n*-hexane/*i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 13.28 min, t (minor) = 16.73 min]; dr 92:8, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.74 (s, 1H),

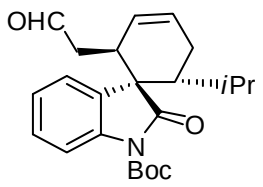
7.62 (d, J = 8.0 Hz, 1H), 7.34-7.26 (m, 2H), 7.15-7.11 (m, 1H), 6.83 (d, J = 8.0 Hz, 2H), 6.53 (d, J = 8.0 Hz, 2H), 6.08-6.05 (m, 1H), 5.86-5.82 (m, 1H), 3.49 (dd, J = 18.4, 8.0 Hz, 1H), 3.25 (dd, J = 10.4, 6.4 Hz, 1H), 3.16-3.15 (m, 1H), 2.55-2.49 (m, 3H), 2.20 (s, 3H), 1.45 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.3, 176.5, 148.8, 139.4, 136.6, 135.9, 130.5, 128.9, 128.6, 128.4, 128.3, 127.6, 124.3, 124.2, 114.6, 83.6, 52.9, 45.4, 43.0, 36.6, 29.5, 27.8, 20.9 ppm;; ESI-HRMS: calcd. for $C_{27}H_{29}NO_4$+Na 454.1994, found 454.1992.



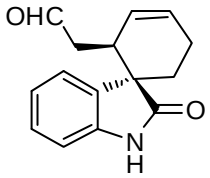
5i, 28 h; 82% yield; $[\alpha]_D^{20}$ = -11.0 (c = 1.60 in $CHCl_3$); 99% ee, determined by HPLC analysis after **5i** was converted to the corresponding α,β-unsaturated ester (Ph_3P=$CHCO_2t$Bu in THF, 25 °C) [Daicel Chiralcel OD, n-hexane/ i-PrOH = 98:2, 1.0 mL/min, λ = 220 nm, t (major) = 6.83 min, t (minor) = 11.57 min]; dr 88:12, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.74 (s, 1H), 7.61 (d, J = 8.4 Hz, 1H), 7.36 (d, J = 7.6 Hz, 1H), 7.33-7.28 (m, 1H), 7.17-7.13 (m, 1H), 7.00 (d, J = 8.4 Hz, 2H), 6.57 (d, J = 8.4 Hz, 2H), 6.08-6.04 (m, 1H), 5.87-5.84 (m, 1H), 3.50 (dd, J = 18.8, 8.0 Hz, 1H), 3.28 (dd, J = 10.0, 6.4 Hz, 1H), 3.16-3.15 (m, 1H), 2.55-2.48 (m, 3H), 1.47 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.0, 176.4, 148.2, 139.3, 137.4, 135.9, 132.9, 130.0, 129.0, 128.6, 127.8, 127.2, 124.3, 124.2, 114.7, 83.9, 52.8, 45.4, 42.8, 36.6, 29.3, 27.8 ppm; ESI-HRMS: calcd. for $C_{26}H_{26}ClNO_4$+Na 474.1448, found 474.1445.



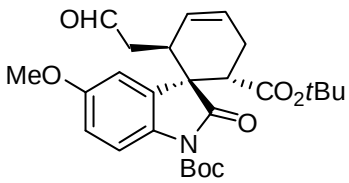
5j, 12 h; 70% yield; $[\alpha]_D^{20}$ = +7.0 (c = 0.50 in MeOH); 98% ee, determined by HPLC analysis after **5j** was converted to the corresponding α,β-unsaturated ketone (Ph_3P=$CHCOCH_3$ in THF, 40 °C) [Daicel Chiralpak IC, n-hexane/i-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 29.18 min, t (minor) = 31.24 min]; dr 88:12, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.71 (s, 1H), 7.85-7.83 (m, 1H), 7.30-7.26 (m, 2H), 7.10-7.07 (m, 1H), 5.97-5.94 (m, 1H), 5.76-5.72 (m, 1H), 3.38 (dd, J = 18.4, 8.0 Hz, 1H), 2.92-2.90 (m, 1H), 2.55-2.48 (m, 1H), 2.42 (dd, J = 18.4, 4.8 Hz, 1H), 2.13-2.06 (m, 1H), 1.99-1.91 (m, 1H), 1.63 (s, 9H), 1.26-1.19 (m, 1H), 0.80 (t, J = 7.2 Hz, 3H), 0.61-0.54 (m, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.3, 178.2, 149.0, 139.0, 131.2, 128.6, 127.9, 127.1, 124.3, 124.2, 114.5, 84.2, 52.7, 45.8, 37.0, 36.8, 28.1, 27.3, 24.0, 11.4 ppm; ESI-HRMS: calcd. for $C_{22}H_{27}NO_4$+Na 392.1838, found 392.1833.



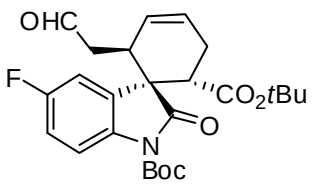
5k, 96 h, 60% yield; $[\alpha]_D^{20}$ = +11.6 (*c* = 1.65 in MeOH); 97% ee, determined by HPLC analysis after **5k** was converted to the corresponding α,β-unsaturated ketone (Ph_3P=$CHCOCH_3$ in THF, 40 °C) [Daicel Chiralpak IC, *n*-hexane/*i*-PrOH = 80:20, 1.0 mL/min, λ = 220 nm, t (major) = 9.27 min, t (minor) = 10.10 min]; dr 91:9, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.70 (s, 1H), 7.82 (d, *J* = 8.0 Hz, 1H), 7.31-7.28 (m, 2H), 7.09-7.05 (m, 1H), 6.01-5.99 (m, 1H), 5.70-5.67 (m, 1H), 3.41 (dd, *J* = 18.4, 8.4 Hz, 1H), 2.85-2.83 (m, 1H), 2.40 (dd, *J* = 18.4, 4.0 Hz, 1H), 2.27-2.18 (m, 3H), 1.63 (s, 9H), 0.86 (d, *J* = 6.8 Hz, 3H), 0.17 (d, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.1, 178.0, 149.1, 138.7, 132.3, 128.2, 127.9, 127.6, 124.6, 124.2, 114.7, 84.2, 52.5, 45.8, 40.4, 38.8, 28.4, 28.1, 23.5, 21.9, 16.8 ppm; ESI-HRMS: calcd. for $C_{23}H_{29}NO_4$+Na 406.1994, found 406.1994.



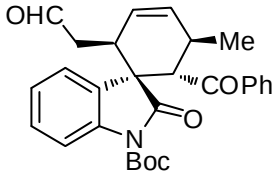
5l, 5 h; 47% yield; dr 78:22, determined by ^{1}H NMR analysis. All the following data were determined after **5l** was converted to the corresponding alcohol [$NaBH(OAc)_3$ in CH_2Cl_2, 25 °C] and the major diastereomer could be separated. $[\alpha]_D^{20}$ = +105.7 (*c* = 0.30 in $CHCl_3$); 98% ee, determined by HPLC analysis [Daicel Chiralpak AS, *n*-hexane/ *i*-PrOH = 90:10, 1.0 mL/min, λ = 254 nm, t (major) = 18.21 min, t (minor) = 25.10 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.32 (s, 1H), 7.22-7.16 (m, 2H), 7.05-7.03 (m, 1H), 6.86 (d, *J* = 7.6 Hz, 1H), 5.97-5.94 (m, 1H), 5.77-5.74 (m, 1H), 3.59-3.47 (m, 2H), 2.72-2.70 (m, 1H), 2.67-2.59 (m, 1H), 2.28-2.13 (m, 2H), 2.05-1.97 (m, 1H), 1.88-1.82 (m, 1H), 1.61-1.48 (m, 1H), 1.44-1.36 (m, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.5, 140.3, 135.2, 127.8, 127.2, 126.8, 122.6, 122.5, 109.4, 60.5, 49.9, 38.0, 33.3, 30.8, 21.7 ppm; ESI-HRMS: calcd. for $C_{15}H_{17}NO_2$+H 244.1338, found 244.1334.



5m, 6 h; 93% yield; $[\alpha]_D^{20}$ = +8.0 (*c* = 2.50 in MeOH); 98% ee, determined by HPLC analysis after **5m** was converted to the corresponding α,β-unsaturated ester (Ph_3P=$CHCO_2$*t*Bu in THF, 25 °C) [Daicel Chiralcel OD, *n*-hexane/*i*-PrOH = 95:5, 1.0 mL/min, λ = 254 nm, t (major) = 4.84 min, t (minor) = 11.77 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.66 (s, 1H), 7.80 (d, *J* = 8.8 Hz, 1H), 6.83-6.78 (m, 2H), 5.96-5.94 (m, 1H), 5.73-5.69 (m, 1H), 3.75 (s, 3H), 3.25-3.14 (m, 2H), 2.93-2.92 (m, 1H), 2.73-2.53 (m, 2H), 2.36 (dd, *J* = 18.4, 4.8 Hz, 1H), 1.60 (s, 9H), 1.16 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.5, 177.1, 170.9, 156.4, 149.1, 132.7, 132.6, 128.1, 126.1, 115.3, 111.6, 111.1, 83.7, 81.7, 55.5, 49.5, 45.7, 41.6, 37.4, 28.0, 27.5, 25.4 ppm; ESI-HRMS: calcd. for $C_{26}H_{33}NO_7$+Na 494.2155, found 494.2150.

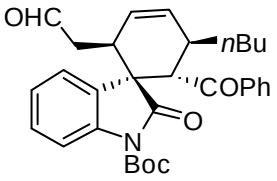


5n, 10 h; 89% yield; $[\alpha]_D^{20}$ = +7.9 (*c* = 1.20 in MeOH); 98% ee, determined by HPLC analysis after **5n** was converted to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2tBu$ in THF, 25 °C) [Daicel Chiralpak IC, *n*-hexane/*i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 9.53 min, t (minor) = 10.86 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.68 (s, 1H), 7.90-7.87 (m, 1H), 7.03-6.96 (m, 2H), 6.00-5.98 (m, 1H), 5.75-5.71 (m, 1H), 3.31-3.17 (m, 2H), 2.93-2.92 (m, 1H), 2.77-2.69 (m, 1H), 2.59-2.51 (m, 1H), 2.39 (dd, *J* = 18.8, 4.4 Hz, 1H), 1.62 (s, 9H), 1.18 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.2, 176.8, 170.7, 160.8, 128.0, 126.2, 115.8, 115.7, 114.4, 114.2, 111.5, 111.2, 84.1, 81.8, 45.5, 41.6, 37.4, 28.0, 27.5, 25.4 ppm; ESI-HRMS: calcd. for $C_{25}H_{30}FNO_6$+Na 482.1955, found 482.1951.



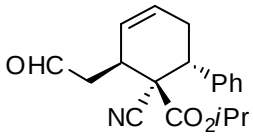
5o, 14 h; 94% yield; $[\alpha]_D^{20}$ = -172.8 (*c* = 0.80 in $CHCl_3$); 94% ee, determined by HPLC analysis after **5o** was converted to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2tBu$ in THF, 25 °C) [Daicel Chiralpak AD, *n*-hexane/ *i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 5.74 min, t (minor) = 6.89 min]; dr 79:21, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.74 (s, 1H), 7.86-7.77 (m, 3H), 7.55-7.51 (m, 1H), 7.47-7.40 (m, 3H), 7.35-7.31 (m, 1H), 7.18-7.14 (m, 1H), 5.90-5.88 (m, 1H), 5.81-5.77 (m, 1H), 3.91 (d, *J* = 10.4 Hz, 1H), 3.51 (dd, *J* = 18.4, 8.0 Hz, 1H), 3.04-3.00 (m, 1H), 2.95-2.90 (m, 1H), 2.55 (dd, *J* = 18.4, 4.8 Hz, 1H), 1.45 (s, 9H), 0.98 (d, *J* = 6.8 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 201.2, 199.6, 176.5, 148.2, 138.6, 138.5, 133.8, 133.1, 131.4, 128.5, 128.4, 128.2, 127.5, 124.3, 124.2, 114.6, 84.0, 51.5, 49.6, 45.8, 37.7, 32.5, 27.8, 19.8 ppm; ESI-HRMS: calcd. for $C_{28}H_{29}NO_5$+H 460.2124, found 460.2131.

The minor diastereomer could be isolated in quite low yield. The ee was determined to be 99% by HPLC analysis after the minor diastereomer was transformed to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2tBu$ in THF, 25 °C) [Daicel Chiralpak AD, *n*-hexane/*i*-PrOH = 95:5, 1.0 mL/min, λ = 254 nm, t (major) = 11.05 min, t (minor) = 9.92 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.58 (s, 1H), 7.85 (d, *J* = 8.4 Hz, 1H), 7.56-7.54 (m, 2H), 7.48-7.41 (m, 1H), 7.33-7.29 (m, 2H), 7.24-7.19 (m, 1H), 7.01-6.99 (m, 1H), 6.88-6.84 (m, 1H), 5.82-5.78 (m, 1H), 5.75-5.72 (m, 1H), 4.01 (d, *J* = 6.4 Hz, 1H), 3.83-3.80 (m, 1H), 3.29-3.25 (m, 1H), 2.47-2.40 (m, 1H), 2.23-2.05 (m, 1H) 1.67 (s, 9H), 0.89 (d, *J* = 7.6 Hz, 3H) ppm.

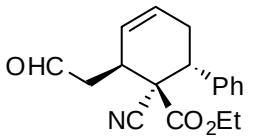


5p, 23 h; 90% yield; $[\alpha]_D^{20}$ = -126.7 (*c* = 3.80 in $CHCl_3$); 96% ee, determined by HPLC analysis after **5p** was converted to the corresponding α,β-unsaturated ester ($Ph_3P{=}CHCO_2tBu$ in THF, 25 °C) [Daicel Chiralpak AD, *n*-hexane/ *i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 5.39 min, t (minor) = 6.04 min]; dr 91:9, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.74 (s, 1H), 7.86-7.75 (m, 3H), 7.54-7.51 (m, 1H), 7.48-7.39 (m, 3H), 7.34-7.26 (m, 1H), 7.21-7.14 (m, 1H), 6.03-6.00 (m, 1H), 5.85-5.81 (m, 1H), 4.03 (d, *J* = 10.8 Hz, 1H), 3.50 (dd, *J* = 18.4, 8.0 Hz, 1H), 3.03-3.01 (m, 1H), 2.96-2.86 (m, 1H), 2.54 (dd, *J* = 18.4, 4.8 Hz, 1H), 1.43 (s, 9H), 1.39-1.04 (m, 6H), 0.75 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 201.2, 199.7, 176.4, 148.3, 138.6, 138.4, 133.1, 131.6, 131.2, 129.2, 128.5, 128.4, 128.2, 127.9, 124.4, 114.6, 84.0, 51.5, 47.5, 45.8, 37.5, 37.0, 32.6, 28.0, 27.8, 22.6, 13.8 ppm; ESI-HRMS: calcd. for $C_{31}H_{35}NO_5$+Na 524.2413, found 524.2417.

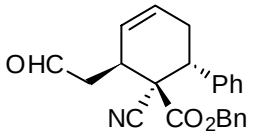
Procedure for the formation of 9: These reactions were performed with **1b** (0.2 mmol), **8** (0.1 mmol), **2c** (0.02 mmol) and OFBA (0.02 mmol) in $CHCl_3$ (0.5 mL) at 50 °C for the specified reaction time. After the reaction completed, the mixture was concentrated and the residue was purified by FC on silica gel (petroleum ether/EtOAc) to afford the Diels-Alder adduct **9**.



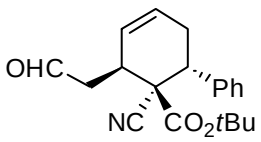
9a, 60 h; 81% yield; 89% ee, determined by HPLC analysis after **9a** was converted to the corresponding α,β-unsaturated ketone (Ph_3P=CHCOPh in THF, 40 °C) [Daicel Chiralcel OD, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 220 nm, t (major) = 13.40 min, t (minor) = 11.13 min]; dr 86:14, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.67 (s, 1H), 7.44 (d, *J* = 6.8 Hz, 2H), 7.32-7.24 (m, 3H), 5.98-5.94 (m, 1H), 5.74-5.70 (m, 1H), 4.69-4.62 (m, 1H), 3.61-3.60 (m, 1H), 3.25-3.15 (m, 2H), 2.72-2.64 (m, 1H), 2.57 (dd, *J* = 19.2, 4.4 Hz, 1H), 2.48-2.41 (m, 1H), 1.14 (d, *J* = 6.4 Hz, 3H), 0.78 (d, *J* = 6.4 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 198.5, 166.7, 139.1, 128.6, 128.4, 127.8, 127.6, 126.4, 118.7, 70.8, 51.2, 45.5, 41.3, 37.0, 31.0, 21.2, 20.9 ppm.



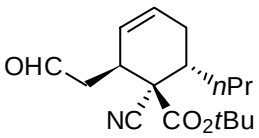
9b, 48h; 87% yield; 86% ee, determined by HPLC analysis after **9b** was converted to the corresponding α,β-unsaturated ketone (Ph_3P=CHCOPh in THF, 40 °C) [Daicel Chiralcel OD, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (major) = 15.65 min, t (minor) = 9.94 min]; dr 80:20, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.66 (s, 1H), 7.44 (d, *J* = 7.2 Hz, 2H), 7.32-7.24 (m, 3H), 5.98-5.94 (m, 1H), 5.74-5.70 (m, 1H), 3.94-3.86 (m, 2H), 3.61-3.60 (m, 1H), 3.24 (dd, *J* = 11.2, 5.6 Hz, 1H), 3.15 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.72-2.64 (m, 1H), 2.58 (dd, *J* = 18.8, 4.4 Hz, 1H), 2.48-2.41 (m, 1H), 0.98 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 198.5, 166.1, 139.1, 128.5, 128.2, 127.8, 127.6, 126.3, 118.6, 62.7, 51.1, 45.5, 41.0, 37.1, 31.0, 13.5 ppm.



9c, 29h; 97% yield; 88% ee, determined by HPLC analysis after **9c** was converted to the corresponding alcohol [$NaBH(OAc)_3$ in DCM, 25 °C] [Daicel Chiralpak AS, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 220 nm, t (major) = 7.66 min, t (minor) = 10.13 min]; dr 78:22, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.59 (s, 1H), 7.44-7.42 (m, 2H), 7.30-7.25 (m, 6H), 7.06-7.04 (m, 2H), 5.97-5.93 (m, 1H), 5.75-5.71 (m, 1H), 4.90 (dd, *J* = 28.8, 12 Hz, 2H), 3.60-3.58 (m, 1H), 3.25 (dd, *J* = 11.6, 5.6 Hz, 1H), 2.96 (dd, *J* = 18.8, 7.6 Hz, 1H), 2.70-2.62 (m, 1H), 2.56 (dd, *J* = 18.8, 4.8 Hz, 1H), 2.47-2.40 (m, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 198.4, 167.0, 139.1, 134.4, 128.6, 128.5, 128.4, 128.3, 127.9, 127.8, 127.7, 126.2, 118.4, 68.1, 51.2, 45.7, 40.8, 37.2, 31.1 ppm.

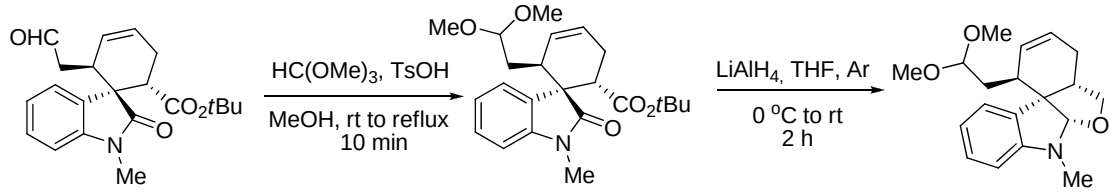


9d, 60 h; 71% yield; $[\alpha]_D^{20}$ = +18.8 (*c* = 0.50 in $CHCl_3$); 89% ee, determined by HPLC analysis after **9a** was converted to the corresponding α,β-unsaturated ketone (Ph_3P=CHCOPh in THF, 40 °C) [Daicel Chiralcel OD, *n*-hexane/*i*-PrOH = 90:10, 1.0 mL/min, λ = 220 nm, t (major) = 9.21 min, t (minor) = 8.14 min]; dr 90:10, determined by ^{1}H NMR analysis; major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.68 (s, 1H), 7.46 (d, *J* = 6.8 Hz, 2H), 7.33-7.24 (m, 3H), 5.97-5.93 (m, 1H), 5.74-5.70 (m, 1H), 3.66-3.58 (m, 1H), 3.25-3.16 (m, 2H), 2.72-2.64 (m, 1H), 2.53 (dd, *J* = 18.8, 4.4 Hz, 1H), 2.47-2.40 (m, 1H), 1.12 (s, 9H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 198.6, 166.2, 139.2, 128.8, 128.4, 127.8, 127.6, 126.6, 119.0, 84.4, 51.6, 45.4, 41.6, 37.0, 31.3, 27.3 ppm; ESI-HRMS: calcd. for $C_{20}H_{23}NO_3$+Na 348.1576, found 348.1574.



9e, 30 h; 72% yield; dr 82:18, determined by ^{1}H NMR analysis; 86% ee, determined by HPLC analysis after **9b** was converted to the corresponding α,β-unsaturated ester (Ph_3P=$CHCO_2C_2H_5$ in THF, 40 °C) [Daicel Chiralpak IC, *n*-hexane/*i*-PrOH = 95:5, 1.0 mL/min, λ = 220 nm, t (major) = 9.42 min, t (minor) = 12.95 min]. All the following data were obtained after **9b** was converted to the corresponding alcohol [$NaBH(OAc)_3$ in CH_2Cl_2, 25 °C] and the major diastereomer could be separated. $[\alpha]_D^{20}$ = +79.3 (*c* = 0.85 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.80-5.77 (m, 2H), 3.79-3.72 (m, 1H), 3.71-3.64 (m, 1H), 2.88-2.85 (m, 1H), 2.40-2.34 (m, 1H), 2.17-2.11 (m, 1H), 1.97-1.90 (m, 1H), 1.77-1.69 (m, 2H), 1.61-1.56 (m, 2H), 1.53 (s, 9H), 1.37-1.23 (m, 2H), 0.85-0.97 (m, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 166.4, 126.6, 125.7, 119.1, 83.9, 59.6, 52.6, 38.4, 34.8, 34.7, 33.2, 28.3, 27.9, 19.9, 14.0 ppm; ESI-HRMS: calcd. for $C_{17}H_{27}NO_3$+Na 316.1889, found 316.1886.

4. Synthetic transformations of the Diels-Alder adducts



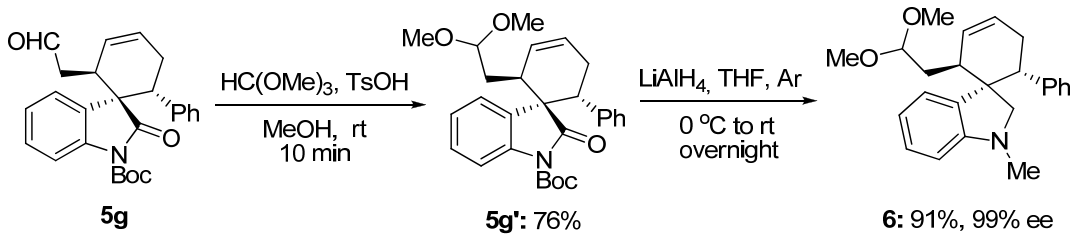
5q **5q':** quant. **7:** 60%, 99% ee

Cycloadduct **5q** was similarly prepared by using 3-olefinic oxindole with *N*-Me group. **5q**: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.68 (s, 1H), 7.30-7.23 (m, 2H), 7.00-6.95 (m, 1H), 6.85 (d, *J* = 8.0 Hz, 1H), 5.99-5.95 (m, 1H), 5.76-5.71 (m, 1H), 3.32 (dd, *J* = 18.4, 8.4 Hz, 1H), 3.17 (s, 3H), 3.15-3.11 (m, 1H), 2.91-2.88 (m, 1H), 2.70-2.58 (m, 2H), 2.32 (dd, *J* = 18.8, 4.8 Hz, 1H), 1.16 (s, 9H) ppm.

To a methanol solution of **5q** (36 mg, 0.1 mmol) was added trimethyl orthoformate (21 mg, 0.2 mmol) and a catalytic amount of TsOH (2 mg, 0.01 mmol) at room temperature. Then the reaction was heated to reflux for 10 min. When the reaction was complete, the mixture was concentrated and the residue was purified by FC on silica gel (petroleum ether/EtOAc = 10:1) to afford the acetal **5q'** in quantitative yield. ^{1}H NMR (400 MHz, $CDCl_3$): 7.29-7.23 (m, 2H), 6.98-6.94 (m, 1H), 6.81 (d, *J* = 7.6 Hz, 1H), 5.96-5.92 (m, 1H), 5.89-5.85 (m, 1H), 4.37 (dd, *J* = 7.2, 4.8 Hz, 1H), 3.24 (s, 3H), 3.20 (s, 3H), 3.18 (s, 3H), 3.14-3.08 (m, 1H), 2.80-2.72 (m, 1H), 2.51-2.44 (m, 2H), 2.11-2.04 (m, 1H), 1.65-1.58 (m, 1H), 1.20 (s, 9H) ppm.

A solution of **5q'** (40 mg, 0.1 mmol) and $LiAlH_4$ (19 mg, 0.5 mmol) in THF (2 mL) was stirred under an argon atmosphere in an ice bath and allowed to slowly warm to room temperature for about 2 h. When the reaction completed, the mixture was quenched with EtOAc (1 mL), MeOH (1 mL), H_2O (5 mL), and then extracted with EtOAc three times, dried over Na_2SO_4 and concentrated. The residue was purified by FC on silica gel (petroleum ether/EtOAc = 5:1) to afford the fused hexahydrofuro[2,3-*b*]indole derivative **7** (19 mg) in 60% yield as a single diastereomer. The enantiomeric excess was determined to be 99% by HPLC analysis on Chiralpak AD column (*n*-hexane/2-propanol = 80:20, 1 mL/min), UV 220 nm, t (major) = 8.04 min, t (minor) = 5.81 min. $[\alpha]_D^{20}$ = -45.0 (*c* = 1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.17-7.10 (m, 2H), 6.64-6.60 (m, 1H), 6.43 (d, *J* = 7.6 Hz, 1H), 6.01-5.98 (m, 1H), 5.93-5.89 (m, 1H), 5.27 (s, 1H), 4.52-4.49 (m, 1H), 3.96 (t, *J* = 6.8 Hz, 1H), 3.31 (s, 3H), 3.29 (s, 3H), 3.07-3.02 (m, 1H), 2.93 (s, 3H), 2.54-2.48 (m, 1H), 2.36-2.29 (m, 3H), 2.01-1.94 (m, 1H), 1.76-1.69 (m, 1H) ppm; ^{13}C NMR

(100 MHz, $CDCl_3$): δ = 151.3, 131.4, 130.9, 128.4, 127.6, 125.5, 117.7, 106.3, 103.0, 98.4, 71.9, 57.0, 53.1, 52.4, 39.5, 38.9, 35.5, 31.1, 24.8 ppm; ESI-HRMS: calcd. for $C_{19}H_{25}NO_3$+Na 338.1732, found 338.1739.

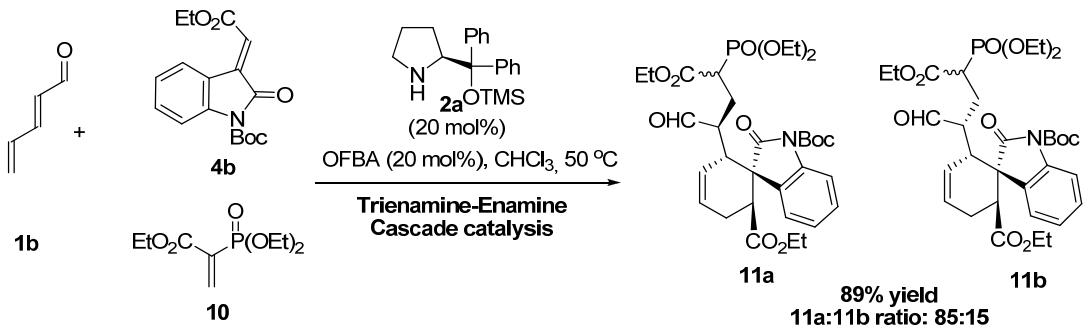


To a methanol solution of the cycloaddition product **5g** (42 mg, 0.1 mmol) was added trimethyl orthoformate (21 mg, 0.2 mmol) and a catalytic amount of TsOH (2 mg, 0.01 mmol) at room temperature. Then, the reaction was stirred for 10 min. When the reaction completed, the mixture was concentrated and the residue was purified by FC on silica gel (petroleum ether/EtOAc = 20:1) to afford the acetal **5g'** in 76% yield. ^{1}H NMR (400 MHz, $CDCl_3$): 7.67 (d, *J* = 8.0 Hz, 1H), 7.26-7.22 (m, 1H), 7.19-7.08 (m, 3H), 7.00-6.96 (m, 1H), 6.82-6.76 (m, 3H), 6.10-6.07 (m, 1H), 5.99-5.95 (m, 1H), 4.42 (dd, *J* = 7.2, 4.8 Hz, 1H), 3.24 (s, 3H), 3.23-3.21 (m, 1H), 3.14 (s, 3H), 2.77-2.71 (m, 1H), 2.58-2.56 (m, 1H), 2.51-2.45 (m, 1H), 2.05-1.98 (m, 1H), 1.79-1.68 (m, 1H), 1.53 (s, 9H) ppm.

A solution of **5g'** (35 mg, 0.08 mmol) and $LiAlH_4$ (15 mg, 0.4 mmol) in THF (2 mL) was stirred under an argon atmosphere in an ice bath and allowed to slowly warm to room temperature. After the reaction was stirred overnight at room temperature, the mixture was quenched with EtOAc (1 mL), MeOH (1 mL), H_2O (5 mL), and then extracted with EtOAc three times, dried over Na_2SO_4 and concentrated. The residue was purified by FC on silica gel (petroleum ether/EtOAc = 10:1) to afford the spirocyclic indoline **6** in 91% yield (25 mg) as a colorless oil. The enantiomeric excess was determined to be 99% ee by HPLC analysis on Chiralcel OD column (*n*-hexane/2-propanol = 95:5, 1 mL/min), UV 220 nm, t (major) = 4.42 min, t (minor) = 4.66 min. $[\alpha]_D^{20}$ = +89.7 (*c* = 0.30 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.18-7.10 (m, 3H), 7.07-7.03 (m, 1H), 6.84-6.83 (m, 2H), 6.74-6.44 (m, 1H), 6.39-6.38 (m, 1H), 6.32-6.30 (m, 1H), 5.98-5.92 (m, 2H), 4.40 (dd, *J* = 7.2, 4.4 Hz, 1H), 3.29 (s, 3H), 3.26-3.22 (m, 1H), 3.13 (s, 3H), 3.12-3.11 (m, 1H), 3.06 (t, *J* = 5.6 Hz, 1H), 2.60-2.57 (m, 2H), 2.54 (s, 3H), 2.42-2.36 (m, 1H), 1.70-1.65 (m, 1H), 1.55-1.47 (m, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.2, 143.0, 132.6, 130.5, 129.0, 128.0, 127.5, 127.3, 126.3, 125.2, 116.5, 106.4, 103.4, 63.5, 53.8, 51.5, 50.1, 45.2, 36.4, 35.1, 34.2, 30.5 ppm; ESI-HRMS: calcd. for $C_{24}H_{27}NO_3$+H 364.2277, found 364.2275.

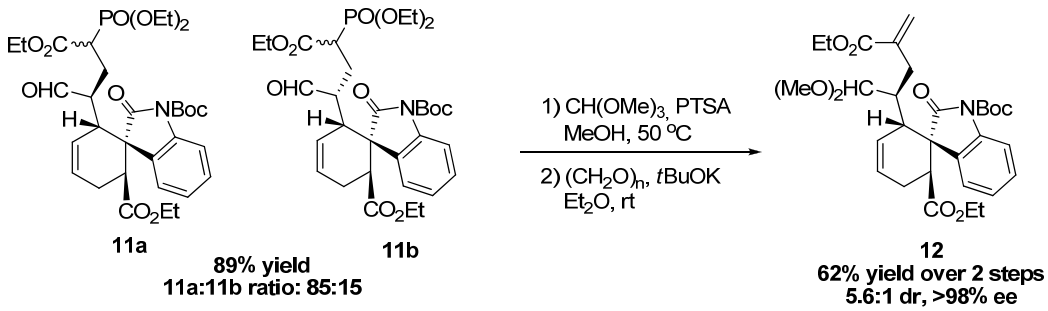
5. Trienamine-enamine tandem reactions

Derivations from General Methods: NMR spectra were run at 400, 162 and 100 MHz for ^{1}H, ^{31}P and ^{13}C, respectively. Chemical shifts (δ) are reported in ppm relative to residual solvent signals ($CHCl_3$, 7.26 ppm for ^{1}H NMR, $CDCl_3$, 77.0 ppm for ^{13}C NMR). ^{13}C NMR spectra were acquired on a broad-band decoupled mode. Chemical shifts for phosphorus are reported in ppm relative to phosphoric acid (H_3PO_4, 0 ppm) used as an external standard. All phosphorus nuclear magnetic resonance spectra are proton-decoupled. The following abbreviations are used to indicate the multiplicity in ^{1}H NMR spectra: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; bs, broad signal. In order to characterize ^{1}H and ^{13}C NMR spectra of diastereomeric mixtures, the following notations are used. *denotes the minor diastereomer; $^{+}$denotes overlap of signals from both diastereomers, the number of protons (or carbons) given in the parentheses represent the sum of protons (or carbons) from both diastereomers. For equimolar mixtures of diastereomers, no individual characterization is made.



An ordinary vial equipped with a magnetic stirring bar was charged with 2,4-hexdienal **1b** (0.45 mmol), 3-olefinic oxindole **4b** (0.3 mmol), secondary amine catalyst **2b** (0.06 mmol), *o*-fluorobenzoic acid (0.06 mmol), ethyl 2-(diethoxyphosphoryl)acrylate **10** (0.45 mmol) and $CHCl_3$ (3 mL). The resultant reaction mixture was stirred at 50 ºC for 4 h. Upon completion of reaction, as monitored by TLC analysis, the mixture was directly charged on silica gel and purified by FC (pentane/EtOAc) to afford the domino product **11** (mixture of diastereomers) as an yellowish oil in 89% yield (**11a**:**11b** ratio: 85:15; judged by ^{31}P NMR, each as a 1:1 mixture of diastereomers resulting from the labile stereocenter, flanked by two EWG-groups). $[\alpha]_D^{20}$ = +41.0 (*c* = 1.00 in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): **11a** (1:1 mixture of isomers): δ 9.54 (s, 1H), 9.51 (s, 1H), 7.89-7.82 (m, 2H), 7.31-7.24 (m, 2H), 7.20-7.13 (m, 2H), 7.07-6.99 (m, 2H), 6.21-6.10 (m, 2H), 5.78-5.68 (m, 2H), 4.28-4.04 (m, 12H), 3.96-3.84 (m, 4H), 3.46-3.09 (m, 4H), 3.06-2.90 (m, 4H), 2.87-2.75 (m, 2H), 2.63-2.46 (m, 2H), 2.44-1.96 (m, 4H), 1.64-1.57 (m, 18H), 1.35-1.19 (m, 18H), 1.05-0.97 (m, 6H) ppm; **11b** (1:1 mixture of isomers): δ 9.83 (s, 1H), 9.75 (s, 1H),

7.89-7.82 (m, 2H), 7.31-7.24 (m, 2H), 7.20-7.13 (m, 2H), 7.07-6.99 (m, 2H), 6.12-6.05 (m, 2H), 5.84-5.77 (m, 2H), 4.28-4.04 (m, 12H), 3.96-3.84 (m, 4H), 3.46-3.09 (m, 4H), 3.06-2.90 (m, 4H), 2.87-2.75 (m, 2H), 2.63-2.46 (m, 2H), 2.44-1.96 (m, 4H), 1.64-1.57 (m, 18H), 1.35-1.19 (m, 18H), 1.05-0.97 (m, 6H) ppm; ^{31}P NMR (162 MHz, $CDCl_3$): **11a**: δ = 22.9, 22.9 ppm; **11b**: δ = 22.8, 22.7 ppm. The presence of the C-P coupling (coupling occurs up to 3 bonds) significantly complicates the characterization of the ^{13}C NMR of **11a**+**11b**, which consist of a mixture of 4 diffirent isomers. Since a full and precise analysis of the ^{13}C NMR spectra is not possible, a copy of the recorded the spectra is attached and the characteristic aldehyde signals are given: δ = 202.7 (**11b**), 202.7 (**11b**), 201.3 (**11a**), 200.5 (**11a**) ppm. ESI-HRMS: calcd. for $C_{32}H_{44}NPO_{11}$+Na 672.2550, found 672.2549.

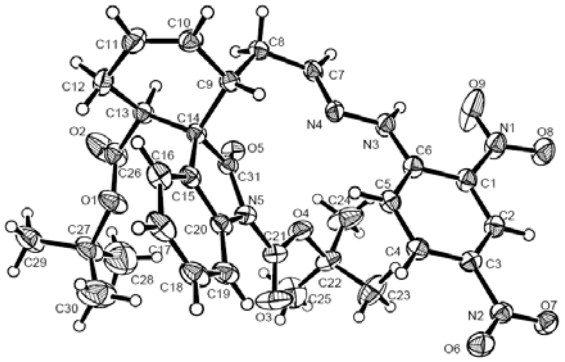


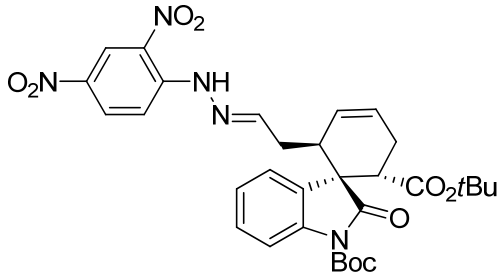
An ordinary vial equipped with a magnetic stirring bar was charged with the mixture of **11a** and **11b** (ratio: 85:15, 0.25 mmol), methyl orthoformate (0.6 mmol), *p*-toluenesulfonic acid (0.08 mmol) and MeOH (2 mL). The resultant reaction mixture was stirred at 50 ºC for 10 min. Upon cooling to room temperature, the excess solvents were removed under reduced pressure and the crude oil was purified by FC on a short pad of silica gel (pentane/EtOAc: 1:1 to 1:5) to afford the corresponding dimethyl acetal. The protected product was then re-dissolved in Et_2O, and *t*BuOK (0.28 mmol) and paraformaldehyde (1.25 mmol) was added. The mixture was stirred at ambient temperature for 30 min and quenched by the addition of water (3 mL). The phases were separated and the aqueous phase was extracted with EtOAc (3 x 5 mL). The combined organic layers were dried over Na_2SO_4, concentrated *in vacuo* and purified by FC on silica gel (pentane/EtOAc: 4:1 to 2:1) to afford **12** in 62% yield over 2 steps as a colorless oil (5.6: 1 dr). $[\alpha]_D^{20}$ = +66.5 (*c* = 0.75 in $CHCl_3$). The enantiomeric excess was determined by chiral stationary phase HPLC analysis using two connected Chiralpak AD columns (*n*-hexane/2-propanol = 98:2, 1 mL/min), UV 220 nm; major diastereomer (98% ee): t (major) = 19.0 min, t (minor) = 20.1 min; minor diastereomer (98% ee): t (major) = 24.0 min, t (minor) = 25.0 min. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.82 (d, *J* = 9.1 Hz, 1H), 7.80* (d, *J* = 6.6 Hz, 1H), 7.25-7.21$^+$ (m, 4H), 7.01$^+$ (t, *J* = 7.6 Hz, 2H), 6.19 (s, 1H), 6.14* (d, *J* = 1.4 Hz, 1H), 6.04-5.95$^+$ (m, 2H), 5.84-5.77$^+$ (m, 2H), 5.60 (s, 1H), 5.52* (s, 1H), 4.26$^+$ (q, *J* = 7.1 Hz, 4H), 4.03* (d, *J* = 7.2 Hz, 1H), 4.00 (d, *J* = 3.5 Hz, 1H), 3.92$^+$ (q, *J* = 7.1 Hz, 4H), 3.47* (apparent q, *J* = 7.1 Hz,

1H), 3.39 (dd, J = 9.8, 7.3 Hz, 1H), 3.28* (s, 3H), 3.25* (s, 3H), 3.23 (s, 3H), 3.11 (s, 3H), 2.88-2.77^{+} (m, 4H), 2.71-2.63^{+} (m, 2H), 2.55-2.44^{+} (m, 4H), 2.31^{+} (dd, J = 14.2, 11.2 Hz, 2H), 1.63* (s, 9H), 1.61 (s, 9H), 1.32^{+} (t, J = 7.1 Hz, 6H), 1.04^{+} (t, J = 7.1 Hz, 6H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 176.8, 176.5*, 172.4*, 172.4, 167.2, 166.7*, 149.3, 149.2*, 140.2, 139.9*, 139.3*, 139.3, 132.1, 131.5*, 128.0^{+} (2C), 127.8^{+} (2C), 125.7^{+} (2C), 125.7^{+} (2C), 124.1*, 124.0, 123.7, 123.5*, 114.4, 114.4*, 107.3, 106.0*, 83.9*, 83.6, 60.8^{+} (2C), 60.6^{+} (2C), 55.3, 55.2, 54.9*, 53.6*, 50.7, 50.4*, 42.1*, 41.9, 40.6, 40.5*, 38.0*, 37.8, 31.3, 30.9*, 28.2* (3C), 28.1 (3C), 25.7, 25.4*, 14.2, 14.1*, 13.7*, 13.7 ppm. ESI-HRMS: calcd. for $C_{31}H_{41}NO_9$+Na 594.2679, found 594.2678.

6. Crystal data and structure refinement for the 2,4-dinitrobenzenehydrozone of enantiopure 5a

The crystals suitable for X-ray crystallographic analysis were obtained from the 2,4-dinitrobenzenehydrozone of enantiopure **5a**.





Derivative of 5a

Crystallographic data of **2,4-dinitrobenzenehydrozone of enantiopure 5a**: $C_{31}H_{35}N_5O_9$, Orthorhombic, space group $P2_12_12_1$, a = 10.9831(3) Å, b = 12.3901(2) Å, c = 19.7187(3) Å , V = 23.3125(4) Å^3, Z = 4, d = 1.302 g/cm3, crystal dimensions 0.30 × 0.30 × 0.40 mm was used for measurements on an Oxford Diffraction Gemini S Ultra CCD diffractometer with a mirror Cu Ka (λ = 1.54184 Å) radiation at 150 K (ω scans, 2θmax = 138.94º). The total number of independent reflections measured was 5550, of which 5105 were observed ($|F|^2 \geq 2\sigma|F|^2$). Final indices ($|F|^2 \geq 2\sigma|F|^2$): R_1= 0.0685, wR_2 = 0.1798, S = 1.067, (Δρ)min = -0.373 e/Å^3, (Δρ)max = 0.576 e/Å^3. Flack x = 0.0(2).

The crystal structures were solved by direct methods using SHELXS-97 (Sheldrich, G. M. Univerisy of Gottingen: Gottingen, Germany, 1997) and expanded using difference Fourier techniques, refined by SHELXL-97 (Sheldrich, G. M. University of Gottingen: Gottingen, Germany, 1997) and full-matrix least-squares calculations. The absolute configuration was determined by anomalous dispersion effects in diffraction measurements on the crystal.

7. Computational investigations

All molecules were optimized at the B3LYP/6-31G(d) level of theory using the Jaguar program.[4] All optimized structures were verified as either a minimum or a transition state by a frequency calculation, i.e. having zero or one imaginary frequencies, respectively.

The continuum solvation effects were modeled by using the implementation of the solvation model ("Standard Poisson-Boltzmann Solvation Model". Parameters: Dielectric Constant: 4.806 Probe Radius: 2.52) in Jaguar. The solvation effects were estimated from a single-point calculation of the gas-phase optimized structures at the B3LYP/6-31G(d).

The orbital coefficients and the energy of the HOMO and LUMO of the trienamine intermediates were calculated using a STO-3G basis set of the optimized structures of **C** and **D**.

4. Jaguar, version 7.6, Schrödinger, LLC, New York, NY, 2009.

Intermediate B

Basis set: 6-31g*

Net molecular charge: 0

Multiplicity: 1

Number of basis functions.... 505

SCFE: Solution phase energy: DFT(b3lyp) -1430.13724642537 hartrees

angstroms

atom	x	y	z
C1	0.9449450000	1.5277790000	10.2830430000
N2	-0.3202190000	0.9408620000	9.8365490000
C3	-1.2092800000	1.8886590000	9.1681220000
C4	-0.5470540000	3.2581680000	9.3726480000
C5	0.9367760000	2.9258470000	9.6237540000
H7	1.7630920000	0.9138370000	9.8934490000
H10	-1.2957390000	1.6245700000	8.1019450000
H11	-2.2185830000	1.8452770000	9.5971690000
H12	-0.6830910000	3.9103860000	8.5045690000
H13	-0.9801000000	3.7637030000	10.2389930000
H14	1.4405390000	3.6811750000	10.2315140000
H15	1.4768520000	2.8671150000	8.6716660000
C14	-0.5267880000	-0.4085600000	9.7362330000
C17	-1.6219100000	-1.0233830000	9.2074120000
C20	-1.7463330000	-2.4559320000	9.1566460000
C23	-2.8046950000	-3.1472400000	8.6610920000
C26	-2.8899600000	-4.5910470000	8.6372560000
C29	-3.9233640000	-5.3064210000	8.1557550000
H19	-2.4490390000	-0.4336330000	8.8185920000
H20	0.2784970000	-1.0073470000	10.1480090000
H21	-3.6532450000	-2.5961690000	8.2534290000
H22	-0.9080280000	-3.0279600000	9.5608350000
H23	-2.0327820000	-5.1261990000	9.0509610000
H24	-3.9221150000	-6.3921400000	8.1699280000

H25	-4.8022240000	-4.8246080000	7.7326010000
C27	1.1352490000	1.5022760000	11.8577750000
C28	-2.4058720000	3.3113920000	13.6393210000
C30	-1.2961580000	4.1024590000	13.3438670000
C31	-0.1499540000	3.5281050000	12.7923990000
C32	-0.0837830000	2.1508550000	12.5320690000
C33	-1.2126460000	1.3717280000	12.8188570000
C34	-2.3596150000	1.9438440000	13.3696530000
H35	-3.2975860000	3.7565930000	14.0732110000
H36	-1.3164770000	5.1705890000	13.5457190000
H37	0.7026640000	4.1636980000	12.5739670000
H38	-1.1918550000	0.3107410000	12.6001170000
H39	-3.2202540000	1.3156380000	13.5853460000
C39	4.9853000000	3.1300640000	13.1544120000
C40	4.8308190000	2.6360180000	11.8597890000
C41	3.5963700000	2.1458030000	11.4316540000
C42	2.4777500000	2.1417380000	12.2797390000
C43	2.6546240000	2.6398620000	13.5812670000
C44	3.8876980000	3.1275570000	14.0145710000
H45	5.9467270000	3.5110090000	13.4883240000
H46	5.6753150000	2.6259730000	11.1755150000
H47	3.5231560000	1.7595110000	10.4211130000
H48	1.8162630000	2.6519910000	14.2688960000
H49	3.9862710000	3.5064770000	15.0288140000
O49	1.1738250000	0.1010300000	12.1578610000
Si50	1.7114510000	-0.8622110000	13.4346470000
C53	1.0659960000	-0.3065170000	15.1211910000
H54	1.5233130000	0.6281680000	15.4614560000
H55	-0.0200390000	-0.1661720000	15.1162120000
H56	1.3000660000	-1.0758750000	15.8687350000
C56	0.9888190000	-2.5512940000	13.0148600000
H57	1.3668530000	-2.9194630000	12.0538270000
H58	1.2558130000	-3.2910000000	13.7800450000
H59	-0.1048560000	-2.5178480000	12.9503660000
C59	3.5938810000	-0.9820320000	13.4826310000
H60	3.8974350000	-1.7270390000	14.2298180000
H61	3.9973080000	-1.3017440000	12.5147490000
H62	4.0683740000	-0.0316250000	13.7464870000

Intermediate C

Basis set: 6-31g*

Net molecular charge: 0

Multiplicity: 1

Number of basis functions.... 505

SCFE: Solution phase energy: DFT(b3lyp) -1430.13147721760 hartrees

angstroms

atom	x	y	z
C1	0.9674000000	1.5760560000	10.2456780000
N2	-0.2775980000	0.9650560000	9.7816300000
C3	-1.2075630000	1.9031430000	9.1581550000
C4	-0.5692710000	3.2849530000	9.3695240000
C5	0.9242450000	2.9849310000	9.6117970000
H7	1.8029010000	0.9894910000	9.8496780000
H10	-1.3219780000	1.6545910000	8.0912260000
H11	-2.2022370000	1.8319920000	9.6173440000
H12	-0.7233170000	3.9408820000	8.5072760000
H13	-1.0086400000	3.7754910000	10.2412920000
H14	1.4086140000	3.7415080000	10.2337590000
H15	1.4641530000	2.9574130000	8.6583230000
C14	-0.4601190000	-0.3871330000	9.6986360000
C17	-1.5633510000	-1.0382790000	9.2336990000
C20	-1.6350830000	-2.4748430000	9.2258010000
C23	-2.6830760000	-3.2232160000	8.7991990000
C26	-2.7652140000	-4.6792020000	8.8352810000
C29	-2.0135270000	-5.5325940000	9.5541320000
H19	-2.4295820000	-0.4814030000	8.8826830000
H20	0.3779160000	-0.9643690000	10.0738400000
H21	-3.5454340000	-2.7067060000	8.3763730000
H22	-0.7523640000	-2.9951360000	9.6016070000

H23	-3.5451880000	-5.1090420000	8.2045460000
H24	-2.1530390000	-6.6067590000	9.4760860000
H25	-1.2437920000	-5.1932110000	10.2431030000
C27	1.1466020000	1.5238340000	11.8215510000
C28	-2.4151530000	3.2771220000	13.6178330000
C30	-1.3029830000	4.0775200000	13.3586110000
C31	-0.1503310000	3.5211280000	12.8018050000
C32	-0.0804130000	2.1527410000	12.5001250000
C33	-1.2114250000	1.3638810000	12.7515060000
C34	-2.3648190000	1.9183070000	13.3070170000
H35	-3.3117110000	3.7082860000	14.0559490000
H36	-1.3264470000	5.1388760000	13.5931930000
H37	0.7042560000	4.1632780000	12.6120560000
H38	-1.1877850000	0.3097720000	12.5013240000
H39	-3.2269460000	1.2831610000	13.4947240000
C39	4.9813110000	3.1285060000	13.1845720000
C40	4.8317240000	2.6896260000	11.8698470000
C41	3.6013440000	2.2090230000	11.4194100000
C42	2.4825590000	2.1602180000	12.2654540000
C43	2.6533820000	2.6063770000	13.5865070000
C44	3.8823840000	3.0830800000	14.0421350000
H45	5.9399530000	3.5005210000	13.5359670000
H46	5.6767440000	2.7152370000	11.1866140000
H47	3.5325350000	1.8667460000	10.3929310000
H48	1.8129880000	2.5850070000	14.2715840000
H49	3.9770440000	3.4196610000	15.0715310000
O49	1.1895490000	0.1192320000	12.0972170000
Si50	1.7083070000	-0.8831460000	13.3500330000
C53	1.0680330000	-0.3653090000	15.0504980000
H54	1.5458060000	0.5456930000	15.4249340000
H55	-0.0143950000	-0.1987790000	15.0437230000
H56	1.2780600000	-1.1648850000	15.7730950000
C56	0.9597620000	-2.5493150000	12.8865790000
H57	1.3357170000	-2.8994170000	11.9180570000
H58	1.2092380000	-3.3130260000	13.6338430000
H59	-0.1326530000	-2.4943500000	12.8168530000
C59	3.5889570000	-1.0272860000	13.3874710000
H60	3.8901410000	-1.7918850000	14.1154260000

H61	3.9812390000	-1.3296660000	12.4093650000
H62	4.0754150000	-0.0876580000	13.6681510000

Intermediate D

Basis set: 6-31g*

Net molecular charge: 0

Multiplicity: 1

Number of basis functions.... 505

SCFE: Solution phase energy: DFT(b3lyp) -1430.13119016640 hartrees

angstroms

atom	x	y	z
C1	0.9478040000	1.4953990000	10.3632460000
N2	-0.2902740000	0.8345100000	9.9496580000
C3	-1.2374030000	1.7170020000	9.2716560000
C4	-0.6197440000	3.1191360000	9.3896780000
C5	0.8797590000	2.8563390000	9.6358010000
H7	1.7870620000	0.8937310000	10.0005880000
H10	-1.3513280000	1.3958610000	8.2243350000
H11	-2.2291550000	1.6616330000	9.7389400000
H12	-0.7911500000	3.7159880000	8.4886540000
H13	-1.0591880000	3.6580510000	10.2323610000
H14	1.3602210000	3.6597540000	10.1992430000
H15	1.4102280000	2.7706580000	8.6804200000
C14	-0.4219960000	-0.5259120000	9.9027110000
C17	-1.5041340000	-1.2205760000	9.4534680000
C20	-1.5871450000	-2.6666870000	9.4031240000
C23	-0.5933950000	-3.5816540000	9.5445450000
C26	-0.8109110000	-5.0114990000	9.5259930000
C29	0.1414440000	-5.9501960000	9.6793710000
H19	-2.3915070000	-0.6763950000	9.1403760000
H20	0.4377320000	-1.0562760000	10.2951780000
H21	0.4367510000	-3.2506180000	9.6789370000
H22	-2.5900180000	-3.0598500000	9.2259080000

H23	-1.8430650000	-5.3342120000	9.3756490000
H24	-0.0926380000	-7.0101070000	9.6553120000
H25	1.1847530000	-5.6844400000	9.8363590000
C27	1.1388710000	1.5561230000	11.9361610000
C28	-2.3806960000	3.4958040000	13.6220280000
C30	-1.2556440000	4.2556960000	13.3039900000
C31	-0.1164000000	3.6413400000	12.7819710000
C32	-0.0724800000	2.2545520000	12.5745870000
C33	-1.2162230000	1.5051620000	12.8844150000
C34	-2.3566490000	2.1178920000	13.4053200000
H35	-3.2667480000	3.9724840000	14.0335740000
H36	-1.2584210000	5.3308090000	13.4655930000
H37	0.7484340000	4.2531510000	12.5452980000
H38	-1.2104740000	0.4356980000	12.7089460000
H39	-3.2290440000	1.5133800000	13.6410540000
C39	5.0040460000	3.2212250000	13.1383990000
C40	4.8340060000	2.6971470000	11.8579800000
C41	3.5952540000	2.1944470000	11.4569800000
C42	2.4876840000	2.2075140000	12.3188500000
C43	2.6794140000	2.7393820000	13.6049920000
C44	3.9167950000	3.2381090000	14.0117160000
H45	5.9690630000	3.6107990000	13.4512400000
H46	5.6692500000	2.6732080000	11.1627510000
H47	3.5122830000	1.7867670000	10.4559750000
H48	1.8484150000	2.7696180000	14.3009280000
H49	4.0270100000	3.6419730000	15.0150570000
O49	1.1628680000	0.1766350000	12.3149690000
Si50	1.6638330000	-0.7372370000	13.6421420000
C53	1.0911910000	-0.0446610000	15.3056000000
H54	1.6470460000	0.8482160000	15.6088650000
H55	0.0254170000	0.2077190000	15.2968810000
H56	1.2465520000	-0.8055720000	16.0819450000
C56	0.8306120000	-2.4006400000	13.3535310000
H57	1.1141690000	-2.8390420000	12.3902470000
H58	1.1077900000	-3.1161820000	14.1381470000
H59	-0.2615980000	-2.3088360000	13.3581320000
C59	3.5384170000	-0.9502840000	13.6503160000
H60	3.8337410000	-1.6443900000	14.4478410000

