Supplementary data

Organocatalyst-mediated asymmetric one-pot/two domino/three-component coupling reactions for the synthesis of *trans*-hydrindanes

Naoki Mori, Toshiki Tachibana, Nariyoshi Umekubo, Yujiro Hayashi*

Department of Chemistry, Graduate School of Science, Tohoku University, Sendai, Miyagi 980-8578, Japan

Contents:

1. General Methods……...S2
2. Experimental Procedures……S3
   2.1. Preparation of Starting Materials…….S3-S6
   2.2. Optimized procedure for the first reaction……..…S7
   2.3. Optimization for the second reaction and determination of the relative configuration of **4ab**……...S8-S9
   2.4. General procedure for the one-pot reaction……..S10-S22
   2.5. Determination of the absolute configuration……S23-S24
   2.6. Unsuccessful substrates for this reaction……..S25-S27
   2.7. Attempts to synthesize ketones with other electron withdrawing groups……S28
   2.8. Attempts to transform **4ab** and its derivatives……S29
   2.9. References……...S30
3. Spectra for Compounds……S31-S90

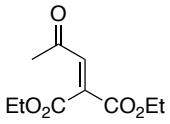
1. General Methods

General Remarks: Unless otherwise shown, all reactions were carried out under nitrogen atmosphere and monitored by thin-layer chromatography using Merck 60 F254 precoated silica gel plates (0.25 mm thickness). Specific optical rotations were measured using a JASCO P-2200 polarimeter. FT-IR spectra were recorded on a JASCO FT/IR-4600 HC1 spectrometer. ^{1}H and ^{13}C NMR spectra were recorded on an Agilent-400 MR (400 MHz for ^{1}H NMR, 100 M Hz for ^{13}C NMR) instrument. Data for ^{1}H NMR are reported as chemical shift (δ ppm), integration multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, td = triplet of doublets, ddd = doublet of doublet of doublets, ddt = double of double of triplets, m = multiplet), coupling constant (Hz), Data for ^{13}C NMR are reported as chemical shift. High resolution ESI-TOF mass spectra were measured by Themo Orbi-trap LTQ XL instrument. HPLC analysis was performed on a HITACHI Elite LaChrom Series HPLC, UV detection monitored at appropriate wavelength respectively, using CHIRALPACK® AD-H (0.46 cm × 25 cm), CHIRALPACK® IB (0.46 cm × 25 cm), CHIRALPACK® ID (0.46 cm × 25 cm). Melting-point apparatus was Yanaco MP-J3.

2. Experimental Procedures

2.1. Preparation of Starting Materials and Catalysts

Ethyl 4-ethoxycarbonyl-2-oxopentenoate (1)

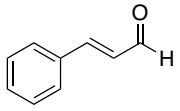


1

^{1}H NMR spectrum of synthesized compound **1** matched with that of the reported one.[1]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.75 (d, *J* = 7.6 Hz, 1H), 7.69 (brs, 4H), 7.51 (d, *J* = 16.4 Hz, 1H), 6.78 (dd, *J* = 16.0, 7.6 Hz, 1H)

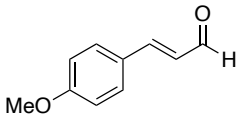
(*E*)-4-Cinnamaldehyde (2a)



2a

Compound **2a** was purchased from TCI (product code: C0352).

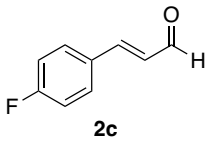
(*E*)-4-Methoxycinnamaldehyde (2b)



2b

Compound **2b** was purchased from TCI (product code: M1012).

(*E*)-4-Fluorocinnamaldehyde (2c)

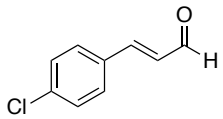


2c

^{1}H NMR spectrum of synthesized compound **2c** matched with that of the reported one.[2]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.68 (d, *J* = 8.0 Hz, 1H), 7.56 (dd, *J* = 8.8, 5.6 Hz, 2H), 7.44 (d, *J* = 16.0 Hz, 1H), 7.12 (t, *J* = 8.4 Hz, 2H), 6.64 (dd, *J* = 16.0, 8.0 Hz, 1H)

(*E*)-4-Chlorocinnamaldehyde (2d)

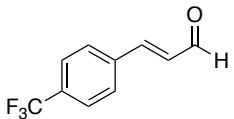


2d

^{1}H NMR spectrum of synthesized compound **2d** matched with that of the reported one.[3]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.70 (d, *J* = 7.6 Hz, 1H), 7.50 (d, *J* = 8.4 Hz, 1H), 7.45-7.40 (m, 3H), 6.69 (dd, *J* = 16.0, 7.6 Hz, 1H)

(*E*)-4-Trifluoromethylcinnamaldehyde (2e)

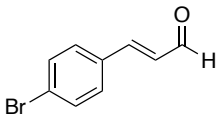


2e

^{1}H NMR spectrum of synthesized compound **2e** matched with that of the reported one.[4]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.75 (d, *J* = 7.6 Hz, 1H), 7.69 (brs, 4H), 7.51 (d, *J* = 16.4 Hz, 1H), 6.78 (dd, *J* = 16.0, 7.6 Hz, 1H)

(*E*)-4-Bromocinnamaldehyde (2f)

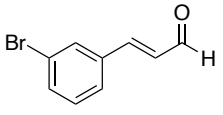


2f

^{1}H NMR spectrum of synthesized compound **2f** matched with that of the reported one.[3]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.71 (d, *J* = 7.6 Hz, 1H), 7.57 (d, *J* = 8.4 Hz, 1H), 7.44-7.39 (m, 3H), 6.70 (dd, *J* = 16.0, 7.6 Hz, 1H)

(*E*)-3-Bromocinnamaldehyde (2g)

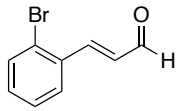


2g

^{1}H NMR spectrum of synthesized compound **2g** matched with that of the reported one.[5]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.71 (d, *J* = 7.6 Hz, 1H), 7.70 (s, 1H), 7.57 (d, *J* = 8.0 Hz, 1H), 7.49 (d, *J* = 7.6 Hz, 1H), 7.40 (d, *J* = 16.4 Hz, 1H), 7.31 (t, *J* = 8.0 Hz, 1H), 6.64 (dd, *J* = 16.0, 8.0 Hz, 1H)

(*E*)-2-Bromocinnamaldehyde (2h)

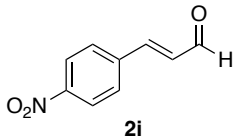


2h

^{1}H NMR spectrum of synthesized compound **2h** matched with that of the reported one.[5]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.78 (d, *J* = 7.6 Hz, 1H), 7.90 (d, *J* = 16.0 Hz, 1H), 7.66 (dt, *J* = 8.0, 1.6 Hz, 1H), 7.38 (t, *J* = 8.0 Hz, 1H), 7.28 (td, *J* = 8.0, 1.6 Hz, 1H), 6.67 (dd, *J* = 16.0, 7.6 Hz, 1H)

(*E*)-4-Nitrocinnamaldehyde (2i)

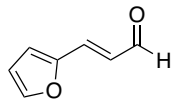


2i

^{1}H NMR spectrum of synthesized compound **2i** matched with that of the reported one.[6]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.78 (d, *J* = 7.2 Hz, 1H), 8.29 (d, *J* = 8.8 Hz, 2H), 7.73 (d, *J* = 8.8 Hz, 2H), 7.53 (d, *J* = 16.0 Hz, 1H), 6.81 (dd, *J* = 16.0, 7.6 Hz, 1H)

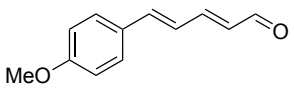
(*E*)-3-(2-Furyl)acrolein (2j)



2j

Compound **2j** was purchased from Sigma-Aldrich (product code: F20602).

(2*E*,4*E*)-5-(4-methoxyphenyl)penta-2,4-dienal (2k)

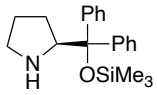


2k

^{1}H NMR spectrum of synthesized compound **2k** matched with that of the reported one.[7]

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.59 (d, *J* = 8.0 Hz, 1H), 7.48-7.43 (m, 2H), 7.25 (dd, *J* = 15.2, 10.8 Hz, 1H), 7.00-6.85 (m, 4H), 6.22 (dd, *J* = 15.2, 8.0 Hz, 1H), 3.84 (s, 3H)

(*S*)-2-(Diphenyl((trimethylsilyl)oxy)methyl)pyrrolidine (catalyst I)

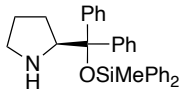


catalyst I

^{1}H NMR spectrum of synthesized catalyst **I** matched with that of the reported one.[8]

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.47-7.45 (m, 2H), 7.39-7.34 (m, 2H), 7.29-7.18 (m, 6H), 4.03 (t, *J* = 7.6 1H), 2.88-2.76 (m, 2H), 1.62-1.51 (m, 3H), 1.41-1.33 (m, 1H), 0.09 (s, 9H)

(*S*)-2-(((methyldiphenylsilyl)oxy)diphenylmethyl)pyrrolidine (catalyst Ⅱ)

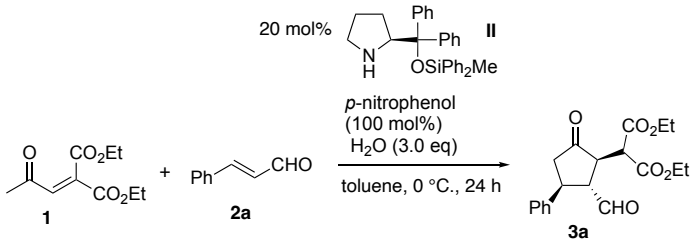


catalyst II

^{1}H NMR spectrum of synthesized catalyst **II** matched with that of the reported one.[9]

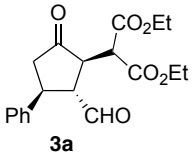
^{1}H NMR (400 MHz, CDCl$_3$): δ 7.53-7.48 (m, 6H), 7.37-7.18 (m, 14H), 3.99 (t, *J* = 7.2 1H), 2.75-2.69 (m, 1H), 2.57-2.52 (m, 1H), 1.62-1.55 (m, 2H), 1.41-1.32 (m, 2H), 1.03-0.94 (m, 1H), 0.19 (s, 3H)

2.2. Optimized procedure for the first reaction



To a stirred solution of **1** (500 mg, 2.33 mmol) and **2a** (308 mg, 2.33 mmol) in toluene (4.7 mL) were added water (126 μL, 7.00 mmol), catalyst **II** (210 mg, 0.467 mmol), *p*-nitrophenol (325 mg, 2.33 mmol) at 0 °C. After stirring for 24 h at 0 °C, sat. K_2CO_3 solution was added and the mixture was extracted with EtOAc. The organic layer was washed with sat. K_2CO_3 solution and brine, dried over anhydrous magnesium sulfate, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (hexane/EtOAc = 8:1) to give **3a** (606 mg, 75%).

Diethyl 2-((1*R*,2*R*,3*S*)-2-formyl-5-oxo-3-phenylcyclopentyl)malonate (3a)



Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{27}$ = +111 (*c* 1.04, $CHCl_3$)

IR (neat): ν_{max} 2983, 1732, 1456, 1371, 1230, 1156, 1028, 864, 765, 702 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.64 (d, *J* = 1.6 Hz, 1H), 7.42-7.27 (m, 5H), 4.27-4.17 (m, 2H), 4.15 (q, *J* = 7.2 Hz, 2H), 4.08 (d, *J* = 4.0 Hz, 1H), 3.85 (td, *J* = 11.2, 1.6 Hz, 1H), 3.35 (td, *J* = 11.2, 8.8 Hz, 1H), 3.20 (ddd, *J* = 11.2, 4.0, 1.2 Hz, 1H), 2.92-2.76 (m, 2H), 1.28 (t, *J* = 7.2 Hz, 3H), 1.27 (t, *J* = 7.2 Hz, 3H)

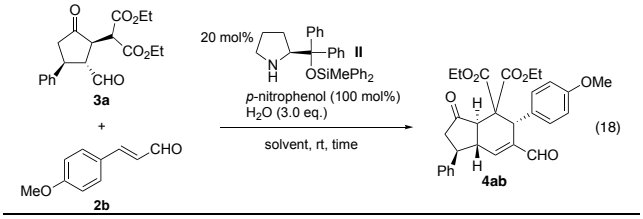
^{13}C NMR (100 MHz, $CDCl_3$): δ 212.6, 201.0, 168.2, 167.9, 140.1, 129.1, 127.7, 127.3, 62.0, 62.0, 57.7, 50.8, 49.2, 45.9, 43.5, 13.9, 13.8

HRMS (ESI): calcd. for $C_{19}H_{22}NaO_6$ $[M+Na]^+$ 369.1309, found 369.1311

Chiral HPLC: (ID, hexane/*i*-PrOH = 95:5, flow rate = 1.0 mL/min, λ = 210 nm) t_{minor} = 28.1 min, t_{major} = 32.0 min (>99% ee)

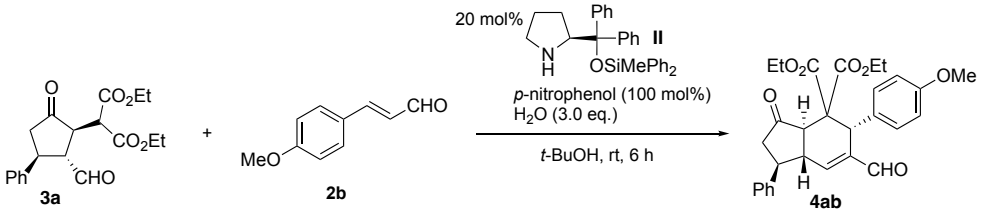
2.3. Optimization for the second reaction and determination of the relative configuration of 4ab

Table S1. The effect of solvent in the reaction of **3a** and **2b**.[a]



entry	solvent	time [h]	yield [%]
1	toluene	24	39[b]
2	MeOH	60	26[c]
3	EtOH	60	42[d]
4	^{i}PrOH	12	55
5	^{t}BuOH	6	72[e]

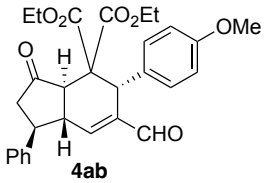
[a] Unless otherwise shown, the reaction was performed by employing **3a** (0.24 mmol), **2b** (0.24 mmol), organocatalyst (0.048 mmol), *p*-nitrophenol (0.24 mmol), water (0.73 mmol), in solvent (0.5 mL) at room temperature. [b] **3a** was recovered in 25% yield. [c] **3a** was recovered in 49% yield. [d] **3a** was recovered in 15% yield. [e] Enantiomeric excess (ee) was determined to be >99% by HPLC analysis on a chiral column material.



To a stirred solution of **3a** (83.7 mg, 0.242 mmol) and **2b** (39.2 mg, 0.242 mmol) in *t*-BuOH (0.48 mL) were added water (13.0 μL, 0.725 mmol), catalyst **II** (21.7 mg, 48.3 μmol), *p*-nitrophenol (33.6 mg, 0.242 mmol) at room temperature. After stirring for 6 h, sat. K_2CO_3 solution was added and the mixture was extracted with EtOAc. The organic layer was washed with sat. K_2CO_3 solution and brine, dried over anhydrous magnesium sulfate, and concentrated under reduced pressure. The residue was purified by silica gel

column chromatography (hexane/EtOAc = 5:1 to 4:1) to give **4ab** (85.2 mg, 72%).

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-5-(4-methoxyphenyl)-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ab)



4ab

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{27} = -183$ (*c* 1.10, $CHCl_3$)

IR (neat): ν_{max} 2979, 1742, 1691, 1609, 1511, 1367, 1252, 1179, 1034, 754, 702 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.30 (s, 1H), 7.54-6.78 (m, 10H), 4.91 (s, 1H), 4.38-4.17 (m, 2H), 3.92 (m, 1H), 3.77 (s, 3H), 3.75 (m, 1H), 3.33 (td, *J* = 10.8, 8.0 Hz, 1H), 3.04 (d, *J* = 14.0 Hz, 1H), 3.00 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.82 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.53 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.29 (t, *J* = 7.2 Hz, 3H), 0.97 (t, *J* = 7.2 Hz, 3H)

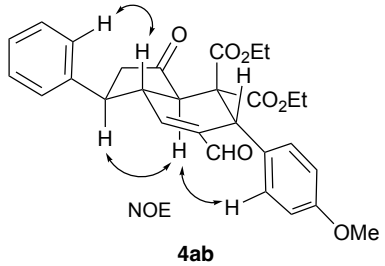
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.7, 191.5, 168.5, 167.1, 159.2, 145.6, 143.0, 139.3, 129.9, 129.2, 127.8, 127.4, 127.3, 113.9, 62.1, 61.5, 59.8, 55.2, 51.4, 47.1, 45.5, 45.0, 44.3, 14.1, 13.5

HRMS (ESI): calcd. for $C_{29}H_{30}NaO_7$ $[M+Na]^+$ 513.1884, found 513.1881

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 25.0 min, t_{major} = 29.7 min (>99% ee)

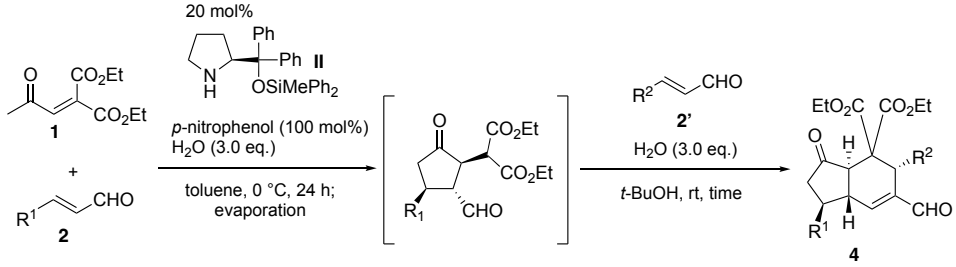
The relative configuration of **4ab** was determined by NOESY experiments.

<NOESY experiment of **4ab**>



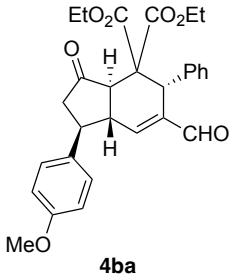
4ab

2.4. General procedure for the one-pot reaction



To a stirred solution of **1** (100 mg, 0.469 mmol) and **2** (0.469 mmol, 1.0 equiv.) in toluene (0.93 mL, 0.5 M for **1**) were added water (25.0 μL, 1.41 mmol, 3.0 equiv.), catalyst **II** (42.0 mg, 93.4 μmol, 0.2 equiv.), *p*-nitrophenol (64.9 mg, 0.469 mmol, 1.0 equiv.) at 0 °C. After stirring for 24 h at 0 °C, the mixture was evaporated under reduced pressure. The crude mixture was dissolved in *t*-BuOH (0.93 mL, 0.5 M for **1**), and water (25.0 μL, 1.41 mmol, 3.0 equiv.) and **2'** (0.469 mmol, 1.0 equiv.) were added to the mixture. After stirring for the indicated time, sat. K_2CO_3 solution was added and the mixture was extracted with EtOAc. The organic layer was washed with sat. K_2CO_3 solution and brine, dried over anhydrous magnesium sulfate, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography to give **4**.

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-1-(4-methoxyphenyl)-3-oxo-5-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ba)



4ba

Second reaction time: 3 h

Isolated yield: 52% (119 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{26} = -99.3$ (*c* 1.03, $CHCl_3$)

IR (neat): ν_{max} 2982, 1747, 1691, 1515, 1455, 1251, 1036, 912, 833, 733, 703 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 7.32-7.20 (m, 5H), 7.12 (d, *J* = 6.8 Hz, 2H), 6.97 (d, *J* = 8.8 Hz, 2H), 6.90 (brs, 1H), 4.96 (s, 1H), 4.39-4.17 (m, 2H), 3.87 (m, 1H), 3.85 (s, 3H), 3.64 (m, 1H), 3.28 (td, *J* = 10.8, 8.0 Hz, 1H), 3.04 (d, *J* = 14.0 Hz, 1H), 2.97 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.78 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.49 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.29 (t, *J* = 7.2 Hz, 3H), 0.90 (t, *J* = 7.2 Hz, 3H)

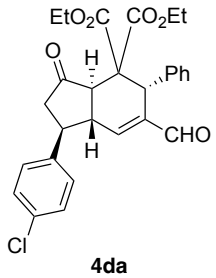
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.8, 191.5, 168.5, 167.1, 159.1, 146.3, 142.8, 138.0, 131.0, 128.8, 128.5, 128.3, 127.8, 114.5, 62.1, 61.5, 59.8, 55.3, 51.5, 47.2, 45.8, 45.7, 43.5, 14.1, 13.4

HRMS (ESI): calcd. for $C_{29}H_{30}NaO_7$ $[M+Na]^+$ 513.1884, found 513.1887.

Chiral HPLC: (IB, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{major} = 19.0 min, t_{minor} = 28.0 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-1-(4-chlorophenyl)-6-formyl-3-oxo-5-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4da)



4da

Second reaction time: 3 h

Isolated yield: 58% (135 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{26} = -95.5$ (*c* 1.14, $CHCl_3$)

IR (neat): ν_{max} 2981, 1748, 1691, 1493, 1227, 1092, 1013, 912, 732, 703 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 7.53-7.07 (m, 9H), 6.86 (brs, 1H), 4.96 (s, 1H), 4.38-4.17 (m, 2H), 3.95-3.59 (m, 2H), 3.32 (td, *J* = 10.8, 8.0 Hz, 1H), 3.06 (d, *J* = 14.0 Hz, 1H), 2.99 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.81 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.48 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.29 (t, *J* = 7.2 Hz, 3H), 0.90 (t, *J* = 7.2 Hz, 3H)

^{13}C NMR (100 MHz, $CDCl_3$): δ 205.1, 191.3, 168.4, 166.9, 145.5, 143.0, 137.8,

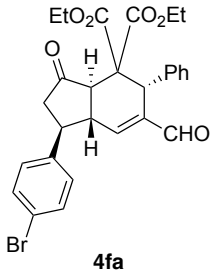
137.7, 133.5, 129.4, 128.8, 128.6, 128.5, 127.8, 62.2, 61.5, 59.7, 51.4, 47.0, 45.6, 45.4, 43.7, 14.1, 13.4

HRMS (ESI): calcd. for $C_{28}H_{27}ClNaO_6$ $[M+Na]^+$ 517.1389, found 517.1385

Chiral HPLC: (IB, hexane/*i*-PrOH = 95:5, flow rate = 1.0 mL/min, λ = 208 nm) t_{major} = 23.1 min, t_{minor} = 43.1 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 6:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-1-(4-bromophenyl)-6-formyl-3-oxo-5-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4fa)



4fa

Second reaction time: 3 h

Isolated yield: 58% (146 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{26} = -85.5$ (*c* 1.10, $CHCl_3$)

IR (neat): ν_{max} 2982, 1747, 1692, 1490, 1367, 1227, 1010, 911, 827, 732, 703 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 7.58-7.07 (m, 9H), 6.86 (brs, 1H), 4.96 (s, 1H), 4.38-4.18 (m, 2H), 3.95-3.59 (m, 2H), 3.31 (td, *J* = 10.8, 8.0 Hz, 1H), 3.05 (d, *J* = 14.0 Hz, 1H), 2.99 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.80 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.48 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.29 (t, *J* = 7.2 Hz, 3H), 0.90 (t, *J* = 7.2 Hz, 3H)

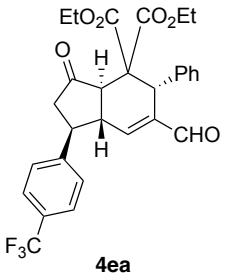
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.1, 191.3, 168.4, 166.9, 145.5, 143.0, 138.2, 137.8, 132.3, 129.2, 129.0, 128.5, 127.8, 121.5, 62.2, 61.5, 59.7, 51.4, 46.9, 45.6, 45.3, 43.8, 14.1, 13.4

HRMS (ESI): calcd. for $C_{28}H_{27}BrNaO_6$ $[M+Na]^+$ 561.0884, found 561.0880

Chiral HPLC: (IB, hexane/*i*-PrOH = 29:1, flow rate = 1.0 mL/min, λ = 208 nm) t_{major} = 36.7 min, t_{minor} = 68.2 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 6:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-3-oxo-5-phenyl-1-(4-(trifluoromethyl)phenyl)-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ea)



4ea

Second reaction time: 3 h

Isolated yield: 56% (138 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{26} = -111$ (*c* 1.00, $CHCl_3$)

IR (neat): ν_{max} 2985, 1748, 1693, 1327, 1228, 1166, 1124, 1069, 733, 703 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 7.71 (d, *J* = 8.0 Hz, 2H), 7.48 (d, J = 8.0 Hz, 2H), 7.36-7.20 (m, 3H), 7.11 (d, *J* = 6.4 Hz, 2H), 6.85 (brs, 1H), 4.97 (s, 1H), 4.40-4.21 (m, 2H), 3.95-3.60 (m, 2H), 3.41 (td, *J* = 10.8, 8.0 Hz, 1H), 3.08 (d, *J* = 14.0 Hz, 1H), 3.03 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.88 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.53 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.30 (t, *J* = 7.2 Hz, 3H), 0.91 (t, *J* = 7.2 Hz, 3H)

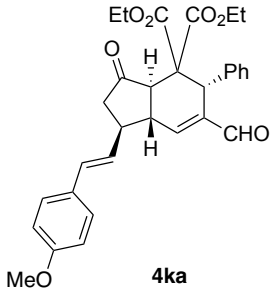
^{13}C NMR (100 MHz, $CDCl_3$): δ 204.8, 191.3, 168.4, 166.9, 145.1, 143.4, 143.1, 137.7, 130.1 (q, *J* = 32.7 Hz), 128.8, 128.5, 127.9, 127.8, 126.2 (q, *J* = 3.1 Hz), 123.9 (q, *J* = 271 Hz), 62.3, 61.6, 59.7, 51.4, 46.8, 45.6, 45.3, 44.1, 14.1, 13.4

HRMS (ESI): calcd. for $C_{29}H_{27}F_3NaO_6$ $[M+Na]^+$ 551.1652, found 551.1649

Chiral HPLC: (IB, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{major} = 9.7 min, t_{minor} = 17.4 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 6:1)

Diethyl (1*R*,3a*R*,5*R*,7a*S*)-6-formyl-1-((*E*)-4-methoxystyryl)-3-oxo-5-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ka)



4ka

Second reaction time: 3 h

Isolated yield: 22% (54 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{24} = -7.10$ (c 1.25, $CHCl_3$)

IR (neat): ν_{max} 2983, 1742, 1690, 1607, 1511, 1251, 1175, 1034, 913, 732 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.39 (s, 1H), 7.37 (d, J = 8.8 Hz, 2H), 7.37-7.07 (m, 6H), 6.89 (d, J = 8.8 Hz, 2H), 6.64 (d, J = 16.0 Hz, 1H), 6.02 (dd, J = 16.0, 8.4 Hz, 1H), 4.96 (s, 1H), 4.31-4.19 (m, 2H), 3.86 (m, 1H), 3.83 (s, 3H), 3.65 (m, 1H), 2.95 (d, J = 14.0 Hz, 1H), 2.93-2.79 (m, 2H), 2.52 (ddt, J = 14.0, 10.8, 2.0 Hz, 1H), 2.29 (dd, J = 18.8, 10.0 Hz, 1H), 1.26 (t, J = 7.2 Hz, 3H), 0.90 (t, J = 7.2 Hz, 3H)

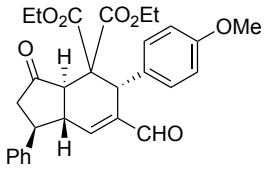
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.8, 191.5, 168.5, 167.1, 159.5, 146.4, 142.9, 138.0, 132.7, 129.0, 128.9, 128.5, 127.8, 127.5, 126.1, 114.2, 62.2, 61.5, 59.8, 55.3, 50.9, 45.8, 45.7, 44.5, 42.5, 14.0, 13.4

HRMS (ESI): calcd. for $C_{31}H_{32}NaO_7$ $[M+Na]^+$ 539.2040, found 539.2037

Chiral HPLC: (IF, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 31.5 min, t_{major} = 38.1 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-5-(4-methoxyphenyl)-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ab)



4ab

Second reaction time: 6 h

Isolated yield: 56% (129 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{27} = -183$ (*c* 1.10, $CHCl_3$)

IR (neat): ν_{max} 2979, 1742, 1691, 1609, 1511, 1367, 1252, 1179, 1034, 754, 702 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.30 (s, 1H), 7.54-6.78 (m, 10H), 4.91 (s, 1H), 4.38-4.17 (m, 2H), 3.92 (m, 1H), 3.77 (s, 3H), 3.75 (m, 1H), 3.33 (td, *J* = 10.8, 8.0 Hz, 1H), 3.04 (d, *J* = 14.0 Hz, 1H), 3.00 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.82 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.53 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.29 (t, *J* = 7.2 Hz, 3H), 0.97 (t, *J* = 7.2 Hz, 3H)

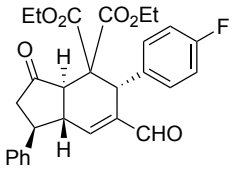
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.7, 191.5, 168.5, 167.1, 159.2, 145.6, 143.0, 139.3, 129.9, 129.2, 127.8, 127.4, 127.3, 113.9, 62.1, 61.5, 59.8, 55.2, 51.4, 47.1, 45.5, 45.0, 44.3, 14.1, 13.5

HRMS (ESI): calcd. for $C_{29}H_{30}NaO_7$ $[M+Na]^+$ 513.1884, found 513.1881

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 25.0 min, t_{major} = 29.7 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 5:1 to 4:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-5-(4-fluorophenyl)-6-formyl-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ac)



4ac

Second reaction time: 3 h

Isolated yield: 65% (145 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{25} = -189$ (*c* 1.06, $CHCl_3$)

IR (neat): ν_{max} 2983, 1744, 1690, 1508, 1367, 1226, 1163, 1097, 912, 732, 701 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.30 (s, 1H), 7.48-6.95 (m, 9H), 6.90 (brs, 1H), 4.94 (s, 1H), 4.39-4.18 (m, 2H), 3.97-3.67 (m, 2H), 3.33 (td, *J* = 10.8, 8.0 Hz, 1H), 3.01 (dd, *J* = 19.2, 8.0 Hz, 1H), 3.00 (d, *J* = 14.0 Hz, 1H), 2.83 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.54 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.30 (t, *J* = 7.2 Hz,

3H), 0.97 (t, J = 7.2 Hz, 3H)

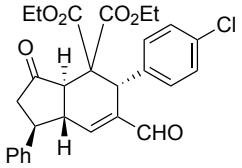
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.4, 191.4, 168.3, 167.0, 162.3 (d, J = 246 Hz), 146.4, 142.8, 139.1, 133.8 (d, J = 3.1 Hz), 130.4, 129.2, 127.8, 127.3, 115.4 (d, J = 21.3 Hz), 62.2, 61.6, 59.7, 51.4, 47.1, 45.5, 44.9, 44.3, 14.1, 13.5

HRMS (ESI): calcd. for $C_{28}H_{27}FNaO_6$ $[M+Na]^+$ 501.1684, found 501.1687

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 15.6 min, t_{major} = 20.7 min (97% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-5-(4-chlorophenyl)-6-formyl-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ad)



4ad

Second reaction time: 2 h

Isolated yield: 65% (151 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{23}$ = –176 (*c* 1.04, $CHCl_3$)

IR (neat): ν_{max} 2983, 1747, 1691, 1493, 1227, 1094, 755, 701 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.30 (s, 1H), 7.48-7.02 (m, 9H), 6.91 (brs, 1H), 4.93 (s, 1H), 4.39-4.18 (m, 2H), 3.97-3.69 (m, 2H), 3.32 (td, J = 10.8, 8.0 Hz, 1H), 3.01 (dd, J = 19.2, 8.0 Hz, 1H), 2.99 (d, J = 14.0 Hz, 1H), 2.84 (ddt, J = 14.0, 10.8, 2.0 Hz, 1H), 2.54 (dd, J = 19.2, 10.8 Hz, 1H), 1.30 (t, J = 7.2 Hz, 3H), 0.96 (t, J = 7.2 Hz, 3H)

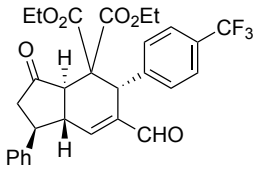
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.4, 191.3, 168.3, 166.9, 146.7, 142.6, 139.1, 136.6, 133.8, 130.1, 129.3, 128.6, 127.8, 127.3, 62.3, 61.7, 59.6, 51.4, 47.0, 45.5, 45.0, 44.2, 14.1, 13.4

HRMS (ESI): calcd. for $C_{28}H_{27}ClNaO_6$ $[M+Na]^+$ 517.1389, found 517.1389

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 14.8 min, t_{major} = 24.5 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 6:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-3-oxo-1-phenyl-5-(4-(trifluoromethyl)phenyl)-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ae)



4ae

Second reaction time: 2 h

Isolated yield: 61% (151 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{21} = -168$ (*c* 1.26, $CHCl_3$)

IR (neat): ν_{max} 2981, 1745, 1691, 1327, 1228, 1166, 1115, 1069, 913, 732, 701 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.32 (s, 1H), 7.58-7.22 (m, 9H), 6.97 (brs, 1H), 5.02 (s, 1H), 4.40-4.19 (m, 2H), 3.93-3.61 (m, 2H), 3.35 (td, *J* = 10.8, 8.0 Hz, 1H), 3.01 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.99 (d, *J* = 14.0 Hz, 1H), 2.86 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.56 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.31 (t, *J* = 7.2 Hz, 3H), 0.88 (t, *J* = 7.2 Hz, 3H)

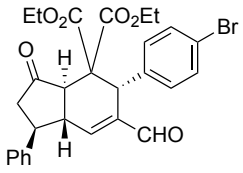
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.3, 191.3, 168.1, 166.9, 147.3, 142.3, 138.9, 130.0 (q, *J* = 32.7 Hz), 129.3, 127.9, 127.2, 125.4 (q, *J* = 3.0 Hz), 123.9 (q, *J* = 271 Hz), 62.4, 61.7, 59.6, 51.5, 47.0, 45.5, 45.3, 44.2, 14.1, 13.2

HRMS (ESI): calcd. for $C_{29}H_{27}F_3NaO_6$ $[M+Na]^+$ 551.1652, found 551.1651

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 9.7 min, t_{major} = 18.4 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 6:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-5-(4-bromophenyl)-6-formyl-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4af)



4af

Second reaction time: 2 h

Isolated yield: 60% (151 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{23} = -165$ (c 1.18, $CHCl_3$)

IR (neat): ν_{max} 2982, 1747, 1692, 1488, 1367, 1227, 1011, 879, 754, 701 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.30 (s, 1H), 7.48-6.95 (m, 9H), 6.91 (brs, 1H), 4.91 (s, 1H), 4.39-4.18 (m, 2H), 3.97-3.69 (m, 2H), 3.32 (td, J = 10.8, 8.0 Hz, 1H), 3.00 (dd, J = 19.2, 8.0 Hz, 1H), 2.98 (d, J = 14.0 Hz, 1H), 2.84 (ddt, J = 14.0, 10.8, 2.0 Hz, 1H), 2.54 (dd, J = 19.2, 10.8 Hz, 1H), 1.30 (t, J = 7.2 Hz, 3H), 0.96 (t, J = 7.2 Hz, 3H)

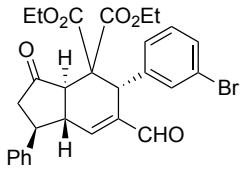
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.3, 191.3, 168.2, 166.9, 146.8, 142.5, 139.0, 137.2, 131.6, 130.4, 129.3, 127.8, 127.3, 121.9, 62.3, 61.7, 59.6, 51.4, 47.0, 45.5, 45.1, 44.2, 14.1, 13.4

HRMS (ESI): calcd. for $C_{28}H_{27}BrNaO_6$ $[M+Na]^+$ 561.0884, found 561.0888

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 15.6 min, t_{major} = 27.6 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 6:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-5-(3-bromophenyl)-6-formyl-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ag)



4ag

Second reaction time: 2 h

Isolated yield: 62% (156 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{26} = -124$ (c 1.16, $CHCl_3$)

IR (neat): ν_{max} 2982, 1747, 1690, 1473, 1366, 1227, 1053, 913, 732, 699 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 7.49-7.00 (m, 9H), 6.93 (brs, 1H), 4.92 (s, 1H), 4.39-4.18 (m, 2H), 3.99-3.68 (m, 2H), 3.33 (td, J = 10.8, 8.0 Hz, 1H), 3.02 (dd, J = 19.2, 8.0 Hz, 1H), 2.98 (d, J = 14.0 Hz, 1H), 2.83 (ddt, J = 14.0, 10.8, 2.0 Hz, 1H), 2.54 (dd, J = 19.2, 10.8 Hz, 1H), 1.30 (t, J = 7.2 Hz, 3H), 0.98 (t, J = 7.2 Hz, 3H)

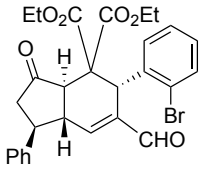
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.4, 191.3, 168.2, 166.8, 147.0, 142.3, 140.5, 139.0, 130.9, 129.9, 129.2, 127.8, 127.3, 122.7, 62.3, 61.8, 59.7, 51.4, 47.1, 45.4, 45.2, 44.1, 14.1, 13.5

HRMS (ESI): calcd. for $C_{28}H_{27}BrNaO_6$ $[M+Na]^+$ 561.0884, found 561.0888

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 17.2 min, t_{major} = 20.3 min (98% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-5-(2-bromophenyl)-6-formyl-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ah)



4ah

Second reaction time: 9 h

Isolated yield: 56% (141 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{26}$ = –95.8 (*c* 1.10, $CHCl_3$)

IR (neat): ν_{max} 2982, 1745, 1692, 1468, 1367, 1257, 1024, 911, 732, 702 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.27 (s, 1H), 7.62-6.97 (m, 9H), 6.94 (brs, 1H), 5.68 (s, 1H), 4.43-4.19 (m, 2H), 3.96 (q, *J* = 7.2 Hz, 2H), 3.32 (m, 1H), 3.10-2.94 (m, 3H), 2.59 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.33 (t, *J* = 7.2 Hz, 3H), 1.02 (t, *J* = 7.2 Hz, 3H)

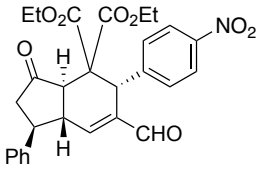
^{13}C NMR (100 MHz, $CDCl_3$): δ 206.2, 191.1, 168.4, 167.0, 146.5, 143.5, 139. 2, 138.0, 133.4, 129.6, 129.3, 129.0, 127.8, 127.3, 127.1, 126. 8, 62.3, 62.0, 58.5, 52.6, 47.1, 45.2, 44.5, 44.2, 14.1, 13.4

HRMS (ESI): calcd. for $C_{28}H_{27}BrNaO_6$ $[M+Na]^+$ 561.0884, found 561.0886

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 35.7 min, t_{major} = 39.7 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-5-(4-nitrophenyl)-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4ai)



4ai

Second reaction time: 3 h

Isolated yield: 66% (157 mg)

Physical state: a brown oil

Optical rotation: $[\alpha]_D^{25} = -136$ (*c* 1.10, $CHCl_3$)

IR (neat): ν_{max} 2979, 1735, 1687, 1522, 1348, 1253, 913, 731, 701 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.32 (s, 1H), 8.16 (d, *J* = 9.2 Hz, 2H), 7.52-7.19 (m, 7H), 7.00 (brs, 1H), 5.05 (s, 1H), 4.41-4.21 (m, 2H), 3.97-3.69 (m, 2H), 3.36 (td, *J* = 10.8, 8.0 Hz, 1H), 3.02 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.97 (d, *J* = 14.0 Hz, 1H), 2.88 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.57 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.31 (t, *J* = 7.2 Hz, 3H), 0.97 (t, *J* = 7.2 Hz, 3H)

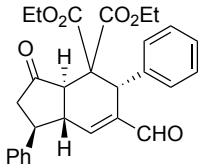
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.0, 191.2, 167.9, 166.6, 147.9, 147.3, 145.8, 142.1, 138.8, 129.3, 127.9, 127.4, 127.2, 123.6, 62.5, 61.9, 59.5, 51.5, 47.0, 45.4, 45.2, 44.2, 14.1, 13.5

HRMS (ESI): calcd. for $C_{28}H_{27}NNaO_8$ $[M+Na]^+$ 528.1629, found 528.1628

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 80:20, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 16.2 min, t_{major} = 29.8 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-3-oxo-1,5-diphenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4aa)



4aa

Second reaction time: 3 h

Isolated yield: 74% (160 mg)

Physical state: a yellow oil

Optical rotation: $[\alpha]_D^{28} = -223$ (*c* 0.98, $CHCl_3$)

IR (neat): ν_{max} 2982, 1747, 1691, 1454, 1367, 1227, 912, 732, 702 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.31 (s, 1H), 7.48-7.08 (m, 10H), 6.90 (brs, 1H), 4.96 (s, 1H), 4.39-4.18 (m, 2H), 3.95-3.60 (m, 2H), 3.34 (td, *J* = 10.8, 8.0 Hz, 1H), 3.07 (d, *J* = 14.0 Hz, 1H), 3.00 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.84 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.54 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.30 (t, *J* = 7.2 Hz, 3H), 0.90 (t, *J* = 7.2 Hz, 3H)

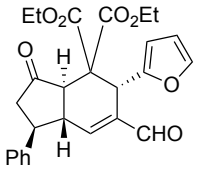
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.6, 191.5, 168.5, 167.1, 146.1, 142.8, 139.2, 137.9, 129.2, 128.5, 127.8, 127.8, 127.3, 62.2, 61.5, 59.8, 51.5, 47.1, 45.7, 45.5, 44.3, 14.1, 13.4

HRMS (ESI): calcd. for $C_{28}H_{28}NaO_6$ $[M+Na]^+$ 483.1778, found 483.1775

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 19.0 min, t_{major} = 23.1 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

Diethyl (1*S*,3a*R*,5*R*,7a*R*)-6-formyl-5-(furan-2-yl)-3-oxo-1-phenyl-1,2,3,3a,5,7a-hexahydro-4*H*-indene-4,4-dicarboxylate (4aj)



4aj

Second reaction time: 2 h

Isolated yield: 35% (73 mg)

Physical state: a brown oil

Optical rotation: $[\alpha]_D^{26}$ = –191 (*c* 0.20, $CHCl_3$)

IR (neat): ν_{max} 2983, 1736, 1690, 1498, 1367, 1254, 1013, 755, 702 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.33 (s, 1H), 7.48-7.08 (m, 6H), 6.82 (brs, 1H), 6.28 (dd, *J* = 3.2, 1.6 Hz, 1H), 6.12 (d, *J* = 3.2 Hz, 1H), 5.02 (s, 1H), 4.38-3.86 (m, 4H), 3.37-3.26 (m, 2H), 3.00 (dd, *J* = 19.2, 8.0 Hz, 1H), 2.79 (ddt, *J* = 14.0, 10.8, 2.0 Hz, 1H), 2.53 (dd, *J* = 19.2, 10.8 Hz, 1H), 1.28 (t, *J* = 7.2 Hz, 3H), 1.13 (t, *J* = 7.2 Hz, 3H)

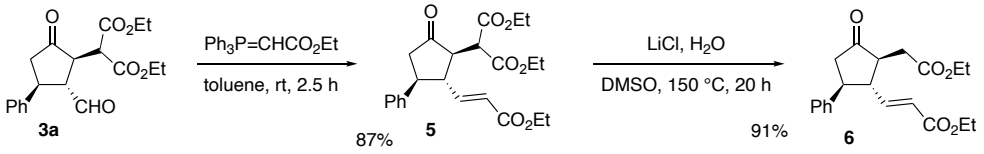
^{13}C NMR (100 MHz, $CDCl_3$): δ 205.6, 191.2, 168.0, 167.1, 150.8, 146.6, 142.6, 140.7, 139.3, 129.2, 127.8, 127.3, 110.7, 109.4, 62.2, 62.0, 58.9, 52.4, 47.0, 45.6, 44.2, 39.7, 14.1, 13.7

HRMS (ESI): calcd. for $C_{26}H_{26}NaO_7$ $[M+Na]^+$ 473.1571, found 473.1568

Chiral HPLC: (AD-H, hexane/*i*-PrOH = 95:5, flow rate = 1.0 mL/min, λ = 208 nm) t_{minor} = 41.9 min, t_{major} = 47.9 min (>99% ee)

Purification: Flash column chromatography on silica gel (hexane/EtOAc = 8:1 to 5:1)

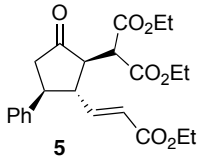
2.5. Determination of the absolute configuration



To a stirred solution of **3a** (808 mg, 2.33 mmol) in toluene (4.7 mL) was added $Ph_3P{=}CHCO_2Et$ (2.03 g, 5.83 mmol) at 0 °C. After stirring for 2.5 h at room temperature, the mixture was concentrated under reduced pressure. The residue was purified by silica gel column chromatography (hexane/EtOAc = 7:1) to give **5** (846 mg, 87%).

