# Enantioselective Syntheses of Furan Atropisomers by an Oxidative Central-to-Axial Chirality Conversion Strategy

*Vivek S. Raut, Marion Jean, Nicolas Vanthuyne, Christian Roussel, Thierry Constantieux, Cyril Bressy, Xavier Bugaut, Damien Bonne, and Jean Rodriguez*

## *SUPPORTING INFORMATION*

# 1. General Information

Reactions were run under argon atmosphere in oven-dried glassware. Unless specified, commercial reagents and solvents were used as received. Commercially available catalysts were purchased from Sigma-Aldrich. $CHCl_3$ was dried using a M-Braun SPS- 800 system.

Analytical thin layer chromatography (TLC) was performed on silica gel 60 F254 aluminum plates (Macherey-Nagel) containing a 254 nm fluorescent indicator. TLC plates were visualized by exposure to short wave ultraviolet light (254 nm) and further visualization was achieved by staining $KMnO_4$ and heating by a hot air gun. Flash column chromatography was performed using silica gel (35–70 μm, 60 Å, Acros). Organic extracts were dried over anhydrous $Na_2SO_4$ or $MgSO_4$.

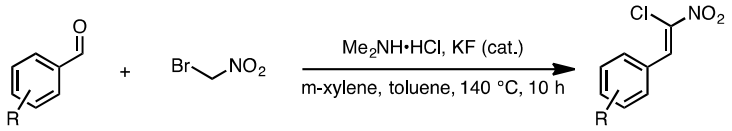
Proton nuclear magnetic resonance ($^1$H NMR) spectra were recorded with a Bruker AV 300, AV 400, AV 500 or AV 600 MHz spectrometer. Proton chemical shifts are reported in parts per million (δ scale), and are referenced using residual protium in the NMR solvent ($CDCl_3$: δ 7.26 ($CHCl_3$)). Data are reported as follows: chemical shift (multiplicity (s = singlet, br s = broad singlet, d = doublet, t = triplet, q = quadruplet, quint = quintuplet, sept = septuplet, m = multiplet), coupling constant(s) (Hz), integration). Carbon-13 nuclear magnetic resonance ($^{13}$C NMR) spectra were recorded with Bruker AV 300, AV 400, AV 500 or AV 600 MHz spectrometers. Carbon chemical shifts are reported in parts per million (δ scale), and are referenced using the carbon resonances of the solvent (δ 77.16 ($CHCl_3$)). Data are reported as follows: chemical shift (CHn where n is the number of hydrogen atoms linked to the carbon atom).

HPLC analyses for the determination of enantiomeric excesses were performed on a Merck-Hitachi system equipped with Chiralpak AZ-H, Chiralpak IA, Chiralpak IB, Chiralpak IC, Chiralpak ID, Chiralpak IE, Chiralpak IF, Lux-Cellulose-2 and Lux- Cellulose-4.

Optical Rotations were recorded on an Anton Paar MCP 200 Polarimeter at 589 nm and 25 °C and specific rotations are reported as follows: specific rotation (concentration in grams/100 mL of solution, solvent).

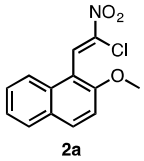
High resolution mass spectra (HRMS) were recorded on a Waters Synapt G2 HDMS apparatus using a positive electrospray (ESI) ionization source.

## 2. General procedure for the preparation of α-chloronitroalkenes



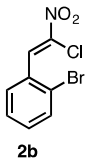

All α-chloronitroalkenes were prepared according to the literature known procedure[1] with slight modification. Substituted benzaldehyde (16.1 mmol, 1.0 equiv), bromonitromethane (4.5 g, 32.2 mmol, 2.0 equiv), dimethylamine hydrochloride (11.82 g, 144.9 mmol, 9.0 equiv), potassium fluoride (0.14 g, 2.4 mmol, 0.15 equiv), toluene (15 mL) and m-xylenes (45 mL) were combined in a 250 mL round bottomed flask and connected to a Dean- Stark trap. The mixture was heated at 140 ºC with azeotropic removal of water for 10 hours. The reaction was cool down up to room temperature and saturated sodium bisulfite ($NaHSO_3$, 20 mL) was poured in it. The reaction mixture was vigorous stirred before being partitioned between aqueous and organic layer. After separation of organic layer, the aqueous layer was extracted three times with dichloromethane. The combined organics layers were dried over anhydrous $Na_2SO_4$ and concentrated to afford a brown oil. The oily residue was subsequently purified on a silica column using ethyl acetate/hexane mixture to produce the product. The corresponding bromonitroalkene is often isolated (5-10 %) along with the desired product, which can be used as such in the domino Michael/*O*-alkylation reaction. Products **2c** (R = 2-Cl),[1] **2e** (R = $CO_2Me$),[2] **2f** (R = 2-$NO_2$),[1] and **2j** (R = 2-Me)[1] have been synthesized previously using the described procedure.

**(Z)-1-(2-chloro-2-nitrovinyl)-2-methoxynaphthalene (2a).**



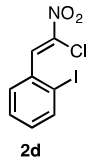

This compound was isolated as a pale yellow solid (3,6 g, 85%); **mp** = 66-67 °C; **R*f*** = 0.50 (ethyl acetate/petroleum ether 1:4); **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.72 (1H, s, CH), 7.98 (1H, d, $J$ = 9.1 Hz, ArH), 7.85 (1H, d, $J$ = 8.2 Hz, ArH), 7.63 (1H, d, $J$ = 8.7 Hz, ArH), 7.54 (1H, ddd, $J$ = 8,7, 6.7, 1.3 Hz, ArH), 7.42 (1H, ddd, $J$ = 8,2, 6.7, 1.3 Hz, ArH), 7.32 (1H, d, $J$ = 9.1 Hz, ArH), 4,01 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 155.5, 141.7, 132.9, 131.1, 129.3, 128.9, 128.8, 127.9, 124.5, 124.0, 112.8, 112.7, 56.4. **HRMS** (ESI+): $[M+NH_4H]^+$ calcd for $C_{13}H_{14}ClN_2O_3^+$ 281.0687, found 281.0695.

**(*Z*)-1-bromo-2-(2-chloro-2-nitrovinyl)benzene (2b).**




This compound was isolated as a pale yellow solid (3,2 g, 75%); **mp** = 50-51 °C; **R*f*** = 0.75 (ethyl acetate/petroleum ether 1:9); **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.62 (1H, s, CH), 7.90 (1H, dd, $J$ = 7.9, 1.8 Hz, ArH), 7.71 (1H, dd, $J$ = 7.9, 1.4 Hz, ArH), 7.44 (1H, ddd, $J$ = 7.7, 7.7, 1.4 Hz, ArH), 7.35 (1H, ddd, $J$ = 7.7, 7.7, 1.6 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 139.9, 136.1, 135.6, 132.6, 130.9, 130.7, 127.8, 126.3. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_8H_5BrClNO_2Ag^+$ 367.8238, found 367.8239.

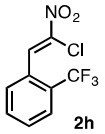
**(*Z*)-1-(2-chloro-2-nitrovinyl)-2-iodobenzene (2d).**



2d

This compound was isolated as a viscous yellow oil (4.0 g, 80%); **R*f*** = 0.65 (ethyl acetate/petroleum ether 1:9); **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.48 (1H, s, CH), 7.98 (1H, dd, $J$ = 8.0, 1.1 Hz, ArH), 7.80 (1H, dd, $J$ = 8.0, 1.7 Hz, ArH), 7.48 (1H, ddd, $J$ = 8.0, 7.3, 1.1 Hz, ArH), 7.17 (1H, ddd, $J$ = 8.0, 7.3, 1.7 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 140.3, 140.1, 135.3, 134.2, 132.4, 130.4, 128.6, 101.6. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_8H_5NO_2IClAg^+$ 415.8099, found 415.8110.

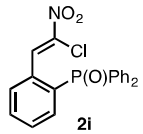
**(Z)-1-(2-chloro-2-nitrovinyl)-2-(trifluoromethyl)benzene (2h).**



2h

This compound was isolated as a pale yellow oil (3.04 g, 69%); **R*f*** = 0.70 (ethyl acetate/petroleum ether 1:9); **$^1$H NMR** (300 MHz, $CDCl_3$) $\delta$ 8.59 (s, 1H), 7.82 (dd, $J$ = 13.7, 7.8 Hz, 2H), 7.69 (t, $J$ = 7.4 Hz, 1H), 7.60 (t, $J$ = 7.6 Hz, 1H). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ δ 141.0, 134.3, 132.3, 130.7, 130.4, 128.7, 128.5, 126.7 (q, J = 5.5 Hz), 123.5 (q, $J$ = 273 Hz). **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_9H_5NO_2ClF_3Ag^+$ 357.9006, found 357.9006.

**(Z)-(2-(2-chloro-2-nitrovinyl)phenyl)diphenylphosphine oxide (2i).**

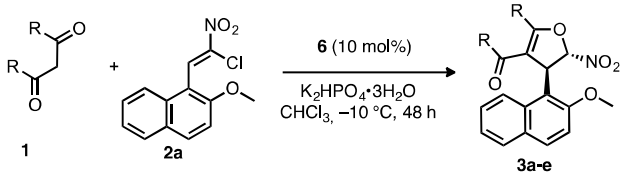


2i

This compound was isolated as a pale yellow solid (2.2 g, 58%); **R*f*** = 0.34 (ethyl acetate/petroleum ether 1:1); **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.9 (1H, s, CH), 7.79 (1H, dd, $J$ = 7.5, 4.1 Hz, ArH), 7.73-7.60 (5H, m, ArH), 7.59-7.53 (1H, m, ArH), 7.53-7.40 (5H, m, ArH), 7.32 (1H, ddd, $J$ = 13.6, 7.78, 1.4 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 139.5, 134.8 (d, $J$ = 6.5 Hz), 133.0 (d, $J$ = 99.0 Hz), 133.7 (d, $J$ = 10.8 Hz), 133.5, 132.6 (d, $J$ = 2.7 Hz), 132.3 (d, $J$ = 1.9 Hz), 132.2, 132.1 (d, $J$ = 9.8 Hz), 131.4 (d, $J$ = 5.4 Hz), 131.2, 130.6 (d, $J$ = 8.9 Hz), 129.9 (d, $J$ = 12.1 Hz), 129.0 (d, $J$ = 12.1 Hz). **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{20}H_{15}NO_3PClAg^+$ 489.9524, found 489.9528.

# 3. General procedure for the enantioselective synthesis of dihydrofurans 3a-e

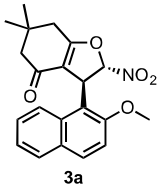
Catalyst **6** was synthetized according to literature procedure.[3] Racemic samples were synthesized according to the following procedure.[4]




A solution of the corresponding α-chloronitroalkenes (0.28 mmol, 1.0 equiv) and catalyst **6** (10 mol %) in $CHCl_3$ (0.03 M, 9 mL) was cooled at 0 ºC. Then, diketone derivate (0.36 mmol, 1.3 equiv) and $K_2HPO_4$ (0.42 mmol, 1.5 equiv) were added sequentially. The reaction mixture was stirred at same temperature for 48 hours. When the reaction was complete as

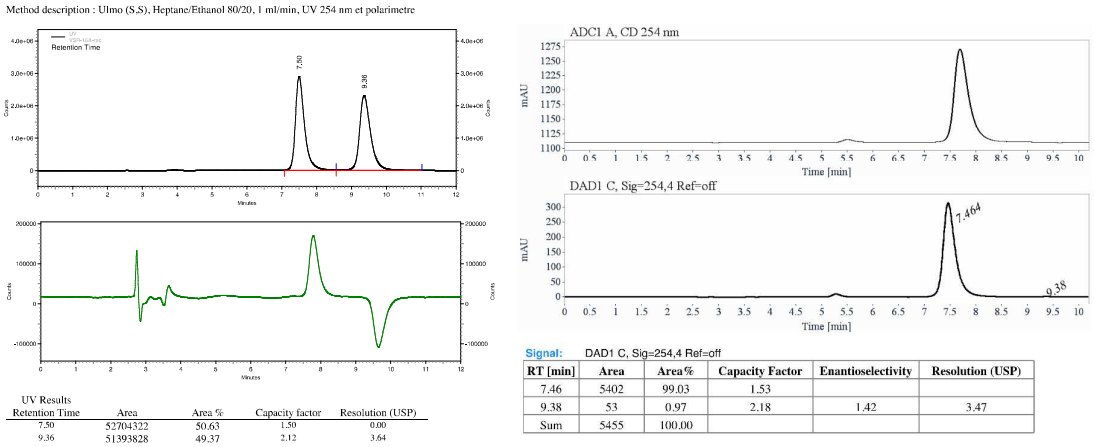
indicated by TLC analysis, the crude product was directly purified by means of flash silica gel column chromatography.

**(2*S*,3*S*)-3-(2-methoxynaphthalen-1-yl)-6,6-dimethyl-2-nitro-3,5,6,7-tetrahydro-benzo-furan-4(2*H*)-one (3a).**



3a

This compound was isolated as a pale yellow solid (94 mg, 92%); **mp** = 154-155 °C; **R*f*** = 0.35 (ethyl acetate/petroleum ether 3:7); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Ulmo (S,S), Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.46 min, $t_{minor}$ = 9.38 min, ee = 99%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +465; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.17 (1H, brs, ArH), 7,85 (1H, d, *J* = 9.0 Hz, ArH), 7,80 (1H, d, *J* = 8.1 Hz, ArH), 7.56 (1H, brs, ArH), 7.39 (1H, dd, *J* = 9.0, 7.6 Hz, ArH), 7.24 (1H, brs, ArH), 6.29 (1H, d, *J* = 2.9 Hz, CH), 5.46 (1H, brs, CH), 3.90 (3H, s, $CH_3$), 2.72-2.47 (2H, m), 2.25 (1H, d, *J* = 16.4 Hz, CH), 2.13 (1H, d, *J* = 16.4 Hz, CH), 1.19 (3H, s, $CH_3$), 1.11 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 193.0, 174.3, 155.3, 132.8, 130.8, 129.5, 128.8, 127.6, 123.9, 122.6, 117.6, 113.8, 112.6, 111.7, 56.0, 51.4, 45.9, 37.4, 34.7, 29.2, 28.0. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{21}H_{22}NO_5^+$ 368.1492, found 368.1492.



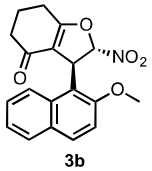

UV Results

| Retention Time | Area | Area % | Capacity factor | Resolution (USP) |
|---|---|---|---|---|
| 7.50 | 52703322 | 50.63 | 1.50 | 0.00 |
| 9.36 | 51393828 | 49.37 | 2.12 | 3.64 |

Signal: DAD1 C, Sig=254,4 Ref=off

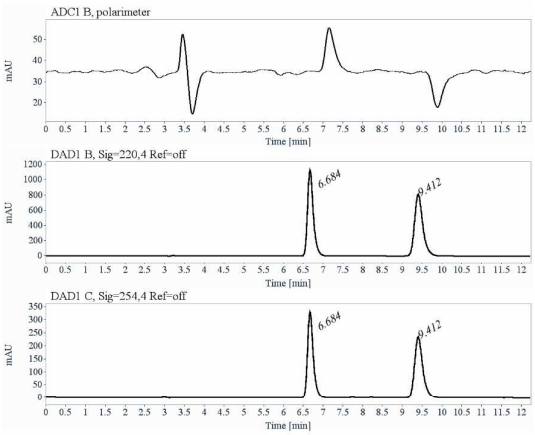
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.46 | 5402 | 99.03 | 1.53 | | |
| 9.38 | 53 | 0.97 | 2.18 | 1.42 | 3.47 |
| Sum | 5455 | 100.00 | | | |

**(2*S*,3*S*)-3-(2-methoxynaphthalen-1-yl)-2-nitro-3,5,6,7-tetrahydrobenzofuran-4(2*H*)-one (3b).**



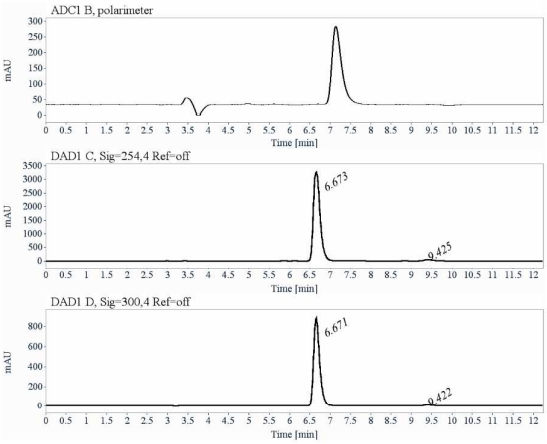
3b

This compound was isolated as a white solid (88 mg, 92%); **mp** = 163-165 °C; **R*f*** = 0.35 (ethyl acetate/petroleum ether 3:7); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Cellulose-4, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.68 min, $t_{minor}$ = 9.41 min, ee = 96%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +489; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.17 (1H, brs, ArH), 7,84 (1H, d, *J* = 9.1 Hz, ArH), 7,80 (1H, d, *J* = 8.2 Hz, ArH), 7.56 (1H, brs, ArH), 7.39 (1H, dd, *J* = 7.6, 7.6 Hz, ArH), 7.28-7.22 (1H, m, ArH), 6.27 (1H, d, *J* = 3.5 Hz, CH), 5.49 (1H, brs, CH), 3.90 (3H, s, $CH_3$), 2.83-2.65 (2H, m), 2.37-2.03 (4H, m). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 193.5, 175.1, 155.6, 132.7, 130.8, 129.6, 128.9, 127.6, 124.0, 122.6, 117.9, 115.3, 113.3, 111.4, 56.5, 45.9, 37.0, 23.6, 21.8. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{18}NO_5^+$ 340.1179, found 340.1179.




Signal: DAD1 B, Sig=220,4 Ref=off

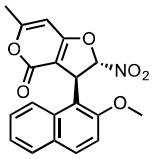
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.68 | 11516 | 49.52 | 1.27 | | |
| 9.41 | 11739 | 50.48 | 2.19 | 1.73 | 8.68 |
| Sum | 23255 | 100.00 | | | |




Signal: DAD1 C, Sig=254,4 Ref=off

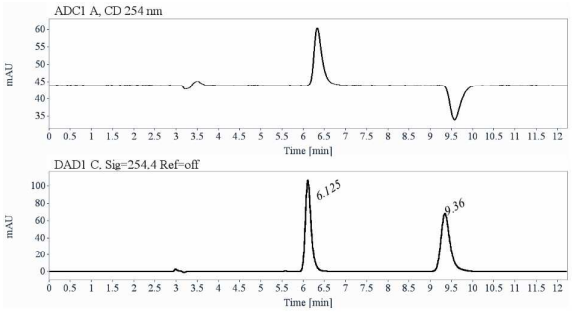
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.67 | 37687 | 97.92 | 1.26 | | |
| 9.43 | 801 | 2.08 | 2.19 | 1.74 | 8.02 |
| Sum | 38489 | 100.00 | | | |

**(2*S*,3*S*)-3-(2-methoxynaphthalen-1-yl)-6-methyl-2-nitro-2,3-dihydro-4*H*-furo[3,2-*c*]pyran-4-one (3c).**



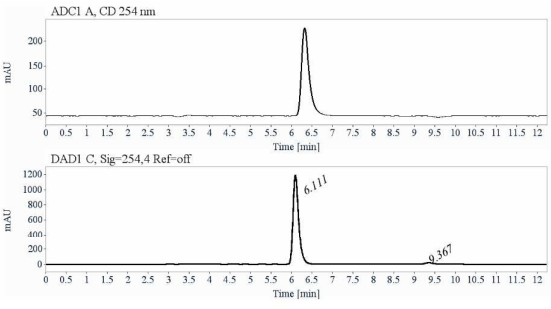
3c

This compound was isolated as a white solid (92 mg, 93%); **mp** = 156-157 °C; **R*f*** = 0.37 (ethyl acetate/petroleum ether 1:1); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Cellulose-4, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.13 min, $t_{minor}$ = 9.36 min, ee = 94%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +381; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.16 (1H, brs, ArH), 7,88 (1H, d, *J* = 9.0 Hz, ArH), 7,82 (1H, d, *J* = 8.3 Hz, ArH), 7.58 (1H, brs, ArH), 7.40 (1H, dd, *J* = 7.8, 6.6 Hz, ArH), 7.24 (1H, d, *J* = 9.0 Hz, ArH), 6.38 (1H, d, *J* = 3.3 Hz, CH), 6.23 (1H, s, CH), 5.62 (1H, brs, CH), 3.83 (3H, s, $CH_3$), 2.31 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 169.9, 167.2, 159.6, 155.6, 132.8, 131.3, 129.5, 129.0, 127.9, 124.1, 122.2, 116.6, 113.0, 111.9, 101.3, 95.0, 56.3, 45.4, 20.7. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{16}NO_6^+$ 354.0972, found 354.0977.




Signal: DAD1 C, Sig=254,4 Ref=off

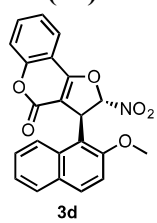
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.12 | 1029 | 49.39 | 1.08 | | |
| 9.36 | 1054 | 50.61 | 2.17 | 2.02 | 10.24 |
| Sum | 2082 | 100.00 | | | |




Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.11 | 11531 | 96.76 | 1.07 | | |
| 9.37 | 387 | 3.24 | 2.18 | 2.03 | 10.22 |
| Sum | 11917 | 100.00 | | | |

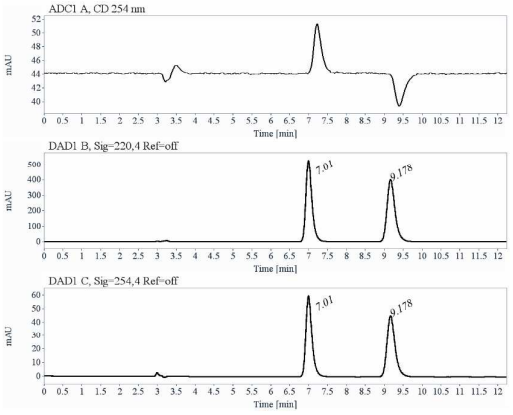
**(2*S*,3*S*)-3-(2-methoxynaphthalen-1-yl)-2-nitro-2,3-dihydro-4*H*-furo[3,2-*c*]chromen-4-one (3d).**

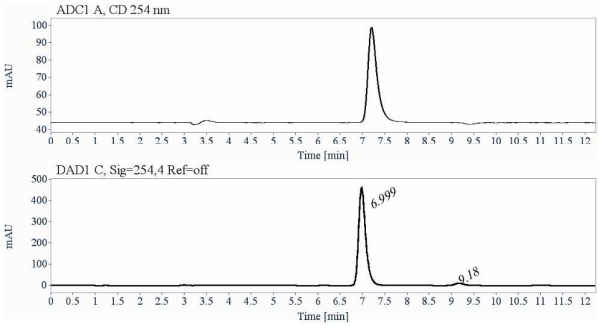


3d

This compound was isolated as a white solid (102 mg, 94%); **mp** = 210-215 °C; **R*f*** = 0.65 (ethyl acetate/petroleum ether 3:7); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Cellulose-4, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ

= 254 nm): $t_{major}$ = 7.01 min, $t_{minor}$ = 9.18 min, ee = 94%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +499; **$^1$H NMR** (400 MHz, DMSO-$d_6$) $\delta$ 8.40 (1H, d, *J* = 9.1 Hz, ArH), 8.02 (1H, d, *J* = 9.1 Hz, ArH), 7,99-7.93 (2H, m, ArH), 7.81-7.76 (1H, m, ArH), 7.62 (1H, dd, *J* = 9.1, 7.1 Hz, ArH), 7.56-7.51 (2H, m, ArH), 7.49-7.43 (2H, m, ArH), 7.09 (1H, d, *J* = 3.5 Hz, CH), 6.10 (1H, d, *J* = 3.5 Hz, CH), 3.72 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, DMSO-$d_6$) $\delta$ 164.2, 157.2, 155.9, 154.4, 133.5, 132.6, 130.6, 128.8, 128.5, 127.2, 125.0, 123.7, 122.9, 122.5, 117.0, 114.0, 111.6, 111.0, 104.5, 56.5, 44.8. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{22}H_{16}NO_6^+$ 390.0972, found 390.0969.



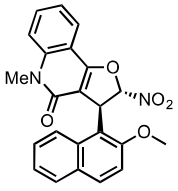

Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.01 | 5939 | 49.85 | 1.38 | | |
| 9.18 | 5976 | 50.15 | 2.11 | 1.53 | 6.55 |
| Sum | 11916 | 100.00 | | | |

Signal: DAD1 C, Sig=254,4 Ref=off

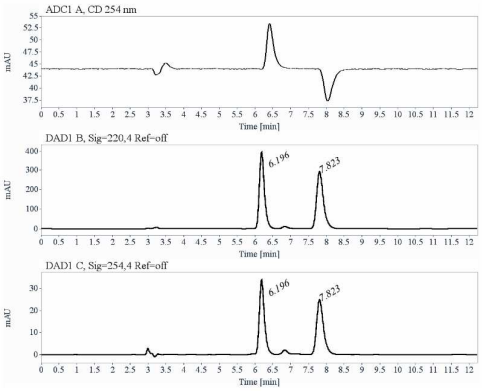
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.00 | 5165 | 96.87 | 1.37 | | |
| 9.18 | 167 | 3.13 | 2.11 | 1.54 | 6.57 |
| Sum | 5331 | 100.00 | | | |

**(2*S*,3*S*)-3-(2-methoxynaphthalen-1-yl)-5-methyl-2-nitro-3,5-dihydrofuro[3,2-*c*]quinolin-4(2*H*)-one (3e).**



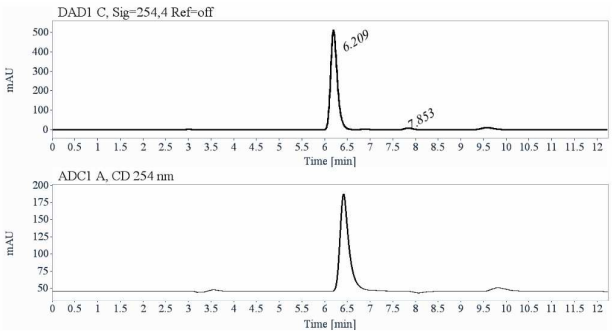

**3e**

This compound was isolated as a white solid (100 mg, 89%); **mp** = 210-215 °C; **R*f*** = 0.50 (ethyl acetate/petroleum ether 1:1); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Cellulose-4, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.20 min, $t_{minor}$ = 7.82 min, ee = 95%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +520; **$^1$H NMR** (400 MHz, DMSO-$d_6$) $\delta$ 8.43 (1H, d, *J* = 9.0 Hz, ArH), 8.01-7.91 (3H, m, ArH), 7,79-7.73 (1H, m, ArH), 7.64-7.57 (2H, m, ArH), 7.48-7.40 (3H, m, ArH), 7.56-7.51 (2H, m, ArH), 7.49-7.43 (2H, m, ArH), 6.95 (1H, d, *J* = 3.1 Hz, CH), 5.97 (1H, d, *J* = 3.1 Hz, CH), 3.66 (3H, s, $CH_3$), 3.48 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, DMSO-$d_6$) $\delta$ 160.3, 158.2, 155.7, 140.4, 132.7, 131.9, 130.2, 128.8, 128.3, 126.9, 123.5, 123.4, 122.3, 118.2, 115.5, 114.1, 111.7, 110.6, 109.3, 56.4, 46.2, 30.7, 28.6. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{23}H_{19}N_2O_5^+$ 403.1288, found 403.1288.




Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.20 | 3900 | 50.15 | 1.10 | | |
| 7.82 | 3878 | 49.85 | 1.65 | 1.50 | 5.51 |
| Sum | 7778 | 100.00 | | | |

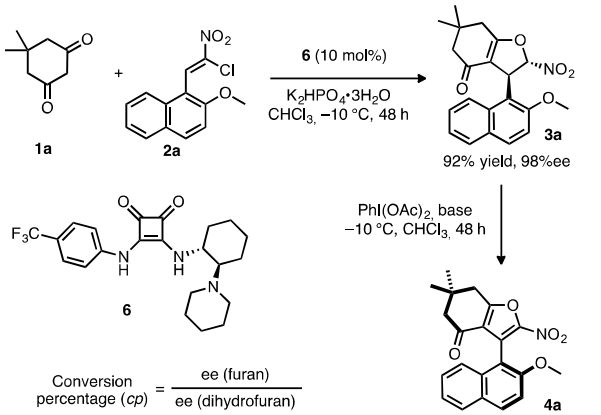



Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.21 | 5271 | 97.65 | 1.10 | | |
| 7.85 | 127 | 2.35 | 1.66 | 1.50 | 5.38 |
| Sum | 5398 | 100.00 | | | |

# 4. General procedure for the oxidation of dihydrofuran 3a-e to furan atropisomers 4a-e

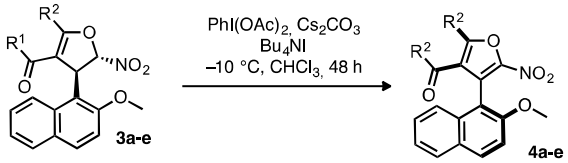
Optimization of the reaction conditions




| Entry | Base | Yield of 4a[a] | ee (%) of 4a[b] | *cp* (%) |
|---|---|---|---|---|
| 1 | $Et_3N$ | 60 | 40 | 42 |
| 2 | DMAP | 62 | 55 | 58 |
| 3 | $K_3PO_4$ | 56 | 87 | 91 |
| 4 | $Cs_2CO_3$ | 72 | 89 | 94 |

[a]Isolated yield after column chromatography. [b]Determined by HPLC analysis on chiral stationary phase.

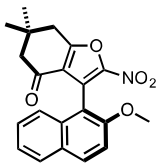
## General procedure




The mixture of enantioenriched 2,3-dihydrofuran **3a-3e** (0.27 mmol, 1.0 equiv), $PhI(OAc)_2$ (210 mg, 0.65 mmol, 2.4 equiv), and $Cs_2CO_3$ (132 mg, 0.41 mmol, 1.6 equiv) in $CHCl_3$ (6

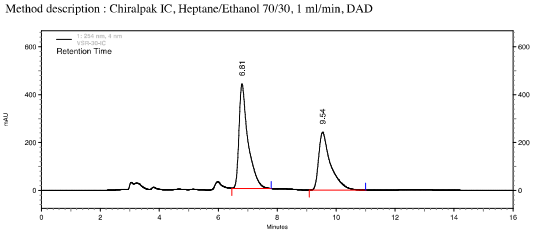
mL) was treated with $Bu_4NI$ (120 mg, 0.32 mmol, 1.2 equiv) at –5 °C. The reaction was allowed to stir at same temperature for 48 h. Upon completion as shown by TLC, the reaction mixture was washed with saturated $Na_2S_2O_3$ (20 mL) and extracted using dichloromethane (3 x 5 mL). The organic layer was dried over $Na_2SO_4$ and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel ($MeOH/CH_2Cl_2$) to provide corresponding furan **4a-e**.

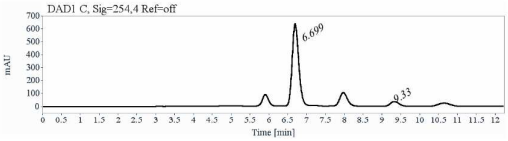
**(*aS*)-3-(2-methoxynaphthalen-1-yl)-6,6-dimethyl-2-nitro-6,7-dihydrobenzofuran-4(5*H*)-one (4a)**



4a

This compound was isolated as an orange solid (71 mg, 72%); **mp** = 165-166 °C; **R*f*** = 0.34 (ethyl acetate/petroleum ether 3:7); **HPLC** (Chiralpak IC, Heptane/ethanol = 70/30, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.81 min, $t_{minor}$ = 9.54 min, ee = 85%; **Chirality conversion percentage** = 94%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –60; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.97 (1H, d, *J* = 9.1 Hz, ArH), 7.84 (1H, dd, *J* = 7.6, 1.8 Hz, ArH), 7.40-7.28 (4H, m, ArH), 3.84 (3H, s, $OCH_3$), 2.95 (2H, d, *J* = 1.0 Hz, $CH_2$), 2.40 (2H, s, $CH_2$), 1.22 (3H, s, $CH_3$), 1.21 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 191.5, 165.9, 155.0, 149.2, 132.1, 131.6, 128.8, 128.7, 127.3, 123.9, 123.5, 122.0, 119.8, 112.8, 110.7, 56.5, 52.6, 37.6, 35.0, 28.7, 28.6. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{21}H_{19}NO_5^+$ 366.1336, found 366.1338.

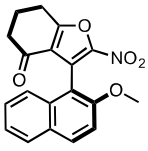



Signal: DAD1 C, Sig=254,4 Ref=off

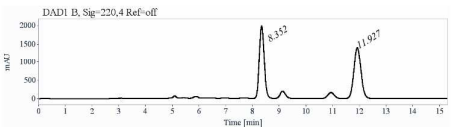
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.70 | 7629 | 92.67 | 1.27 | | |
| 9.33 | 603 | 7.33 | 2.16 | 1.70 | 7.06 |
| Sum | 8232 | 100.00 | | | |

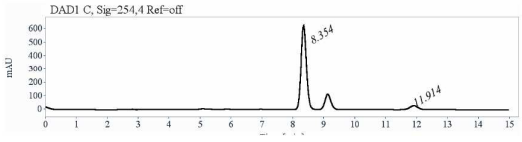
**(*aS*)-3-(2-methoxynaphthalen-1-yl)-2-nitro-6,7-dihydrobenzofuran-4(5*H*)-one (4b)**



4b

This compound was isolated as a yellow solid (46 mg, 51%); **mp** = 203-204 °C; **R*f*** = 0.35 (ethyl acetate/petroleum ether 3:7); **HPLC** (Lux-Cellulose-2, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 8.35 min, $t_{minor}$ = 11.93 min, ee = 86%; **Chirality conversion percentage** = 90%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –20; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.97 (1H, d, *J* = 9.1 Hz, ArH), 7.85-7.82 (1H, m, ArH), 7.38-7.28 (4H, m, ArH), 3.85 (3H, s, $OCH_3$), 3.11 (2H, t, *J* = 6.3 Hz, $CH_2$), 2.52 (2H, dd, *J* = 7.4, 5.1 Hz, $CH_2$), 2.30 (2H, pent, *J* = 6.3, $CH_2$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 191.8, 166.8, 155.0, 132.2, 131.7, 128.9, 128.7, 127.3, 123.9, 123.5, 123.0, 119.9, 112.9, 110.8, 56.6, 38.4, 23.9, 21.9. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{16}NO_5^+$ 338.1023, found 338.1023.



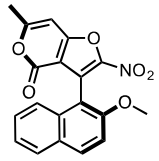

Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 8.35 | 25450 | 49.58 | 1.83 | | |
| 11.93 | 25879 | 50.42 | 3.04 | 1.66 | 8.73 |
| Sum | 51329 | 100.00 | | | |

Signal: DAD1 C, Sig=254,4 Ref=off

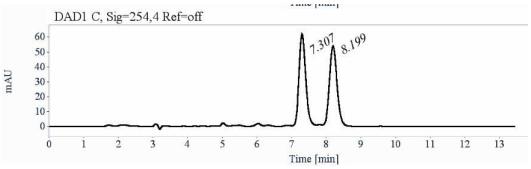
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 8.35 | 7490 | 93.01 | 1.83 | | |
| 11.91 | 563 | 6.99 | 3.04 | 1.66 | 8.80 |
| Sum | 8053 | 100.00 | | | |

**(*aS*)-3-(2-methoxynaphthalen-1-yl)-6-methyl-2-nitro-4*H*-furo[3,2-*c*]pyran-4-one (4c)**



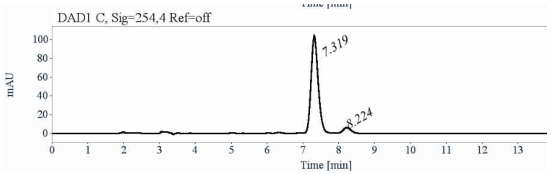
4c

This compound was isolated as a yellow solid (76 mg, 80%); **mp** = 227-229 °C; **R*f*** = 0.45 (ethyl acetate/petroleum ether 3:7); **HPLC** (Chiralpak AZ-H, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.31 min, $t_{minor}$ = 8.20 min, ee = 87%; **Chirality conversion percentage** = 92%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –158; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.01 (1H, d, *J* = 9.1 Hz, ArH), 7.86 (1H, dd, *J* = 7.72, 1.76 Hz, ArH), 7.43-7.31 (4H, m, ArH), 6.54 (1H, s, CH), 3.90 (3H, s, $OCH_3$), 2.39 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 165.9, 160.6, 156.7, 155.4, 148.5, 132.4, 132.0, 128.9, 127.7, 124.2, 123.3, 121.2, 112.8, 110.3, 109.3, 95.1, 56.6, 29.9, 21.0. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{14}NO_6^+$ 352.0816, found 352.0815.




Signal: DAD1 B, Sig=220,4 Ref=off

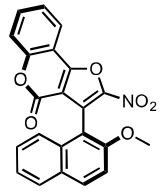
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.31 | 5642 | 50.51 | 1.48 | | |
| 8.20 | 5529 | 49.49 | 1.78 | 1.20 | 2.38 |
| Sum | 11171 | 100.00 | | | |




Signal: DAD1 B, Sig=220,4 Ref=off

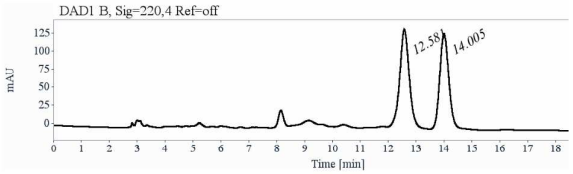
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.32 | 9748 | 93.71 | 1.48 | | |
| 8.22 | 654 | 6.29 | 1.79 | 1.21 | 2.33 |
| Sum | 10403 | 100.00 | | | |

**(*aS*)-3-(2-methoxynaphthalen-1-yl)-2-nitro-4*H*-furo[3,2-*c*]chromen-4-one (4d)**



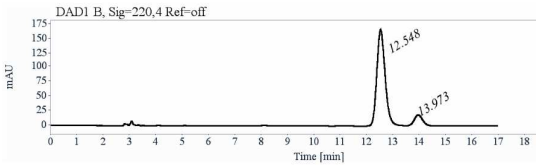
4d

This compound was isolated as an orange solid (91 mg, 87%); **mp** = 227-229 °C; **R*f*** = 0.72 (ethyl acetate/petroleum ether 3:7); **HPLC** (Lux-Cellulose-2, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 12.54 min, $t_{minor}$ = 13.97 min, ee = 79%; **Chirality conversion percentage** = 81%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –174; **$^1$H NMR** (400 MHz, $CD_2Cl_2$) $\delta$ 8.15 (1H, td, *J* = 7.3, 1.6 Hz, ArH), 8.10 (1H, dd, *J* = 8.8, 1.8 Hz, ArH), 7.96-7.91 (1H, m, ArH), 7.76-7.70 (1H, m, ArH), 7.55-7.39 (6H, m, ArH), 3.90 (3H, s, $OCH_3$), 2.39 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CD_2Cl_2$) $\delta$ 142.7, 141.4, 141.3, 140.4, 135.5, 119.7, 118.1, 117.9, 114.7, 114.6, 113.6, 111.4, 110.1, 109.2, 108.2, 107.5, 103.7, 98.8, 98.4, 97.2, 95.2, 42.5. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{22}H_{14}NO_6^+$ 388.0816, found 388.0818.




Signal: DAD1 B, Sig=220,4 Ref=off

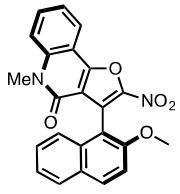
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 12.58 | 3205 | 51.69 | 3.26 | | |
| 14.00 | 2996 | 48.31 | 3.75 | 1.15 | 2.39 |
| Sum | 6201 | 100.00 | | | |




Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 12.55 | 3636 | 89.36 | 3.25 | | |
| 13.97 | 433 | 10.64 | 3.74 | 1.15 | 2.47 |
| Sum | 4068 | 100.00 | | | |

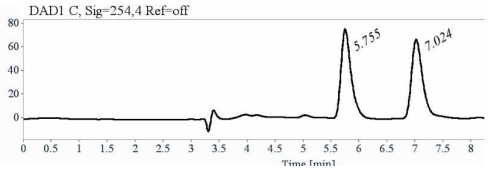
**(*aS*)-3-(2-methoxynaphthalen-1-yl)-5-methyl-2-nitrofuro[3,2-*c*]quinolin-4(5*H*)-one (4e)**

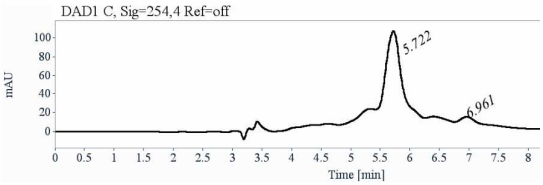


4e

This compound was isolated as an orange solid (75 mg, 69%). This product proved to be very insoluble in most organic solvents; **mp** = 312-314 °C; **R*f*** = 0.50 (ethyl acetate/petroleum ether 1:1); **HPLC** (Chiralpak IB, Heptane/ethanol/chloroform = 50/40/10, flow rate = 1.0 mL/min, λ = 254

nm): $t_{major}$ = 5.72 min, $t_{minor}$ = 6.96 min, ee = 86%; **Chirality conversion percentage** = 90%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +9; **$^1$H NMR** (400 MHz, DMSO-$d_6$) $\delta$ 8.21 (1H, d, *J* = 7.9, ArH), 8.12 (1H, d, *J* = 9.0 Hz, ArH), 7.96 (1H, d, *J* = 7.8 Hz, ArH), 7.84 (1H, ddd, *J* = 8.7, 7.8, 1.1 Hz, ArH), 7.72 (1H, d, *J* = 8.6 Hz, ArH), 7.58 (1H, d, *J* = 9.2 Hz, ArH), 7.55-7.49 (2H, m, ArH), 7.41-7.32 (2H, m, ArH), 3.81 (3H, s, $OCH_3$), 3.56 (3H, s, $CH_3$). **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{23}H_{17}N_2O_5^+$ 401.1132, found 401.1132.




Signal: DAD1 C, Sig=254,4 Ref=off

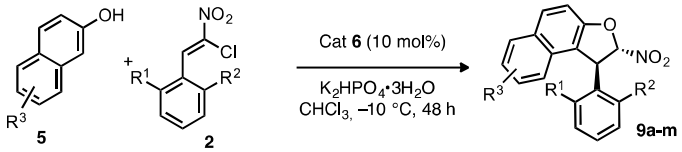
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.75 | 952 | 50.25 | 0.95 | | |
| 7.02 | 942 | 49.75 | 1.38 | 1.45 | 3.77 |
| Sum | 1894 | 100.00 | | | |

Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.72 | 1416 | 92.78 | 0.94 | | |
| 6.96 | 110 | 7.22 | 1.36 | 1.45 | 3.06 |
| Sum | 1526 | 100.00 | | | |

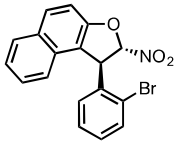
# 5. General procedure for the enantioselective synthesis of dihydrofurans 10a-10m

The synthesis of racemic dihydrofuran was accomplished using the following procedure: Triethylamine (2.0 equiv) was added to a solution of chloronitroalkene **2** (1.0 equiv) and 2-naphthol derivative **5** (1.2 equiv) in chloroform (C = 0.1 mol.L$^{-1}$). The reaction was stirred at room temperature until TLC showed consumption of stating materials. Purification by flash column chromatography affords the desired product.




A solution of the corresponding α-chloronitroalkenes (0.38 mmol, 1.0 equiv) and catalyst **6** (10 mol %) in $CHCl_3$ (0.1 M, 4 mL) was cooled at 0 ºC. Then, 2-naphthol derivative (0.49 mmol, 1.3 equiv) and $K_2HPO_4$ (0.95 mmol, 2.5 equiv) were added sequentially. The reaction mixture was stirred at same temperature for 48-72 hours. When the reaction was complete as indicated by TLC analysis, the crude product was directly purified by flash column chromatography on silica gel.

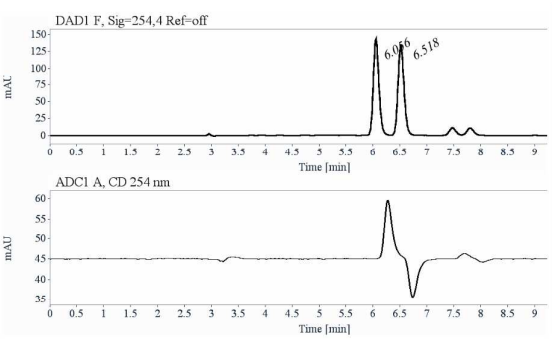
**(1*R*,2*S*)-1-(2-bromophenyl)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan (9a)**

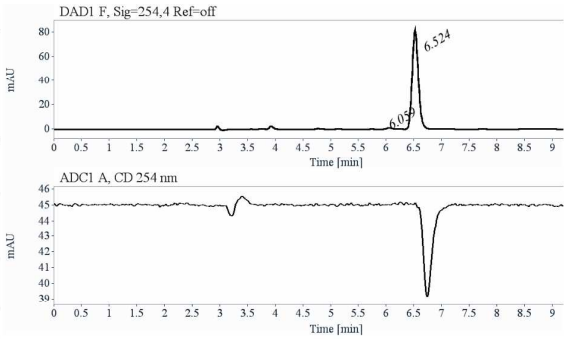


9a

This compound was isolated as a white solid (105 mg, 75%); **mp** = 115-117 °C; **R*f*** = 0.42 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Cellulose 2, Heptane/ethanol = 90/10, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.52 min, $t_{minor}$ = 6.06 min, ee = 97%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +201; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.94 (1H, d, *J* = 8.8 Hz,

ArH), 7.91-7.87 (1H, m, ArH), 7.73 (1H, dd, *J* = 7.9, 1.5 Hz, ArH), 7.46 (1H, d, *J* = 8.8 Hz, ArH), 7.42-7.34 (3H, m, ArH), 7.17 (1H, ddd, *J* = 7.6, 7.6, 2.2 Hz, ArH), 7.14-7.08 (1H, m, ArH), 6.63 (1H, brd, *J* = 6.5 Hz, ArH), 6.11 (1H, s, CH), 5.91 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 156.7, 137.0, 133.7, 131.8, 131.1, 130.1, 129.5, 129.4, 129.2, 128.5, 128.1, 124.8, 124.1, 123.2, 118.9, 112.1, 112.0, 53.9. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{18}H_{12}BrNO_3Ag^+$ 475.9046, found 475.9046.



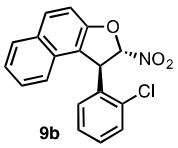

Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.06 | 18113 | 49.71 | 1.05 | | |
| 6.52 | 18323 | 50.29 | 1.21 | 1.15 | 2.29 |
| Sum | 36436 | 100.00 | | | |

Signal: DAD1 D, Sig=220,4 Ref=off

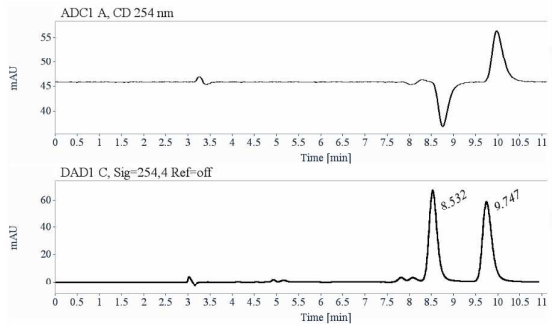
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.06 | 163 | 1.40 | 1.05 | | |
| 6.52 | 11451 | 98.60 | 1.21 | 1.15 | 2.35 |
| Sum | 11614 | 100.00 | | | |

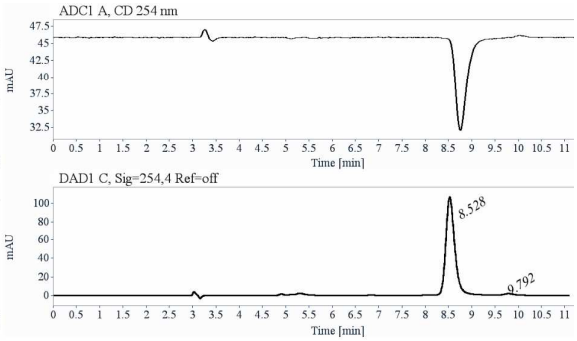
**(1*R*,2*S*)-1-(2-chlorophenyl)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan (9b)**



9b

This compound was isolated as a white solid (101 mg, 82%); **mp** = 112-114 °C; **R*f*** = 0.57 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Amylose 2, Heptane/ethanol = 90/10, flow rate = 1.0 mL/min, $\lambda$ = 254 nm): $t_{major}$ = 8.53 min, $t_{minor}$ = 9.79 min, ee = 97%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +185; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.94 (1H, d, *J* = 9.0 Hz, ArH), 7.91-7.87 (1H, m, ArH), 7.54 (1H, d, *J* = 7.7, ArH), 7.45 (1H, d, *J* = 9.0 Hz, ArH), 7.42-7.33 (3H, m, ArH), 7.28-7.23 (1H, m, ArH), 7.07 (1H, dd, *J* = 7.7, 7.7 Hz, ArH), 6.64 (1H, brd, *J* = 7.7 Hz, ArH), 6.11 (1H, d, *J* = 1.2 Hz, CH), 5.88 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 156.7, 135.2, 133.8, 131.8, 131.1, 130.4, 129.9, 129.6, 129.3, 129.2, 128.1, 127.9, 124.8, 123.1, 118.9, 112.1, 112.0, 51.4. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{18}H_{12}ClNO_3Ag^+$ 431.9551, found 431.9558.



