Asymmetric Diels–Alder Reaction of β,β-Disubstituted Enals with Chromone-Fused Dienes and Cascade: Construction of Collections with High Molecular Complexity and Skeletal Diversity

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Supplementary Information

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1. General methods

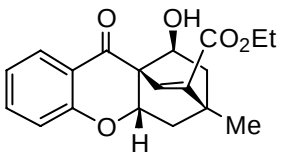
NMR data were obtained for ^{1}H at 400 MHz and for ^{13}C at 100 MHz. Chemical shifts were reported in ppm from tetramethylsilane with the solvent resonance as the internal standard in $CDCl_3$ solution. ESI HRMS was recorded on a Bruker Apex-2. In each case, enantiomeric ratio was determined by HPLC analysis on a chiral column in comparison with authentic racemate, using a Daicel Chiralpak OD-H Column (250 x 4.6 mm), Chiralpak AD-H Column (250 x 4.6 mm) or Chiralpak IC Column (250 x 4.6 mm), *etc*. UV detection was monitored at 220 nm, 254 nm or 280 nm. Optical rotation data were examined in $CHCl_3$ or EtOH solution at 20 °C. Column chromatography was performed on silica gel (200-300 mesh) eluting with ethyl acetate and petroleum ether. TLC was performed on glass-backed silica plates. UV light and I_2 were used to visualize products. All chemicals including the enals were used without purification as commercially available unless otherwise noted. The electron deficient chromone-fuse dienes were prepared according to the literature procedures.[1] The secondary amine catalysts were synthesized according to the literature procedures.[2]

1 (*a*) A.-T. Dang, D. O. Miller, L. N. Dawe and G. J. Bodwell, *Org. Lett.,* 2008, **10**, 233; (*b*) D. Kim and S. Hong, *Org. Lett.,* 2011, **13**, 4466.

2 (*a*) M. Marigo, T. C. Wabnitz, D. Fielenbach and K. A. Jørgensen, *Angew. Chem., Int. Ed.,* 2005, **44**, 794; (*b*) Y. Hayashi, H. Gotoh, T. Hayashi and M. Shoji, *Angew. Chem., Int. Ed.,* 2005, **44**, 4212; (*c*) Y.-K. Liu, C. Ma, K. Jiang, T.-Y. Liu and Y.-C. Chen, *Org. Lett.,* 2009, **11**, 2848.

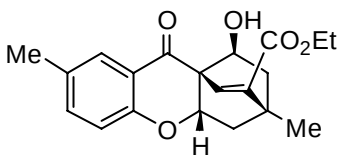
2. General procedure for the asymmetric Diels–Alder (and cascade) reaction

The reaction was carried out with enal **3** (0.2 mmol) and electron deficient chromone-fuse diene **2** (0.1 mmol) in the presence of amine catalyst **1b** (7.3 mg, 0.02 mmol) or **1e** (14.8 mg, 0.02 mmol), *o*-fluorobenzoic acid (2.8 mg, 0.02 mmol) in 1,4-dioxane (1.0 mL) at room temperature (about 25 °C) for a specified time. When the reaction completed, the mixture was concentrated and the residue was purified by flash chromatography on silica gel (petroleum ether/ethyl acetate) to afford the cycloadduct.

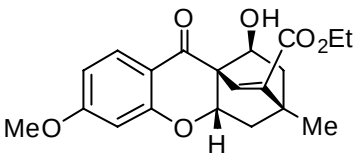


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-11-hydroxy-6-methyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5a) was obtained in 89% yield after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak IC column (20% 2-propanol/*n*-hexane, 1 mL/min), UV

220 nm, t_{major} = 23.47 min, t_{minor} = 25.67 min. $[\alpha]_D^{20}$ = -21.3 (*c* = 0.79 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 8.01 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.52 (td, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.30 (s, 1H), 7.09 (t, *J* = 8.0 Hz, 1H), 6.97 (d, *J* = 8.4 Hz, 1H), 4.59 (d, *J* = 7.6 Hz, 1H), 4.36 (dd, *J* = 10.0 Hz, *J* = 3.2 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 2.21 (dd, *J* = 13.6 Hz, *J* = 8.0 Hz, 1H), 2.06-1.99 (m, 1H), 1.54 (dd, *J* = 14.0 Hz, *J* = 3.2 Hz, 1H), 1.49 (s, 3H), 1.40 (dt, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.32 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.8, 164.7, 161.0, 142.6, 136.2, 134.5, 128.0, 122.1, 119.7, 117.8, 77.9, 67.3, 60.6, 55.4, 46.9, 40.5, 37.3, 22.6, 14.1 ppm; ESI HRMS: calcd. for $C_{19}H_{20}O_5$+Na 351.1208, found 351.1207.

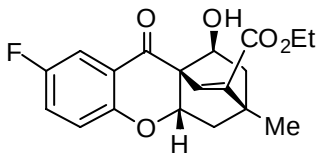


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-11-hydroxy-2,6-dimethyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5b) was obtained in 88% yield after flash chromatography and the enantiomeric excess was determined to be 96% by HPLC analysis on Chiralpak IC column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 25.09 min, t_{minor} = 27.84 min. $[\alpha]_D^{20}$ = -15.2 (*c* = 0.90 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.81 (s, 1H), 7.33 (dd, *J* = 8.4 Hz, *J* = 2.0 Hz, 1H), 7.30 (s, 1H), 6.88 (d, *J* = 8.4 Hz, 1H), 4.58 (d, *J* = 6.8 Hz, 1H), 4.33 (dd, *J* = 10.0 Hz, *J* = 2.8 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 2.34 (s, 3H), 2.21 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.05-1.98 (m, 1H), 1.54 (dd, *J* = 14.0 Hz, *J* = 3.2 Hz, 1H), 1.50 (s, 3H), 1.40 (dt, *J* = 13.6 Hz, *J* = 2.8 Hz, 1H), 1.33 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 193.1, 164.7, 159.2, 142.8, 137.4, 134.6, 131.7, 127.6, 119.4, 117.6, 77.9, 67.5, 60.6, 55.5, 47.0, 40.6, 37.3, 22.6, 20.4, 14.2 ppm; ESI HRMS: calcd. for $C_{20}H_{22}O_5$+H 343.1545, found 343.1546.

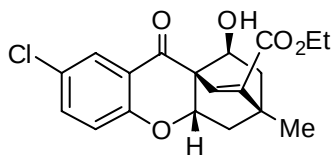


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-11-hydroxy-3-methoxy-6-methyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5c) was obtained in 67% yield after flash chromatography and the enantiomeric excess was determined to be 90% by HPLC analysis on Chiralpak OD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 18.12 min, t_{major} = 20.51 min. $[\alpha]_D^{20}$ = -15.5 (*c* = 0.60 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.95 (d, *J* = 8.8 Hz, 1H), 7.29 (s, 1H), 6.65 (dd, *J* = 8.8 Hz, *J* = 2.4 Hz, 1H), 6.42 (d, *J* = 2.4 Hz, 1H), 4.55 (d, *J* = 7.6 Hz, 1H), 4.34 (dd, *J* = 10.0 Hz, *J* = 3.2 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 3.85 (s, 3H), 2.18 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.06-1.99 (m, 1H), 1.54-1.50 (m, 4H), 1.41 (dt, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.32 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 191.7, 166.2, 164.7, 163.1, 142.5, 134.8, 129.7, 113.6, 110.7, 100.7, 78.2, 67.5, 60.6, 55.7, 55.1, 46.8, 40.5, 37.3,

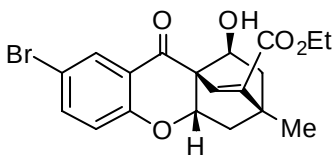
22.6, 14.2 ppm; ESI HRMS: calcd. for $C_{20}H_{22}O_6$+H 381.1314, found 381.1315.



(6*R*,8a*R*,10a*S*,11*S*)-ethyl-2-fluoro-11-hydroxy-6-methyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5d) was obtained in 92% yield after flash chromatography and the enantiomeric excess was determined to be 90% by HPLC analysis on Chiralpak IC column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 220 nm, t_{major} = 19.51 min, t_{minor} = 21.85 min. $[\alpha]_D^{20}$ = -18.2 (*c* = 1.17 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.04 (dd, *J* = 8.8 Hz, *J* = 6.4 Hz, 1H), 7.27 (d, *J* = 1.6 Hz, 1H), 6.82 (td, *J* = 8.8 Hz, *J* = 2.4 Hz, 1H), 6.67 (dd, *J* = 10.0 Hz, *J* = 2.4 Hz, 1H), 4.56 (dd, *J* = 8.0 Hz, *J* = 2.4 Hz, 1H), 4.37 (dd, *J* = 10.4 Hz, *J* = 3.2 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 2.22 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.07-2.00 (m, 1H), 1.54 (dd, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.50 (s, 3H), 1.41 (dt, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.32 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 191.5, 168.8, 166.2, 164.6, 162.8, 142.9, 134.0, 130.6, 110.7, 110.5, 104.8, 104.6, 78.5, 67.4, 60.7, 55.2, 47.0, 40.4, 37.3, 22.6, 14.1 ppm; ESI HRMS: calcd. for $C_{19}H_{19}FO_5$+H 347.1295, found 347.1286.

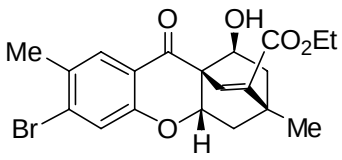


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-2-chloro-11-hydroxy-6-methyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5e) was obtained in 86% yield after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak OD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 10.95 min, t_{major} = 13.87 min. $[\alpha]_D^{20}$ = -43.8 (*c* = 0.72 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.96 (d, *J* = 2.4 Hz, 1H), 7.45 (dd, *J* = 8.8 Hz, *J* = 2.4 Hz, 1H), 7.27 (s, 1H), 6.95 (d, *J* = 8.8 Hz, 1H), 4.55-4.54 (m, 1H), 4.35 (dd, *J* = 10.0 Hz, *J* = 3.2 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 2.22 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.06-1.99 (m, 1H), 1.54 (dd, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.50 (s, 3H), 1.41 (dt, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.33 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 191.6, 164.6, 159.5, 143.0, 136.0, 133.8, 127.6, 127.3, 120.6, 119.5, 78.3, 67.3, 60.7, 55.2, 47.1, 40.4, 37.4, 22.5, 14.2 ppm; ESI HRMS: calcd. for $C_{19}H_{19}ClO_5$+H 363.0999, found 363.0997.

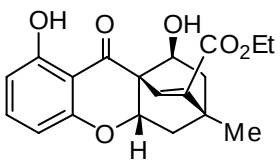


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-2-bromo-11-hydroxy-6-methyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5f) was obtained in 71% yield after flash chromatography and the enantiomeric excess was determined to be 88% by HPLC analysis on Chiralpak OD column (20%

2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 6.89 min, t_{major} = 8.46 min. $[\alpha]_D^{20}$ = -23.1 (*c* = 1.30 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 8.11 (s, 1H), 7.59 (dd, *J* = 8.8 Hz, *J* = 2.4 Hz, 1H), 7.27 (s, 1H), 6.89 (d, *J* = 8.8 Hz, 1H), 4.55 (dd, *J* = 8.4 Hz, *J* = 2.4 Hz, 1H), 4.35 (dd, *J* = 10.0 Hz, *J* = 2.8 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 2.22 (dd, *J* = 13.6 Hz, *J* = 8.0 Hz, 1H), 2.06-1.99 (m, 1H), 1.54 (dd, *J* = 14.0 Hz, *J* = 3.2 Hz, 1H), 1.50 (s, 3H), 1.41 (dt, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.32 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 191.6, 164.6, 159.9, 143.0, 138.8, 133.8, 130.4, 121.1, 119.9, 114.8, 78.2, 67.3, 60.7, 55.2, 47.0, 40.4, 37.4, 22.5, 14.2 ppm; ESI HRMS: calcd. for $C_{19}H_{19}BrO_5$+H 407.0494 (^{79}Br), 409.0474 (^{81}Br), found 407.0495, 409.0483.

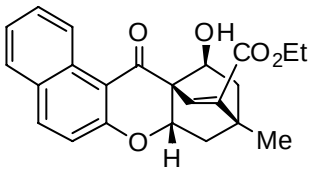


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-3-bromo-11-hydroxy-2,6-dimethyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5g) was obtained in 74% yield after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak OD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 11.45 min, t_{major} = 15.48 min. $[\alpha]_D^{20}$ = -18.6 (*c* = 0.87 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.84 (s, 1H), 7.27 (s, 1H), 7.24 (s, 1H), 4.55 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 4.33 (dd, *J* = 10.0 Hz, *J* = 2.8 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 2.38 (s, 3H), 2.21 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.05-1.98 (m, 1H), 1.52 (dd, *J* = 14.0 Hz, *J* = 2.8 Hz, 1H), 1.49 (s, 3H), 1.40 (dt, *J* = 13.6 Hz, *J* = 2.8 Hz, 1H), 1.32 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.3, 164.6, 159.1, 142.9, 134.1, 133.4, 132.1, 128.7, 121.6, 118.7, 78.3, 67.4, 60.7, 55.4, 47.0, 40.5, 37.4, 22.6, 21.9, 14.2 ppm; ESI HRMS: calcd. for $C_{20}H_{21}BrO_5$+Na 443.0470 (^{79}Br), 445.0450 (^{81}Br), found 443.0473, 445.0470.

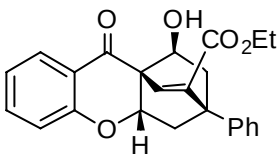


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-1,11-dihydroxy-6-methyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5h) was obtained in 72% yield after flash chromatography and the enantiomeric excess was determined to be 82% by HPLC analysis on Chiralpak AD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 8.95 min, t_{major} = 12.47 min. $[\alpha]_D^{20}$ = -34.0 (*c* = 2.00 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.71 (s, 1H), 7.39 (t, *J* = 8.0 Hz, 1H), 7.25 (s, 1H), 6.57 (d, *J* = 8.4 Hz, 1H), 6.44 (d, *J* = 8.0 Hz, 1H), 4.62 (d, *J* = 6.8 Hz, 1H), 4.33 (dd, *J* = 10.0 Hz, *J* = 2.8 Hz, 1H), 4.21 (q, *J* = 7.2 Hz, 2H), 2.23 (dd, *J* = 13.6 Hz, *J* = 8.0 Hz, 1H), 2.04-1.98 (m, 1H), 1.52 (dd, *J* = 14.0 Hz, *J* = 3.2 Hz, 1H), 1.50 (s, 3H), 1.40 (dt, *J* = 14.0 Hz, *J* =

3.2 Hz, 1H), 1.33 (t, J = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 198.9, 164.6, 162.8, 161.0, 143.1, 138.3, 133.4, 110.2, 107.4, 107.0, 77.6, 68.1, 60.8, 55.2, 47.1, 40.2, 37.4, 22.6, 14.2 ppm; ESI HRMS: calcd. for $C_{19}H_{20}O_6$+Na 367.1158, found 367.1157.

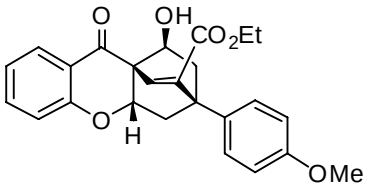


(7a*S*,9*R*,11a*R*,13*S*)-ethyl-13-hydroxy-9-methyl-12-oxo-7a,8,9,12-tetrahydro-11a,9-ethanobenzo[a]xanthene-10-carboxylate (5i) was obtained in 93% yield after flash chromatography and the enantiomeric excess was determined to be 97% by HPLC analysis on Chiralpak IA column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 17.04 min, t_{minor} = 19.23 min. $[\alpha]_D^{20}$ = -46.9 (c = 1.76 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.54 (d, J = 8.8 Hz, 1H), 7.95 (d, J = 9.2 Hz, 1H), 7.77 (d, J = 8.0 Hz, 1H), 7.67 (t, J = 7.2 Hz, 1H), 7.46 (t, J = 7.2 Hz, 1H), 7.42 (s, 1H), 7.08 (d, J = 9.2 Hz, 1H), 4.60 (d, J = 6.4 Hz, 1H), 4.45 (dd, J = 10.0 Hz, J = 3.2 Hz, 1H), 4.21 (q, J = 7.2 Hz, 2H), 2.18 (dd, J = 13.6 Hz, J = 8.0 Hz, 1H), 2.07-2.01 (m, 1H), 1.59 (dd, J = 13.6 Hz, J = 3.2 Hz, 1H), 1.51 (s, 3H), 1.42 (dt, J = 13.6 Hz, J = 3.2 Hz, 1H), 1.33 (t, J = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 194.2, 164.7, 163.4, 142.2, 137.8, 135.3, 131.8, 129.9, 129.5, 128.5, 125.9, 125.1, 118.4, 111.4, 77.7, 67.8, 60.6, 55.6, 46.9, 40.4, 37.2, 22.6, 14.2 ppm; ESI HRMS: calcd. for $C_{23}H_{22}O_5$+H 379.1545, found 379.1546.

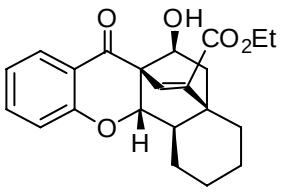


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-11-hydroxy-9-oxo-6-phenyl-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5j) was obtained in 90% yield after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak OD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 13.43 min, t_{minor} = 17.43 min. $[\alpha]_D^{20}$ = -56.4 (c = 1.85 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.03 (dd, J = 8.0 Hz, J = 1.6 Hz, 1H), 7.55-7.51 (m, 1H), 7.38-7.26 (m, 5H), 7.20 (s, 1H), 7.10 (t, J = 8.0 Hz, 1H), 6.99 (d, J = 8.4 Hz, 1H), 4.71 (d, J = 8.0 Hz, 1H), 4.51 (dd, J = 10.0 Hz, J = 2.8 Hz, 1H), 3.87 (q, J = 7.2 Hz, 2H), 2.66-2.56 (m, 2H), 2.28 (br s, 1H), 1.98-1.93 (m, 2H), 0.91 (t, J = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.4, 165.7, 161.0, 145.3, 143.0, 136.2, 132.0, 128.3, 128.0, 126.8, 126.2, 122.2, 119.7, 117.8, 77.8, 67.3, 60.6, 55.5, 45.4, 44.7, 39.3, 13.5 ppm; ESI HRMS: calcd. for $C_{24}H_{22}O_5$+H 391.1545, found 391.1544.

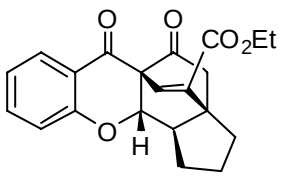
(6*R*,8a*R*,10a*S*,11*S*)-ethyl-11-hydroxy-6-(4-methoxyphenyl)-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5k) was obtained in 82% yield after flash chromatography and the



enantiomeric excess was determined to be 86% by HPLC analysis on Chiralpak OD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 18.54 min, t_{minor} = 35.13 min. $[\alpha]_D^{20}$ = -38.5 (*c* = 1.30 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 8.04 (d, *J* = 7.6 Hz, 1H), 7.55-7.51 (m, 1H), 7.22 (d, *J* = 8.8 Hz, 2H), 7.18 (s, 1H), 7.11 (t, *J* = 7.6 Hz, 1H), 6.99 (d, *J* = 8.0 Hz, 1H), 6.90 (d, *J* = 8.8 Hz, 2H), 4.71 (d, *J* = 7.2 Hz, 1H), 4.51 (dd, *J* = 10.0 Hz, *J* = 2.8 Hz, 1H), 3.91 (q, *J* = 7.2 Hz, 2H), 3.81(s, 3H), 2.63-2.55 (m, 2H), 2.22 (br s, 1H), 1.94-1.90 (m, 2H), 0.98 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.6, 165.6, 161.1, 158.3, 145.6, 136.3, 134.9, 131.7, 128.1, 127.3, 122.3, 119.8, 117.9, 113.6, 77.9, 67.4, 60.7, 55.5, 55.2, 45.6, 44.1, 39.5, 13.8 ppm; ESI HRMS: calcd. for $C_{25}H_{24}O_6$+Na 443.1471, found 443.1472.

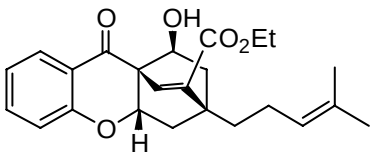


(4a*R*,6a*R*,12a*S*,*12bR*,13*S*)-ethyl-13-hydroxy-7-oxo-2,3,4,7,12a,12b-hexahydro-1H-6a,4a-ethanobenzo[c]xanthene-5-carboxylate (5l) was obtained in 76% yield after flash chromatography and the enantiomeric excess was determined to be 97% by HPLC analysis on Chiralpak OD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 7.46 min, t_{minor} = 13.07 min. $[\alpha]_D^{20}$ = -25.1 (*c* = 0.59 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 8.01 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.51 (td, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.22 (s, 1H), 7.08 (t, *J* = 8.0 Hz, 1H), 6.98 (d, *J* = 8.4 Hz, 1H), 4.58 (dd, *J* = 8.0 Hz, *J* = 2.4 Hz, 1H), 4.28-4.18 (m, 2H), 3.85 (d, *J* = 3.2 Hz, 1H), 2.81-2.78 (m, 1H), 2.16-2.12 (m, 1H), 1.85 (d, *J* = 13.2 Hz, 1H), 1.74-1.72 (m, 2H), 1.59 (dt, *J* = 12.8 Hz, *J* = 3.6 Hz, 1H), 1.42 (dd, *J* = 13.6 Hz, *J* = 2.8 Hz, 1H), 1.33 (t, *J* = 7.6 Hz, 3H), 1.28-1.20 (m, 3H), 0.97 (dd, *J* = 13.2 Hz, *J* = 3.2 Hz, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.7, 165.9, 161.3, 141.6, 136.2, 133.3, 128.0, 122.0, 119.8, 117.8, 84.1, 67.5, 60.8, 55.3, 48.0, 47.3, 42.5, 32.3, 31.6, 25.8, 23.4, 14.2 ppm; ESI HRMS: calcd. for $C_{22}H_{24}O_5$+H 369.1702, found 369.1703.

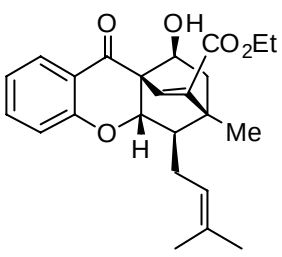


(3a*R*,5a*S*,11a*S*,11b*R*)-ethyl-6,12-dioxo-1,2,3,6,11a,11b-hexahydro-3a,5a-ethanocyclopenta[c]xanthene-4-carboxylate (6m) was obtained in 72% yield for two steps after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak AD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 6.54 min, t_{minor} = 7.64 min. $[\alpha]_D^{20}$ = -37.8 (*c* = 0.70 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 8.02 (dd, *J* = 8.0 Hz, *J* = 1.2 Hz, 1H), 7.51 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.35 (s, 1H), 7.10 (t, *J* = 7.6 Hz, 1H), 6.96 (d, *J* = 8.4 Hz,

1H), 4.40 (d, *J* = 3.2 Hz, 1H), 4.29-4.20 (m, 2H), 2.98-2.93 (m, 1H), 2.55 (d, *J* = 18.0 Hz, 1H), 2.33-2.19 (m, 4H), 2.00-1.90 (m, 2H), 1.57-1.49 (m, 1H), 1.34 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 204.4, 189.1, 164.2, 160.6, 142.7, 136.3, 132.5, 127.5, 122.4, 120.9, 118.0, 83.1, 66.9, 61.0, 53.5, 50.8, 45.8, 30.3, 28.9, 23.5, 14.2 ppm; ESI HRMS: calcd. for $C_{21}H_{20}O_5$+Na 375.1208, found 375.1207.

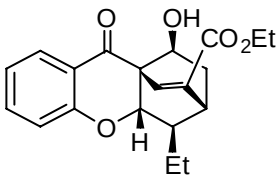


(6*R*,8a*R*,10a*S*,11*S*)-ethyl-11-hydroxy-6-(4-methylpent-3-en-1-yl) -9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5n) was obtained in 54% yield after flash chromatography and the enantiomeric excess was determined to be 95% by HPLC analysis on Chiralpak AD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 9.53 min, t_{major} = 12.80 min. $[\alpha]_D^{20}$ = -36.3 (*c* = 0.60 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.00 (d, *J* = 7.6 Hz, 1H), 7.51 (t, *J* = 7.6 Hz, 1H), 7.20 (s, 1H), 7.08 (t, *J* = 7.6 Hz, 1H), 6.96 (d, *J* = 8.4 Hz, 1H), 5.14 (br s, 1H), 4.59 (d, *J* = 6.8 Hz, 1H), 4.36 (dd, *J* = 10.0 Hz, *J* = 2.8 Hz, 1H), 4.20 (q, *J* = 7.2 Hz, 2H), 2.27 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.10-2.03 (m, 1H), 1.98-1.91 (m, 4H), 1.69 (s, 3H), 1.60 (s, 3H), 1.56-1.53 (m, 1H), 1.43-1.39 (m, 1H), 1.31 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.8, 165.3, 161.1, 143.1, 136.3, 134.0, 131.6, 128.1, 124.2, 122.1, 119.8, 117.8, 77.9, 67.4, 60.8, 55.3, 44.4, 41.0, 38.0, 34.9, 25.7, 23.8, 17.7, 14.2 ppm; ESI HRMS: calcd. for $C_{24}H_{28}O_5$+Na 419.1834, found 419.1832.

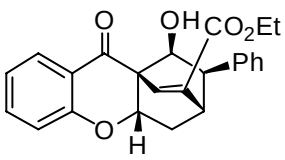


(5*R*,6*R*,8a*R*,10a*S*,11*S*)-ethyl-11-hydroxy-6-methyl-5-(3-methylbut-2-en -1-yl)-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5n′) was obtained in 27% yield after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak AS column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 7.10 min, t_{minor} = 13.26 min. $[\alpha]_D^{20}$ = -42.9 (*c* = 0.45 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.02 (d, *J* = 7.6 Hz, 1H), 7.52 (t, *J* = 7.2 Hz, 1H), 7.28 (s, 1H), 7.09 (t, *J* = 8.0 Hz, 1H), 6.98 (d, *J* = 8.4 Hz, 1H), 5.08-5.06 (m, 1H), 4.56 (d, *J* = 5.6 Hz, 1H), 4.21 (q, *J* = 7.2 Hz, 2H), 3.91 (d, *J* = 2.4 Hz, 1H), 2.41-2.36 (m, 1H), 2.24 (dd, *J* = 13.6 Hz, *J* = 8.0 Hz, 1H), 1.78-1.67 (m, 1H), 1.65 (s, 3H), 1.53 (s, 3H), 1.45 (s, 3H), 1.42 (dd, *J* = 13.2 Hz, *J* = 2.4 Hz, 1H), 1.33 (t, *J* = 7.2 Hz, 3H), 1.26 (d, *J* = 12.0 Hz, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 193.0, 165.0, 161.4, 141.6, 136.3, 133.9, 133.5, 128.0, 122.0, 120.7, 119.8, 117.9, 83.2, 67.2, 60.6, 55.6, 50.5, 48.1, 40.8, 29.8, 25.8, 20.9, 18.0, 14.2 ppm; ESI HRMS: calcd. for $C_{24}H_{28}O_5$+Na 419.1834, found

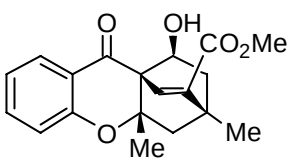
419.1835.



(5*R*,6*R*,8a*R*,10a*S*,11*S*)-ethyl-5-ethyl-11-hydroxy-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5o) was obtained in 47% yield after flash chromatography and the enantiomeric excess was determined to be 91% by HPLC analysis on Chiralpak AD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 12.91 min, t_{major} = 13.78 min. $[\alpha]_D^{20}$ = -30.0 (*c* = 0.65 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.01 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.52 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.40 (s, 1H), 7.09 (t, *J* = 7.6 Hz, 1H), 6.99 (d, *J* = 8.0 Hz, 1H), 4.58 (dd, *J* = 7.6 Hz, *J* = 2.4 Hz, 1H), 4.27-4.21 (m, 2H), 3.84 (d, *J* = 3.2 Hz, 1H), 3.33 (s, 1H), 2.44-2.38 (m, 1H), 1.79-1.76 (m, 1H), 1.41-1.26 (m, 6H), 0.99 (t, *J* = 7.6 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.9, 164.4, 161.4, 139.6, 136.3, 134.2, 128.0, 122.1, 119.8, 117.9, 83.7, 66.6, 60.9, 56.2, 46.4, 38.7, 34.5, 27.8, 14.2, 11.6 ppm; ESI HRMS: calcd. for $C_{20}H_{22}O_5$+Na 365.1365, found 365.1364.

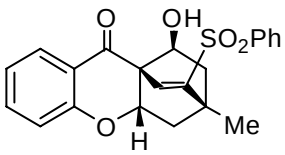


(3*S*,4a*S*,9a*R*,11*S*,12*R*)-ethyl-11-hydroxy-9-oxo-12-phenyl-3,4,4a,9-tetrahydro-3,9a-ethanoxanthene-2-carboxylate (5p) was obtained in 38% yield after flash chromatography and the enantiomeric excess was determined to be 98% by HPLC analysis on Chiralpak AD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 21.95 min, t_{major} = 28.23 min. $[\alpha]_D^{20}$ = -22.9 (*c* = 0.70 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.06 (dd, *J* = 8.0 Hz, *J* = 1.2 Hz, 1H), 7.57 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.50-7.44 (m, 3H), 7.37 (t, *J* = 8.0 Hz, 2H), 7.29-7.28 (m, 1H), 7.13 (t, *J* = 7.2 Hz, 1H), 7.08 (d, *J* = 8.4 Hz, 1H), 4.90 (s, 1H), 4.46 (dd, *J* = 10.0 Hz, *J* = 3.6 Hz, 1H), 4.28 (q, *J* = 7.2 Hz, 2H), 3.43 (s, 1H), 2.74 (s, 1H), 2.06-2.01 (m, 1H), 1.95-1.88 (m, 1H), 1.79 (br s, 1H), 1.36 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 192.4, 164.0, 161.3, 141.7, 139.6, 136.5, 135.2, 128.6, 128.5, 128.1, 126.9, 122.4, 119.9, 118.0, 78.1, 70.8, 61.1, 56.6, 54.7, 36.9, 25.8, 14.2 ppm; ESI HRMS: calcd. for $C_{24}H_{22}O_5$+H 391.1545, found 391.1547. The relative configuration of **5p** was determined by NOEDS analysis.

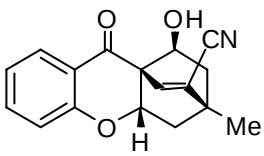


(6*R*,8a*R*,10a*S*,11*S*)-methyl-11-hydroxy-6,10a-dimethyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carboxylate (5q) was obtained in 36% yield after flash chromatography and the enantiomeric excess was determined to be 97% by HPLC analysis on Chiralpak OD column (20%

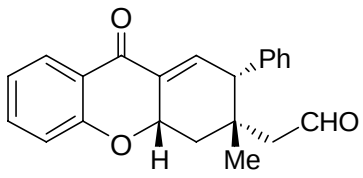
2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 6.51 min, t_{minor} = 7.95 min. $[\alpha]_D^{20}$ = +62.2 (*c* = 1.25 in EtOH); Since some decomposition was observed for **5q** in $CDCl_3$ solution, NMR data of its ketone derivative **6q** was provided: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.98 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.51 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.44 (s, 1H), 7.06 (t, *J* = 8.0 Hz, 1H), 6.93 (d, *J* = 8.4 Hz, 1H), 3.77 (s, 3H), 2.31-2.28 (m, 3H), 2.031-1.99 (m, 1H), 1.57 (s, 3H), 1.28 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 204.3, 189.1, 164.6, 158.1, 142.2, 136.1, 132.4, 126.9, 121.9, 121.2, 118.4, 85.7, 69.5, 51.9, 50.4, 45.8, 39.3, 22.6, 22.1 ppm; ESI HRMS: calcd. for $C_{19}H_{20}O_5$+Na (**5q**) 351.1208, found 351.1204; for $C_{19}H_{18}O_5$+Na (**6q**) 349.1052, found 349.1054.



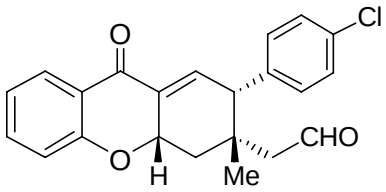
(6*R*,8a*R*,10a*S*,11*S*)-11-hydroxy-6-methyl-7-(phenylsulfonyl)-5,10a-dihydro-8a,6-ethanoxanthen-9(6H)-one (5r) was obtained in 89% yield after flash chromatography and the enantiomeric excess was determined to be 85% by HPLC analysis on Chiralpak AD column (40% 2-propanol/*n*-hexane, 1 mL/min), UV 220 nm, t_{minor} = 8.95 min, t_{major} = 18.01 min. $[\alpha]_D^{20}$ = -67.2 (*c* = 0.50 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.96 (d, *J* = 8.0 Hz, 1H), 7.87 (d, *J* = 7.6 Hz, 2H), 7.62-7.59 (m, 1H), 7.54-7.49 (m, 4H), 7.07 (t, *J* = 7.6 Hz, 1H), 6.95 (d, *J* = 8.4 Hz, 1H), 4.59 (d, *J* = 6.8 Hz, 1H), 4.36 (dd, *J* = 10.0 Hz, *J* = 2.4 Hz, 1H), 2.34 (br s, 1H), 2.11-1.98 (m, 2H), 1.52 (dd, *J* = 13.6 Hz, *J* = 2.4 Hz, 1H), 1.28 (s, 3H), 1.21 (d, *J* = 13.6 Hz, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 191.9, 160.9, 148.8, 139.8, 137.0, 136.4, 133.5, 129.2, 128.0, 127.8, 122.3, 119.4, 117.8, 77.2, 67.4, 56.5, 46.5, 40.9, 38.2, 20.5 ppm; ESI HRMS: calcd. for $C_{22}H_{20}O_5S$+Na 419.0929, found 419.0929.



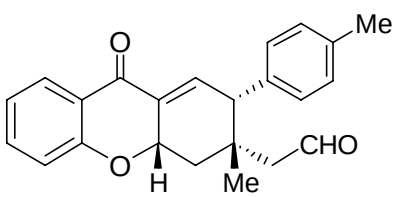
(6*R*,8a*R*,10a*S*,11*S*)-11-hydroxy-6-methyl-9-oxo-5,6,9,10a-tetrahydro-8a,6-ethanoxanthene-7-carbonitrile (5s) was obtained in 85% yield after flash chromatography and the enantiomeric excess was determined to be 80% by HPLC analysis on Chiralpak AD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 23.59 min, t_{major} = 26.61 min. $[\alpha]_D^{20}$ = -22.8 (*c* = 0.90 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.00 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.55 (td, *J* = 8.0 Hz, *J* = 2.0 Hz, 1H), 7.32 (s, 1H), 7.12 (t, *J* = 8.0 Hz, 1H), 6.99 (d, *J* = 8.4 Hz, 1H), 4.65 (dd, *J* = 8.0 Hz, *J* = 2.0 Hz, 1H), 4.39 (dd, *J* = 10.0 Hz, *J* = 3.2 Hz, 1H), 2.29 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.08-1.96 (m, 1H), 1.65 (dd, *J* = 14.0 Hz, *J* = 3.2 Hz, 1H), 1.46 (s, 3H), 1.38 (dt, *J* = 14.0 Hz, *J* = 3.2 Hz, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 191.6, 160.9, 141.8, 136.6, 128.1, 125.2, 122.5, 119.5, 117.9, 115.1, 77.5, 67.5, 55.8, 45.3, 39.4, 37.2, 22.2 ppm; ESI HRMS: calcd. for $C_{17}H_{15}NO_3$+Na 304.0950, found 304.0947.



2-((2*S*,3*S*,4a*S*)-3-methyl-9-oxo-2-phenyl-3,4,4a,9-tetrahydro-2H-xanthen-3-yl)acetaldehyde (4t) was obtained in 62% yield after flash chromatography and the enantiomeric excess was determined to be 84% by HPLC analysis on Chiralpak OD column (30% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 8.70 min, t_{major} = 9.55 min. $[\alpha]_D^{20}$ = +97.3 (*c* = 1.50 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.59 (d, *J* = 1.6 Hz, 1H), 8.02 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.52 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.33-7.26 (m, 3H), 7.18-7.16 (m, 2H), 7.11-7.06 (m, 2H), 7.02 (d, *J* = 8.8 Hz, 1H), 5.11-5.08 (m, 1H), 3.56 (s, 1H), 2.31 (dd, *J* = 13.6 Hz, *J* = 8.4 Hz, 1H), 2.20-2.05 (m, 3H), 1.31 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 201.4, 182.0, 161.6, 138.7, 137.9, 135.9, 132.2, 130.0, 128.6, 128.0, 127.8, 122.3, 122.0, 118.0, 73.8, 52.7, 52.4, 36.3, 35.2, 25.5 ppm; ESI HRMS: calcd. for $C_{22}H_{20}O_3$+MeOH+Na 387.1572, found 387.1571. The relative configuration of **4t** was determined by NOEDS analysis.

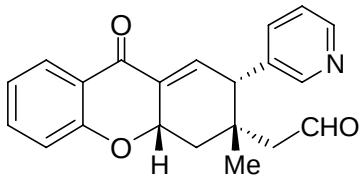


2-((2*S*,3*S*,4a*S*)-2-(4-chlorophenyl)-3-methyl-9-oxo-3,4,4a,9-tetrahydro-2H-xanthen-3-yl)acetaldehyde (4u) was obtained in 75% yield after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak AD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 10.96 min, t_{major} = 12.09 min. $[\alpha]_D^{20}$ = +109.1 (*c* = 2.25 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.63 (d, *J* = 1.6 Hz, 1H), 8.00 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.51 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.29-7.26 (m, 2H), 7.11-7.06 (m, 3H), 7.01-6.99 (m, 2H), 5.09-5.06 (m, 1H), 3.58-3.57 (m, 1H), 2.26-2.02 (m, 4H), 1.29 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 201.1, 181.9, 161.5, 138.0, 136.4, 136.0, 133.7, 132.4, 131.2, 128.7, 127.9, 122.1, 122.0, 118.0, 73.6, 52.4, 51.4, 36.1, 35.2, 25.2 ppm; ESI HRMS: calcd. for $C_{22}H_{19}ClO_3$+MeOH+Na 421.1183, found 421.1185.



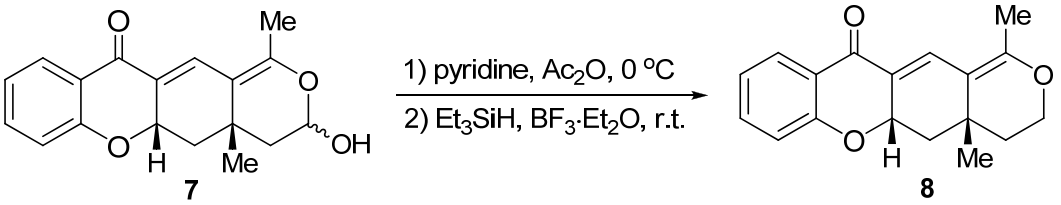
2-((2*S*,3*S*,4a*S*)-3-methyl-9-oxo-2-(p-tolyl)-3,4,4a,9-tetrahydro-2H-xanthen-3-yl)acetaldehyde (4v) was obtained in 44% yield after flash chromatography and the enantiomeric excess was determined to be 86% by HPLC analysis on Chiralpak AD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 220 nm, t_{major} = 15.14 min, t_{minor} = 16.65 min. $[\alpha]_D^{20}$ = +115.1 (*c* = 0.95 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.59 (t, *J* = 1.6 Hz, 1H), 8.02 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.52 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.13-7.09 (m, 3H), 7.06-7.01 (m, 4H), 5.11-5.07 (m, 1H), 3.53-3.51 (m, 1H), 2.32 (s, 3H), 2.30-2.26 (m, 1H),

2.19-2.05 (m, 3H), 1.30 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 201.6, 182.0, 161.5, 139.0, 137.6, 135.8, 134.7, 131.9, 129.9, 129.2, 128.0, 122.2, 122.0, 118.0, 73.8, 52.7, 51.9, 36.2, 35.1, 25.5, 21.0 ppm; ESI HRMS: calcd. for $C_{23}H_{22}O_3$+Na 369.1467, found 369.1465.



2-((2*S*,3*S*,4a*S*)-3-methyl-9-oxo-2-(pyridin-3-yl)-3,4,4a,9-tetrahydro-2H-xanthen-3-yl)acetaldehyde (4w) was obtained in 74% yield after flash chromatography and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak AD column (40% 2-propanol/*n*-hexane, 1 mL/min), UV 220 nm, t_{major} = 10.14 min, t_{minor} = 13.60 min. $[\alpha]_D^{20}$ = +51.9 (*c* = 0.75 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.68 (s, 1H), 8.55 (d, *J* = 4.0 Hz, 1H), 8.49 (s, 1H), 8.02 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.55-7.50 (m, 2H), 7.29-7.26 (m, 1H), 7.10 (t, *J* = 7.6 Hz, 1H), 7.03-6.99 (m, 2H), 5.12-5.09 (m, 1H), 3.65-3.64 (m, 1H), 2.30-2.15 (m, 3H), 2.08-2.04 (m, 1H), 1.34 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.7, 181.8, 161.4, 151.0, 149.1, 137.2, 137.1, 136.1, 133.7, 133.1, 128.0, 123.4, 122.2, 122.1, 118.1, 73.5, 52.1, 49.6, 36.1, 35.3, 25.1 ppm; ESI HRMS: calcd. for $C_{21}H_{19}NO_3$+Na 356.1263, found 356.1264.

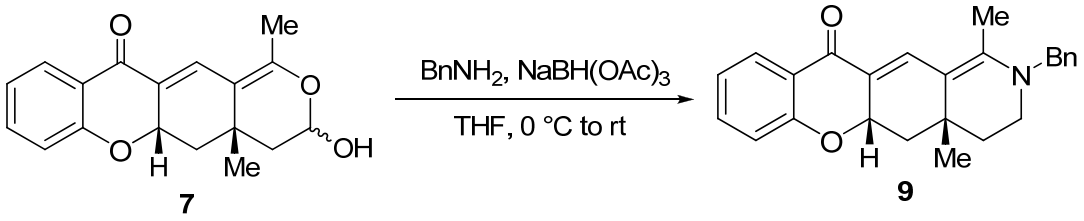
3. Synthetic transformation of the chiral cycloadducts.



7 **8**

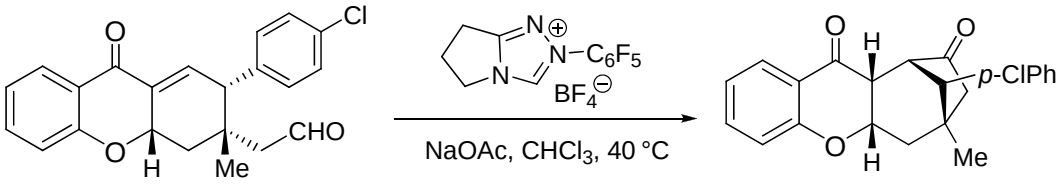
To a solution of product **7** (28 mg, 0.09 mmol), which was generated from the domino DA-hemiacetalization of **2b** and **3a**, in 0.5 mL of pyridine was added Ac_2O (11 mg, 0.11 mmol) at 0 °C. Then, the mixture was stirred for 10 minutes. When the reaction completed, DCM (3 mL) was added and the organic phase was washed with dilute hydrochloric acid (10%). The aqueous solution was further extracted with DCM for three times and the combined organic solution was evaporation in vacuum to give a yellow oil, which was purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate = 10:1) to afford a hydroxyl-protected intermediate. Next, to an anhydrous DCM solution of the hydroxyl-protected intermediate was added triethyl silane (34.8 mg, 0.3 mmol) and $BF_3.Et_2O$ (36 μL, 0.3 mmol). The mixture was stirred at 0 °C for 5 minutes and then at room temperature for another 6 hours until the reaction completed (monitored by TLC). The reaction was quenched with aqueous $NaHCO_3$, extracted with DCM. The organic layer was dried over Na_2SO_4 and concentrated. The crude product was purified by

column chromatography (petroleum ether/ethyl acetate = 10:1) to give the final product **8** in 45% yield for two steps and the enantiomeric excess was determined to be 91% by HPLC analysis on Chiralpak AD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{minor} = 7.12 min, t_{major} = 7.76 min. $[\alpha]_D^{20}$ = +20.4 (*c* = 0.45 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.99 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.62-7.60 (m, 1H), 7.44 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.04 (t, *J* = 8.0 Hz, 1H), 6.95 (d, *J* = 8.0 Hz, 1H), 5.21-5.17 (m, 1H), 4.33-4.29 (m, 1H), 4.23-4.16 (m, 1H), 2.24 (dd, *J* = 12.0 Hz, *J* = 5.6 Hz, 1H), 2.07 (s, 3H), 1.78 (dd, *J* = 12.8 Hz, *J* = 4.8 Hz, 1H), 1.72-1.66 (m, 1H), 1.32-1.19 (m, 1H), 1.08 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 181.4, 161.0, 158.5, 134.9, 133.8, 127.7, 124.5, 123.0, 121.6, 117.6, 112.1, 77.3, 74.0, 63.1, 41.8, 36.0, 25.2, 17.2 ppm; ESI HRMS: calcd. for $C_{18}H_{18}O_3$+Na 305.1154, found 305.1153.



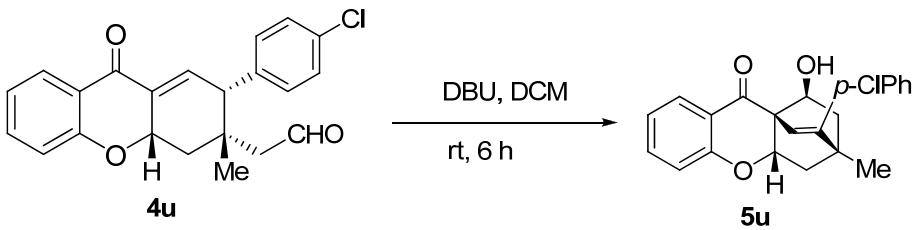
7 **9**

To the anhydrous THF solution of the product **7** (30 mg, 0.1 mmol) was added $BnNH_2$ (53.5 mg, 0.5 mmol). Then the mixture was stirred at 0 °C for about 10 minutes. $NaBH(OAc)_3$ (169.6 mg, 0.8 mmol) was added to the mixture, and the reaction was stirred at room temperature for additional 4 hours. When the reaction completed, the reaction mixture was quenched by water and extracted with DCM for three times and evaporation in vacuum to give a yellow oil, which was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 5:1) to afford the desired product **9** in 68% yield and the enantiomeric excess was determined to be 91% by HPLC analysis on Chiralpak AS column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 280 nm, t_{minor} = 10.52 min, t_{major} = 11.78 min. $[\alpha]_D^{20}$ = +9.3 (*c* = 0.90 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.99 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.89 (s, 1H), 7.40-7.36 (m, 3H), 7.32-7.29 (m, 1H), 7.14 (d, *J* = 7.2 Hz, 2H), 7.02 (t, *J* = 7.2 Hz, 1H), 6.93 (d, *J* = 8.4 Hz, 1H), 5.26 (dd, *J* = 10.4 Hz, *J* = 6.0 Hz, 1H), 4.64-4.54 (m, 2H), 3.54-3.48 (m, 1H), 3.31-3.26 (m, 1H), 2.34 (s, 3H), 2.18 (dd, *J* = 12.0 Hz, *J* = 5.6 Hz, 1H), 1.77-1.70 (m, 3H), 1.02 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.9, 160.6, 150.1, 137.0, 135.6, 133.7, 129.0, 127.6, 127.4, 125.9, 124.1, 121.3, 117.9, 117.1, 109.4, 74.3, 55.2, 45.8, 42.4, 35.3, 31.2, 25.1, 14.9 ppm; ESI HRMS: calcd. for $C_{25}H_{25}NO_2$+H 372.1964, found 372.1965.



4u **10**

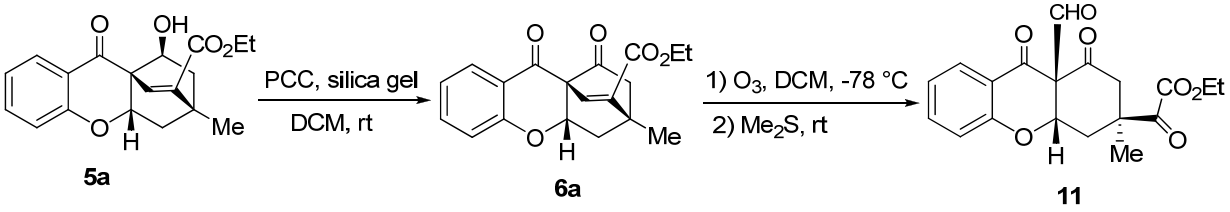
To an anhydrous chloroform solution of the product **4u** (37 mg, 0.1 mmol) was added the carbene precatalyst (7.3 mg, 0.02 mmol) and sodium acetate (9.8 mg, 0.12 mmol) at ambient temperature. Then the mixture was stirred at 40 °C for 15 hours. When the reaction completed, the mixture was evaporated and purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 8:1) to afford the desired product **10** in 92% yield and the enantiomeric excess was determined to be 90% by HPLC analysis on Chiralpak OD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 220 nm, t_{minor} = 11.96 min, t_{major} = 17.04 min. $[\alpha]_D^{20}$ = +128.8 (*c* = 0.90 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.92 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.50 (td, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.27-7.25 (m, 2H), 7.07 (t, *J* = 8.0 Hz, 1H), 6.95-6.92 (m, 3H), 4.79-4.78 (m, 1H), 3.10 (t, *J* = 3.6 Hz, 1H), 2.99 (br s, 2H), 2.71 (d, *J* = 18.4 Hz, 1H), 2.45 (d, *J* = 15.2 Hz, 1H), 2.24-2.20 (m, 1H), 2.09 (d, *J* = 18.0 Hz, 1H), 1.01 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 216.4, 191.4, 160.6, 137.7, 136.5, 132.9, 129.3, 128.5, 127.2, 122.3, 120.9, 118.3, 75.5, 58.1, 55.1, 54.9, 46.5, 45.8, 42.1, 24.4 ppm; ESI HRMS: calcd. for $C_{22}H_{19}ClO_3$+Na 389.0920, found 389.0921.



4u **5u**

To an anhydrous dichloromethane solution of the product **4u** (33 mg, 0.09 mmol) was added DBU (15.2 mg, 0.1 mmol) at ambient temperature. Then the mixture was stirred for 6 hours. When the reaction completed, the mixture was evaporated and purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 8:1) to afford the desired product **5u** in 88% yield and the enantiomeric excess was determined to be 94% by HPLC analysis on Chiralpak AD column (20% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 11.14 min, t_{minor} = 19.03 min. $[\alpha]_D^{20}$ = -17.0 (*c* = 0.50 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.03 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.52 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.31 (d, *J* = 8.4 Hz, 2H), 7.12-7.07 (m, 3H), 6.99 (d, *J* = 8.4 Hz, 1H), 6.33 (s, 1H), 4.60 (t, *J* = 6.0 Hz, 1H), 4.48 (dd, *J* =

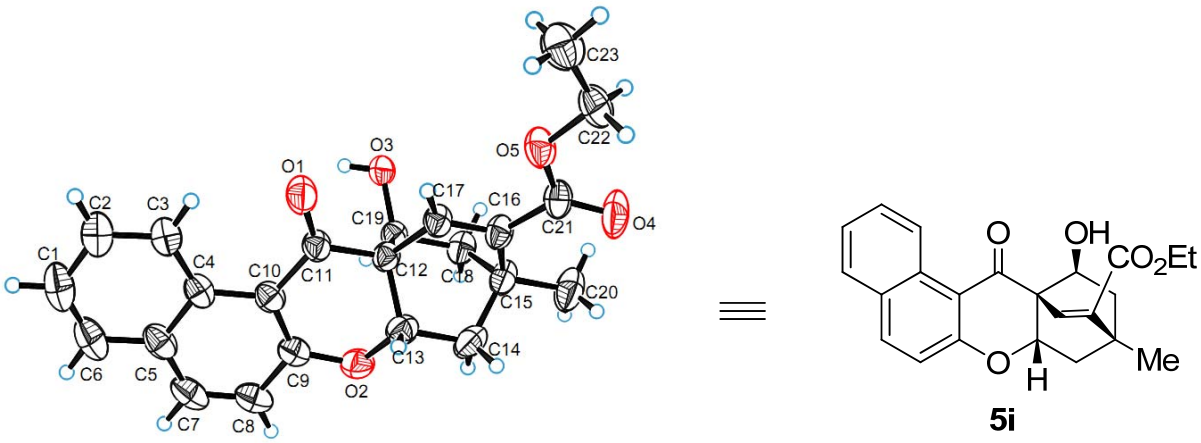
10.0 Hz, *J* = 2.8 Hz, 1H), 2.30 (dd, *J* = 13.6 Hz, *J* = 8.0 Hz, 1H), 2.12-2.05 (m, 1H), 1.65 (dd, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.43 (dt, *J* = 13.6 Hz, *J* = 3.2 Hz, 1H), 1.15 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 193.8, 161.3, 152.8, 137.3, 136.1, 133.4, 129.5, 128.2, 128.1, 122.2, 122.0, 119.9, 117.8, 78.6, 67.4, 55.2, 47.4, 40.8, 38.3, 23.3 ppm; ESI HRMS: calcd. for $C_{22}H_{19}ClO_3$+Na 389.0920, found 389.0922.



