Supporting Information

Three-component tandem remote C-H functionalization of naphthalenes by ruthenium catalysis: Modular and concise synthesis of multifunctional naphthalenes

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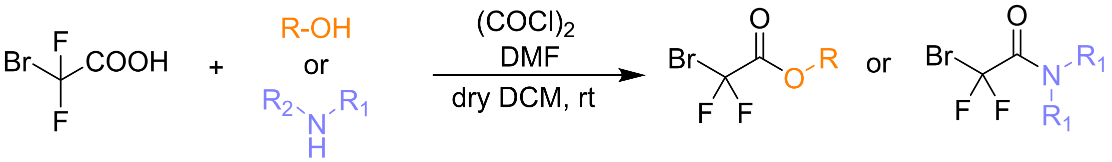
1. General Information

Unless otherwise noted, all reactions were carried out in a flamedried, sealed Schlenk reaction tube under an atmosphere of argon. Materials were purchased from Alfa-Aesar, Laa*J*oo, Macklin, Adamas, Bidepharm and Aladdin and used as received. All the solvents were purchased from commercial suppliers and purified by standard procedures as specified in *Purification of Laboratory Chemicals*, 4th Ed (W. L. F. Armarego, D. D. Perrin, Butterworth-Heinemann: 1997). Analytical thin layer chromatography (TLC) was performed on silica gel plates with F-254 indicator and compounds were visualized by irradiation with UV light. Flash column chromatography was carried out using silica gel (200-300 mesh) at increased pressure. The ^{1}H, ^{13}C, ^{31}P and ^{19}F NMR spectroscopic data were recorded on Bruker Mercury Plus 400 MHz or 500 MHz NMR spectrometers. Chemical shifts (δ) for ^{1}H and ^{13}C are referenced to internal solvent resonances and reported relative to $SiMe_4$. Chemical shifts for ^{31}P are reported relative to an external 85% H_3PO_4 standard. ^{1}H NMR coupling constants were reported in Hz, and multiplicity was indicated as follows: s (singlet); d (doublet); t (triplet); q (quartet); m (multiplet); dd (doublet of doublets); dt (doublet of triplets); td (triplet of doublets); tt (triplet of triplets). The diffraction data of crystals were collected on a Rigaku XtaLAB Synergy CCD diffractometer with graphite monochromated Cu-Ka radiation (λ = 1.54184 Å) at 293 K. The ellipsoid contour is 50% probability in the caption for the image of the 4f. Absorption corrections were applied by SADABS. All the structures were solved by direct methods and refined by full-matrix least-squares method on F^2 using SHELXTL-2014. All non-hydrogen atoms were refined with anisotropic displacement parameters. The hydrogen atoms of the ligand were generated geometrically. High resolution mass spectra (HRMS) were recorded on the Thermo Scientific Exactive Plus equipped with ESI ionization source. (naphthalen-1-yl-8-d)diphenylphosphane, (naphthalen-1-yl-5-d)diphenylphosphane were synthesized according to the published procedures.[3]

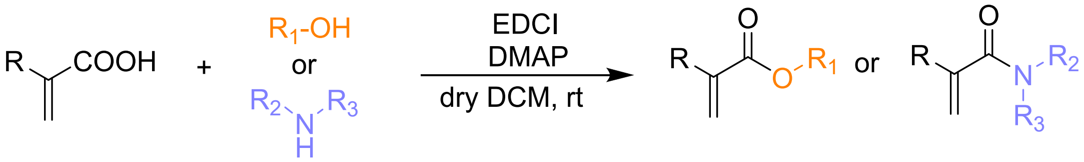
2. Experimental procedures

2.1 Synthesis of substrates



General procedure for substrates 3[1]

2-bromo-2,2-difluoroacetic acid (1 equiv.) was dissolved in dry DCM in a dry round bottom flask under an atmosphere of nitrogen. Oxalyl chloride (1.1 equiv) was then added followed by two drops of DMF. The solution was then stirred at room temperature for 2 hours or until no more gas evolved. The corresponding alcohol (2 equiv.) or amine (2 equiv.) and triethylamine (1.1 equiv.) were then added dropwise as a solution in DCM at 0 ℃ over 20 min. The cooling was removed and stirring was continued for 2 hours. The crude reaction was then diluted with water and extracted three times with DCM. The combined organic phases were washed with saturated bicarbonate and dried over Na_2SO_4, filtered and concentrated in vacuo. The resulting residue was then filtered through a short plug of silica and the fractions containing product were concentrated to afford the corresponding product.

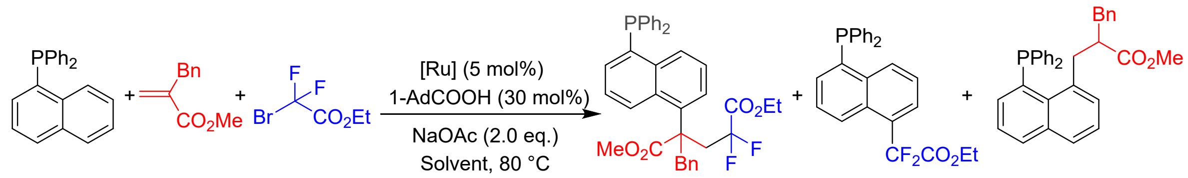


General procedure for substrates 2[2]

To a solution of acrylic acid (2 mmol) in CH_2Cl_2 (5 mL) at 0 °C was added the corresponding alcohol equiv.) or amine (1.1 eq, 2.2 mmol), followed by EDC·HCl (1.2 eq, 2.4 mmol), and DMAP (0.2 eq, 0.4 mmol). The mixture was allowed to warm up to room temperature and continued stirring for 12 hrs. Saturated aqueous solution of $NaHCO_3$ (15 mL) was added to quench the reaction, and the resulting mixture was extracted with CH_2Cl_2 several times (3 x 15 mL). The combined organic extracts were washed with brine, and dried over Na_2SO_4, filtered and concentrated in vacuo. The resulting residue was then filtered through a short plug of silica and the fractions containing product were concentrated to afford the corresponding products.

2.2 Optimization studies

Table S1: Investigation of solvent

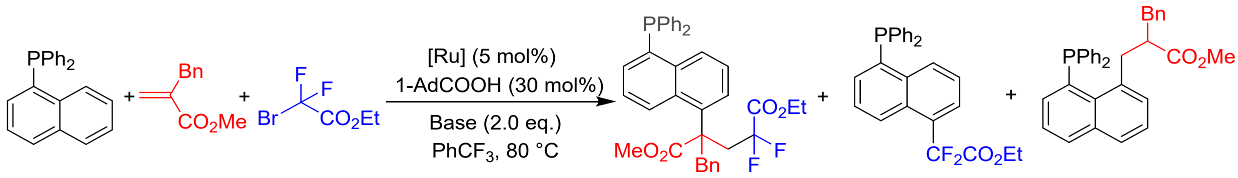


1a **2a** **3a** **4a** **5** (C5-product) **6** (C8-product)

Entry[a]	Solvent	yield **4a** (%)[b]	yield **5** (%)[b]	yield **6** (%)[b]
1	$PhCF_3$	82	0	0
2	Cyclohexane	60	0	0
3	MeCN	22	0	0
4	PhMe	78	0	0
5	*t*-BuOMe	80	0	0
6	EA	30	0	0
7	EtOH	28	0	0

[a]Reaction conditions: **1** (0.1 mmol), **2a** (0.3 mmol), **3a** (0.3 mmol), $[RuCl_2(p\text{-cymene})]_2$ (5.0 mol %), 1-AdCOOH (30 mol%), NaOAc (0.2 mmol), Solvent (1 mL), 12 h, under Ar. [b]Yields were determined by ^1H NMR.

Table S2: Influence of base

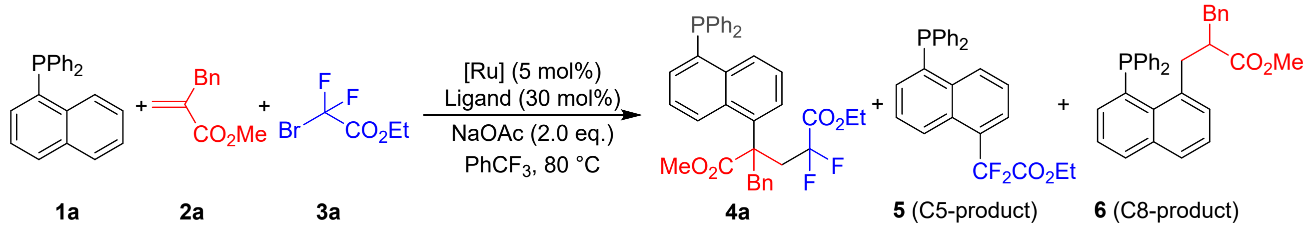


1a **2a** **3a** **4a** **5** (C5-product) **6** (C8-product)

Entry[a]	Base	yield **4a** (%)[b]	yield **5** (%)[b]	yield **6** (%)[b]
1	NaOAc	82	0	0
2	NaH_2PO_4	15	0	0
3	Na_2HPO_4	50	0	0
4	Na_2CO_3	70	0	0
5	*t*-BuONa	10	0	0
6	CF_3COONa	trace	0	0
7	PivONa	71	0	0
8	$NaHCO_3$	75	0	0

[a]Reaction conditions: **1** (0.1 mmol), **2a** (0.3 mmol), **3a** (0.3 mmol), $[RuCl_2(p\text{-cymene})]_2$ (5.0 mol %), 1-AdCOOH (30 mol%), Base (0.2 mmol), $PhCF_3$ (1 mL), 12 h, under Ar. [b]Yields were determined by ^1H NMR.

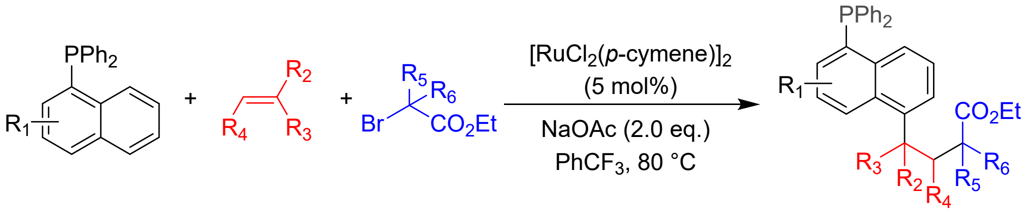
Table S3: Influence of Ligand



Entry[a]	Ligand	yield **4a** (%)[b]	yield **5** (%)[b]	yield **6** (%)[b]
1	1-AdCOOH	82	0	0
2	MesCOOH	80	0	0
3	N-Ac-L-Ala-OH	79	0	0
4	N-Boc-L-Ala-OH	80	0	0
5	L-Ala-OH	70	0	0
6	DPPE	trace	0	0
7	(p-OMePh)$_3$P	78	0	0
8	no	85	0	0

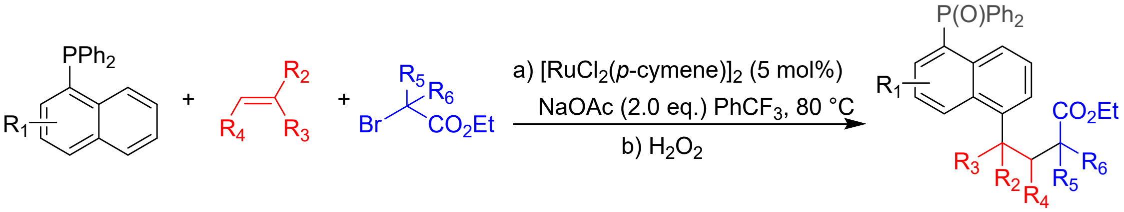
[a] Reaction conditions: **1** (0.1 mmol), **2a** (0.3 mmol), **3a** (0.3 mmol), [RuCl$_2$(*p*-cymene)]$_2$ (5.0 mol %), Ligand (30 mol%), NaOAc (0.2 mmol), PhCF$_3$ (1 mL), 12 h, under Ar. [b] Yields were determined by ^{1}H NMR.

2.3 General procedure for Ru(II)-catalyzed three-component reaction of naphthalenes, olefins and alkyl bromides.



1 **2** **3** **4 or 5**

General procedure A: To a 25 mL Schlenk tube was added **1** (0.1 mmol, 1.0 equiv), **2** (0.3 mmol, 3.0 equiv), **3** (0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5 mol%), NaOAc (16.4 mg, 2.0 equiv). The tube was purged with Ar three times, followed by addition of PhCF$_3$ (1 mL). The mixture was stirred at 80 °C in heating module for 12 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The crude product was purified by column chromatography on silica gel affording the products.

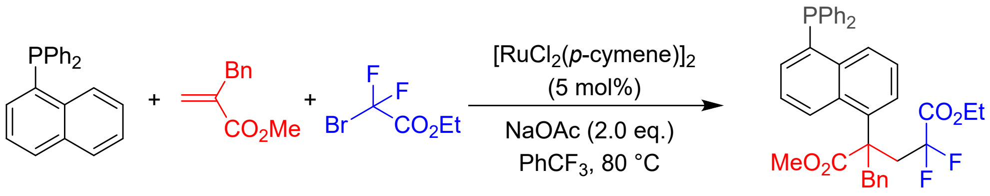


1 **2** **3** **4 or 5**

General procedure B:To a 25 mL Schlenk tube was added **1** (0.1 mmol, 1.0 equiv), **2** (0.3 mmol, 3.0 equiv), **3** (0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5 mol%), NaOAc (16.4 mg, 2.0 equiv). The tube was purged with Ar three times, followed by addition of PhCF$_3$ (1 mL). The mixture was stirred at 80 °C in heating module for 12 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The crude product was purified by column chromatography on silica gel affording the products. The obtained product was dissolved by DCM, and 1mL H$_2$O$_2$ was added to obtain the oxidized product.

2.4 Synthetic applications

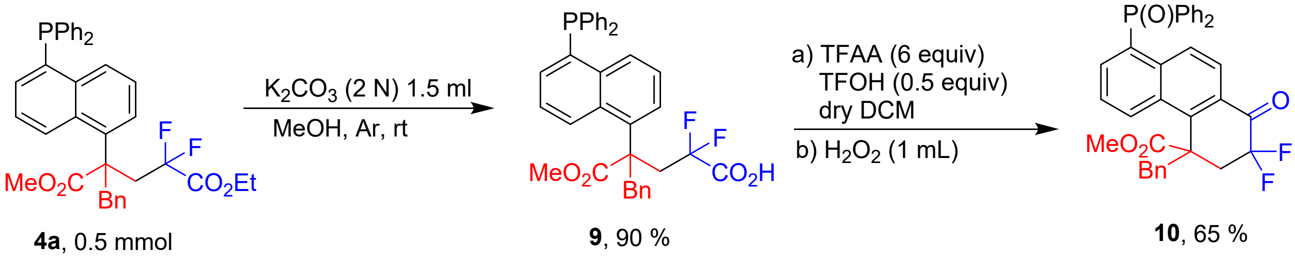
a) Gram-scale reaction



1a, 3 mmol **2a, 3 eq.** **3a, 3 eq.** **4a, 75 %, 1.37 g**

To a 50 mL Schlenk tube was added 1-naphthalenyldiphenylphosphane **1a** (3 mmol, 936 mg, 1.0 equiv), methyl 2-benzylacrylate **2a** (9 mmol, 1.5 mL, 3.0 equiv), ethyl 2-bromo-2,2-difluoroacetate **3a** (9 mmol, 1.2 mL, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (90 mg, 5 mol%), NaOAc (492 mg, 2.0 equiv). The tube was purged with Ar three times, followed by addition of $PhCF_3$ (20 mL). The mixture was stirred at 80 °C in an oil bath for 18 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The crude product was purified by column chromatography on silica gel (R_f = 0.5, PE/DCM/EA = 10/1/1) affording the product **4a** (white solid, 1.37 g, 75% yield).

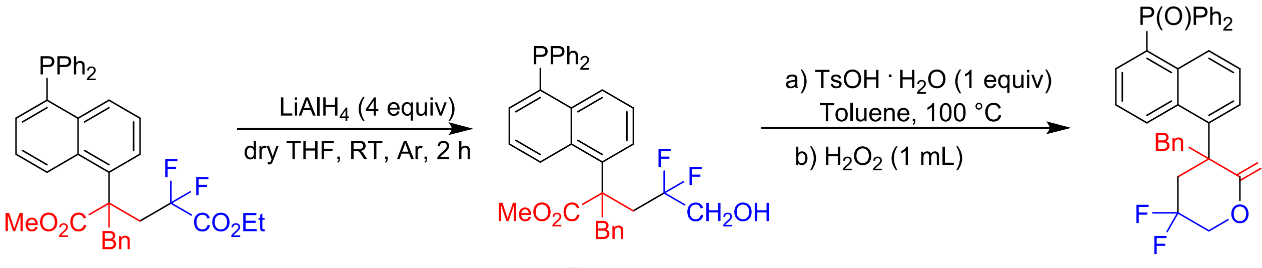
b) Derivatization of product



To a 50 mL Schlenk tube was added 4a (305mg, 0.5 mmol), K_2CO_3 (1.5 mL, 2N). The tube was purged with Ar three times, followed by the addition of MeOH (3 mL). The mixture was stirred at room temperature for 2 h and poured into 5% HCl (3.0 mL), and successively extracted with EtOAc (10 mL × 3). The combined organic phase was washed with brine and dried over anhydrous Na_2SO_4. The crude product was purified by column chromatography on silica gel (DCM/MeOH: 4/1) affording the pure product **9** (white solid, 262 mg, 90 %).[3] The obtained product was dissolved by DCM, and 1mL H_2O_2 was added to obtain the oxidized product. **^{1}H NMR** (400 MHz, $CDOD_3$) δ 8.44 (d, *J* = 8.6 Hz, 1H), 8.29 (d, *J* = 8.8 Hz, 1H), 7.67 - 7.44 (m, 12H), 7.36 - 7.26 (m, 2H), 7.16 - 7.03 (m, 3H), 6.96 - 6.66 (m, 2H), 3.95 (d, *J* = 13.2 Hz, 1H), 3.69 (d, *J* = 13.2 Hz, 1H), 3.59 (s, 3H), 3.14 - 2.84 (m, 2H). **^{13}C NMR** (126 MHz, $CDOD_3$) δ 177.9, 140.3, 137.7, 135.7 (d, *J* = 7.6 Hz), 134.7 (d, *J* = 11.3 Hz), 133.8, 133.7, 133.5 (d, *J* = 6.3 Hz), 133.2, 133.1, 133.0, 132.6 (d, *J* = 2.5 Hz), 131.9, 130.4 (d, *J* = 1.3 Hz), 130.3 (d, *J* = 103.3 Hz), 130.1, 130.0, 128.8, 128.3 (d, *J* = 6.3 Hz), 127.7, 127.4, 127.3, 125.5 (d, *J* = 15.1 Hz), 119.2, 53.5, 52.9, 42.8, 39.2 (t, *J* = 21.4 Hz). **^{31}P NMR** (202 MHz, $CDOD_3$) δ 36.0. **^{19}F NMR** (471 MHz, $CDOD_3$) δ -102.5 (d, *J* = 249.6 Hz), -104.7 (d, *J* = 244.9 Hz). **HRMS** (ESI) m/z: $[M-H]^-$ calcd for $C_{35}H_{27}F_2O_5P^-$ 597.1648; found 597.1643.

A solution of 4-benzyl-4-(5-(diphenylphosphanyl)naphthalen-1-yl)-2,2-difluoro-5-methoxy-5-oxopenta--noic acid (0.1 mmol), TFAA (6 equiv), triflic acid (0.5 equiv) in dry dichloromethane (1 mL) was stirred for 12 h at room temperature. The reaction mixture was evaporated under reduced pressure, and after quenching with water,the residue was redissolved in dichloromethane (10 mL),washed with 5% $NaHCO_3$ (2 × 3 mL), water (2 × 3 mL), and dried over Na_2SO_4. The solvent was removed in vacuum, and the crude reaction mixture was purified by silica gel chromatography ((R_f = 0.5, EA/PE = 1/15) affording the pure product.[4] The obtained product was dissolved by DCM, and 1mL H_2O_2 was added to obtain the oxidized product **10** (white solid, 37.7 mg, 65 %). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 (d, *J* = 8.6 Hz, 1H), 8.07 - 7.98 (m, 2H), 7.74 - 7.66 (m, 5H), 7.74 - 7.66 (m, 5H), 7.60 - 7.53 (m, 6H), 7.42 - 7.37 (m, 1H), 7.25 - 7.31 (m, 1H), 7.19 (d, *J* = 7.6 Hz, 1H), 4.40 (d, *J* = 14.2 Hz, 1H), 3.79 - 3.64 (m, 2H), 3.36 (s, 3H), 2.86

(ddd, J = 15.4, 13.6, 10.8 Hz, 1H). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 189.6 (t, J = 25.3 Hz), 175.6, 139.6, 135.2 (d, J = 8.1 Hz), 134.3, 133.6, 133.5, 133.2 (d, J = 22.2 Hz), 132.4, 132.3, 132.2, 132.1, 132.0, 131.5 (d, J = 8.1 Hz), 131.5, 130.6, 130.5, 129.0, 128.9, 128.8, 128.6 (d, J = 6.1 Hz), 128.3, 127.9, 126.8, 125.2 (d, J = 14.1 Hz), 124.0, 116.6 (t, J = 48.5Hz), 53.0, 50.2 (d, J = 11.1 Hz), 41.7 (d, J = 6.1 Hz), 41.4 (d, J = 4.0 Hz). **^{31}P NMR** (162 MHz, CDCl$_3$) δ 33.2. **^{19}F NMR (377 MHz, CDCl3)** δ -94.2 (d, J = 275.2 Hz), -101.8 (d, J = 275.2 Hz). **HRMS** (ESI) m/z: [M+H]$^+$ calcd for $C_{35}H_{28}F_2O_4P^+$ 581.1688; found 581.1680.



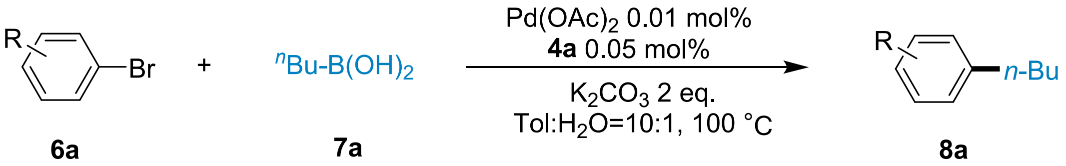
4a, 0.5 mmol **7**, 75 % **8**, 82 %

Into a dry 50 mL round bottom flask charged with a PTFE-coated magnetic stir bar were added **4a** (305 mg, 0.2 mmol, 1.0 equiv) and 10 mL of THF. The solution was chilled in an ice bath and purged with argon. To this mixture, lithium aluminum hydride (0.8 mmol, 4.0 equiv) was added in four approximately equal portions over 10 minutes. The reaction was allowed to warm to room temperature and stir for an additional 2 h. The flask was returned to an ice bath and quenched with 10 mL of 1 M aqueous HCl. The primary alcohol product was extracted with EtOAc (3 x 20 mL). The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. the residue was purified by prepared column chromatography (R_f = 0.5, PE/EA=15:1) on silica gel to afford the pure product **7** (white solid, 213 mg, 75%).[5] **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.49 (dd, J = 8.4, 5.2 Hz, 1H), 7.96 (d, J = 8.6 Hz, 1H), 7.49 - 7.26 (m, 13H), 7.23 - 7.13 (m, 13H), 7.04 - 6.70 (m, 3H), 3.96 (d, J = 13.2 Hz, 1H), 3.72 - 3.65 (m, 1H), 3.61 (s, 3H), 3.40 - 2.72 (m, 4H). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 176.4, 137.8 (d, J = 2.0 Hz), 136.6 (d, J = 14.1 Hz), 136.4 (d, J = 4.1 Hz), 136.3, 136.2 (d, J = 15.2 Hz), 134.5, 134.3, 131.6, 131.5, 130.8, 129.1, 128.8, 128.7, 128.1, 127.1, 126.8, 126.2, 125.5 (d, J = 2.0 Hz), 125.3, 124.4, 123.3, 65.2 (t, J = 32.3 Hz), 52.6, 52.0, 41.9. **^{31}P NMR** (162 MHz, CDCl$_3$) δ -12.4. **^{19}F NMR (377 MHz,** CDCl$_3$**)** δ -106.6 (m), -107.2 (m). **HRMS** (ESI) m/z: [M-H]$^-$ calcd for $C_{35}H_{30}F_2O_3P^-$ 567.1906; found 567.1904.

A solution of compound **7** (56.8 mg, 0.1 mmol) and *p*-toluenesulfonic acid monohydrate (19 mg, 0.1 mmol) in toluene (1 mL) was stirred under an atmosphere of dry argon and heated to 100°C for 12 hours. The cooled solution was filtered and concentrated under reduced pressure. the residue was purified by prepared column chromatography (R_f = 0.5, PE/EA=15:1) on silica gel to afford the pure product.[6] The obtained product was dissolved by DCM, and 1mL H_2O_2 was added to obtain the oxidized product **8** (45 mg, 82 %). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.85 - 8.77 (m, 2H), 7.72 - 7.65 (m, 4H), 7.63 - 7.55 (m, 2H), 7.54 - 7.47 (m, 5H), 7.36 - 7.27 (m, 2H), 7.17- 7.12 (m, 1H), 7.08 - 7.04 (m, 3H), 6.46 (d, J = 7.2 Hz, 2H), 4.07 (dd, J = 15.6, 12.8 Hz, 1H), 3.85 - 3.71 (m, 2H), 3.41 - 3.29 (m, 2H), 2.59 - 2.46 (m, 1H). **^{13}C**

NMR (101 MHz, $CDCl_3$) δ 174.6, 135.5 (d, *J* = 8.1 Hz), 134.7, 134.1 (d, *J* = 6.1 Hz), 133.1 (d, *J* = 8.1 Hz), 132.3, 132.2, 132.1, 132.0, 131.9 (d, *J* = 9.1 Hz), 130.8 (t, *J* = 43.4 Hz), 130.7, 129.6 (d, *J* = 7.1 Hz), 128.9, 128.8, 128.5 (d, *J* = 2.0 Hz), 128.1, 127.4 (d, *J* = 4.0 Hz), 127.3, 126.1, 125.5 (d, *J* = 14.1 Hz), 119.6 (t, *J* = 247.5 Hz), 69.2 (dd, *J* = 39.4, 30.3 Hz), 51.4 (d, *J* = 6.1 Hz), 44.6, 41.0 (dd, *J* = 28.3, 24.2 Hz). **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.3. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -85.6 (d, *J* = 252.6 Hz), -96.8 (dt, *J* = 252.6, 15.1 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{34}H_{28}F_2O_3P^+$ 553.1739; found 553.1734.

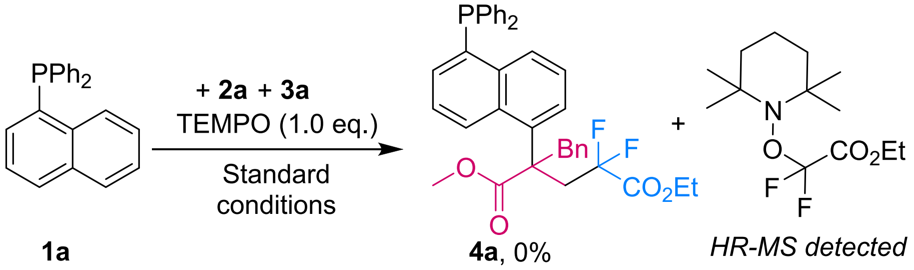
2.5 General procedures for Phosphine-Promoted Pd-catalyzed Suzuki-Miyaura Coupling



First, catalyst stock solutions were prepared by dissolving $Pd(OAc)_2$ (2.3 mg) and **4a** (20.6 mg) in DCM (10 mL) under nitrogen atmosphere at room temperature with continuous stirring for 5 min. Add 0.1 mL of the stock solution to a 25 mL Schlenk tube and remove the solvent under vacuum. Aryl bromide **6a** (1 mmol, 1.0 equiv), *n*-butylboronic acid **7a** (1.3 mmol, 1.3 equiv), K_2CO_3 (276.0 mg, 2 equiv) were added to a Schlenk tube. The tube was then purged 3 times with Ar followed by addition of toluene and water (10:1, 2 mL). The mixture was stirred at 100 °C for 12 h. The solution was then cooled to room temperature and the yields were determined by GC-MS.

2.6 Mechanism studies

2.6.1 Radical trapping experiment



To a 25 mL Schlenk tube was added **1** (0.1 mmol, 1.0 equiv), **2a** (0.3 mmol, 51 μL, 3.0 equiv), **3a** (0.3 mmol, 39 μL, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5 mol%), NaOAc (16.4 mg, 2.0 equiv), TEMPO (15.6 mg, 1.0 equiv). The tube was purged with Ar three times, followed by addition of $PhCF_3$ (1 mL). The mixture was stirred at 80 °C in heating module for 12 h. After cooling to room temperature, Take out the appropriate reaction solution for HR-MS test.

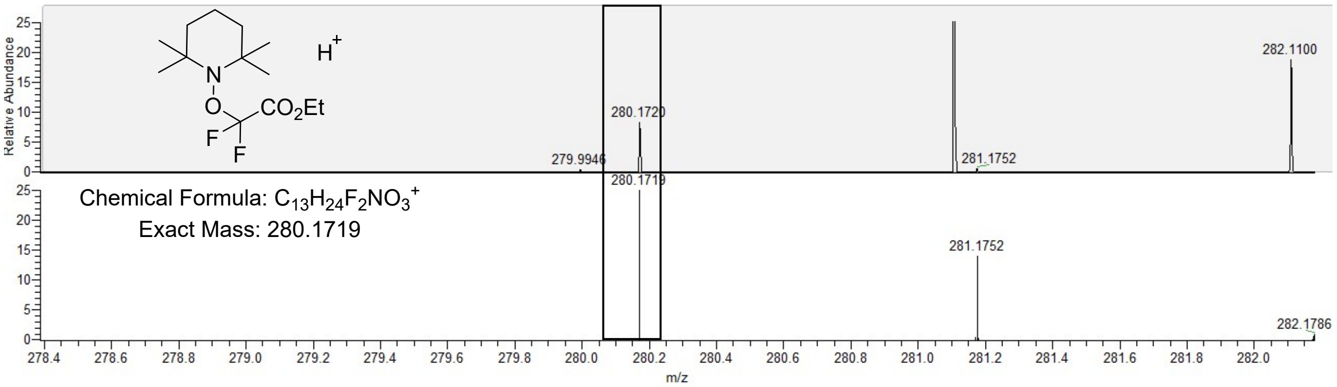
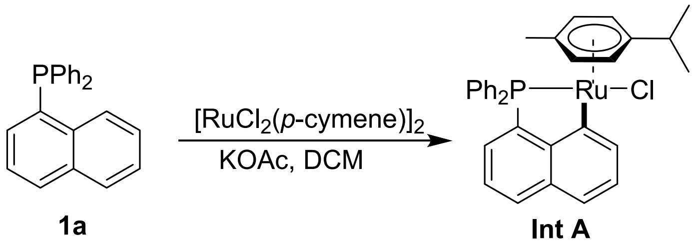


Figure S1 Radical trapping experiment of HRMS in-situ capture spectrogram

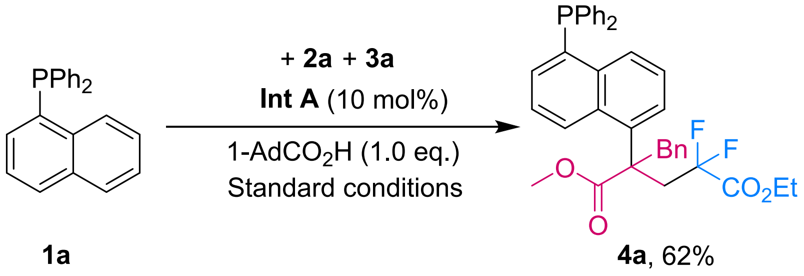
2.6.2 Synthesis of ruthenium complexes

Synthesis of ruthenium(II) Int A[3]



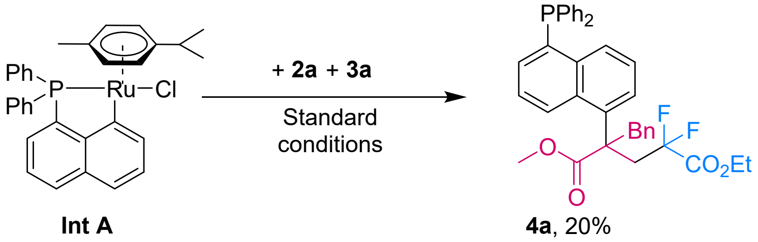
To a 50 mL Schlenk flask was added 1-naphthalenyldiphenylphosphane **1a** (2 mmol, 625 mg, 1.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (1 mmol, 612 mg, 0.5 equiv), KOAc (4 mmol, 392 mg, 2.0 equiv). The tube was purged with Ar three times, followed by addition of 30 mL DCM. The mixture was stirred vigorously in room temperature for 48 h. The solvent was then removed under vacuum directly. The crude product was purified by neutral alumina (Al_2O_3) column chromatography (R_f = 0.5, EA/hexane = 1/2) affording the product **Int A** as pale yellow powder (583 mg, 50% yield).

Int A as the catalyst



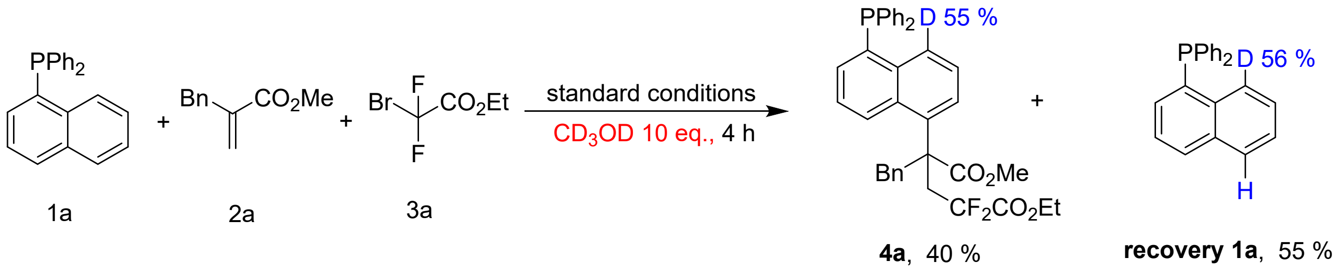
To a 25 mL Schlenk tubes were added naphthalen-1-yldiphenylphosphane **1a** (0.1 mmol, 31.2 mg, 1.0 equiv), **2a** (0.3 mmol, 51 μL, 3.0 equiv), **3a** (0.3 mmol, 39 μL, 3.0 equiv), **Int A** (11.7 mg, 10 mol%), 1-AdCOOH (5.4 mg, 30 mol%), and NaOAc (16.4 mg, 2.0 equiv). The tube was purged with Ar three times, followed by addition of $PhCF_3$ (1 mL). The mixture was stirred at 120 °C in heating module for 12 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The yield of alkylated product **3a** was 62% by ^1H NMR yield analyzed.

Int A as the substrate

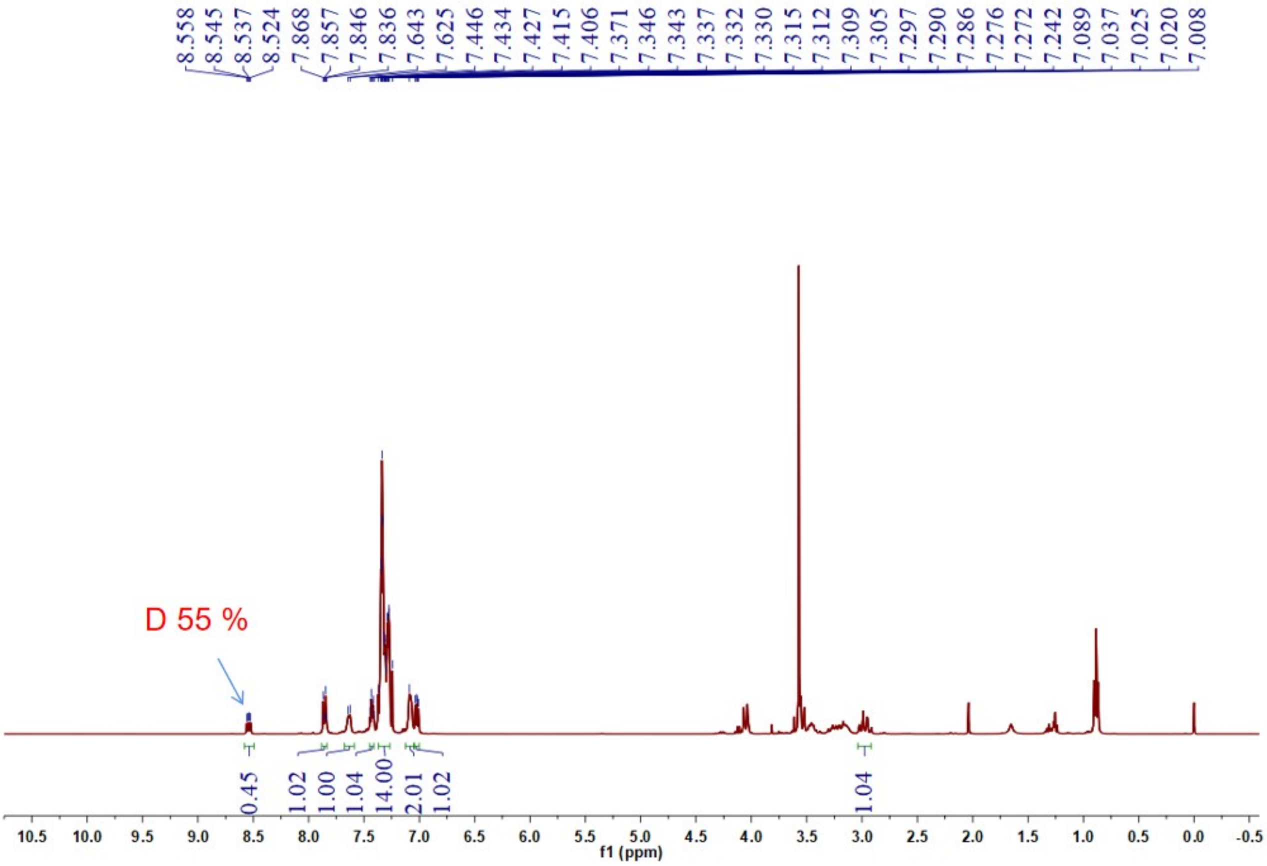


To a 25 mL Schlenk tubes were added **Int A** (0.1 mmol, 58.3 mg, 1.0 equiv), **2a** (0.3 mmol, 51 μL, 3.0 equiv), **3a** (0.3 mmol, 39 μL, 3.0 equiv), 1a (0.1 mmol, 31.2 mg, 1.0 equiv) and NaOAc (16.4 mg, 2.0 equiv). The tube was purged with Ar three times, followed by addition of $PhCF_3$ (1 mL). The mixture was stirred at 80 °C in heating module for 12 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The yield of alkylated product **4a** was 20% by ^{1}H NMR yield analyzed.

2.6.3 H/D exchange experiment

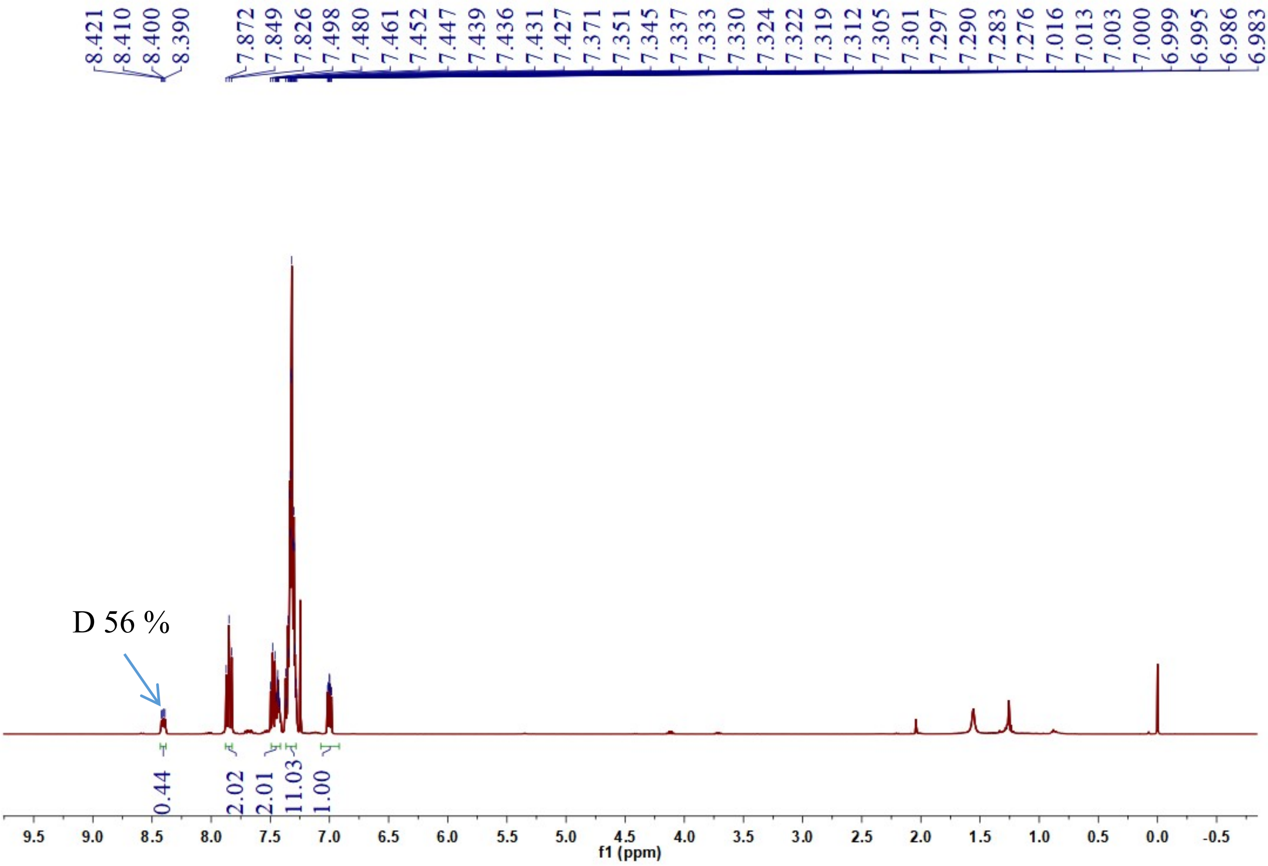


A mixture of 1-naphthalenyldiphenylphosphane **1a** (31.2mg, 0.1 mmol, 1.0 equiv), **2a** (0.3 mmol, 51 μL, 3.0 equiv), **3a** (0.3 mmol, 39 μL, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), CD_3OD (37mg, 1.0 mmol, 10.0 equiv), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 4 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by prepared column chromatography to afford the mixture products **4a-D8** in 40% yield and recovery 1a-D in 55% yield, which was analyzed by ^{1}H NMR spectroscopy.



D 55 %

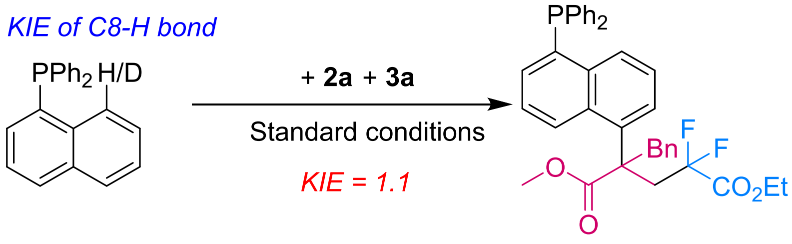
Figure S2 ^{1}H NMR spectroscopy of **4a-D8**



D 56 %

Figure S3 ^{1}H NMR spectroscopy of recovery 1a-D

2.6.4 Kinetic isotopic effect studies



1a/1a-D8 **4a**

Kinetic isotopic effect was determined by performing two independent experiments of naphthalen-1-yldiphenylphosphane **1a** (0.1 mmol) or deuterated naphthalen-1-yldiphenylphosphane **1a**-***d8*** (0.1 mmol) as a substrate. A mixture of **2a** (0.3 mmol, 51 μL, 3.0 equiv), **3a** (0.3 mmol, 39 μL, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 4 h under an atmosphere of argon. Yields determined by ^{1}H NMR using CH$_2$Br$_2$ as the internal standard were recorded at predetermined time intervals for 4 h to evaluate the yield of the reaction. The yield of alkylated product using starting material **1a** was 44%, The yield of alkylated product using starting material **1a**-***d8*** was 40%. The k_H/k_D ratio of 1.1 was obtained.

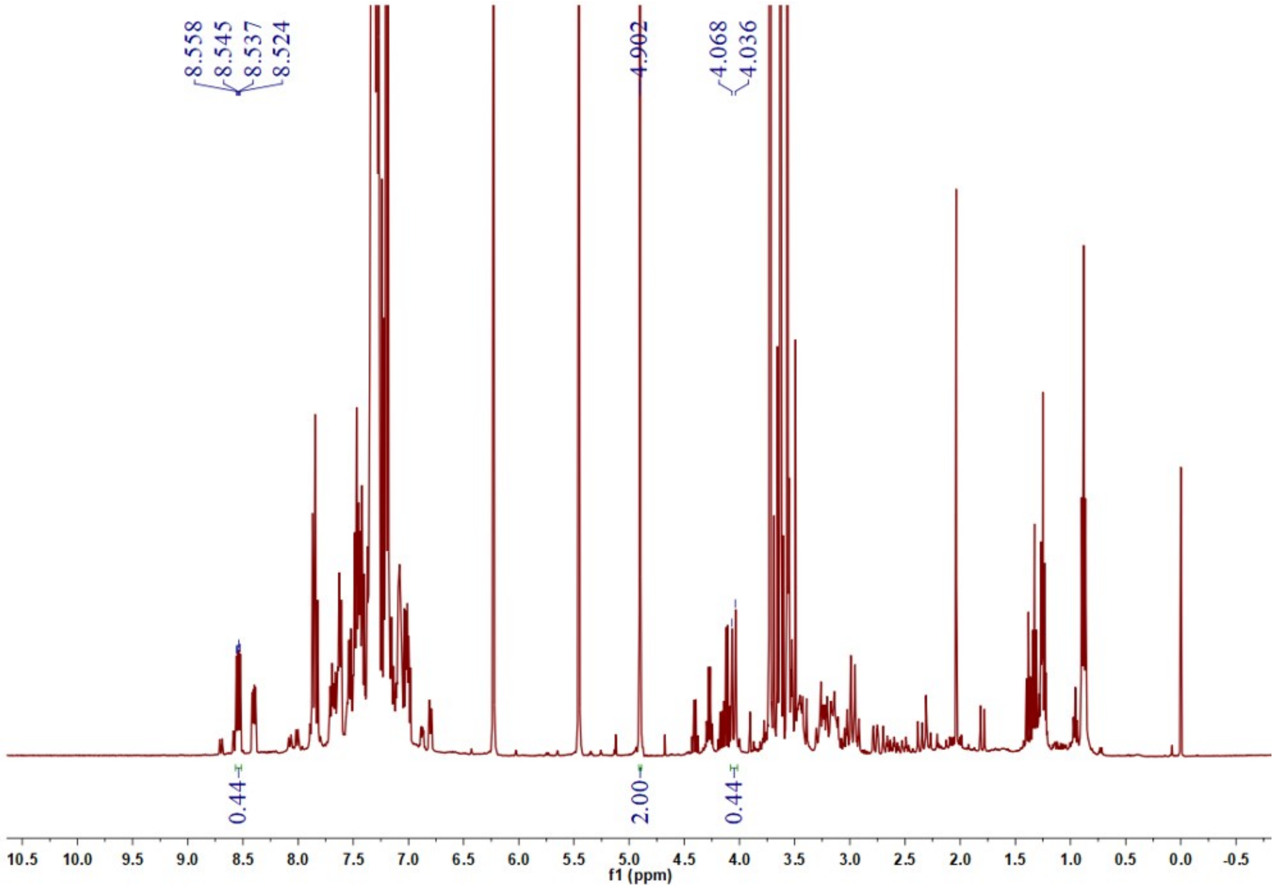


Figure S4 ^{1}H NMR spectroscopy of using starting material 1a

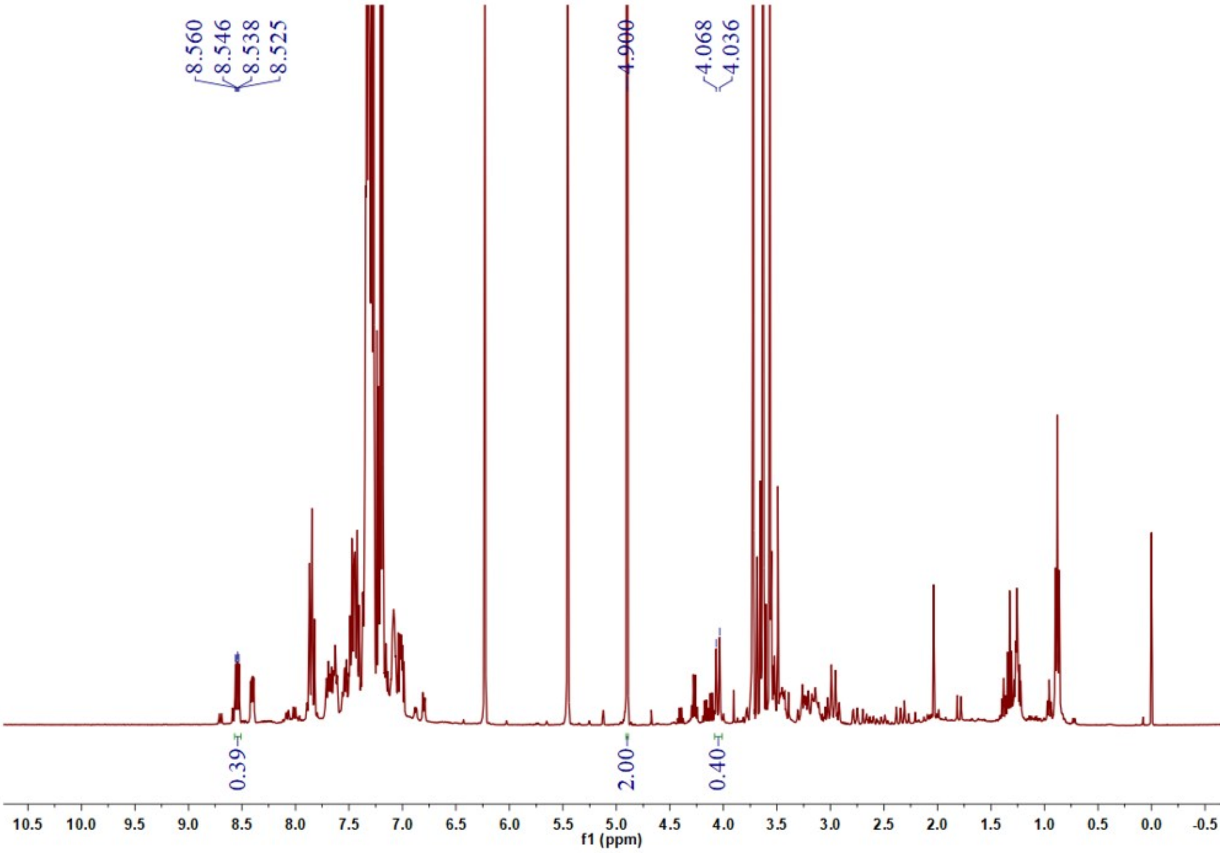
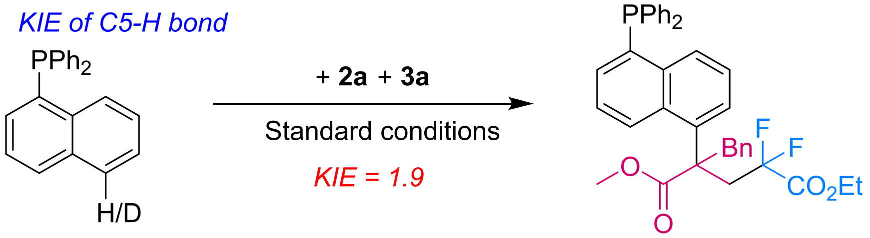


Figure S5 ^{1}H NMR spectroscopy of using starting material 1a-*d8*



1a/1a-D5 **4a**

Kinetic isotopic effect was determined by performing two independent experiments of naphthalen-1-yldiphenylphosphane **1a** (0.1 mmol) or deuterated naphthalen-1-yldiphenylphosphane **1a-*d5*** (0.1 mmol) as a substrate. A mixture of **2a** (0.3 mmol, 51 μL, 3.0 equiv), **3a** (0.3 mmol, 39 μL, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 4 h under an atmosphere of argon. Yields determined by ^{1}H NMR using CH$_2$Br$_2$ as the internal standard were recorded at predetermined time intervals for 4 h to evaluate the yield of the reaction. The yield of alkylated product using starting material **1a** was 44%, The yield of alkylated product using starting material **1a-*d5*** was 23%. The k$_H$/k$_D$ ratio of 1.9 was obtained.

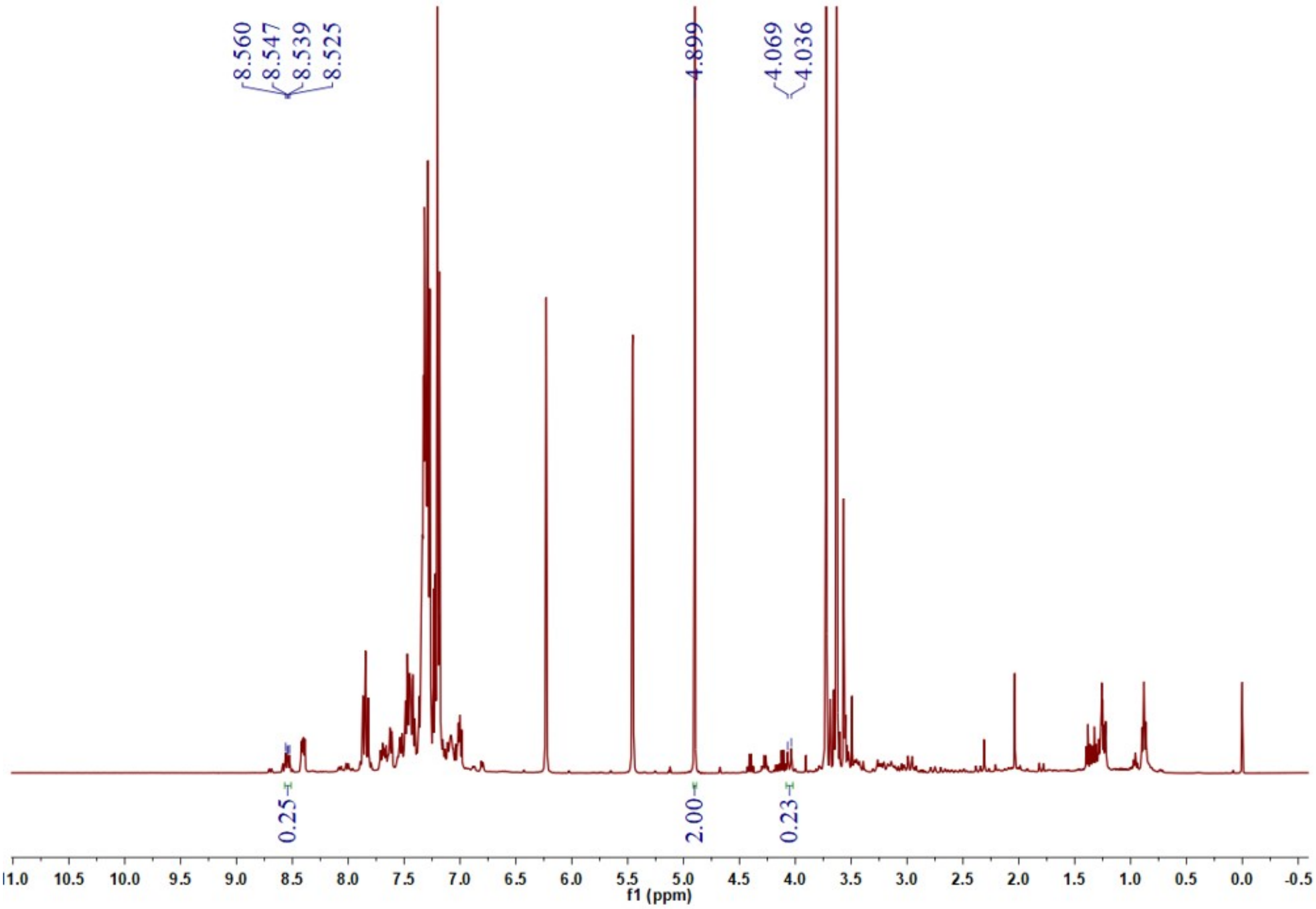
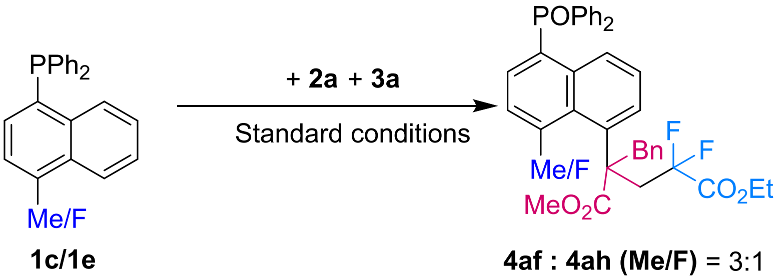


Figure S6 ^{1}H NMR spectroscopy of using starting material 1a-*d5*

2.6.5 Intermolecular competition experiment



A mixture of (4-methylnaphthalen-1-yl)diphenylphosphane **1c** (32.6 mg, 0.1 mmol, 1.0 equiv), (4-fluoronaphthalen-1-yl)diphenylphosphane **1e** (33.0 mg, 0.1 mmol, 1.0 equiv), **2a** (0.6 mmol, 102 µL, 6.0 equiv), **3a** (0.6 mmol, 78 µL, 6.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (6.0 mg, 10.0 mol%),]NaOAc (32.8 mg, 4.0 equiv) in PhCF$_3$ (2.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was added 10ml of DCM and 2ml of H_2O_2, and after complete oxidation, add 10ml of H_2O for liquid separation, remove the water phase, dry Na_2SO_4, and spin-dry the solvent in vacuum. The residue subject to ^{1}H NMR test to determine the ratio of **4af** and **4ah**.

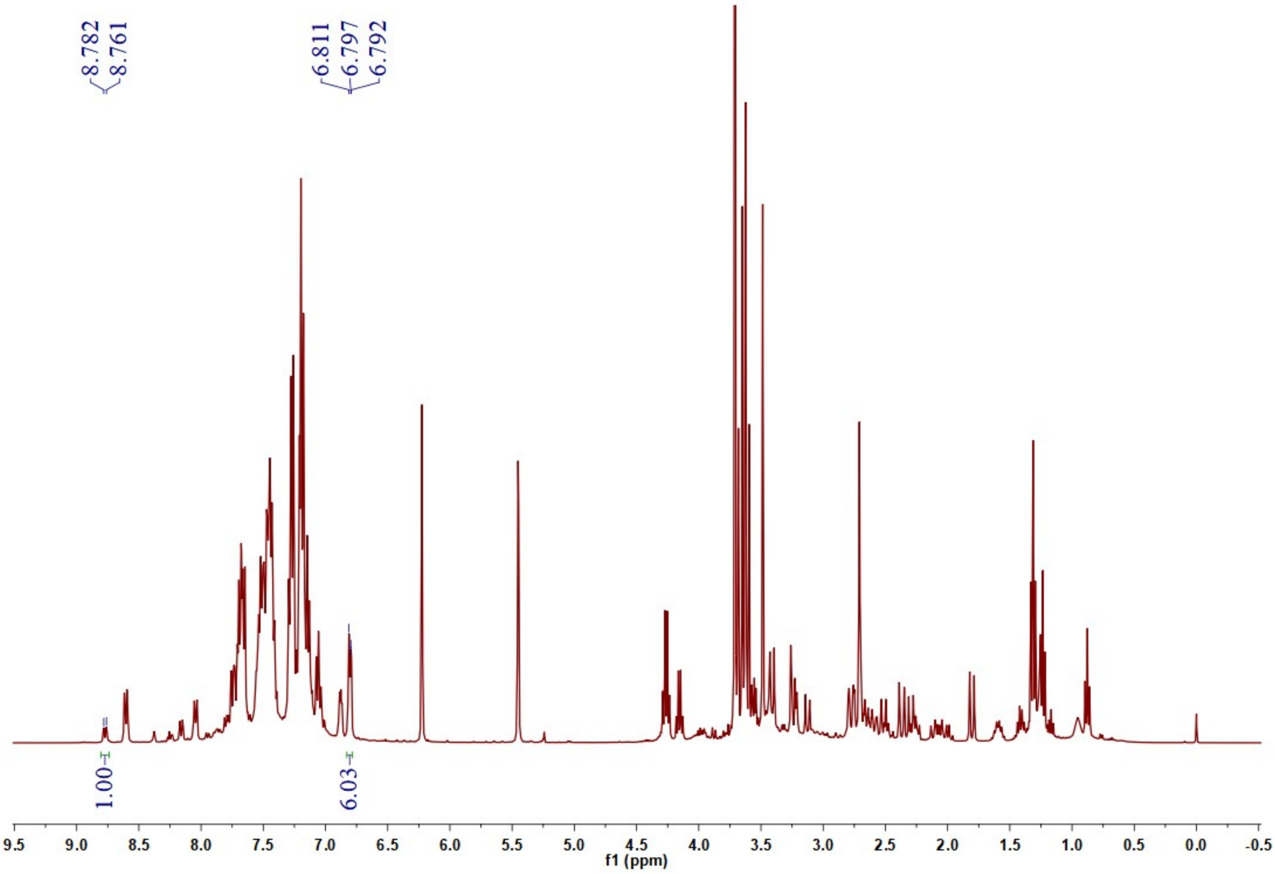
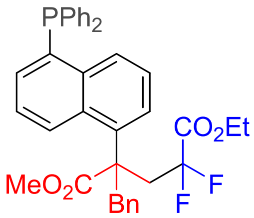


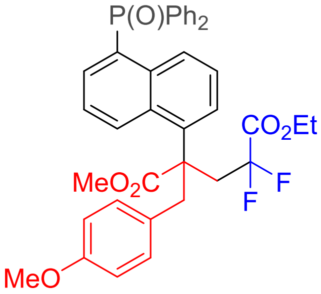
Figure S7 ^{1}H NMR spectrum of the mixture of compounds 4af and 4ah

3. Characterization data



5-ethyl-1-methyl-2-benzyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4a**)

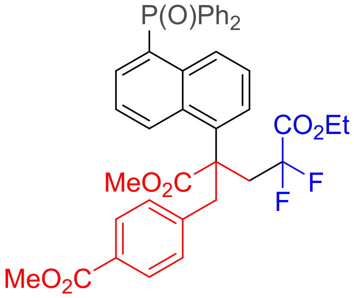
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product **4a** (49 mg, 80 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) 8.54 (dd, *J* = 8.4, 5.2 Hz, 1H), 7.85 (d, *J* = 8.8 Hz, 1H), 7.64 (d, *J* = 6.8 Hz, 1H), 7.46 - 7.41 (m, 1H), 7.37 - 7.31 (m, 10H), 7.29 - 7.27 (m, 4H), 7.09 (d, *J* = 4.4 Hz, 2H), 7.04 - 7.00 (m, 1H), 4.06 (d, *J* = 12.8 Hz, 1H), 3.57 (s, 3H), 3.56 - 3.52 (m, 1H), 3.49 - 3.40 (m, 1H), 3.31 - 3.08 (m, 2H), 2.97 (q, *J* = 14 Hz, 1H), 0.88 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 175.6, 162.8 (t, *J* = 32.3 Hz), 136.5, 136.4, 136.3, 136.2, 136.0, 135.9, 134.6, 134.4, 134.3, 134.1, 131.9 (d, *J* = 4.0 Hz), 131.7, 130.9, 129.2, 129.0, 128.8, 128.7, 128.4, 127.4, 127.1, 126.2, 125.5 (d, *J* = 3.0 Hz), 124.5, 116.1 (dd, *J* = 215.1, 247.5 Hz), 62.6, 52.5, 52.1 (d, *J* = 5.0 Hz), 42.3 (d, *J* = 4.0 Hz), 36.7 (dd, *J* = 25.3, 20.2 Hz), 13.5. **^{31}P NMR** (162 MHz, CDCl$_3$) δ -13.1. **^{19}F NMR** (377 MHz, CDCl$_3$) δ -105.7, -106.5. **HRMS** (ESI) m/z: [M+H]$^+$ calcd for $C_{37}H_{34}F_2O_4P^+$ 611.2157; found 611.2153.



5-ethyl-1-methyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-2-(4-methoxybenzyl)pentanedioate (**4b**)

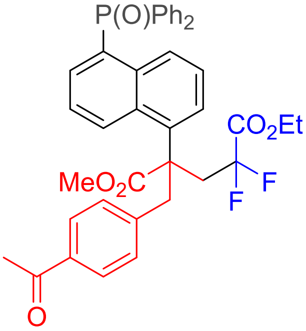
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2b** (61.8 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography

(R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **4b** (54 mg, 82 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 (d, *J* = 8.6 Hz, 1H), 8.07 (d, *J* = 8.7 Hz, 1H), 7.74 - 7.61 (m, 5H), 7.60 - 7.54 (m, 2H), 7.51 - 7.37 (m, 6H), 7.33 - 7.27 (m, 1H), 6.97 (d, *J* = 8.2 Hz, 2H), 6.82 (d, *J* = 8.6 Hz, 2H), 3.96 (d, *J* = 13.2 Hz, 1H), 3.80 (s, 3H), 3.56 (s, 3H), 3.53 - 3.08 (m, 4H), 2.95 (q, *J* =13.2 Hz, 1H), 0.96 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.7, 163.1 (t, *J* = 31.5 Hz), 158.9, 136.7, 134.8 134.3 (d, *J* = 8.8 Hz), 133.4, 133.3, 133.2, 132.7, 132.6, 132.4, 132.3, 132.2, 132.1, 131.9, 131.7 134.3 (d, *J* = 102.1 Hz), 128.8, 128.7, 128.5 (d, *J* = 6.3 Hz), 128.2, 127.6, 126.5, 124.7 (d, *J* = 15.1 Hz), 116.1 (dd, *J* = 257.0, 248.2 Hz), 113.9, 62.7, 55.3, 52.5, 52.2 (d, *J* = 5.0 Hz), 41.5, 36.7 (t, *J* = 23.9 Hz), 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.8. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.5, -106.1. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{38}H_{36}F_2O_6P^+$ 657.2212; found 657.2215.



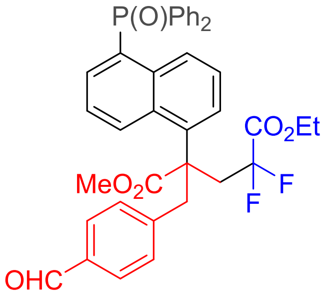
5-ethyl-1-methyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-2-(4-(methoxycarbonyl)benzyl)pentanedioate (**4c**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2c** (70.2 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **4c** (57 mg, 84 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.72 (d, *J* = 8.6 Hz, 1H), 8.06 (d, *J* = 8.6 Hz, 1H), 7.94 (d, *J* = 8.2 Hz, 2H), 7.73 - 7.66 (m, 4H), 7.61 - 7.53 (m, 3H), 7.52 - 7.45 (m, 4H), 7.44 - 7.38 (m, 2H), 7.31 (dd, *J* = 15.6, 6.4 Hz, 1H), 7.09 (d, *J* = 7.8 Hz, 2H), 4.06 (d, *J* = 13.0 Hz, 1H), 3.91 (s, 3H), 3.66 - 3.40 (m, 6H), 3.16 (dd, *J* = 36.8, 16 Hz, 1H), 2.90 (dd, *J* = 28.9, 16 Hz, 1H), 1.00 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.3, 167.0, 163.0 (t, *J* = 31.5 Hz), 141.3, 136.3, 134.8 (d, *J* = 7.6 Hz), 133.4, 133.3 (d, *J* = 5.0 Hz), 133.1, 132.5 (d, *J* = 2.5 Hz), 132.4, 132.3, 132.2, 132.1, 131.3, 130.9, 130.5, 129.6, 129.3, 128.9, 128.8, 128.7, 128.0 (d, *J* = 1.3 Hz), 126.5, 126.3, 125.0, 124.8, 116.0 (dd, *J* = 243.5, 249.5 Hz), 62.9, 52.6, 52.2, 52.1 (d, *J* = 3.8 Hz), 42.01(d, *J* = 3.8 Hz), 36.9 (dd, *J* = 21.4, 23.9 Hz), 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.8. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.3, -105.8. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{39}H_{36}F_2O_7P^+$ 685.2161; found 685.2158.



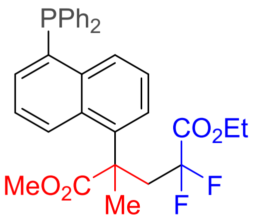
5-ethyl-1-methyl-2-(4-acetylbenzyl)-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4d**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2d** (65.4 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **4d** (55 mg, 82 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.73 (d, *J* = 8.6 Hz, 1H), 8.06 (d, *J* = 8.6 Hz, 1H), 7.86 (d, *J* = 8.2 Hz, 2H), 7.73 - 7.67 (m, 4H), 7.61 - 7.55 (m, 3H), 7.52 - 7.45 (m, 4H), 7.44 - 7.38 (m, 2H), 7.31 (dd, *J* = 15.6, 6.4 Hz, 1H), 7.11 (d, *J* = 7.6 Hz, 2H), 4.06 (d, *J* = 12.8 Hz, 1H), 3.66 - 3.40 (m, 6H), 3.23 - 3.10 (m, 1H), 2.91 (dd, *J* = 28.8, 15.6 Hz, 1H), 2.59 (s, 3H), 0.99 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 197.9, 175.4, 163.0 (t, *J* = 31.5 Hz), 141.5, 136.3, 134.9 (d, *J* = 8.8 Hz), 133.4, 133.3, 133.1, 132.5, 132.4, 132.3, 132.2, 132.1, 131.1, 130.4 (d, *J* = 25.2 Hz), 128.9, 128.8, 128.7, 128.4, 128.0, 126.5, 126.3, 124.9 (d, *J* = 13.9 Hz), 116.0 (dd, *J* = 248.2, 257.0 Hz), 62.9, 52.7, 52.1 (d, *J* = 3.8 Hz), 42.0 (d, *J* = 2.5 Hz), 37.0 (t, *J* = 45.4 Hz), 26.7, 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.8. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.2, -105.8. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{39}H_{36}F_2O_6P^+$ 669.2212; found 669.2206.



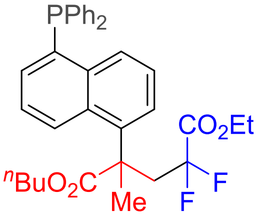
5-ethyl-1-methyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-2-(4-formylbenzyl)pentanedioate (**4e**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2e** (61.2 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R$_f$ = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R$_f$ = 0.3, PE/DCM/EA = 1/1/1) afforded the product **4e** (54 mg, 82 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) δ 10.00 (s, 1H), 8.73 (d, *J* = 8.6 Hz, 1H), 8.06 (d, *J* = 8.6 Hz, 1H), 7.78 (d, *J* = 8.0 Hz, 2H), 7.74 - 7.66 (m, 4H), 7.60 - 7.39 (m, 9H), 7.31 (dd, *J* = 15.6, 6.4 Hz, 1H), 7.17 (d, *J* = 7.6 Hz, 2H), 4.08 (d, *J* = 12.8 Hz, 1H), 3.71 - 3.38 (m, 6H), 3.16 (dd, *J* = 36.4, 16.0 Hz, 1H), 2.90 (dd, *J* = 29.0, 15.8 Hz, 1H), 1.00 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 192.0, 175.3, 163.0 (t, *J* = 32.3 Hz), 143.2, 136.1, 135.5, 134.8 (d, *J* = 8.1 Hz), 133.4 (d, *J* = 12.1 Hz), 133.3 (d, *J* = 22.7 Hz), 132.4 - 132.0 (m), 131.5, 130.9 (d, *J* = 102.0 Hz), 129.7, 128.9, 128.8, 128.7, 127.9 (d, *J* = 2.0 Hz), 126.4, 126.3, 125.0, 124.9, 63.0, 52.7, 52.1 (d, *J* = 4.0 Hz), 42.2 (d, *J* = 3.0 Hz), 37.0 (t, *J* = 24.2 Hz), 13.6. **^{31}P NMR** (162 MHz, CDCl$_3$) δ 32.8. **^{19}F NMR** (377 MHz, CDCl$_3$) δ -105.2, -105.9. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{38}H_{34}F_2O_6P^+$ 655.2056; found 655.2054.



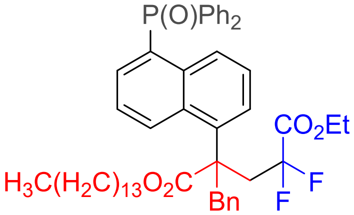
5-ethyl-1-methyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoro-2-methylpentanedioate (**4f**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2f** (30 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product **4f** (39 mg, 73 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.51 (dd, *J* = 8.4, 5.2 Hz, 1H), 7.74 (d, *J* = 8.8 Hz, 1H), 7.56 (d, *J* = 7.2 Hz, 1H), 7.45 - 7.40 (m, 1H), 7.38 - 7.29 (m, 11H), 7.01 (dd, *J* = 6.8, 5.0 Hz, 1H), 3.59 (s, 3H), 3.56 - 3.48 (m, 1H), 3.37 - 3.24 (m, 1H), 3.18 - 3.07 (m, 2H), 1.97 (s, 3H), 0.84 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 177.8, 163.0 (dd, *J* = 31.3, 34.3 Hz), 136.6, 136.4, 136.3, 136.2, 136.1, 134.5, 134.4, 134.3, 134.2, 131.7, 131.5 (d, *J* = 4.0 Hz), 129.1, 129.0, 128.8, 128.7, 127.1 (d, *J* = 30.3 Hz), 126.1, 125.9, 125.5 (d, *J* = 3.0 Hz), 124.5, 115.8 (dd, *J* = 247.5, 255.5 Hz), 62.5, 53.0, 47.6 (d, *J* = 7.1 Hz), 41.4 (dd, *J* = 21.2, 25.3 Hz), 25.2 (d, *J* = 4.0 Hz), 13.5. **^{31}P NMR** (162 MHz, $CDCl_3$) δ -13.3. **^{19}F NMR** (377 MHz, $CDCl_3$) δ-93.2, -93.8, -93.9 -103.0, -103.1, -103.7, -103.8. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{31}H_{30}F_2O_4P^+$ 535.1844; found 535.1837.



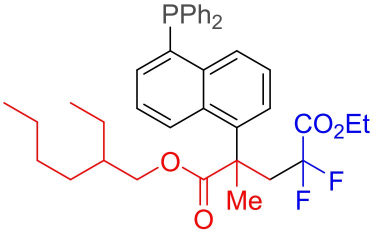
5-ethyl 1-methyl 2-benzyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4g**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2g** (42.6 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product **4g** (35 mg, 61 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) 8.48 (dd, *J* = 8.4, 5.2 Hz, 1H), 7.79 (d, *J* = 8.6 Hz, 1H), 7.55 (d, *J* = 7.2 Hz, 1H), 7.41 (dd, *J* = 8.4, 7.6 Hz, 1H), 7.37 - 7.28 (m, 9H), 7.26 - 7.23 (m, 2H), 7.00 (ddd, *J* = 7.2, 4.4, 0.8 Hz, 1H), 4.07 - 3.97 (m, 2H), 3.57 - 3.49 (m, 1H), 3.39 - 3.26 (m, 1H), 3.17 - 3.05 (m, 2H), 1.96 (s, 3H), 1.37 - 1.29 (m, 2H), 0.93 - 0.80 (m, 5H), 0.64 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 177.5, 163.1 (dd, *J* = 34.3, 31.3 Hz), 136.5, 136.4, 136.3, 136.2, 136.0, 134.6, 134.4, 134.2, 134.0, 131.6, 131.5 (d, *J* = 4 Hz), 129.2, 129.0, 128.8, 128.7, 127.1, 126.8, 125.9, 125.5 (d, *J* = 2 Hz), 124.9, 115.9 (dd, *J* = 255.5, 246.4 Hz), 65.6, 62.5, 58.6, 47.7 (d, *J* = 8.1 Hz), 41.3 (dd, *J* = 26.3, 21.2 Hz), 30.3, 25.3 (d, *J* = 5.1 Hz), 18.8, 13.5. **^{31}P NMR** (162 MHz, $CDCl_3$) δ -13.2. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -93.3 (d, *J* = 267.7 Hz), -103.4 (d, *J* = 267.7 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{34}H_{36}F_2O_4P^+$ 577.2314; found 577.2311.



5-ethyl-1-tetradecyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (4h)

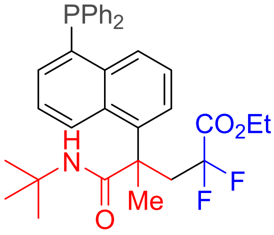
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2h** (107.4 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4h** (40 mg, 50 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.72 (d, *J* = 8.6 Hz, 1H), 8.11 (d, *J* = 8.6 Hz, 1H), 7.72 - 7.53 (m, 7H), 7.50 - 7.26 (m, 10H), 7.17 - 6.94 (m, 2H), 4.09 - 3.88 (m, 3H), 3.59 - 3.11 (m, 4H), 2.97 (dd, *J* = 28.6, 15.2 Hz, 1H), 1.39 - 1.05 (m, 23H), 0.89 - 10.86 (m, 4H), 0.88 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 175.0, 163.0 (t, *J* = 32.3 Hz), 136.7, 135.8, 134.8 (d, *J* = 8.1 Hz), 133.4 (d, *J* = 3.0 Hz), 133.2 (d, *J* = 12.1 Hz), 132.5 (d, *J* = 9.1 Hz), 132.3 (d, *J* = 3.0 Hz), 132.2, 132.1, 130.91 130.1 (d, *J* = 102.0 Hz), 128.8, 128.7, 128.6, 128.5, 128.4, 127.3, 126.5, 124.5 (d, *J* = 14.1 Hz), 116.1 (dd, *J* = 248.5, 257.6 Hz), 65.8, 62.7, 52.1 (d, *J* = 4.0 Hz), 42.2 (d, *J* = 2.0 Hz), 36.7 (t, *J* = 22.2 Hz), 32.0, 29.8, 29.7, 2 9.4, 29.1, 28.0, 25.7, 22.8, 14.2, 13.5. **^{31}P NMR** (162 MHz, CDCl$_3$) δ 32.7. **^{19}F NMR** (377 MHz, CDCl$_3$) δ -105.4, -106.1. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{50}H_{60}F_2O_5P^+$ 809.4141; found 809.4128.



5-ethyl-1-(2-ethylhexyl)-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoro-2-methylpentanedioate (**4i**)

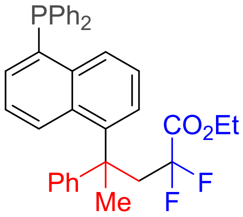
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2i** (59.4 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography

(R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product **4i** (dr = 1:1) (36 mg, 57 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.54 - 8.39 (m, 2H), 7.79 (dd, *J* = 8.8, 2.8 Hz, 2H), 7.55 (d, *J* = 7.2 Hz, 2H), 7.46 - 7.37 (m, 2H), 7.37 - 7.21 (m, 22H), 7.02 - 6.95 (m, 2H), 4.01 - 3.79 (m, 4H), 3.62 - 3.45 (m, 2H), 3.42 - 3.23 (m, 2H), 3.20 - 3.01 (m, 4H), 1.96 (s, 6H), 1.34 - 1.21 (m, 4H), 1.12 - 0.96 (m, 6H), 0.95 - 0.84 (m, 8H), 0.82 (t, *J* = 7.2 Hz, 6H), 0.78 - 0.63 (m, 6H), 0.58 (t, *J* = 7.5 Hz, 3H), 0.51 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 177.6, 163.1 (dd, *J* = 33.3, 30.3 Hz), 136.5, 136.4, 136.3, 136.2, 136.0, 134.6, 134.4, 134.3, 134.2, 134.1, 134.0, 131.6, 131.5, 129.1, 129.0, 128.8, 128.7, 128.6, 127.0, 126.7, 126.0, 125.9, 125.4, 125.4, 124.8, 115.9 (dd, *J* = 255.5, 247.5 Hz), 67.9, 67.8, 62.5, 47.7, 47.6, 41.3 (dd, *J* = 24.2, 21.2 Hz), 38.5, 38.4, 30.7, 30.1, 28.9, 28.7, 25.3, 23.6, 23.5, 22.9, 14.1, 13.4, 10.9, 10.7. **^{31}P NMR** (162 MHz, $CDCl_3$) δ -13.0, -13.1. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -93.3 (d, *J* = 263.9 Hz), -93.4 (d, *J* = 267.7 Hz), -102.3 (d, *J* = 267.7 Hz), -103.3 (d, *J* = 263.9 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{38}H_{44}F_2O_4P^+$ 633.2940; found 633.2930.



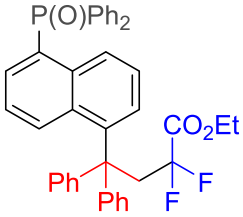
Ethyl-5-(tert-butylamino)-4-(5-(diphenylphosphanyl)naphthalen-1-yl)-2,2-difluoro-4-methyl-5-oxopentanoate (**4j**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2j** (42.3 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product **4j** (37 mg, 65 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.53 (dd, *J* = 8.4, 5.2 Hz, 1H), 7.88 (d, *J* = 8.6 Hz, 1H), 7.61 (d, *J* = 7.2 Hz, 1H), 7.44 - 7.41 (m, 1H), 7.40 - 7.37 (m, 1H), 7.37 - 7.29 (m, 8H), 7.28 - 7.24 (m, 2H), 7.00 - 6.97 (m, 1H), 4.76 (s, 1H), 3.59 - 3.51 (m, 1H), 3.27 - 3.10 (m, 3H), 1.91 (s, 3H), 1.09 (s, 9H), 0.86 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 176.3, 163.3 (dd, *J* = 33.3, 31.3 Hz), 136.7 (d, *J* = 1 Hz), 136.3, 136.2, 136.1, 136.0, 134.5, 134.4, 134.3, 134.2, 131.9, 131.4 (d, *J* = 4 Hz), 129.2, 129.1, 128.8, 128.7, 127.7, 127.4, 127.0, 126.4, 126.0 (d, *J* = 1 Hz), 125.5 (d, *J* = 2 Hz), 116.4 (dd, *J* = 254.5, 247.5 Hz), 62.4, 51.2, 48.8, 48.7, 40.8 (dd, *J* = 24.2, 21.2 Hz), 28.2, 26.6 (d, *J* = 4 Hz), 13.5. **^{31}P NMR** (162 MHz, $CDCl_3$) δ -13.3. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -94.2 (d, *J* = 263.9 Hz), -102.9 (d, *J* = 263.9 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{34}H_{37}F_2NO_3P^+$ 576.2474; found 576.2466.



5-ethyl 1-methyl 2-benzyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4k**)

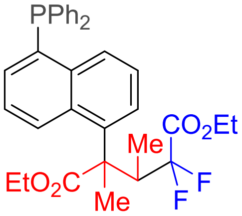
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2k** (35.4 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 20/1/1) afforded the product **4k** (29 mg, 53 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.52 (dd, *J* = 8.4, 5.2 Hz, 1H), 7.77 (d, *J* = 7.2 Hz, 1H), 7.47 (dd, *J* = 8.4, 7.6 Hz, 1H), 7.41 (d, *J* = 8.8 Hz, 1H), 7.33 - 7.21 (m, 12H), 7.17 - 7.14 (m, 3H), 7.00 - 6.94 (m, 1H), 6.88 - 6.96 (m, 1H), 3.66 - 3.53 (m, 1H), 3.39 - 3.30 (m, 1H), 3.26 - 3.16 (m, 1H), 3.09 - 3.01 (m, 1H), 1.94 (s, 3H), 0.85 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 163.0 (t, *J* = 33.3 Hz), 150.4, 140.5, 137.0, 136.7, 136.6, 136.5, 136.4, 135.6, 135.4, 134.5, 134.3, 134.1, 131.5 (d, *J* = 4.0 Hz), 131.3, 129.0, 128.9, 128.8, 128.7, 128.6, 128.4, 127.0, 126.9, 126.7, 126.2, 125.6, 125.3 (d, *J* = 3.0 Hz), 124.6 (d, *J* = 1.0 Hz), 116.4 (dd, *J* = 256.5, 246.4 Hz), 62.4, 45.1, 45.0, 43.9 (t, *J* = 22.2 Hz), 43.6, 32.6, 13.5. **^{31}P NMR** (162 MHz, CDCl$_3$) δ -13.2. **^{19}F NMR** (377 MHz, CDCl$_3$) δ -91.9 (d, *J* = 267.7 Hz), -103.2 (d, *J* = 233.7 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{35}H_{32}F_2O_2P^+$ 553.2102; found 553.2095.



Ethyl-4-(5-(diphenylphosphoryl)naphthalen-1-yl)-2,2-difluoro-4,4-diphenylbutanoate (**4l**)

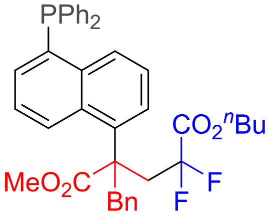
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2l** (54.0 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 20/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 2/1/1) afforded the product **4l** (32 mg, 51 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.66

(d, *J* = 8.6 Hz, 1H), 7.71 - 7.65 (m, 5H), 7.61 (d, *J* = 7.2 Hz, 1H), 7.57 - 7.53 (m, 2H), 7.49 - 7.44 (m, 4H), 7.41 - 7.31 (m, 5H), 7.24 - 7.20 (m, 4H), 7.17 - 7.08 (m, 3H), 6.99 - 6.94 (m, 1H), 3.93 (t, *J* = 15.2 Hz, 2H), 3.54 (dd, *J* = 14.0 Hz, 6.8 Hz, 2H), 1.02 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 163.5 (t, *J* = 32.8 Hz), 145.0, 140.1, 135.3 (d, *J* = 7.6 Hz), 133.5, 133.1, 133.0, 132.7, 132.3, 132.2, 132.1, 132.0, 130.8, 129.8 (d, *J* = 102.1 Hz), 128.8, 128.7, 128.4 (d, *J* = 7.6K Hz), 128.2, 126.4, 126.2, 122.6 (d, *J* = 13.9 Hz), 115.5 (t, *J* = 225.8 Hz), 62.7, 55.4, 43.4 (t, *J* = 22.7 Hz), 13.6. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.3. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -98.2. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{40}H_{34}F_2O_3P^+$ 631.2208; found 631.2205.



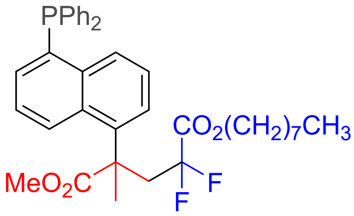
Eiethyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoro-2,3-dimethylpentanedioate (4m)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2m** (38.4 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 10/1/1) afforded the product **4m** (31 mg, 55 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.49 (dd, *J* = 8.4, 5.2 Hz, 1H), 8.19 (d, *J* = 8.8 Hz, 1H), 7.56 (d, *J* = 7.2 Hz, 1H), 7.43 (dd, *J* = 8.3, 7.6 Hz, 1H), 7.36 - 7.24 (m, 11H), 7.00 - 6.97 (m, 1H), 4.46 - 4.38 (m, 2H), 4.05 - 3.96 (m, 2H), 3.91 - 3.78 (m, 1H), 1.93 (s, 3H), 1.44 (t, *J* = 7.2 Hz, 3H), 0.92 (t, *J* = 7.2 Hz, 3H), 0.62 (dd, *J* = 7.2, 2.4 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 176.8, 164.9 (t, *J* = 33.3 Hz), 138.6 (d, *J* = 1.0 Hz) , 136.5, 136.4, 136.2, 136.0, 134.5, 134.4, 134.3, 134.2, 131.7, 131.6 (d, *J* = 4.0 Hz), 129.1, 129.0, 128.8, 128.7, 126.9, 126.6, 125.9, 125.7, 125.5 (d, *J* = 3.0 Hz), 124.9, 117.7 (dd, *J* = 262.6, 250.5 Hz), 62.9, 61.4, 52.3, 41.1 (t, *J* = 21.2 Hz), 20.5, 20.4, 14.2, 13.9, 10.4 (dd, *J* = 8.1, 3.0 Hz). **^{31}P NMR** (162 MHz, $CDCl_3$) δ -12.8. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -98.5 (d, *J* = 271.4 Hz), -108.4 (d, *J* = 267.7 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{33}H_{34}F_2O_4P^+$ 563.2157; found 563.2150.



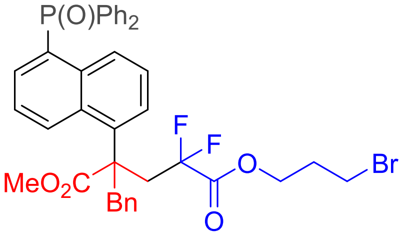
5-butyl-1-methyl-2-benzyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4o**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3b** (69.3 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product **4o** (50 mg, 79 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.53 (dd, *J* = 8.4, 5.2 Hz, 1H), 7.86 (d, *J* = 8.8 Hz, 1H), 7.61 (d, *J* = 6.8 Hz, 1H), 7.44 - 7.39 (m, 1H), 7.37 - 7.29 (m, 10H), 7.29 - 7.25 (m, 4H), 7.10 - 7.03 (m, 2H), 7.00 (dd, *J* = 6.8, 4.8 Hz, 1H), 4.05 (d, *J* = 13.2 Hz, 1H), 3.58 - 3.44 (m, 5H), 3.29 - 3.08 (m, 2H), 2.98 (q, *J* = 14.8 Hz, 1H), 1.29 - 1.23 (m, 2H), 1.19 - 1.10 (m, 2H), 0.81 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 175.7, 162.9 (t, *J* = 32.3 Hz), 136.5, 136.4, 136.4, 136.3, 136.0, 134.6, 134.4, 134.2, 131.9 (d, *J* = 4 Hz), 131.7, 130.9, 129.1, 129.0, 128.8, 128.7, 128.4, 127.4, 127.1, 126.1, 125.5 (d, *J* = 2 Hz), 124.5, 116.2 (dd, *J* = 257.6, 248.5 Hz), 66.3, 52.5, 52.1 (d, *J* = 5.0 Hz) , 42.3 (d, *J* = 4.0 Hz), 36.7 (dd, *J* = 25.3, 20.2 Hz), 30.0, 18.9, 13.7. **^{31}P NMR** (162 MHz, $CDCl_3$) δ -12.8. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -105.6, -106.3. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{39}H_{38}F_2O_4P^+$ 639.2470; found 639.2463.



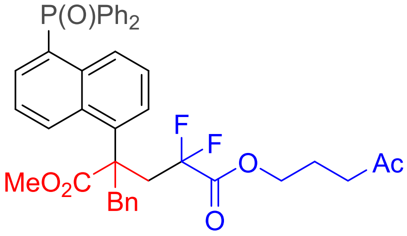
5-heptyl-1-methyl-2-benzyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4p**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2f** (30 mg, 0.3 mmol, 3.0 equiv), **3c** (86.1 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product **4p** (31 mg, 50 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.49 (dd, *J* = 8.4, 5.2 Hz, 1H), 7.74 (d, *J* = 8.8 Hz, 1H), 7.56 (d, *J* = 7.2 Hz, 1H), 7.44 - 7.39 (m, 1H), 7.37 - 7.26 (m, 11H), 6.99 (dd, *J* = 6.8, 4.8 Hz, 1H), 3.60 - 3.48 (m, 4H), 3.37 - 3.23 (m, 1H), 3.18 - 3.05 (m, 2H), 1.97 (s, 3H), 1.28 - 1.14 (m, 10H), 1.10 - 1.01 (m, 2H), 0.87 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 178.0, 163.1 (t, *J* = 34.3 Hz), 136.3 (d, *J* = 43.4 Hz), 136.4 - 136.3 (m), 134.5, 134.4, 134.3, 134.2, 131.7, 131.5 (d, *J* = 5.1 Hz), 129.1, 129.0, 128.8, 128.7, 127.3, 127.0, 126.1, 125.8, 125.5, 124.5, 115.8 (t, *J* = 255.5 Hz), 66.6, 53.0, 47.6 (d, *J* = 7.1 Hz), 41.4 (dd, *J* = 25.3, 21.2 Hz), 31.9, 29.2, 27.9, 25.6, 25.3 (d, *J* = 4.0 Hz), 22.8, 14.2. **^{31}P NMR** (162 MHz, $CDCl_3$)) δ -13.1. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -93.4, -93.5, -94.1, -94.2, -103.0, -103.1, -103.7, -103.8, **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{37}H_{42}F_2O_4P^+$ 619.2783; found 619.2775.



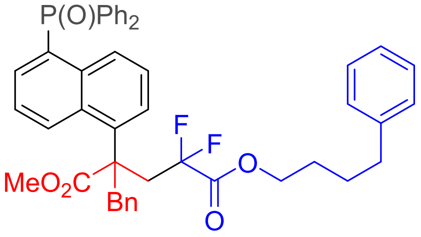
5-(3-bromopropyl)-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioatee (**4q**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3d** (88.5 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 1/1/1) afforded the product **4q** (43 mg, 60 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.72 (d, *J* = 8.6 Hz, 1H), 8.06 (d, *J* = 8.6 Hz, 1H), 7.74 - 7.61 (m, 5H), 7.60 - 7.54 (m, 2H), 7.51 - 7.38 (m, 6H), 7.33 - 7.26 (m, 4H), 7.12 - 6.98 (m, 2H), 4.01 (d, *J* = 12.8 Hz, 1H), 3.60 - 3.38 (m, 6H), 3.36 - 3.05 (m, 3H), 2.97 (dd, *J* = 28.4, 15.2 Hz, 1H), 1.90 - 1.76 (m, 2H). **^{13}C NMR** (126 MHz, CDCl$_3$) δ 175.5, 162.9 (d, *J* = 32.8 Hz), 136.7, 135.7, 134.8 (d, *J* = 7.6 Hz), 133.4, 133.3, 132.6 (d, *J* = 8.8 Hz), 132.4 (d, *J* = 8.8 Hz), 132.3, 132.2, 131.26, 130.9 (d, *J* = 100.8 Hz), 130.9, 128.9, 128.8, 128.7, 128.5, 128.1 (d, *J* = 1.3 Hz), 127.5, 126.5, 124.9 (d, *J* = 13.9 Hz), 116.1 (dd, *J* = 258.3, 247.0 Hz), 64.3, 52.5, 52.1 (d, *J* = 5.0 Hz), 42.3 (d, *J* = 7.6 Hz), 36.8 (dd, *J* = 25.2, 18.9 Hz), 31.0, 28.7. **^{31}P NMR** (202 MHz, CDCl$_3$) δ 32.75. **^{19}F NMR** (471 MHz, CDCl$_3$) δ -105.4, -106.0. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{38}H_{35}BrF_2O_5P^+$ 719.1368; found 719.1360.



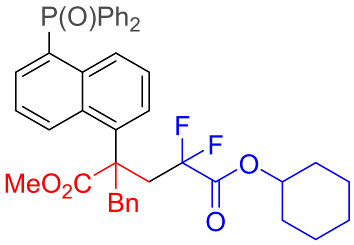
1-methyl-5-(4-oxopentyl)-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4r**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3e** (77.7 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4r** (53 mg, 78 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.70 (d, *J* = 8.6 Hz, 1H), 8.06 (d, *J* = 8.6 Hz, 1H), 7.73 - 7.55 (m, 7H), 7.51 - 7.37 (m, 6H), 7.32 - 7.26 (m, 4H), 7.13 - 6.93 (m, 2H), 4.01 (d, *J* = 12.8 Hz, 1H), 3.61 - 3.39 (m, 5H), 3.37 - 3.08 (m, 2H), 2.96 (dd, *J* = 28.4, 15.6 Hz, 1H), 2.32 (t, *J* = 7.2 Hz, 2H), 2.10 (s, 3H), 1.62 - 1.55 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 207.2, 175.5, 163.0 (dd, *J* = 30.2, 30.4 Hz), 136.6, 135.8, 134.8 (d, *J* = 7.6 Hz), 133.4, 133.3, 133.2, 132.6 (d, *J* = 8.6 Hz), 132.4 (d, *J* = 12.6 Hz), 132.3, 132.2, 132.1, 130.9, 130.8 (d, *J* = 100.8 Hz), 128.9, 128.8, 128.7 (d, *J* = 6.3 Hz), 128.5, 128.1, 127.5, 126.5, 124.9 (d, *J* = 13.9 Hz), 116.1 (dd, *J* = 247.0, 257.0 Hz), 65.7, 52.2, 52.1 (d, *J* = 5.0 Hz), 42.2 (d, *J* = 2.5 Hz) 36.8 (dd, *J* = 25.2, 20.2 Hz), 30.1, 22.0. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.8. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.1, -105.7. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{40}H_{38}F_2O_6P^+$ 683.2369; found 683.2357.



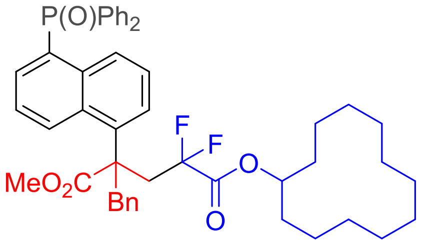
1-methyl-5-(4-phenylbutyl)-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4s**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3f** (92.1 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4s** (65 mg, 89 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 (d, *J* = 8.4 Hz, 1H), 8.05 (d, *J* = 8.4 Hz, 1H), 7.70 - 7.65 (m, 4H), 7.61 - 7.40 (m, 7H), 7.38 - 7.23 (m, 8H), 7.21 - 7.15 (m, 1H), 7.11 - 6.99 (m, 4H), 4.00 (d, *J* = 13.2 Hz, 1H), 3.63 - 3.42 (m, 5H), 3.37 - 3.09 (m, 2H), 2.96 (dd, *J* = 28.4, 15.6 Hz, 1H), 2.53 (t, *J* = 7.2 Hz, 2H), 1.50 - 1.42 (m, 2H), 1.41 - 1.31 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.5, 163.0 (d, *J* = 32.8 Hz), 141.7, 136.6, 135.7, 134.7 (d, *J* = 7.6 Hz), 133.3 (d, *J* = 3.8 Hz), 133.2, 132.5 (d, *J* = 8.8 Hz), 132.4 (d, *J* = 17.6 Hz), 132.2, 132.1, 132.0, 130.8, 130.6 (d, J = 100.8 Hz), 128.8, 128.7, 128.6 (d, J = 6.3 Hz), 128.5, 128.4, 128.1 (d, J = 2.5 Hz), 127.4, 126.4, 126.0, 124.7 (d, J = 15.1 Hz), 116.1 (dd, J = 258.3, 248.2 Hz), 66.5, 52.4, 52.1 (d, J = 5.0 Hz), 42.2 (d, J = 2.5 Hz), 36.7 (t, J = 22.7 Hz), 35.3, 27.4, 27.2. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.7. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.3, -105.9. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{45}H_{42}F_2O_5P^+$ 731.2732 found 731.2719.



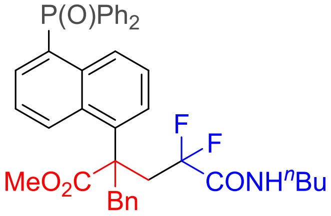
5-cyclohexyl-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4t**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3g** (77.1 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4t** (59 mg, 88 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 (d, J = 8.8 Hz, 1H), 8.11 (d, J = 8.8 Hz, 1H), 7.72 - 7.64 (m, 4H), 7.59 - 7.44 (m, 7H), 7.41 - 7.36 (m, 2H), 7.30 - 7.22 (m, 4H), 7.08 - 6.82 (m, 2H), 4.54 - 4.29 (m, 1H), 4.00 (d, J = 13.2 Hz, 1H), 3.62 (d, J = 13.2 Hz, 1H), 3.57 (s, 3H), 3.17 - 2.87 (m, 2H), 1.72 - 1.26 (m, 10H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.7, 162.9 (d, J = 31.5 Hz), 137.1, 135.9, 134.9 (d, J = 7.6 Hz), 133.4 (d, J = 16.4 Hz), 133.2 (d, J = 11.3 Hz), 132.5 (d, J = 21.4 Hz), 132.4 (d, J = 13.9 Hz), 132.3, 132.2, 132.1, 132.0, 130.8, 130.6 (d, J = 102.1 Hz), 128.8, 128.7, 128.4 (d, J = 6.3 Hz), 128.2, 128.1 (d, J = 1.3 Hz), 127.3, 126.4, 126.0, 124.7 (d, J = 13.9 Hz), 116.1 (dd, J = 257.0, 250.7 Hz), 75.9, 52.5, 52.1, 42.1, 36.9 (t, J = 21.4 Hz), 30.9, 30.8, 25.2, 23.2. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.9. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -104.2, -104.8. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{41}H_{40}F_2O_5P^+$ 681.2576; found 681.2567.



5-cyclododecyl-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4u**)

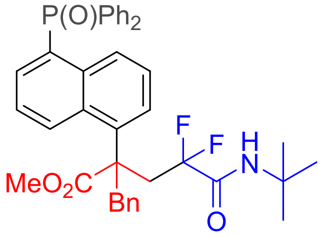
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3h** (102.3 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4u** (63 mg, 82 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.70 (d, *J* = 8.6 Hz, 1H), 8.11 (d, *J* = 8.6 Hz, 1H), 7.68 (dd, *J* = 10.4, 8.6 Hz, 4H), 7.60 - 7.35 (m, 9H), 7.32 - 7.19 (m, 4H), 7.01 - 6.79 (m, 2H), 4.86 - 4.61 (m, 1H), 3.98 (d, *J* = 13.2 Hz, 1H), 3.65 (d, *J* = 12.8 Hz, 1H), 3.57 (s, 3H), 3.12 - 2.84 (m, 2H), 1.73 - 1.55 (m, 2H), 1.46 - 1.22 (m, 20H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 175.8, 163.2 (t, *J* = 32.3 Hz), 137.2, 135.9, 134.9 (d, *J* = 9.1 Hz), 134.8, 133.4 (d, *J* = 6.1 Hz), 133.3 (d, *J* = 9.1 Hz), 132.4, 132.3, 132.2, 132.1, 132.0, 130.8, 130.5 (d, *J* = 102.0 Hz), 128.8, 128.7, 128.4 (d, *J* = 8.1 Hz), 128.2, 128.1 (d, *J* = 2.0 Hz), 127.2, 126.4, 125.9, 124.8 (d, *J* = 15.2 Hz), 116.1 (t, *J* = 256.5 Hz), 76.5, 52.6, 52.1, 42.1, 36.8 (t, *J* = 20.2 Hz), 28.2, 24.4, 23.1, 23.0, 22.9, 22.8, 20.2. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.1. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -103.9, -104.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{47}H_{52}F_2O_5P^+$ 765.3515; found 765.3506.



Methyl-2-benzyl-5-(butylamino)-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-oxopentanoate (**4v**)

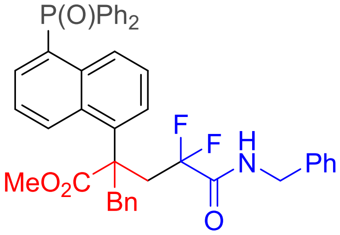
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3i** (69.0 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4v** (39 mg, 60 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.70

(d, J = 8.6 Hz, 1H), 8.09 (d, J = 8. 6Hz, 1H), 7.73 - 7.60 (m, 4H), 7.59 - 7.54 (m, 2H), 7.49 - 7.45 (m, 5H), 7.40 - 7.33 (m, 2H), 7.28 - 7.19 (m, 4H), 7.00 - 6.80 (m, 2H), 6.02 (s, 1H), 3.91 (d, J = 12.8 Hz, 1H), 3.64 - 3.47 (m, 4H), 3.18 (dd, J = 35.0, 17.8 Hz, 1H), 3.06 - 2.89 (m, 2H), 2.85 - 2.69 (m, 1H), 1.40 - 1.28 (m, 2H), 1.26 - 1.17 (m, 2H), 0.86 (t, J = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 175.8, 163.3 (t, J = 28.3 Hz), 137.4, 135.8, 134.8 (d, J = 8.1 Hz), 133.5, 133.3, 132.5, 132.5 (d, J = 9.1 Hz), 132.2, 132.1, 130.8, 129.8, 128.8, 128.7, 128.4, 128.3, 127.3, 126.2, 125.8, 124.7 (d, J = 14.1 Hz), 118.0 (t, J = 257.6 Hz), 52.5, 52.0, 42.2, 39.2, 36.3 (t, J = 21.2 Hz), 31.0, 19.9, 13.8. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.3. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -104.8, -105.4. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{39}H_{39}F_2NO_4P^+$ 654.2579; found 654.2576.



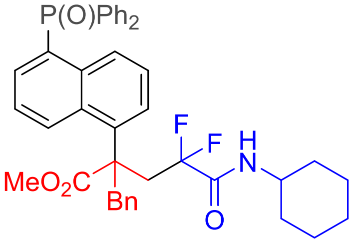
Methyl-2-benzyl-5-(tert-butylamino)-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-oxopentanoate (**4w**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3j** (69.0 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4w** (38 mg, 58 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 (d, J = 8.6 Hz, 1H), 8.11 (d, J = 8.6 Hz, 1H), 7.72 - 7.64 (m, 4H), 7.60 - 7.54 (m, 2H), 7.50 - 7.43 (m, 5H), 7.41 - 7.36 (m, 2H), 7.29 - 7.23 (m, 1H), 7.20 - 7.19 (m, 3H), 6.99 - 6.80 (m, 2H), 5.86 (s, 1H), 3.91 (d, J = 13.2 Hz, 1H), 3.62 (d, J = 13.2 Hz, 1H), 3.57 (s, 3H), 3.17 - 2.93 (m, 2H), 1.25 (s, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 176.0, 162.7 (t, J = 27.3 Hz), 137.8, 135.9, 134.9 (d, J = 8.1 Hz), 133.4 (d, J = 2.0 Hz), 133.3 (d, J = 2.0 Hz), 132.5, 132.4, 132.3, 132.2, 132.1, 130.8, 130.5 (d, J = 102.0 Hz), 128.8, 128.7, 128.3 (d, J = 3.0 Hz), 128.2, 127.2, 126.3, 125.9, 124.6 (d, J = 15.2 Hz), 117.8 (d, J = 257.6 Hz), 52.0, 51.9, 42.1, 36.4 (d, J = 17.2 Hz), 28.4. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.3. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -99.7 (d, J = 256.4 Hz), -102.15 (d, J = 256.4 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{39}H_{39}F_2NO_4P^+$ 654.2579; found 654.2569.



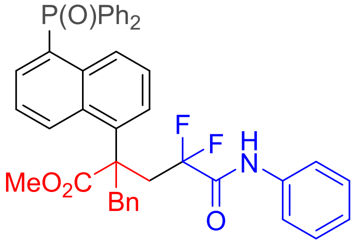
Methyl-2-benzyl-5-(benzylamino)-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-oxopentanoate (**4x**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3k** (79.2 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R$_f$ = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H$_2$O$_2$, then DCM (10mL) and H$_2$O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R$_f$ = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4x** (35 mg, 51 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.74 (d, *J* = 8.6 Hz, 1H), 8.09 (d, *J* = 8.6 Hz, 1H), 7.72 - 7.65 (m, 4H), 7.59 - 7.55 (m, 1H), 7.51 - 7.32 (m, 8H), 7.30 - 7.24 (m, 7H), 7.11 - 7.05 (m, 2H), 7.03 - 6.92 (m, 2H), 6.22 (s, 1H), 4.10 (dd, *J* = 14.5, 6.4 Hz, 1H), 3.90 (d, *J* = 12.8 Hz, 1H), 3.78 - 3.63 (m, 1H), 3.57 (d, *J* = 15.3 Hz, 4H), 3.27 (dd, *J* = 35.2, 17.6 Hz, 1H), 3.00 (dd, *J* = 32.0, 15.8 Hz, 1H). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 175.7, 163.2 (t, *J* = 27.3 Hz), 137.2, 136.5, 135.7, 134.8 (d, *J* = 8.1 Hz), 133.5 (d, *J* = 12.1 Hz), 133.3, 132.7 (d, *J* = 8.1 Hz), 132.2, 132.1, 130.8, 130.4 (d, *J* = 102.0 Hz), 128.9, 128.8, 128.7, 128.6 (d, *J* = 6.1 Hz), 128.4 (d, *J* = 3.0 Hz), 128.4, 128.0, 127.4, 126.2, 125.9, 124.8 (d, *J* = 14.1 Hz), 118.0 (t, *J* = 259.6 Hz), 52.5, 52.0 (d, *J* = 2.0 Hz), 43.5, 42.3, 36.1 (t, *J* = 22.2 Hz). **^{31}P NMR** (162 MHz, CDCl$_3$) δ 33.2. **^{19}F NMR** (377 MHz, CDCl$_3$) δ -105.6, -106.4. **HRMS** (ESI) m/z: [M+H]$^+$ calcd for $C_{42}H_{37}F_2NO_4P^+$ 688.2423; found 688.2418.



Methyl-2-benzyl-5-(cyclohexylamino)-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-oxopentanoate (**4y**)

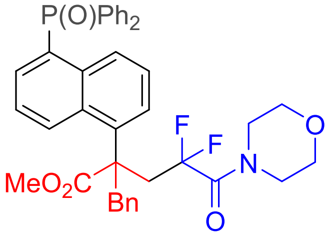
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3l** (76.8 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4y** (33 mg, 48 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.70 (d, *J* = 8.6 Hz, 1H), 8.10 (d, *J* = 8.6 Hz, 1H), 7.71 - 7.55 (m, 6H), 7.51 - 7.33 (m, 7H), 7.28 - 7.19 (m, 4H), 6.98 - 6.77 (m, 2H), 5.91 (s, 1H), 3.90 (d, *J* = 13.2 Hz, 1H), 3.66 - 3.44 (m, 5H), 3.18 - 2.94 (m, 2H), 1.85 - 1.57 (m, 6H), 1.39 - 0.98 (m, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.9, 162.6 (t, *J* = 29.0 Hz), 137.5, 135.7, 134.8 (d, *J* = 7.6 Hz), 133.3, 133.2, 132.5, 132.4, 132.3, 132.2, 132.1, 132.0, 130.7, 130.4 (d, *J* = 102.1 Hz), 128.7, 128.6, 128.3, 128.2, 128.1, 127.1, 126.2, 125.7, 124.5 (d, *J* = 15.1 Hz), 117.80 (t, *J* = 255.8 Hz), 52.4, 51.9, 48.6, 42.0, 36.7 - 36.4 (m), 32.4, 25.3, 24.5. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.4. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -100.2 (d, *J* = 256.4 Hz), -103.1(d, *J* = 256.4 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{41}H_{41}F_2NO_4P^+$ 680.2736; found 680.2724.



Methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-oxo-5-(phenylamino)pentanoate (**4z**)

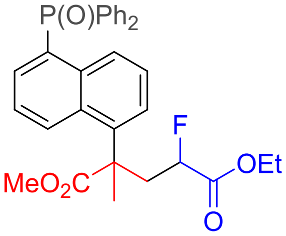
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3m** (75.0 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4z** (42 mg, 63 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.65 (d, *J* = 8.6 Hz, 1H), 8.10 (d, *J* = 8.6 Hz, 1H), 7.97 (s, 1H), 7.71 - 7.62 (m, 4H), 7.58 - 7.54 (m, 2H), 7.49 - 7.35 (m, 8H), 7.28 - 7.20 (m, 7H), 7.15 - 7.12 (m, 1H), 6.98 - 6.85 (m, 2H), 3.90 (d, *J* = 13.2 Hz, 1H), 3.61 (d, *J* = 13.2 Hz, 1H), 3.54 (s, 3H), 3.25 - 3.07 (m, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 175.9, 161.4 (t, *J* = 28.3 Hz), 137.4, 135.9, 135.7, 134.9 (d, *J* = 25.3 Hz), 133.4 (d, *J* = 4.0 Hz), 133.3 (d, *J* = 5.1 Hz), 132.4 (d, *J* = 6.1 Hz), 132.3, 132.2, 132.1, 130.8, 130.5 (d, *J* = 102.0 Hz), 129.2, 128.8, 128.7, 128.4 (d,

$J = 8.1$ Hz), 128.3, 128.2 (d, $J = 3.0$ Hz), 127.3, 126.3, 125.9, 125.6, 124.7 (d, $J = 15.2$ Hz), 120.4, 116.4 (t, $J = 40.4$ Hz), 52.6, 52.0, 42.2, 36.6 (t, $J = 23.2$ Hz). **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.3. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -99.6 (d, $J = 260.1$ Hz), -101.1 (d, $J = 260.1$ Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{41}H_{35}F_2NO_4P^+$ 674.2266; found 674.2263.



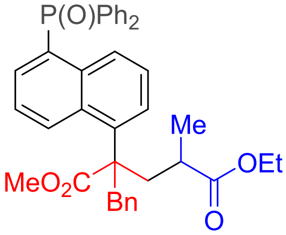
Methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-morpholino-5-oxopentanoate (**4ab**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3n** (73.2 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 1/1/1) afforded the product **4ab** (31 mg, 46 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.68 (d, $J = 8.6$ Hz, 1H), 8.15 (d, $J = 8.6$ Hz, 1H), 7.72 - 7.66 (m, 4H), 7.59 - 7.55 (m, 2H), 7.52 - 7.44 (m, 5H), 7.41 - 7.35 (m, 2H), 7.29 - 7.24 (m, 1H), 7.20 - 7.16 (m, 3H), 6.86 - 6.72 (m, 2H), 3.92 (d, $J = 13.2$ Hz, 1H), 3.69 (d, $J = 13.2$ Hz, 1H), 3.63 - 3.36 (m, 11H), 3.18 - 3.07 (m, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 176.2, 161.7 (t, $J = 29.3$ Hz), 137.9, 136.0, 134.9 (d, $J = 8.1$ Hz), 133.4, 133.3, 133.2, 132.4, 132.3, 132.2, 132.1, 130.7, 130.6 (d, $J = 102.0$ Hz), 128.8, 128.7, 128.2, 127.2, 126.5, 126.2, 124.6 (d, $J = 15.2$ Hz), 119.3, 66.7, 52.5, 52.1, 46.6 (t, $J = 6.1$ Hz), 43.5, 42.1. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 32.2. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -96.4. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{39}H_{37}F_2NO_5P^+$ 668.2372; found 668.2369.



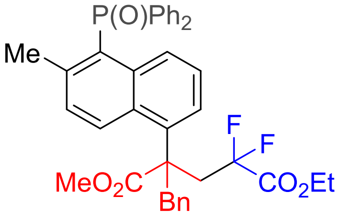
5-ethyl-1-methyl-2-(5-(diphenylphosphanyl)naphthalen-1-yl)-4-fluoro-2-methylpentanedioate (**4ac**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3o** (55.2 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4ac** (dr = 1 : 0.75) (32 mg, 60 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.61 - 8.36 (m, 1.74H), 7.78 (dd, *J* = 8.6, 6.2 Hz, 1.74H), 7.58 (dd, *J* = 19.8, 7.2 Hz, 1.75H), 7.47 - 7.40 (m, 1.75H), 7.37 - 7.27 (m, 19.26H), 7.02 - 6.95 (m, 1.76H), 5.17 (ddd, *J* = 49.2, 8.2, 2.0 Hz, 0.75H), 4.32 (ddd, *J* = 49.8, 10.0, 1.6 Hz, 1H), 4.18 - 4.00 (m, 3.52H), 3.61 (s, 3H), 3.60 (s, 2.17H), 3.12 - 2.93 (m, 1.74H), 2.78 - 2.58 (m, 1.76H), 1.90 (s, 3H), 1.88 (d, *J* = 0.8 Hz, 2.19H), 1.22 (t, *J* = 7.2 Hz, 2.24H), 1.12 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 178.3, 178.2, 169.8 (d, *J* = 24.2 Hz), 169.6 (d, *J* = 23.2 Hz), 138.7, 137.3, 136.5, 136.4, 136.3, 136.2, 134.5, 134.4, 134.3, 134.2, 131.8, 131.7, 131.4 (d, *J* = 4.0 Hz), 131.3 (d, *J* = 4.0 Hz), 129.1, 129.0, 128.8, 128.7, 126.9 (d, *J* = 29.3 Hz), 126.7 (d, *J* = 29.3 Hz), 126.1, 125.9, 125.6 (d, *J* = 2.0 Hz), 125.6 (d, *J* = 2.0 Hz), 125.3, 124.9, 124.7, 124.1, 87.0 (d, *J* = 185.8 Hz), 86.8 (d, *J* = 185.8 Hz), 61.8, 61.7, 52.9, 52.8, 49.1, 48.7, 41.5 (d, *J* = 21.2 Hz), 40.6 (d, *J* = 20.2 Hz), 25.9 (d, *J* = 3.0 Hz), 25.6 (d, *J* = 2.0 Hz), 14.2, 14.0. **^{31}P NMR** (162 MHz, $CDCl_3$) δ -12.9, -13.0. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -185.8, -187.7. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{31}H_{31}FO_5P^+$ 533.1888; found 533.1884.



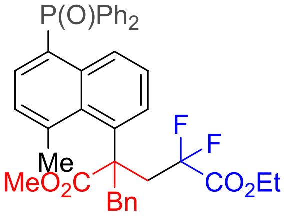
5-ethyl-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4-methylpentanedioate (**4ad**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3p** (54.3 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4ad** (dr > 20:1)(38 mg, 63 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.65 (d, *J* = 8.6 Hz, 1H), 8.10 (d, *J* = 8.6 Hz, 1H), 7.73 - 7.66 (m, 4H), 7.60 - 7.52 (m, 2H), 7.51 - 7.43 (m, 4H), 7.40 - 7.26 (m, 4H), 7.21 - 7.11 (m, 3H), 6.70 (d, *J* = 6.4 Hz, 2H), 3.67 (d, *J* = 13.2 Hz, 1H), 3.54 (s, 3H), 3.46 (d, *J* = 13.2 Hz, 1H), 3.43 - 3.26 (m, 1H), 2.82 - 2.63 (m, 2H), 2.07 (dd, *J* = 14.4, 1.2 Hz, 1H), 1.18 (d, *J* = 6..8 Hz, 3H), 0.93 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 176.9, 175.9, 137.6, 136.4, 134.9 (d, *J* = 8.9 Hz), 133.5, 133.4, 133.3, 132.8 (d, *J* = 8.9 Hz), 132.6 (d, *J* = 22.7 Hz), 132.4, 132.3, 132.2, 132.1, 132.0, 130.6, 130.3 (d, *J* = 102.0 Hz), 128.8, 128.7, 128.0, 127.0, 126.1, 125.9, 124.4 (d, *J* = 13.9 Hz), 60.3, 54.2, 52.2, 42.6, 37.3, 35.7, 20.2, 13.9. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.1. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{38}H_{38}O_5P^+$ 605.2451; found 605.2446.



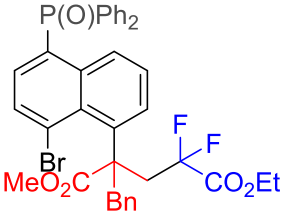
5-ethyl-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)-6-methylnaphthalen-1-yl)-4,4-difluoropentanedioate (**4ae**)

The general procedure was applied to **1b** (32.6 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4ae** (49 mg, 76 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.56 (d, *J* = 8.8 Hz, 1H), 7.96 (d, *J* = 8.8 Hz, 1H), 7.72 - 7.65 (m, 4H), 7.57 - 7.48 (m, 3H), 7.47 - 7.42 (m, 4H), 7.32 - 7.26 (m, 4H), 7.22 (dd, *J* = 8.6, 7.8 Hz, 1H), 7.12 - 6.99 (m, 2H), 4.00 (d, *J* = 13.2 Hz, 1H), 3.64 - 3.49 (m, 5H), 3.41 - 3.29 (m, 1H), 3.25 - 3.16 (1, 4H), 2.96 (dd, *J* = 28.6, 15.6 Hz, 1H), 2.27 (d, *J* = 1.2 Hz, 3H), 0.98 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.6, 163.0 (t, *J* = 32.8 Hz), 143.2 (d, *J* = 8.8 Hz), 136.2, 136.1, 136.0, 135.9 135.8, 135.4, 135.1, 131.8, 131.7, 131.6, 131.1, 131.0, 130.9, 128.9, 128.8, 128.5 (d, *J* = 7.6 Hz), 128.4, 127.6 (d, *J* = 2.5 Hz), 127.4, 127.0, 126.2, 125.3, 116.1 (dd, *J* = 257.0, 248.2 Hz), 62.7, 52.5, 52.1 (d, *J* = 3.8 Hz), 42.3 (d, *J* = 3.8 Hz), 36.9 - 36.6 (m), 24.6 (d, *J* = 5.0 Hz), 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 30.3. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -100.0 (d, *J* = 263.8 Hz), -101.8 (d, *J* = 263.8 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{38}H_{36}F_2O_5P^+$ 641.2263; found 641.2255.



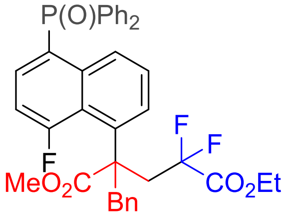
5-ethyl-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)-8-methylnaphthalen-1-yl)-4,4-difluoropentanedioate (**4af**)

The general procedure was applied to **1c** (32.6 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4af** (24 mg, 38 % yield), **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.48 - 8.20 (m, 1H), 7.95 (dd, *J* = 8.8, 1.6 Hz, 1H), 7.76 - 7.68 (m, 4H), 7.55 - 7.41 (m, 7H), 7.31 - 7.26 (m, 2H), 7.19 - 7.08 (m, 3H), 6.80 (dd, *J* = 7.6, 1.6 Hz, 2H), 4.08 - 3.92 (m, 2H), 3.56 (s, 3H), 3.31 (q, *J* = 13.6 Hz, 2H), 2.81 - 2.57 (m, 5H), 1.19 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, CDCl$_3$) δ 174.1, 163.8 (t, *J* = 32 8Hz), 140.1 (d, *J* = 2.5 Hz), 138.9, 136.2, 134.4 (d, *J* = 10.1 Hz), 133.6 (d, *J* = 45.4 Hz), 133.3 (d, *J* = 6.3 Hz), 132.7 (d, *J* = 59.2 Hz), 132.3, 132.2, 132.1, 132.0, 131.9, 130.6, 128.8, 128.7, 128.2, 127.6 (d, *J* = 103.3 Hz), 126.9, 126.2 (d, *J* = 6.3 Hz), 125.9 (d, *J* = 13.9 Hz), 125.4, 124.8, 115.8 (dd, *J* = 253.3, 255.8 Hz), 62.9, 53.1, 52.4, 41.0, 37.5 (t, *J* = 121.4 Hz), 20.0, 13.9. **^{31}P NMR** (202 MHz, CDCl$_3$) δ 30.1. **^{19}F NMR** (471 MHz, CDCl$_3$) δ -.100.0 (d, *J* = 263.8 Hz), -101.7 (d, *J* = 263.8 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{38}H_{36}F_2O_5P^+$ 641.2263; found 641.2258.



5-ethyl-1-methyl-2-benzyl-2-(8-bromo-5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**4ag**)

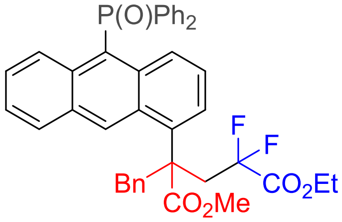
The general procedure was applied to **1d** (39.1 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), [RuCl$_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in PhCF$_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4ag** (30 mg, 42 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.70 (d, *J* = 8.4 Hz, 1H), 8.07 (d, *J* = 8.8 Hz, 1H), 7.72 - 7.54 (m, 7H), 7.51 - 7.37 (m, 6H), 7.33 - 7.27 (m, 3H), 7.11 - 6.97 (m, 2H), 4.02 (d, *J* = 13.2 Hz, 1H), 3.61 - 3.31 (m, 6H), 3.25 - 3.12 (m, 1H), 2.96 (dd, *J* = 28.4, 15.6 Hz, 1H), 0.97 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.6, 163.1 (t, *J* = 32.8 Hz), 136.6, 135.8, 134.8 (d, *J* = 7.6 Hz), 133.4 (d, *J* = 3.8 Hz), 133.3 (d, *J* = 6.3 Hz), 132.6, 132.5 (d, *J* = 30.2 Hz), 132.3, 132.2, 132.1, 130.9, 130.7 (d, *J* = 100.8 Hz), 128.8, 128.7, 128.6 (d, *J* = 6.3 Hz), 128.5, 128.2 (d, *J* = 1.3 Hz), 127.4, 126.5, 124.8 (d, *J* = 13.9 Hz), 116.1 (dd, *J* = 257.0, 248.2 Hz), 62.8, 52.5, 52.2 (d, *J* = 5.0 Hz), 42.3 (d, *J* = 2.5 Hz), 36.8 (dd, *J* = 21.4, 18.9 Hz), 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.7. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.5, -106.0. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{37}H_{33}BrF_2O_5P^+$ 705.1212; found 705.1206.



5-ethyl-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)-8-fluoronaphthalen-1-yl)-4,4-difluoropentanedioate (**4ah**)

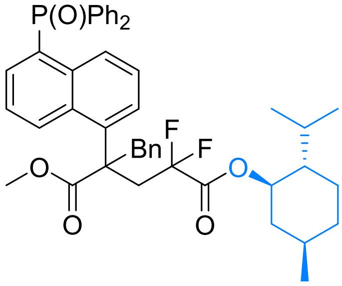
The general procedure was applied to **1e** (33.0 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4ah** (17 mg, 26 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.76 (d, *J* = 8.4 Hz, 1H), 7.98 - 7.54 (m, 7H), 7.53 - 7.43 (m, 5H), 7.34 - 7.24 (m, 4H), 7.24 - 7.00 (m, 3H), 4.18 - 3.80 (m, 1H), 3.77 - 2.82 (m, 8H), 1.12 - 0.90 (m, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 163.4 (d, *J* = 34.0 Hz), 162.4 (d, *J* = 2.5 Hz), 160.3, 137.8 (dd, *J* = 8.8, 6.3 Hz) 136.4, 134.9 (m), 134.5, 134.4, 134.3, 133.2, 132.4, 132.2, 130.9, 130.0 (d, *J* = 2.5 Hz), 128.9, 128.8, 128.6 (d, *J* = 5.0 Hz), 128.3, 127.4 (d, *J* = 3.8 Hz), 127.3, 127.1, 126.6 (d, *J* = 2.5 Hz), 123.4 - 123.2 (m), 116.4 (t, *J* = 252.0 Hz), 111.1 -110.7 (m), 62.8, 53.6, 51.7 - 51.5 (m), 44.5 -43.9 (m), 13.6. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 32.4. **^{19}F NMR** (377

MHz, $CDCl_3$) δ -97.8, -99.2, -104.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{37}H_{33}F_3O_5P^+$ 645.2012; found 645.2007.



