Redox-Active Esters in Fe-catalyzed C–C Coupling

Fumihiko Toriyama,[†§] Josep Cornella,[†§] Laurin Wimmer,[†] Tie-Gen Chen,[†]
Darryl D. Dixon,[‡] Gardner Creech,[‡] Phil S. Baran[†,*]

[†] *Department of Chemistry, The Scripps Research Institute,*
10550 North Torrey Pines Road, La Jolla, California 92037
[‡] *Chemical Development, Bristol-Myers Squibb,*
One Squibb Drive, New Brunswick, New Jersey 08903

SUPPORTING INFORMATION

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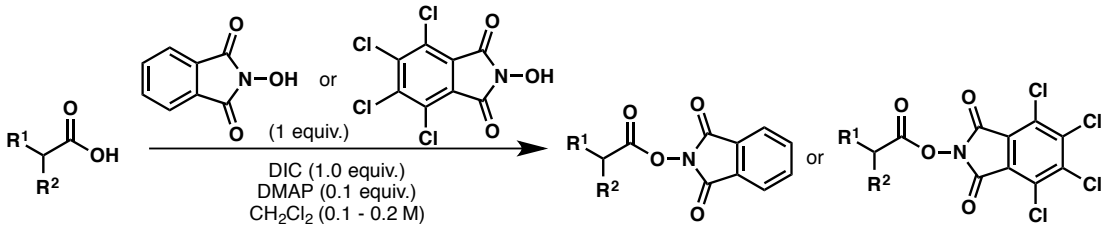
1. General considerations.

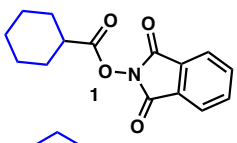
Tetrahydrofuran (THF), toluene (PhMe), and dichloromethane (CH_2Cl_2) were obtained by passing the previously degassed solvents through an activated alumina column. Reagents were purchased at the highest commercial quality and used without further purification, unless otherwise stated. $Fe(acac)_3$, $FeCl_3 \cdot 6\ H_2O$ and $FeCl_3$ anhydrous were purchased from Strem and Aldrich. $Ni(acac)_2$ was purchased from Aldrich. Yields refer to chromatographically and spectroscopically (^1H NMR) homogeneous material, unless otherwise stated. Reactions were monitored by GC/FID, GC/MS, and thin layer chromatography (TLC). TLC was performed using 0.25 mm E. Merck silica plates (60F-254), using short-wave UV light as the visualizing agent or I_2 or $KMnO_4$ and heat as developing agents. NMR spectra were recorded on Bruker DRX-600, DRX-500, and AMX-400 instruments and are calibrated using residual non-deuterated solvent ($CHCl_3$, ^1H NMR at 7.26 ppm, ^{13}C NMR at 77.16 ppm), TMS or hexafluorobenzene (^{19}F NMR at -164.9 ppm) as an internal reference. The following abbreviations were used to explain multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. Column chromatography was performed using E. Merck silica gel (60, particle size 0.043–0.063 mm), and preparative TLC was performed on Merck silica plates (60F-254). High-resolution mass spectra (HRMS) were recorded on an Agilent LC/MSD TOF mass spectrometer by electrospray ionization time of flight reflectron experiments. Melting points were recorded on a Fisher-Johns 12-144 melting point apparatus and are uncorrected.

2. General Procedure A: Synthesis of NHPI and TCNHPI esters.

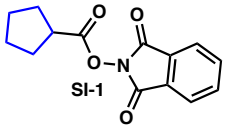


A round-bottom flask or culture tube was charged with (if solid) carboxylic acid (1.0 equiv), nucleophile (*N*-hydroxyphthalimide, tetrachloro-*N*-hydroxyphthalimide, 1.0 equiv) and DMAP (0.1 equiv). Dichloromethane was added (0.1 – 0.2 M), and the mixture was stirred vigorously. Carboxylic acid (1.0 equiv) was added via syringe (if liquid). DIC (1.1 equiv) was then added dropwise via syringe, and the mixture was allowed to stir until the acid was consumed (determined by TLC). Typical reaction times were between 0.5 to 12 h. The mixture was filtered (over Celite, SiO_2, or through a fritted funnel) and rinsed with additional CH_2Cl_2. The solvent was removed under reduced pressure, and purification by column chromatography afforded corresponding activated esters, which were used without further purification unless otherwise noted. **Note**: Some esters are prone to hydrolysis on silica gel during column chromatography and should be purified as quickly as possible to obtain reasonable separation.

We have previously reported the synthesis of redox-active esters shown below, including graphical support on their preparation.[1,2,3]



1



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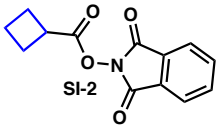

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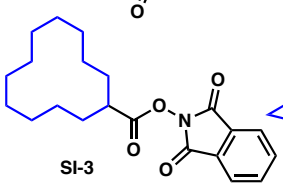

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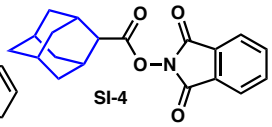

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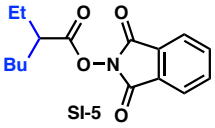

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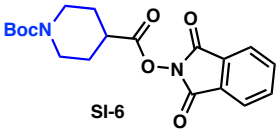

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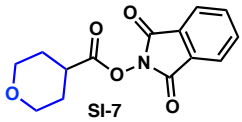

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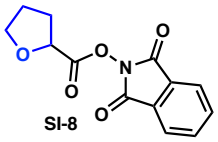

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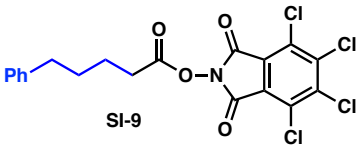

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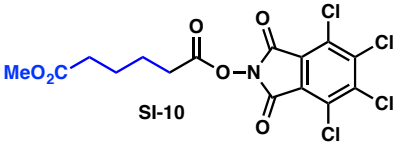

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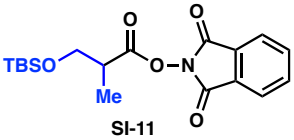

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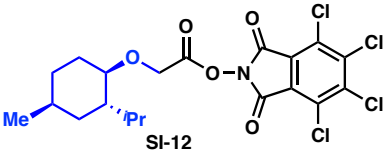

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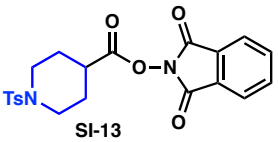

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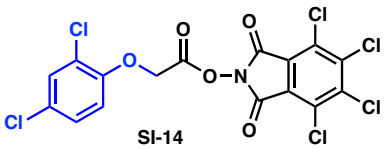

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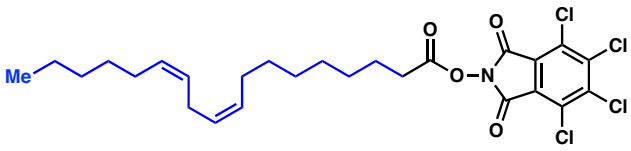

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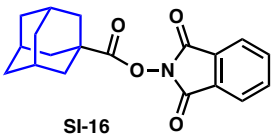

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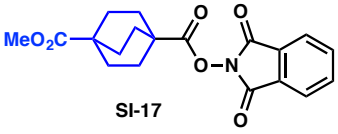

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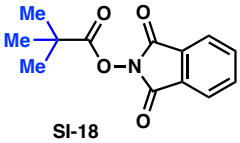

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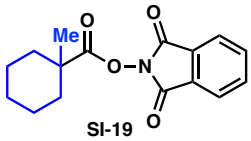

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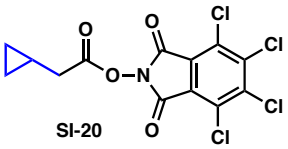

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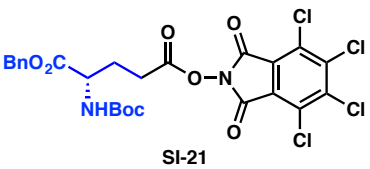

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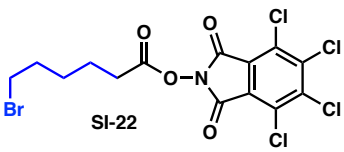

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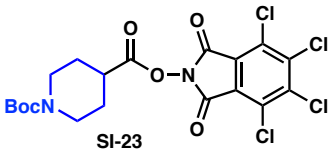

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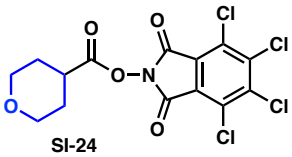

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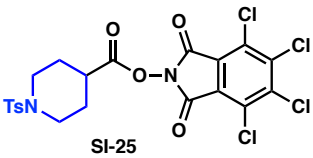
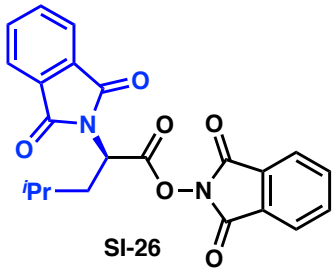


SI-25

1,3-Dioxoisoindolin-2-yl (*R*)-2-(1,3-dioxoisoindolin-2-yl)-4-methylpentanoate (SI-26).



SI-26

Compound **SI-26** was prepared following General Procedure A, using (*R*)-2-(1,3-dioxoisoindolin-2-yl)-4-methylpentanoic acid (2.00 g, 7.7 mmol). Product **SI-26** was isolated by column chromatography (hexanes:ethyl acetate 5:1) to afford 1.7 g (54%) as a white solid.

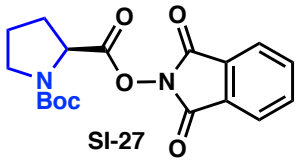
m.p. 140 – 141 °C.

R_f= 0.20 (hexanes:ethyl acetate 5:1).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.92 – 7.89 (m, 2H), 7.86-7.84 (m, 2H), 7.78 – 7.74 (m, 4H), 5.37 (dd, *J* = 12.0, 4.8 Hz, 1H), 2.58 - 2.53 (m, 1H), 2.11 – 2.06 (m, 1H), 1.61 – 1.54 (m, 1H), 1.01 (d, *J* = 7.2 Hz, 3H), 0.97 (d, *J* = 7.2 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 167.1, 166.7, 161.5, 134.9, 134.5, 131.8, 128.9, 124.2, 123.9, 49.0, 37.4, 25.0, 23.2, 21.2.

(*S*)-1-*Tert*-butyl 2-(1,3-dioxoisoindolin-2-yl) pyrrolidine-1,2-dicarboxylate (SI-27).



SI-27

Compound **SI-27** was prepared following General Procedure, using (*S*)-1-(*tert*-butoxycarbonyl)pyrrolidine-2-carboxylic acid (2.15 g, 10.0 mmol). Product **SI-27** was isolated by column chromatography (hexanes:ethyl acetate 4:1) to afford 2.6 g (72%) as a white solid.

R_f = 0.28 (hexanes:ethyl acetate 4:1)

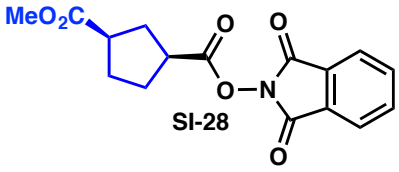
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.88 (dd, *J* = 5.4, 3.0 Hz, 2H), 7.79 (dd, *J* = 5.4, 3.0 Hz, 2H), 4.61 (dd, *J* = 8.4, 3.6 Hz, 1H), 3.65 – 3.61 (m, 1H), 3.51 – 3.47

(m, 1H), 2.47 – 2.40 (m, 1H), 2.38 – 2.33 (m, 1H), 2.11-2.05 (m, 1H), 2.01 – 1.95 (m, 1H), 1.51 (s, 9H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 169.8, 161.8, 153.7, 134.9, 129.1, 124.1, 81.3, 57.3, 46.4, 31.5, 28.2, 23.7.

Spectral data are in accordance with those reported in the literature.[4]

1-(1,3-Dioxoisoindolin-2-yl) 3-methyl *cis*-cyclopentane-1,3-dicarboxylate (SI-28).



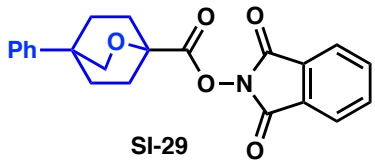
Compound **SI-28** was prepared following General Procedure A, using *cis*-3-(methoxycarbonyl)cyclopentane-1-carboxylic acid (410 mg, 2.38 mmol) at 0 ºC (reaction run at 0 ºC to hamper the formation of the bis-phthalimide ester, which was observed at r.t.). Product **SI-28** was isolated by column chromatography (hexanes:MTBE 0 to 50% gradient) to afford 641 mg (84%) as a crystalline solid.

R_f = 0.35 (silica gel, 2:1 heptane:MTBE)

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 – 7.87 (m, 2H), 7.83 – 7.78 (m, 2H), 3.71 (s, 3H), 3.24 – 3.15 (m, 1H), 2.95 – 2.86 (m, 1H), 2.49 – 2.41 (m, 1H), 2.37 – 2.28 (m, 1H), 2.26 – 2.12 (m, 2H), 2.12 – 1.99 (m, 2H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 175.0, 171.6, 162.0, 134.8, 129.0, 124.0, 52.0, 44.0, 40.8, 33.2, 29.4, 29.2.

1,3-Dioxoisoindolin-2-yl 4-phenyl-2-oxabicyclo[2.2.2]octane-1-carboxylate (SI-29).



SI-29

Compound **SI-29** was prepared following General Procedure A, using 1,3-dioxoisoindolin-2-yl 4-phenyl-2-oxabicyclo[2.2.2]octane-1-carboxylate (60 mg, 0.26 mmol). Product **SI-29** was isolated by column chromatography (CH_2Cl_2) to afford 71 mg (78%) as a white solid.

R_f = 0.45 (CH_2Cl_2)

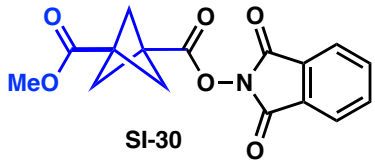
m.p. 139 – 140 ºC

^{1}H-NMR (600 MHz, $CDCl_3$) δ 7.90 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.80 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.42 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.34 (t, *J* = 7.8 Hz, 2H), 7.28 – 7.22 (m, 1H), 4.36 (t, *J* = 1.4 Hz, 2H), 2.40 – 2.27 (m, 4H), 2.24 – 2.13 (m, 4H).

^{13}C-NMR (151 MHz, $CDCl_3$) δ 171.2, 162.0, 145.3, 134.9, 129.1, 128.3, 127.2, 124.8, 124.1, 72.6, 69.5, 39.5, 32.6, 28.0.

HRMS (ESI-TOF): calc'd for $C_{22}H_{20}NO_5$ $[M+H]^+$ 378.1336; found 378.1337.

1-(1,3-Dioxoisoindolin-2-yl) 3-methyl bicyclo[1.1.1]pentane-1,3-dicarboxylate (SI-30).



SI-30

Compound **SI-30** was prepared following General Procedure A, using 3-(methoxycarbonyl)bicyclo[1.1.1]pentane-1-carboxylic acid (150 mg, 0.89 mmol). Product **SI-30** was isolated by column chromatography (hexanes:ethyl acetate 8:2) to afford 202 mg (72%) as a white solid.

R_f = 0.17 (hexanes:ethyl acetate 4:1)

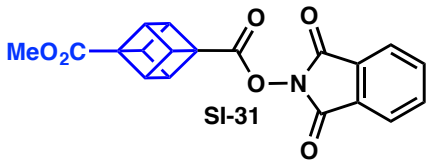
m.p. 193 – 197 ºC.

^{1}H-NMR (600 MHz, $CDCl_3$) δ 7.89 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.80 (dd, *J* = 5.5, 3.1 Hz, 2H), 3.72 (s, 3H), 2.56 (s, 6H).

^{13}C-NMR (151 MHz, $CDCl_3$) δ 169.0, 164.8, 161.8, 135.0, 129.0, 124.2, 53.8, 52.2, 38.7, 35.6.

HRMS (ESI-TOF): calc'd for $C_{16}H_{14}NO_6$ $[M+H]^+$ 316.0816; found 316.0816.

1-(1,3-Dioxoisoindolin-2-yl) 4-methyl cubane-1,4-dicarboxylate (SI-31).



SI-31

Compound **SI-31** was prepared following General Procedure A, using 1-(1,3-dioxoisoindolin-2-yl) 4-methyl cubane-1,4-dicarboxylate (1.71 g, 8.3 mmol). Product **SI-31** was isolated by column chromatography (CH_2Cl_2:ethyl acetate 10:1), and subsequent crystallization from CH_2Cl_2:hexanes to afford 2.21 g (76%) as a white solid.

R_f = 0.66 (CH_2Cl_2:ethyl acetate 10:1)

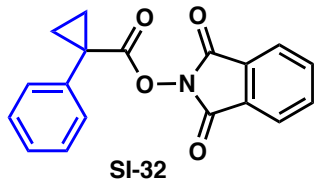
m.p. 202 – 203 ºC

^{1}H-NMR (600 MHz, $CDCl_3$) δ 7.89 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.79 (dd, *J* = 5.5, 3.1 Hz, 2H), 4.51 – 4.45 (m, 3H), 4.39 – 4.33 (m, 3H), 3.73 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 171.6, 167.0, 162.1, 134.9, 129.1, 124.1, 55.9, 53.2, 51.9, 47.8, 47.7.

HRMS (ESI-TOF): calc'd for $C_{19}H_{14}NO_6$ $[M+H]^+$ 352.0816; found 352.0817.

1,3-Dioxoisoindolin-2-yl 1-phenylcyclopropane-1-carboxylate (SI-32).



SI-32

Compound **SI-32** was prepared following General Procedure A, using 1,3-dioxoisoindolin-2-yl 1-phenylcyclopropane-1-carboxylate (1.62 g, 10 mmol). Product **SI-32** was isolated by column chromatography (hexanes:CH_2Cl_2:ethyl acetate 5:1:1.5), and subsequent crystallization from CH_2Cl_2:hexanes to afford 2.54 g (83%) as a white solid.

R_f = 0.45 (hexanes:CH_2Cl_2:ethyl acetate 5:1:1.5)

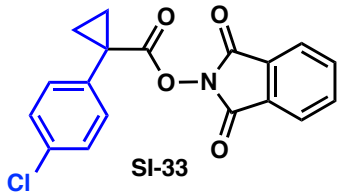
m.p.. 176 – 177 ºC

^{1}H-NMR (600 MHz, $CDCl_3$) δ 7.85 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.76 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.52 (dd, *J* = 8.2, 1.3 Hz, 2H), 7.37 (t, *J* = 7.4 Hz, 2H), 7.34 – 7.29 (m, 1H), 1.91 (m, 2H), 1.52 – 1.46 (m, 2H).

^{13}C-NMR (151 MHz, $CDCl_3$) δ 171.2, 162.0, 137.1, 134.8, 130.7, 129.1, 128.6, 128.1, 124.0, 123.9, 27.4, 18.8.

HRMS (ESI-TOF): calc'd for $C_{18}H_{14}NO_4$ $[M+H]^+$ 308.0917; found 308.0918.

1,3-Dioxoisoindolin-2-yl 1-(4-chlorophenyl)cyclopropane-1-carboxylate (SI-33).



SI-33

Compound **SI-33** was prepared following General Procedure A, using 1-(4-chlorophenyl)cyclopropanecarboxylic acid (1.97 g, 10.0 mmol). Product **SI-33** was isolated by column chromatography (hexanes:ethyl acetate 6:1) to afford 2.7g (75%) as a white solid.

R_f = 0.32 (hexanes:ethyl acetate 4:1)

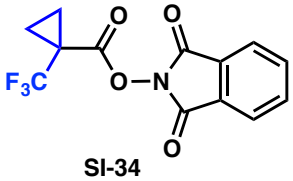
m.p. 139 – 140 °C

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.87 – 7.84(m, 2H), 7.78 – 7.74 (m, 2H), 7.46 – 7.44 (m, 2H), 7.34 – 7.32 (m, 2H), 1.91 (q, *J* = 3.6 Hz, 2H), 1.46 (q, *J* = 3.6 Hz, 2H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 170.8, 161.9, 135.6, 134.8, 134.0, 132.1, 129.0, 128.8, 124.0, 26.8, 18.9.

HRMS (ESI-TOF): calc'd for $C_{18}H_{13}ClNO_4$ $[M+H]^+$ 342.0528; found 342.0522.

1,3-dioxoisoindolin-2-yl 1-(trifluoromethyl)cyclopropane-1-carboxylate (SI-34).



SI-34

Compound **SI-34** was prepared following General Procedure A, using 1-(trifluoromethyl)cyclopropane-1-carboxylic acid (1.54 g, 10 mmol). Product **SI-34** was isolated by column chromatography (hexanes:ethyl acetate 3:1), and subsequent crystallization from CH_2Cl_2:MeOH to afford 1.80 g (60%) as a white solid.

R_f = 0.43 (hexanes:ethyl acetate 3:1)

m.p. 105 – 106 °C

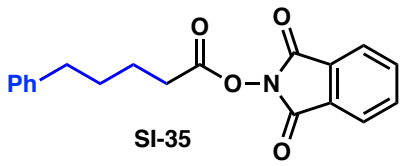
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.90 – 7.86 (m, 2H), 7.81 – 7.77 (m, 2H), 1.84 – 1.80 (m, 2H), 1.66 – 1.62 (m, 2H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 165.2, 161.5, 135.1, 128.8 124.2, 123. 7 (q, J = 273.2 Hz), 25.7 (q, J = 35.9 Hz), 14.8.

^{19}F NMR (376 MHz, $CDCl_3$) δ –67.8.

HRMS (ESI-TOF): calc'd for $C_{13}H_9F_3NO_4$ $[M+H]^+$ 300.0478; found 300.0481.

1,3-dioxoisoindolin-2-yl 5-phenylpentanoate (SI-35).



SI-35

Compound **SI-35** was prepared following General Procedure A, using 5-phenylpentanoic acid (1.78 g, 10 mmol). Product **SI-35** was isolated by column chromatography (hexanes:ethyl acetate 4:1), and subsequent crystallization from CH_2Cl_2:hexanes to afford 2.35 g (73%) as a colorless needle crystal.

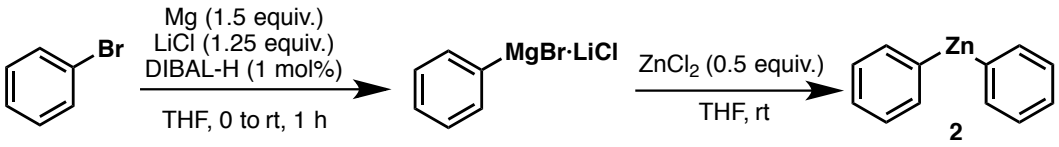
R_f = 0.30 (hexanes:ethyl acetate 4:1)

m.p. 87 – 88 °C.

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.88 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.78 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.29 (t, *J* = 7.5 Hz, 2H), 7.23 – 7.17 (m, 3H), 2.71 – 2.67 (m, 4H), 1.87 – 1.76 (m, 4H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.6, 163.1, 141.8, 134.9, 129.0, 128.5, 128.5, 126.0, 124.1, 35.5, 31.0, 30.5, 24.4.

3. General Procedure for the Preparation of Diphenylzinc Reagent 2.

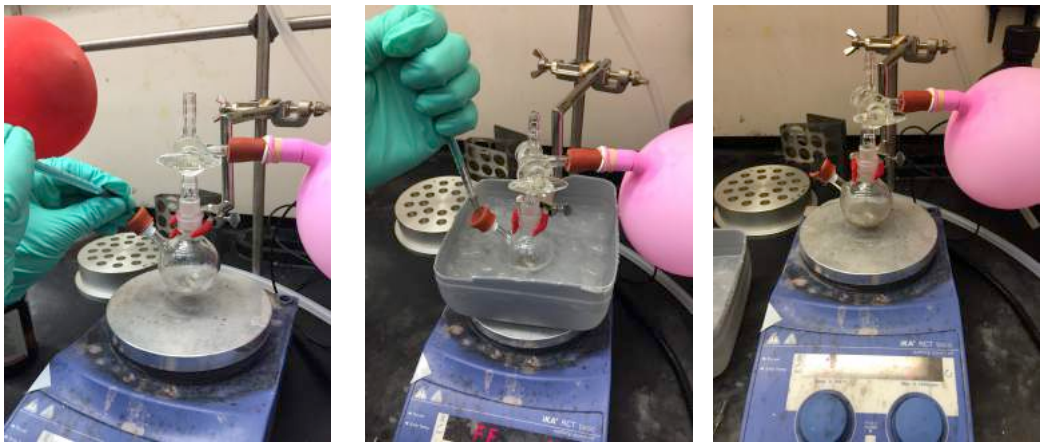


3.1. Preparation of PhMgBr·LiCl.

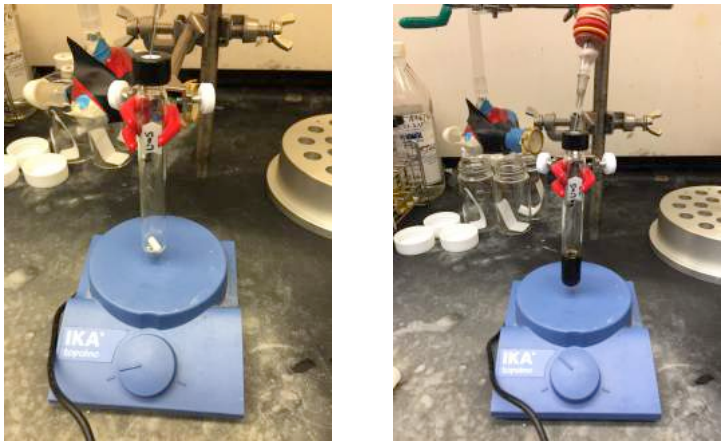
In an oven-dried 50 mL 2-necked flask equipped with a double manifold, Mg turnings (874 mg, 36 mmol) and LiCl (1.27 g, 30 mmol) were weighed. The flask was sealed, evacuated and back-filled with Ar (3 times). THF (12 mL) was added at r.t. and stirred for 5 minutes. DIBAL-H (0.24 mL, 0.24 mmol, 1M in THF) was then added dropwise at r.t. and stirred for 5 minutes. The mixture was then cooled to 0 ºC and PhBr (2.52 mL, 24 mmol) was added dropwise. The mixture was removed from the ice bath and allowed to stir for 1 h at r.t. Titration of the mixture with I_2 (50 mg, 0.2 mmol) and LiCl (1.0 mmol, 42 mg) in THF (2 mL) normally affords concentration of about 1 – 1.3 M.

3.2. Graphical Guide for the Preparation of PhMgBr·LiCl.

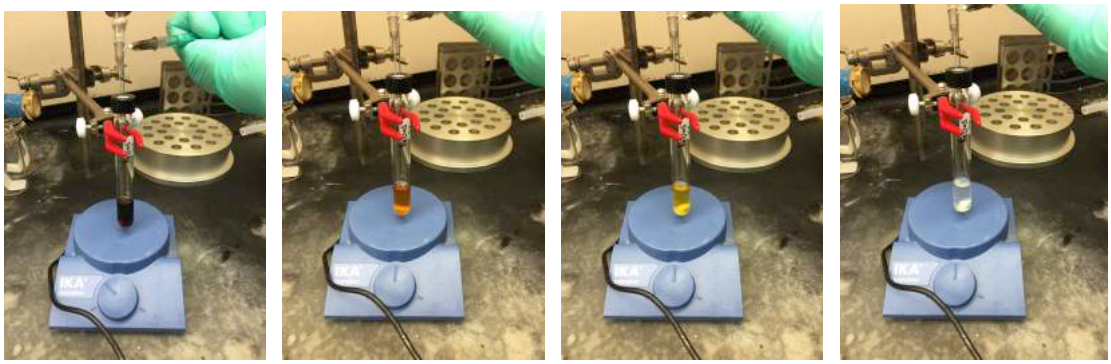
Left: Mg turnings and LiCl in a 2-necked flask connected to Ar line. **Center**: The flask is flame dried with a torch. **Right**: After cooling down, THF is added.



Left: Addition of DiBAL-H (1.0 M) in THF. **Center**: Addition of PhBr at 0 ºC. **Right**: After addition of PhBr and stirred for 1 h at r.t.



Left: I_2 and LiCl in a culture test tube for titration of the Grignard. **Right**: Addition of THF.



Progress of the titration: Color change upon dropwise addition of PhMgBr·LiCl to the I_2 solution.

3.3. Preparation of Ph_2Zn (2).

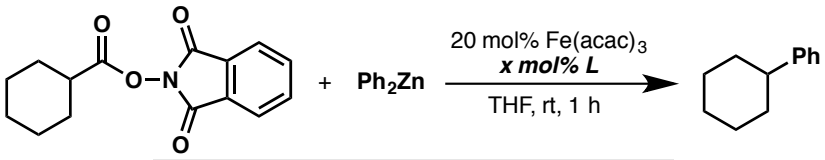
In an oven-dried 2-necked flask equipped with a double manifold, $ZnCl_2$ was weighed (680 mg, 5 mmol) and the flask was heated under vaccum for 5 minutes with the help of a heat gun. After cooling down, THF (5 mL) was added under Ar and the mixture allowed stirring at r.t. for 5 minutes. Then, PhMgBr·LiCl (10 mmol, 10 mL, 1 M) was added dropwise. A dense-grey solution was formed and used without further titration (Ph_2Zn, c = 0.33 M).

Left: $ZnCl_2$ dried under vacuum with a heatgun. **Center:** Addition of THF after cooling down. **Right:** Addition of PhMgBr·LiCl.

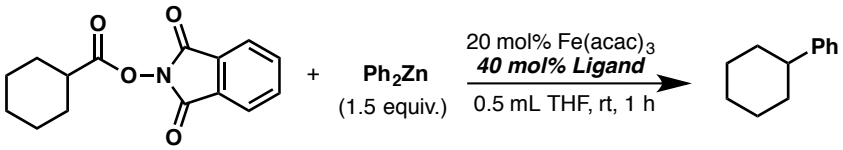
4. Optimization details

From isolated redox-active ester: A screw-capped culture tube with Teflon™ septum containing a stirring bar was charged with Fe catalyst, ligand and compound **1** (27 mg, 0.1 mmol, 1.0 equiv.) on the bench top. The tube was evacuated and back-filled with Ar. Then, 0.5 mL of respective solvent were added. The mixture was stirred for 5 minutes under Ar and Ph_2Zn (**2**) in THF was added in one portion at the indicated temperature (**do not add it dropwise**) to the mixture and stirred at the same temperature. After 1 hour, the reaction was quenched with 1N HCl and diluted with diethyl ether or ethyl acetate. Cyclooctane (internal standard, 0.1 mmol, 13 μL) was then added to the mixture and an aliquot was analyzed by GC-FID.

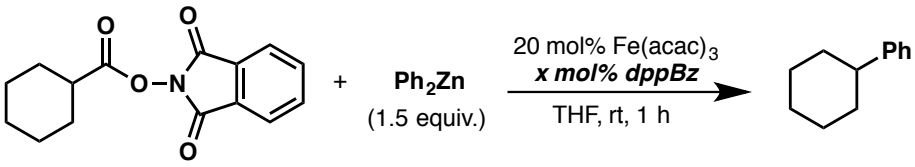
From in situ generation of redox-active ester with HATU and HBTU. In a 10 mL screwed-capped vial cyclohexylcarboxylic acid (13 mg, 0.1 mmol), HATU (38 mg, 0.1 mmol) or HBTU (38 mg, 0.1 mmol) were weighed. The vial was sealed and evacuated and refilled with Ar 3 times. Then, Et_3N (14 μL, 0.1 mmol) followed by THF (0.2 mL) were added via syringe under Ar. The mixture was stirred for 2 hours at room temperature (usually, the solution becomes clear after this time). In another 10 mL screwed-capped vial, $Fe(acac)_3$ (0.01 mmol) and dppBz (0.02 mmol) were weighed. The vial evacuated and backfilled with Ar 3 times. Then, THF was added (0.3 mL) to form a red solution. The solution was stirred until all solids were soluble (5 min). At this point, the mixture was transferred to the redox-active ester vial in one portion at room temperature, followed by the addition of Ph_2Zn (0.25 mmol, 2.5 equiv.) via syringe in one portion (**do not add it dropwise**). The mixture was stirred for 1 h at room temperature before quench with HCl 1M and diluted with ether or ethyl acetate. Cyclooctane (internal standard, 0.1 mmol, 13 μL) was then added to the mixture and an aliquot was analyzed by GC-FID.



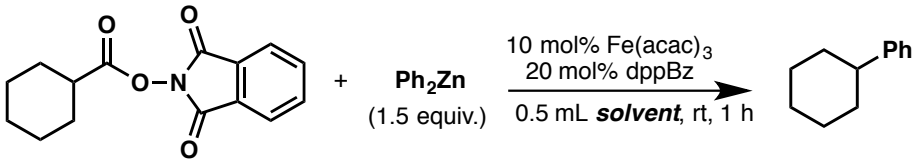
mol %	L	Yield
20	dppe	51
40	dppe	54
20	dppp	43
40	dppp	47
20	dppb	37
40	dppb	36
20	Xantphos	39
20	***dppBz***	***70***
40	***dppBz***	***77***
20	PPh_3	34
40	PPh_3	32
60	PPh_3	37
80	PPh_3	36
blank	acac	38



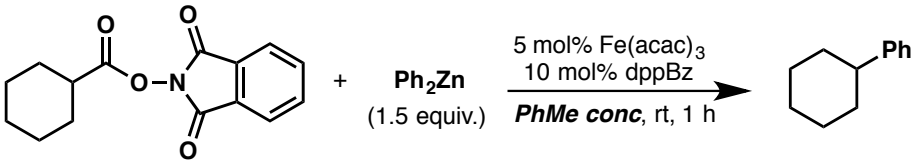
Ligand (40 mol%)	Yield
BINAP (20 mol%)	45
CyJohnPhos	57
SPhos	43
DavePhos	43
CPhos	40
DPEPhos	43
1,1′-Bis(phenylphosphinidene)ferrocene	43
cataCXium A	44
$(Cy)_3P$	47
dppf (20 mol%)	40
$(o\text{-tolyl})_3P$	47
$(2\text{-furyl})_3P$	41



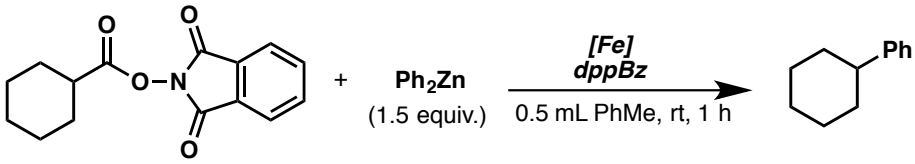
dppBz (mol %)	Yield
20	74
22	75
24	74
26	75
28	76
30	74
32	73
34	74
36	75
38	75



Solvent	Yield
toluene	73
benzene	73
DMF	74
dioxane	53
DCM	68
diethylether	72
hexanes	70



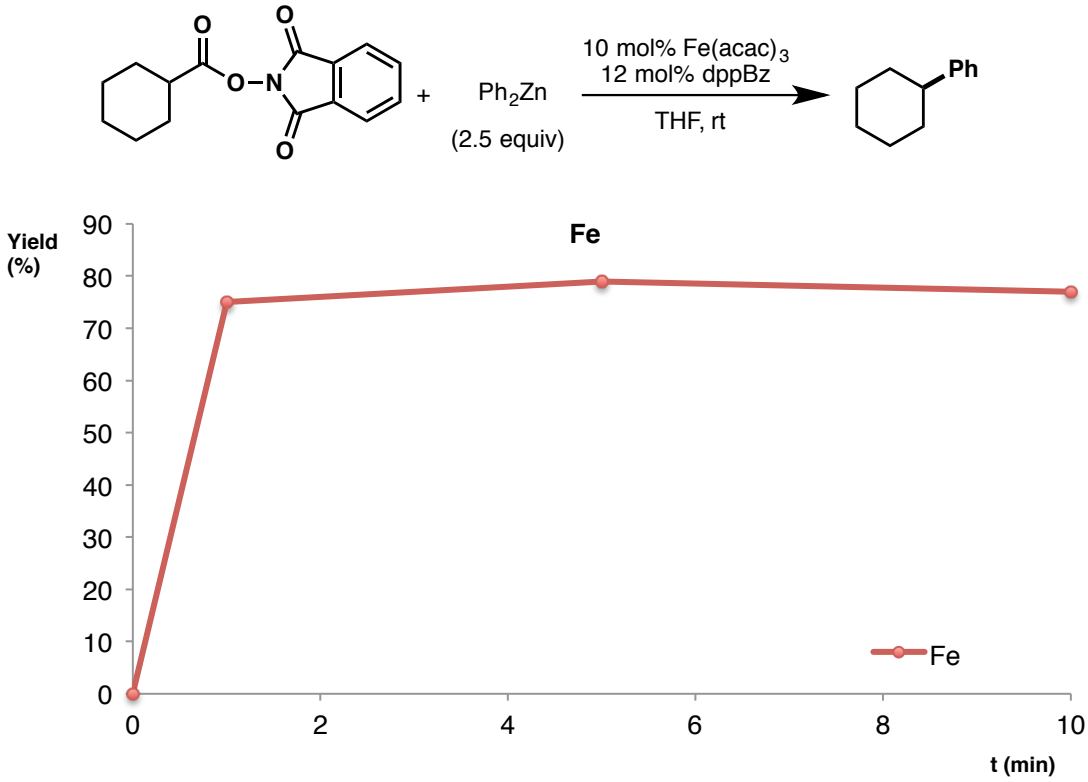
conc (PhMe)	Yield
0.25 mL	69
0.5 mL	68
0.75mL	68
1 mL	70
2 mL	63



$Fe(acac)_3$	dppBz	Yield
20 mol%	40 mol%	77
20 mol%	20 mol%	71
10 mol%	20 mol%	71
5 mol%	10 mol%	70
2 mol%	4 mol%	61
1 mol%	2 mol%	56

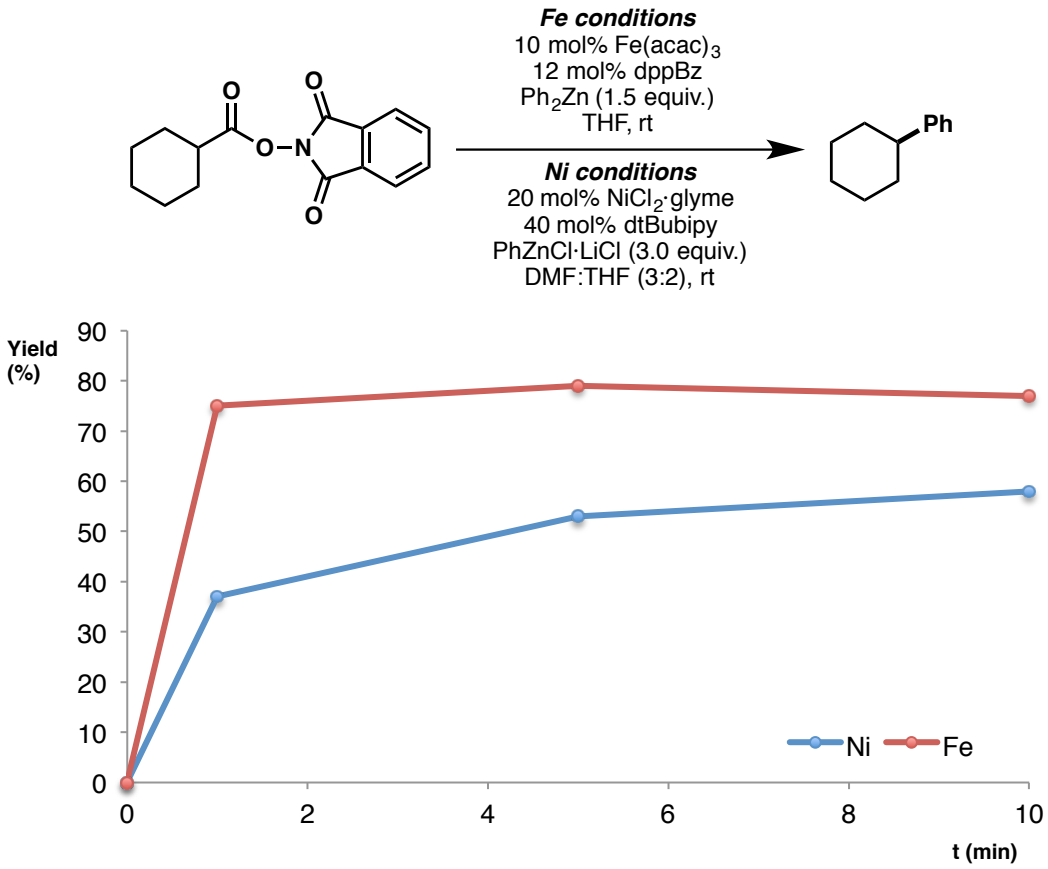
4.1. Time course of the model reaction.