H61	3.8936870000	-1.3675920000	12.7007800000
H62	4.0632920000	-0.0042990000	13.8186310000

Transition state B to C

Basis set: 6-31g*

Net molecular charge: 0

Multiplicity: 1

number of basis functions.... 505

SCFE: Solution phase energy: DFT(b3lyp) -1430.12125570344 hartrees

angstroms

atom	x	y	z
C1	0.8451620000	1.5232570000	10.3162580000
N2	-0.4368280000	0.9326770000	9.9219160000
C3	-1.3162510000	1.8666860000	9.2213740000
C4	-0.6742590000	3.2416040000	9.4421080000
C5	0.8177300000	2.9204750000	9.6535370000
H7	1.6480500000	0.9064090000	9.9002070000
H10	-1.3655810000	1.6033750000	8.1518450000
H11	-2.3378240000	1.8109880000	9.6182460000
H12	-0.8396010000	3.9115080000	8.5926810000
H13	-1.0941420000	3.7196500000	10.3307230000
H14	1.3336850000	3.6799650000	10.2462570000
H15	1.3314520000	2.8621280000	8.6868970000
C14	-0.5964170000	-0.4230320000	9.7678820000
C17	-1.6410910000	-1.0575610000	9.1753380000
C20	-1.6961630000	-2.5000030000	9.0693490000
C23	-2.6662340000	-3.2128680000	8.4625200000
C26	-2.6969920000	-4.6960060000	8.3925610000
C29	-2.2708430000	-5.4240410000	7.3570620000
H19	-2.4718660000	-0.4907020000	8.7607080000
H20	0.2116220000	-1.0070140000	10.1961530000
H21	-3.5139020000	-2.6821450000	8.0228520000
H22	-0.8622410000	-3.0453240000	9.5164200000

H23	-3.1166700000	-5.2238610000	9.2543160000
H24	-2.3317140000	-6.5101140000	7.3605230000
H25	-1.8449070000	-4.9596530000	6.4705150000
C27	1.0903400000	1.5120580000	11.8805050000
C28	-2.3103170000	3.4660220000	13.7783470000
C30	-1.1773940000	4.2101140000	13.4516530000
C31	-0.0754720000	3.5904330000	12.8601100000
C32	-0.0780110000	2.2138080000	12.5898230000
C33	-1.2312800000	1.4822200000	12.9063680000
C34	-2.3332740000	2.0997160000	13.4981300000
H35	-3.1664490000	3.9461560000	14.2453370000
H36	-1.1440420000	5.2764590000	13.6610640000
H37	0.7968640000	4.1898890000	12.6191040000
H38	-1.2617150000	0.4226100000	12.6820590000
H39	-3.2132030000	1.5084190000	13.7389090000
C39	5.0381680000	3.0333580000	12.9925000000
C40	4.8094350000	2.5529750000	11.7044790000
C41	3.5442900000	2.0958280000	11.3342850000
C42	2.4688850000	2.1114110000	12.2364000000
C43	2.7212720000	2.5971160000	13.5300520000
C44	3.9849620000	3.0513620000	13.9057580000
H45	6.0238860000	3.3887730000	13.2809540000
H46	5.6186910000	2.5287600000	10.9792320000
H47	3.4141640000	1.7219430000	10.3252980000
H48	1.9172030000	2.6278550000	14.2563530000
H49	4.1424120000	3.4215930000	14.9157260000
O49	1.0918310000	0.1169960000	12.2083200000
Si50	1.6289530000	-0.8412100000	13.4876820000
C53	1.1175770000	-0.1993770000	15.1907890000
H54	1.6998090000	0.6717170000	15.5079050000
H55	0.0574190000	0.0731770000	15.2236150000
H56	1.2821210000	-0.9894180000	15.9354620000
C56	0.7704950000	-2.4877400000	13.1675130000
H57	1.0551220000	-2.9051530000	12.1947930000
H58	1.0384040000	-3.2241970000	13.9354710000
H59	-0.3202170000	-2.3800560000	13.1744630000
C59	3.4993760000	-1.0833860000	13.4334600000
H60	3.8039950000	-1.8104710000	14.1975660000

H61	3.8210870000	-1.4719870000	12.4601210000
H62	4.0455470000	-0.1533200000	13.6208400000

Transition state B to D

Basis set: 6-31g*

Net molecular charge: 0

Multiplicity: 1

number of basis functions.... 505

SCFE: Solution phase energy: DFT(b3lyp) -1430.11838245521 hartrees

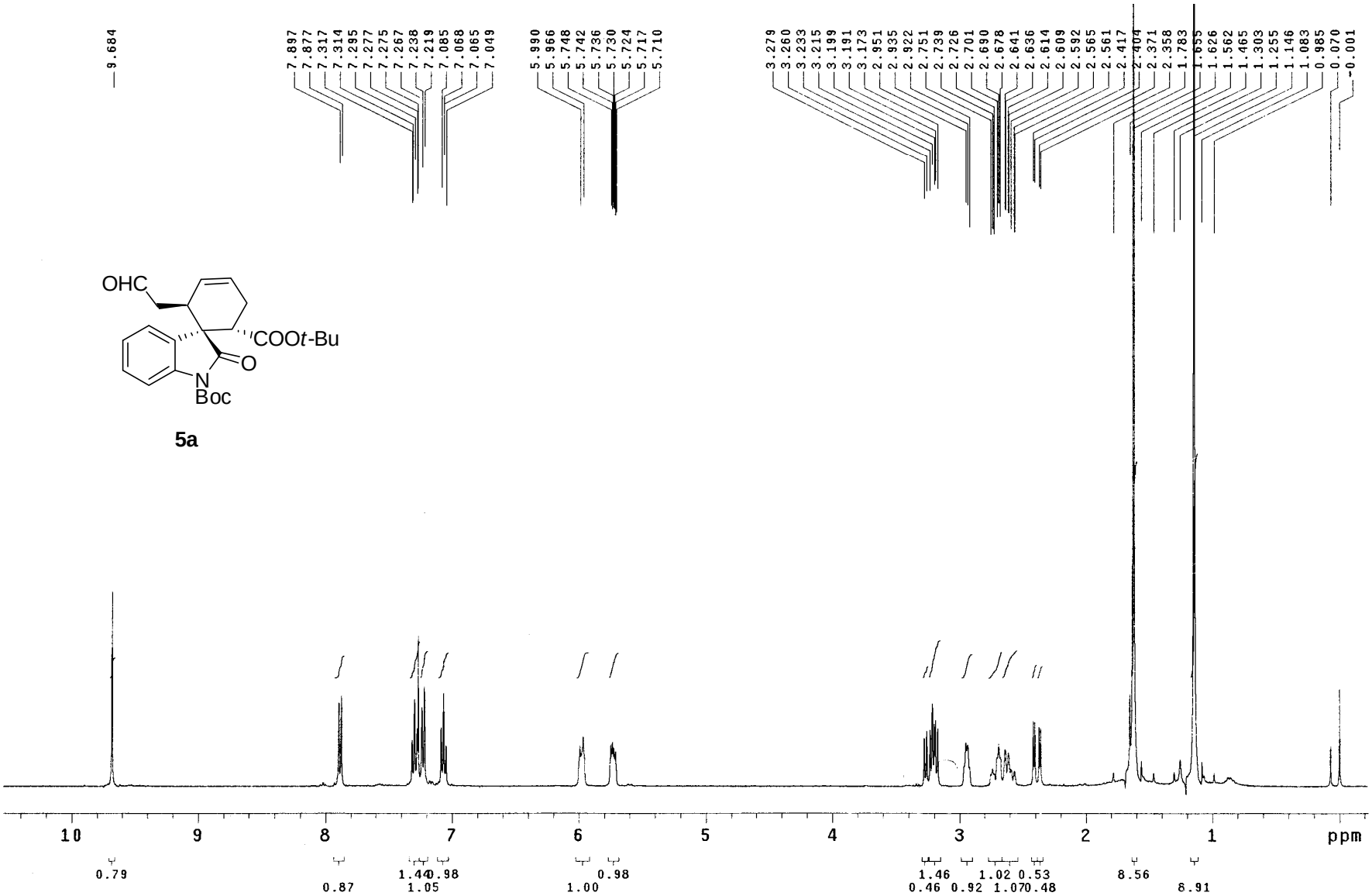
angstroms

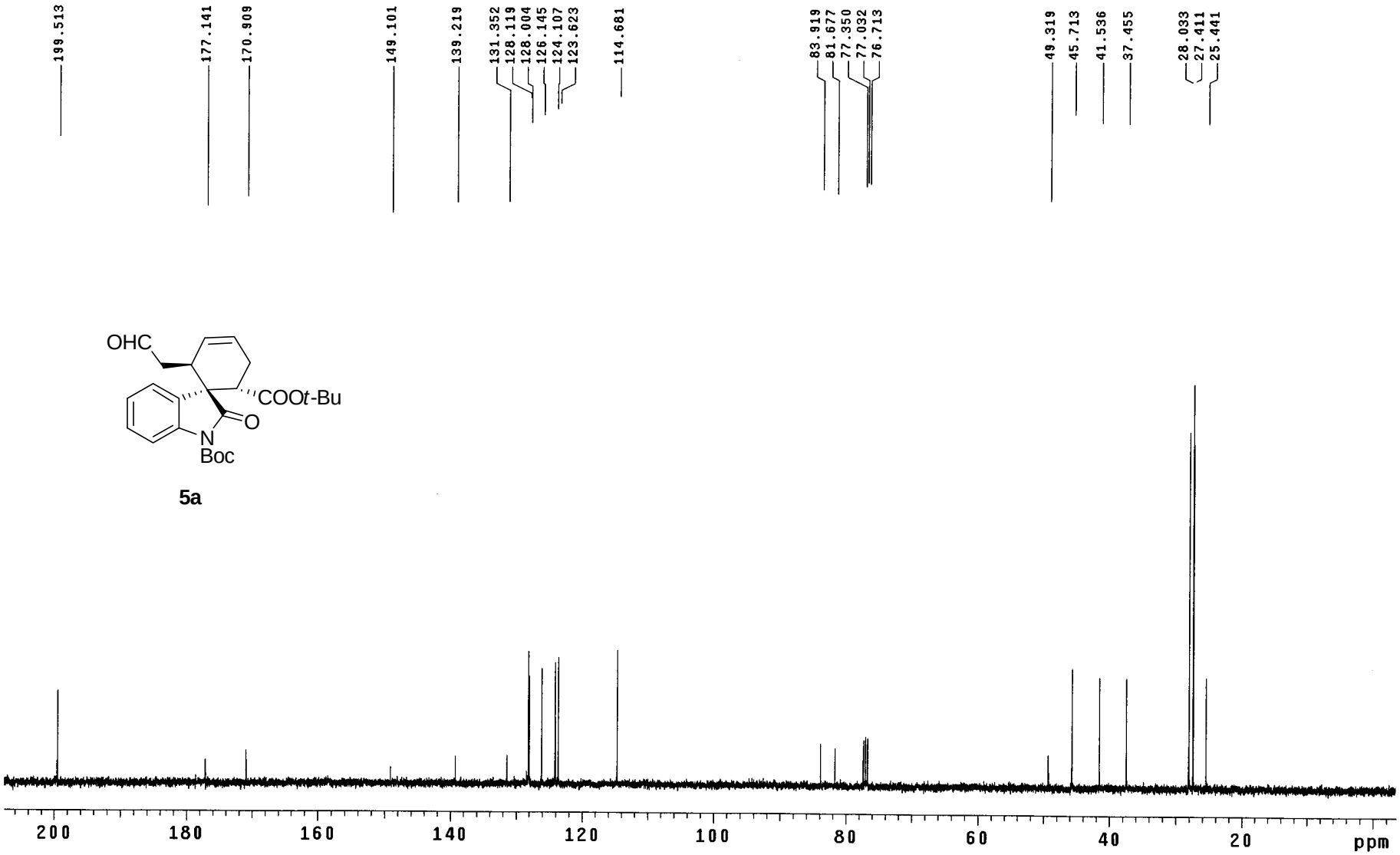
atom	x	y	z
C1	0.8333700000	1.5325360000	10.3096560000
N2	-0.4500730000	0.9478350000	9.9167610000
C3	-1.3270030000	1.8854730000	9.2215560000
C4	-0.6814130000	3.2590220000	9.4433880000
C5	0.8096500000	2.9336230000	9.6546640000
H7	1.6366520000	0.9173740000	9.8911090000
H10	-1.3814940000	1.6241700000	8.1509880000
H11	-2.3489690000	1.8346710000	9.6193680000
H12	-0.8448860000	3.9301000000	8.5943230000
H13	-1.1004050000	3.7379230000	10.3319680000
H14	1.3270870000	3.6894070000	10.2510830000
H15	1.3238050000	2.8790490000	8.6879810000
C14	-0.6040730000	-0.4108660000	9.7262840000
C17	-1.6445060000	-1.0251050000	9.1240440000
C20	-1.7398960000	-2.5008790000	9.0035330000
C23	-1.3199530000	-3.2178240000	7.9447660000
C26	-1.4366120000	-4.6655700000	7.8397640000
C29	-1.0092080000	-5.3938070000	6.7971820000
H19	-2.4940960000	-0.4429870000	8.7678440000
H20	0.2132560000	-1.0009550000	10.1268670000
H21	-0.8553710000	-2.6991020000	7.1055620000
H22	-2.2061250000	-3.0483110000	9.8299490000

H23	-1.9087560000	-5.1715130000	8.6832720000
H24	-1.1202160000	-6.4737920000	6.7696080000
H25	-0.5336250000	-4.9304430000	5.9353590000
C27	1.0797830000	1.5133550000	11.8745890000
C28	-2.3212060000	3.4461520000	13.7950710000
C30	-1.1989780000	4.1990900000	13.4514360000
C31	-0.0972760000	3.5862320000	12.8523900000
C32	-0.0884940000	2.2078720000	12.5911000000
C33	-1.2311060000	1.4676750000	12.9245870000
C34	-2.3330840000	2.0779490000	13.5241050000
H35	-3.1773990000	3.9210140000	14.2675400000
H36	-1.1742210000	5.2671840000	13.6531350000
H37	0.7665420000	4.1925870000	12.5982220000
H38	-1.2536190000	0.4070190000	12.7050850000
H39	-3.2048030000	1.4795490000	13.7774460000
C39	5.0290120000	3.0246290000	12.9953260000
C40	4.8046440000	2.5302970000	11.7115830000
C41	3.5389570000	2.0759640000	11.3402170000
C42	2.4584540000	2.1104510000	12.2356900000
C43	2.7064570000	2.6086500000	13.5251970000
C44	3.9710810000	3.0591080000	13.9026580000
H45	6.0153680000	3.3773960000	13.2851730000
H46	5.6179490000	2.4923810000	10.9913500000
H47	3.4111830000	1.6889140000	10.3358130000
H48	1.8991760000	2.6508130000	14.2472370000
H49	4.1255460000	3.4391160000	14.9095000000
O49	1.0800710000	0.1162370000	12.1965790000
Si50	1.6424680000	-0.8498640000	13.4580750000
C53	1.1769720000	-0.2119380000	15.1760190000
H54	1.7711800000	0.6556750000	15.4800910000
H55	0.1192650000	0.0662050000	15.2347780000
H56	1.3553290000	-1.0044770000	15.9148470000
C56	0.7651530000	-2.4901250000	13.1555530000
H57	0.9887240000	-2.8861890000	12.1585670000
H58	1.0767560000	-3.2424400000	13.8912800000
H59	-0.3229460000	-2.3811190000	13.2312440000
C59	3.5094800000	-1.1031070000	13.3584060000
H60	3.8278820000	-1.8364080000	14.1108780000

H61	3.8054930000	-1.4878710000	12.3754370000
H62	4.0651980000	-0.1771510000	13.5379200000

8. NMR spectra and HPLC chromatograms

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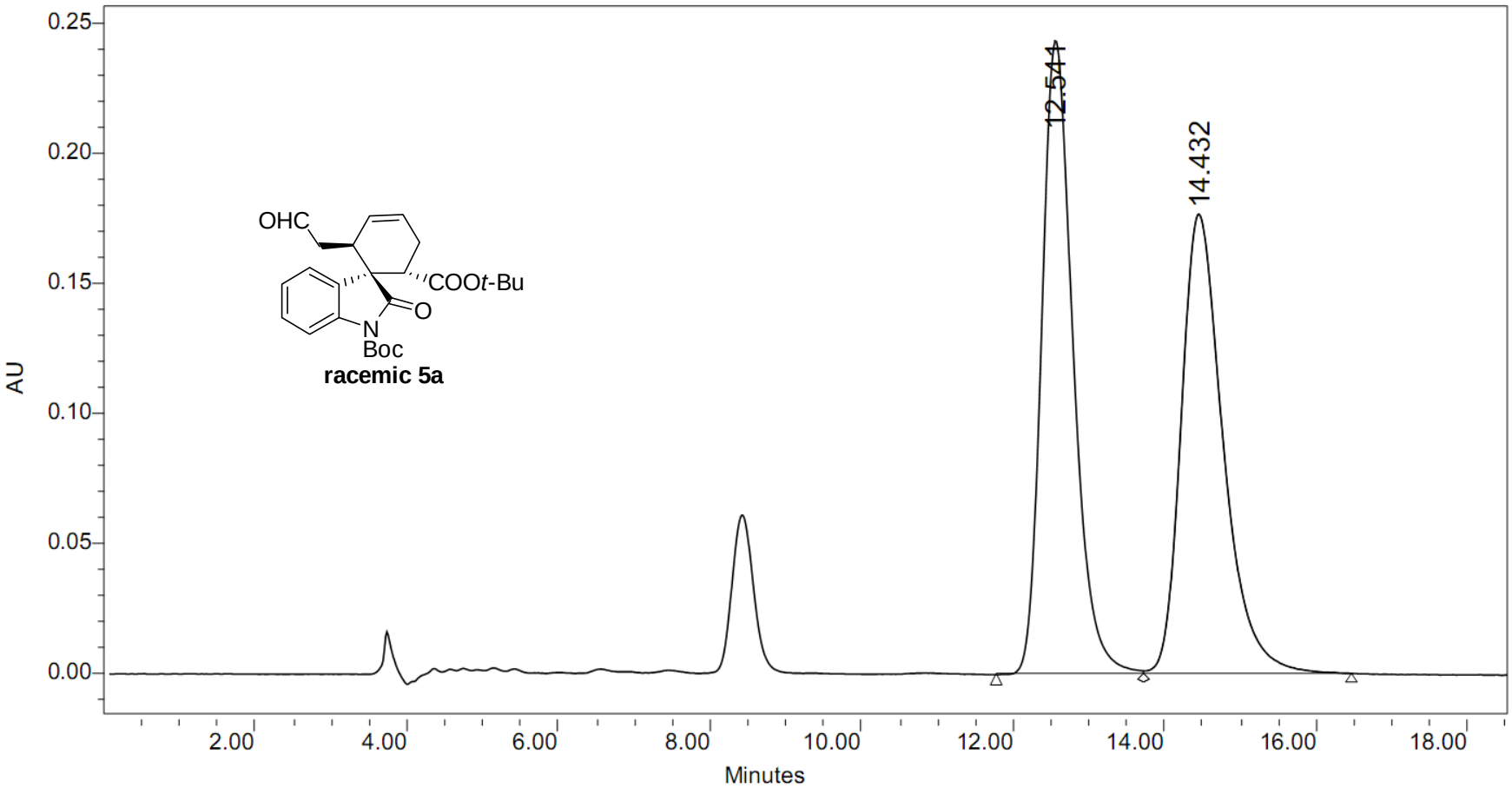
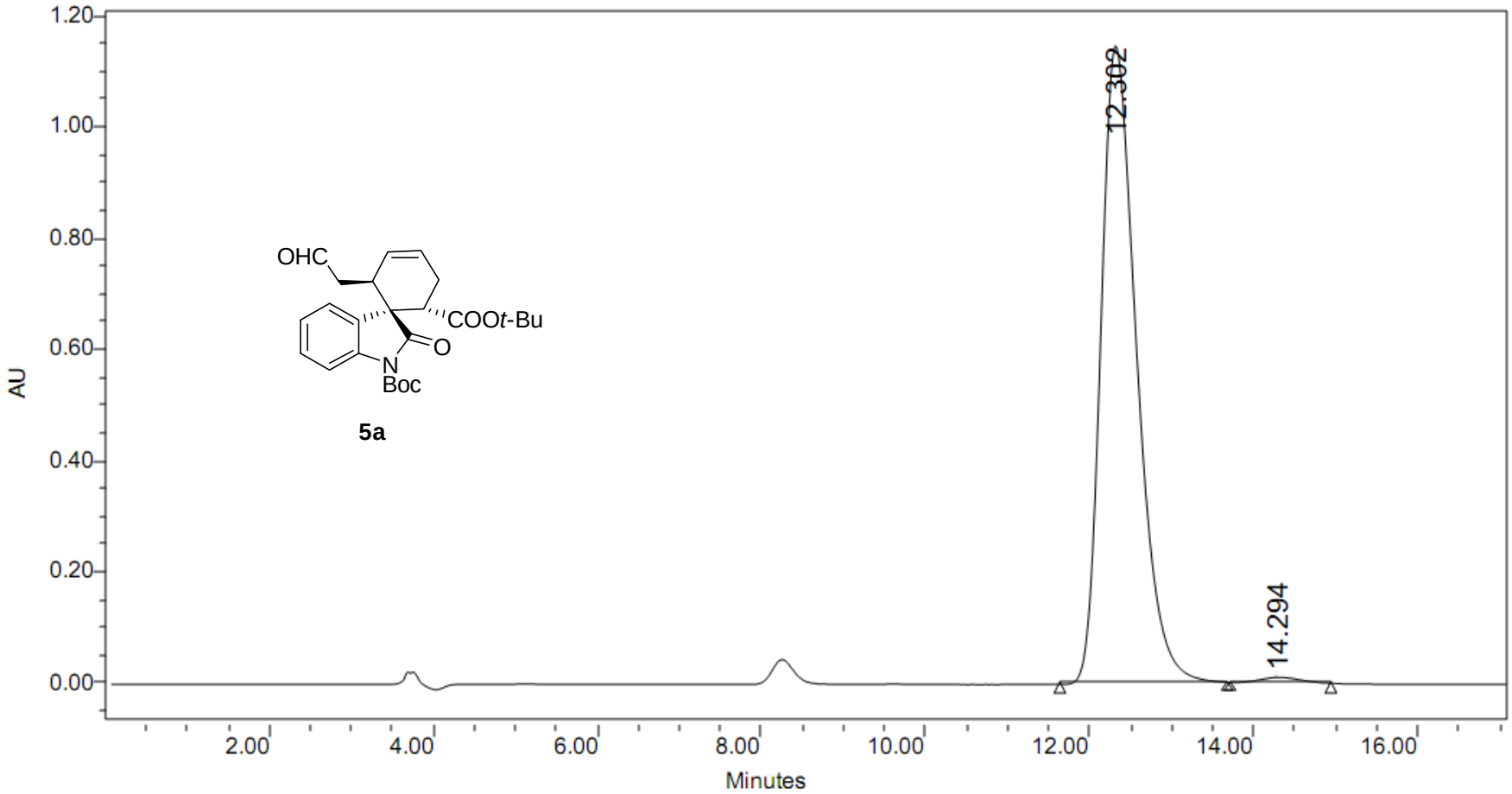
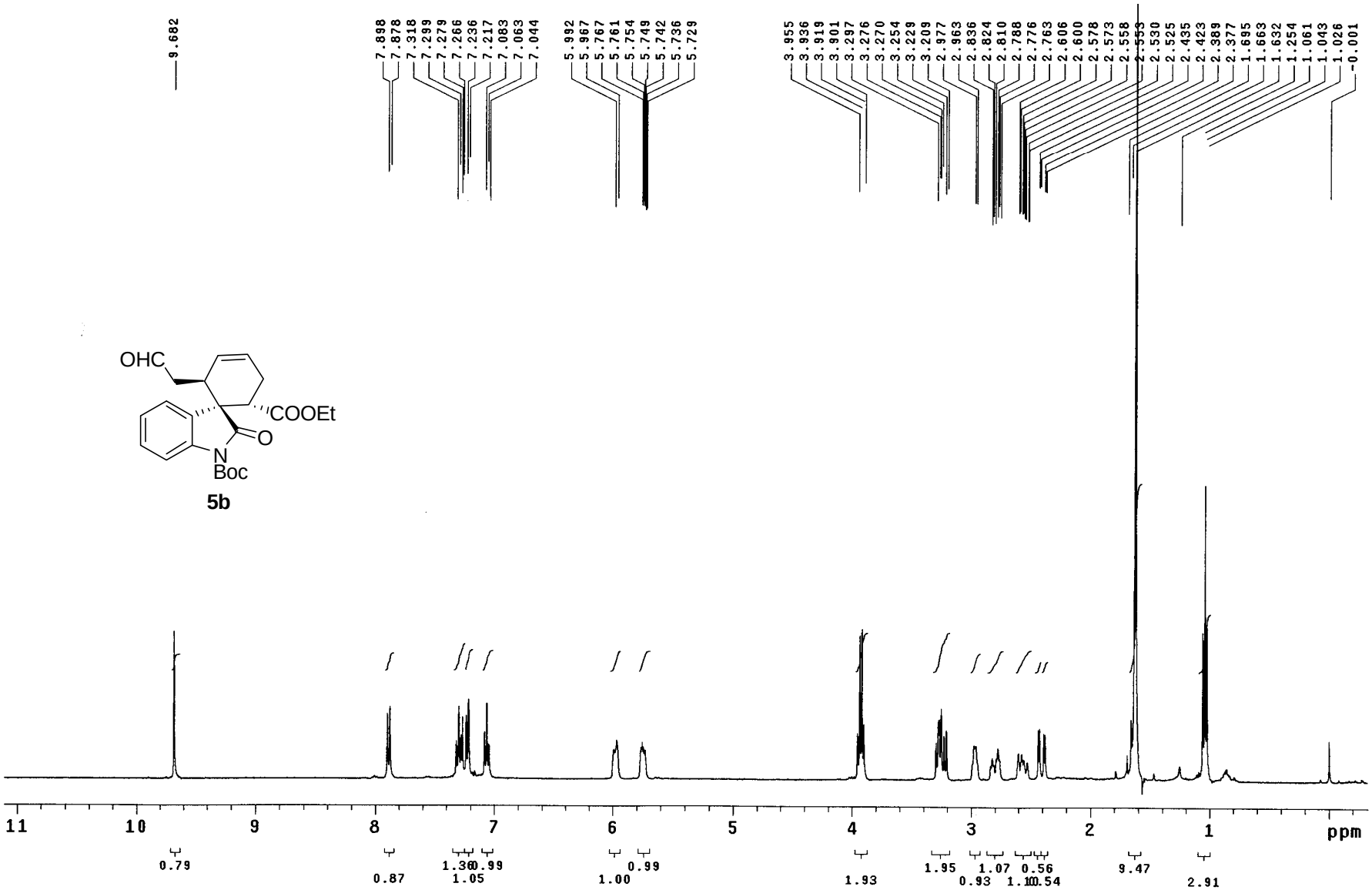
128.004
126.145
124.107
123.623
114.681
83.919
81.677
77.350
77.032
76.713
49.319
45.713
41.536
37.455
28.033
27.411
25.441
OHC
COOt-Bu
O
N
Boc
5a
200
180
160
140
120
100
80
60
40
20
ppm



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	12.541	7030432	50.77	244072	57.96
2	14.432	6816885	49.23	177042	42.04



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	12.302	34631386	99.06	1147010	99.15
2	14.294	330364	0.94	9791	0.85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COOEt
O
N
Boc
5b
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7.236
7.217
7.083
7.063
7.044
5.992
5.967
5.767
5.761
5.754
5.749
5.742
5.736
5.729
3.955
3.936
3.919
3.901
3.297
3.276
3.270
3.254
3.229
3.209
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2.963
2.836
2.824
2.810
2.788
2.776
2.763
2.606
2.600
2.578
2.573
2.558
2.553
2.530
2.525
2.435
2.423
2.389
2.377
1.695
1.663
1.632
1.254
1.061
1.043
1.026
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11
10
9
8
7
6
5
4
3
2
1
ppm
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0.87
1.36
0.99
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1.95
1.07
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0.93
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0.54
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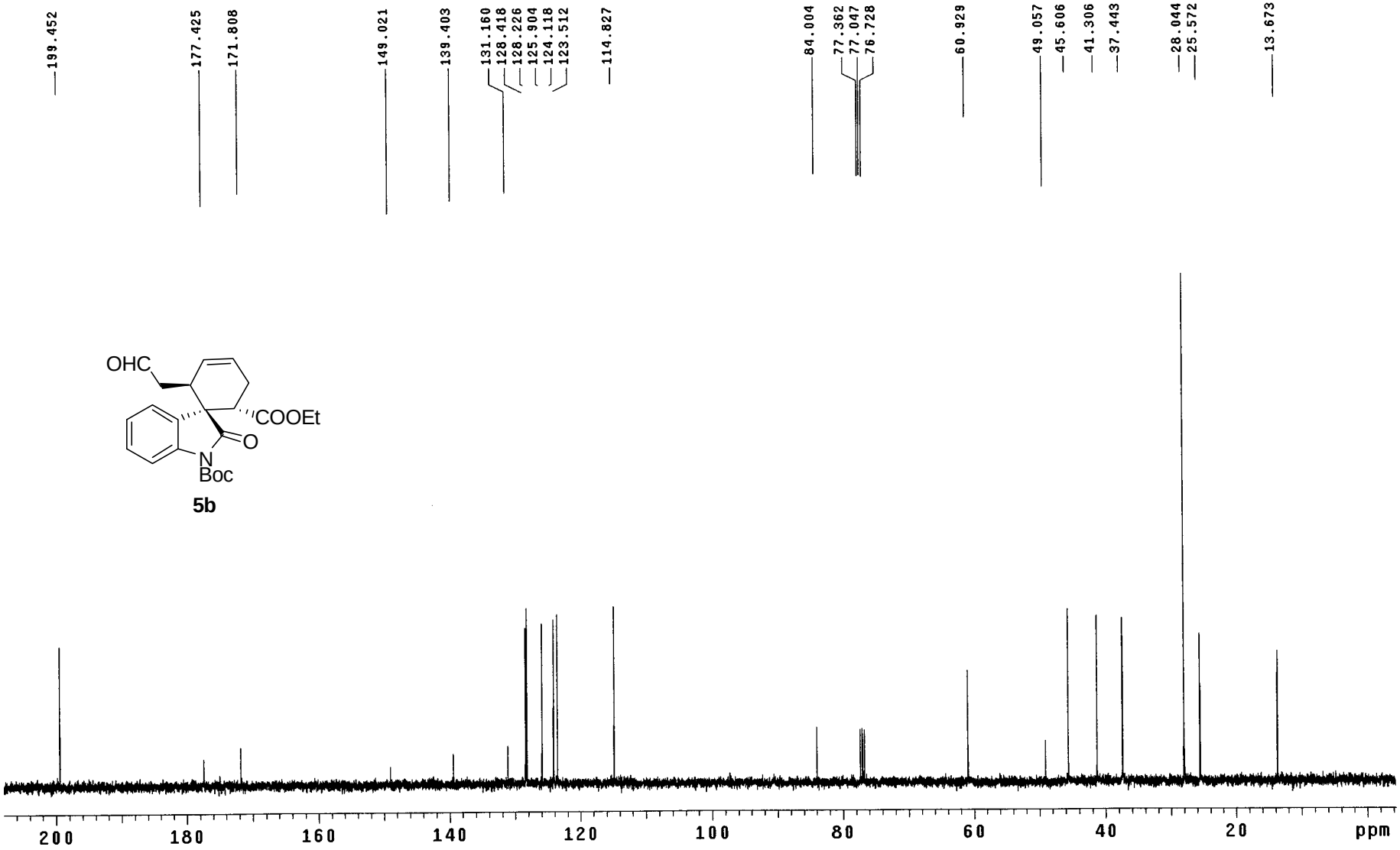
2.91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114.827
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77.362
77.047
76.728
60.929
49.057
45.606
41.306
37.443
28.044
25.572
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COOEt
O
N
Boc
5b
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140
120
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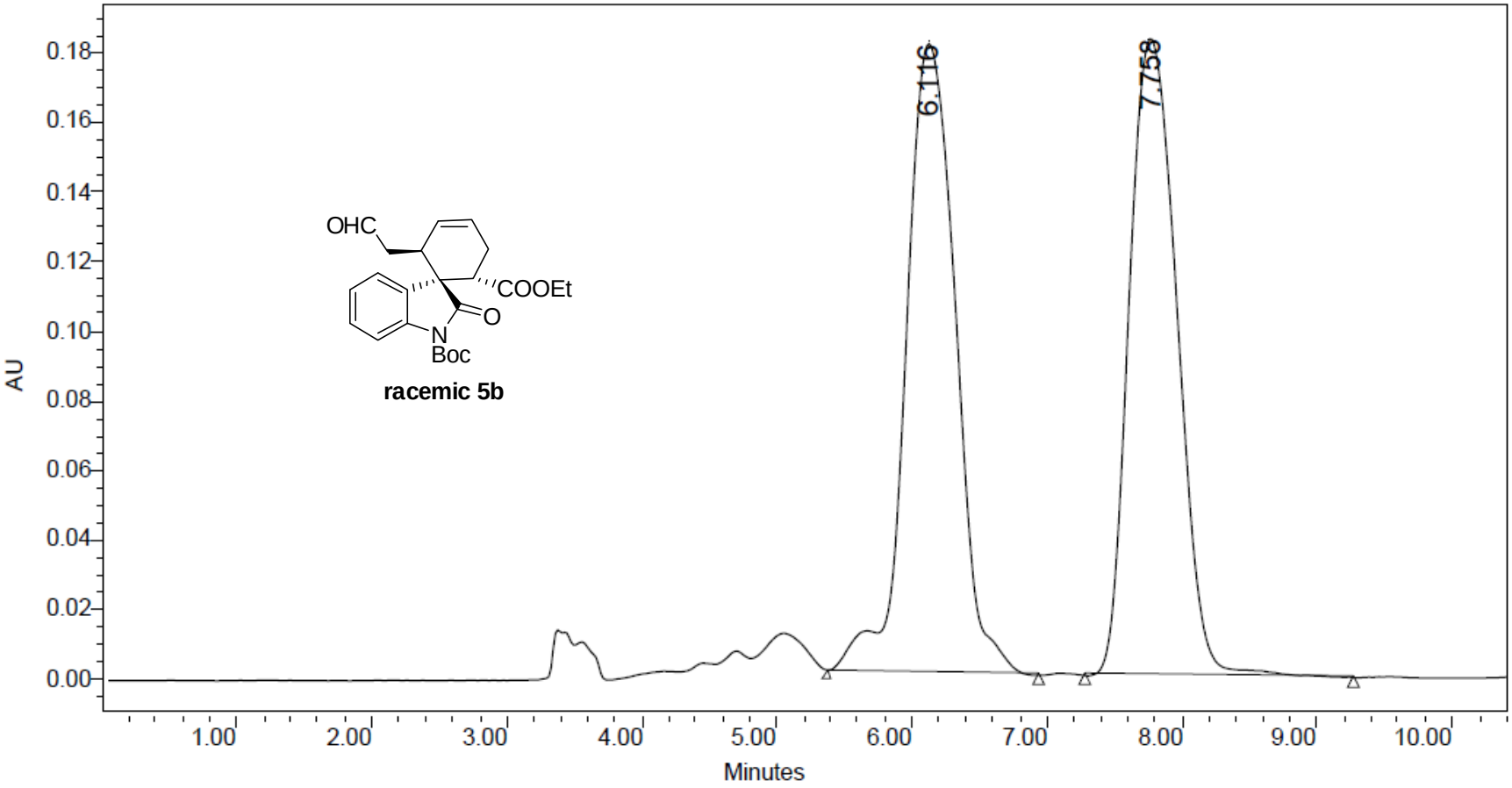
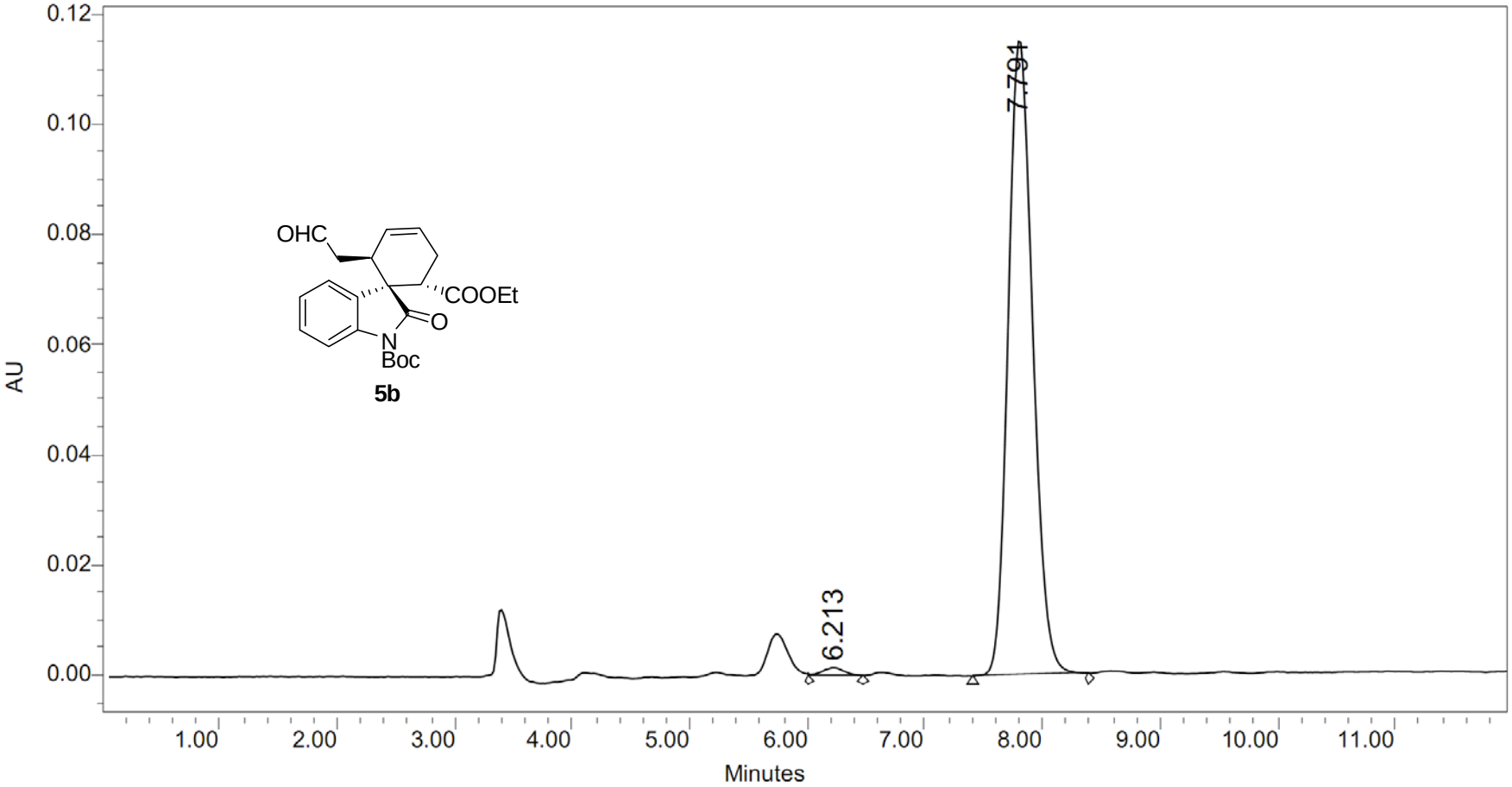
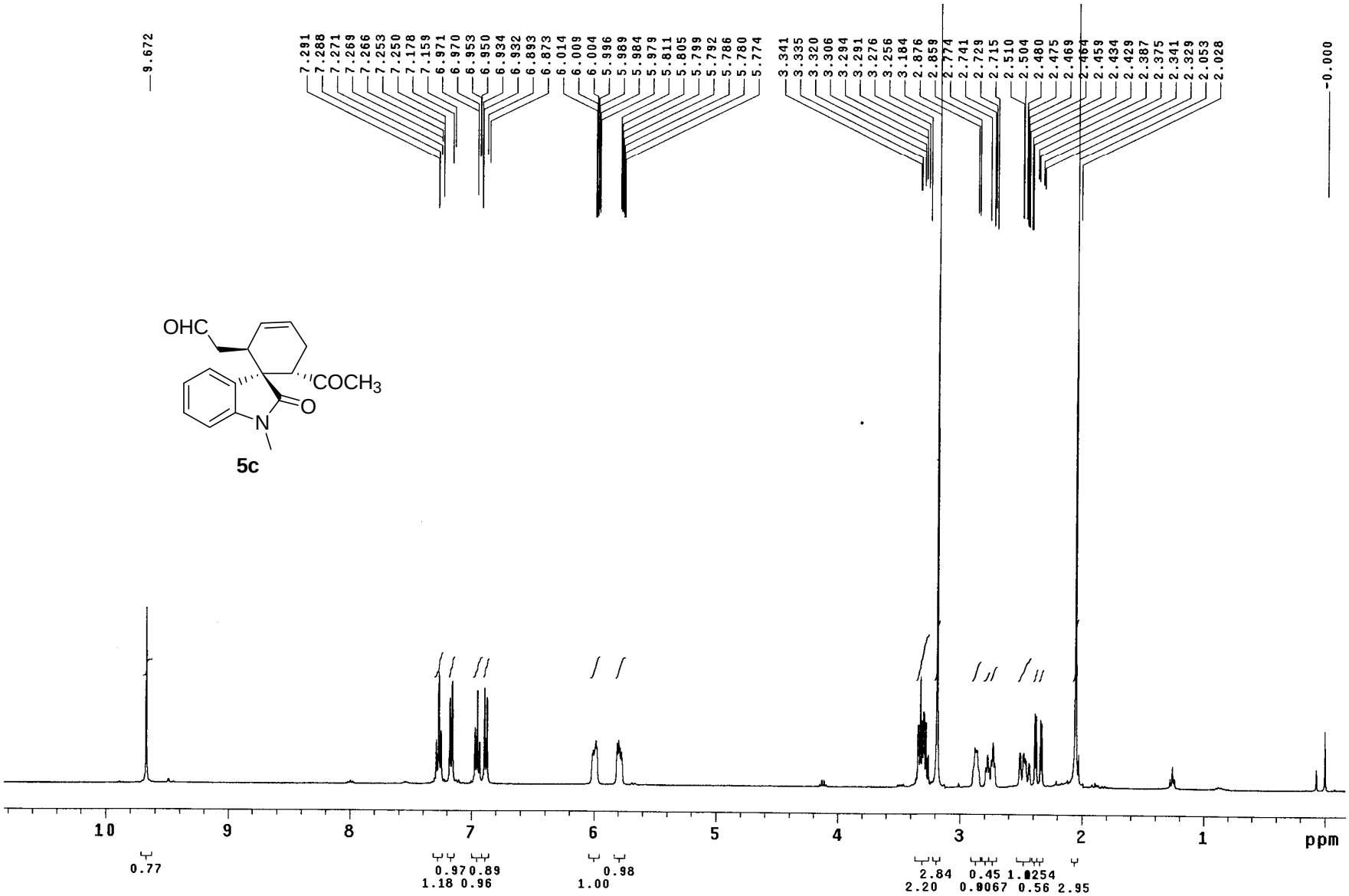
80
60
40
20
ppm



	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	6.116	4627359	50.51	180771	49.65
2	7.758	4533281	49.49	183316	50.35



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	6.213	20346	1.20	1513	1.29
2	7.791	1682049	98.80	115351	98.71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7.253
7.250
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6.953
6.950
6.934
6.932
6.893
6.873
6.014
6.009
6.004
5.996
5.989
5.984
5.979
5.811
5.805
5.799
5.792
5.786
5.780
5.774
3.341
3.335
3.320
3.306
3.294
3.291
3.276
3.256
3.184
2.876
2.859
2.774
2.741
2.729
2.715
2.510
2.504
2.480
2.475
2.469
2.464
2.459
2.434
2.429
2.387
2.375
2.341
2.329
2.053
2.028
-0.000
OHC
COCH3
O
N
5c
10
9
8
7
6
5
4
3
2
1
ppm
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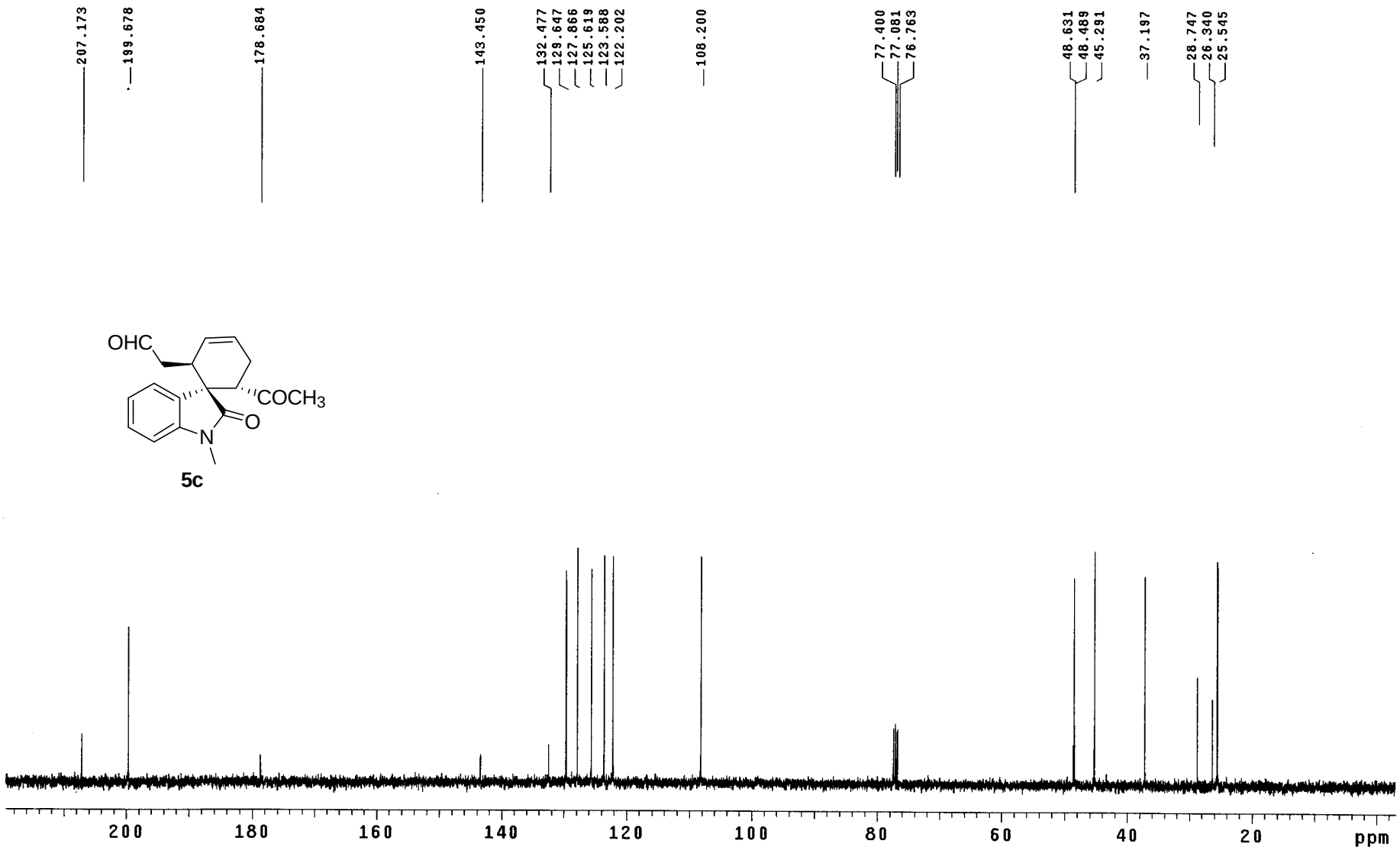
1.18 0.96
1.00
0.98
2.84
0.45
2.20
0.56
2.95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125.619
123.588
122.202
108.200
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77.081
76.763
48.631
48.489
45.291
37.197
28.747
26.340
25.545
OHC
COCH3
O
N
5c
200
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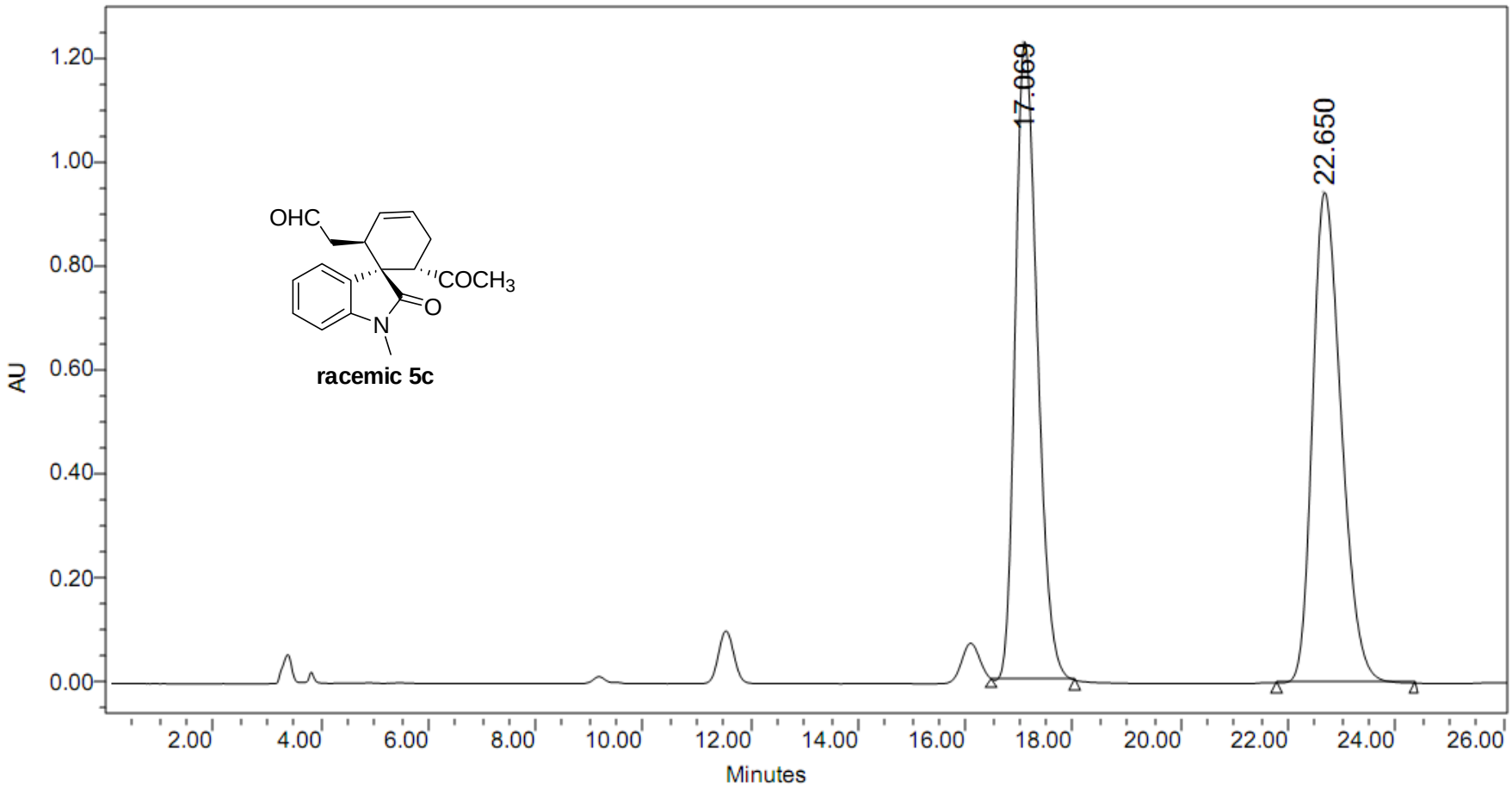
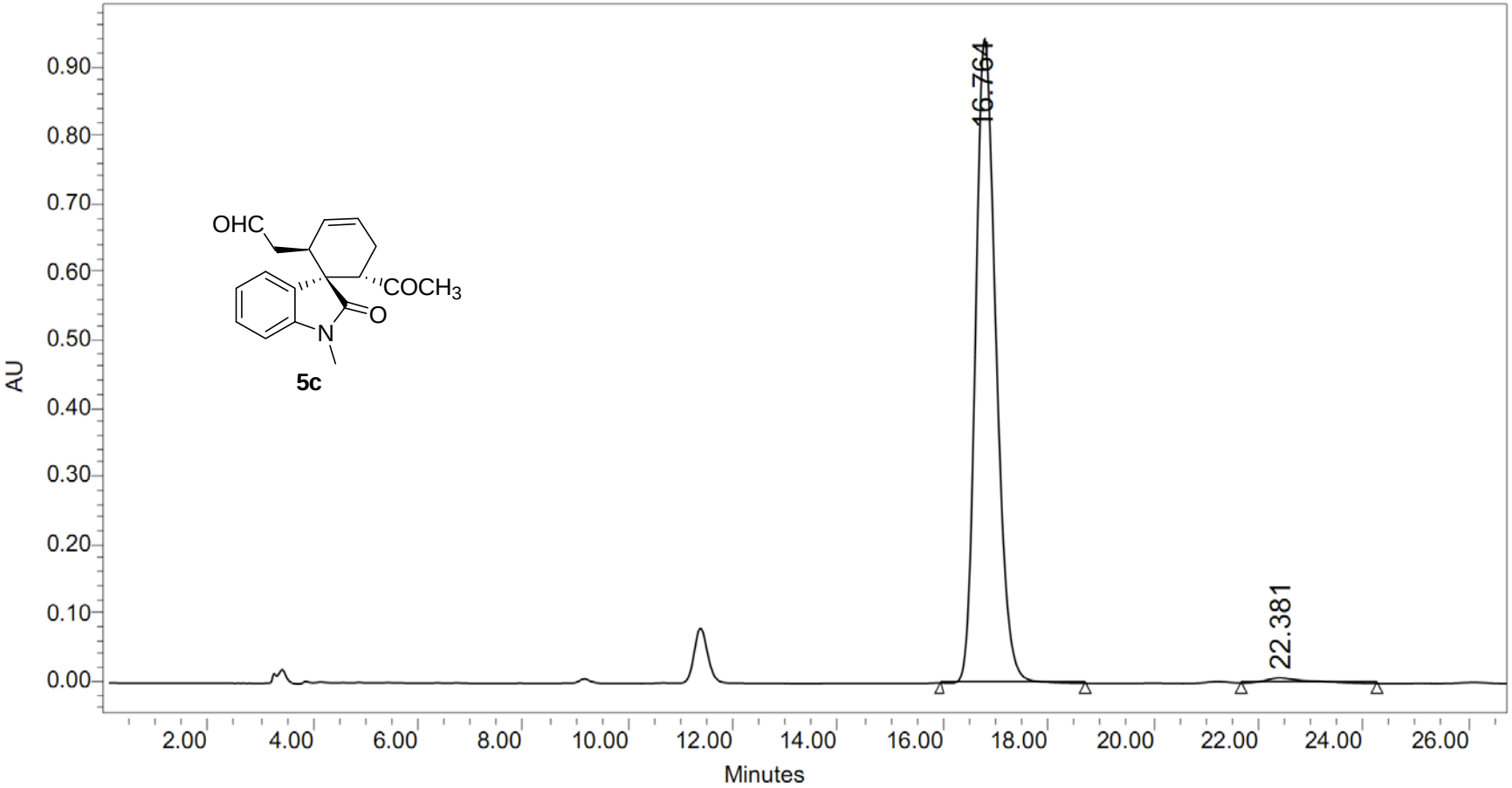
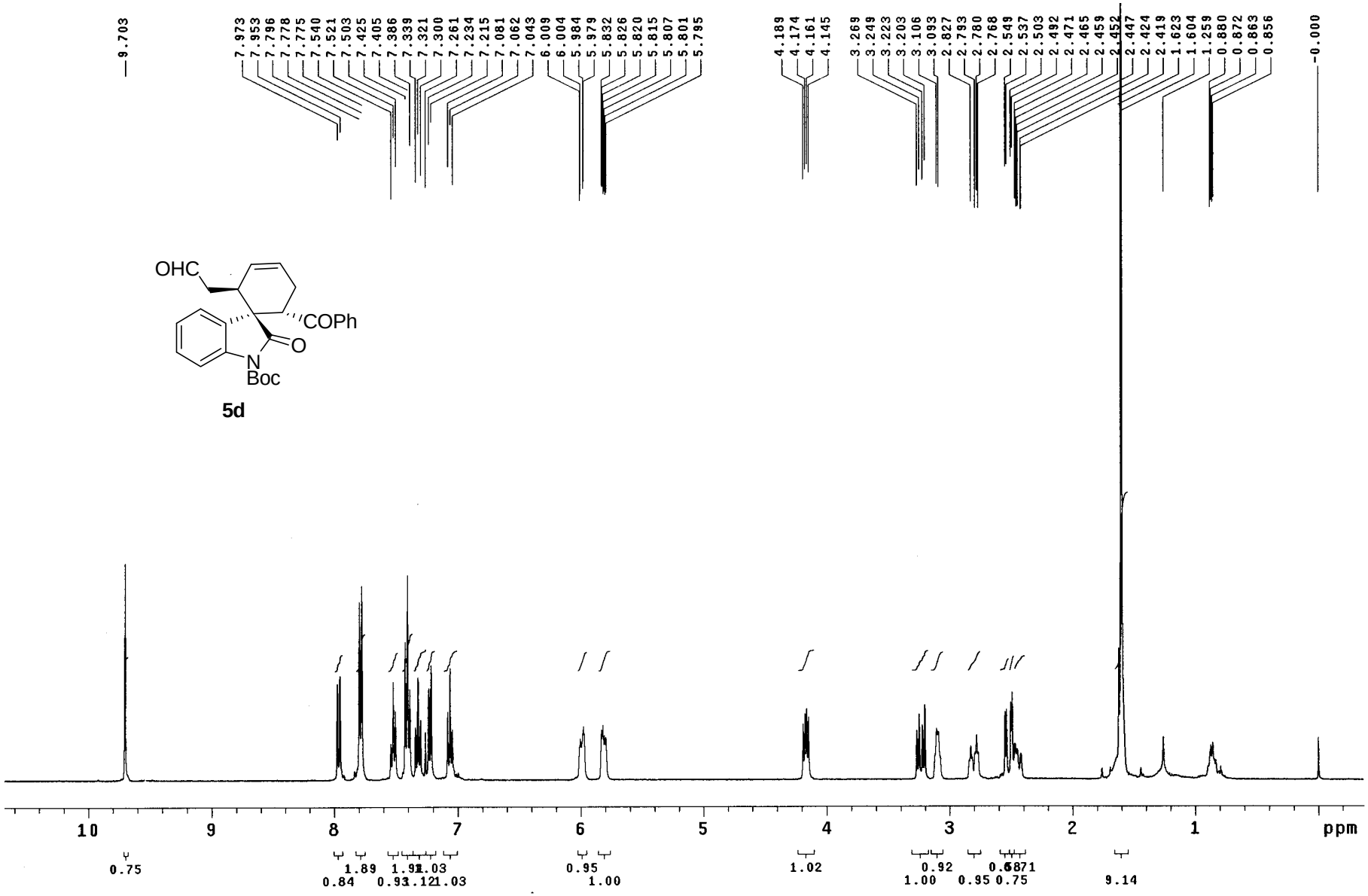
160
140
120
100
80
60
40
20
ppm