To a stirred solution of **5** (108 mg, 0.259 mmol) in DMSO (2.6 mL) were added lithium chloride (10.9 mg, 0.259 mmol) and water (9.8 mg, 0.545 mmol) at room temperature. After heating at 150 °C using an oil bath for 20 h, the mixture was extracted with EtOAc. The organic layer was washed with water, dried over anhydrous sodium sulfate, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (hexane/EtOAc = 4:1) to give **6** (81.3 mg, 91%).

Diethyl 2-((1*R*,2*R*,3*S*)-2-((*E*)-3-ethoxy-3-oxoprop-1-en-1-yl)-5-oxo-3-phenylcyclopentyl)malonate (5)



Physical state: a yellow oil

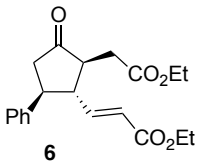
Optical rotation: $[\alpha]_D^{26} = +70.9$ (*c* 1.0, $CHCl_3$)

IR (neat): ν_{max} 2982, 1736, 1455, 1371, 1339, 1307, 1227, 1175, 1094, 1033, 702 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35-7.21 (m, 5H), 6.73 (dd, *J* = 15.6, 9.2 Hz, 1H), 5.55 (d, *J* = 15.6 Hz, 1H), 4.30-4.04 (m, 6H), 3.90 (d, *J* = 4.4 Hz, 1H), 3.34 (q, *J* = 10.0 Hz, 1H), 3.15 (td, *J* = 11.6, 8.4 Hz, 1H), 2.86 (dd, *J* = 12.4, 4.4 Hz, 1H), 2.81 (dd, *J* = 18.8, 8.4 Hz, 1H), 2.70 (dd, *J* = 18.8, 12.4 Hz, 1H), 1.32-1.19 (m, 9H)

^{13}C NMR (100 MHz, $CDCl_3$): δ 212.9, 167.9, 167.6, 165.6, 146.7, 139.9, 128.7, 127.4, 127.2, 123.7, 61.7, 61.6, 60.3, 53.9, 50.2, 49.8, 46.7, 45.3, 14.0, 13.9, 13.8
HRMS (ESI): calcd. for $C_{23}H_{28}NaO_7$ $[M+Na]^+$ 439.1727, found 439.1727

Ethyl (*E*)-3-((1*R*,2*S*,5*S*)-2-(2-ethoxy-2-oxoethyl)-3-oxo-5-phenylcyclopentyl)acrylate (6)

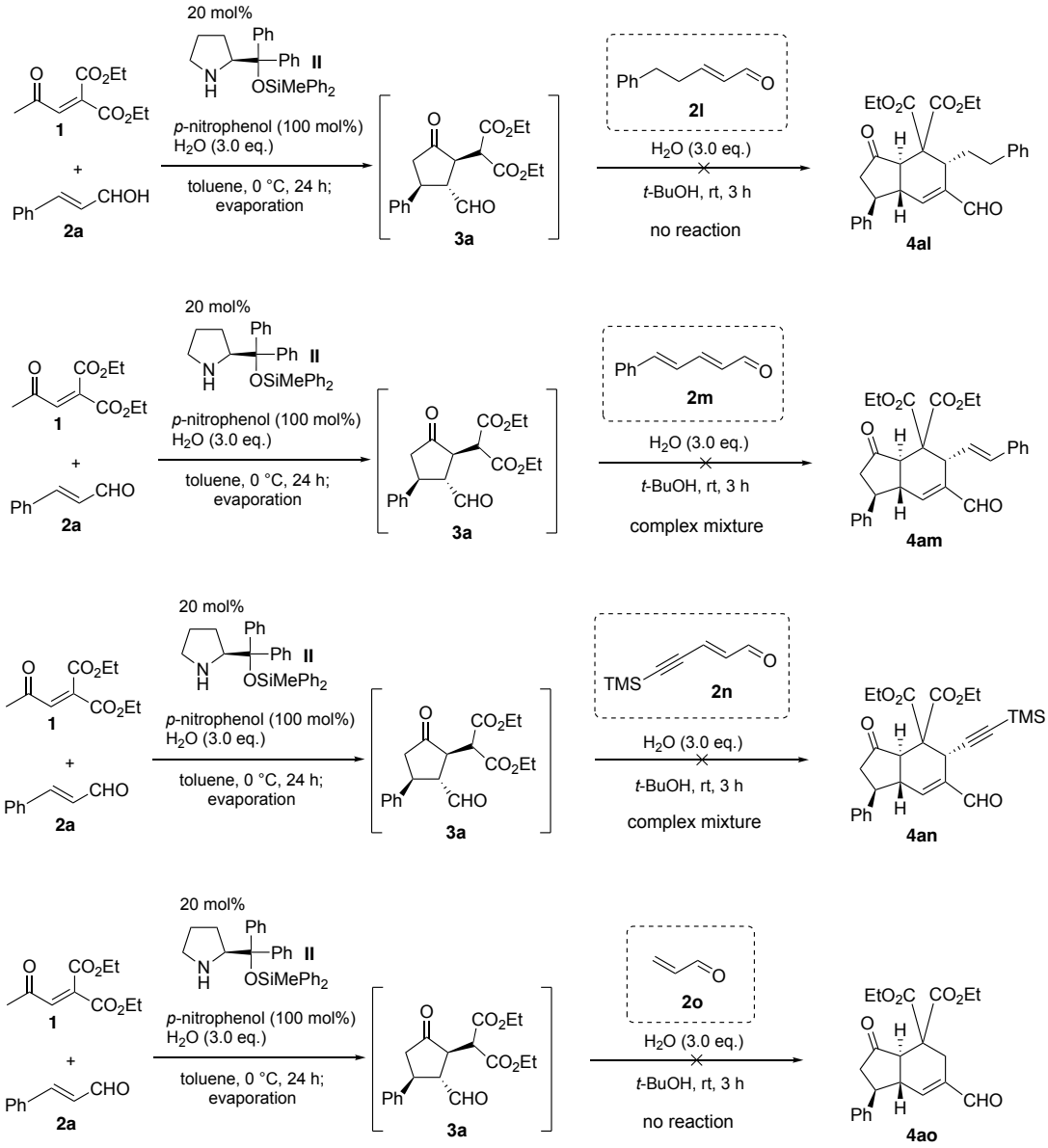


6

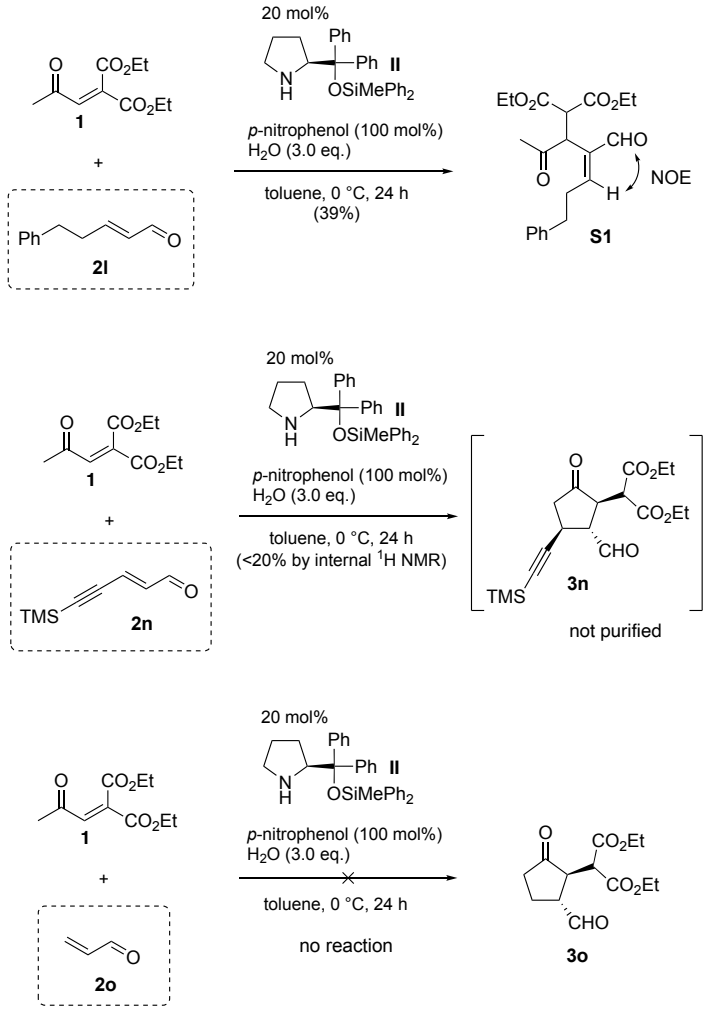
The spectroscopic data of the product agreed with the literature values (*Chem. Sci.* **2020**, *11*, 1205).
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36-7.20 (m, 5H), 6.80 (dd, *J* = 15.6, 8.8 Hz, 1H), 5.66 (d, *J* = 15.6 Hz, 1H), 4.20-4.06 (m, 4H), 3.18 (td, *J* = 11.6, 8.0 Hz, 1H), 3.05 (dd, *J* = 11.2, 8.8 Hz, 1H), 2.84 (dd, *J* = 18.8, 8.0 Hz, 1H), 2.79 (dd, *J* = 17.6, 5.2 Hz, 1H), 2.63 (dd, *J* = 18.8, 12.4 Hz, 1H), 2.58 (dd, *J* = 17.6, 4.8 Hz, 1H), 2.51 (m, 1H), 1.26 (t, *J* = 7.2 Hz, 3H), 1.24 (t, *J* = 7.2 Hz, 3H)
Optical rotation: $[\alpha]_D^{24}$ = +92.0 (*c* 1.0, $CHCl_3$), Lit.: $[\alpha]_D^{26}$ = +91.61 (*c* 1.2, $CHCl_3$)
The absolute configuration was determined by comparison of the optical rotation.

2.6. Unsuccessful substrates for this reaction

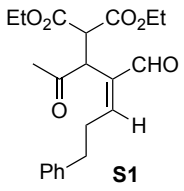
α,β-Unsaturated aldehydes **2l**, **2m**, **2n**, **2o** were not suitable for the second reaction.



α,β-Unsaturated aldehydes **2l**, **2n**, **2o** were not suitable for the first reaction.



Diethyl (*E*)-2-(4-formyl-2-oxo-7-phenylhept-4-en-3-yl)malonate (S1)



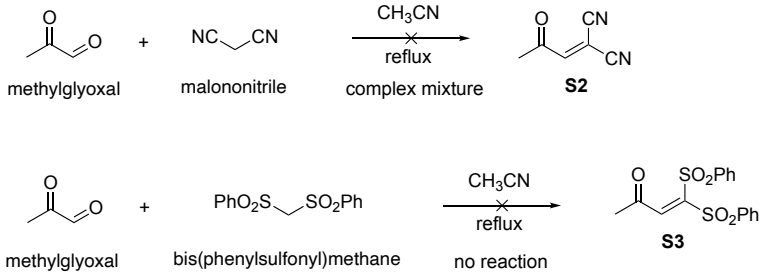
To a stirred solution of **1** (100 mg, 0.467 mmol) and **2l** (75.0 mg, 0.467 mmol) in toluene (0.93 mL) were added water (25.0 μL, 1.38 mmol), catalyst **II** (42.0 mg, 93.4 μmol), *p*-nitrophenol (65.0 mg, 0.467 mmol) at 0 °C. After stirring for 24 h at 0 °C, sat. K_2CO_3 solution was added and the mixture was extracted with EtOAc. The organic layer was washed with sat. K_2CO_3 solution and

brine, dried over anhydrous magnesium sulfate, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (hexane/EtOAc = 7:1 to 5:1) to give **S1** (69.0 mg, 39%).

Physical state: a yellow oil
Optical rotation: $[\alpha]_D^{24}$ = +82.6 (*c* 1.1, $CHCl_3$)
IR (neat): ν_{max} 2981, 1730, 1686, 1454, 1368, 1264, 1159, 1032, 753, 700 cm^{-1}
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.34 (s, 1H), 7.35-7.15 (m, 5H), 6.75 (t, *J* = 7.2 Hz, 1H), 4.47 (m, 1H), 4.25-3.96 (m, 5H), 2.88-2.75 (m, 4H), 1.81 (s, 3H), 1.24 (t, *J* = 7.2 Hz, 3H), 1.15 (t, *J* = 7.2 Hz, 3H)
^{13}C NMR (100 MHz, $CDCl_3$): δ 212.9, 192.9, 167.8, 159.1, 139.8, 128.7, 128.4, 126.5, 61.8, 61.5, 50.9, 34.2, 31.0, 27.3, 13.9, 13.9, 11.7
HRMS (ESI): calcd. for $C_{21}H_{26}NaO_6$ $[M+Na]^+$ 397.1622, found 397.1631
Chiral HPLC: (OZ-H, hexane/*i*-PrOH = 90:10, flow rate = 1.0 mL/min, λ = 208 nm) t_{major} = 11.6 min, t_{minor} = 30.0 min (61% ee)

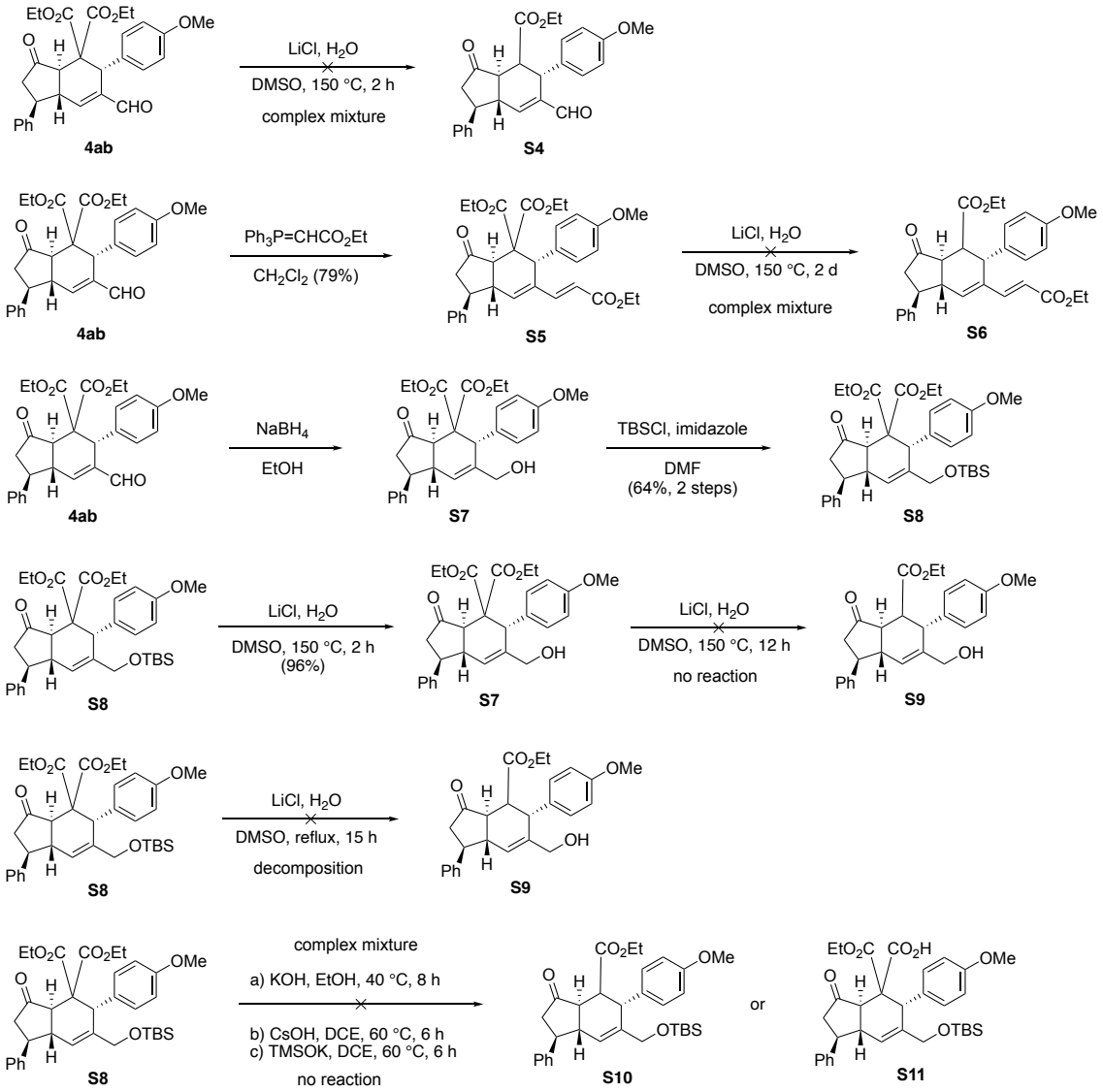
2.7. Attempts to synthesize ketones with other electron withdrawing groups

Preparation of 2-(2-oxopropylidene)malononitrile (**S2**) and 4,4-bis(phenylsulfonyl)but-3-en-2-one (**S3**) with other electron withdrawing functional groups was unsuccessful.



2.8. Attempts to transform 4ab and its derivatives

Decarboxylation of **4ab** and its derivatives **S5**, **S7**, **S8** was tried but failed.



2.9. References

[1] K. Okuro, H. Alper, *J. Org. Chem.* **2012**, *77*, 4420−4424.

[2] S. R. Smith, S. M. Leckie, R. Holmes, J. Douglas, C. Fallan, P. Shapland, D. Pryde, A. M. Z. Slawin, A. D. Smith, *Org. Lett.* **2014**, *16*, 2506–2509.

[3] N. T. Patil, V. Singh, *Chem. Commun.* **2011**, *47*, 11116–11118.

[4] R. Beaud, B. Michelet, Y. Reviriot, A. Martin-Mingot, J. Rodriguez, D. Bonne, S. Thibaudeau, *Angew. Chem. Int. Ed.* **2020**, *59*, 1279–1285.

[5] E. Kim, M. Koh, B. J. Lim, S. B. Park, *J. Am. Chem. Soc*. **2011**, *133*, 6642–6649.

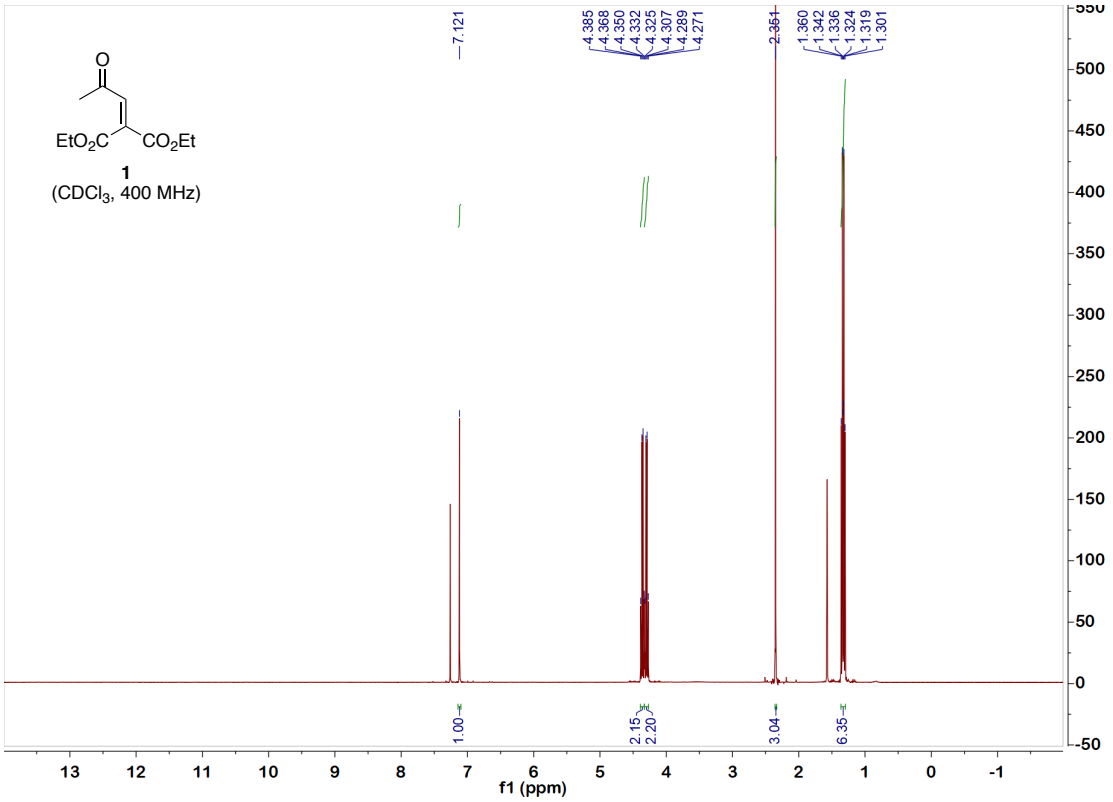
[6] L. C. Bencze, A. Filip, G. Bánóczi, M. I. Toşa, F. D. Irimie, Á. Gellért, L. Poppe, C. Paizs, *Org. Biomol. Chem.* **2017**, *15*, 3717–3727.

[7] P. An, N.-S. Xu, H.-L. Zhang, X.-P. Cao, Z.-F. Shi, W. Wen, *Chem. Asian. J.* **2015**, *10*, 1959–1966.

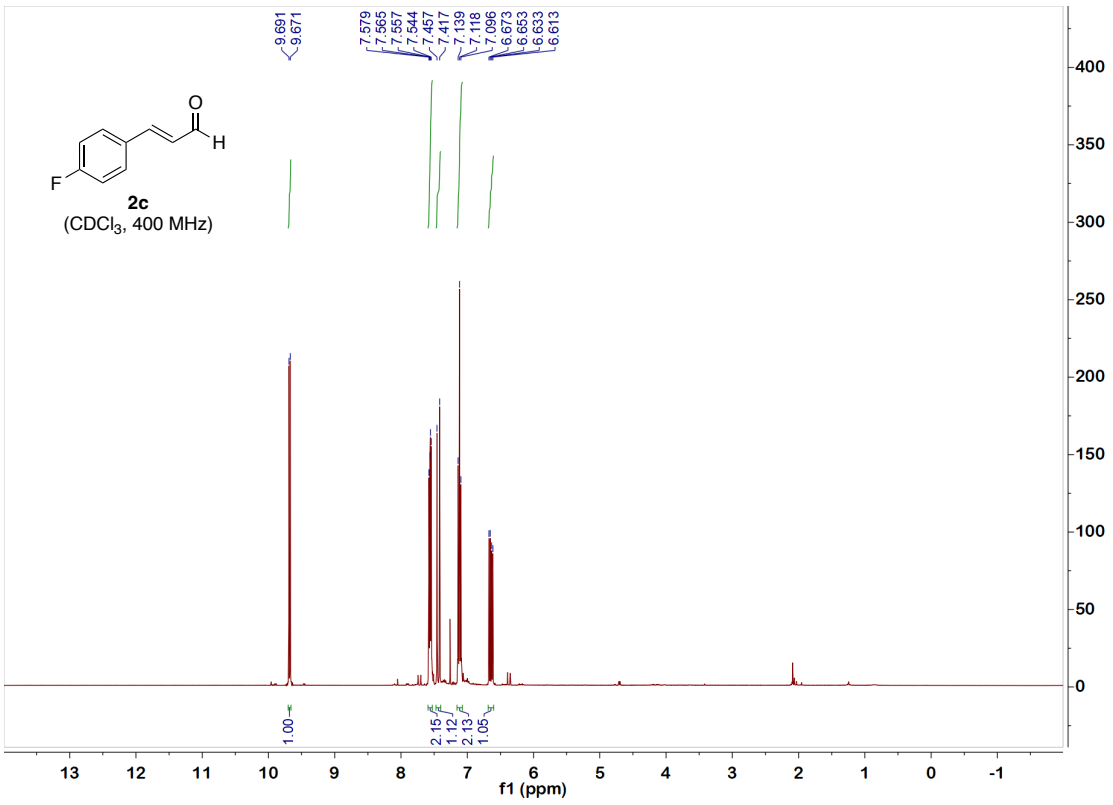
[8] Y. Hayashi, H. Gotoh, T. Hayashi, M. Shoji, *Angew. Chem. Int. Ed*. **2005**, 44, 4212–4215.

[9] U. Grošelj, D. Seebach, D. M. Badine, W. B. Schweizer, A. K. Beck, I. Krossing, P. Klose, Y. Hayashi, T. Uchimaru, *Helv. Chim. Acta.* **2009**, *92*, 1225–1259.

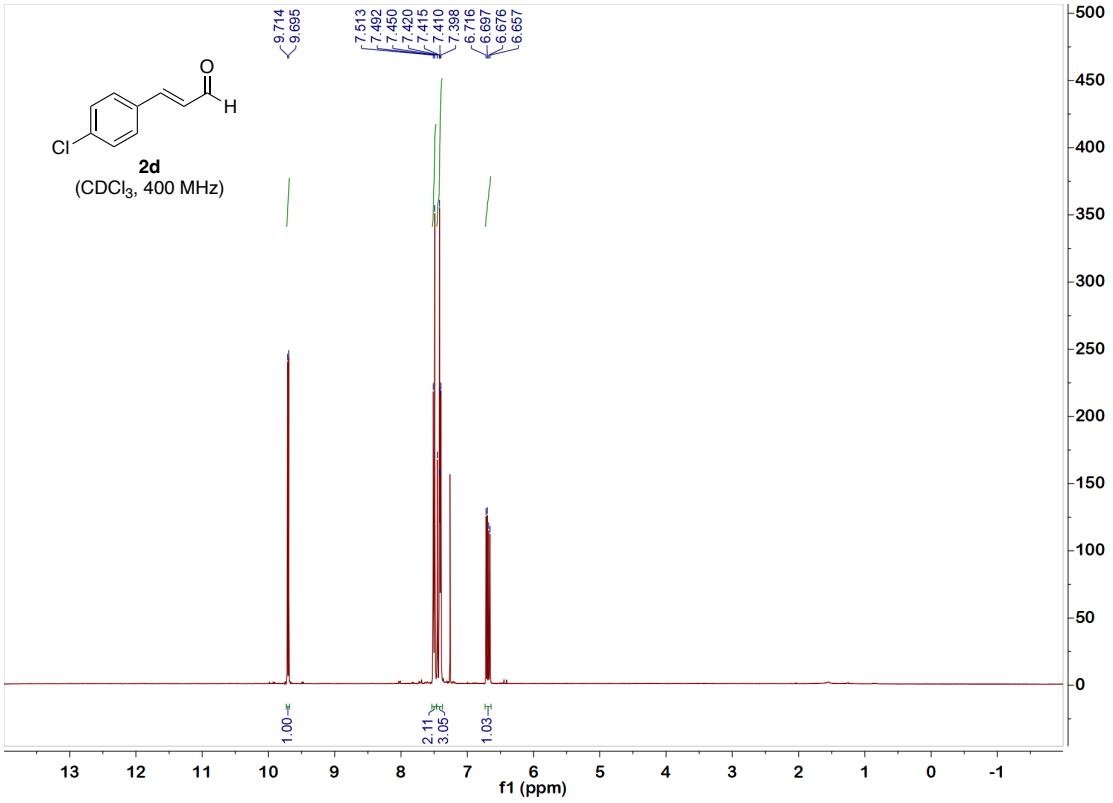
3. Spectra for compounds

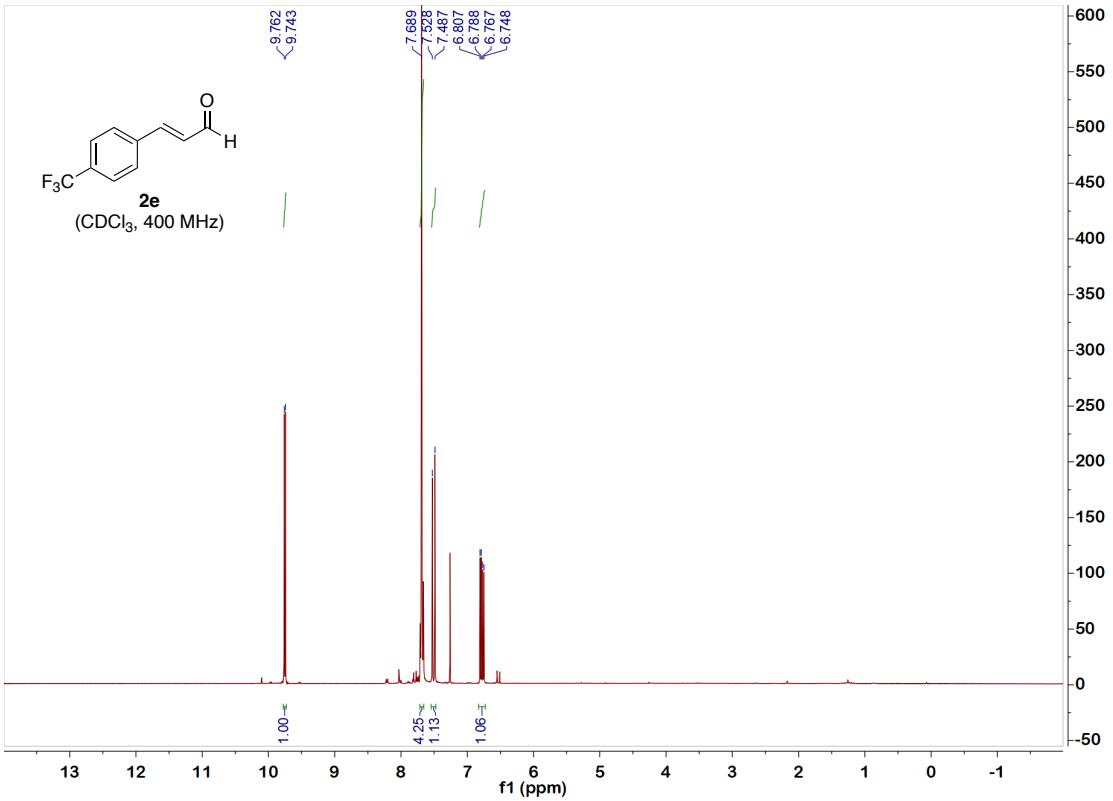


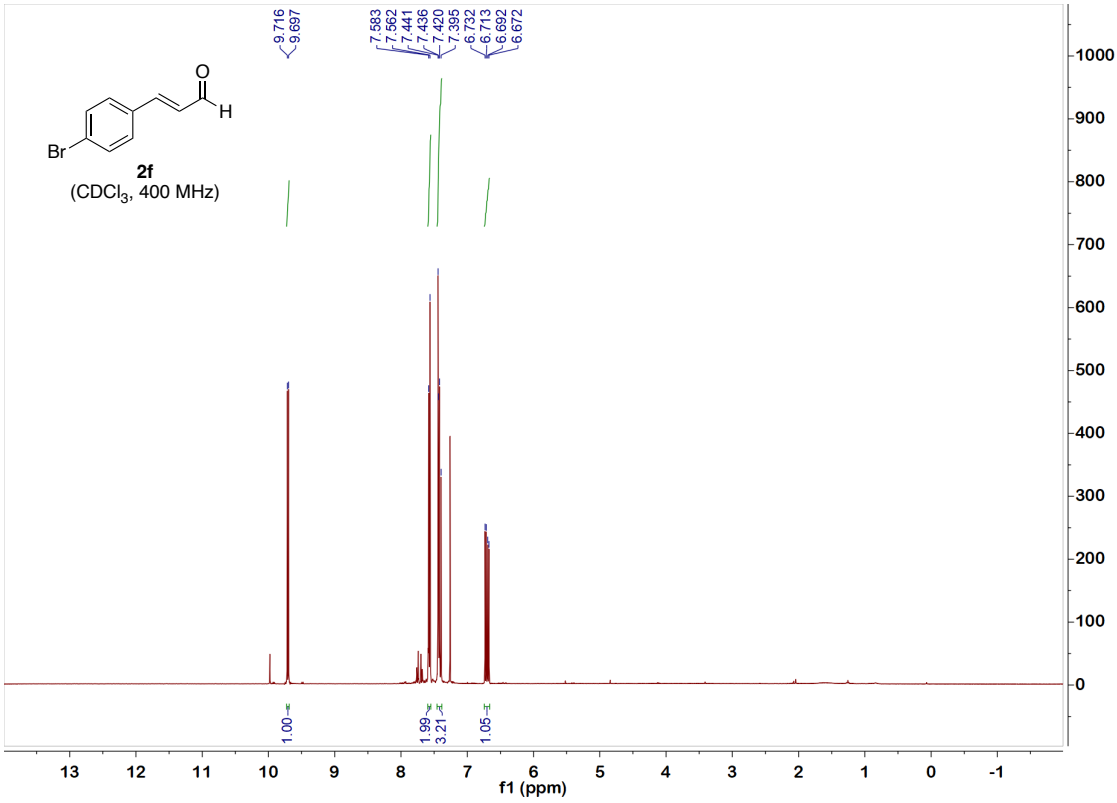
1
($CDCl_3$, 400 MHz)