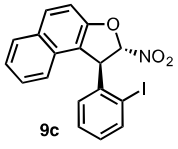

Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 8.53 | 859 | 49.73 | 1.89 | | |
| 9.75 | 868 | 50.27 | 2.30 | 1.22 | 3.39 |
| Sum | 1727 | 100.00 | | | |

Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 8.53 | 1382 | 98.31 | 1.89 | | |
| 9.79 | 24 | 1.69 | 2.32 | 1.23 | 3.59 |
| Sum | 1406 | 100.00 | | | |

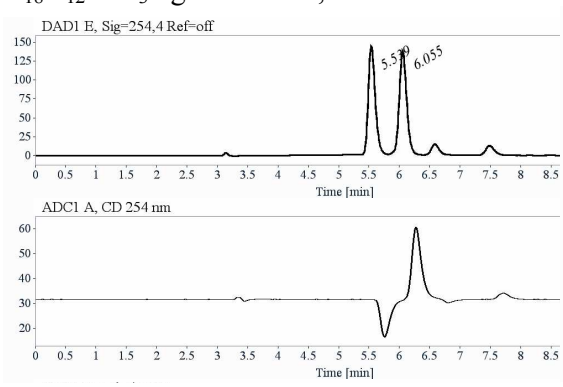
**(1*R*,2*S*)-1-(2-iodophenyl)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan (9c)**

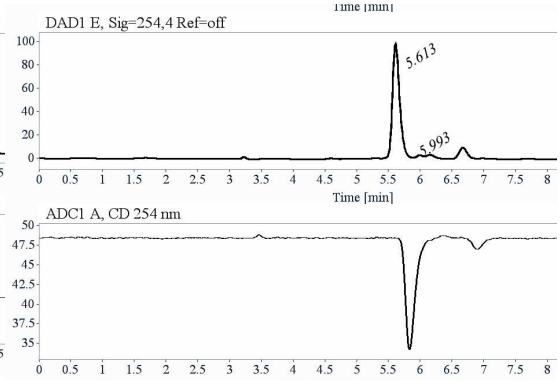


9c

This compound was synthesiszed on 0.59 mmol scale and was isolated as a light green solid (196 mg, 80%); **mp** = 104-105 °C; **R*f*** = 0.40 (ethyl

acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak IB, Heptane/ethanol = 90/10, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 5.61 min, $t_{minor}$ = 5.99 min, ee = 97%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +221; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.01 (1H, dd, *J* = 7.9, 1.1 Hz, ArH), 7.93 (1H, d, *J* = 9.0 Hz, ArH), 7.88 (1H, dd, *J* = 7.3, 1.6 Hz, ArH), 7.45 (1H, d, *J* = 8.9 Hz, ArH), 7.44-7.32 (3H, m, ArH), 7.18-7.11 (1H, m, ArH), 6.99 (1H, ddd, *J* = 7.8, 7.8, 1.6 Hz, ArH), 6.59 (1H, d, *J* = 7.2 Hz, ArH), 6.06 (1H, s, CH), 5.82 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 156.6, 140.6, 140.5, 131.9, 131.1, 130.3, 129.5, 129.4, 129.2, 128.8, 128.1, 127.5, 124.9, 123.5, 119.7, 112.3, 112.0, 58.8. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{18}H_{12}INO_3Ag^+$ 523.8907, found 523.8912.



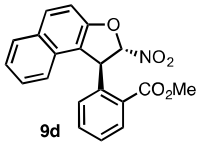

Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.54 | 16161 | 49.40 | 0.88 | | |
| 6.06 | 16552 | 50.60 | 1.05 | 1.20 | 2.37 |
| Sum | 32714 | 100.00 | | | |

Signal: DAD1 E, Sig=254,4 Ref=off

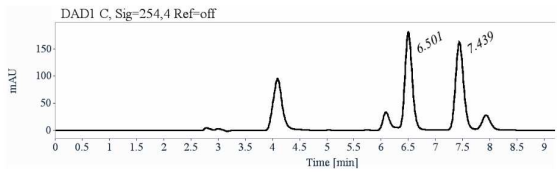
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.61 | 782 | 97.27 | 0.90 | | |
| 5.99 | 22 | 2.73 | 1.03 | 1.14 | 1.66 |
| Sum | 804 | 100.00 | | | |

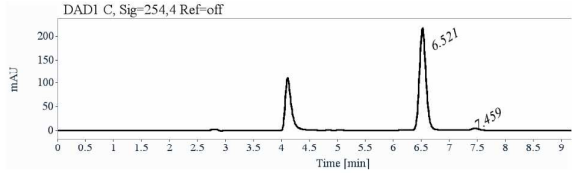
**Methyl 2-((1*S*,2*S*)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan-1-yl)benzoate (9d)**



**9d**

This compound was isolated as a white solid (91 mg, 69%); **mp** = 165-167 °C; **R*f*** = 0.47 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Cellulose 2, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.52 min, $t_{minor}$ = 7.46 min, ee = 96%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +194; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.07 (1H, d, *J* = 7.8 Hz, ArH), 7.92 (1H, d, *J* = 8.9 Hz, ArH), 7.92-7.87 (1H, m, ArH), 7.44-7.26 (6H, m, ArH), 6.73 (1H, d, *J* = 6.1 Hz, ArH), 6.42 (1H, s, CH), 6.14 (1H, s, CH), 4.02 (3H, s, $OCH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 168.1, 156.9, 138.6, 133.1, 131.5, 131.4, 131.0, 129.8, 129.7, 129.2, 129.1, 128.5, 127.8, 124.6, 123.4, 119.1, 113.7, 111.9, 52.9, 50.3. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{20}H_{15}NO_5Ag^+$ 455.9996, found 456.0002.



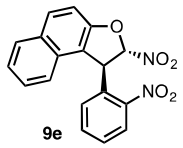

Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.50 | 1608 | 49.51 | 1.20 | | |
| 7.44 | 1640 | 50.49 | 1.52 | 1.26 | 3.69 |
| Sum | 3248 | 100.00 | | | |

Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.52 | 1737 | 97.87 | 1.21 | | |
| 7.46 | 38 | 2.13 | 1.53 | 1.26 | 4.16 |
| Sum | 1775 | 100.00 | | | |

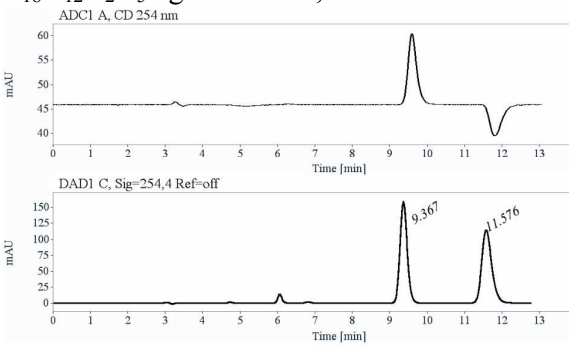
**(1*S*,2*S*)-2-nitro-1-(2-nitrophenyl)-1,2-dihydronaphtho[2,1-*b*]furan (9e)**

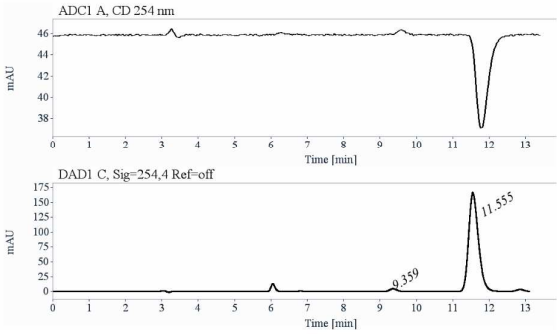


**9e**

This compound was synthesized on 0.62 mmol and isolated as a white solid (193 mg, 93%); **mp** = 95-97 °C; **R*f*** = 0.42 (ethyl acetate/petroleum ether 2:8); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak AZ-H, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 11.56 min, $t_{minor}$ = 9.36 min, ee = 96%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +230; **$^1$H NMR** (400 MHz,

$CDCl_3$) $\delta$ 8.08 (1H, d, $J$ = 8.1 Hz, ArH), 7.96 (1H, d, $J$ = 8.9 Hz, ArH), 7.93-7.88 (1H, m, ArH), 7.50 (1H, ddd, $J$ = 8.1, 7.1, 1.6 Hz, ArH), 7.46-7.37 (4H, m, ArH), 7.33-7.28 (1H, m, ArH), 6.80 (1H, d, $J$ = 6.3 Hz, ArH), 6.20 (1H, s, CH), 6.06 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 157.1, 149.0, 134.2, 132.3, 132.0, 131.1, 130.3, 129.8, 129.4, 129.3, 128.3, 125.5, 125.0, 122.9, 117.5, 112.4, 111.9, 49.2. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{18}H_{12}N_2O_5Ag^+$ 442.9792, found 442.9791.



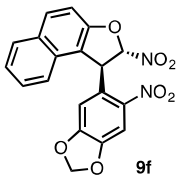

Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 9.37 | 2142 | 49.98 | 2.18 | | |
| 11.58 | 2143 | 50.02 | 2.92 | 1.34 | 5.23 |
| Sum | 4285 | 100.00 | | | |

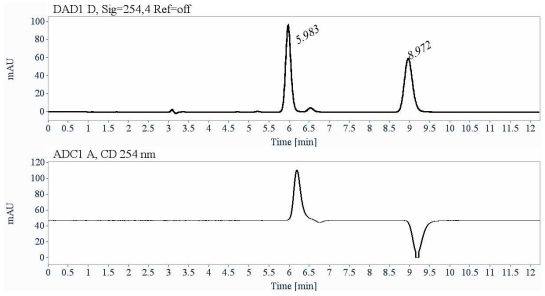
Signal: DAD1 C, Sig=254,4 Ref=off

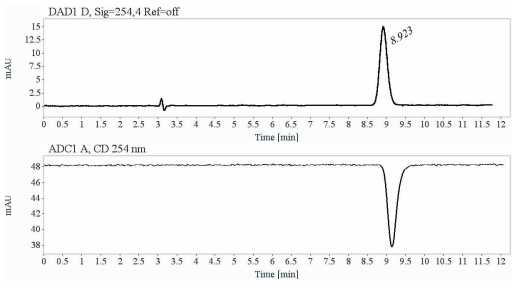
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 9.36 | 68 | 2.12 | 2.17 | | |
| 11.55 | 3122 | 97.88 | 2.92 | 1.34 | 5.16 |
| Sum | 3189 | 100.00 | | | |

**(1*S*,2*S*)-2-Nitro-1-(6-nitrobenzo[*d*][1,3]dioxol-5-yl)-1,2-dihydronaphtho[2,1-*b*]furan (9f).**




This compound was isolated as a slightly brown solid (556 mg, 83%); **mp** = 201 °C; **R*f*** = 0.45 (ethyl acetate/petroleum ether 1:4); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak IE, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 8.97 min, $t_{minor}$ = 5.98 min, ee > 99%; $[\alpha]_D^{25}$ ($CHCl_3$, $c$ = 1.6) = +234; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.95 (1H, d, $J$ = 9.0 Hz, ArH), 7.92-7.88 (1H, m, ArH), 7.59 (1H, s, ArH), 7.44-7.38 (3H, m, ArH), 7.37-7.31 (1H, m, ArH), 6.16 (1H, s, ArH), 6.13 (2H, s, $CH_2$), 6.06 (1H, s, CH), 6.02 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 157.1, 152.7, 148.3, 143.0, 132.3, 131.2, 129.5, 129.4, 128.9, 128.3, 125.0, 122.9, 117.7, 112.7, 112.0, 108.7, 106.3, 103.5, 49.3. **HRMS** (ESI+): $[M+NH_4]^+$ calcd for $C_{19}H_{16}N_3O_7^+$ 398.0983, found 398.0982.



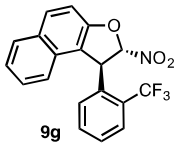

Signal: DAD1 D, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.98 | 898 | 50.89 | 1.03 | | |
| 8.97 | 867 | 49.11 | 2.04 | 1.99 | 9.58 |
| Sum | 1765 | 100.00 | | | |

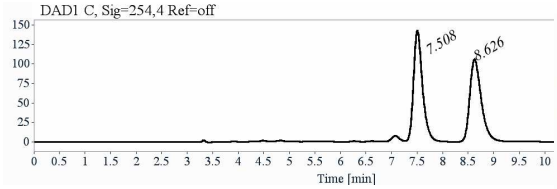
Signal: DAD1 D, Sig=254,4 Ref=off

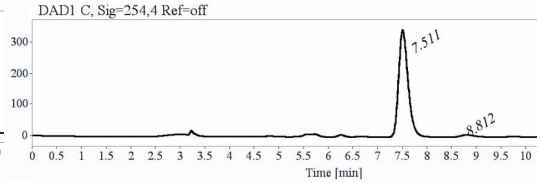
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 8.92 | 213 | 100.00 | 2.02 | | |
| Sum | 213 | 100.00 | | | |

**(1*S*,2*S*)-2-nitro-1-(2-(trifluoromethyl)phenyl)-1,2-dihydronaphtho[2,1-b]furan (9g).** This compound was isolated as a white solid (72 mg, 53%); **mp** = 87-89 °C; **R*f*** = 0.30 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Amylose-2, Heptane/ethanol = 95/5, flow rate = 1.0 mL/min, λ = 254 nm):



$t_{major}$ = 7.51 min, $t_{minor}$ = 8.81 min, ee = 94%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +204; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.96 (1H, d, *J* = 9.0 Hz, ArH), 7.92-7.81 (2H, m, ArH), 7.50-7.31 (6H, m, ArH), 6.76 (1H, d, *J* = 7.8 Hz, ArH), 6.07 (1H, s, CH), 5.80 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 156.8, 136.1, 133.2, 132.1, 131.2, 129.6, 129.4, 129.3, 128.8, 128.4, 128.2, 126.7 (q, *J* = 5.8 Hz), 126.3, 124.9, 122.8, 119.1, 112.3, 111.8, 50.0. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{19}H_{12}NO_3F_3Ag^+$ 465.9815, found 465.9810.



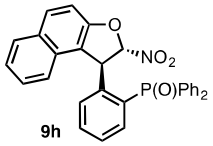

Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.51 | 1751 | 51.28 | 1.54 | | |
| 8.63 | 1663 | 48.72 | 1.92 | 1.25 | 3.13 |
| Sum | 3414 | 100.00 | | | |

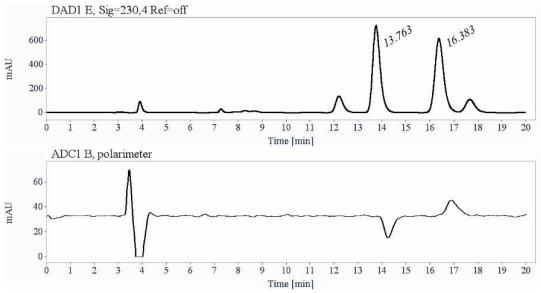
Signal: DAD1 C, Sig=254,4 Ref=off

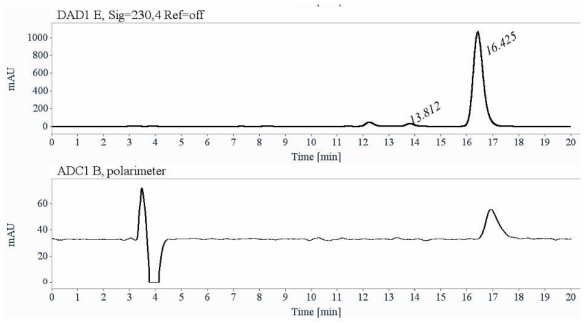
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.51 | 4576 | 96.96 | 1.55 | | |
| 8.81 | 143 | 3.04 | 1.99 | 1.29 | 3.02 |
| Sum | 4720 | 100.00 | | | |

**(2-((1*R*,2*S*)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan-1-yl)phenyl)diphenylphosphine oxide (9h).**




This compound was synthesized on 0.59 mmol and was isolated as a white solid (211 mg, 73%); **mp** = 174-176 °C; **R*f*** = 0.47 (ethyl acetate/petroleum ether 1:1); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Lux-Cellulose-4, Heptane/ethanol = 95/5, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 16.43 min, $t_{minor}$ = 13.81 min, ee = 95%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +393; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.86-7.74 (6H, m, ArH), 7.66-7.52 (6H, m, ArH), 7.34-7.14 (7H, m, ArH), 6.74 (1H, dd, *J* = 7.7, 4.0 Hz, ArH), 6.44 (1H, s, CH), 6.11 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 156.5, 142.8 (d, *J* = 7.0 Hz), 133.8 (d, *J* = 12.7 Hz), 133.0, 132.6, 132.5, 132.4 (d, *J* = 9.9 Hz), 132.0, 131.5 (d, *J* = 5.4 Hz), 131.3, 131.0, 130.0 (d, *J* = 8.9 Hz), 129.8, 129.0 (d, *J* = 12.1 Hz), 128.9, 126.7 (d, *J* = 12.1 Hz), 127.6, 124.5, 123.9, 120.2, 113.5, 111.8, 49.9. **$^{31}$P NMR** (162 MHz, $CDCl_3$) $\delta$ 31.8. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{30}H_{22}NO_4F_3Ag^+$ 598.0332, found 598.0342.



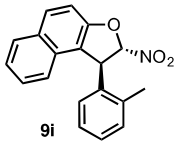

Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 13.76 | 15589 | 50.33 | 3.67 | | |
| 16.38 | 15383 | 49.67 | 4.55 | 1.24 | 4.24 |
| Sum | 30972 | 100.00 | | | |

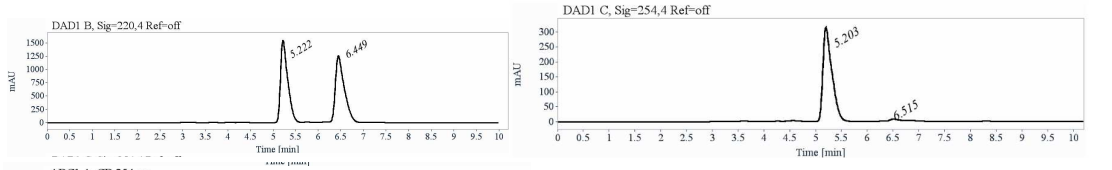
Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 13.81 | 693 | 2.39 | 3.68 | | |
| 16.43 | 28344 | 97.61 | 4.57 | 1.24 | 4.02 |
| Sum | 29037 | 100.00 | | | |

**(1*S*,2*S*)-2-nitro-1-(*o*-tolyl)-1,2-dihydronaphtho[2,1-*b*]furan (9i).** This compound was isolated as a white solid (165 mg, 89%); **mp** = 127-128 °C; **R*f*** = 0.60 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak AD-H, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ =



5.20 min, $t_{minor}$ = 6.52 min, ee = 93%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +131; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.98-7.86 (2H, m, ArH), 7.48 (1H, d, *J* = 8.7, ArH), 7.41-7.32 (3H, m, ArH), 7.28-7.18 (2H, m, ArH), 7.00 (1H, dd, *J* = 7.9, 7.3 Hz, ArH), 6.52 (1H, d, *J* = 7.2 Hz, ArH), 6.05 (1H, d, *J* = 1.5 Hz, CH), 5.55 (1H, s, CH), 2.76 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 156.7, 136.2, 135.9, 131.5, 131.4, 131.1, 129.6, 129.2, 128.5, 127.9, 127.6, 127.1, 124.7, 123.1, 119.1, 112.4, 112.0, 51.8, 20.3. **HRMS** (ESI+): $[M+Ag]^+$ calcd for $C_{19}H_{15}NO_3Ag^+$ 412.0097, found 412.0096.



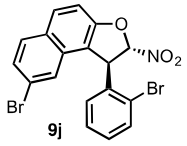

Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.22 | 17145 | 50.17 | 0.77 | | |
| 6.45 | 17030 | 49.83 | 1.19 | 1.54 | 3.84 |
| Sum | 34175 | 100.00 | | | |

Signal: DAD1 C, Sig=254,4 Ref=off

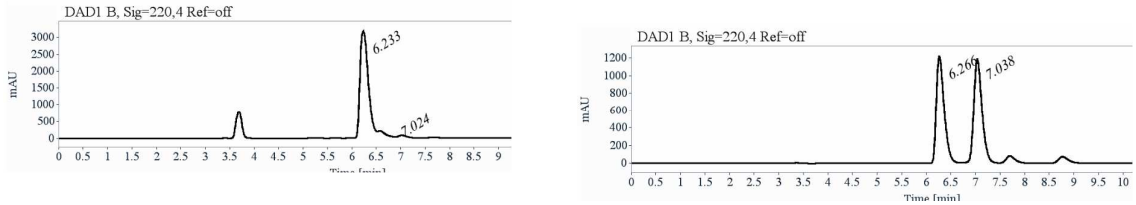
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.20 | 3791 | 96.23 | 0.76 | | |
| 6.51 | 148 | 3.77 | 1.21 | 1.58 | 3.95 |
| Sum | 3939 | 100.00 | | | |

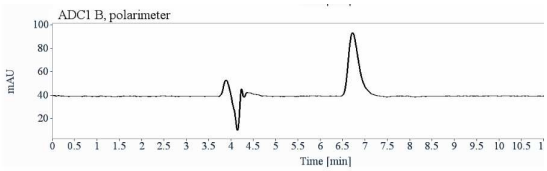
**(1*R*,2*S*)-8-bromo-1-(2-bromophenyl)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan (9j)**



**9j**

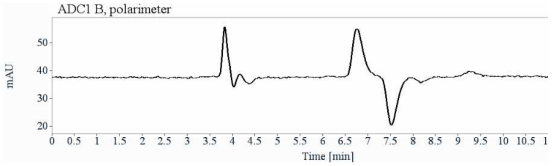
This compound was isolated as a white solid (140 mg, 82%); **mp** = 166-167 °C; **R*f*** = 0.40 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak IB, Heptane/ethanol = 95/5, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.23 min, $t_{minor}$ = 7.02 min, ee = 96%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +128; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.88 (1H, d, *J* = 8.9 Hz, ArH), 7.76-7.70 (2H, m, ArH), 7.50 (1H, d, *J* = 1.6 Hz, ArH), 7.46-7.41 (2H, m, ArH), 7.21-7.09 (2H, m, ArH), 6.57 (1H, brs, ArH), 6.08 (1H, s, CH), 5.81 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 157.5, 136.5, 134.0, 131.9, 130.9, 130.8, 130.4, 129.5, 129.2, 128.7, 128.5, 125.5, 124.1, 122.7, 118.2, 112.4, 112.0, 53.6. **HRMS** (ESI+): $[M+NH_4]^+$ calcd for $C_{18}H_{15}Br_2N_2O_3$ 466.9425, found 466.9425.






Signal: DAD1 B, Sig=220,4 Ref=off

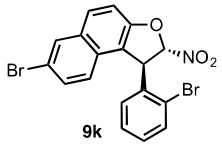
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.23 | 37856 | 97.37 | 1.11 | | |
| 7.02 | 1023 | 2.63 | 1.38 | 1.24 | 2.49 |
| Sum | 38879 | 100.00 | | | |




Signal: DAD1 B, Sig=220,4 Ref=off

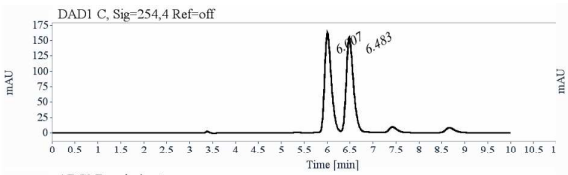
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.27 | 13401 | 49.55 | 1.12 | | |
| 7.04 | 13647 | 50.45 | 1.39 | 1.23 | 2.62 |
| Sum | 27048 | 100.00 | | | |

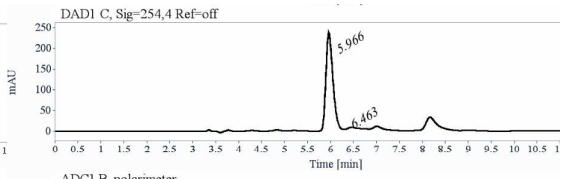
**(1*R*,2*S*)-7-bromo-1-(2-bromophenyl)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan (9j)**



9k

This compound was isolated as a white solid (136 mg, 80%); **mp** = 145-147 °C; **R*f*** = 0.45 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak IB, Heptane/ethanol = 95/5, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 5.97 min, $t_{minor}$ = 6.46 min, ee = 95%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +128; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.05 (1H, d, *J* = 1.8 Hz, ArH), 7.84 (1H, d, *J* = 8.9 Hz, ArH), 7.73 (1H, dd, *J* = 8.0, 1.3 Hz, ArH), 7.49-7.44 (2H, m, ArH), 7.27-7.09 (3H, m, ArH), 6.58 (1H, brs, ArH), 6.11 (1H, s, CH), 5.87 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 156.9, 136.7, 133.8, 132.2, 131.4, 131.2, 131.0, 130.4, 129.3, 128.7, 128.1, 124.9, 124.1, 119.3, 118.6, 113.1, 112.0, 53.7. **HRMS** (ESI+): $[M+Na]^+$ calcd for $C_{18}H_{11}Br_2NO_3Na^+$ 471.8978, found 471.8980.



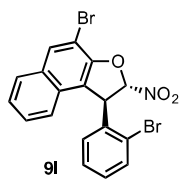

Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.01 | 13211 | 49.75 | 1.04 | | |
| 6.48 | 13343 | 50.25 | 1.20 | 1.16 | 1.75 |
| Sum | 26555 | 100.00 | | | |

Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 5.97 | 20167 | 97.45 | 1.02 | | |
| 6.45 | 528 | 2.55 | 1.19 | 1.16 | 1.58 |
| Sum | 20695 | 100.00 | | | |

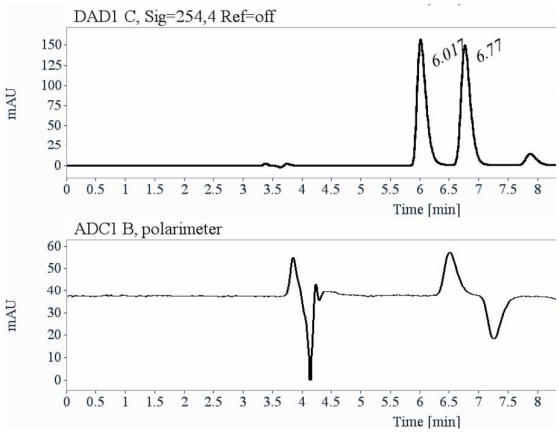
**(1*R*,2*S*)-7-bromo-1-(2-bromophenyl)-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan (9j)**

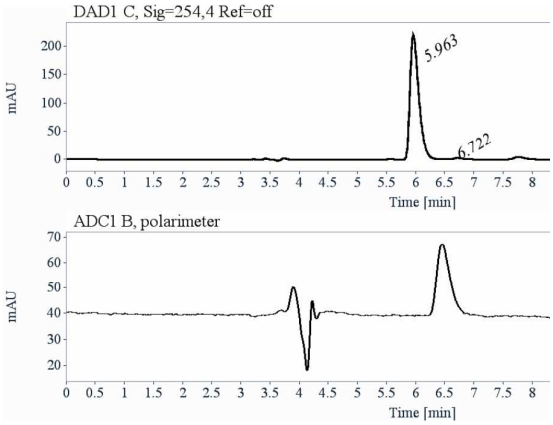


9l

This compound was isolated as a white solid (131 mg, 77%); **mp** = 154-156 °C; **R*f*** = 0.50 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak IB, Heptane/ethanol = 95/5, flow rate = 1.0 mL/min, λ =

254 nm): $t_{major}$ = 5.96 min, $t_{minor}$ = 6.72 min, ee = 97%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +152; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.14 (1H, s, ArH), 7.86-7.81 (1H, m, ArH), 7.76 (1H, dd, *J* = 7.7, 1.5 Hz, ArH), 7.46-7.39 (2H, m, ArH), 7.37-7.32 (1H, m, ArH), 7.24-7.13 (2H, m, ArH), 6.67 (1H, brs, ArH), 6.18 (1H, s, CH), 6.00 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 153.8, 136.4, 133.9, 133.7, 132.1, 130.4, 129.4, 128.7, 128.5, 128.4, 128.3, 125.8, 124.0, 123.3, 120.4, 111.4, 104.4, 54.8. **HRMS** (ESI+): $[M+NH_4]^+$ calcd for $C_{18}H_{15}Br_2N_2O_3^+$ 466.9425, found 466.9427.



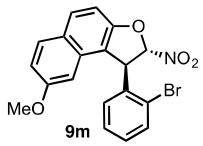

Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity |
|---|---|---|---|---|
| 6.02 | 16138 | 50.00 | 1.04 | |
| 6.77 | 16139 | 50.00 | 1.29 | 1.25 |
| Sum | 32277 | 100.00 | | |

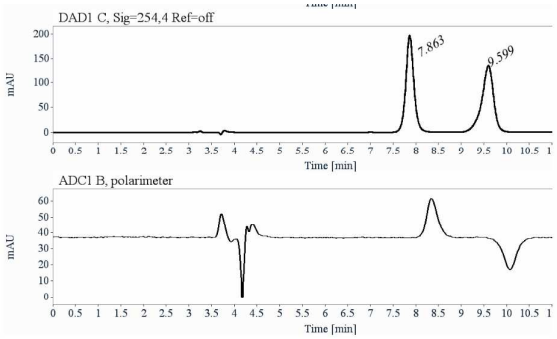
Signal: DAD1 B, Sig=220,4 Ref=off

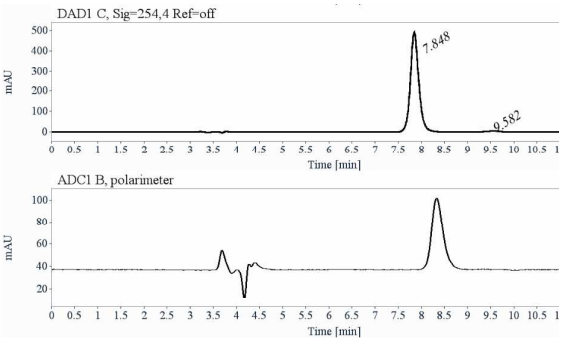
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity |
|---|---|---|---|---|
| 5.96 | 22552 | 98.61 | 1.02 | |
| 6.72 | 317 | 1.39 | 1.28 | 1.25 |
| Sum | 22870 | 100.00 | | |

**(1*R*,2*S*)-1-(2-bromophenyl)-8-methoxy-2-nitro-1,2-dihydronaphtho[2,1-*b*]furan (9m)**




This compound was isolated as a white solid (133 mg, 88%); **mp** = 161-162 °C; **R*f*** = 0.42 (ethyl acetate/petroleum ether 1:9); **dr** (*trans*/*cis*) > 20:1; **HPLC** (Chiralpak IB, Heptane/ethanol = 95/5, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.85 min, $t_{minor}$ = 9.58 min, ee = 96%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +227; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.82 (1H, d, *J* = 8.9 Hz, ArH), 7.75 (1H, d, *J* = 8.9 Hz, ArH), 7.73-7.69 (1H, m, ArH), 7.29 (1H, d, *J* = 8.9 Hz, ArH), 7.19-7.14 (1H, m, ArH), 7.01 (1H, dd, *J* = 8.9, 2.5 Hz, ArH), 6.74 (1H, brs, ArH), 6.68 (1H, d, *J* = 2.5 Hz, ArH), 6.12 (1H, s, CH), 5 .86 (1H, s, CH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 159.3, 156.9, 137.2, 133.5, 131.4, 130.9, 130.7, 130.1, 129.3, 128.8, 126.4, 123.9, 118.6, 117.6, 112.1, 109.2, 101.6, 55.6, 53.9. **HRMS** (ESI+): $[M+Na]^+$ calcd for $C_{19}H_{14}BrNO_4Na^+$ 421.9998, found 421.0000.



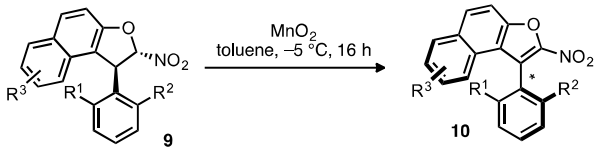

Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.86 | 17216 | 50.05 | 1.67 | | |
| 9.60 | 17181 | 49.95 | 2.25 | 1.35 | 4.69 |
| Sum | 34397 | 100.00 | | | |

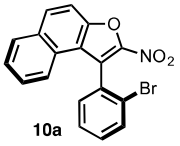
Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.85 | 42408 | 98.18 | 1.66 | | |
| 9.58 | 785 | 1.82 | 2.25 | 1.35 | 4.51 |
| Sum | 43193 | 100.00 | | | |

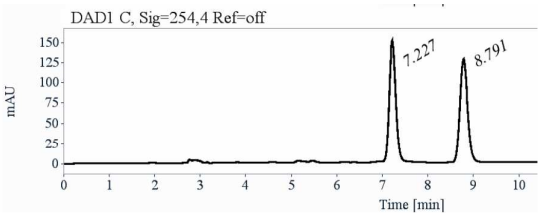
## General procedure for the oxidation of dihydrofuran 9a-m to furan atropisomers 10a-m

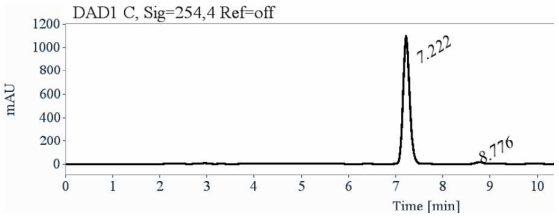



$MnO_2$ (20 equiv) was added in a clear solution of the corresponding enantioenriched 2,3-dihydrofuran in toluene **9a-m** at –5 ºC and reaction mass stirred for 16 h at same temperature. The progress of the reaction was monitored by TLC. After completion of the reaction, the crude product was directly purified by means of flash silica gel column chromatography using pad of celite on the top of silica in column to give the desired furan **10a-m**.




**(*aS*)-1-(2-bromophenyl)-2-nitronaphtho[2,1-*b*]furan (10a).** This compound was isolated as a yellow solid (32 mg, 84%); **mp** = 140-142 °C; **R*f*** = 0.36 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose 2, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.23 min, $t_{minor}$ = 8.79 min, ee = 97%; **Chirality conversion percentage** = 100%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –9; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.06 (1H, d, *J* = 9.0 Hz, ArH), 7.98 (1H, d, *J* = 8.1 Hz, ArH), 7.88-7.84 (1H, m, ArH), 7.59 (1H, s, ArH), 7.76 (1H, d, *J* = 9.0 Hz, ArH), 7.58-7.46 (4H, m, ArH), 7.44-7.35 (2H, m, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 150.6, 148.2, 133.5, 132.9, 132.1, 131.4, 131.1, 130.7, 129.8, 128.6, 128.4, 128.3, 126.4, 123.5, 123.2, 122.8, 121.5, 112.4. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{18}H_{11}NO_3Br^+$ 367.9917, found 367.9917.



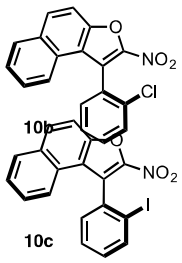




Signal: DAD1 B, Sig=220,4 Ref=off

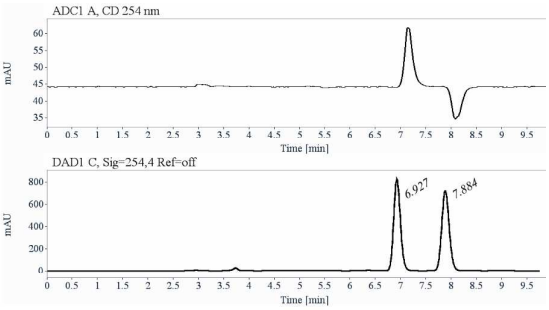
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity |
|---|---|---|---|---|
| 7.23 | 9459 | 50.10 | 1.45 | |
| 8.79 | 9420 | 49.90 | 1.98 | 1.37 |
| Sum | 18879 | 100.00 | | |

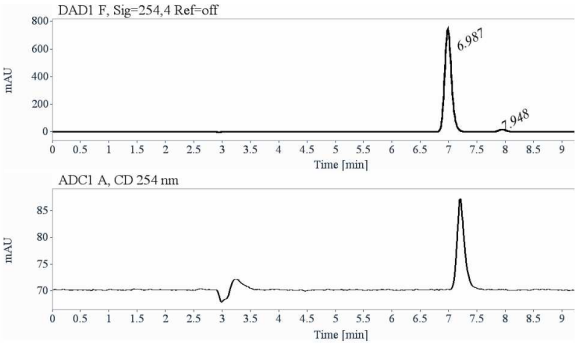
Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity |
|---|---|---|---|---|
| 7.22 | 10686 | 98.68 | 1.45 | |
| 8.78 | 143 | 1.32 | 1.97 | 1.36 |
| Sum | 10829 | 100.00 | | |




**(*aS*)-1-(2-chlorophenyl)-2-nitronaphtho[2,1-*b*]furan (10b).** This compound was isolated as a yellow solid (106 mg, 92%); **mp** = 182-184 °C; **R*f*** = 0.50 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose 2, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.99 min, $t_{minor}$ = 7.95 min, ee = 93%; **Chirality conversion percentage** = 96%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –34; **$^1$H NMR** (400 MHz, $CDCl_3$) *δ* 8.06 (1H, d, *J* = 9.0 Hz, ArH), 7.98 (1H, d, *J* = 8.2 Hz, ArH), 7.76 (1H, d, *J* = 9.0 Hz, ArH), 7.68 (1H, ddd, *J* = 8.0, 0.9, 0.9 Hz, ArH), 7.60-7.48 (4H, m, ArH), 7.44-7.39 (2H, m, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) *δ* 150.6, 148.3, 133.9, 132.8, 131.4, 131.0, 130.8, 130.3, 129.9, 129.8, 128.6, 128.3, 127.7, 126.4, 122.7, 121.6, 121.4, 112.4. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{18}H_{11}NO_3Cl^+$ 324.0422, found 324.0421.



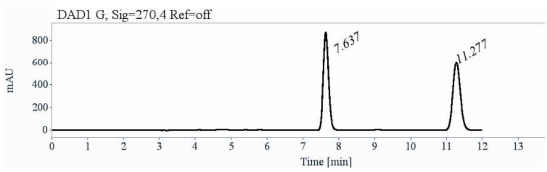

Signal: DAD1 C, Sig=254,4 Ref=off

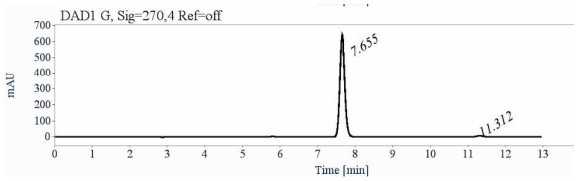
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.93 | 7761 | 50.81 | 1.35 | | |
| 7.88 | 7513 | 49.19 | 1.67 | 1.24 | 3.68 |
| Sum | 15274 | 100.00 | | | |

Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.99 | 30207 | 96.70 | 1.37 | | |
| 7.95 | 1031 | 3.30 | 1.69 | 1.24 | 3.86 |
| Sum | 31239 | 100.00 | | | |

**(*aS*)-1-(2-iodoophenyl)-2-nitronaphtho[2,1-*b*]furan (10c).** This compound was isolated as a dark-green solid (447 mg, 90%); **mp** = 180-181 °C; **R*f*** = 0.40 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose 2, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.66 min, $t_{minor}$ = 11.31 min, ee = 97%; **Chirality conversion percentage** = 100%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –3; **$^1$H NMR** (400 MHz, $CDCl_3$) *δ* 8.12 (1H, dd, *J* = 8.2, 1.1 Hz, ArH), 8.07 (1H, d, *J* = 9.1 Hz, ArH), 7.99 (1H, d, *J* = 8.2 Hz, ArH), 7.76 (1H, d, *J* = 9.1 Hz, ArH), 7.62-7.52 (2H, m, ArH), 7.47-7.38 (2H, m, ArH), 7.35-7.28 (2H, m, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) *δ* 150.6, 148.0, 139.8, 136.3, 132.9, 131.4, 131.0, 129.9, 129.8, 129.1, 128.6, 128.4, 126.5, 126.3, 122.9, 121.4, 112.4, 98.5. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{18}H_{11}NO_3I^+$ 415.9778, found 415.9780.



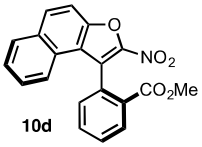




Signal: DAD1 F, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.64 | 7609 | 50.60 | 1.59 | | |
| 11.28 | 7430 | 49.40 | 2.82 | 1.78 | 11.19 |
| Sum | 15040 | 100.00 | | | |

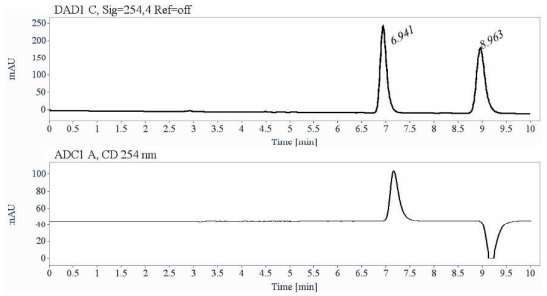
Signal: DAD1 F, Sig=254,4 Ref=off

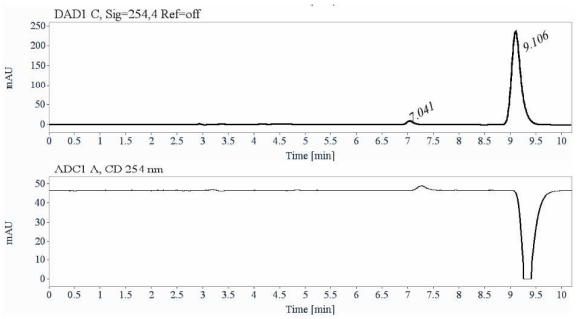
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.66 | 5019 | 98.32 | 1.60 | | |
| 11.31 | 86 | 1.68 | 2.83 | 1.78 | 12.26 |
| Sum | 5105 | 100.00 | | | |



10d

**(*aS*)-methyl 2-(2-nitronaphtho[2,1-*b*]furan-1-yl)benzoate (10d).** This compound was isolated as a yellow solid (100 mg, 89%); **mp** = 156-159 °C; **R*f*** = 0.45 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose 4, Heptane/ethanol = 60/40, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 8.94 min, $t_{minor}$ = 6.95 min, ee = 95%; **Chirality conversion percentage** = 99%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +102; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.34 (1H, dd, *J* = 7.7, 1.7 Hz, ArH), 8.04 (1H, d, *J* = 9.1 Hz, ArH), 7.97 (1H, d, *J* = 8.2 Hz, ArH), 7.79-7.68 (3H, m, ArH), 7.51-7.47 (2H, m, ArH), 7.35 (1H, ddd, *J* = 8.2, 7.0, 1.4 Hz, ArH), 7.26 (1H, d, *J* = 8.2 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 166.2, 150.6, 147.8, 133.3, 132.6, 132.4, 131.7, 131.4, 130.5, 129.8, 129.7, 129.6, 128.7, 128.1, 126.2, 124.8, 122.8, 122.2, 112.5, 52.4. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{20}H_{14}NO_5^+$ 348.0866, found 348.0866.



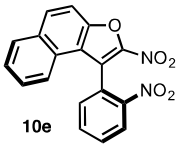




Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.94 | 14160 | 49.90 | 1.35 | | |
| 8.96 | 14217 | 50.10 | 2.04 | 1.51 | 7.24 |
| Sum | 28376 | 100.00 | | | |

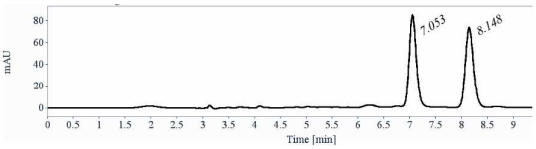
Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.04 | 551 | 2.96 | 1.39 | | |
| 9.11 | 18058 | 97.04 | 2.09 | 1.50 | 7.26 |
| Sum | 18609 | 100.00 | | | |



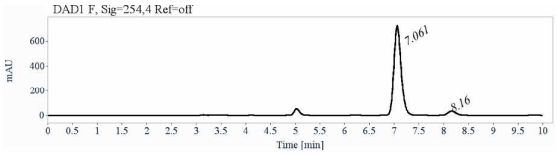
10e

**(*aS*)-2-nitro-1-(2-nitrophenyl)naphtho[2,1-*b*]furan (10e).** This compound was isolated as a yellow solid (90 mg, 87%); **mp** = 222-224 °C; **R*f*** = 0.35 (ethyl acetate/petroleum ether 1:4); **HPLC** (Chiralpak IC, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.06 min, $t_{minor}$ = 8.16 min, ee = 89%; **Chirality conversion percentage** = 93%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +110; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.45 (1H, dd, *J* = 8.0, 1.6 Hz, ArH), 8.07 (1H, d, *J* = 9.0 Hz, ArH), 7.99 (1H, d, *J* = 8.3 Hz, ArH), 7.87 (1H, ddd, *J* = 7,3, 7.3, 1.6 Hz, ArH), 7.82 (1H, ddd, *J* = 7.6, 7.6, 1.6 Hz, ArH), 7.76 (1H, d, *J* = 9.0 Hz, ArH), 7.58 (1H, dd, *J* = 7.3, 1.8 Hz, ArH), 7.53 (1H, ddd, *J* = 7.6, 7.3, 1.3 Hz, ArH), 7.37 (1H, ddd, *J* = 8.3, 7.0, 1.3 Hz, ArH), 7.25 (1H, d, *J* = 8.3 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 150.9, 148.1, 147.5, 134.5, 133.1, 131.7, 131.5, 130.9, 130.1, 128.4, 128.3, 126.6, 126.5, 125.9, 122.4, 121.6, 121.1, 112.5. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{18}H_{11}N_2O_5^+$ 335.0662, found 335.0661.




Signal: DAD1 B, Sig=220,4 Ref=off

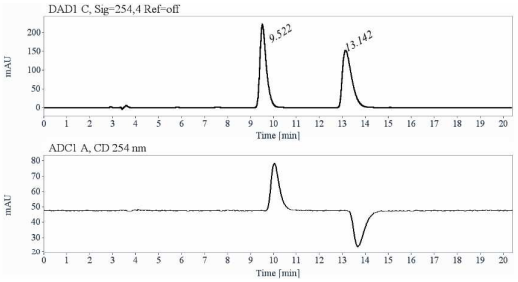
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.05 | 3069 | 49.94 | 1.39 | | |
| 8.15 | 3077 | 50.06 | 1.76 | 1.27 | 4.05 |
| Sum | 6146 | 100.00 | | | |




Signal: DAD1 D, Sig=220,4 Ref=off

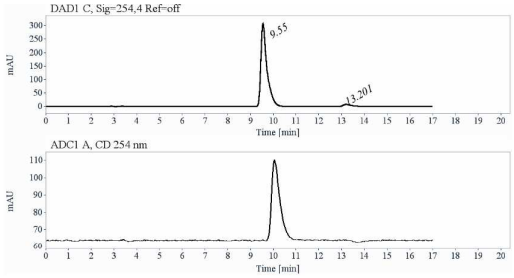
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.06 | 26734 | 94.65 | 1.39 | | |
| 8.16 | 1511 | 5.35 | 1.77 | 1.27 | 3.81 |
| Sum | 28244 | 100.00 | | | |

**(*aS*)-2-Nitro-1-(6-nitrobenzo[*d*][1,3]dioxol-5-yl)naphtho[2,1-*b*]furan (10f).** This compound was isolated as a yellow-brown solid (200 mg, 85%); **mp** = 203-204 °C; **R*f*** = 0.41 (ethyl acetate/petroleum ether 1:4); **HPLC** (Chiralpak IB, Heptane/ethanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 9.52 min, $t_{minor}$ = 13.14 min, ee = 93%; **Chirality conversion percentage** = 93%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +91.7; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.06 (1H, d, *J* = 9.0 Hz, ArH), 7.99 (1H, d, *J* = 8.3 Hz, ArH), 7.92 (1H, s, ArH), 7.59 (1H, s, ArH), 7.75 (1H, d, *J* = 9.0 Hz, ArH), 7.55 (1H, ddd, *J* = 8.2, 6.6, 1.6 Hz, ArH), 7.47-7.39 (2H, m, ArH), 6.87 (1H, s, ArH), 6.32 (1H, d, *J* = 1.0 Hz, C*H*H), 6.28 (1H, d, *J* = 1.0 Hz, CH*H*). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 152.8, 150.7, 149.3, 142.2, 132.8, 131.3, 129.8, 128.3, 128.2, 126.3, 122.3, 122.2, 121.3, 121.2, 112.3, 109.8, 106.4, 103.8. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{11}N_2O_7^+$ 379.0561, found 379.0563.