5a **6a** **11**

To an anhydrous DCM solution of the product **5a** (38 mg, 0.12 mmol) was added PCC (77.8 mg, 0.36 mmol) and silica gel (78 mg) at ambient temperature. Then the mixture was stirred for 3 hours. When the reaction completed, the mixture was evaporated and purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate = 10:1) to afford the ketone product **6a** which was directly dissolved in dichloromethane and ozone was introduced at -78 °C. After 20 minutes, 20 uL of dimethyl sulfide was added to the mixture and stirred for an additional 4 hours at room temperature. The mixture was evaporated and purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 10:1) to afford the final product **11** in 82% yield for two steps and the enantiomeric excess was slightly dropped to be 90% determined by HPLC analysis on Chiralpak AD column (10% 2-propanol/*n*-hexane, 1 mL/min), UV 254 nm, t_{major} = 10.59 min, t_{minor} = 11.92 min. $[\alpha]_D^{20}$ = -23.5 (*c* = 0.95 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 14.76 (s, 1H), 7.83 (dd, *J* = 8.0 Hz, *J* = 1.6 Hz, 1H), 7.43 (td, *J* = 8.4 Hz, *J* = 1.6 Hz, 1H), 7.05 (t, *J* = 7.6 Hz, 1H), 6.92 (d, *J* = 8.0 Hz, 1H), 5.00-4.96 (m, 1H), 4.38-4.31 (m, 2H), 2.96-2.91 (m, 2H), 2.41-2.36 (m, 1H), 2.03 (dd, *J* = 12.8 Hz, *J* = 10.8 Hz, 1H), 1.49 (s, 3H), 1.36 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 197.9, 181.0, 179.6, 162.3, 159.9, 135.3, 126.6, 122.0, 121.2, 117.4, 103.4, 72.0, 62.5, 46.0, 38.7, 37.4, 24.8, 14.0 ppm; ESI HRMS: calcd. for $C_{19}H_{18}O_7$–CHO+Na 353.1001, found 353.0995.

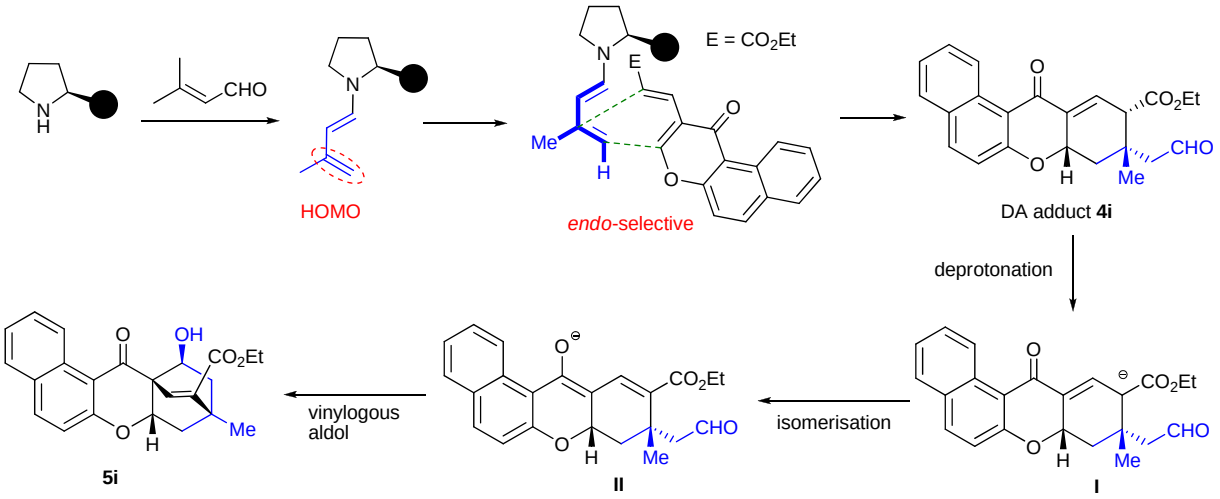
4. Crystal data and structure refinement for enantiopure 5i and the proposed catalytic mechanism



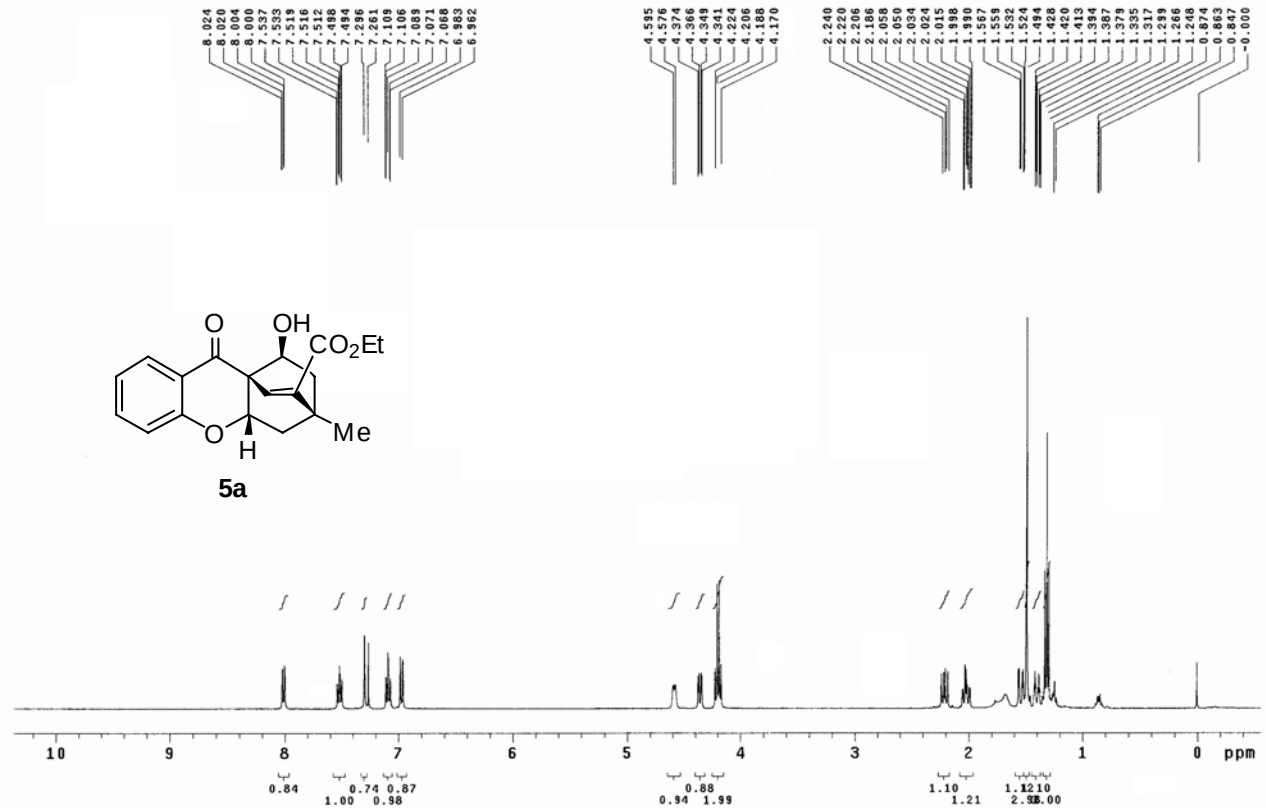
Identification code	**5i**
Empirical formula	$C_{23}H_{22}O_5$
Formula weight	378.41
Temperature	291(2) K
Wavelength	1.54184 A
Crystal system, space group	Triclinic, P 1
Unit cell dimensions	a = 7.7512(3) A alpha = 70 deg. b = 8.1381(3) A beta = 80 deg. c = 8.4256(3) A gamma = 74 deg.
Volume	476.8(3) A^3
Z, Calculated density	1, 1.318 mg/mm^3
Absorption coefficient	0.756 m/mm^-1
F(000)	200
Crystal size	0.40 x 0.36 x 0.35 mm
Theta range for data collection	5.96 to 66.58 deg.
Limiting indices	-9<=h<=9, -9<=k<=9, -9<=l<=10
Reflections collected / unique	5866 / 2997 [R(int) = 0.0136]
Data / restraints / parameters	2997 / 3 / 256
Goodness-of-fit on F^2	1.018
Final R indices [I>2sigma(I)]	R1 = 0.0278, wR2 = 0.0736

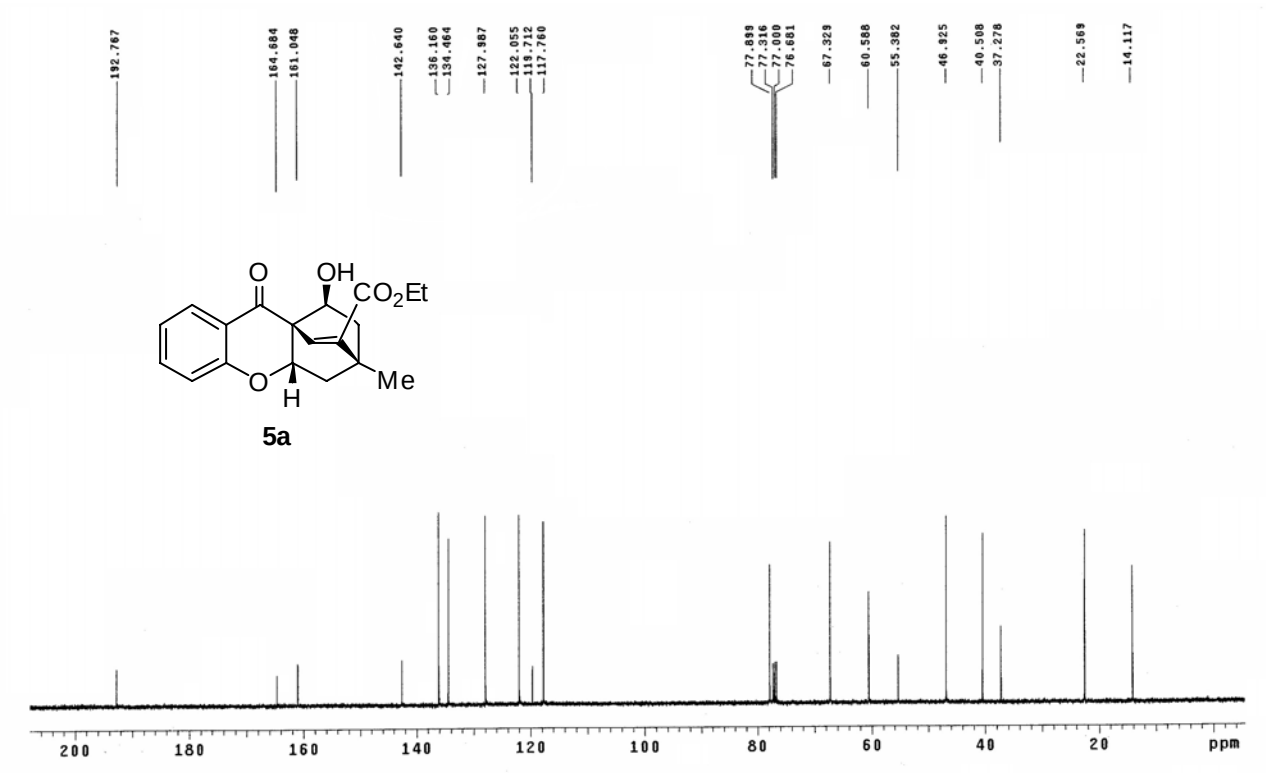
R indices (all data)	R1 = 0.0279, wR2 = 0.0737
Absolute structure parameter	-0.07(14)
Largest diff. peak and hole	0.109 and -0.105 e.A^-3

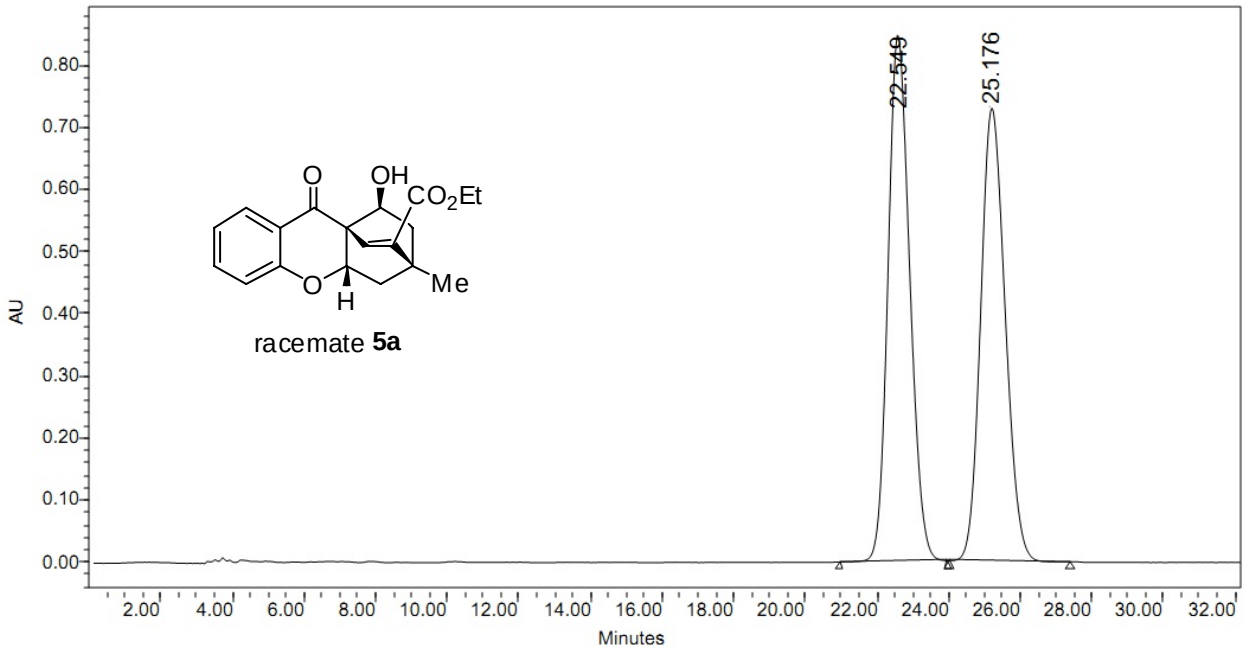
Based on the absolute configuration of enantiopure **5i**, a plausible catalytic mechanism has been proposed for the IEDDA/vinylogous aldol cascade reaction. As outlined in the following scheme, the observed major enantiomer **4i** could be obtained from *endo*-selective concerted cycloaddition of the dienamine intermediate and chromone-fused diene (the similar transitional state is adopted when crotonaldehyde is applied in the IEDDA reaction, see: *Angew. Chem., Int. Ed.*, 2010, **49**, 6418). Subsequently, the vinylogous C-H could be deprotonated to give anion **I**, and isomerises to enolate **II**. Then an intramolecular vinylogous aldol reaction could occur to afford the caged system **5i**.



5. NMR spectra and HPLC chromatograms

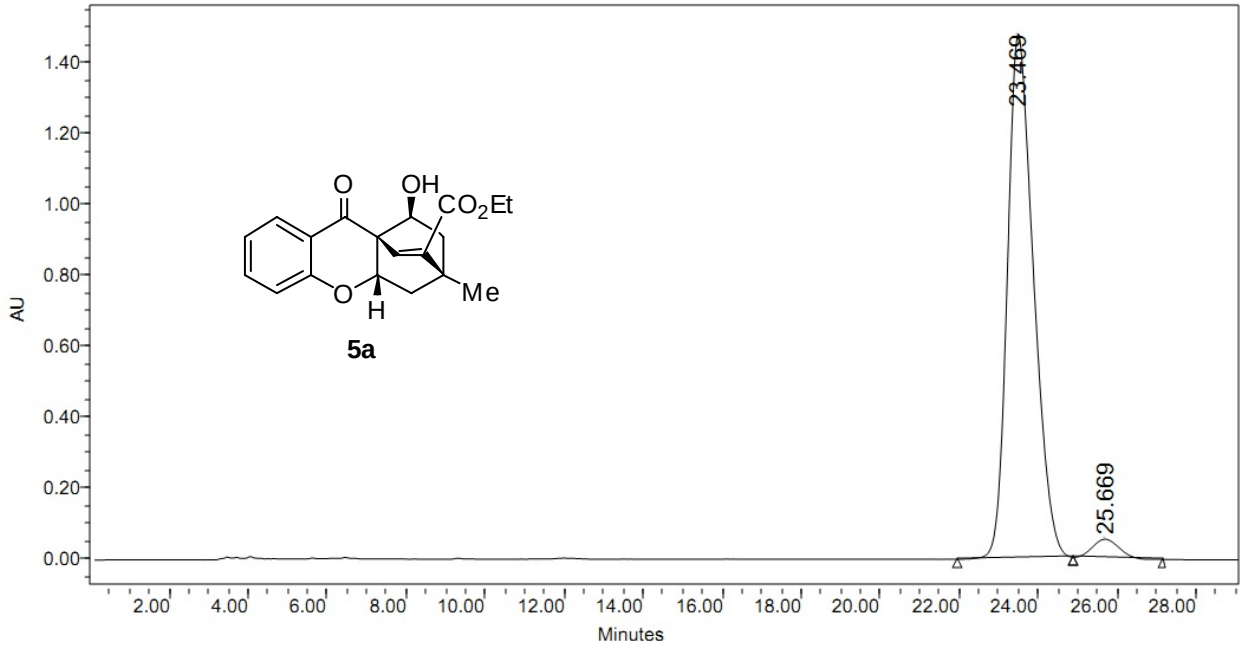






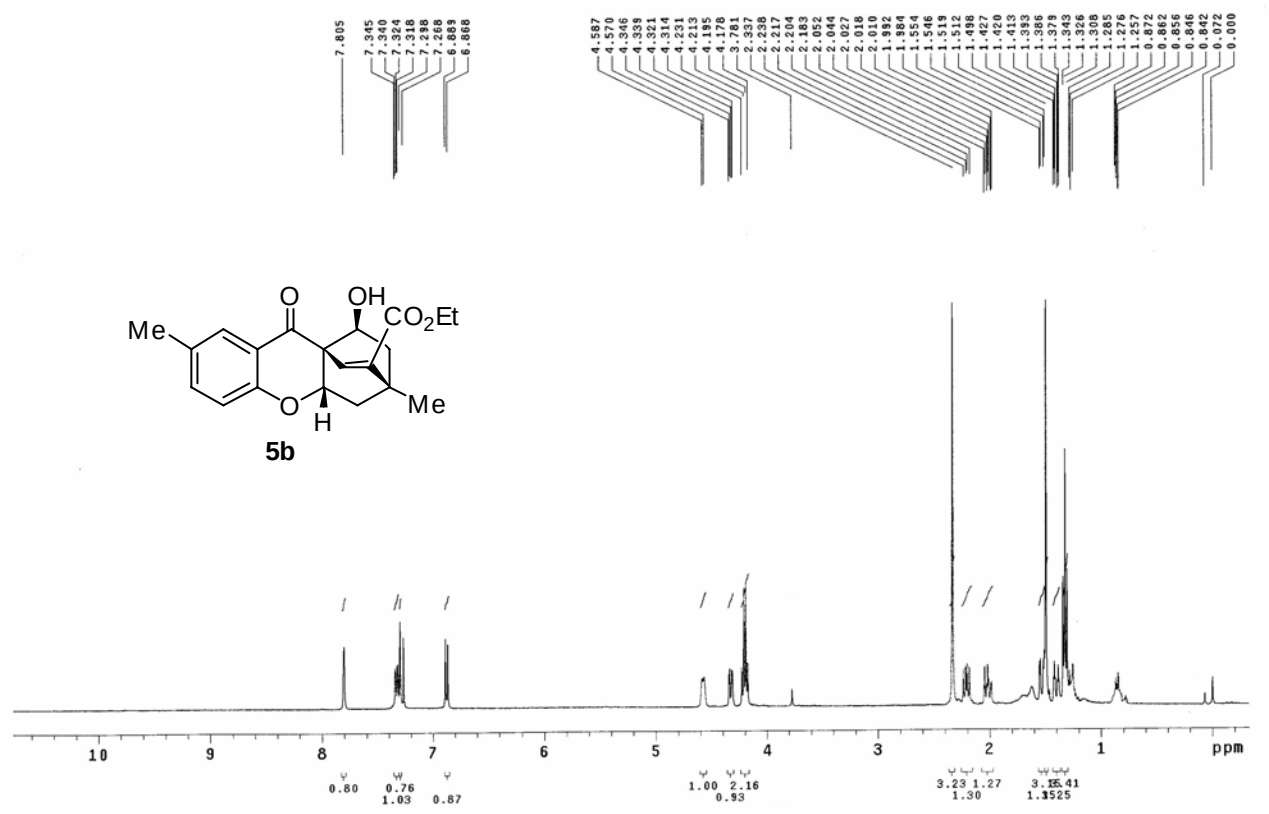
racemate **5a**

	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	22.549	35843296	50.85	847129	53.73
2	25.176	34648969	49.15	729615	46.27



5a

	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	23.469	67659191	96.87	1478614	96.74
2	25.669	2185433	3.13	49776	3.26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6.866
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4.570
4.346
4.339
4.321
4.314
4.231
4.211
4.195
4.178
3.781
2.337
2.238
2.217
2.204
2.183
2.052
2.044
2.027
2.018
2.010
1.992
1.984
1.554
1.546
1.519
1.512
1.498
1.427
1.420
1.413
1.393
1.386
1.379
1.343
1.326
1.308
1.285
1.276
1.257
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0.856
0.846
0.842
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0.000
O
OH
CO2Et
Me
O
H
Me
10
9
8
7
6
5
4
3
2
1
ppm
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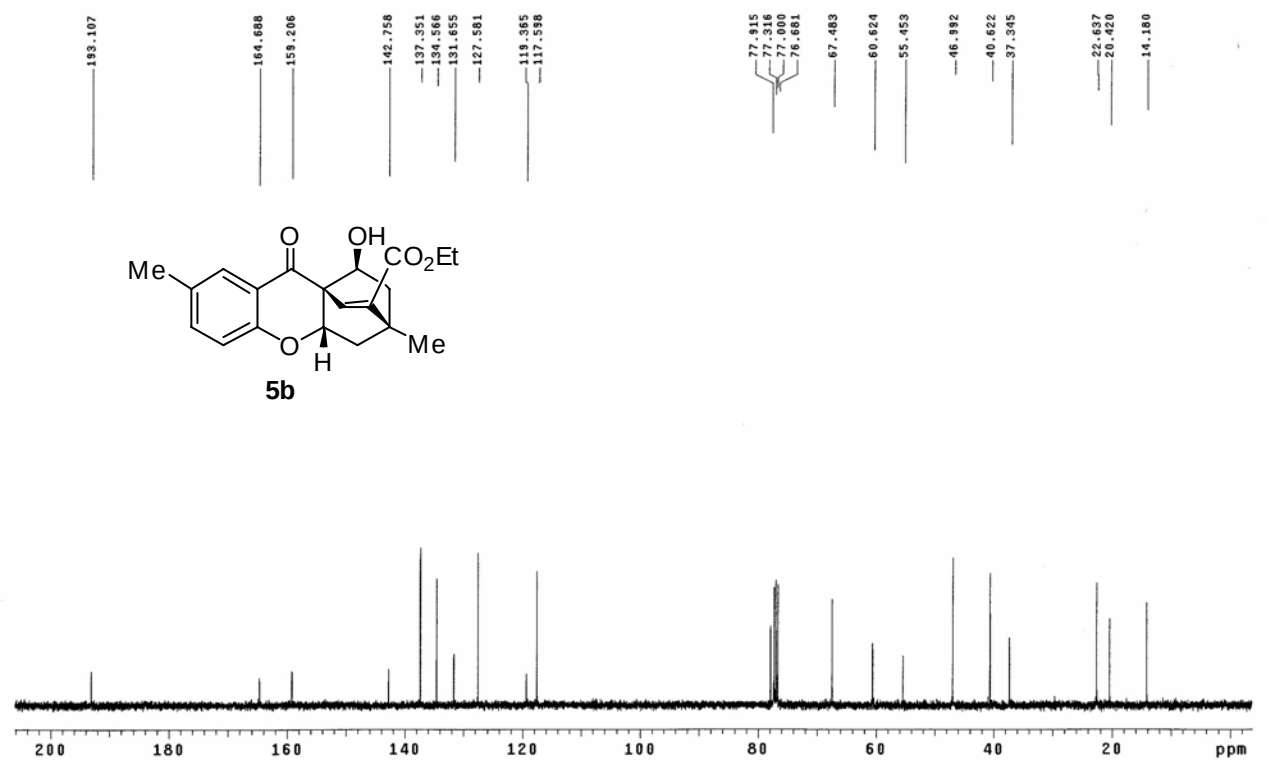
3.41
1.1525

5b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127.581
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22.637
20.420
14.180
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Me
O
H
Me
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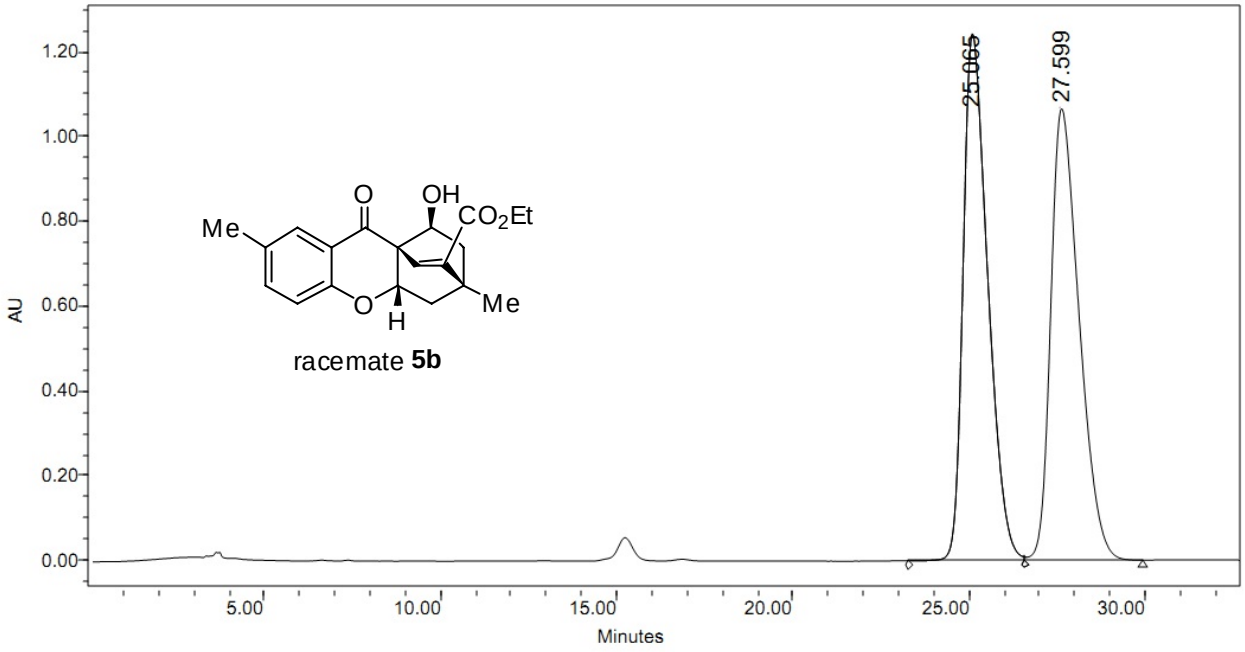
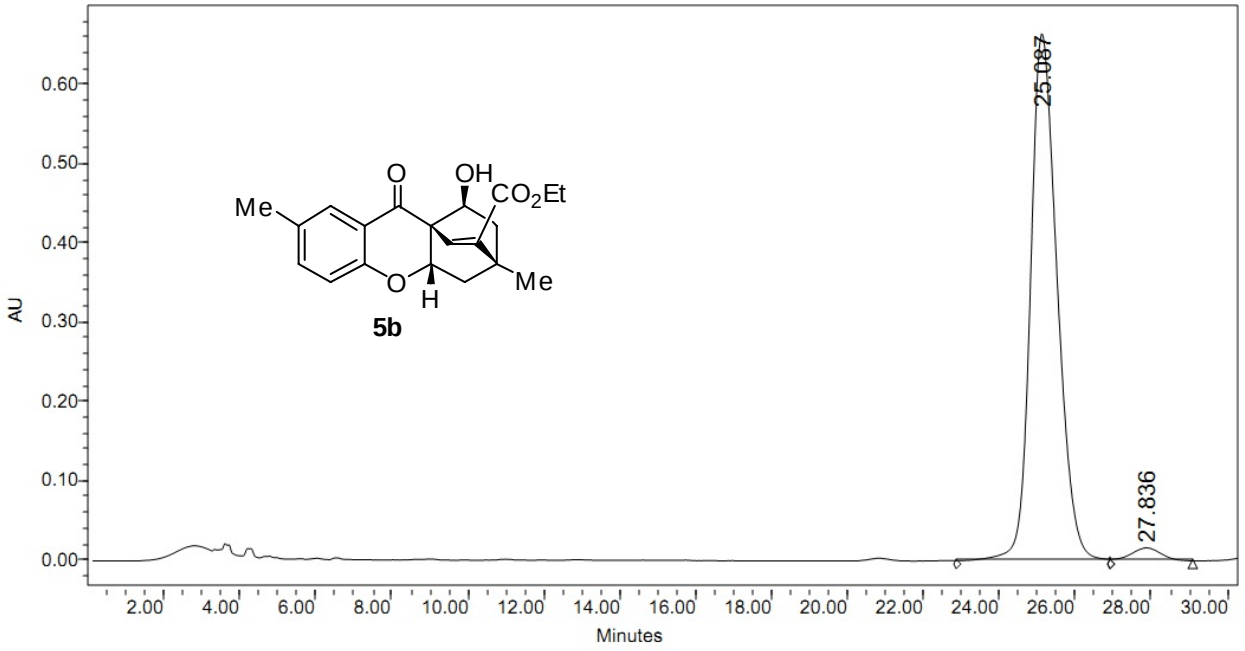
120
100
80
60
40
20
ppm

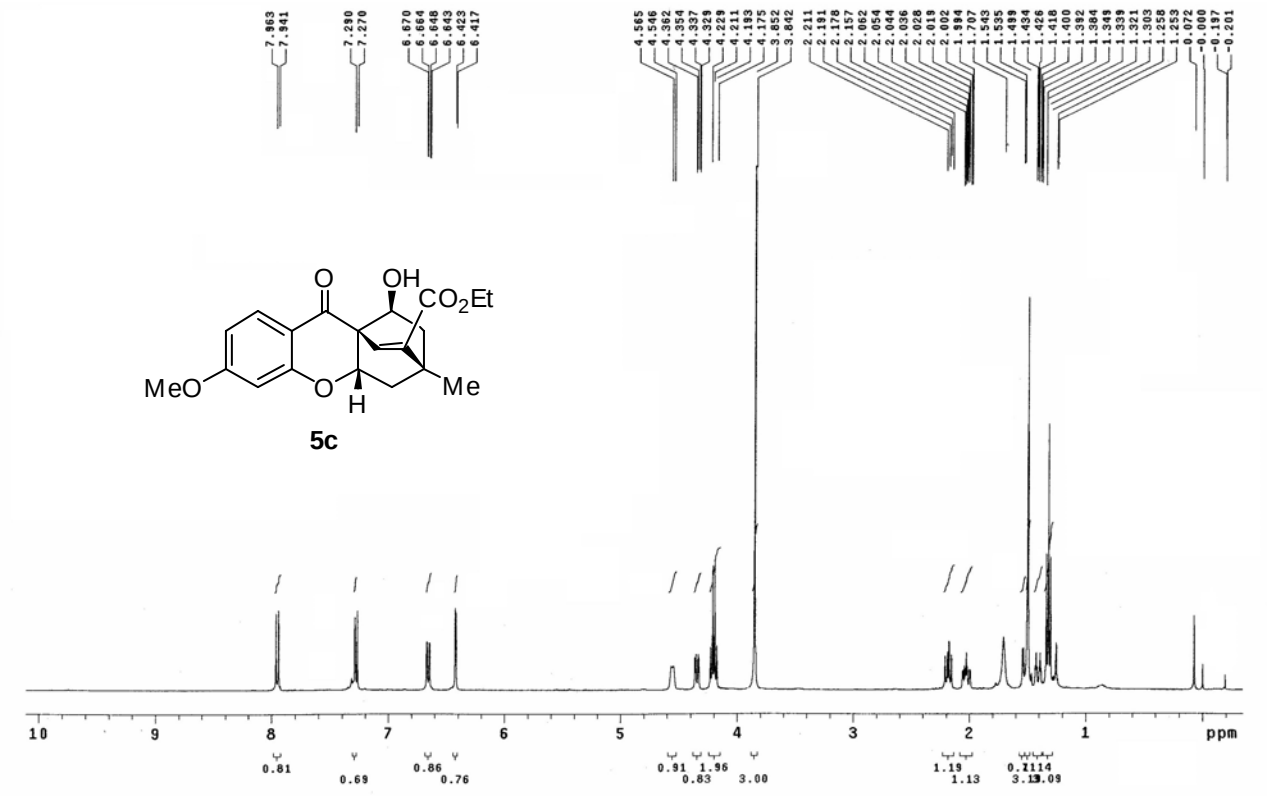
5b



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	25.065	60393402	50.27	1242124	53.83
2	27.599	59755192	49.73	1065228	46.17



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	25.087	32202462	97.81	663863	97.84
2	27.836	721777	2.19	14674	2.16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4.354
4.337
4.329
4.228
4.211
4.183
4.175
3.852
3.842
2.211
2.191
2.178
2.157
2.062
2.054
2.044
2.036
2.028
2.018
2.002
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1.434
1.426
1.418
1.400
1.392
1.384
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1.339
1.321
1.303
1.258
1.253
0.072
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-0.187
-0.201
O
OH
CO2Et
MeO
O
H
Me
5c
10
9
8
7
6
5
4
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2
1
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0.69
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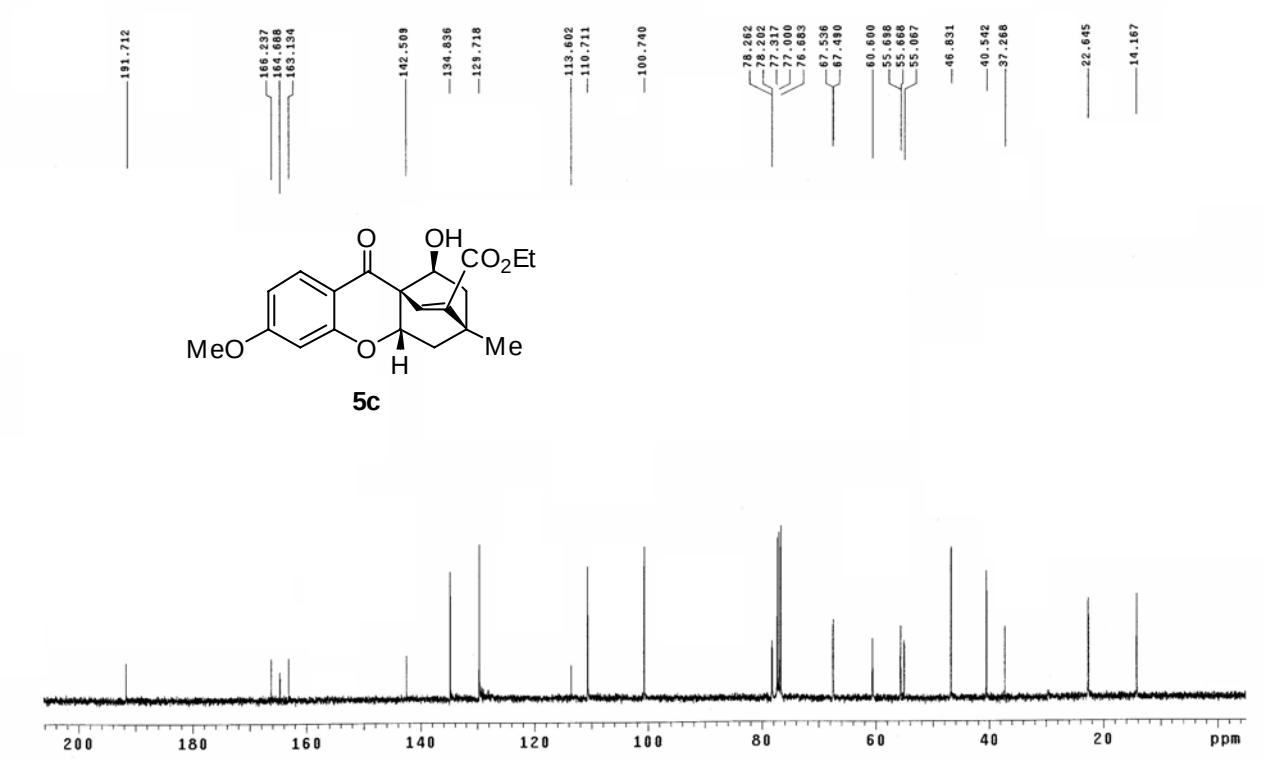
0.76
0.91
1.95
0.83
3.00
1.19
1.13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163.134
142.509
134.836
129.718
113.602
110.711
100.740
78.262
78.202
77.317
77.000
76.683
67.536
67.490
60.600
55.698
55.668
55.067
46.831
40.542
37.268
22.645
14.167
O
OH
CO2Et
MeO
O
H
Me
5c
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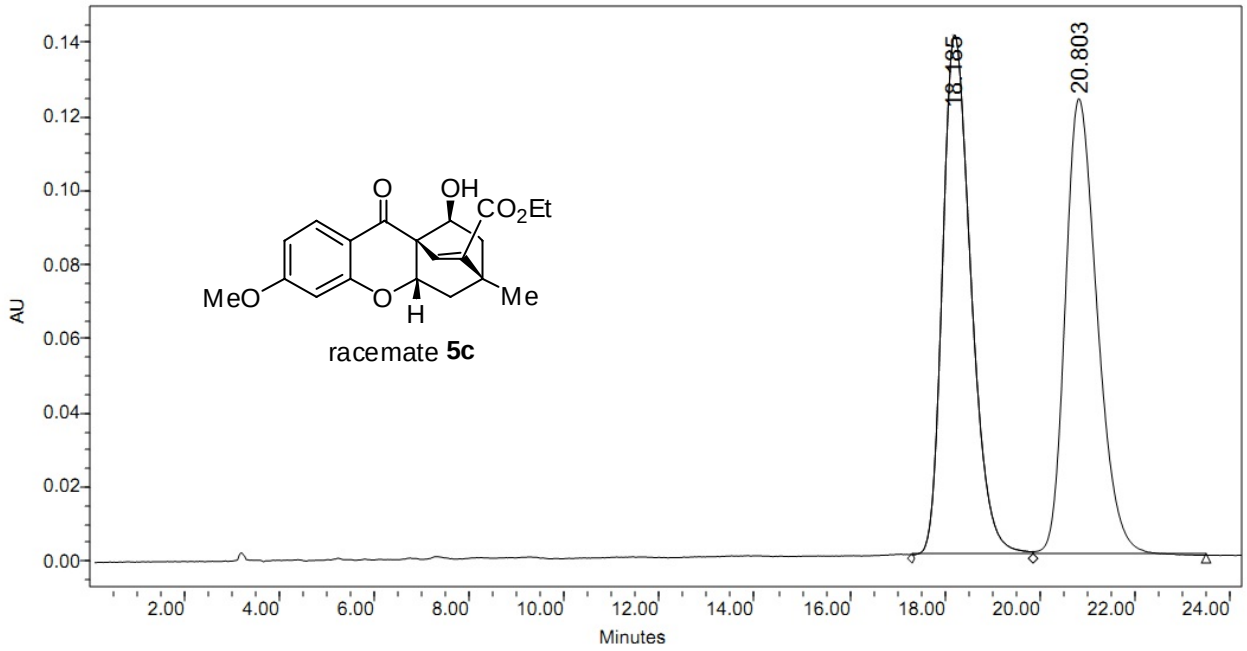
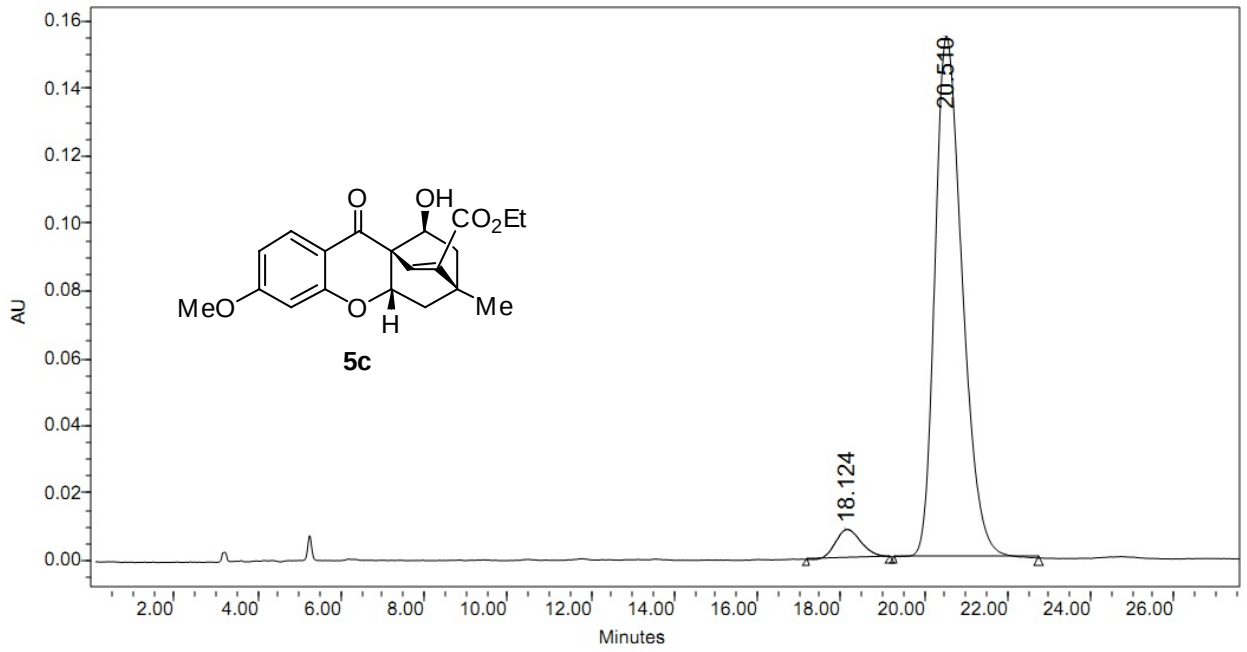
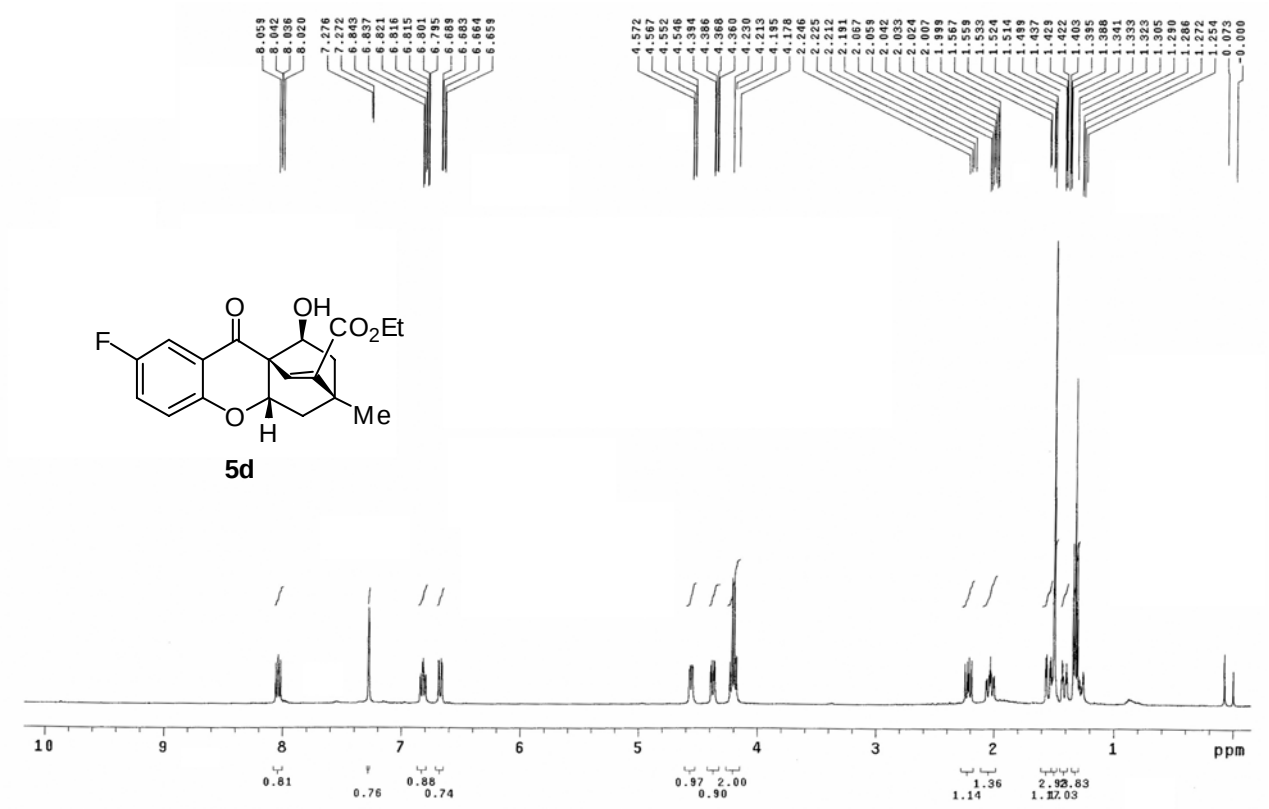
140
120
100
80
60
40
20
ppm

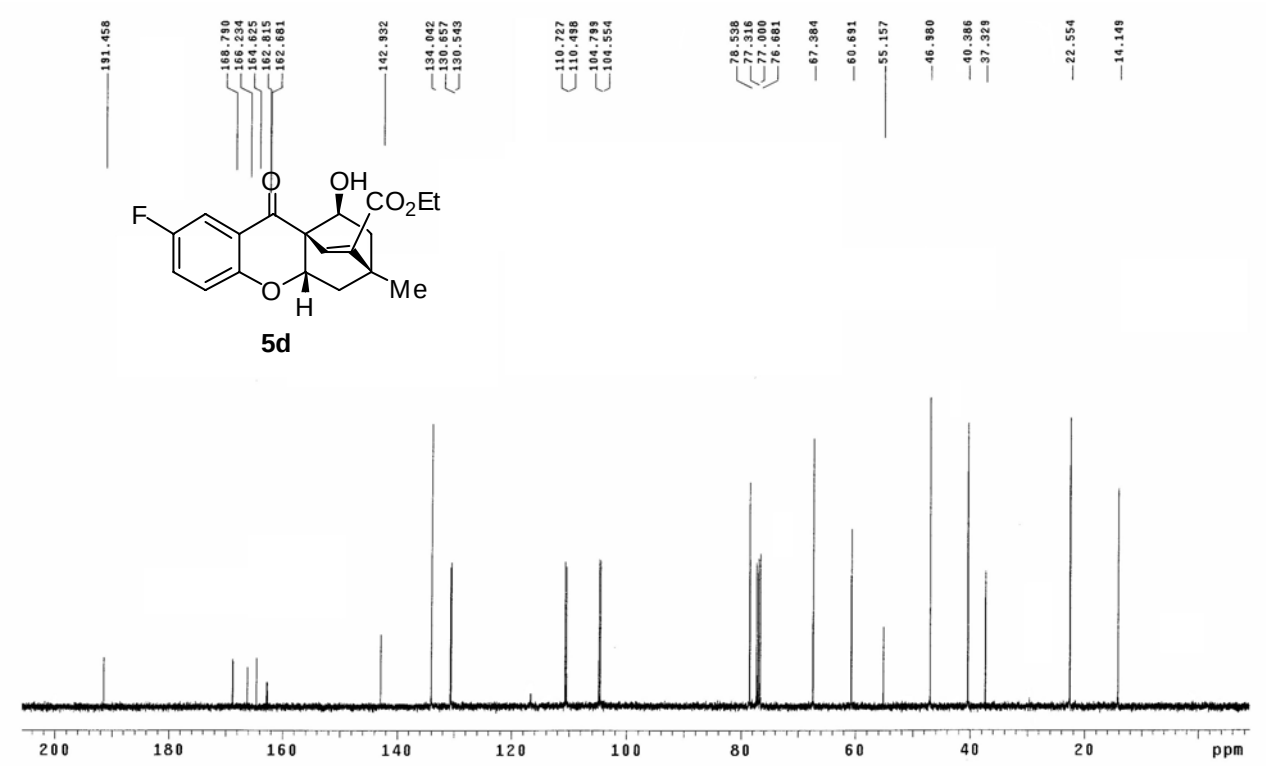


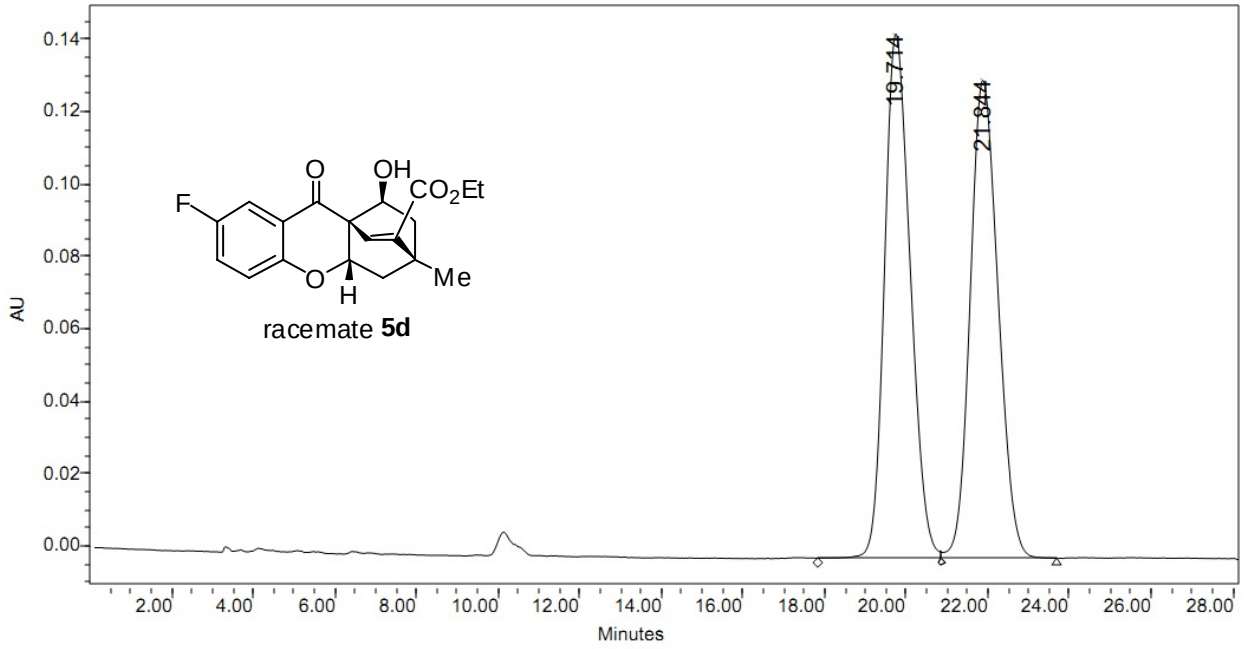
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	18.185	5910296	50.40	140643	53.28
2	20.803	5817000	49.60	123333	46.72



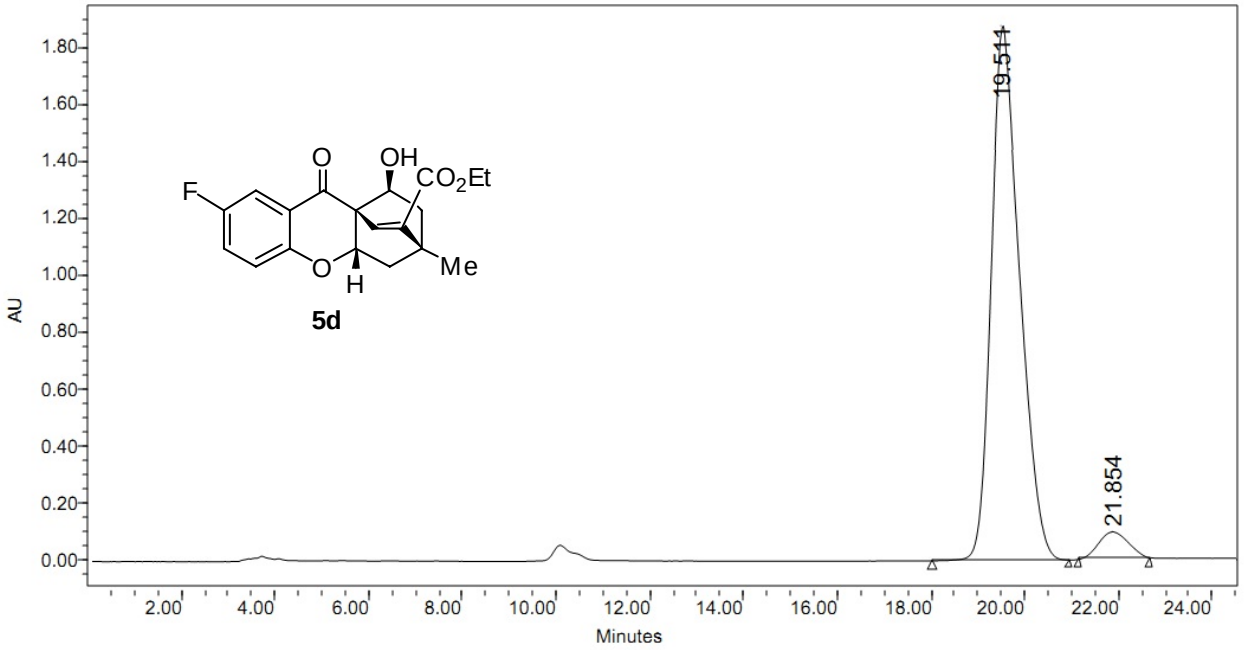
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	18.124	361547	4.87	8472	5.19
2	20.510	7055137	95.13	154643	94.81