Identical reactions were set up following the general procedure for the Fe-catalyzed Negishi cross-coupling described for the optimization and quenched at the indicated times of the graphic. As depicted in Graphic S1, the reaction is incredibly fast and in about 5 minutes after the addition of the Ph_2Zn, the reaction is finished. Since we observed different kinetics on different substrates, we standarized the reaction time to 1 hour. It is worth mentioning that the reaction carried out with Fe affords 75-79% yield with a 100% conversion from the redox-active ester. The mass balance corresponds to a 25% of the starting carboxylic acid, which is hydrolyzed in situ.



Graphic S1. Kinetic profile for the formation of cyclohexylphenyl (**3**) with Fe catalysis.

As a comparison, the same reaction was performed but following the protocol for the Ni catalysis developed by our group. As shown in Graphic S2, the reaction with Fe is much faster providing higher yields at shorter reaction times when compared to the previously reported reaction using Ni.



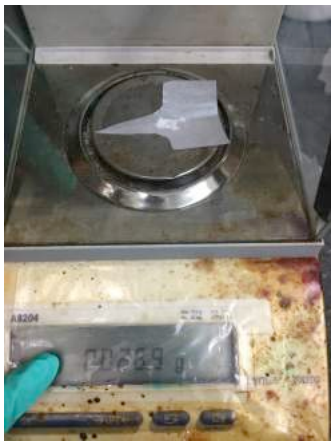
Graphic S2. Comparison of kinetic profiles for the formation of cyclohexylphenyl (**3**) with Fe and Ni catalysis.

5. General Procedure for the Fe-catalyzed Negishi cross-coupling with redox-active esters and diarylzinc reagents (General Procedure B).

In a 10 mL screwed-capped vial redox-active ester (0.1 mmol), $Fe(acac)_3$ or $FeCl_3$ (0.005 – 0.04 mmol) and dppBz (0.006 – 0.048 mmol) were weighed. The vial was then sealed, evacuated and back-filled with Ar (this process was repeated 3 times). Then, 0.5 mL of distilled THF or toluene were added. The mixture was stirred for 5 minutes under Ar and diarylzinc reagent in THF (0.15 – 0.25 mmol, typical concentration after titration is 0.3 M) was added in one portion at 0 - 25 ºC (**do not add it dropwise**) to the mixture and stirred at the same temperature for 1 h. After this time, the reaction was quenched with HCl 1N, saturated NH_4Cl or H_2O and diluted with diethyl ether. The organic layer was separated and dried over Na_2SO_4 anhydrous, filtered and evaporated to

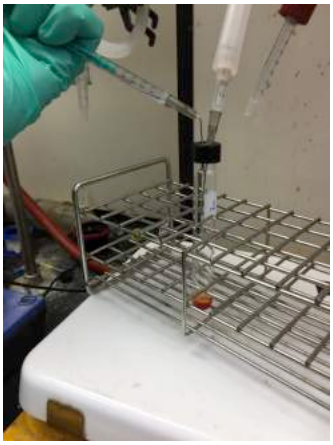
dryness (for volatile compounds the solvent was carefully evaporated under rotary evaporation at 200 mbar at 25 ºC). Pure products were obtained after column chromatography or preparative TLC (PTLC).

5.1. Graphical guide for the Fe-catalyzed Negishi cross-coupling with redox-active esters.

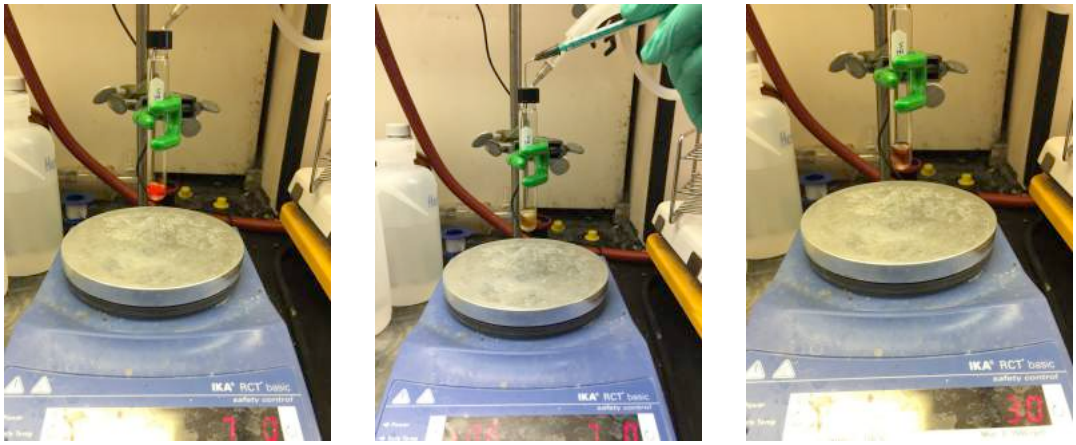




Left: Redox-active ester, $Fe(acac)_3$, dppBz. **Center:** Redox-active ester weight. **Right:** $Fe(acac)_3$ weight.

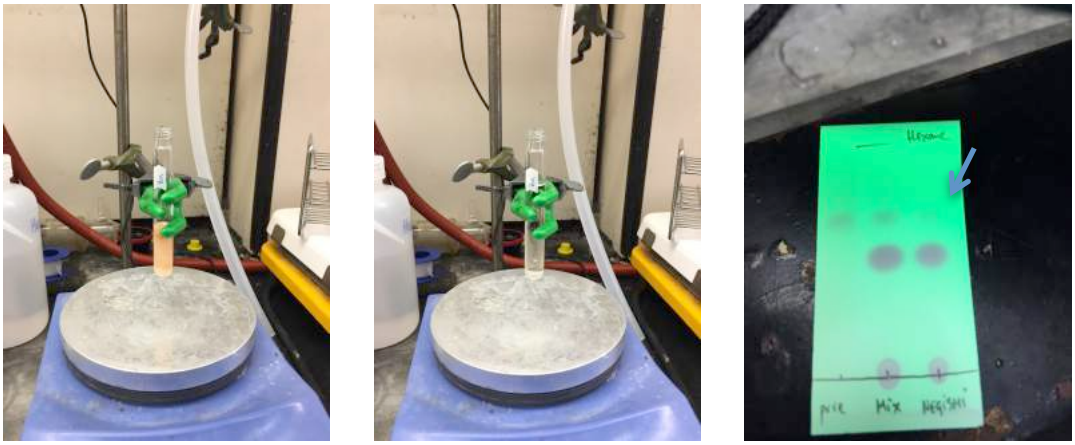




Left: DppBz weight. **Center:** Reagents in a culture tube under vacuum. **Right:** Addition of THF to the reaction vessel.



Left: Reaction vessel after addition of THF. **Center:** Addition of Ph_2Zn. **Right:** After addition of the Ph_2Zn.



Left. Quench of the reaction after 1 h with HCl 1M. **Center:** Dilution of the mixture with diethyl ether. **Right:** TLC plate of the reaction (left: Pure product; center: cross-spot; right: reaction crude).

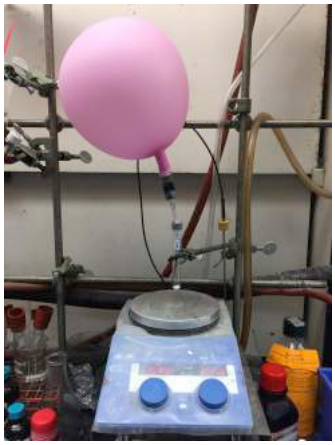
6. General Procedure for the Fe-catalyzed Negishi cross-coupling with redox-active esters generated *in situ* (General Procedure C).

In a 10 mL screwed-capped vial carboxylic acid (0.1 mmol), HATU (38 mg, 0.1 mmol) or HBTU (38 mg, 0.1 mmol) were weighed. The vial was sealed, evacuated and refilled with Ar 3 times. Then, Et_3N (14 μL, 0.1 mmol) followed by THF (0.2 mL) were added via syringe under Ar. The mixture was stirred for 2 h at room temperature (usually, the solution becomes clear after this time).

In another 10 mL screwed-capped vial, $Fe(acac)_3$ (0.01 – 0.02 mmol) and dppBz (0.02 – 0.04 mmol) were weighed. The vial evacuated and backfilled with Ar 3 times. Then, THF (0.3 mL) was added to form a red solution. The solution was stirred until all solids were soluble (5 min). At this point, the mixture was transferred to the redox-active ester vial in one portion at 25 ºC, followed by the addition of Ph_2Zn (0.25 mmol, 2.5 equiv.) via syringe in one portion. The mixture was stirred for 1 h at room temperature before quench with 1N HCl, saturated NH_4Cl or H_2O and diluted with diethyl ether. The organic layer was separated and dried over Na_2SO_4 anhydrous, filtered and evaporated to dryness (for volatile compounds the solvent was carefully evaporated under rotary evaporation at 200 mbar at 25 ºC). Pure products were obtained after column chromatography or preparative TLC (PTLC).

6.1. Graphical guide for the Fe-catalyzed Negishi cross-coupling with in situ-formation of the redox-active esters.

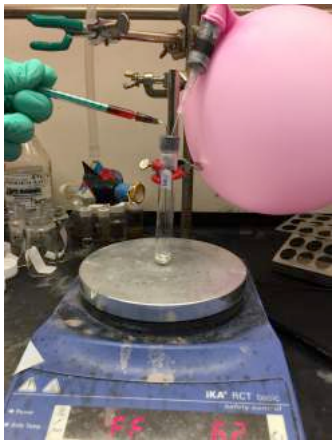
Left: Cyclohexancarboxylic acid and HATU**. Center:** Weight of Cyclohexancarboxylic acid. **Right:** Weight of HATU.

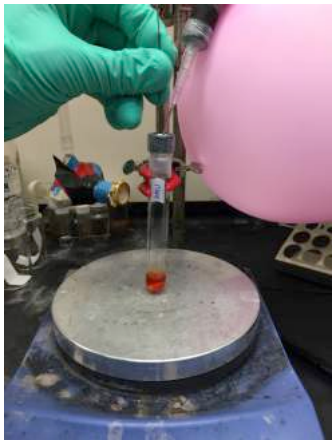
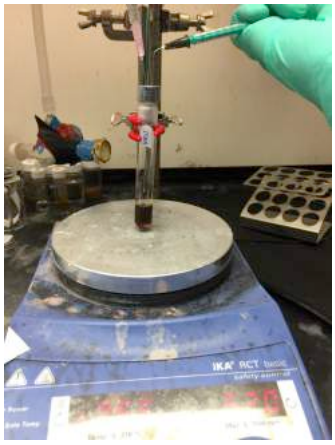


Left: Weighted solids in a culture test tube under Ar. **Center:** Anhydrous triethylamine utilized. **Right:** Addition of triethylamine.

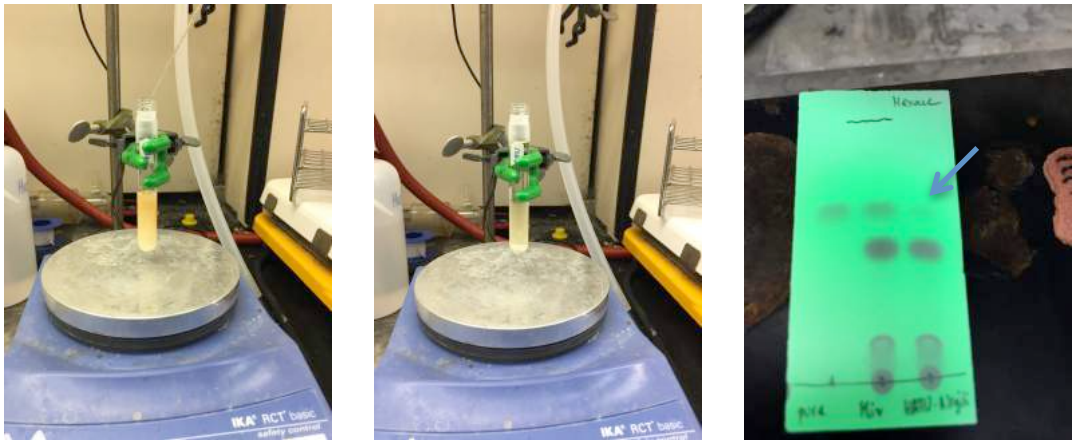


Left: Addition of THF. **Center:** After addition of THF (white suspension). **Right:** Solution after 2 hours stirring at r.t. (it becomes a clear solution).



Left: Reaction prior to addition of Fe/ligand solution. **Center:** Solution after addition of Fe/ligand solution. **Right:** Addition of Ph_2Zn in one portion.

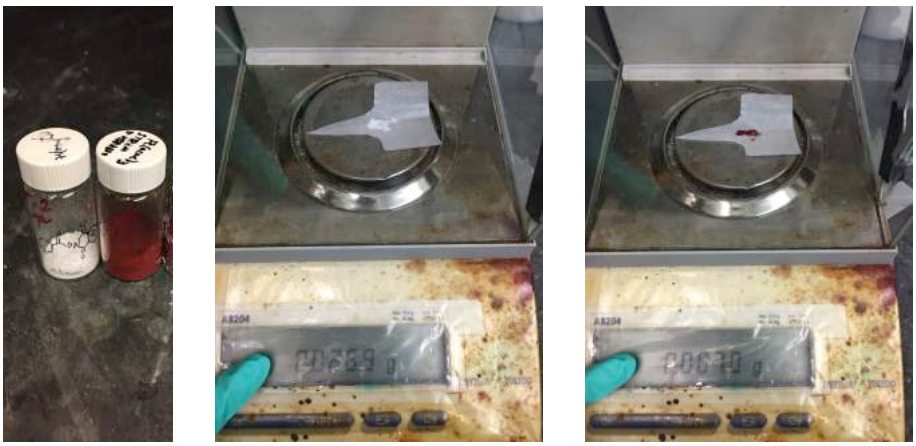


Left. Quench of the reaction after 1 h with 1 M HCl. **Center:** Dilution of the mixture with diethyl ether. **Right:** TLC plate of the reaction (left: Pure product; center: cross-spot; right: reaction crude).

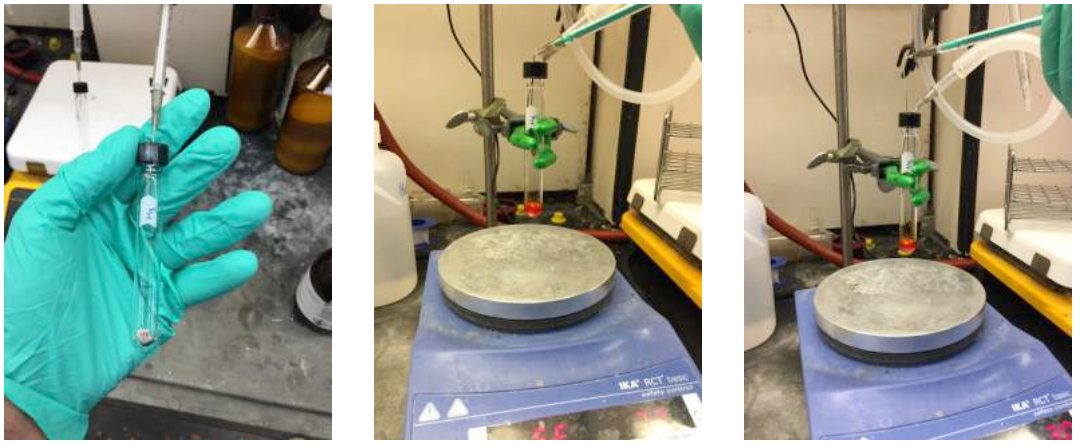
7. General Procedure for the Fe-catalyzed Kumada-Corriu cross-coupling of redox-active esters and aryl Grignards (General Procedure D).

In a 10 mL screwed-capped vial redox-active ester (0.1 mmol) and $Fe(acac)_3$ (0.02 – 0.10 mmol) were weighed. The vial was then sealed, evacuated and back-filled with Ar (this process was repeated 3 times). Then, 0.35 mL of distilled THF and 0.21 mL of anhydrous DMPU were added. The mixture was stirred for 5 minutes at 25 ºC. At this point, PhMgBr·LiCl in THF (0.2 – 0.3 mmol, typical concentration after titration is 1.2 – 1.3 M) was added in one portion at 0 or 25 ºC (**do not add it dropwise**) and stirred at this temperature for 1 h. The mixture was quenched with 1N HCl, saturated NH_4Cl or H_2O and diluted with diethyl ether. The organic layer was separated and dried over Na_2SO_4 anhydrous, filtered and evaporated to dryness (for volatile compounds the solvent was carefully evaporated under rotary evaporation at 200 mbar at 25 ºC). Pure products were obtained after column chromatography or preparative TLC (PTLC).

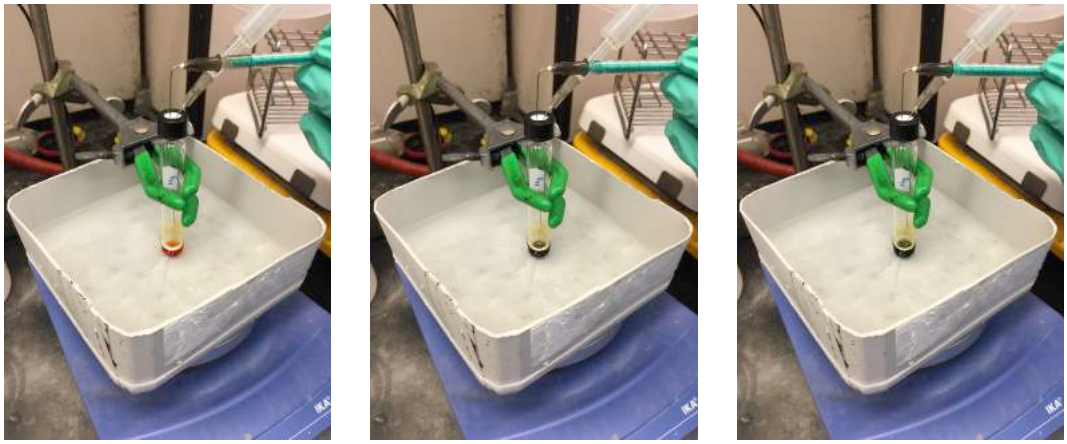
7.1. Graphical guide for the Fe-catalyzed Kumada-Corriu cross-coupling.



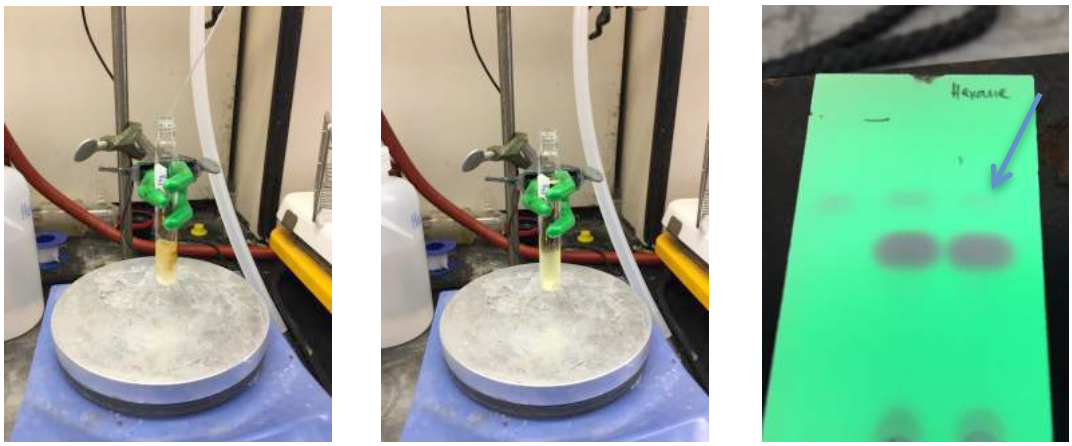
Left: redox-active ester and catalyst. **Center:** redox-active weight. **Right:** $Fe(acac)_3$ weight.



Left: Reagents in a culture tube under vacuum. **Center:** Addition of THF. **Right:** Addition of DMPU.



Addition of Grignard. Left: before the addition. **Center:** during addition. **Right:** After addition.



Left: Quench with HCl 1M. **Center:** Dilution with diethyl ether. **Right:** TLC plate of the reaction (left: Pure product; center: cross-spot; right: reaction crude).

8. General Procedure for the Ni-catalyzed Negishi cross-coupling of redox-active esters and arylzinc reagents (General Procedure E).

For detailed information and graphical support on this procedure, see Ref. 1a and 1b of the manuscript.

A culture tube with a Teflon™ septum screw-cap and stir bar was charged with $NiCl_2$·glyme (20 mol%), di-*t*Bubipy (40 mol%) and (if solid) NHPI-ester (1.0 equiv., 0.1 mmol). The tube was evacuated and backfilled with Ar. Reactions were run with a 3:2 ratio of THF:DMF. The volume of DMF used was calculated based on the titre of the THF solution of the arylzinc chloride reagent. DMF (anhydrous) was added via syringe, and the mixture stirred for 2 minutes at r.t. for solid NHPI-esters. NHPI-ester (if liquid) was dissolved in DMF (anhydrous) and added to the culture tube containing [Ni] and di-*t*Bubipy, and the mixture was stirred for 2 minutes at r.t. Then, arylzinc reagent in THF (3.0 equiv.) was added in one portion, and the mixture was stirred for 12 – 16 h at r.t. The mixture was diluted with EtOAc or Et_2O and quenched with 1M HCl (aq). The reaction can also be quenched with H_2O or half-saturated NH_4Cl (aq) solution for acid-sensitive substrates. The organic layer was washed with H_2O and brine, dried over anhydrous Na_2SO_4, and concentrated

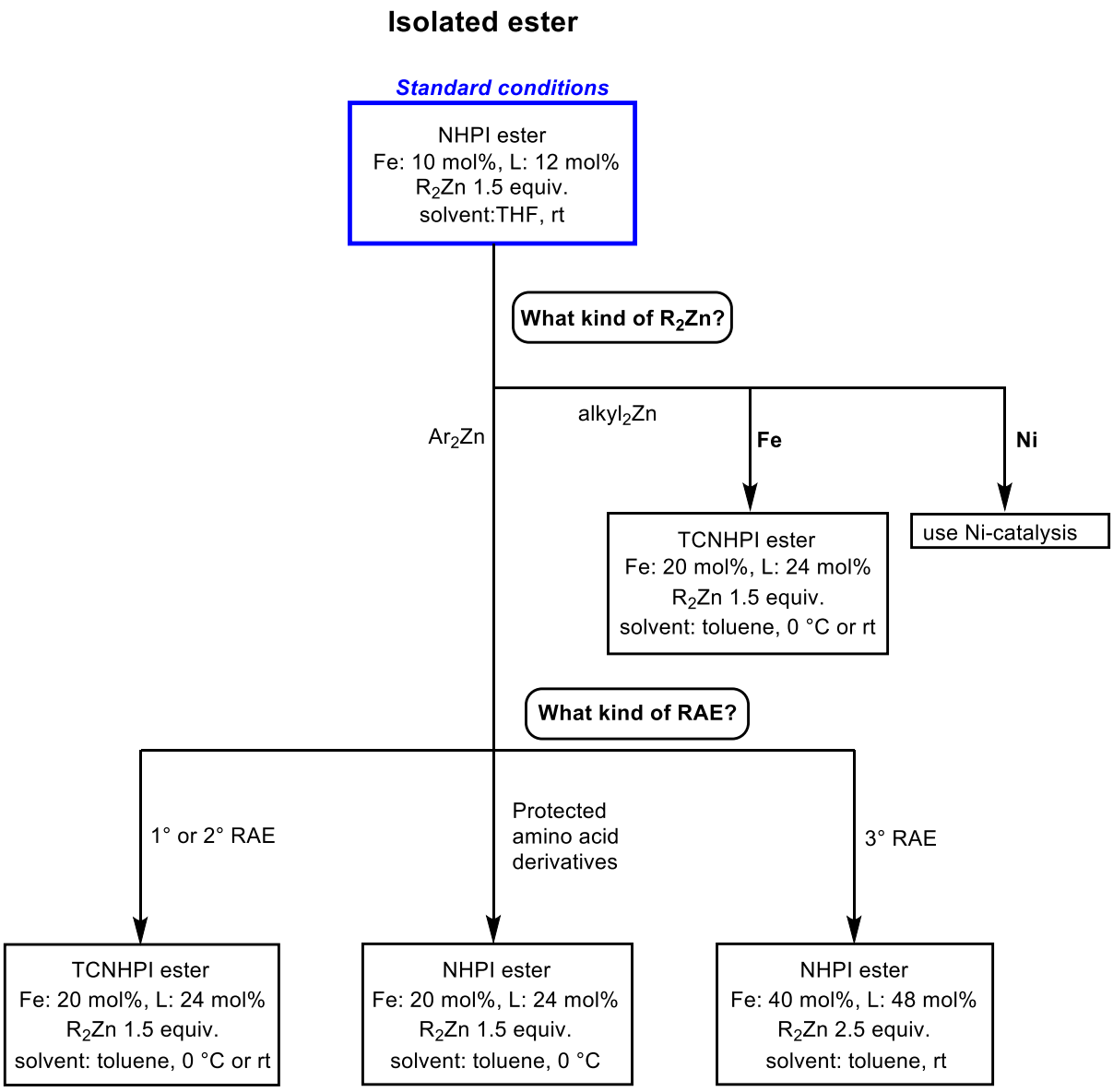
under reduced pressure. The crude material was purified by silica gel column chromatography or preparative TLC.

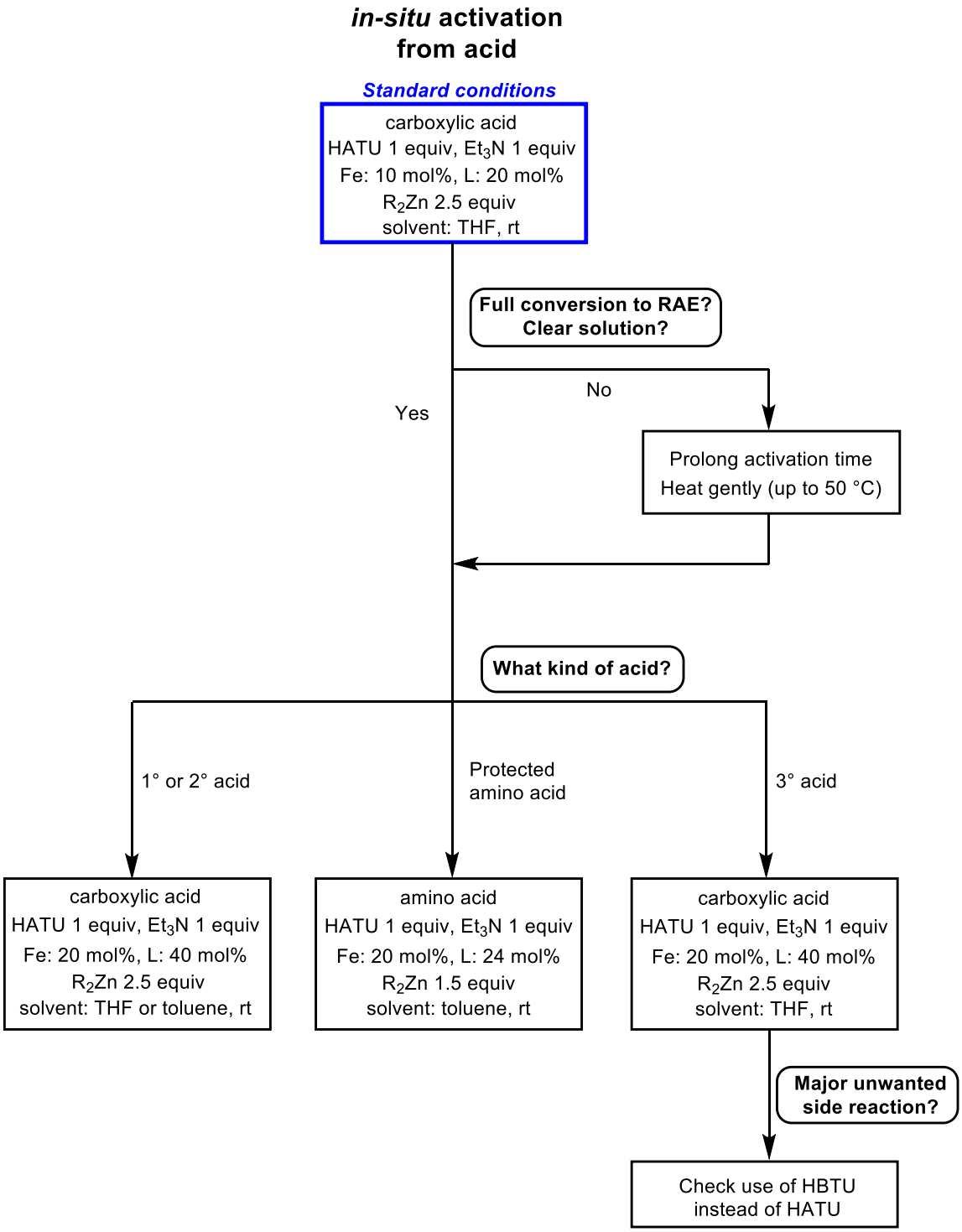
9. General Procedure for the Ni-catalyzed Negishi cross-coupling of *in situ* generated redox-active esters and arylzinc reagents (General Procedure F).

For detailed information and graphical support on this procedure, see Ref. 1a and 1b of the manuscript.

A screw-cap culture tube with Teflon™ septum and stir bar was charged with carboxylic acid (0.1 mmol) and HATU (38 mg, 0.1 mmol) in DMF (anhydrous, 0.5 mL) followed by the addition of TEA (14 μL, 0.1 mmol). The mixture was stir at r.t. for 30 min. A solution of $NiCl_2$·glyme (20 mol%) and di-*t*Bubipy (40 mol%) in 0.5 mL of DMF was added to the reaction mixture and stir at r.t. for 5 min. PhZnCl·LiCl (in THF, 3 equiv) was added dropwise to the reaction mixture, which was stirred for 12 h. The reaction can also be quenched with H_2O or half-saturated NH_4Cl (aq) solution for acid-sensitive substrates. The organic layer was washed with H_2O and brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The crude material was purified by silica gel column chromatography or preparative TLC.

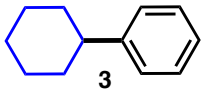
10. Guide for choosing reaction conditions




in-situ activation from acid
Standard conditions
carboxylic acid
HATU 1 equiv, Et3N 1 equiv
Fe: 10 mol%, L: 20 mol%
R2Zn 2.5 equiv
solvent: THF, rt
Full conversion to RAE? Clear solution?
No
Yes
Prolong activation time
Heat gently (up to 50 °C)
What kind of acid?
1° or 2° acid
Protected amino acid
3° acid
carboxylic acid
HATU 1 equiv, Et3N 1 equiv
Fe: 20 mol%, L: 40 mol%
R2Zn 2.5 equiv
solvent: THF or toluene, rt
amino acid
HATU 1 equiv, Et3N 1 equiv
Fe: 20 mol%, L: 24 mol%
R2Zn 1.5 equiv
solvent: toluene, rt
carboxylic acid
HATU 1 equiv, Et3N 1 equiv
Fe: 20 mol%, L: 40 mol%
R2Zn 2.5 equiv
solvent: THF, rt
Major unwanted side reaction?
Check use of HBTU instead of HATU

11. Description of compounds

Phenylcyclohexane (3).



3

From isolated redox-active ester: Following General Procedure B, with **1** (27 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **3** was isolated by PTLC (hexanes) to afford 12.2 mg (75%) as a transparent oil (**note**: volatile product).

1.0 Mmol scale from isolated redox-active ester: Following General Procedure B, with **1** (273 mg, 1.0 mmol), $Fe(acac)_3$ (36 mg, 0.1 mmol), dppBz (54 mg, 0.12 mmol), Ph_2Zn (1.5 mmol) at 25 ºC. Product **3** was isolated by column chromatography (pentane) to afford 130 mg (81%) as a transparent oil.

From in situ redox-active ester: Following the General Procedure C with cyclohexancarboxylic acid (13 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **3** was isolated by PTLC (hexanes) to afford 11.4 mg (71%) as a transparent oil.

Kumada-coupling using Fe-catalysis from isolated redox-active ester. Following General Procedure D*:* with **1** (27 mg, 0.1 mmol), $Fe(acac)_3$ (7 mg, 0.02 mmol), PhMgBr·LiCl (0.3 mmol) at 25 ºC. Product **3** was isolated by PTLC (hexanes) to afford 9.9 mg (61%) as a transparent oil.

1.0 Mmol scale Kumada-coupling using Fe-catalysis from isolated redox-active ester. Following General Procedure D*:* with **1** (273 mg, 1.0 mmol), $Fe(acac)_3$ (72 mg, 0.2 mmol), PhMgBr·LiCl (3.0 mmol) at 25 ºC. Product **3** was isolated by column chromatography (pentane) to afford 127 mg (79%) as a transparent oil.

Kumada-coupling using Fe-catalysis from in situ generated redox-active ester: Following the General Procedure D with cyclohexancarboxylic acid (13 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $Fe(acac)_3$ (7 mg, 0.02 mmol), PhMgBr·LiCl (0.3 mmol) at 25 ºC. Product **3** was isolated by PTLC (hexanes) to afford 8.1 mg (50%) as a transparent oil.

Kumada-coupling using Ni-catalysis. Following General Procedure D, with **1** (27 mg, 0.1 mmol), $Ni(acac)_2$ (5.1 mg, 0.02 mmol), PhMgBr·LiCl (1.5 mL, 0.3 mmol) at 25 ºC. The yield of product **3** (8%) was determined by NMR using 1,1,2-trichloroethane as internal standard.

Negishi-coupling using Ni-catalysis. Following General Procedure E, with **1** (27 mg, 0.1 mmol), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. The yield of product **3** (85%) was determined by GC using cyclooctane as internal standard.

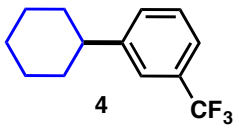
R_f = 0.78 (hexanes)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.33 – 7.27 (m, 2H), 7.24 – 7.20 (m, 2H), 7.19 (tt, *J* = 7.2, 1.4 Hz, 1H), 2.51 (td, *J* = 11.5, 3.5 Hz, 1H), 1.91 – 1.82 (m, 4H), 1.76 (dtt, *J* = 12.9, 3.2, 1.6 Hz, 1H), 1.49 – 1.33 (m, 4H), 1.31 – 1.16 (m, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 148.2, 128.4, 127.0, 125.9, 44.8, 34.6, 27.1, 26.3.

Spectral data are in accordance with those reported in the literature.[5]

1-Cyclohexyl-3-(trifluoromethyl)benzene (4).



Following the General Procedure B with **1** (27 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), $(3\text{-}(CF_3)Ph)_2Zn$ (1.25 mL, c = 0.12 M, 0.15 mmol, 1.5 equiv) at 25 ºC. Product **4** was isolated by PTLC (hexanes/ethyl acetate 9:1) to afford 13.6 mg (60%) as transparent oil.

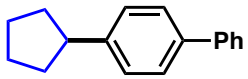
R_f = 0.65 (hexanes/ethyl acetate 9:1).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45 (s, 1H), 7.45 – 7.41 (m, 1H), 7.41 – 7.36 (m, 2H), 2.63 – 2.50 (m, 1H), 1.94 – 1.81 (m, 4H), 1.81 – 1.71 (m, 1H), 1.49 – 1.35 (m, 4H), 1.32 – 1.21 (m, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 149.0, 130.7 (q, *J* = 31.9 Hz), 130.4, 128.8, 124.6 (q, *J* = 272 Hz), 123.7 (q, *J* = 3.6 Hz), 122.8 (q, *J* = 3.5 Hz), 44.6, 34.4, 26.9, 26.2

Spectral data are in accordance with those reported in the literature.[6]

4-Cyclopentyl-1,1'-biphenyl (5).



5

Following the General Procedure B with **SI-1** (26 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), $(4\text{-}(1,1'\text{-biphenyl}))_2Zn$ (1.27 mL, 0.12 M, 0.15 mmol, 1.5 equiv) at 25 ºC. Product **5** was isolated by PTLC (hexanes) to afford 13.7 mg (62%) as transparent oil.

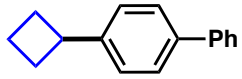
R_f = 0.30 (hexanes).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.60 – 7.57 (m, 2H), 7.54 – 7.51 (m, 2H), 7.45 – 7.40 (m, 2H), 7.35 – 7.30 (m, 3H), 3.09 – 2.99 (m, 1H), 2.15 – 2.05 (m, 2H), 1.90 – 1.79 (m, 2H), 1.77 – 1.67 (m, 2H), 1.67 – 1.57 (m, 2H);

^{13}C NMR (150 MHz, $CDCl_3$): δ 145.8, 141.3, 138.8, 128.8, 127.7, 127.2, 127.1, 127.1, 45.8, 34.8, 25.7.

Spectral data are in accordance with those reported in the literature.1

4-Cyclobutyl-1,1'-biphenyl (6).



6

Following the General Procedure B with **SI-2** (25 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), $(4\text{-}(1,1'\text{-biphenyl}))_2Zn$ (1.27 mL, 0.12 M, 0.15 mmol, 1.5 equiv) at 25 ºC. Product **6** was isolated by PTLC (hexanes) to afford 12.9 mg (62%) as a transparent oil.

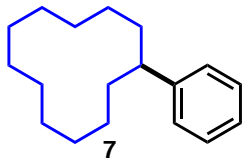
R_f = 0.30 (hexanes).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.60 – 7.57 (m, 2H), 7.55 – 7.52 (m, 2H), 7.45 – 7.41 (m, 2H), 7.34 – 7.32 (m, 1H), 7.32 – 7.28 (m, 2H), 3.64 – 3.55 (m, 1H), 2.42 – 2.32 (m, 2H), 2.25 – 2.14 (m, 2H), 2.10 – 1.99 (m, 1H), 1.93 – 1.84 (m, 1H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 145.5, 141.3, 138.8, 128.8, 127.2, 127.1, 127.1, 126.9, 40.2, 30.0, 18.5.