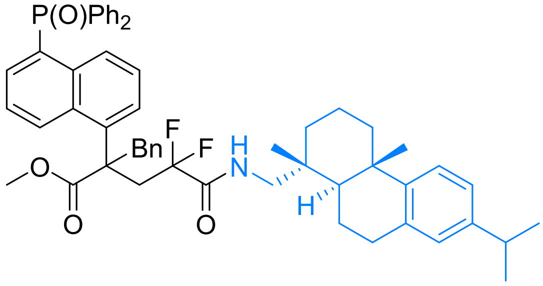
5-ethyl-1-methyl-2-benzyl-2-(10-(diphenylphosphoryl)anthracen-1-yl)-4,4-difluoropentanedioate (**4ai**)

The general procedure was applied to **1f** (36.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **4ai** (31 mg, 46 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.76 (s, 1H), 8.70 (d, J = 9.2 Hz, 1H), 8.51 (d, J = 9.2 Hz, 1H), 7.95 (d, J = 8.4 Hz, 1H), 7.75 - 7.66 (m, 4H), 7.58 - 7.49 (m, 3H), 7.45 - 7.39 (m, 5H), 7.32 - 7.26 (m, 3H), 7.26 - 7.20 (m, 2H), 7.14 - 7.05 (m, 2H), 4.09 (d, J = 13.2 Hz, 1H), 3.68 - 3.48 (m, 5H), 3.43 - 3.27 (m, 1H), 3.24 - 2.94 (m, 2H), 0.80 (t, J = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.7, 163.0 (t, J = 32.8 Hz), 136.4 (d, J = 16.4 Hz), 136.3, 136.2 (d, J = 8.8 Hz), 135.8, 135.6 (d, J = 15.1 Hz), 134.4 (d, J = 8.8 Hz), 131.8, 131.7, 131.6, 131.4 (d, J = 11.3 Hz), 131.0, 129.9, 129.8 (d, J = 1.3 Hz), 129.7, 129.0, 128.9, 128.5, 128.4, 127.5, 127.1, 127.0, 125.7, 125.5, 125.3, 124.8 (d, J = 98.3 Hz), 116.1 (dd, J = 257.0, 248.2 Hz), 62.7, 52.6, 52.4 (d, J = 5.0 Hz), 42.4 (d, J = 2.5 Hz), 36.9 (d, J = 22.7 Hz), 13.4. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 31.5. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -105.6, -106.3. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{41}H_{36}F_2O_5P^+$ 677.2263; found 677.2257.



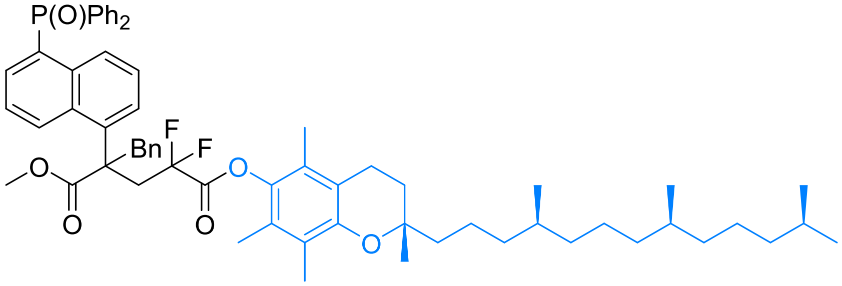
5-((1R,2S,5R)-2-isopropyl-5-methylcyclohexyl)-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7a**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3r** (93.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7a** (dr = 1:1) (55 mg, 75 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.71 - 8.66 (m, 1H), 8.16 - 8.12 (m, 1H), 7.71 - 7.64 (m, 4H), 7.59 - 7.35 (m, 9H), 7.30 - 7.17 (m, 4H), 6.98 - 6.69 (m, 2H), 4.73 - 4.64 (m, 1H), 3.96 (dd, *J* = 13.2, 7.2 Hz, 1H), 3.70 (dd, *J* = 13.2, 2.8 Hz, 1H), 3.59 (s, 3H), 3.07 - 2.81 (m, 2H), 1.90 - 1.68 (m, 5H), 1.51 - 1.37 (m, 2H), 1.10 - 0.95 (m, 2H), 0.92 - 0.86 (m, 6H), 0.71 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.9, 163.5 (t, *J* = 31.5 Hz), 163.5 (t, *J* = 31.5 Hz), 137.7, 137.5, 135.9, 135.0 (d, *J* = 8.8 Hz), 135.0 (d, *J* = 7.6 Hz), 133.4, 133.3, 133.2, 132.6, 132.5 (d, *J* = 3.8 Hz), 132.3, 132.2, 132.1, 130.8, 130.7 (d, *J* = 102.1 Hz), 130.6 (d, *J* = 102.1 Hz), 128.8, 128.7, 128.4, 128.3, 128.2, 127.2 (d, *J* = 5.0 Hz), 126.4, 125.8, 125.7, 124.7 (d, *J* = 15.1 Hz), 116.2 (t, *J* = 254.5 Hz), 116.1 (t, *J* = 255.8 Hz), 77.9, 52.6, 52.2, 47.0, 42.1 (d, *J* = 2.5 Hz), 40.4, 40.3, 37.0 (t, *J* = 20.2 Hz), 34.1, 31.5, 26.3, 23.5, 22.0, 20.8, 16.3. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.2, 33.1. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -103.6, -103.8, -104.0, -104.5. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{45}H_{48}F_2O_5P^+$ 737.3202; found 737.3201.



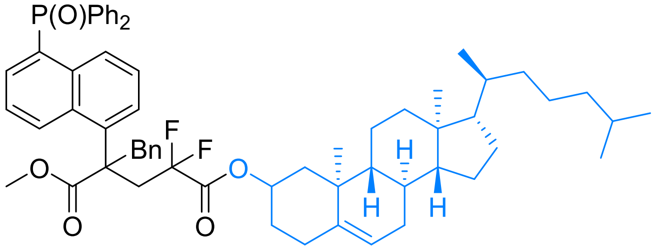
Methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-((((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)amino)-5-oxopentanoate (**7b**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3s** (132.6 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7b** (dr = 1:1) (35 mg, 40 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.71 (dd, *J* = 8.4, 4.8 Hz, 2H), 8.10 - 8.05 (m, 2H), 7.71 - 7.62 (m, 8H), 7.58 - 7.29 (m, 18H), 7.27 - 7.23 (m, 2H), 7.18 - 7.13 (m, 8H), 7.02 - 6.73 (m, 8H), 5.95 (s, 2H), 3.87 (d, *J* = 13.2 Hz, 2H), 3.70 - 3.47 (m, 8H), 3.19 - 2.66 (m, 14H), 2.32 - 2.22 (m, 2H), 1.78 - 1.59 (m, 8H), 1.37 - 1.27 (m, 6H), 1.23 - 1.06 (m, 20H), 0.89 (s, 3H), 0.88 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.9, 163.9 (t, *J* = 32.8 Hz), 163.7 (t, *J* = 27.7 Hz), 147.0, 146.9, 145.8, 137.6, 137.4, 135.8, 135.0 (d, *J* = 7.6 Hz), 135.0 (d, *J* = 8.8 Hz), 134.7, 134.6, 133.5 (d, *J* = 6.3 Hz), 133.4, 133.3, 132.5 (d, *J* = 21.4 Hz), 132.5, 132.4, 132.3, 132.2, 132.1, 130.8, 130.5 (d, *J* = 102.1 Hz), 130.5 (d, *J* = 102.1 Hz), 128.8, 128.7, 128.5, 128.4, 128.3, 128.2, 127.2, 127.0, 126.2, 125.8, 124.8, 124.6, 124.3, 124.1, 124.0, 118.1 (t, *J* = 255.8 Hz), 52.5, 52.0, 49.9, 45.9, 45.8, 42.2, 38.4, 38.3, 37.6, 37.5, 37.4, 36.8 -36.4 (m), 36.3, 36.1, 33.6, 33.5, 30.3, 25.4, 24.1, 19.1, 18.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.3, 33.2. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -103.8, -104.3, -104.9. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{55}H_{59}F_2NO_4P^+$ 866.4144; found 866.4138.



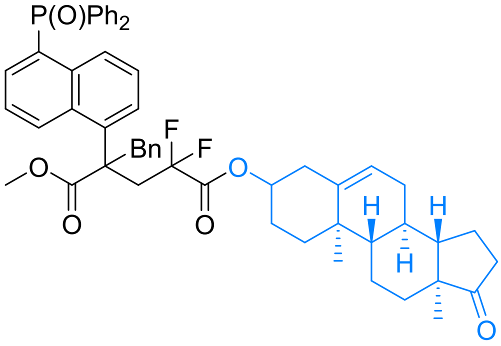
1-methyl-5-((S)-2,5,7,8-tetramethyl-2-((4S,8S)-4,8,12-trimethyltridecyl)chroman-6-yl)-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7c**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3t** (176.1 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7c** (45 mg, 45 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.71 (d, *J* = 8.8 Hz, 1H), 8.18 (d, *J* = 8.8 Hz, 1H), 7.74 - 7.65 (m, 4H), 7.60 - 7.53 (m, 2H), 7.51 - 7.38 (m, 4H), 7.32 - 7.26 (m, 1H), 7.22 - 7.14 (m, 3H), 6.92 - 6.79 (m, 2H), 4.02 (d, *J* = 13.2 Hz, 1H), 3.78 (d, *J* = 13.2 Hz, 1H), 3.63 (s, 3H), 3.24 - 3.04 (m, 1H), 2.58 (t, *J* = 6.8 Hz, 2H), 2.08 (s, 3H), 1.95 (s, 3H), 1.91 (s, 3H), 1.85 - 1.72 (m, 3H), 1.60 - 1.49 (m, 3H), 1.44 - 1.33 (m, 4H), 1.30 - 1.24 (m, 8H), 1.16 - 1.04 (m, 6H), 0.88 - 0.83 (m, 12H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.9, 162.6 (t, J = 32.8 Hz), 150.2, 139.7, 137.6, 135.9, 135.1 (d, J = 7.6 Hz), 133.3 (d, J = 12.6 Hz), 132.5 (d, J = 11.3 Hz), 132.4, 132.3, 132.2, 132.1, 130.8, 130.7 (d, J = 102.1 Hz), 128.8, 128.7, 128.4 (d, J = 7.6 Hz), 128.3, 128.1, 127.3, 126.5, 126.3, 125.8, 124.8 (d, J = 15.1 Hz), 124.6, 123.6, 117.9, 116.5 (t, J = 255.8 Hz), 75.4, 52.7, 52.3, 42.2, 39.5, 37.7 - 37.4 (m), 37.2 (d, J = 20.2 Hz), 32.9, 32.8, 31.1 (d, J = 5.0 Hz), 28.1, 24.9, 24.6, 24.0, 22.9, 22.8, 21.1, 20.7, 19.9, 19.8, 19.7, 12.8, 12.0, 11.9. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.3. ^{19}F NMR (471 MHz, $CDCl_3$) δ -102.3 (d, J = 259.1 Hz), -105.1 (d, J = 244.9 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{64}H_{78}F_2O_6P^+$ 1011.5499; found 1011.5480.



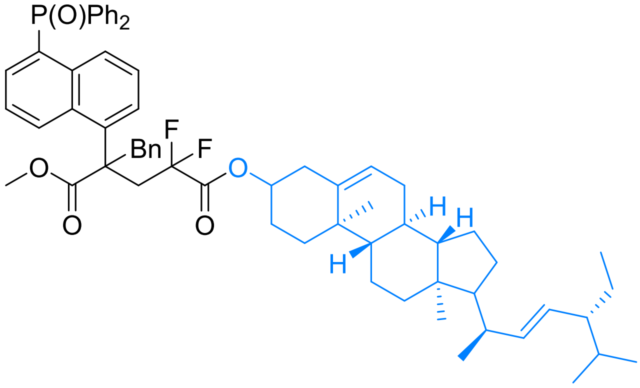
5-((8R,9R,10S,13S,14R,17S)-10,13-dimethyl-17-((S)-6-methylheptan-2-yl)-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-2-yl)-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7d**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3u** (162.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7d** (dr = 1:1) (66 mg, 68 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.67 (d, J = 8.0 Hz, 1H), 8.10 (d, J = 8.8 Hz, 1H), 7.71 - 7.64 (m, 4H), 7.60 - 7.44 (m, 7H), 7.43 - 7.36 (m, 2H), 7.30 - 7.24 (m, 4H), 7.06 - 6.86 (m, 2H), 5.42 - 5.22 (m, 1H), 4.32 - 4.09 (m, 1H), 4.00 (dd, J = 13.2, 5.6 Hz, 1H), 3.63 - 3.56 (m, 4H), 3.18 - 2.88 (m, 2H), 2.25 (d, J = 7.6 Hz, 1H), 2.19 - 1.94 (m, 3H), 1.89 - 1.77 (m, 4H), 1.62 - 1.39 (m, 8H), 1.37 - 1.30 (m, 3H), 1.19 - 1.02 (m, 7H), 1.00 - 0.97 (m, 4H), 0.95 - 0.90 (m, 4H), 0.87 (d, J = 1.6 Hz, 3H), 0.86 (d, J = 1.6 Hz, 3H), 0.68 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.7, 162.8 (t, J = 32.8 Hz), 162.7 (d, J = 31.5 Hz), 139.0, 138.8, 137.1, 137.0, 135.9, 135.0 (d, J = 7.6 Hz), 134.9 (d, J = 8.8 Hz), 133.5 - 133.2 (m), 132.6 - 132.1 (m), 130.9, 130.7 (d, J = 102.1 Hz), 130.6 (d, J = 102.1 Hz), 128.9, 128.8, 128.7, 128.6, 128.5, 128.3, 128.1, 127.5, 127.3, 126.5, 126.2, 124.8, 124.7, 123.5, 123.4, 116.1 (t, J = 253.3 Hz), 116.0 (t, J = 254.5 Hz), 56.9, 56.8, 56.3, 52.5, 52.2, 50.1, 42.5, 42.2, 39.9, 39.7, 37.6, 37.3, 37.1 -37.0 (m), 36.8, 36.7, 36.6, 36.3, 35.9, 32.0, 31.9, 28.3, 28.1, 27.3, 27.2, 24.4, 24.0, 23.0, 22.7, 21.2, 21.1, 19.4, 18.9, 12.0. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.0, 32.8. ^{19}F NMR (471 MHz, $CDCl_3$) δ -104.0, -104.6, -104.7, -105.3. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{62}H_{74}F_2O_5P^+$ 967.5236; found 967.5236.



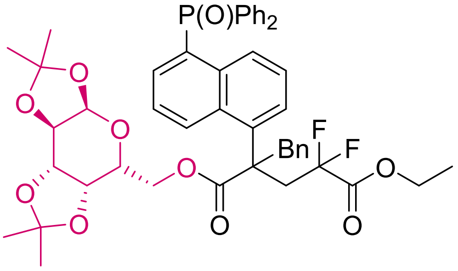
5-((8R,9S,10R,13S,14S)-10,13-dimethyl-17-oxo-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl)-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7e**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3v** (133.5 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.3$, PE/DCM/EA = 1/1/1) afforded the product **7e** (dr = 1:1) (61 mg, 70 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 (dd, *J* = 8.2, 5.2 Hz, 1H), 8.10 (d, *J* = 8.8 Hz, 1H), 7.70 - 7.65 (m, 4H), 7.59 - 7.53 (m, 3H), 7.49 - 7.46 (m, 4H), 7.42 - 7.36 (m, 2H), 7.31 - 7.25 (m, 4H), 7.02 - 6.90 (m, 2H), 5.41 - 5.35 (m, 1H), 4.29 - 4.14 (m, 1H), 4.01 (d, *J* = 12.8 Hz, 1H), 3.64 - 3.55 (m, 4H), 3.17 - 3.04 (m, 1H), 3.00 - 2.87 (m, 1H), 2.47 (dd, *J* = 19.2, 9.2 Hz, 1H), 2.31 - 2.23 (m, 1H), 2.19 - 2.05 (m, 3H), 1.98 - 1.93 (m, 1H), 1.89 - 1.75 (m, 3H), 1.67 - 1.63 (m, 2H), 1.59 - 1.38 (m, 4H), 1.35 - 1.28 (m, 2H), 1.06 - 0.97 (m, 5H), 0.89 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.7, 162.7 (d, *J* = 31.5 Hz), 139.2, 139.1, 137.0 (d, *J* = 2.2 Hz), 135.8, 135.0 - 134.9 (m), 133.4 -133.2 (m), 132.5 -132.1 (m), 130.9, 130.7 (d, *J* = 102.1 Hz), 130.6 (d, *J* = 102.1 Hz), 128.8, 128.7, 128.6 -128.5 (m), 128.3, 128.1 (d, *J* = 5.0 Hz), 127.3, 126.5, 126.2, 124.8, 124.7, 122.7, 122.7, 116.0 (t, *J* = 252.0 Hz), 116.0 (t, *J* = 248.2 Hz), 52.5, 52.2, 51.8, 50.2, 50.1, 47.6, 42.2, 37.5, 37.3, 36.9 -36.7 (m), 36.6, 35.9, 31.5, 30.9, 29.8, 27.2, 27.0, 22.0, 20.4, 19.4, 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.0, 32.9. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -104.0, -104.5, -104.5, -105.1. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{54}H_{56}F_2O_6P^+$ 869.3777; found 869.3771.



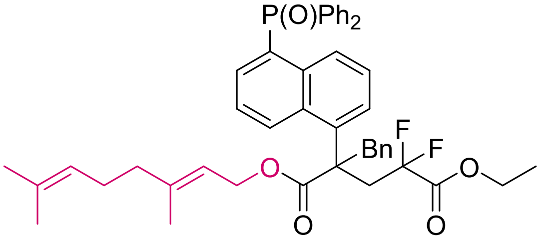
5-((8S,9S,10R,13R,14S)-17-((2R,5R,E)-5-ethyl-6-methylhept-3-en-2-yl)-10,13-dimethyl-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl)-1-methyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7f**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2a** (52.8 mg, 0.3 mmol, 3.0 equiv), **3w** (170.7 mg, 0.3 mmol, 3.0 equiv), [$RuCl_2$(*p*-cymene)]$_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7f** (dr = 1:1) (58 mg, 58 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.68 (d, *J* = 8.4 Hz, 1H), 8.10 (d, *J* = 8.8 Hz, 1H), 7.72 - 7.64 (m, 4H), 7.60 - 7.51 (m, 3H), 7.51 - 7.44 (m, 4H), 7.42 - 7.36 (m, 2H), 7.29 (dd, *J* = 6.8, 4.4 Hz, 1H), 7.26 - 7.21 (m, 3H), 7.09 - 6.87 (m, 2H), 5.36 - 5.29 (m, 1H), 5.16 (dd, *J* = 15.2, 8.8 Hz, 1H), 5.02 (dd, *J* = 15.2, 8.8 Hz, 1H), 4.30 - 4.10 (m, 1H), 4.01 (dd, *J* = 13.2, 5.6 Hz, 1H), 3.63 - 3.56 (m, 4H), 3.19 - 2.89 (m, 2H), 2.25 (d, *J* = 7.8 Hz, 1H), 2.18 - 1.91 (m, 5H), 1.86 - 1.63 (m, 3H), 1.56 - 1.39 (m, 9H), 1.28 - 1.15 (m, 4H), 1.04 - 1.02 (m, 4H), 0.97 (s, 3H), 0.86 - 0.78 (m, 9H), 0.70 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.7, 162.8 (t, *J* = 32.8 Hz), 162.7 (t, *J* = 32.8 Hz), 139.0, 138.8, 138.4, 137.1, 137.0, 135.9, 135.0 (d, *J* = 8.8 Hz), 134.9 (d, *J* = 7.6 Hz), 133.5 (d, *J* =7.6 Hz), 133.3, 133.2, 132.6 (d, *J* = 7.6 Hz), 132.5 - 132.1 (m), 130.9, 130.7 (d, *J* = 102.1 Hz), 130. (d, *J* = 102.1 Hz), 129.5, 128.9, 128.8, 128.7, 128.6, 128.5, 128.3, 128.1, 127.3, 126.5, 126.2, 124.8 (d, *J* = 15.1 Hz), 124.7 (d, *J* = 13..9 Hz), 123.5, 123.4, 116.0 (t, *J* = 258.3 Hz), 116.0 (t, *J* = 254.5 Hz), 57.0, 56.9, 56.1, 52.5, 52.2, 51.4, 50.1, 42.3, 42.2, 40.6, 39.7, 37.6, 37.3, 37.1 - 36.6 (m), 32.0, 31.9, 29.0, 27.2, 27.1, 25.5, 24.5, 21.4, 21.2, 21.1, 19.4, 19.1, 12.4, 12.2. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.1, 32.9. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -104.0, -104.6, -104.8 -105.3. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{64}H_{76}F_2O_5P^+$ 993.5393; found 993.5395.



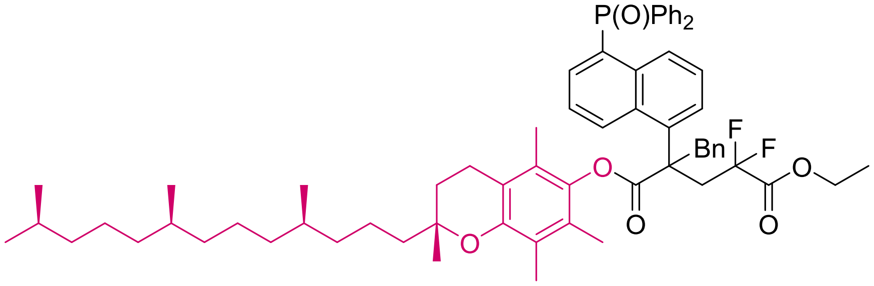
5-ethyl-1-(((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetrahydro-5H-bis([1,3]dioxolo)[4,5-b:4',5'-d]pyran-5-yl)methyl)-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7g**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2n** (121.2 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7g** (dr = 1:1) (73 mg, 85 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.72 - 8.68 (m, 1H), 8.14 - 8.09 (m, 1H), 7.73 - 7.61 (m, 5H), 7.59 - 7.53 (m, 2H), 7.50 - 7.39 (m, 6H), 7.35 - 7.26 (m, 4H), 7.24 - 7.08 (m, 2H), 5.44 (dd, *J* = 36.0, 4.8 Hz, 1H), 4.52 - 4.09 (m, 3H), 4.13 - 3.87 (m, 2H), 3.79 - 3.15 (m, 6H), 2.97 (qd, *J* = 15.2, 4.8 Hz, 1H), 1.41 - 1.40 (m, 3H), 1.36 - 1.28 (m, 6H), 1.24 - 1.23 (m, 3H), 0.96 - 0.91 (m, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 174.5, 163.0 (d, *J* = 32.8 Hz), 162.9 (d, *J* = 32.8 Hz), 136.5, 136.4, 135.8, 135.7, 134.8, 134.7, 133.4 - 133.2 (m), 132.6 - 132.4 (m), 132.2, 132.1, 131.0, 130.3 (d, *J* = 102.1 Hz), 130.2, 128.8 - 128.5 (m), 128.4, 127.3, 126.6, 124.9, 124.8, 116.1 (dd, *J* = 257.0, 247.0 Hz), 109.7, 109.4, 108.9, 108.8, 96.2, 96.1, 71.1, 70.7, 70.6, 70.4, 70.2, 66.2, 64.7, 64.6, 63.2, 62.7, 62.6, 52.3, 42.3 (d, *J* = 29.0 Hz), 36.6 - 36.2 (m), 26.1, 26.0, 25.1, 25.0, 24.5, 24.4, 13.5. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.5, 32.4. **^{19}F** NMR (471 MHz, CDCl3) δ -105.3 - 106.4 (m). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{48}H_{50}F_2O_{10}P^+$ 855.3104; found 855.3089.



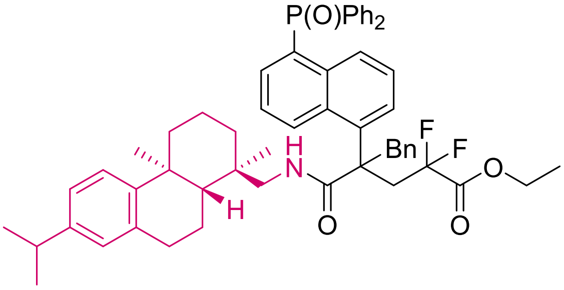
(E)-1-(3,7-dimethylocta-2,6-dien-1-yl)-5-ethyl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7h**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2o** (89.4 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 1/1/1) afforded the product **7h** (dr = 1:1) (47 mg, 63 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.70 (d, J = 8.4 Hz, 1H), 8.10 (d, J = 8.4 Hz, 1H), 7.71 - 7.64 (m, 5H), 7.59 - 7.53 (m, 2H), 7.50 - 7.40 (m, 5H), 7.39 - 7.26 (m, 5H), 7.17 - 7.03 (m, 2H), 5.08 - 5.00 (m, 2H), 4.60 (dd, J = 12.0, 7.4 Hz, 1H), 4.39 (dd, J = 12.0, 7.2 Hz, 1H), 4.02 (d, J = 12.8 Hz, 1H), 3.54 (d, J = 12.8 Hz, 1H), 3.50 - 3.12 (m, 3H), 3.02 - 2.91 (m, 1H), 2.02 - 1.97 (m, 2H), 1.94 - 1.88 (m, 2H), 1.65 (s, 3H), 1.54 (s, 3H), 1.49 (s, 3H), 0.94 (t, J = 7.2 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 174.8, 163.0 (t, J = 32.8 Hz), 143.0, 136.8, 135.8, 134.7 (d, J = 8.8 Hz), 133.3, 133.2, 133.1, 132.6, 132.5, 132.4, 132.2, 132.1, 131.9, 131.0, 130.4 (d, J = 102.1 Hz), 128.8, 128.7, 128.4 (d, J = 6.3 Hz), 128.3, 127.3, 126.5, 124.4 (d, J = 13.9 Hz), 123.7, 117.4, 116.1 (dd, J = 258.3, 248.2 Hz), 62.7, 62.4, 52.1 (d, J = 5.0 Hz), 42.2, 39.5, 36.7 (t, J = 21.4 Hz), 26.2, 25.8, 17.8, 16.4, 13.5. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.7. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.5, -106.1. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{46}H_{48}F_2O_5P^+$ 749.3202; found 749.3185.



5-ethyl-1-((R)-2,5,7,8-tetramethyl-2-((4R,8R)-4,8,12-trimethyltridecyl)chroman-6-yl)-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-2-methylpentanedioate (**7i**)

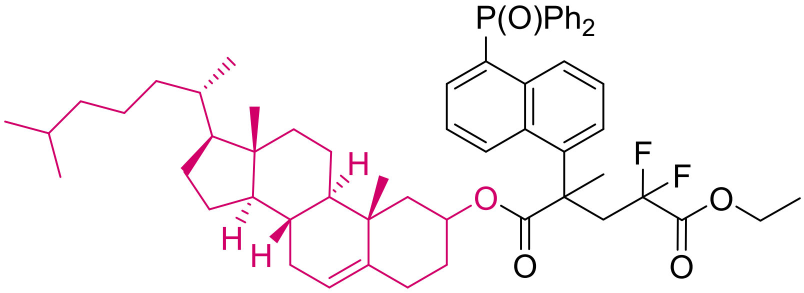
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2p** (172.2 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography ($R_f = 0.5$, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7i** (dr > 20:1)(45 mg, 47 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.78 (d, *J* = 8.4 Hz, 1H), 8.68 (d, *J* = 8.8 Hz, 1H), 7.80 (d, *J* = 7.6 Hz, 1H), 7.72 - 7.65 (m, 4H), 7.60 - 7.54 (m, 2H), 7.51 - 7.39 (m, 6H), 7.34 (dd, *J* = 15.2, 6.4 Hz, 1H), 7.23 - 7.16 (m, 3H), 7.14 - 7.04 (m, 2H), 4.24 (d, *J* = 14.2 Hz, 1H), 4.02 (d, *J* = 14.2 Hz, 1H), 3.74 - 3.47 (m, 3H), 3.39 - 3.28 (m, 1H), 2.47 (t, *J* = 6.8 Hz, 2H), 2.08 - 1.93 (m, 4H), 1.80 - 1.69 (m, 2H), 1.58 - 1.49 (m, 8H), 1.47 - 1.32 (m, 5H), 1.32 - 1.23 (m, 7H), 1.20 (s, 3H), 1.16 - 1.03 (m, 9H), 0.90 - 0.84 (m, 12H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 172.2, 163.4 (t, *J* = 32.8 Hz), 149.6, 140.7, 136.2, 135.9, 135.2 (d, *J* = 7.6 Hz), 133.5 (d, *J* = 11.3 Hz), 133.1 (d, *J* = 3.8 Hz), 132.9 (d, *J* = 8.8 Hz), 132.4 - 132.0 (m), 131.3, 130.3 (d, *J* = 102.1 Hz), 130.3, 128.9 (d, *J* = 6.3 Hz), 128.8, 128.7, 128.4, 127.3, 127.1, 126.8, 126.7, 125.6, 124.5 (d, *J* = 13..9 Hz), 123.2, 117.6, 115.9 (dd, *J* = 257.0, 250.7 Hz), 75.2, 75.1, 62.9, 58.3, 52.8 (d, *J* = 2.5 Hz), 41.7, 40.1 (d, *J* = 6.3 Hz), 39.5, 37.9 - 37.4 (m), 32.9, 32.8, 31.2 (d, *J* = 3.8 Hz), 29.8, 28.1, 24.9, 24.5, 24.0, 22.8, 22.7, 21.1, 20.7, 19.9, 19.8, 19.7, 18.4, 13.8, 13.7 13.0, 11.9. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.8. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -95.5, -96.0, -102.6, -103.2. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{59}H_{76}F_2O_6P^+$ 949.5342; found 949.5360.



Ethyl-4-benzyl-4-(5-(diphenylphosphoryl)naphthalen-1-yl)-2,2-difluoro-5-((((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)amino)-5-oxopentanoate (dr = 1:1) (**7j + 7j'**)

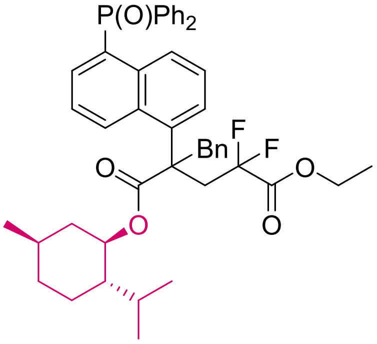
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2q** (128.7 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7j** (20 mg, 25 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.75 (d, J = 6.8 Hz, 1H), 8.22 (d, J = 8.8 Hz, 1H), 7.67 - 7.35 (m, 12H), 7.26 - 6.19 (m, 10H), 5.22 (s, 1H), 4.25 - 2.66 (m, 10H), 2.16 - 1.90 (m, 3H), 1.73 - 1.39 (m, 3H), 1.27 - 1.09 (m, 15H), 0.77 - 0.44 (m, 4H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.1, 163.7 (t, *J* = 37.8 Hz), 147.1, 145.9, 136.5, 136.1, 135.0, 133.9, 133.8, 133.4, 133.1, 132.6, 132.3, 132.2, 132.1, 132.1, 132.0, 130.8, 129.9, 129.1 (d, J = 6.3 Hz), 128.8, 128.7, 128.0, 127.1, 127.0, 126.2, 125.1, 125.0, 124.0, 123.7, 116.3 (t, J = 247.0 Hz), 63.0, 52.9, 38.2, 37.23, 36.0 33.5, 30.0, 29.8, 25.3, 24.1, 19.1, 18.4, 13.8. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.9. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -95.5, -96.1, -100.1, -100.5, -102.8, -105.0, -105.5. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{56}H_{61}F_2NO_4P^+$ 880.4301; found 880.4299.

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2q** (128.7 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7j'** (20 mg, 25 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.72 (d, J = 8.6 Hz, 1H), 8.01 - 7.26 (m, 17H), 7.24 - 703 (m, 2H), 6.93 - 6.88 (m, 1H), 6.88 - 6.47 (m, 3H), 5.80 (s, 1H), 5.25 (dd, J = 8.8, 4.0 Hz, 1H), 4.16 - 3.72 (m, 2H), 3.52 - 3.06 (m, 4H), 3.01 - 2.83 (m, 3H), 2.80 - 2.73 (m, 1H), 2.40 - 2.12 (m, 1H), 2.04 - 1.95 (m, 2H), 1.64 - 1.45 (m, 2H), 1.30 - 1.25 (m, 1H), 1.15 - 1.10 (m, 6H), 1.06 (s, 3H), 0.95 - 0.84 (m, 5H), 0.76 (s, 3H), 0.22 - 0.12 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.1, 163.7 (t, J = 37.8 Hz), 147.1, 145.9, 136.5, 136.1, 135.0, 133.9, 133.8, 133.4, 133.1, 132.6, 132.3, 132.2, 132.1, 132.1, 132.0, 130.8, 129.9, 129.1 (d, J = 6.3 Hz), 128.8, 128.7, 128.0, 127.1, 127.0, 126.2, 125.1, 125.0, 124.0, 123.7, 116.3 (t, J = 247.0 Hz), 63.0, 52.9, 38.2, 37.23, 36.0 33.5, 30.0, 29.8, 25.3, 24.1, 19.1, 18.4, 13.8. 174.6, 163.3 (t, J = 31.5 Hz), 147.2, 146.0, 136.1, 135.9, 135.5, 134.6, 134.1, 133.8, 133.1, 132.9, 132.5 - 132.4 (m), 132.2, 132.1, 131.0, 129.4, 129.2, 128.8, 128.7, 128.6, 128.4, 127.5, 127.0, 126.3, 125.3 (d, J = 12.6 Hz), 124.0, 123.5, 62.6, 52.9, 49.9, 44.0, 42.2, 37.9, 37.8, 37.0, 35.8, 33.6, 30.0, 29.8, 25.5, 24.2, 24.0, 19.1, 18.2, 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.5. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -95.2 (d, J = 263.8 Hz), -105.4 (d, J = 263.8 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{56}H_{61}F_2NO_4P^+$ 880.4301; found 880.4297.



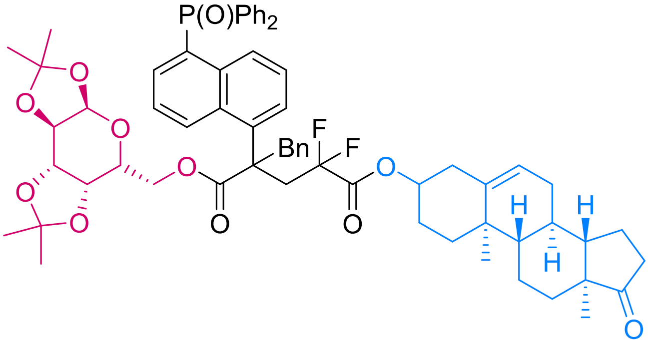
1-((8R,9R,10S,13S,14R,17S)-10,13-dimethyl-17-((S)-6-methylheptan-2-yl)-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-2-yl)-5-ethyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-2-methylpentanedioate (**7k**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2r** (136.2 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7k** (dr = 1:1) (59 mg, 65 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 (dd, *J* = 8.4, 3.6 Hz, 1H), 8.09 - 7.94 (m, 1H), 7.71 - 7.61 (m, 4H), 7.58 - 7.51 (m, 3H), 7.49 - 7.35 (m, 6H), 7.27 (dd, *J* = 9.2, 6.4 Hz, 1H), 5.36 - 5.20 (m, 1H), 4.73 - 4.47 (m, 1H), 3.58 - 3.48 (m, 1H), 3.35 - 3.04 (m, 3H), 2.19 - 1.66 (m, 11H), 1.60 - 1.31 (m, 10H), 1.24 - 0.93 (m, 11H), 0.92 - 0.85 (m, 14H), 0.64 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 176.6, 163.2 (d, *J* = 37.8 Hz), 139.5, 137.0, 134.8 (d, *J* = 8.8 Hz), 133.2, 133.0 (d, *J* = 104.6 Hz), 133.0 (d, *J* = 104.6 Hz), 132.3 - 132.0133.0 (m), 130.9, 130.0, 128.8, 128.7, 128.3, 126.5, 126.2, 124.3 (d, *J* = 15.1 Hz), 122.9, 122.8, 115.9 (dd, *J* = 255.8, 248.2 Hz), 75.5, 75.4, 62.6, 56.8, 56.3, 50.1, 47.6 (d, *J* = 7.6 Hz), 42.4, 41.4 (t, *J* = 21.4 Hz), 39.8, 39.6, 37.7, 37.5, 36.6, 36.3, 35.9, 32.0, 31.9, 28.3, 28.1, 27.4, 27.1, 25.3, 24.4, 23.9, 22.9, 22.7, 21.1, 19.4, 18.8, 13.6, 11.9. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.9. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -93.8, -94.3, -103.0, -103.0, -103.6, -103.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{57}H_{72}F_2O_5P^+$ 905.5080; found 905.5065.



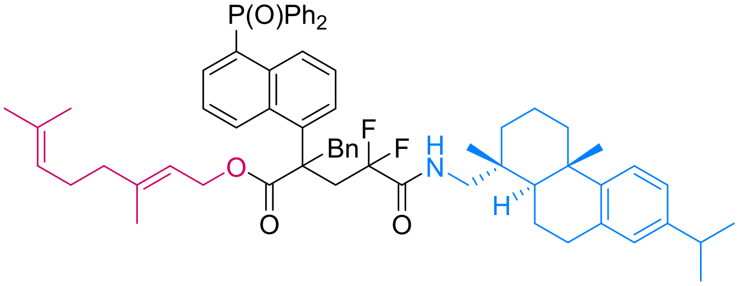
5-ethyl-1-((1R,2S,5R)-2-isopropyl-5-methylcyclohexyl)-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7l**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2s** (90.0 mg, 0.3 mmol, 3.0 equiv), **3a** (60.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7l** (dr = 1:1) (50 mg, 67 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.49 (dd, *J* = 20.0, 8.4 Hz, 2H), 8.12 - 8.08 (m, 2H), 7.53 - 7.44 (m, 8H), 7.41 - 6.72 (m, 30H), 4.39 - 4.20 (m, 2H), 3.81 (t, *J* = 12.4 Hz, 2H), 3.56 - 2.64 (m, 10H), 2.04 - 1.99 (m, 2H), 1.80 - 1.74 (m, 1H), 1.50 - 1.10 (m, 7H), 0.94 - -0.02 (m, 32H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 174.5, 174.4, 163.3 (d, *J* = 31.5 Hz), 163.2 (d, *J* = 32.8 Hz), 137.0, 136.9, 135.9, 135.8, 134.9 (d, *J* = 7.6 Hz), 134.8 (d, *J* = 7.6 Hz), 133.5 (d, *J* = 5.0 Hz), 133.3 - 133.2 (m), 132.7 - 132.4 (m), 132.3, 132.2, 132.1, 132.0, 131.2, 131.1, 130.5 (d, *J* = 97.0 Hz), 130.4 (d, *J* = 102.1 Hz), 129.4, 129.3, 128.8, 128.7, 128.4, 128.3, 128.2, 127.2, 127.1, 126.5, 126.3, 126.1, 124.5 (d, *J* = 11.3 Hz), 124.3 (d, *J* = 13.9 Hz), 116.1 (dd, *J* = 252.0, 255.8 Hz), 76.7, 62.8, 52.1, 46.8, 46.7, 41.7, 41.6, 40.8, 39.6, 37.3 - 36.6 (m), 34.0, 33.9, 31.4, 31.2, 25.4, 24.7, 22.8, 22.7, 22.1, 22.0, 21.1, 21.0, 15.9, 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.9, 32.4. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -105.3, -105.9. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{46}H_{50}F_2O_5P^+$ 751.3358; found 751.3354.



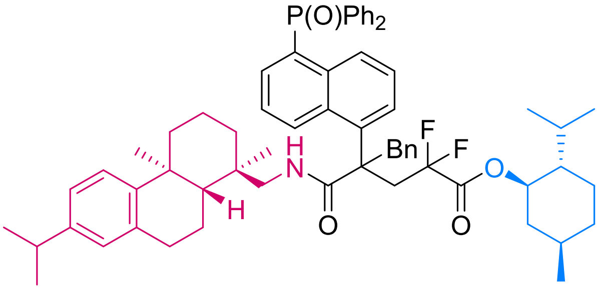
5-((8R,9S,10R,13S,14S)-10,13-dimethyl-17-oxo-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl)-1-(((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetrahydro-5H-bis([1,3]dioxolo)[4,5-b:4',5'-d]pyran-5-yl)methyl)-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7m**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2n** (121.2 mg, 0.3 mmol, 3.0 equiv), **3v** (133.5 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 10/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 1/1/1) afforded the product **7m** (55 mg, 50 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.68 (dd, J = 8.4, 4.0 Hz, 2H), 8.14 (d, J = 8.8 Hz, 2H), 7.68 - 7.52 (m, 14H), 7.49 - 7.38 (m, 12H), 7.32 - 7.23 (m, 8H), 7.14 - 7.05 (m, 4H), 5.44 (dd, J = 28.8, 4.8 Hz, 2H), 5.37 (d, J = 3.6 Hz, 2H), 4.51 - 4.40 (m, 3H), 4.29 - 4.08 (m, 7H), 4.04 (dd, J = 12.8, 4.8 Hz, 2H), 3.89 - 3.68 (m, 4H), 3.61 - 3.54 (m, 3H), 3.21 - 2.89 (m, 4H), 2.52 - 2.43 (m, 2H), 2.28 - 2.03 (m, 11H), 2.00 - 1.93 (m, 2H), 1.90 - 1.75 (m, 5H), 1.70 - 1.60 (m, 6H), 1.58 - 1.45 (m, 5H), 1.41 (d, J = 1.2 Hz, 6H), 1.36 - 1.23 (m, 20H), 1.04 - 0.99 (m, 10H), 0.89 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 174.6, 162.7 (d, J = 32.8 Hz), 162.6 (d, J = 32.8 Hz), 139.2, 139.1, 137.0, 136.9, 135.9, 135.8, 134.9 (d, J = 7.6 Hz), 134.8 (d, J = 8.8 Hz), 133.5, 133.4 (d, J = 3.8 Hz), 133.2 (d, J = 6.3 Hz), 133.1 (d, J = 6.3 Hz), 132.6, 132.5 (d, J = 3.8 Hz), 132.4 - 132.0 (m), 131.0, 130.5 (d, J = 102.1 Hz), 130.4 (d, J = 102.1 Hz), 128.8, 128.7, 128.6, 128.5 - 128.4 (m), 128.3, 127.2, 126.4, 126.3, 126.2, 124.9, 124.8, 122.6, 116.0 (t, J = 254.5 Hz), 115.9 (t, J = 254.5 Hz), 109.7, 109.4, 108.9, 108.8, 96.1, 96.0, 76.8, 71.0, 70.7, 70.6, 70.4, 70.2, 66.1, 64.7, 64.6, 63.3, 52.3, 51.8, 50.1, 47.6, 42.4 - 42.1 (m), 37.4, 37.2, 36.7, 36.6, 35.9, 31.5, 30.8, 27.1, 26.9, 26.1, 26.0, 25.1, 25.0, 24.5, 24.4, 21.9, 20.4, 19.3, 13.6. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 32.6. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -104.1, -104.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{65}H_{72}F_2O_{11}P^+$ 1097.4775; found 1097.4775.



(E)-3,7-dimethylocta-2,6-dien-1-yl-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoro-5-((((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)amino)-5-oxopentanoate (**7n**)

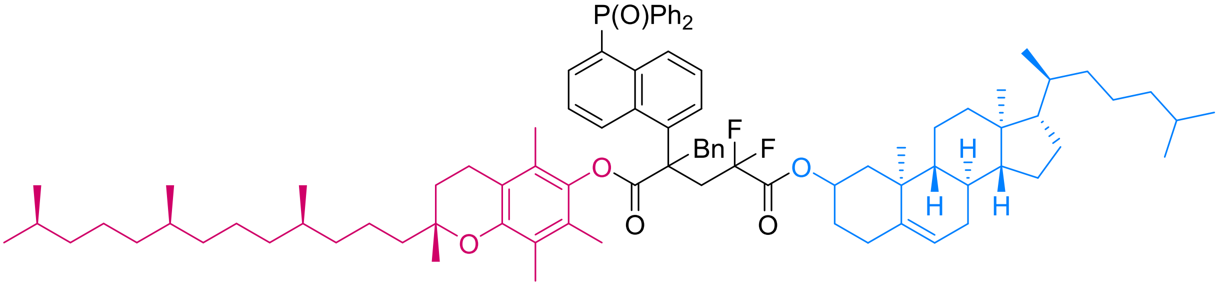
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2o** (89.4 mg, 0.3 mmol, 3.0 equiv), **3s** (132.6 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7n** (dr = 1:1) (35 mg, 36 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.71 (dd, J = 8.4, 4.8 Hz, 1H), 8.15 - 8.05 (m, 1H), 7.68 - 7.62 (m, 4H), 7.59 - 7.42 (m, 7H), 7.36 - 7.27 (m, 2H), 7.25 - 7.12 (m, 5H), 7.04 - 6.89 (m, 3H), 6.86 (dd, J = 22.0, 1.2 Hz, 1H), 5.87 (s, 1H), 5.08 - 5.00 (m, 1H), 4.61 (dd, J = 12.0, 7.2Hz, 1H), 4.40 (dd, J = 11.6, 7.2 Hz, 1H), 3.88 (d, J = 13.2 Hz, 1H), 3.60 (dd, J = 12.8, 7.6 Hz, 1H), 3.20 - 3.06 (m, 1H), 3.05 - 2.93 (m, 2H), 2.90 - 2.63 (m, 4H), 2.26 (dd, J = 12.8, 2.8 Hz, 1H), 2.01 - 1.96 (m, 2H), 1.93 - 1.88 (m, 2H), 1.81 - 1.59 (m, 9H), 1.54 (s, 3H), 1.48 (s, 3H), 1.43 - 1.23 (m, 4H), 1.23 - 1.17 (m, 9H), 1.12 - 1.04 (m, 1H), 0.87 (d, J = 4.4 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.2, 164.1 - 163.5 (m), 147.0, 145.8, 143.0, 137.8 (d, J = 8.8 Hz), 135.9, 135.0 - 135.0 (m), 134.7, 134.6, 133.6, 133.4, 133.3, 133.2 - 132.4 (m), 132.3, 132.2, 132.1, 132.0, 130.9, 130.3 (d, J = 102.1Hz), 130.2 (d, J = 102.1 Hz), 128.9, 128.8, 128.7, 128.4 -128.3 (m), 128.2, 127.2, 127.0, 127.0, 126.2, 125.8, 124.5, 124.3, 124.0, 123.8, 118.2 (t, J = 257.0 Hz), 117.5, 62.4, 52.1, 49.9, 46.0, 45.8, 42.3, 39.6, 38.4, 38.3, 37.6, 37.5, 37.4, 36.8 -36.1 (m), 33.6, 30.3, 29.8, 26.3, 25.8, 25.5, 25.4, 24.1, 24.1, 19.1, 18.6, 17.8, 16.5. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.3, 33.2. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -103.7, -104.4, -105.0. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{64}H_{73}F_2NO_4P^+$ 988.5240; found 988.5235.



(1R,2S,5R)-2-isopropyl-5-methylcyclohexyl-4-benzyl-4-(5-(diphenylphosphoryl)naphthalen-1-yl)-2,2-difluoro-5-((((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)amino)-5-oxopentanoate (**7o**)

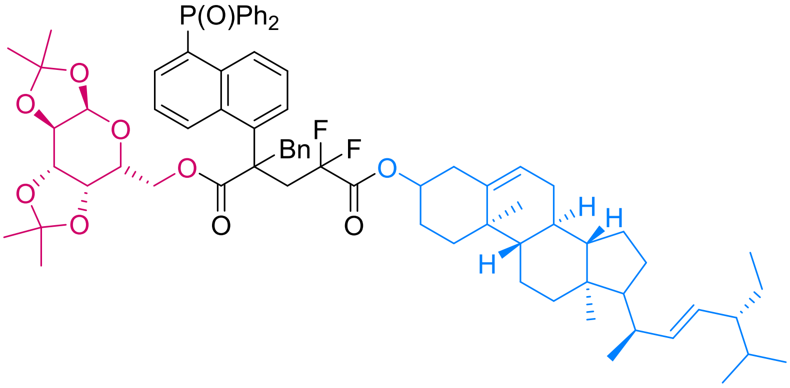
The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2q** (128.7 mg, 0.3 mmol, 3.0 equiv), **3r** (93.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7o** (dr = 1:1) (49 mg, 50 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.73 (d, J = 5.6 Hz, 1H), 8.27 - 8.16 (m, 1H), 7.73 - 7.26 (m, 12H), 7.14 - 5.78 (m, 10H), 5.29 (s, 1H), 5.02 - 4.33 (m, 1H), 3.97 - 3.60 (m, 2H), 3.04 - 2.66 (m, 5H), 2.14 - 1.38 (m, 12H), 1.24 - 0.31 (m, 29H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 175.1, 175.0, 163.6 (t, J = 32.8 Hz), 147.2, 145.6, 136.3, 135.0 (d, J = 8.8 Hz), 133.8 (d, J = 8.8 Hz), 133.5, 133.1, 132.6, 132.3, 132.2, 132.1, 132.0, 131.9, 130.7, 129.9 (d, J = 104.6 Hz), 129.9, 128.9 - 128.8 (m), 128.7, 128.6, 127.8, 127.0, 126.9 - 126.8 (m), 126.2 - 125.9 (m), 125.0 (d, J = 13.9 Hz), 124.9 (d, J = 15.1 Hz), 123.9, 123.6, 116.2 (t, J = 254.5

Hz), 77.8, 53.1, 53.0 - 50.4 (m), 46.9, 43.8 - 41.5 (m), 40.3, 38.2, 37.2, 37.1, 36.0, 34.1, 33.5, 33.0, 32.0 (d, J = 7.6 Hz), 31.5, 31.4, 29.9, 29.8, 26.3, 26.2, 25.2, 24.1, 23.4, 22.0, 20.8, 19.1, 18.3, 16.2. **^{31}P NMR** (202 MHz, $CDCl_3$) δ 33.2, 33.1. **^{19}F NMR** (471 MHz, $CDCl_3$) δ -100.6 - -104.5 (m). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{64}H_{75}F_2NO_4P^+$ 990.5396; found 990.5391.



1-((8R,9R,10S,13S,14R,17S)-10,13-dimethyl-17-((S)-6-methylheptan-2-yl)-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-2-yl)-5-((R)-2,5,7,8-tetramethyl-2-((4R,8R)-4,8,12-trimethyltridecyl)chroman-6-yl)-4-(5-(diphenylphosphoryl)naphthalen-1-yl)-2,2-difluoro-4-methylpentanedioate (**7p**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2p** (172.2 mg, 0.3 mmol, 3.0 equiv), **3u** (162.9 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7p** (dr = 1:1) (49 mg, 38 % yield), **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.76 (d, J = 8.4 Hz, 1H), 8.71 (d, J = 8.8 Hz, 1H), 7.74 - 7.62 (m, 5H), 7.59 - 7.54 (m, 5H), 7.50 - 7.37 (m, 6H), 7.29 (dd, J = 15.6, 7.2 Hz, 1H), 7.20 - 7.12 (m, 3H), 7.04 - 6.91 (m, 2H), 5.35 (t, J = 5.2 Hz, 1H), 4.42 - 4.31 (m, 1H), 4.25 (d, J = 14.4 Hz, 1H), 4.00 (d, J = 14.0 Hz, 1H), 3.48 - 3.27 (m, 2H), 2.46 (t, J = 6.4 Hz, 2H), 2.29 - 2.12 (m, 2H), 2.04 - 1.94 (m, 5H), 1.88 - 1.65 (m, 7H), 1.53 - 1.22 (m, 27H), 1.21 - 0.97 (m, 23H), 0.94 - 0.81 (m, 23H), 0.68 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 172.4, 172.3, 163.2 (t, J = 37.8 Hz), 163.2 (d, J = 31.5 Hz), 149.6, 140.8, 139.0, 138.9, 136.7 (d, J = 5.0 Hz), 136.1, 135.4 (d, J = 7.6 Hz), 135.3 (d, J = 7.6 Hz)1, 133.5, 133.4, 133.0 (d, J = 7.6 Hz), 132.6 (d, J = 10.1 Hz), 132.3, 132.2, 132.1, 130.5 (d, J = 102.1 Hz), 130.5 (d, J = 102.1 Hz), 130.3, 128.9, 128.8, 128.7, 128.3, 127.4, 127.1, 127.0, 126.8, 126.4, 125.7, 124.5 (d, J = 13.9 Hz), 123.5, 123.2, 117.9, 115.9 (t, J = 255.8 Hz), 115.8 (t, J = 255.8 Hz), 77.3, 75.2, 56.9, 56.8, 56.3, 53.0, 50.1, 42.4, 41.5, 40.2, 39.9, 39.7, 39.5, 37.7, 37.6, 37.5, 37.4, 36.9, 36.6, 36.3, 35.9, 32.2, 32.9, 32.8, 32.1, 32.0, 31.2, 29.8, 28.4, 28.2, 28.1, 27.3, 24.9, 24.6, 24.4, 24.0, 23.0, 22.9, 22.8, 22.7, 21.2, 20.8, 19.9, 19.8 - 19.7 (m), 19.4, 18.9, 13.8, 13.0, 12.0, 11.9. ^{31}**P NMR** (202 MHz, $CDCl_3$) δ 33.1. ^{19}**F NMR** (471 MHz, $CDCl_3$) δ -99.0, -101.2. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{84}H_{116}F_2O_6P^+$ 1289.8472; found 1289.8469.

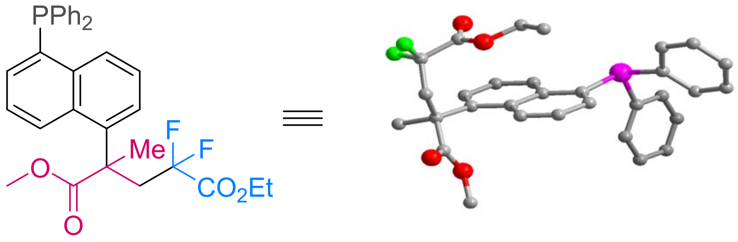


5-((8S,9S,10R,13R,14S)-17-((2R,5R,E)-5-ethyl-6-methylhept-3-en-2-yl)-10,13-dimethyl-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl)-1-(((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetrahydro-5H-bis([1,3]dioxolo)[4,5-b:4',5'-d]pyran-5-yl)methyl)-2-benzyl-2-(5-(diphenylphosphoryl)naphthalen-1-yl)-4,4-difluoropentanedioate (**7q**)

The general procedure was applied to **1a** (31.2 mg, 0.1 mmol, 1 equiv), **2n** (121.2 mg, 0.3 mmol, 3.0 equiv), **3w** (170.7 mg, 0.3 mmol, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 5.0 mol%), NaOAc (16.4 mg, 2.0 equiv) in $PhCF_3$ (1.0 mL) was stirred at 80 °C in heating mantle for 12 h under an atmosphere of argon. At ambient temperature, EtOAc (15 mL) was added, and the mixture was filtered through a short pad of silica gel. The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.5, PE/DCM/EA = 8/1/1) afforded the product, the product was oxidized by adding 1mL H_2O_2, then DCM (10mL) and H_2O (10mL) were added for liquid separation to remove the water phase, The solvent was removed in vacuo and the residue was purified by preparative chromatography (R_f = 0.3, PE/DCM/EA = 1/1/1) afforded the product **7q** (dr = 1:1) (71 mg, 58 % yield), ^{1}**H NMR** (400 MHz, $CDCl_3$) δ 8.70 - 8.65 (m, 2H), 8.18 - 8.07 (m, 2H), 7.69 - 7.52 (m, 14H), 7.49 - 7.37 (m, 12H), 7.30 - 7.24 (m, 8H), 7.09 (d, J = 30.4 Hz, 4H), 5.43 (dd, J = 29.6, 4.8 Hz, 2H), 5.32 (d, J = 2.8 Hz, 2H), 5.16 (dd, J = 15.2, 8.8 Hz, 2H), 5.02 (dd, J = 15.2, 8.8 Hz, 2H), 4.50 - 4.39 (m, 3H), 4.27 - 4.01 (m, 8H), 3.89 - 3.68 (m, 4H), 3.64 - 3.48 (m, 3H), 3.22 - 3.05 (m, 2H), 2.96 (dd, J = 30.8, 16.0 Hz, 2H), 2.23 - 1.94 (m, 10H), 1.82 - 1.69 (m, 6H), 1.59 - 1.40 (m, 23H), 1.38 - 1.32 (m, 4H), 1.30 - 1.21 (m, 18H), 1.21 - 1.14 (m, 5H), 1.09 - 0.90 (m, 20H), 0.87 - 0.82 (m, 8H), 0.81 - 0.79 (m, 10H), 0.70 (s, 6H). ^{13}**C NMR** (126 MHz, $CDCl_3$) δ 174.7, 162.7 (t, J = 32.8 Hz), 162.7 (d, J = 32.8 Hz), 139.0, 138.8, 138.4, 137.1, 136.9, 136.0, 135.8, 134.9 (d, J = 6.3 Hz), 133.6, 133.4 (d, J = 3.8 Hz), 133.3 (d, J = 11.3 Hz), 133.2 (d, J = 11.3 Hz), 132.8, 132.5 (d, J = 21.4 Hz), 132.4 (d, J = 21.4 Hz), 132.3 - 132.1 (m), 131.1, 131.0, 130.4 (d, J = 98.3 Hz), 130.2, 129.5, 128.8 - 128.5 (m), 128.3, 127.3, 126.5, 126.3, 124.9 (d, J = 15.1 Hz), 124.8 (d, J = 15.1 Hz), 123.5, 123.4, 116.1 (t, J = 252.0 Hz), 116.0 (t, J = 252.0 Hz), 109.8, 109.4, 108.9, 108.8, 96.2, 96.1, 77.1, 71.1, 70.7, 70.6, 70.5, 70.3, 66.2, 64.7, 63.3, 57.0, 56.9, 56.1, 52.4, 51.4, 50.1, 42.3, 40.6, 39.8, 37.5, 37.3, 36.8, 36.7, 36.6, 32.0, 31.9, 29.0, 27.3, 27.1, 26.2, 25.5, 25.1, 24.5, 21.4, 21.2, 21.1, 19.4, 19.1, 12.4, 12.2. **^{31}P NMR** (162 MHz, $CDCl_3$) δ 32.8, 32.7. **^{19}F NMR** (377 MHz, $CDCl_3$) δ -104.0 - -104.3 (m), -104.7 - -105.0 (m). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{75}H_{92}F_2O_{10}P^+$ 1221.6391; found 1221.6387.

4. Crystallographic Data

X-ray data for **4f**



Compound **4f**

Compound	4f
Formula	$C_{31}H_{29}F_2O_4P$
Formula weight	534.51
T(K)	293
Crystal systemc	triclinic
Space group	P -1
a (Å)	9.62340(10)
b (Å)	10.49270(10)
c (Å)	14.0802(2)
α (°)	99.3100(10)
β (°)	98.0540(10)
γ (°)	100.6190(10)
V (Å^3)	1357.67(3)
Z	2
D_c. (g cm^3)	1.307
μ(mm^{-1})	1.311
reflns coll.	17430
unique reflns	5457
R_{int}	0.0332
^{a}*R1* [I ≥ 2σ(I)]	0.0366
^{b}*w R$_2$* (all data)	0.1050

GOF	1.117

$^{a}R_1 = \Sigma||F_o|-|F_c||/\Sigma|F_o|$, $^{b}wR_2 = [\Sigma w\,(F_o^2-F_c^2)^2/\Sigma w\,(F_o^2)^2]^{1/2}$

5. References

[1] Bao, Z.-P.; Zhang, Y.; Wu, X.-F. Palladium-catalyzed difluoroalkylative carbonylation of styrenes toward difluoropentanedioates. *Chem. Sci.*, **2022**, *13*, 9387 - 9391.

[2] Han, X.; Wang, Y.; Zhong, F.; Lu, Y. Enantioselective [3 + 2] Cycloaddition of Allenes to Acrylates Catalyzed by Dipeptide-Derived Phosphines: Facile Creation of Functionalized Cyclopentenes Containing Quaternary Stereogenic Centers. *J. Am. Chem. Soc.*, **2011**, *133*, 1726 - 1729.

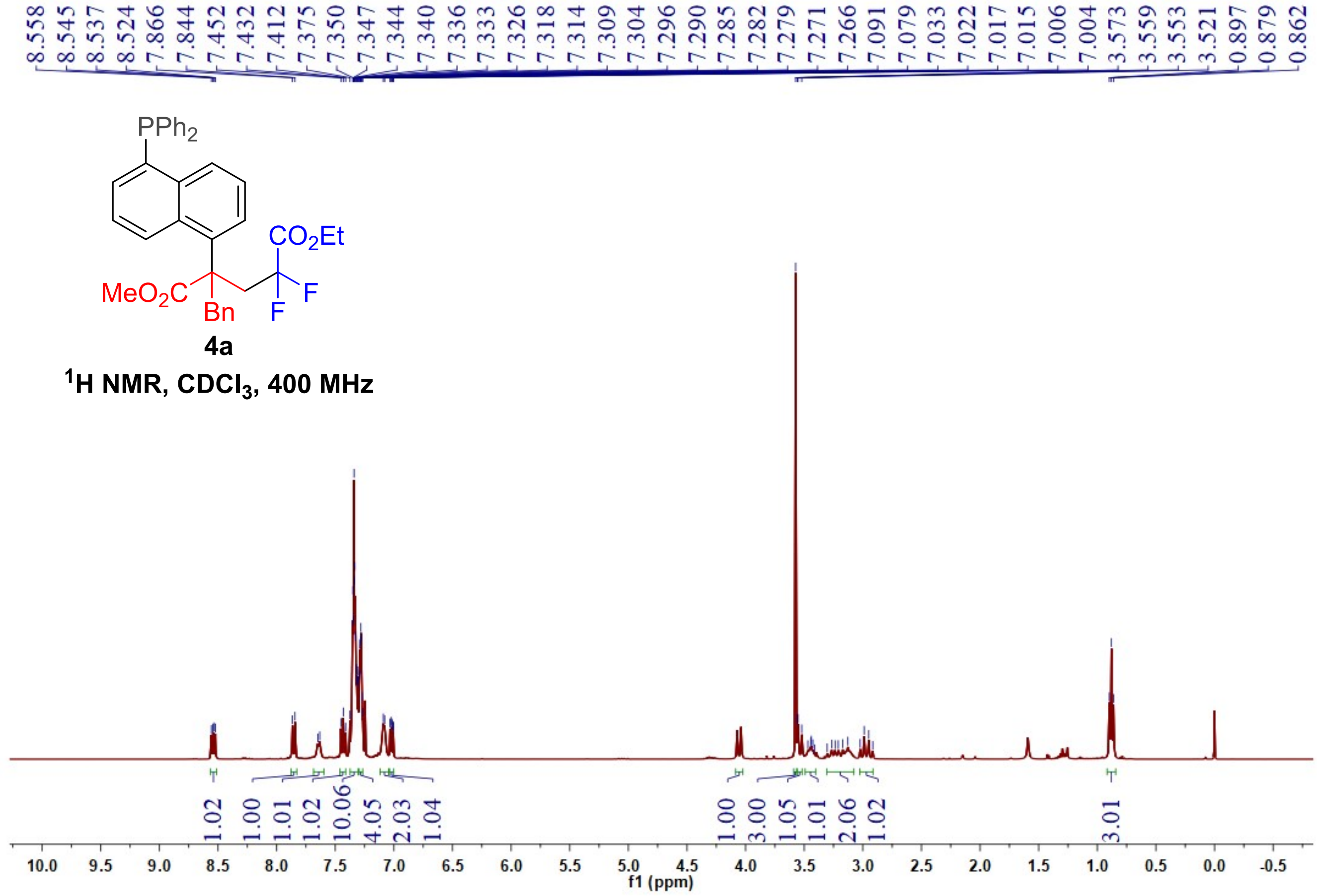
[3] Fu, Y.; Chen, C.-H.; Huang, M.-G.; Tao, J.-Y.; Peng, X.; Xu, H.-B.; Liu, Y.-J.; Zeng, M.-H. Remote C5-Selective Functionalization of Naphthalene Enabled by P-Ru-C Bond-Directed δ-Activation. *ACS Catal.*, **2022**, *12*, 5036 - 5047.

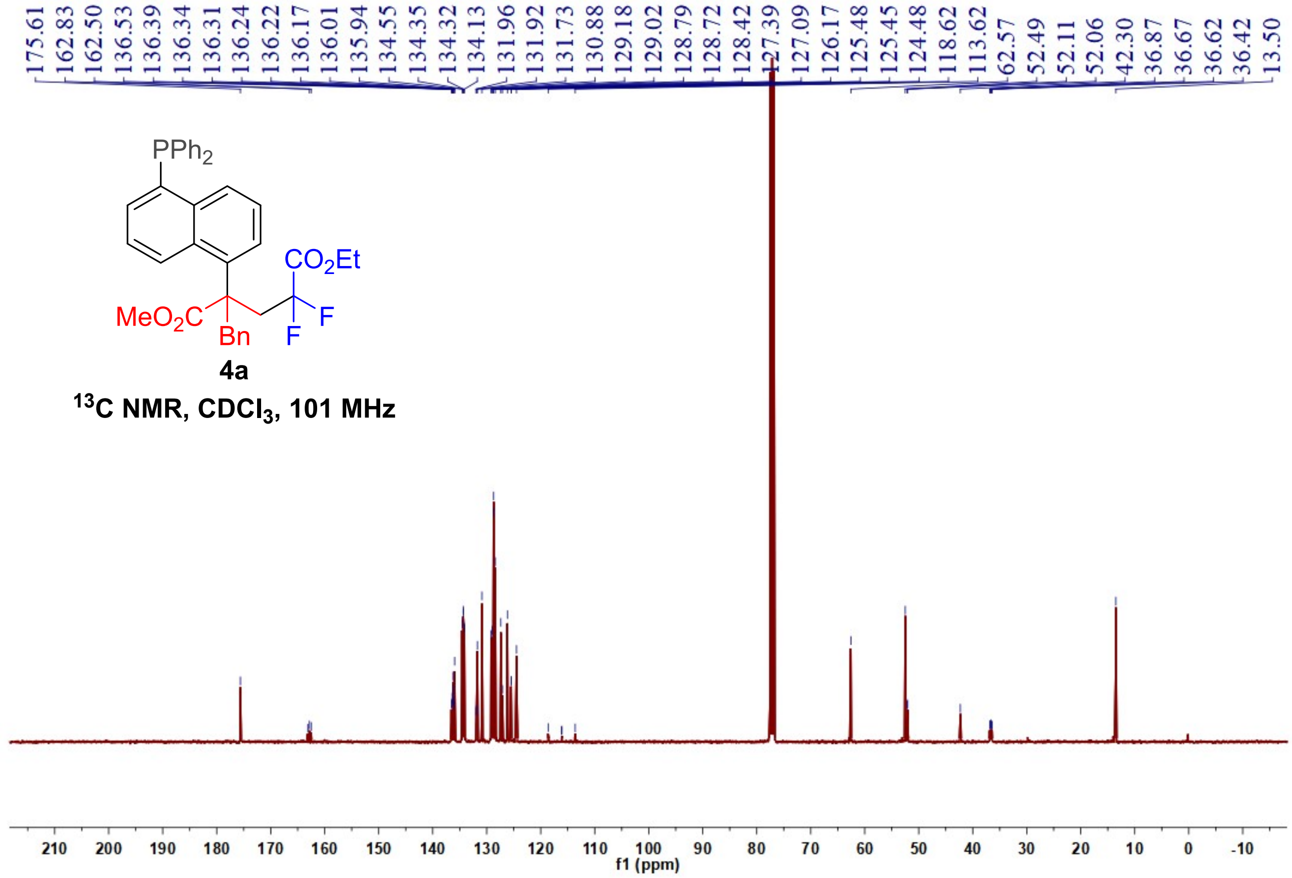
[4] Kim, J.; Shokova, E.; Tafeenko, V.; Kovalev, V. $(CF_3CO)_2O/CF_3SO_3H$-mediated synthesis of 1,3-diketones from carboxylic acids and aromatic ketones. Beilstein *J. Org. Chem.*, **2014**, *10*, 2270 - 2278.

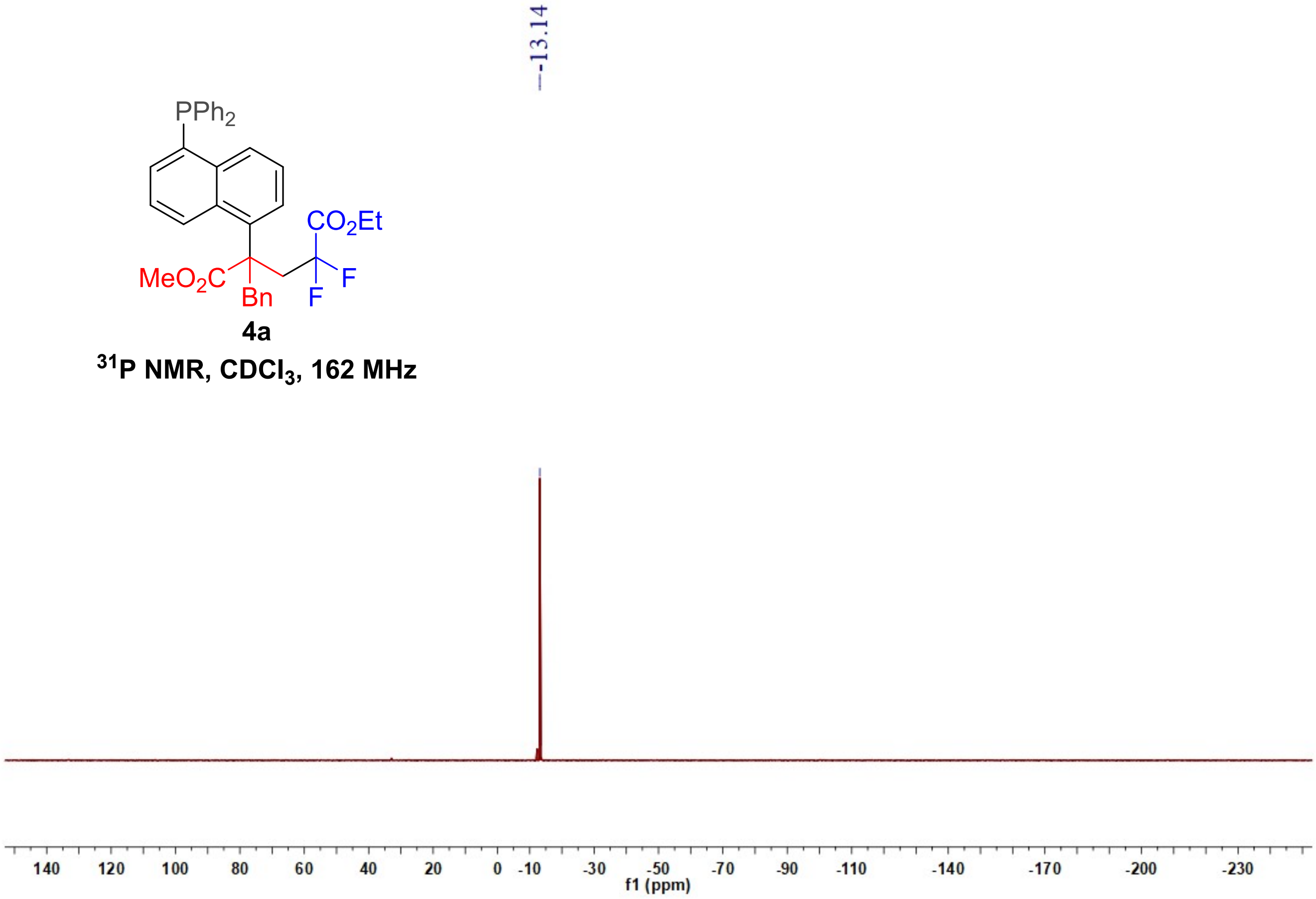
[5] Xu, W.-Q.; Tao, J.-Y.; Liu. Y.-J.; Zeng, M.-H. Ruthenium-catalyzed meta-difluoromethylation of arene phosphines enabled by 1,3-dione. *Org. Chem. Front.*, **2022**, *9*, 4052 - 4056.

[6] Y. Shen, D. L. Burgoyne, R. W. Lauener, Y. Zhou, P. J. Rebstein, S. D. M. Abraham, Patent *US20030186943.*

6. NMRspectra

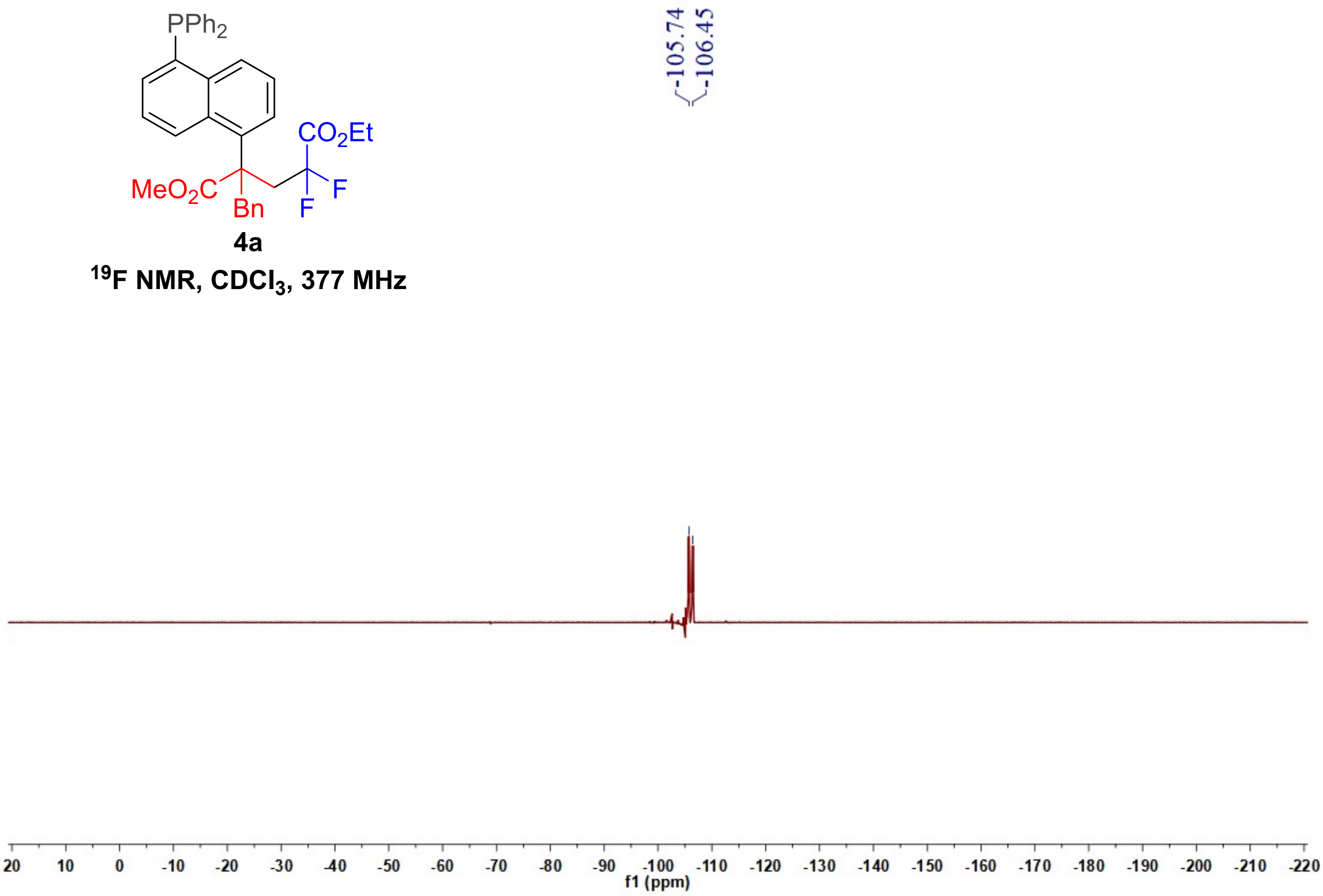






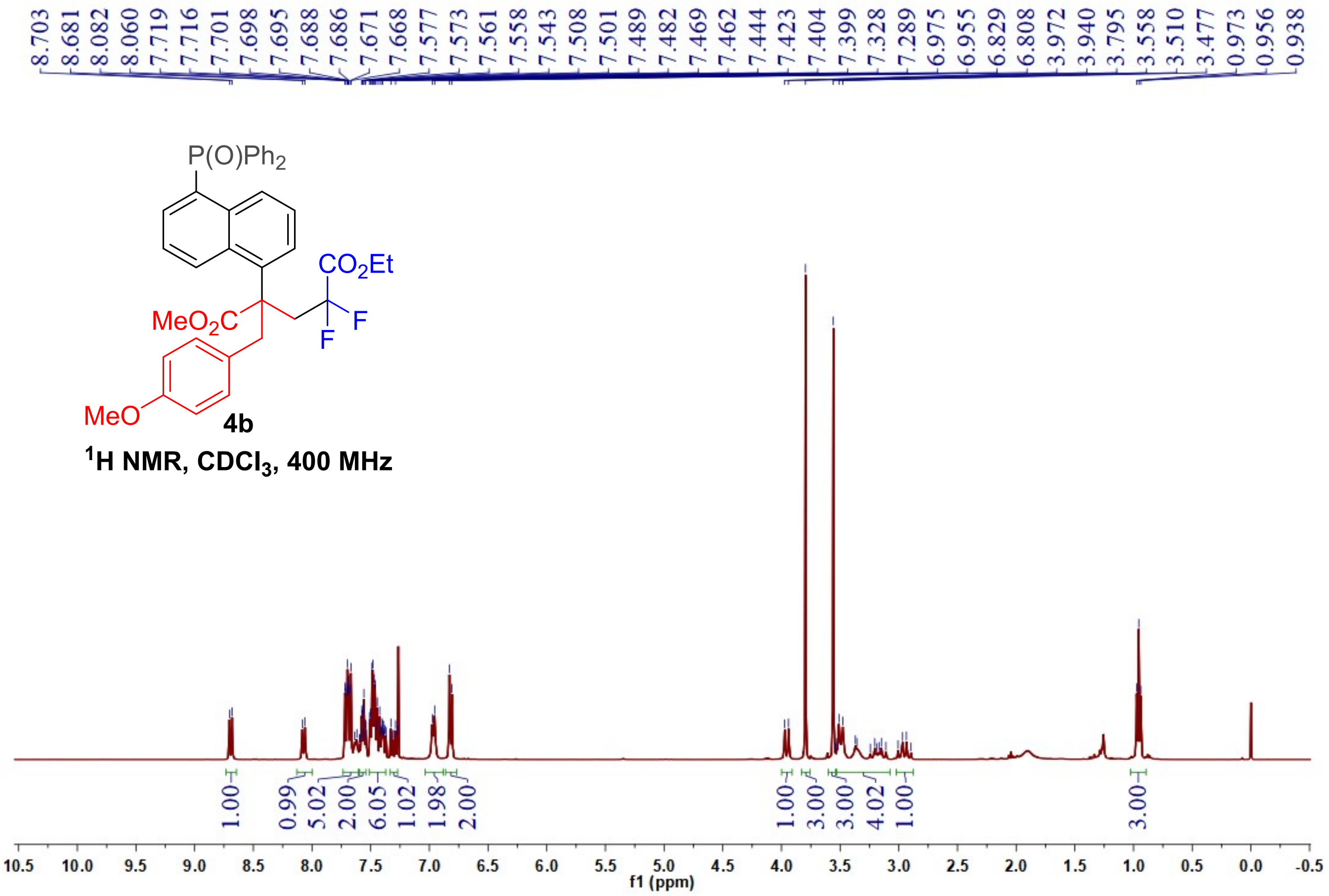
4a

^{31}P NMR, CDCl$_3$, 162 MHz



4a

^{19}F NMR, CDCl$_3$, 377 MHz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8.082
8.060
7.719
7.716
7.701
7.698
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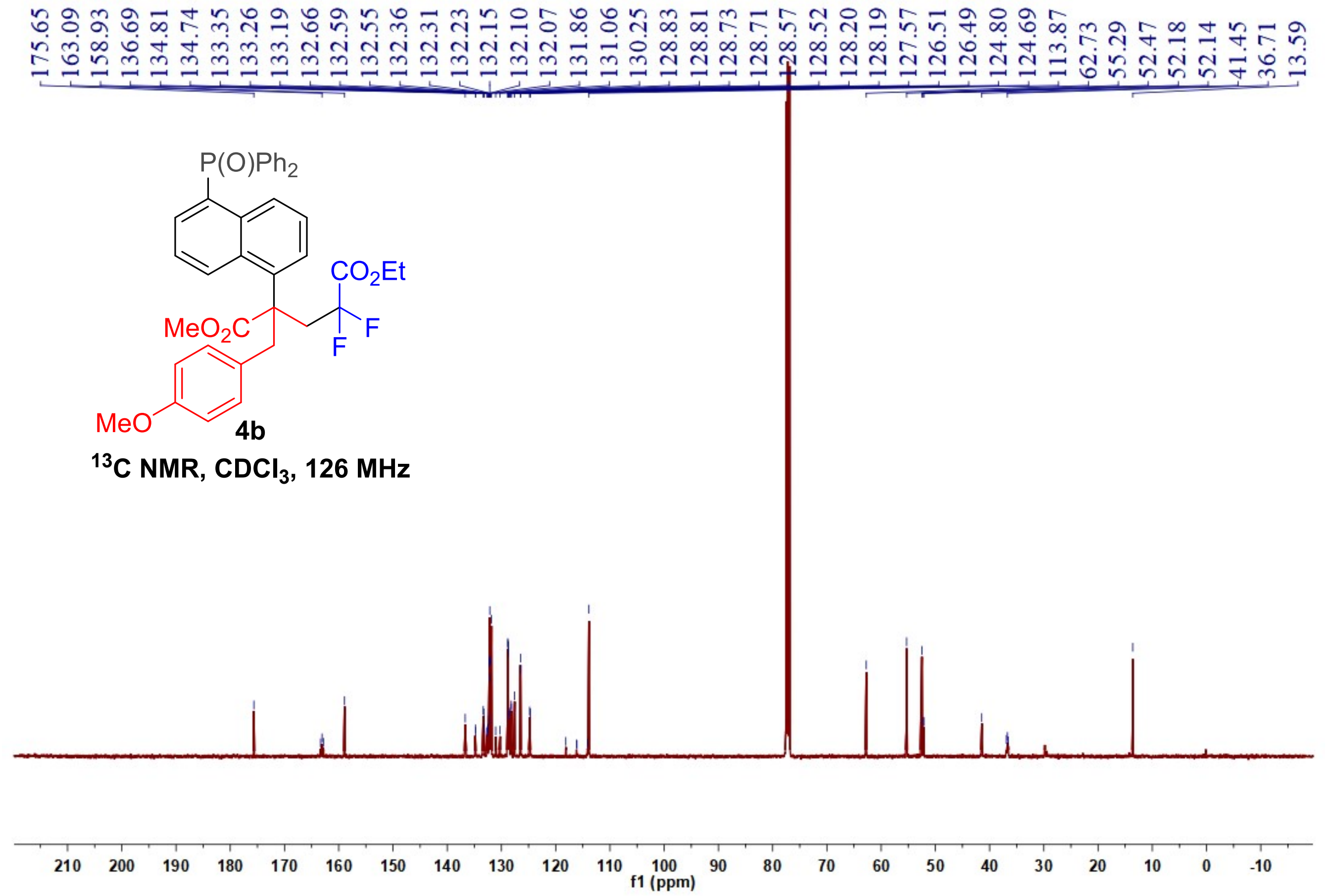
7.688
7.686
7.671
7.668
7.577
7.573
7.561
7.558
7.543
7.508
7.501
7.489
7.482
7.469
7.462
7.444
7.423
7.404
7.399
7.328
7.289
6.975
6.955
6.829
6.808
3.972
3.940
3.795
3.558
3.510
3.477
0.973
0.956
0.938
P(O)Ph2
CO2Et
MeO2C
F
F
MeO
4b
1H NMR, CDCl3, 400 MHz
1.00
0.99
5.02
2.00
6.05
1.02
1.98
2.00
1.00
3.00
3.00
4.02
1.00
3.00
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)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158.93
136.69
134.81
134.74
133.35
133.26
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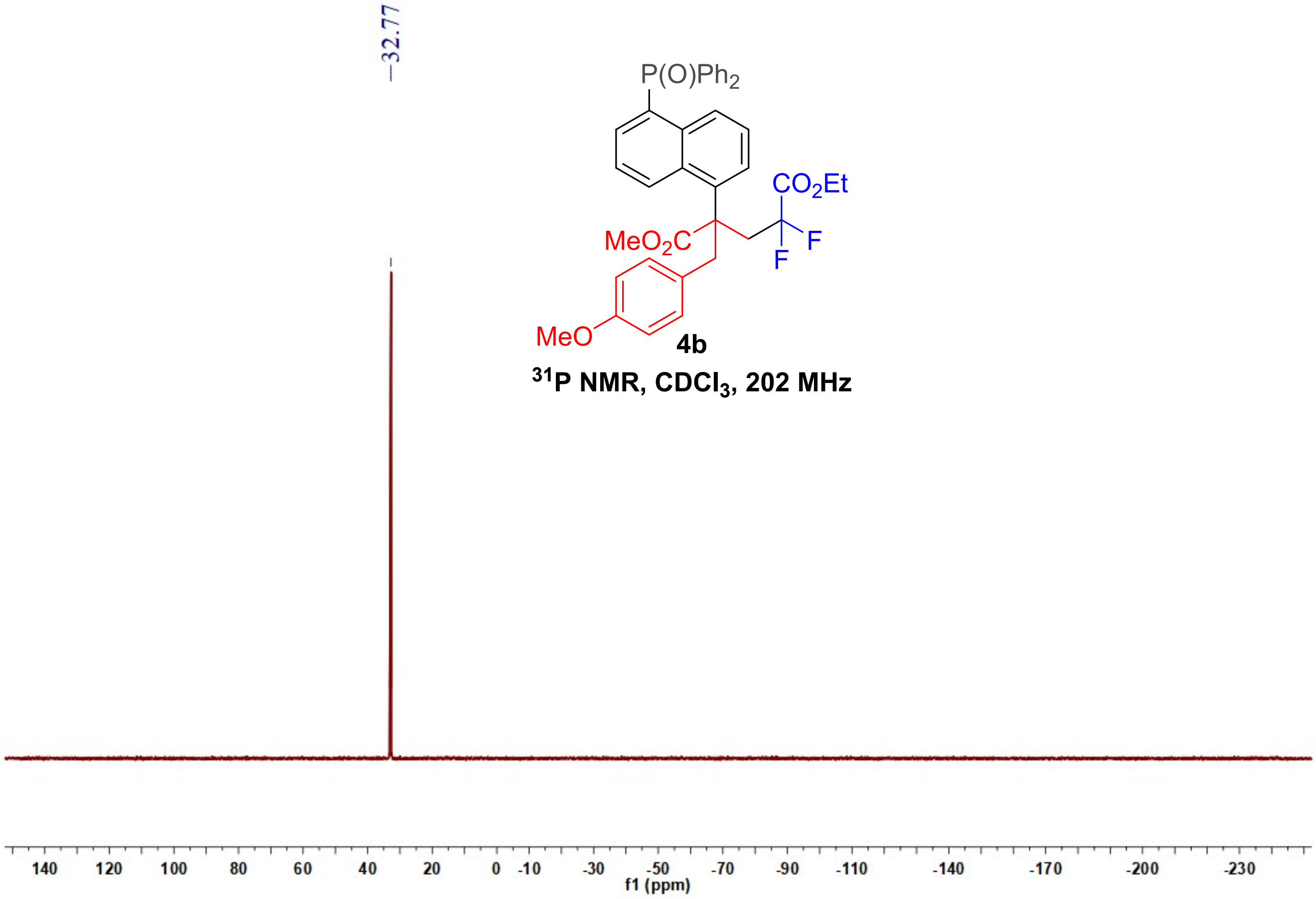
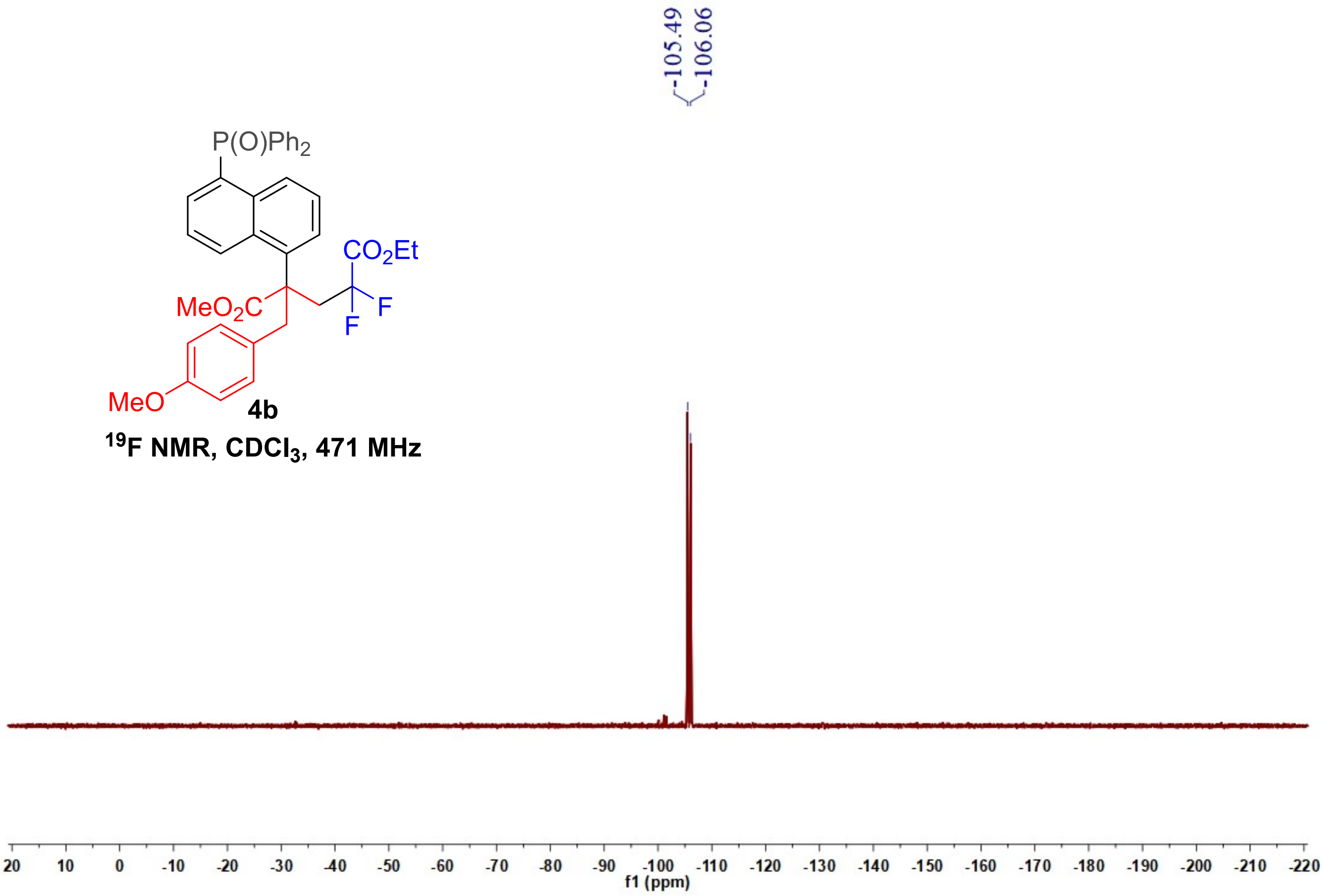
132.66
132.59
132.55
132.36
132.31
132.23
132.15
132.10
132.07
131.86
131.06
130.25
128.83
128.81
128.73
128.71
128.57
128.52
128.20
128.19
127.57
126.51
126.49
124.80
124.69
113.87
62.73
55.29
52.47
52.18
52.14
41.45
36.71
13.59
P(O)Ph2
CO2Et
MeO2C
F
F
MeO
4b
13C NMR, CDCl3, 126 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



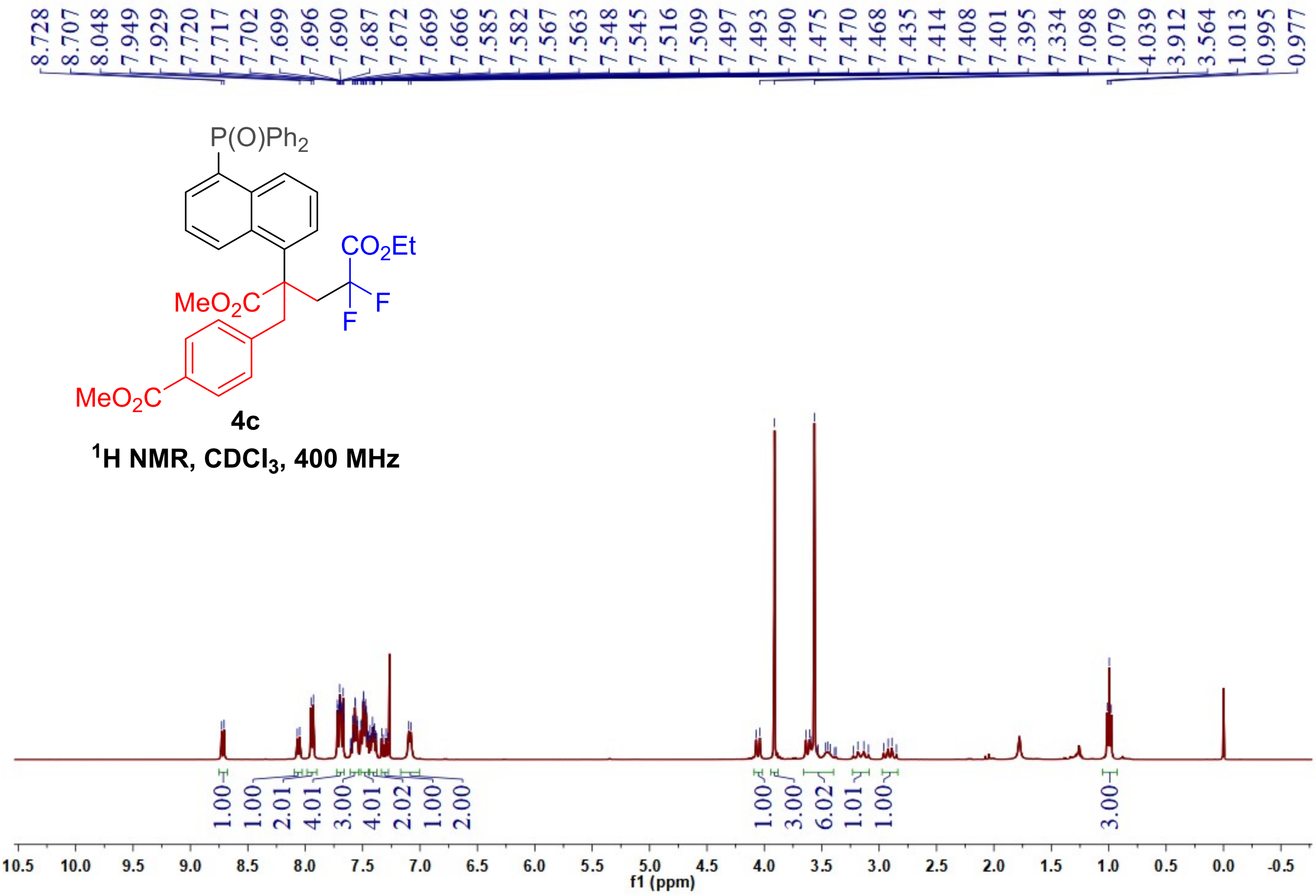
4b

^{31}P NMR, CDCl$_3$, 202 MHz



4b

^{19}F NMR, CDCl$_3$, 471 MHz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8.707
8.048
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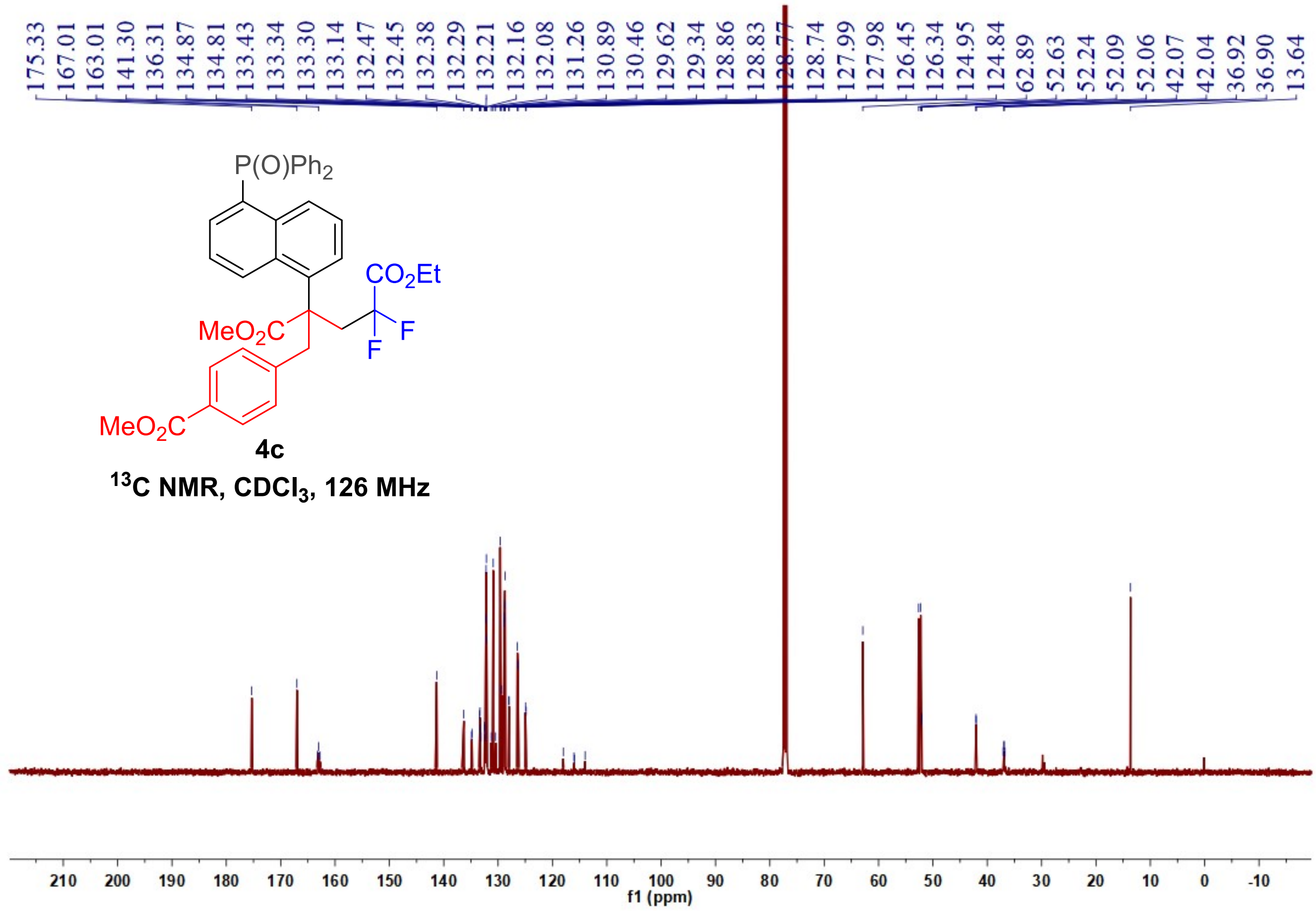
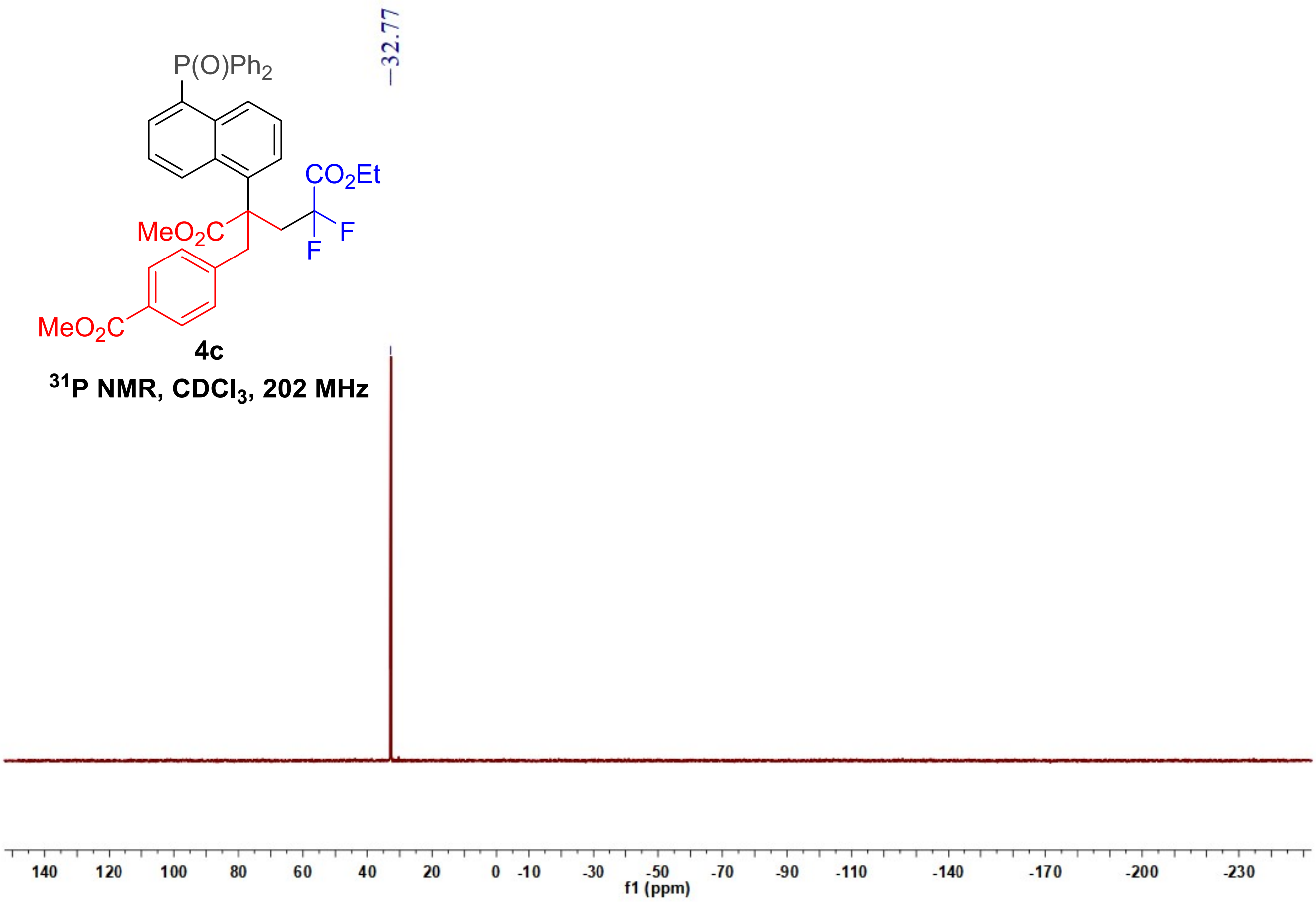
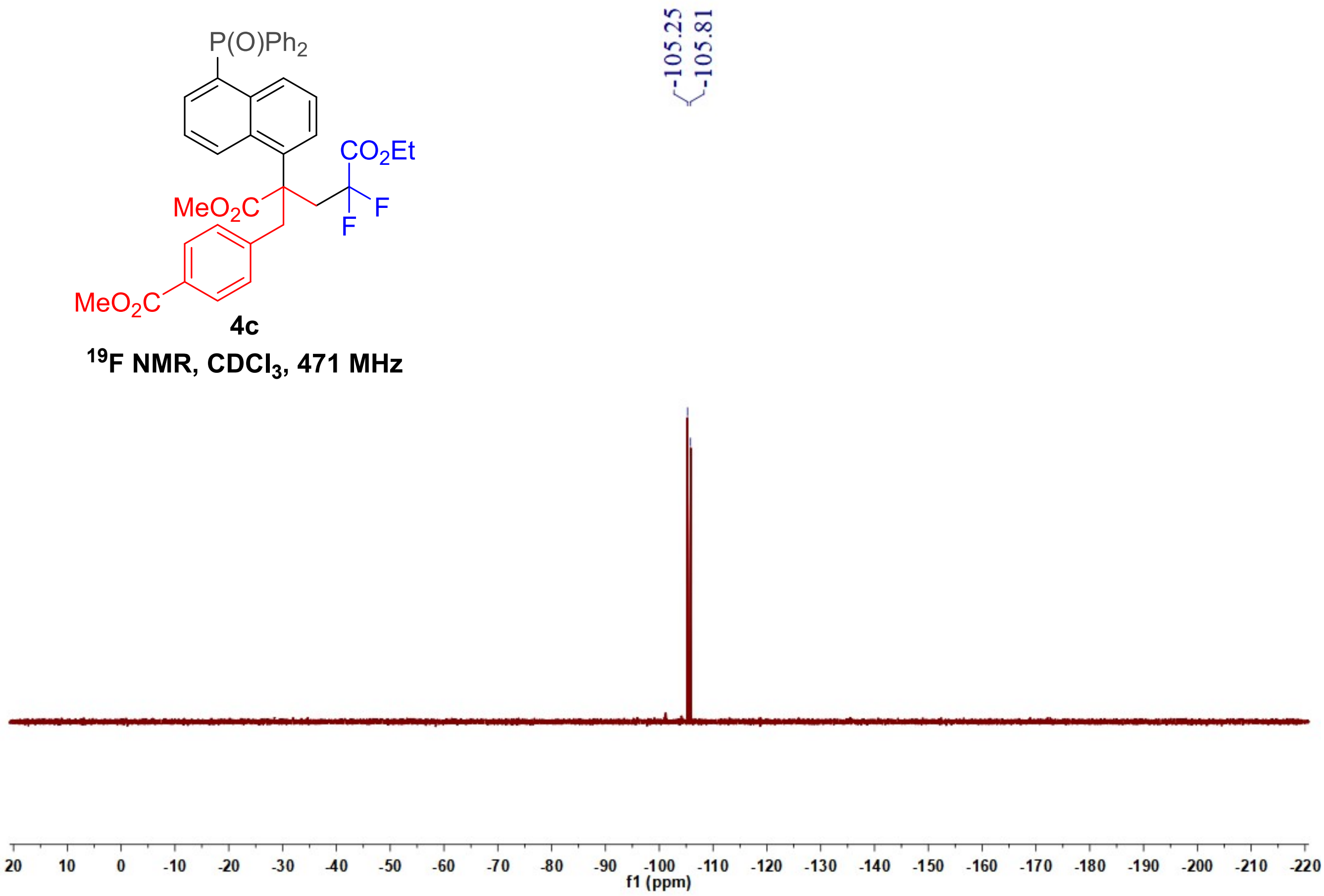
7.717
7.702
7.699
7.696
7.690
7.687
7.672
7.669
7.666
7.585
7.582
7.567
7.563
7.548
7.545
7.516
7.509
7.497
7.493
7.490
7.475
7.470
7.468
7.435
7.414
7.408
7.401
7.395
7.334
7.098
7.079
4.039
3.912
3.564
1.013
0.995
0.977
P(O)Ph$_2$
CO$_2$Et
MeO$_2$C
F
F
MeO$_2$C
4c
^{1}H NMR, CDCl$_3$, 400 MHz
1.00
1.00
2.01
4.01
3.00
4.01
2.02
1.00
2.00
1.00
3.00
6.02
1.01
1.00
3.00
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


175.33
167.01
163.01
141.30
136.31
134.87
134.81
133.43
133.34
133.30
133.14
132.47
132.45
132.38
132.29
132.21
132.16
132.08
131.26
130.89
130.46
129.62
129.34
128.86
128.83
128.77
128.74
127.99
127.98
126.45
126.34
124.95
124.84
62.89
52.63
52.24
52.09
52.06
42.07
42.04
36.92
36.90
13.64
P(O)Ph$_2$
CO$_2$Et
MeO$_2$C
F
F
MeO$_2$C
4c
^{13}C NMR, CDCl$_3$, 126 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