Signal: DAD1 B, Sig=220,4 Ref=off

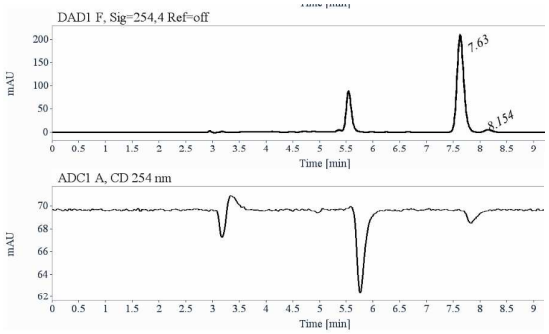
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 9.52 | 16857 | 49.94 | 2.23 | | |
| 13.14 | 16895 | 50.06 | 3.45 | 1.55 | 5.89 |
| Sum | 33752 | 100.00 | | | |

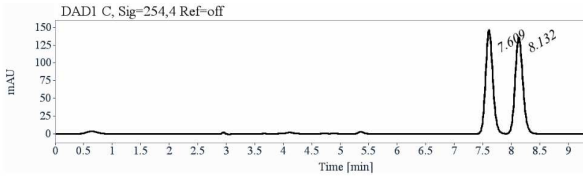



Signal: DAD1 B, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 9.55 | 22354 | 96.73 | 2.24 | | |
| 13.20 | 756 | 3.27 | 3.48 | 1.55 | 7.12 |
| Sum | 23110 | 100.00 | | | |

**(*aS*)-2-nitro-1-(2-(trifluoromethyl)phenyl)naphtho[2,1-*b*]furan (10g).** This compound was isolated as a yellow solid (113 mg, 83%); **mp** = 170-172 °C; **R*f*** = 0.27 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose-2, Heptane/ethanol = 90/10, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.63 min, $t_{minor}$ = 8.15 min, ee = 97%; **Chirality conversion percentage** = 100%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +152; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.06 (1H, d, *J* = 9.1 Hz, ArH), 8.01-7.95 (2H, m, ArH), 7.82-7.71 (3H, m, ArH), 7.55-7.49 (2H, m, ArH), 7.36 (1H, ddd, *J* = 8.5, 7.0, 1.3 Hz, ArH), 7.17 (1H, d, *J* = 8.4 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 150.4, 148.4, 132.9, 132.8, 131.5, 130.6, 129.8, 129.7, 129 (q, *J* = 30.5 Hz), 128.4, 128.2, 127.1 (q, *J* = 5.1 Hz), 126.4, 125.1, 122.9, 122.4, 122.3, 120.9, 112.3. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{11}NO_3F_3^+$ 358.0686, found 358.0683.



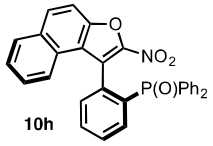

Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.63 | 9805 | 97.08 | 1.59 | | |
| 8.15 | 295 | 2.92 | 1.76 | 1.11 | 2.18 |
| Sum | 10100 | 100.00 | | | |

Signal: DAD1 B, Sig=220,4 Ref=off

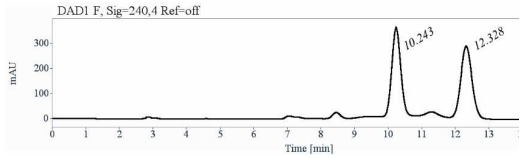
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.61 | 6790 | 49.98 | 1.58 | | |
| 8.13 | 6796 | 50.02 | 1.76 | 1.11 | 2.18 |
| Sum | 13586 | 100.00 | | | |

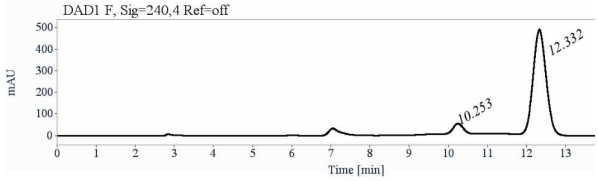
**(*aS*)-(2-(2-nitronaphtho[2,1-*b*]furan-1-yl)phenyl)diphenylphosphine oxide (10h).**



10h

This compound was isolated as a dark green solid (65 mg, 85%); **mp** = 169-170 °C; **R*f*** = 0.22 (ethyl acetate/petroleum ether 1:1); **HPLC** (Lux-Cellulose-2, Heptane/ethanol = 50/50, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 12.33 min, $t_{minor}$ = 10.25 min, ee = 85%; **Chirality conversion percentage** = 89%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = +17; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.90 (1H, d, *J* = 9.1 Hz, ArH), 7.87 (1H, d, *J* = 8.2 Hz, ArH), 7.80-7.71 (1H, m, ArH), 7.68-7.60 (2H, m, ArH), 7.59-7.37 (8H, m, ArH), 7.30-7.23 (3H, m, ArH), 7.18 (1H, d, *J* = 8.3 Hz, ArH), 7.15-7.09 (1H, m, ArH), 7.04-6.97 (2H, m, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 149.8, 148.8, 135.4 (d, *J* = 6.7 Hz), 134.5 (d, *J* = 11.1 Hz), 132.7, 132.0 (d, *J* = 9.8 Hz), 131.9, 131.6 (d, *J* = 9.6 Hz), 131.4, 131.2, 130.9 (d, *J* = 9.2 Hz), 129.4, 129.0 (d, *J* = 12.0 Hz), 128.7, 128.3 (d, *J* = 12.2 Hz), 128.1 (d, *J* = 12.2 Hz), 127.5, 126.0, 123.4, 122.5, 122.1 (d, *J* = 4.3 Hz), 112.2. **$^{31}$P NMR** (162 MHz, $CDCl_3$) $\delta$ 26.8. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{30}H_{21}NO_4P^+$ 490.1203, found 490.1207.



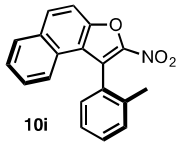




Signal: DAD1 D, Sig=230,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 10.24 | 19391 | 49.76 | 2.47 | | |
| 12.33 | 19579 | 50.24 | 3.18 | 1.29 | 3.79 |
| Sum | 38970 | 100.00 | | | |

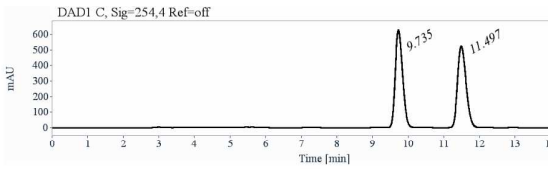
Signal: DAD1 D, Sig=230,4 Ref=off

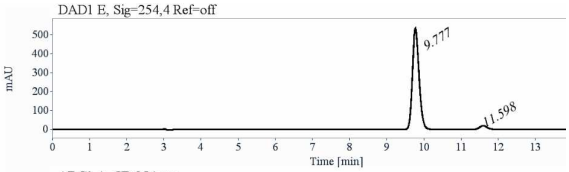
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 10.25 | 2611 | 7.30 | 2.48 | | |
| 12.33 | 33176 | 92.70 | 3.18 | 1.28 | 3.78 |
| Sum | 35786 | 100.00 | | | |



10i

**(*aS*)-2-nitro-1-(*o*-tolyl)naphtho[2,1-*b*]furan (10i).** This compound was isolated as a yellow solid (113 mg, 83%); **mp** = 140-142 °C; **R*f*** = 0.57 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose-2, Heptane/isopropanol = 95/5, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 9.78 min, $t_{minor}$ = 11.60 min, ee = 92%; **Chirality conversion percentage** = 100%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –36; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.06 (1H, d, *J* = 9.1 Hz, ArH), 7.97 (1H, d, *J* = 8.3 Hz, ArH), 7.76 (1H, d, *J* = 9.1 Hz, ArH), 7.55-7.45 (3H, m, ArH), 7.43-7.33 (4H, m, ArH), 2.17 (3H, s, $CH_3$). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 150.6, 148.2, 136.7, 132.8, 131.3, 130.7, 130.0, 129.7, 128.9, 128.3, 126.7, 126.3, 124.1, 122.6, 121.7, 112.4, 20.0. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{14}NO_3^+$ 304.0968, found 304.0969.



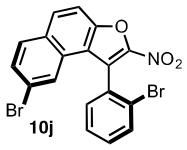




Signal: DAD1 C, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 9.73 | 9015 | 50.72 | 2.30 | | |
| 11.50 | 8759 | 49.28 | 2.90 | 1.26 | 4.28 |
| Sum | 17774 | 100.00 | | | |

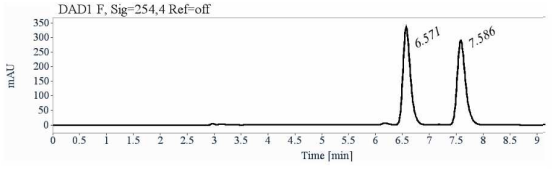
Signal: DAD1 E, Sig=254,4 Ref=off

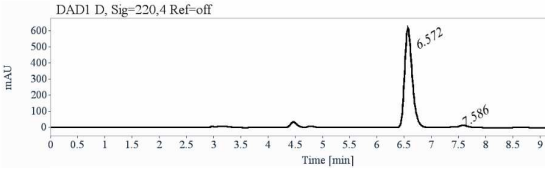
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 9.78 | 6609 | 95.96 | 2.31 | | |
| 11.60 | 278 | 4.04 | 2.93 | 1.27 | 5.18 |
| Sum | 6887 | 100.00 | | | |



**10j**

**(*aS*)-8-bromo-1-(2-bromophenyl)-2-nitronaphtho[2,1-*b*]furan (10j).** This compound was isolated as a dark-green solid (48 mg, 98%); **mp** = 233-234 °C; **R*f*** = 0.50 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose-4, Heptane/isopropanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.57 min, $t_{minor}$ = 7.58 min, ee = 95%; **Chirality conversion percentage** = 100%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –17; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.02 (1H, d, *J* = 9.1 Hz, ArH), 7.88 (1H, dd, *J* = 7.9, 1.3 Hz, ArH), 7.83 (1H, d, *J* = 8.7 Hz, ArH), 7.77 (1H, d, *J* = 9.1 Hz, ArH), 7.64-7.59 (1H, m, ArH), 7.57 (1H, dd, *J* = 7.5, 1.3 Hz, ArH), 7.54-7.44 (3H, m, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 150.6, 148.1, 133.4, 132.2, 131.1, 131.1, 131.0, 130.5, 129.7, 129.6, 129.5, 128.2, 125.3, 123.3, 122.7, 122.6, 120.5, 112.7. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{18}H_{10}NO_3Br_2^+$ 447.9003, found 447.9004.



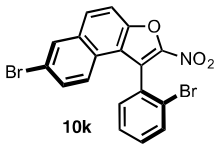




Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.57 | 19076 | 50.48 | 1.23 | | |
| 7.59 | 18711 | 49.52 | 1.57 | 1.28 | 3.86 |
| Sum | 37787 | 100.00 | | | |

Signal: DAD1 D, Sig=220,4 Ref=off

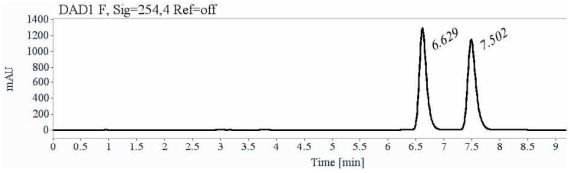
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.57 | 5956 | 97.44 | 1.23 | | |
| 7.59 | 156 | 2.56 | 1.57 | 1.28 | 3.78 |
| Sum | 6112 | 100.00 | | | |



**10k**

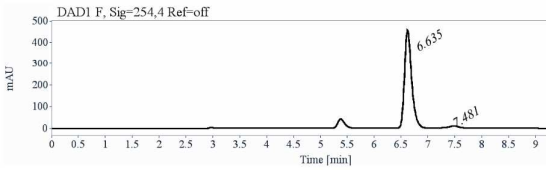
**(*aS*)-7-bromo-1-(2-bromophenyl)-2-nitronaphtho[2,1-*b*]furan (10k).** This compound was isolated as a dark-green solid (47 mg, 96%); **mp** = 168-169 °C; **R*f*** = 0.47 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose-4, Heptane/isopropanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 6.63 min, $t_{minor}$ = 7.48 min, ee = 92%; **Chirality conversion percentage** = 97%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –52; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.13 (1H, d, *J* = 2.1 Hz, ArH), 7.96 (1H, d, *J* = 9.1 Hz, ArH), 7.85 (1H, dd, *J* = 7.9, 1.5 Hz, ArH), 7.79 (1H, d, *J* = 9.1 Hz, ArH), 7.58-7.44 (4H, m, ArH), 7.23 (1H, d, *J* = 9.1 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 150.4, 148.3, 133.6, 132.7, 131.8, 131.7, 131.6, 131.5, 131.3, 130.7, 128.4, 127.2,

124.3, 123.5, 122.7, 121.6, 120.4, 113.7. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{18}H_{10}NO_3Br_2^+$ 447.9003, found 447.9000.



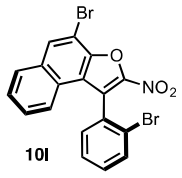

Signal: DAD1 F, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.63 | 11760 | 49.99 | 1.25 | | |
| 7.50 | 11765 | 50.01 | 1.54 | 1.24 | 3.54 |
| Sum | 23524 | 100.00 | | | |

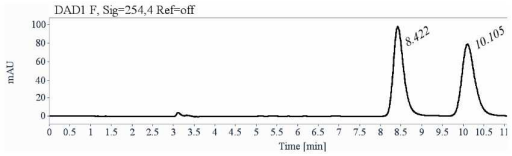



Signal: DAD1 F, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 6.63 | 4221 | 96.12 | 1.25 | | |
| 7.48 | 170 | 3.88 | 1.54 | 1.23 | 2.95 |
| Sum | 4391 | 100.00 | | | |

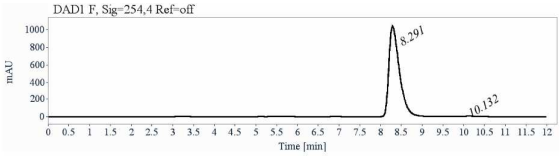



**(*aS*)-4-bromo-1-(2-bromophenyl)-2-nitronaphtho[2,1-*b*]furan (10l).** This compound was isolated as a dark-green solid (48 mg, 96%); **mp** = 246-247 °C; **R*f*** = 0.47 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose-4, Heptane/isopropanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 8.29 min, $t_{minor}$ = 10.13 min, ee = 98%; **Chirality conversion percentage** = 100%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –29; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 8.25 (1H, s, ArH), 7.91 (1H, d, *J* = 8.2 Hz, ArH), 7.86 (1H, dd, *J* = 7.9, 1.2 Hz, ArH), 7.60-7.39 (5H, m, ArH), 7.33 (1H, d, *J* = 8.2 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 148.3, 147.5, 134.4, 133.6, 132.4, 131.6, 131.4, 130.7, 128.9, 128.6, 128.4, 127.8, 127.2, 123.5, 123.3, 122.9, 122.5, 104.6. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{18}H_{10}NO_3Br_2^+$ 447.9003, found 447.8999.




Signal: DAD1 D, Sig=220,4 Ref=off

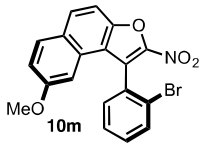
| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 8.42 | 12316 | 50.13 | 1.85 | | |
| 10.11 | 12251 | 49.87 | 2.43 | 1.31 | 3.27 |
| Sum | 24568 | 100.00 | | | |

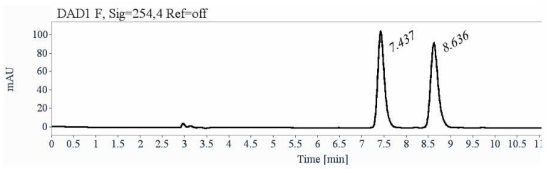



Signal: DAD1 F, Sig=254,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 8.29 | 18374 | 99.23 | 1.81 | | |
| 10.13 | 143 | 0.77 | 2.43 | 1.34 | 3.45 |
| Sum | 18518 | 100.00 | | | |

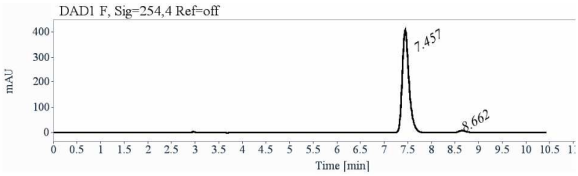
**(*aS*)-1-(2-bromophenyl)-8-methoxy-2-nitronaphtho[2,1-*b*]furan (10m).** This compound was isolated as a dark-green solid (51 mg, 98%); **mp** = 181-182 °C; **R*f*** = 0.40 (ethyl acetate/petroleum ether 1:9); **HPLC** (Lux-Cellulose-4, Heptane/isopropanol = 80/20, flow rate = 1.0 mL/min, λ = 254 nm): $t_{major}$ = 7.45 min, $t_{minor}$ = 8.65 min, ee = 95%; **Chirality conversion percentage** = 99%; $[\alpha]_D^{25}$ ($CHCl_3$, *c* = 1.0) = –6; **$^1$H NMR** (400 MHz, $CDCl_3$) $\delta$ 7.97 (1H, d, *J* = 9.0 Hz, ArH), 7.89-7.82 (2H, m, ArH), 7.62-7.42 (4H, m, ArH), 7.14 (1H, dd, *J* = 9.0, 2.5 Hz, ArH). **$^{13}$C NMR** (100 MHz, $CDCl_3$) $\delta$ 159.5, 151.3, 147.9, 133.4, 132.5, 132.4, 131.1, 131.0, 130.9, 130.2, 128.2, 126.2, 123.7, 123.2, 120.8, 118.2, 109.7, 102.4, 55.0. **HRMS** (ESI+): $[M+H]^+$ calcd for $C_{19}H_{13}NO_4Br^+$ 398.0022, found 398.0023.






Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.43 | 6685 | 49.99 | 1.52 | | |
| 8.63 | 6686 | 50.01 | 1.92 | 1.27 | 4.23 |
| Sum | 13370 | 100.00 | | | |




Signal: DAD1 D, Sig=220,4 Ref=off

| RT [min] | Area | Area% | Capacity Factor | Enantioselectivity | Resolution (USP) |
|---|---|---|---|---|---|
| 7.45 | 24177 | 97.69 | 1.52 | | |
| 8.65 | 572 | 2.31 | 1.93 | 1.27 | 4.42 |
| Sum | 24749 | 100.00 | | | |

# 6. Enantiomerisation barrier determination.

The enantiomerisation barrier, corresponding to barrier to rotation for the following atropisomers, was obtained by kinetic of racemisation of an enantiomer. The slope of the first-order kinetic line gives the racemisation constant ($k_{racemisation} = 2 \times k_{enantiomerisation}$). Eyring equation gives the enantiomerisation barrier ($\Delta G^{\neq}_{enantiomerisation}$) from enantiomerisation constant ($k_{enantiomerisation}$), R = 8.31451 $J.K^{-1}.mol^{-1}$, h =6.62608 $10^{-34}$ J.s and $k_B$ =1.38066 $10^{-23}$ $J.K^{-1}$.

The calculated values of $\Delta G^{\neq}_{enantiomerisation}$ are ± 0.5 kJ/mol.

The half-life time $t_{1/2}$, given in the following pages of supplementary material, is $t_{1/2}$ at the temperature used for the kinetic. The half-life time $t_{1/2}$, given in the article, is the half-life time at 25°C, calculated with the hypothesis that the enantiomerisation barrier $\Delta G^{\neq}_{enantiomerisation}$ is independent of temperature.

**Enantiomerisation barrier for (4a)**

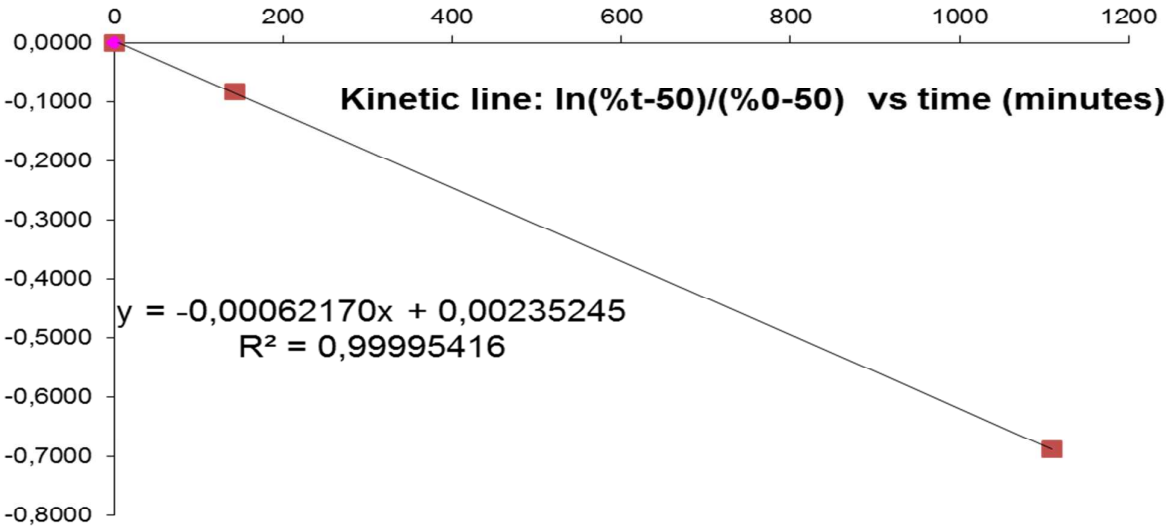
About 3 mg of enantio-enriched (**4a**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Chiralpak IC (heptane / ethanol 70/30, 1 mL/min, UV detection at 254 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 99.210 | 0.0000 |
| 142 | 95.280 | -0.0832 |
| 1110 | 74.730 | -0.6881 |

| | | |
|---|---|---|
| k racemisation = | 1.03617E-05 | $s^{-1}$ |
| k enantiomerisation = | 5.1808E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | 122.12 | $kJ.mol^{-1}$ |
| | 29.22 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 66895 | seconds |
| | 1114.92 | minutes |
| | 18.58 | hours |
| | 0.77 | days |



**Enantiomerisation barrier for (4b)**

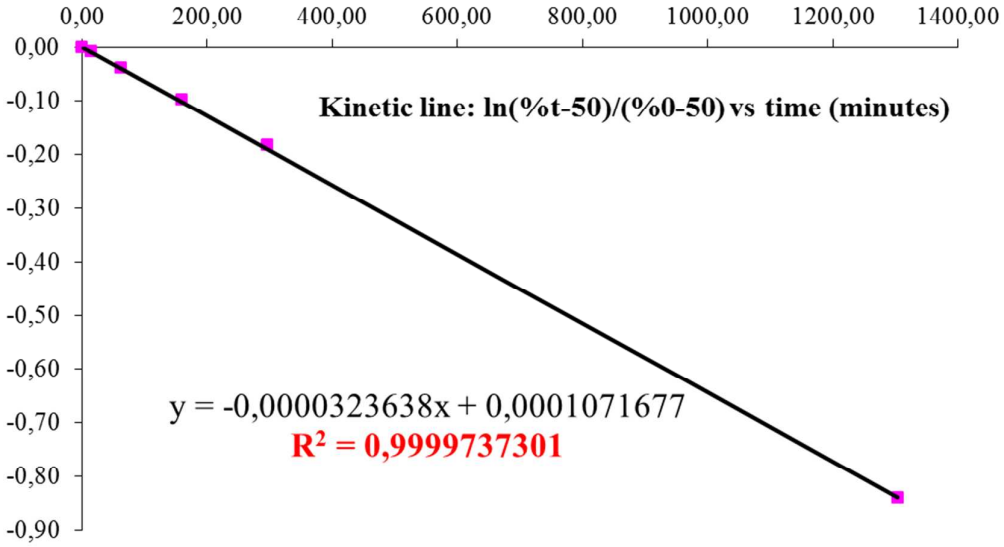
About 3 mg of enantio-enriched (**4b**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-2 (heptane / ethanol 50/50, 1 mL/min, UV detection at 254 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0.00 | 91.08 | 0.0000 |
| 15.00 | 90.73 | -0.0086 |
| 62.00 | 89.54 | -0.0382 |
| 160.00 | 87.23 | -0.0984 |
| 297.00 | 84.23 | -0.1824 |
| 1304.00 | 67.73 | -0.8403 |

| | | |
|---|---|---|
| k racemisation = | 1.07597E-05 | $s^{-1}$ |
| k enantiomerisation = | 5.3799E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | 122.01 | $kJ.mol^{-1}$ |
| | 29.19 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 64420 | seconds |
| | 1073.67 | minutes |
| | 17.89 | hours |
| | 0.75 | days |



**Enantiomerisation barrier for (4c)**

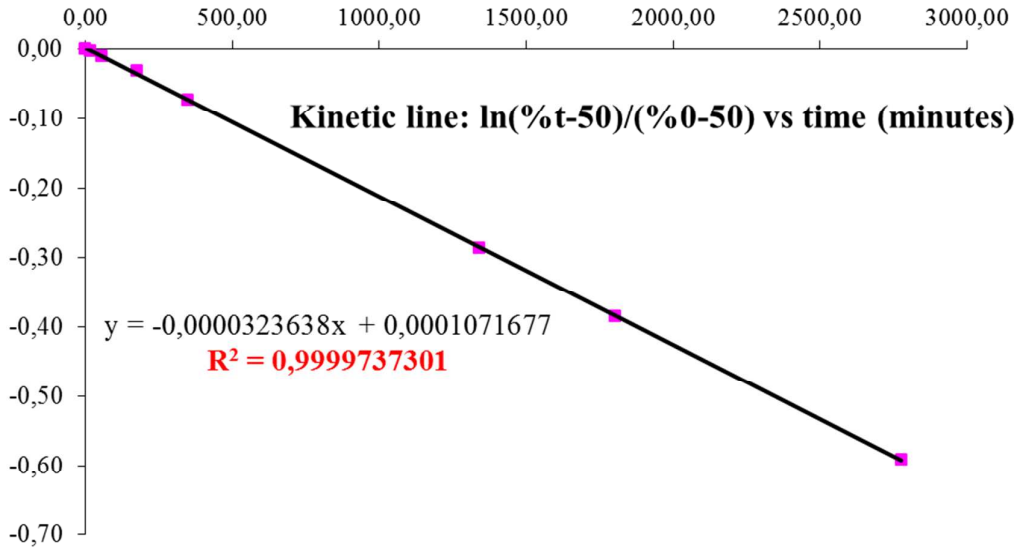
About 3 mg of enantio-enriched (**4c**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Chiralpak AZ-H (heptane / ethanol 50/50, 1 mL/min, UV detection at 254 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 94.34 | 0.0000 |
| 16 | 94.17 | -0.0038 |
| 57 | 93.84 | -0.0113 |
| 175 | 92.97 | -0.0314 |
| 350 | 91.22 | -0.0730 |
| 1340 | 83.30 | -0.2863 |
| 1804 | 80.14 | -0.3860 |
| 2777 | 74.55 | -0.5912 |

| | | |
|---|---|---|
| k racemisation = | 3.56395E-06 | $s^{-1}$ |
| k enantiomerisation = | 1.7820E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **125.24** | $kJ.mol^{-1}$ |
| | 29.96 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 194488 | seconds |
| | 3241.47 | minutes |
| | 54.02 | hours |
| | 2.25 | days |



**Enantiomerisation barrier for (4d)**

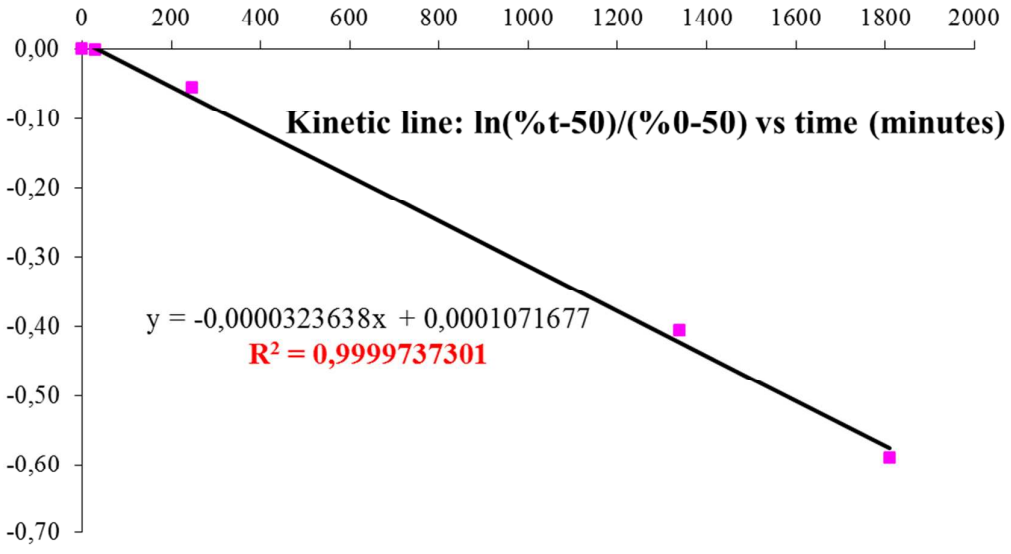
About 3 mg of enantio-enriched (**4d**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-2 (heptane / ethanol 50/50, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 90.03 | 0.0000 |
| 30 | 89.95 | -0.0020 |
| 247 | 87.86 | -0.0557 |
| 1340 | 76.66 | -0.4065 |
| 1811 | 72.18 | -0.5904 |

| | | |
|---|---|---|
| k racemisation = | 5.41033E-06 | $s^{-1}$ |
| k enantiomerisation = | 2.7052E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **123.91** | $kJ.mol^{-1}$ |
| | 29.64 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 128115 | seconds |
| | 2135.26 | minutes |
| | 35.59 | hours |
| | 1.48 | days |



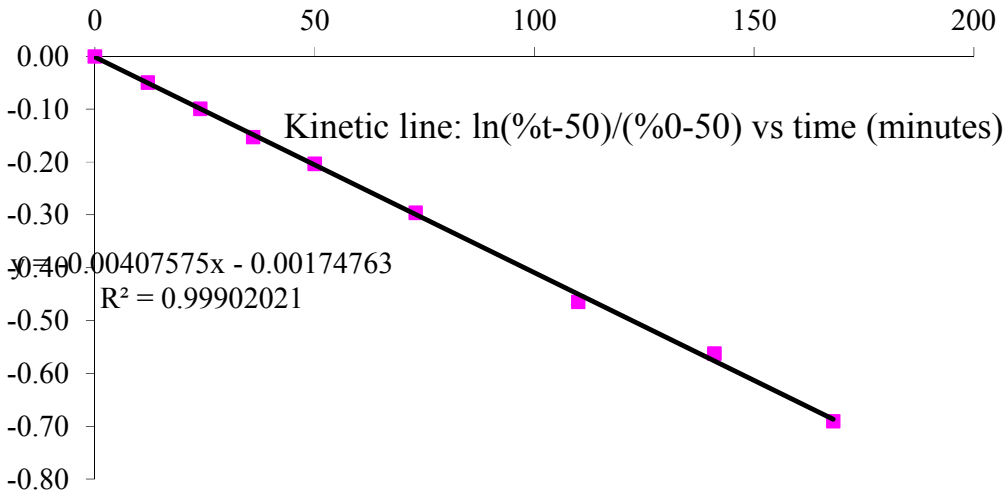
**Enantiomerisation barrier for (4e)**

About 3 mg of enantio-enriched (**4e**) were refluxed in 15 mL of chlorobenzene. Samples of 10 μL of this solution were injected on Chiralpak IB (heptane / ethanol/ chloroform 50/40/10, 1 mL/min, UV detection at 290 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : chlorobenzene
Temperature = 131 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 89.64 | 0.0000 |
| 12 | 87.71 | -0.0499 |
| 24 | 85.89 | -0.0994 |
| 36 | 84.03 | -0.1526 |
| 50 | 82.34 | -0.2035 |
| 73 | 79.49 | -0.2958 |
| 110 | 74.91 | -0.4646 |
| 141 | 72.59 | -0.5623 |
| 168 | 69.88 | -0.6901 |

| | | |
|---|---|---|
| k racemisation = | 6.79291E-05 | $s^{-1}$ |
| k enantiomerisation = | 3.3965E-05 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **134.59** | $kJ.mol^{-1}$ |
| | 32.20 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 10204 | seconds |
| | 170.07 | minutes |
| | 2.83 | hours |
| | 0.12 | days |



**Enantiomerisation barrier for (10a)**

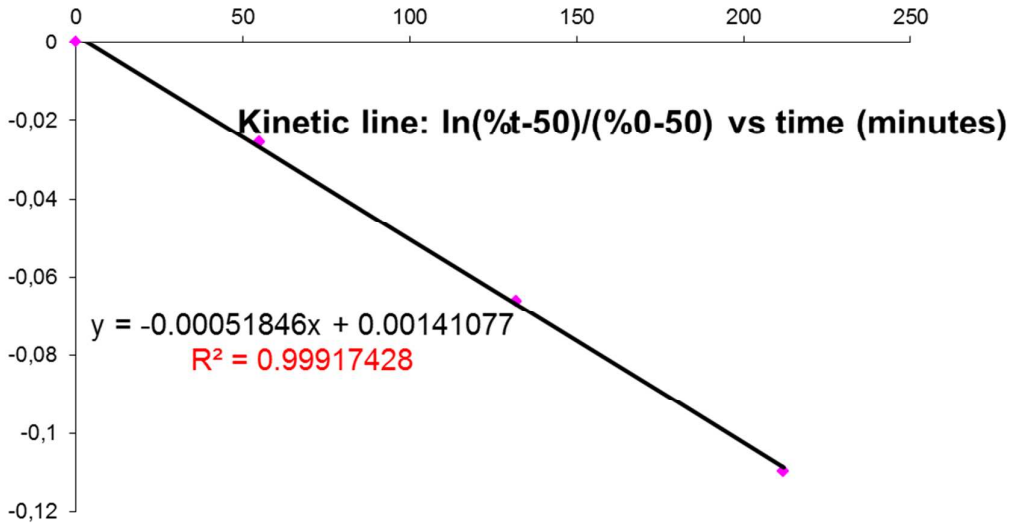
About 3 mg of enantio-enriched (**10a**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-2 (heptane / ethanol 80/20, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 99.02 | 0 |
| 55 | 97.78 | -0.025621236 |
| 132 | 95.88 | -0.066199086 |
| 212 | 93.94 | -0.109403311 |

| | | |
|---|---|---|
| k racemisation = | 8.64105E-06 | $s^{-1}$ |
| k enantiomerisation = | 4.3205E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **122.64** | $kJ.mol^{-1}$ |
| | 29.34 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 80216 | seconds |
| | 1336.93 | minutes |
| | 22.28 | hours |
| | 0.928421669 | days |



**Enantiomerisation barrier for (10b)**

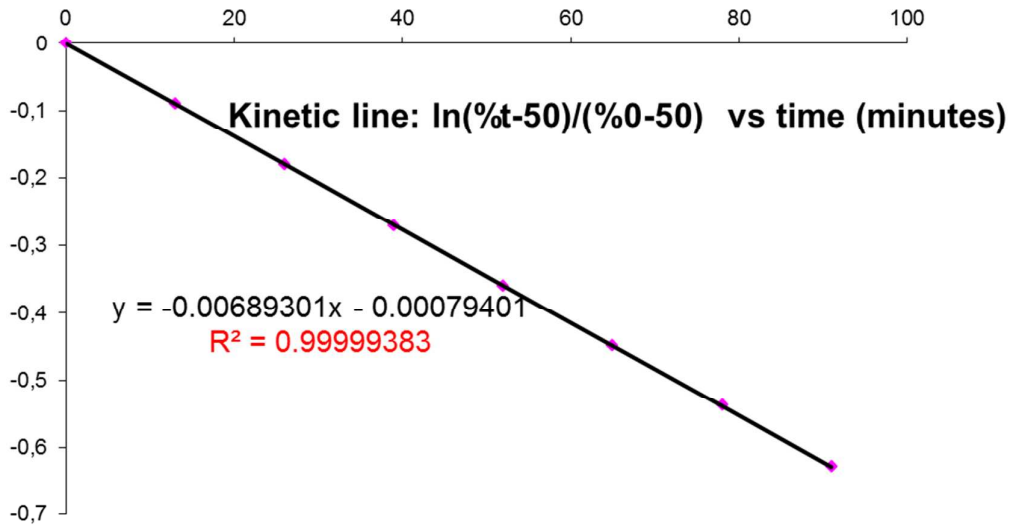
About 3 mg of enantio-enriched (**10b**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-2 (heptane / ethanol 80/20, 1 mL/min, UV detection at 205 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 93.89 | 0 |
| 13 | 90.09 | -0.090559577 |
| 26 | 86.65 | -0.180273075 |
| 39 | 83.49 | -0.270439617 |
| 52 | 80.63 | -0.359706583 |
| 65 | 78.03 | -0.448411139 |
| 78 | 75.63 | -0.537922963 |
| 91 | 73.42 | -0.628096146 |

| | | |
|---|---|---|
| k racemisation = | 1.14884E-04 | $s^{-1}$ |
| k enantiomerisation = | 5.7442E-05 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **115.08** | $kJ.mol^{-1}$ |
| | 27.53 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 6033 | seconds |
| | 100.56 | minutes |
| | 1.68 | hours |
| | 0.069831894 | days |



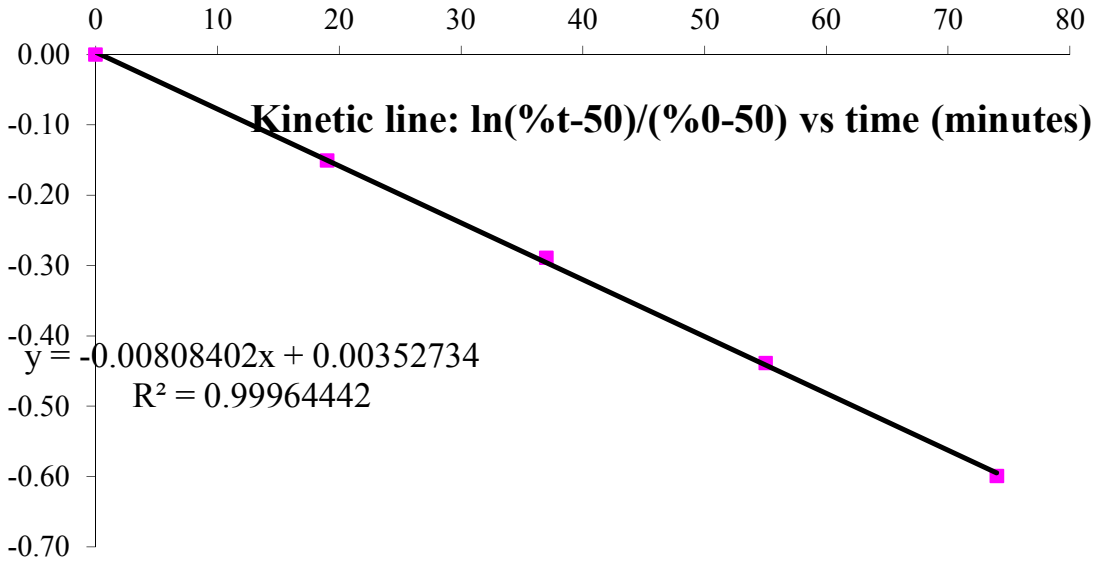
**Enantiomerisation barrier for (10c)**

About 3 mg of enantio-enriched (**10c**) were refluxed in 15 mL of chlorobenzene. Samples of 10 µL of this solution were injected on Chiralpak IC (heptane / isopropanol 95/5, 1 mL/min, UV detection at 300 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : chlorobenzene
Temperature = 131 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 89.77 | 0.0000 |
| 19 | 84.22 | -0.1503 |
| 37 | 79.78 | -0.2893 |
| 55 | 75.64 | -0.4390 |
| 74 | 71.84 | -0.5994 |

| | | |
|---|---|---|
| k racemisation = | 0.000134734 | $s^{-1}$ |
| k enantiomerisation = | 6.7367E-05 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **132.29** | $kJ.mol^{-1}$ |
| | 31.65 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 5145 | seconds |
| | 85.74 | minutes |
| | 1.43 | hours |
| | 0.06 | days |



**Enantiomerisation barrier for (10d)**

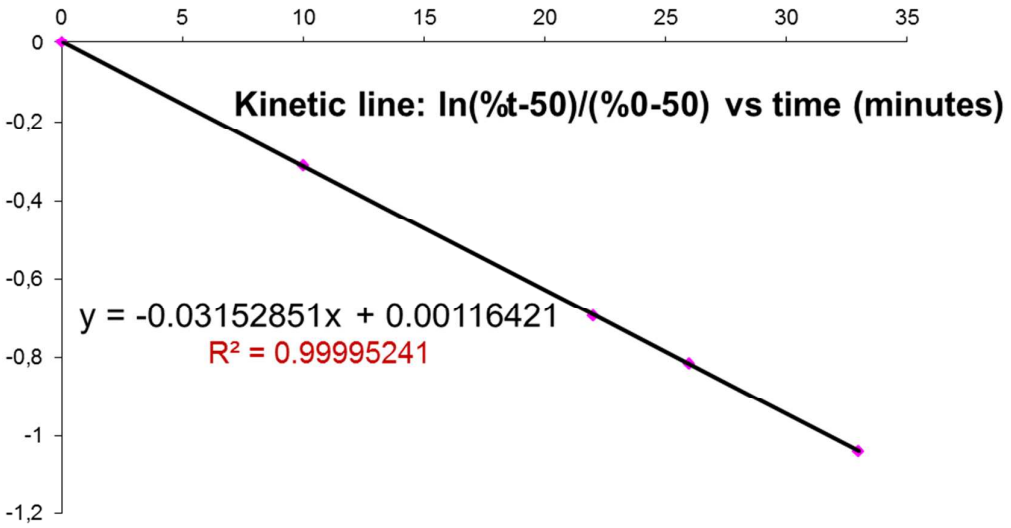
About 3 mg of enantio-enriched (**10d**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-4 (heptane / ethanol 60/40, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 86.4 | 0 |
| 10 | 76.66 | -0.31140446 |
| 22 | 68.14 | -0.69644933 |
| 26 | 66.1 | -0.815749503 |
| 33 | 62.87 | -1.039669753 |

| | | |
|---|---|---|
| k racemisation = | 5.25475E-04 | $s^{-1}$ |
| k enantiomerisation = | 2.6274E-04 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **110.64** | $kJ.mol^{-1}$ |
| | 26.47 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 1319 | seconds |
| | 21.98 | minutes |
| | 0.37 | hours |
| | 0.015267206 | days |



**Enantiomerisation barrier for (10e)**

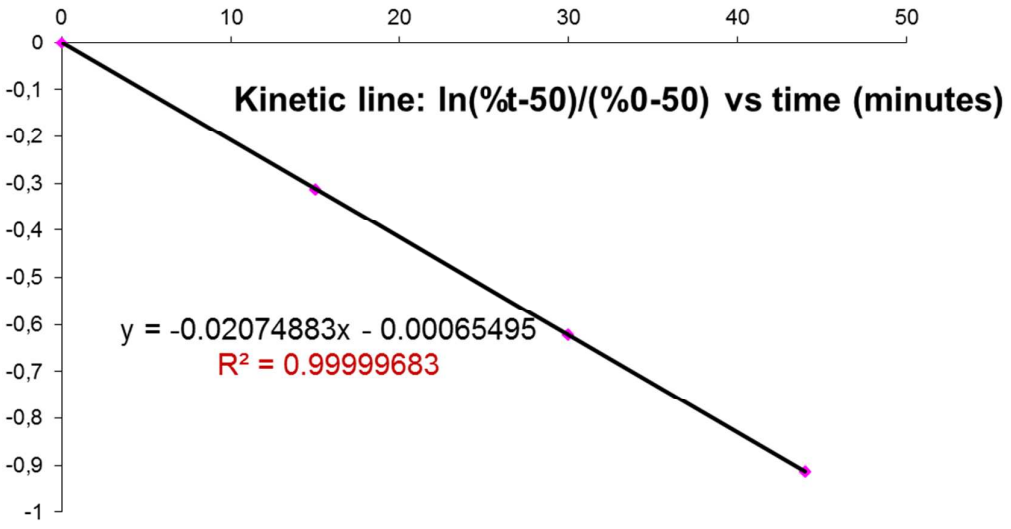
About 3 mg of enantio-enriched (**10e**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Chiralpak IC (heptane / ethanol 80/20, 1 mL/min, UV detection at 254 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 88.68 | 0 |
| 15 | 78.29 | -0.312814285 |
| 30 | 70.74 | -0.623258468 |
| 44 | 65.52 | -0.913193156 |

| | | |
|---|---|---|
| k racemisation = | 3.45814E-04 | $s^{-1}$ |
| k enantiomerisation = | 1.7291E-04 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **111.86** | $kJ.mol^{-1}$ |
| | 26.76 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 2004 | seconds |
| | 33.41 | minutes |
| | 0.56 | hours |
| | 0.023199002 | days |



**Enantiomerisation barrier for (10f)**

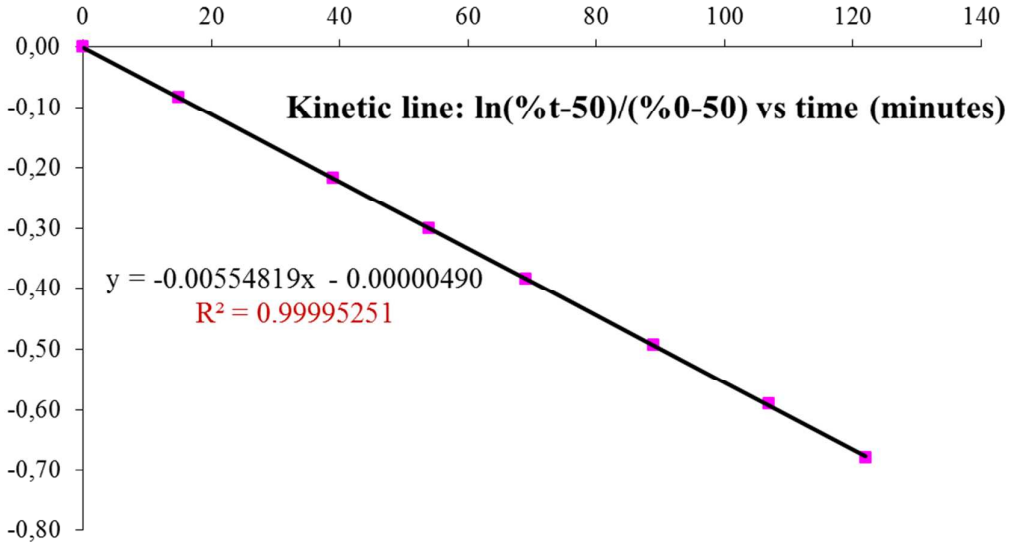
About 3 mg of enantio-enriched (**10f**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Chiralpak IB (heptane / ethanol 80/20, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 96.18 | 0.0000 |
| 15 | 92.51 | -0.0828 |
| 39 | 87.18 | -0.2168 |
| 54 | 84.21 | -0.3000 |
| 69 | 81.46 | -0.3838 |
| 89 | 78.20 | -0.4932 |
| 107 | 75.59 | -0.5903 |
| 122 | 73.41 | -0.6794 |

| | | |
|---|---|---|
| k racemisation = | 9.24699E-05 | $s^{-1}$ |
| k enantiomerisation = | 4.6235E-05 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **115.63** | $kJ.mol^{-1}$ |
| | 27.66 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 7496 | seconds |
| | 124.93 | minutes |
| | 2.08 | hours |
| | 0.09 | days |