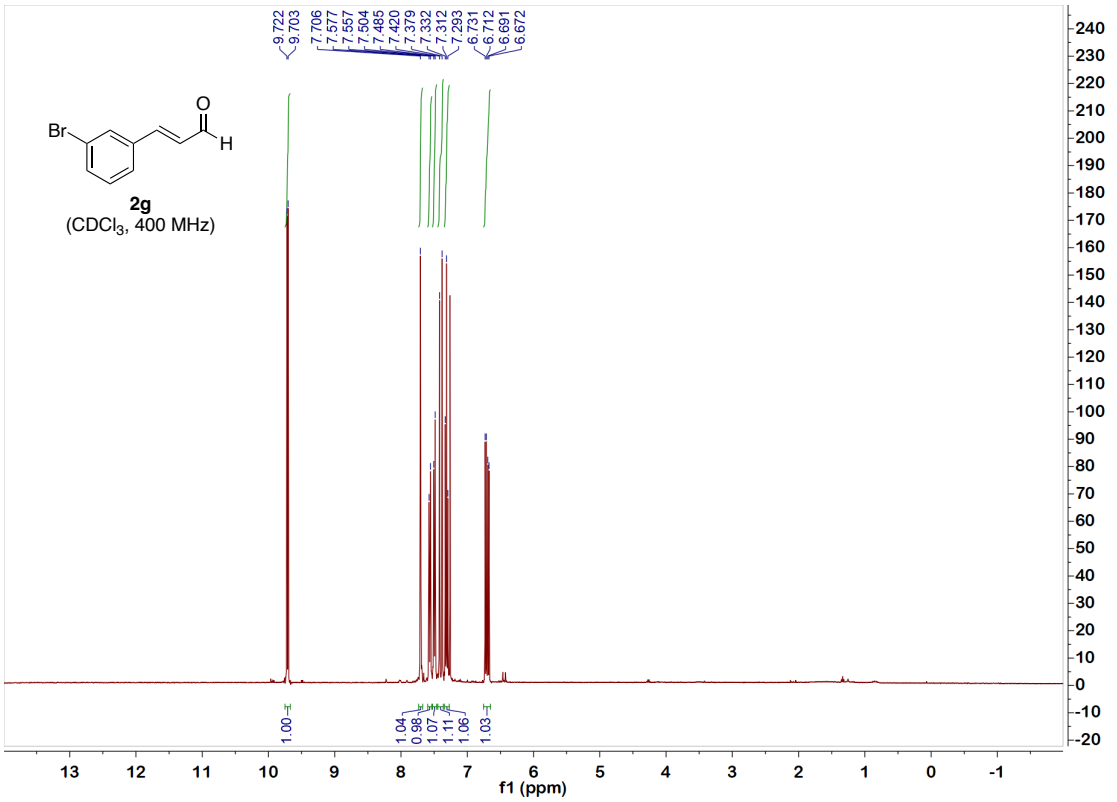


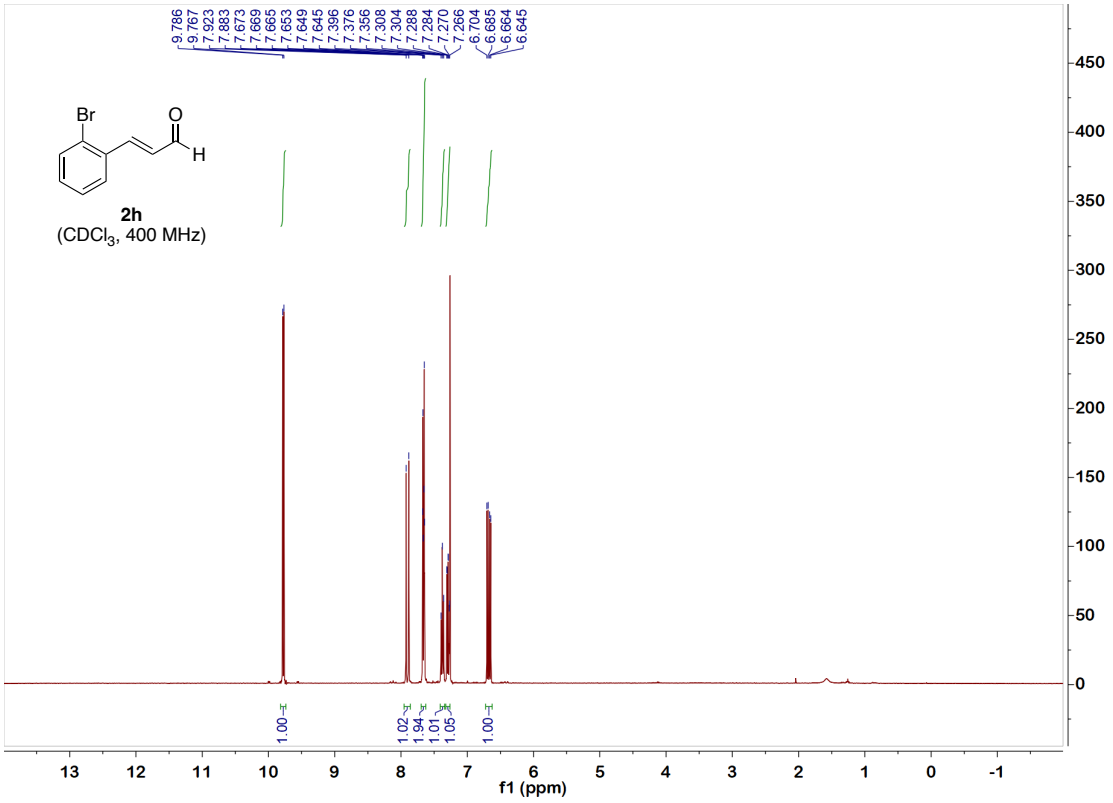
2c
($CDCl_3$, 400 MHz)

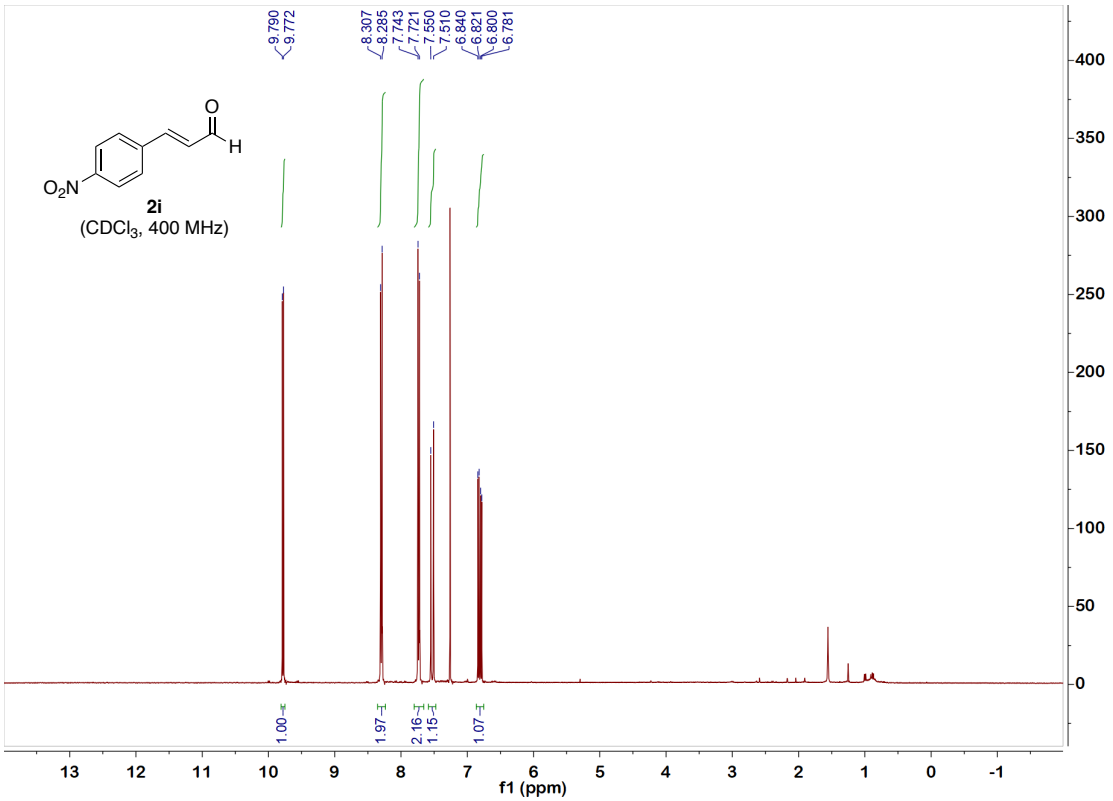

9.714
9.695
7.513
7.492
7.450
7.420
7.415
7.410
7.398
6.716
6.697
6.676
6.657
O
H
Cl
2d
(CDCl3, 400 MHz)
1.00
2.11
3.05
1.03
f1 (ppm)

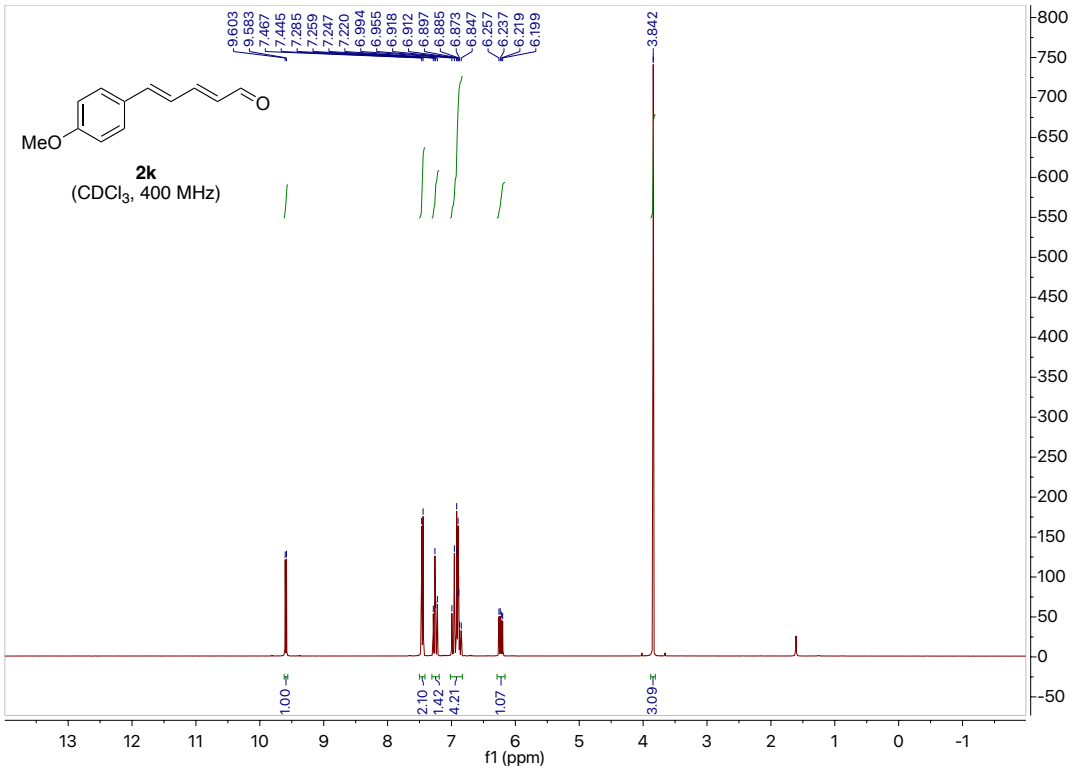

9.762
9.743
7.689
7.528
7.487
6.807
6.788
6.767
6.748
O
H
F3C
2e
(CDCl3, 400 MHz)
1.00
4.25
1.13
1.06
f1 (ppm)

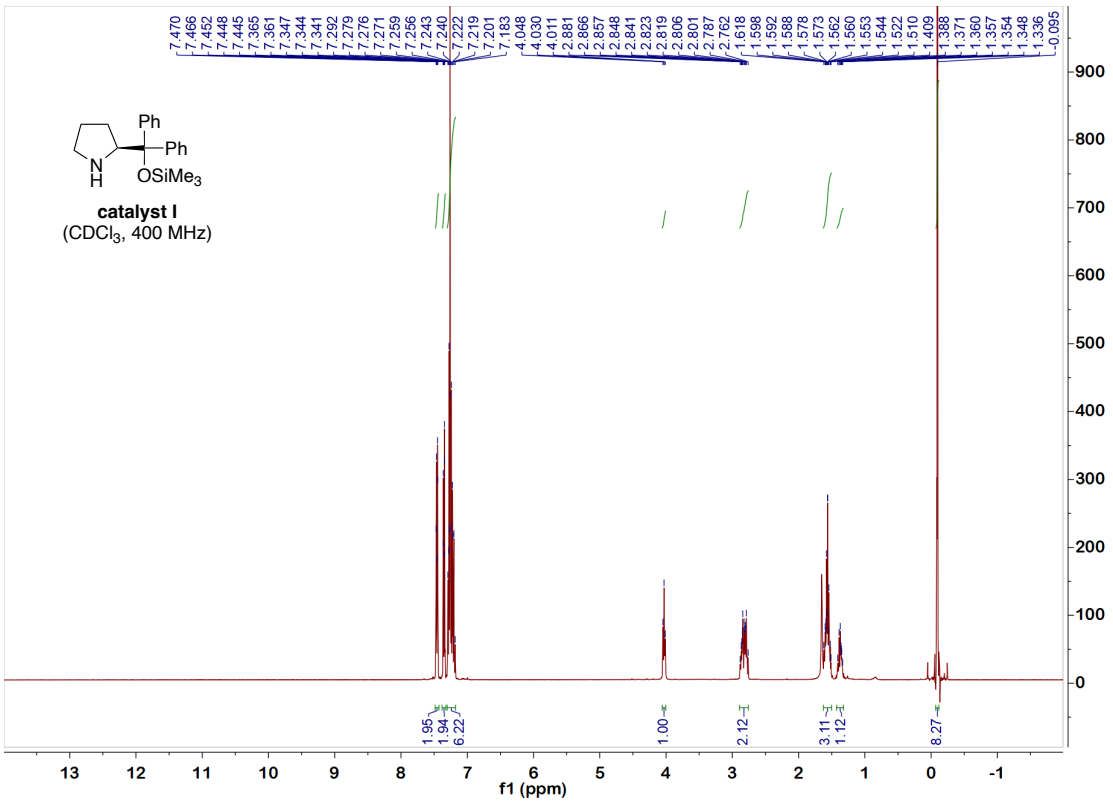

9.716
9.697
7.583
7.562
7.441
7.436
7.420
7.395
6.732
6.713
6.692
6.672
O
H
Br
2f
(CDCl3, 400 MHz)
1.00
1.99
3.21
1.05
f1 (ppm)

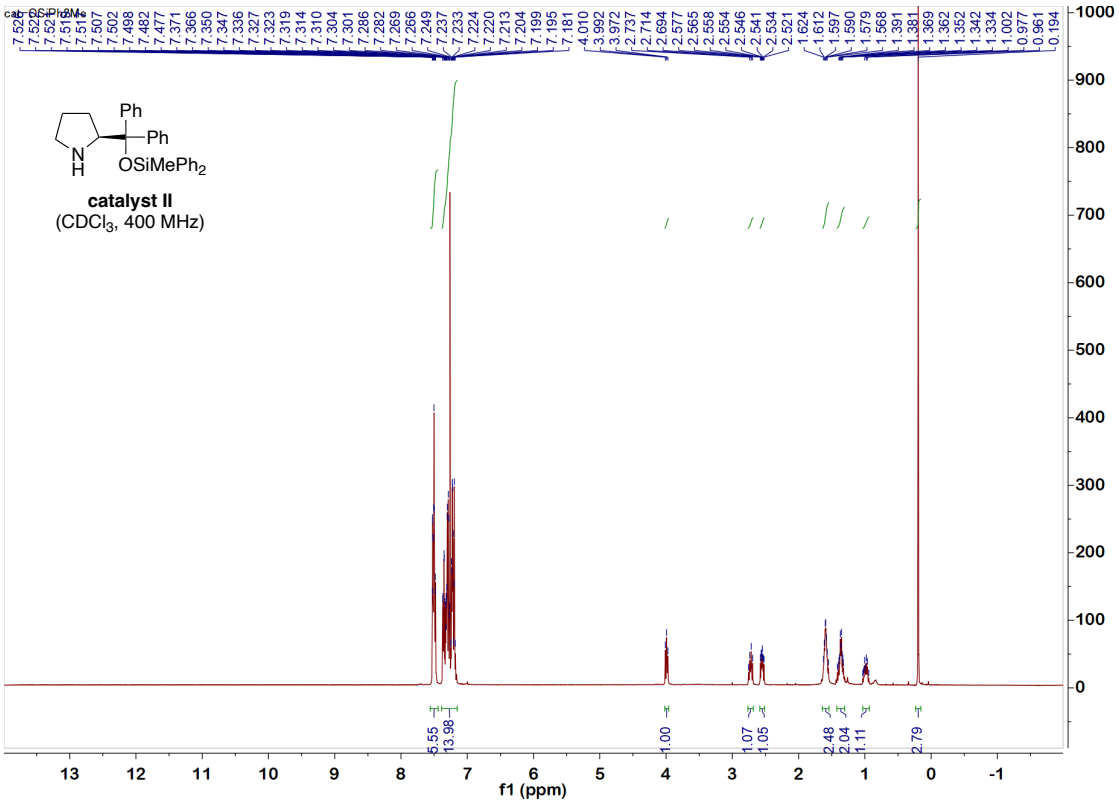

9.722
9.703
7.706
7.577
7.557
7.504
7.485
7.420
7.379
7.332
7.312
7.293
6.731
6.712
6.691
6.672
O
H
Br
2g
(CDCl3, 400 MHz)
1.00
1.04
0.98
1.07
1.11
1.06
1.03
f1 (ppm)

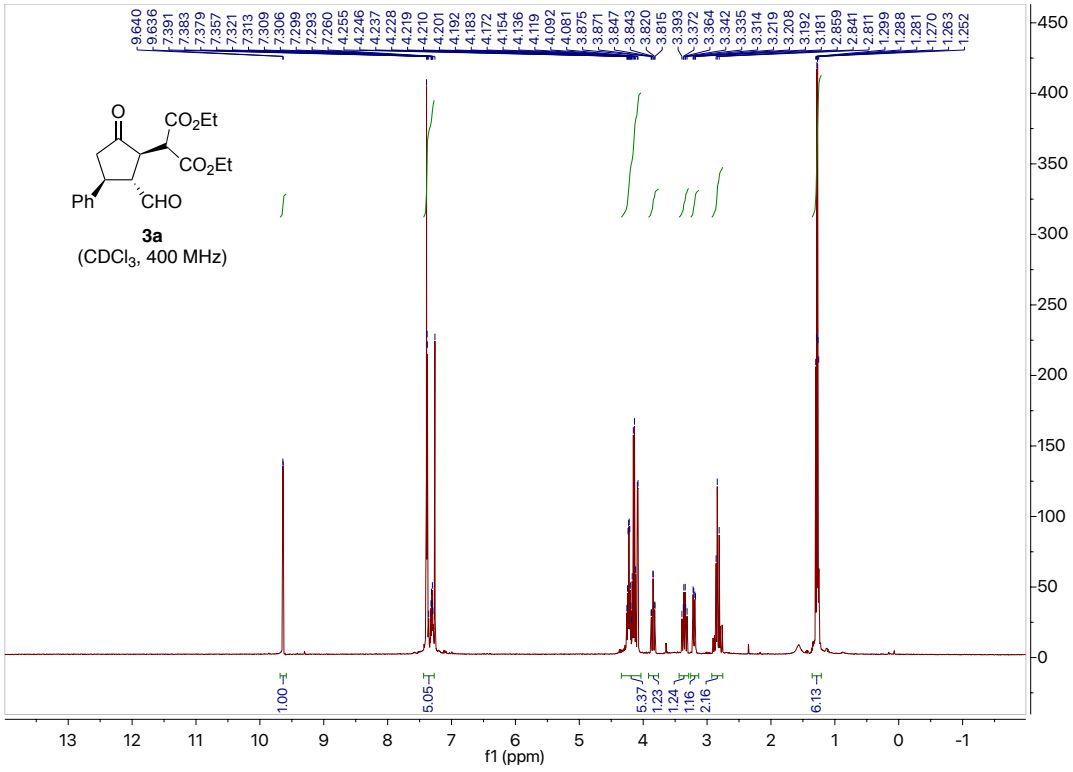

9.786
9.767
7.923
7.883
7.673
7.669
7.665
7.653
7.649
7.645
7.396
7.376
7.356
7.308
7.304
7.288
7.284
7.270
7.266
6.704
6.685
6.664
6.645
Br
O
H
2h
(CDCl3, 400 MHz)
1.00
1.02
1.94
1.01
1.05
1.00
f1 (ppm)

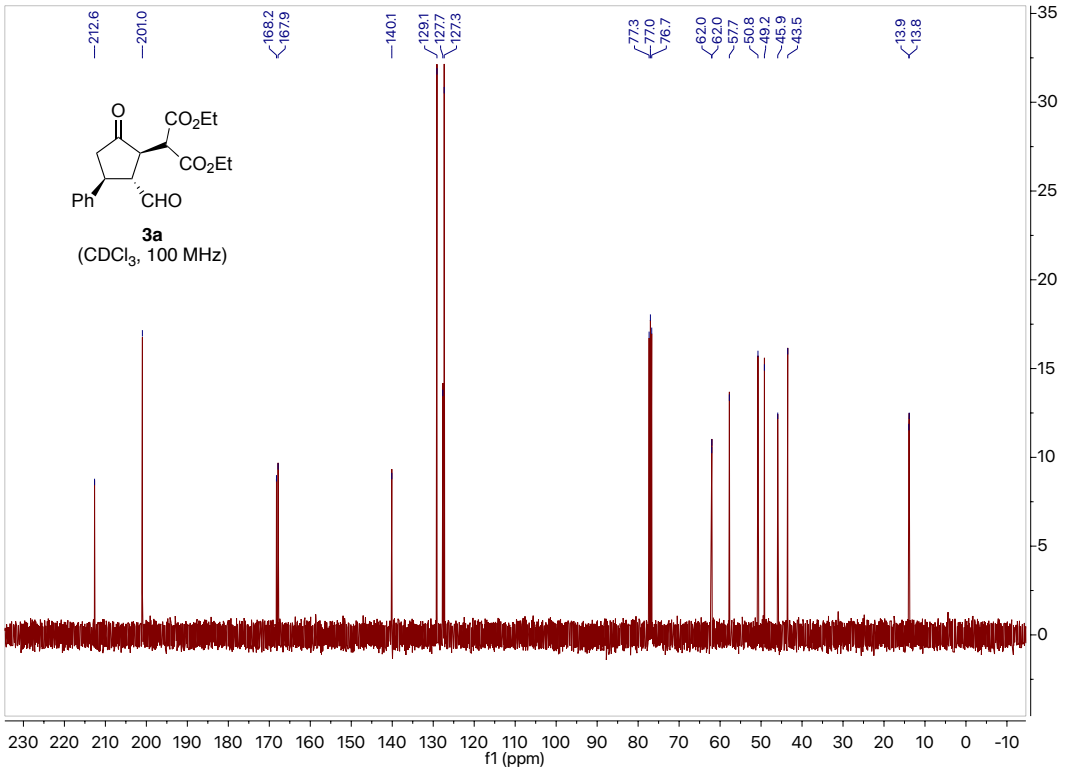

9.790
9.772
8.307
8.285
7.743
7.721
7.550
7.510
6.840
6.821
6.800
6.781
O
H
O2N
2i
(CDCl3, 400 MHz)
1.00
1.97
2.16
1.15
1.07
f1 (ppm)

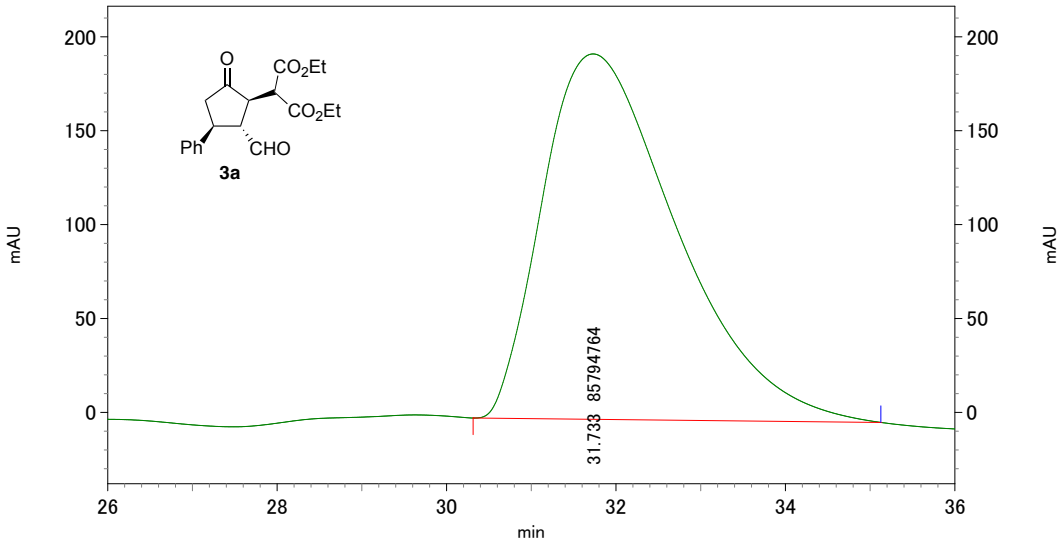

MeO
O
2k
(CDCl3, 400 MHz)
f1 (ppm)


Ph
Ph
N
H
OSiMe3
catalyst I
(CDCl3, 400 MHz)
f1 (ppm)


Ph
Ph
N
H
OSiMePh2
catalyst II
(CDCl3, 400 MHz)
f1 (ppm)


3a
(CDCl3, 400 MHz)
f1 (ppm)


3a
(CDCl3, 100 MHz)
f1 (ppm)



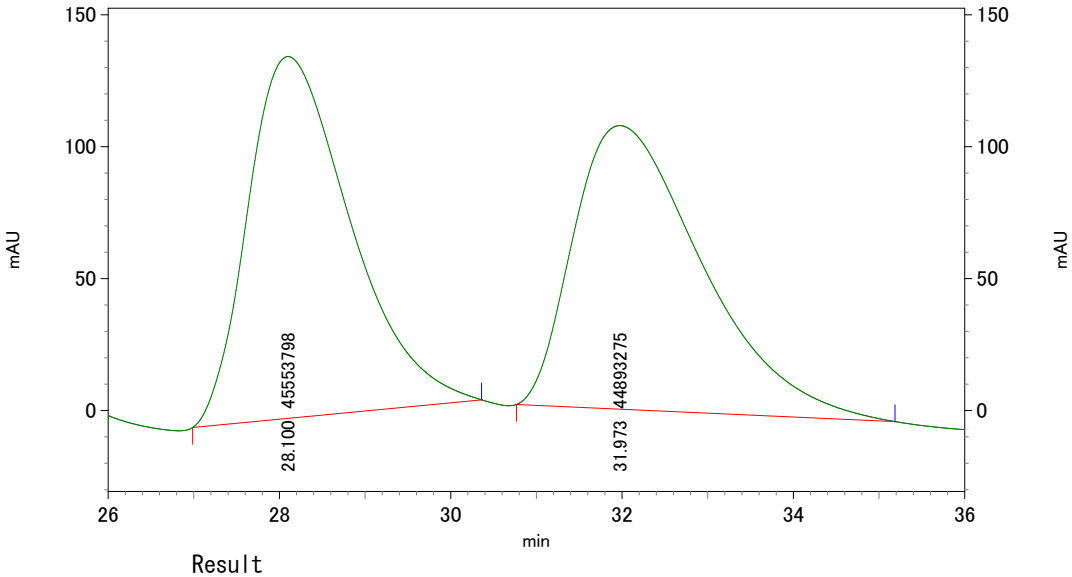
Result

1: 210.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	31.733	100.000

合計		100.000

Total



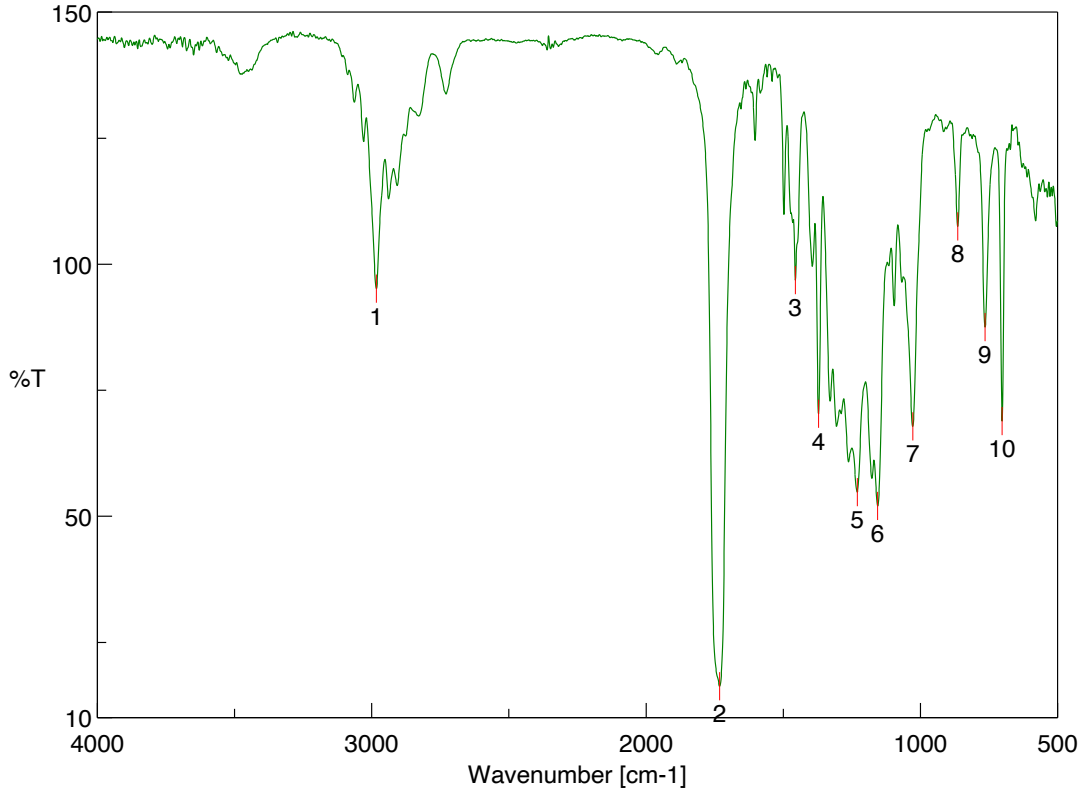
Result

1: 210.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	28.100	50.365
2	31.973	49.635

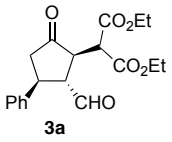
合計		100.000

Total

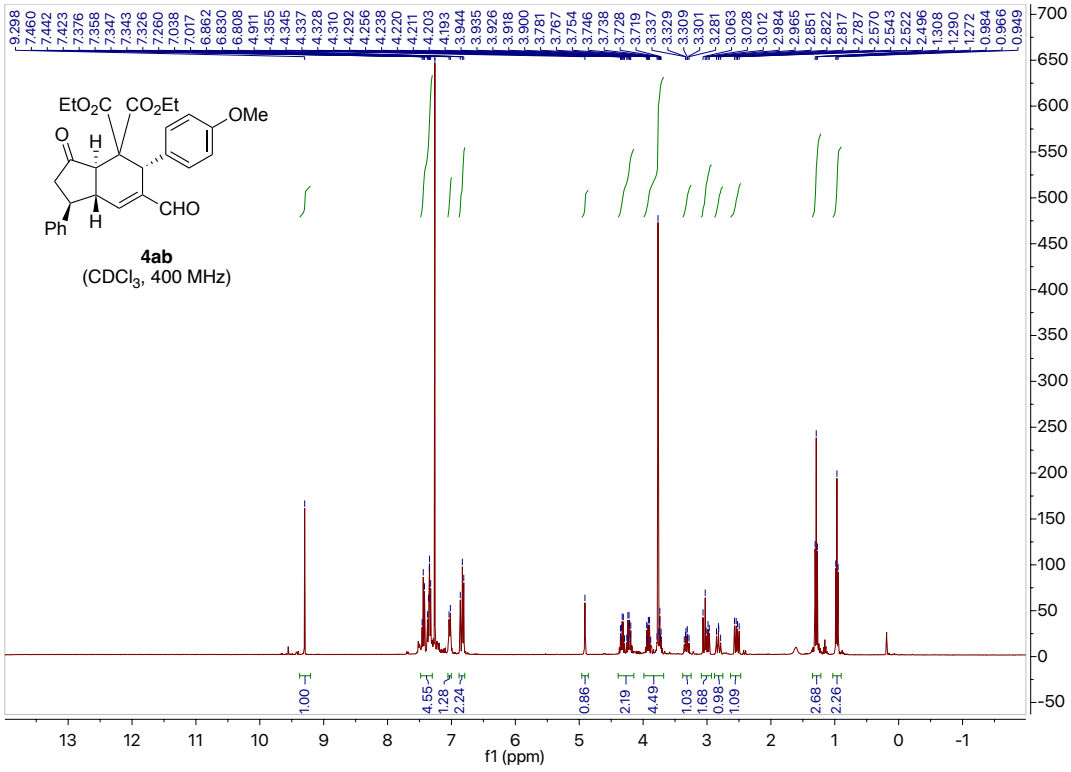


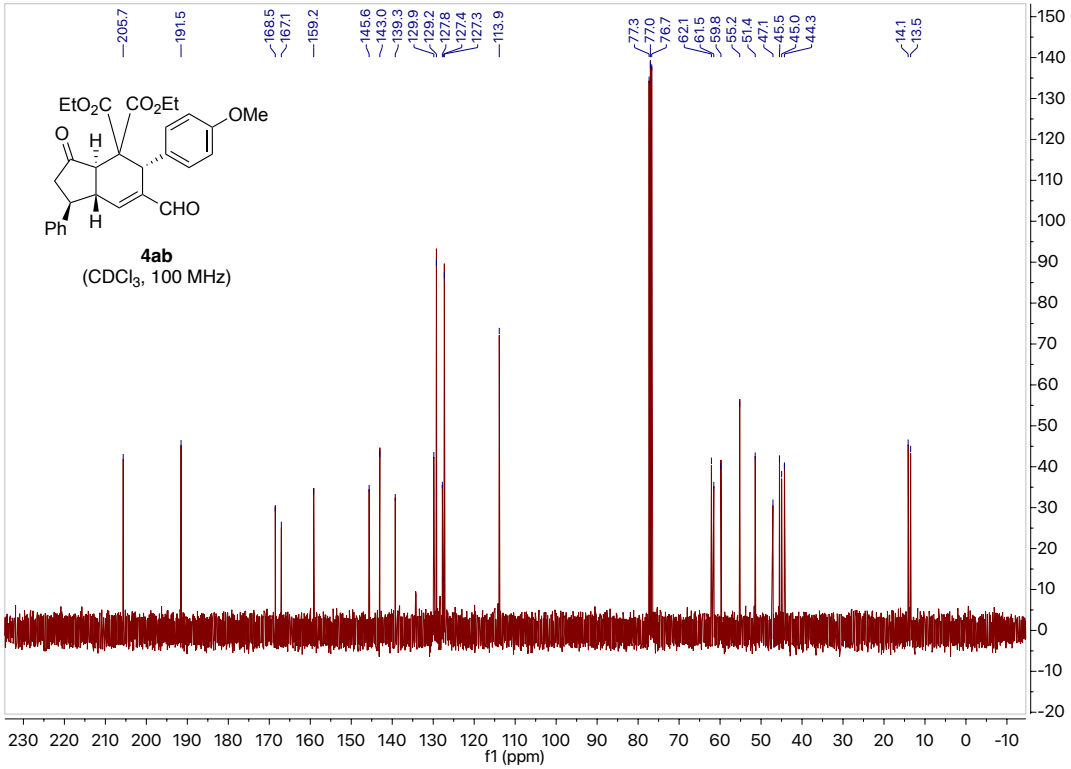
[ピーク検出結果]

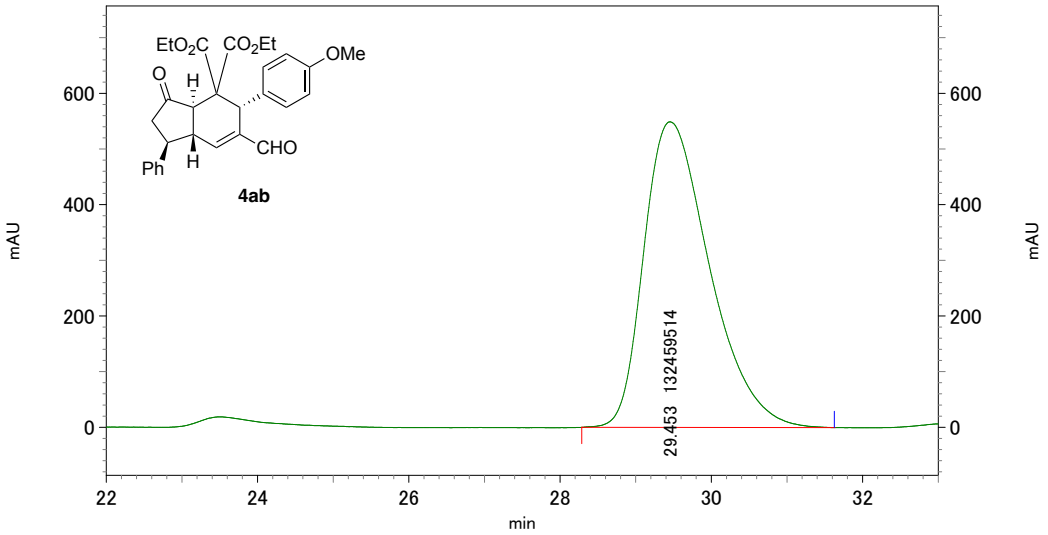
No.	位置	強度	No.	位置	強度
1	2983.34	95.1094	2	1731.76	16.2121
3	1455.99	96.8144	4	1371.14	70.307
5	1230.36	54.754	6	1156.12	52.0091
7	1027.87	67.8091	8	863.953	107.479
9	764.637	87.5083	10	701.962	68.8245



3a


EtO2C CO2Et
OMe
O
H
CHO
Ph
H
4ab
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
OMe
O
H
CHO
Ph
H
4ab
(CDCl3, 100 MHz)
f1 (ppm)



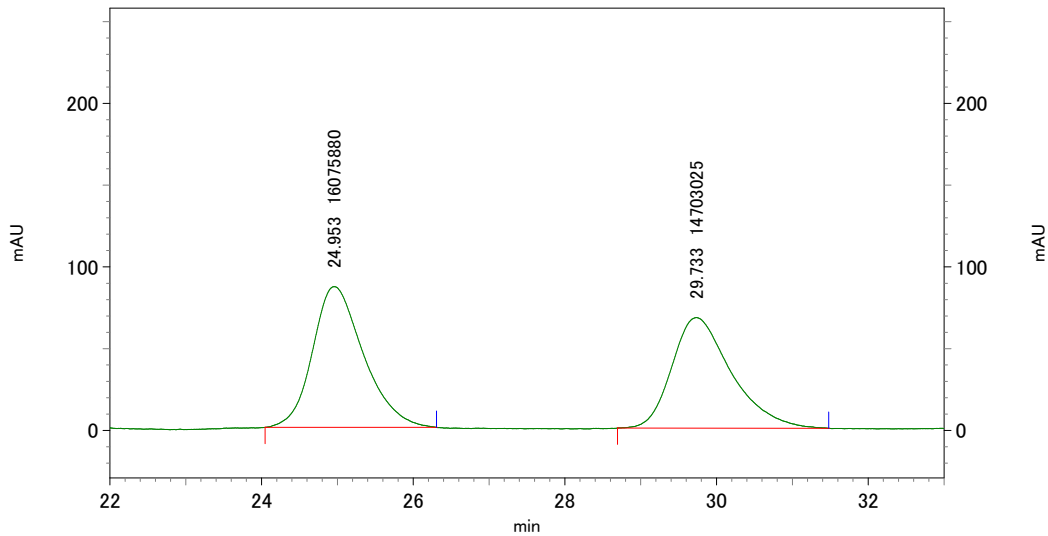
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	29.453	100.000

トータル		100.000

Total



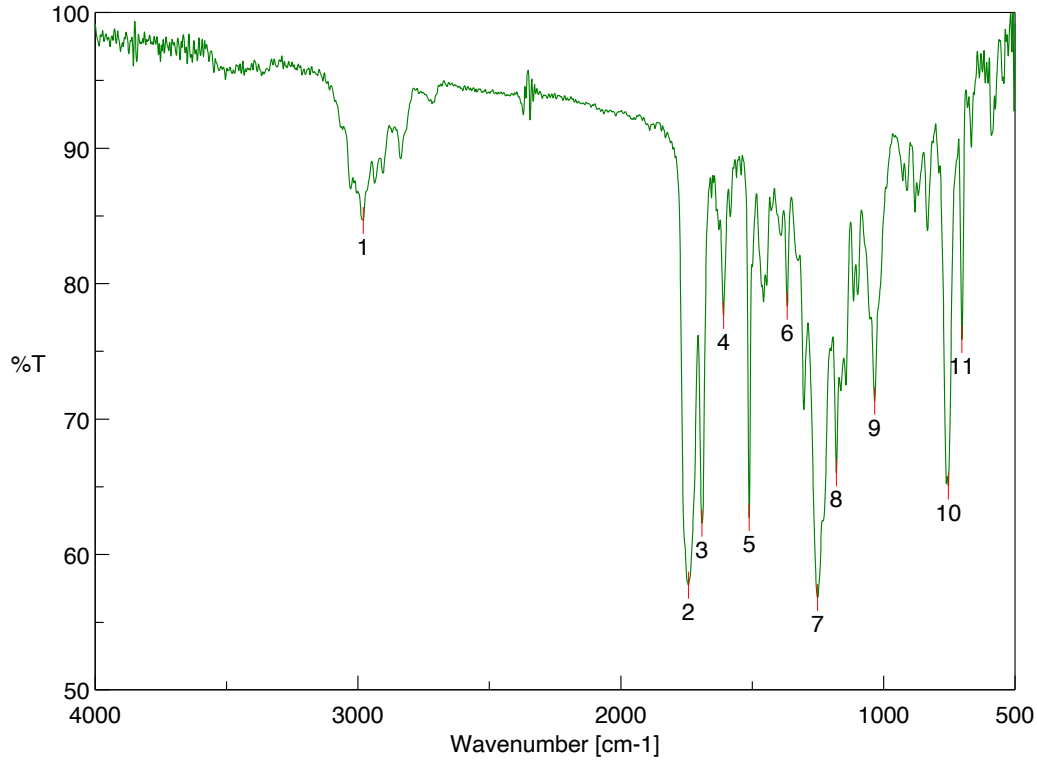
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	24.953	52.230
2	29.733	47.770