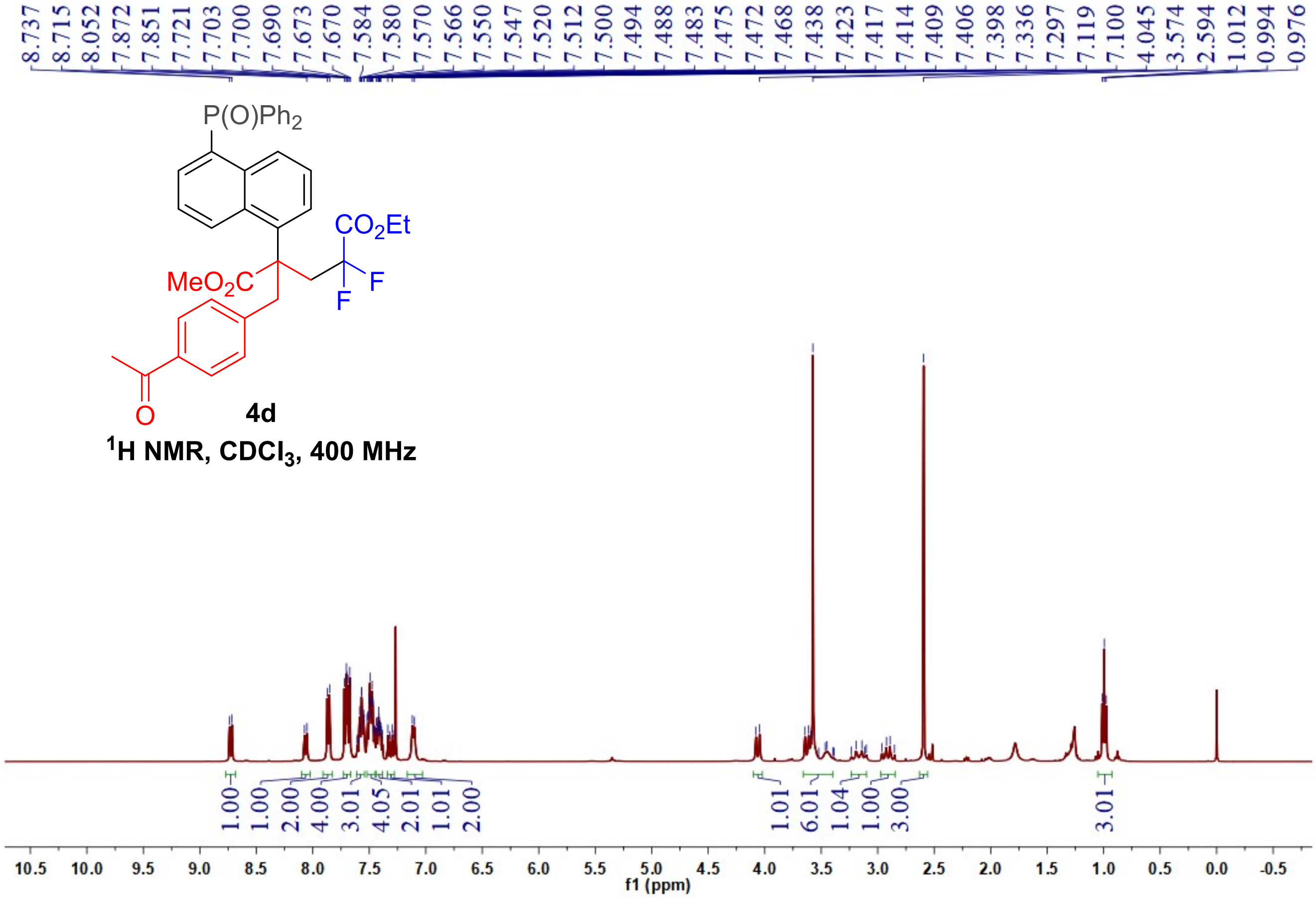
4c

^{31}P NMR, CDCl$_3$, 202 MHz



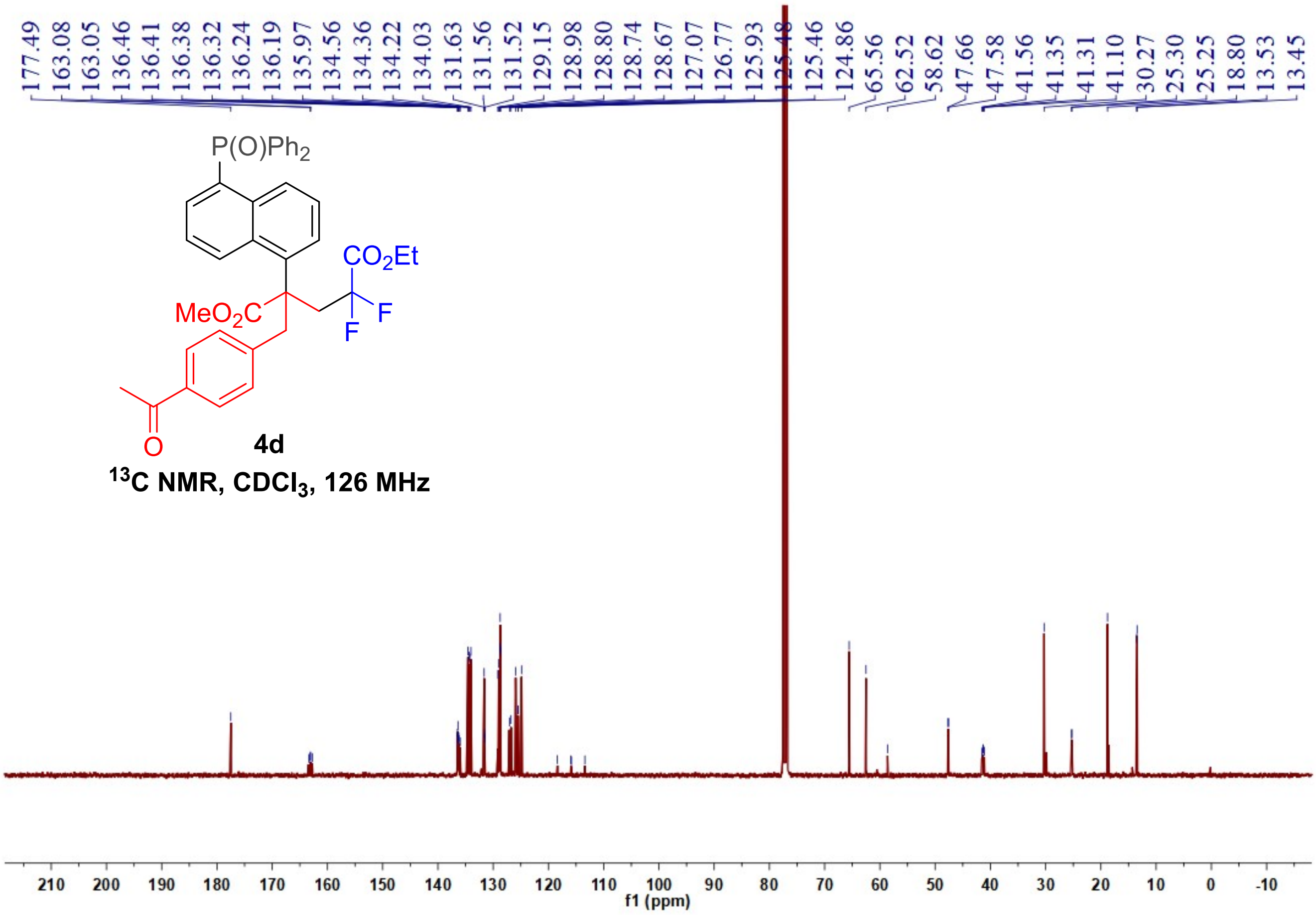
4c

^{19}F NMR, CDCl$_3$, 471 MHz



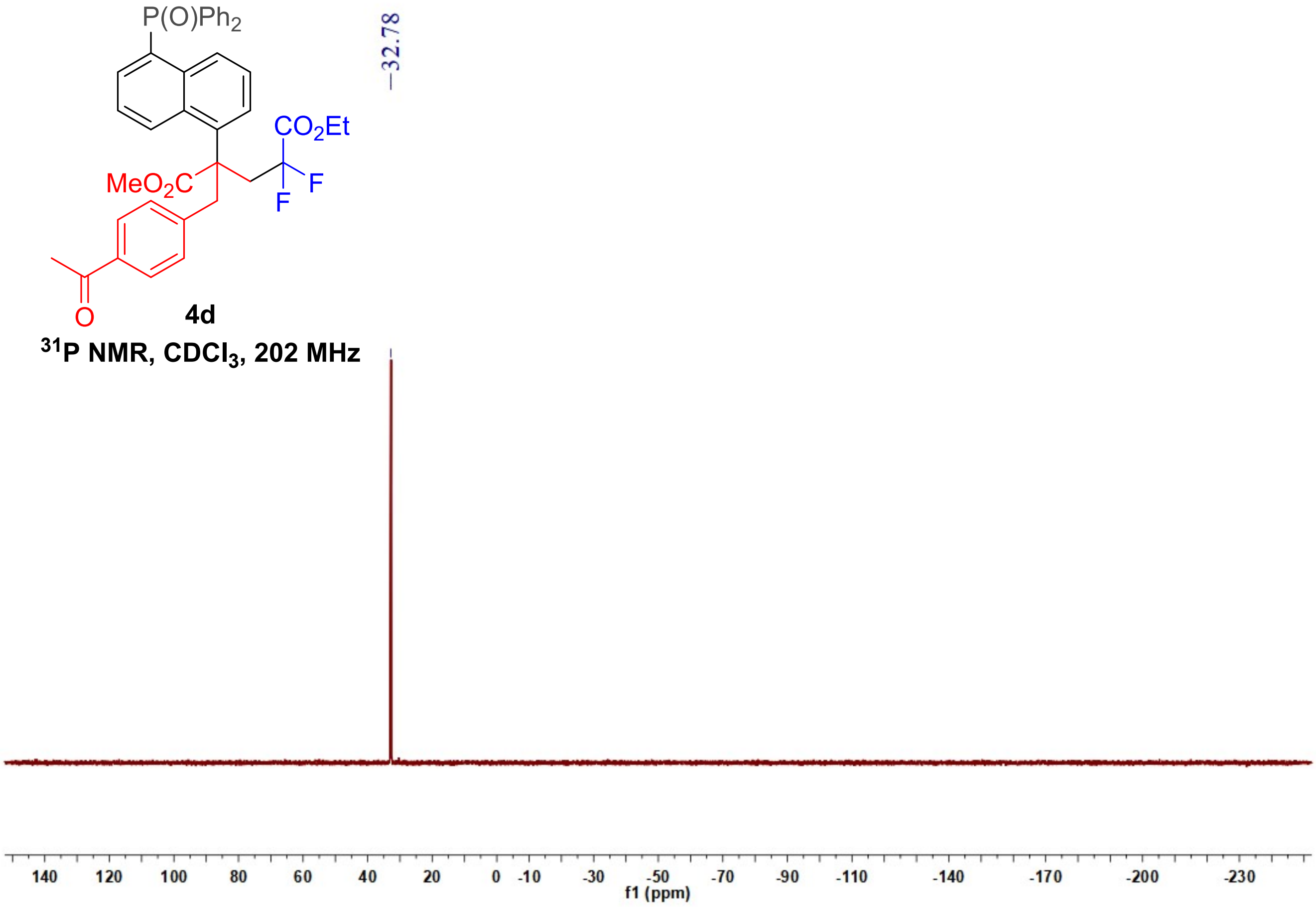
4d

^{1}H NMR, CDCl$_3$, 400 MHz



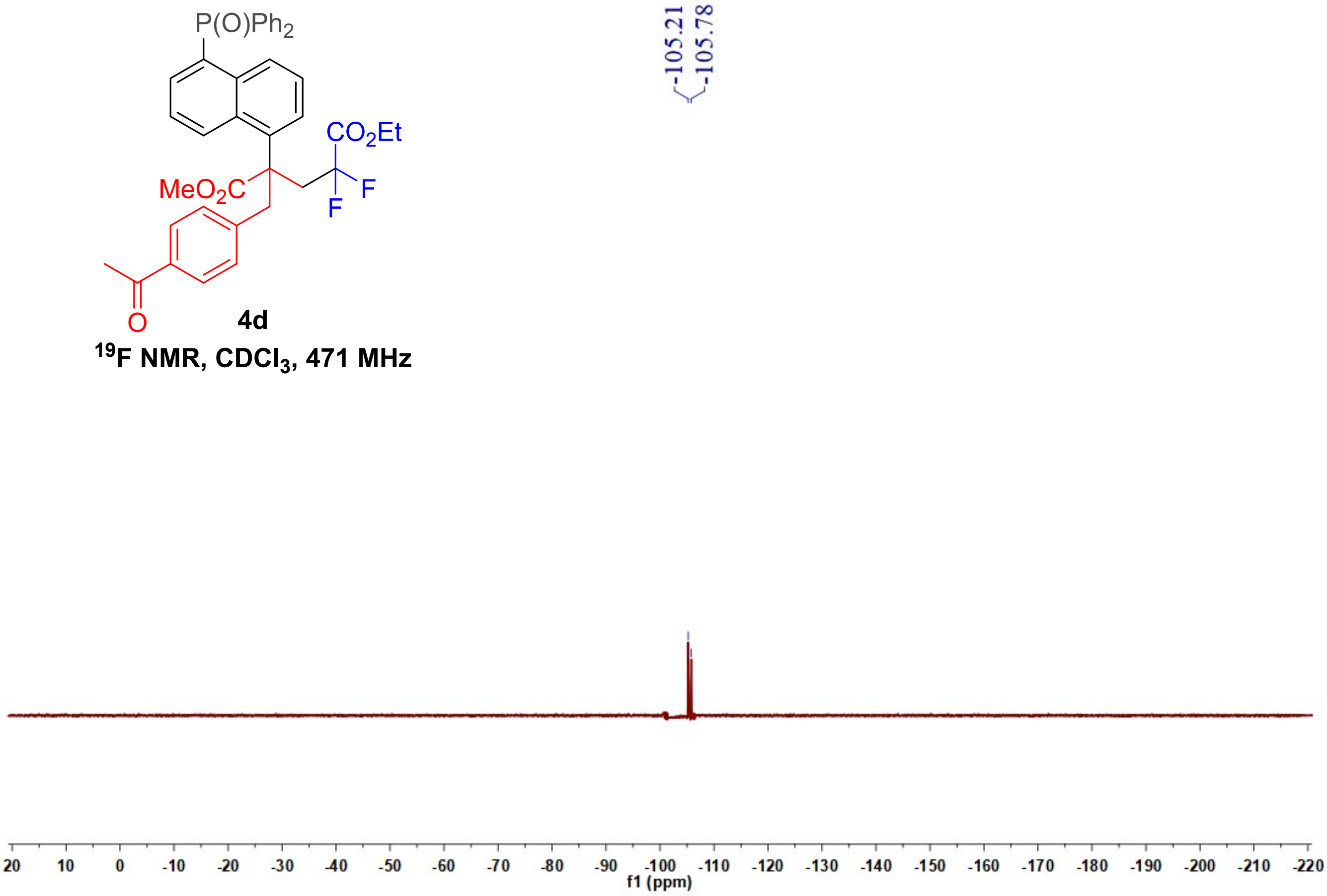
4d

^{13}C NMR, CDCl$_3$, 126 MHz



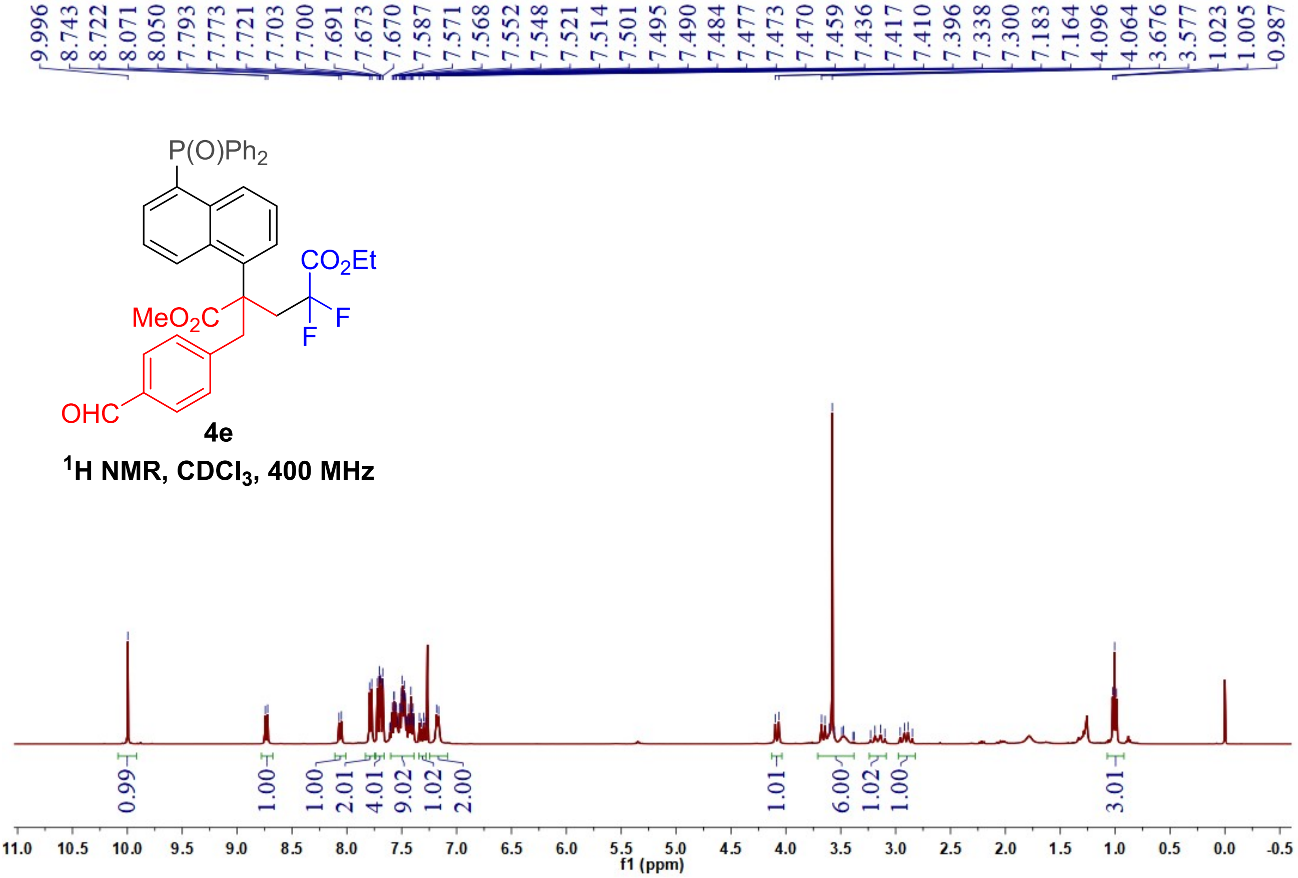
4d

^{31}P NMR, CDCl$_3$, 202 MHz



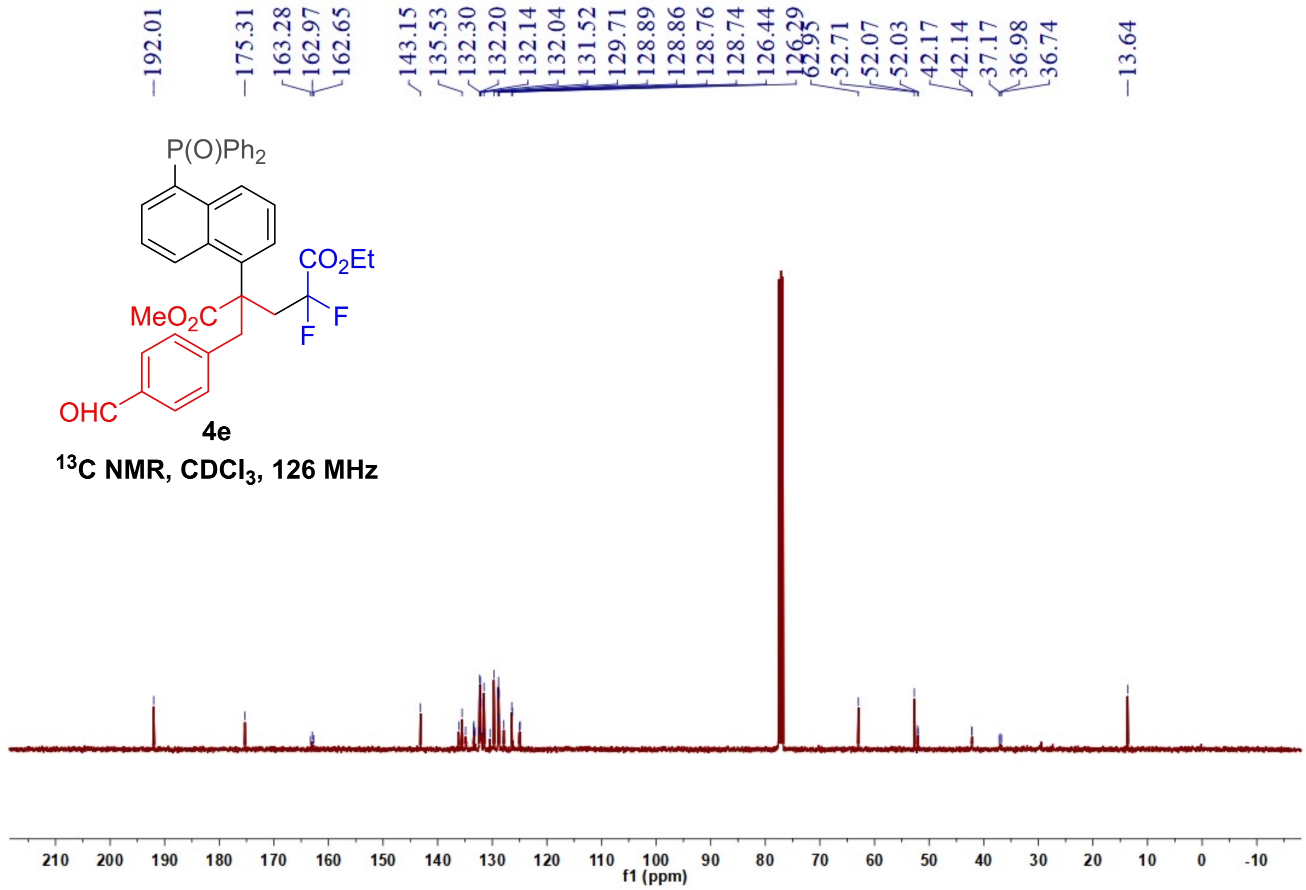
4d

^{19}F NMR, CDCl$_3$, 471 MHz



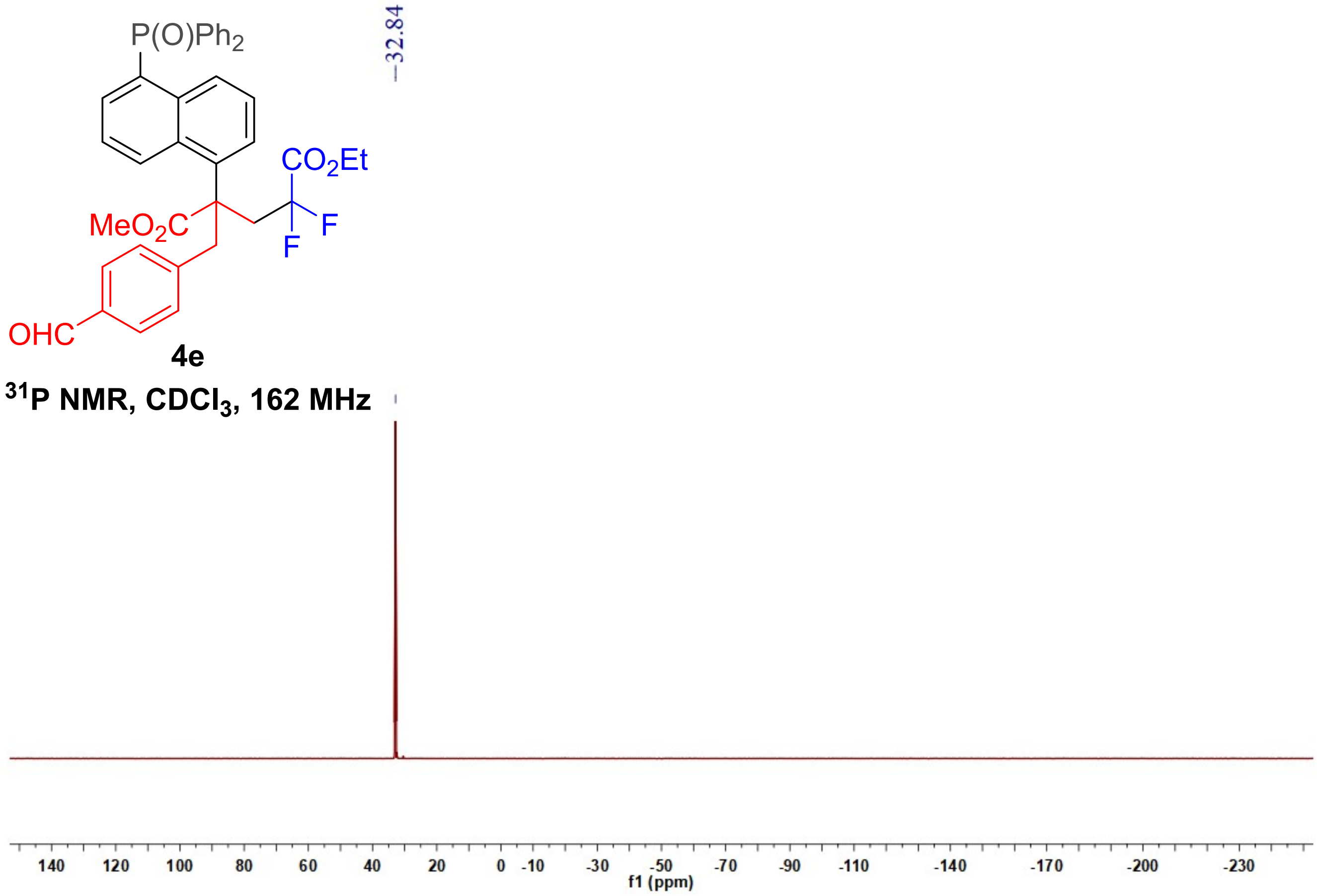
4e

^{1}H NMR, CDCl$_3$, 400 MHz



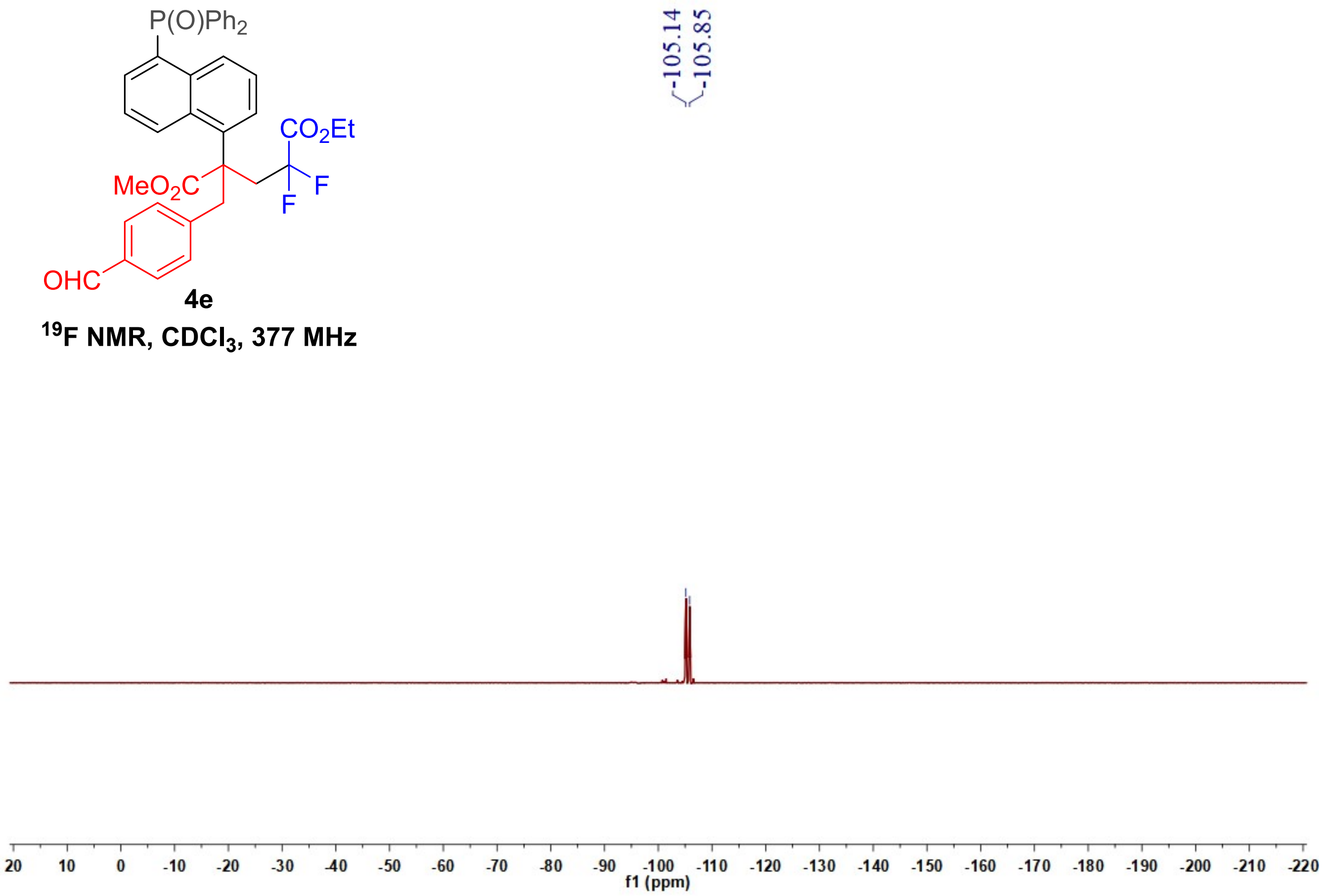
4e

^{13}C NMR, CDCl$_3$, 126 MHz



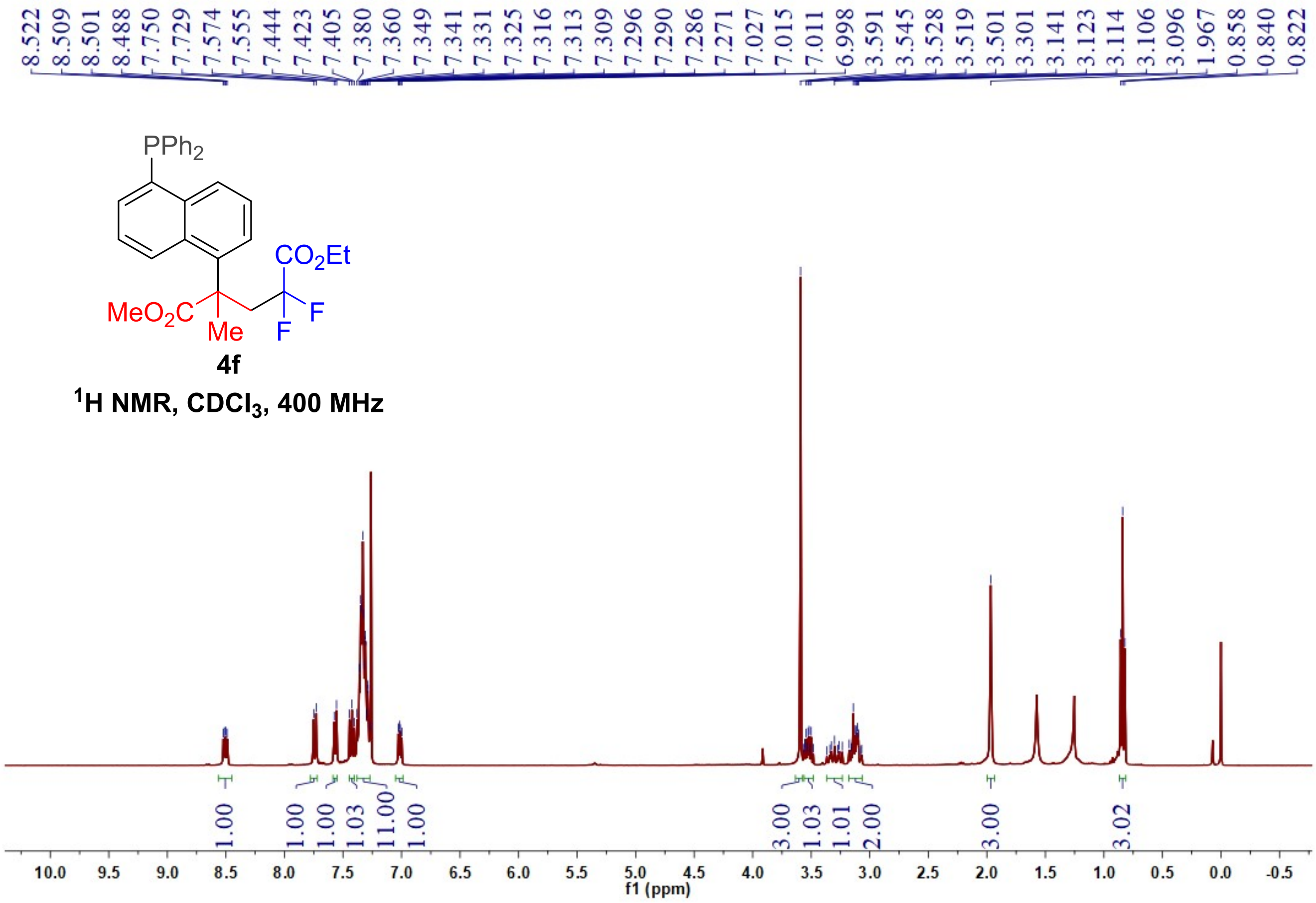
4e

^{31}P NMR, CDCl$_3$, 162 MHz



4e

^{19}F NMR, CDCl$_3$, 377 MHz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7.423
7.405
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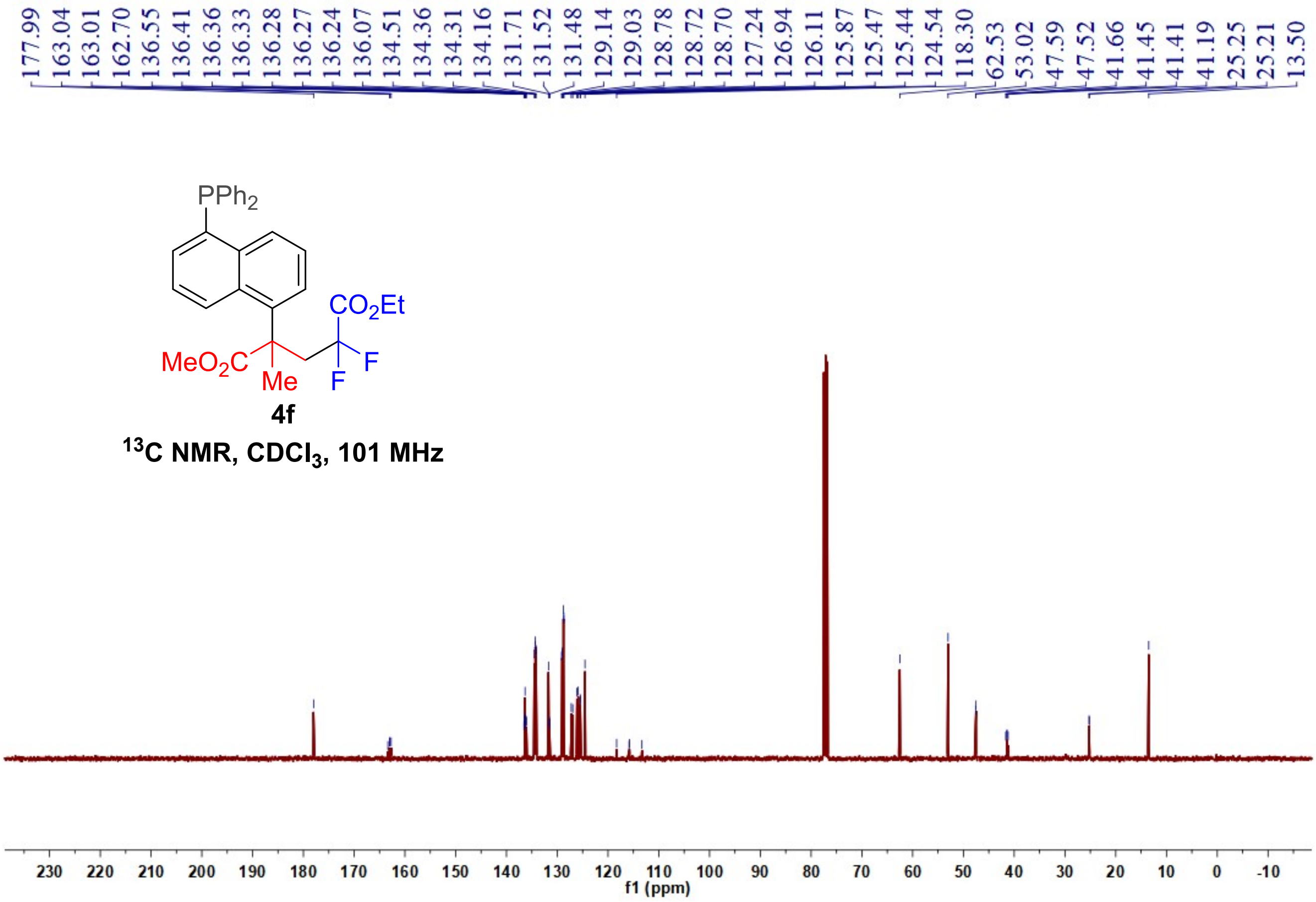
7.360
7.349
7.341
7.331
7.325
7.316
7.313
7.309
7.296
7.290
7.286
7.271
7.027
7.015
7.011
6.998
3.591
3.545
3.528
3.519
3.501
3.301
3.141
3.123
3.114
3.106
3.096
1.967
0.858
0.840
0.822
PPh2
CO2Et
MeO2C
Me
F
F
4f
1H NMR, CDCl3, 400 MHz
1.00
1.00
1.00
1.03
11.00
1.00
3.00
1.03
1.01
2.00
3.00
3.02
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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162.70
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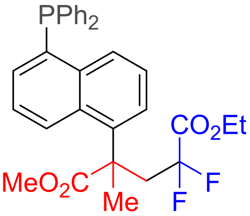
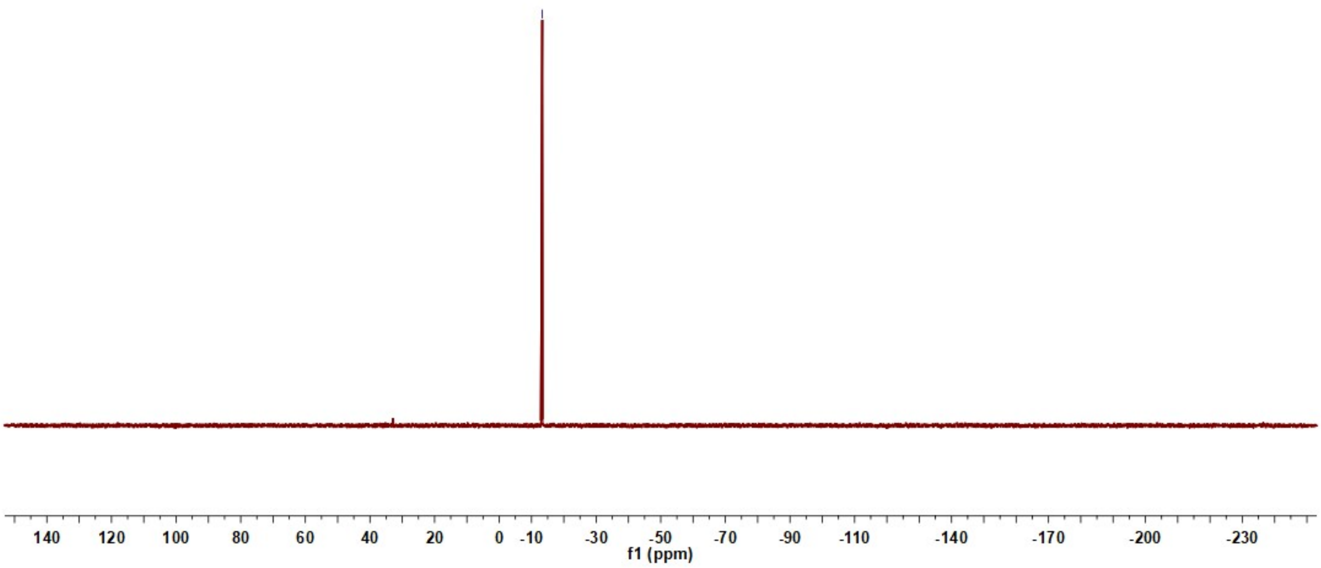
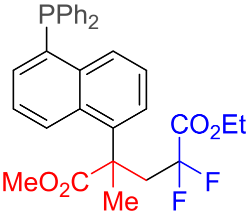
136.41
136.36
136.33
136.28
136.27
136.24
136.07
134.51
134.36
134.31
134.16
131.71
131.52
131.48
129.14
129.03
128.78
128.72
128.70
127.24
126.94
126.11
125.87
125.47
125.44
124.54
118.30
62.53
53.02
47.59
47.52
41.66
41.45
41.41
41.19
25.25
25.21
13.50
PPh2
CO2Et
MeO2C
Me
F
F
4f
13C NMR, CDCl3, 101 MHz
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



4f

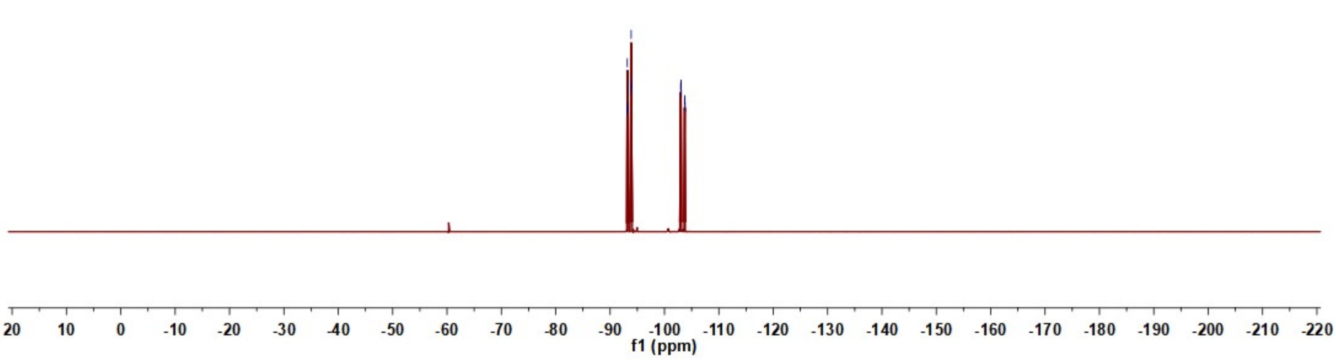
^{31}P NMR, $CDCl_3$, 162 MHz

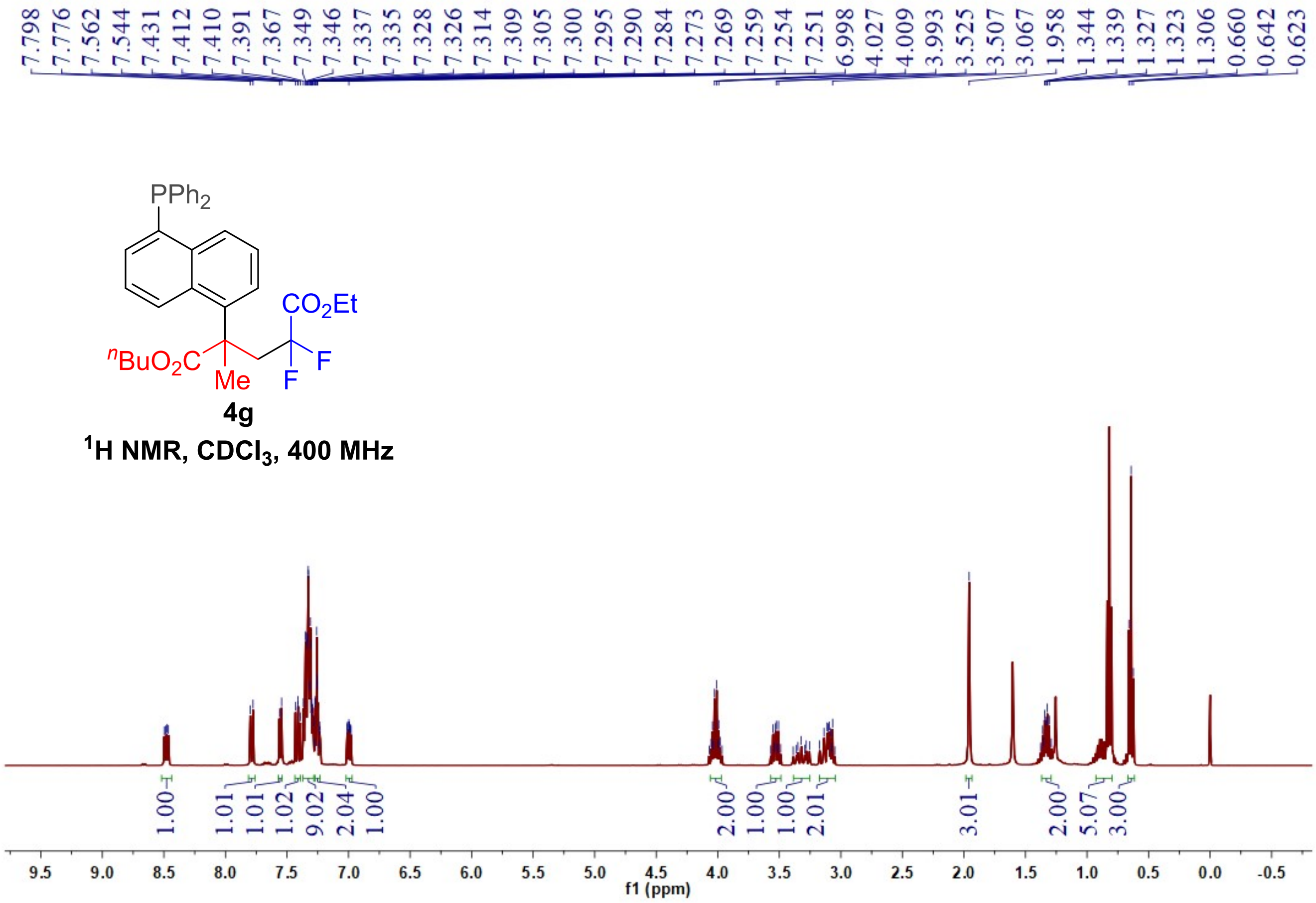




4f

^{19}F NMR, $CDCl_3$, 377 MHz

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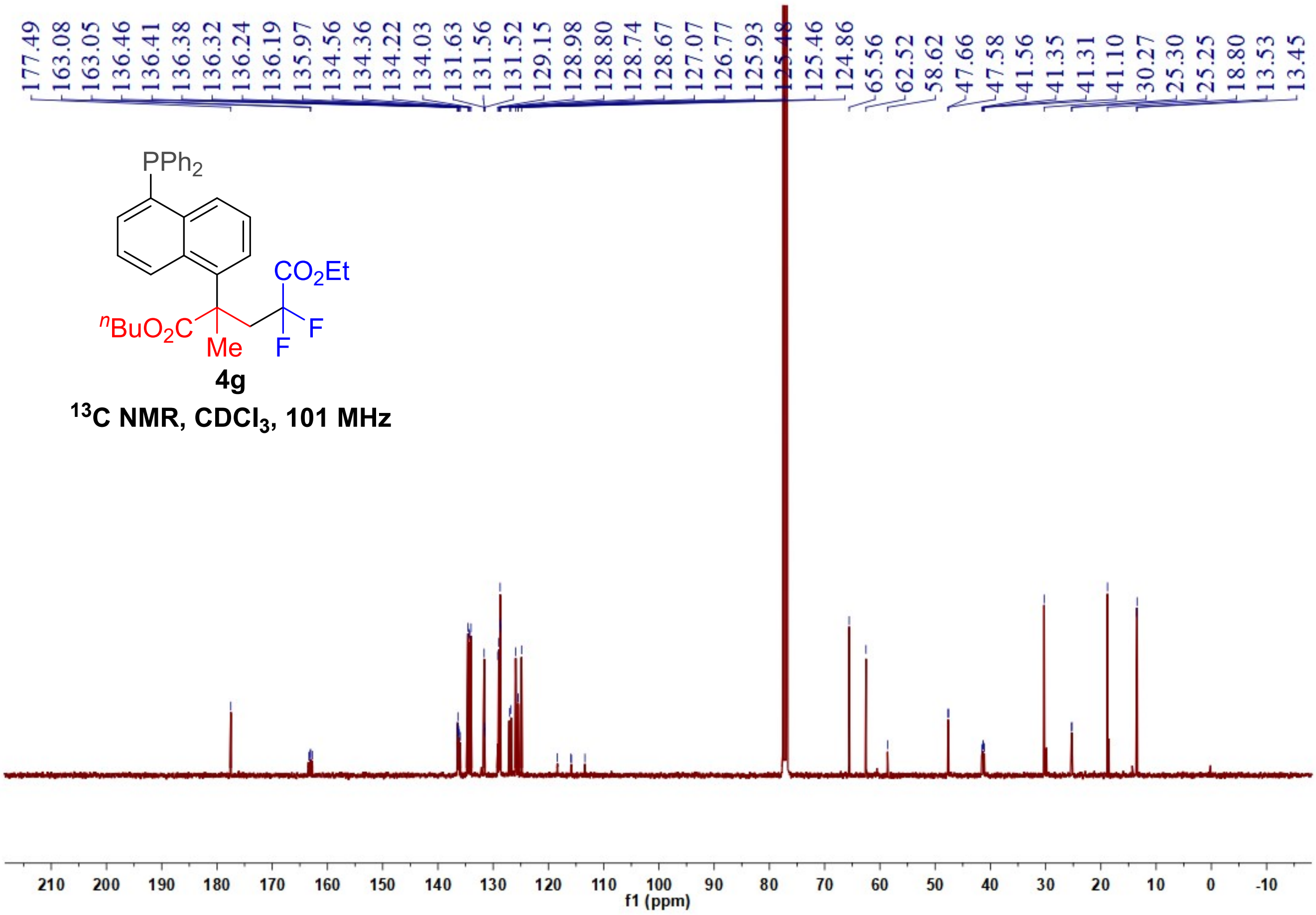
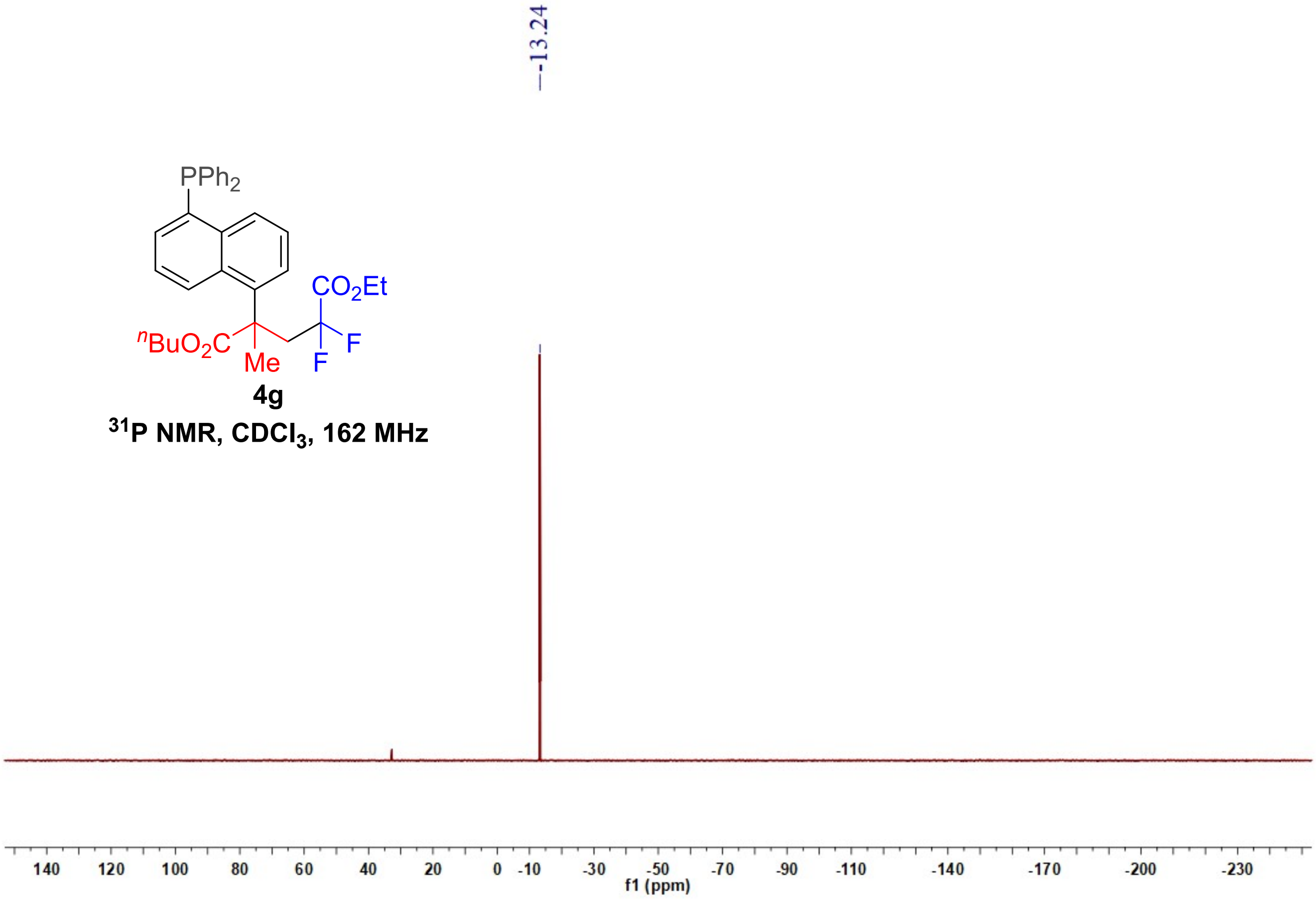
7.273
7.269
7.259
7.254
7.251
6.998
4.027
4.009
3.993
3.525
3.507
3.067
1.958
1.344
1.339
1.327
1.323
1.306
0.660
0.642
0.623
PPh2
CO2Et
nBuO2C
Me
F
F
4g
1H NMR, CDCl3, 400 MHz
1.00
1.01
1.01
1.02
9.02
2.04
1.00
2.00
1.00
1.00
2.01
3.01
2.00
5.07
3.00
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)