O
OH
CO2Et
F
O
H
Me
5d
ppm

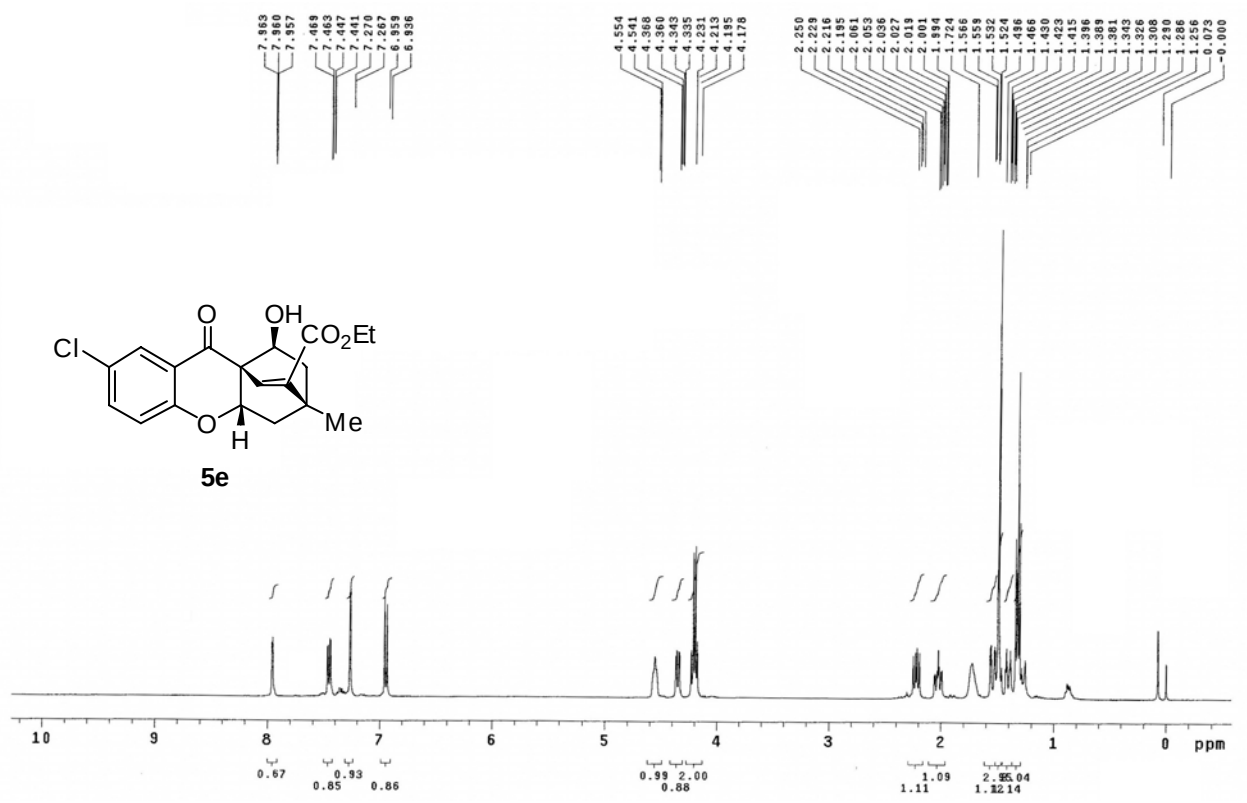

O
OH
CO2Et
F
O
H
Me
5d
ppm

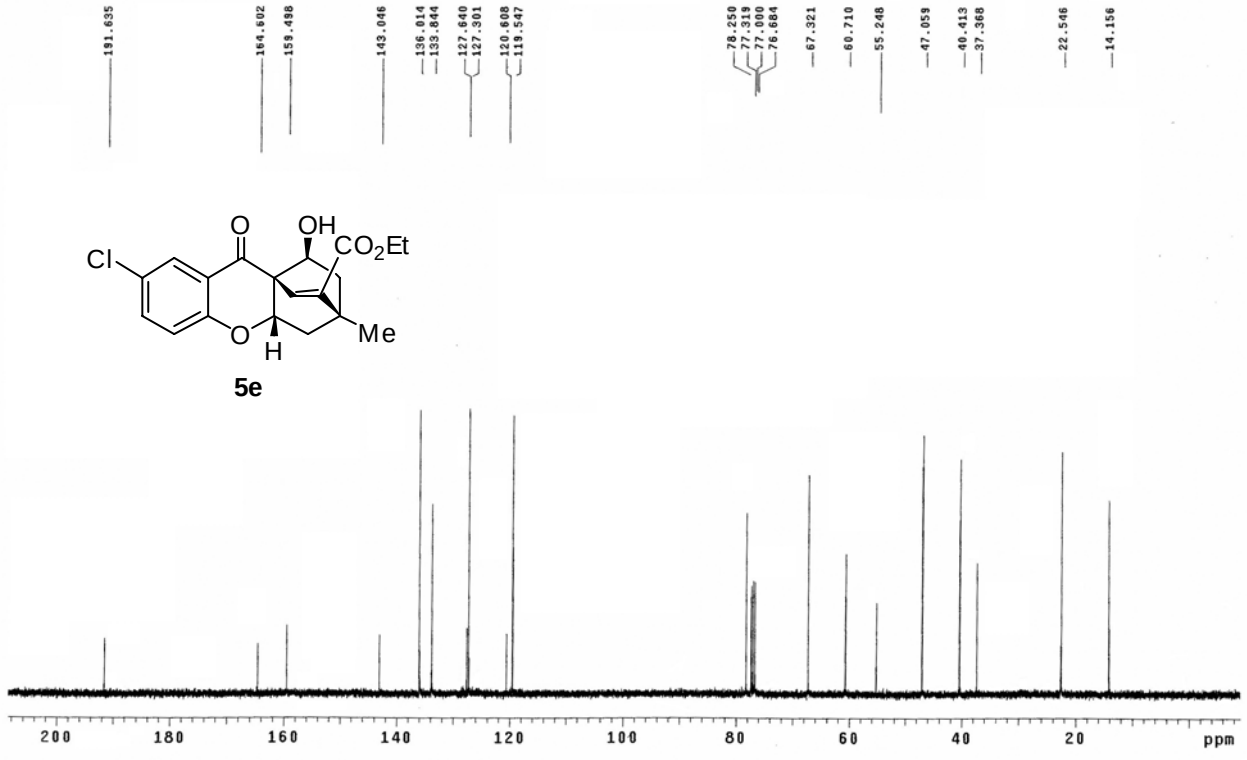


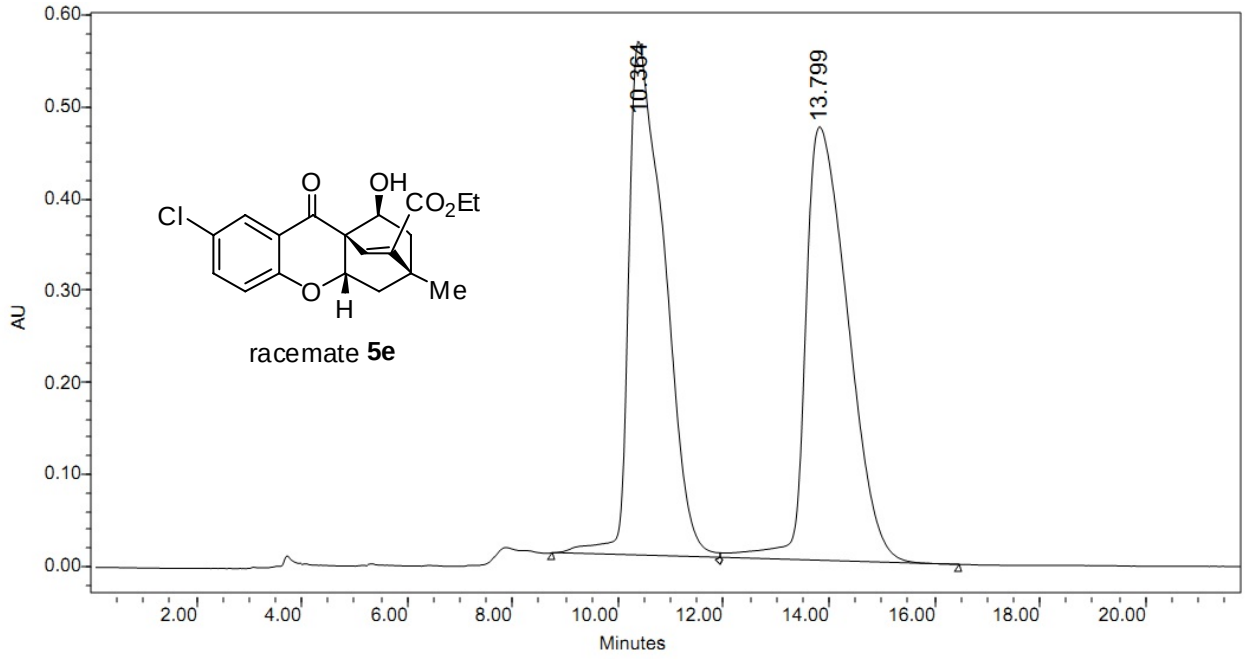
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	19.714	6378760	50.42	144899	52.32
2	21.844	6273243	49.58	132074	47.68



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	19.511	78178645	94.86	1849999	95.13
2	21.854	4235895	5.14	94739	4.87

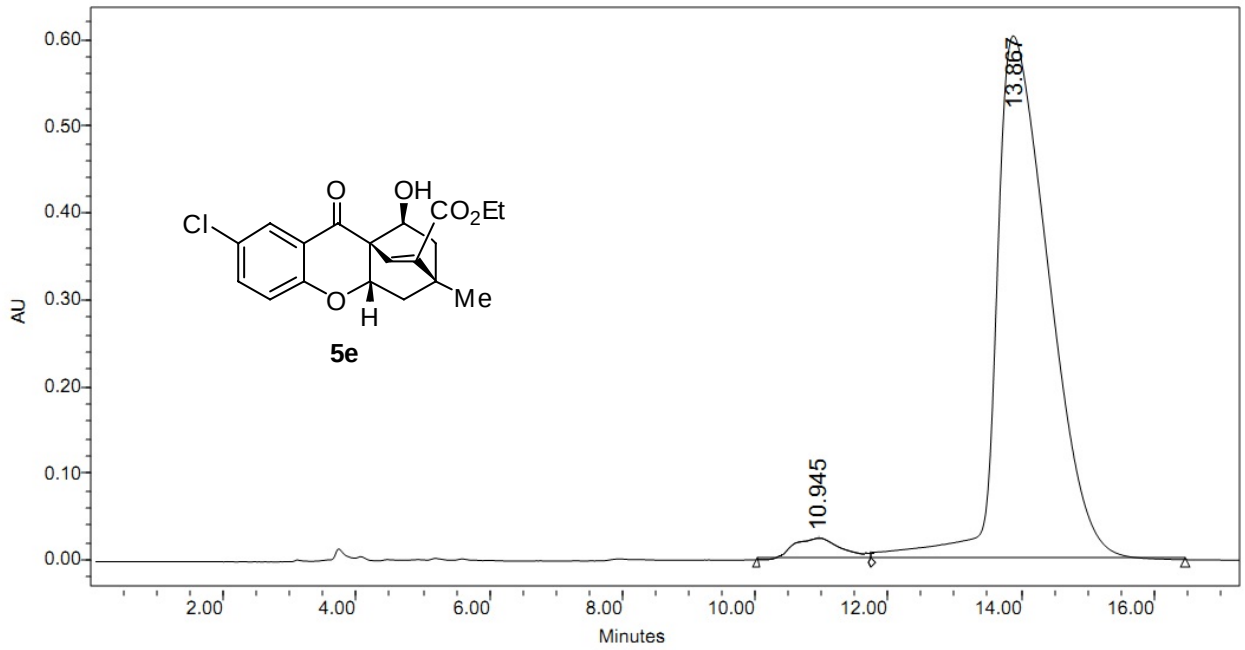

O
OH
CO2Et
Cl
O
Me
H
5e
ppm


O
OH
CO2Et
Cl
O
Me
H
5e
ppm



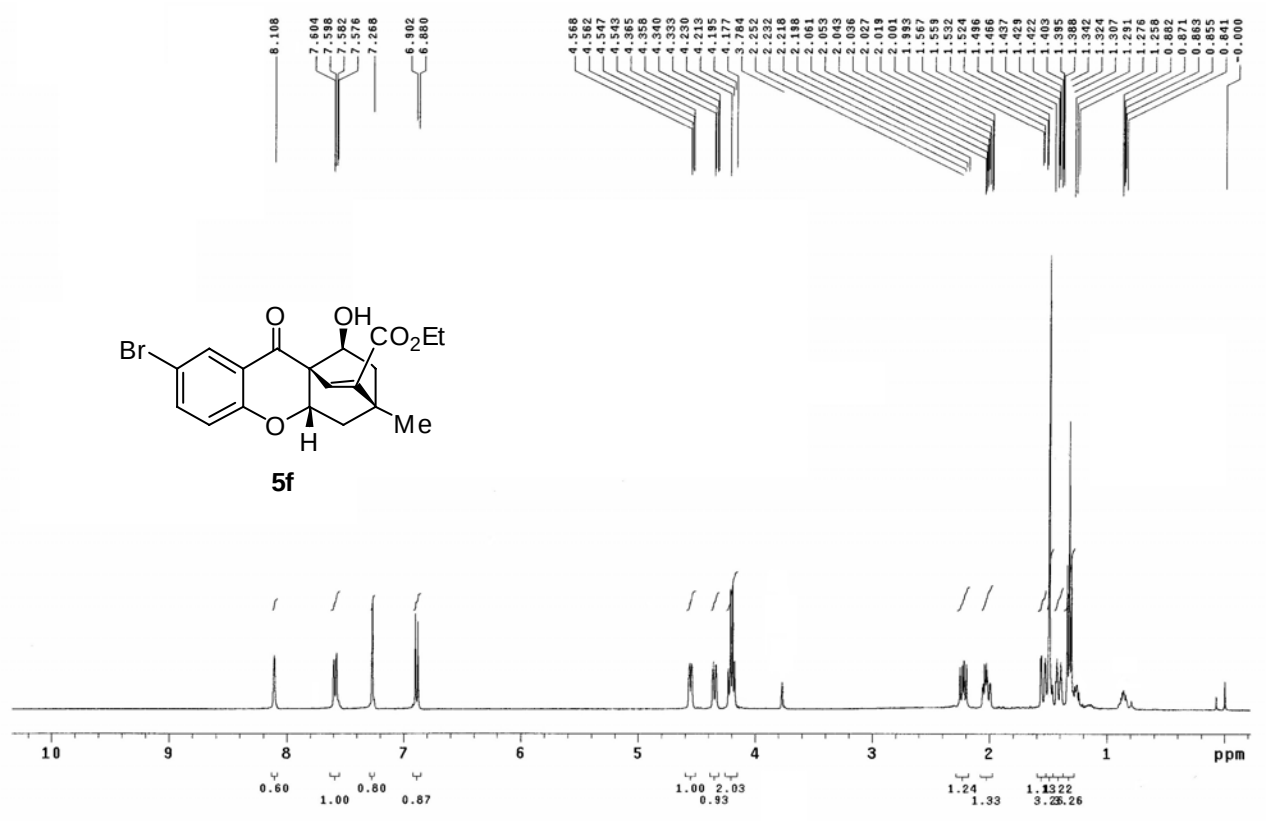
racemate **5e**

	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.364	26294352	49.82	559959	54.25
2	13.799	26481616	50.18	472238	45.75



5e

	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.945	1056927	3.13	22274	3.57
2	13.867	32676768	96.87	600812	96.43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4.543
4.365
4.358
4.340
4.333
4.230
4.213
4.195
4.177
3.784
2.252
2.232
2.218
2.188
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2.053
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CO2Et
Br
O
H
Me
10
9
8
7
6
5
4
3
2
1
ppm
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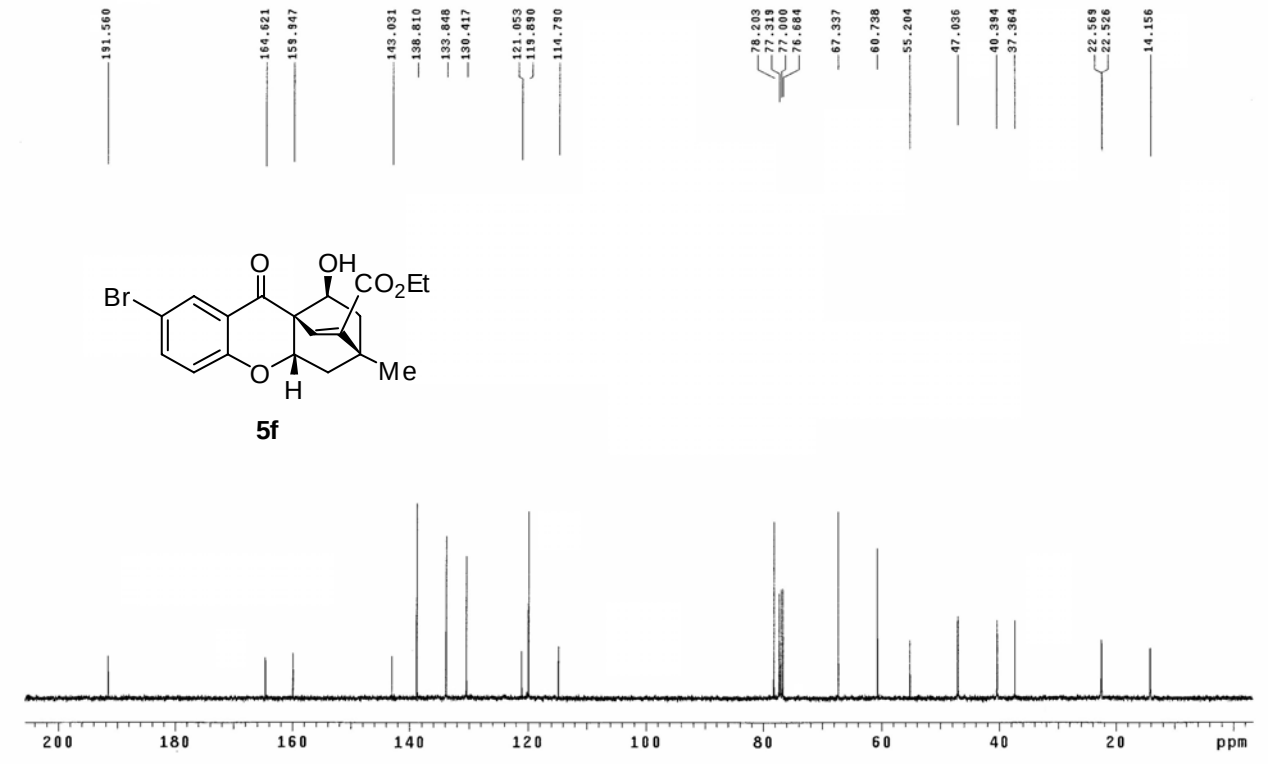
1.13
3.22
3.26

5f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40.394
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22.526
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Br
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H
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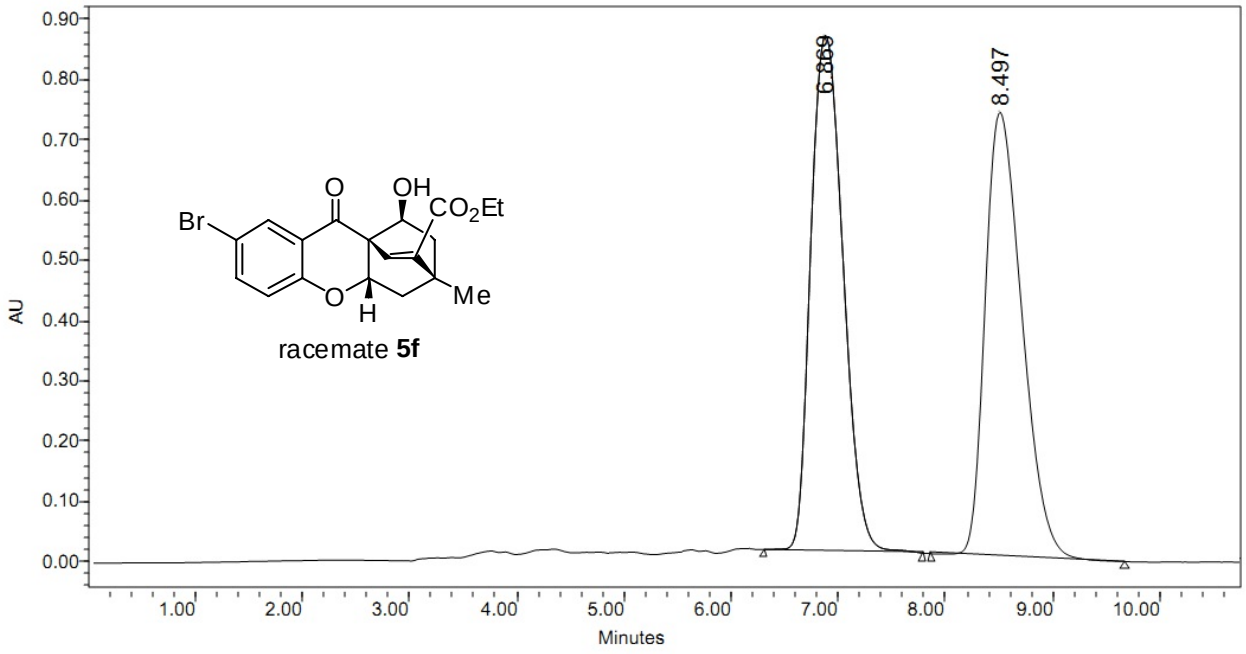
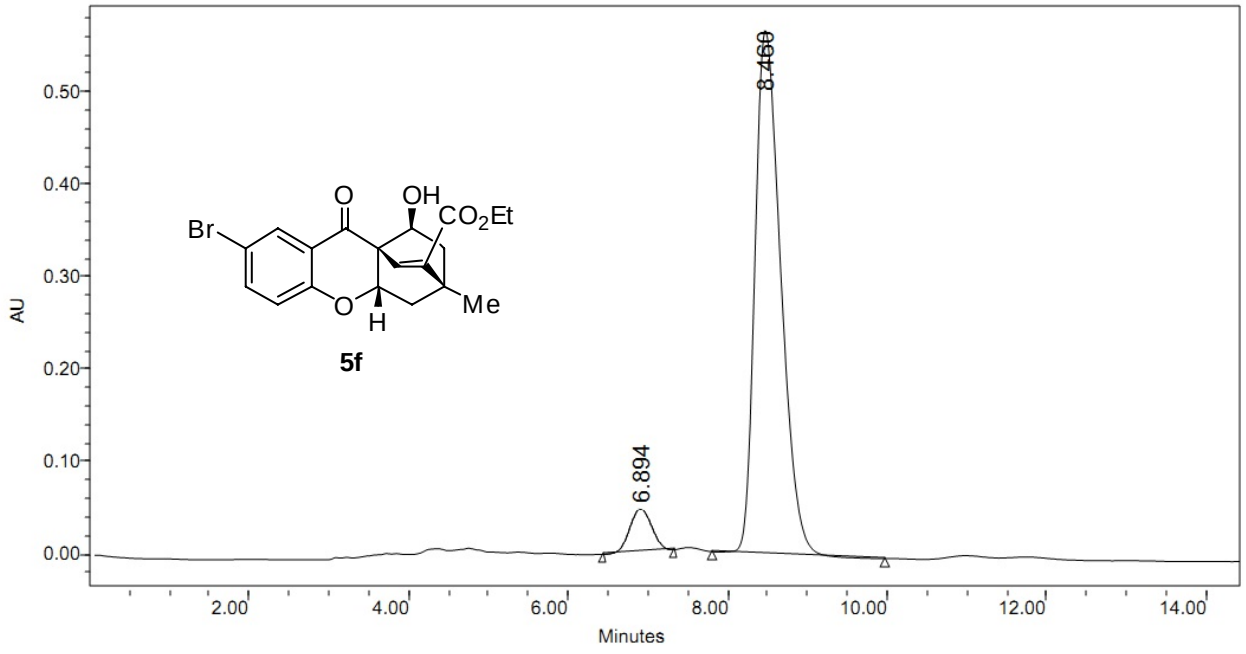
60
40
20
ppm

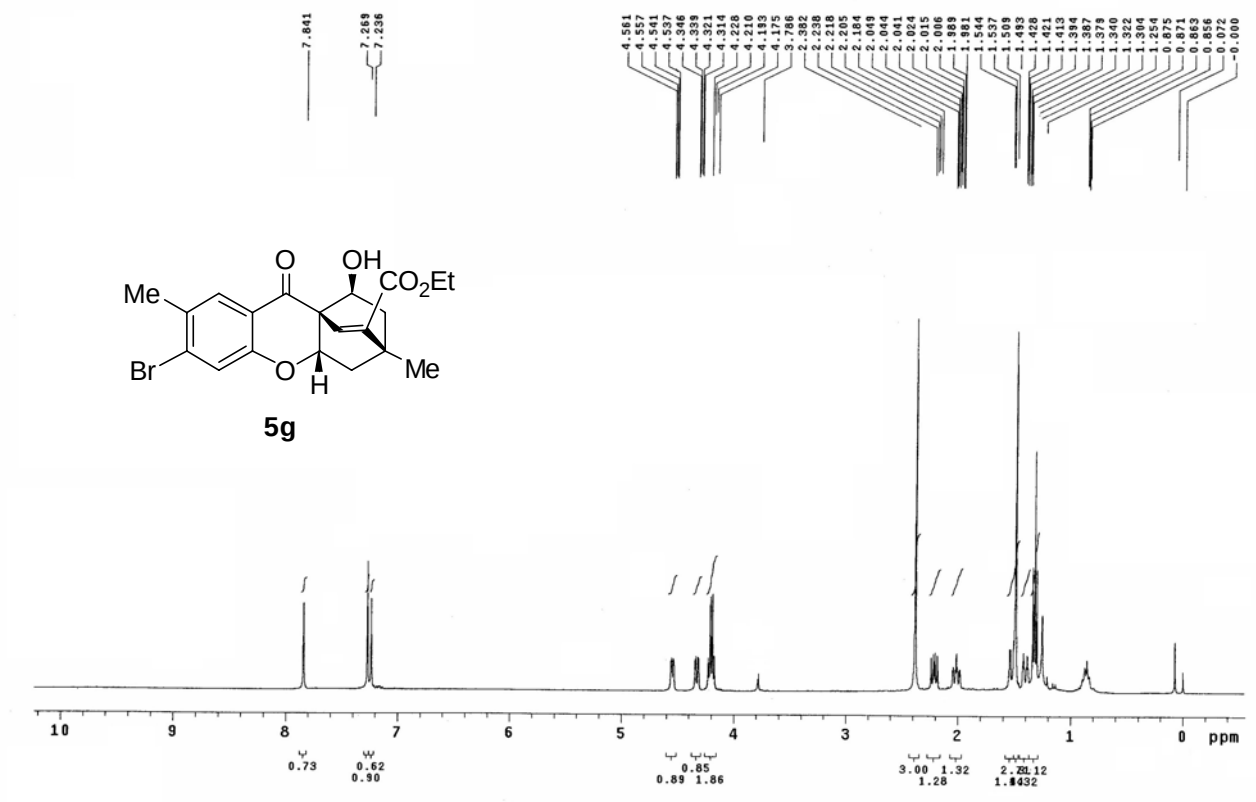
5f



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	6.869	17937344	50.52	855964	53.72
2	8.497	17564891	49.48	737408	46.28



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	6.894	1083807	6.29	62446	7.92
2	8.460	16156725	93.71	725796	92.08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2.044
2.041
2.024
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1.304
1.254
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0.871
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0.856
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OH
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Me
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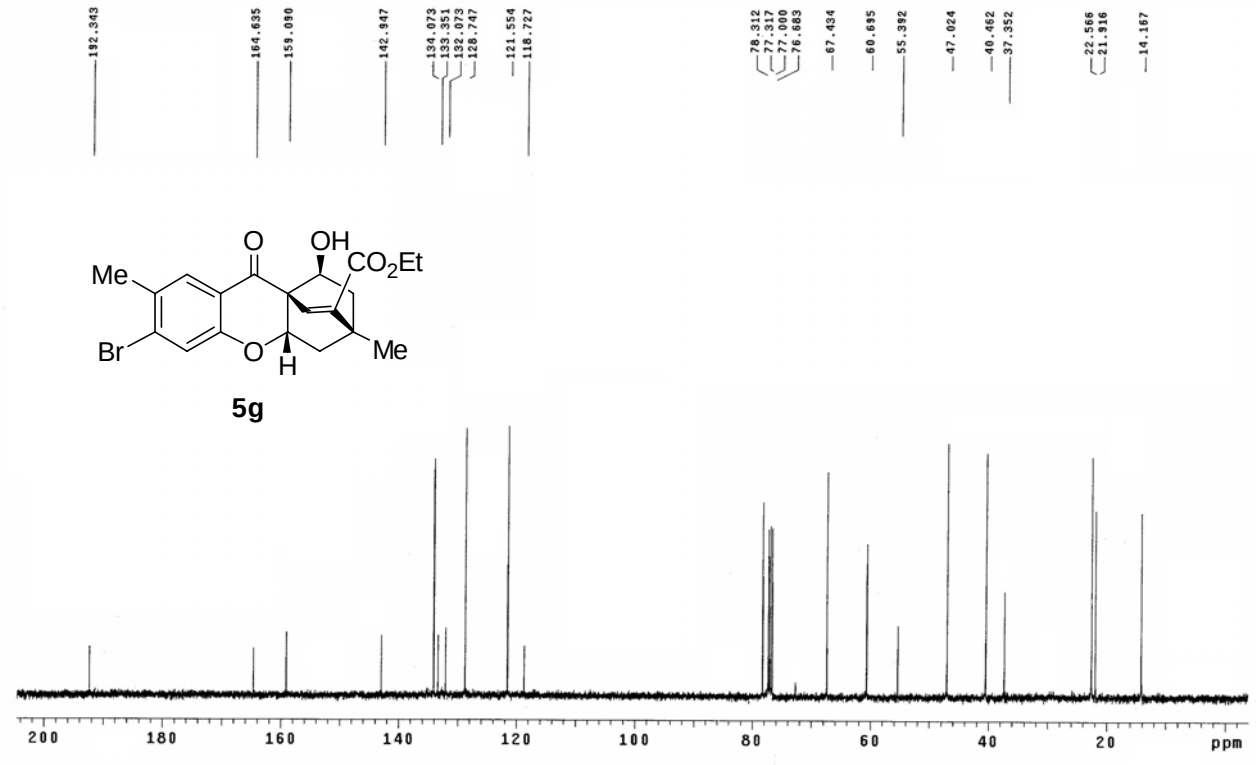
1.28
2.12
1.32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132.073
128.747
121.554
118.727
78.312
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67.434
60.695
55.392
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40.462
37.352
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14.167
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5g
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140
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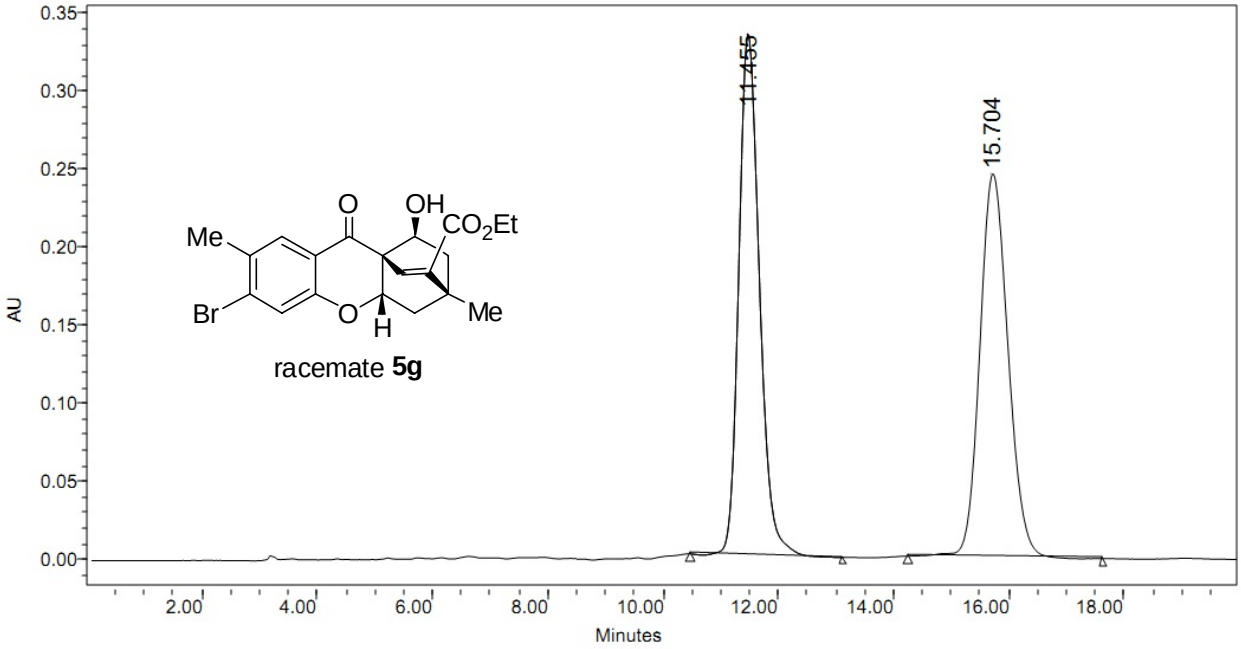
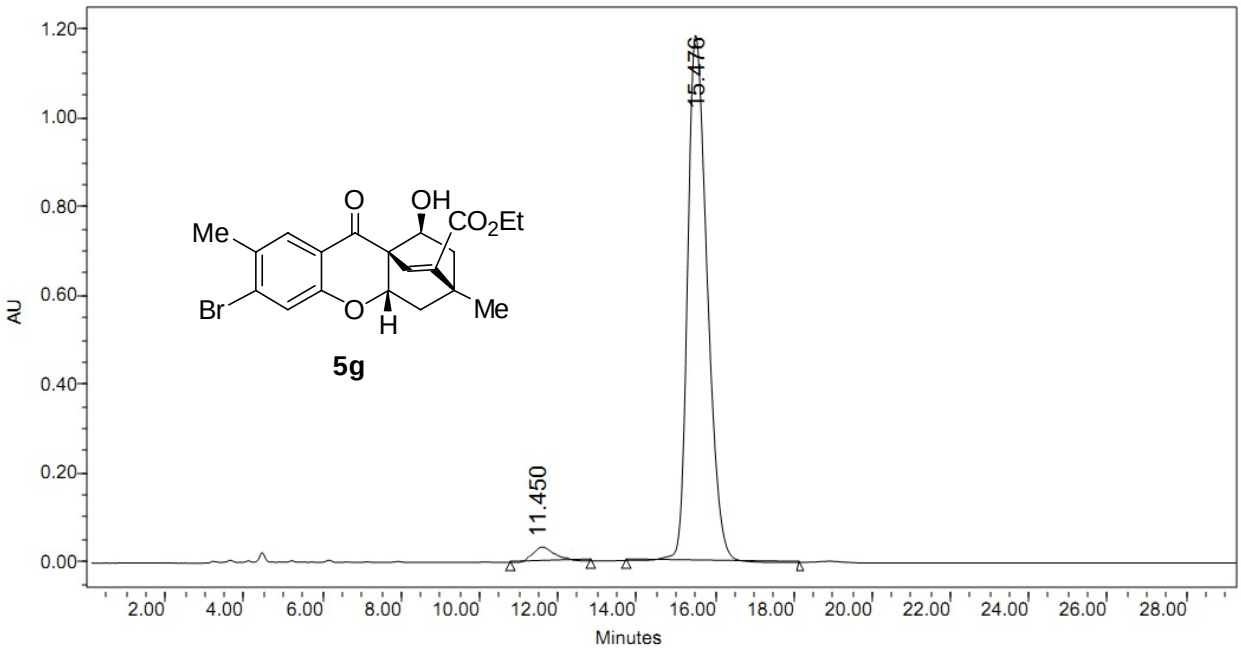
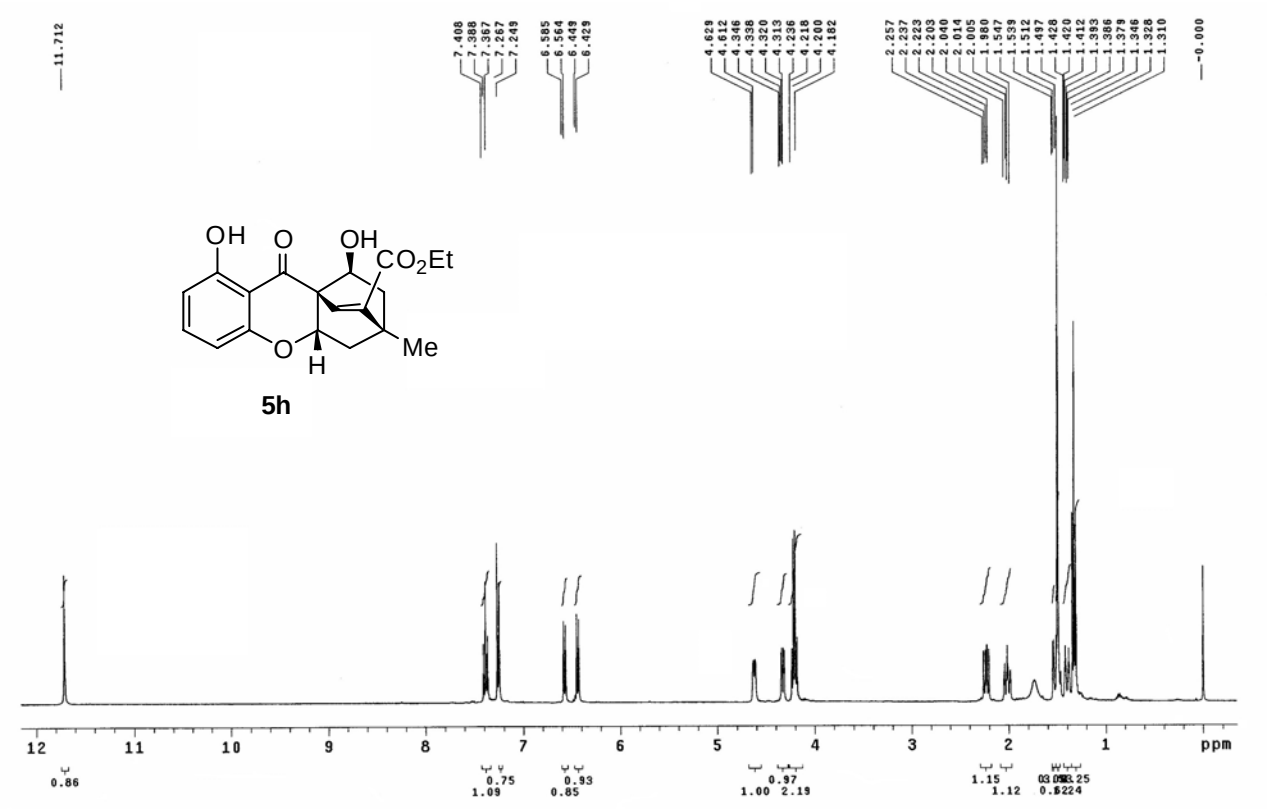
ppm



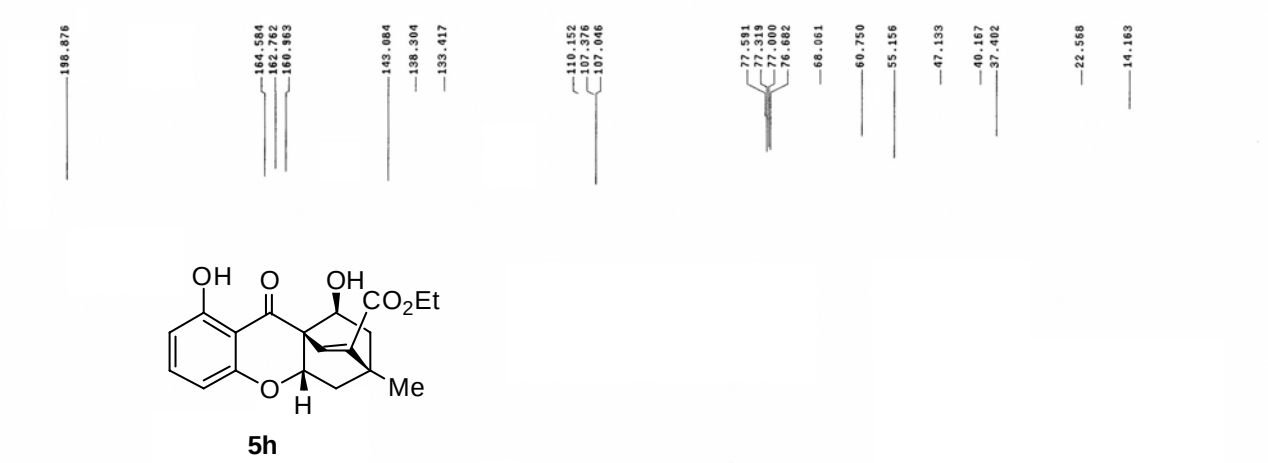
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	11.455	8342325	49.88	334375	57.63
2	15.704	8383719	50.12	245813	42.37

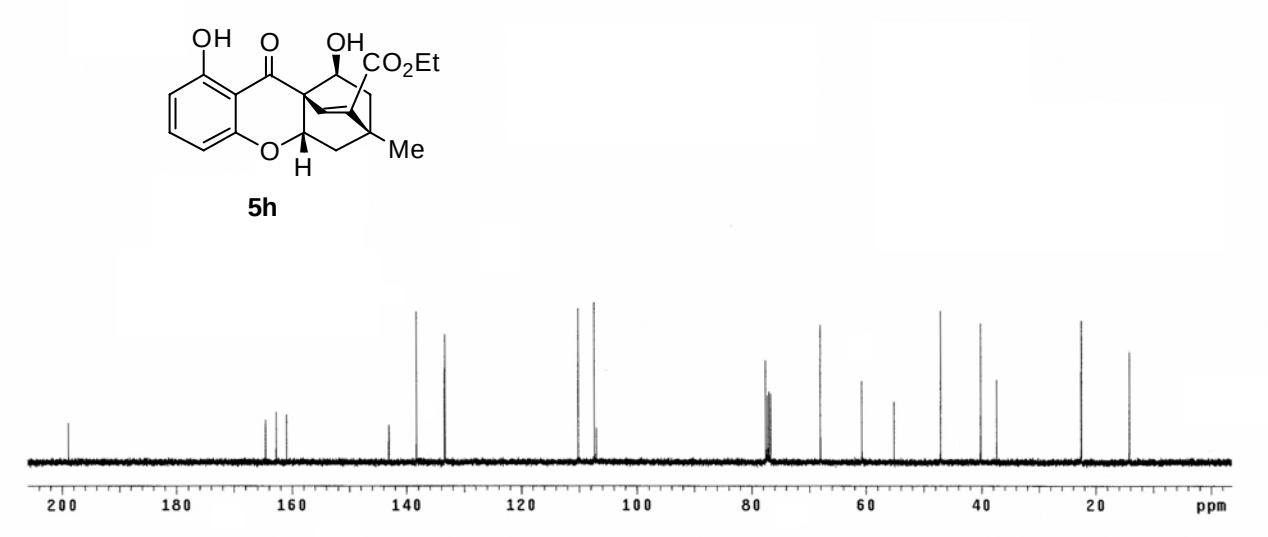


	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	11.450	1301352	3.06	42162	3.44
2	15.476	41228607	96.94	1184157	96.56

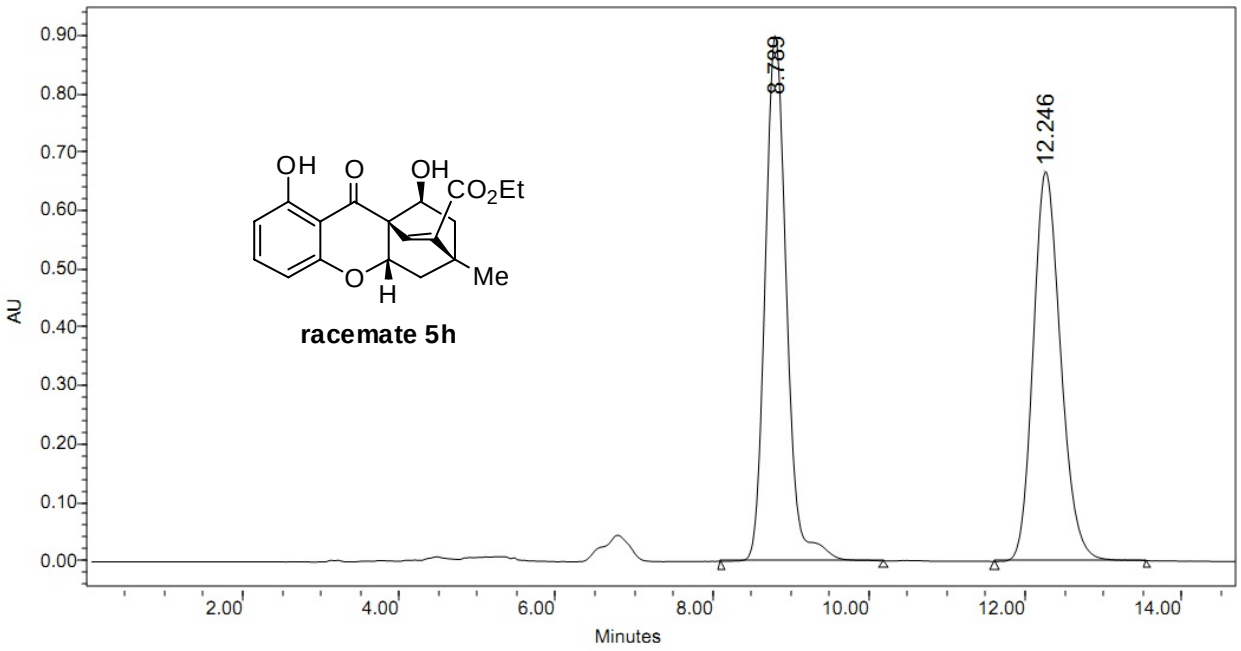


5h

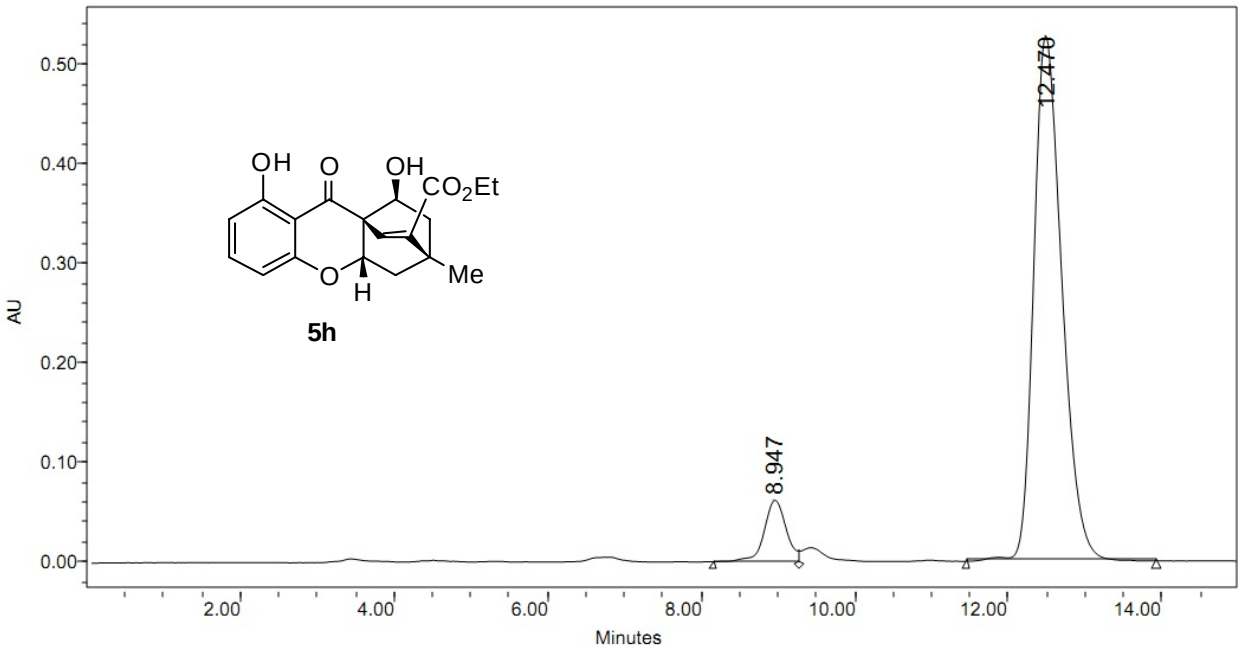




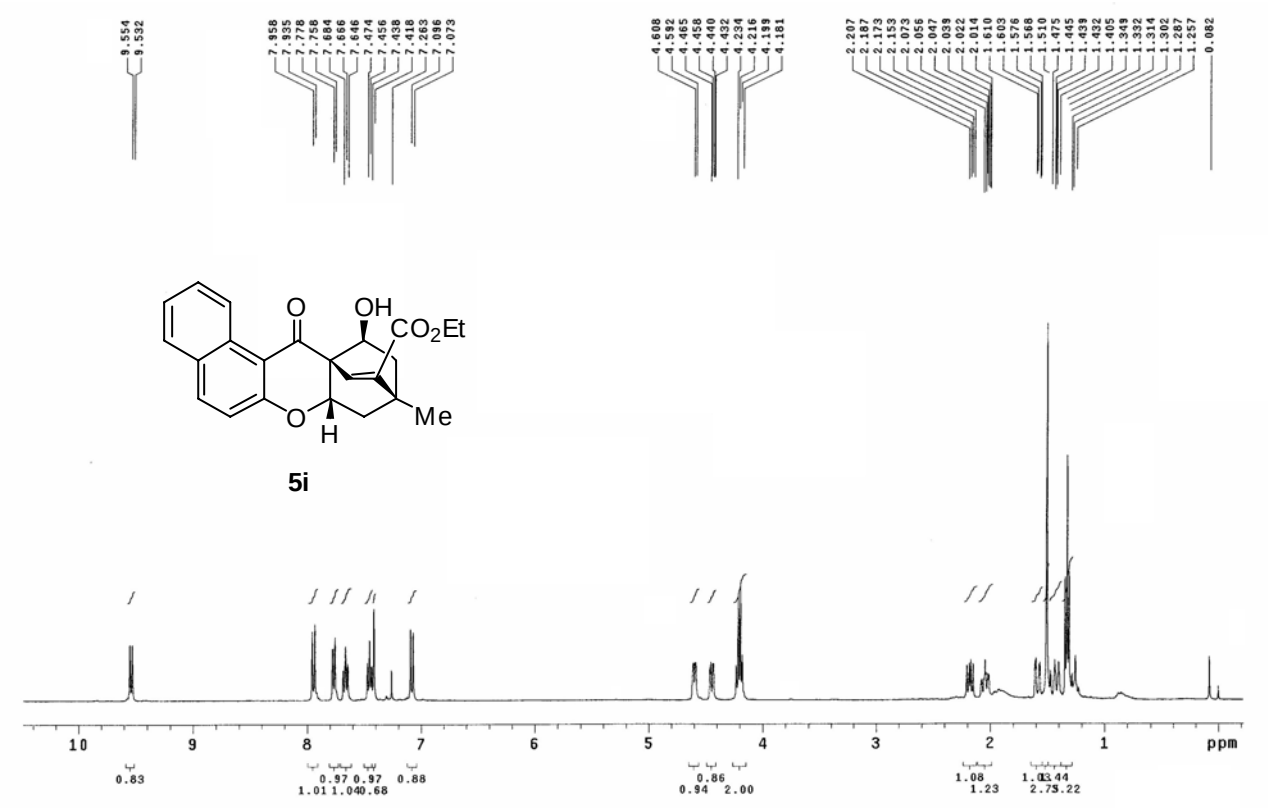
5h



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	8.789	17087567	51.13	900985	57.42
2	12.246	16334802	48.87	668075	42.58



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	8.947	731953	8.91	36828	10.79
2	12.470	7484906	91.09	304634	89.21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7.418
7.263
7.096
7.073
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4.582
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4.458
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4.216
4.199
4.181
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2.073
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2.047
2.039
2.022
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1.578
1.568
1.510
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1.439
1.432
1.405
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1.332
1.314
1.302
1.287
1.257
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O
OH
CO2Et
O
H
Me
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8
7
6
5
4
3
2
1
ppm
0.83
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2.75 5.22