Spectral data are in accordance with those reported in the literature.1

Phenylcyclododecane (7).



7

From isolated redox-active ester: Following General Procedure B, with **SI-3** (36 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **7** was isolated by PTLC (hexanes) to afford 18 mg (74%) as a white solid.

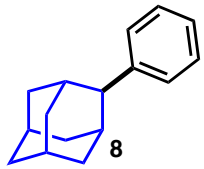
R_f = 0.76 (hexanes).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.32 (t, *J* = 7.6 Hz, 2H), 7.26 – 7.17 (m, 3H), 2.80 (p, *J* = 6.5 Hz, 1H), 1.94 – 1.71 (m, 2H), 1.64 – 1.00 (m, 20H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 147.2, 127.7, 127.2, 125.2, 39.2, 31.1, 23.5, 23.5, 23.0, 22.8, 22.3.

Spectral data are in accordance with those reported in the literature.1

2-Phenyladamantane (8).



8

From isolated redox-active ester: Following General Procedure B, with **SI-4** (33 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **8** was isolated by PTLC (hexanes) to afford 14 mg (67%) as a white solid.

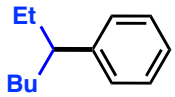
R_f = 0.69 (Hexanes);

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.45 – 7.31 (m, 4H), 7.22 (t, *J* = 7.1 Hz, 1H), 3.06 (s, 1H), 2.52 (s, 2H), 2.09 – 1.74 (m, 10H), 1.60 (d, *J* = 12.5 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 144.4, 128.1, 126.9, 125.2, 46.8, 39.2, 37.9, 32.0, 31.1, 28.1, 27.8.

Spectral data are in accordance with those reported in the literature.1

Heptan-3-ylbenzene (9).



9

From isolated redox-active ester: Following General Procedure B, with **SI-5** (29 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **9** was isolated by PTLC (pentane) to afford 12 mg (68%) as colorless oil (**note**: volatile product).

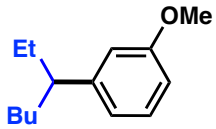
R_f = 0.76 (hexanes).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.28 (t, *J* = 7.6 Hz, 2H), 7.22 – 7.15 (m, 1H), 7.15 – 7.07 (m, 2H), 2.39 (tt, *J* = 9.5, 5.3 Hz, 1H), 1.75 – 1.59 (m, 2H), 1.59 – 1.46 (m, 2H), 1.33 – 1.00 (m, 4H), 0.83 (t, *J* = 7.3 Hz, 3H), 0.77 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 146.5, 128.5, 128.1, 126.1, 48.2, 36.61, 30.2, 30.1, 23.2, 14.4, 12.6.

Spectral data are in accordance with those reported in the literature.1

1-(Heptan-3-yl)-3-methoxybenzene (10).



10

Following the General Procedure B with **SI-5** (29 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), $(3\text{-OMePh})_2Zn$ (0.15 mmol) at 25 ºC. Product **10** was isolated by PTLC (hexanes/ethyl acetate 9:1) to afford 12.2 mg (59%) as a transparent oil.

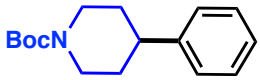
R_f = 0.33 (0.5:99.5 acetone/hexanes).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.20 (t, *J* = 7.8 Hz, 1H), 6.82 – 6.71 (m, 2H), 6.69 (d, *J* = 1.9 Hz, 1H), 2.36 (tt, *J* = 9.6, 5.3 Hz, 1H), 1.73 – 1.58 (m, 2H), 1.57 – 1.49 (m, 2H), 1.39 – 1.19 (m, 2H), 1.20 – 1.01 (m, 2H), 0.83 (t, *J* = 7.3 Hz, 3H), 0.77 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 159.6, 148.1, 129.1, 120.5, 113.9, 110.7, 55.2, 48.1, 36.4, 30.0, 29.8, 23.0, 14.2, 12.4.

Spectral data are in accordance with those reported in the literature.[1]

***Tert*-butyl 4-phenylpiperidine-1-carboxylate (11).**



11

From isolated redox-active ester: Following General Procedure B, with **SI-6** (37 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **11** was isolated by PTLC (hexanes:ethyl acetate 8:2) to afford 17 mg (67%) as a colorless oil.

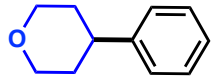
R_f = 0.55 (6:1 hexanes:ethyl acetate).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32 – 7.30 (m, 2H), 7.22 – 7.20 (m, 3H), 4.24 (d, *J* = 13.3 Hz, 2H), 2.85 – 2.76 (m, 2H), 2.64 (tt, *J* = 12.2, 3.6 Hz, 1H), 1.89 – 1.78 (m, 2H), 1.67 – 1.58 (m, 2H), 1.48 (s, 9H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 155.0, 146.0, 128.7, 126.9, 126.5, 79.6, 44.6, 42.9, 33.3, 28.7.

Spectral data are in accordance with those reported in the literature.[1]

4-Phenyltetrahydro-2*H*-pyran (12).



12

From isolated redox-active ester: Following General Procedure B, with **SI-7** (28 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **12** was isolated by PTLC (hexanes:ethyl acetate 8:2) to afford 10 mg (63%) as a yellowish oil.

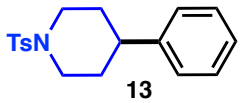
R_f = 0.53 (10:1 hexanes:ethyl acetate).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.34 – 7.31 (m, 2H), 7.24 – 7.21 (m, 3H), 4.09 (dd, *J* = 11.3, 4.0 Hz, 2H), 3.54 (td, *J* = 11.7, 2.0 Hz, 2H), 2.79 – 2.73 (m, 1H), 1.91 – 1.71 (m, 4H);

^{13}C NMR (151 MHz, $CDCl_3$): δ 146.0, 128.7, 126.9, 126.5, 68.6, 41.7, 34.1.

Spectral data are in accordance with those reported in the literature.[1]

4-Phenyl-1-tosylpiperidine (13).



13

From isolated redox-active ester: Following General Procedure B, with **SI-13** (43 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **13** was isolated by Column chromatography (hexanes:ethyl acetate 9:1) to afford 24 mg (76%) as a white solid.

From redox-active ester generated in situ with HATU: Following General Procedure C, with *N*-tosylpiperidine-4-carboxylic acid **46** (28 mg, 0.1 mmol), HATU (38 mg, 0.1 mmol), Et_3N (14 μL, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (8.9 mg, 0.02 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **13** was isolated by column chromatography (hexanes:ethyl acetate 9:1) to afford 24 mg (76%) as a white solid.

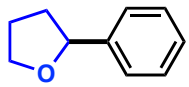
R_f = 0.51 (hexanes:ethyl acetate 3:1)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.71 – 7.66 (m, 2H), 7.38 – 7.32 (m, 2H), 7.32 – 7.27 (m, 2H), 7.23 – 7.19 (m, 1H), 7.17 – 7.12 (m, 2H), 3.96 – 3.90 (m, 2H), 2.45 (s, 3H), 2.41 (tt, *J* = 11.6, 4.2 Hz, 1H), 2.34 (td, *J* = 11.8, 3.3 Hz, 2H), 1.92 – 1.79 (m, 4H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 145.0, 143.6, 133.3, 129.8, 128.7, 127.9, 126.8, 126.7, 47.0, 42.0, 32.7, 21.7.

Spectral data are in accordance with those reported in the literature.[7]

2-Phenyltetrahydrofuran (14).



14

From isolated redox-active ester: Following General Procedure B, with **SI-8** (26 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012

mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **14** was isolated by PTLC (hexanes:ethyl acetate 8:2) to afford 11 mg (68%) as a yellowish oil.

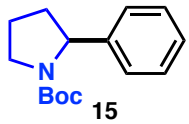
R_f = 0.53 (10:1 hexanes:ethyl acetate).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.35 – 7.32 (m, 4H), 7.26 – 7.24 (m, 1H), 4.90 (t, *J* = 7.2, Hz, 1H), 4.20 – 4.05 (m, 1H), 3.94 (td, *J* = 7.9, 6.4 Hz, 1H), 2.33 (ddd, *J* = 12.4, 7.2, 5.5 Hz, 1H), 2.07 – 1.94 (m, 2H), 1.81 (dq, *J* = 12.3, 7.7 Hz, 1H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 143.6, 128.4, 127.2, 125.8, 80.8, 68.8, 34.8, and 26.2.

Spectral data are in accordance with those reported in the literature.1

***Tert*-butyl 2-phenylpyrrolidine-1-carboxylate (15).**



15

From isolated redox-active ester: Following General Procedure B, with **SI-27** (36 mg, 0.1 mmol), $FeCl_3$ (0.8 mg, 0.005 mmol), dppBz (2.7 mg, 0.006 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **15** was isolated by PTLC (hexanes:ethyl acetate 20:3) to afford 15.2 mg (62%) as a colorless oil.

$\mathbf{R}_f$ = 0.53 (20:3 hexanes:ethyl acetate).

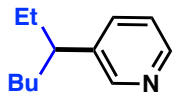
The product gives two sets of NMR signals, owing to the presence of rotamers.

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.27 – 7.23 (m, 2H), 7.19 – 7.13 (m, 3H), 4.93 (brs, 0.3H), 4.73 (brs, 0.7H), 3.60 – 3.49 (m, 2H), 2.30 (br, 1H), 1.89 (br, 1H), 1.85 – 1.75 (m, 2H), 1.43 (s, 3H), 1.15 (s, 6H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 154.7, 145.3, 144.2, 128.4, 128.2, 126.6, 125.6, 125.5, 79.3, 61.5, 60.8, 47.5, 47.2, 36.2, 35.0, 28.7, 28.3, 23.6, 23.3.

Spectral data are in accordance with those reported in the literature.1

3-(Heptane-3-yl)pyridine (16).



16

Following the General Procedure B with **SI-5** (29 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), $(3\text{-pyridyl})_2Zn$ (0.15 mmol) at 25 ºC. Product **16** was isolated by PTLC (hexanes:ethyl acetate 5:1) to afford 8.4 mg (44%) as a transparent oil.

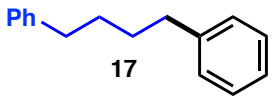
R_f = 0.50 (hexanes:ethyl acetate 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.43 (dd, *J* = 4.7, 1.7 Hz, 1H), 8.41 – 8.37 (m, 1H), 7.45 (dt, *J* = 7.8, 2.0 Hz, 1H), 7.22 (ddd, *J* = 7.9, 4.8, 0.9 Hz, 1H), 2.41 (td, *J* = 9.3, 4.8 Hz, 1H), 1.69 (dddt, *J* = 21.6, 13.5, 10.7, 5.5 Hz, 2H), 1.59 – 1.49 (m, 2H), 1.32 – 1.19 (m, 2H), 1.19 – 1.11 (m, 1H), 1.10-1.03 (m, 1H), 0.82 (t, *J* = 7.3 Hz, 3H), 0.76 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 150.0, 147.5, 141.3, 134.9, 123.5, 45.4, 36.0, 29.8, 29.6, 22.8, 14.1, 12.2.

Spectral data are in accordance with those reported in the literature.1

1,4-Diphenylbutane (17).



17

From isolated redox-active ester: Following General Procedure B, with **SI-9** (47.5 mg, 0.1 mmol), $FeCl_3$ (1.6 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **17** was isolated by PTLC (hexanes) to afford 14.1 mg (67%) as yellowish oil.

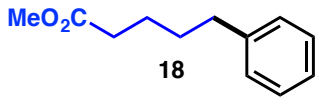
Kumada-coupling using Fe-catalysis from isolated redox-active ester: with **SI-35** (32 mg, 0.1 mmol), $Fe(acac)_3$ (7 mg, 0.02 mmol), PhMgBr·LiCl (0.2 mmol) at 0 ºC. The crude product was purified on silica gel (hexanes) resulting in an

inseparable mixture (17.8 mg) of biphenyl and product **17**. Percent yield was calculated by NMR resulting in a 57.9 wt% mixture of **17**(10.3 mg, 49% yield).

Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-9** (47.5 mg, 0.1 mmol), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **17** was isolated by PTLC (hexanes) to afford 14.3 mg (68%) as yellowish oil.

R_f = 0.90 (hexanes).
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.30 – 7.27 (m, 4H), 7.20 – 7.17 (m, 6H), 2.67 – 2.64 (m, 4H), 1.72 – 1.65 (m, 4H).
^{13}C NMR (151 MHz, $CDCl_3$): δ 142.7, 128.6, 128.4, 125.8, 36.0, 31.2.
Spectral data are in accordance with those reported in the literature.[8]

Methyl 5-phenylpentanoate (18).



18

From isolated redox-active ester: Following General Procedure B, with **SI-10** (44.3 mg, 0.1 mmol), $FeCl_3$ (0.8 mg, 0.005 mmol), dppBz (2.7 mg, 0.006 mmol), Ph_2Zn (0.15 mmol) at 0 ºC. Product **18** was isolated by PTLC (hexanes:ethyl acetate 12:1) to afford 12.1 mg (63%) as a yellowish oil.

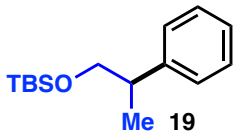
Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-10** (44.3 mg, 0.1 mmol), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **18** was isolated by PTLC (hexanes) to afford 9.7 mg (51%) as yellowish oil.

R_f = 0.50 (hexanes:ethyl acetate 12:1).
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.29 – 7.27 (m, 2H), 7.19 – 7.17 (m, 3H), 3.67 (s, 3H), 2.63 (t, *J* = 7.2 Hz, 2H), 2.34 (t, *J* = 7.2 Hz, 2H), 1.71 – 1.63 (m, 4H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 174.2, 142.3, 128.5, 128.5, 125.9, 51.6, 35.7, 34.1, 31.0, 24.7.

Spectral data are in accordance with those reported in the literature.[9]

***Tert*-butyldimethyl(2-phenylpropoxy)silane (19).**



19

From isolated redox-active ester: Following General Procedure B, with **SI-11** (36 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), Ph_2Zn (0.15 mmol) at 25 ºC. Product **19** was isolated by PTLC (hexanes:ethyl acetate 9:1) to afford 16 mg (64%) as yellowish oil.

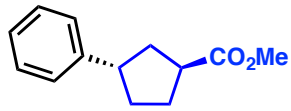
R_f = 0.33 (9:1 hexanes:ethyl acetate).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.31 – 7.27 (m, 2H), 7.24 – 7.18 (m, 3H), 3.69 (dd, *J* = 9.8, 5.9 Hz, 1H), 3.59 (dd, *J* = 9.8, 7.6 Hz, 1H), 2.94 – 2.84 (m, 1H), 1.29 (d, *J* = 7.0 Hz, 3H), 0.86 (s, 9H), -0.03 (s, 3H), -0.04 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 144.7, 128.3, 127.7, 126.4, 69.4, 42.6, 26.1, 18.5, 17.6, -5.30, -5.33.

Spectral data are in accordance with those reported in the literature.1

Methyl-3-phenylcyclopentane-1-carboxylate.



20

From isolated redox-active ester: Following General Procedure B, with **SI-28** (160 mg, 0.5 mmol), $Fe(acac)_3$ (19 mg, 0.054 mmol), dppBz (28 mg, 0.061 mmol), Ph_2Zn (1.5 mmol) at 25 ºC for 15 minutes. Upon concentration, a viscous, red oil was obtained with mass of 172 mg. Quantitative NMR of the oil (CD_3OD, fumaric acid internal standard) revealed a potency of 38%, corresponding to a yield of 63% (64.7 mg, 0.317 mmol). The oil was purified by silica gel chromatography (hexanes:MTBE, 0-10% gradient); the desired product 20 eluted at 5-6% MTBE, and was concentrated to a colorless oil.

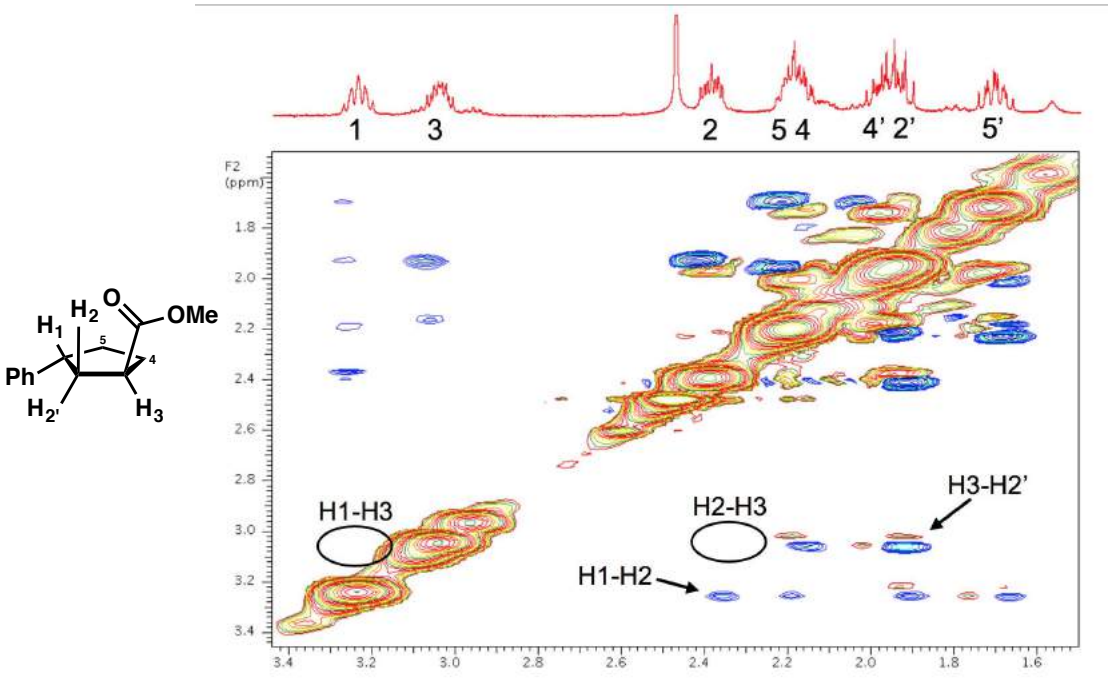
Using Ni-catalysis. Following General Procedure E, with **SI-28** (100 mg, 0.32 mmol), $NiCl_2$·glyme (14.1 mg, 0.063 mmol), di-*tert*-butylbipyridine (35.3 mg, 0.13 mmol), PhZnCl (2.2 mL, 0.95 mmol, 0.43 M) at 25 ºC. The oil was purified by silica gel chromatography (hexanes:MTBE, 0–10% gradient); the desired product **20** eluted at 5–6% MTBE, and was concentrated to a colorless oil of mass 34.2 mg (53% yield). The diastereoselectivity, as determined by NMR, was 1.3:1.

R_f = 0.75 (silica gel, 2:1 heptane:MTBE);

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.36 – 7.19 (m, 5H), 3.74 (s, 3H), 3.29 – 3.21 (trans diastereomer, m, 1H), 3.10 – 3.02 (m, 1H), 3.01 – 2.93 (cis diastereomer, m, 1H), 2.44 – 2.36 (m, 1H), 2.26 – 2.09 (m, 2H), 2.09 – 1.90 (m, 2H), 1.90 – 1.78 (*cis* diastereomer, m, 1H), 1.78 – 1.66 (*trans* diastereomer, m, 1H).

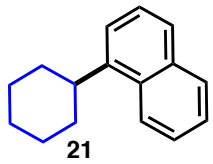
^{13}C NMR (126 MHz, $CDCl_3$) δ 177.2, 145.0, 128.4, 127.0, 126.1, 51.8, 44.9, 43.0, 37.5, 34.6, 30.0.

Spectral data are in accordance with those reported in the literature.[10]



The ROESY spectrum then was able to observe NOE transfer between protons H1 and H2, H3 and H2'. Finally, NOE transfer was observed between neither H1 and H3, nor H2 and H3, confirming a *trans* relationship between H1 and H3.

1-Cyclohexylnaphthalene (21).



From isolated redox-active ester: Following General Procedure B, with **1** (27 mg, 0.1 mmol), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (5.4 mg, 0.012 mmol), THF (0.5 mL), and Np_2Zn (0.15 mmol) at 25 ºC. The crude white solid was purified on silica gel (heptanes) resulting in an inseparable mixture (26.8 mg) of naphthalene and product **21**. Percent yield was calculated by QNMR using trimethoxybenzene as the internal standard resulting in a 46.33 wt% mixture of **21** (12.4 mg, 60% yield).

Kumada-coupling using Fe-catalysis from isolated redox-active ester: Following General Procedure D, with **1** (27 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.02 mmol), 1-NpMgBr · LiCl (0.88 M, 0.3 mmol) at 0 ºC. Product **21** was isolated by PTLC (hexanes), and subsequent removal of naphthalene *in vacuo* to afford 12 mg (57%) as a colorless oil.

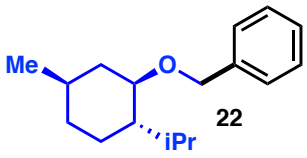
R_f = 0.55 (hexanes)

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.13 (d, *J* = 8.5 Hz, 1H), 7.86 (d, *J* = 8.1 Hz, 1H), 7.70 (d, *J* = 8.0 Hz, 1H), 7.51 (ddd, *J* = 8.5, 6.8, 1.5 Hz, 1H), 7.47 (ddd, *J* = 8.0, 6.8, 1.3 Hz, 1H), 7.45 (d, 1H), 7.40 (dd, *J* = 7.3, 1.3 Hz, 1H), 3.34 (tt, *J* = 11.3, 3.1 Hz, 1H), 2.09 – 2.01 (m, 2H), 1.98 – 1.90 (m, 2H), 1.88 – 1.83 (m, 1H), 1.62 – 1.52 (m, 4H), 1.40 – 1.32 (m, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 144.0, 134.1, 131.5, 129.1, 126.3, 125.8, 125.7, 125.3, 123.3, 122.4, 39.4, 34.4, 27.5, 26.7.

Spectral data are in accordance with those reported in the literature.[11]

(((1*R*,2*S*,5*R*)-2-Isopropyl-5-methylcyclohexyloxy)methyl)benzene (22).



22

From isolated redox-active ester: Following General Procedure B, with **SI-12** (49.7 mg, 0.1 mmol), $FeCl_3$ (0.8 mg, 0.005 mmol), dppBz (2.7 mg, 0.006 mmol), Ph_2Zn (0.15 mmol) at 0 ºC. Product **22** was isolated by PTLC (hexanes:ethyl acetate 15:1) to afford 14.2 mg (58%) as a yellowish oil.

Negishi-coupling using Ni-catalysis: Following General Procedure E, with **SI-12** (49.7 mg, 0.1 mmol), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **22** was isolated by PTLC (hexanes:ethyl acetate 15:1) to afford 12.6 mg (51%) as a yellowish oil.

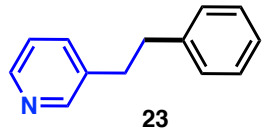
R_f= 0.50 (hexanes:ethyl acetate 12:1).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.37 – 7.32(m, 4H), 7.28 – 7.26 (m, 1H), 4.66 (d, *J* = 11.4 Hz, 2H), 4.41 (d, *J* = 11.4 Hz, 2H), 3.18 (td, *J* = 10.8, 4.2 Hz, 1H), 2.34 – 2.28 (m, 1H), 2.20 – 2.18 (m, 1H), 1.69 – 1.61 (m, 1H), 1.41 – 1.34 (m, 1H), 1.33 – 1.28 (m, 1H), 1.02 – 0.83 (m, 10H), 0.72 (d, *J* = 6.6 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 139.3, 128.4, 128.0, 127.6, 78.9, 70.6, 48.5, 40.5, 34.7, 31.7, 25.7, 23.4, 22.5, 21.2, 16.2.

Spectral data are in accordance with those reported in the literature.[12]

3-Phenethylpyridine (23).



23

From in situ generation of redox-active ester: Following the General Procedure C with 3-pyridylpropionic acid (15 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (8.9 mg, 0.02 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **23** was isolated by PTLC (hexanes:ethyl acetate 1:1) to afford 13.1 mg (72%) as a transparent oil.

1.0 Mmol scale from in situ generation of redox-active ester: Following the General Procedure C with 3-pyridylpropionic acid (150 mg, 1.0 mmol), HATU (380 mg), Et_3N (140 μL), $Fe(acac)_3$ (35 mg, 0.1 mmol), dppBz (89 mg, 0.2 mmol), Ph_2Zn (2.5 mmol) at 25 ºC. Product **23** was isolated by column chromatography (hexanes:ethyl acetate 1:1) to afford 128 mg (70%) as a transparent oil.

Using Ni-catalysis and in situ generation of redox-active ester. Following General Procedure F, with 3-pyridylpropionic acid (15 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **23** was isolated by PTLC (hexanes:EtOAc 1:1) to afford 6.0 mg (33%) as a transparent oil.

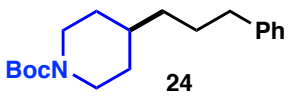
R_f = 0.43 (hexanes:ethylacetate 1:1)

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.47 (dd, *J* = 4.8, 1.6 Hz, 2H), 8.45 (d, *J* = 2.3 Hz, 1H), 7.33 – 7.29 (m, 2H), 7.25 – 7.20 (m, 2H), 7.17 (dd, *J* = 8.0, 1.3 Hz, 2H), 2.95 (s, 4H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 149.5, 147.0, 140.3, 136.4, 135.5, 128.0, 127.9, 125.7, 122.8, 37.00, 34.5.

Spectral data are in accordance with those reported in the literature.[13]

***Tert*-butyl 4-(3-(benzyloxy)propyl)piperidine-1-carboxylate (24).**



24

From isolated redox-active ester: Following General Procedure B, with **SI-23** (51.2 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), $(PhCH_2CH_2CH_2)_2Zn$ (0.15 mmol) at r.t. Product **24** was isolated by PTLC (hexanes:ethyl acetate 5:1) to afford 16.3 mg (55%) as yellowish oil.

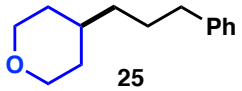
R_f= 0.30 (hexanes:ethyl acetate 5:1).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.29-7.26 (m, 2H), 7.19-7.16 (m, 3H), 4.05 (br, 2H), 2.66 (br, 2H), 2.60 (t, *J* = 7.8 Hz, 2H), 1.66-1.61 (m, 4H), 1.45 (s, 9H), 1.41-1.35 (m, 1H), 1.30-1.26 (m, 2H), 1.10-1.03 (m, 2H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 155.1, 142.7, 128.5, 128.4, 125.8, 79.3, 44.3, 36.3, 36.2, 36.1, 32.3, 28.7, 28.6.

HRMS (ESI-TOF): calc'd for $C_{19}H_{30}NO_2$ $[M+H]^+$ 304.2271; found 304.2271.

4-(3-(Benzyloxy)propyl)tetrahydro-2*H*-pyran (25).



25

From isolated redox-active ester: Following General Procedure B, with **SI-24** (41.3 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), $(BnOCH_2CH_2CH_2)_2Zn$ (0.15 mmol) at r.t.. Product **25** was isolated by PTLC (hexanes:ethyl acetate 8:1) to afford 11.0 mg (54%) as a yellowish oil.

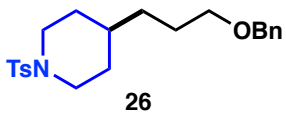
R_f= 0.30 (hexanes:ethyl acetate 8:1).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.29 – 7.27(m, 2H), 7.20 – 7.17 (m, 3H), 3.94 (dd, *J* = 11.4, 4.8 Hz, 2H), 3.36 (td, *J* = 12.0, 1.8 Hz, 2H), 2.60 (t, *J* = 7.2 Hz, 2H), 1.67 – 1.58 (m, 4H), 1.53 – 1.45 (m, 1H), 1.33 – 1.23 (m, 4H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 142.8, 128.5, 128.4, 125.8, 68.3, 36.7, 36.3, 35.1, 33.3, 28.5.

Spectral data are in accordance with those reported in the literature.[14]

4-(3-(Benzyloxy)propyl)-1-tosylpiperidine (26).



26

From isolated redox-active ester: Following General Procedure B, with **SI-25** (56.6 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), $(BnOCH_2CH_2CH_2)_2Zn$ (0.15 mmol) at 0 ºC. Product **26** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 21.6 mg (56%) as a yellowish solid.

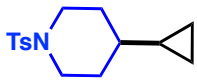
R_f = 0.30 (hexanes:ethyl acetate 10:1).

^{1}H NMR (600 MHz, $CDCl_3$):δ 7.64 – 7.62(m, 2H), 7.34 – 7.27 (m, 7H), 4.48 (s, 2H), 3.75 (d, *J* = 12.0 Hz, 2H), 3.42 (t, *J* = 6.6 Hz, 2H), 2.43 (s, 3H), 2.19 (td, *J* = 12.0, 3.0 Hz, 2H), 1.71 (dd, *J* = 13.2, 2.4 Hz, 2H), 1.59 – 1.54 (m, 2H), 1.31 – 1.24 (m, 4H), 1.17 – 1.10 (m, 1H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 143.5, 138.6, 133.3, 129.7, 128.5, 127.9, 127.8, 127.7, 73.1, 70.5, 46.6, 35.1, 32.7, 31.6, 27.0, 21.6.

Spectral data are in accordance with those reported in the literature.2

4-cyclopropyl-1-tosylpiperidine (27).



27

From isolated redox-active ester: Following General Procedure B, with **SI-25** (56.6 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), dicyclopropylzinc (0.15 mmol) at r.t. Product **27** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 12.6 mg (45%) as a pale white solid.

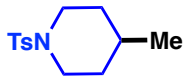
R_f= 0.30 (hexanes:ethyl acetate 10:1).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.63(d, *J* = 8.4 Hz, 2H), 7.30 (d, *J* = 8.4 Hz, 2H), 3.73 (d, *J* = 11.4 Hz, 2H), 2.42 (s, 3H), 2.19 (td, *J* = 12.0, 2.4 Hz, 2H), 1.77 (dd, *J* = 13.2, 1.8 Hz, 2H), 1.46 (qd, *J* = 12.0, 4.2 Hz, 2H), 0.52-0.47 (m, 1H), 0.39-0.36 (m, 2H), 0.00 – (–0.03) (m, 2H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 143.4, 133.4, 129.7, 127.9, 46.6, 40.7, 31.3, 21.7, 16.4, 3.3.

Spectral data are in accordance with those reported in the literature.2

4-Methyl-1-tosylpiperidine (28).



28

From isolated redox-active ester: Following General Procedure B, with **SI-25** (56.6 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), Me_2Zn (0.15 mmol) at r.t. Product **28** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 9.4 mg (37%) as a pale white solid.

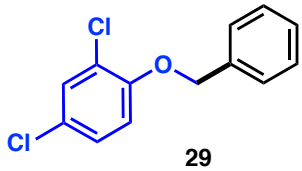
R_f = 0.30 (hexanes:ethyl acetate 10:1).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.64 – 7.62(m, 2H), 7.31 (dd, *J* = 8.4, 1.2 Hz, 2H), 3.74 – 3.71 (m, 2H), 2.43 (s, 3H), 2.22 (td, *J* = 11.4, 2.4 Hz, 2H), 1.66 – 1.64 (m, 2H), 1.32 – 1.24 (m, 3H), 0.90 (d, *J* = 6.0 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 143.4, 133.5, 129.7, 127.9, 46.6, 33.5, 30.3, 21.64, 21.59.

Spectral data are in accordance with those reported in the literature.2

1-(Benzyloxy)-2,4-dichlorobenzene (29).



29

From isolated redox-active ester: Following General Procedure B, with **SI-14** (50.4 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), Ph_2Zn (0.15 mmol) at 0 °C. Product **29** was isolated by PTLC (hexanes) to afford 19.0 mg (75%) as a yellowish oil.

From in situ generation of redox-active ester: Following General Procedure C, with 2-(2,4-dichlorophenoxy)acetic acid (22.1 mg, 0.1 mmol), HATU (38.0 mg, 0.1 mmol), Et_3N (10.1 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz

(10.7 mg, 0.024 mmol), Ph_2Zn (0.25 mmol) at r.t. Product **29** was isolated by PTLC (hexanes) to afford 11.4 mg (45%) as yellowish oil

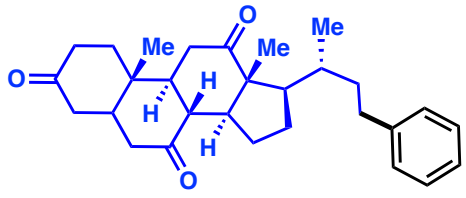
R_f = 0.80 (hexanes).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.44 (d, *J* = 9.6 Hz, 2H), 7.41-7.38 (m, 3H), 7.33 (t, *J* = 9.0, 1.2 Hz, 1H), 7.15 (dd, *J* = 10.8, 3.6 Hz, 1H), 6.88 (d, *J* = 10.8 Hz, 1H), 5.14 (s, 2H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 153.2, 136.2, 130.2, 128.8, 128.3, 127.7, 127.2, 126.2, 124.3, 115.0, 71.3.

Spectral data are in accordance with those reported in the literature.[15]

(8*R*,9*S*,10*S*,13*R*,14*S*,17*R*)-10,13-dimethyl-17-(4-phenylbutan-2-yl)dodecahydro-3*H*-cyclopenta[*a*]phenanthrene-3,7,12(2*H*,4*H*)-trione (30).



30

From in situ generation of redox-active ester: Following the General Procedure C with dehydrocholic acid (40 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (8.9 mg, 0.02 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **30** was isolated by PTLC (hexanes:ethyl acetate 3:2) to afford 27 mg (62%) as a white solid.

0.5 Mmol from in situ generation of redox-active ester: Following the General Procedure C with dehydrocholic acid (201 mg, 0.5 mmol), HATU (190 mg), Et_3N (70 μL), $Fe(acac)_3$ (18 mg, 0.05 mmol), dppBz (44 mg, 0.1 mmol), Ph_2Zn (1.25 mmol) at 25 ºC. Product **30** was isolated by column chromatography (hexanes:ethyl acetate 1:1) to afford 132 mg (61%) as a white solid.

Using Ni-catalysis and in situ generation of redox-active ester. Following General Procedure F, with dehydrocholic acid (40 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11

mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **30** was isolated by PTLC (hexanes:ethyl acetate 3:2) to afford 22.0 mg (51%) as a white solid.

m.p. 271 – 273 °C (decomposition)

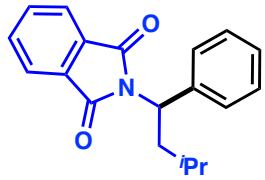
R_f = 0.33 (hexanes:ethyl acetate 1.25:1)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.32 – 7.29 (m, 2H), 7.22 – 7.16 (m, 3H), 3.00–2.83 (m, 3H), 2.77 (ddd, *J* = 13.5, 11.0, 4.9 Hz, 1H), 2.51 (ddd, *J* = 13.6, 10.7, 6.2 Hz, 1H), 2.40 – 2.21 (m, 5H), 2.19 – 2.14 (m, 2H), 2.13 – 2.11 (m, 1H), 2.08 – 1.95 (m, 3H), 1.88 (td, *J* = 11.3, 7.0 Hz, 1H), 1.78 (dddd, *J* = 13.6, 11.0, 6.2, 2.7 Hz, 1H), 1.64 (td, *J* = 14.4, 4.6 Hz, 1H), 1.52 – 1.44 (m, 1H), 1.43 (s, 3H), 1.39 – 1.24 (m, 3H), 1.09 (s, 3H), 0.97 (d, *J* = 6.7 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 211.6, 208.6, 208.3, 142.7, 127.9, 127.8, 125.1, 56.5, 51.3, 48.6, 46.4, 45.3, 45.1, 44.5, 42.4, 38.2, 37.1, 36.0, 35.6, 35.4, 34.9, 32.5, 27.3, 24.7, 21.5, 18.5, 11.4.

HRMS (ESI-TOF): calc'd for $C_{29}H_{39}O_3$ $[M+H]^+$ 435.2894; found 435.2899.

2-(3-Methyl-1-phenylbutyl)isoindoline-1,3-dione (31).



31

From isolated redox-active ester: Following General Procedure B, with **SI-26** (40.6 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), Ph_2Zn (0.15 mmol) at 0 °C. Product **31** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 12.1 mg (41%) as a pale white solid in racemic form.

From in situ generation of redox-active ester following General Procedure C: Activation was carried out with (*R*)-2-(1,3-dioxoisoindolin-2-yl)-4-methylpentanoic acid (26.1 mg, 0.1 mmol), HATU (38.0 mg, 0.1 mmol), and Et_3N (10.1 mg, 0.1 mmol) in 0.2 mL of THF, followed by addition of $Fe(acac)_3$

(7.1 mg, 0.020 mmol) and dppBz (10.7 mg, 0.024 mmol) in 0.5 mL of toluene. Ph_2Zn (0.15 mmol) was added at r.t. Product **31** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 19.3 mg (66%) as a pale white solid in racemic form.

1.0 Mmol scale from in situ generation of redox-active ester following General Procedure C: Activation was carried out with (*R*)-2-(1,3-dioxoisoindolin-2-yl)-4-methylpentanoic acid (261 mg, 1.0 mmol), HATU (380 mg, 1.0 mmol), and Et_3N (101 mg, 1.0 mmol) in 2.0 mL of THF, followed by addition of $Fe(acac)_3$ (71 mg, 0.20 mmol) and dppBz (107 mg, 0.24 mmol) in 5.0 mL of toluene. Ph_2Zn (4.6 mL, 0.33M in THF, 1.5 mmol) was added at r.t. Product **31** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 220.9 mg (75%) as a pale white solid in racemic form.

m.p. 82 – 83 °C

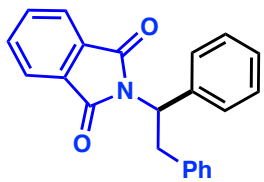
R_f= 0.30 (hexanes:ethyl acetate 10:1).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.81 – 7.78 (m, 2H), 7.70 – 7.67 (m, 2H), 7.55 (d, *J* = 7.5 Hz, 2H), 7.32 (t, *J* = 7.5 Hz, 2H), 7.25 (t, *J* = 7.5 Hz, 1H), 5.45 (dd, *J* = 10.0, 6.5 Hz, 1H), 2.64 – 2.58 (m, 1H), 2.64 – 2.58 (m, 1H), 2.06 – 2.00 (m, 1H), 1.57 – 1.49 (m, 1H), 0.98 (d, *J* = 4.0 Hz, 3H), 0.97 (d, *J* = 4.0 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 168.6, 140.1, 134.0, 132.0, 128.6, 128.3, 127.8, 123.3, 53.2, 39.9, 25.6, 23.1, 22.1.

HRMS (ESI-TOF): calc'd for $C_{19}H_{19}NO_2$ $[M+H]^+$ 294.1488; found 294.1485.

2-(1,2-diphenylethyl)isoindoline-1,3-dione (32).