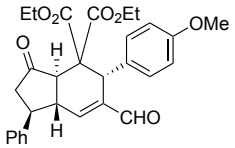
トータル		100.000

Total

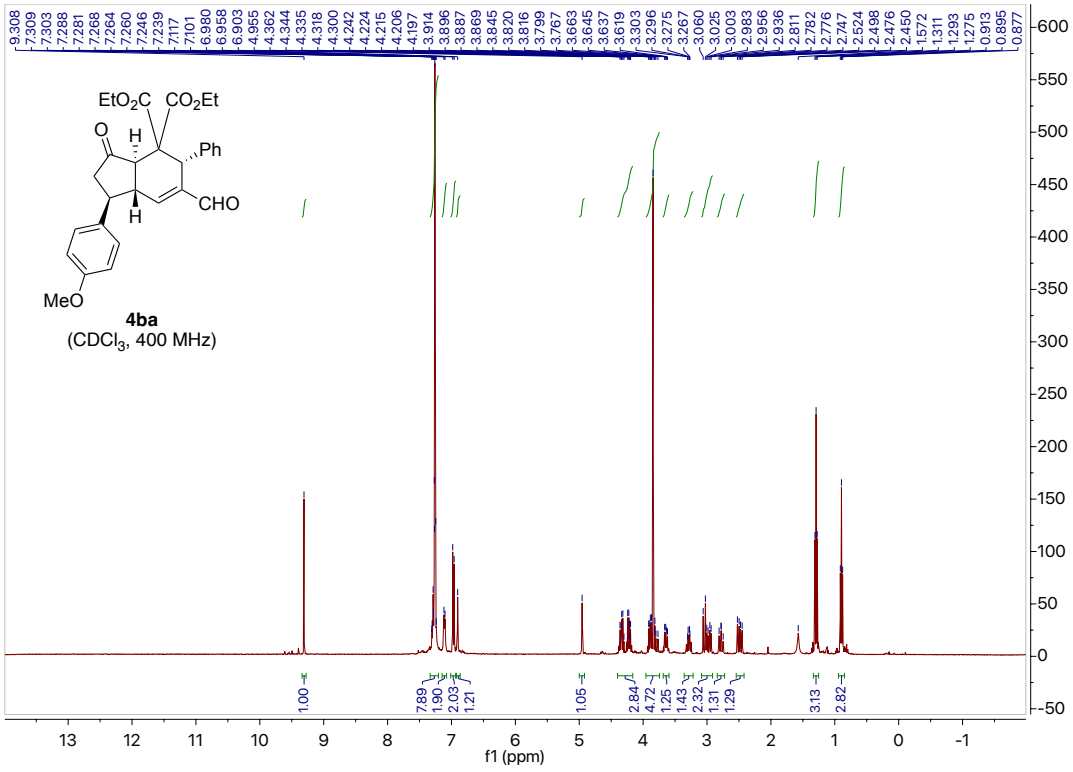


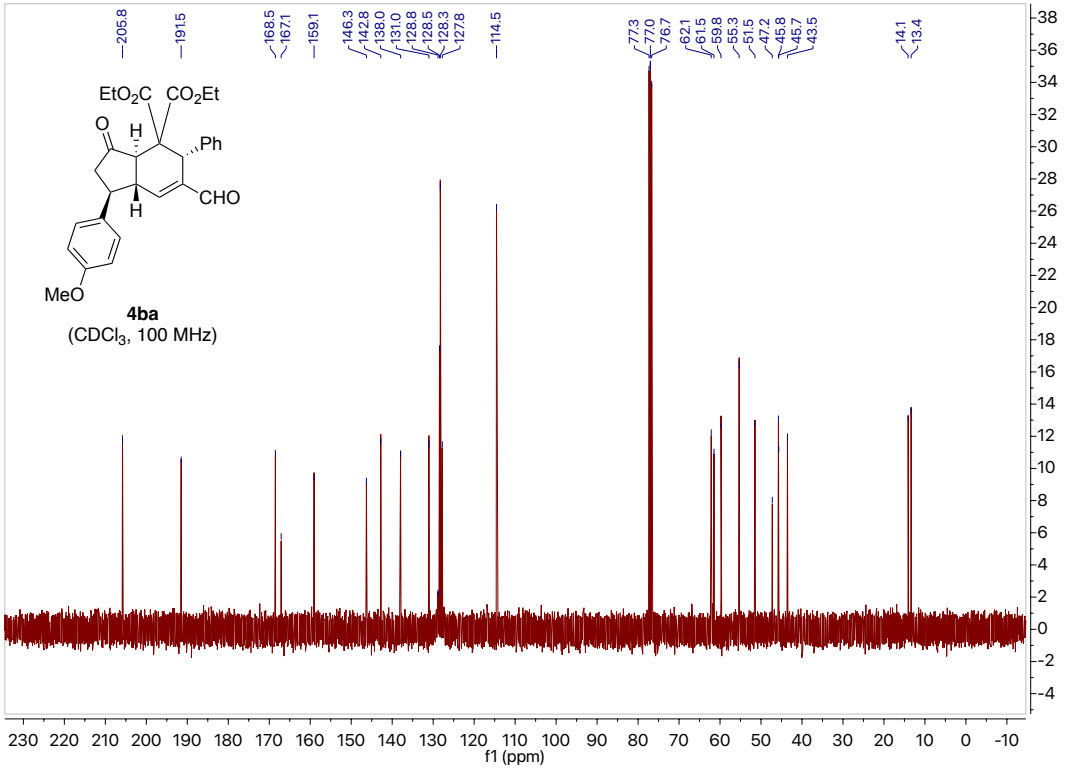
[ピーク検出結果]

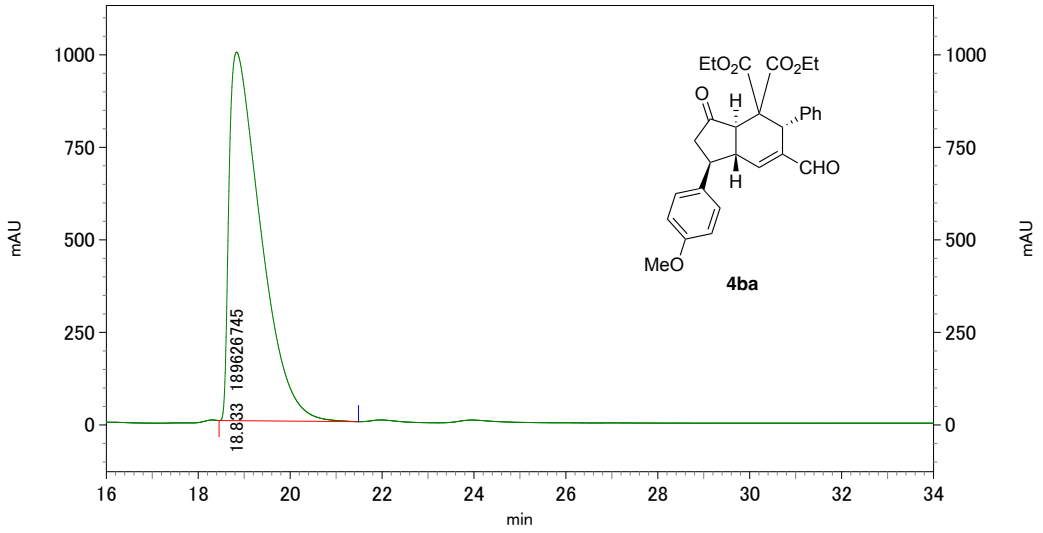
No.	位置	強度	No.	位置	強度
1	2979.48	84.6404	2	1742.37	57.7265
3	1691.27	62.3055	4	1609.31	77.6312
5	1510.95	62.7212	6	1367.28	78.3097
7	1251.58	56.8047	8	1179.26	66.0168
9	1033.66	71.3007	10	754.031	65.0532
11	701.962	75.8544			



4ab


EtO2C CO2Et
O
H
Ph
CHO
H
MeO
4ba
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
O
H
Ph
CHO
H
MeO
4ba
(CDCl3, 100 MHz)
f1 (ppm)



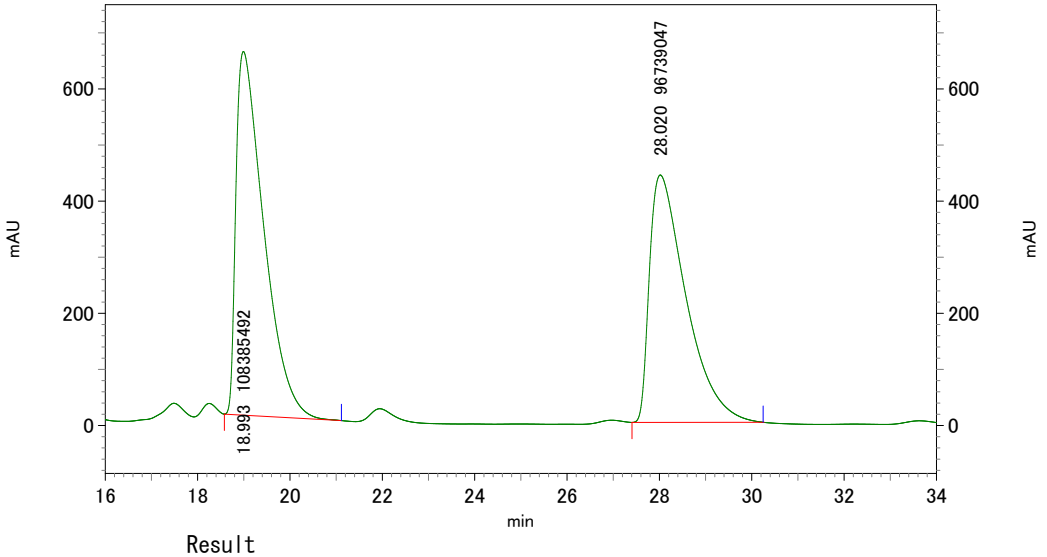
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	18.833	99.999
2	59.513	0.000
3	59.733	0.000
4	59.847	0.000

合計		100.000

Total



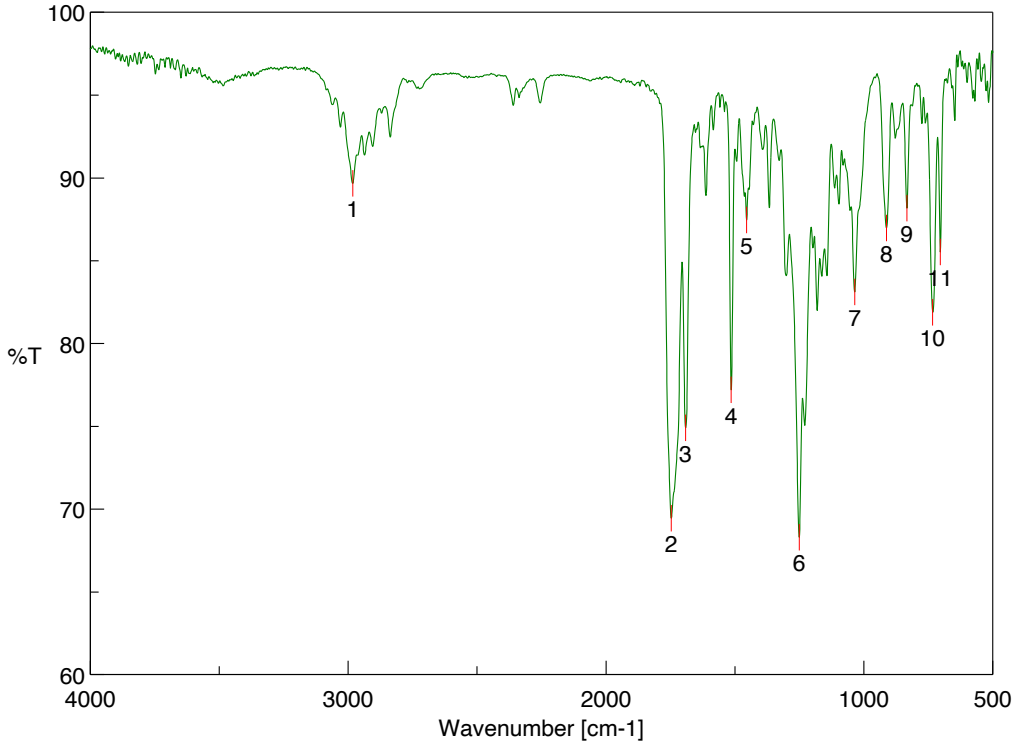
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	18.993	52.839
2	28.020	47.161

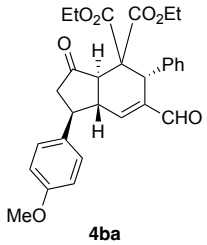
合計		100.000

Total

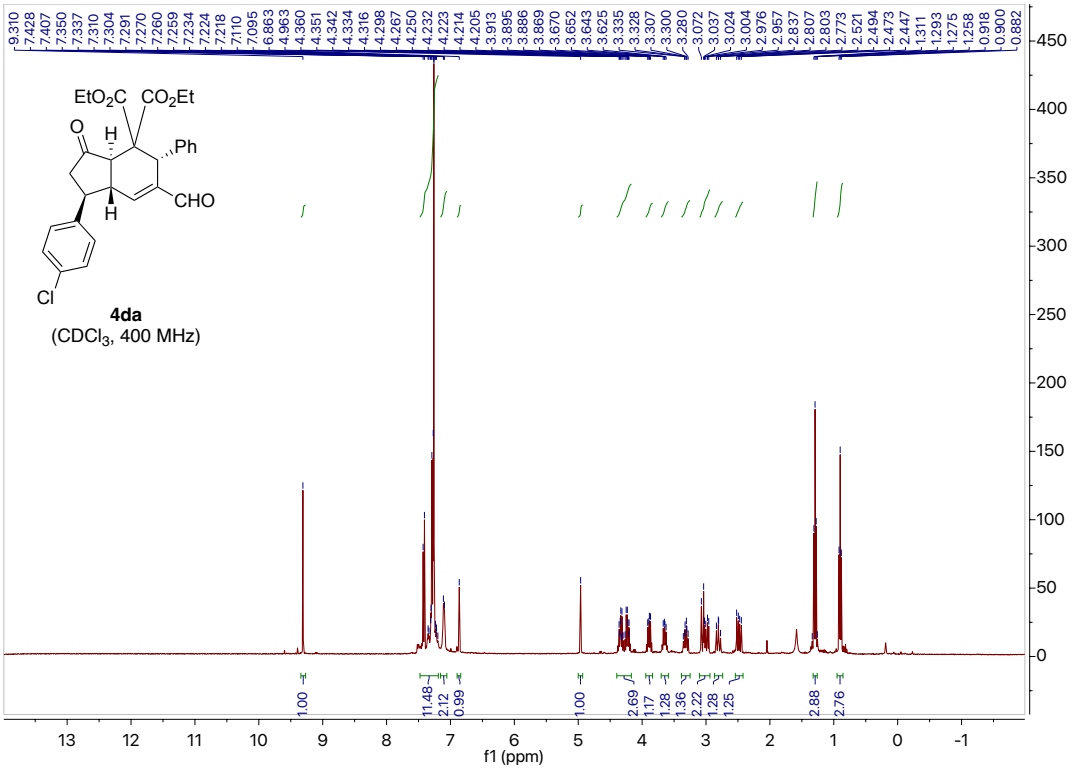


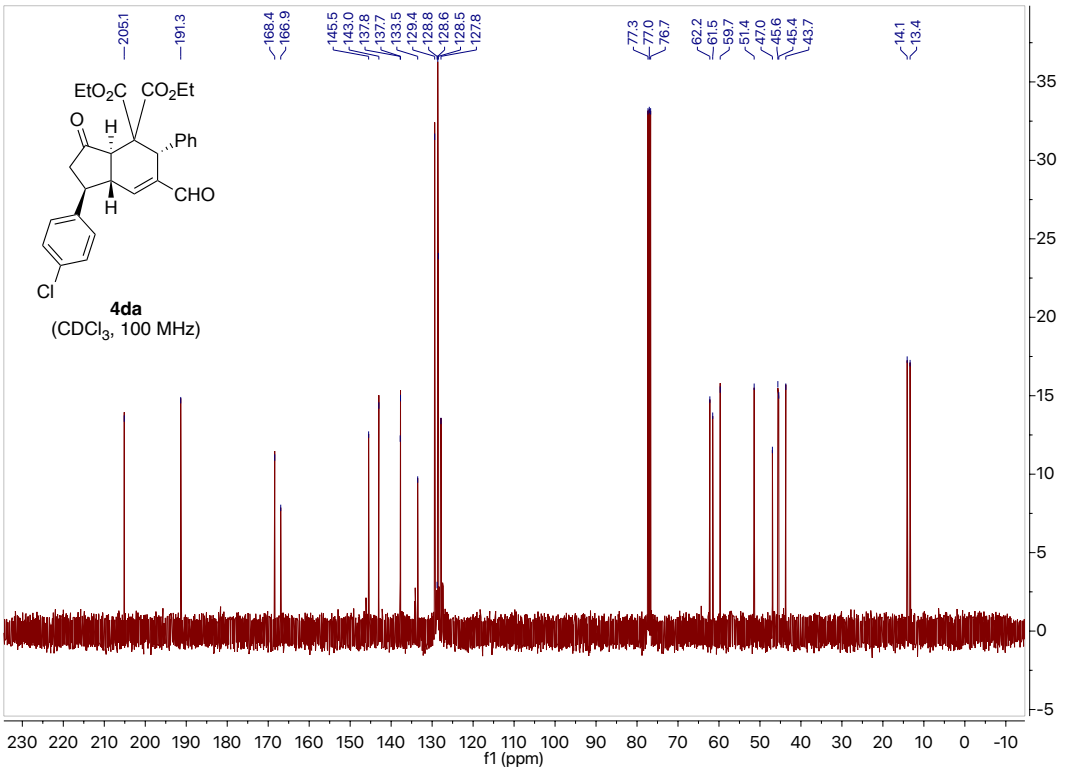
[ピーク検出結果]

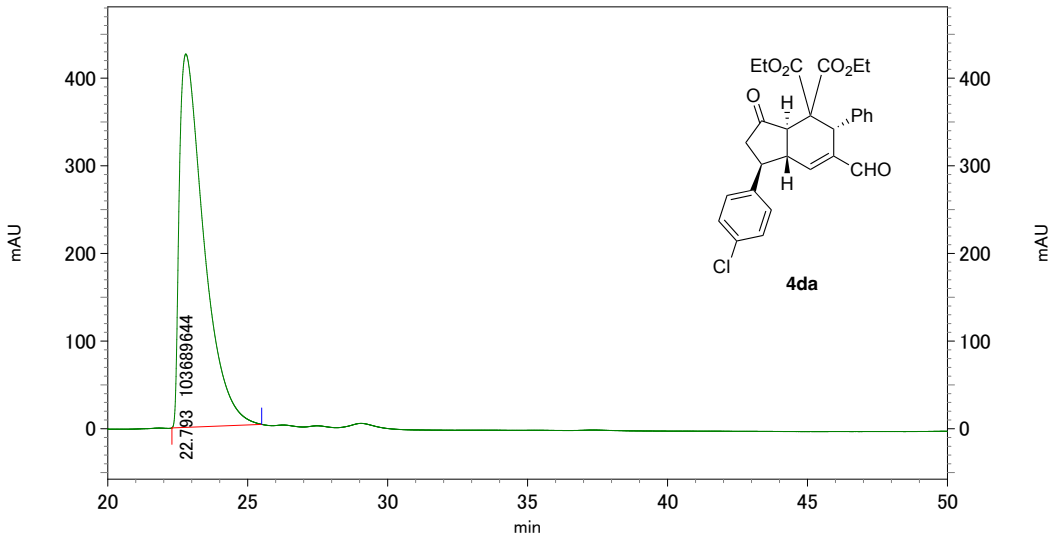
No.	位置	強度	No.	位置	強度
1	2982.37	89.6565	2	1747.19	69.4333
3	1691.27	74.9006	4	1514.81	77.1908
5	1455.03	87.4477	6	1250.61	68.286
7	1035.59	83.1125	8	912.165	86.9742
9	833.098	88.1666	10	732.817	81.876
11	702.926	85.5258			



4ba


EtO2C CO2Et
O
H
Ph
CHO
H
Cl
4da
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
O
H
Ph
CHO
H
Cl
4da
(CDCl3, 100 MHz)
f1 (ppm)



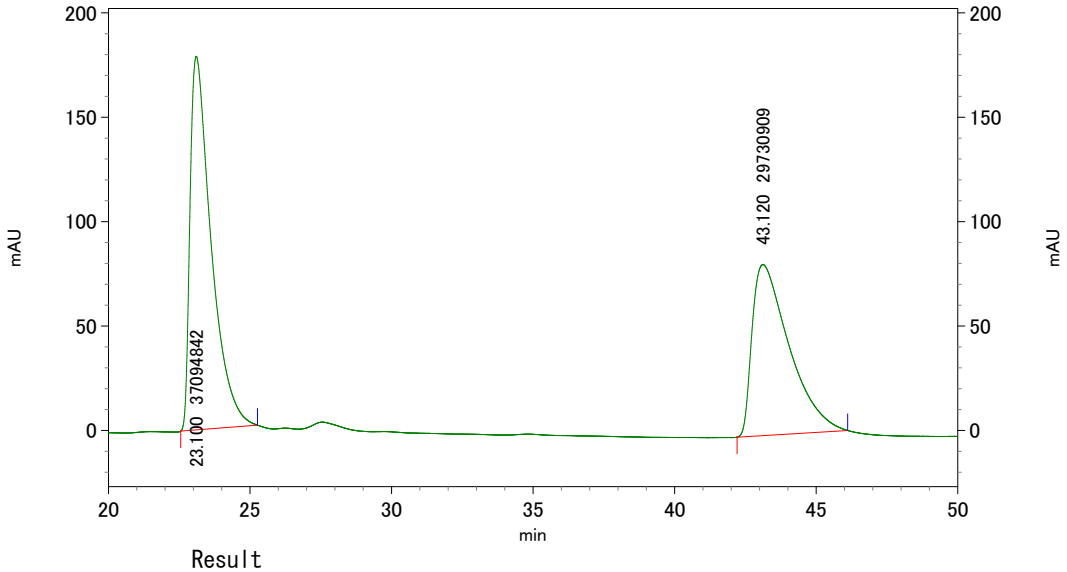
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	22.793	100.000

合計		100.000

Total



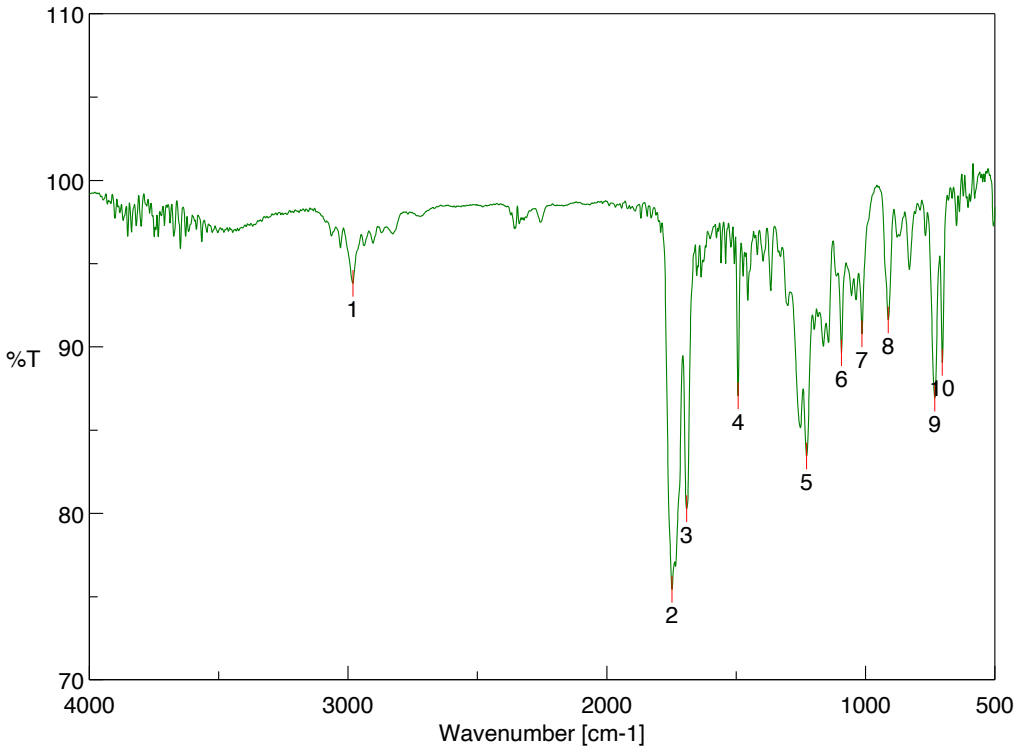
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	23.100	55.510
2	43.120	44.490

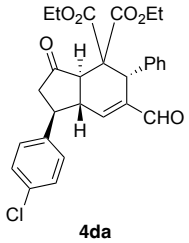
合計		100.000

Total

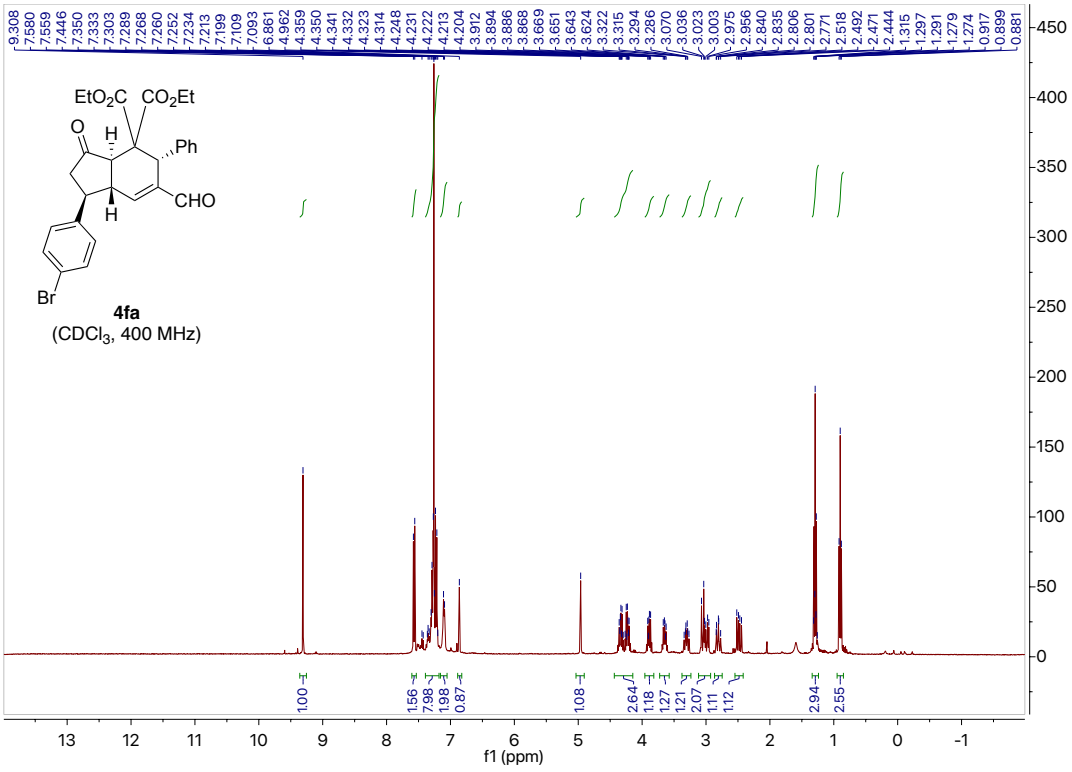


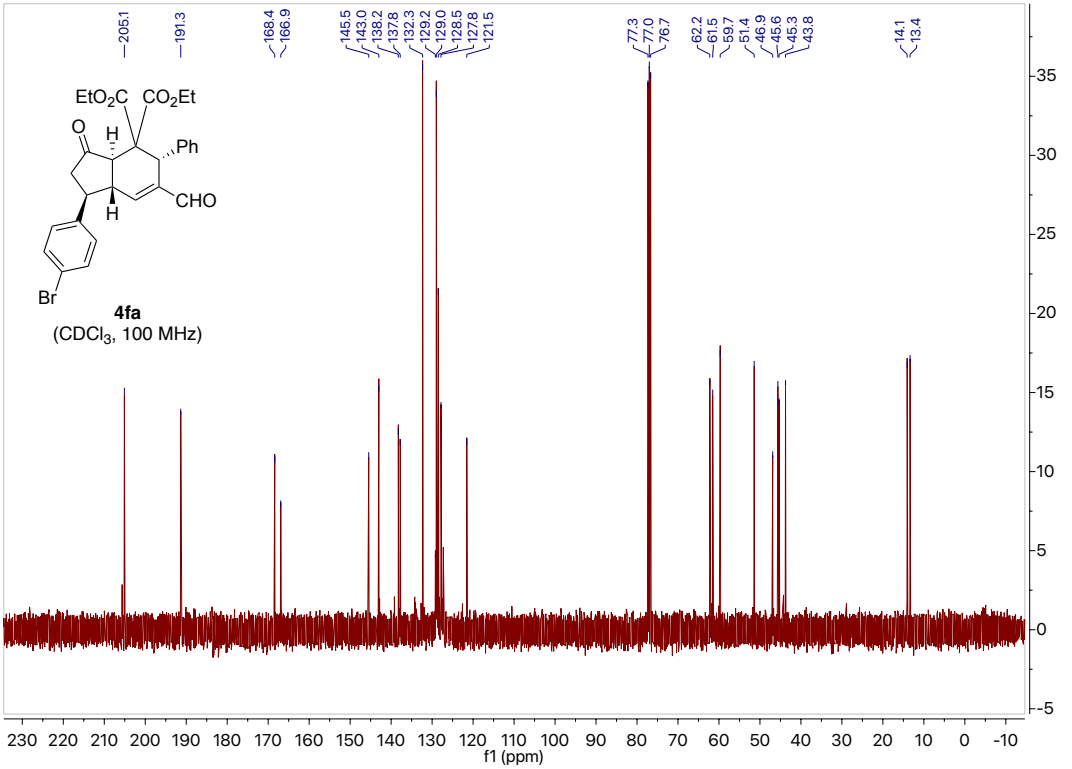
[ピーク検出結果]

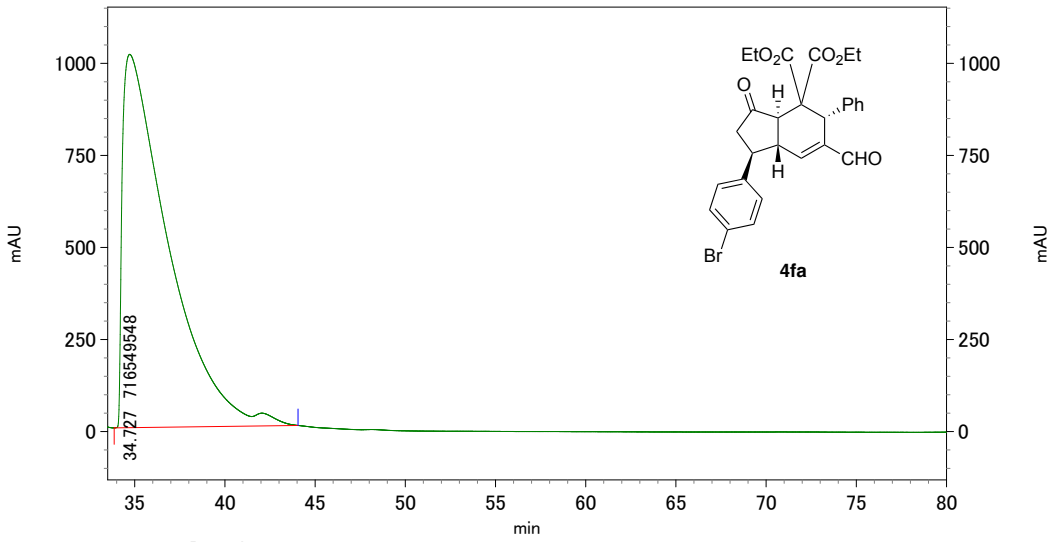
No.	位置	強度	No.	位置	強度
1	2981.41	93.811	2	1748.16	75.4318
3	1691.27	80.2634	4	1492.63	87.0418
5	1227.47	83.4319	6	1092.48	89.6401
7	1013.41	90.7719	8	912.165	91.6095
9	731.853	86.92	10	702.926	89.0587



4da


EtO2C CO2Et
O
H
Ph
CHO
H
Br
4fa
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
O
H
Ph
CHO
H
Br
4fa
(CDCl3, 100 MHz)
f1 (ppm)



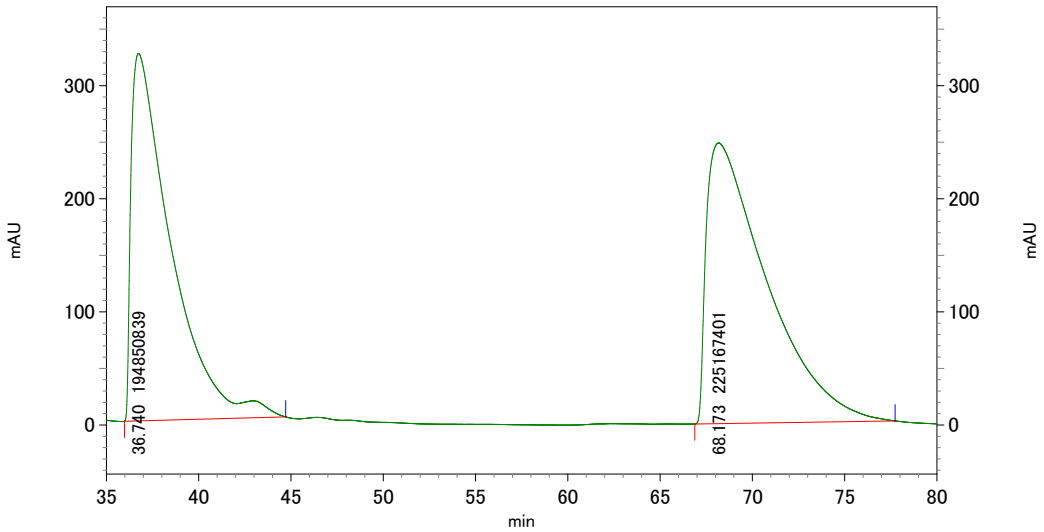
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	34.727	100.000

合計		100.000

Total



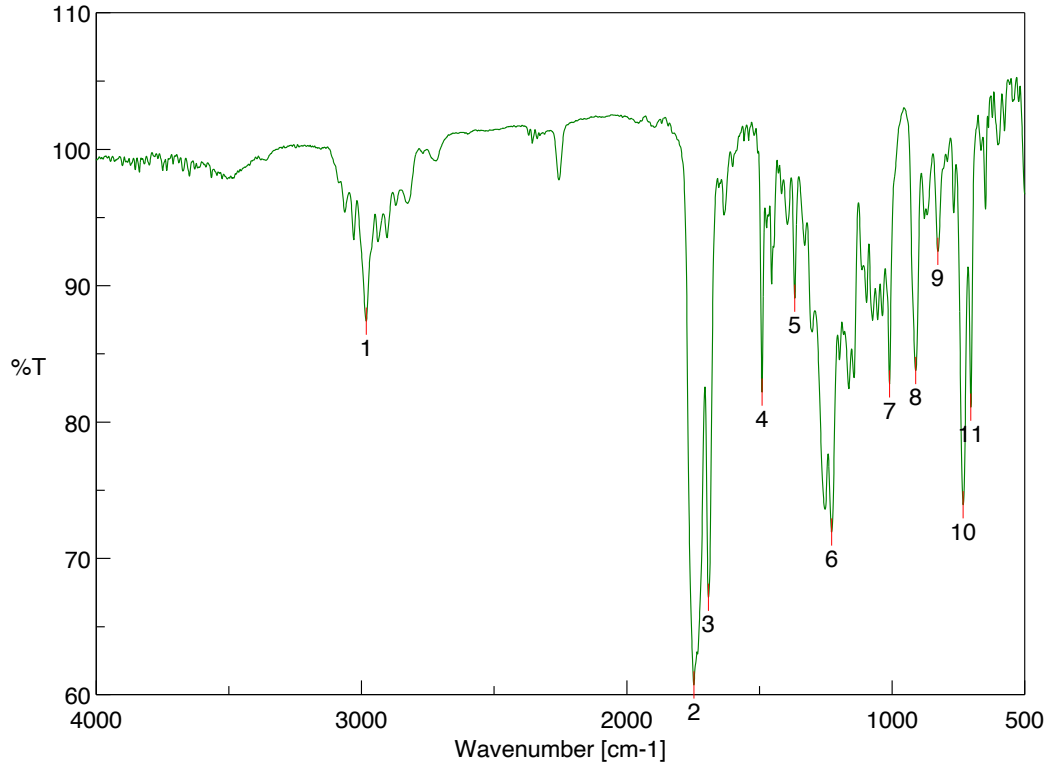
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	36.740	46.391
2	68.173	53.609