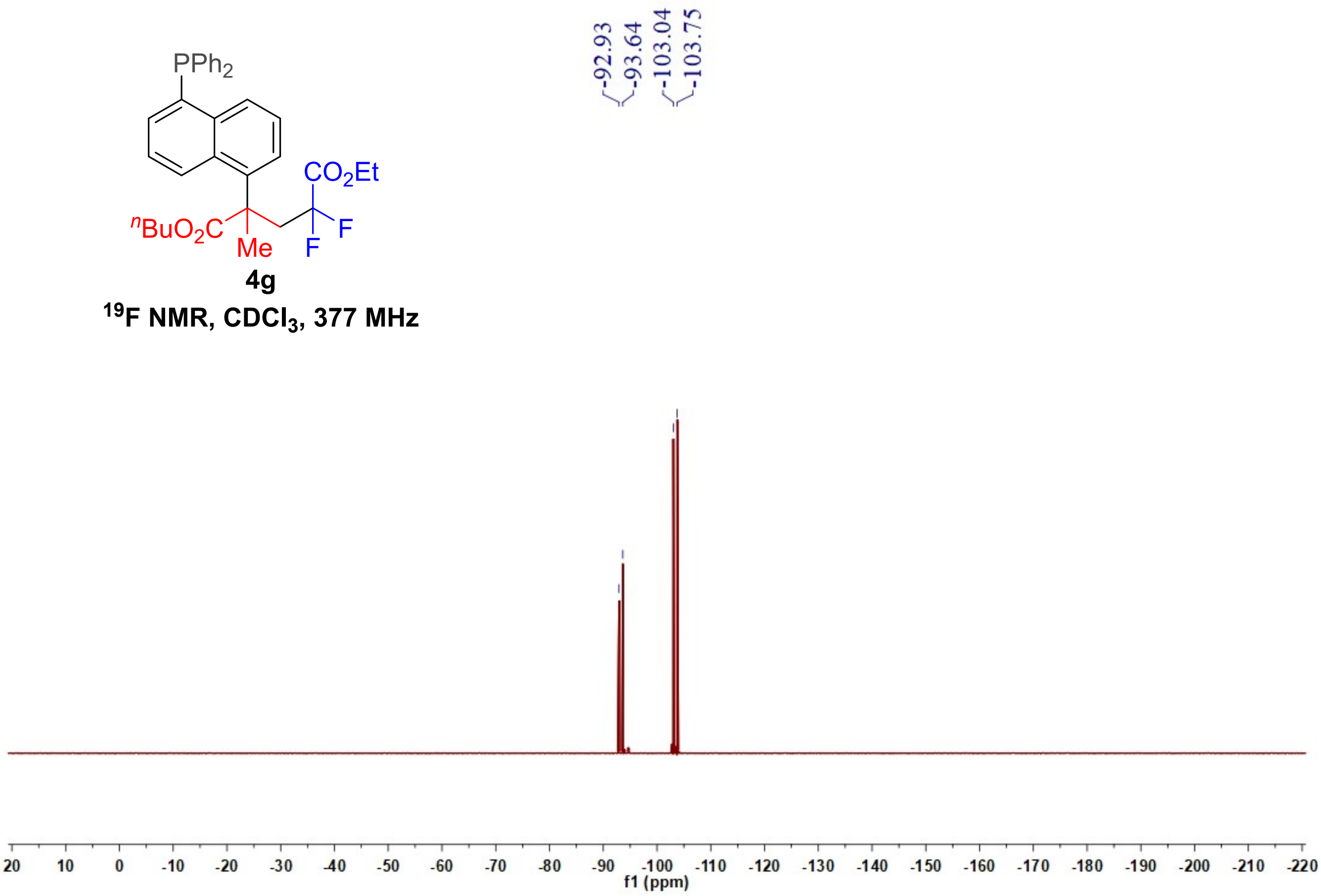
4g

^{13}C NMR, $CDCl_3$, 101 MHz



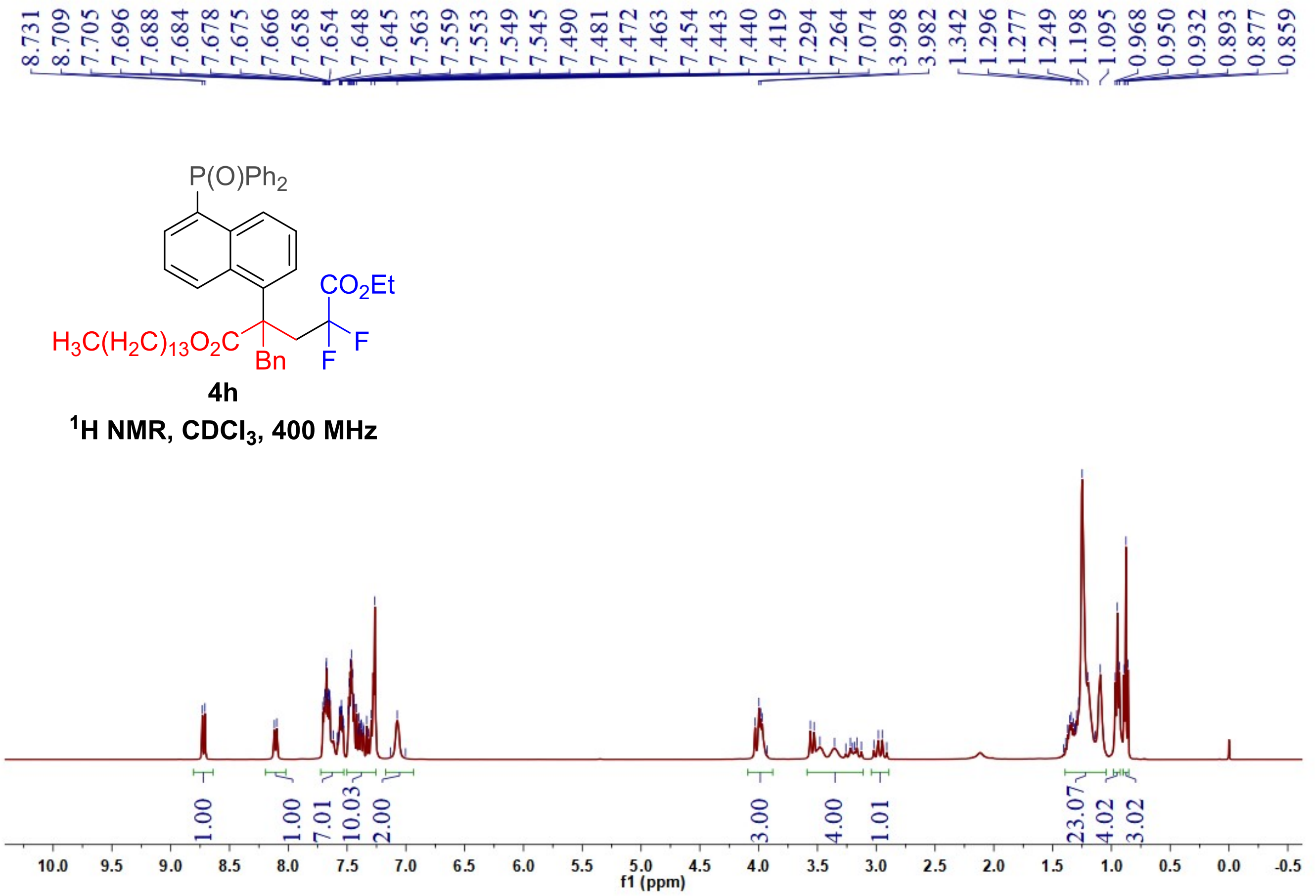
4g

^{31}P NMR, $CDCl_3$, 162 MHz



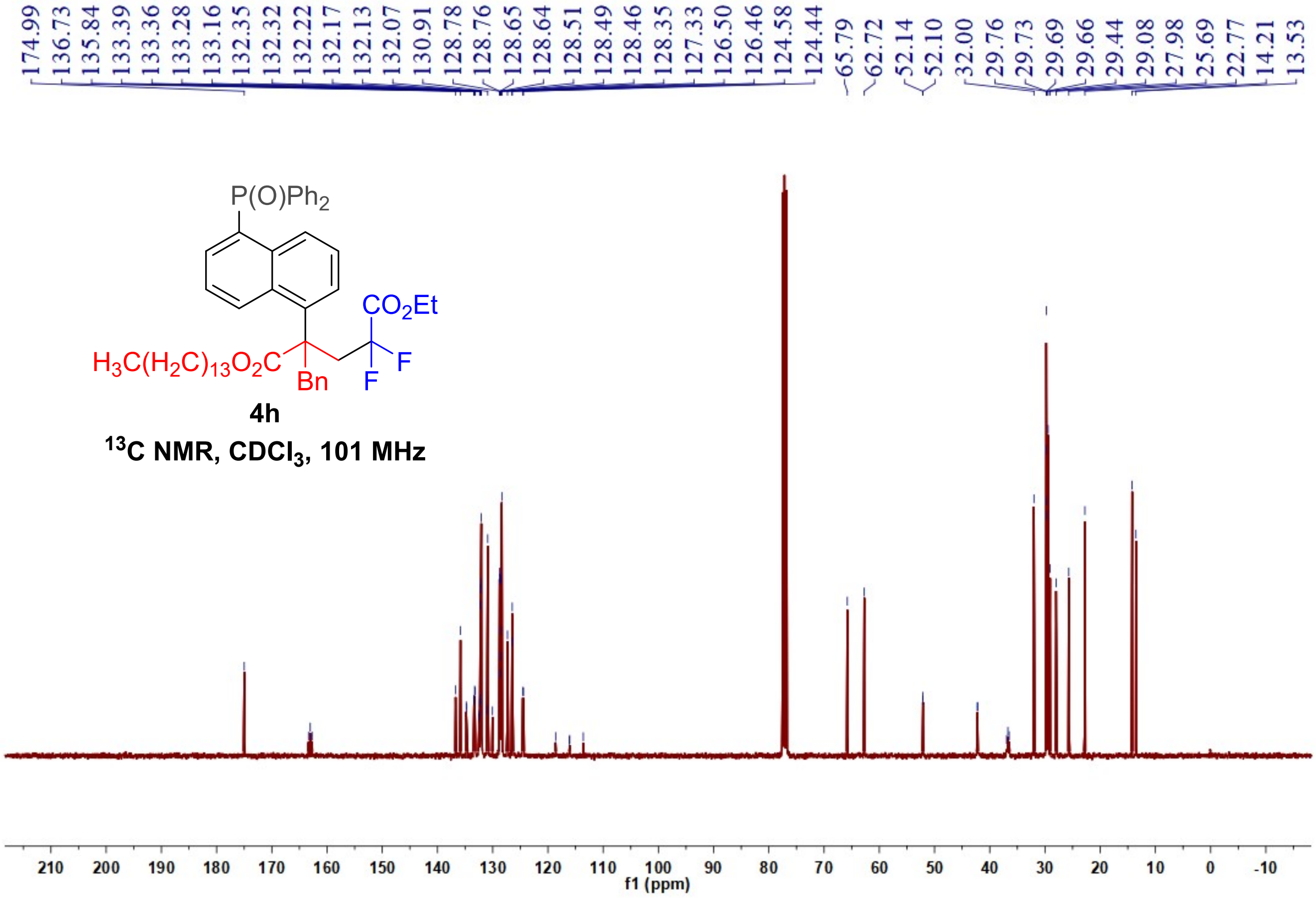
4g

^{19}F NMR, CDCl$_3$, 377 MHz



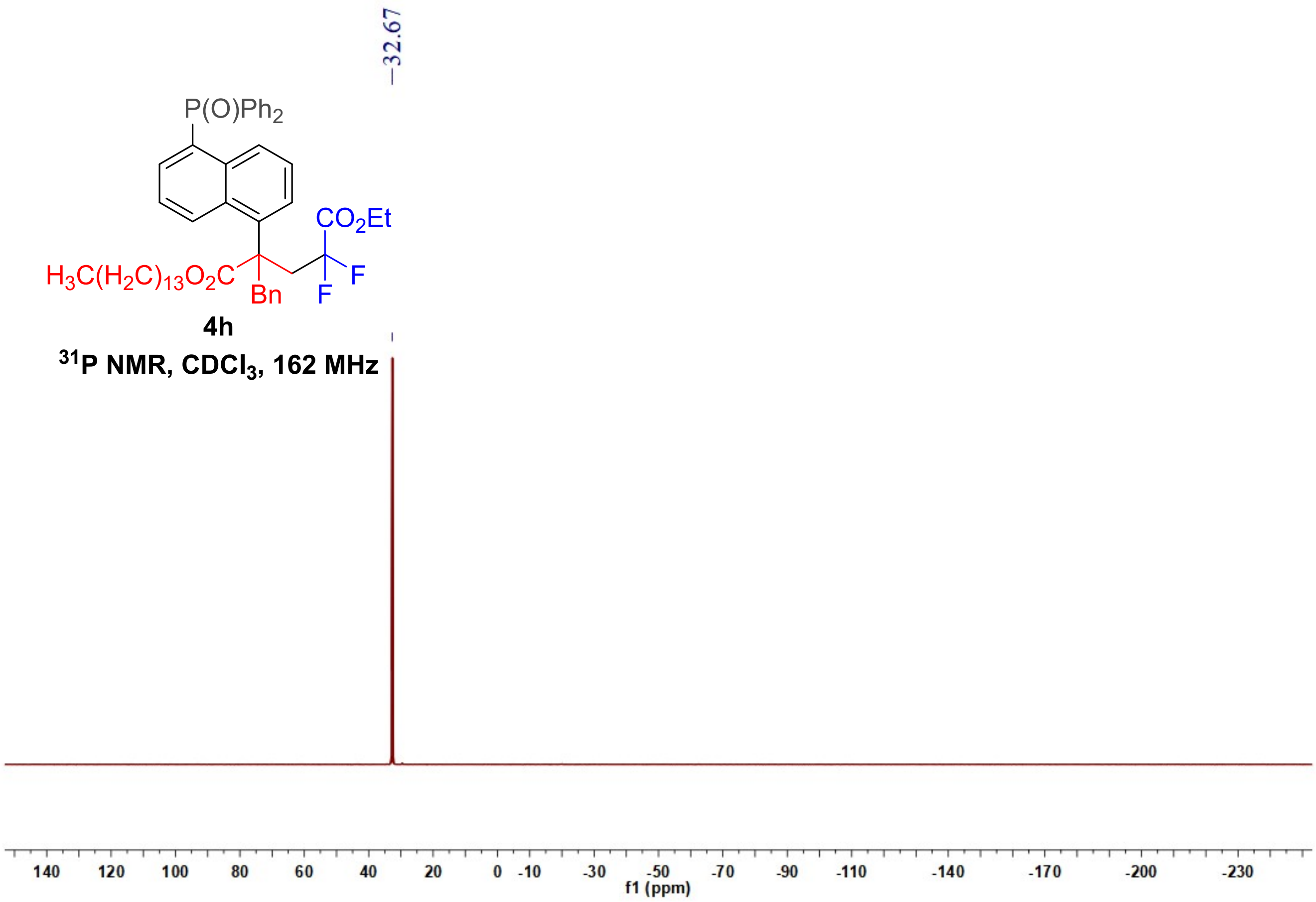
4h

^{1}H NMR, CDCl$_3$, 400 MHz



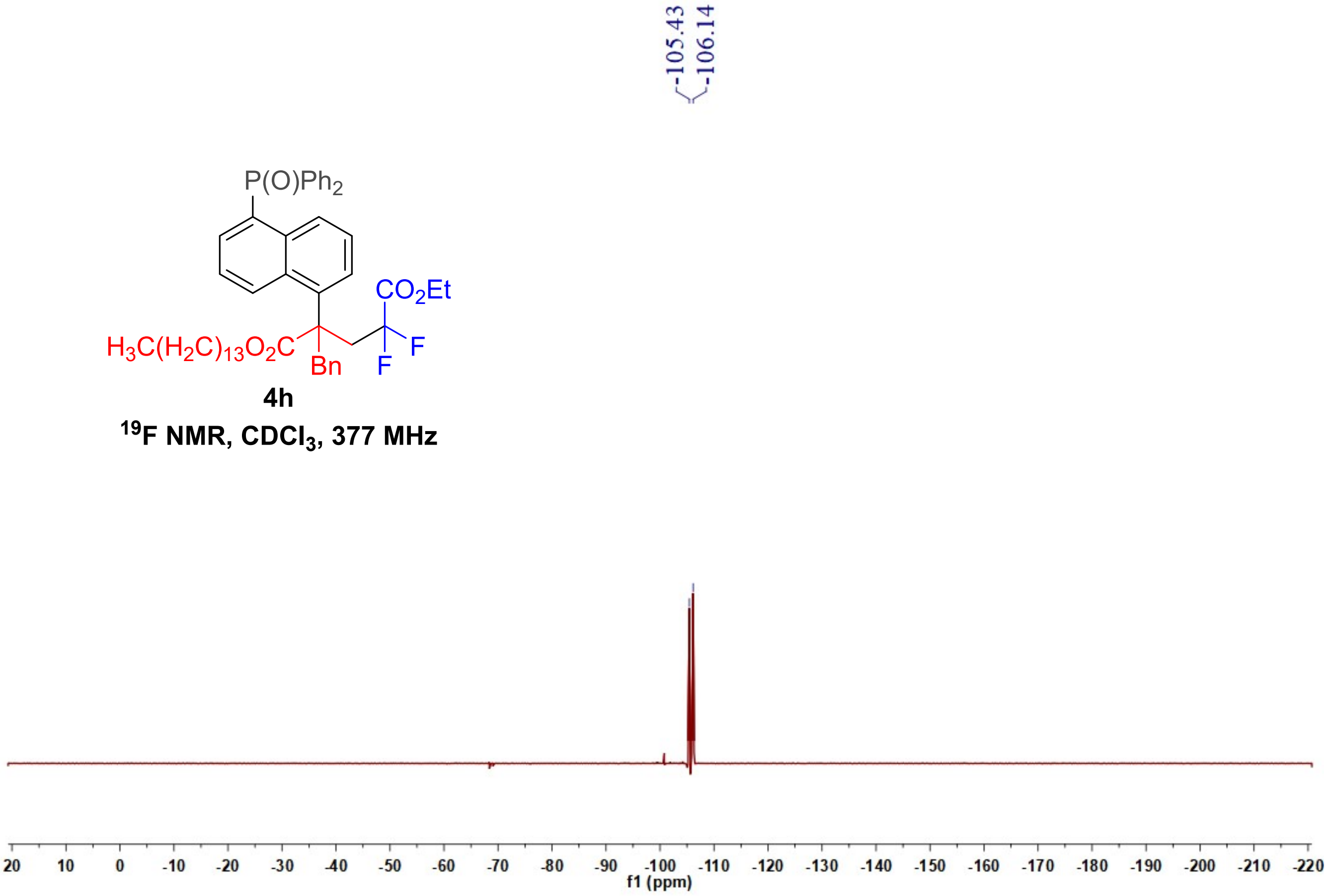
4h

^{13}C NMR, CDCl$_3$, 101 MHz



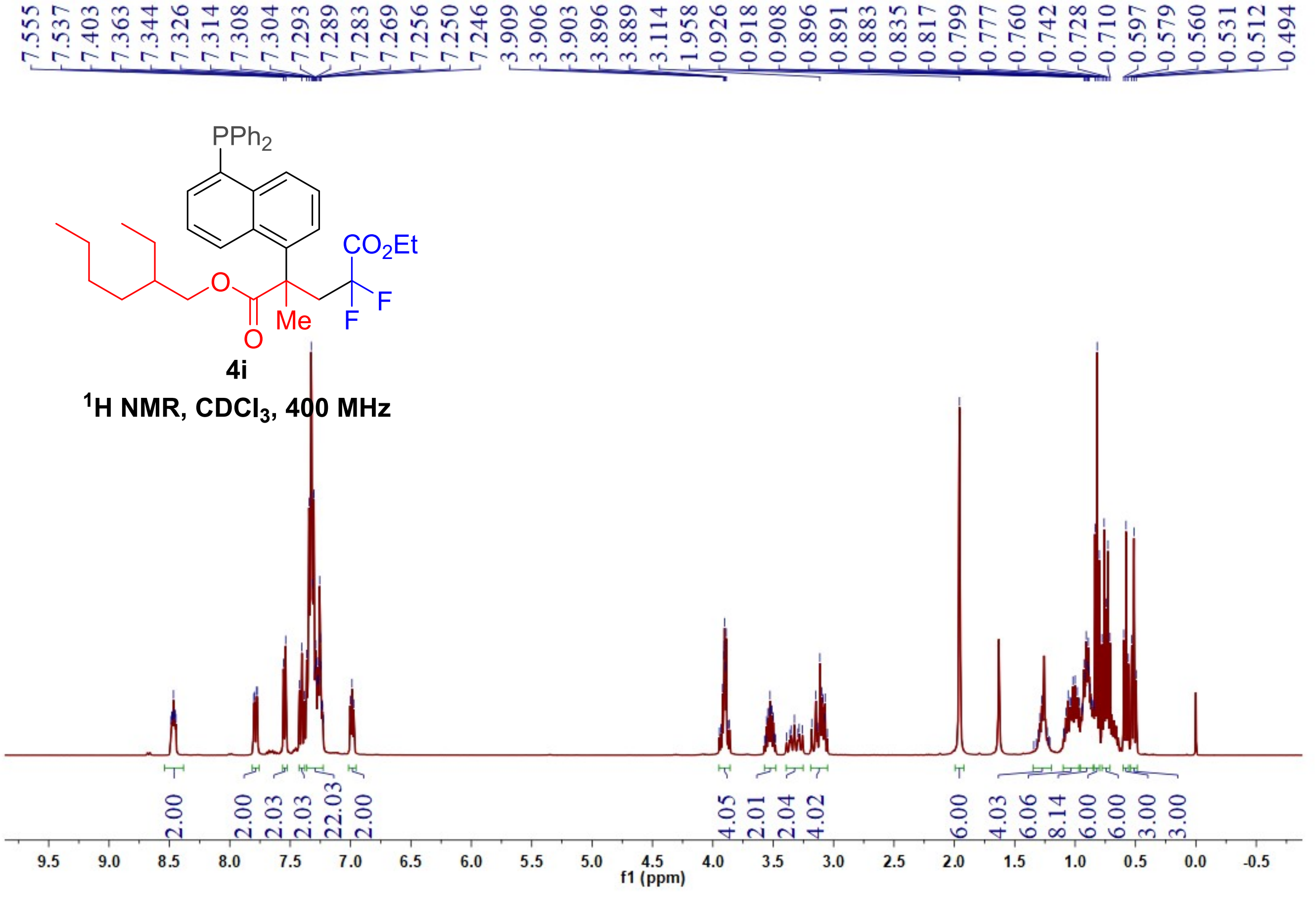
4h

^{31}P NMR, CDCl$_3$, 162 MHz



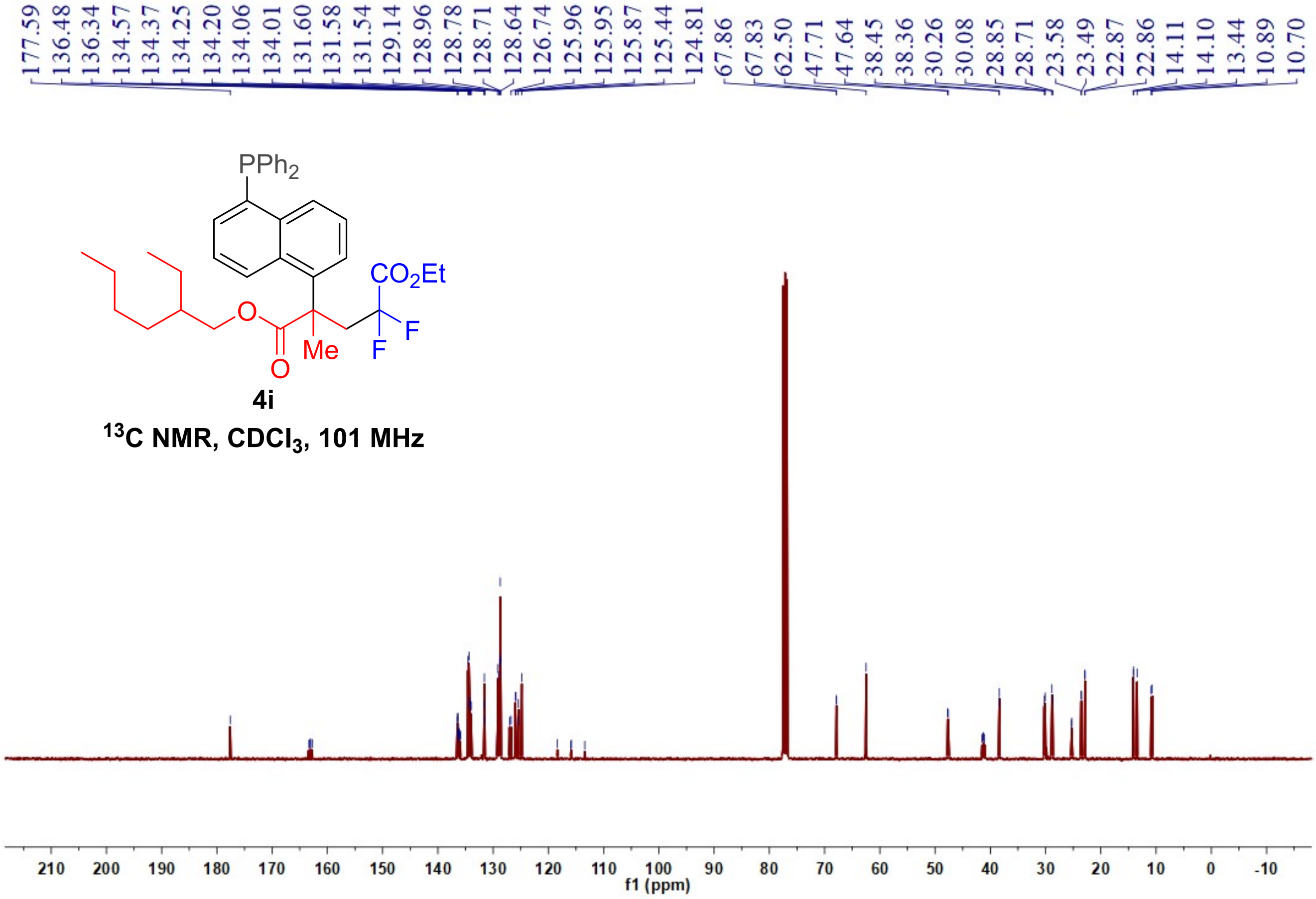
4h

^{19}F NMR, CDCl$_3$, 377 MHz



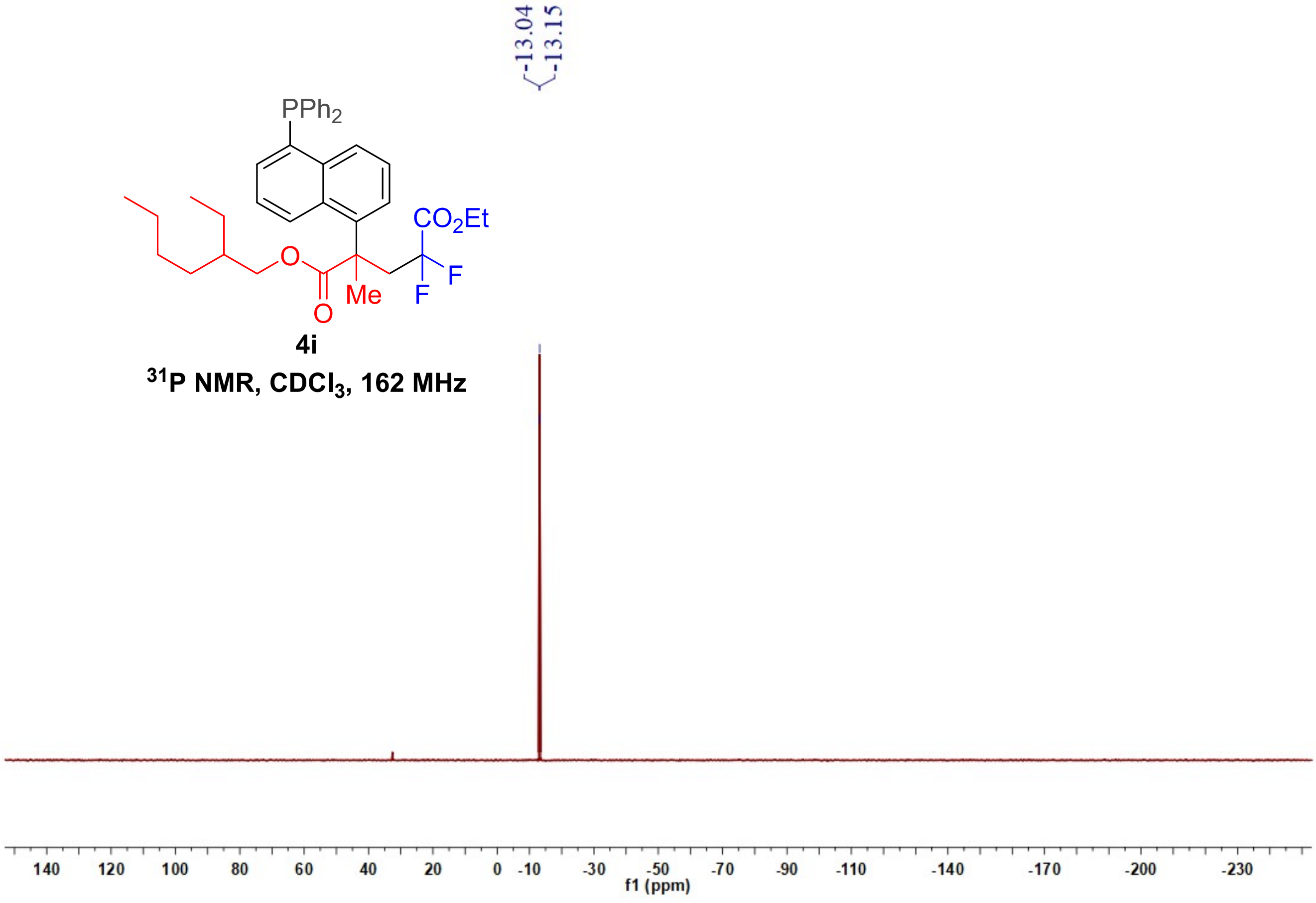
4i

^{1}H NMR, CDCl$_3$, 400 MHz



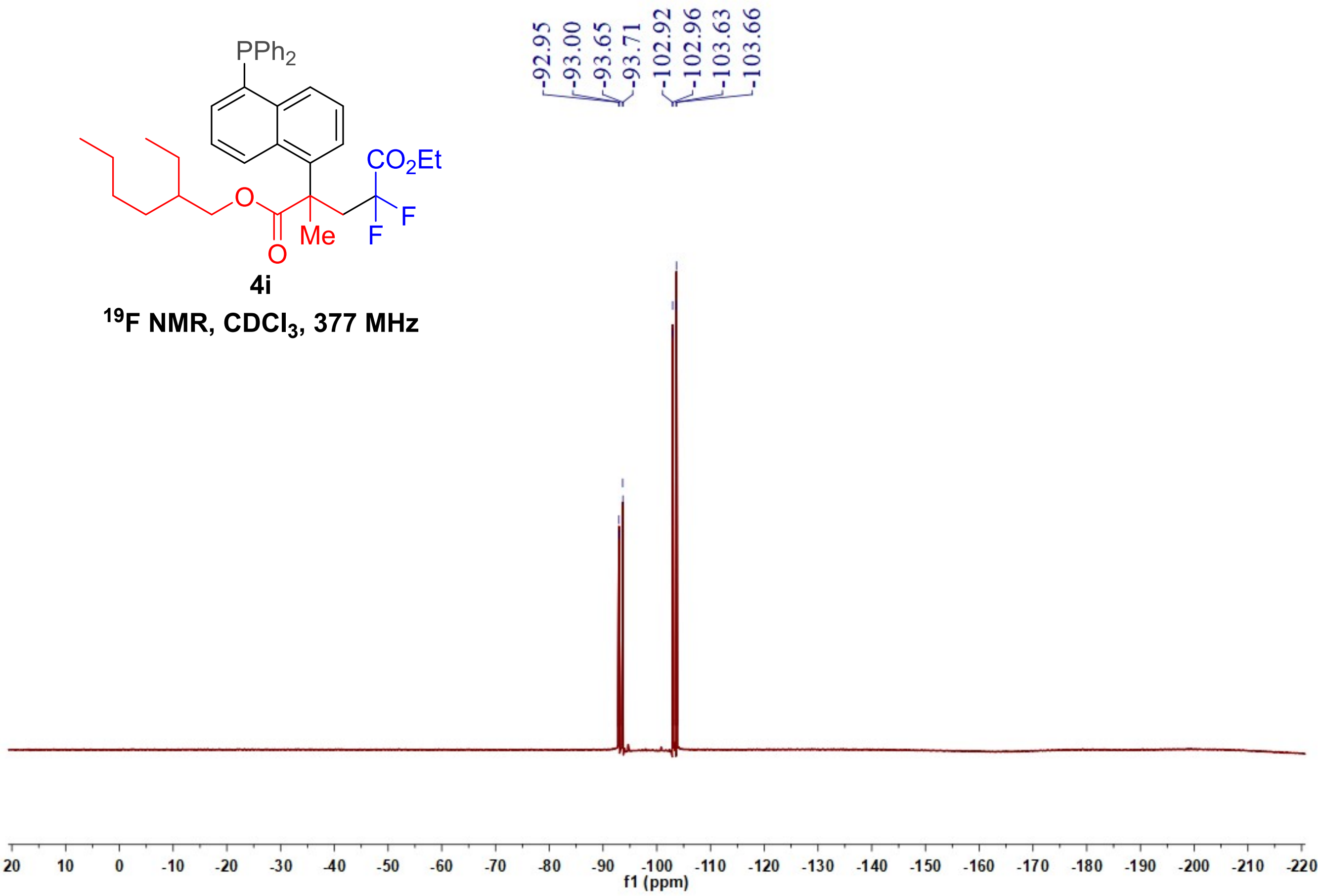
4i

^{13}C NMR, CDCl$_3$, 101 MHz



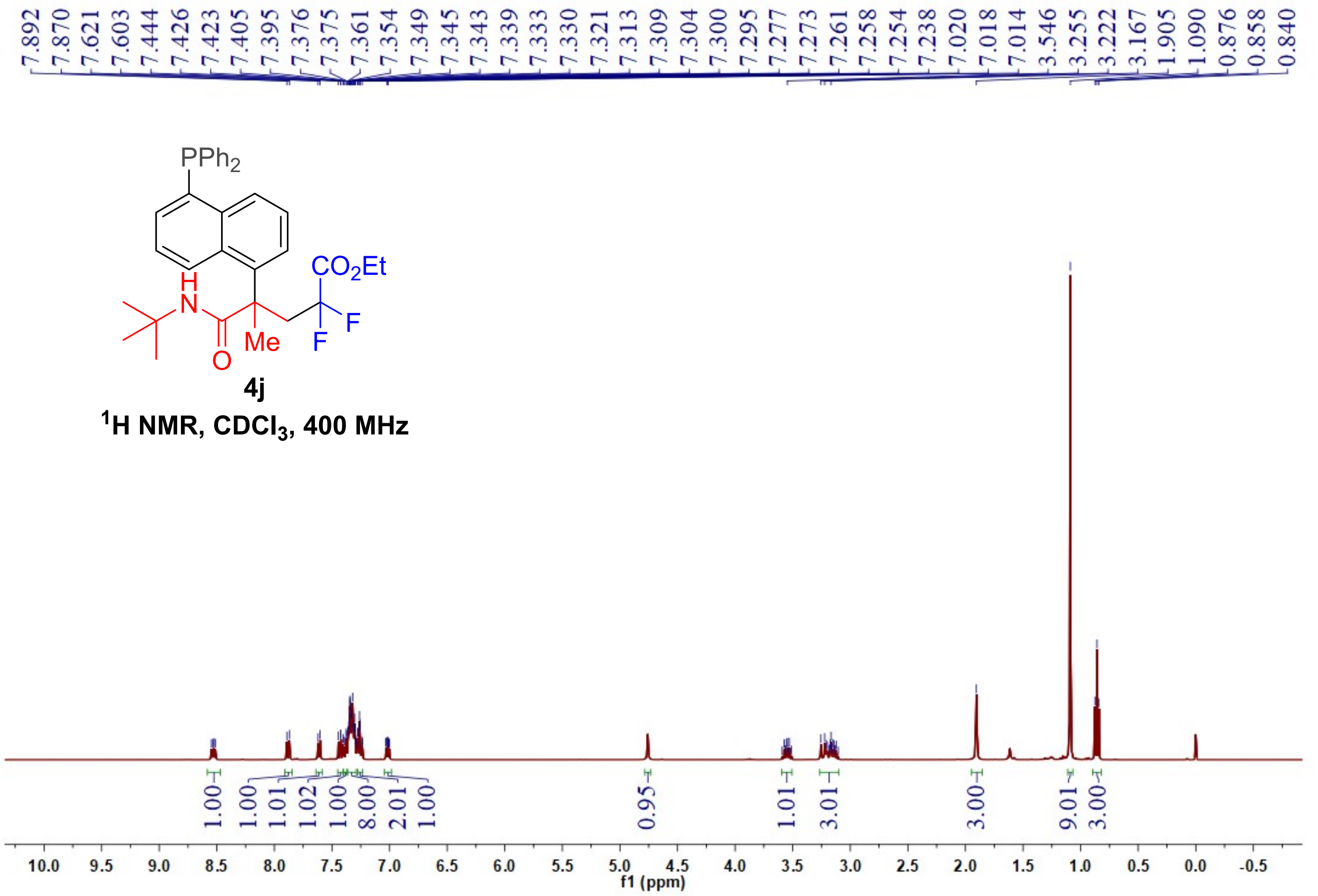
4i

^{31}P NMR, CDCl$_3$, 162 MHz



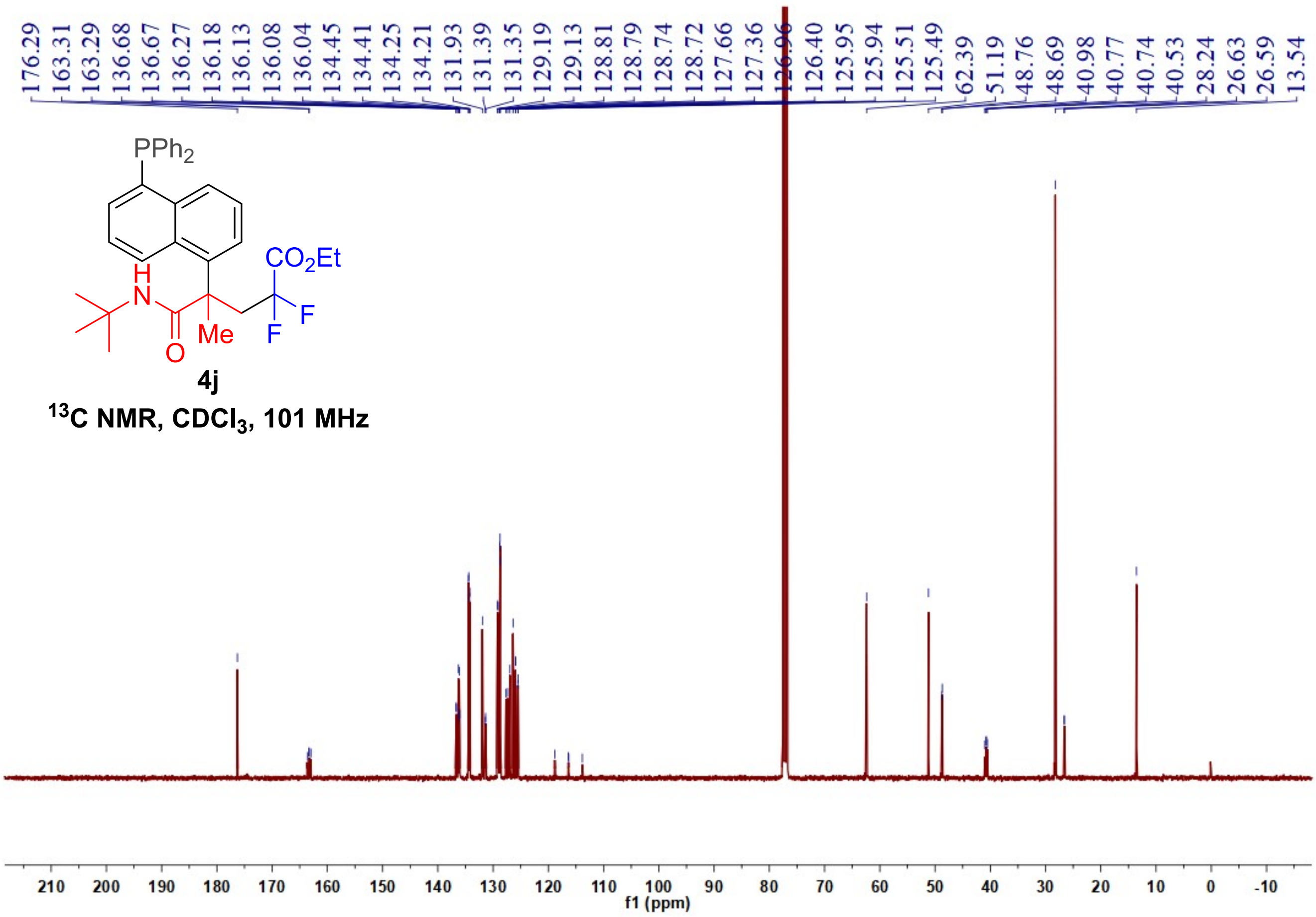
4i

^{19}F NMR, CDCl$_3$, 377 MHz



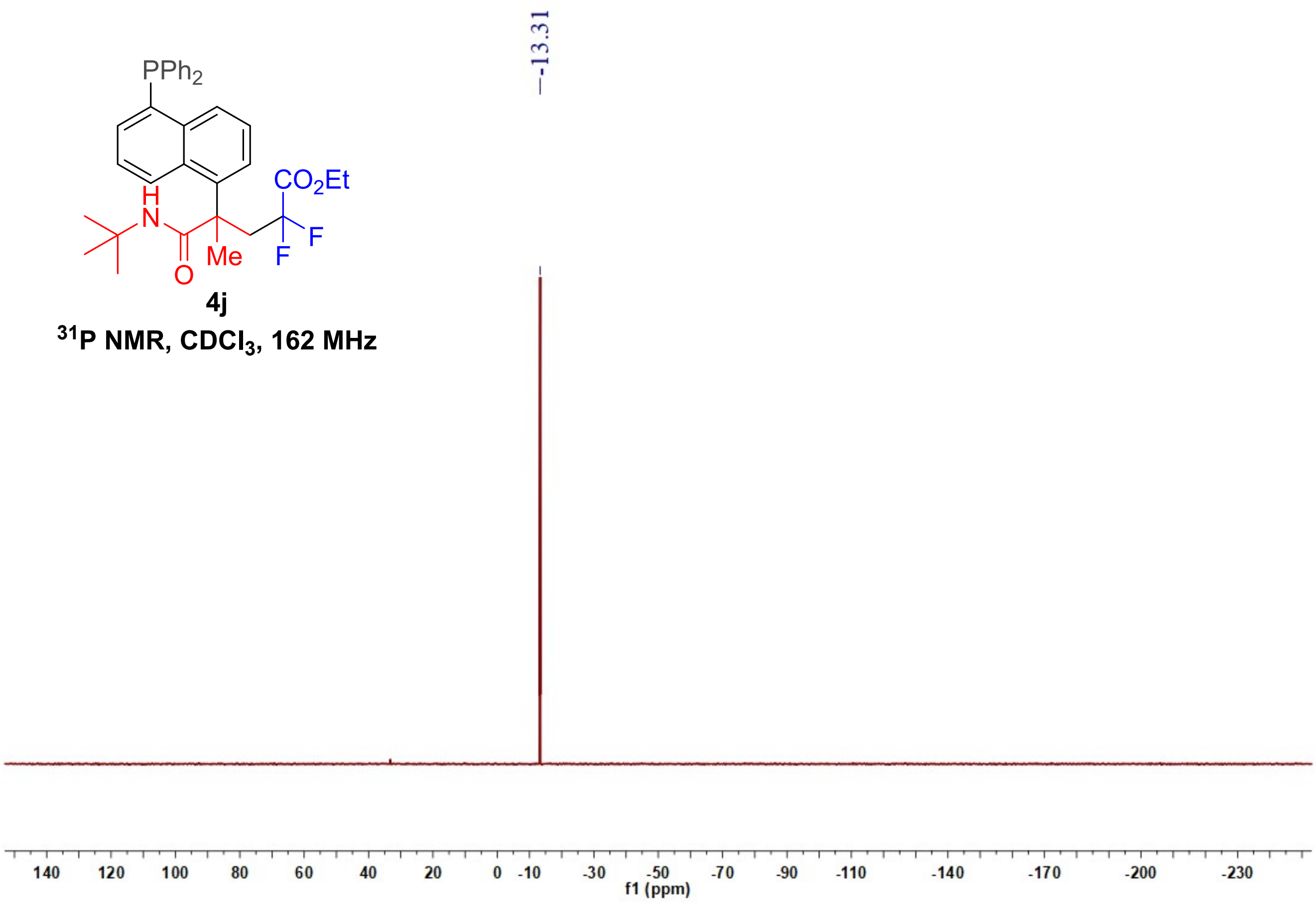
4j

^{1}H NMR, CDCl$_3$, 400 MHz



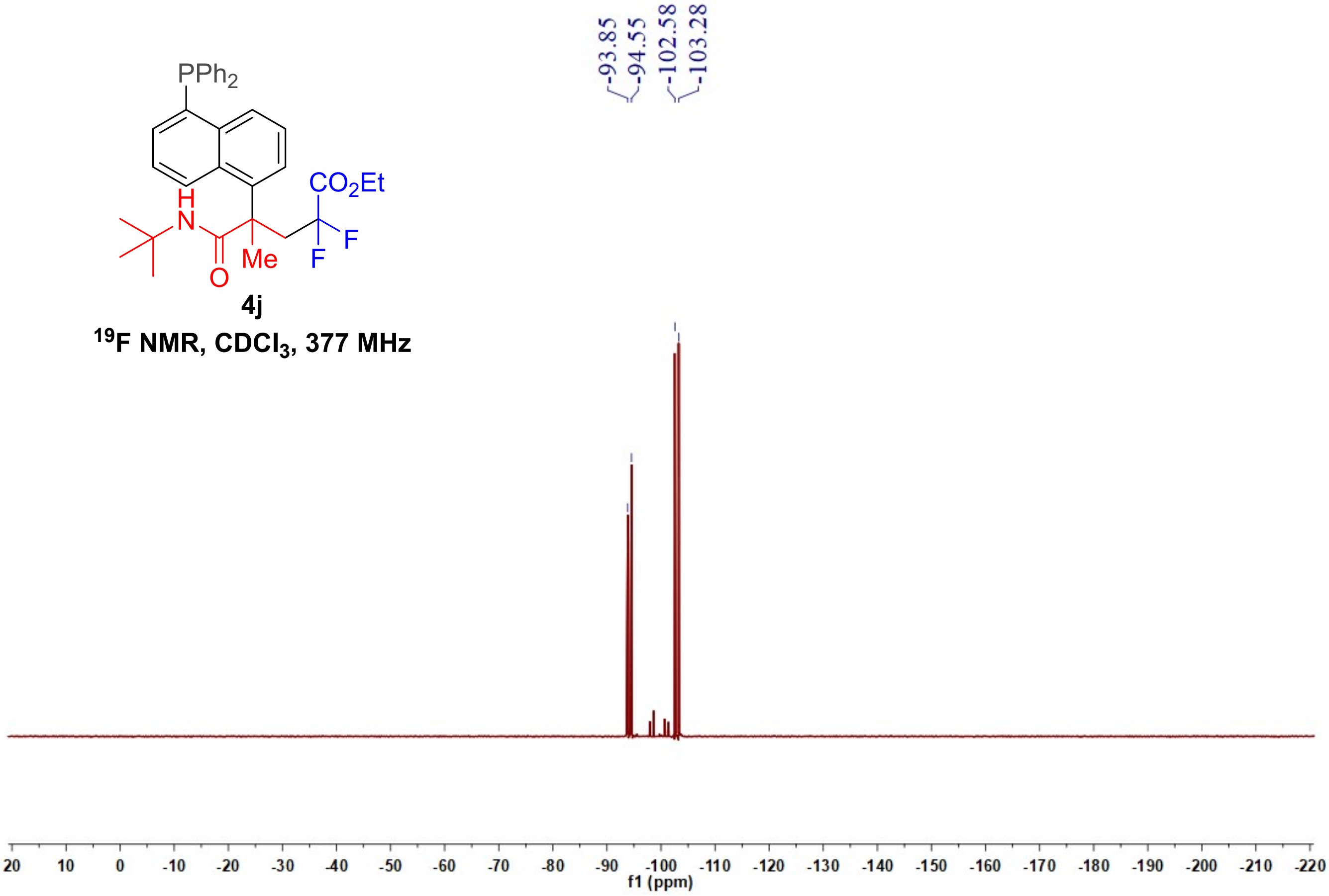
4j

^{13}C NMR, $CDCl_3$, 101 MHz



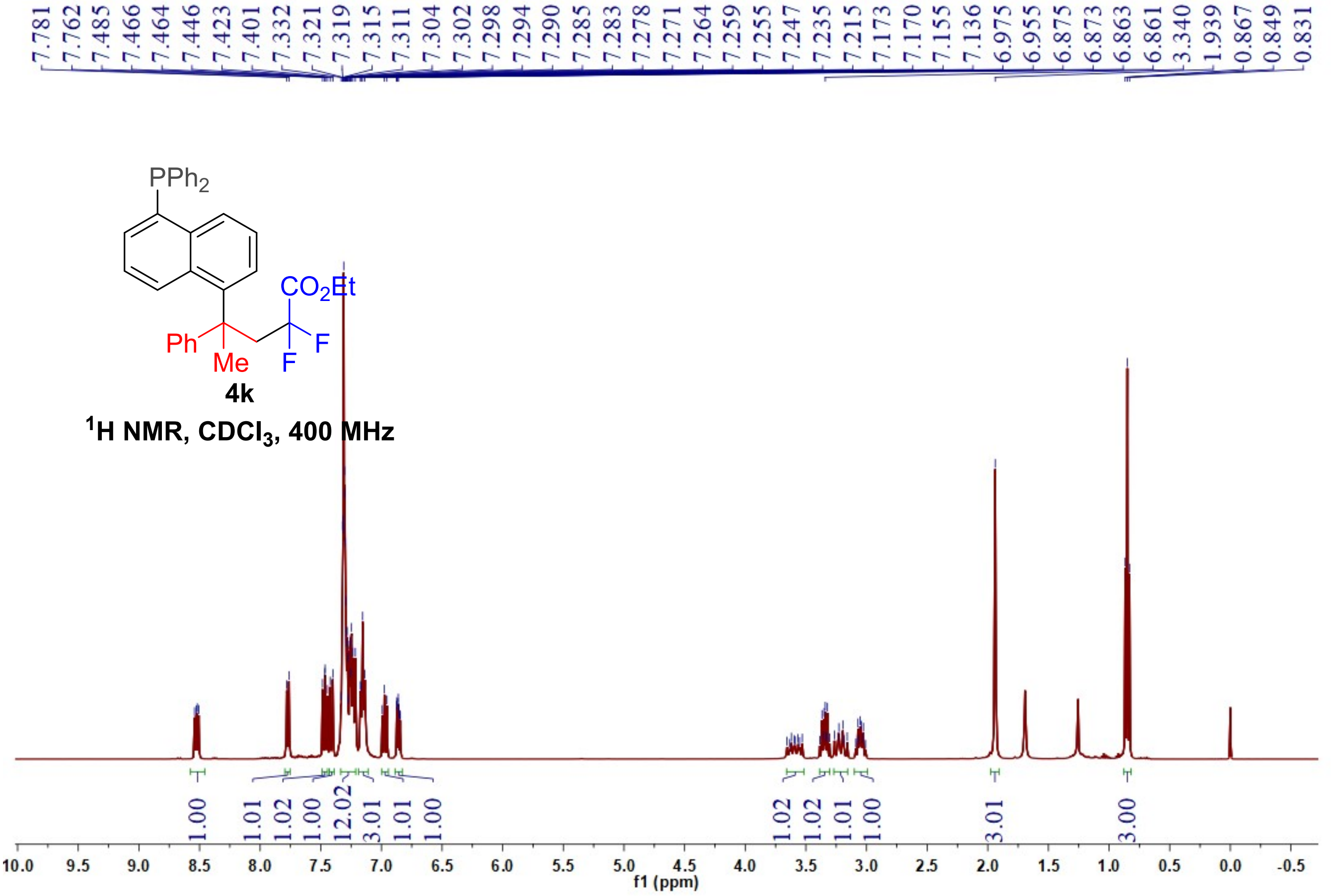
4j

^{31}P NMR, $CDCl_3$, 162 MHz



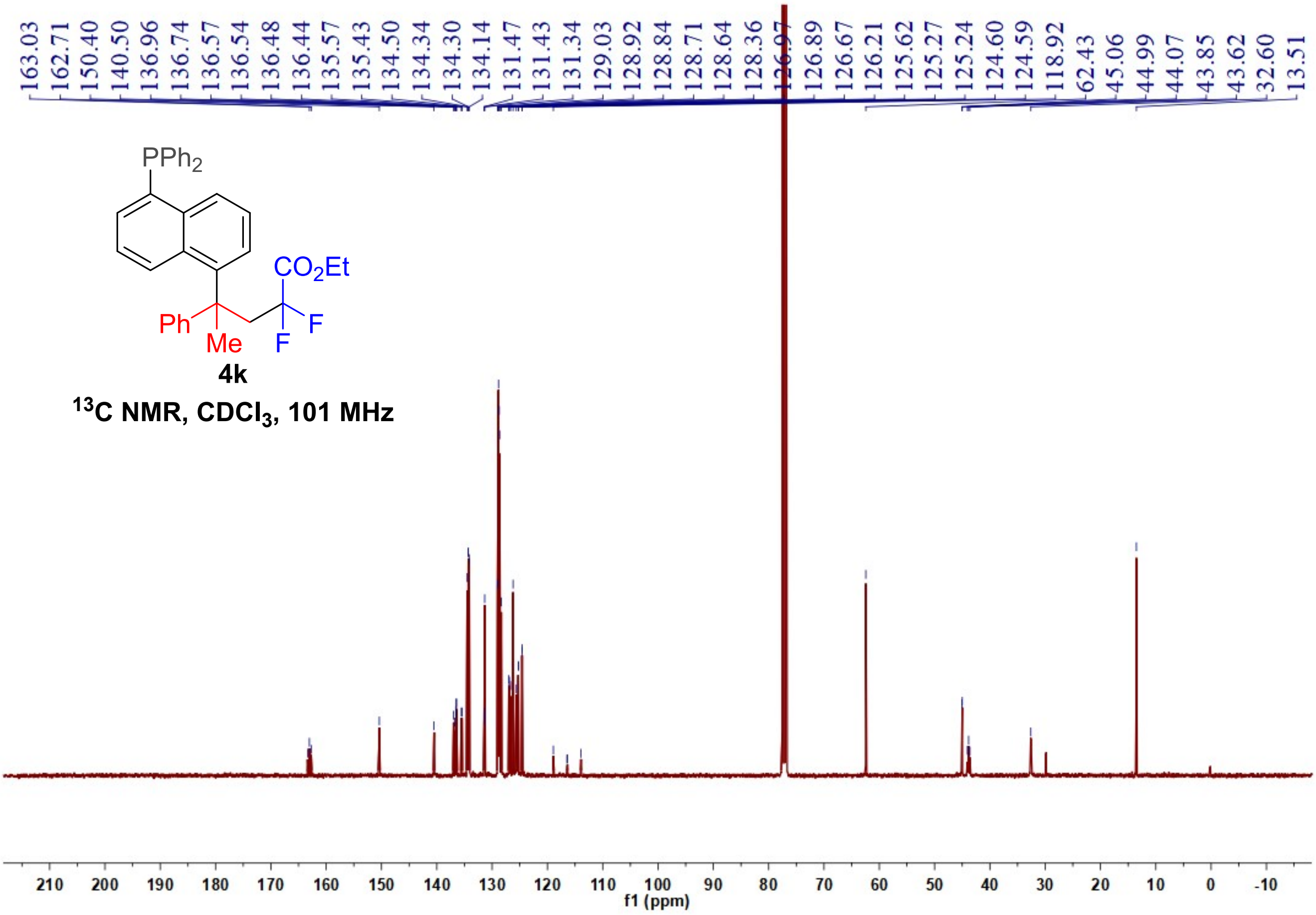
4j

^{19}F NMR, CDCl$_3$, 377 MHz



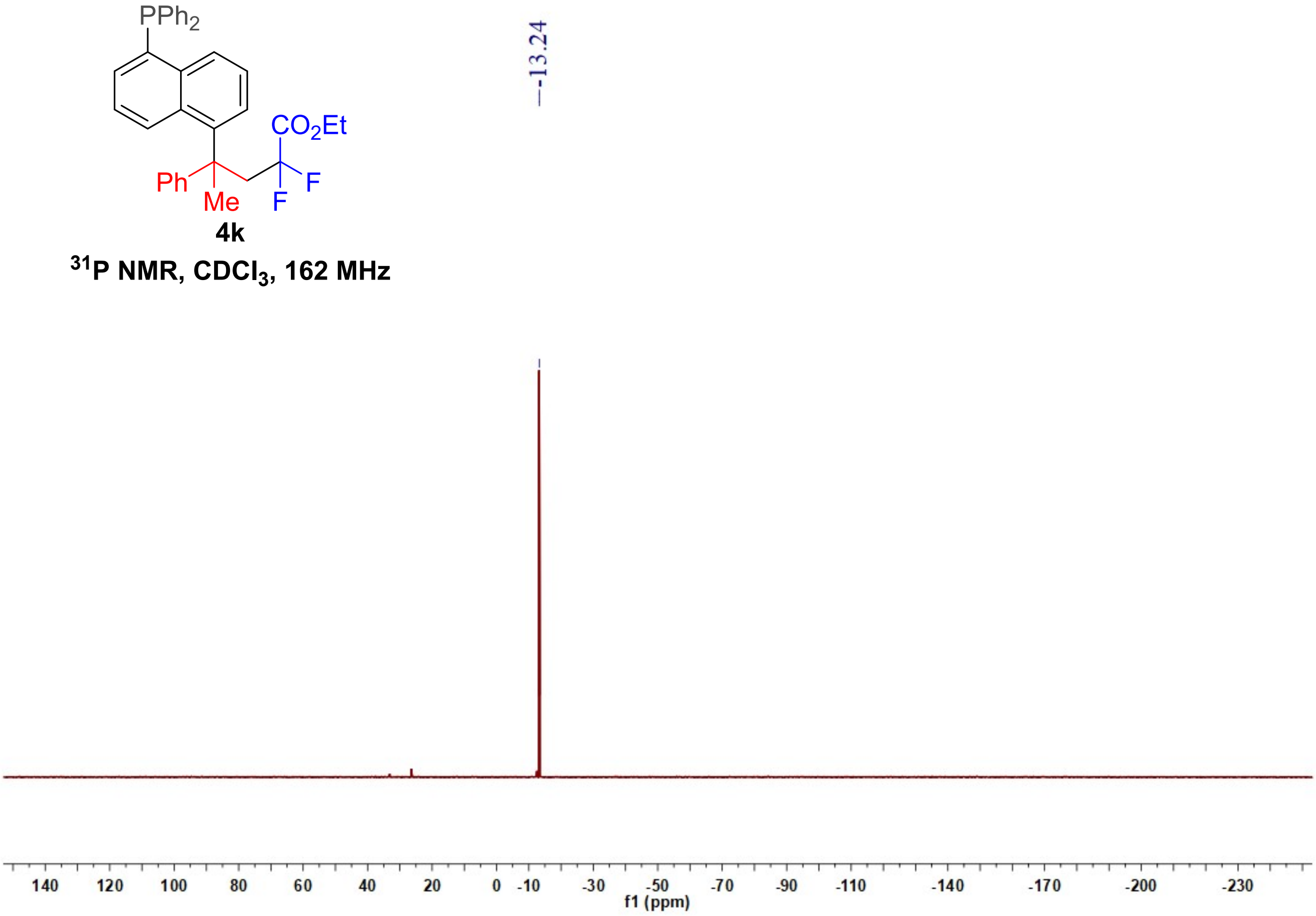
4k

^{1}H NMR, CDCl$_3$, 400 MHz



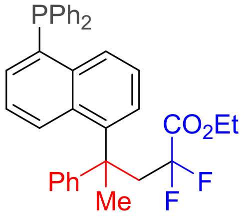
4k

^{13}C NMR, CDCl$_3$, 101 MHz



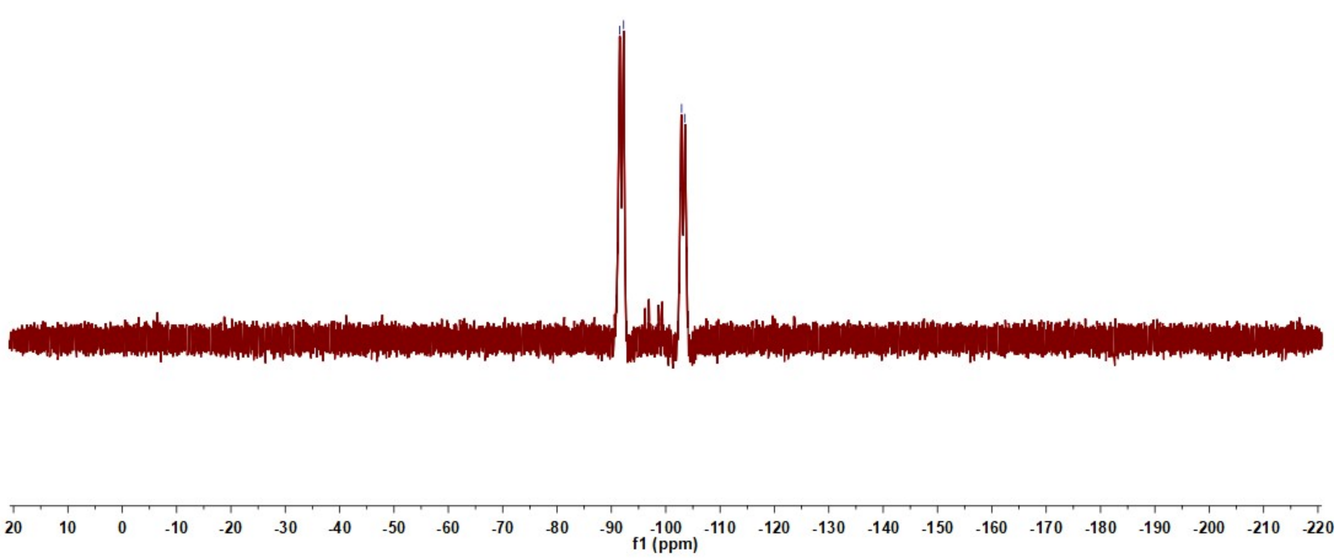
4k

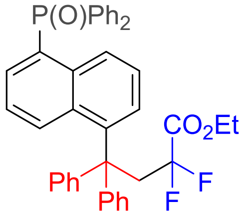
^{31}P NMR, CDCl$_3$, 162 MHz



4k

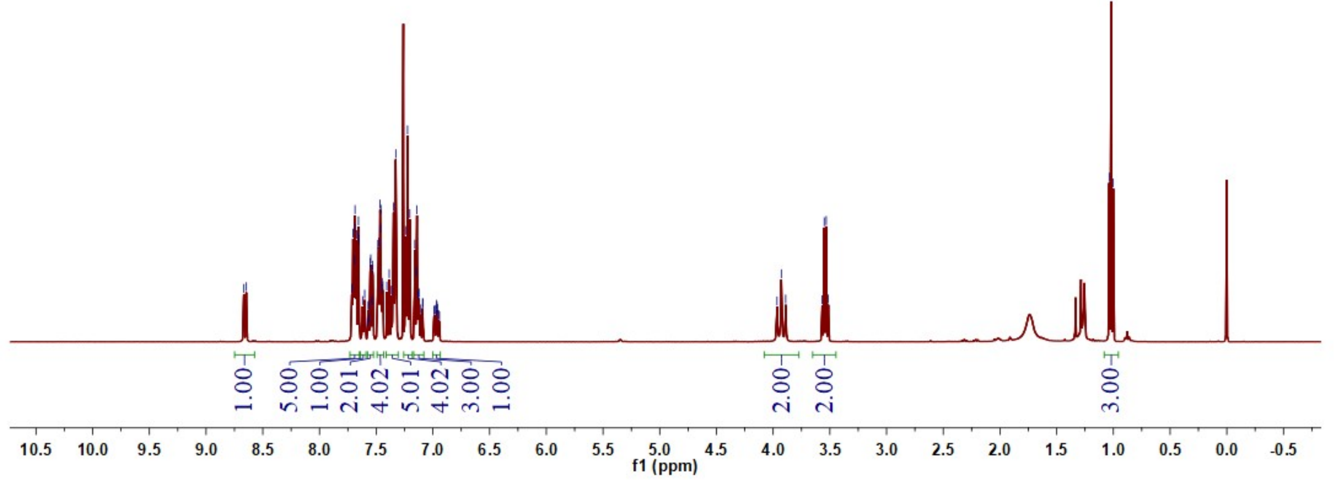
^{19}F NMR, $CDCl_3$, 377 MHz

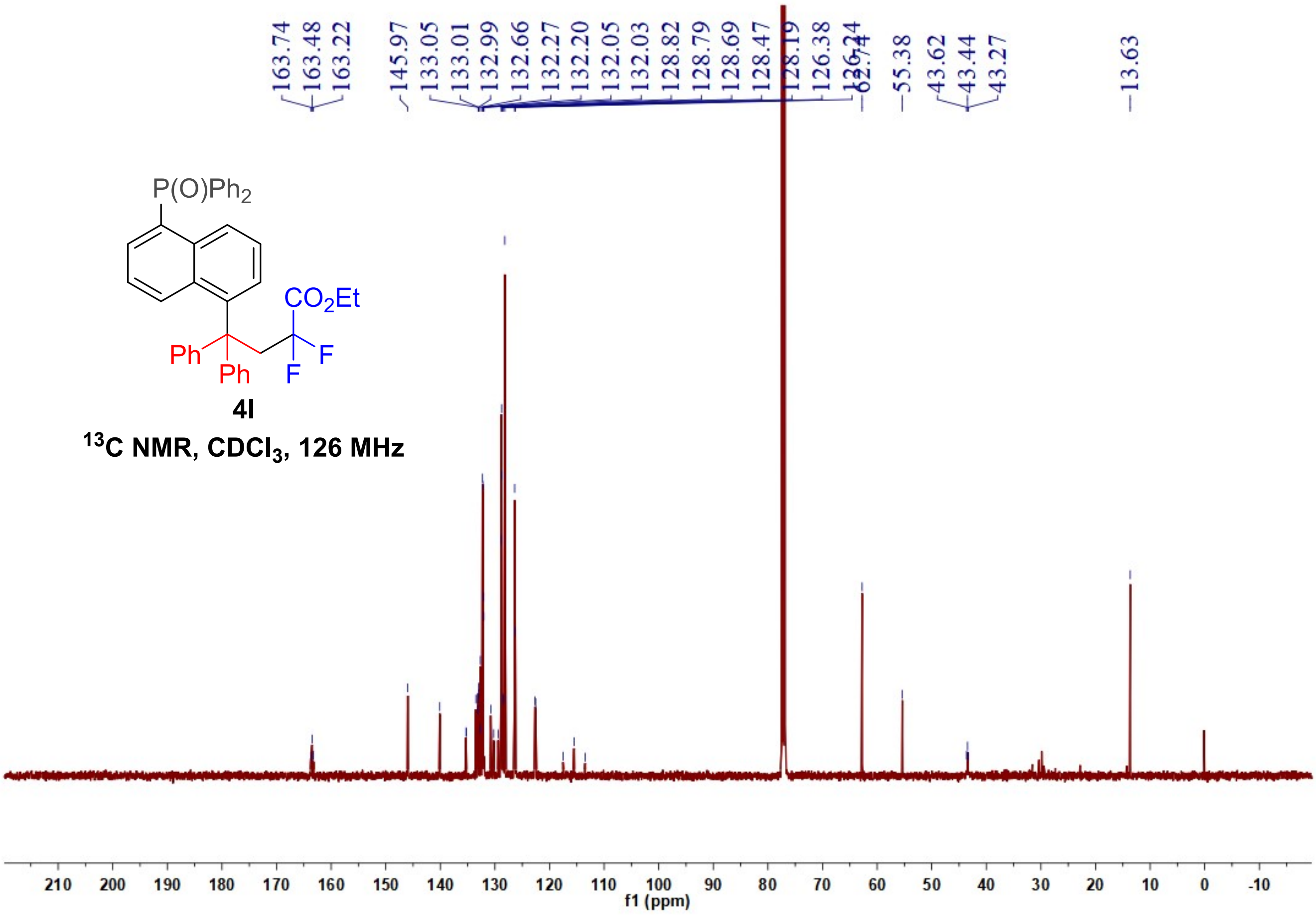




4l

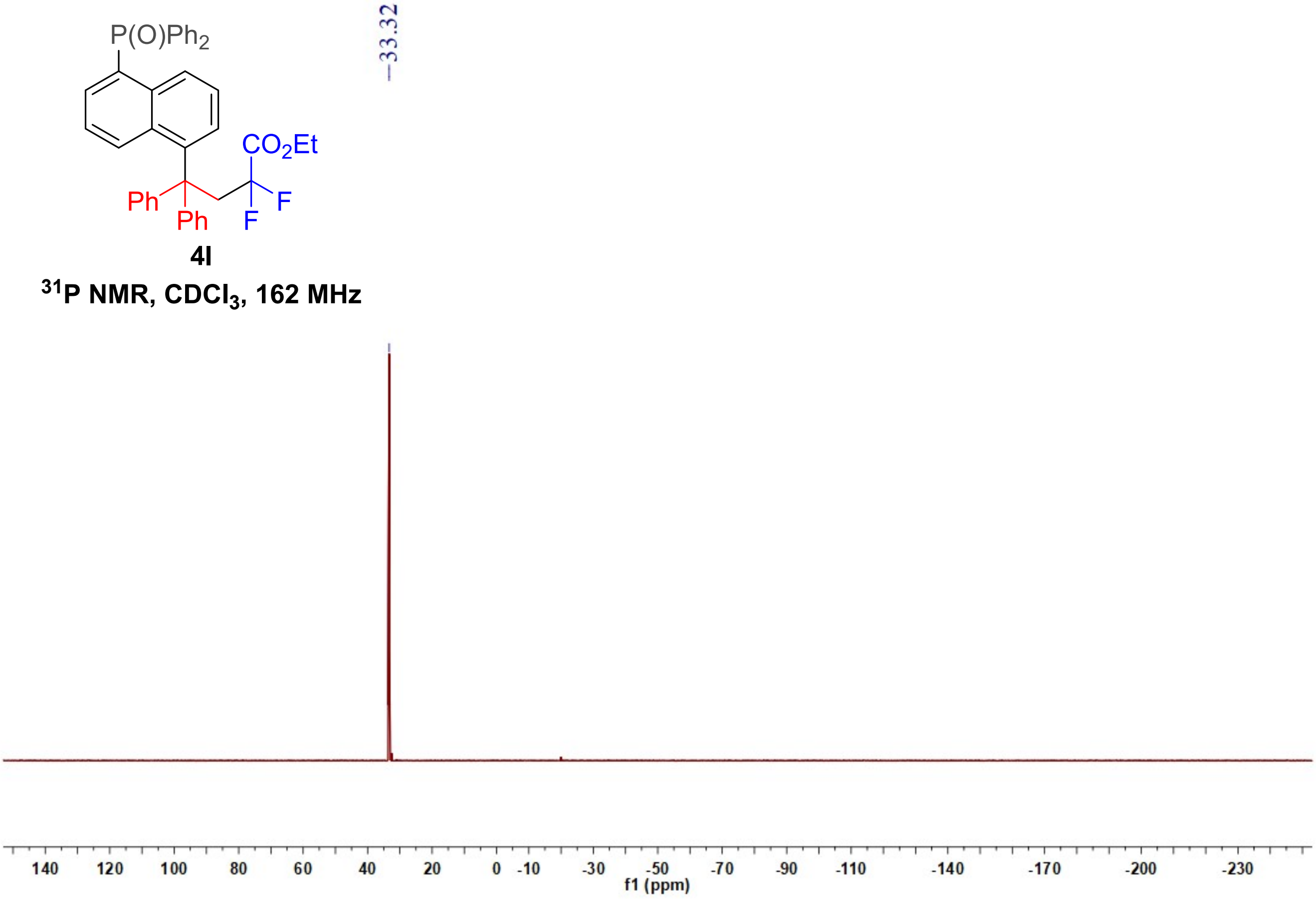
^{1}H NMR, $CDCl_3$, 400 MHz





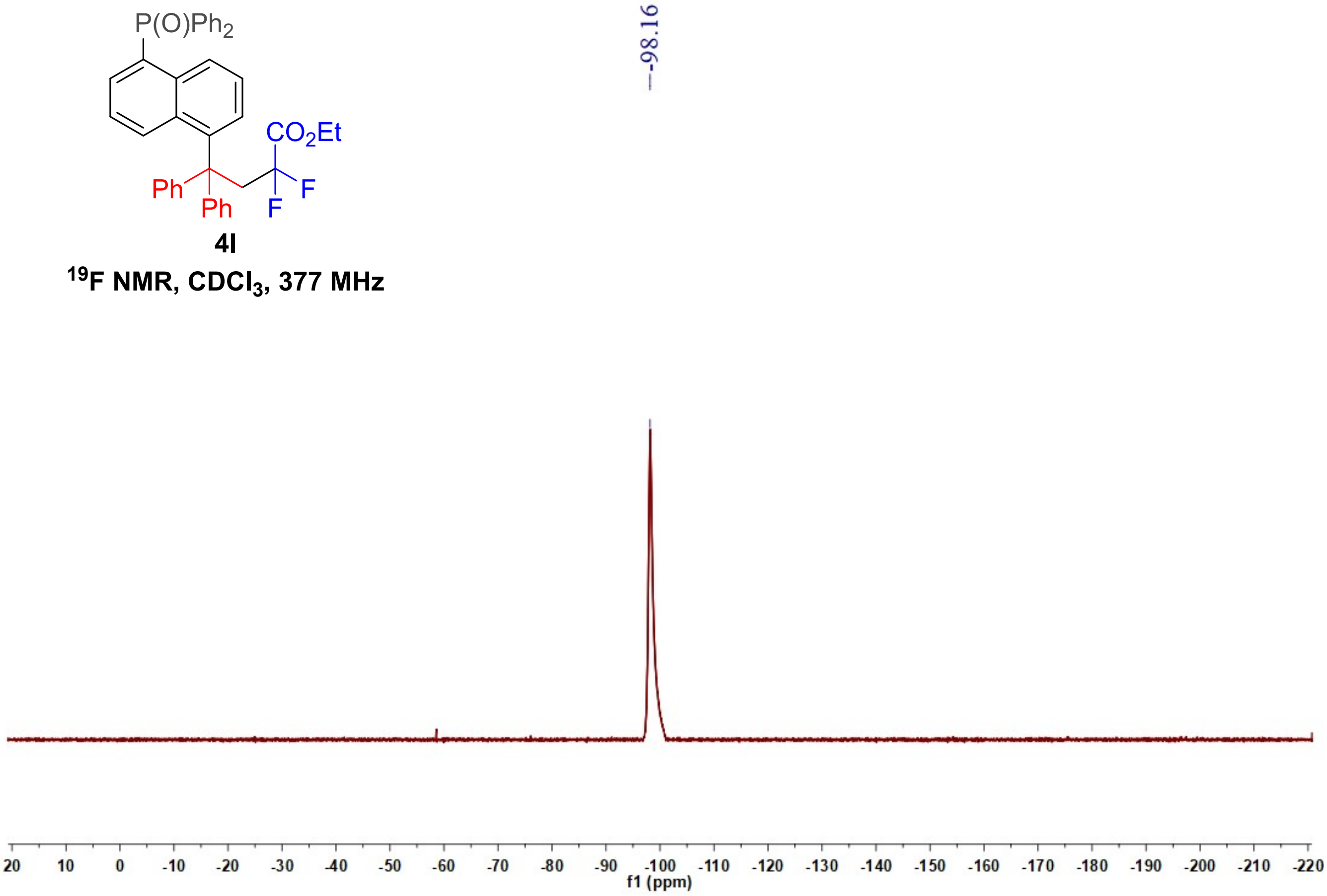
4l

^{13}C NMR, CDCl$_3$, 126 MHz



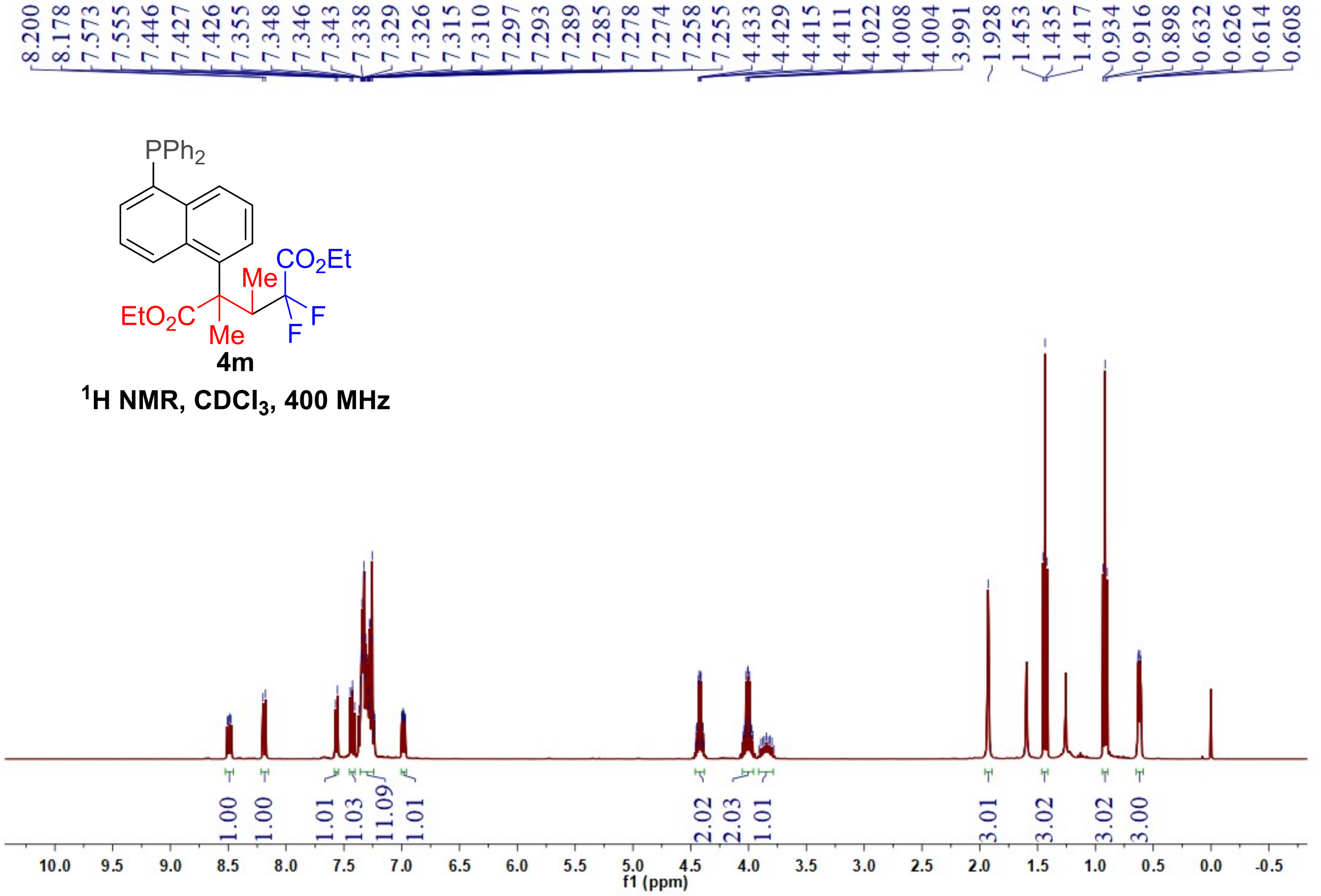
4l

^{31}P NMR, CDCl$_3$, 162 MHz



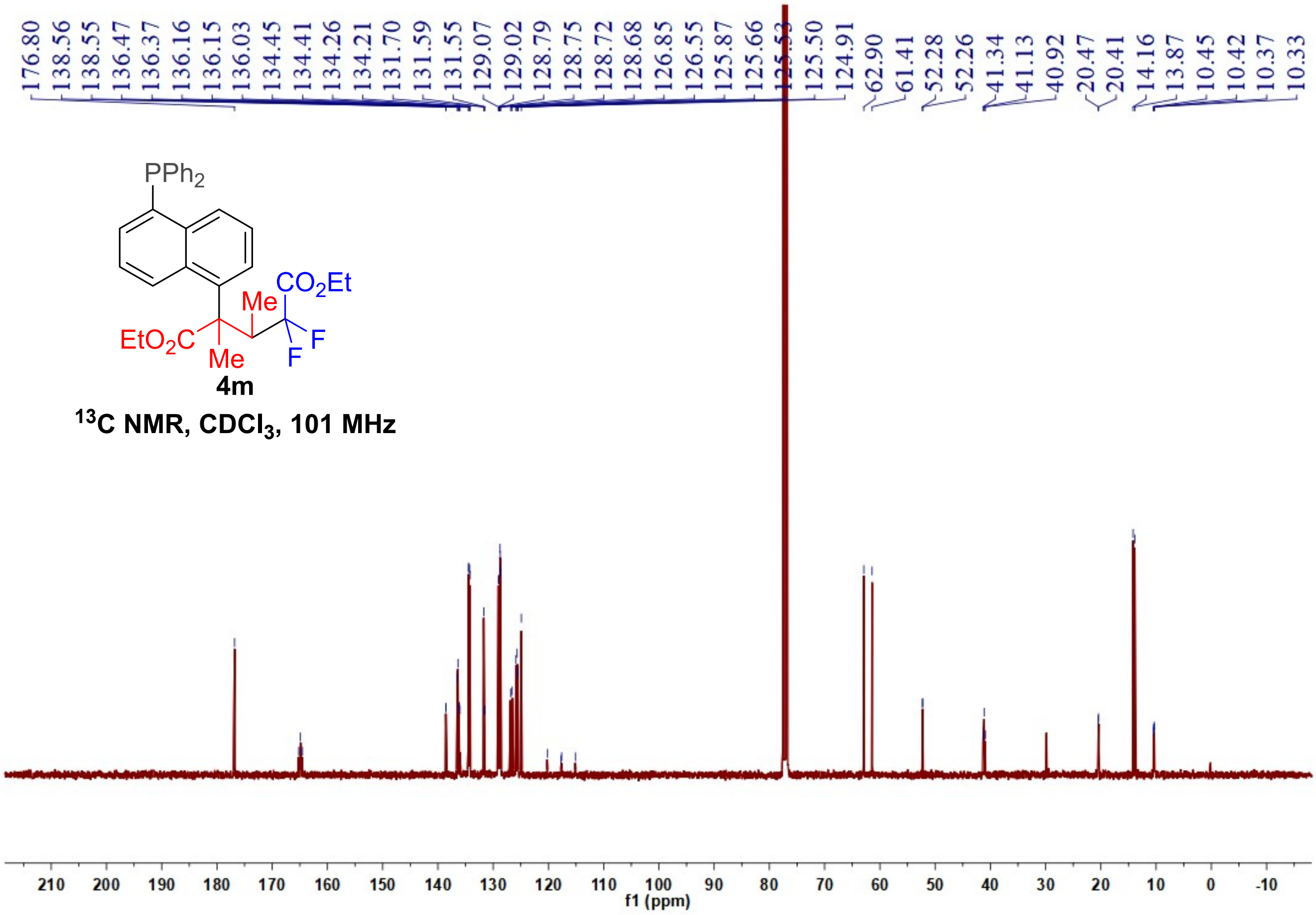
4l

^{19}F NMR, CDCl$_3$, 377 MHz



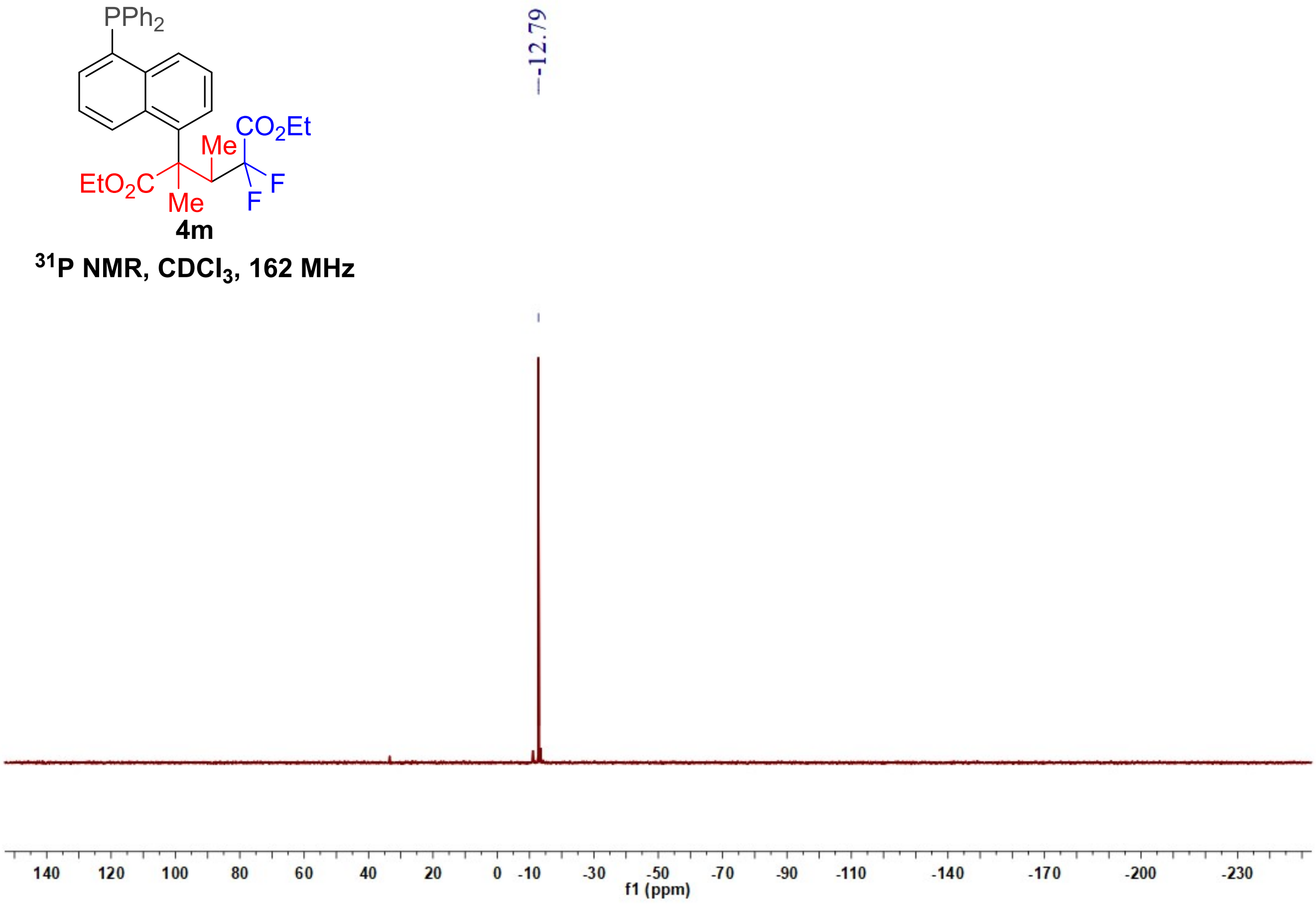
4m

^{1}H NMR, CDCl$_3$, 400 MHz



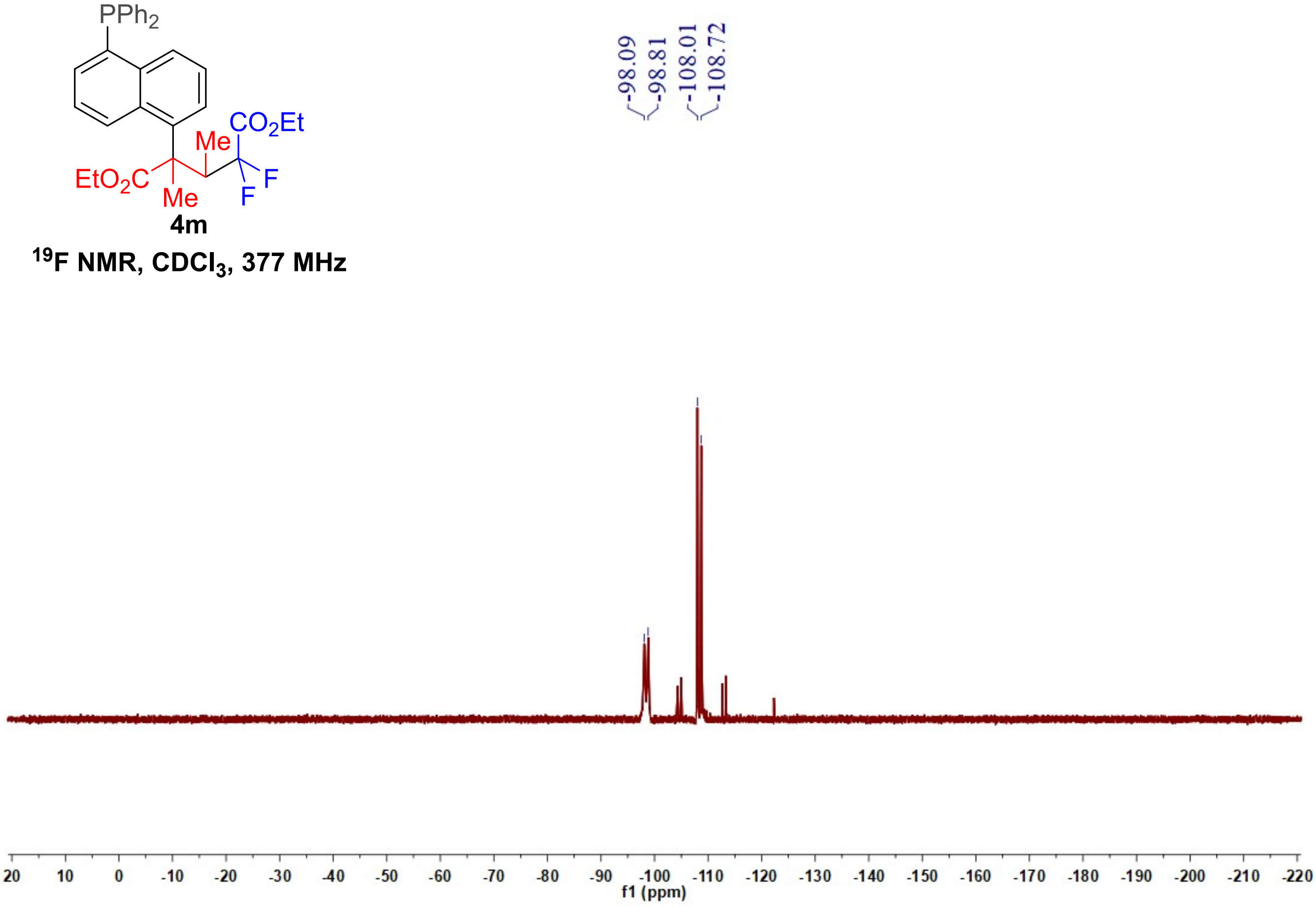
4m

^{13}C NMR, $CDCl_3$, 101 MHz

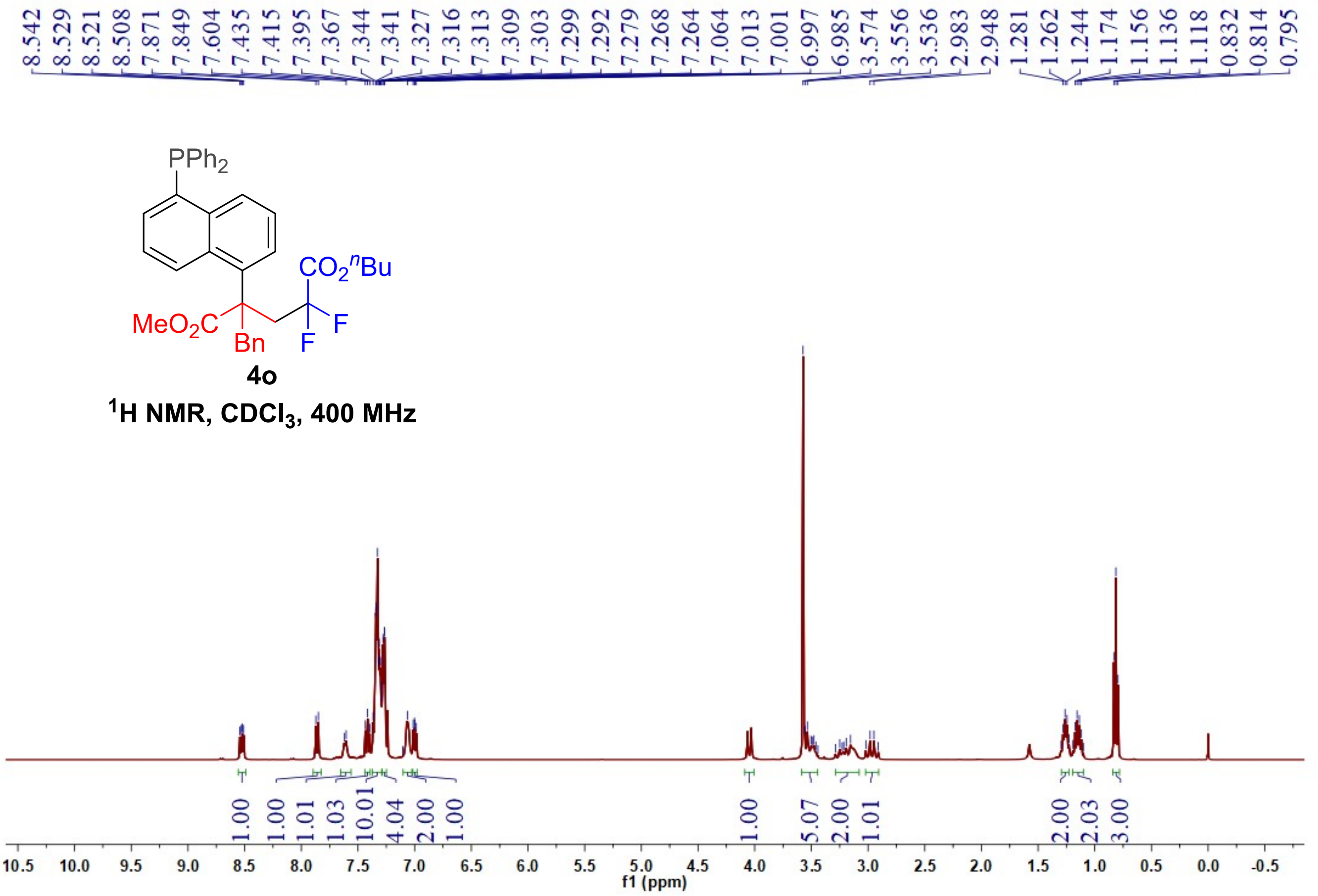


4m

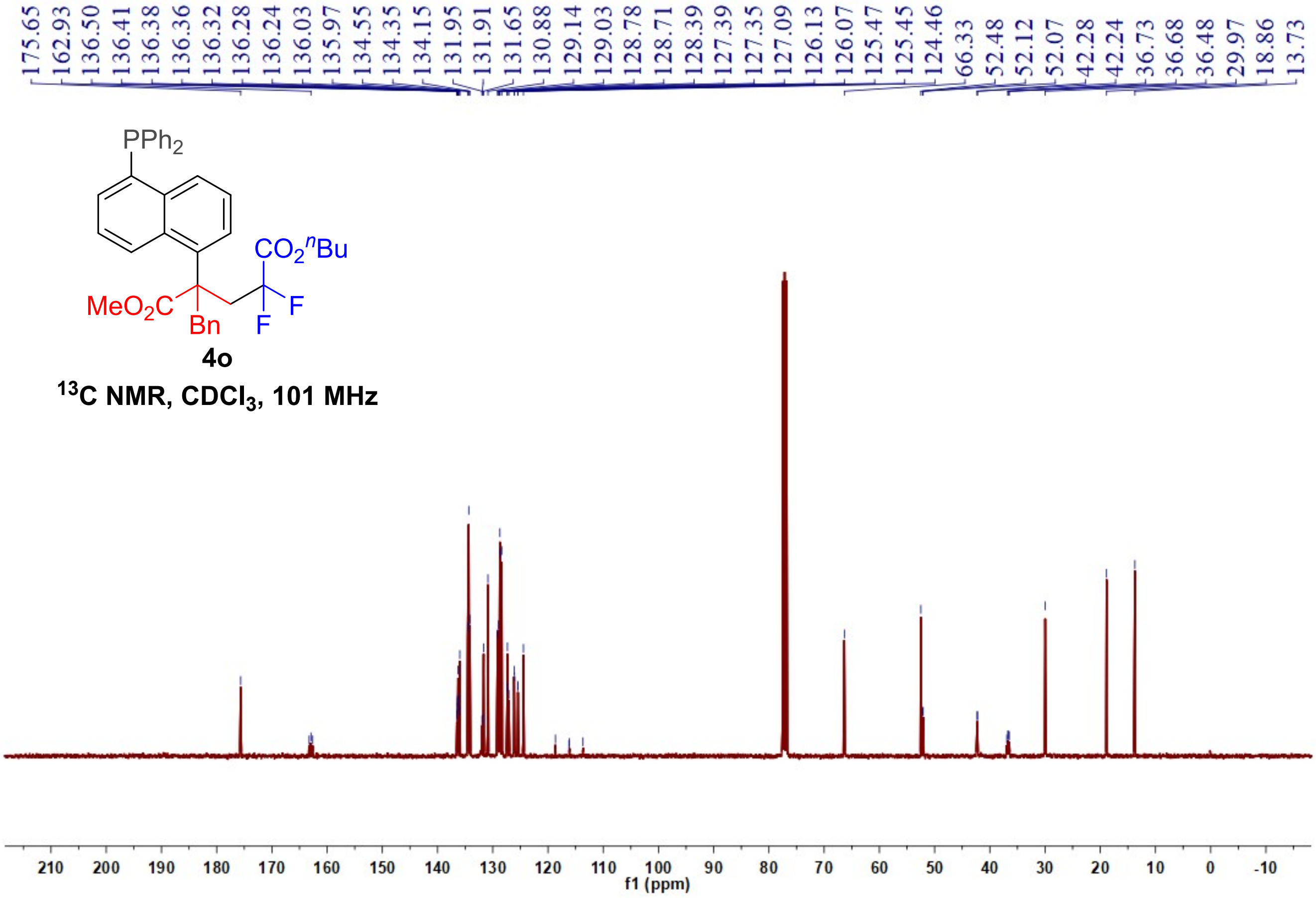
^{31}P NMR, $CDCl_3$, 162 MHz


4m

^{19}F NMR, $CDCl_3$, 377 MHz

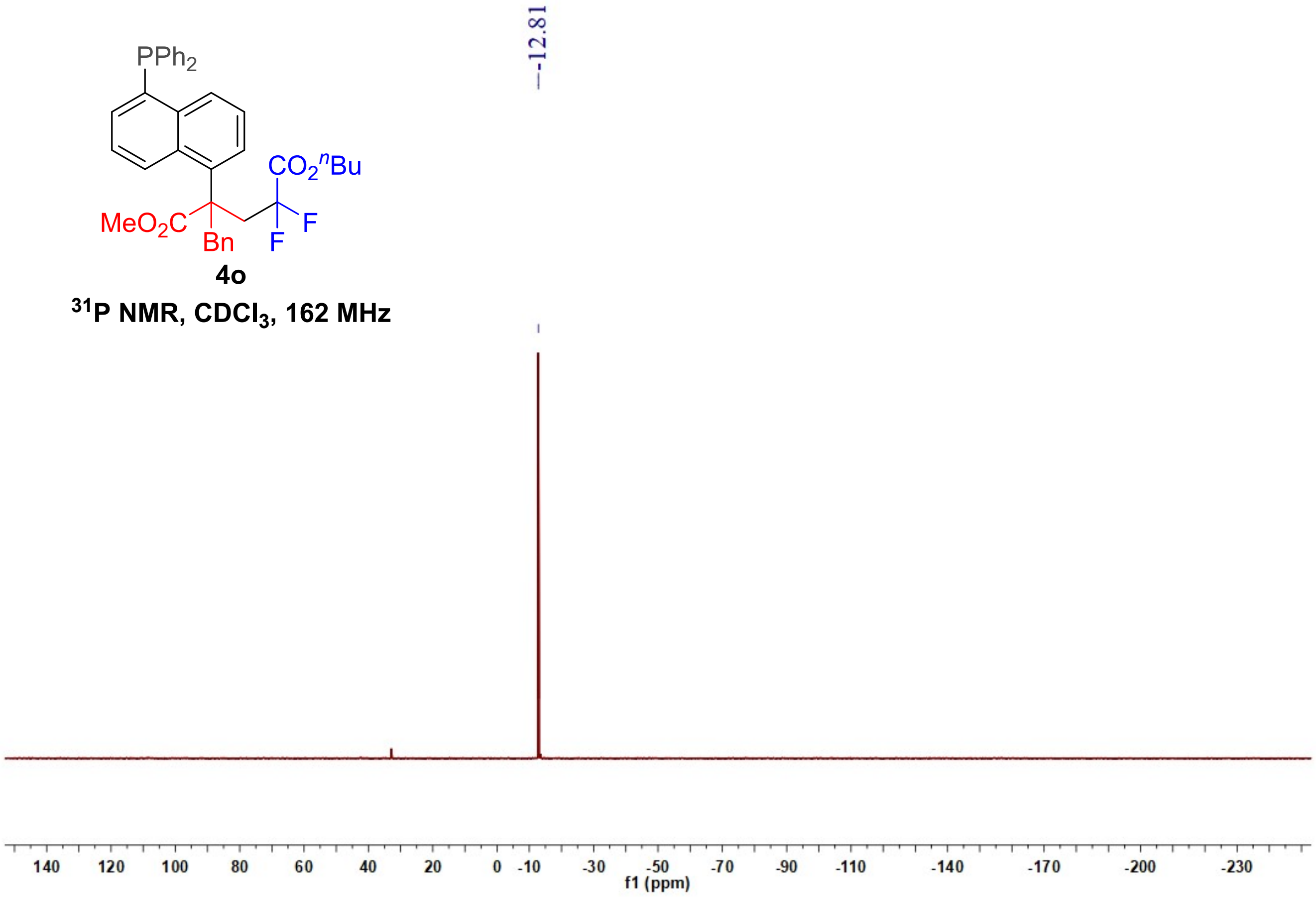

4o

^{1}H NMR, $CDCl_3$, 400 MHz



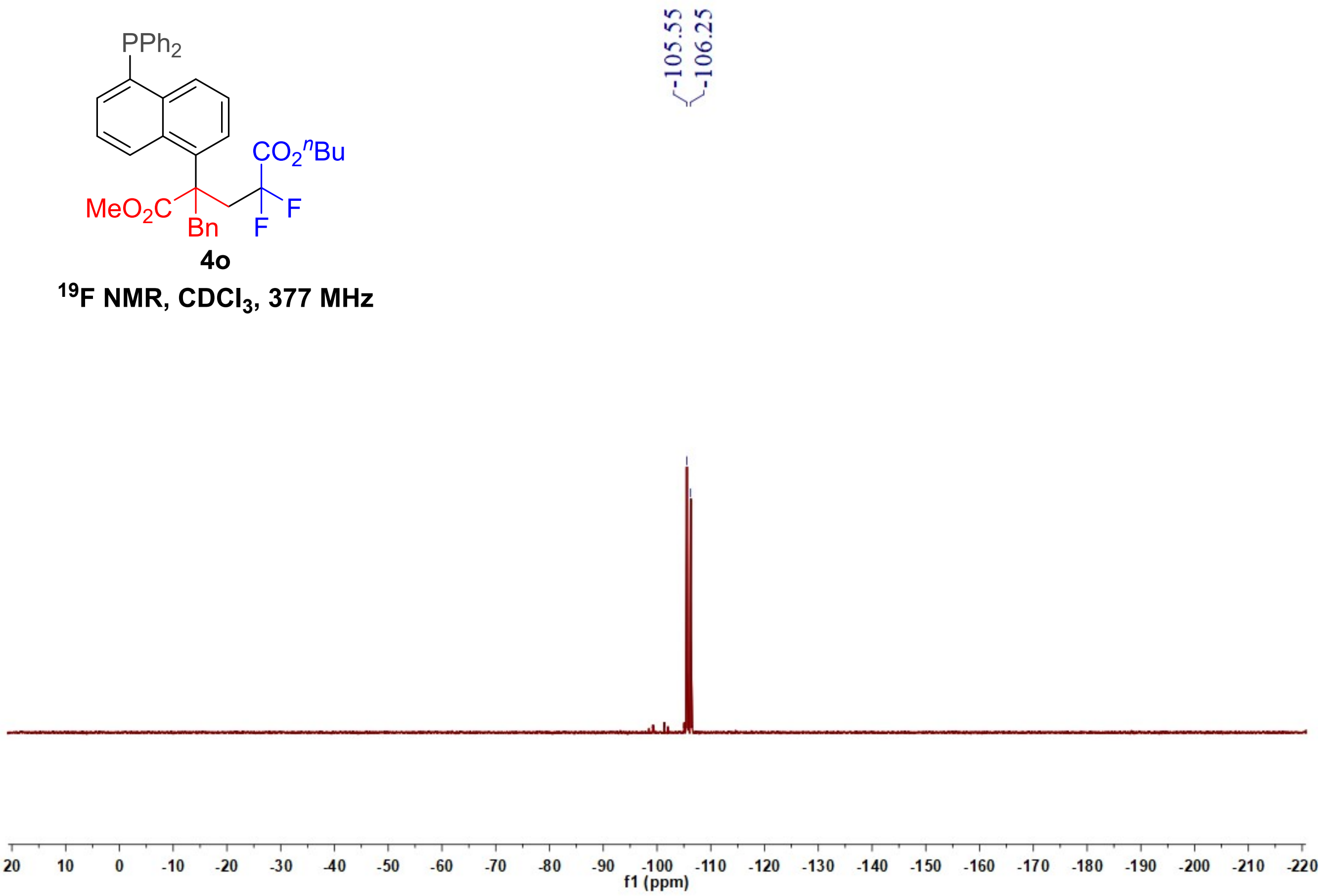
4o

^{13}C NMR, CDCl$_3$, 101 MHz



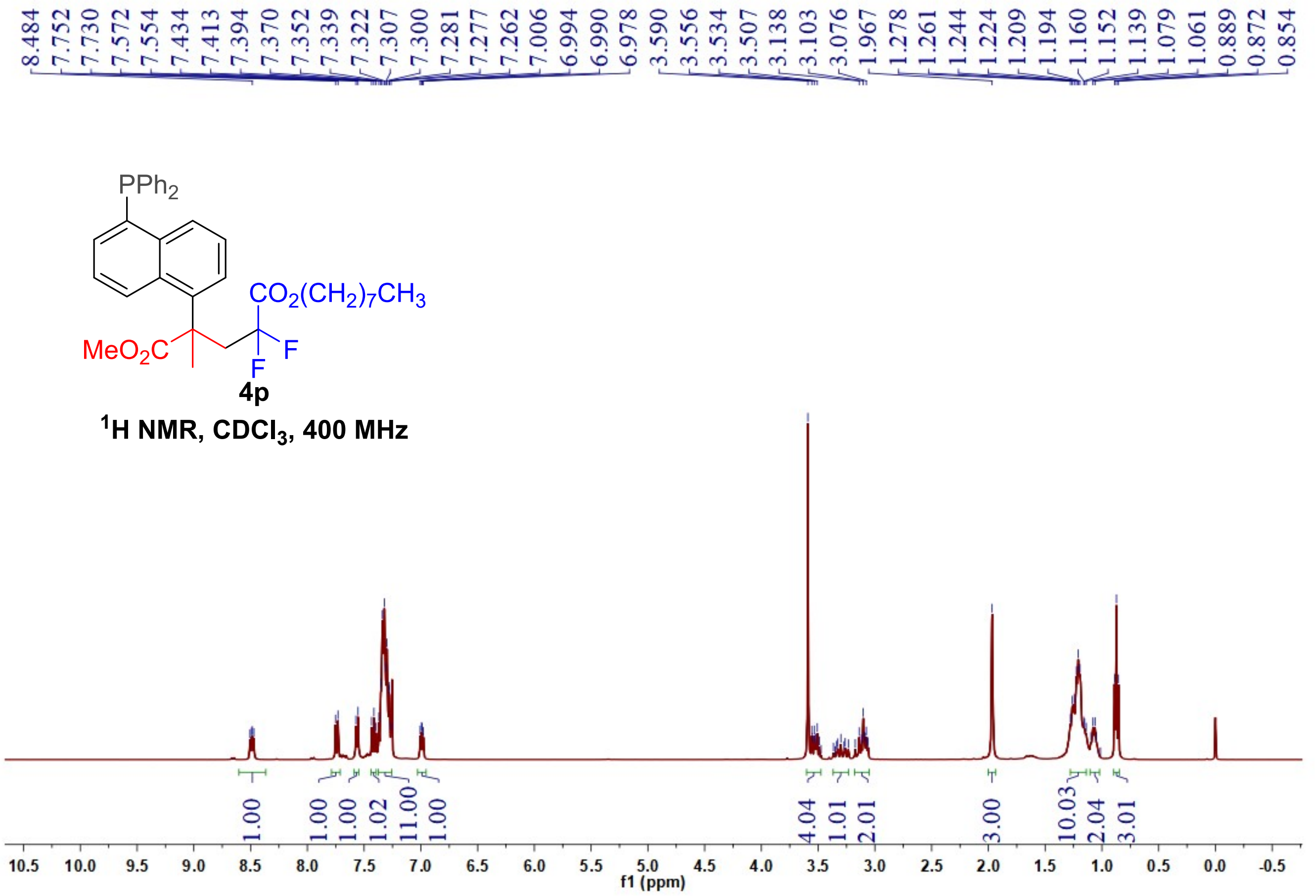
4o

^{31}P NMR, CDCl$_3$, 162 MHz



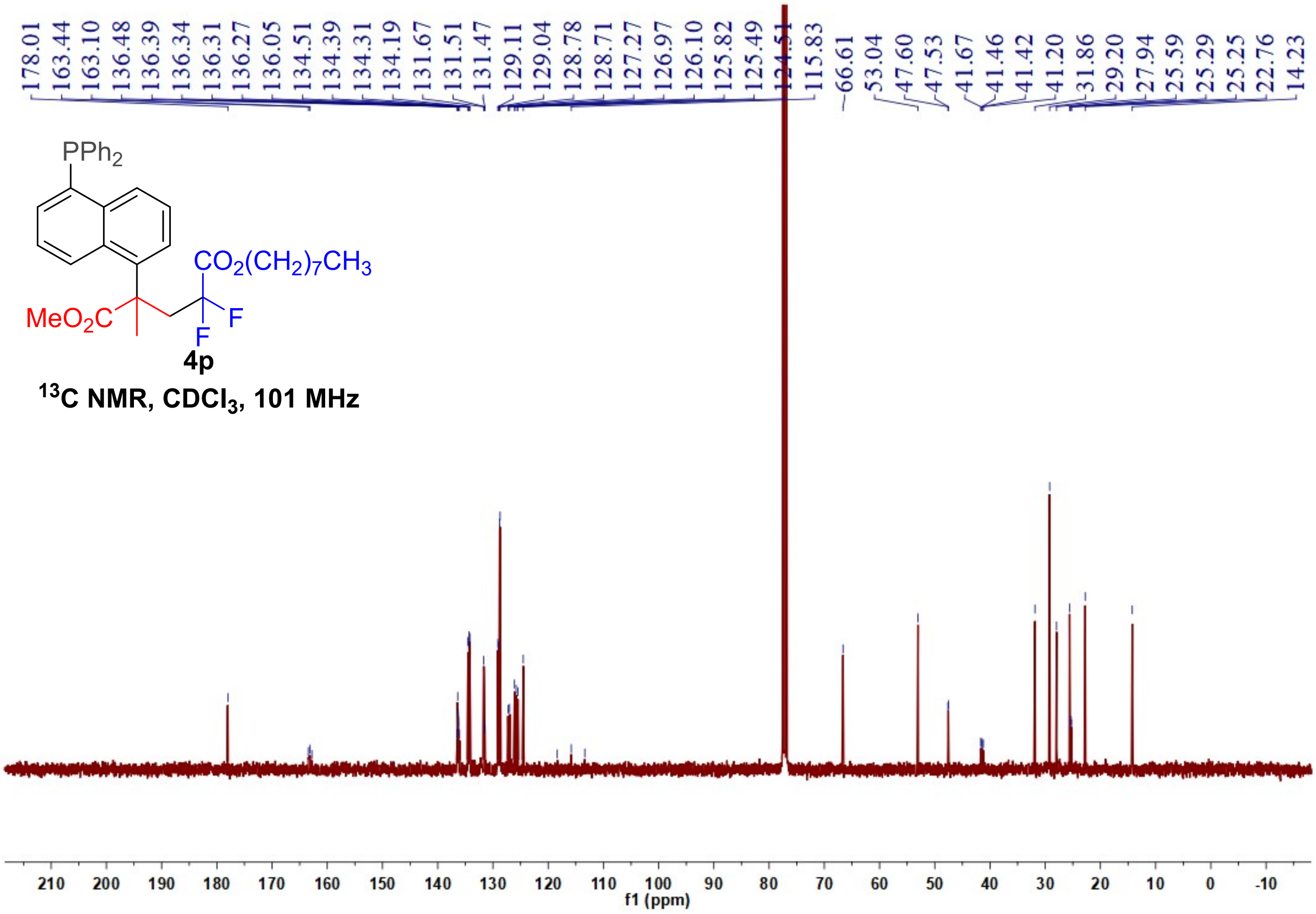
4o

^{19}F NMR, CDCl$_3$, 377 MHz



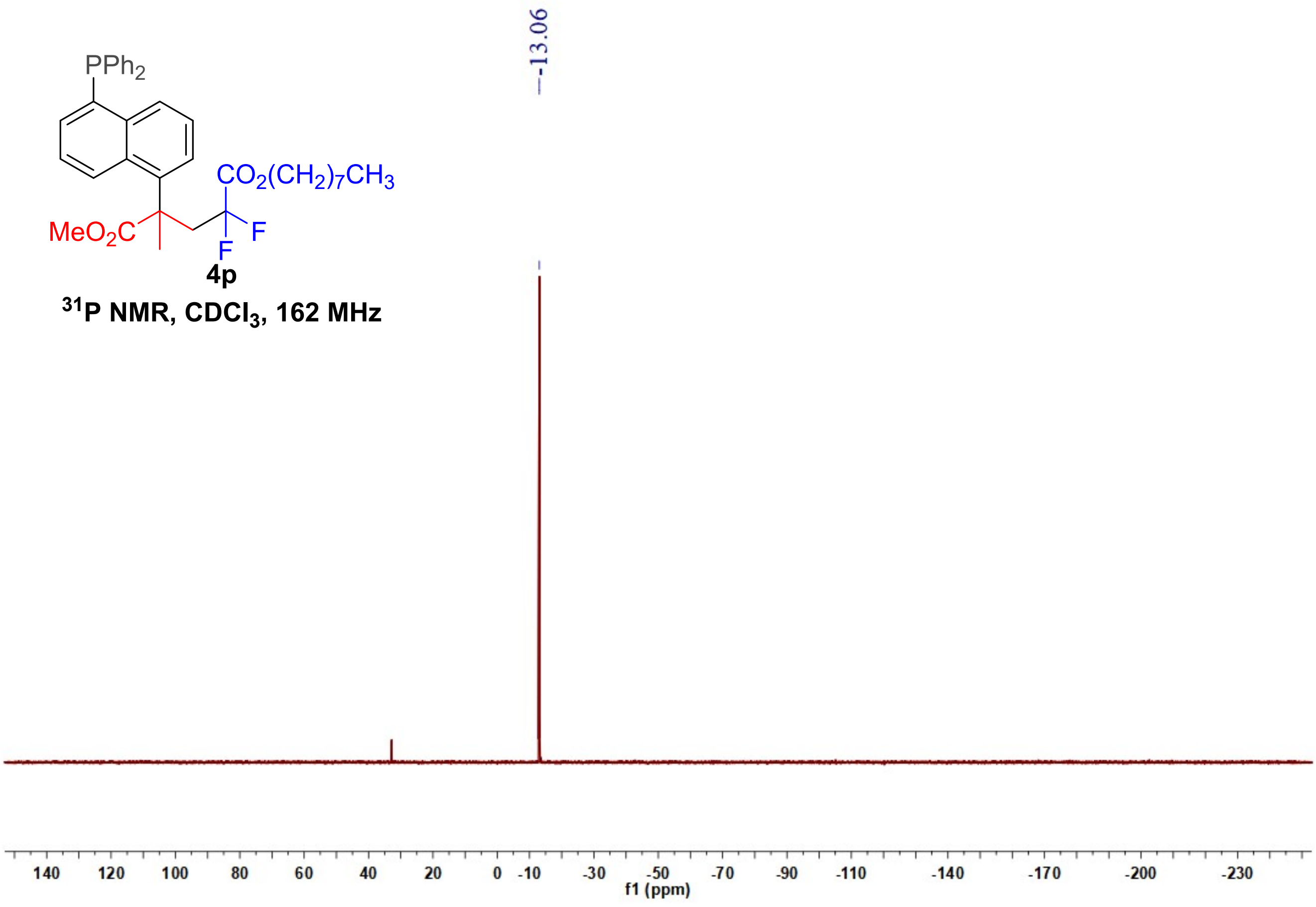
4p

^{1}H NMR, CDCl$_3$, 400 MHz



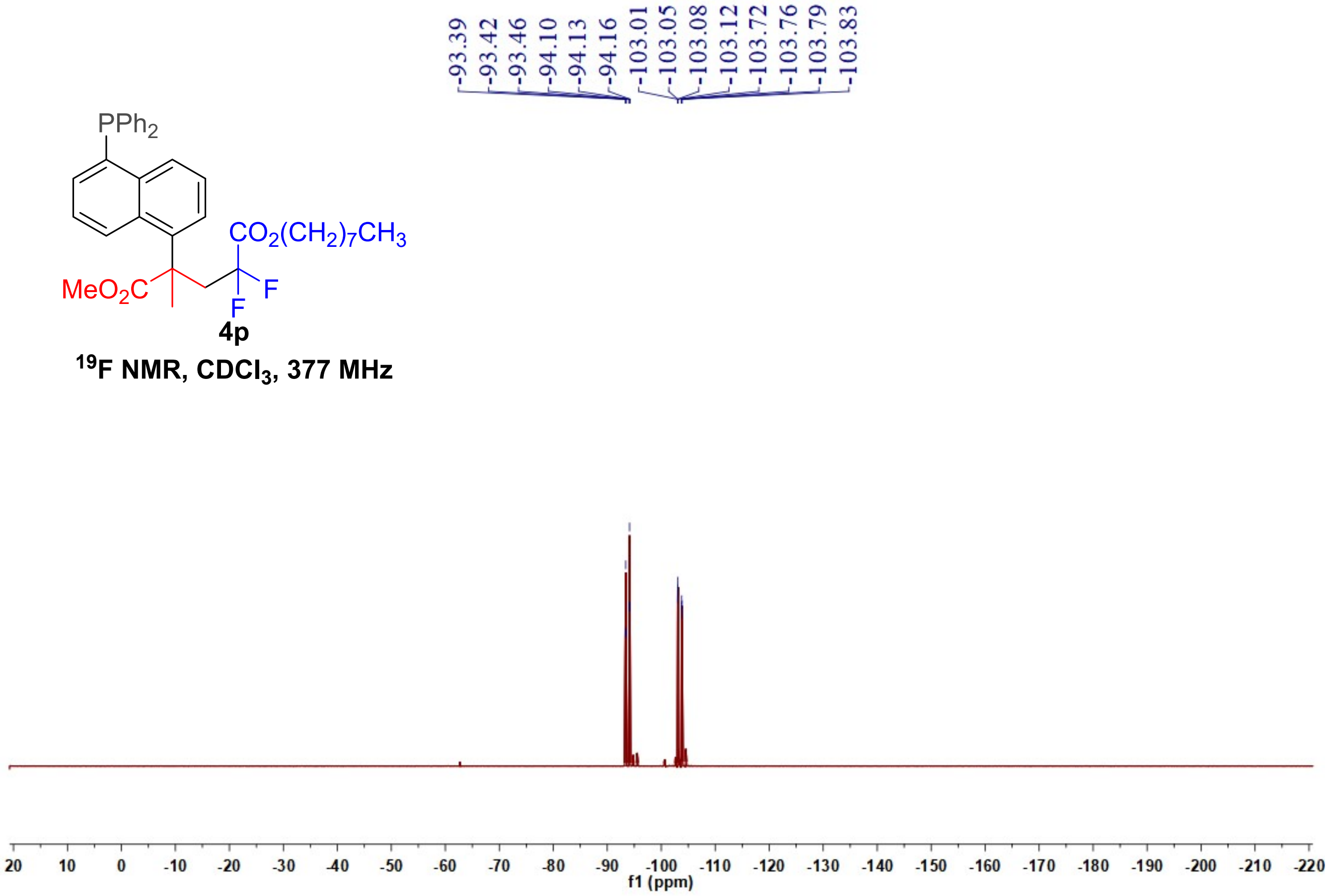
4p

^{13}C NMR, $CDCl_3$, 101 MHz



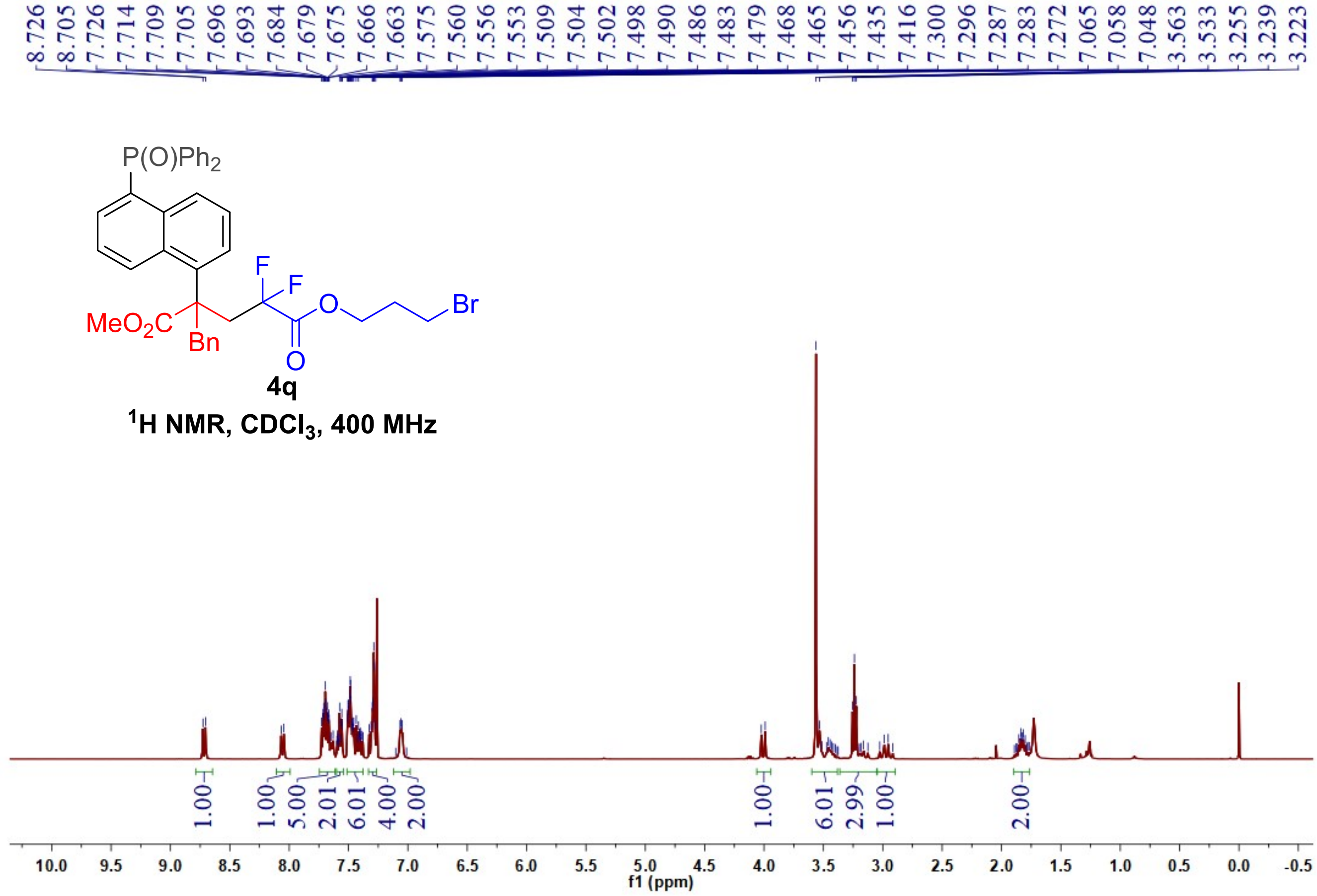
4p

^{31}P NMR, $CDCl_3$, 162 MHz



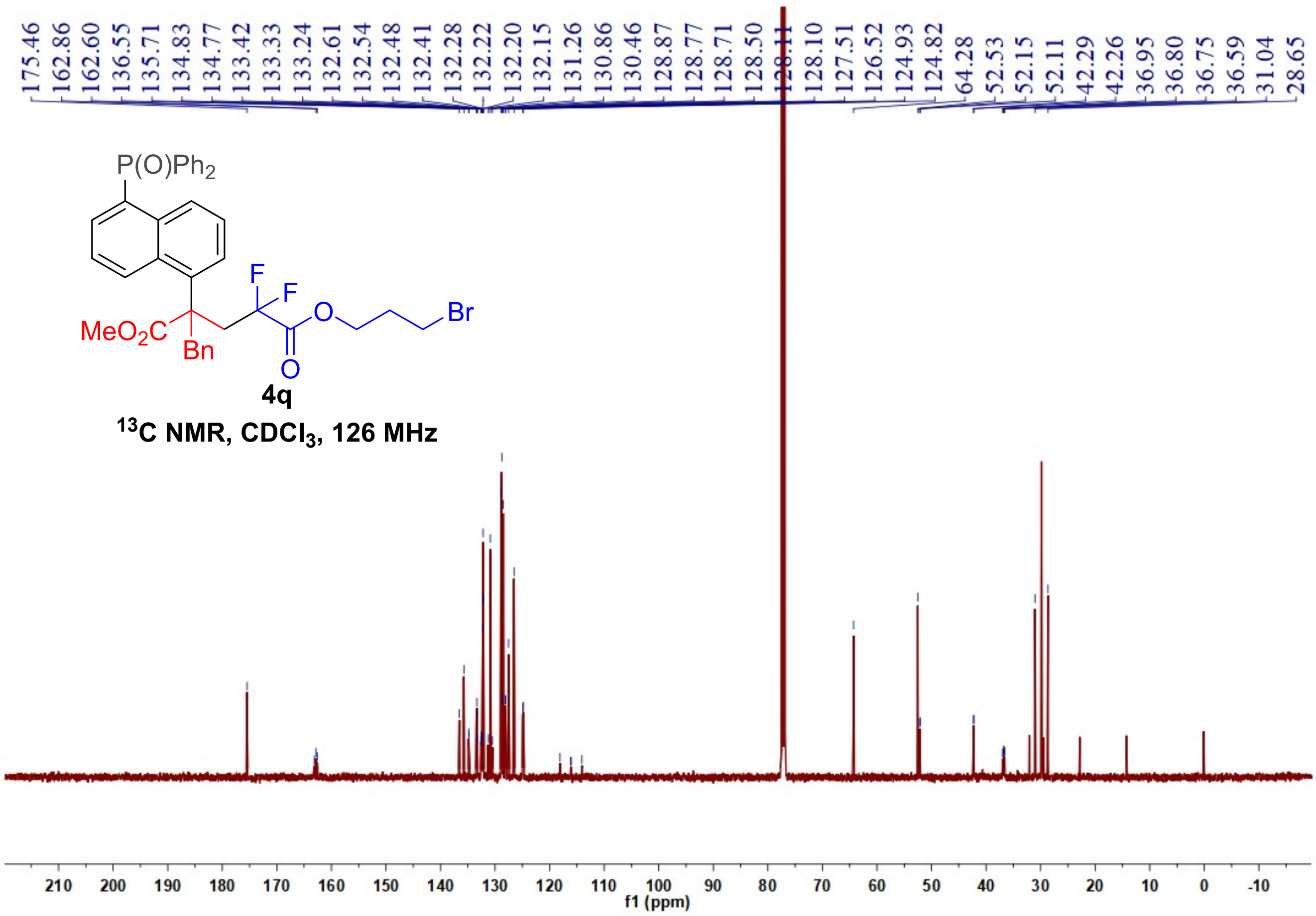
4p

^{19}F NMR, CDCl$_3$, 377 MHz



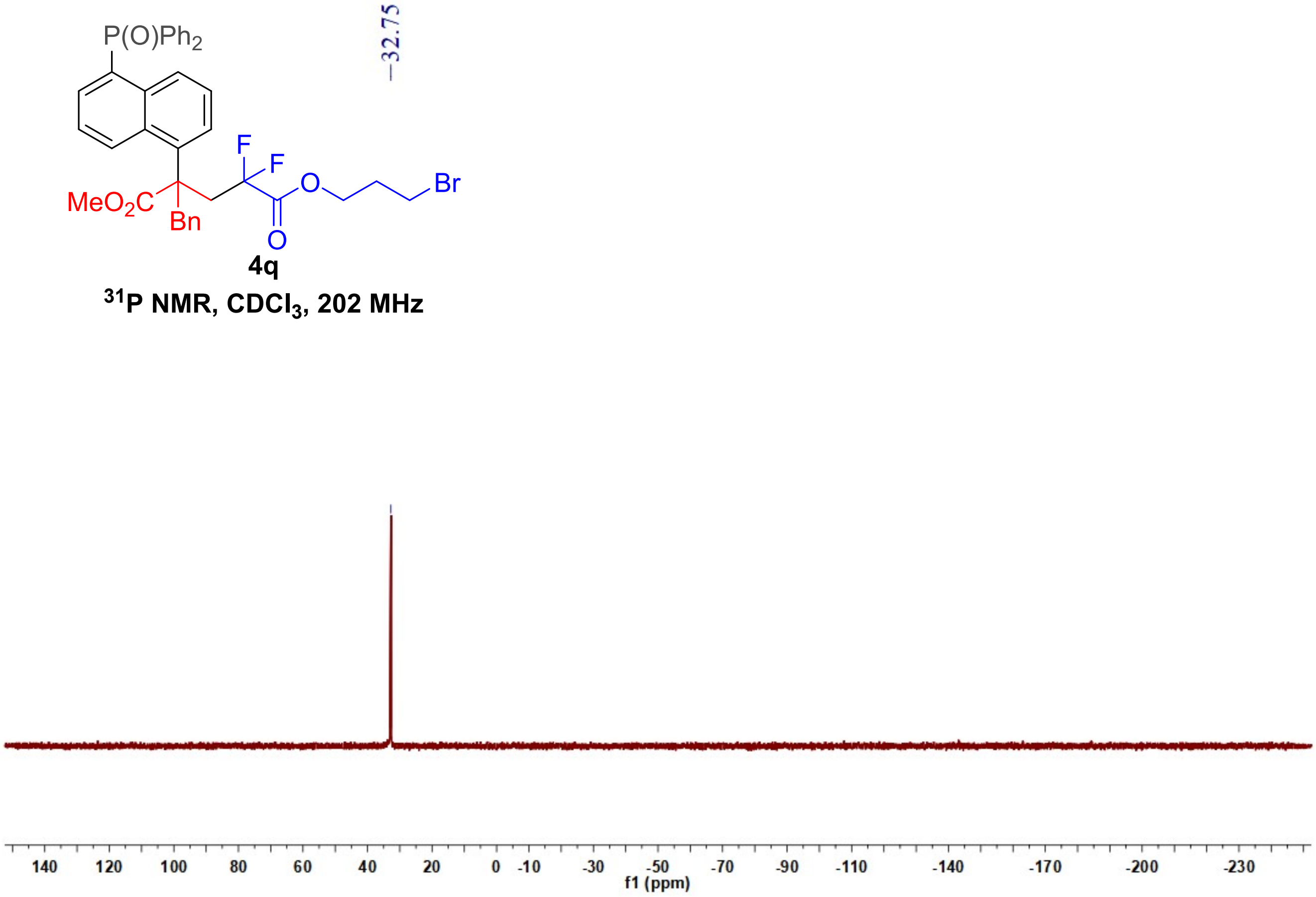
4q

^{1}H NMR, CDCl$_3$, 400 MHz



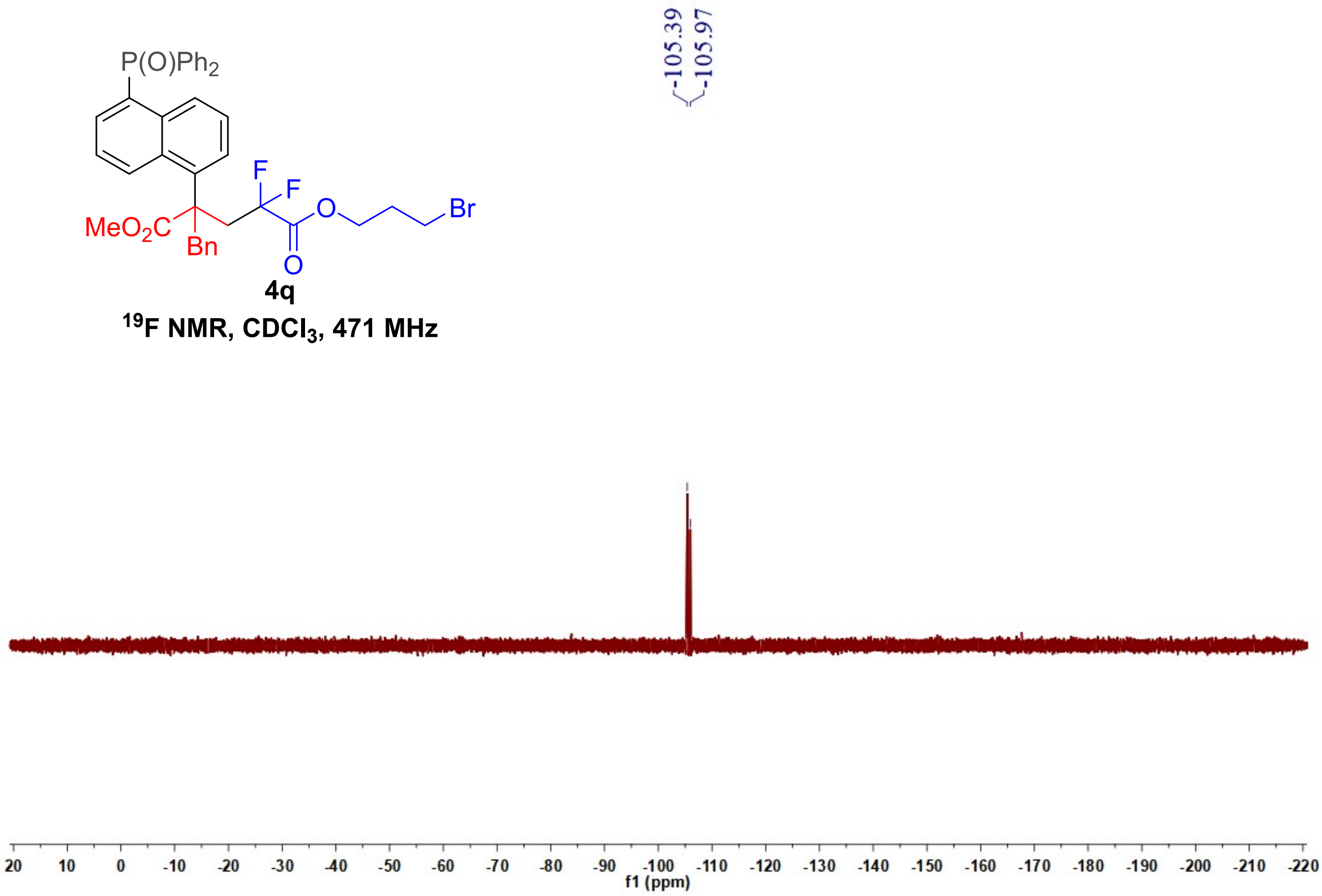
4q

^{13}C NMR, CDCl$_3$, 126 MHz



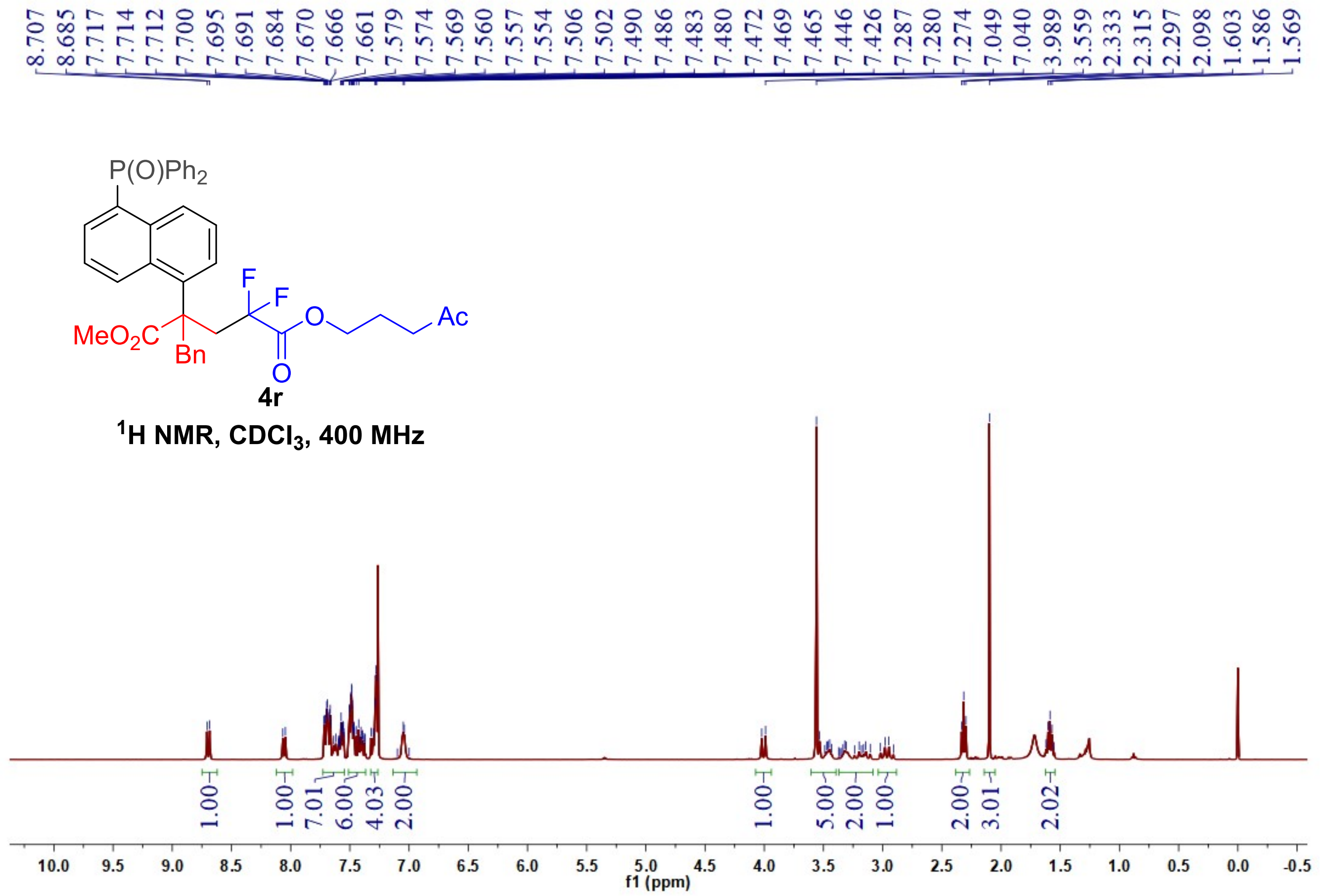
4q

^{31}P NMR, CDCl$_3$, 202 MHz



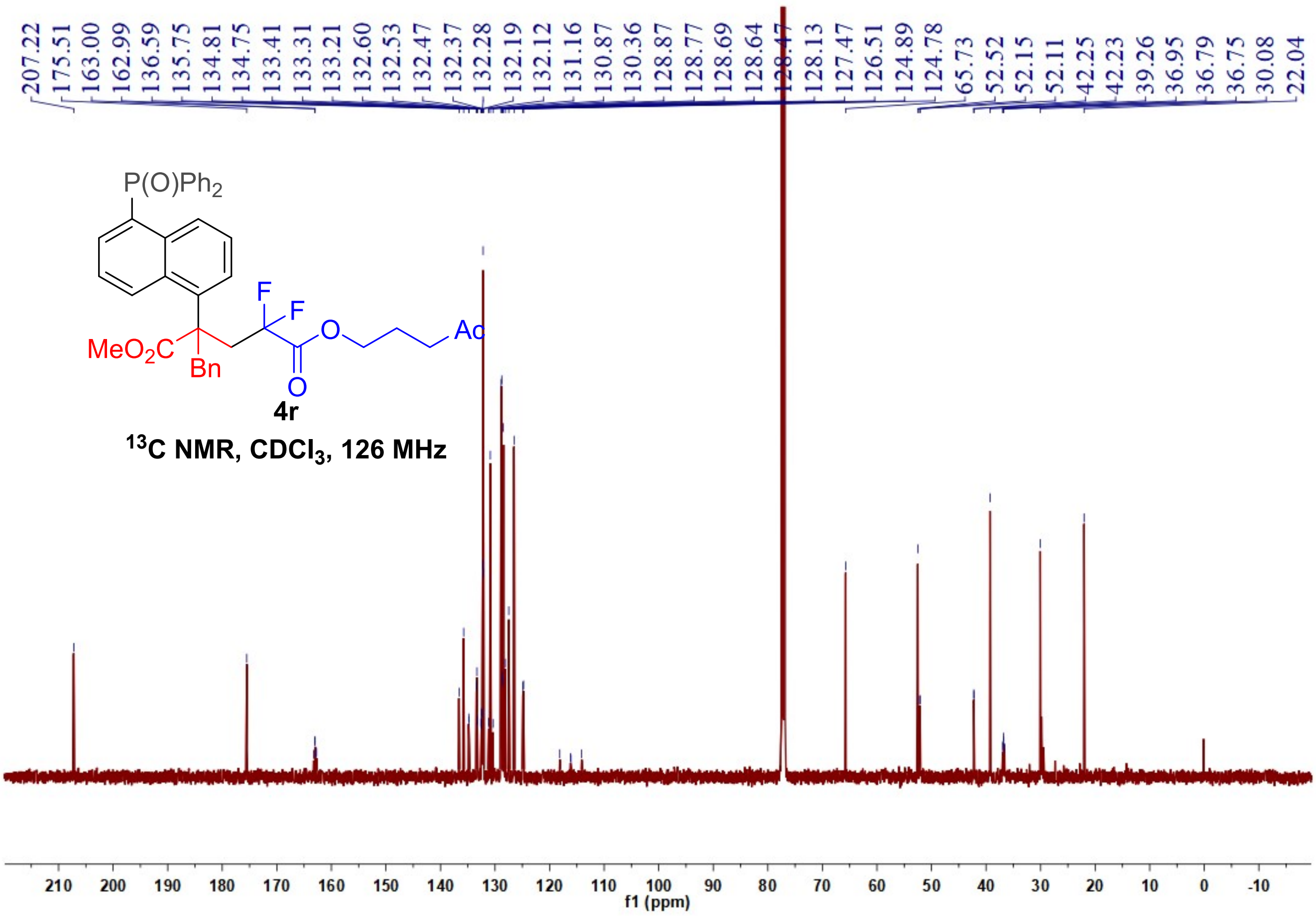
4q

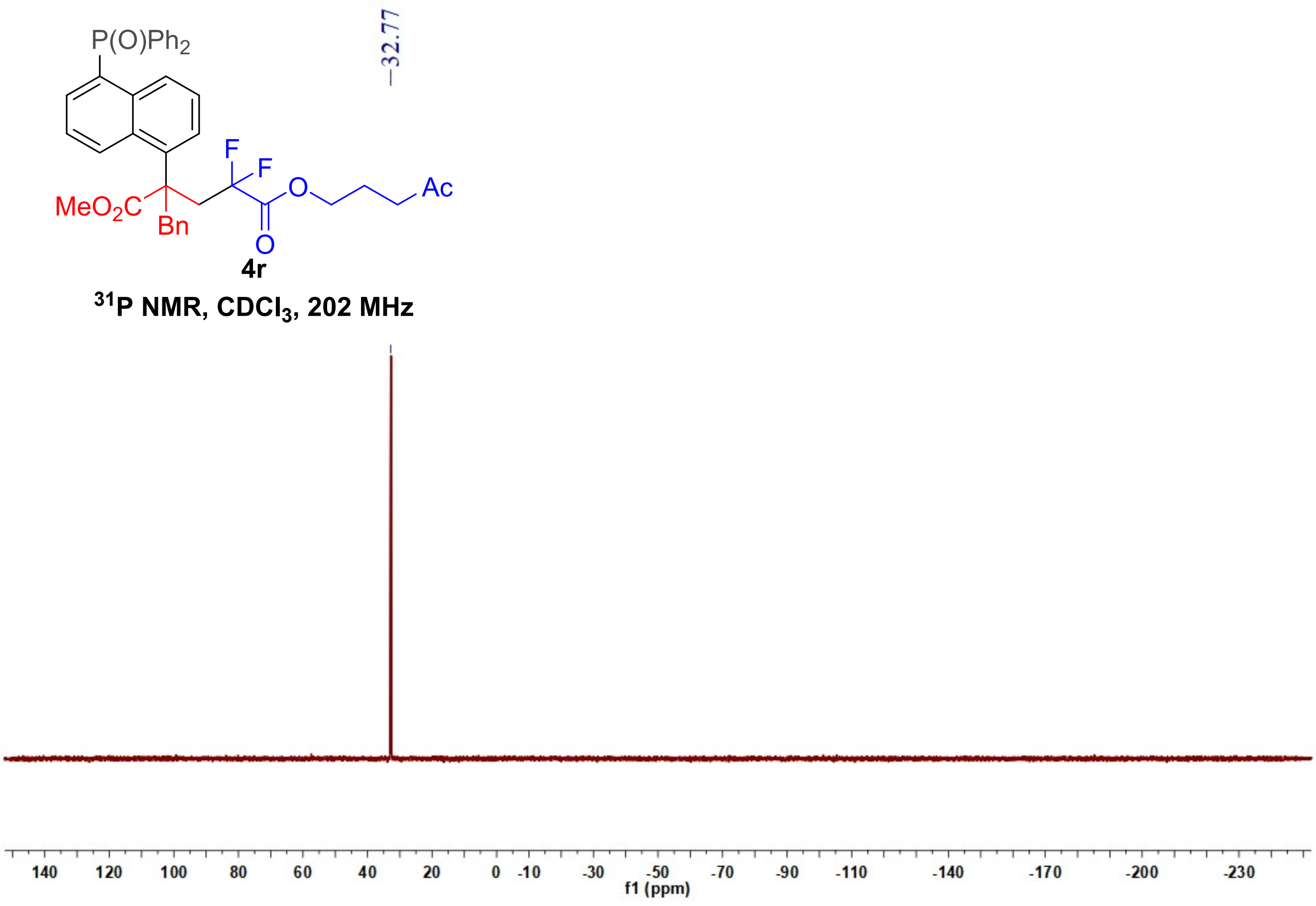
^{19}F NMR, CDCl$_3$, 471 MHz

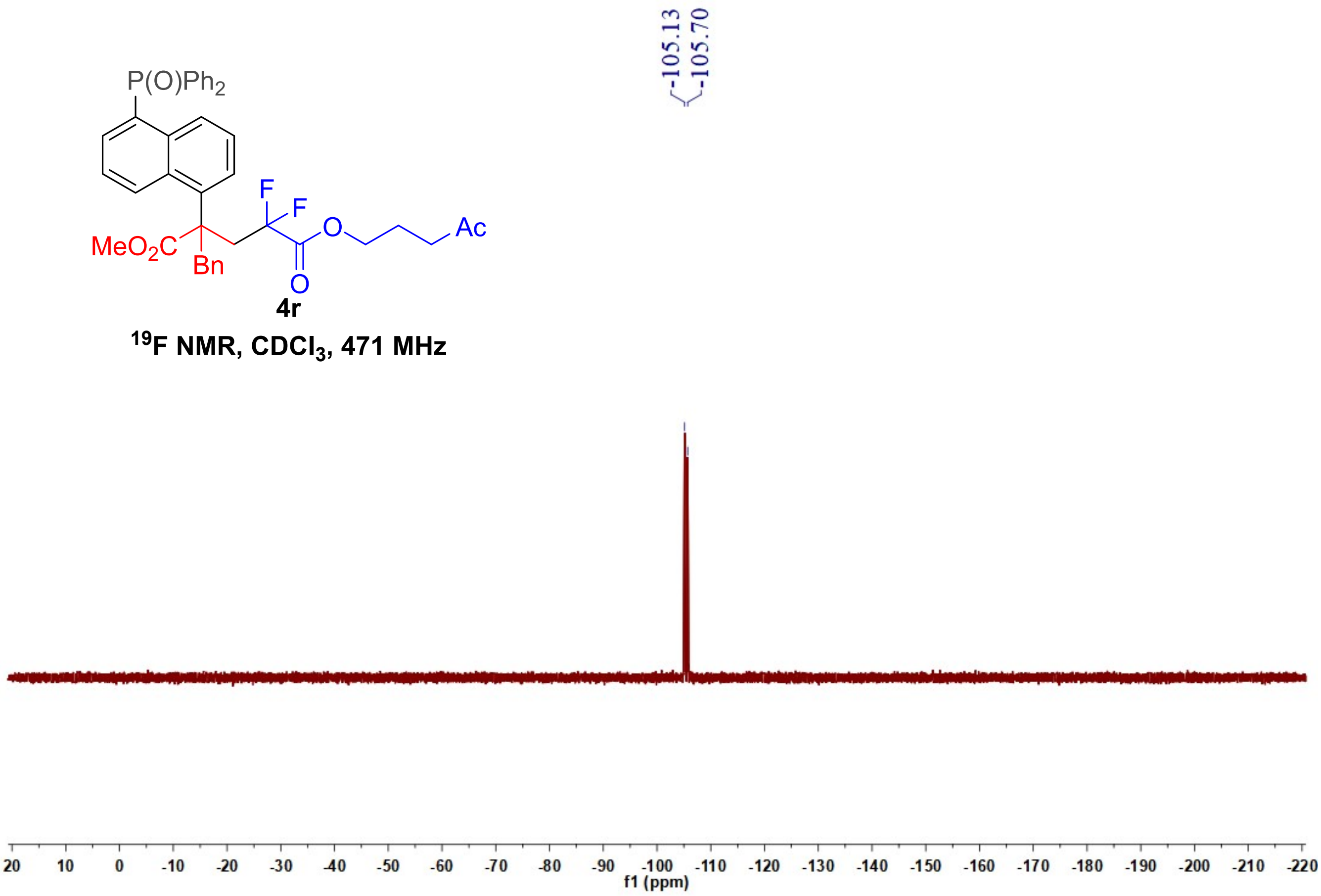


4r

^{1}H NMR, CDCl$_3$, 400 MHz

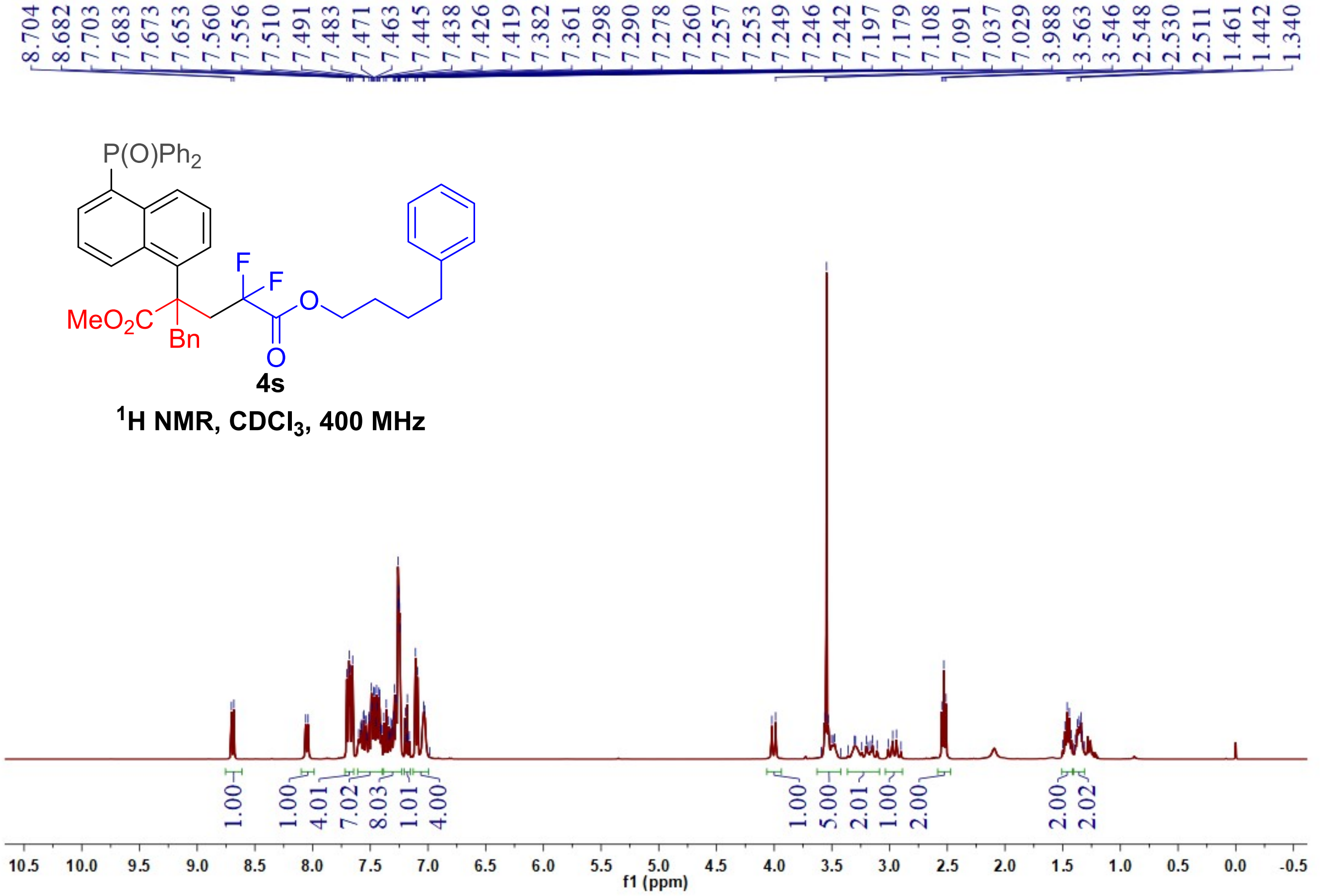

207.22
175.51
163.00
162.99
136.59
135.75
134.81
134.75
133.41
133.31
133.21
132.60
132.53
132.47
132.37
132.28
132.19
132.12
131.16
130.87
130.36
128.87
128.77
128.69
128.64
128.47
128.13
127.47
126.51
124.89
124.78
65.73
52.52
52.15
52.11
42.25
42.23
39.26
36.95
36.79
36.75
30.08
22.04
P(O)Ph2
F
F
MeO2C
Bn
O
O
Ac
4r
13C NMR, CDCl3, 126 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


32.77
P(O)Ph2
F
F
MeO2C
Bn
O
O
Ac
4r
31P NMR, CDCl3, 202 MHz
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-110
-140
-170
-200
-230
f1 (ppm)



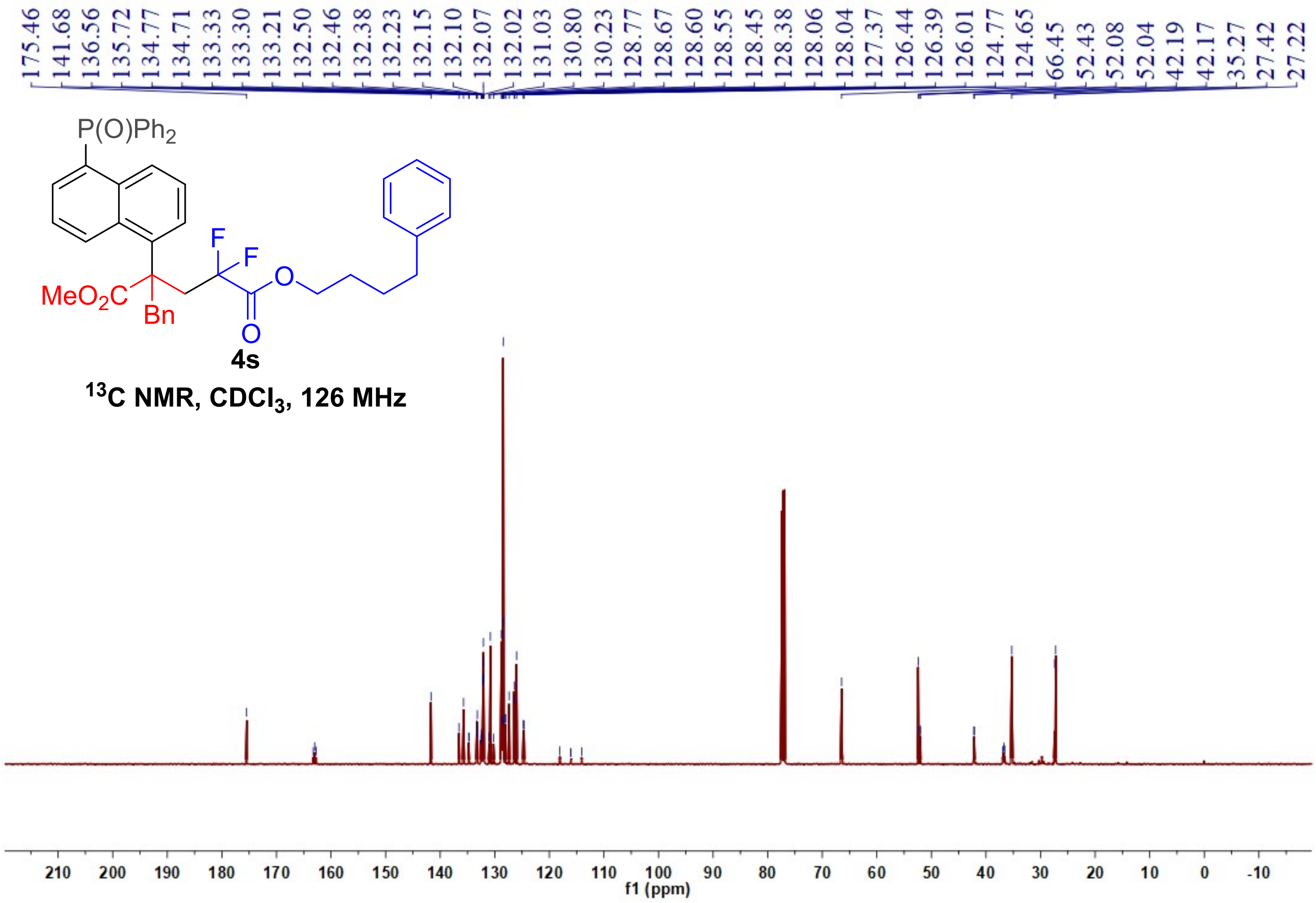
4r

^{19}F NMR, CDCl$_3$, 471 MHz



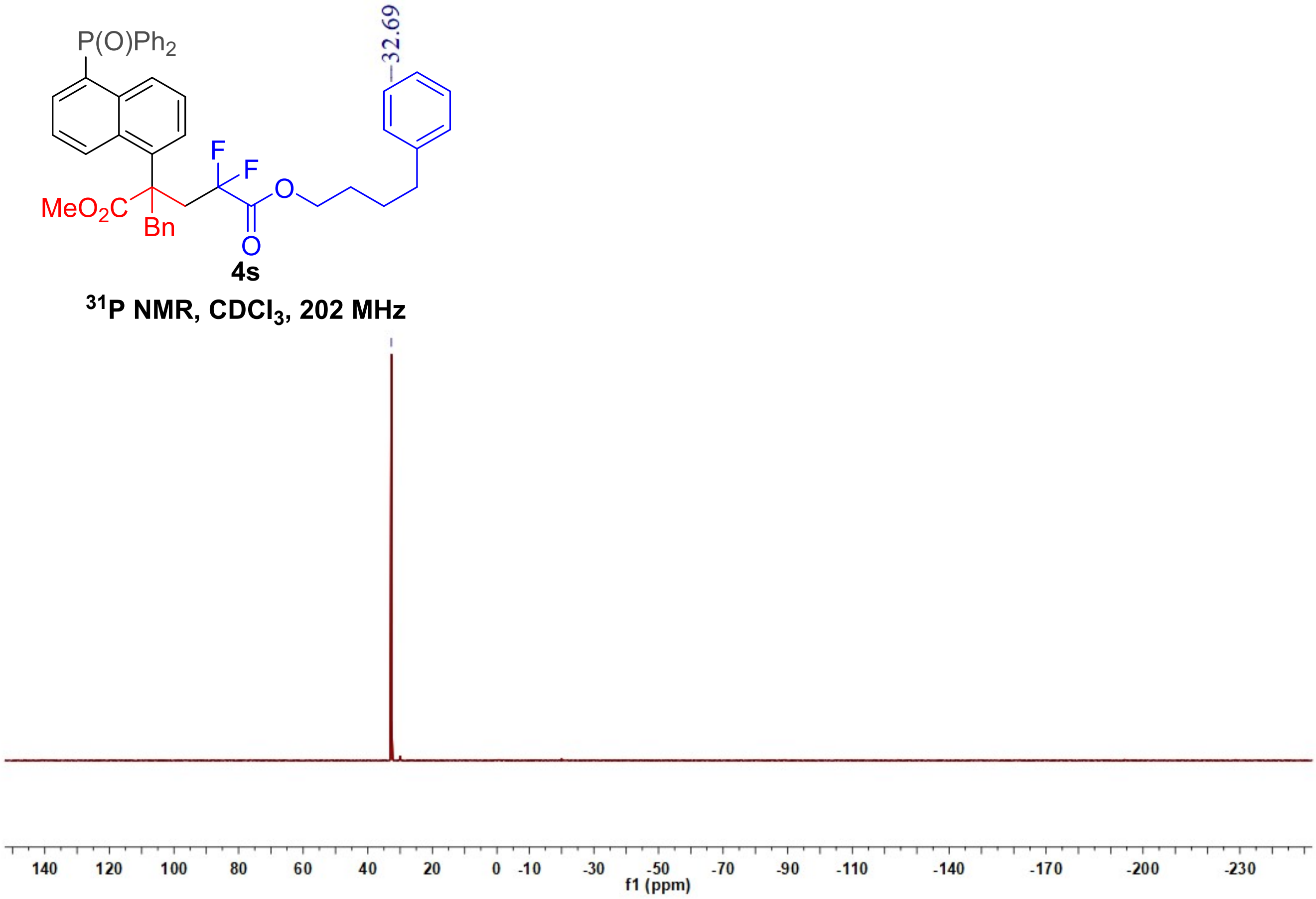
4s

^{1}H NMR, CDCl$_3$, 400 MHz



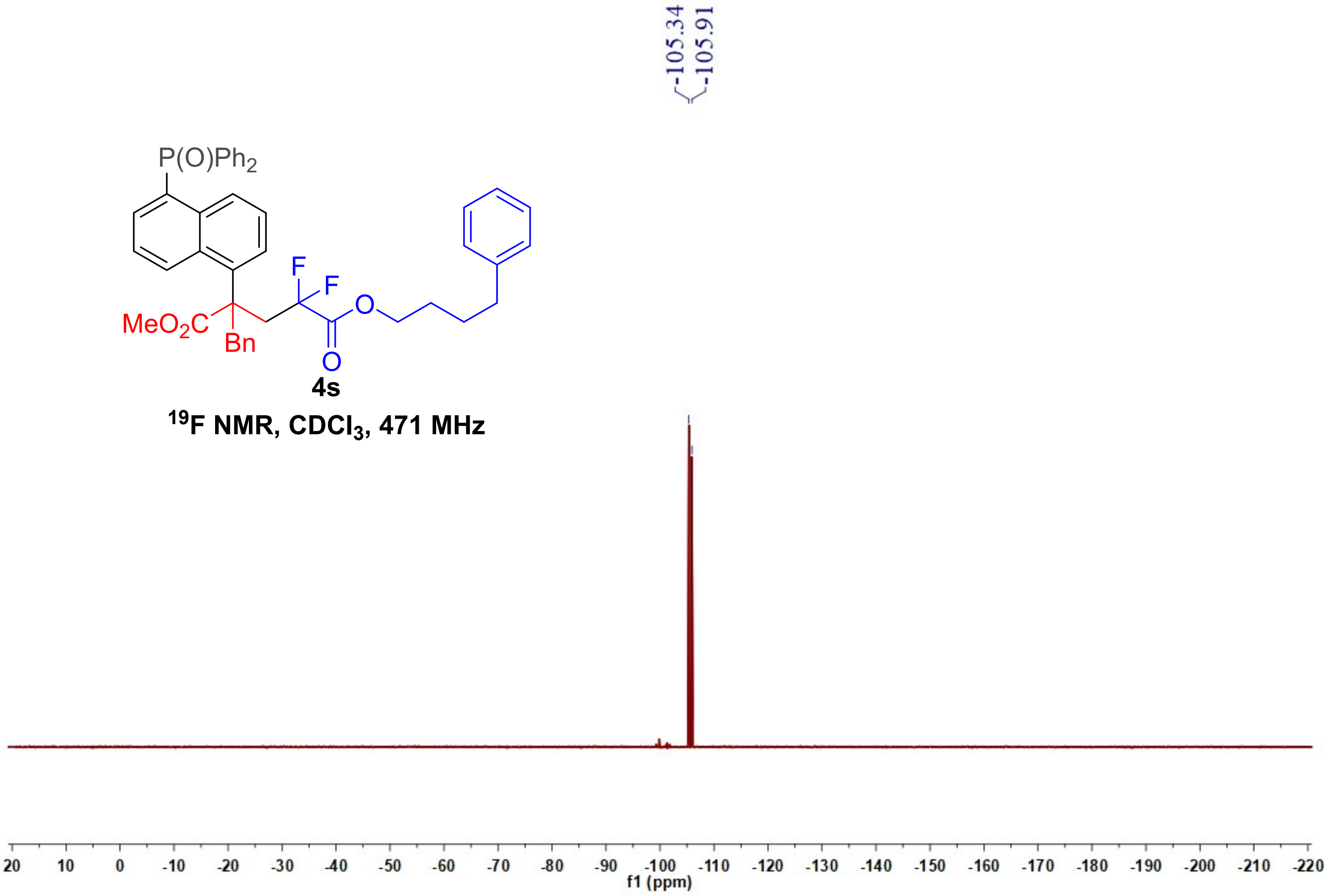
4s

^{13}C NMR, CDCl$_3$, 126 MHz

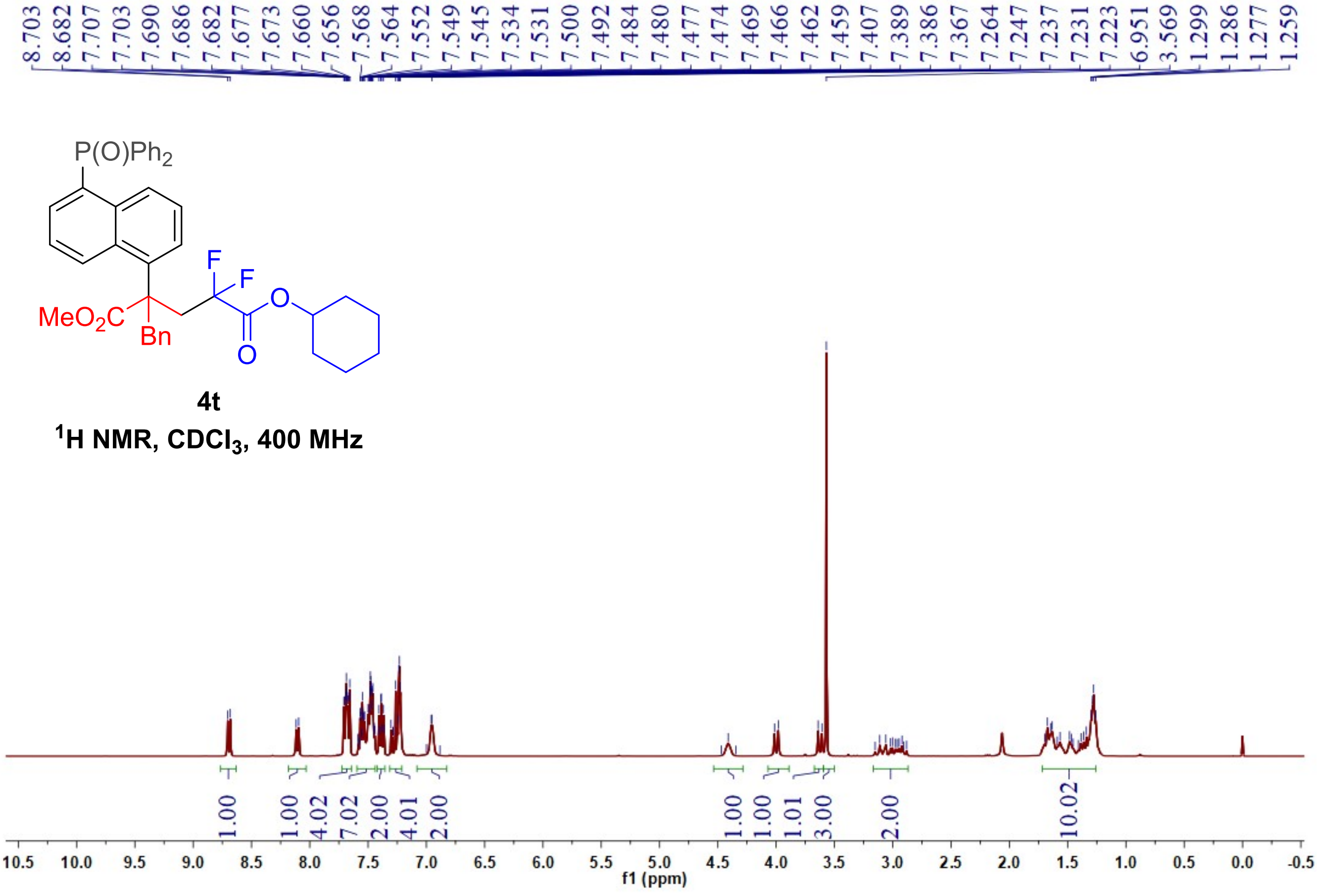


4s

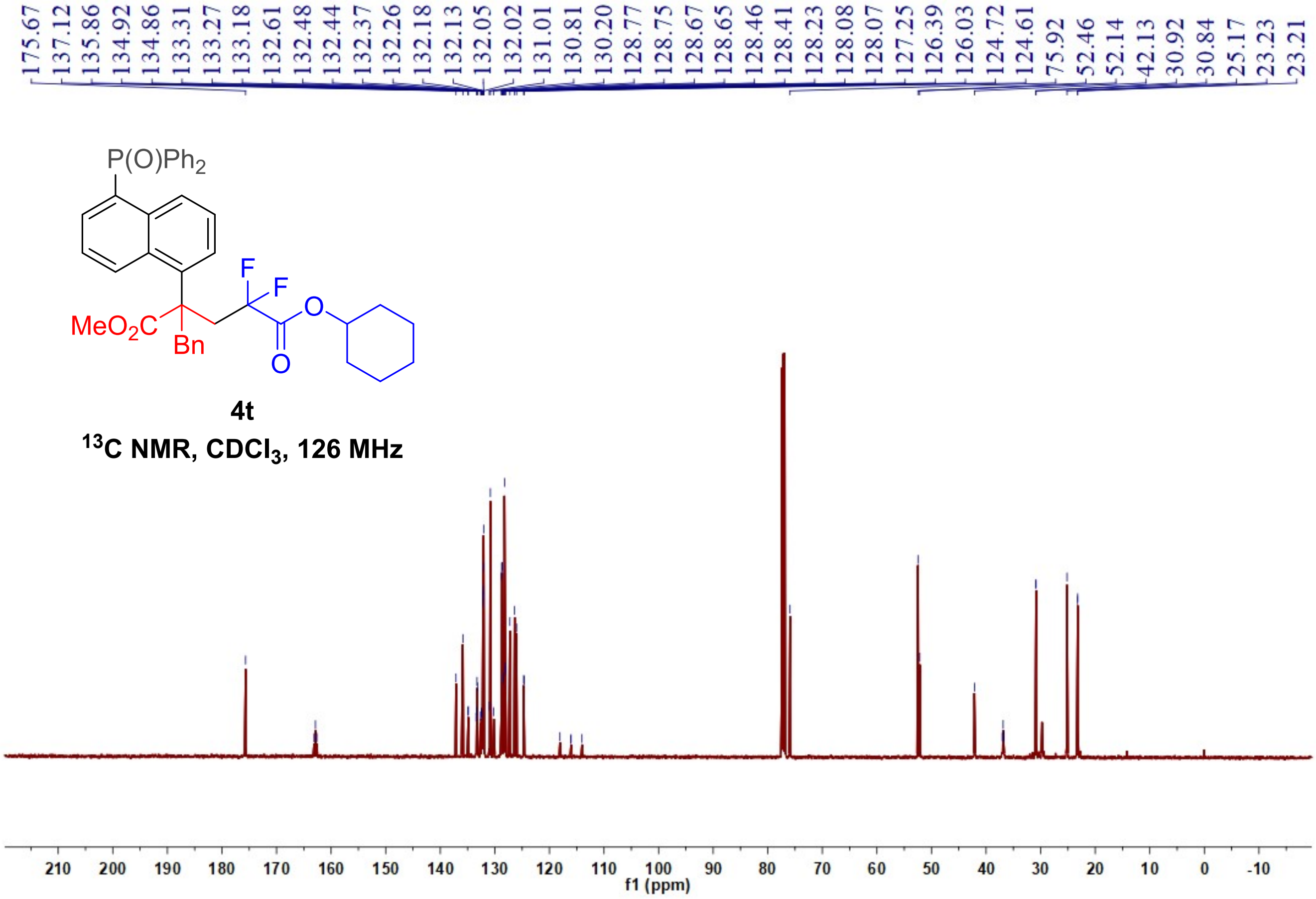
^{31}P NMR, CDCl$_3$, 202 MHz


4s

^{19}F NMR, CDCl$_3$, 471 MHz

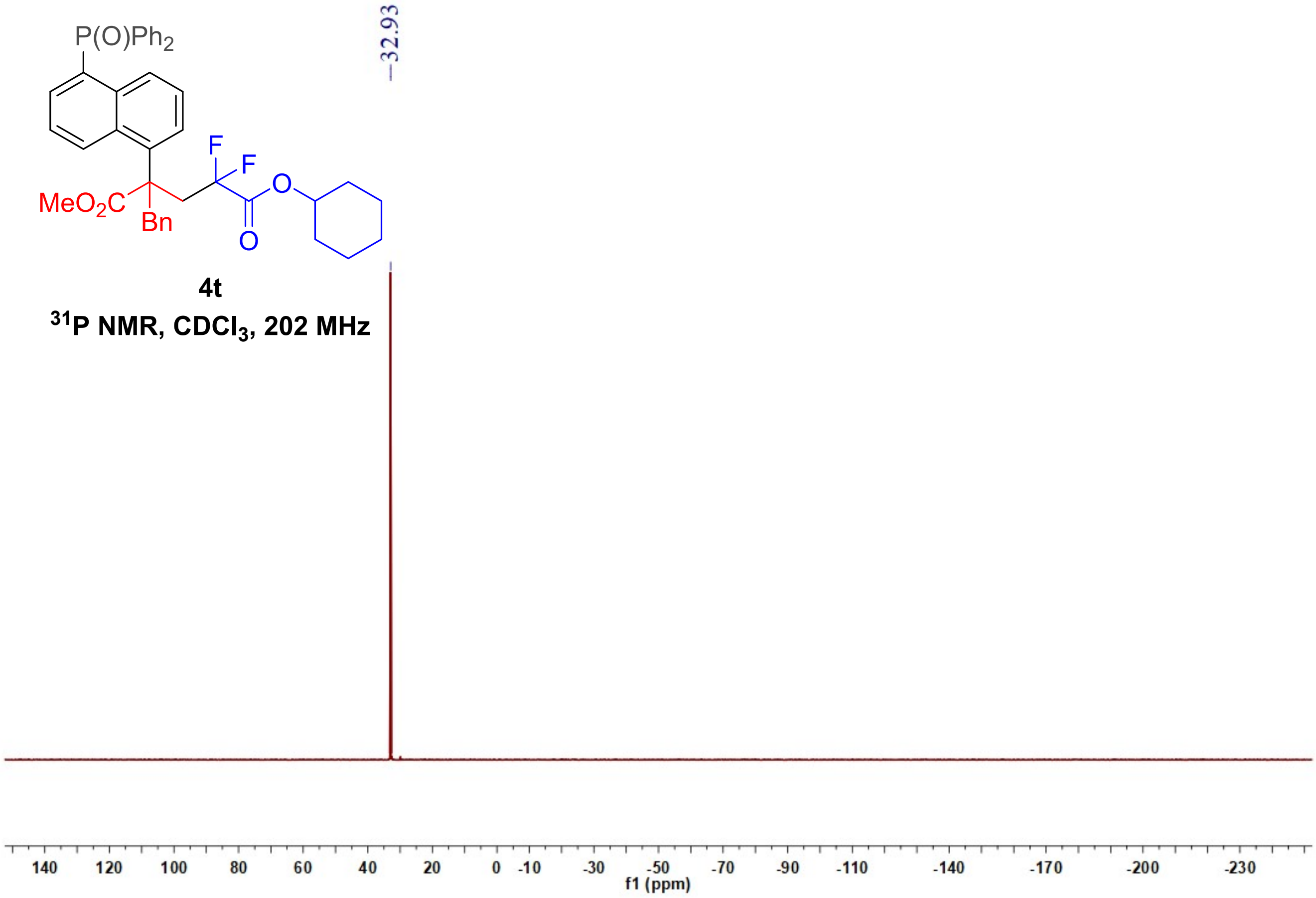

4t

^{1}H NMR, CDCl$_3$, 400 MHz



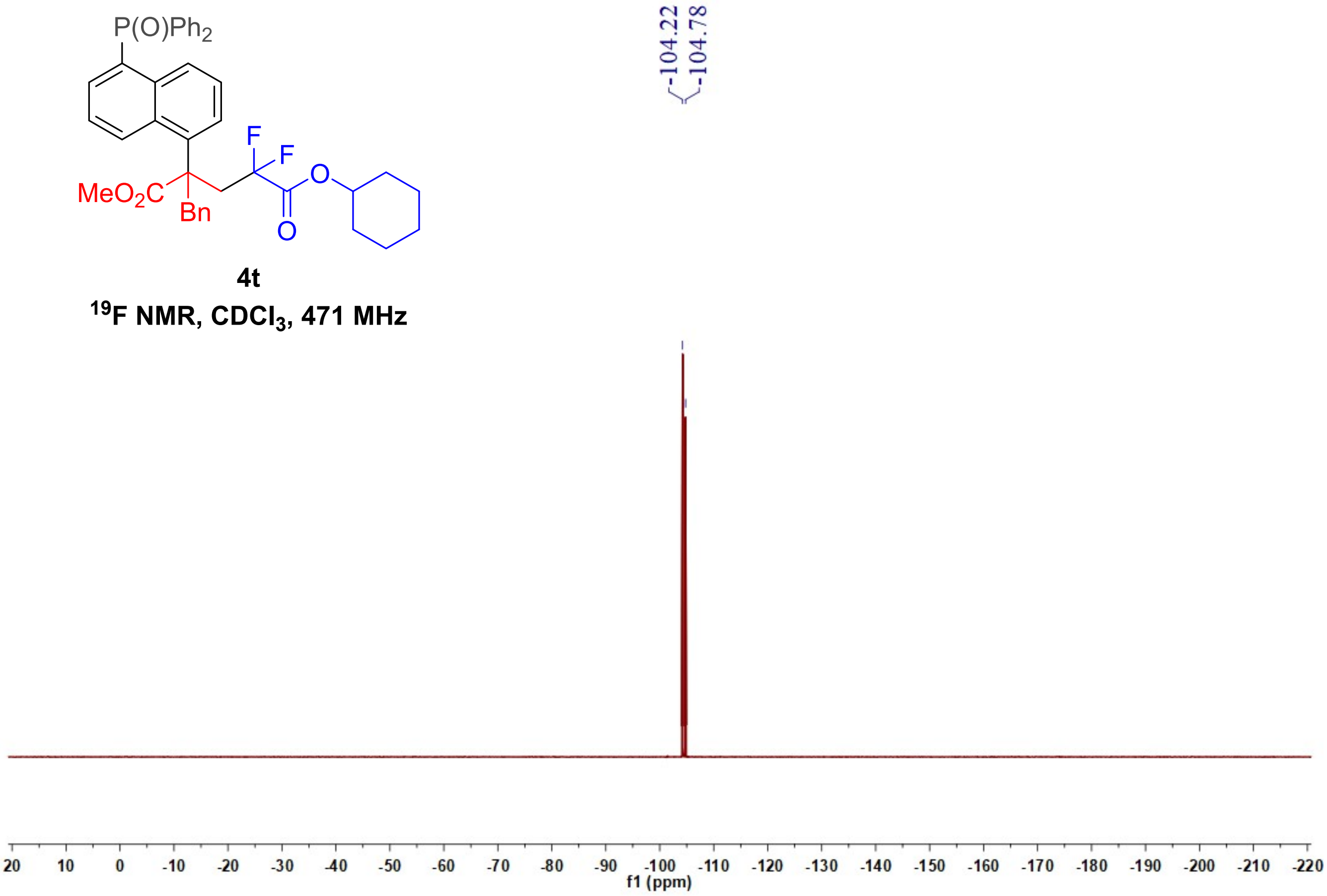
4t

^{13}C NMR, CDCl$_3$, 126 MHz



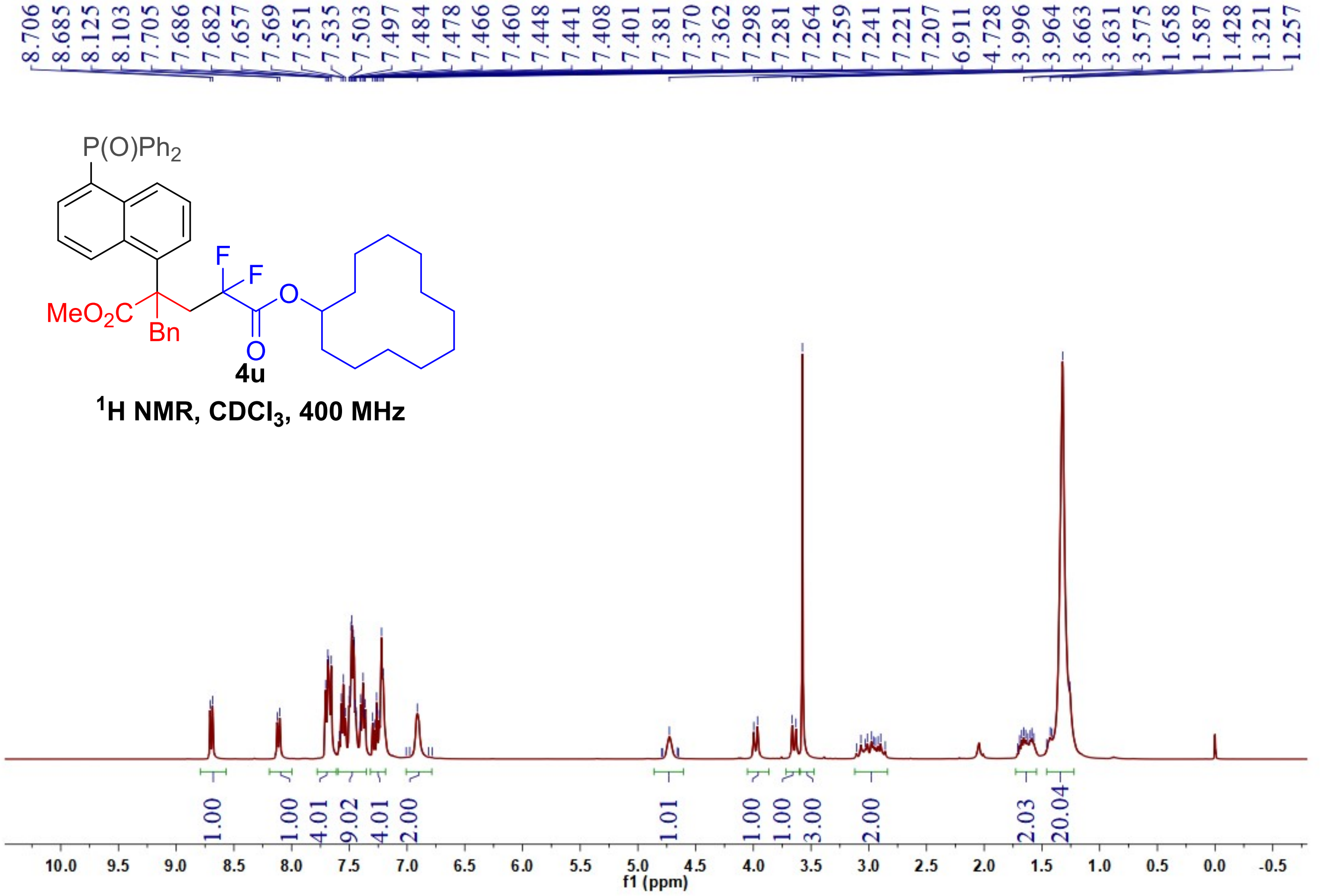
4t

^{31}P NMR, CDCl$_3$, 202 MHz



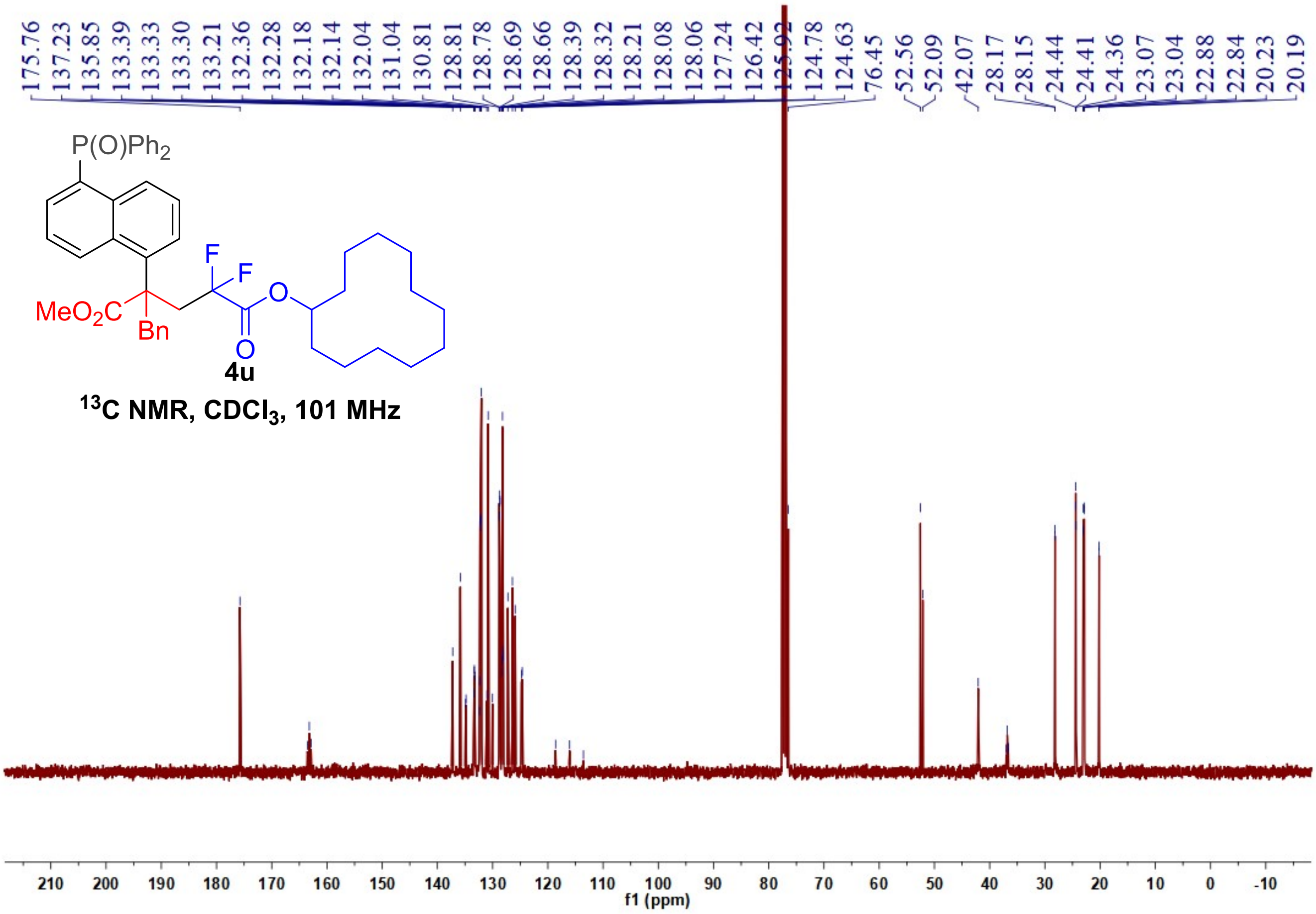
4t

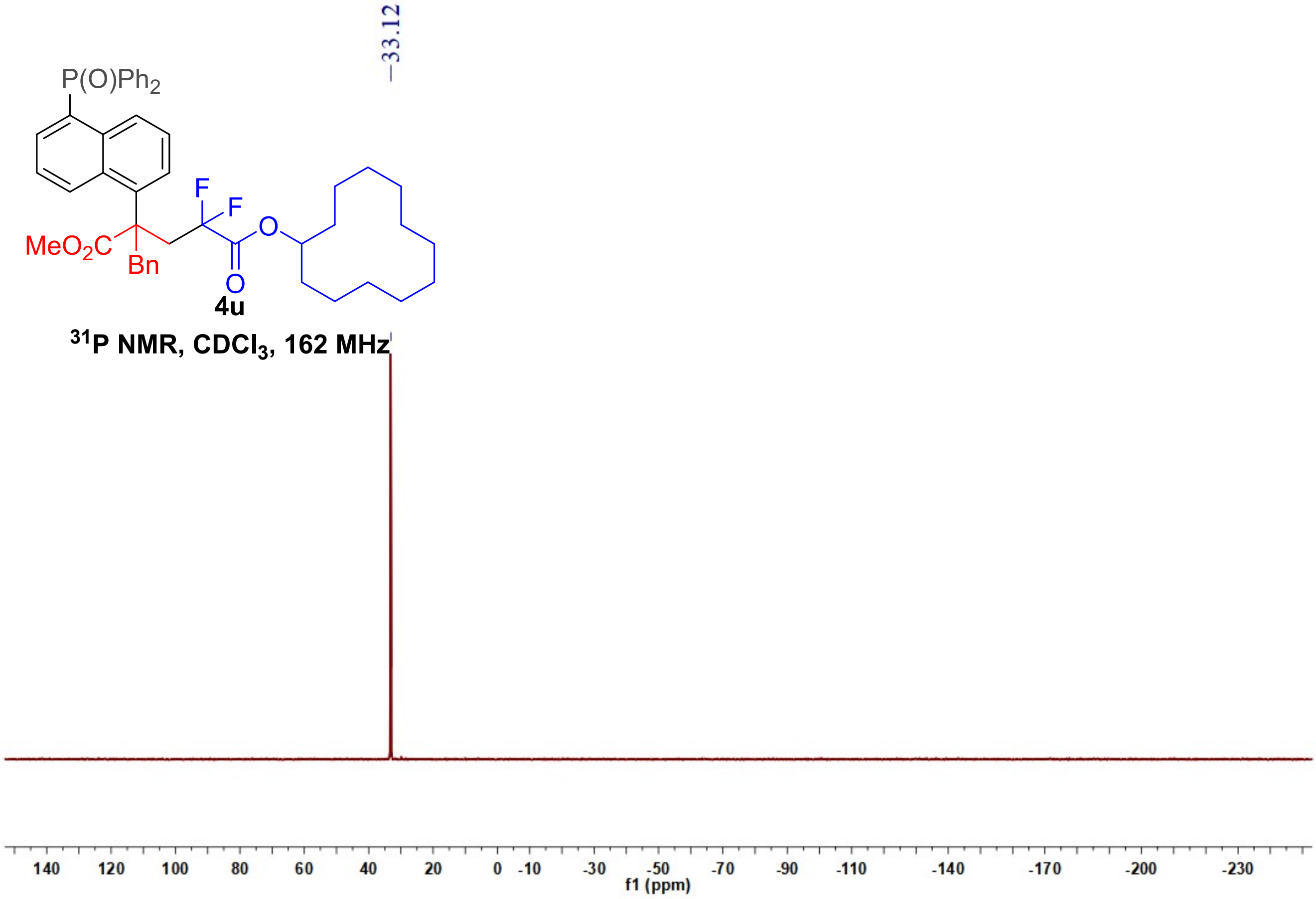
^{19}F NMR, CDCl$_3$, 471 MHz

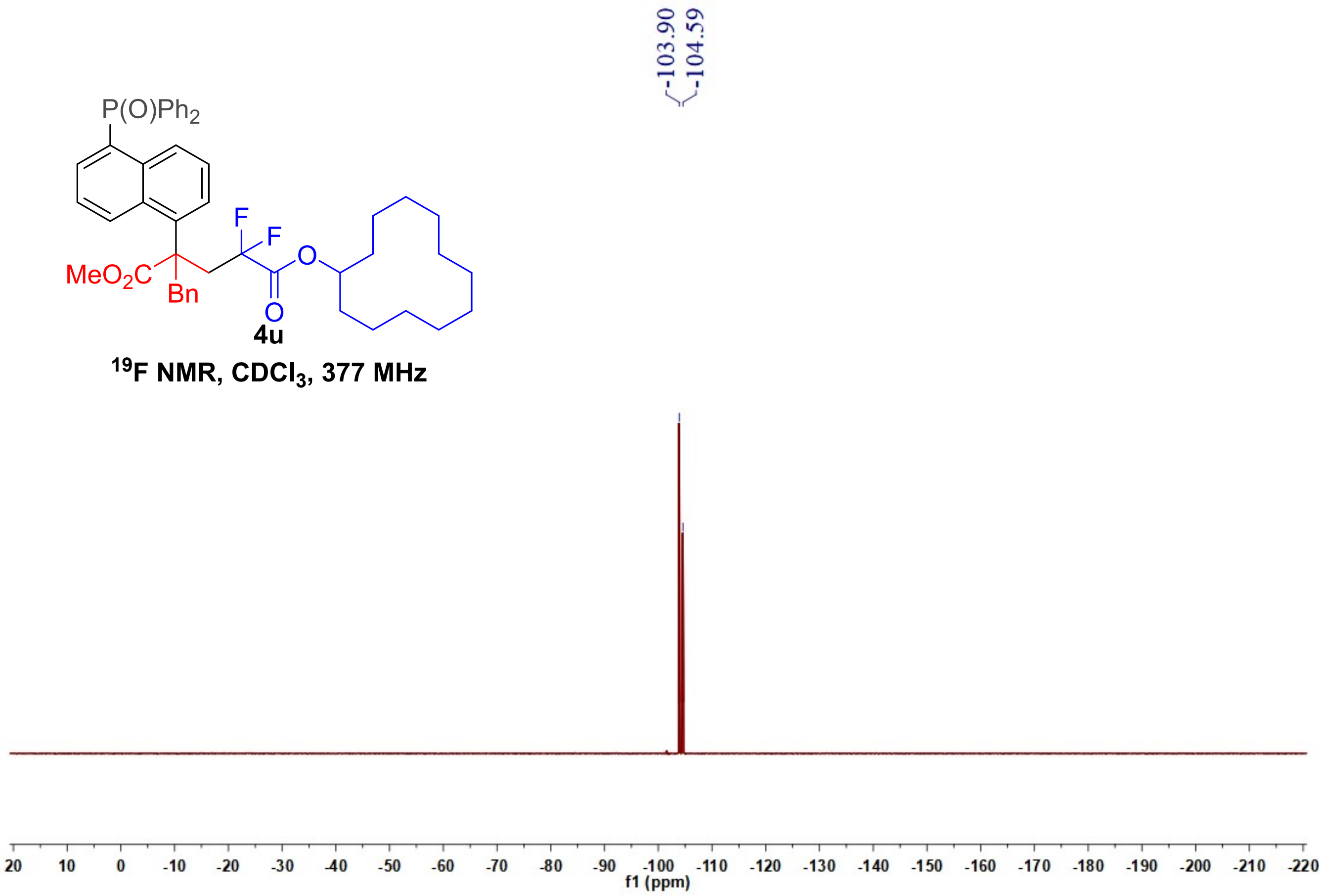


4u

^{1}H NMR, CDCl$_3$, 400 MHz

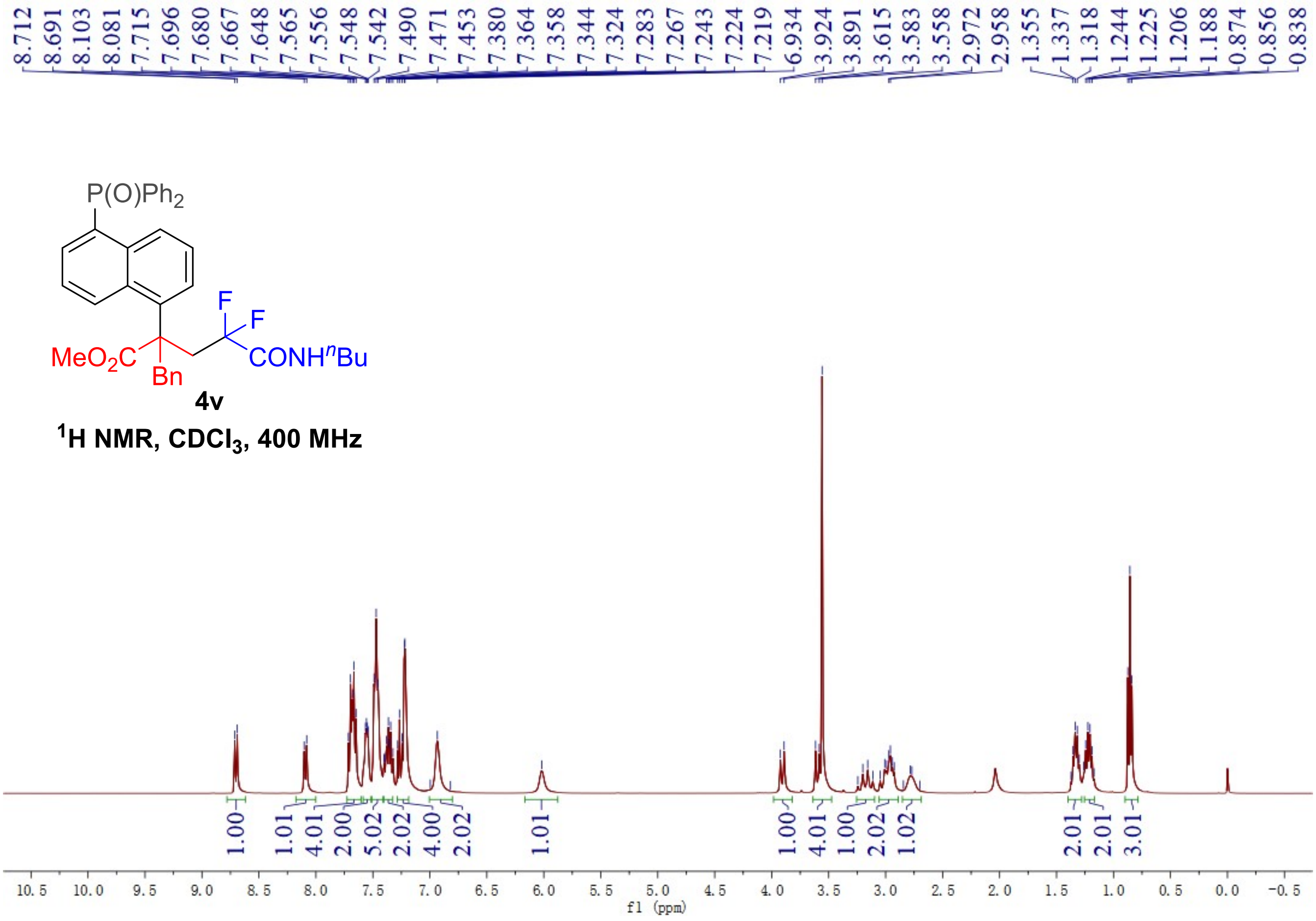

175.76
137.23
135.85
133.39
133.33
133.30
133.21
132.36
132.28
132.18
132.14
132.04
131.04
130.81
128.81
128.78
128.69
128.66
128.39
128.32
128.21
128.08
128.06
127.24
126.42
125.92
124.78
124.63
76.45
52.56
52.09
42.07
28.17
28.15
24.44
24.41
24.36
23.07
23.04
22.88
22.84
20.23
20.19
P(O)Ph$_2$
F
F
MeO$_2$C
Bn
O
O
4u
^{13}C NMR, CDCl$_3$, 101 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


33.12
P(O)Ph$_2$
F
F
MeO$_2$C
Bn
O
O
4u
^{31}P NMR, CDCl$_3$, 162 MHz
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-110
-140
-170
-200
-230
f1 (ppm)



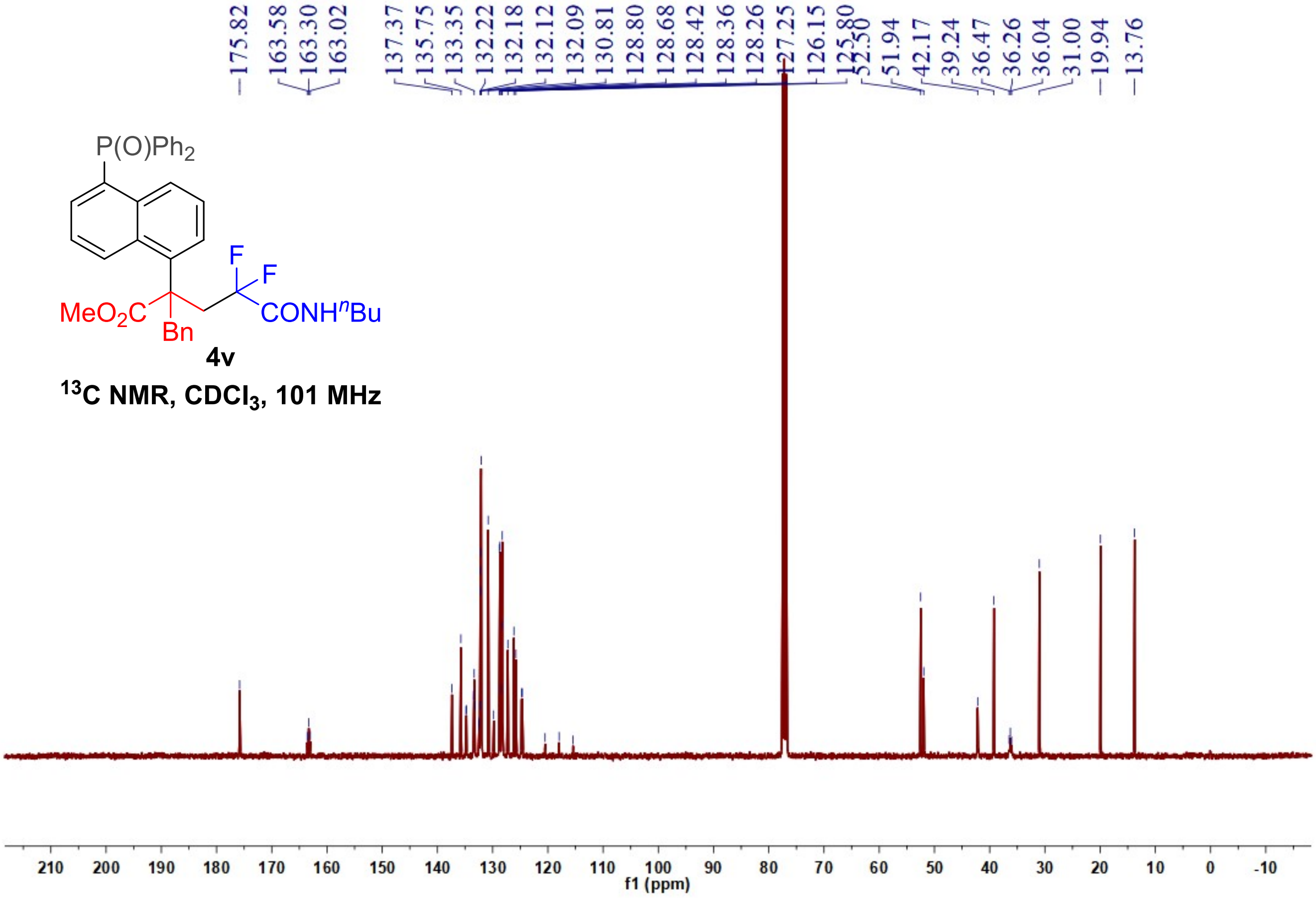
4u

^{19}F NMR, CDCl$_3$, 377 MHz



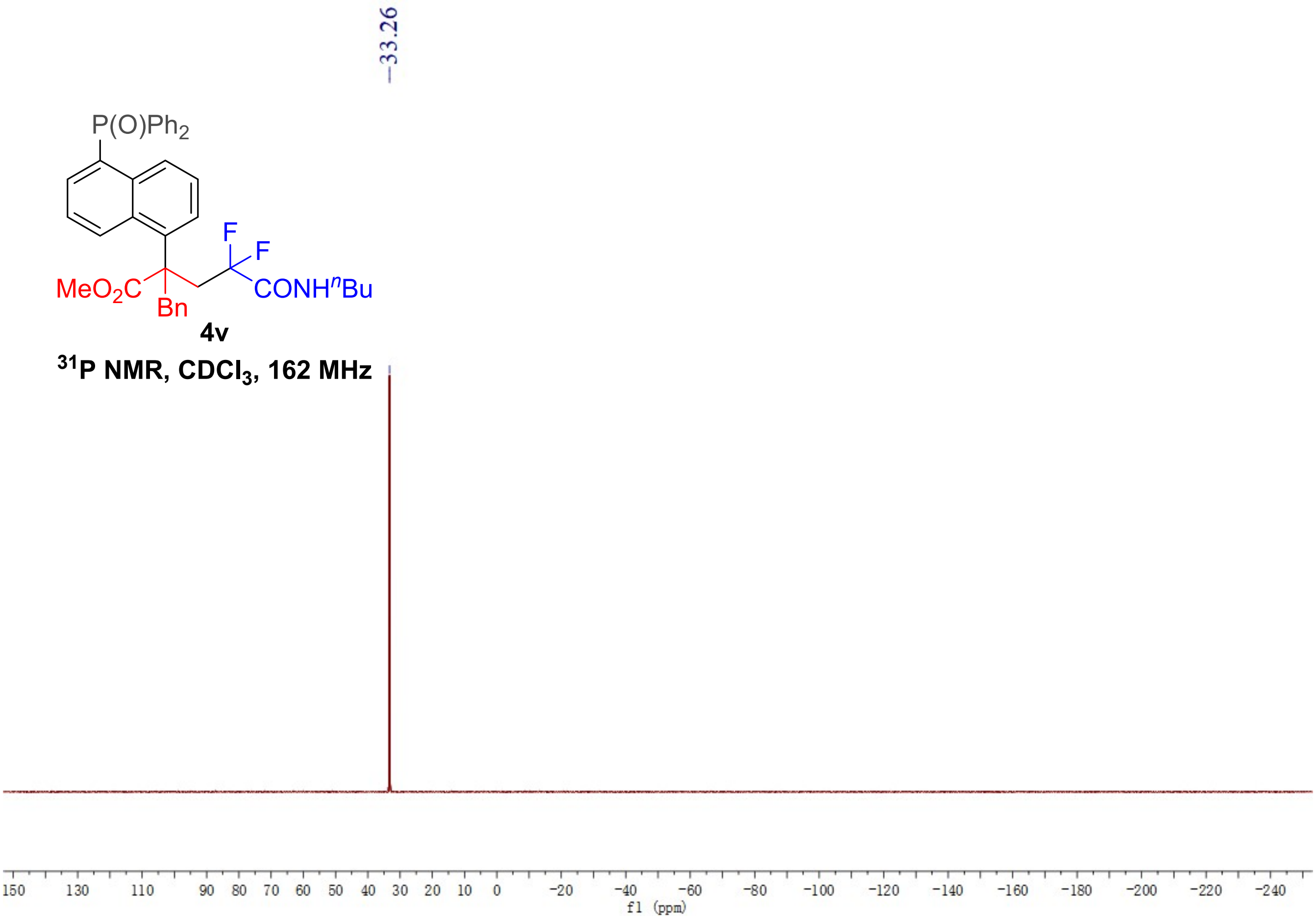
4v

^{1}H NMR, CDCl$_3$, 400 MHz



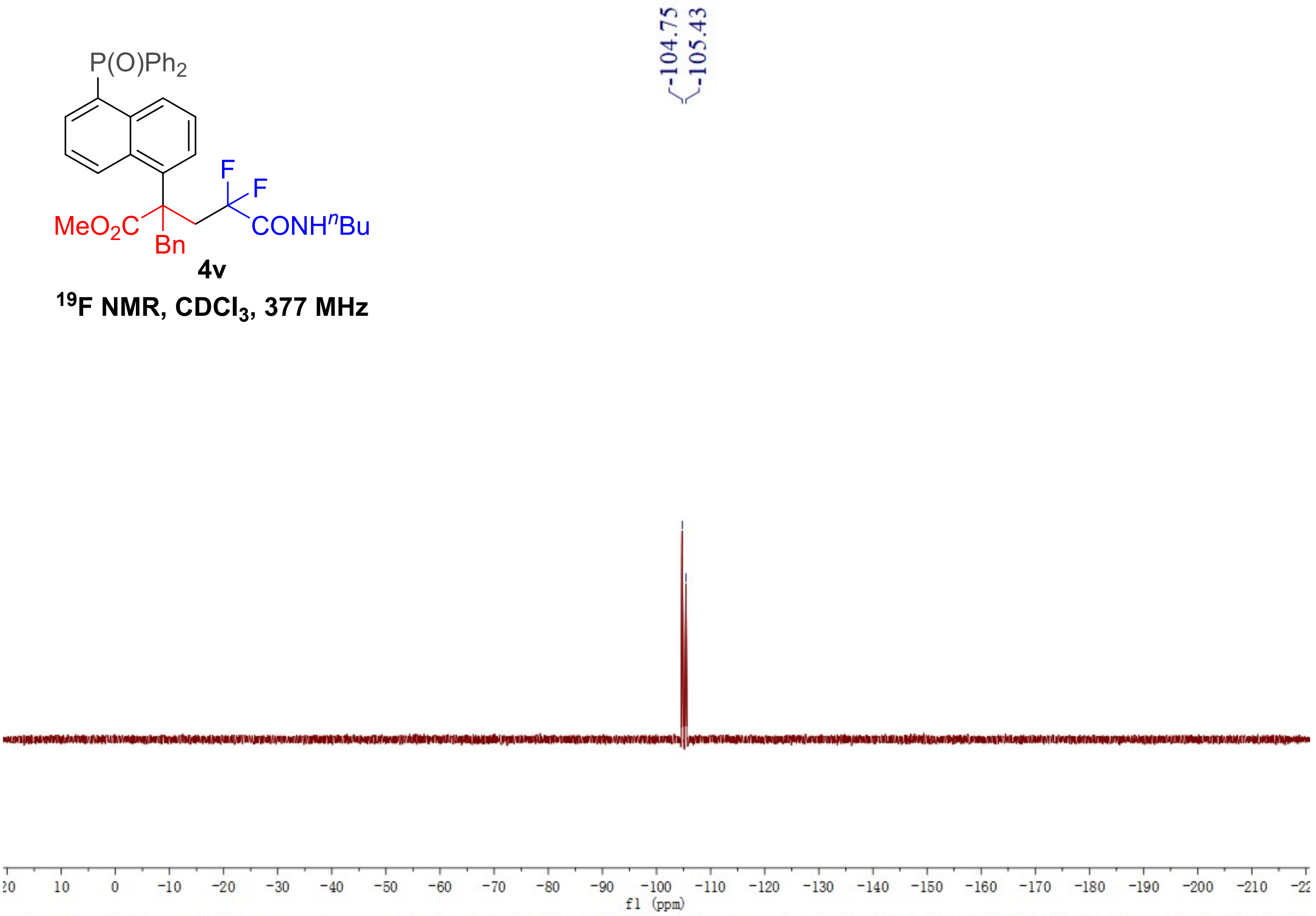
4v

^{13}C NMR, CDCl$_3$, 101 MHz



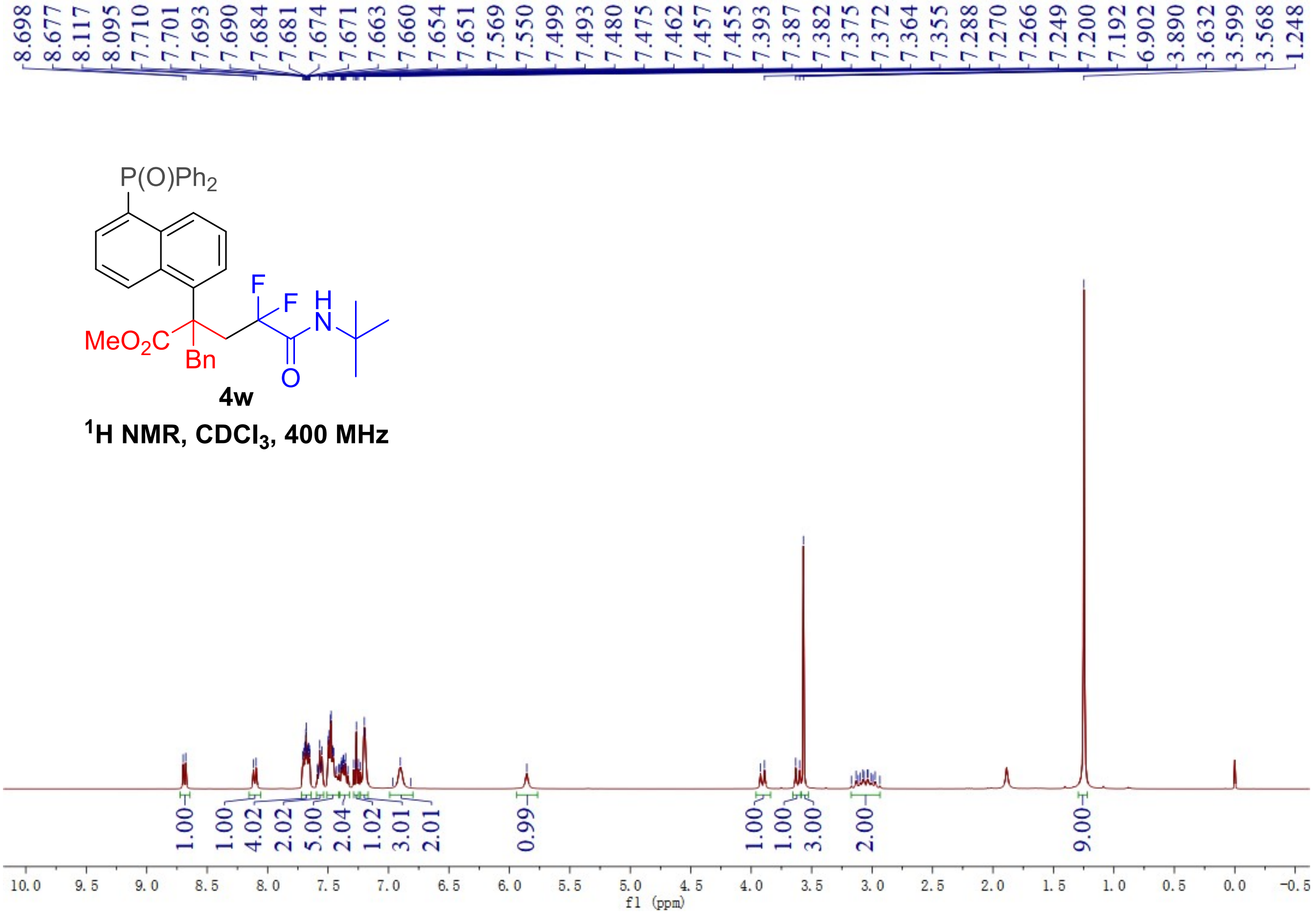
4v

^{31}P NMR, CDCl$_3$, 162 MHz



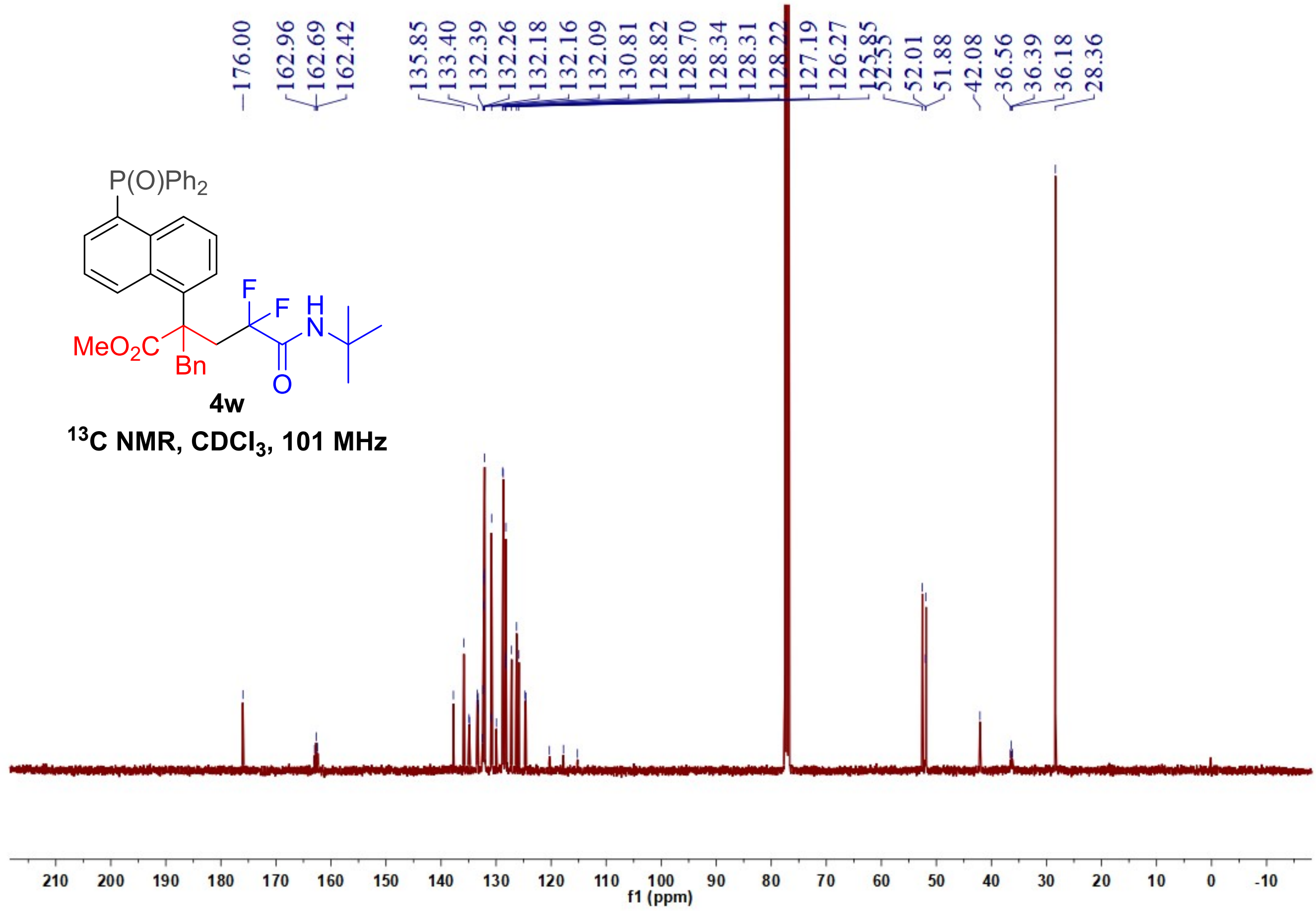
4v

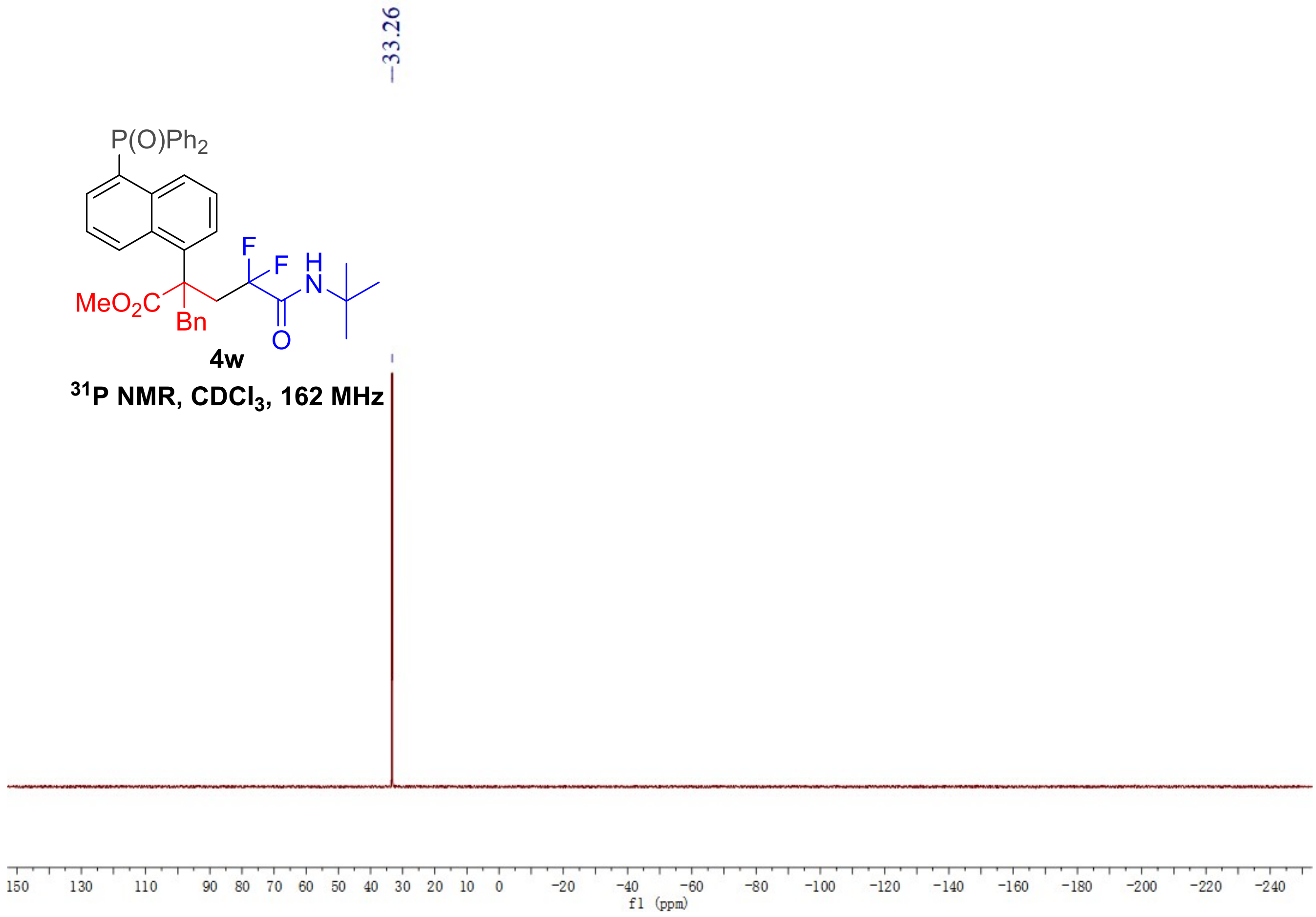
^{19}F NMR, CDCl$_3$, 377 MHz



4w

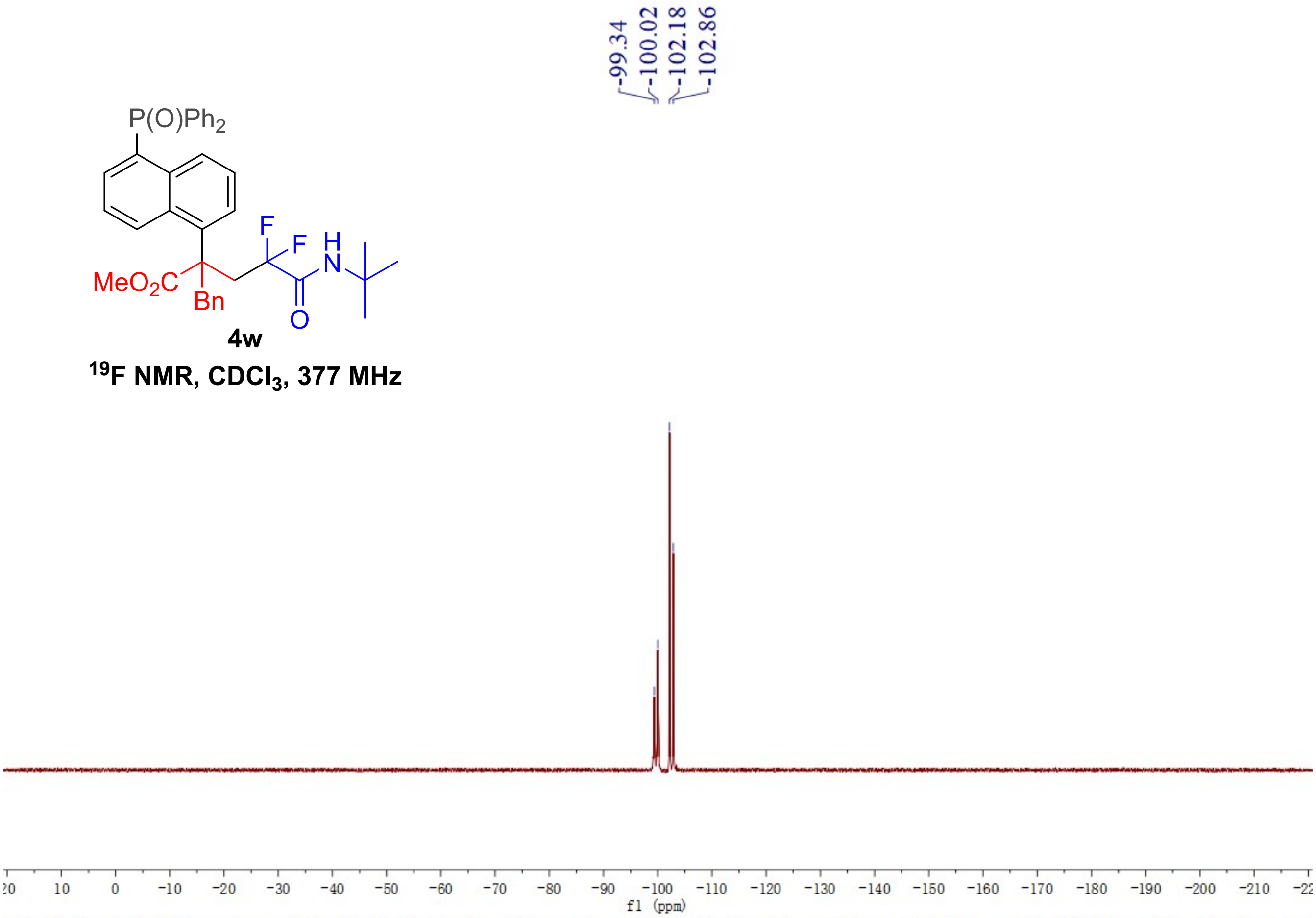
^{1}H NMR, CDCl$_3$, 400 MHz

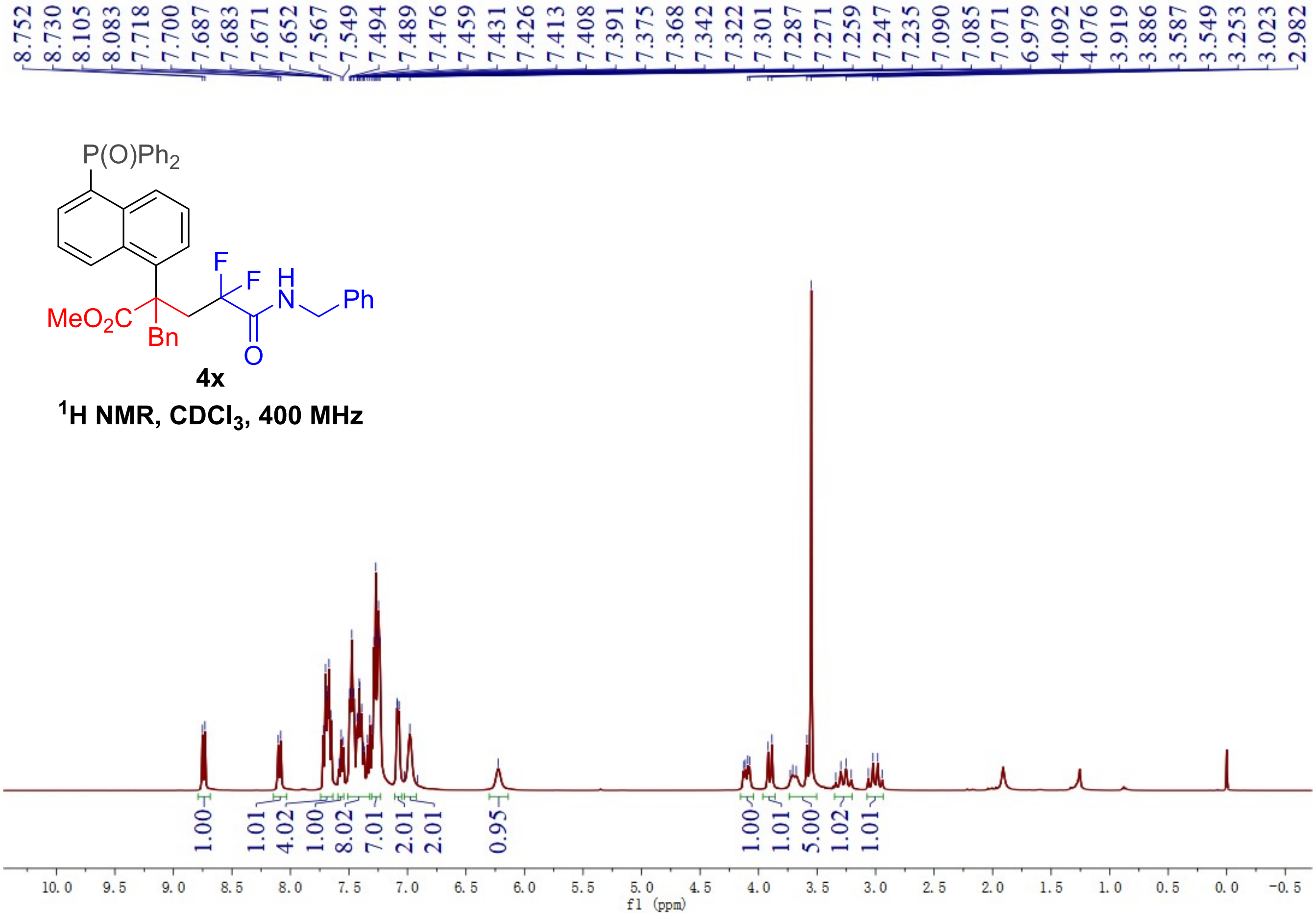

176.00
162.96
162.69
162.42
135.85
133.40
132.39
132.26
132.18
132.16
132.09
130.81
128.82
128.70
128.34
128.31
128.22
127.19
126.27
125.85
52.55
52.01
51.88
42.08
36.56
36.39
36.18
28.36
P(O)Ph2
F
F
H
N
MeO2C
Bn
O
4w
13C NMR, CDCl3, 101 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


