A formal homo-Nazarov cyclization of enantioenriched donor-acceptor cyclopropanes and following transformations: asymmetric synthesis of multi-substituted dihydronaphthalenes

Seijiro Takada, Naoya Takaki, Kenta Yamada, and Yoshinori Nishii*

Department of Chemistry, Faculty of Textile Science and Technology, Shinshu University, Ueda, Nagano 386-8567, Japan.

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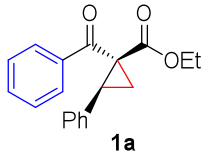
Supporting Information

General: All reactions were carried out in oven-dried glassware under an argon atmosphere. Tetrahydrofuran (THF) was distilled from sodium benzophenone ketyl. Column chromatography was performed with silica gel Merck 60 (70-230 mesh ASTM). TLC analysis was performed on 0.25 mm Silicagel Merck 60 F_{254} plates. NMR spectra were recorded on 400 MHz spectrometer, operating at 400 MHz for ^{1}H NMR and 100 MHz for ^{13}C NMR. Chemical shifts (δ ppm) in $CDCl_3$ were reported downfield from TMS (= 0) for ^{1}H NMR. For ^{13}C NMR, chemical shifts were reported in the scale relative to $CDCl_3$ (77.00 ppm) as an internal reference. Mass spectra were obtained by APCI.

Preparation of a D–A cyclopropanes 1

D–A cyclopropanes 1

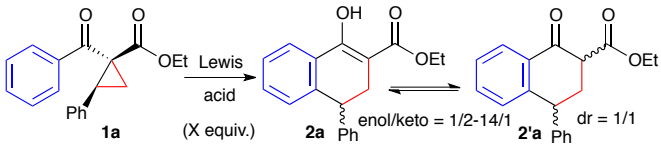


1a
(racemic)

A CH_2Cl_2 solution (5.0 ml) of styrene (6.31 ml, 54.9 mmol) and α,α-diazo-β-ketoseter (2.40 g, 11.0 mmol) was added to a solution of $Rh_2[CH_3(CH_2)_7CO_2]_4$ (427 mg, 0.549 mmol) in CH_2Cl_2 (28 ml) at rt in an Ar atmosphere, and followed by being stirred at same temp for 1h. Water was added to the reaction mixture, which was extracted with $CHCl_3$. The organic phase was washed with brine, dried (Na_2SO_4) and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 10/1) to give the product **1a** (3.23 g, 72%).

1a: colorless solid ; mp = 52~54 ˚C ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.69 (t, J = 7.1 Hz, 3H), 1.68 (dd, J = 9.1, 4.8 Hz, 1H), 2.45 (dd, J = 8.1, 4.8 Hz, 1H), 3.58 (t, J = 8.6 Hz, 1H), 3.66 (dq, J = 10.8, 7.1 Hz, 1H), 3.73 (dq, J = 10.8, 7.1 Hz, 1H), 7.20-7.34 (m, 5H), 7.45 (t, J = 7.5 Hz, 2H), 7.54 (t, J = 7.5 Hz, 1H), 7.89-7.94 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 13.8, 20.4, 31.0, 42.8, 61.5, 127.6, 128.4, 128.6, 128.9, 129.5, 133.2, 135.2, 137.8, 168.7, 195.3 ; IR (KBr,neat) 3064, 3032, 2985, 2933, 1728, 1676, 1452, 1309, 1280, 1147, 709 cm^{-1} ; HRMS (APCI) calcd for $C_{19}H_{18}O_3$ $(M+H)^+$ 295.1329 , found 295.1338.

A optimal procedure for the ring-opening cyclization of D–A cyclopropanes 1a



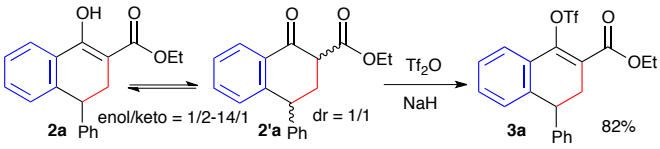
1a (racemic) **2a** Ph **2'a** Ph

A ethylene dichloride (EDC) solution of cyclopropanedicarbxylis ester **1a** (294 mg, 1.0 mmol) was added dropwise to a solution of $TiCl_4$ (164 μl, 1.5 mmol) in EDC (4 ml) at 70 ˚C in an Ar atmosphere, and followed by being stirred at 83˚C for 1h. 1N-HCl aqueous solution was added to the reaction mixture, which was extracted with $CHCl_3$. The organic phase was washed with brine, dried (Na_2SO_4) and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 30/1) to give a 14/1 enol-keto mixture of **2a** and **2'a** (270 mg, 92%).

2a and **2'a** : ^{1}H NMR (400MHz,$CDCl_3$) δ 1.29 (t, J = 7.2 Hz, 3H), 2.86 (dd, J = 15.7, 10.5 Hz, 1H), 2.94 (dd, J = 15.7, 6.7 Hz, 1H), 4.15 (dd, J = 10.5, 6.7 Hz, 1H), 4.32 (q, J = 7.2 Hz, 3H), 6.86 (dd, J = 6.2, 1.0 Hz, 1H), 7.19-7.23 (m, 2H), 7.26-7.43 (m, 5H), 7.89 (dd, J = 7.6, 1.8 Hz, 1H), 12.48 (s,

1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.7, 29.5, 44.5, 61.0, 96.4, 124.9, 127.2, 127.3, 128.1, 128.9, 129.0, 130.5, 131.2, 142.1, 143.7, 165.1, 173.0 ; HRMS (APCI) calcd for $C_{19}H_{18}O_3$ $(M+H)^+$ 295.1329 , found 295.1336.

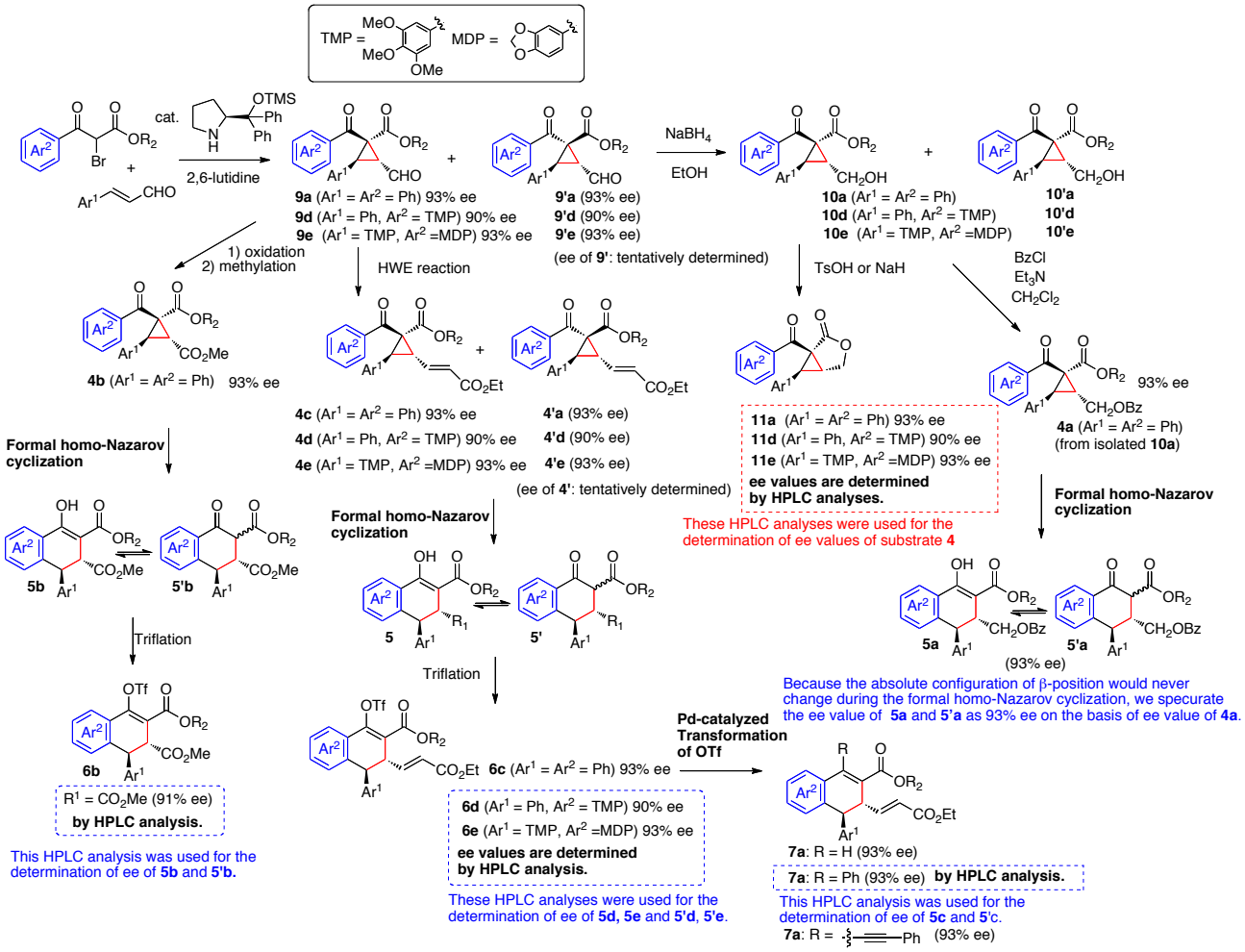
Trifration of a enol-keto mixture of 2 and 2' to furnish Dihydronaphthalene trifrate 3



A CH_2Cl_2 solution (0.8 ml) of a enol-keto mixture of **2a** and **2**'a (270 mg, 0.92 mmol) was added dropwise to a suspension of NaH (74 mg, 1.84 mmol) in CH_2Cl_2 (2 ml) at 0 ˚C in an Ar atmosphere, and followed by being stirred at the same temperature for 1h. Then, Tf_2O (302 μl, 1.84mmol) was added to the reaction mixture at 0 ˚C, and followed by being stirred at the same temperature for 30 minutes. Saturated $NaHCO_3$ aqueous solution was added to the reaction mixture with cooling, which was extracted with AcOEt. The organic phase was washed with brine, dried (Na_2SO_4) and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 30/1) to give the trifrate **3a** (321 mg, 82%).

3a: colorless solid ; mp = 75~77 ˚C; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.35 (t, J = 7.1 Hz, 3H), 3.06 (dd, J = 17.3, 10.9 Hz, 1H), 3.15 (dd, J = 17.3, 6.9 Hz, 1H), 4.21 (dd, J = 10.9, 6.9 Hz, 1H), 6.88-6.92 (m, 1H), 7.19-7.23 (m, 2H), 7.28-7.38 (m, 5H), 7.56-7.59 (m, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.3, 32.7, 43.3, 62.3, 120.6, 123.9, 127.5, 127.6, 128.4, 128.7, 129.0, 129.2, 131.5, 141.0, 141.8, 164.7 ; IR (KBr,neat) 3032, 2987, 2943, 1703, 1639, 1431, 1224, 1141, 1037, 835 cm^{-1} ; HRMS (APCI) calcd for $C_{20}H_{17}F_3O_3S$ $(M+H)^+$ 427.0822 , found 427.0832.

Overview of experimental supports for Table 2 and Scheme 5.



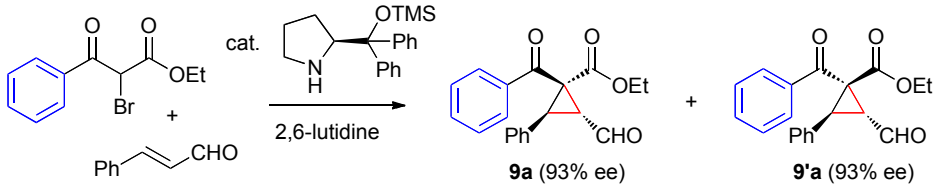
Preparation of enantioenriched D–A cyclopropanes 4a, 4b, 4b + 4'b, 4c, 4c + 4'c, 4d + 4'd, and 4e + 4'e

Following Wang's asymmetric cyclopropanation[9] (see, the supporting information of our previous report[4f]), aldehyde **9a, 9d** and **9e** were prepared in good yields with high ee.

4f) J. Ito, D. Sakuma and Y. Nishii, *Chem. Lett.* **2015**, *44*, 297 (open access).

9) Xie, H.; Zu, L.; Li, H.; Wang, J.; Wang, W. *J. Am. Chem. Soc.* **2007**, *129*, 10886.

Asymmetric cyclopropanation using Hayashi-Jørgensen catalyst



A solution of Hayashi-Jørgensen catalyst (derived from L-proline) (814 mg, 2.50 mmol) in CH_2Cl_2 (2 ml) was added to a solution of Cinnamaldehyde (1.26 ml, 10.0 mmol) in CH_2Cl_2 (25 ml)

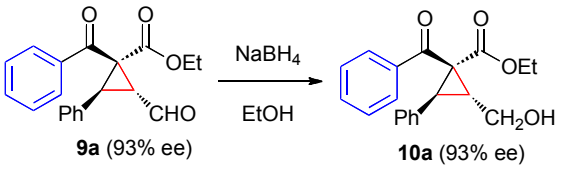
at 0˚C under an Ar atmosphere, additionally, a solution of Ethy α-bromobenzoylacetate (2.69 g, 10.0 mmol) in CH_2Cl_2 (3 ml) and 2,6-lutidine (1.28 ml, 11.0 mmol) was added to the reaction mixture at the same temperature, followed by being stirred at 0˚C for 119 h. Then, the reaction was quenched with 1M-HCl aqueous solution. Water was added to the mixture, which was extracted with $CHCl_3$. The organic phase was washed with brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 8/1) to give the product **9a** (2.16 g, 67%, 93% ee). When the the purification was carried out by short column chromatography (SiO_2, hexane/AcOEt = 8/1) instead of normal column chromatography, a 5:1 mixture of **9a** and **9'a** (2.45 g, 76%, dr = 5/1) was obtained. As described in the overview (page S4), based on the HPLC analysis of lactone **11a** (page S13-14) derived from **9a**, the ee of **9a** was estimated as 93% ee.

9a : yellow liquid ; $[\alpha]_D^{28}$= -280.3 (c 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.92 (t, J = 7.1 Hz, 3H), 3.66 (dd, J = 5.1, 7.6 Hz, 1H), 4.05 (q, J = 7.1 Hz, 1H), 4.11 (q, J = 7.1 Hz, 1H), 4.15 (d, J = 7.6 Hz, 1H), 7.10-7.18 (m, 5H), 7.30-7.36 (m, 2H), 7.42-7.48 (m, 1H), 7.70-7.74 (m, 2H), 9.50 (d, J = 5.1 Hz, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 13.9, 36.9, 37.8, 49.9, 62.8, 128.2, 128.3, 128.6, 128.8, 128.9, 131.9, 133.6, 136.6, 167.7, 189.6, 196.7 ; IR (KBr,neat) 2981, 1716, 1647, 1429, 1276, 1039 cm^{-1} ; HRMS (APCI) calcd for $C_{20}H_{18}O_4$ $(M+H)^+$ 323.1278, found 323.1280.

Selected data for **9'a ;** ^{1}H NMR (400MHz,$CDCl_3$) δ 0.74 (t, J = 7.1 Hz, 3H), 4.19-4.18 (m, 5H), 9.13 (d, J = 5.8 Hz, 1H). The ee of minor product **9'a** was tentatively determined as the same ee value of **9a**. This was deductively proved after HPLC analysis of **7b** (page S30–32, 93% ee) derived from a 5:1 mixture of **9a** and **9a'** via **6c**. (See the overview in page S4.)

Preparation of 4b

i) Reduction of aldehyde of **9a** to afford **10a**.



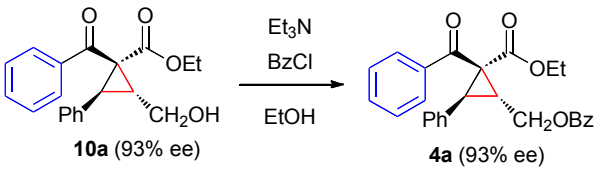
9a (93% ee) **10a** (93% ee)

$NaBH_4$ (31 mg, 0.81 mmol) was added to a solution of cyclopropane **9a** (1.05 g, 3.25 mmol) in EtOH (6.5 mL) at 0˚C under an Ar atmosphere, followed by being stirred at 0˚C for 5 minutes. Then, the reaction was quenched with sat. NH_4Cl aqueous solution. Water was added to the mixture, which was extracted with AcOEt. The organic phase was washed with brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 4/1) to give the product **10a** (455 mg, 43%). As described in the overview (page

S4), based on the HPLC analysis of lactone **11a** (page S13-14) derived from **9a** via **10a**, the ee of **10a** was estimated as 93% ee.

10a : colorless liquid ; $[\alpha]_D^{28}$= -189.5 (c 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.88 (t, J = 7.1 Hz, 3H), 1.71 (br, 1H), 3.16-3.21 (m, 1H), 3.53 (d, J = 8.1 Hz, 1H), 3.81 (dd, J = 11.6, 8.7 Hz, 1H), 4.02 (q, J = 7.1 Hz, 1H), 4.09 (q, J = 7.1 Hz, 1H), 3.97-4.15 (m, 1H), 7.04-7.16 (m, 5H), 7.27-7.33 (m, 2H), 7.38-7.43 (m, 1H), 7.67-7.70 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 13.9, 31.6, 3s7.7, 47.4, 53.9, 60.4, 127.6, 128.4, 128.5, 128.6, 128.7, 133.0, 134.1, 137.7, 169.0, 192.8.

ii) Benzoylation of alcohol **10a**

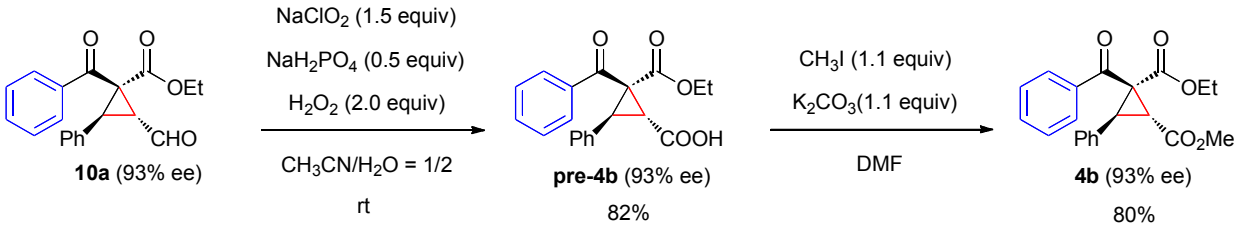


10a (93% ee) **4a** (93% ee)

Triethylamine (177 μl, 1.52 mmol) was added to a solution (2.5 ml) of a mixture of **10a** (411 mg, 1.27 mmol) in CH_2Cl_2 (2.5 ml) at 0˚C, followed by BzCl (210 μl, 1.52 mmol) was added dropwise to the mixture at the same tempereature. Then, The reaction mixture was stirred at the same temperature for 2.5 h. sat. $NaHCO_3$ aqueous solution was added to the reaction mixture with cooling by an ice bath and extracted with AcOEt. The organic phase was washed with brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 4/1) to give the product **4a** (493 mg, 91%). As described in the overview (page S4), based on the HPLC analysis of lactone **11a** (page S13-14) derived from **10a** using a chiral column, the ee of **4a** derived from **10a** was estimated as 93% ee.

4a : colorless liquid ; $[\alpha]_D^{29}$= 120.2 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.82 (t, J = 7.1 Hz, 3H), 3.39 (ddd, J = 9.3, 7.9, 6.0 Hz, 1H), 3.63 (d, J = 7.9 Hz, 1H), 3.93 (dq, J = 10.8, 7.1 Hz, 1H), 4.05 (dq, J = 10.8, 7.1 Hz, 1H), 4.39 (dd, J = 11.9, 9.4 Hz, 1H), 4.88 (dd, J = 11.9, 6.0 Hz, 1H), 7.06-7.10 (m, 1H), 7.12-7.19 (m, 4H), 7.27-7.32 (m, 2H), 7.39-7.45 (m, 3H), 7.53-7.58 (m, 1H), 7.69-7.72 (m, 2H), 8.02-8.06 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 13.9, 27.9, 37.7, 47.2, 62.3, 62.8, 127.8, 128.4, 128.5, 128.7, 128.8, 130.1, 130.3, 133.1, 133.4, 133.5, 137.6, 166.5, 169.2, 191.9, 203.1 ; IR (NaCl,neat) 3062, 2981, 2937, 1737, 1714, 1681, 1600, 1450, 1112, 709 cm^{-1} ; HRMS (APCI) calcd for $C_{27}H_{24}O_5$ $(M+H)^+$ 429.1697 , found 429.1700.

Preparation of 4b



H_2O_2 (39 µl, 1.30 mmol) was added to a mixture solution (1.3 ml) of aldehyde **9a** (210 mg, 0.652 mmol) and $NaH_2PO_4 \cdot 2H_2O$ (51 mg, 0.326 mmol) in CH_3CN (1.3 ml) at 0˚C, followed by $NaClO_2$(88 mg, 0.978 mmol) aqueous solution (1.3 ml) was added dropwise to the mixture at the same tempereature. Then, The reaction mixture was stirred at the room temperature for 1 h. sat. $Na_2S_2O_3$ aqueous solution was added to the reaction mixture for reaction quenching. After addition of sat. $NaHCO_3$ aueous solution, mixture and extracted with ether. The organic phase was washed with 1N-HCl aueous solution, water, brine, dried (Na_2SO_4), and concentrated to give the carboxylic acid **pre-4b** (180 mg, 91% yield).

References for Kraus-Pinnick oxidation: a) G. A. Kraus, M. J. Taschner, J. Org. Chem. 1980, 45, 1175. b) G. A. Kraus, B. Roth, *J. Org. Chem.* **1980**, *45*, 4825. c) B. S. Bal, W. E. Childers, Jr., H. W. Pinnick, *Tetrahedron* **1981**, *37*, 2091. d) Johan Hygum Dam and Robert Madsen**,** *Eur. J. Org. Chem.* **2009**, 4666–4673.

Next, K_2CO_3 (81 mg, 0.586 mmol) was added to a solution of a carboxylic acid **pre-4b** (180 mg, 0.532 mmol) in DMF (1.3 ml) at 0˚C, followed by being stirred at the same temperature for 15 min. Then, MeI (36 µl, 0.586 mmol) was added dropwise to the mixture at the same tempereature, followed by being stirred at room temperature for 15 min. 1N-HCl aqueous solution was added to the reaction mixture and extracted with AcOEt. The organic phase was washed with 1N-HCl aueous solution, water, brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 4/1) to give the product **4b** (150 mg, 80% yield).

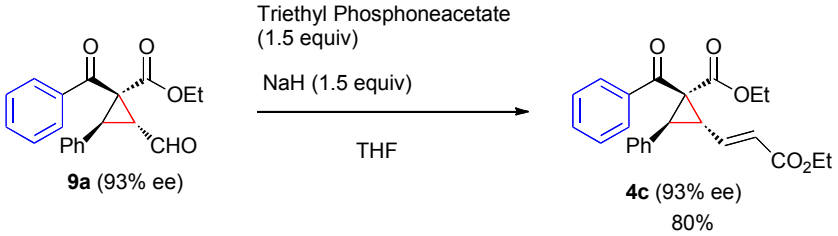
pre-4b : colorless solid ; $[\alpha]_D^{26}$= -69.9 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.97 (t, J = 7.1 Hz, 3H), 3.66 (d, J = 7.7 Hz, 1H), 3.98 (d, J = 7.7 Hz, 1H), 4.07 (q, J = 7.1 Hz, 2H), 7.08-7.22 (m, 1H), 7.12-7.19 (m, 5H), 7.30-7.36 (m, 2H), 7.42-7.47 (m, 1H), 7.76-7.80 (m, 2H), 11.24 (brs, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.0, 30.2, 37.9, 51.2, 62.7, 128.2, 128.3, 128.8, 132.5, 133.7, 136.7, 167.8, 175.5, 190.1 ; IR (KBr,neat) 3064, 2956, 1743, 1683, 1448, 1288, 1010, 696 cm^{-1} ; HRMS (APCI) calcd for $C_{20}H_{18}O_5$ $(M+H)^+$ 339.1227 , found 339.1240.

4b : colorless liquid ; $[\alpha]_D^{24}$= -127.8 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.96 (t, J = 7.2 Hz, 3H), 3.64 (d, J = 7.8 Hz, 1H), 3.75 (s, 3H), 3.95 (d, J = 7.8 Hz, 1H), 4.07 (q, J = 7.2 Hz, 2H), 7.08-7.20 (m, 5H), 7.29-7.34 (m, 2H), 7.41-7.46 (m, 1H), 7.74-7.78 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.0, 30.5, 37.5, 50.6, 52.8, 62.5, 128.0, 128.3, 128.8, 132.8, 133.5, 136.8,

167.6, 169.7, 190.4 ; IR (NaCl,neat) 3062, 2983, 2954, 1747, 1732, 1681, 1598, 1446, 1136, 694 cm^{-1} ; HRMS (APCI) calcd for $C_{21}H_{20}O_5$ $(M+H)^+$ 353.1384 , found 353.1386.

As described in the overview (page S4), based on the HPLC analysis of lactone **11a** (page S13-14) derived from **9a** using a chiral column, the ee of **4a** derived from **9a** was estimated as 93% ee.

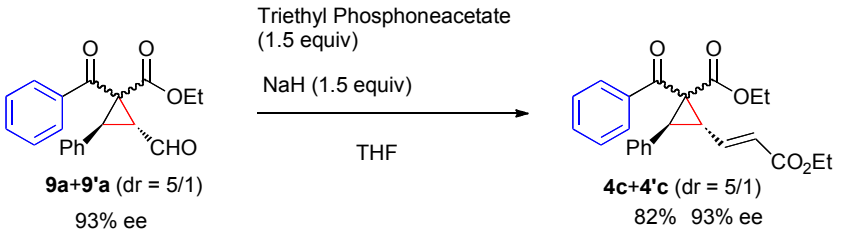
Preparation of 4c



A THF-solution (1.5 ml) of triethyl phosphonoacetate (295 µl, 1.5 mmol) was added dropwise to a suspension of 60%-dispersion in Paraffin Liquid NaH(60 mg, 1.5 mmol) at 0˚C, and followed by being stirred for 1h at the same temperarure. Then, A THF solution (1.5 ml) of aldehyde **9a** (322 mg, 1.0 mmol) was added to the reaction mixture at 0 ˚C, and followed by being stirred at the same temperature for 10 minutes. 1N-HCl aqueous solution was added to the reaction mixture and extracted with ether. The organic phase was washed with water, brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 8/1) to give the product **4c** (313 mg, 80% yield).

4c : colorless liquid ; $[\alpha]_D^{29}$= -68.1 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.89 (t, J = 7.1 Hz, 3H), 1.29 (t, J = 7.1 Hz, 3H), 3.57 (dd, J = 9.6, 7.8 Hz, 1H), 3.76 (d, J = 7.8 Hz, 1H), 4.01 (dq, J = 10.8, 7.1 Hz, 1H), 4.10 (dq, J = 10.8, 7.1 Hz, 1H), 4.20 (q, J = 7.1 Hz, 2H), 6.26 (d, J = 15.7 Hz, 1H), 6.83 (dd, J = 15.7, 9.6 Hz, 1H), 7.06-7.21 (m, 5H), 7.29-7.34 (m, 2H), 7.40-7.46 (m, 13H), 7.66-7.72 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.0, 14.6, 31.7, 39.3, 50.3, 60.7, 62.4, 125.2, 127.9, 128.2, 128.5, 128.7, 133.2, 133.3, 137.9, 142.9, 166.1, 168.4, 191.2 ; IR (NaCl,neat) 2985, 1714, 1681, 1450, 1369, 1269, 1033, 763, 700 cm^{-1} ; HRMS (APCI) calcd for $C_{24}H_{24}O_5$ $(M+H)^+$ 393.1697 , found 393.1707. As described in the overview (page S4), based on the HPLC analysis of lactone **11a** (page S 13-14) derived from **9a** using a chiral column, the ee of **4a** derived from **9a** was estimated as 93% ee.

Preparation of a mixture of 4c and 4'c.

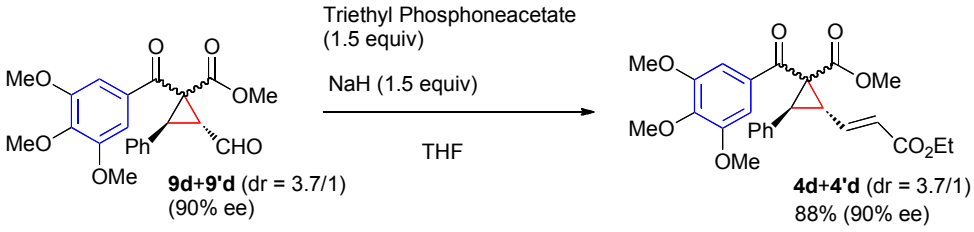


Following the preparation of **4c**, the reaction of a 5:1 mixture of **9a** and **9'a** (322 mg, 1.0 mmol) using of NaH (60 mg, 1.5 mmol), triethyl Phosphoneacetate (295 µl, 1.5 mmol) gave a 5:1 mixture of **4c** and **4'c** (321 mg, 80% yield).

Selected data for minor diastereomer **4'c** : ^{1}H NMR (400MHz,$CDCl_3$) δ 0.67 (t, J = 7.1 Hz, 3H), 1.21 (t, J = 7.1 Hz, 3H), 5.99 (d, J = 15.4 Hz, 1H), 6.45 (dd, J = 15.4, 9.9 Hz, 1H).

The ee of minor product **4'c** was tentatively determined as the same ee value of **4c**. This was deductively proved after HPLC analysis of **7b** (page S30–32, 93% ee) derived from a 5:1 mixture of **4c** and **4'c** via **6c**. (See the overview in page S4.)

Preparation of a mixture of 4d and 4'd.



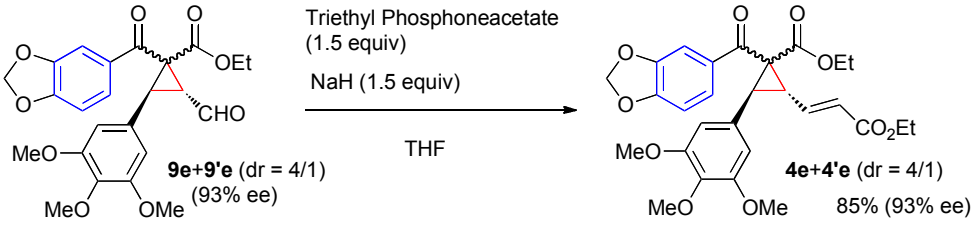
Following the preparation of **4c**, the reaction of a 3.7:1 mixture of **9b** and **9'b** (398 mg, 1.0 mmol) using of NaH (60 mg, 1.5 mmol), triethyl phosphoneacetate (295 µl, 1.5 mmol) gave a 3.7:1 mixture of **4d** and **4'd** (412 mg, 88% yield). As described in page S15-S16, based on the HPLC analysis of lactone **11d** derived from **9d** using a chiral column, the ee of **4d** derived from **9d** was estimated as 90% ee. The ee of minor product **4'd** was tentatively determined as the same ee value of **4d**. This was deductively proved after HPLC analysis of **6d** (page S24–S25, 90% ee) derived from a 3.7:1 mixture of **4d** and **4'd**. (See the overview in page S4.)

4d and **4'd** : yellow liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.30 (t, J = 7.2 Hz, 3H), 3.51 (dd, J = 9.6, 7.7 Hz, 1H), 3.62 (s, 3H), 3.72 (d, J = 7.7 Hz, 1H), 3.82 (s, 6H), 3.85 (s, 3H), 4.20 (q, J = 7.2 Hz, 2H), 6.26 (dd, J = 15.5, 0.5 Hz, 1H), 6.80 (dd, J = 15.5, 9.6 Hz, 1H), 6.96 (s, 2H), 7.08-7.20 (m, 5H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.6, 30.0, 32.0, 39.1, 50.2, 53.4, 56.5, 60.8, 61.1, 106.1, 125.2, 127.9, 128.0, 128.8, 132.1, 133.4, 142.7, 142.8, 153.2, 166.1, 169.0, 189.8 ; IR (NaCl,neat) 3061,

2953, 2839, 1714, 1678, 1585, 1334, 1128 cm^{-1} ; HRMS (APCI) calcd for $C_{26}H_{28}O_8$ $(M+H)^+$ 469.1857, found 469.1857.

Selected data for **4'd :** ^{1}H NMR (400MHz,$CDCl_3$) δ 1.23 (t, J = 7.1 Hz, 3H), 3.54 (dd, J = 9.9, 7.7 Hz, 1H), 3.31 (s, 3H), 3.73 (d, J = 7.6 Hz, 1H), 3.87 (s, 6H), 3.91 (s, 3H), 4.11 (q, J = 7.2 Hz, 1H), 4.12 (q, J = 7.2 Hz, 1H), 6.21 (dd, J = 15.4 Hz, 1H), 6.43 (dd, J = 15.4, 9.9 Hz, 1H).

Preparation of a mixture of 4e and 4'e.

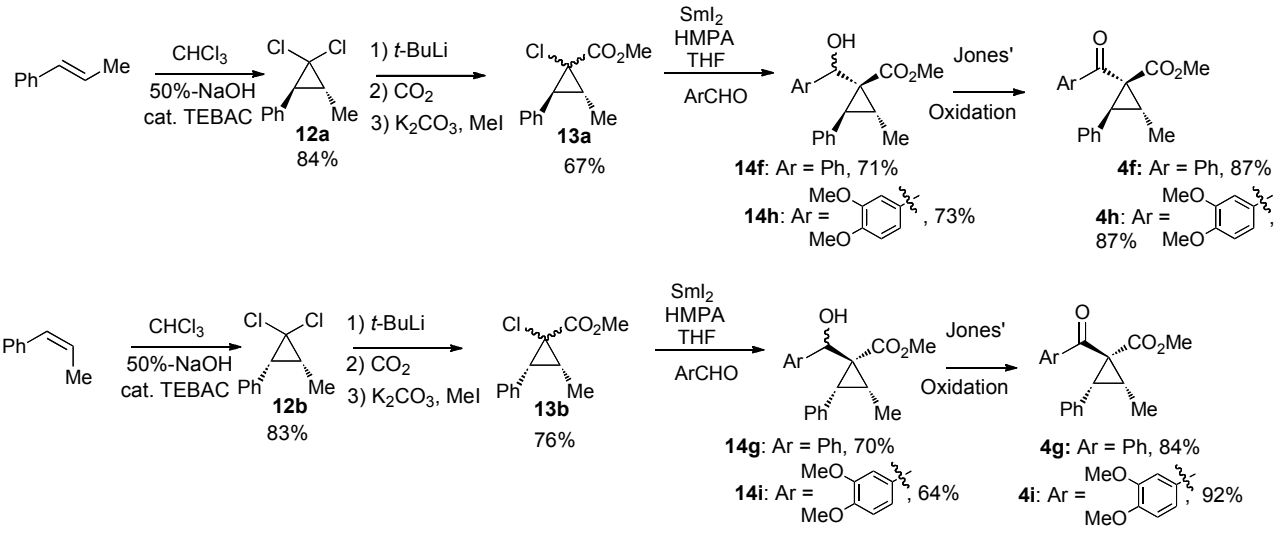


Following the preparation of **4c**, the reaction of a 4:1 mixture of **9e** and **9'e** (322 mg, 1.0 mmol) using of NaH (60 mg, 1.5 mmol), triethyl phosphoneacetate (295 μl, 1.5 mmol) gave a 4:1 mixture of **4e** and **4'e** (321 mg, 80% yield). As described in page S18-S19, based on the HPLC analysis of lactone **11e** derived from **9e** using a chiral column, the ee of **4e** derived from **9e** was estimated as 93% ee. The ee of minor product **4'e** was tentatively determined as the same ee value of **4e**. This was deductively proved after HPLC analysis of **6e** (page S27–S29, 94% ee: Increase of 1% ee is considered as an error range.) derived from a 4:1 mixture of **4e** and **4'e**. (See the overview in page S4.)

4e and **4'e** : yellow liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.02 (t, J = 7.1 Hz, 3H), 1.29 (t, J = 7.1 Hz, 3H), 3.41 (dd, J = 9.7, 7.6 Hz, 1H), 3.61 (d, J = 7.6 Hz, 1H), 3.72 (s, 3H), 3.73 (s, 6H), 4.07-4.21 (m, 2H), 4.21 (q, J = 7.1 Hz, 2H), 5.99 (dd, J = 4.3, 1.2 Hz, 2H), 6.25 (d, J = 15.6 Hz, 1H), 6.28 (s, 2H), 6.71 (d, J = 8.2 Hz, 1H), 6.81 (dd, J = 15.6, 9.7 Hz, 1H), 7.22 (d, J = 1.7 Hz, 1H), 7.34 (dd, J = 8.3, 1.7 Hz, 1H) ; HRMS (APCI) calcd for $C_{28}H_{30}O_{10}$ $(M+H)^+$ 527.1912 , found 527.1920.

Selected data for **4'e :** ^{1}H NMR (400MHz,$CDCl_3$) δ 0.80 (t, J = 7.1 Hz, 3H), 1.22 (t, J = 7.1 Hz, 3H), 3.45 (dd, J = 9.7, 7.4 Hz, 1H), 3.67 (d, J = 7.4 Hz, 1H), 3.81 (s, 3H), 3.84 (s, 6H), 4.04-4.20 (m, 4H), 6.04 (dd, J = 3.8, 1.2 Hz, 2H), 6.19 (d, J = 15.5 Hz, 1H), 6.48 (s, 2H), 6.40 (dd, J = 15.8, 9.8 Hz, 1H), 6.82 (d, J = 8.2, 1.8 Hz, 1H).

Preparation of racemic D–A cyclopropanes 4f–i



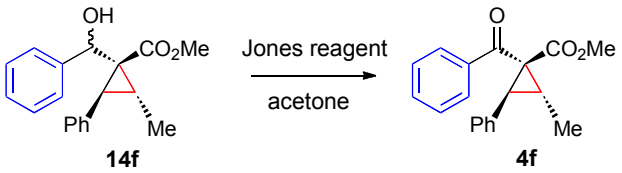
Following our previous report,[4a,4b] *trans*-substrate **14f** and **14g** were prepeared from (*E*)-1-phenyl-1-propene in three steps: (i) Dichlorocyclopropanation, (ii) carboxylation via lithiation, and sequencing methylation (iii) SmI_2-promoted Reformatsky reaction. Using (*Z*)-1-phenyl-1-propene, the preparative method afforded *cis*-substrate **14g** and **14i**.

Procedures were described in detail in supporting information of the previous literature:

4a) Nagano, T.; Motoyoshiya, J.; Kakehi, A.; Nishii, Y. *Org. Lett.* **2008**, *10*, 5453. And

4b) Sakuma, D.; Ito, J.; Sakai, R.; Taguchi, R.; Nishii, Y. *Chem. Lett.* **2014**, *39*, 194 (open access).

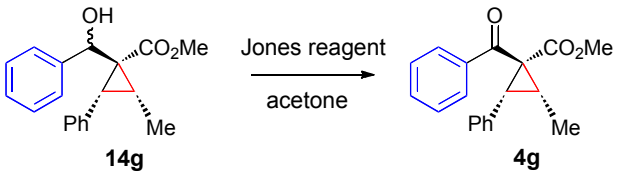
Preparation of racemic D–A cyclopropanes 4f.



Jones reagent (2.5 M) was added to a solution (0.2 ml) of a cyclopropanecarbinol **14f** (147 mg, 0.5 mmol) in acetone (2 ml) at 0˚C, followed by being stirred at the same temperature for 15 min. Then, 2-propanol (0.2 mol) was added dropwise to the mixture at the same tempereature, followed by being stirred at room temperature for 30 min. 1M-NaOH aqueous solution was added to the reaction to ajust neutral condition and evaporate the acetone and 2-propanol. Then, the mixture was extracted with diethylether (3ml x 3). The organic phase was washed with 1N-HCl aueous solution, water, brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 8/1) to give the product **4f** (128 mg, 87% yield).

4f : colorless liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.15 (d, *J* = 6.4 Hz, 3H), 2.87 (dq, *J* = 7.9, 6.4 Hz, 1H), 3.22 (s, 3H), 3.34(d, *J* = 7.9 Hz, 1H), 7.20-7.29 (m, 5H), 7.44-7.49 (m, 2H), 7.53-7.59 (m, 1H), 7.90-7.94 (m, 2H) ; HRMS (APCI) calcd for $C_{19}H_{18}O_3$ $(M+H)^+$ 295.1329 , found 295.1335.

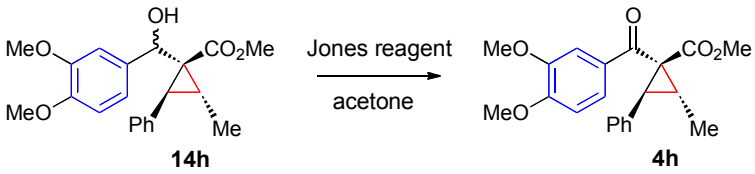
Preparation of *trans*-substrate 4g (racemic).



Following the procedure for the preparation of **4f**, oxidation of **14g** (147 mg, 0.5 mmol) afforded **4g** (123 mg, 84%).

4g : colorless solid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.61 (d, J = 6.7 Hz, 3H), 2.05 (dq, J = 9.7, 6.7 Hz, 3H), 3.41 (s, 3H), 3.47 (d, J = 9.8 Hz, 1H), 7.23-7.35 (m, 5H), 7.45-7.51 (m, 2H), 7.54-7.59 (m,1H), 7.91-7.97 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 10.4, 28.9, 34.2, 43.0, 52.2, 127.4, 128.6, 128.7, 129.1, 130.4, 133.2, 134.5, 137.5, 169.7, 195.4 ; HRMS (APCI) calcd for $C_{19}H_{18}O_3$ $(M+H)^+$ 295.1329 , found 295.1333.

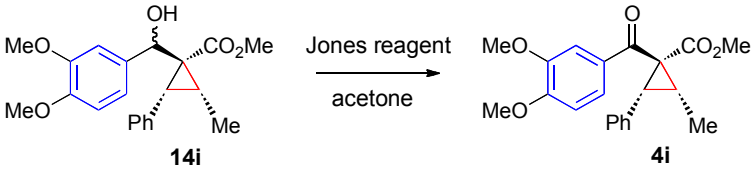
Preparation of *trans*-substrate 4h (racemic).



Following the procedure for the preparation of **4f**, oxidation of **14h** (177 mg, 0.5 mmol) afforded **4h** (154 mg, 87%).

4h : yellow solid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.13 (d, *J* = 6.4 Hz, 3H), 2.82 (dq, *J* = 6.4, 7.8 Hz, 1H), 3.25 (s, 3H), 3.29 (d, *J* = 7.8 Hz, 1H), 3.95 (s, 6H), 6.87-6.92 (m, 1H), 7.17-7.32 (m, 5H), 7.52-7.57(m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 13.2, 26.5, 36.5, 48.0, 52.6, 56.3, 56.4, 110.6, 110.9, 123.4, 127.4, 128.4, 128.5, 129.2, 131.2, 135.9, 149.5, 153.7, 169.6, 192.2 ; IR (KBr,neat) 3014, 2960, 2933, 1737, 1666, 1597, 1514, 1419, 1026, 700 cm^{-1} ; HRMS (APCI) calcd for $C_{21}H_{22}O_5$ $(M+H)^+$ 355.1545 , found 355.1546.

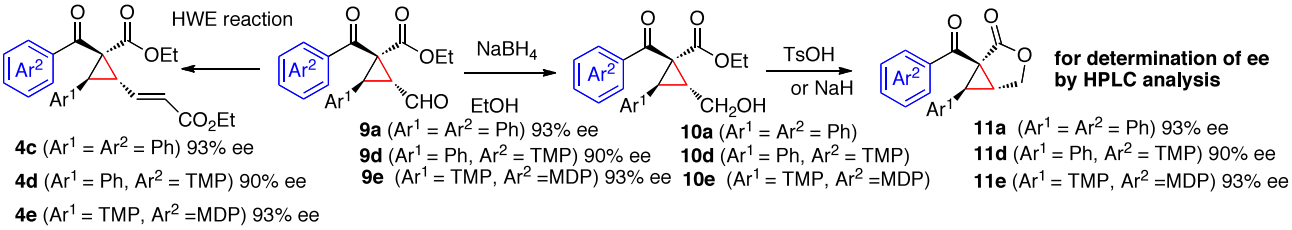
Preparation of *trans*-substrate 4i (racemic).