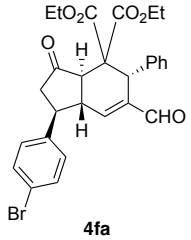
合計		100.000

Total

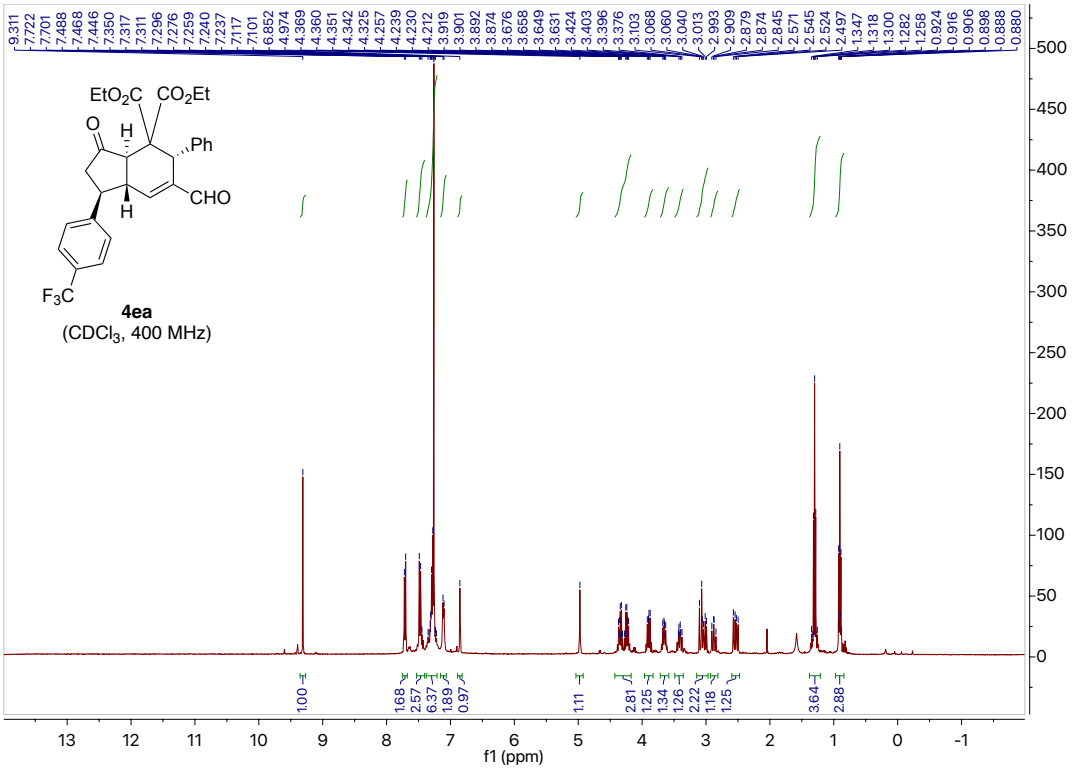


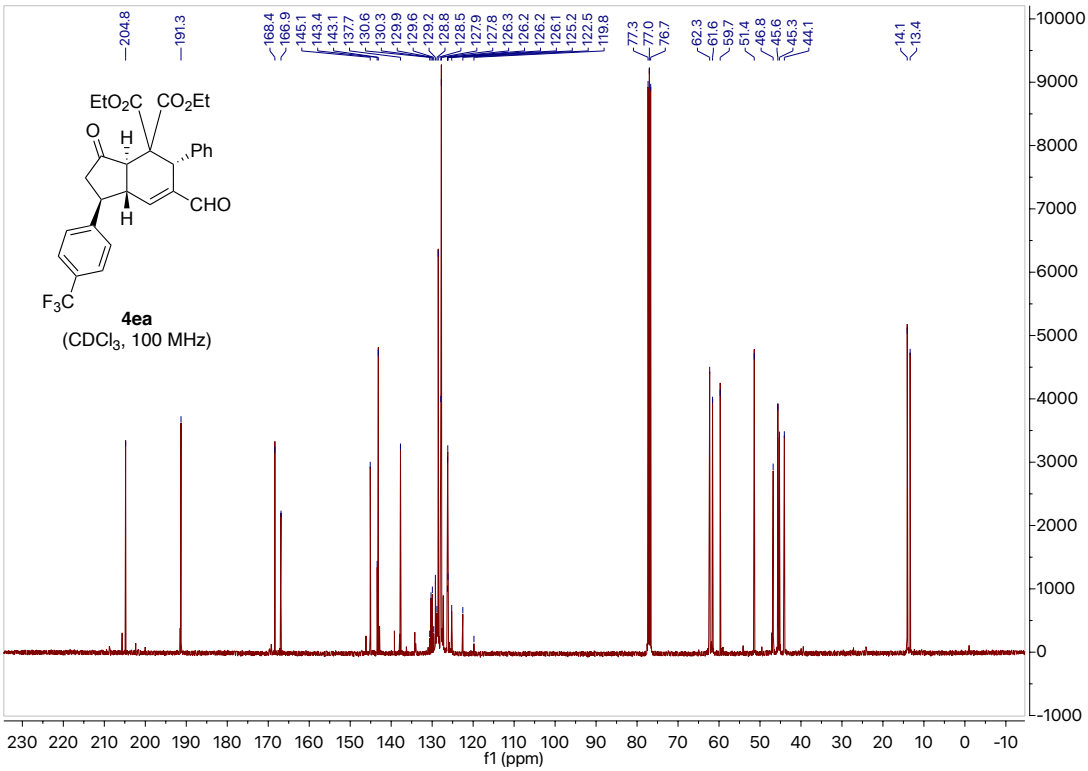
[ピーク検出結果]

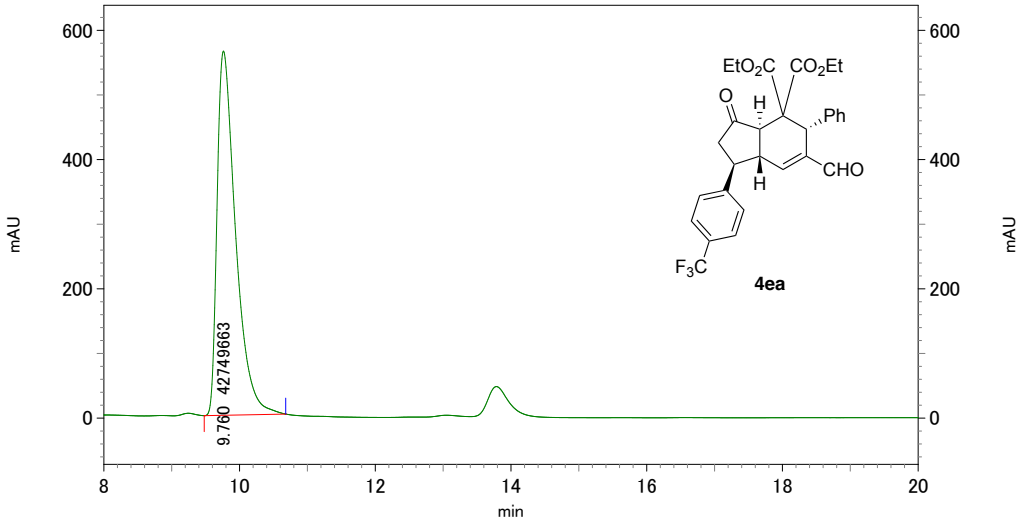
No.	位置	強度	No.	位置	強度
1	2982.37	87.3868	2	1747.19	60.7073
3	1692.23	67.1384	4	1489.74	82.1905
5	1367.28	89.0616	6	1227.47	71.9202
7	1009.55	82.7896	8	911.201	83.76
9	827.312	92.4941	10	731.853	73.9175
11	702.926	81.0776			



4fa


EtO2C
CO2Et
O
H
Ph
CHO
H
F3C
4ea
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C
CO2Et
O
H
Ph
CHO
H
F3C
4ea
(CDCl3, 100 MHz)
f1 (ppm)



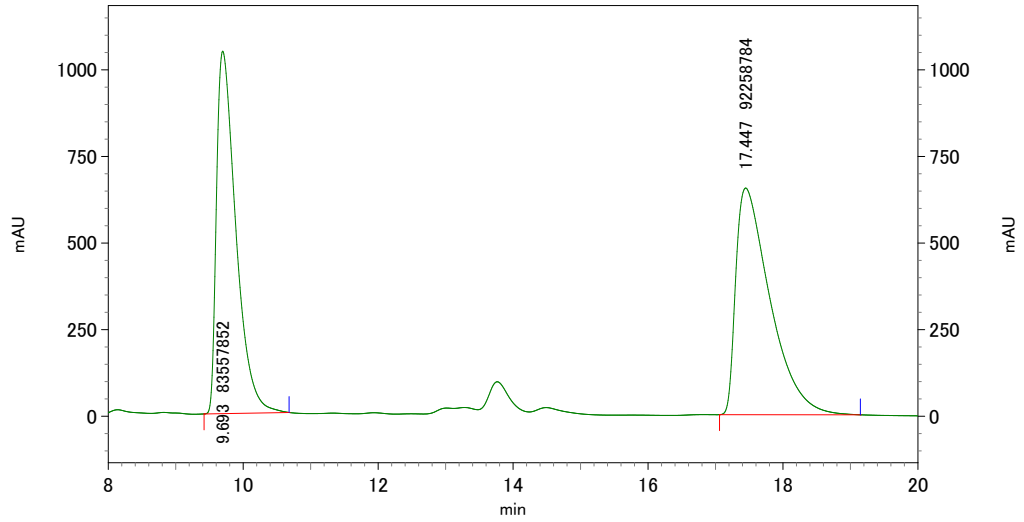
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	9.760	100.000

合計		100.000

Total



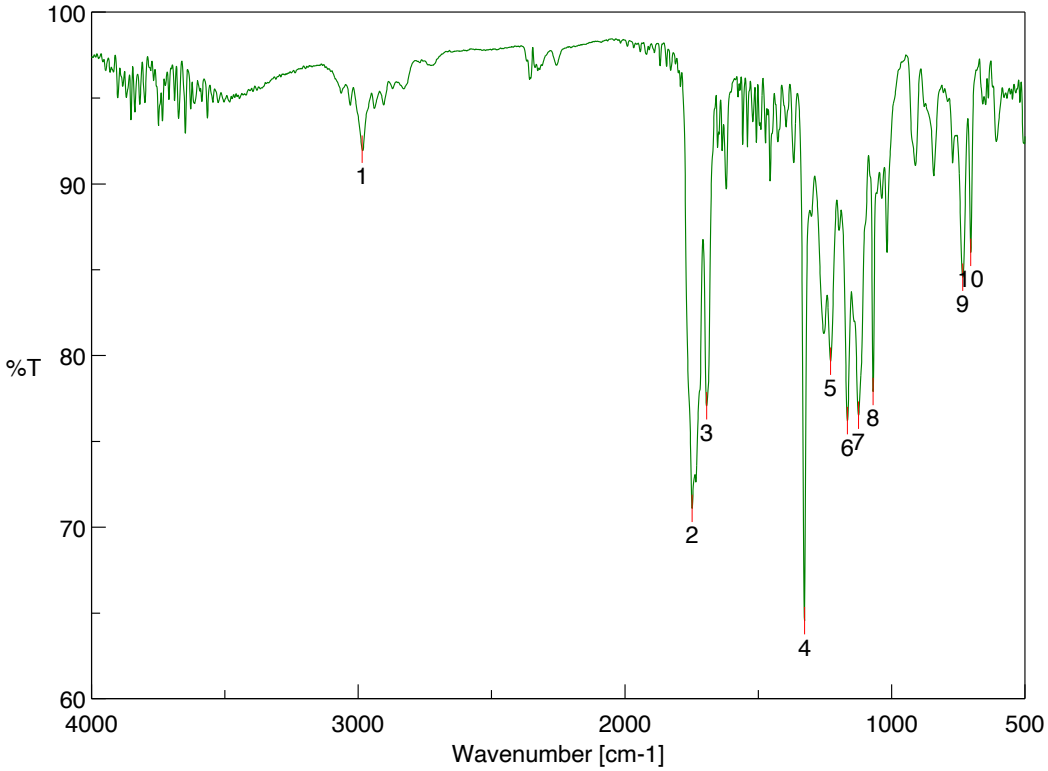
Result

2: 208.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	9.693	47.526
2	17.447	52.474

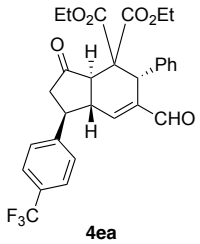
合計		100.000

Total

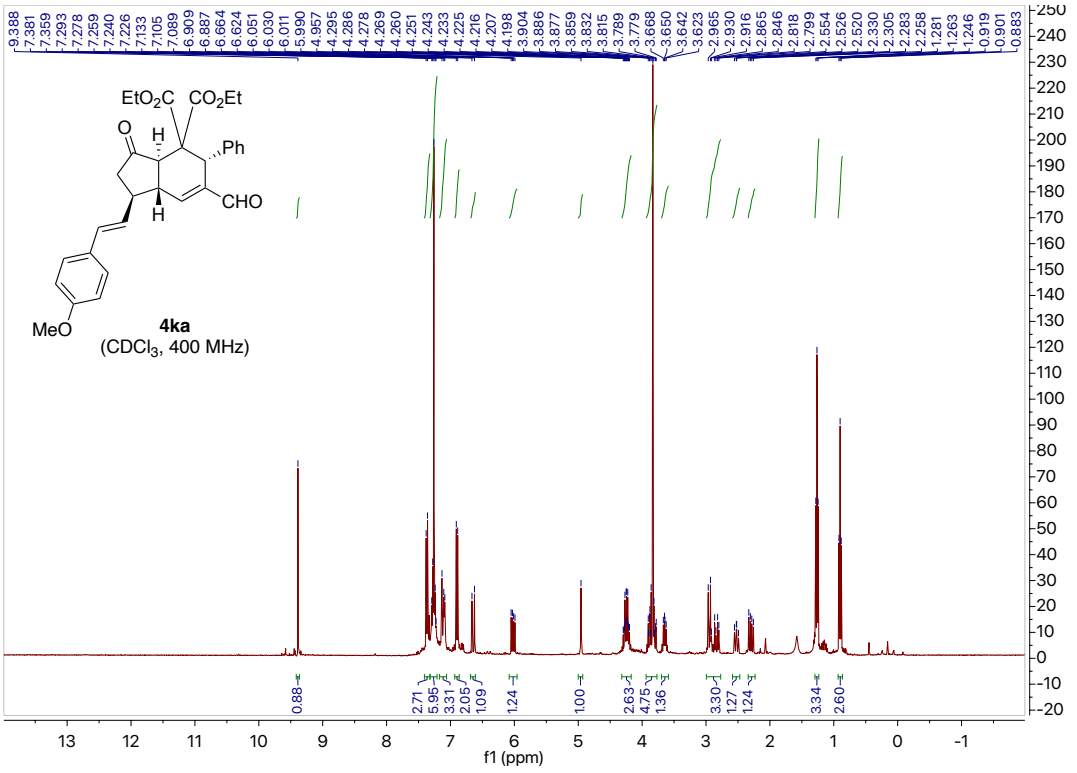


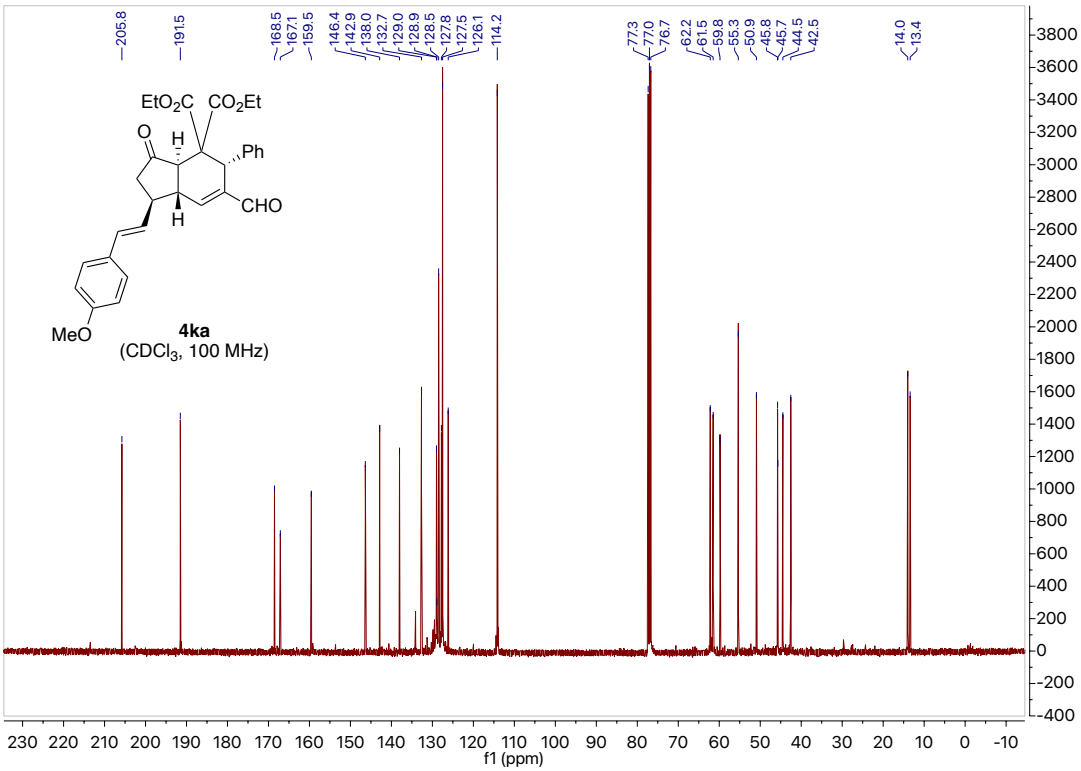
[ピーク検出結果]

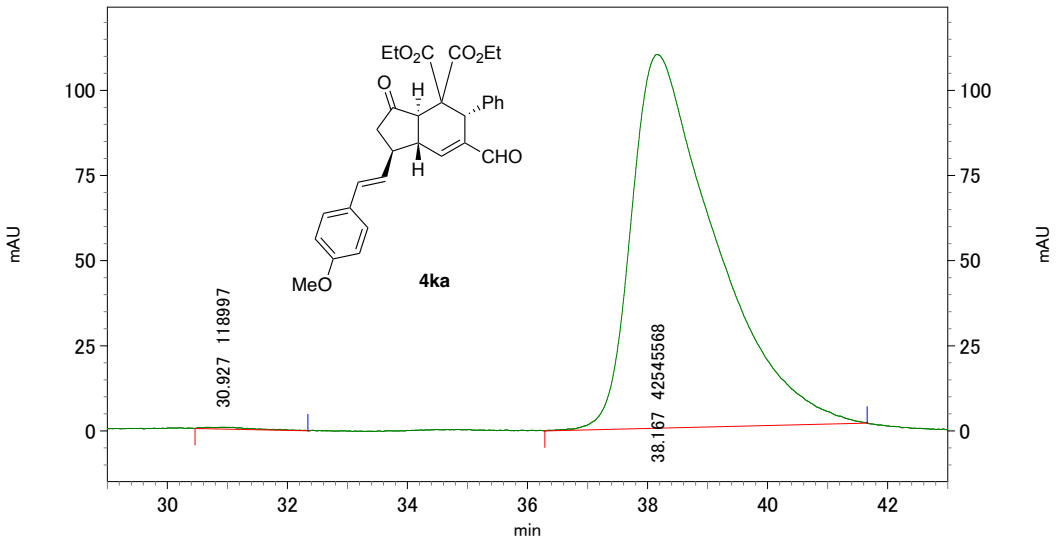
No.	位置	強度	No.	位置	強度
1	2985.27	92.0077	2	1748.16	71.0815
3	1693.19	77.0557	4	1326.79	64.5447
5	1228.43	79.6575	6	1165.76	76.194
7	1124.3	76.5139	8	1069.33	77.8933
9	732.817	84.5525	10	702.926	86.009



4ea


EtO2C CO2Et
O
H
Ph
CHO
H
MeO
4ka
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
O
H
Ph
CHO
H
MeO
4ka
(CDCl3, 100 MHz)
f1 (ppm)



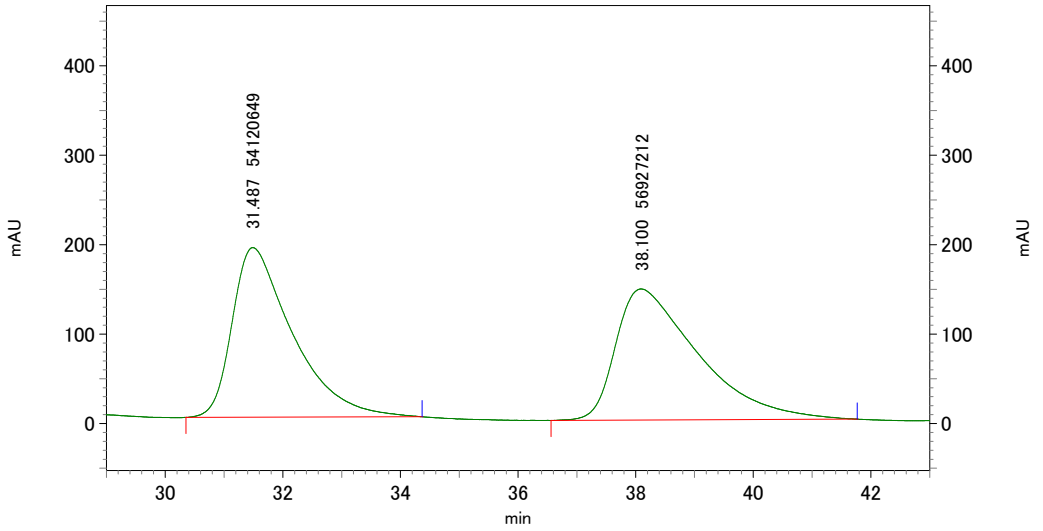
Result

1: 210 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	30.927	0.279
2	38.167	99.721

トータル		100.000

Total



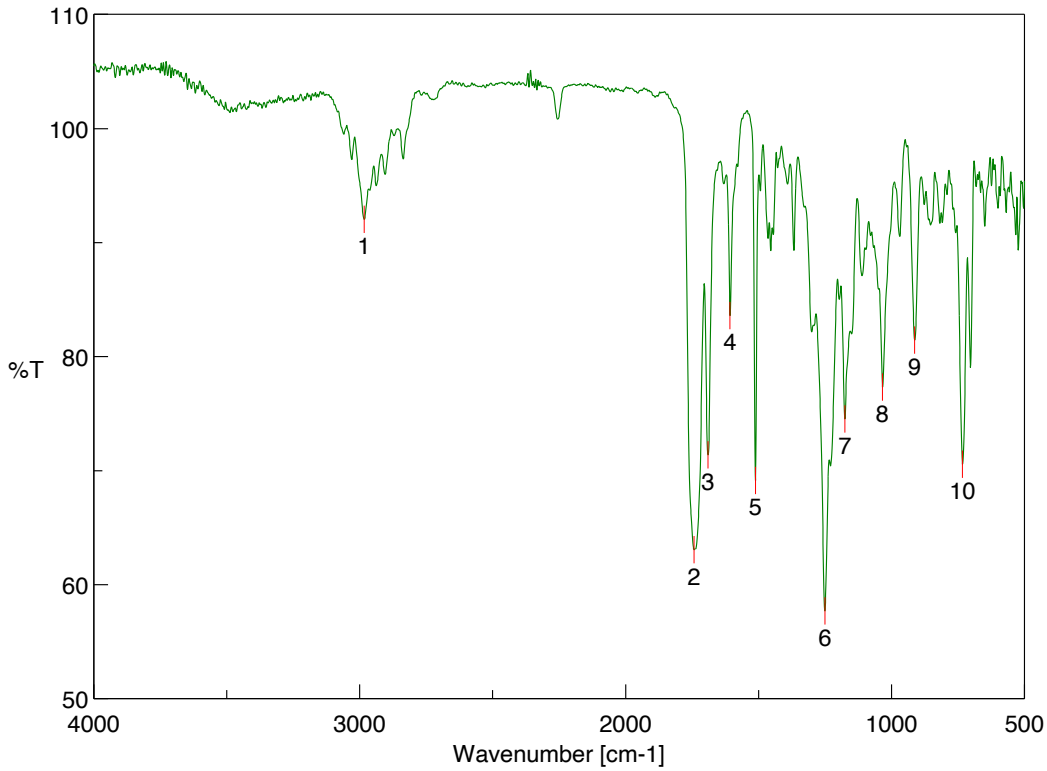
Result

1: 210 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	31.487	48.736
2	38.100	51.264

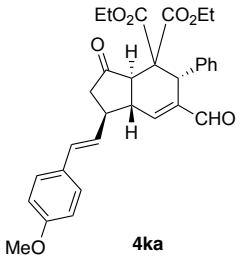
トータル		100.000

Total

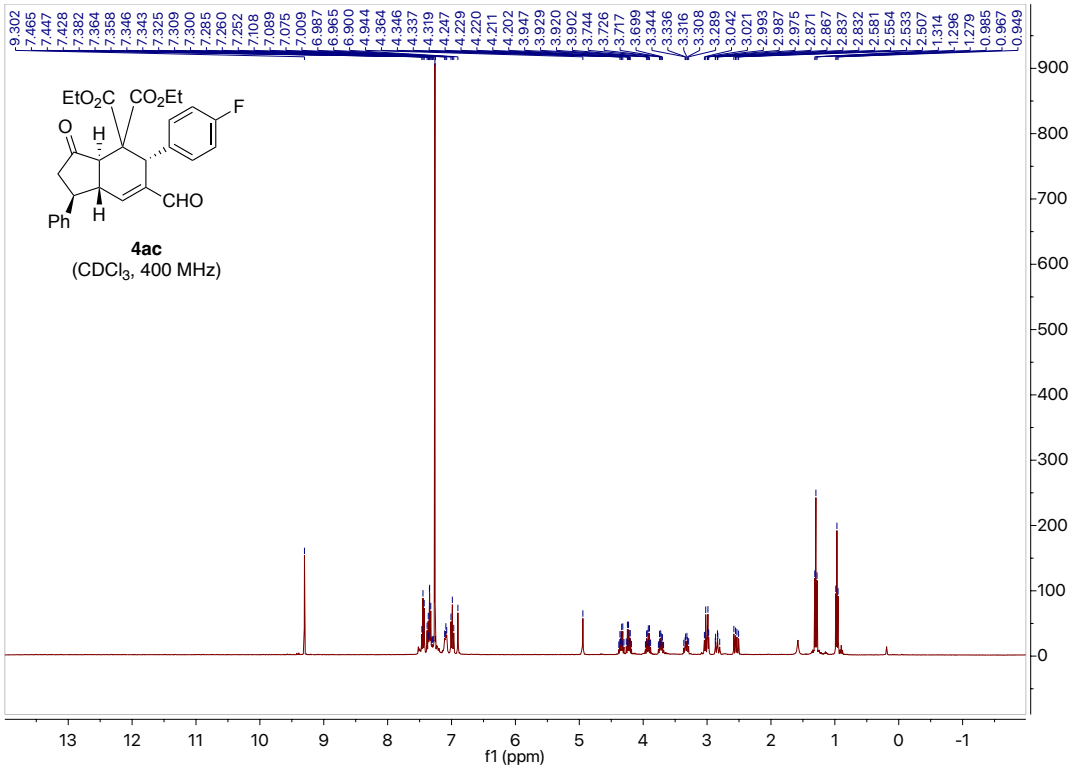


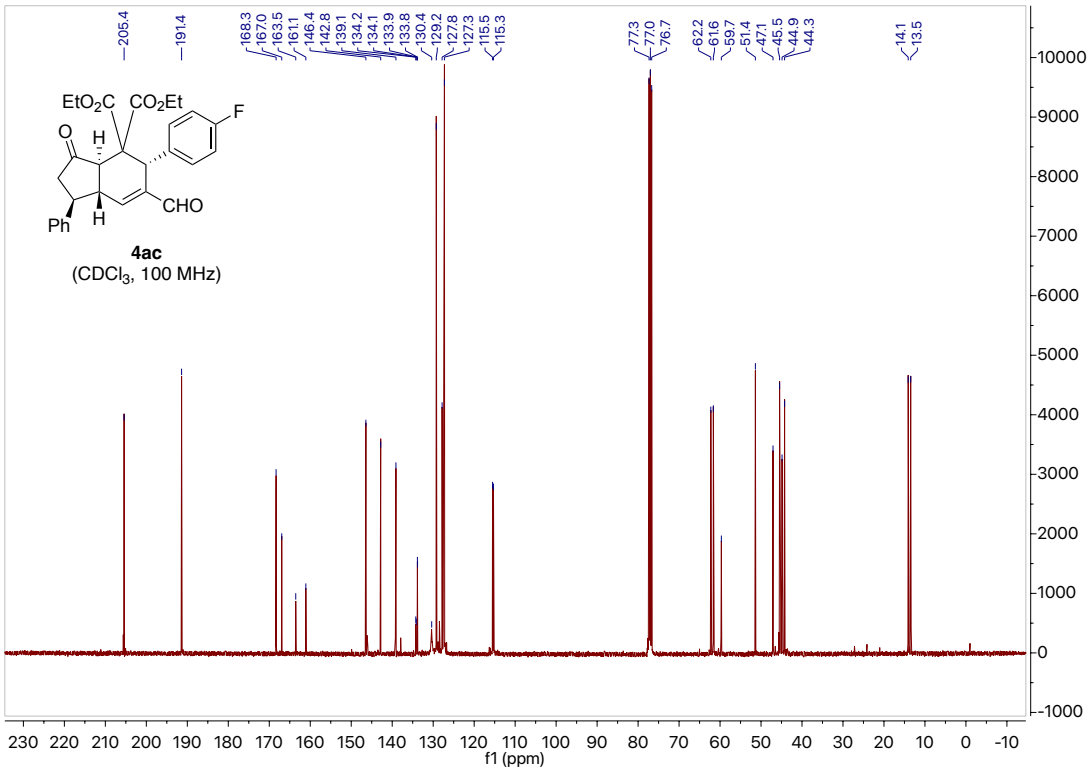
[ピーク検出結果]

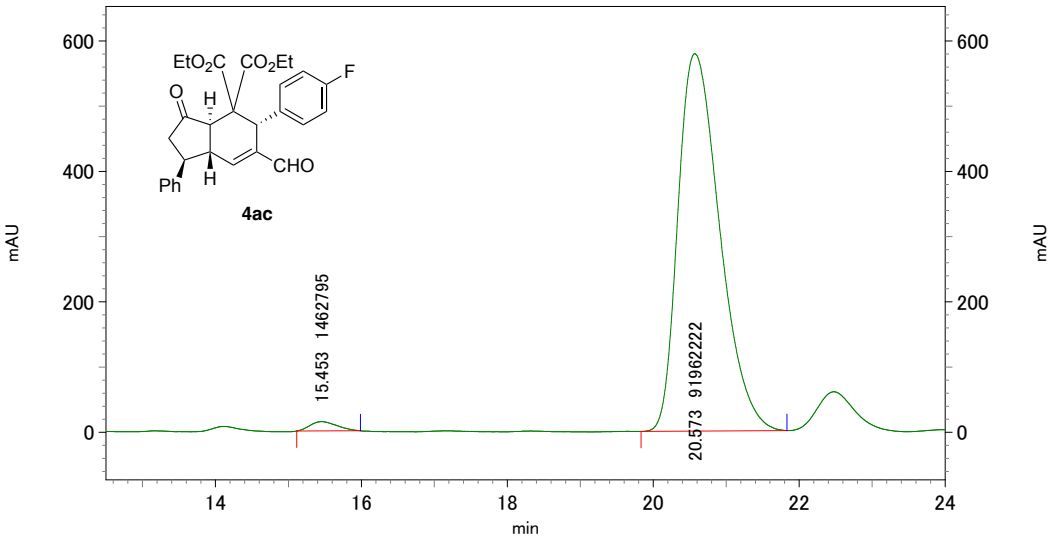
No.	位置	強度	No.	位置	強度
1	2983.34	92.0144	2	1742.37	63.0588
3	1690.3	71.3659	4	1607.38	83.593
5	1511.92	69.1276	6	1250.61	57.6938
7	1175.4	74.5111	8	1033.66	77.3139
9	913.129	81.4345	10	732.817	70.5584



4ka


EtO2C
CO2Et
F
O
H
CHO
Ph
H
4ac
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C
CO2Et
F
O
H
CHO
Ph
H
4ac
(CDCl3, 100 MHz)
f1 (ppm)



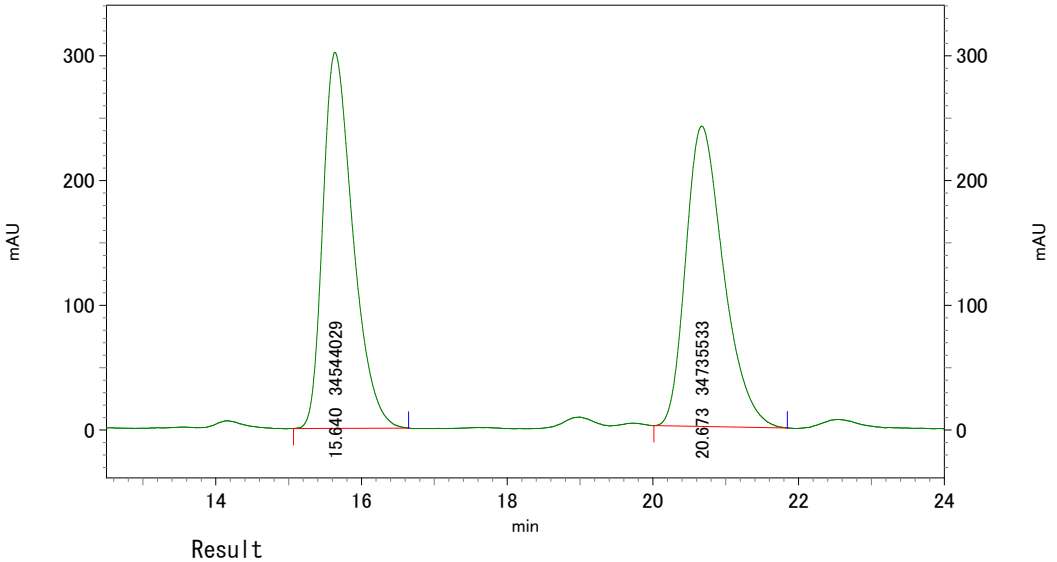
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	15.453	1.566
2	20.573	98.434

トータル		100.000

Total



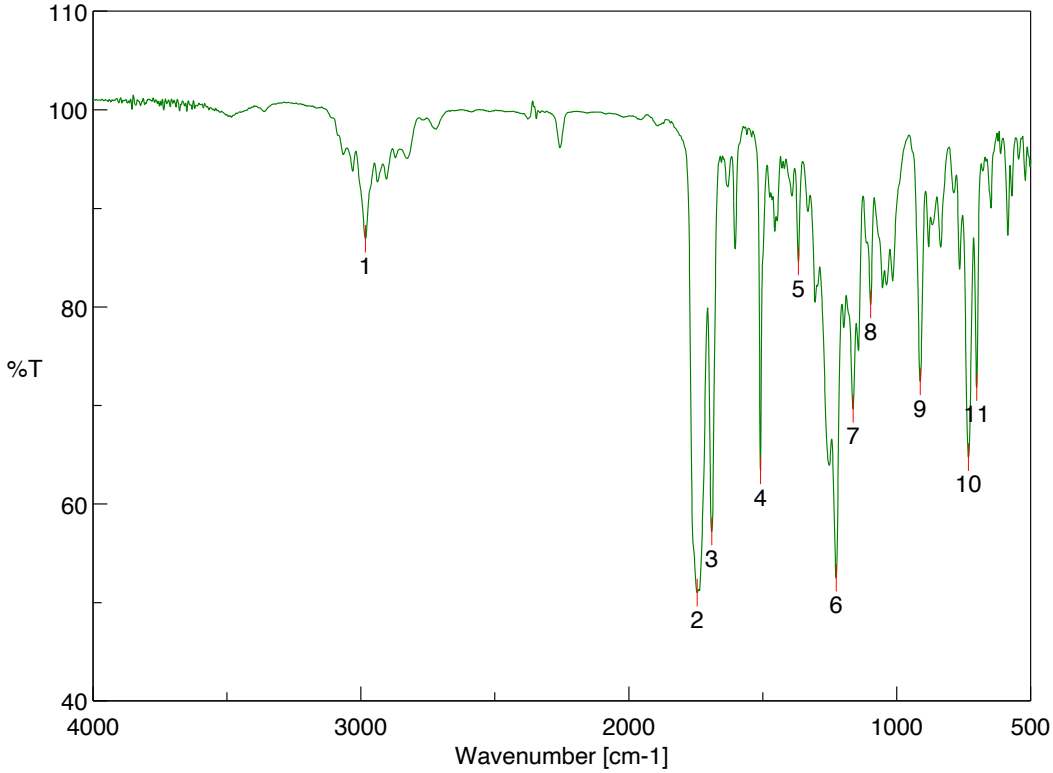
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	15.640	49.862
2	20.673	50.138

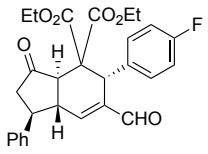
トータル		100.000

Total

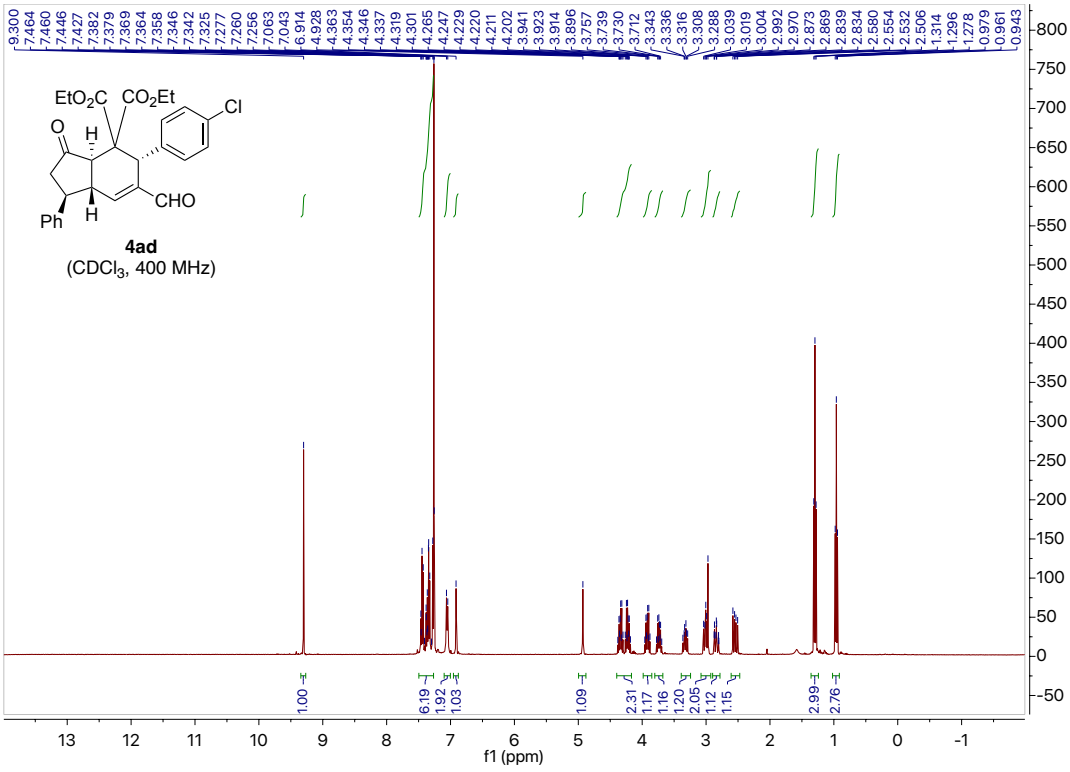


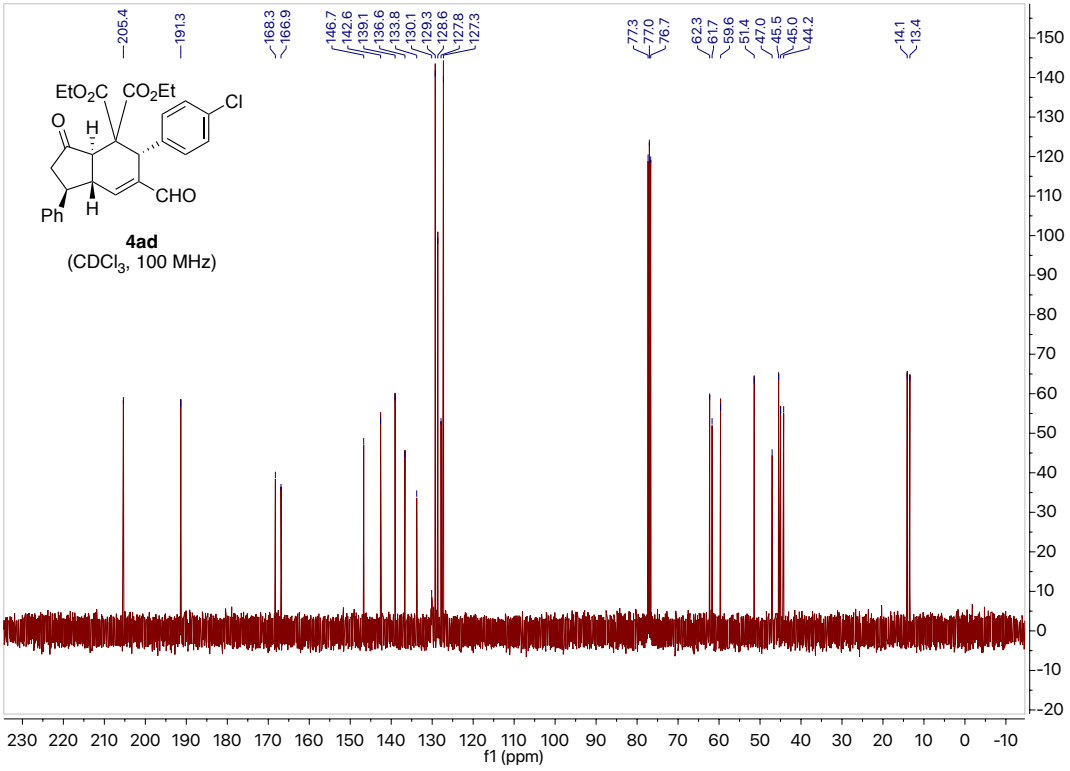
[ピーク検出結果]