	RT (min)	Area (µV*sec)	% Area	Height (µV)	% Height
1	17.069	35064964	49.95	1229081	56.54
2	22.650	35139612	50.05	944589	43.46



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	16.764	25559644	98.44	943009	99.22
2	22.381	404924	1.56	7443	0.78


OHC
COPh
O
N
Boc
5d
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7.503
7.425
7.405
7.386
7.339
7.321
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7.261
7.234
7.215
7.081
7.062
7.043
6.009
6.004
5.984
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5.826
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10
9
8
7
6
5
4
3
2
1
ppm
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1.91
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1.03
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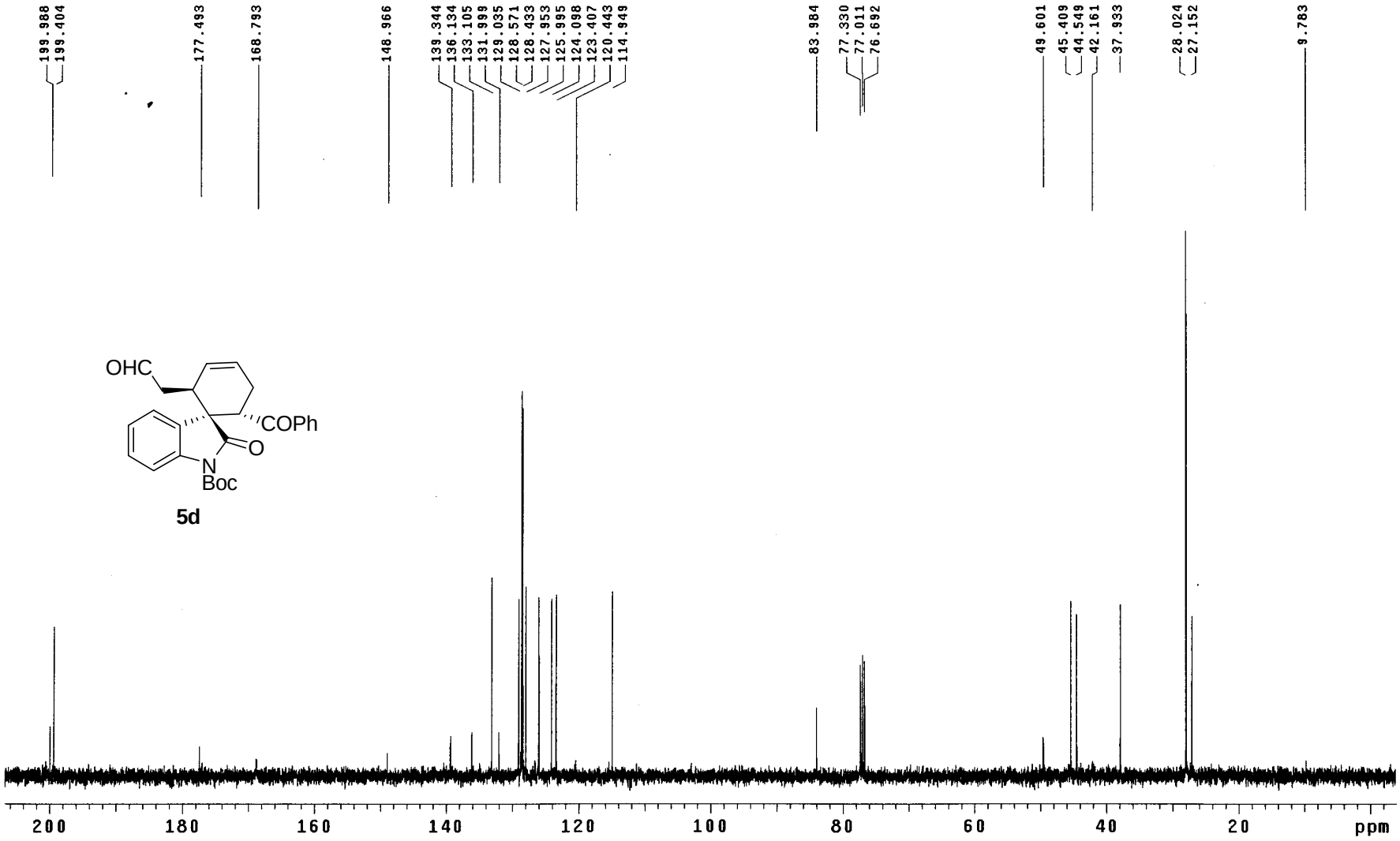
9.14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133.105
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127.953
125.995
124.098
123.407
120.443
114.949
83.984
77.330
77.011
76.692
49.601
45.409
44.549
42.161
37.933
28.024
27.152
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OHC
COPh
O
N
Boc
5d
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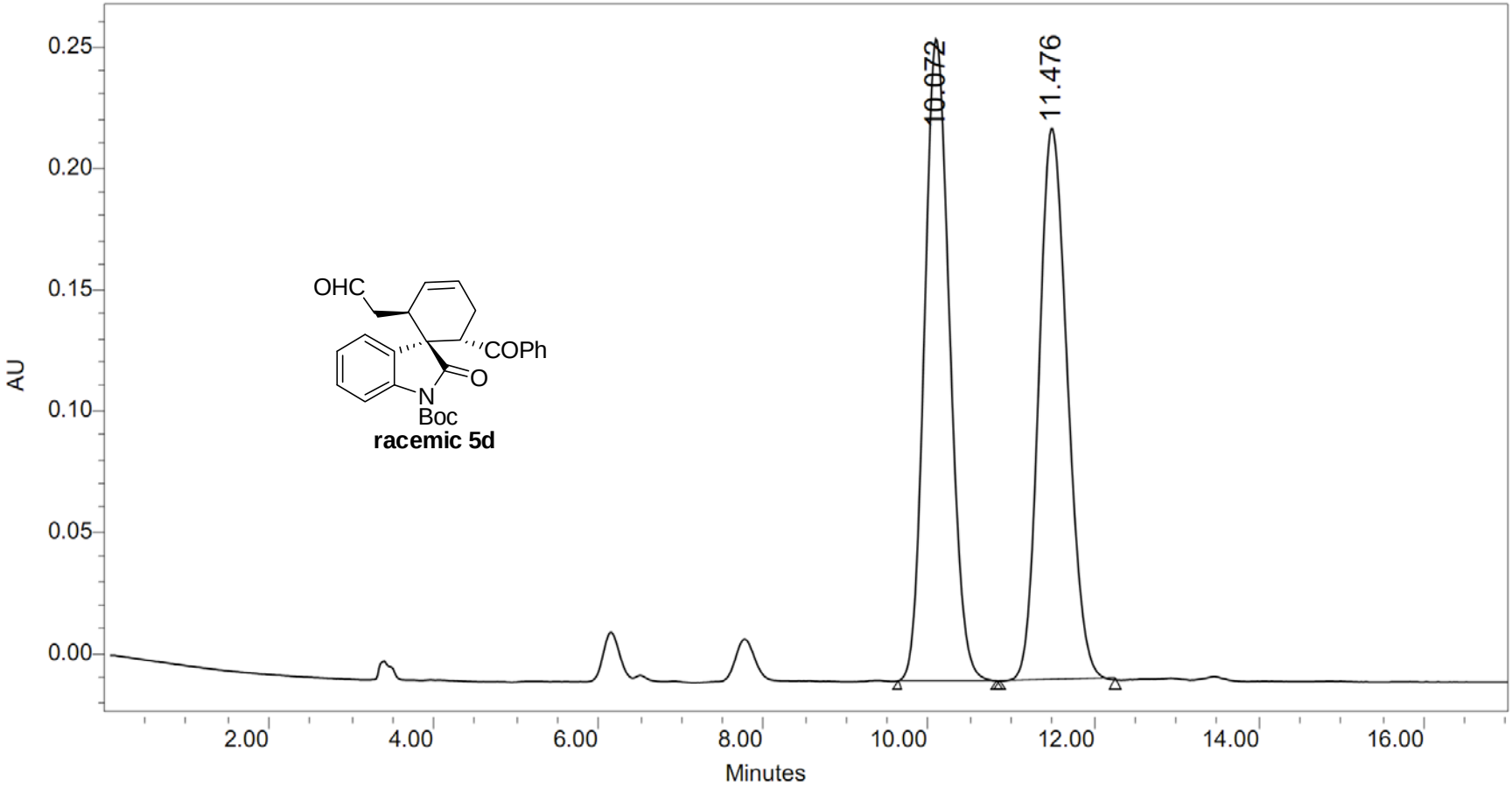
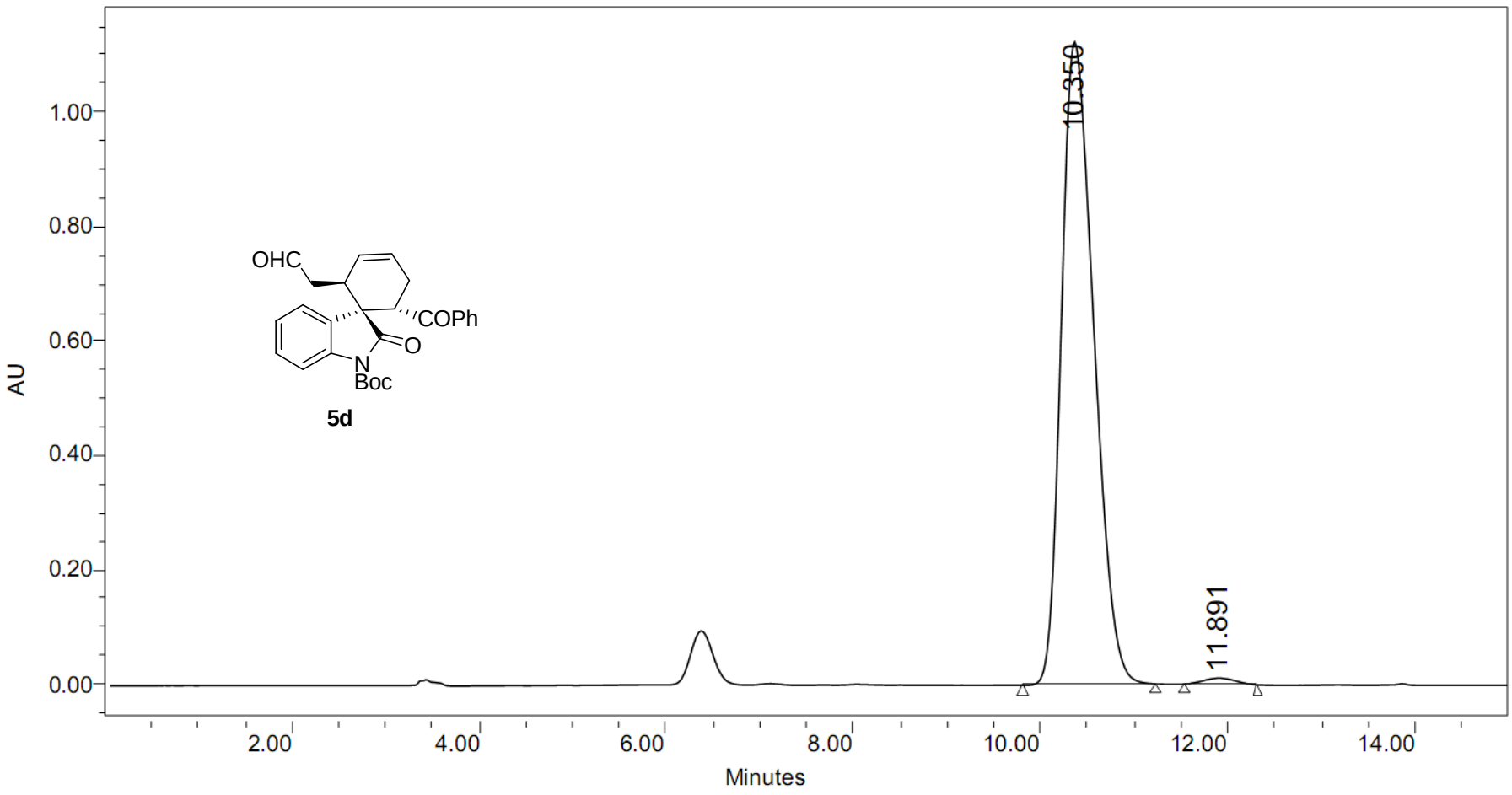
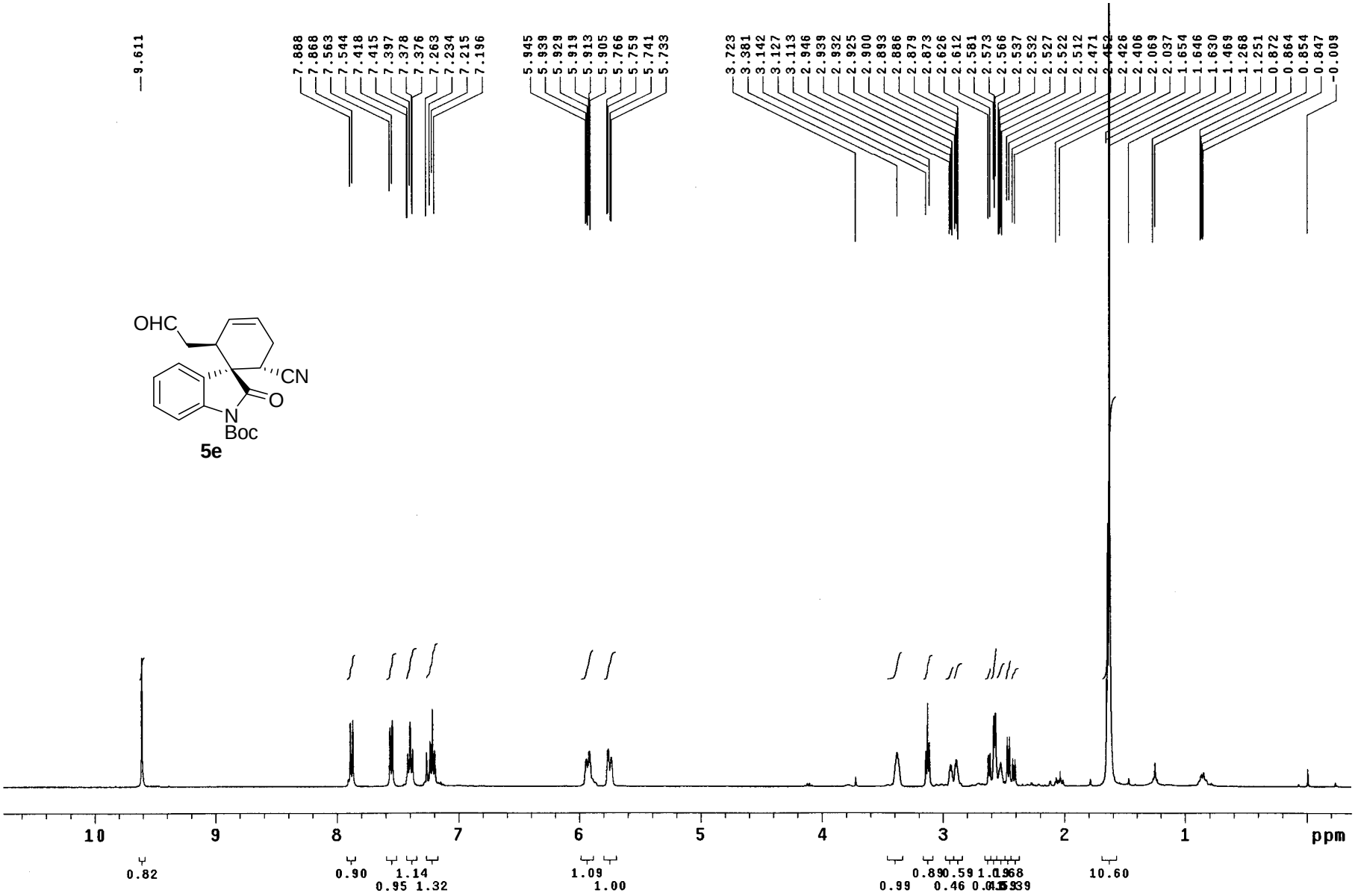
140
120
100
80
60
40
20
ppm



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	10.072	5607131	50.55	264224	53.74
2	11.476	5484524	49.45	227436	46.26



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	10.350	27059177	99.06	1122980	99.03
2	11.891	257854	0.94	10994	0.97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CN
O
N
Boc
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7.378
7.376
7.263
7.234
7.215
7.196
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5.939
5.929
5.919
5.913
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5.733
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2.873
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2.612
2.581
2.573
2.566
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2.532
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2.522
2.512
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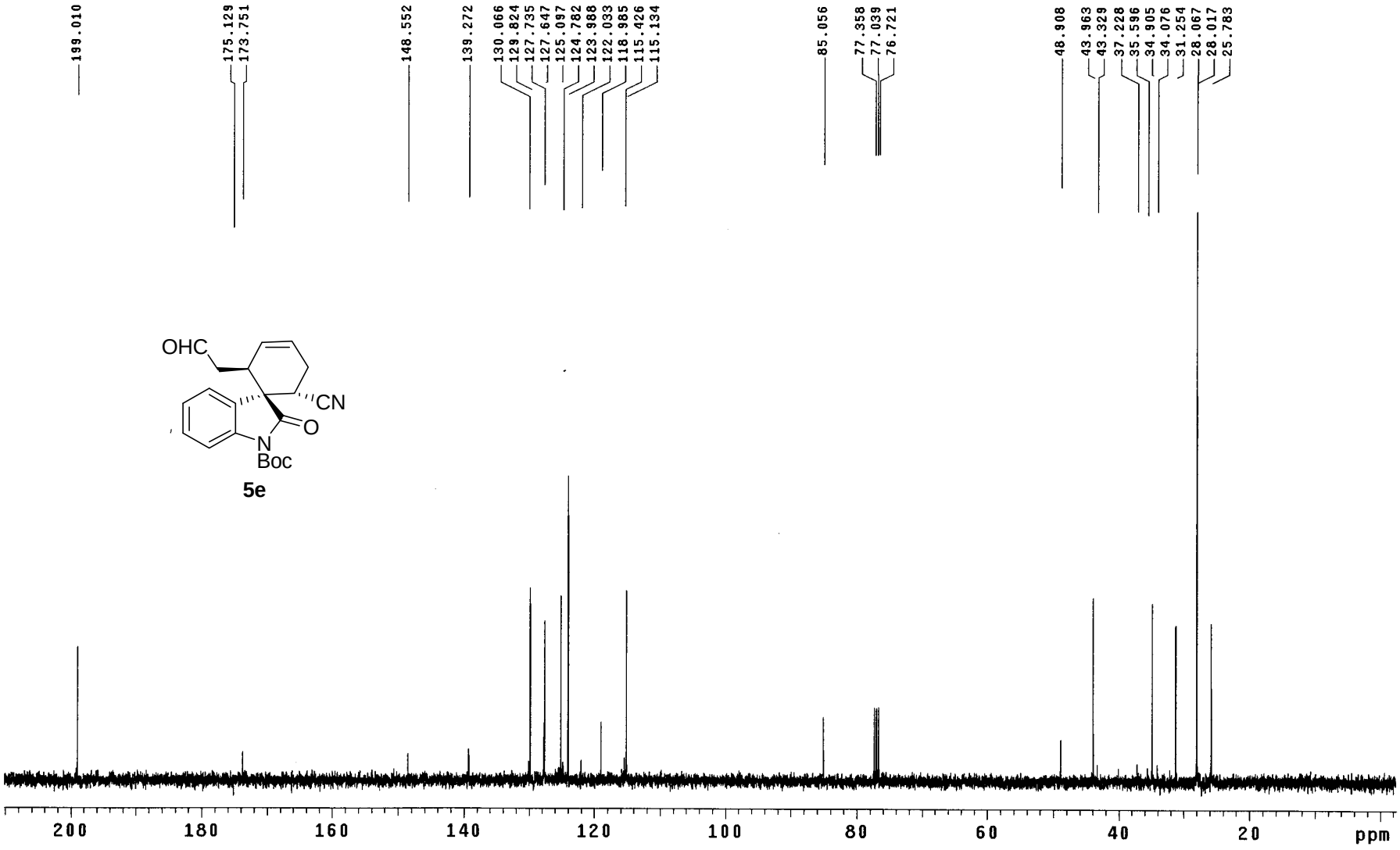
10.60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122.033
118.985
115.426
115.134
85.056
77.358
77.039
76.721
48.908
43.963
43.329
37.228
35.596
34.905
34.076
31.254
28.067
28.017
25.783
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CN
O
N
Boc
5e
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140
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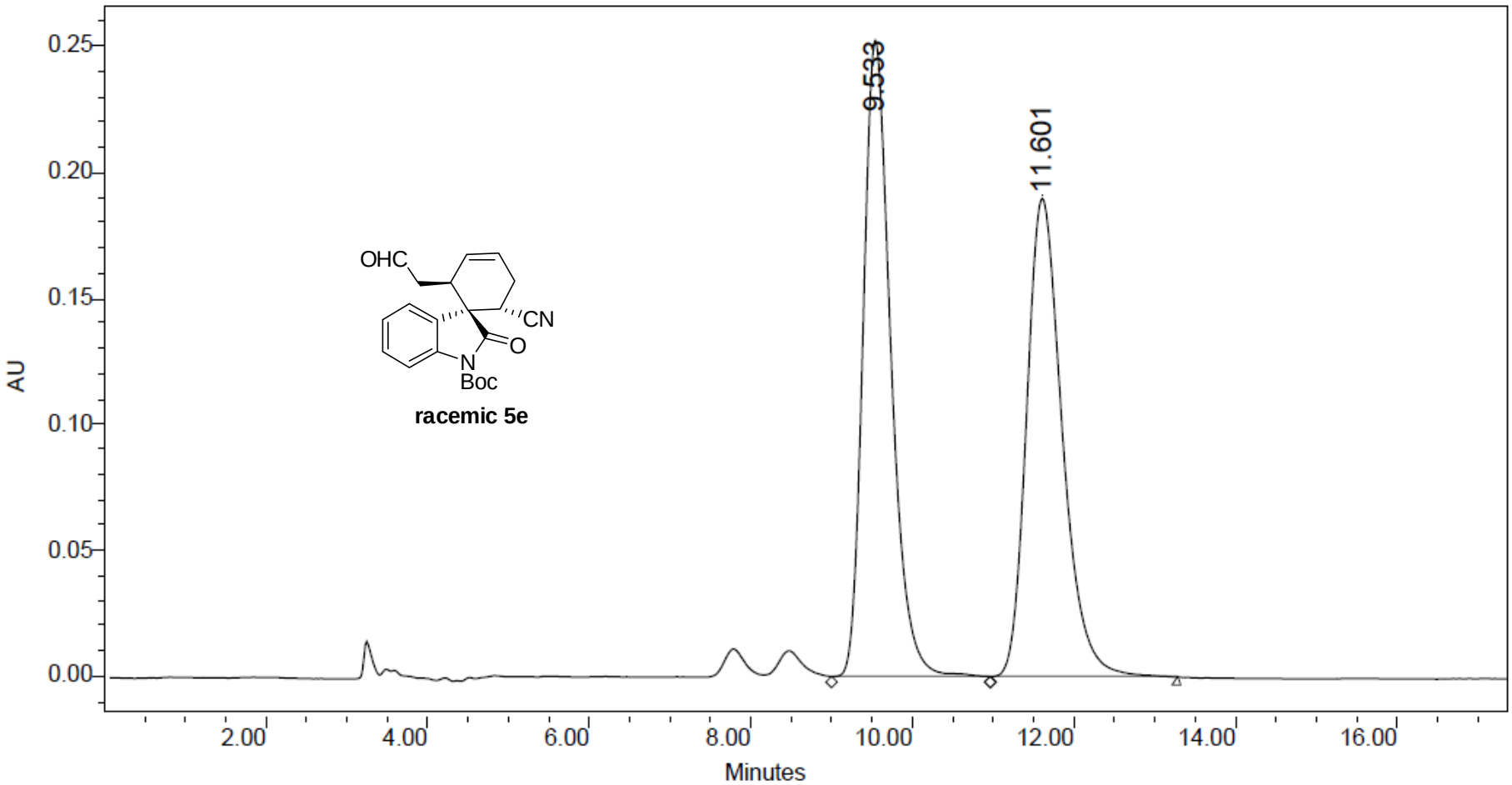
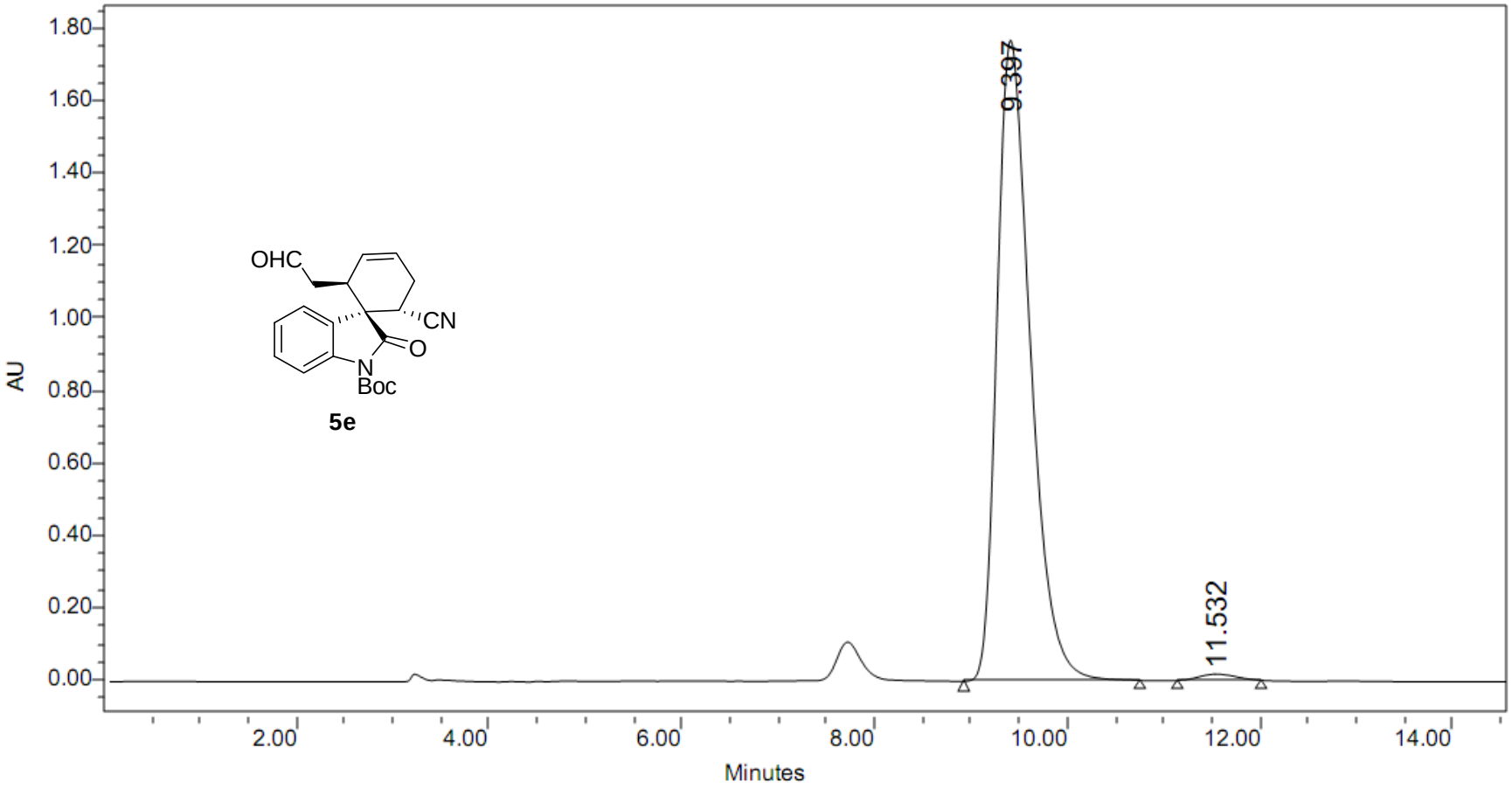
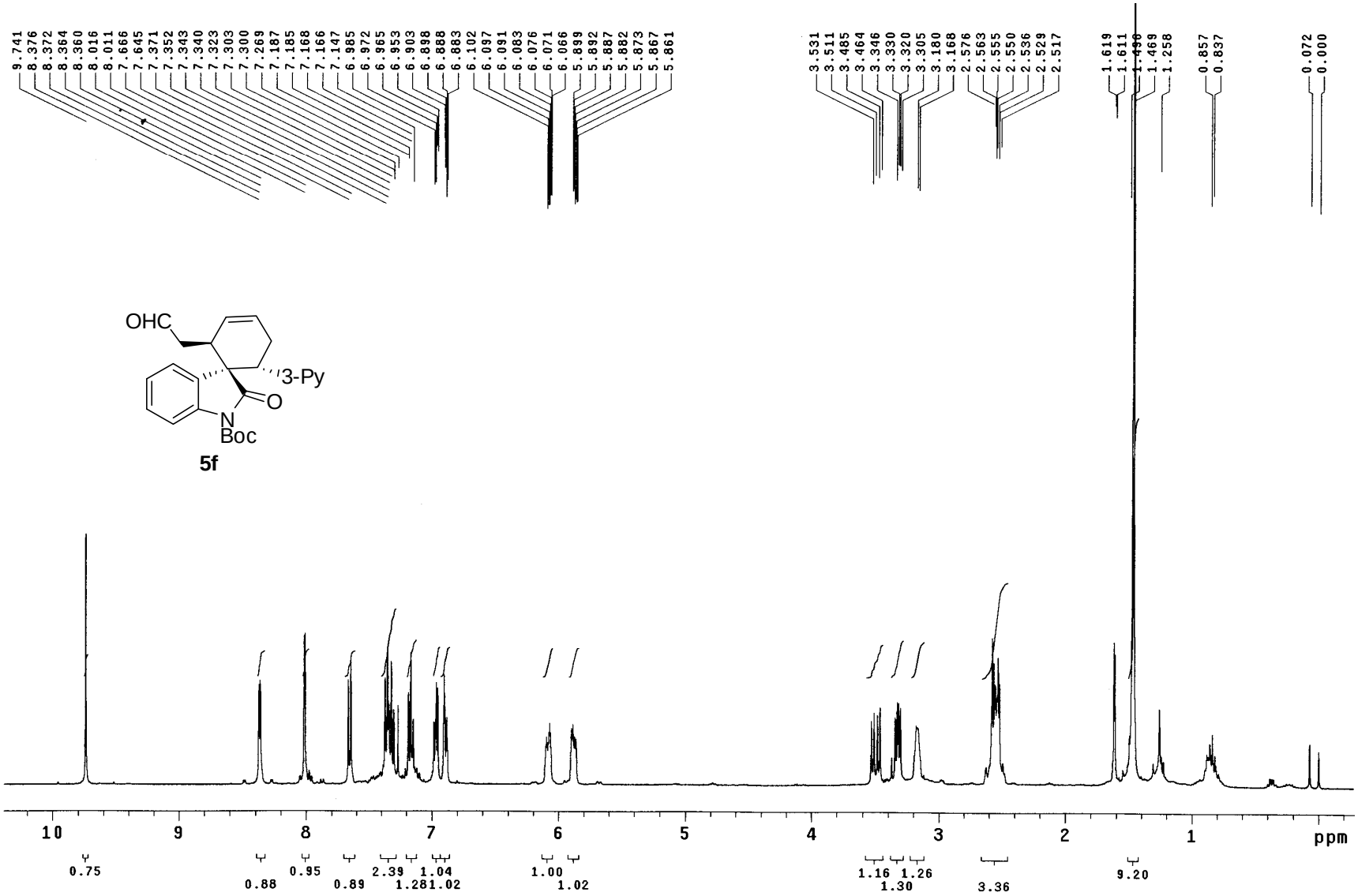
80
60
40
20
ppm



	RT (min)	Area (μV *sec)	% Area	Height (μV)	% Height
1	9.533	6107366	50.97	253335	57.10
2	11.601	5873887	49.03	190325	42.90



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	9.397	42691201	98.94	1770026	99.03
2	11.532	456239	1.06	17406	0.97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7.323
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7.300
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6.883
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6.097
6.091
6.083
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6.071
6.066
5.899
5.892
5.887
5.882
5.873
5.867
5.861
3.531
3.511
3.485
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3.346
3.330
3.320
3.305
3.180
3.168
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2.563
2.555
2.550
2.536
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2.517
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1.611
1.469
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0.837
0.072
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OHC
3-Py
O
N
Boc
5f
10
9
8
7
6
5
4
3
2
1
ppm
0.75
0.88
0.95
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1.02
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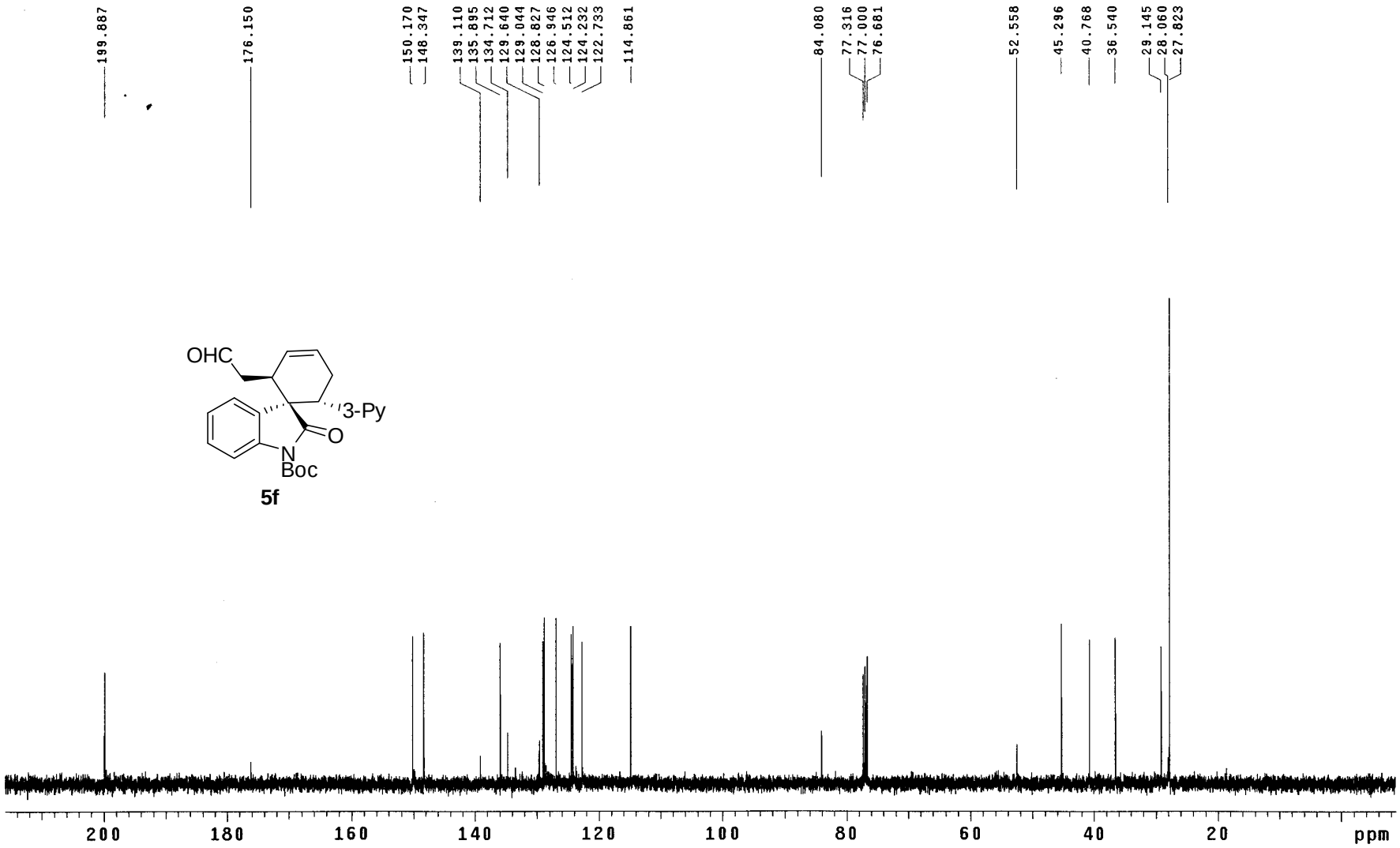
3.36
9.20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124.232
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114.861
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77.000
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52.558
45.296
40.768
36.540
29.145
28.060
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O
N
Boc
5f
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180
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140
120
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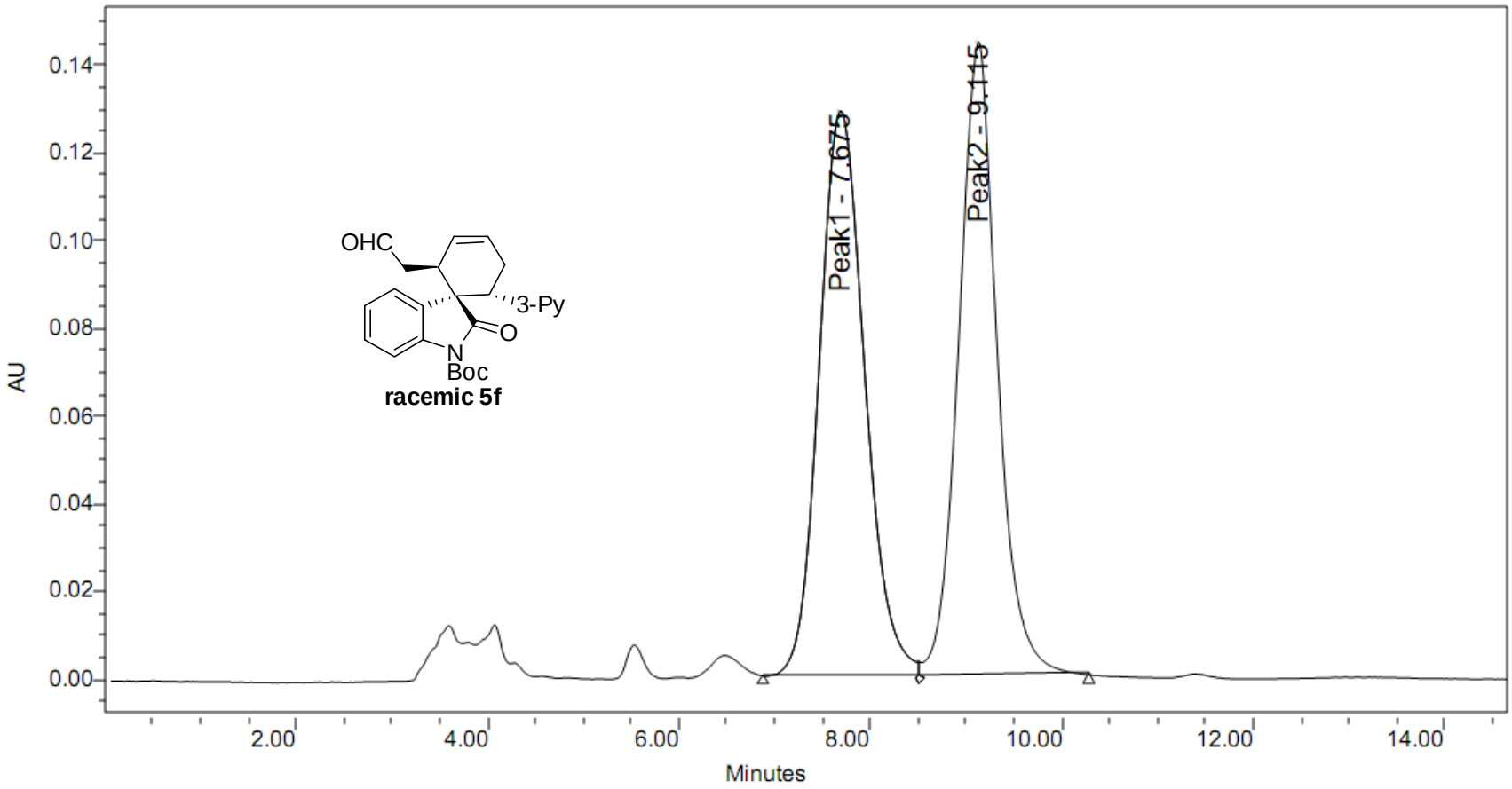
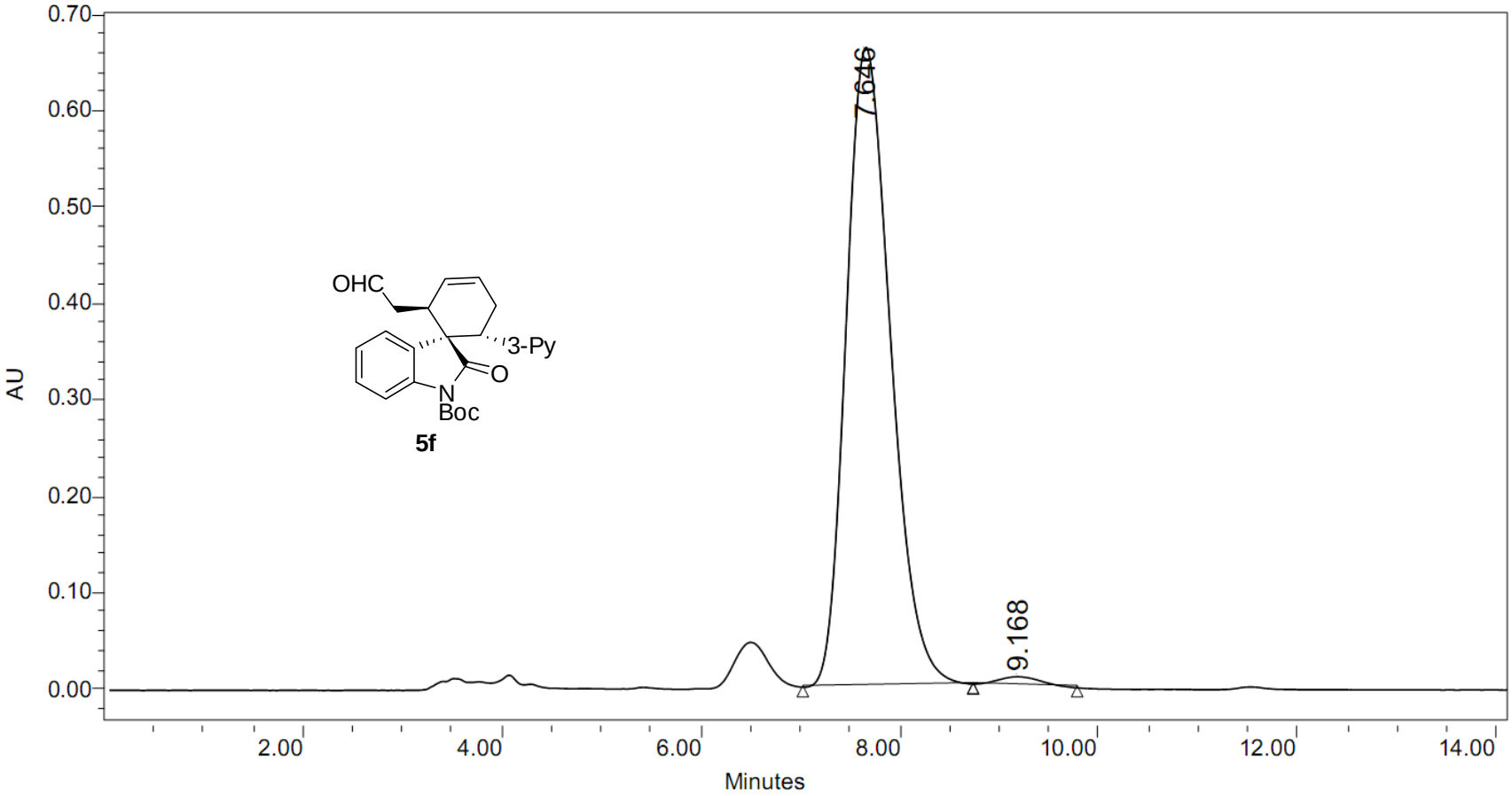
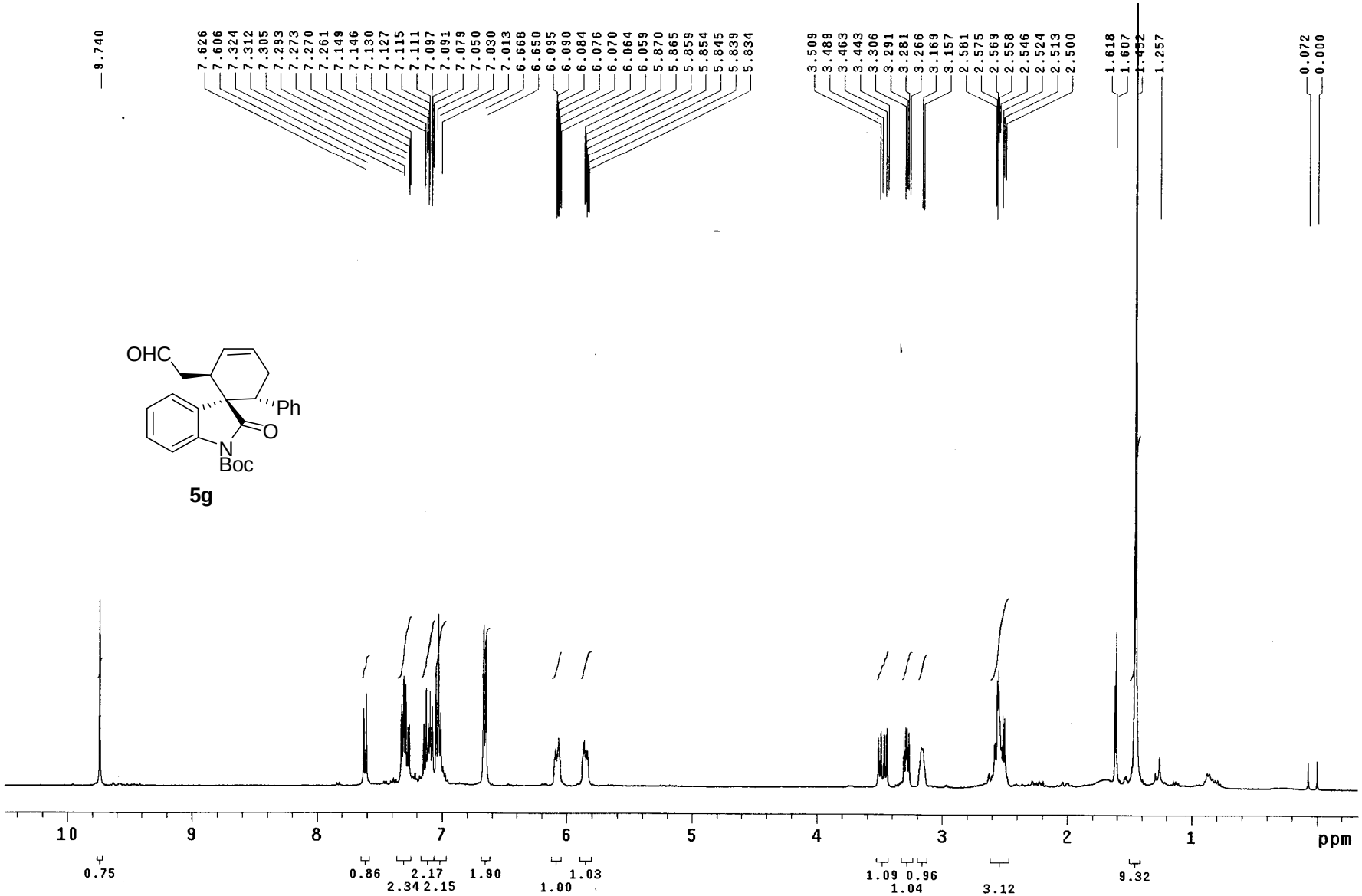
20
ppm



	Peak Name	RT (min)	Area (µV*sec)	% Area	Height (µV)	% Height
1	Peak1	7.675	4248913	51.32	128725	47.14
2	Peak2	9.115	4031032	48.68	144365	52.86