Following the procedure for the preparation of **4f**, oxidation of **14i** (177 mg, 0.5 mmol) afforded **4i** (163 mg, 92%).

4i : colorless solid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.60 (d, *J* = 6.7 Hz, 3H), 2.00 (dq, *J* = 9.7. 6.7 Hz, 1H), 3.41 (d, *J* = 9.7 Hz, 1H), 3.46 (s, 3H), 3.95 (s, 3H), 3.96 (s, 3H), 6.91 (d, *J* = 8.4 Hz, 1H), 7.22-7.34 (m, 5H), 7.54 (d, *J* = 2.0 Hz, 1H), 7.59 (dd, *J* = 8.4, 2.0 Hz, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 10.3, 28.1, 33.8, 42.6, 52.3, 56.4, 56.5, 110.6, 111.1, 123.2, 127.4, 128.6, 130.1, 130.3, 134.6, 149.5, 153.5, 169.9, 193.6 ; HRMS (APCI) calcd for $C_{21}H_{22}O_5$ $(M+H)^+$ 355.1545 , found 355.1544.

Determination of ee values of substrates 11 derived from aldehydes 9: HPLC analysis of ee of bicyclic lactone 11 derived from 9 using chiral columns.

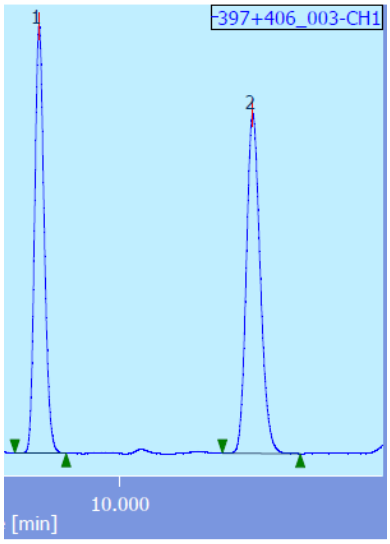


The alcohol **10a** (455 mg, 1.40 mol) was resolved in $CHCl_3$ (14 mL), then *p*-TsOH·H_2O (15.7 mg, 70 μmol) was added to the solution, followed by being stirred at 45˚C for 20 h. Then, the reaction was quenched with sat. $NaHCO_3$ aqueous solution. Water was added to the mixture, which was extracted with $CHCl_3$. The organic phase was washed with brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 4/1) to give the product **11a** (335 mg, 86%, 93% ee). The ee was observed by HPLC analysis of **11** with chiral column (Daicel CHIRALPAK IC).

11a : colorless solid ; mp = 101~103˚C ; $[\alpha]_D^{29}$= -11.3 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 3.04 (d, J = 5.1 Hz, 1H), 3.45 (t, J = 5.1 Hz, 1H), 4.46 (d, J = 9.4 Hz, 1H), 4.59 (dd, J = 9.4, 5.1 Hz, 1H), 7.06-7.19 (m, 5H), 7.31-7.38 (m, 2H), 7.44-7.50 (m, 1H), 7.84-7.89 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 26.6, 38.6, 45.0, 68.4, 128.0, 128.4, 128.5, 128.9, 130.5, 132.3,

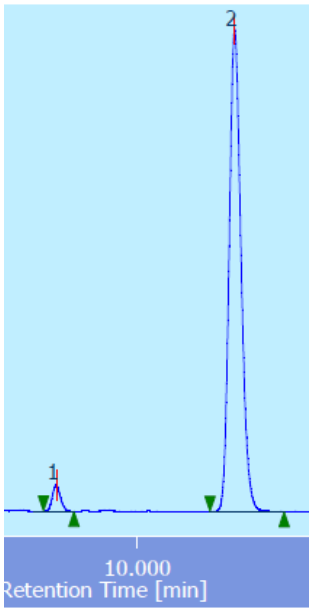
134.2, 135.9, 171.6, 190.2 ; IR (KBr,neat) 3062, 2974, 2908, 1762, 1668, 1450, 1033, 765, 694 cm^{-1} ; HRMS (APCI) calcd for $C_{18}H_{14}O_3$ $(M+H)^+$ 279.1021 , found 279.1024.

93% ee : HPLC analysis [Daicel CHIRALPAK IC (25cm) at 25˚C, flow rate 0.8 ml/min, solvent: hexane / ethanol = 2/1, t_R(racemic) = 8.57 min and 12.32 min, t_R(**11a)** = 8.39 min for minor and 11.90 min for major].



Pseudo-racemic-**11a** [46.4:53.5 mixture was prepared by mixing (-)-**11a** with (+)-**11a**] : HPLC analysis using chiral column

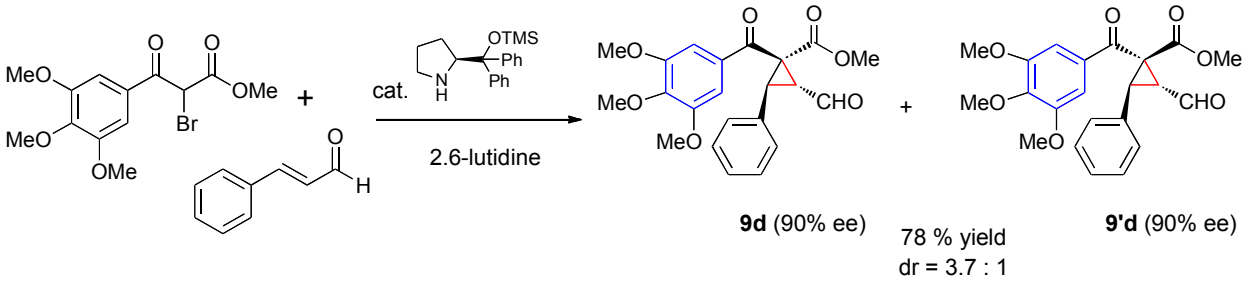
1	Unknown	1	8.575	13379992	1140897	46.433
2	Unknown	1	12.325	15435594	909169	53.567



Enantioenriched **11a (**93% ee): HPLC analysis using chiral column.

1	Unknown	1	8.392	567769	51244	3.611
2	Unknown	1	11.908	15157536	937661	96.389

Asymmetric cyclopropanation to afford a mixture of 9d and 9'd.

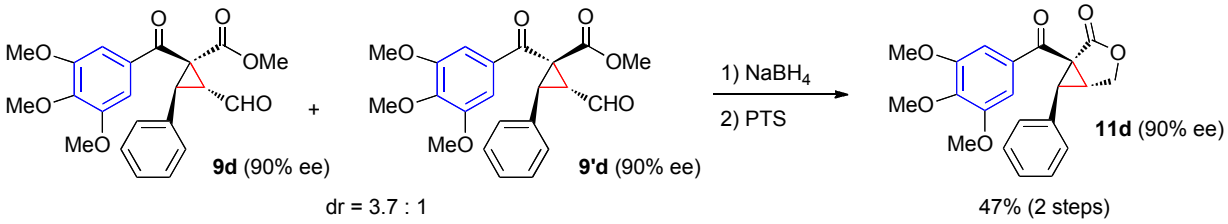


Following the procedure for the synthesis of **9a**, the cyclopropanation using a Metyl α-bromobenzoylacetate delivative instead of Ethy α-bromobenzoylacetate gave a mixture of **9d** and **9'd** (78%, dr = 3.7:1, 90% ee). Based on the similar HPLC analysis of lactone **11d** (page S15-16) derived from **9d**, the ee was estimated as 90% ee. The ee of minor product **9'd** was tentatively determined as the same ee value of **9d**. This was deductively proved after HPLC analysis of **6d** (page S26–27, 90% ee) derived from a 3.7:1 mixture of **9d** and **9'd**. (See the overview in page S4.)

9d and **9'd** : yellow liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 3.65 (dd, J = 7.6, 4.7 Hz, 1H), 3.66 (s, 3H), 3.83 (s, 6H), 3.86 (s, 3H), 4.08 (d, J = 7.6 Hz, 1H), 7.01 (s, 2H), 7.12-7.22 (m, 5H), 9.56 (d, J = 4.7 Hz, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 37.0, 37.8, 50.1, 53.7, 56.5, 61.2, 106.3, 127.9, 128.4, 129.0, 131.2, 143.1, 153.2, 168.3, 188.1, 196.6 ; IR (NaCl,neat) 3007, 2839, 1747, 1668, 1573, 1002 cm^{-1} ; HRMS (APCI) calcd for $C_{22}H_{22}O_7$ $(M-H)^-$ 397.1282 , found 397.1279.

Selected data for **9'd ;** ^{1}H NMR (400MHz,$CDCl_3$) δ 3.68 (dd, J = 7.2, 5.7 Hz, 1H), 3.88 (s, 3H), 3.91 (s, 6H), 3.93 (s, 3H), 4.03 (d, J = 7.2 Hz, 1H), 7.21 (s, 2H), 9.11 (d, J = 5.7 Hz, 1H).

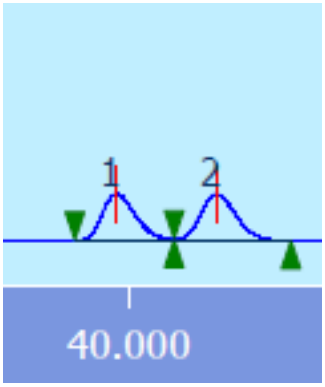
Preparation of 11d and HPLC analysis of 11d



Following the procedure for the preparation of **11a**, the reaction of **9d** and **9d'** (179 mg, 0.45 mmol) with $NaBH_4$ (4.3 mg, 0.11 mmol) gave the crude solid. Then, the reaction of the crude solid with *p*-TsOH·H_2O (7.7 mg, 0.045 mmol) in $CHCl_3$ (4.5 ml) gave the product **11d** (78 mg, 47%).

11d : ^{1}H NMR (400MHz,$CDCl_3$) δ 3.00 (d, J = 5.2 Hz, 1H), 3.42 (t, J = 4.9 Hz, 1H), 3.84 (s, 6H), 3.87 (s, 3H), 4.47 (d, J = 9.4 Hz, 1H), 4.61 (dd, J = 9.4, 4.9 Hz, 1H), 7.03-7.07 (m, 2H), 7.13-7.21 (m, 5H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 26.7, 38.4, 44.9, 56.6, 61.2, 68.5, 108.2, 127.7, 128.4, 129.0, 130.9, 132.5, 143.6, 152.9, 171.6, 188.7 ; IR (KBr,neat) 2941, 1766, 1664, 1585, 1504, 1458, 1234, 1126 cm^{-1} ; HRMS (APCI) calcd for $C_{18}H_{14}O_3$ $(M+H)^+$ 369.1338 , found 369.1340.

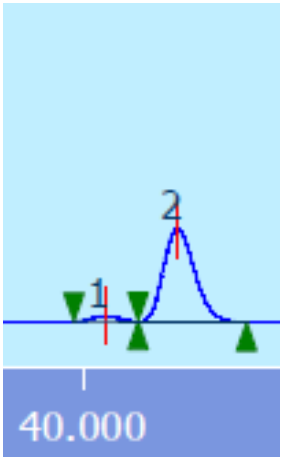
90% ee : HPLC analysis [Daicel CHIRALPAK IC (25cm) at 25˚C, flow rate 0.5 ml/min, solvent: hexane / ethanol = 3/1, t_R(racemic) = 39.64 min and 42.33 min, t_R(**11d**) = 40.71 min for minor and 43.12 min for major].



Pseudo-racemic-**11d** [48.4:51.5 mixture was prepared by mixing (-)-**11d** with (+)-**11d**]

HPLC analysis using chiral column

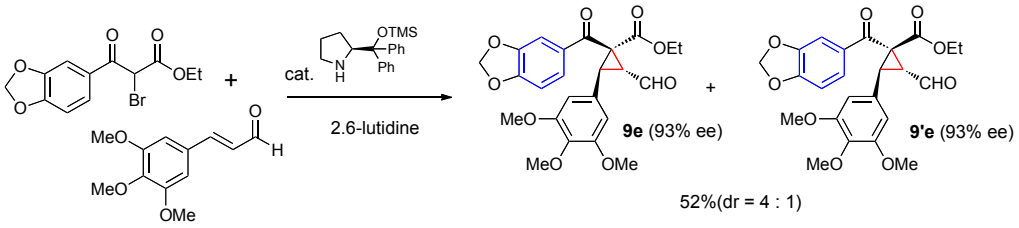
1	Unknown	1	39.642	3364502	54129	48.421
2	Unknown	1	42.333	3583879	53801	51.579



Enantioenriched **11d** (90% ee): HPLC analysis using chiral column.

1	Unknown	1	40.717	457791	7373	5.086
2	Unknown	1	43.125	8543251	118524	94.914

Preparation of a 4:1 mixture of 9e and 9'e.

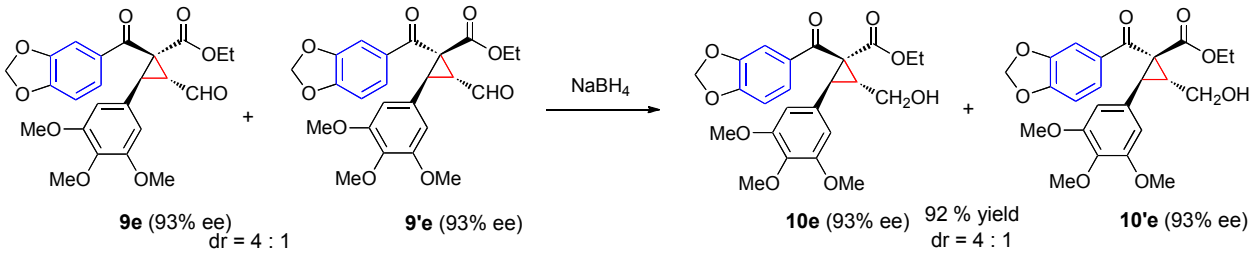


Following the procedure for the synthesis of **9a**, the cyclopropanation using a *trans*-3-(3'4'5'-trimethoxyphenyl)-2-propenal instead of cinnamaldehyde gave a mixture of **9e** and **9'e** (52%, dr = 4:1, 93% ee). As described in page S18-S19, based on the HPLC analysis of lactone **11e** derived from **9e** using a chiral column, the ee of **9e** was estimated as 93% ee. The ee of minor product **9'e** was tentatively determined as the same ee value of **9e**. This was deductively proved after HPLC analysis of **6e** (page S27–28, 93% ee) derived from a 4:1 mixture of **4e** and **4'e**. (See the overview in page S4.)

9e and **9'e** : yellow liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.04 (t, J = 7.3 Hz, 3H), 3.53 (dd, J = 7.5, 5.2 Hz, 1H), 3.73 (s, 3H), 3.74 (s, 6H), 4.15 (q, J = 7.3 Hz, 2H), 6.00 (dd, J = 4.4, 1.3 Hz, 1H), 6.31 (s, 2H), 6.72 (d, J = 8.2 Hz, 1H), 7.23 (d, J = 1.8 Hz, 1H), 7.37 (dd, J = 8.2, 1.8 Hz, 1H), 9.48 (d, J = 5.2 Hz, 1H) ; HRMS (APCI) calcd for $C_{24}H_{24}O_9$ $(M-H)^-$ 455.1342 , found 455.1349.

Selected data for **9'e** : ^{1}H NMR (400MHz,$CDCl_3$) δ 0.84 (t, J = 7.1 Hz, 3H), 3.61 (dd, J = 7.0, 5.7 Hz, 1H), 3.82 (s, 3H), 3.86 (s, 6H), 6.06 (dd, J = 2.6, 1.3 Hz, 1H), 6.52 (s, 2H), 6.85 (d, J = 8.2 Hz, 1H), 7.42 (d, J = 1.8 Hz, 1H), 7.52 (dd, J = 8.2, 1.8 Hz, 1H), 9.05 (d, J = 5.7 Hz, 1H).

Preparation of a 4:1 mixture of 10e and 10'e.



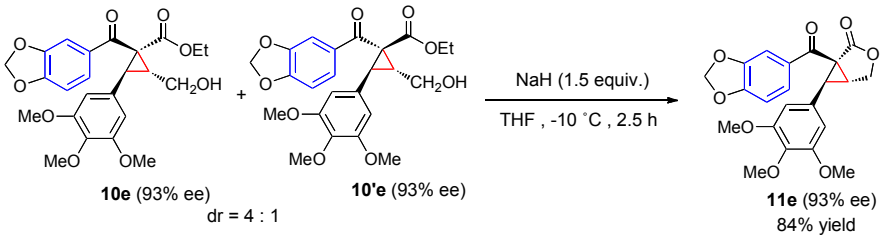
Following the procedure for the synthesis of **10a and 10'a**, the reaction of **9e** and **9'e** with $NaBH_4$ gave a mixture of **10e** and **10'e** (92%, dr = 4:1, 93% ee).

10e and 10'e : ^{1}H NMR (400MHz,$CDCl_3$) δ 1.02 (t, J = 7.0 Hz, 3H), 3.00-3.05 (m, 1H), 3.38 (d, J = 8.0 Hz, 1H), 3.71 (s, 3H), 3.74 (s, 6H), 5.98 (dd, J = 4.2, 1.3 Hz, 1H), 6.30 (s, 2H), 6.69 (d, J = 8.2 Hz, 1H), 7.21 (d, J = 1.8 Hz, 1H), 7.33 (dd, J = 8.2, 1.8 Hz, 1H).

Selected data for **10'e** : ^{1}H NMR (400MHz,$CDCl_3$) δ 0.79 (t, J = 7.0 Hz, 3H), 3.05-3.10 (m, 1H)3.32 (d, J = 7.9 Hz, 1H), 3.81 (s, 3H), 3.85 (s, 6H), 6.06 (dd, J = 3.2, 1.3 Hz, 1H), 6.52 (s, 2H), 6.86 (d, J = 8.3 Hz, 1H), 7.47 (d, J = 1.6 Hz, 1H), 7.61 (dd, J = 8.3, 1.6 Hz, 1H).

As described in page S18-S19, based on the HPLC analysis of lactone **11e** derived from **9e** via **10e**, the ee of **10e** was estimated as 93% ee. The ee of minor product **9'e** was tentatively determined as the same ee value of **9e**. This was deductively proved after HPLC analysis of **6e** (page S27–28, 93% ee) derived from a 4:1 mixture of **9e** and **9'e**. (See the overview in page S4.)

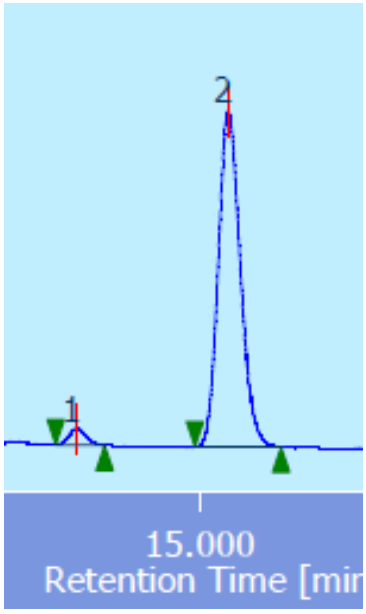
Preparation of 11e and HPLC analysis of 11e



A THF solution (1.0 ml) of a mixture of **10e** and **10'e** (192 mg, 0.42 mmol) was dropwise added to a suspension of NaH (15 mg, 0.63 mmol) in THF (1.0 ml) at -10°C, followed by being stirred at the same temperature for 2.5 h. 1N-HCl aqueous solution was added to the reaction mixture and extracted with AcOEt. The organic phase was washed with brine, dried (Na_2SO_4), and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 2/1) to give the product **11e** (145 mg, 84%,93% ee).

11e : ^{1}H NMR (400MHz,$CDCl_3$) δ 2.89 (d, J = 5.2 Hz, 1H), 3.33 (t, J = 4.9 Hz, 1H), 3.73 (s, 3H), 3.74 (s, 6H), 4.45 (d, J = 9.4 Hz, 1H), 4.58 (dd, J = 9.4, 4.9 Hz, 1H), 6.00 (s, 2H), 6.25 (s, 2H), 6.79 (d, J = 8.2 Hz, 1H), 7.34 (d, J = 1.7 Hz, 1H), 7.60 (dd, J = 8.2, 1.7 Hz, 1H) ; IR (KBr,neat) 2939, 1768, 1668, 1589, 1261, 1128 cm^{-1} ; HRMS (APCI) calcd for $C_{22}H_{20}O_8$ $(M+H)^+$ 413.1231 , found 413.1250.

93% ee : HPLC analysis [Daicel CHIRALPAK IC (25cm) at 25°C, flow rate 0.8 ml/min, solvent: hexane / ethanol = 1/1, t_R(**11e**) = 12.55 min for minor and 15.55 min for major].

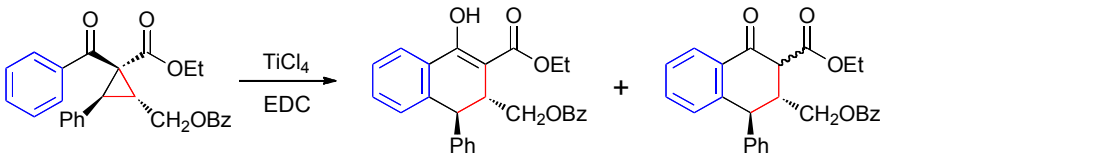


Enantioenriched **11e (**93% ee): HPLC analysis using chiral column.

1	Unknown	1	12.558	44736	1884	3.687
2	Unknown	1	15.550	116852	38603	96.313

The $TiCl_4$-mediated ring-opening cyclization of D–A cyclopropane 4 to furnish an enol-keto mixture of 5 and 5'

Table 2, entry 1, formal homo-Nazalov cyclization.



4a (93% ee) **5a** (93% ee) **5'a** (93% ee) (**5a** : **5'a** = 18 : 1)

Following the procedure for the preparation of **2** and **2'**, the reaction of cyclopropane **4a** (86 mg, 0.20 mmol) with $TiCl_4$ (33 μl, 0.30 mmol) gave a 18:1 enol-keto mixture of **5a** and **5'a** (26 mg, 31%, 93% ee).

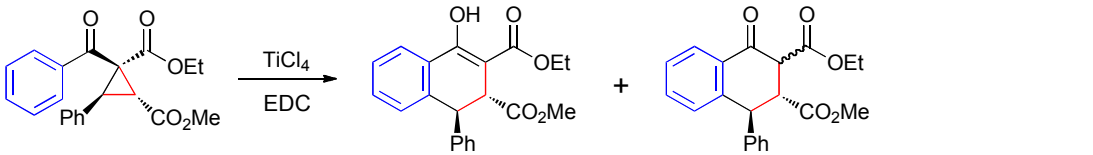
Because the absolute configuration of β-position never changed during the ring-opening cyclization, we specurate the ee value of a 18:1 moxture of **5a** and **5'a** as 93% ee on the basis of ee value of **4a**.

5a and **5'a**: colorless solid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.24 (t, J = 7.1 Hz, 3H), 3.53 (ddd, J = 7.8, 4.6, 1.0 Hz, 1H), 4.15 (dq, J = 7.1, 10.9 Hz, 1H), 4.19-4.26 (m, 2H), 4.35 (brs, 1H), 4.40 (dd, J = 10.8, 4.6 Hz, 1H), 7.00-7.05 (m, 2H), 7.15-7.26 (m, 4H), 7.37-7.42 (m, 4H), 7.52-7.57 (m, 1H), 7.81-7.85 (m, 2H), 7.94-7.98 (m, 1H), 12.78 (brs, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.5, 40.1, 45.8, 61.3, 67.0, 94.5, 125.2, 127.0, 127.9, 128.0, 128.7, 128.9, 129.6, 129.9, 130.1, 130.5, 132.1,

133.3, 139.2, 143.9, 166.8, 172.8 ; HRMS (APCI) calcd for $C_{27}H_{24}O_5$ $(M+H)^-$ 428.1623 , found 428.1626.

Selected data for **5'a** : ^{1}H NMR (400MHz,$CDCl_3$) δ 3.17-3.25 (m, 1H), 3.98 (d, J = 12.6 Hz, 1H), 6.80-6.84 (m, 1H), 8.02-8.06 (m, 2H), 8.09-8.13 (m, 1H).

Table 2, entry 2, formal homo-Nazalov cyclization.



4b (93% ee) **5b** (91% ee) **5'b** (91% ee) (**5b** : **5'b** = 8 : 1)

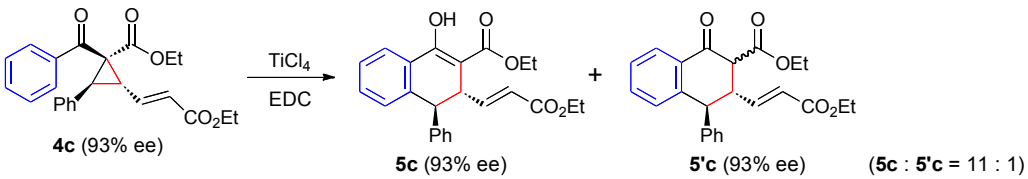
Following the procedure for the preparation of **2** and **2'**, the reaction of cyclopropane **4b** (70 mg, 0.20 mmol) with $TiCl_4$ (33 μl, 0.30 mmol) gave a 8:1 enol-keto mixture of **5b** and **5'b** (62 mg, 89%, 91% ee).

Loss of 2% ee was observed by HPLC analysis of trifrate **6b** (page S24-25, 91% ee) derived from a 8:1 mixture of **5b** and **5'b**. Thus, ee of a 8:1 mixture of **5b** and **5'b** is determined as 91% ee. (See the overview in page S4.)

5b and **5'b**: yellow liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.23 (t, J = 7.1 Hz, 3H), 3.62 (s, 3H), 3.97 (d, J = 2.0 Hz, 1H), 4.10 (dq, J = 10.7, 7.1 Hz, 1H), 4.29 (dq, J = 10.7, 7.1 Hz, 1H), 4.67 (d, J = 2.0 Hz, 1H), 7.01-7.05 (m, 2H), 7.12-7.25 (m, 4H), 7.35-7.39 (m, 2H), 7.92-7.98 (m, 1H), 12.70 (brs, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.5, 46.1, 46.5, 52.7, 61.1, 93.8, 125.2, 127.2, 127.9, 128.0, 128.9, 129.4, 129.6, 131.9, 138.8, 143.0, 166.3, 173.9 ; IR (NaCl,neat) 3062, 2983, 2953, 1732, 1645, 1573, 1273, 1215, 1087, 833, cm^{-1} ; HRMS (APCI) calcd for $C_{21}H_{20}O_5$ $(M+H)^+$ 353.1384 , found 353.1387.

Selected data for **5'b** : ^{1}H NMR (400MHz,$CDCl_3$) δ 1.29 (t, J = 7.1 Hz, 3H), 3.39 (s, 3H), 3.76 (dd, J = 12.4, 10.8 Hz, 1H), 4.48 (d, J = 10.8 Hz, 1H), 6.83-6.87 (m, 1H), 8.08-8.11 (m, 1H).

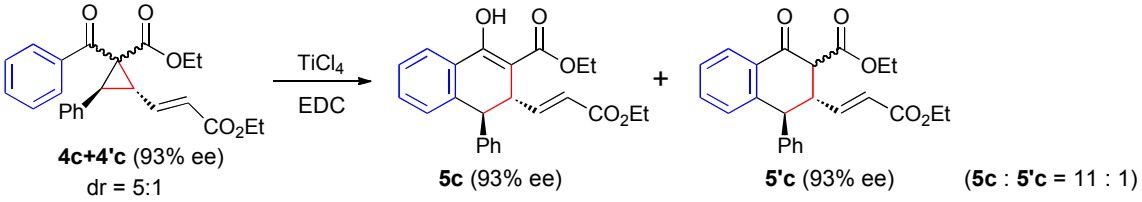
Table 2, entry 3, formal homo-Nazalov cyclization.



4c (93% ee) **5c** (93% ee) **5'c** (93% ee) (**5c** : **5'c** = 11 : 1)

i) Following the procedure for the preparation of **2** and **2'**, the reaction of cyclopropane **4c** (78 mg, 0.20 mmol) with $TiCl_4$ (33 μl, 0.30 mmol) gave a 11:1 enol-keto mixture of **5c** and **5'c** (70 mg, 89%). For spectral data of **5c** and **5'c**, see the experimental procedure for entry 4 in next page.

Table 2, entry 4, formal homo-Nazalov cyclization.



4c+4'c (93% ee)
dr = 5:1

5c (93% ee) **5'c** (93% ee) (**5c** : **5'c** = 11 : 1)

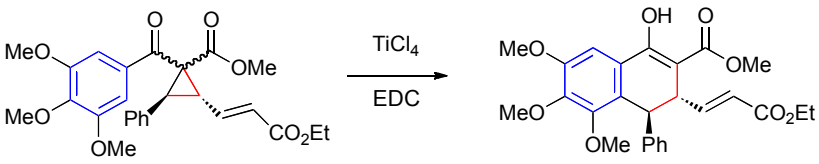
ii) Following the procedure i), the same reaction of cyclopropane **4c** and **4'c** (78 mg, 0.20 mmol, dr = 5:1) with $TiCl_4$ (33 µl, 0.30 mmol) gave a 11:1 enol-keto mixture of **5c** and **5'c** (66 mg, 85%, 93% ee).

As described in the overview in page S4, based on the HPLC analysis of **7b** (S30-32) derived from a mixture of **5c** and **5'c** via **6c**, the ee of a mixture of **5c and 5'c** was estimated as 93% ee.

5c and **5'c**: yellow liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.24 (t, J = 7.1 Hz, 3H), 1.25 (t, J = 7.1 Hz, 3H), 3.81 (dt, J = 7.8, 1.3 Hz, 1H), 4.16 (brs, 1H), 4.08-4.18 (m, 4H), 5.84 (dd, J = 15.5, 1.3 Hz, 1H), 6.88 (dd, J = 15.5, 1.3 Hz, 1H), 6.97-7.01 (m, 2H), 7.14-7.24 (m, 4H), 7.37-7.42 (m, 2H), 7.93-7.98 (m, 1H), 12.68 (brs, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.5, 14.6, 43.0, 48.0, 60.8, 61.2, 95.3, 121.3, 125.3, 127.1, 127.9, 128.1, 128.9, 129.6, 130.0, 132.1, 138.6, 143.1, 149.0, 166.1, 167.1, 172.5 ; IR (NaCl,neat) 3061, 2981, 2938, 1714, 1651, 1570, 1273, 1219, 1085, 1029, 835, 700 cm^{-1} ; HRMS (APCI) calcd for $C_{24}H_{24}O_5$ $(M+H)^+$ 393.1697 , found 393.1702.

Selected data for **5'c** : ^{1}H NMR (400MHz,$CDCl_3$) δ 4.21-4.30 (m, 4H), 5.60 (dd, J = 15.8, 0.7 Hz, 1H), 6.68 (dd, J = 15.8, 9.0 Hz, 1H).

Table 2, entry 5, formal homo-Nazalov cyclization.



4d+4'd (dr = 3.7/1)
(90% ee)

5d (90% ee)

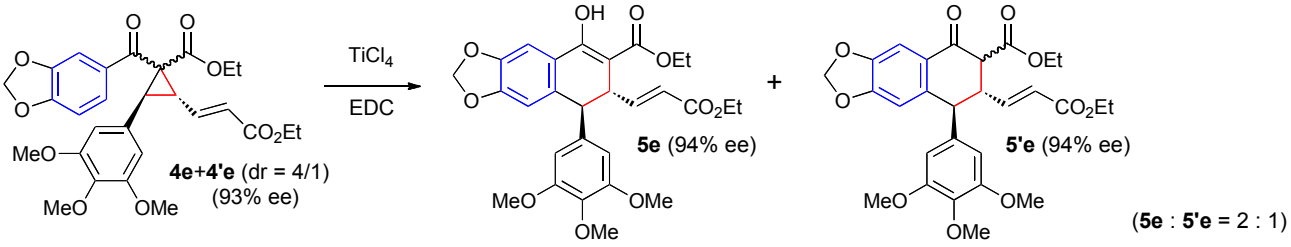
Following the procedure for the preparation of **2** and **2'**, the reaction of cyclopropane **4d** and **4'd** (96 mg, 0.20 mmol, dr = 3.7:1) with $TiCl_4$ (33 µl, 0.30 mmol) gave the product **5d** (49 mg, 51%, 90% ee).

5d: amorphous ; $[\alpha]_D^{21}$= 305.9 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.26 (t, J = 7.2 Hz, 3H), 3.46 (s, 3H), 3.73 (dt, J = 7.6, 1.2 Hz, 1H), 3.90 (s, 3H), 3.95 (s, 3H), 4.14 (q, J = 7.2 Hz, 1H), 4.15 (q, J = 7.2 Hz, 1H), 4.46 (brs, 1H), 5.82 (dd, J = 15.5, 1.2 Hz, 1H), 6.88 (dd, J = 15.5, 7.6 Hz, 1H), 7.00-7.04 (m, 2H), 7.14-7.25 (m, 3H), 7.31 (s, 1H), 12.70 (brs, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.6, 41.5, 42.9, 52.2, 56.4, 60.7, 61.1, 61.2, 94.7, 104.2, 121.0, 124.8, 125.9,

127.0, 128.0, 128.8, 143.1, 145.8, 149.5, 151.5, 153.2, 166.0, 167.2, 173.0 ; IR (KBr,neat) 2939, 1718, 1647, 1568, 1492, 1251, 1114 cm^{-1} ; HRMS (APCI) calcd for $C_{26}H_{28}O_8$ $(M+H)^+$ 469.1857 , found 489.1852.

As described in the overview in page S4, based on the HPLC analysis of trifrate **6d** (S26-27) derived from **5d**, the ee of a mixture of **5d** was estimated as 90% ee.

Table 2, entry 6, formal homo-Nazalov cyclization.



Following the procedure for the preparation of **2** and **2'**, the reaction of cyclopropane **4e** and **4'e** (105 mg, 0.20 mmol, dr = 4:1) with $TiCl_4$ (33 µl, 0.30 mmol) gave a 2 :1 enol-keto mixture of **5e** and **5'e** (48 mg, 46%, 94% ee).

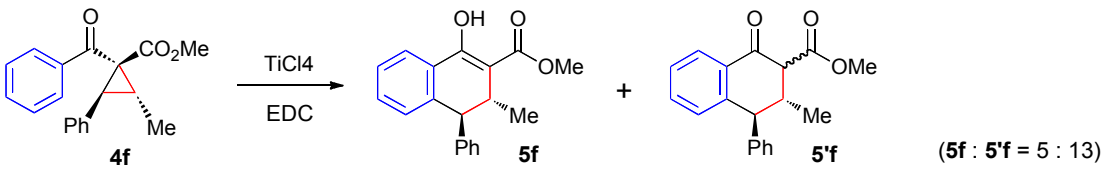
As described in the overview in page S4, based on the HPLC analysis of trifrate **6e** (S27-28, 94% ee: Increase of 1% ee is a error range.) derived from a enol/keto-mixture of **5e** and **5'e**, the ee of a mixture of **5e** and **5'e** was estimated as 93% ee.

5e and **5'e**: amorphous ; HRMS (APCI) calcd for $C_{28}H_{30}O_{10}$ $(M+H)^+$ 527.1912 , found 527.1923

Selected data for **5e** : ^1H NMR (400MHz,$CDCl_3$) δ 1.25 (t, J = 7.2 Hz, 3H), 1.26 (t, J = 7.2 Hz, 3H), 3.74 (s, 6H), 3.81 (s, 3H), 3.96 (brs, 1H), 4.08-4.17 (m, 3H), 4.24 (q, J = 7.2 Hz, 1H), 5.84 (dd, J = 15.5, 1.2 Hz, 1H), 6.03 (dd, J = 4.0, 1.2 Hz, 2H), 6.22 (s, 2H), 6.62 (s, 1H), 6.87 (dd, J = 15.6, 7.6 Hz, 1H), 7.39 (s, 1H), 12.76 (brs, 1H).

Selected data for **5'e** : ^1H NMR (400MHz,$CDCl_3$) δ 3.81 (s, 6H), 3.86 (s, 3H), 5.64 (dd, J = 15.6, 0.6 Hz, 1H), 6.00 (dd, J = 5.6, 1.3 Hz, 2H), 6.68 (dd, J = 15.6, 8.9 Hz, 1H), 7.50 (s, 1H).

Table 2, entry 7, formal homo-Nazalov cyclization.



i) Following the procedure for the preparation of **2** and **2'**, the reaction of cyclopropane **4f** (59 mg, 0.20 mmol) with $TiCl_4$ (33 µl, 0.30 mmol) gave a 5:13 enol-keto mixture of **5f** and **5'f** (46 mg, 78%).

Relative structure of **5f** is determined as trans based on the analogy with **5h**.

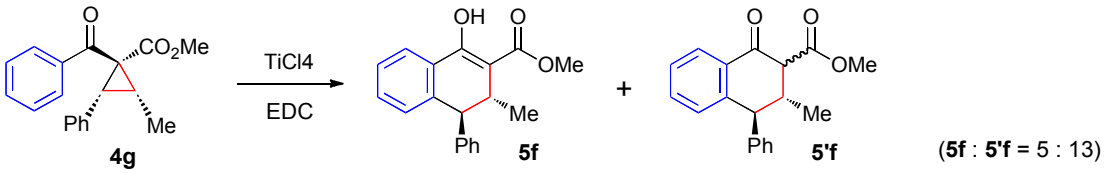
5f and **5'f**: yellow liquid ; IR (NaCl,neat) 2954, 1747, 1681, 1651, 1494, 1454, 1080, 1002, 771, 700 cm^{-1} ; HRMS (APCI) calcd for $C_{19}H_{18}O_3$ $(M+H)^+$ 295.1329 , found 295.1336.

Selected data for **5f** : ^1H NMR (400MHz,$CDCl_3$) δ 1.17 (d, J = 6.8 Hz, 3H), 3.15 (dq, J = 6.8, 1.2 Hz, 1H), 3.74 (s, 3H), 3.95 (brs, 1H), 6.94-6.98 (m, 2H), 7.14-7.22 (m, 4H), 7.36-7.39 (m, 2H), 7.91-7.95 (m, 1H), 12.42 (brs, 1H).

Selected data for **5'f** (major) : ^1H NMR (400MHz,$CDCl_3$) δ 0.91 (d, J = 6.4 Hz, 3H), 2.83-2.91 (m, 1H), 3.51 (d, J = 12.6 Hz, 1H), 3.83 (s, 3H), 3.85 (d, J = 11.8 Hz, 1H).

Selected data for **5'f** (minor) : ^1H NMR (400MHz,$CDCl_3$) δ 1.09 (d, J = 6.8 Hz, 3H), 2.70-2.77 (m, 1H), 3.72 (s, 3H), 3.78 (d, J = 4.5 Hz, 1H).

Table 2, entry 8, formal homo-Nazalov cyclization.

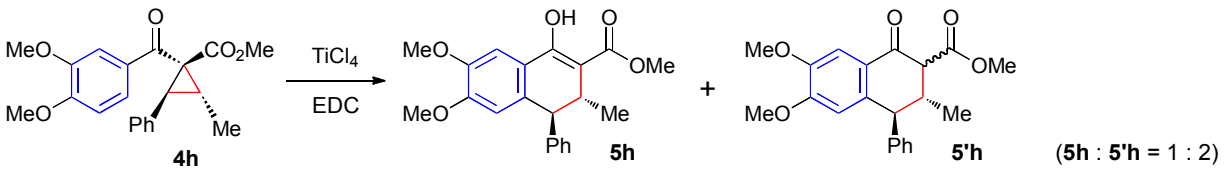


ii) Following the procedure i), the same reaction of cyclopropane **4g** (59 mg, 0.20 mmol) with $TiCl_4$ (33 µl, 0.30 mmol) gave a 5:13 enol-keto mixture of **5f** and **5'f** (51 mg, 87%).

On the basis of the full agreement of spectral data, the obtained mixture of **5f** and **5'f** is the same as those betained from the same reaction of *trans*-substrate **4f** (see, below).

Relative structure of **5f** is determined as trans based on the analogy with **5h**.

Table 2, entry 9, formal homo-Nazalov cyclization.



i) Following the procedure for the preparation of **2** and **2'**, the reaction of cyclopropane **4h** (71 mg, 0.20 mmol) with $TiCl_4$ (33 μl, 0.30 mmol) gave a 1:2 enol-keto mixture of **5h** and **5'h** (52 mg, 74%).

Relative structure of **5h** is determined as *trans* based on the NOESY observation of 6h derived from a enol-keto mixture of **5h** and **5'h**.

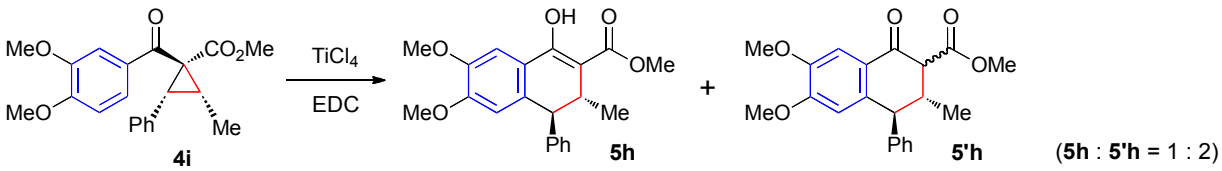
5h and **5'h**: yellow liquid ; IR (NaCl,neat) 2956, 1747, 1732, 1674, 1668, 1600, 1514, 1506, 1454, 1134, 732 cm^{-1} ; HRMS (APCI) calcd for $C_{21}H_{22}O_5$ $(M+H)^+$ 355.1540 , found 355.1550.

Selected data for **5h** :^{1}H NMR (400MHz,$CDCl_3$) δ 1.18 (d, J = 6.9 Hz, 3H), 3.09 (dq, J = 6.9, 1.2 Hz, 1H), 3.72 (s, 3H), 3.86 (s, 3H), 3.97 (s, 3H), 6.64 (s, 1H), 6.95-6.97 (m, 1H), 7.14-7.22 (m, 2H), 7.28-7.40 (m, 2H), 7.45 (s, 1H), 12.57 (brs, 1H).

Selected data for **5'h** (major) : ^{1}H NMR (400MHz,$CDCl_3$) δ 0.90 (d, J = 6.4 Hz, 3H), 2.78-2.89 (m, 1H), 3.45 (d, J = 12.5 Hz, 1H), 3.59 (s, 3H), 3.78 (d, J = 11.0 Hz, 1H), 3.81 (s, 3H), 3.91 (s, 3H), 6.13 (s, 1H), 6.95-6.97 (m, 1H), 7.14-7.22 (m, 2H), 7.28-7.40 (m, 2H), 7.54 (s, 1H).

Selected data for **5'h** (minor) : ^{1}H NMR (400MHz,$CDCl_3$) δ 1.08 (d, J = 6.8 Hz, 3H), 2.68-2.73 (m, 1H), 3.68 (s, 3H), 3.72 (s, 3H), 3.93 (s, 3H), 6.29 (s, 1H), 6.95-6.97 (m, 1H), 7.09-7.11 (m, 2H), 7.28-7.31 (m, 2H), 7.55 (s, 1H).

Table 2, entry 10, formal homo-Nazalov cyclization.



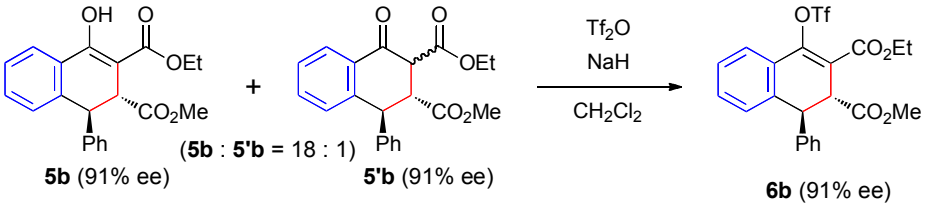
ii) Following the procedure i), the same reaction of cyclopropane **4i** (71 mg, 0.20 mmol) with $TiCl_4$ (33 μl, 0.30 mmol) gave a 1:2 enol-keto mixture of **5h** and **5'h** (57 mg, 80%).