**Enantiomerisation barrier for (10g)**

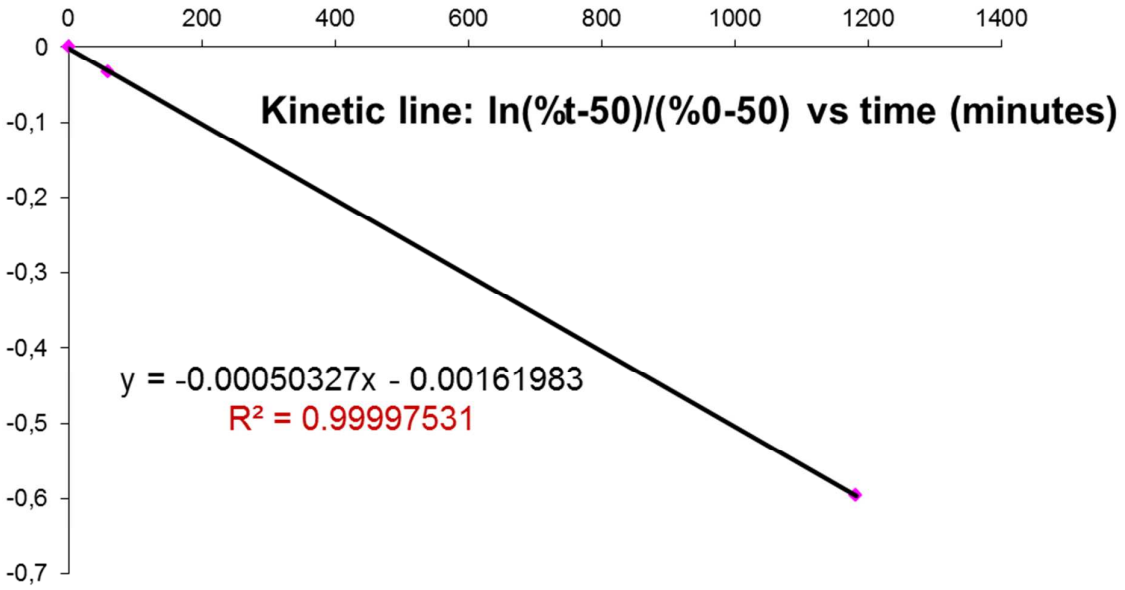
About 3 mg of enantio-enriched (**10g**) were refluxed in 15 mL of chlorobenzene. Samples of 10 μL of this solution were injected on (*S*,*S*)-Whelk-O1 (heptane / isopropanol 95/5, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : chlorobenzene

Temperature = 132 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 96.8 | 0 |
| 59 | 95.28 | -0.033017769 |
| 1181 | 75.79 | -0.595896383 |

| | | |
|---|---|---|
| k racemisation = | 8.38783E-06 | $s^{-1}$ |
| k enantiomerisation = | 4.1939E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **141.97** | $kJ.mol^{-1}$ |
| | 33.96 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 82637 | seconds |
| | 1377.29 | minutes |
| | 22.95 | hours |
| | 0.956449469 | days |



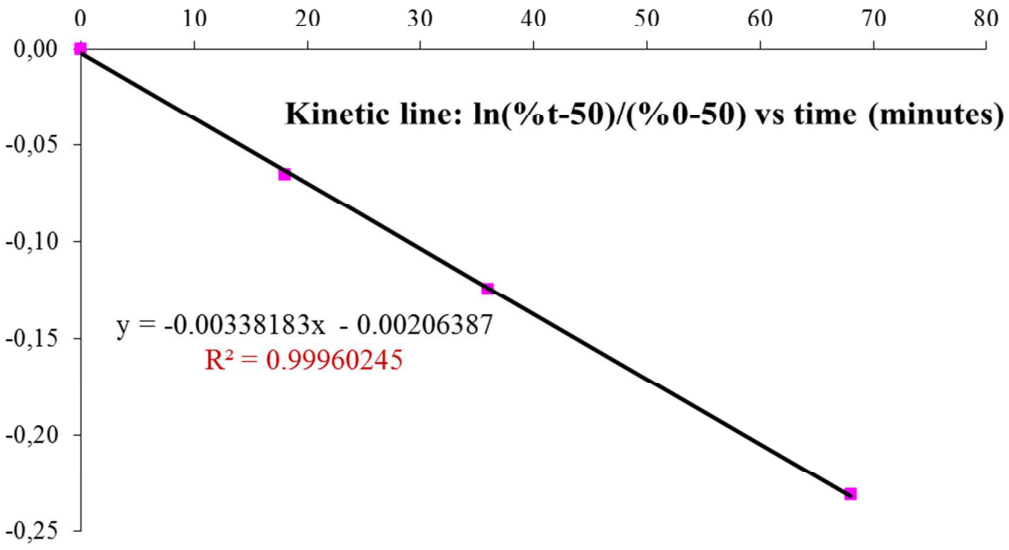
**Enantiomerisation barrier for (10h)**

About 3 mg of enantio-enriched (**10h**) were refluxed in 15 mL of 1,2-dichlorobenzene. Samples of 10 μL of this solution were injected on (*S*,*S*)-Whelk-O1 (heptane / ethanol 50/50, 1 mL/min, UV detection at 230 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : 1,2-dichlorobenzene
Temperature = 182 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 91.39 | 0.0000 |
| 18 | 88.77 | -0.0654 |
| 36 | 86.55 | -0.1244 |
| 68 | 82.85 | -0.2311 |

| | | |
|---|---|---|
| k racemisation = | 5.63638E-05 | $s^{-1}$ |
| k enantiomerisation = | 2.8182E-05 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **152.73** | $kJ.mol^{-1}$ |
| | 36.54 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 12298 | seconds |
| | 204.96 | minutes |
| | 3.42 | hours |
| | 0.14 | days |



**Enantiomerisation barrier for (10i)**

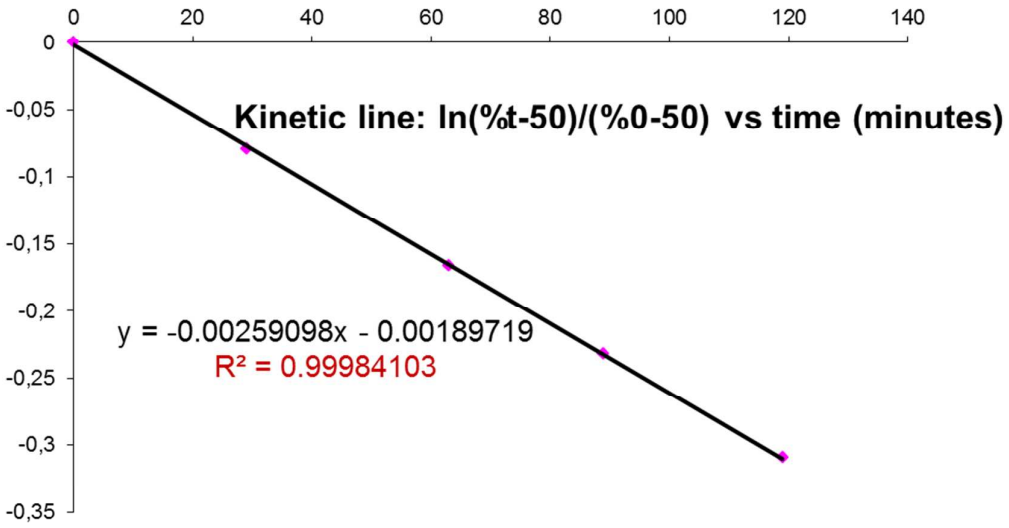
About 3 mg of enantio-enriched (**10i**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-2 (heptane / isopropanol 95/5, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : Ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 93.95 | 0 |
| 29 | 90.61 | -0.079038282 |
| 63 | 87.22 | -0.166206373 |
| 89 | 84.85 | -0.231999487 |
| 119 | 82.25 | -0.309534581 |

| | | |
|---|---|---|
| k racemisation = | 4.31829E-05 | $s^{-1}$ |
| k enantiomerisation = | 2.1591E-05 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **117.94** | $kJ.mol^{-1}$ |
| | 28.22 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 16051 | seconds |
| | 267.52 | minutes |
| | 4.46 | hours |
| | 0.185780272 | days |



## Enantiomerisation barrier for (10j)

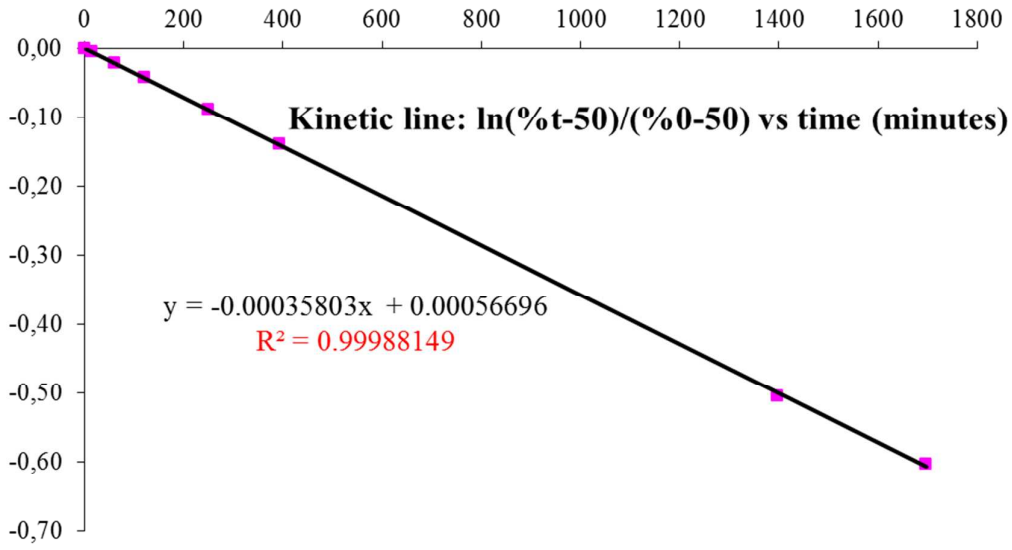
About 3 mg of enantio-enriched (**10j**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-4 (heptane / ethanol 80/20, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 97.77 | 0.0000 |
| 14 | 97.56 | -0.0044 |
| 60 | 96.77 | -0.0212 |
| 120 | 95.80 | -0.0421 |
| 249 | 93.76 | -0.0877 |
| 393 | 91.56 | -0.1393 |
| 1397 | 78.83 | -0.5050 |
| 1697 | 76.14 | -0.6029 |

| | | |
|---|---|---|
| k racemisation = | 5.96718E-06 | $s^{-1}$ |
| k enantiomerisation = | 2.9836E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **123.73** | $kJ.mol^{-1}$ |
| | 29.60 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 116160 | seconds |
| | 1936.00 | minutes |
| | 32.27 | hours |
| | 1.34 | days |



**Enantiomerisation barrier for (10k)**

About 3 mg of enantio-enriched (**10k**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-4 (heptane / ethanol 80/20, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : Ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 96.15 | 0.0000 |
| 52 | 94.96 | -0.0261 |
| 190 | 92.43 | -0.0840 |
| 348 | 89.54 | -0.1546 |
| 1387 | 74.44 | -0.6357 |

k racemisation = 7.63939E-06 $s^{-1}$

k enantiomerisation = 3.8197E-06 $s^{-1}$

$\Delta G^{\neq}$ enantiomerisation = **123.01** $kJ.mol^{-1}$

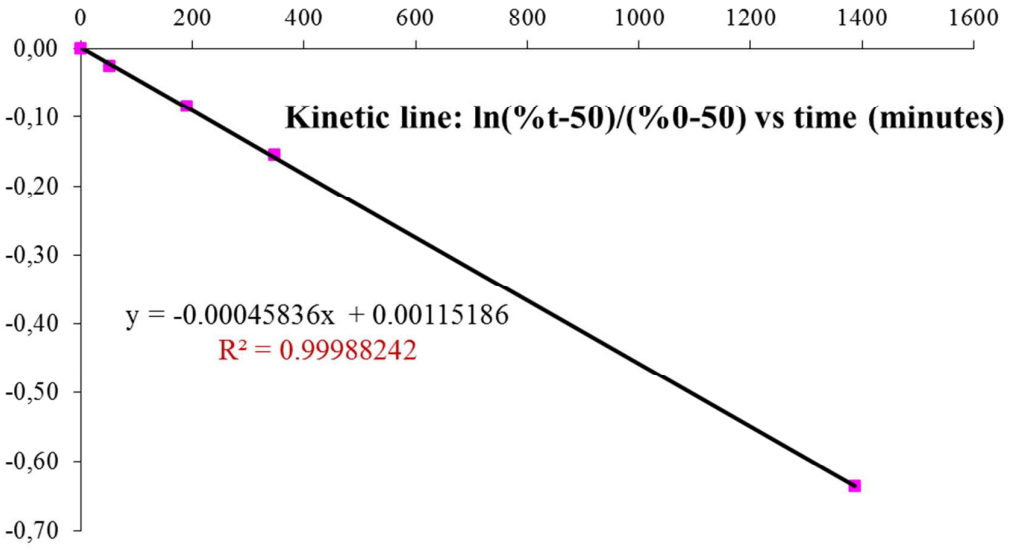
29.43 $kcal.mol^{-1}$

half-life time $t_{1/2}$ = 90733 seconds

1512.22 minutes

25.20 hours

1.05 days



**Enantiomerisation barrier for (10l)**

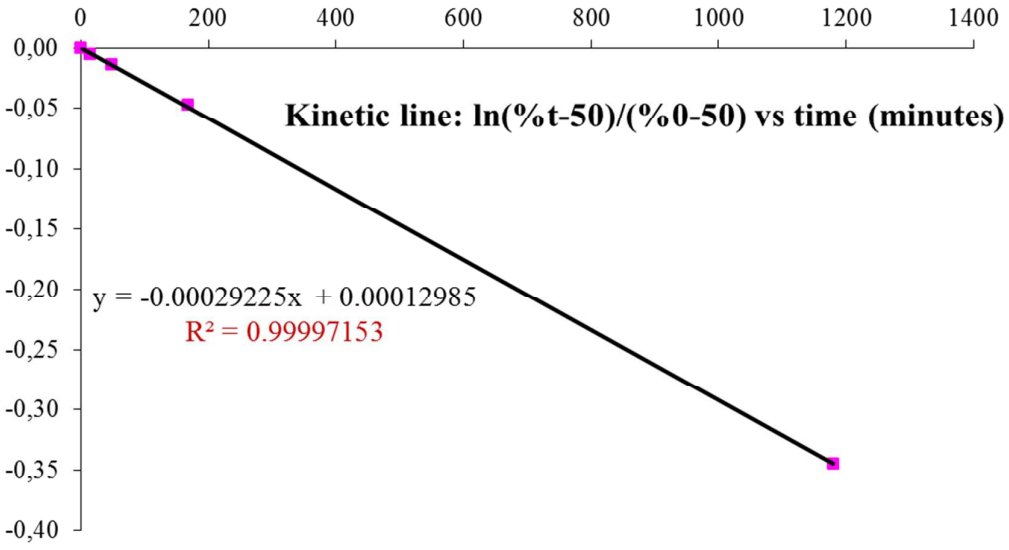
About 3 mg of enantio-enriched (**10l**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-3 (heptane / ethanol 80/20, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : Ethanol

Temperature = 78.29 °C

| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 97.72 | 0.0000 |
| 15 | 97.48 | -0.0050 |
| 48 | 97.05 | -0.0141 |
| 168 | 95.50 | -0.0476 |
| 1180 | 83.80 | -0.3449 |

| | | |
|---|---|---|
| k racemisation = | 4.87077E-06 | $s^{-1}$ |
| k enantiomerisation = | 2.4354E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **124.33** | $kJ.mol^{-1}$ |
| | 29.74 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 142308 | seconds |
| | 2371.79 | minutes |
| | 39.53 | hours |
| | 1.65 | days |



**Enantiomerisation barrier for (10m)**

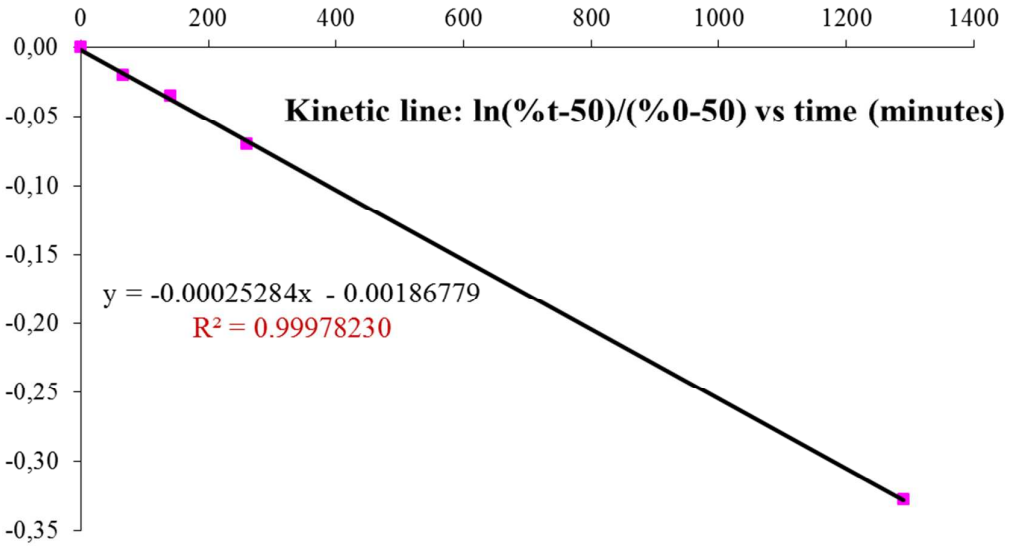
About 3 mg of enantio-enriched (**10m**) were refluxed in 15 mL of ethanol. Samples of 10 μL of this solution were injected on Lux-Cellulose-4 (heptane / ethanol 80/20, 1 mL/min, UV detection at 220 nm) to monitor the percentage decrease of the second eluted enantiomer over time.

Solvent : Ethanol

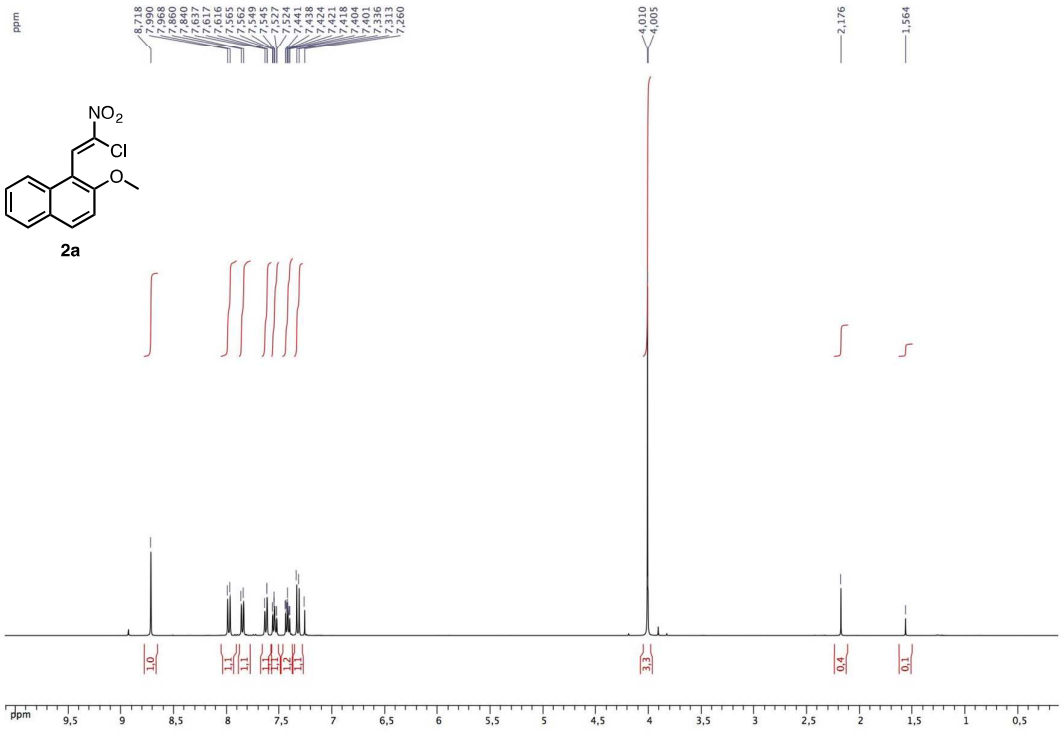
Temperature = 78.29 °C

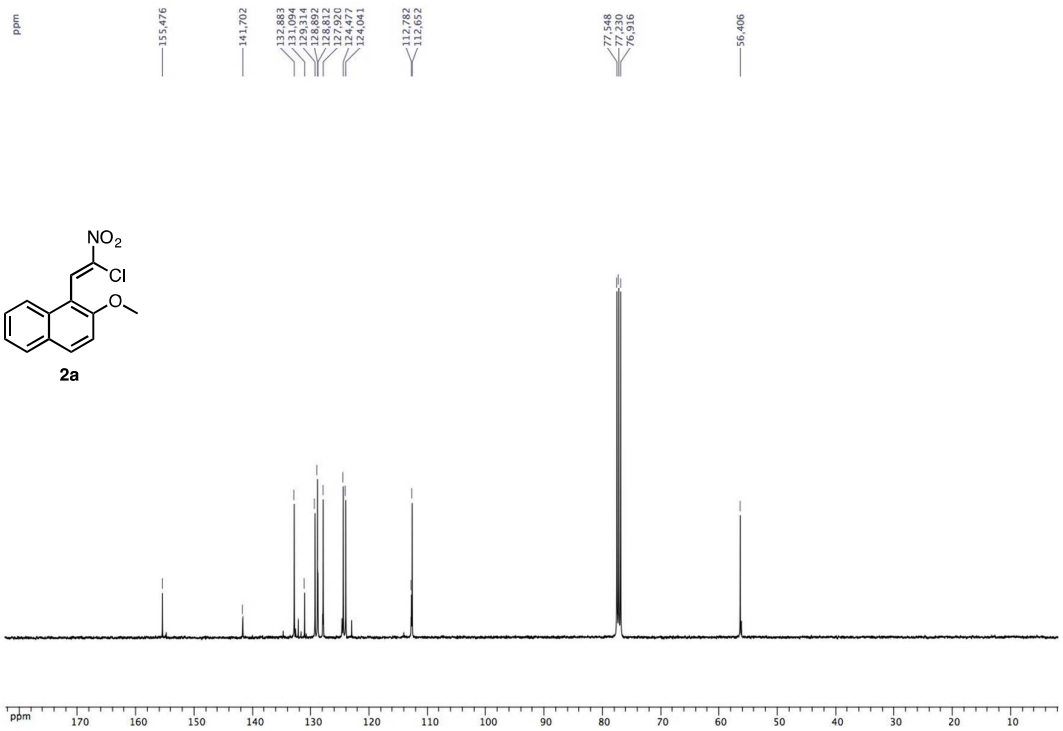
| Time (min) | % second eluted enantiomer (%t) | ln ((%t-50)/(%0-50)) |
|---|---|---|
| 0 | 97.93 | 0.0000 |
| 66 | 96.98 | -0.0200 |
| 140 | 96.26 | -0.0355 |
| 260 | 94.68 | -0.0702 |
| 1290 | 84.54 | -0.3276 |

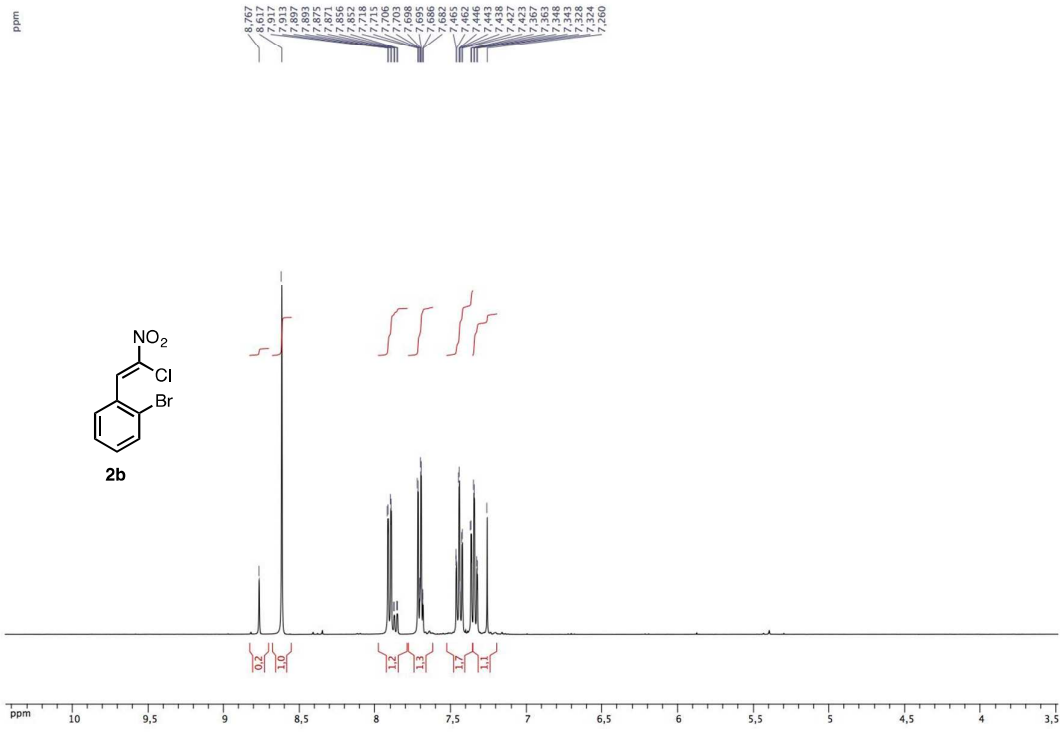
| | | |
|---|---|---|
| k racemisation = | 4.21397E-06 | $s^{-1}$ |
| k enantiomerisation = | 2.1070E-06 | $s^{-1}$ |
| $\Delta G^{\neq}$ enantiomerisation = | **124.75** | $kJ.mol^{-1}$ |
| | 29.84 | $kcal.mol^{-1}$ |
| half-life time $t_{1/2}$ = | 164488 | seconds |
| | 2741.47 | minutes |
| | 45.69 | hours |
| | 1.90 | days |

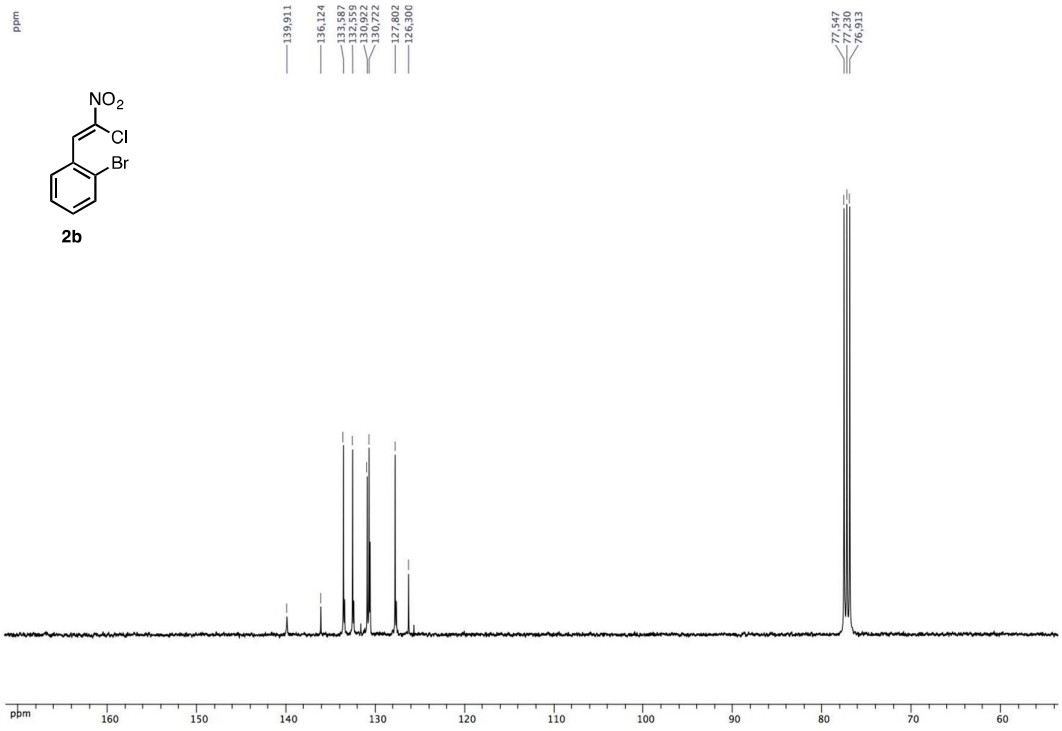


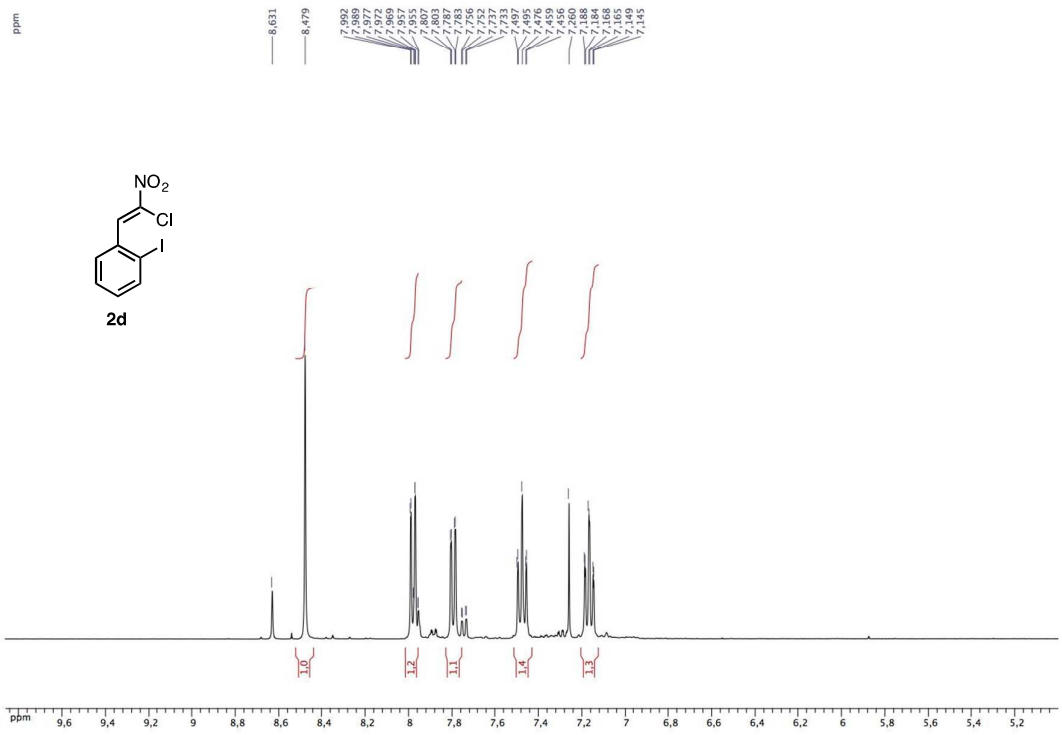
# 7. $^{1}H$ and $^{13}C$ NMR spectra

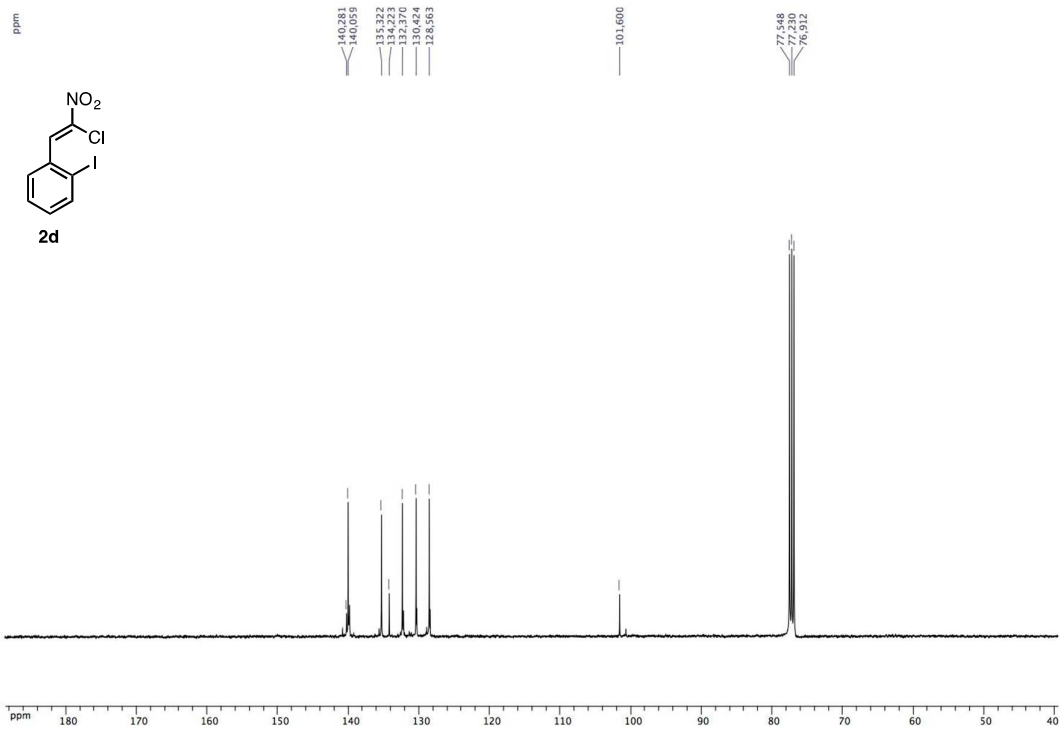


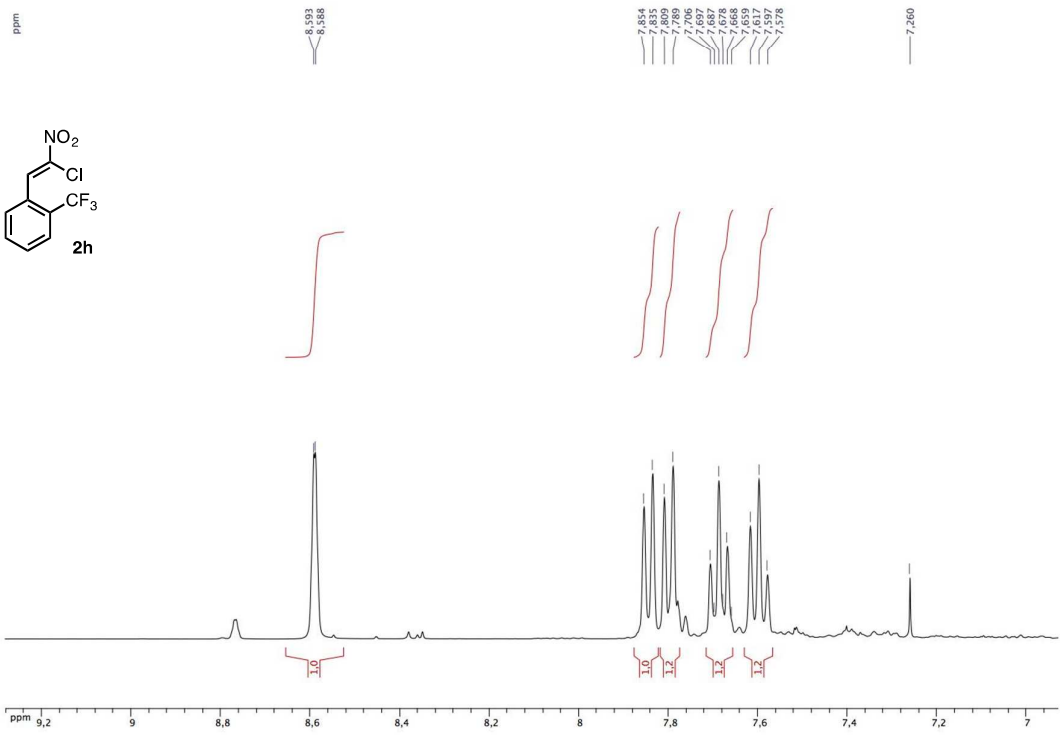



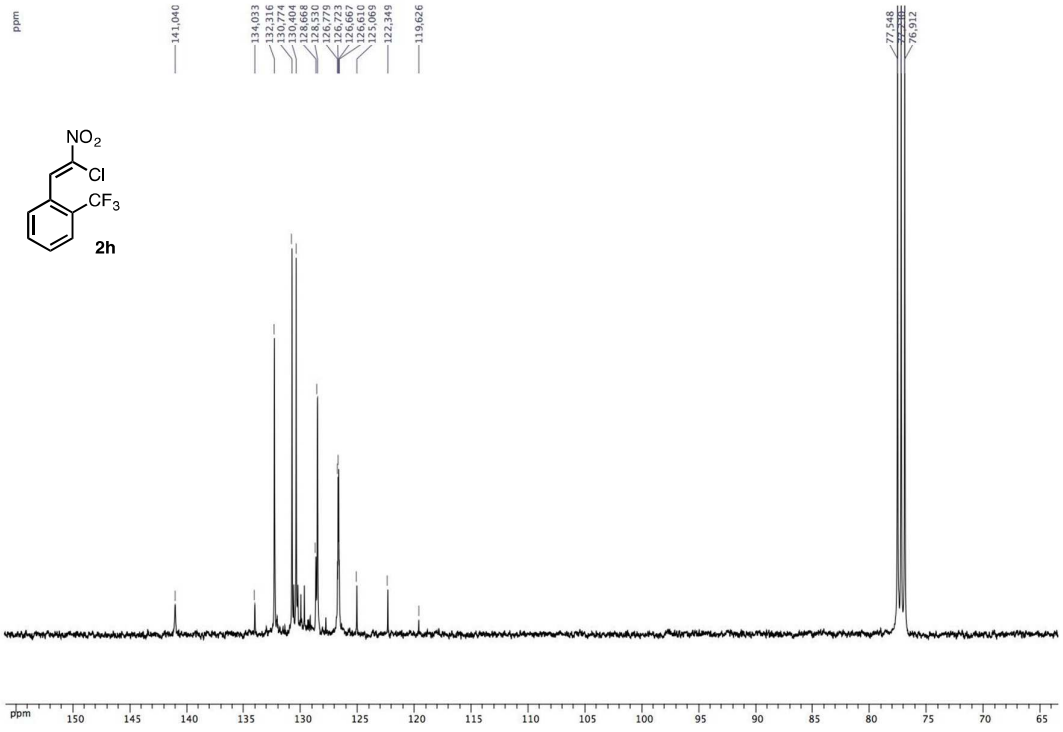

8.767
8.617
7.917
7.913
7.897
7.893
7.875
7.871
7.856
7.852
7.718
7.715
7.706
7.703
7.698
7.695
7.686
7.682
7.465
7.462
7.446
7.443
7.438
7.427
7.423
7.367
7.363
7.348
7.343
7.328
7.324
7.260
NO2
Cl
Br
2b
0.2
1.0
1.2
1.3
1.7
1.1
ppm
10
9,5
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5

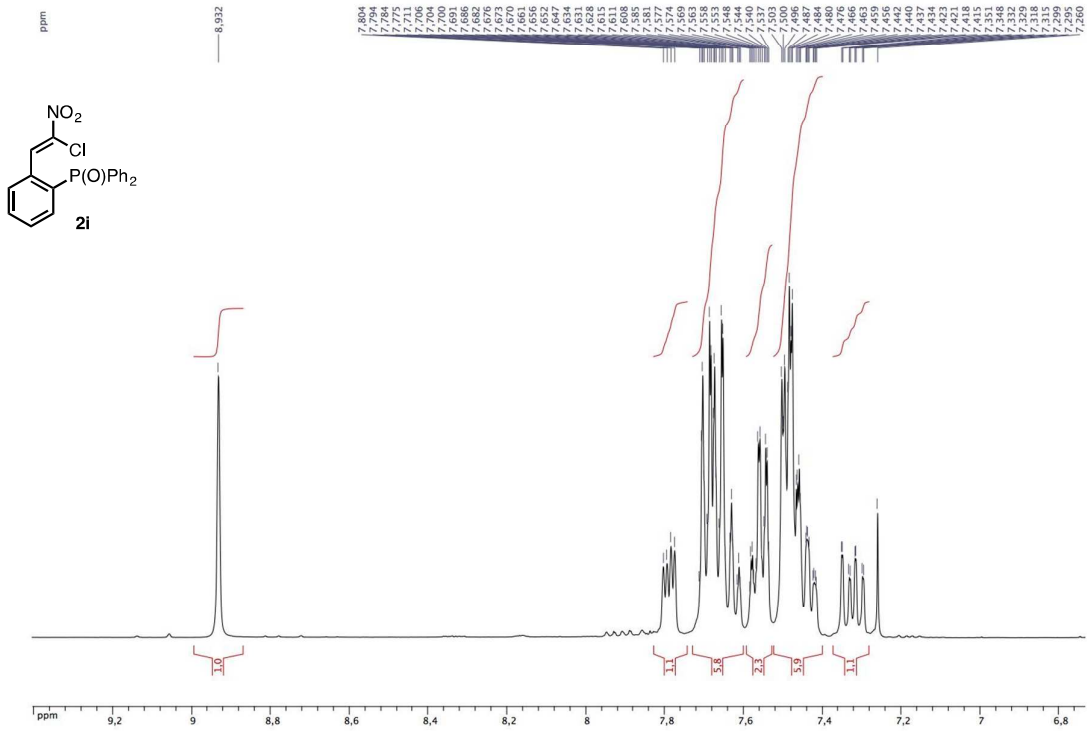

139,911
136,124
133,587
132,559
130,922
130,722
127,802
126,300
77,547
77,230
76,913
NO2
Cl
Br
2b
ppm
160
150
140
130
120
110
100
90
80
70
60

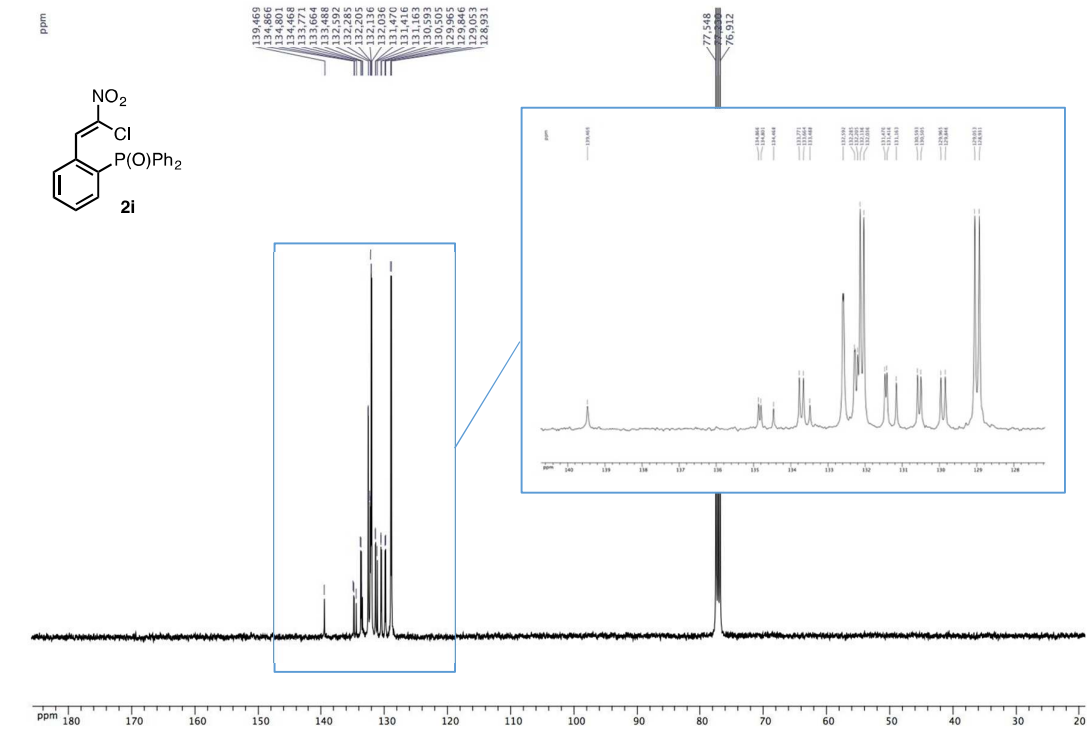

ppm
8,631
8,479
7,992
7,989
7,977
7,972
7,969
7,957
7,955
7,807
7,803
7,787
7,783
7,756
7,752
7,737
7,733
7,497
7,495
7,476
7,459
7,456
7,260
7,188
7,184
7,168
7,165
7,149
7,145
NO2
Cl
I
2d
1,0
1,2
1,1
1,4
1,3
ppm
9,6
9,4
9,2
9
8,8
8,6
8,4
8,2
8
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6
5,8
5,6
5,4
5,2

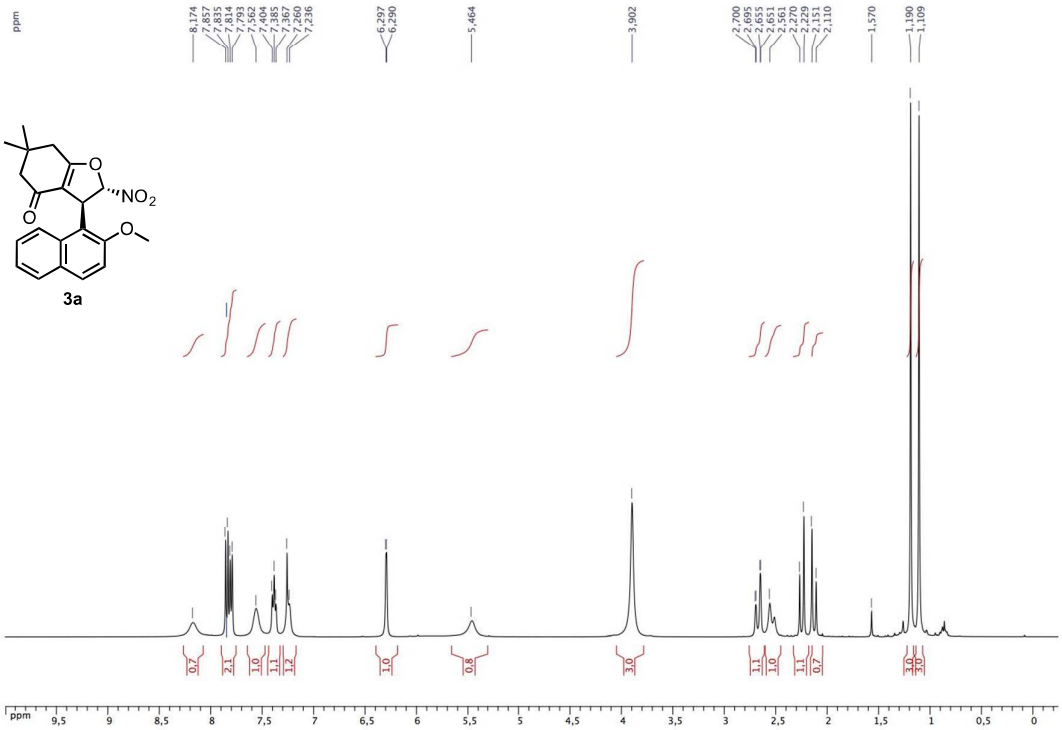

ppm
140,281
140,059
135,322
134,223
133,270
130,424
128,563
101,600
77,548
77,230
76,912
NO2
Cl
I
2d
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40

