Electronic Supplementary Material (ESI) for Organic Chemistry Frontiers.

Rational design of naphthoquinone-based antibacterial agents through iridium-catalyzed enantioselective β-allenylation of 2-hydroxynaphthoquinones

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A. General information:

Infrared (FT-IR) spectra were recorded on Bruker alfa FT-IR, ν_{max} in cm^{-1} and the bands are characterized as broad (br), strong (s), medium (m), and weak (w). NMR spectra were recorded on Bruker Ultrashield spectrometer at 400 MHz (for ^{1}H-NMR), 100 MHz (for ^{13}C-NMR) and 376 MHz (for ^{19}F-NMR). Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as internal standard ($CDCl_3$: δ 7.26 for ^{1}H-NMR and δ 77.16 for ^{13}C-NMR). For ^{1}H-NMR, data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, dd = double doublet, ddd = doublet of doublet of doublets, t = triplet, q = quartet, sept = septet, br = broad, m = multiplet), coupling constants (Hz) and integration. High resolution mass spectrometry was performed on XEVO G2-XS QTof instrument. Optical rotations were measured on JASCO P-2000 polarimeter. Melting points were measured in an open glass capillary on a Buchi M-560 melting point apparatus. Enantiomeric ratios were determined by Shimadzu LC-20AD HPLC instrument and SPD-20A Diode Array detector using stationary phase chiral columns (25 cm × 0.46 cm) in comparison with authentic racemic compounds.

Unless stated otherwise, all reactions were carried out with distilled and dried solvents under an atmosphere of nitrogen or argon in oven (120 °C) dried glassware with standard vacuum-line techniques. The reactions, which required heating, were carried out in a pre-heated oil bath at the specified temperature. Organic solvents used for carrying out reactions were dried using standard methods. $[Ir(COD)Cl]_2$ was purchased from Merck; (*S*)-BINOL and (*R*)-BINOL were purchased from Combi-Blocks; Naphthoquinone **1a** was purchased from Merck and used as received. Other naphthoquinones (**1b-1f)** were prepared according to the literature procedure.[1] All work up and purification were carried out with reagent-grade solvents in air.[2] Thin-layer chromatography was performed using Merck silica gel 60 F_{254} pre-coated plates (0.25 mm). Column chromatography was performed using silica gel (230-400 or 100-200 mesh). NMR yields were determined by using mesitylene as an internal standard. Unless otherwise noted, all reported yields of the Ir-catalyzed β-allenylation reactions correspond to the isolated yield after chromatographic purification. Chiral ligands used in this work were prepared according to the literature procedure.[3]

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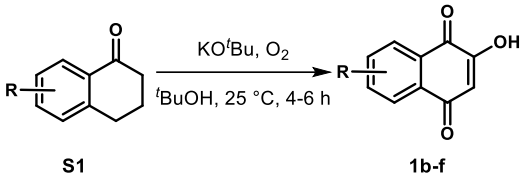
[1]L. Wu, X. Ma, X. Yang, C. Zhang, *Eur. J. Med. Chem.* **2020**, *203*, 112594.

[2] W. L. F. Armarego, C. L. L. Chai, Purification of Laboratory Chemicals (Fifth Edition); Butterworth-Heinemann: Burlington, 2003.

[3]C. Defieber, M. A. Ariger, P. Moriel, E. M. Carreira, *Angew. Chem., Int. Ed.* **2007**, *46*, 3139.

B. General procedure for the synthesis of 2-hydroxy naphthoquinones:

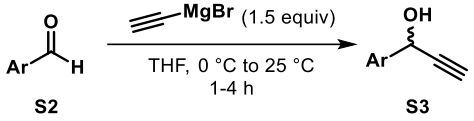
General procedure: Naphthoquinones (**1b-f**) were prepared according to the previously reported procedure.[1]



In an oven dried 50 mL round-bottom flask, 5 mL of anh. ^{t}BuOH was taken and purged with O_2 for 15 min. To this oxygen-saturated solution of ^{t}BuOH, α-tetralone **S1** (1.0 equiv) and KO^{t}Bu (2.5 equiv) were added sequentially under a positive O_2 atmosphere. The resulting deep red heterogenous solution was then allowed to stir at ambient temperature for 4-6 h under O_2 atmosphere. Upon completion (monitored by TLC), the reaction mixture was quenched with dropwise addition of 1 (N) HCl until the pH of the solution reached 2. The yellow precipitate was filtered and washed with hexane (3 × 2 mL) and dried under reduced pressure to obtain a yellow solid (**1b-f)**. The spectroscopic data of the naphthoquinones (**1b-f)** thus obtained were found to be consistent with the literature.

C. General procedure for the synthesis of allenylic alcohols:

Allenylic alcohols (**2a-r**) were prepared according to the reported literature procedure.[4]



In an oven dried 100 mL round-bottom flask, aldehyde **S2** (1.0 gm, 1.0 equiv) was dissolved in 30 mL of anh. THF under positive argon pressure and the resulting solution was cooled to 0 °C. To this, ethynylmagnesium bromide (0.5 M in THF, 1.5 equiv) was added dropwise over 10 min via a syringe. The reaction mixture was then allowed to attain ambient temperature over 30 min. Upon completion (TLC in 10% EtOAc in petroleum ether), the reaction was quenched with 10 mL of saturated aqueous NH_4Cl and diluted with 10 mL of distilled H_2O. The organic phase was separated, and the aqueous phase was extracted with EtOAc (2 × 5 mL). The combined organic phase was washed with brine (3 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain a yellow oil. The crude residue was purified by silica gel flash column chromatography (3-4% EtOAc in petroleum ether) to obtain propargylic alcohol **S3** (90 to >99% yield).

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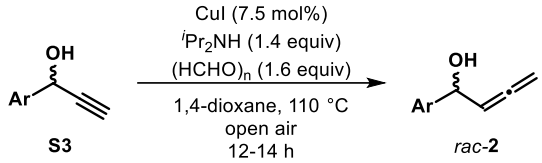
[1]L. Wu, X. Ma, X. Yang, C. Zhang, *Eur. J. Med. Chem.* **2020**, *203*, 112594.

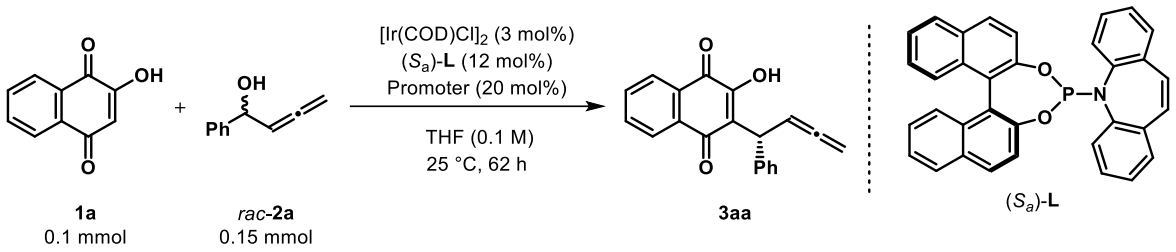
[4](a) H. Luo, S. Ma, *Eur. J. Org. Chem.* **2013**, *2013*, 3041; (b) M. Isomura, D. A. Petrone, E. M. Carreira, *J. Am. Chem. Soc.* **2019**, *141*, 4738.



In a 100 mL two neck round-bottom flask equipped with a water-cooled reflux condenser, CuI (7.5 mol%) and paraformaldehyde (1.6 equiv) were dissolved in 10 mL of 1,4-dioxane. To this, $^{i}Pr_2NH$ (1.4 equiv) was added, and the resulting solution was heated to 110 °C in open air. After 5 min, a solution of propargylic alcohol **S3** in 10 mL of 1,4-dioxane was added dropwise and the reaction mixture was allowed to stir at 110 °C for 12-14 h. Upon completion (TLC in 10% EtOAc in petroleum ether), the reaction mixture was filtered through a short pad of Celite®, washed with CH_2Cl_2 and concentrated under reduced pressure to obtain a brown oil. The residue was purified by silica gel flash column chromatography (3-6% EtOAc in petroleum ether) to obtain *rac*-**2** (80 to 89% yield).

D. Optimization studies for enantioselective allenylation of Lawsone:

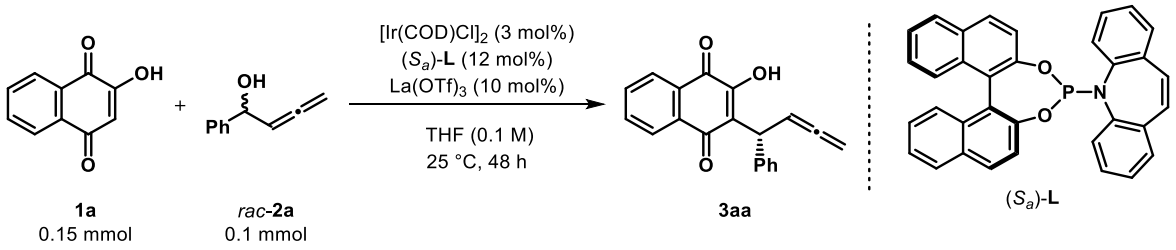
Table S1. Promoter screening [a]



Entry	promoter	NMR yield (%)	er[c]
1	$Sc(OTf)_3$	11	n.d
2	$La(OTf)_3$	72 (65[b])	>99.5:0.5
3	$Fe(OTf)_2$	66[b]	>99.9:0.1
4	$Zn(OTf)_2$	<5	n.d
5	$BF_3.Et_2O$	<5	n.d
6[d,e,g]	$Fe(OTf)_2$	76	>99.9:0.1
7[d,f,g]	$Bi(OTf)_3$	31	>99.9:0.1
8[d,f,g]	$InCl_3$	43	n.d.
9[d,f,g]	$InBr_3$	29	n.d.
10[d,f,g]	$Yb(OTf)_3$	17	n.d.
11[d,f,g]	$ZnCl_2$	<5	n.d.
12 [d,e,g]	$La(OTf)_3$	85	>99.9:0.1
13 [d,f,g]	$La(OTf)_3$	(83[b])	>99.9:0.1

[a]Reactions were carried out on a 0.1 mmol scale. [b]Yields correspond to the isolated yield after chromatographic purification. [c]Enantiomeric ratio (er) as determined by HPLC analysis on a chiral stationary phase. [d]10mol % of promoter was used. [e]Using 2.0 equiv of *rac*-**2a**. [f]Using 1.5 equiv of **1a**. [g]Reaction time was 48 h.