The supectral data of the obtained enol-keto mixture is consistent with those obtained from the formal homo-Nazarov cyclization of **4h**.

Relative structure of **5h** is determined as *trans* based on the NOESY observation of triflate **6h** derived from a enol-keto mixture of **5h** and **5'h**. On the basis of the full agreement of spectral data, the obtained mixture of **5h** and **5'h** is the same products those betained from the same reaction of *trans*-substrate **4h**.

Trifration of enol-keto mixtures of 5 and 5' to furnish the corresponding trifrates 6

Table 2, entry 2, Trifration of a enol/keto-mixture of 5b and 5'b.

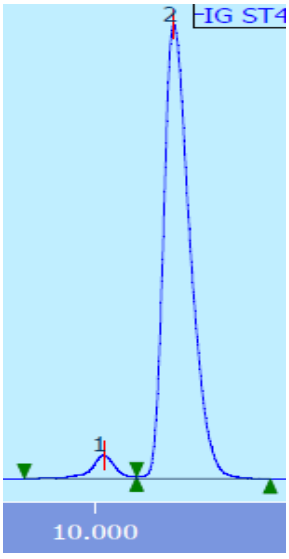


5b (91% ee) (**5b** : **5'b** = 18 : 1) **5'b** (91% ee) **6b** (91% ee)

Following the procedure for the preparation of **3**, the reaction of a enol-keto mixture of **5b** and **5'b** (62 mg, 0.176 mmol) with Tf_2O (57 µl, 0.352 mmol) in the presence of NaH (8.5 mg, 0.352 mmol) gave the trifrate **6b** (77 mg, 90%, 91% ee).

6b: yellow liquid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.33 (t, J = 7.2 Hz, 3H), 3.64 (s, 3H), 4.27 (dq, J = 10.7, 7.2 Hz, 1H), 4.34 (dq, J = 10.7, 7.2 Hz, 1H), 4.40 (d, J = 1.7 Hz, 1H), 4.80 (brs, 1H), 7.05-7.09 (m, 2H), 7.18-7.29 (m, 4H), 7.39-7.42 (m, 2H), 7.61-7.66 (m, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.2, 44.9, 48.9, 53.2, 62.6, 117.4, 124.4, 127.6, 127.7, 128.2, 128.4, 129.0, 129.9, 132.3, 138.2, 141.1, 149.4, 164.4, 171.4 ; IR (NaCl,neat) 3028, 2985, 2956, 1732, 1714, 1643, 1496, 1139, 1031, 813 cm^{-1} ; HRMS (APCI) calcd for $C_{22}H_{19}F_3O_7S$ $(M+H)^+$ 485.0876 , found 485.0887.

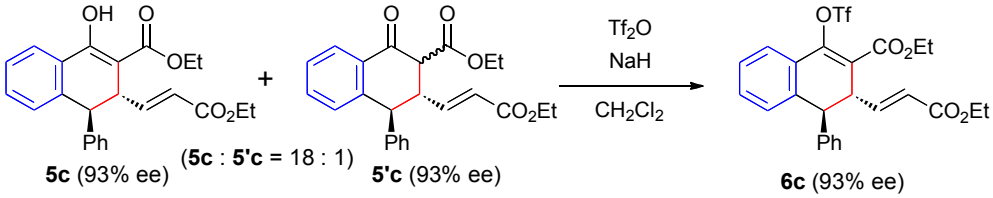
91% ee : HPLC analysis [Daicel CHIRALPAK IG (25cm) at 25˚C, flow rate 0.5 ml/min, solvent: hexane / CH_2Cl_2 = 3/1, t_R(**6b**) = 10.09 min for minor and 10.90 min for major].



Enantioenriched **6b** (91% ee): HPLC analysis using chiral column.

1	Unknown	1	10.092	588078	29996	4.587
2	Unknown	1	10.908	12233836	576944	95.413

Table 2, entries 3 and 4, Trifration of a enol/keto-mixture of 5c and 5'c.



5c (93% ee) (**5c** : **5'c** = 18 : 1) **5'c** (93% ee) **6c** (93% ee)

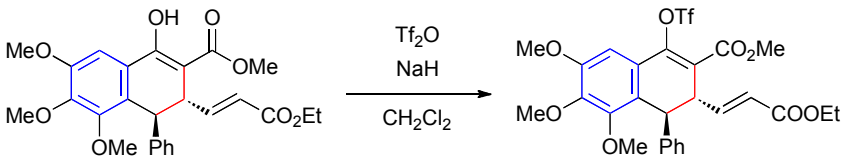
(Entry 3) Following the procedure for the preparation of **3**, the reaction of a 11:1 mixture of **5c** and **5'c** (70 mg, 0.178 mmol) with Tf_2O (58 µl, 0.356 mmol) in the presence of NaH (8.5 mg, 0.356 mmol) gave the trifrate **6c** (84 mg, 90%, 93% ee).

(Entry 4) Following the procedure for the preparation of **3**, the reaction of a 12:1 mixture of **5c** and **5'c** (70 mg, 0.178 mmol) with Tf_2O (58 µl, 0.356 mmol) in the presence of NaH (8.5 mg, 0.356 mmol) gave the trifrate **6c** (84 mg, 90%, 93% ee).

6c: yellow liquid ; $[\alpha]_D^{21}$= 344.0 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.24 (t, J = 7.1 Hz, 3H), 1.31 (t, J = 7.1 Hz, 3H), 4.12 (q, J = 7.1 Hz, 2H), 4.21 (brs, 1H), 4.23-4.33 (m, 3H), 5.91 (dd, J = 15.6, 1,3 Hz, 1H), 6.80 (dd, J = 15.6, 7.6 Hz, 1H), 7.03-7.06 (m, 2H), 7.17-7.28 (m, 4H), 7.38-7.47 (m, 2H), 7.62-7.66 (m, 2H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.2, 14.5, 45.0, 47.5, 61.0, 62.6, 119.4, 123.4, 124.5, 127.6, 128.2, 128.4, 129.0, 130.3, 132.4, 138.0, 141.3, 145.2, 149.4, 164.1, 166.4 ; IR (NaCl,neat) 2983, 1714, 1651, 1429, 1369, 1139, 1045, 1029, 812, 603 cm^{-1} ; HRMS (APCI) calcd for $C_{25}H_{23}F_3O_7S$ $(M+H)^+$ 525.1189 , found 525.1191.

As described in the overview in page S4, based on the HPLC analysis of **7b** (page S30-32) derived **6c**, the ee of a mixture of **6c and 6'c** was estimated as 93% ee.

Table 2, entry 5, Trifration of a 5d.



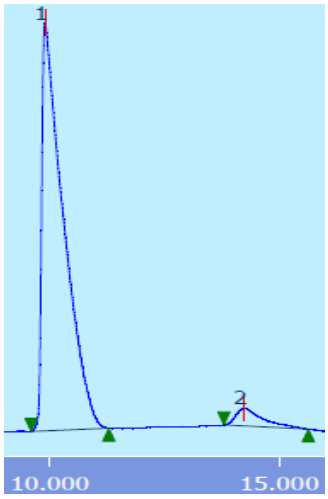
5d (90% ee) **6d** (90% ee)

Following the procedure for the preparation of **3**, the reaction of **5d** (49 mg, 0.100 mmol) with Tf_2O (33 µl, 0.2 mmol) in the presence of NaH (4.8 mg, 0.2 mmol) gave the trifrate **6d** (68 mg, 75%, 90% ee).

6d: yellow liquid ; $[\alpha]_D^{25}$= 295.4 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.25 (t, J = 7.1 Hz, 3H), 3.52 (s, 3H), 3.77 (s, 3H), 3.91 (s, 3H), 4.11-4.17 (m, 3H), 4.52 (brs, 1H), 5.90 (dd, J = 15.5, 1,3 Hz, 1H), 6.82 (dd, J = 15.5, 7.6 Hz, 1H), 7.06-7.09 (m, 2H), 7.18-7.25 (m, 3H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.5, 41.1, 45.9, 52.3, 56.3, 60.9, 61.2, 61.3, 103.9, 117.8, 123.1, 123.4, 125.3, 127.5, 127.8, 129.0, 141.4, 145.7, 146.0, 149.8, 151.8, 153.3, 164.1, 166.6 ;

IR (KBr,neat) 2981, 2943, 1724, 1651, 1492, 1348, 1033, 867, 700 cm^{-1} ; HRMS (APCI) $C_{27}H_{27}F_3O_{10}S$ $(M+H)^+$ 601.1350 , found 601.1351.

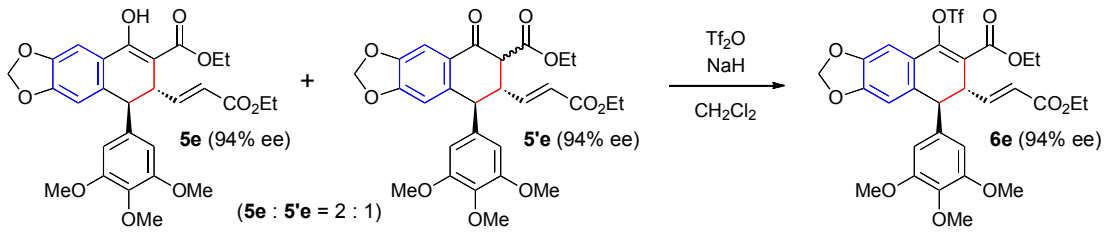
90% ee : HPLC analysis [Daicel CHIRALPAK IG (25cm) at 25°C, flow rate 0.5 ml/min, solvent: hexane / CH_2Cl_2 = 4/1, t_R(**6d**) = 9.89 min for major and 14.22 min for minor].



Enantioenriched **6d** (90% ee): HPLC analysis using chiral column.

1	Unknown	1	9.892	1224420	37329	94.789
2	Unknown	1	14.225	67308	1631	5.211

Table 2, entry 5, Trifration of a enol/keto-mixture of 5e and 5'e

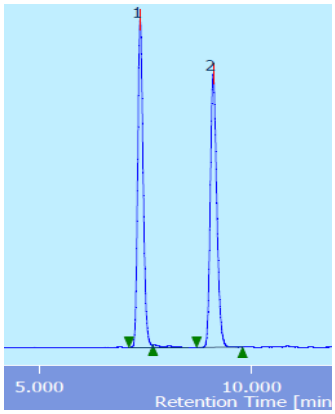


Following the procedure for the preparation of **3**, the reaction of a enol-keto mixture of **5e** and **5'e** (48 mg, 0.091 mmol) with Tf_2O (30 µl, 0.182 mmol) in the presence of NaH (4.4 mg, 0.182 mmol) gave the product **6e** (49 mg, 82%, 94% ee).

6e: yellow amorphous ; $[\alpha]_D^{25}$= 261.2 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.26 (t, J = 7.1 Hz, 3H), 1.32 (t, J = 7.1 Hz, 3H), 3.77 (s, 6H), 3.80 (s, 3H), 3.99 (brs, 1H), 4.12-4.19 (m, 3H), 4.24-4.34 (m, 2H), 5.90 (dd, J = 15.6, 1,3 Hz, 1H), 6.06 (dd, J = 4.2, 1.3 Hz, 1H), 6.31 (s, 2H), 6.70 (s, 1H), 6.81 (dd, J = 15.5, 7.6 Hz, 1H), 6.81 (s, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.2, 14.5, 45.3, 48.2, 56.4, 61.0, 61.1, 62.5, 102.5, 104.5, 104.8, 110.6, 117.2, 121.5,

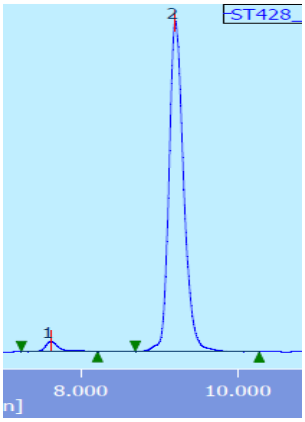
123.1, 133.9, 137.4, 137.8, 145.4, 148.1, 149.1, 151.1, 153.8, 164.1, 166.4 ; IR (KBr,neat) 2983, 1716, 1593, 1487, 1246, 1132, 1039 cm^{-1} ; HRMS (APCI) $C_{27}H_{27}F_3O_{10}S$ $(M+H)^+$ 659.1405 , found 659.1413.

94% ee : HPLC analysis [Daicel CHIRALPAK IC (25cm) at 25˚C, flow rate 0.5 ml/min, solvent: hexane / CH_2Cl_2 = 1/1, t_R(racemic) = 7.37 min and 9.09 min, t_R(**6e**) = 7.61 min for minor and 9.20 min for major].



Racemic-**6e**: HPLC analysis using chiral column

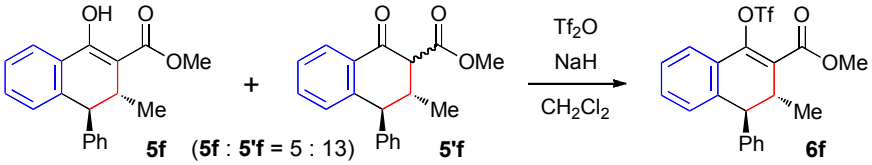
1	Unknown	1	7.375	4383740	492781	49.854
2	Unknown	1	9.092	4409418	411524	50.146



Enantioenriched **6e** (94% ee): HPLC analysis using chiral column.

1	Unknown	1	7.617	286153	22466	3.038
2	Unknown	1	9.200	9132627	699325	96.962

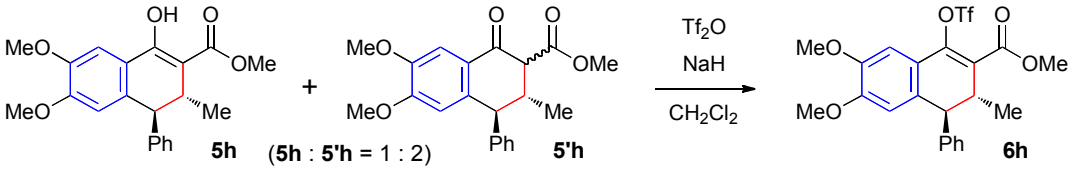
Table 2, entry 7, Trifration of a enol/keto-mixture of 5f and 5'f



Following the procedure for the preparation of **3**, the reaction of a enol-keto mixture of **5f** and **5'f** (59 mg, 0.172 mmol) with Tf_2O (56 µl, 0.346 mmol) in the presence of NaH (8.3 mg, 0.346 mmol) gave the product **6f** (50 mg, 68%). The relative structure of **6f** was determined by the analogy with the spectral data of **6h** (see, below.)

6f: colorless solid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.18 (t, J = 7.0 Hz, 3H), 3.50 (dq, J = 7.0, 1.6 Hz, 1H), 3.81 (s, 3H), 3.91 (brs, 1H), 7.00-7.04 (m, 2H), 7.14-7.28 (m, 4H), 7.36-7.44 (m, 2H), 7.60-7.64 (m, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 19.2, 38.6, 49.9, 52.7, 123.7, 124.1, 127.2, 127.7, 128.0, 128.1, 128.8, 130.6, 132.0, 138.6, 142.6, 148.2, 165.1 ; HRMS (APCI) calcd for $C_{20}H_{17}F_3O_5S$ $(M+H)^+$ 427.0822 , found 427.0826.

Table 2, entry 9, Trifration of a enol/keto-mixture of 5h and 5'h



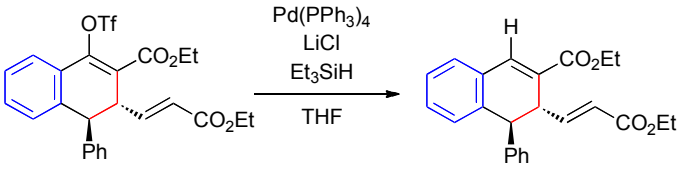
Following the procedure for the preparation of **3**, the reaction of a enol-keto mixture of **5h** and **5'h** (57 mg, 0.160 mmol) with Tf_2O (52 µl, 0.320 mmol) in the presence of NaH (7.7 mg, 0.320mmol) gave the product **6h** (60 mg, 77%).

The relative structure of **6h** was determined based on NOESY spectrum (see, page S74.)

6h: colorless solid ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.20 (t, J = 7.0 Hz, 3H), 3.43 (dq, J = 7.0, 1.3 Hz, 1H), 3.77 (s, 3H), 3.87 (s, 3H), 3.89 (brs, 1H), 3.93 (s, 3H), 6.72 (s, 1H), 6.99-7.02 (m, 2H), 7.14 (s, 1H), 7.16-7.24 (m, 3H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 19.3, 39.1, 49.9, 52.5, 56.3, 56.4, 107.0, 113.1, 120.6, 120.9, 127.2, 127.7, 128.9, 128.1, 132.3, 142.6, 148.6, 152.2, 165.1 ; IR (NaCl,neat) 2960, 1714, 1519, 1427, 1355, 1247, 1118, 991 cm^{-1} ; HRMS (APCI) calcd for $C_{22}H_{21}F_3O_7S$ 487.1033 , found 487.1040.

Pd-catalyzed hydrogenation of trifrates

(Scheme 5, A)



6c (93% ee) **7a** (93% ee)

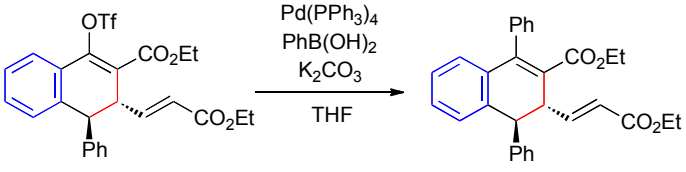
A THF solution (0.65 ml) of $Pd(PPh_3)_4$ (2.5 mg, 2.22 μmol) was added dropwise to a solution of trifrate **6c** (58 mg, 0.11 mmol) and LiCl (14 mg, 0.33 mmol) in THF (1.0 ml) at 0 ˚C under an Ar atmosphere. Then, Et_3SiH (26 μl, 0.167 mmol) was added to the mixture, and followed by being stirred at 66˚C for 22h. 1N-HCl aqueous solution was added to the reaction mixture at 0˚C, which was extracted with AcOEt. The organic phase was washed with brine, dried (Na_2SO_4) and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 8/1) to give the hydrated product **7a** (38 mg, 97%, 93% ee).

7a: yellow liquid ; $[\alpha]_D^{25}$= 211.5 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.24 (t, J = 7.1 Hz, 3H), 1.29 (t, J = 7.1 Hz, 3H), 3.93 (dt, J = 7.8, 1.2 Hz, 1H), 4.23 (brs, 1H), 4.09-4.33 (m, 4H), 5.90 (dd, J = 15.6, 1,2 Hz, 1H), 6.88 (dd, J = 15.6, 7.8 Hz, 1H), 7.03-7.06 (m, 2H), 7.17-7.28 (m, 4H), 7.38-7.47 (m, 2H), 7.69 (s, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.2, 14.5, 45.0, 47.5, 61.0, 62.6, 119.4, 123.4, 124.5, 127.6, 128.2, 128.4, 129.0, 130.3, 132.4, 138.0, 141.3, 145.2, 149.4, 164.1, 166.4 ; IR (NaCl,neat) 3061, 2981, 2938, 1714, 1651, 1570, 1273, 1219, 1085, 1029, 835, 700 cm^{-1} ; HRMS (APCI) calcd for $C_{24}H_{24}O_4$ $(M+H)^+$ 377.1747 , found 377.1751.

As described in the overview in page S4, based on the HPLC analysis of **7b** (page S30-32) derived from **6c**, the ee of **7a** derived from **6c**, was determined as 93% ee.

Pd-catalyzed Suzuki-Miyaura coupling of trifrate 6c.

(Scheme 5, B)



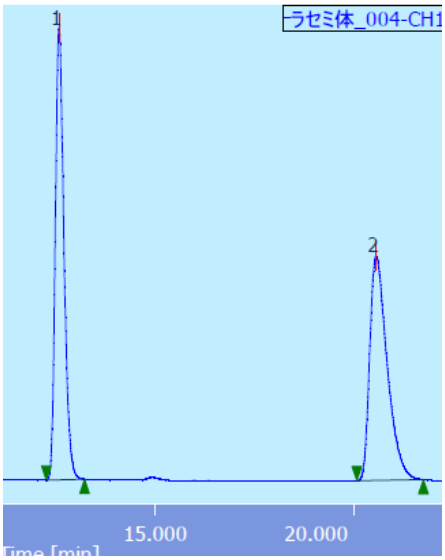
6c (93% ee) **7b** (93% ee)

A THF solution (0.65 ml) of $Pd(PPh_3)_4$ (3.2 mg, 2.78 μmol) was added dropwise to a suspension of trifrate **6c** (58 mg, 0.11 mmol), $PhB(OH)_2$ (20 mg, 0.167 mmol) and K_2CO_3 (23 mg, 0.166 mmol) in THF (1.0 ml) at 0 ˚C under an Ar atmosphere, followed by being stirred at 66˚C for 22h. 1N-HCl aqueous solution was added to the reaction mixture at 0˚C, which was extracted with AcOEt. The

organic phase was washed with brine, dried (Na_2SO_4) and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 8/1) to give the hydrated product **7b** (48 mg, 92%, 93% ee).

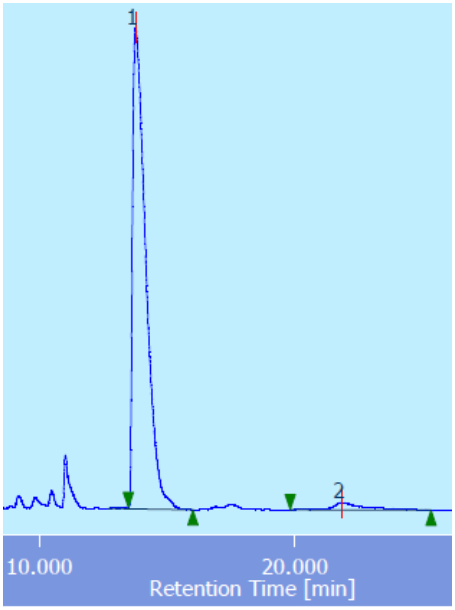
7b: yellow liquid ; $[\alpha]_D^{25}$= 219.6 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 0.77 (t, J = 7.1 Hz, 3H), 1.26 (t, J = 7.1 Hz, 3H), 3.72-3.86 (m, 2H), 4.04 (dt, J = 7.6, 1.5 Hz, 1H), 4.15 (q, J = 7.1 Hz, 2H), 4.26 (brs, 1H), 6.01 (dd, J = 15.6, 1,3 Hz, 1H), 7.01 (dd, J = 15.6, 7.6 Hz, 1H), 7.10-7.30 (m, 10H), 7.35-7.43 (m, 3H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 13.8, 14.6, 45.8, 48.4, 60.6, 60.8, 122.5, 125.1, 127.2, 127.8, 127.9, 128.1, 128.4, 128.9, 129.2, 129.9, 130.3, 135.2, 136.4, 139.5, 142.8, 147.3, 148.2, 167.0, 167.7 ; IR (NaCl,neat) 3061, 2981, 2983, 1714, 1693, 1651, 1446, 1369, 700 cm^{-1} ; HRMS (APCI) calcd for $C_{30}H_{28}O_4$ $(M+H)^+$ 453.2060 , found 453.2053.

93% ee : HPLC analysis [Daicel CHIRALPAK IC (25cm) at 25˚C, flow rate 0.5 ml/min, solvent: hexane / CH_2Cl_2 = 2/1, t_R(racemic) = 12.57 min and 20.53 min, t_R(**7b**) = 13.76 min for major and 21.85 min for minor].



Racemic-**7b**: HPLC analysis using chiral column

1	Unknown	1	12.575	784345	51978	49.929
2	Unknown	1	20.533	786573	25821	50.071

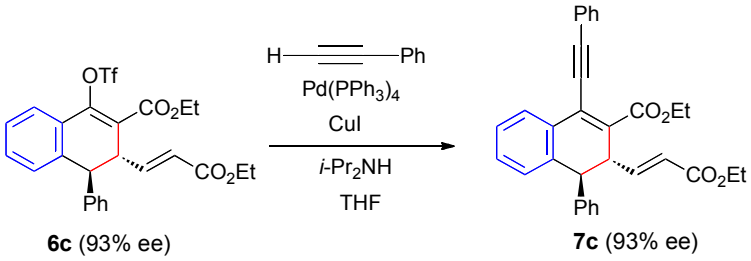


Enantioenriched **7b** (93% ee): HPLC analysis using chiral column.

1	Unknown	1	13.767	31825323	885871	96.579
2	Unknown	1	21.850	1127171	13665	3.421

Pd-catalyzed Sonogashira coupling of trifrate 6c.

(Scheme 5, C)



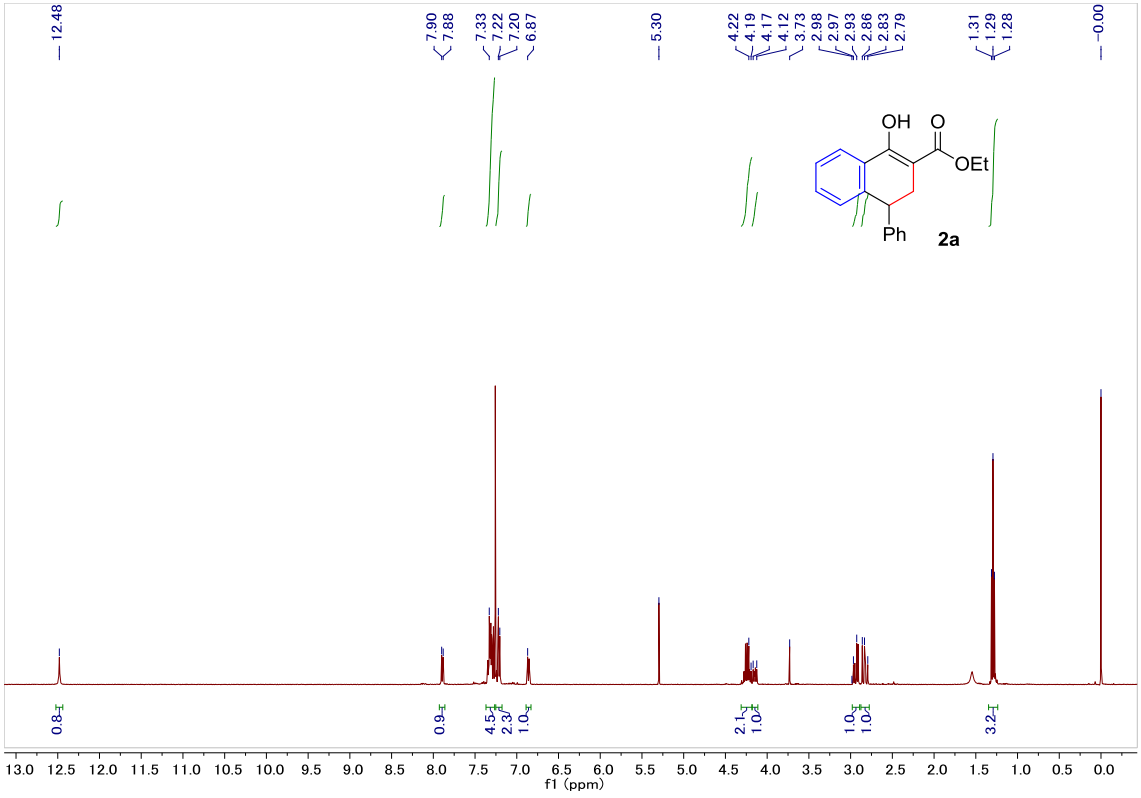
6c (93% ee) **7c** (93% ee)

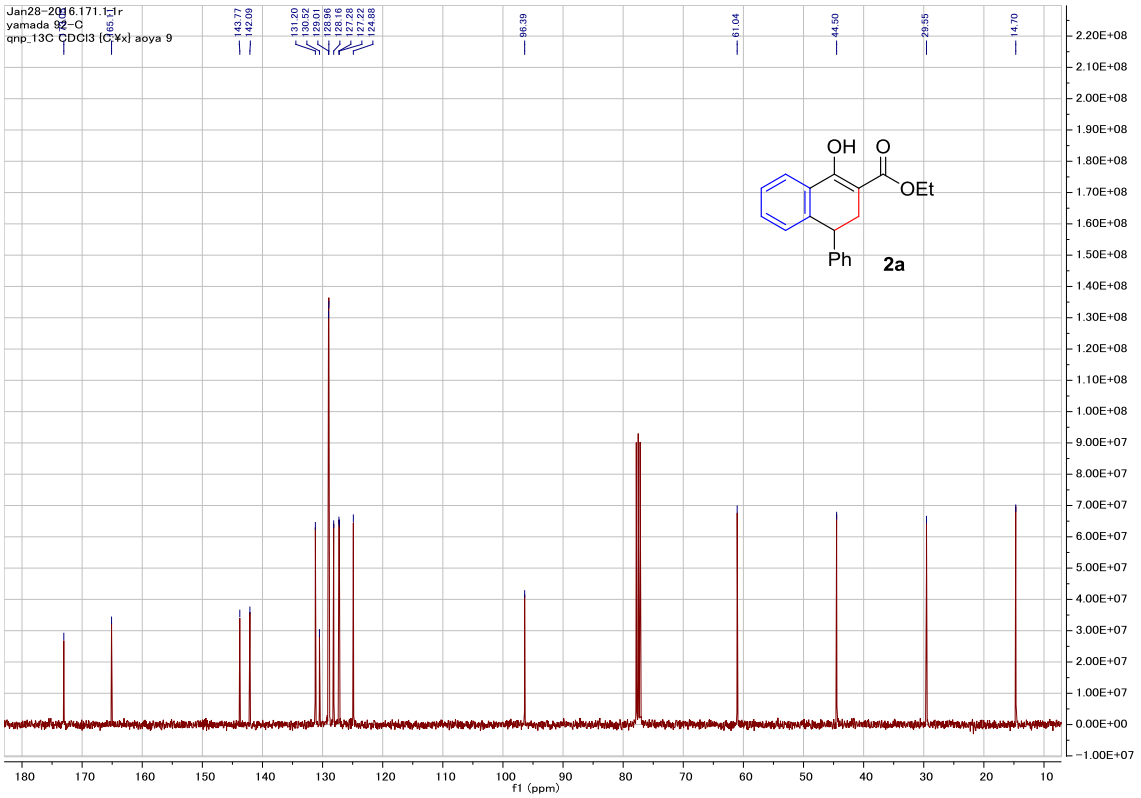
A THF solution (0.65 ml) of $Pd(PPh_3)_4$ (3.2 mg, 2.78 μmol) was added dropwise to a suspension of trifrate **6c** (58 mg, 0.11 mmol), CuI (3.2 mg, 16.7 μmol) in THF (1.0 ml) at 0 ˚C under an Ar atmosphere. Then, phenyl acetylene (18 μl, 0.17 mmol) and diisopropyl amine (47 ml, 0.33 mmol) were successively added dropwise to the mixture, followed by being stirred at 66˚C for 22h. 1N-HCl aqueous solution was added to the reaction mixture at 0˚C, which was extracted with AcOEt. The organic phase was washed with brine, dried (Na_2SO_4) and concentrated. The obtained crude oil was purified by column chromatography (SiO_2, hexane/AcOEt = 8/1) to give the hydrated product **7c** (53 mg, 94%, 93% ee).

7c: yellow liquid ; $[\alpha]_D^{25}$= 235.7 (*c* 1.00, chloroform, λ = 589 nm) ; ^{1}H NMR (400MHz,$CDCl_3$) δ 1.24 (t, J = 7.1 Hz, 3H), 1.29 (t, J = 7.1 Hz, 3H), 4.12 (q, J = 7.1 Hz, 2H), 4.17 (dt, J = 7.3, 1.3 Hz,

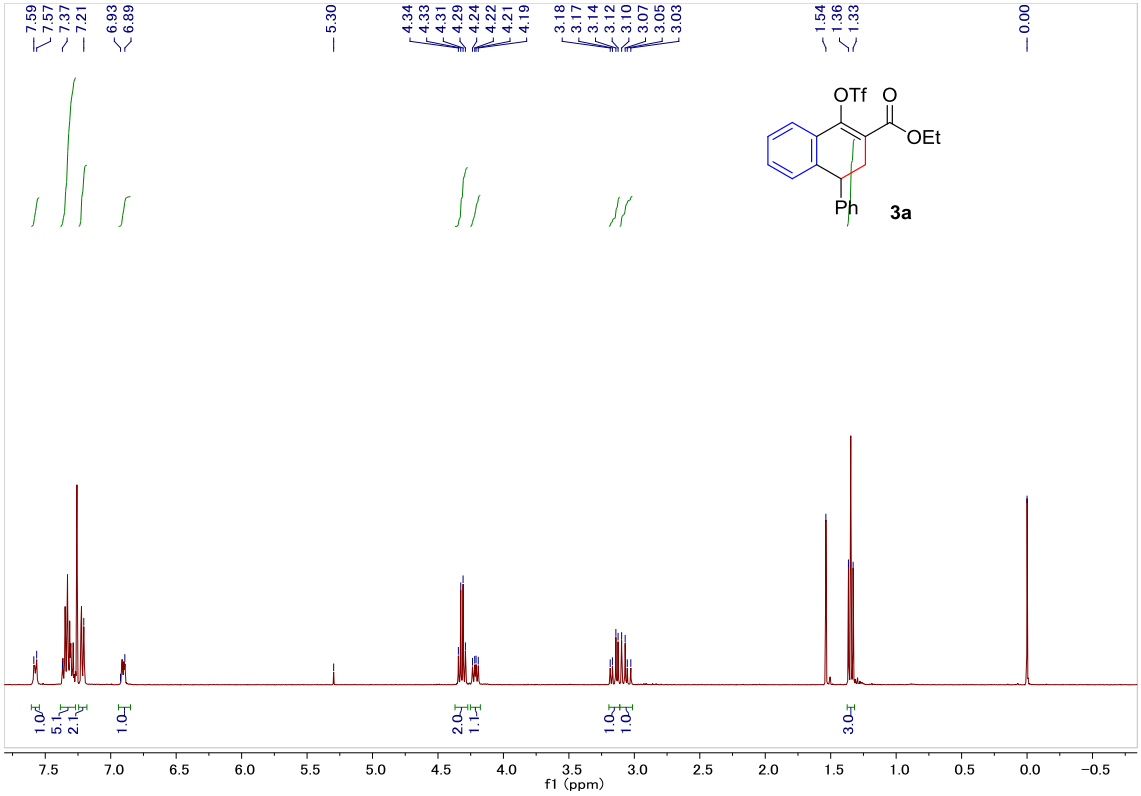
2H), 4.22 (brs, 1H), 5.92 (dd, J = 15.5, 1,3 Hz, 1H), 6.86 (dd, J = 15.5, 7.6 Hz, 1H), 7.01-7.05 (m, 2H), 7.16-7.24 (m, 4H), 7.36-7.42 (m, 5H), 7.61-7.67 (m, 2H), 8.09 (dd, J = 7.7, 1.5 Hz, 1H) ; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.6, 14.7, 45.3, 47.9, 60.8, 61.4, 86.7, 101.6, 122.6, 123.3, 127.2, 127.9, 128.3, 128.6, 128.9, 129.0, 129.5, 129.9, 130.2, 130.4, 131.0, 132.2, 132.4, 135.9, 142.4, 147.1, 166.3, 166.8 ; IR (NaCl,neat) 3061, 2981, 2935, 2004, 1714, 1693, 1269, 910, 734 cm^{-1} ; HRMS (APCI) calcd for $C_{32}H_{28}O_4$ $(M+H)^+$ 477.2060 , found 477.2059. As described in the overview in page S4, based on the HPLC analysis of **7b** (page S30-32) derived from **6c**, the ee of of **7c** derived from **6c** was determined as 93% ee.

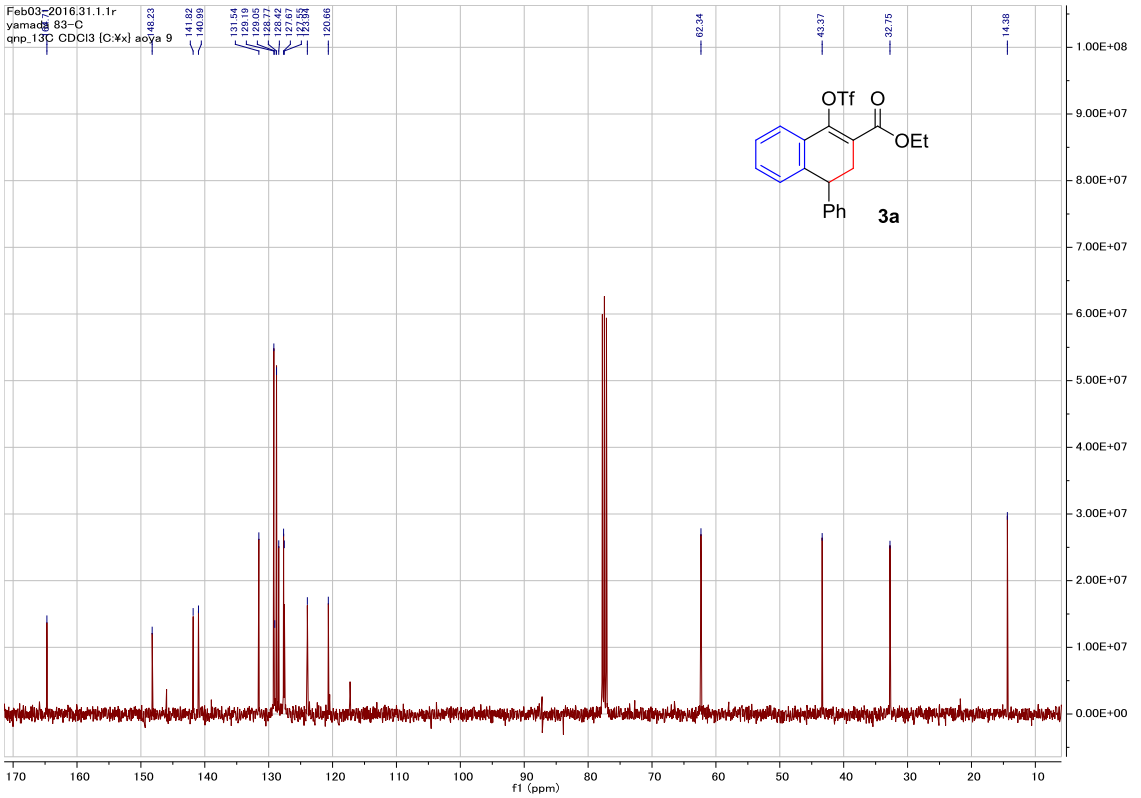
2a


12.48
7.90
7.88
7.33
7.22
7.20
6.87
5.30
4.22
4.19
4.17
4.12
3.73
2.98
2.97
2.93
2.86
2.83
2.79
1.31
1.29
1.28
0.00
OH
O
OEt
Ph
2a
f1 (ppm)

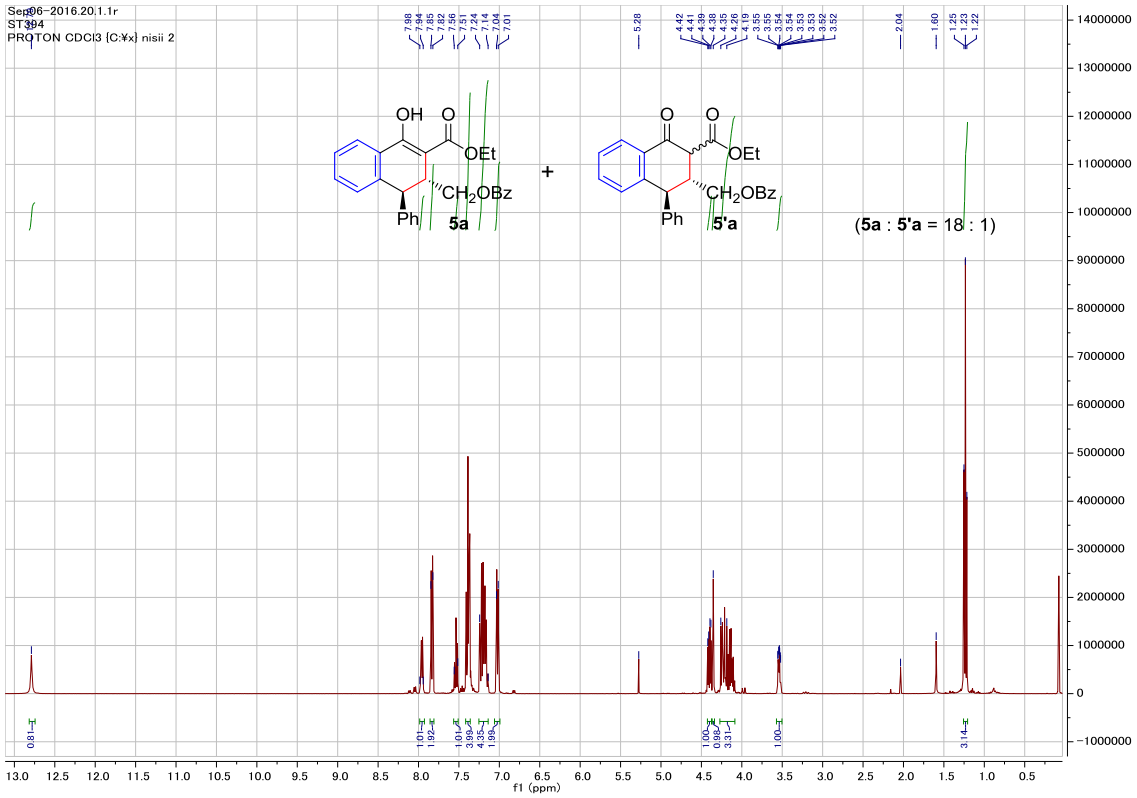

143.77
142.09
131.20
130.52
129.01
128.96
128.16
127.28
127.22
124.88
96.39
61.04
44.50
29.55
14.70
OH
O
OEt
Ph
2a
f1 (ppm)