32

From in situ generation of redox-active ester following General Procedure C: Activation was carried out with (*R*)-2-(1,3-dioxoisoindolin-2-yl)-3-phenylpropanoic acid (29.5 mg, 0.1 mmol), HATU (38.0 mg, 0.1 mmol) and Et_3N (10.1 mg, 0.1 mmol) in 0.2 mL of THF, followed by addition of $Fe(acac)_3$

(7.1 mg, 0.020 mmol) and dppBz (10.7 mg, 0.024 mmol) in 0.5 mL of toluene. Ph_2Zn (0.15 mmol) was added at r.t. Product **32** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 15.0 mg (46%) as a pale white solid in a racemic form.

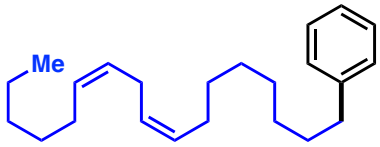
R_f = 0.30 (hexanes:ethyl acetate 10:1).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.73 (dd, *J* = 5.0, 3.0 Hz, 2H), 7.64 – 7.60 (m, 4H), 7.35 (t, *J* = 7.5 Hz, 2H), 7.28 (t, *J* = 7.0 Hz, 1H), 7.24 – 7.18 (m, 4H), 7.12 (t, *J* = 7.0 Hz, 1H), 5.67 (dd, *J* = 11.0, 6.0 Hz, 1H), 3.99 (dd, *J* = 14.0, 11.5 Hz, 1H), 3.51 (dd, *J* = 14.5, 6.0 Hz, 1H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 168.4, 139.5, 138.1, 134.0, 131.8, 129.0, 128.8, 128.6, 128.2, 128.1, 126.7, 123.3, 56.2, 37.2.

Spectral data are in accordance with those reported in the literature.[16]

((8*Z*,11*Z*)-Heptadeca-8,11-dien-1-yl)benzene (33).



33

From isolated redox-active ester: Following General Procedure B, with **SI-15** (56.3 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), Ph_2Zn (0.15 mmol) at 0 °C. Product **33** was isolated by PTLC (hexanes) to afford 21.3 mg (68%) as yellowish oil.

From in situ generation of redox-active ester: Following the General Procedure C with linoleic acid (28 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $Fe(acac)_3$ (3.5 mg, 0.01 mmol), dppBz (8.9 mg, 0.02 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **33** was isolated by PTLC (hexanes) to afford 25 mg (80%) as yellow oil.

0.5 Mmol scale from in situ generation of redox-active ester: Following the General Procedure C with linoleic acid (140 mg, 0.05 mmol), HATU (190 mg), Et_3N (70 μL), $Fe(acac)_3$ (18 mg, 0.1 mmol), dppBz (44 mg, 0.2 mmol), Ph_2Zn (1.25 mmol) at 25 ºC. Product **33** was isolated by column chromatography (hexanes) to afford 121 mg (76%) as yellow oil.

Using Ni-catalysis and in situ generation of redox-active ester. Following General Procedure F, with linoleic acid (28 mg, 0.1 mmol), HATU (38 mg), Et_3N (14 μL), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **33** was isolated by PTLC (hexanes) to afford 7.0 mg (23%) as a white solid.

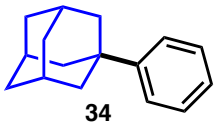
R_f = 0.90 (hexanes)

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.29 – 7.26 (m, 2H), 7.19 – 7.16 (m, 3H), 5.42 – 5.32 (m, 4H), 2.78 (t, *J* = 7.2 Hz, 2H), 2.61 (t, *J* = 7.8 Hz, 2H), 2.08 – 2.02 (m, 4H), 2.08 – 2.02 (m, 4H), 1.65 – 1.60 (m, 2H), 1.39 – 1.27 (m, 16H), 0.90 (t, *J* = 6.6 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 143.1, 130.4, 130.3, 128.5, 128.4, 128.2, 128.1, 125.7, 36.1, 31.7, 31.7, 29.8, 29.6, 29.5, 29.5, 29.4, 27.4, 25.8, 22.7, 14.2.

MS (GCMS-CI): *m/z* 312, 207, 131, 117, 104, 91, 81, 67, 55.

2-Phenyladamantane (34).



34

From isolated redox-active ester: Following General Procedure B, with **SI-16** (33 mg, 0.1 mmol), $Fe(acac)_3$ (14.1 mg, 0.04 mmol), dppBz (21.4 mg, 0.048 mmol), toluene (0.5 mL), and Ph_2Zn (0.25 mmol) at 25 ºC. Product **34** was isolated by PTLC (hexanes) to afford 13.1 mg (62%) as a white solid.

1.0 Mmol from isolated redox-active ester: Following General Procedure B, with **SI-16** (330 mg, 1.0 mmol), $Fe(acac)_3$ (141 mg, 0.4 mmol), dppBz (214 mg, 0.48 mmol), toluene (5 mL), and Ph_2Zn (2.5 mmol) at 25 ºC. Product **34** was isolated by PTLC (hexanes) to afford 125 mg (59%) as a white solid.

From redox-active ester generated in situ with HATU: Following General Procedure C, with adamantane-1-carboxylic acid (18 mg, 0.1 mmol), HATU

(38 mg, 0.1 mmol), Et_3N (14 μL, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.02 mmol), dppBz (17.9 mg, 0.04 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **34** was isolated by PTLC (hexanes) to afford 3.2 mg (15%) as a white solid.

From redox-active ester generated in situ with HBTU: Following General Procedure C, with adamantane-1-carboxylic acid (18 mg, 0.1 mmol), HBTU (38 mg, 0.1 mmol), Et_3N (14 μL, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.02 mmol), dppBz (17.9 mg, 0.04 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **34** was isolated by PTLC (hexanes) to afford 11.6 mg (55%) as a white solid.

Kumada-coupling using Fe-catalysis from isolated redox-active ester: Following General Procedure D, with **SI-16** (33 mg, 0.1 mmol), $Fe(acac)_3$ (35 mg, 0.1 mmol), PhMgBr · LiCl (0.3 mmol) at 25 ºC. Product **34** was isolated by PTLC (hexanes) to afford 12.4 mg (58%) as a white solid.

Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-16** (33 mg, 0.1 mmol), $Ni(acac)_2$ (5.1 mg, 0.02 mmol), 6,6'-dimethyl-2,2'-bipyridine (3.7 mg, 0.02 mmol), PhZnCl (0.2 mmol, *c* = 0.9 M in THF) in acetonitrile (0.2 mL) at 80 ºC overnight. Product **34** was isolated by PTLC (hexanes) to afford 8.1 mg (38%) as a white solid.

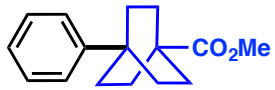
R_f = 0.47 (hexanes)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.38 (d, *J* = 7.5 Hz, 2H), 7.33 (t, *J* = 7.8 Hz, 2H), 7.18 (t, *J* = 7.2 Hz, 1H), 2.11 (m, 3H), 1.93 (d, *J* = 3.0 Hz, 6H), 1.84 – 1.74 (m, 6H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 151.5, 128.2, 125.6, 125.0, 43.3, 37.0, 36.3, 29.1.

Spectral data are in accordance with those reported in the literature.[17]

Methyl 4-phenylbicyclo[2.2.2]octane-1-carboxylate (35).



35

From isolated redox-active ester: Following General Procedure B, with **SI-17** (36 mg, 0.1 mmol), $Fe(acac)_3$ (14.1 mg, 0.04 mmol), dppBz (21.4 mg, 0.048 mmol), toluene (0.5 mL), and Ph_2Zn (0.25 mmol) at 25 ºC. Product **35** was isolated by PTLC (hexanes:ethyl acetate 10:1 and toluene) to afford 13.7 mg (56%) as a white solid.

Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-17** (36 mg, 0.1 mmol), $Ni(acac)_2$ (5.1 mg, 0.02 mmol), 6,6'-dimethyl-2,2'-bipyridine (3.7 mg, 0.02 mmol), PhZnCl (0.2 mmol, *c* = 0.9 M in THF) in acetonitrile (0.2 mL) at 80 ºC overnight. Product **35** was isolated by PTLC (hexanes:ethyl acetate 10:1) to afford 10.6 mg (43%) as a white solid.

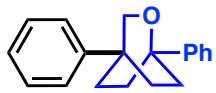
R_f = 0.40 (hexanes:ethyl acetate 10:1)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.34 – 7.28 (m, 4H), 7.20 – 7.16 (m, 1H), 3.68 (s, 3H), 1.95 – 1.90 (m, 6H), 1.89 – 1.85 (m, 6H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 178.6, 149.3, 128.3, 125.9, 125.6, 51.8, 39.2, 34.7, 31.8, 28.9.

Spectral data are in accordance with those reported in the literature.[18]

1,4-Diphenyl-2-oxabicyclo[2.2.2]octane (36).



36

From isolated redox-active ester: Following General Procedure B, with **SI-29** (38 mg, 0.1 mmol), $Fe(acac)_3$ (14.1 mg, 0.04 mmol), dppBz (21.4 mg, 0.048 mmol), toluene (0.5 mL), and Ph_2Zn (0.25 mmol) at 25 ºC. Product **36** was

isolated by PTLC (hexanes:ethyl acetate 4:1 and CH_2Cl_2) to afford 7.9 mg (30%) as a white solid.

From redox-active ester generated in situ with HATU: Following General Procedure C, with 1-phenyl-2-oxabicyclo[2.2.2]octane-4-carboxylic acid (23 mg, 0.1 mmol), HATU (38 mg, 0.1 mmol), Et_3N (14 μL, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.02 mmol), dppBz (17.9 mg, 0.04 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **36** was isolated by PTLC (hexanes: ethyl acetate 4:1 and CH_2Cl_2) to afford 6.8 mg (26%) as a white solid.

Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-29** (19 mg, 0.05 mmol), $Ni(acac)_2$ (2.6 mg, 0.01 mmol), 6,6'-dimethyl-2,2'-bipyridine (1.8 mg, 0.01 mmol), PhZnCl (0.1 mmol, *c* = 0.9 M in THF) in acetonitrile (0.1 mL) at 80 ºC overnight. Product **36** was isolated by PTLC (CH_2Cl_2) to afford 1.4 mg (11 %) as a white solid.

R_f = 0.68 (CH_2Cl_2)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.49 – 7.39 (m, 1H), 7.40 – 7.30 (m, 3H), 7.26 – 7.22 (m, 1H), 4.22 (dd, *J* = 1.9, 1.2 Hz, 1H), 2.25 – 2.16 (m, 3H), 2.09 (ddt, *J* = 11.0, 7.9, 1.8 Hz, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 145.9, 128.0, 127.6, 126.2, 126.0, 125.1, 124.2, 73.7, 72.0, 35.3, 33.1, 30.8.

HRMS (ESI-TOF): calc'd for $C_{19}H_{21}O$ $[M+H]^+$ 265.1587; found 265.1588.

Methyl 3-phenylbicyclo[1.1.1]pentane-1-carboxylate (37).

37

From isolated redox-active ester: Following General Procedure B, with **SI-30** (32 mg, 0.1 mmol), $Fe(acac)_3$ (14.1 mg, 0.04 mmol), dppBz (21.4 mg, 0.048 mmol), toluene (0.5 mL), and Ph_2Zn (0.25 mmol) at 25 ºC. Product **37** was isolated by PTLC (hexanes:ethyl acetate 1.25:1) to afford 7.1 mg (35%) as a white solid.

R_f = 0.80 (hexanes:ethyl acetate 1.25:1).

^{1}H NMR (600 MHz, Acetone-d_6) δ 7.33 (ddt, *J* = 7.8, 7.0, 0.8 Hz, 2H), 7.30 – 7.24 (m, 3H), 3.68 (s, 3H), 2.31 (s, 6H).

^{13}C NMR (151 MHz, Acetone-d_6) δ 169.2, 139.3, 127.7, 126.3, 125.5, 53.6, 52.4, 50.4, 41.0.

Spectral data are in accordance with those reported in the literature.[19]

Methyl 4-phenylcubane-1-carboxylate (38).

38

From isolated redox-active ester: Following General Procedure B, with **SI-31** (35 mg, 0.1 mmol), $Fe(acac)_3$ (14.1 mg, 0.04 mmol), dppBz (21.4 mg, 0.048 mmol), toluene (0.5 mL), and Ph_2Zn (0.25 mmol) at 25 ºC. Product **38** was isolated by PTLC (hexanes: ethyl acetate 10:1, CH_2Cl_2, and toluene) to afford 6.0 mg (25%) as a pale yellow solid.

From redox-active ester generated in situ with HATU, see "iterative diarylation of cubane" (Section 11)

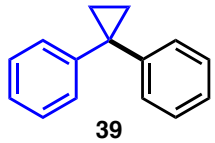
m.p. 78 – 80 ºC

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.39 – 7.34 (m, 2H), 7.23 – 7.18 (m, 3H), 4.28 – 4.21 (m, 3H), 4.19 – 4.13 (m, 3H), 3.74 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 172.9, 142.2, 128.6, 126.3, 124.9, 60.4, 56.6, 51.7, 48.9, 46.2.

HRMS (ESI-TOF): calc'd for $C_{16}H_{15}O_2$ $[M+H]^+$ 239.1067; found 239.1068.

Cyclopropane-1,1-diyldibenzene (39).



39

From isolated redox-active ester: Following General Procedure B, with **SI-32** (31 mg, 0.1 mmol), $Fe(acac)_3$ (14.1 mg, 0.04 mmol), dppBz (21.4 mg, 0.048 mmol), toluene (0.5 mL), and Ph_2Zn (0.25 mmol) at 25 ºC. Product **39** was isolated by PTLC (pentane) to afford 8.5 mg (44%) as a colorless oil.

From redox-active ester generated in situ with HATU: Following General Procedure C, with 1-phenylcyclopropane-1-carboxylic acid (16 mg, 0.1 mmol), HATU (38 mg, 0.1 mmol), Et_3N (14 μL, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.02

mmol), dppBz (17.9 mg, 0.04 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **39** was isolated by PTLC (pentane) to afford 12.3 mg (63%) as a colorless oil.

1.0 Mmol from redox-active ester generated in situ with HATU: Following General Procedure C, with 1-phenylcyclopropane-1-carboxylic acid (162 mg, 1.0 mmol), HATU (380 mg, 1.0 mmol), Et_3N (101 mg, 0.1 mmol), $Fe(acac)_3$ (71 mg, 0.20 mmol) and dppBz (179 mg, 0.4 mmol), Ph_2Zn (2.5 mmol) at 25 ºC. Product **39** (126.3 mg, 65%) and biphenyl (86.7 mg) were isolated as mixture by PTLC (pentane).

Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-32** (31 mg, 0.1 mmol), $Ni(acac)_2$ (5.1 mg, 0.02 mmol), 6,6'-dimethyl-2,2'-bipyridine (3.7 mg, 0.02 mmol), PhZnCl (0.2 mmol, *c* = 0.9 M in THF) in acetonitrile (0.2 mL) at 80 ºC overnight. Product **39** was isolated by PTLC (heptane) to afford 3.2 mg (16 %) as a colorless oil.

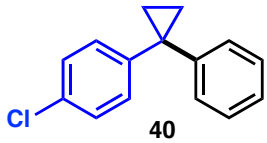
R_f = 0.37 (hexanes)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.27 (t, *J* = 7.4 Hz, 4H), 7.24 – 7.21 (m, 4H), 7.20 – 7.15 (m, 2H), 1.30 (s, 4H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 145.9, 128.6, 128.4, 126.1, 30.0, 16.6.

Spectral data are in accordance with those reported in the literature.[20]

1-Chloro-4-(1-phenylcyclopropyl)benzene (40).



40

From isolated redox-active ester: Following General Procedure B, with **SI-33** (34 mg, 0.1 mmol), $Fe(acac)_3$ (14.1 mg, 0.04 mmol), dppBz (21.4 mg, 0.048 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **40** was isolated by PTLC (pentane) to afford 8.9 mg (39%) as a colorless oil.

From redox-active ester generated in situ with HATU: Following General Procedure C, with 1-(4-chlorophenyl)cyclopropane-1-carboxylic acid (20 mg,

0.1 mmol), HATU (38 mg, 0.1 mmol), Et_3N (14 μL, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.02 mmol), dppBz (17.9 mg, 0.04 mmol), Ph_2Zn (0.25 mmol) at 25 ºC. Product **40** was isolated by PTLC (pentane) to afford 14.6 mg (64%) as a colorless oil.

Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-33** (34 mg, 0.1 mmol), $Ni(acac)_2$ (5.1 mg, 0.02 mmol), 6,6'-dimethyl-2,2'-bipyridine (3.7 mg, 0.02 mmol), PhZnCl (0.2 mmol, *c* = 0.9 M in THF) in acetonitrile (0.2 mL) at 80 ºC overnight. Product **40** was isolated by PTLC (heptane) to afford 4.4 mg (19%) as a colorless oil.

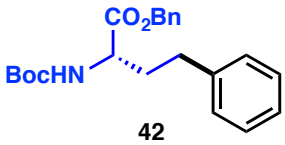
R_f = 0.43 (hexanes)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.28 (t, *J* = 8.5 Hz, 2H), 7.23 (d, *J* = 8.5 Hz, 2H), 7.22 – 7.18 (m, 3H), 7.16 (d, *J* = 8.5 Hz, 2H), 1.34 – 1.30 (m, 2H), 1.29 – 1.25 (m, 2H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 145.3, 144.4, 131.8, 129.9, 128.5, 128.5, 128.5, 126.3, 29.6, 16.6.

HRMS (GCMS-CI): *m/z* 228 (M+), 193, 178, 165, 150

(*S*)-Benzyl 2-(*tert*-butoxycarbonylamino)-4-phenylbutanoate (42).



42

From isolated redox-active ester: Following General Procedure B, with **SI-21** (62.1 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.020 mmol), dppBz (10.7 mg, 0.024 mmol), Ph_2Zn (0.15 mmol) at r.t. Product **42** was isolated by PTLC (hexanes:ethyl acetate 6:1) to afford 9.8 mg (27%) as a yellowish oil.

R_f = 0.30 (hexanes:ethyl acetate 5:1).

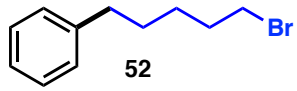
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.38 – 7.32 (m, 5H), 7.26 (t, *J* = 7.8 Hz, 2H), 7.18 (t, *J* = 7.2 Hz, 1H), 7.11 (dd, *J* = 8.4, 1.2 Hz, 2H), 5.18 (d, *J* = 12.6 Hz,

1H), 5.12 (d, *J* = 12.6 Hz, 1H), 5.07 (d, *J* = 7.2 Hz, 1H), 4.40 (br, 1H), 2.67 – 2.56 (m, 2H), 2.18 – 2.12 (m, 1H), 1.98 - 1.91 (m, 1H), 1.45 (s, 9H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 172.7, 155.5, 141.0, 135.4, 128.8, 128.7, 128.6, 128.54, 128.51, 126.3, 80.1, 67.2, 53.5, 34.6, 31.7, 28.5.

Spectral data are in accordance with those reported in the literature.[21]

5-Bromo-1-phenylpentane (52)

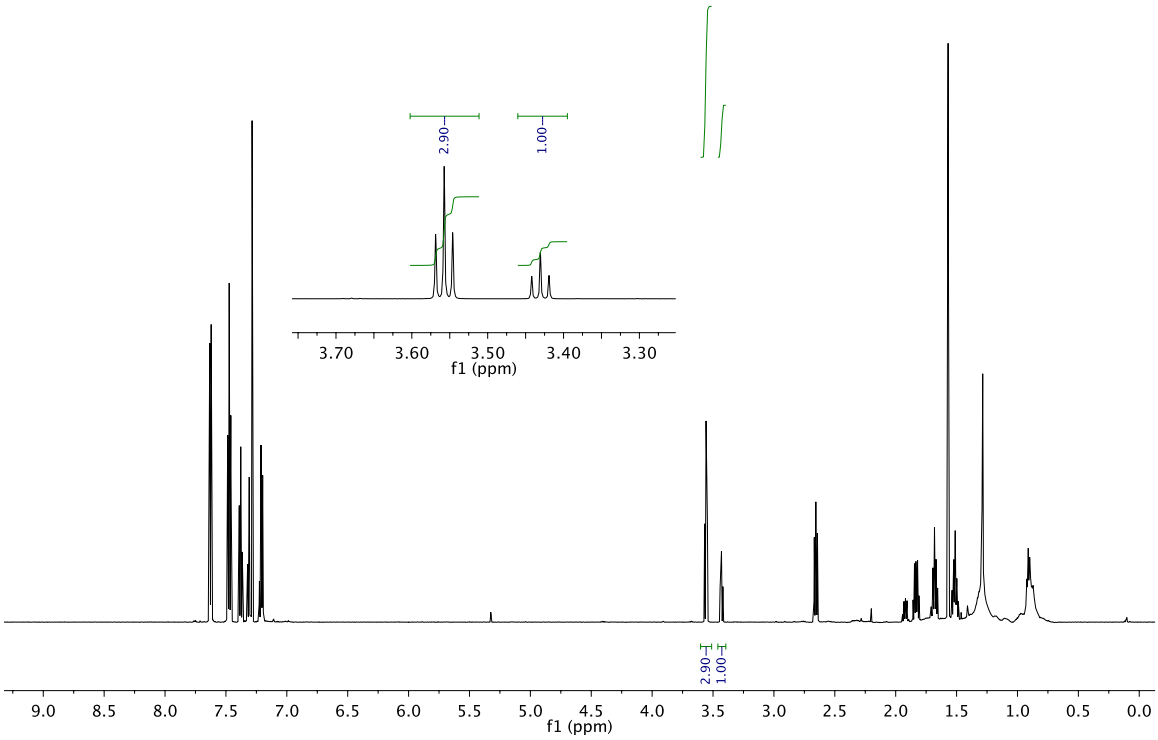


52

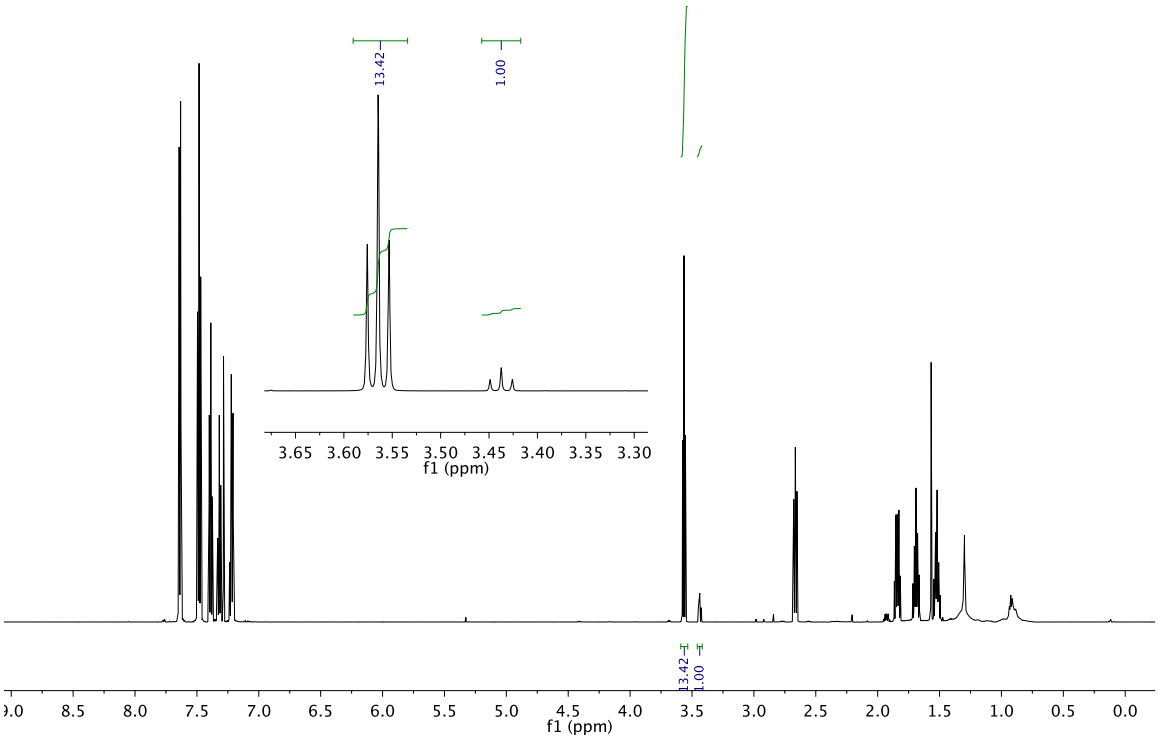
From isolated redox-active ester: Following General Procedure B, with **SI-22** (47.8 mg, 0.1 mmol), $Fe(acac)_3$ (7.1 mg, 0.02 mmol), dppBz (10.7 mg, 0.024 mmol) in toluene. Ph_2Zn (0.15 mmol) was added at 25 ºC. Product **52** was isolated by PTLC (hexanes) to afford 11.8 mg (52%) as transparent oil.

From 6-bromohexanoic acid following General Procedure C: Activation was carried out with 6-bromohexanoic acid (19.5 mg, 0.1 mmol), HATU (38.0 mg, 0.1 mmol) and Et_3N (10.1 mg, 0.1 mmol) in 0.2 mL of THF, followed by $Fe(acac)_3$ (7.1 mg, 0.020 mmol) and dppBz (10.7 mg, 0.024 mmol) in 0.5 mL of toluene. Ph_2Zn (0.15 mmol) was added at r.t. Product **52** was isolated by PTLC (hexanes) to afford 16.3 mg (72%) as yellowish oil.

Negishi-coupling using Ni-catalysis using in-situ generated RAE. Following General Procedure F, with *6-bromohexanoic acid* (19.5 mg, 0.1 mmol), HATU (38.0 mg, 0.1 mmol), Et_3N (10.1 mg, 0.1 mmol), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **52** and **52-Cl** (10.4 mg, 54%) were isolated as mixture of isomers (Br: Cl = 1 : 2.9 mol/mol) by PTLC (hexanes). The mixture contained biphenyl as impurity (9.4 mg).



Negishi-coupling using Ni-catalysis. Following General Procedure E, with **SI-22** (47.8 mg, 0.1 mmol), $NiCl_2$·glyme (4.4 mg, 0.02 mmol), di-*tert*-butylbipyridine (11 mg, 0.04 mmol), PhZnCl (0.3 mmol) at 25 ºC. Product **52** and **52-Cl** (4.1 mg, 22%) were isolated as mixture of isomers (Br : Cl = 1 : 13.4 mol/mol) by PTLC (hexanes). The mixture contained biphenyl as impurity (4.4 mg).



R_f = 0.90 (hexanes).

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.29 – 7.27 (m, 2H), 7.20 – 7.16 (m, 3H), 3.40 (t, *J* = 7.2 Hz, 2H), 2.63 (t, *J* = 7.8 Hz, 1H), 1.92 – 1.87 (m, 2H), 1.68 – 1.63 (m, 2H), 1.51 – 1.46 (m, 2H).

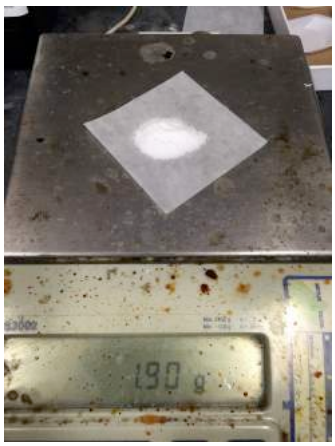
^{13}C NMR (151 MHz, $CDCl_3$): δ 142.5, 128.5, 128.5, 125.9, 35.9, 33.9, 32.8, 30.8, 28.0.

Spectral data are in accordance with those reported in the literature. [22]

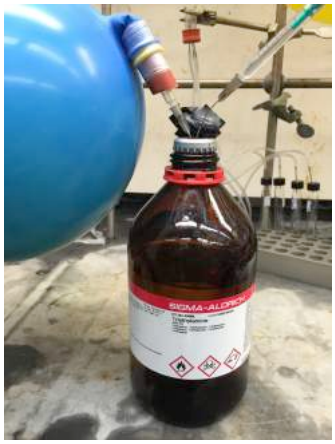
12. Procedure for a mock-medicinal chemistry gram-scale Fe-catalyzed Negishi cross-coupling with redox-active esters generated *in situ*.

In a 50 mL round-bottomed flask, 1-tosylpiperidine-4-carboxylic acid **46** (1.42 g, 5.0 mmol), HATU (1.90 g, 5.0 mmol) were weighed. The flask was equipped with a rubber septum, evacuated and refilled with Ar 3 times. Then, Et_3N (0.69 mL, 5.0 mmol) followed by THF (10 mL) were added via syringe under Ar. The mixture was stirred for 2 h at room temperature (usually, the solution becomes clear after this time). In a separate round-bottomed flask, $Fe(acac)_3$ (177 mg, 0.5 mmol) and dppBz (446 mg, 1.0 mmol) were weighed. The flask was evacuated and backfilled with Ar 3 times. Then, THF (15 mL) was added to form a red solution. The solution was stirred until all solids were soluble (20 min). At this point, the mixture was transferred to the redox-active ester flask in one portion at 0 ºC, followed by the addition of Ph_2Zn (36.8 mL, 0.34 M, 12.5 mmol, 2.5 equiv.) via syringe in one portion at the same temperature. The mixture was warmed to room temperature immediately after the addition of the Ph_2Zn and stirred for 1 h. The mixture was quenched with 1N HCl and diluted with diethyl ether. The aqueous layer was extracted with additional diethyl ether (3 times) and the combined organic layers were washed with 3 M NaOH, separated dried over Na_2SO_4 anhydrous, filtered and evaporated to dryness. Pure product **13** (1.08 g, 69% yield) was obtained after column chromatography (hexanes:ethyl acetate 8:2).

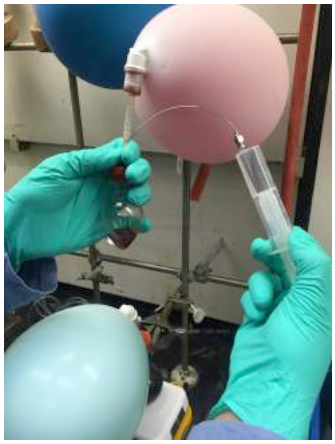
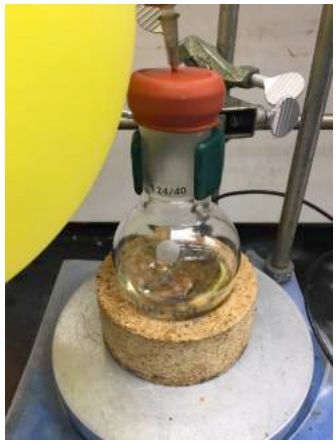
12.1. Graphical Guide for the Fe-catalyzed Negishi coupling at gram scale.


Left: 4-tosylpiperidine-1-carboxylic acid weight. **Center:** HATU weight. **Right:** evacuation and backfilling with Ar of the HATU/carboxylic acid mixture.

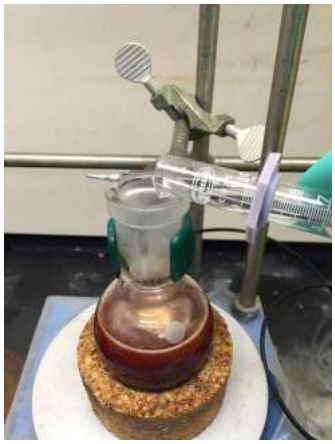




Left: addition of THF. **Center:** triethylamine anhydrous. **Right:** addition of triethylamine.

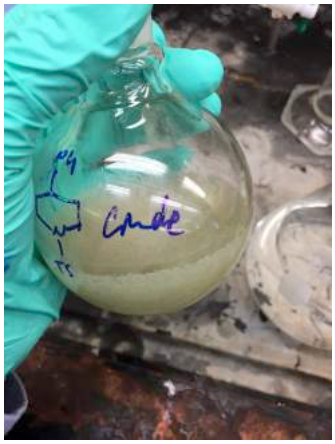
Left: $Fe(acac)_3$ and dppBz in a flask. Evacuated and backfilled with Ar. **Center:** addition of THF. **Right:** redox-active ester after 2 h at r.t.



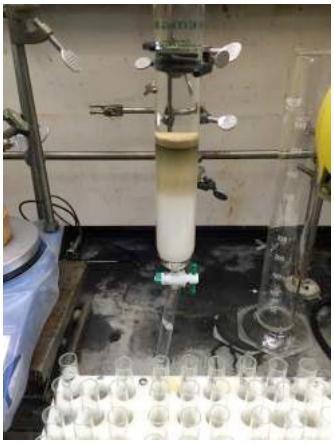
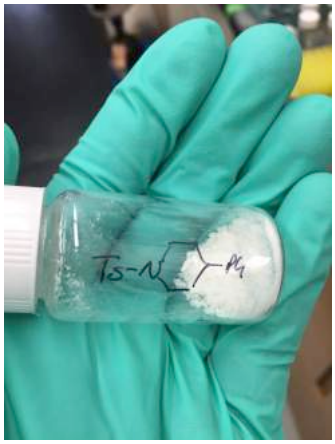


Left: addition of Fe/ligand solution. **Center:** addition of the organozinc at 0 ºC. **Right:** quench the reaction after 1 h with 1M HCl.





Left: dilution with diethyl ether or ethyl acetate and extract. **Center:** filtration of the drying agent. **Right:** crude reaction mixture after solvent evaporation.

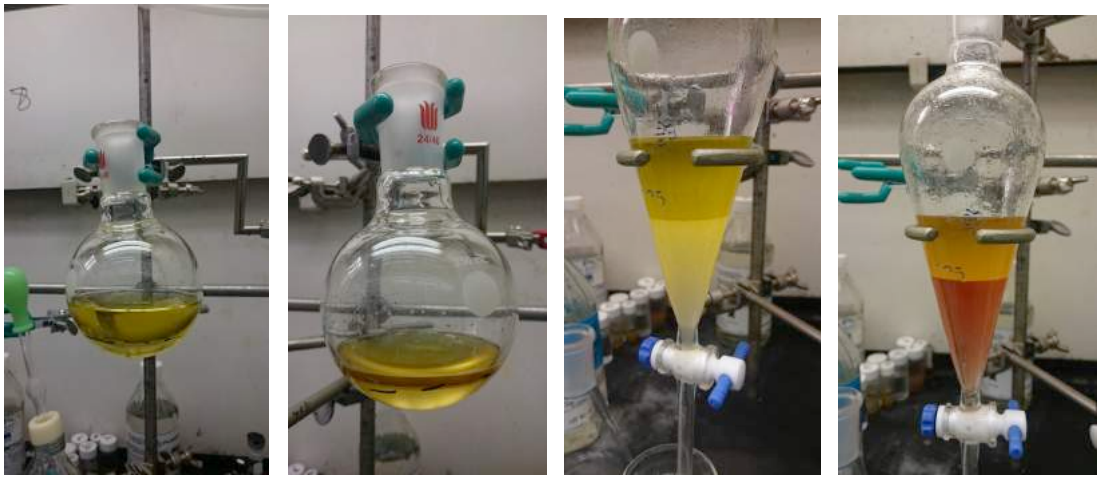
Left: TLC plate of the reaction (left: reaction mixture; center: cross-spot; right: pure material). **Center:** column chromatography. **Right:** isolated pure material.

13. Procedure for the mock-process chemistry scale-up and isolation of the Fe-catalyzed Negishi cross-coupling.

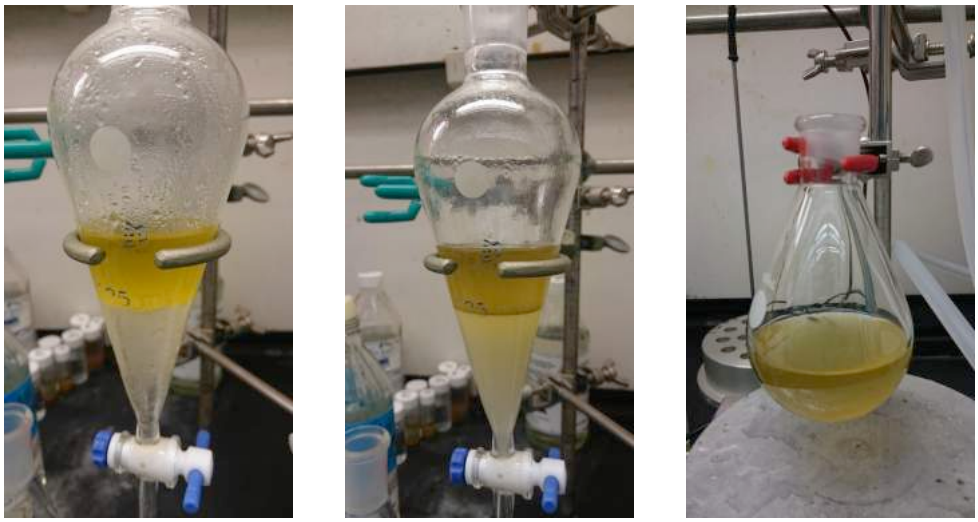
In a 100 mL 3-necked flask equipped with a double manifold and a temperature sensor, 1-tosylpiperidine-4-carboxylic acid **46** (1.42 g, 5.0 mmol), HATU (1.90 g, 5.0 mmol) were weighed. The flask was equipped with a rubber septum, evacuated and refilled with Ar 3 times. Then, Et_3N (0.69 mL, 5.0 mmol) followed by THF (10 mL) were added via syringe under Ar. The mixture was stirred for 2 hours at room temperature (the solution becomes clear after this time). In a separate 2-necked flask equipped with a double manifold, $Fe(acac)_3$ (18 mg, 0.05 mmol) and dppBz (27 mg, 0.06 mmol) were weighed. The flask was evacuated and backfilled with Ar 3 times. Then, THF (15 mL) was added to form a red solution. The solution was stirred until all solids were soluble (10 min). At this point, the mixture was transferred to the redox-active ester vial in one portion at the same temperature. The mixture was cooled at 0 ºC, followed by the addition of Ph_2Zn (37.9 mL, 0.33 M, 12.5 mmol, 2.5 equiv.) via syringe in one portion at the same temperature (internal temperature rose from 1.5 to 19.0 ºC after addition of Ph_2Zn). The mixture was stirred at room temperature for 1 h. The mixture was quenched with 3M HCl (20 mL) after cooling to 3.4 ºC and THF was removed *in vacuo*. The aqueous layer was extracted with toluene (25 mL), the organic layers were washed with water (20 mL x 2) and 2M NaOH (20 mL), and evaporated to 10 mL. To the residue, 2-PrOH (20 mL) was added dropwise and evaporated to 10 mL (The process of addition of 2-PrOH and evaporation was repeated 2 times). To the resulting mixture 2-PrOH (15 mL) was added at 50 ºC and stirred for 1 h at the same temperature. After this time, stirred at room temperature for 30 min. Then, filtered through a sintered funnel followed by a 2-PrOH (10 mL) wash and dry under vacuum. Product **13** was obtained as a white crystalline solid (0.96 g, 61% yield, 99 wt% purity).

13.1. Graphical guide for the mock-process chemistry scale-up and isolation of the Fe-catalyzed Negishi cross-coupling.

For graphical support for carrying out the reaction on large scale, see Section 12.1.