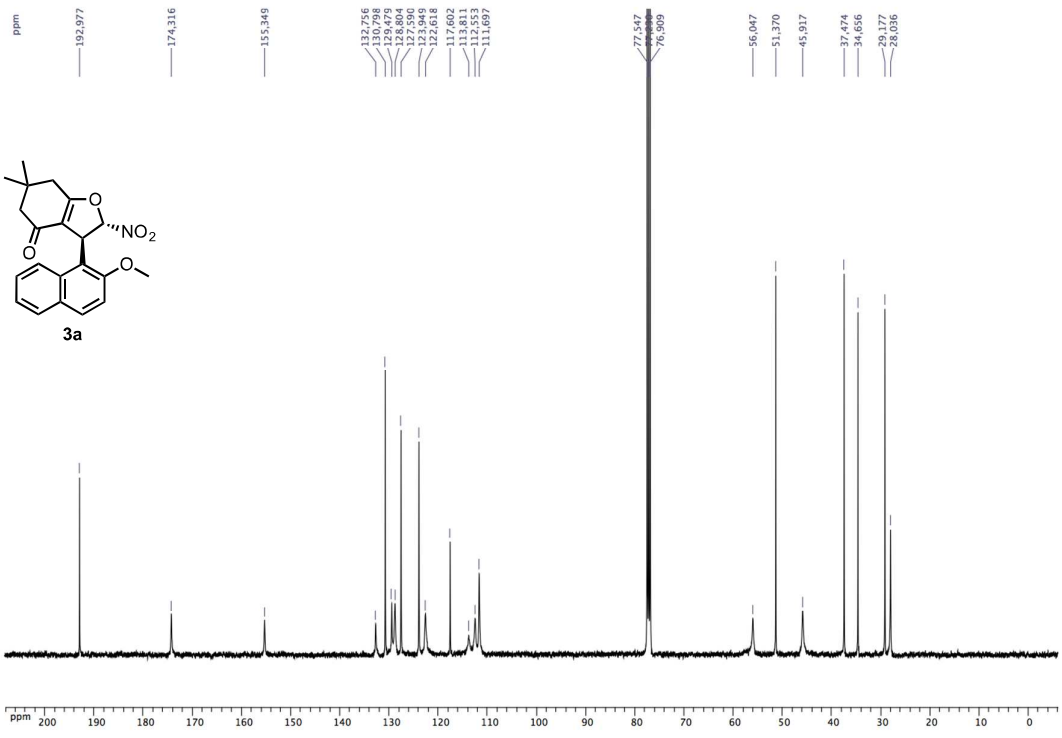

ppm
8,593
8,588
7,854
7,835
7,809
7,789
7,706
7,697
7,687
7,678
7,668
7,659
7,617
7,597
7,578
7,260
NO2
Cl
CF3
2h
1,0
1,0
1,2
1,2
1,2
ppm 9,2 9 8,8 8,6 8,4 8,2 8 7,8 7,6 7,4 7,2 7

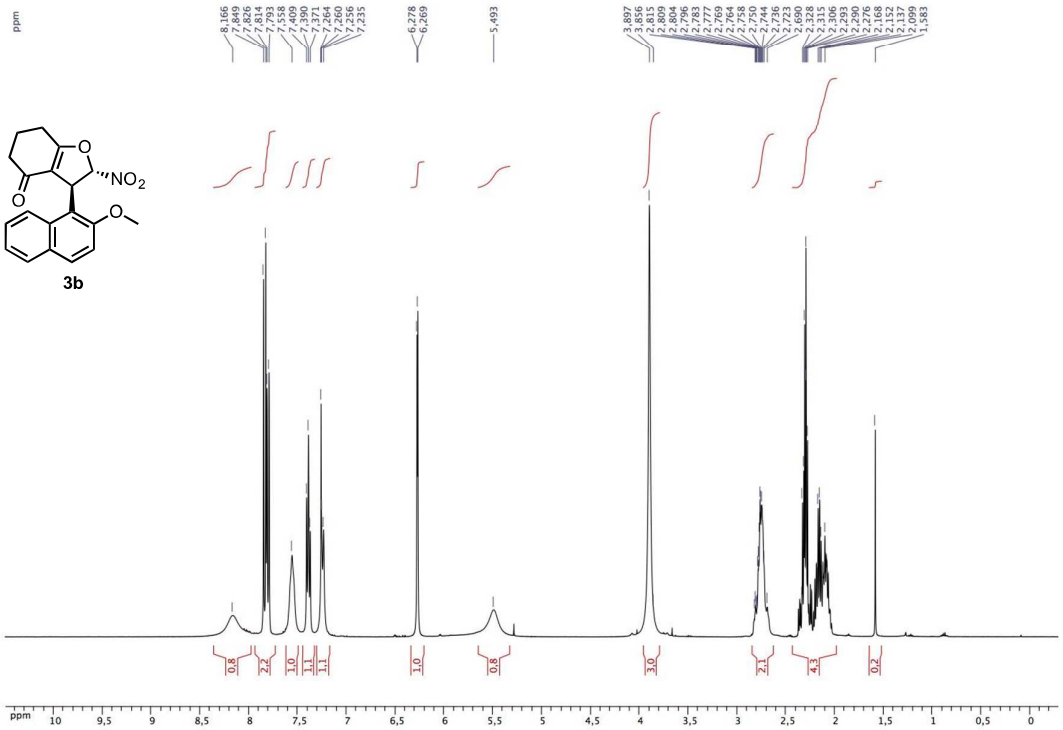

ppm
141,040
134,033
132,316
130,774
130,404
128,868
128,530
126,779
126,723
126,667
126,610
125,069
122,349
119,626
77,548
77,230
76,912
NO2
Cl
CF3
2h
ppm 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65

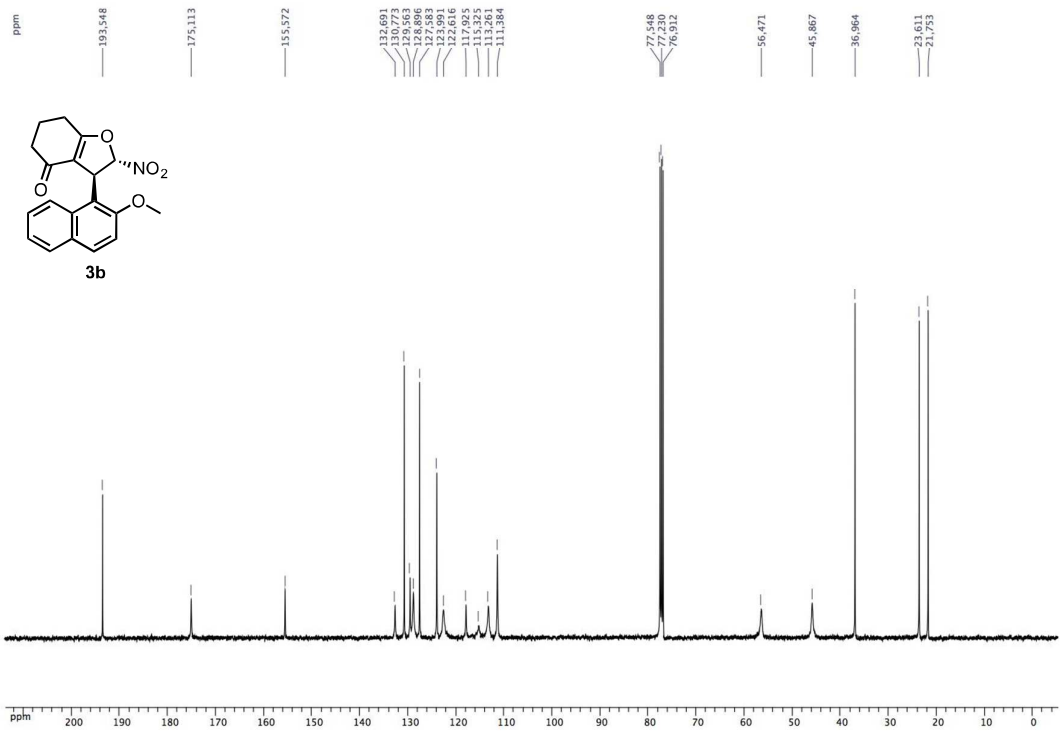

NO2
Cl
P(O)Ph2
2i
ppm
9,2
9
8,8
8,6
8,4
8,2
8
7,8
7,6
7,4
7,2
7
6,8

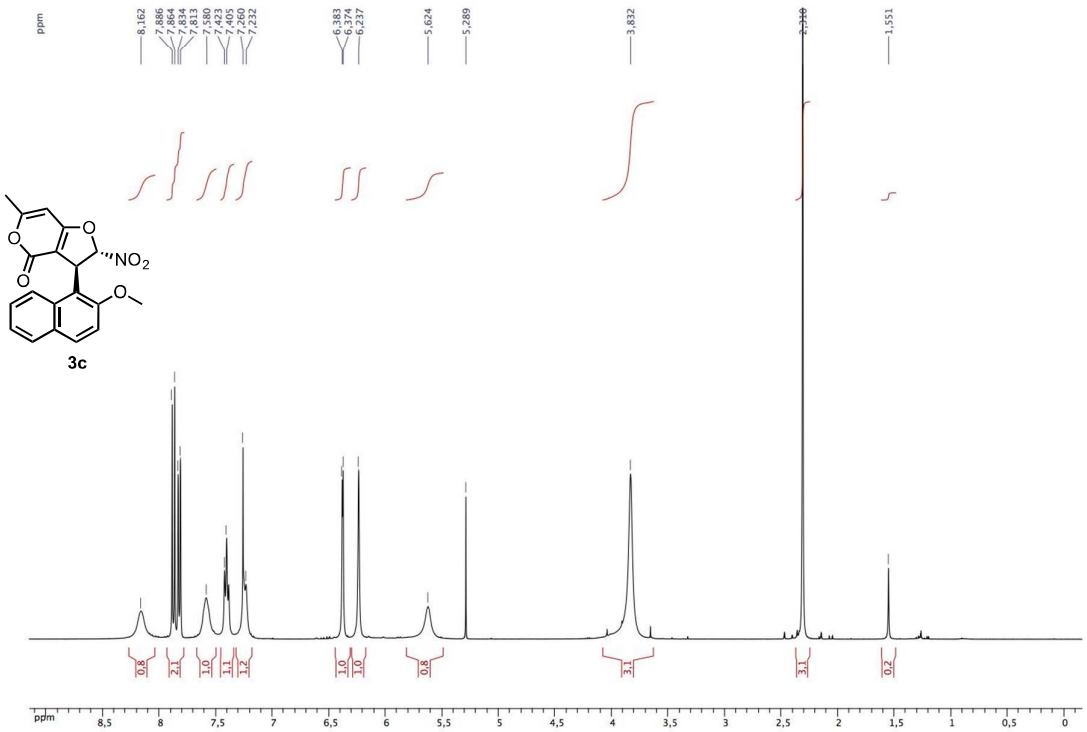

NO2
Cl
P(O)Ph2
2i
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20

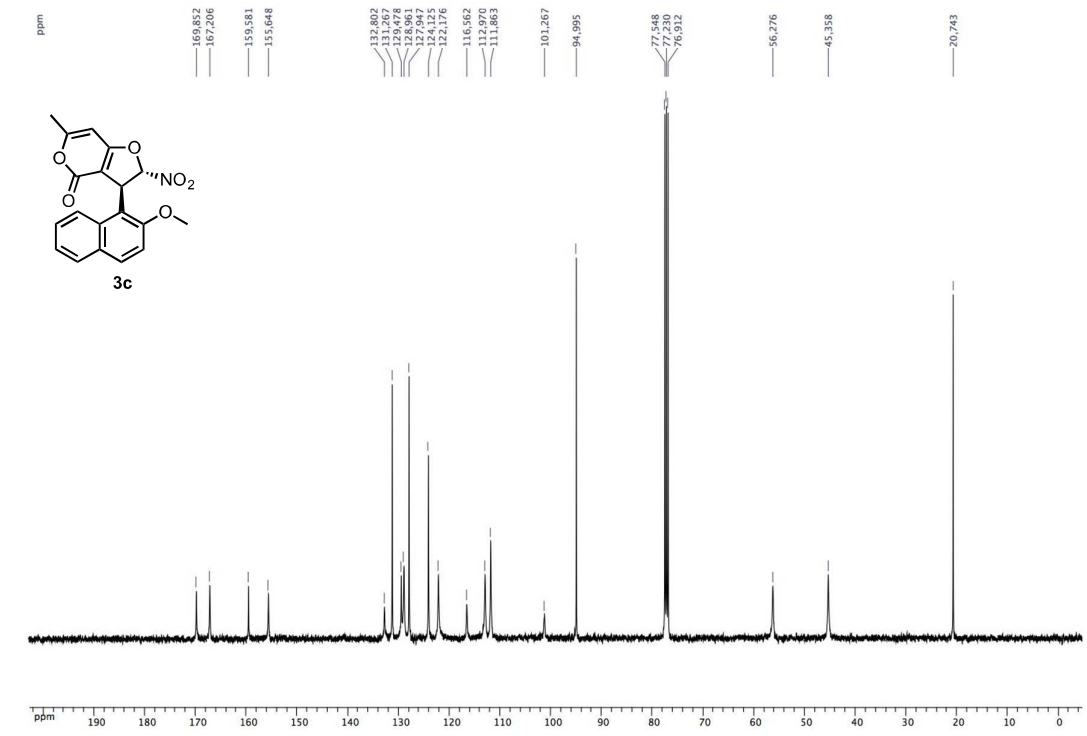

ppm
8,174
7,857
7,835
7,814
7,793
7,562
7,404
7,385
7,367
7,260
7,236
6,297
6,290
5,464
3,902
2,700
2,695
2,655
2,651
2,561
2,270
2,229
2,151
2,110
1,570
1,190
1,109
NO2
O
O
O
3a
0,7
2,1
1,0
1,1
1,2
1,0
0,8
3,0
1,1
1,0
1,1
0,7
3,0
3,0
ppm
9,5
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

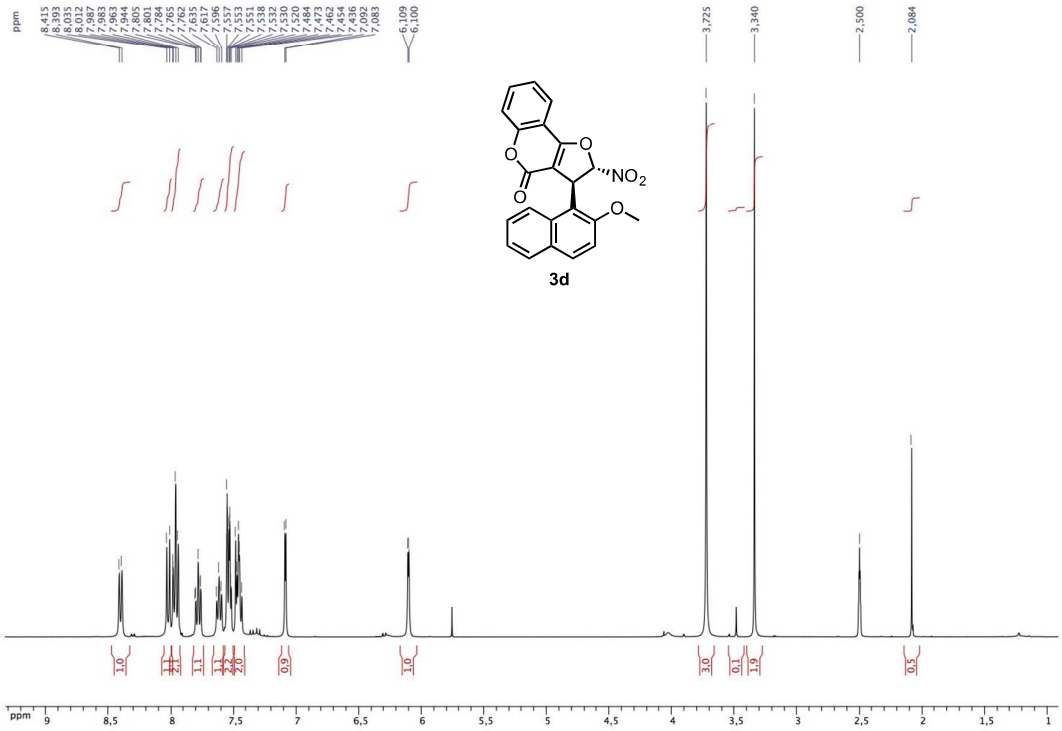

ppm
192,977
174,316
155,349
132,756
130,798
130,479
128,804
127,590
123,949
122,618
117,602
113,811
112,553
111,697
77,547
77,226
76,909
56,047
51,370
45,917
37,474
34,656
29,177
28,036
NO2
O
O
O
3a
ppm
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
8.166
7.849
7.826
7.814
7.793
7.558
7.409
7.390
7.371
7.264
7.260
7.256
7.235
6.278
6.269
5.493
3.807
3.856
2.815
2.809
2.804
2.796
2.788
2.777
2.769
2.764
2.758
2.750
2.744
2.736
2.723
2.690
2.318
2.315
2.306
2.293
2.290
2.276
2.168
2.152
2.137
2.099
1.583
O
NO2
O
O
3b
0,8
2,2
1,0
1,1
1,1
1,0
0,8
3,0
2,1
4,3
0,2
ppm
10
9,5
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

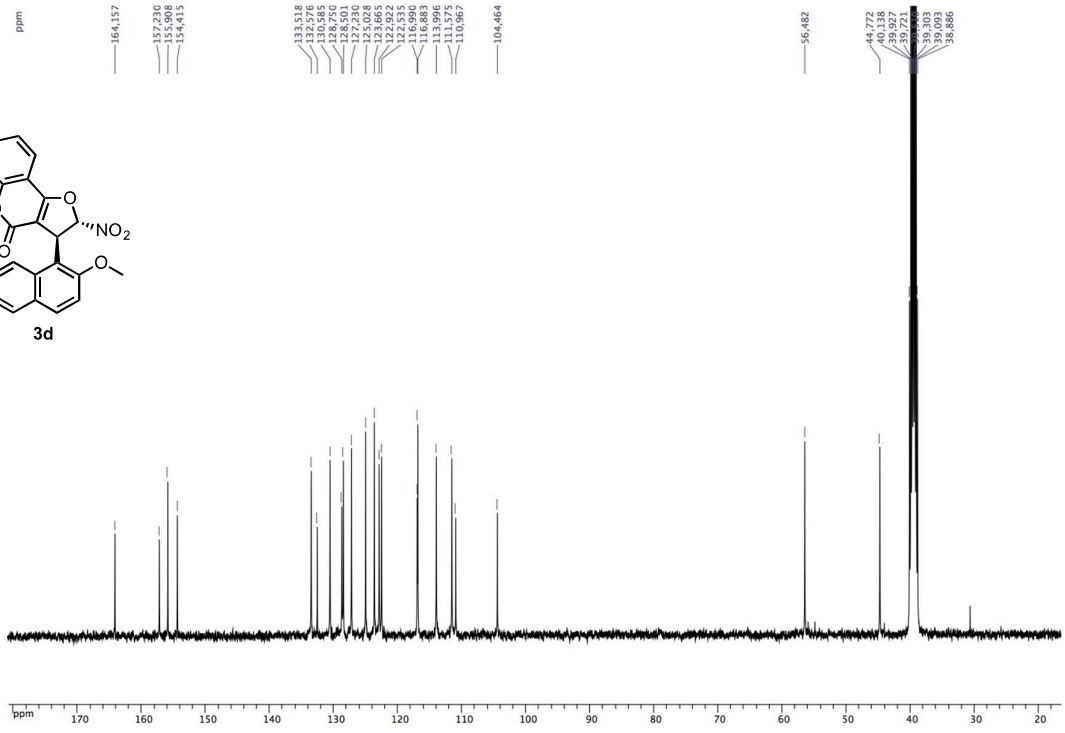

ppm
193,548
175,113
155,572
132,691
130,773
129,563
129,486
128,253
123,991
122,616
117,925
115,325
113,261
111,384
77,548
77,230
76,912
56,471
45,867
36,964
23,611
21,753
O
NO2
O
O
3b
ppm
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
8,162
7,886
7,864
7,834
7,813
7,580
7,423
7,405
7,260
7,232
6,383
6,374
6,237
5,624
5,289
3,832
2,000
1,551
0,8
2,1
1,0
1,1
1,2
1,0
1,0
0,8
3,1
3,1
0,2
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
O
O
O
NO2
O
3c


ppm
169,852
167,206
159,581
155,648
132,802
131,477
130,478
128,961
127,947
124,125
122,176
116,562
112,970
111,863
101,267
94,995
77,548
77,230
76,912
56,276
45,358
20,743
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
O
O
O
NO2
O
3c

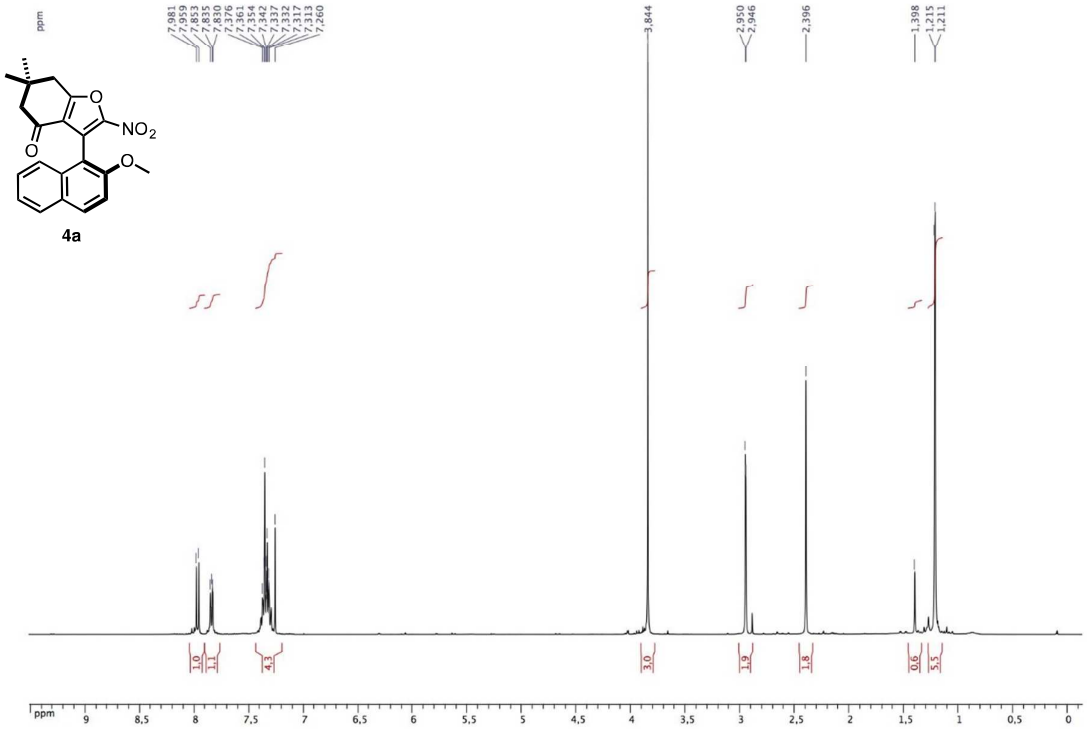

ppm
8,415
8,393
8,035
8,012
7,987
7,983
7,963
7,944
7,801
7,784
7,765
7,762
7,615
7,617
7,596
7,557
7,553
7,551
7,538
7,532
7,530
7,520
7,484
7,477
7,462
7,454
7,436
7,092
7,083
6,109
6,100
3,725
3,340
2,500
2,084
O
O
O
NO2
O
1,0
1,1
1,1
1,2
2,2
2,0
0,9
1,0
3,0
0,1
1,9
0,5
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1

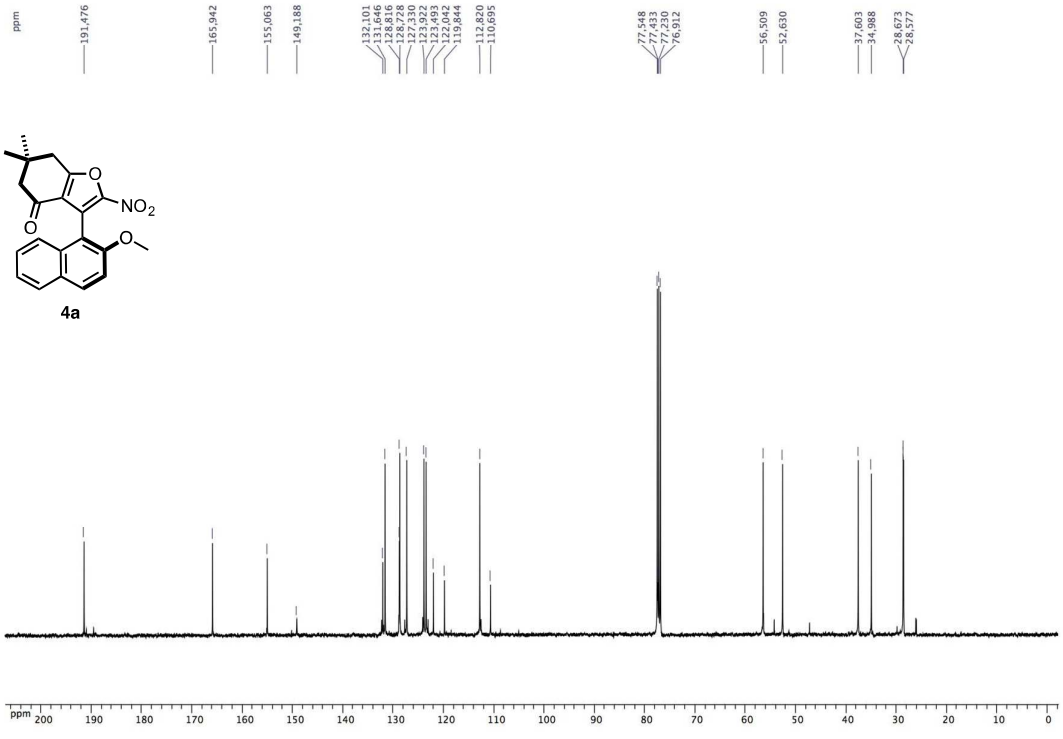
3d

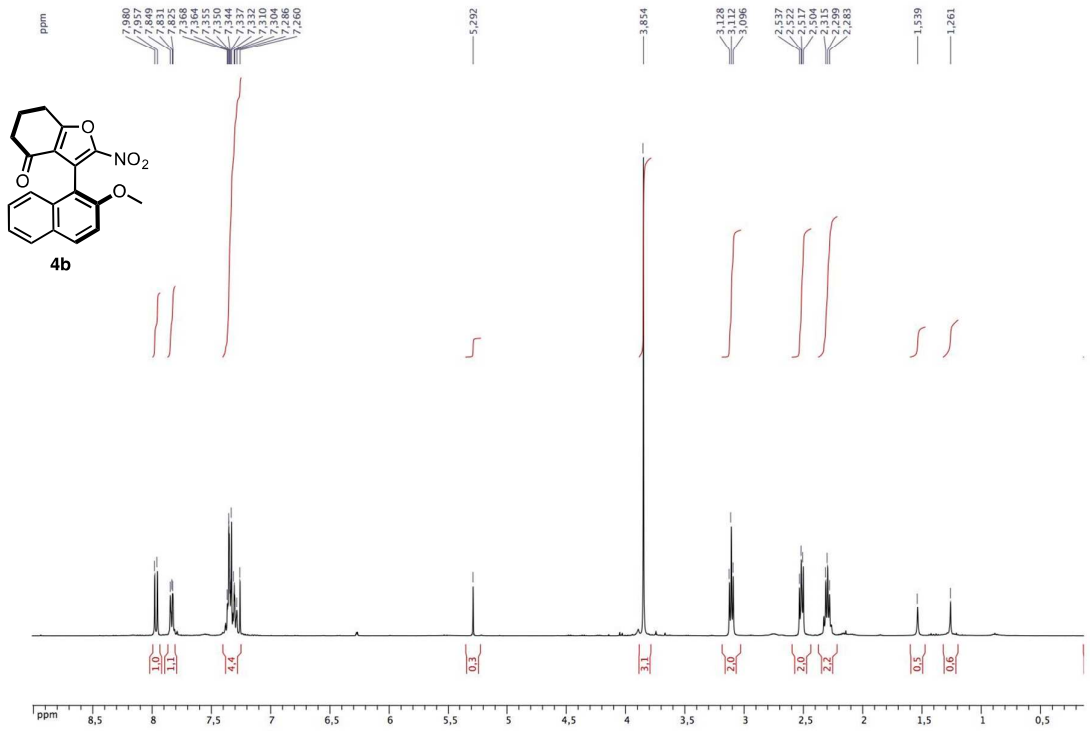

ppm
164,157
157,230
155,698
154,415
133,518
132,576
131,555
128,750
128,501
127,230
125,028
123,655
122,932
122,535
116,990
116,883
113,996
111,575
110,967
104,464
56,482
44,772
40,138
39,927
39,721
39,510
39,303
39,093
38,886
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20

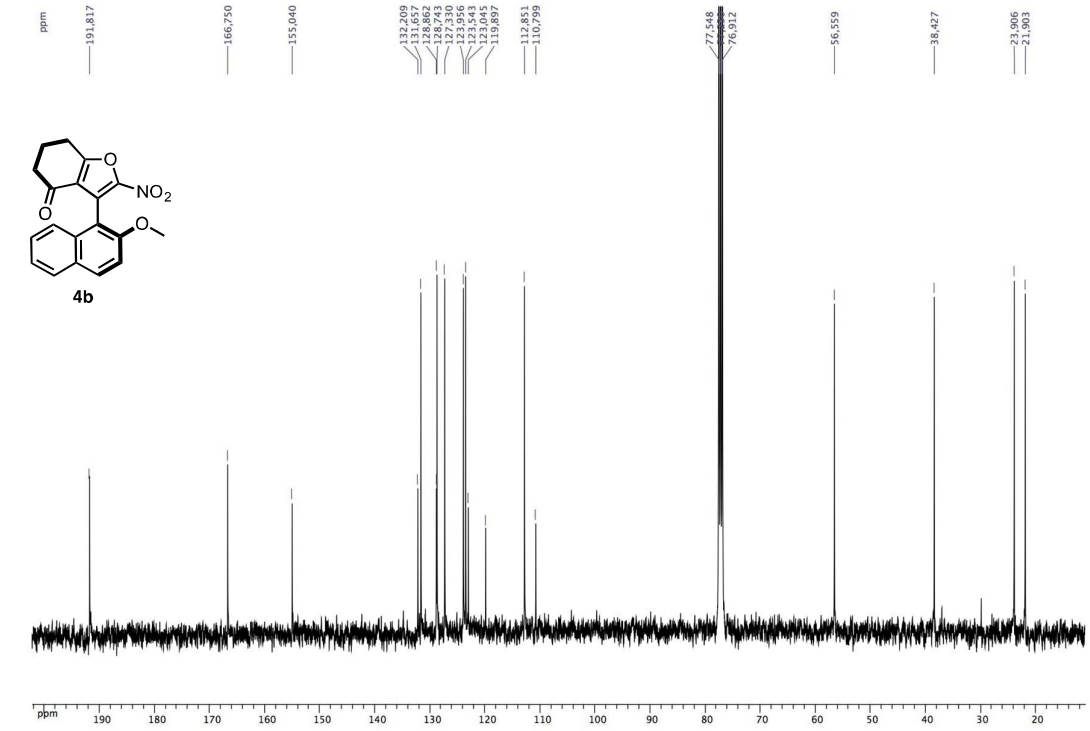

O
O
O
NO2
O

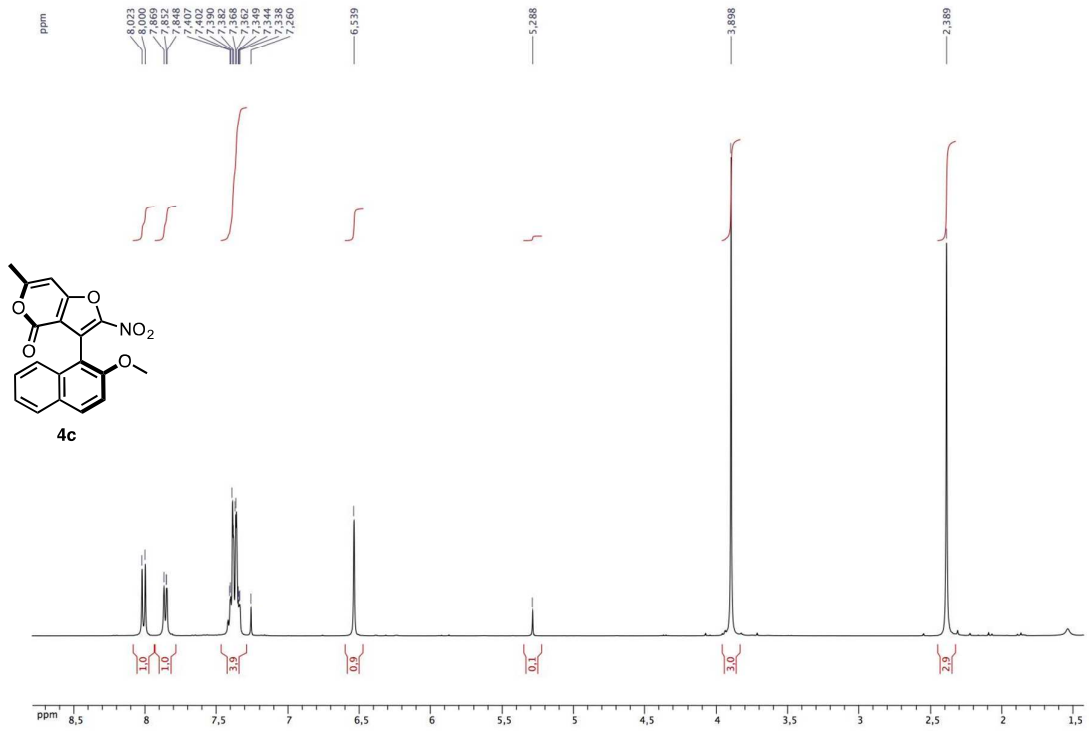
3d

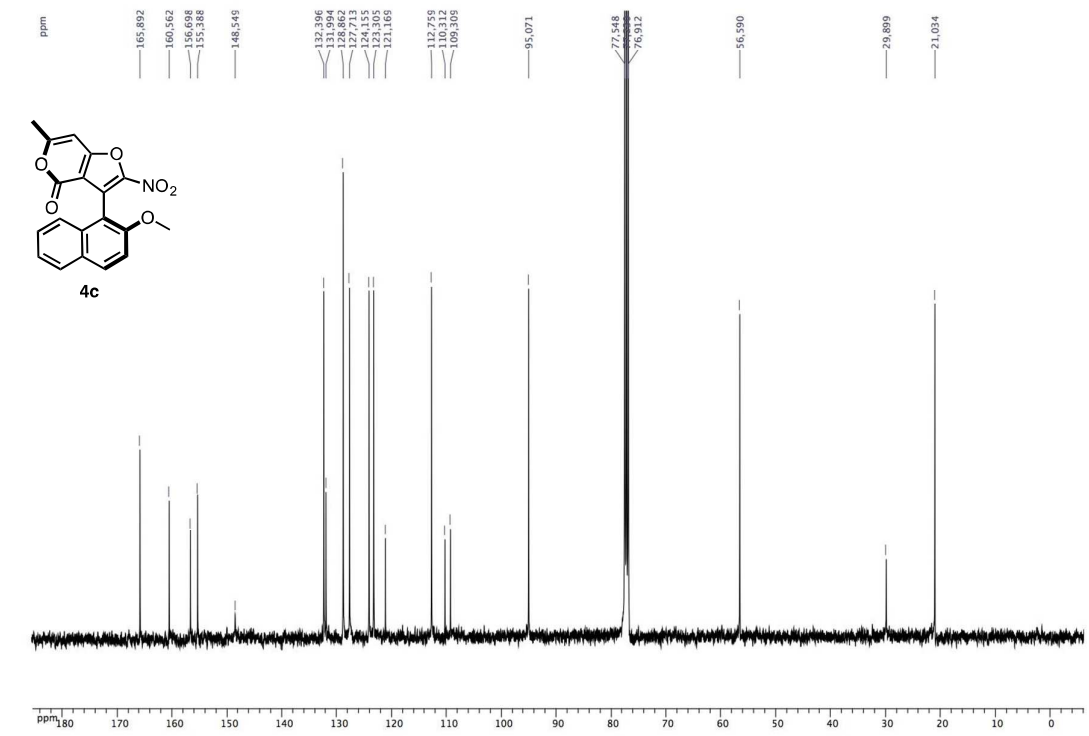

4a

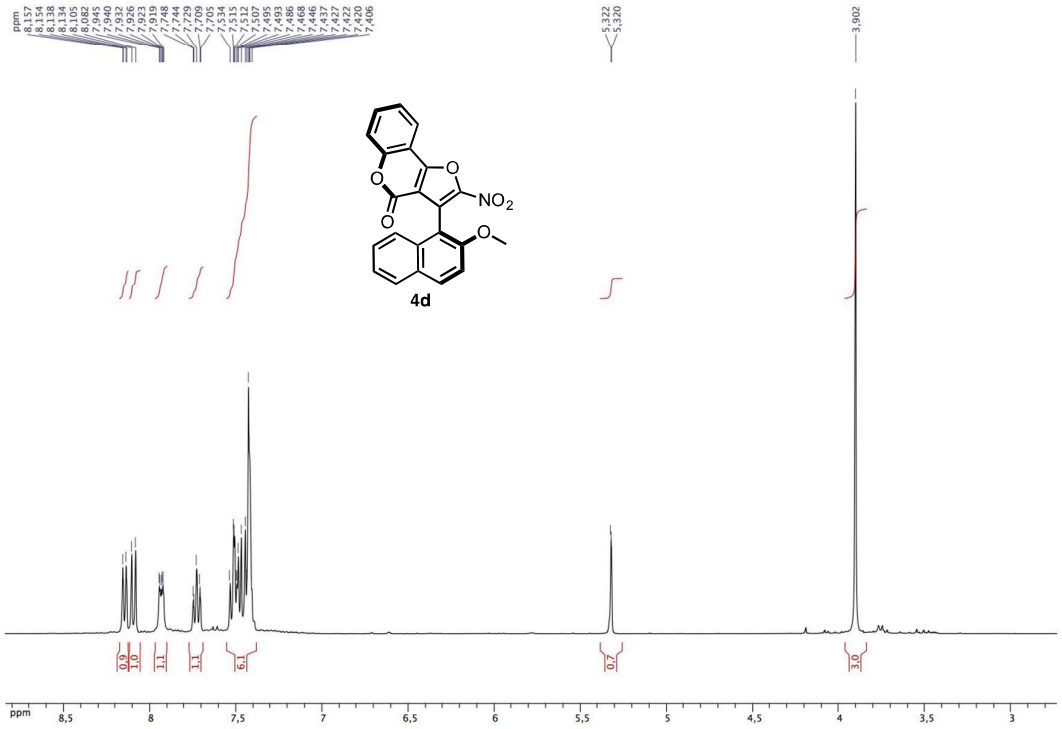

4a

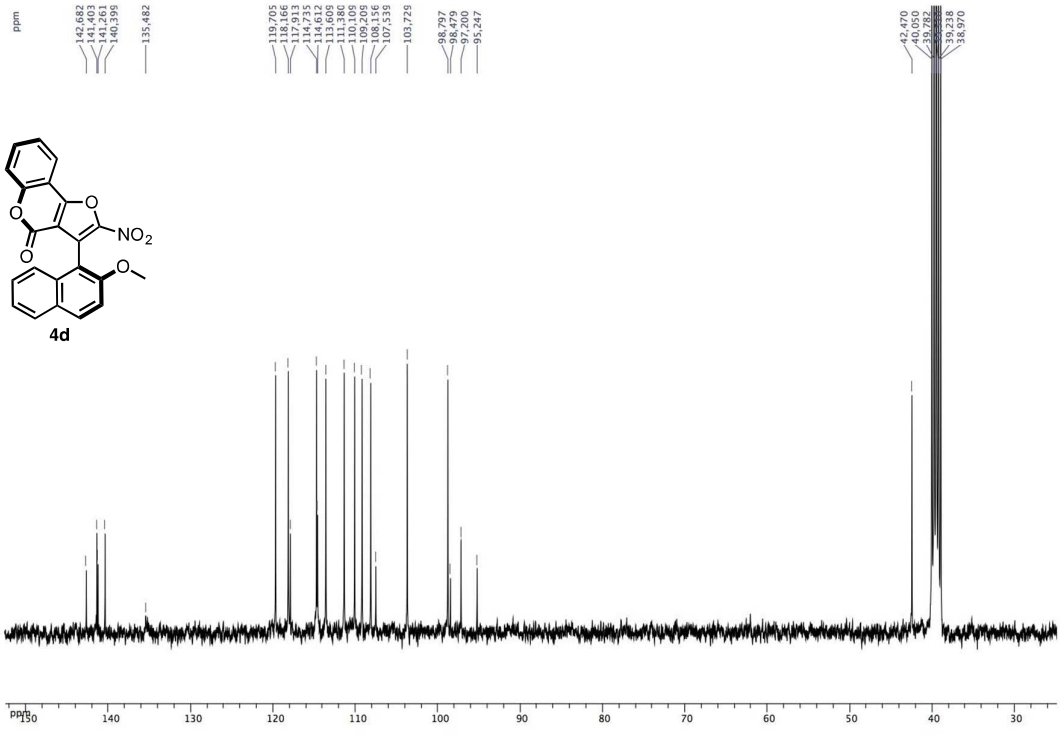

ppm
7,980
7,957
7,849
7,831
7,825
7,368
7,364
7,355
7,350
7,344
7,337
7,332
7,310
7,304
7,286
7,260
5,292
3,854
3,128
3,112
3,096
2,537
2,522
2,517
2,504
2,315
2,299
2,283
1,539
1,261
O
NO2
O
O
4b
1,0
1,1
4,4
0,3
3,1
2,0
2,0
2,2
0,5
0,6
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5

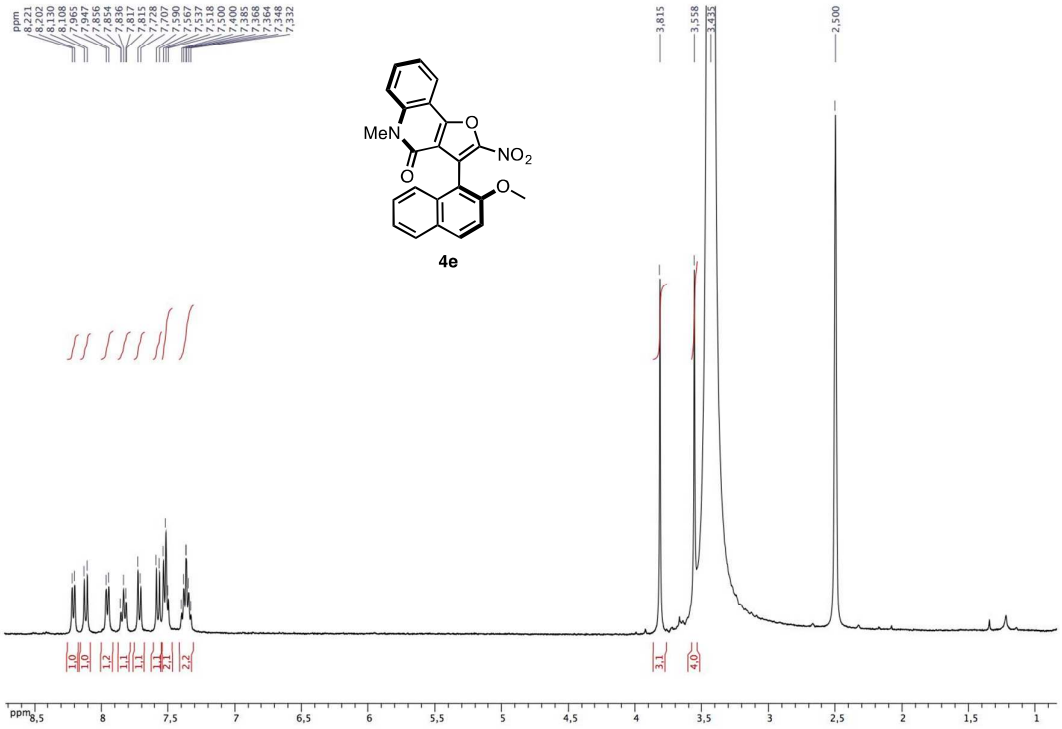

ppm
191,817
166,750
155,040
132,209
131,657
128,862
128,743
127,330
123,956
123,643
123,045
119,897
112,851
110,799
77,548
77,236
76,912
56,559
38,427
23,906
21,903
O
NO2
O
O
4b
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20

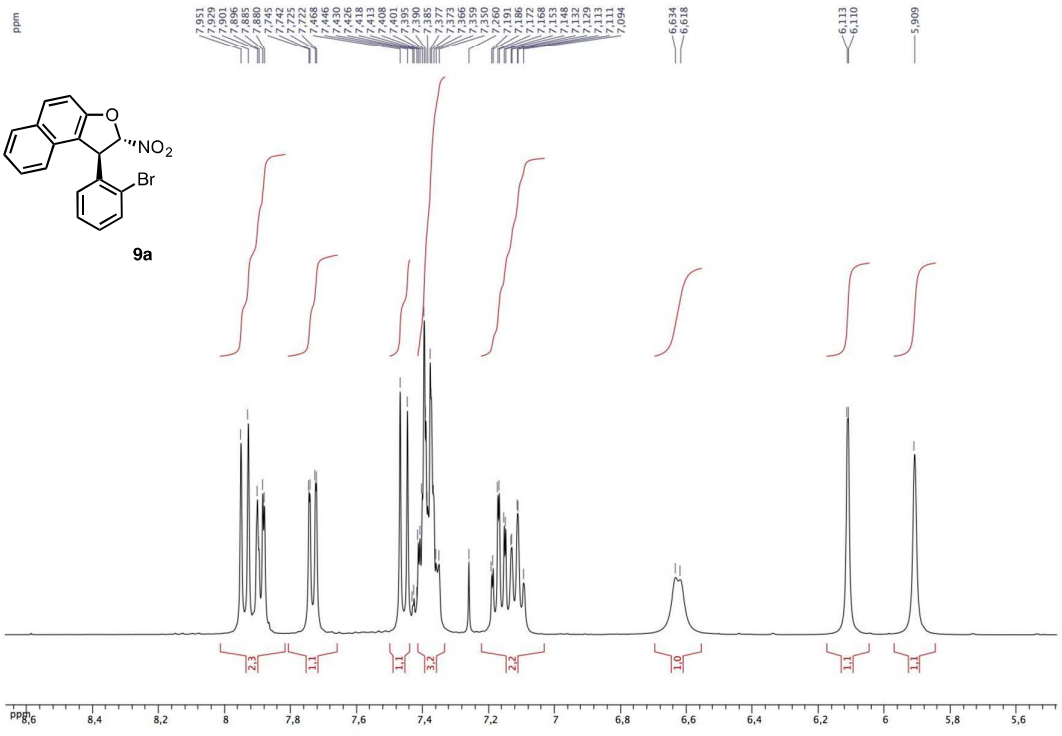

ppm
8,023
8,000
7,869
7,852
7,848
7,407
7,402
7,390
7,382
7,368
7,362
7,349
7,344
7,338
7,260
6,539
5,288
3,898
2,389
NO2
O
O
O
O
4c
1,0
1,0
3,9
0,9
0,1
3,0
2,9
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5

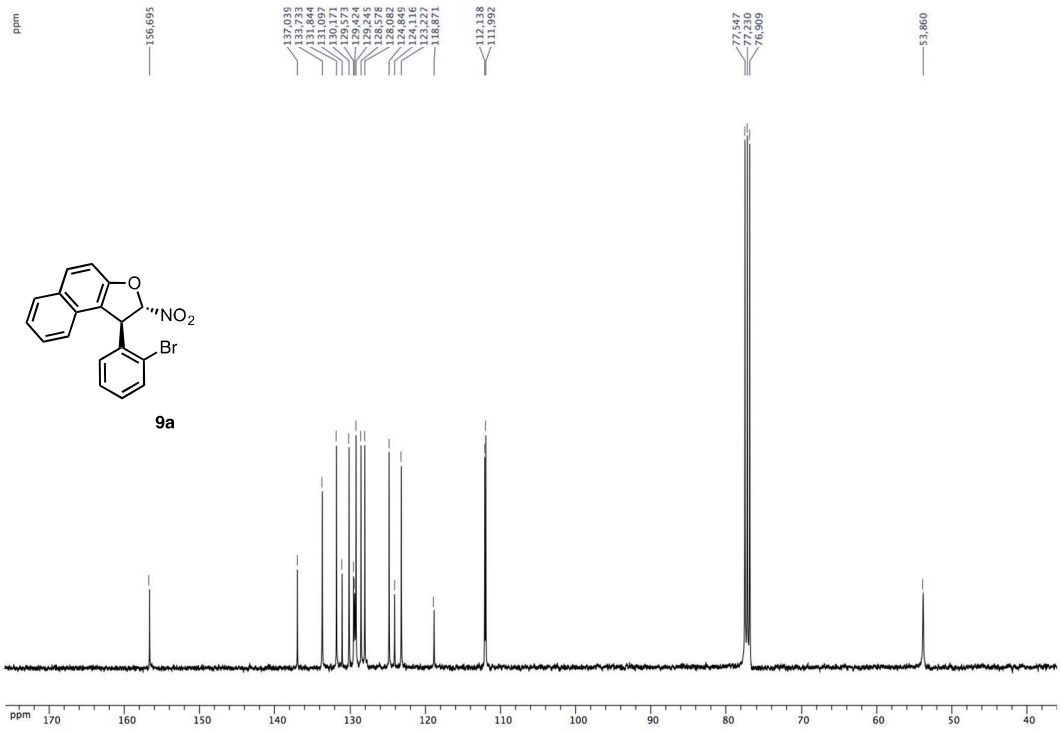

ppm
165,892
160,562
156,698
155,388
148,549
132,396
131,994
128,862
127,713
124,155
123,305
121,169
112,759
110,312
109,309
95,071
77,548
77,232
76,912
56,590
29,899
21,034
NO2
O
O
O
O
4c
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