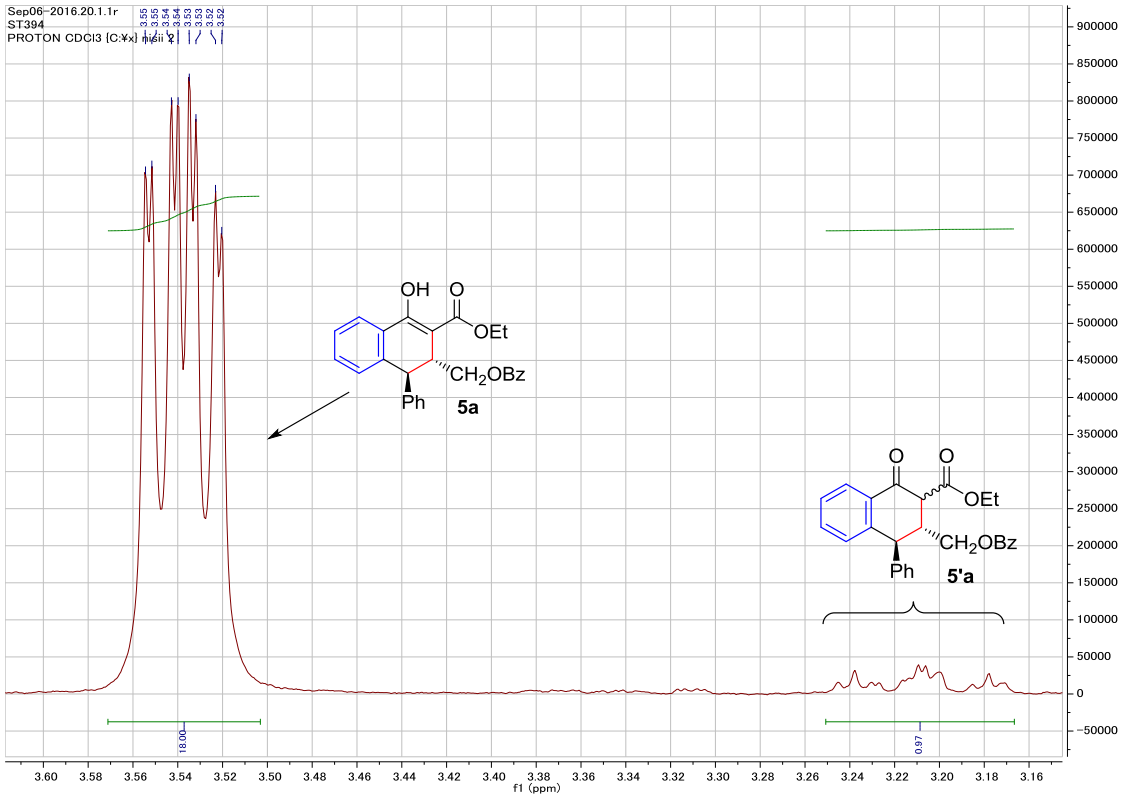
3a

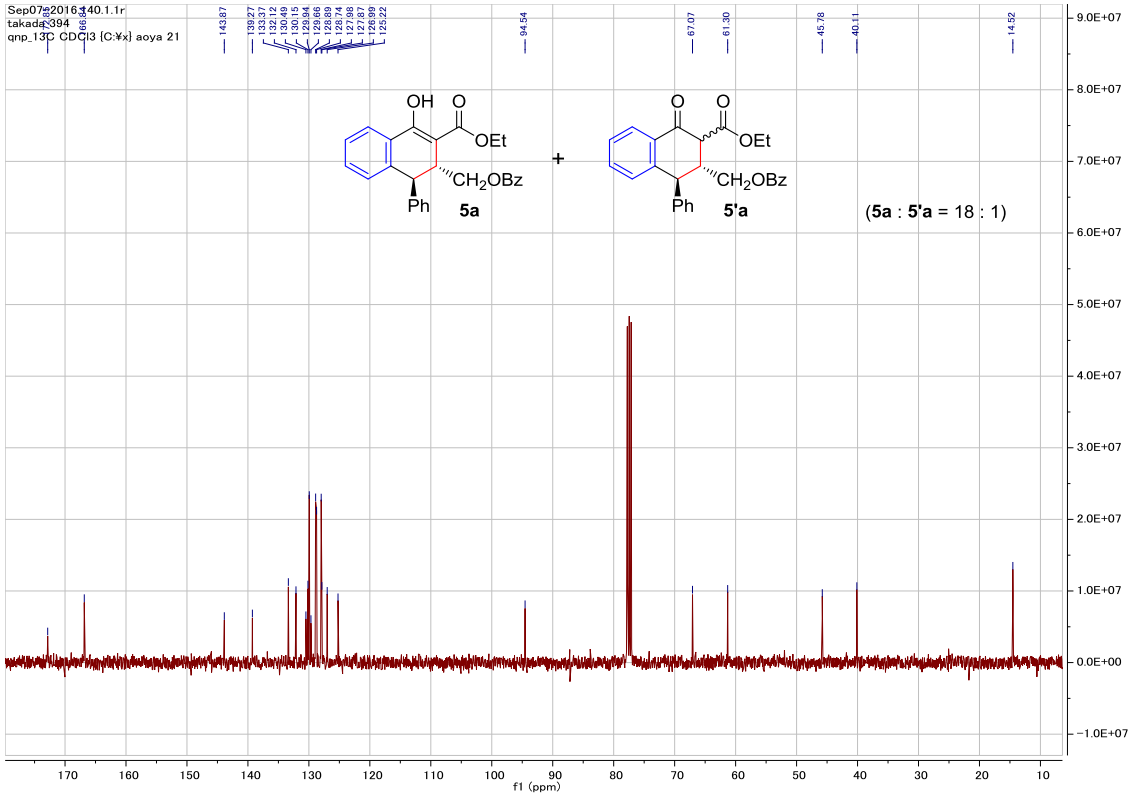

7.59
7.57
7.37
7.21
6.93
6.89
5.30
4.34
4.33
4.31
4.29
4.24
4.22
4.21
4.19
3.18
3.17
3.14
3.12
3.10
3.07
3.05
3.03
1.54
1.36
1.33
0.00
OTf
O
OEt
Ph
3a
f1 (ppm)


Feb03_2016,31.1.1r
yamada 83-C
qnp_13C CDCl3 [C:¥x] aoya 9
148.23
141.82
140.99
131.54
129.19
129.05
128.77
128.42
127.67
123.52
123.34
120.66
62.34
43.37
32.75
14.38
OTf
O
OEt
Ph
3a
f1 (ppm)

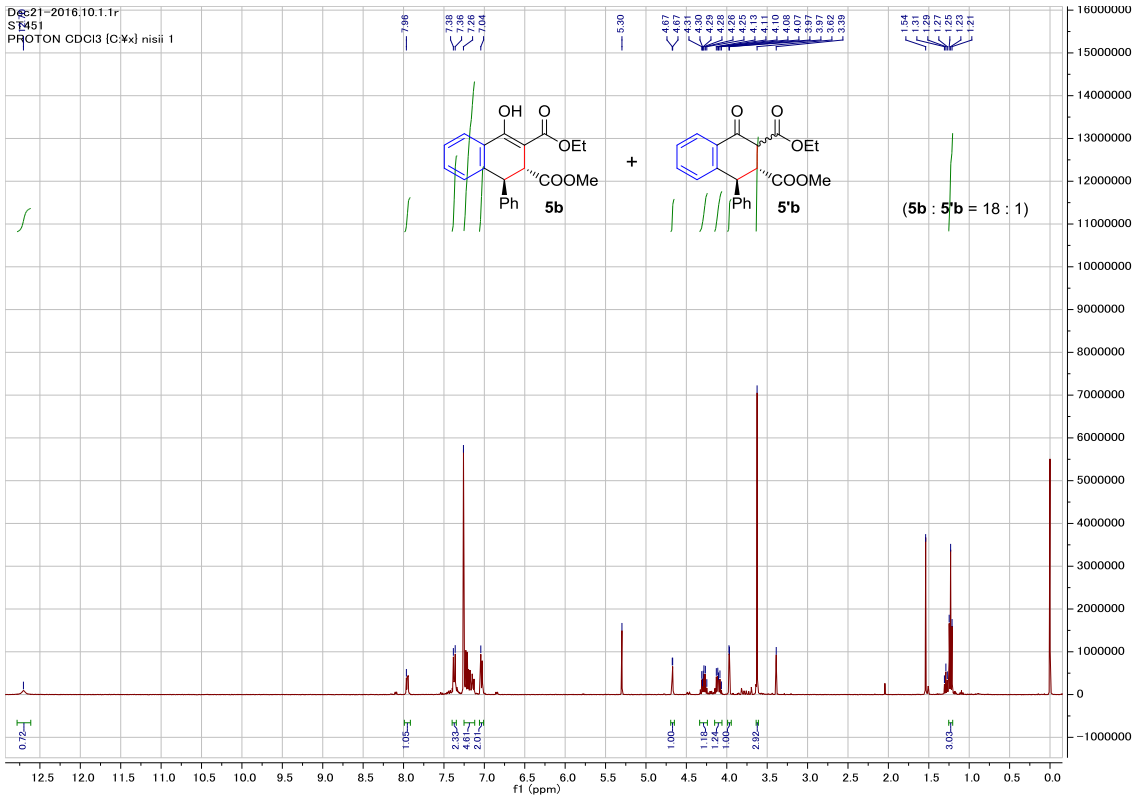
5a+**5'a**

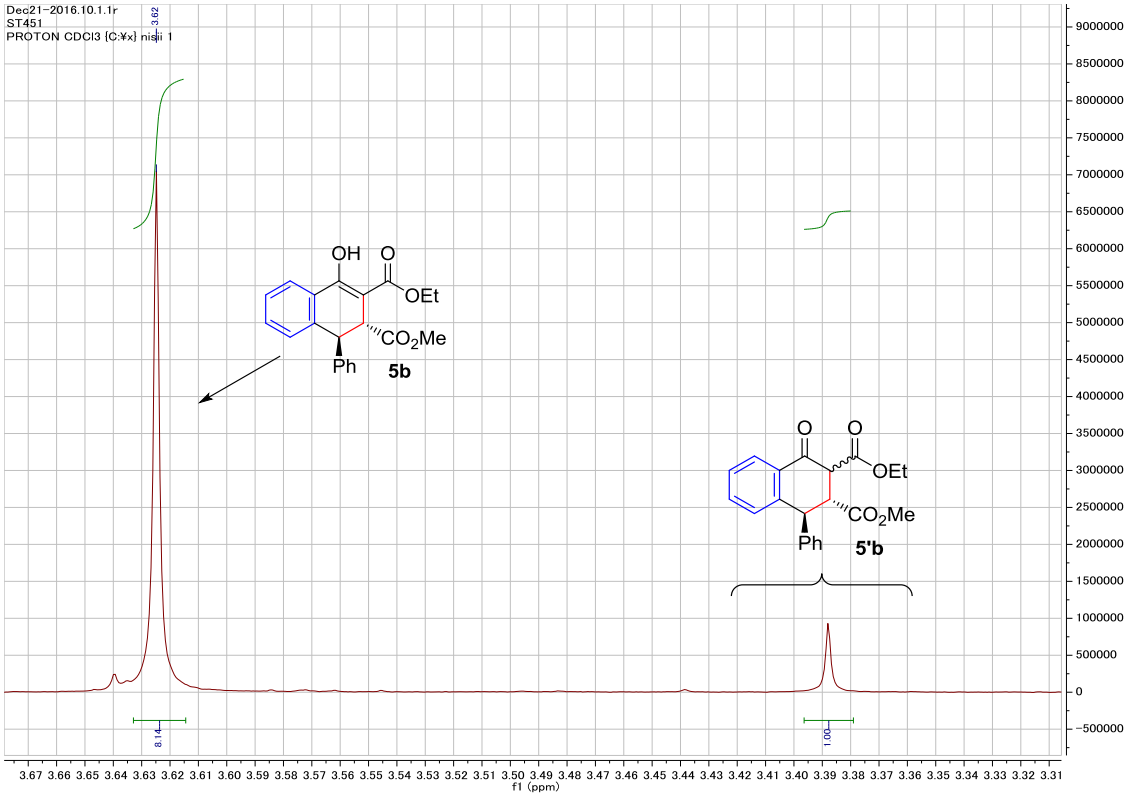

Sep06-2016.20.1.1r
ST394
PROTON CDCl3 (C:¥x) nisii 2
OH O
OEt
CH2OBz
Ph
5a
+
O O
OEt
CH2OBz
Ph
5'a
(5a : 5'a = 18 : 1)
f1 (ppm)

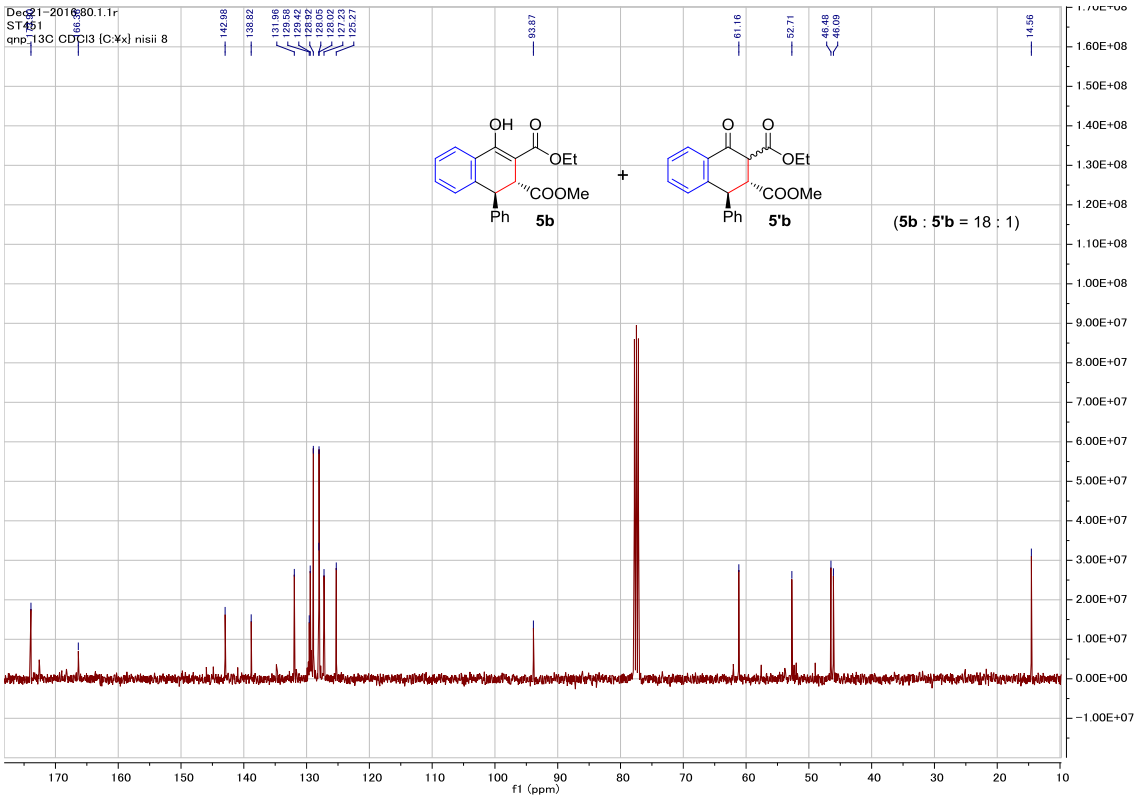

Sep06-2016.20.1.1r
ST394
PROTON CDCl3 (C:¥x) nisii 2
OH O
OEt
CH2OBz
Ph
5a
O O
OEt
CH2OBz
Ph
5'a
f1 (ppm)


Sep07-2016.140.1.1r
takada-394
qnp_13C CDCl3 (C:¥x) aoya 21
143.87
139.27
133.37
132.12
130.49
130.15
129.94
129.66
128.89
128.74
127.89
127.87
126.99
125.22
94.54
67.07
61.30
45.78
40.11
14.52
OH
O
OEt
CH2OBz
Ph
5a
+
O
O
OEt
CH2OBz
Ph
5'a
(5a : 5'a = 18 : 1)
f1 (ppm)

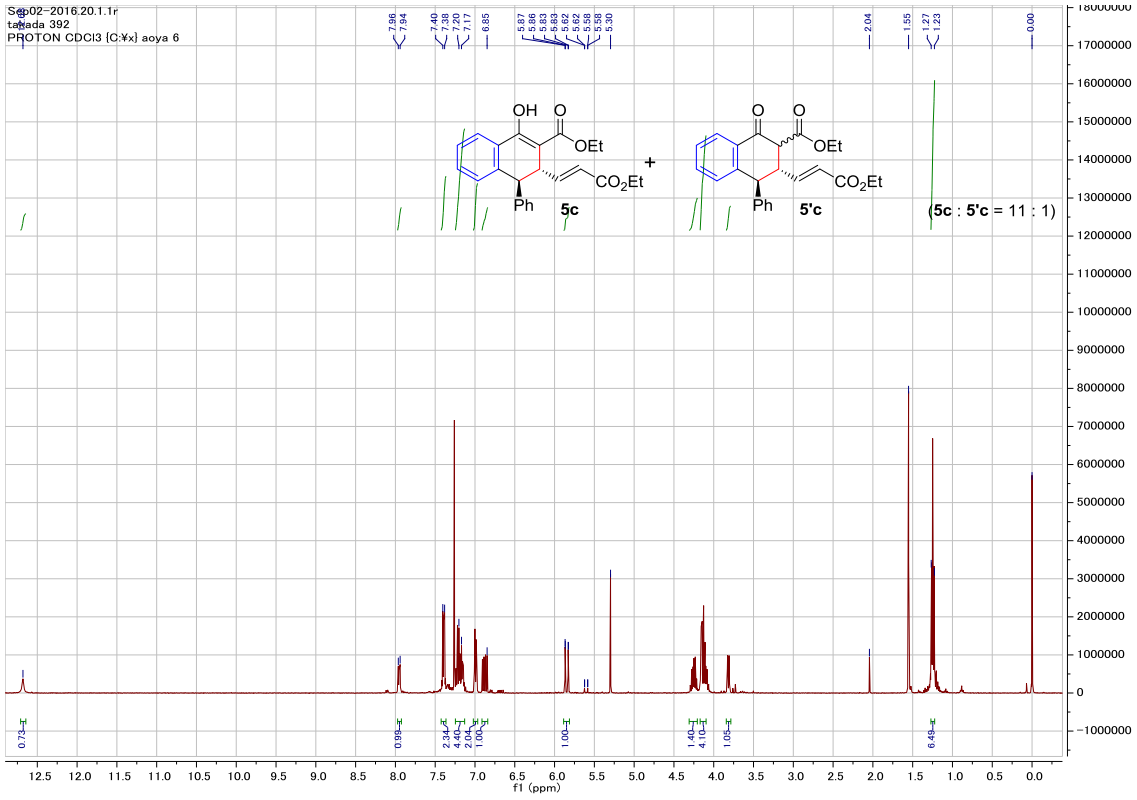
5b+**5'b**

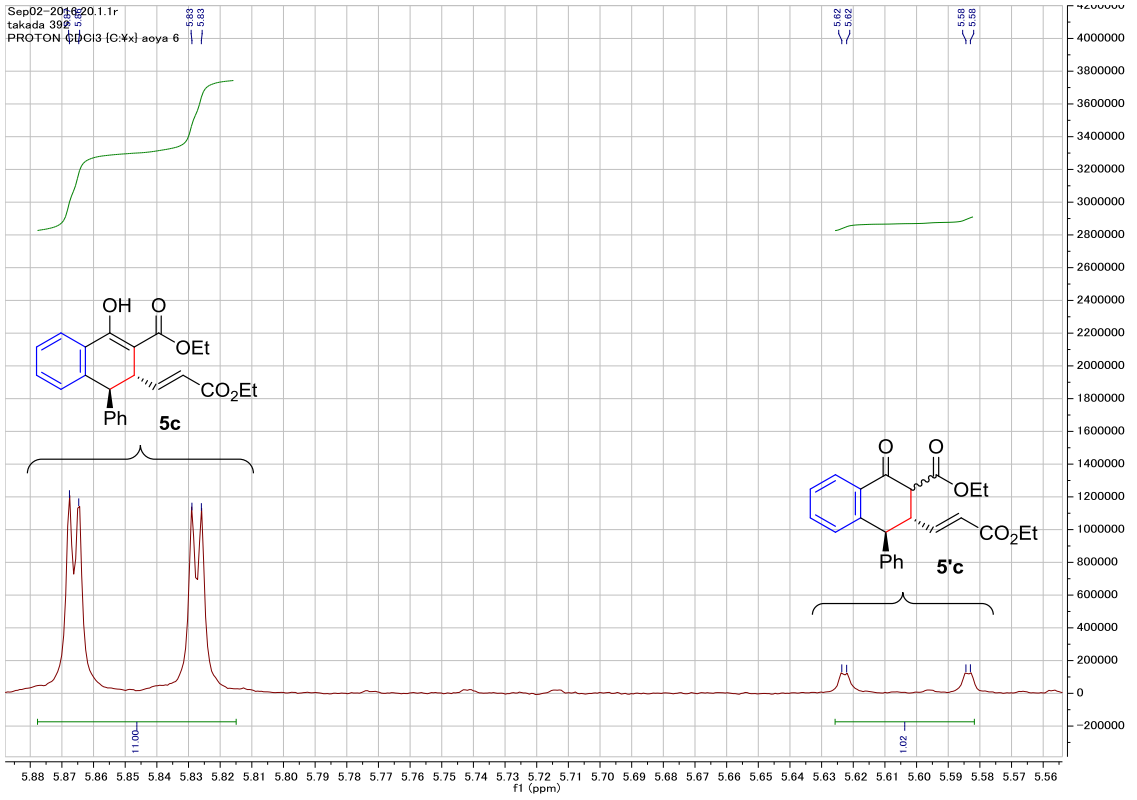

D-21-2016.10.1.1r
ST451
PROTON CDCl3 (C:¥x) nisii 1
7.96
7.38
7.36
7.26
7.04
5.30
4.67
4.67
4.31
4.30
4.29
4.28
4.26
4.25
4.13
4.11
4.10
4.08
4.07
3.97
3.97
3.02
3.01
3.00
1.54
1.31
1.29
1.27
1.25
1.23
1.21
OH
O
OEt
COOMe
Ph
5b
+
O
O
OEt
COOMe
Ph
5'b
(5b : 5'b = 18 : 1)
0.72
1.05
2.33
4.61
2.01
1.00
1.18
1.14
1.00
2.02
3.03
f1 (ppm)

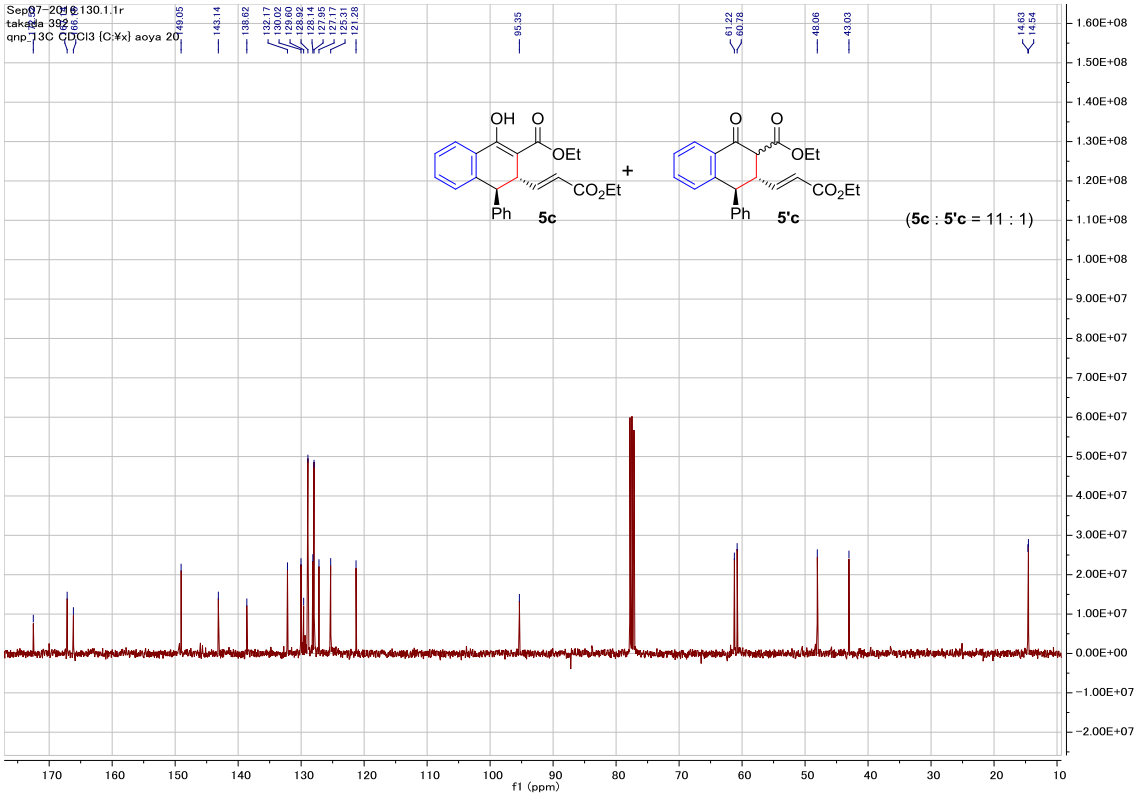

Dec21-2016.10.1.1r
ST451
PROTON CDCl3 (C:¥x) nisii 1
OH
O
OEt
CO2Me
Ph
5b
O
O
OEt
CO2Me
Ph
5'b
f1 (ppm)


Dec21-2016.80.1.1r
ST451
qnp 13C CDCl3 (C:¥x) nisii 8
OH
O
OEt
COOMe
Ph
5b
+
O
O
OEt
COOMe
Ph
5'b
(5b : 5'b = 18 : 1)
f1 (ppm)

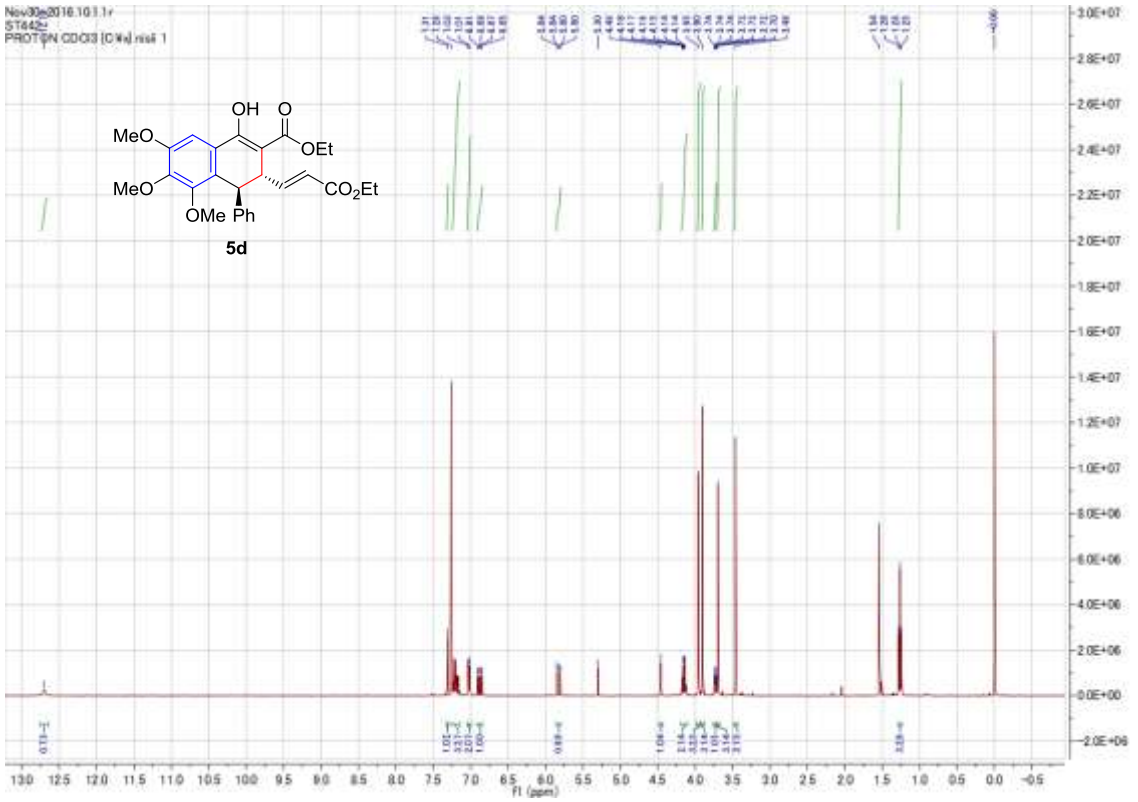
5c+5'c

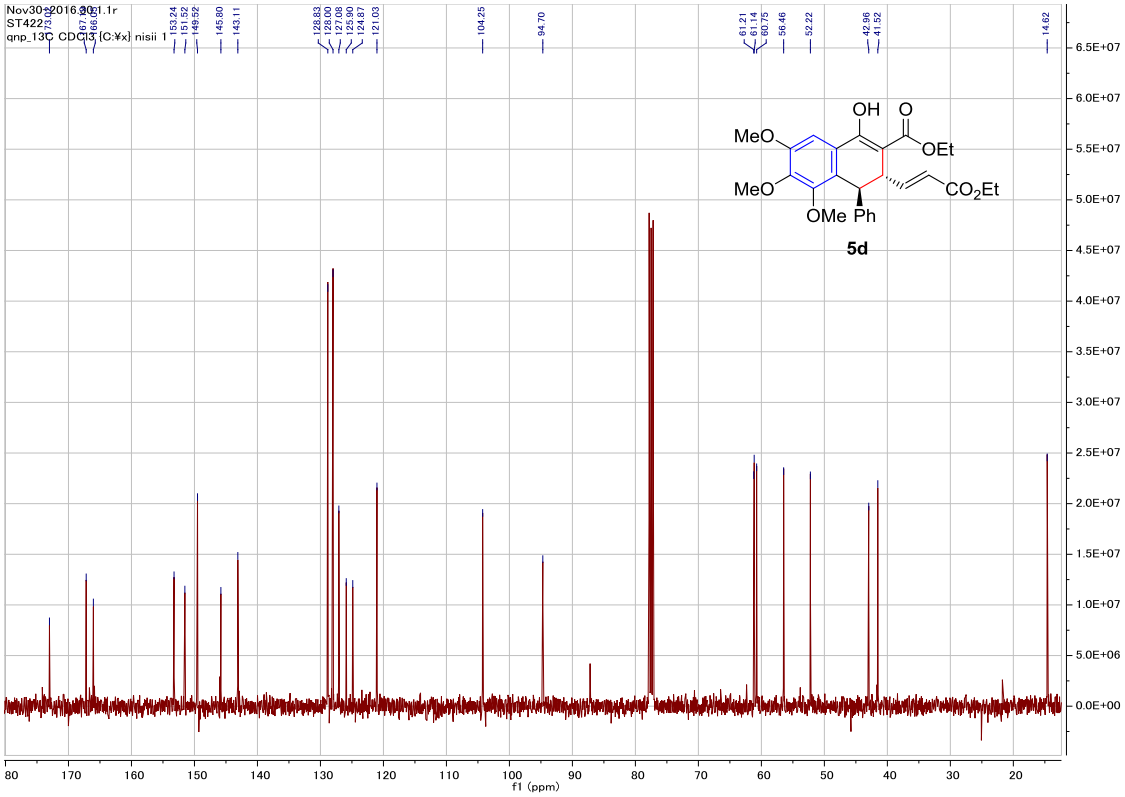

Sep02-2016.20.1.1r
takada 392
PROTON CDCl3 {C:¥x} aoya 6
OH O
OEt
CO2Et
Ph
5c
+
O O
OEt
CO2Et
Ph
5'c
(5c : 5'c = 11 : 1)
f1 (ppm)


Sep02-2016.20.1.1r
takada 392
PROTON CDCl3 {C:¥x} aoya 6
OH O
OEt
CO2Et
Ph
5c
O O
OEt
CO2Et
Ph
5'c
f1 (ppm)

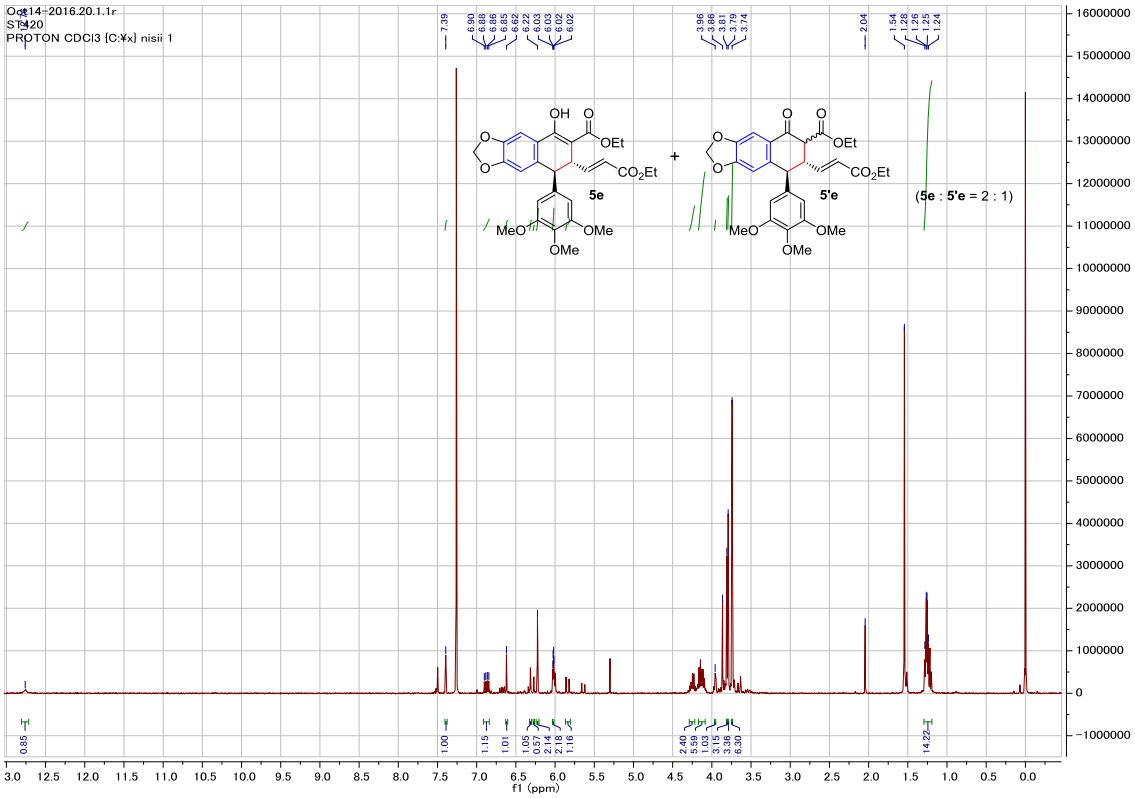

OH O
OEt
CO2Et
Ph
5c
+
O O
OEt
CO2Et
Ph
5'c
(5c : 5'c = 11 : 1)
f1 (ppm)

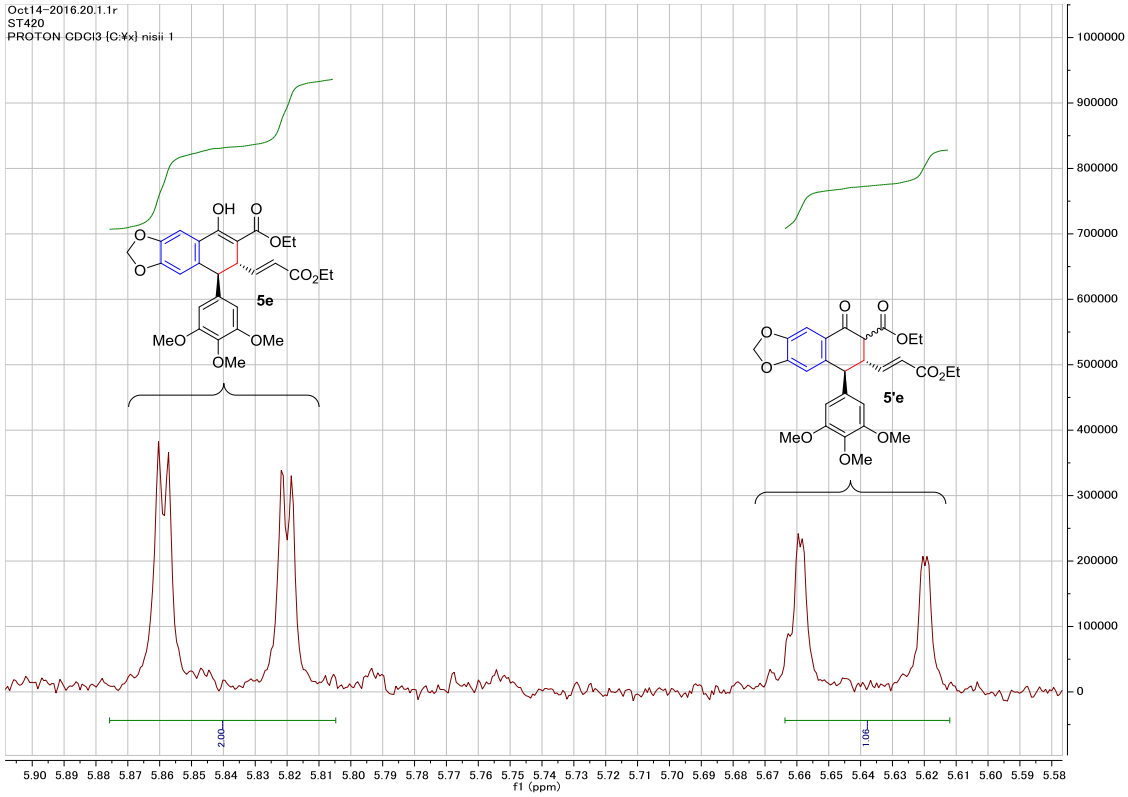
5d


OH O
MeO
OEt
MeO
CO2Et
OMe Ph
5d
f1 (ppm)

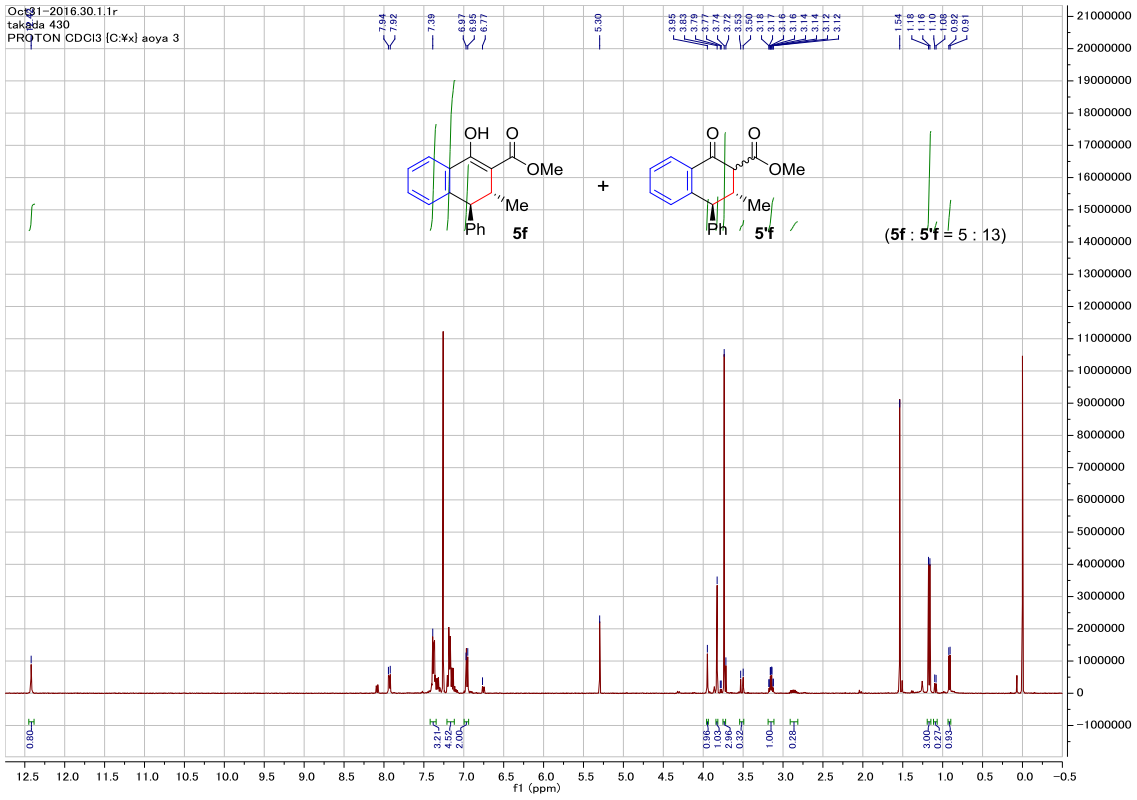

Nov30-2016.30.1.1r
ST422
qnp_13C CDCl3 (C:¥x) nisii 1
OH
O
MeO
OEt
MeO
CO2Et
OMe Ph
5d
f1 (ppm)

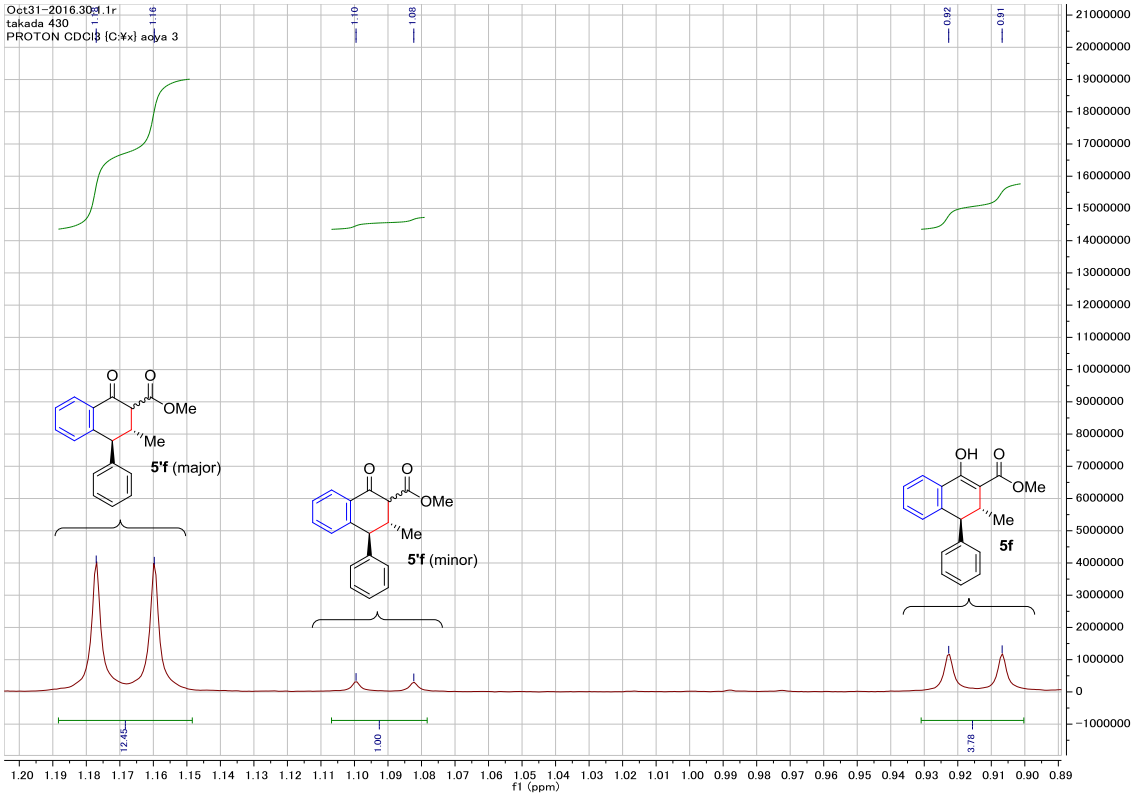
5e+5'e


Oct14-2016.20.1.1r
ST420
PROTON CDCl3 (C:¥x) nisii 1
5e
5'e
(5e : 5'e = 2 : 1)
f1 (ppm)

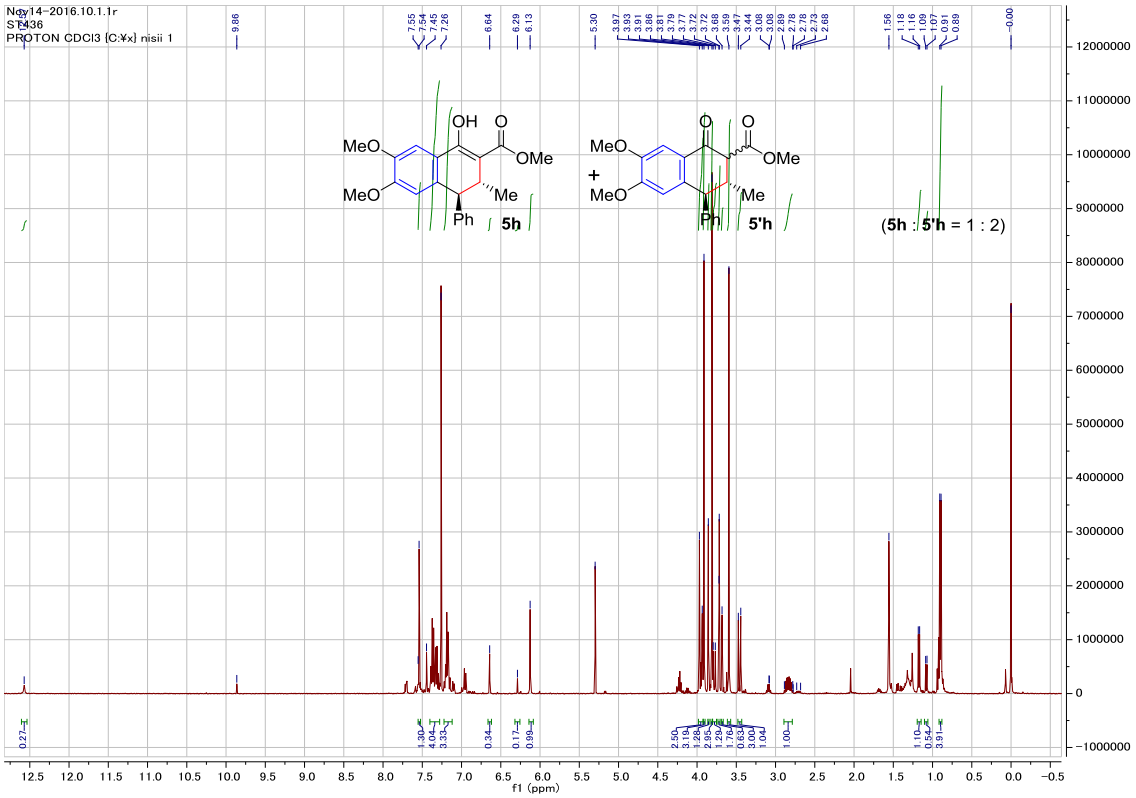

Oct14-2016.20.1.1r
ST420
PROTON CDCl3 (C:¥x) nisii 1
OH
O
OEt
CO2Et
5e
MeO
OMe
OMe
O
O
OEt
CO2Et
5'e
MeO
OMe
OMe
2.00
1.06
f1 (ppm)