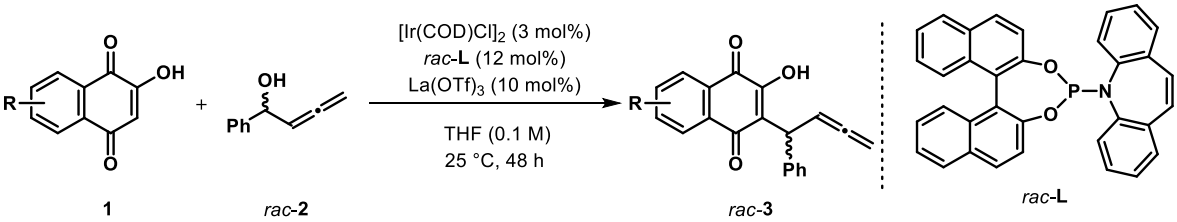
Table S2. Solvent screening [a]



Entry	solvent	NMR yield (%)	er[c]
1	$(CH_2Cl)_2$	<10	n.d
2	Toluene	<10	n.d
3	CH_2Cl_2	<10	n.d
4	2-Me THF	<10	n.d
5[d]	THF	59	>99.9:0.1
6[e]	THF	(82[b])	>99.9:0.1

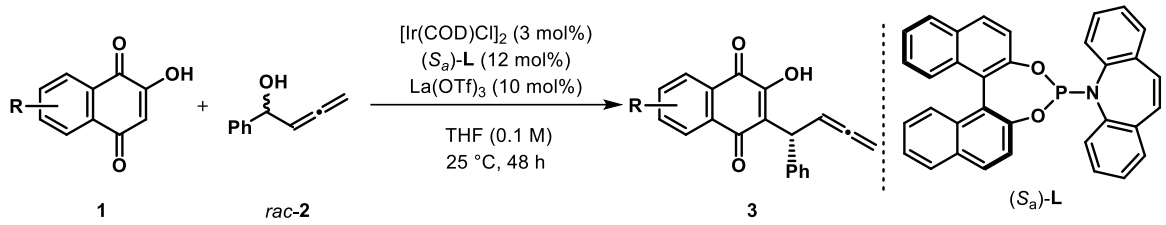
[a]Reactions were carried out on a 0.1 mmol scale. [b]Yields correspond to the isolated yield after chromatographic purification. [c]Enantiomeric ratio (er) as determined by HPLC analysis on a chiral stationary phase. [d]100 mg 4 Å MS was used as an additive. [e] Reaction was performed on a 0.2 mmol.

E. General procedure for the preparation of racemic allenylation products (*rac*-3):



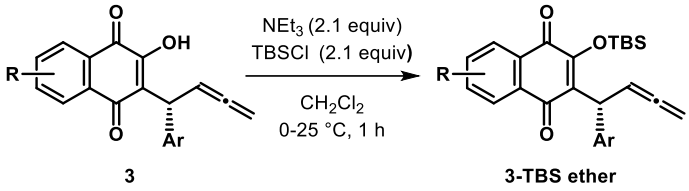
In an oven and vacuum-dried reaction tube, $[Ir(COD)Cl]_2$ (2.0 mg, 0.003 mmol, 3 mol%) and *rac*-**L** (5.0 mg, 0.012 mmol, 12 mol%) were taken in 0.5 mL of anh. THF under positive argon pressure and stirred vigorously at room temperature for 15 min to obtain a deep red solution. A solution of *rac*-**2** (0.1 mmol, 1.0 equiv) in 0.2 mL of THF was then added and the resulting pale yellow solution was stirred for 5 min at 25 °C. To this, 2-hydroxynaphthoquinone **1** (0.15 mmol, 1.5 equiv) and $La(OTf)_3$ (10 mol%, 5.9 mg) were added sequentially followed by the addition of another 0.3 mL of THF. The reaction tube was purged with argon, sealed with a glass stopper and the reaction mixture was allowed to stir at 25 °C for 48 h. The residue, without any further work-up, was purified by preparative TLC (Merck silica-gel 60 F_{254} pre-coated plates of 0.25 mm thickness) to obtain *rac*-**3** samples for HPLC analysis.

F. General procedure for Ir-catalyzed enantioselective allenylation of 2-hydroxynaphthoquinones:



In an oven and vacuum-dried reaction tube, $[Ir(COD)Cl]_2$ (4.0 mg, 0.006 mmol, 3 mol%) and (S_a)-**L** (12.2 mg, 0.024 mmol, 12 mol%) were taken in 1 mL of anh. THF under positive argon pressure and stirred vigorously at room temperature for 15 min to obtain a deep red solution. A solution of *rac*-**2** (0.2 mmol, 1.0 equiv) in 0.4 mL of THF was then added and the resulting pale yellow solution was stirred for 5 min at room temperature. To this, 2-hydroxynaphthoquinone **1** (0.3 mmol, 1.5 equiv) and $La(OTf)_3$ (10 mol%, 11.8 mg) were added sequentially followed by the addition of another 0.6 mL of THF. The reaction tube was purged with argon, sealed with a glass stopper and the reaction mixture was allowed to stir at 25 °C until TLC (10% EtOAc in petroleum ether) revealed complete consumption of *rac*-**2**. The reaction mixture was filtered through a short pad of Celite®, washed with CH_2Cl_2 and concentrated under reduced pressure to obtain a yellow sticky liquid. The residue was purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether) to obtain β-allenylic 2-hydroxynaphthoquinone **3**.

G. Procedure for the synthesis of *tert*-butyldimethylsilyl ether:



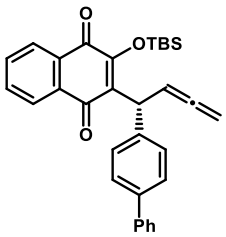
In an oven dried 10 mL round-bottom flask, β-allenylic 2-hydroxynaphthoquinone **3** (1.0 equiv) was dissolved in 0.8 mL of anh. CH_2Cl_2 under argon atmosphere and cooled to 0 °C. To this solution, NEt_3 (2.1 equiv) was added dropwise at 0 °C to obtain deep red solution followed by dropwise addition of a solution of *tert*-butyldimethylsilyl chloride (TBSCl) (2.1 equiv) in 0.2 mL of CH_2Cl_2. The resulting mixture was then allowed to attain ambient temperature and stirred at that temperature for 1 h. upon completion, the reaction mixture was diluted with 3 mL saturated solution of $NaHCO_3$, 1 mL of distilled H_2O and 1 mL of CH_2Cl_2. The organic phase was separated, and the aqueous phase was extracted with CH_2Cl_2 (2 × 2 mL). The combined organic phase was washed with brine (1 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure. The residue was purified by silica gel flash

column chromatography (1-2% EtOAc in petroleum ether) to obtain **3**-TBS ether, usually in quantitative yield (>99% yield).

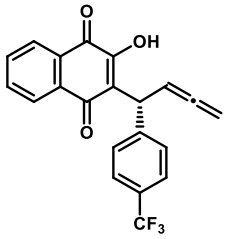
Compound 3aa: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (50 mg, 0.163 mmol, 82% yield); **FT-IR (Thin film):** 3359 (br), 3061 (w), 3026 (w), 2924 (w), 1953 (w), 1664 (s), 1592 (m), 1372 (s), 1337 (m), 1279 (m), 1254 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.11 (d, *J* = 7.8 Hz, 1H), 8.07 (d, *J* = 7.8 Hz, 1H), 7.78-7.74 (m, 1H), 7.70-7.66 (m, 1H), 7.50 (br, 1H), 7.45-7.43 (m, 2H), 7.31-7.27 (m, 2H), 7.22-7.18 (m, 1H), 6.01-5.95 (m, 1H), 5.29-5.26 (m, 1H), 4.79-4.71 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 183.8, 181.9, 153.0, 141.5, 135.3, 133.1, 132.9, 129.3, 128.4, 128.0, 127.3, 126.7, 126.3, 124.6, 90.0, 76.1, 40.7; **HRMS (ESI+):** Calcd. for $C_{20}H_{15}O_3$ ($[M+H]^+$): 303.1021, Found: 303.1020; **Optical rotation:** $[\alpha]_D^{22}$ +159.3 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IG column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 241 nm, τ_{major} = 11.9 min, τ_{minor} = 13.2 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3aa** was assigned in analogy with *trans*-**10** (see below).

Compound 3ab: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (58.0 mg, 0.168 mmol, 84% yield); **FT-IR (Thin film):** 3362 (br), 2960 (m), 2925 (w), 2868 (w), 1953 (w), 1664 (s), 1594 (m), 1510 (w), 1460 (w), 1371 (s), 1279 (s), 1254 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.12 (dd, *J* = 7.8, 1.1 Hz, 1H), 8.07 (dd, *J* = 7.6, 1.1 Hz, 1H), 7.72 (dt, *J* = 7.5, 1.3 Hz, 1H), 7.67 (dt, *J* = 7.5, 1.3 Hz, 1H), 7.50 (s, 1H), 7.37 (d, *J* = 8.2 Hz, 2H), 7.15 (d, *J* = 8.2 Hz, 2H), 6.03-5.97 (m, 1H), 5.26-5.24 (m, 1H), 4.77-4.70 (m, 2H), 2.86 (sept, 1H), 1.23 (d, *J* = 1.0 Hz, 3H), 1.21 (d, *J* = 1.0 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.0, 183.9, 182.0, 152.9, 147.3, 138.8, 135.3, 133.09, 133.05, 129.4, 128.0, 127.3, 126.5, 126.2, 124.9, 90.3, 75.9, 40.5, 33.8, 24.1; **HRMS (ESI+):** Calcd. for $C_{23}H_{20}O_3Na$ ($[M+Na]^+$): 367.1310, Found: 367.1310; **Optical rotation:** $[\alpha]_D^{22}$ +127.3 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AS-H column (90:10 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 260 nm, τ_{major} = 17.2 min, τ_{minor} = 19.2 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ab** was assigned in analogy with *trans*-**10** (see below).

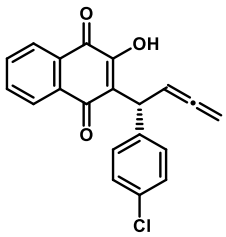
Compound 3ac: Reaction time 48 h (for 1st step); Isolated and characterized as the TBS-ether; Purified by silica-gel flash column chromatography (1% EtOAc in petroleum ether); yellow oil (59.0 mg, 0.121 mmol, 61% yield (over 2 steps)); **FT-IR (Thin film):** 3427 (w), 2891 (w), 2932 (w), 1953 (w), 1672 (m), 1598 (m), 1518 (s), 1481 (w), 1343 (m), 1261 (m), 1212 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.08-8.06 (m, 1H), 8.02-8.00 (m, 1H), 7.71-7.65 (m, 2H), 7.58-7.53 (m, 4H), 7.47 (d, *J* = 8.2 Hz, 2H), 7.42 (t, *J* = 7.3 Hz, 2H), 7.34-7.30 (m, 1H), 6.09-6.03 (m, 1H), 5.40-5.39 (m, 1H), 4.84-4.79 (m, 1H), 4.76-4.72 (m, 1H), 0.98 (s, 9H), 0.44 (s, 3H), 0.37 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.5, 184.8, 181.9, 154.6, 141.2, 141.0, 139.3, 134.3, 133.1, 132.6, 131.3, 130.6, 128.8, 127.8, 127.2, 126.5, 126.2, 90.4, 75.8, 40.8, 26.1, 19.3, –3.3, –3.5; **HRMS (ESI+):** Calcd. for $C_{32}H_{33}SiO_3$ ($[M+H]^+$): 493.2199, Found: 493.2198; **Optical rotation:** $[\alpha]_D^{22}$ +31.8 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 99:1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 263 nm, τ_{major} = 10.3 min, τ_{minor} = 11.5 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product 3**ac** was assigned in analogy with *trans*-**10** (see below).