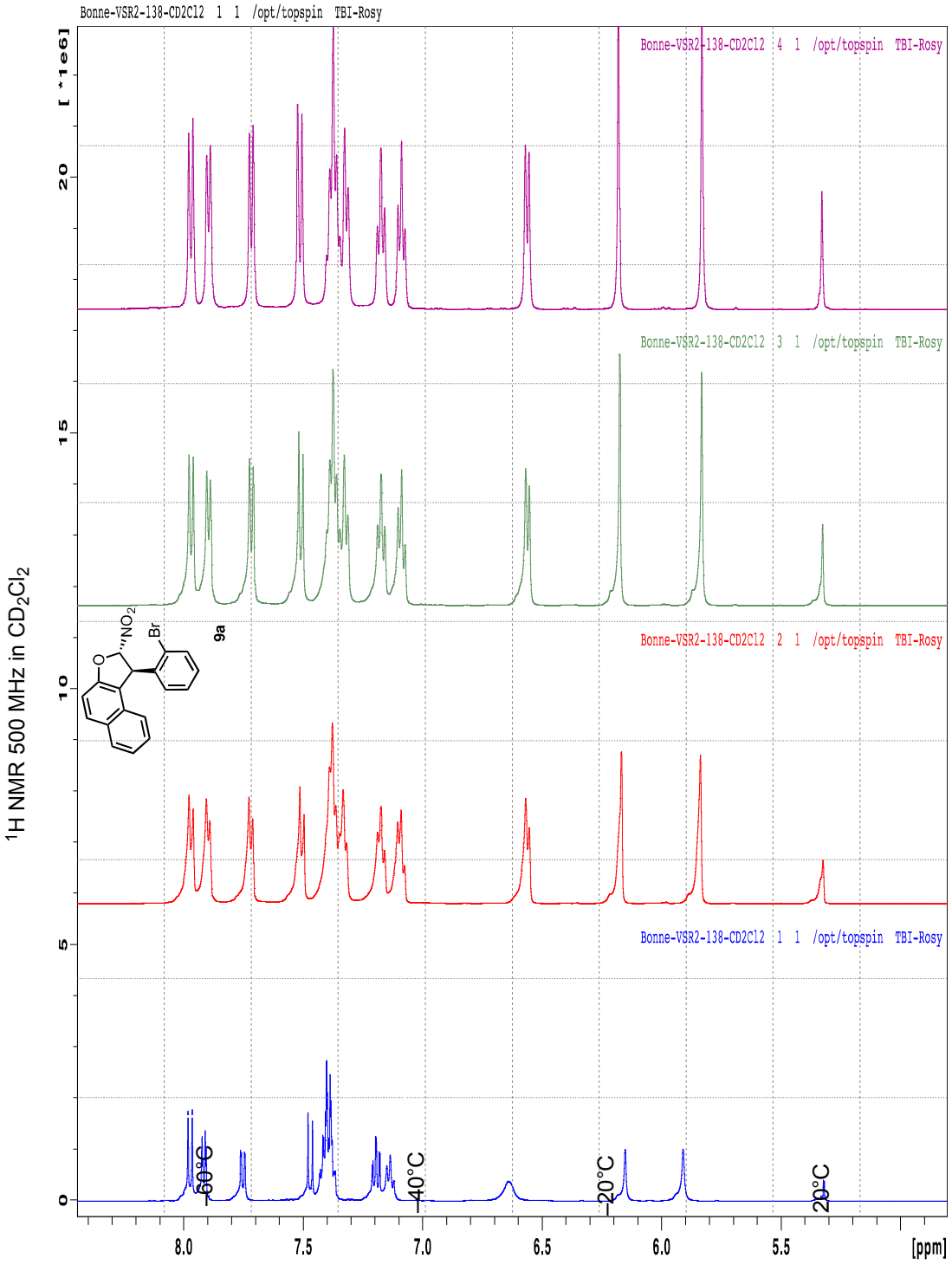

ppm
8.157
8.154
8.138
8.134
8.105
8.082
7.945
7.940
7.932
7.926
7.923
7.919
7.748
7.744
7.729
7.709
7.705
7.534
7.515
7.512
7.507
7.495
7.493
7.486
7.468
7.446
7.437
7.427
7.422
7.420
7.406
5.322
5.320
3.902
NO2
O
O
O
4d
0.9
1.0
1.1
1.1
6.1
0.7
3.0
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3

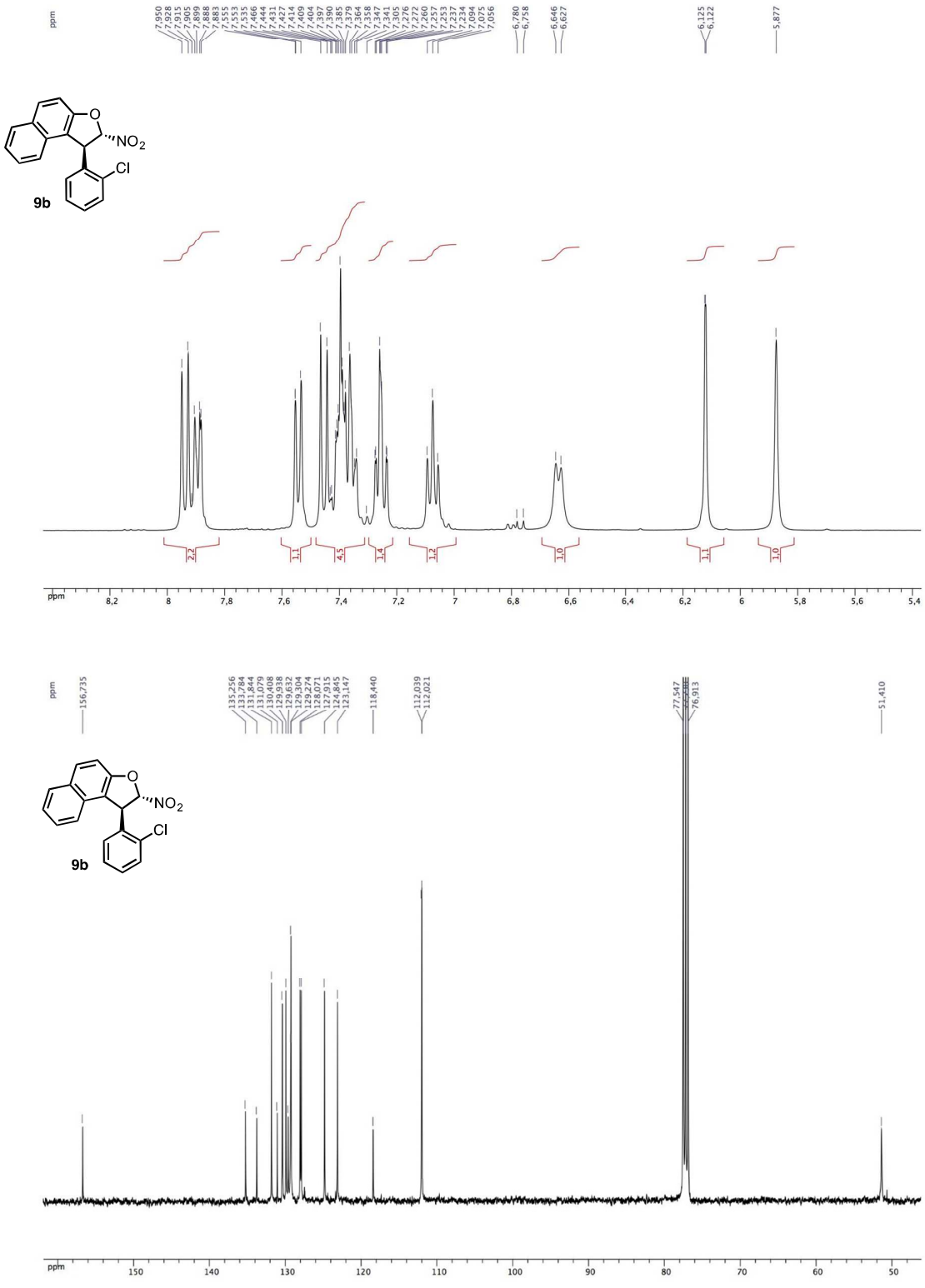

ppm
142,682
141,403
141,261
140,399
135,482
119,705
118,166
117,913
114,735
114,672
113,609
111,380
110,109
109,209
108,556
107,535
103,729
98,797
98,479
97,200
95,247
42,470
40,050
39,782
39,238
38,226
38,070
NO2
O
O
O
4d
ppm
150
140
130
120
110
100
90
80
70
60
50
40
30

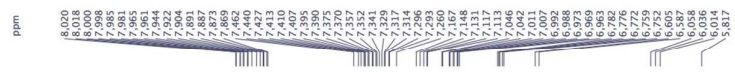

MeN
O
NO2
O
O
4e

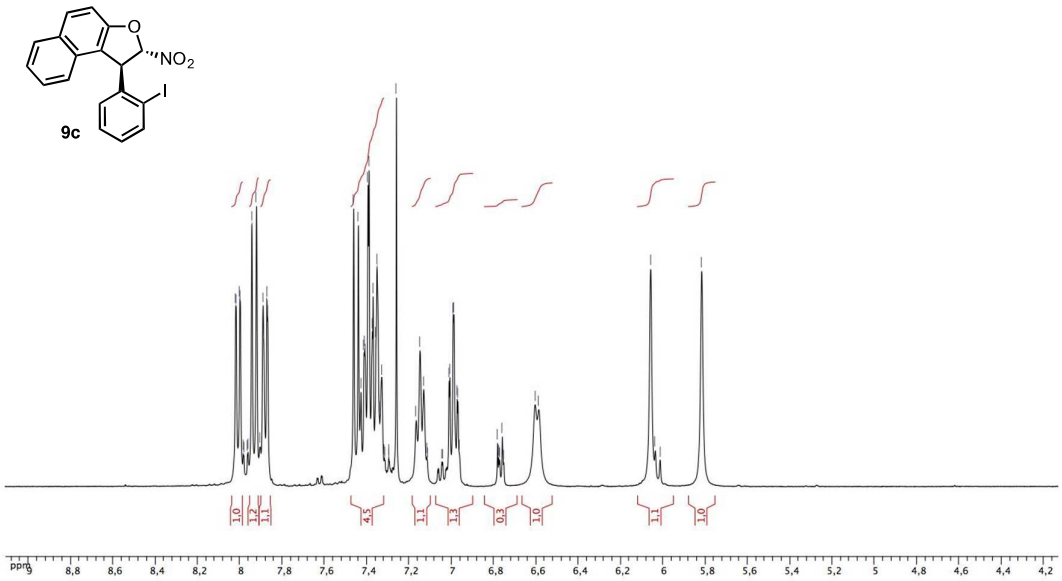

O
NO2
Br
9a

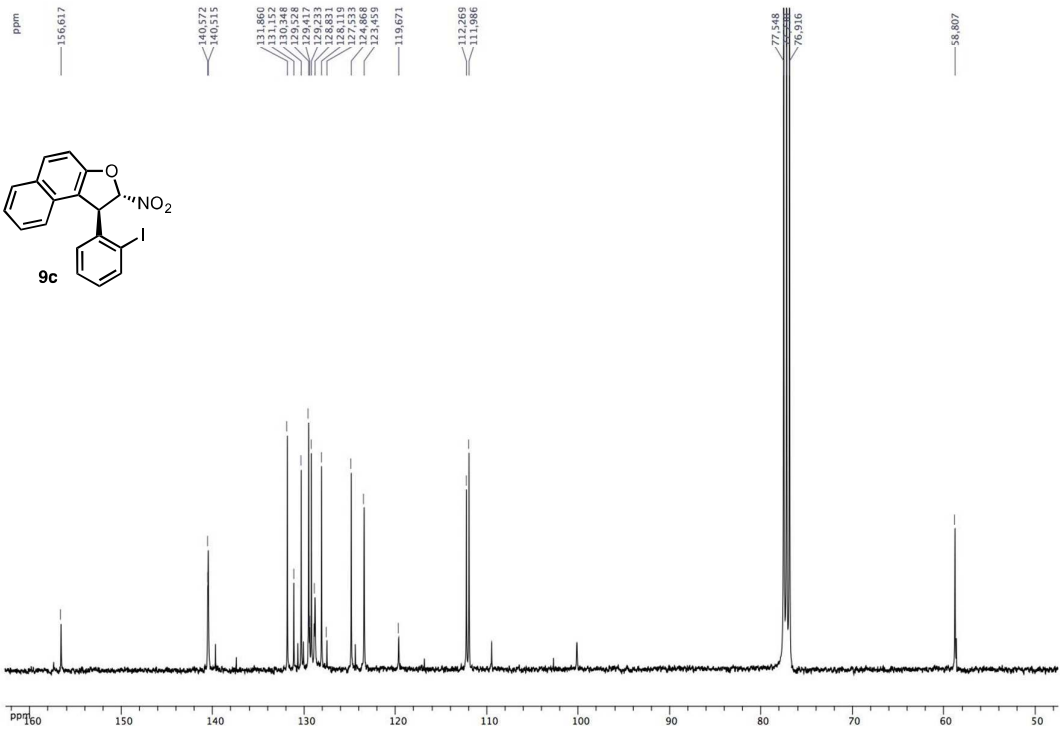

ppm
156,695
137,039
133,733
131,844
131,097
130,171
129,573
129,424
129,245
128,578
128,082
124,845
124,116
123,227
118,871
112,138
111,992
77,547
77,230
76,909
53,860
O
NO2
Br
9a
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40

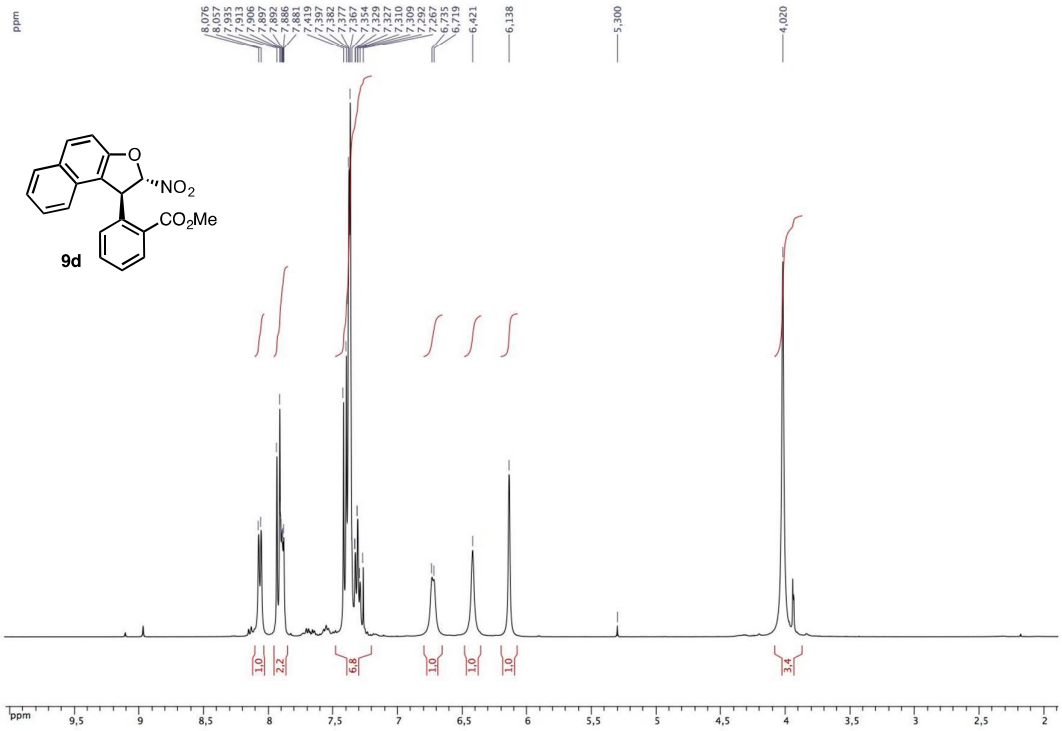

Bonne-VSR2-138-CD2Cl2 1 1 /opt/topspin TBI-Rosy
Bonne-VSR2-138-CD2Cl2 4 1 /opt/topspin TBI-Rosy
Bonne-VSR2-138-CD2Cl2 3 1 /opt/topspin TBI-Rosy
Bonne-VSR2-138-CD2Cl2 2 1 /opt/topspin TBI-Rosy
Bonne-VSR2-138-CD2Cl2 1 1 /opt/topspin TBI-Rosy
[ *1e6]
20
15
10
5
0
$^1$H NMR 500 MHz in $CD_2Cl_2$
$NO_2$
Br
9a
60°C
40°C
20°C
20°C
8.0
7.5
7.0
6.5
6.0
5.5
[ppm]

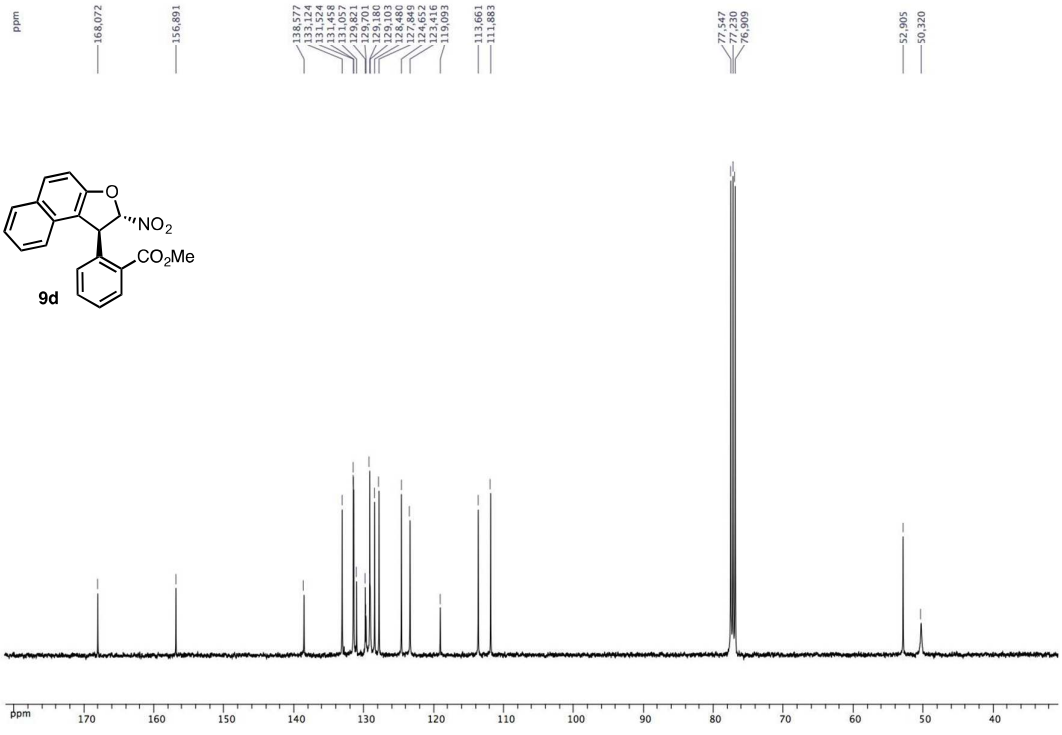

9b
9b

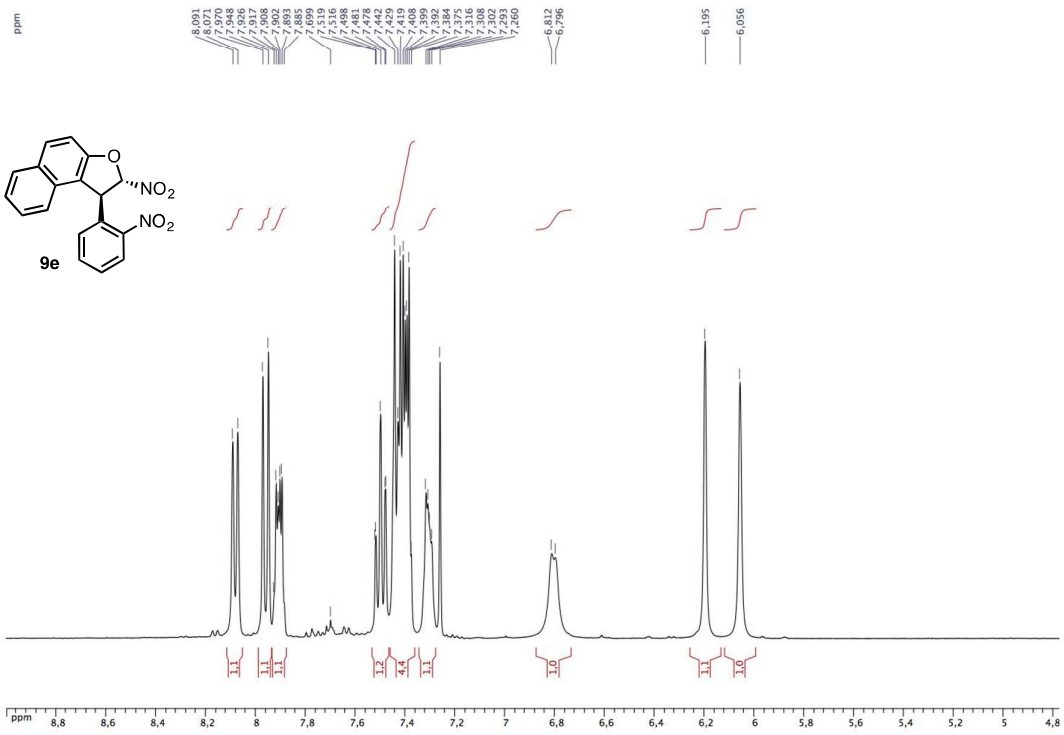

ppm
8.020
8.018
8.000
7.998
7.985
7.981
7.965
7.961
7.944
7.922
7.904
7.891
7.887
7.873
7.869
7.462
7.460
7.427
7.413
7.410
7.407
7.395
7.390
7.375
7.370
7.357
7.352
7.341
7.329
7.317
7.314
7.296
7.293
7.260
7.167
7.148
7.131
7.117
7.113
7.046
7.042
7.011
7.007
6.992
6.988
6.973
6.969
6.963
6.782
6.776
6.772
6.759
6.752
6.665
6.587
6.058
6.036
6.014
5.817

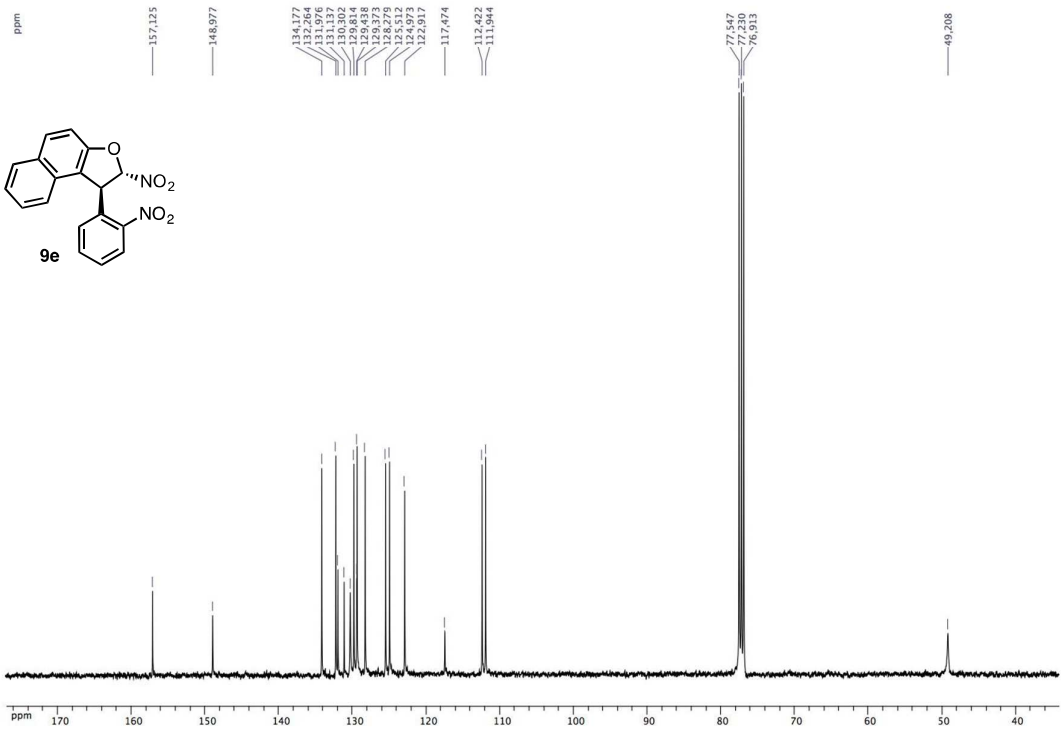

O
NO2
I
9c
1.0
1.2
1.1
4.5
1.1
1.3
0.3
1.0
1.1
1.0
ppm
9
8,8
8,6
8,4
8,2
8
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6
5,8
5,6
5,4
5,2
5
4,8
4,6
4,4
4,2

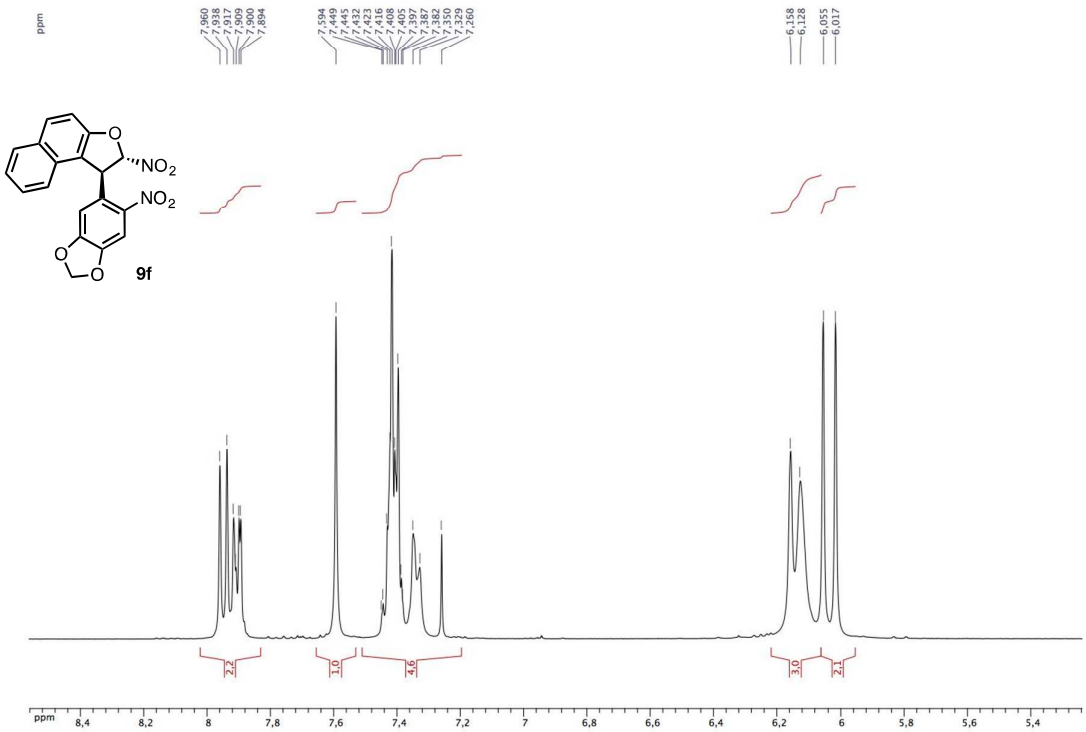

ppm
156,617
140,572
140,515
131,860
131,152
130,348
129,528
129,417
128,233
128,831
128,119
127,533
124,868
123,459
119,671
112,269
111,986
77,548
77,232
76,916
58,807
O
NO2
I
9c
160
150
140
130
120
110
100
90
80
70
60
50

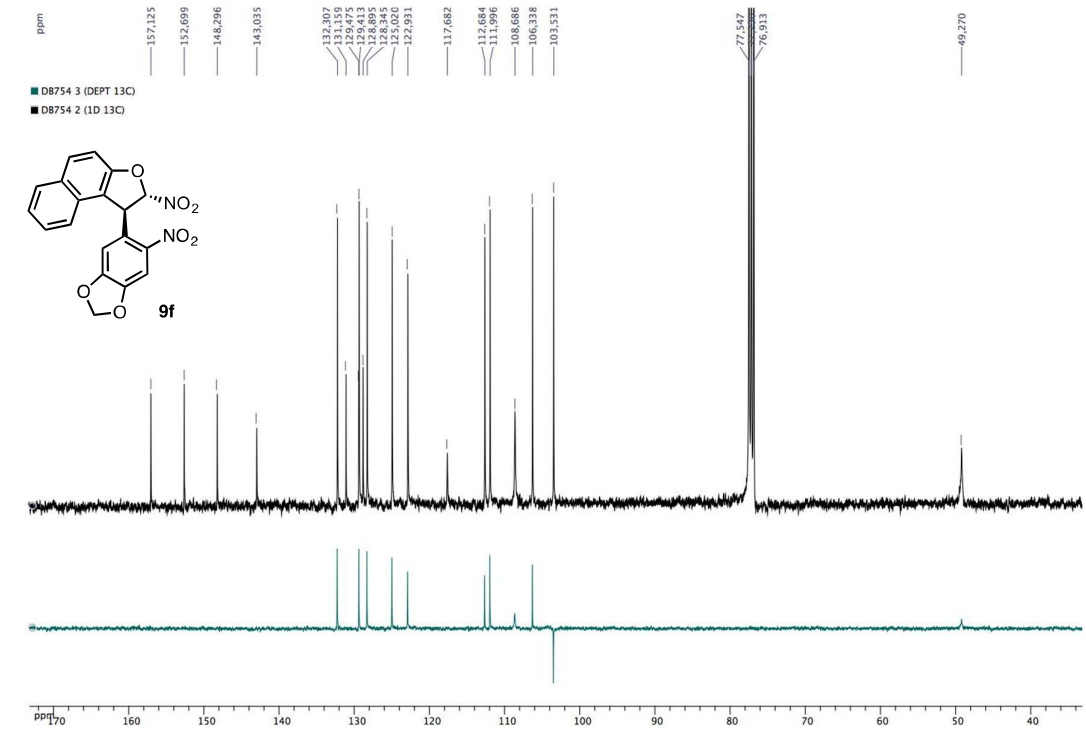

ppm
8,076
8,057
7,935
7,913
7,906
7,897
7,892
7,886
7,881
7,419
7,397
7,382
7,377
7,367
7,354
7,329
7,327
7,310
7,309
7,292
7,267
6,735
6,719
6,421
6,138
5,300
4,020
O
NO2
CO2Me
9d
1,0
2,2
6,8
1,0
1,0
1,0
3,4
ppm
9,5
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2

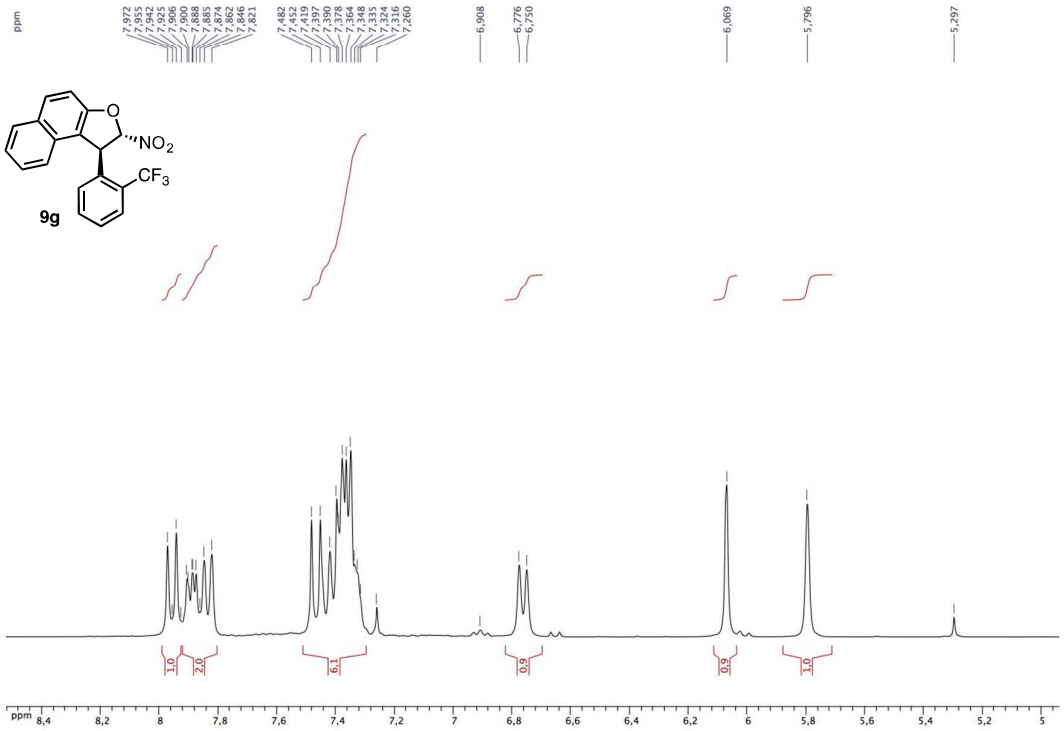

ppm
168,072
156,891
138,577
133,124
132,574
131,458
131,057
129,821
129,701
129,180
129,133
128,480
127,849
124,652
123,416
119,093
113,661
111,883
77,547
77,230
76,909
52,905
50,320
O
NO2
CO2Me
9d
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40

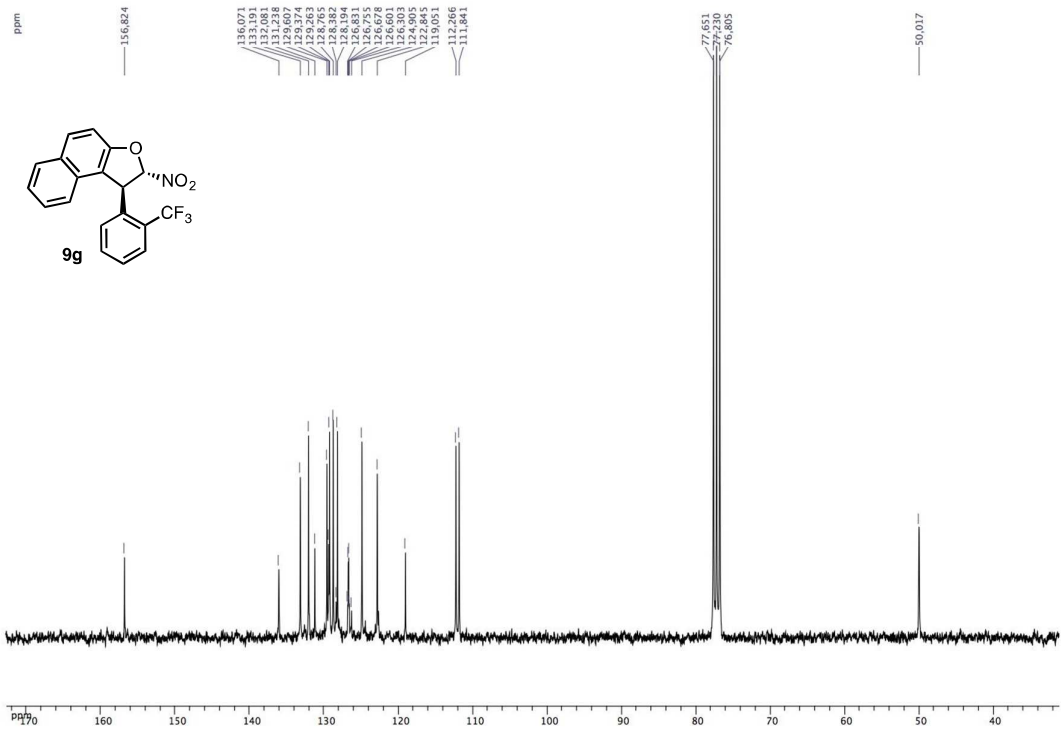

ppm
8,091
8,077
7,970
7,948
7,926
7,917
7,908
7,902
7,893
7,885
7,699
7,519
7,516
7,498
7,481
7,478
7,442
7,420
7,419
7,408
7,399
7,392
7,384
7,375
7,316
7,308
7,302
7,293
7,260
6,812
6,796
6,195
6,056
O
NO2
NO2
9e
1,1
1,1
1,1
1,2
4,4
1,1
1,0
1,1
1,0
ppm
8,8
8,6
8,4
8,2
8
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6
5,8
5,6
5,4
5,2
5
4,8

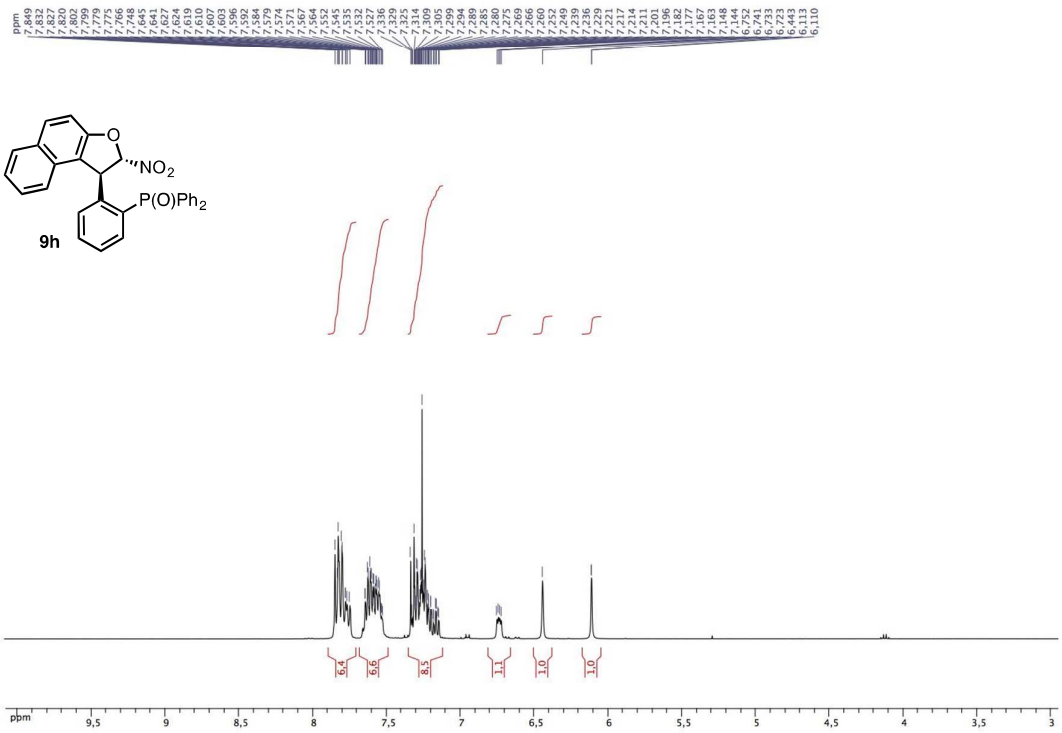

ppm
157,125
148,977
134,177
132,264
131,976
131,137
130,302
129,814
129,438
128,373
128,279
125,512
124,973
122,917
117,474
112,422
111,944
77,547
77,230
76,913
49,208
O
NO2
NO2
9e
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40

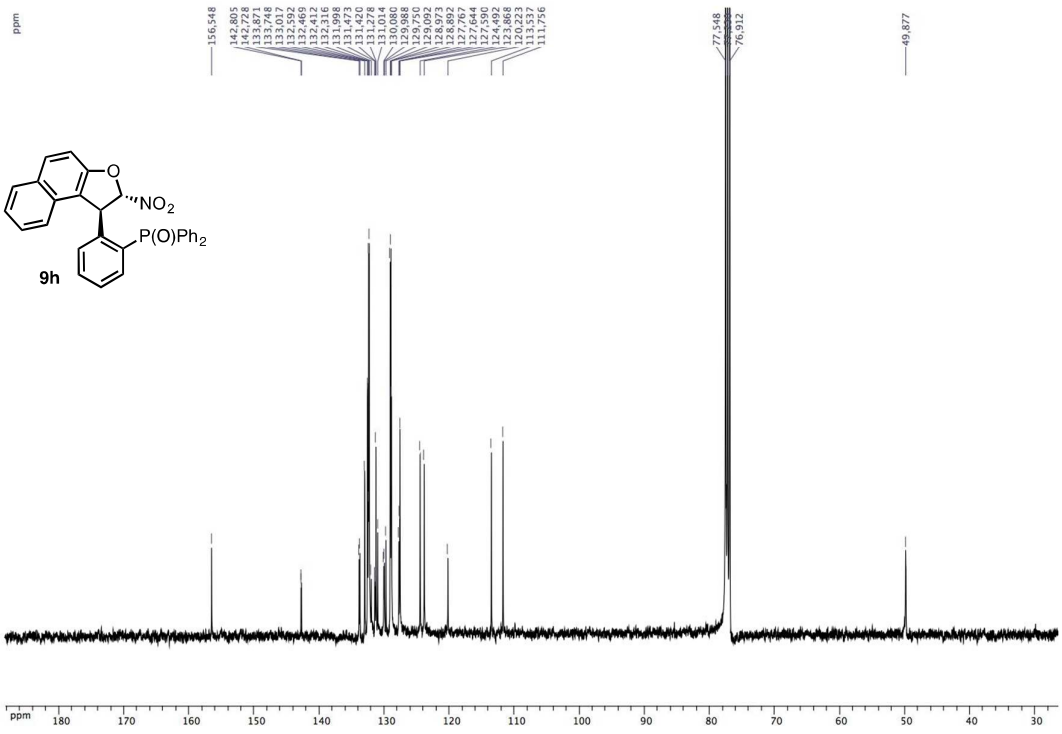

ppm
7,960
7,938
7,917
7,909
7,900
7,894
7,594
7,449
7,445
7,432
7,423
7,416
7,408
7,405
7,397
7,387
7,382
7,350
7,329
7,260
6,158
6,128
6,055
6,017
NO2
NO2
O
O
O
9f
2,2
1,0
4,6
3,0
2,1
8,4
8,2
8
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6
5,8
5,6
5,4

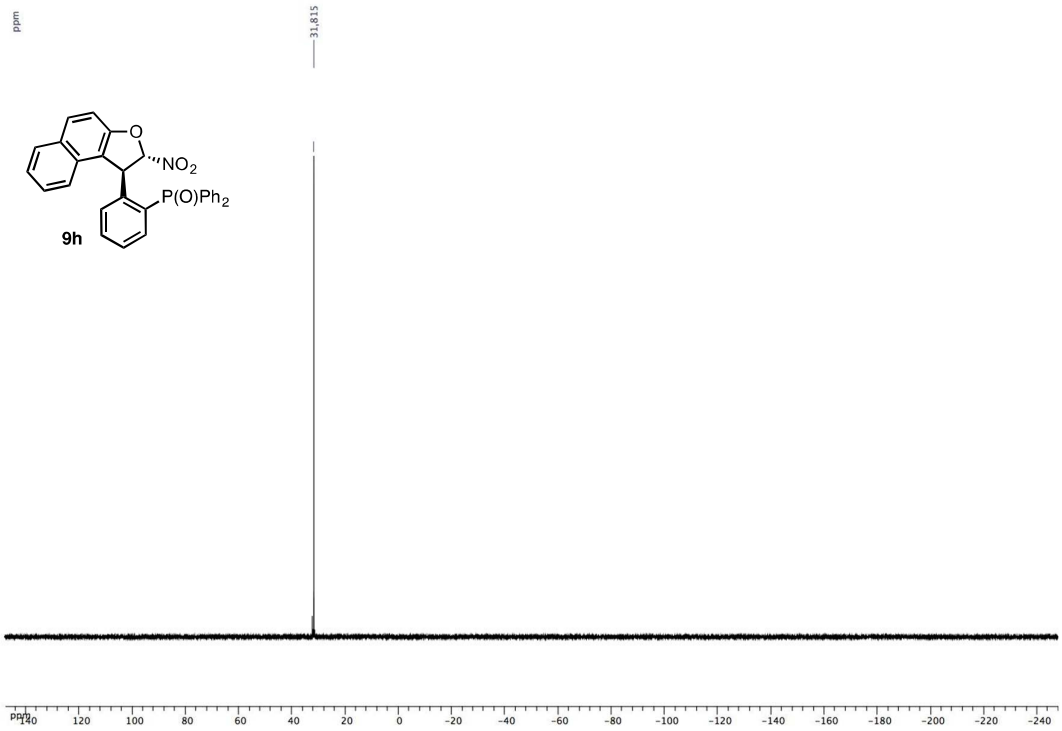

ppm
157,125
152,699
148,296
143,035
132,307
131,159
129,475
129,413
128,895
128,355
125,020
122,931
117,682
112,684
111,996
108,686
106,338
103,531
77,547
76,913
49,270
D8754 3 (DEPT 13C)
D8754 2 (1D 13C)
NO2
NO2
O
O
O
9f
170
160
150
140
130
120
110
100
90
80
70
60
50
40

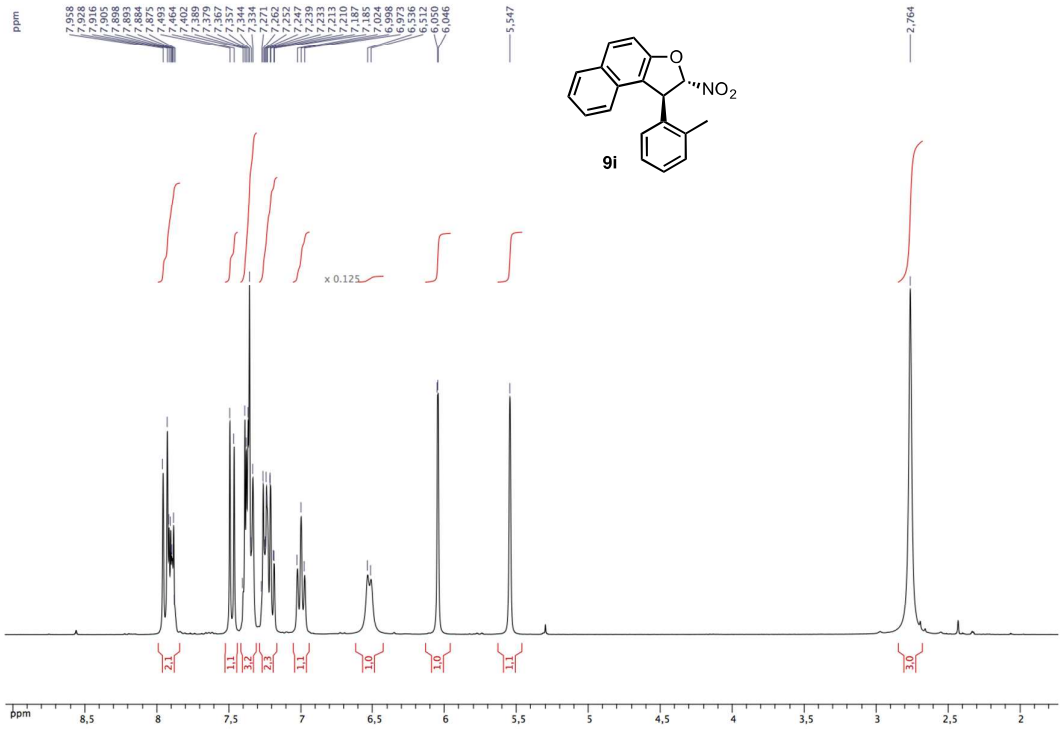

ppm
7,972
7,955
7,942
7,925
7,906
7,900
7,888
7,885
7,874
7,862
7,846
7,821
7,482
7,452
7,419
7,397
7,390
7,378
7,364
7,348
7,335
7,324
7,316
7,260
6,908
6,776
6,750
6,069
5,796
5,297
O
NO2
CF3
9g
1,0
2,0
6,1
0,9
0,9
1,0
ppm 8,4 8,2 8 7,8 7,6 7,4 7,2 7 6,8 6,6 6,4 6,2 6 5,8 5,6 5,4 5,2 5