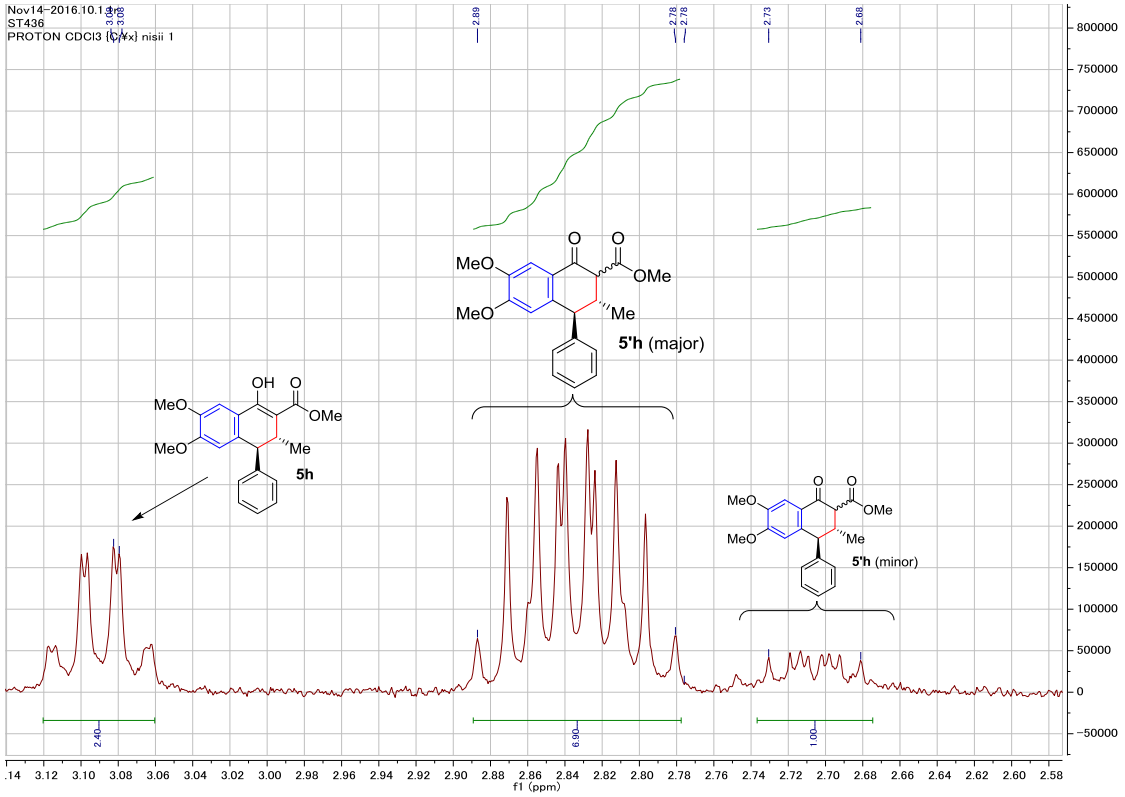
5f+**5'f**


Oct31-2016.30.1.1r
takeda 430
PROTON CDCl3 (C:¥x) aoya 3
OH
O
OMe
Me
Ph
5f
+
O
O
OMe
Me
Ph
5'f
(5f : 5'f = 5 : 13)
f1 (ppm)

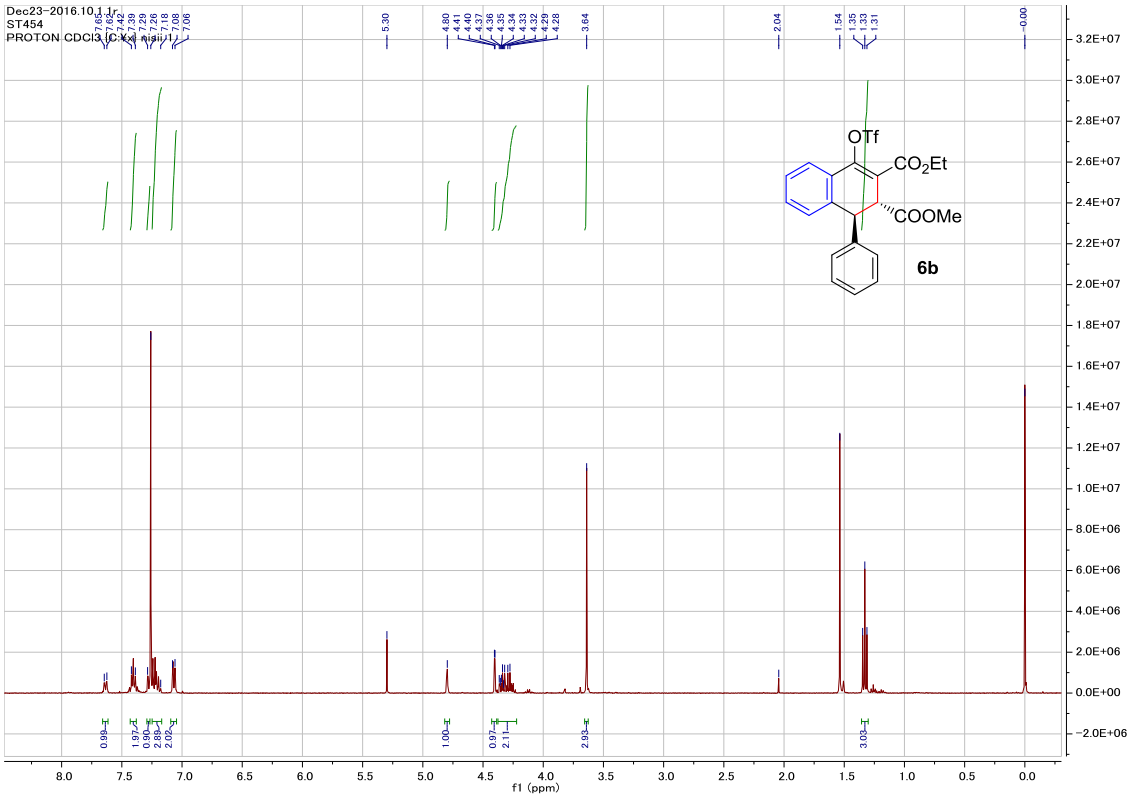

Oct31-2016.30.1.1r
takada 430
PROTON CDCl3 (C:¥x) adya 3
OMe
Me
5'f (major)
OMe
Me
5'f (minor)
OH
OMe
Me
5f
f1 (ppm)

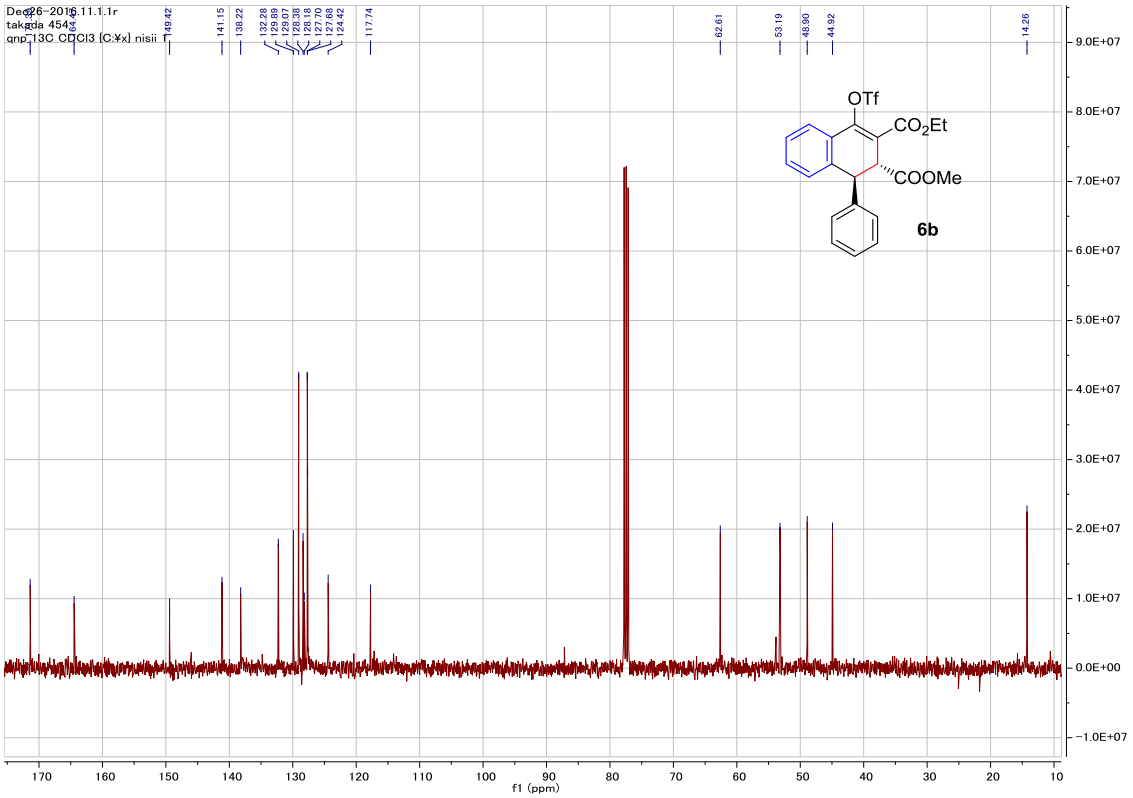
5h+**5'h**


Nov14-2016.10.1.1r
ST436
PROTON CDCl3 (C:¥x) nisii 1
MeO
MeO
OH
OMe
Me
Ph
5h
MeO
MeO
OMe
Me
Ph
5'h
(5h : 5'h = 1 : 2)
f1 (ppm)

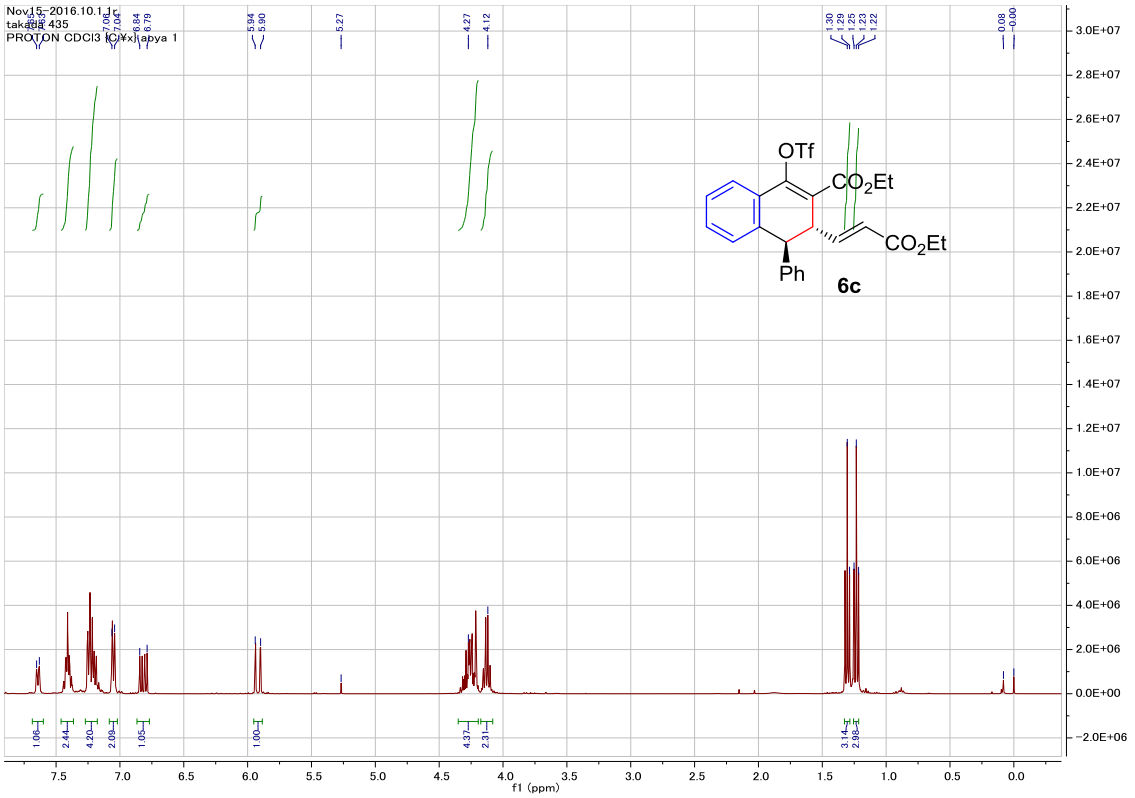

Nov14-2016.10.1.fid
ST436
PROTON CDCl3 {C:/Vx} nisii 1
2.89
2.78
2.78
2.73
2.68
3.04
3.03
MeO
MeO
OMe
Me
O
O
5'h (major)
OH
5h
5'h (minor)
2.40
6.90
1.00
f1 (ppm)

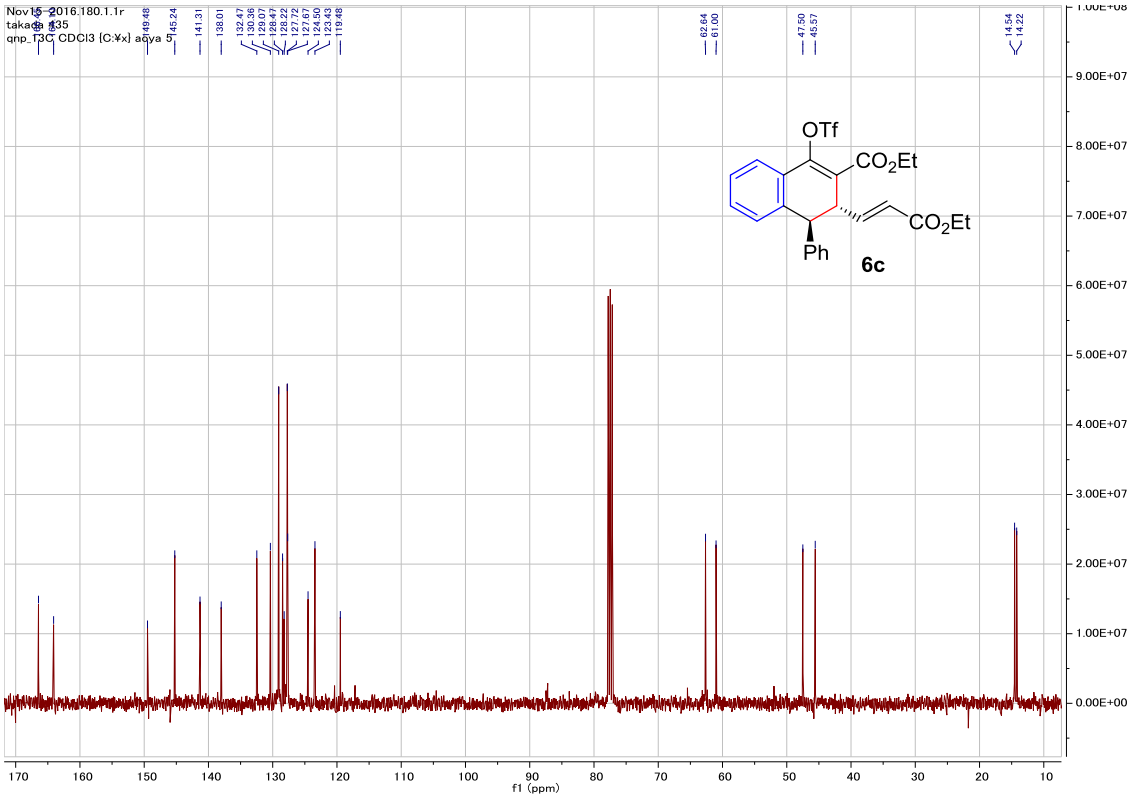
6b



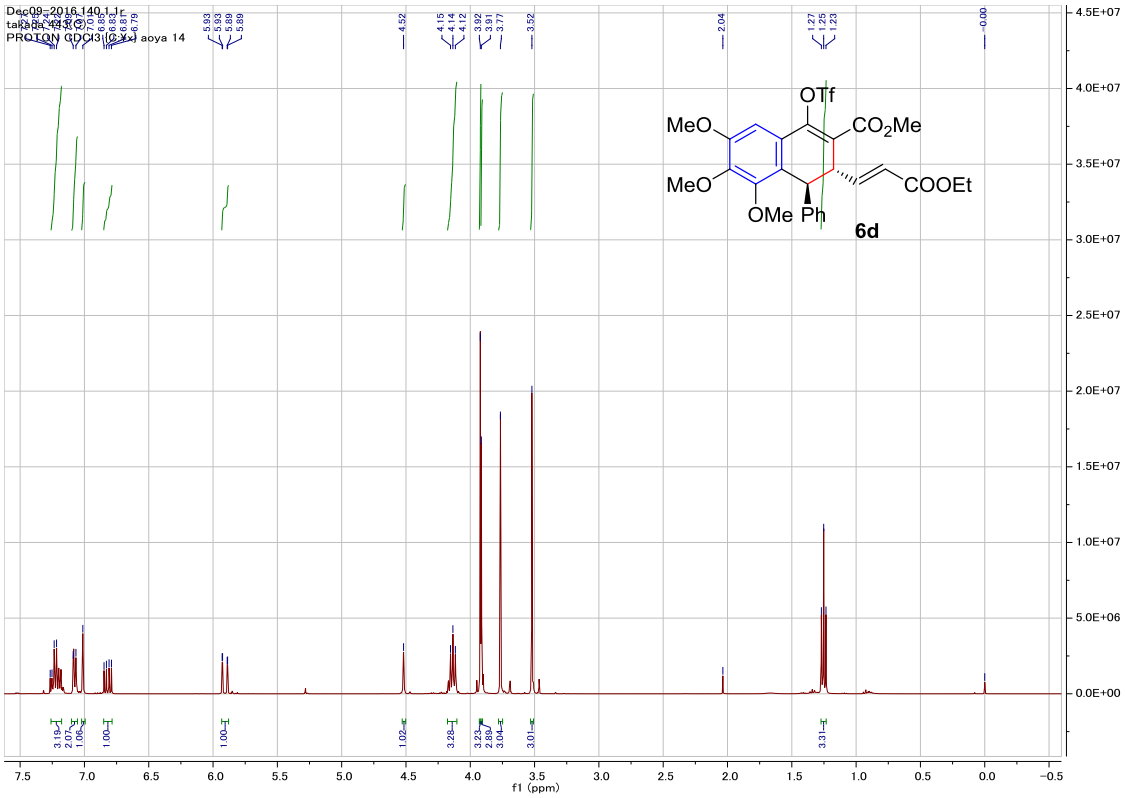


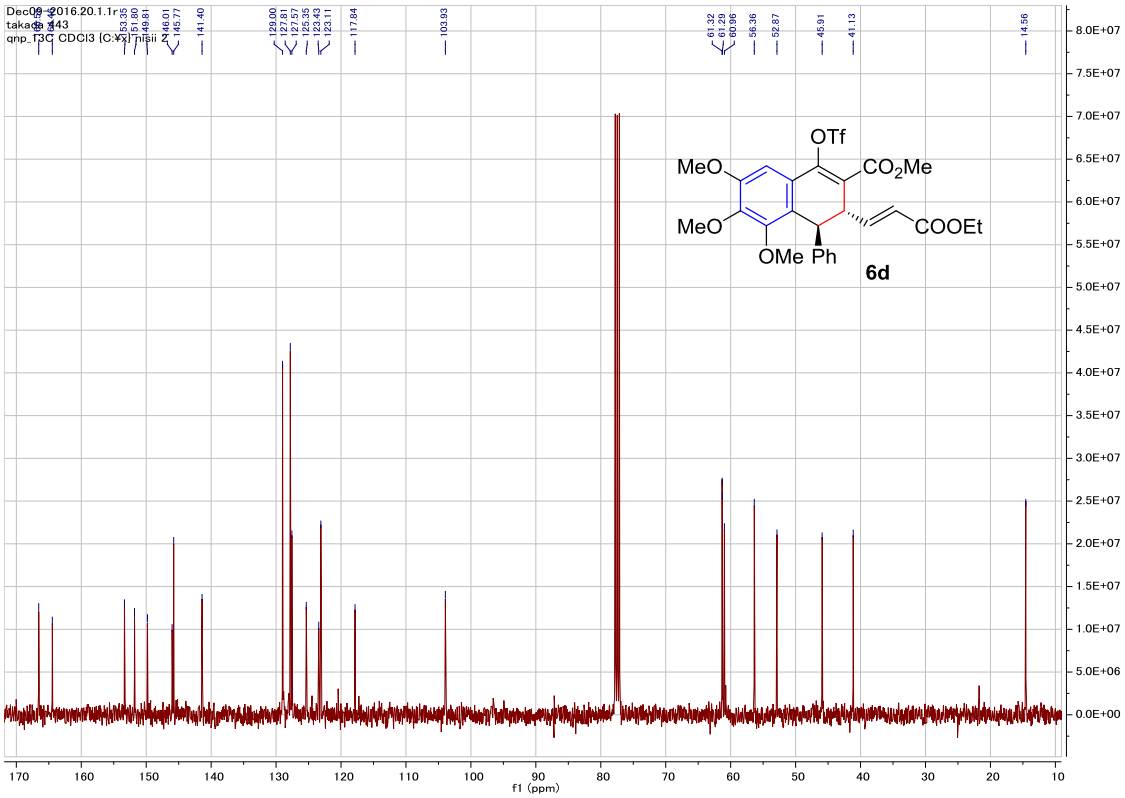
6c



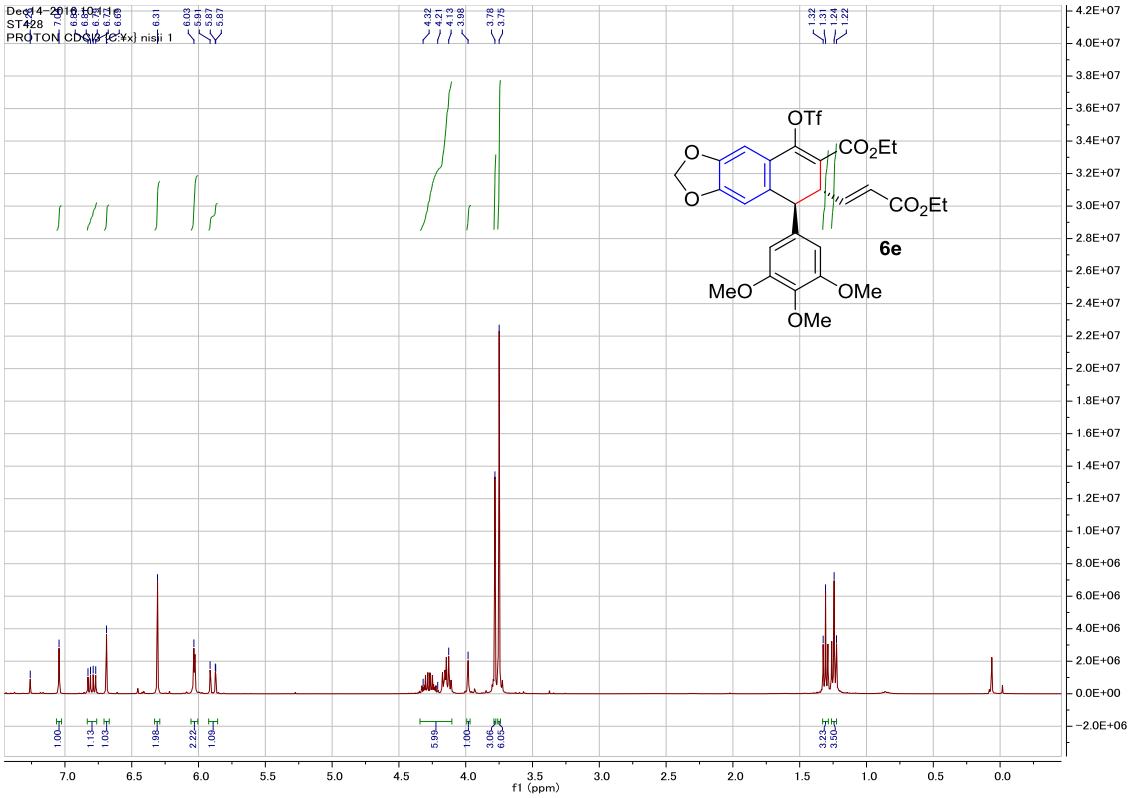


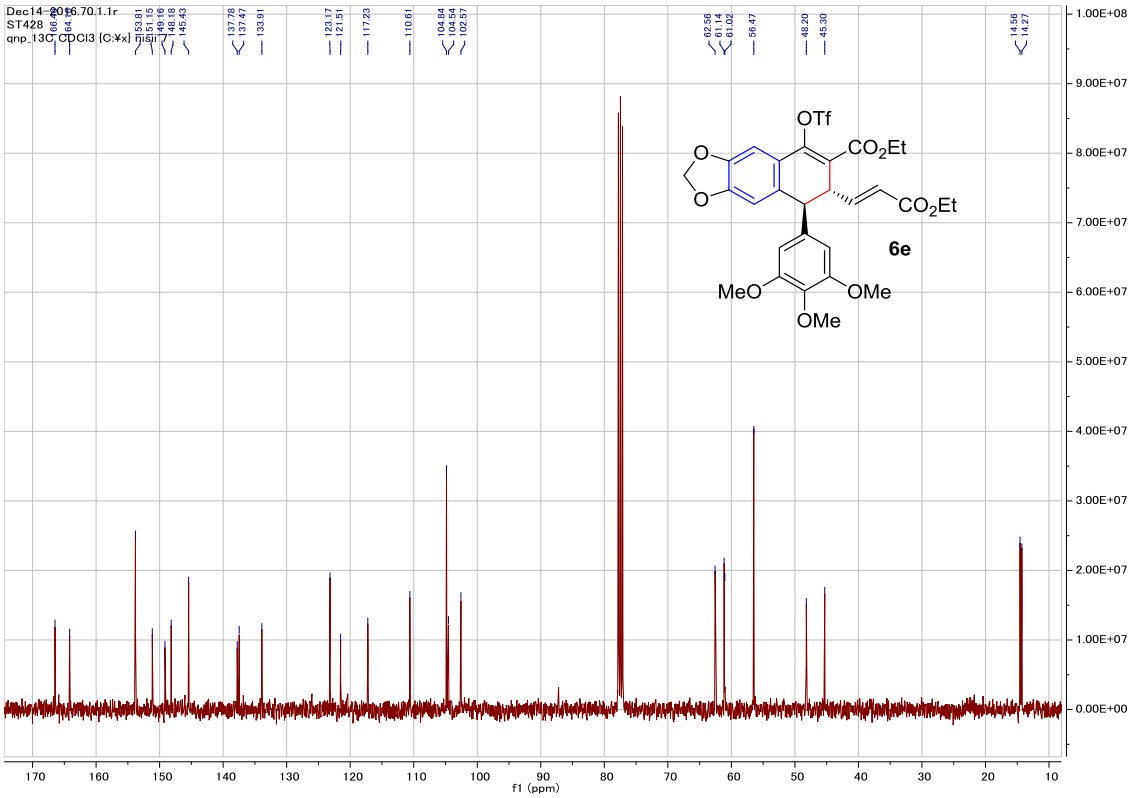
6d


OTf
MeO
CO2Me
MeO
COOEt
OMe Ph
6d
f1 (ppm)

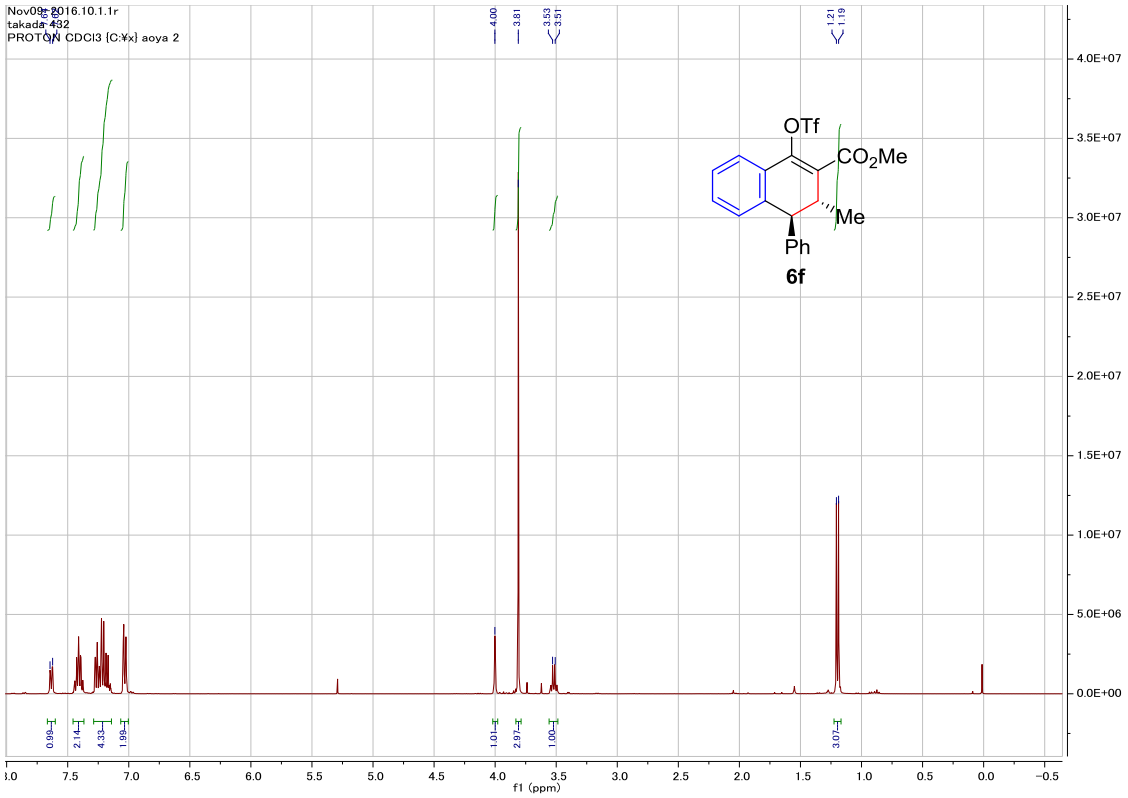

OTf
MeO
CO2Me
MeO
COOEt
OMe Ph
6d
f1 (ppm)

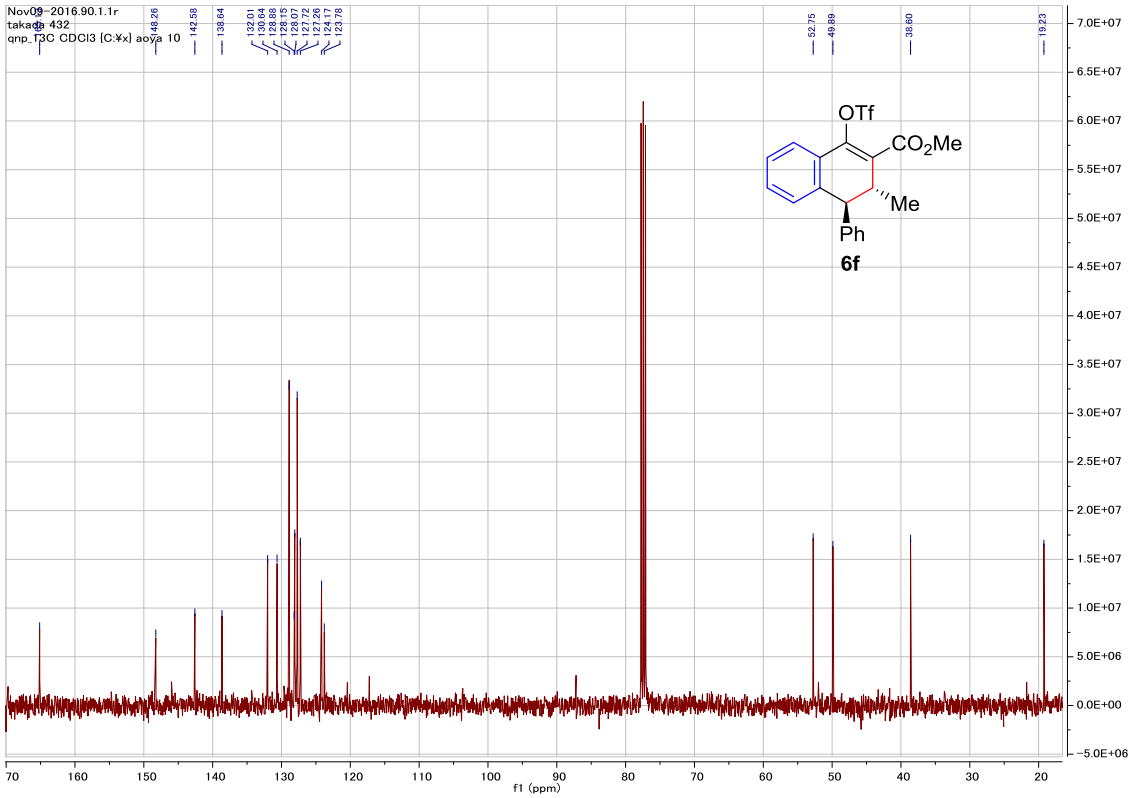
6e


OTf
CO2Et
CO2Et
6e
MeO
OMe
OMe
f1 (ppm)

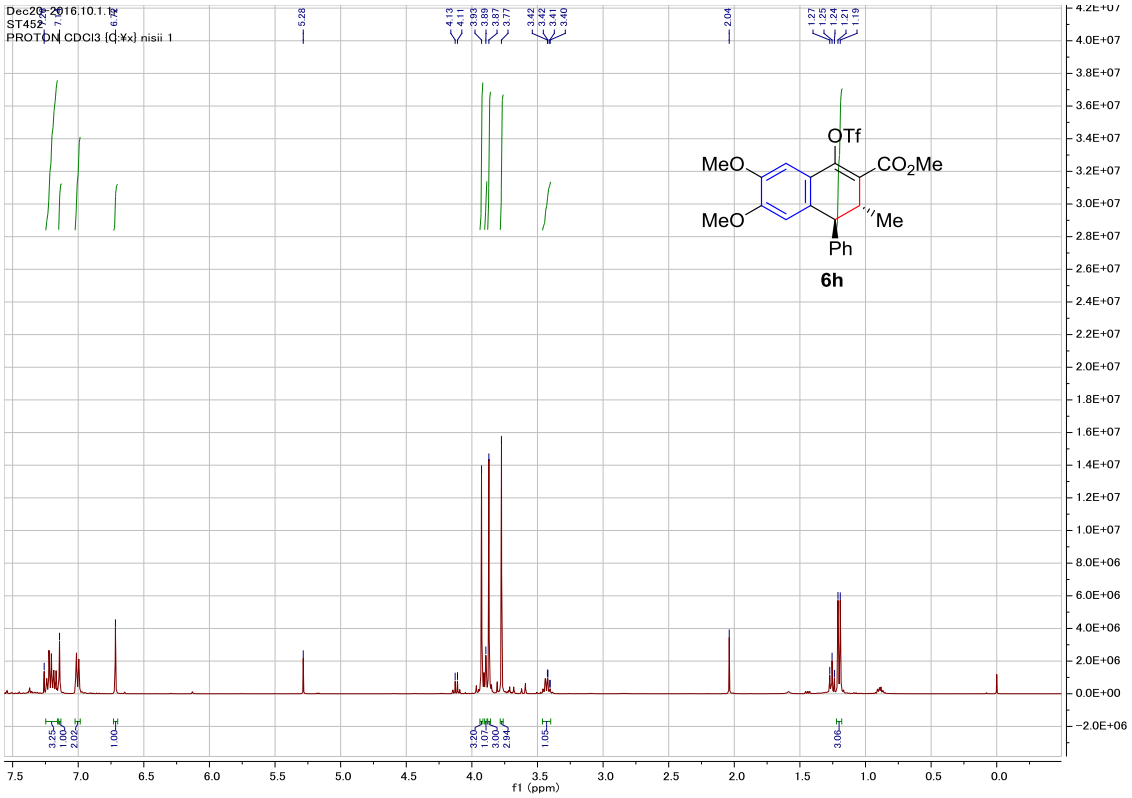

OTf
CO2Et
CO2Et
6e
MeO
OMe
OMe
f1 (ppm)

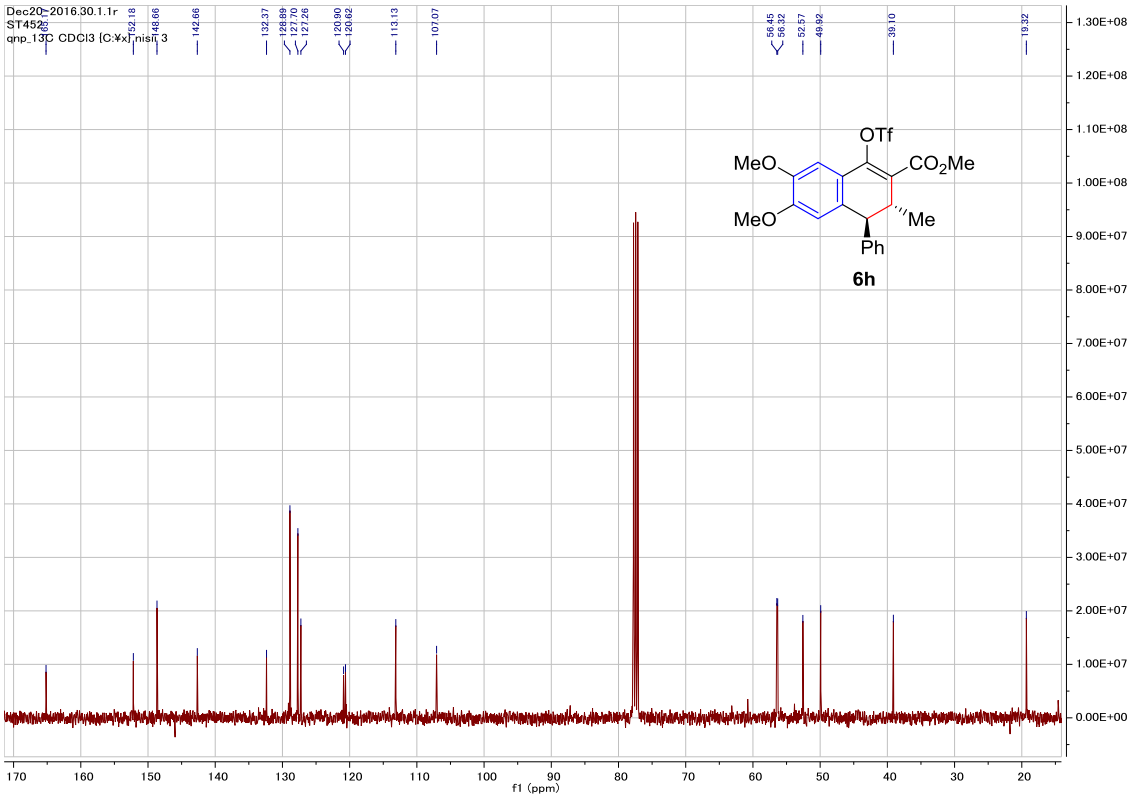
6f


Nov09-2016.10.1.1r
takada 432
PROTON CDCl3 (C:¥x) aoya 2
OTf
CO2Me
Me
Ph
6f
f1 (ppm)

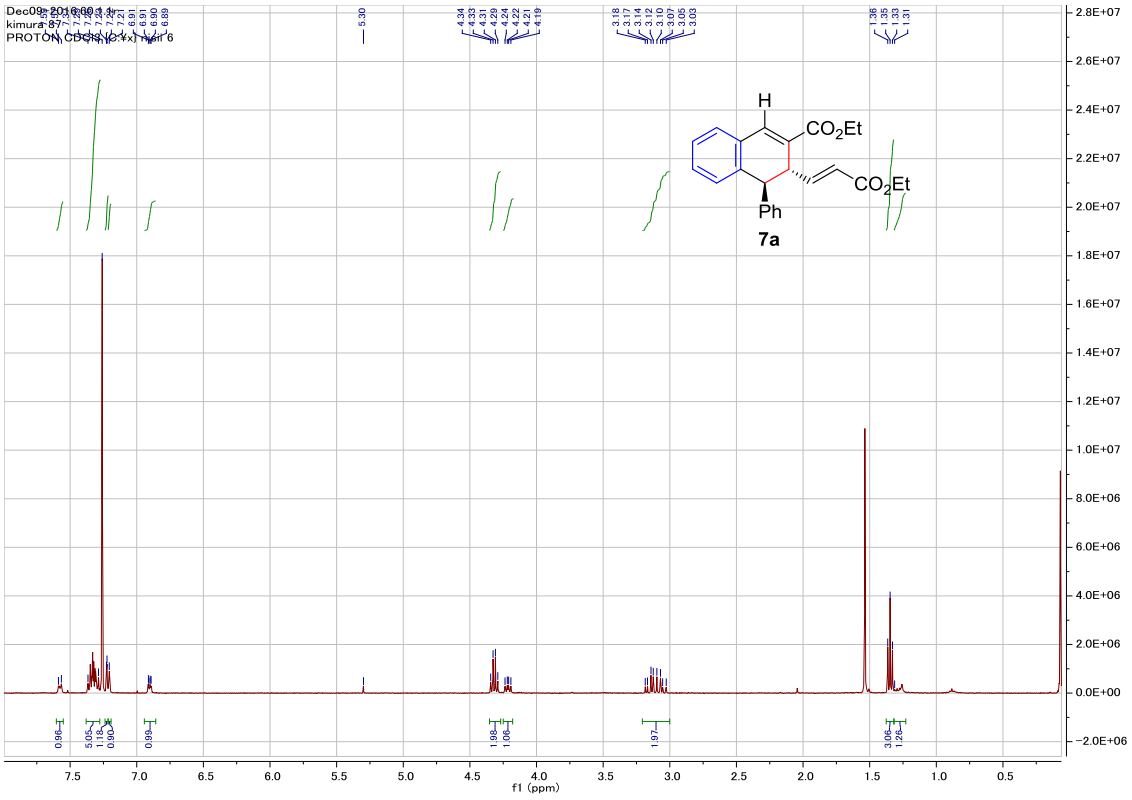

Nov09-2016.90.1.1r
takada 432
qnp_13C CDCl3 (C:¥x) aoya 10
OTf
CO2Me
Me
Ph
6f
f1 (ppm)