33.26
P(O)Ph2
F
F
H
N
MeO2C
Bn
O
4w
31P NMR, CDCl3, 162 MHz
150 130 110 90 80 70 60 50 40 30 20 10 0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 -220 -240
f1 (ppm)

4w

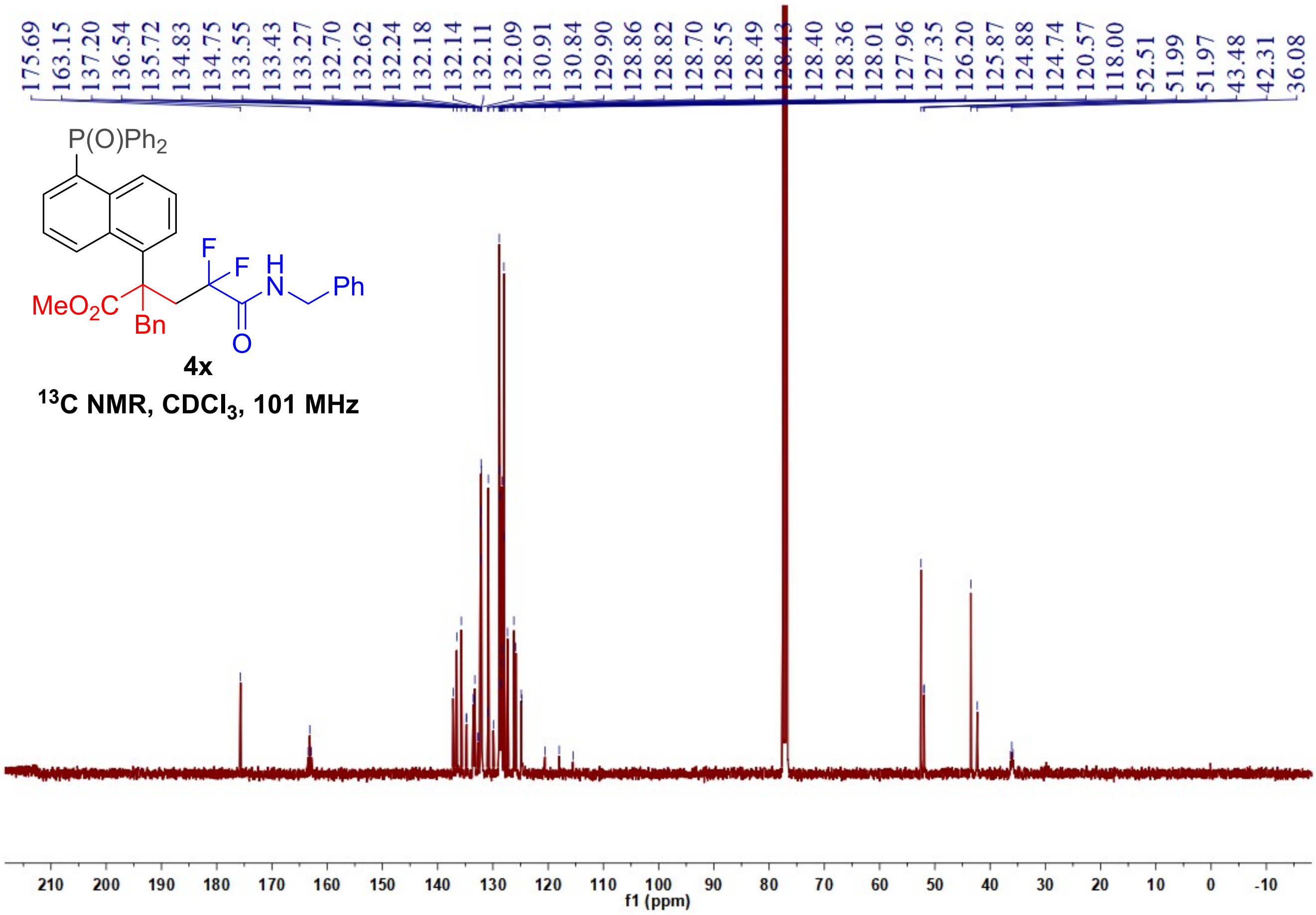
^{19}F NMR, CDCl$_3$, 377 MHz





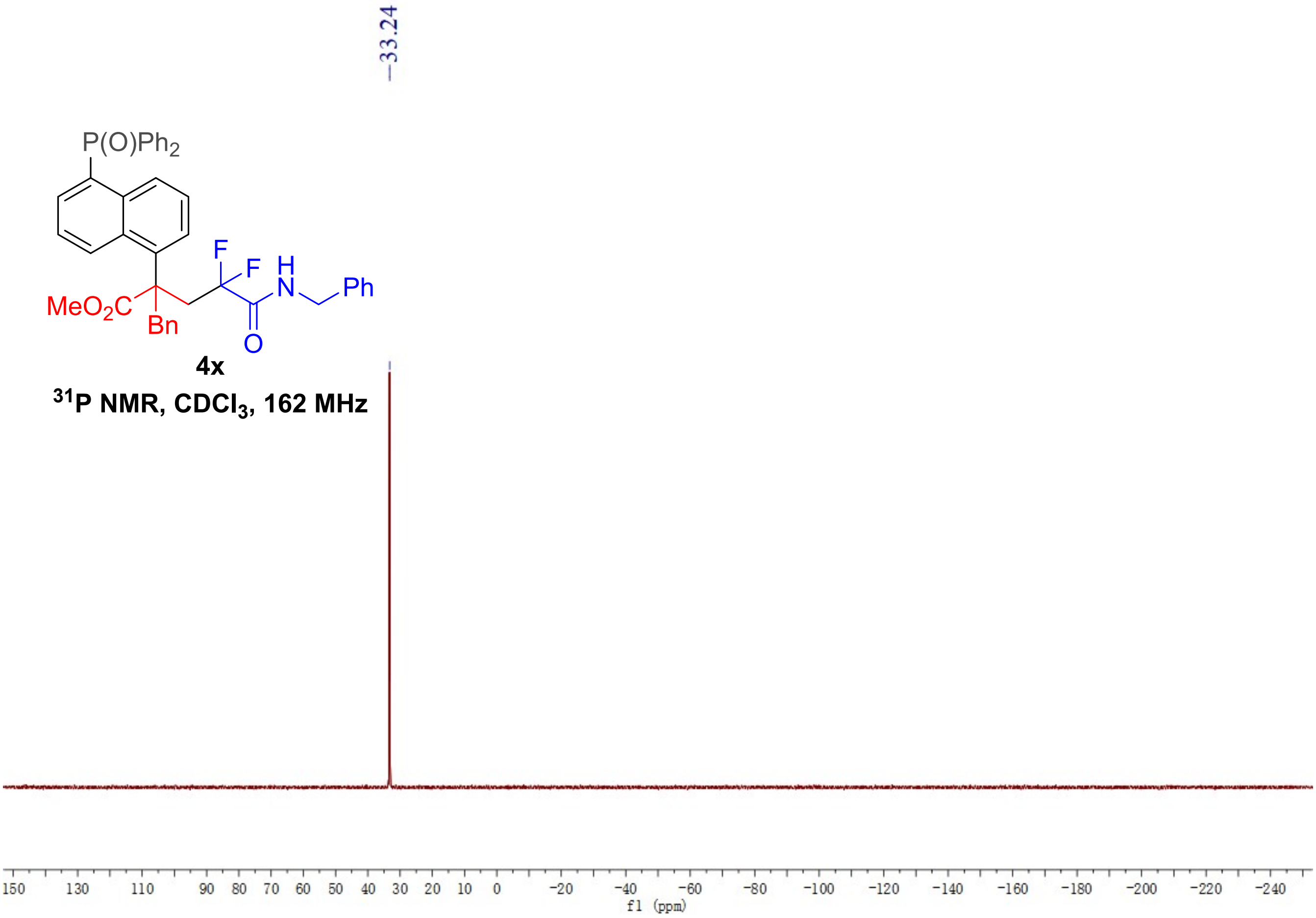
4x

^{1}H NMR, CDCl$_3$, 400 MHz



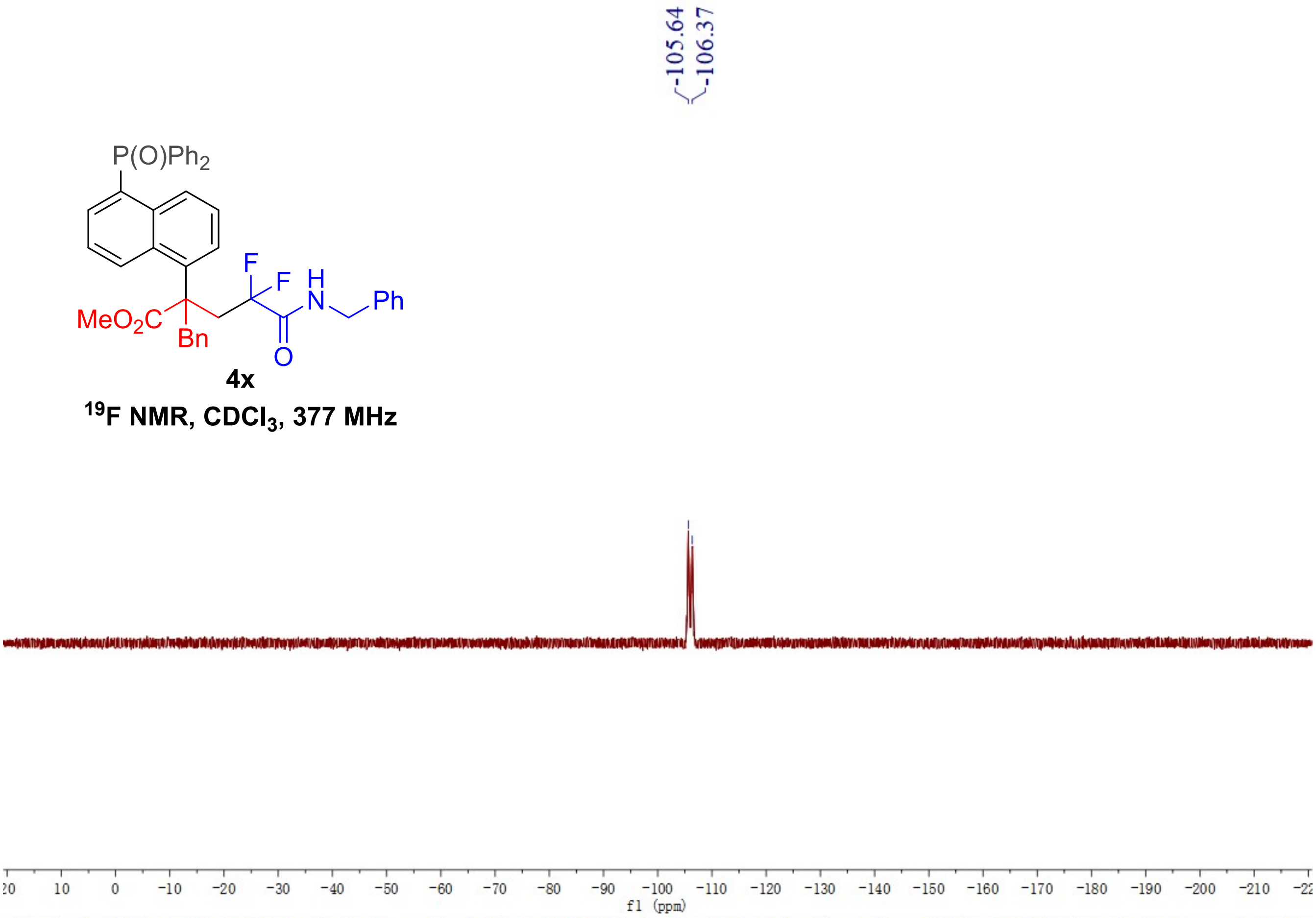
4x

^{13}C NMR, CDCl$_3$, 101 MHz



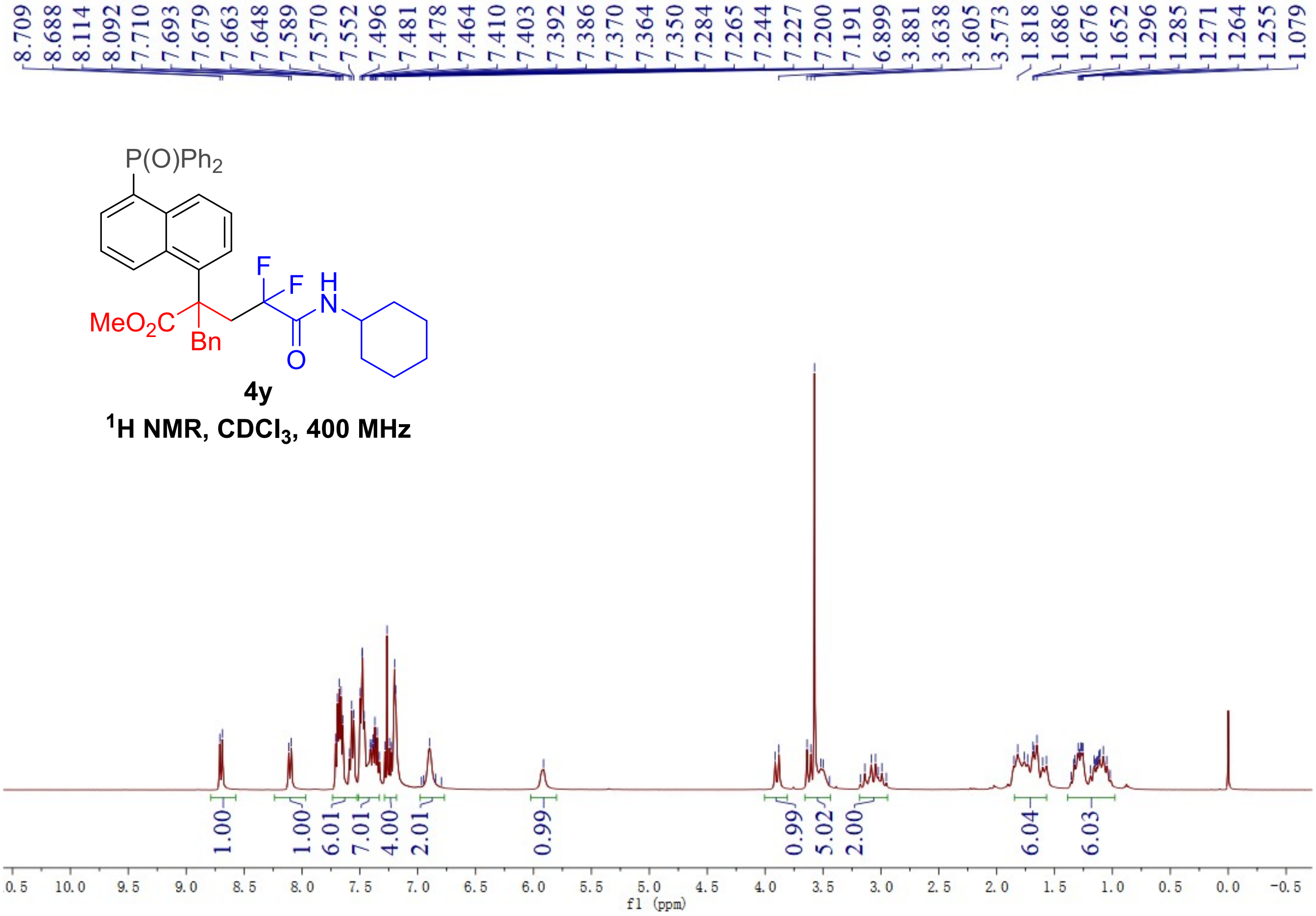
4x

^{31}P NMR, CDCl$_3$, 162 MHz



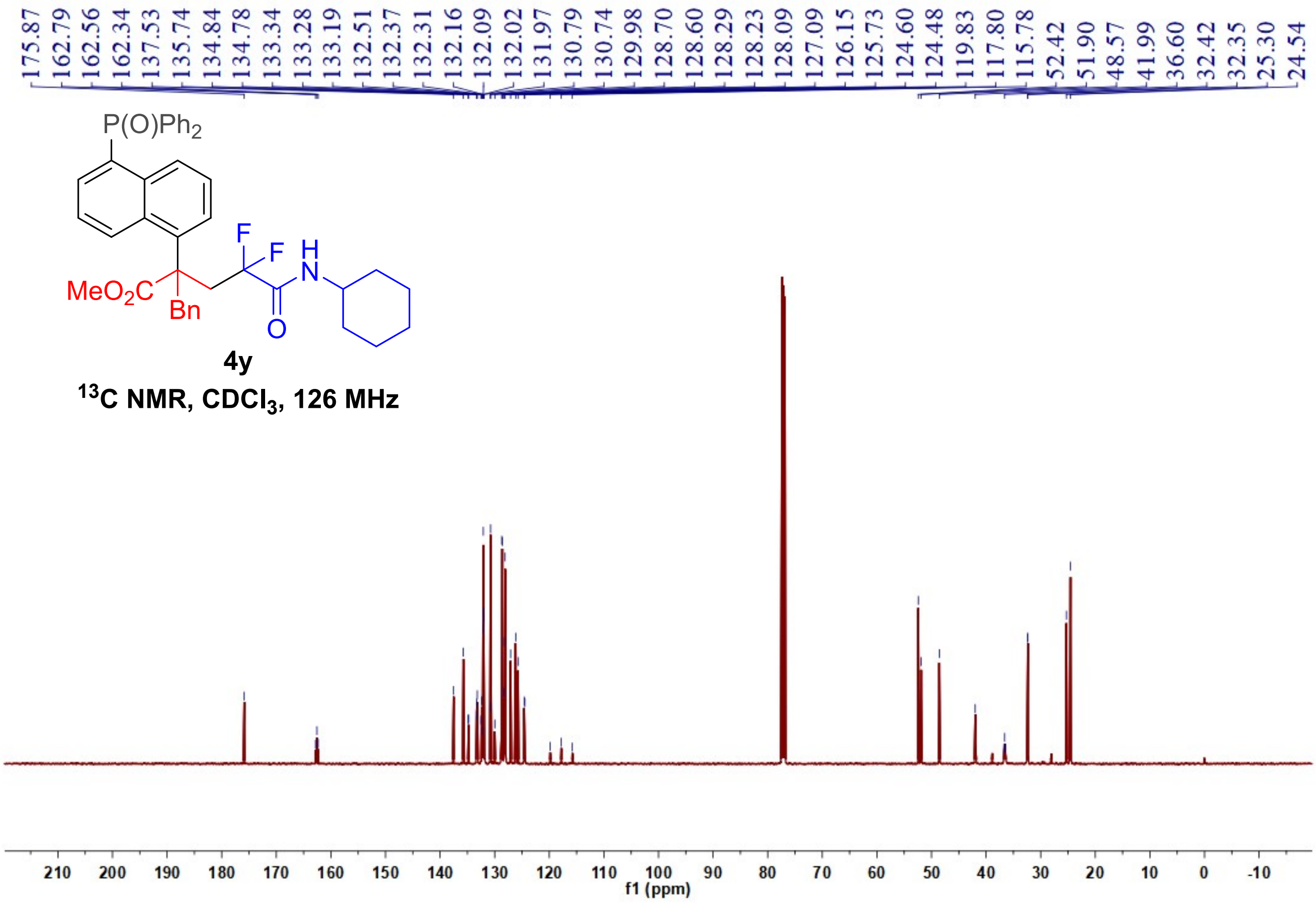
4x

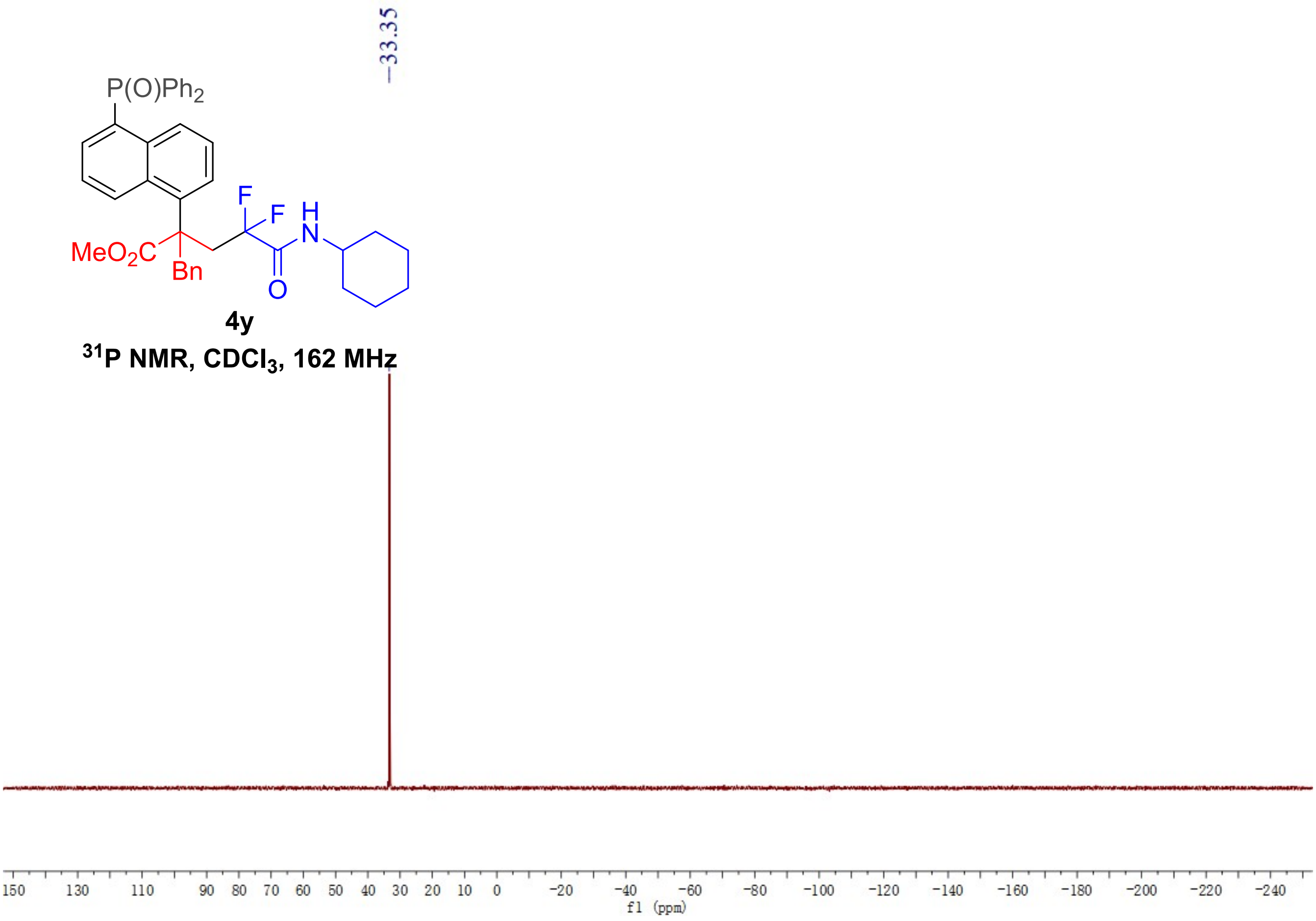
^{19}F NMR, CDCl$_3$, 377 MHz

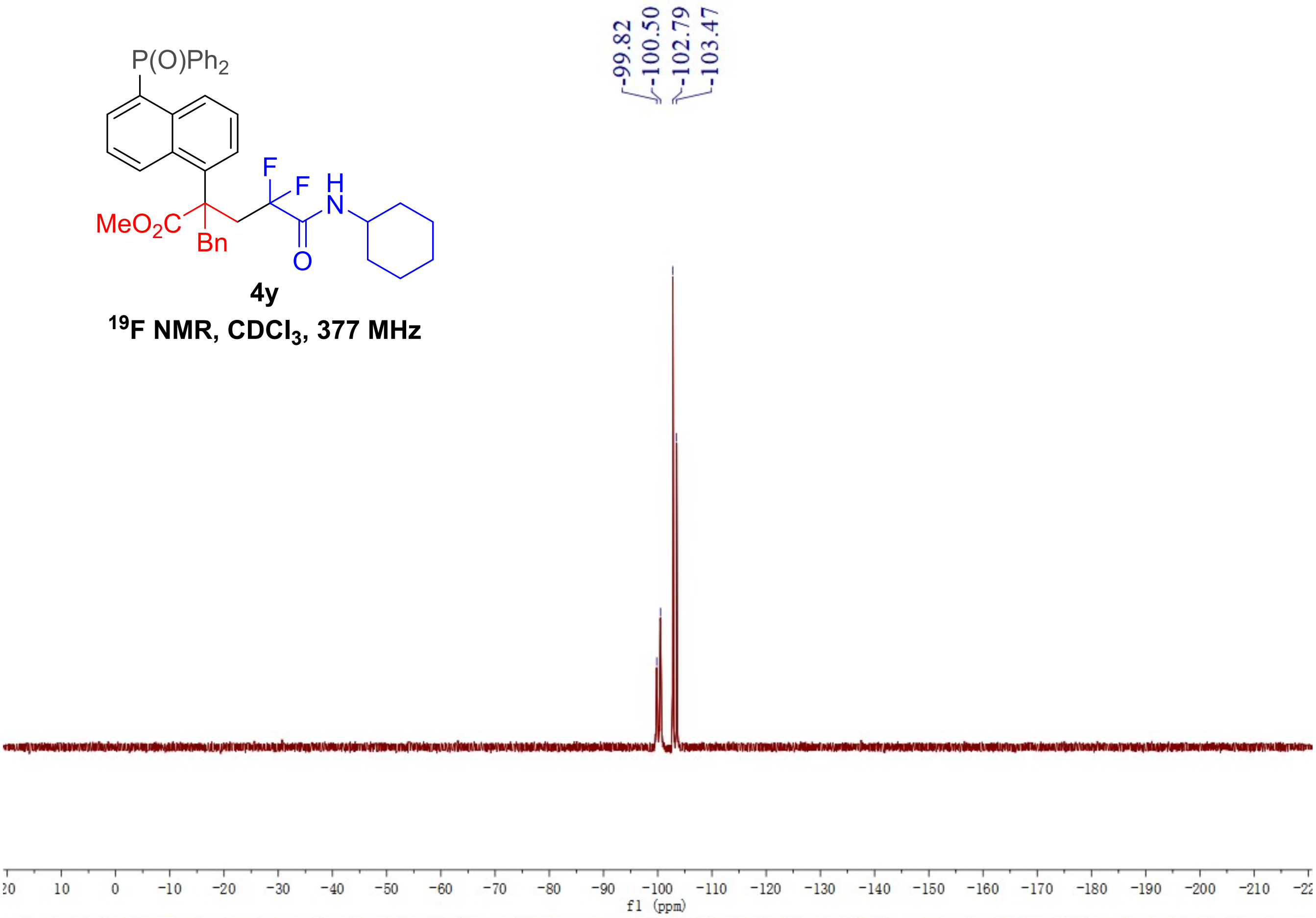


4y

^{1}H NMR, CDCl$_3$, 400 MHz

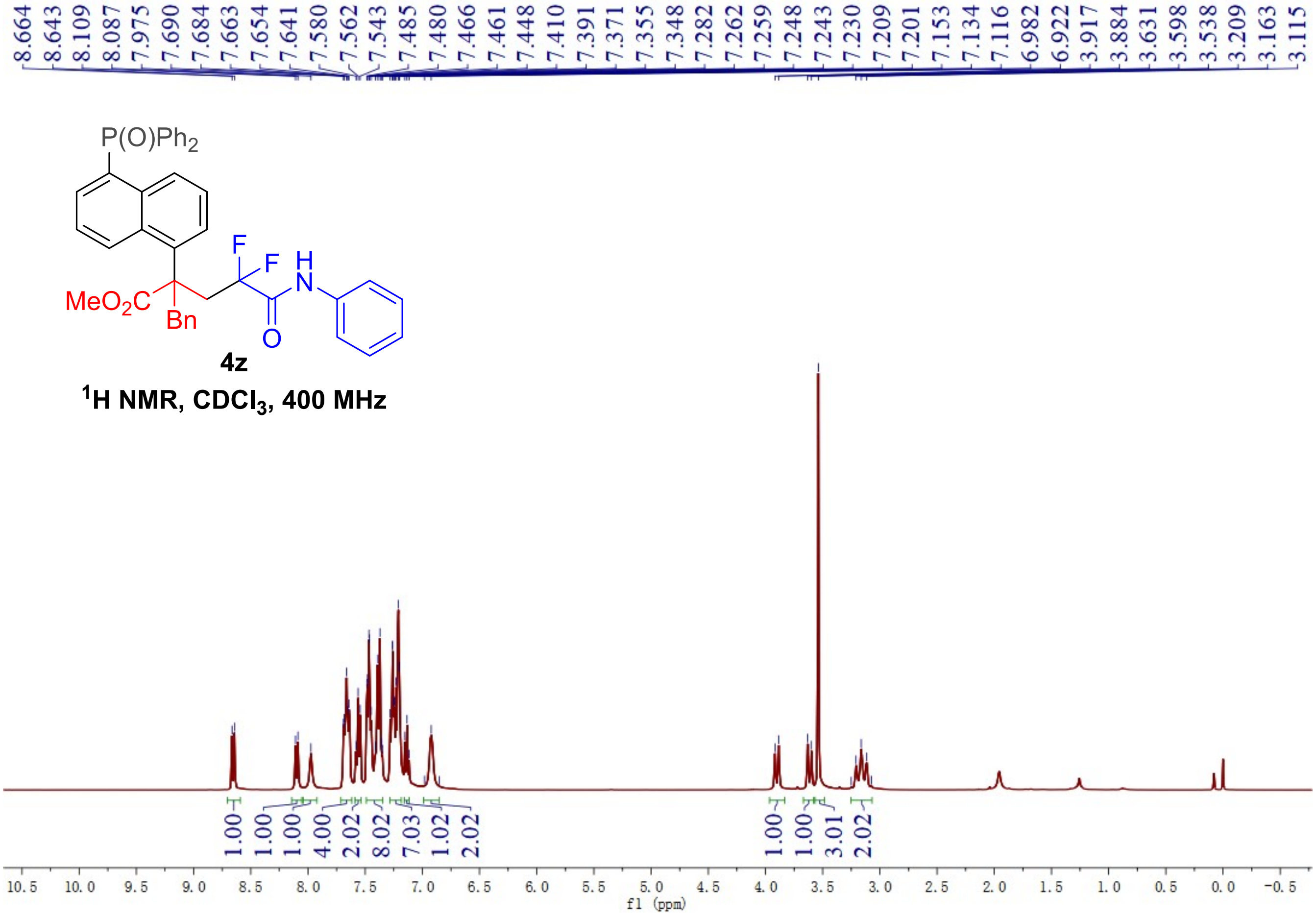

175.87
162.79
162.56
162.34
137.53
135.74
134.84
134.78
133.34
133.28
133.19
132.51
132.37
132.31
132.16
132.09
132.02
131.97
130.79
130.74
129.98
128.70
128.60
128.29
128.23
128.09
127.09
126.15
125.73
124.60
124.48
119.83
117.80
115.78
52.42
51.90
48.57
41.99
36.60
32.42
32.35
25.30
24.54
P(O)Ph2
MeO2C
Bn
F
F
H
N
O
4y
13C NMR, CDCl3, 126 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


33.35
P(O)Ph2
MeO2C
Bn
F
F
H
N
O
4y
31P NMR, CDCl3, 162 MHz
150
130
110
90
80
70
60
50
40
30
20
10
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
f1 (ppm)



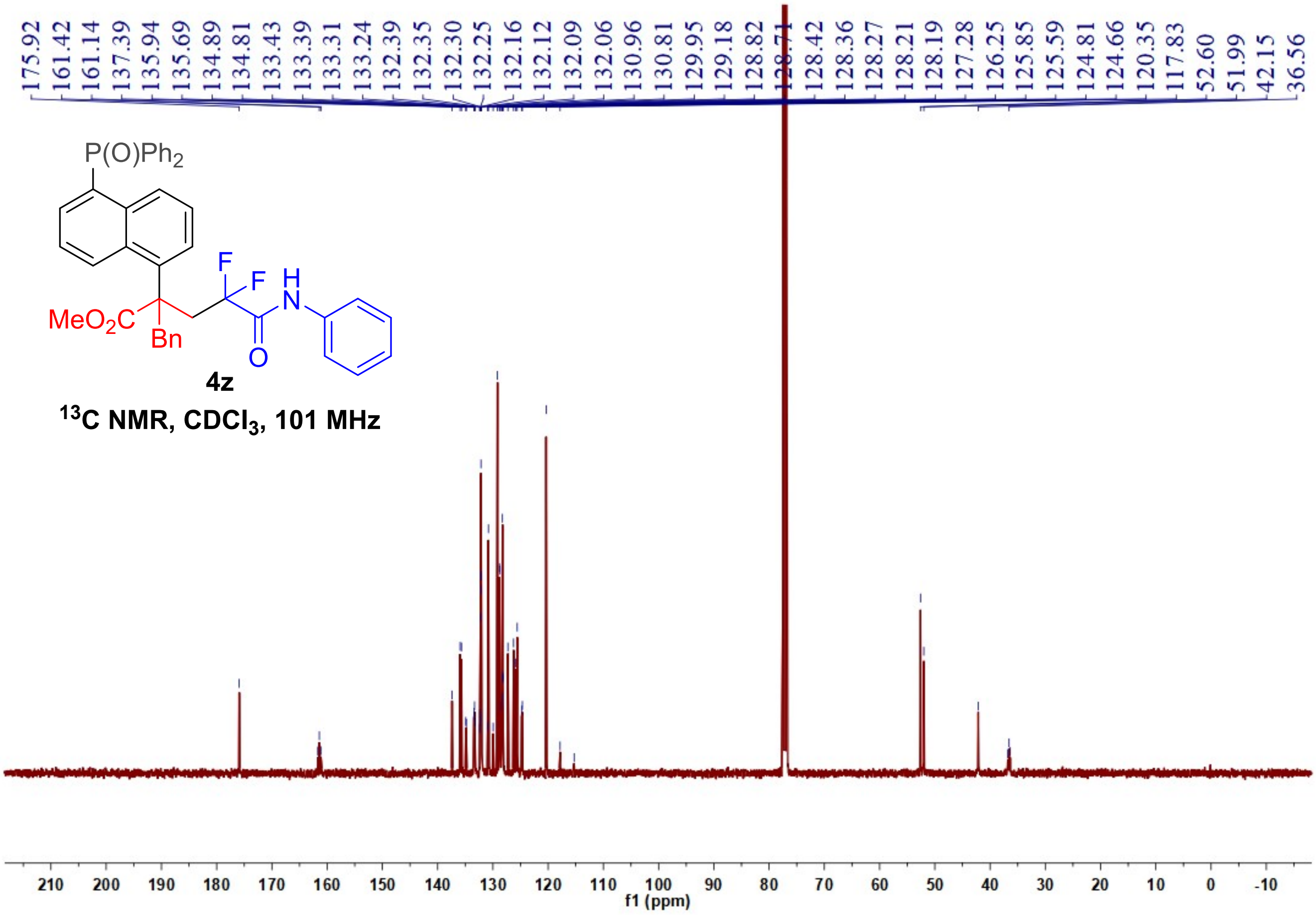
4y

^{19}F NMR, CDCl$_3$, 377 MHz



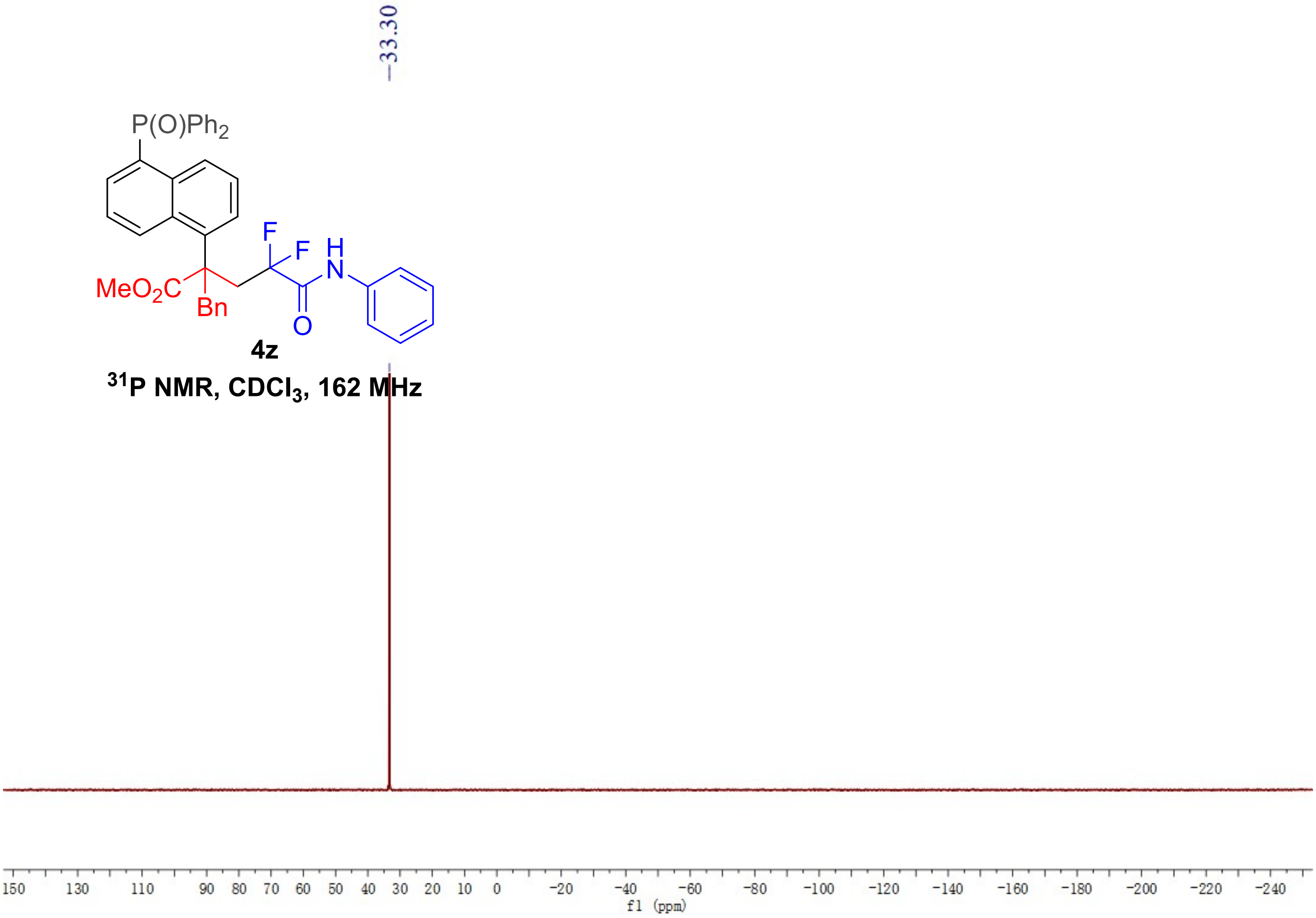
4z

^{1}H NMR, CDCl$_3$, 400 MHz



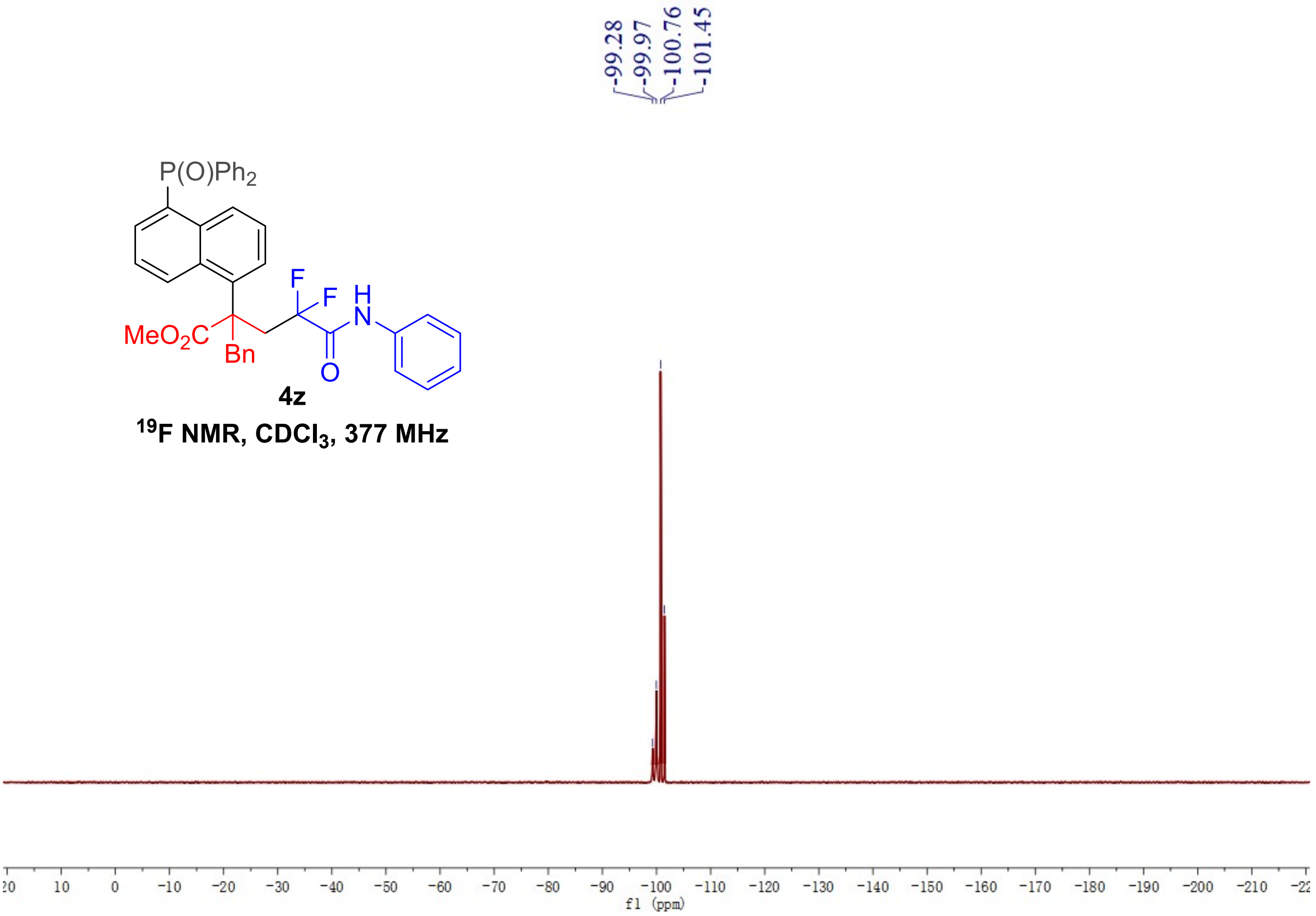
4z

^{13}C NMR, CDCl$_3$, 101 MHz



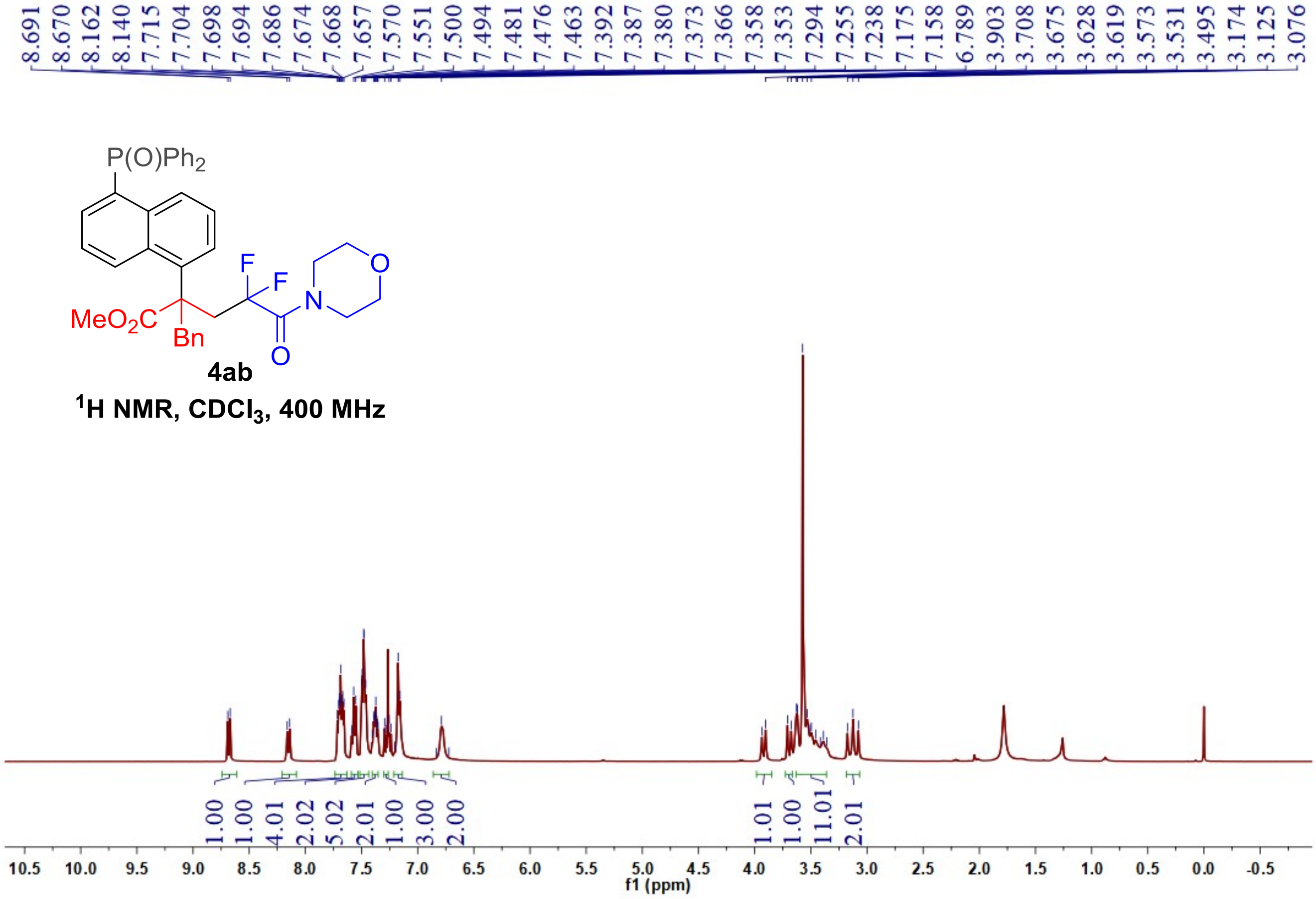
4z

^{31}P NMR, CDCl$_3$, 162 MHz



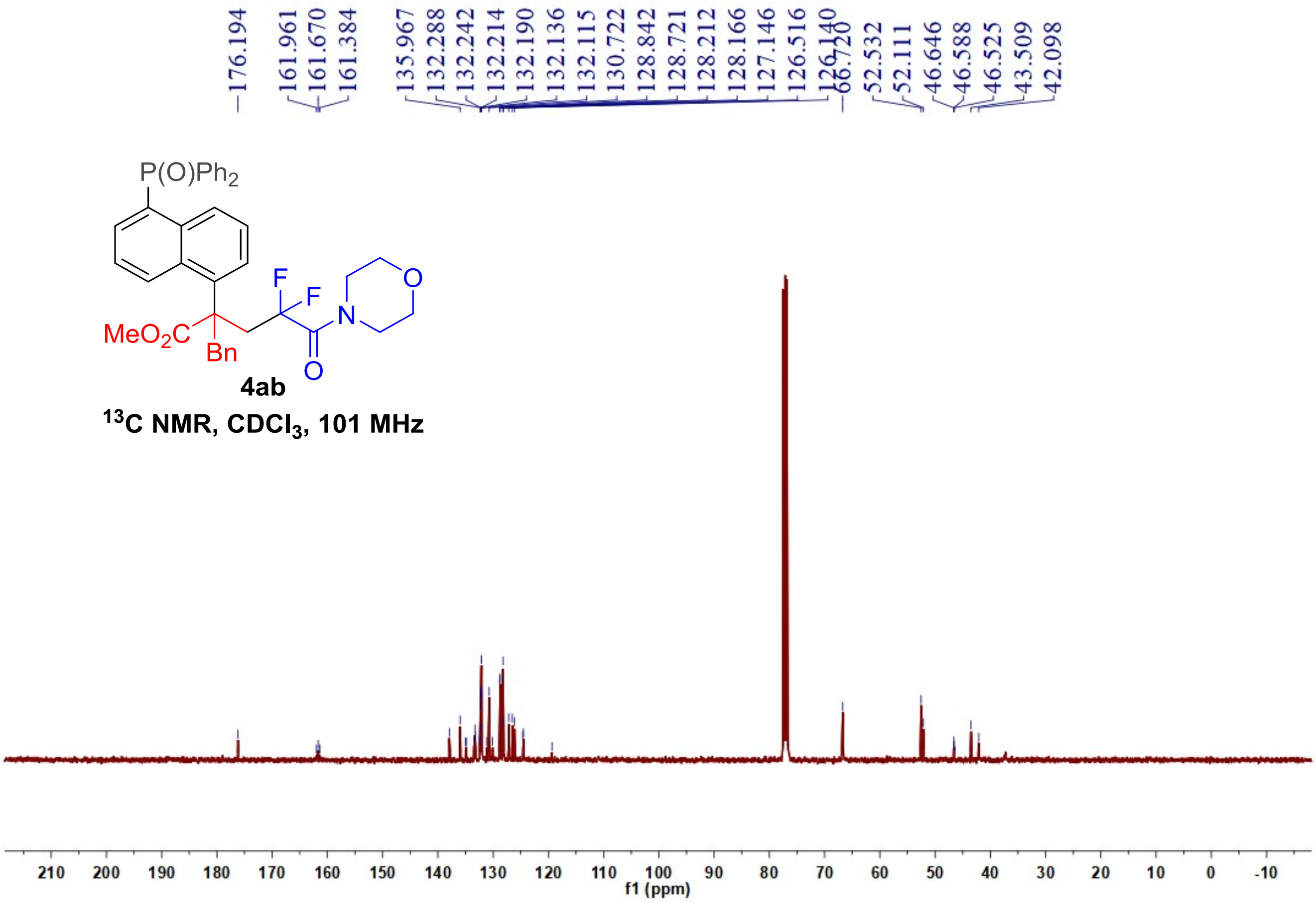
4z

^{19}F NMR, $CDCl_3$, 377 MHz



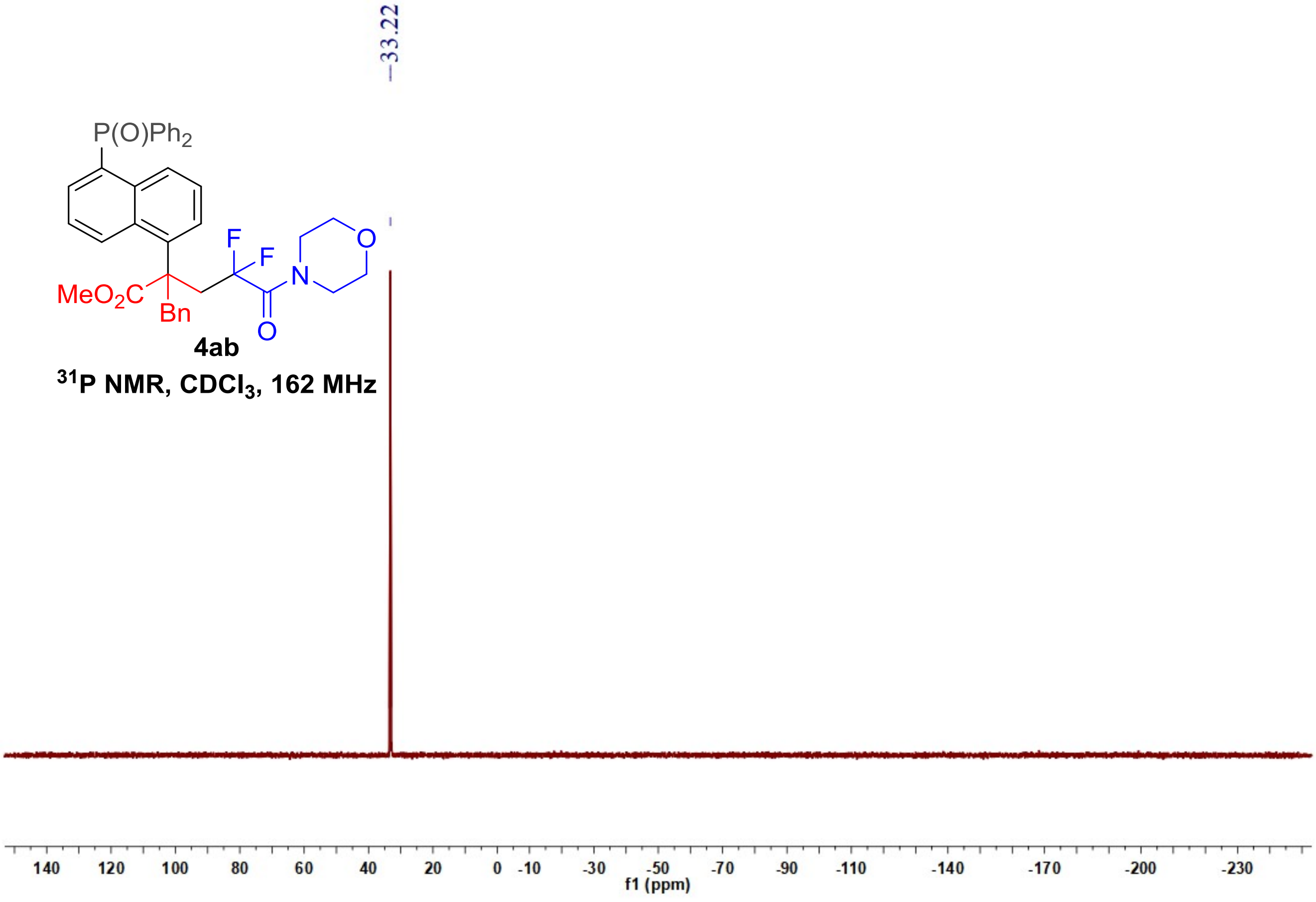
4ab

^{1}H NMR, $CDCl_3$, 400 MHz



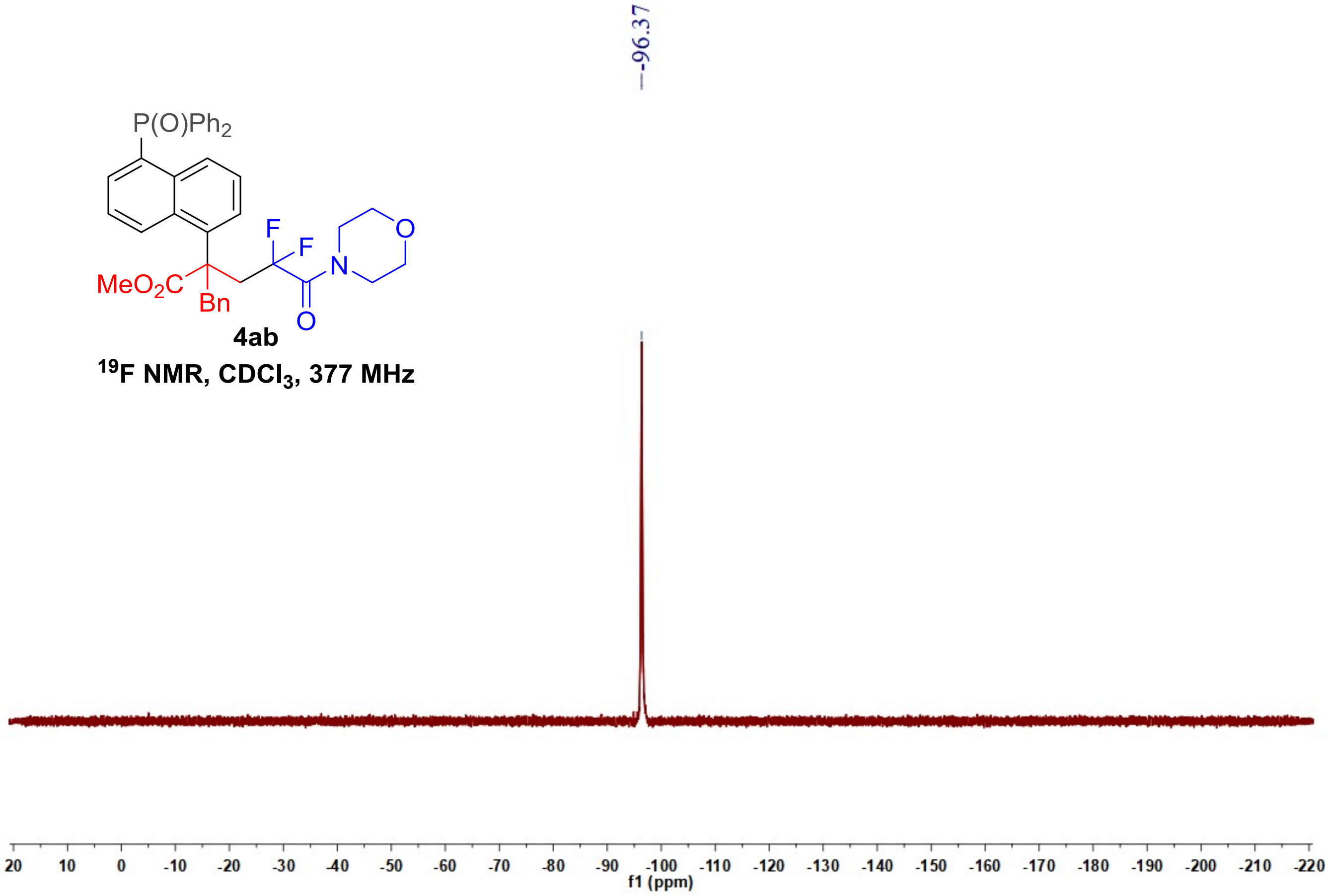
4ab

^{13}C NMR, CDCl$_3$, 101 MHz



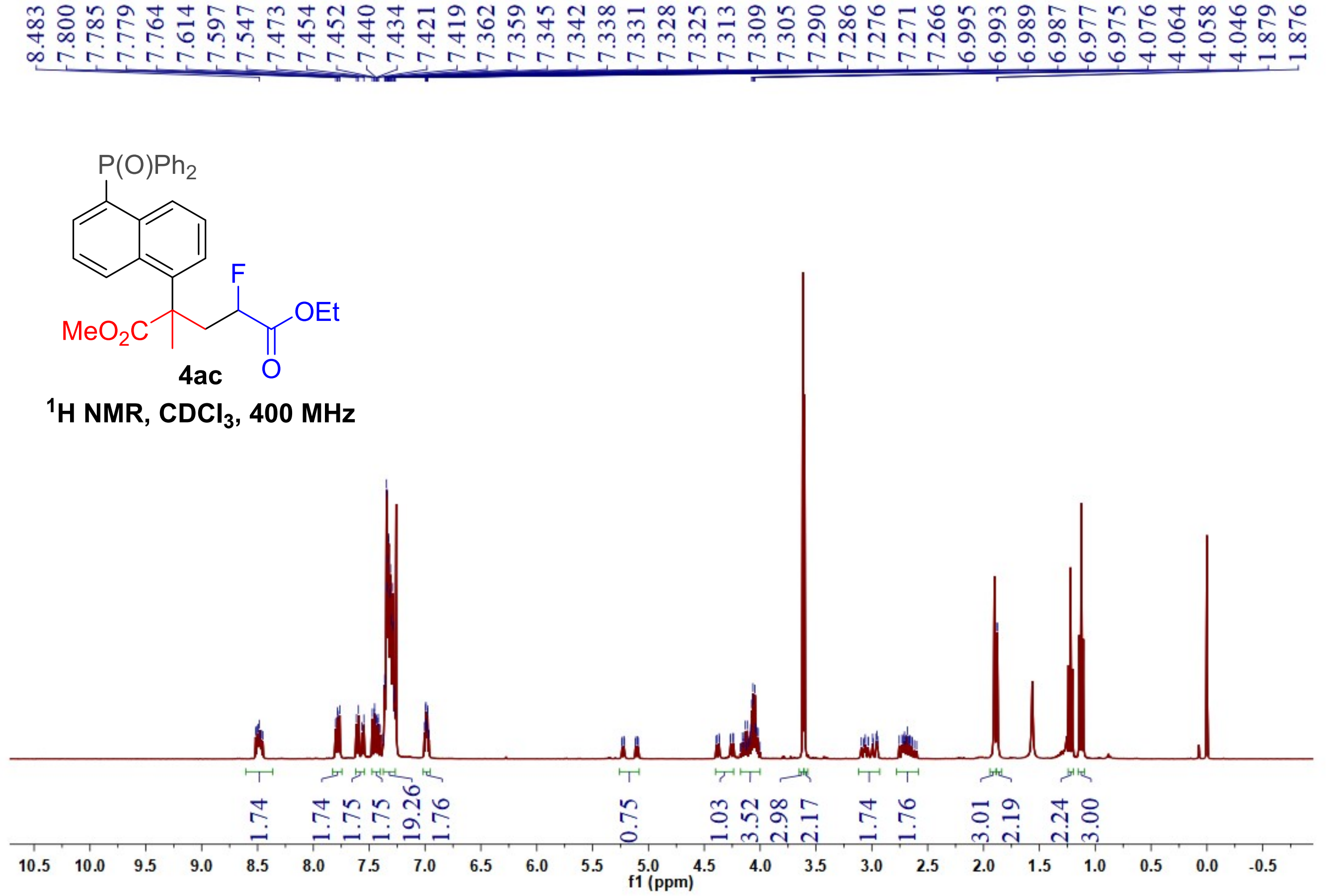
4ab

^{31}P NMR, CDCl$_3$, 162 MHz



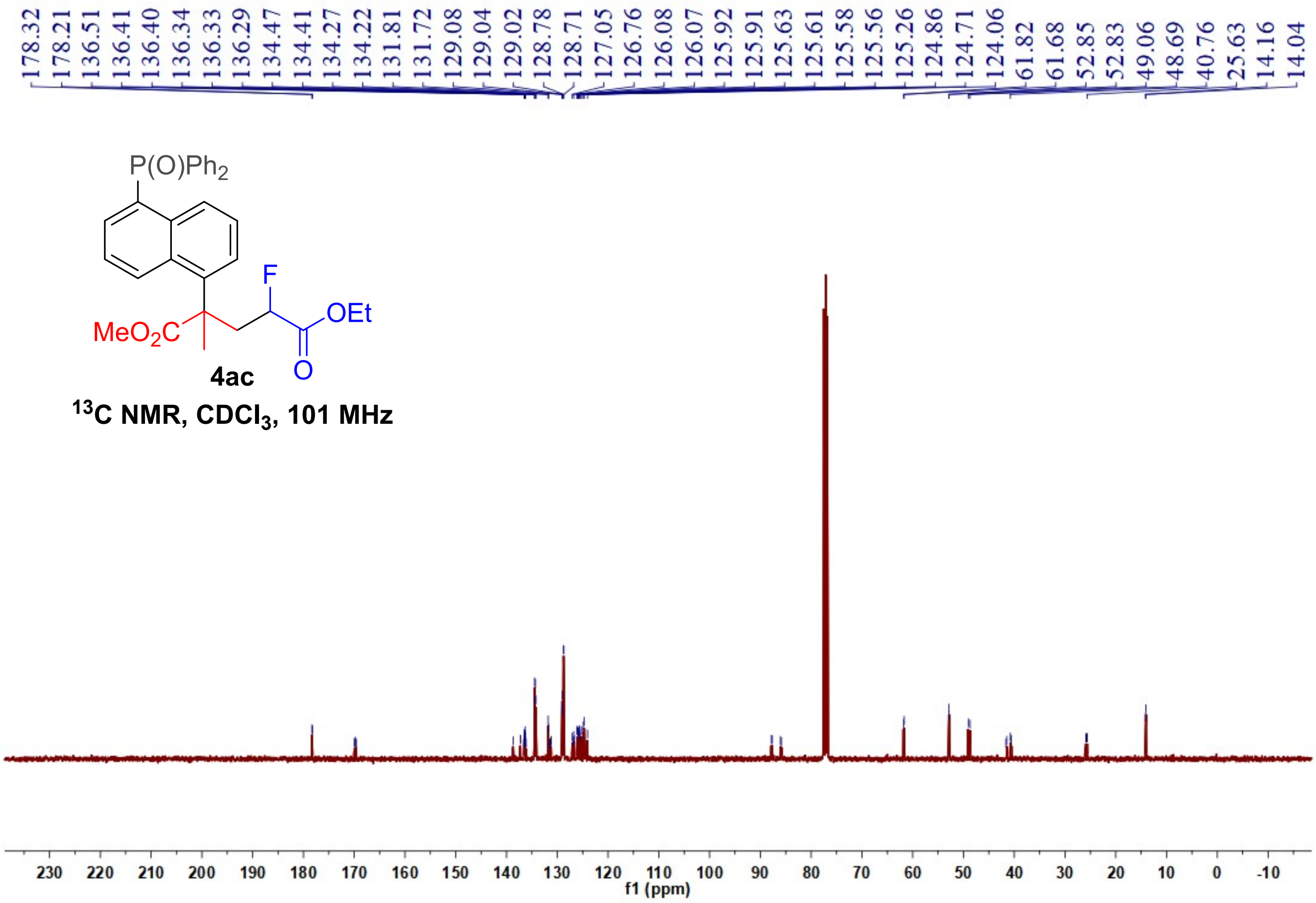
4ab

^{19}F NMR, CDCl$_3$, 377 MHz



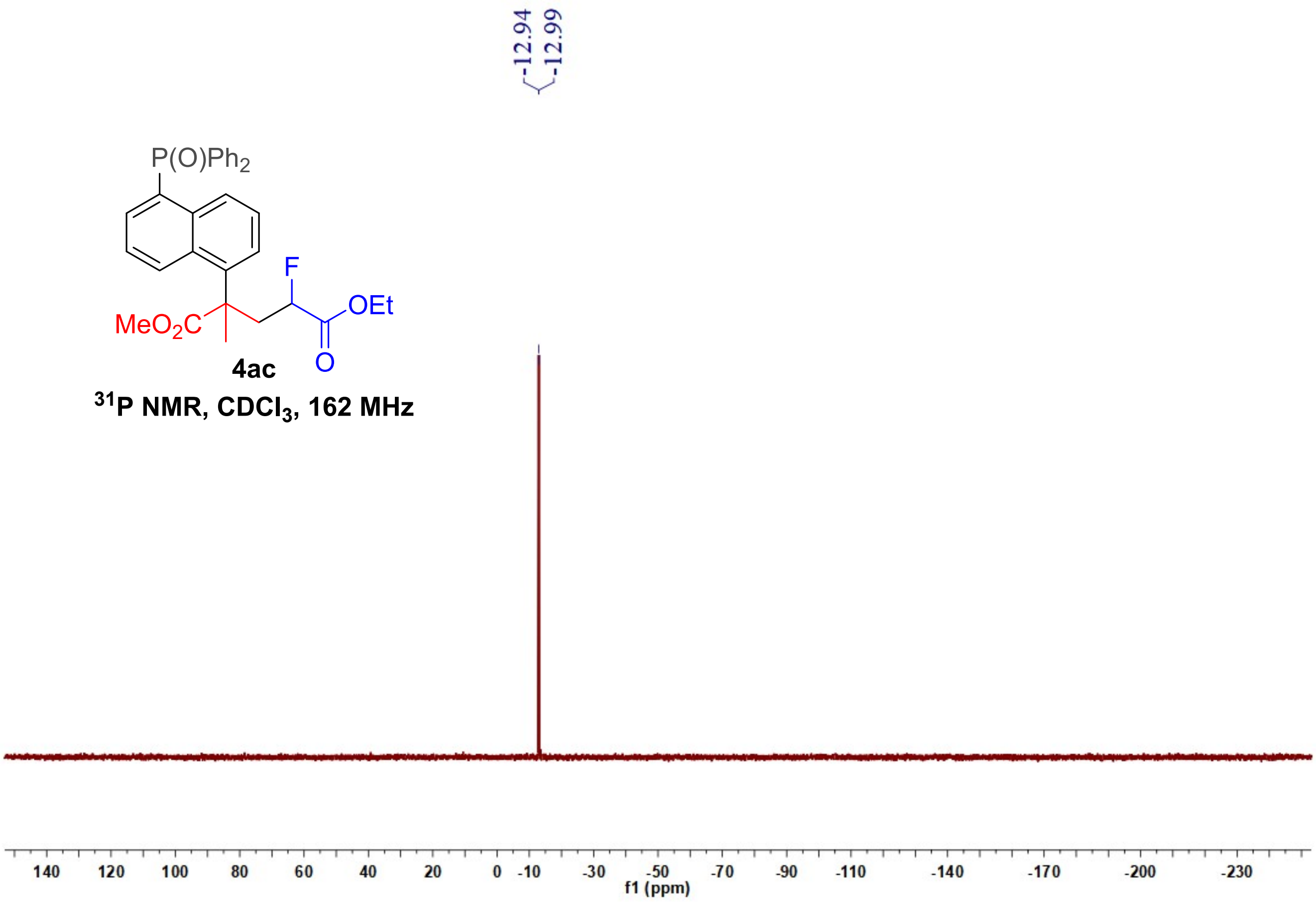
4ac

^{1}H NMR, CDCl$_3$, 400 MHz



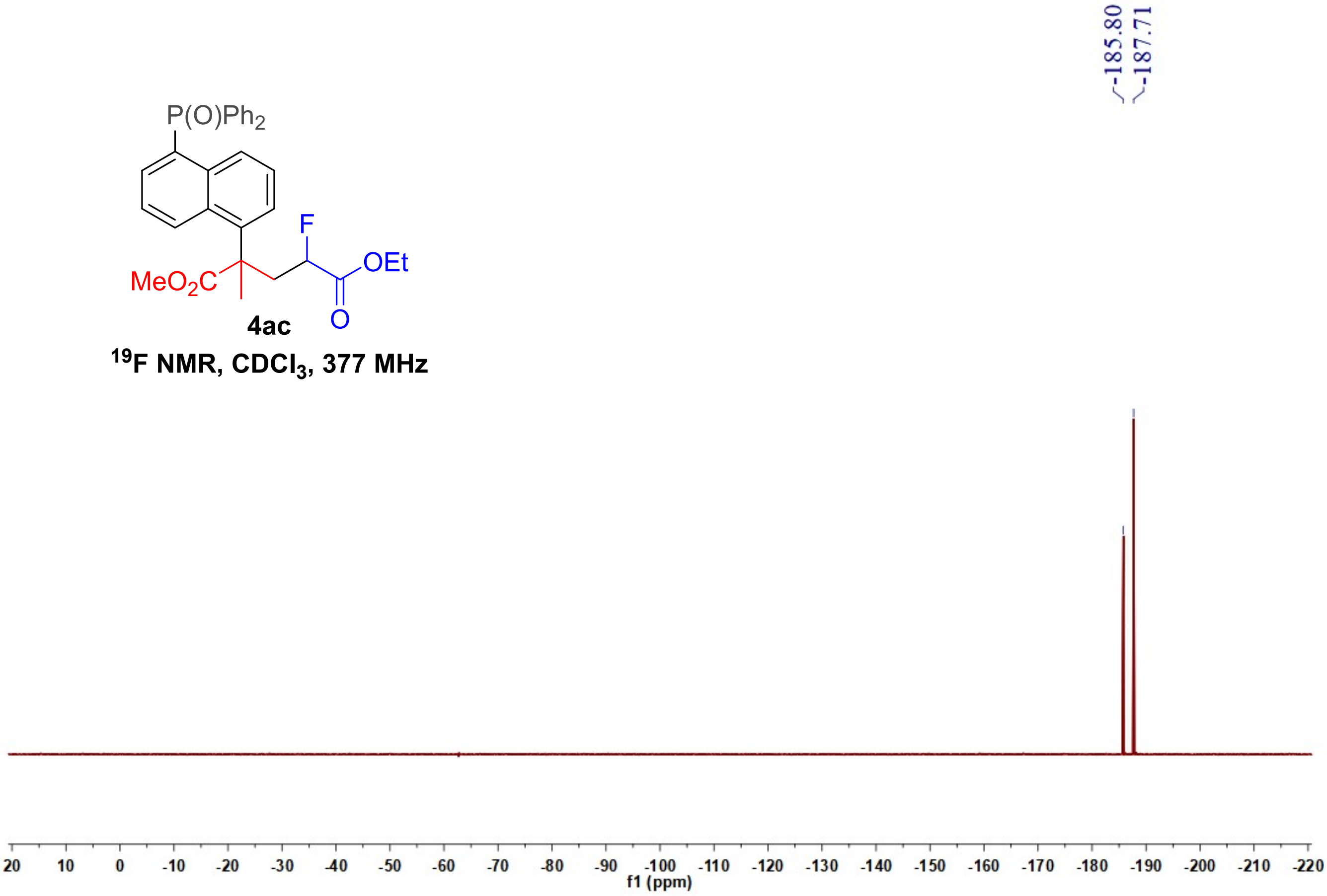
4ac

^{13}C NMR, CDCl$_3$, 101 MHz



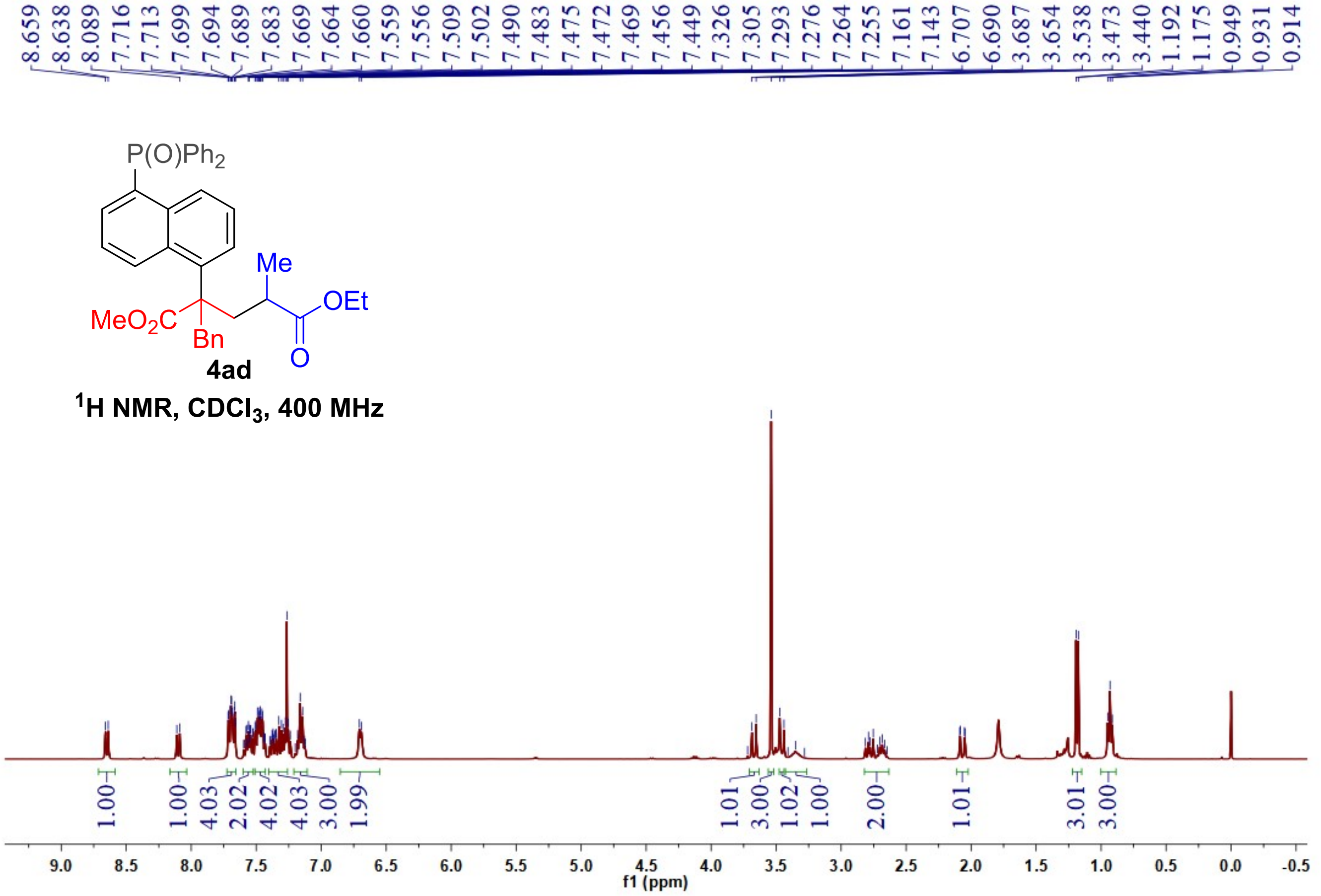
4ac

^{31}P NMR, CDCl$_3$, 162 MHz



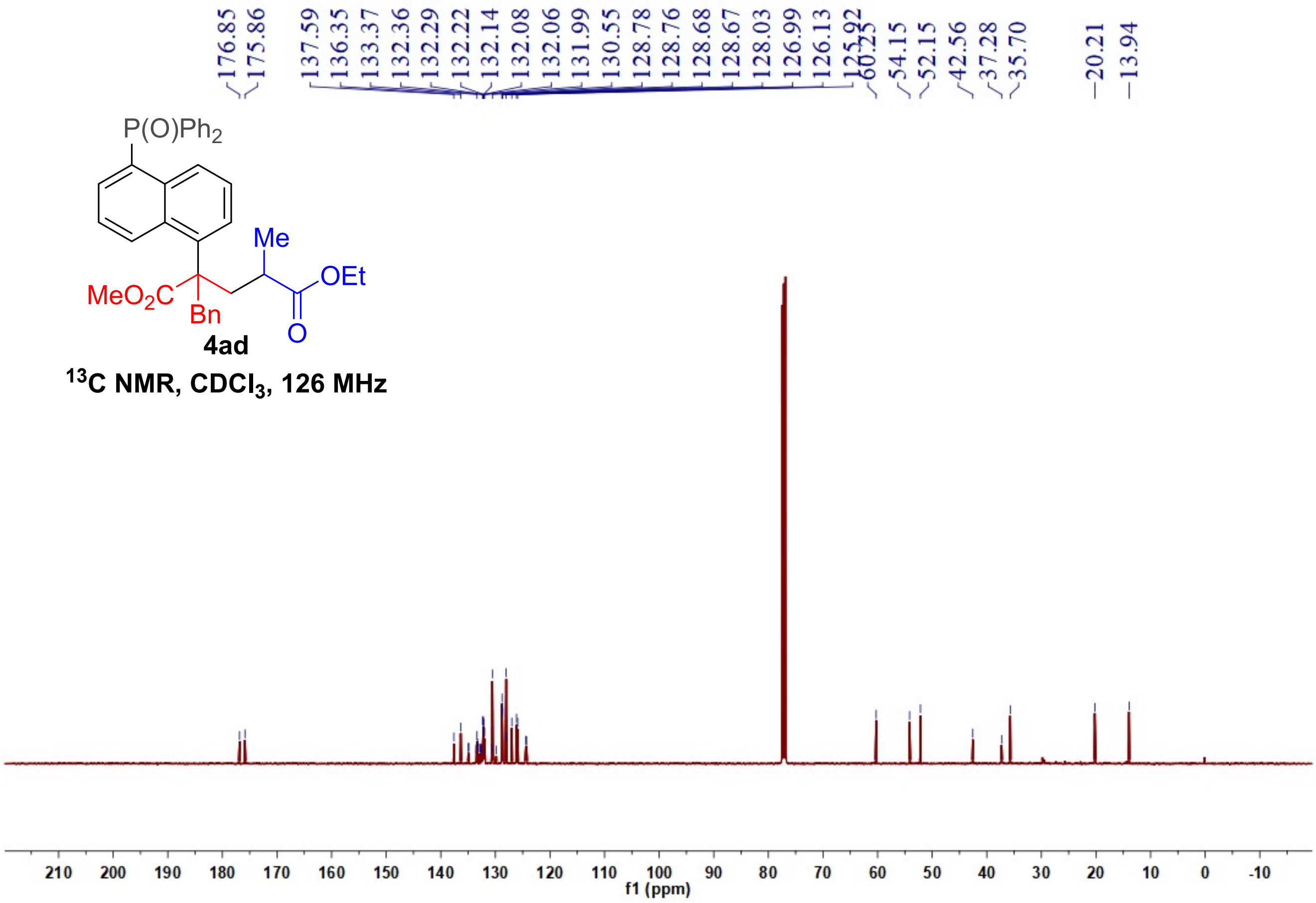
4ac

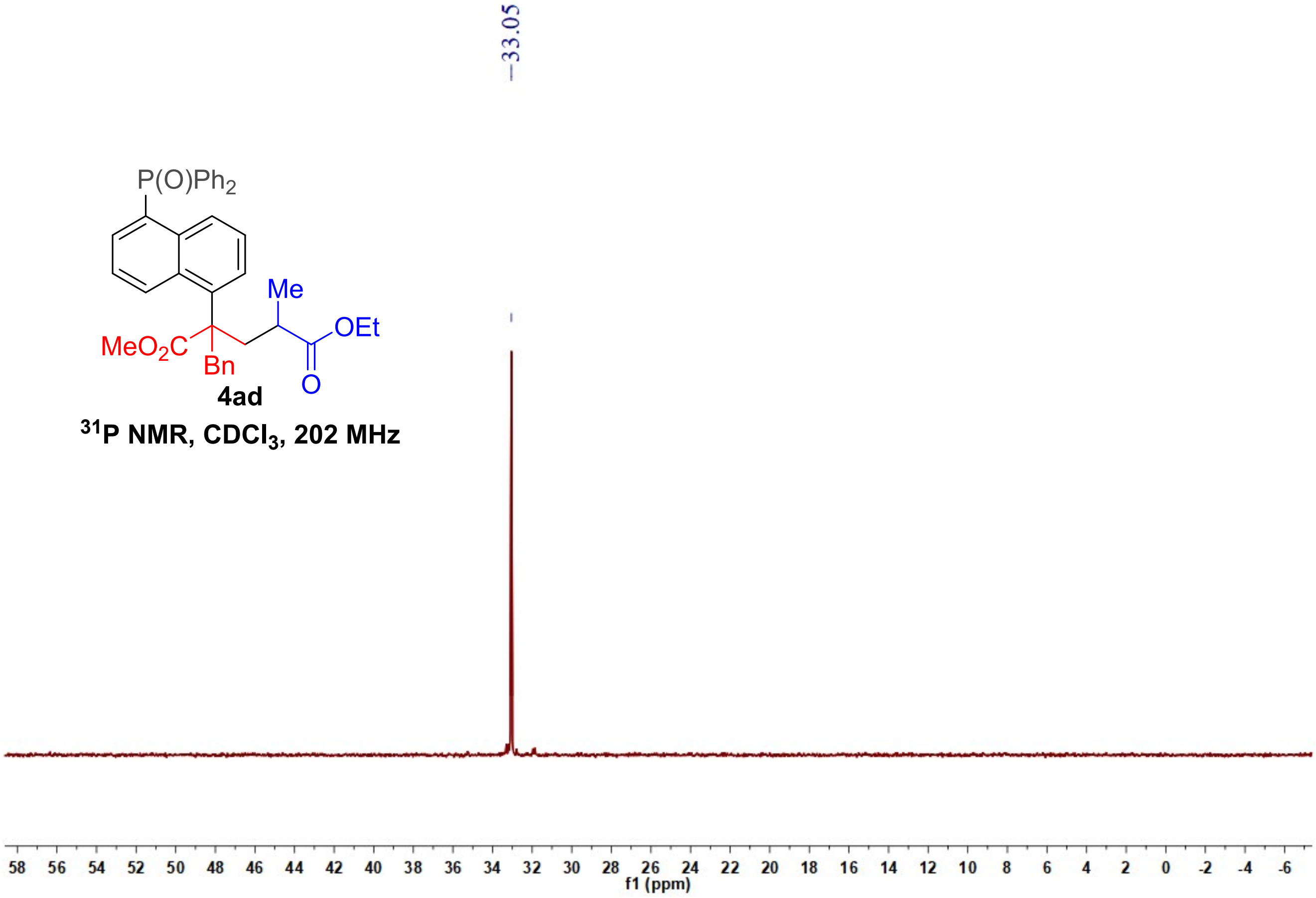
^{19}F NMR, CDCl$_3$, 377 MHz

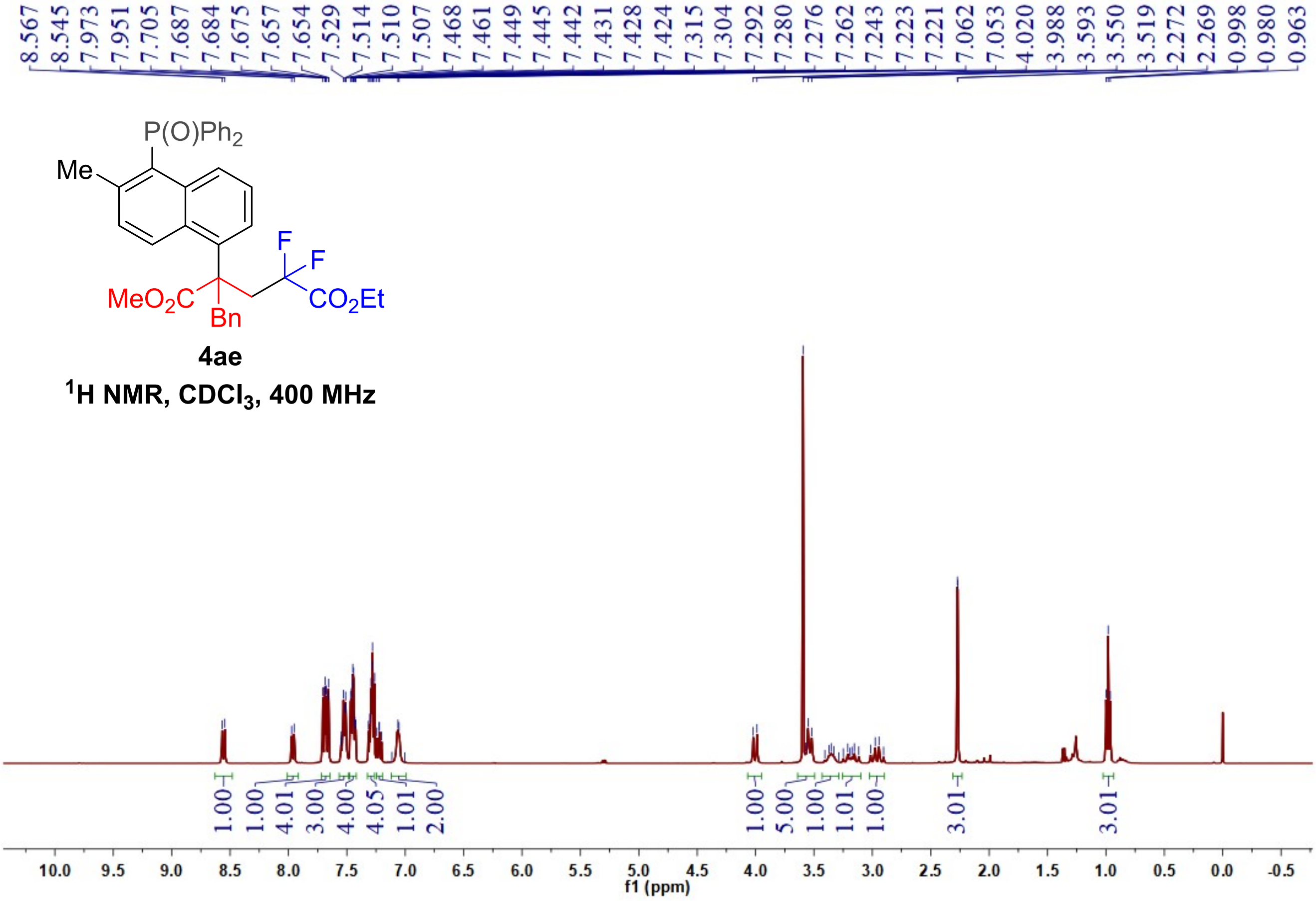


4ad

^{1}H NMR, CDCl$_3$, 400 MHz

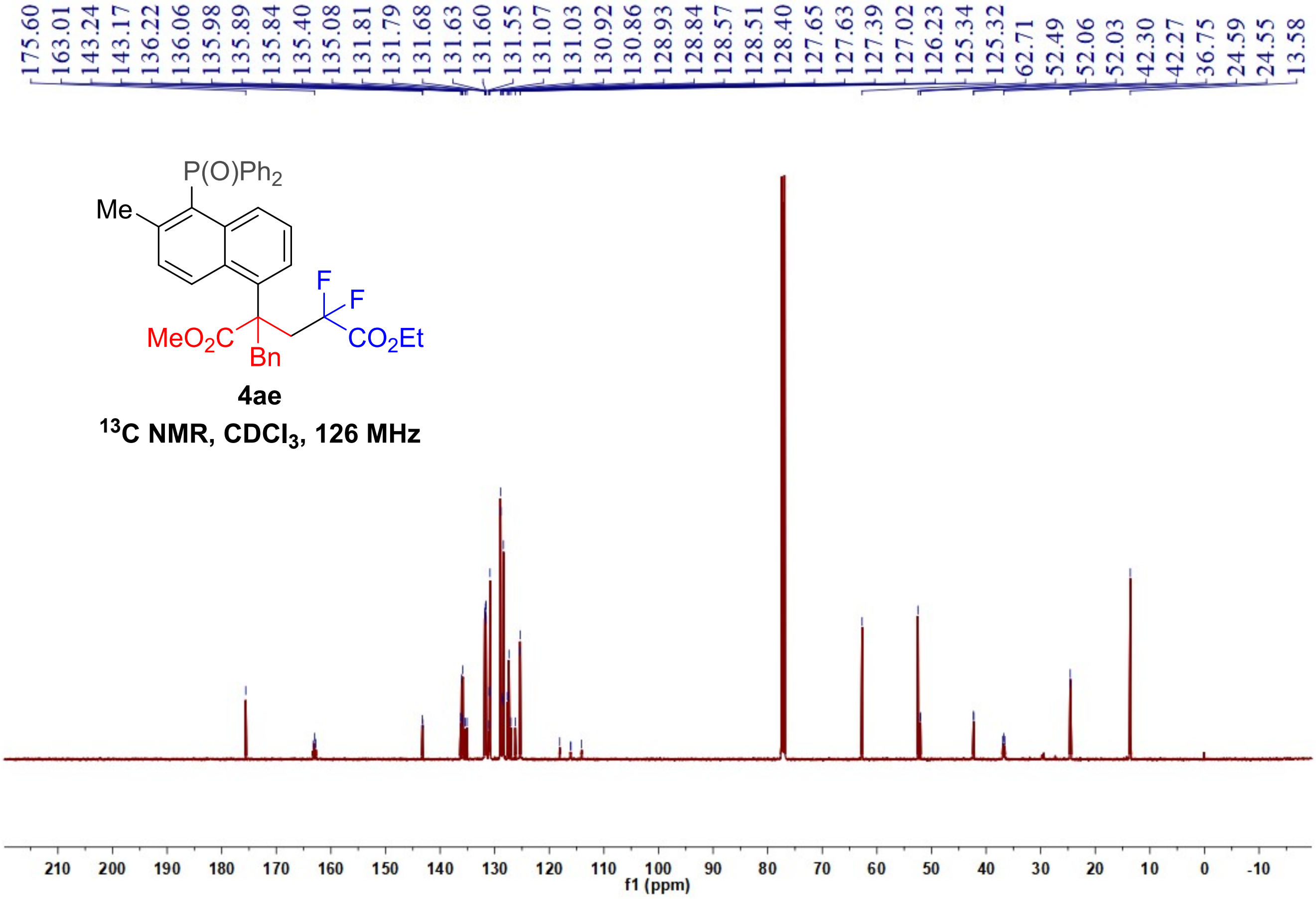

176.85
175.86
137.59
136.35
133.37
132.36
132.29
132.22
132.14
132.08
132.06
131.99
130.55
128.78
128.76
128.68
128.67
128.03
126.99
126.13
125.92
60.25
54.15
52.15
42.56
37.28
35.70
20.21
13.94
P(O)Ph$_2$
Me
OEt
MeO$_2$C
Bn
O
4ad
^{13}C NMR, CDCl$_3$, 126 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


33.05
P(O)Ph$_2$
Me
OEt
MeO$_2$C
Bn
O
4ad
^{31}P NMR, CDCl$_3$, 202 MHz
58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0 -2 -4 -6
f1 (ppm)