Compound 3ad: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (38.0 mg, 0.103 mmol, 52% yield); **FT-IR (Thin film):** 3350 (br), 1954 (w), 1651 (s), 1460 (w), 1414 (w), 1367 (m), 1319 (s), 1258 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.13-8.08 (m, 2H), 7.78 (dt, *J* = 7.5, 1.3 Hz, 1H), 7.70 (dt, *J* = 7.5, 1.3 Hz, 1H), 7.54 (m, 5H), 5.96-5.91 (m, 1H), 5.31-5.29 (m, 1H), 4.83-4.74 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 183.5, 181.6, 153.0, 145.4, 135.3, 133.2, 132.7, 129.3, 129.2, 128.8 (q, *J* = 32.6 Hz), 128.3, 127.2, 126.3, 125.2 (q, *J* = 3.7 Hz), 124.2 (q, *J* = 274.0 Hz), 89.3, 76.3, 40.5; **^{19}F-NMR (376 MHz, $CDCl_3$):** δ –62.4; **HRMS (ESI+):** Calcd. for $C_{21}H_{14}F_3O_3$ ($[M+H]^+$): 371.0895, Found: 371.0894; **Optical rotation:** $[\alpha]_D^{20}$ +72.7 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 269 nm, τ_{major} = 10.5 min, τ_{minor} = 12.1 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ad** was assigned in analogy with *trans*-**10** (see below).

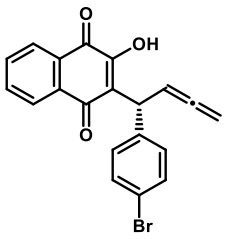


Compound 3ae: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (53.0 mg, 0.157 mmol, 79% yield); **FT-IR (Thin film):** 3360 (br), 1954 (w), 1666 (s), 1592 (m), 1489 (m), 1373 (s), 1338 (s), 1279 (s), 1253 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.05-7.99 (m, 2H), 7.69 (dt, *J* = 7.6, 1.3 Hz, 1H), 7.62 (dt, *J* = 7.6, 1.3 Hz, 1H), 7.45 (br, 1H), 7.30 (d, *J* = 8.4 Hz, 2H), 7.18 (d, *J* = 8.3 Hz, 2H), 5.86-5.81 (m, 1H), 5.16-5.14 (m, 1H), 4.73-4.65 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.2, 183.7, 181.8, 153.0, 140.0, 135.4, 133.3, 132.9, 132.5, 129.5, 129.3, 128.5, 127.3, 126.4, 124.2, 89.8, 76.3, 40.2; **HRMS (ESI+):** Calcd.

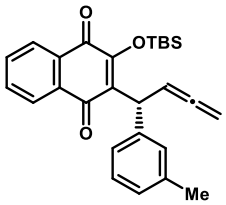


for $C_{20}H_{14}ClO_3$ ([M+H]$^+$): 337.0631, Found: 337.0630; **Optical rotation:** $[\alpha]_D^{22}$ +145.4 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IG column (90:10 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 241 nm, τ_{major} = 22.4 min, τ_{minor} = 26.0 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ae** was assigned in analogy with *trans*-**10** (see below).

Compound 3af: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (60.0 mg, 0.157 mmol, 79% yield); **FT-IR (Thin film):** 3358 (br), 2924 (w), 2364 (w), 2332 (w), 1953 (w), 1665 (s), 1644 (s), 1590 (m), 1485 (m), 1371 (s), 1338 (s), 1279 (s), 1253 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.12-8.07 (m, 2H), 7.79-7.75 (m, 1H), 7.71-7.67 (m, 1H), 7.53 (br, 1H), 7.40 (d, *J* = 8.5 Hz, 2H), 7.31 (d, *J* = 8.4 Hz, 2H), 5.93-5.87 (m, 1H), 5.22-5.20 (m, 1H), 4.81-4.72 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 183.7, 181.8, 153.0, 140.5, 135.4, 133.2, 132.8, 131.4, 129.8, 129.3, 127.2, 126.3, 124.0, 120.6, 89.7, 76.4, 40.2; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}BrO_3$ ([M+H]$^+$): 381.0126, Found: 381.0124; **Optical rotation:** $[\alpha]_D^{22}$ +108.6 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IG column (90:10 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 258 nm, τ_{major} = 23.5 min, τ_{minor} = 27.0 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3af** was assigned in analogy with *trans*-**10** (see below).



Compound 3ag: Reaction time 48 h (for 1st step); Isolated and characterized as the TBS-ether; Purified by silica-gel flash column chromatography (1% EtOAc in petroleum ether); yellow oil (72.0 mg, 0.167 mmol, 84% yield (over two steps)); **FT-IR (Thin film):** 2934 (w), 2858 (w), 1953 (w), 1669 (m), 1508 (m), 1465 (w), 1343 (m), 1261 (s), 1211 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.07-8.04 (m, 1H), 8.00-7.98 (m, 1H), 7.70-7.64 (m, 2H), 7.20-7.17 (m, 3H), 7.00 (m, 1H), 6.04-5.99 (m, 1H), 5.32-5.29 (m, 1H), 4.80-4.76 (m, 1H), 4.73-4.69 (m, 1H), 2.33 (s, 3H), 0.97 (s, 9H), 0.42 (s, 3H), 0.34 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.4, 184.7, 181.9, 154.6, 141.8, 137.9, 134.2, 132.9, 132.6, 131.6, 130.6, 128.3, 128.1, 127.2, 126.5, 126.1, 124.5, 90.6, 75.7, 41.0, 26.1, 21.7, 19.3, –3.3, –3.5; **HRMS (ESI+):** Calcd. for $C_{27}H_{30}SiO_3Na$ ([M+Na]$^+$): 453.1862, Found: 453.1865; **Optical rotation:** $[\alpha]_D^{22}$ +97.3 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 99:1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 247 nm, τ_{major} = 9.4 min, τ_{minor} = 10.9 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ag** was assigned in analogy with *trans*-**10** (see below).



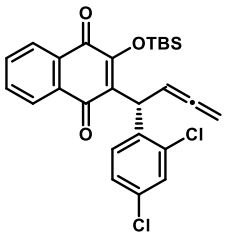
Compound 3ah: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (54.0 mg, 0.168 mmol, 84% yield); **FT-IR (Thin film):** 3361 (br), 2923 (w), 2359 (w), 1953 (w), 1667 (s), 1644 (s), 1587 (s), 1372 (s), 1338 (s), 1280 (s), 1245 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.11 (dd, *J* = 7.8, 0.9 Hz, 1H), 8.08 (dd, *J* = 7.6, 0.9 Hz, 1H), 7.79-7.75 (m, 1H), 7.71-7.67 (m, 1H), 7.54 (s, 1H), 7.25-7.15 (m, 3H), 6.92-6.87 (m, 1H), 5.95-5.89 (m, 1H), 5.26-5.24 (m, 1H), 4.81-4.75 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.2, 183.7, 181.8, 163.5 (d, *J* = 245.4 Hz), 153.1, 144.1 (d, *J* = 6.8 Hz), 135.4, 133.3, 132.9, 129.6 (d, *J* = 8.5 Hz), 129.3, 127.3, 126.4, 124.0, 123.6 (d, *J* = 2.8 Hz), 115.0 (d, *J* = 21.9 Hz), 113.6 (d, *J* = 21.3 Hz), 89.6, 76.3, 40.4; **^{19}F-NMR (376 MHz, $CDCl_3$):** δ –113.4; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}FO_3$ ($[M+H]^+$): 321.0297, Found: 321.0297; **Optical rotation:** $[\alpha]_D^{22}$ +192.2 (*c* 3.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak ID column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 252 nm, τ_{major} = 11.7 min, τ_{minor} = 22.0 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ah** was assigned in analogy with *trans*-**10** (see below).

Compound 3ai: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (46.0 mg, 0.136 mmol, 68% yield); **FT-IR (Thin film):** 3342 (br), 2925 (w), 1953 (w), 1650 (s), 1589 (m), 1470 (w), 1421 (w), 1367 (m), 1271 (m), 1220 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.05-8.00 (m, 2H), 7.69 (dt, *J* = 7.5, 1.0 Hz, 1H), 7.62 (dt, *J* = 7.6, 1.0 Hz, 1H), 7.46 (br, 1H), 7.34 (s, 1H), 7.25-7.23 (m, 1H), 7.18-7.09 (m, 2H), 5.85-5.81 (m, 1H), 5.16 (d, *J* = 8.6 Hz, 1H), 4.75-4.65 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.2, 183.7, 181.8, 153.1, 143.6, 135.4, 134.3, 133.3, 132.9, 129.6, 129.3, 128.2, 127.3, 126.9, 126.4, 126.2, 123.9, 89.5, 76.4, 40.4; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}ClO_3$ ($[M+H]^+$): 337.0631, Found: 337.0631; **Optical rotation:** $[\alpha]_D^{22}$ –4.6 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/EtOH, 0.5 mL/min, 20 °C, 242 nm, τ_{major} = 21.9 min, τ_{minor} = 24.8 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ai** was assigned in analogy with *trans*-**10** (see below).

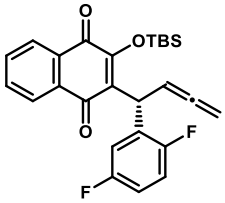
Compound 3aj: Reaction time 48 h, purified by silica-gel flash column chromatography (100% toluene); yellow solid (32.0 mg, 0.101 mmol, 51% yield); **m.p.** 146-147 °C; **FT-IR (Thin film):** 3352 (br), 2923 (w), 2857 (w), 1952 (w), 1654 (s), 1593 (m), 1459 (m), 1368 (s), 1263 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.13-8.06 (m, 2H), 7.78-7.74 (m, 1H), 7.70-7.66 (m, 1H), 7.62-7.60 (m, 1H), 7.52 (br. 1H), 7.21-7.12 (m, 3H), 5.86-5.81 (m, 1H), 5.36-5.34 (m, 1H), 4.74-4.72 (m, 2H), 2.35 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 208.6, 183.8, 181.9, 153.4, 139.5, 136.6, 135.3, 133.1, 133.0, 130.4, 129.3, 129.0, 127.3, 126.9, 126.3, 125.9, 123.9, 91.0, 76.4, 38.4, 20.0; **HRMS (ESI+):** Calcd. for

$C_{21}H_{17}O_3$ ([M+H]$^+$): 317.1178, Found: 317.1179; **Optical rotation:** $[\alpha]_D^{22}$ +133.1 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 274 nm, τ_{major} = 11.7 min, τ_{minor} = 13.5 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3aj** was assigned in analogy with *trans*-**10** (see below).