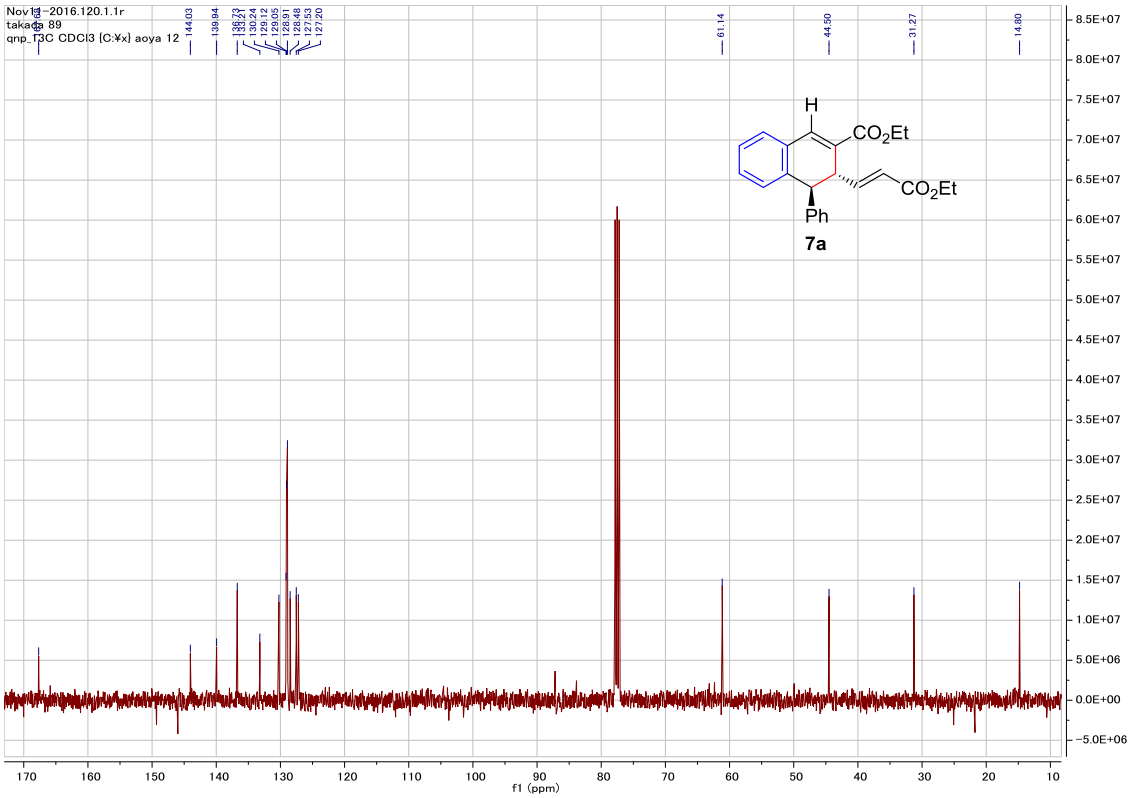
6h


Dec20~2016.10.1.1r
ST452
PROTON CDCl3 (C:¥xj_nisii_1
OTf
MeO
CO2Me
MeO
Me
Ph
6h
f1 (ppm)

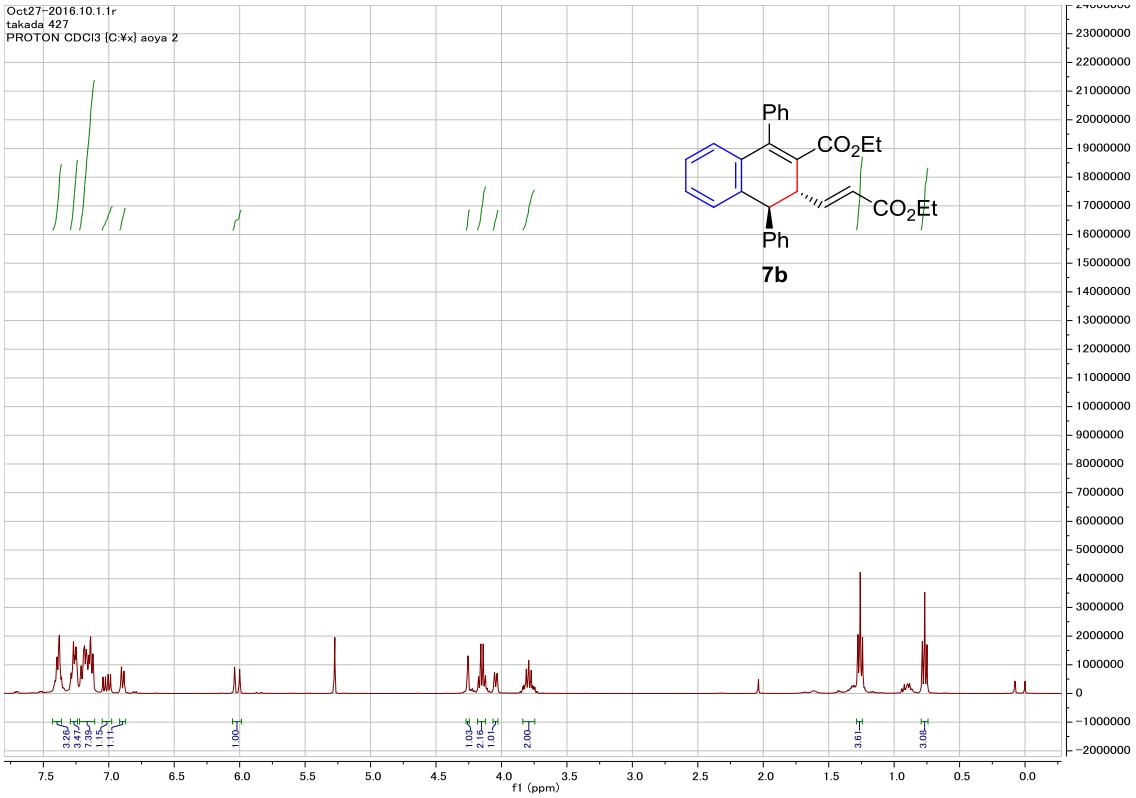

Dec20~2016.30.1.1r
ST452
qnp_13C CDCl3 (C:¥xj_nisii_3
OTf
MeO
CO2Me
MeO
Me
Ph
6h
f1 (ppm)

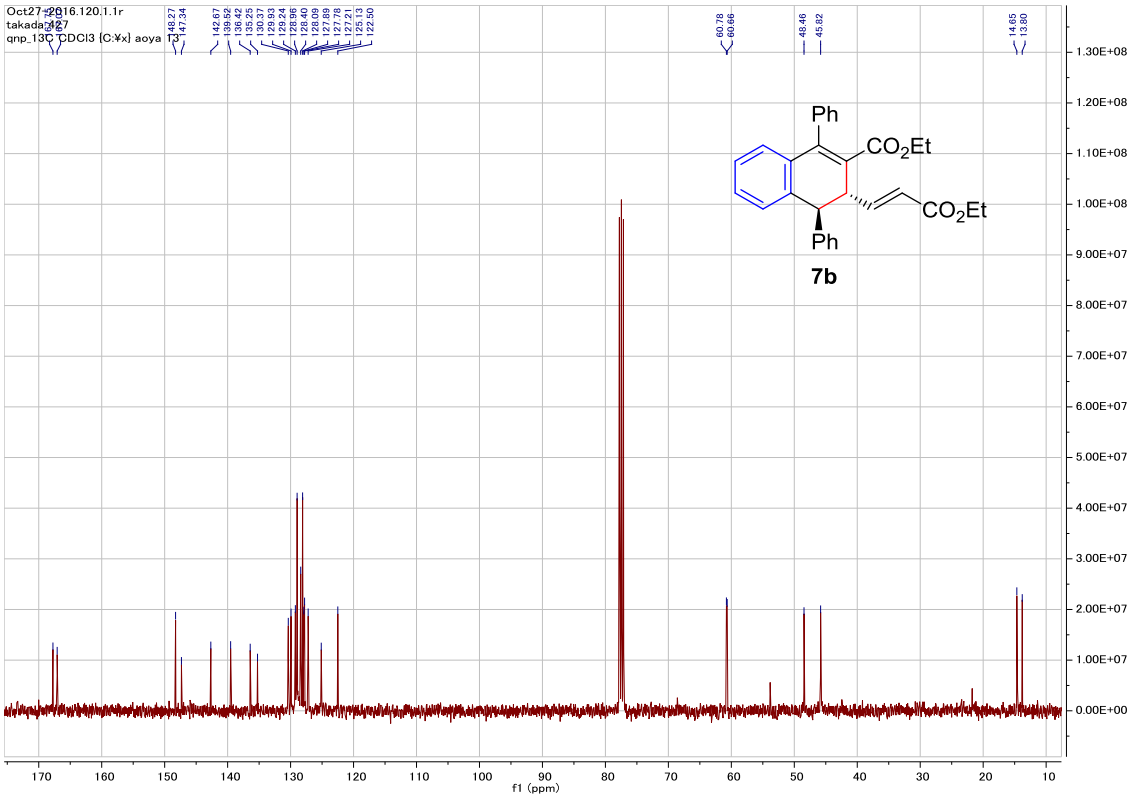
7a



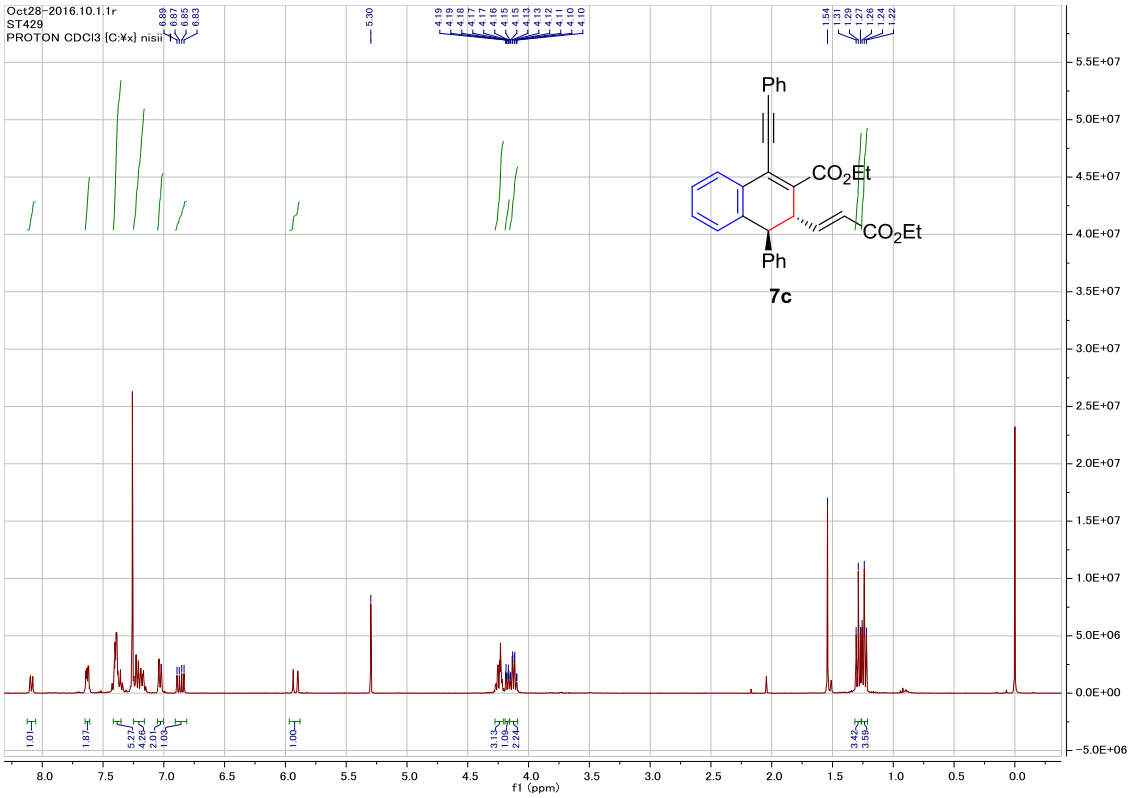


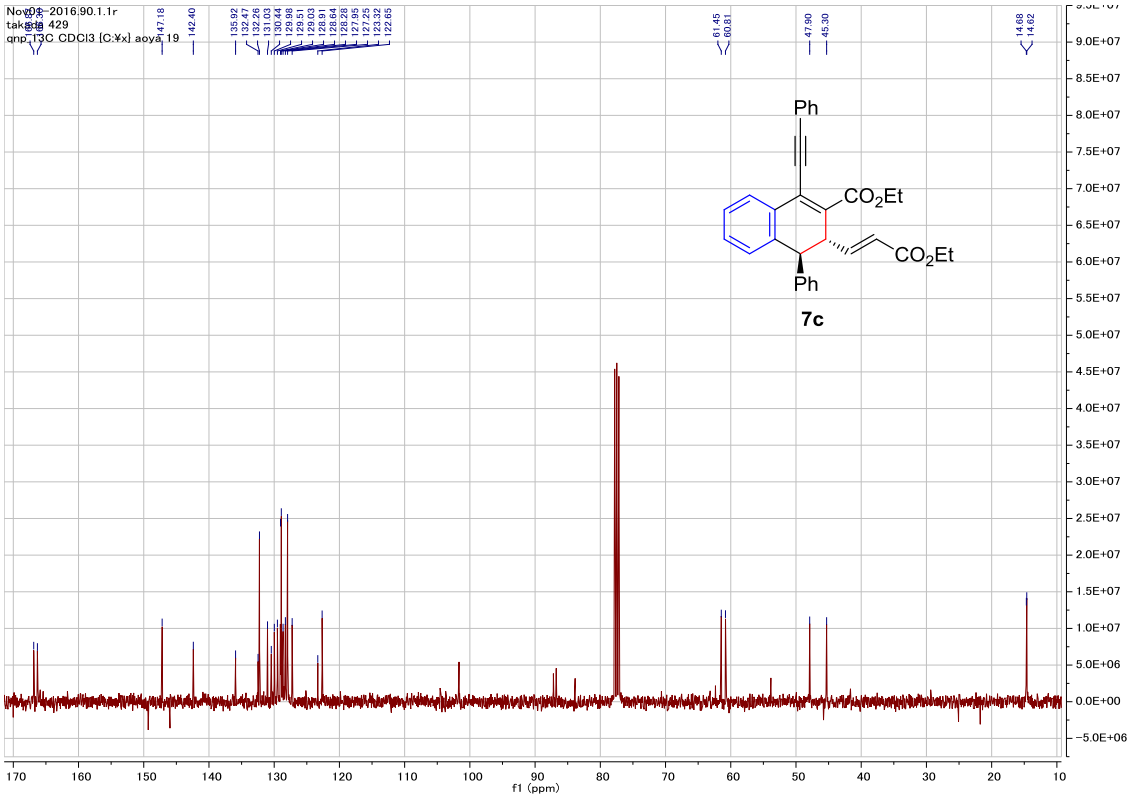
7b


Oct27-2016.10.1.1r
takada 427
PROTON CDCl3 {C:¥x} aoya 2
Ph
CO2Et
CO2Et
Ph
7b
f1 (ppm)

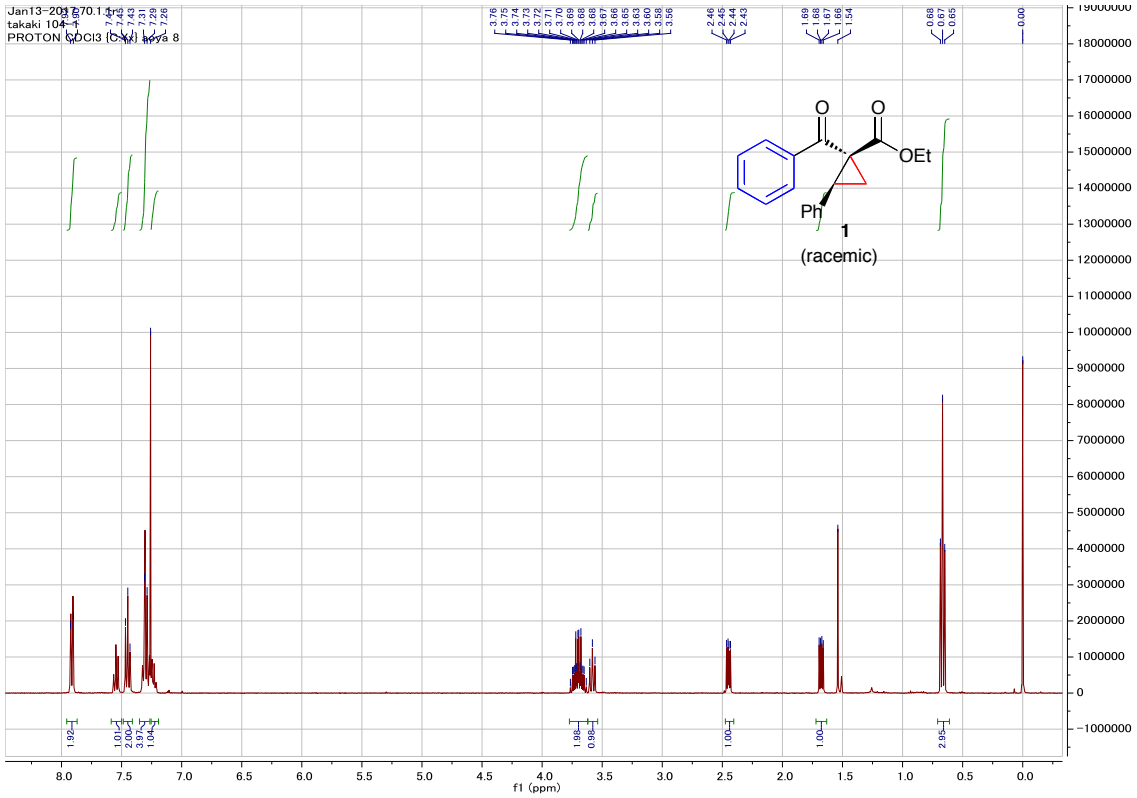

Oct27-2016.120.1.1r
takada 427
qnp_13C CDCl3 {C:¥x} aoya 13
Ph
CO2Et
CO2Et
Ph
7b
f1 (ppm)

7c

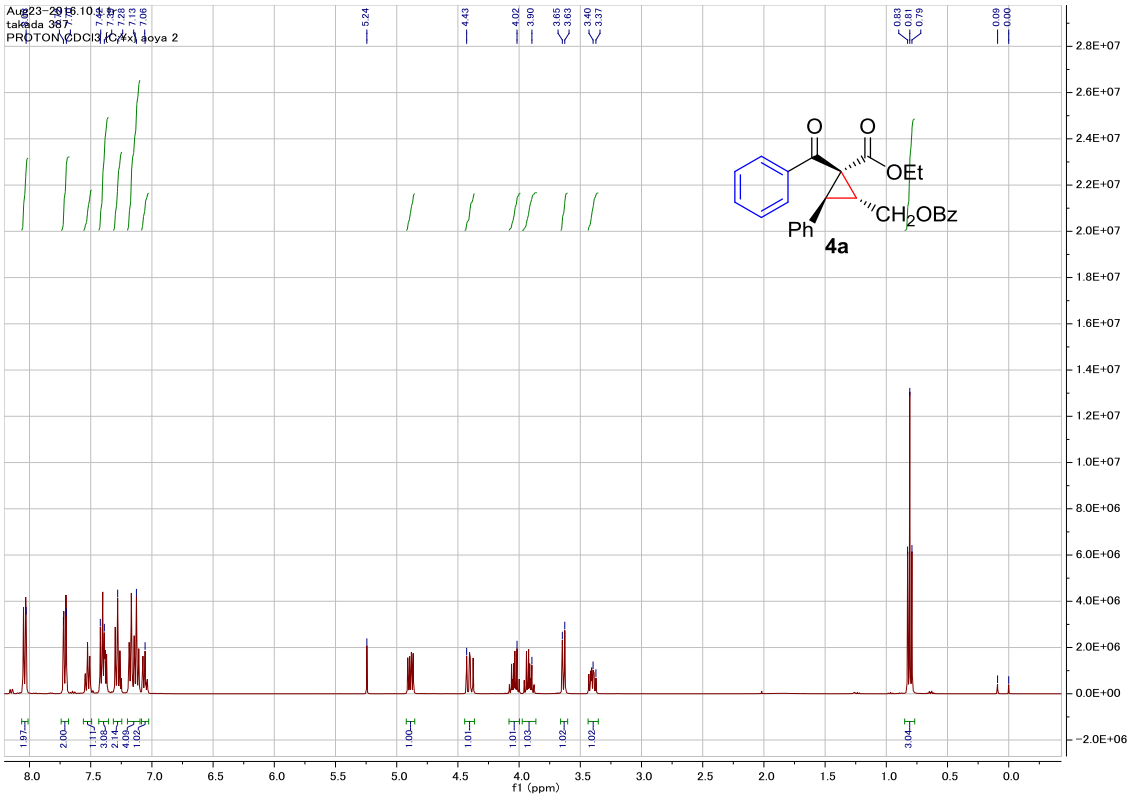

Oct28-2016.10.1.1r
ST429
PROTON CDCl3 (C:¥x) nisii
Ph
CO2Et
CO2Et
Ph
7c
f1 (ppm)

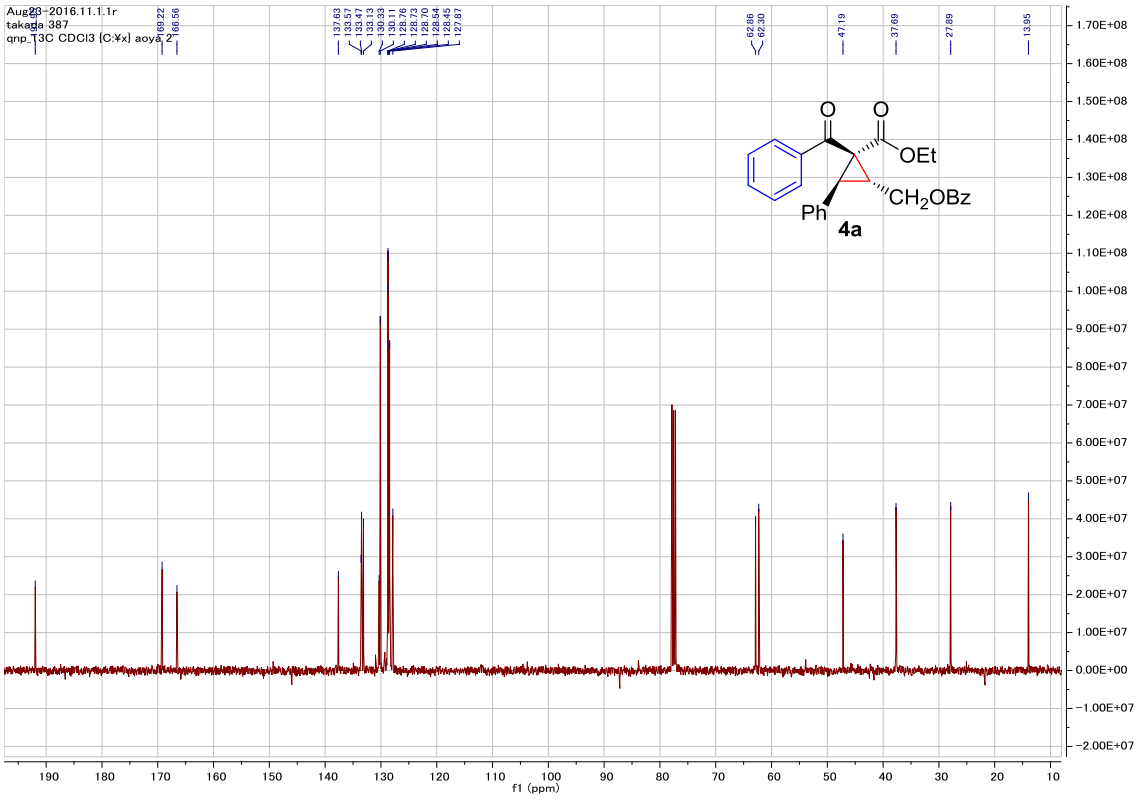

Nov09-2016.90.1.1r
takeda 429
qnp_13C CDCl3 (C:¥x) aoya 19
Ph
CO2Et
CO2Et
Ph
7c
f1 (ppm)

1

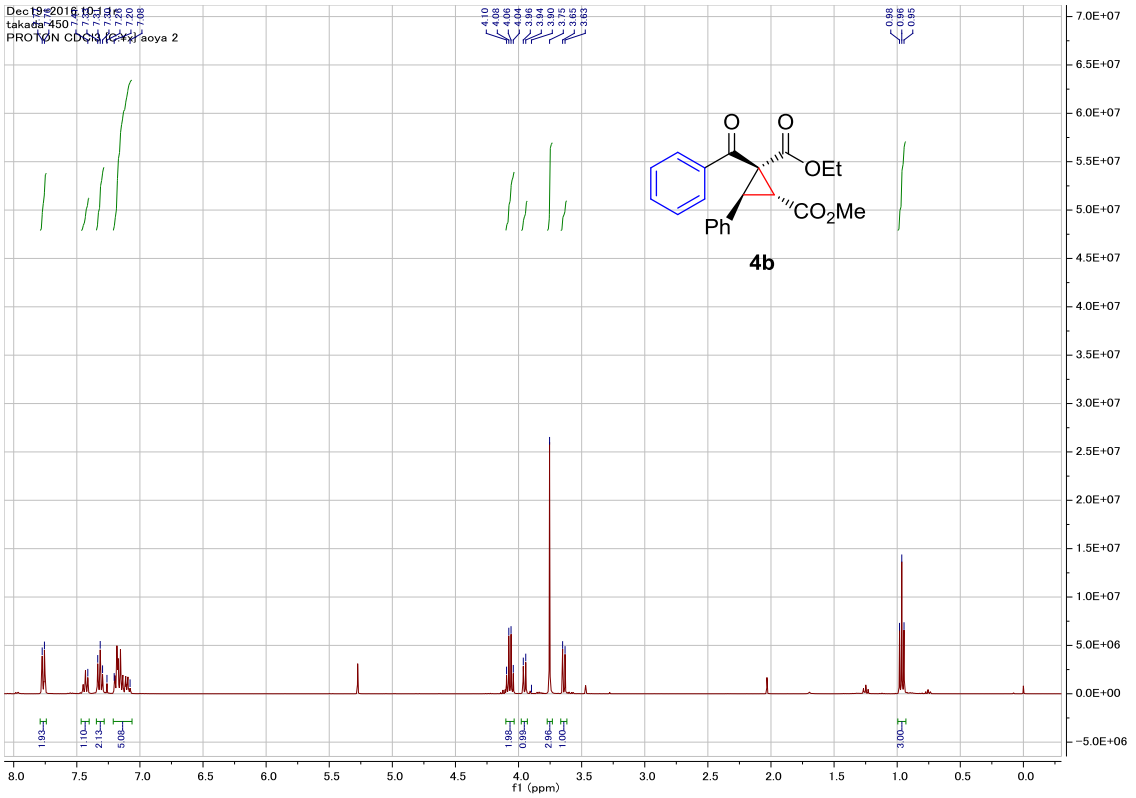


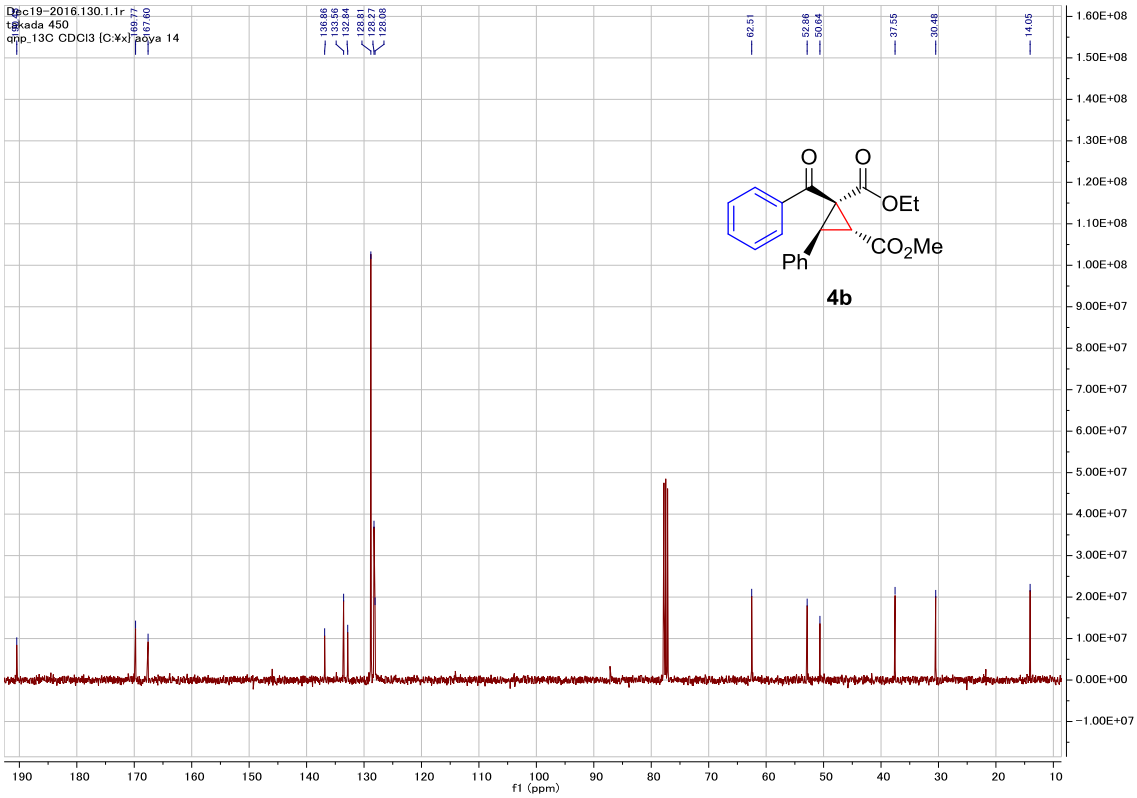
4a


takada 387
PROTON CDCl3 [C:¥x] aoya 2
5.24
4.43
4.02
3.90
3.65
3.63
3.40
3.37
0.83
0.81
0.79
0.09
0.00
7.46
7.28
7.13
7.06
O
O
OEt
CH2OBz
Ph
4a
f1 (ppm)

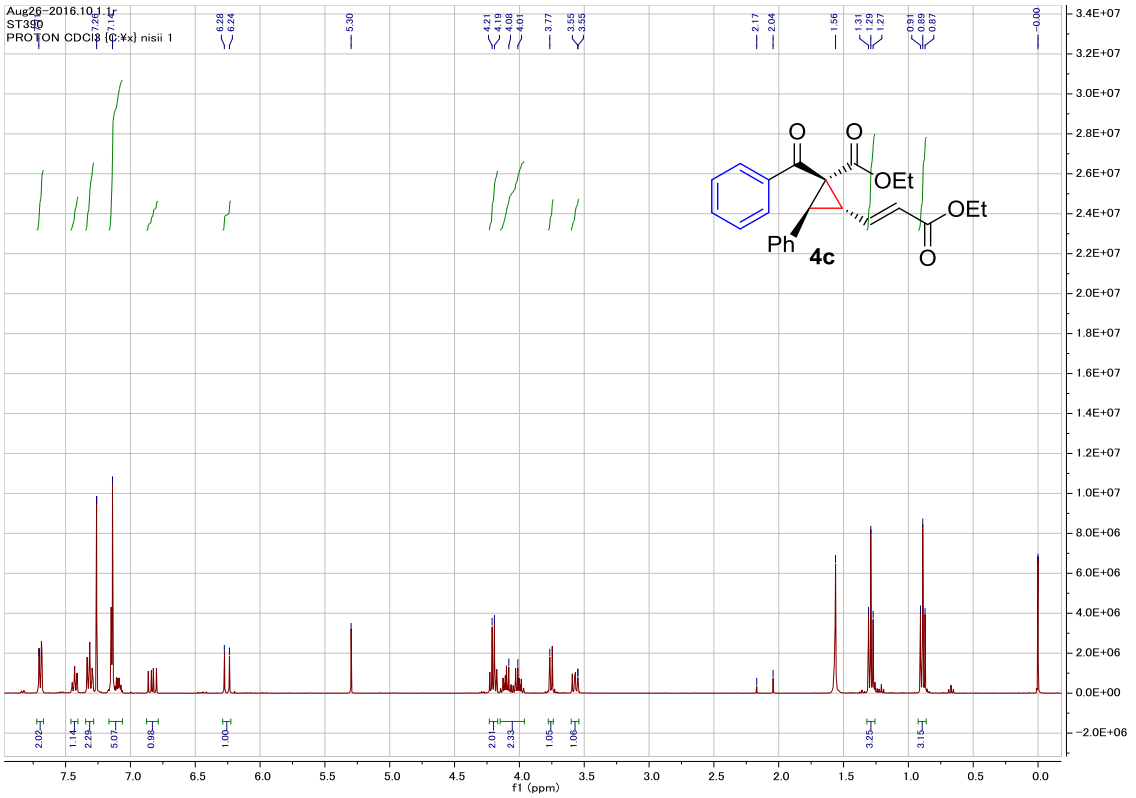

takada 387
qnp_13C CDCl3 [C:¥x] aoya 2
169.22
166.56
137.63
133.57
133.47
133.13
130.33
130.11
128.76
128.73
128.70
128.44
128.35
127.87
62.86
62.30
47.19
37.69
27.89
13.95
O
O
OEt
CH2OBz
Ph
4a
f1 (ppm)

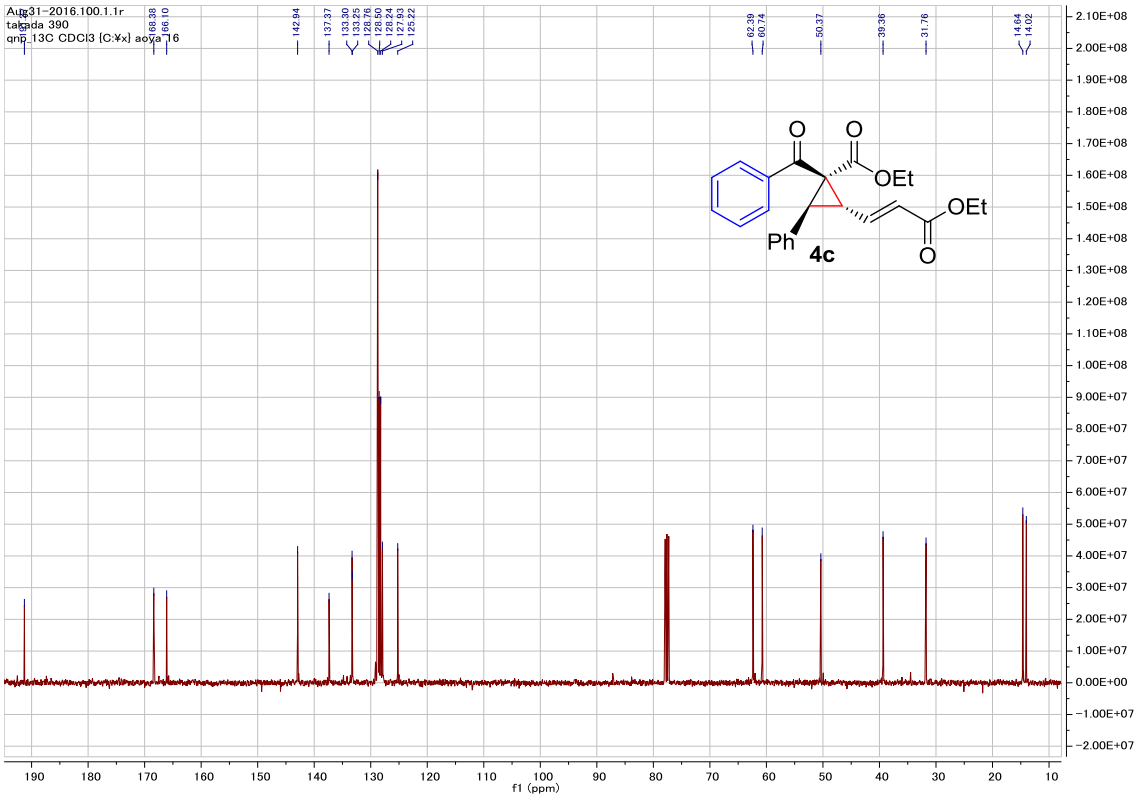
4b


Dec19-2016.10.1.1r
takada 450
PROTON CDCl3 [C:¥xx] aoya 2
4.10
4.08
4.06
4.04
3.96
3.94
3.90
3.75
3.65
3.63
0.98
0.96
0.95
7.26
7.20
7.08
O
O
OEt
CO2Me
Ph
4b
1.93
1.10
2.13
5.08
1.98
0.99
2.96
1.00
3.00
f1 (ppm)

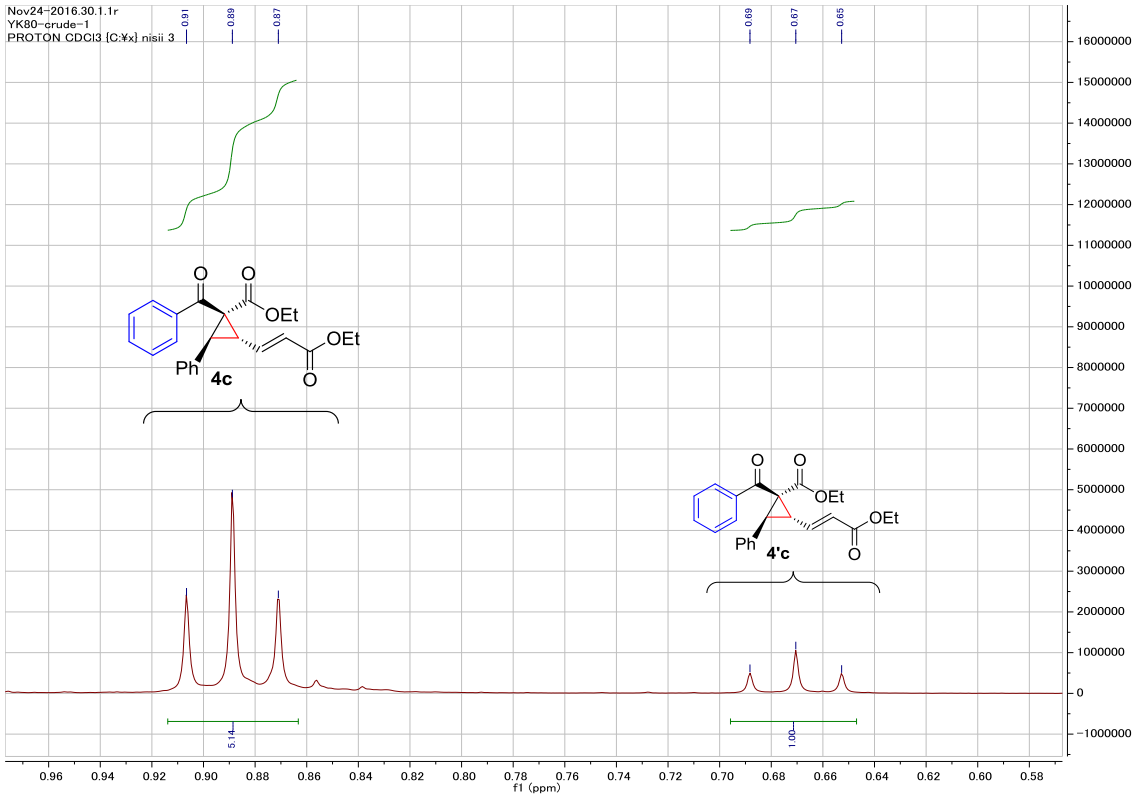

Dec19-2016.130.1.1r
takada 450
qnp_13C CDCl3 [C:¥xx] aoya 14
136.86
133.56
132.84
128.81
128.27
128.06
69.77
67.60
62.51
52.86
50.64
37.55
30.48
14.05
O
O
OEt
CO2Me
Ph
4b
f1 (ppm)

4c

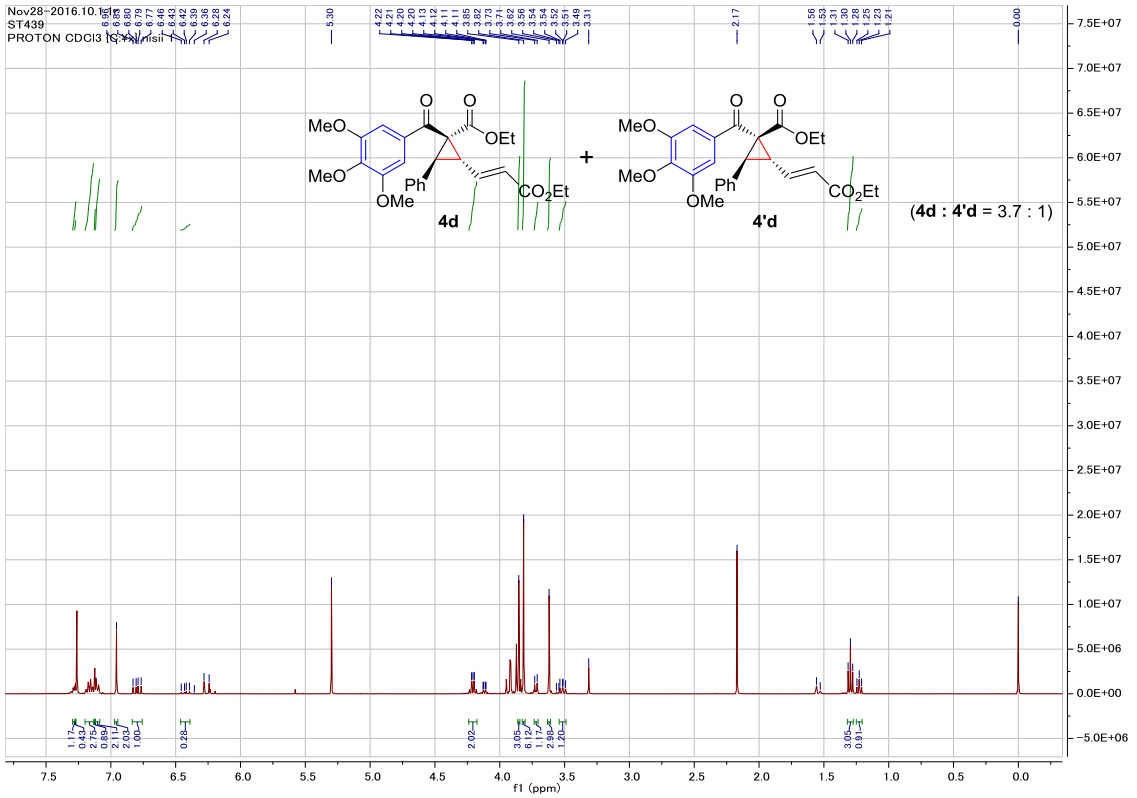

Aug26-2016.10.1.1r
ST390
PROTON CDCl3 [C:¥x] nisii 1
OEt
OEt
Ph
4c
f1 (ppm)

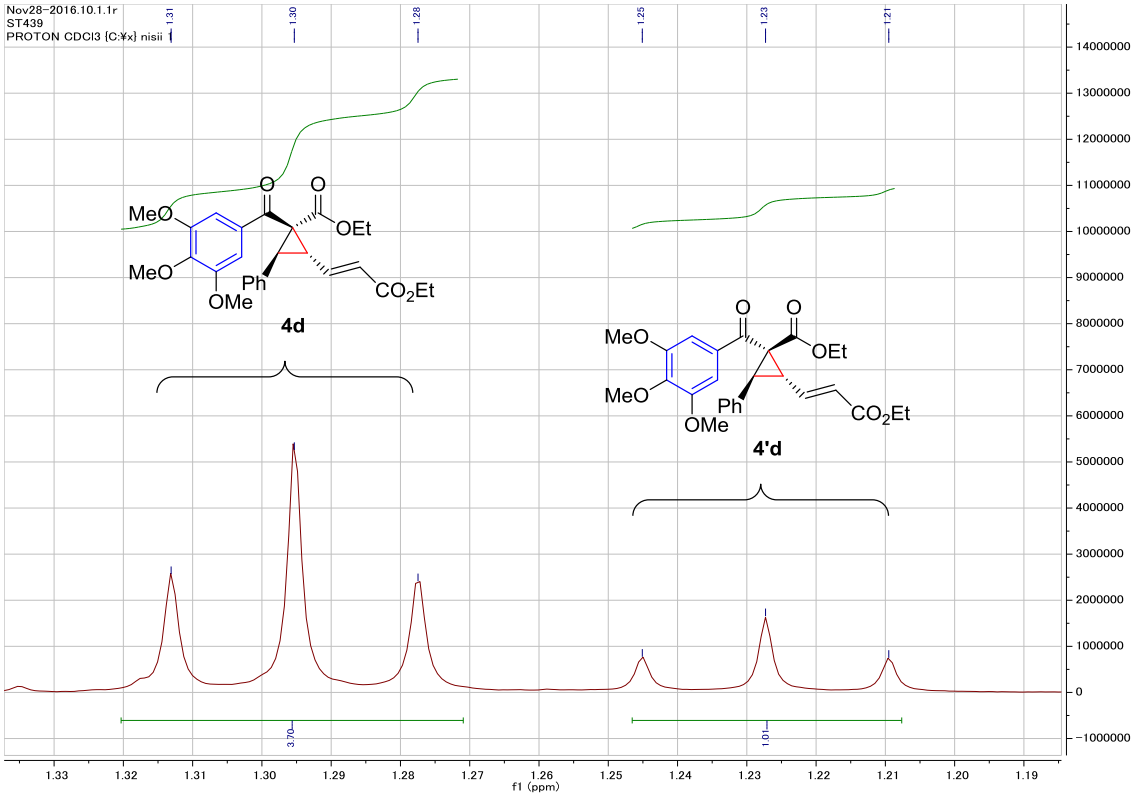

Aug31-2016.100.1.1r
takada 390
qn5_13C CDCl3 [C:¥x] aoya 16
OEt
OEt
Ph
4c
f1 (ppm)