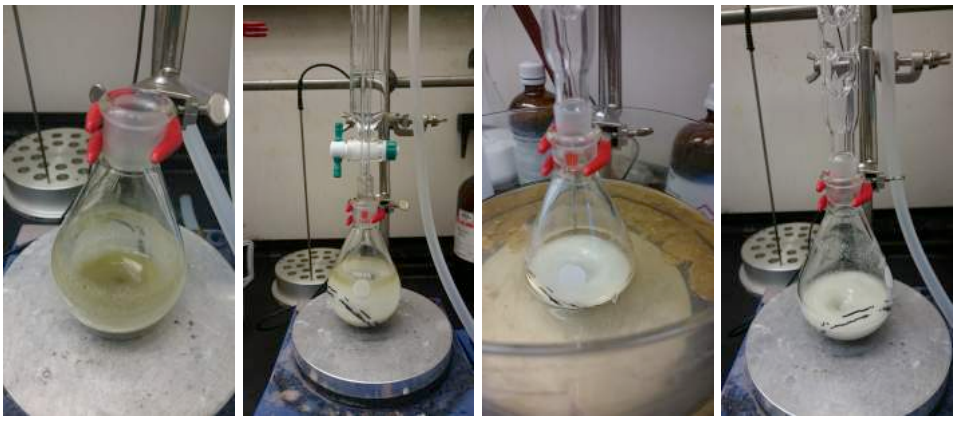


Left: reaction mixture after quench with HCl. **Center-left:** after removal of THF. **Center-right:** addition of toluene and extraction. **Right:** initial wash with water (pH = 0).



Left: second wash with water (pH = 3). **Center:** wash with 2M NaOH. **Right:** organic solution after separation of aqueous layer.

TLC plate (left: pure material; center: cross-spot; right: organic solution after washing).



Left: concentration to 10 mL of toluene. **Center-left: d**ropwise addition of 2-PrOH using an addition funnel. **Center-right:** stirring the system at 50 ºC. **Right: a**fter cooling down and crystallization.

Left: filtration using a sintered funnel. **Right:** isolated crystalline material and mother liquor.

14. Troubleshooting & FAQ

When do I choose Fe- over Ni-catalysis?

Fe-catalysis has proven particularly effective for the arylation of tertiary bridge-head carbons, which are inaccessable using Ni-catalysis. In the Fe-catalyzed reaction, HATU or HBTU activation afforded comparable yields to using isolated RAE. In contrast, in the case of Ni-catalyzed arylation, activation using HATU or HBTU provided workable yields only for α-heteroatom containing acids, e.g. proline. Moreover, the kinetic profile established faster reaction rates for Fe over Ni.

What can I do if I observe significant amounts of H-atom abstraction in the reaction.

We observed that the use of toluene as a co-solvent limited the formation of by-products originating from H-atom abstraction by the alkyl radical generated. These by-products were primarily observed in reactions of tertiary carboxylic acids.

Is the HATU-protocol or the protocol using isolated redox-active esters best for my purpose?

Typically, primary and secondary carboxylic acids performed equally well under conditions. However, in certain cases either HATU or isolated RAE showed superior performance. We recommend to the use of HATU as the standard procedure. If yields are not satisfactory it might be worth looking into the use of isolated RAE.
In couplings of certain tertiary carboxylic acids (e.g. adamantane) the use of HATU led to deminished yields accompanied by formation of Minisci by-products. Switching to HBTU restored the yield of cross-coupling and suppressed the formation of these by-products.

Which conditions should I choose for my particular reaction?

Conditions differ depending on whether isolated ester or in situ activation will be used, and on the type of RAE (primary, secondary, tertiary or amino acid). We have devised a decision tree to aid practitioners in selecting optimal Fe-catalyzed cross-coupling conditions for their particular problem (see Chapter 10)

Can I employ any tertiary carboxylic acid in this reaction?

Currently, our Fe-protocol is limited to bridge-head carboxylic acids and 1-phenylcyclopropyl-1-carboxylic acids. Compounds structurally similar to pivalic acid or 1-methylcyclohexyl-1-carboxylic acid were found to be incompetent reaction partners.

Is it necessary to wait for two hours for the HATU activation?

Compared to the traditional activation of carboxylic acids in DMF, this process is relatively slow in THF. Furthermore low solubility of some carboxylic acids in THF can lead to prolonged activation times. Across a wide range of different carboxylic acids we have found that two hours reaction time reliably afford full conversion to the RAE. This process can be accelerated by gentle heating (50 °C) of the activation reaction.

How important is the solvent quality?

All our experiments were performed with high-quality THF free of stabilizers. We have previously found that solvents containing stabilizers can completely shut down cross-coupling of RAE. Hence, we highly recommend avoiding stabilized solvents.

Can I use other Fe-sources in this reaction?

We have found, that other iron (III) sources are also competent in this reaction. However, we recommend the use of $Fe(acac)_3$, anhydrous $FeCl_3$ or $FeCl_3$ hydrate for best performance.

How long do I have to stir my reaction to reach full conversion?

The reactions were found to be extremely fast. Our kinetic experiment showed, that full conversion was already reached after 5 minutes. We ran our reactions with a standardized reaction time of one hour to ensure reproducibility across the wide range of acids tested. In our experience, longer reaction times do not affect the outcome of the reactions.

Can I use Fe-catalysis for the coupling of two primary centers?

Unfortunately, at the current stage coupling of two primary centers is not viable. We have observed the formation of large amounts β-hydride elimination of both coupling partners. We highly recommend the use of our complementary method using Ni-catalysis.

Which procedure should I follow to prepare the dppBz ligand?

We have performed experiments with either commercial or in-house prepared dppBz without noticing any differences in performance. For the preparation of dppBz, see Ref 23.

How long do I have to stir the Fe/ligand solution?

We have stirred the solution at least for 5 minutes. We suggest stirring until all components are dissolved. In cases were 40 mol% of ligand were used a small quantity of solid remained undissolved.

Can I syringe-pump the diarylzinc solution?

Rapid addition of the arylzinc reagent is critical for the success of the reaction. We do not recommend the use of syringe pumps.

Can I use arylzinc chloride in place of diarylzinc?

For primary and secondary carboxylic acids, arylzinc chlorides are competent coupling partners in the Fe-catalyzed couplings, albeit in slightly diminished yields. Our attempts to couple tertiary carboxylic acids afforded only trace amounts of product.

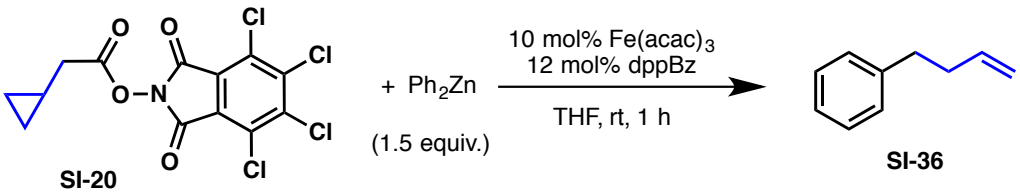
Where can I find addition information and a comprehensive visual guide for the preparation of RAE and HATU activation?

In the three publications preceeding this report we have given detailed information on the preparation of RAE, see Ref 1 and 2.

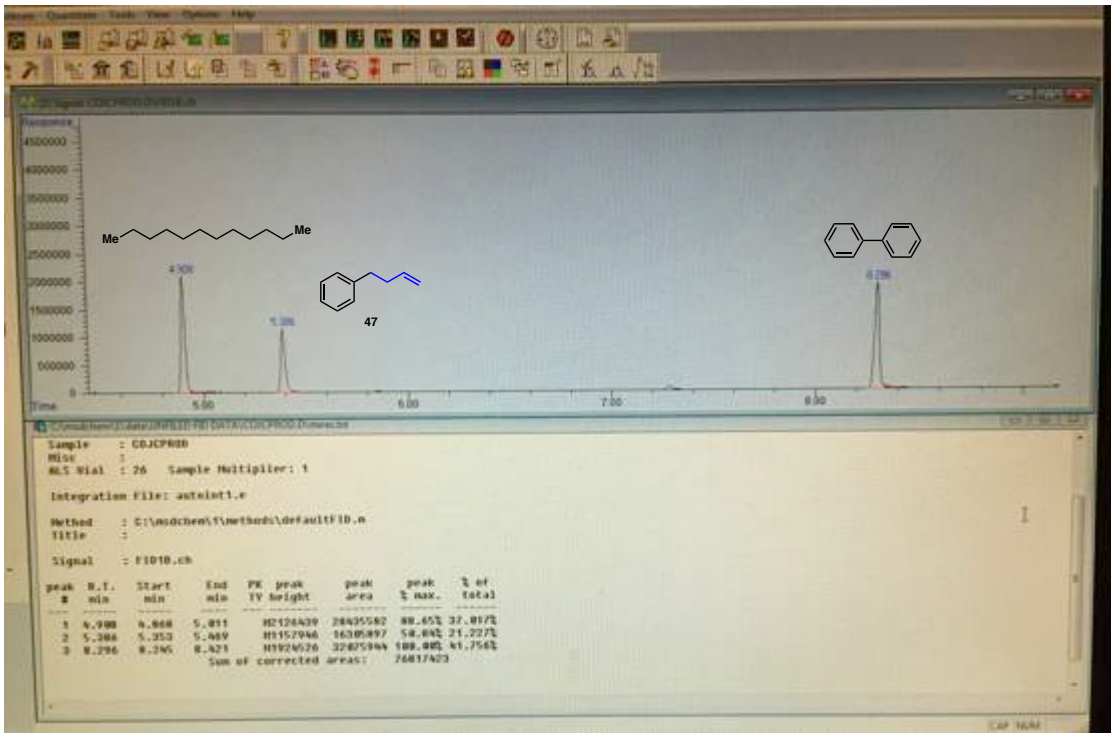
Which by-products should I expect in this reaction?

The main by-product originating from the arylzinc reagent are its homodimerization product along with protodemetalation. The major side product formed from RAE is the hydrolysis product, which in turn is the starting carboxylic acid.
Other by-products observed in variable amounts are β-hydride elimination of the RAE and hydrogen abstraction by the alkyl radical.

15. Mechanistic investigation.

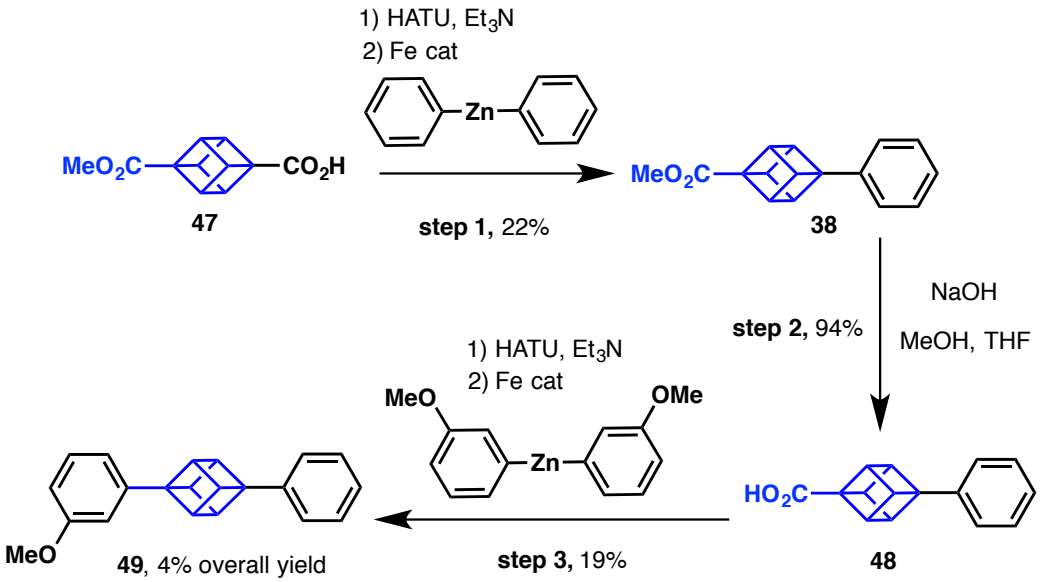


The reaction was carried out following the General Procedure B with **SI-20** (38 mg, 0.1 mmol). After 1 h, dodecane (internal standard, 0.1 mmol, 23 μL) was then added to the mixture and an aliquot was analyzed by GC-FID. Correction factor for **SI-36** versus dodecane is 0.98.



GC-FID of the crude reaction mixture.

16. Iterative diarylation of cubane carboxylic acid.



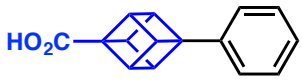
Step 1. In a 100 mL round bottom flask, 4-(methoxycarbonyl)cubane-1-carboxylic acid (**47**) (825 mg, 4.0 mmol), HATU (1.52 g, 4.0 mmol) were weighed. The flask was sealed, evacuated and refilled with Ar 3 times. Then, Et_3N (0.55 mL, 4.0 mmol) followed by THF (8 mL) were added via syringe under Ar. The mixture was stirred for 2 hours at room temperature. In another 25 mL round bottom flask, $Fe(acac)_3$ (283 mg, 0.8 mmol) and dppBz (714 mg, 1.6 mmol) were weighed. The vial evacuated and backfilled with Ar 3 times. Then, THF (12 mL) was added to form a red solution. The solution was stirred until all solids were soluble (10 min). At this point, the mixture was transferred to the redox-active ester vial in one portion at 0 ºC, followed by the addition of Ph_2Zn (23.8 mL, 0.42 M, 10.0 mmol, 2.5 equiv.) via syringe in one portion. The mixture was stirred for 1 h at r.t. before quench with 1N HCl and diluted with diethyl ether and extracted (3 times). The organic layer was separated and dried over Na_2SO_4 anhydrous, filtered and evaporated to dryness. Pure product **38** (215 mg, 22%) was obtained after column chromatography hexanes:ethyl acetate 15:1 and subsequent crystallization from MeOH:H_2O.

Step 2. In a 25 mL round bottom flask, ester **38** (97 mg, 0.41 mmol) was dissolved in THF (4 mL). Then, a solution of NaOH in MeOH (0.49 mL, 1 M,

0.49 mmol, 1.2 equiv.) was added. The mixture was stirred at 25 ºC for 16 h before evaporate to dryness. The crude was then redissolved in H_2O, washed with CH_2Cl_2 (2 times), and the pH adjusted to 1 – 2 with 2M HCl. The mixture was further extracted with CH_2Cl_2, dried with $MgSO_4$ anhydrous, filtered and evaporated to afford pure acid **48** (86 mg, 94%) without further purification. Spectroscopic data for **48** matches those reported in the literature.[24]

Step 3. Compound **49** was prepared following General Procedure C, using **48** (67 mg, 0.3 mmol), $Fe(acac)_3$ (21 mg, 0.06 mmol), dppBz (54 mg, 0.12 mmol), bis(3-methoxyphenyl)zinc (2.27 mL, 0.33 M, 0.75 mmol, 2.5 equiv.). Compound **49** was obtained in pure form (16.5 mg, 19%) after two PTLC (hexanes:toluene 4:1 and hexanes:CH_2Cl_2 4:1).

4-Phenylcubane-1-carboxylic acid (48).[25]

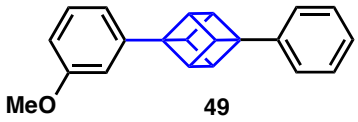


48

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.39 – 7.35 (m, 2H), 7.25 – 7.19 (m, 3H), 4.35 – 4.25 (m, 3H), 4.25 – 4.14 (m, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 178.3, 142.0, 128.6, 126.4, 124.9, 77.4, 77.2, 76.9, 60.4, 56.3, 48.9, 46.2.

1-(3-Methoxyphenyl)-4-phenylcubane (49).



49

m.p. 79 – 81 ºC

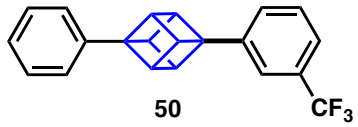
R_f = 0.56 (hexanes/ethyl acetate 15:1)

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 – 7.36 (m, 2H), 7.31 (ddd, *J* = 8.1, 7.5, 0.5 Hz, 1H), 7.30 – 7.25 (m, 2H), 7.25 – 7.19 (m, 1H), 6.87 (ddd, *J* = 7.5, 1.5, 0.9 Hz, 1H), 6.80 (dd, *J* = 2.6, 1.5 Hz, 1H), 6.77 (ddd, *J* = 8.2, 2.6, 1.0 Hz, 1H), 4.18 – 4.13 (m, 6H), 3.85 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 160.0, 145.0, 143.2, 129.6, 128.6, 126.0, 124.9, 117.3, 111.4, 110.6, 77.4, 77.2, 76.9, 61.03, 61.98, 55.4, 47.9

HRMS (ESI-TOF) calc'd for $C_{21}H_{19}O$ $[M+H]^+$ 287.1430 found 287.1432.

1-Phenyl-4-(3-(trifluoromethyl)phenyl)cubane (50)



50

Compound **50** was prepared via the above mentioned three-step procedure, only differing in step 3.

Following General Procedure C, using **48** (22 mg, 70%wt by NMR, 0.07 mmol), $Fe(acac)_3$ (7 mg, 0.02 mmol), dppBz (18 mg, 0.04 mmol), bis(3-benzotrifluoride)zinc (1.32 mL, 0.19 M, 0.25 mmol, 2.5 equiv.). Compound **50** was obtained in pure form (4.0 mg, 18%) after two PTLC (hexanes and CH_2Cl_2).

m.p. 60 – 62 ºC.

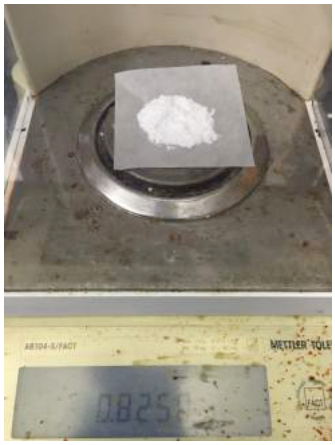
^{1}H-NMR (600 MHz, $CDCl_3$) δ 7.55 – 7.45 (m, 4H), 7.44 – 7.38 (m, 2H), 7.31 – 7.28 (m, 2H), 7.27 – 7.23 (m, 1H), 4.21 (s, 6H).

^{13}C-NMR (151 MHz, $CDCl_3$) δ 143.5, 142.3, 130.3 (q, J = 31.8 Hz), 128.4, 128.0, 127.8, 125.6, 123.0, 123.9 (q, J = 272.4 Hz), 122.2 (q, J = 3.4 Hz), 121.2 (q, J = 3.8 Hz), 60.5, 60.0, 47.3, 47.2.

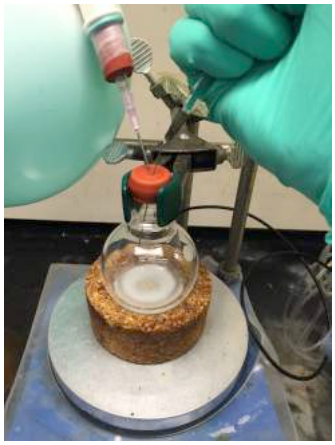
^{19}F-NMR (376 MHz, $CDCl_3$) δ -62.8.

16.1. Graphical guide for the diarylation of cubane carboxylic acid.

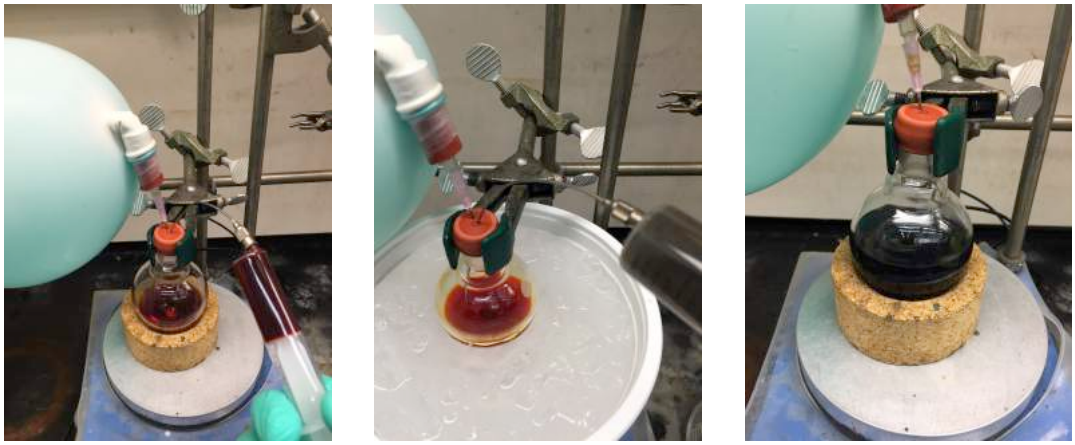
Step 1. First arylation.



Left: carboxylic acid weight. **Center:** HATU weight. **Right:** carboxylic acid and HATU in a flask, evacuated and backfilled with Ar.

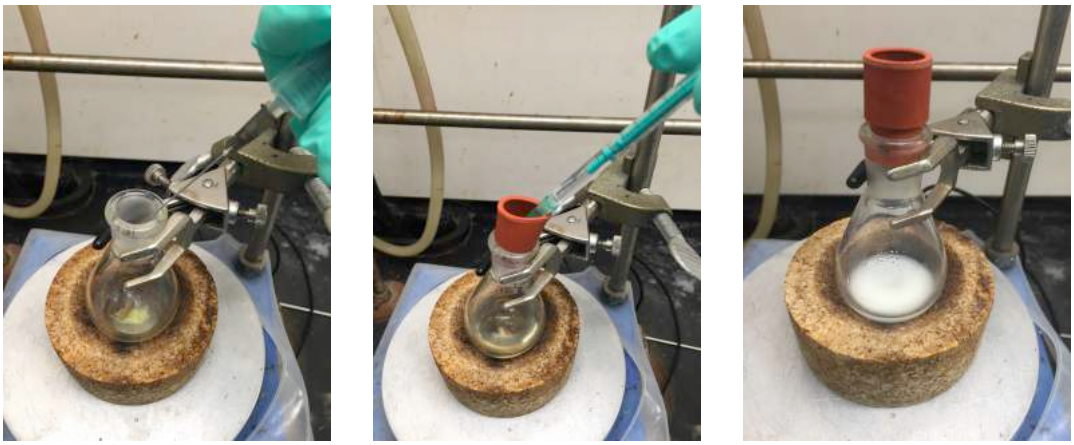

Left: addition of THF. **Center:** addition of triethylamine. **Right:** activation after 2 hours at rt.



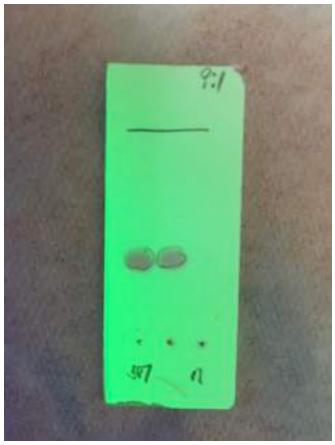
Left: addition of Fe/ligand solution. **Center:** addition of the organozinc at 0 ºC. **Right:** reaction after 1 h at r.t.

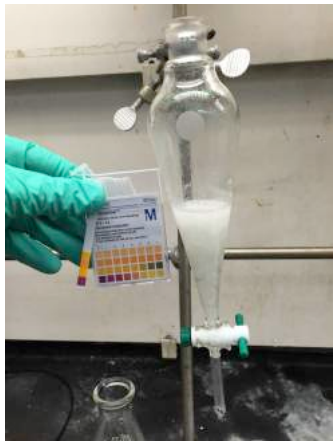
Left: quench of the reaction with 1M HCl. **Center:** dilution and extraction of the organic layer. **Right:** pure product after column chromatography.

Step 2: hydrolysis.



Left: THF is added to the ester in an open flask. **Center:** addition of NaOH in MeOH. **Right:** after stirring at r.t. for 16 h.

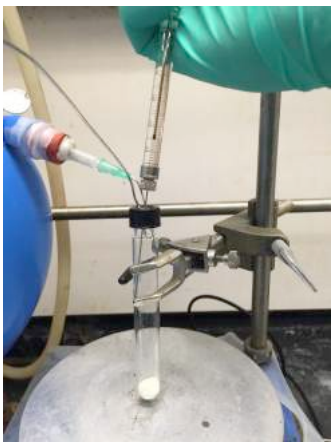
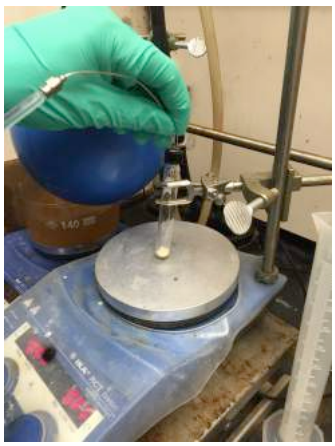




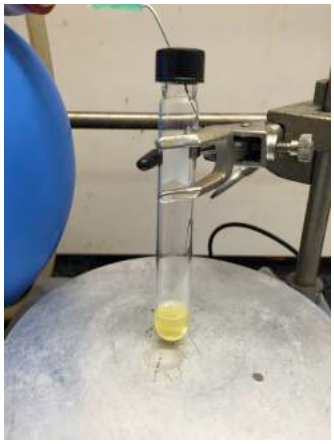
Left: TLC plate of the reaction mixture (left: starting material; center: cross-spot; right: reaction mixture). **Center:** evaporation to dryness. **Right.** pH adjusted with 1M HCl in a separating funnel after dissolving with CH_2Cl_2.

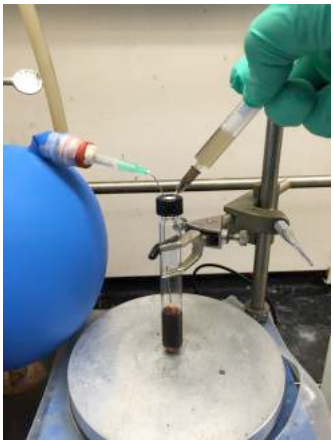

Left: two phases. **Right:** pure product after evaporation of the organic layer.

Step 3. Second arylation

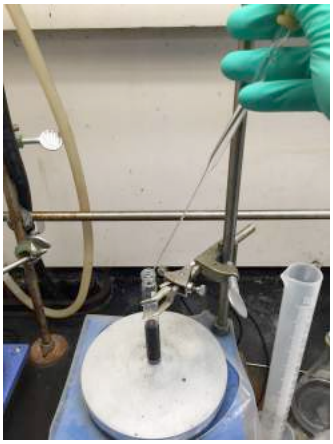




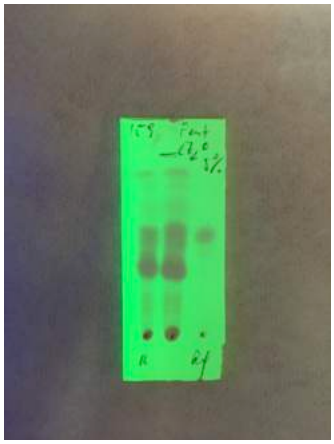
Left: starting carboxylic acid and HATU in aculture tube under Ar. **Center:** addition of triethylamine. **Right:** addition of THF.





Left: reaction tube after 2 h activation at r.t. **Center:** addition of Fe/ligand solution. **Right:** addition of the organozinc reagent at r.t. in one portion.

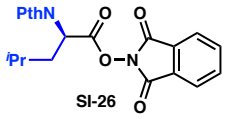




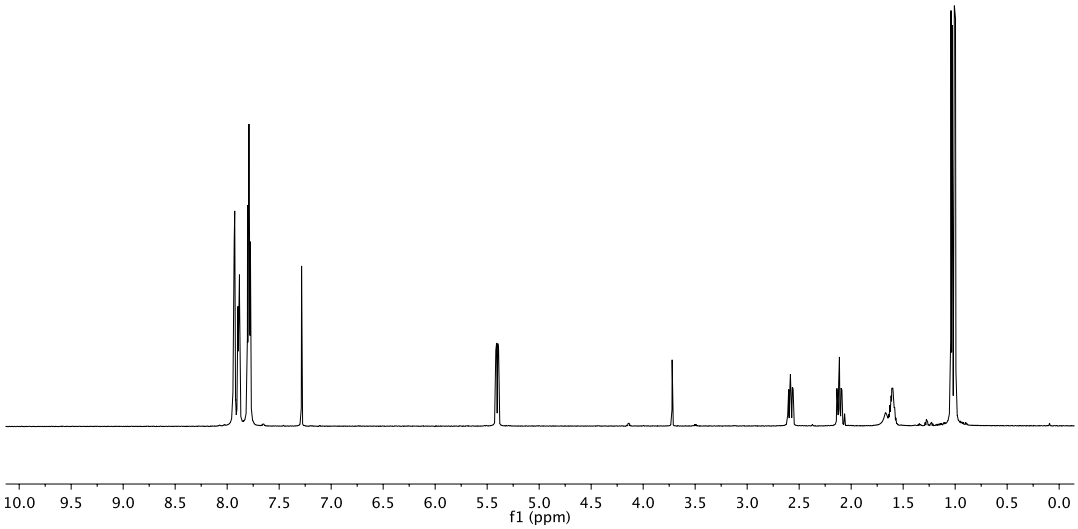
Left: quench of the reaction mixture after 1 h with 1N HCl. **Center:** extraction after dilution with diethyl ether. **Right:** TLC plate of the crude (left: reaction mixture; center: cross-spot; right: pure product).

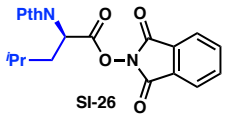
Final product after PTLC.

17. NMR spectra

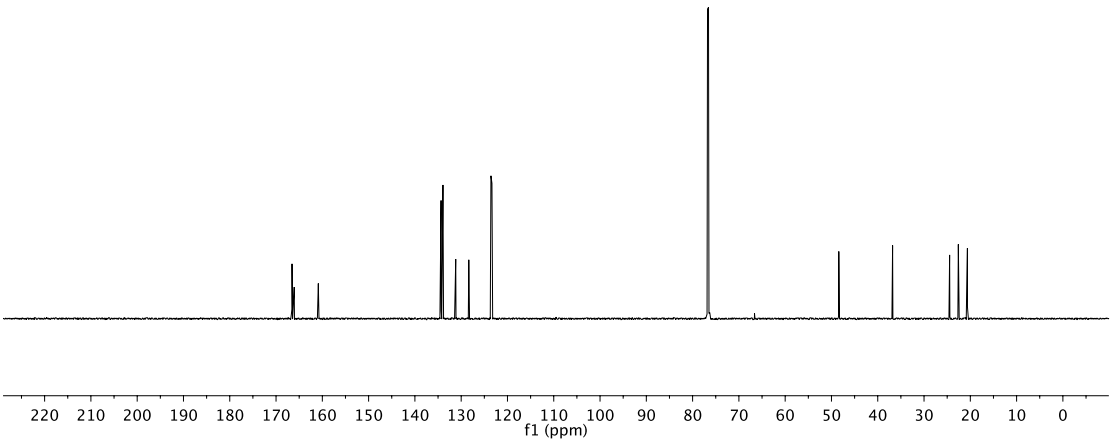


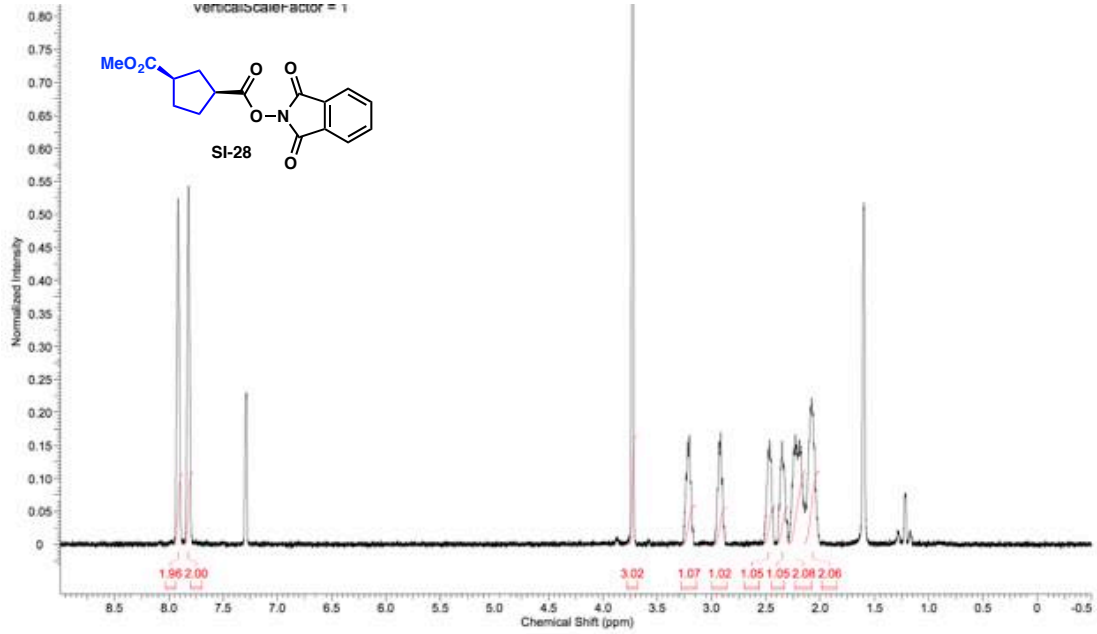
SI-26





SI-26

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O
O
O
N
O
SI-28
Normalized Intensity
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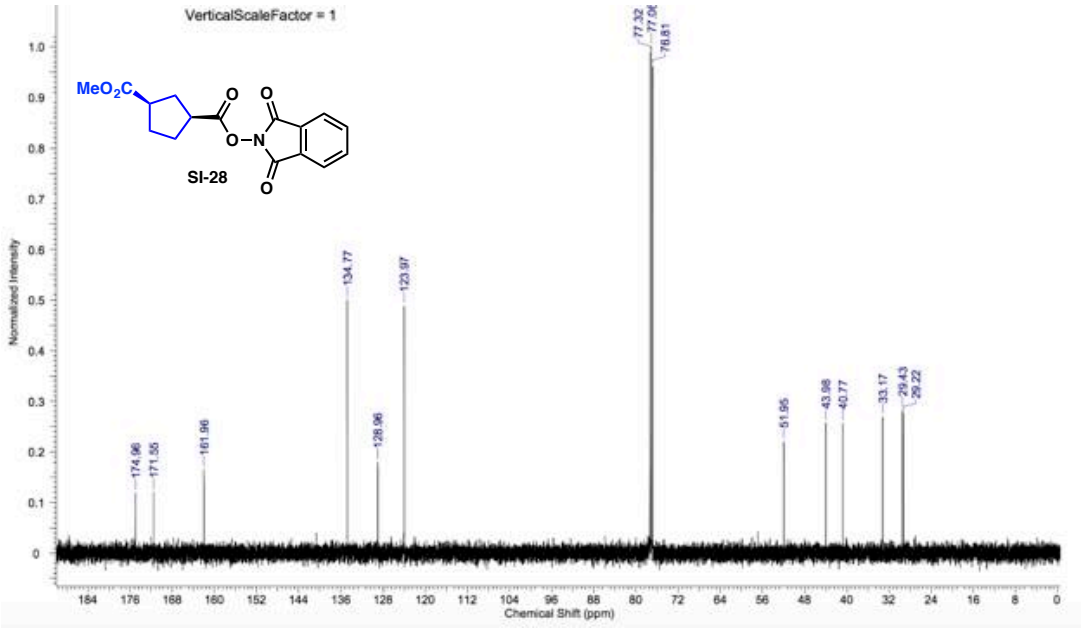
2.00
3.02
1.07
1.02
1.05
1.05
2.08
2.06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O
O
O
N
O
SI-28
Normalized Intensity
Chemical Shift (ppm)
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77.04
76.81
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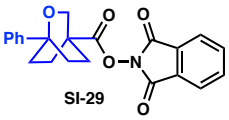
128.96
174.96
171.55
161.96
51.95
43.98
40.77
33.17
29.43
29.22


Ph
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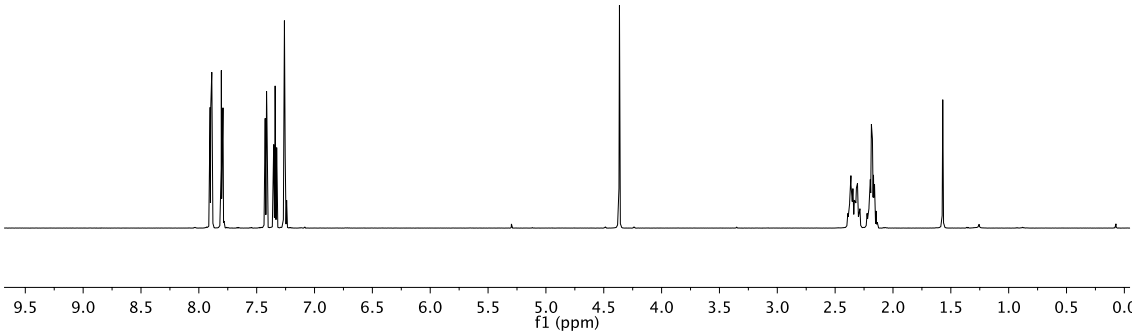
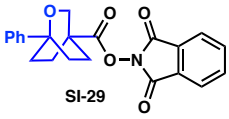
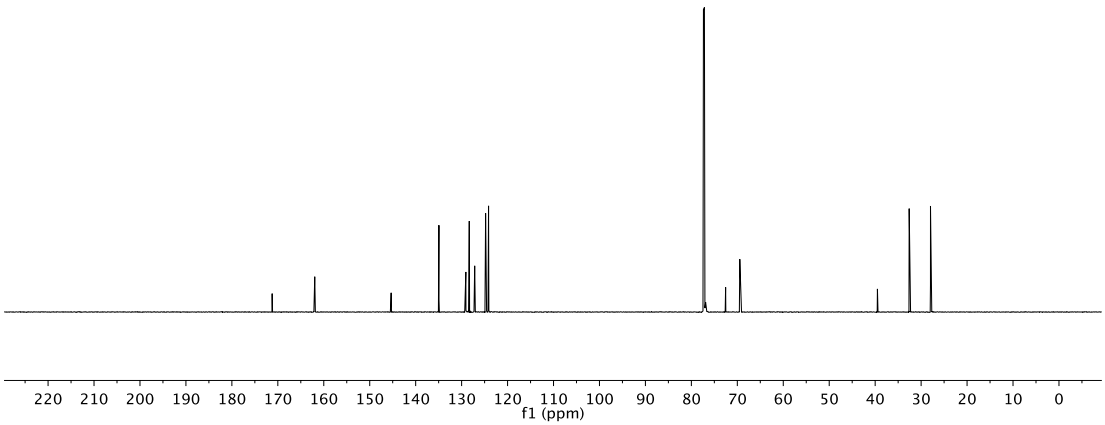
O
O
O
N
O
O

SI-29


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
f1 (ppm)


Ph
O
O
O
O
N
O
O

SI-29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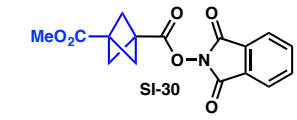
f1 (ppm)


MeO2C
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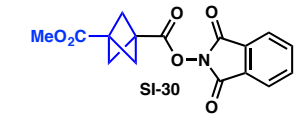
O
O
N
O
O

SI-30

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
f1 (ppm)


MeO2C
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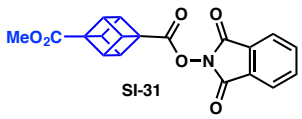
O