Compound 3ak: Reaction time 48 h (for 1st step), purified by silica-gel flash column chromatography (2-3% EtOAc in petroleum ether); yellow liquid (40.0 mg, 0.083 mmol, 42% yield (over 2 steps)); **m.p.** 90-91 °C; **FT-IR (Thin film):** 3074 (w), 2955 (w), 2862 (w), 2808 (w), 1957 (w), 1663 (s), 1593 (m), 1469 (m), 1364 (s), 1266 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.03-8.01 (m, 1H), 7.92-7.90 (m, 1H), 7.75 (d, *J* = 8.2 Hz, 1H), 7.67-7.64 (m, 2H), 7.30-7.26 (m, 2H), 5.77-5.72 (m, 1H), 5.32-5.30 (m, 1H), 4.74-4.73 (m, 2H), 1.02 (s, 9H), 0.41 (s, 3H), 0.34 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.0, 184.7, 181.6, 155.1, 137.9, 134.33, 134.30, 133.0, 132.95, 132.5, 130.5, 129.0, 128.2, 126.7, 126.4, 126.2, 90.3, 76.8, 39.3, 26.2, 19.5, –3.2, –3.5; **HRMS (ESI+):** Calcd. for $C_{26}H_{27}Cl_2O_3Si$ ([M+H]$^+$): 485.1107, Found: 485.1104; **Optical rotation:** $[\alpha]_D^{20}$ +53.5 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 99:1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 263 nm, τ_{major} = 10.3 min, τ_{minor} = 11.5 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ak** was assigned in analogy with *trans*-**10** (see below).



Compound 3al: Reaction time 48 h (for 1st step), purified by silica-gel flash column chromatography (2-3% EtOAc in petroleum ether); yellow sticky liquid (43.0 mg, 0.095 mmol, 47% yield (over 2 steps)); **FT-IR (Thin film):** 2931 (w), 2858 (w), 1955 (w), 1668 (s), 1598 (m), 1422 (w), 1353 (s), 1268 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.03 (d, *J* = 6.9 Hz, 1H), 7.95 (d, *J* = 7.4 Hz, 1H), 7.69-7.63 (m, 2H), 7.43-7.39 (m, 1H), 6.87-6.84 (m, 2H), 5.87-5.81 (m, 1H), 5.41 (d, *J* = 8.6 Hz, 1H), 4.80-4.72 (m, 2H), 0.99 (s, 9H), 0.39 (s, 3H), 0.37 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.3, 184.6, 181.7, 159.87, 159.85, 158.04, 157.5, 155.63, 155.61, 154.6, 134.3, 133.1, 132.5, 130.83, 130.75, 130.7, 130.6, 130.5, 129.0, 126.4, 126.2, 117.39, 117.35, 117.14, 117.1, 116.0, 115.9, 115.74, 115.66, 114.6, 114.5, 114.3, 114.2, 89.3, 76.6, 35.8, 26.1, 19.4, –3.4, –3.5; **^{19}F-NMR (376 MHz, $CDCl_3$):** δ –119.0 (d, *J* = 18.0 Hz), –122.0 (d, *J* = 17.9 Hz); **HRMS (ESI+):** Calcd. for $C_{26}H_{27}F_2O_3Si$ ([M+H]$^+$): 453.1698, Found: 453.1694; **Optical rotation:** $[\alpha]_D^{20}$ +30.9 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (85:15 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 290 nm, τ_{minor} = 10.5 min, τ_{major} = 12.1 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3al** was assigned in analogy with *trans*-**10** (see below).



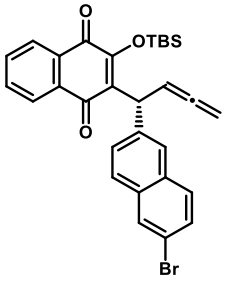
Compound 3am: Reaction time 48 h, purified by silica-gel flash column chromatography (3% EtOAc in petroleum ether); yellow sticky liquid (53.0 mg, 0.142 mmol, 71% yield); **FT-IR (Thin film):** 3344 (br), 3071 (w), 3021 (w), 2924 (w), 2856 (w), 1954 (w), 1654 (s), 1591 (m), 1467 (m), 1367 (s), 1271 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.05-8.00 (m, 2H), 7.70 (dt, *J* = 7.5, 1.1 Hz, 1H), 7.63 (dt, *J* = 7.5, 1.0 Hz, 1H), 7.50 (br, 1H), 7.44-7.43 (m, 1H), 7.27 (d, *J* = 8.3 Hz, 1H), 7.20-7.18 (m, 1H), 5.82-5.76 (m, 1H), 5.12 (d, *J* = 8.6 Hz, 1H), 4.76-4.67 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.2, 183.6, 181.7, 153.1, 141.8, 135.5, 133.4, 132.8, 132.4, 130.7, 130.3, 130.0, 129.3, 127.5, 127.3, 126.4, 123.5, 89.3, 76.6, 39.9; **HRMS (ESI+):** Calcd. for $C_{20}H_{13}Cl_2O_3$ ($[M+H]^+$): 371.0242, Found: 371.0241; **Optical rotation:** $[\alpha]_D^{22}$ –2.74 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/EtOH, 0.5 mL/min, 20 °C, 299 nm, τ_{major} = 23.4 min, τ_{minor} = 27.7 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3am** was assigned in analogy with *trans*-**10** (see below).

Compound 3an: Reaction time 48 h (for 1st step), purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); yellow sticky liquid (37.0 mg, 0.08 mmol, 40% yield (over 2 steps)); **FT-IR (Thin film):** 2923 (w), 2857 (w), 1955 (w), 1715 (s), 1653 (s), 1593 (m), 1488 (m), 1364 (s), 1244 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.05-8.03 (m, 1H), 7.99-7.97 (m, 1H), 7.70-7.63 (m, 2H), 6.88 (s, 1H), 6.83-6.81 (m, 1H), 6.72 (d, *J* = 8.2 Hz, 1H), 5.97-5.90 (m, 3H), 5.23 (d, *J* = 9.0 Hz, 1H), 4.79-4.75 (m, 1H), 4.72-4.67 (m, 1H), 0.96 (s, 9H), 0.40 (s, 3H), 0.34 (s, 3H) ; **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.4, 184.8, 181.9, 154.5, 147.7, 146.1, 135.9, 134.3, 133.1, 132.6, 131.4, 130.6, 126.5, 126.2, 120.4, 108.22, 108.16, 101.0, 90.7, 75.8, 40.8, 26.1, 19.3, –3.3, –3.5; **HRMS (ESI+):** Calcd. for $C_{21}H_{14}O_5Na$ ($[M+Na]^+$): 369.0739, Found: 369.0739 [*Note*: HRMS data matched with corresponding unprotected product]; **Optical rotation:** $[\alpha]_D^{20}$ +30.0 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 91:9 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IG column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 8.5 min, τ_{minor} = 10.2 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3an** was assigned in analogy with *trans*-**10** (see below).

Compound 3ao: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (56.0 mg, 0.159 mmol, 79% yield); **FT-IR (Thin film):** 3340 (br), 3055 (w), 3018 (w), 2925 (w), 2854 (w), 1953 (w), 1664 (s), 1647 (s), 1594 (m), 1460 (m), 1365 (s), 1276 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.12 (d, *J* = 7.4 Hz, 1H), 8.08 (d, *J* = 7.6 Hz, 1H), 7.89 (s, 1H), 7.81-7.74 (m, 4H), 7.70-7.66 (m, 1H), 7.57-7.54 (m, 2H), 7.46-7.39 (m, 2H), 6.11-6.06 (m, 1H), 5.45 (d, *J* = 8.7 Hz, 1H), 4.84-4.75 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.2, 183.9, 181.9, 153.1, 138.9, 135.3, 133.5, 133.2, 132.9, 132.4, 129.3, 128.04, 128.00, 127.7, 127.3,

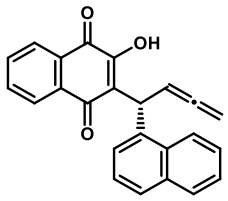
126.6, 126.4, 126.3 126.1, 125.7, 124.5, 90.0, 76.2, 40.8; **HRMS (ESI+):** Calcd. for $C_{24}H_{17}O_3$ ($[M+H]^+$): 353.1178, Found: 353.1176; **Optical rotation:** $[\alpha]_D^{22}$ +26.4 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 226 nm, τ_{major} = 21.6 min, τ_{minor} = 25.8 min,). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ao** was assigned in analogy with *trans*-**10** (see below).

Compound 3ap: Reaction time 48 h (for 1st step), purified by silica-gel flash column chromatography



(3-4% EtOAc in petroleum ether); pale yellow sticky liquid ((64.0 mg, 0.150 mmol, 75% yield) (1st step), (65 mg, 0.12 mmol, >99% yield) (for 2nd step); [*Note:* 2nd step was performed on 0.12 mmol scale]; **FT-IR (Thin film):** 2935 (w), 2857 (w), 1952 (w), 1667 (s), 1590 (s), 1463 (m), 1344 (m), 1261 (s), 1212 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.07-8.05 (m, 1H), 7.97-7.94 (m, 1H), 7.93 (br, 1H), 7.81 (s, 1H), 7.68-7.65 (m, 4H), 7.51-7.47 (m, 2H), 6.10-6.04 (m, 1H), 5.45 (d, *J* = 8.8 Hz, 1H), 4.85-4.81 (m, 1H), 4.78-4.73 (m, 1H), 0.93 (s, 9H), 0.42 (s, 3H), 0.36 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.6, 184.7, 181.9, 154.8, 140.0, 134.4, 133.4, 133.1, 132.5, 132.0, 131.0, 130.6, 129.7, 129.4, 127.1, 126.5, 126.2, 125.8, 119.4, 90.3, 76.0, 41.2, 26.1, 19.3, –3.3, –3.5; **HRMS (ESI+):** Calcd. for $C_{30}H_{29}BrO_3SiNa$ ($[M+Na]^+$): 567.0967, Found: 567.0964; **Optical rotation:** $[\alpha]_D^{20}$ +4.6 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 99:1 er. [Note: The enantiomeric ratio was determined for unprotected alcohol by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C), 269 nm, τ_{minor} = 24.3 min, τ_{major} = 26.9 min)]. See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ap** was assigned in analogy with *trans*-**10** (see below).

Compound 3aq: Reaction time 48 h, purified by silica-gel flash column chromatography (toluene);



yellow solid (46.0 mg, 0.130 mmol, 65% yield); **m.p.** 119-120 °C; **FT-IR (Thin film):** 3350 (br), 3051 (w), 2923 (w), 1953 (w), 1654 (s), 1592 (s), 1368 (s), 1268 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.16-8.11 (m, 2H), 8.04-8.03 (m, 1H), 7.88-7.83 (m, 2H), 7.77-7.74 (m, 2H), 7.67-7.64 (m, 1H), 7.51-7.43 (m, 4H), 5.97-5.94 (m, 2H), 4.80-4.77 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 208.7, 183.8, 181.7, 153.6, 136.8, 135.3, 133.9, 133.1, 132.9, 131.9, 129.3, 129.0, 127.7, 127.4, 127.1, 126.34, 126.26, 125.5, 125.3, 124.0, 123.6, 90.8, 76.8, 37.4; **HRMS (ESI+):** Calcd. for $C_{24}H_{17}O_3$ ($[M+H]^+$): 353.1178, Found: 353.1178; **Optical rotation:** $[\alpha]_D^{22}$ +3.0 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 98:2 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 230 nm, τ_{minor} = 21.5 min, τ_{major} = 28.7 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3aq** was assigned in analogy with *trans*-**10** (see below).