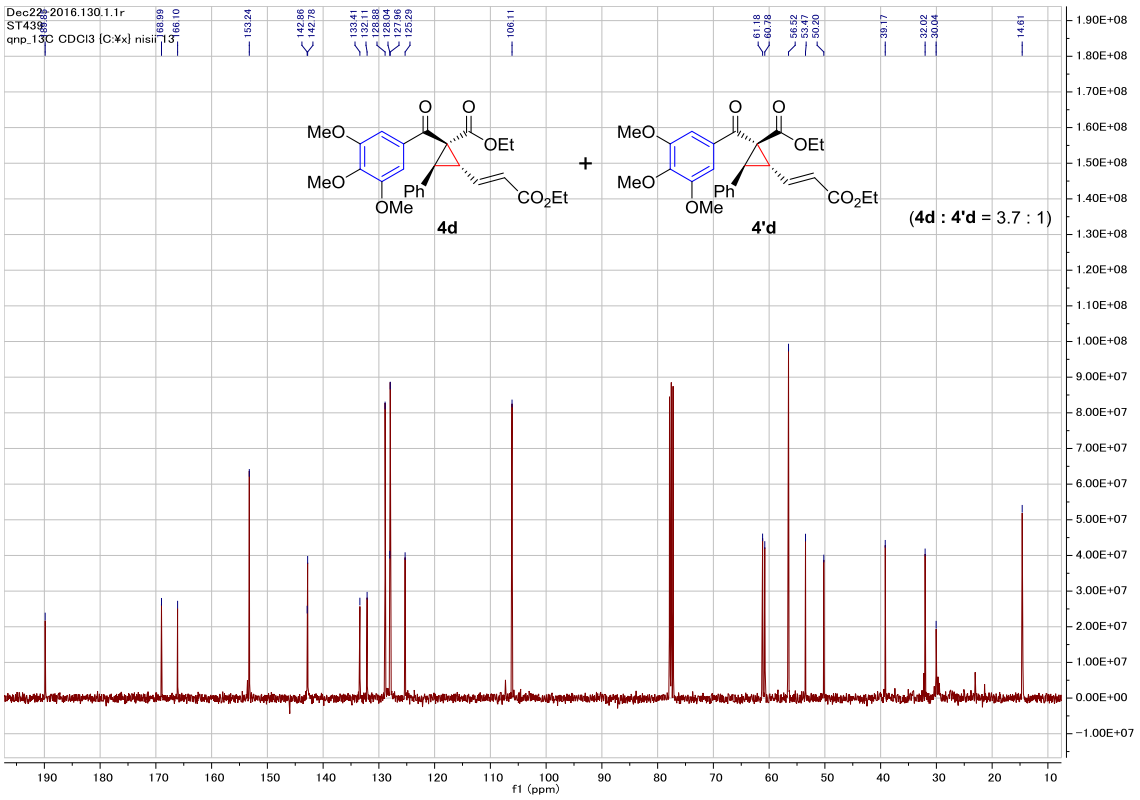
4c+4’c


Nov24-2016.30.1.1r
YK80-crude-1
PROTON CDCl3 (C:¥x) nisii 3
4c
4'c
f1 (ppm)

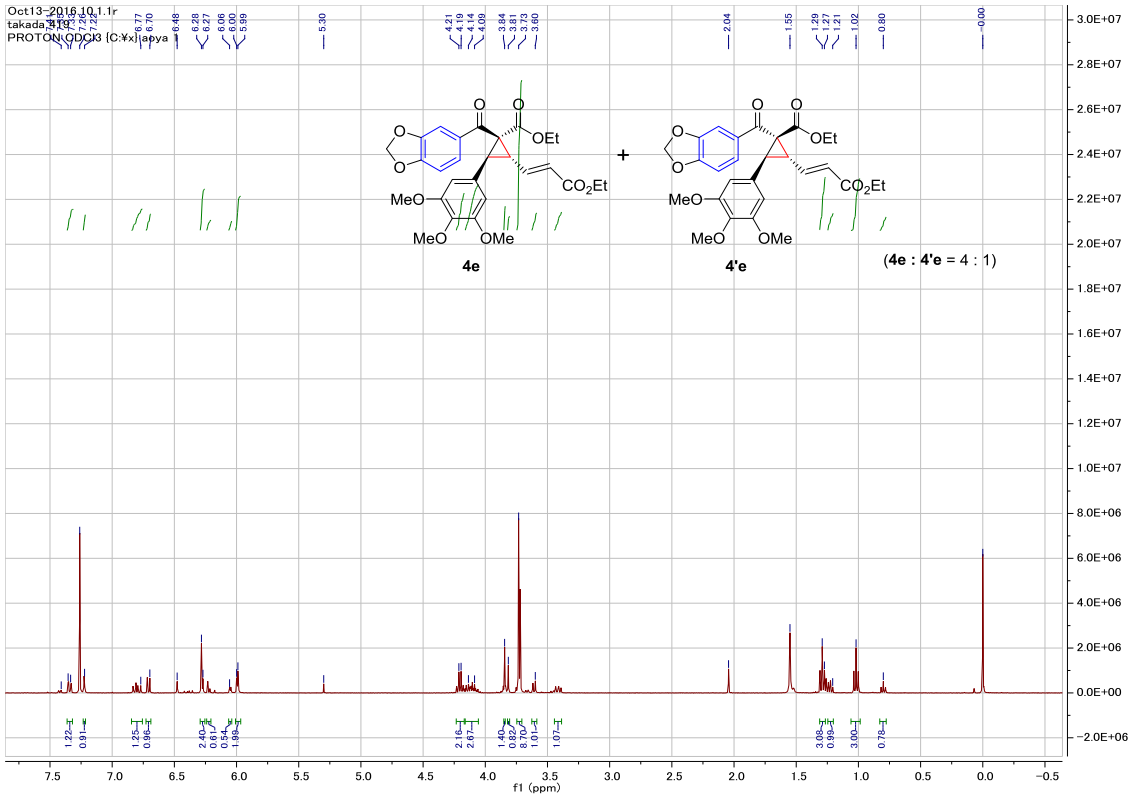
4d+4’d

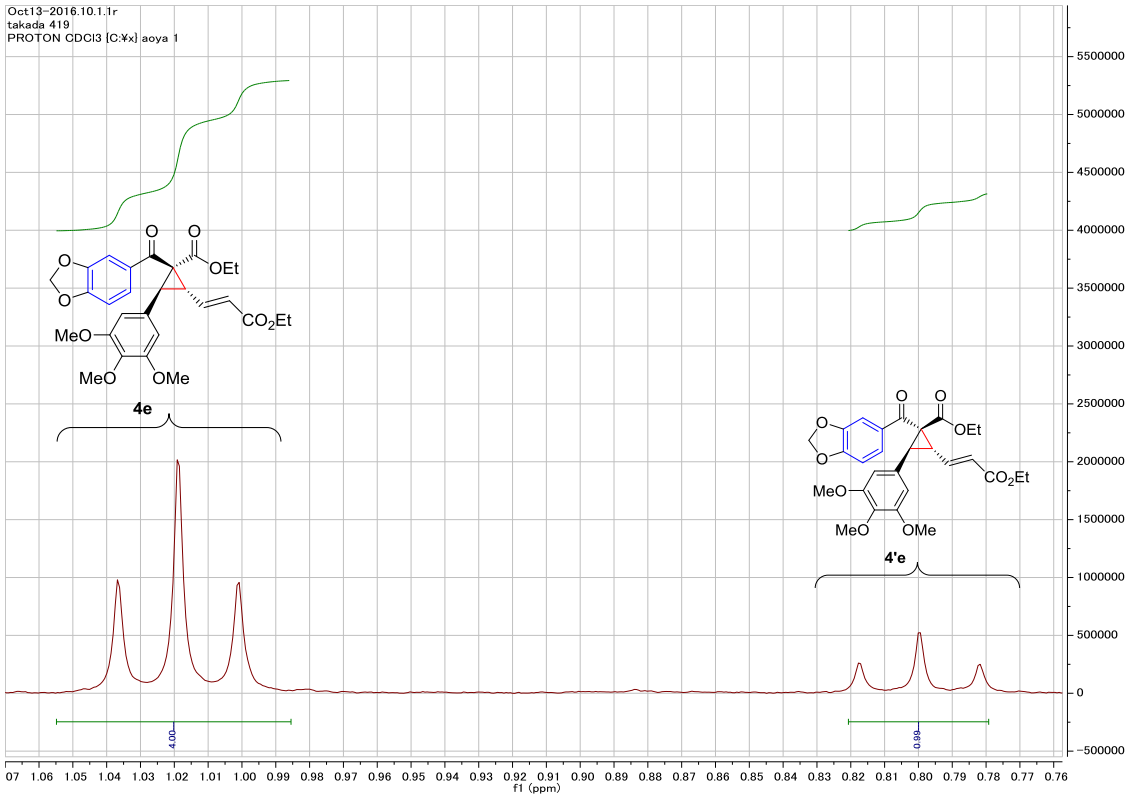

Nov28-2016.10.1r
ST439
PROTON CDCl3 (C:¥x) nisii
4d
4'd
(4d : 4'd = 3.7 : 1)
f1 (ppm)


Nov28-2016.10.1.1r
ST439
PROTON CDCl3 (C:¥x) nisii
MeO
MeO
OMe
Ph
OEt
CO2Et
4d
4'd
f1 (ppm)

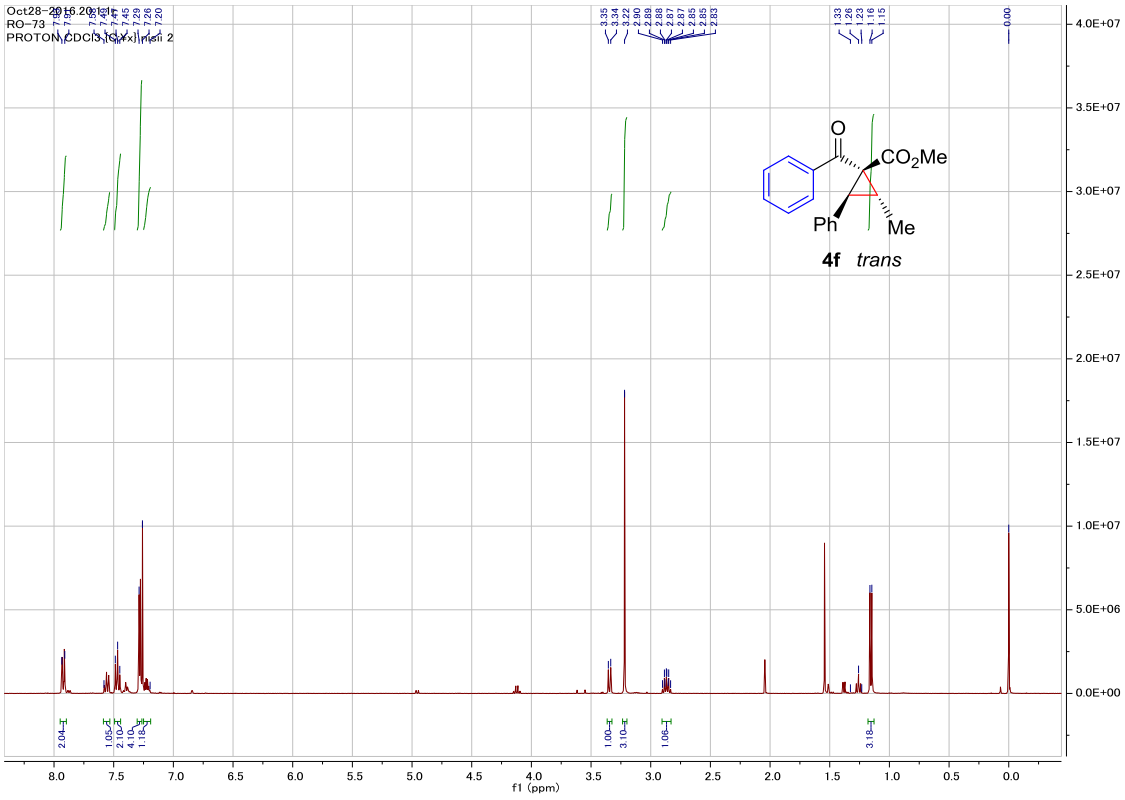

Dec22-2016.130.1.1r
ST439
qnp_13C CDCl3 (C:¥x) nisii
4d
4'd
(4d : 4'd = 3.7 : 1)
f1 (ppm)

4e+4’e

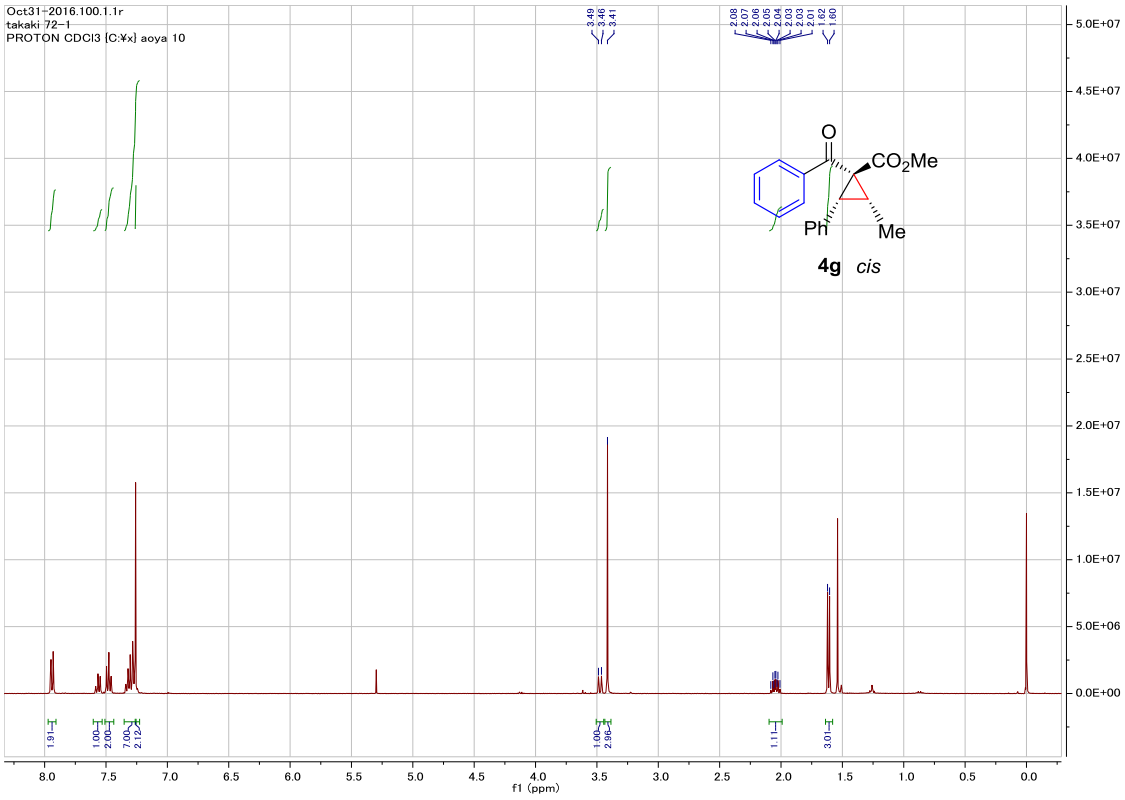

Oct13-2016.10.1.1r
takada 419
PROTON CDCl3 (C:¥x) aoya 1
4e
4'e
(4e : 4'e = 4 : 1)
f1 (ppm)


Oct13-2016.10.1.1r
takada 419
PROTON CDCl3 (C:¥x) aoya 1
4e
4'e
f1 (ppm)

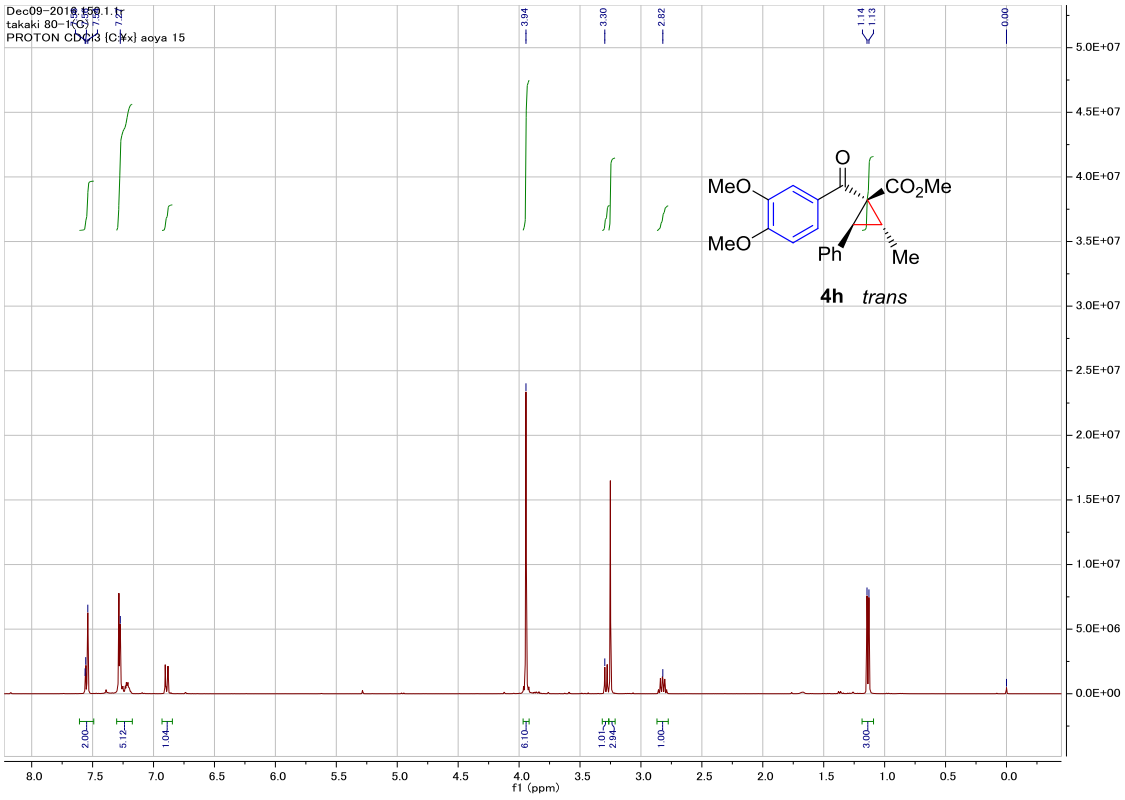
4f

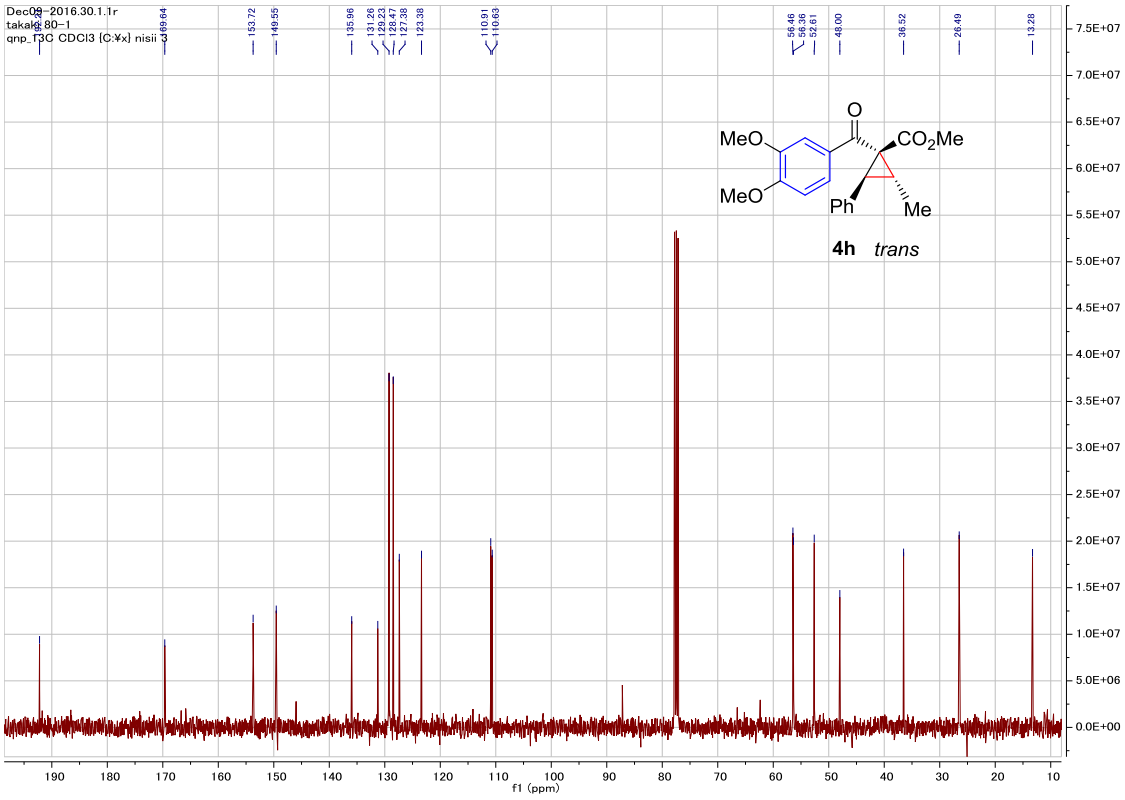

Oct28-2016.20.1r
RO-73
PROTON CDCl3 [C:¥x] nell 2
O
CO2Me
Ph
Me
4f trans
f1 (ppm)

4g

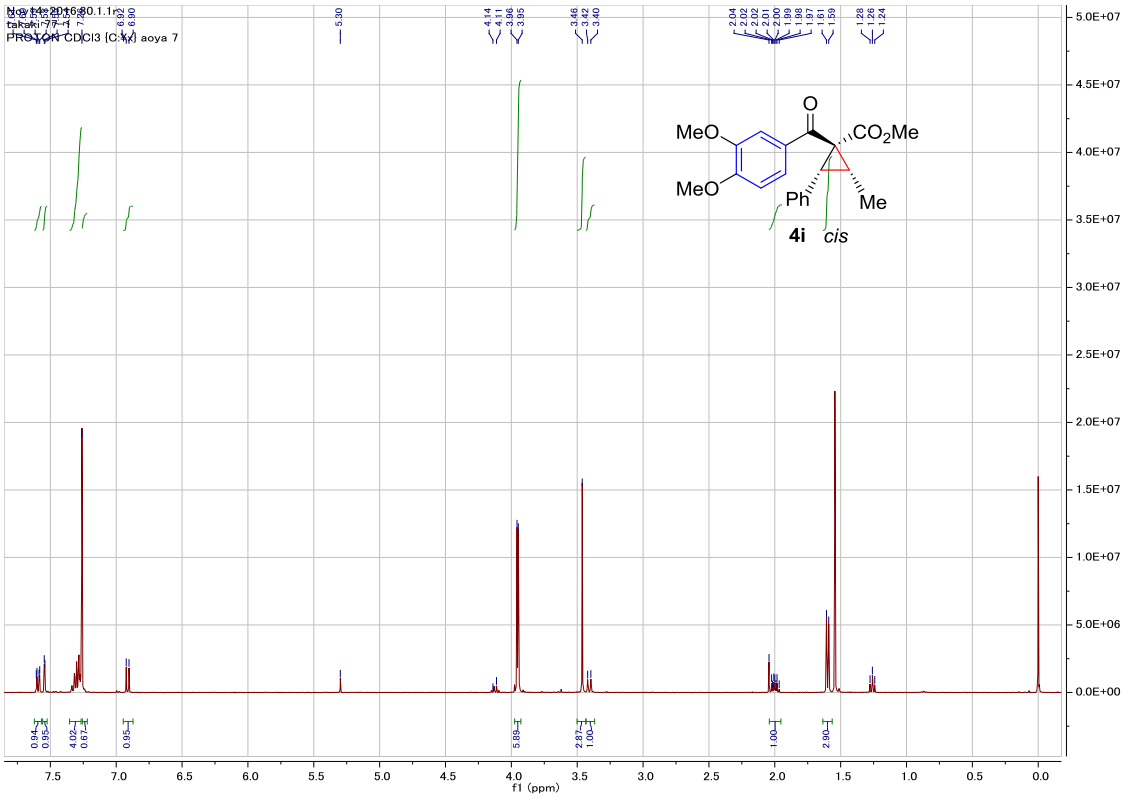

Oct31-2016.100.1.1r
takaki-72-1
PROTON CDCl3 [C:¥x] aoya 10
O
CO2Me
Ph
Me
4g cis
f1 (ppm)

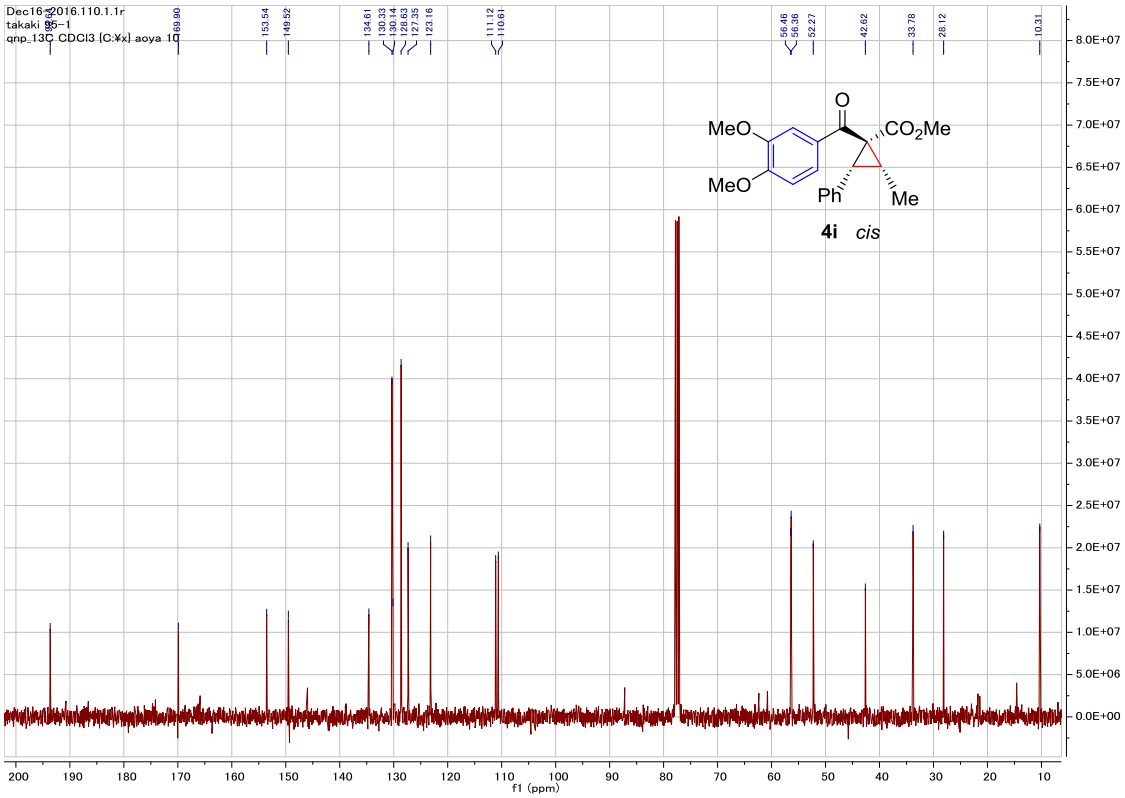
4h


PROTON CDCl3 {C:¥x} aoya 15
3.84
3.30
2.82
1.14
1.13
0.00
MeO
MeO
O
CO2Me
Ph
Me
4h trans
f1 (ppm)

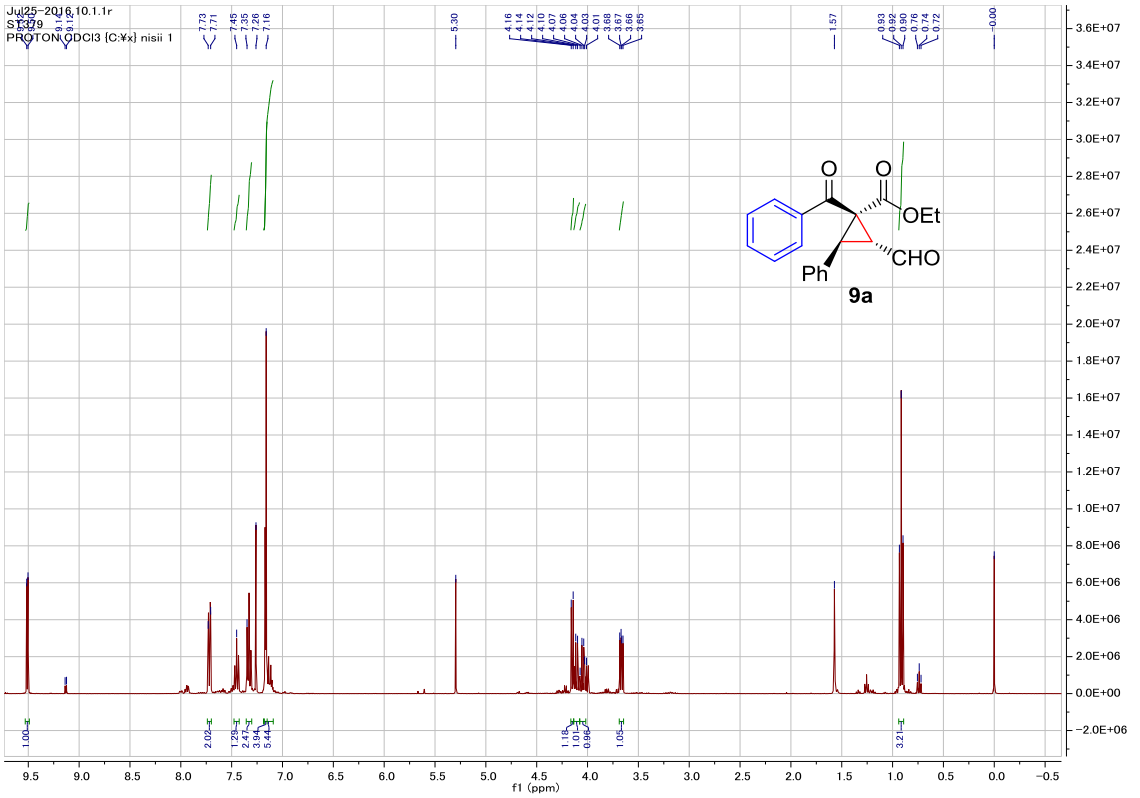

takaki 80-1
qnp_13C CDCl3 {C:¥x} nisii 3
169.64
153.72
149.55
135.96
131.26
128.23
128.17
127.38
123.38
110.91
110.63
56.46
56.36
52.61
48.00
36.52
26.49
13.28
MeO
MeO
O
CO2Me
Ph
Me
4h trans
f1 (ppm)

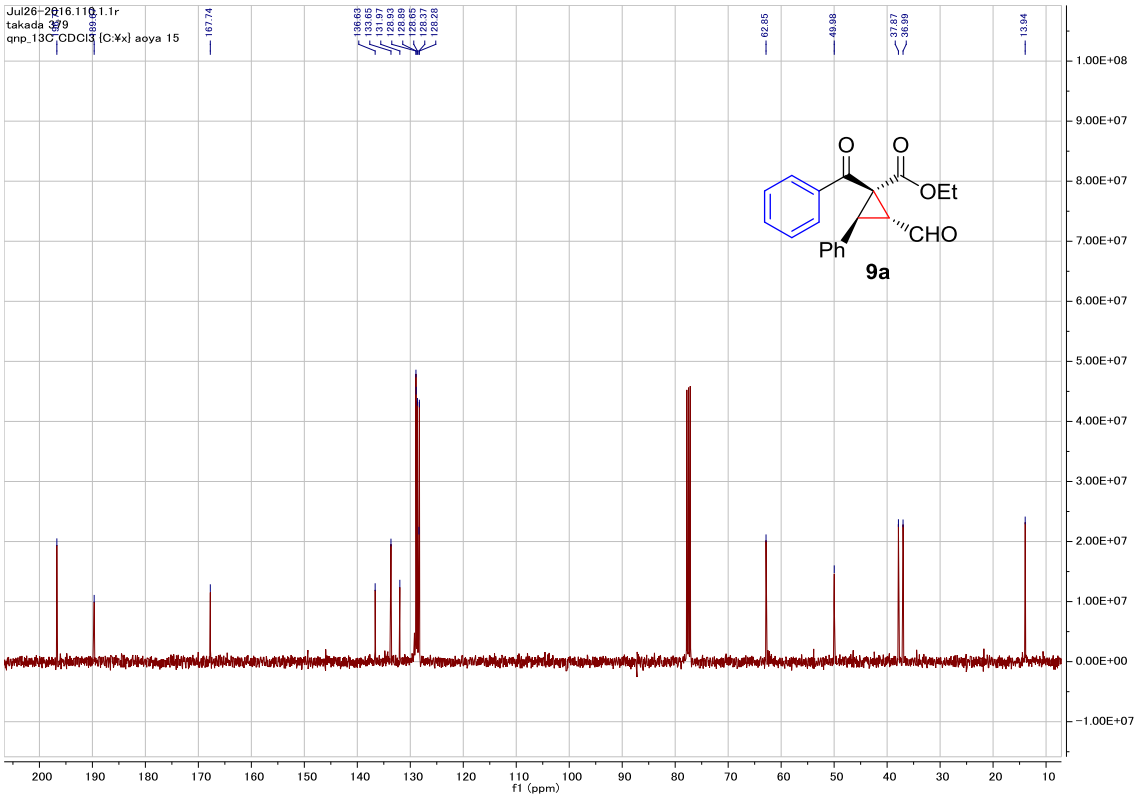
4i


MeO
MeO
O
CO2Me
Ph
Me
4i cis
f1 (ppm)

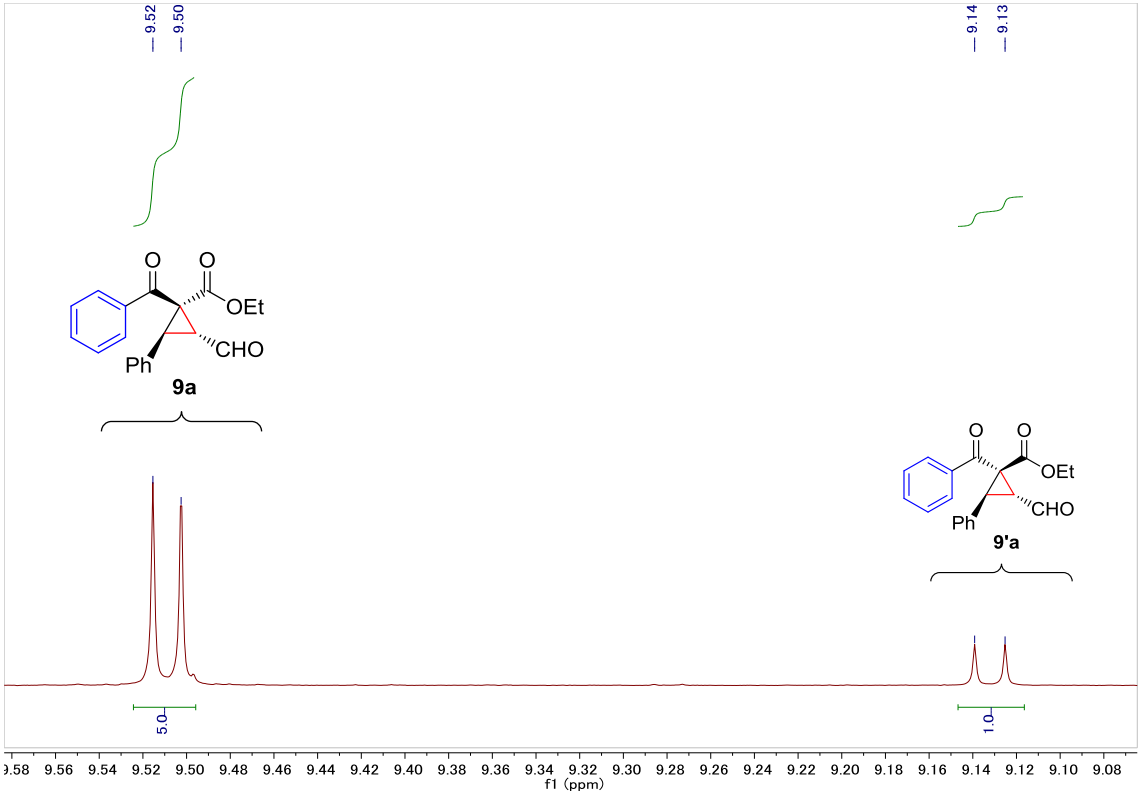

MeO
MeO
O
CO2Me
Ph
Me
4i cis
f1 (ppm)

9a

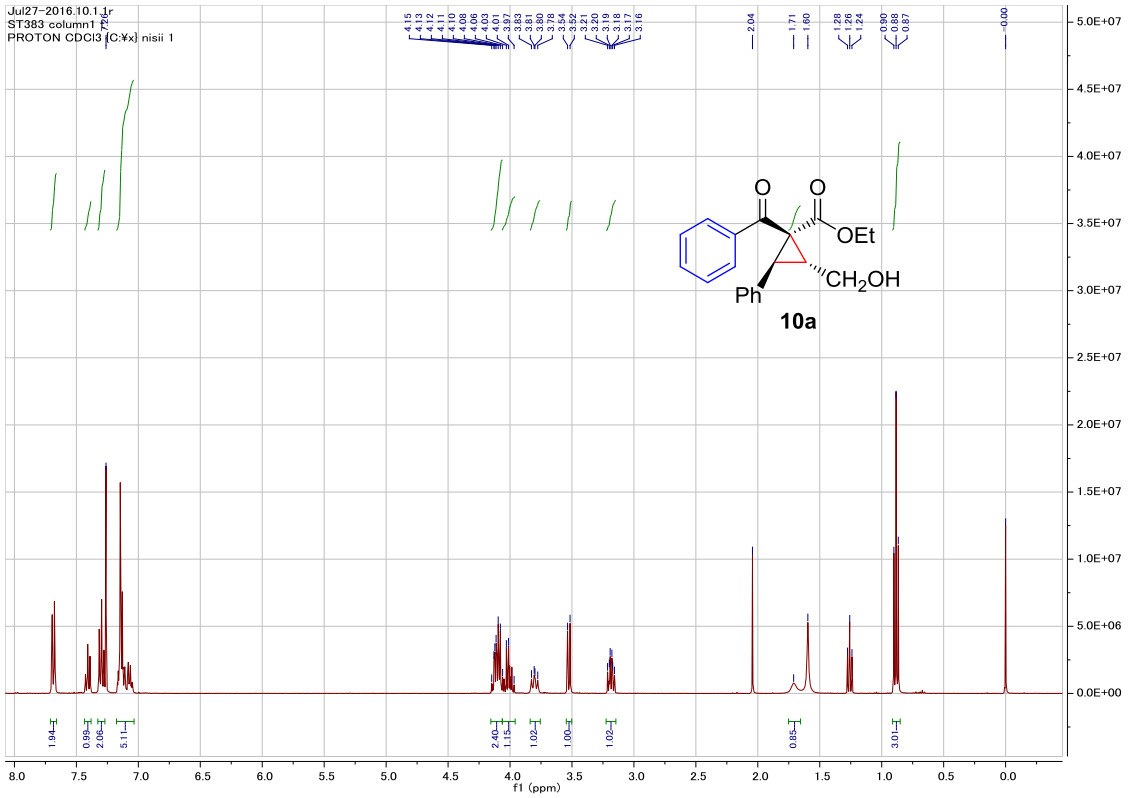

Jul25-2016.10.1.1r
ST379
PROTON.ODCl3 (C:¥x) nisii 1
O
O
OEt
CHO
Ph
9a
f1 (ppm)

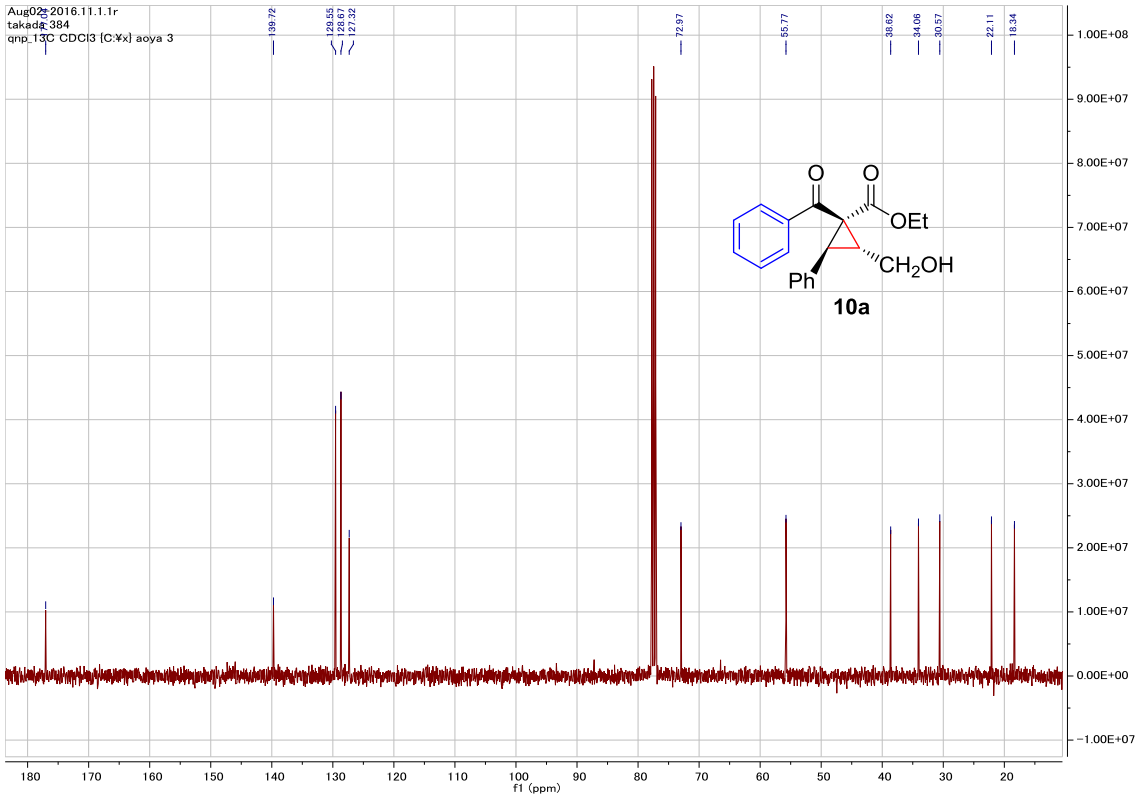

Jul26-2016.11.0.1r
takada 379
qnp_13C_CDCl3 (C:¥x) aoya 15
O
O
OEt
CHO
Ph
9a
f1 (ppm)