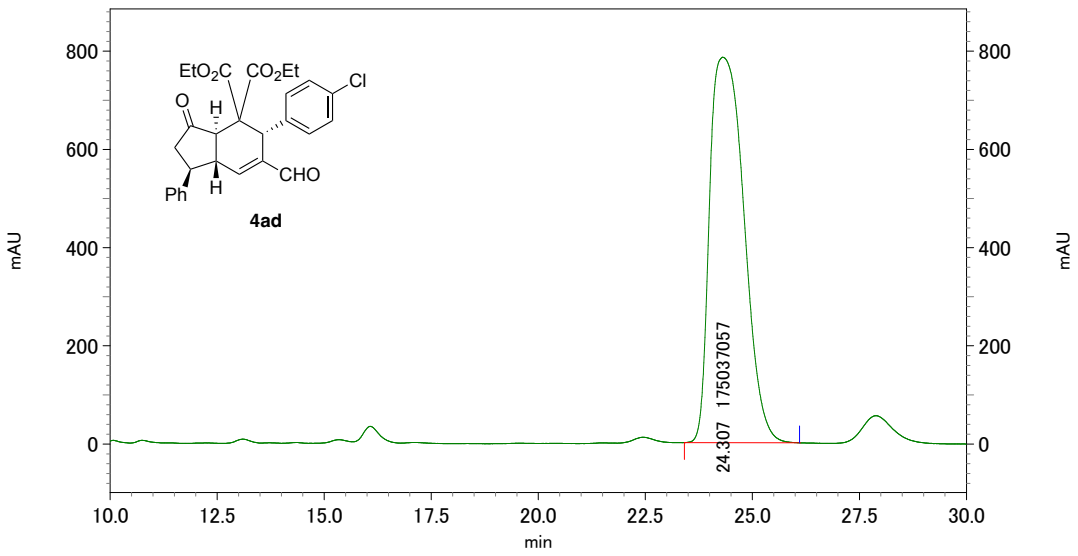
No.	位置	強度	No.	位置	強度
1	2983.34	86.9017	2	1744.3	50.985
3	1690.3	57.1976	4	1508.06	63.4037
5	1367.28	84.5976	6	1225.54	52.5012
7	1162.87	69.6204	8	1097.3	80.2259
9	912.165	72.428	10	731.853	64.7203
11	700.998	71.8327			



4ac


EtO2C CO2Et
Cl
O
H
CHO
Ph
H
4ad
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
Cl
O
H
CHO
Ph
H
4ad
(CDCl3, 100 MHz)
f1 (ppm)



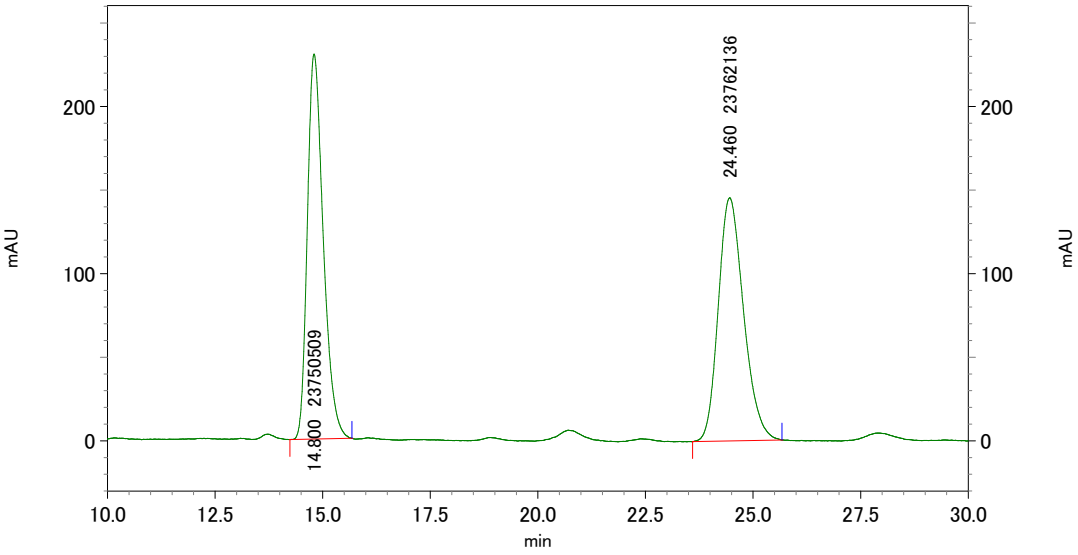
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	24.307	100.000

トータル		100.000

Total



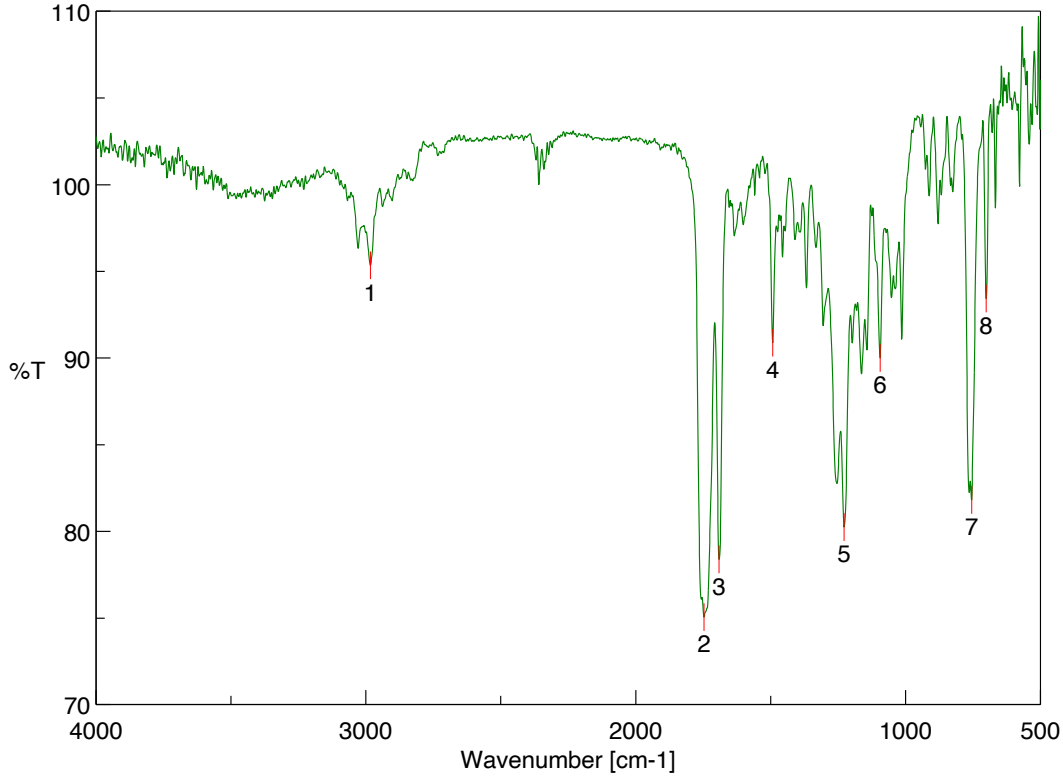
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	14.800	49.988
2	24.460	50.012

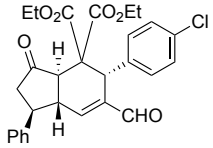
トータル		100.000

Total

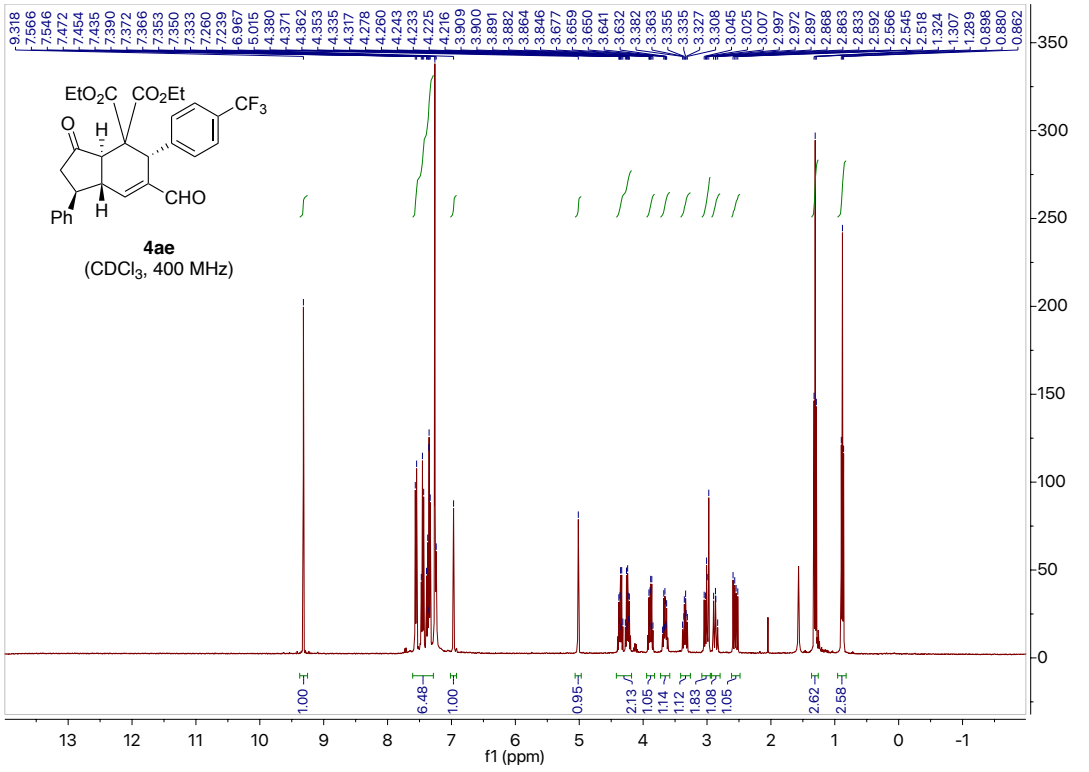


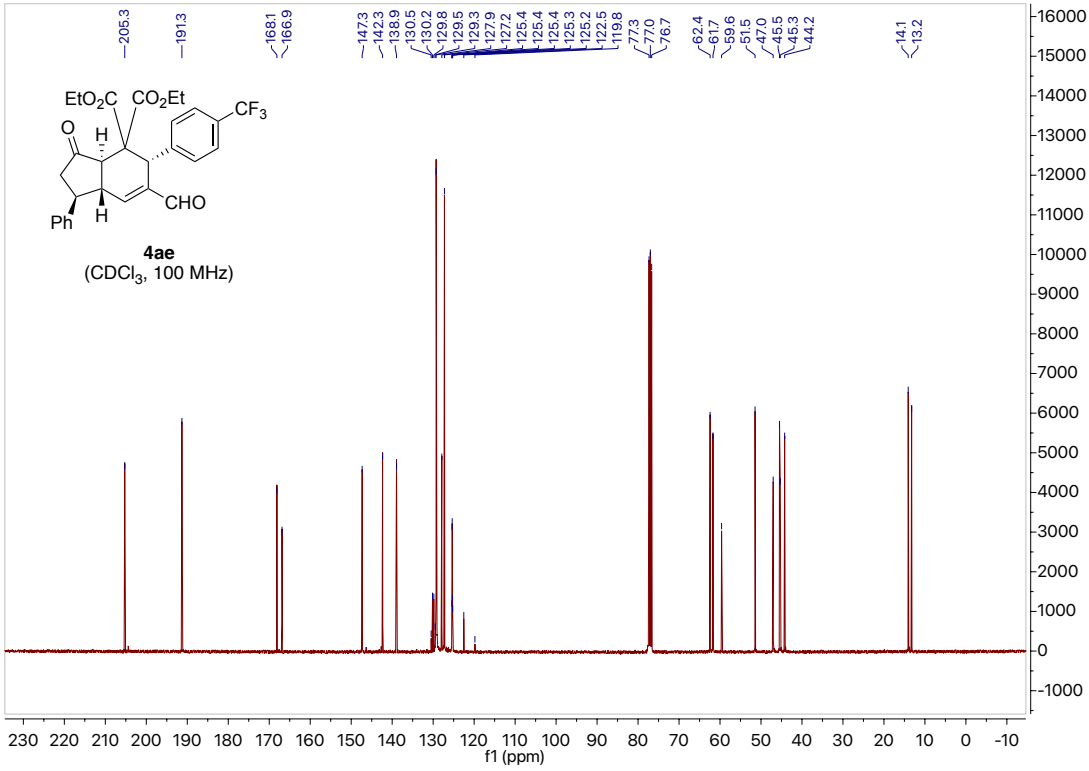
[ピーク検出結果]

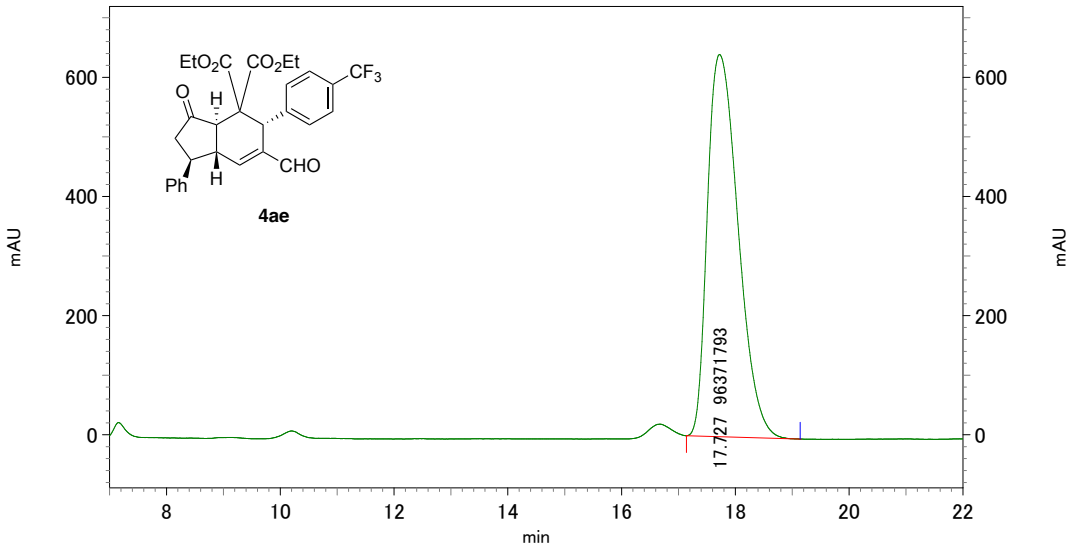
No.	位置	強度	No.	位置	強度
1	2983.34	95.3392	2	1747.19	75.0427
3	1691.27	78.3739	4	1492.63	90.869
5	1227.47	80.2433	6	1094.4	89.985
7	754.995	81.8014	8	700.998	93.4221



4ad


EtO2C
CO2Et
CF3
O
H
CHO
Ph
H
4ae
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C
CO2Et
CF3
O
H
CHO
Ph
H
4ae
(CDCl3, 100 MHz)
f1 (ppm)



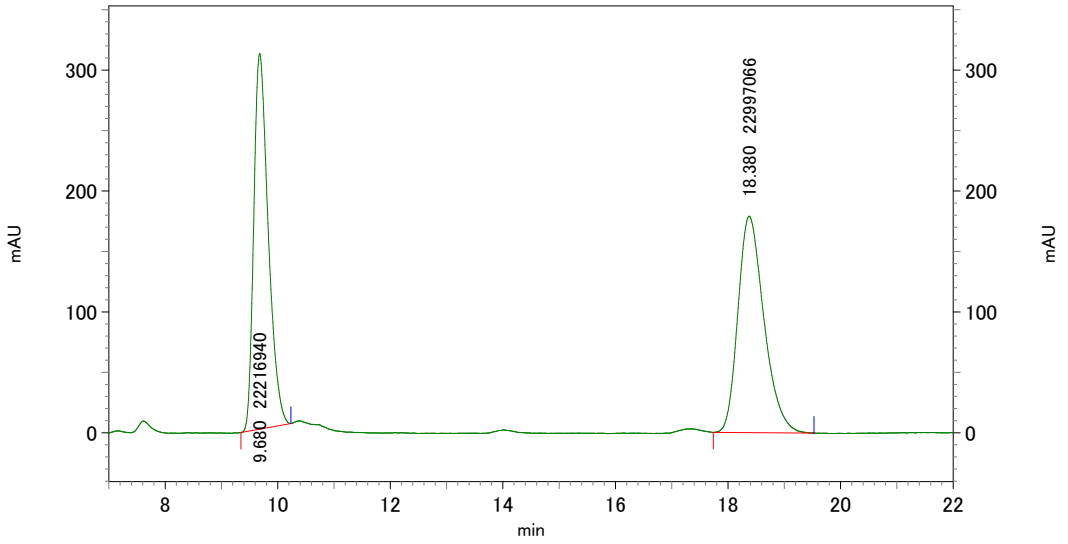
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	17.727	100.000

トータル		100.000

Total



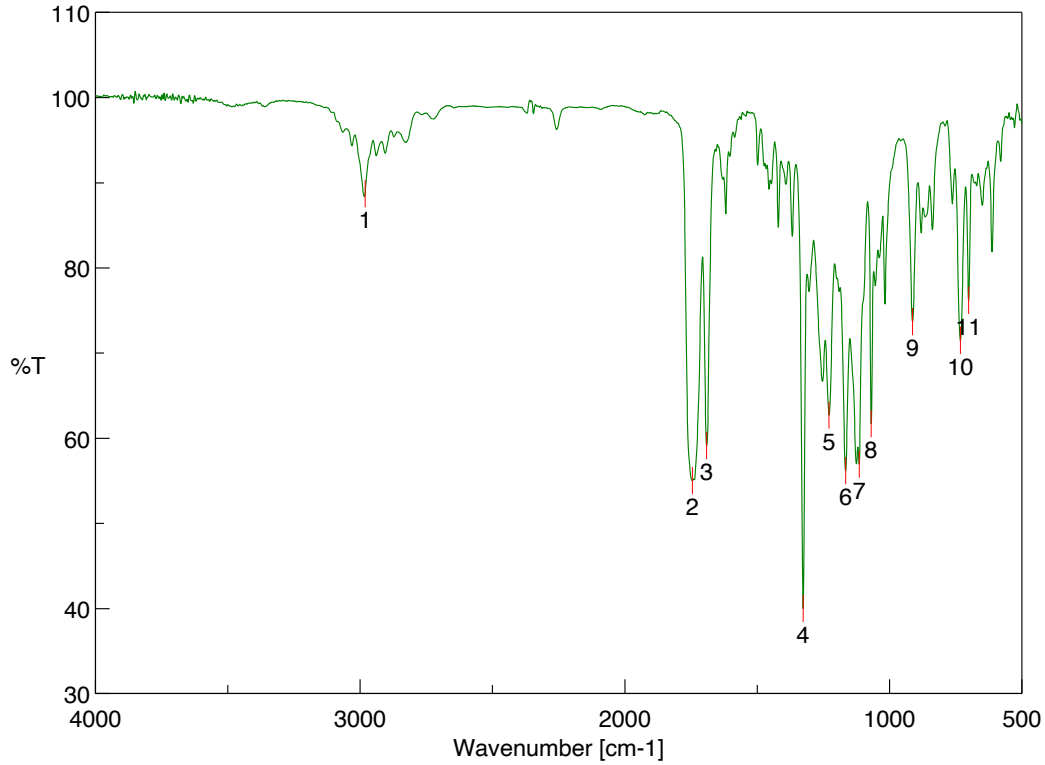
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	9.680	49.137
2	18.380	50.863

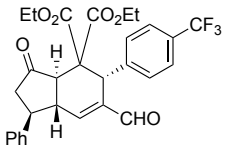
トータル		100.000

Total

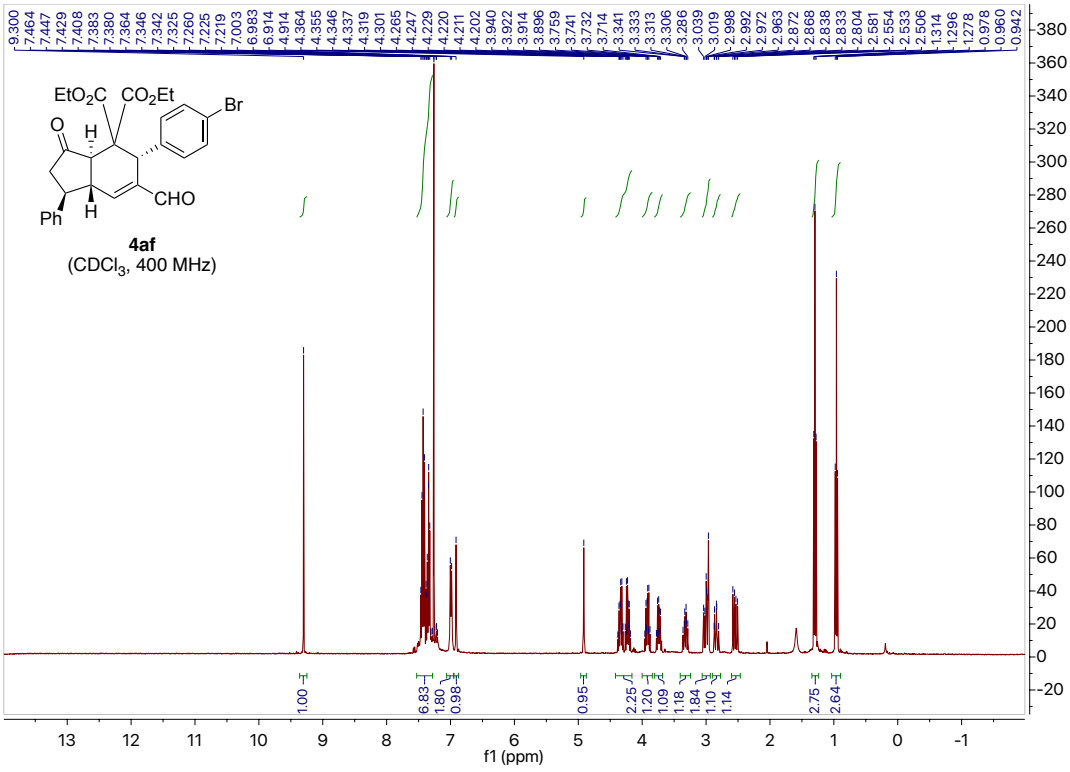


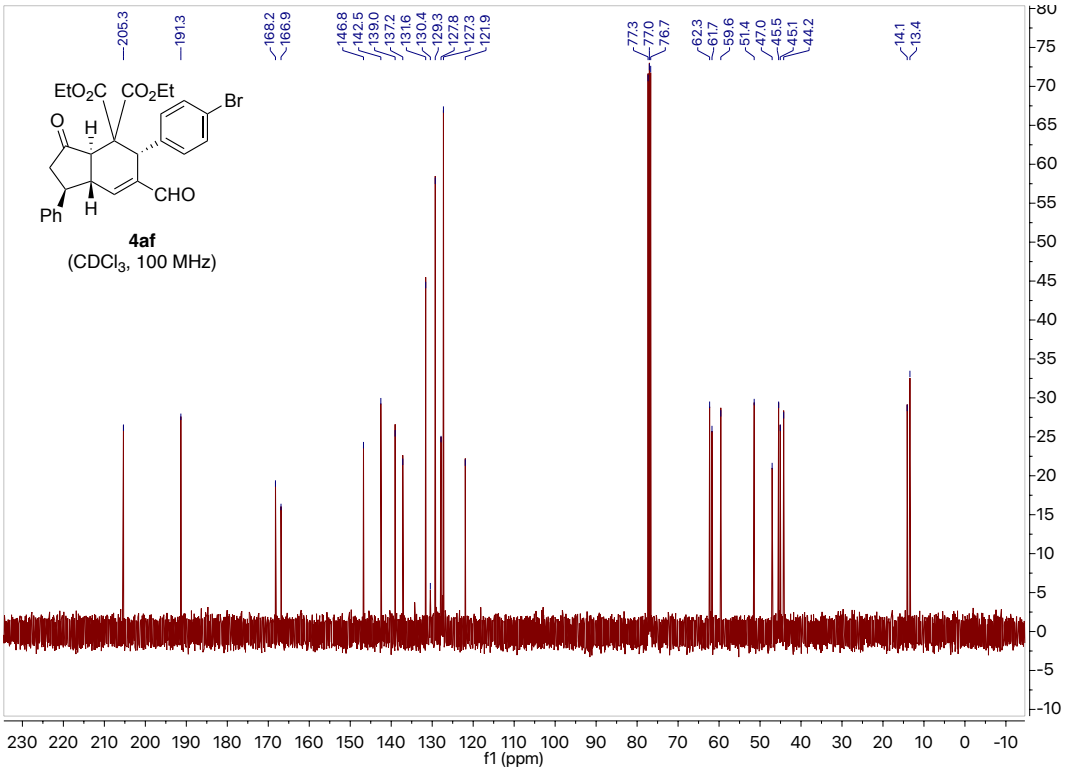
[ピーク検出結果]

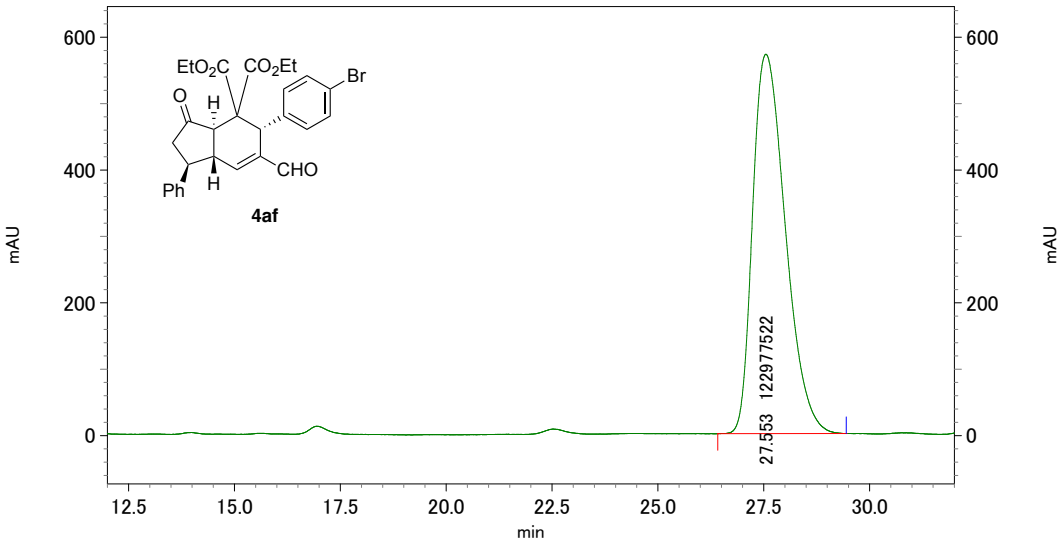
No.	位置	強度	No.	位置	強度
1	2981.41	88.7081	2	1745.26	54.9948
3	1691.27	59.1406	4	1326.79	39.9955
5	1228.43	62.7038	6	1165.76	56.1624
7	1114.65	56.9458	8	1069.33	61.6875
9	913.129	73.6797	10	731.853	71.4939
11	700.998	76.1615			



4ae


EtO2C CO2Et
Br
O
H
CHO
Ph
H
4af
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
Br
O
H
CHO
Ph
H
4af
(CDCl3, 100 MHz)
f1 (ppm)



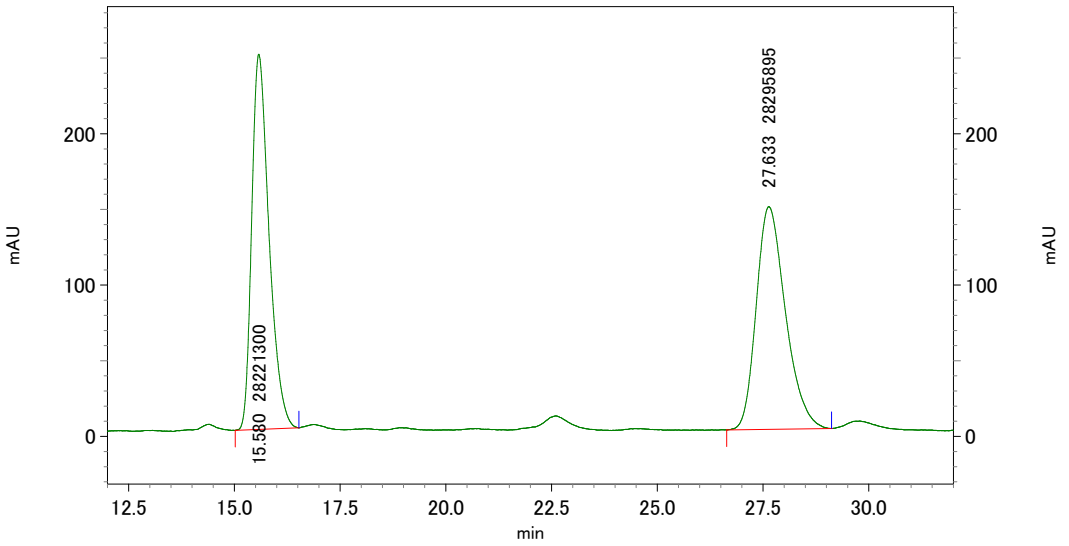
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	27.553	100.000

トータル		100.000

Total



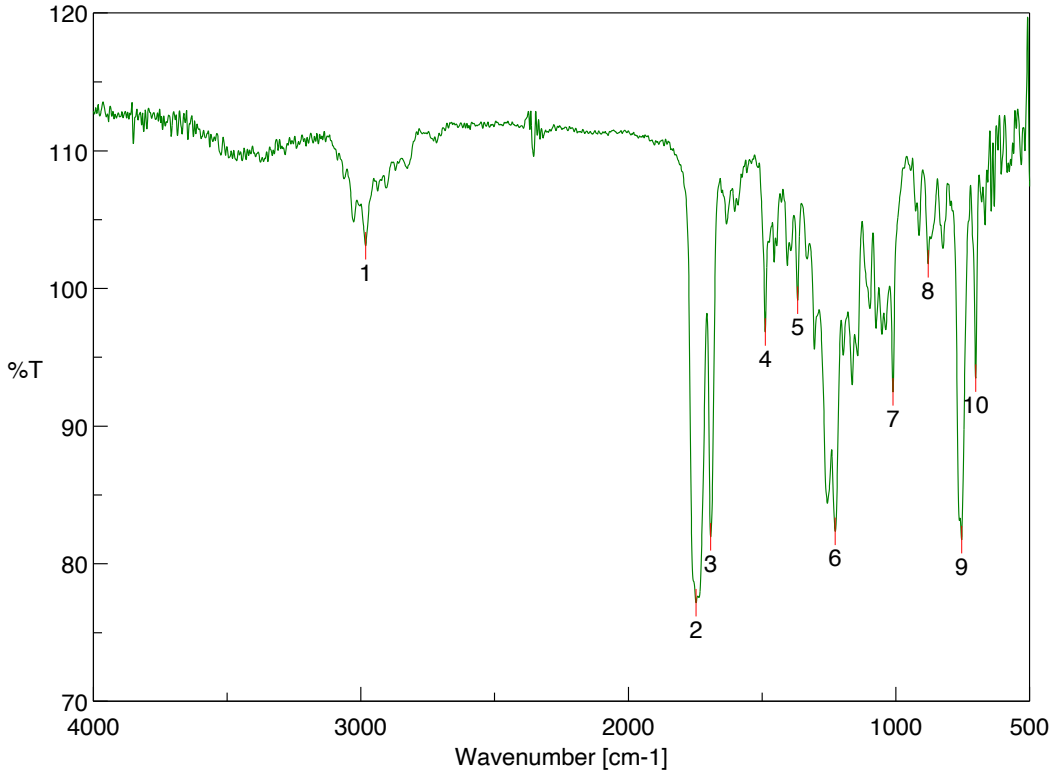
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	15.580	49.934
2	27.633	50.066

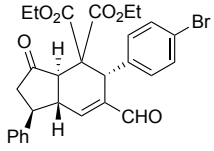
トータル		100.000

Total

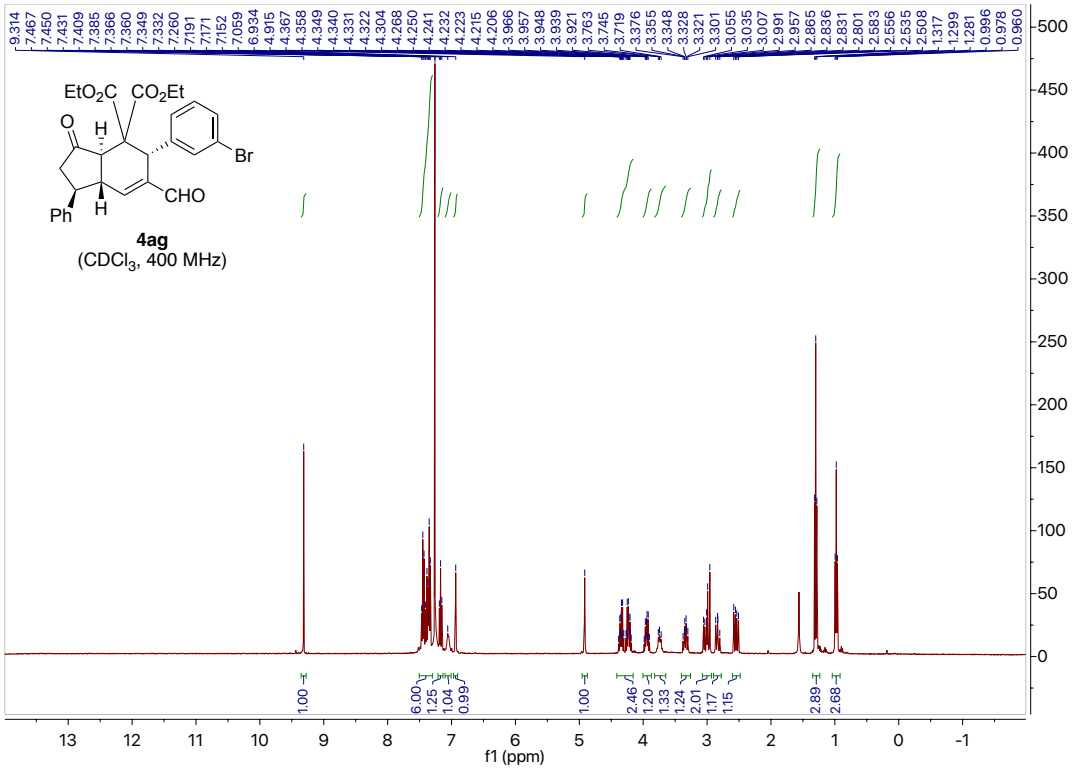


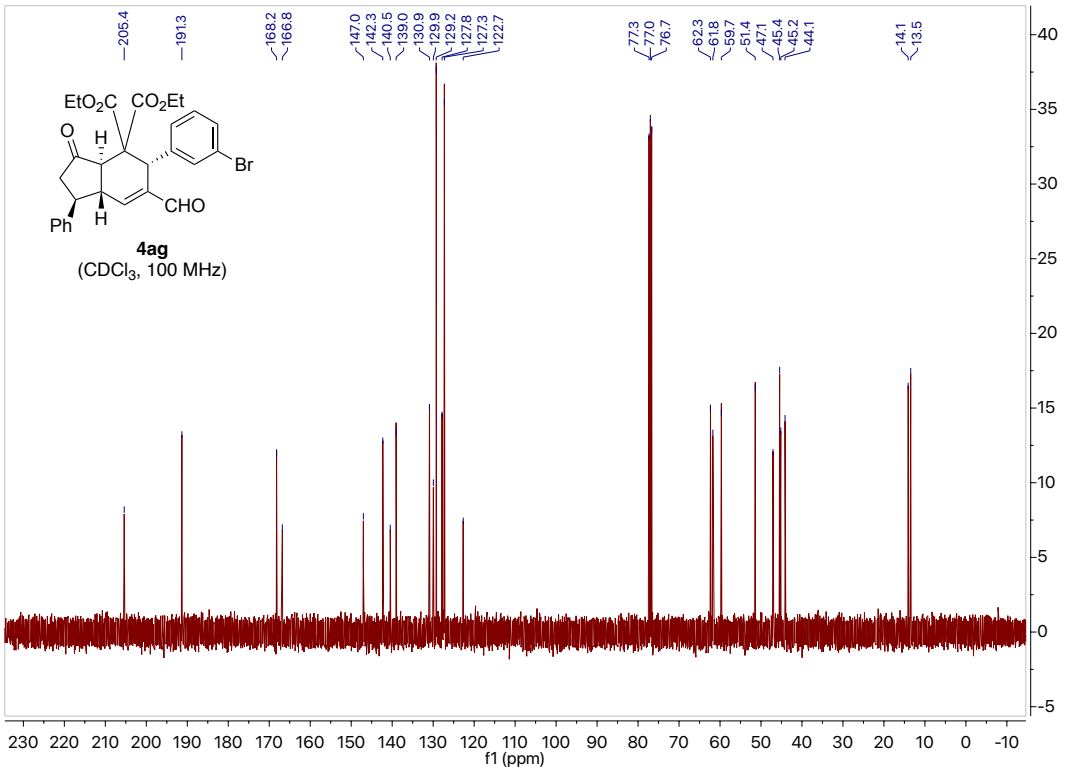
[ピーク検出結果]

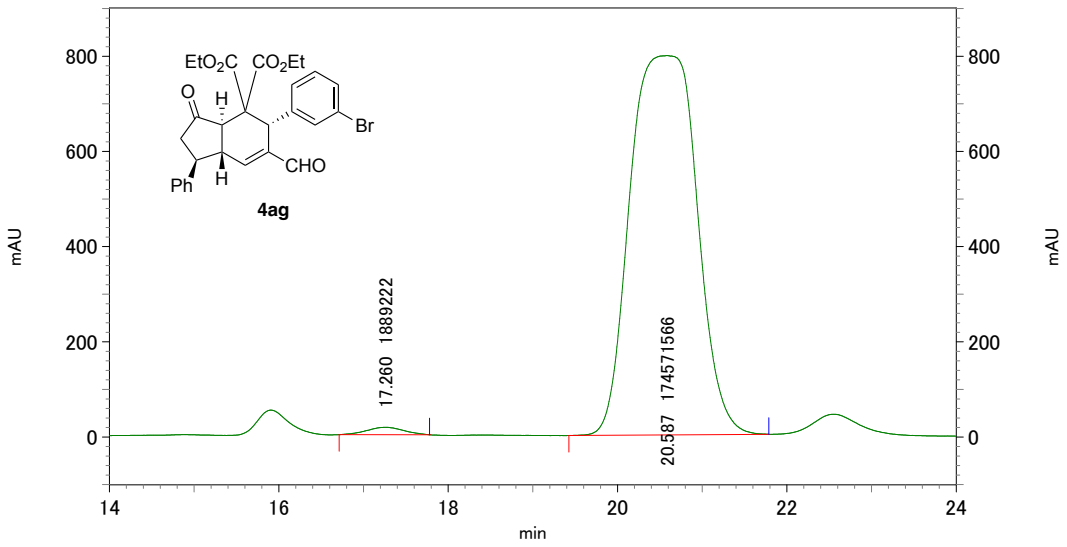
No.	位置	強度	No.	位置	強度
1	2982.37	103.082	2	1747.19	77.1648
3	1692.23	81.9425	4	1487.81	96.822
5	1367.28	99.1295	6	1226.5	82.3304
7	1010.52	92.4804	8	879.381	101.769
9	754.031	81.7418	10	700.998	93.4735



4af


EtO2C CO2Et
O
H
Br
CHO
Ph
H
4ag
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
O
H
Br
CHO
Ph
H
4ag
(CDCl3, 100 MHz)
f1 (ppm)