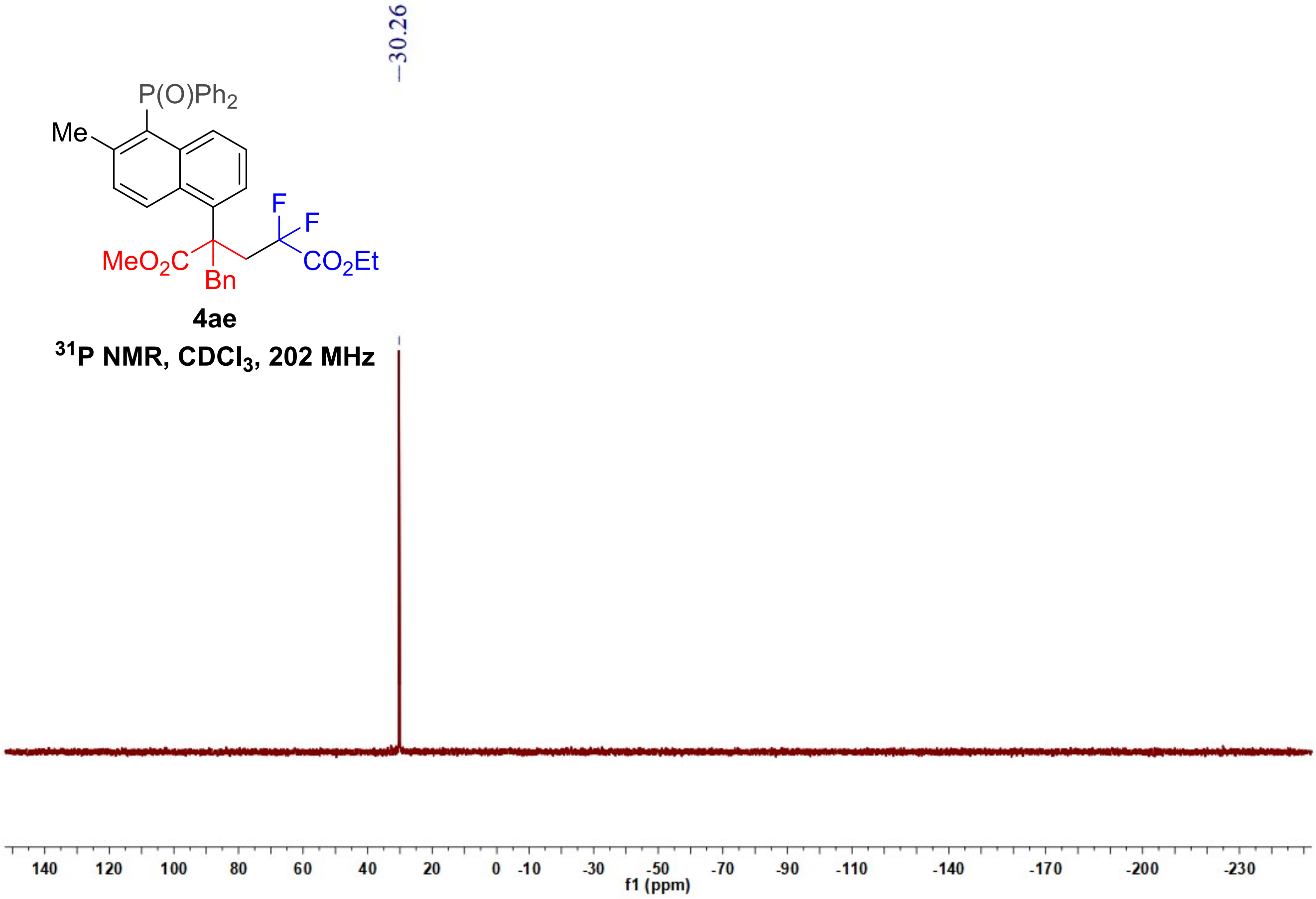
4ae

^{1}H NMR, $CDCl_3$, 400 MHz



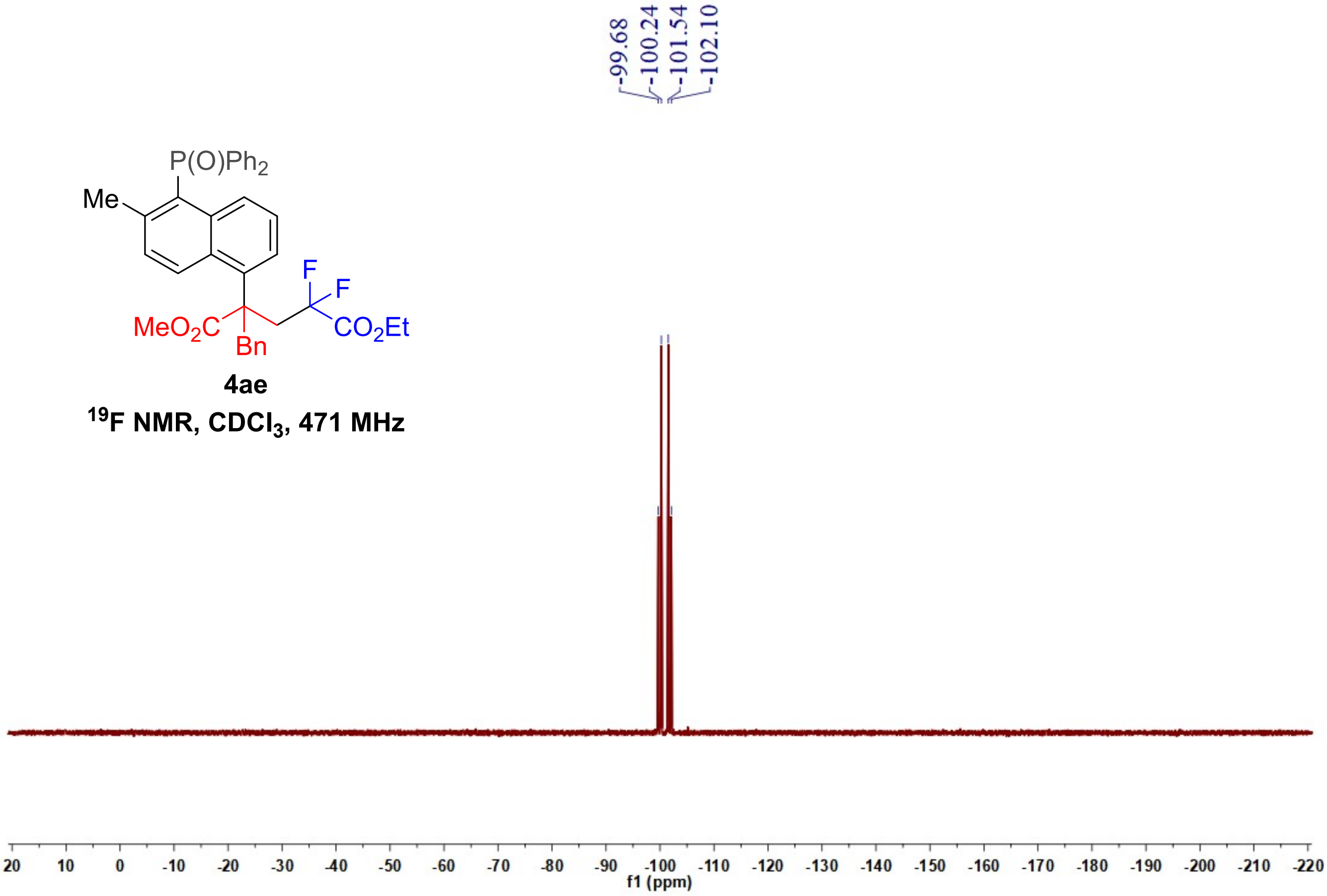
4ae

^{13}C NMR, $CDCl_3$, 126 MHz



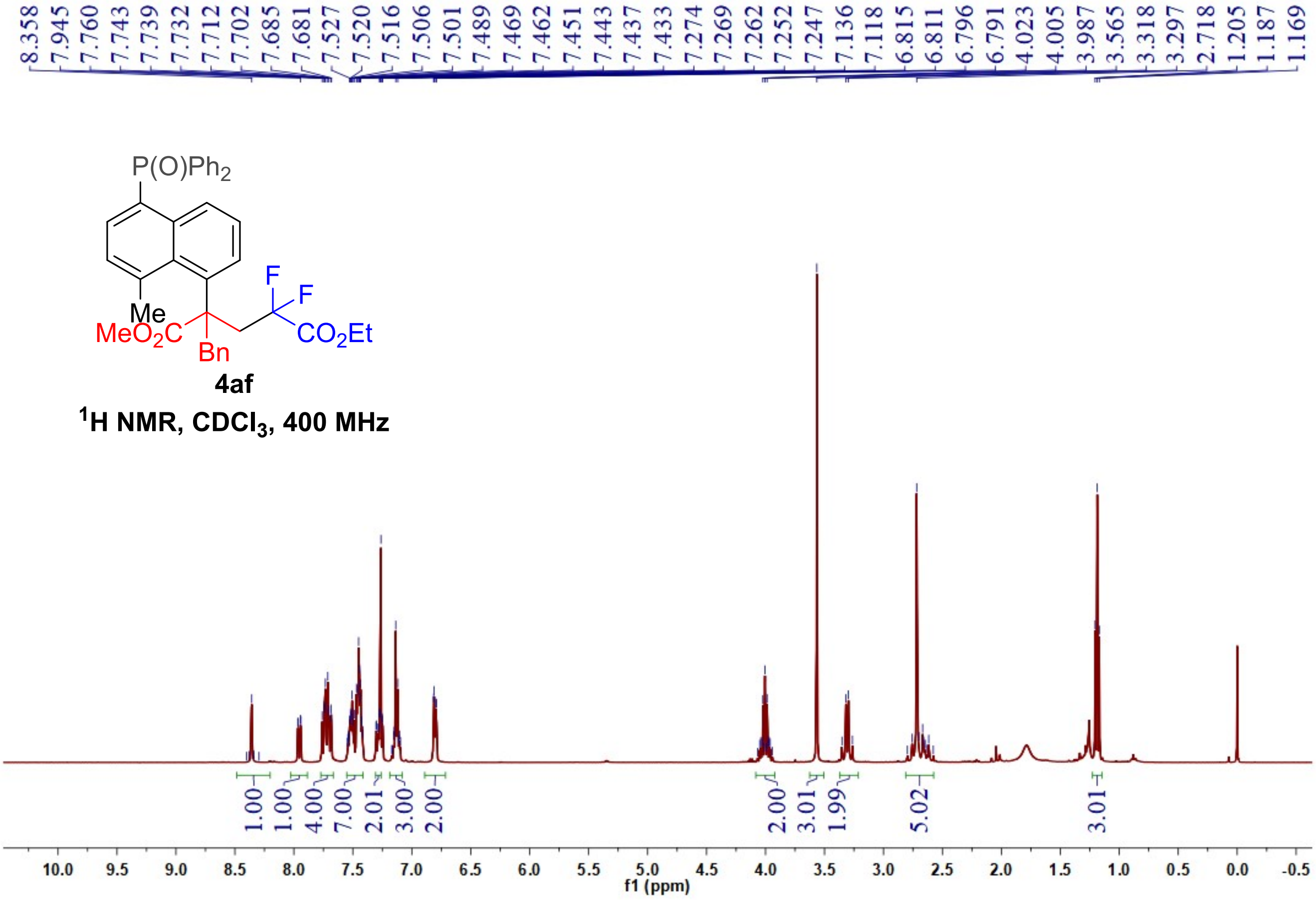
4ae

^{31}P NMR, CDCl$_3$, 202 MHz



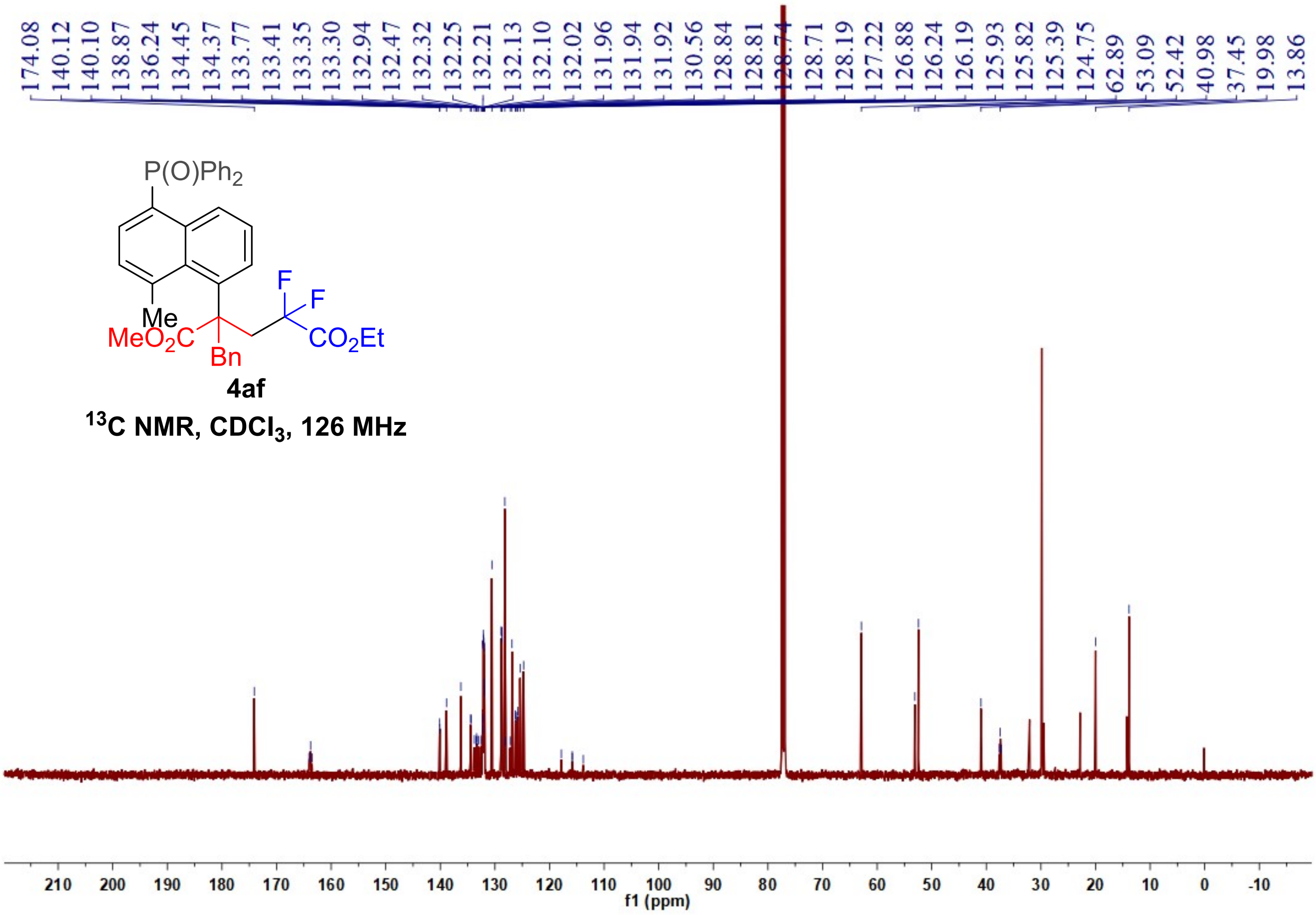
4ae

^{19}F NMR, CDCl$_3$, 471 MHz



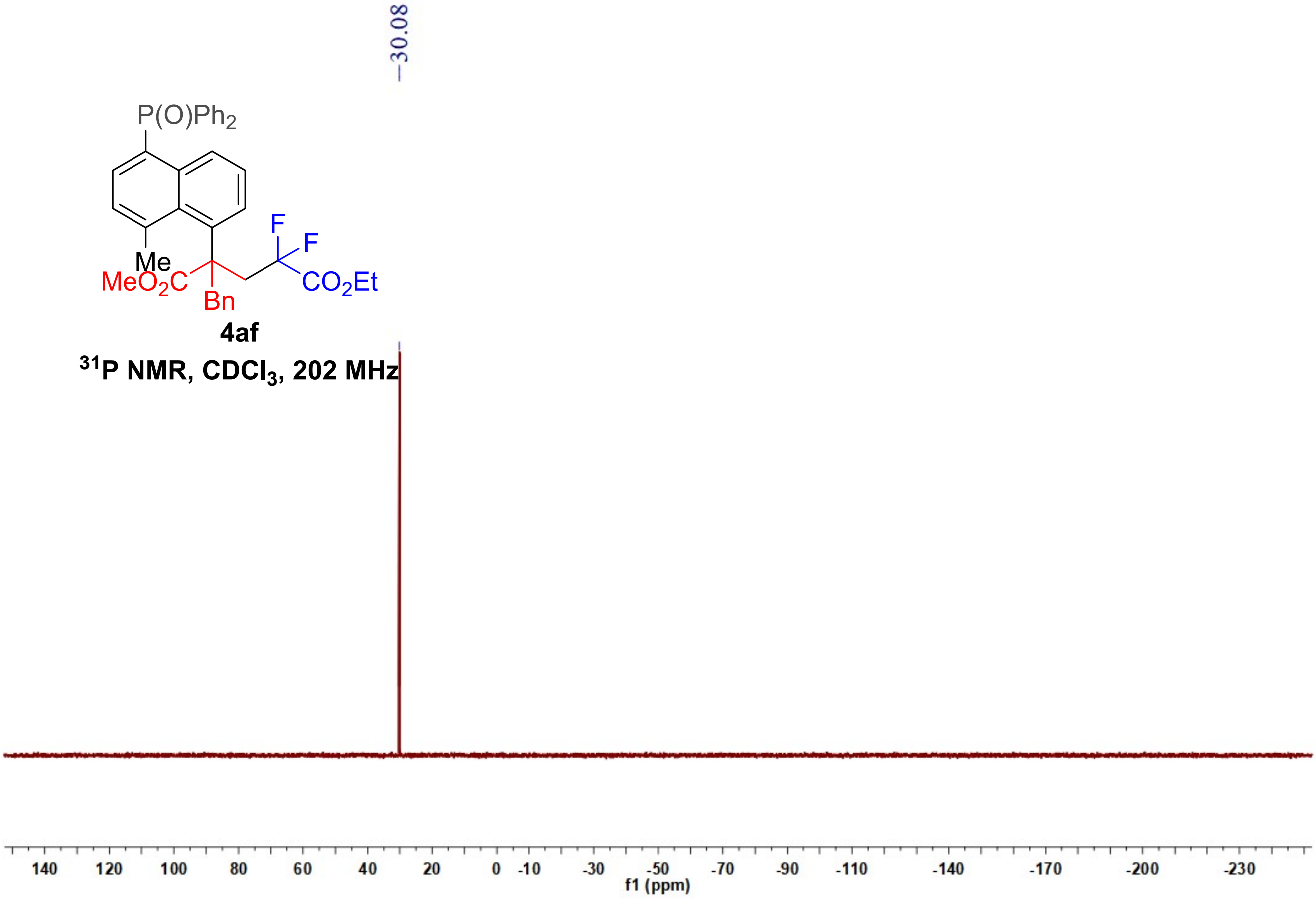
4af

^{1}H NMR, $CDCl_3$, 400 MHz



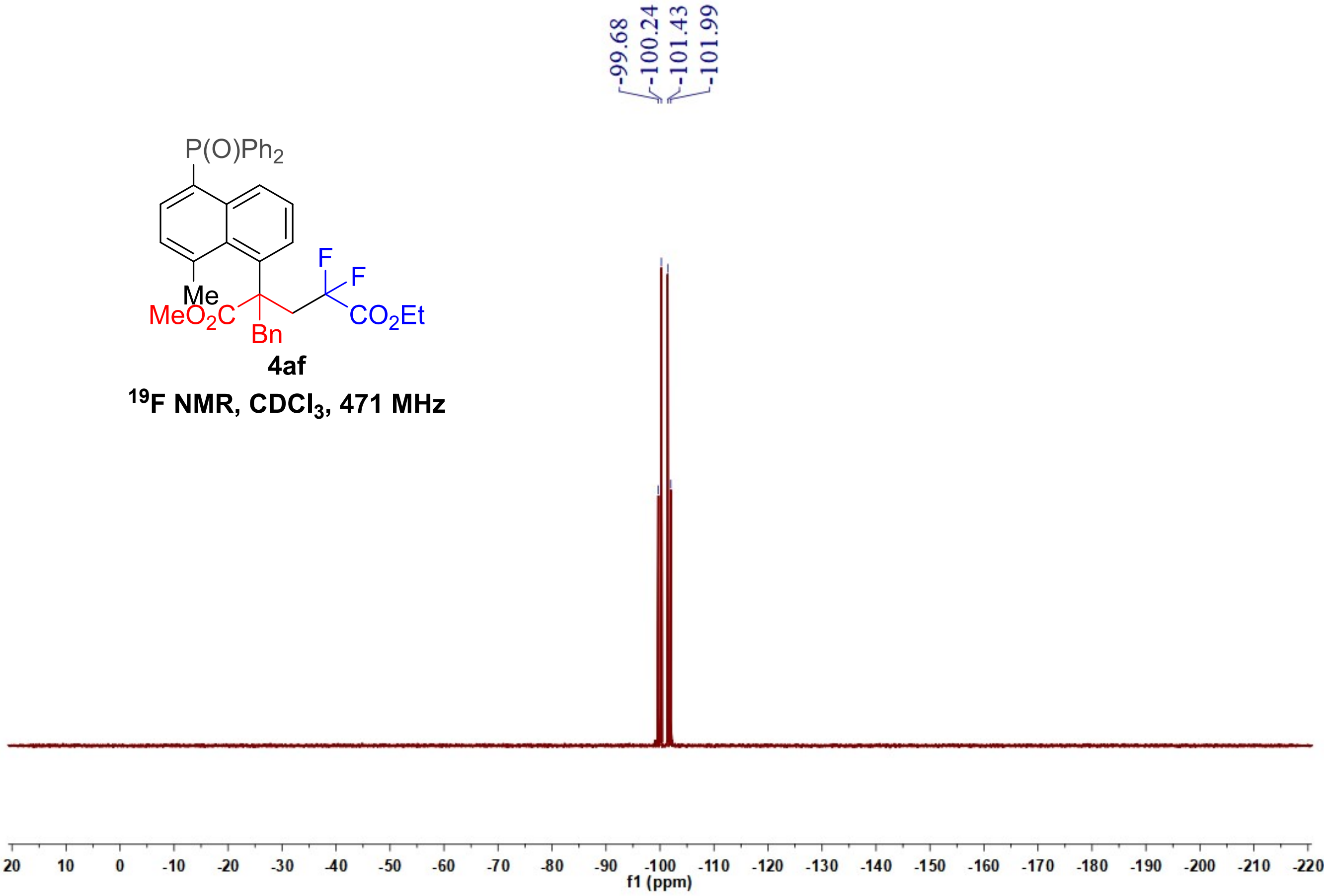
4af

^{13}C NMR, $CDCl_3$, 126 MHz



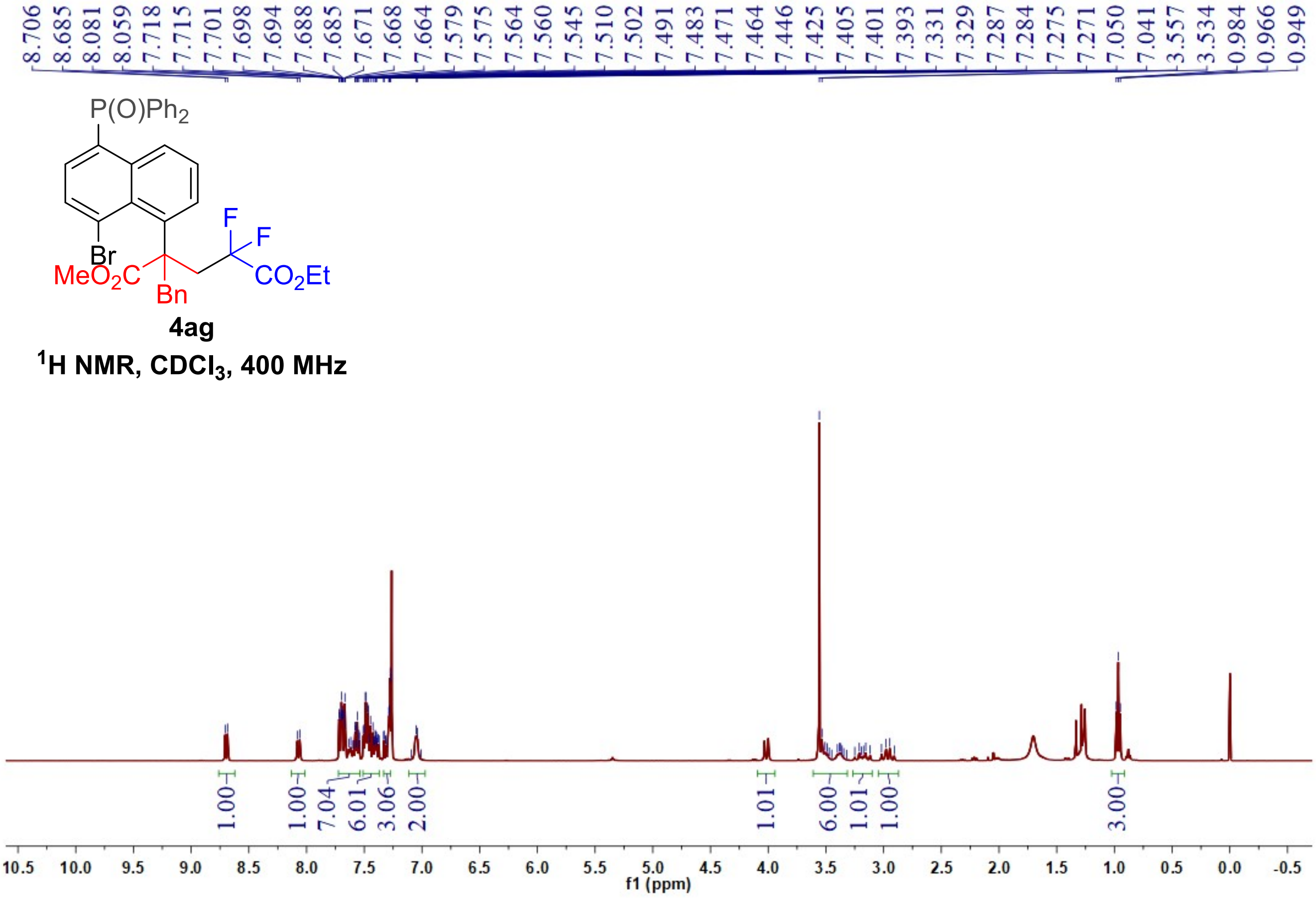
4af

^{31}P NMR, CDCl$_3$, 202 MHz



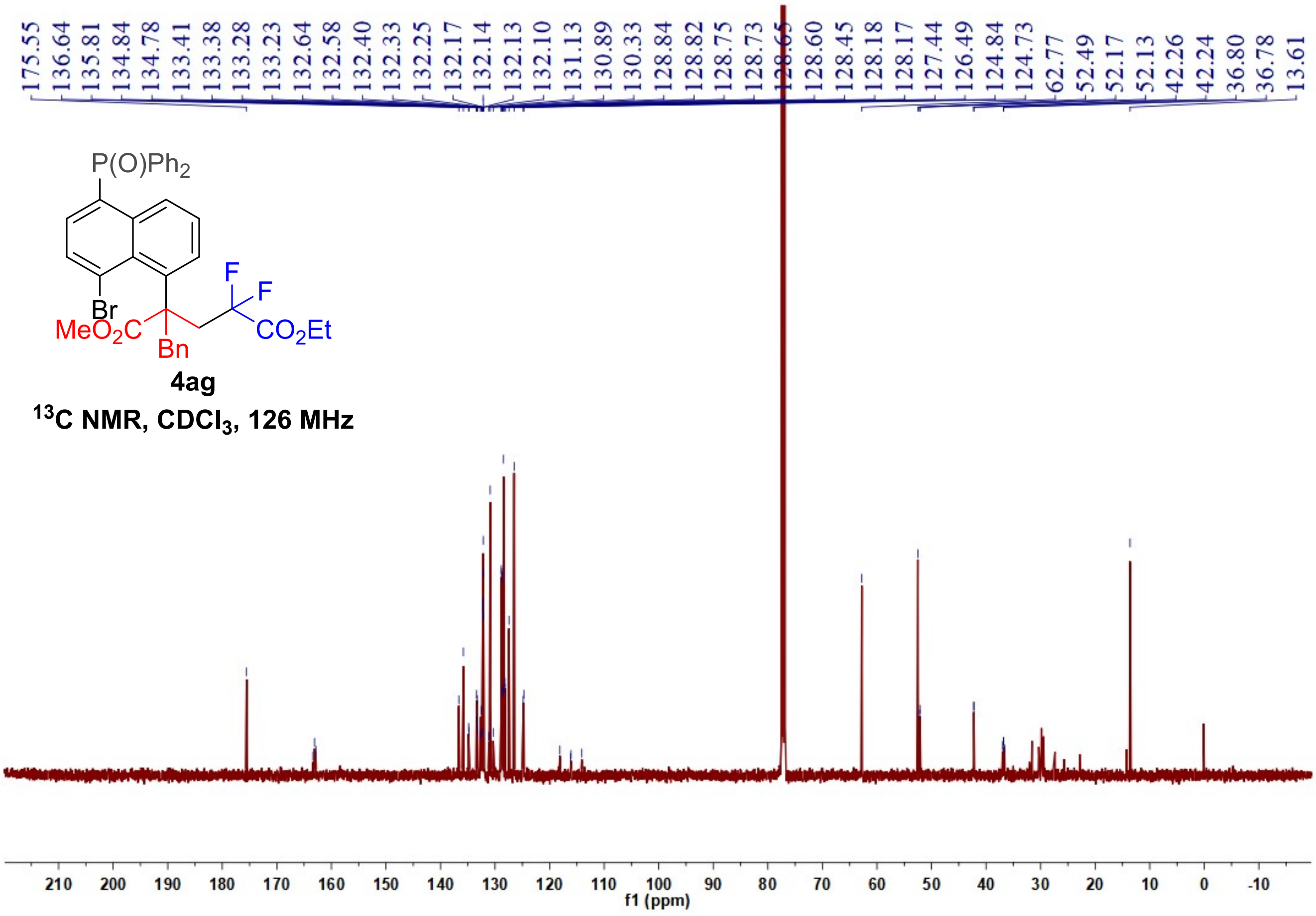
4af

^{19}F NMR, CDCl$_3$, 471 MHz



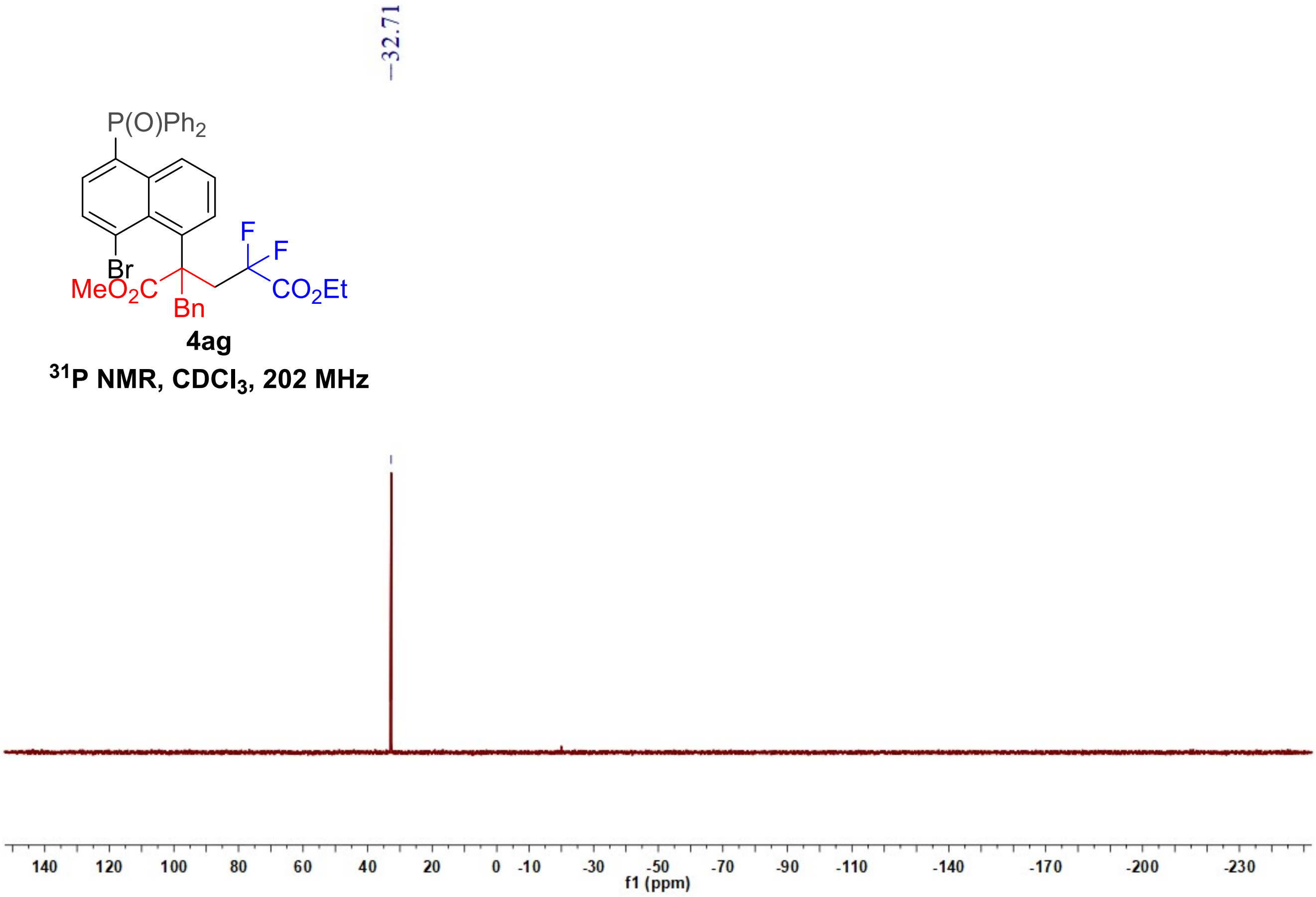
4ag

^{1}H NMR, CDCl$_3$, 400 MHz



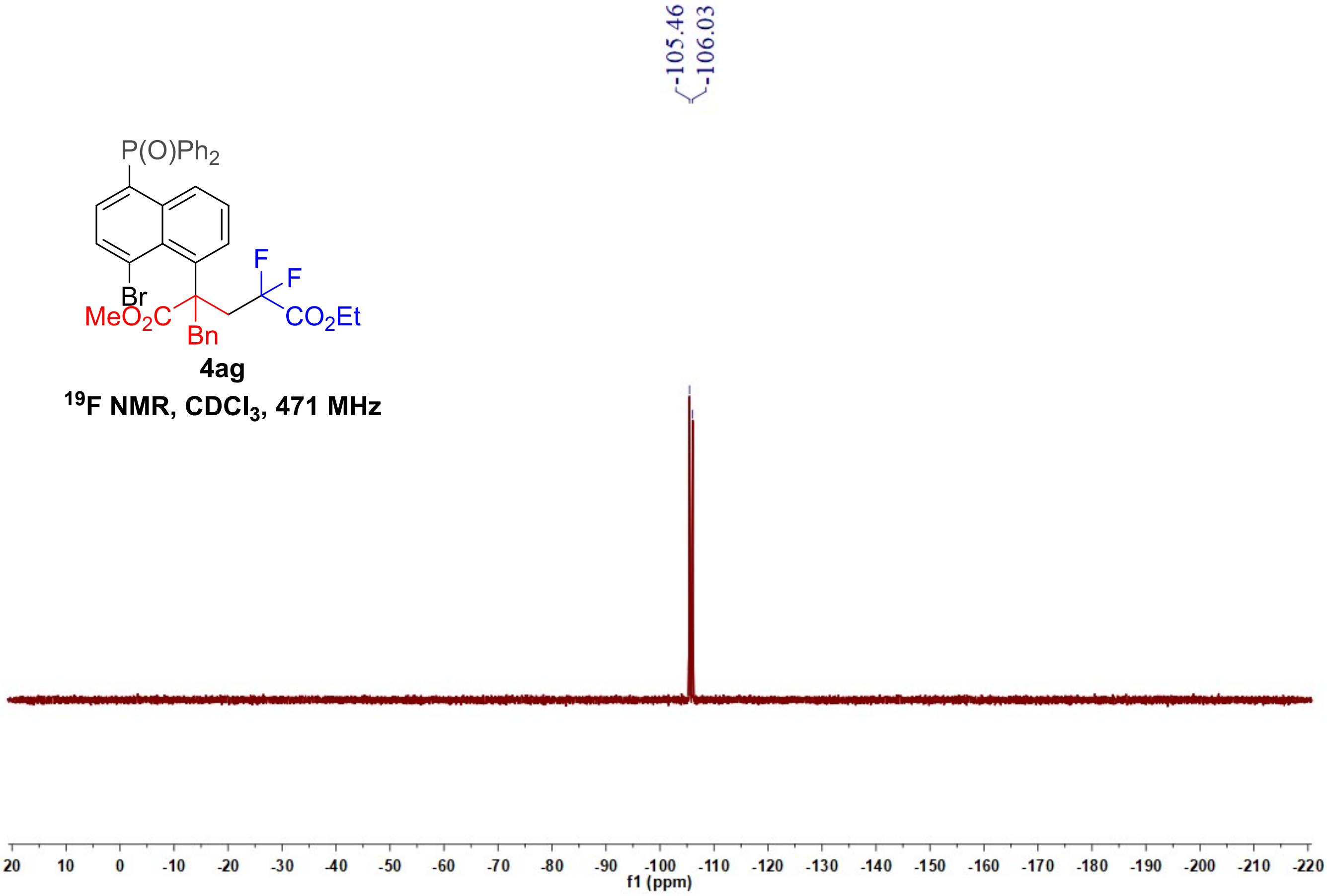
4ag

^{13}C NMR, CDCl$_3$, 126 MHz



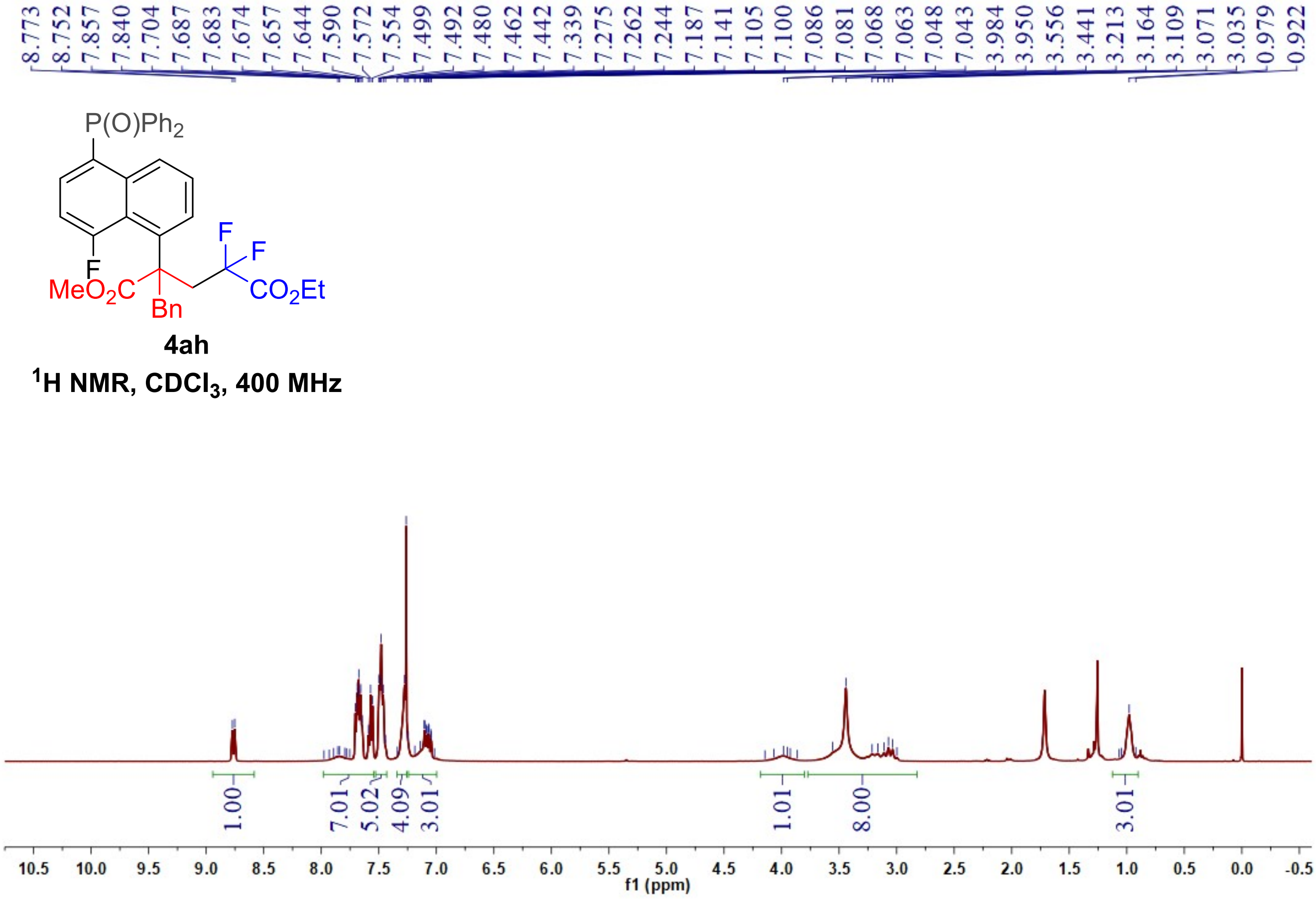
4ag

^{31}P NMR, CDCl$_3$, 202 MHz



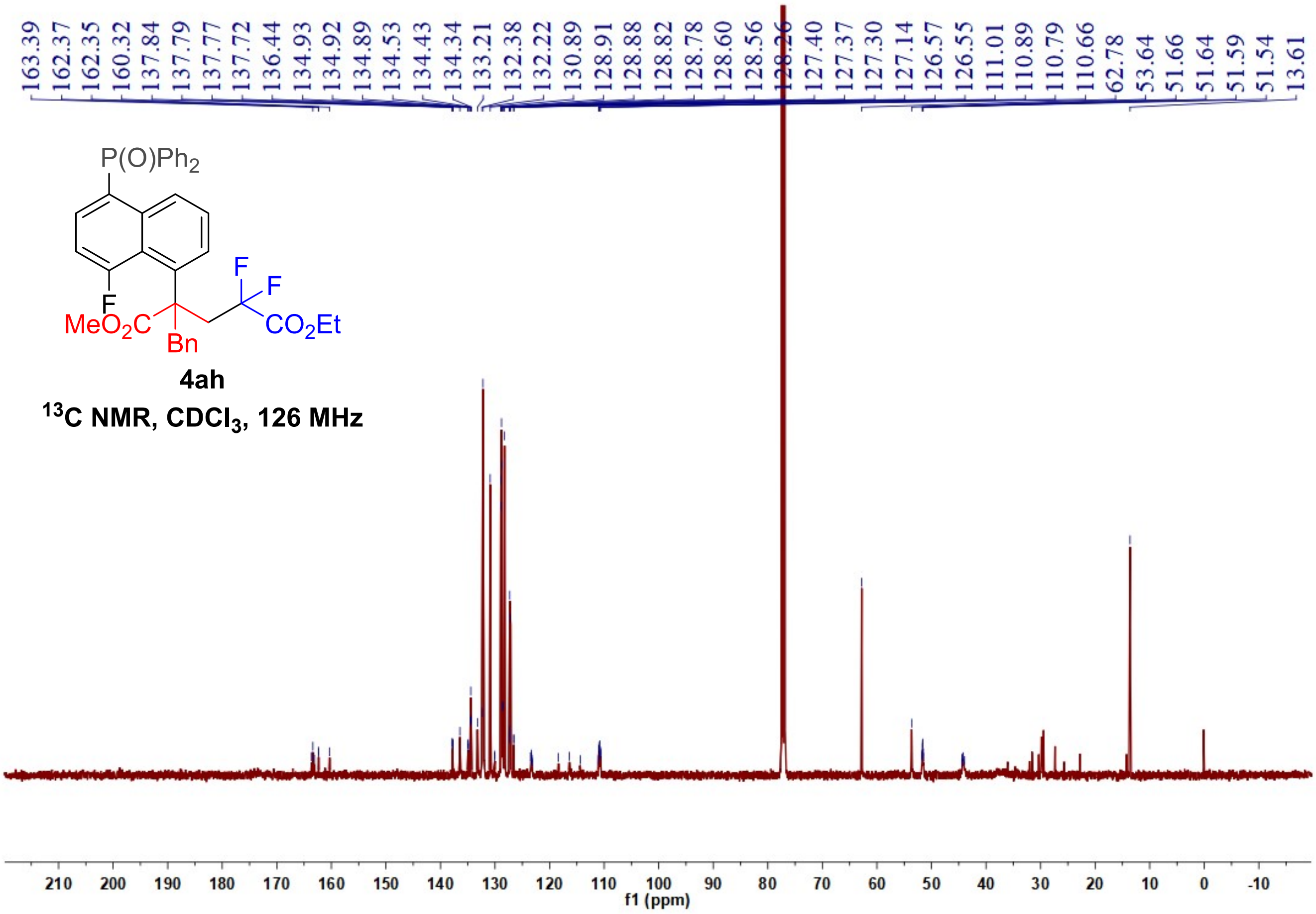
4ag

^{19}F NMR, CDCl$_3$, 471 MHz



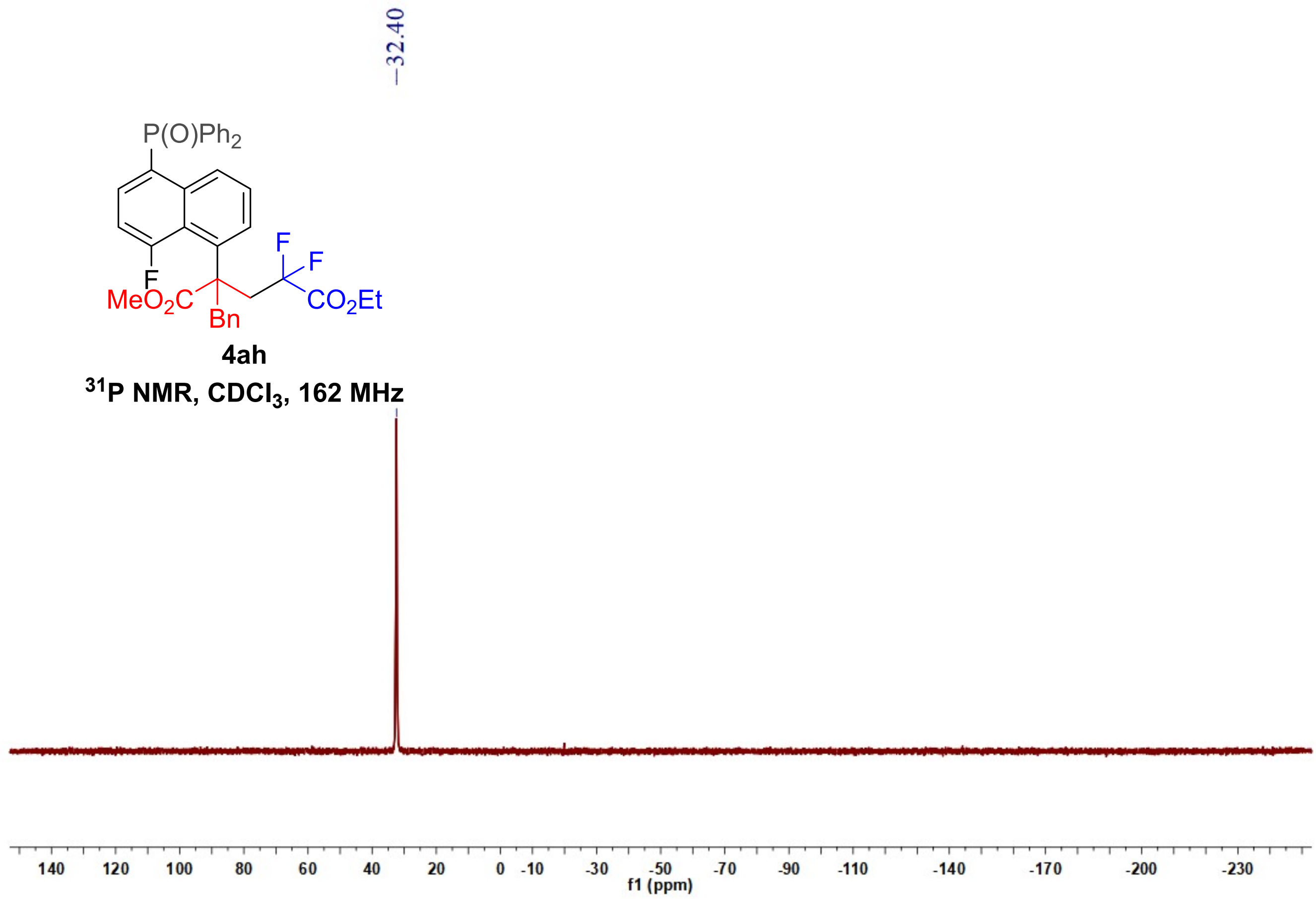
4ah

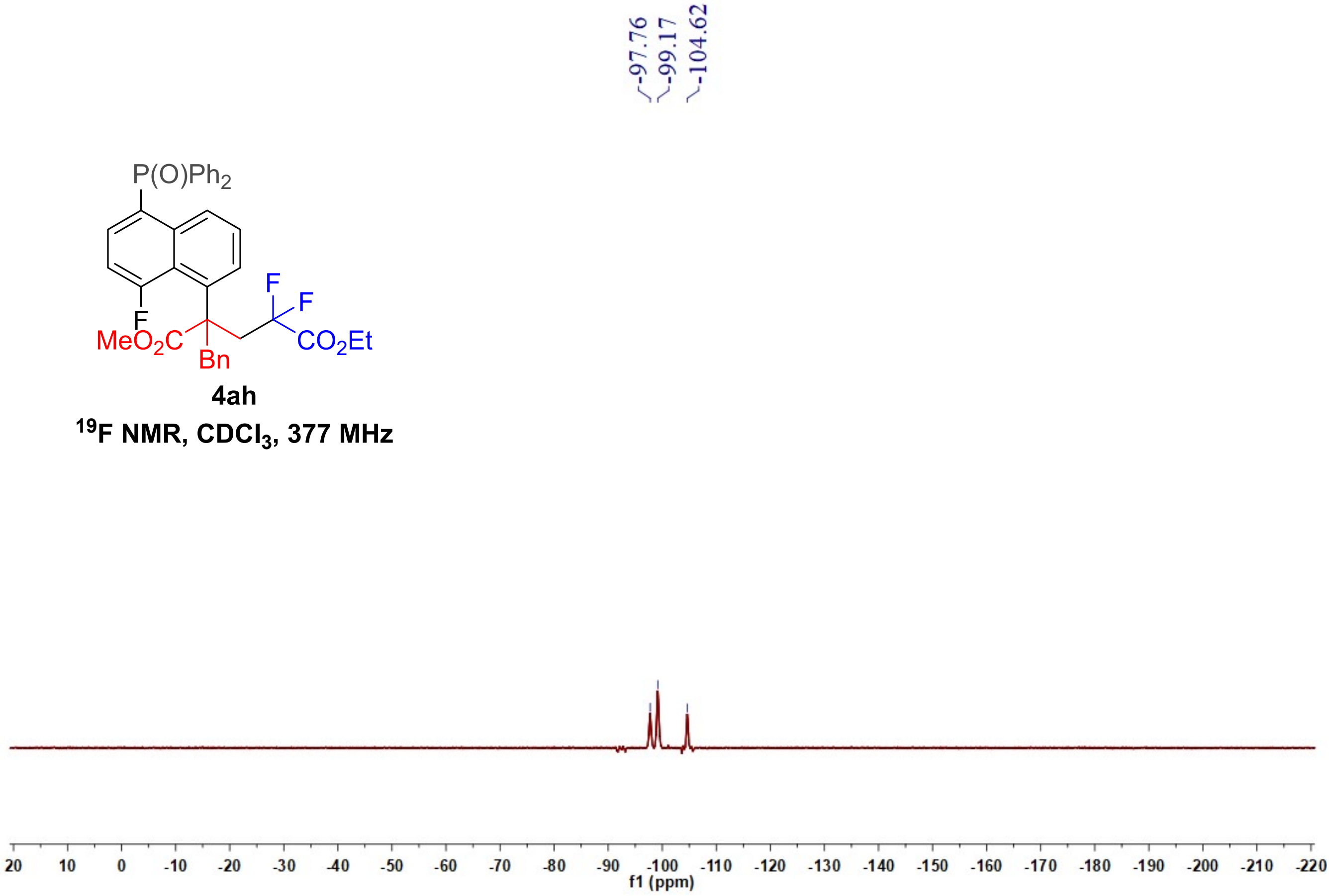
^{1}H NMR, CDCl$_3$, 400 MHz



4ah

^{13}C NMR, CDCl$_3$, 126 MHz


32.40
P(O)Ph2
F
F
F
MeO2C
Bn
CO2Et
4ah
31P NMR, CDCl3, 162 MHz
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-110
-140
-170
-200
-230
f1 (ppm)


-97.76
-99.17
-104.62
P(O)Ph2
F
F
F
MeO2C
Bn
CO2Et
4ah
19F NMR, CDCl3, 377 MHz
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
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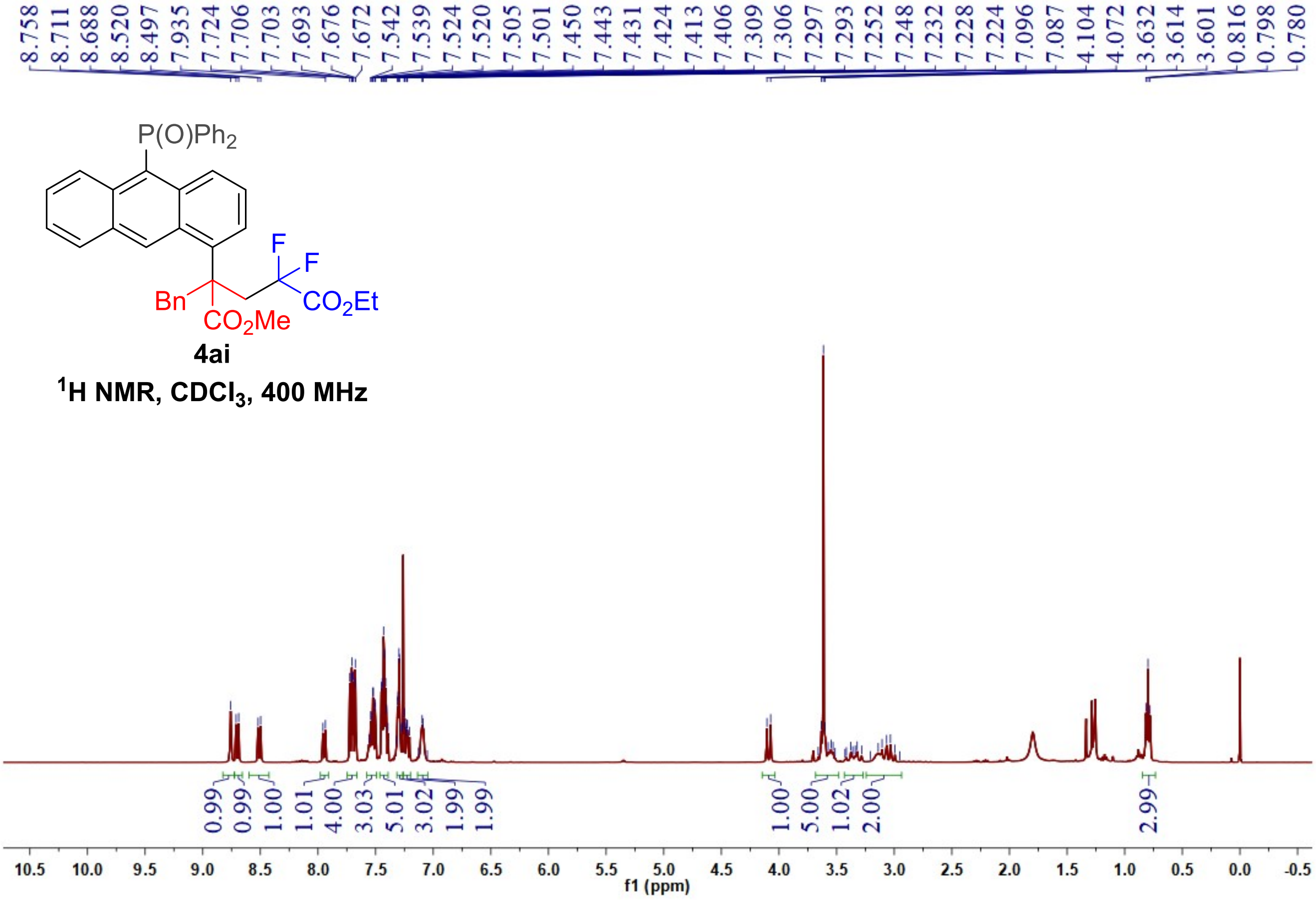
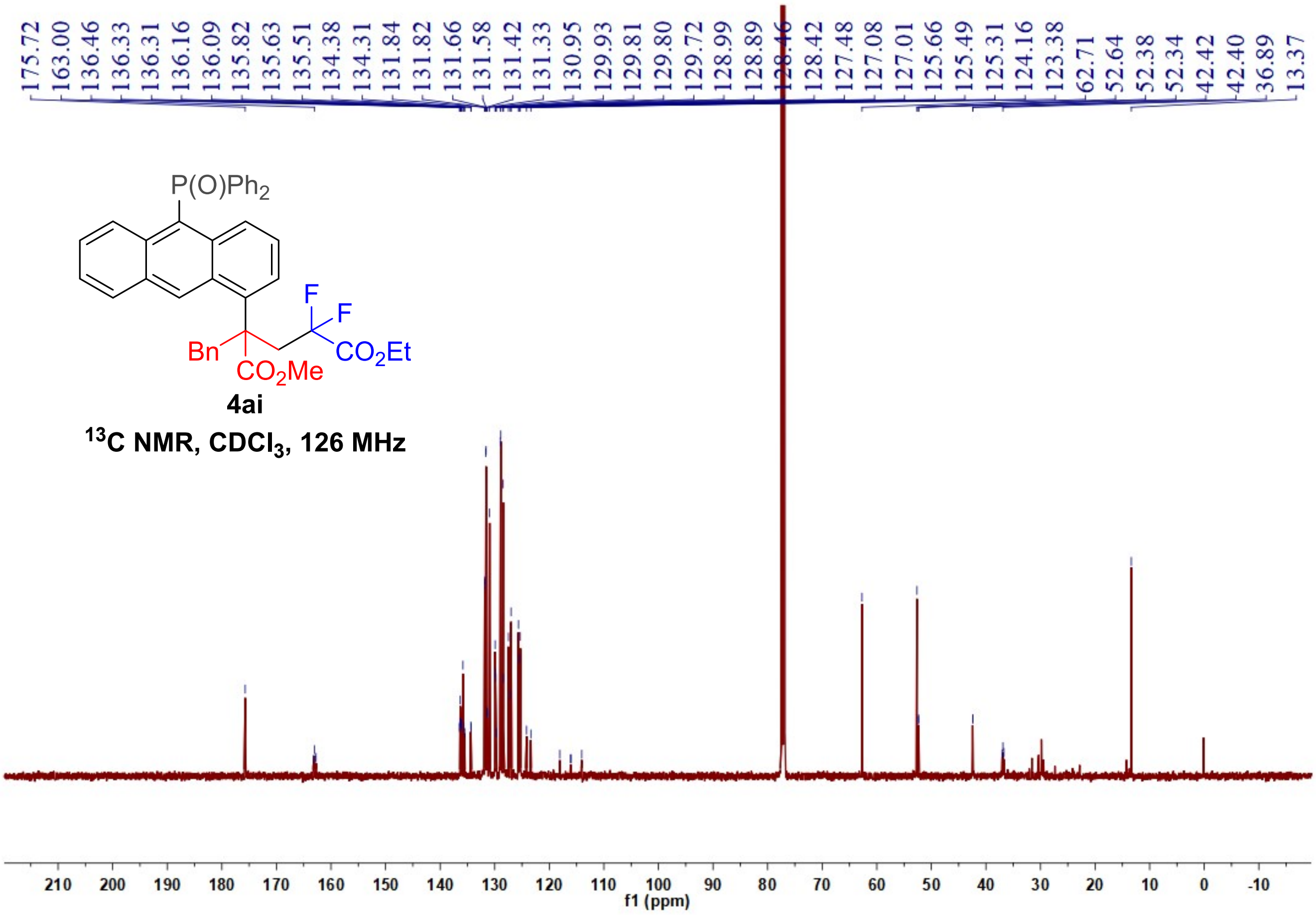
-190
-200
-210
-220
f1 (ppm)