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	7.646	20638548	98.66	663182	98.61
2	9.168	280608	1.34	9340	1.39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7.111
7.097
7.091
7.079
7.050
7.030
7.013
6.668
6.650
6.095
6.090
6.084
6.076
6.070
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6.059
5.870
5.865
5.859
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5.845
5.839
5.834
3.509
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3.463
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3.306
3.291
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3.169
3.157
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2.524
2.513
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1.257
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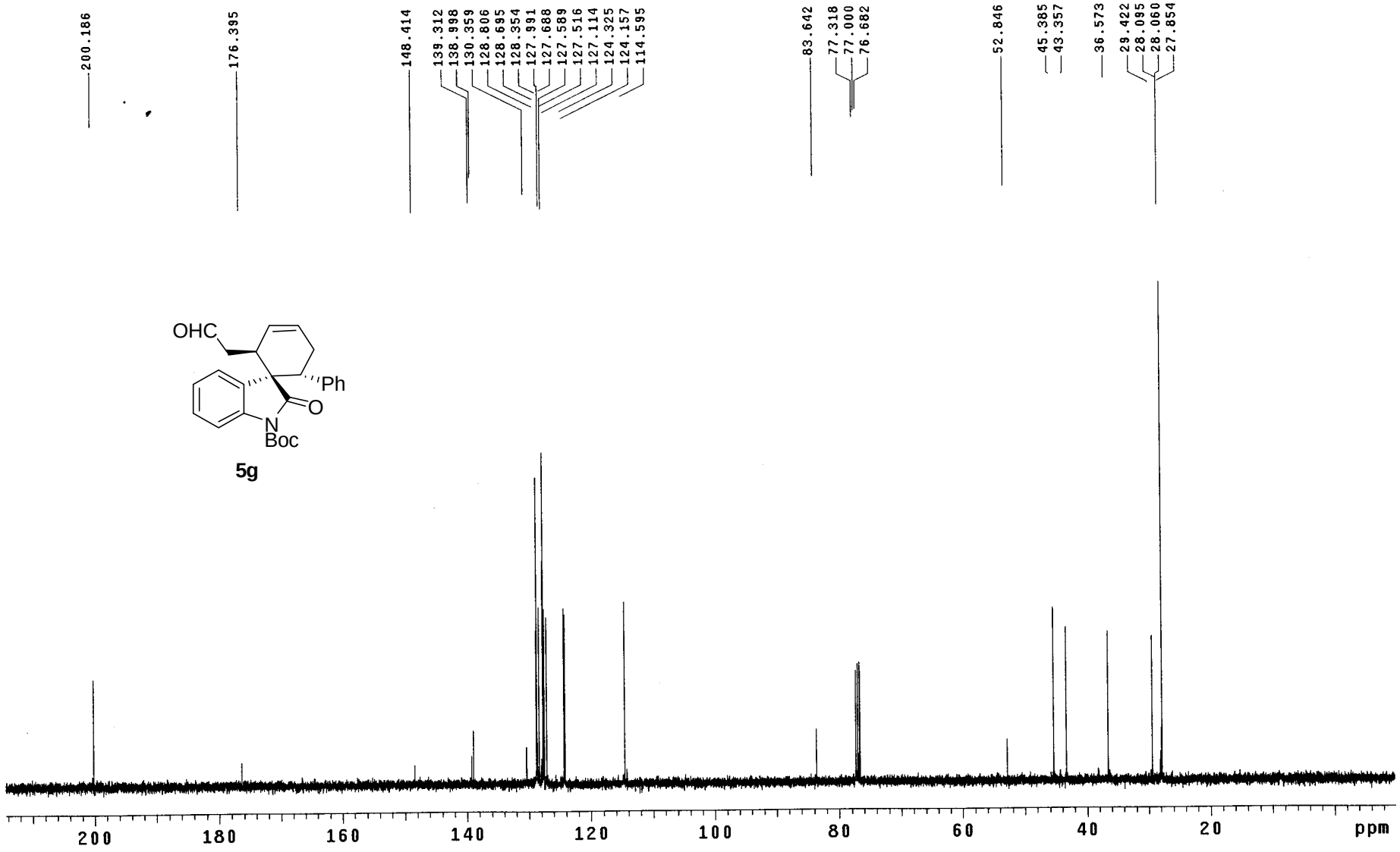
0.000
OHC
Ph
O
N
Boc
5g
10
9
8
7
6
5
4
3
2
1
ppm
0.75
0.86
2.34
2.17
2.15
1.90
1.00
1.03
1.09
1.04
0.96
3.12
9.32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77.318
77.000
76.682
52.846
45.385
43.357
36.573
29.422
28.095
28.060
27.854
OHC
Ph
O
N
Boc
5g
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80
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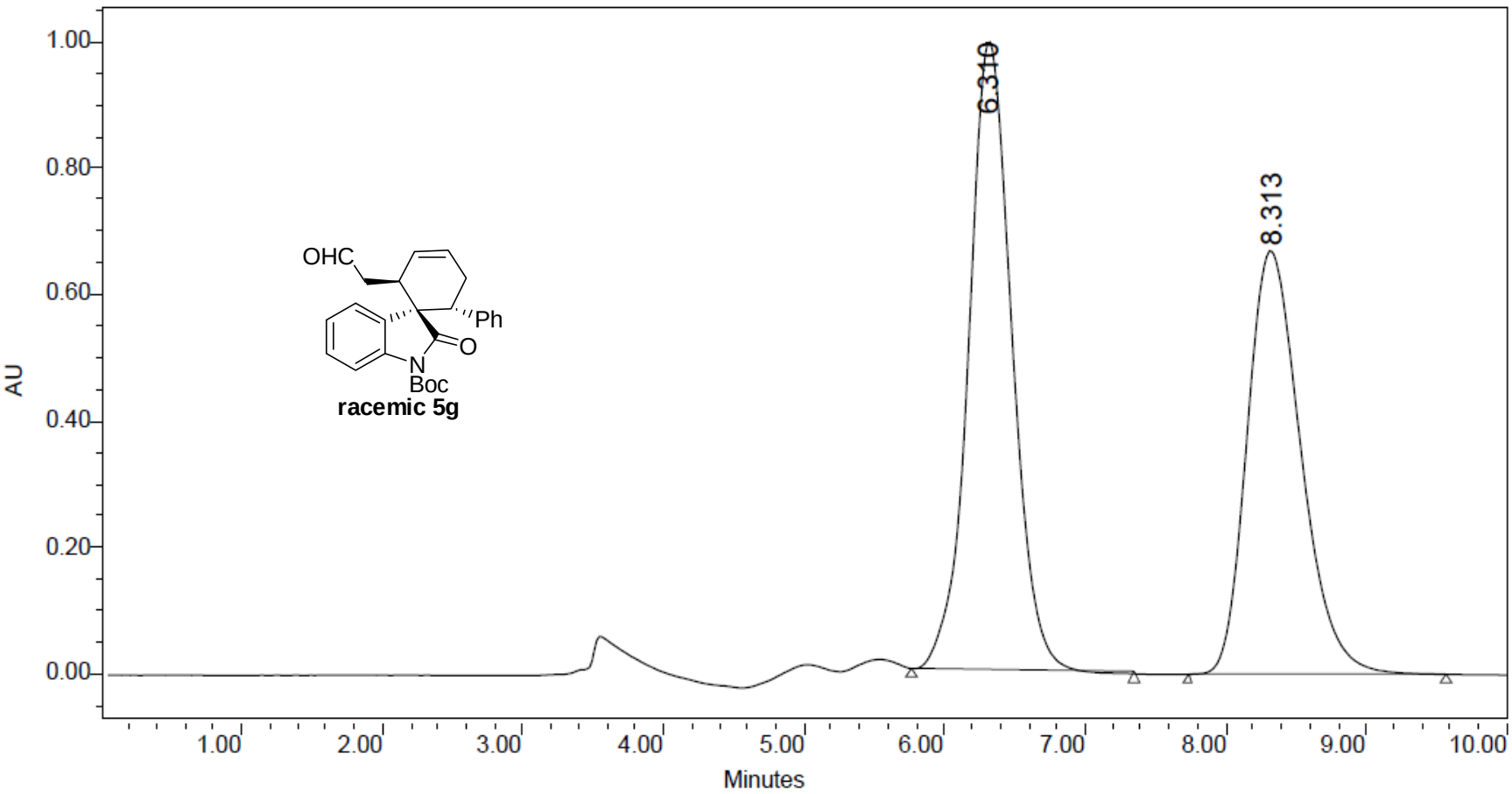
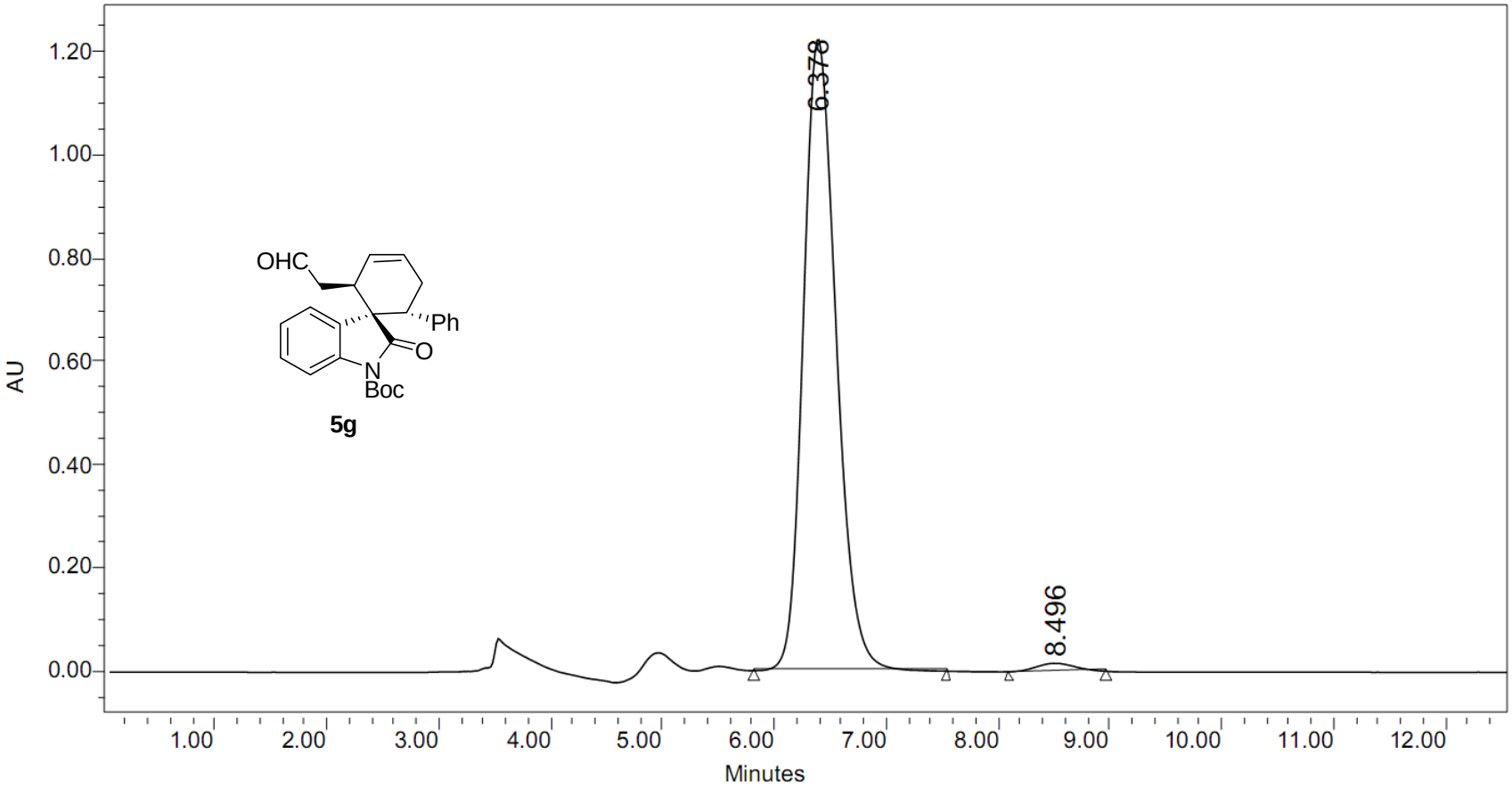
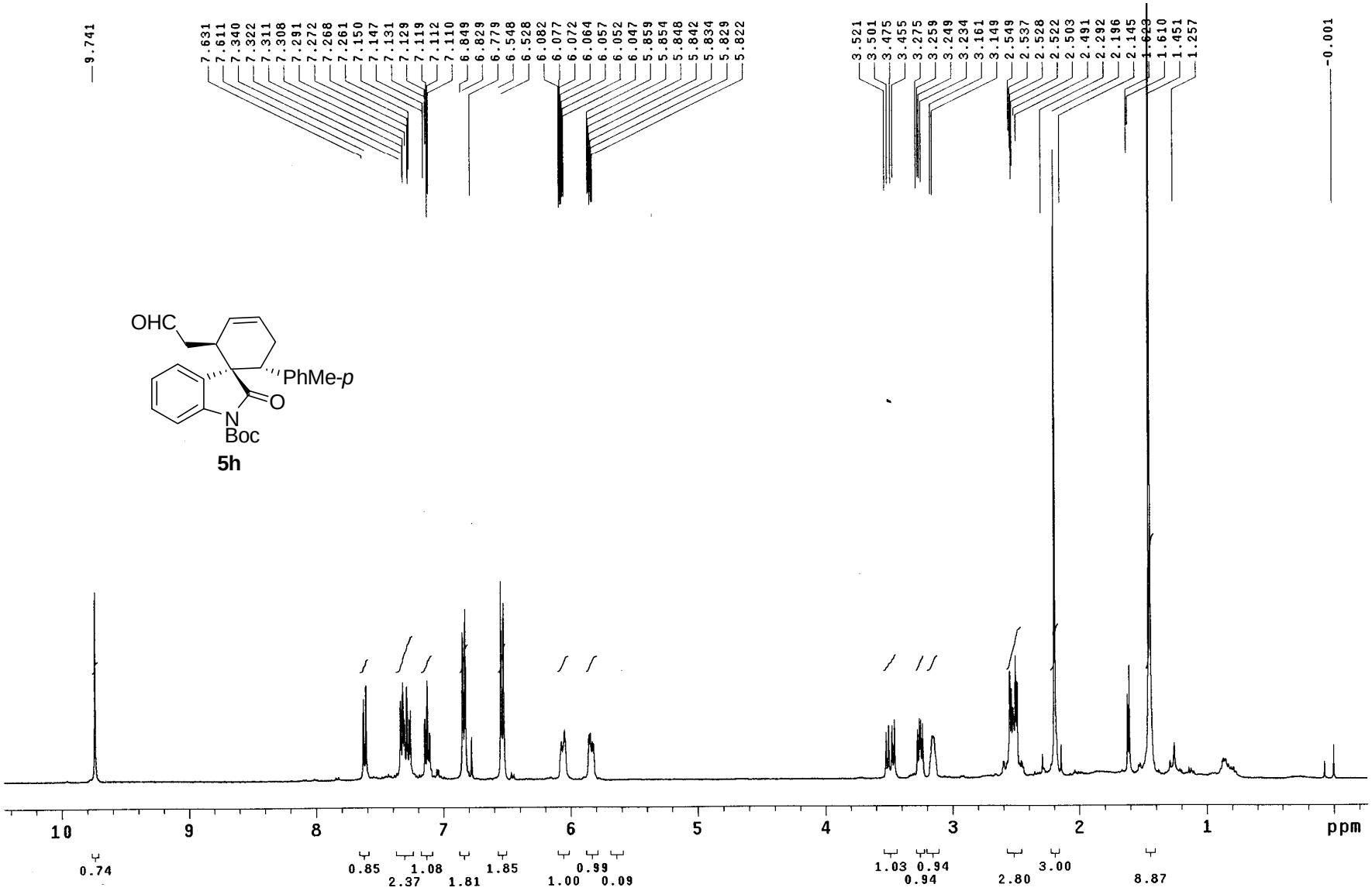
20
ppm



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	6.310	18188701	50.68	934602	58.30
2	8.313	17700809	49.32	668577	41.70



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	6.378	25025945	98.47	1224196	98.72
2	8.496	387988	1.53	15909	1.28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3.234
3.161
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2.503
2.491
2.292
2.196
2.145
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1.451
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-0.001
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PhMe-p
O
N
Boc
5h
10
9
8
7
6
5
4
3
2
1
ppm
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0.85
2.37
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0.09
1.03
0.94
0.94
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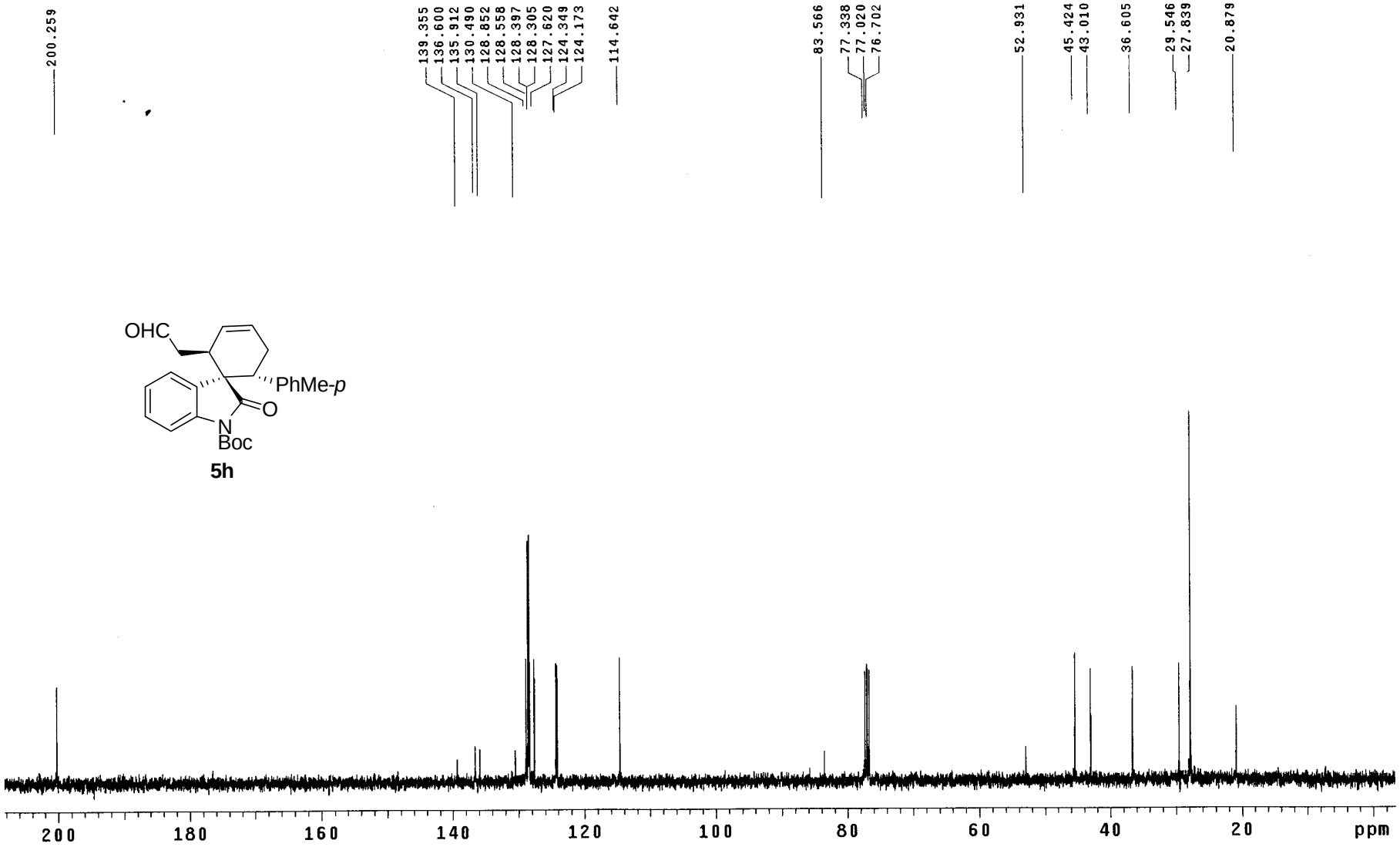
3.00
8.87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76.702
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36.605
29.546
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OHC
PhMe-p
O
N
Boc
5h
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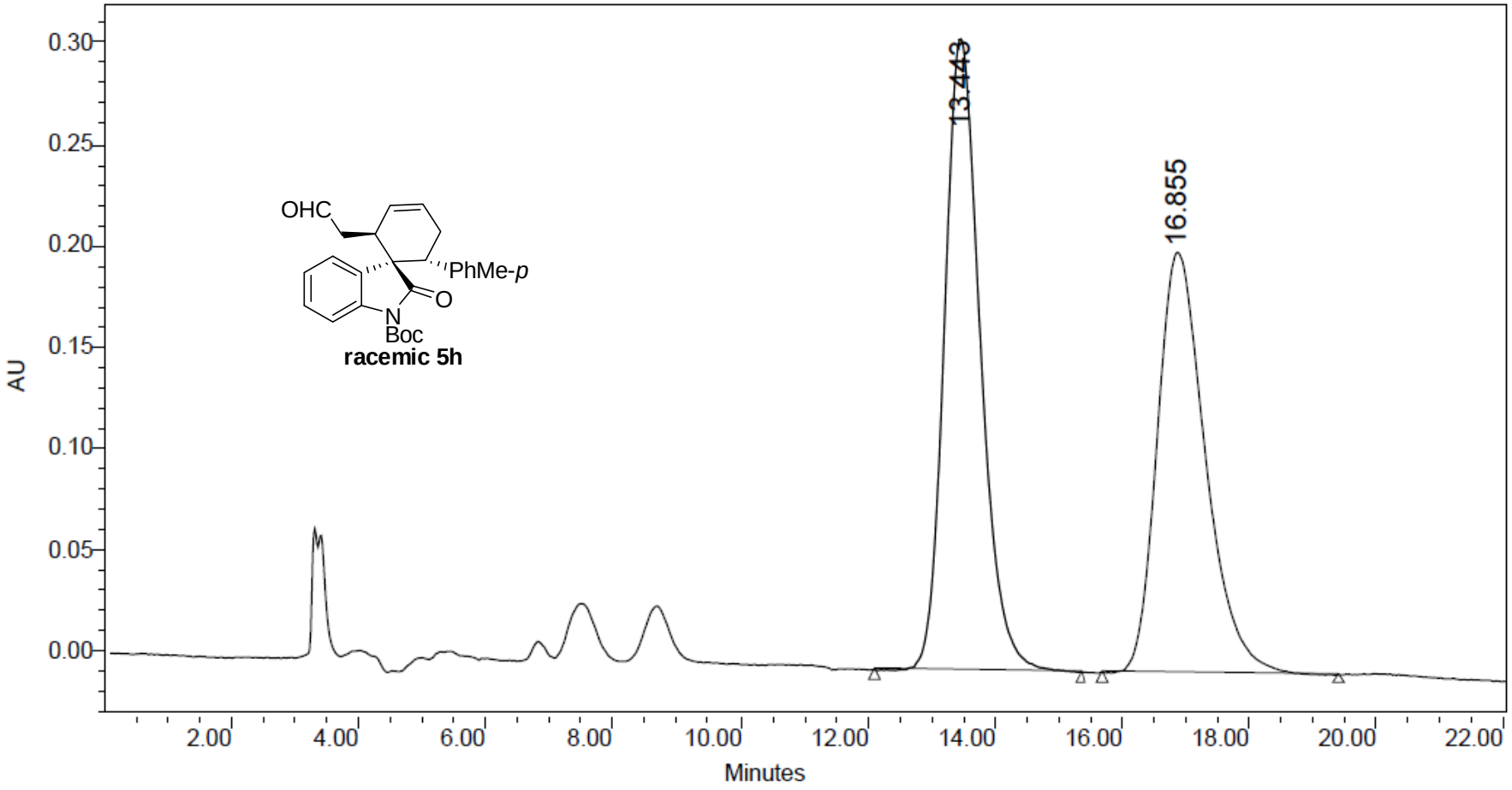
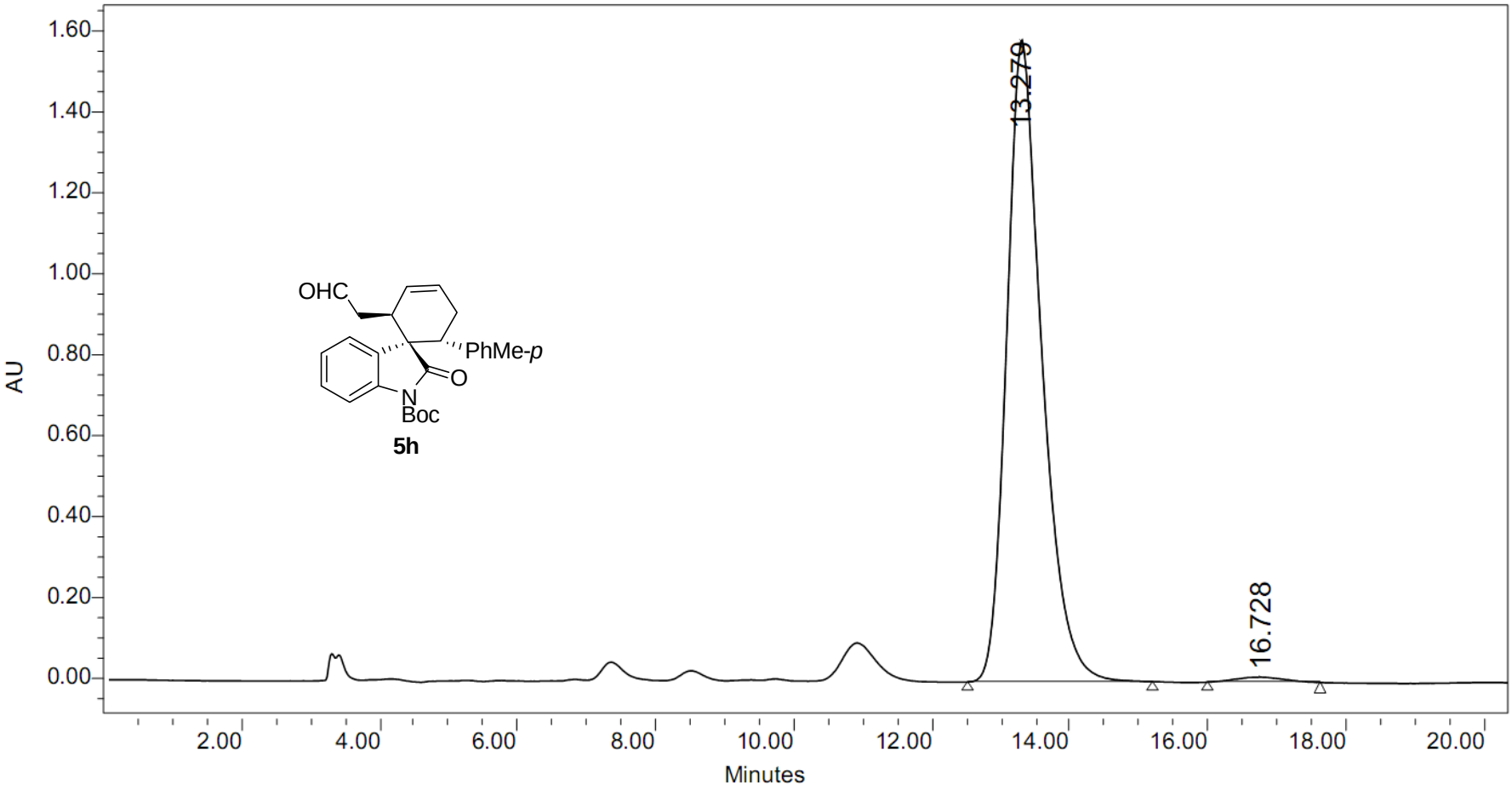
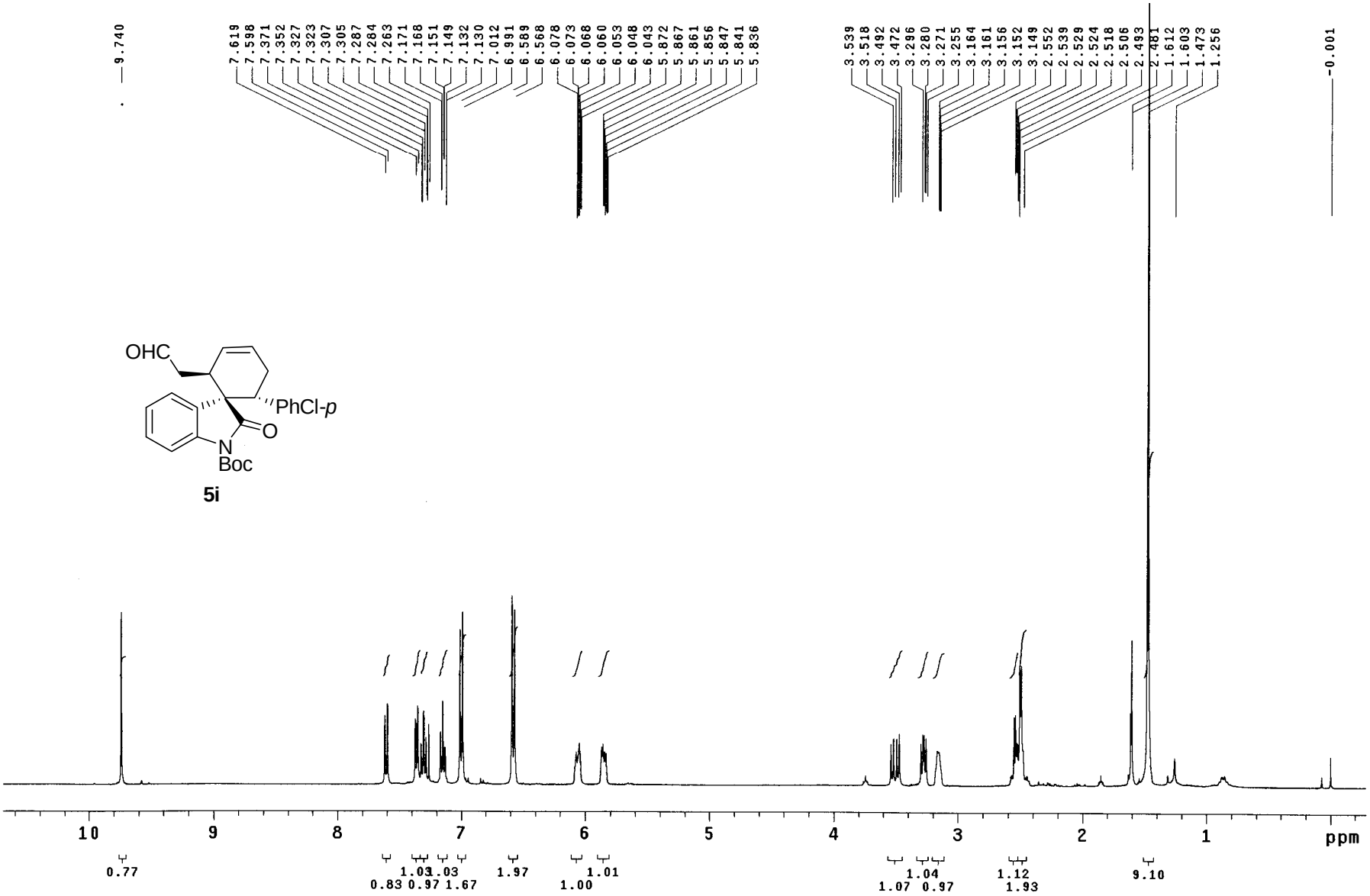
ppm



	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	13.443	10954964	50.61	298299	59.17
2	16.855	10690184	49.39	205843	40.83



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	13.279	56218006	98.90	1586238	99.21
2	16.728	626133	1.10	12664	0.79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7.168
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7.149
7.132
7.130
7.012
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6.589
6.568
6.078
6.073
6.068
6.060
6.053
6.048
6.043
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5.861
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5.841
5.836
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3.518
3.492
3.472
3.296
3.280
3.271
3.255
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3.161
3.156
3.152
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2.552
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2.529
2.524
2.518
2.506
2.493
2.481
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1.603
1.473
1.256
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OHC
PhCl-p
O
N
Boc
5i
10
9
8
7
6
5
4
3
2
1
ppm
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1.03
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1.04
0.97
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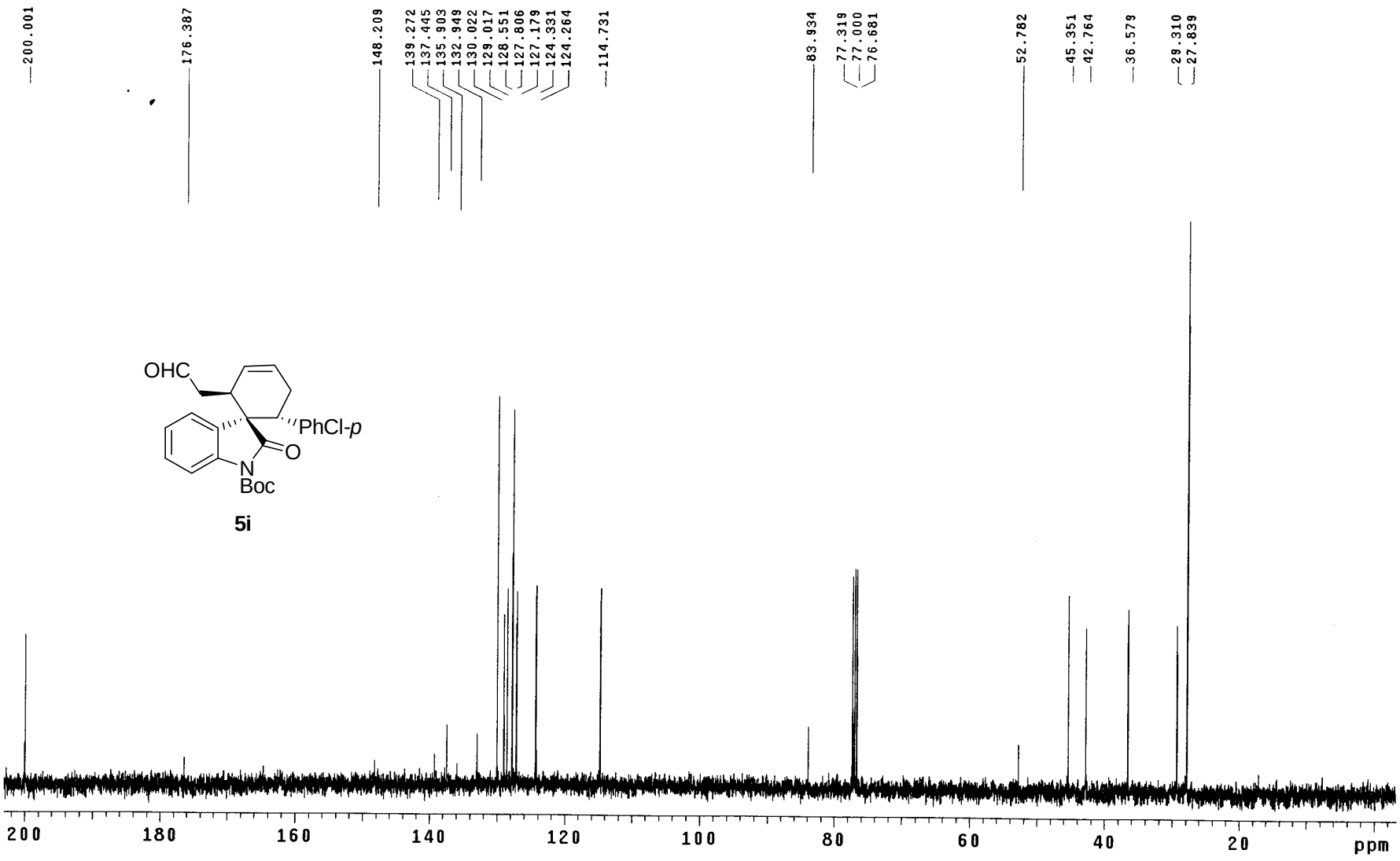
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77.000
76.681
52.782
45.351
42.764
36.579
29.310
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OHC
PhCl-p
O
N
Boc
5i
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140
120
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80
60
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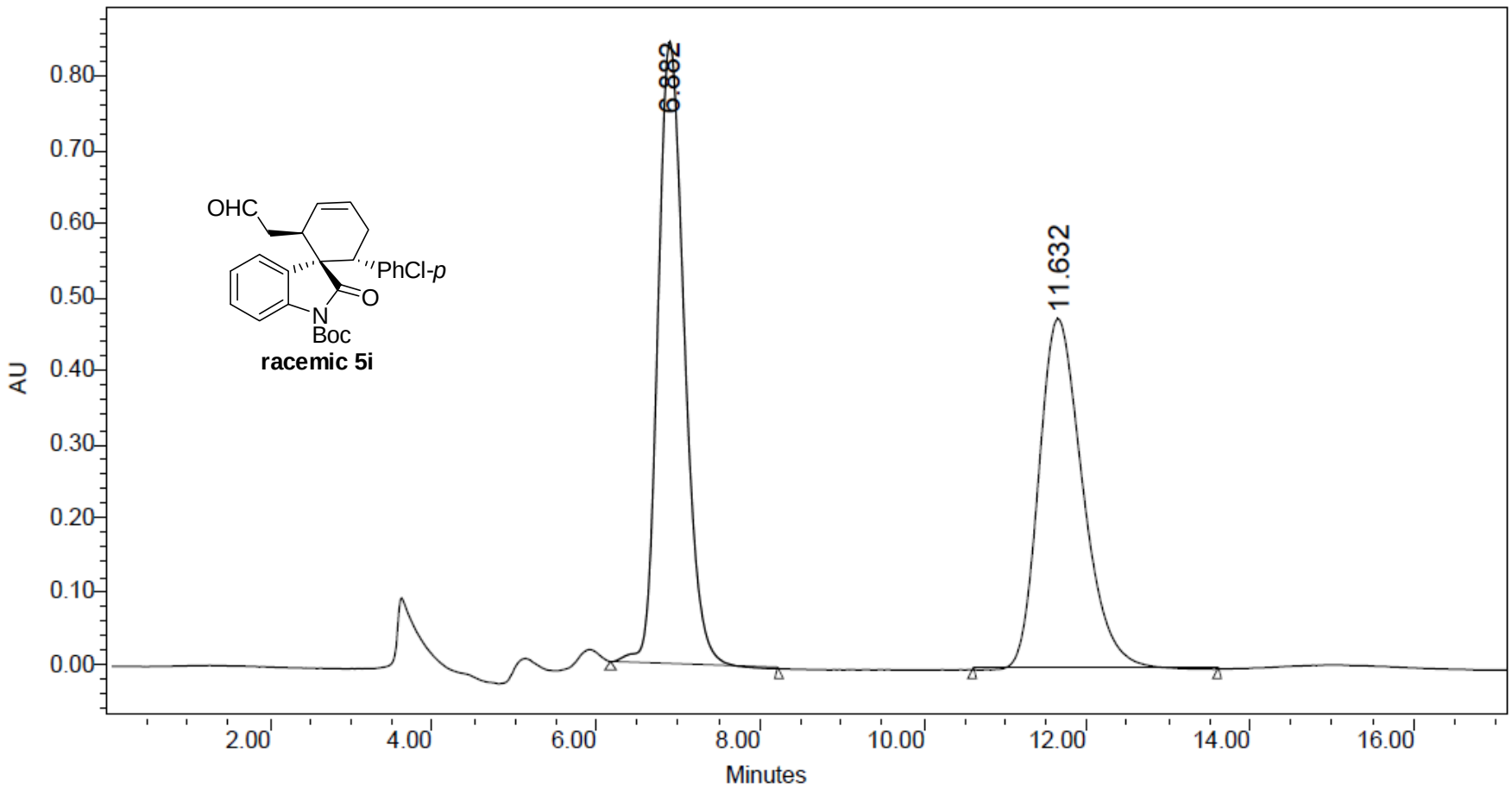
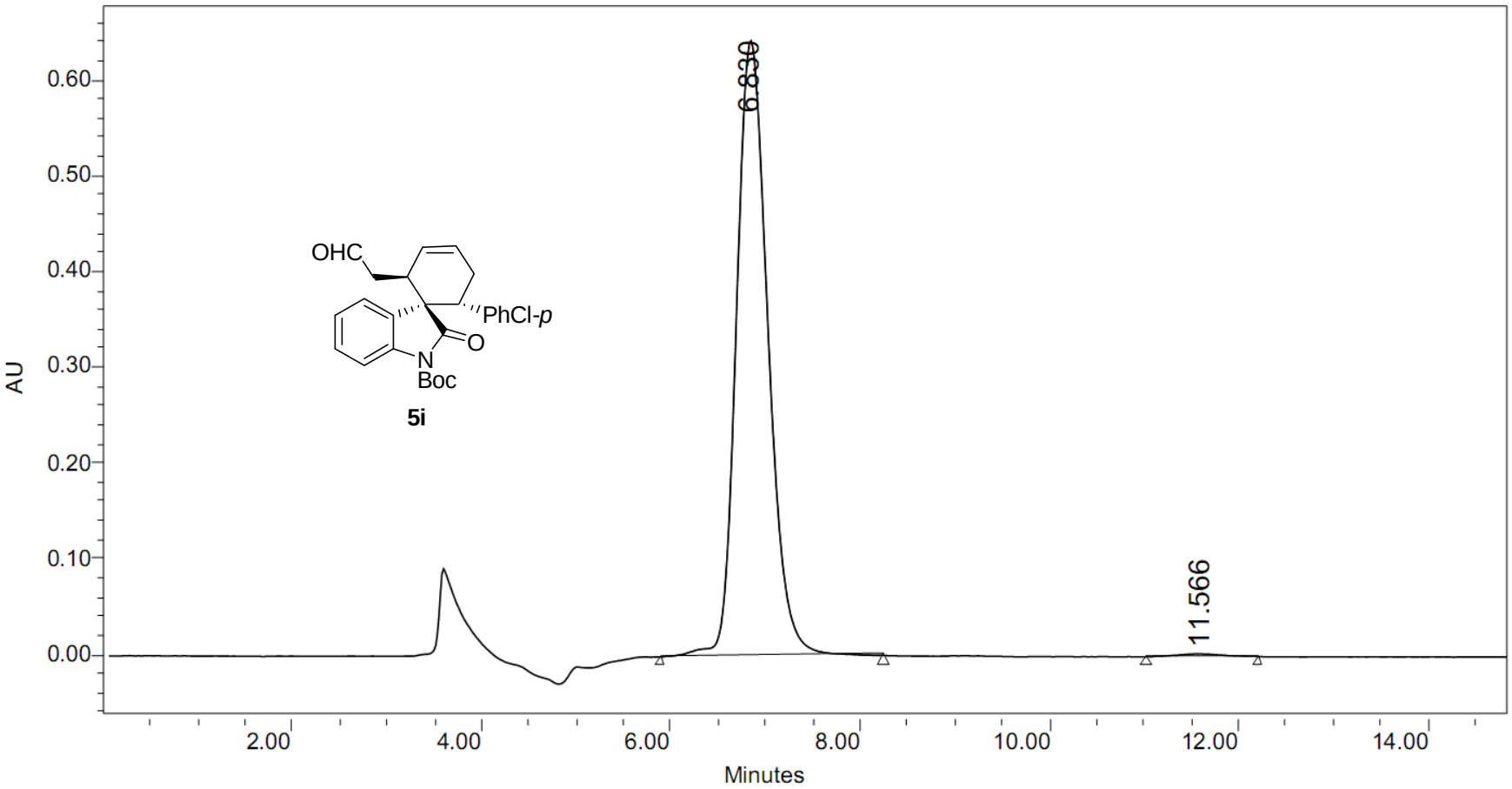
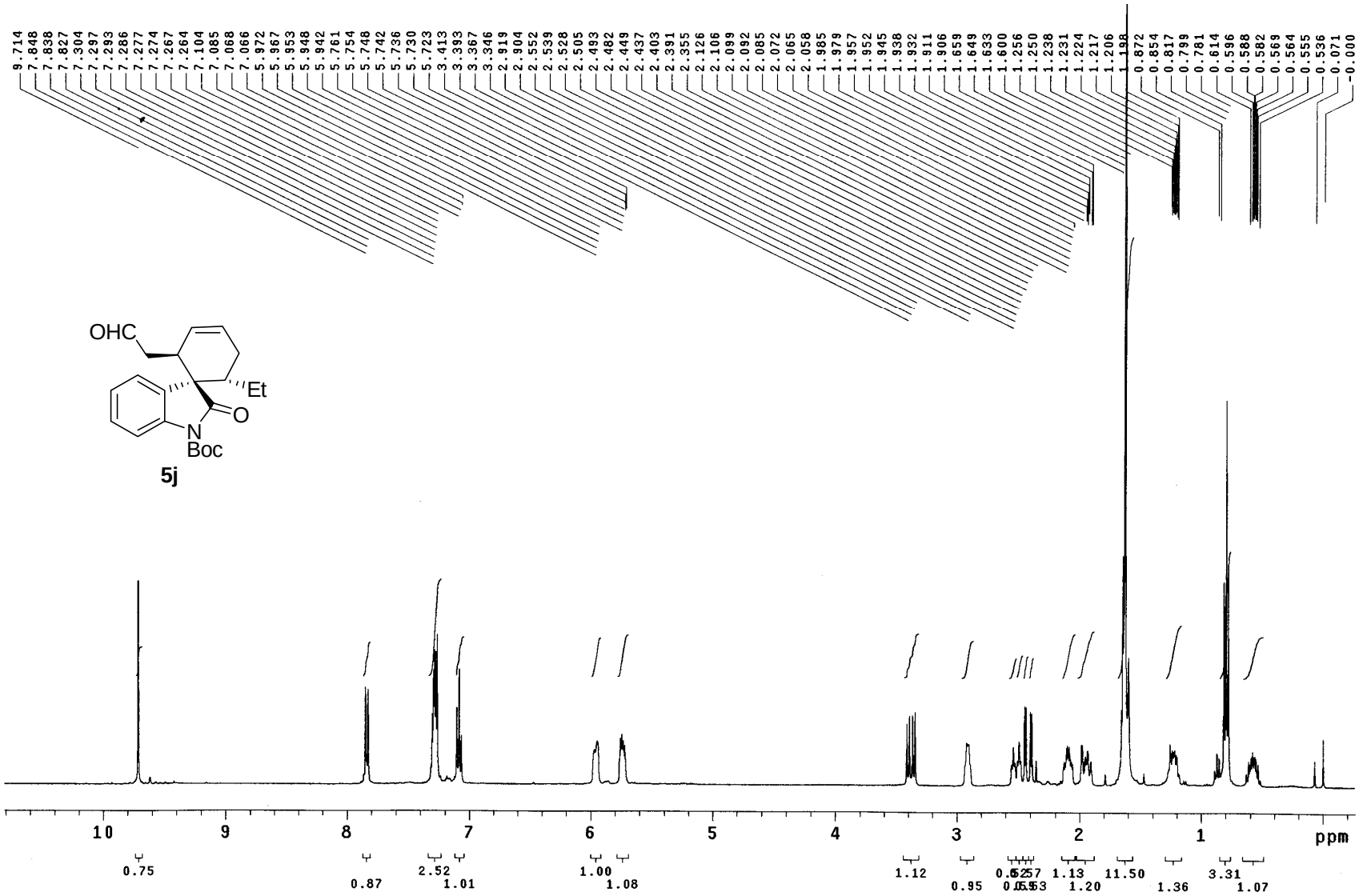
20
ppm

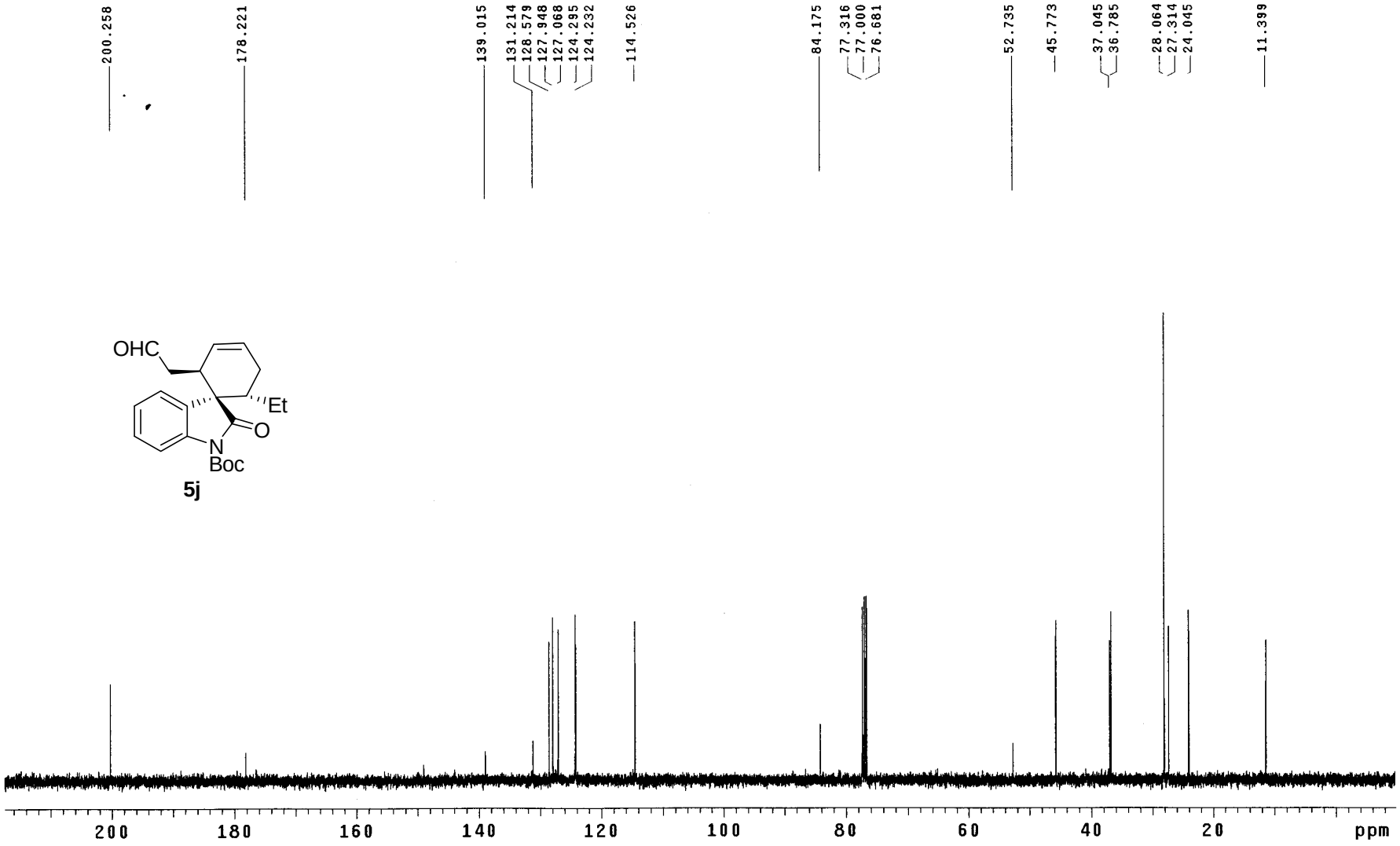


	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	6.882	17795579	50.48	824541	63.50
2	11.632	17457470	49.52	473894	36.50



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	6.830	14969376	99.42	642626	99.57
2	11.566	87297	0.58	2796	0.43


OHC
Et
O
N
Boc
5j
ppm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76.681
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37.045
36.785
28.064
27.314
24.045
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OHC
Et
O
N
Boc
5j
200
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140
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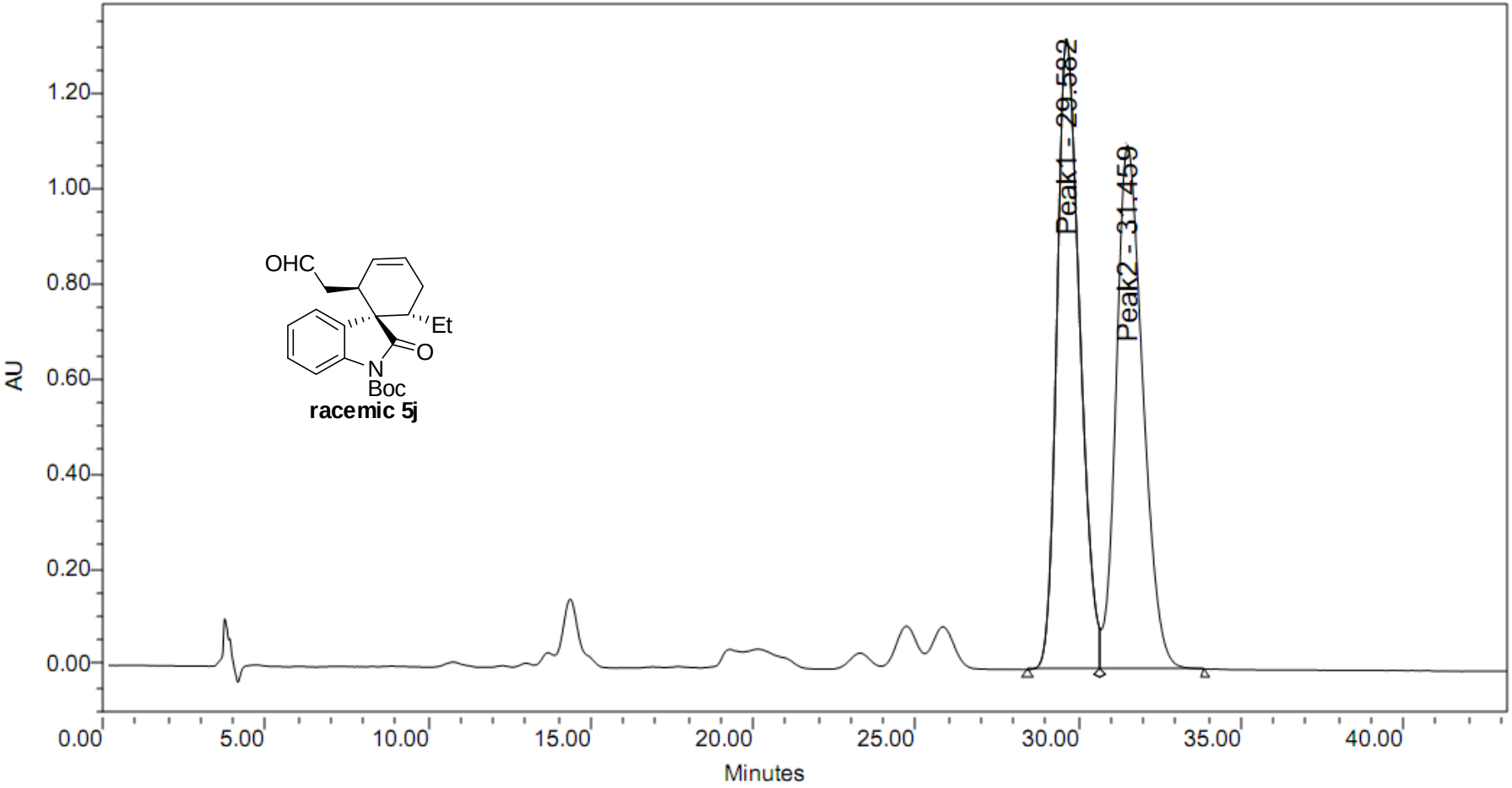
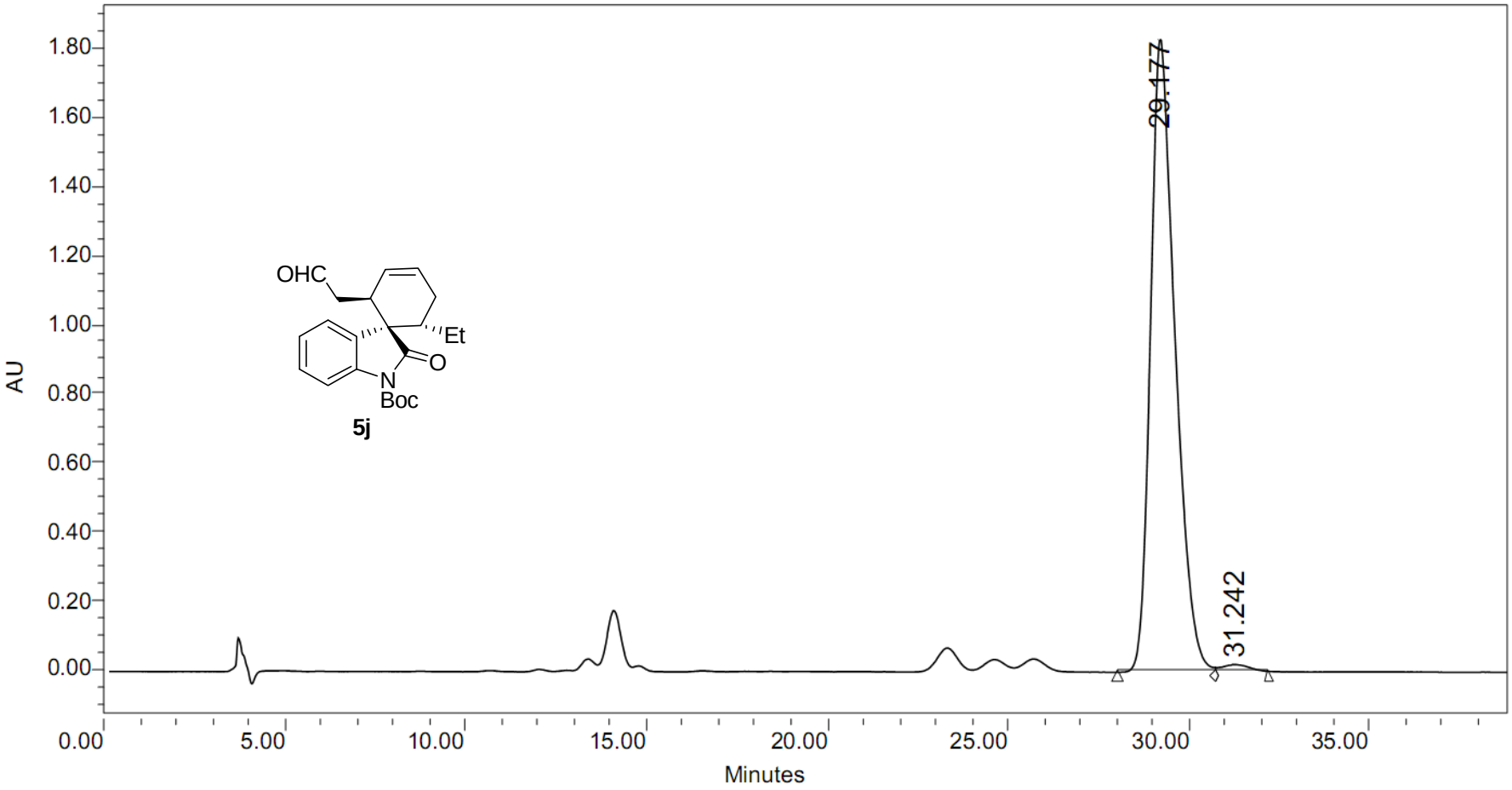
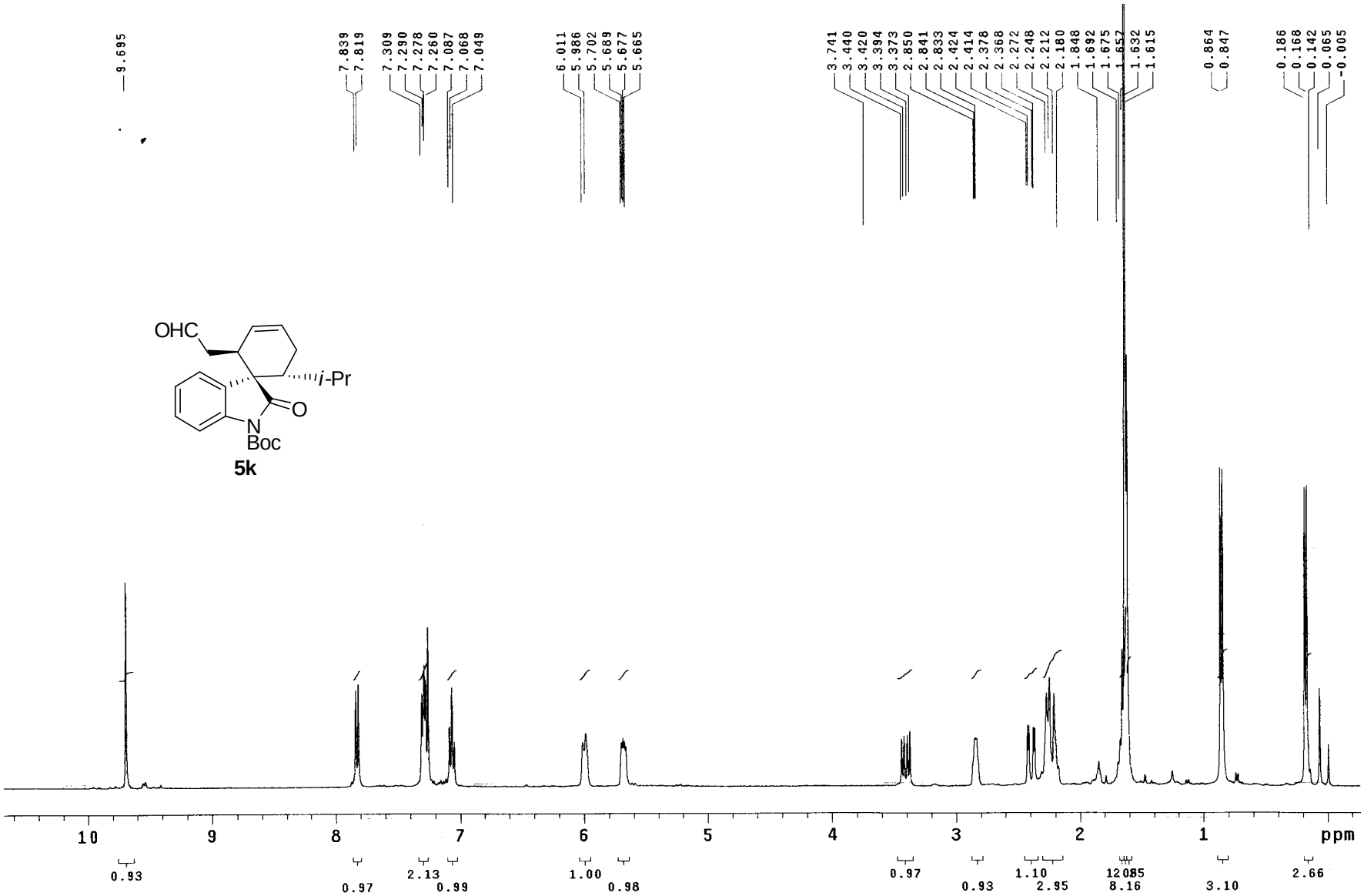
40
20
ppm