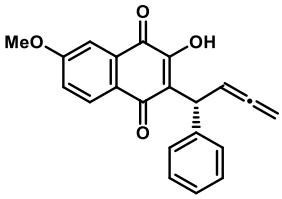
Compound 3ar: Reaction time 48 h (for 1st step), purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); pale yellow sticky liquid (30.0 mg, 0.07 mmol, 35% yield (over 2 steps)); **FT-IR (Thin film):** 2924 (w), 2855 (w), 1955 (w), 1709 (s), 1659 (s), 1589 (m), 1459 (m), 1365 (s), 1268 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.05-8.02 (m, 2H), 7.72-7.66 (m, 2H), 7.12 (dd, *J* = 5.1, 1.1 Hz, 1H), 6.95-6.90 (m, 2H), 6.06-6.02 (m, 1H), 5.47 (dd, *J* = 9.0, 1.3 Hz, 1H), 4.81-4.79 (m, 1H), 4.75-4.73 (m, 1H), 0.97 (s, 9H), 0.39 (s, 3H), 0.34 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 184.6, 181.9, 145.8, 134.4, 133.1, 132.6, 130.6, 130.5, 126.8, 126.6, 126.2, 124.5, 123.9, 91.4, 76.3, 37.5, 26.1, 19.3, –3.4, –3.5; **HRMS (ESI+):** Calcd. for $C_{18}H_{12}O_3SNa$ ([M+Na]$^+$): 331.0405, Found: 331.0409 [*Note*: HRMS data matched with corresponding unprotected product]; **Optical rotation:** $[\alpha]_D^{20}$ +36.4 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 254 nm, τ_{major} = 10.7 min, τ_{minor} = 14.5 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ar** was assigned in analogy with *trans*-**10** (see below).

Compound 3ba: Reaction time 48 h, purified by silica-gel flash column chromatography (8-9% EtOAc in petroleum ether); yellow sticky liquid (41.0 mg, 0.123 mmol, 62% yield); **FT-IR (Thin film):** 3432 (br), 2926 (w), 2848 (w), 1952 (w), 1647 (s), 1583 (m), 1466 (m), 1375 (m), 1277 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.75 (dd, *J* = 7.5, 0.9 Hz, 1H), 7.64-7.60 (m, 1H), 7.45 (d, *J* = 7.4 Hz, 2H), 7.34 (d, *J* = 8.5 Hz, 1H), 7.29-7.27 (m, 2H), 7.26-7.25 (m, 1H), 7.20-7.16 (m, 1H), 6.01-5.96 (m, 1H), 5.28 (d, *J* = 8.7 Hz, 1H), 4.77-4.69 (m, 2H), 4.00 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 183.5, 182.2, 160.0, 151.2, 141.7, 134.2, 131.5, 128.3, 128.1, 126.5, 126.2, 119.80, 119.77, 119.1, 90.1, 75.9, 56.7, 40.7; **HRMS (ESI+):** Calcd. for $C_{21}H_{17}O_4$ ([M+H]$^+$): 333.1127, Found: 333.1127; **Optical rotation:** $[\alpha]_D^{22}$ +100.9 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 99:1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 343 nm, τ_{minor} = 18.7 min, τ_{major} = 28.8 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ba** was assigned in analogy with *trans*-**10** (see below).

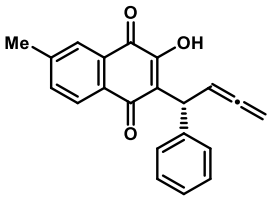
Compound 3ca: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow sticky liquid (56.0 mg, 0.166 mmol, 83% yield); **FT-IR (Thin film):** 3356 (br), 3069 (w), 2925 (w), 1953 (w), 1657 (s), 1585 (m), 1494 (w), 1364 (m), 1321 (m), 1259 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.07 (d, *J* = 2.1 Hz, 1H), 8.01 (d, *J* = 8.3 Hz, 1H), 7.64 (dd, *J* = 8.3, 2.1 Hz, 1H), 7.54 (s, 1H), 7.42 (d, *J* = 7.7 Hz, 2H), 7.32-7.28 (m, 2H), 7.23-7.19 (m, 1H), 5.99-5.94 (m, 1H), 5.25 (d, *J* = 8.6 HZ, 1H), 4.80-4.72 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 182.7, 181.0, 153.1, 142.5, 141.2, 134.2, 133.2, 128.5, 128.0, 127.9, 127.6, 126.8, 124.8, 89.9, 76.2,

40.8; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}ClO_3$ ($[M+H]^+$): 337.0631, Found: 337.0633; **Optical rotation:** $[\alpha]_D^{22}$ +4.8 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 380 nm, τ_{major} = 7.3 min, τ_{minor} = 9.8 min,). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ca** was assigned in analogy with *trans*-**10** (see below).

Compound 3da: Reaction time 48 h, purified by silica-gel flash column chromatography (4-5% EtOAc in petroleum ether); yellow solid (45.0 mg, 0.135 mmol, 70% yield); **m.p.** 66-67 °C; **FT-IR (Thin film):** 3360 (br), 3021 (w), 2930 (w), 2845 (w), 1953 (w), 1651 (s), 1594 (s), 1492 (w), 1447 (m), 1358 (s), 1279 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.07 (d, *J* = 8.6 Hz, 1H), 7.51 (*J* = 2.6 Hz, 1H), 7.48-7.46 (m, 3H), 7.34-7.30 (m, 2H), 7.24-7.21 (m, 2H), 6.04-5.98 (m, 1H), 5.30 (d, *J* = 8.8 Hz, 1H), 4.83-4.74 (m, 2H), 3.95 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 183.3, 182.1, 163.5, 152.8, 141.6, 131.1, 129.5, 128.4, 128.0, 126.6, 126.3, 124.4, 121.2, 109.9, 90.1, 76.0, 56.1, 40.6; **HRMS (ESI+):** Calcd. for $C_{21}H_{17}O_4$ ($[M+H]^+$): 333.1127, Found: 333.1125; **Optical rotation:** $[\alpha]_D^{22}$ +63.9 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.5:0.5 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C), 327 nm, τ_{minor} = 20.7 min, τ_{major} = 22.1 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3da** was assigned in analogy with *trans*-**10** (see below).

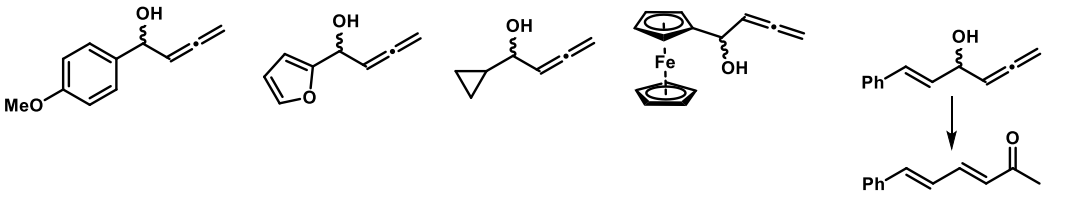


Compound 3ea: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow solid (51.0 mg, 0.16 mmol, 80% yield); **m.p.** 76-77 °C; **FT-IR (Thin film):** 3356 (br), 3027 (w), 2926 (w), 2857 (w), 1954 (w), 1653 (s), 1601 (m), 1492 (w), 1441 (m), 1358 (s), 1263 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.99 (d, *J* = 7.6 Hz, 1H), 7.86-7.85 (m, 1H), 7.56-7.51 (m, 2H), 7.45-7.44 (m, 2H), 7.31-7.28 (m, 2H), 7.22-7.18 (m, 1H), 6.02-5.96 (m, 1H), 5.27 (d, *J* = 9.0 Hz, 1H), 4.80-4.71 (m, 2H), 2.47 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 183.8, 182.2, 152.9, 144.1, 141.6, 135.9, 130.7, 129.2, 128.4, 128.0, 127.4, 126.7, 126.6, 124.4, 90.1, 76.0, 40.7, 21.7; **HRMS (ESI+):** Calcd. for $C_{21}H_{17}O_3$ ($[M+H]^+$): 317.1178, Found: 317.1177; **Optical rotation:** $[\alpha]_D^{22}$ +63.7 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.5:0.5 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 380 nm, τ_{major} = 7.9 min, τ_{minor} = 10.0 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3ea** was assigned in analogy with *trans*-**10** (see below).



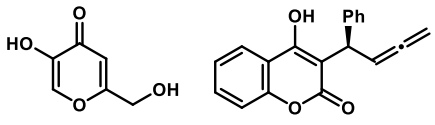
Compound 3fa: Reaction time 48 h, purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether); yellow solid (60.0 mg, 0.157 mmol, 78% yield); **m.p.** 111-112°C; **FT-IR (Thin film):** 3366 (br), 3068 (w), 3028 (w), 2925 (w), 1953 (w), 1655 (s), 1583 (m), 1492 (w), 1417 (w), 1354 (s), 1252 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.11 (d, *J* = 1.4 Hz, 1H), 7.90 (d, *J* = 8.3 Hz, 1H), 7.80 (dd, *J* = 8.3, 1.4 Hz, 1H), 7.36-7.34 (m, 3H), 7.24-7.18 (m, 2H), 7.15-7.11 (m, 1H), 5.91-5.86 (m, 1H), 5.19 (d, *J* = 8.9 Hz, 1H), 4.73-4.64 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.1, 183.1, 181.0, 152.8, 141.2, 138.1, 131.5, 130.5, 129.1, 129.0, 128.5, 128.4, 128.0, 126.8, 125.1, 89.9, 76.2, 40.7; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}BrO_3$ ($[M+H]^+$): 381.0126, Found: 381.0124; **Optical rotation:** $[\alpha]_D^{22}$ +26.3 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 380 nm, τ_{major} = 7.5 min, τ_{minor} = 9.0 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **3fa** was assigned in analogy with *trans*-**10** (see below).