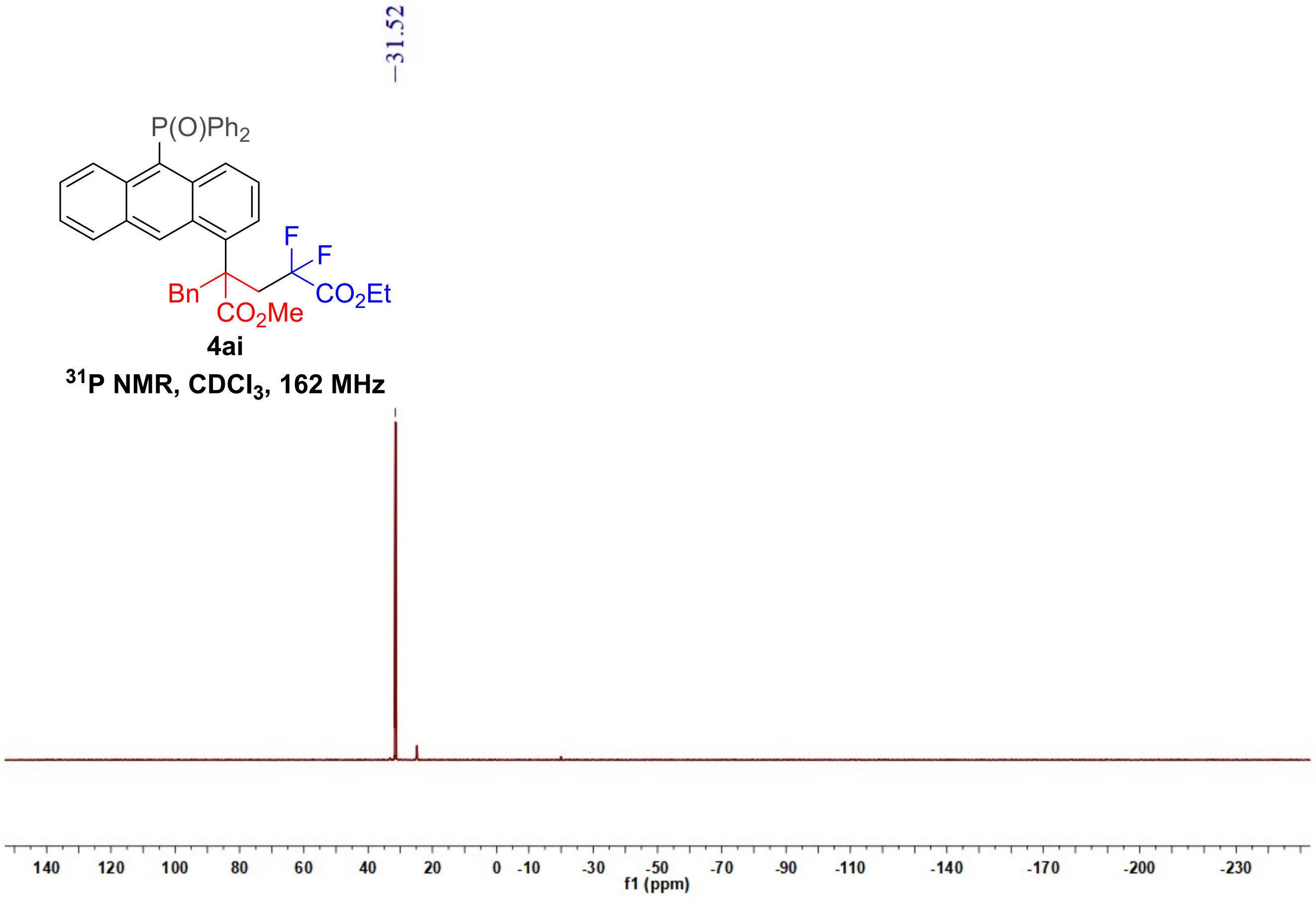
4ai

^{1}H NMR, CDCl$_3$, 400 MHz

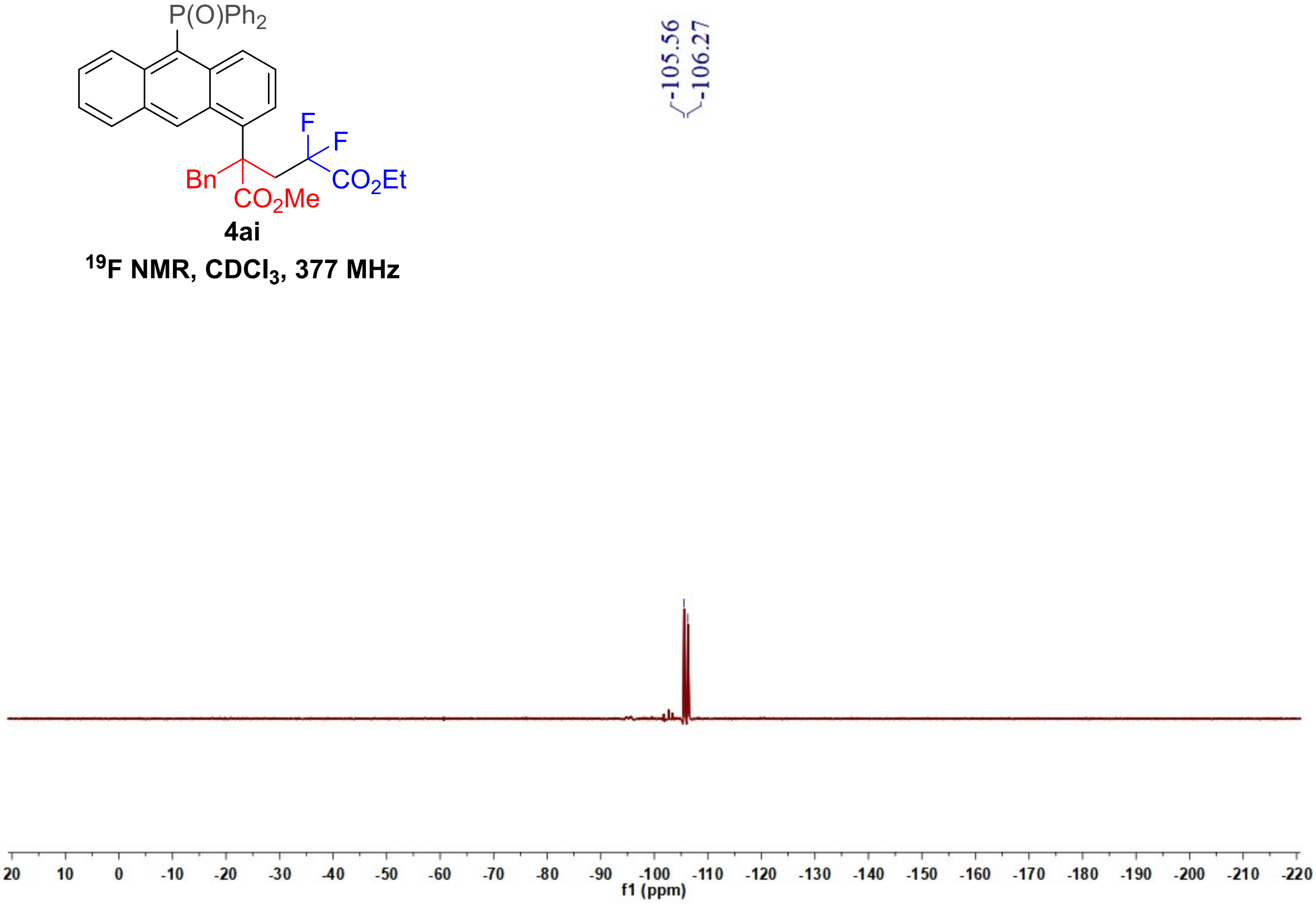


4ai

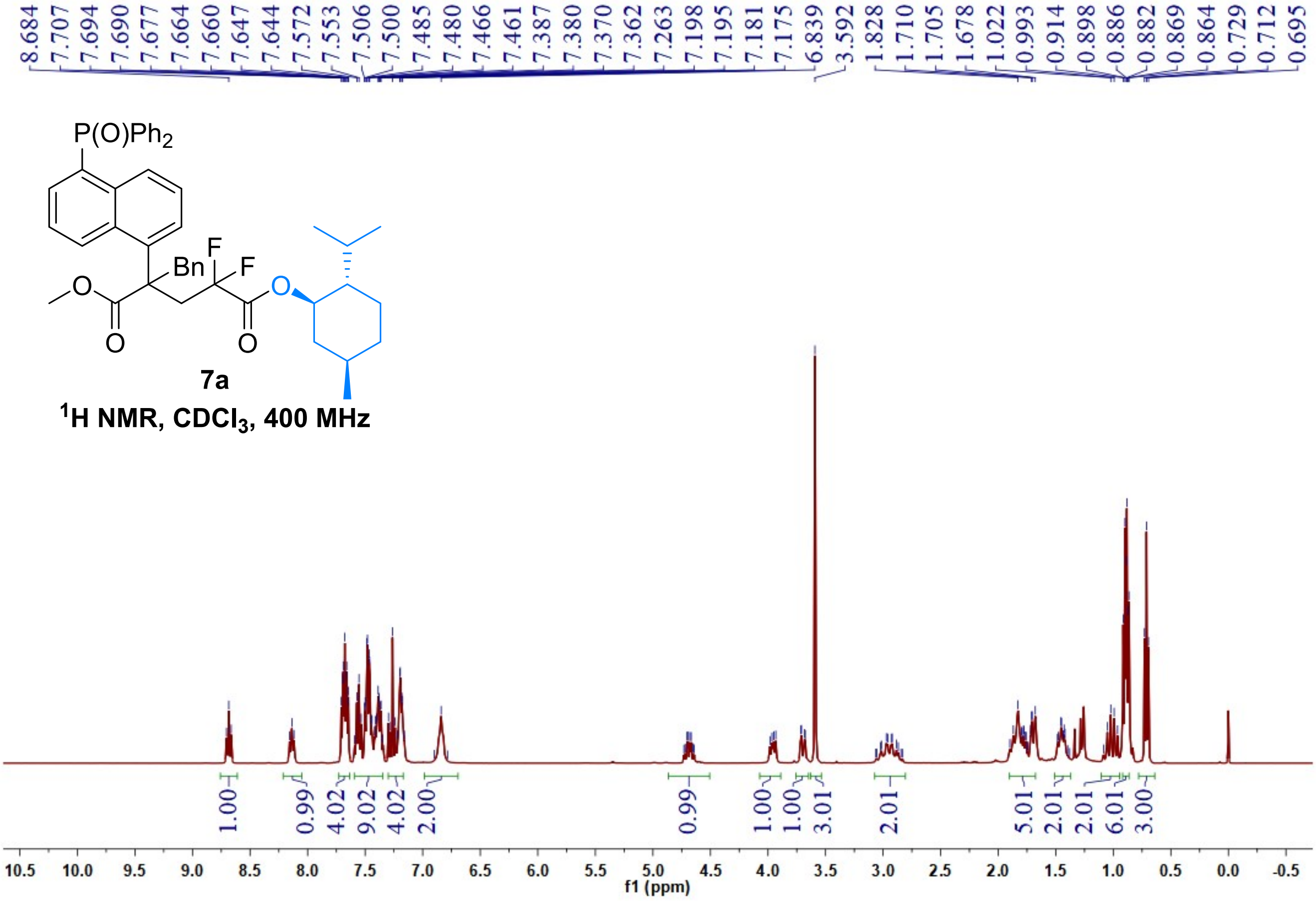
^{13}C NMR, CDCl$_3$, 126 MHz


4ai

^{31}P NMR, $CDCl_3$, 162 MHz

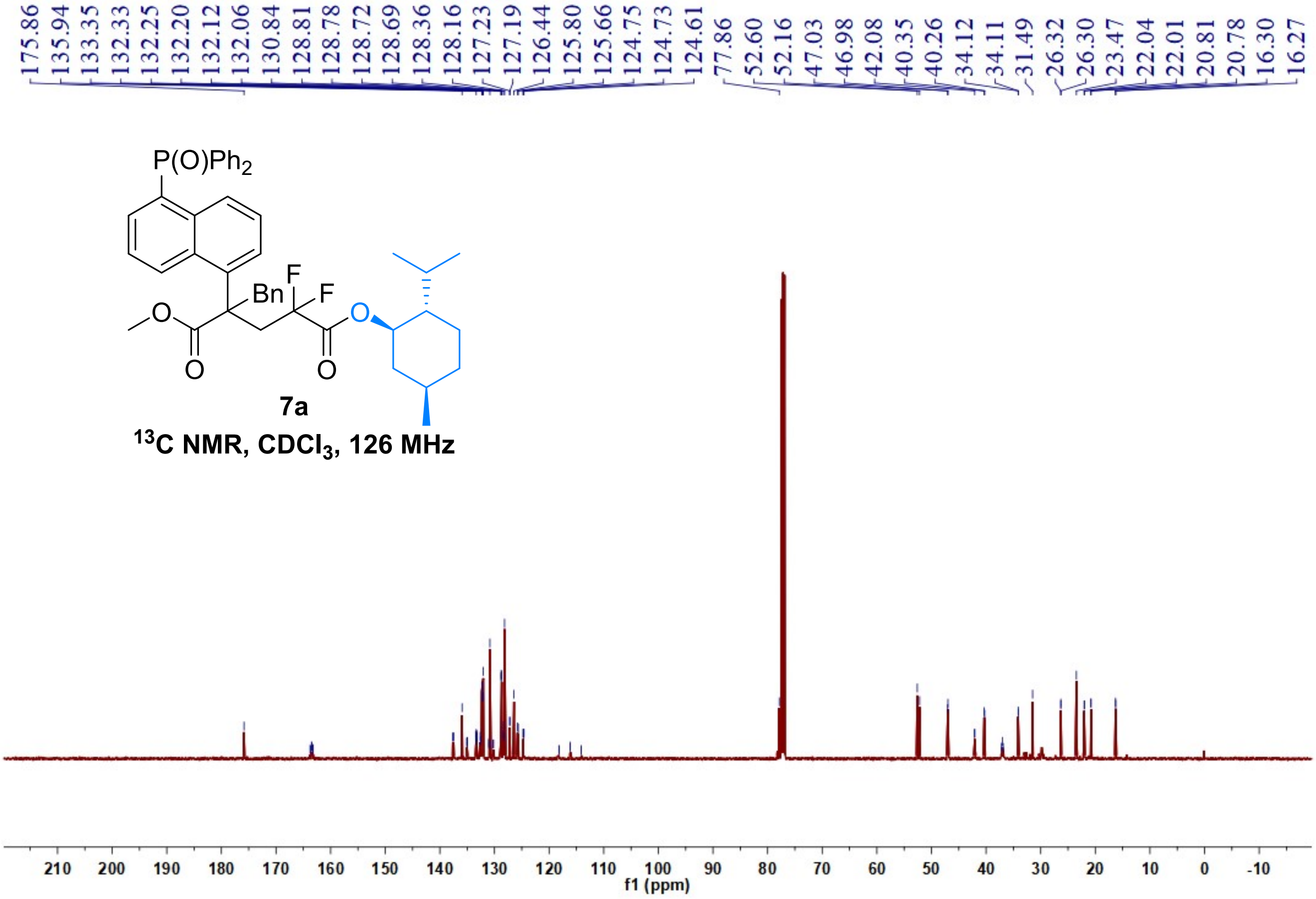

4ai

^{19}F NMR, $CDCl_3$, 377 MHz



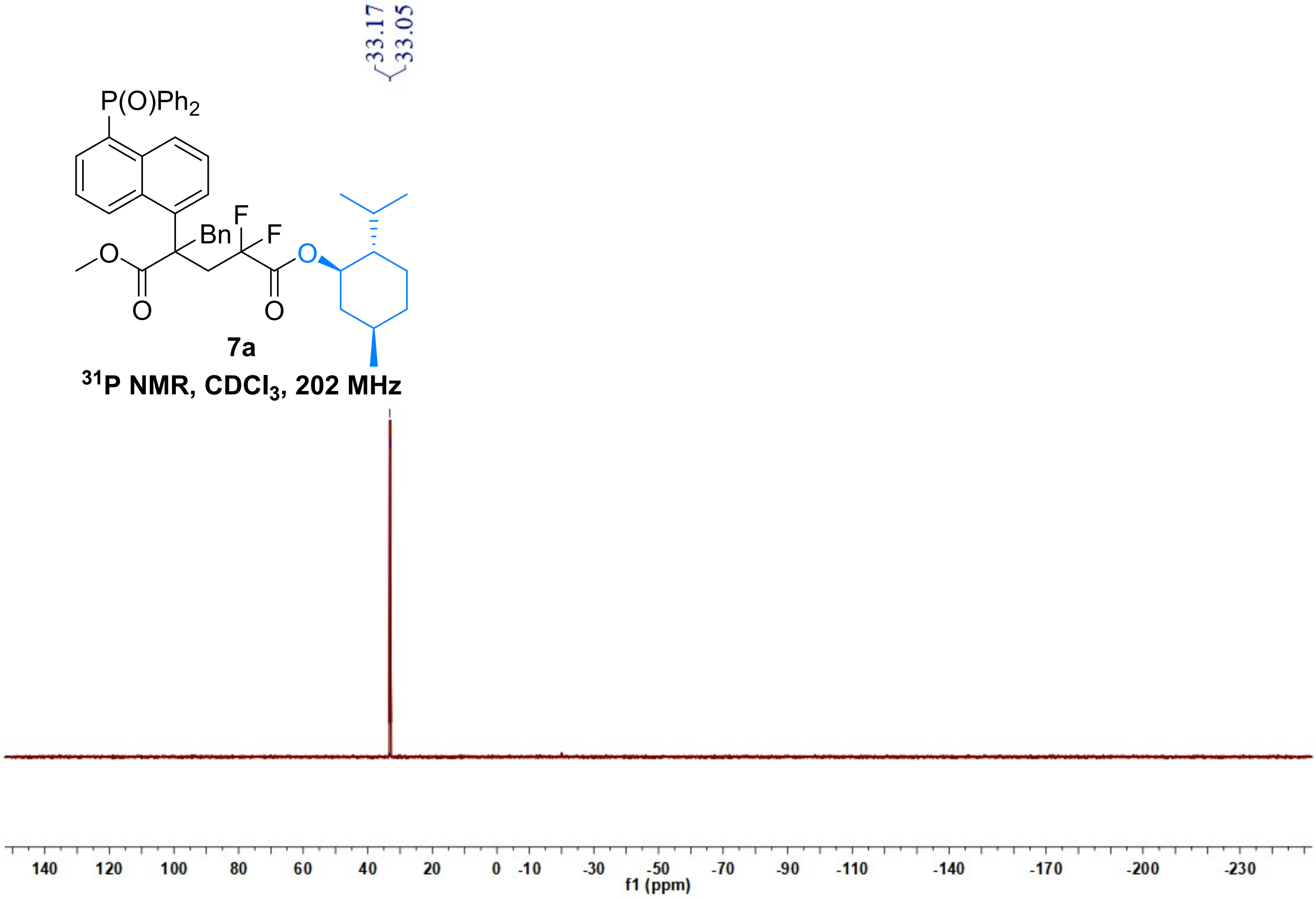
7a

^{1}H NMR, CDCl$_3$, 400 MHz



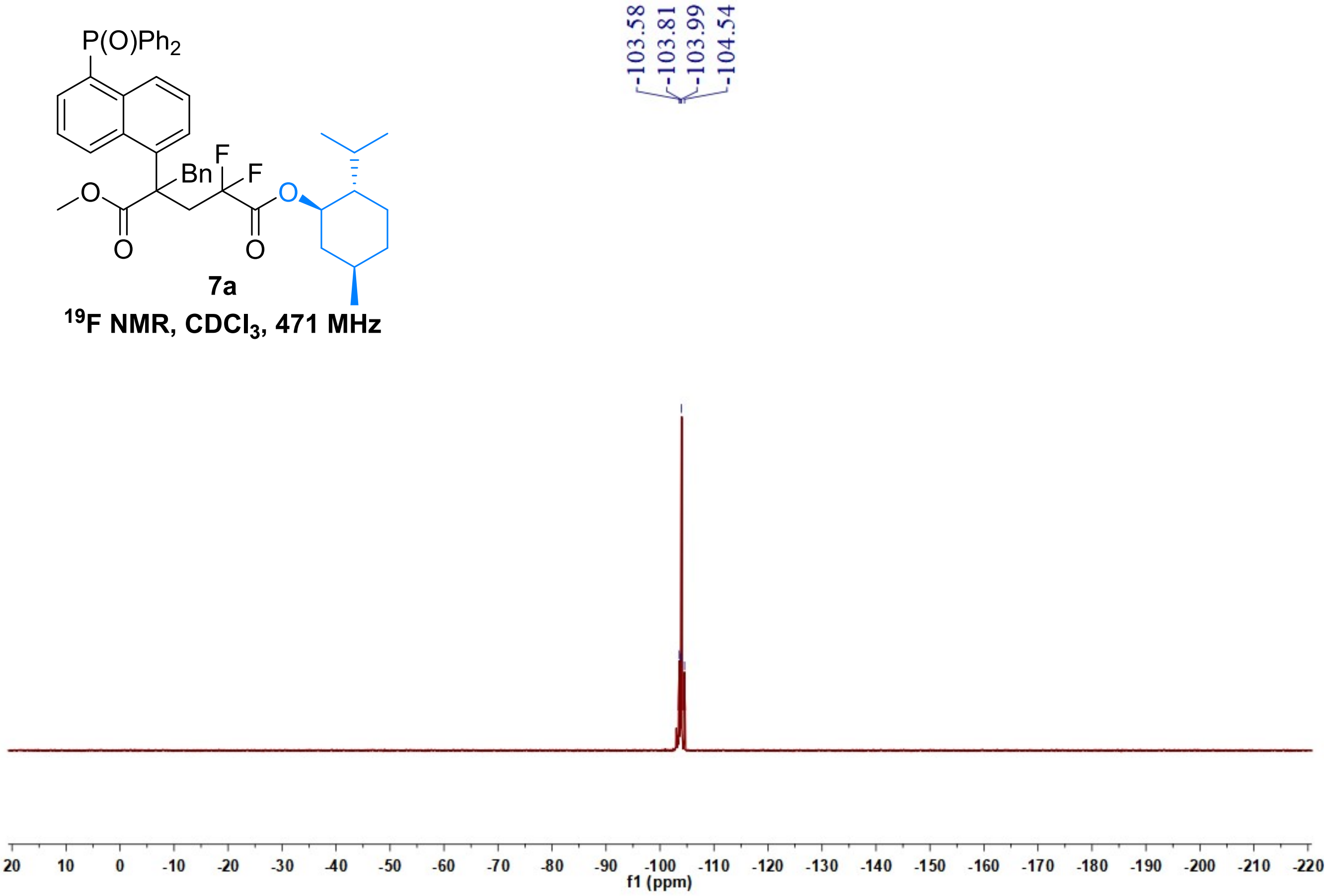
7a

^{13}C NMR, CDCl$_3$, 126 MHz



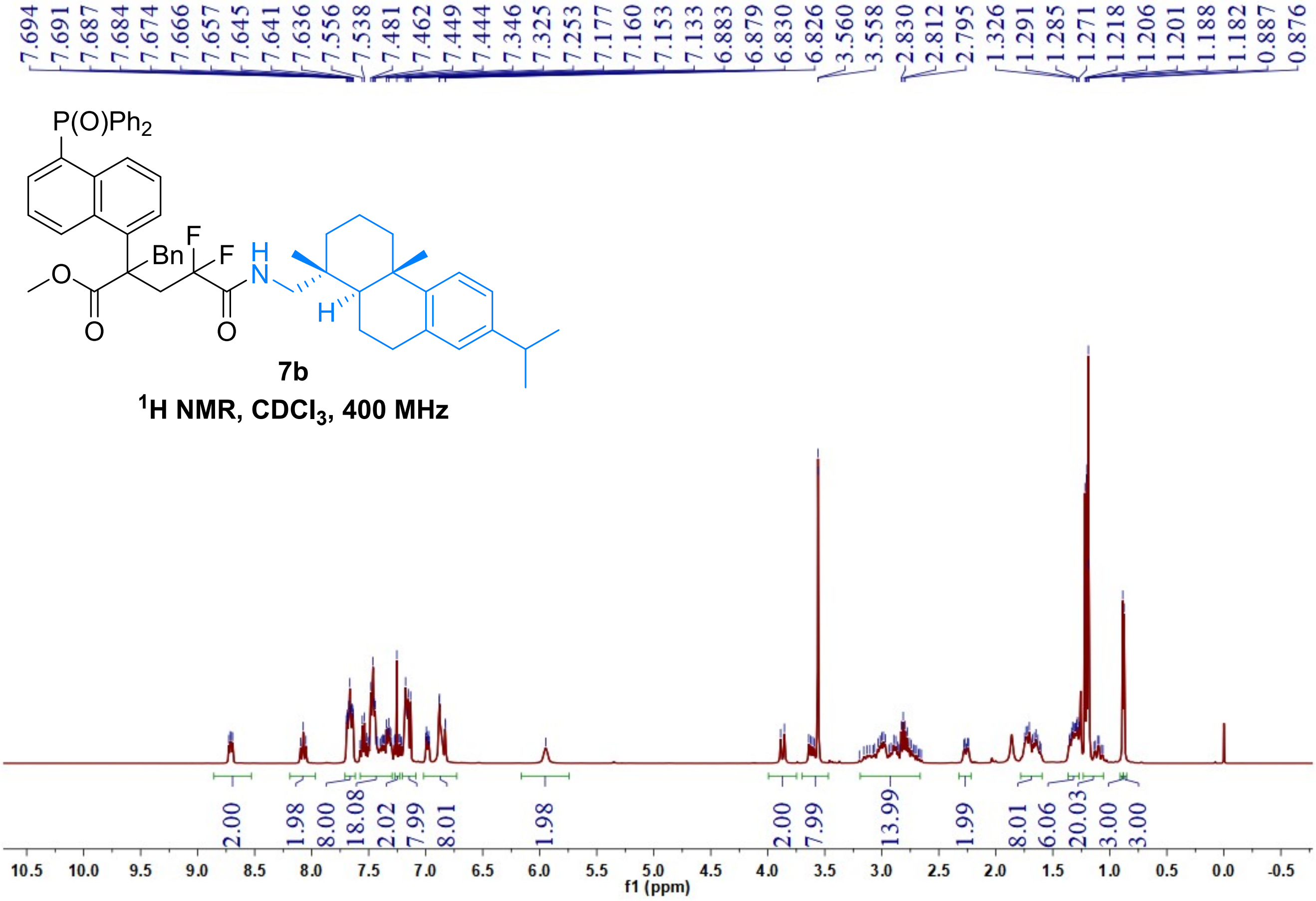
7a

^{31}P NMR, CDCl$_3$, 202 MHz



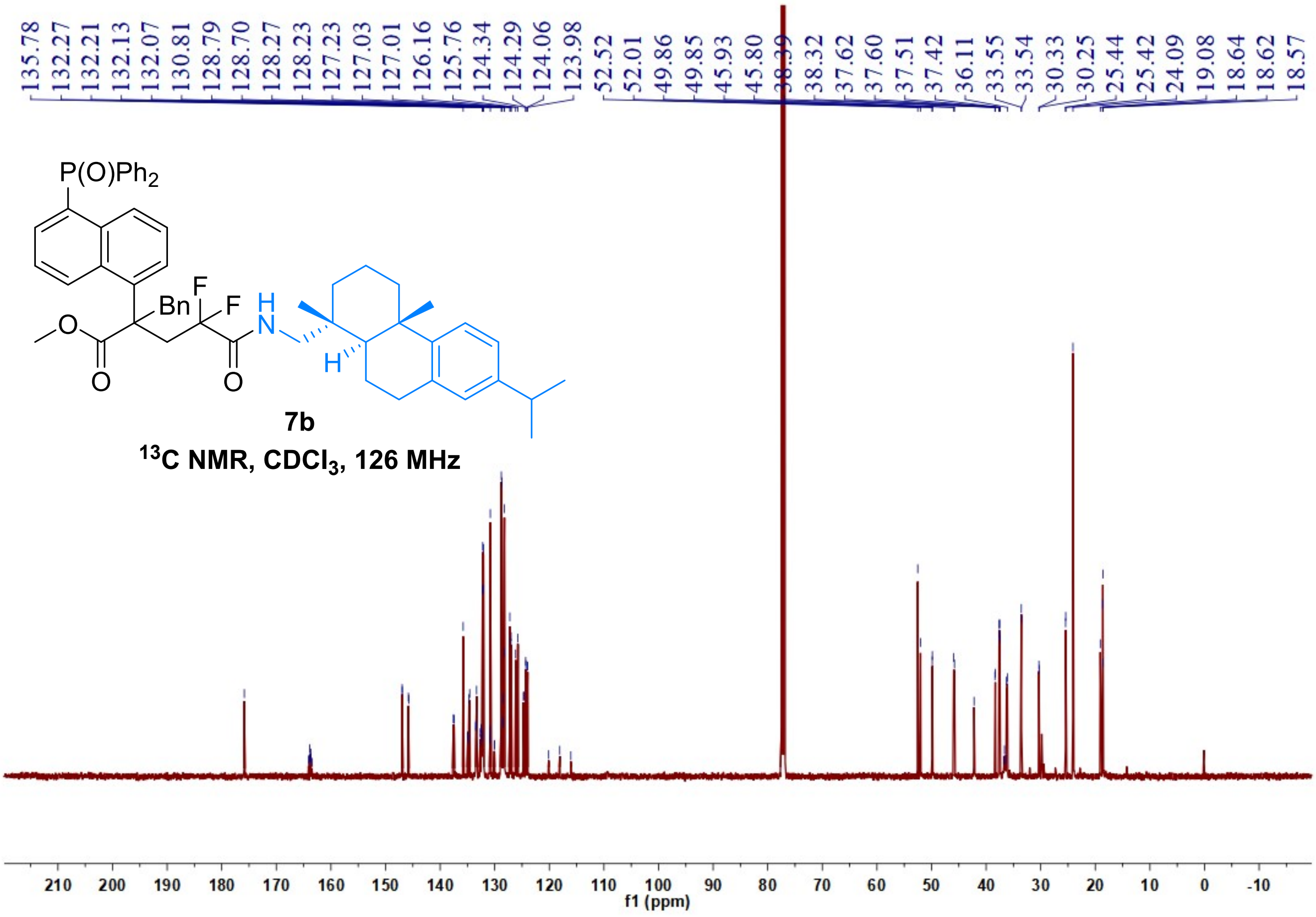
7a

^{19}F NMR, CDCl$_3$, 471 MHz



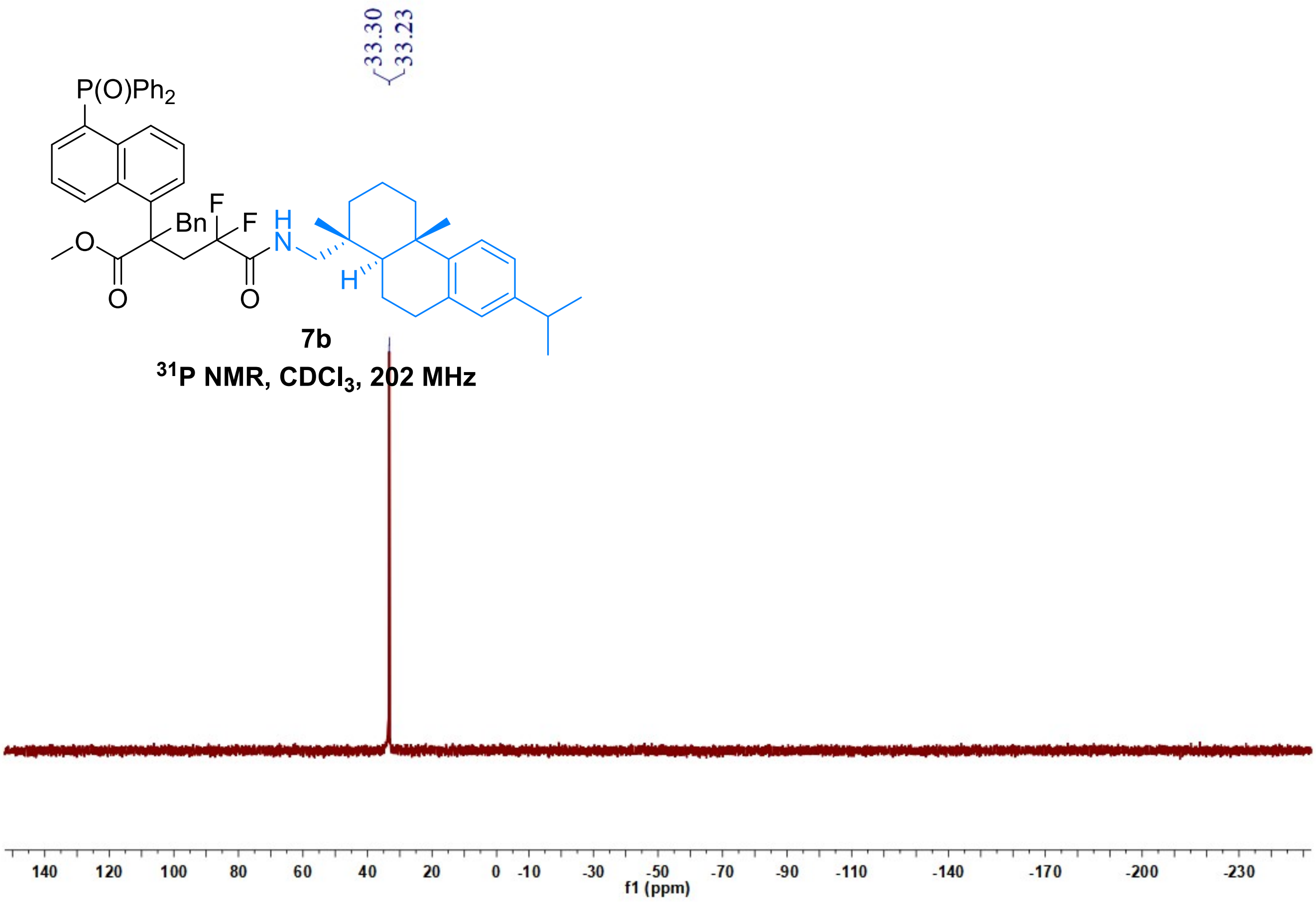
7b

^{1}H NMR, $CDCl_3$, 400 MHz



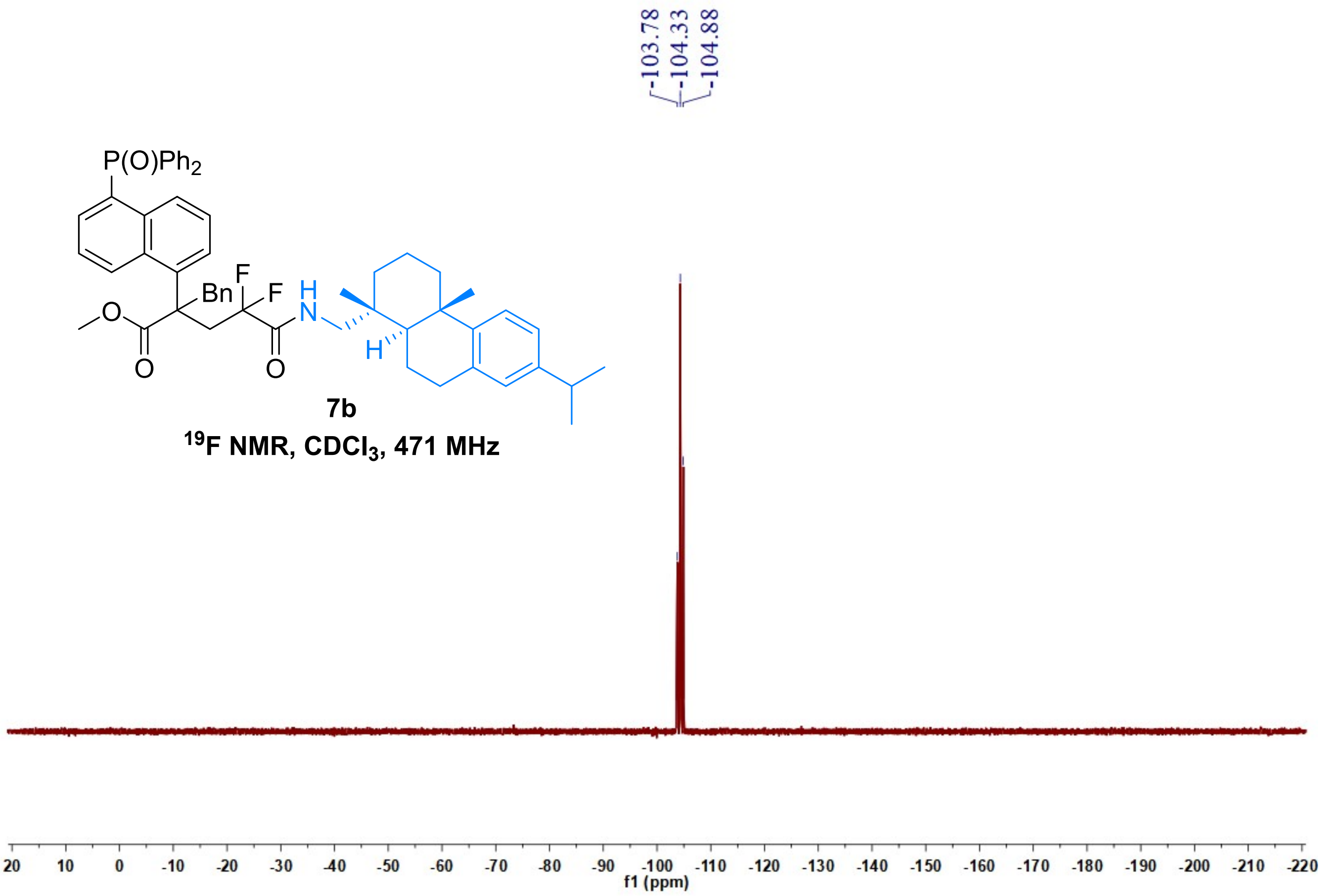
7b

^{13}C NMR, $CDCl_3$, 126 MHz



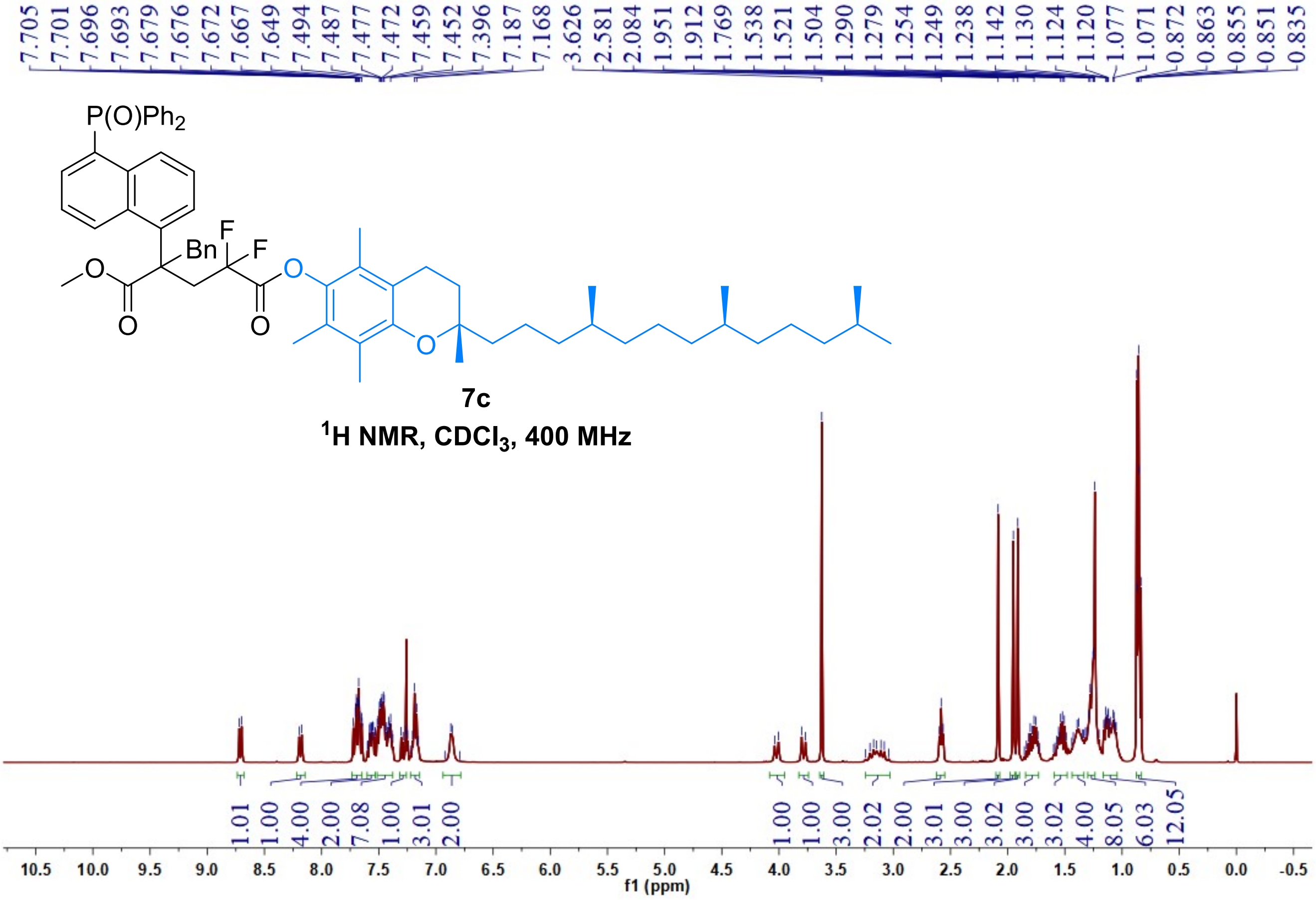
7b

^{31}P NMR, CDCl$_3$, 202 MHz



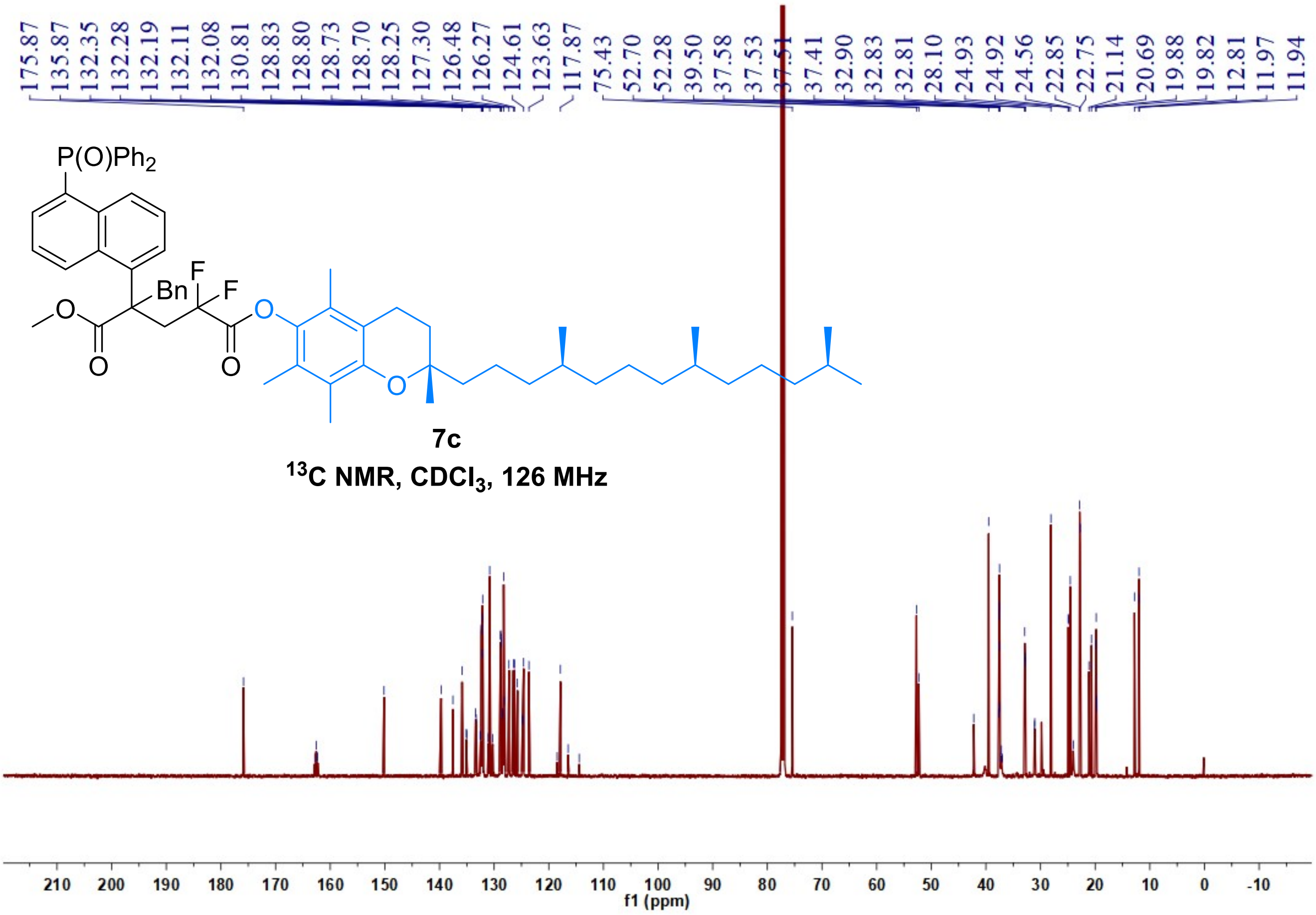
7b

^{19}F NMR, CDCl$_3$, 471 MHz



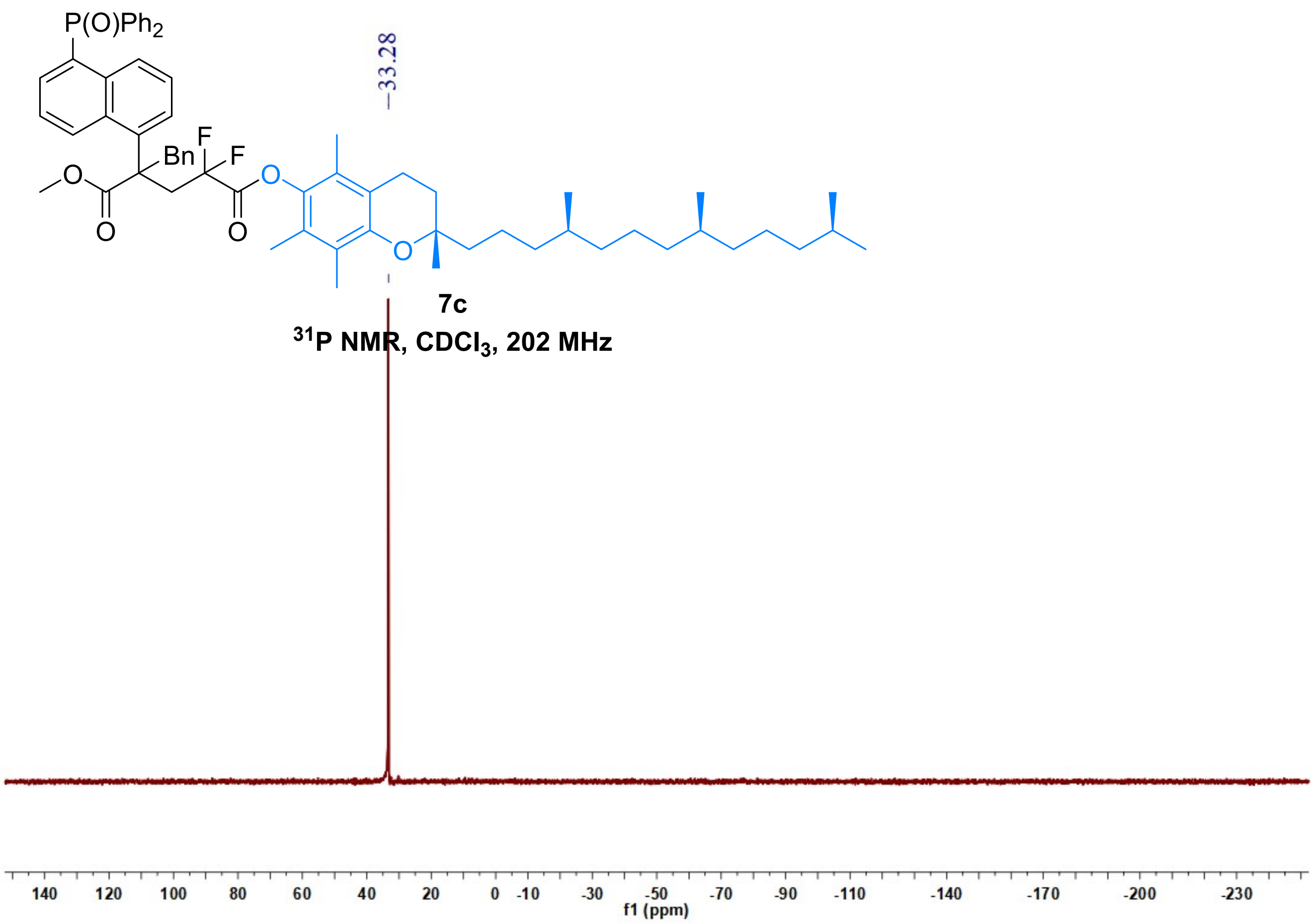
7c

^{1}H NMR, CDCl$_3$, 400 MHz



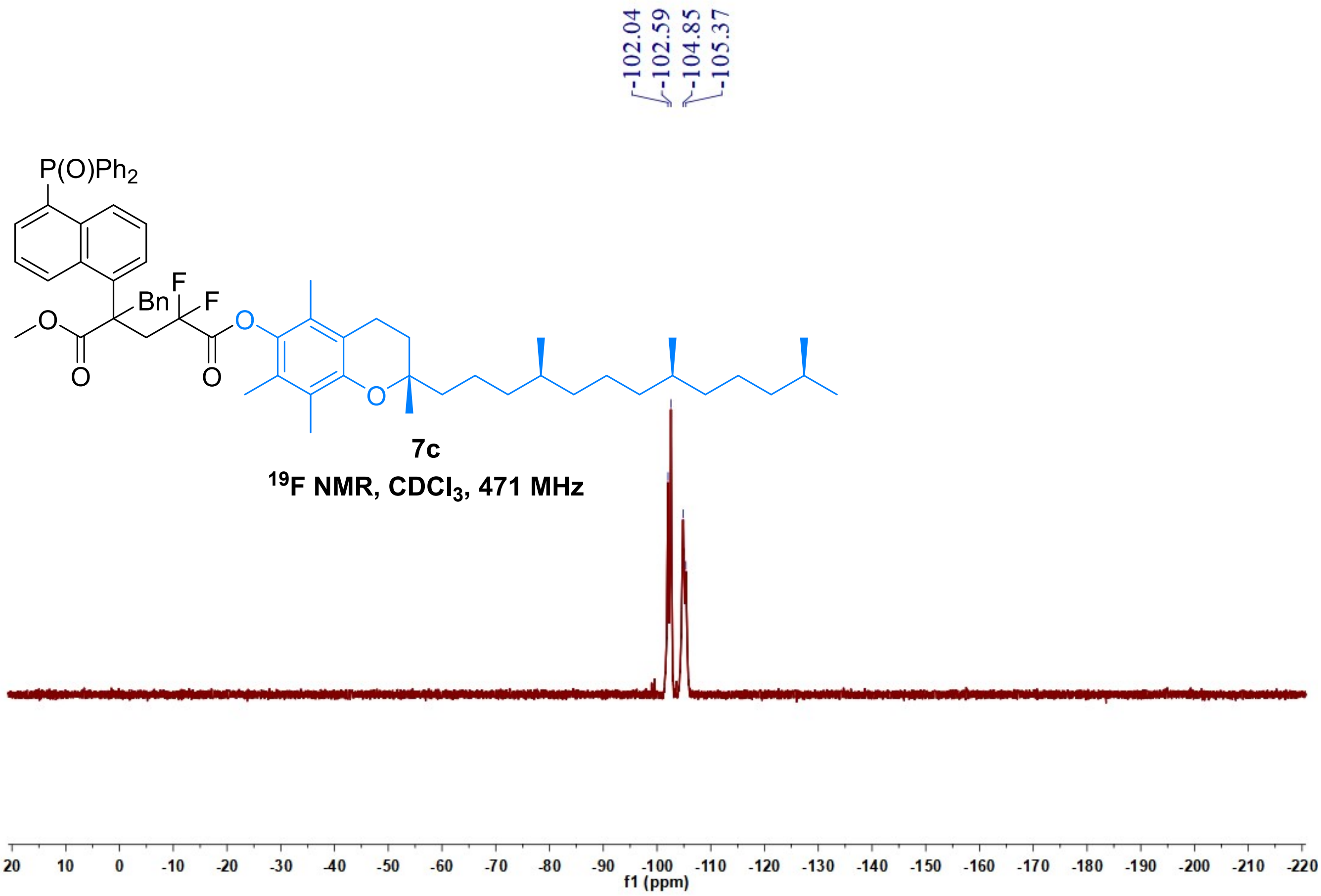
7c

^{13}C NMR, CDCl$_3$, 126 MHz



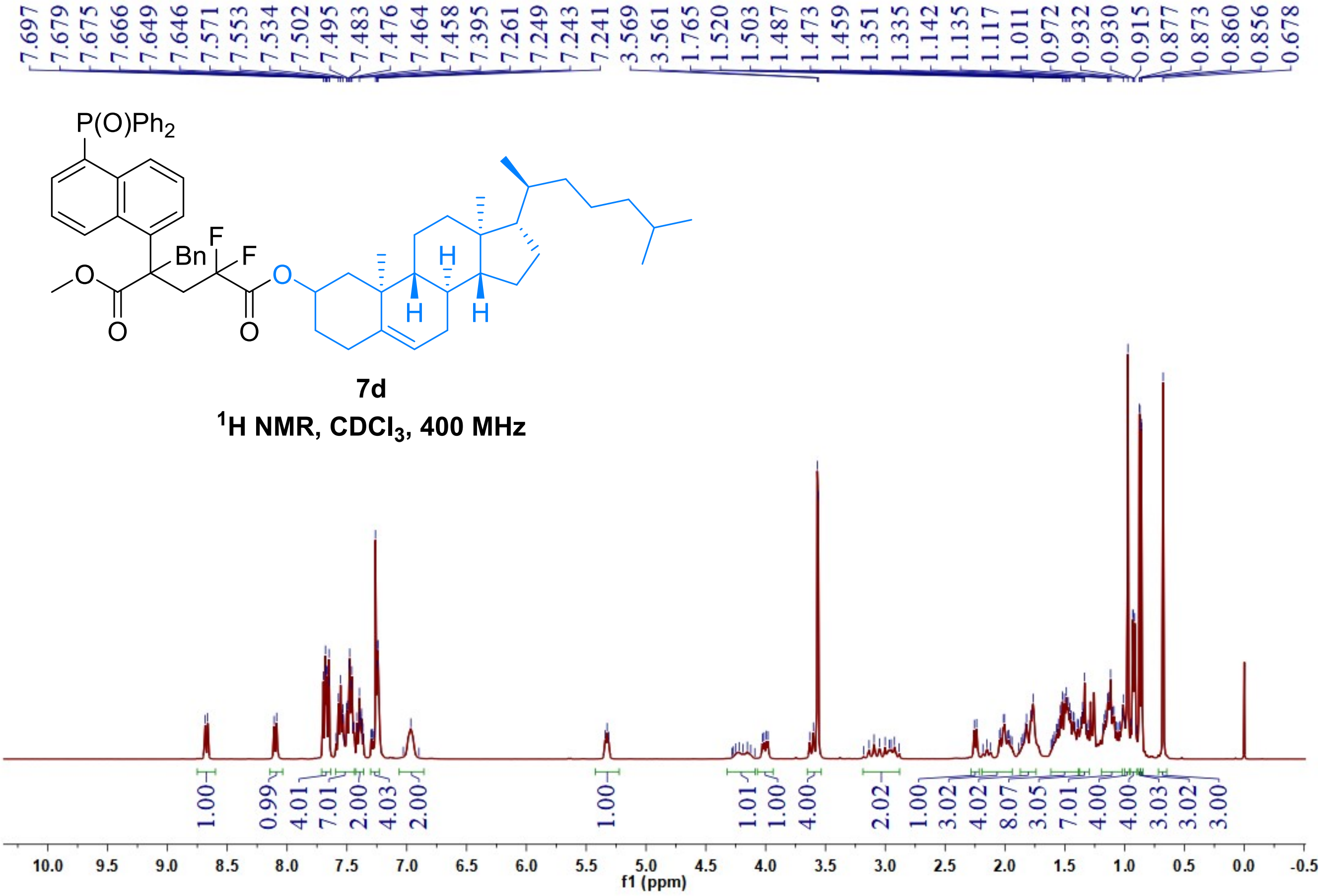
7c

^{31}P NMR, CDCl$_3$, 202 MHz



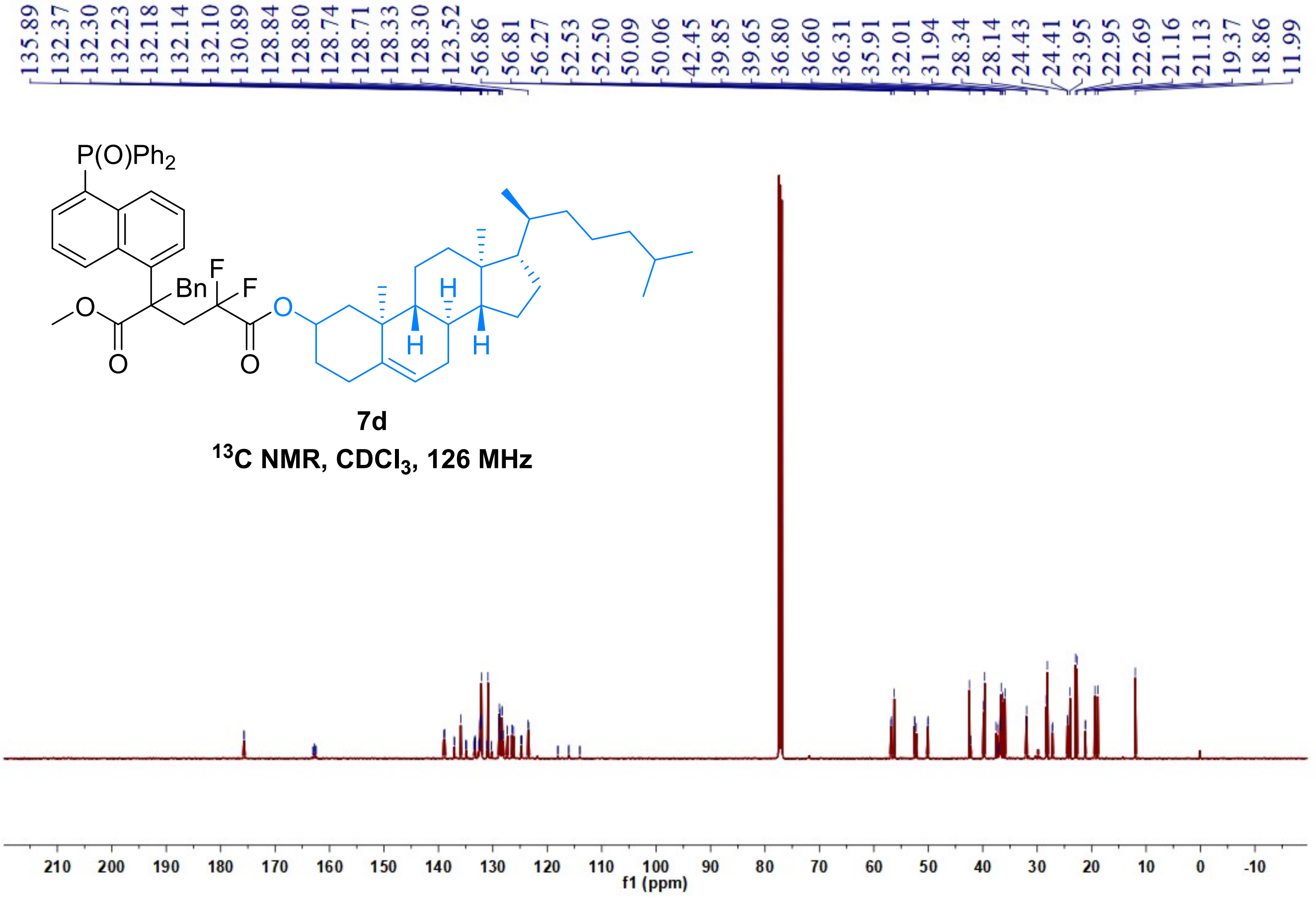
7c

^{19}F NMR, CDCl$_3$, 471 MHz



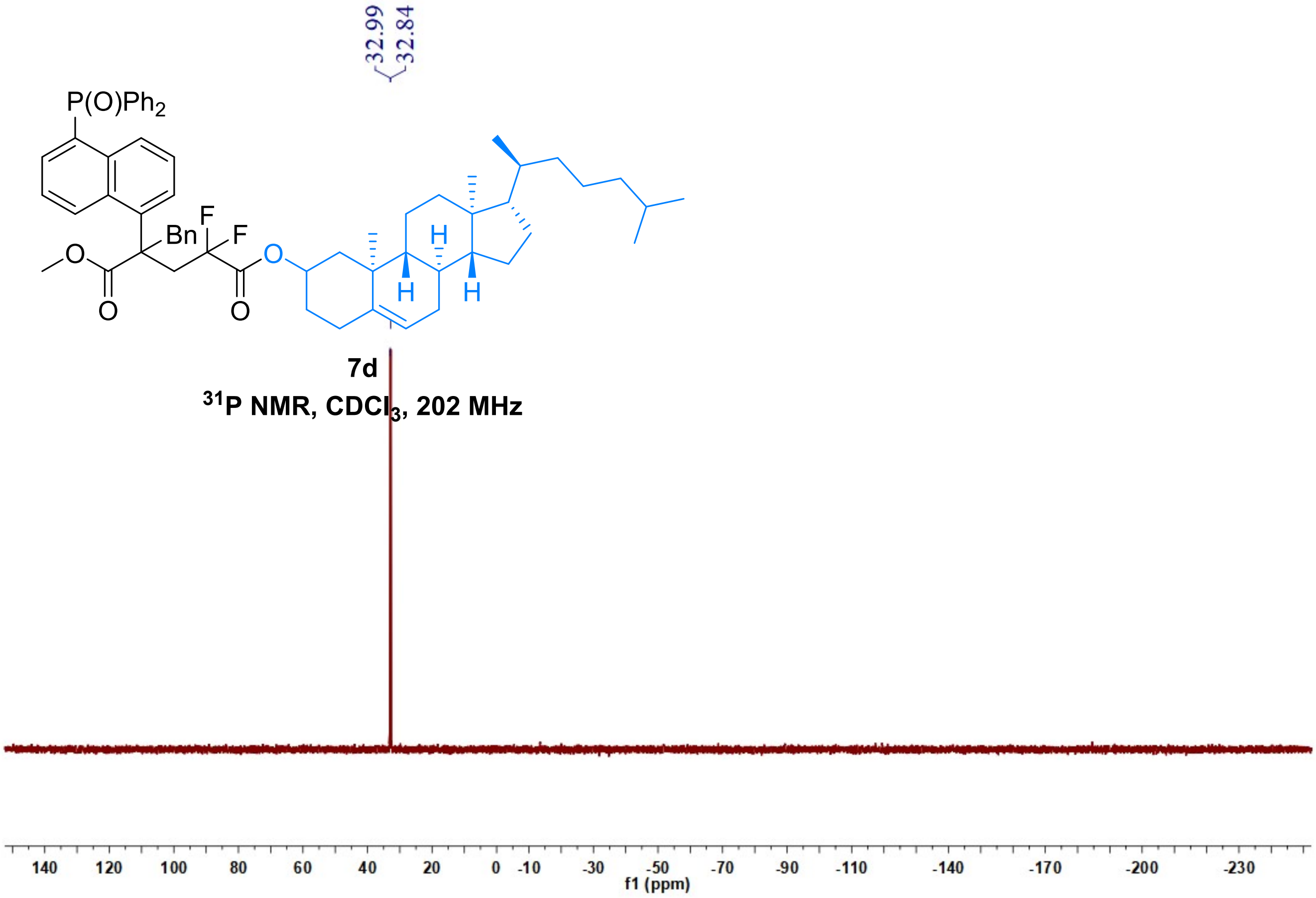
7d

^{1}H NMR, CDCl$_3$, 400 MHz



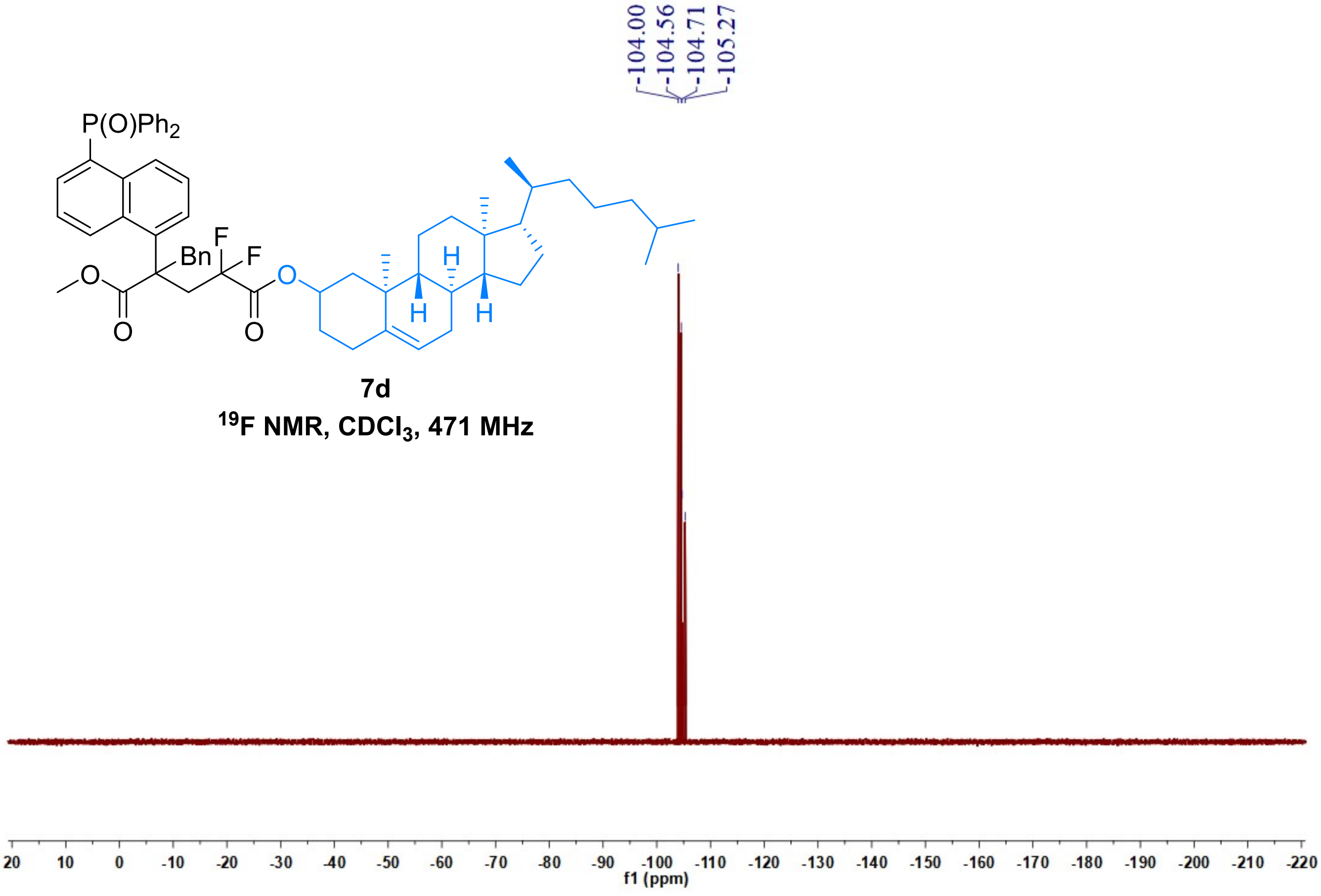
7d

^{13}C NMR, CDCl$_3$, 126 MHz



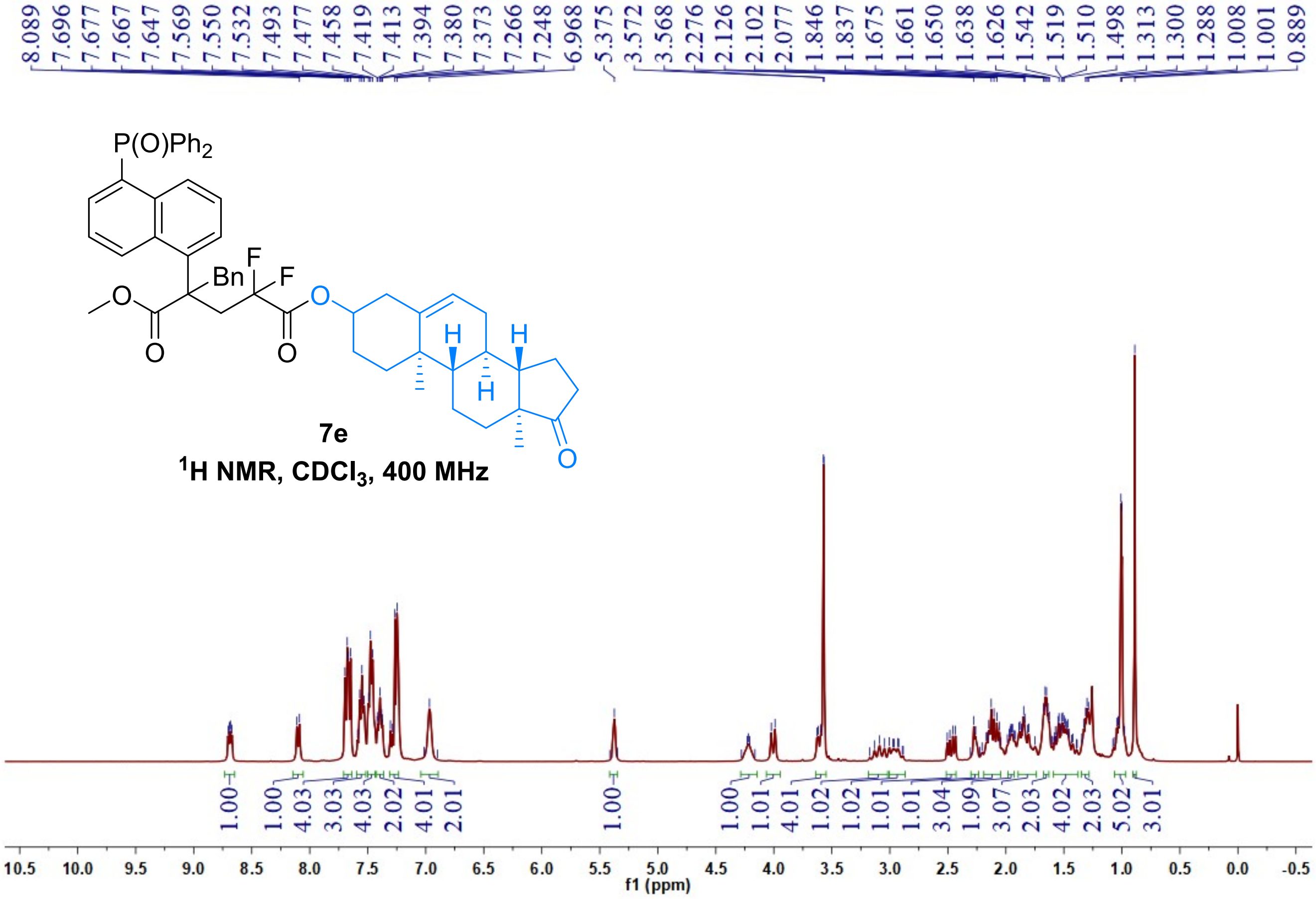
7d

^{31}P NMR, CDCl$_3$, 202 MHz



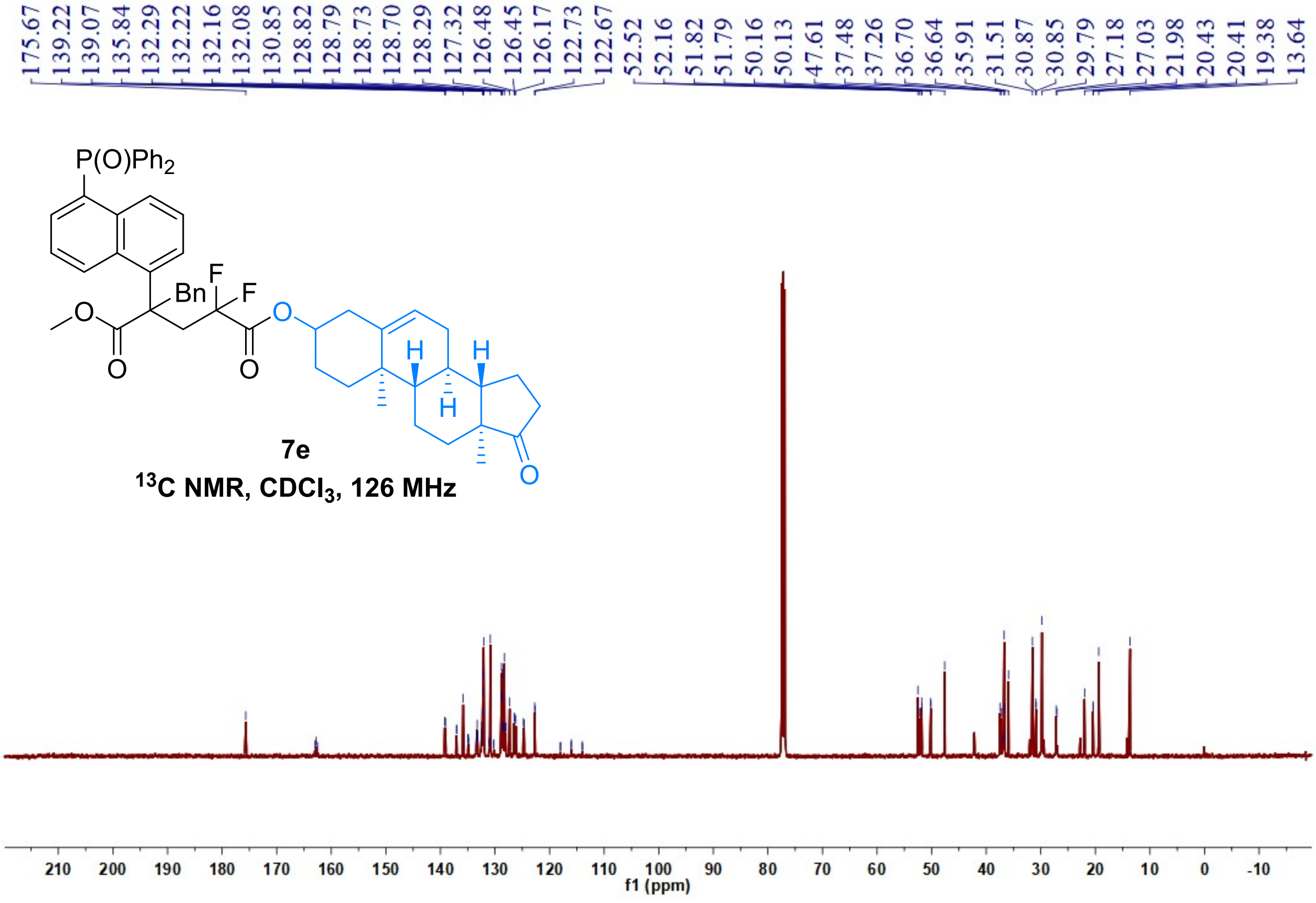
7d

^{19}F NMR, CDCl$_3$, 471 MHz



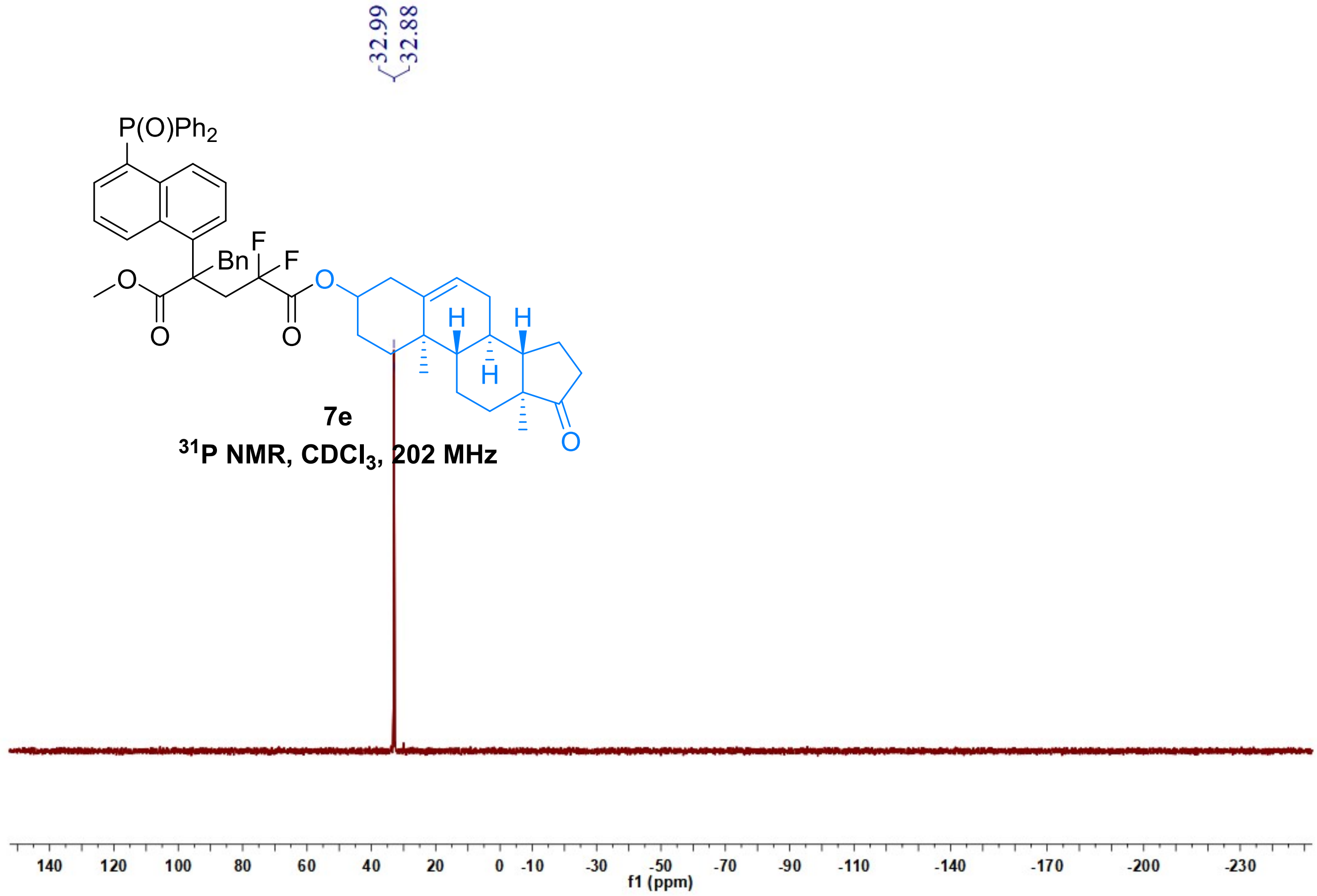
7e

^{1}H NMR, $CDCl_3$, 400 MHz

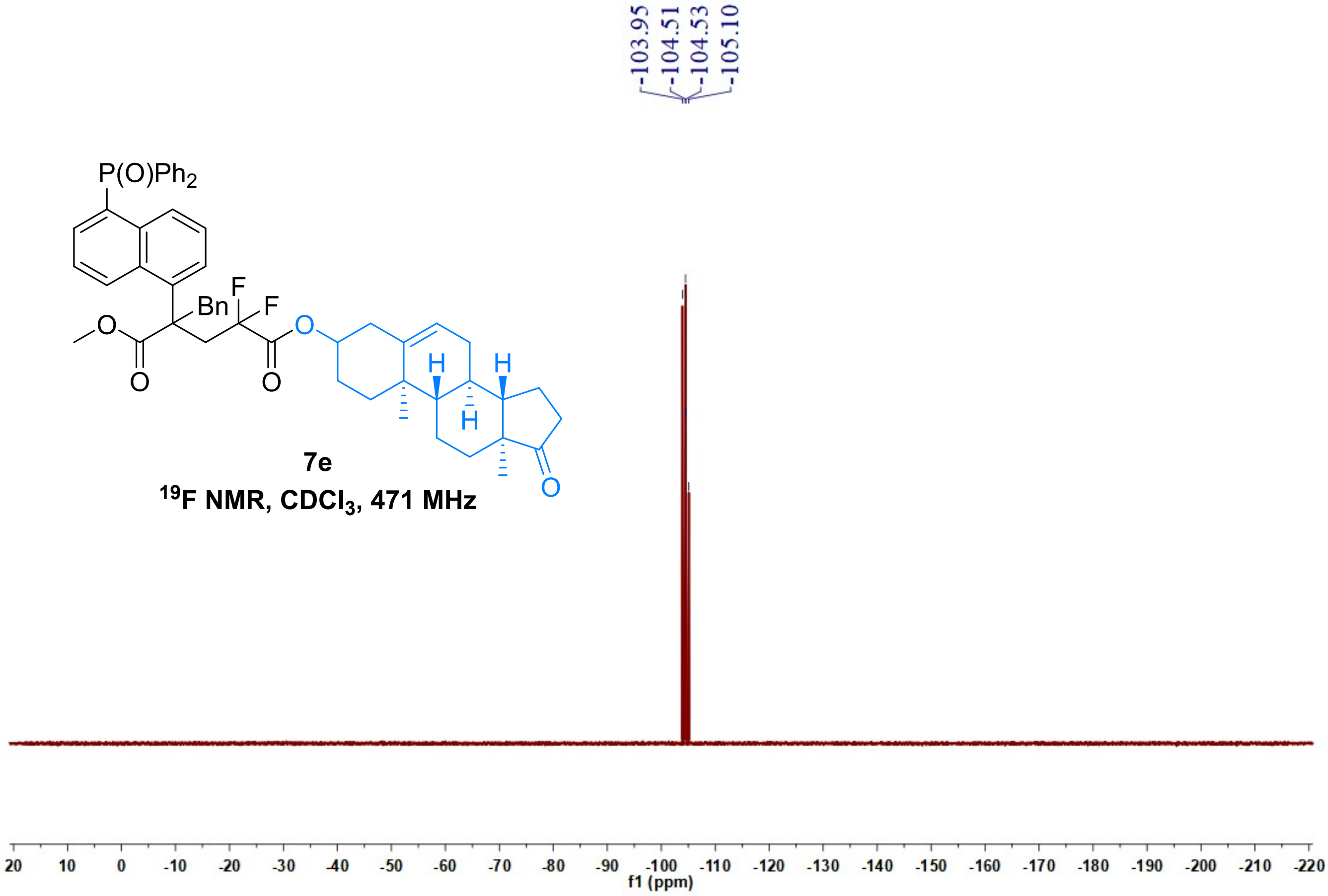


7e

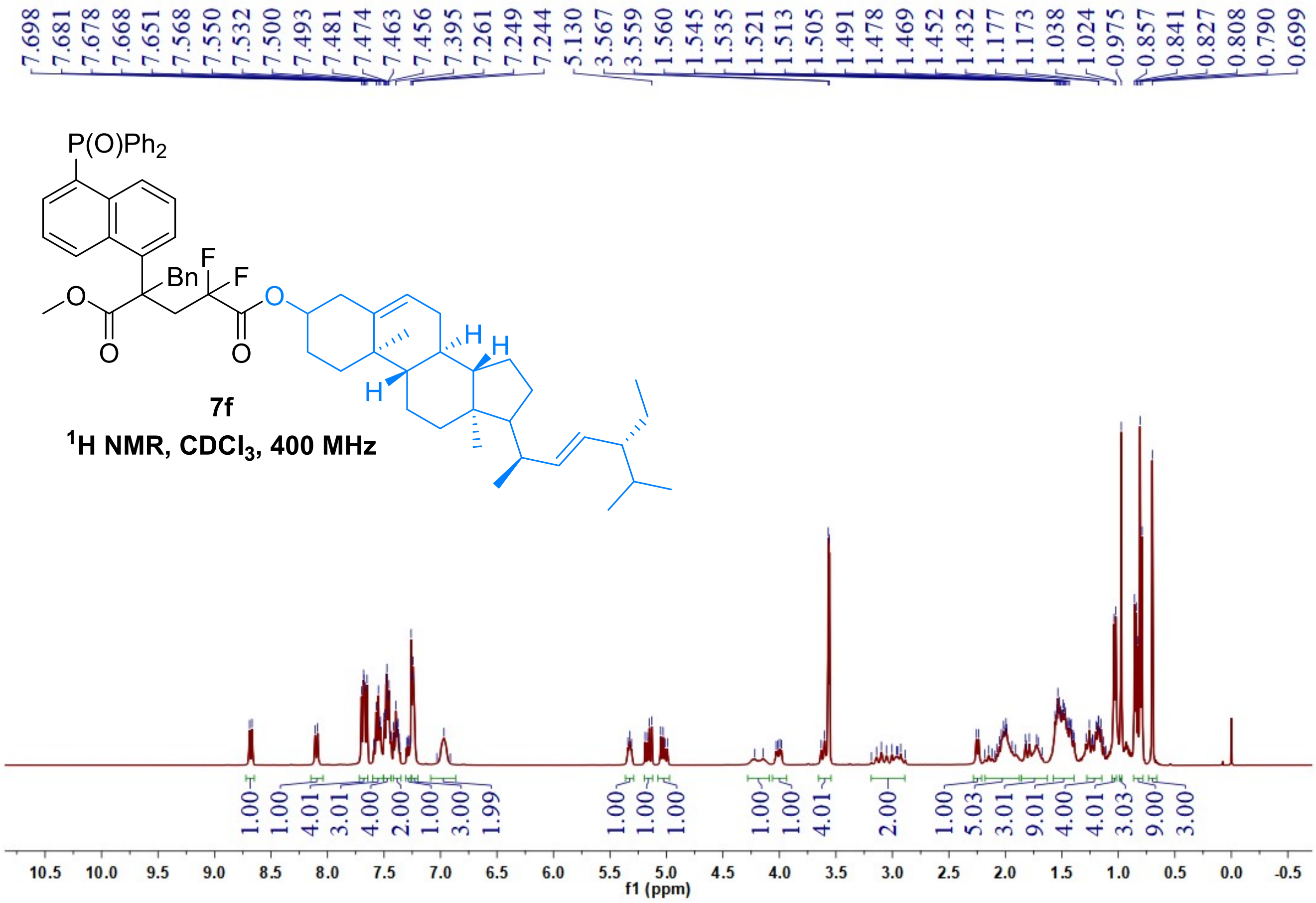
^{13}C NMR, $CDCl_3$, 126 MHz


7e

^{31}P NMR, CDCl$_3$, 202 MHz

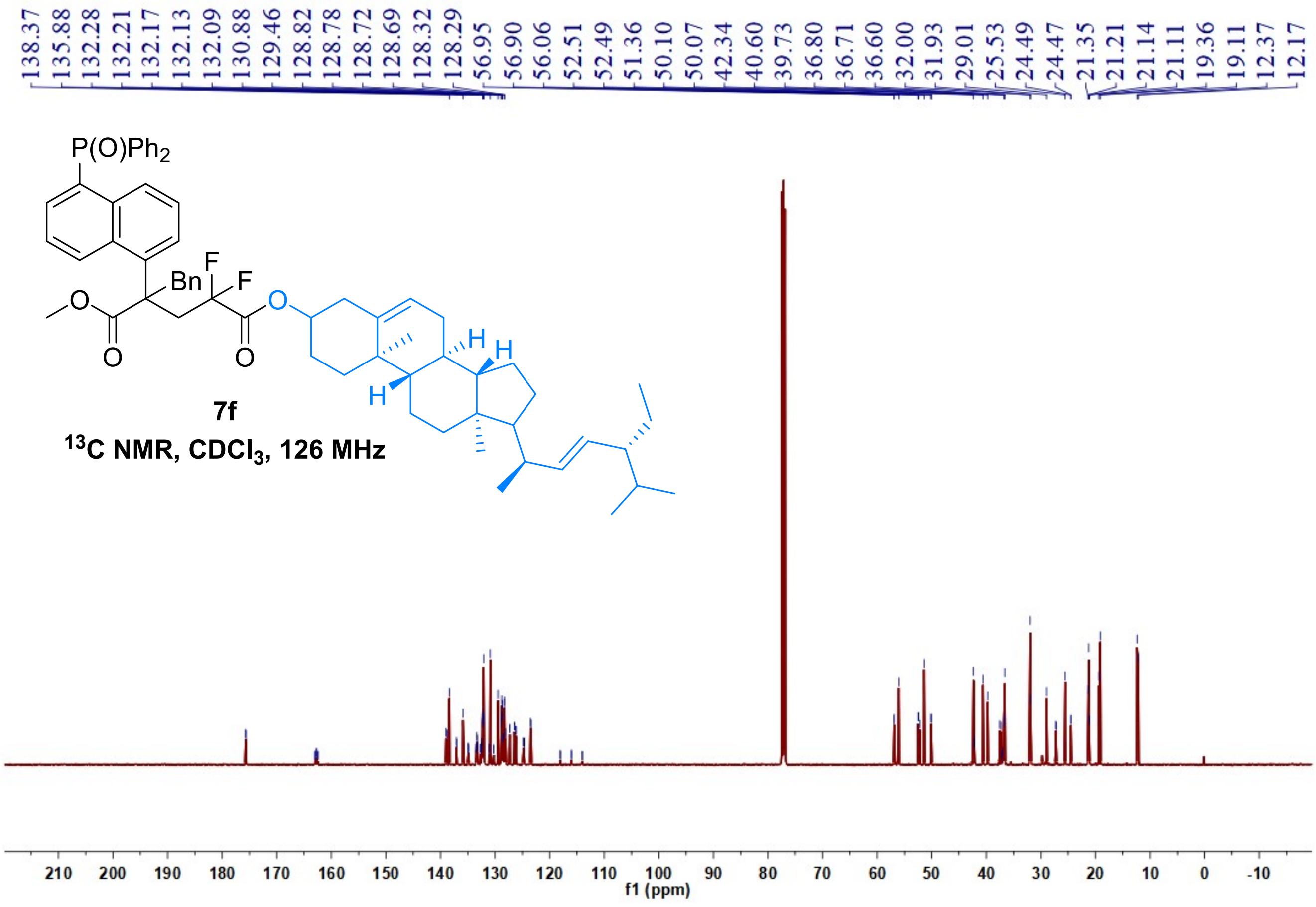

7e

^{19}F NMR, CDCl$_3$, 471 MHz



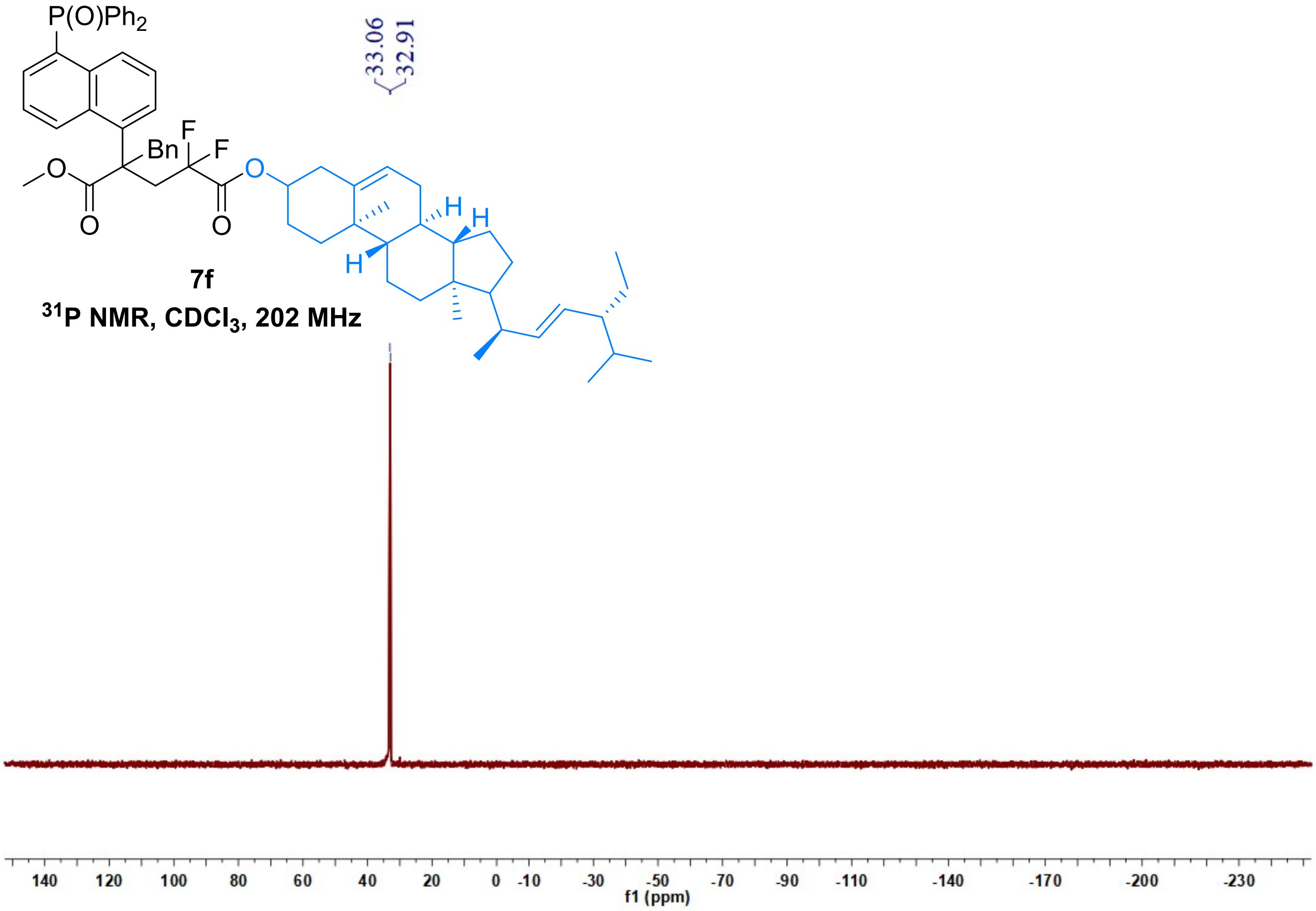
7f

^{1}H NMR, CDCl$_3$, 400 MHz

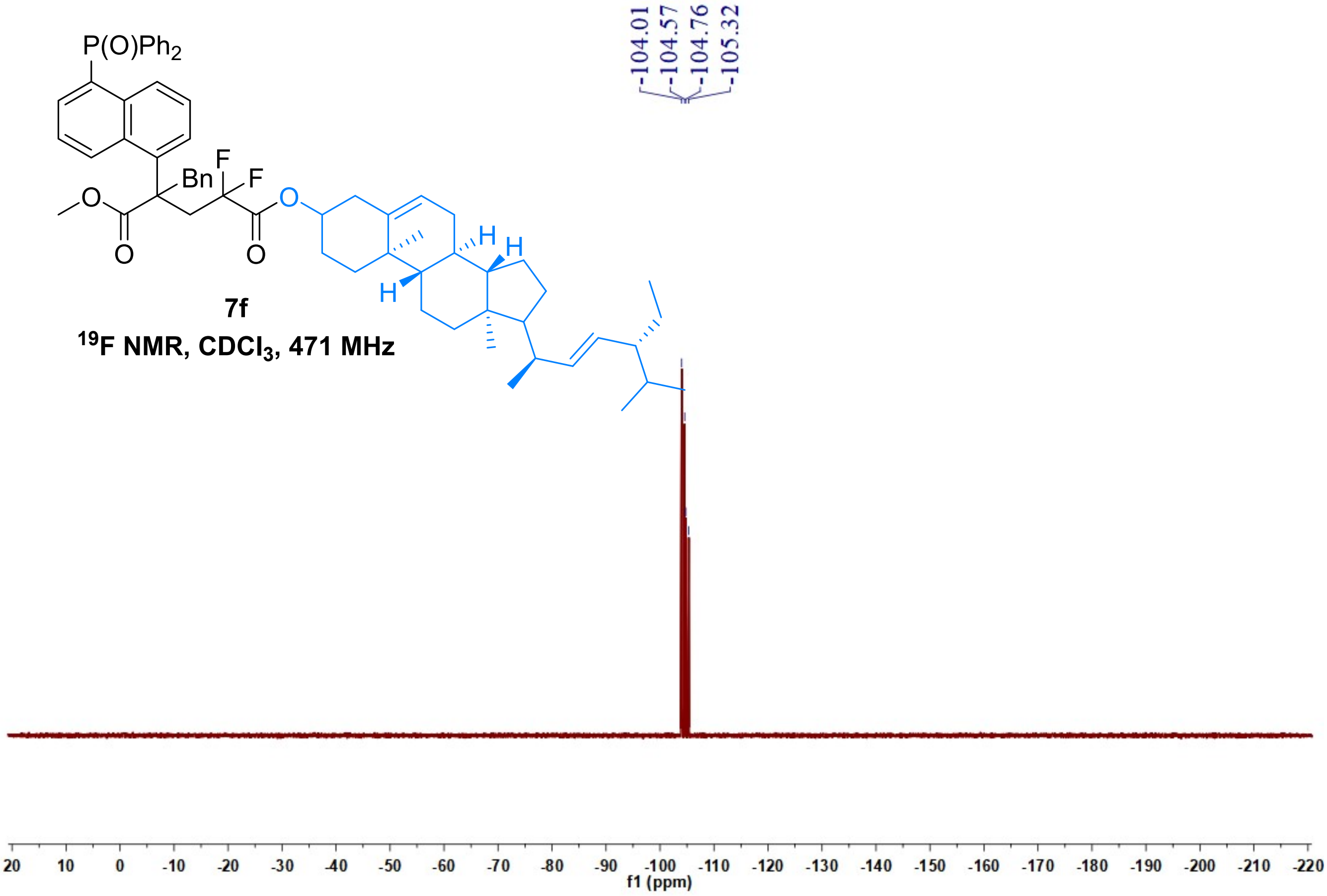


7f

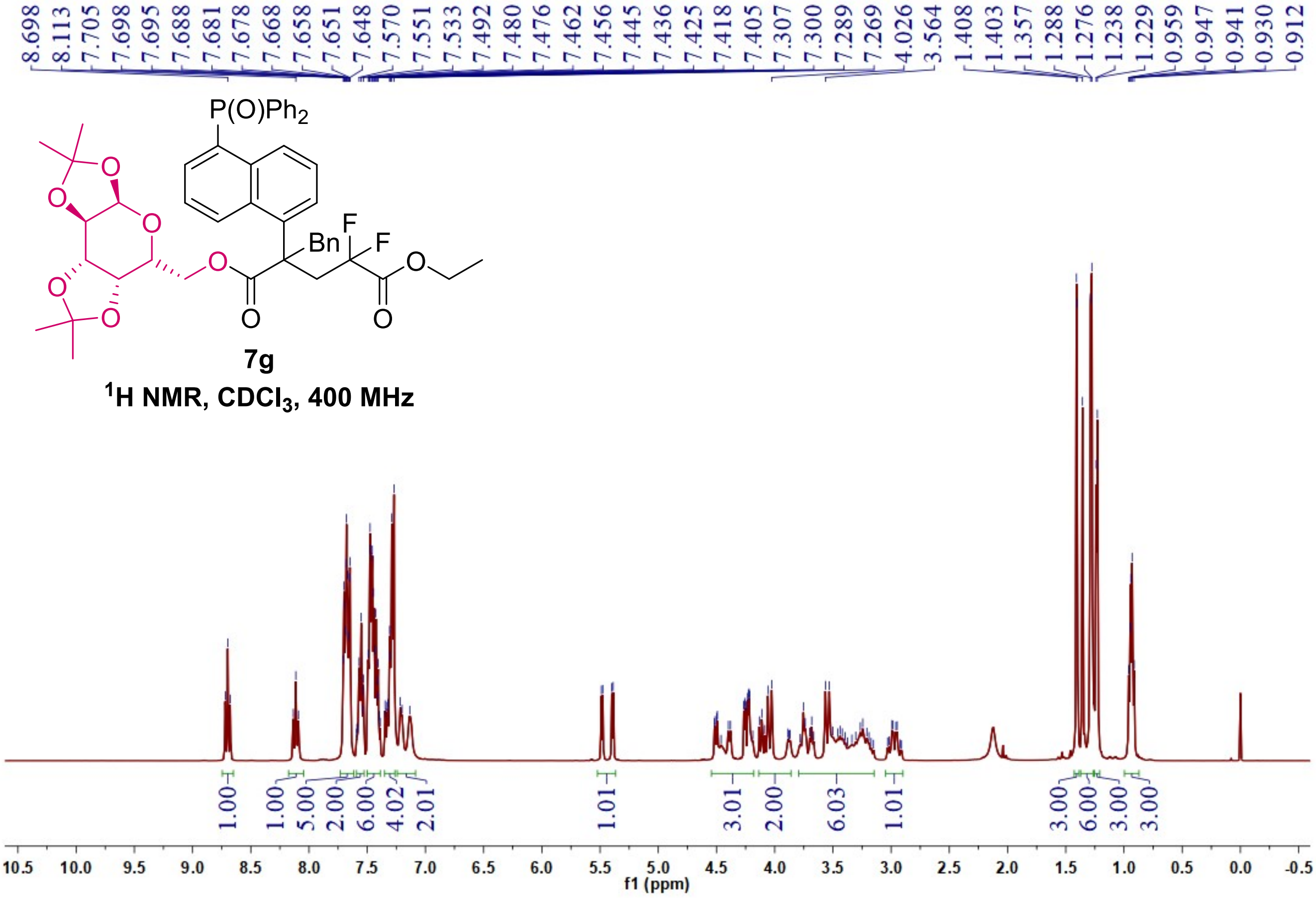
^{13}C NMR, CDCl$_3$, 126 MHz


7f

^{31}P NMR, $CDCl_3$, 202 MHz

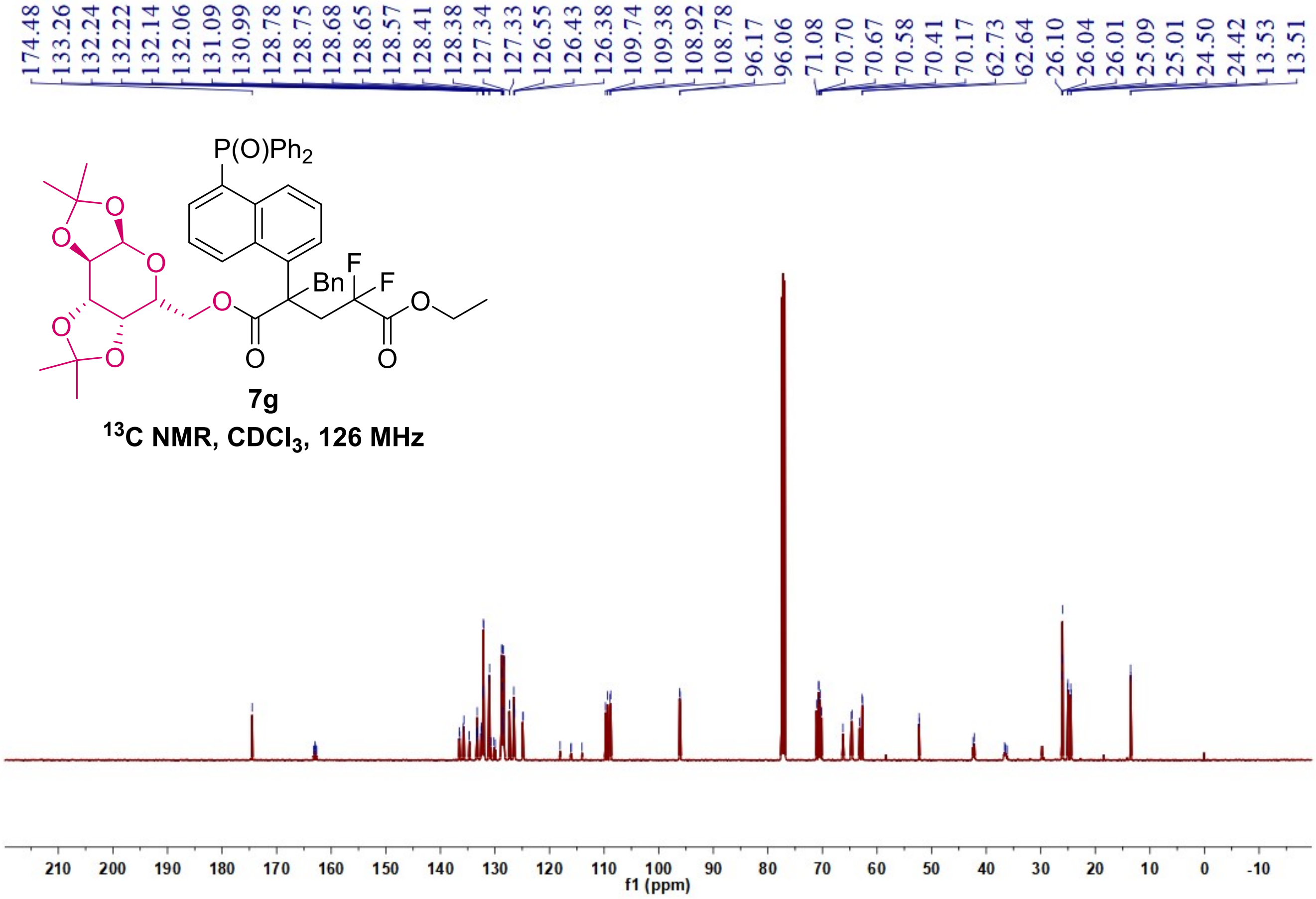

7f

^{19}F NMR, $CDCl_3$, 471 MHz



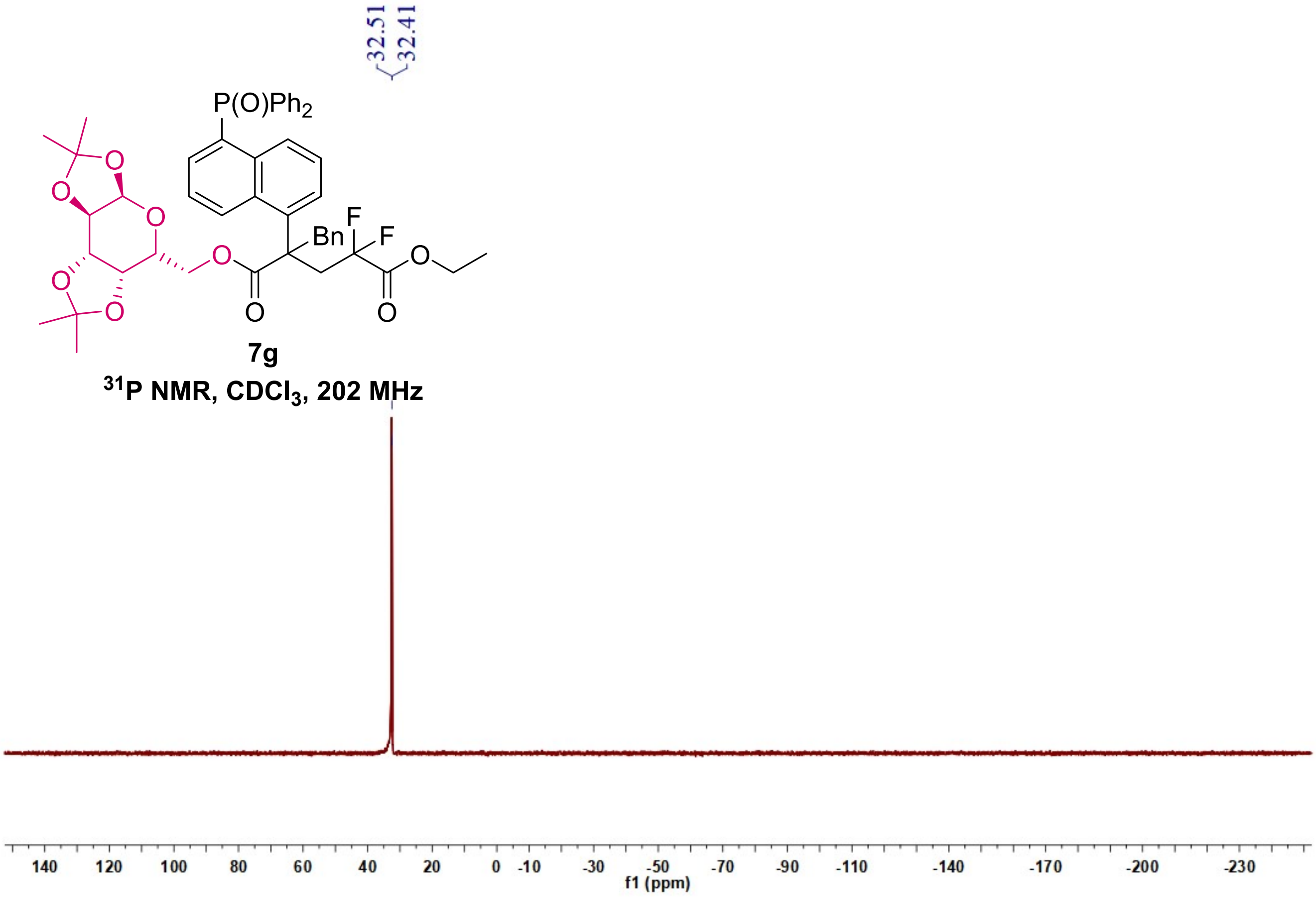
7g

^{1}H NMR, CDCl$_3$, 400 MHz

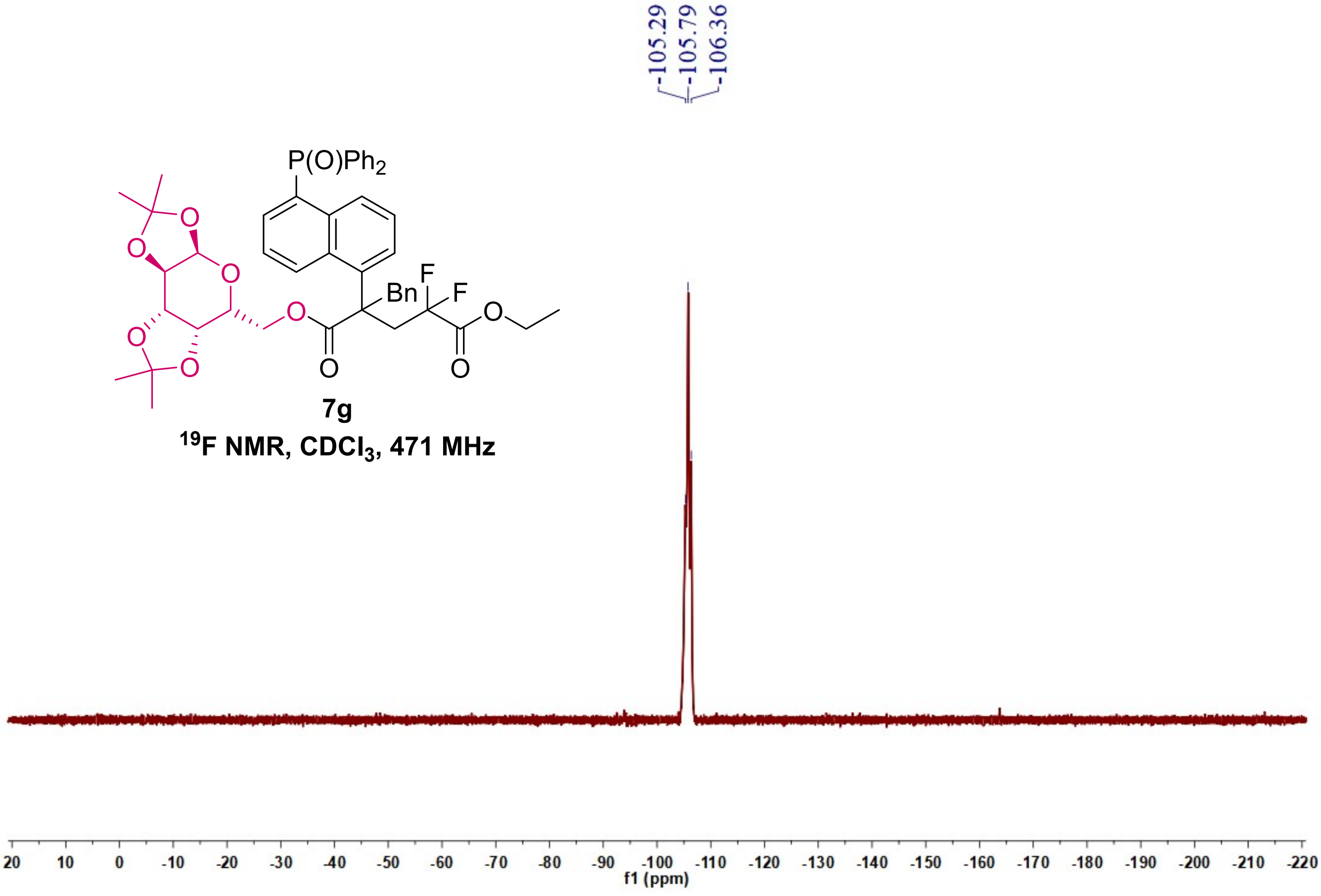


7g

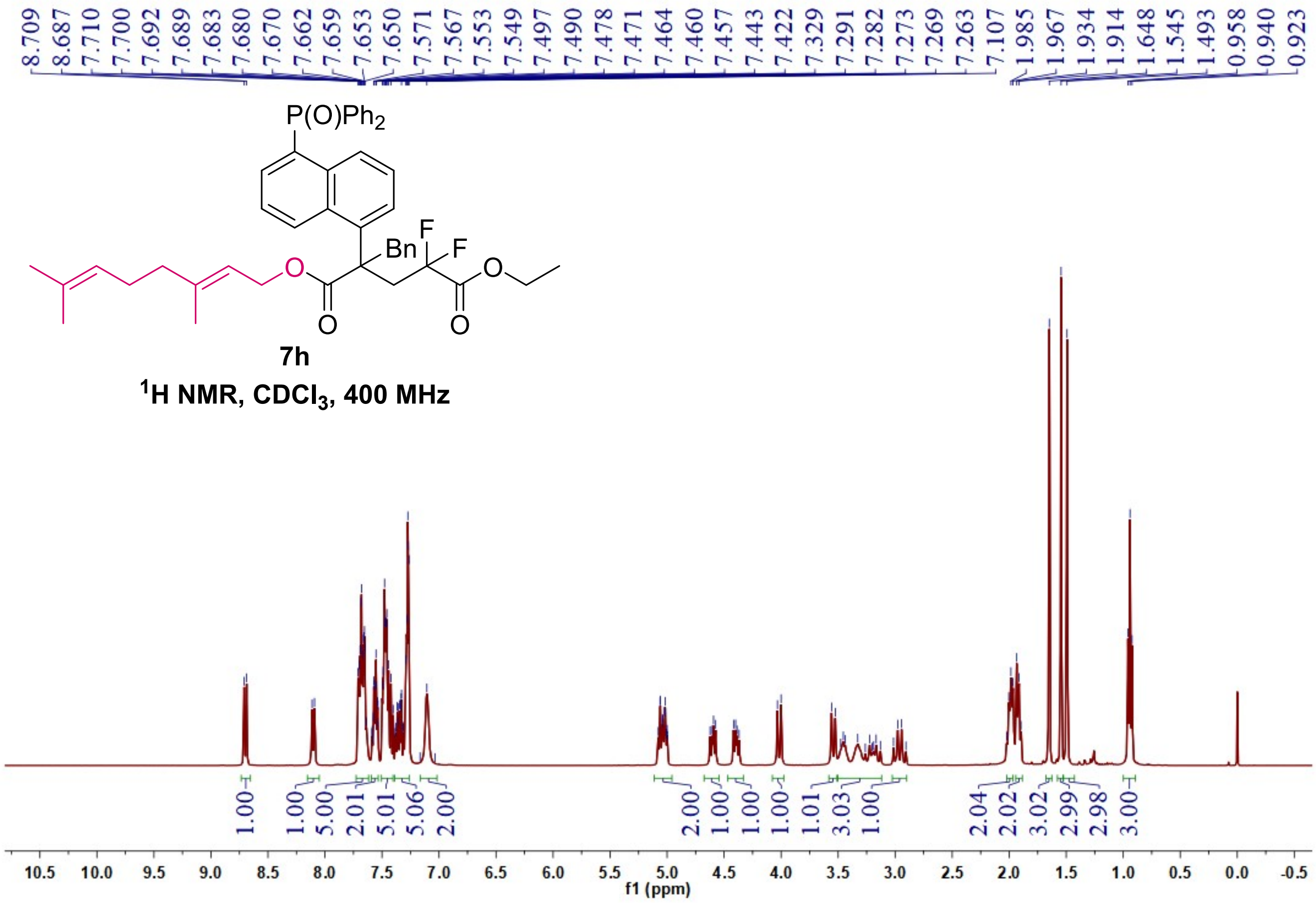
^{13}C NMR, CDCl$_3$, 126 MHz


7g

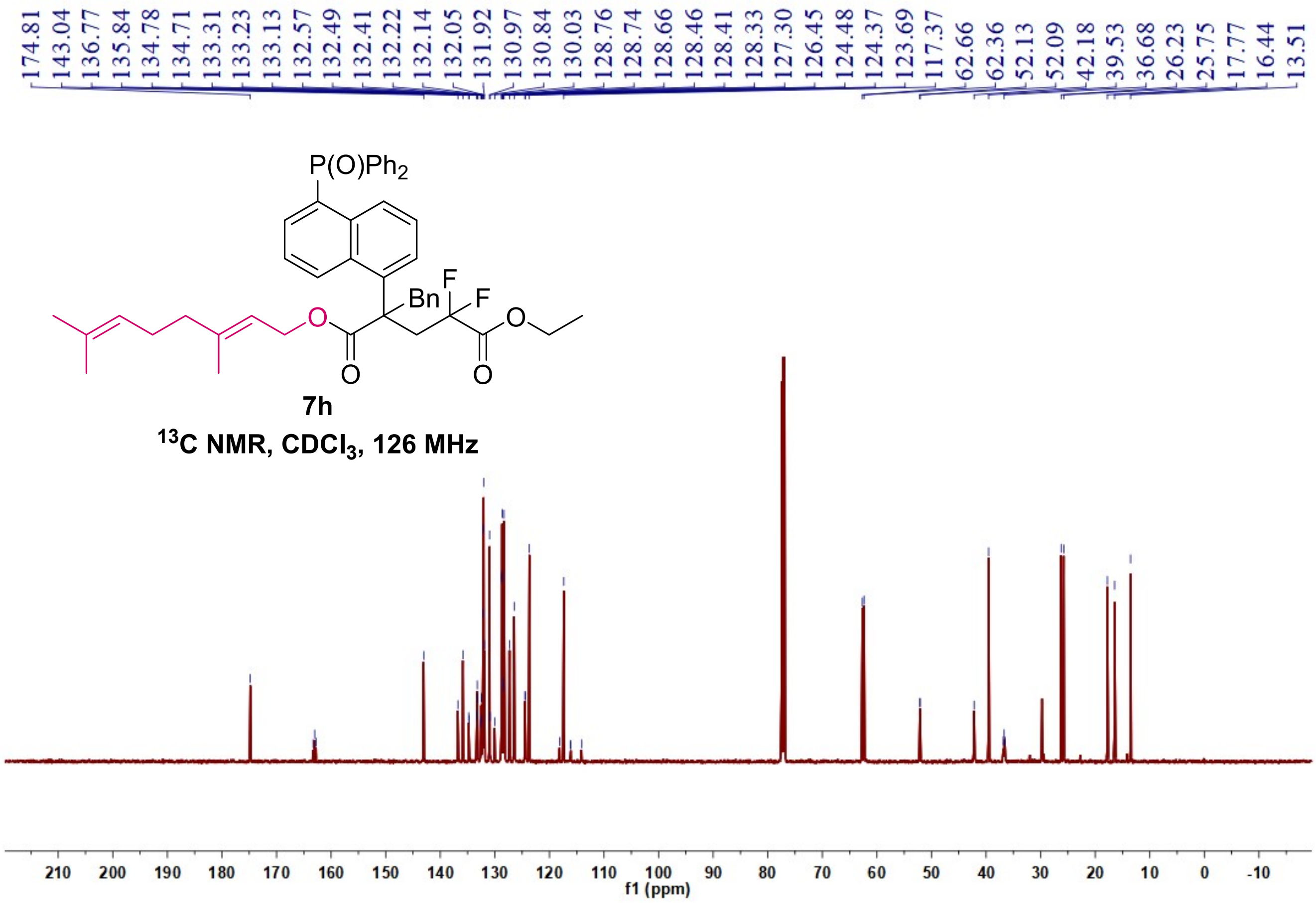
^{31}P NMR, CDCl$_3$, 202 MHz


7g

^{19}F NMR, CDCl$_3$, 471 MHz


7h

^{1}H NMR, $CDCl_3$, 400 MHz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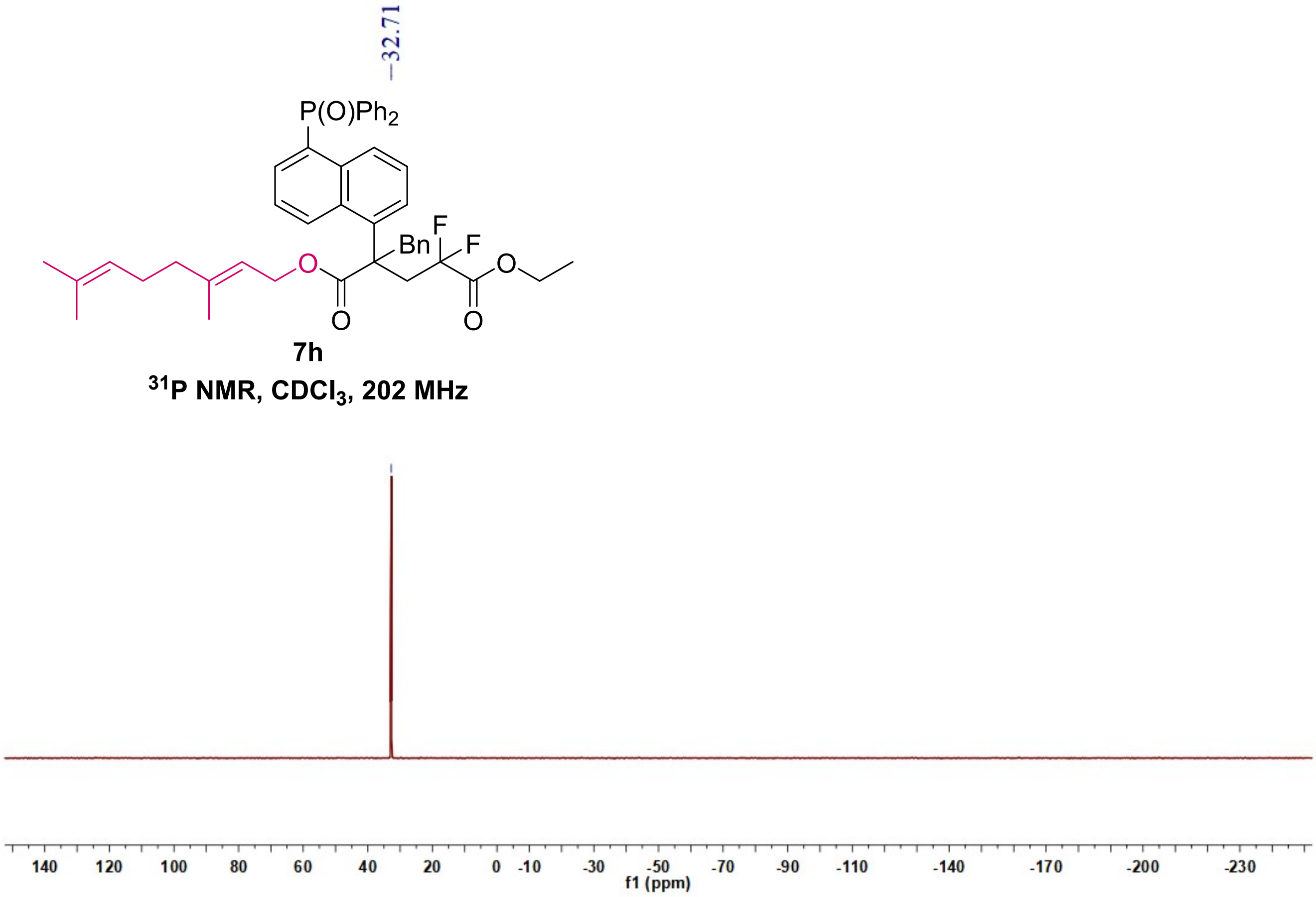
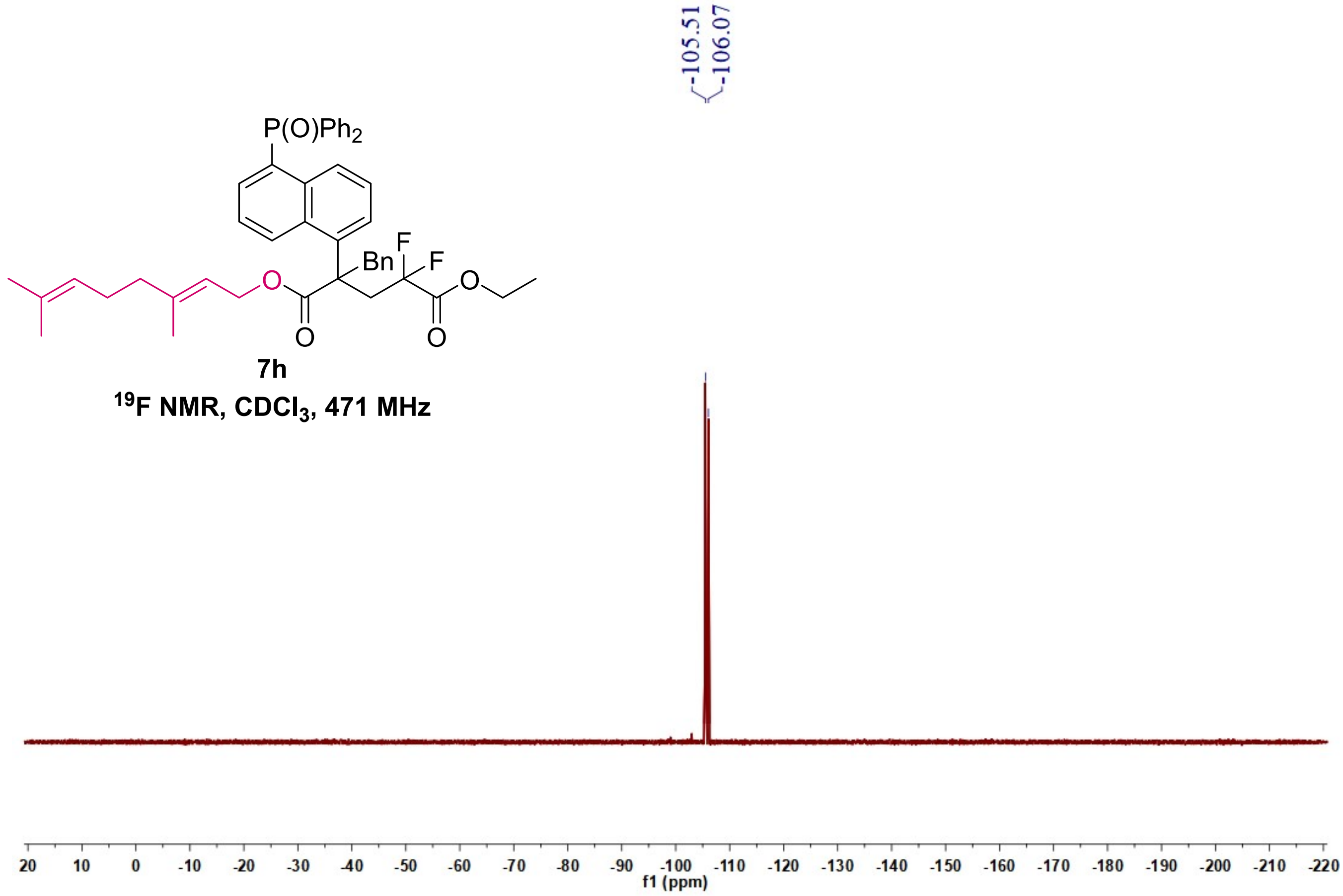
^{13}C NMR, $CDCl_3$, 126 MHz



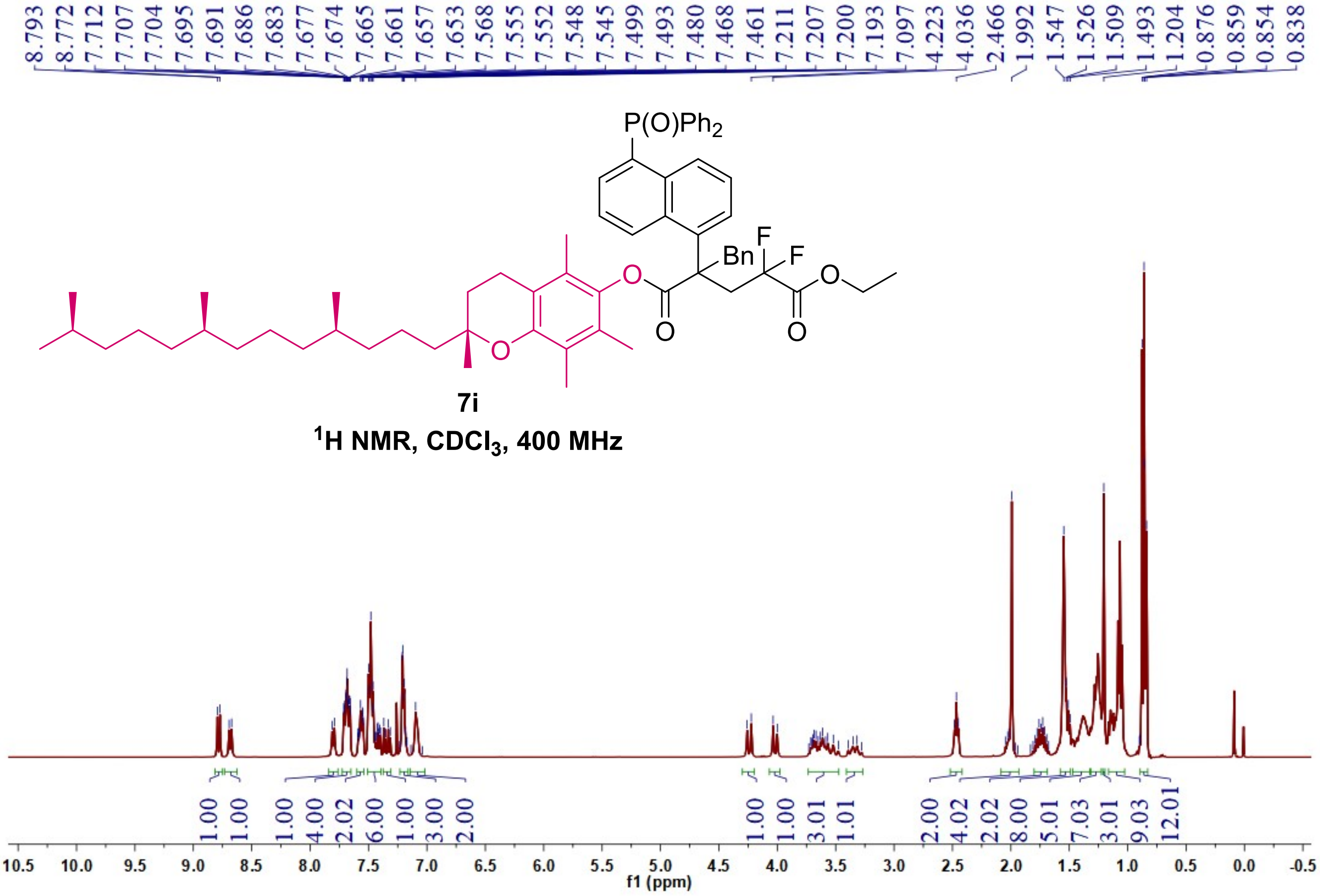
7h

^{31}P NMR, CDCl$_3$, 202 MHz



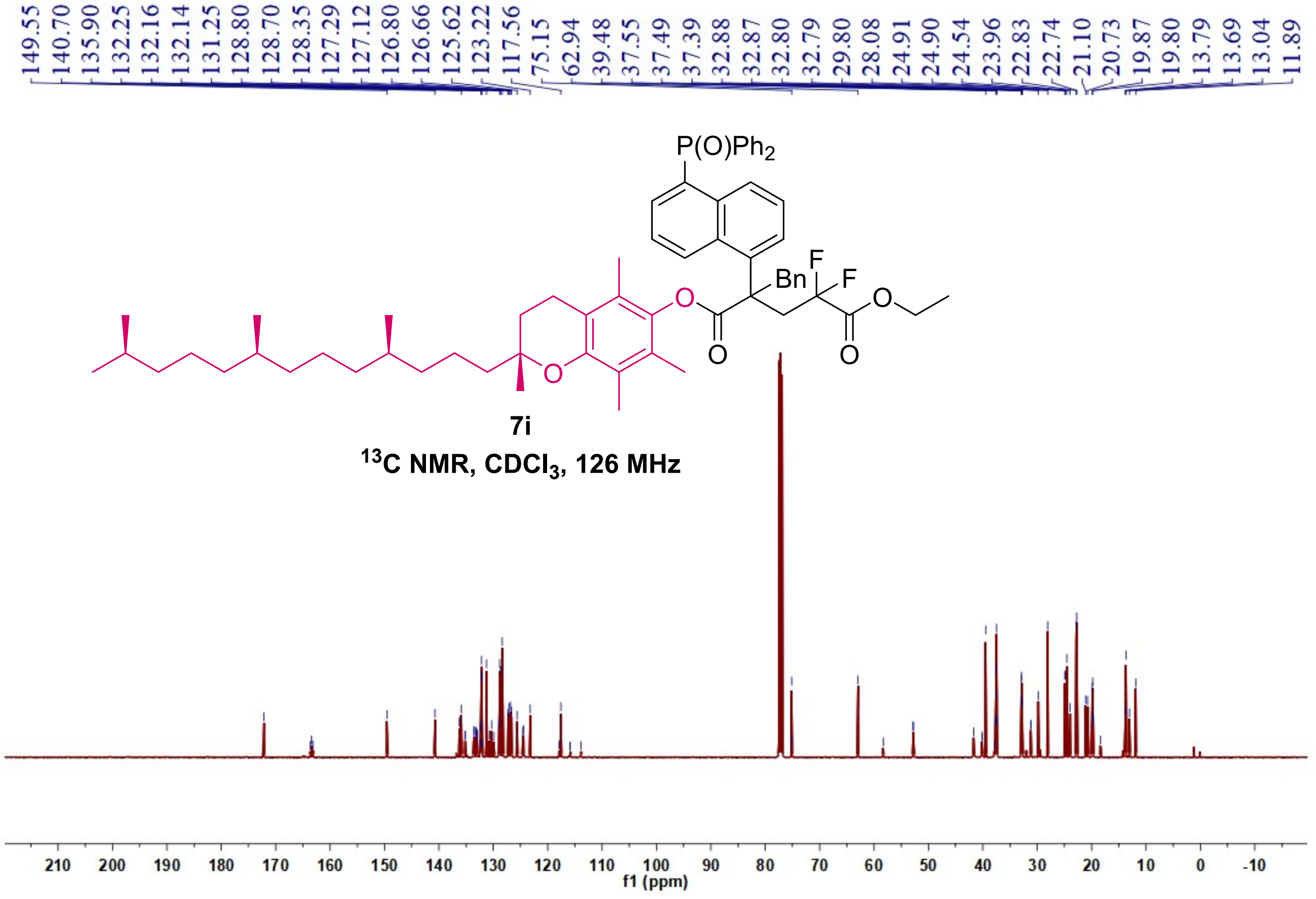
7h

^{19}F NMR, CDCl$_3$, 471 MHz



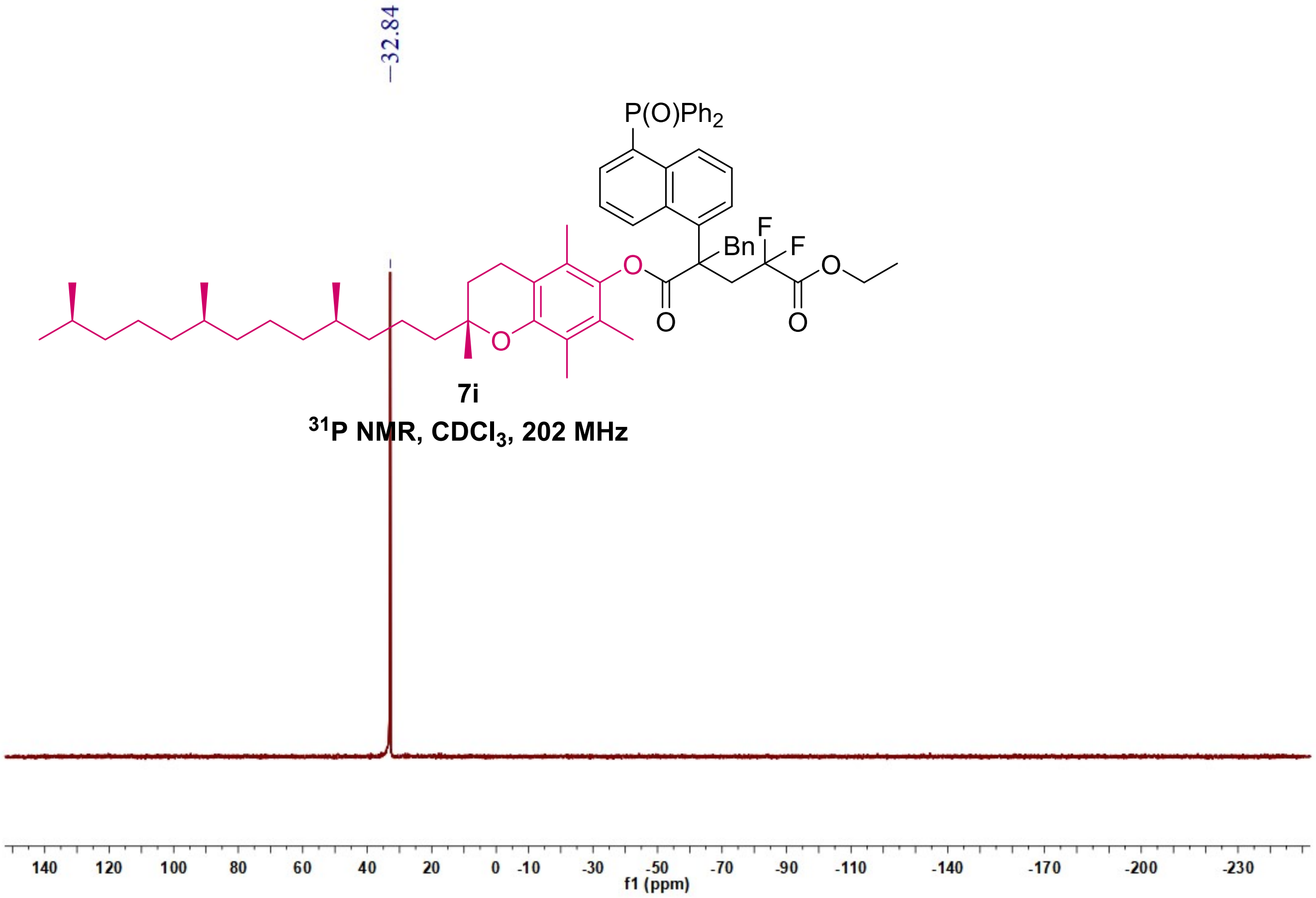
7i

^{1}H NMR, CDCl$_3$, 400 MHz



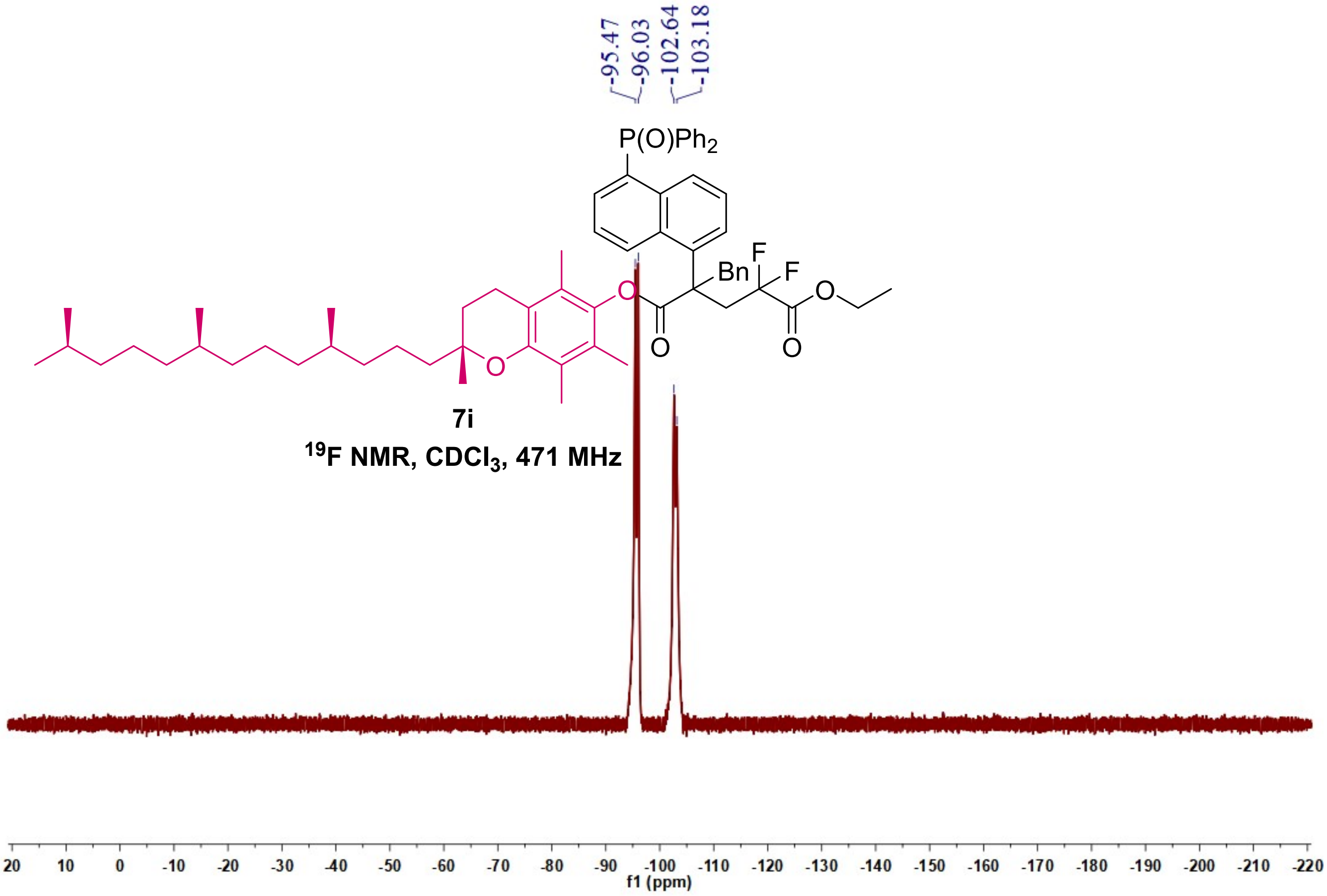
7i

^{13}C NMR, CDCl$_3$, 126 MHz



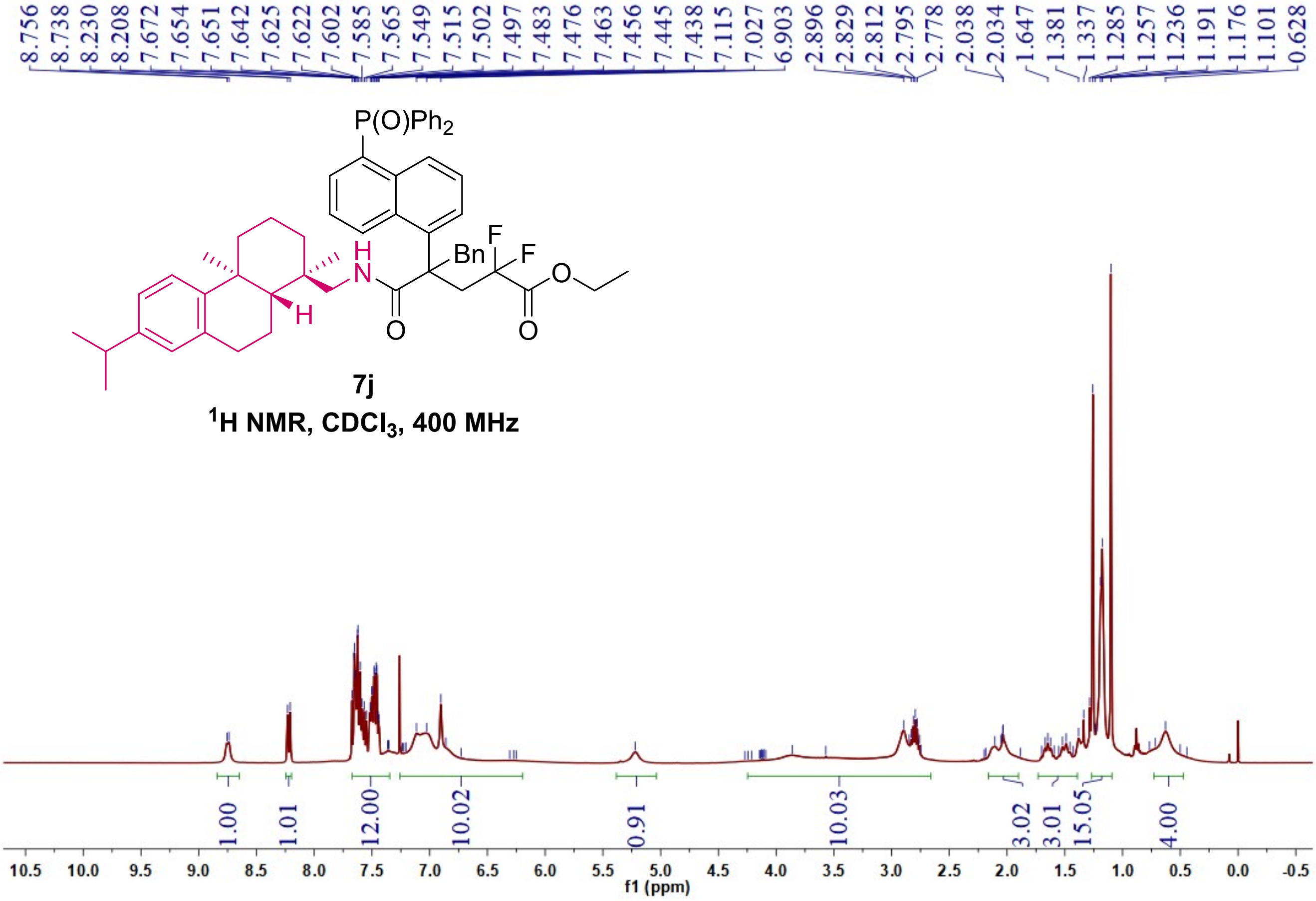
7i

^{31}P NMR, CDCl$_3$, 202 MHz

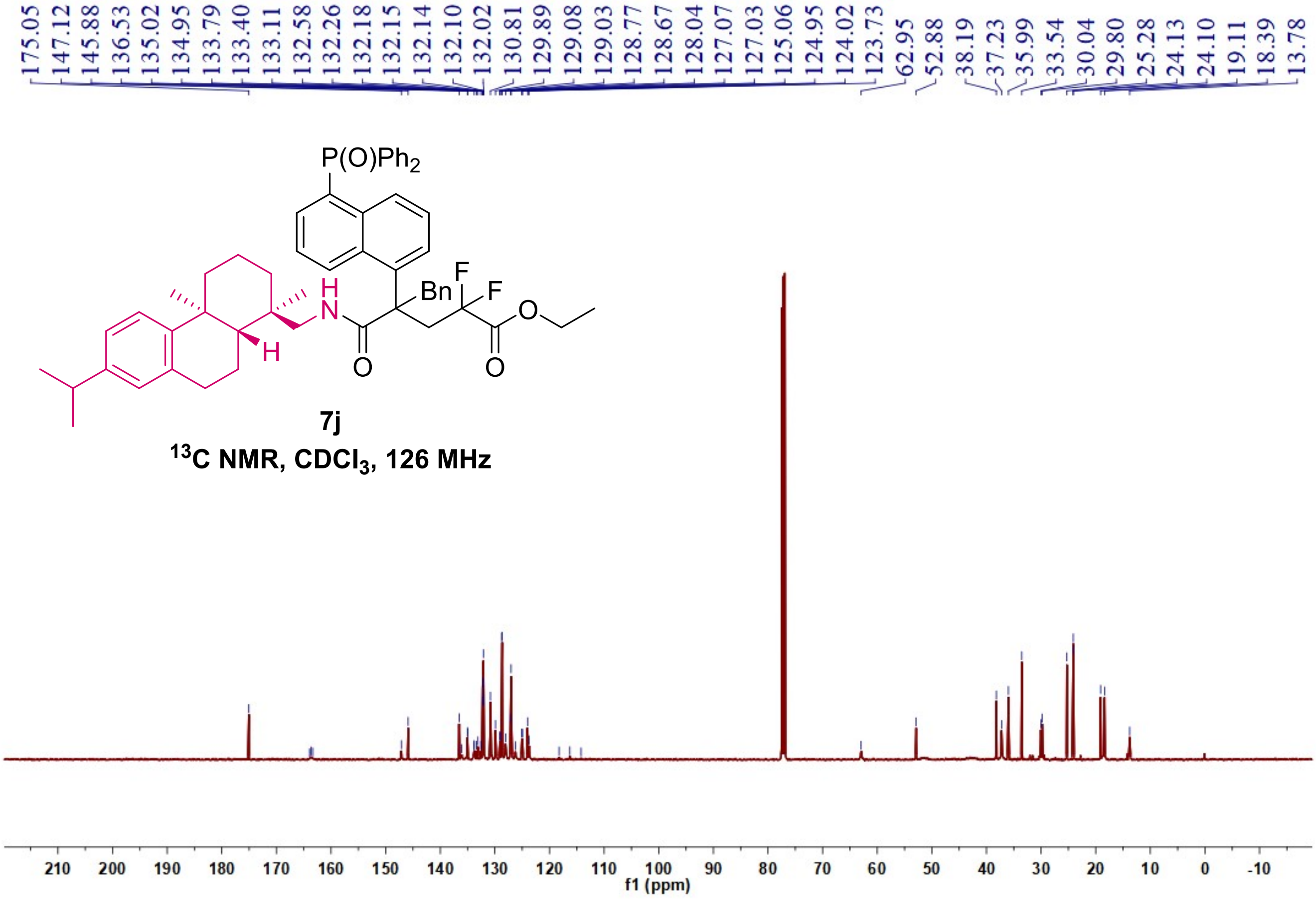


7i

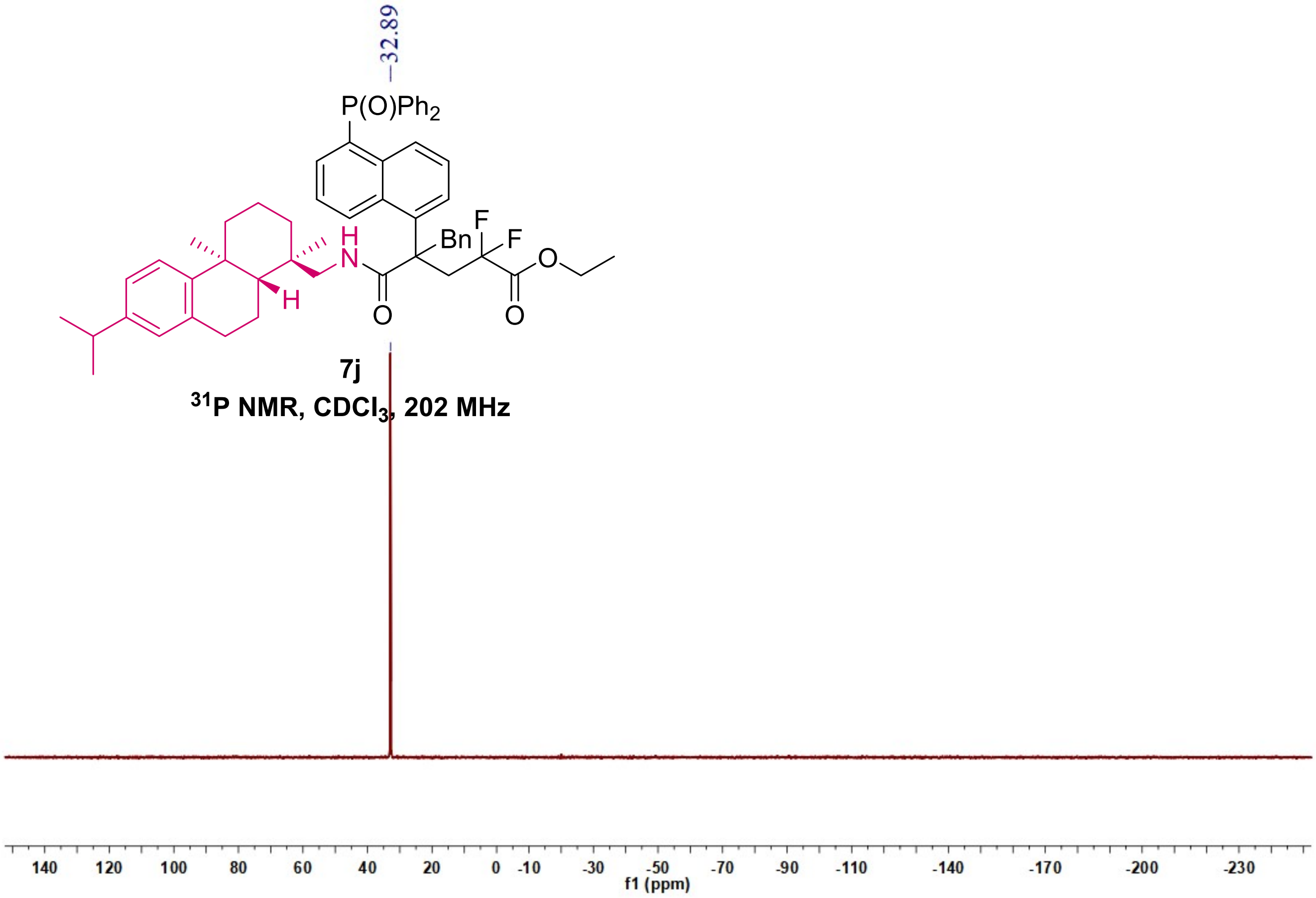
^{19}F NMR, CDCl$_3$, 471 MHz


7j

^{1}H NMR, CDCl$_3$, 400 MHz

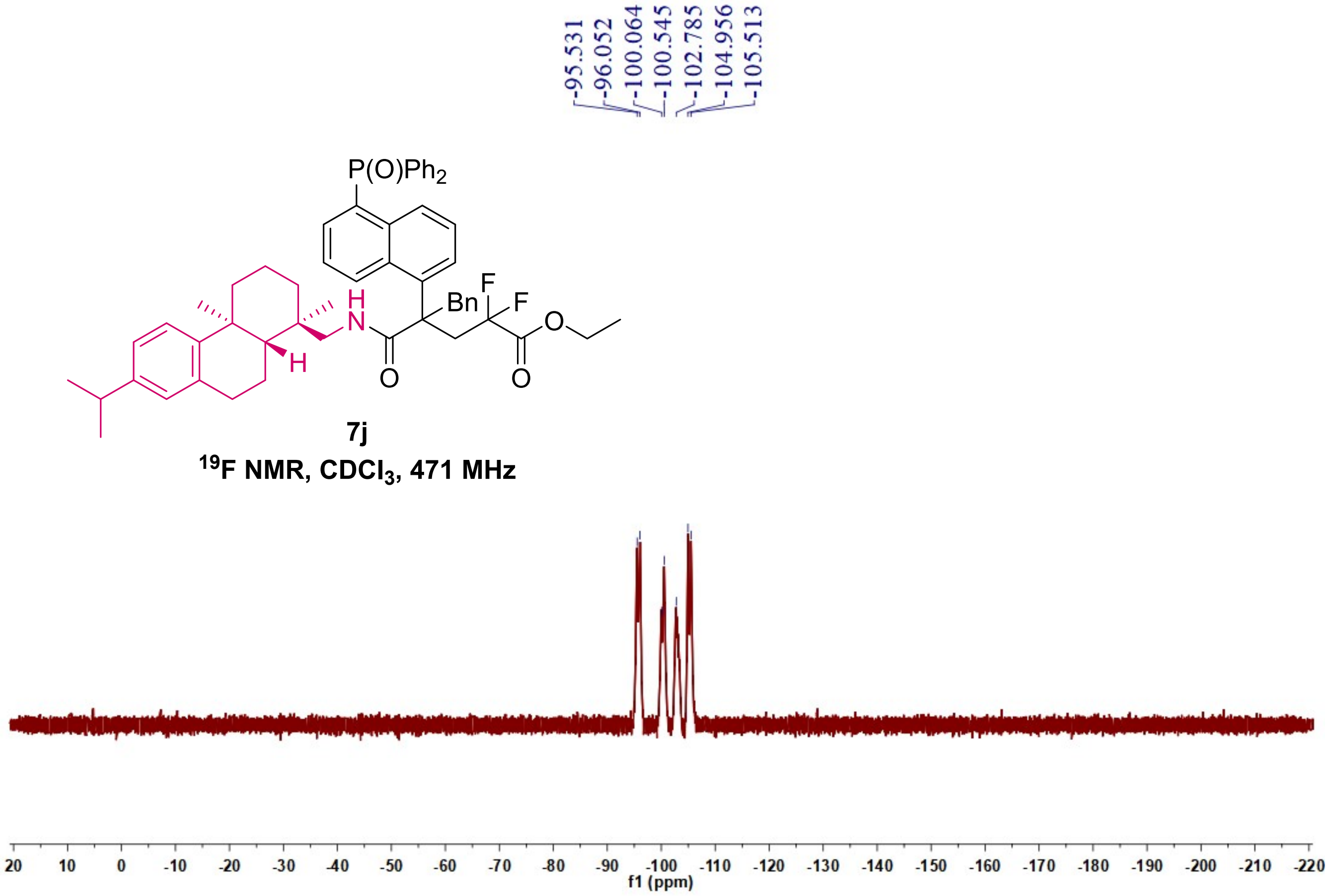

7j

^{13}C NMR, CDCl$_3$, 126 MHz



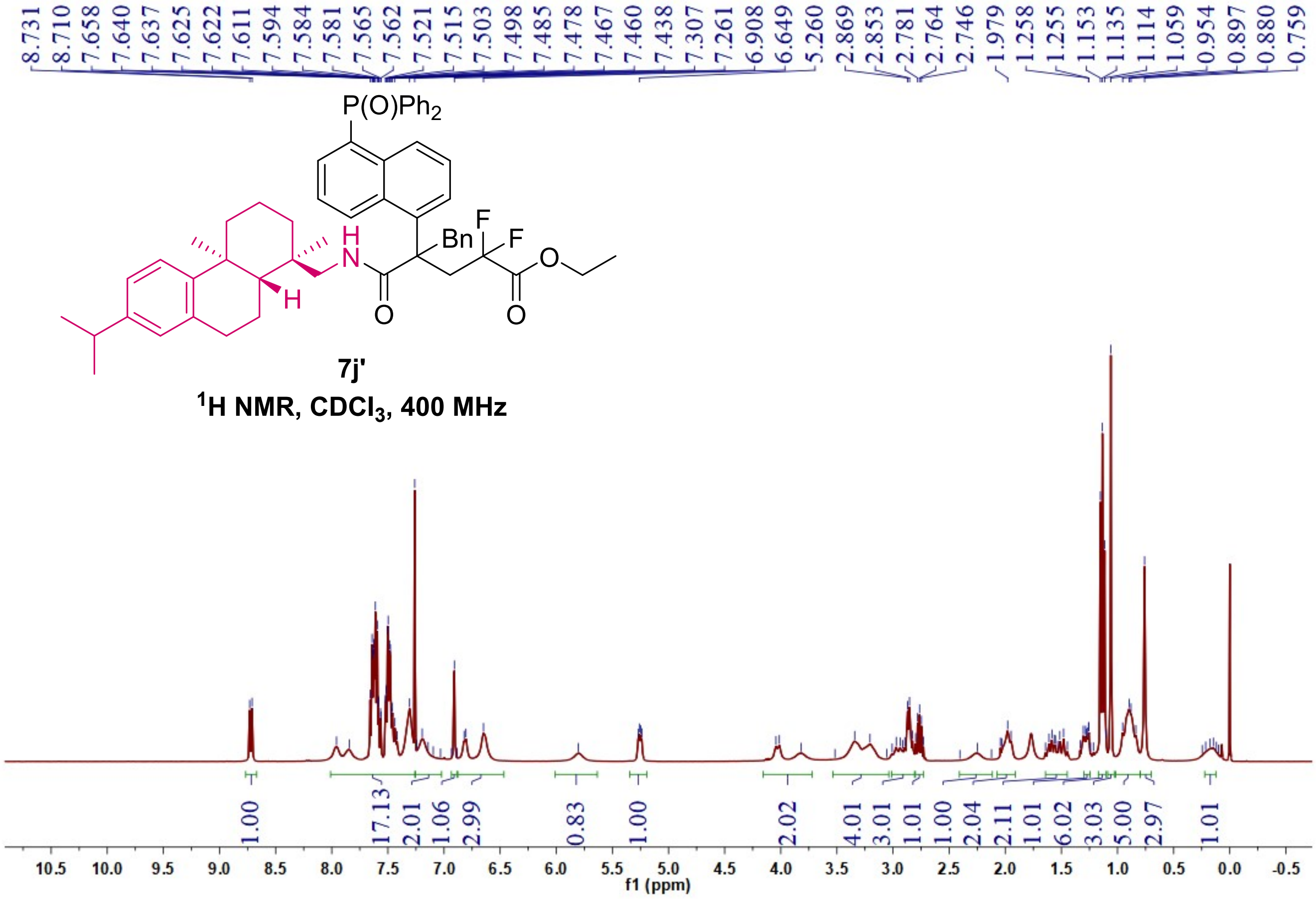
7j

^{31}P NMR, CDCl$_3$, 202 MHz



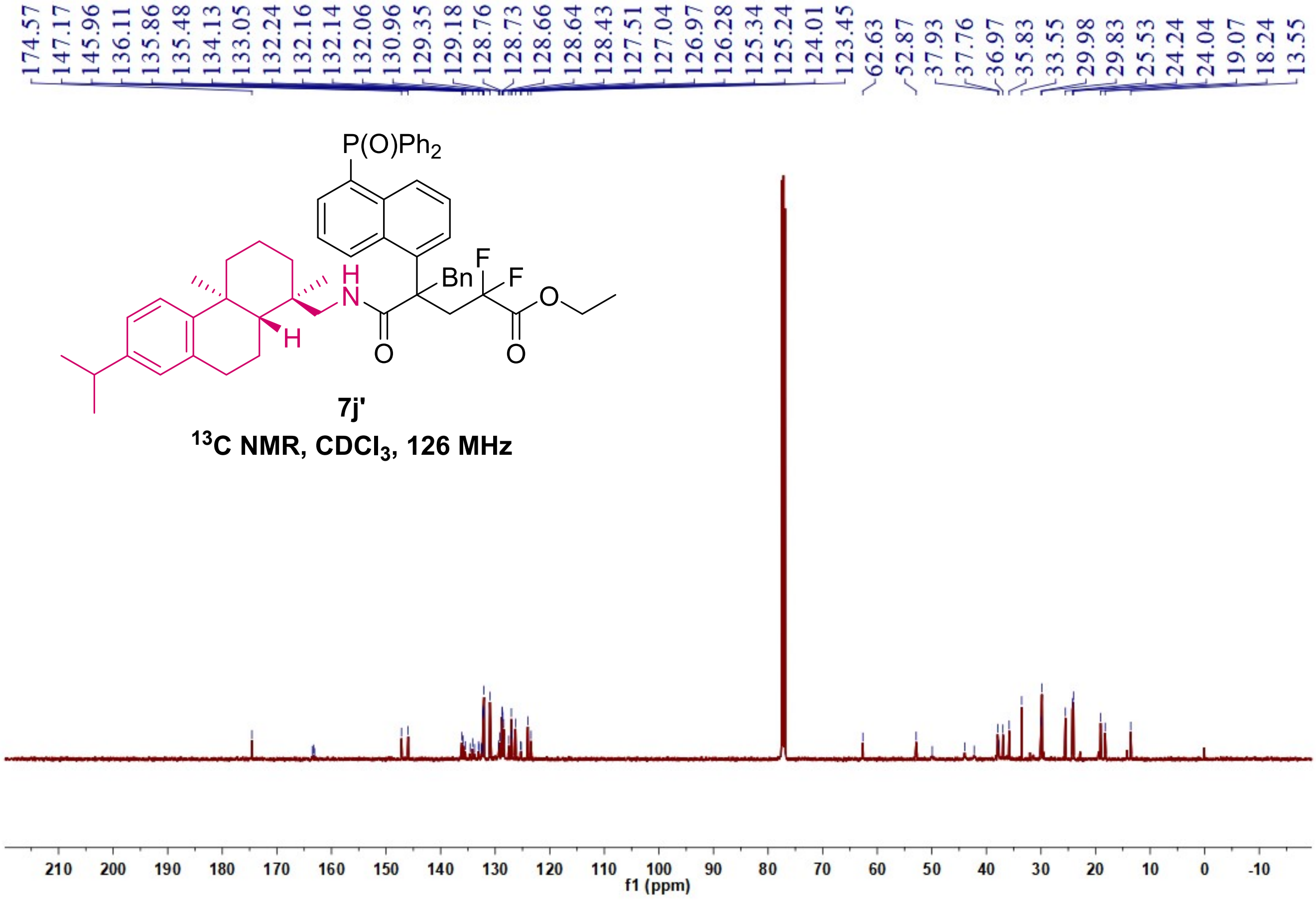
7j

^{19}F NMR, CDCl$_3$, 471 MHz



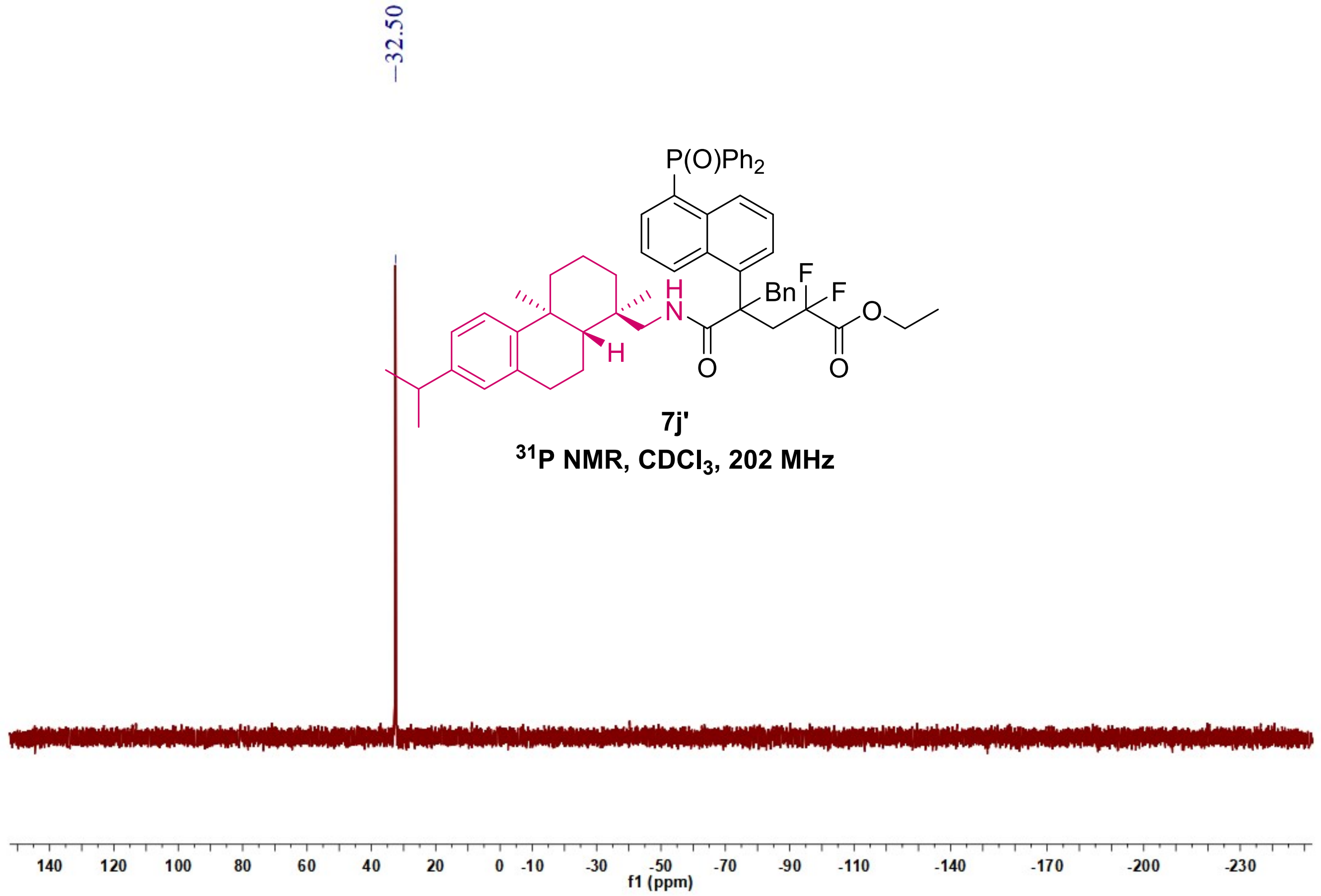
7j'

^1H NMR, $CDCl_3$, 400 MHz



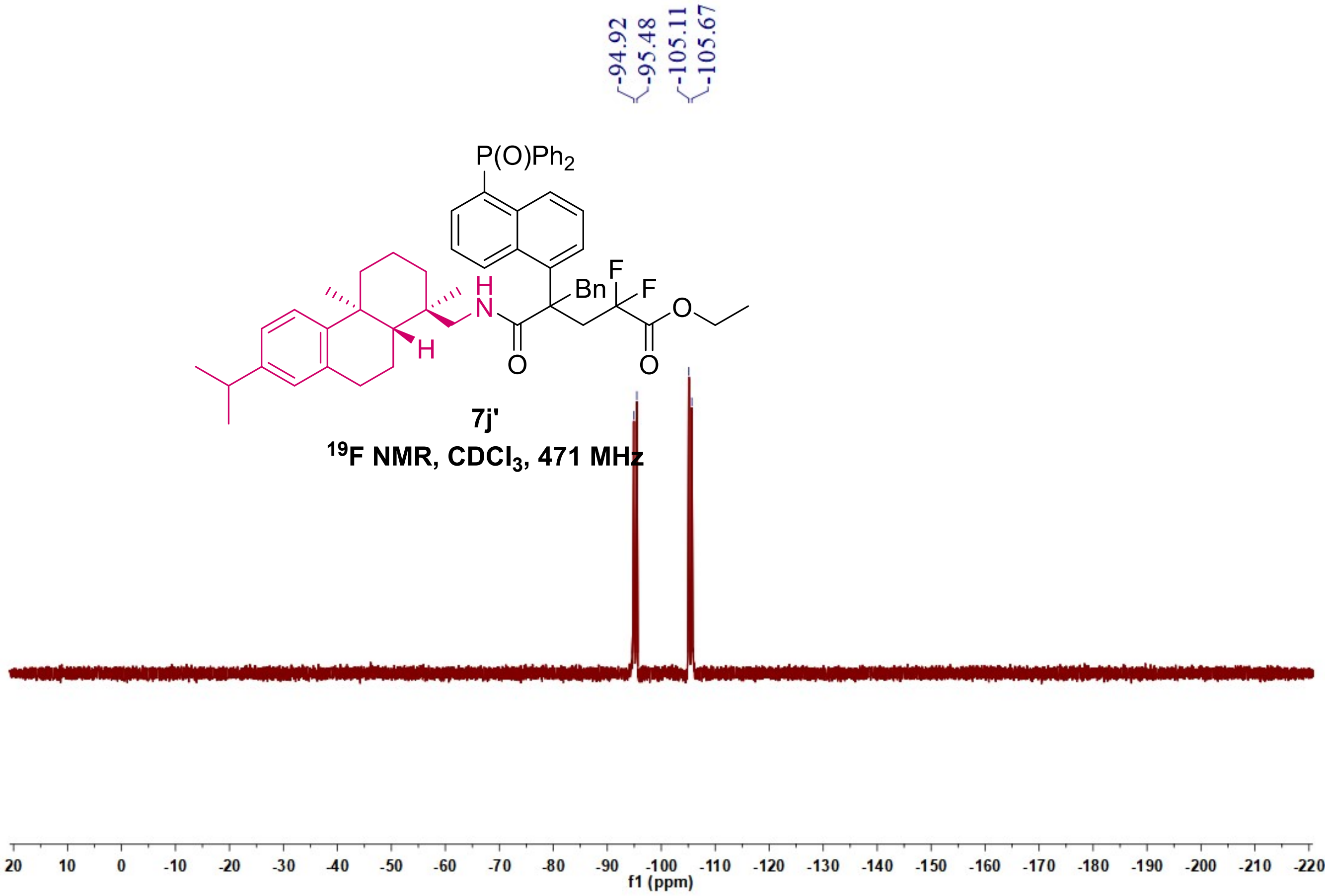
7j'

^{13}C NMR, $CDCl_3$, 126 MHz



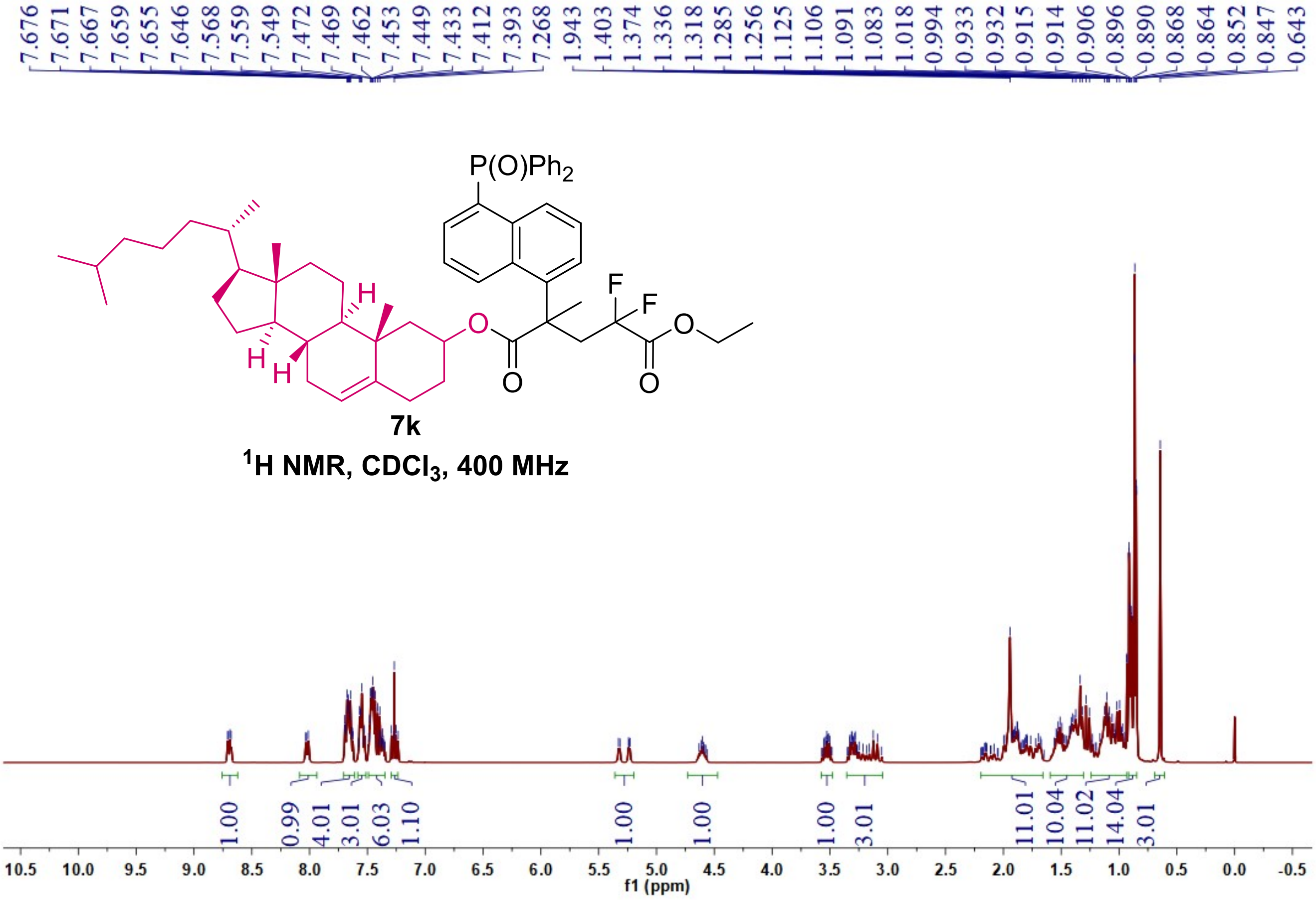
7j'

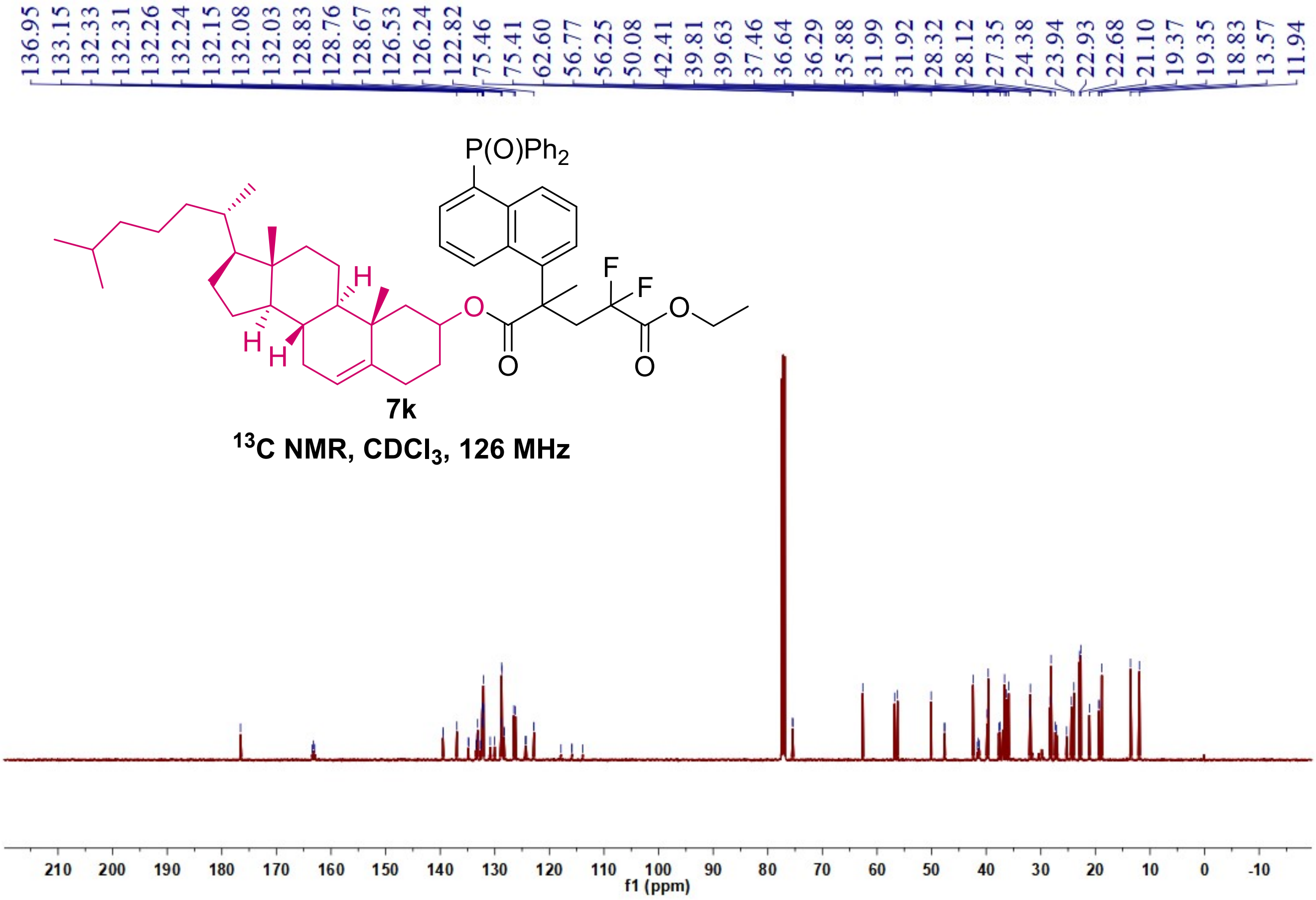
^{31}P NMR, CDCl$_3$, 202 MHz

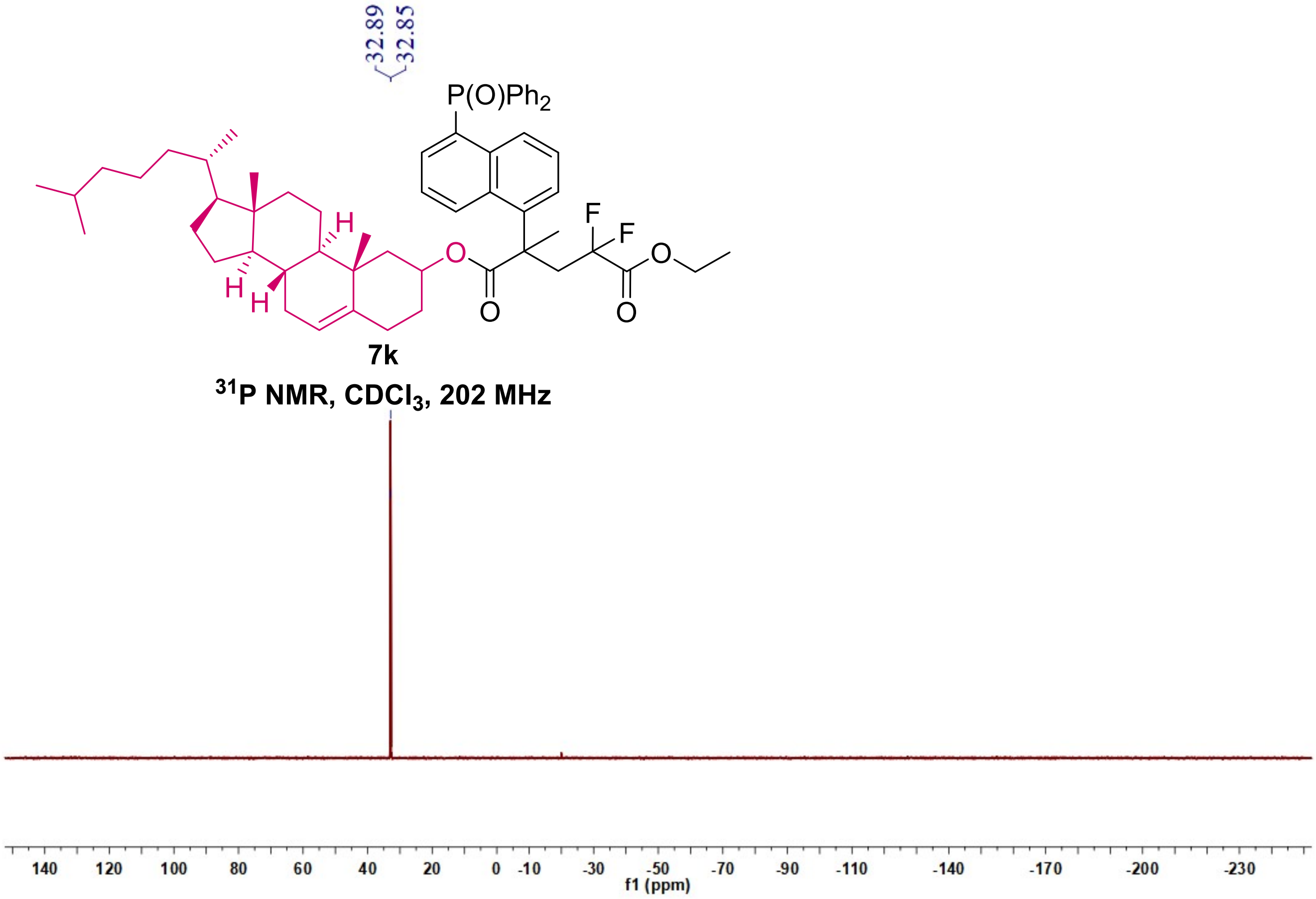


7j'

^{19}F NMR, CDCl$_3$, 471 MHz

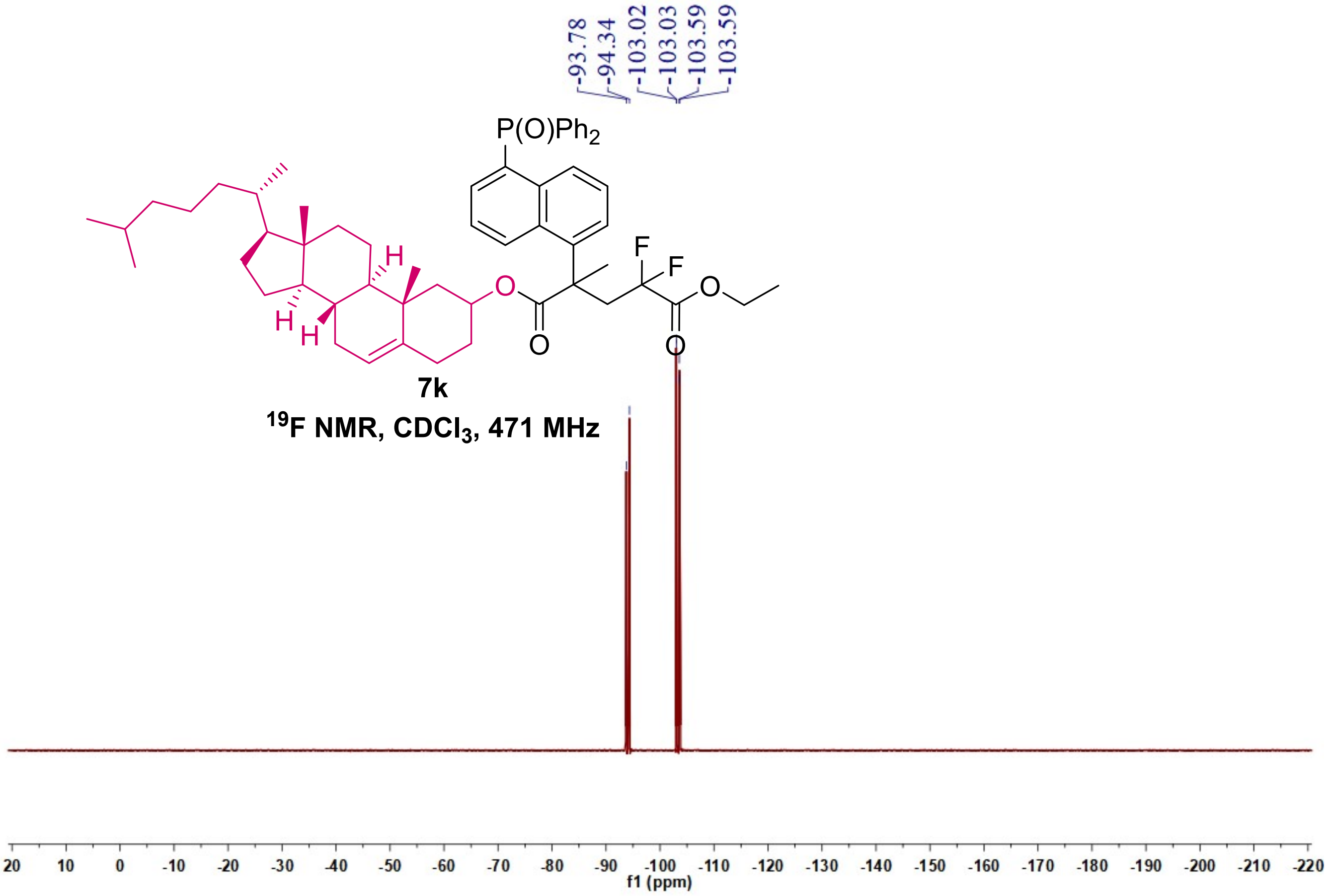

7.676
7.671
7.667
7.659
7.655
7.646
7.568
7.559
7.549
7.472
7.469
7.462
7.453
7.449
7.433
7.412
7.393
7.268
1.943
1.403
1.374
1.336
1.318
1.285
1.256
1.125
1.106
1.091
1.083
1.018
0.994
0.933
0.932
0.915
0.914
0.906
0.896
0.890
0.868
0.864
0.852
0.847
0.643
P(O)Ph$_2$
F
F
O
O
O
O
H
H
H
7k
^{1}H NMR, CDCl$_3$, 400 MHz
1.00
0.99
4.01
3.01
6.03
1.10
1.00
1.00
1.00
3.01
11.01
10.04
11.02
14.04
3.01
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


136.95
133.15
132.33
132.31
132.26
132.24
132.15
132.08
132.03
128.83
128.76
128.67
126.53
126.24
122.82
75.46
75.41
62.60
56.77
56.25
50.08
42.41
39.81
39.63
37.46
36.64
36.29
35.88
31.99
31.92
28.32
28.12
27.35
24.38
23.94
22.93
22.68
21.10
19.37
19.35
18.83
13.57
11.94
P(O)Ph$_2$
F
F
O
O
O
O
H
H
H
7k
^{13}C NMR, CDCl$_3$, 126 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



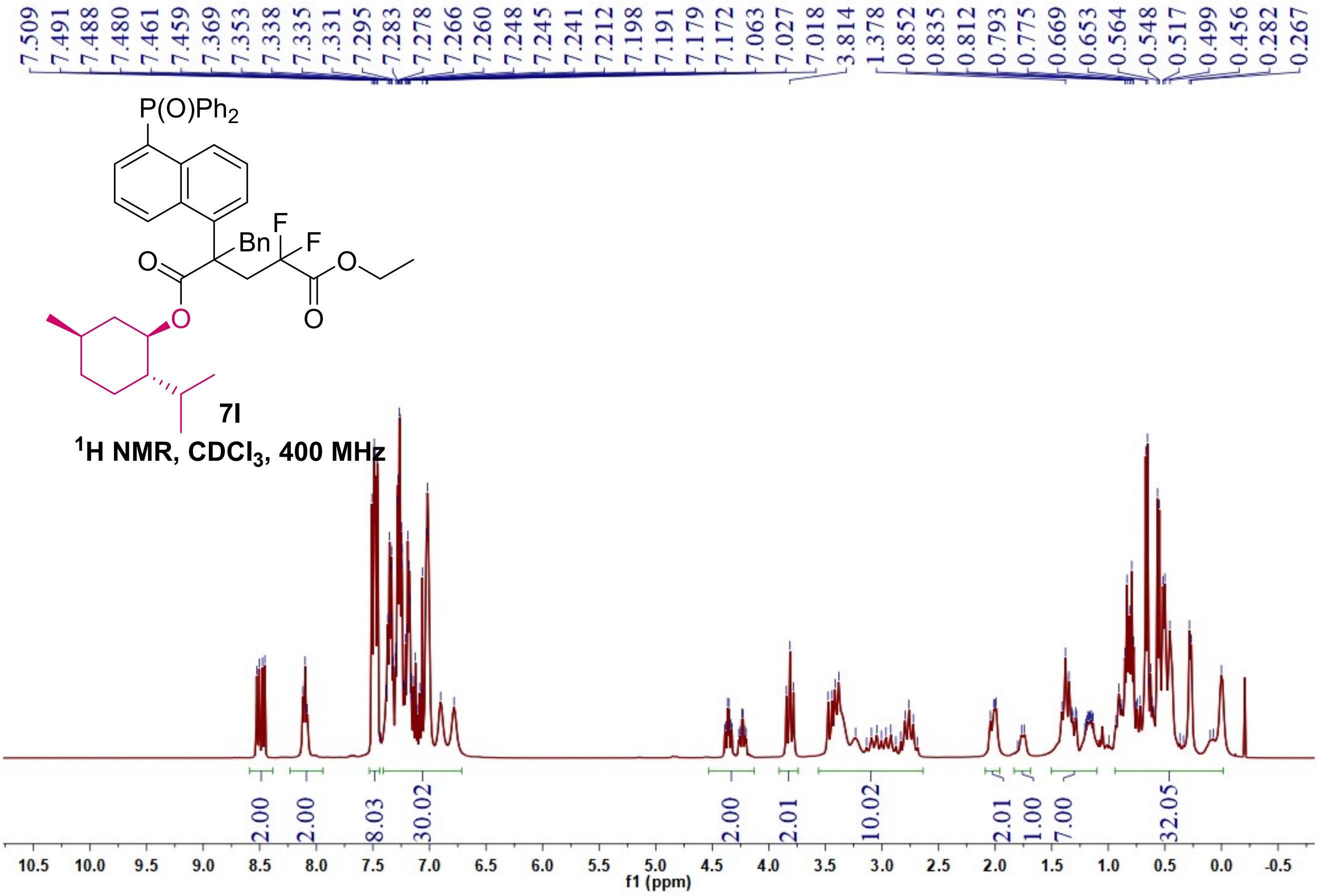
7k

^{31}P NMR, CDCl$_3$, 202 MHz

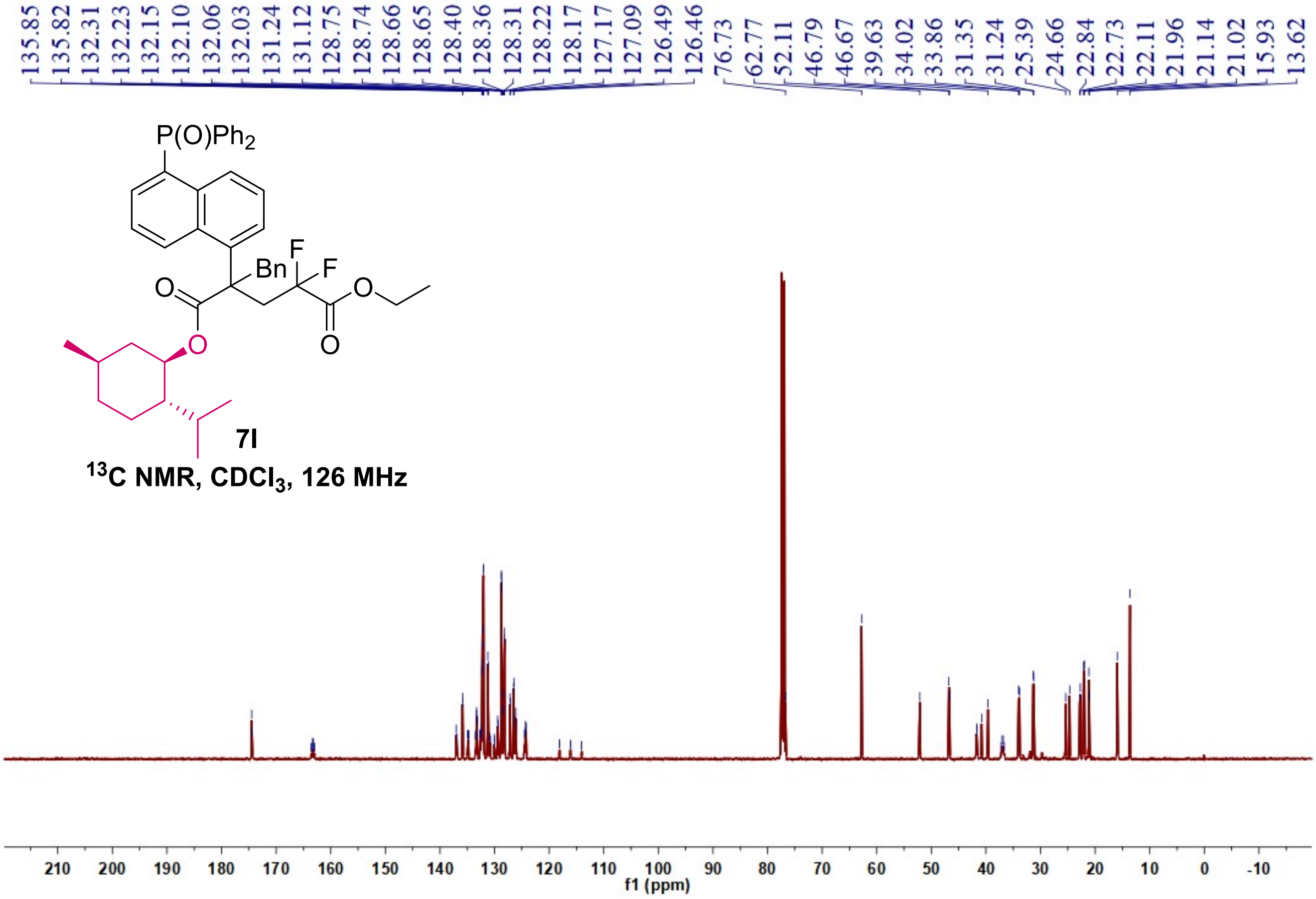


7k

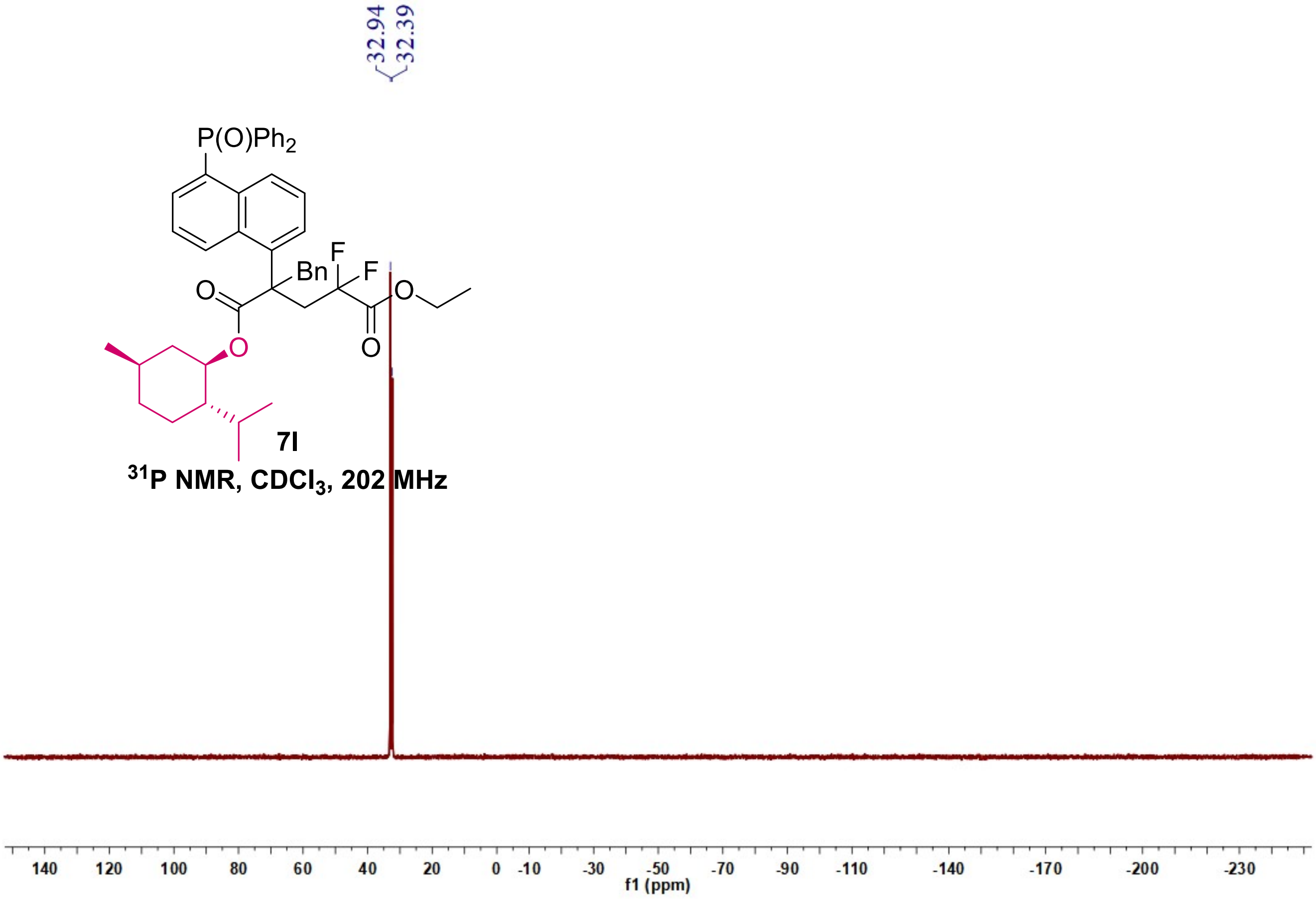
^{19}F NMR, CDCl$_3$, 471 MHz

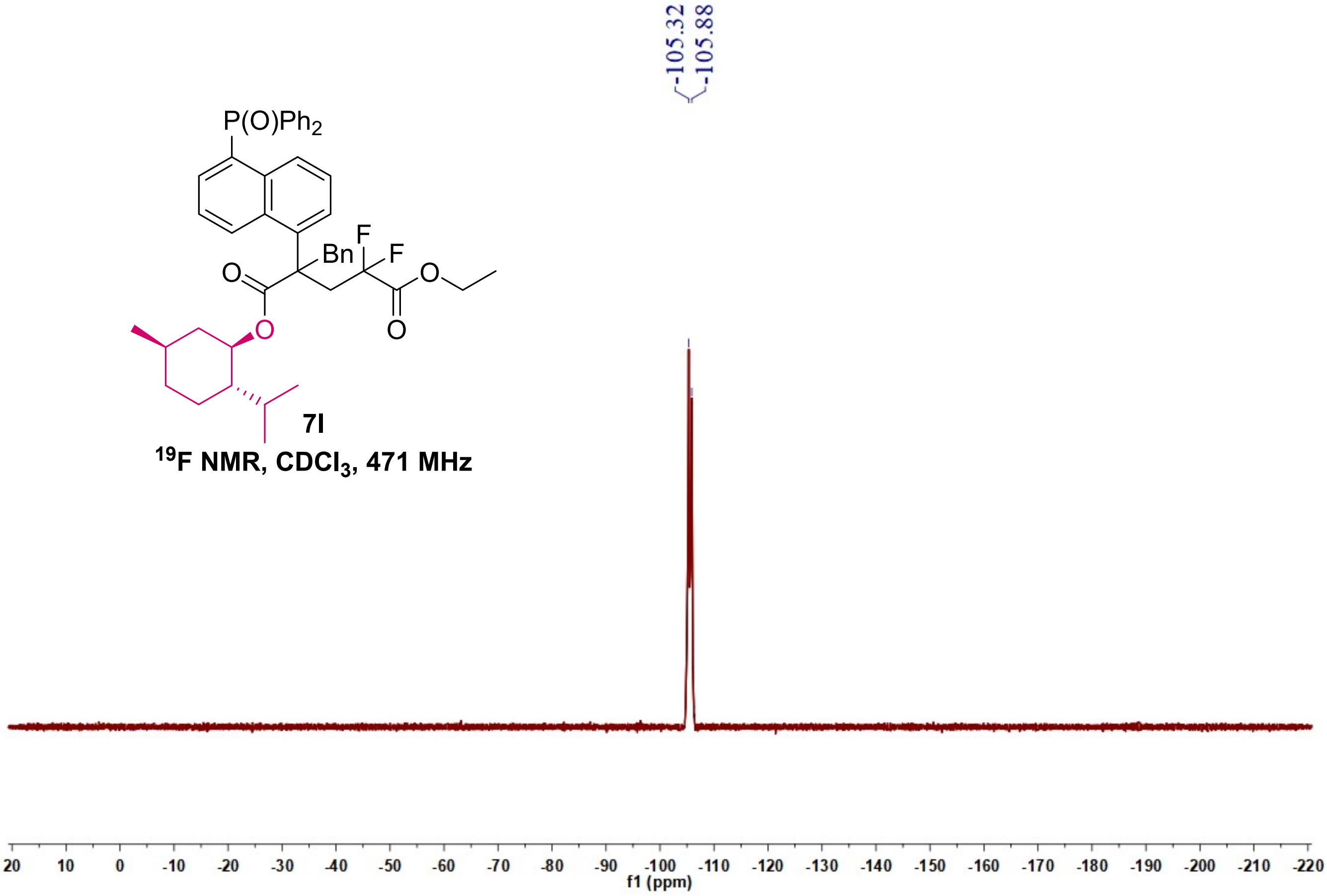

7l

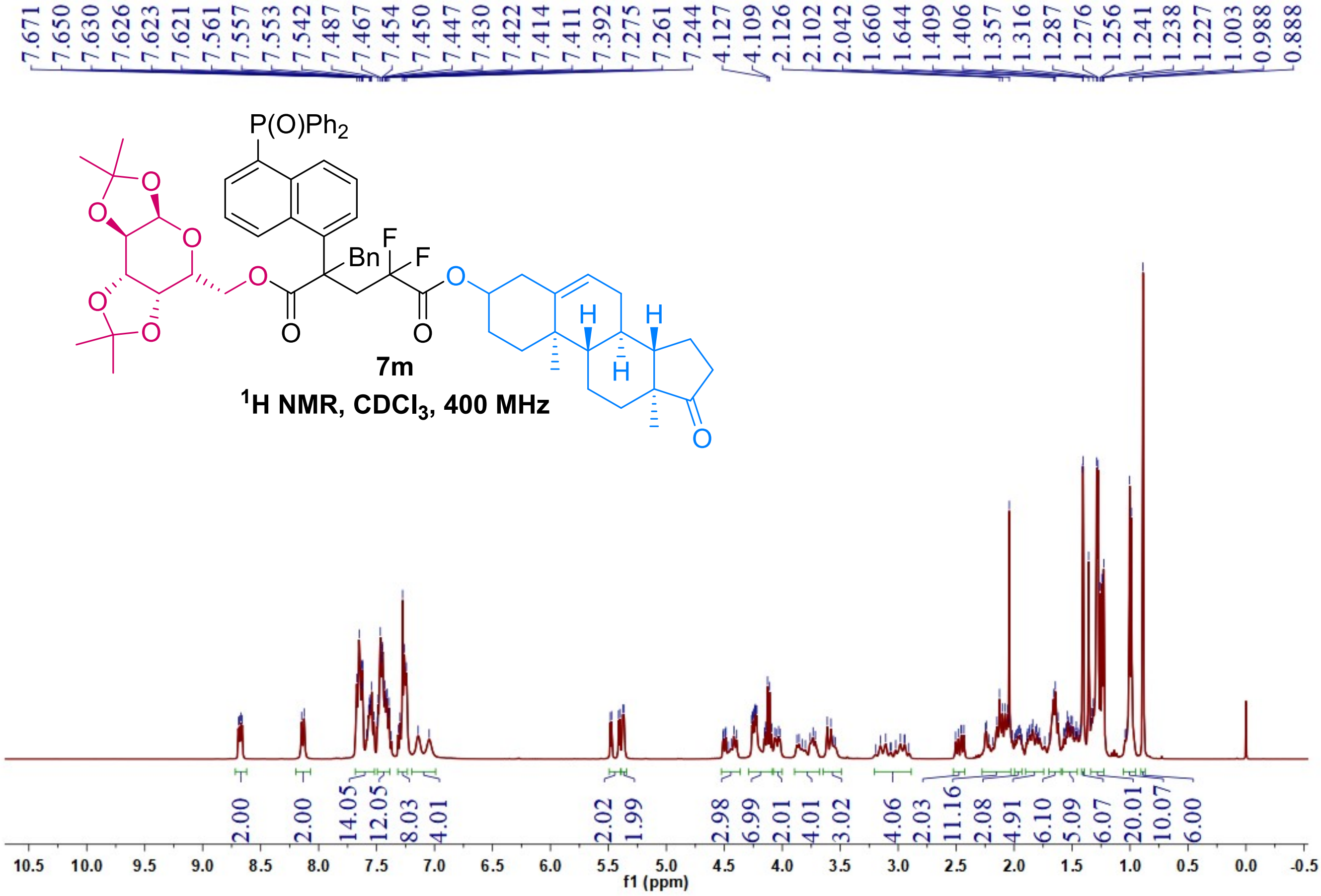
^{1}H NMR, CDCl$_3$, 400 MHz

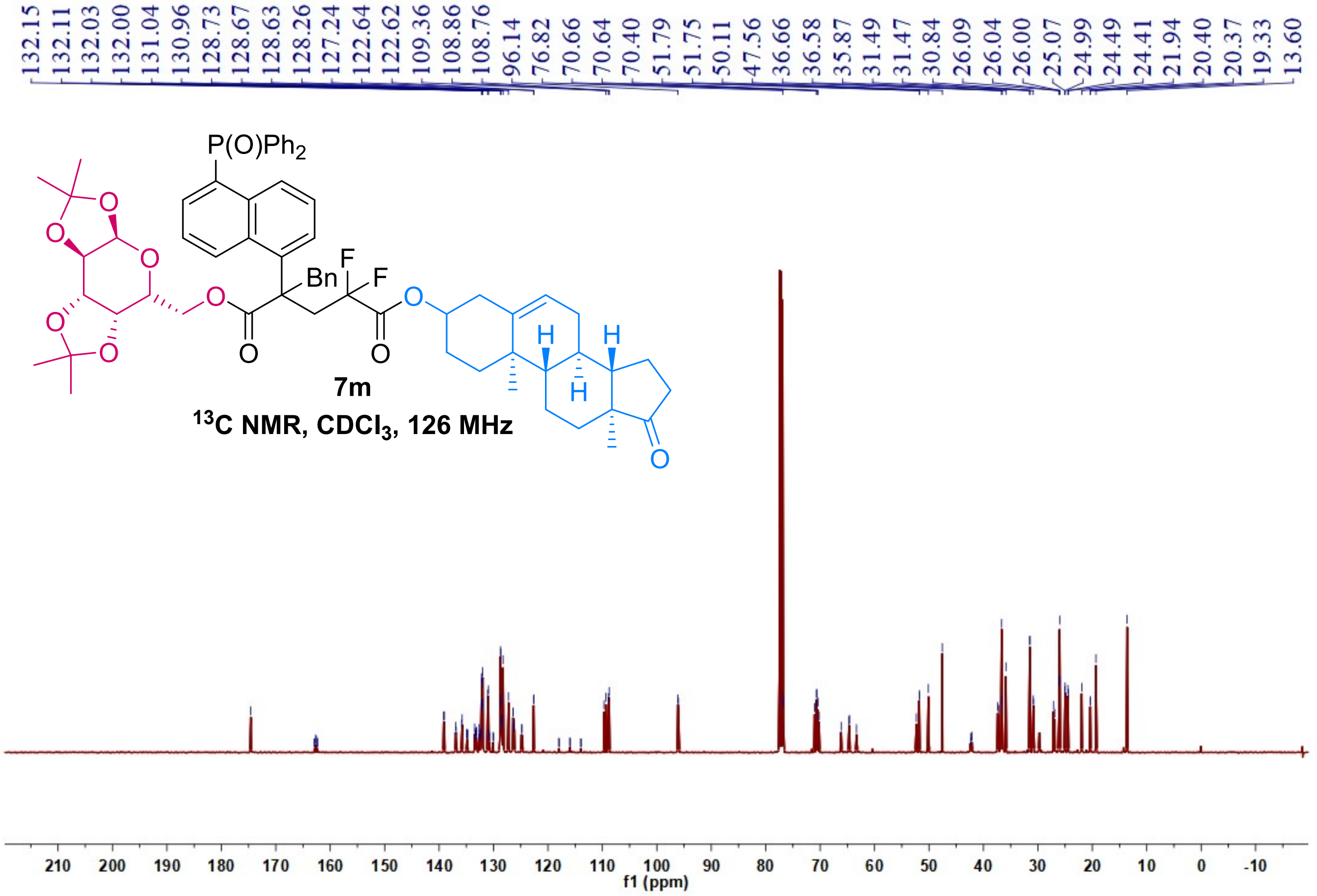

7l

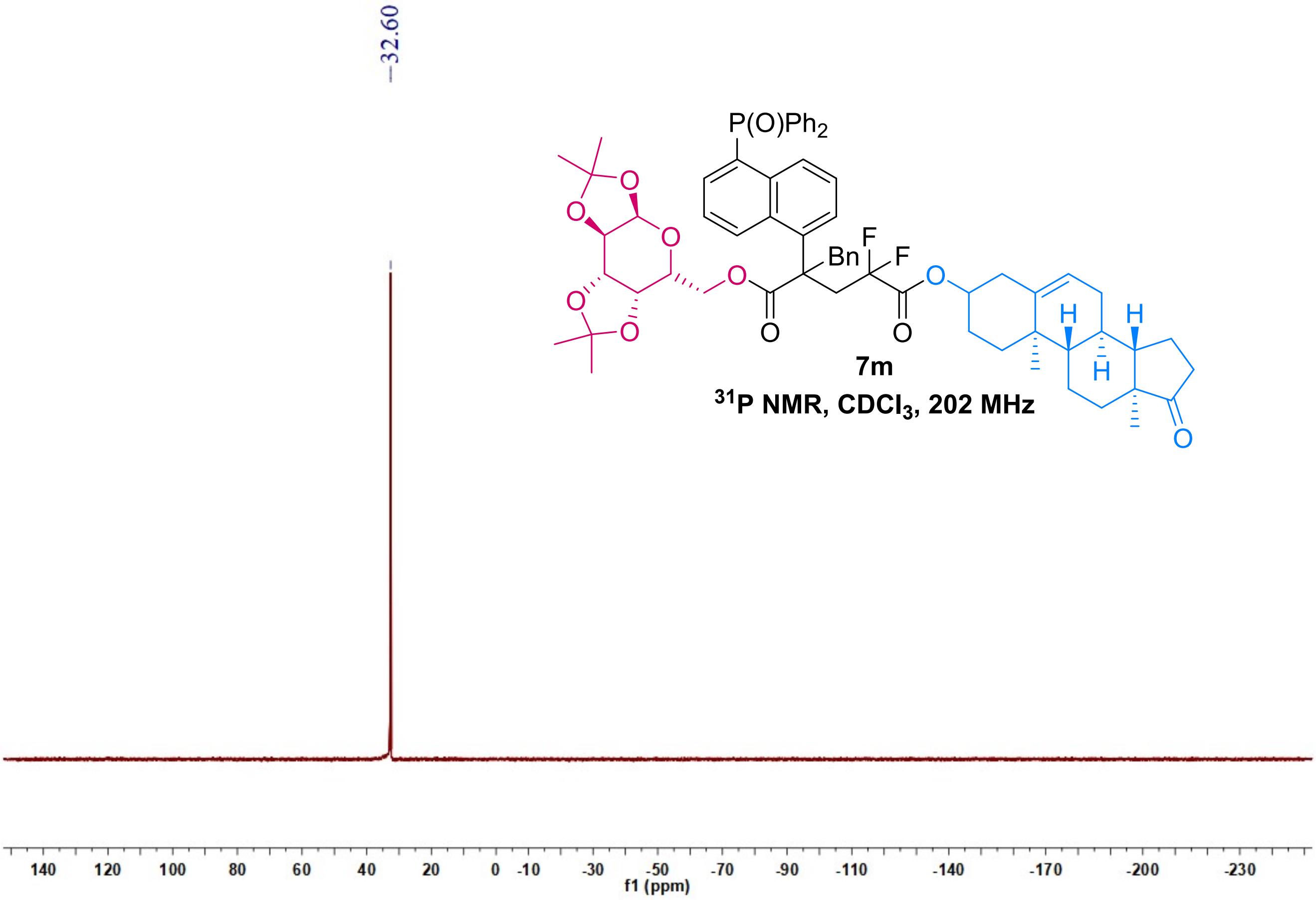
^{13}C NMR, CDCl$_3$, 126 MHz

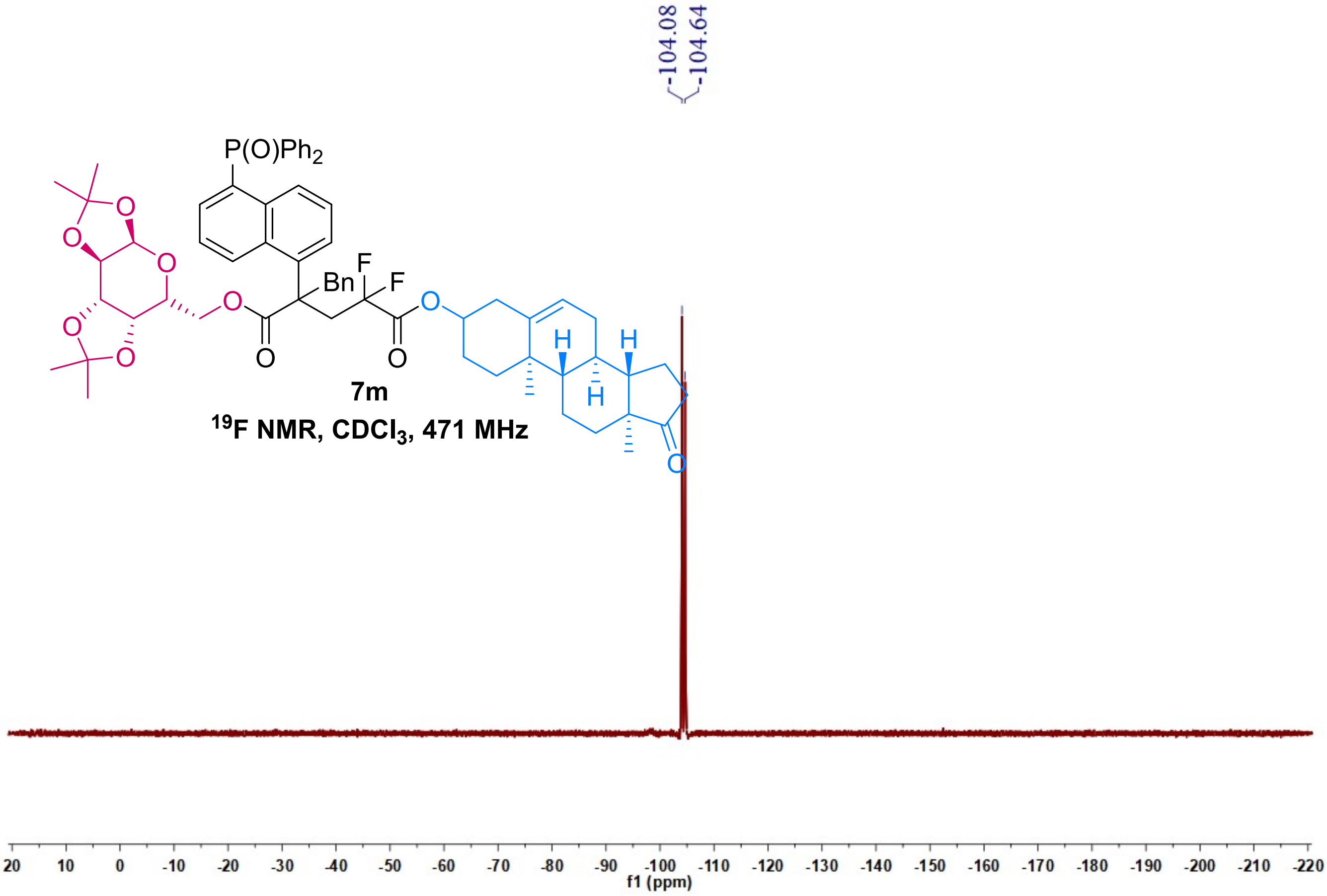

32.94
32.39
P(O)Ph2
Bn
F
F
O
O
O
O
7l
31P NMR, CDCl3, 202 MHz
140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -110 -140 -170 -200 -230
f1 (ppm)