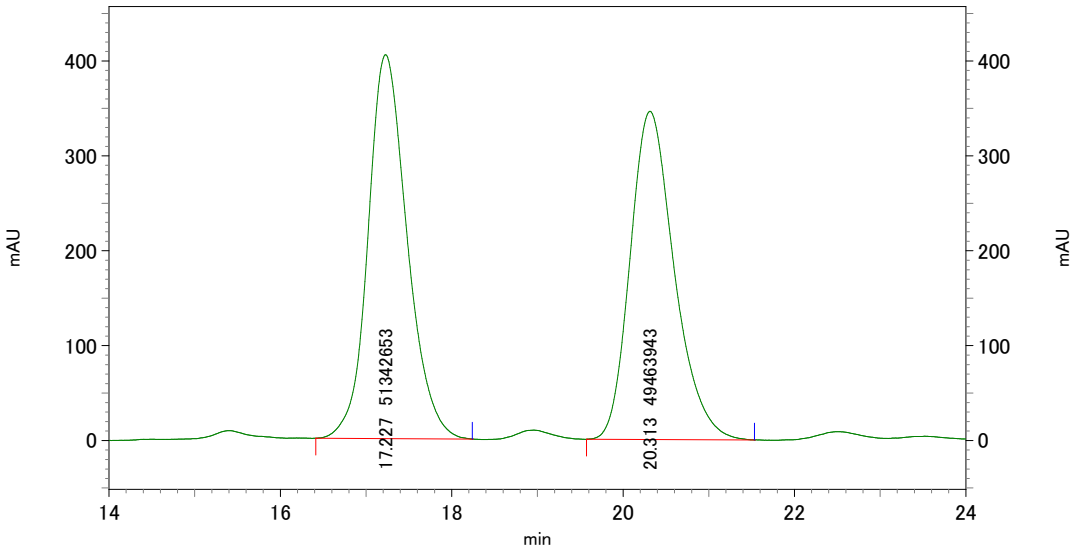
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	17.260	1.071
2	20.587	98.929

トータル		100.000

Total



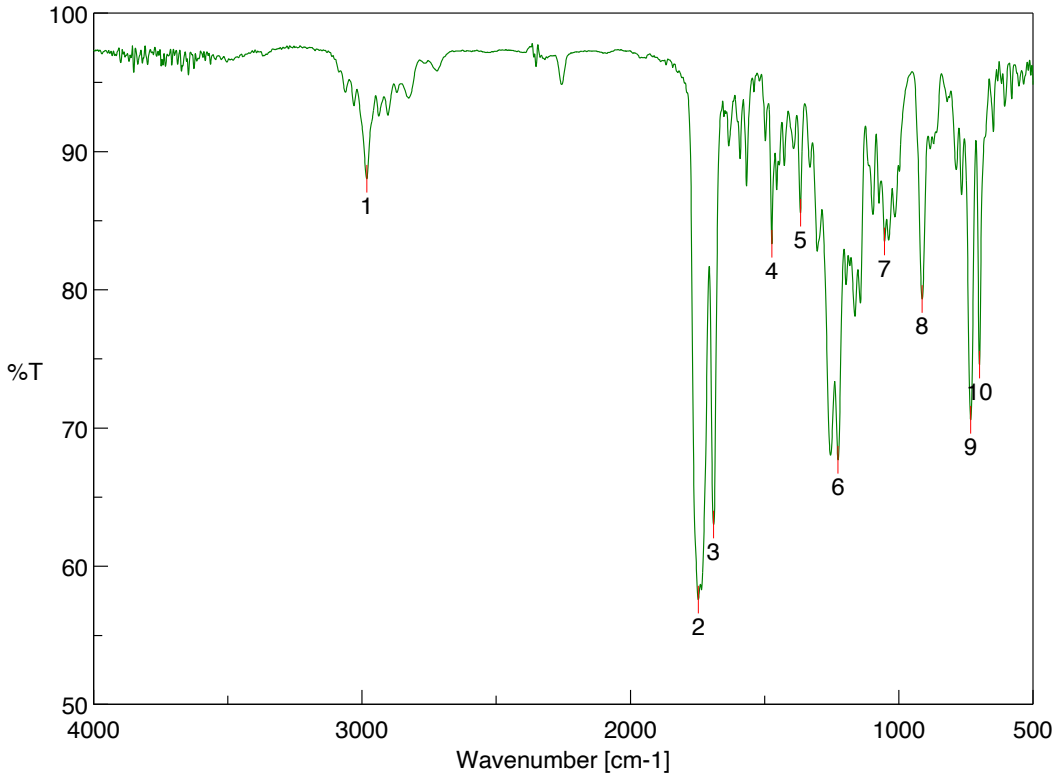
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	17.227	50.932
2	20.313	49.068

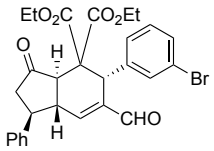
トータル		100.000

Total

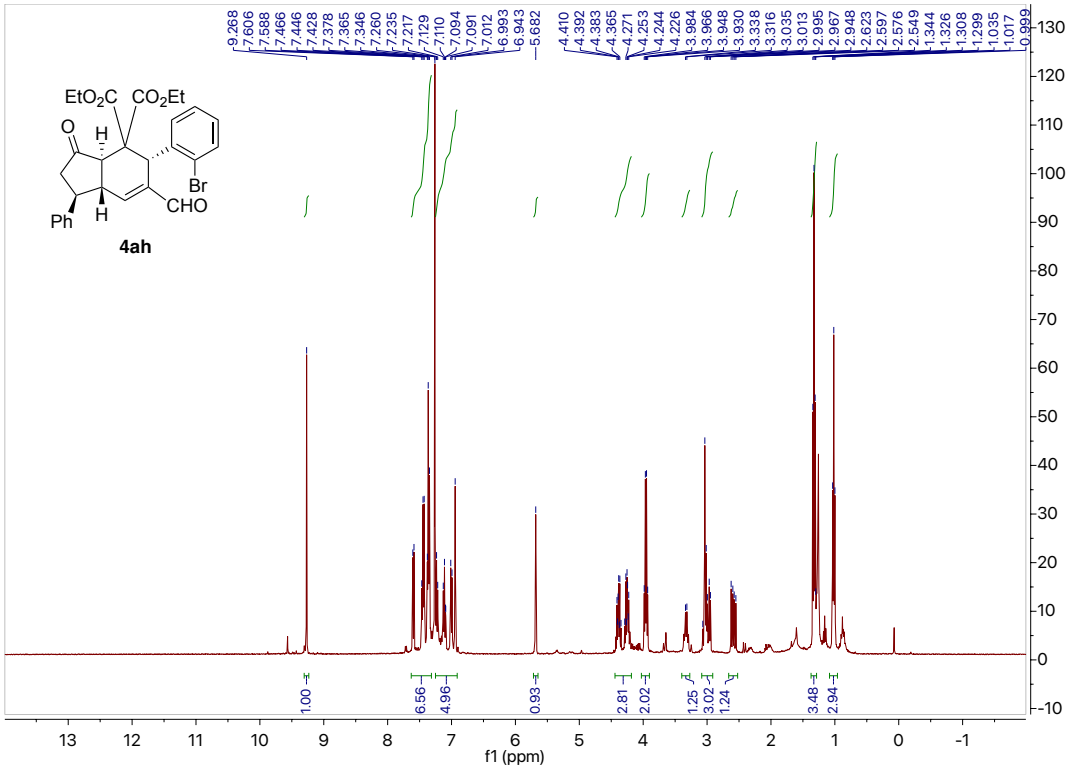


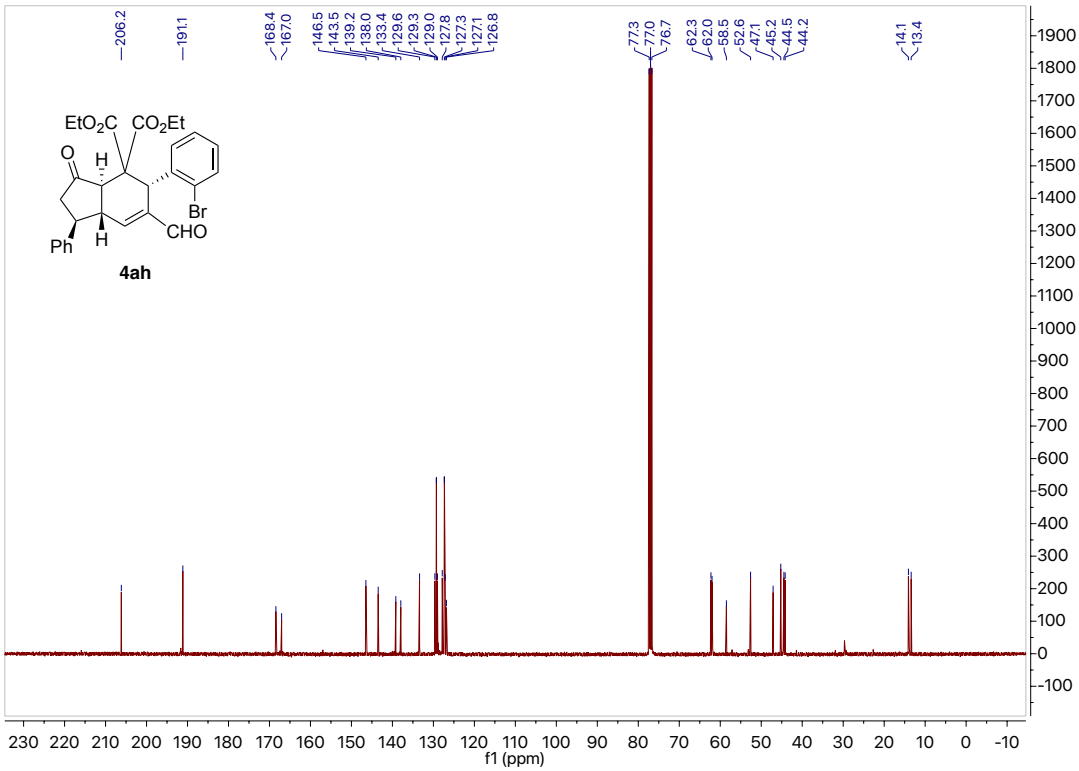
[ピーク検出結果]

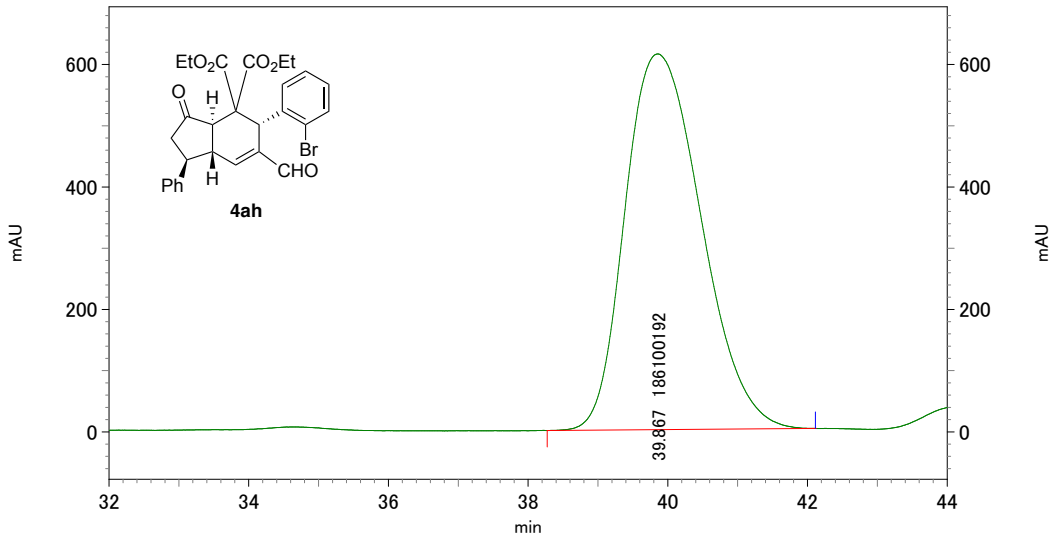
No.	位置	強度	No.	位置	強度
1	2982.37	88.0083	2	1747.19	57.5698
3	1690.3	63.0109	4	1473.35	83.3197
5	1366.32	85.5669	6	1226.5	67.6817
7	1052.94	83.4753	8	913.129	79.3109
9	731.853	70.5871	10	699.069	74.5755



4ag


EtO2C CO2Et
O
H
Br
CHO
Ph
H
4ah
f1 (ppm)


EtO2C CO2Et
O
H
Br
CHO
Ph
H
4ah
f1 (ppm)



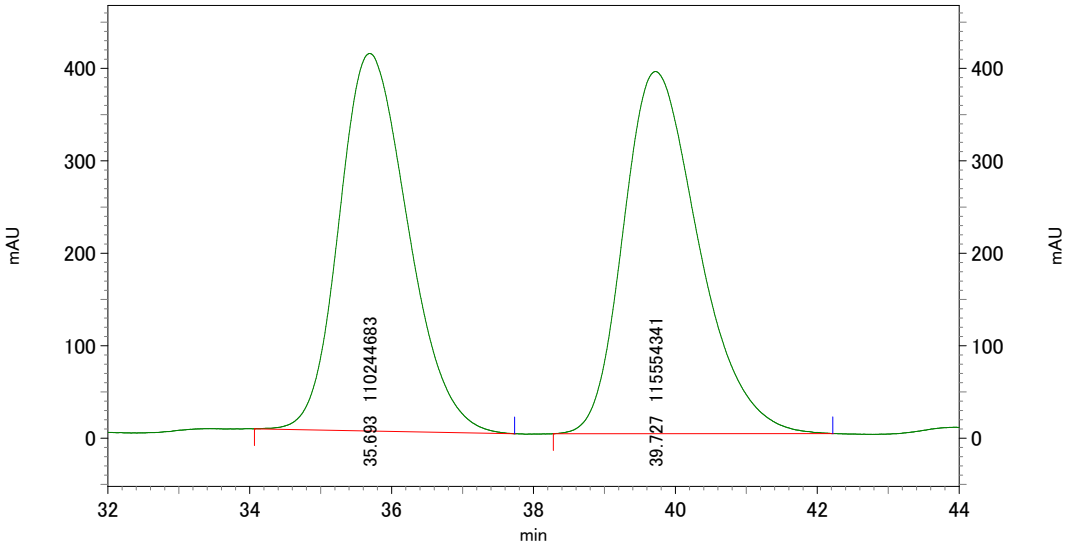
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	39.867	100.000

ﾄｰﾀﾙ		100.000

Total



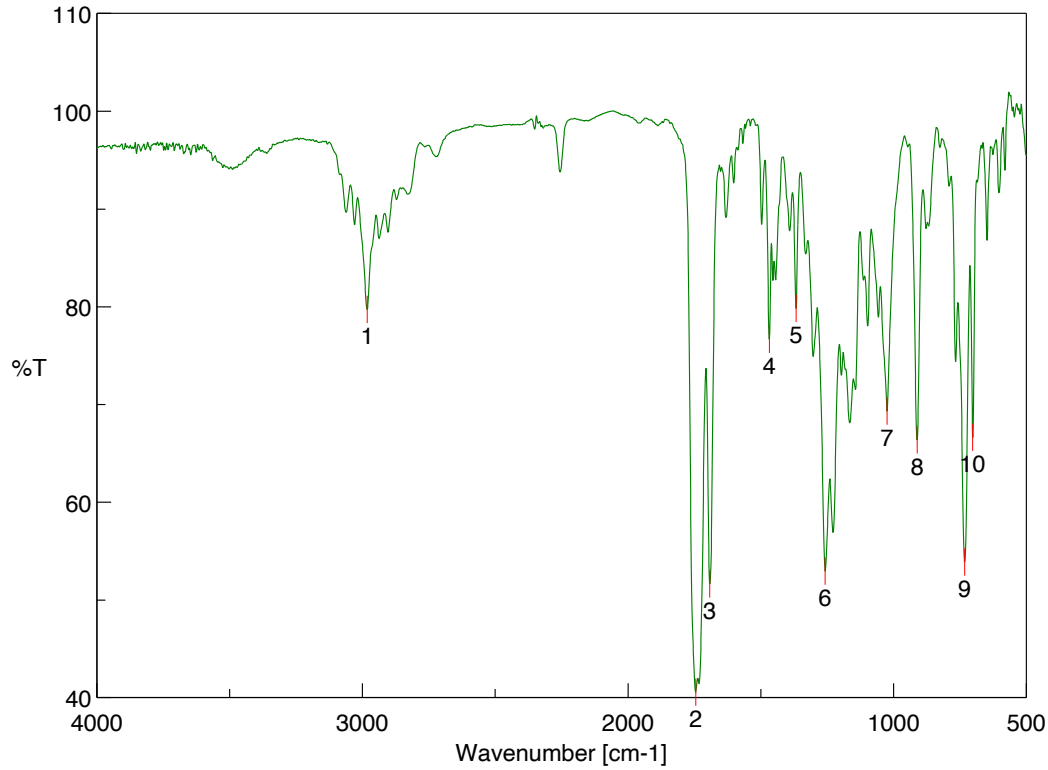
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	35.693	48.824
2	39.727	51.176

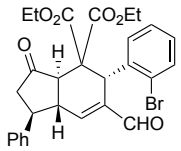
ﾄｰﾀﾙ		100.000

Total

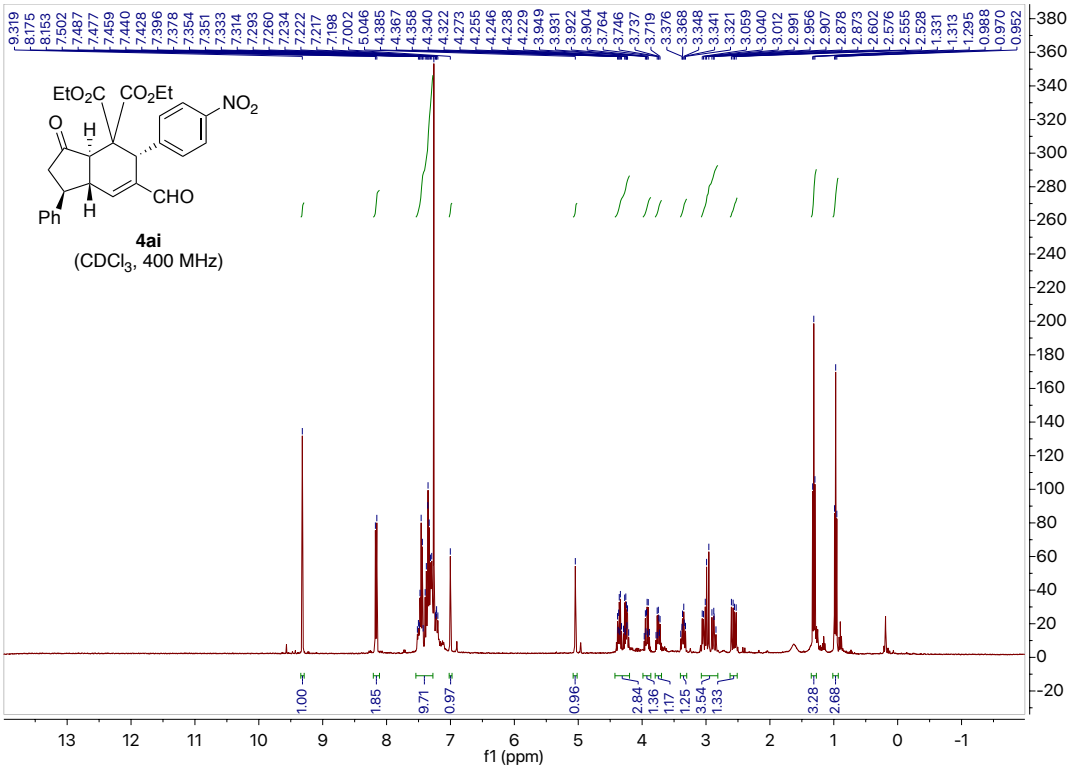


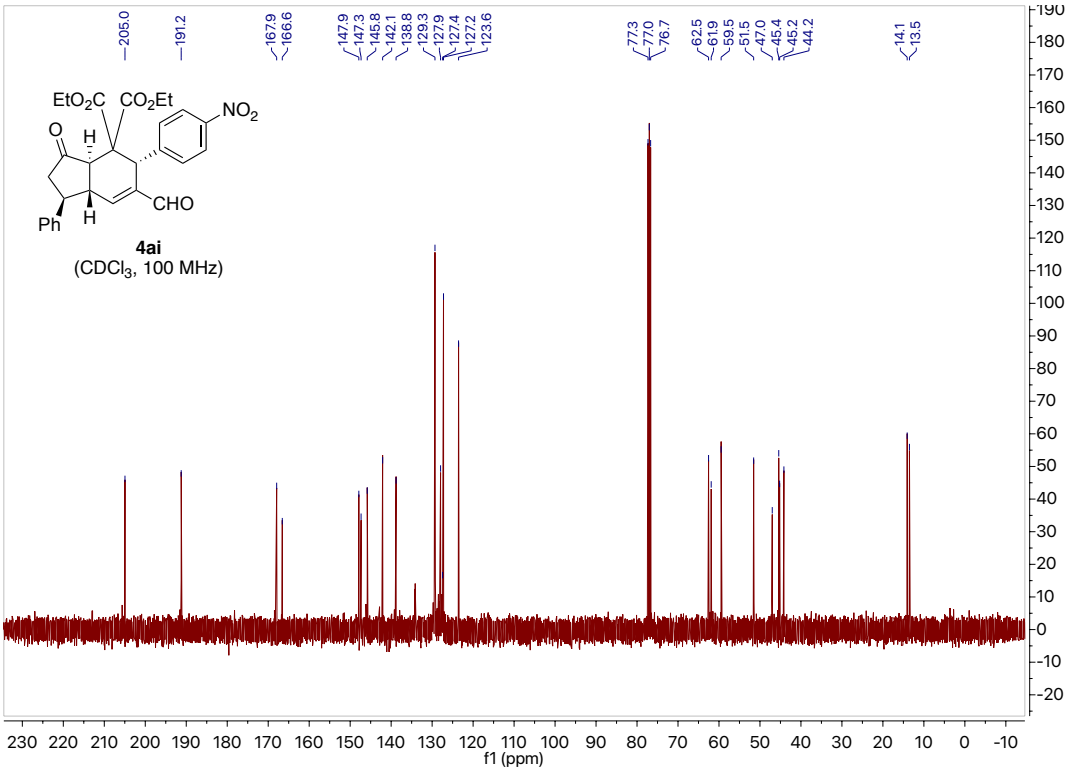
[ピーク検出結果]

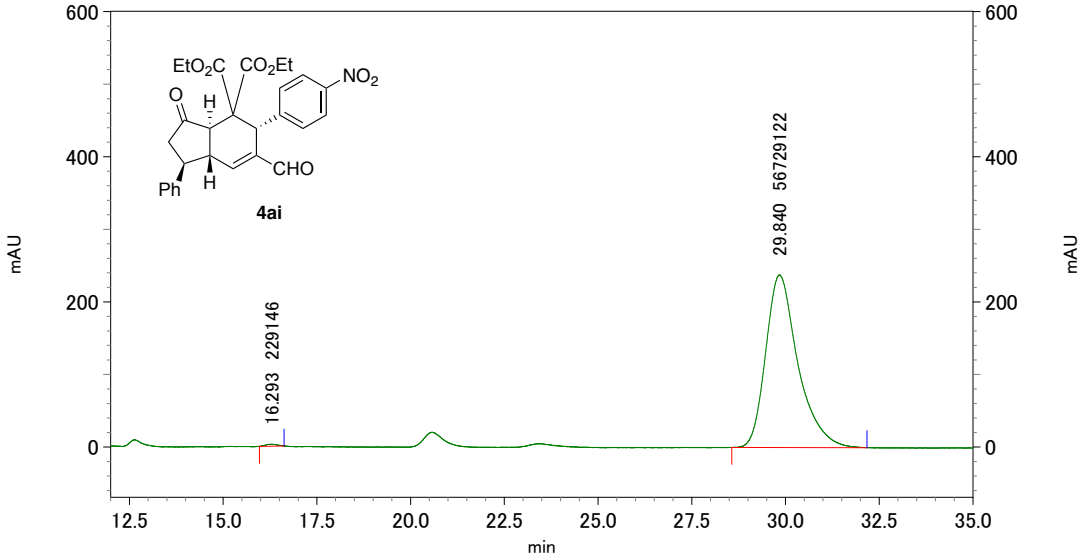
No.	位置	強度	No.	位置	強度
1	2982.37	79.6948	2	1745.26	40.56
3	1692.23	51.629	4	1467.56	76.6521
5	1367.28	79.8348	6	1257.36	52.9369
7	1024.02	69.299	8	911.201	66.3525
9	731.853	53.8615	10	701.962	66.6162



4ah


EtO2C
CO2Et
NO2
O
H
CHO
Ph
H
4ai
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C
CO2Et
NO2
O
H
CHO
Ph
H
4ai
(CDCl3, 100 MHz)
f1 (ppm)



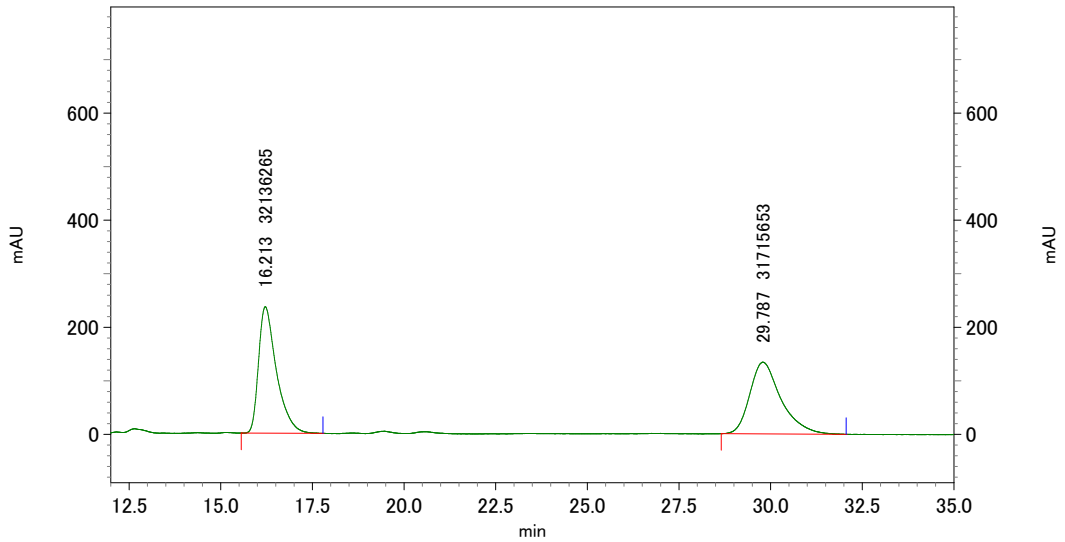
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	16.293	0.402
2	29.840	99.598

トータル		100.000

Total



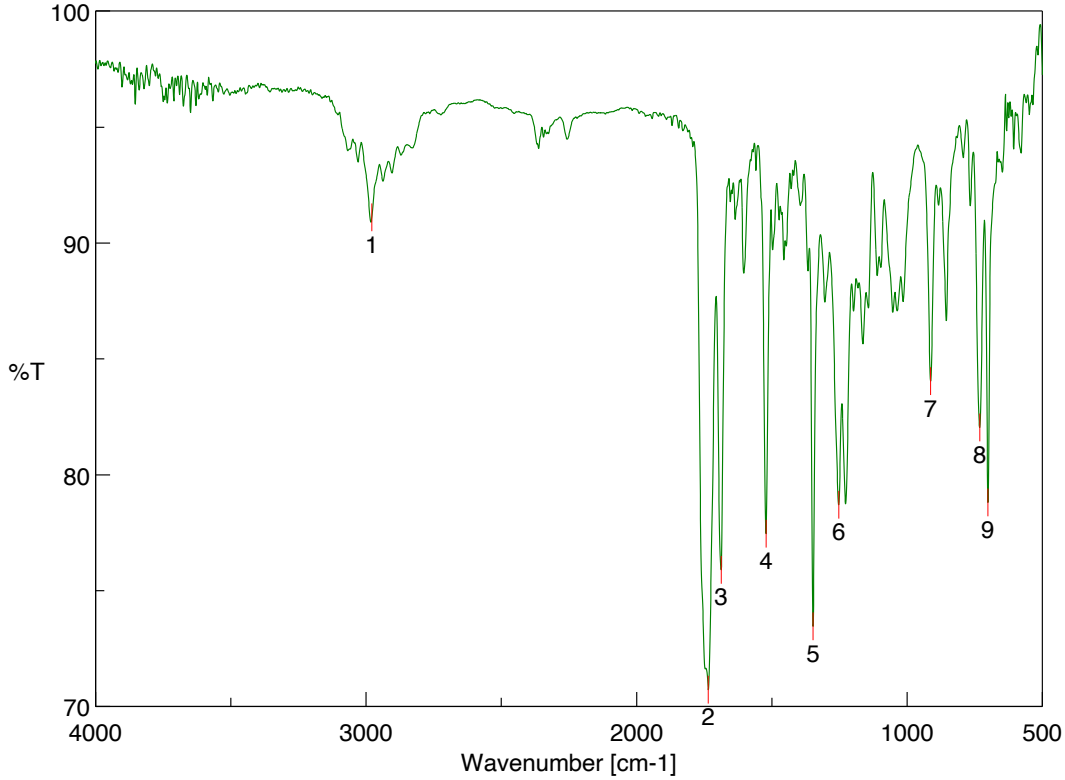
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	16.213	50.329
2	29.787	49.671

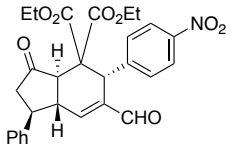
トータル		100.000

Total

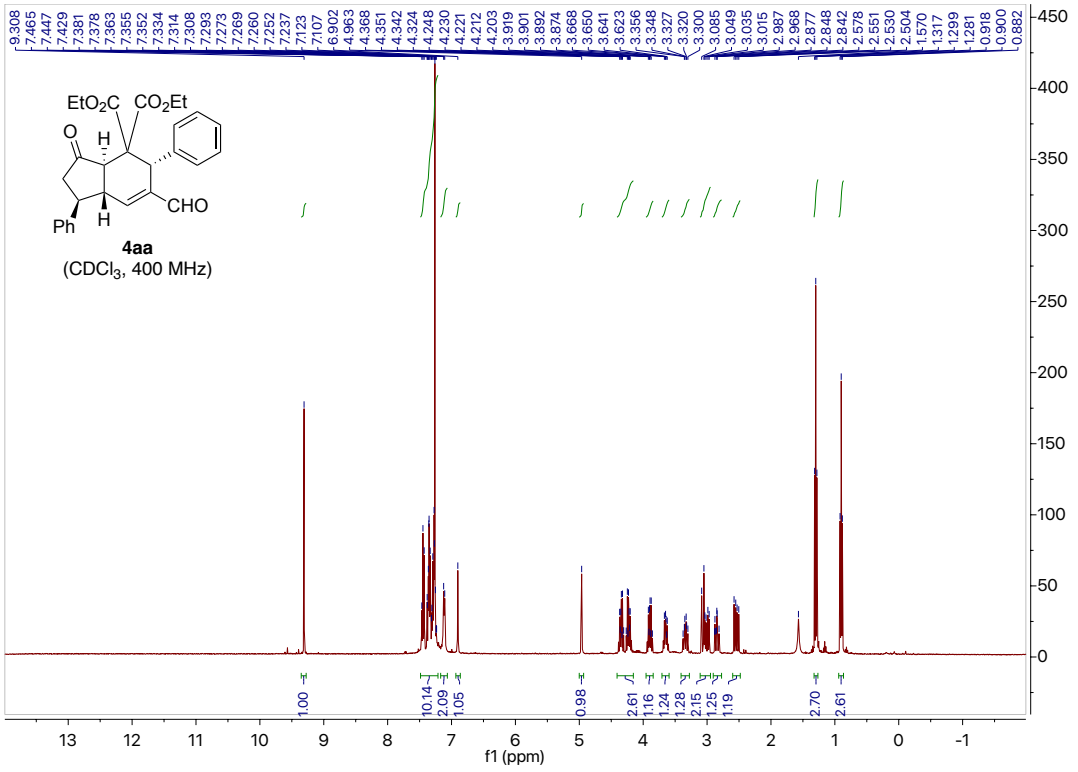


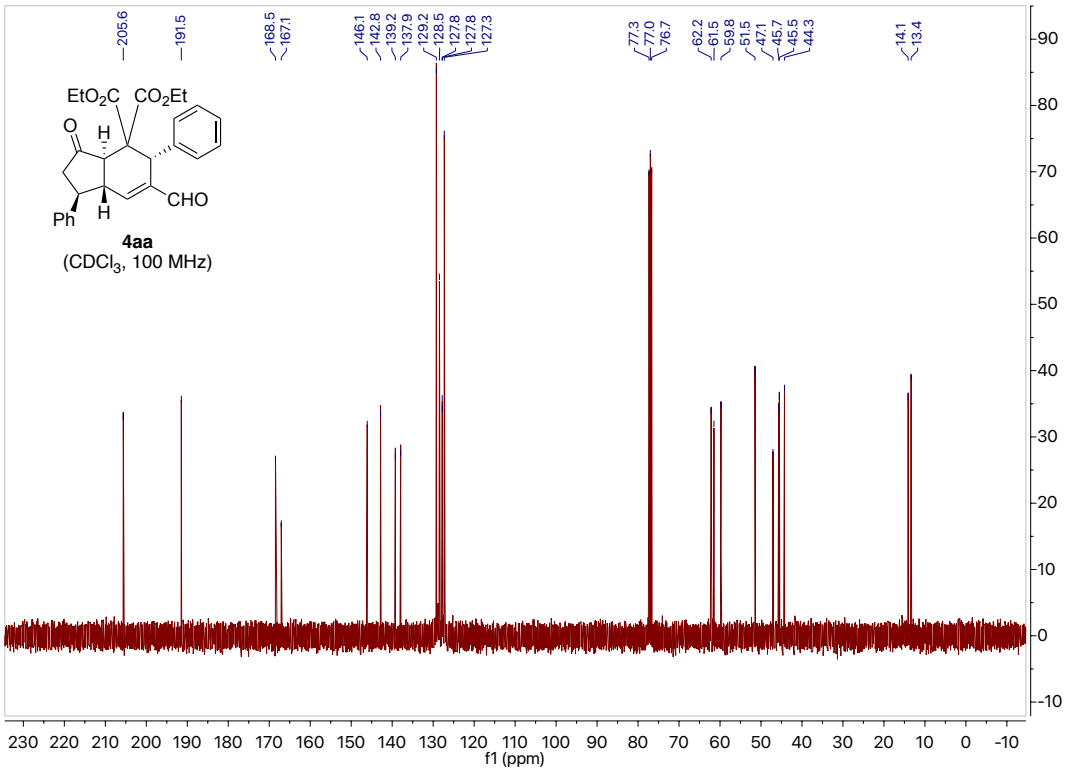
[ピーク検出結果]

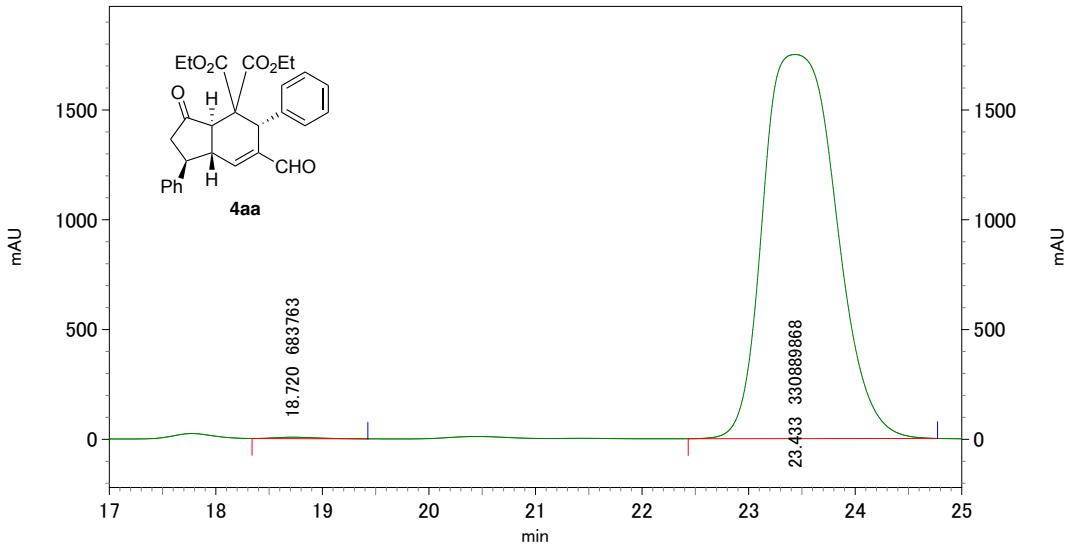
No.	位置	強度	No.	位置	強度
1	2978.52	91.0931	2	1734.66	70.7226
3	1687.41	75.8886	4	1521.56	77.4493
5	1348	73.4577	6	1252.54	78.703
7	913.129	84.0271	8	730.889	82.0366
9	700.998	78.8059			



4ai


EtO2C CO2Et
O
H
Ph
H
CHO
4aa
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C CO2Et
O
H
Ph
H
CHO
4aa
(CDCl3, 100 MHz)
f1 (ppm)



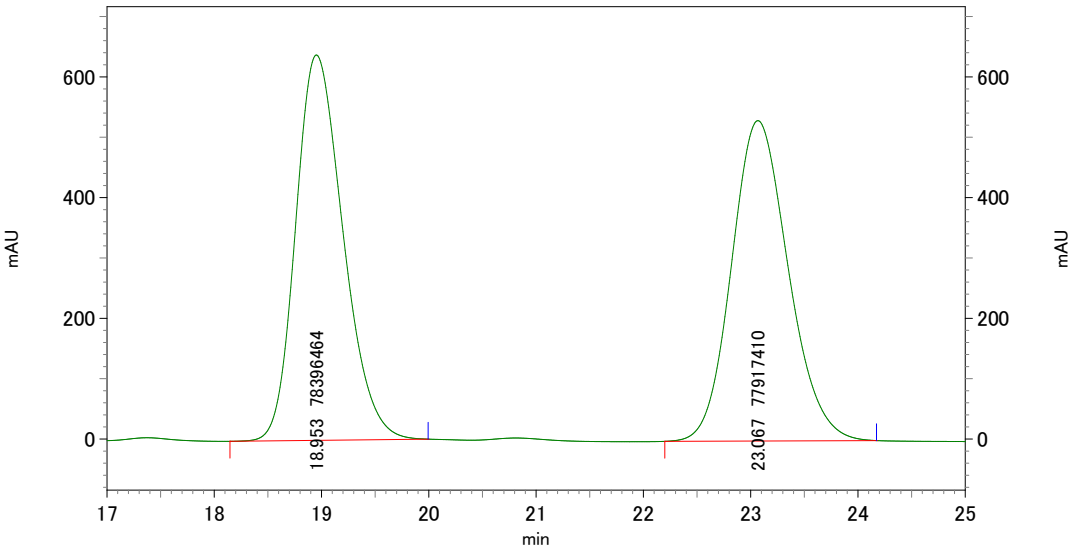
Result

2: 210.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	18.720	0.206
2	23.433	99.794