H. Unsuccessful substrates:



<5% Yield | <5% Yield | <5% Yield | <5% Yield | 58% yield (with <5% desired product)

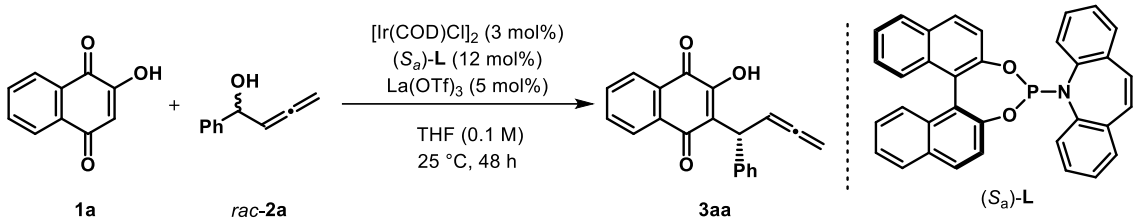
Unsuccessful electrophiles



<5% Yield | 34% Yield, 98.5:1.5 er

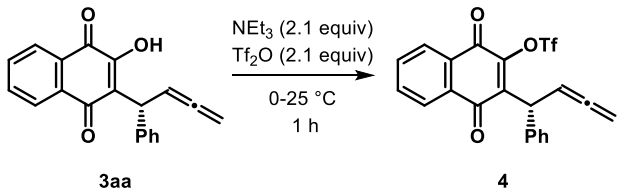
Unsuccessful nucleophiles

I. Catalytic enantioselective β-allenylation of 2-hydroxynaphthoquinone 1a on a 2.0 mmol scale:



In an oven and vacuum-dried round-bottom flask, $[Ir(COD)Cl]_2$ (40.3 mg, 0.06 mmol, 3 mol%) and (S_a)-**L** (121.8 mg, 0.24 mmol, 12 mol%) were taken in 15 mL of anh. THF under positive argon pressure and stirred vigorously at room temperature for 15 min to obtain a deep red solution. A solution of *rac*-**2a** (292.4 mg, 2 mmol, 1.0 equiv) in 4 mL of THF was then added and the resulting pale-yellow solution was stirred for 5 min at room temperature. To this solution, **1a** (522.5 mg, 3 mmol, 1.5 equiv) and $La(OTf)_3$ (58.6 mg, 0.1 mmol, 5 mol%) were added sequentially followed by the addition of another 1 mL of THF. The reaction flask was purged with argon, sealed with a glass stopper and the mixture was allowed to stir at 25 °C until TLC (10% EtOAc in petroleum ether) revealed complete consumption of *rac*-**2a**. The reaction mixture was filtered through a short pad of Celite®, washed with CH_2Cl_2 and concentrated under reduced pressure to obtain a yellow sticky liquid. The residue was purified by silica-gel flash column chromatography (3-4% EtOAc in petroleum ether) to obtain β-allenylic 2-hydroxynaphthoquinone **3aa** as yellow sticky liquid (454 mg, 1.5 mmol, 75% yield and 99.5:0.5 er).

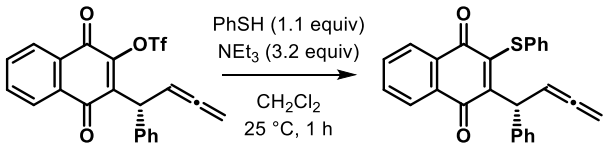
J. Procedure for the synthesis of 4:



In an oven dried 10 mL round-bottom flask, **3aa** (50.0 mg, 0.165 mmol, 1.0 equiv) was dissolved in 2 mL of anh. CH_2Cl_2 under argon atmosphere and cooled to 0 °C. To this yellow solution, NEt_3 (48 µL, 0.347 mmol, 2.1 equiv) was added dropwise at 0 °C to obtain deep red solution followed by dropwise addition of triflic anhydride (Tf_2O) (58 µL, 0.347 mmol, 2.1 equiv). The resulting mixture was then allowed to attain ambient temperature and stirred at that temperature for 1 h. Upon completion (monitored by TLC), the reaction mixture was quenched with 2 mL saturated $NaHCO_3$ solution and diluted with 2 mL of distilled H_2O, and 2 mL of CH_2Cl_2. The organic phase was separated, and the aqueous phase was extracted with CH_2Cl_2 (2 × 2 mL). The combined organic phase was washed with brine (3 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure. The residue was purified by silica gel flash column chromatography (1-2% EtOAc in petroleum ether) to obtain **4** as a sticky yellow liquid (60.0 mg, 0.135 mmol, 83% yield); **FT-IR (Thin film):** 2923 (w), 2853 (w), 1955

(w), 1681 (s), 1593 (m), 1287 (m), 1220 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.11-8.09 (m, 1H), 7.96-7.92 (m, 1H), 7.73-7.67 (m, 2H), 7.30-7.23 (m, 4H), 7.19-7.15 (m, 1H), 5.87-5.82 (m, 1H), 5.05 (d, *J* = 8.6 Hz, 1H), 4.82-4.71 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.7, 182.7, 177.5, 149.2, 140.4, 139.0, 135.2, 134.7, 131.9, 129.9, 128.8, 127.6, 127.5, 127.4, 127.1, 118.8 (q, *J* = 332.5 Hz), 89.2, 76.8, 42.8; **^{19}F-NMR (376 MHz, $CDCl_3$):** δ –71.6; **HRMS (ESI+):** Calcd. for $C_{21}H_{14}F_3O_5S$ ($[M+H]^+$): 435.0514, Found: 435.0511; **Optical rotation:** $[\alpha]_D^{22}$ +7.3 (*c* 2.0, $CHCl_3$). The absolute stereochemistry of the product **4** was assigned in analogy with *trans*-**10** (see below).

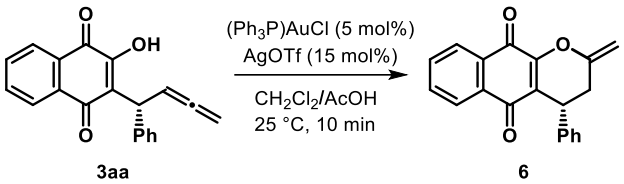
K. Procedure for the synthesis of thioether 5:



4 **5**

In an oven dried 10 mL round-bottom flask, **4** (20.0 mg, 0.046 mmol, 1.0 equiv) was dissolved in 1 mL of anh. CH_2Cl_2 under the argon atmosphere. To this yellow solution, PhSH (8 µL, 0.055 mmol, 1.1 equiv) was added dropwise and stirred at ambient temperature for 30 min. NEt_3 (22.3 µL, 0.16 mmol, 3.2 equiv) was then added and the resulting mixture was allowed to stir for 30 min. Upon completion (monitored by TLC), the reaction mixture was quenched with 2 mL saturated aqueous NH_4Cl solution, diluted with 1 mL of distilled H_2O and 1 mL of CH_2Cl_2. The organic phase was separated, and the aqueous phase was extracted with CH_2Cl_2 (2 × 2 mL). The combined organic phase was washed with brine (1 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure. The residue was purified by silica gel flash column chromatography (1-2% EtOAc in petroleum ether) to obtain **5** as a sticky yellow liquid (17 mg, 0.043 mmol, 93% yield); **FT-IR (Thin film):** 3062 (w), 2923 (w), 2856 (w), 1952 (w), 1664 (s), 1590 (m), 1483 (w), 1444 (w), 1319 (w), 1274 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.96-7.94 (m, 1H), 7.88-7.86 (m, 1H), 7.63-7.55 (m, 2H), 7.35-7.33 (m, 2H), 7.29-7.26 (m, 2H), 7.24-7.14 (m, 6H), 6.00-5.95 (m, 1H), 5.77 (d, *J* = 8.3 Hz, 1H), 4.75-4.69 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 209.8, 182.2, 180.6, 153.3, 146.5, 140.9, 134.6, 134.0, 133.8, 132.6, 132.4, 130.8, 129.3, 128.6, 127.62, 127.56, 127.2, 127.0, 126.8, 90.6, 76.4, 46.7; **HRMS (ESI+):** Calcd. for $C_{26}H_{19}SO_2$ ($[M+H]^+$): 395.1106, Found: 395.1106; **Optical rotation:** $[\alpha]_D^{22}$ –12.6 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 98:2 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 251 nm, τ_{major} = 5.8 min, τ_{minor} = 7.0 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **5** was assigned in analogy with *trans*-**10** (see below).

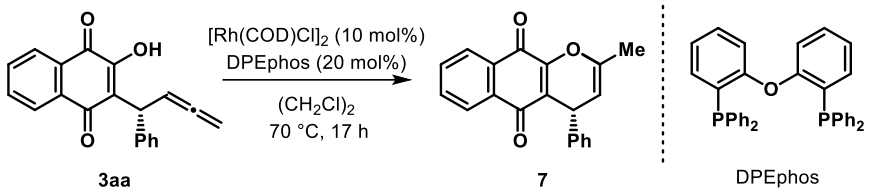
L. Procedure for Au-catalyzed cyclization of 3aa:



3aa **6**

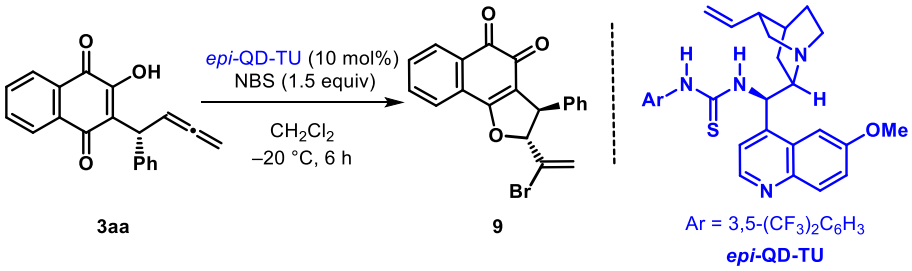
In an oven dried reaction tube, **3aa** (20.0 mg, 0.066 mmol, 1.0 equiv), PPh_3AuCl (1.7 mg, 0.0053 mmol, 5 mol%) and AgOTf (2.7 mg, 0.0105 mmol, 15 mol%) were dissolved in 1 mL of CH_2Cl_2. To this cloudy colorless solution, 4.8 µL of AcOH was added and the resulting light brown solution was allowed to stir at ambient temperature under argon atmosphere for 10 min. Upon completion, the reaction mixture was quenched with 2 mL saturated solution of $NaHCO_3$, diluted with 2 mL of distilled H_2O and 3 mL of CH_2Cl_2. The organic phase was separated, and the aqueous phase was extracted with CH_2Cl_2 (2 × 2 mL). The combined organic phase was washed with brine (3 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure. The residue was purified by silica gel flash column chromatography (7-8% EtOAc in petroleum ether) to obtain **6** as a sticky yellow liquid (20.0 mg, 0.066 mmol, >99% yield); **FT-IR (Thin film):** 3024 (w), 2920 (w), 2853 (w), 1653 (s), 1601 (s), 1485 (m), 1447 (m), 1363 (s), 1285 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.05 (d, *J* = 7.5 Hz, 1H), 7.93 (d, *J* = 7.7 Hz, 1H), 7.69-7.65 (m, 1H), 7.53-7.50 (m, 1H), 7.48-7.40 (m, 1H), 7.21-7.18 (m, 2H), 7.16-7.13 (m, 2H), 4.95 (s, 1H), 4.33-4.31 (m, 2H), 2.81 (dd, *J* = 14.5, 6.2 Hz, 1H), 2.62 (d, *J* = 14.4 Hz, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 179.1, 177.7, 160.0, 152.0, 142.1, 135.2, 131.4, 131.3, 130.6, 129.4, 128.6, 127.6, 127.1, 124.7, 116.4, 97.5, 34.4, 33.2; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}O_3Na$ ($[M+Na]^+$): 325.0841, Found: 325.0842; **Optical rotation:** $[\alpha]_D^{22}$ –13.4 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (80:20 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 317 nm, τ_{major} = 7.8 min, τ_{minor} = 11.2 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **6** was assigned in analogy with *trans*-**10** (see below).