	Peak Name	RT (min)	Area (µV*sec)	% Area	Height (µV)	% Height
1	Peak1	29.582	65650256	51.02	1327253	54.60
2	Peak2	31.459	63032386	48.98	1103427	45.40



	RT (min)	Area (µV*sec)	% Area	Height (µV)	% Height
1	29.177	86482921	98.79	1831316	98.91
2	31.242	1059445	1.21	20265	1.09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5.689
5.677
5.665
3.741
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3.420
3.394
3.373
2.850
2.841
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2.424
2.414
2.378
2.368
2.272
2.248
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1.675
1.657
1.632
1.615
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0.186
0.168
0.142
0.065
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OHC
i-Pr
O
N
Boc
5k
10
9
8
7
6
5
4
3
2
1
ppm
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0.97
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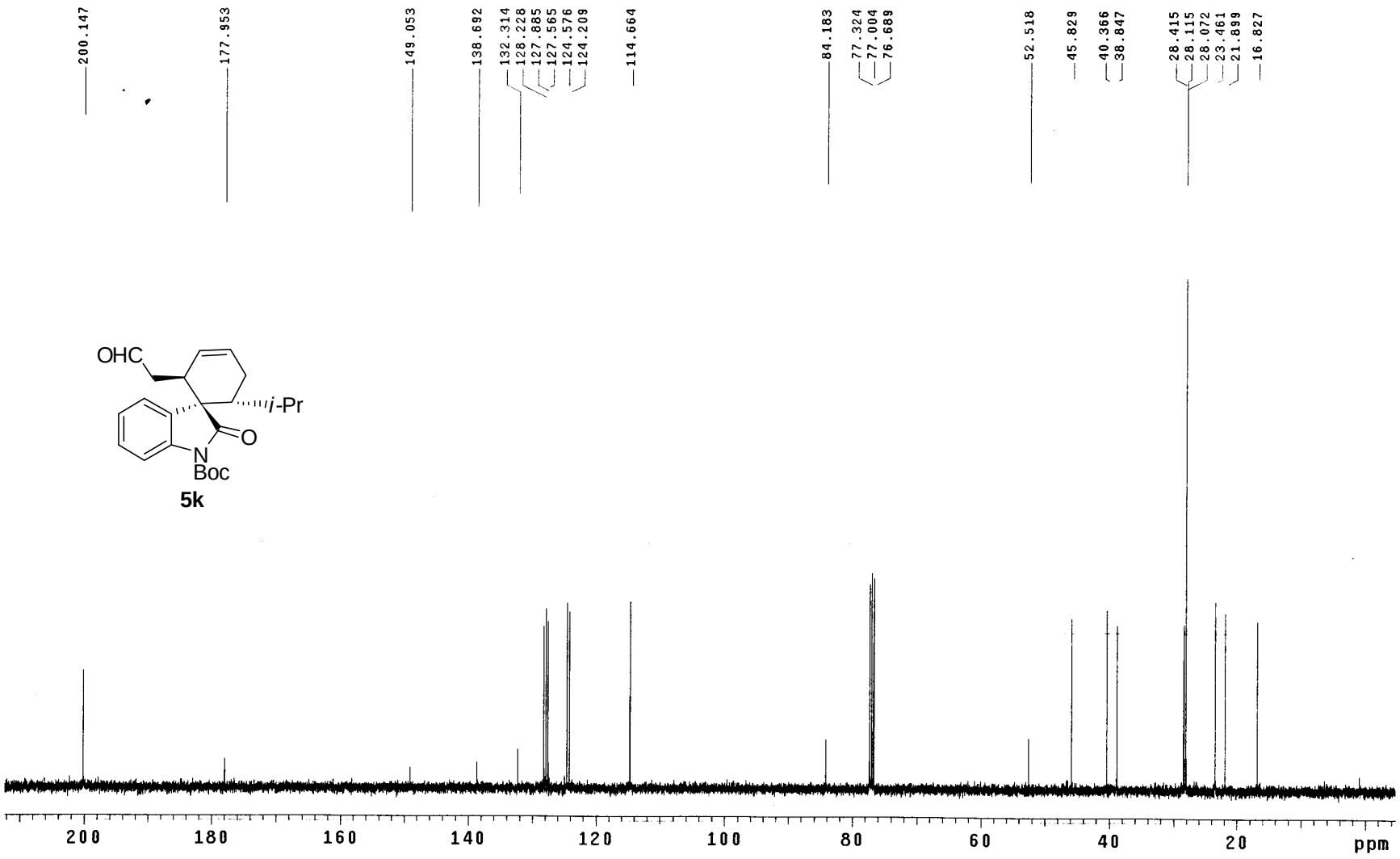
2.66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77.004
76.689
52.518
45.829
40.366
38.847
28.415
28.115
28.072
23.461
21.899
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OHC
i-Pr
O
N
Boc
5k
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140
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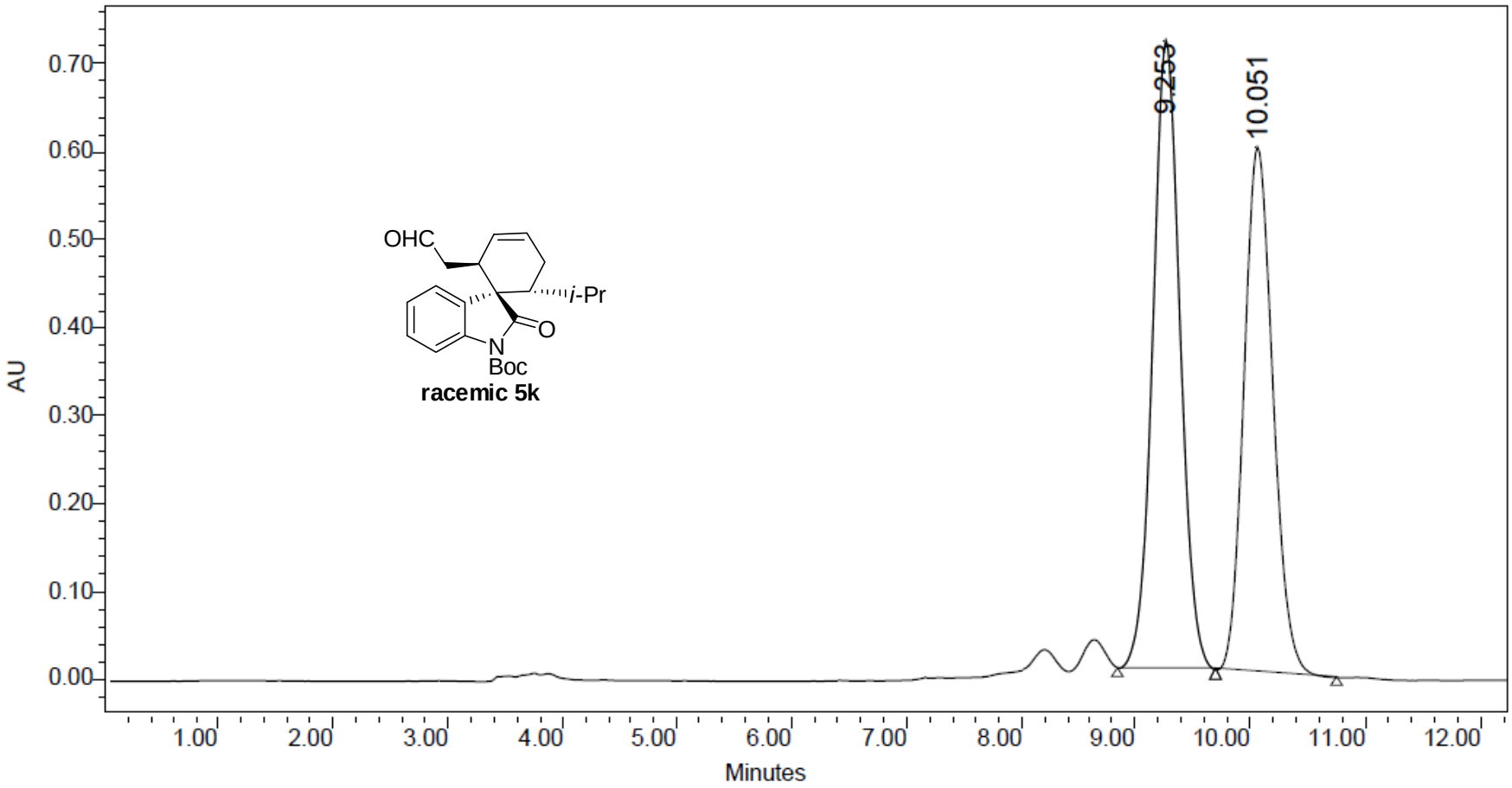
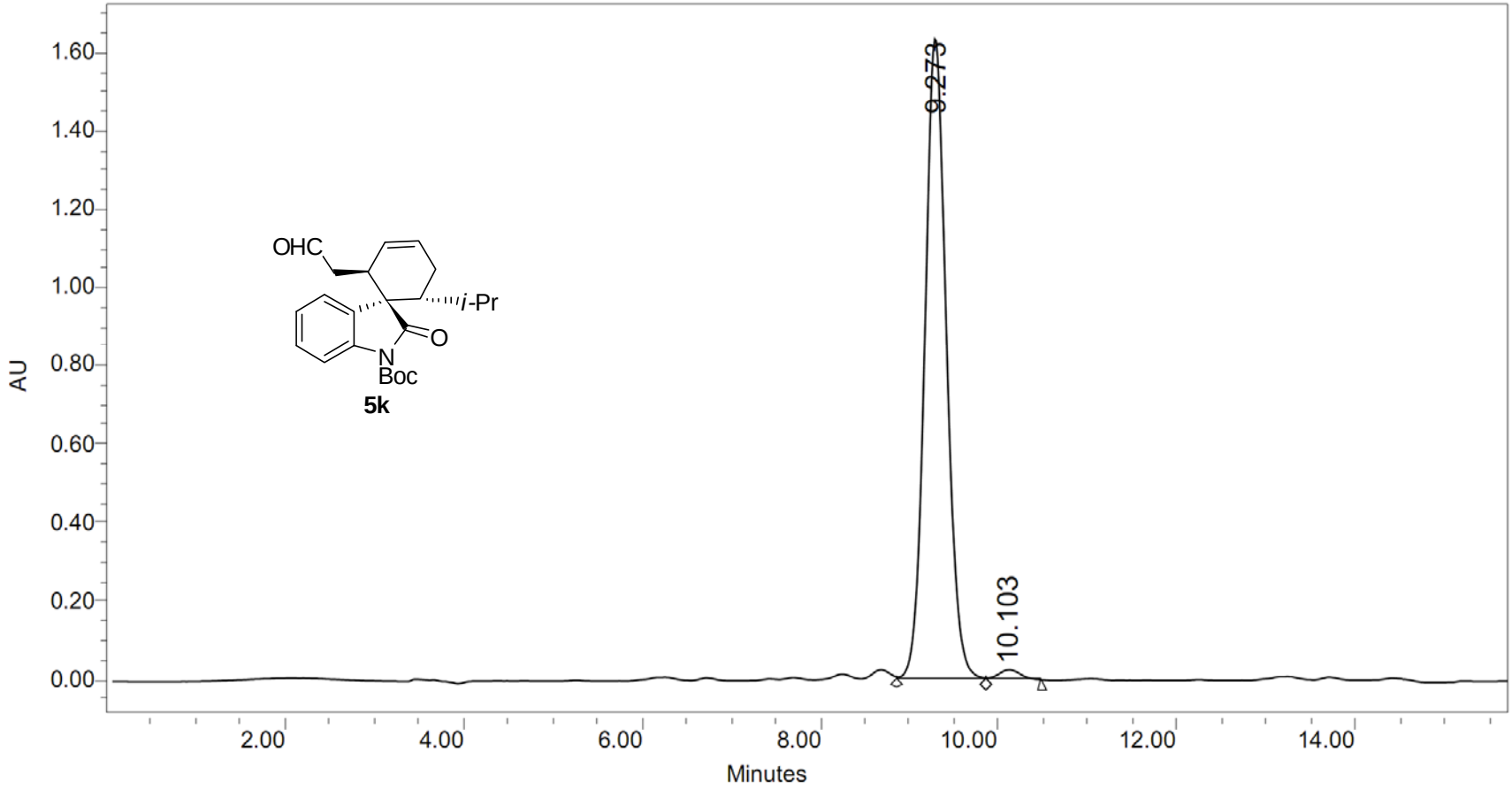
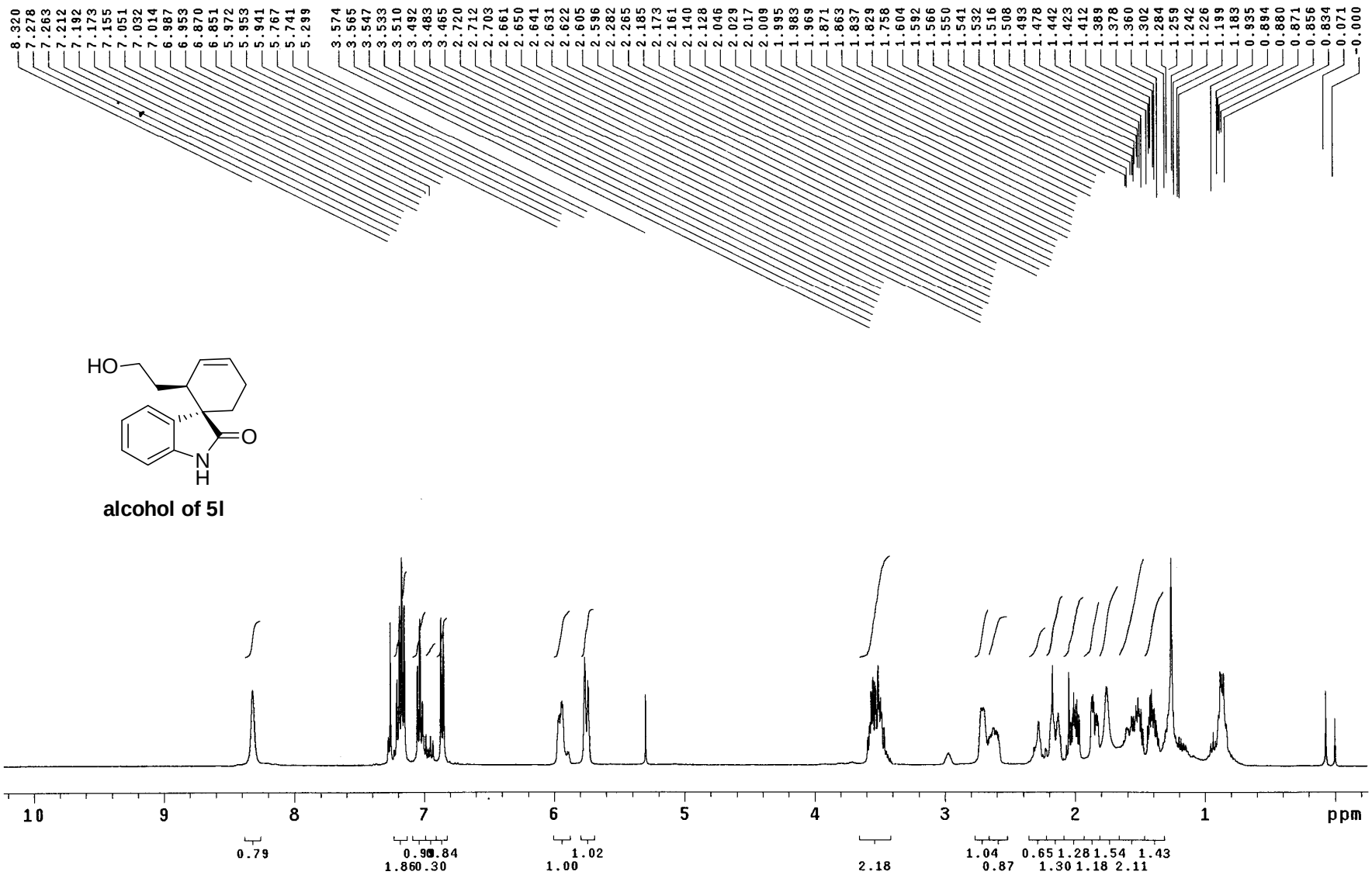
100
80
60
40
20
ppm



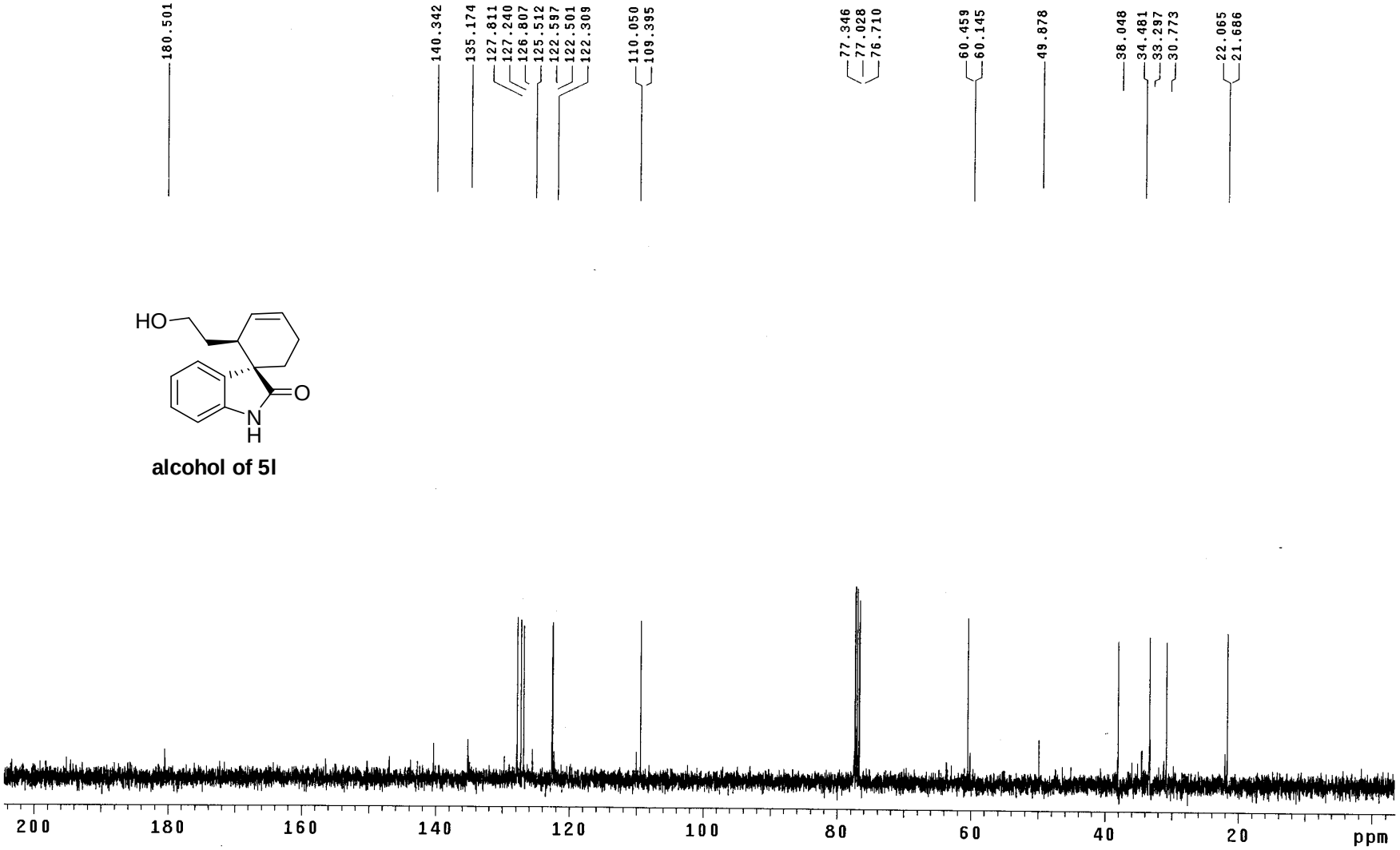
	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	9.253	10587393	50.76	684210	53.60
2	10.051	10272404	49.24	592366	46.40



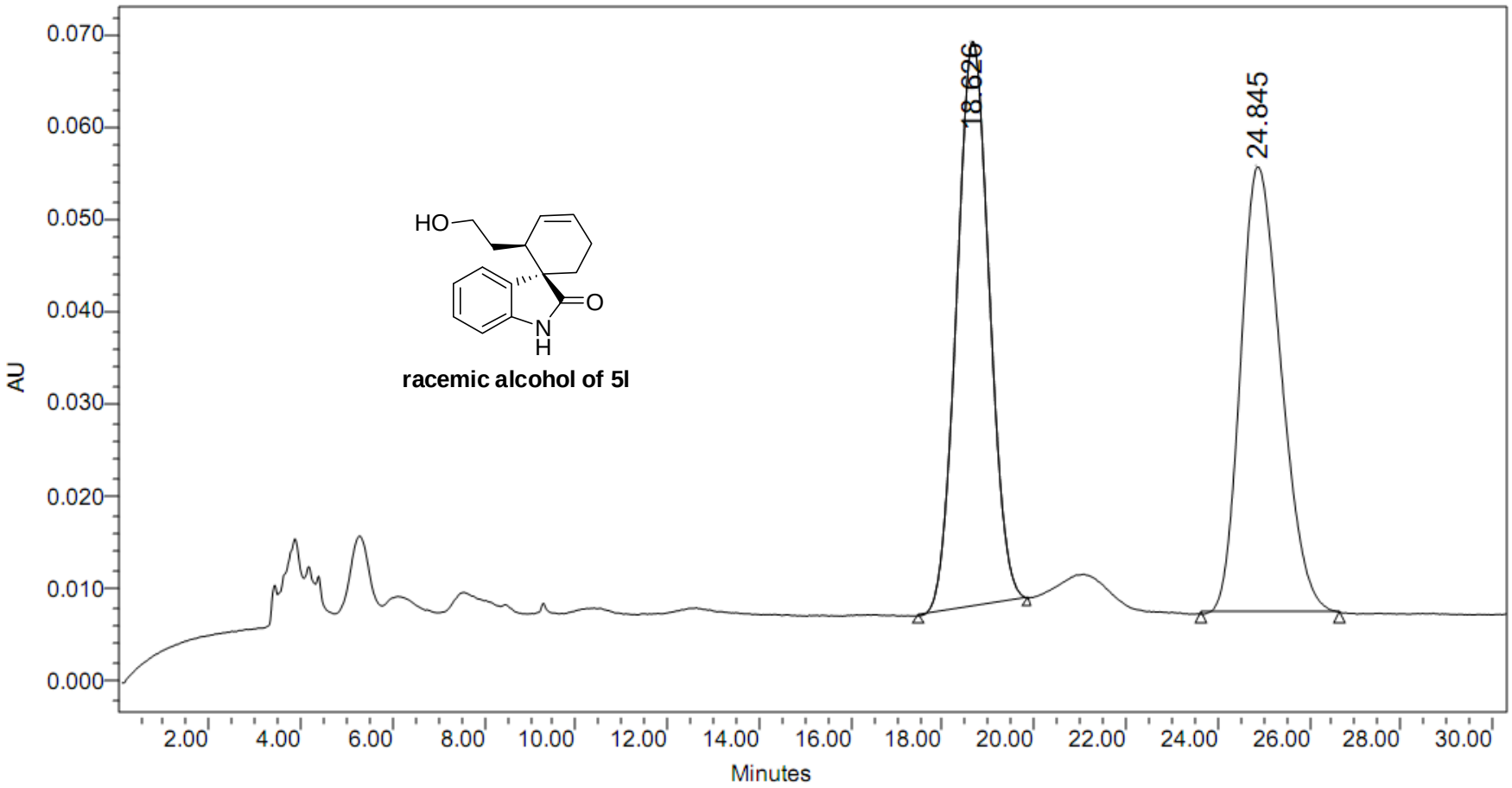
	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	9.273	27502086	98.39	1635101	98.46
2	10.103	448881	1.61	25509	1.54



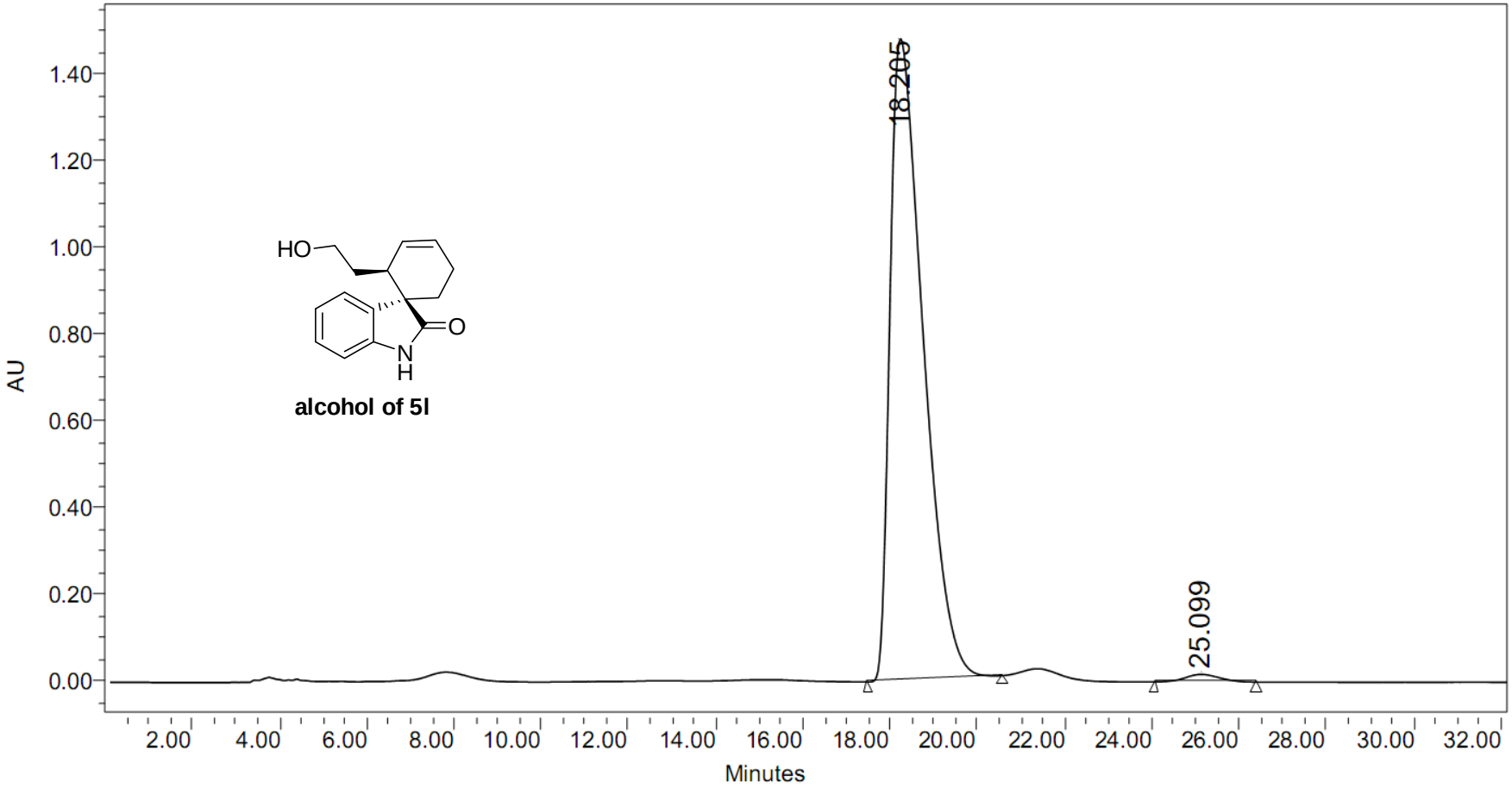
alcohol of 5l



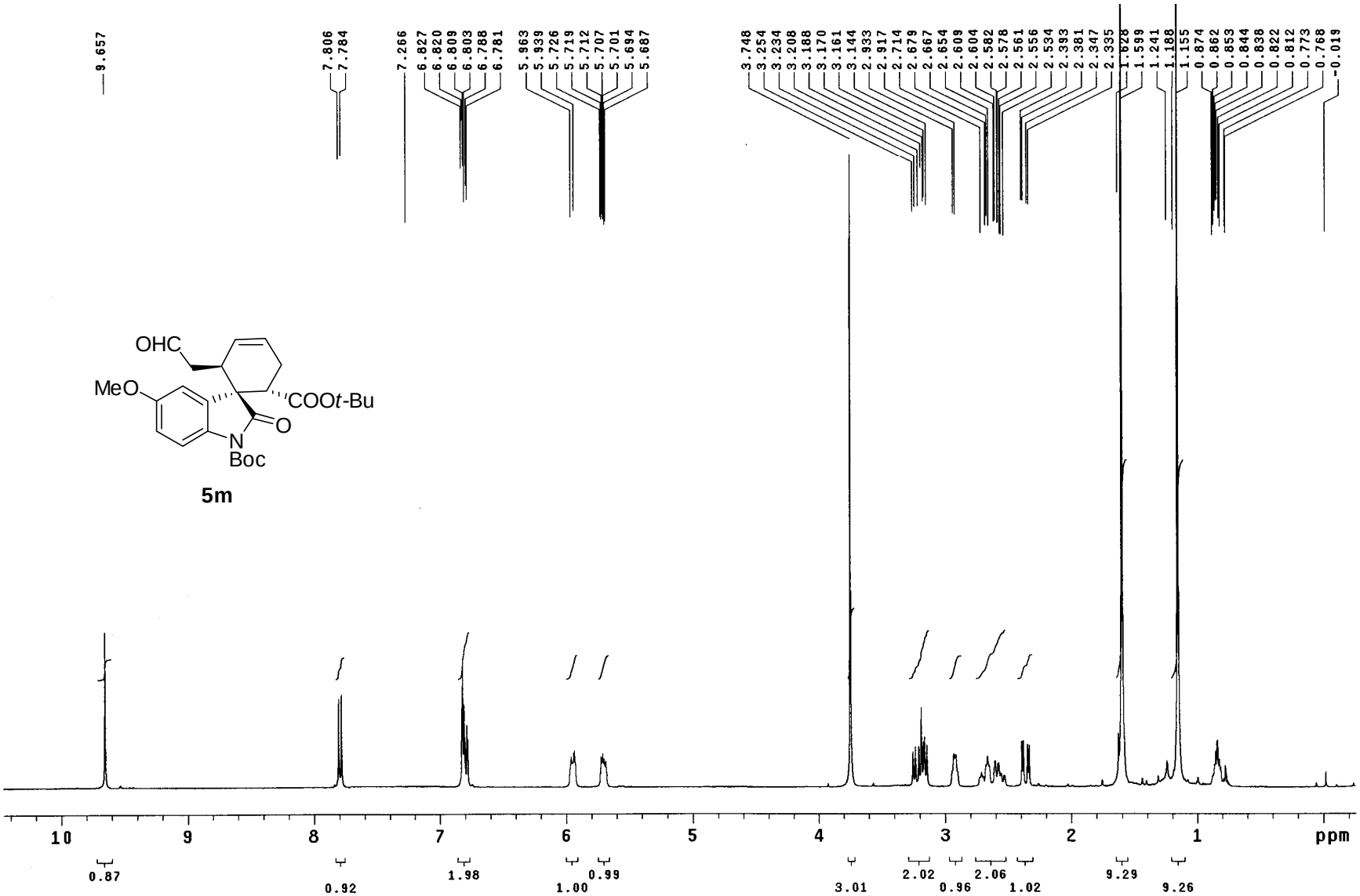
alcohol of 5l



	RT (min)	Area (µV*sec)	% Area	Height (µV)	% Height
1	18.626	3038390	50.45	61291	55.86
2	24.845	2984002	49.55	48434	44.14



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	18.205	78336361	98.81	1480338	98.84
2	25.099	944837	1.19	17360	1.16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MeO
COOt-Bu
O
N
Boc
5m
10
9
8
7
6
5
4
3
2
1
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0.96
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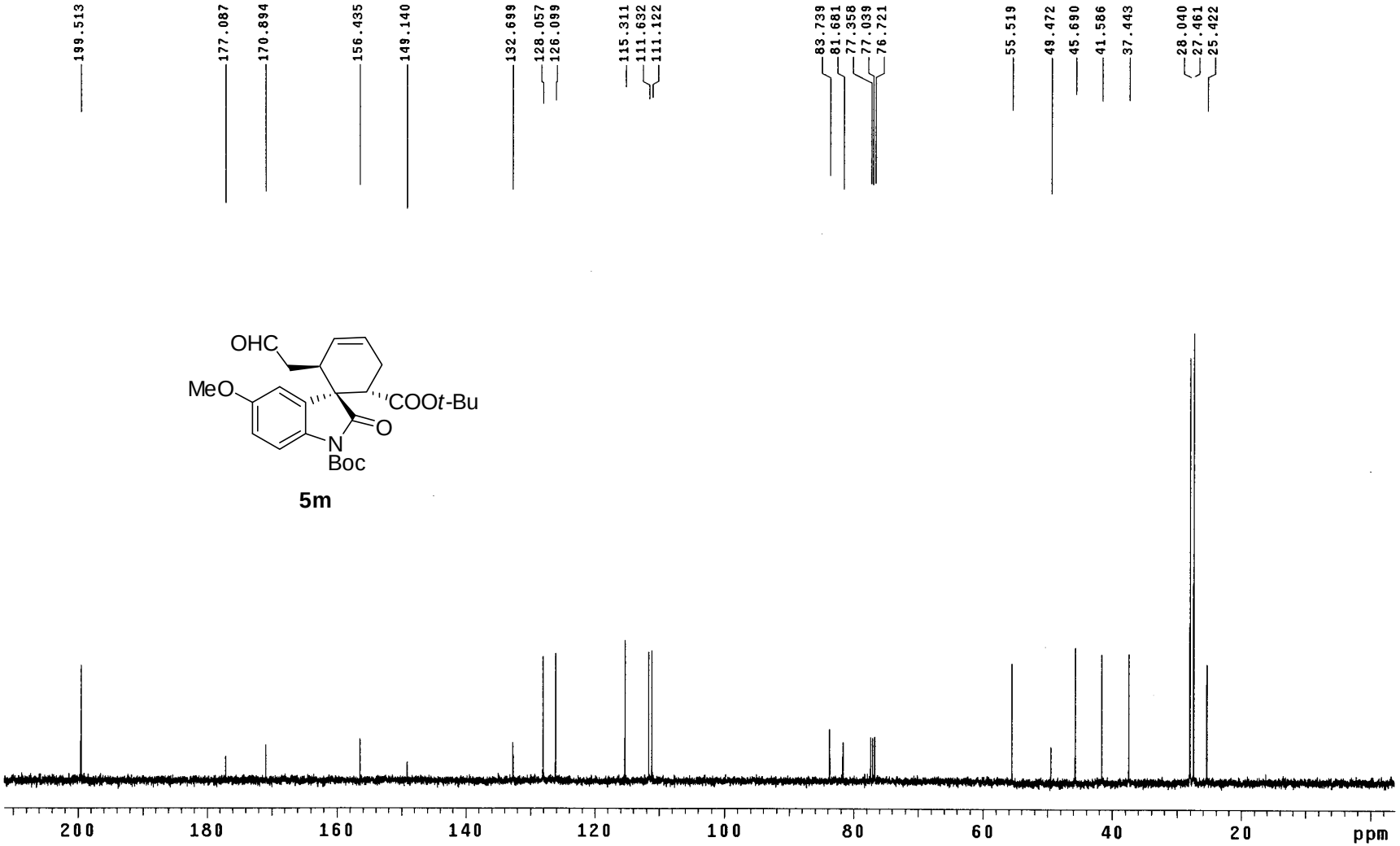
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45.690
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28.040
27.461
25.422
OHC
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N
Boc
5m
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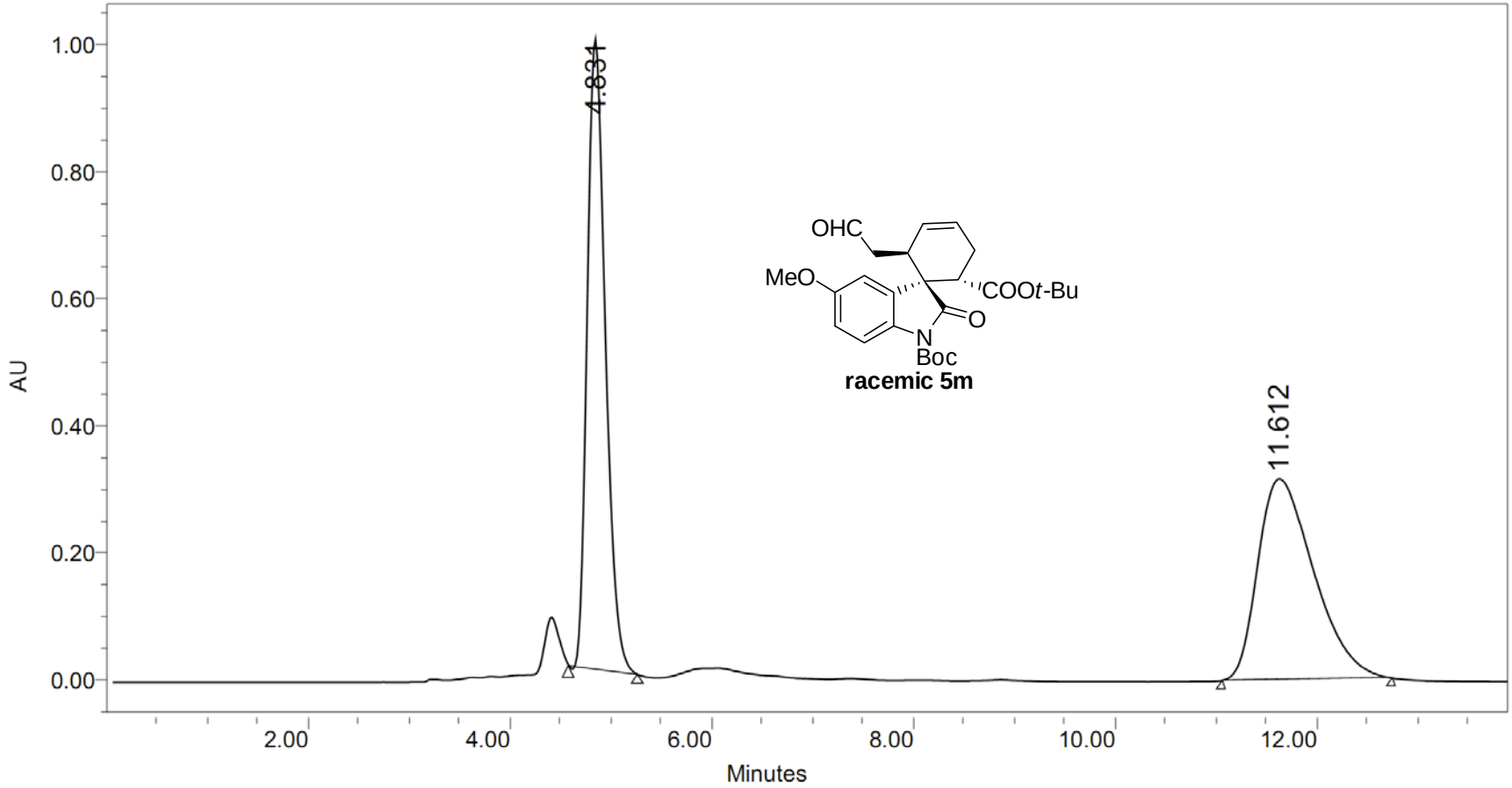
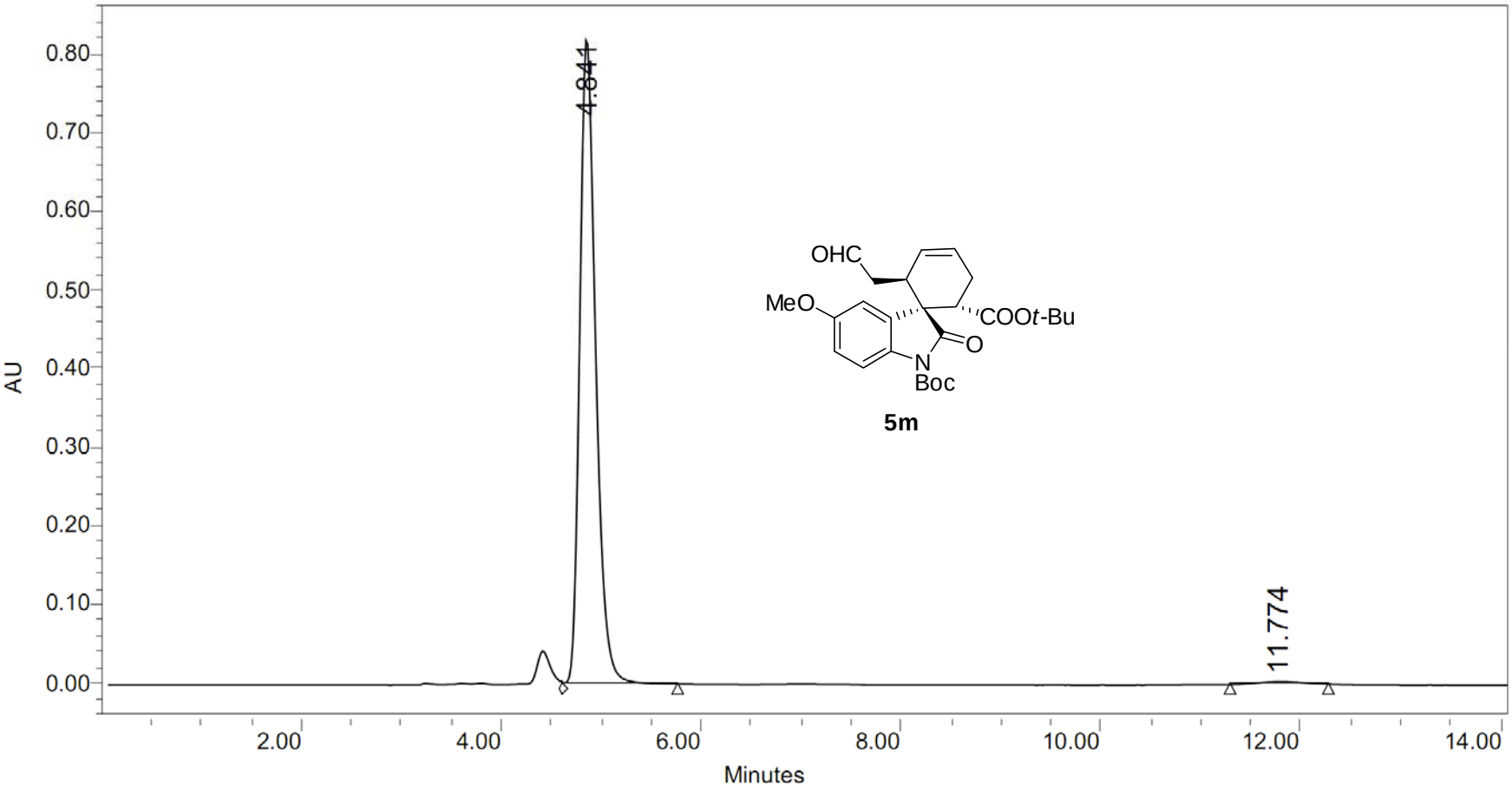
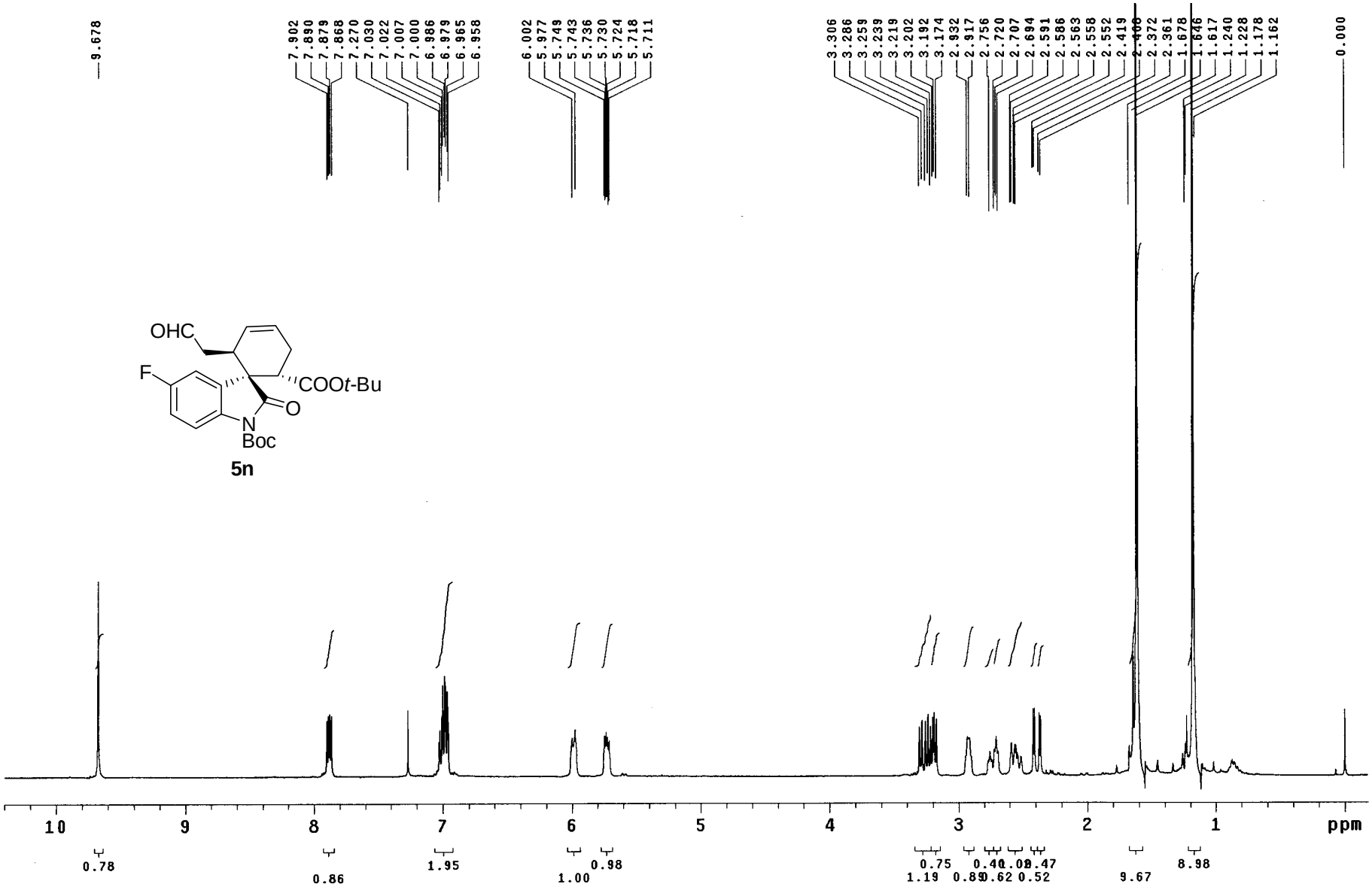
20
ppm



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	4.831	12491030	50.66	993643	75.82
2	11.612	12166059	49.34	316802	24.18