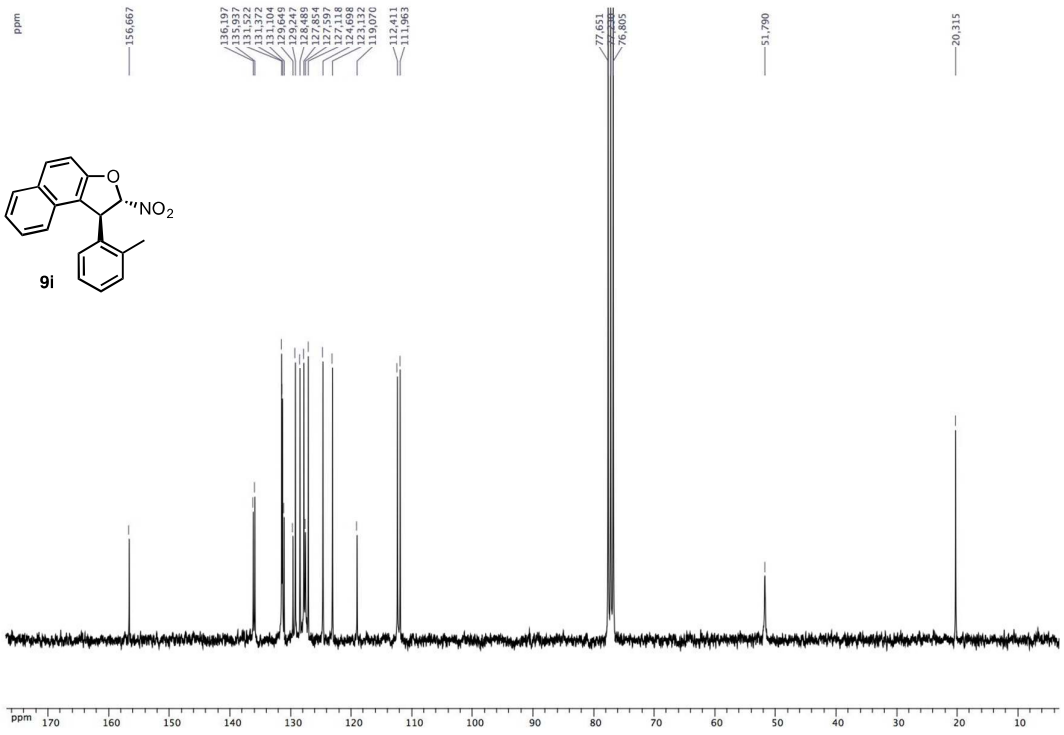

ppm
156,824
136,071
133,191
132,988
131,238
129,607
129,374
129,263
128,765
128,382
128,194
126,831
126,755
126,678
126,601
126,303
124,905
122,845
119,051
112,266
111,841
77,651
77,230
76,805
50,017
O
NO2
CF3
9g
ppm 170 160 150 140 130 120 110 100 90 80 70 60 50 40

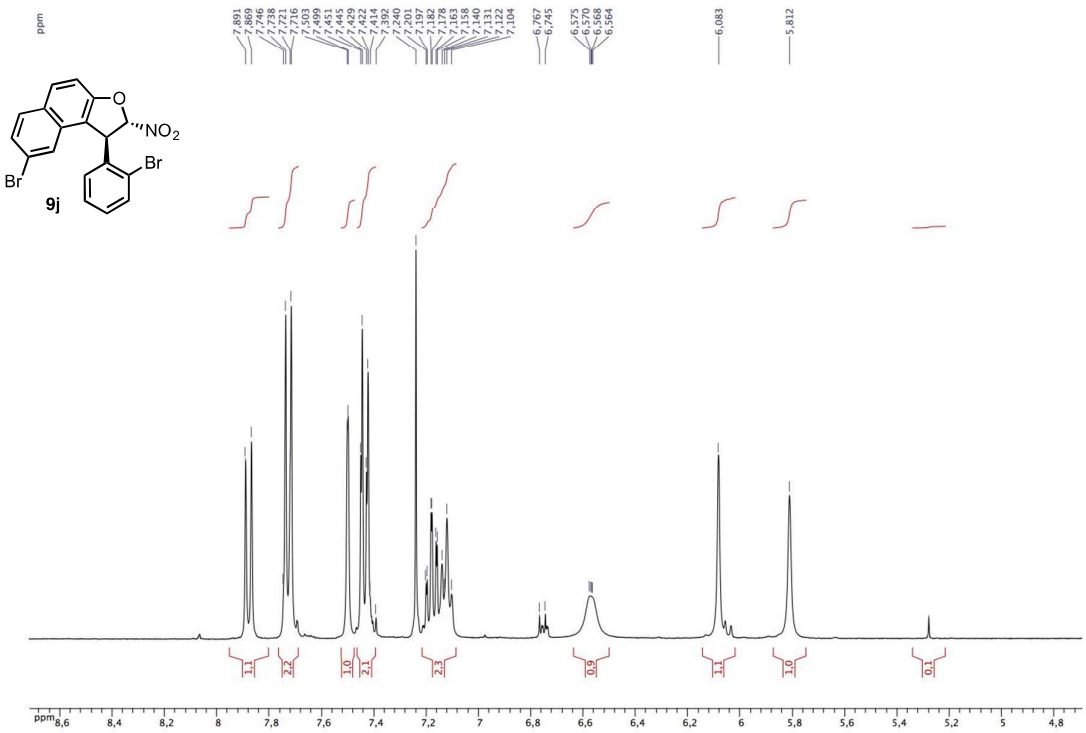

ppm
7,849
7,832
7,822
7,820
7,802
7,799
7,779
7,775
7,766
7,748
7,645
7,641
7,627
7,624
7,619
7,610
7,607
7,603
7,596
7,592
7,584
7,579
7,574
7,571
7,567
7,564
7,552
7,545
7,535
7,532
7,527
7,336
7,329
7,325
7,314
7,309
7,305
7,299
7,294
7,289
7,285
7,280
7,275
7,269
7,266
7,260
7,252
7,249
7,239
7,236
7,229
7,221
7,217
7,214
7,211
7,201
7,196
7,182
7,177
7,167
7,163
7,148
7,144
6,752
6,741
6,733
6,723
6,443
6,113
6,110
O
NO2
P(O)Ph2
9h
6,4
6,6
8,5
1,1
1,0
1,0
ppm
9,5
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3

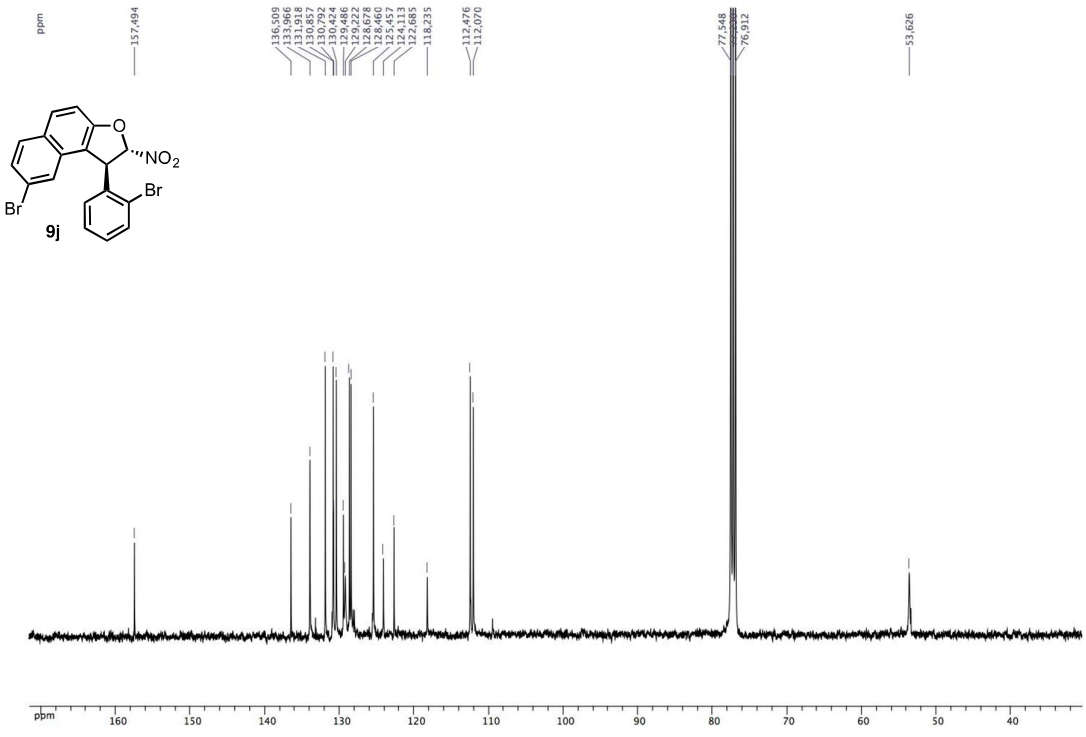

ppm
156,548
142,805
142,728
133,871
133,748
133,017
132,592
132,465
132,412
132,316
131,998
131,473
131,420
131,278
131,014
130,080
129,988
129,755
129,092
128,973
128,892
127,767
127,644
127,590
124,492
123,868
120,223
113,537
111,756
77,548
77,232
76,912
49,877
O
NO2
P(O)Ph2
9h
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30

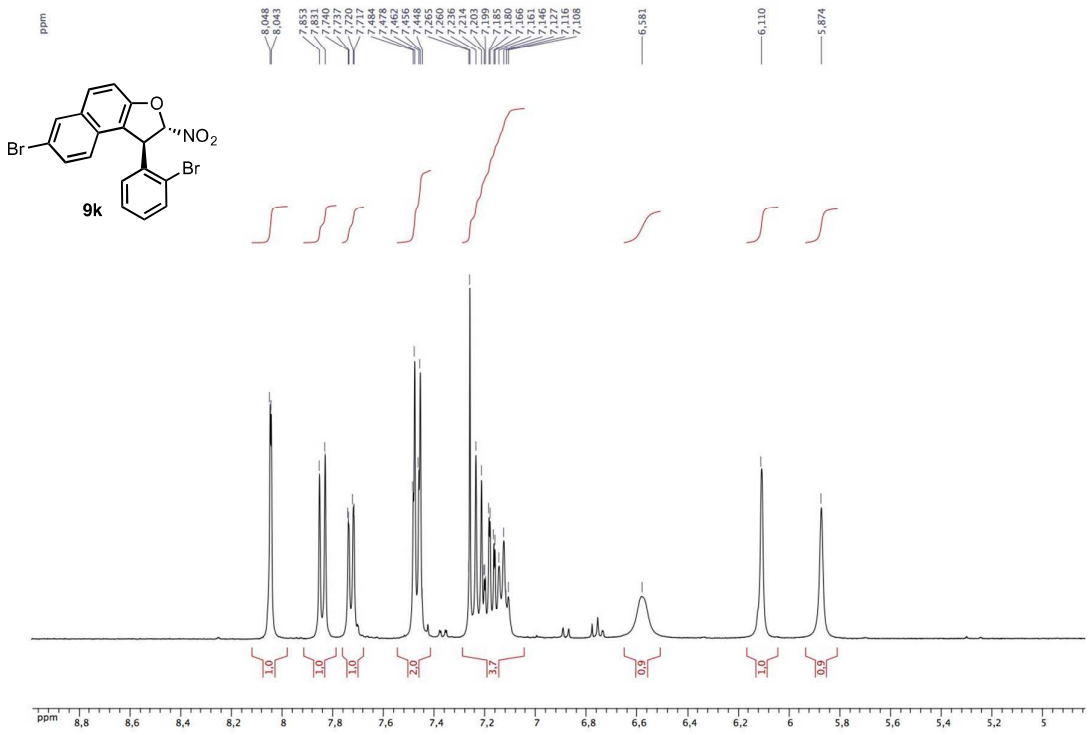

ppm
31,815
O
NO2
P(O)Ph2
9h
ppm
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240

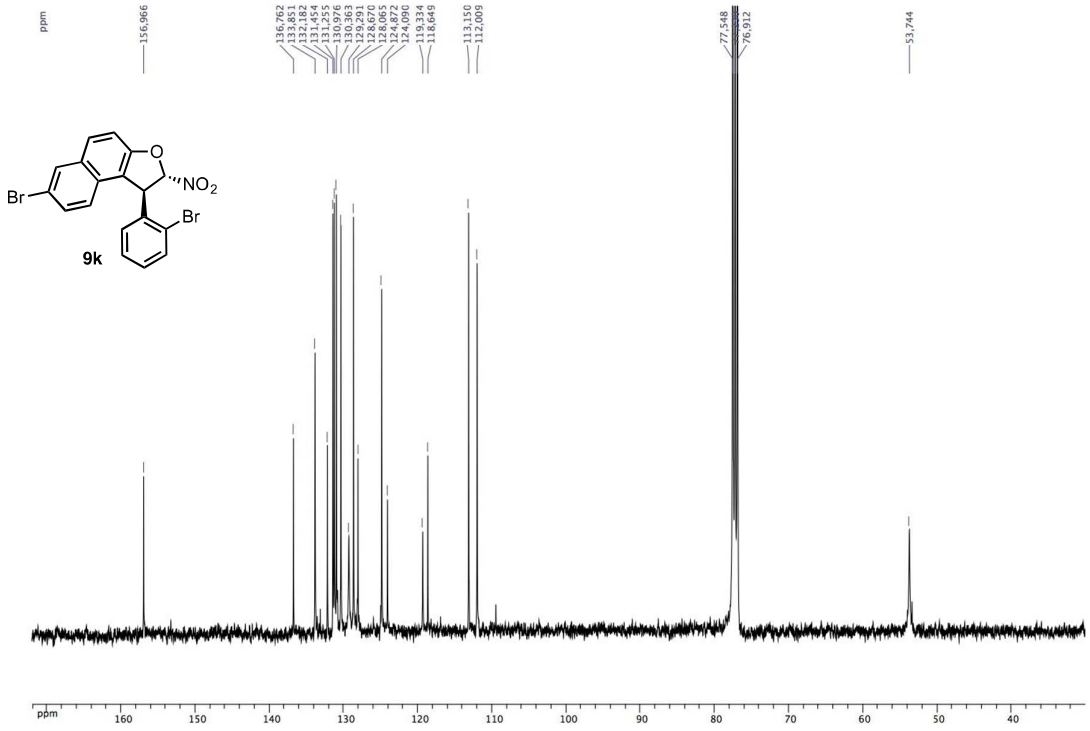

ppm
7,958
7,938
7,916
7,905
7,898
7,893
7,884
7,875
7,493
7,464
7,402
7,389
7,379
7,367
7,357
7,344
7,334
7,271
7,262
7,252
7,247
7,239
7,233
7,213
7,210
7,187
7,185
7,024
6,998
6,973
6,536
6,512
6,050
6,046
5,547
2,764
O
NO2
9i
x 0.125
2,1
1,1
3,2
2,3
1,1
1,0
1,0
1,1
3,0
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2

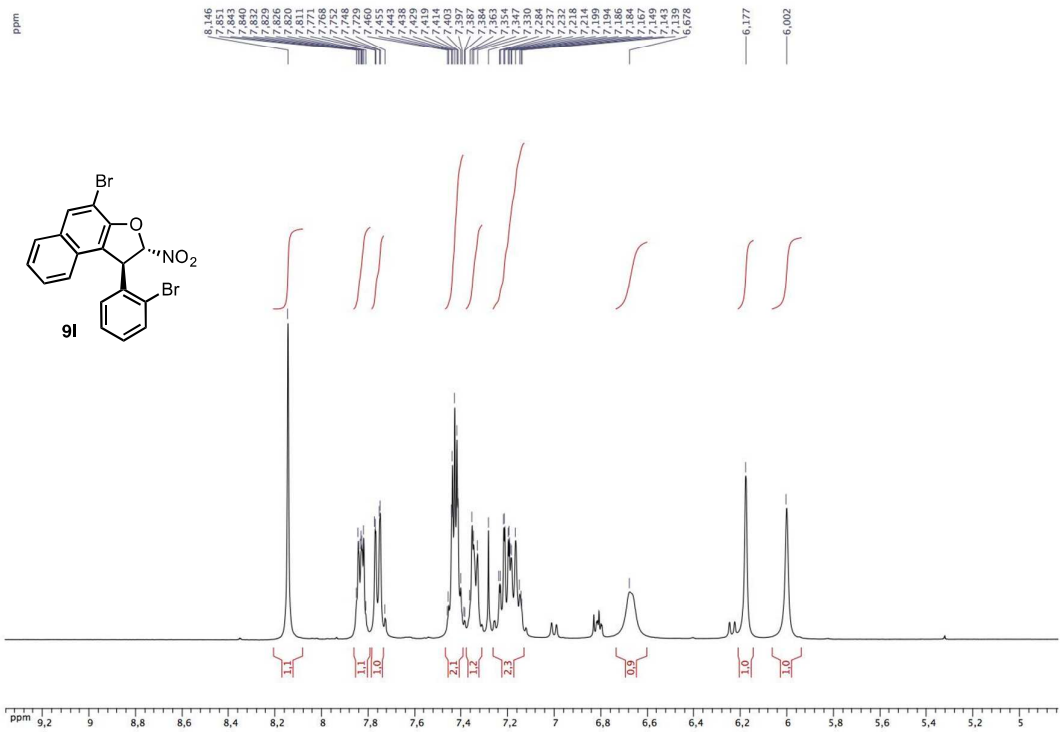

ppm
156,667
136,197
131,522
131,372
131,104
129,649
128,487
127,854
127,597
127,118
124,698
123,172
119,070
112,411
111,963
77,651
76,805
51,790
20,315
O
NO2
9i
ppm 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10

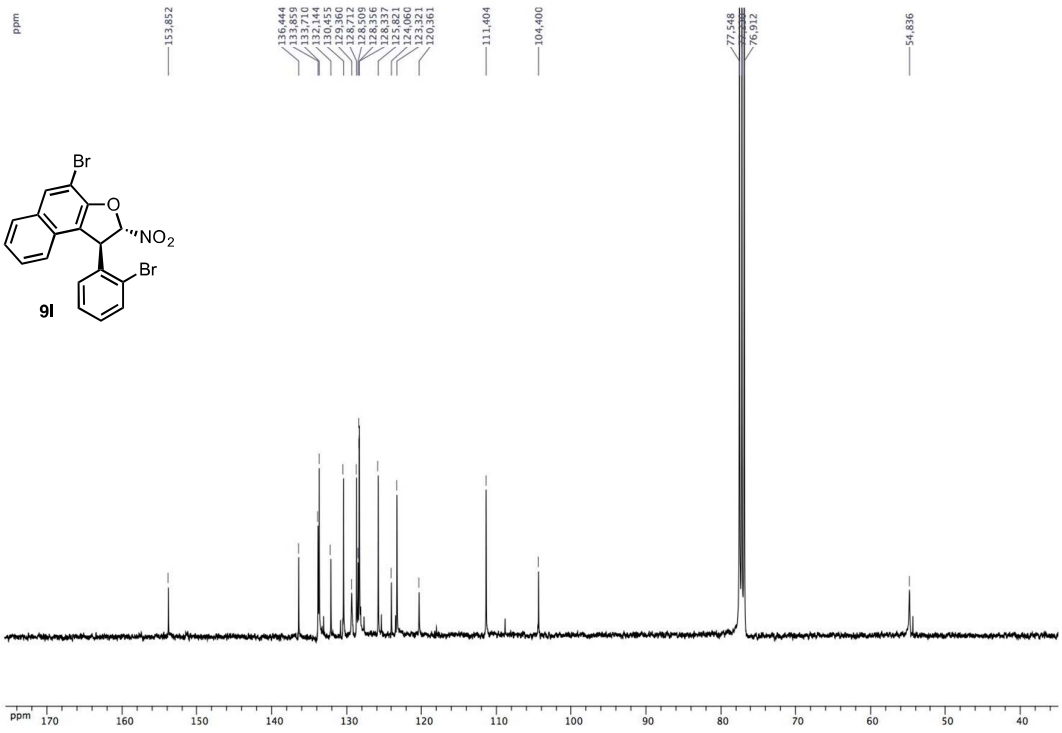

9j
Br
Br
NO2
O
ppm
7,891
7,869
7,746
7,728
7,721
7,716
7,503
7,499
7,451
7,445
7,429
7,422
7,414
7,392
7,240
7,201
7,197
7,182
7,178
7,163
7,158
7,140
7,131
7,122
7,104
6,767
6,745
6,575
6,570
6,568
6,564
6,083
5,812
1,1
2,2
1,0
2,1
2,3
0,9
1,1
1,0
0,1
ppm
8,6
8,4
8,2
8
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6
5,8
5,6
5,4
5,2
5
4,8

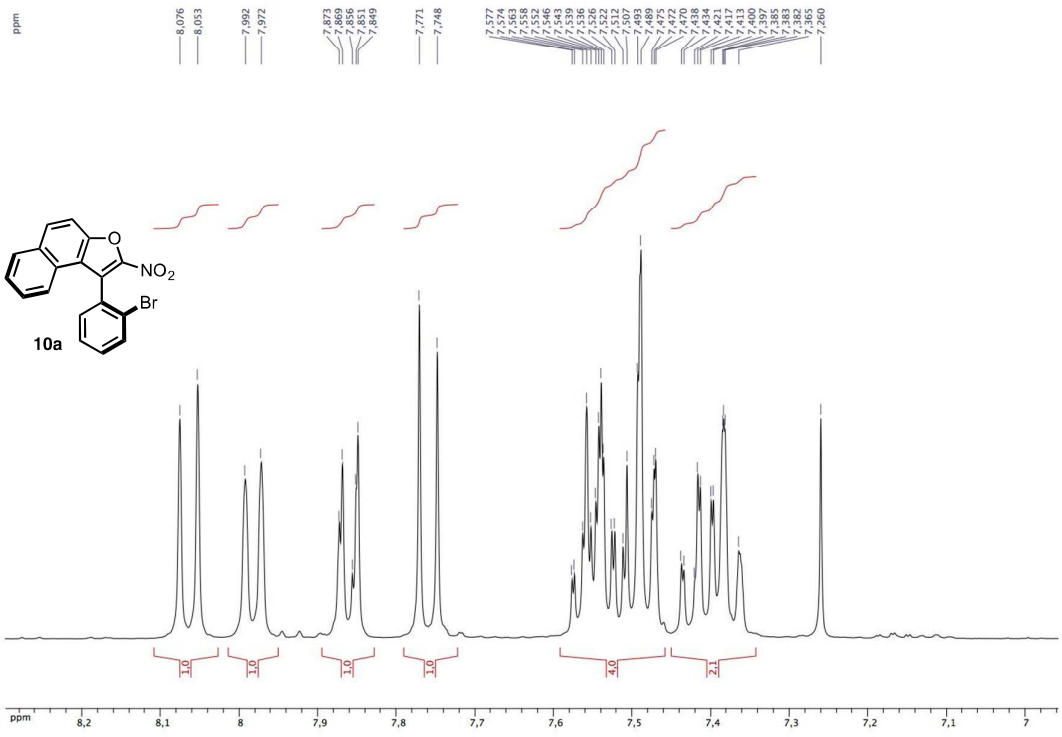

9j
Br
Br
NO2
O
ppm
157,494
136,509
135,466
131,918
130,857
130,792
130,424
129,486
128,772
128,678
128,460
125,457
124,113
122,685
118,235
112,476
112,070
77,548
77,232
76,912
53,626
ppm
160
150
140
130
120
110
100
90
80
70
60
50
40

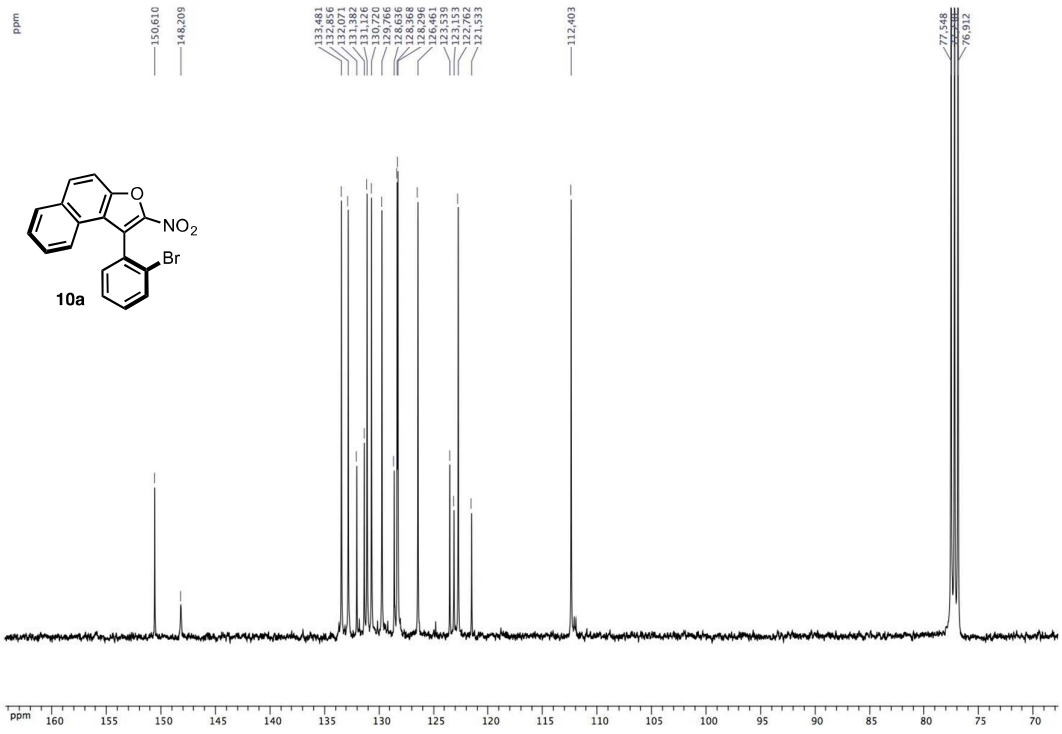

8,048
8,043
7,853
7,831
7,740
7,737
7,720
7,717
7,484
7,478
7,462
7,456
7,448
7,435
7,260
7,236
7,214
7,203
7,199
7,185
7,180
7,166
7,161
7,146
7,127
7,116
7,108
6,581
6,110
5,874
1,0
1,0
1,0
2,0
3,7
0,9
1,0
0,9
ppm
8,8
8,6
8,4
8,2
8
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6
5,8
5,6
5,4
5,2
5
Br
O
NO2
Br
9k

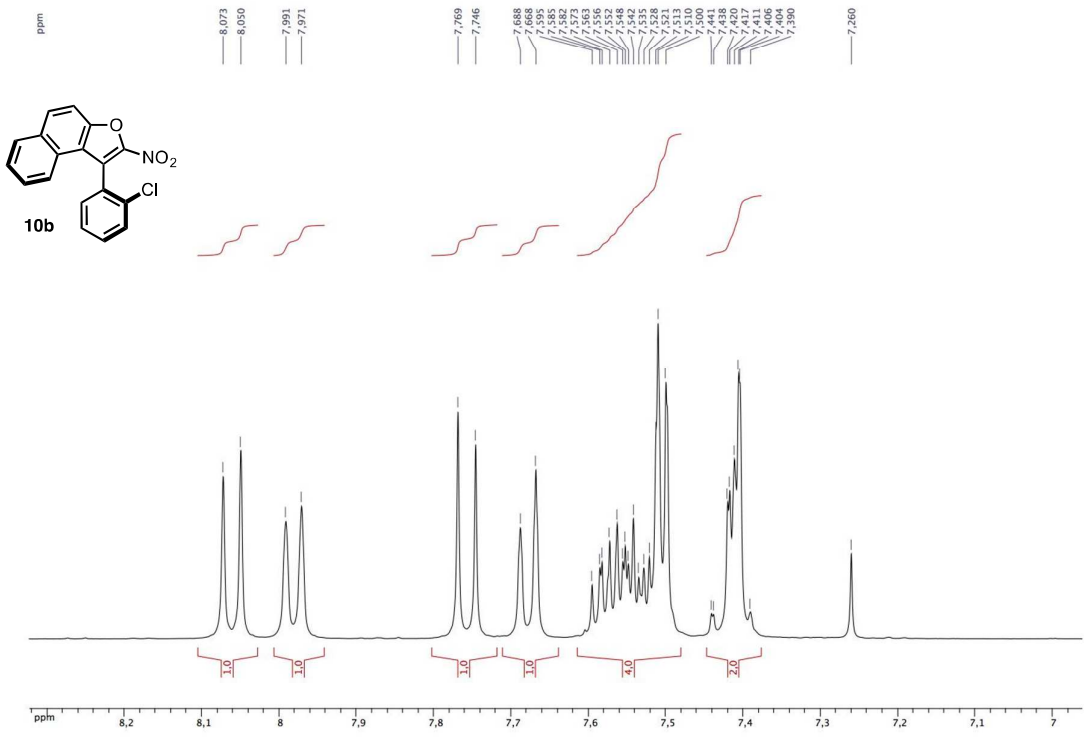

156,966
136,762
133,851
133,132
131,454
131,255
130,976
130,363
129,791
128,670
128,065
124,872
124,090
119,334
118,649
113,150
112,009
77,548
77,388
76,912
53,744
ppm
160
150
140
130
120
110
100
90
80
70
60
50
40
Br
O
NO2
Br
9k

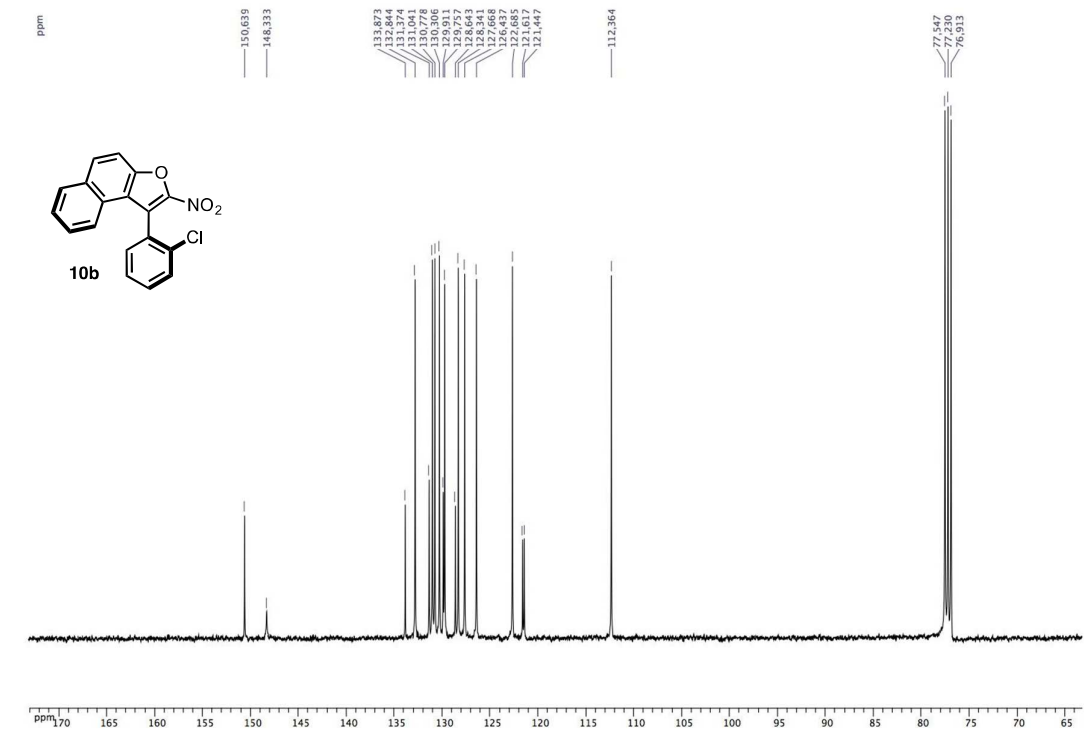

Br
O
NO2
Br
9l

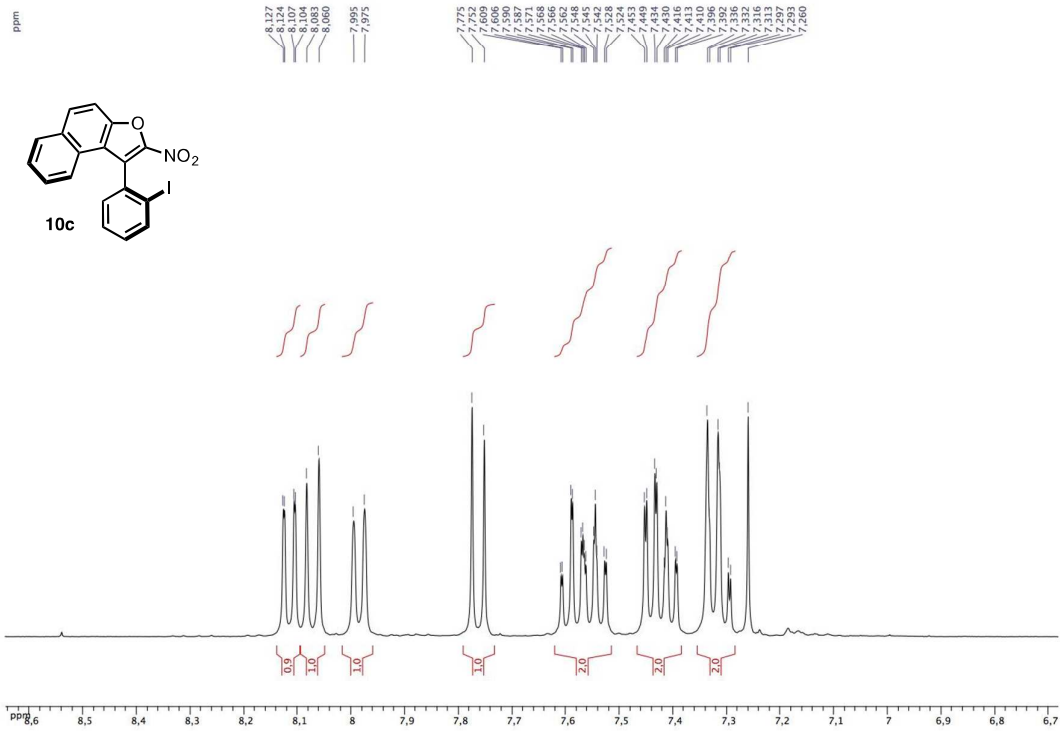

Br
O
NO2
Br
9l

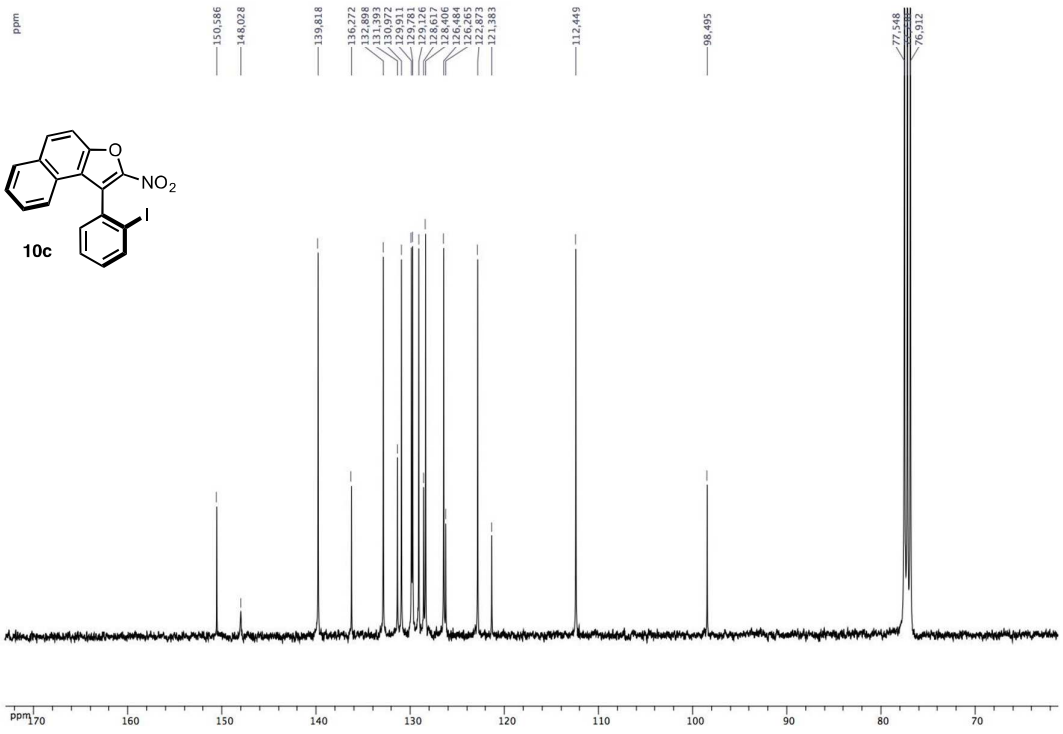

ppm
8,076
8,053
7,992
7,972
7,873
7,869
7,856
7,851
7,849
7,771
7,748
7,577
7,574
7,565
7,558
7,552
7,546
7,543
7,539
7,536
7,526
7,522
7,512
7,507
7,493
7,489
7,475
7,472
7,470
7,438
7,434
7,421
7,417
7,413
7,409
7,397
7,385
7,383
7,382
7,365
7,260
O
NO2
Br
10a
1,0
1,0
1,0
1,0
4,0
2,1
ppm
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1
7

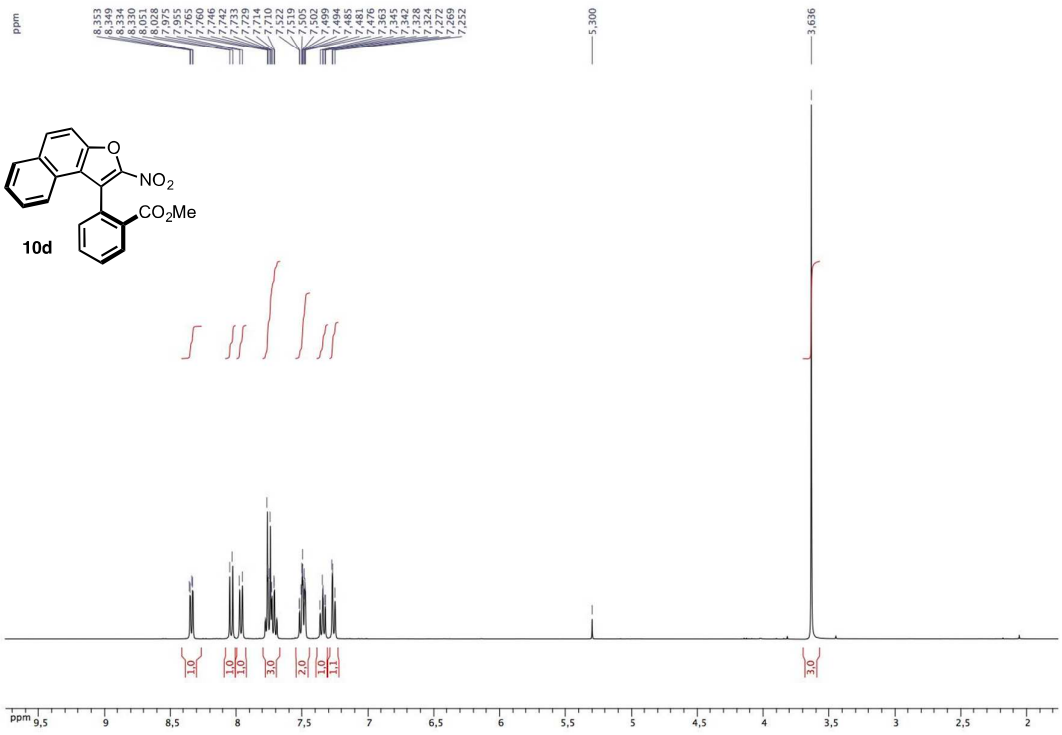

ppm
150,610
148,209
133,481
132,856
132,071
131,382
131,126
130,770
129,766
128,636
128,368
128,296
126,461
123,538
123,153
122,762
121,533
112,403
77,548
77,386
76,912
O
NO2
Br
10a
ppm
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70

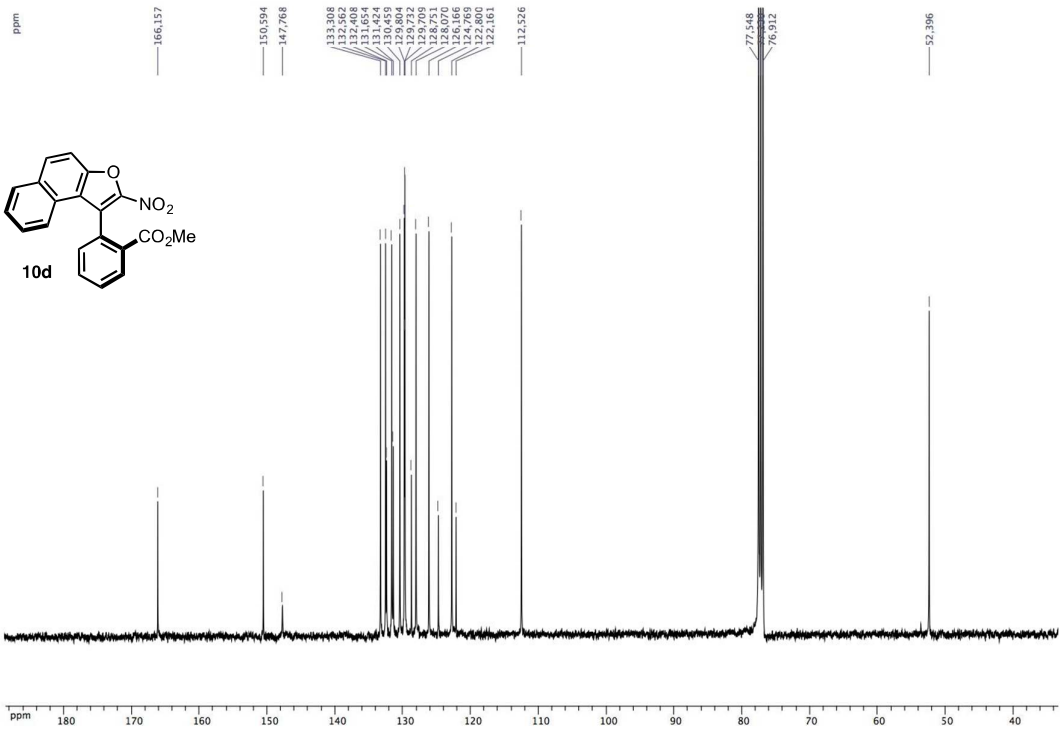

ppm
8.073
8.050
7.991
7.971
7.769
7.746
7.688
7.668
7.595
7.585
7.582
7.573
7.563
7.556
7.552
7.548
7.542
7.535
7.528
7.521
7.511
7.510
7.500
7.441
7.438
7.420
7.417
7.411
7.406
7.404
7.390
7.260
O
NO2
Cl
10b
1.0
1.0
1.0
1.0
4.0
2.0
ppm
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1
7

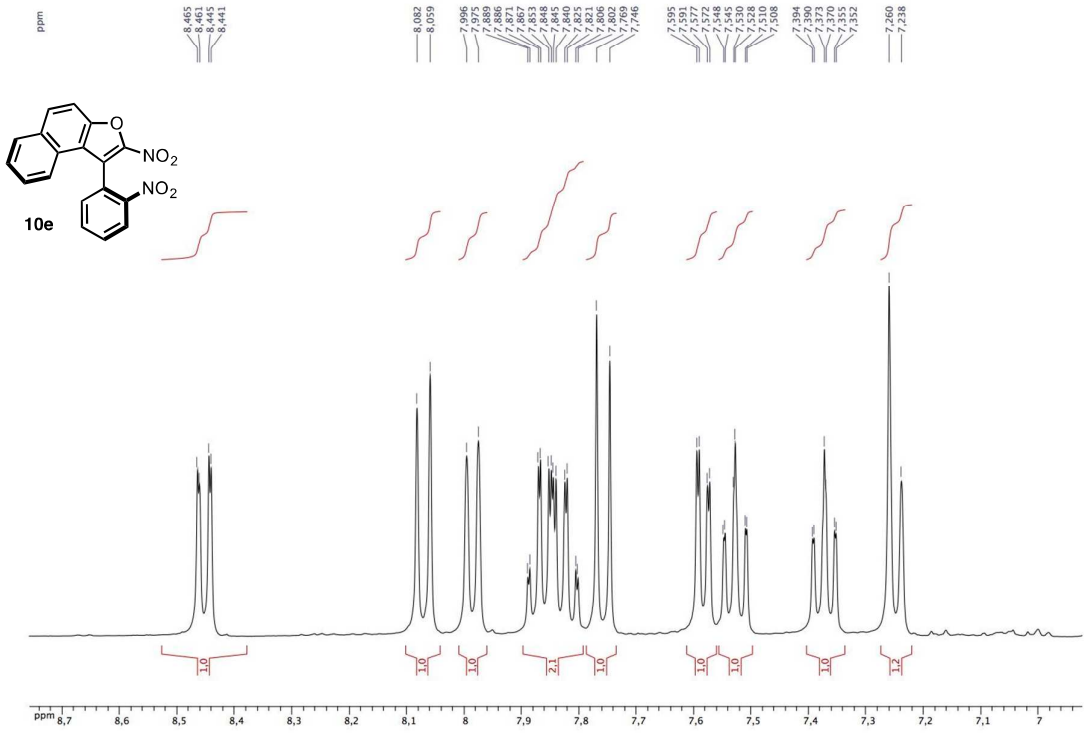

ppm
150,639
148,333
133,873
132,844
131,374
131,141
130,778
130,306
129,911
129,757
128,643
128,341
127,668
126,437
122,685
121,617
121,447
112,364
77,547
77,230
76,913
O
NO2
Cl
10b
ppm
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65

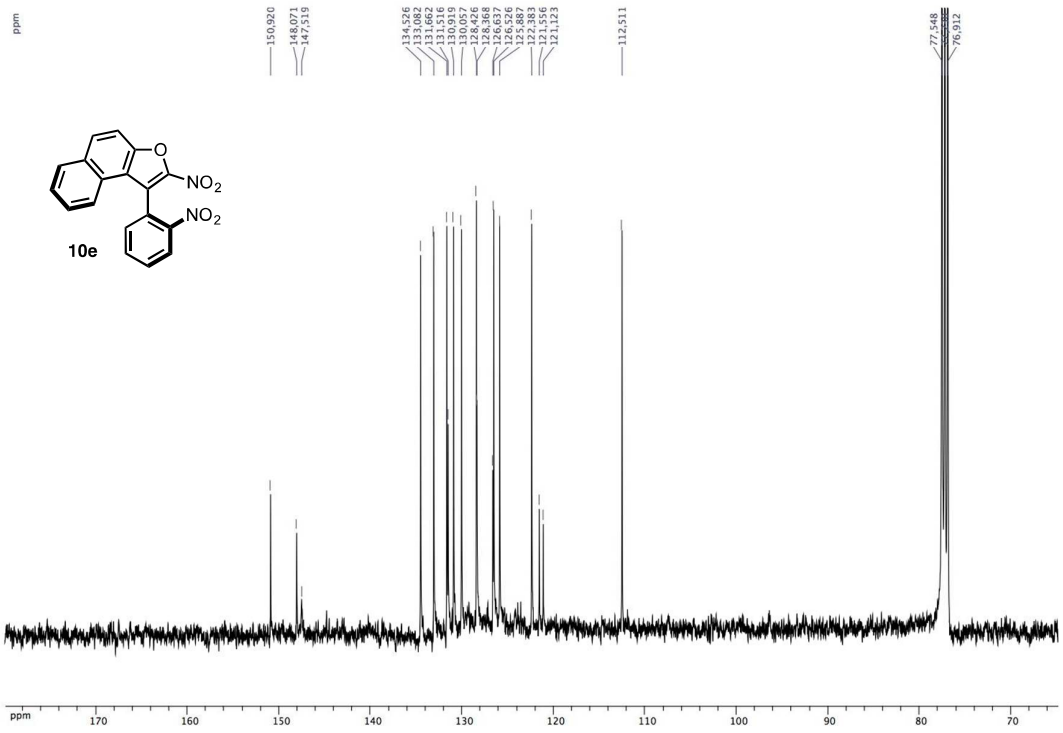

ppm
8.127
8.124
8.107
8.104
8.083
8.060
7.995
7.975
7.775
7.752
7.609
7.606
7.590
7.587
7.571
7.568
7.566
7.562
7.548
7.545
7.542
7.528
7.524
7.453
7.449
7.434
7.430
7.416
7.413
7.410
7.396
7.392
7.336
7.332
7.316
7.313
7.299
7.293
7.260
O
NO2
I
10c
0.9
1.0
1.0
1.0
2.0
2.0
2.0
ppm
8,6
8,5
8,4
8,3
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1
7
6,9
6,8
6,7