M. Procedure for Rh-catalyzed cyclization of 3aa:



In a 10 mL round bottom flask, **3aa** (20.0 mg, 0.066 mmol, 1.0 equiv), $[Rh(COD)Cl]_2$ (4.9 mg, 0.0066 mmol, 10 mol%), and DPEphos (10.8 mg, 0.132 mmol, 20 mol%) were taken along with 1 mL of anhydrous $(CH_2Cl_2)_2$ under positive argon pressure. The resulting orange solution was then heated to 70 °C for 17 h. Upon completion, the reaction mixture was passed through a short pad of Celite® and the filtrate was concentrated under reduced pressure to obtain yellow sticky liquid. The residue was purified by silica gel flash column chromatography (3-4% EtOAC in petroleum ether) to obtain **7** as a yellow solid (15.0 mg, 0.049 mmol, 74% yield); **m.p.** 185-186 °C; **FT-IR (Thin film):** 3025 (w), 2922 (w), 1676 (s), 1589 (m), 1449 (w), 1373 (w), 1330 (m), 1298 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.13-8.11 (m, 1H), 7.98-7.95 (m, 1H), 7.69-7.67 (m, 2H), 7.37-7.35 (m, 2H), 7.32-7.29 (m, 2H), 7.22-7.19 (m, 1H), 5.03 (d, *J* = 4.3 Hz, 1H), 4.65 (d, *J* = 4.1 Hz, 1H), 2.08 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 184.1, 179.0, 151.2, 147.1, 144.5, 134.3, 133.5, 132.0, 131.0, 128.8, 128.5, 127.3, 126.5, 126.4, 122.1, 103.5, 36.1, 18.8; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}O_3Na$ ($[M+Na]^+$): 325.0841, Found: 325.0840; **Optical rotation:** $[\alpha]_D^{22}$ +273.0 (*c* 1.0 $CHCl_3$) for an enantiomerically enriched sample with 99:1 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IH column (80:20 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 234 nm, τ_{minor} = 6.1 min, τ_{major} = 6.6 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **7** was assigned in analogy with *trans*-**10** (see below).

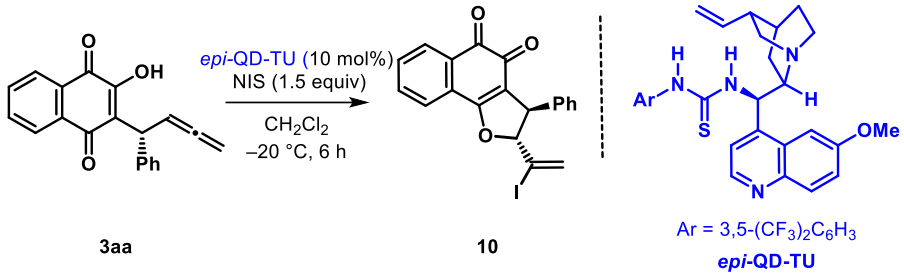
N. Procedure for bromocyclization of 3aa:



In an oven dried 10 mL round-bottom flask, ***epi*-QD-TU** (9.8 mg, 0.0165 mmol, 10 mol%) and recrystallized *N*-bromosuccinimide (NBS) (44 mg, 0.248 mmol, 1.5 equiv) were taken in 1.6 mL of dry CH_2Cl_2 under argon atmosphere and cooled to –20 °C. The resulting orange solution was allowed to stir at –20 °C for 2 min. To this, a solution of **3aa** (50 mg, 0.165 mmol, 1.0 equiv) in 0.4 mL of CH_2Cl_2 was added under positive argon pressure. The reaction mixture was allowed to stir at –20 °C for 6 h. Upon completion (monitored by TLC), the clear yellow solution was allowed to attain ambient

temperature and quenched with dropwise addition of 2 mL of saturated aqueous $Na_2S_2O_3$ solution. The organic layer was separated, and the aqueous layer was extracted with CH_2Cl_2 (3 × 2 mL). The combined organic layer was washed with brine (3 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain a sticky yellow liquid. The diastereomeric ratio (dr) was determined to be 10:1 by ^{1}H NMR analysis of the unpurified reaction mixture. The residue was purified by silica-gel flash column chromatography (7-9% EtOAc in petroleum ether) to obtain *trans*-**9** and *cis*-**9** separately (53 mg, 0.137 mmol, 82% combined yield). For *trans*-**9** (sticky yellow liquid, 45 mg, 0.117 mmol, 71% yield); **FT-IR (Thin film):** 3020 (w), 2925 (w), 2856 (w), 1654 (s), 1620 (s), 1451 (m), 1392 (m), 1278 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.06 (d, *J* = 7.5 Hz, 1H), 7.73-7.71 (m, 1H), 7.68-7.64 (m, 1H), 7.60-7.56 (m, 1H), 7.19-7.16 (m, 3H), 7.11-7.09 (m, 2H), 5.96 (s, 1H), 5.69 (d, *J* = 9.5 Hz, 1H), 5.49 (s, 1H), 4.77 (d, *J* = 9.2 Hz, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 180.5, 174.8, 168.7, 135.2, 134.9, 132.5, 131.1, 130.0, 129.4, 128.1, 128.0, 127.1, 124.9, 124.5, 119.3, 91.5, 49.1; **HRMS (ESI+):** Calcd. for $C_{20}H_{13}BrO_3Na$ ($[M+Na]^+$): 402.9946, Found: 402.9942; **Optical rotation:** $[\alpha]_D^{24}$ +14.1 (*c* 0.5, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (70:30 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 274 nm, τ_{major} = 39.4 min, τ_{minor} = 46.2 min). See Supporting Information: Part B for HPLC chromatograms. The absolute and relative stereochemistry of the product *trans*-**9** was assigned in analogy with *trans*-**10** (see below). For *cis*-**9** (sticky yellow liquid, 7 mg, 0.018 mmol, 11% yield); **FT-IR (Thin film):** 3066 (w), 2924 (w), 2855 (w), 1655 (s), 1620 (s), 1492 (w), 1451 (m), 1392 (m), 1279 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.07 (d, *J* = 7.4 Hz, 1H), 7.73-7.71 (m, 1H), 7.68-7.64 (m, 1H), 7.60-7.56 (m, 1H), 7.29-7.26 (m, 2H), 7.23-7.19 (m, 3H), 5.93 (s, 1H), 5.68 (s, 1H), 5.24 (d, *J* = 5.5 Hz, 1H), 4.58 (d, *J* = 5.4 Hz, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 180.7, 175.1, 168.9, 139.8, 134.9, 132.5, 131.3, 130.0, 129.6, 129.3, 128.0, 127.5, 127.2, 124.9, 120.1, 117.9, 95.9, 51.8; **HRMS (ESI+):** Calcd. for $C_{20}H_{14}BrO_3$ ($[M+H]^+$): 381.0126, Found: 381.0125; **Optical rotation:** $[\alpha]_D^{24}$ +13.2 (*c* 0.5, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (70:30 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 264 nm, τ_{minor} = 19.6 min τ_{major} = 21.1 min). See Supporting Information: Part B for HPLC chromatograms. The absolute and relative stereochemistry of the product *cis*-**9** was assigned in analogy with *trans*-**10** (see below).

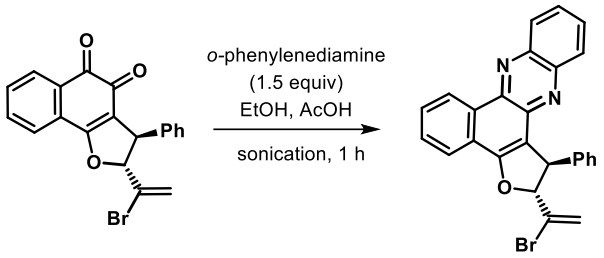
O. Procedure for iodocyclization of 3aa:



In an oven dried 10 mL round-bottom flask, ***epi*-QD-TU** (9.8 mg, 0.0165 mmol, 10 mol%) and *N*-iodosuccinimide (NIS) (56 mg, 0.248 mmol, 1.5 equiv) were taken in 1.6 mL of dry CH_2Cl_2 under argon atmosphere and cooled to –20 °C. The resulting orange solution was allowed to stir at –20 °C for 2 min. To this, a solution of **3aa** (50 mg, 0.165 mmol, 1.0 equiv) in 0.4 mL of CH_2Cl_2 was added under positive argon pressure. The reaction mixture was allowed to stir at –20 °C for 6 h. Upon completion, the clear yellow solution was allowed to attain ambient temperature and quenched with dropwise addition of 2 mL of saturated aqueous $Na_2S_2O_3$ solution. The organic layer was separated, and the aqueous layer was extracted with CH_2Cl_2 (3 × 2 mL). The combined organic layer was washed with brine (3 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain a sticky yellow liquid. The diastereomeric ratio (dr) was determined to be 1.5:1 by ^{1}H NMR analysis of the unpurified reaction mixture. The crude residue was purified by silica-gel flash column chromatography (7-9% EtOAc in petroleum ether) to obtain *trans*-**10** and *cis*-**10** separately (60 mg, 0.142 mmol, 86% combined yield). For *trans*-**10** (yellow solid, 36 mg, 0.086 mmol, 52% yield); **m.p.** 145-146 °C; **FT-IR (Thin film):** 3014 (w), 2922 (w), 2854 (w), 1616 (s), 1575 (s), 1489 (m), 1451 (w), 1389 (m), 1279 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.06 (d, *J* = 7.6 Hz, 1H), 7.73-7.71 (m, 1H), 7.68-7.64 (m, 1H), 7.59-7.56 (m, 1H), 7.19-7.16 (m, 3H), 7.13-7.12 (m, 2H), 6.44 (s, 1H), 5.81 (s, 1H), 5.70 (d, *J* = 9.1 Hz, 1H), 4.79 (d, *J* = 8.8 Hz, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 180.5, 174.8, 168.7, 135.1, 134.9, 132.5, 131.1, 130.0, 129.8, 128.1, 127.9, 127.8, 127.2, 124.9, 119.4, 100.0, 93.7, 49.2; **HRMS (ESI+):** Calcd. for $C_{20}H_{13}IO_3Na$ ($[M+Na]^+$): 450.9807, Found: 450.9808; **Optical rotation:** $[\alpha]_D^{24}$ +24.6 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (70:25:5 *n*-Hexane/IPA/EtOH, 3.0 mL/min, 20 °C, 257 nm, τ_{major} = 12.5 min, τ_{minor} = 14.7 min). See Supporting Information: Part B for HPLC chromatograms. The absolute and relative stereochemistry of the product *trans*-**10** was determined by single crystal X-ray diffraction analysis (see below). For *cis*-**10** (yellow sticky liquid, 24 mg, 0.056 mmol, 34% yield); **FT-IR (Thin film):** 3013 (w), 2922 (w), 2854 (w), 1651 (s), 1615 (s), 1489 (w), 1450 (w), 1390 (m), 1277 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.07 (d, *J* = 8.7 Hz, 1H), 7.73-7.71 (m, 1H), 7.68-7.64 (m, 1H), 7.60-7.56 (m, 1H), 7.29-7.26 (m, 2H), 7.23-7.19 (m, 3H), 6.39-6.38 (m, 1H), 5.96 (d, *J* = 2.1 Hz, 1H), 4.96 (d, *J* = 6.0 Hz, 1H), 4.44 (d, *J* = 5.8 Hz, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 180.7, 175.0, 168.9, 139.5, 134.9, 132.5, 131.2, 129.9, 129.2, 128.5, 128.0, 127.6, 127.2, 125.0, 117.7, 107.6, 97.9, 52.9; **HRMS (ESI+):** Calcd. for $C_{20}H_{13}IO_3$ ($[M+Na]^+$):

450.9807, Found: 450.9807; **Optical rotation:** $[\alpha]_D^{24}$ +15.1 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (70:30 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 280 nm, τ_{minor} = 20.3 min τ_{major} = 22.2 min). See Supporting Information: Part B for HPLC chromatograms. The absolute and relative stereochemistry of the product *cis*-**10** was assigned in analogy with *trans*-**10**.