9a+9'a

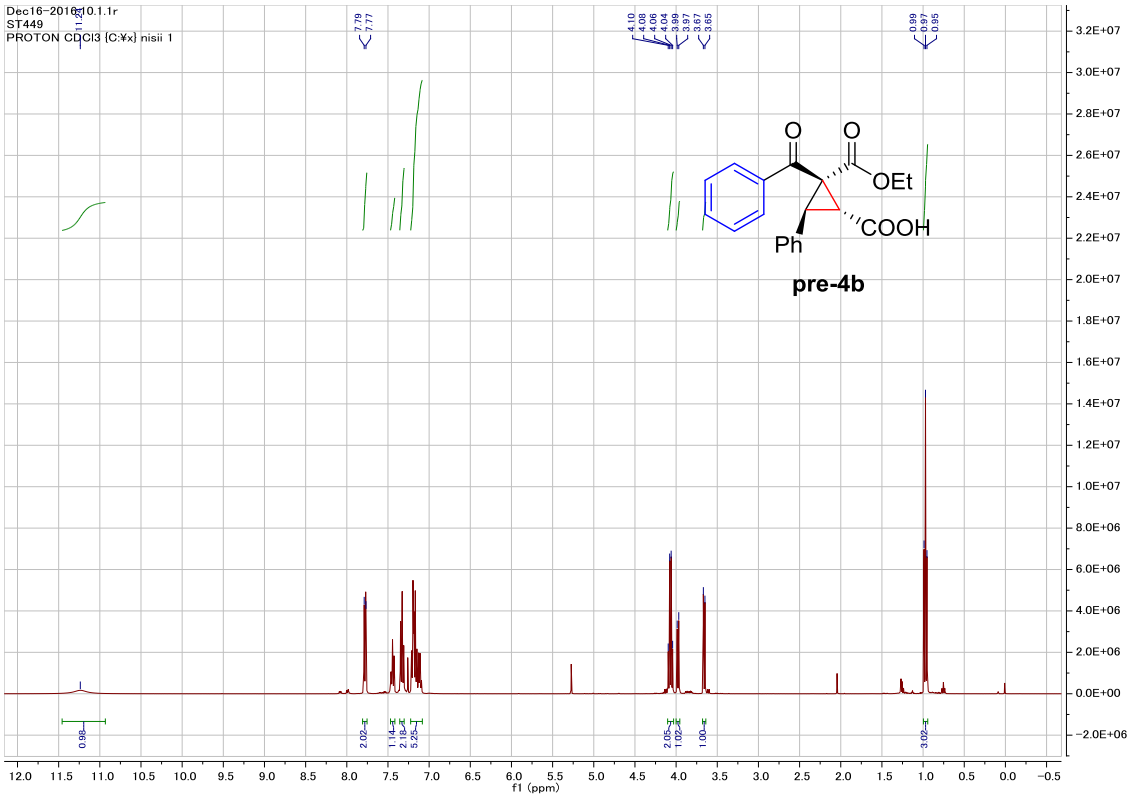

9.52
9.50
9.14
9.13
O
O
OEt
CHO
Ph
9a
O
O
OEt
CHO
Ph
9'a
5.0
1.0
9.58 9.56 9.54 9.52 9.50 9.48 9.46 9.44 9.42 9.40 9.38 9.36 9.34 9.32 9.30 9.28 9.26 9.24 9.22 9.20 9.18 9.16 9.14 9.12 9.10 9.08
f1 (ppm)

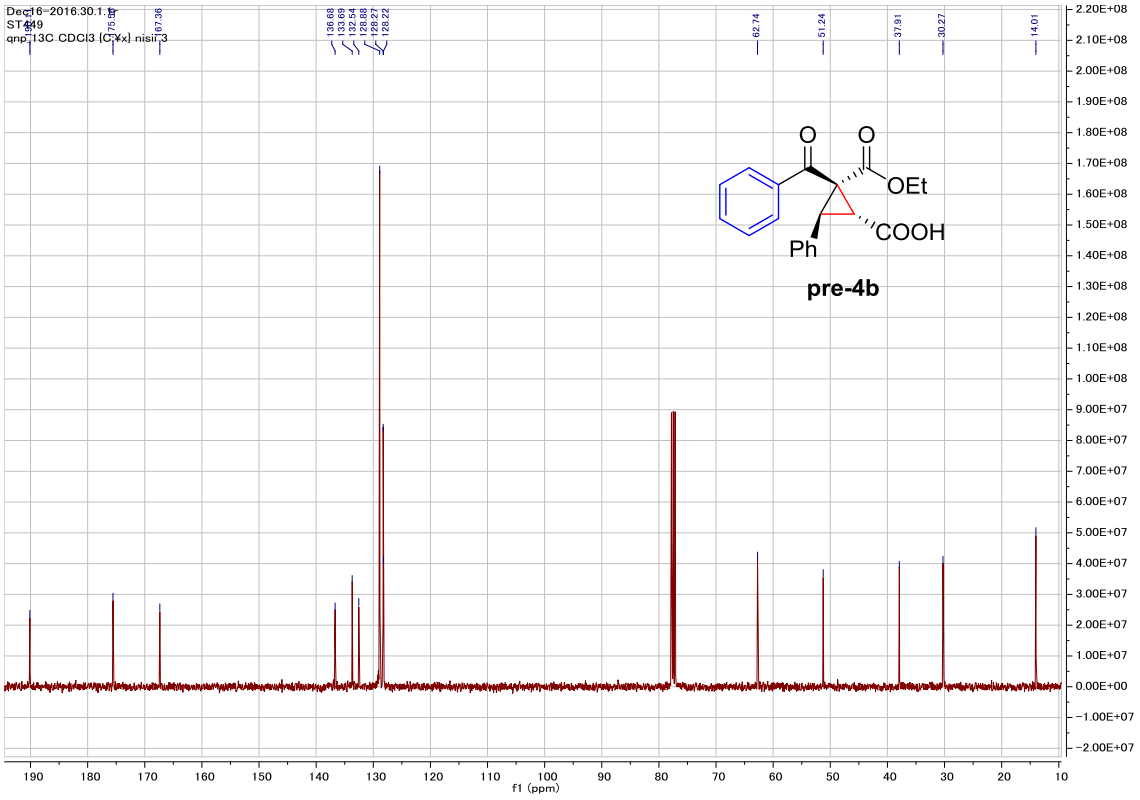
10a


Jul27-2016.10.1.1r
ST383 column1
PROTON CDCl3 [C:¥x] nisii 1
O
O
OEt
CH2OH
Ph
10a
f1 (ppm)

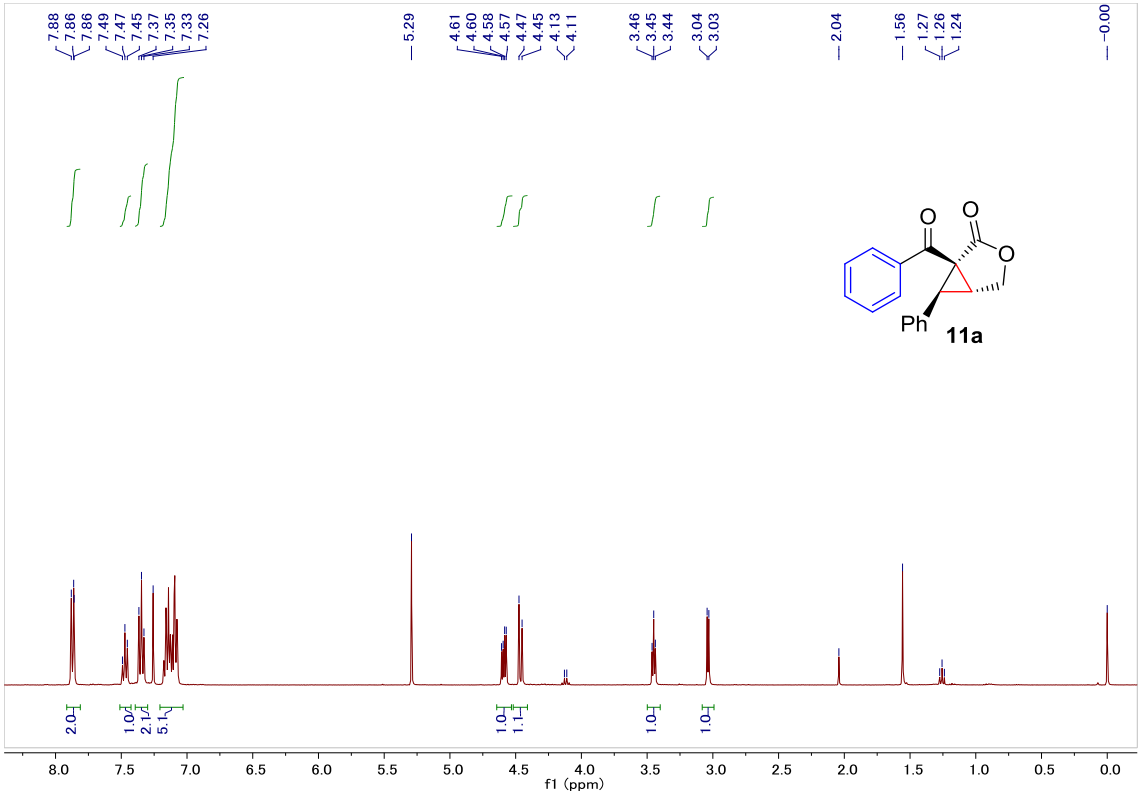

Aug02-2016.11.1.1r
takada 384
qnp_13C CDCl3 [C:¥x] aoya 3
O
O
OEt
CH2OH
Ph
10a
f1 (ppm)

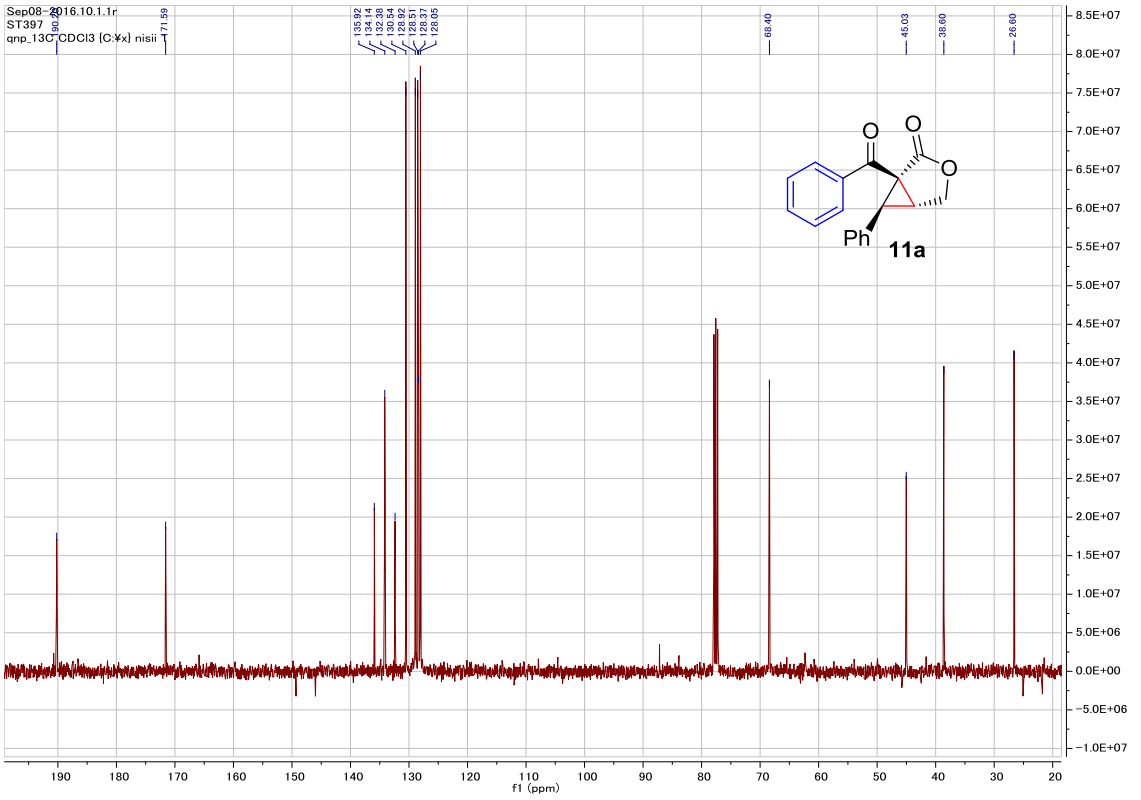
pre-4b


Dec16-2016.10.1.1r
ST449
PROTON CDCl3 (C:¥x) nisii 1
pre-4b
f1 (ppm)

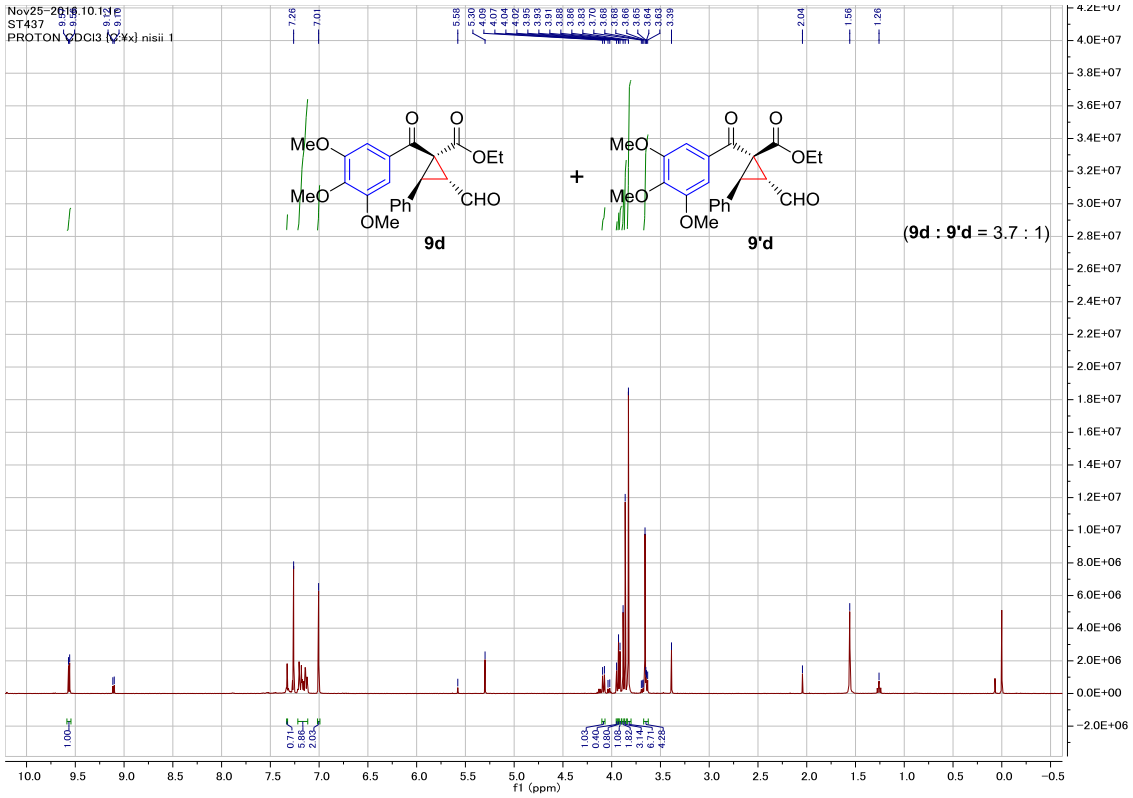

Dec16-2016.30.1.1r
ST449
qnp 13C CDCl3 (C:¥x) nisii 3
pre-4b
f1 (ppm)

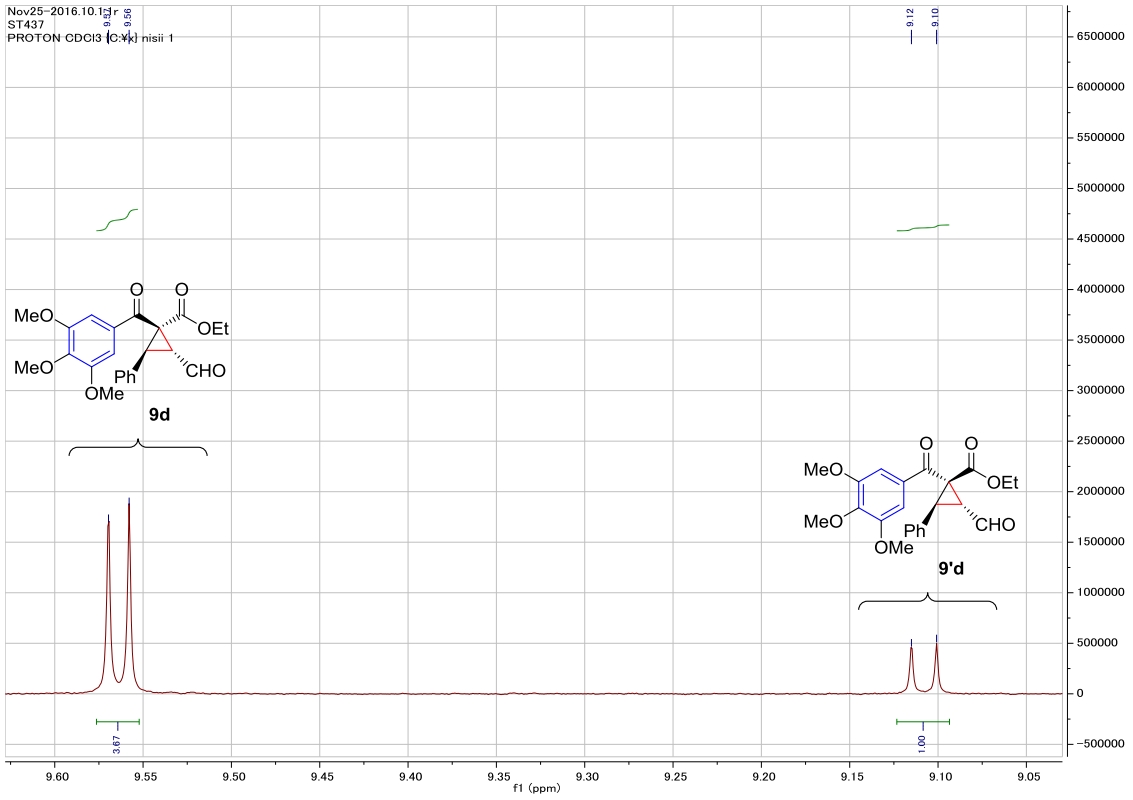
11a


7.88
7.86
7.86
7.49
7.47
7.45
7.37
7.35
7.33
7.26
5.29
4.61
4.60
4.58
4.57
4.47
4.45
4.13
4.11
3.46
3.45
3.44
3.04
3.03
2.04
1.56
1.27
1.26
1.24
0.00
O
O
O
Ph
11a
2.0
1.0
2.1
5.1
1.0
1.1
1.0
1.0
f1 (ppm)

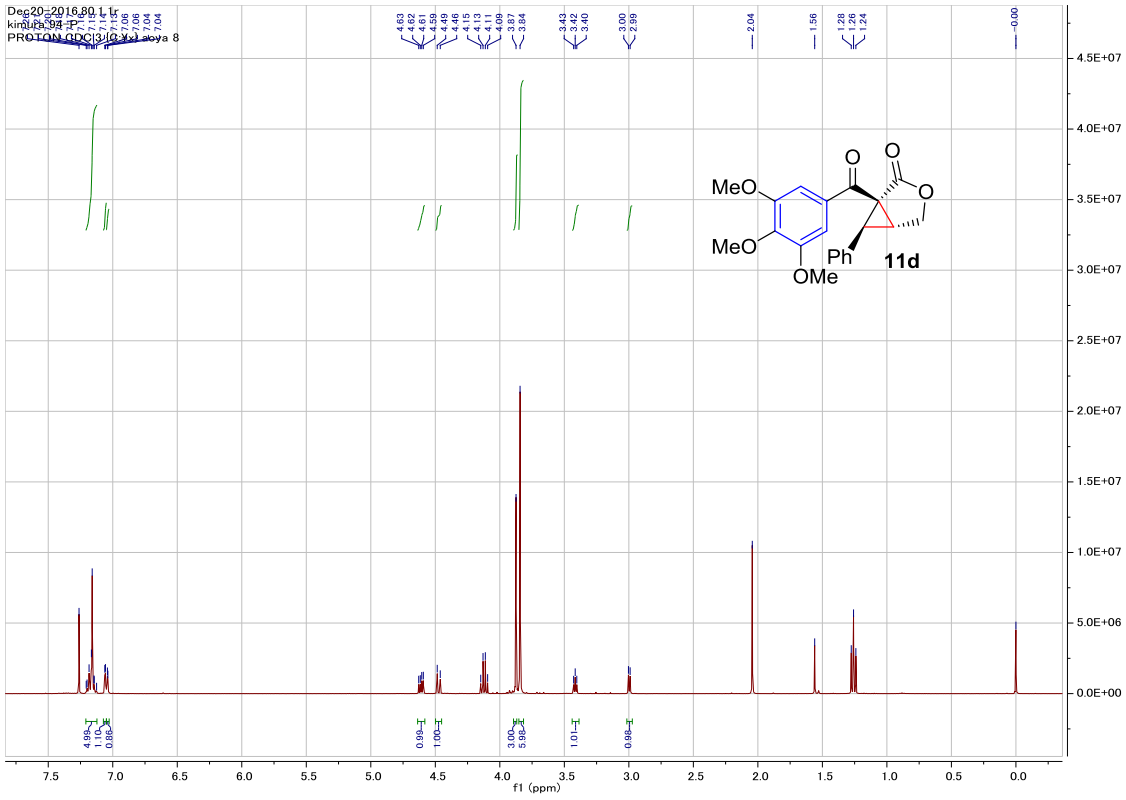

Sep08-2016.10.1.1r
ST397
qnp_13C_CDCl3 (C:¥x) nisii
190.90
171.59
135.92
134.14
130.88
130.54
128.92
128.51
128.37
126.95
68.40
45.03
38.60
26.60
O
O
O
Ph
11a
f1 (ppm)

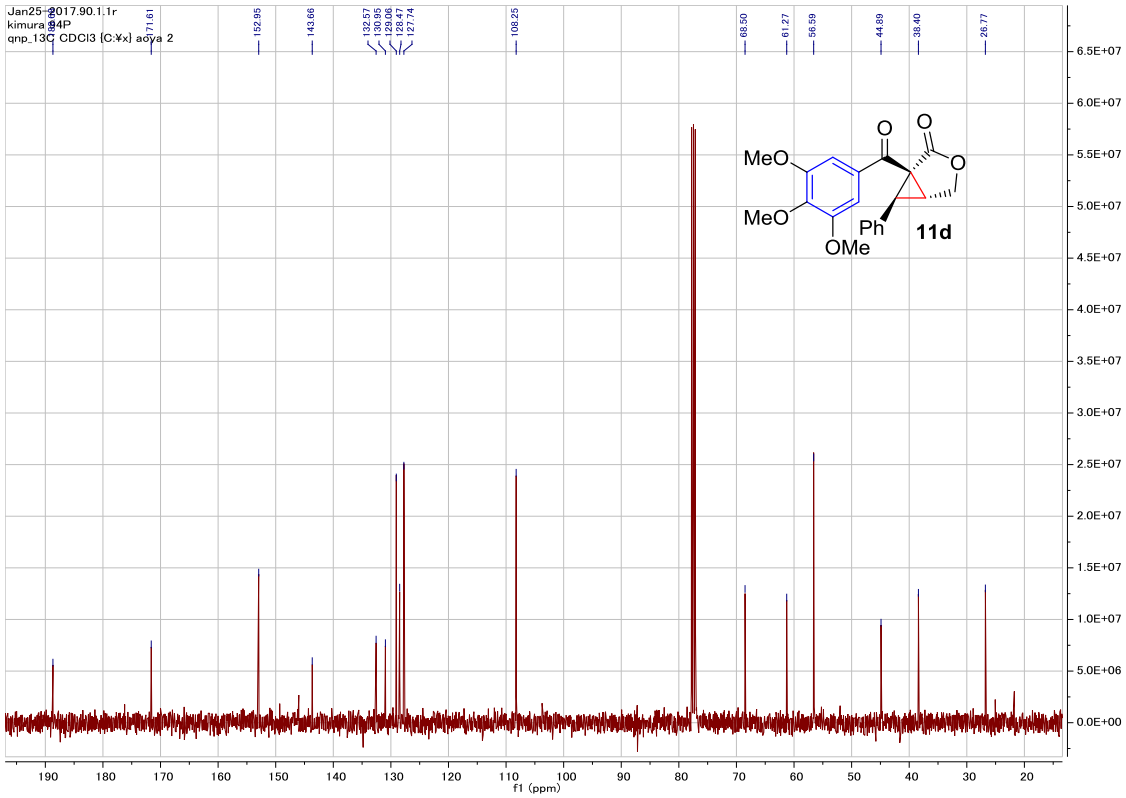
9d+**9'd**


Nov25-2016.10.1r
ST437
PROTON CDCl3 (C:¥x) nisii 1
MeO
MeO
OMe
Ph
OEt
CHO
O
9d
9'd
(9d : 9'd = 3.7 : 1)
f1 (ppm)

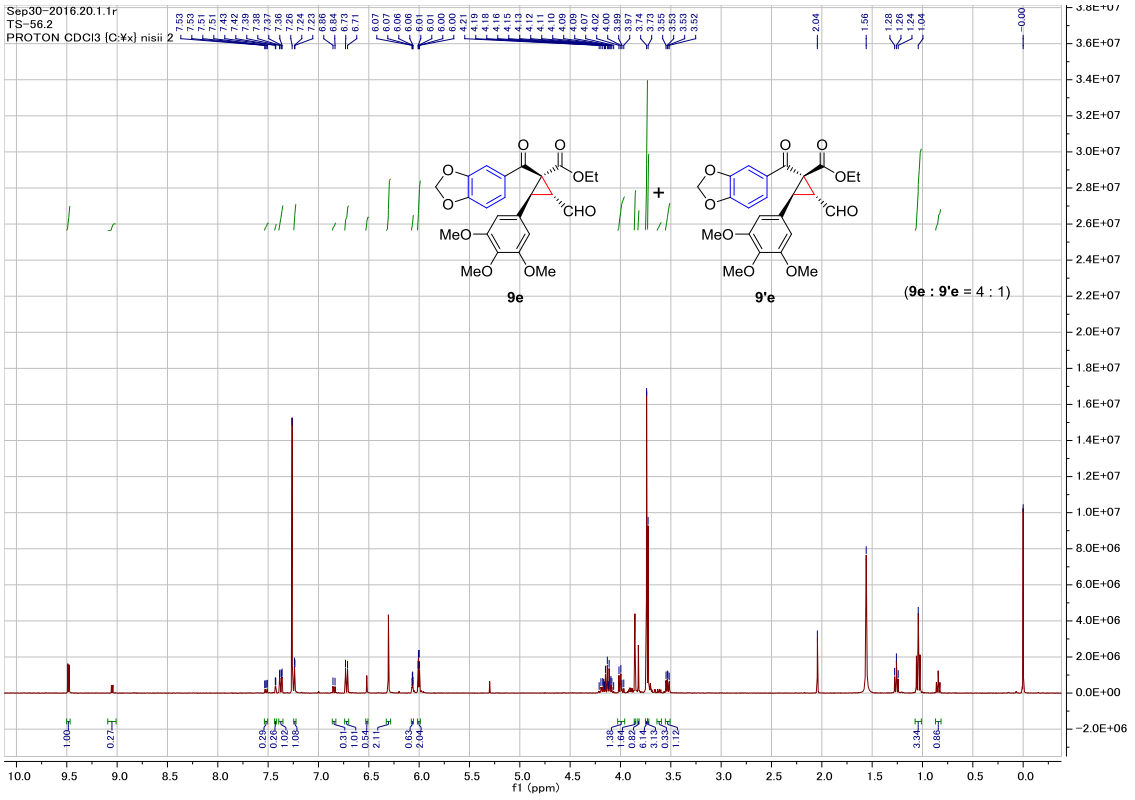

Nov25-2016.10.1r
ST437
PROTON CDCl3 (C:¥x) nisii 1
MeO
MeO
OMe
Ph
OEt
CHO
O
9d
9'd
f1 (ppm)

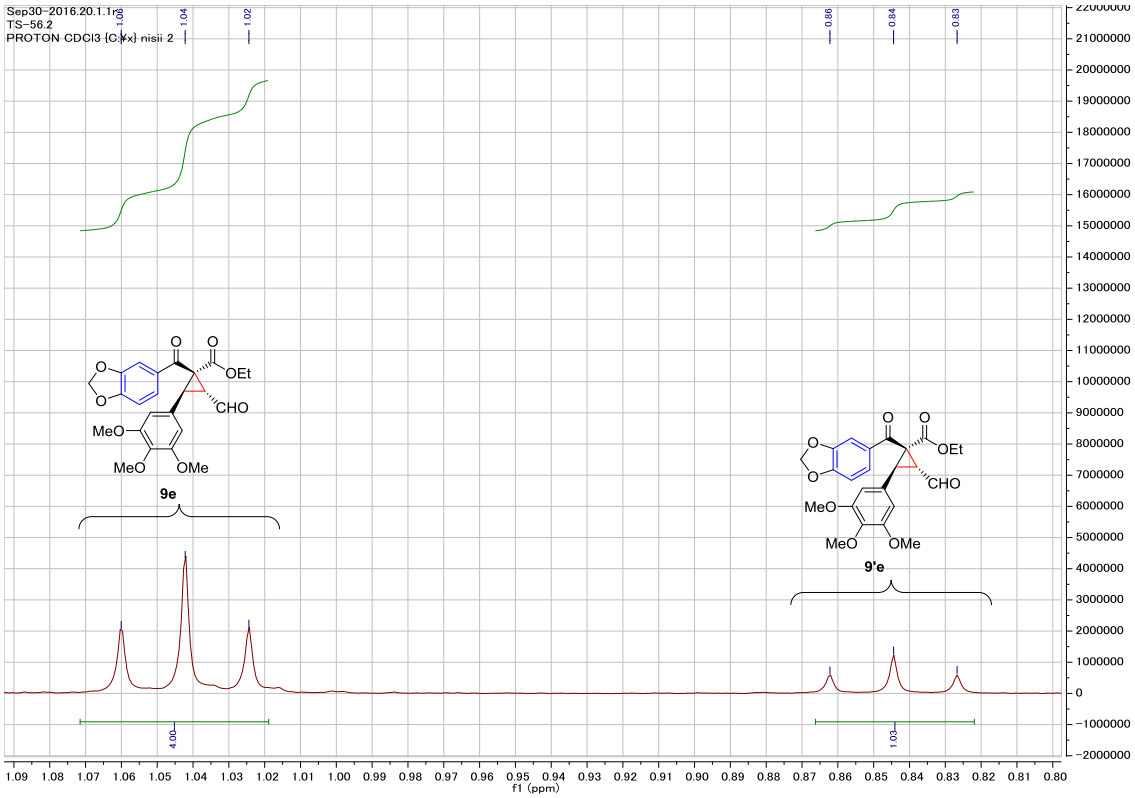
11d



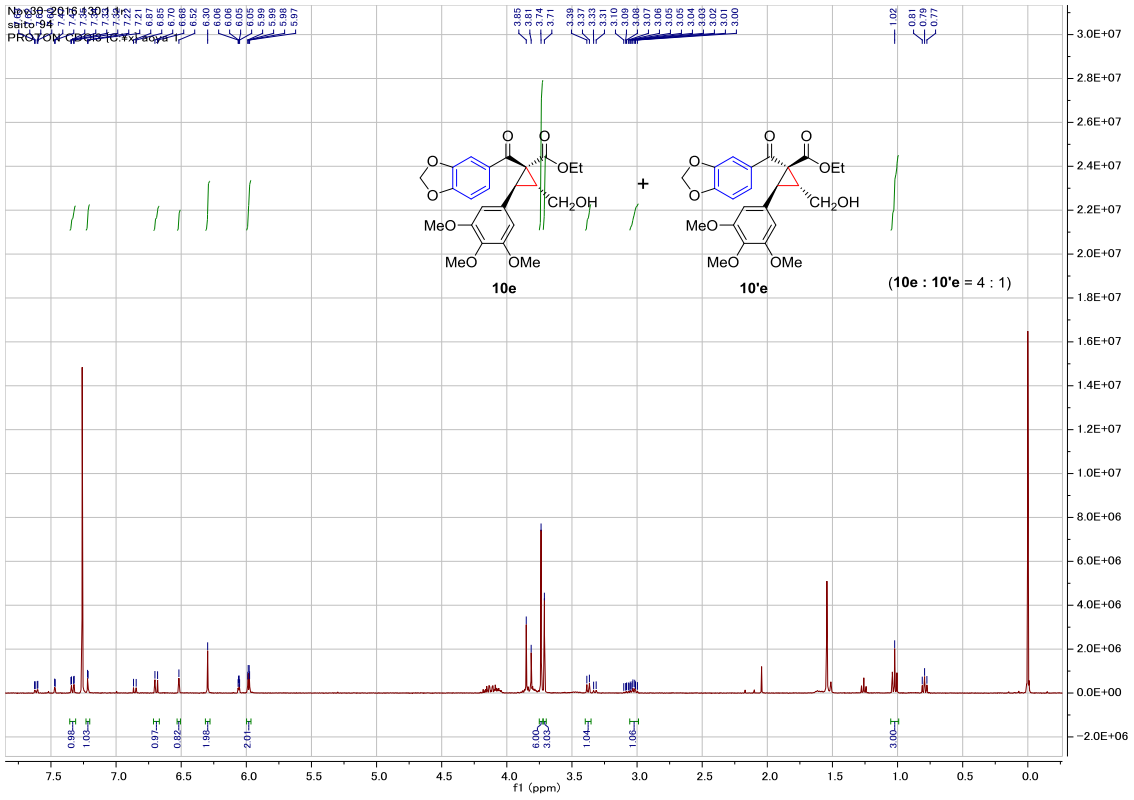


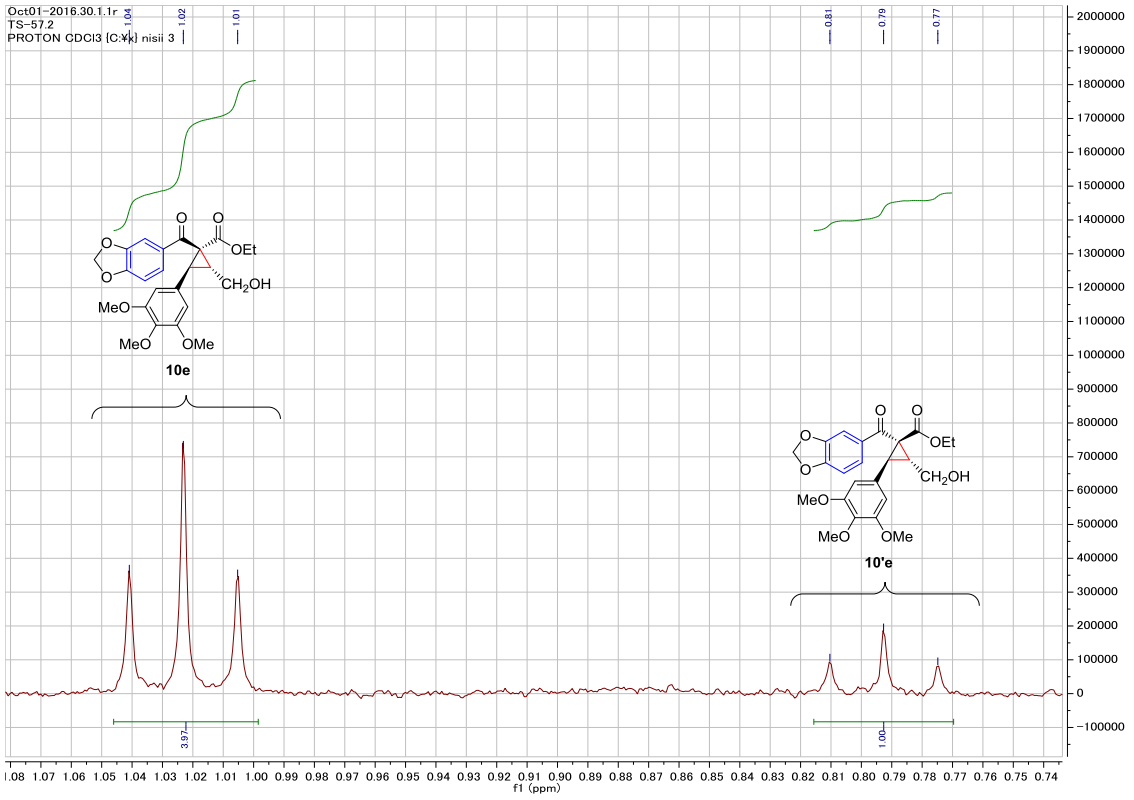
9e+9’e


Sep30-2016.20.1.1r
TS-56.2
PROTON CDCl3 (C:¥x) nisii 2
9e
9'e
(9e : 9'e = 4 : 1)
f1 (ppm)

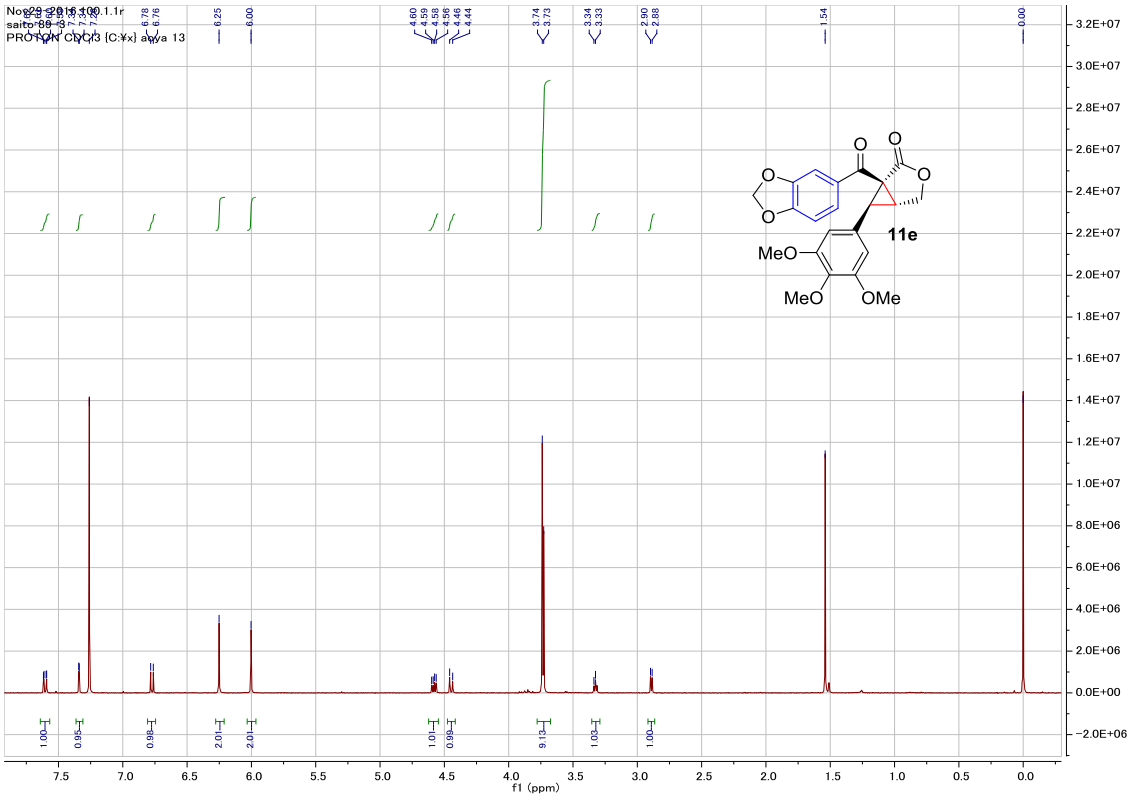

Sep30-2016.20.1.1r
TS-56.2
PROTON CDCl3 (C:¥x) nisii 2
9e
9'e
f1 (ppm)

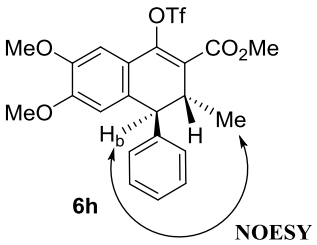
10e +**10'e**

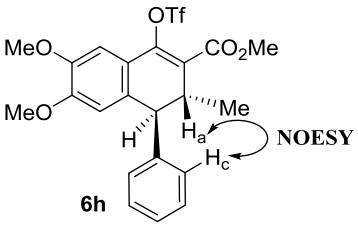


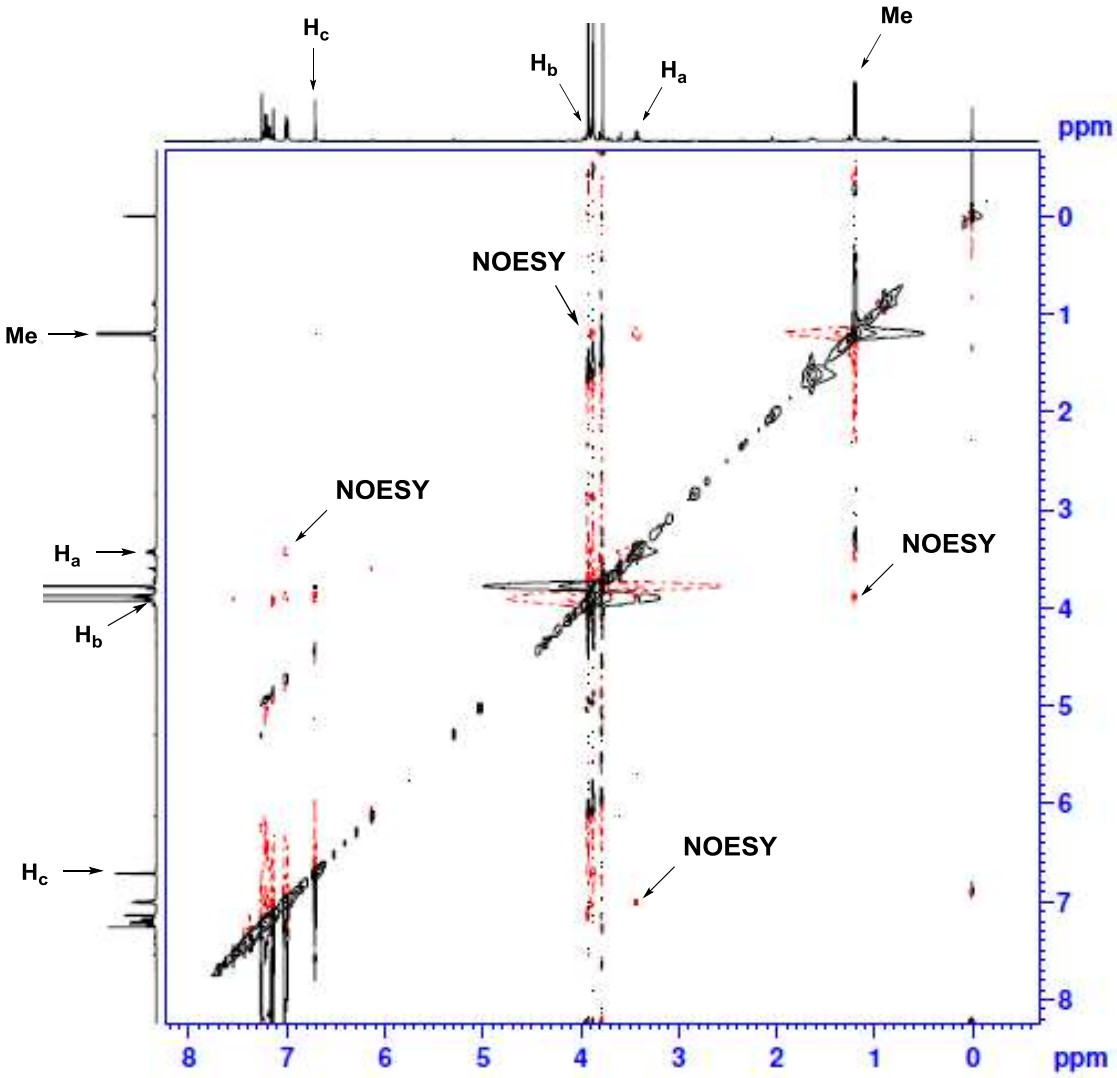


11e




OTf
MeO
CO2Me
MeO
Me
Hb
H
6h
NOESY


OTf
MeO
CO2Me
MeO
Me
H
Ha
NOESY
Hc
6h


Hc
Hb
Ha
Me
ppm
NOESY
Me
NOESY
Ha
Hb
NOESY
NOESY
Hc
0
1
2
3
4
5
6
7
8
8
7
6
5
4
3
2
1
0
ppm