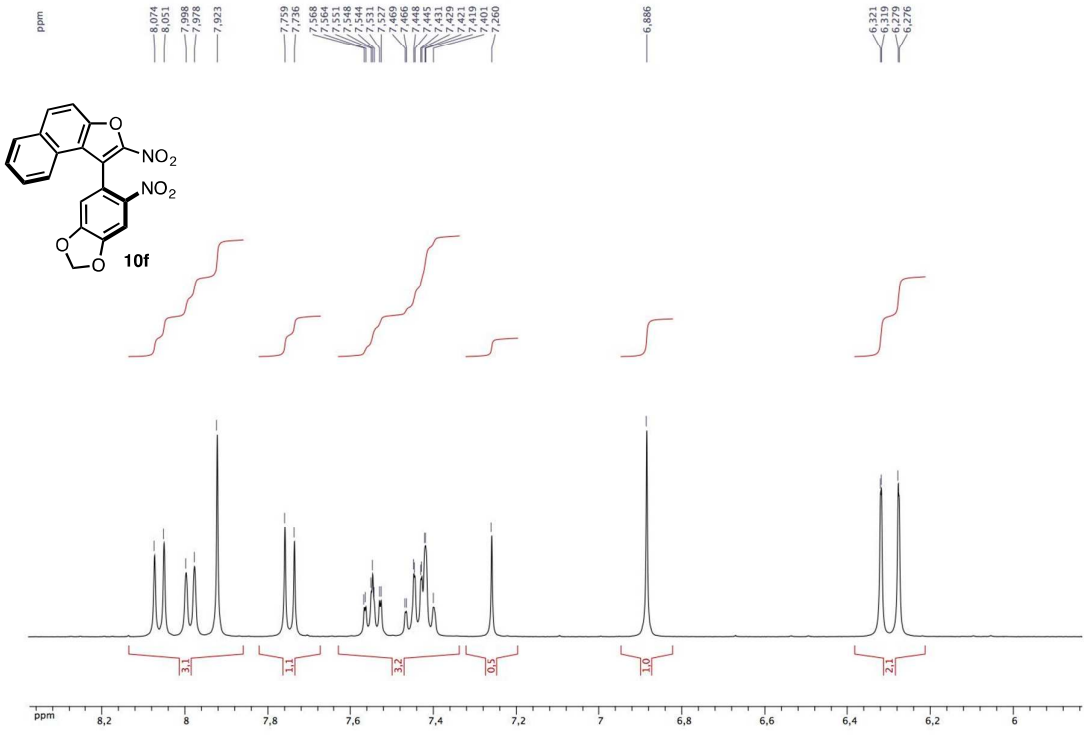

ppm
150,586
148,028
139,818
136,272
132,898
131,393
130,272
129,911
129,781
129,126
128,617
128,466
126,484
126,265
122,873
121,383
112,449
98,495
77,548
77,232
76,912
O
NO2
I
10c
ppm
170
160
150
140
130
120
110
100
90
80
70

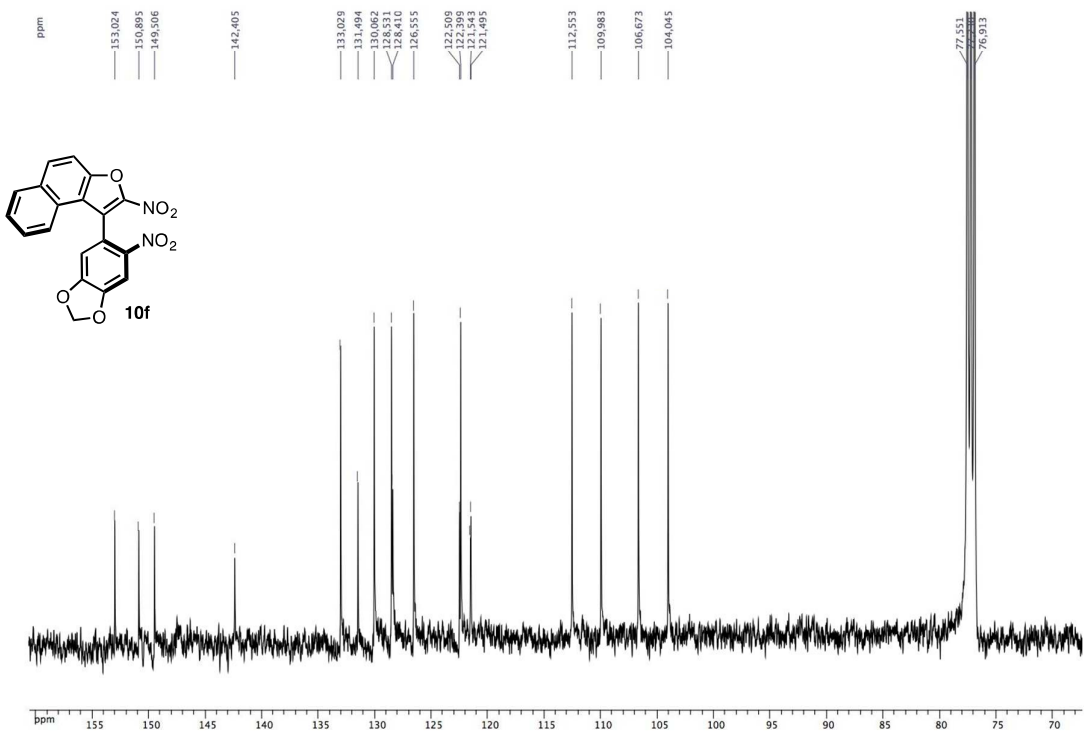

ppm
8.353
8.349
8.334
8.330
8.051
8.028
7.975
7.955
7.765
7.760
7.746
7.742
7.733
7.729
7.714
7.710
7.522
7.519
7.505
7.502
7.499
7.494
7.485
7.481
7.476
7.363
7.345
7.342
7.328
7.324
7.272
7.269
7.252
5.300
3.636
NO2
CO2Me
10d
1.0
1.0
1.0
3.0
2.0
1.0
1.1
3.0
ppm 9,5 9 8,5 8 7,5 7 6,5 6 5,5 5 4,5 4 3,5 3 2,5 2

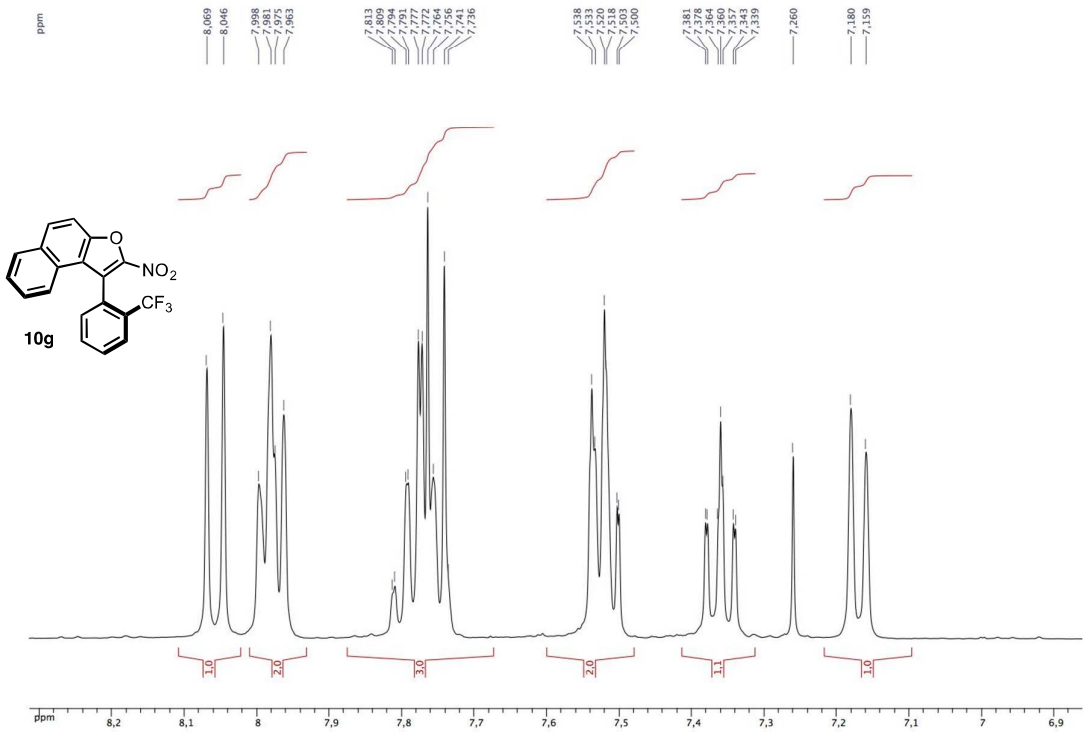

ppm
166,157
150,594
147,768
133,308
132,562
132,408
131,654
131,424
130,455
129,804
129,732
129,709
128,751
128,070
126,166
124,769
122,800
122,161
112,526
77,548
77,232
76,912
52,396
NO2
CO2Me
10d
ppm 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40

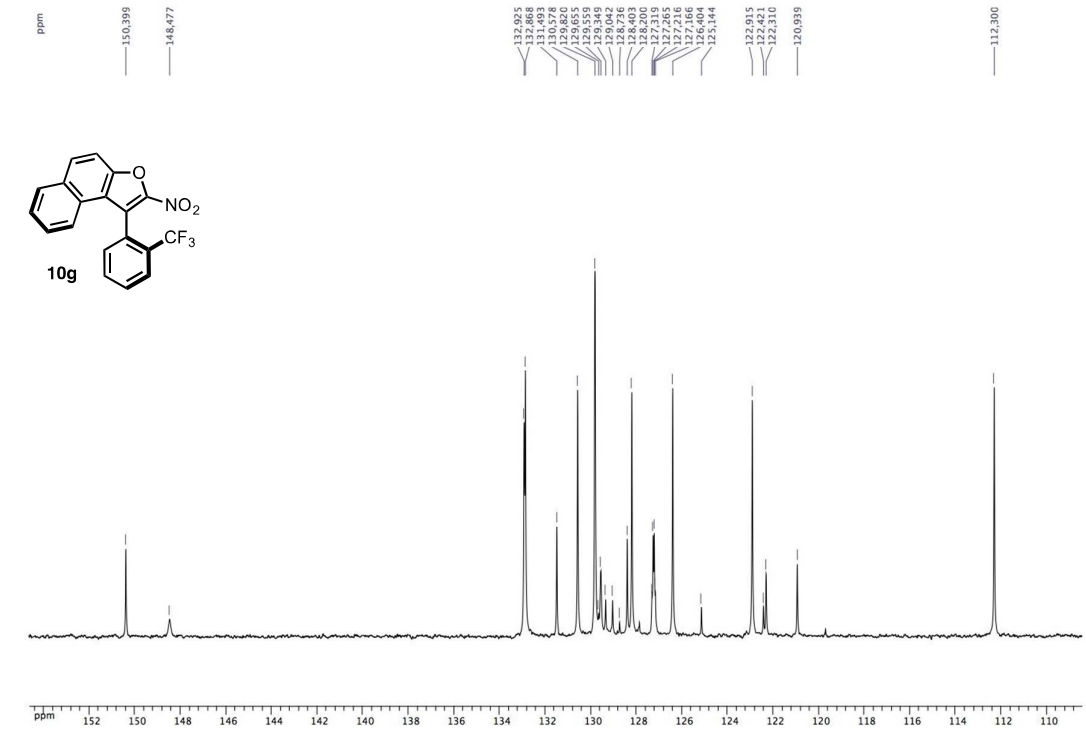

ppm
8.465
8.461
8.445
8.441
8.082
8.059
7.996
7.975
7.889
7.886
7.871
7.867
7.853
7.848
7.845
7.840
7.825
7.821
7.806
7.802
7.769
7.746
7.595
7.591
7.577
7.572
7.548
7.545
7.530
7.528
7.510
7.508
7.394
7.390
7.373
7.370
7.355
7.352
7.760
7.238
O
NO2
NO2
10e
1.0
1.0
1.0
2.1
1.0
1.0
1.0
1.0
1.2
ppm
8,7
8,6
8,5
8,4
8,3
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1
7

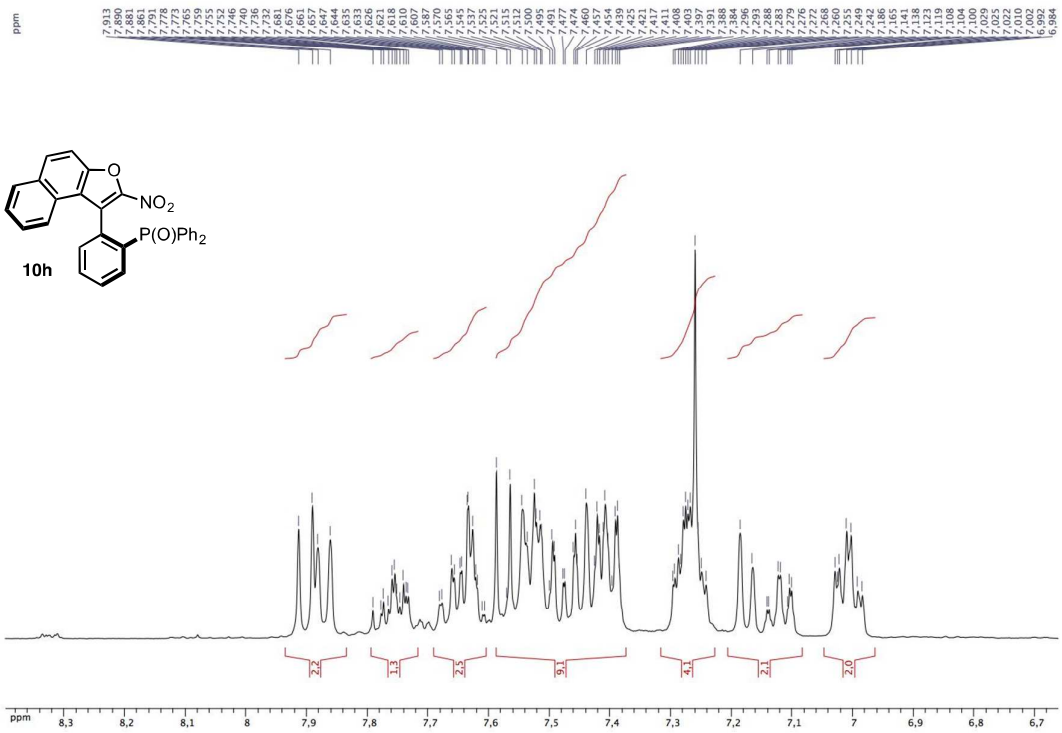

ppm
150,920
148,071
147,519
134,526
133,082
131,662
131,516
130,919
130,057
128,426
128,388
126,637
126,526
125,887
122,383
121,556
121,123
112,511
77,548
77,232
76,912
O
NO2
NO2
10e
ppm
170
160
150
140
130
120
110
100
90
80
70

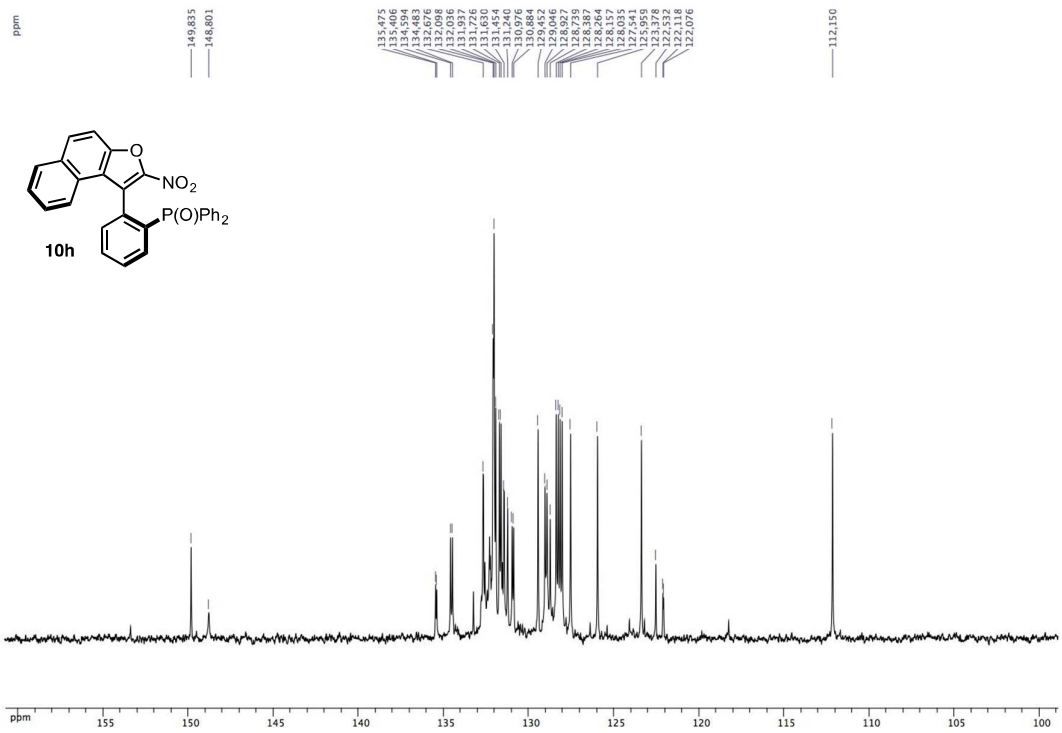

ppm
8,074
8,051
7,998
7,978
7,923
7,759
7,736
7,568
7,564
7,551
7,548
7,544
7,533
7,527
7,469
7,466
7,448
7,445
7,431
7,429
7,421
7,419
7,401
7,381
7,260
6,886
6,321
6,319
6,279
6,276
NO2
NO2
O
O
O
10f
3,1
1,1
3,2
0,5
1,0
2,1
ppm
8,2
8
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6

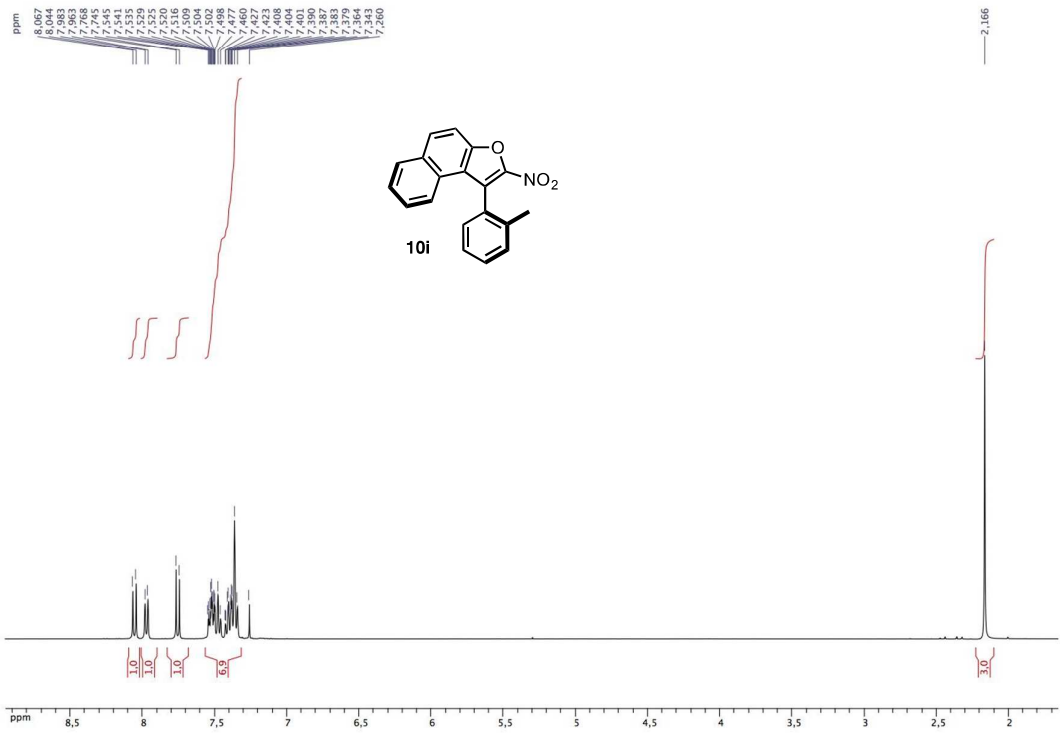

ppm
153,024
150,895
149,506
142,405
133,029
131,494
130,062
128,531
128,410
126,555
122,509
122,399
121,543
121,495
112,553
109,983
106,673
104,045
77,551
77,339
77,126
76,913
NO2
NO2
O
O
O
10f
ppm
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70

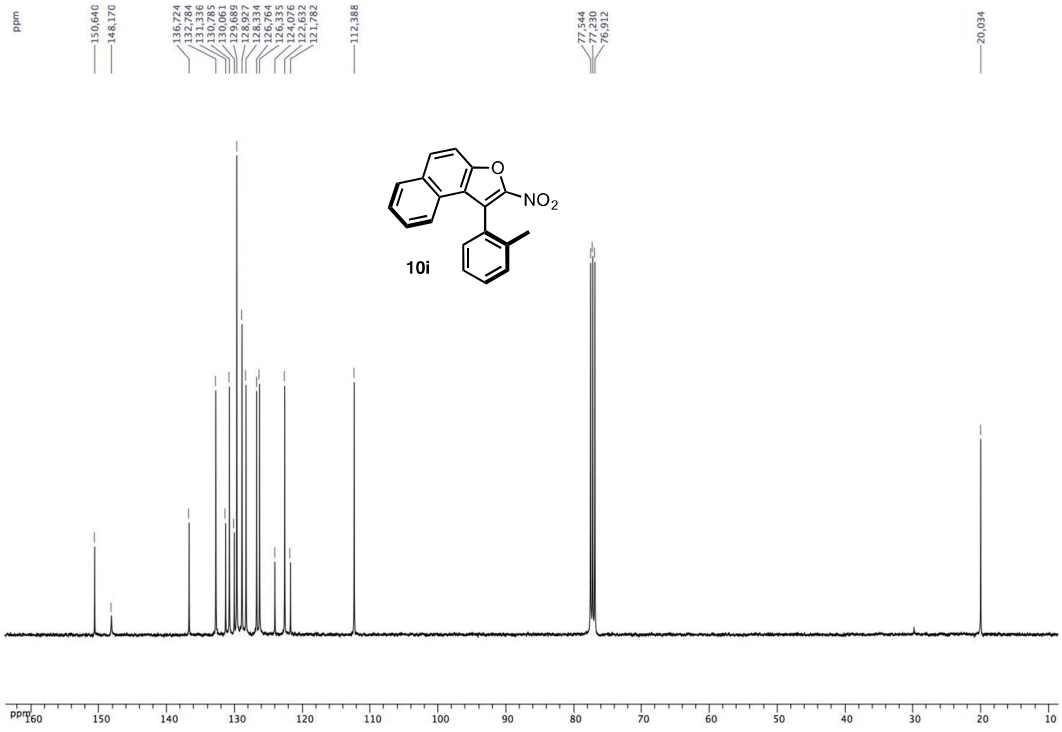

ppm
8,069
8,046
7,998
7,981
7,975
7,963
7,813
7,809
7,794
7,791
7,777
7,772
7,764
7,756
7,741
7,736
7,538
7,533
7,520
7,518
7,503
7,500
7,381
7,378
7,364
7,360
7,357
7,343
7,339
7,260
7,180
7,159
O
NO2
CF3
10g
1,0
2,0
3,0
2,0
1,1
1,0
ppm
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1
7
6,9

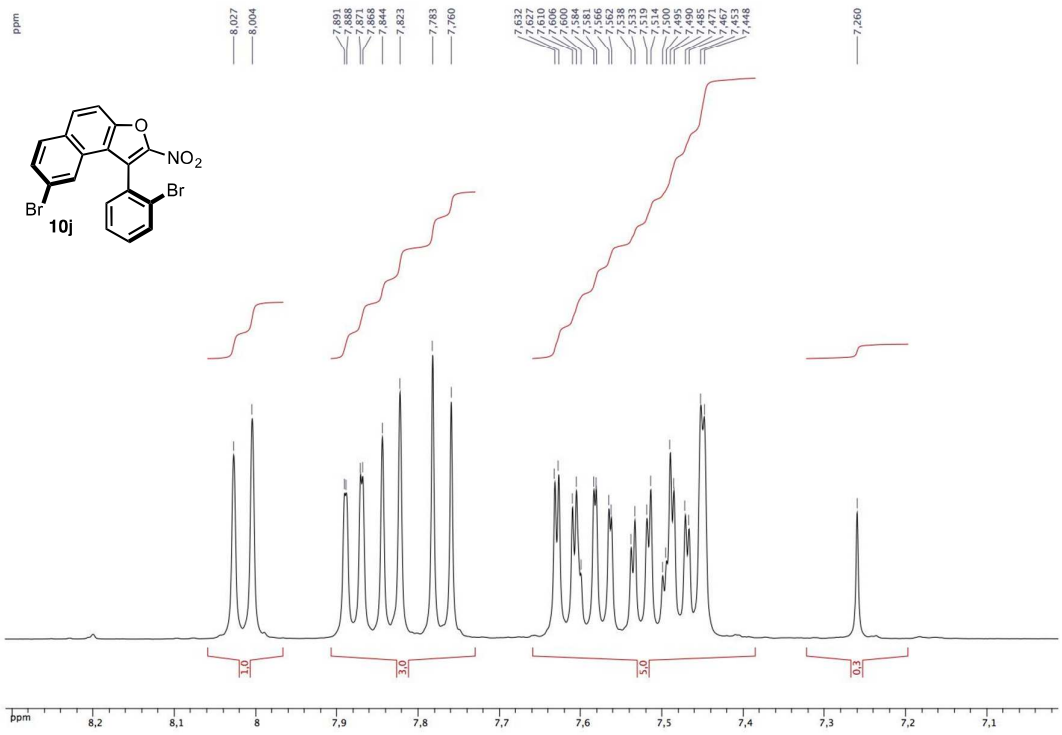

ppm
150,399
148,477
132,925
132,868
131,493
131,378
129,820
129,655
129,559
129,349
129,042
128,736
128,403
128,200
127,319
127,265
127,216
127,166
126,404
125,144
122,915
122,421
122,310
120,939
112,300
O
NO2
CF3
10g
ppm
152
150
148
146
144
142
140
138
136
134
132
130
128
126
124
122
120
118
116
114
112
110

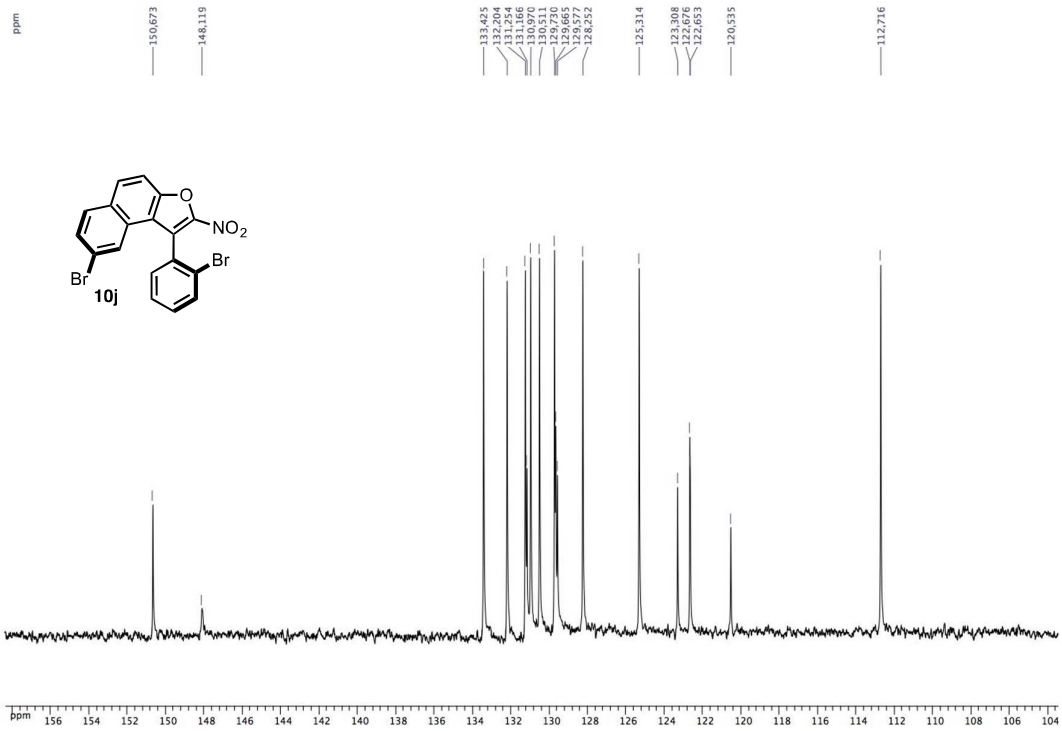

10h
NO2
P(O)Ph2
ppm

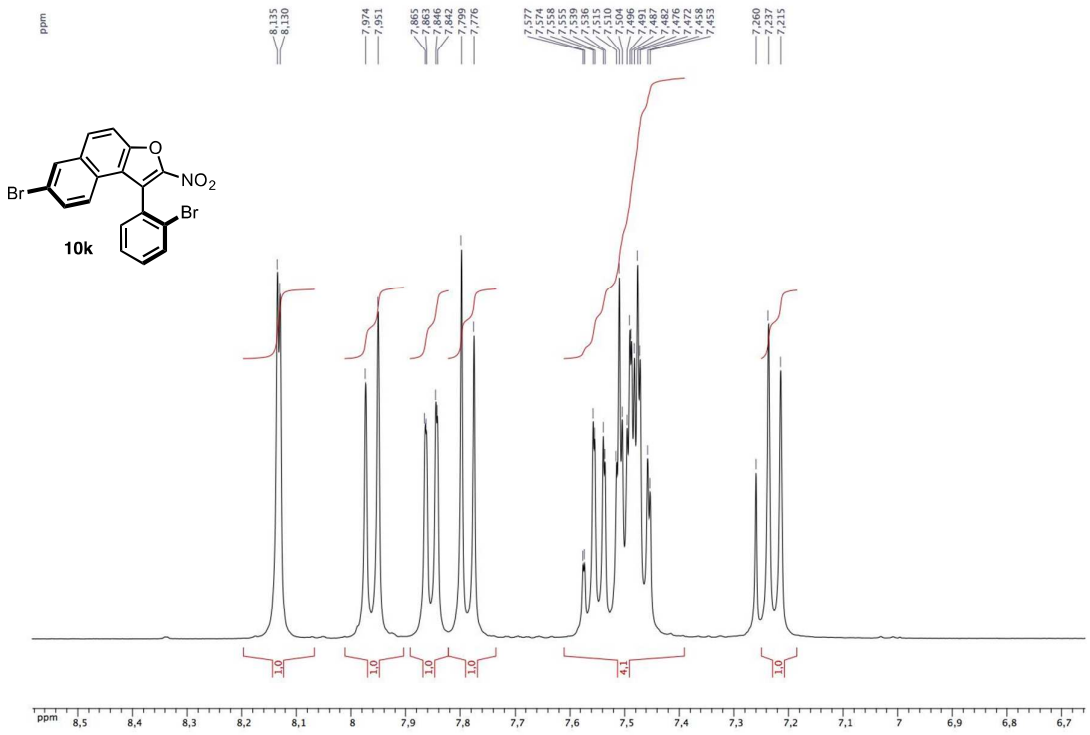

10h
NO2
P(O)Ph2
ppm

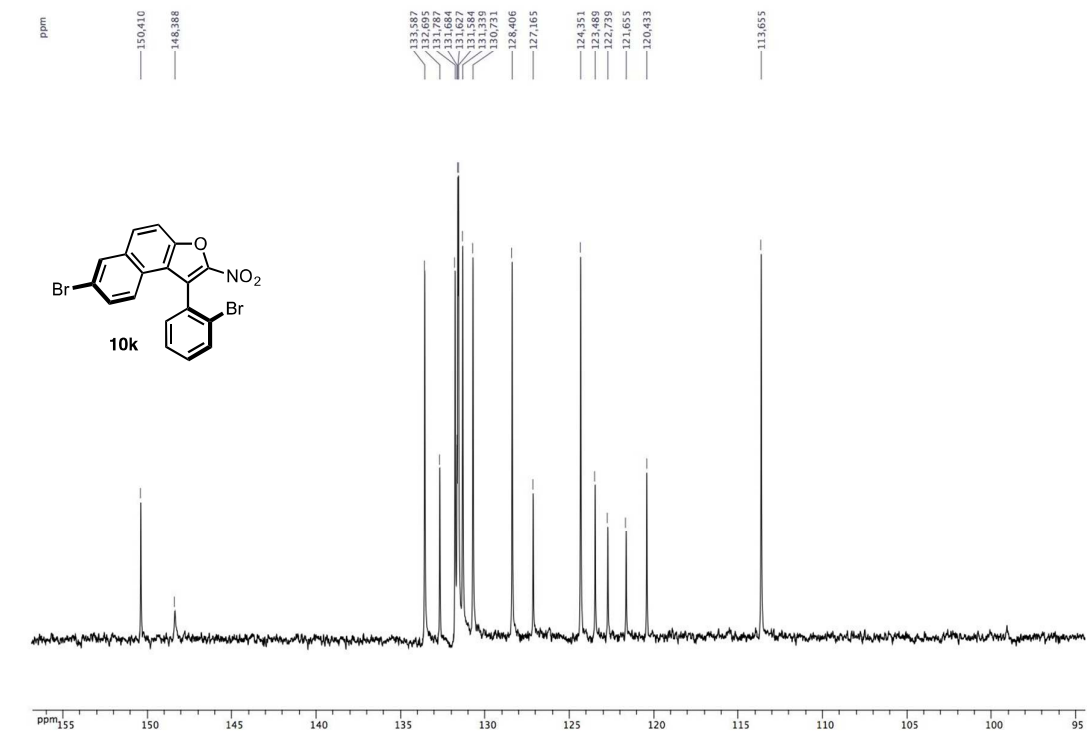

ppm
8,067
8,044
7,983
7,963
7,768
7,745
7,545
7,541
7,535
7,529
7,525
7,520
7,516
7,509
7,504
7,502
7,489
7,477
7,460
7,427
7,423
7,408
7,404
7,401
7,390
7,387
7,383
7,379
7,364
7,343
7,260
2,166
O
NO2
10i
1,0
1,0
1,0
6,9
3,0
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2

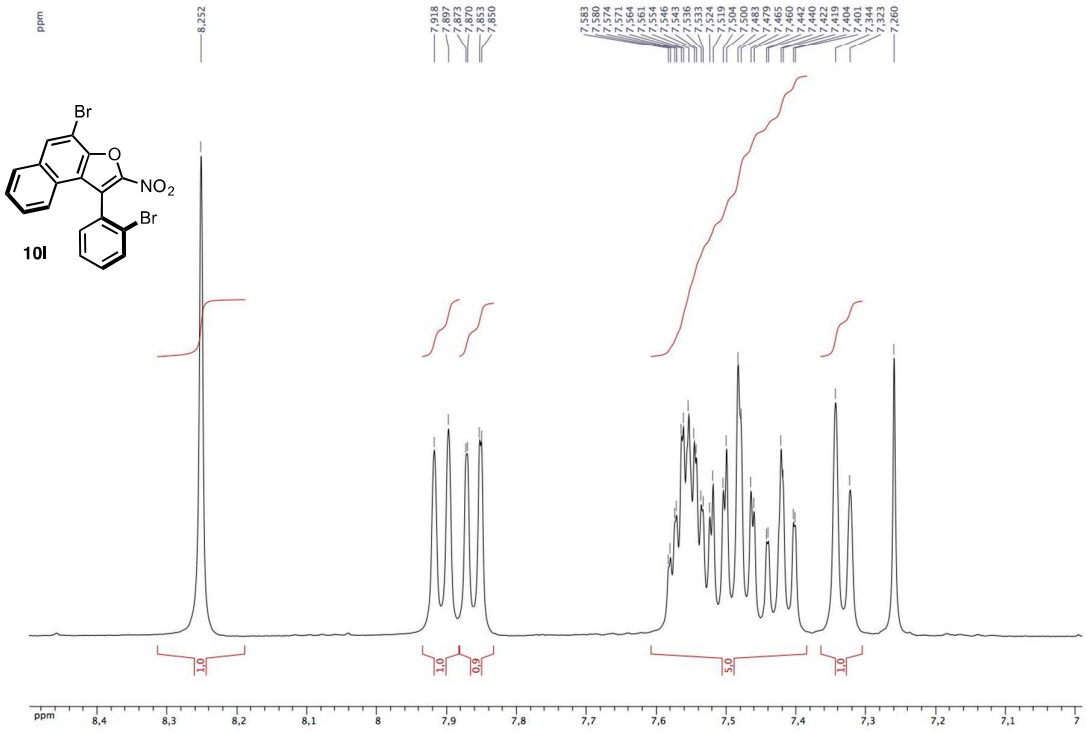

ppm
150,640
148,170
136,724
132,784
131,336
130,785
130,061
129,868
128,927
128,334
126,764
126,335
124,075
122,613
121,782
112,388
77,544
77,230
76,912
20,034
O
NO2
10i
ppm
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

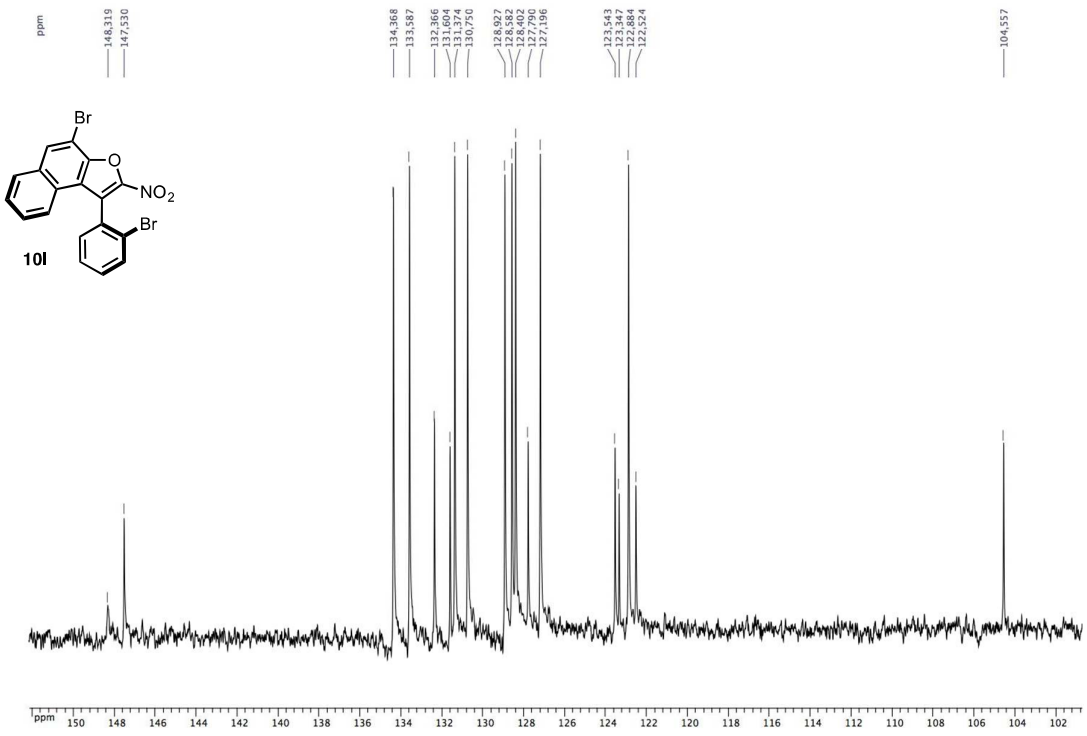

ppm
8,027
8,004
7,891
7,888
7,871
7,868
7,844
7,823
7,783
7,760
7,632
7,627
7,610
7,606
7,600
7,584
7,581
7,565
7,562
7,538
7,533
7,519
7,514
7,500
7,495
7,490
7,485
7,471
7,467
7,453
7,448
7,260
O
NO2
Br
Br
10j
1,0
3,0
5,0
0,3
ppm
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1

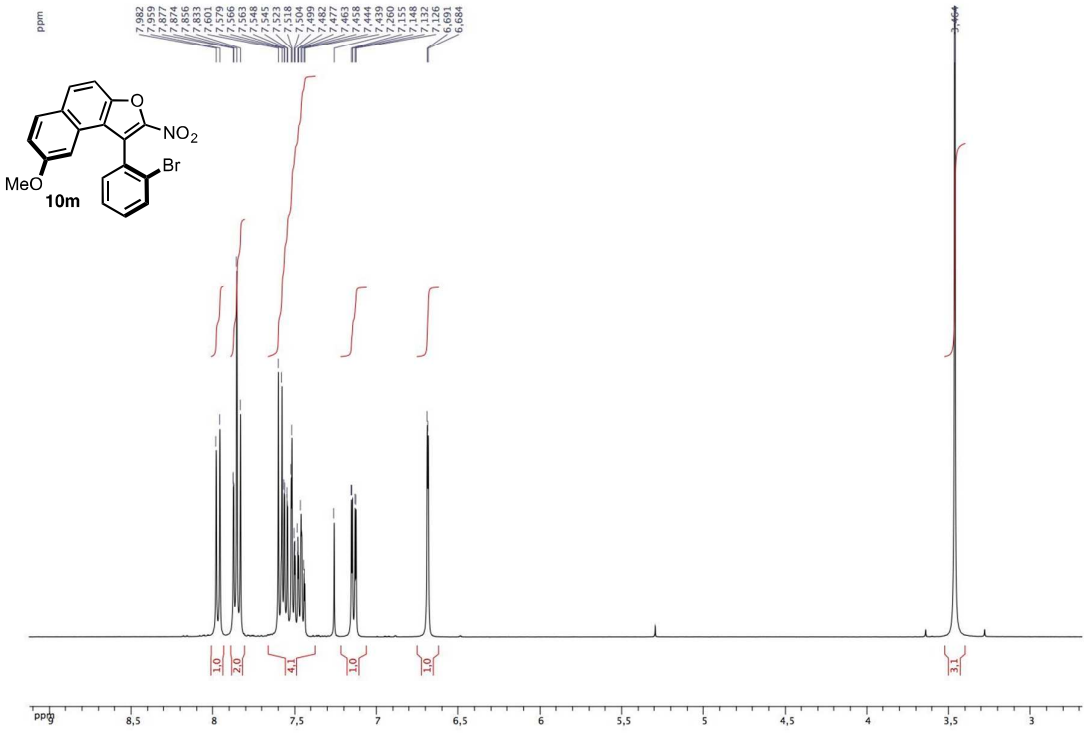

ppm
150,673
148,119
133,425
132,204
131,254
131,166
130,970
130,151
129,730
129,665
129,577
128,252
125,314
123,308
122,676
122,653
120,535
112,716
O
NO2
Br
Br
10j
ppm
156
154
152
150
148
146
144
142
140
138
136
134
132
130
128
126
124
122
120
118
116
114
112
110
108
106
104

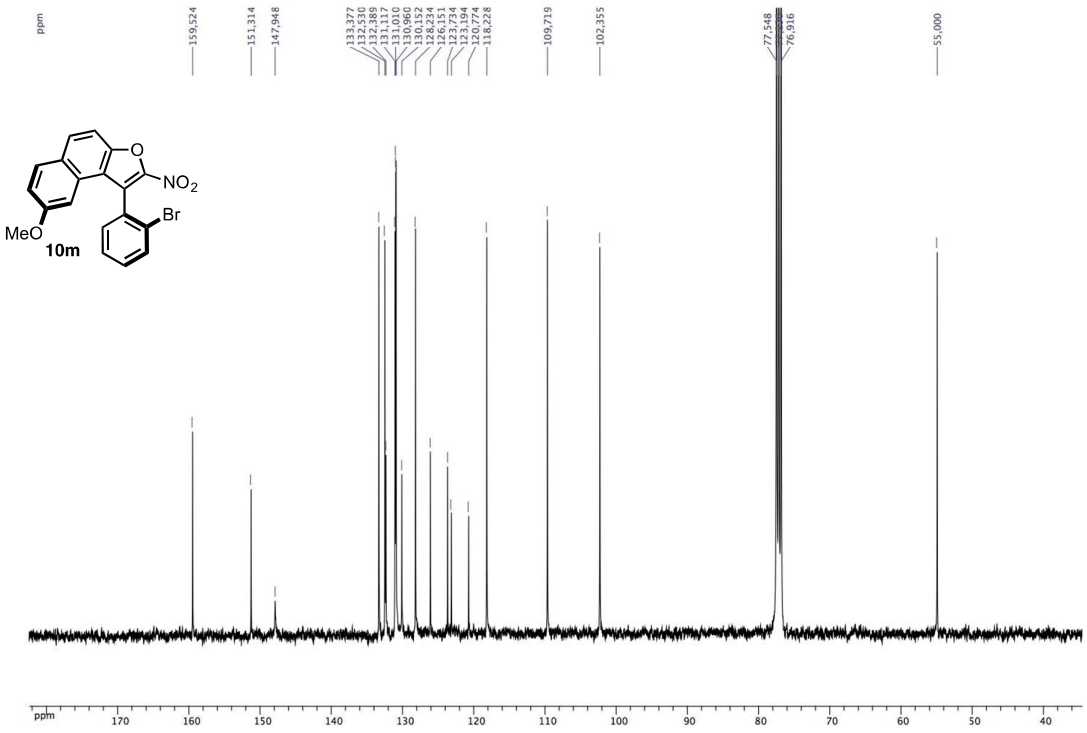

ppm
8.135
8.130
7.974
7.951
7.865
7.863
7.846
7.842
7.799
7.776
7.577
7.574
7.558
7.555
7.539
7.536
7.515
7.510
7.504
7.496
7.491
7.487
7.482
7.476
7.472
7.458
7.453
7.260
7.237
7.215
Br
O
NO2
Br
10k
1.0
1.0
1.0
1.0
4.1
1.0
ppm
8,5
8,4
8,3
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1
7
6,9
6,8
6,7


ppm
150,410
148,388
133,587
132,695
131,787
131,684
131,627
131,584
131,339
130,731
128,406
127,165
124,351
123,489
122,739
121,655
120,433
113,655
Br
O
NO2
Br
10k
ppm
155
150
145
140
135
130
125
120
115
110
105
100
95


Br
O
NO2
Br
10l
ppm
8,252
7,918
7,897
7,873
7,870
7,853
7,850
7,583
7,580
7,574
7,571
7,564
7,561
7,554
7,546
7,543
7,536
7,533
7,524
7,519
7,501
7,500
7,483
7,479
7,465
7,460
7,442
7,440
7,422
7,419
7,404
7,401
7,344
7,323
7,260
1,0
1,0
0,9
5,0
1,0
ppm
8,4
8,3
8,2
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
7,3
7,2
7,1
7


Br
O
NO2
Br
10l
ppm
148,319
147,530
134,368
133,587
132,366
131,604
131,374
130,750
128,927
128,582
128,402
127,790
127,196
123,543
123,347
122,884
122,524
104,557
ppm
150
148
146
144
142
140
138
136
134
132
130
128
126
124
122
120
118
116
114
112
110
108
106
104
102




(1) Dauzonne, D.; Royer, R. *Synthesis* **1987**, 1020.

(2) Bauvois, B.; Puiffe, M.-L.; Bongui,J.-B.; Paillat,S.; Monneret,C.; Dauzonne, D. *J. Med. Chem.* **2003,** *46,* 3900.
(3) Zhu, Y.; Malerich, J. P.; Rawal, V. R. *Angew. Chem. Int. Ed.* **2010**, *49*, 153–156.
(4) Xie, J.-W.; Wang, T.; Zhou, F.T. *Tetrahedron Lett.* **2011**, *52*, 2379–2382.