	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	4.841	9102038	98.88	821975	99.60
2	11.774	102745	1.12	3322	0.40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2.917
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COOt-Bu
O
N
Boc
5n
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8
7
6
5
4
3
2
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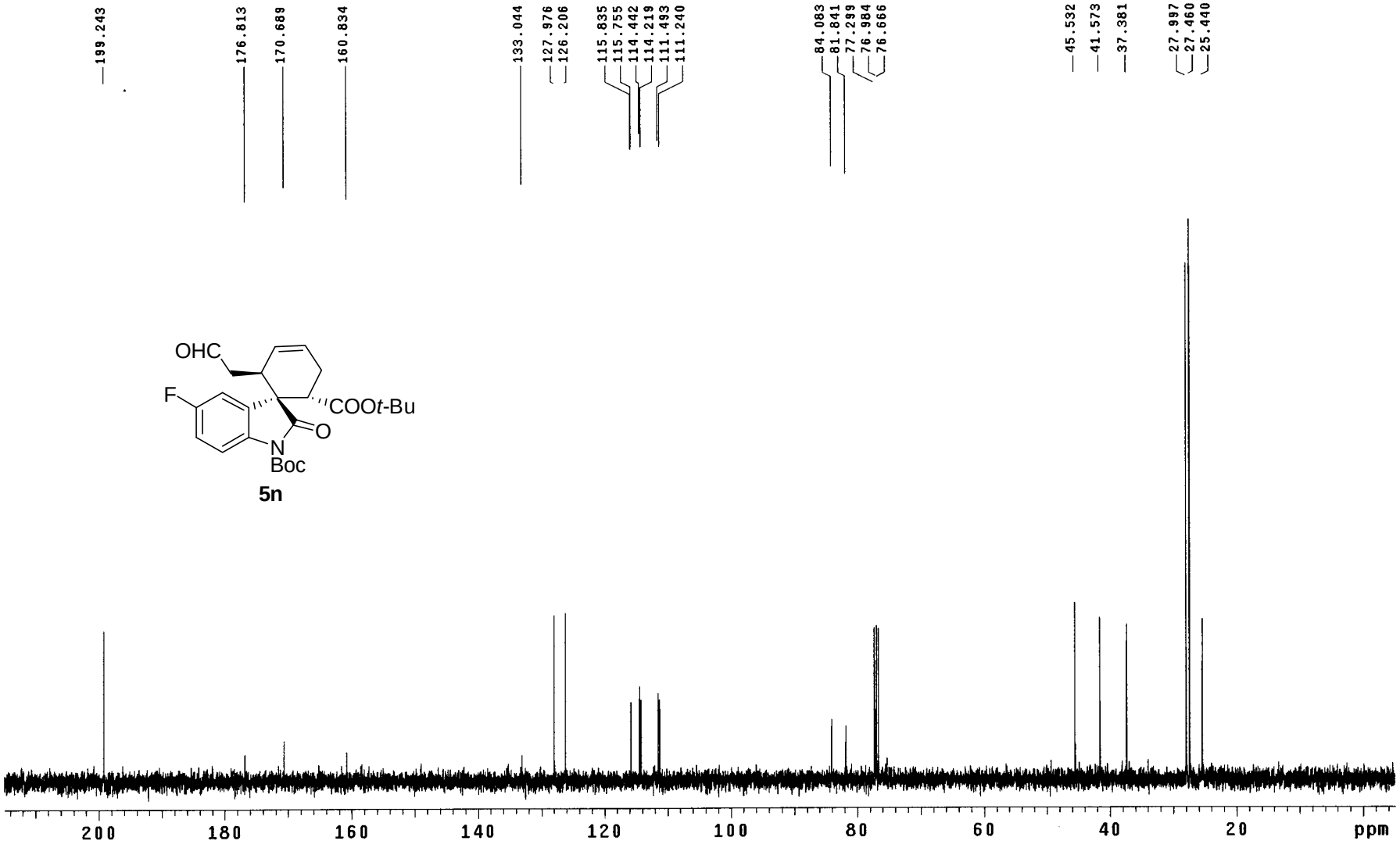
8.98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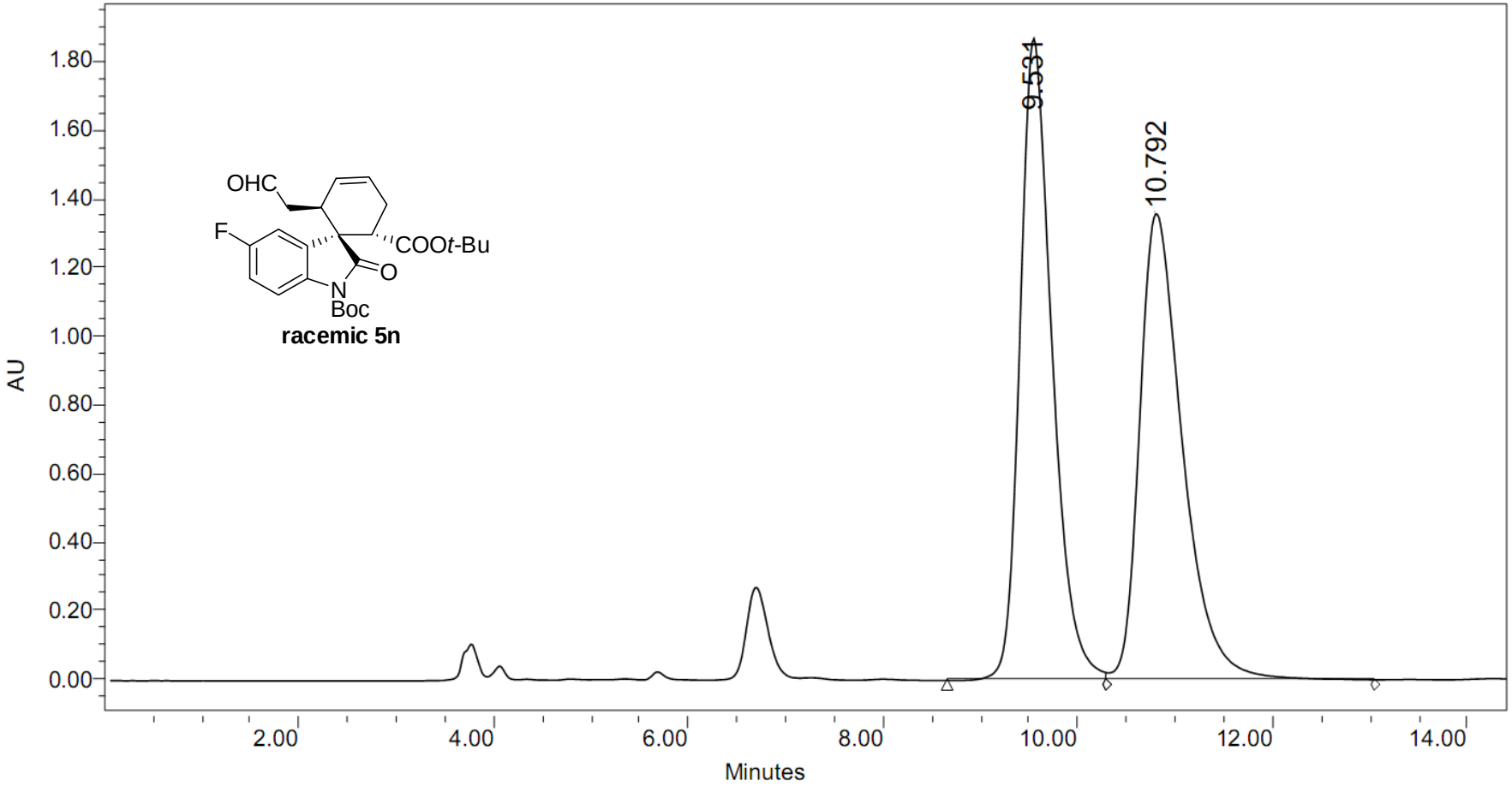
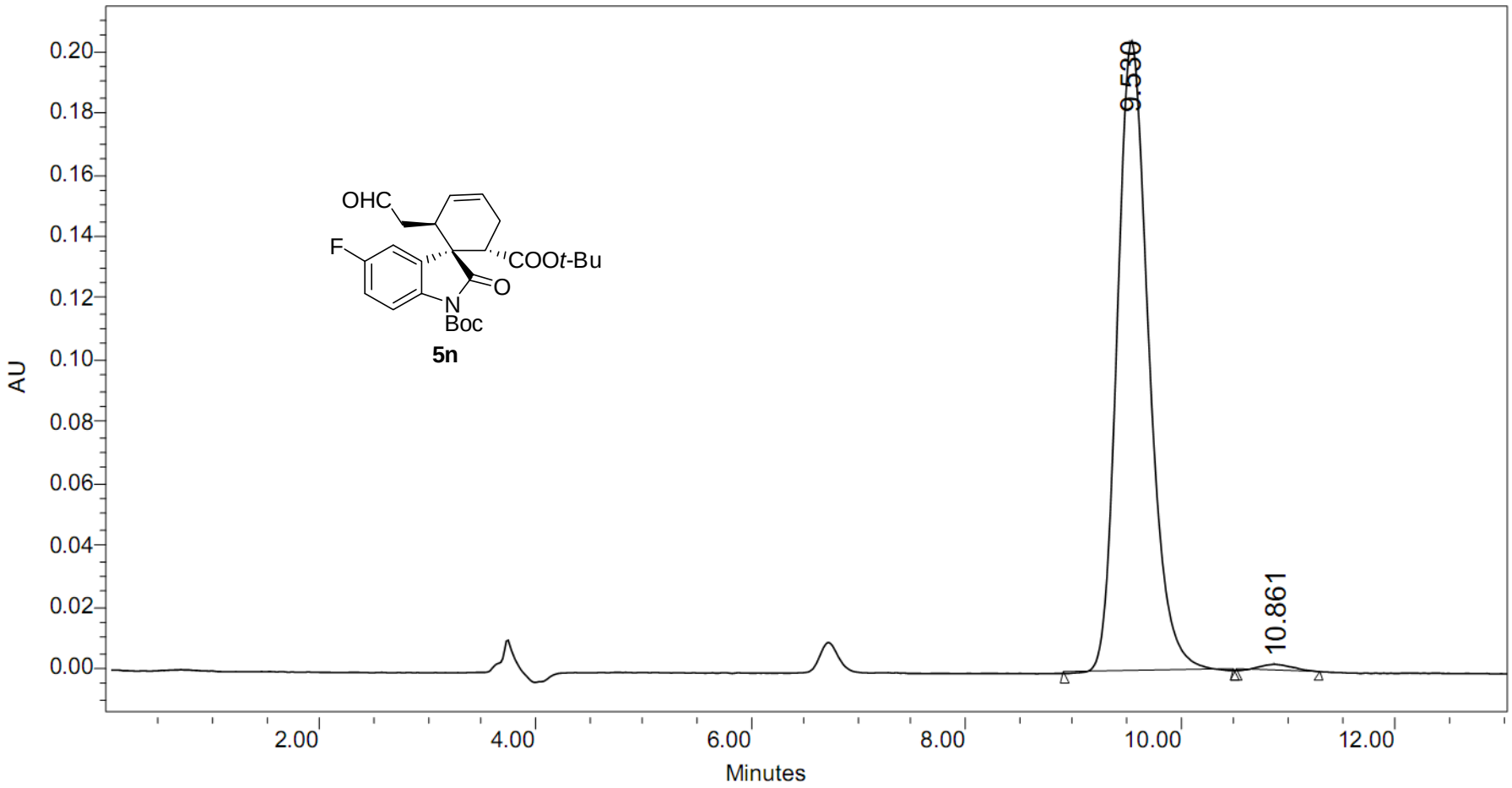
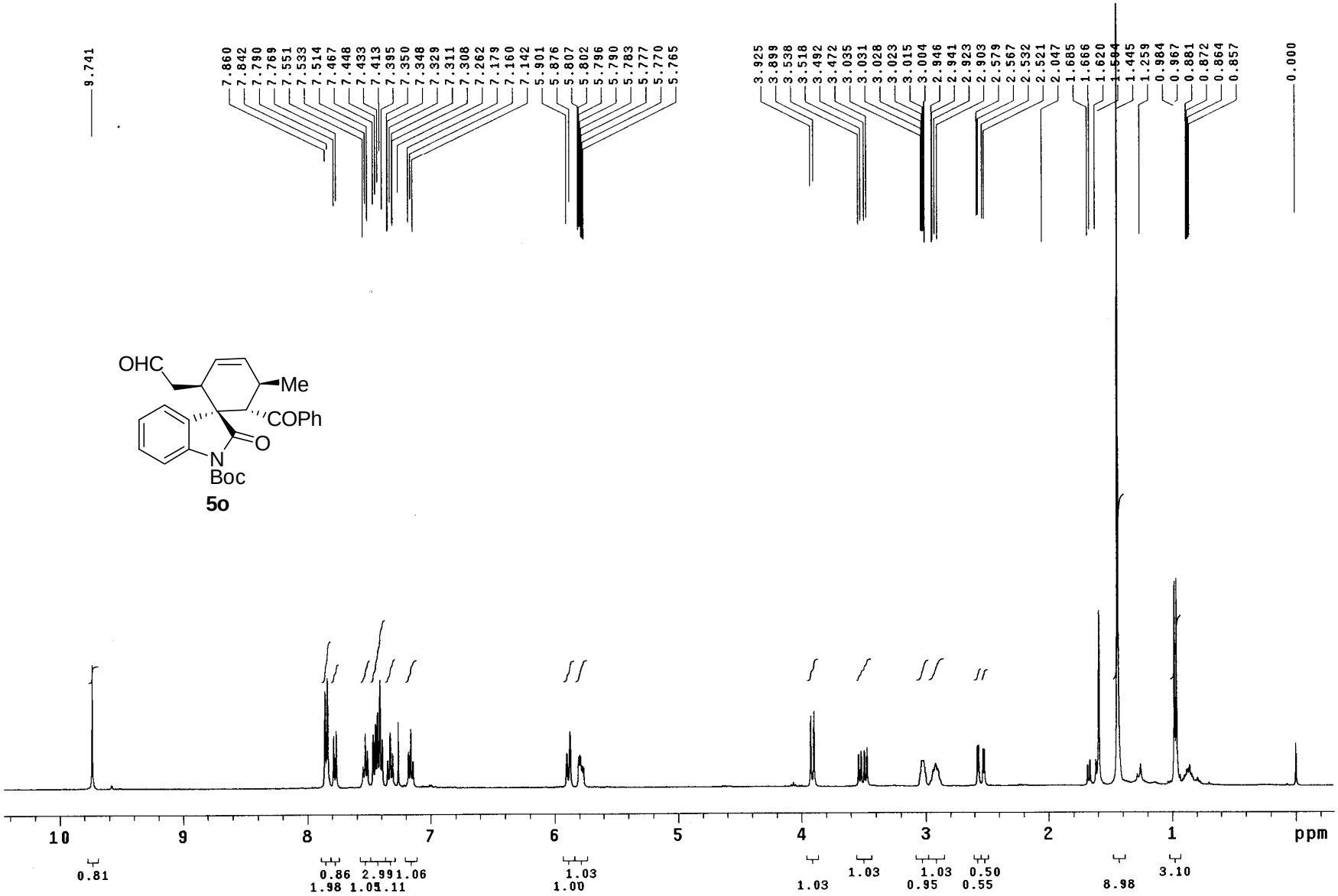
111.240
84.083
81.841
77.299
76.984
76.666
45.532
41.573
37.381
27.997
27.460
25.440
OHC
F
COOt-Bu
O
N
Boc
5n
200
180
160
140
120
100
80
60
40
20
ppm

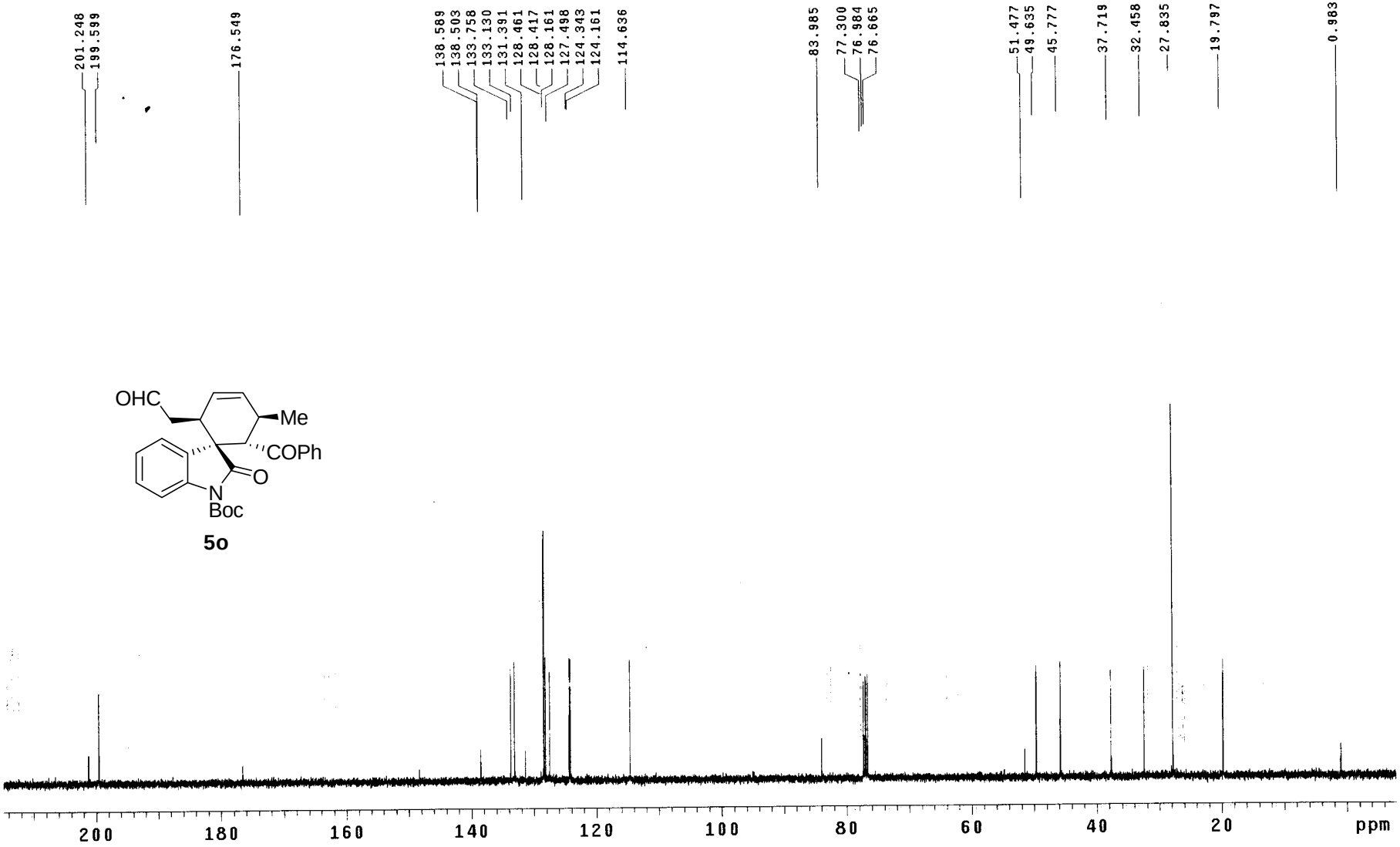


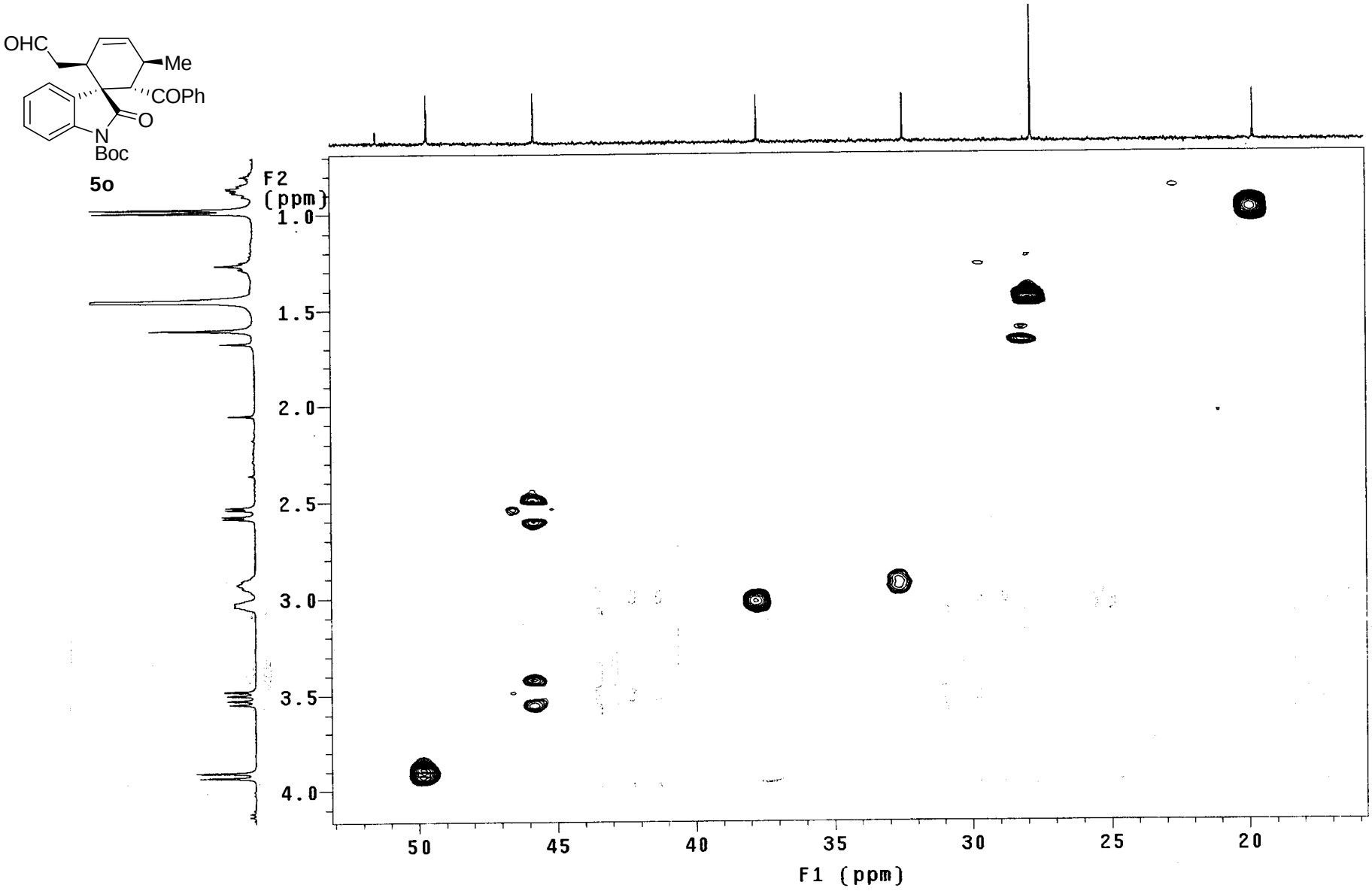
	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	9.531	42977999	50.77	1868663	57.88
2	10.792	41679924	49.23	1359800	42.12

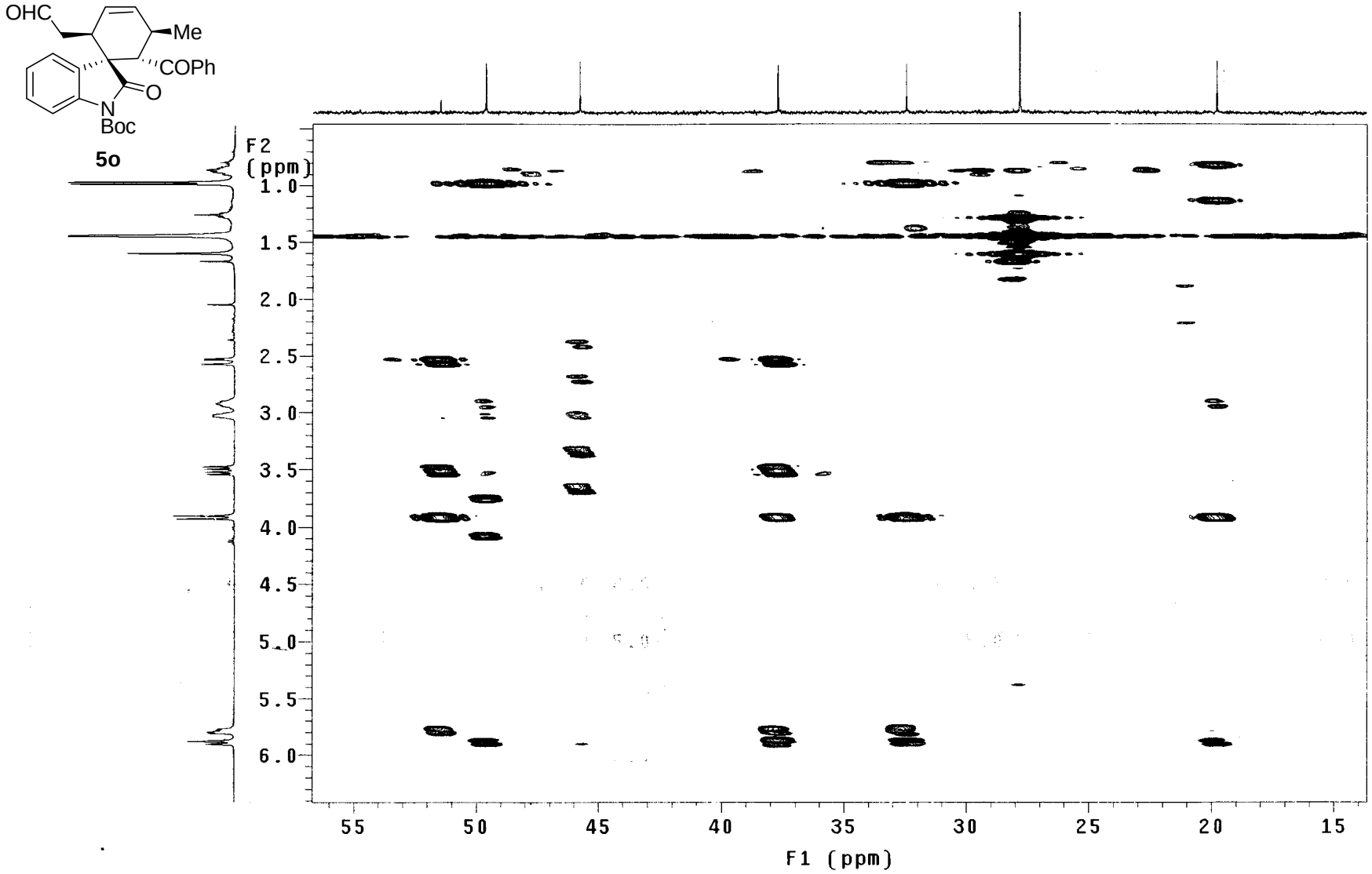


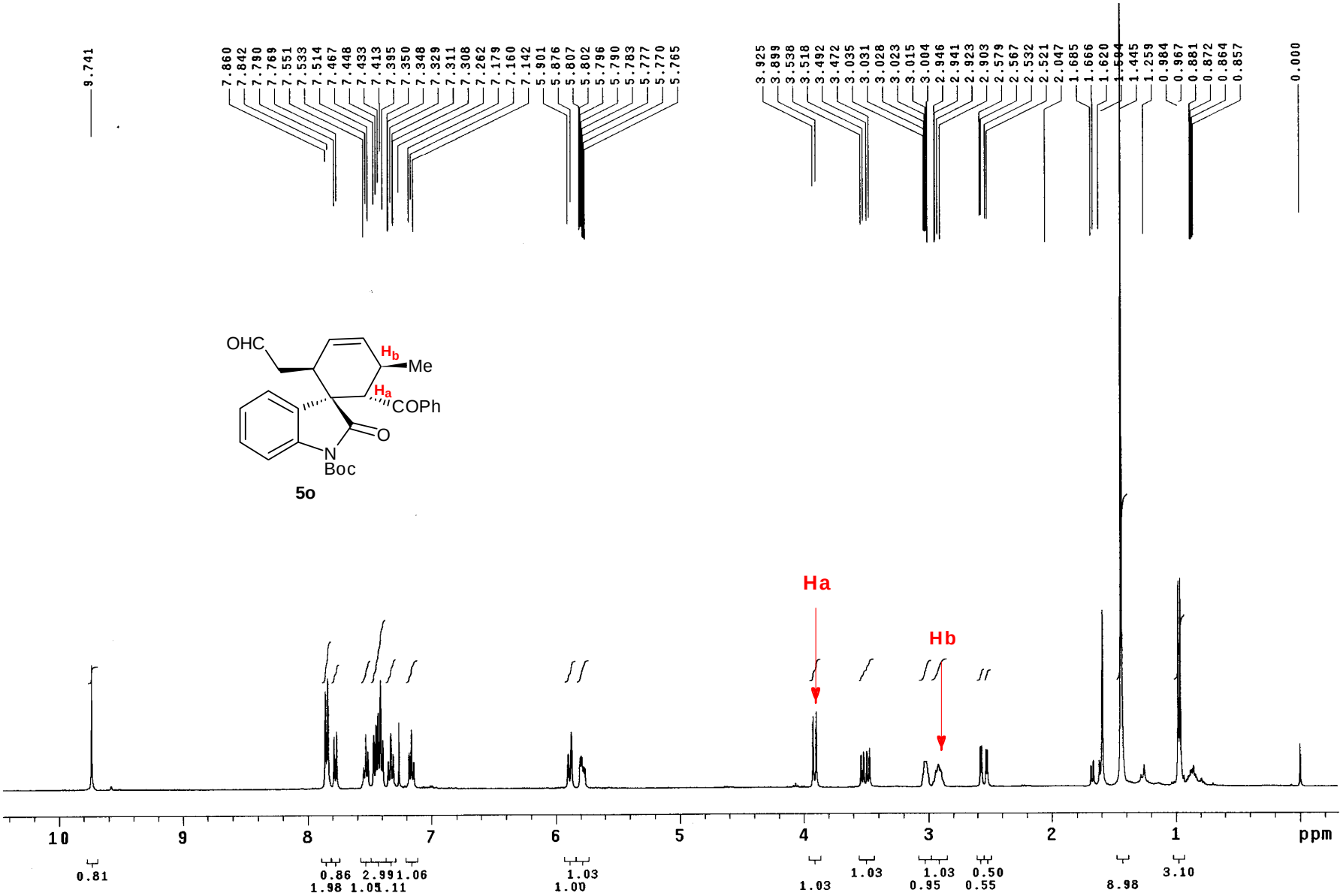
	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	9.530	4188058	98.85	204497	98.94
2	10.861	48881	1.15	2190	1.06

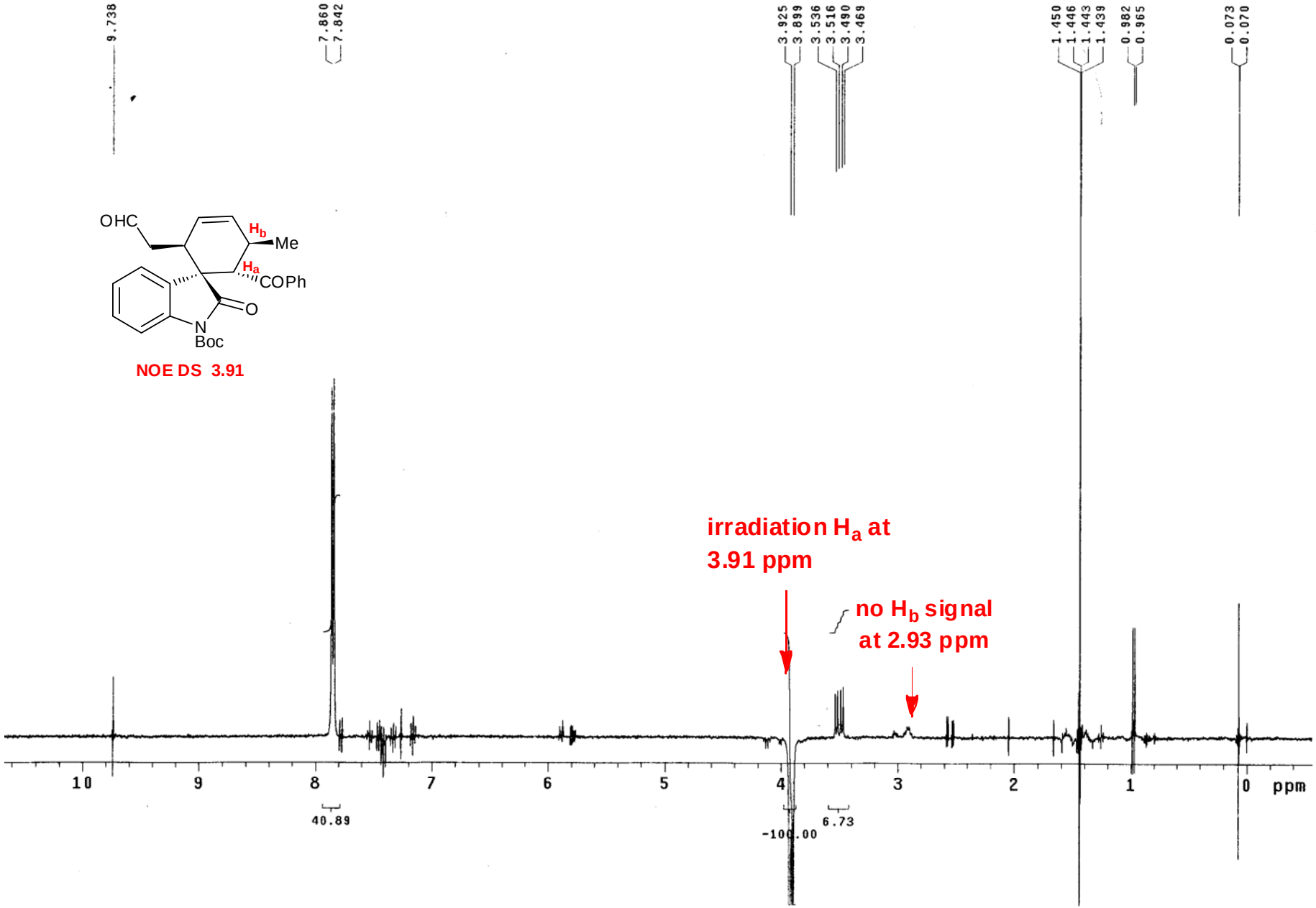

9.741
7.860 7.842 7.790 7.769 7.551 7.533 7.514 7.467 7.448 7.433 7.413 7.395 7.350 7.348 7.329 7.311 7.308 7.262 7.179 7.160 7.142
5.901 5.876 5.807 5.802 5.796 5.790 5.783 5.777 5.770 5.765
3.925 3.899 3.538 3.518 3.492 3.472 3.035 3.031 3.028 3.023 3.015 3.004 2.946 2.941 2.923 2.903 2.579 2.567 2.532 2.521 2.047 1.685 1.666 1.620 1.504 1.445 1.259 0.984 0.967 0.881 0.872 0.864 0.857
0.000
OHC
Me
COPh
O
N
Boc
5o
10 9 8 7 6 5 4 3 2 1 ppm
0.81
0.86 2.99 1.06
1.98 1.05 1.11
1.03
1.00
1.03
1.03
1.03 0.50
0.95 0.55
8.98
3.10

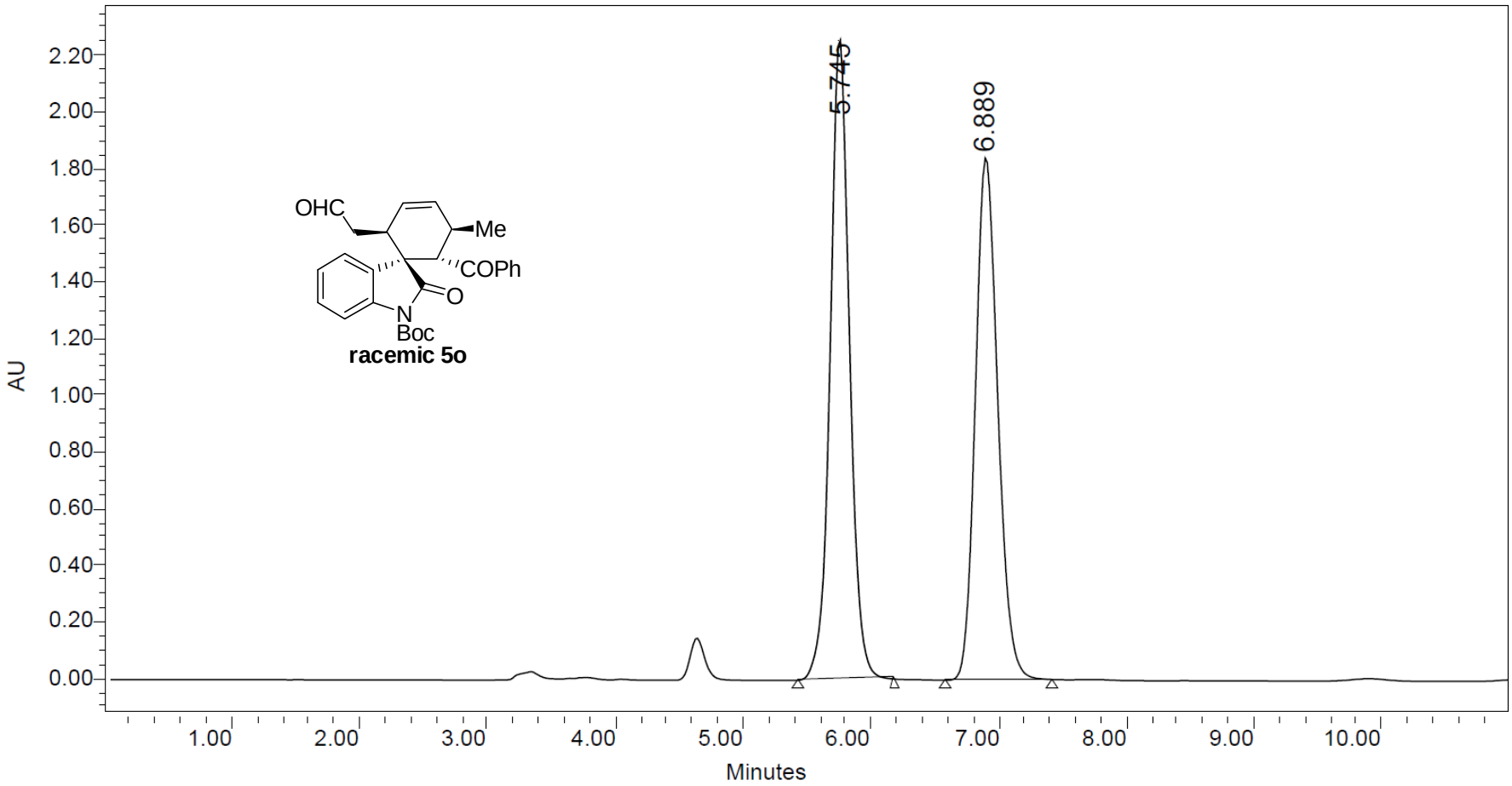

201.248
199.599
176.549
138.589
138.503
133.758
133.130
131.391
128.461
128.417
128.161
127.498
124.343
124.161
114.636
83.985
77.300
76.984
76.665
51.477
49.635
45.777
37.719
32.458
27.835
19.797
0.983
OHC
Me
COPh
O
N
Boc
5o
200
180
160
140
120
100
80
60
40
20
ppm


OHC
Me
COPh
O
N
Boc
5o
F2 (ppm)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
50
45
40
35
30
25
20
F1 (ppm)

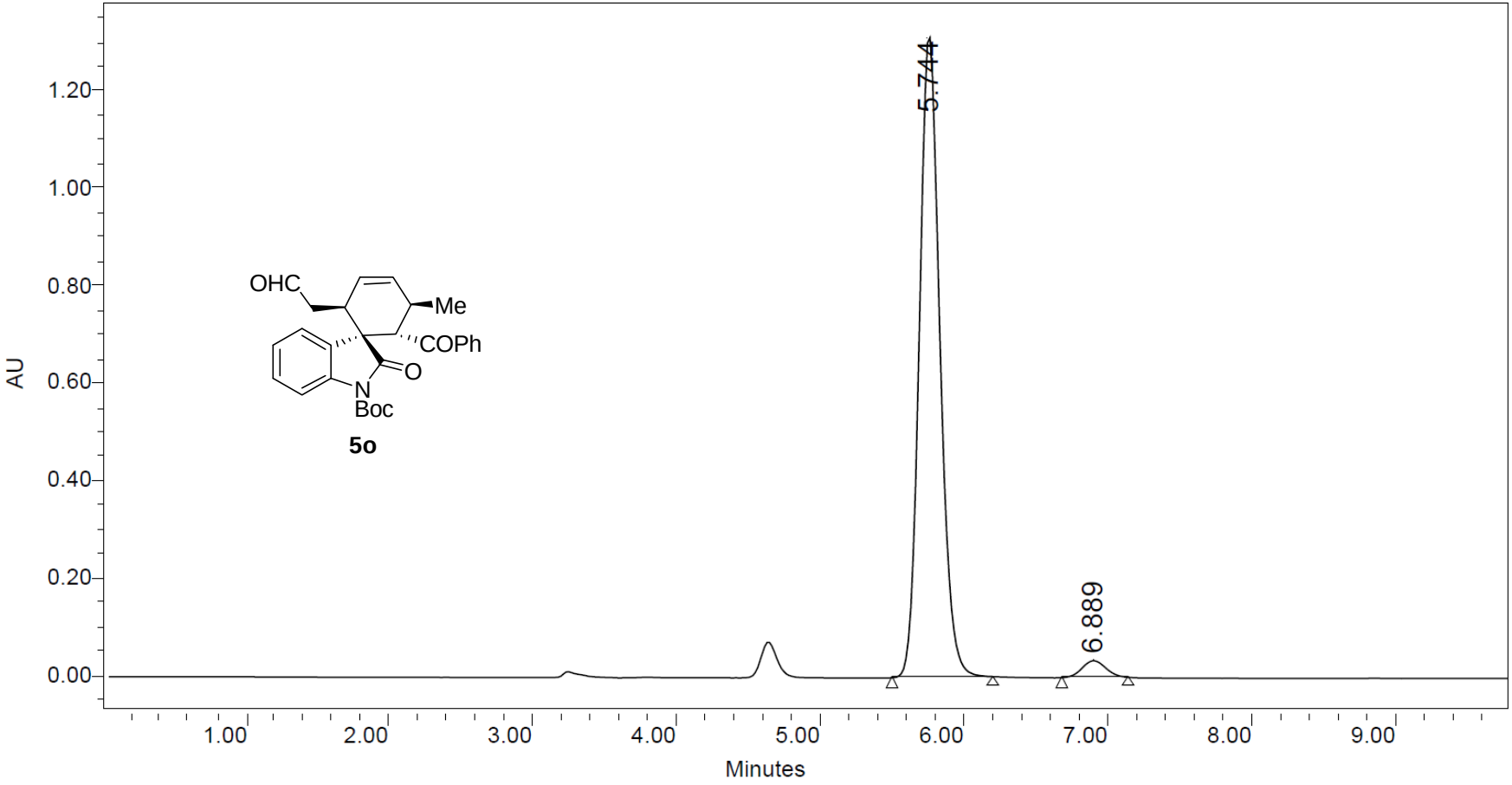

OHC
Me
COPh
O
N
Boc
5o
F2 (ppm)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
55
50
45
40
35
30
25
20
15
F1 (ppm)


OHC
Hb
Me
Ha
COPh
O
N
Boc
5o
Ha
Hb
ppm

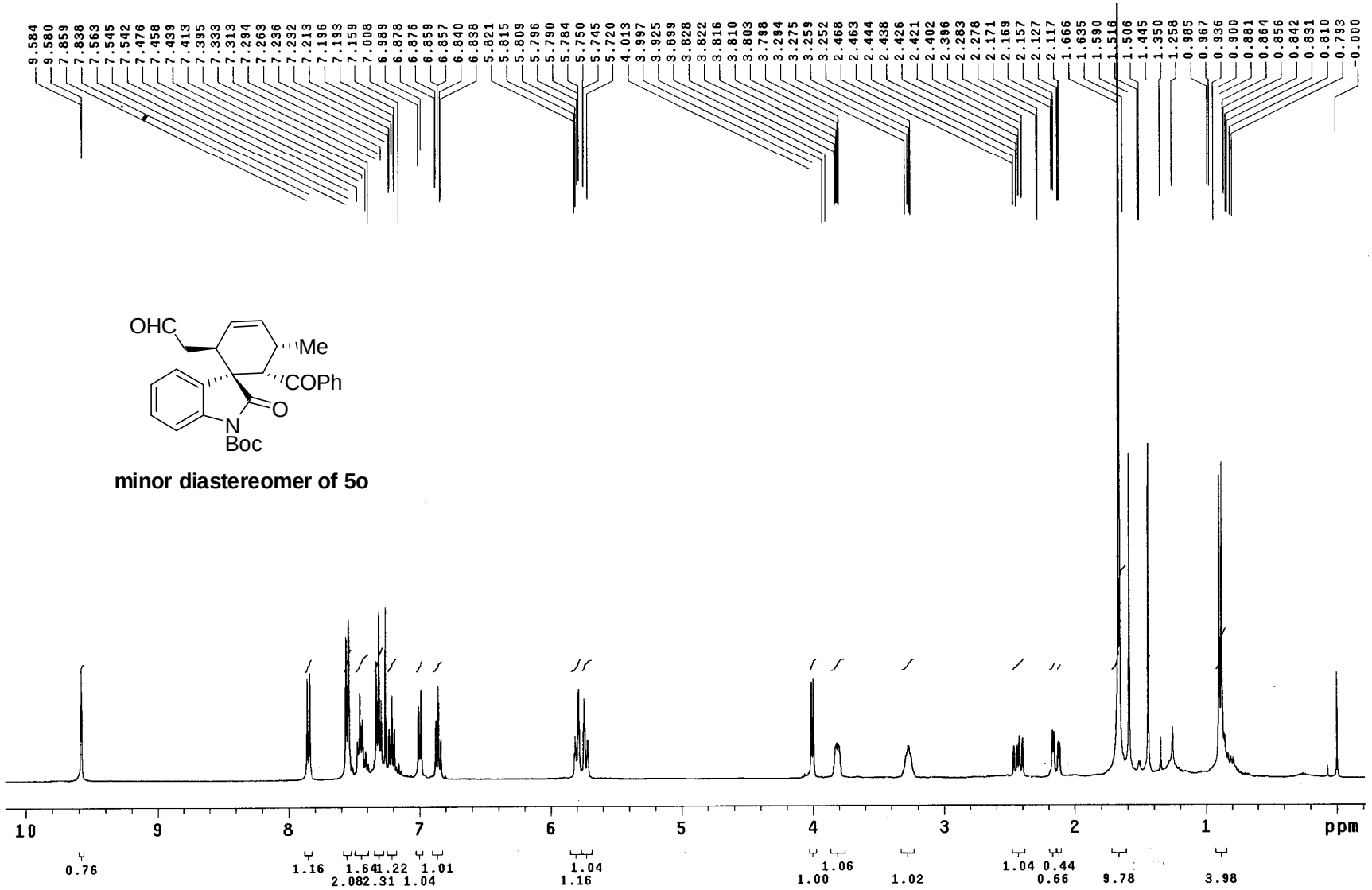

9.738
7.860
7.842
3.925
3.899
3.536
3.516
3.490
3.469
1.450
1.446
1.443
1.439
0.982
0.965
0.073
0.070
OHC
Me
COPh
O
N
Boc
NOE DS 3.91
irradiation Ha at
3.91 ppm
no Hb signal
at 2.93 ppm
10
9
8
7
6
5
4
3
2
1
0
ppm
40.89
-100.00
6.73

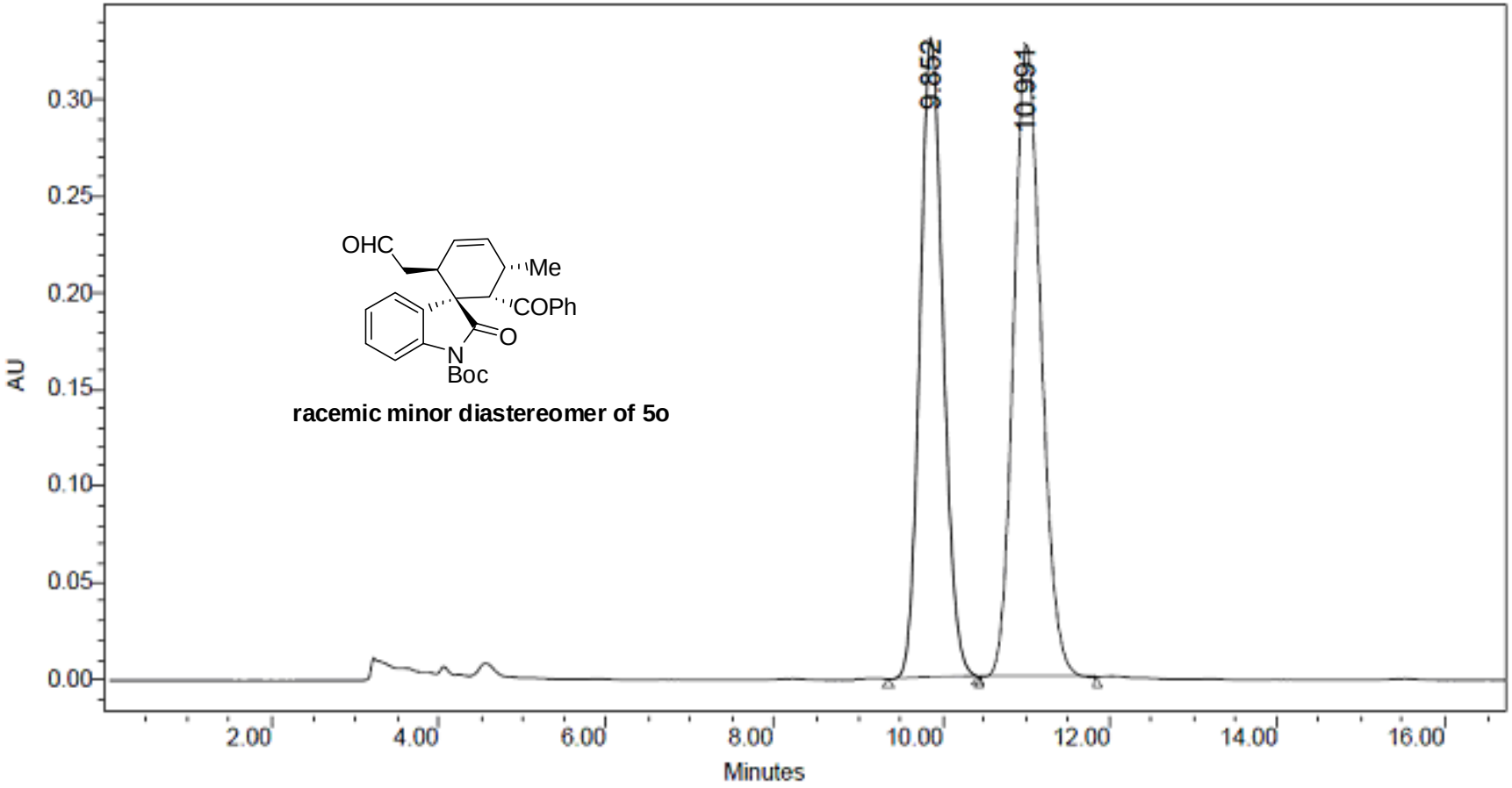


	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	5.745	23802082	51.45	2261667	55.05
2	6.889	22464682	48.55	1846452	44.95

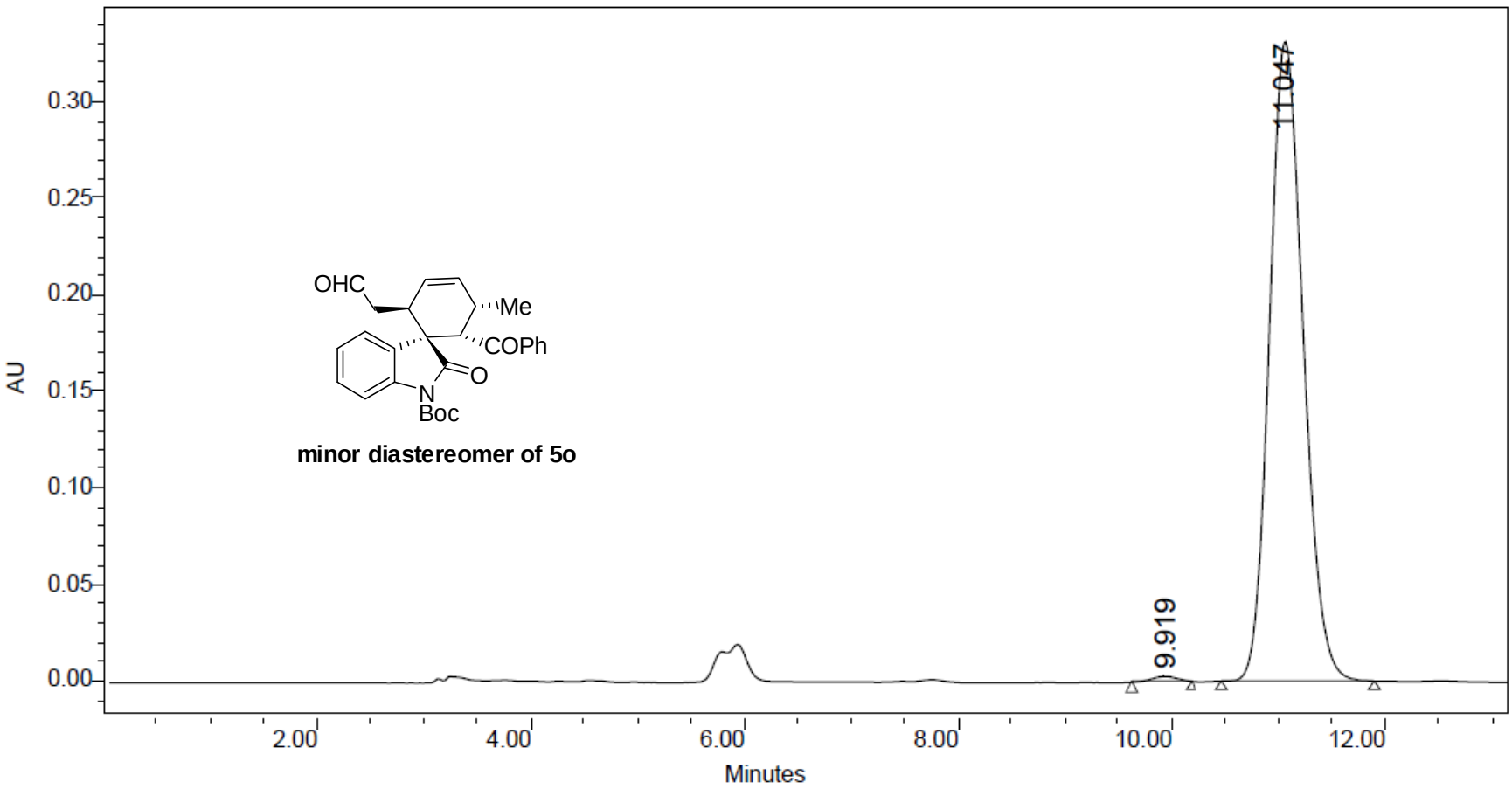


	RT (min)	Area (□V *sec)	% Area	Height (□V)	% Height
1	5.744	13051090	97.08	1315480	97.46
2	6.889	392165	2.92	34350	2.54

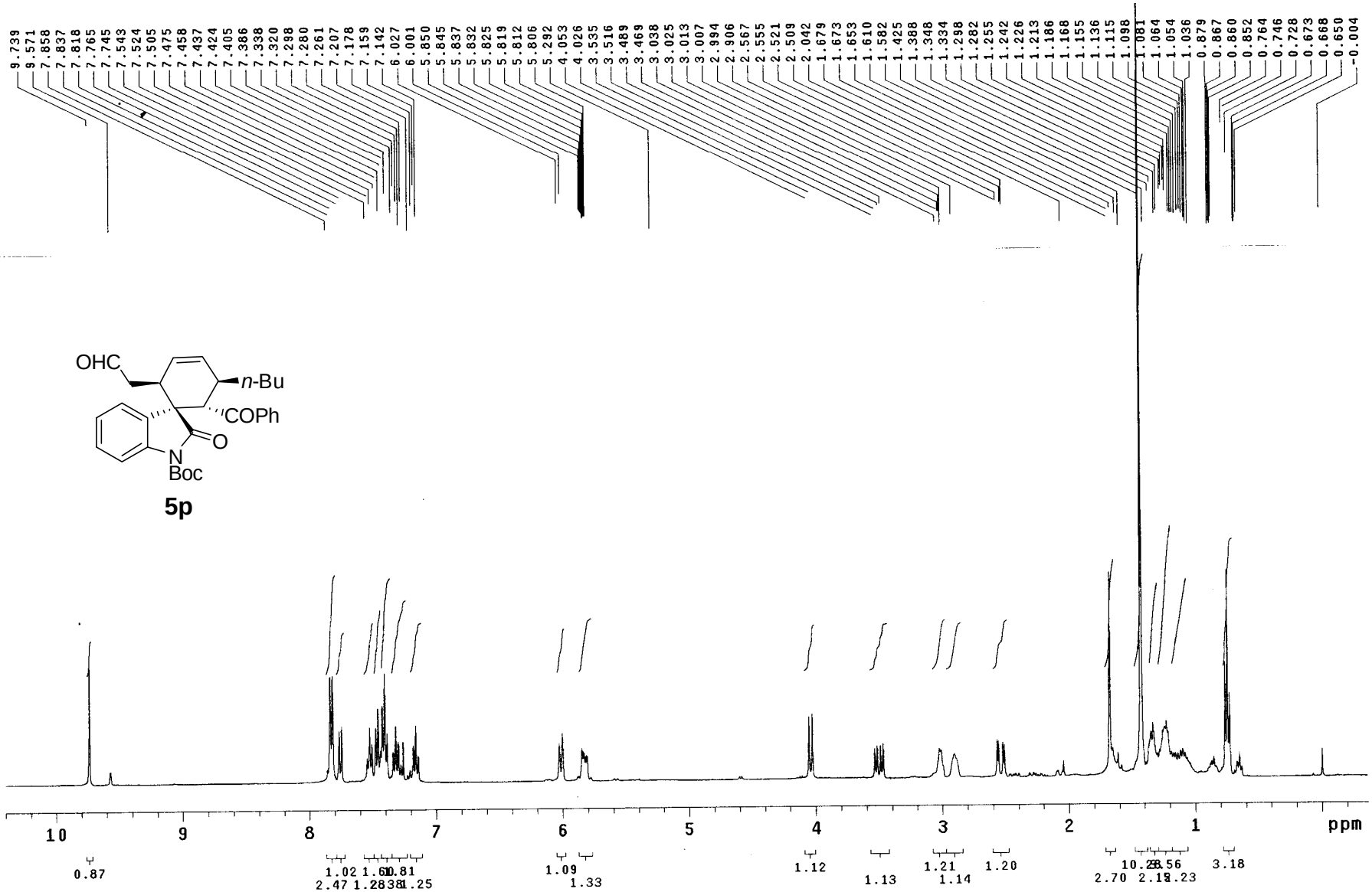

OHC
Me
COPh
O
N
Boc
minor diastereomer of 5o
9.584 9.580 7.859 7.838 7.563 7.545 7.542 7.476 7.458 7.439 7.413 7.395 7.333 7.313 7.294 7.263 7.236 7.232 7.213 7.196 7.193 7.159 7.008 6.989 6.878 6.876 6.859 6.857 6.840 6.838 5.821 5.815 5.809 5.796 5.790 5.784 5.750 5.745 5.720 4.013 3.997 3.925 3.899 3.828 3.822 3.816 3.810 3.803 3.798 3.294 3.275 3.259 3.252 2.468 2.463 2.444 2.438 2.426 2.421 2.402 2.396 2.283 2.278 2.171 2.169 2.157 2.127 2.117 1.666 1.635 1.590 1.516 1.506 1.445 1.350 1.258 0.985 0.967 0.936 0.900 0.881 0.864 0.856 0.842 0.831 0.810 0.793 -0.000
10 9 8 7 6 5 4 3 2 1 ppm
0.76
1.16 1.64 1.22 1.01
2.08 2.31 1.04
1.04
1.16
1.06
1.00
1.02
1.04 0.44
0.66
9.78
3.98