SI-30

200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


MeO2C
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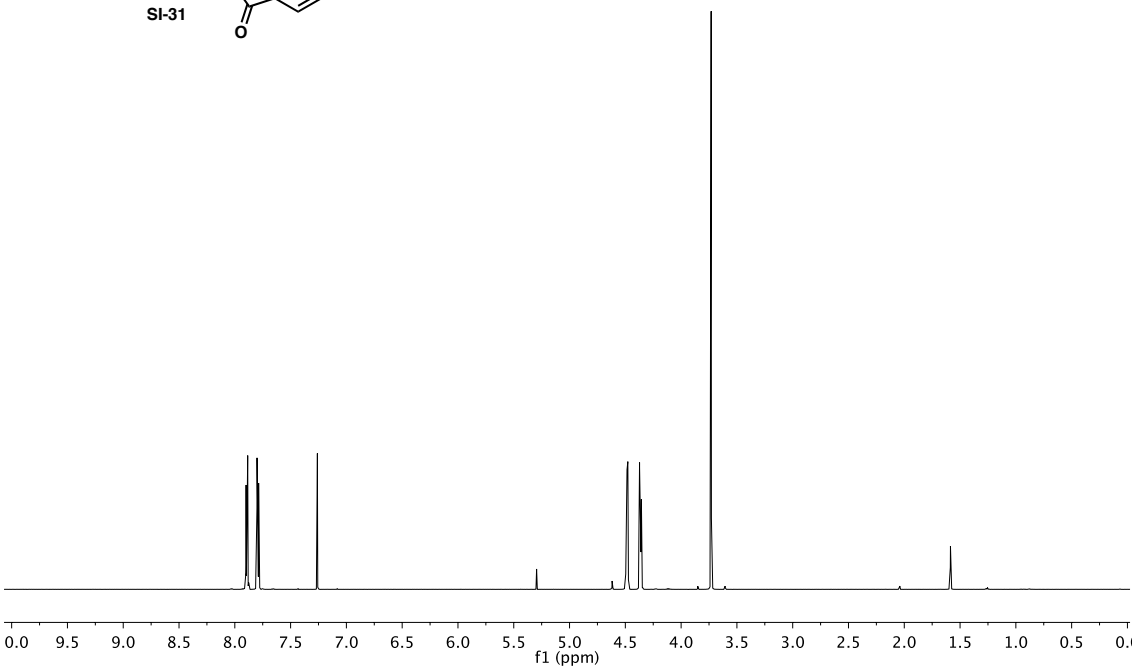
O
O
O
N
O

SI-31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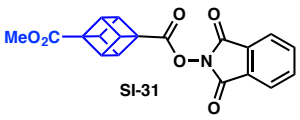
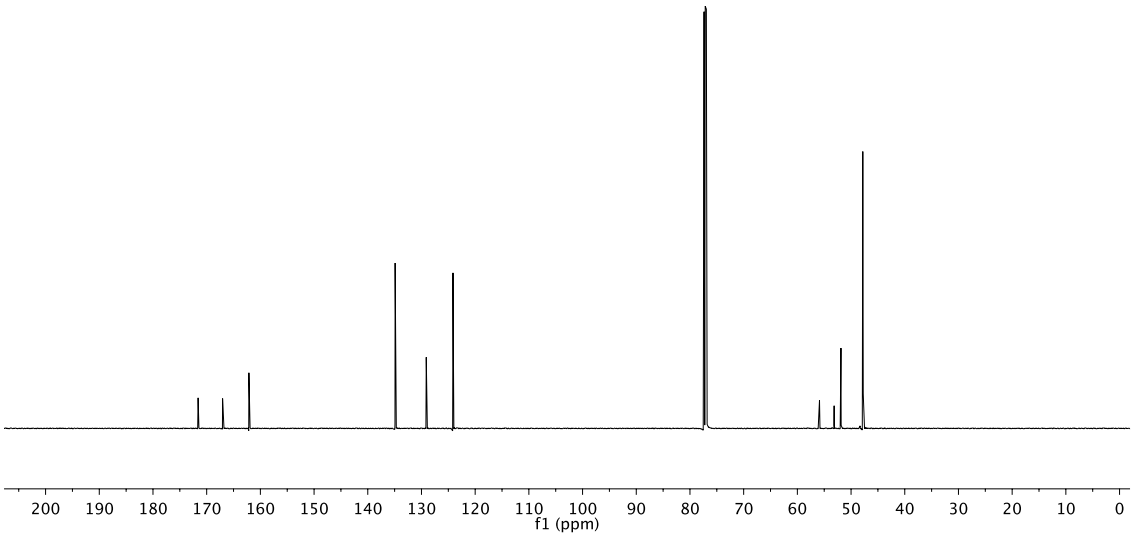
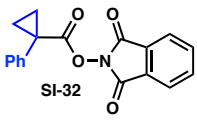
f1 (ppm)

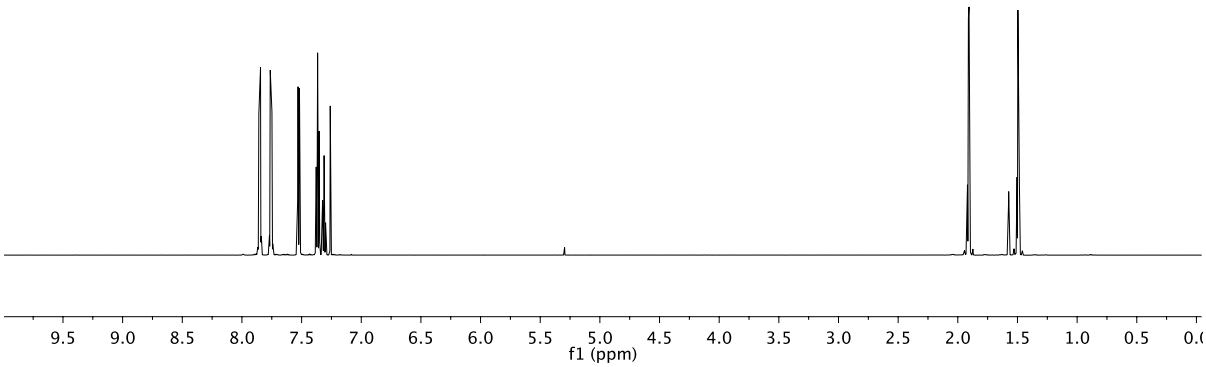

MeO2C
O
O
O
O
N
O

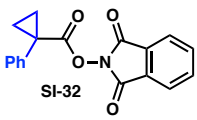
SI-31


200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

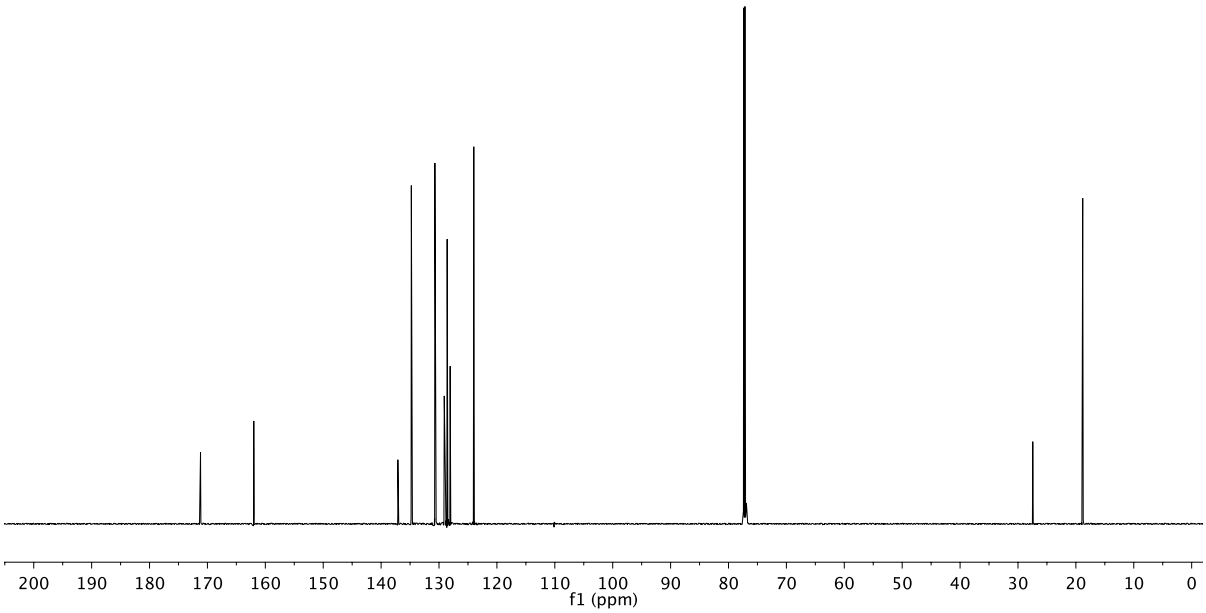

Ph
O
O
O–N
O
O

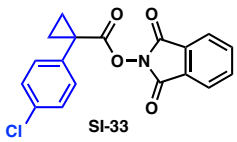
SI-32


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
f1 (ppm)

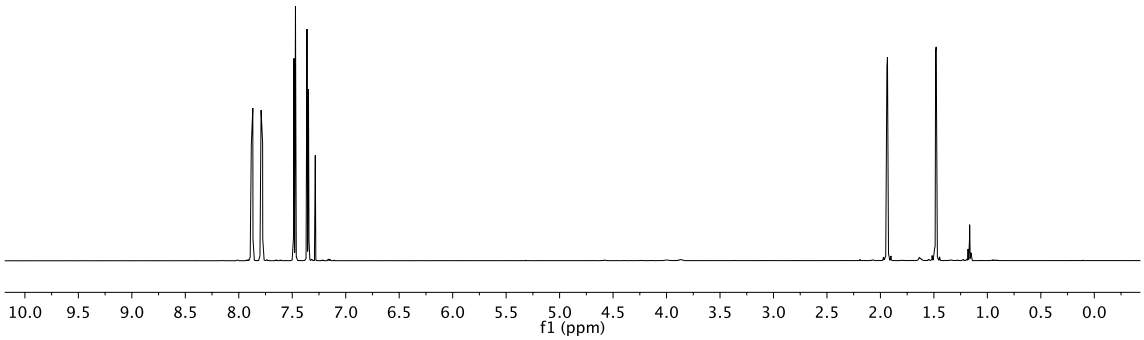

Ph
O
O
O–N
O
O

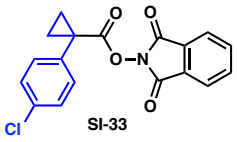
SI-32


200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

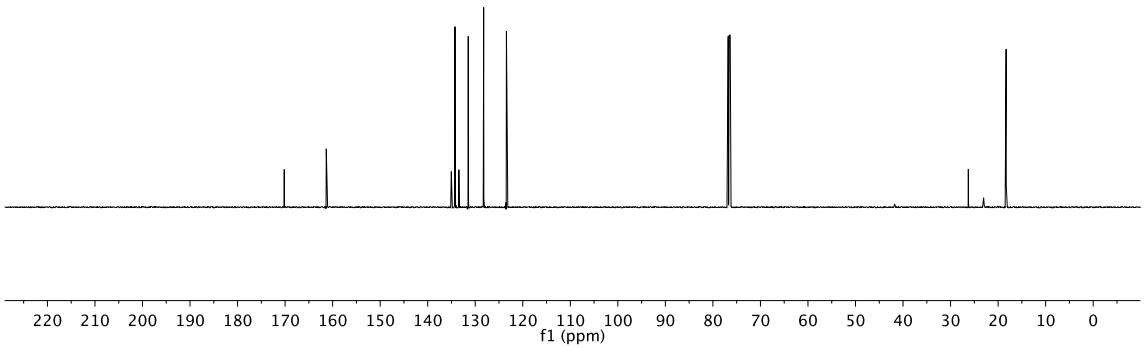

O
O
O
N
O
Cl

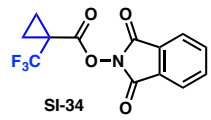
SI-33


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
f1 (ppm)

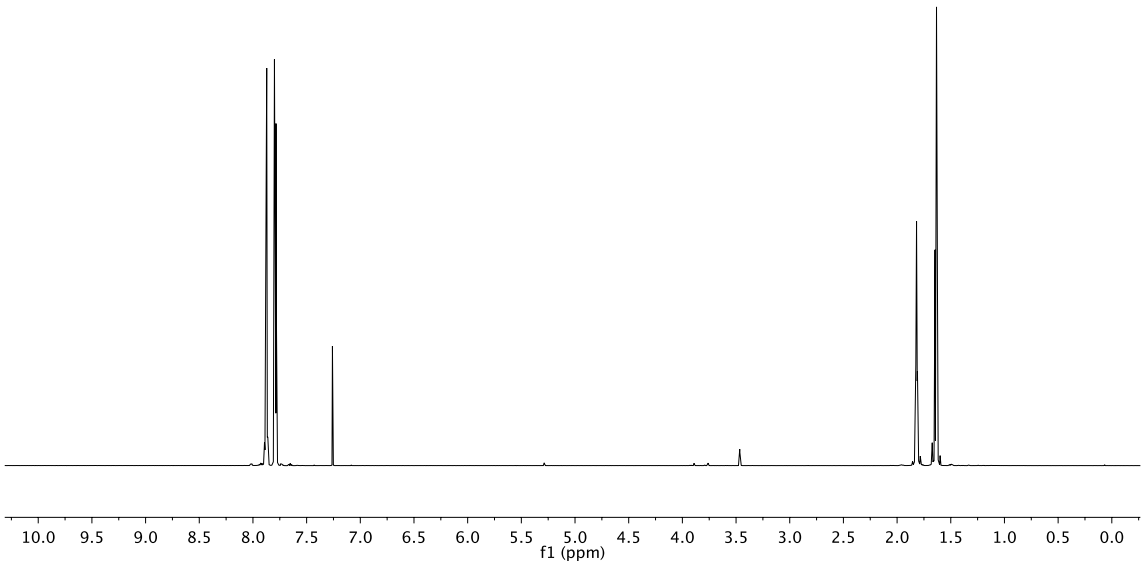

O
O
O
N
O
Cl

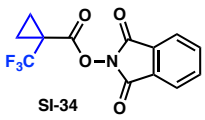
SI-33


220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

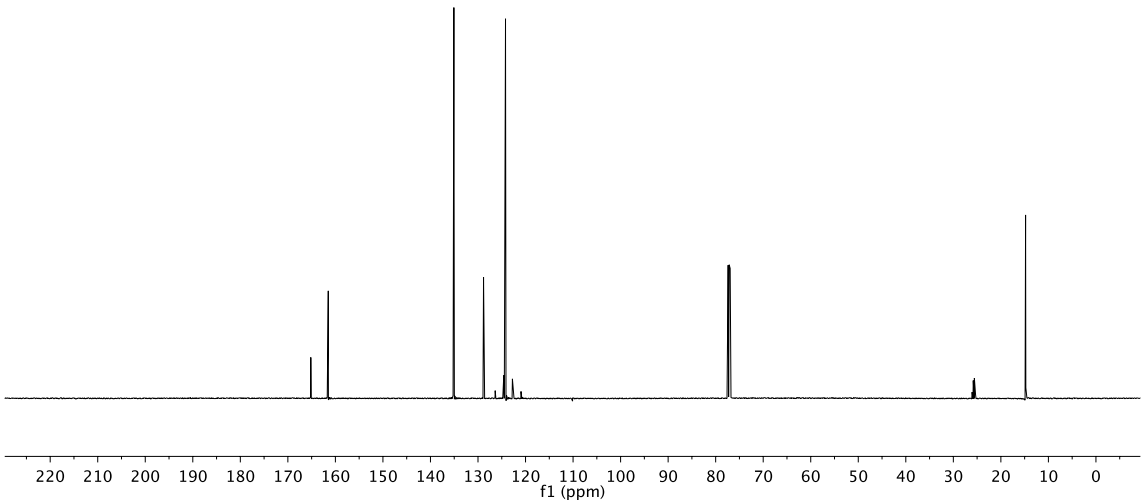

F3C
O
O
O
N
O
O

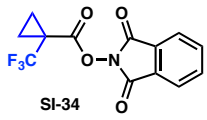
SI-34


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
f1 (ppm)

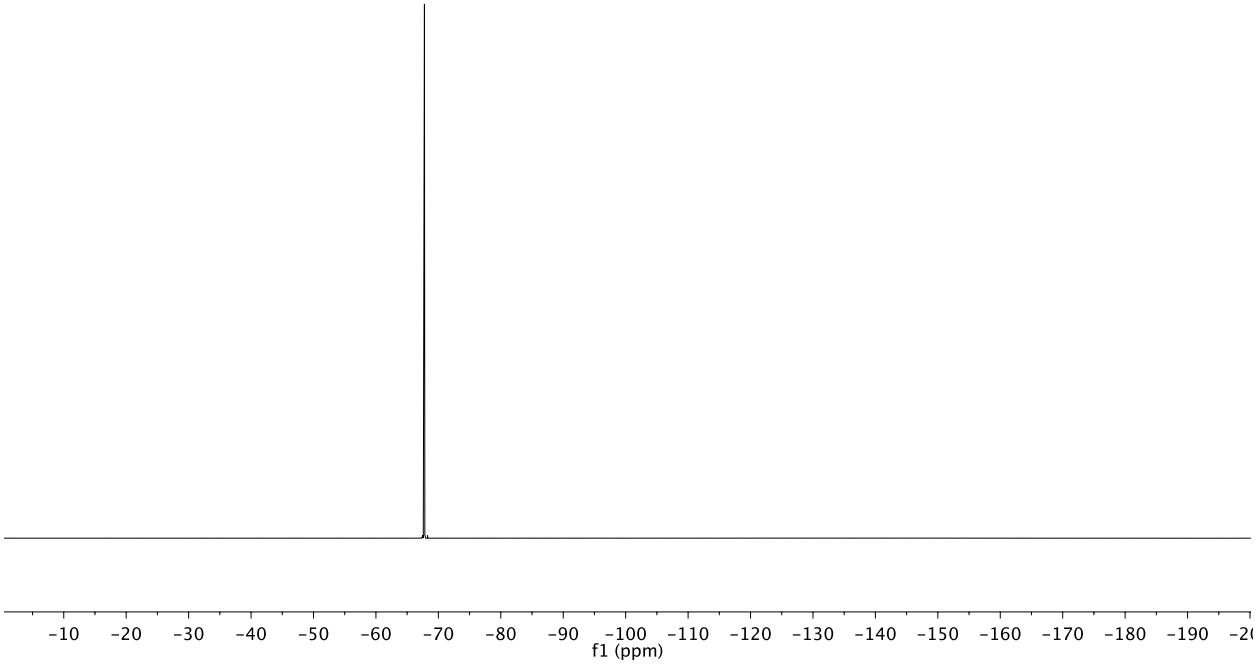

F3C
O
O
O
N
O
O

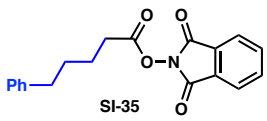
SI-34


220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

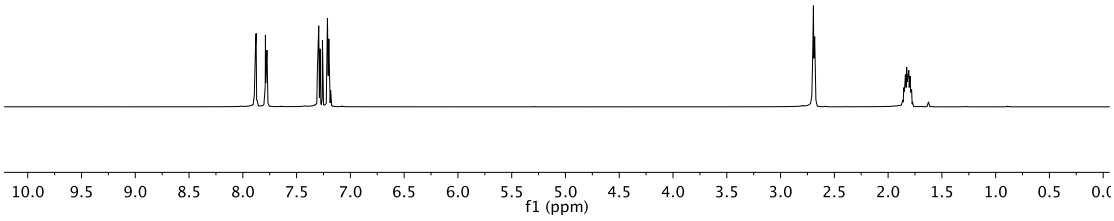

F3C
O
O
O
N
O

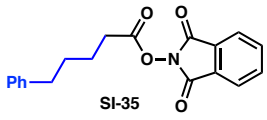
SI-34


−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
−110
−120
−130
−140
−150
−160
−170
−180
−190
f1 (ppm)

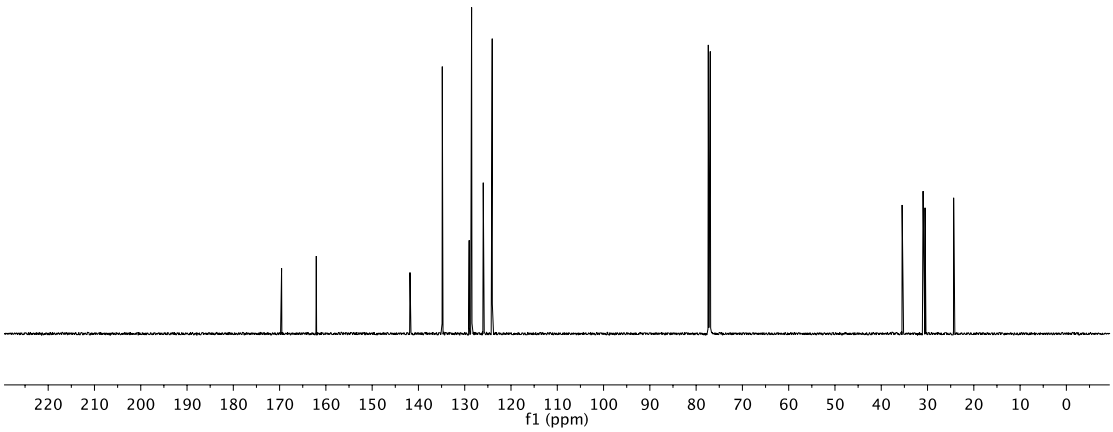

Ph
O
O
O
N
O
O

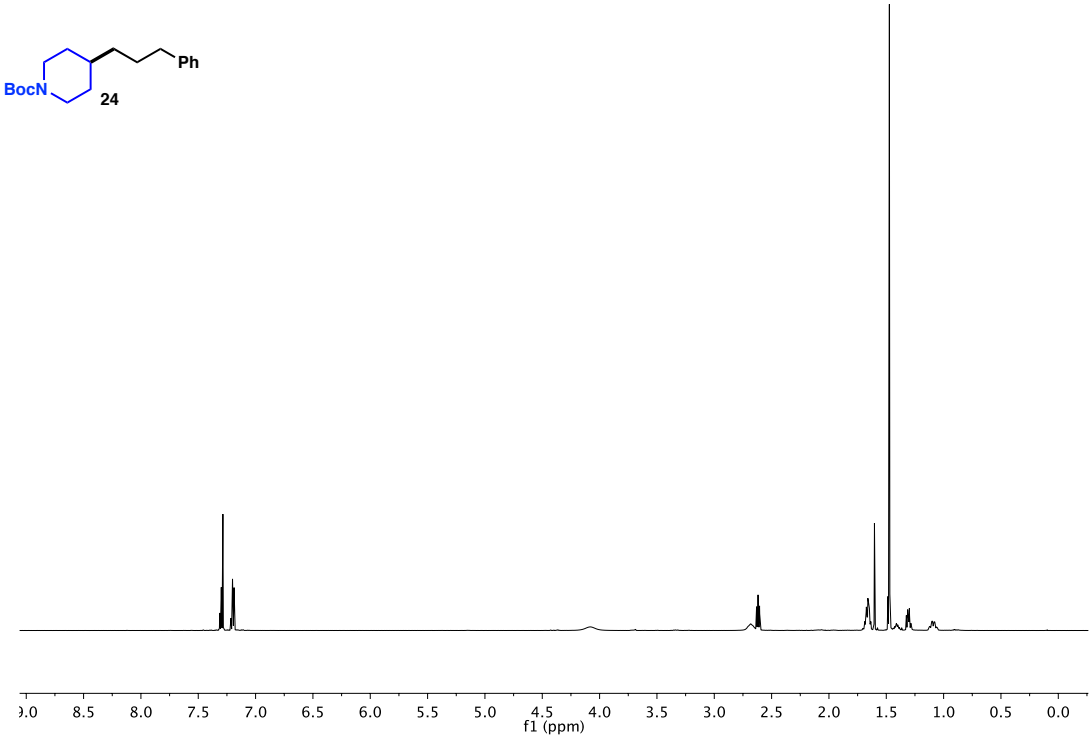
SI-35

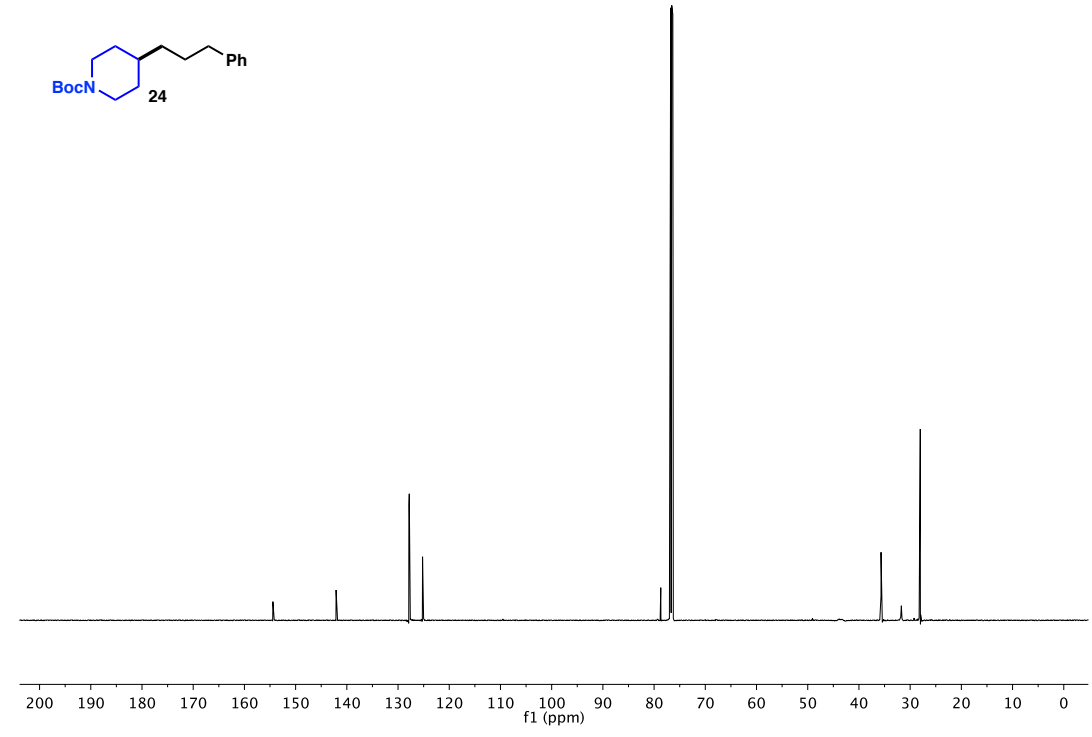

10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)

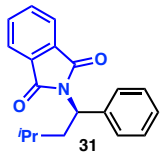

Ph
O
O
O
N
O
O

SI-35

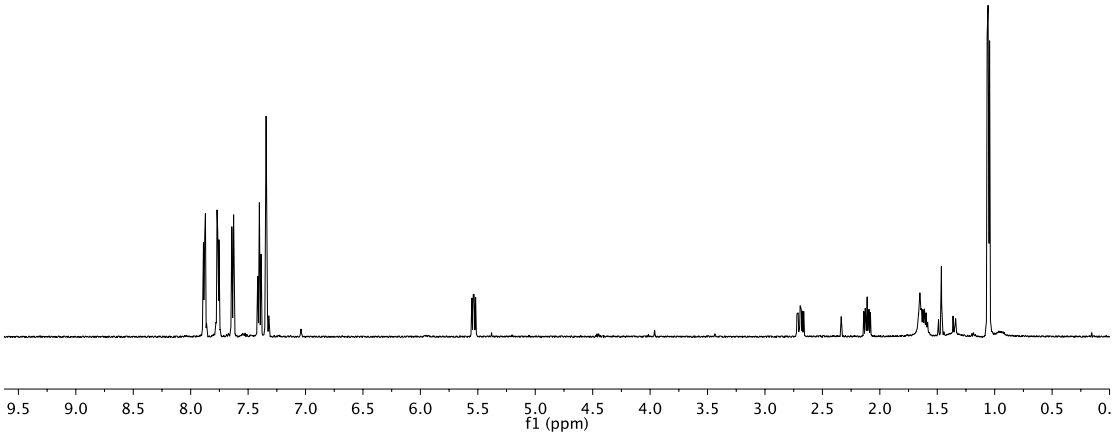

220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

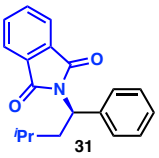

BocN
Ph
24
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


BocN
Ph
24
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

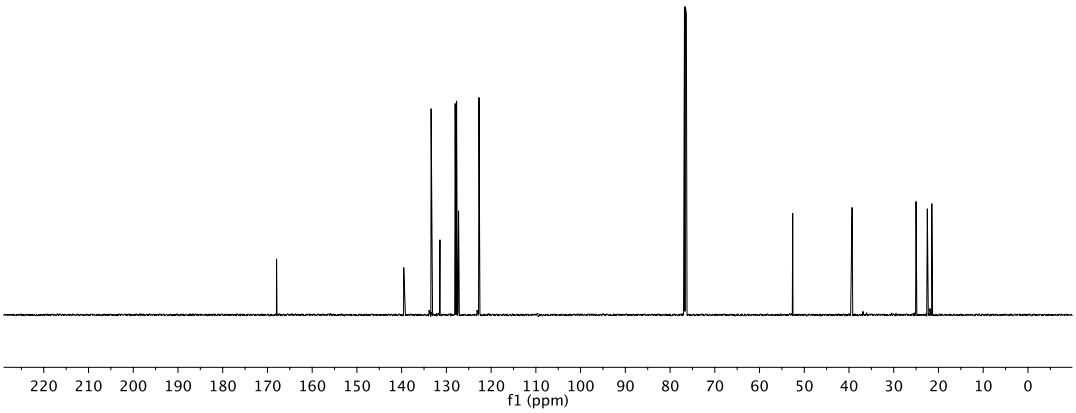

O
O
N
iPr

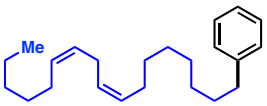
31


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.
f1 (ppm)

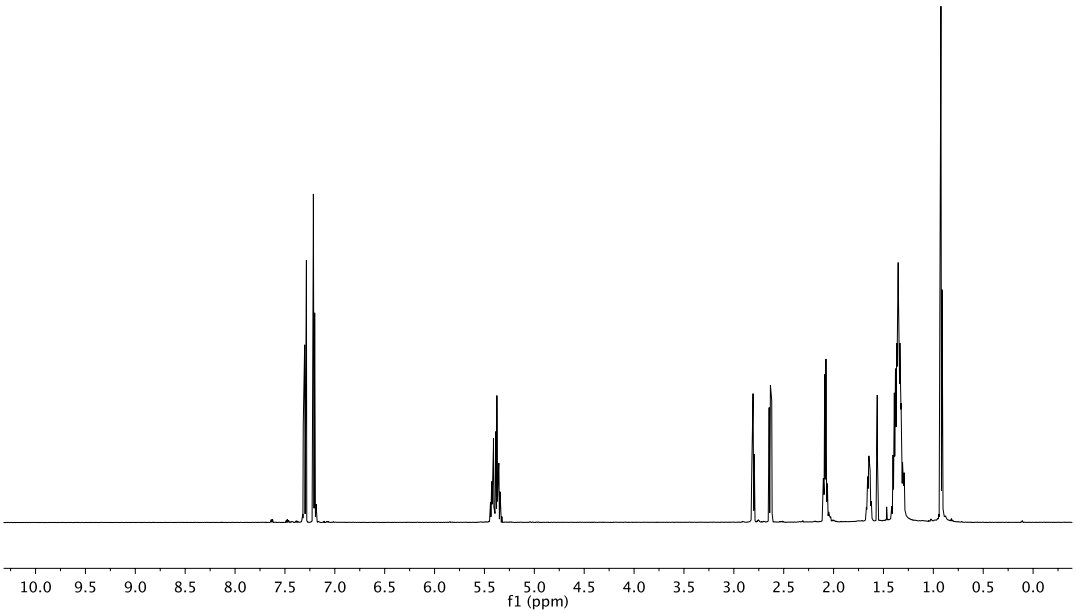

O
O
N
iPr

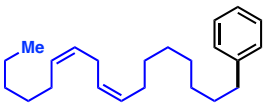
31


220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

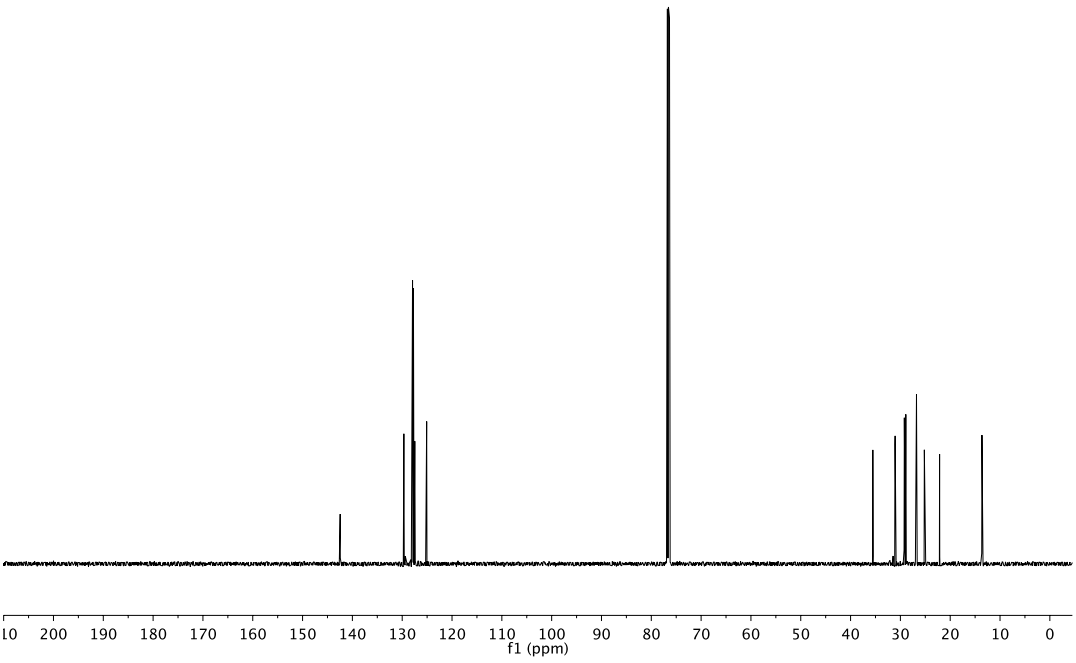

Me

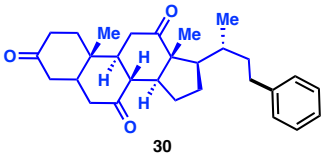
33


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
f1 (ppm)

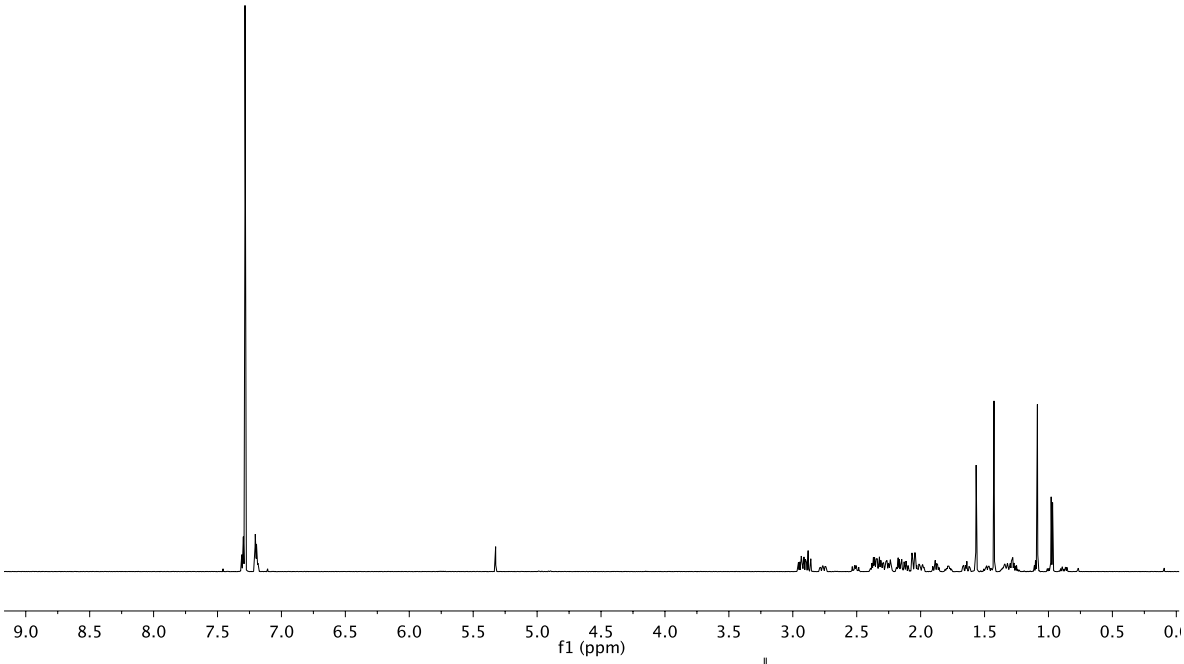

Me

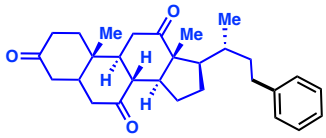
33


200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


Me
Me
Me
O
O
H
H
H
O

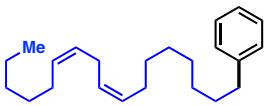
30


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
f1 (ppm)

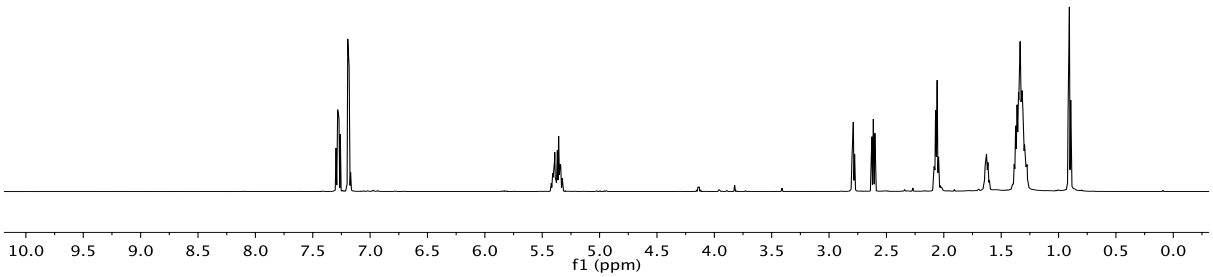

Me
Me
Me
O
O
H
H
H
O

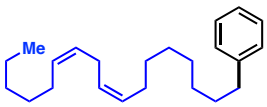
30

220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

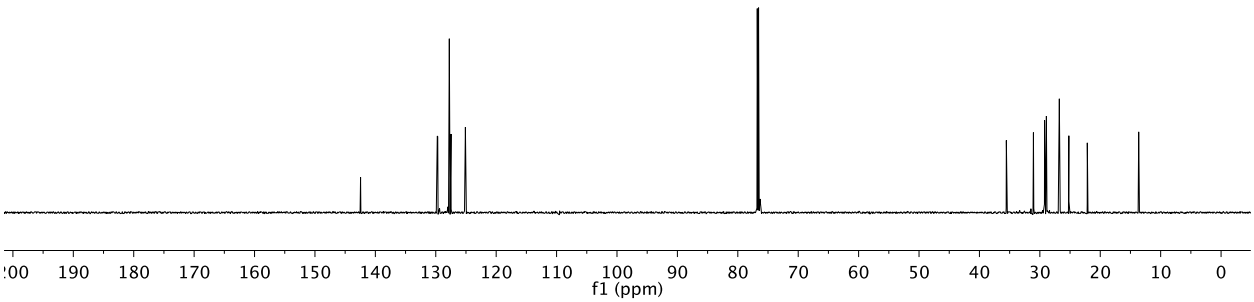

Me

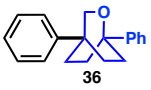
33


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
f1 (ppm)