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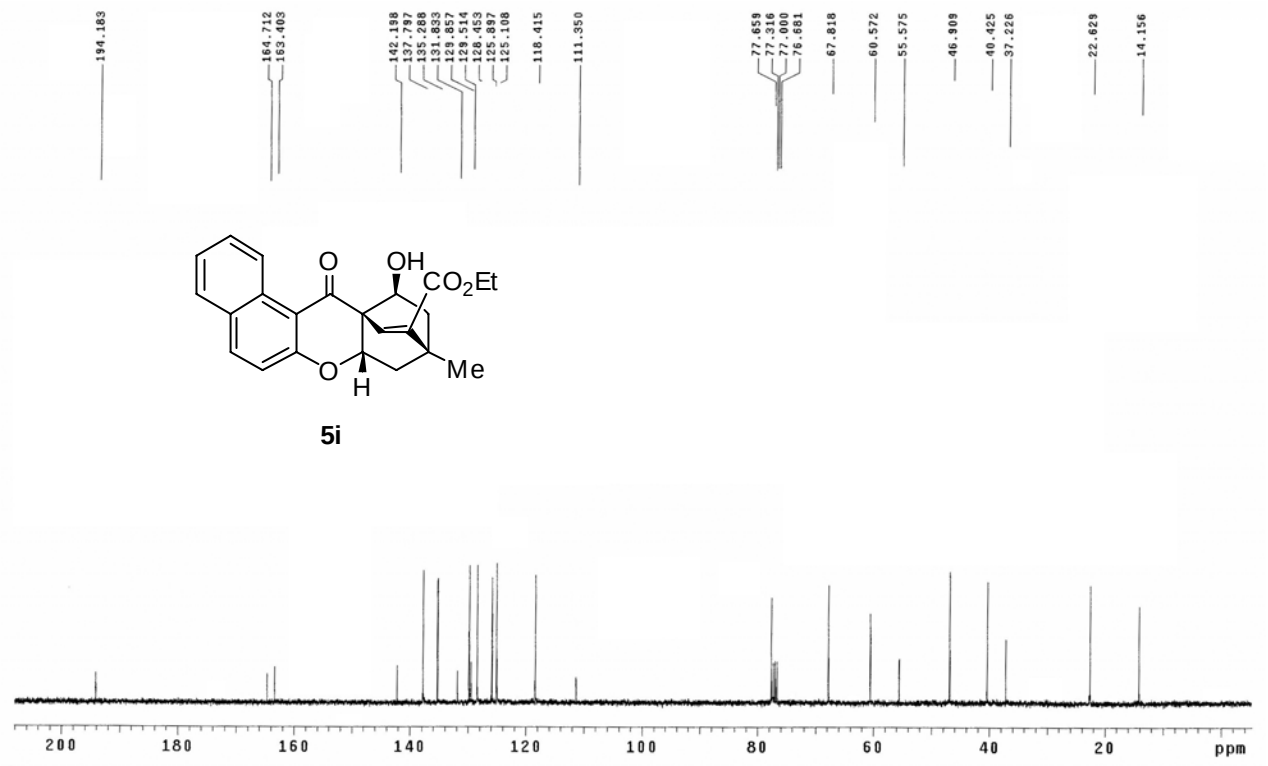
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77.316
77.000
76.681
67.818
60.572
55.575
46.909
40.425
37.226
22.629
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H
Me
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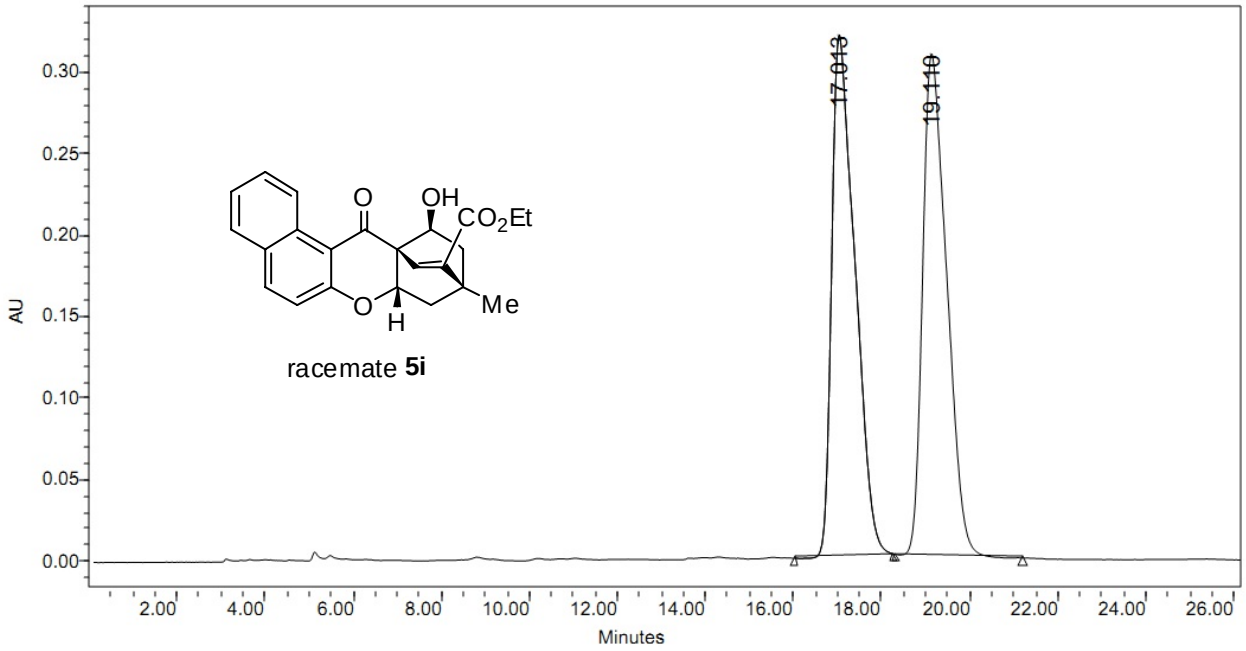
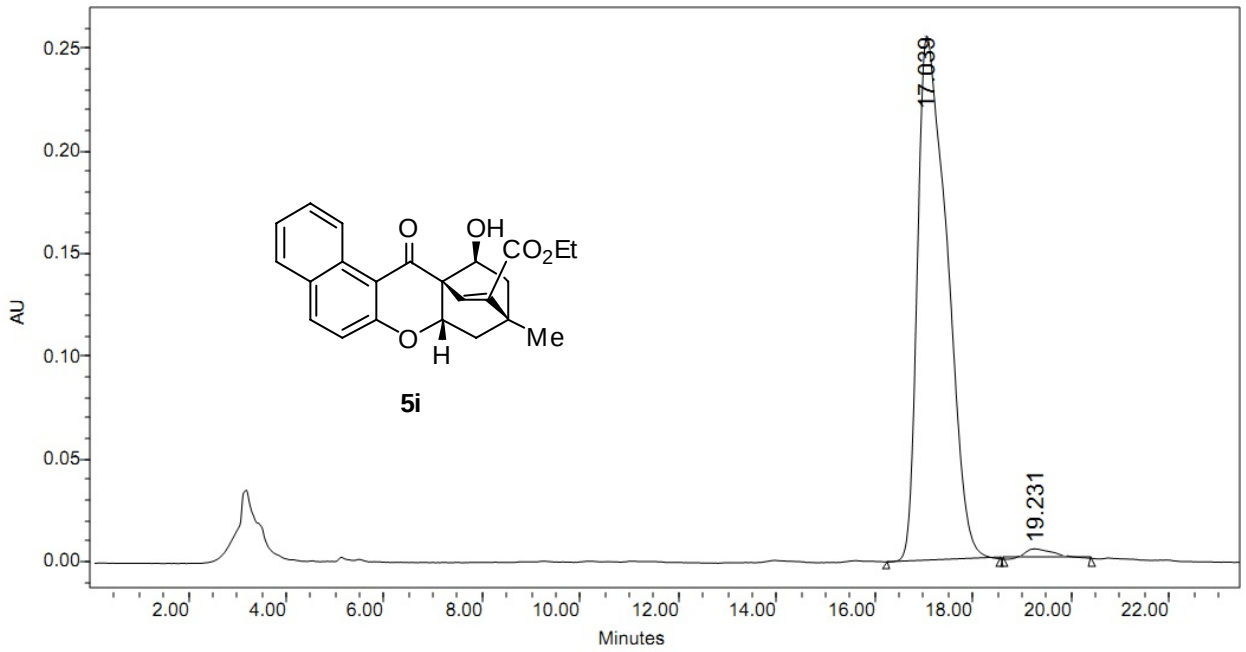
ppm

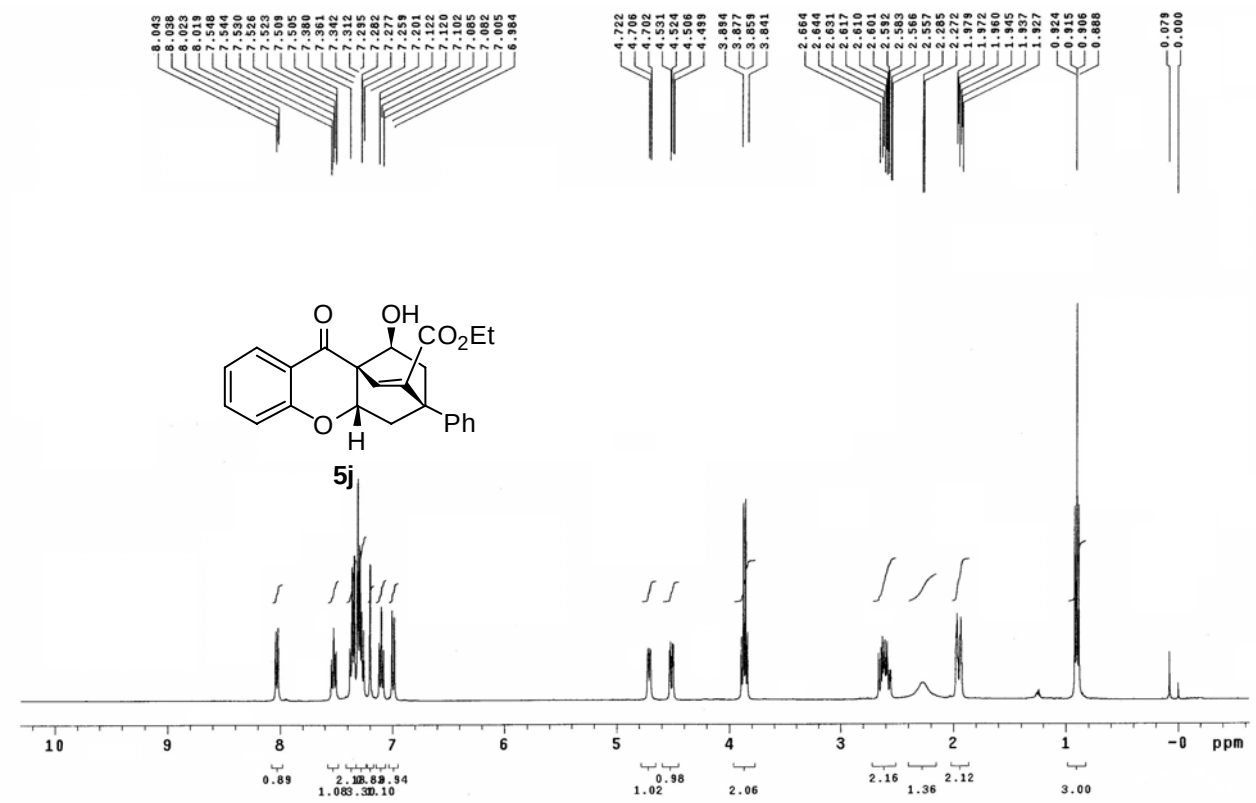
5i



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	17.013	11691818	50.07	320145	50.98
2	19.110	11659669	49.93	307827	49.02



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	17.039	10701269	98.37	255459	98.21
2	19.231	177753	1.63	4653	1.79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O
H
Ph
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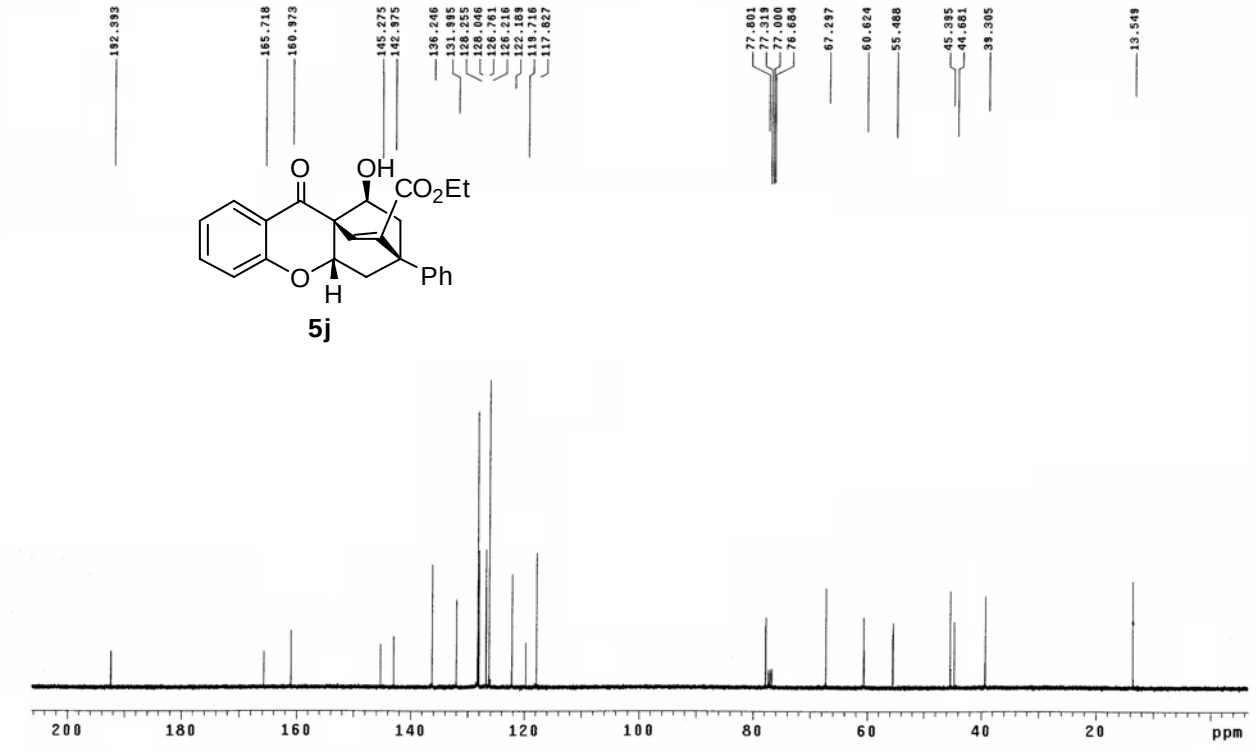
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67.297
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CO2Et
O
H
Ph
5j
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140
120
100
80
60
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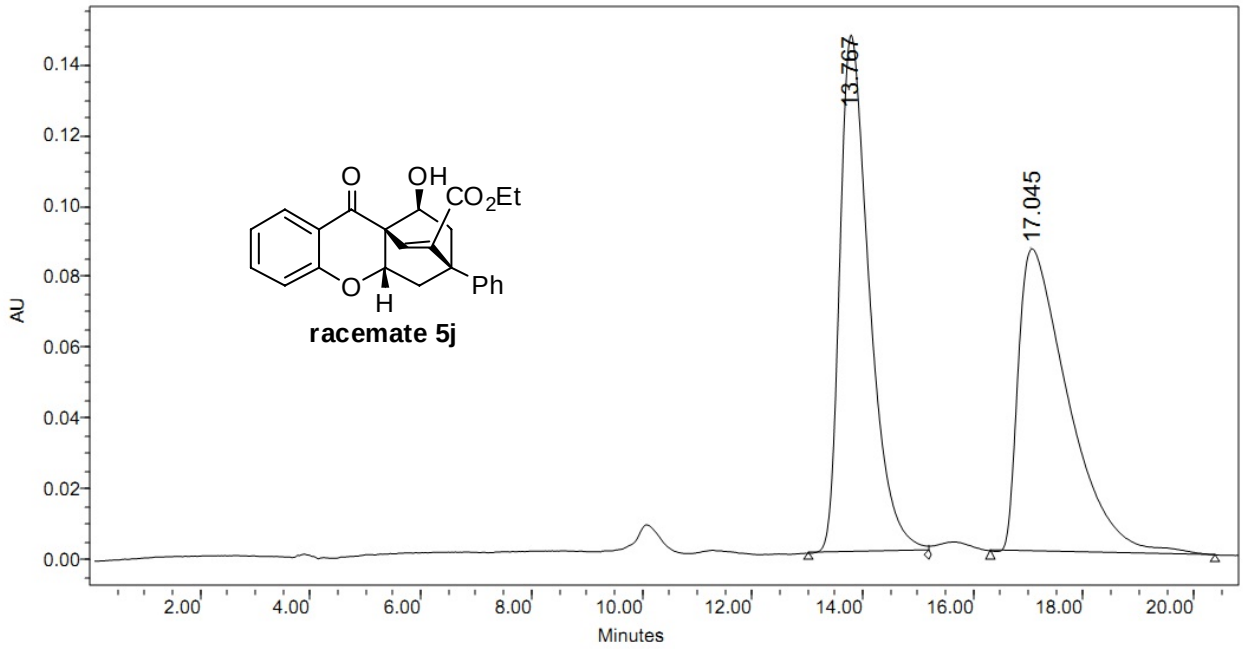
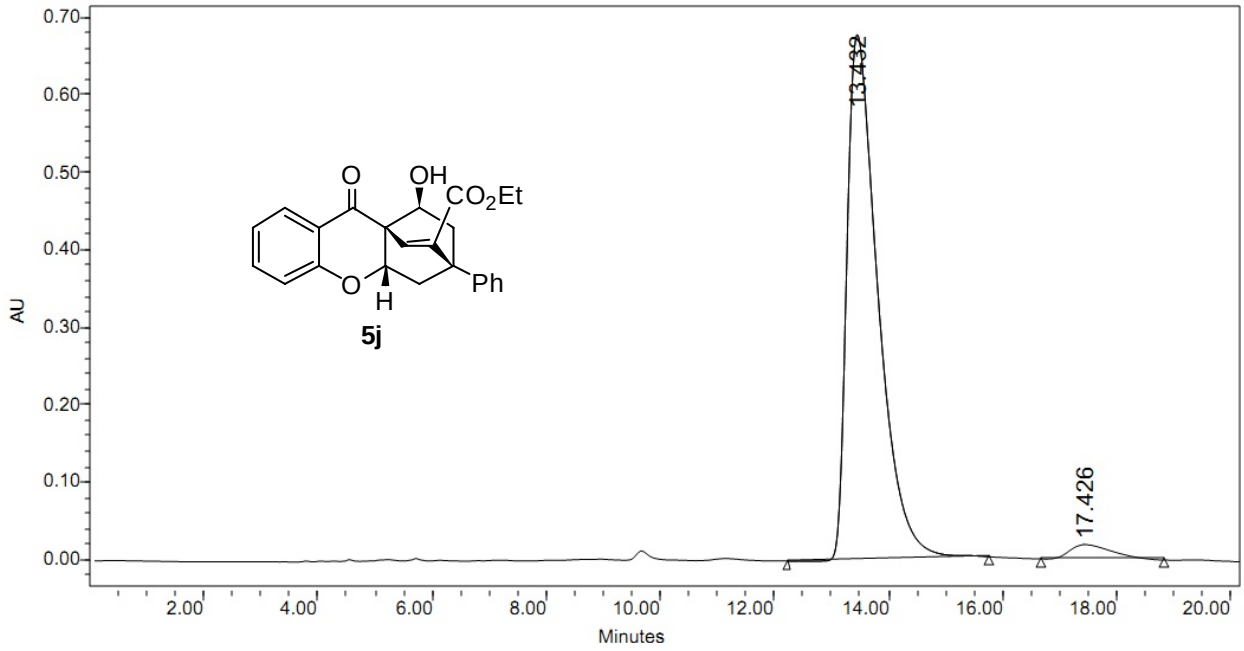
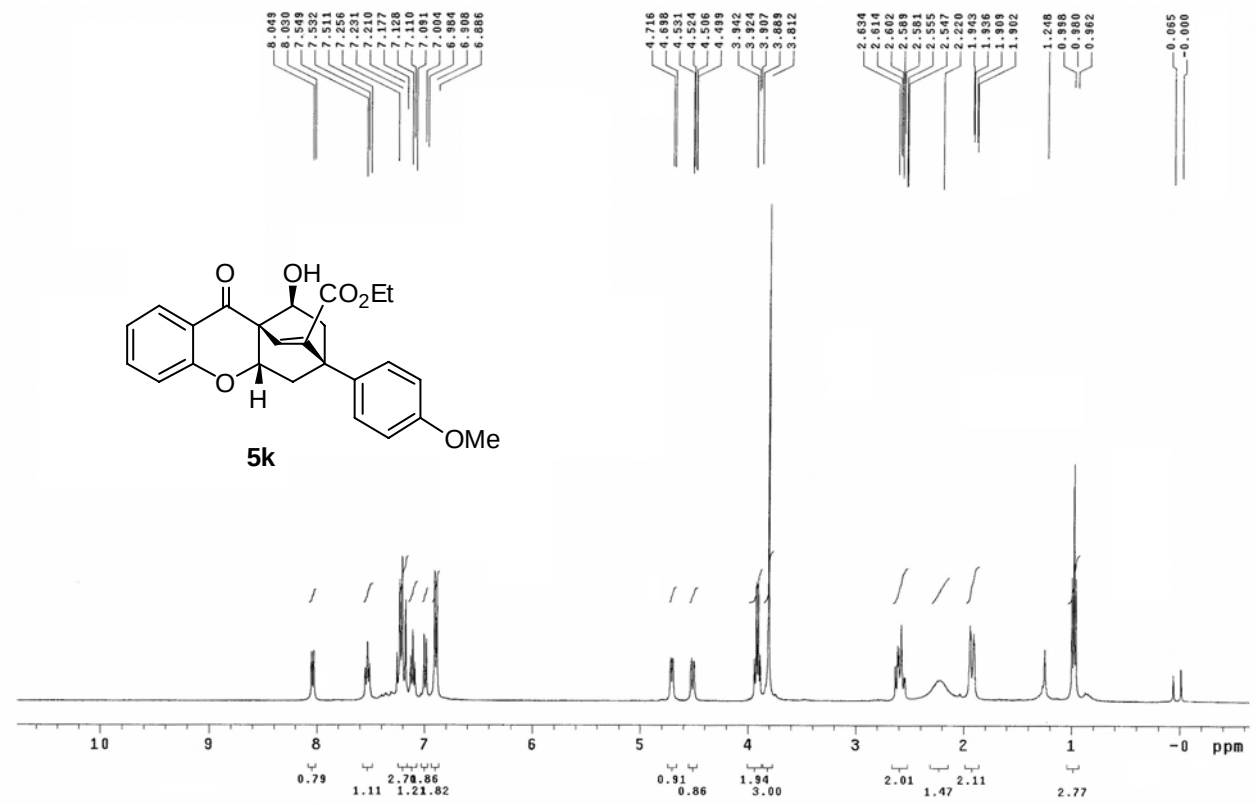
20
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	13.767	5483259	50.42	146371	63.08
2	17.045	5392016	49.58	85674	36.92



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	13.432	25626408	96.92	677665	97.48
2	17.426	814955	3.08	17485	2.52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7.004
6.984
6.908
6.886
4.716
4.698
4.531
4.524
4.506
4.489
3.942
3.924
3.907
3.889
3.812
2.634
2.614
2.602
2.581
2.555
2.547
2.220
1.943
1.936
1.909
1.902
1.248
0.998
0.980
0.962
0.065
-0.000
O
OH
CO2Et
O
H
OMe
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8
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5
4
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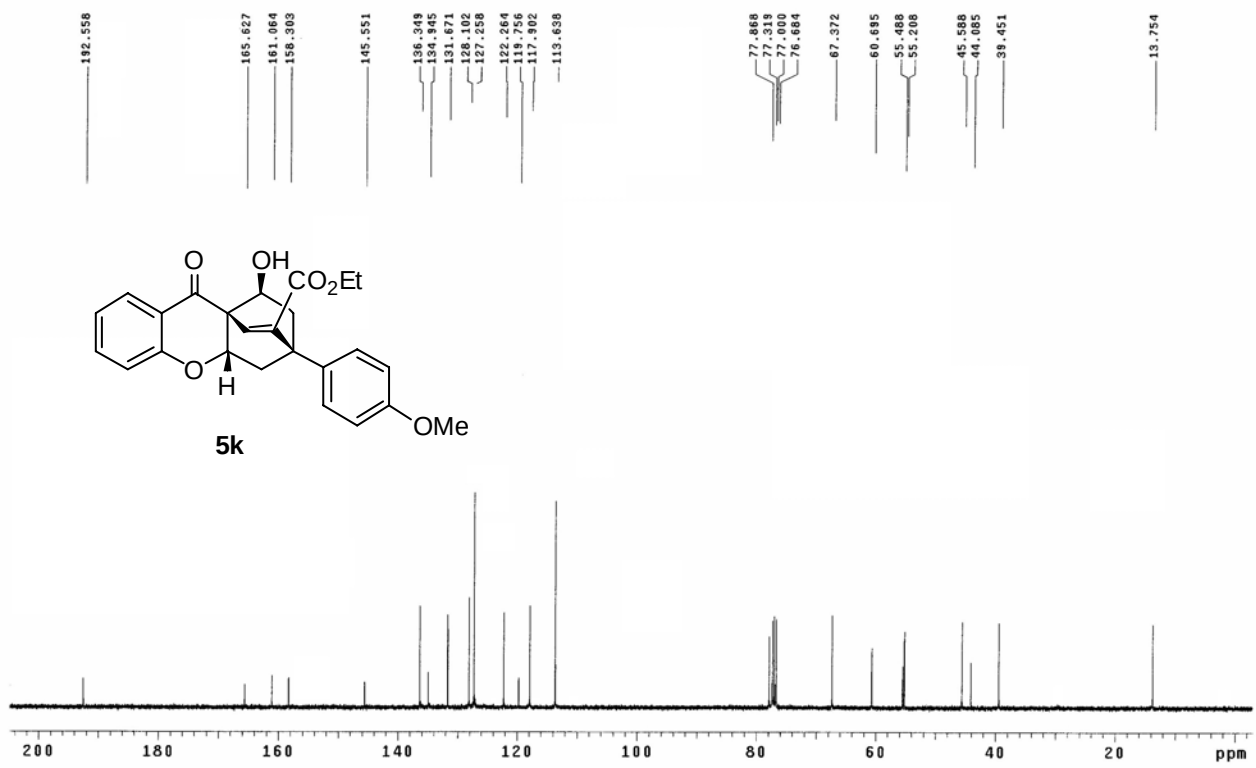
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39.451
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O
H
OMe
5k
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140
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60
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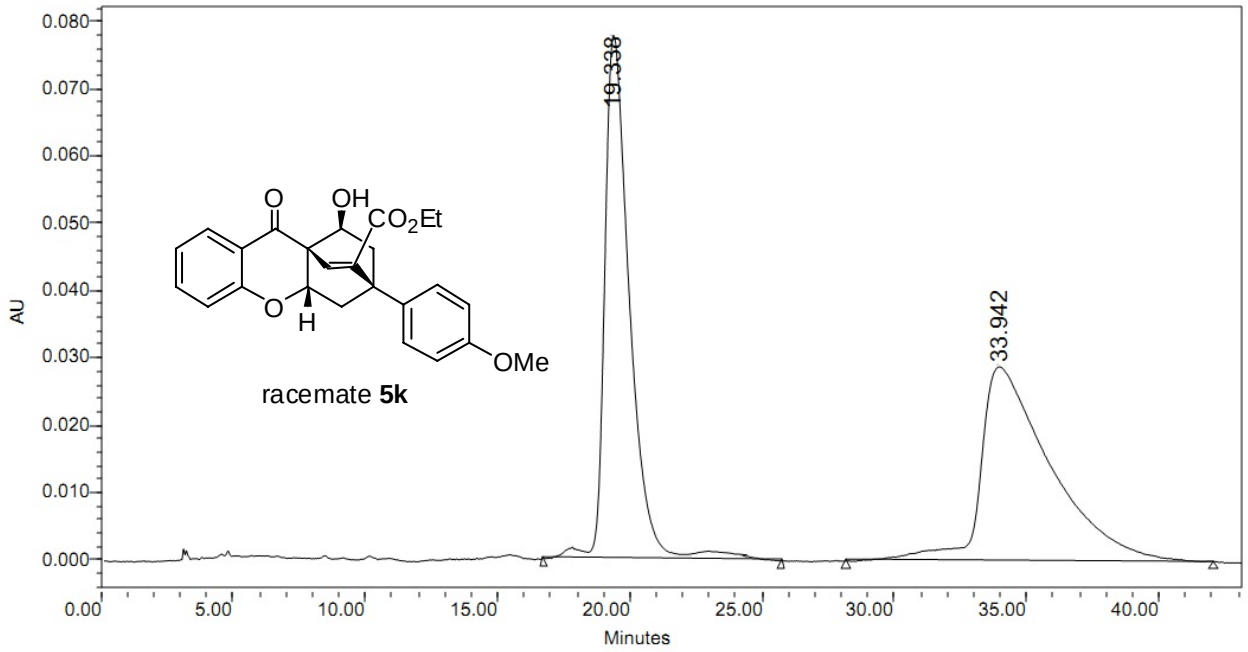
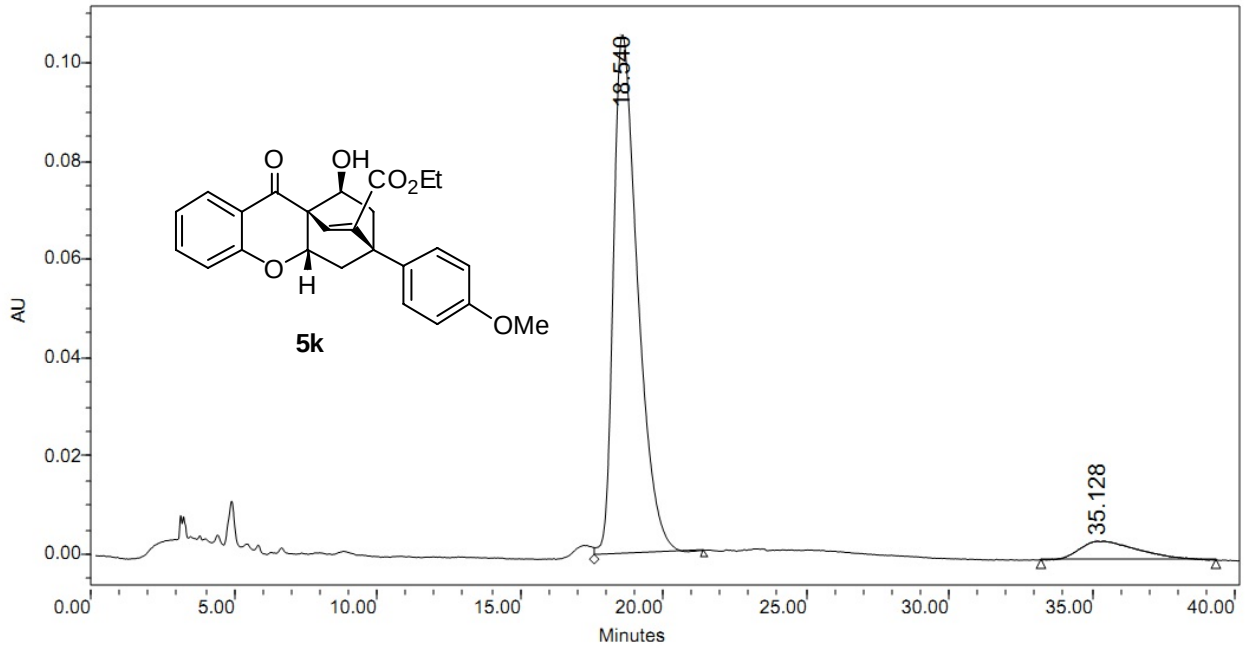
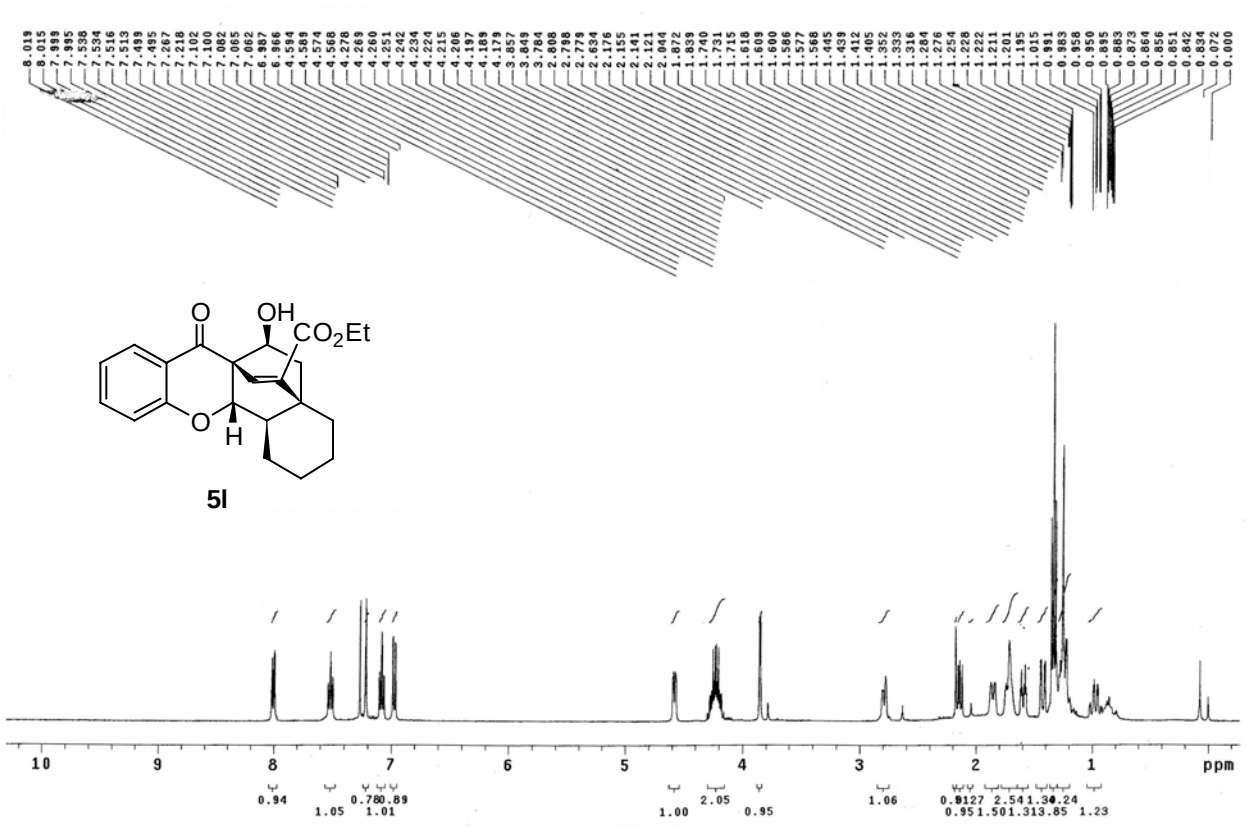
20
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	19.338	5277229	49.77	77938	72.95
2	33.942	5326851	50.23	28899	27.05



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	18.540	6260099	93.12	105845	96.73
2	35.128	462604	6.88	3579	3.27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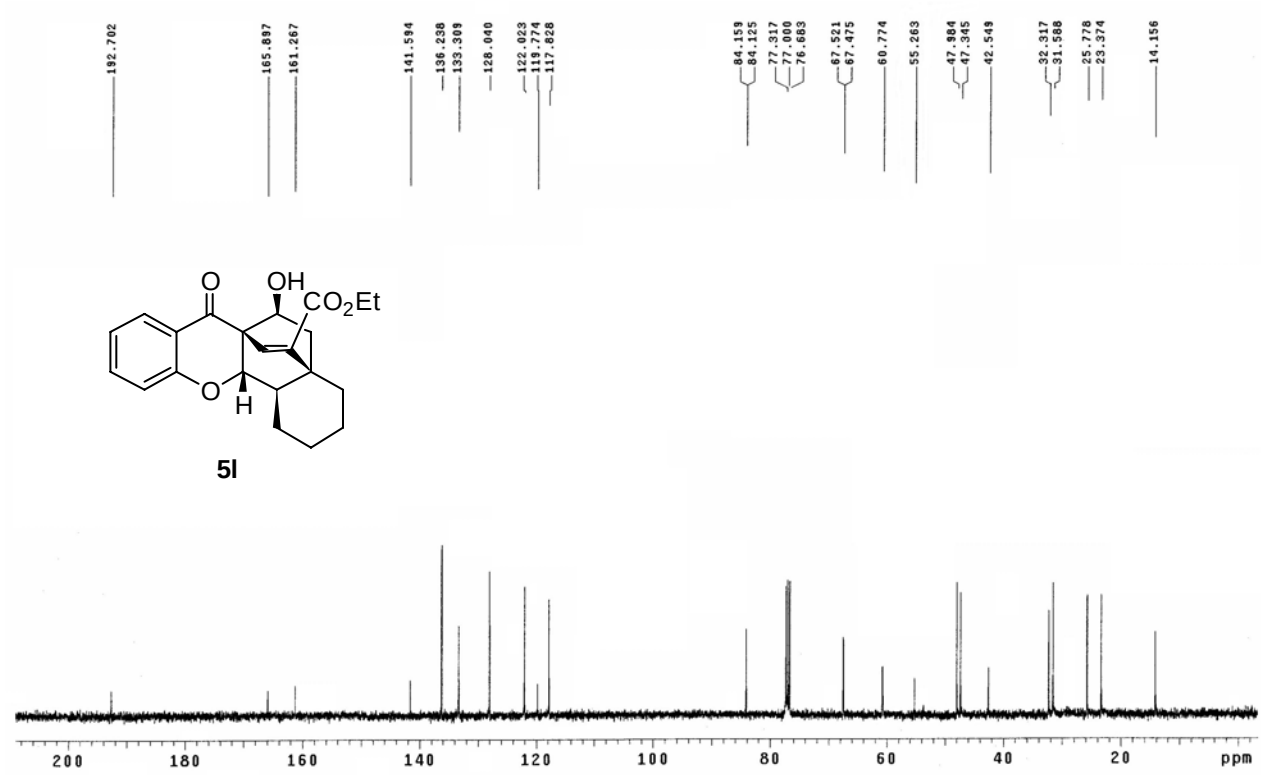
CO2Et
O
H
5l
ppm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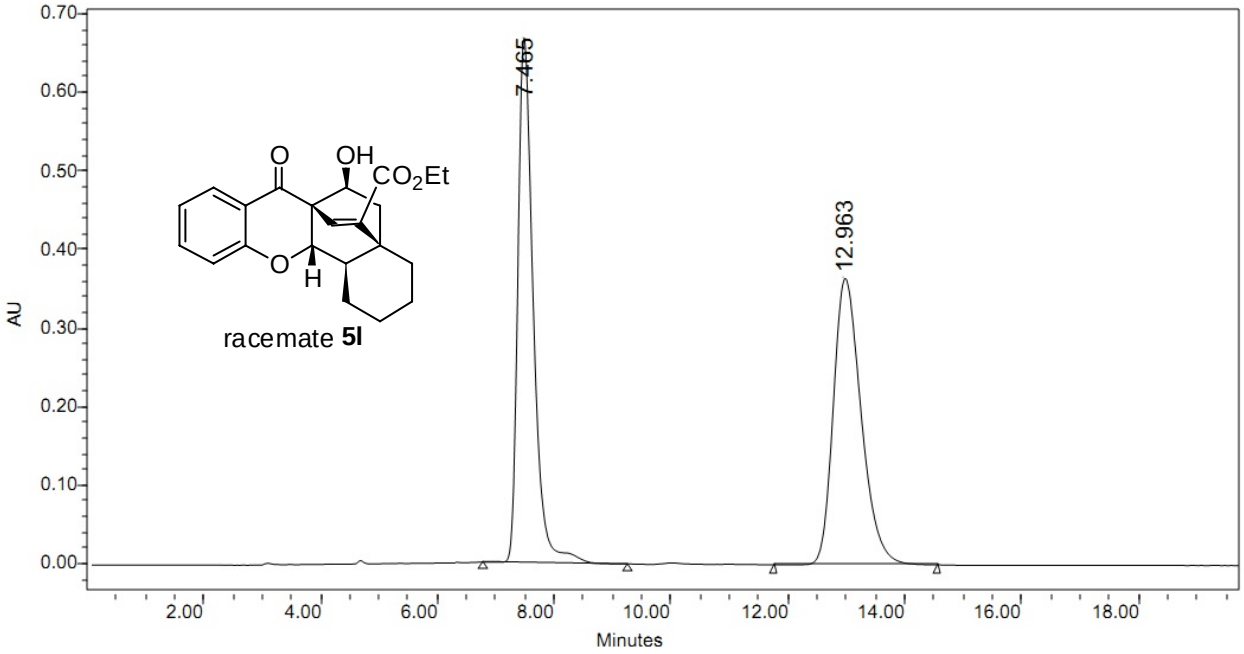
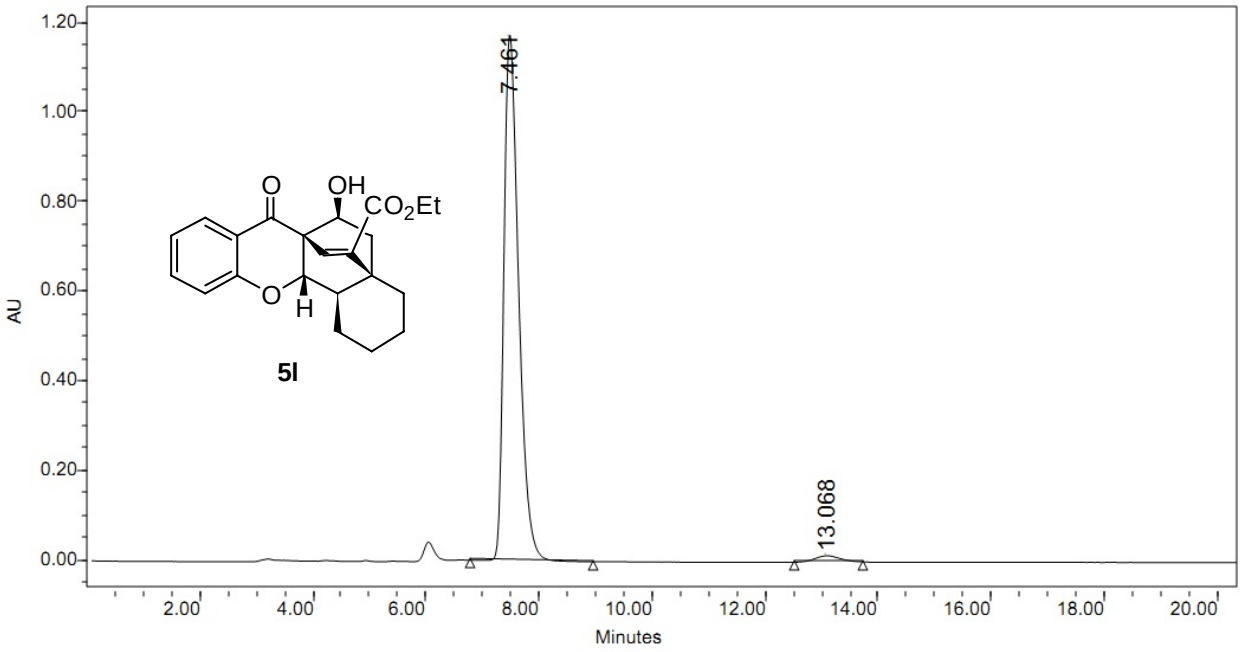
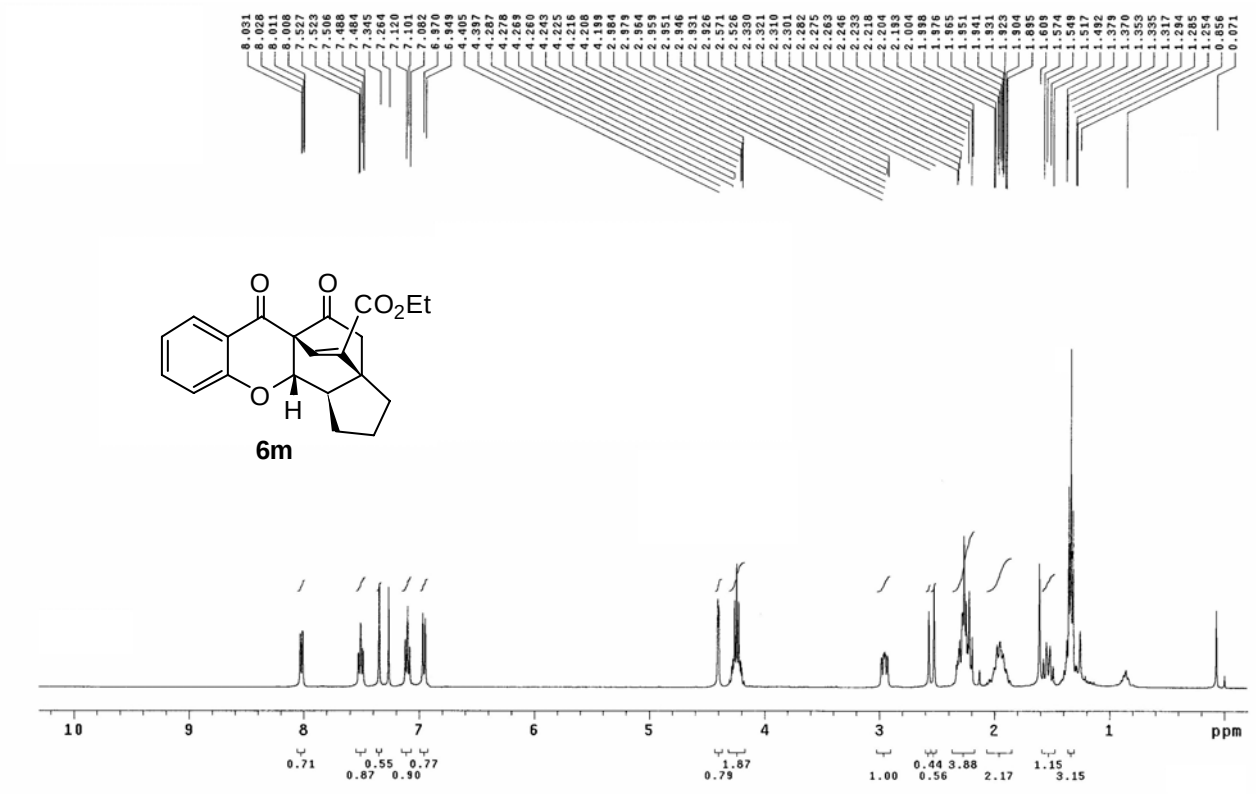
CO2Et
O
H
5l
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	7.465	12269865	50.36	668059	64.68
2	12.963	12094787	49.64	364736	35.32



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	7.461	21248120	98.49	1174713	98.97
2	13.068	325689	1.51	12280	1.03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4.278
4.269
4.260
4.243
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1.254
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O
CO2Et
O
H
6m
10
9
8
7
6
5
4
3
2
1
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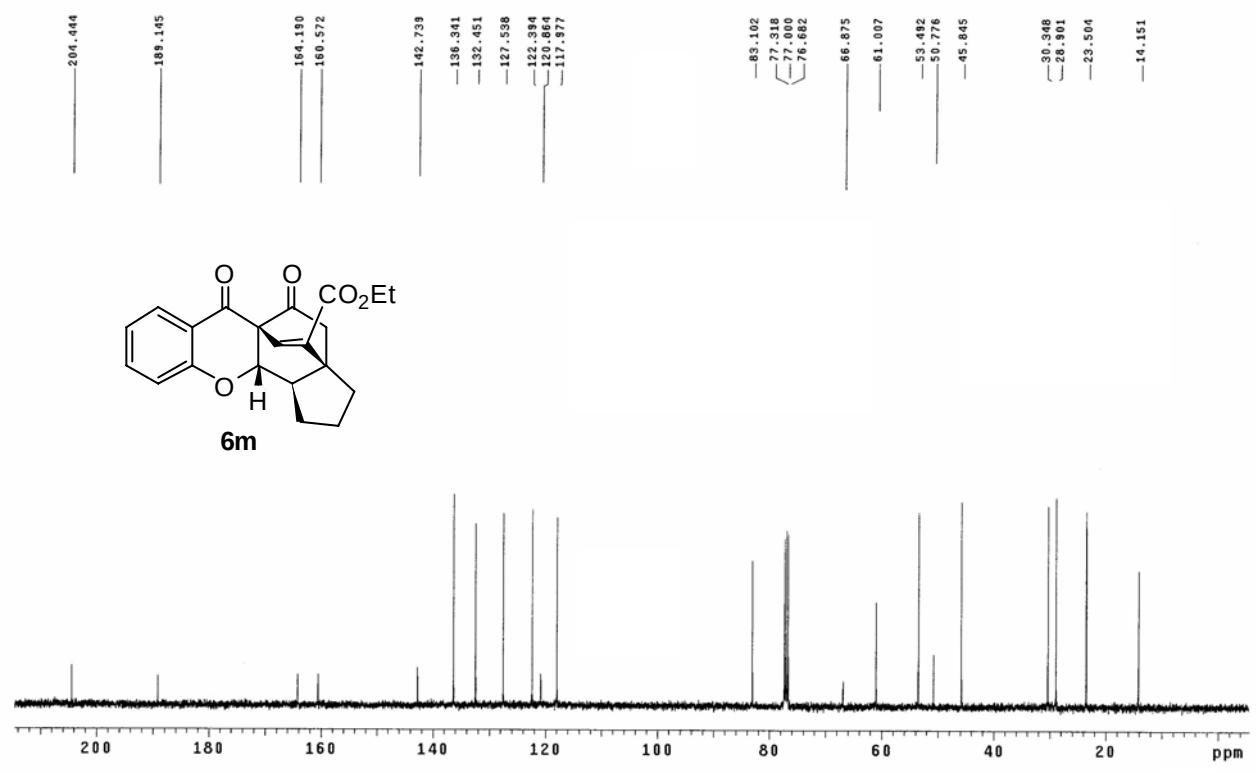
3.15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28.901
23.504
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CO2Et
O
H
6m
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140
120
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80
60
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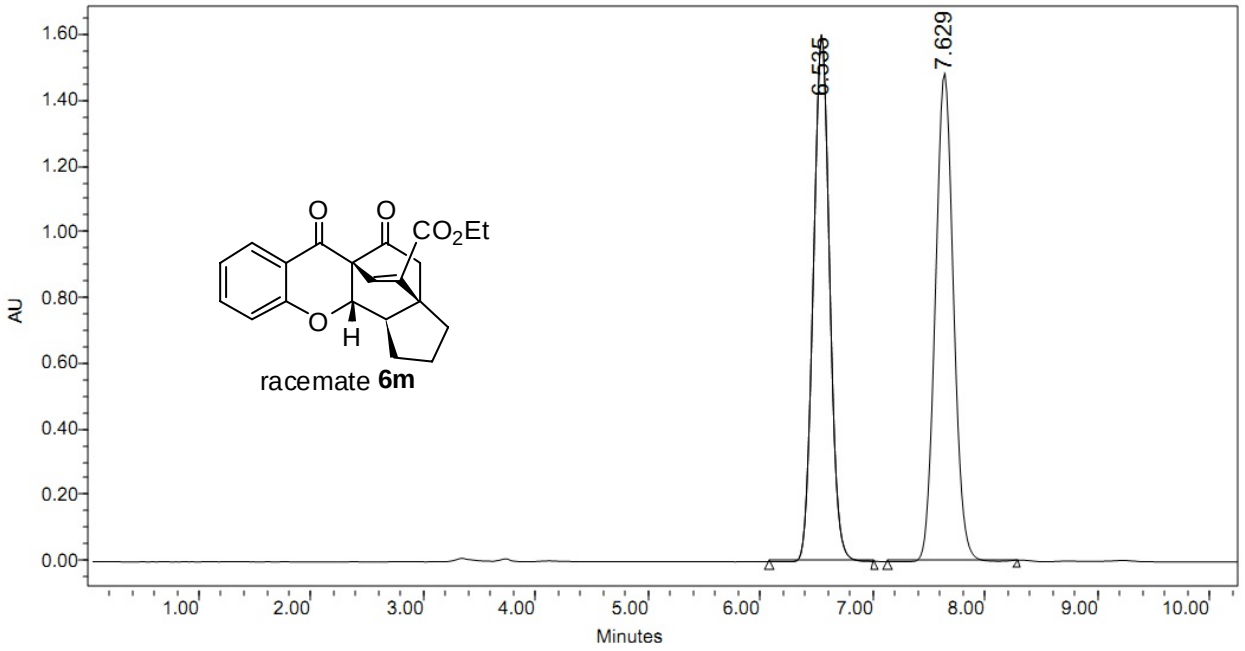
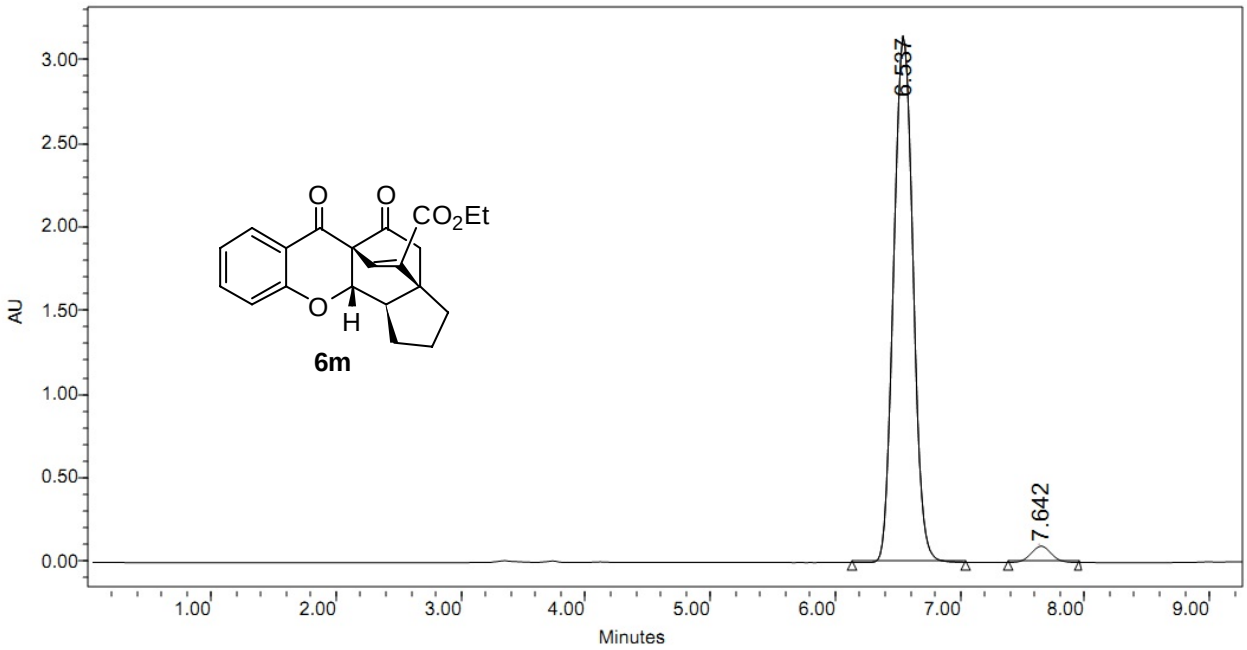
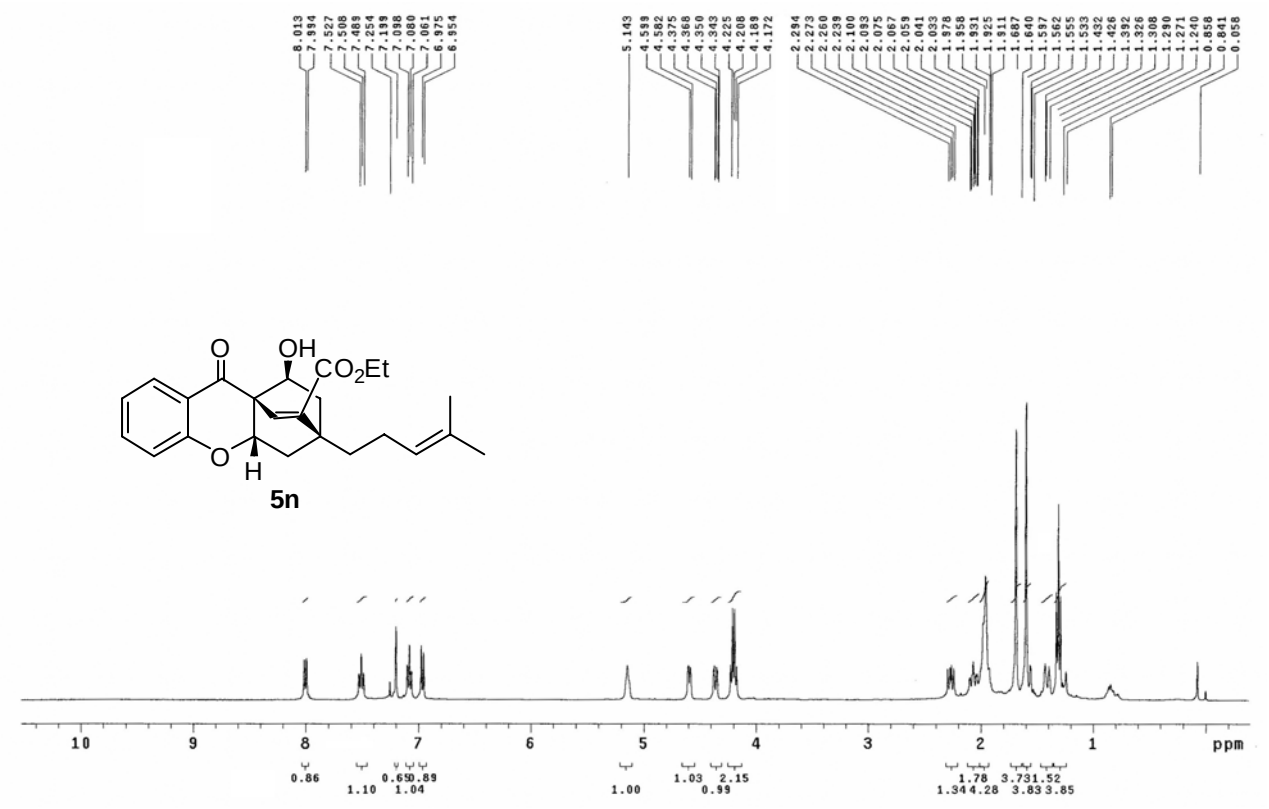
20
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	6.535	16273274	49.38	1601449	51.89
2	7.629	16679542	50.62	1485045	48.11