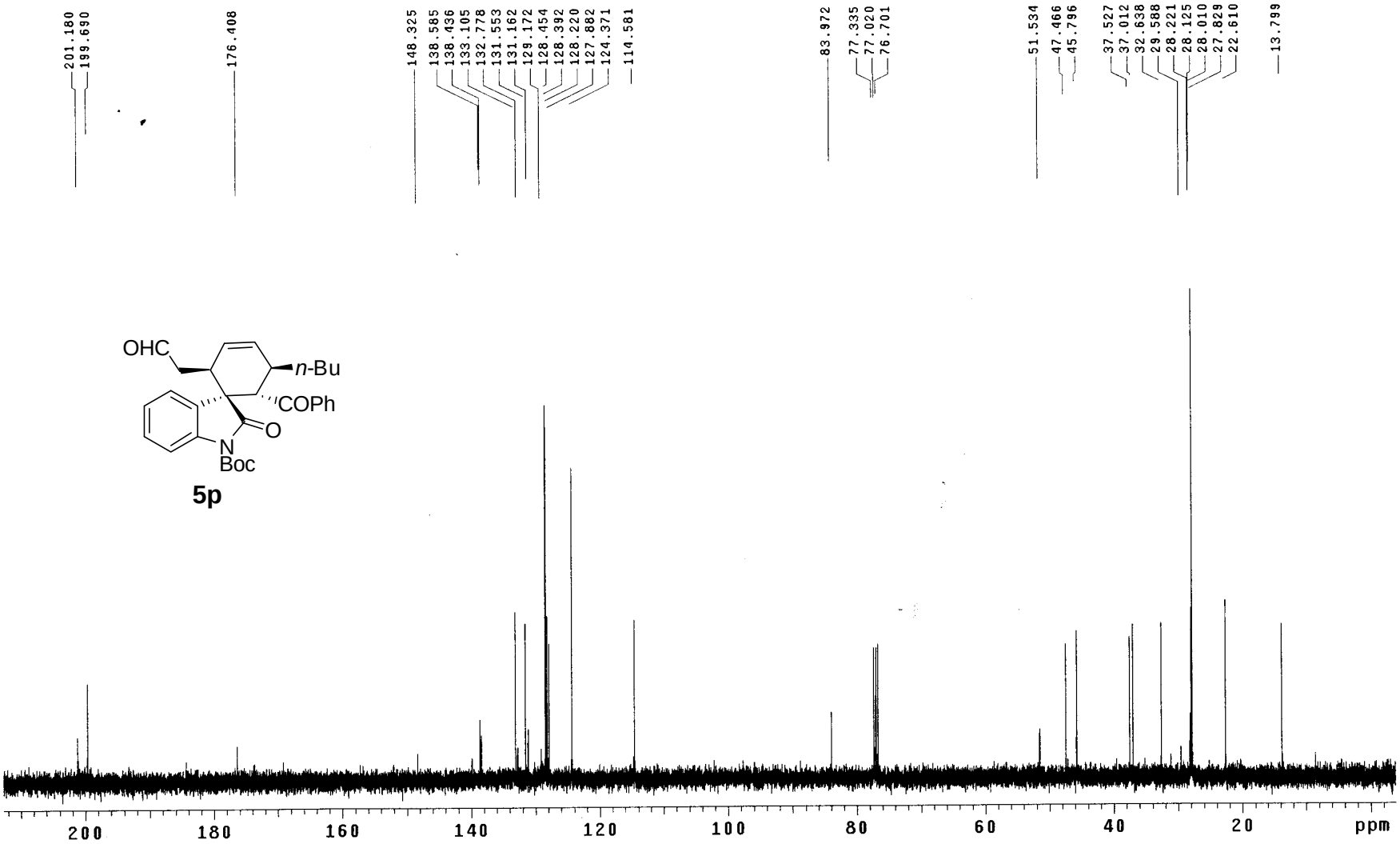


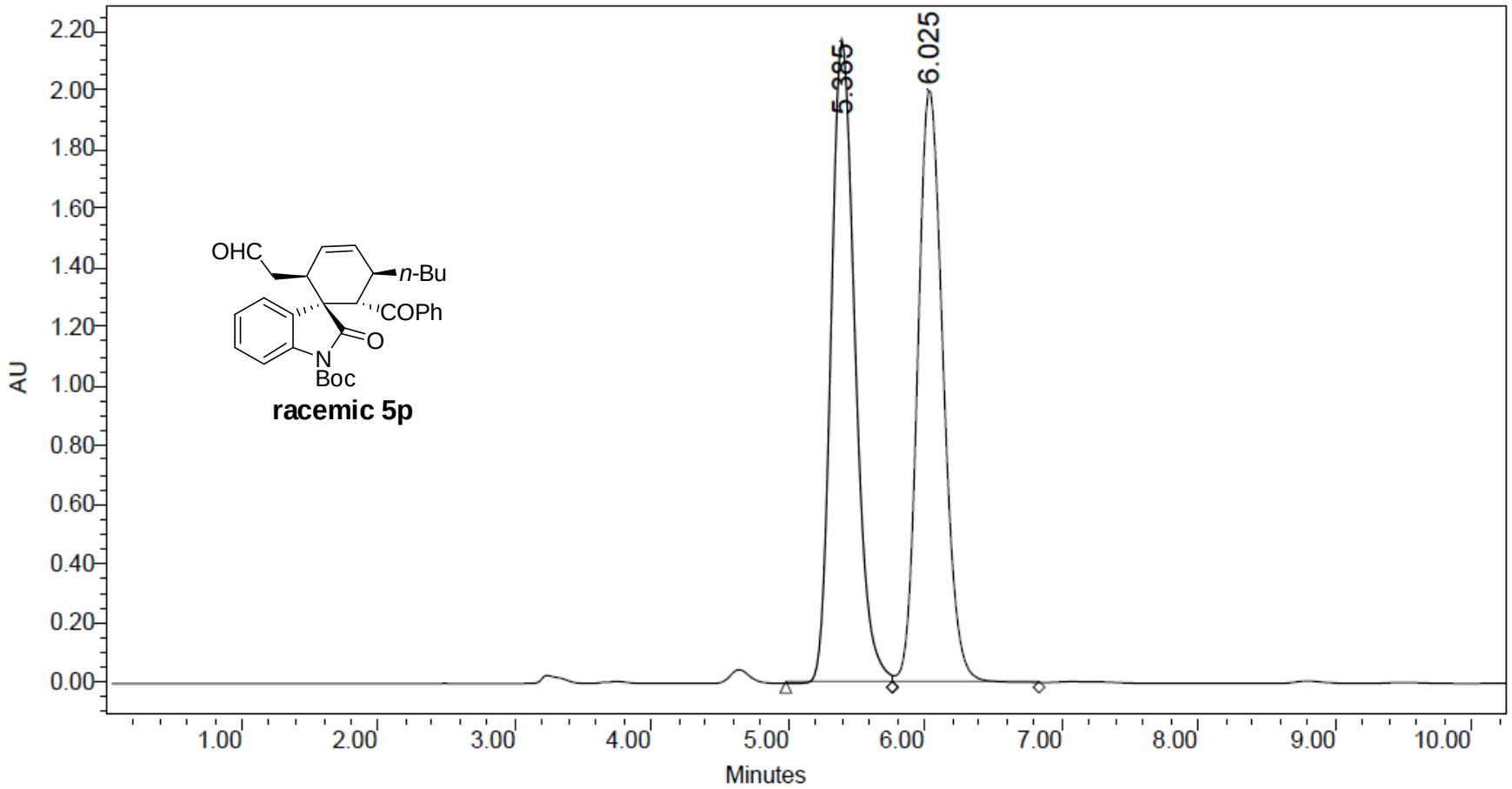
	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	9.852	6370616	46.08	330822	50.21
2	10.991	7454578	53.92	328097	49.79



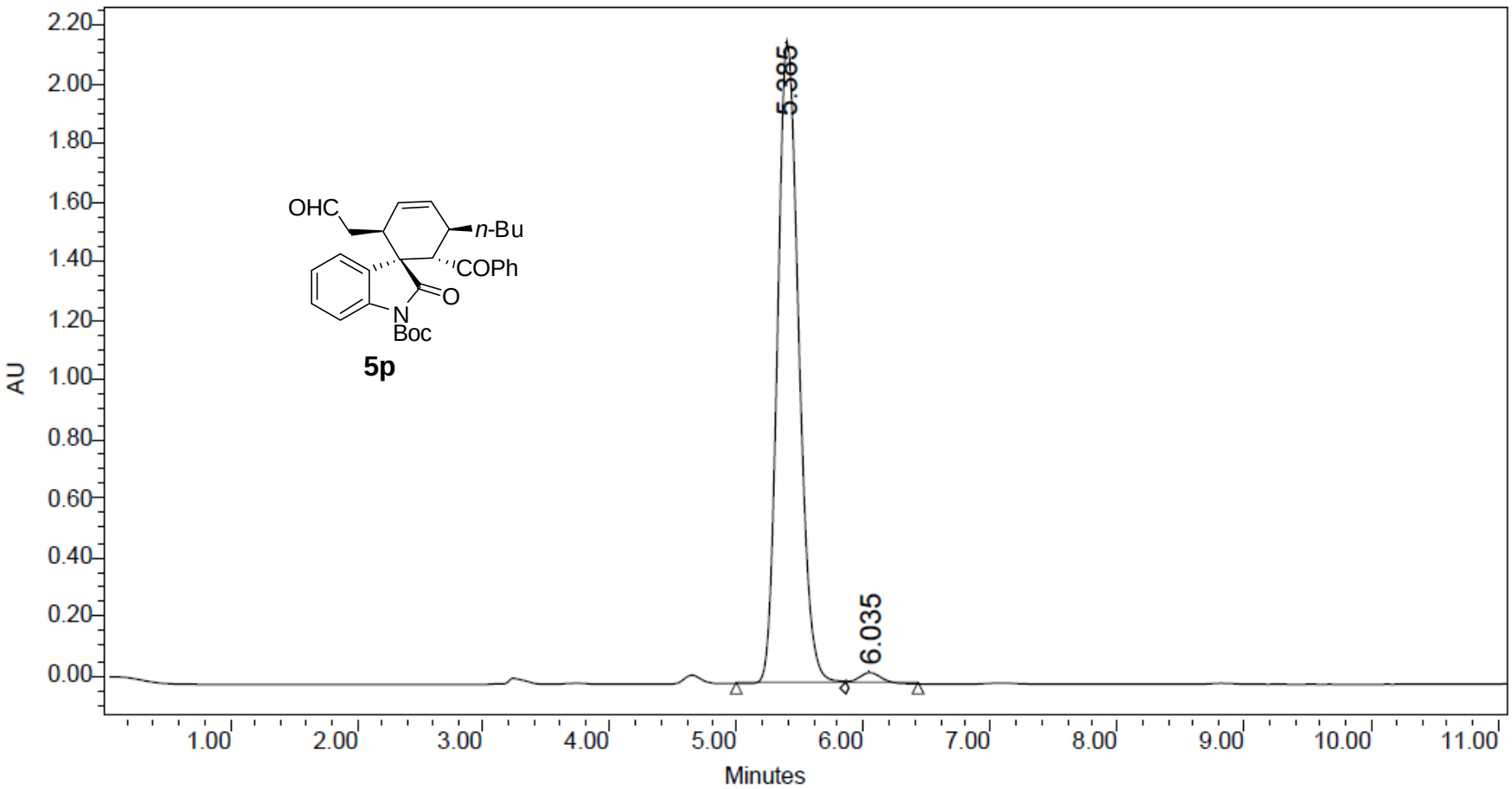
	RT (min)	Area (µV*sec)	% Area	Height (µV)	% Height
1	9.919	46009	0.63	2780	0.83
2	11.047	7274555	99.37	330962	99.17


OHC
n-Bu
COPh
O
N
Boc
5p
ppm

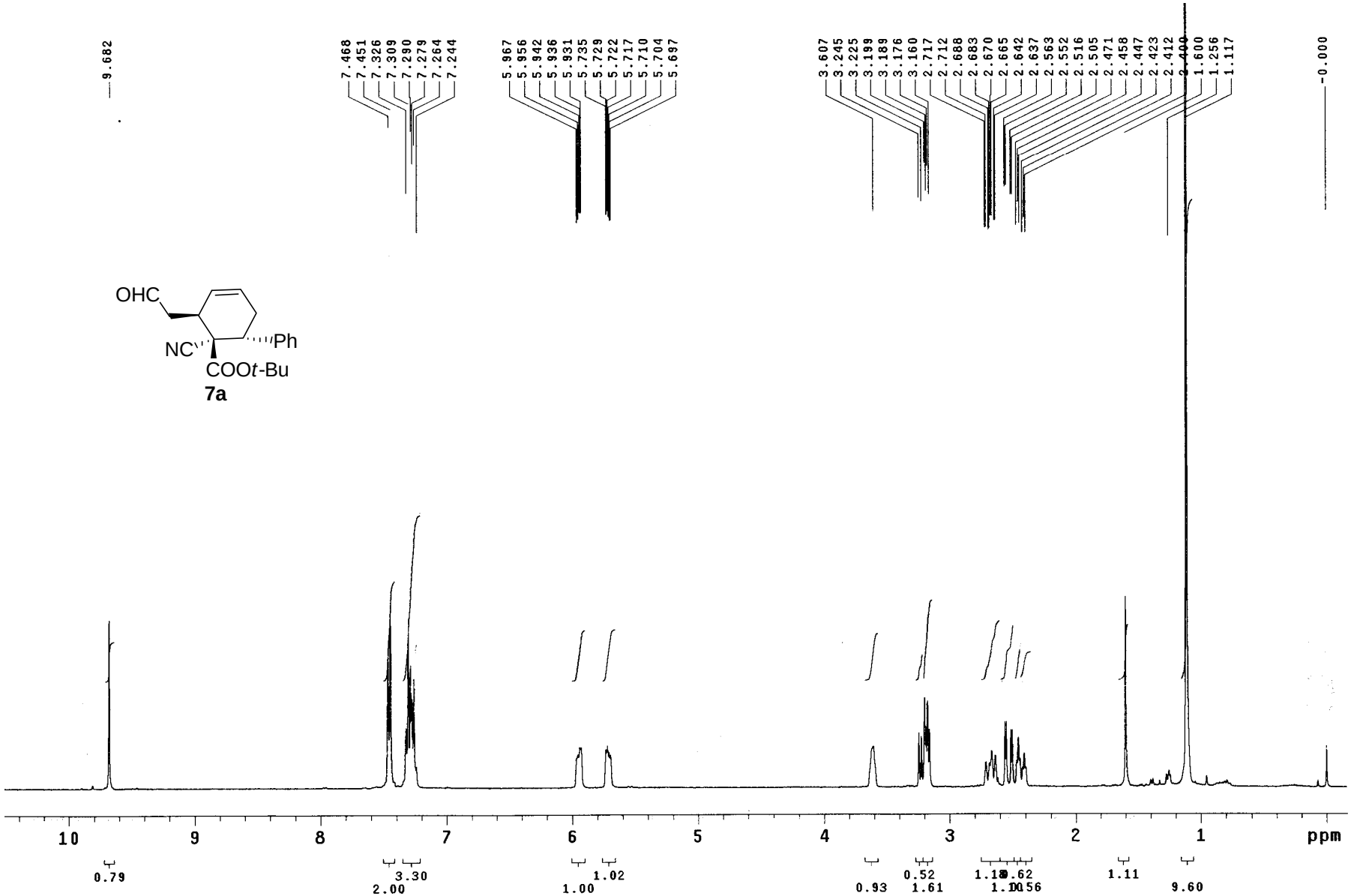

201.180
199.690
176.408
148.325
138.585
138.436
133.105
132.778
131.553
131.162
129.172
128.454
128.392
128.220
127.882
124.371
114.581
83.972
77.335
77.020
76.701
51.534
47.466
45.796
37.527
37.012
32.638
29.588
28.221
28.125
28.010
27.829
22.610
13.799
OHC
n-Bu
COPh
O
N
Boc
5p
200
180
160
140
120
100
80
60
40
20
ppm

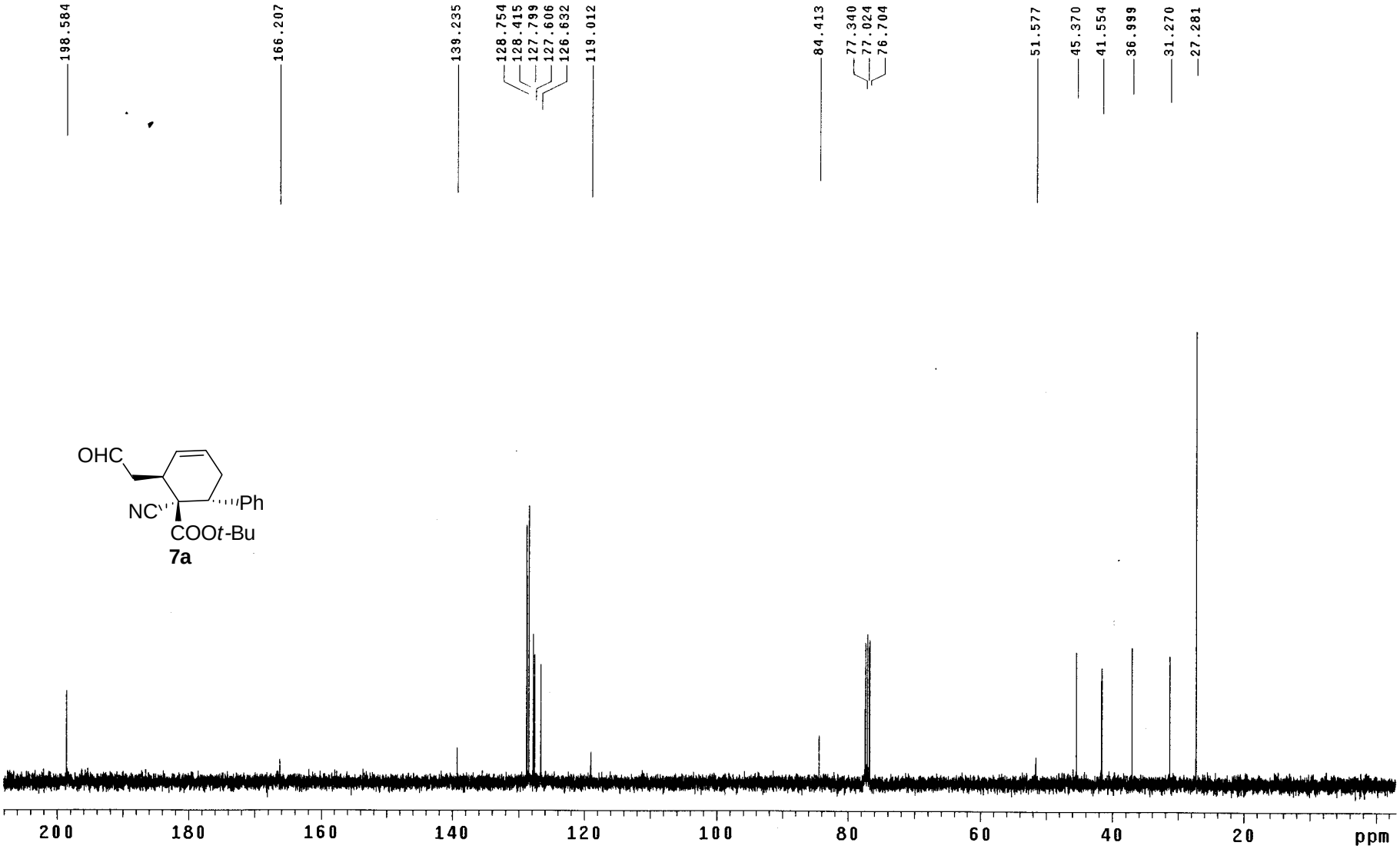


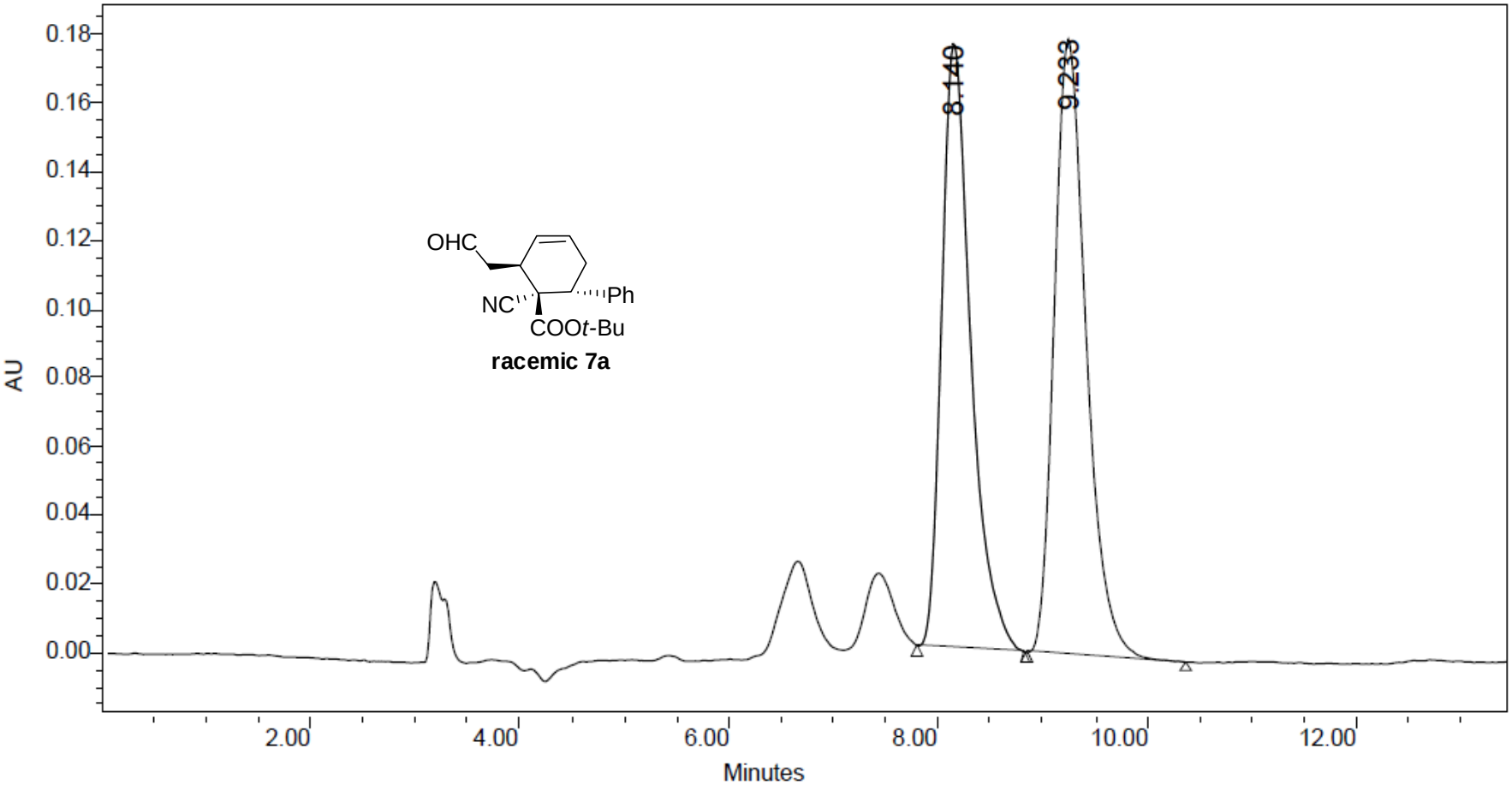
	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	5.385	26565502	50.49	2173612	51.92
2	6.025	26045761	49.51	2013082	48.08



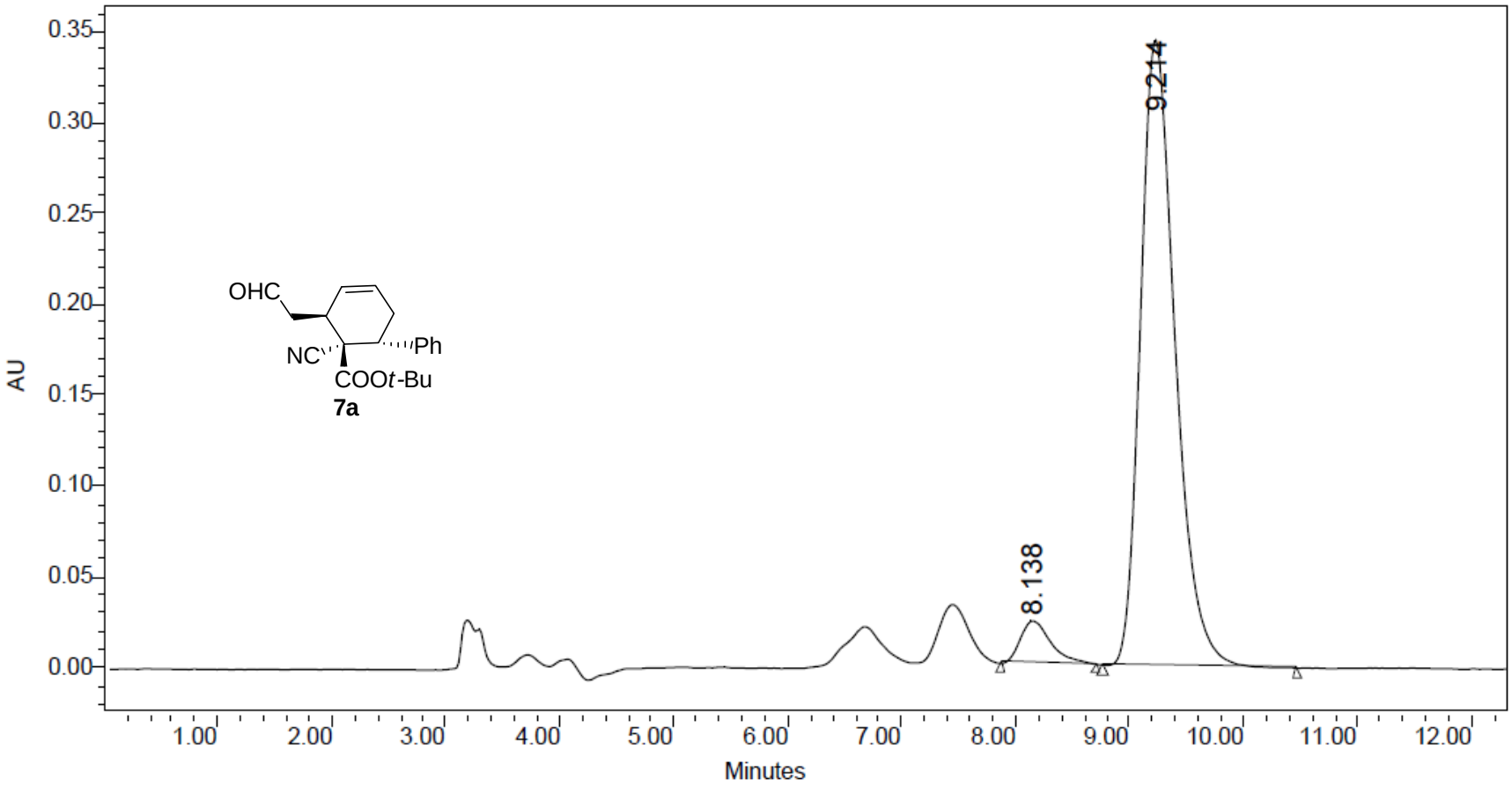
	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	5.385	25344585	98.11	2168667	98.28
2	6.035	487988	1.89	37920	1.72


OHC
NC
Ph
COOt-Bu
7a
9.682
7.468
7.451
7.326
7.309
7.290
7.279
7.264
7.244
5.967
5.956
5.942
5.936
5.931
5.735
5.729
5.722
5.717
5.710
5.704
5.697
3.607
3.245
3.225
3.199
3.189
3.176
3.160
2.717
2.712
2.688
2.683
2.670
2.665
2.642
2.637
2.563
2.552
2.516
2.505
2.471
2.458
2.447
2.423
2.412
1.600
1.256
1.117
-0.000
10
9
8
7
6
5
4
3
2
1
ppm
0.79
2.00
3.30
1.00
1.02
0.93
0.52
1.61
1.11
9.60

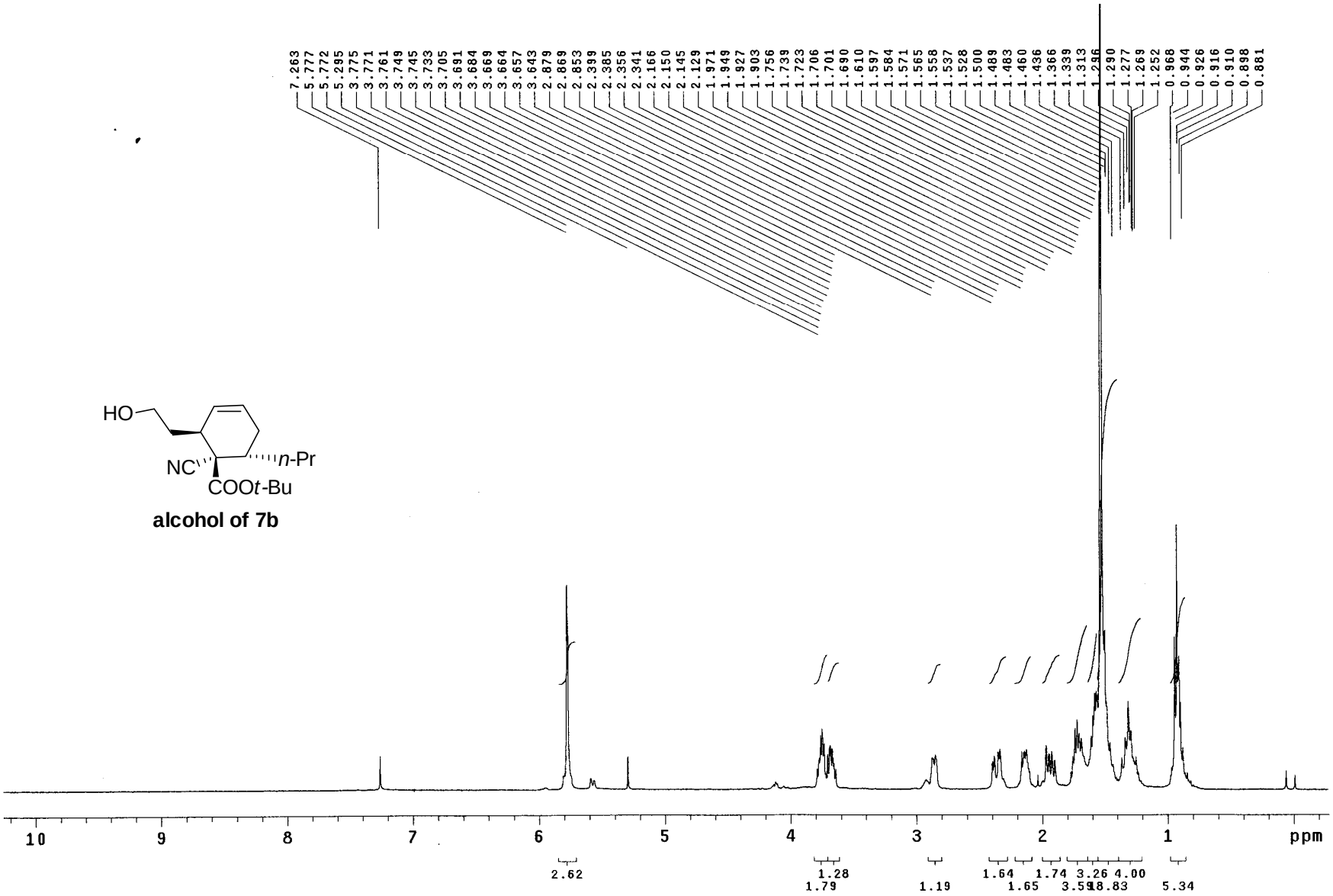

198.584
166.207
139.235
128.754
128.415
127.799
127.606
126.632
119.012
84.413
77.340
77.024
76.704
51.577
45.370
41.554
36.999
31.270
27.281
OHC
NC
Ph
COOt-Bu
7a
200
180
160
140
120
100
80
60
40
20
ppm

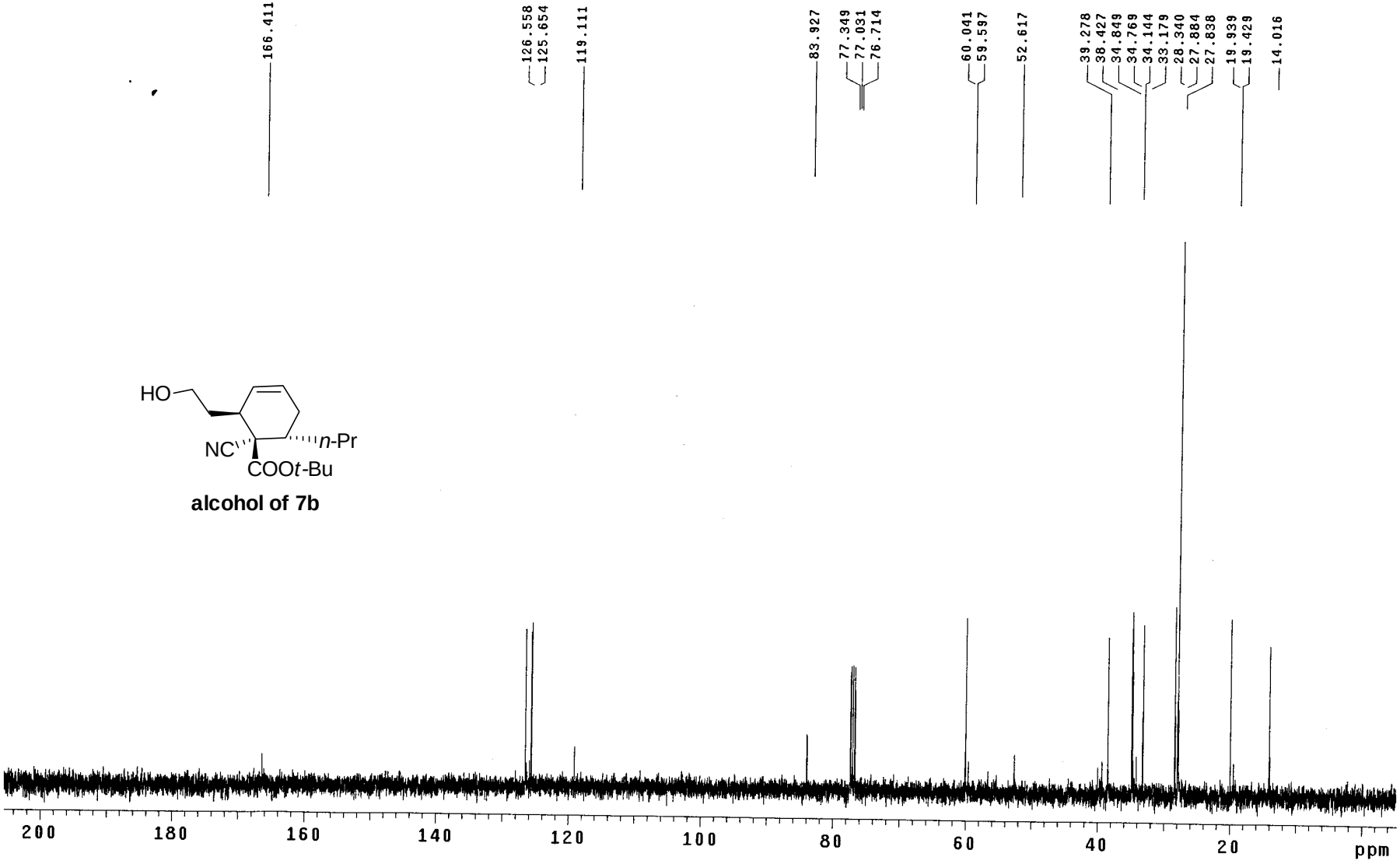


	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	8.140	3393092	49.45	175760	50.25
2	9.233	3468105	50.55	174024	49.75

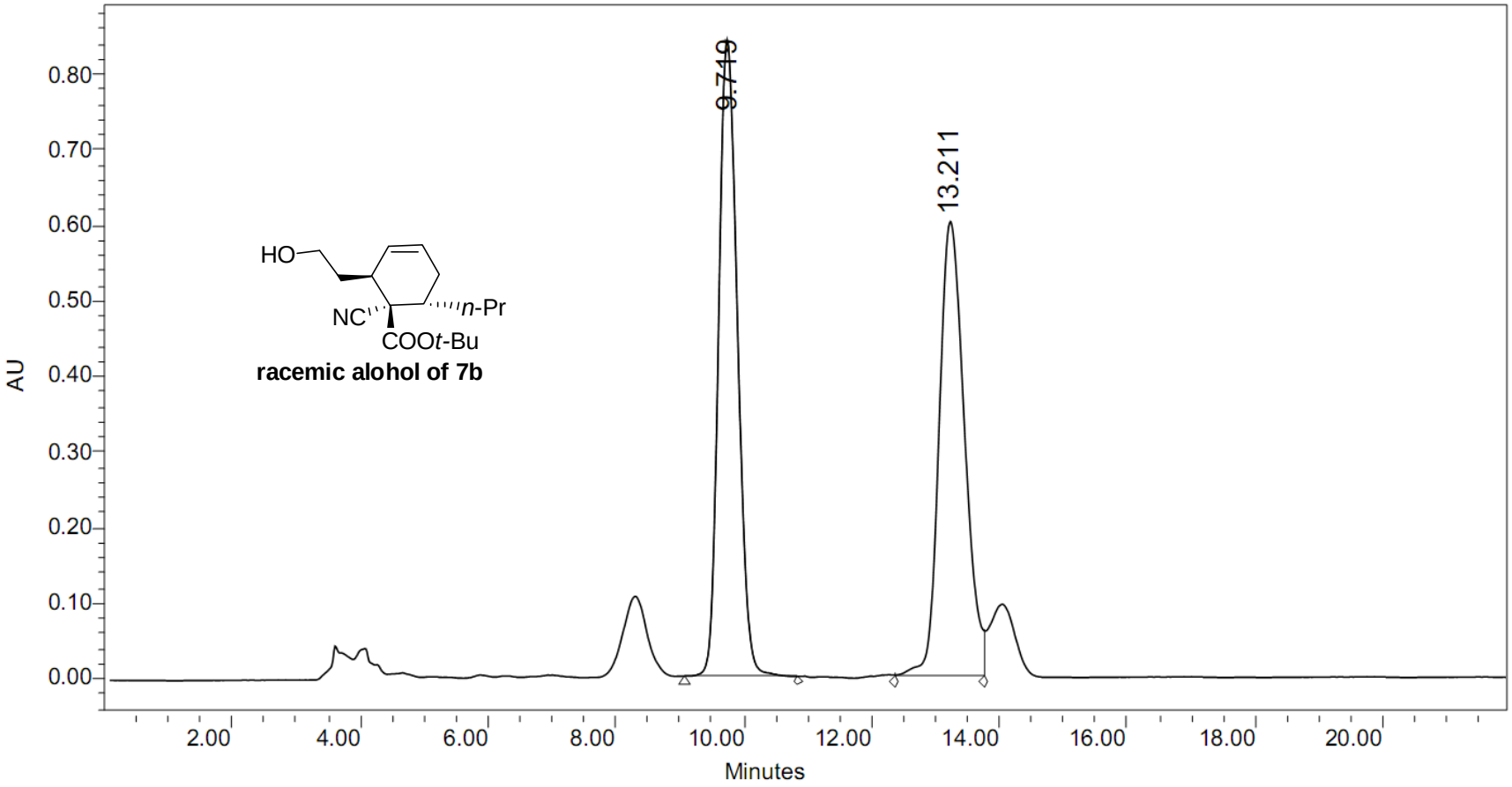


	RT (min)	Area (µV *sec)	% Area	Height (µV)	% Height
1	8.138	443627	5.74	23452	6.38
2	9.214	7282013	94.26	344057	93.62

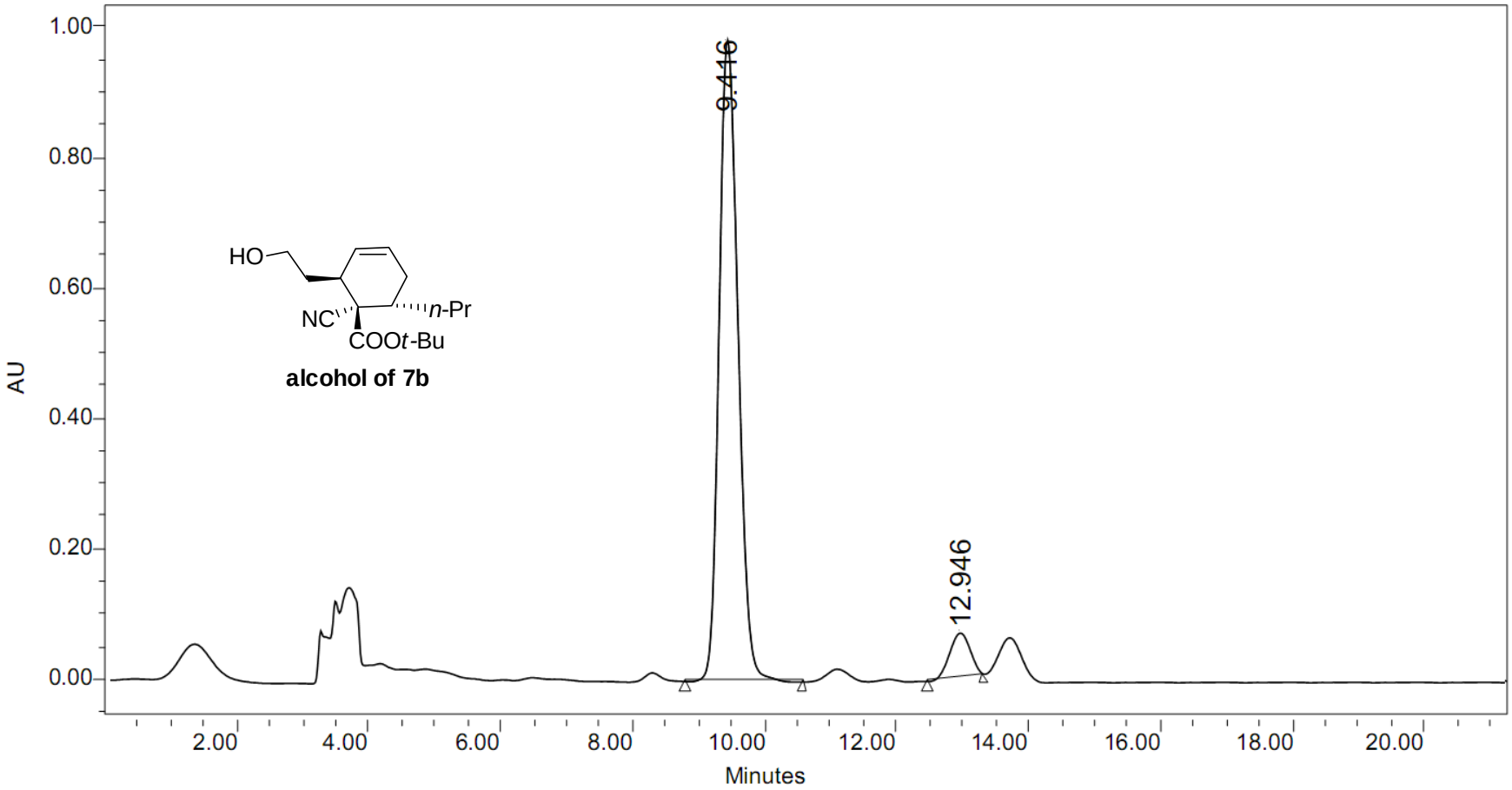

7.263
5.777
5.772
5.295
3.775
3.771
3.761
3.749
3.745
3.733
3.705
3.691
3.684
3.669
3.664
3.657
3.643
2.879
2.869
2.853
2.399
2.385
2.356
2.341
2.166
2.150
2.145
2.129
1.971
1.949
1.927
1.903
1.756
1.739
1.723
1.706
1.701
1.690
1.610
1.597
1.584
1.571
1.565
1.558
1.537
1.528
1.500
1.489
1.483
1.460
1.436
1.366
1.339
1.313
1.286
1.290
1.277
1.269
1.252
0.968
0.944
0.926
0.916
0.910
0.898
0.881
HO
NC
n-Pr
COOt-Bu
alcohol of 7b
10
9
8
7
6
5
4
3
2
1
ppm
2.62
1.28
1.79
1.19
1.64
1.65
1.74
3.59
3.26
8.83
4.00
5.34



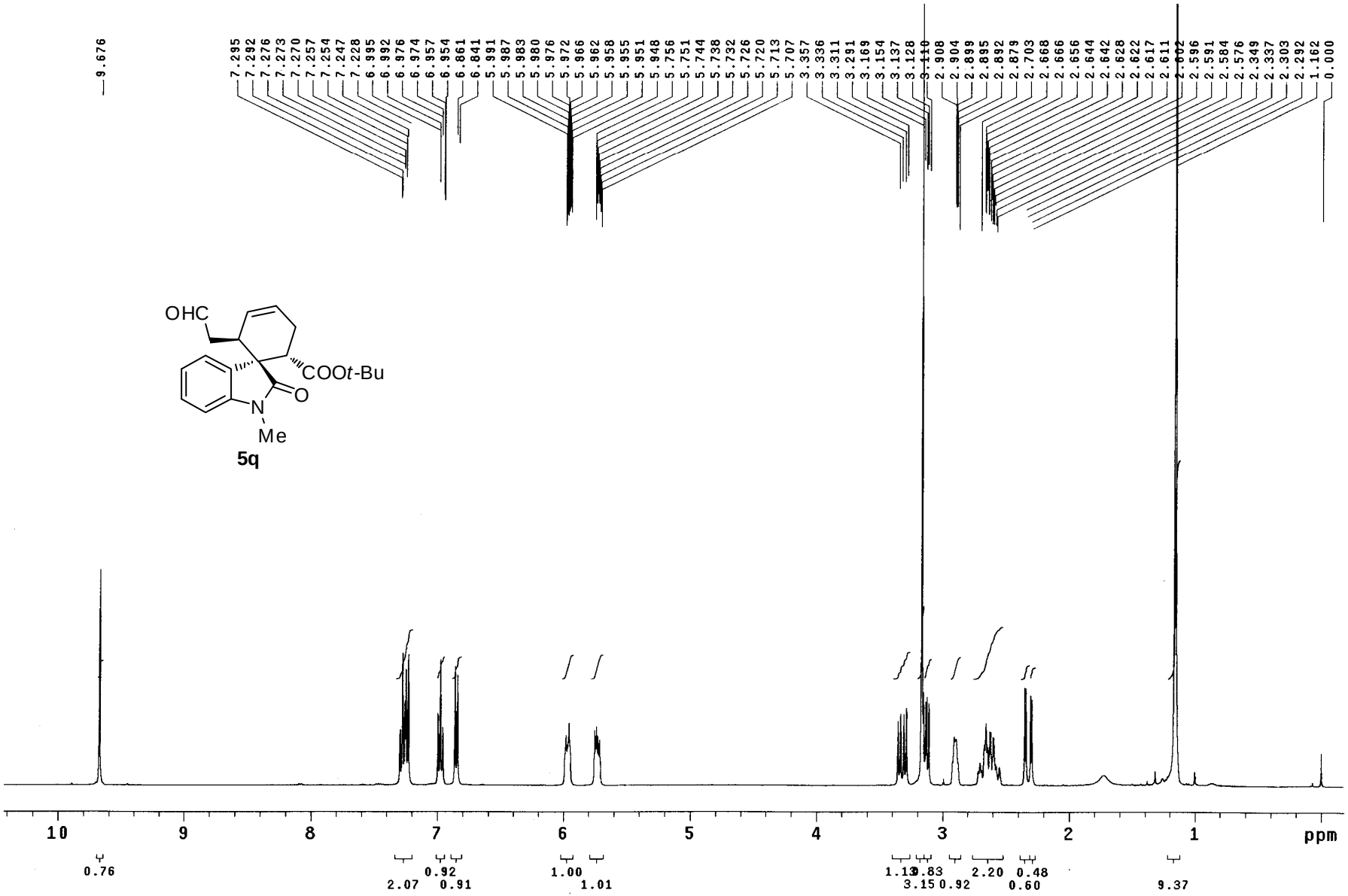
alcohol of 7b

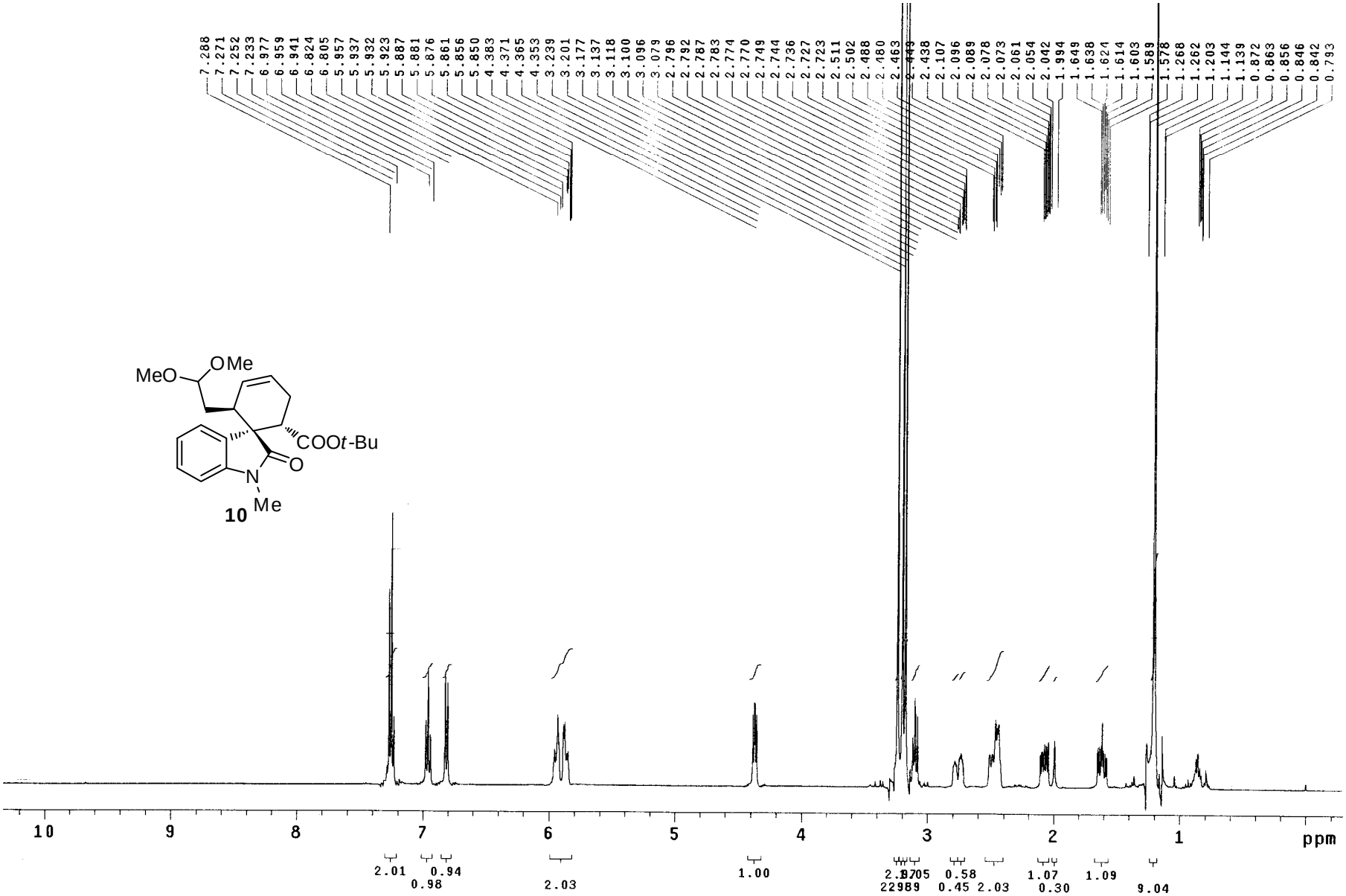


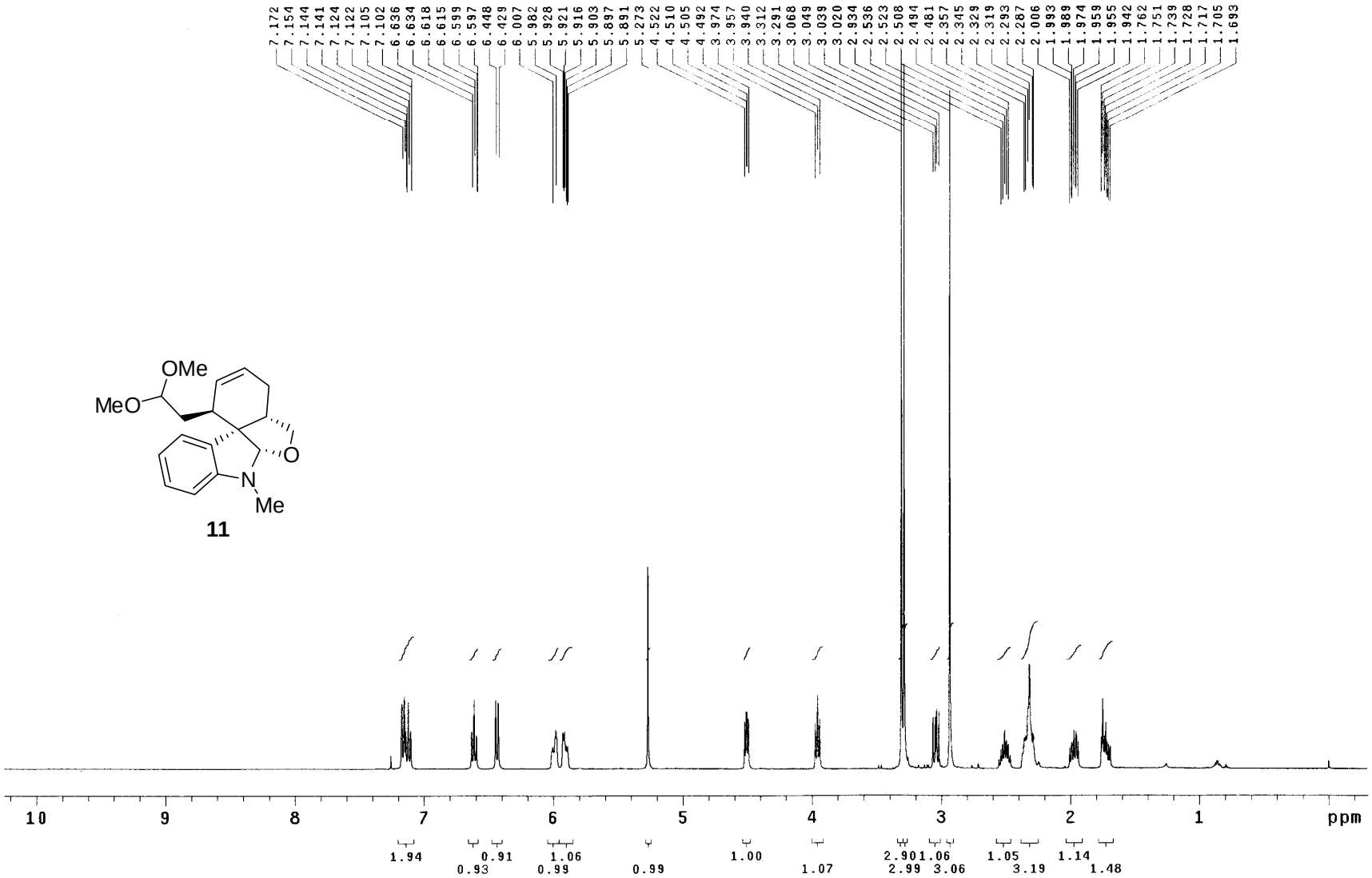
	RT (min)	Area (μV*sec)	% Area	Height (μV)	% Height
1	9.719	17255097	50.73	842442	58.30
2	13.211	16758994	49.27	602449	41.70