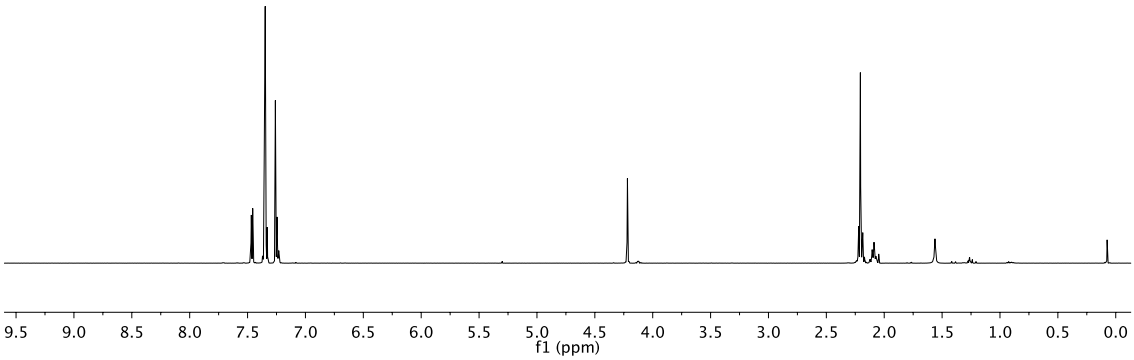

Me

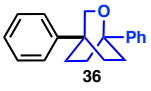
33


:00 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


O
Ph

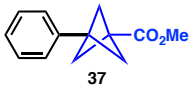
36


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
f1 (ppm)

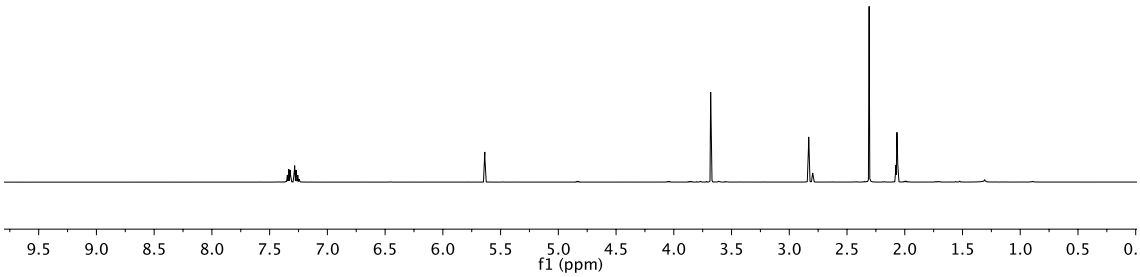

O
Ph

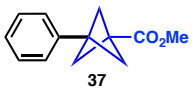
36

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


CO2Me

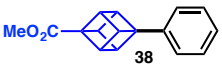
37


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.
f1 (ppm)

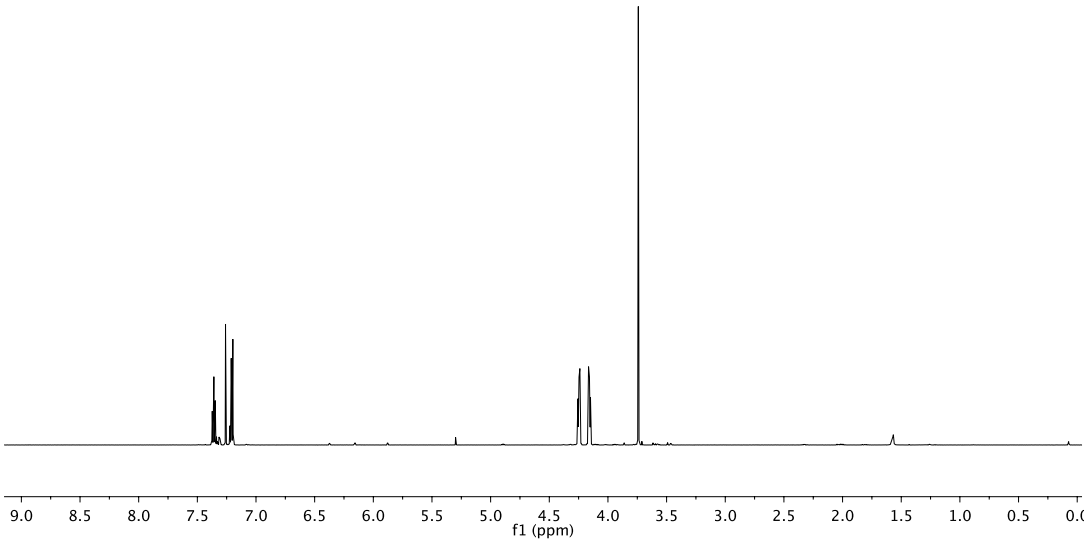

CO2Me

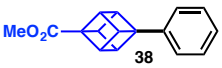
37

00 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20
f1 (ppm)

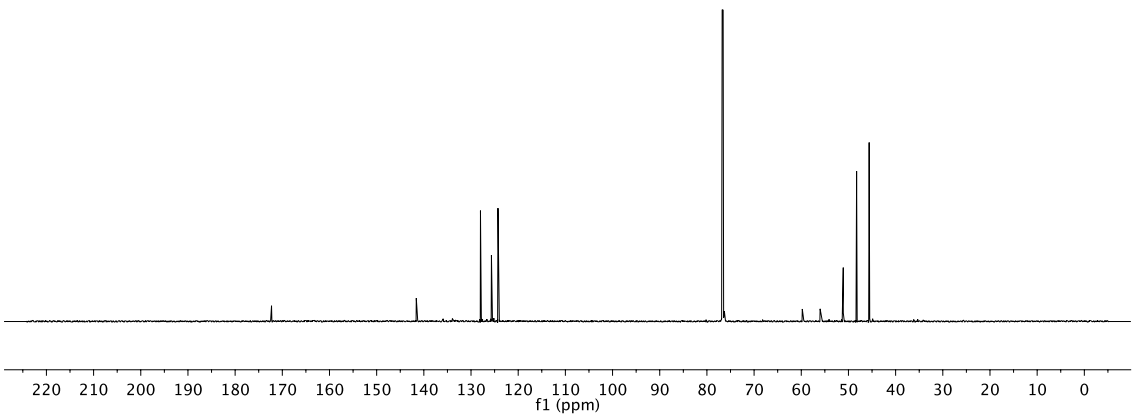

MeO2C

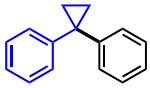
38


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
f1 (ppm)

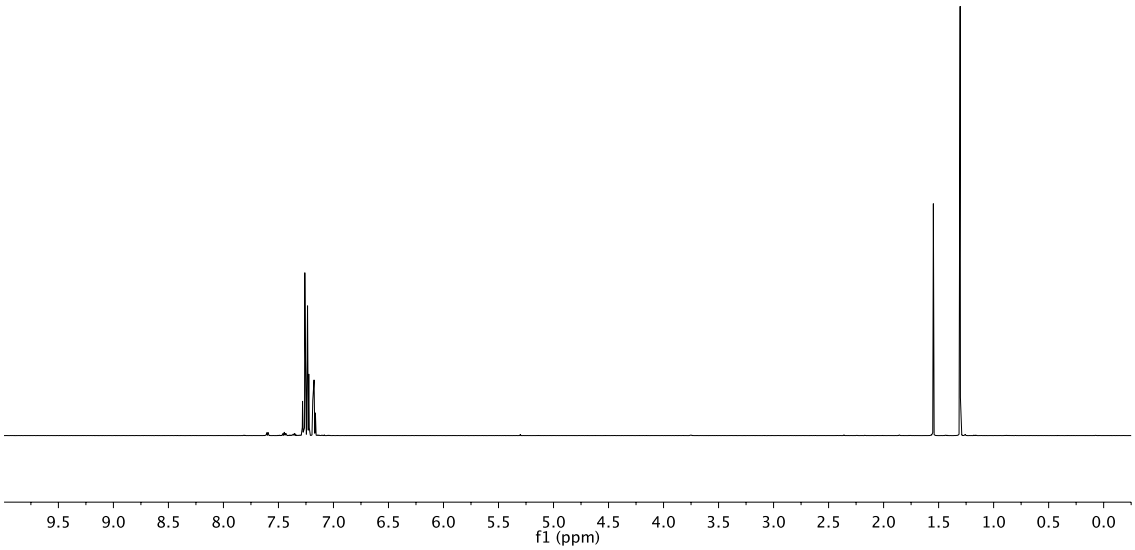

MeO2C

38


220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)



39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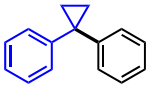
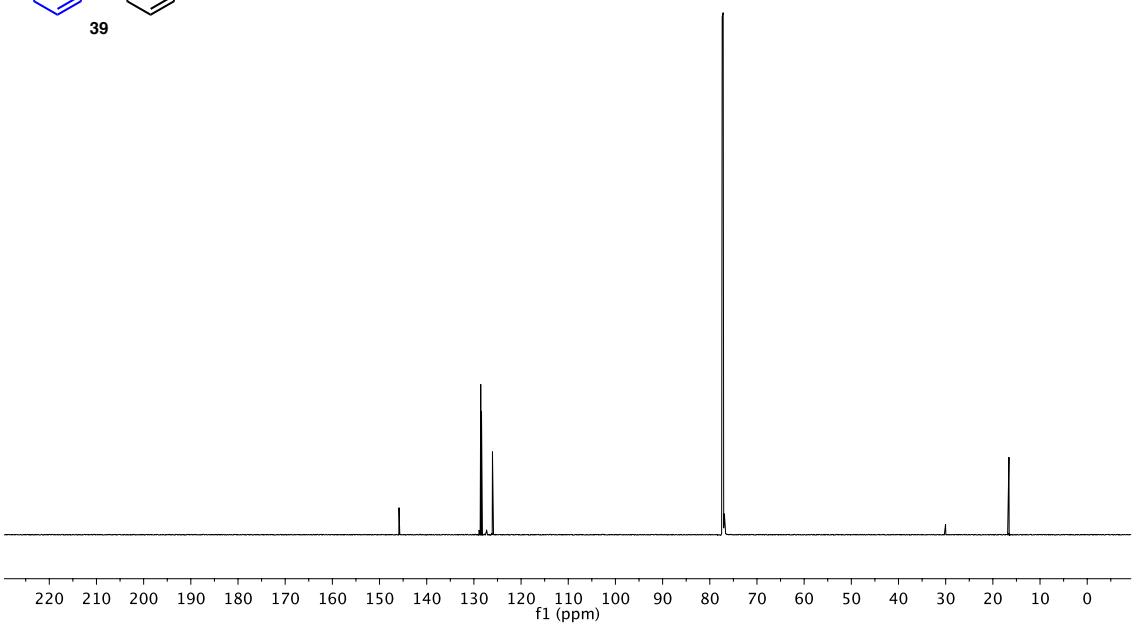
f1 (ppm)



39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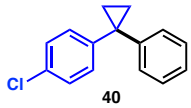
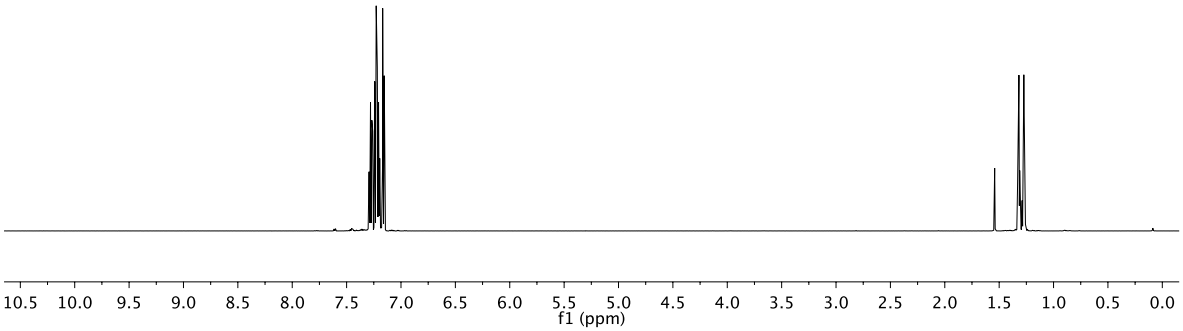
f1 (ppm)


Cl

40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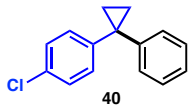
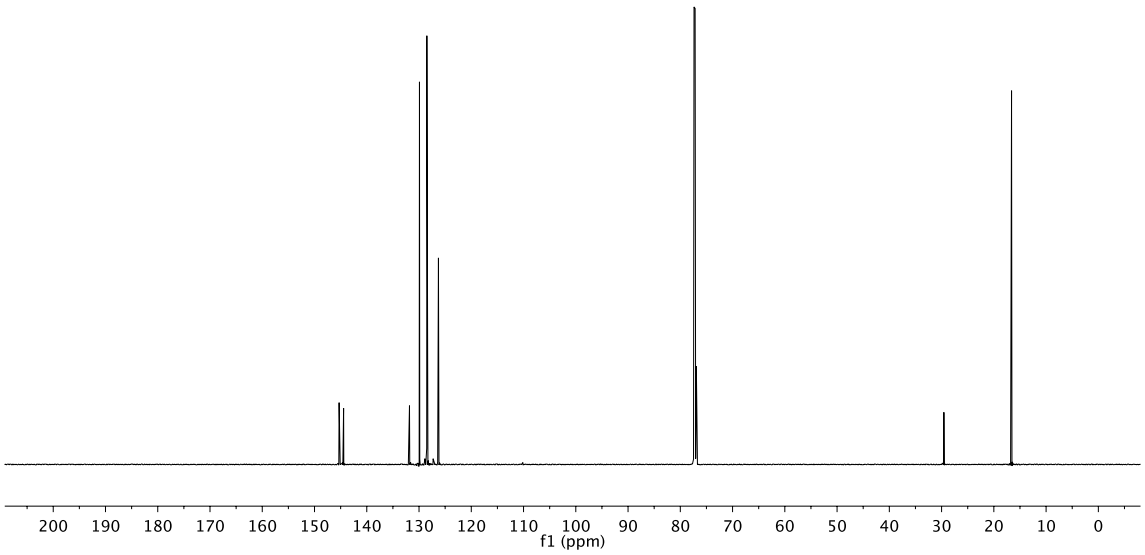
f1 (ppm)


Cl

40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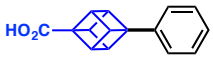
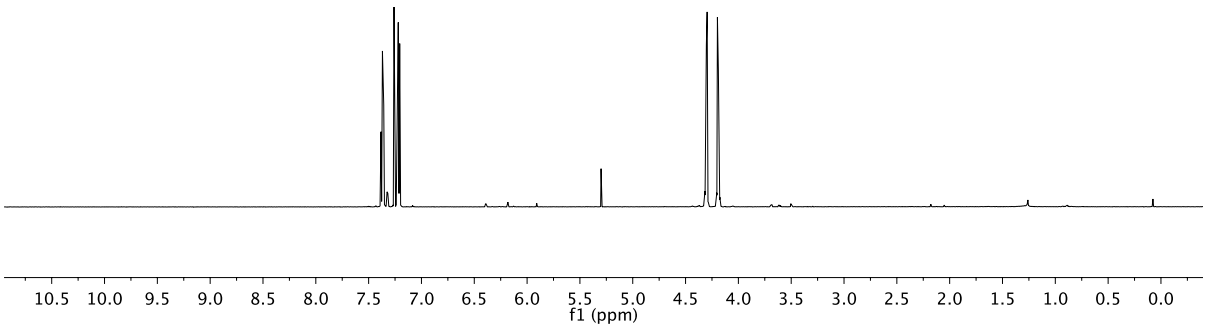
f1 (ppm)



SI-33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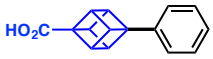
f1 (ppm)



SI-33

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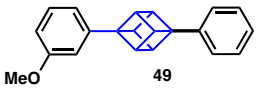
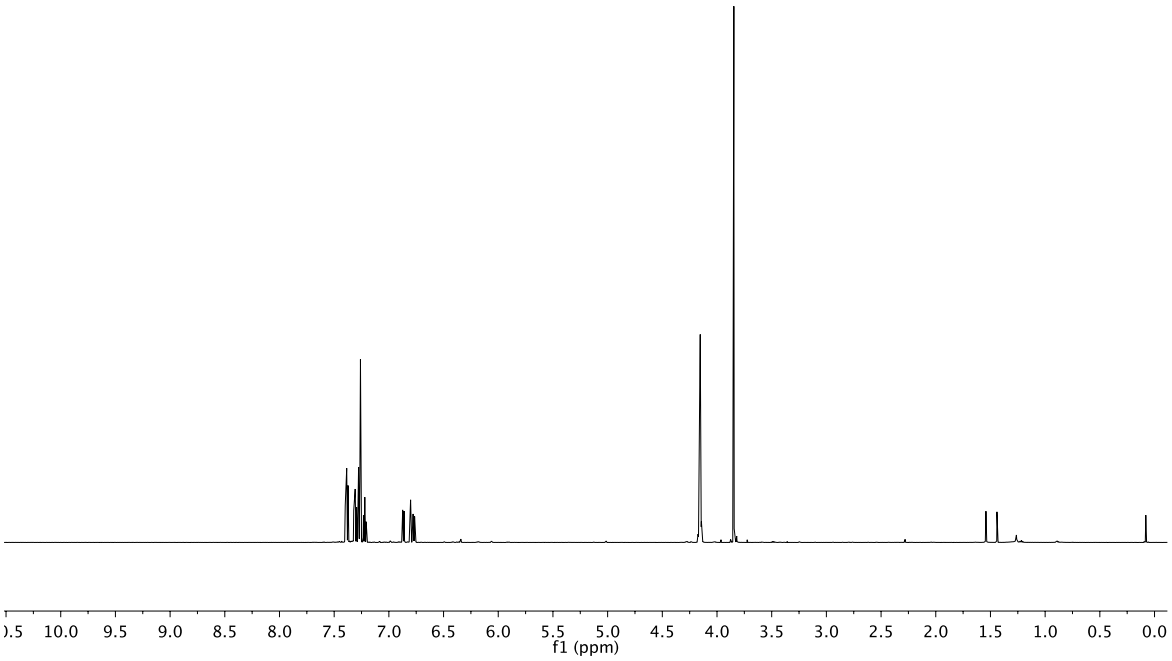
f1 (ppm)


MeO

49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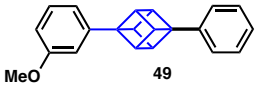
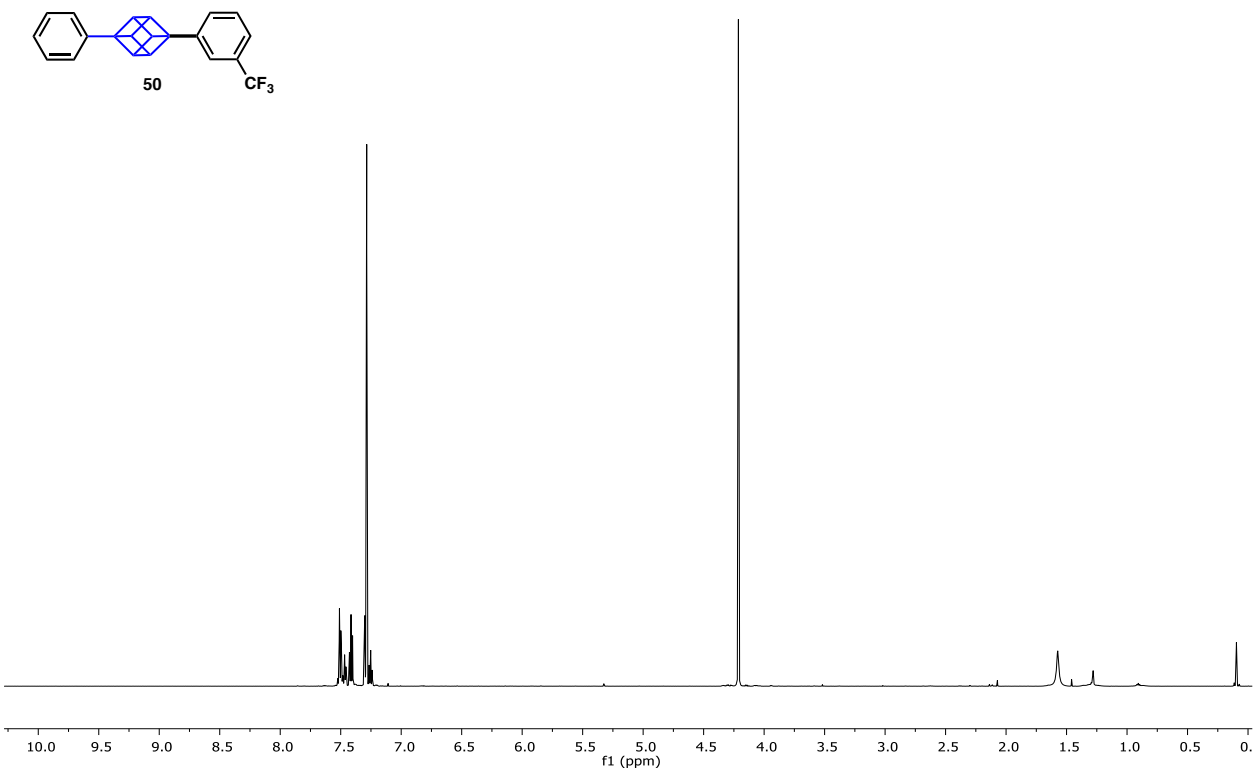
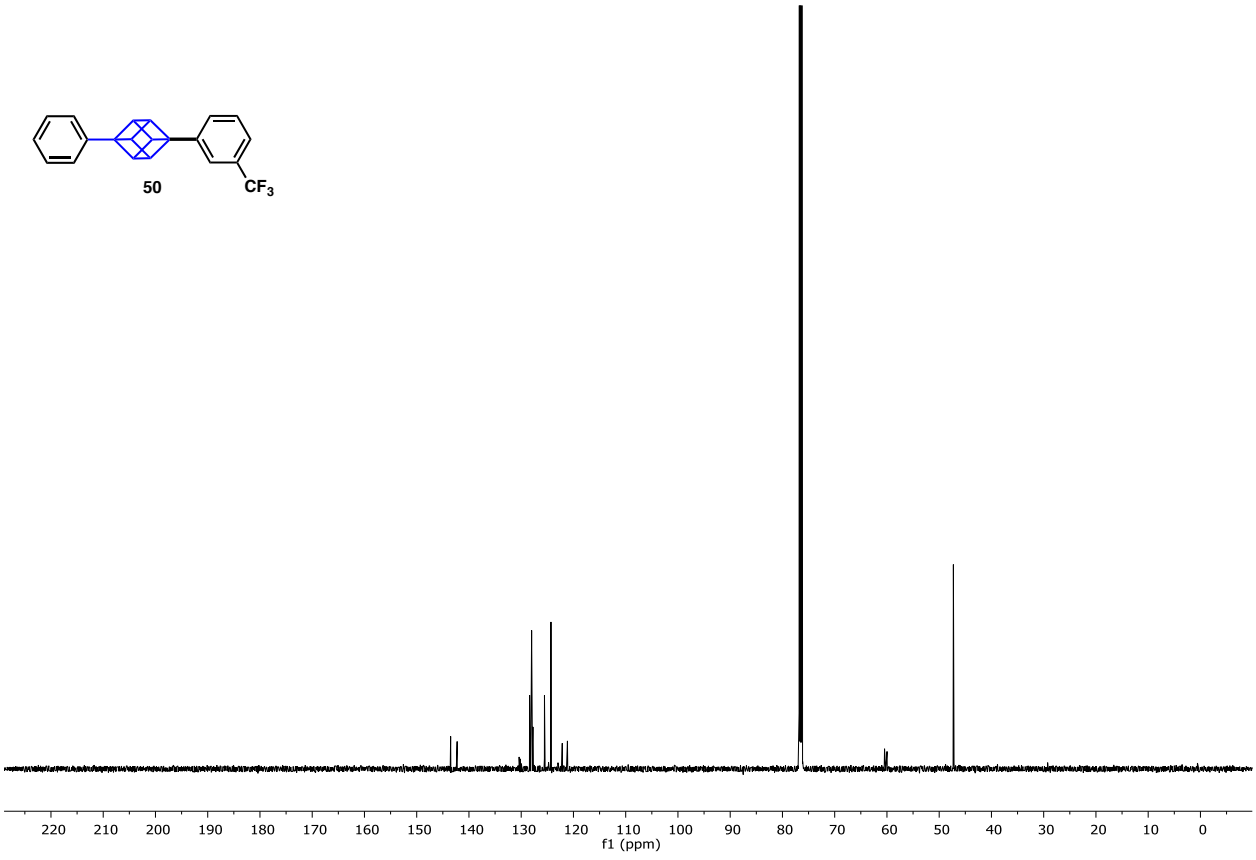
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

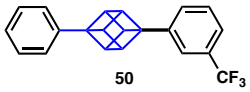

MeO

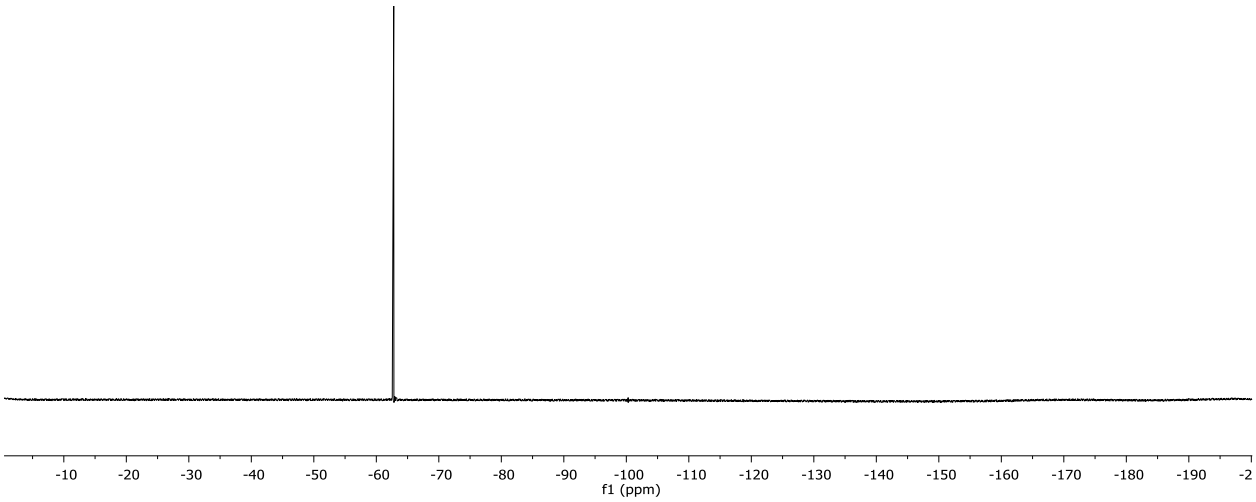
49

210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


50
CF3
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.
f1 (ppm)


50
CF3
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


50
CF3


-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
-2
f1 (ppm)

18. Crystallographic data

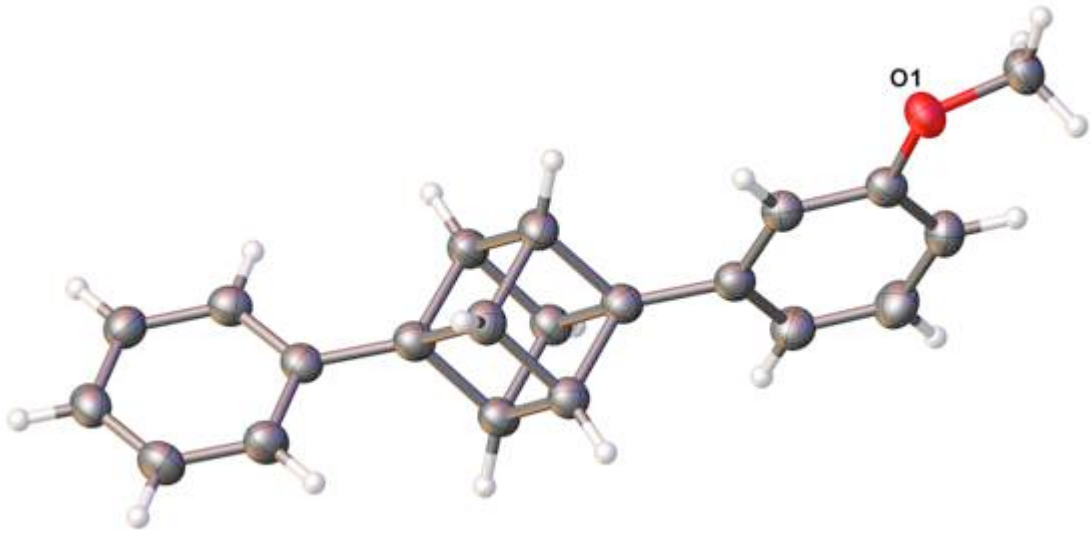


Table 1. Crystal data and structure refinement for **49**.

Identification code	LAU159	
Empirical formula	C21 H18 O	
Formula weight	286.35	
Temperature	100.0 K	
Wavelength	1.54178 Å	
Crystal system	Monoclinic	
Space group	C 2/c	
Unit cell dimensions	a = 17.8244(5) Å	α= 90°.
	b = 7.5148(2) Å	β= 99.790(2)°.
	c = 22.2760(6) Å	γ = 90°.
Volume	2940.35(14) $Å^3$	
Z	8	
Density (calculated)	1.294 Mg/m^3	
Absorption coefficient	0.600 mm^{-1}	
F(000)	1216	
Crystal size	0.3 x 0.27 x 0.14 mm^3	
Theta range for data collection	4.028 to 68.247°.	
Index ranges	-21<=h<=21, -8<=k<=8, -25<=l<=26	
Reflections collected	11451	
Independent reflections	2647 [R(int) = 0.0297]	
Completeness to theta = 67.679°	98.8 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.1665 and 0.0667	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	2647 / 0 / 200	
Goodness-of-fit on F^2	1.055	
Final R indices [I>2sigma(I)]	R1 = 0.0392, wR2 = 0.1052	
R indices (all data)	R1 = 0.0425, wR2 = 0.1081	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.219 and -0.186 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for baran588. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
O(1)	8887(1)	8365(1)	7273(1)	35(1)
C(1)	5377(1)	289(2)	3392(1)	36(1)
C(2)	5649(1)	1953(2)	3274(1)	40(1)
C(3)	5917(1)	3103(2)	3749(1)	37(1)
C(4)	5924(1)	2598(2)	4354(1)	31(1)
C(5)	6232(1)	3846(2)	4852(1)	31(1)
C(6)	5874(1)	5705(2)	4976(1)	31(1)
C(7)	6672(1)	6599(2)	5047(1)	32(1)
C(8)	6811(1)	6181(2)	5756(1)	31(1)
C(9)	7105(1)	7418(2)	6264(1)	31(1)
C(10)	7868(1)	7410(2)	6535(1)	31(1)
C(11)	8125(1)	8509(2)	7031(1)	31(1)
C(12)	9132(1)	9162(2)	7857(1)	38(1)
C(13)	6602(1)	8557(2)	6494(1)	37(1)
C(14)	6865(1)	9649(2)	6983(1)	40(1)
C(15)	7626(1)	9642(2)	7258(1)	36(1)
C(16)	6370(1)	3448(2)	5554(1)	33(1)
C(17)	7172(1)	4351(2)	5625(1)	34(1)
C(18)	7036(1)	4769(2)	4927(1)	33(1)
C(19)	6004(1)	5288(2)	5672(1)	32(1)
C(20)	5375(1)	-218(2)	3988(1)	36(1)
C(21)	5650(1)	924(2)	4466(1)	33(1)

Table 3. Bond lengths [Å] and angles [°] for baran588.

O(1)-C(11)	1.3766(15)
O(1)-C(12)	1.4313(15)
C(1)-H(1)	0.9500
C(1)-C(2)	1.382(2)
C(1)-C(20)	1.3835(19)
C(2)-H(2)	0.9500
C(2)-C(3)	1.3868(19)
C(3)-H(3)	0.9500
C(3)-C(4)	1.3969(18)
C(4)-C(5)	1.4861(18)
C(4)-C(21)	1.3875(19)
C(5)-C(6)	1.5787(18)
C(5)-C(16)	1.5690(17)
C(5)-C(18)	1.5761(17)
C(6)-H(6)	1.0000
C(6)-C(7)	1.5567(17)
C(6)-C(19)	1.5595(17)
C(7)-H(7)	1.0000
C(7)-C(8)	1.5886(17)
C(7)-C(18)	1.5628(18)
C(8)-C(9)	1.4883(18)
C(8)-C(17)	1.5666(18)
C(8)-C(19)	1.5694(17)
C(9)-C(10)	1.3913(17)
C(9)-C(13)	1.3985(18)
C(10)-H(10)	0.9500
C(10)-C(11)	1.3929(18)
C(11)-C(15)	1.3876(19)
C(12)-H(12A)	0.9800
C(12)-H(12B)	0.9800
C(12)-H(12C)	0.9800
C(13)-H(13)	0.9500
C(13)-C(14)	1.381(2)
C(14)-H(14)	0.9500
C(14)-C(15)	1.3917(19)
C(15)-H(15)	0.9500

C(16)-H(16)	1.0000
C(16)-C(17)	1.5658(18)
C(16)-C(19)	1.5695(18)
C(17)-H(17)	1.0000
C(17)-C(18)	1.5646(18)
C(18)-H(18)	1.0000
C(19)-H(19)	1.0000
C(20)-H(20)	0.9500
C(20)-C(21)	1.3895(19)
C(21)-H(21)	0.9500

C(11)-O(1)-C(12)	116.77(10)
C(2)-C(1)-H(1)	120.3
C(2)-C(1)-C(20)	119.32(12)
C(20)-C(1)-H(1)	120.3
C(1)-C(2)-H(2)	119.8
C(1)-C(2)-C(3)	120.39(12)
C(3)-C(2)-H(2)	119.8
C(2)-C(3)-H(3)	119.6
C(2)-C(3)-C(4)	120.75(13)
C(4)-C(3)-H(3)	119.6
C(3)-C(4)-C(5)	119.40(12)
C(21)-C(4)-C(3)	118.33(12)
C(21)-C(4)-C(5)	122.26(11)
C(4)-C(5)-C(6)	125.42(10)
C(4)-C(5)-C(16)	126.88(11)
C(4)-C(5)-C(18)	124.76(11)
C(16)-C(5)-C(6)	89.68(9)
C(16)-C(5)-C(18)	89.66(9)
C(18)-C(5)-C(6)	88.81(9)
C(5)-C(6)-H(6)	125.0
C(7)-C(6)-C(5)	90.61(9)
C(7)-C(6)-H(6)	125.0
C(7)-C(6)-C(19)	90.42(9)
C(19)-C(6)-C(5)	89.97(9)
C(19)-C(6)-H(6)	125.0
C(6)-C(7)-H(7)	125.3
C(6)-C(7)-C(8)	90.04(9)

C(6)-C(7)-C(18)	90.09(9)
C(8)-C(7)-H(7)	125.3
C(18)-C(7)-H(7)	125.3
C(18)-C(7)-C(8)	89.83(9)
C(9)-C(8)-C(7)	127.39(11)
C(9)-C(8)-C(17)	125.98(10)
C(9)-C(8)-C(19)	123.72(11)
C(17)-C(8)-C(7)	89.29(9)
C(17)-C(8)-C(19)	89.93(9)
C(19)-C(8)-C(7)	88.90(9)
C(10)-C(9)-C(8)	121.30(11)
C(10)-C(9)-C(13)	118.92(12)
C(13)-C(9)-C(8)	119.70(11)
C(9)-C(10)-H(10)	119.7
C(9)-C(10)-C(11)	120.50(12)
C(11)-C(10)-H(10)	119.7
O(1)-C(11)-C(10)	115.64(11)
O(1)-C(11)-C(15)	123.79(11)
C(15)-C(11)-C(10)	120.57(12)
O(1)-C(12)-H(12A)	109.5
O(1)-C(12)-H(12B)	109.5
O(1)-C(12)-H(12C)	109.5
H(12A)-C(12)-H(12B)	109.5
H(12A)-C(12)-H(12C)	109.5
H(12B)-C(12)-H(12C)	109.5
C(9)-C(13)-H(13)	120.0
C(14)-C(13)-C(9)	120.04(12)
C(14)-C(13)-H(13)	120.0
C(13)-C(14)-H(14)	119.3
C(13)-C(14)-C(15)	121.35(12)
C(15)-C(14)-H(14)	119.3
C(11)-C(15)-C(14)	118.61(12)
C(11)-C(15)-H(15)	120.7
C(14)-C(15)-H(15)	120.7
C(5)-C(16)-H(16)	125.2
C(5)-C(16)-C(19)	89.97(9)
C(17)-C(16)-C(5)	90.18(9)
C(17)-C(16)-H(16)	125.2

C(17)-C(16)-C(19)	89.96(9)
C(19)-C(16)-H(16)	125.2
C(8)-C(17)-H(17)	125.0
C(16)-C(17)-C(8)	90.16(9)
C(16)-C(17)-H(17)	125.0
C(18)-C(17)-C(8)	90.57(10)
C(18)-C(17)-C(16)	90.20(9)
C(18)-C(17)-H(17)	125.0
C(5)-C(18)-H(18)	125.1
C(7)-C(18)-C(5)	90.49(9)
C(7)-C(18)-C(17)	90.30(10)
C(7)-C(18)-H(18)	125.1
C(17)-C(18)-C(5)	89.96(9)
C(17)-C(18)-H(18)	125.1
C(6)-C(19)-C(8)	90.65(9)
C(6)-C(19)-C(16)	90.37(9)
C(6)-C(19)-H(19)	125.0
C(8)-C(19)-C(16)	89.93(9)
C(8)-C(19)-H(19)	125.0
C(16)-C(19)-H(19)	125.0
C(1)-C(20)-H(20)	119.8
C(1)-C(20)-C(21)	120.45(13)
C(21)-C(20)-H(20)	119.8
C(4)-C(21)-C(20)	120.76(12)
C(4)-C(21)-H(21)	119.6
C(20)-C(21)-H(21)	119.6

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for baran588. The anisotropic displacement factor exponent takes the form: $-2\pi^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O(1)	30(1)	41(1)	32(1)	-5(1)	1(1)	-2(1)
C(1)	32(1)	38(1)	36(1)	-6(1)	1(1)	4(1)
C(2)	42(1)	45(1)	30(1)	2(1)	4(1)	0(1)

C(3)	38(1)	36(1)	37(1)	4(1)	4(1)	-4(1)
C(4)	24(1)	34(1)	33(1)	1(1)	2(1)	1(1)
C(5)	28(1)	33(1)	32(1)	2(1)	3(1)	-1(1)
C(6)	28(1)	33(1)	31(1)	2(1)	2(1)	-1(1)
C(7)	28(1)	33(1)	34(1)	1(1)	4(1)	-2(1)
C(8)	26(1)	33(1)	33(1)	1(1)	2(1)	1(1)
C(9)	31(1)	30(1)	32(1)	3(1)	4(1)	-1(1)
C(10)	30(1)	32(1)	31(1)	1(1)	7(1)	1(1)
C(11)	31(1)	32(1)	31(1)	3(1)	4(1)	-2(1)
C(12)	40(1)	39(1)	33(1)	-4(1)	0(1)	-4(1)
C(13)	30(1)	36(1)	43(1)	-1(1)	3(1)	3(1)
C(14)	38(1)	36(1)	47(1)	-5(1)	10(1)	5(1)
C(15)	40(1)	33(1)	36(1)	-5(1)	6(1)	-2(1)
C(16)	32(1)	32(1)	32(1)	2(1)	1(1)	-2(1)
C(17)	30(1)	33(1)	36(1)	-3(1)	0(1)	2(1)
C(18)	27(1)	36(1)	36(1)	-4(1)	5(1)	-2(1)
C(19)	28(1)	35(1)	31(1)	1(1)	3(1)	-1(1)
C(20)	35(1)	31(1)	41(1)	1(1)	4(1)	1(1)
C(21)	31(1)	35(1)	33(1)	3(1)	4(1)	0(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for baran588.

	x	y	z	U(eq)
H(1)	5193	-498	3066	43
H(2)	5652	2311	2866	47
H(3)	6099	4248	3663	45
H(6)	5395	6206	4737	37
H(7)	6784	7759	4860	38
H(10)	8217	6648	6381	37
H(12A)	9063	10454	7825	57
H(12B)	9671	8890	7997	57
H(12C)	8829	8686	8149	57
H(13)	6079	8578	6313	44
H(14)	6518	10422	7134	48
H(15)	7801	10398	7595	44
H(16)	6258	2293	5743	39
H(17)	7652	3848	5862	40
H(18)	7418	4581	4652	40
H(19)	5620	5479	5945	38
H(20)	5184	-1355	4072	43
H(21)	5650	555	4874	40

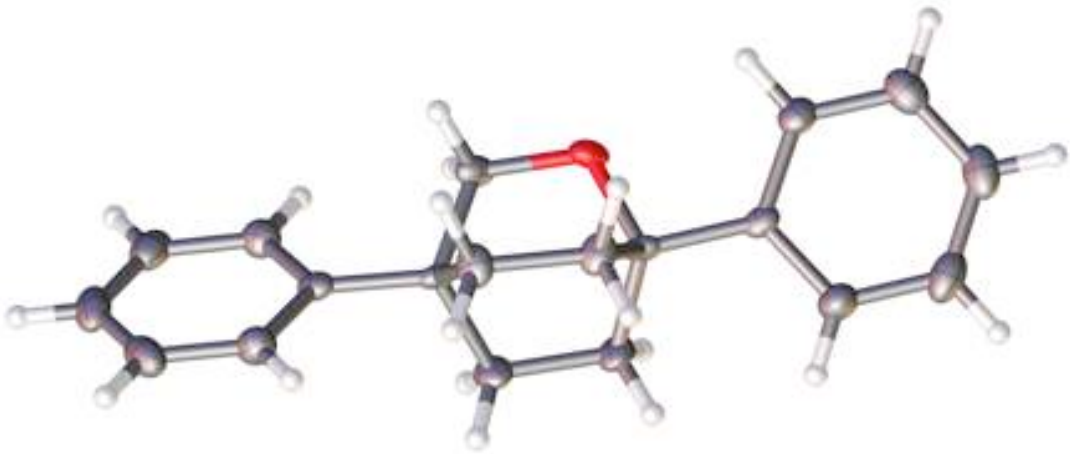


Table 1. Crystal data and structure refinement for **36**.