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	6.537	34009515	96.87	3147549	97.00
2	7.642	1098317	3.13	97344	3.00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0.058
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OH
CO2Et
O
H
5n
10
9
8
7
6
5
4
3
2
1
ppm
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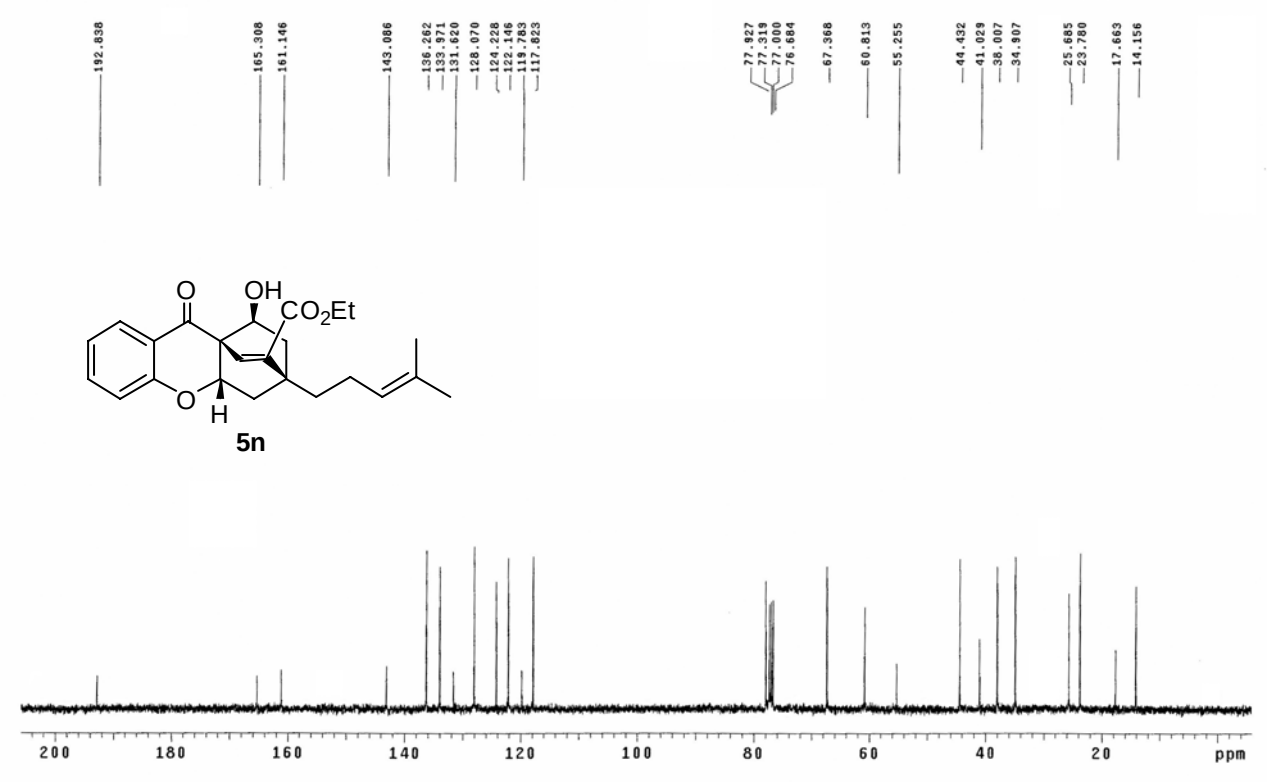
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44.432
41.029
38.007
34.907
25.685
23.780
17.663
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O
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5n
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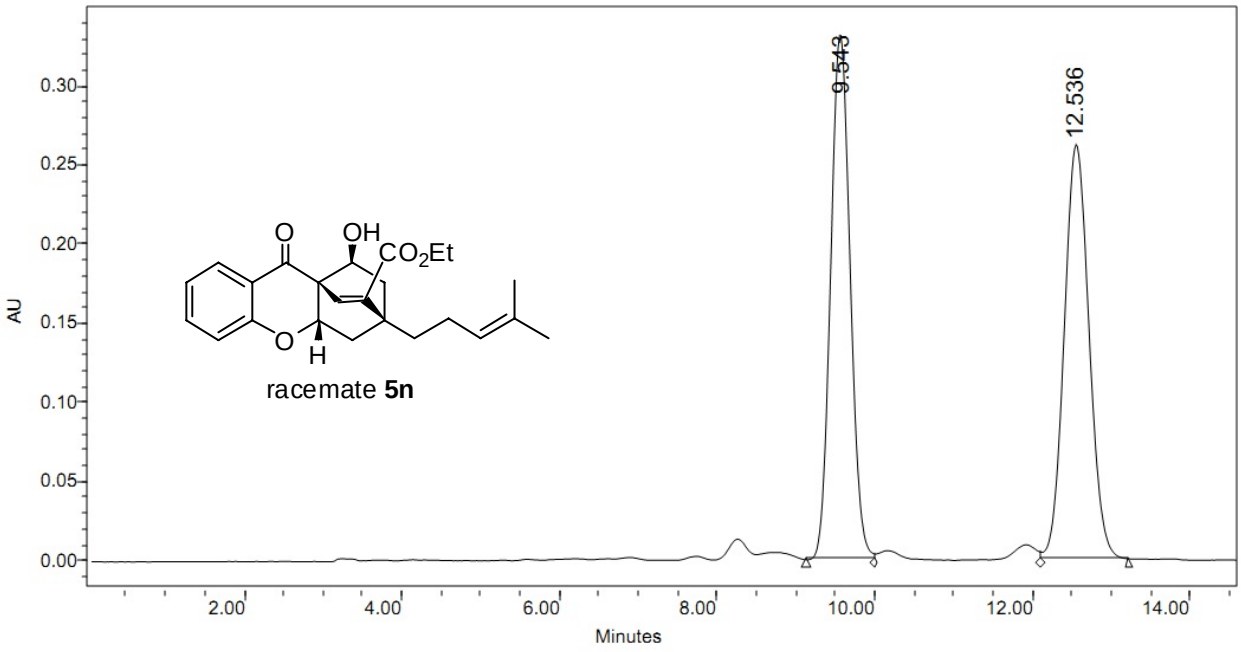
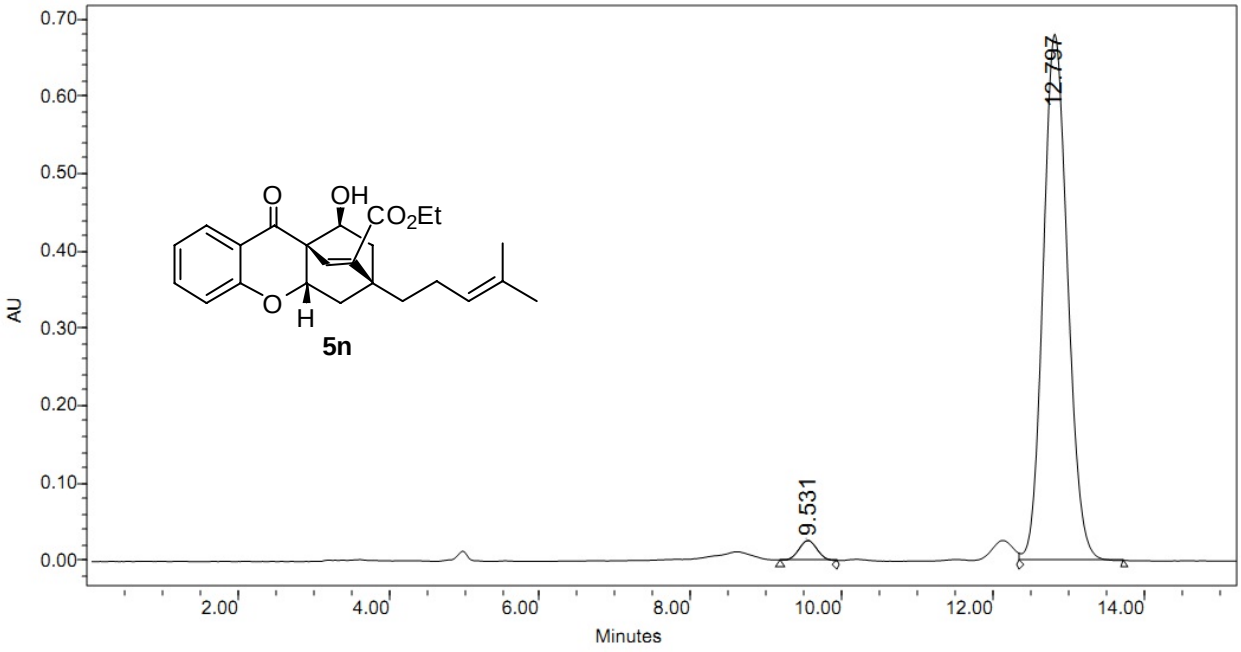
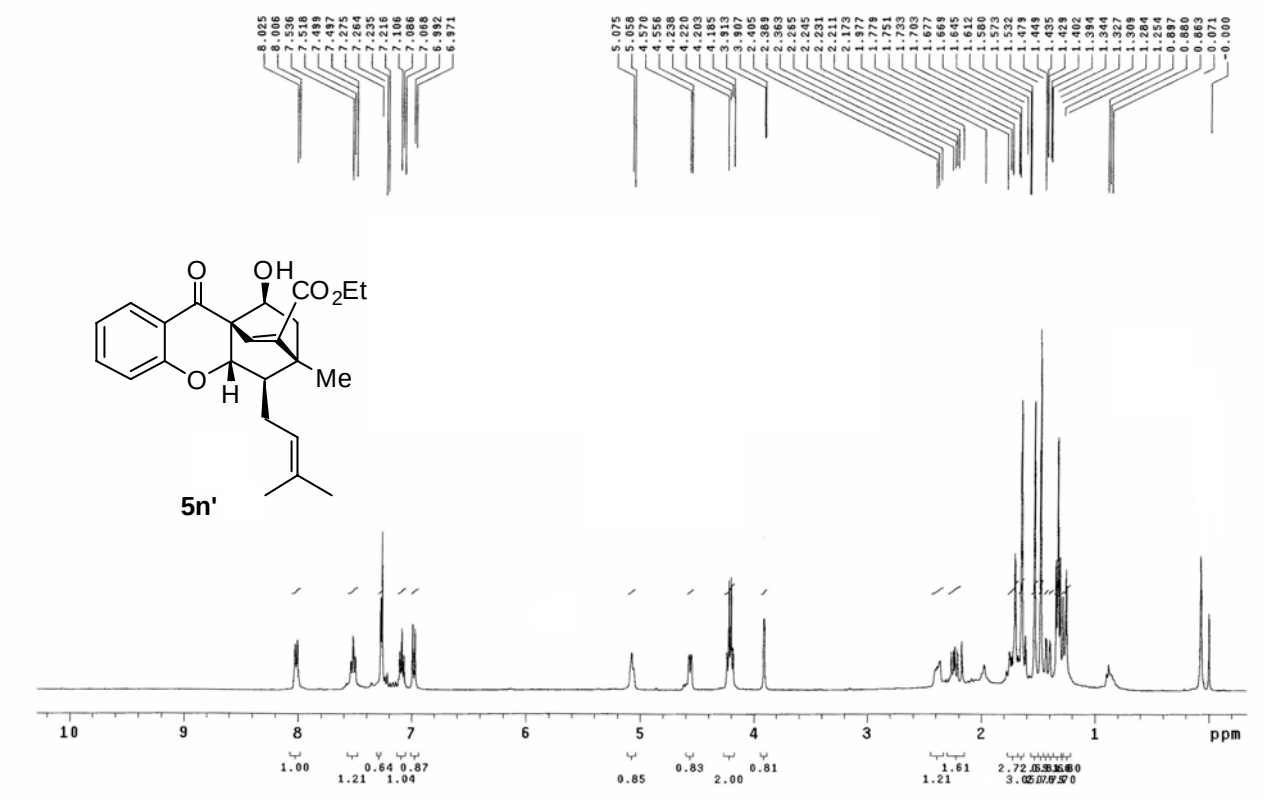
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	9.543	5710624	49.89	332160	55.89
2	12.536	5735714	50.11	262136	44.11



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	9.531	430324	2.73	25670	3.63
2	12.797	15321870	97.27	680890	96.37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Me
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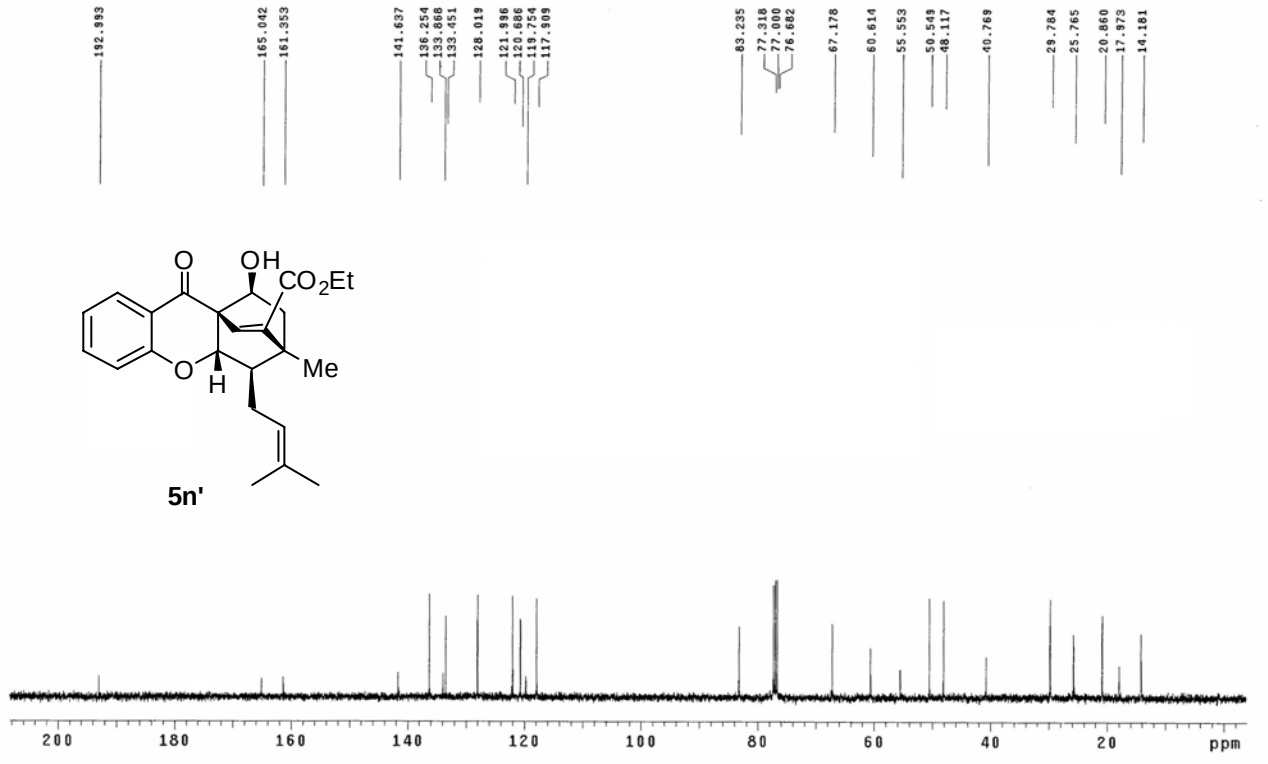
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67.178
60.614
55.553
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40.769
29.784
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H
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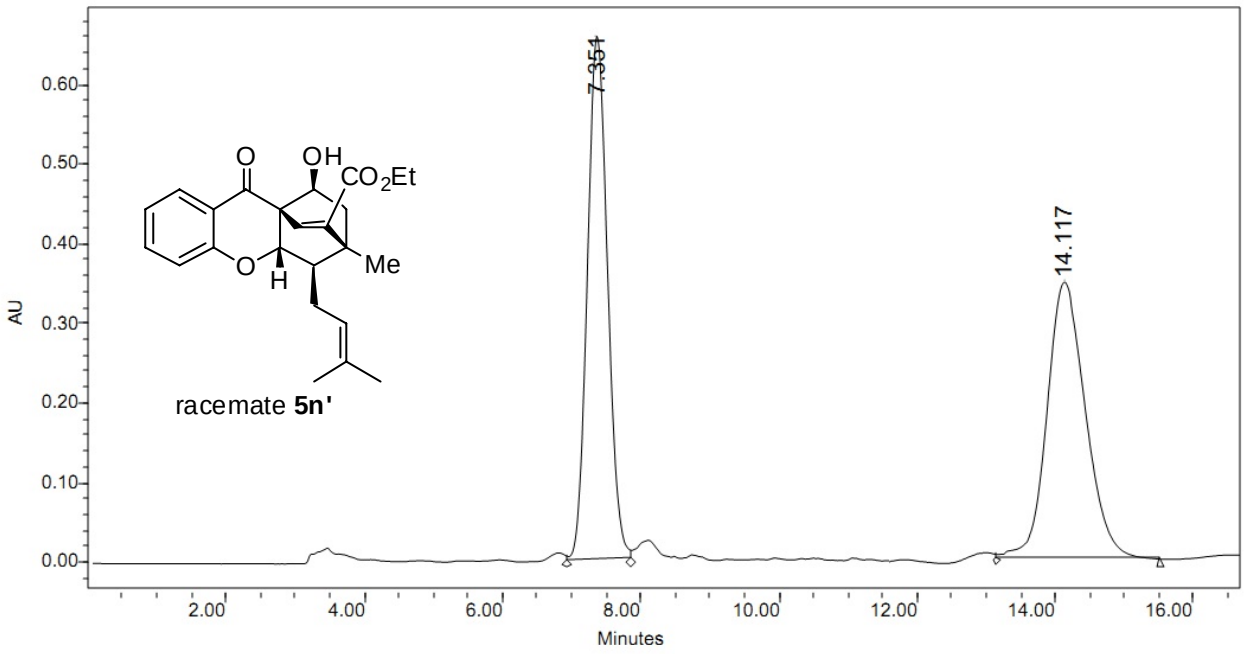
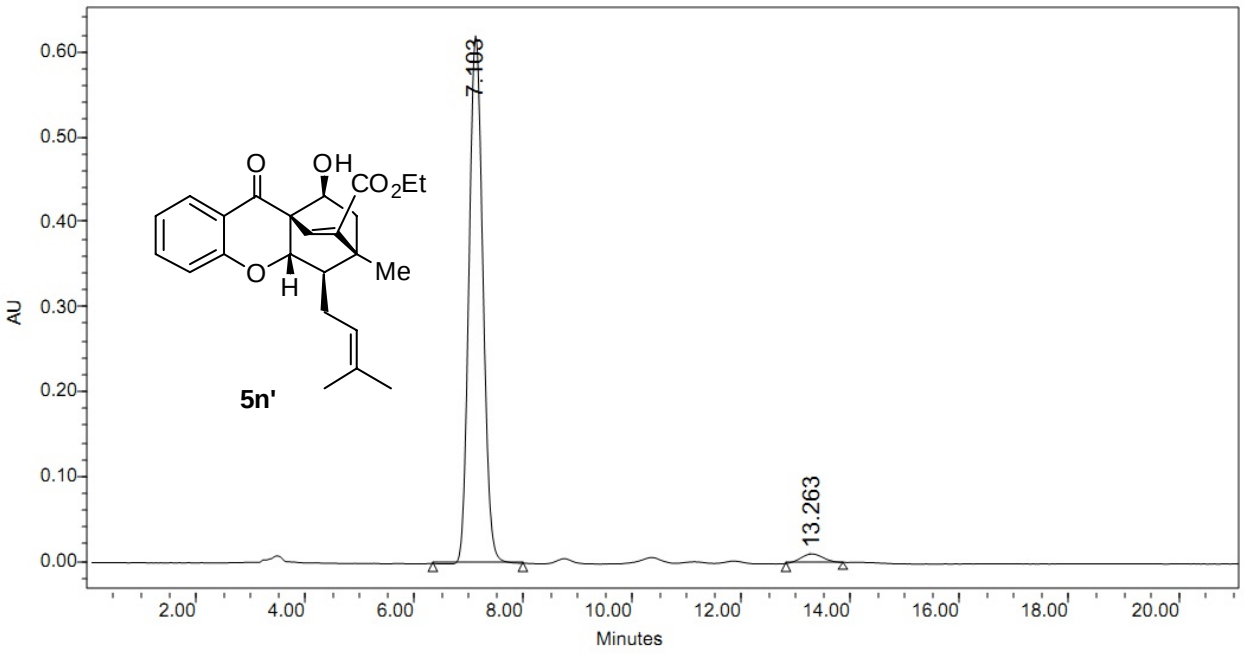
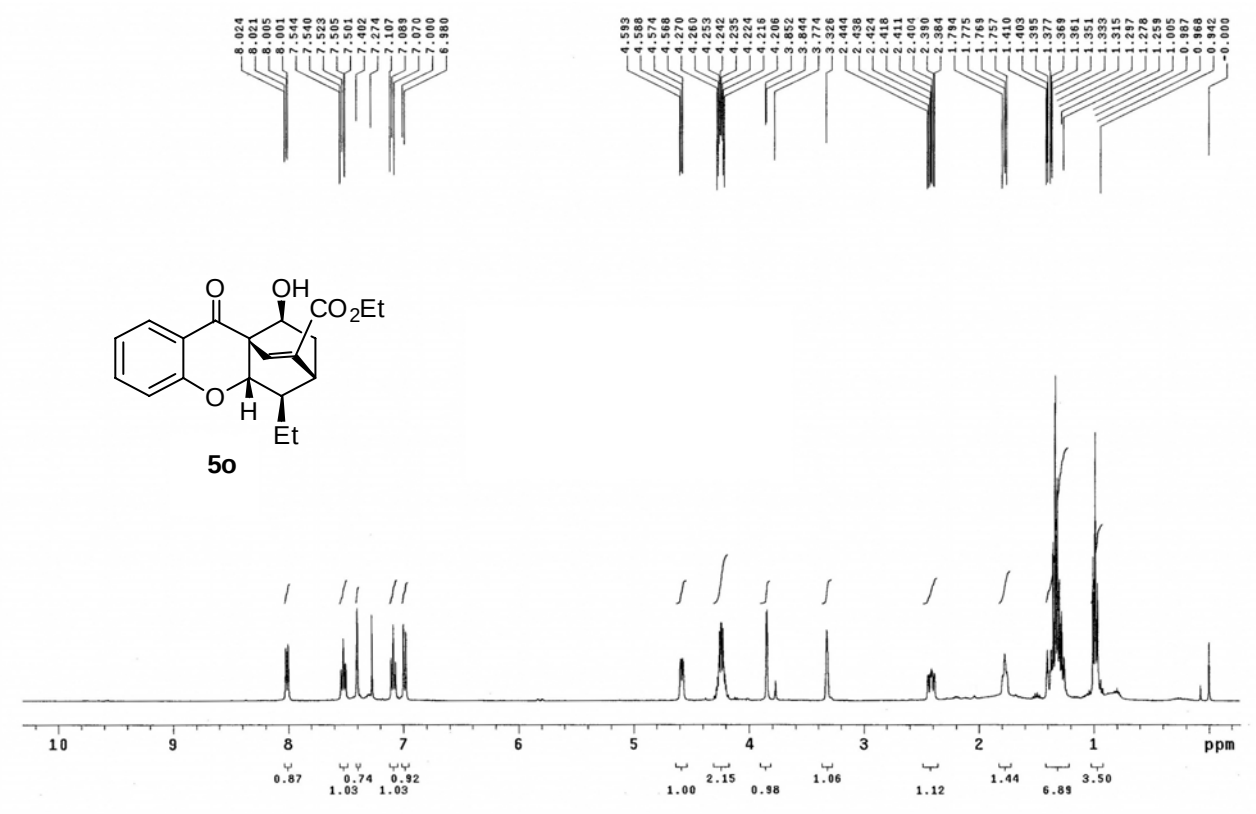
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	7.351	13346005	49.92	657500	65.48
2	14.117	13389056	50.08	346582	34.52



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	7.103	11018386	97.31	621255	98.32
2	13.263	304438	2.69	10586	1.68



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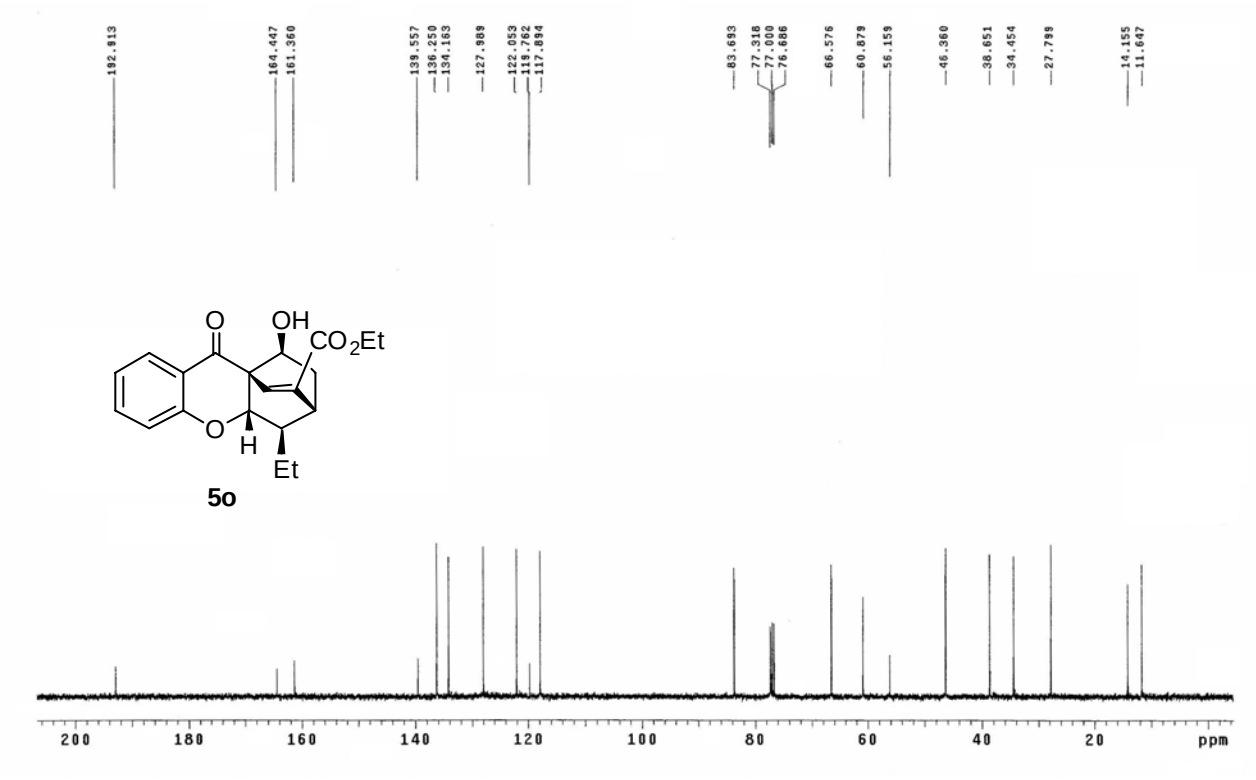

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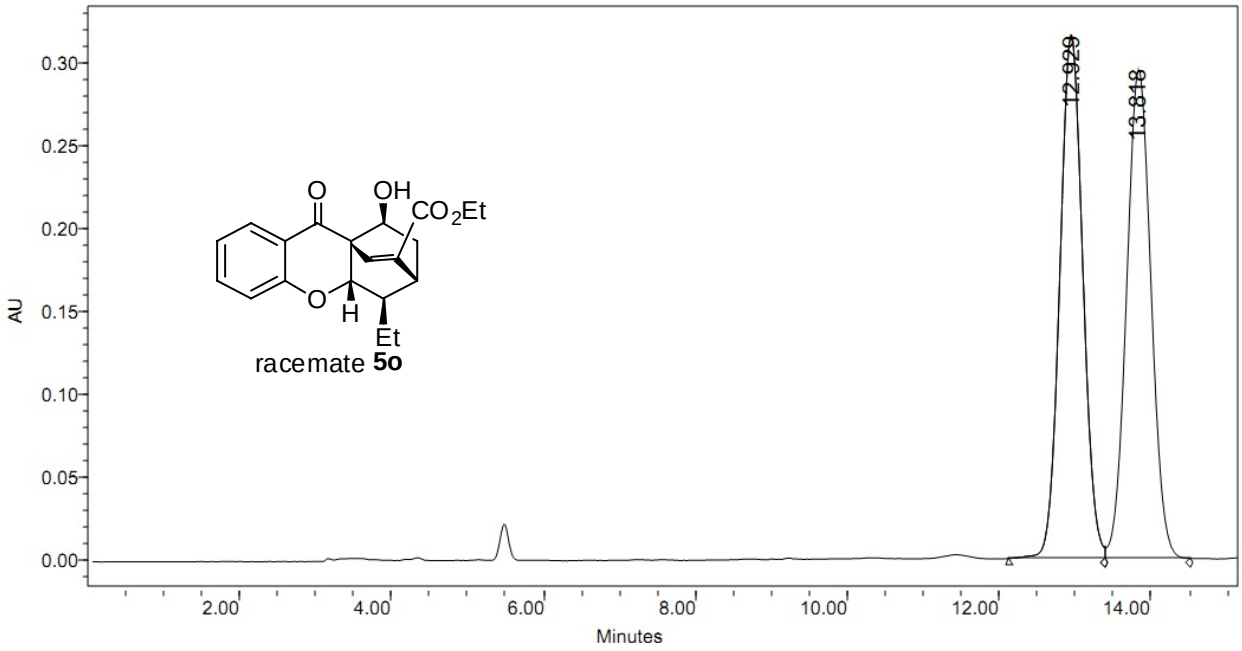
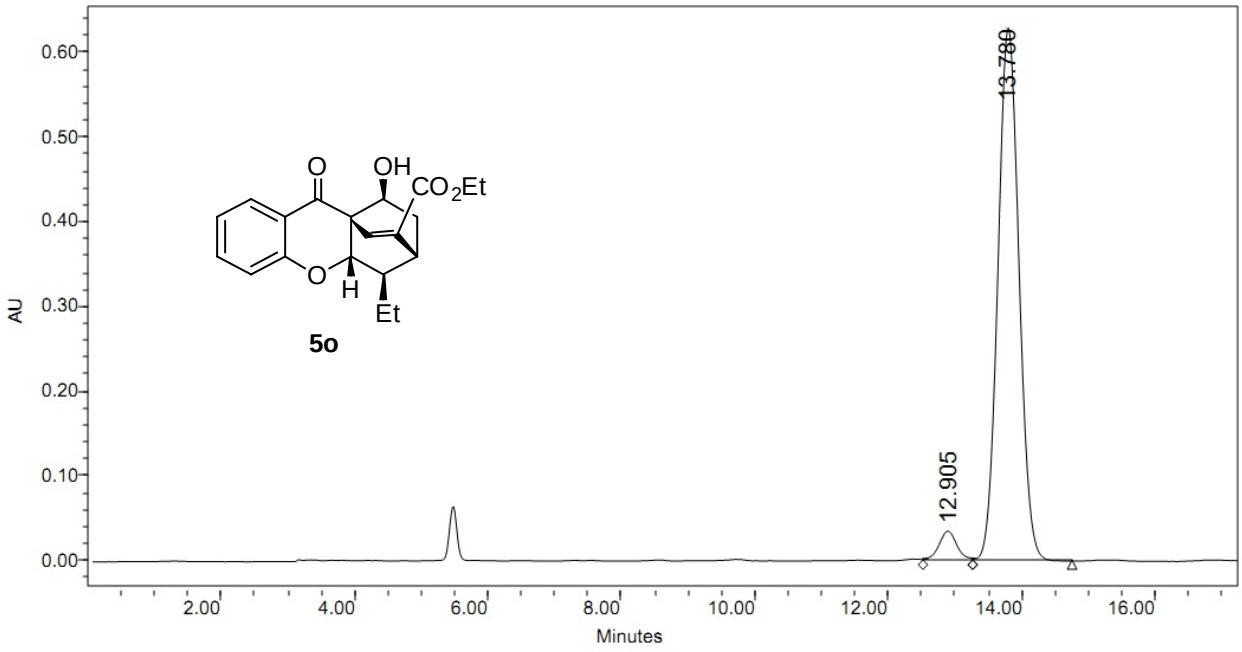
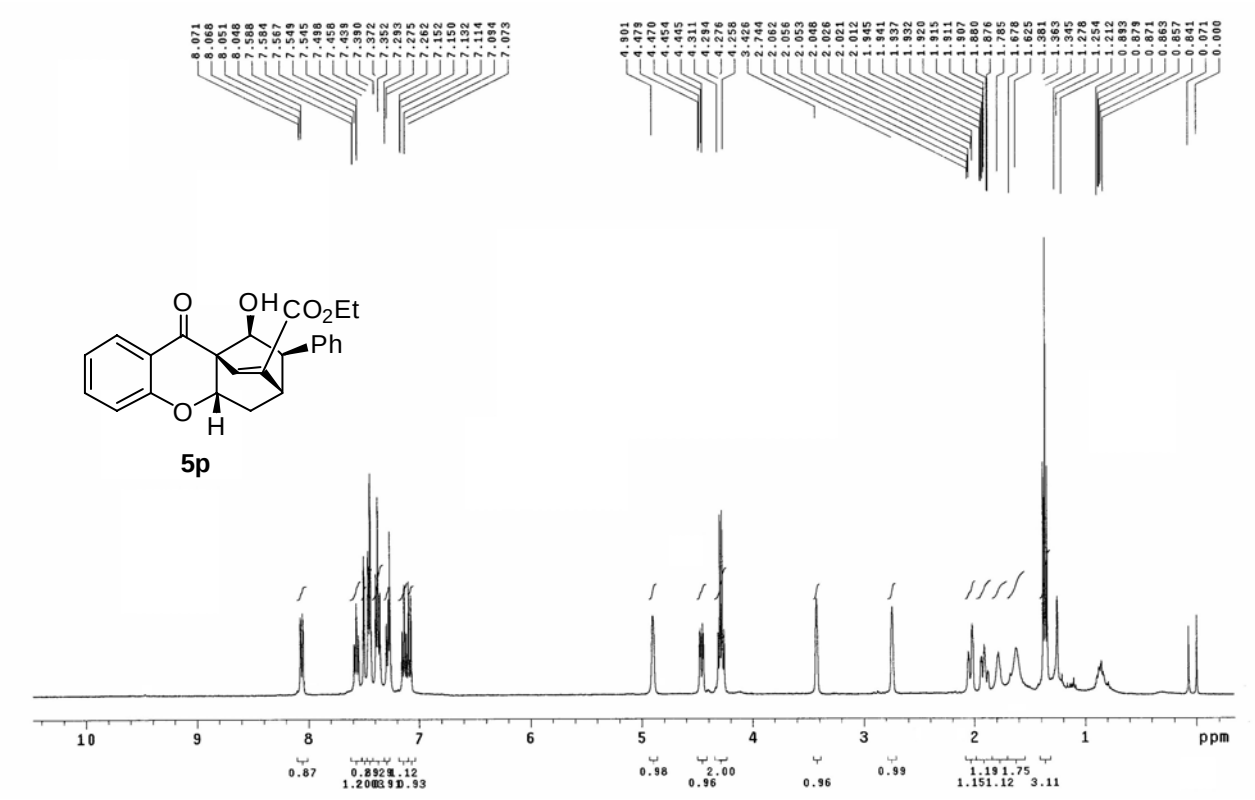


	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	12.929	6635541	50.14	316212	51.70
2	13.818	6598845	49.86	295411	48.30



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	12.905	660309	4.59	35227	5.37
2	13.780	13714801	95.41	621061	94.63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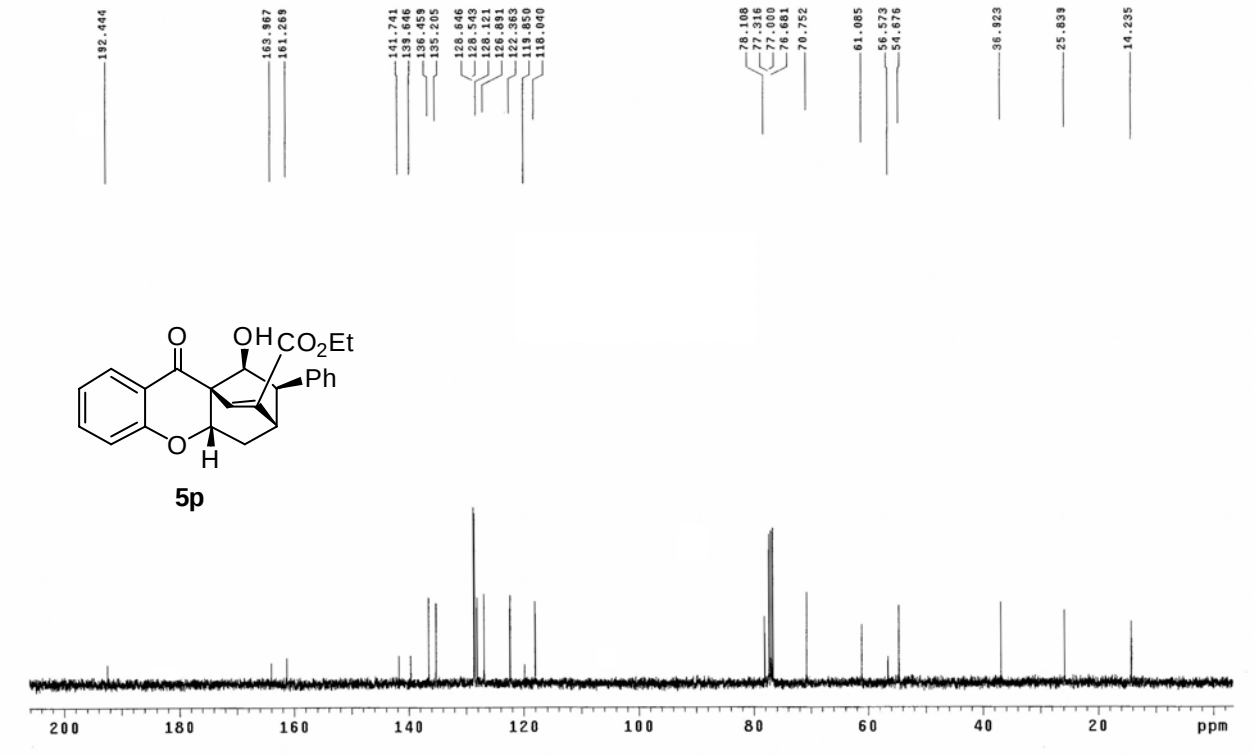
CO2Et
Ph
O
H
5p
ppm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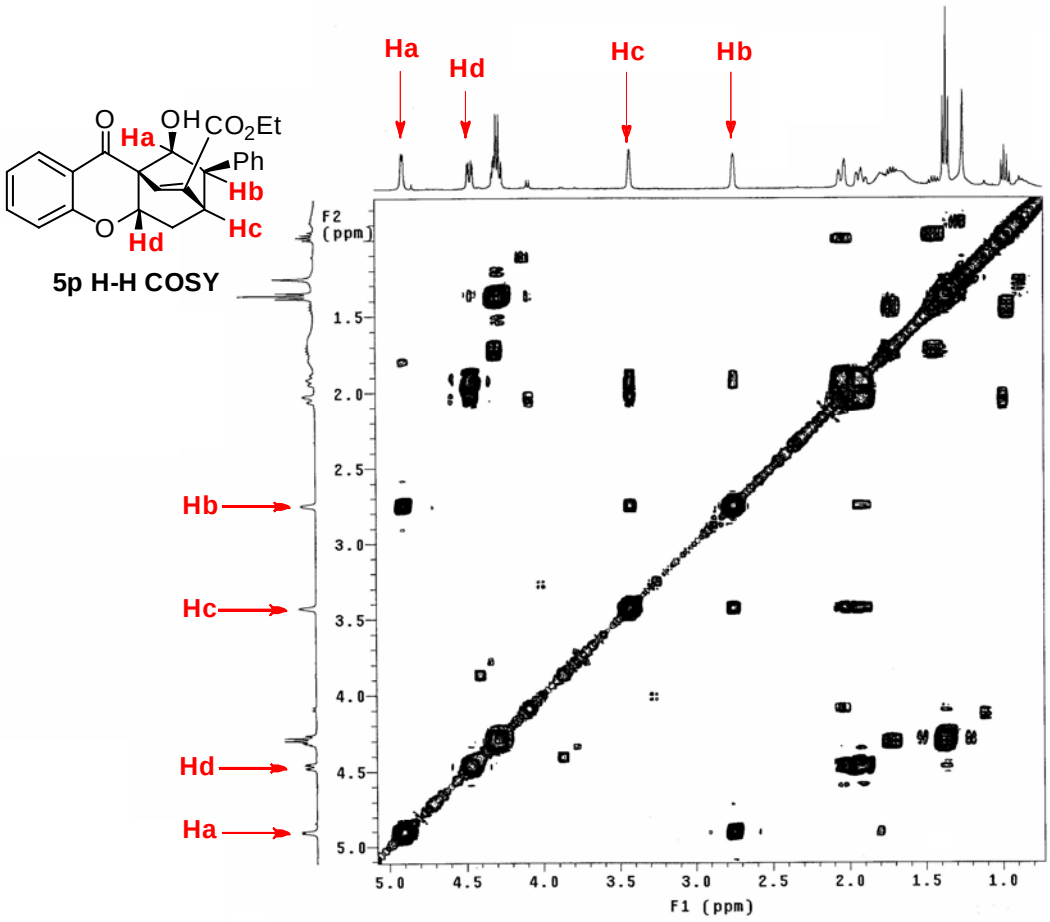
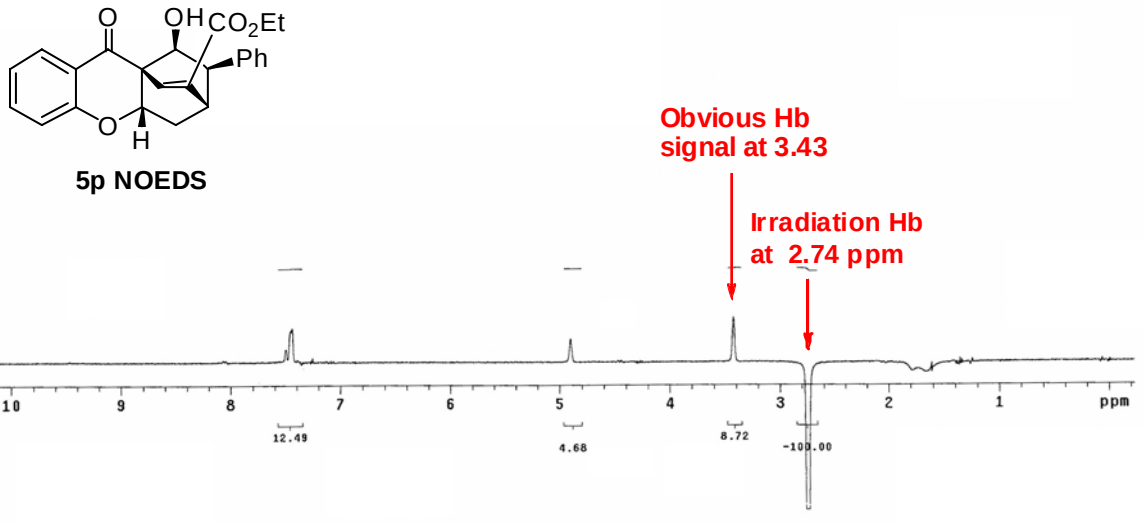
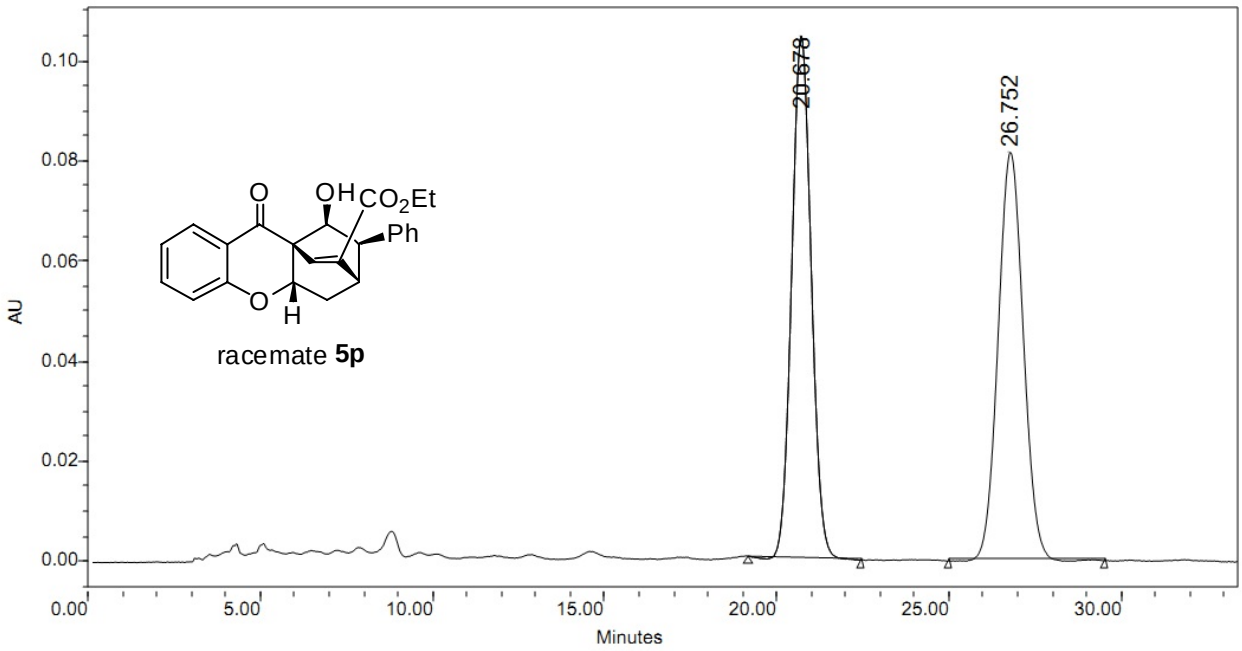
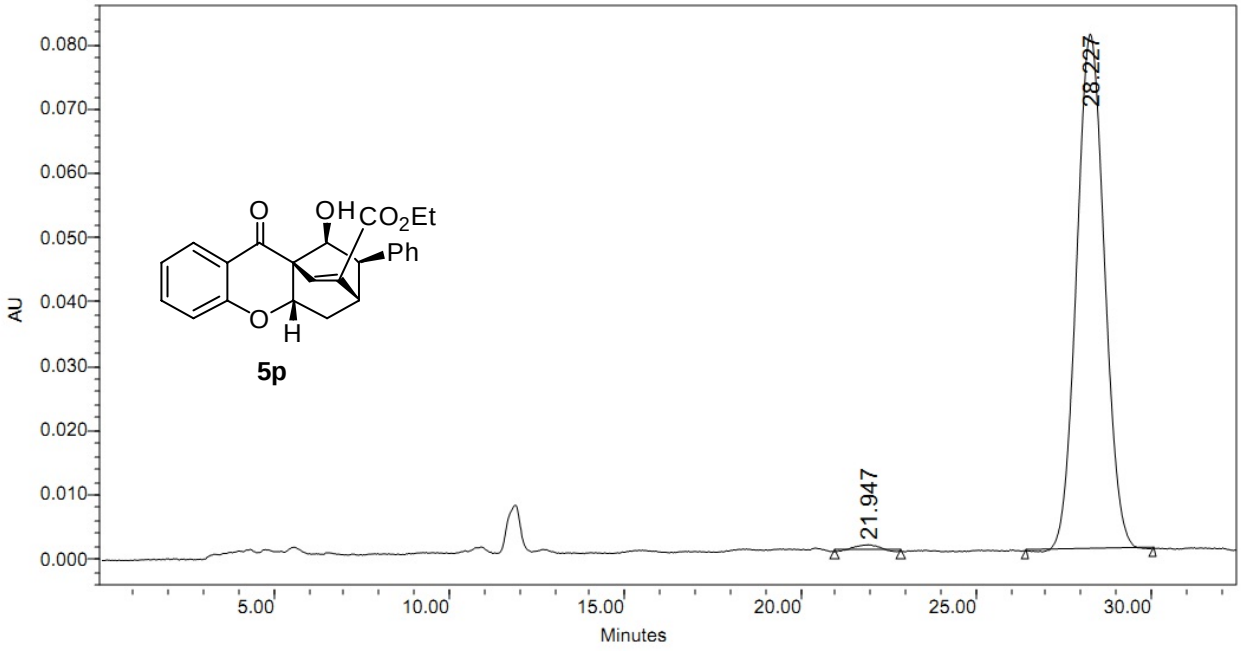
OH
CO2Et
Ph
O
H
5p
ppm