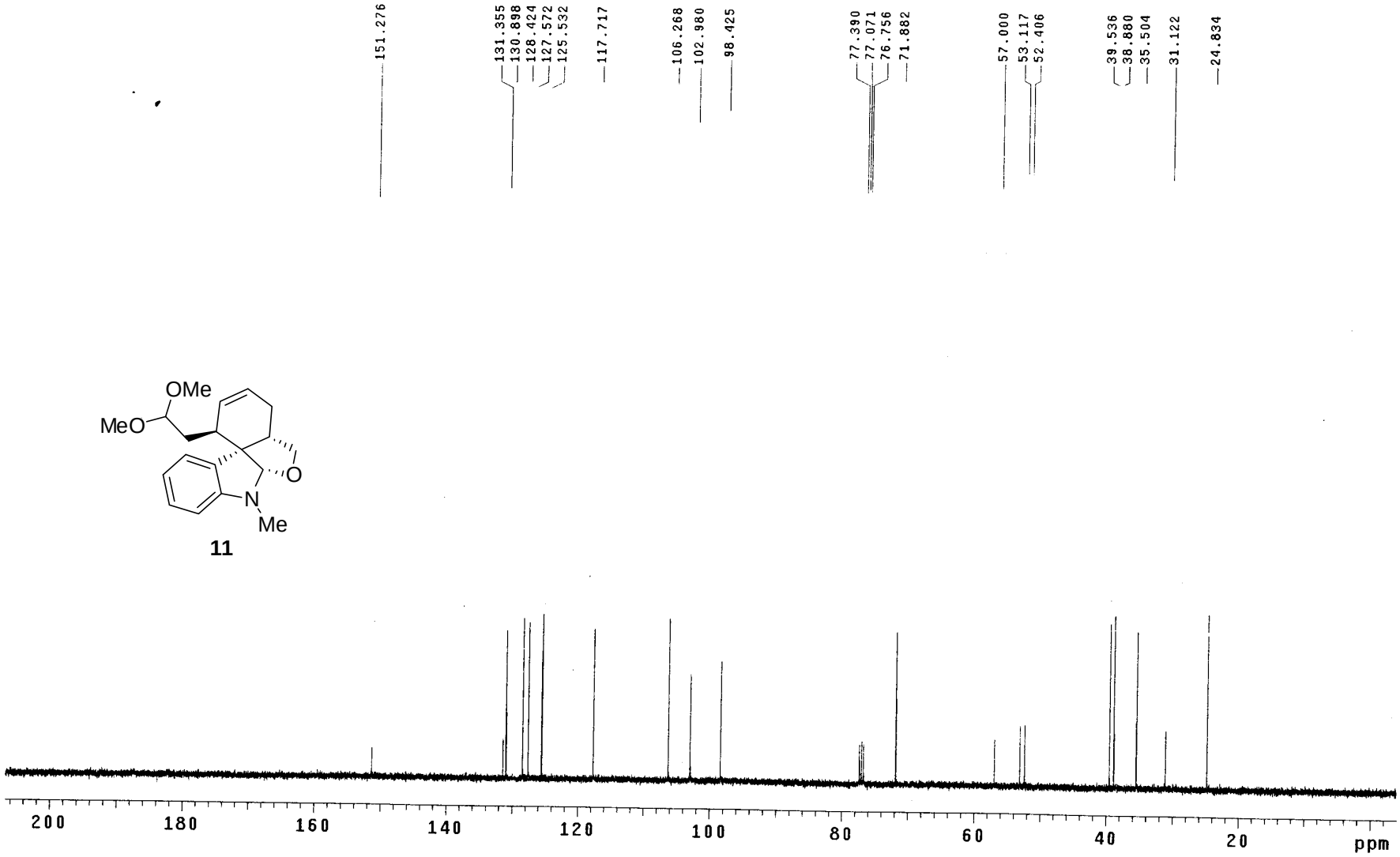


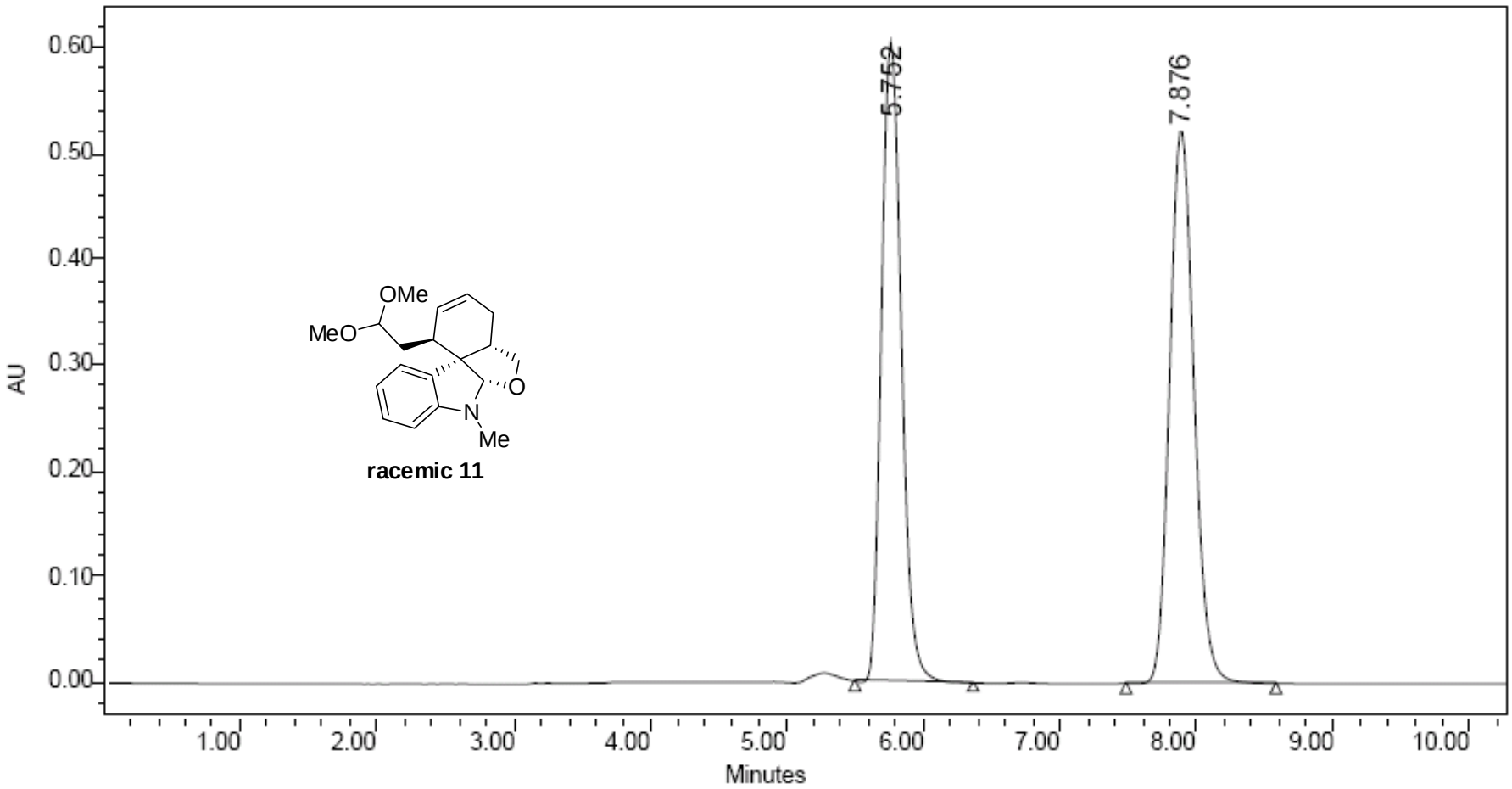
	RT (min)	Area (µV*sec)	% Area	Height (µV)	% Height
1	9.416	19760024	93.03	984187	93.55
2	12.946	1480284	6.97	67866	6.45


OHC
COOt-Bu
O
N
Me
5q
9.676
7.295
7.292
7.276
7.273
7.270
7.257
7.254
7.247
7.228
6.995
6.992
6.976
6.974
6.957
6.954
6.861
6.841
5.991
5.987
5.983
5.980
5.976
5.972
5.966
5.962
5.958
5.955
5.951
5.948
5.756
5.751
5.744
5.738
5.732
5.726
5.720
5.713
5.707
3.357
3.336
3.311
3.291
3.169
3.154
3.137
3.128
3.110
2.908
2.904
2.899
2.895
2.892
2.879
2.703
2.668
2.666
2.656
2.644
2.642
2.628
2.622
2.617
2.611
2.602
2.596
2.591
2.584
2.576
2.349
2.337
2.303
2.292
1.162
0.000
10
9
8
7
6
5
4
3
2
1
ppm
0.76
2.07
0.92
0.91
1.00
1.01
1.13
3.15
0.83
0.92
2.20
0.48
0.60
9.37

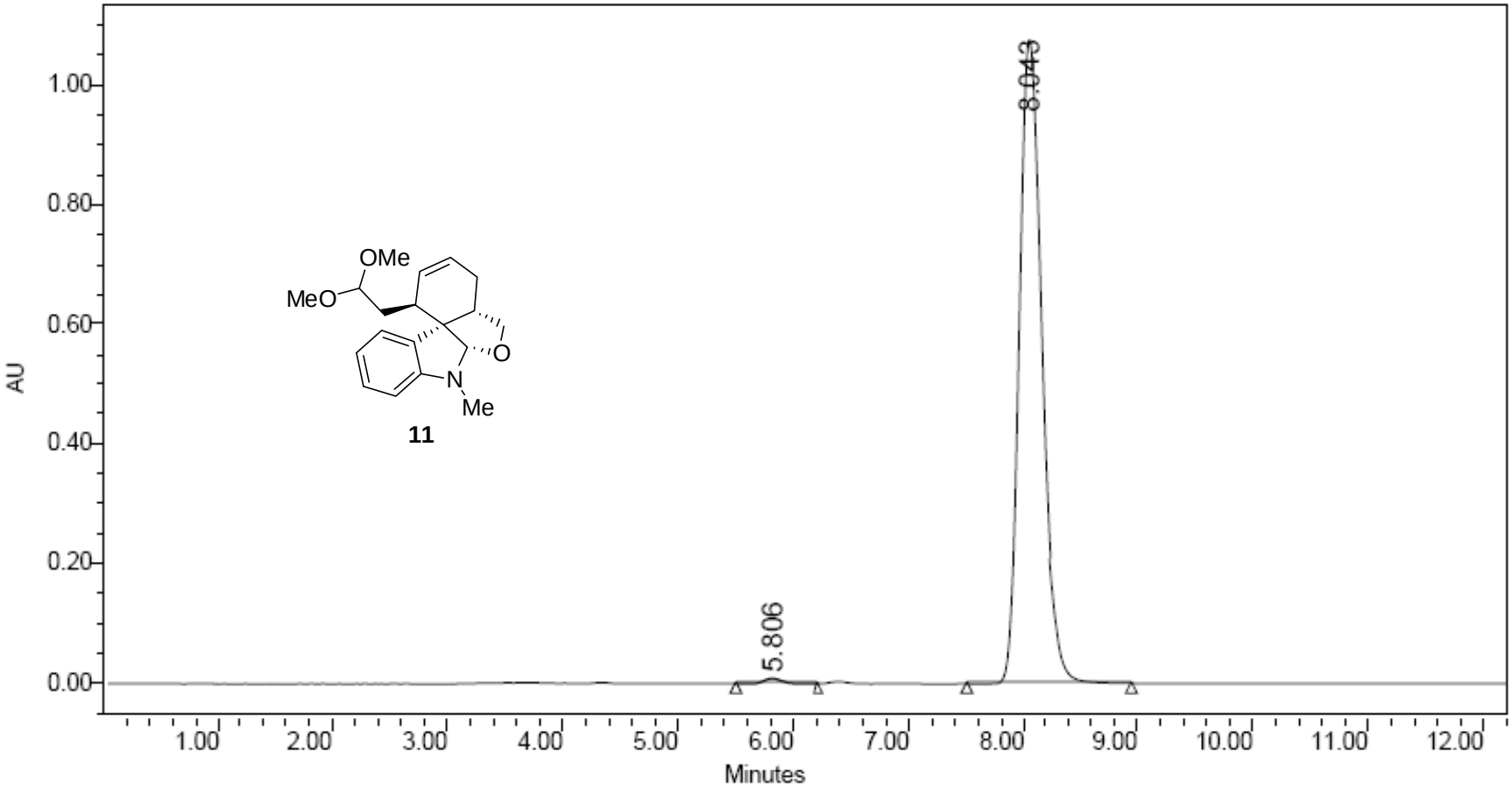

MeO
OMe
COOt-Bu
O
N
Me
10
ppm


OMe
MeO
O
N
Me
11
7.172 7.154 7.144 7.141 7.124 7.122 7.105 7.102 6.636 6.634 6.618 6.615 6.599 6.597 6.448 6.429 6.007 5.982 5.928 5.921 5.916 5.903 5.897 5.891 5.273 4.522 4.510 4.505 4.492 3.974 3.957 3.940 3.312 3.291 3.068 3.049 3.039 3.020 2.934 2.536 2.523 2.508 2.494 2.481 2.357 2.345 2.329 2.319 2.293 2.287 2.006 1.993 1.989 1.974 1.959 1.955 1.942 1.762 1.751 1.739 1.728 1.717 1.705 1.693
10 9 8 7 6 5 4 3 2 1 ppm
1.94 0.93 0.91 1.06 0.99 0.99 1.00 1.07 2.90 2.99 1.06 3.06 1.05 3.19 1.14 1.48

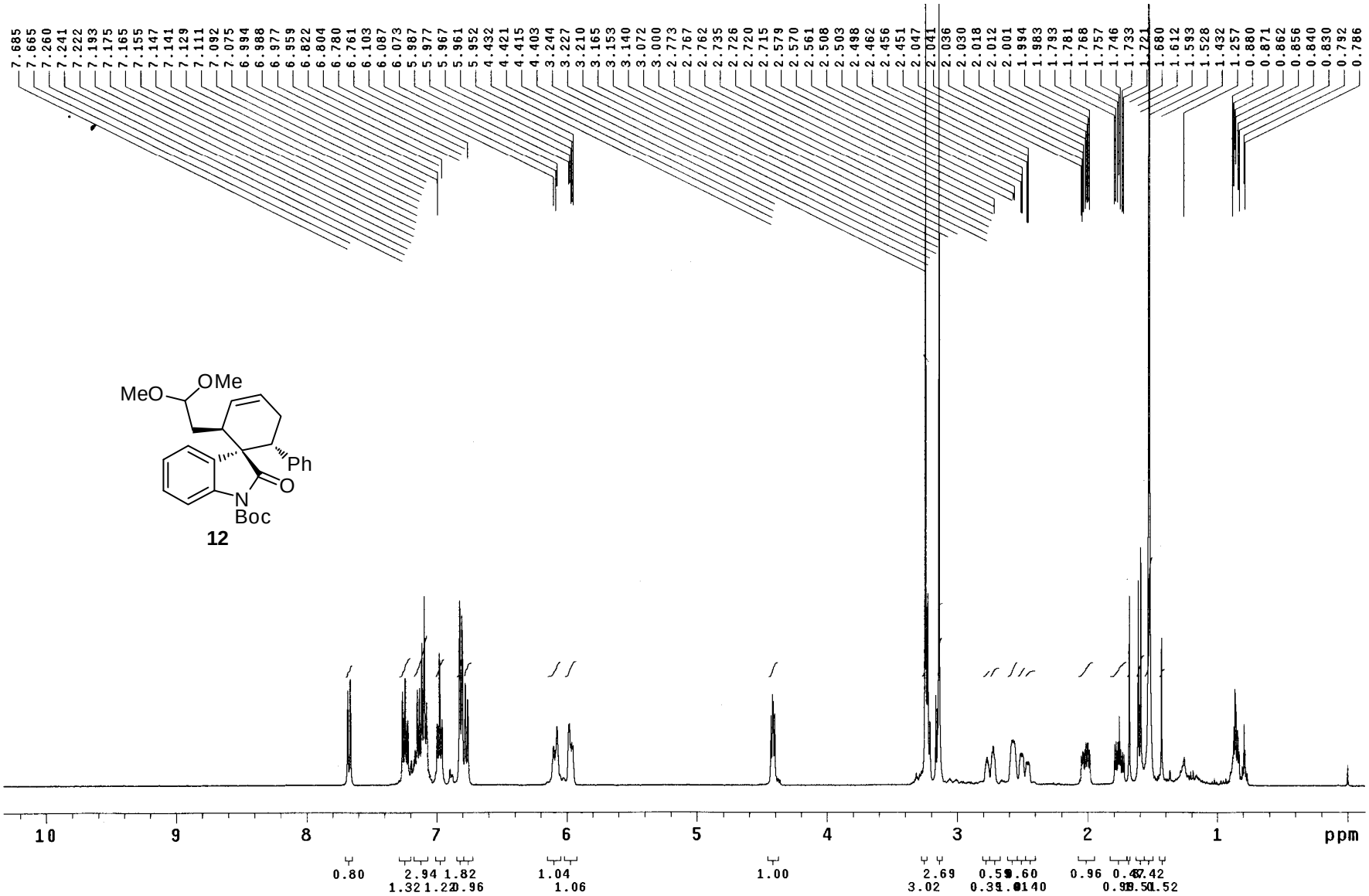

151.276
131.355
130.898
128.424
127.572
125.532
117.717
106.268
102.980
98.425
77.390
77.071
76.756
71.882
57.000
53.117
52.406
39.536
38.880
35.504
31.122
24.834
OMe
MeO
O
N
Me
11
200
180
160
140
120
100
80
60
40
20
ppm

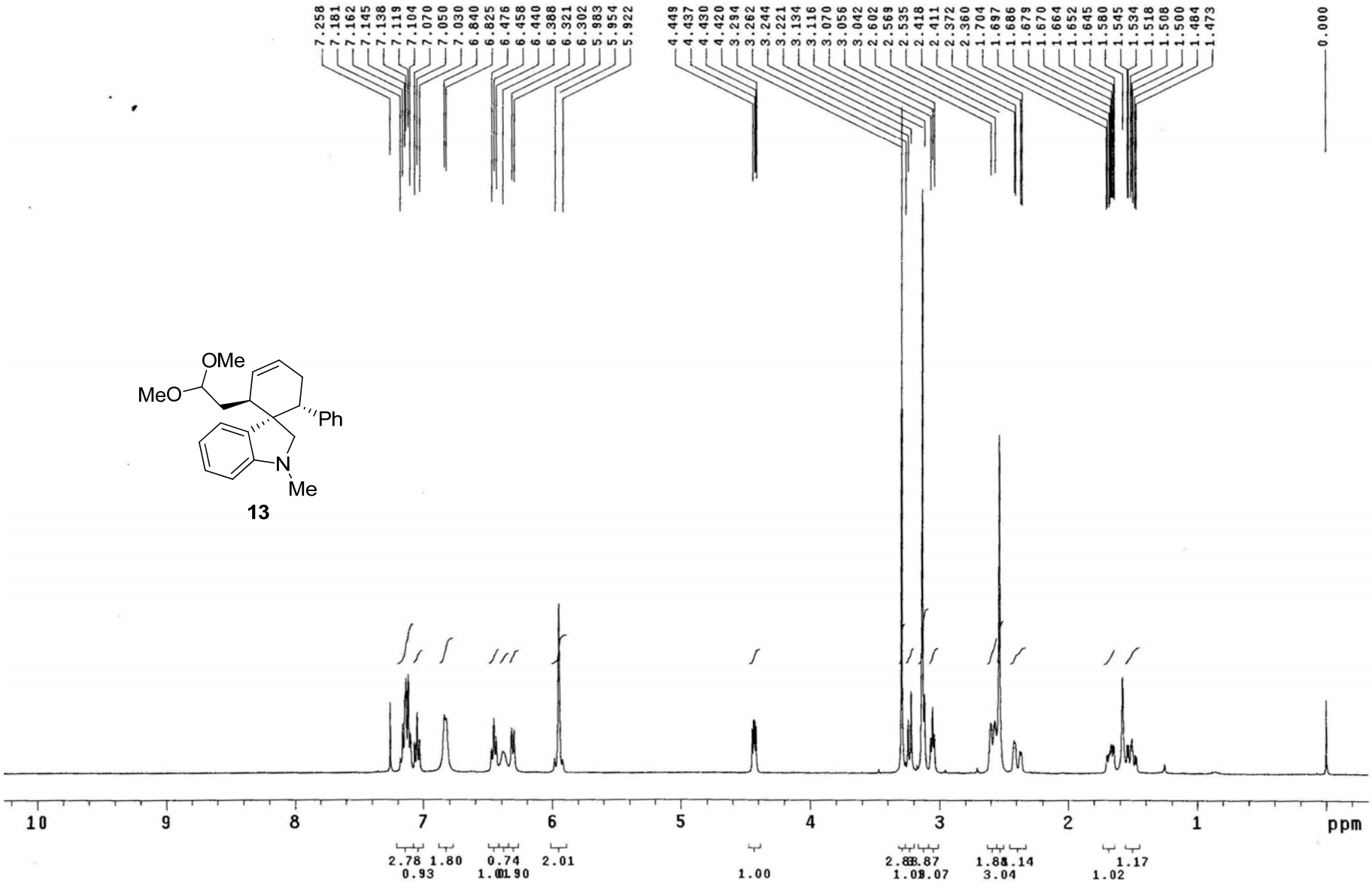


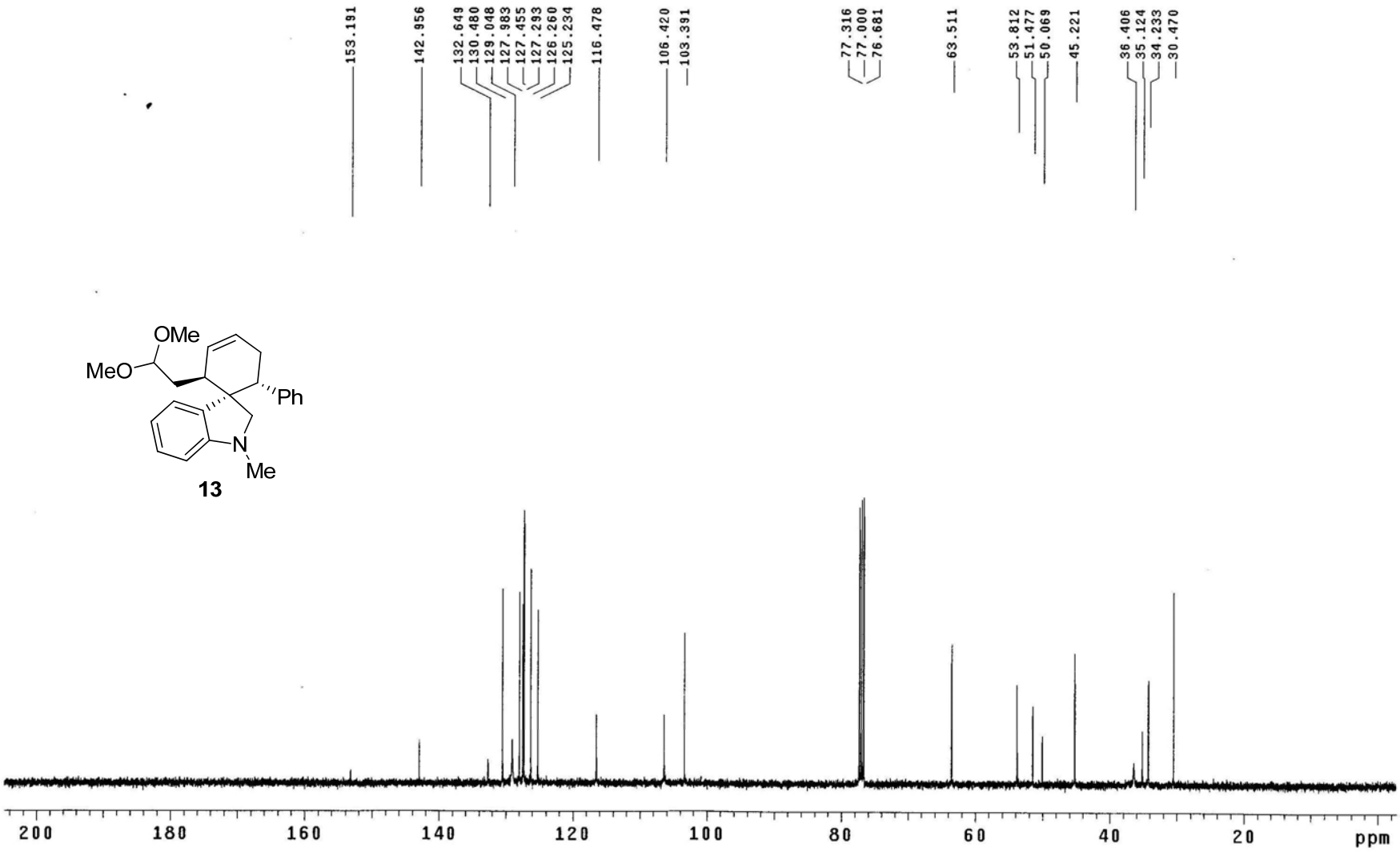
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	5.752	6138552	49.32	605370	53.79
2	7.876	6307211	50.68	519999	46.21

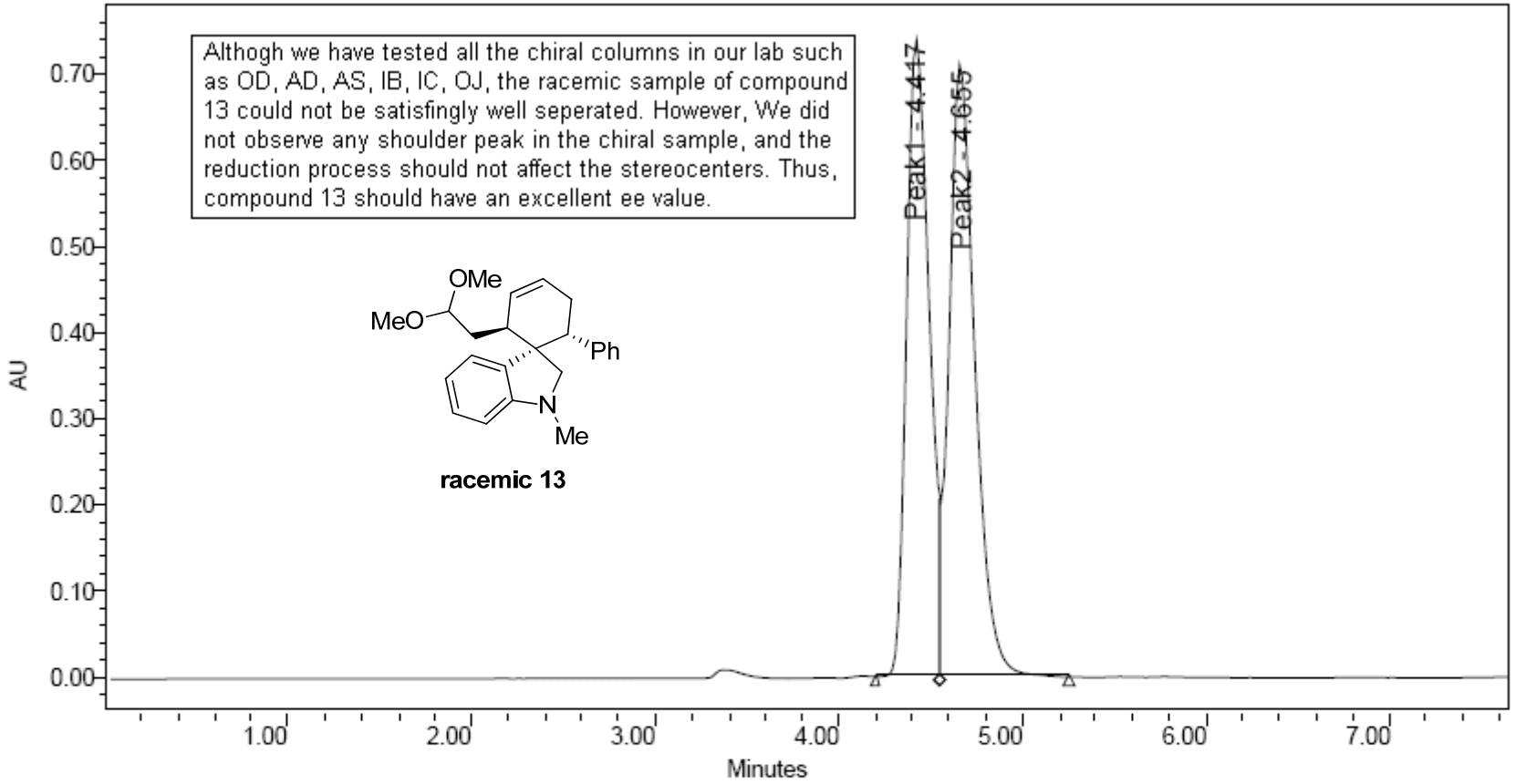


	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	5.806	93693	0.63	8771	0.80
2	8.043	14764160	99.37	1081161	99.20

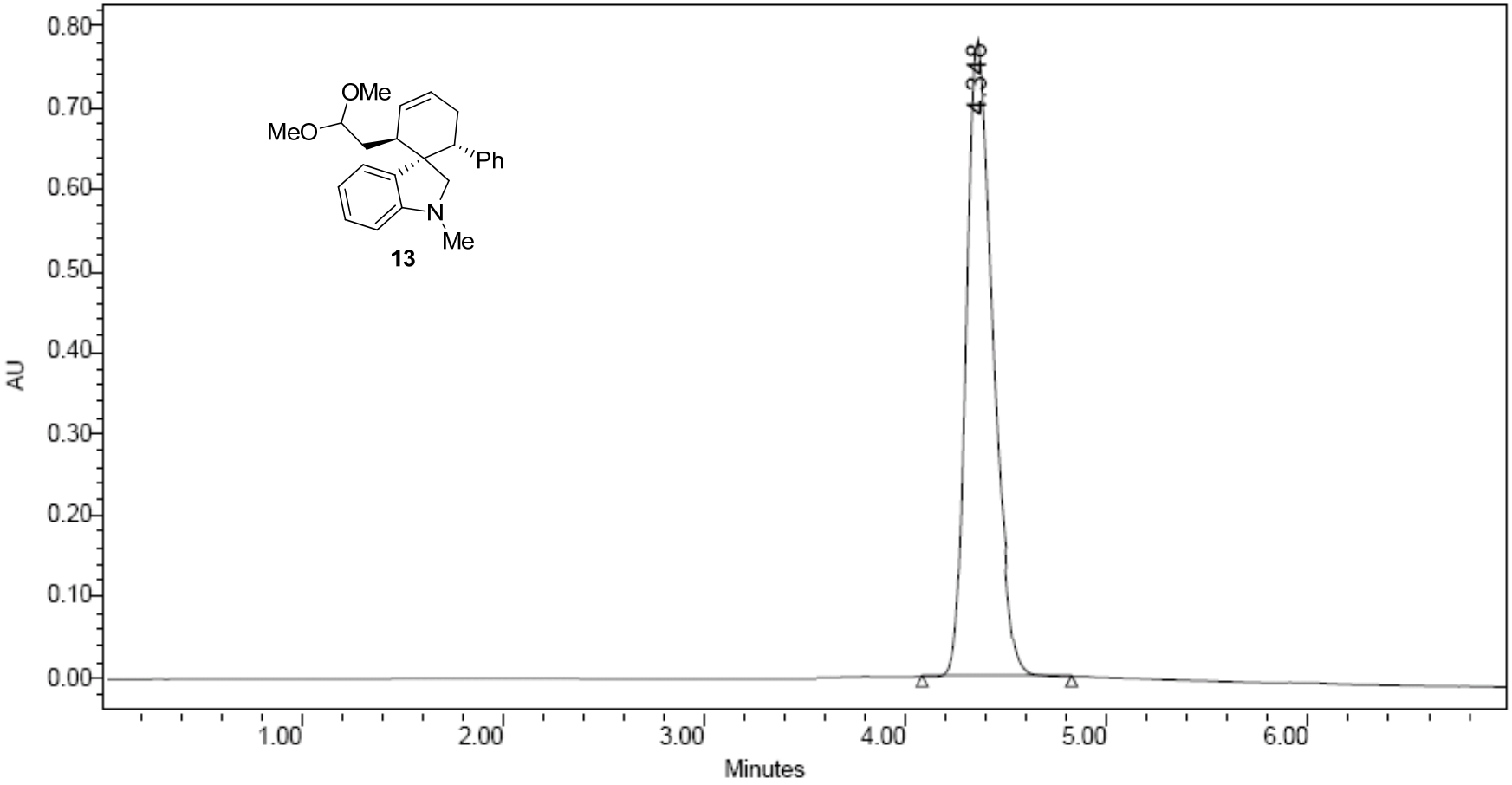

MeO
OMe
Ph
O
N
Boc
12
ppm


OMe
MeO
Ph
N
Me
13
ppm

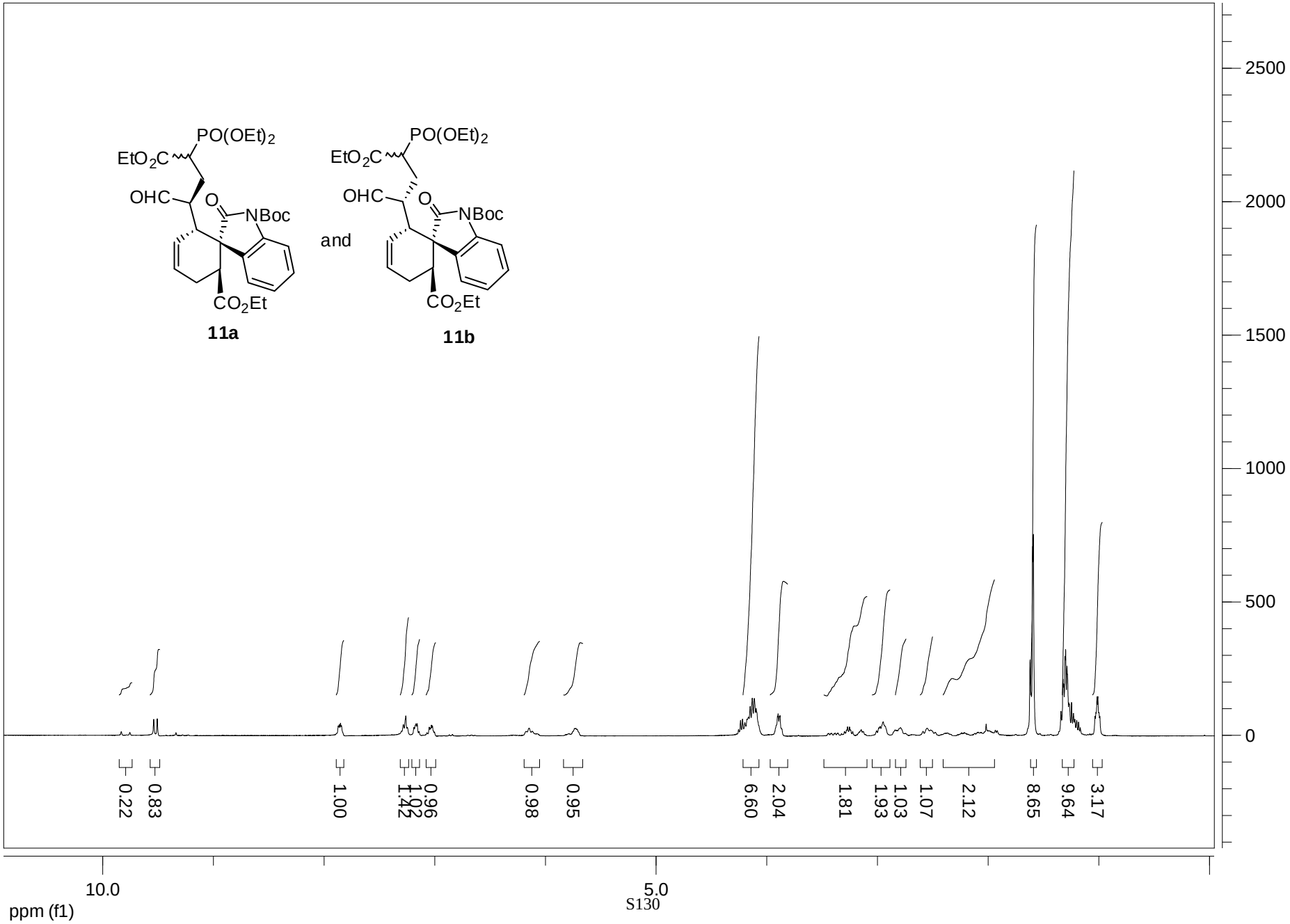

153.191
142.956
132.649
130.480
129.048
127.983
127.455
127.293
126.260
125.234
116.478
106.420
103.391
77.316
77.000
76.681
63.511
53.812
51.477
50.069
45.221
36.406
35.124
34.233
30.470
OMe
MeO
Ph
N
Me
13
200
180
160
140
120
100
80
60
40
20
ppm

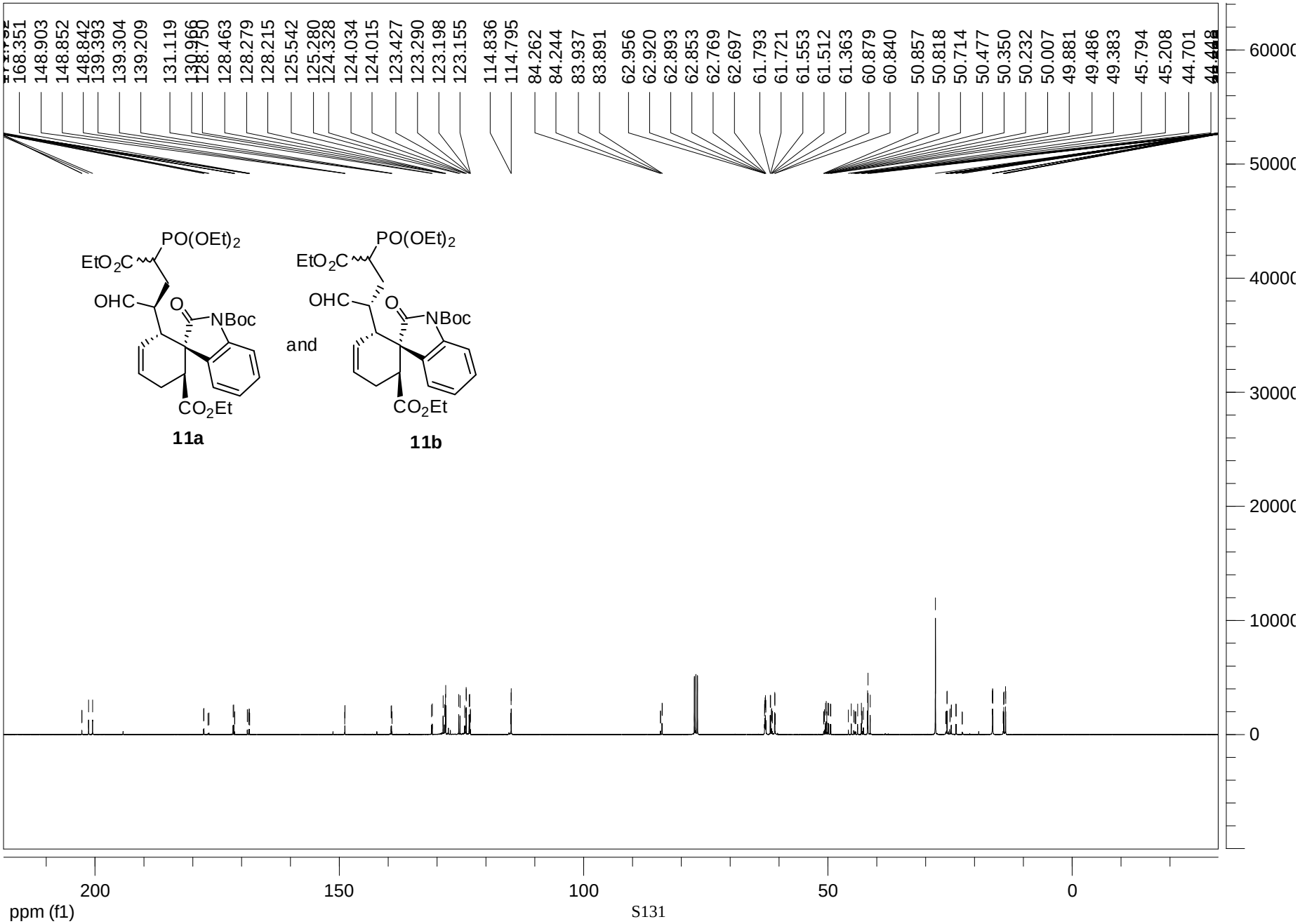


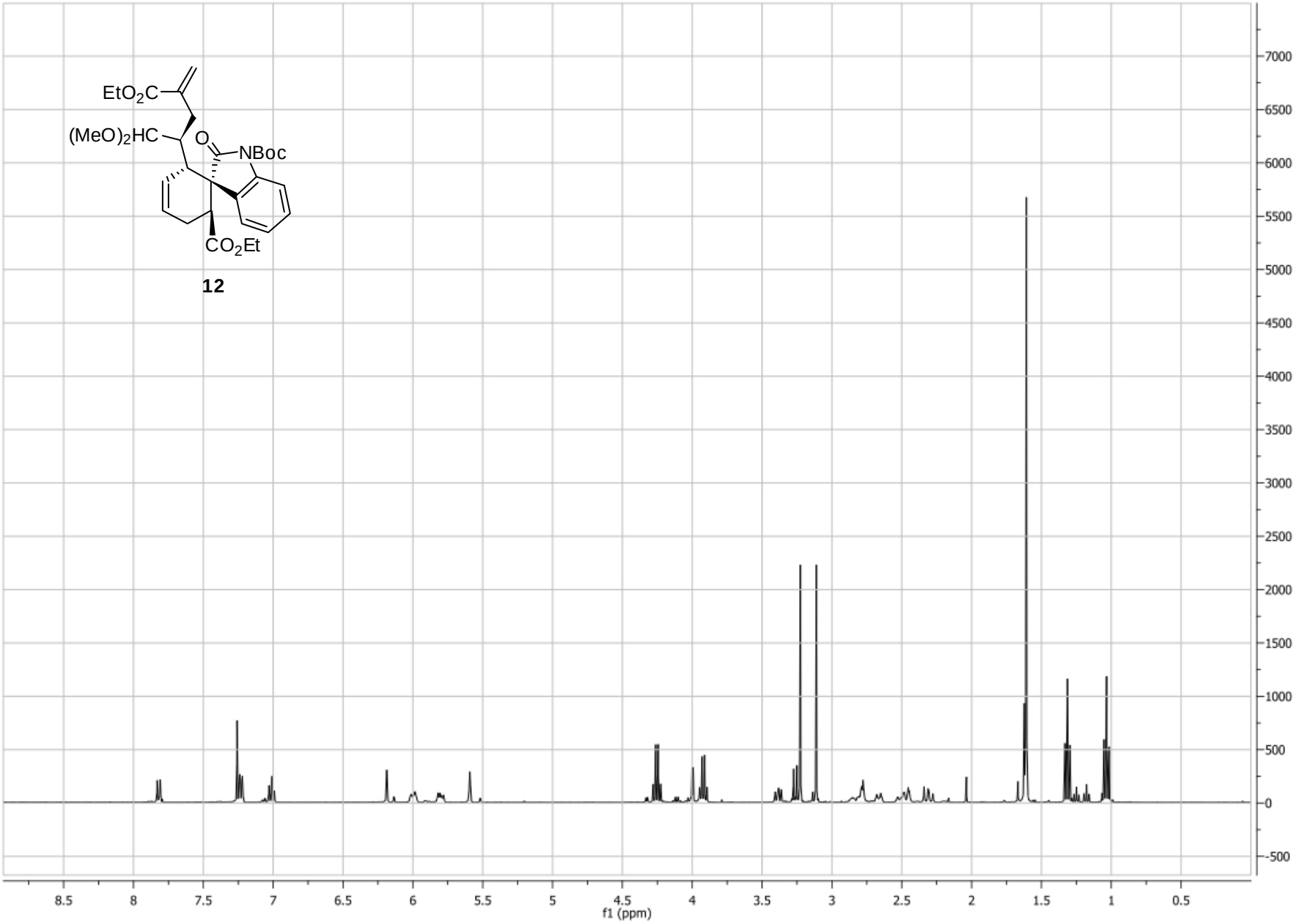
	Peak Name	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	Peak1	4.417	6368686	49.63	738260	50.92
2	Peak2	4.655	6916657	50.37	711599	49.08

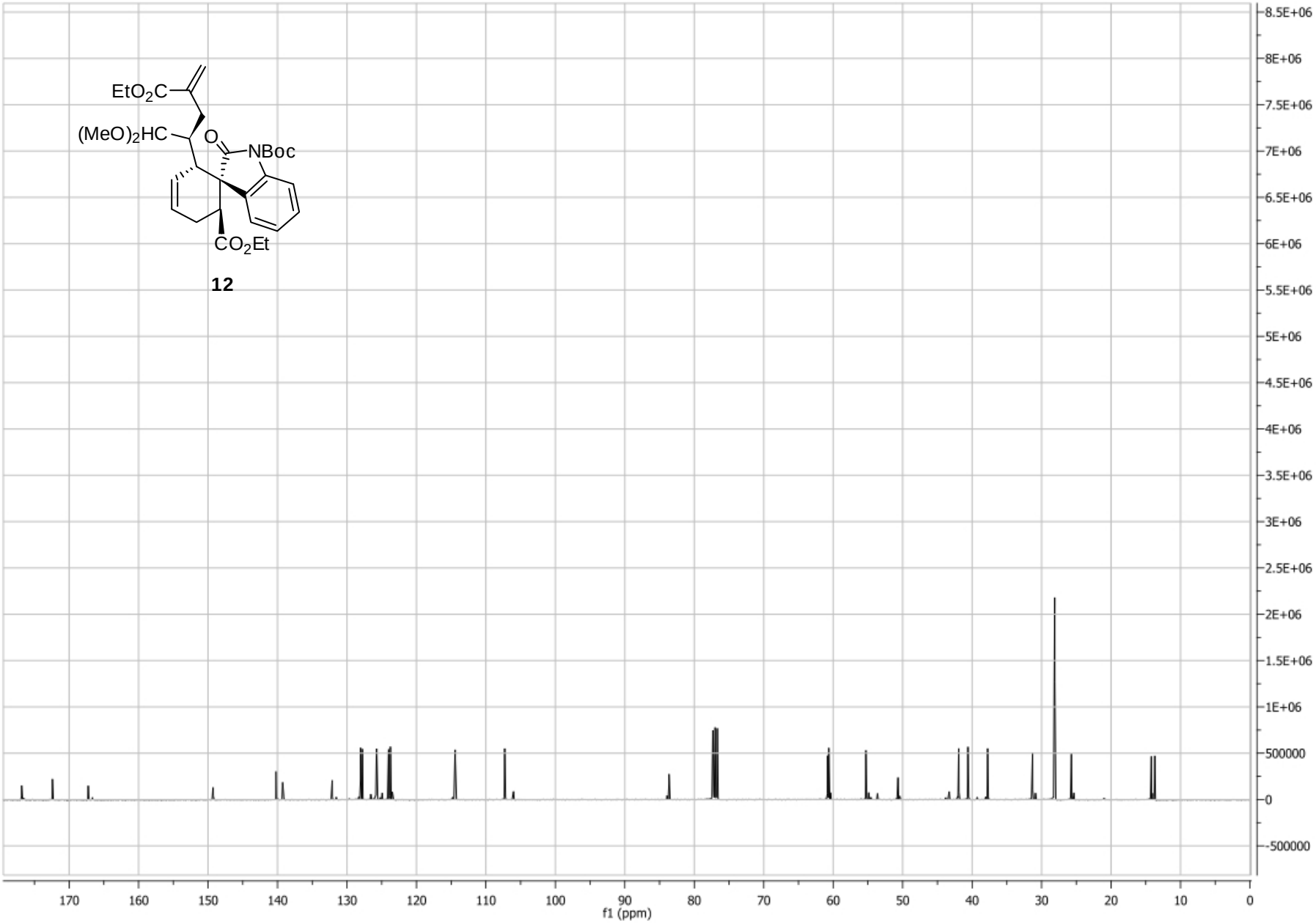


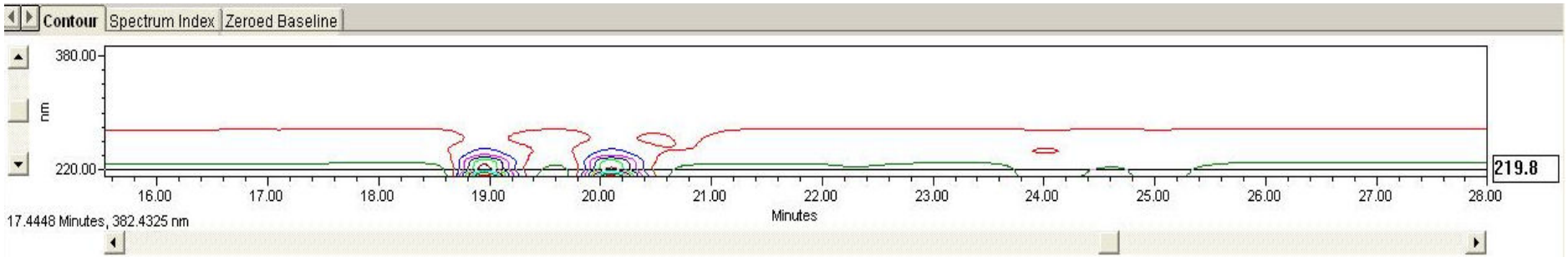
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	4.348	6874599	100.00	754398	100.00

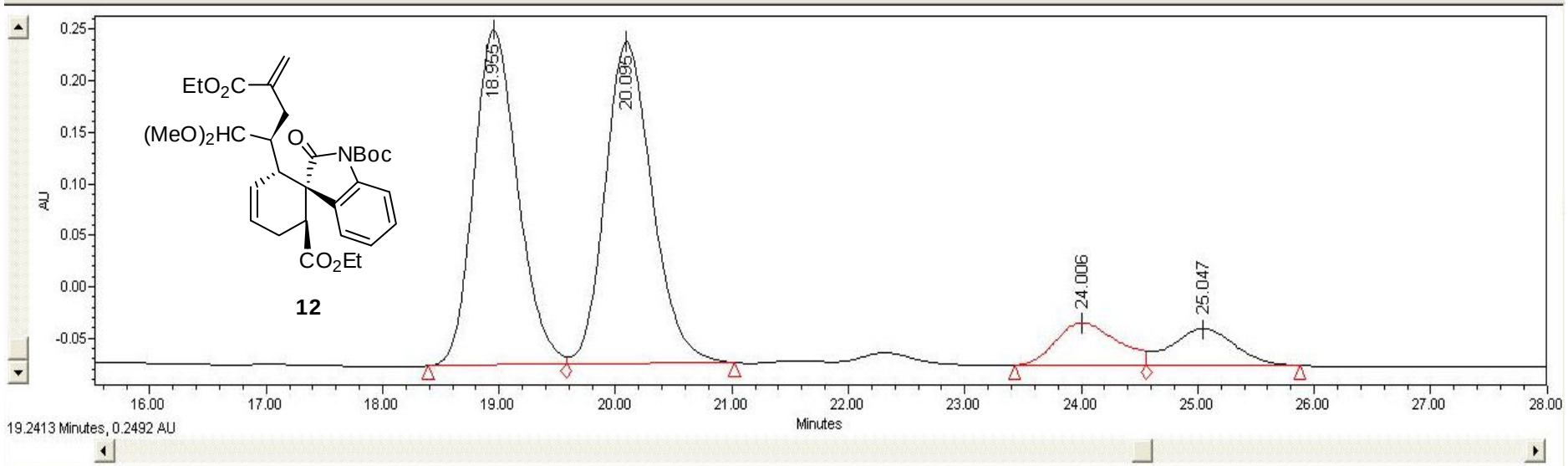

PO(OEt)2
EtO2C
OHC
O
NBoc
CO2Et
11a
and
11b
2500
2000
1500
1000
500
0
0.22
0.83
1.00
1.42
0.96
0.98
0.95
6.60
2.04
1.81
1.93
1.03
1.07
2.12
8.65
9.64
3.17
10.0
5.0
ppm (f1)


168.351
148.903
148.852
148.842
139.393
139.304
139.209
131.119
128.463
128.279
128.215
125.542
125.280
124.328
124.034
124.015
123.427
123.290
123.198
123.155
114.836
114.795
84.262
84.244
83.937
83.891
62.956
62.920
62.893
62.853
62.769
62.697
61.793
61.721
61.553
61.512
61.363
60.879
60.840
50.857
50.818
50.714
50.477
50.350
50.232
50.007
49.881
49.486
49.383
45.794
45.208
44.701
PO(OEt)2
EtO2C
OHC
O
NBoc
CO2Et
11a
and
11b
60000
50000
40000
30000
20000
10000
0
200
150
100
50
0
ppm (f1)


EtO2C
(MeO)2HC
O
NBoc
CO2Et
12
f1 (ppm)

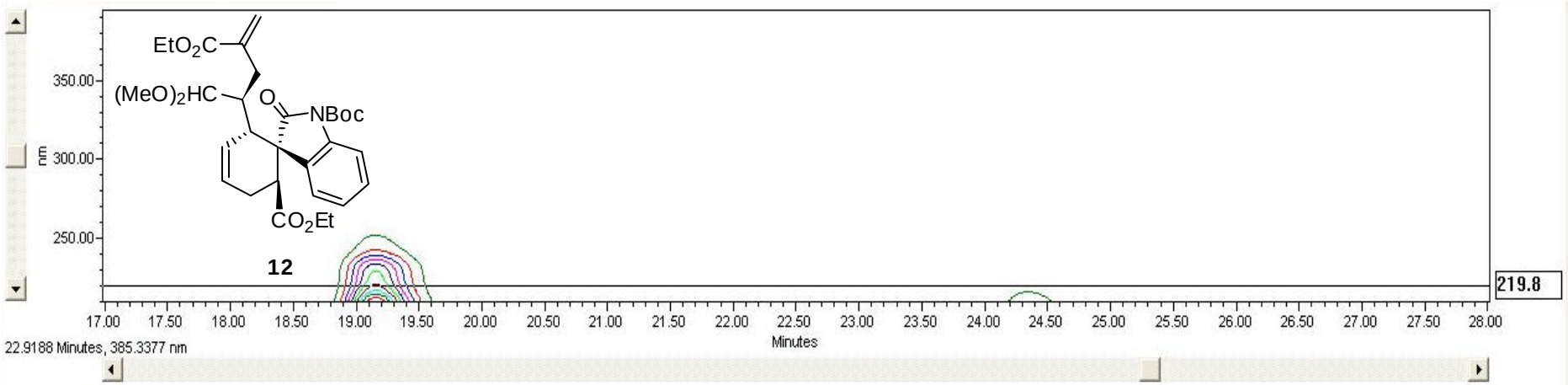

EtO2C
(MeO)2HC
O
NBoc
CO2Et
12
f1 (ppm)

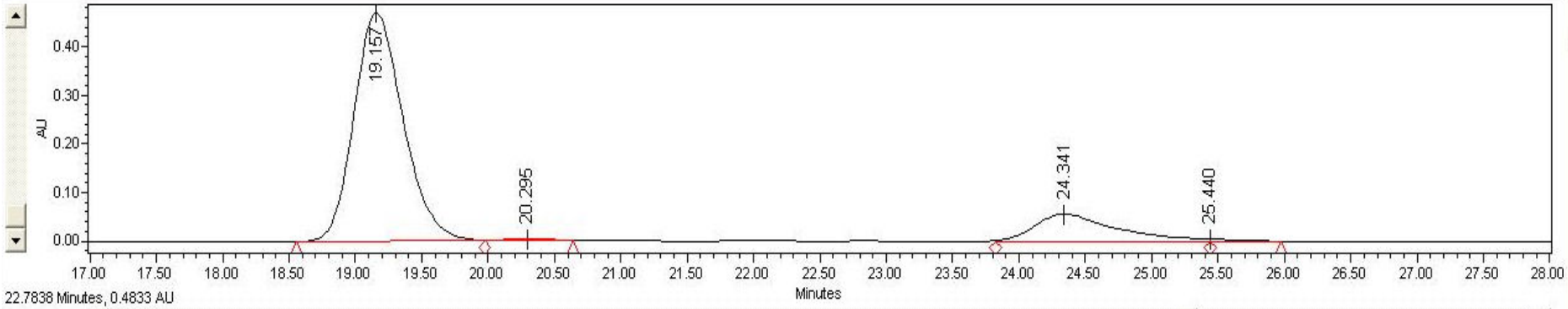




	Name	Retention Time (min)	Purity1 Angle	Purity1 Threshold	PDA Match1 Spect. Name	PDA Match1 Angle	PDA Match1 Threshold	PDA Match1 Lib. Name	Area (µV*sec)	% Area	Height (µV)	Int Type	Amount	Units	Peak Type	Peak Codes
1		18.955							8526491	42.30	325362	bv			Unknown	
2		20.095							8773052	43.52	312402	vb			Unknown	
3		24.006							1510545	7.49	41257	bv			Unknown	
4		25.047							1347025	6.68	35826	vb			Unknown	

3D Channels / 2D Channels / Peaks





	Name	Retention Time (min)	Purity1 Angle	Purity1 Threshold	PDA Match1 Spect. Name	PDA Match1 Angle	PDA Match1 Threshold	PDA Match1 Lib. Name	Area (µV*sec)	% Area	Height (µV)	Int Type	Amount	Units	Peak Type	Peak Codes
1		19.157							12079590	83.07	469238	bv			Unknown	
2		20.295							95930	0.66	4172	vb			Unknown	
3		24.341							2307861	15.87	55783	vv			Unknown	
4		25.440							57426	0.39	4497	vb			Unknown	I06

3D Channels / 2D Channels / Peaks