Report date	2016-06-27	
Identification code	baran589	
Empirical formula	C19 H20 O	
Molecular formula	2(C9.5 H10 O0.5)	
Formula weight	264.35	
Temperature	100.0 K	
Wavelength	0.71073 Å	
Crystal system	Monoclinic	
Space group	P 1 2/c 1	
Unit cell dimensions	a = 18.758(3) Å	α= 90°.
	b = 5.7669(8) Å	β= 110.826(4)°.
	c = 13.563(2) Å	γ = 90°.
Volume	1371.4(4) $Å^3$	
Z	4	
Density (calculated)	1.280 Mg/m^3	
Absorption coefficient	0.077 mm^{-1}	
F(000)	568	
Crystal size	0.33 x 0.18 x 0.15 mm^3	
Crystal color, habit	colourless block	
Theta range for data collection	1.161 to 25.679°.	
Index ranges	-22<=h<=22, -6<=k<=7, -16<=l<=16	
Reflections collected	10661	
Independent reflections	2580 [R(int) = 0.0468]	
Completeness to theta = 25.242°	99.8 %	
Absorption correction	None	
Max. and min. transmission	0.4906 and 0.3378	
Refinement method	Full-matrix least-squares on F^2	

Data / restraints / parameters	2580 / 24 / 188
Goodness-of-fit on F^2	1.089
Final R indices [I>2sigma(I)]	R1 = 0.0819, wR2 = 0.2146
R indices (all data)	R1 = 0.0909, wR2 = 0.2226
Extinction coefficient	n/a
Largest diff. peak and hole	0.725 and -0.417 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for Baran589. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
O(1)	9634(4)	6210(20)	7676(9)	19(2)
C(1)	9826(8)	6230(40)	7856(14)	19(2)
C(2)	10273(2)	2640(7)	8662(3)	25(1)
C(3)	9180(2)	2550(7)	6959(3)	23(1)
C(4)	9530(2)	3854(6)	8004(3)	17(1)
C(5)	8961(2)	4067(6)	8566(2)	18(1)
C(6)	8867(2)	2278(7)	9201(3)	26(1)
C(7)	8330(2)	2465(8)	9696(3)	32(1)
C(8)	7880(2)	4411(8)	9560(3)	32(1)
C(9)	7963(2)	6197(7)	8934(3)	31(1)
C(10)	8497(2)	6035(7)	8437(3)	24(1)
O(2)	5367(8)	4190(40)	3009(17)	31(2)
C(11)	5215(14)	4190(60)	3010(30)	31(2)
C(12)	5804(2)	495(8)	2708(3)	33(1)
C(13)	4756(2)	696(7)	3429(3)	30(1)
C(14)	5493(2)	1788(7)	3446(3)	21(1)
C(15)	6062(2)	2000(7)	4575(3)	23(1)
C(16)	6567(2)	211(7)	5001(3)	26(1)
C(17)	7064(2)	275(8)	6041(3)	31(1)
C(18)	7065(2)	2160(8)	6671(3)	31(1)
C(19)	6566(2)	3967(7)	6249(3)	32(1)
C(20)	6066(2)	3878(7)	5207(3)	30(1)

Table 3. Bond lengths [Å] and angles [°] for Baran589.

O(1)-C(4)	1.465(14)
C(1)-O(1)#1	1.437(10)
C(1)-H(1A)	0.999(16)
C(1)-H(1B)	0.980(18)
C(1)-C(4)	1.52(2)
C(2)-H(2A)	0.9900
C(2)-H(2B)	0.9900
C(2)-C(3)#1	1.544(5)
C(2)-C(4)	1.531(4)
C(3)-C(2)#1	1.544(5)
C(3)-H(3A)	0.9900
C(3)-H(3B)	0.9900
C(3)-C(4)	1.531(4)
C(4)-C(5)	1.521(5)
C(5)-C(6)	1.395(5)
C(5)-C(10)	1.402(5)
C(6)-H(6)	0.9500
C(6)-C(7)	1.399(6)
C(7)-H(7)	0.9500
C(7)-C(8)	1.377(6)
C(8)-H(8)	0.9500
C(8)-C(9)	1.378(6)
C(9)-H(9)	0.9500
C(9)-C(10)	1.396(5)
C(10)-H(10)	0.9500
O(2)-C(14)	1.49(2)
C(11)-O(2)#2	1.428(12)
C(11)-H(11A)	0.99(3)
C(11)-H(11B)	1.00(3)
C(11)-C(14)	1.52(4)
C(12)-H(12A)	0.9900
C(12)-H(12B)	0.9900
C(12)-C(13)#2	1.531(5)
C(12)-C(14)	1.520(5)
C(13)-C(12)#2	1.531(5)
C(13)-H(13A)	0.9900
C(13)-H(13B)	0.9900
C(13)-C(14)	1.513(5)

C(14)-C(15)	1.528(5)
C(15)-C(16)	1.382(5)
C(15)-C(20)	1.380(6)
C(16)-H(16)	0.9500
C(16)-C(17)	1.387(5)
C(17)-H(17)	0.9500
C(17)-C(18)	1.381(6)
C(18)-H(18)	0.9500
C(18)-C(19)	1.382(6)
C(19)-H(19)	0.9500
C(19)-C(20)	1.392(5)
C(20)-H(20)	0.9500

O(1)#1-C(1)-C(4)	114.6(18)
H(1A)-C(1)-H(1B)	107.7(19)
C(4)-C(1)-H(1A)	107.7(12)
C(4)-C(1)-H(1B)	108.8(16)
H(2A)-C(2)-H(2B)	108.2
C(3)#1-C(2)-H(2A)	109.7
C(3)#1-C(2)-H(2B)	109.7
C(4)-C(2)-H(2A)	109.7
C(4)-C(2)-H(2B)	109.7
C(4)-C(2)-C(3)#1	109.9(3)
C(2)#1-C(3)-H(3A)	109.7
C(2)#1-C(3)-H(3B)	109.7
H(3A)-C(3)-H(3B)	108.2
C(4)-C(3)-C(2)#1	109.9(3)
C(4)-C(3)-H(3A)	109.7
C(4)-C(3)-H(3B)	109.7
O(1)-C(4)-C(2)	114.2(4)
O(1)-C(4)-C(3)	103.5(5)
O(1)-C(4)-C(5)	105.7(5)
C(1)-C(4)-C(2)	101.0(6)
C(1)-C(4)-C(3)	112.1(7)
C(1)-C(4)-C(5)	110.4(8)
C(3)-C(4)-C(2)	108.5(3)
C(5)-C(4)-C(2)	113.6(3)
C(5)-C(4)-C(3)	110.9(3)
C(6)-C(5)-C(4)	120.9(3)
C(6)-C(5)-C(10)	117.8(3)

C(10)-C(5)-C(4)	121.2(3)
C(5)-C(6)-H(6)	119.7
C(5)-C(6)-C(7)	120.6(4)
C(7)-C(6)-H(6)	119.7
C(6)-C(7)-H(7)	119.7
C(8)-C(7)-C(6)	120.7(4)
C(8)-C(7)-H(7)	119.7
C(7)-C(8)-H(8)	120.2
C(7)-C(8)-C(9)	119.6(4)
C(9)-C(8)-H(8)	120.2
C(8)-C(9)-H(9)	119.8
C(8)-C(9)-C(10)	120.3(4)
C(10)-C(9)-H(9)	119.8
C(5)-C(10)-H(10)	119.5
C(9)-C(10)-C(5)	120.9(3)
C(9)-C(10)-H(10)	119.5
O(2)#2-C(11)-C(14)	114(3)
H(11A)-C(11)-H(11B)	107(3)
C(14)-C(11)-H(11A)	109(3)
C(14)-C(11)-H(11B)	109(2)
H(12A)-C(12)-H(12B)	108.2
C(13)#2-C(12)-H(12A)	109.7
C(13)#2-C(12)-H(12B)	109.7
C(14)-C(12)-H(12A)	109.7
C(14)-C(12)-H(12B)	109.7
C(14)-C(12)-C(13)#2	109.8(3)
C(12)#2-C(13)-H(13A)	109.6
C(12)#2-C(13)-H(13B)	109.6
H(13A)-C(13)-H(13B)	108.2
C(14)-C(13)-C(12)#2	110.1(3)
C(14)-C(13)-H(13A)	109.6
C(14)-C(13)-H(13B)	109.6
O(2)-C(14)-C(12)	103.8(9)
O(2)-C(14)-C(13)	111.4(6)
O(2)-C(14)-C(15)	106.2(8)
C(11)-C(14)-C(15)	109.6(12)
C(12)-C(14)-C(11)	110.6(13)
C(12)-C(14)-C(15)	113.8(3)
C(13)-C(14)-C(11)	100.7(10)
C(13)-C(14)-C(12)	110.4(3)

C(13)-C(14)-C(15)	110.9(3)
C(16)-C(15)-C(14)	119.4(3)
C(20)-C(15)-C(14)	122.3(3)
C(20)-C(15)-C(16)	118.3(3)
C(15)-C(16)-H(16)	119.4
C(15)-C(16)-C(17)	121.2(4)
C(17)-C(16)-H(16)	119.4
C(16)-C(17)-H(17)	119.9
C(18)-C(17)-C(16)	120.2(4)
C(18)-C(17)-H(17)	119.9
C(17)-C(18)-H(18)	120.5
C(17)-C(18)-C(19)	119.1(4)
C(19)-C(18)-H(18)	120.5
C(18)-C(19)-H(19)	119.8
C(18)-C(19)-C(20)	120.3(4)
C(20)-C(19)-H(19)	119.8
C(15)-C(20)-C(19)	120.9(4)
C(15)-C(20)-H(20)	119.6
C(19)-C(20)-H(20)	119.6

Table 1. Crystal data and structure refinement for **50**.

Report date	2016-06-28
Identification code	baran585
Empirical formula	C21 H15 F3
Molecular formula	C21 H15 F3
Formula weight	324.33
Temperature	125 K
Wavelength	1.54178 Å
Crystal system	Orthorhombic
Space group	$Pna2_1$

Unit cell dimensions	a = 16.6380(7) Å	α= 90°.
	b = 5.4810(3) Å	β= 90°.
	c = 33.4803(15) Å	γ = 90°.
Volume	3053.2(3) $Å^3$	
Z	8	
Density (calculated)	1.411 Mg/m^3	
Absorption coefficient	0.889 mm^{-1}	
F(000)	1344	
Crystal size	0.3 x 0.07 x 0.07 mm^3	
Crystal color, habit	colorless needle	
Theta range for data collection	2.639 to 68.749°.	
Index ranges	-19<=h<=17, -6<=k<=6, -40<=l<=40	
Reflections collected	38783	
Independent reflections	5611 [R(int) = 0.0706]	
Completeness to theta = 67.679°	99.8 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.6612 and 0.5284	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	5611 / 1 / 434	
Goodness-of-fit on F^2	1.050	
Final R indices [I>2sigma(I)]	R1 = 0.0481, wR2 = 0.1186	
R indices (all data)	R1 = 0.0572, wR2 = 0.1244	
Absolute structure parameter	0.5	
Extinction coefficient	0.0012(2)	
Largest diff. peak and hole	0.261 and -0.229 e.$Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for Baran585_a. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
F(1')	4979(3)	5347(7)	4816(1)	69(1)
F(2')	5487(2)	8574(7)	5084(1)	57(1)
F(3')	4251(2)	7691(6)	5171(1)	54(1)
C(1')	4988(3)	6669(10)	5149(2)	38(1)
C(2')	5197(3)	5252(9)	5506(1)	25(1)
C(3')	5891(2)	5666(8)	5721(1)	23(1)

C(4')	6099(2)	4204(8)	6048(1)	19(1)
C(5')	5582(2)	2315(7)	6154(1)	22(1)
C(6')	4880(3)	1896(9)	5942(1)	28(1)
C(7')	4683(3)	3334(9)	5615(1)	29(1)
C(8')	6874(2)	4608(7)	6259(1)	20(1)
C(9')	7232(2)	7157(8)	6370(1)	24(1)
C(10')	7477(2)	6168(8)	6786(1)	24(1)
C(11')	7126(2)	3600(8)	6678(1)	23(1)
C(12')	7959(2)	2835(8)	6506(1)	24(1)
C(13')	8323(2)	5380(7)	6615(1)	20(1)
C(14')	8065(2)	6397(8)	6197(1)	25(1)
C(15')	7718(2)	3830(8)	6089(1)	25(1)
C(16')	9111(2)	5711(7)	6819(1)	19(1)
C(17')	9603(2)	7724(8)	6739(1)	23(1)
C(18')	10325(2)	8016(9)	6937(1)	25(1)
C(19')	10579(2)	6329(8)	7216(1)	25(1)
C(20')	10103(3)	4311(8)	7293(1)	24(1)
C(21')	9375(2)	4005(8)	7097(1)	22(1)
F(1)	7371(3)	341(7)	5242(1)	72(1)
F(2)	6865(2)	3564(7)	4980(1)	59(1)
F(3)	8089(2)	2696(6)	4886(1)	52(1)
C(1)	7359(3)	1715(10)	4913(2)	36(1)
C(2)	7142(3)	259(9)	4552(1)	27(1)
C(3)	6440(2)	718(8)	4341(1)	25(1)
C(4)	6236(2)	-726(7)	4014(1)	21(1)
C(5)	6749(2)	-2597(9)	3899(1)	25(1)
C(6)	7456(3)	-3030(9)	4111(1)	31(1)
C(7)	7652(3)	-1620(9)	4436(1)	32(1)
C(8)	5461(2)	-306(8)	3805(1)	22(1)
C(9)	5077(2)	2236(8)	3706(1)	22(1)
C(10)	4856(2)	1296(7)	3278(1)	21(1)
C(11)	5222(2)	-1251(8)	3377(1)	24(1)
C(12)	4389(2)	-2113(8)	3540(1)	25(1)
C(13)	4005(2)	407(7)	3436(1)	21(1)
C(14)	4242(2)	1367(8)	3864(1)	23(1)
C(15)	4609(3)	-1178(8)	3965(1)	26(1)
C(16)	3231(2)	694(8)	3221(1)	22(1)
C(17)	2711(3)	2629(8)	3289(1)	27(1)

C(18)	2002(3)	2856(8)	3076(2)	30(1)
C(19)	1798(3)	1126(9)	2789(1)	30(1)
C(20)	2303(3)	-850(9)	2721(1)	28(1)
C(21)	3003(3)	-1064(8)	2938(1)	24(1)

Table 3. Bond lengths [Å] and angles [°] for Baran585_a.

F(1')-C(1')	1.329(6)
F(2')-C(1')	1.352(6)
F(3')-C(1')	1.351(6)
C(1')-C(2')	1.468(6)
C(2')-C(3')	1.378(6)
C(2')-C(7')	1.403(6)
C(3')-H(3')	0.9500
C(3')-C(4')	1.399(6)
C(4')-C(5')	1.393(6)
C(4')-C(8')	1.487(5)
C(5')-H(5')	0.9500
C(5')-C(6')	1.387(6)
C(6')-H(6')	0.9500
C(6')-C(7')	1.388(6)
C(7')-H(7')	0.9500
C(8')-C(9')	1.563(6)
C(8')-C(11')	1.563(6)
C(8')-C(15')	1.575(6)
C(9')-H(9')	1.0000
C(9')-C(10')	1.551(6)
C(9')-C(14')	1.558(6)
C(10')-H(10')	1.0000
C(10')-C(11')	1.566(6)
C(10')-C(13')	1.578(6)
C(11')-H(11')	1.0000
C(11')-C(12')	1.556(6)
C(12')-H(12')	1.0000
C(12')-C(13')	1.564(6)
C(12')-C(15')	1.552(6)

C(13')-C(14')	1.566(6)
C(13')-C(16')	1.490(5)
C(14')-H(14')	1.0000
C(14')-C(15')	1.563(6)
C(15')-H(15')	1.0000
C(16')-C(17')	1.399(6)
C(16')-C(21')	1.391(6)
C(17')-H(17')	0.9500
C(17')-C(18')	1.381(6)
C(18')-H(18')	0.9500
C(18')-C(19')	1.380(6)
C(19')-H(19')	0.9500
C(19')-C(20')	1.385(6)
C(20')-H(20')	0.9500
C(20')-C(21')	1.388(6)
C(21')-H(21')	0.9500
F(1)-C(1)	1.335(6)
F(2)-C(1)	1.323(6)
F(3)-C(1)	1.331(6)
C(1)-C(2)	1.491(6)
C(2)-C(3)	1.390(6)
C(2)-C(7)	1.389(7)
C(3)-H(3)	0.9500
C(3)-C(4)	1.392(6)
C(4)-C(5)	1.389(6)
C(4)-C(8)	1.486(5)
C(5)-H(5)	0.9500
C(5)-C(6)	1.395(6)
C(6)-H(6)	0.9500
C(6)-C(7)	1.373(6)
C(7)-H(7)	0.9500
C(8)-C(9)	1.568(6)
C(8)-C(11)	1.573(5)
C(8)-C(15)	1.590(6)
C(9)-H(9)	1.0000
C(9)-C(10)	1.567(5)
C(9)-C(14)	1.563(6)
C(10)-H(10)	1.0000

C(10)-C(11)	1.559(6)
C(10)-C(13)	1.588(6)
C(11)-H(11)	1.0000
C(11)-C(12)	1.563(6)
C(12)-H(12)	1.0000
C(12)-C(13)	1.561(6)
C(12)-C(15)	1.555(6)
C(13)-C(14)	1.579(5)
C(13)-C(16)	1.483(5)
C(14)-H(14)	1.0000
C(14)-C(15)	1.559(6)
C(15)-H(15)	1.0000
C(16)-C(17)	1.389(6)
C(16)-C(21)	1.403(6)
C(17)-H(17)	0.9500
C(17)-C(18)	1.383(6)
C(18)-H(18)	0.9500
C(18)-C(19)	1.393(7)
C(19)-H(19)	0.9500
C(19)-C(20)	1.389(7)
C(20)-H(20)	0.9500
C(20)-C(21)	1.376(6)
C(21)-H(21)	0.9500

F(1')-C(1')-F(2')	107.0(4)
F(1')-C(1')-F(3')	105.1(4)
F(1')-C(1')-C(2')	113.5(4)
F(2')-C(1')-C(2')	113.2(4)
F(3')-C(1')-F(2')	104.2(4)
F(3')-C(1')-C(2')	113.0(4)
C(3')-C(2')-C(1')	122.4(4)
C(3')-C(2')-C(7')	120.0(4)
C(7')-C(2')-C(1')	117.5(4)
C(2')-C(3')-H(3')	119.3
C(2')-C(3')-C(4')	121.4(4)
C(4')-C(3')-H(3')	119.3
C(3')-C(4')-C(8')	120.1(4)
C(5')-C(4')-C(3')	118.2(4)

C(5')-C(4')-C(8')	121.7(4)
C(4')-C(5')-H(5')	119.6
C(6')-C(5')-C(4')	120.8(4)
C(6')-C(5')-H(5')	119.6
C(5')-C(6')-H(6')	119.7
C(5')-C(6')-C(7')	120.6(4)
C(7')-C(6')-H(6')	119.7
C(2')-C(7')-H(7')	120.5
C(6')-C(7')-C(2')	119.0(4)
C(6')-C(7')-H(7')	120.5
C(4')-C(8')-C(9')	125.2(4)
C(4')-C(8')-C(11')	127.4(3)
C(4')-C(8')-C(15')	124.1(3)
C(9')-C(8')-C(11')	90.1(3)
C(9')-C(8')-C(15')	89.3(3)
C(11')-C(8')-C(15')	89.3(3)
C(8')-C(9')-H(9')	125.0
C(10')-C(9')-C(8')	90.0(3)
C(10')-C(9')-H(9')	125.0
C(10')-C(9')-C(14')	90.3(3)
C(14')-C(9')-C(8')	90.7(3)
C(14')-C(9')-H(9')	125.0
C(9')-C(10')-H(10')	125.1
C(9')-C(10')-C(11')	90.4(3)
C(9')-C(10')-C(13')	90.3(3)
C(11')-C(10')-H(10')	125.1
C(11')-C(10')-C(13')	90.2(3)
C(13')-C(10')-H(10')	125.1
C(8')-C(11')-C(10')	89.5(3)
C(8')-C(11')-H(11')	125.4
C(10')-C(11')-H(11')	125.4
C(12')-C(11')-C(8')	90.3(3)
C(12')-C(11')-C(10')	89.8(3)
C(12')-C(11')-H(11')	125.4
C(11')-C(12')-H(12')	125.0
C(11')-C(12')-C(13')	91.0(3)
C(13')-C(12')-H(12')	125.0
C(15')-C(12')-C(11')	90.4(3)

C(15')-C(12')-H(12')	125.0
C(15')-C(12')-C(13')	89.8(3)
C(12')-C(13')-C(10')	89.0(3)
C(12')-C(13')-C(14')	90.2(3)
C(14')-C(13')-C(10')	89.0(3)
C(16')-C(13')-C(10')	125.9(3)
C(16')-C(13')-C(12')	123.8(3)
C(16')-C(13')-C(14')	127.3(4)
C(9')-C(14')-C(13')	90.5(3)
C(9')-C(14')-H(14')	125.4
C(9')-C(14')-C(15')	89.9(3)
C(13')-C(14')-H(14')	125.4
C(15')-C(14')-C(13')	89.3(3)
C(15')-C(14')-H(14')	125.4
C(8')-C(15')-H(15')	125.1
C(12')-C(15')-C(8')	90.0(3)
C(12')-C(15')-C(14')	90.7(3)
C(12')-C(15')-H(15')	125.1
C(14')-C(15')-C(8')	90.1(3)
C(14')-C(15')-H(15')	125.1
C(17')-C(16')-C(13')	121.6(4)
C(21')-C(16')-C(13')	120.1(4)
C(21')-C(16')-C(17')	118.3(4)
C(16')-C(17')-H(17')	119.7
C(18')-C(17')-C(16')	120.5(4)
C(18')-C(17')-H(17')	119.7
C(17')-C(18')-H(18')	119.6
C(19')-C(18')-C(17')	120.9(4)
C(19')-C(18')-H(18')	119.6
C(18')-C(19')-H(19')	120.4
C(18')-C(19')-C(20')	119.1(4)
C(20')-C(19')-H(19')	120.4
C(19')-C(20')-H(20')	119.8
C(19')-C(20')-C(21')	120.5(4)
C(21')-C(20')-H(20')	119.8
C(16')-C(21')-H(21')	119.7
C(20')-C(21')-C(16')	120.7(4)
C(20')-C(21')-H(21')	119.7

F(1)-C(1)-C(2)	111.7(5)
F(2)-C(1)-F(1)	107.5(4)
F(2)-C(1)-F(3)	105.5(5)
F(2)-C(1)-C(2)	113.5(4)
F(3)-C(1)-F(1)	105.6(4)
F(3)-C(1)-C(2)	112.5(4)
C(3)-C(2)-C(1)	121.2(4)
C(7)-C(2)-C(1)	118.4(4)
C(7)-C(2)-C(3)	120.3(4)
C(2)-C(3)-H(3)	119.9
C(2)-C(3)-C(4)	120.1(4)
C(4)-C(3)-H(3)	119.9
C(3)-C(4)-C(8)	119.6(4)
C(5)-C(4)-C(3)	119.2(4)
C(5)-C(4)-C(8)	121.1(4)
C(4)-C(5)-H(5)	119.9
C(4)-C(5)-C(6)	120.1(4)
C(6)-C(5)-H(5)	119.9
C(5)-C(6)-H(6)	119.7
C(7)-C(6)-C(5)	120.5(4)
C(7)-C(6)-H(6)	119.7
C(2)-C(7)-H(7)	120.2
C(6)-C(7)-C(2)	119.6(4)
C(6)-C(7)-H(7)	120.2
C(4)-C(8)-C(9)	126.2(3)
C(4)-C(8)-C(11)	126.8(3)
C(4)-C(8)-C(15)	124.6(3)
C(9)-C(8)-C(11)	89.9(3)
C(9)-C(8)-C(15)	88.6(3)
C(11)-C(8)-C(15)	89.0(3)
C(8)-C(9)-H(9)	125.0
C(10)-C(9)-C(8)	89.8(3)
C(10)-C(9)-H(9)	125.0
C(14)-C(9)-C(8)	91.1(3)
C(14)-C(9)-H(9)	125.0
C(14)-C(9)-C(10)	90.1(3)
C(9)-C(10)-H(10)	125.1
C(9)-C(10)-C(13)	90.3(3)

C(11)-C(10)-C(9)	90.4(3)
C(11)-C(10)-H(10)	125.1
C(11)-C(10)-C(13)	90.1(3)
C(13)-C(10)-H(10)	125.1
C(8)-C(11)-H(11)	125.2
C(10)-C(11)-C(8)	89.9(3)
C(10)-C(11)-H(11)	125.2
C(10)-C(11)-C(12)	90.0(3)
C(12)-C(11)-C(8)	90.4(3)
C(12)-C(11)-H(11)	125.2
C(11)-C(12)-H(12)	124.8
C(13)-C(12)-C(11)	91.0(3)
C(13)-C(12)-H(12)	124.8
C(15)-C(12)-C(11)	90.6(3)
C(15)-C(12)-H(12)	124.8
C(15)-C(12)-C(13)	90.5(3)
C(12)-C(13)-C(10)	88.9(3)
C(12)-C(13)-C(14)	89.4(3)
C(14)-C(13)-C(10)	88.8(3)
C(16)-C(13)-C(10)	125.4(3)
C(16)-C(13)-C(12)	123.9(3)
C(16)-C(13)-C(14)	128.5(3)
C(9)-C(14)-C(13)	90.8(3)
C(9)-C(14)-H(14)	125.2
C(13)-C(14)-H(14)	125.2
C(15)-C(14)-C(9)	89.9(3)
C(15)-C(14)-C(13)	89.7(3)
C(15)-C(14)-H(14)	125.2
C(8)-C(15)-H(15)	125.1
C(12)-C(15)-C(8)	90.0(3)
C(12)-C(15)-C(14)	90.3(3)
C(12)-C(15)-H(15)	125.1
C(14)-C(15)-C(8)	90.4(3)
C(14)-C(15)-H(15)	125.1
C(17)-C(16)-C(13)	122.8(4)
C(17)-C(16)-C(21)	117.8(4)
C(21)-C(16)-C(13)	119.3(4)
C(16)-C(17)-H(17)	119.5

C(18)-C(17)-C(16)	121.0(4)
C(18)-C(17)-H(17)	119.5
C(17)-C(18)-H(18)	119.9
C(17)-C(18)-C(19)	120.2(4)
C(19)-C(18)-H(18)	119.9
C(18)-C(19)-H(19)	120.1
C(20)-C(19)-C(18)	119.7(4)
C(20)-C(19)-H(19)	120.1
C(19)-C(20)-H(20)	120.3
C(21)-C(20)-C(19)	119.5(4)
C(21)-C(20)-H(20)	120.3
C(16)-C(21)-H(21)	119.1
C(20)-C(21)-C(16)	121.8(4)
C(20)-C(21)-H(21)	119.1

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for Baran585_a. The anisotropic displacement factor exponent takes the form: $-2\pi^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
F(1')	110(3)	74(2)	22(2)	5(2)	-19(2)	15(2)
F(2')	48(2)	73(2)	50(2)	35(2)	-13(1)	-16(2)
F(3')	38(2)	61(2)	62(2)	23(2)	-19(2)	10(2)
C(1')	37(3)	45(3)	31(3)	11(2)	-11(2)	1(2)
C(2')	19(2)	37(3)	18(2)	3(2)	-5(2)	-1(2)
C(3')	21(2)	28(2)	20(2)	1(2)	-1(2)	-1(2)
C(4')	14(2)	26(2)	17(2)	-2(2)	-1(1)	1(2)
C(5')	23(2)	26(2)	16(2)	2(2)	-4(2)	-3(2)
C(6')	21(2)	38(2)	23(2)	4(2)	-4(2)	-7(2)
C(7')	19(2)	46(3)	21(2)	1(2)	-8(2)	-5(2)
C(8')	14(2)	22(2)	24(2)	-4(2)	-3(2)	0(2)
C(9')	18(2)	20(2)	34(2)	-3(2)	-6(2)	0(2)
C(10')	16(2)	34(2)	23(2)	-9(2)	-4(2)	2(2)
C(11')	14(2)	32(2)	22(2)	2(2)	-6(2)	-4(2)
C(12')	19(2)	25(2)	29(2)	-4(2)	-4(2)	-1(2)
C(13')	14(2)	22(2)	24(2)	-4(2)	-2(2)	1(2)
C(14')	20(2)	29(2)	26(2)	0(2)	-3(2)	-1(2)
C(15')	16(2)	36(2)	23(2)	-9(2)	-2(2)	-1(2)
C(16')	15(2)	23(2)	18(2)	-6(2)	-1(1)	2(2)
C(17')	18(2)	23(2)	27(2)	-1(2)	-4(2)	3(2)
C(18')	20(2)	29(2)	26(2)	0(2)	-2(2)	-1(2)
C(19')	16(2)	41(3)	17(2)	-7(2)	-2(1)	-4(2)
C(20')	25(2)	34(2)	14(2)	2(2)	-1(2)	0(2)
C(21')	18(2)	28(2)	20(2)	-4(2)	1(2)	-2(2)
F(1)	113(3)	81(3)	21(2)	-1(2)	-22(2)	-16(2)
F(2)	50(2)	79(3)	49(2)	-44(2)	-16(1)	17(2)
F(3)	38(2)	58(2)	61(2)	-20(2)	-21(2)	-1(2)
C(1)	30(3)	51(3)	28(2)	-12(3)	-12(2)	6(2)
C(2)	23(2)	41(3)	17(2)	1(2)	-2(2)	-2(2)
C(3)	21(2)	34(2)	20(2)	-3(2)	-2(2)	3(2)
C(4)	20(2)	29(2)	14(2)	2(2)	0(1)	1(2)
C(5)	21(2)	33(2)	21(2)	-6(2)	-3(2)	-1(2)
C(6)	23(2)	39(3)	31(2)	-4(2)	-2(2)	10(2)

C(7)	19(2)	52(3)	24(2)	0(2)	-8(2)	9(2)
C(8)	21(2)	27(2)	17(2)	-4(2)	-2(2)	0(2)
C(9)	21(2)	24(2)	21(2)	-1(2)	-4(2)	-4(2)
C(10)	19(2)	25(2)	20(2)	3(2)	0(2)	0(2)
C(11)	19(2)	28(2)	23(2)	-3(2)	-4(2)	2(2)
C(12)	22(2)	22(2)	30(3)	5(2)	-11(2)	-1(2)
C(13)	18(2)	23(2)	23(2)	3(2)	0(2)	-1(2)
C(14)	18(2)	34(2)	18(2)	-2(2)	-1(2)	2(2)
C(15)	20(2)	36(2)	21(2)	7(2)	-4(2)	-1(2)
C(16)	17(2)	28(2)	19(2)	7(2)	0(2)	-4(2)
C(17)	25(2)	27(2)	28(2)	0(2)	-6(2)	1(2)
C(18)	26(2)	29(2)	36(3)	8(2)	-3(2)	5(2)
C(19)	19(2)	41(3)	30(2)	12(2)	-7(2)	-2(2)
C(20)	26(2)	38(2)	19(2)	0(2)	-2(2)	0(2)
C(21)	21(2)	32(2)	19(2)	2(2)	-1(2)	3(2)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for Baran585_a.

	x	y	z	U(eq)
H(3')	6235	6970	5646	28
H(5')	5711	1301	6375	26
H(6')	4531	612	6020	33
H(7')	4207	3025	5466	35
H(9')	6961	8758	6320	29
H(10')	7390	7037	7045	29
H(11')	6782	2577	6856	27
H(12')	8227	1230	6556	29
H(14')	8408	7424	6019	30
H(15')	7807	2962	5830	30
H(17')	9439	8899	6547	27
H(18')	10651	9397	6880	30
H(19')	11074	6549	7352	30
H(20')	10276	3127	7482	29
H(21')	9053	2617	7154	27
H(3)	6098	2020	4419	30
H(5)	6618	-3585	3675	30
H(6)	7805	-4309	4031	37
H(7)	8133	-1928	4581	38
H(9)	5329	3852	3766	27
H(10)	4948	2218	3024	26
H(11)	5578	-2218	3196	28
H(12)	4138	-3732	3481	30
H(14)	3883	2330	4045	28
H(15)	4517	-2099	4219	31
H(17)	2843	3814	3486	32
H(18)	1653	4194	3126	36
H(19)	1316	1297	2639	36
H(20)	2167	-2045	2527	33
H(21)	3340	-2438	2895	29

Symmetry transformations used to generate equivalent atoms:

#1 -x+2,y,-z+3/2 #2 -x+1,y,-z+1/2

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for Baran589. The anisotropic displacement factor exponent takes the form: $-2\pi^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O(1)	14(4)	15(2)	25(4)	-1(2)	2(3)	2(3)
C(1)	14(4)	15(2)	25(4)	-1(2)	2(3)	2(3)
C(2)	24(2)	33(2)	15(2)	8(2)	5(1)	4(2)
C(3)	24(2)	30(2)	13(2)	-4(2)	2(1)	-7(2)
C(4)	22(2)	10(2)	14(2)	-1(1)	0(1)	0(1)
C(5)	23(2)	16(2)	11(2)	-1(1)	2(1)	-2(1)
C(6)	31(2)	23(2)	22(2)	2(2)	9(2)	1(2)
C(7)	34(2)	41(2)	20(2)	0(2)	9(2)	-12(2)
C(8)	25(2)	53(3)	18(2)	-10(2)	7(2)	-5(2)
C(9)	26(2)	36(2)	27(2)	-10(2)	6(2)	0(2)
C(10)	25(2)	27(2)	17(2)	2(2)	4(2)	1(1)
O(2)	37(5)	19(2)	32(2)	-3(1)	7(4)	-2(4)
C(11)	37(5)	19(2)	32(2)	-3(1)	7(4)	-2(4)
C(12)	33(2)	36(2)	28(2)	-3(2)	8(2)	9(2)
C(13)	33(2)	31(2)	28(2)	4(2)	11(2)	-4(2)
C(14)	25(2)	21(2)	17(2)	2(1)	6(2)	3(1)
C(15)	24(2)	28(2)	17(2)	-1(2)	7(1)	-4(2)
C(16)	31(2)	26(2)	22(2)	-1(2)	8(2)	1(2)
C(17)	28(2)	30(2)	33(2)	2(2)	7(2)	2(2)
C(18)	29(2)	41(2)	22(2)	4(2)	7(2)	-6(2)
C(19)	42(2)	28(2)	25(2)	-7(2)	10(2)	-5(2)
C(20)	30(2)	31(2)	28(2)	-3(2)	9(2)	-3(2)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for Baran589.

	x	y	z	U(eq)
H(1A)	9378	7190	7435	23
H(1B)	10058	6965	8547	23
H(2A)	10160	1046	8835	30
H(2B)	10517	3492	9332	30
H(3A)	8686	3265	6536	28
H(3B)	9085	916	7099	28
H(6)	9171	920	9298	31
H(7)	8275	1236	10130	38
H(8)	7515	4523	9896	38
H(9)	7654	7544	8839	37
H(10)	8548	7276	8006	29
H(11A)	5023	5007	3507	37
H(11B)	5658	5094	2974	37
H(12A)	5881	-1159	2915	39
H(12B)	6304	1156	2762	39
H(13A)	4528	1657	3845	37
H(13B)	4860	-863	3754	37
H(16)	6575	-1088	4574	32
H(17)	7403	-981	6322	37
H(18)	7405	2213	7383	37
H(19)	6564	5278	6673	39
H(20)	5723	5126	4928	36

14. References

For full description of Ref. 10 of the manuscript, see

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