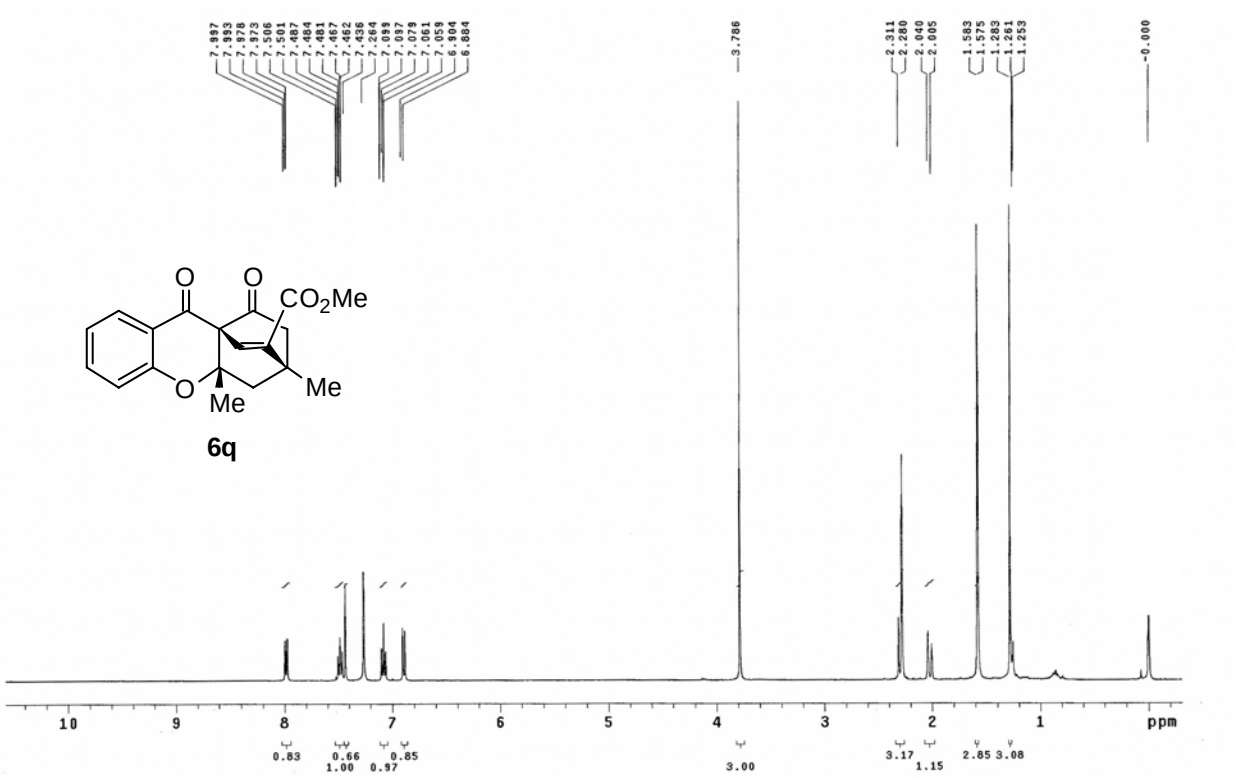




	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	20.678	4124242	49.75	104312	56.09
2	26.752	4165554	50.25	81660	43.91



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	21.947	56071	1.25	1044	1.28
2	28.227	4441389	98.75	80215	98.72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7.501
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7.484
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7.467
7.462
7.436
7.264
7.099
7.097
7.079
7.051
7.055
6.904
6.884
3.786
2.311
2.280
2.040
2.005
1.583
1.575
1.283
1.261
1.253
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O
CO2Me
O
Me
Me
10
9
8
7
6
5
4
3
2
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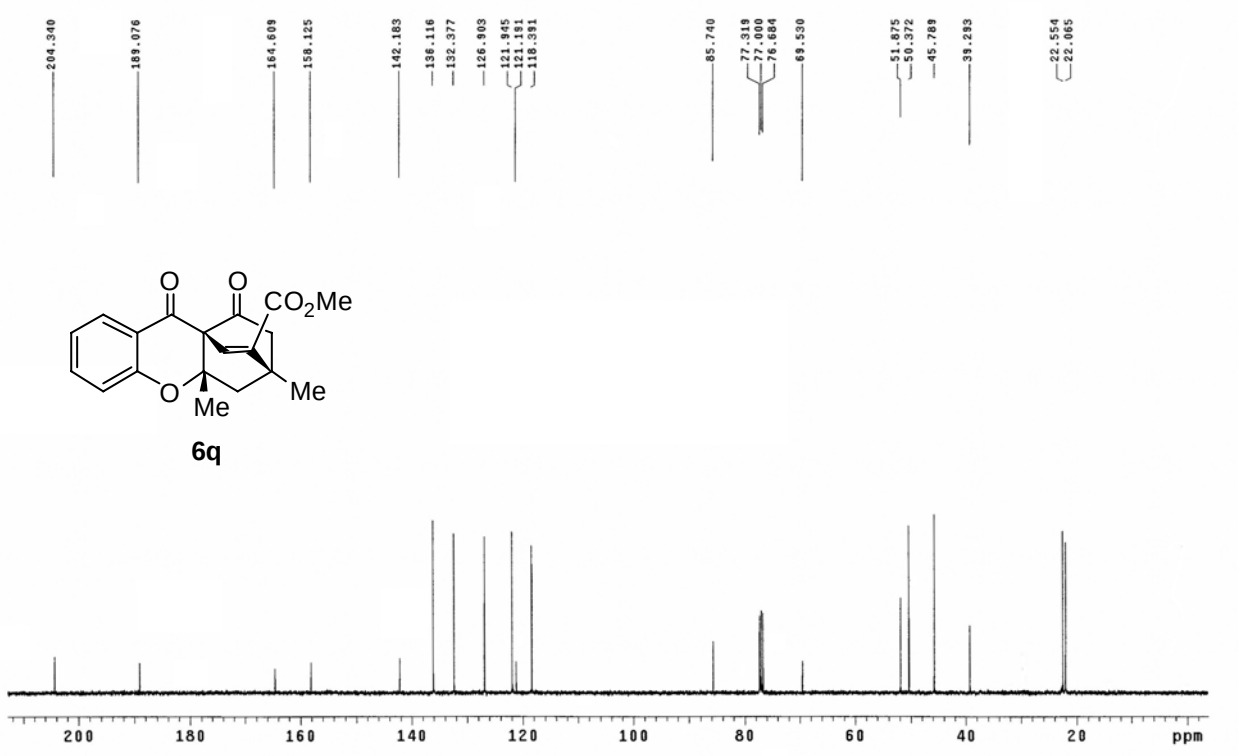
0.97
3.00
3.17
1.15
2.85
3.08

6q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164.609
158.125
142.183
136.116
132.377
126.903
121.945
121.191
118.391
85.740
77.319
77.000
76.684
69.530
51.875
50.372
45.709
39.293
22.554
22.065
O
O
CO2Me
O
Me
Me
200
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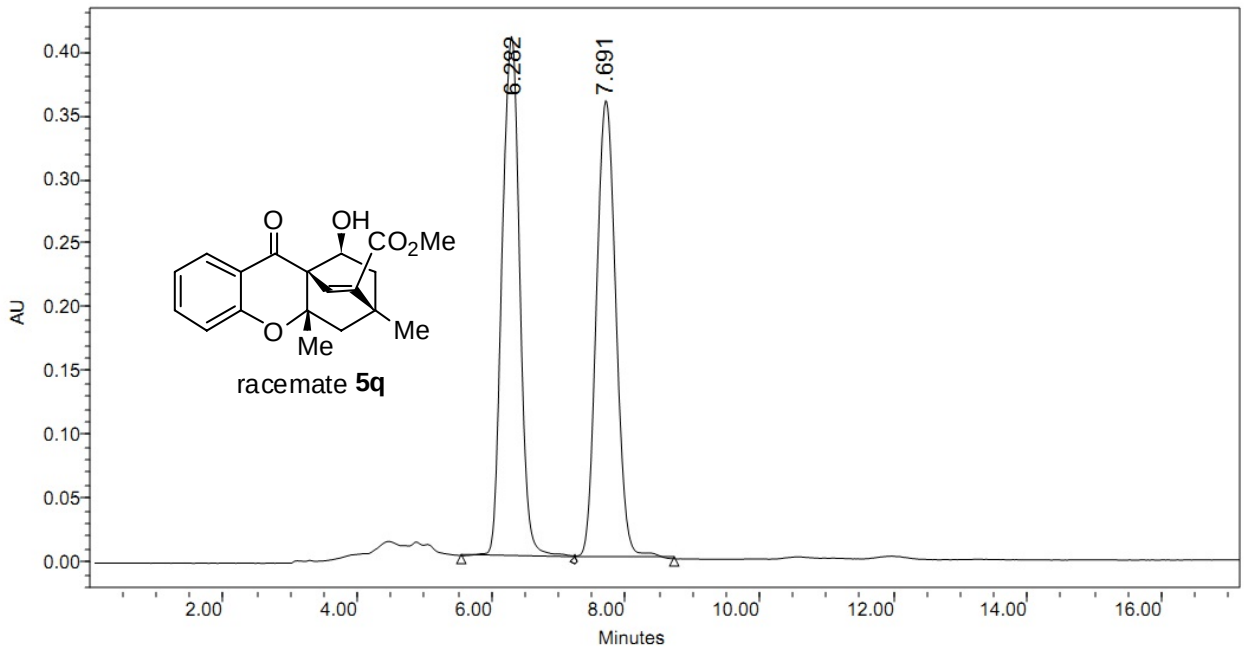
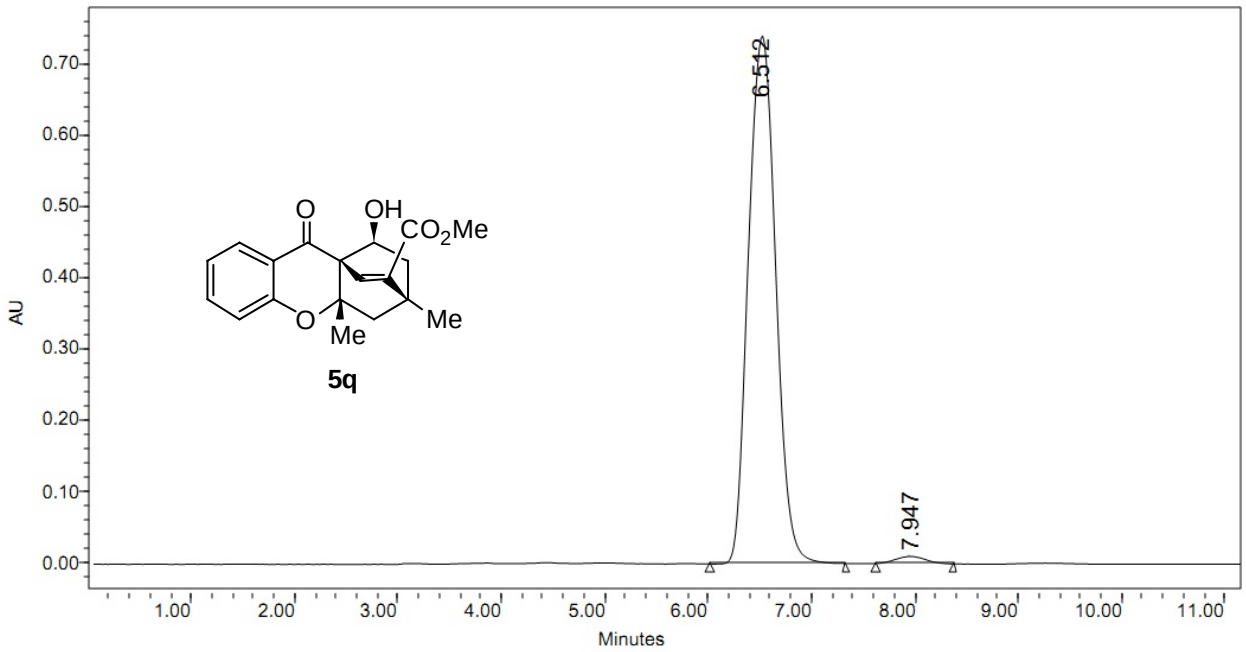
140
120
100
80
60
40
20
ppm

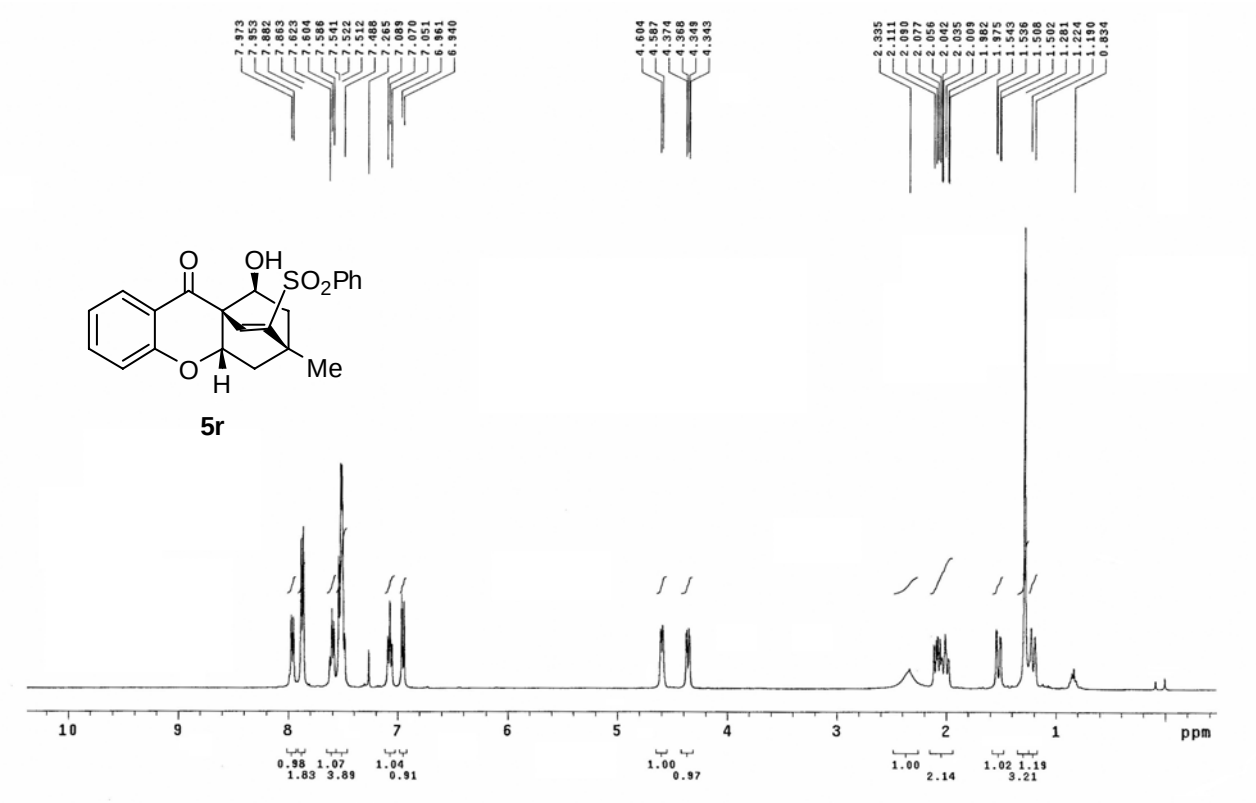
6q



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	6.282	7351315	50.50	406381	53.21
2	7.691	7205978	49.50	357292	46.79



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	6.512	13603558	98.55	741301	98.66
2	7.947	200119	1.45	10077	1.34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7.541
7.522
7.512
7.488
7.265
7.088
7.070
7.051
6.961
6.940
4.604
4.587
4.374
4.366
4.348
4.343
2.335
2.111
2.090
2.077
2.056
2.042
2.035
2.009
1.982
1.975
1.543
1.536
1.508
1.502
1.281
1.224
1.190
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10
9
8
7
6
5
4
3
2
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ppm
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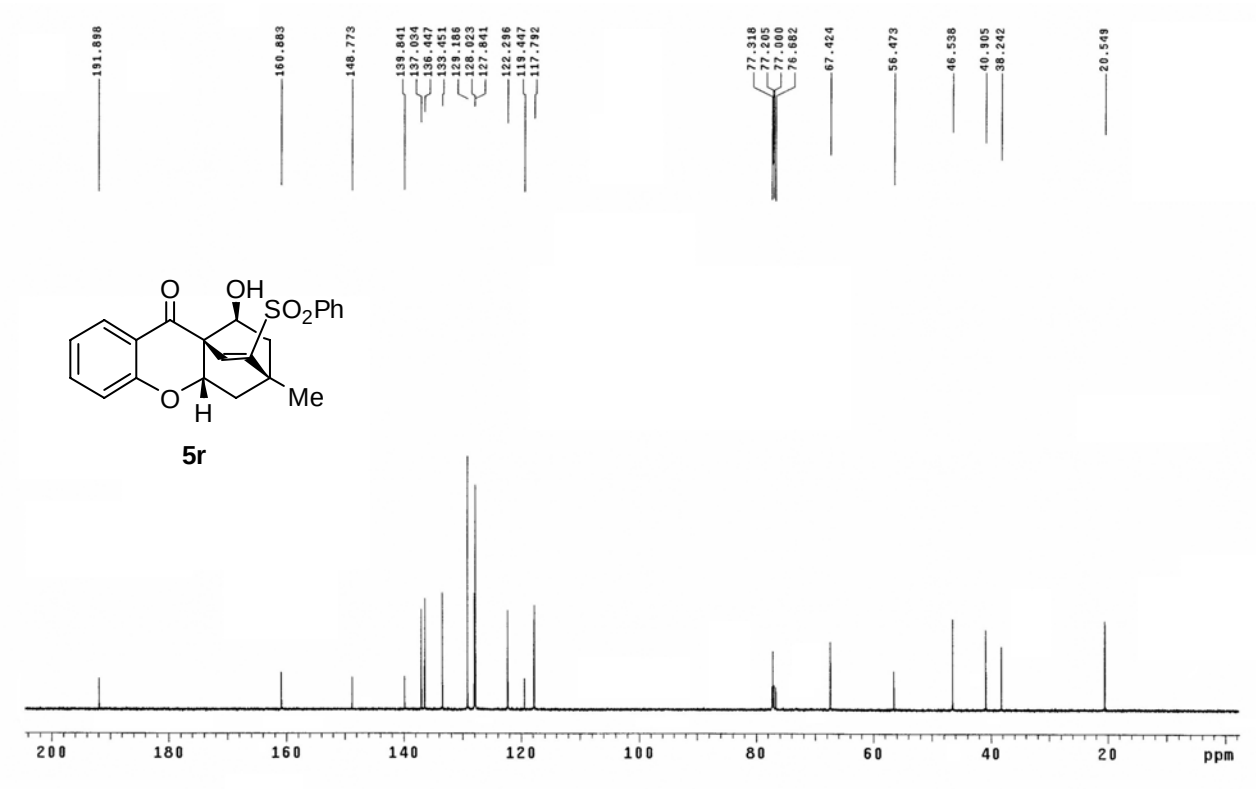
1.83 3.89 0.91
1.00
0.97
1.00
2.14
1.02 1.19
3.21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122.296
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117.792
77.318
77.205
77.000
76.682
67.424
56.473
46.538
40.905
38.242
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O
OH
SO2Ph
Me
O
H
5r
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140
120
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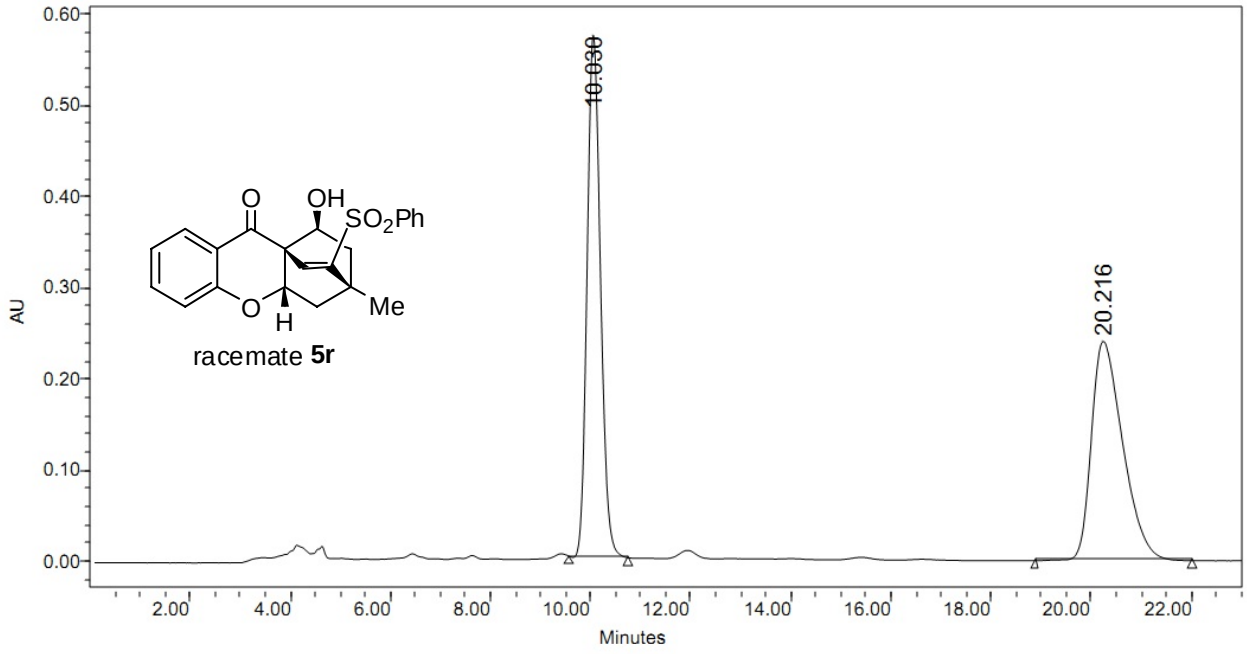
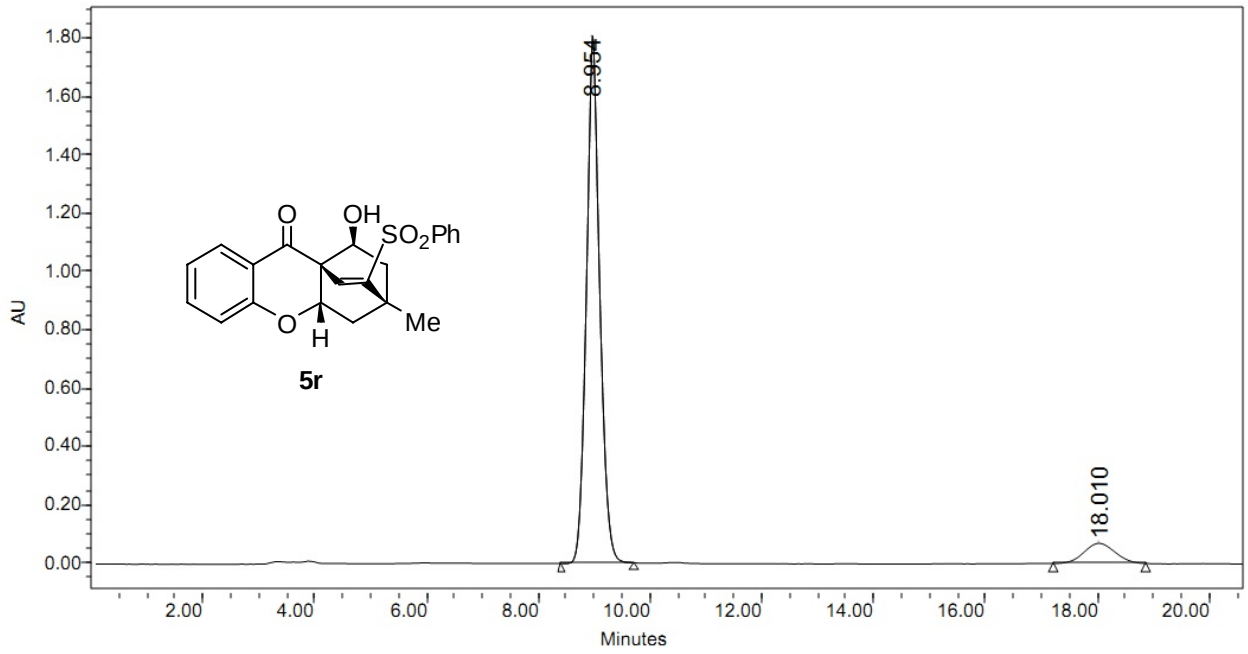
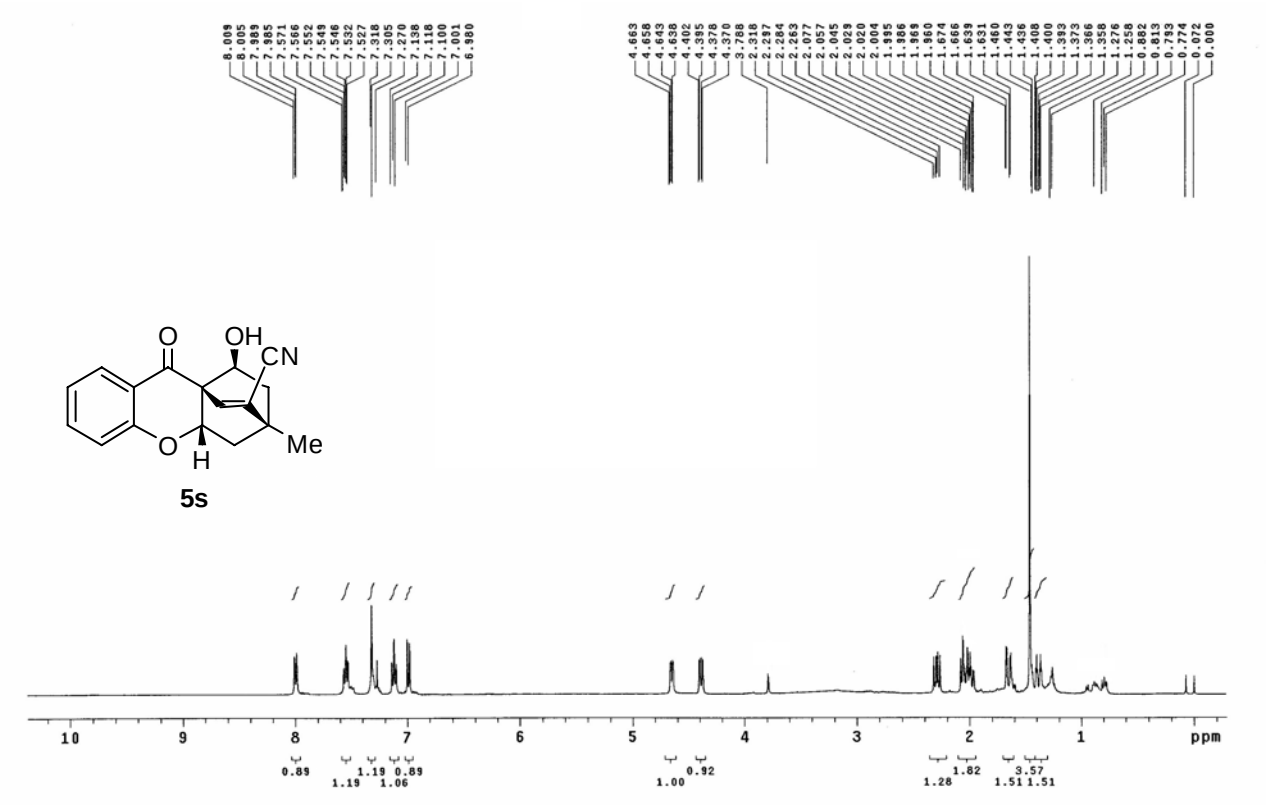
60
40
20
ppm



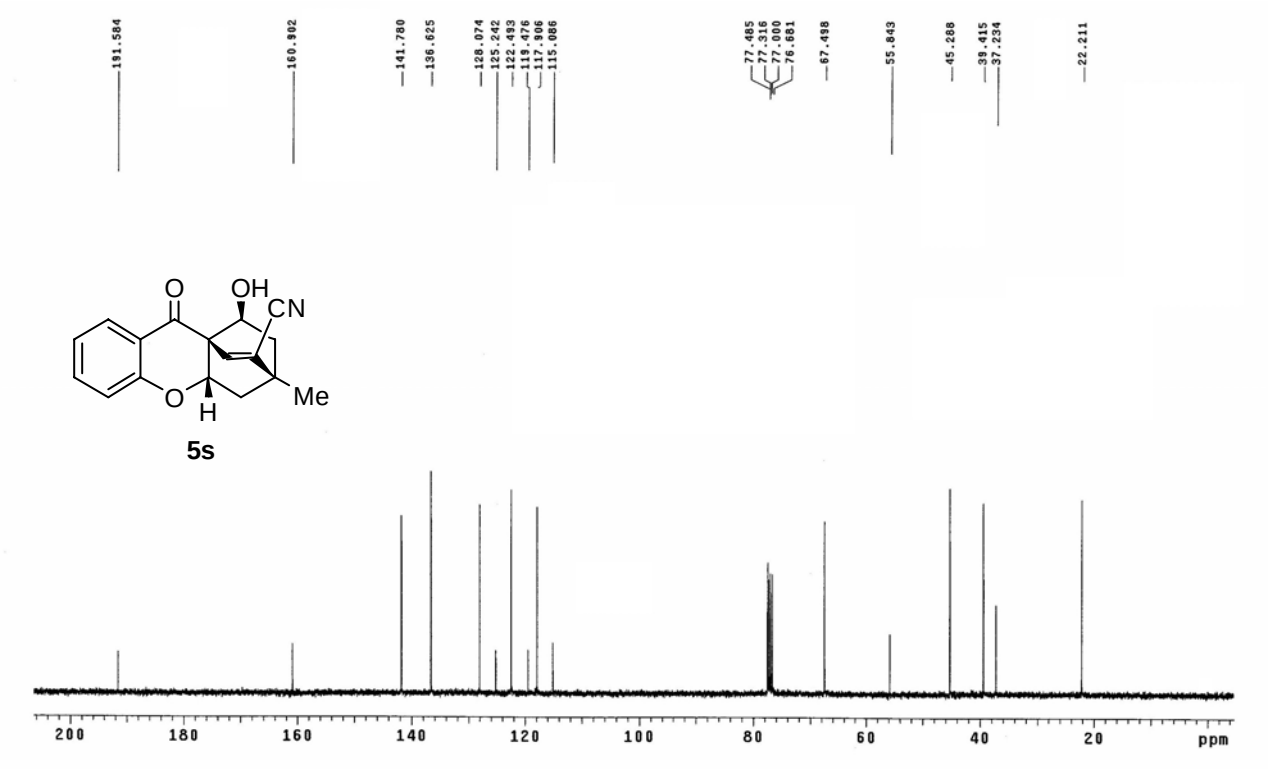
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.030	10613816	50.28	572333	70.42
2	20.216	10496088	49.72	240404	29.58



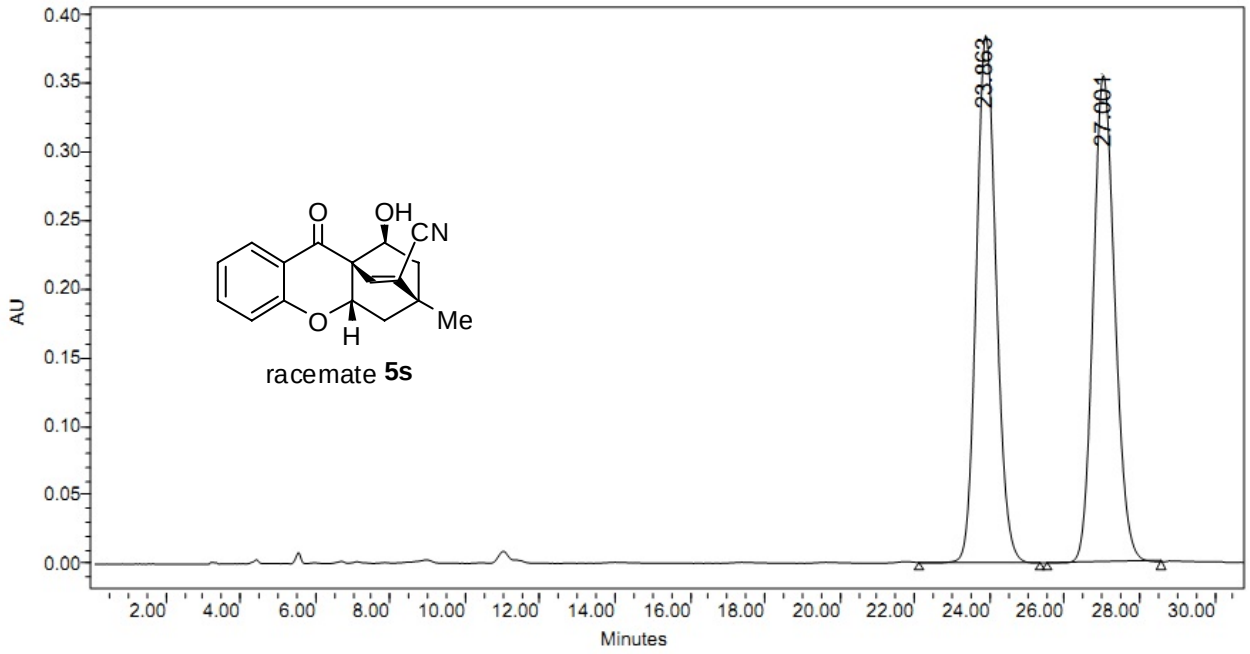
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	8.954	29924368	92.25	1809296	96.41
2	18.010	2513455	7.75	67299	3.59



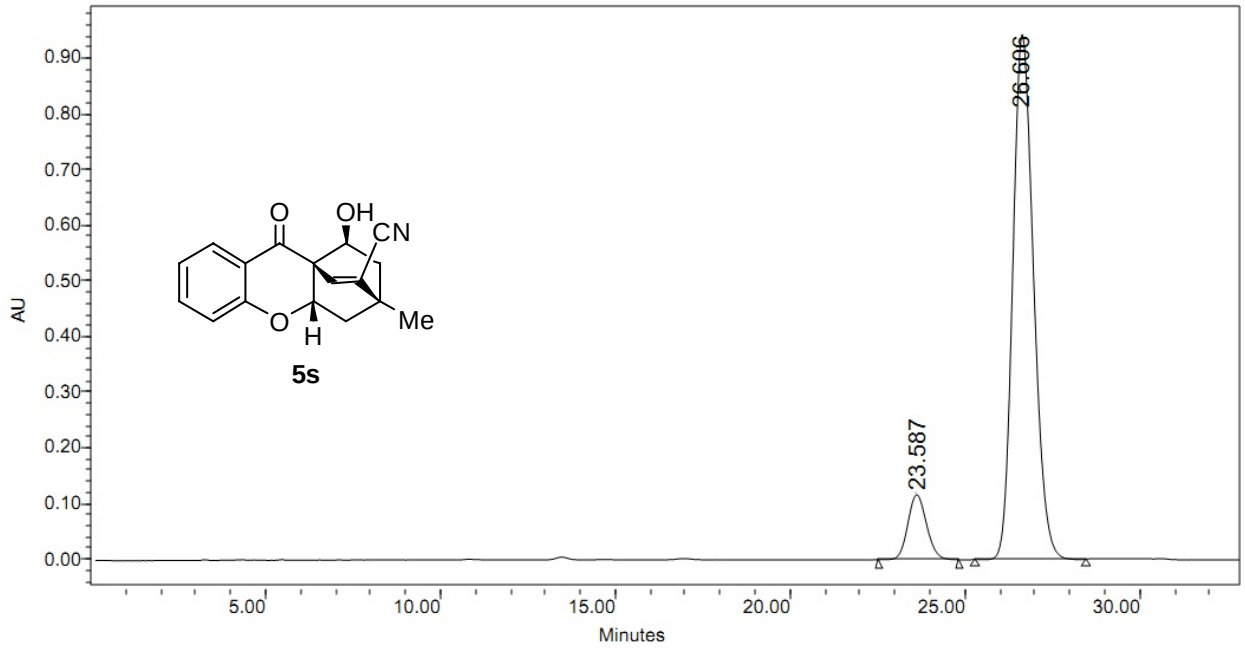
5s



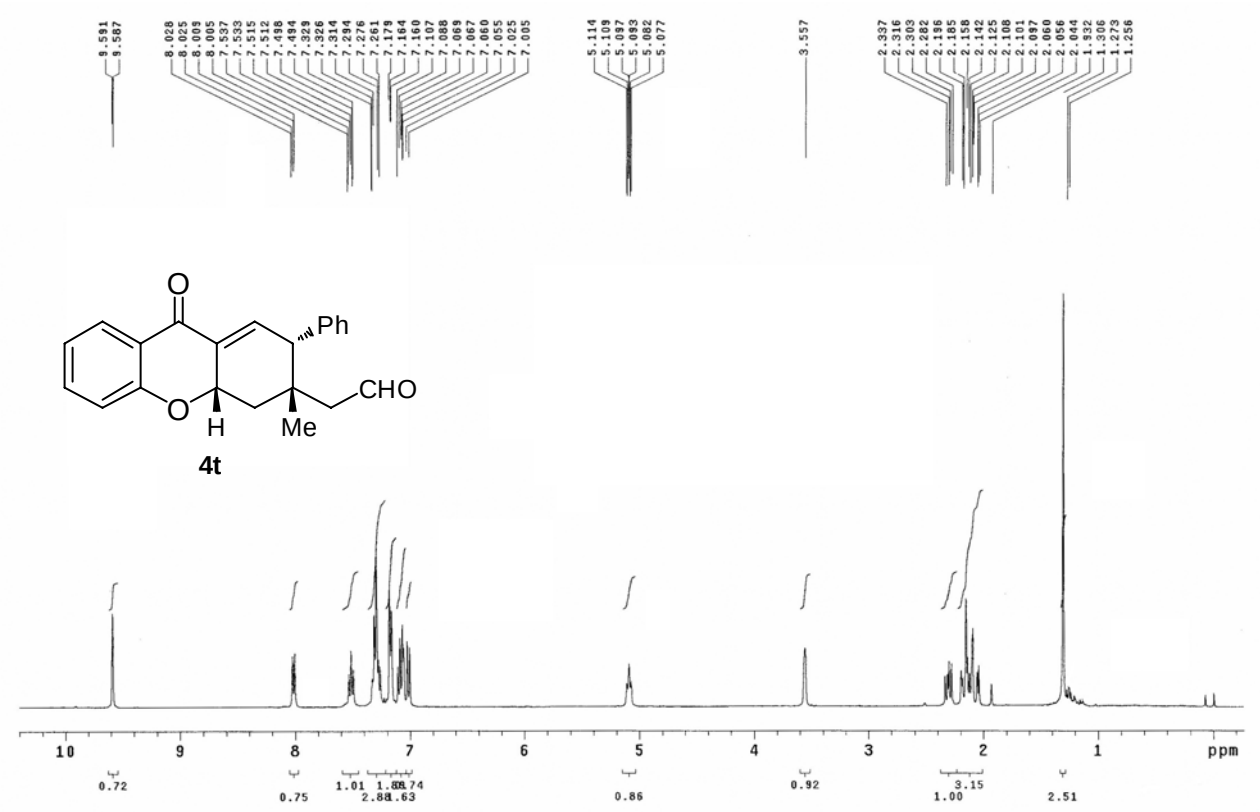
5s



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	23.863	14141114	49.88	384419	51.97
2	27.001	14208674	50.12	355227	48.03



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	23.587	4354069	10.08	116708	11.01
2	26.606	38852242	89.92	943038	88.99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7.494
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7.314
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7.179
7.164
7.160
7.107
7.088
7.069
7.067
7.060
7.055
7.025
7.005
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5.109
5.097
5.093
5.082
5.077
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2.316
2.303
2.282
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2.185
2.158
2.142
2.125
2.108
2.101
2.097
2.060
2.056
2.044
1.932
1.306
1.273
1.256
O
Ph
CHO
O
H
Me
4t
10
9
8
7
6
5
4
3
2
1
ppm
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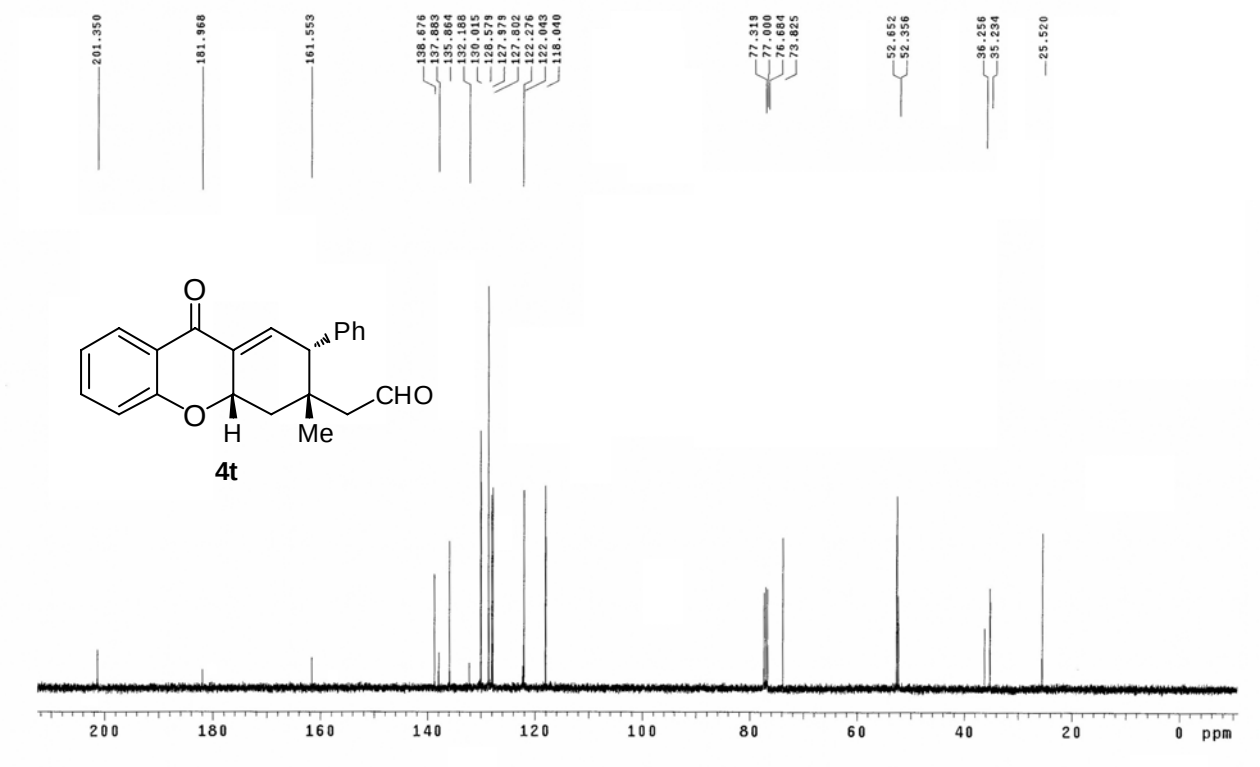
1.00
2.51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127.802
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122.043
118.040
77.318
77.000
76.684
73.825
52.652
52.356
36.256
35.234
25.520
O
Ph
CHO
O
H
Me
4t
200
180
160
140
120
100
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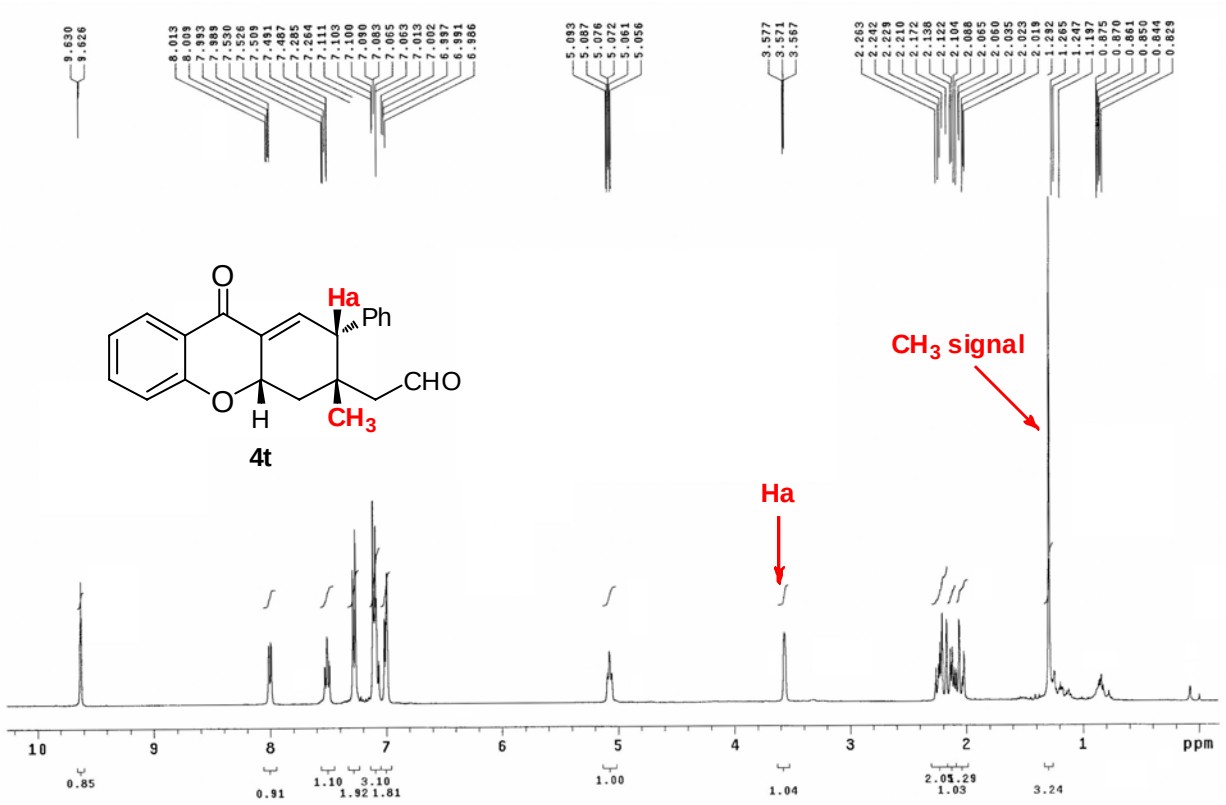
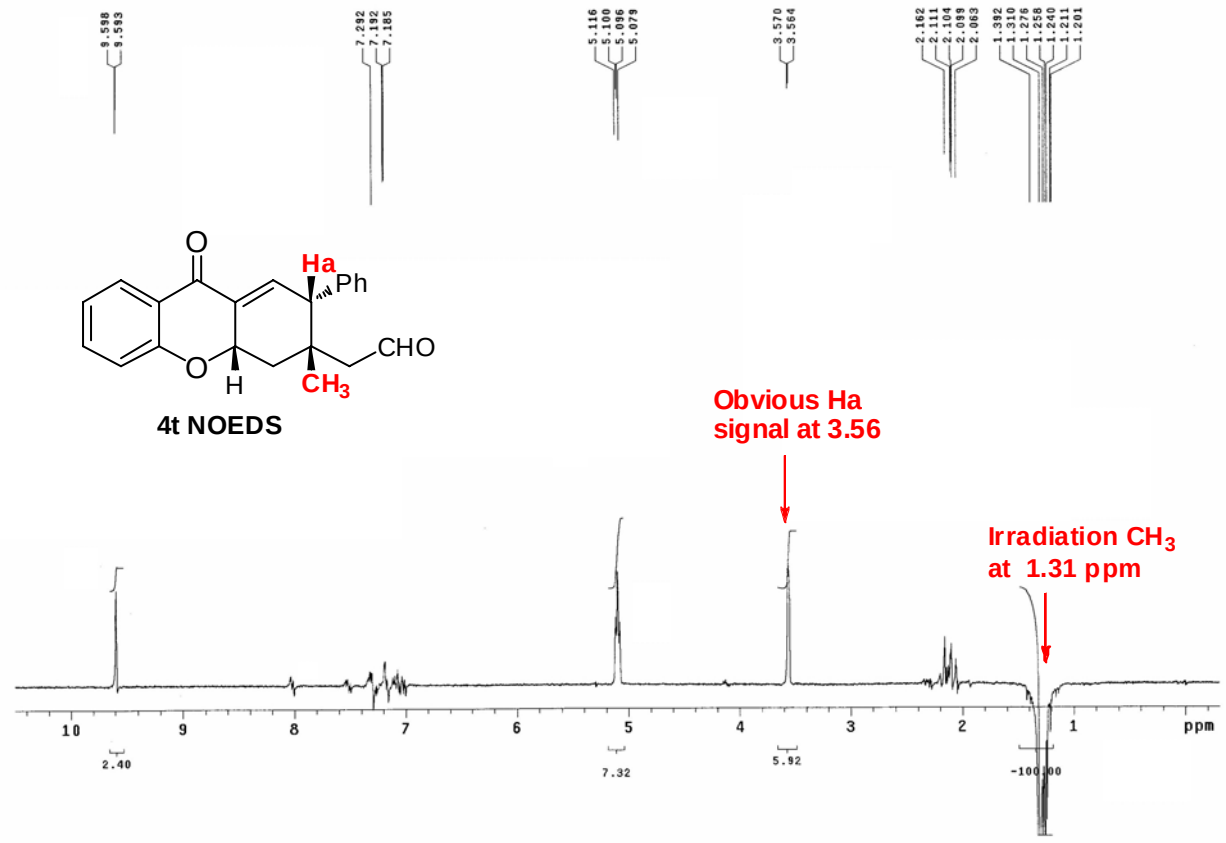
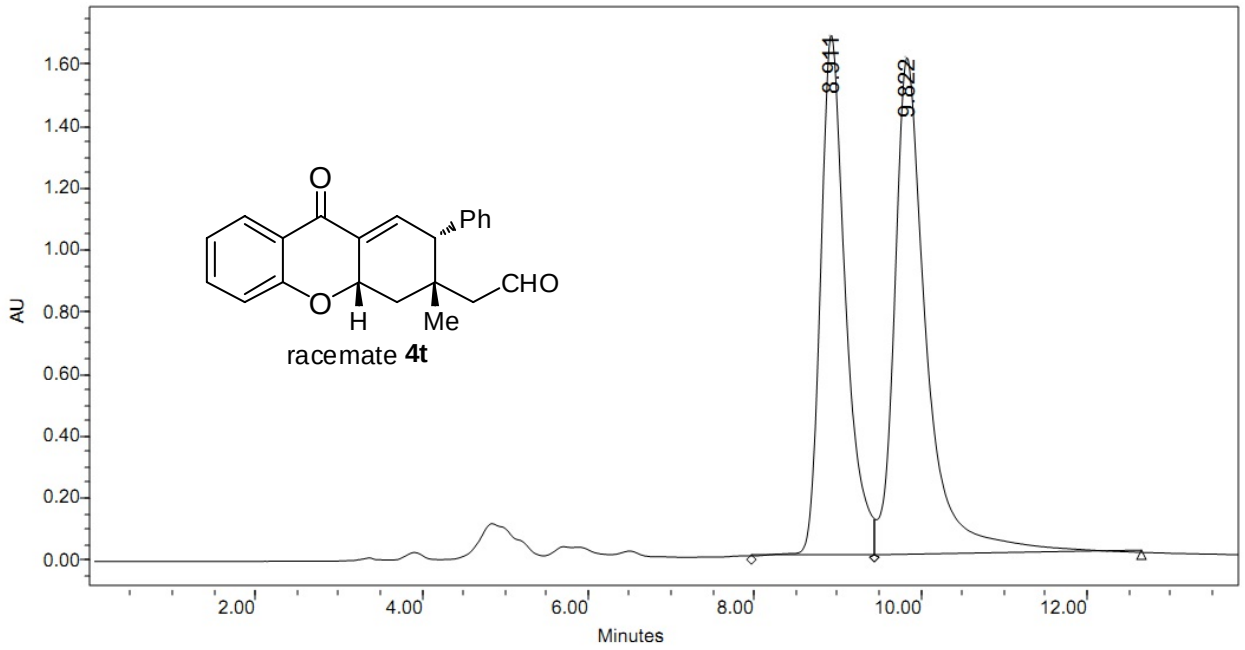
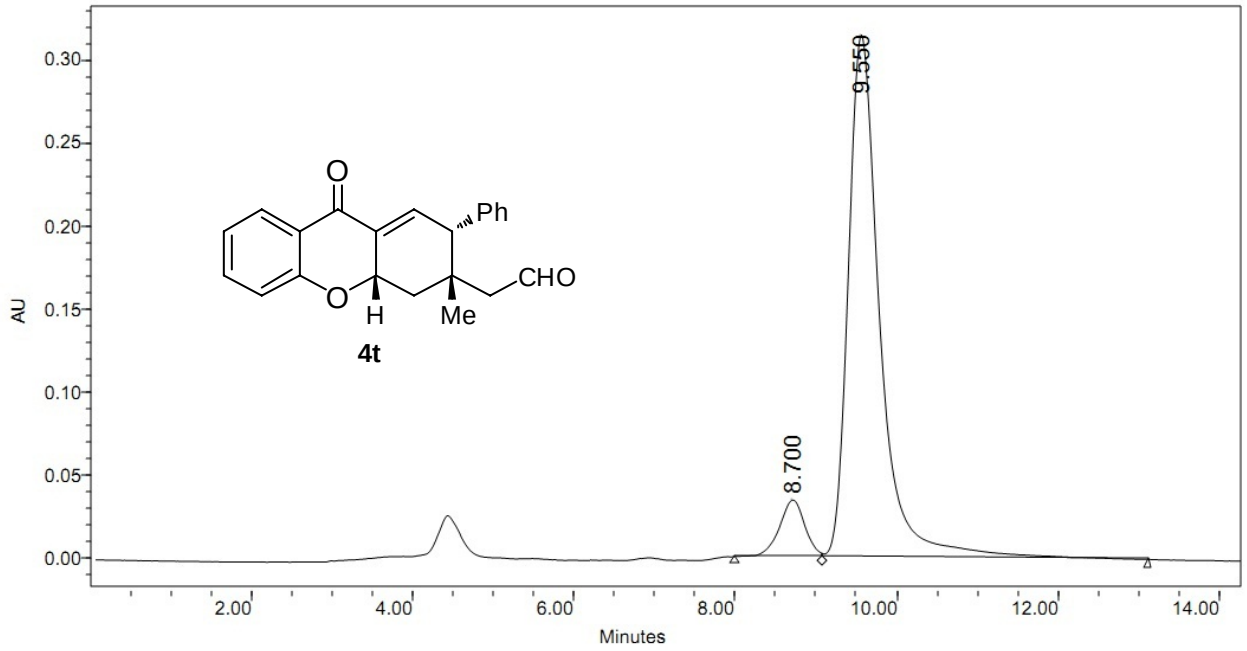
60
40
20
0
ppm