合計		100.000

Total



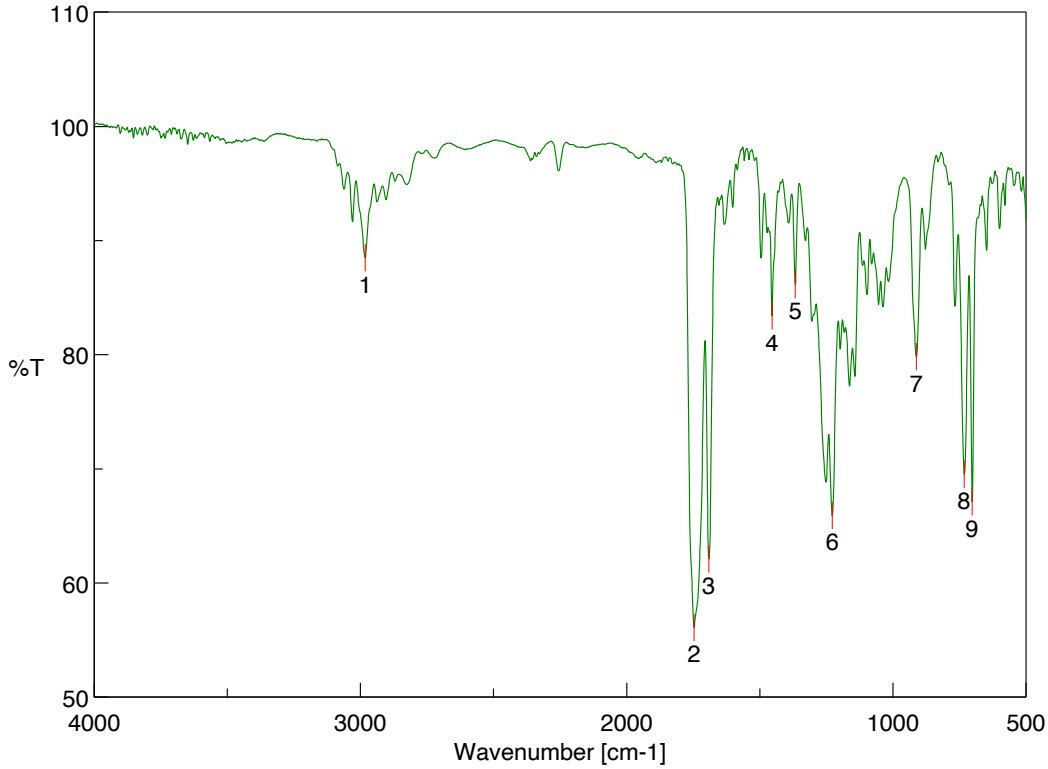
Result

2: 210.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	18.953	50.153
2	23.067	49.847

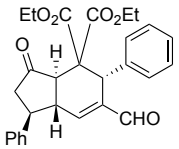
合計		100.000

Total

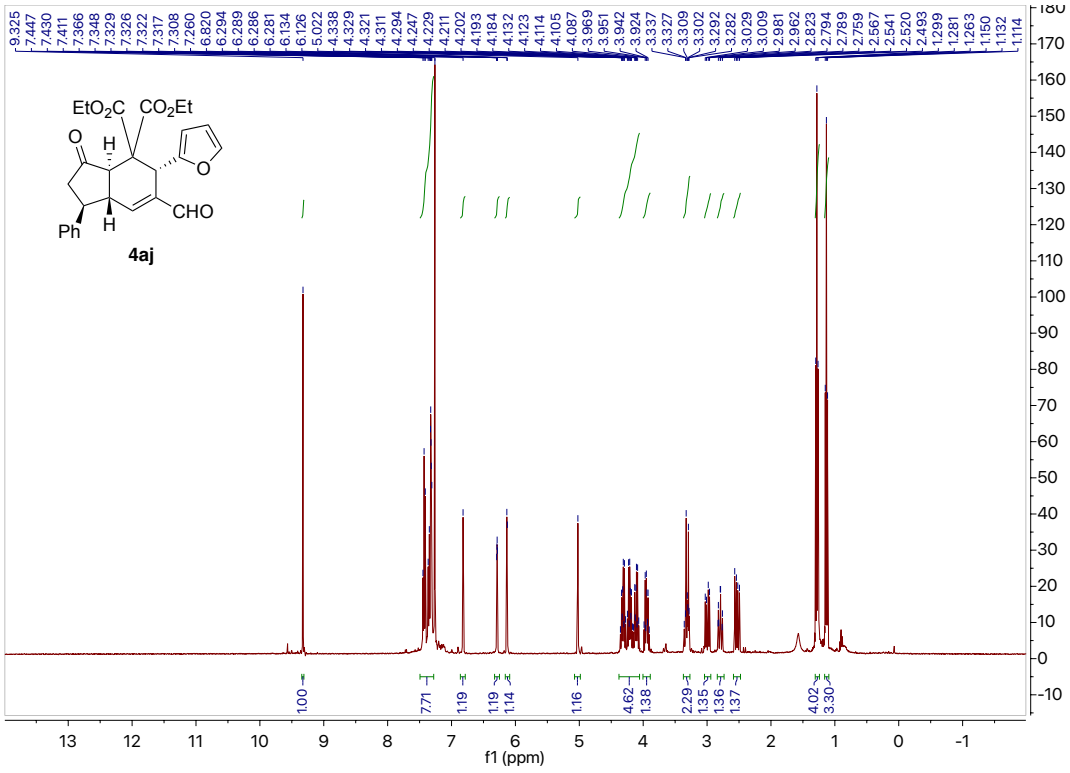


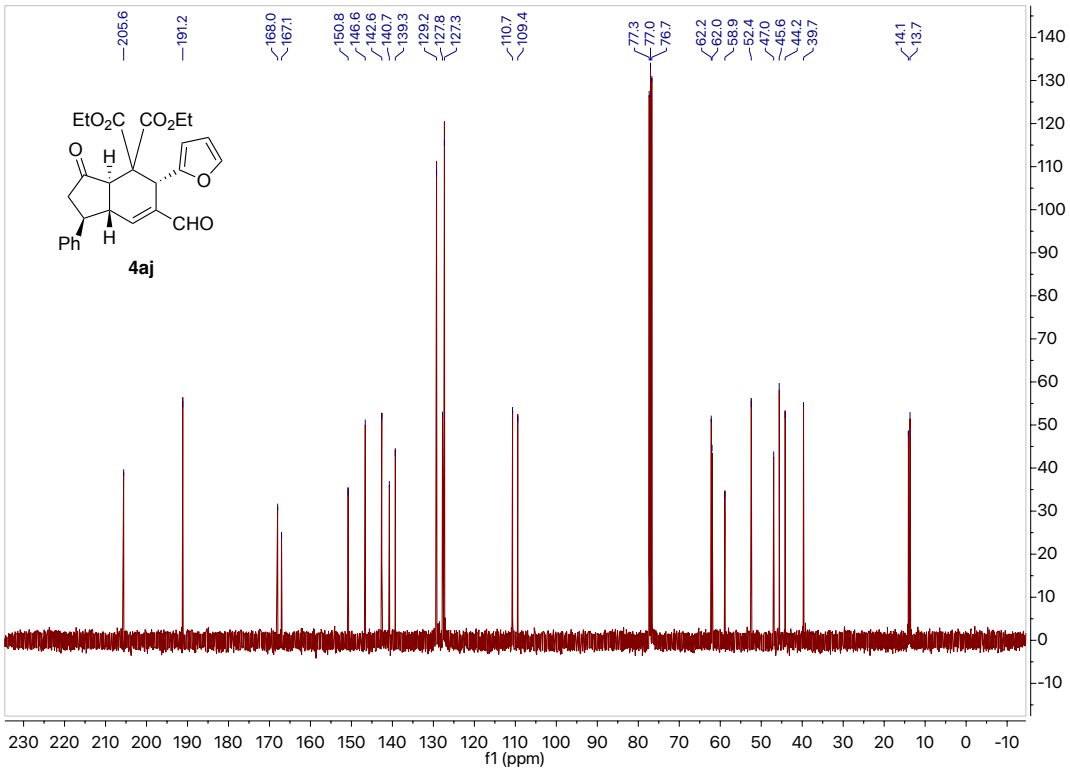
[ピーク検出結果]

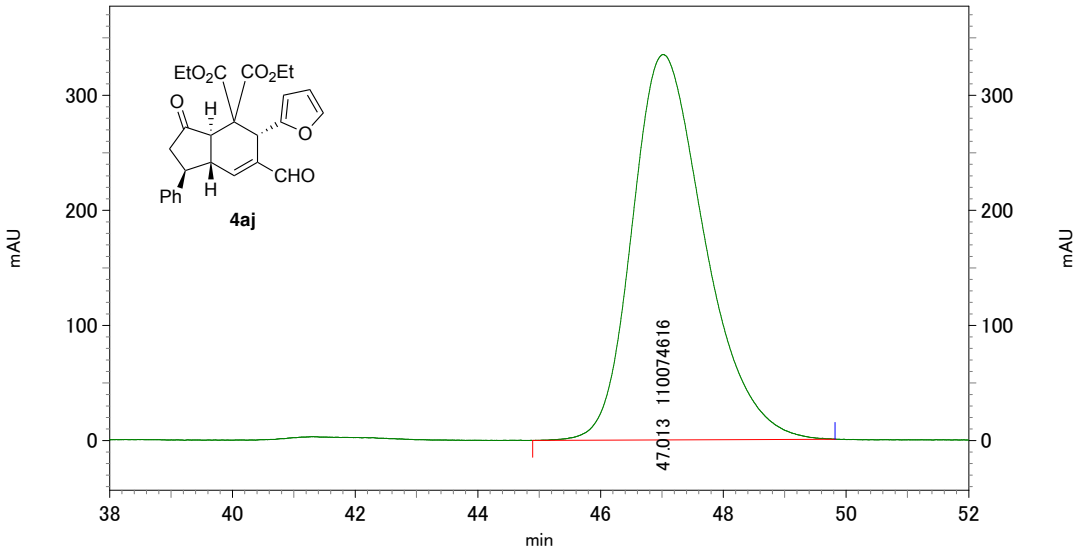
No.	位置	強度	No.	位置	強度
1	2982.37	88.4697	2	1747.19	56.0956
3	1691.27	62.0784	4	1454.06	83.3873
5	1367.28	86.1377	6	1227.47	65.9015
7	912.165	79.8155	8	731.853	69.5228
9	701.962	67.0953			



4aa


EtO2C CO2Et
O
H
O
CHO
Ph
H
4aj
f1 (ppm)


EtO2C CO2Et
O
H
O
CHO
Ph
H
4aj
f1 (ppm)



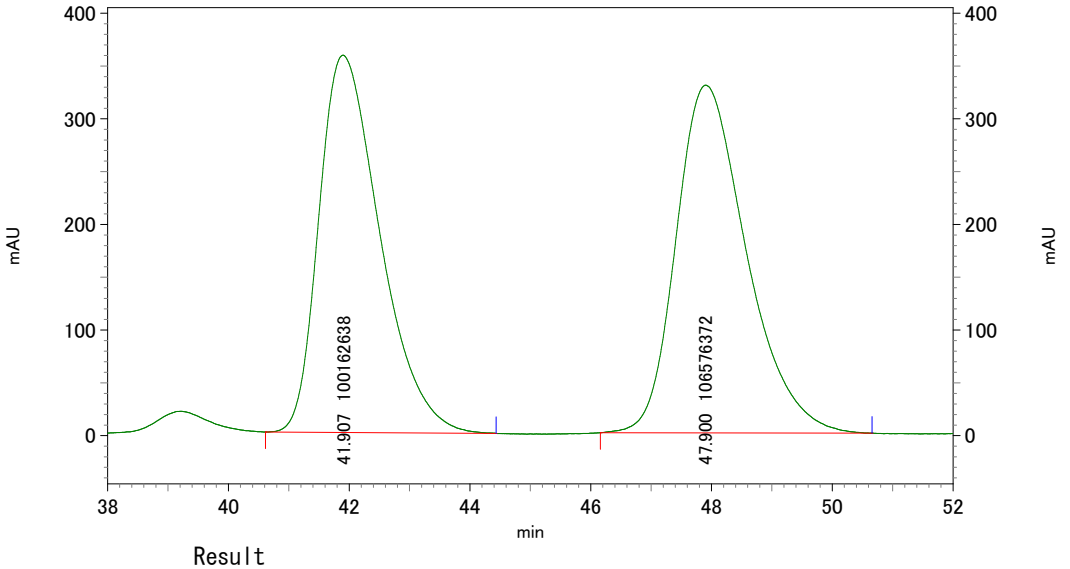
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	47.013	100.000

トータル		100.000

Total



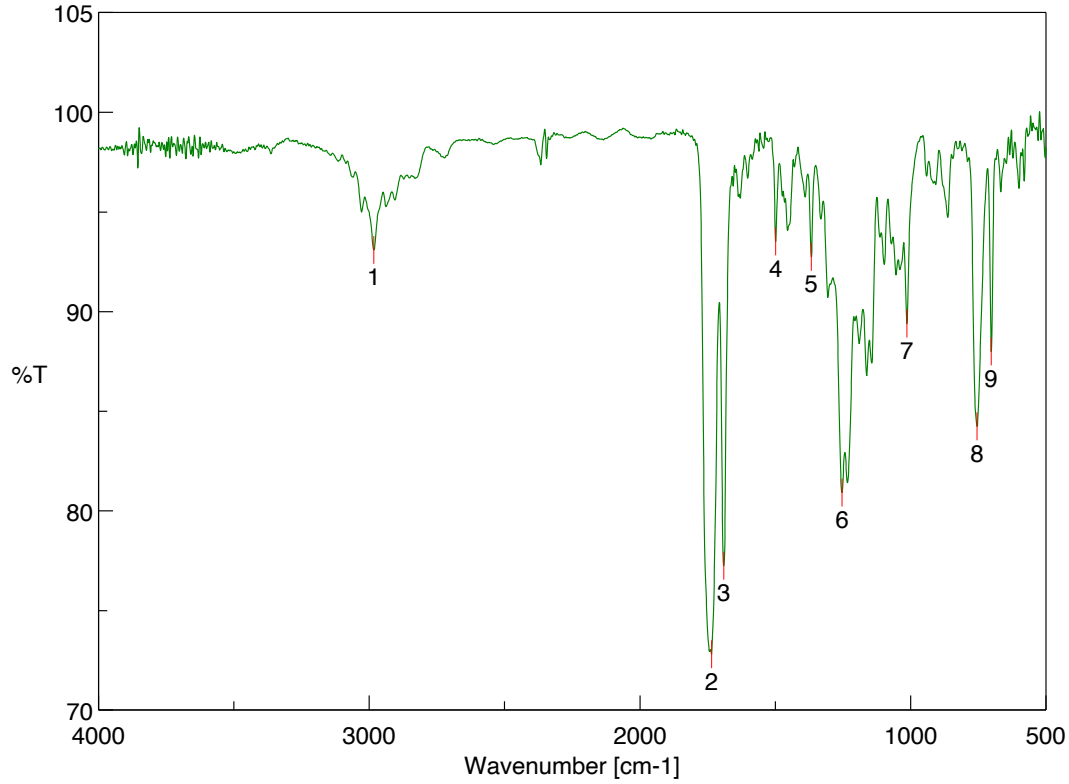
Result

2: 208 nm, 4 nm結果

Pk #	Retention time / min	Integration/ %
1	41.907	48.449
2	47.900	51.551

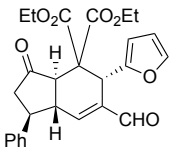
トータル		100.000

Total

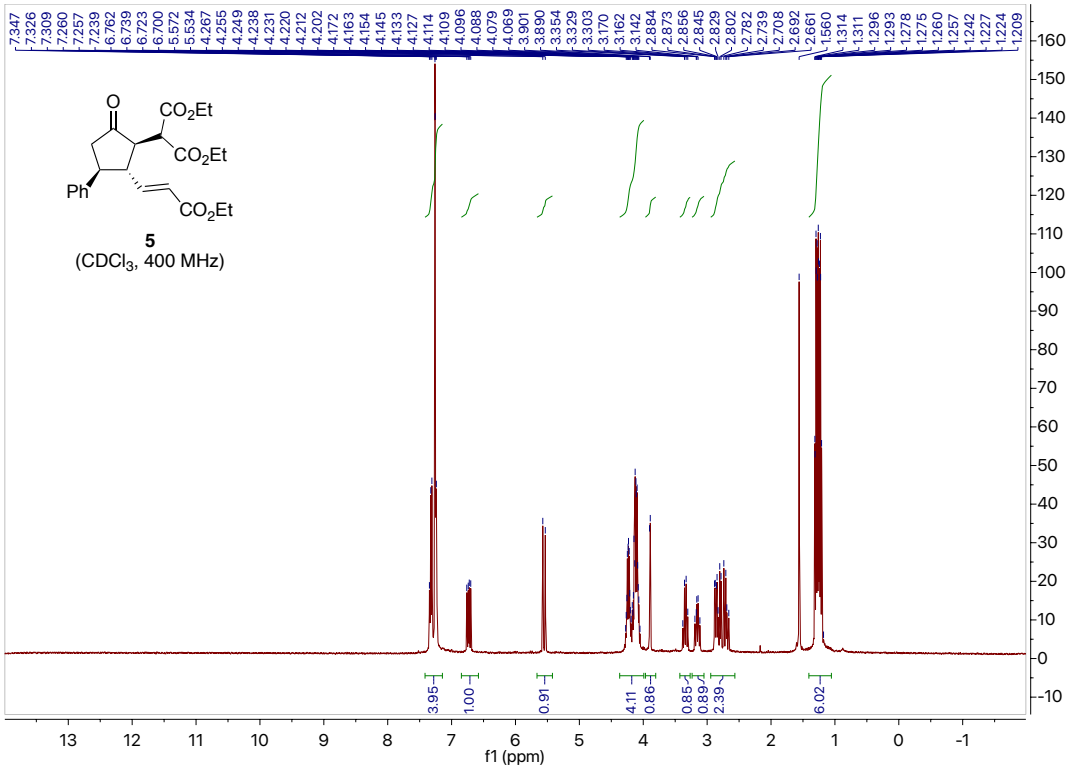


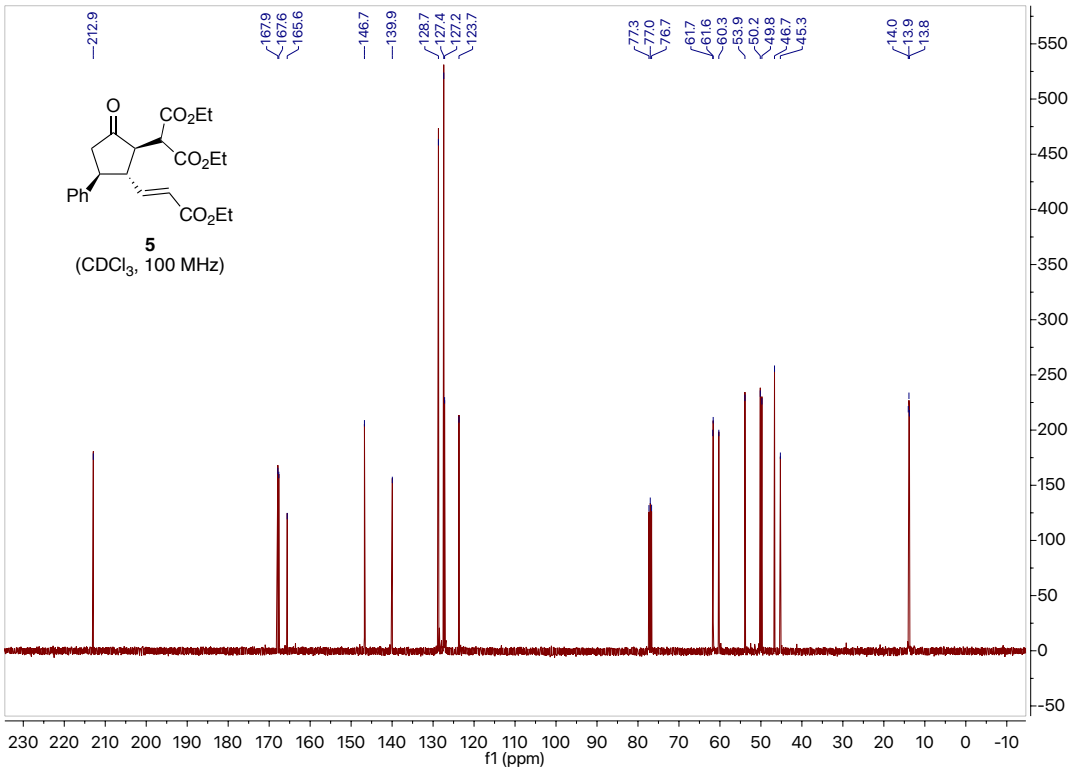
[ピーク検出結果]

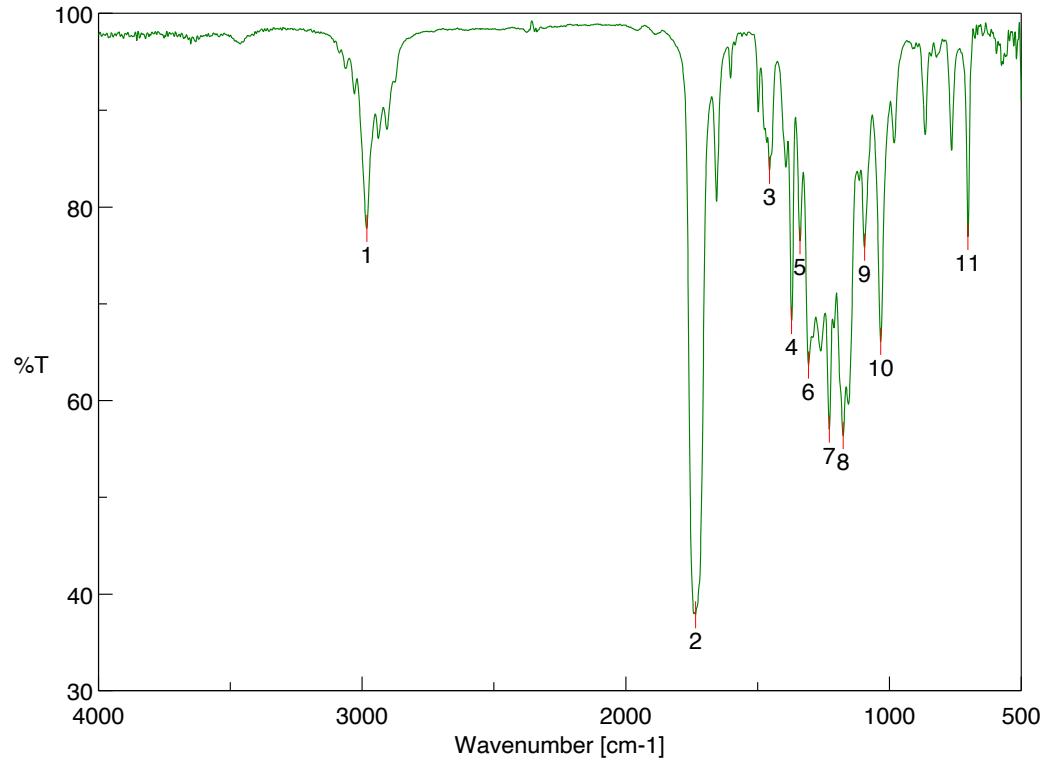
No.	位置	強度	No.	位置	強度
1	2983.34	93.0797	2	1735.62	72.7979
3	1690.3	77.2346	4	1498.42	93.5111
5	1367.28	92.7335	6	1253.5	80.9119
7	1013.41	89.3806	8	754.995	84.2305
9	701.962	87.9843			



4aj

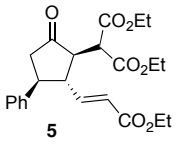

7.347
7.326
7.309
7.260
7.257
7.239
6.762
6.739
6.723
6.700
5.572
5.534
4.267
4.255
4.249
4.238
4.231
4.220
4.212
4.202
4.172
4.163
4.154
4.145
4.133
4.127
4.114
4.109
4.096
4.088
4.079
4.069
3.901
3.890
3.354
3.329
3.303
3.170
3.162
3.142
2.884
2.873
2.856
2.845
2.829
2.802
2.782
2.739
2.708
2.692
2.661
1.560
1.314
1.311
1.296
1.293
1.278
1.275
1.260
1.257
1.242
1.227
1.224
1.209
O
CO2Et
CO2Et
Ph
CO2Et
5
(CDCl3, 400 MHz)
3.95
1.00
0.91
4.11
0.86
0.85
0.89
2.39
6.02
f1 (ppm)


212.9
167.9
167.6
165.6
146.7
139.9
128.7
127.4
127.2
123.7
77.3
77.0
76.7
61.7
61.6
60.3
53.9
50.2
49.8
46.7
45.3
14.0
13.9
13.8
O
CO2Et
CO2Et
Ph
CO2Et
5
(CDCl3, 100 MHz)
f1 (ppm)

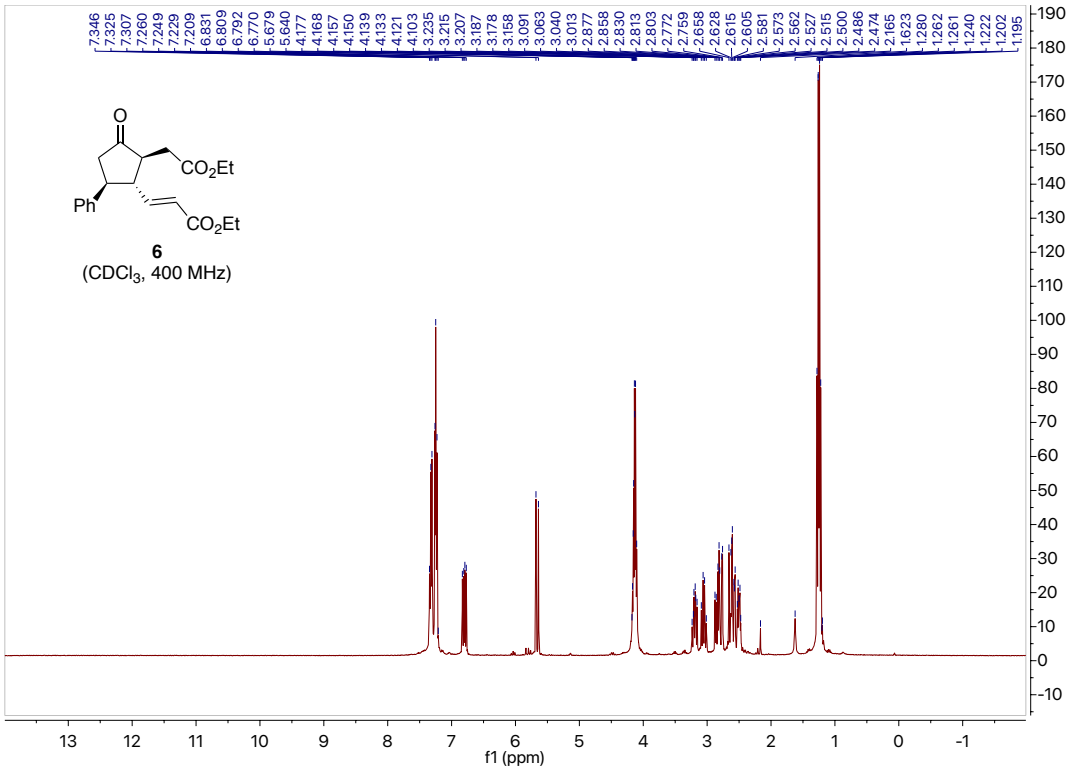


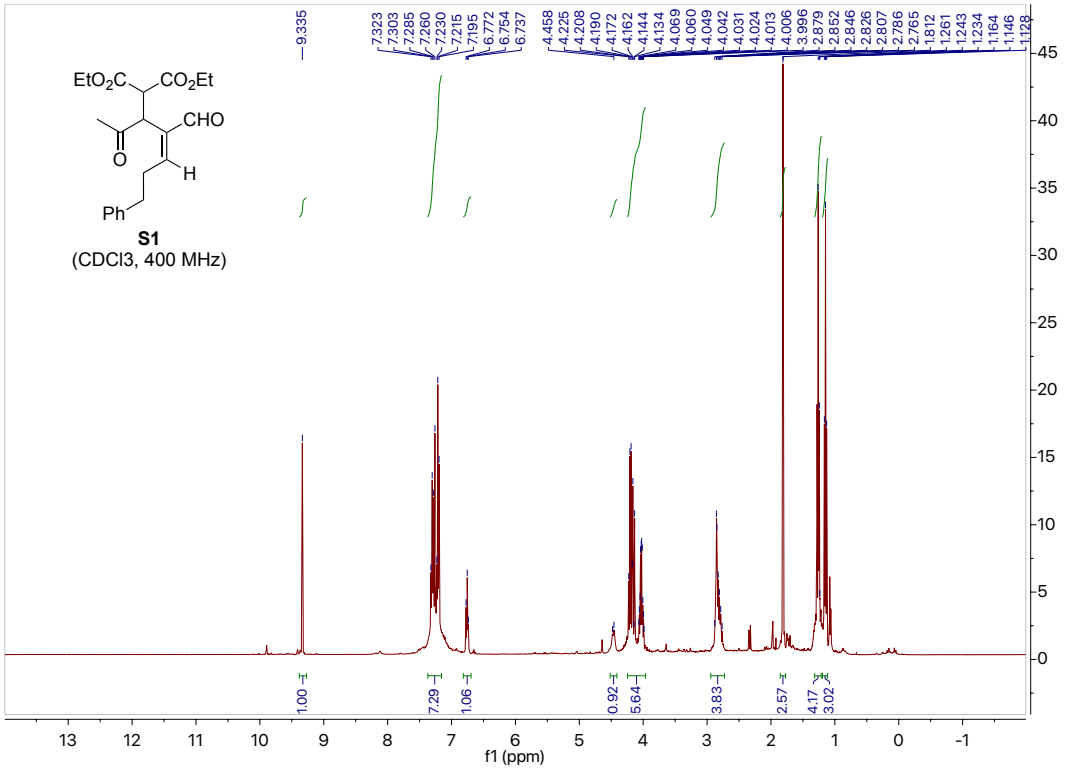
[ピーク検出結果]

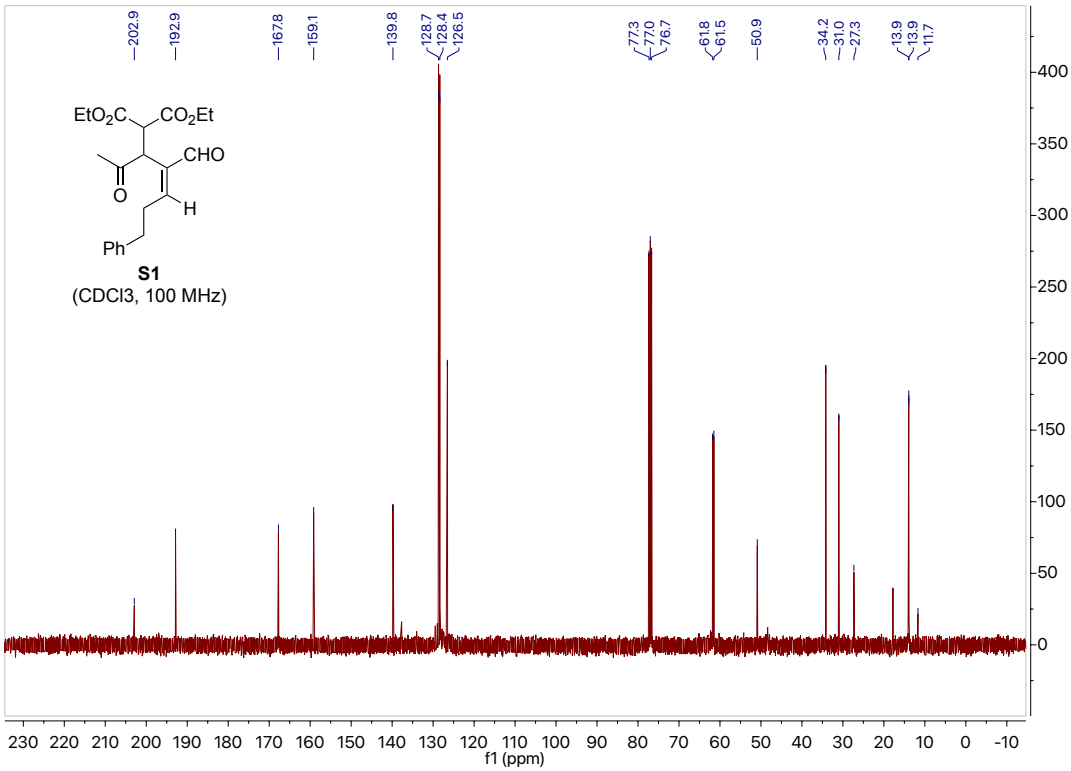
No.	位置	強度	No.	位置	強度
1	2982.37	77.7857	2	1735.62	37.8413
3	1455.03	83.7879	4	1371.14	68.2394
5	1339.32	76.5011	6	1306.54	63.6379
7	1227.47	57.0413	8	1175.4	56.369
9	1094.4	75.8134	10	1032.69	66.092
11	701.962	76.933			

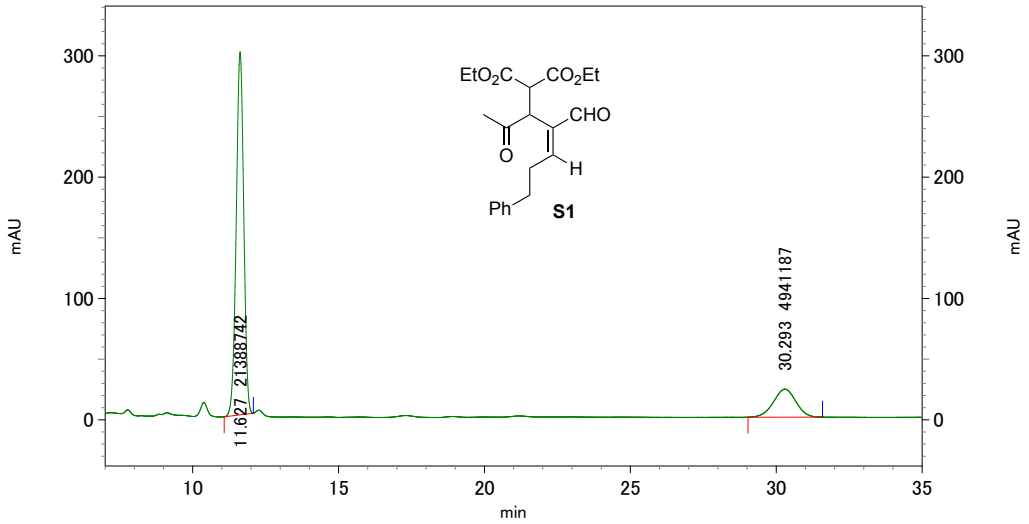


5


7.346
7.325
7.307
7.260
7.249
7.229
7.209
6.831
6.809
6.792
6.770
5.679
5.640
4.177
4.168
4.157
4.150
4.139
4.133
4.121
4.103
3.235
3.215
3.207
3.187
3.178
3.158
3.091
3.063
3.040
3.013
2.877
2.858
2.830
2.813
2.803
2.772
2.759
2.658
2.628
2.615
2.605
2.581
2.573
2.562
2.527
2.515
2.500
2.486
2.474
2.165
1.623
1.280
1.262
1.261
1.240
1.222
1.202
1.195
O
CO2Et
Ph
CO2Et
6
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C
CO2Et
CHO
O
H
Ph
S1
(CDCl3, 400 MHz)
f1 (ppm)


EtO2C
CO2Et
CHO
O
H
Ph
S1
(CDCl3, 100 MHz)
f1 (ppm)

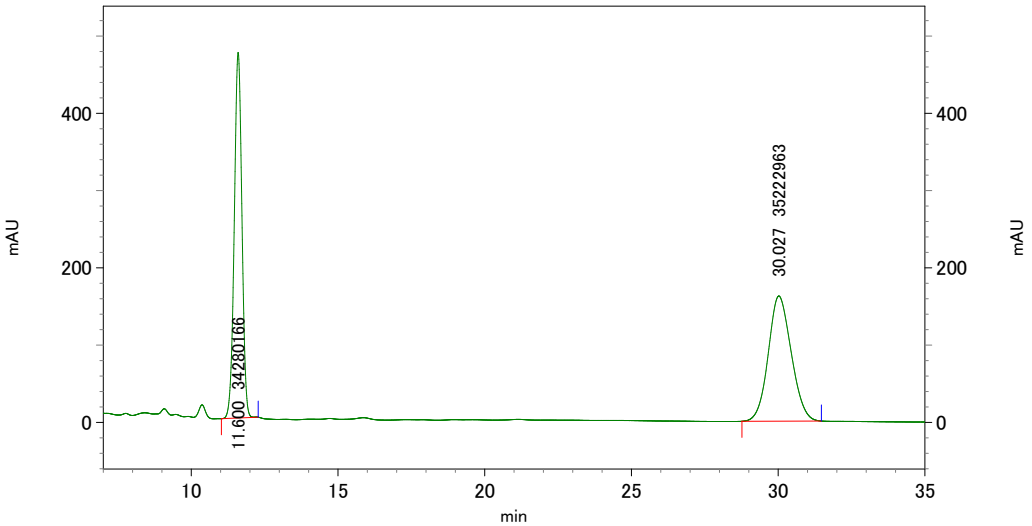


Result

1: 210.0 nm, 4.0 nm 結果

Pk #	Retention time / min	Integration/ %
1	11.627	81.234
2	30.293	18.766
合計		100.000

Total

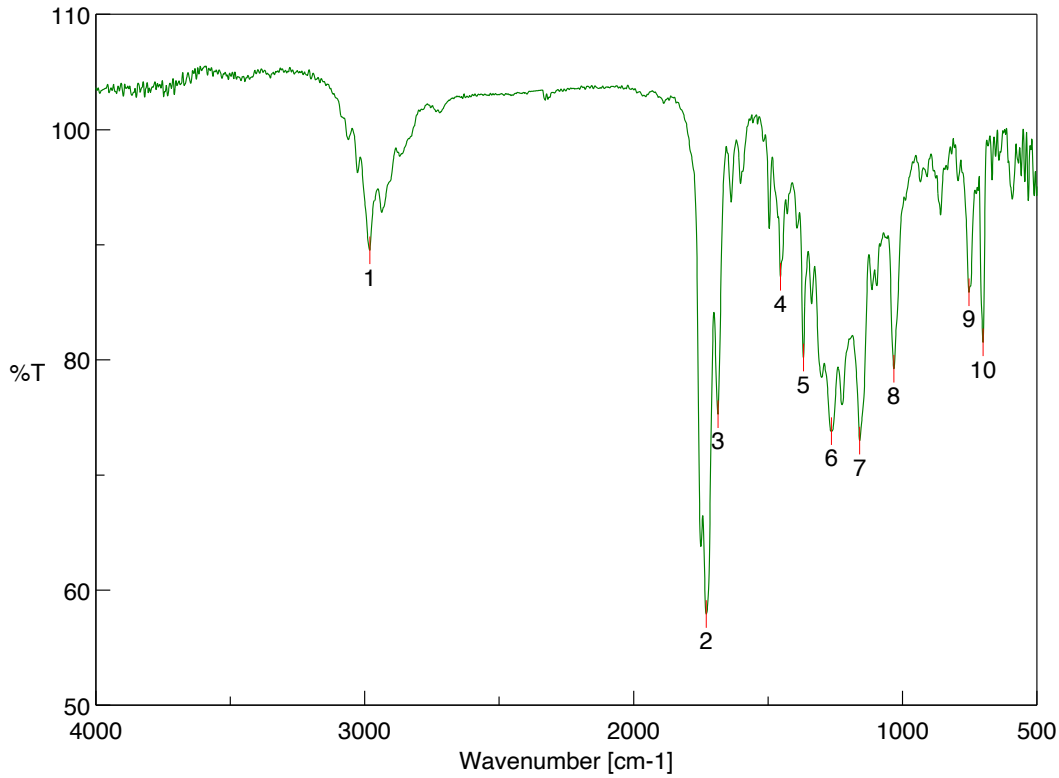


Result

1: 210.0 nm, 4.0 nm 結果

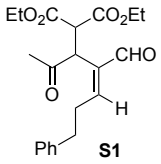
Pk #	Retention time / min	Integration/ %
1	11.600	49.322
2	30.027	50.678
合計		100.000

Total



[ピーク検出結果]

No.	位置	強度	No.	位置	強度
1	2981.41	89.5103	2	1729.83	57.9122
3	1686.44	75.2587	4	1454.06	87.21
5	1368.25	80.1891	6	1264.11	73.7849
7	1159.01	72.9677	8	1031.73	79.2077
9	753.066	85.8468	10	700.034	81.5084



S1