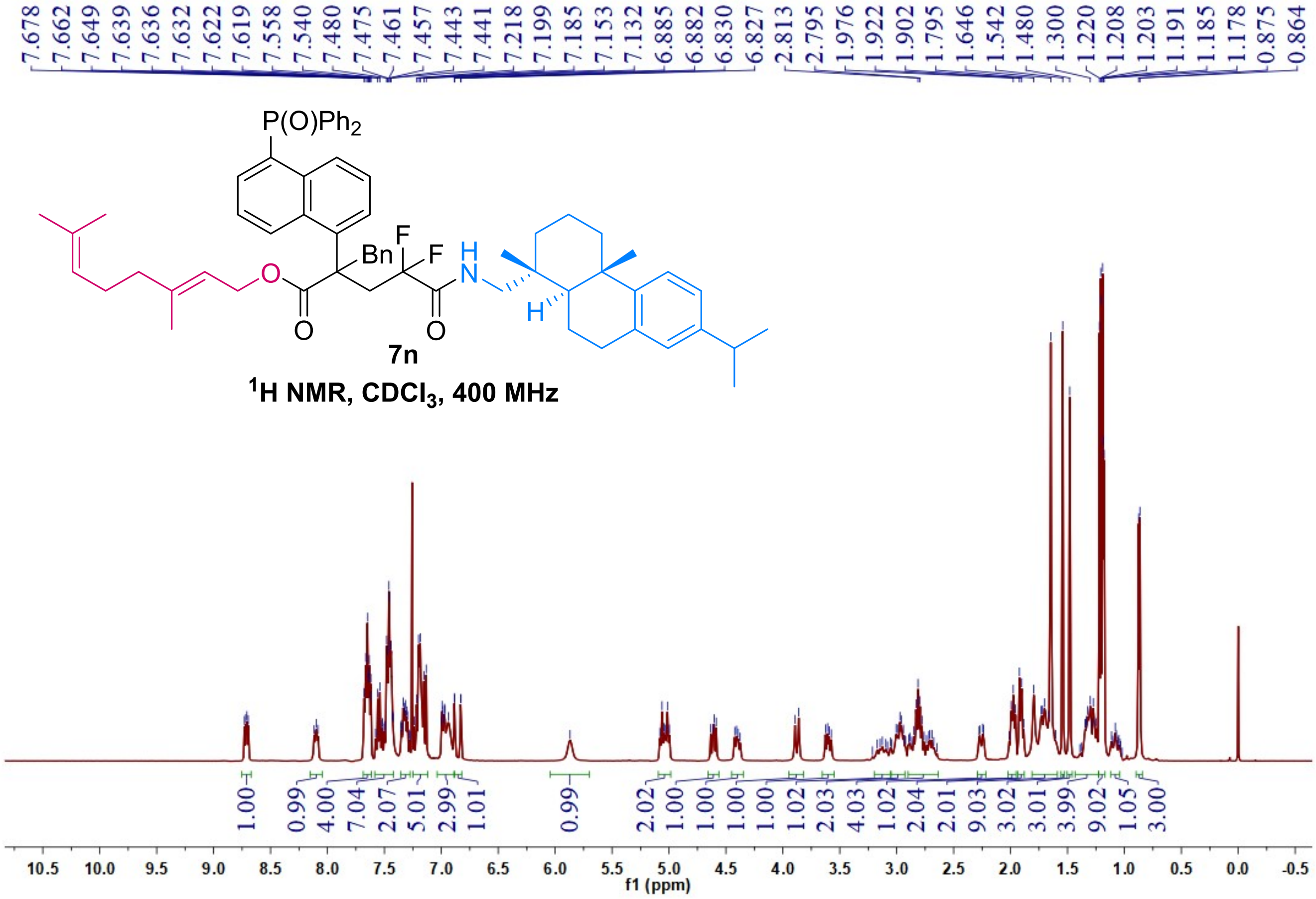

-105.32
-105.88
P(O)Ph2
Bn
F
F
O
O
O
O
7l
19F NMR, CDCl3, 471 MHz
20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210 -220
f1 (ppm)


7.671
7.650
7.630
7.626
7.623
7.621
7.561
7.557
7.553
7.542
7.487
7.467
7.454
7.450
7.447
7.430
7.422
7.414
7.411
7.392
7.275
7.261
7.244
4.127
4.109
2.126
2.102
2.042
1.660
1.644
1.409
1.406
1.357
1.316
1.287
1.276
1.256
1.241
1.238
1.227
1.003
0.988
0.888
P(O)Ph$_2$
Bn
F
F
O
H
H
H
7m
^{1}H NMR, CDCl$_3$, 400 MHz
2.00
2.00
14.05
12.05
8.03
4.01
2.02
1.99
2.98
6.99
2.01
4.01
3.02
4.06
2.03
11.16
2.08
4.91
6.10
5.09
6.07
20.01
10.07
6.00
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


132.15
132.11
132.03
132.00
131.04
130.96
128.73
128.67
128.63
128.26
127.24
122.64
122.62
109.36
108.86
108.76
96.14
76.82
70.66
70.64
70.40
51.79
51.75
50.11
47.56
36.66
36.58
35.87
31.49
31.47
30.84
26.09
26.04
26.00
25.07
24.99
24.49
24.41
21.94
20.40
20.37
19.33
13.60
P(O)Ph$_2$
Bn
F
F
O
H
H
H
7m
^{13}C NMR, CDCl$_3$, 126 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

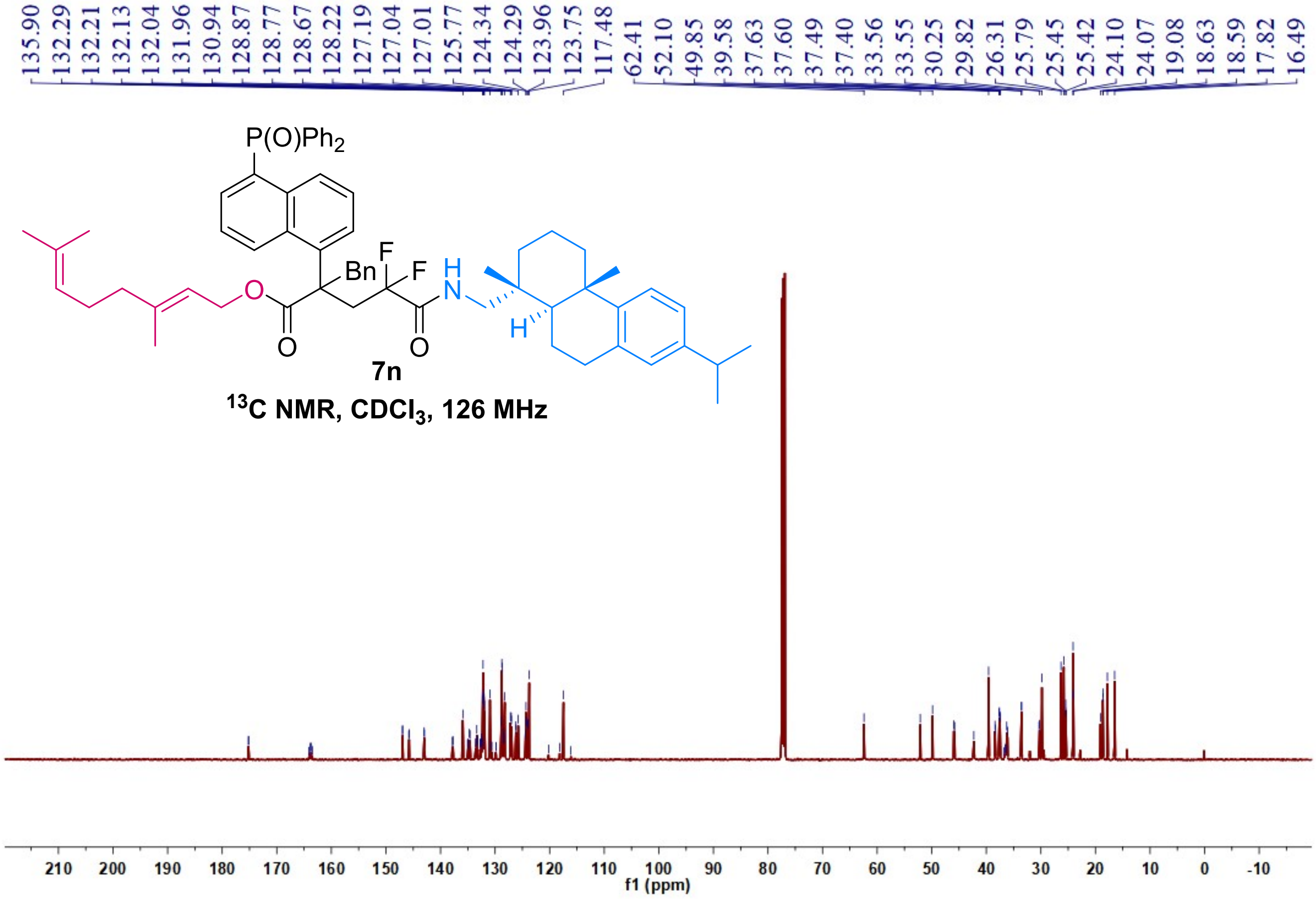

-32.60
P(O)Ph2
Bn
F
F
O
O
O
O
O
O
O
O
O
H
H
H
O
7m
31P NMR, CDCl3, 202 MHz
140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -110 -140 -170 -200 -230
f1 (ppm)


-104.08
-104.64
P(O)Ph2
Bn
F
F
O
O
O
O
O
O
O
O
O
H
H
H
O
7m
19F NMR, CDCl3, 471 MHz
20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210 -220
f1 (ppm)



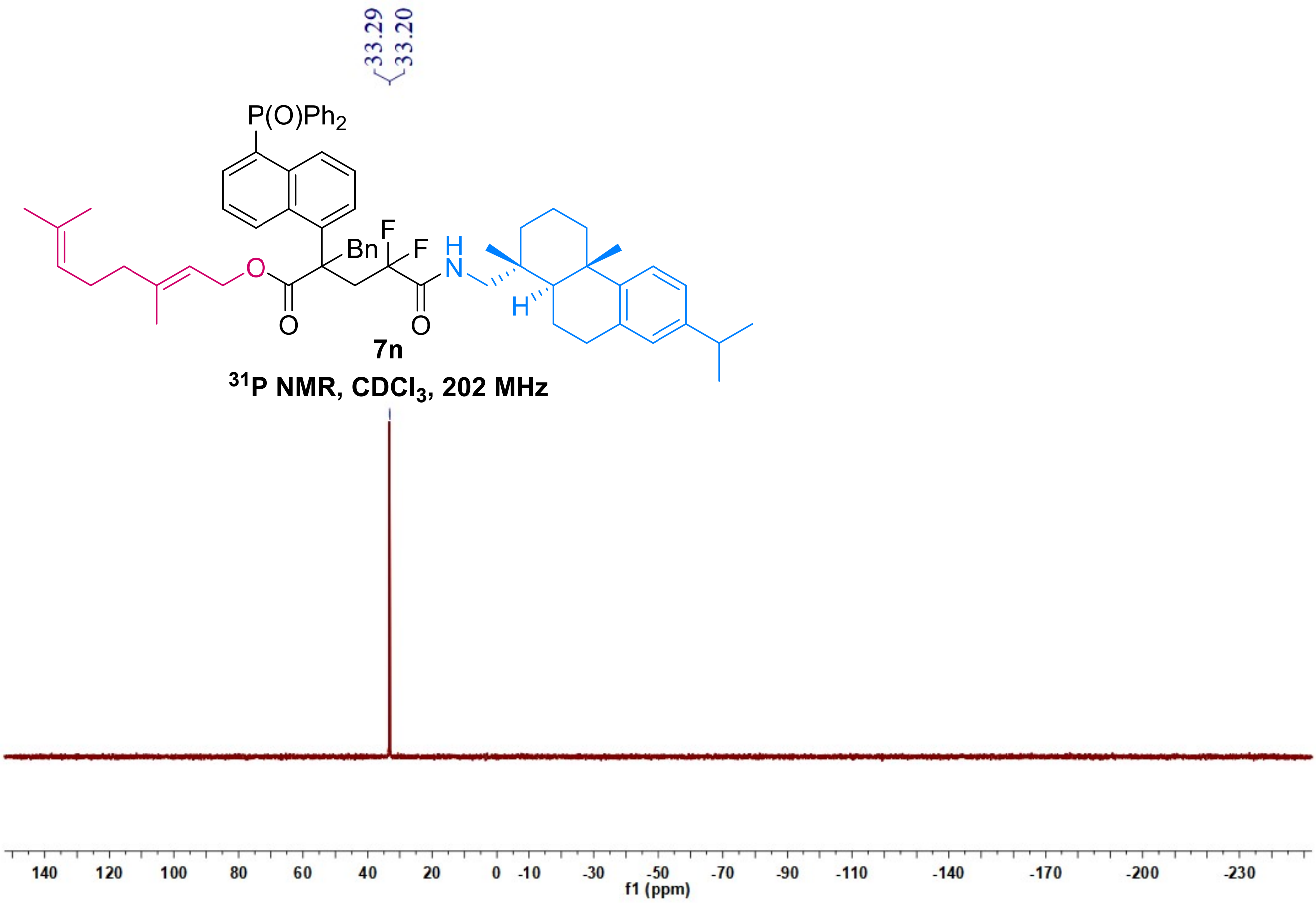
7n

^{1}H NMR, CDCl$_3$, 400 MHz



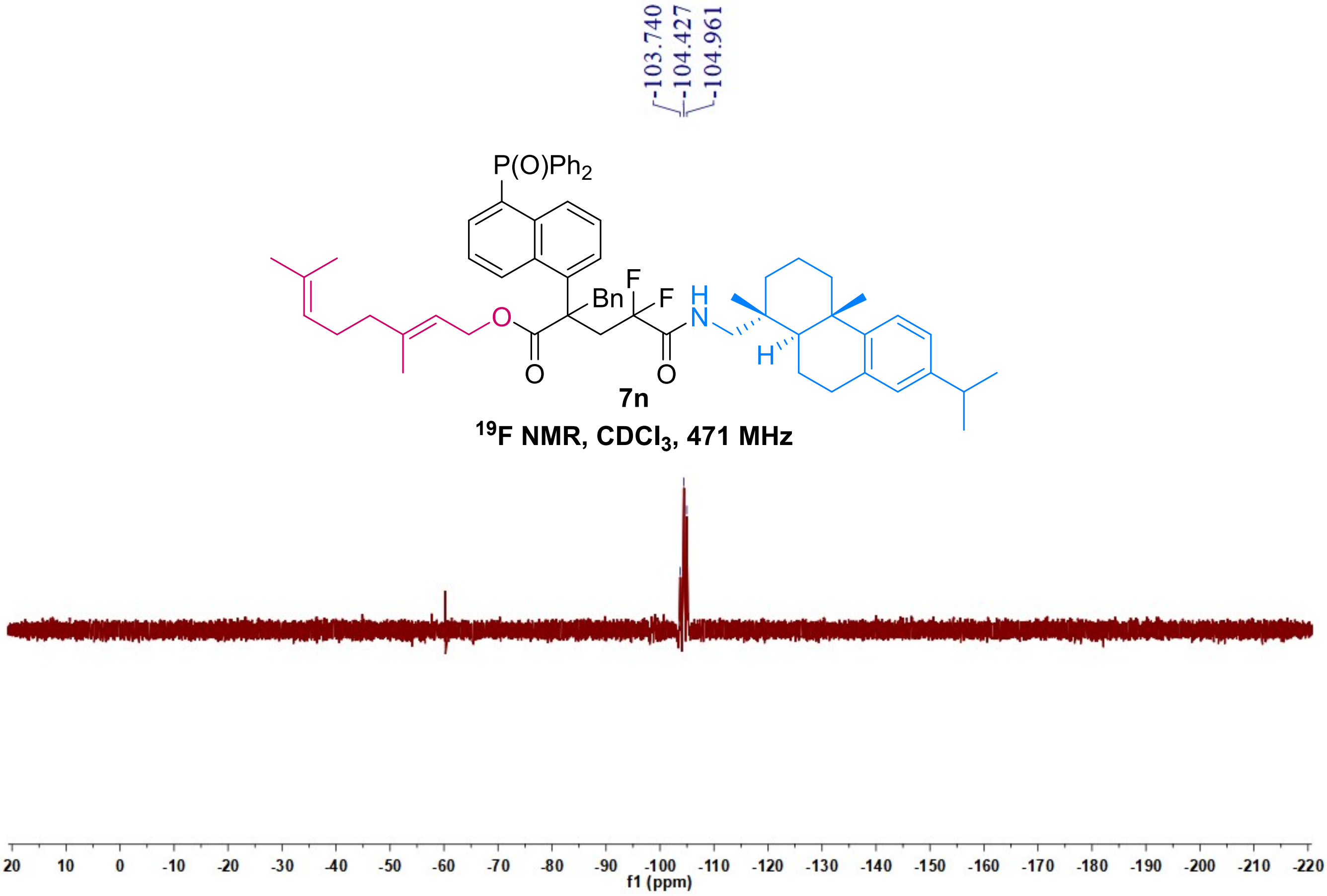
7n

^{13}C NMR, CDCl$_3$, 126 MHz



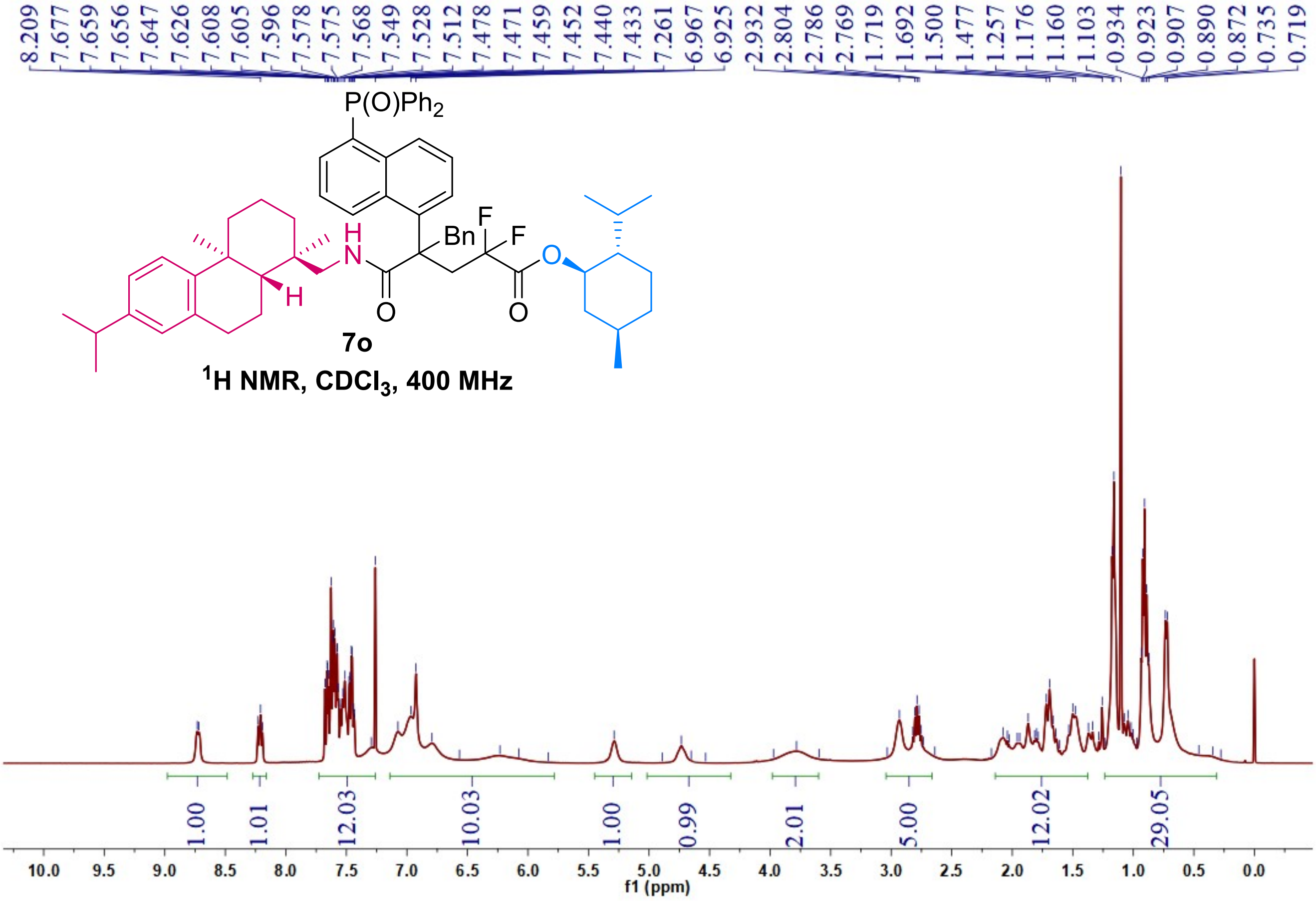
7n

^{31}P NMR, CDCl$_3$, 202 MHz



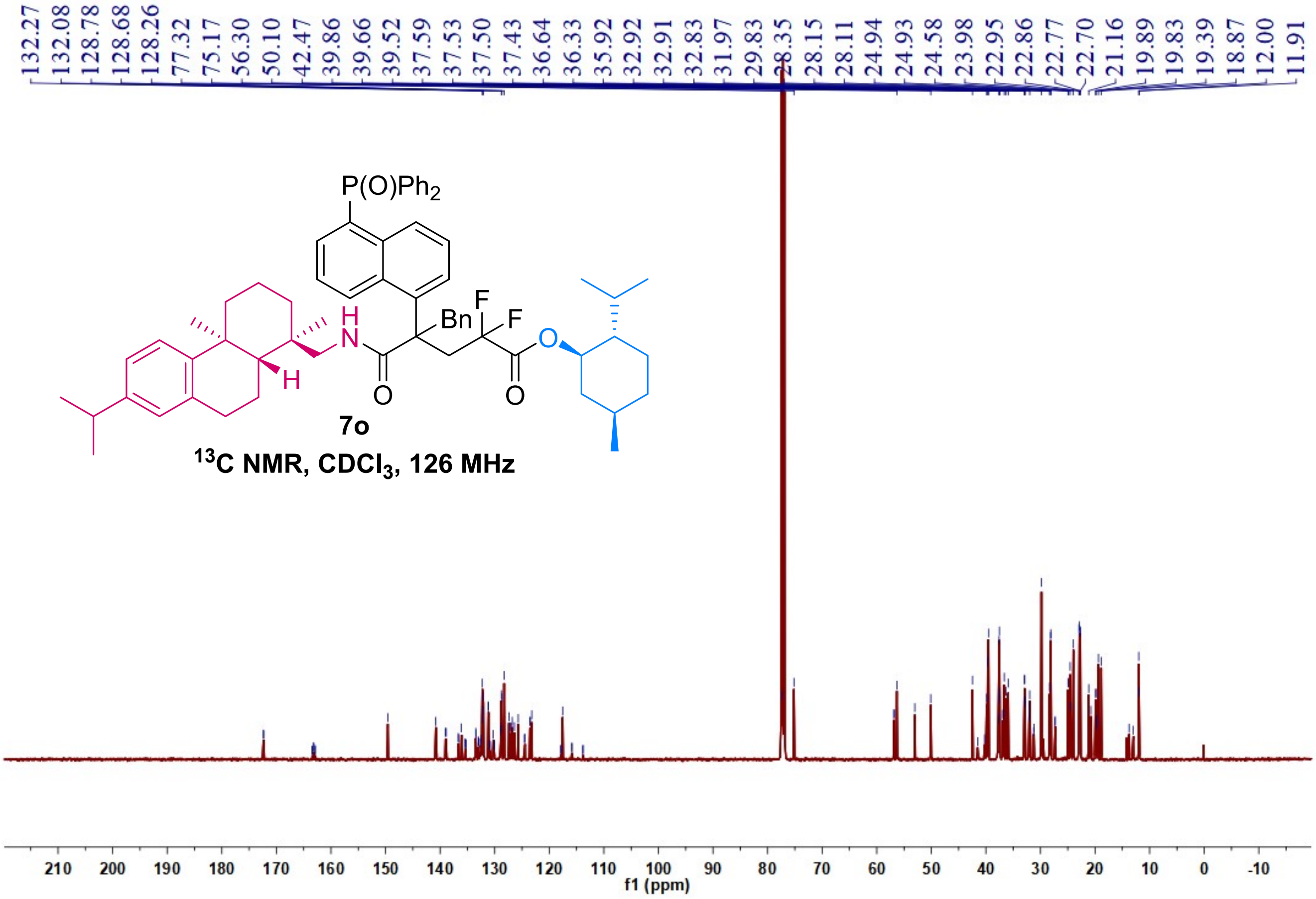
7n

^{19}F NMR, CDCl$_3$, 471 MHz



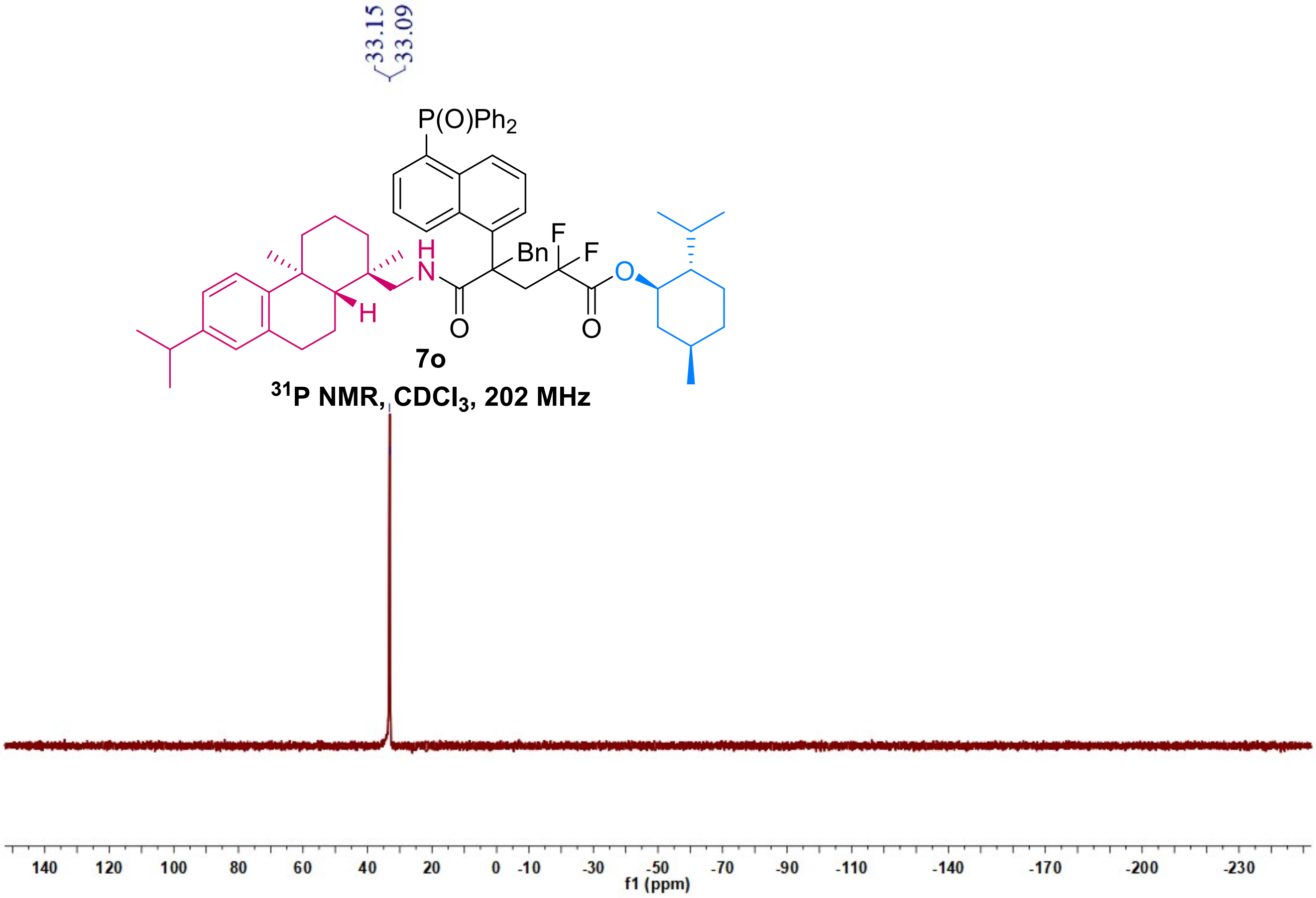
7o

^{1}H NMR, CDCl$_3$, 400 MHz



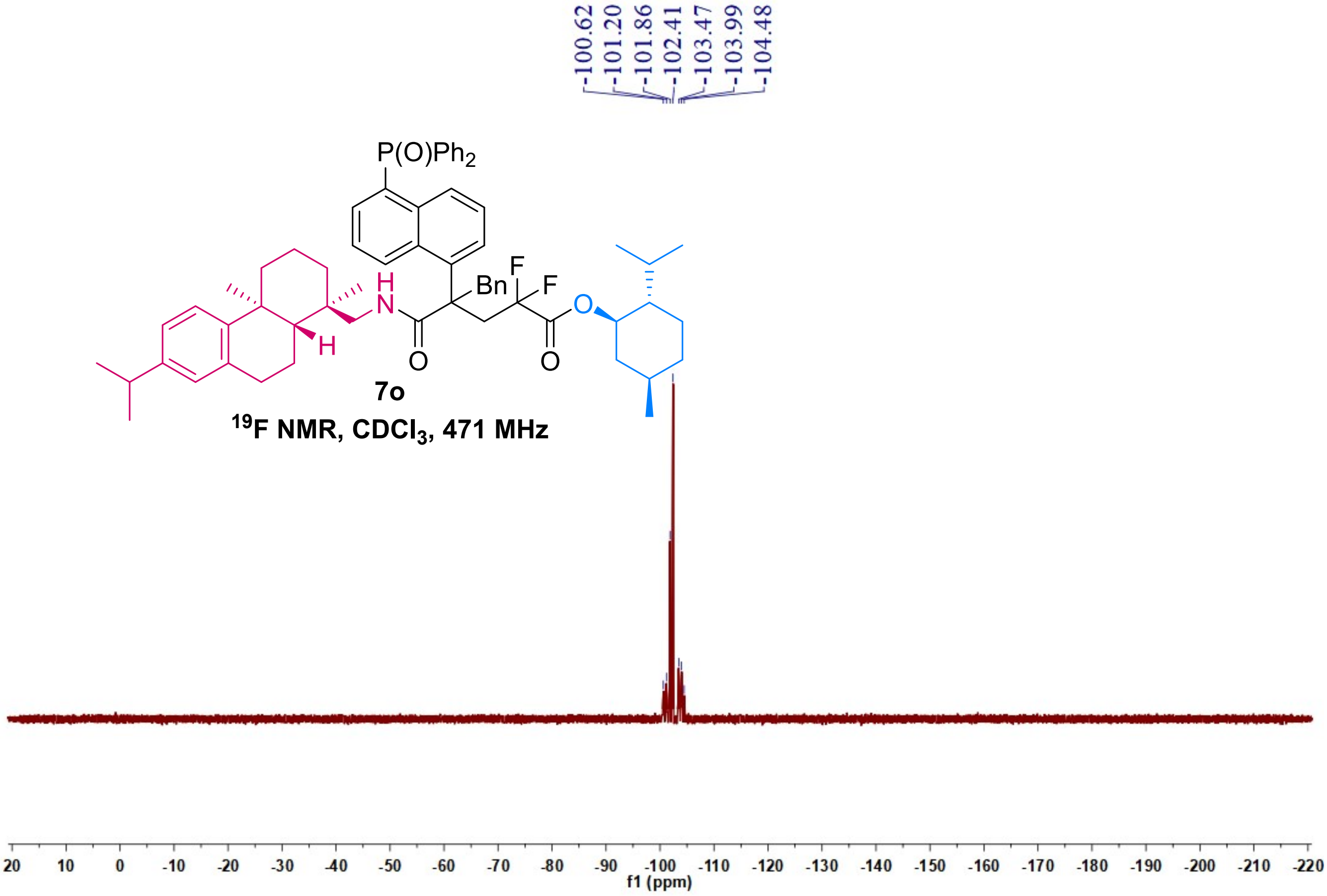
7o

^{13}C NMR, CDCl$_3$, 126 MHz



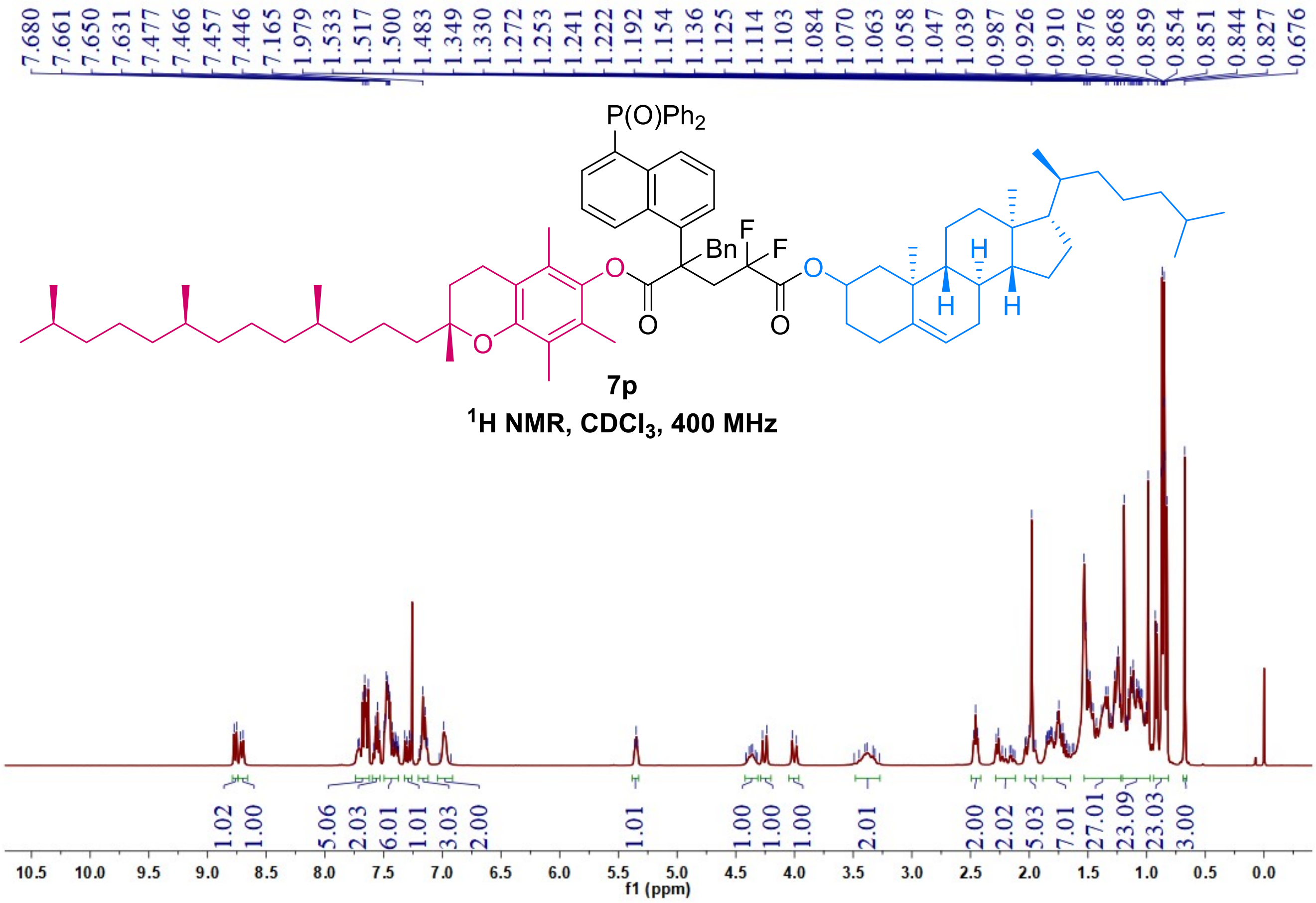
7o

^{31}P NMR, CDCl$_3$, 202 MHz



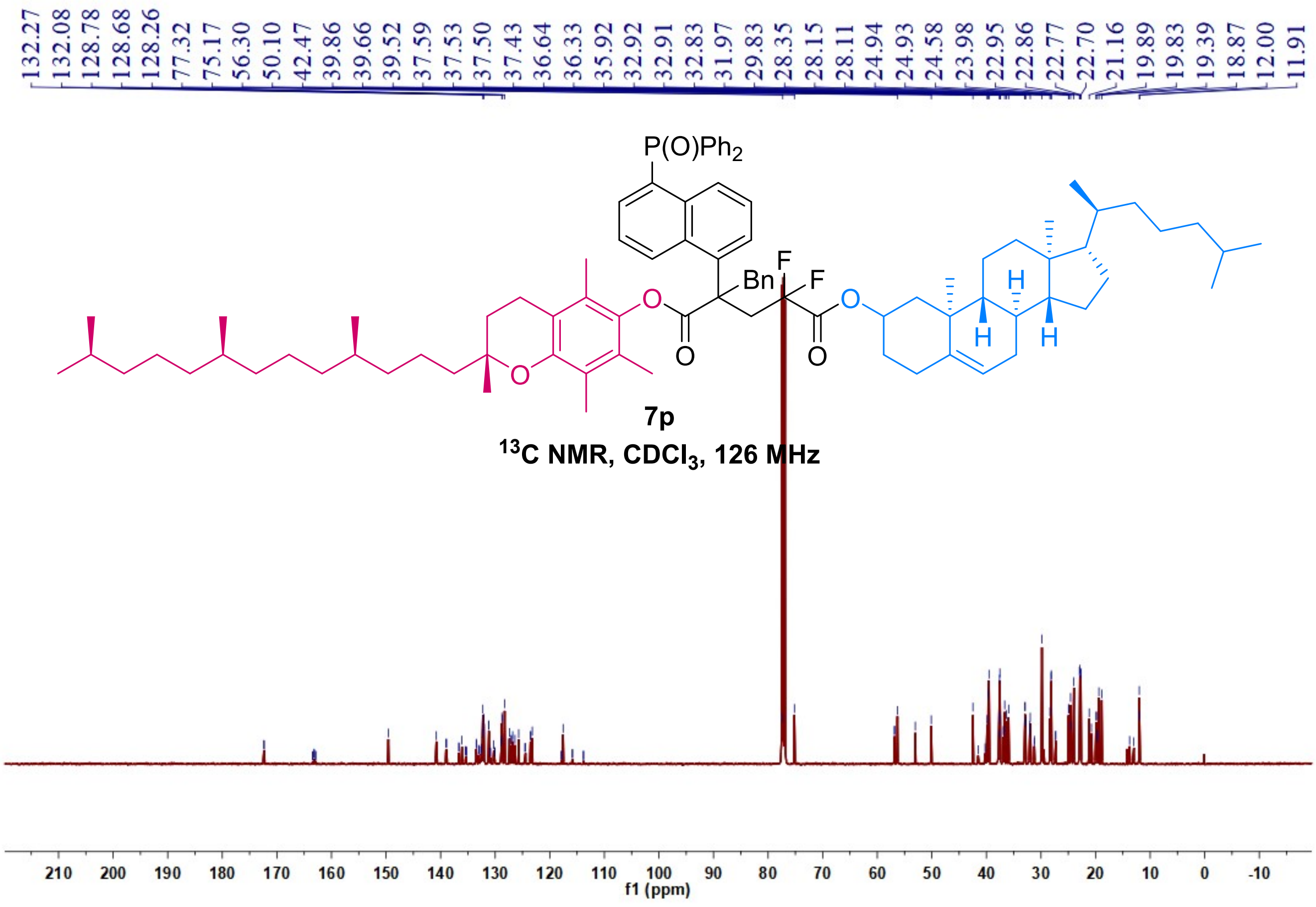
7o

^{19}F NMR, CDCl$_3$, 471 MHz



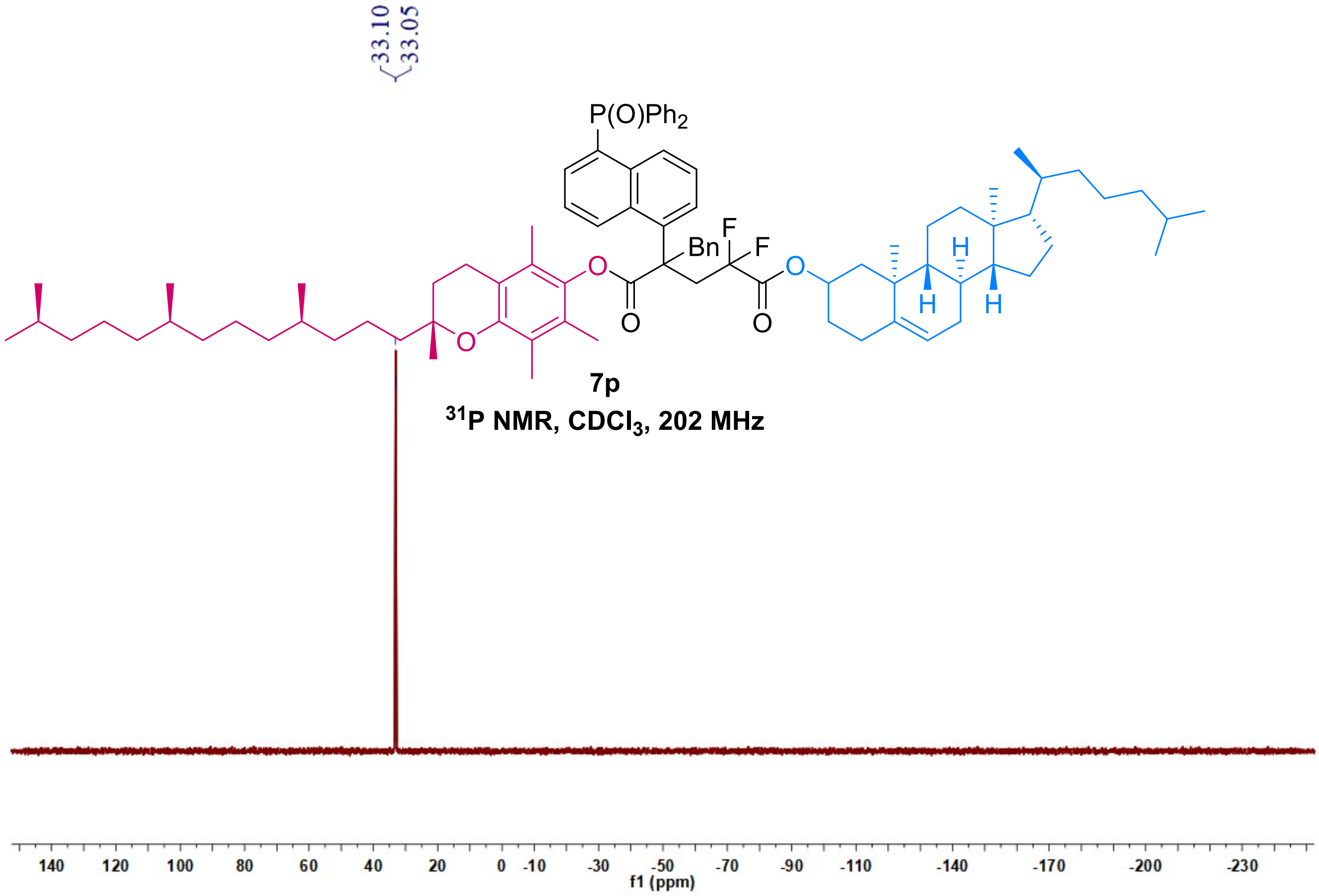
7p

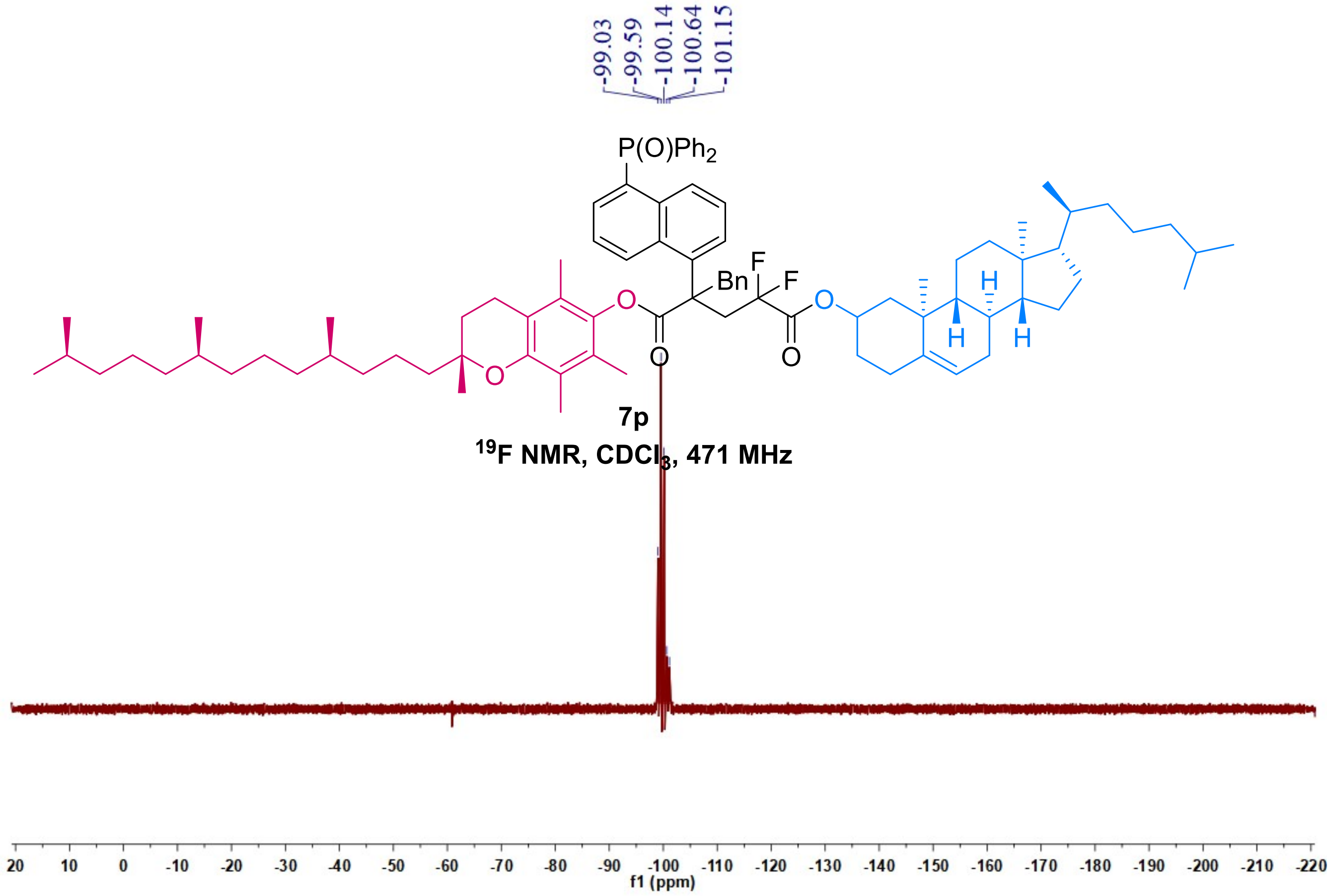
^{1}H NMR, $CDCl_3$, 400 MHz



7p

^{13}C NMR, $CDCl_3$, 126 MHz


33.10
33.05
P(O)Ph2
Bn
F
F
O
O
O
O
O
H
H
H
7p
31P NMR, CDCl3, 202 MHz
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-110
-140
-170
-200
-230
f1 (ppm)


-99.03
-99.59
-100.14
-100.64
-101.15
P(O)Ph2
Bn
F
F
O
O
O
O
O
H
H
H
7p
19F NMR, CDCl3, 471 MHz
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
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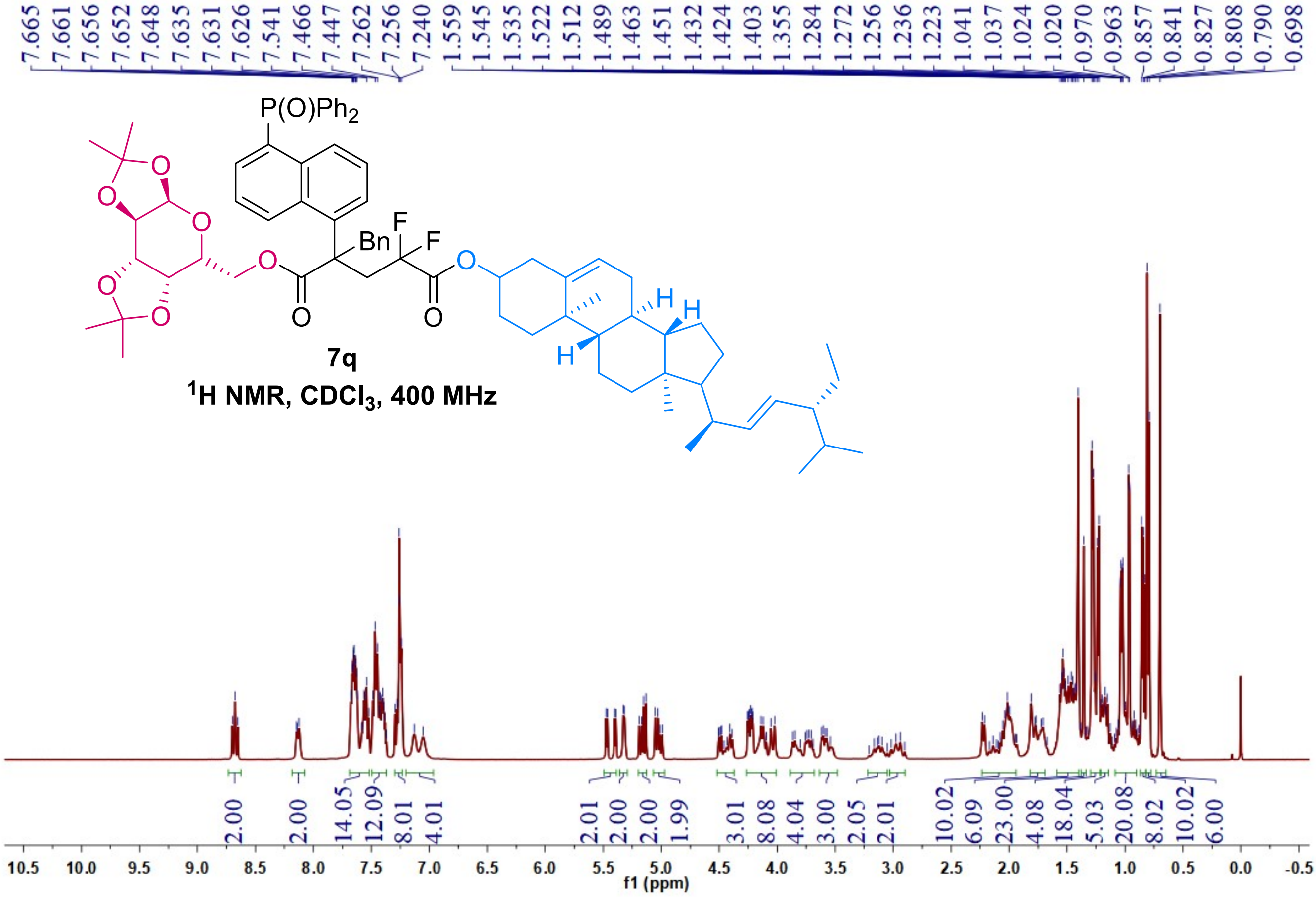
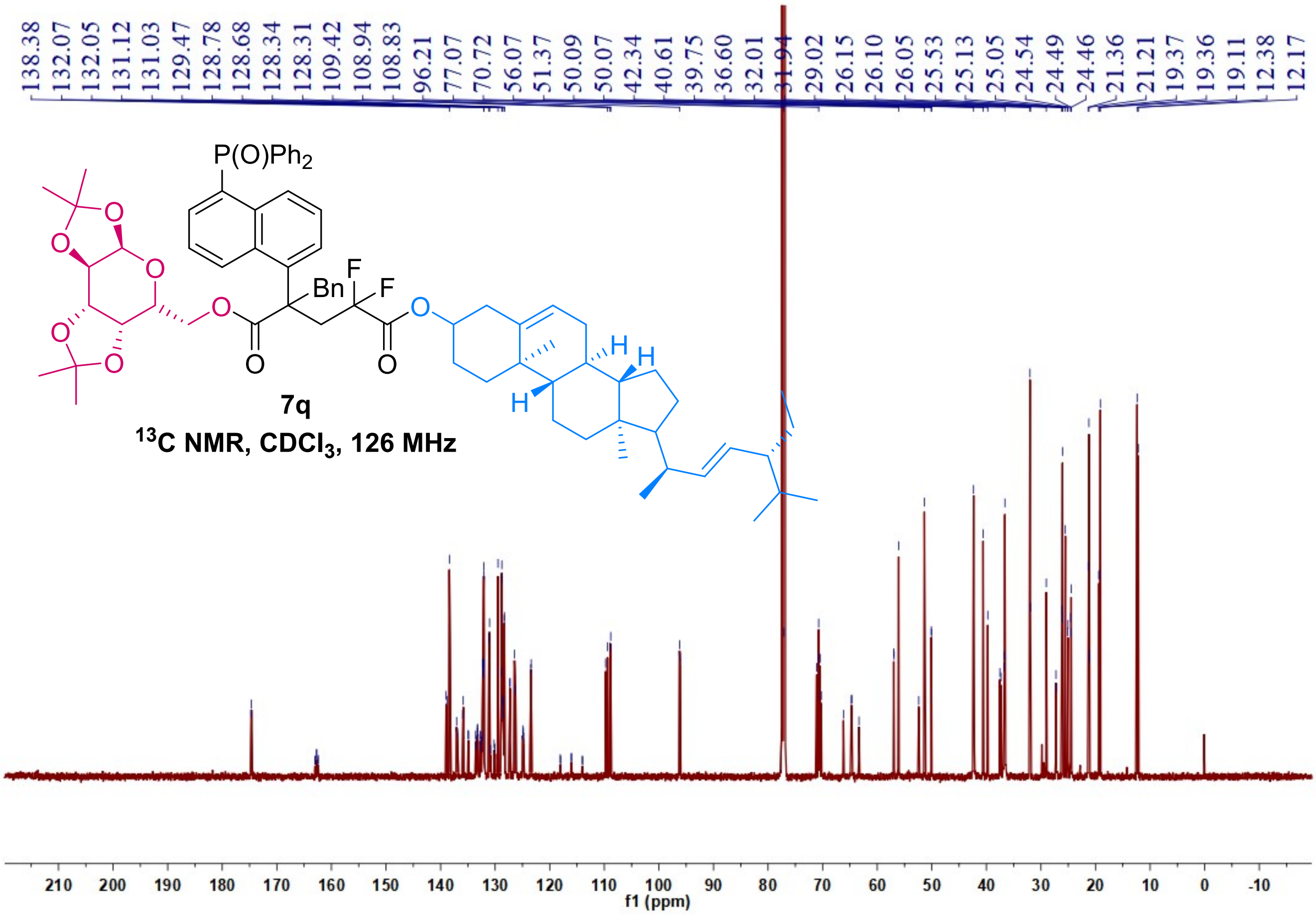
-190
-200
-210
-220
f1 (ppm)



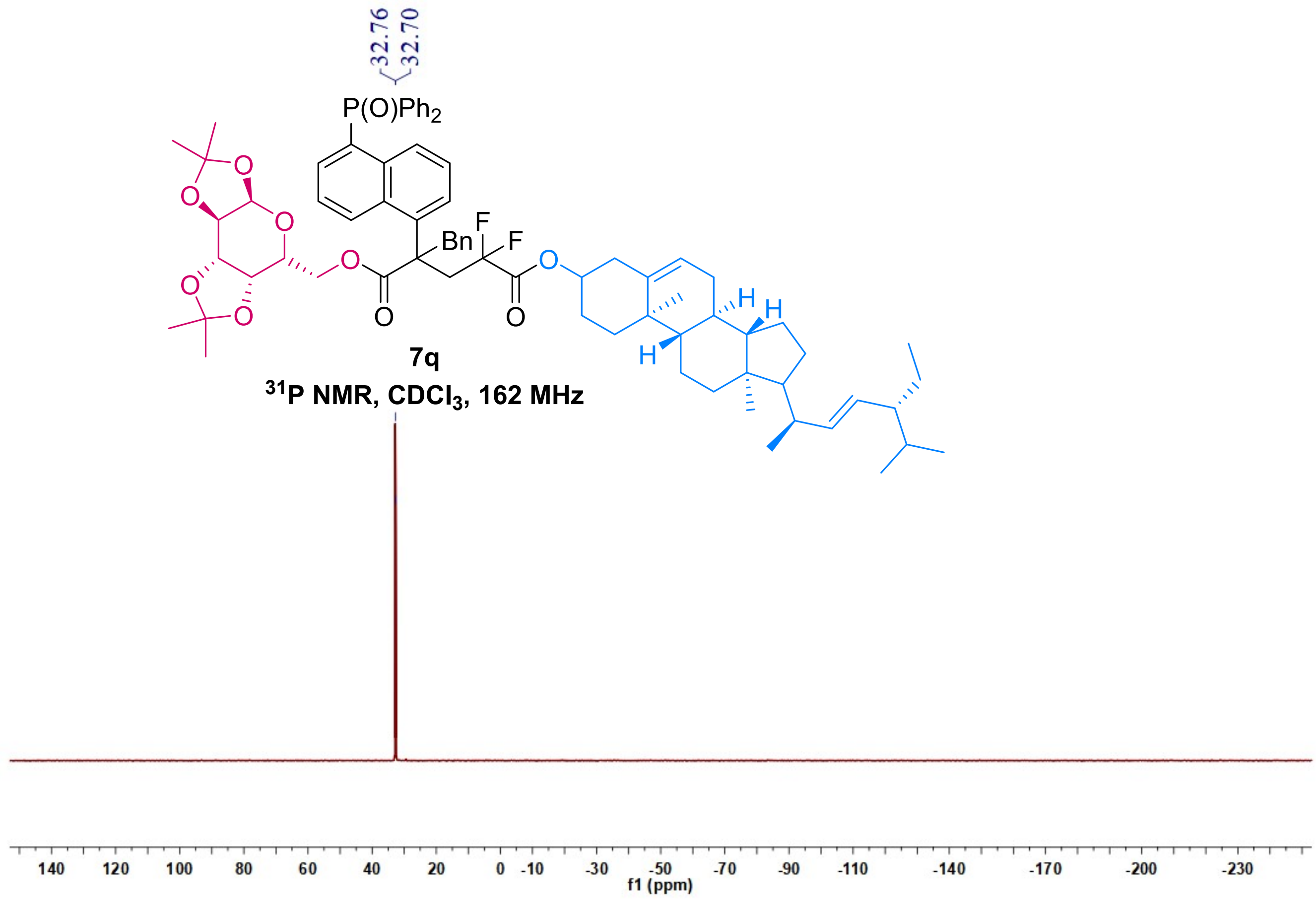
7q

^{1}H NMR, CDCl$_3$, 400 MHz



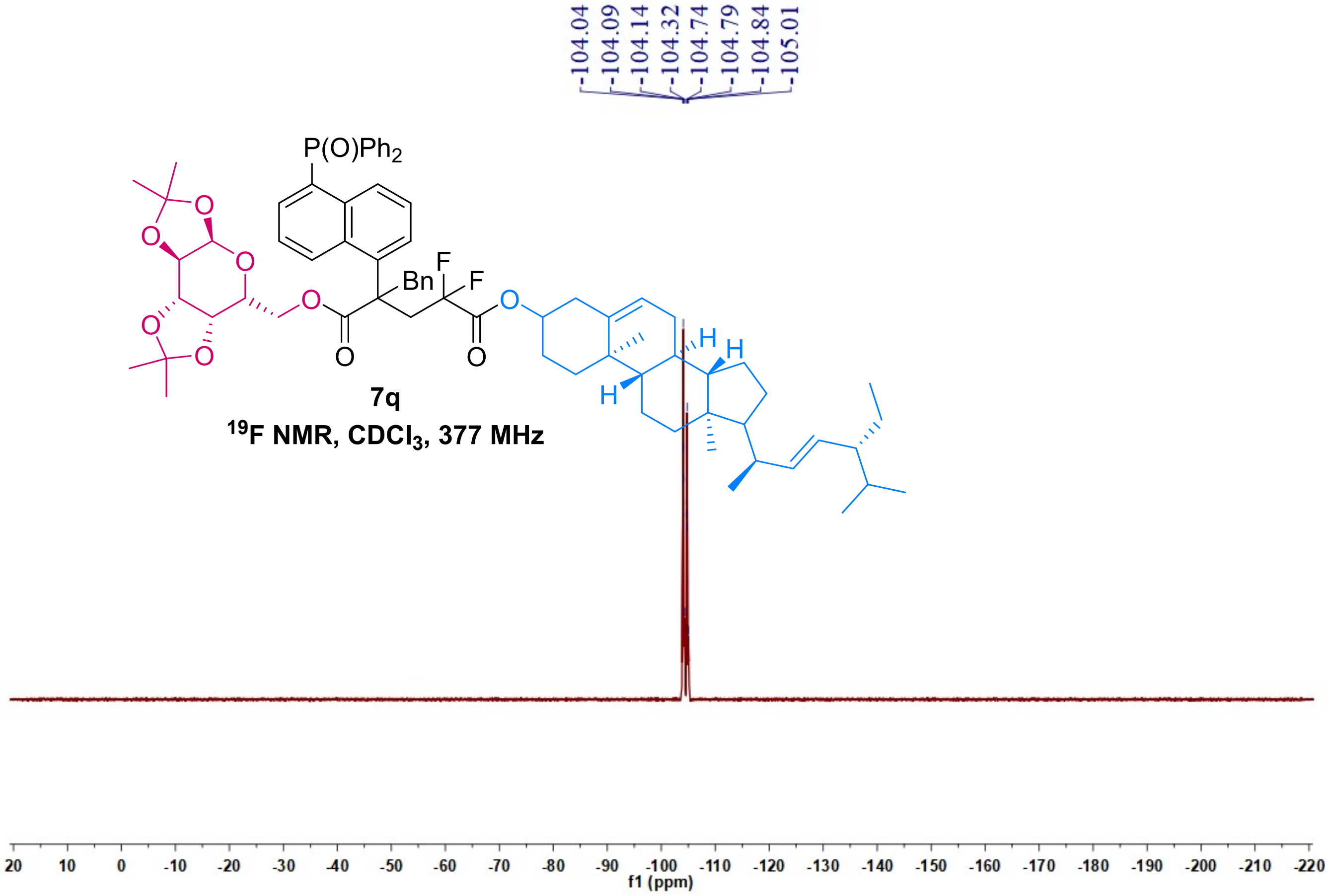
7q

^{13}C NMR, CDCl$_3$, 126 MHz



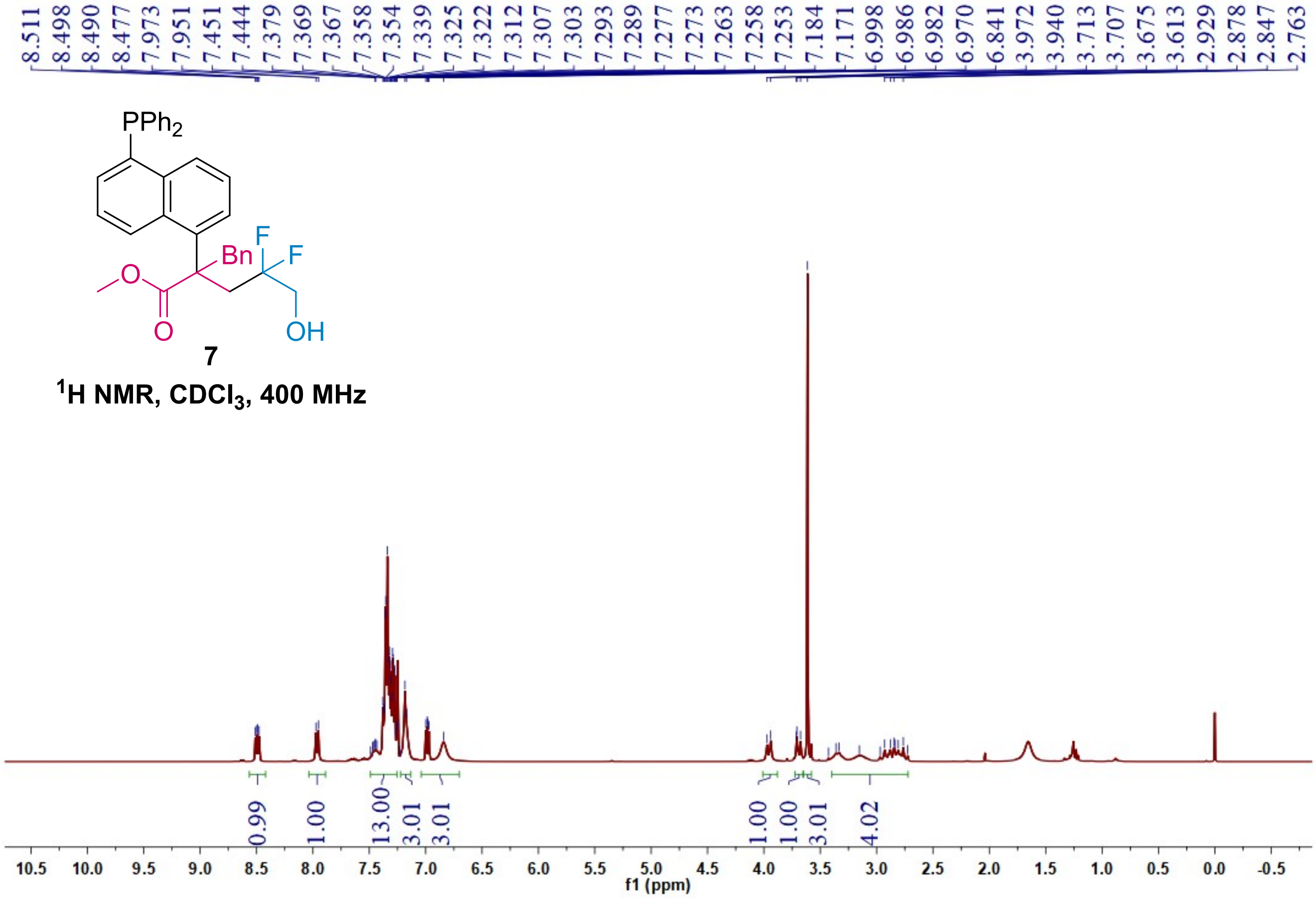
7q

^{31}P NMR, CDCl$_3$, 162 MHz



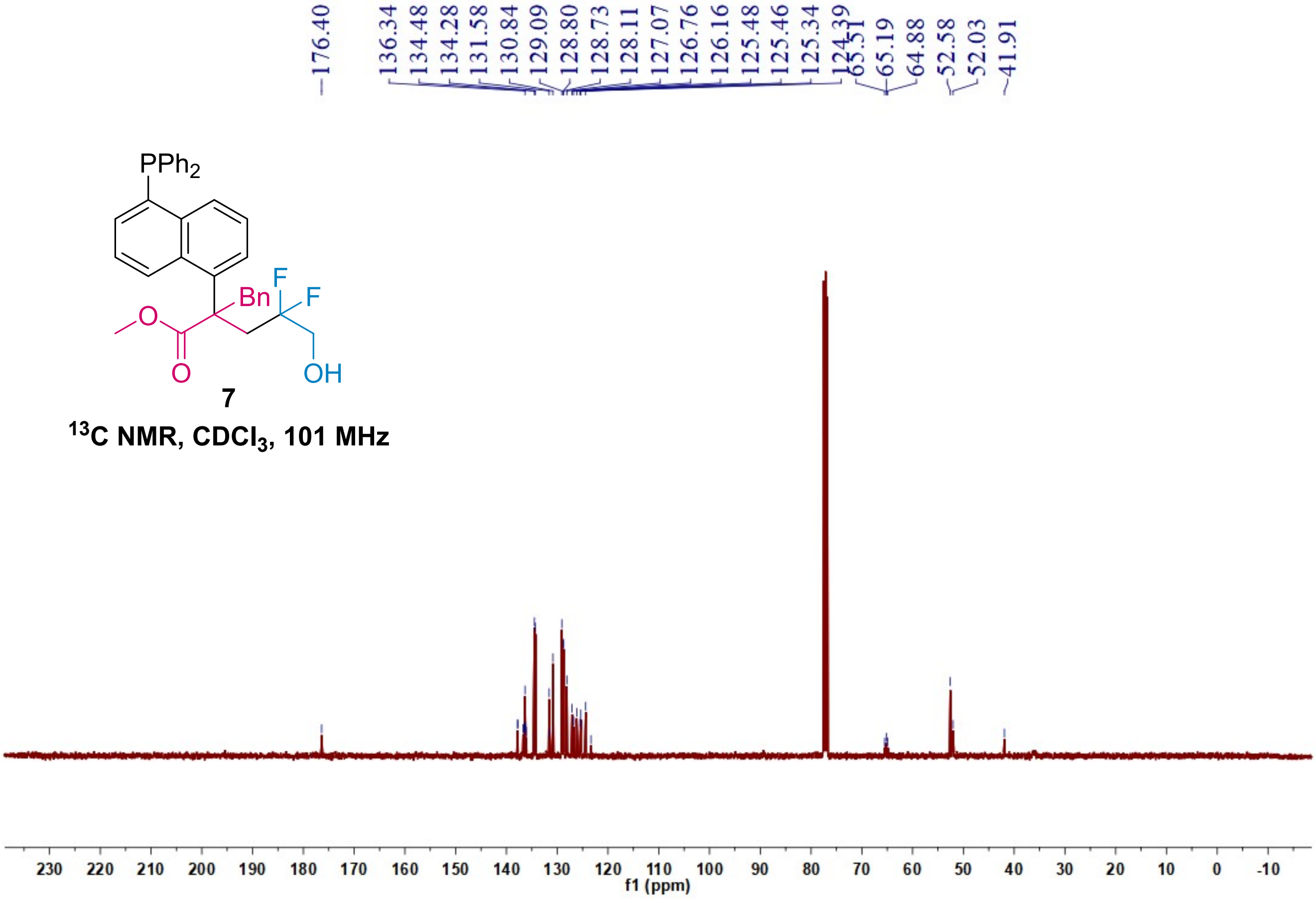
7q

^{19}F NMR, CDCl$_3$, 377 MHz



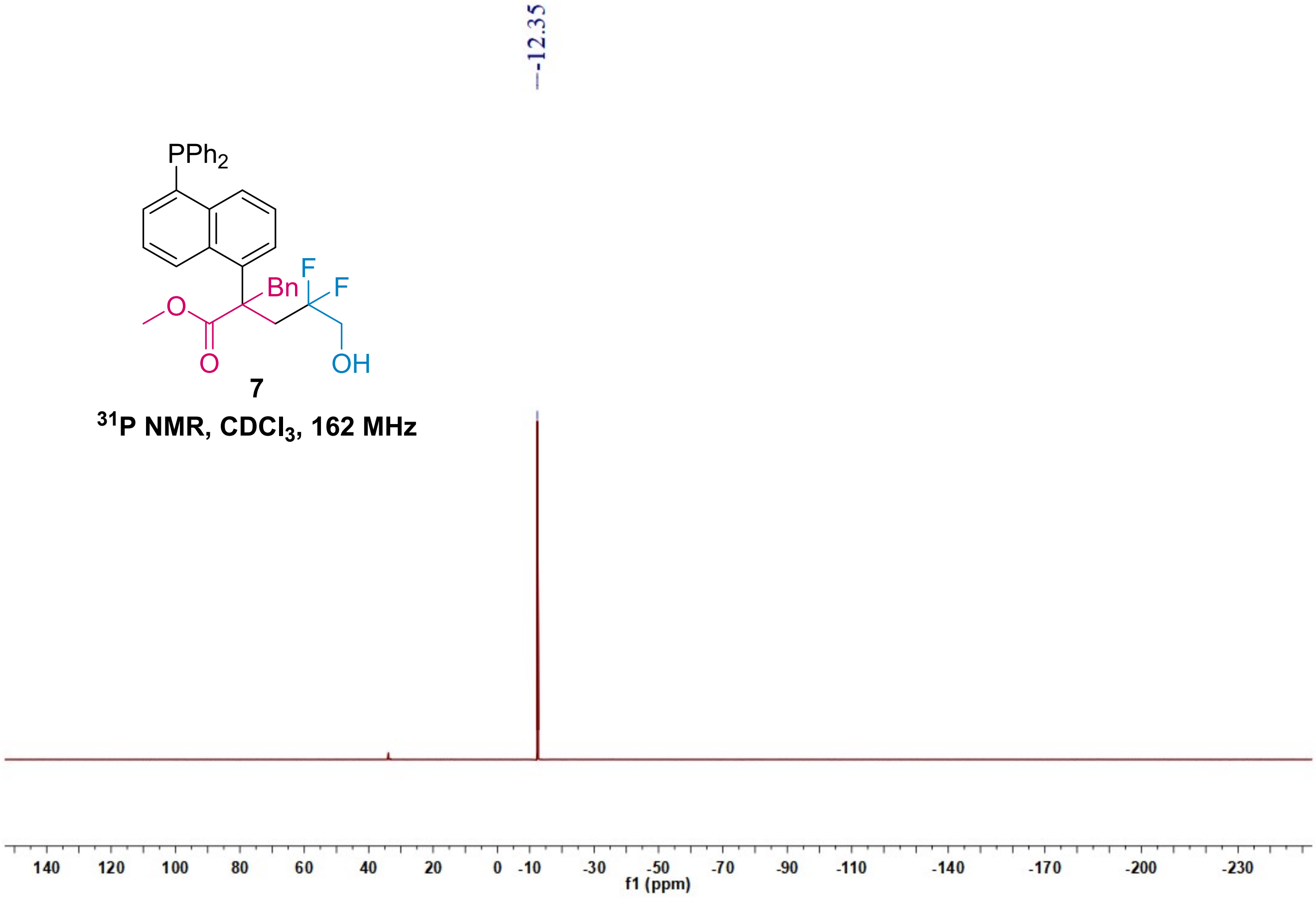
7

^{1}H NMR, CDCl$_3$, 400 MHz



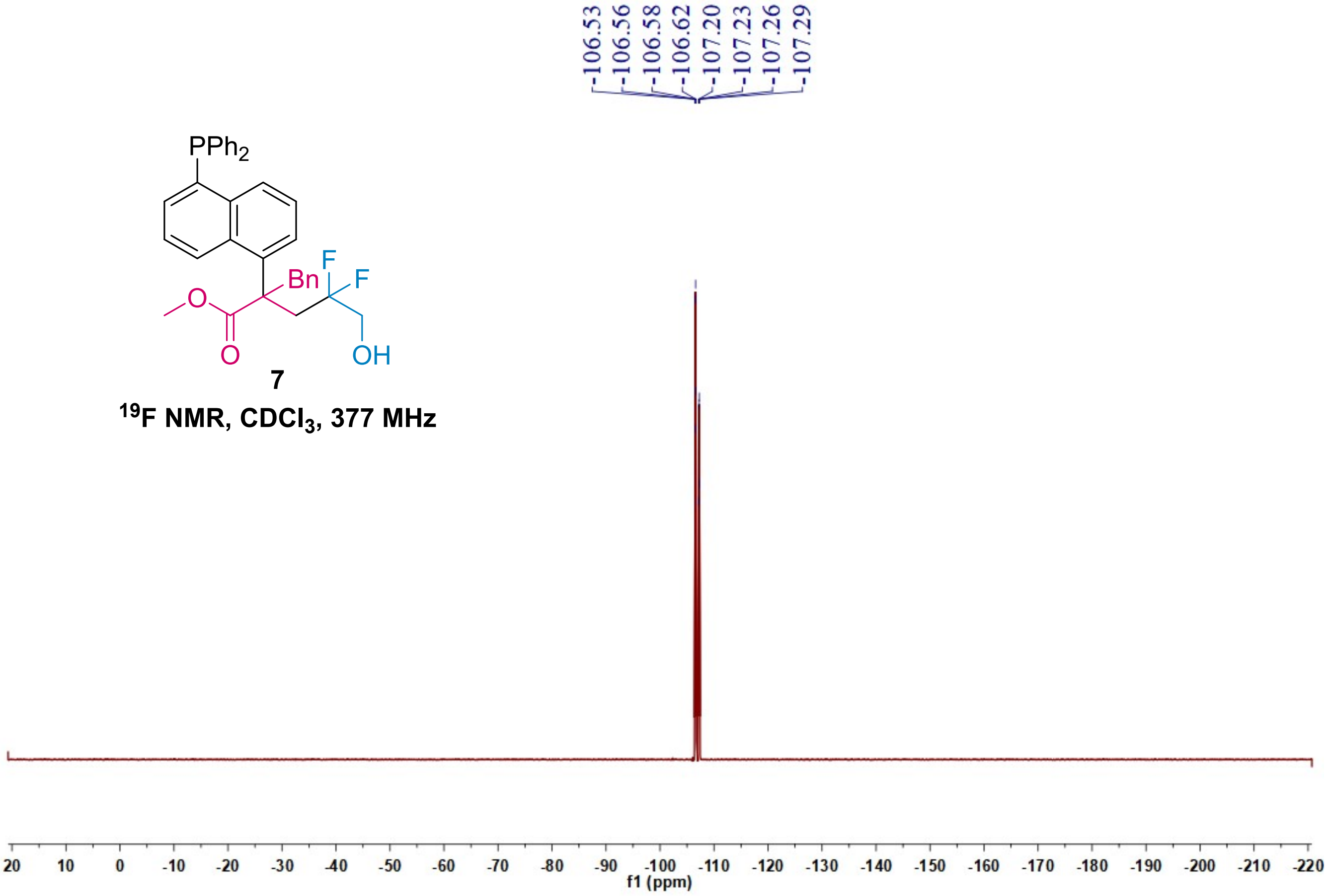
7

^{13}C NMR, CDCl$_3$, 101 MHz



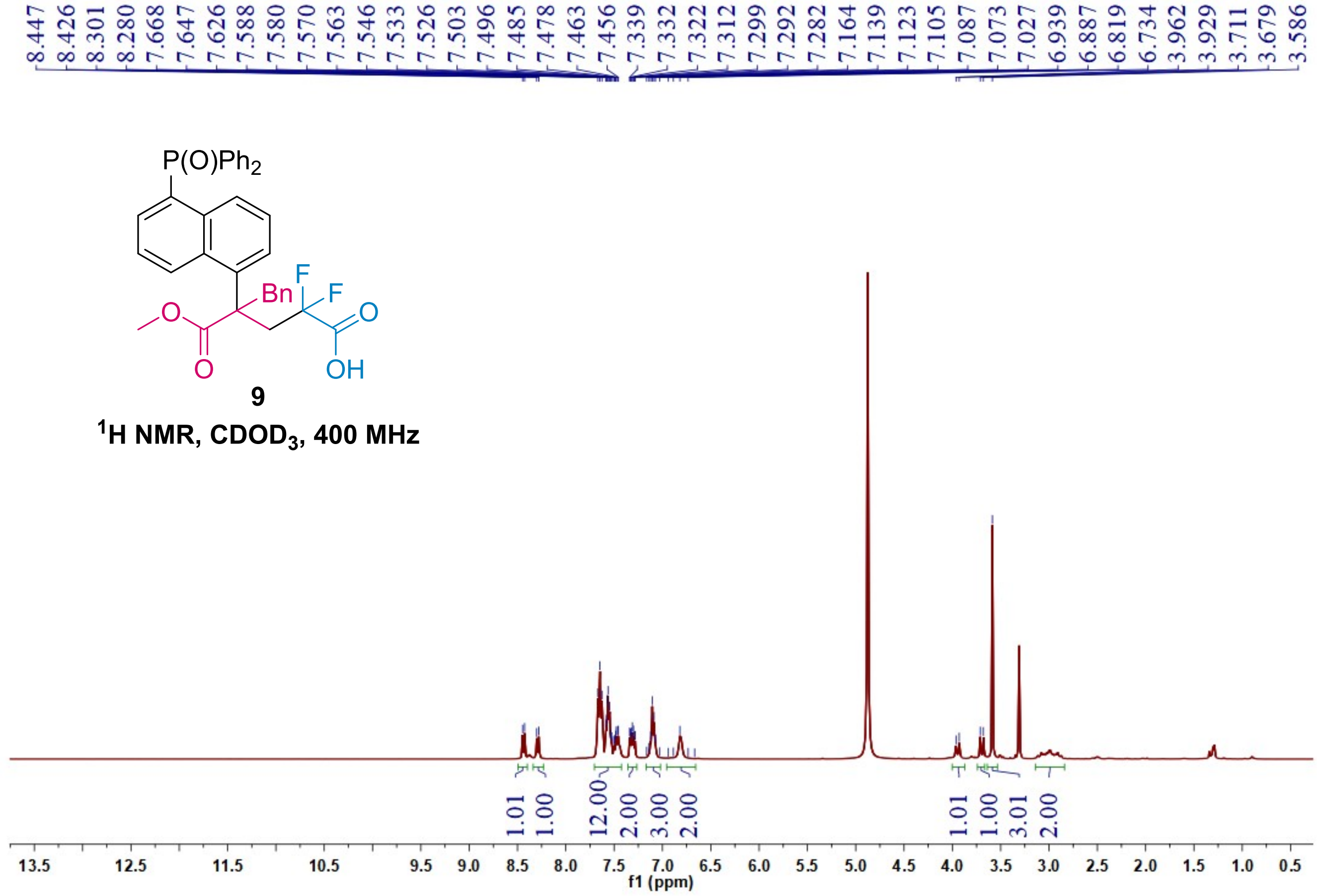
7

^{31}P NMR, CDCl$_3$, 162 MHz

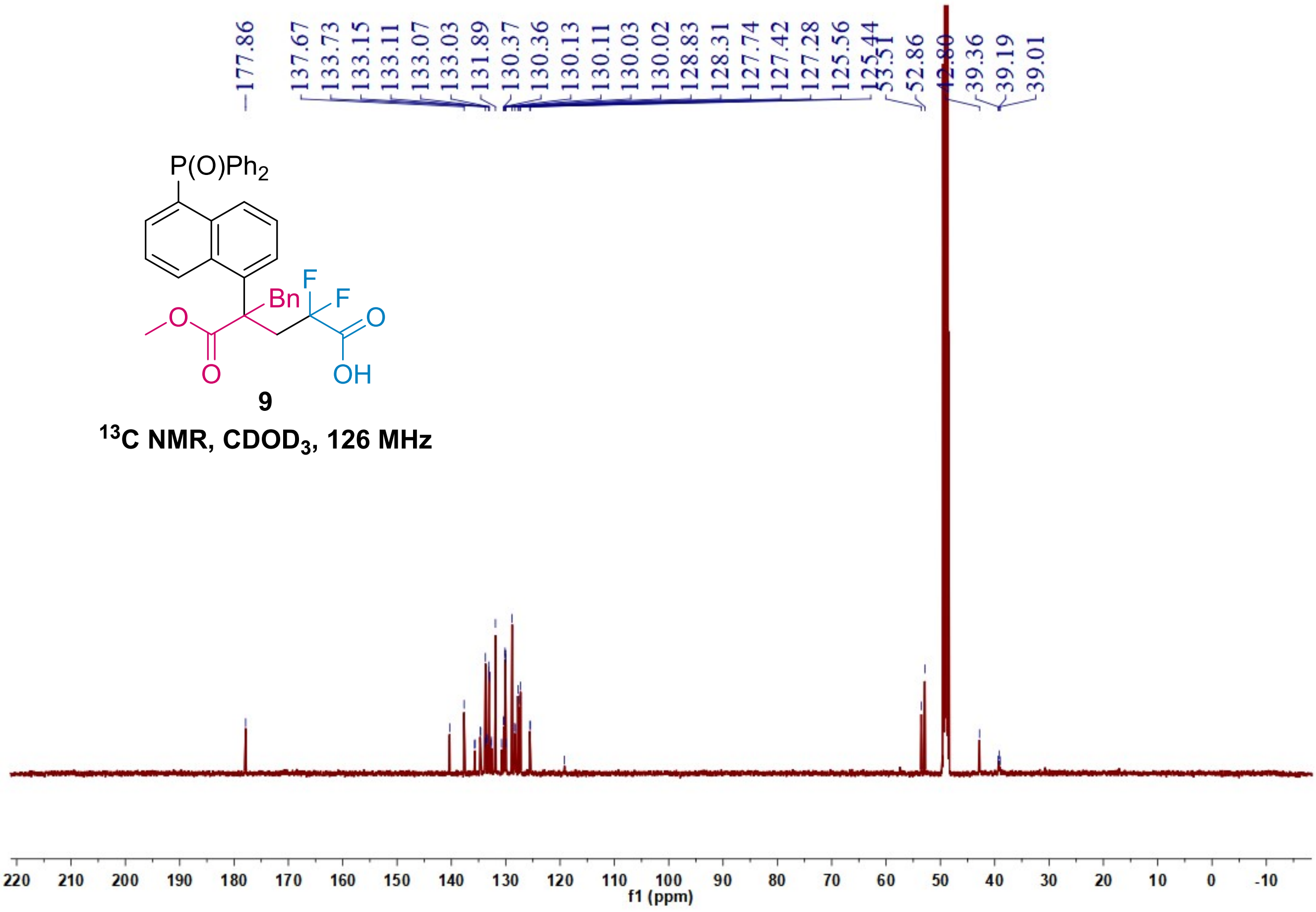


7

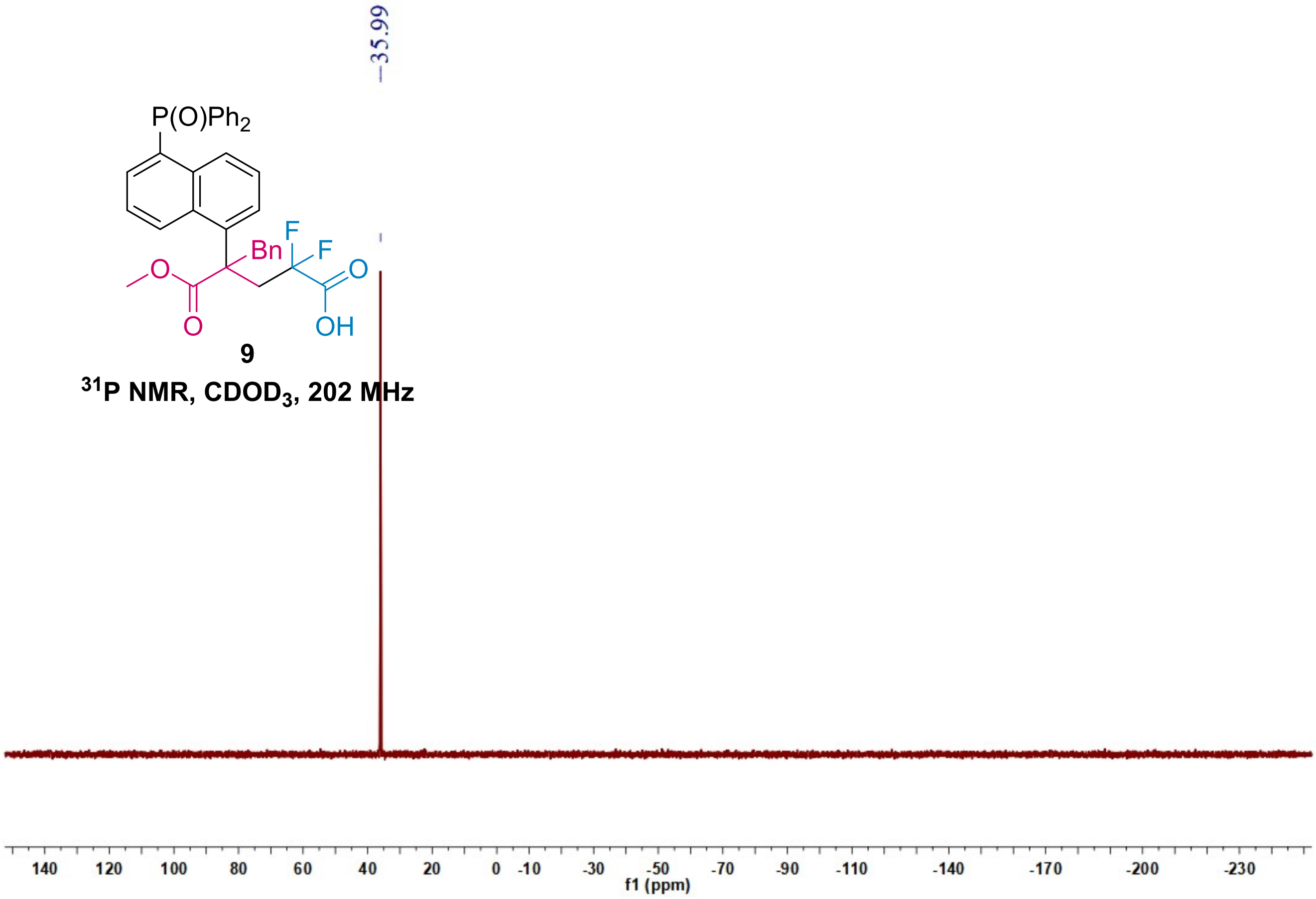
^{19}F NMR, CDCl$_3$, 377 MHz


9

^{1}H NMR, $CDOD_3$, 400 MHz


9

^{13}C NMR, $CDOD_3$, 126 MHz



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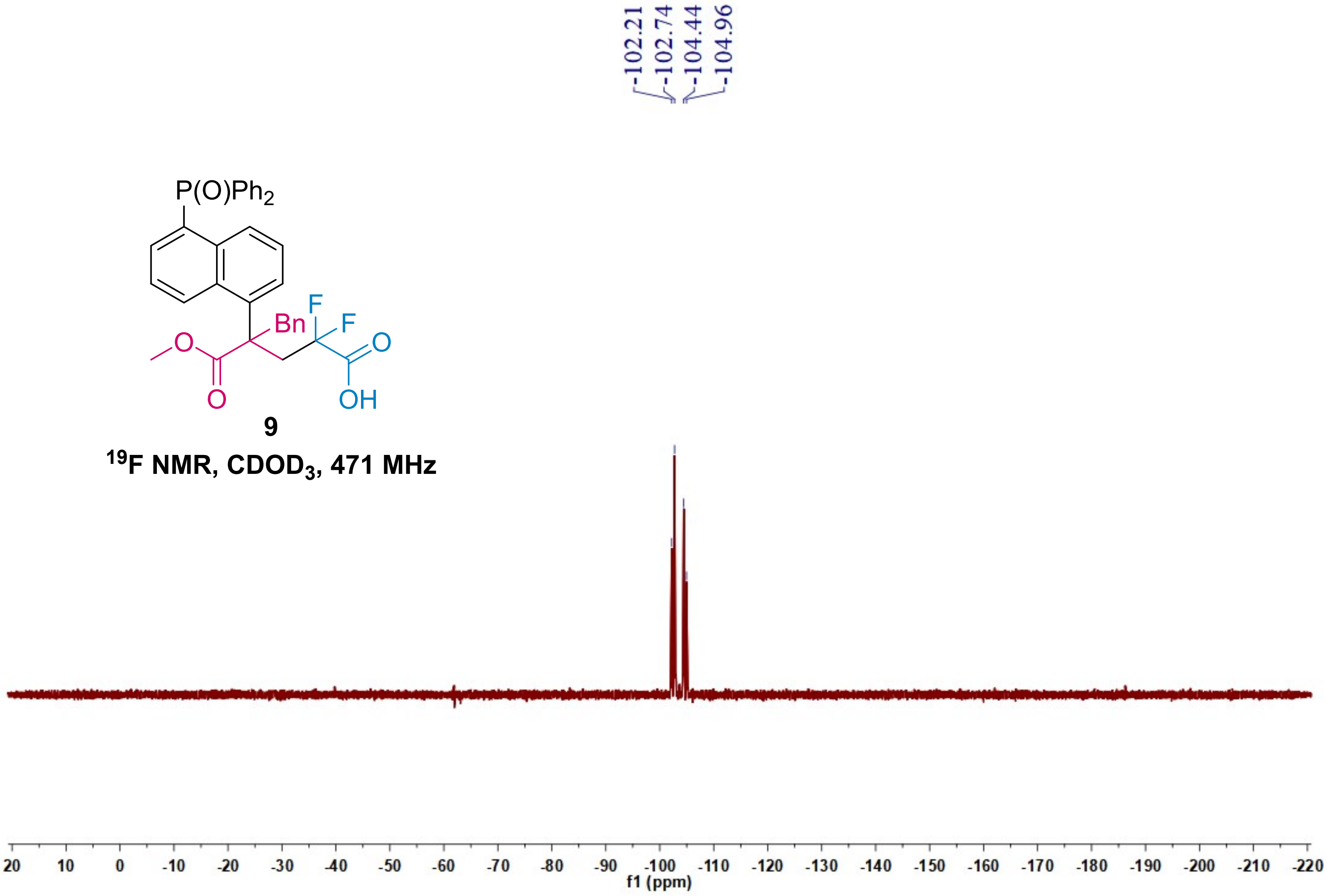
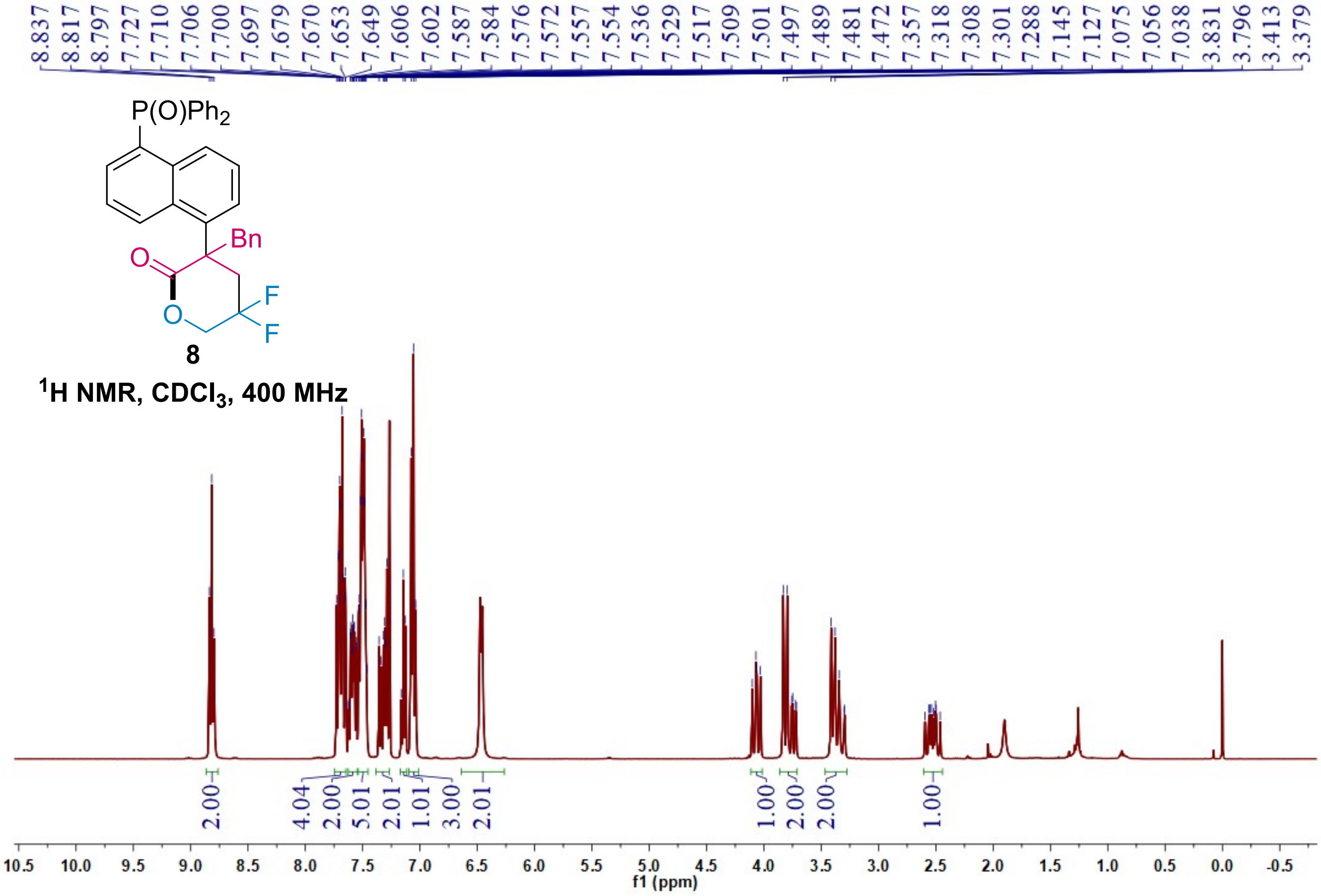
^{31}P NMR, $CDOD_3$, 202 MHz



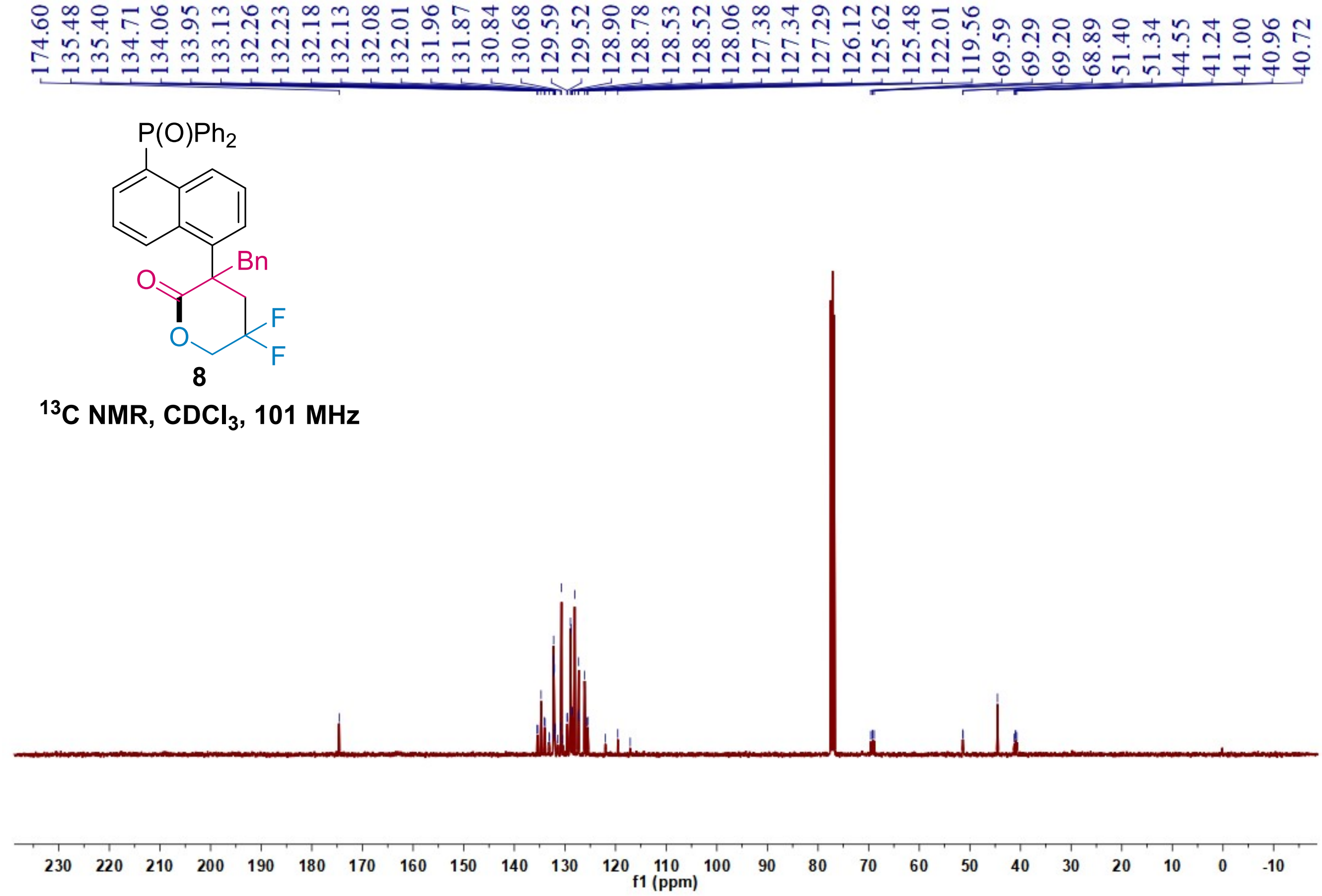
9

^{19}F NMR, $CDOD_3$, 471 MHz



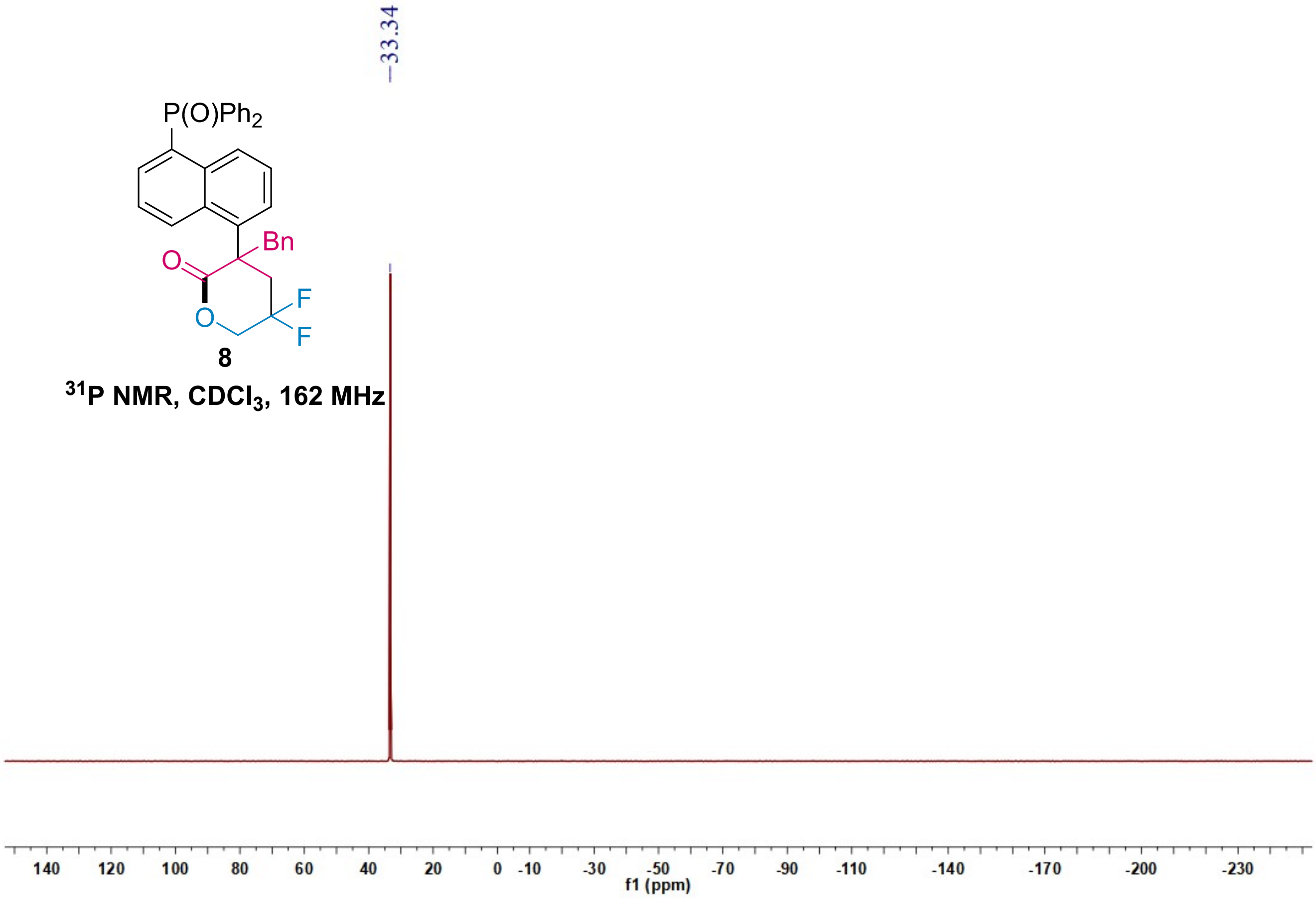
8

^{1}H NMR, CDCl$_3$, 400 MHz



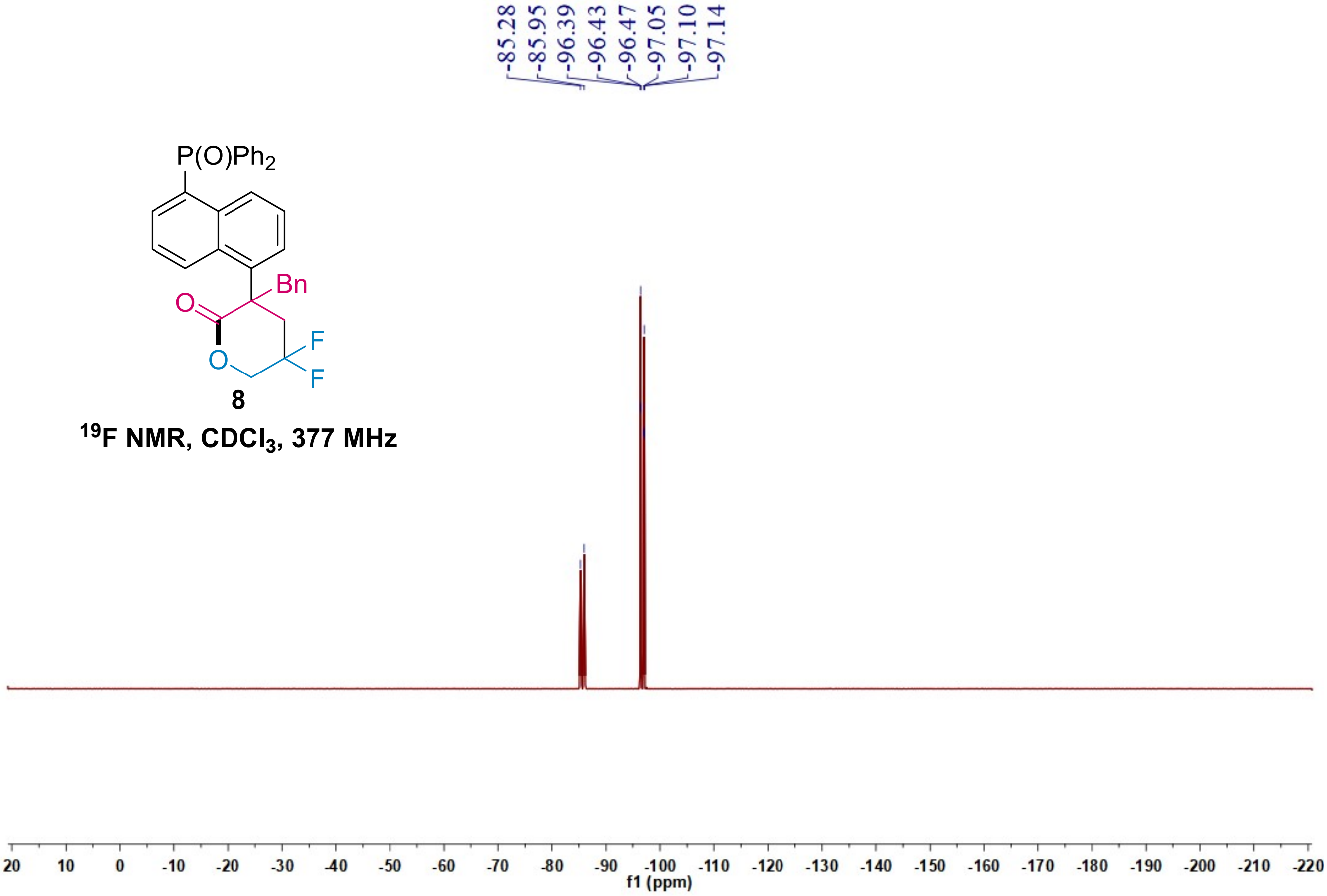
8

^{13}C NMR, CDCl$_3$, 101 MHz



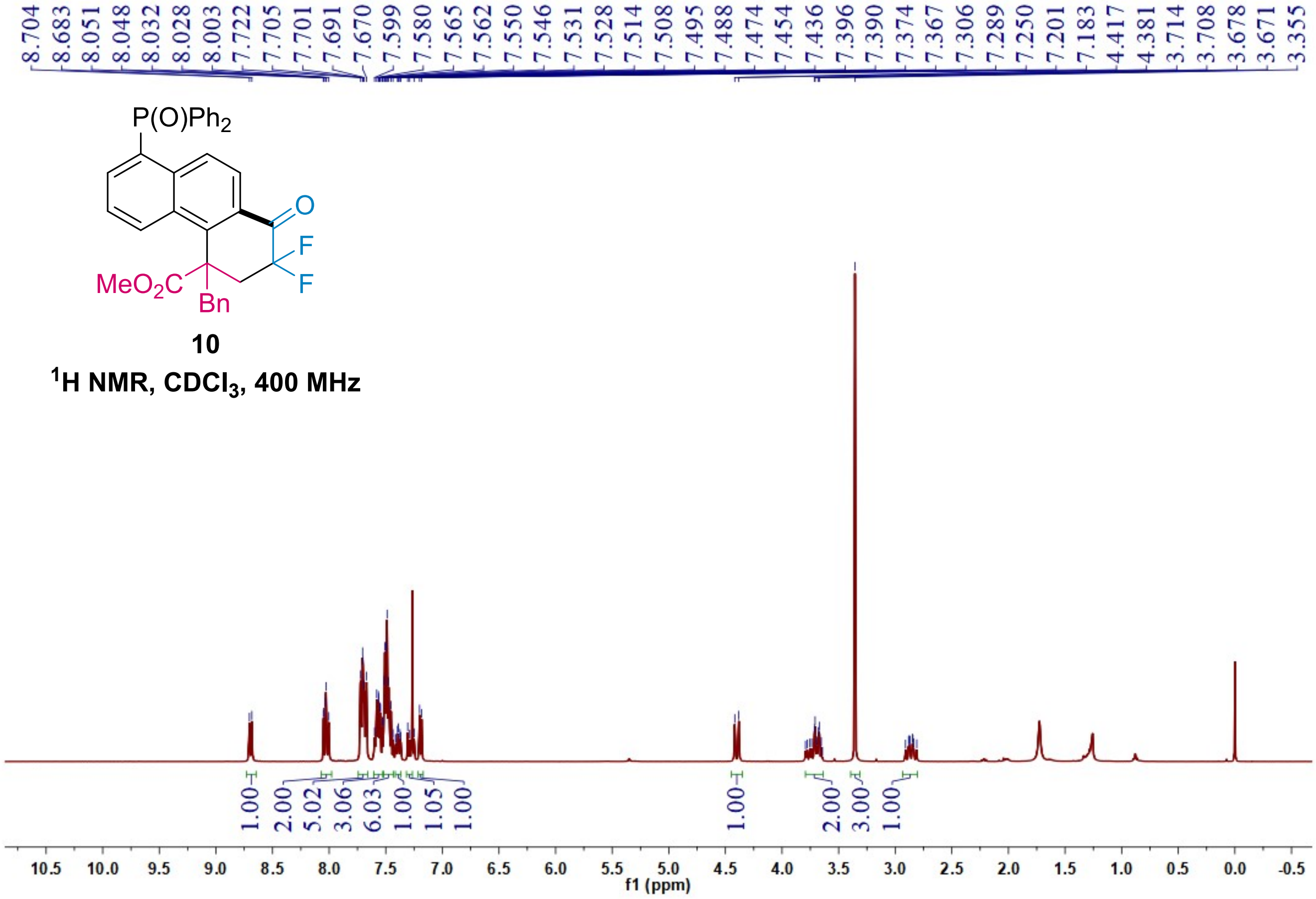
8

^{31}P NMR, CDCl$_3$, 162 MHz



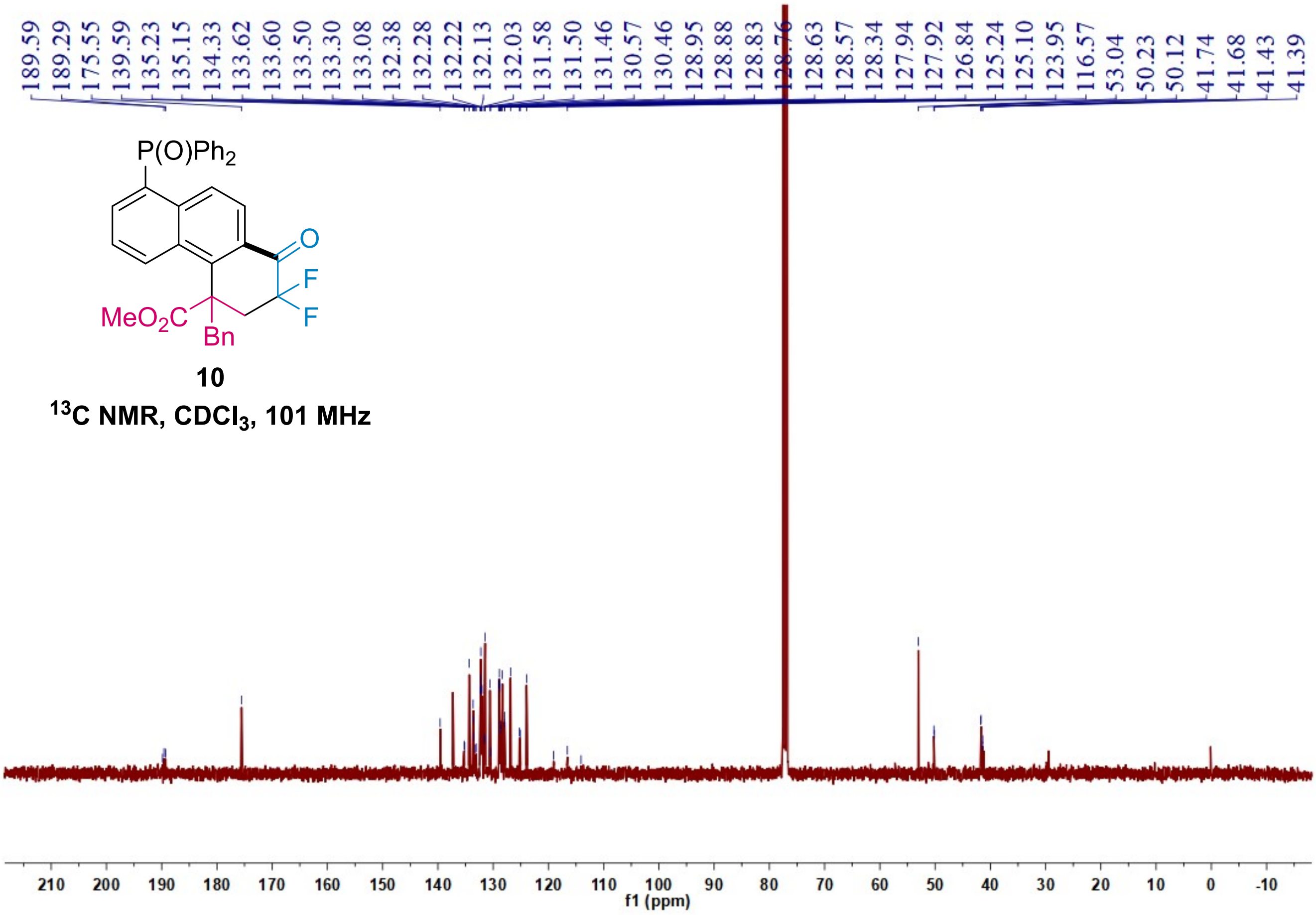
8

^{19}F NMR, CDCl$_3$, 377 MHz



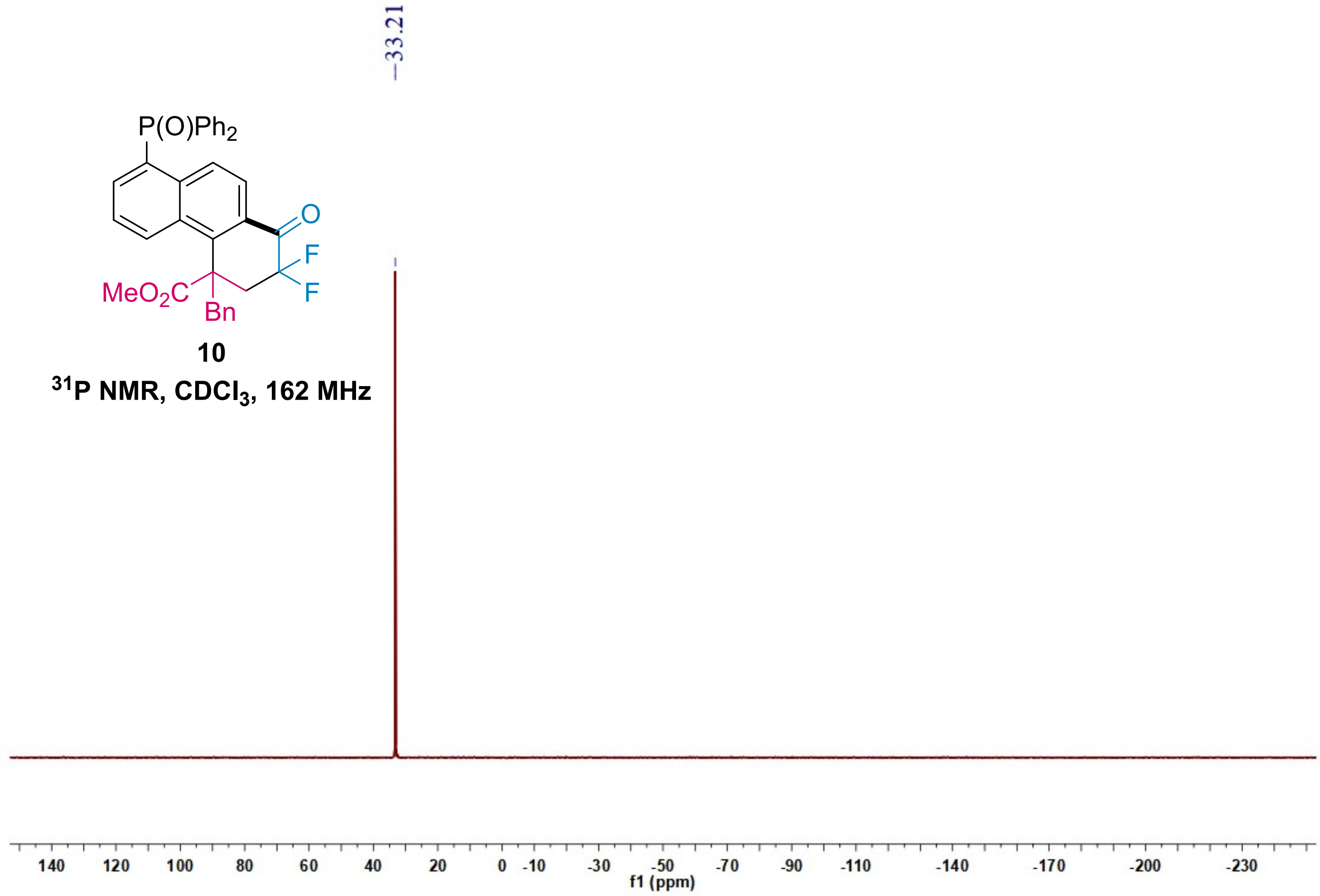
10

^{1}H NMR, CDCl$_3$, 400 MHz



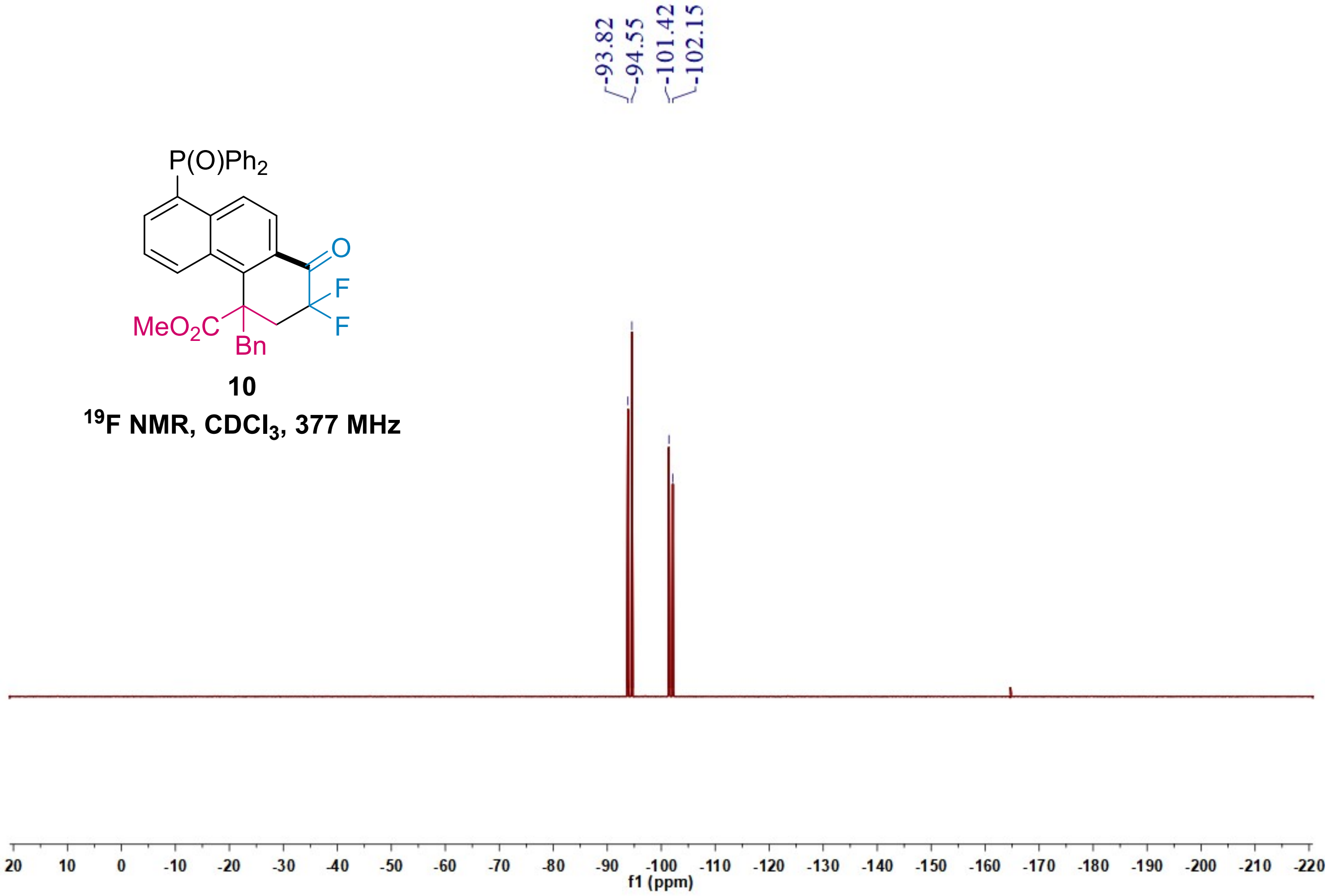
10

^{13}C NMR, CDCl$_3$, 101 MHz



10

^{31}P NMR, CDCl$_3$, 162 MHz



10

^{19}F NMR, CDCl$_3$, 377 MHz