Ha
Ph
CHO
CH3
H
O
4t
CH3 signal
Ha
ppm

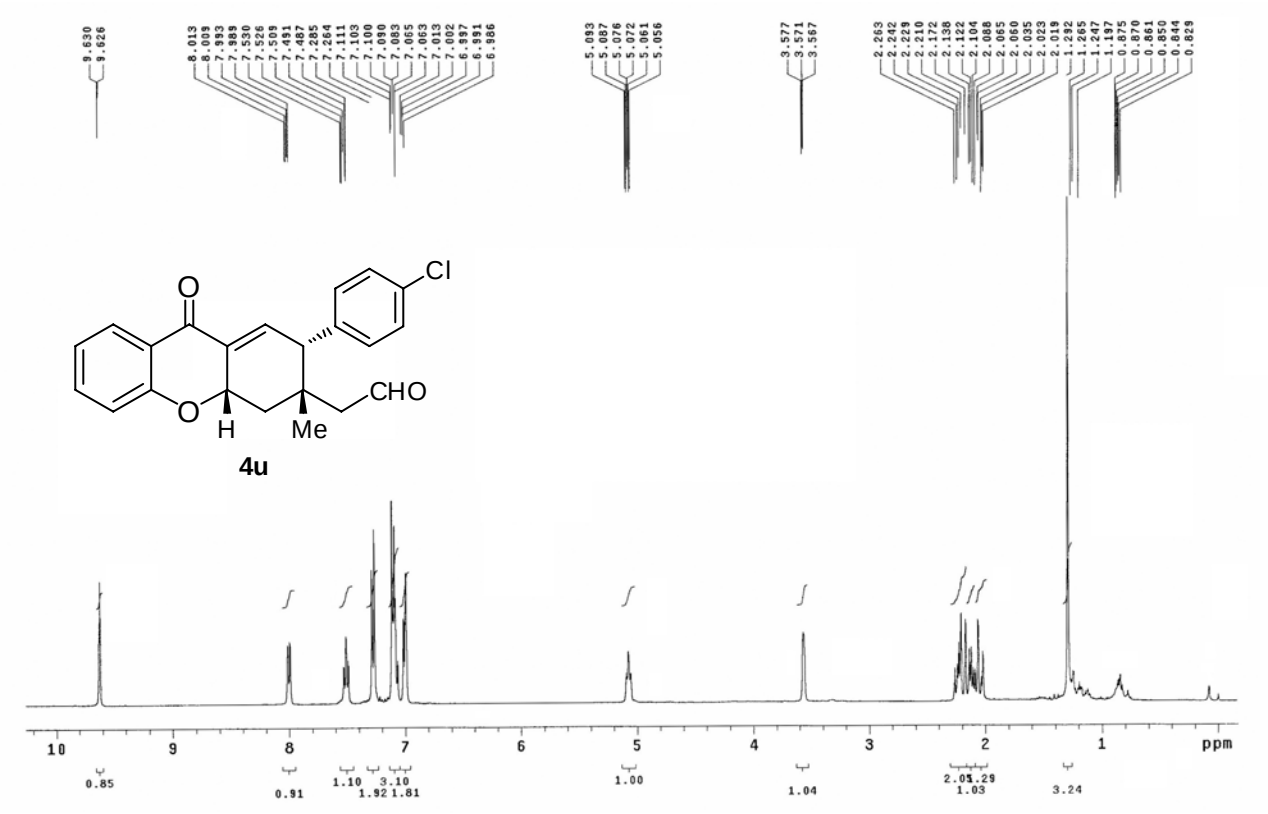

Ha
Ph
CHO
CH3
H
O
4t NOEDS
Obvious Ha
signal at 3.56
Irradiation CH3
at 1.31 ppm
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	8.911	34016284	47.78	1655314	51.42
2	9.822	37178239	52.22	1563674	48.58



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	8.700	761295	8.09	34363	9.84
2	9.550	8648039	91.91	314947	90.16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7.264
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7.065
7.063
7.013
7.002
6.997
6.991
6.986
5.093
5.087
5.076
5.072
5.061
5.056
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3.571
3.567
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2.229
2.210
2.172
2.138
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2.060
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1.265
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0.861
0.850
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0.829
Cl
O
CHO
O
H
Me
4u
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7
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1
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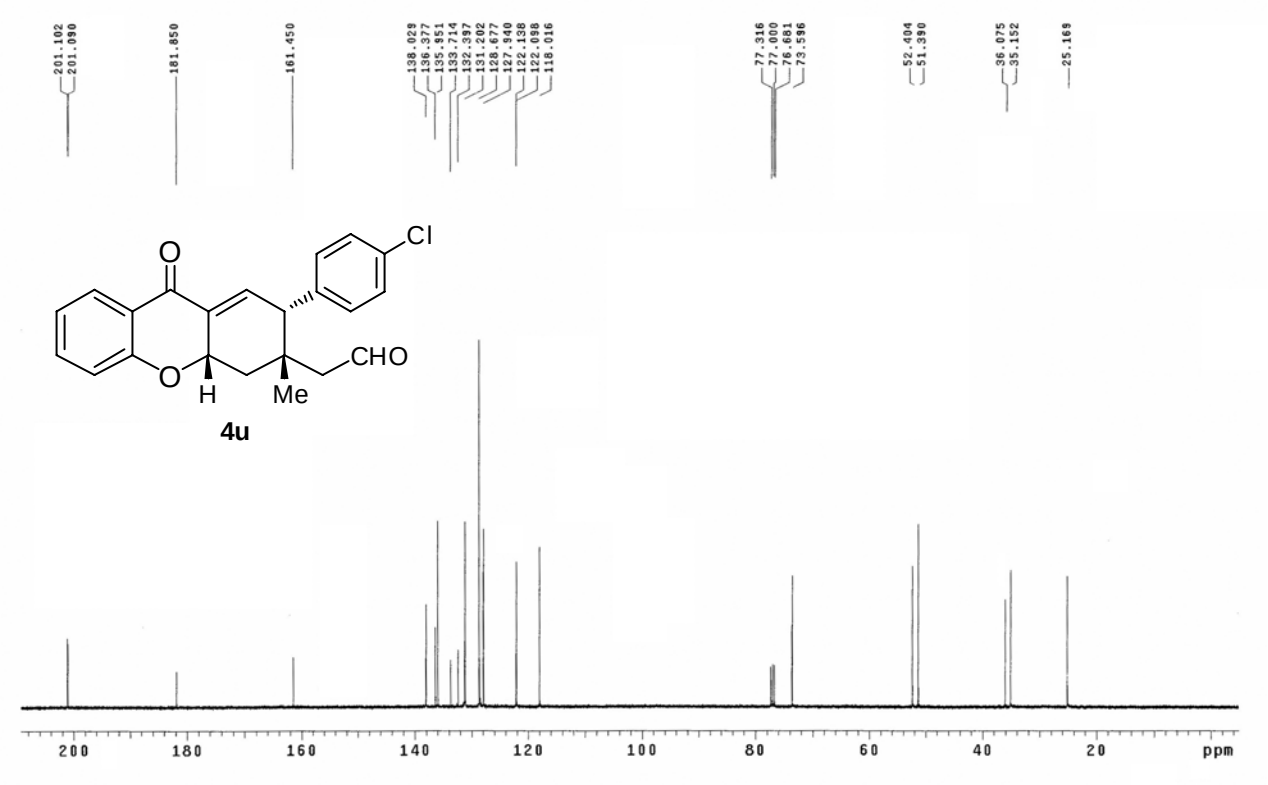
1.03
3.24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122.098
118.016
77.316
77.000
76.681
73.596
52.404
51.390
36.075
35.152
25.169
Cl
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CHO
O
H
Me
4u
200
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140
120
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80
60
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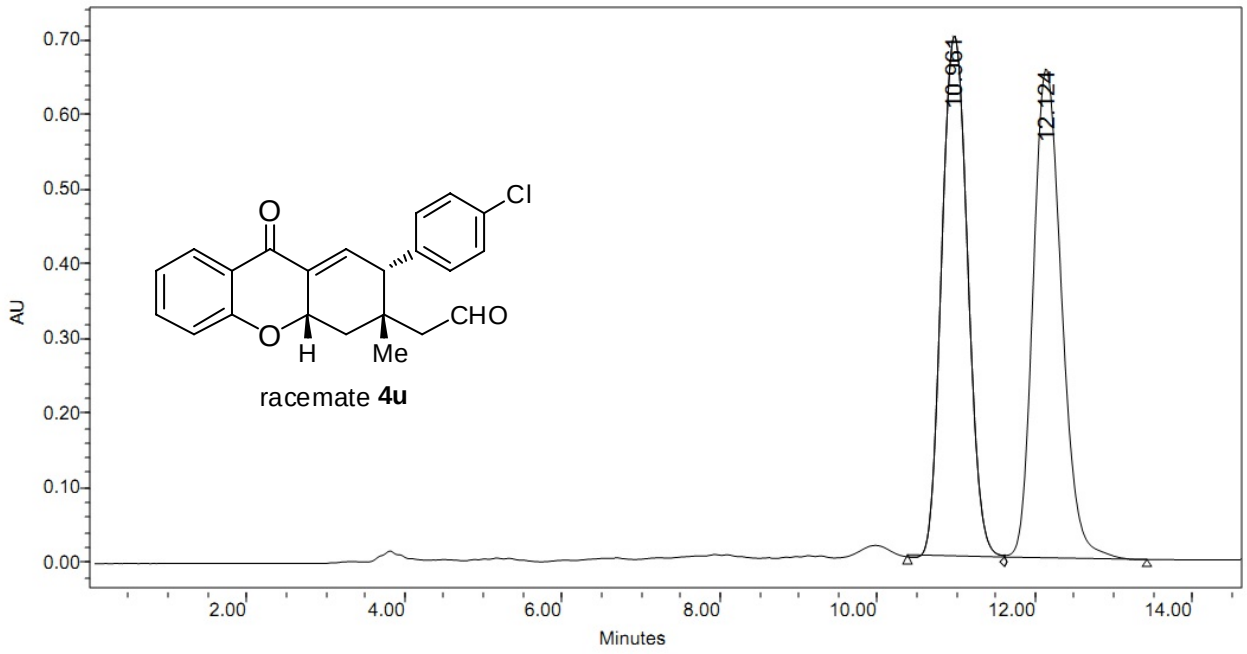
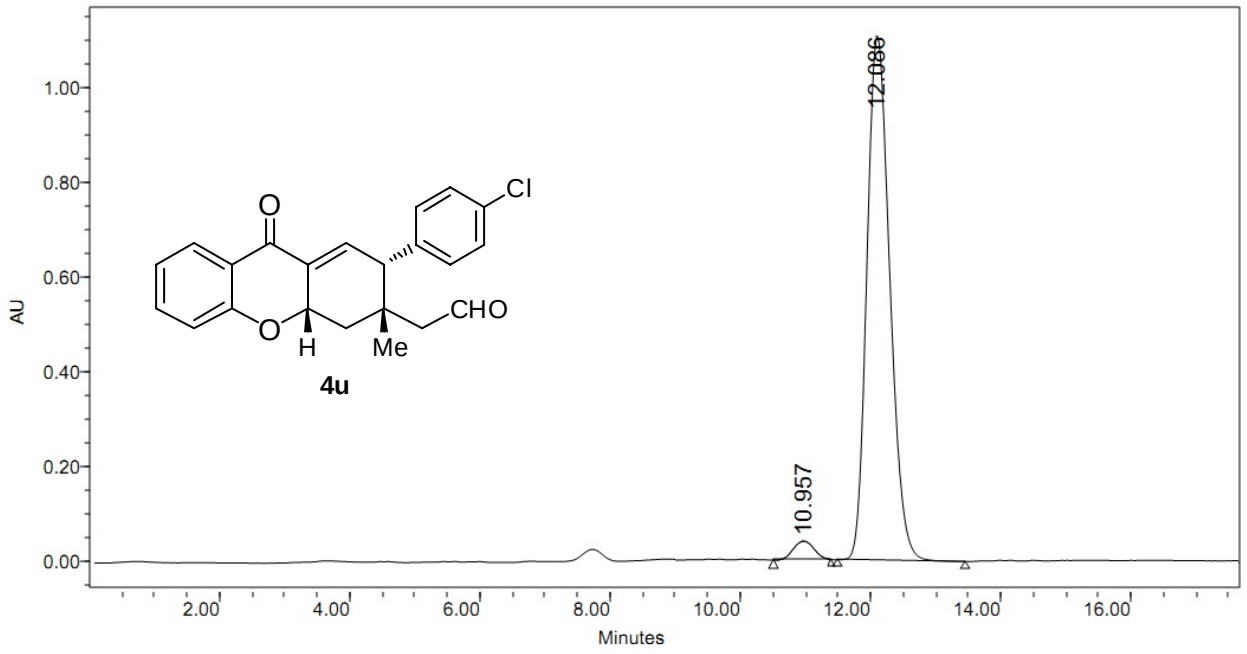
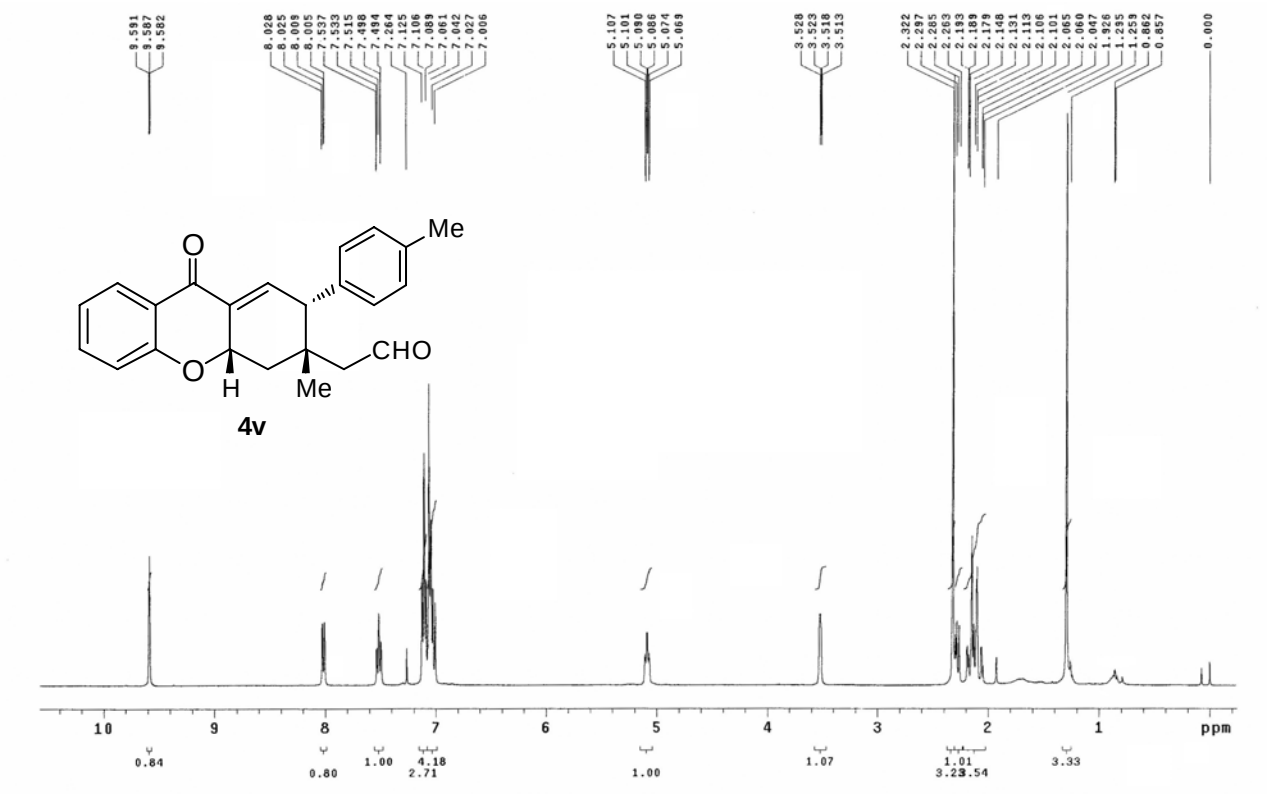
20
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.961	16097313	49.40	699758	51.59
2	12.124	16486042	50.60	656661	48.41



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.957	875082	3.14	39304	3.43
2	12.086	27022245	96.86	1108199	96.57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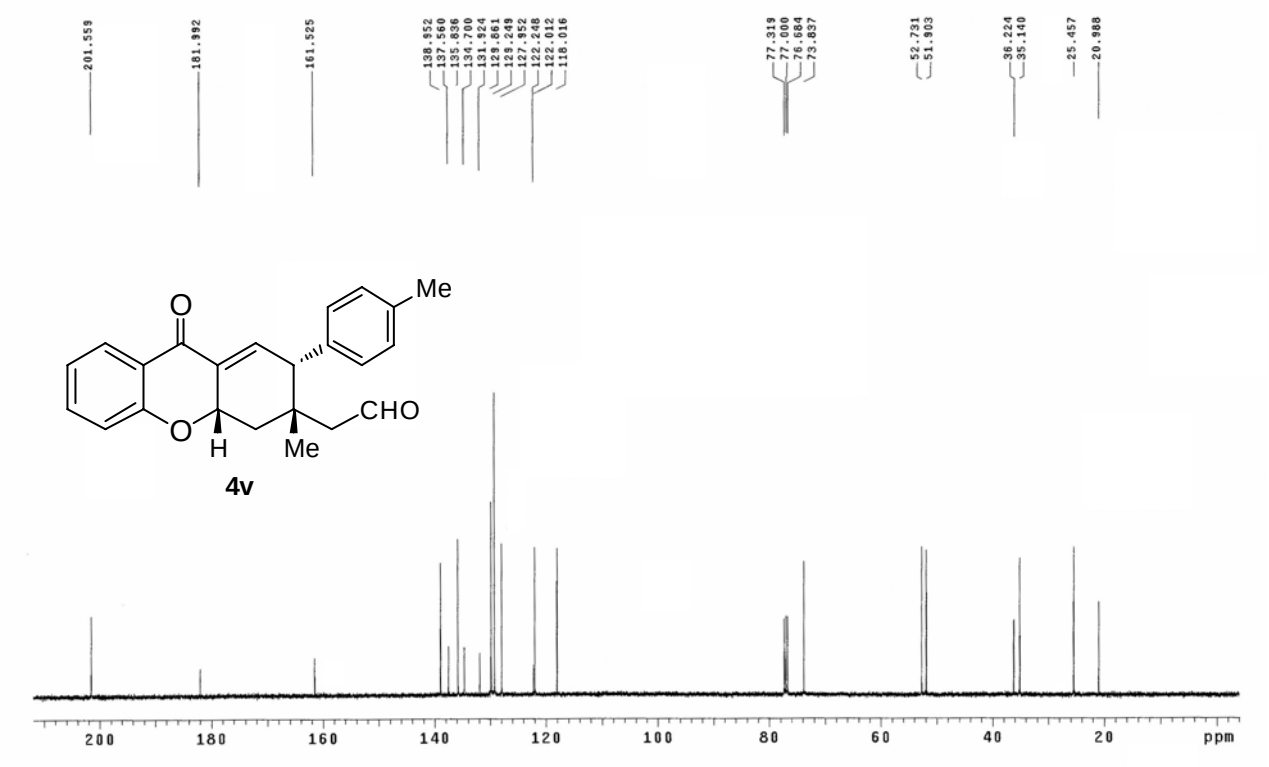
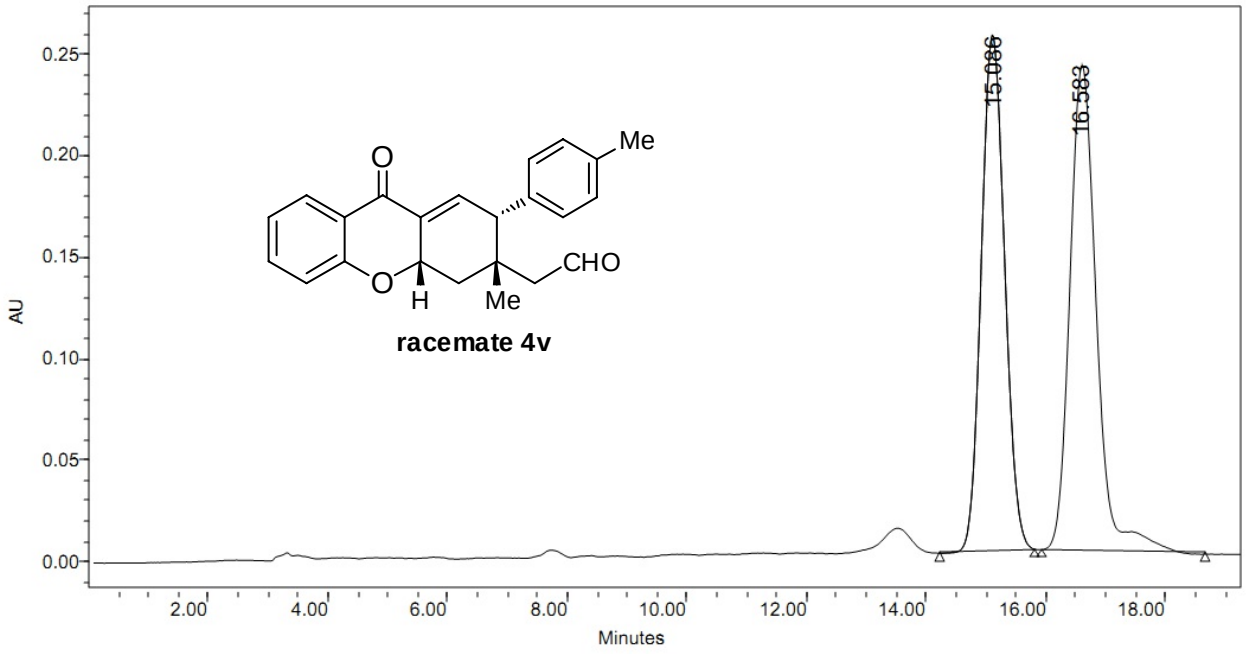
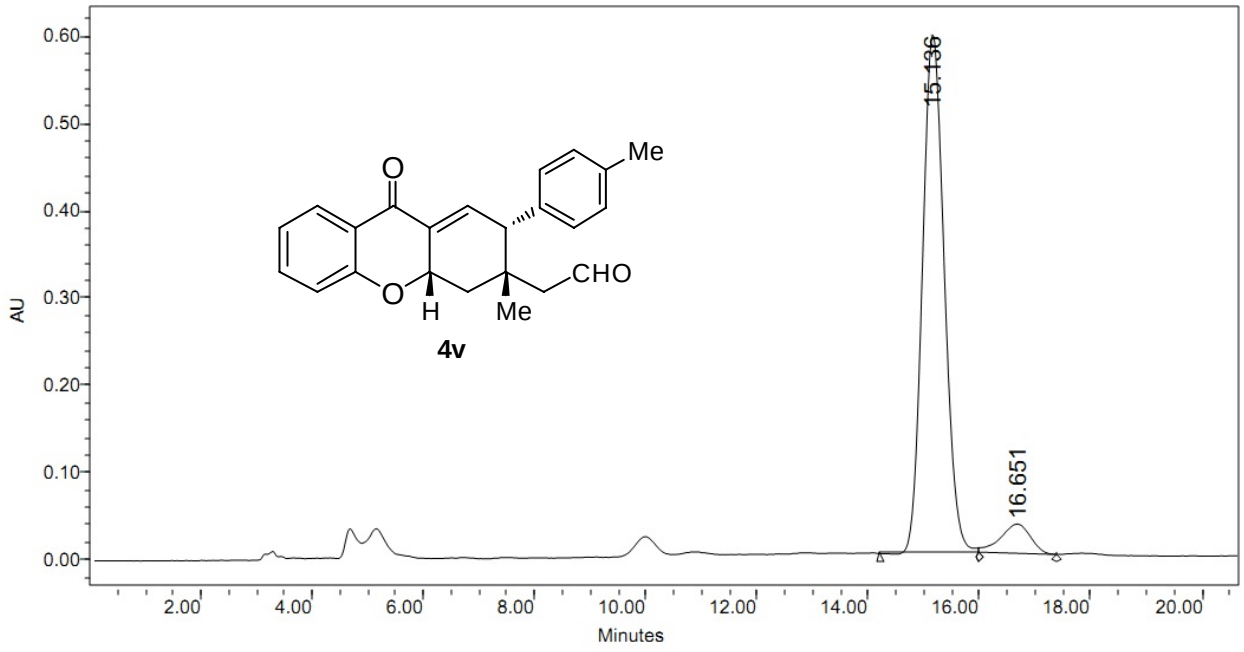
CHO
O
H
Me
4v
ppm

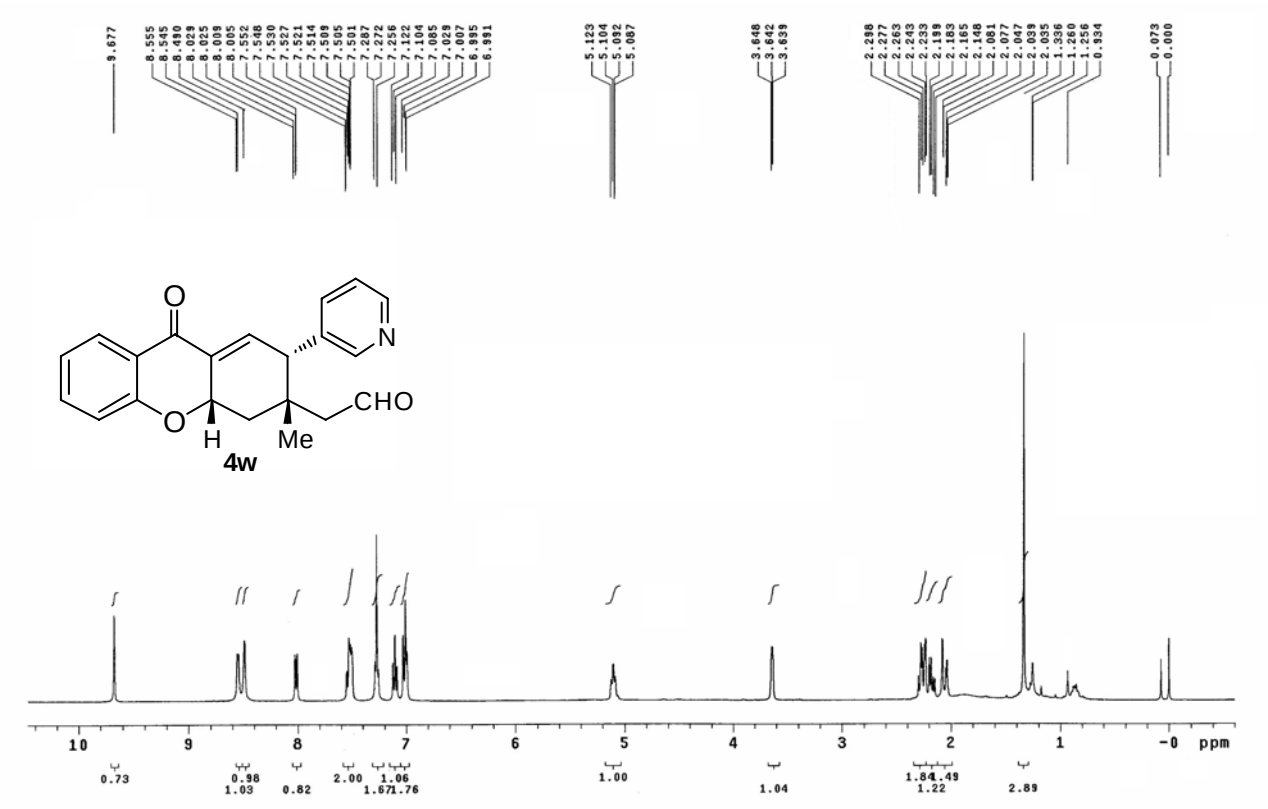

Me
O
CHO
O
H
Me
4v
ppm

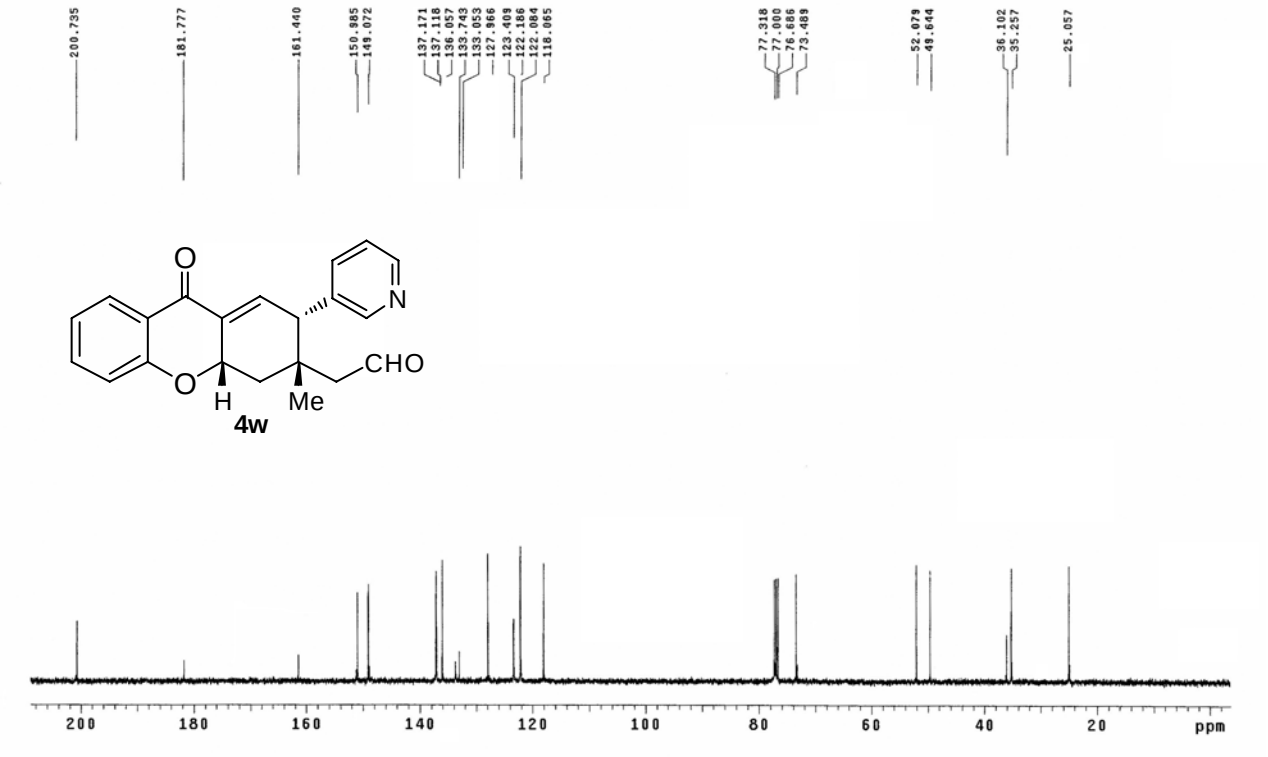


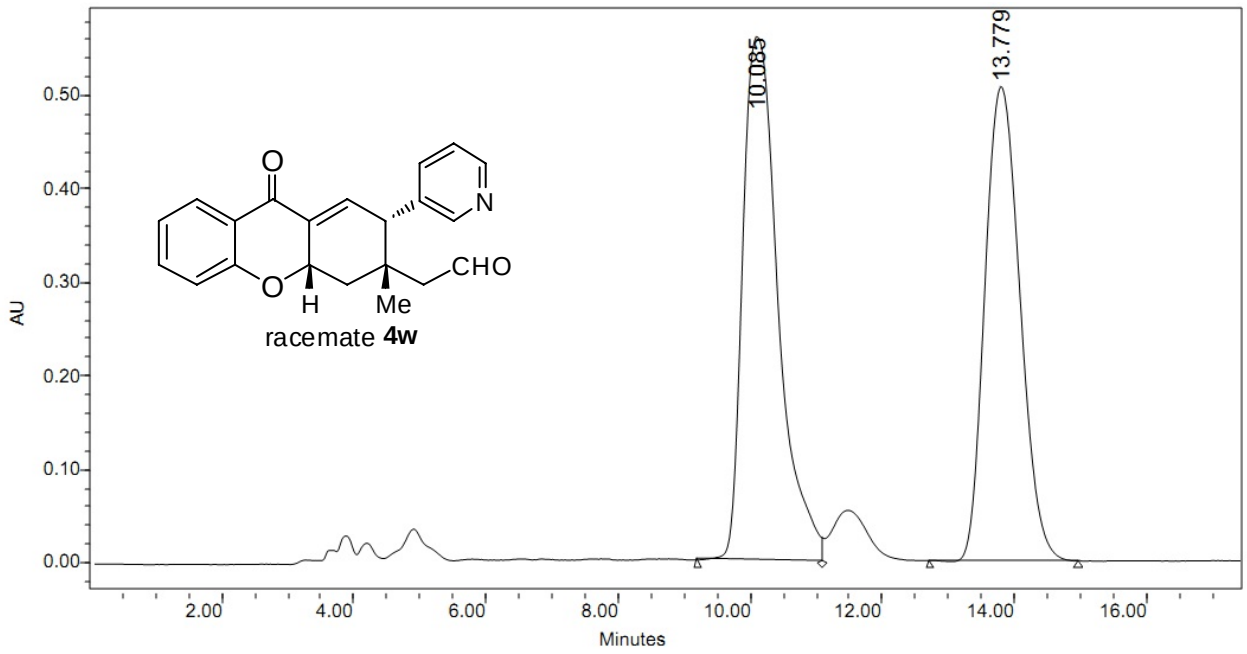
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	15.086	6901528	48.28	254424	51.52
2	16.583	7393265	51.72	239418	48.48



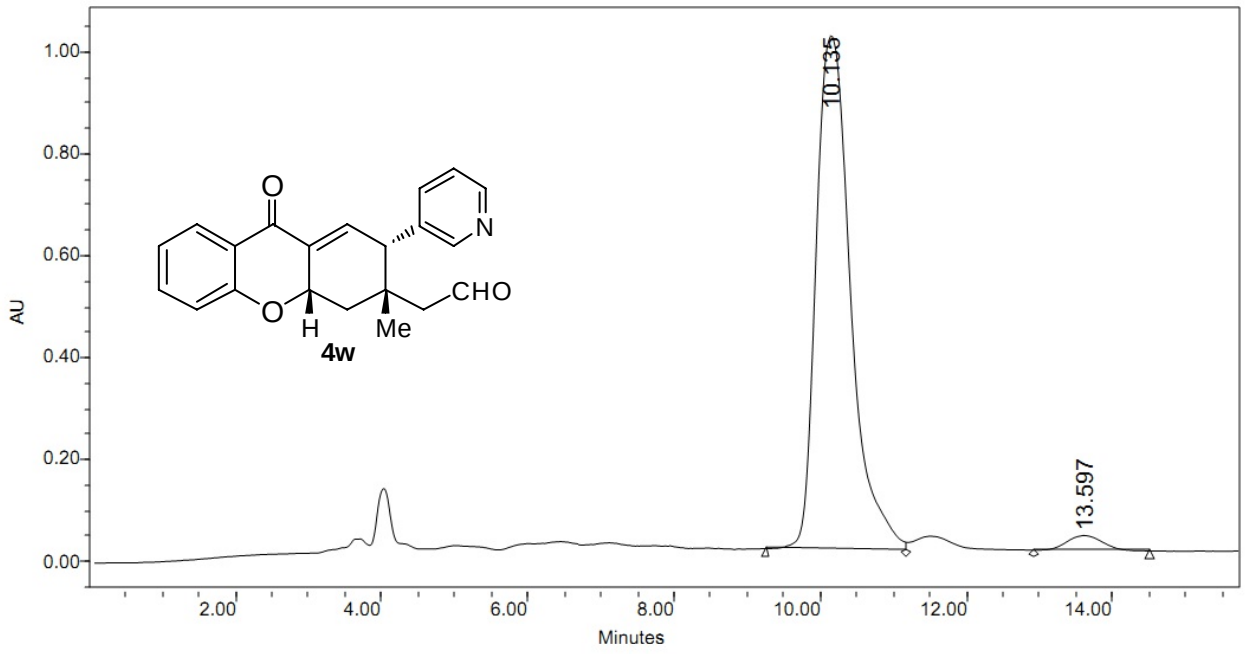
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	15.136	16324230	92.91	595202	94.62
2	16.651	1245624	7.09	33840	5.38



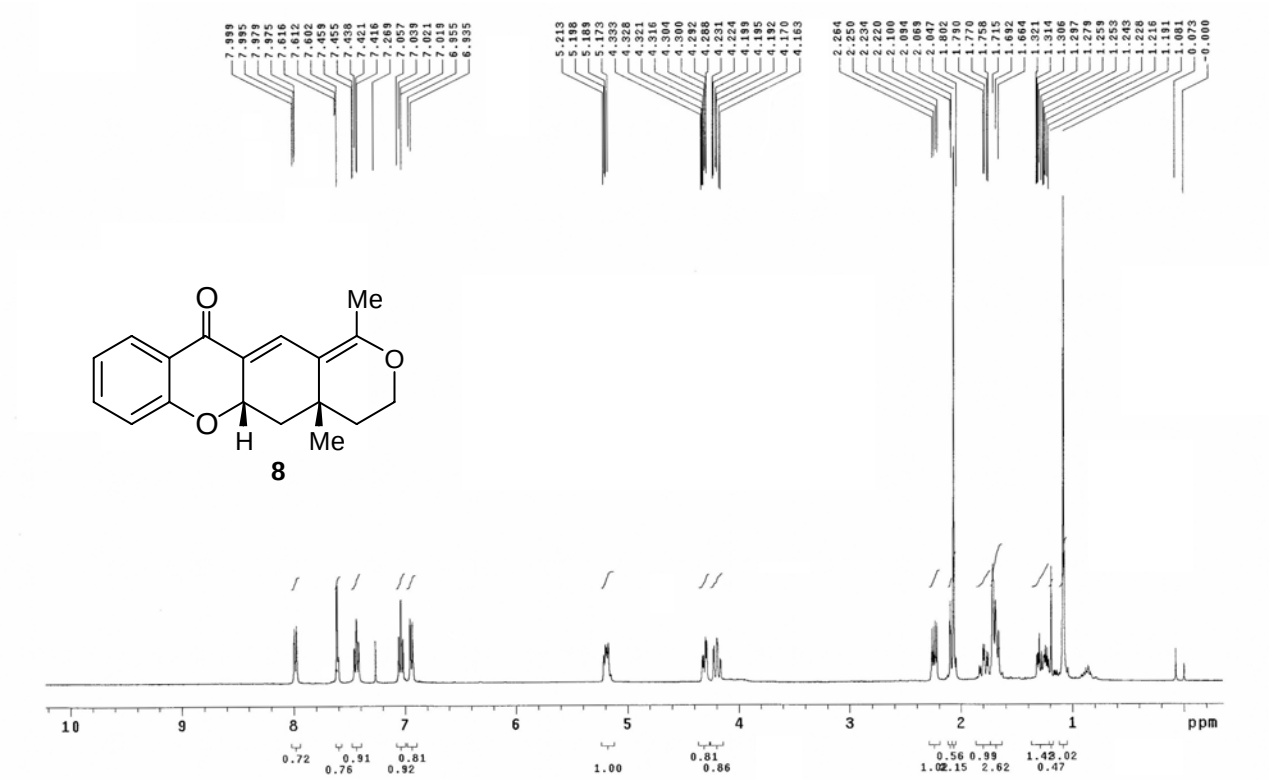


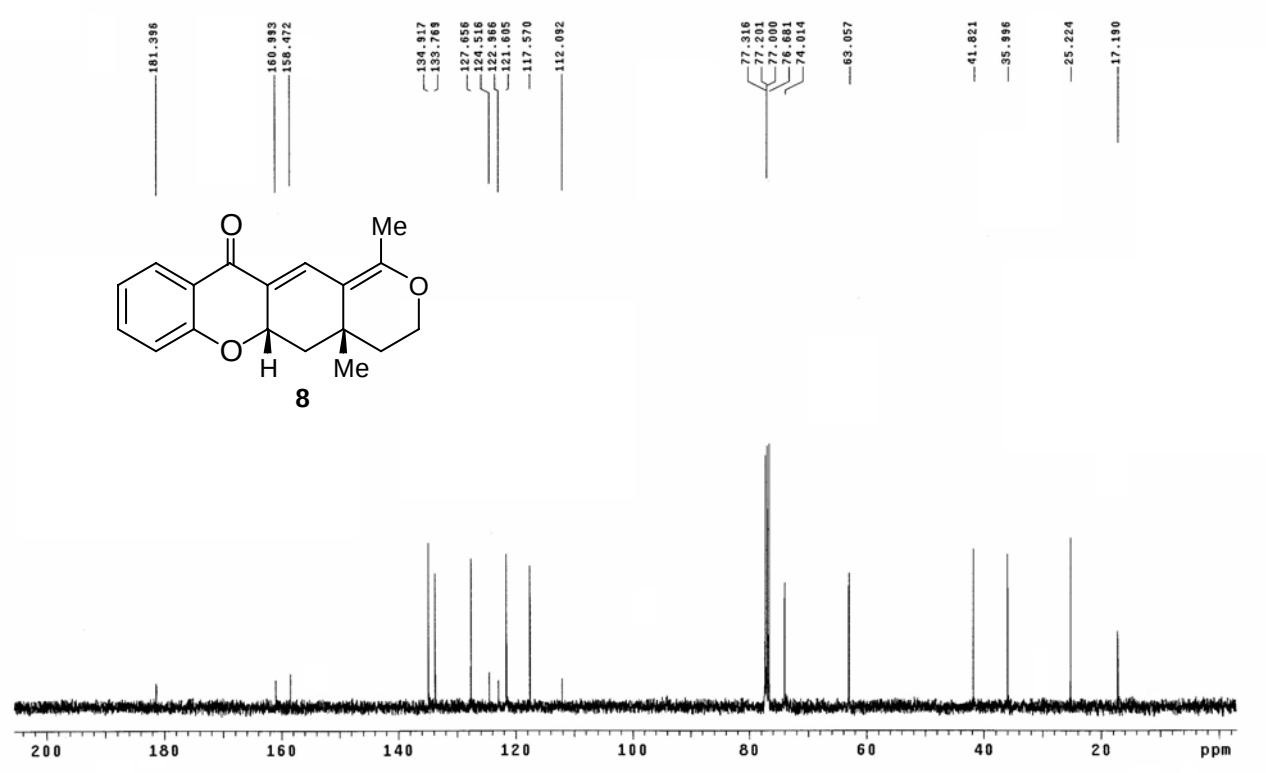


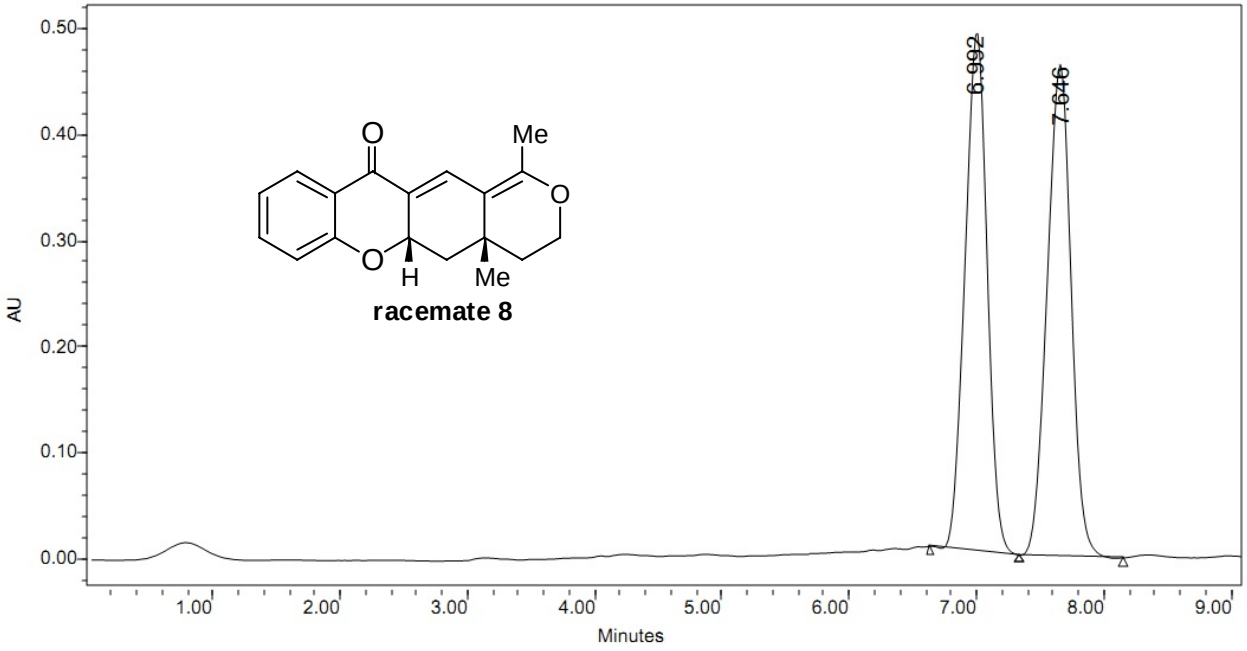
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.085	20938910	52.85	560644	52.49
2	13.779	18682178	47.15	507357	47.51



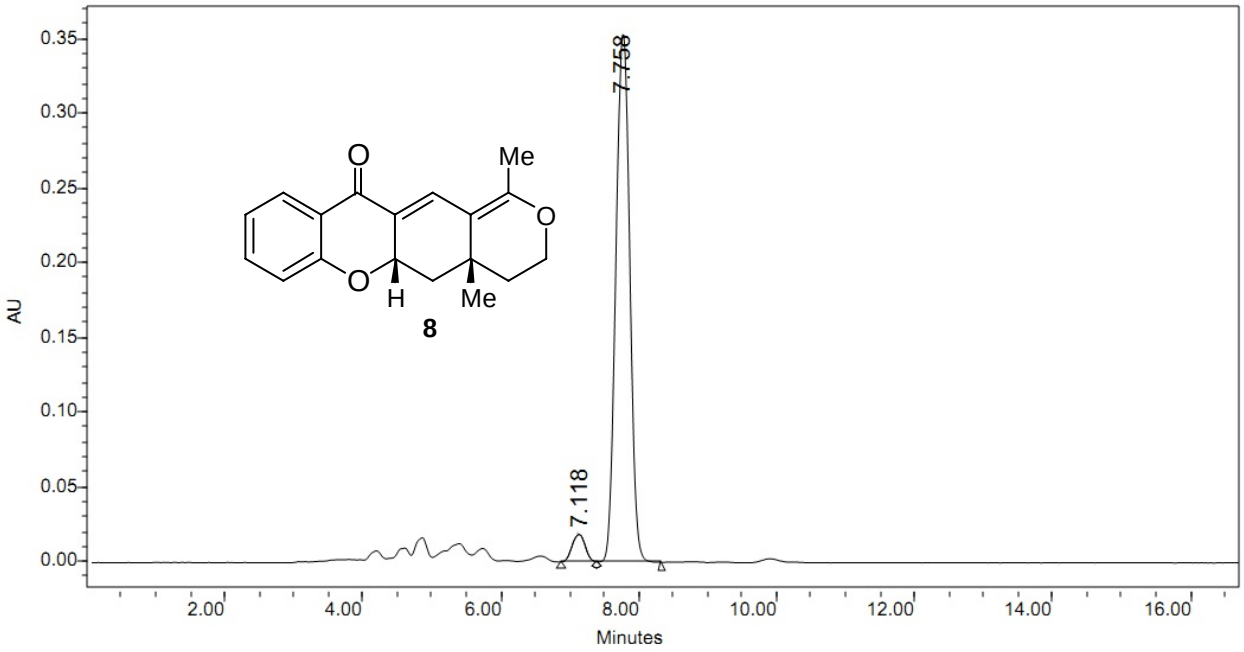
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.135	32974727	97.07	1006314	97.17
2	13.597	995571	2.93	29334	2.83


O
Me
O
O
H
Me
8
ppm

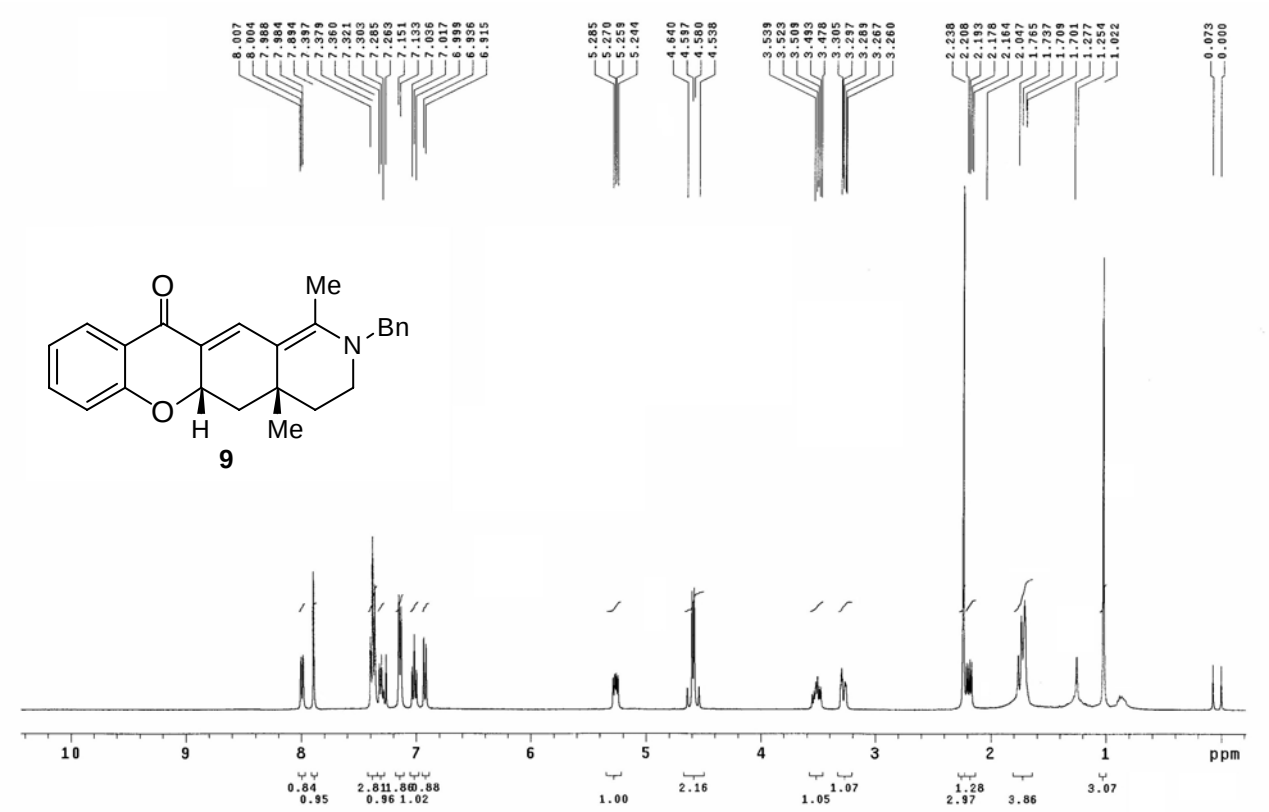

O
Me
O
O
H
Me
8
ppm



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	6.992	5910546	49.33	489996	51.35
2	7.646	6070840	50.67	464143	48.65



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	7.118	238198	4.59	18233	4.90
2	7.758	4949999	95.41	354006	95.10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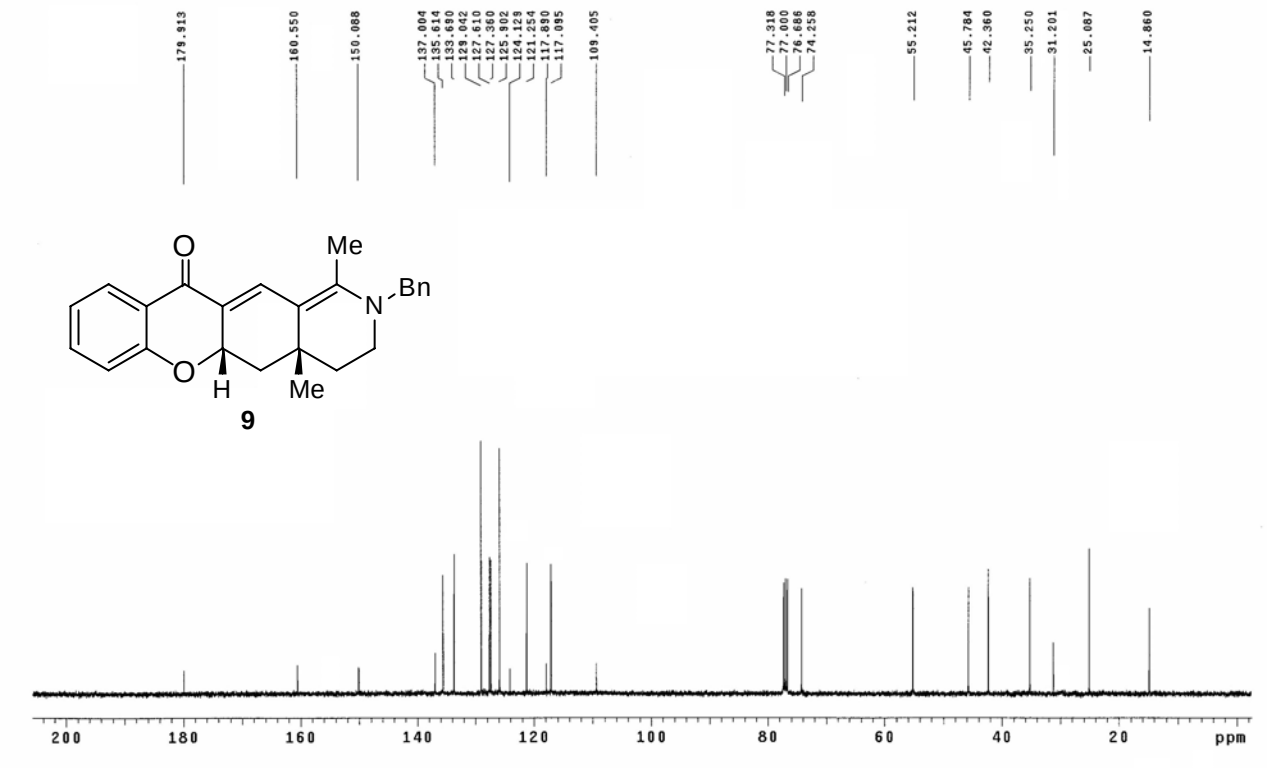
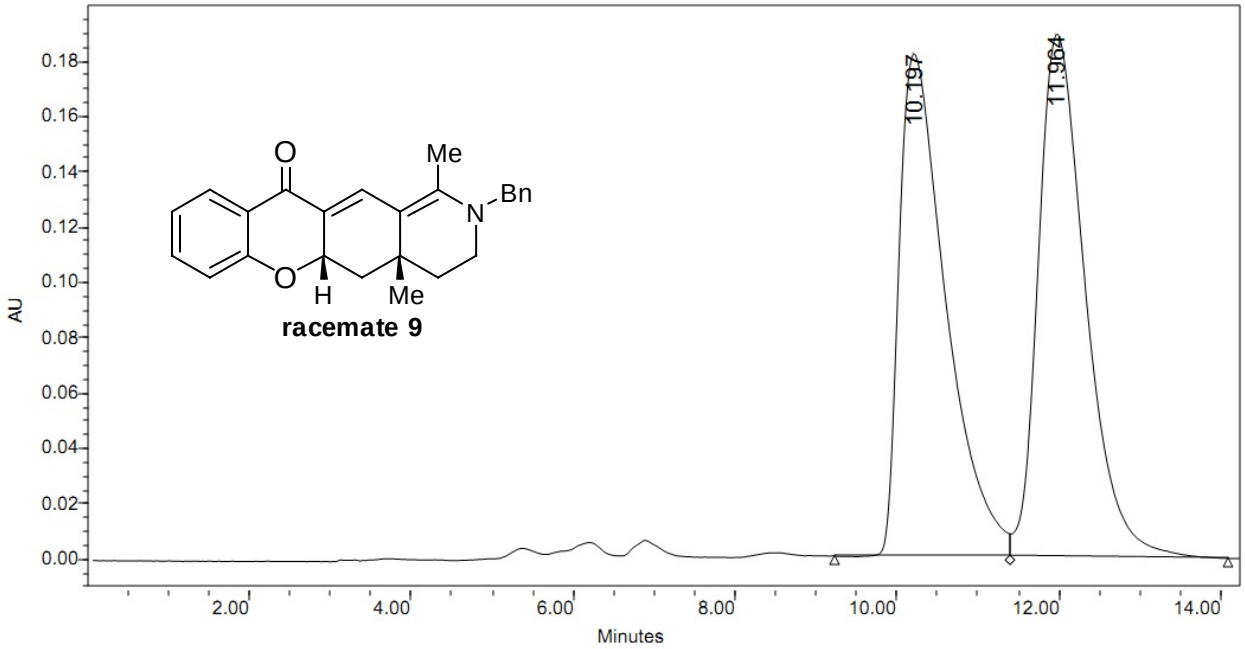
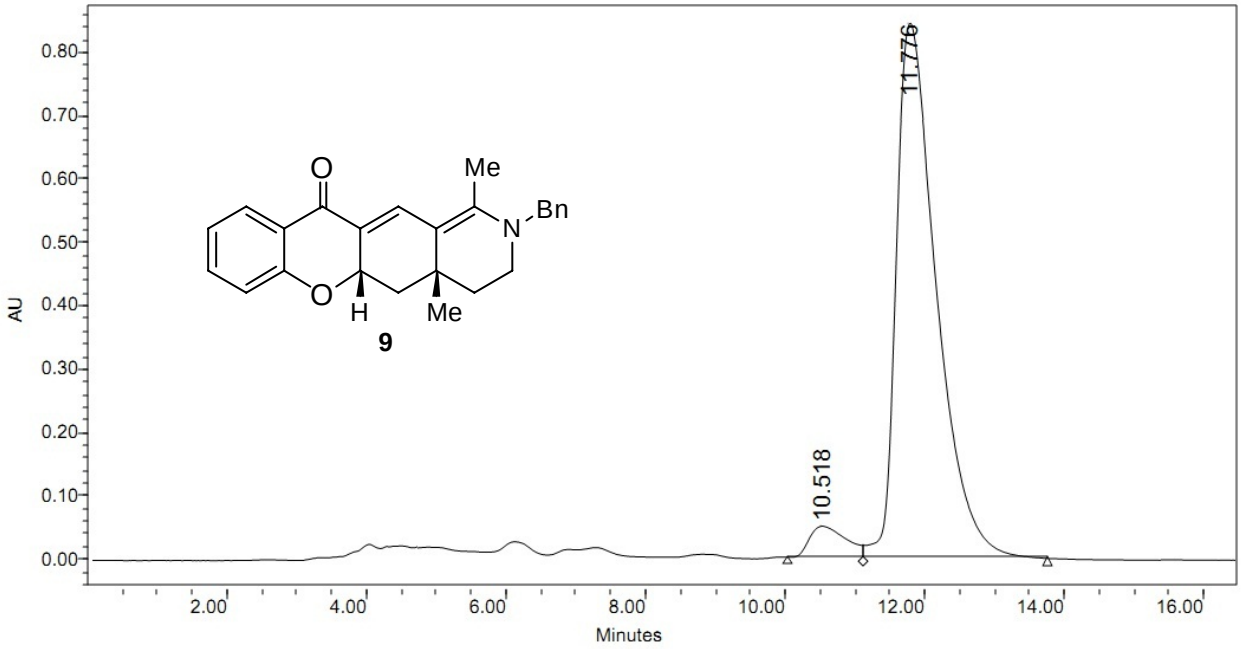
8.004
7.988
7.984
7.884
7.397
7.379
7.360
7.321
7.303
7.285
7.263
7.151
7.133
7.036
7.017
6.998
6.936
6.915
5.285
5.270
5.259
5.244
4.640
4.597
4.580
4.538
3.539
3.523
3.509
3.493
3.478
3.305
3.297
3.289
3.267
3.260
2.238
2.208
2.193
2.178
2.164
2.047
1.765
1.737
1.709
1.701
1.277
1.254
1.022
0.073
0.000
O
Me
N
Bn
O
H
Me
9
10
9
8
7
6
5
4
3
2
1
ppm
0.84
0.95
2.81
1.86
0.96
0.88
1.02
1.00
2.16
1.05
1.07
2.97
1.28
3.86
3.07

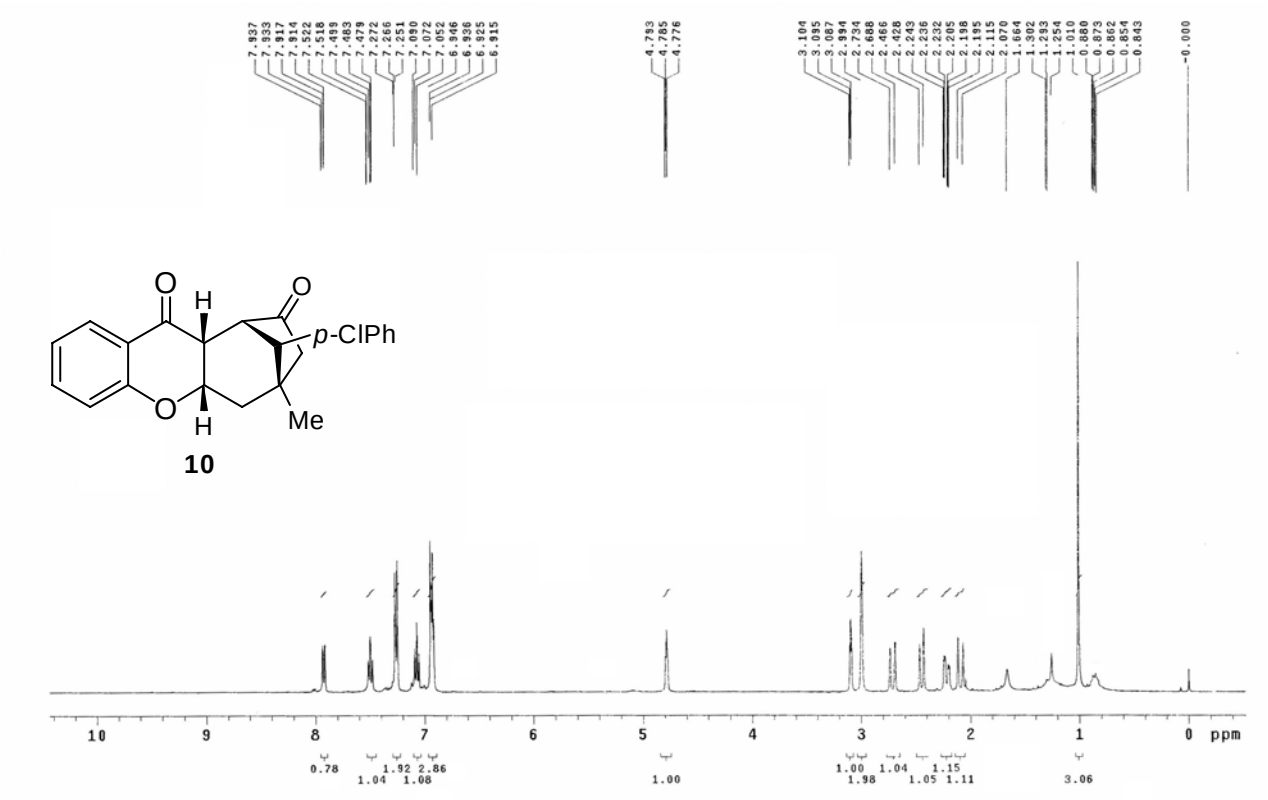

179.913
160.550
150.088
137.004
135.614
133.690
129.042
127.610
127.360
125.902
124.128
121.254
117.890
117.095
109.405
77.318
77.000
76.686
74.258
55.212
45.784
42.360
35.250
31.201
25.087
14.860
O
Me
N
Bn
O
H
Me
9
200
180
160
140
120
100
80
60
40
20
ppm

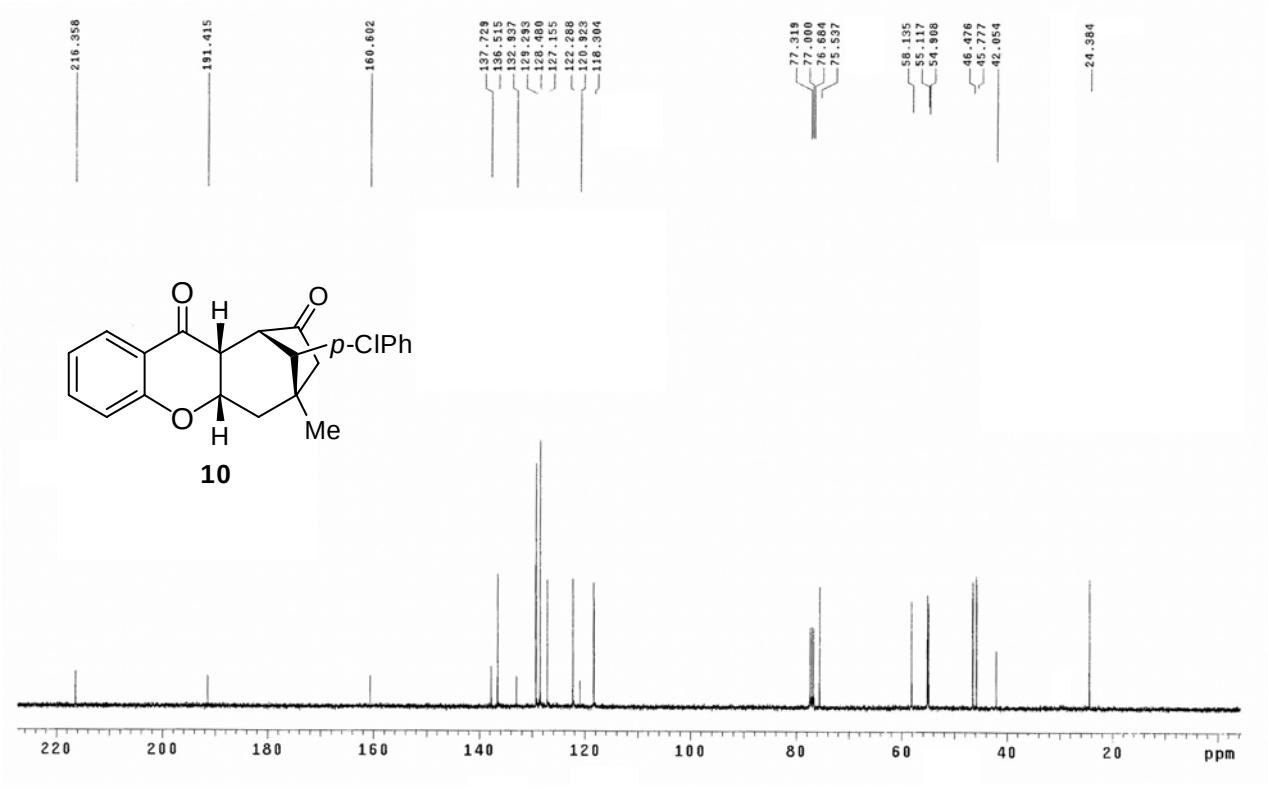


	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.197	7320215	48.76	181711	49.00
2	11.964	7692348	51.24	189104	51.00



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.518	1526181	4.42	44053	5.07
2	11.776	32990697	95.58	824323	94.93


7.937
7.933
7.917
7.914
7.522
7.518
7.499
7.483
7.479
7.272
7.266
7.251
7.090
7.072
7.052
6.946
6.936
6.925
6.915
4.783
4.785
4.776
3.104
3.095
3.087
2.994
2.734
2.688
2.466
2.428
2.243
2.236
2.232
2.205
2.198
2.195
2.115
2.070
1.664
1.392
1.253
1.254
1.010
0.880
0.873
0.862
0.854
0.843
0.000
O
H
O
p-ClPh
O
H
Me
10
10
9
8
7
6
5
4
3
2
1
0
ppm
0.78
1.92
2.86
1.04
1.08
1.00
1.00
1.04
1.15
1.98
1.05
1.11
3.06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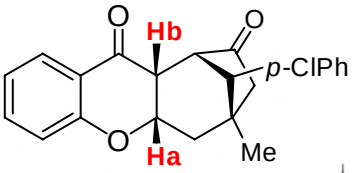
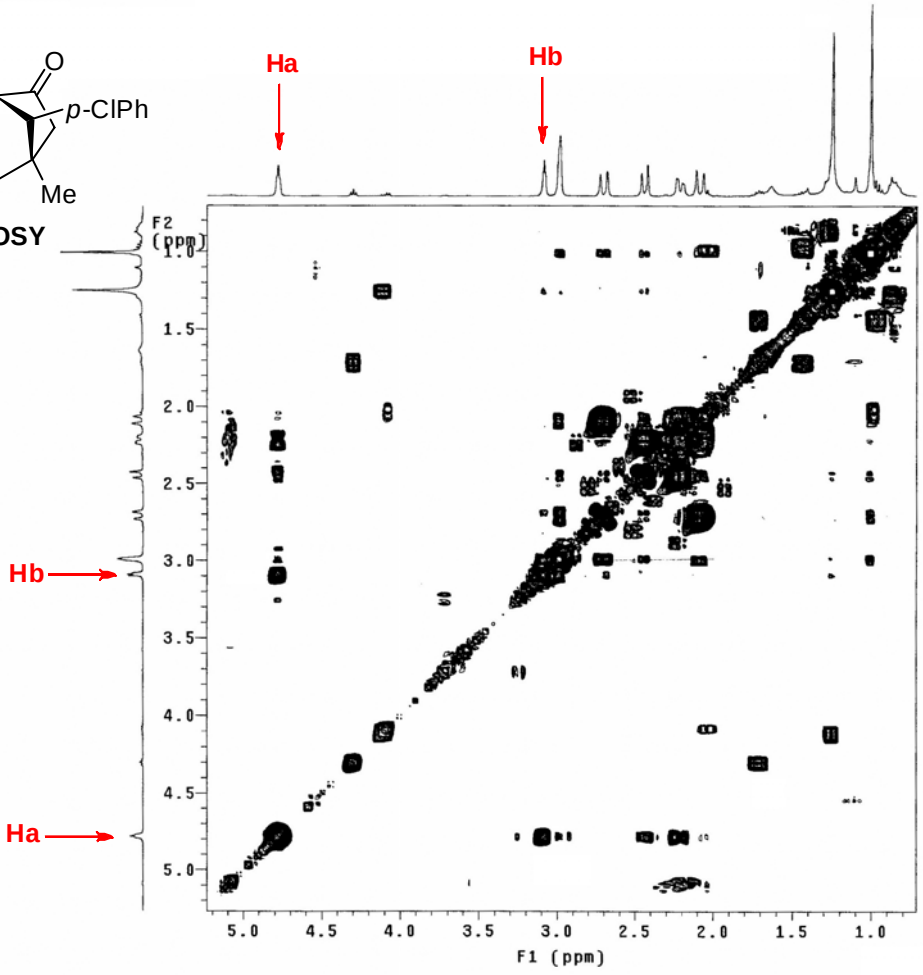
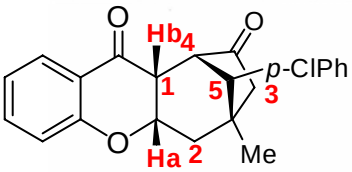
191.415
160.602
137.729
135.515
132.337
128.293
128.080
127.155
122.268
120.923
118.304
77.319
77.000
76.684
75.537
58.135
55.117
54.908
46.476
45.777
42.054
24.384
O
H
O
p-ClPh
O
H
Me
10
220
200
180
160
140
120
100
80
60
40
20
ppm

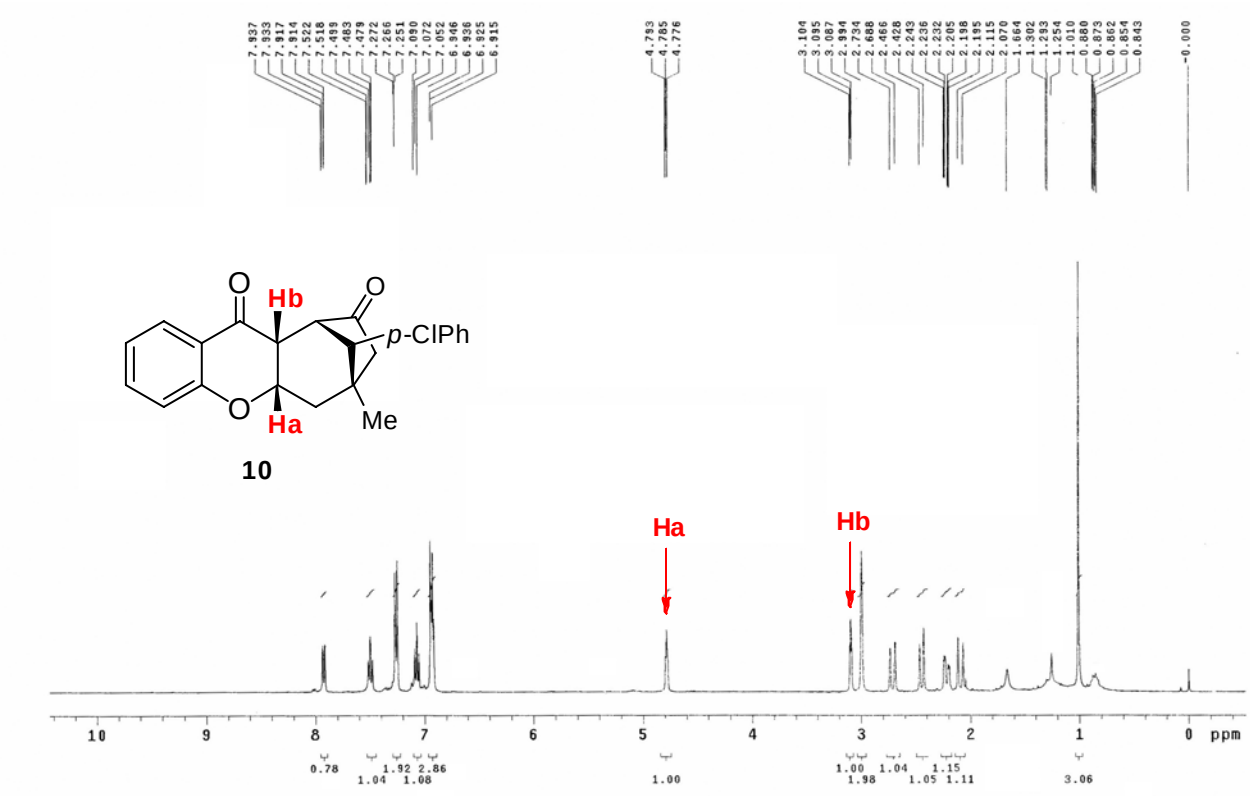


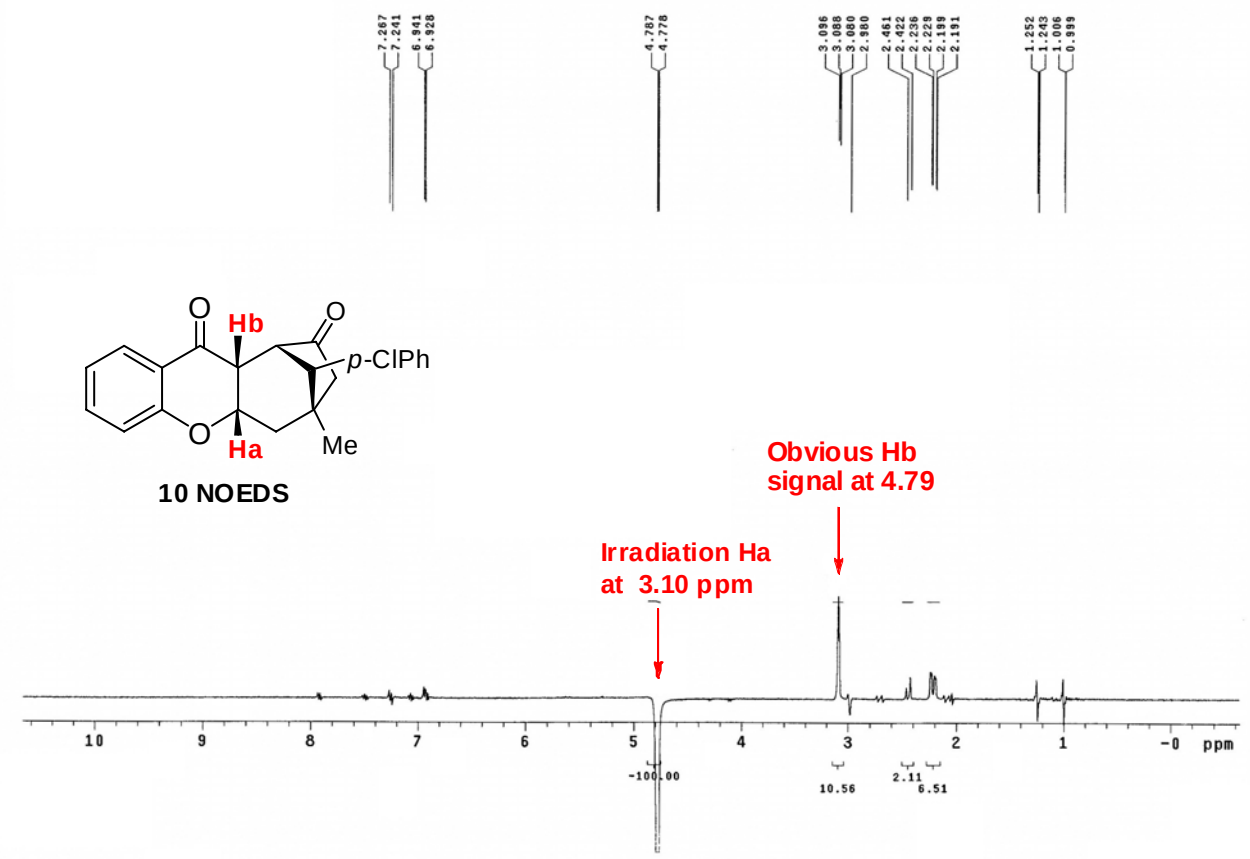
10 H-H COSY

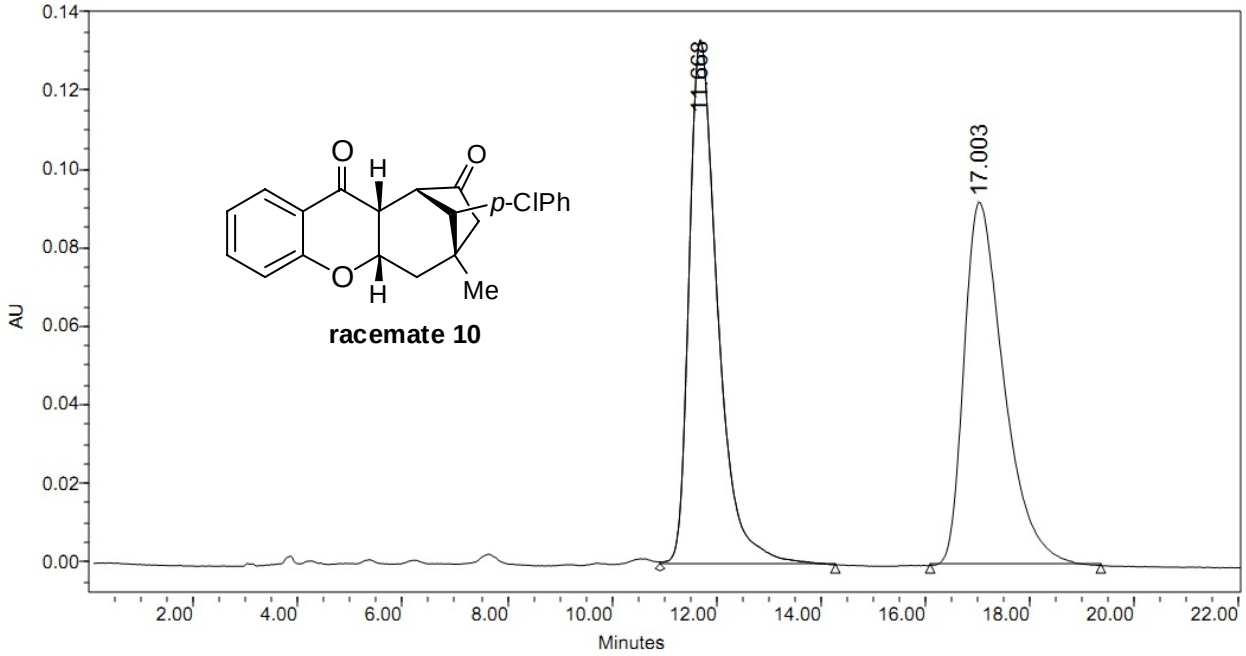




10 HMQC

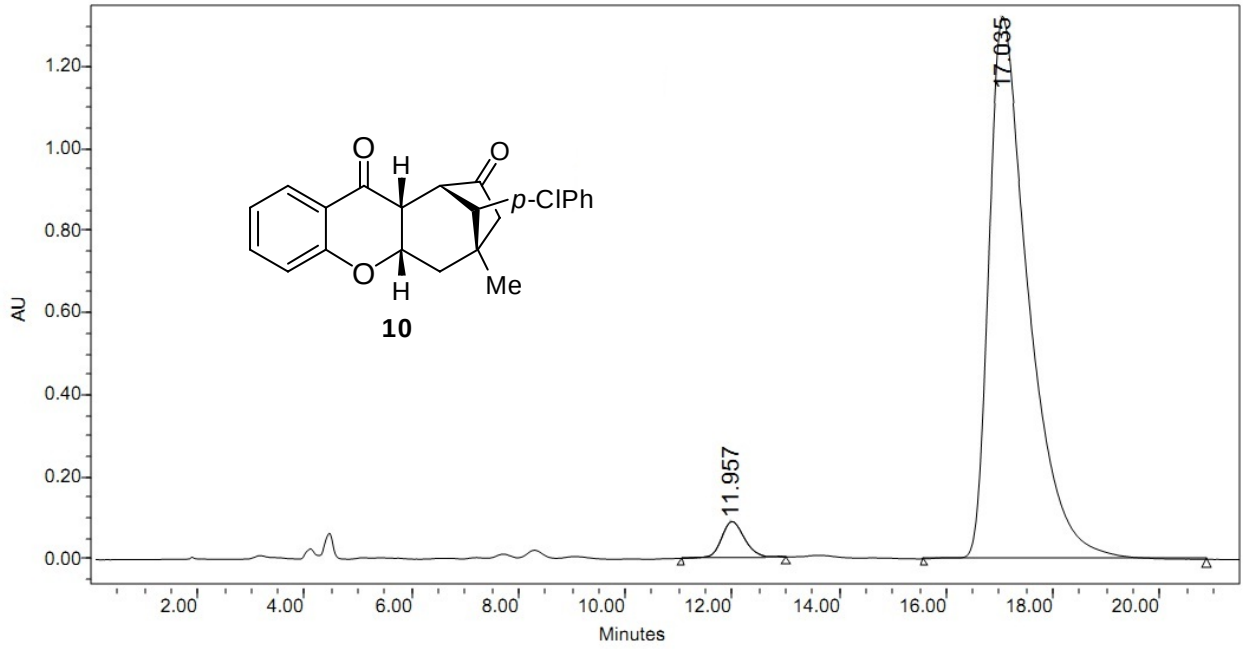

Hb
p-ClPh
Ha
Me
10
Ha
Hb
ppm


Hb
p-ClPh
Ha
Me
10 NOEDS
Obvious Hb
signal at 4.79
Irradiation Ha
at 3.10 ppm
ppm



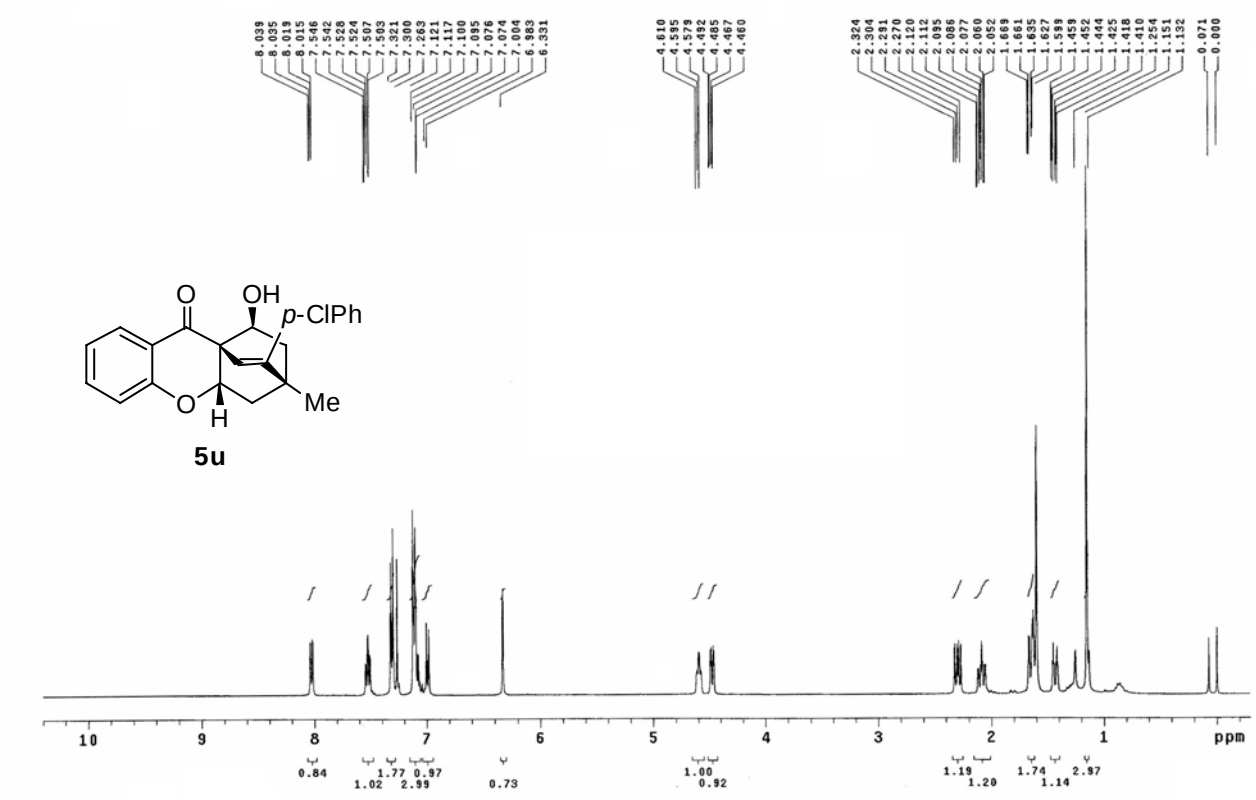
racemate 10

	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	11.668	5102825	50.91	133513	59.07
2	17.003	4920699	49.09	92518	40.93



10

	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	11.957	3649819	5.18	104316	7.53
2	17.035	66798267	94.82	1281079	92.47


8.039
8.035
8.019
8.015
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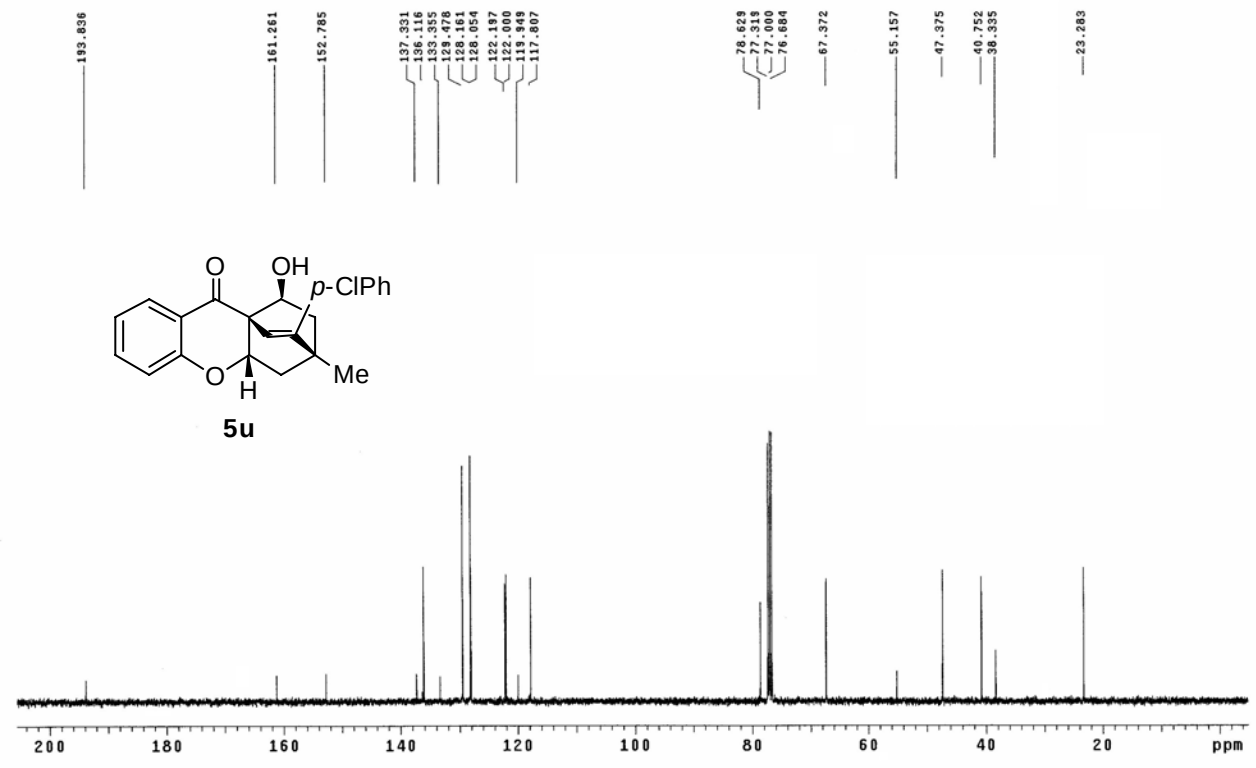
7.542
7.528
7.524
7.507
7.503
7.321
7.300
7.263
7.121
7.117
7.100
7.095
7.076
7.074
7.004
6.983
6.331
4.610
4.595
4.579
4.492
4.485
4.467
4.460
2.324
2.304
2.291
2.270
2.120
2.112
2.095
2.086
2.077
2.060
2.052
1.669
1.661
1.635
1.627
1.598
1.455
1.452
1.444
1.425
1.418
1.410
1.254
1.151
1.132
0.071
0.000
O
OH
p-ClPh
O
H
Me
5u
10
9
8
7
6
5
4
3
2
1
ppm
0.84
1.02
1.77
2.99
0.97
0.73
1.00
0.92
1.19
1.20
1.74
1.14
2.97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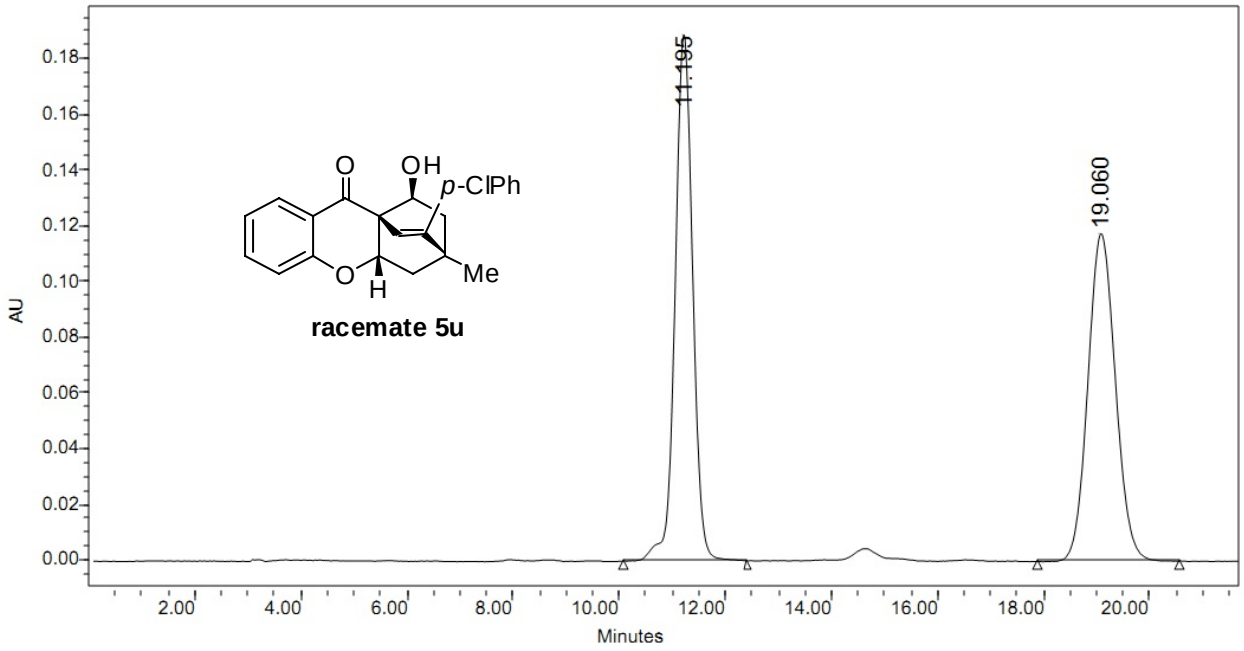
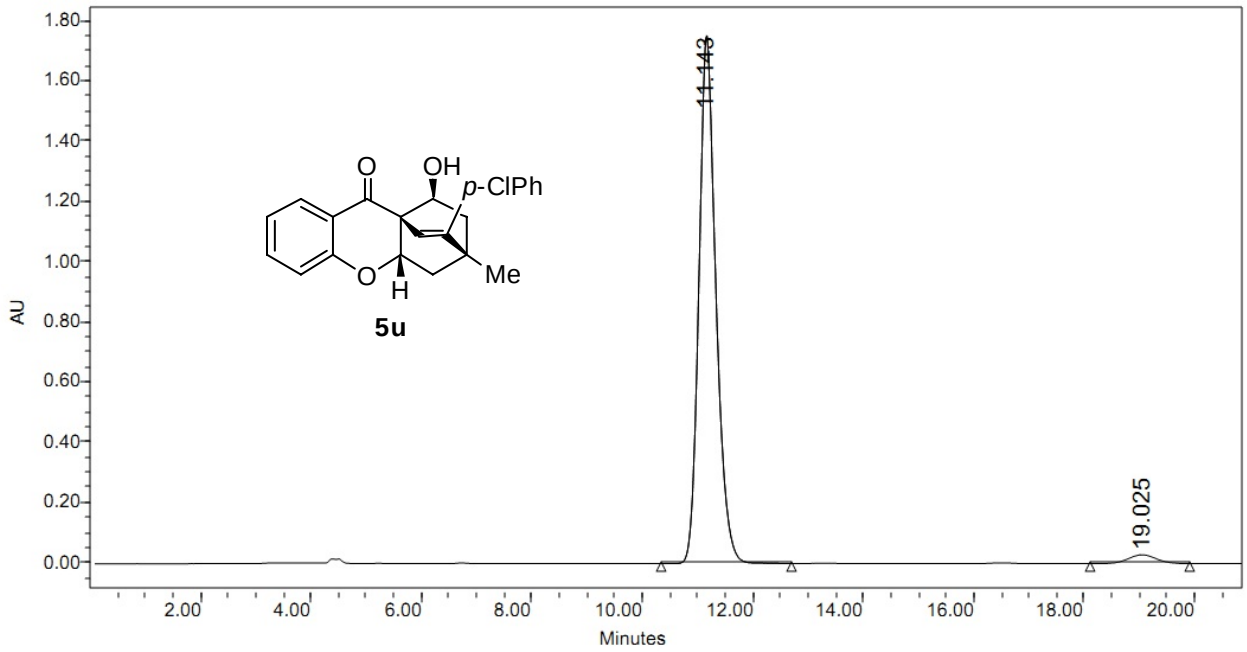
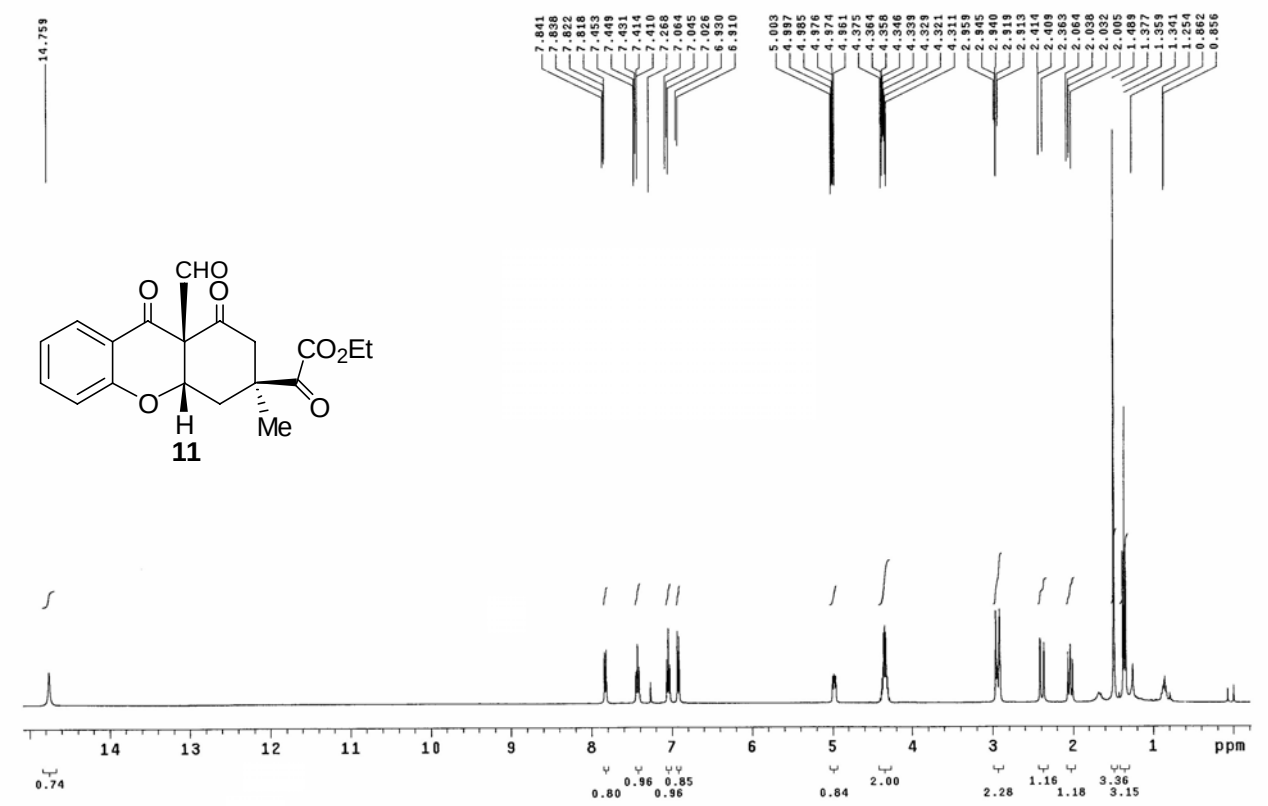
161.261
152.785
137.331
136.116
133.355
129.478
128.161
128.054
122.197
122.000
119.849
117.807
78.629
77.319
77.000
76.684
67.372
55.157
47.375
40.752
38.335
23.283
O
OH
p-ClPh
O
H
Me
5u
200
180
160
140
120
100
80
60
40
20
ppm



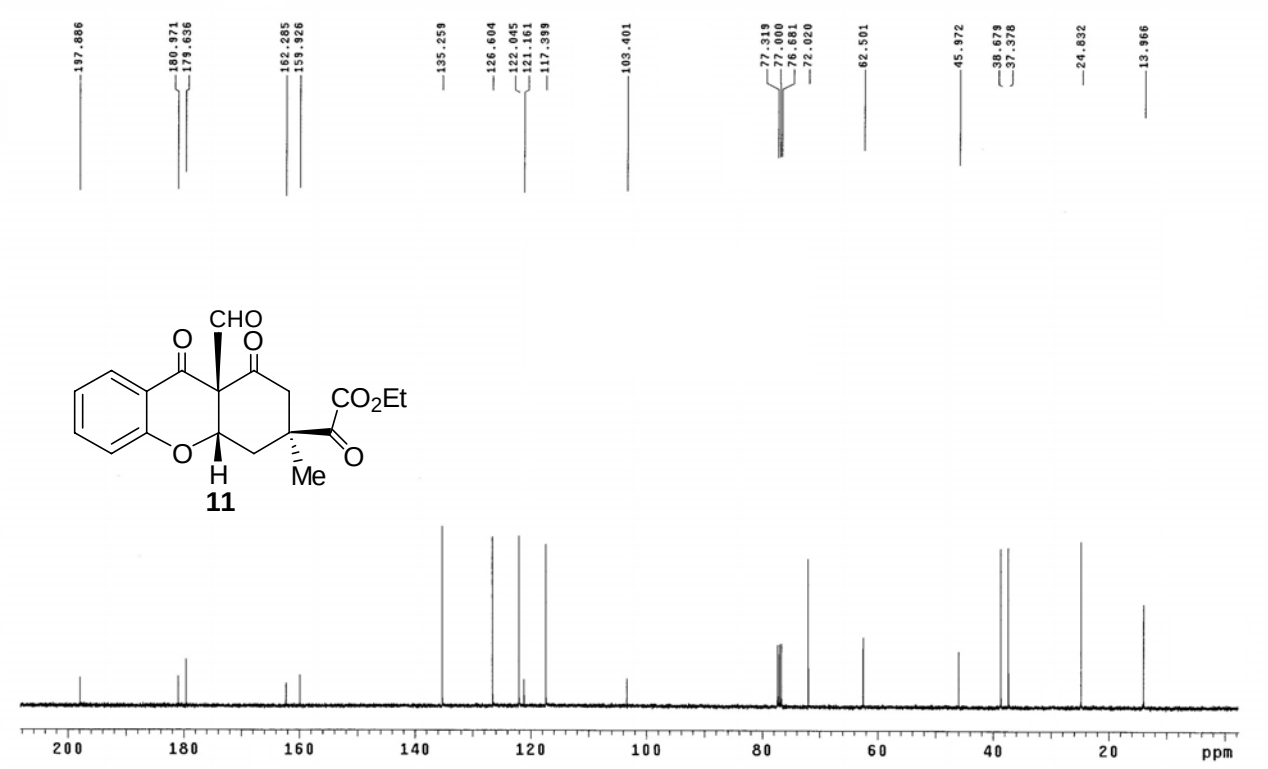
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	11.195	4357631	50.68	188976	61.64
2	19.060	4241214	49.32	117620	38.36



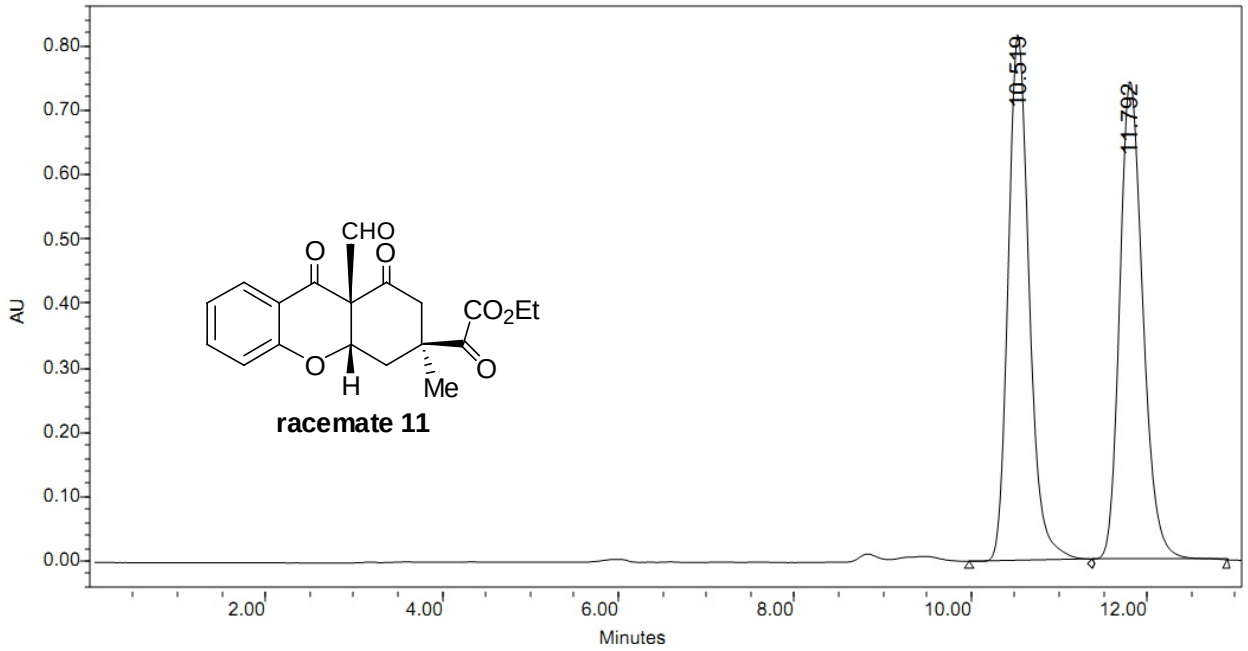
	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	11.143	37344266	97.31	1753292	98.37
2	19.025	1032868	2.69	29079	1.63



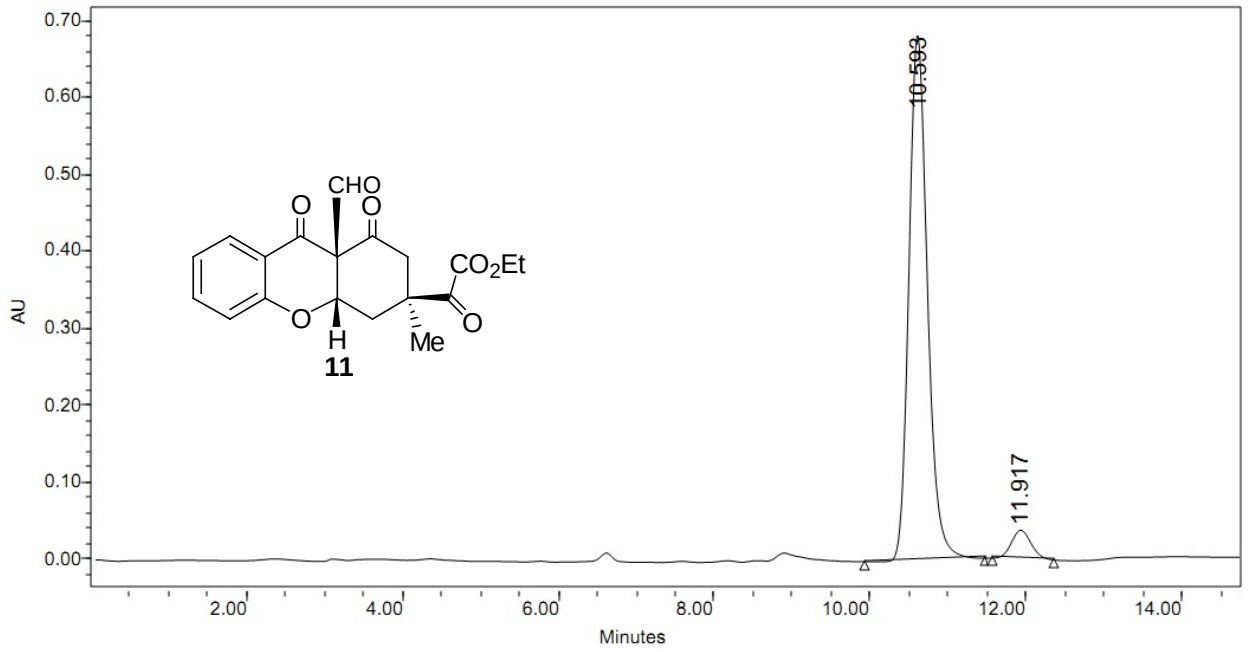
11



11



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.519	13640573	49.86	816935	52.32
2	11.792	13716401	50.14	744457	47.68



	RT (min)	Area (V *sec)	% Area	Height (V)	% Height
1	10.593	11299652	94.81	683614	94.95
2	11.917	618000	5.19	36364	5.05