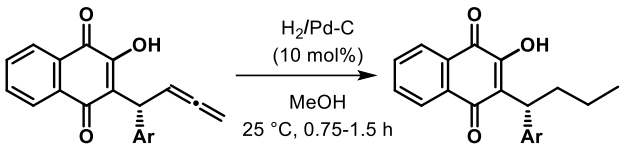
P. Procedure for the synthesis of quinoxaline 11:



trans-**9** **11**

In an oven dried 10 mL round-bottom flask, *trans*-**9** (25.0 mg, 0.07 mmol, 1.0 equiv) and *o*-phenylenediamine (11.4 mg, 0.105 mmol, 1.5 equiv) were taken in 1 mL of ethanol under argon atmosphere. To this yellow solution, 10µL of AcOH was added and the resulting mixture was sonicated at 25 °C for 1 h. After TLC revealed the complete consumption of *trans*-**9**, the volatiles were evaporated under reduced pressure to obtain a sticky yellow liquid. The residue was purified by silica gel (100-200 mesh) column chromatography (1-2 % EtOAc in Petroleum ether) to obtain **11** as a yellow solid (32 mg, 0.07 mmol, >99% yield); **m.p.** 243-244 °C; **FT-IR (Thin film):** 3058 (w), 2923 (m), 2855 (w), 1949 (w), 1683 (m), 1637 (s), 1499 (m), 1425 (m), 1343 (s), 1291 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 9.34-9.32 (m, 1H), 8.17-8.12 (m, 2H), 7.97-7.95 (m, 1H), 7.79-7.77 (m, 2H), 7.65-7.61 (m, 2H), 7.17-7.14 (m, 2H), 7.11-7.06 (m, 3H), 6.12-6.11 (m, 1H), 5.84 (d, *J* = 8.4 Hz, 1H), 5.50 (s, 1H), 5.40 (d, *J* = 8.2 Hz, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 141.5, 140.4, 137.4, 132.4, 130.2, 130.1, 129.8, 129.6, 129.0, 128.7, 127.8, 127.3, 126.3, 125.9, 124.1, 122.6, 118.7, 117.8, 91.2, 50.8; **HRMS (ESI+):** Calcd. for $C_{26}H_{18}BrN_2O$ ($[M+H]^+$): 453.0603, Found: 453.0603; **Optical rotation:** $[\alpha]_D^{22}$ –66.0 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 96:4 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Amylose-2 column (95:5 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 280 nm, τ_{minor} = 9.2 min, τ_{major} = 9.8 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **11** was assigned in analogy with *trans*-**10** (see below).

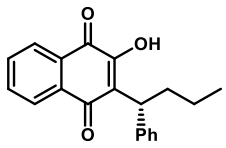
Q. General procedure for the hydrogenation of 3:



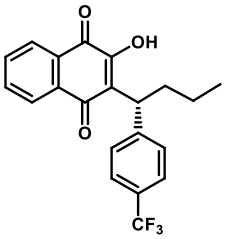
3 **12**

In an oven and vacuum-dried 10 mL round-bottom flask, a solution of **3** (1.0 equiv) in MeOH (2.0 mL), 10% Pd/C (10 mol%) were added. The resulting mixture was degassed and stirred under H_2 balloon pressure for 45 min to 1.5 h at 25 °C. The reaction mixture was filtered over Celite® and washed with CH_2Cl_2. The filtrate was concentrated under reduced pressure and the residue was purified by silica gel flash column chromatography (1-2% EtOAc in petroleum ether) to obtain **12**.

Compound 12a: Reaction was performed on 0.25 mmol scale, reaction time 45 min, purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); sticky yellow liquid (77.0 mg, 0.25 mmol, >99% yield); **FT-IR (Thin film):** 3351 (br), 3052 (w), 2924 (w), 1953 (w), 1654 (s), 1592 (m), 1368 (s), 1269 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.02 (d, *J* = 7.7 Hz, 1H), 7.96 (d, *J* = 7.6 Hz, 1H), 7.68-7.64 (m, 1H), 7.59-7.55 (m, 1H), 7.41-7.39 (m, 2H), 7.21-7.18 (m, 2H), 7.11-7.08 (m, 1H), 4.44 (t, *J* = 7.8 Hz, 1H), 2.23-2.21 (m, 1H), 2.12-2.07 (m, 1H), 1.29-1.23 (m, 2H), 0.87 (t, *J* = 6.7 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 184.5, 182.1, 153.2, 143.1, 135.2, 133.1, 133.0, 129.3, 128.6, 128.3, 127.2, 126.4, 126.1, 125.9, 40.8, 33.7, 21.7, 14.3; **HRMS (ESI+):** Calcd. for $C_{20}H_{18}O_3Na$ ($[M+Na]^+$): 329.1154, Found: 329.1151; **Optical rotation:** $[\alpha]_D^{20}$ +74.0 (*c* 1.0, $CHCl_3$). The absolute stereochemistry of the product **12a** was assigned in analogy with *trans*-**10**.



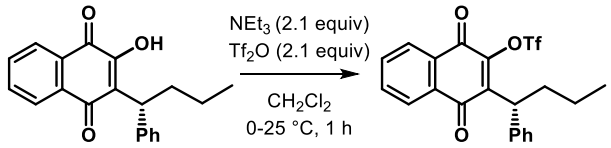
Compound 12b: Reaction was performed on 0.05 mmol scale; reaction time 45 min, purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); sticky yellow liquid (20.0 mg, 0.054 mmol, >99% yield); **FT-IR (Thin film):** 3362 (br), 2960 (w), 2930 (w), 2867 (w), 1657 (s), 1594 (w), 1373 (m), 1326 (s), 1277 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.10 (d, *J* = 7.7 Hz, 1H), 8.06 (d, *J* = 7.7 Hz, 1H), 7.77-7.74 (m, 1H), 7.69-7.66 (m, 1H), 7.59-7.57 (m, 3H), 7.53-7.51 (m, 2H), 4.56 (t, *J* = 7.9 Hz, 1H), 2.34-2.27 (m, 1H), 2.22-2.13 (m, 1H), 1.37-1.31 (m, 2H), 0.95 (t, *J* = 7.5 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 184.4, 181.8, 153.2, 147.0, 135.4, 133.2, 133.0, 129.3, 129.1, 128.6 (q, *J* = 32.7 Hz), 128.0, 127.3, 126.3, 124.4 (q, *J* = 271.4 Hz), 125.2 (q, *J* = 3.8 Hz), 40.7, 33.4, 21.6, 14.2; **^{19}F-NMR (376 MHz, $CDCl_3$):** δ –62.4; **HRMS (ESI+):** Calcd. for $C_{21}H_{18}F_3O_3$ ($[M+H]^+$): 375.1208, Found: 375.1206; **Optical rotation:** $[\alpha]_D^{24}$ +66.6 (*c* 0.75, $CHCl_3$) for an enantiomerically enriched sample with 99.3:0.7 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (95:5 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 280 nm, τ_{minor}



= 14.5 min τ_{major} = 15.4 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **12b** was assigned in analogy with *trans*-**10** (see below).

Compound 12c: Reaction was performed on 0.06 mmol scale, reaction time 1.5 h, purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); sticky yellow liquid (21.0 mg, 0.062 mmol, >99% yield); **FT-IR (Thin film):** 3357 (br), 3071 (w), 2927 (w), 2865 (w), 1654 (s), 1591 (m), 1454 (m), 1370 (s), 1275 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.10 (d, *J* = 7.5 Hz, 1H), 8.05 (d, *J* = 7.5 Hz, 1H), 7.76-7.73 (m, 1H), 7.68-7.64 (m, 1H), 7.58 (s, 1H), 7.21-7.19 (m, 3H), 6.88-6.84 (m, 1H), 4.50 (t, *J* = 7.8 Hz, 1H), 2.33-2.23 (m, 1H), 2.19-2.10 (m, 1H), 1.36-1.30 (m, 2H), 0.94 (t, *J* = 7.4 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 184.4, 181.9, 162.9 (d, *J* = 247.5 Hz), 153.2, 145.6, 145.5, 135.3, 133.1 (d, *J* = 7.7 Hz), 129.6 (d, *J* = 8.6 Hz), 129.3, 127.2, 126.2, 125.2, 124.3 (d, *J* = 2.9 Hz), 115.5 (d, *J* = 21.9 Hz), 113.3 (d, *J* = 20.7 Hz), 40.5, 33.5, 21.6, 14.2; **^{19}F-NMR (376 MHz, $CDCl_3$):** δ –113.4; **HRMS (ESI+):** Calcd. for $C_{20}H_{18}FO_3$ ($[M+H]^+$): 325.1240, Found: 325.1243; **Optical rotation:** $[\alpha]_D^{24}$ +137.4 (*c* 0.5, $CHCl_3$) for an enantiomerically enriched sample with 99.4.0.6 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (95:5 *n*-Hexane/IPA, 0.5 mL/min, 20 °C, 253 nm, τ_{minor} = 18.6 min τ_{major} = 19.9 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **12c** was assigned in analogy with *trans*-**10** (see below).

R. Procedure for the synthesis of 13:

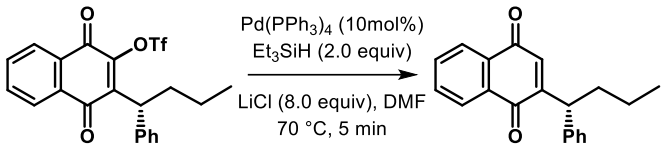


12a **13**

In an oven dried 10 mL round-bottom flask, **12a** (77.0 mg, 0.25 mmol, 1.0 equiv) was dissolved in 2 mL of anh. CH_2Cl_2 under argon atmosphere and cooled to 0 °C. To this yellow solution, NEt_3 (74 µL, 0.53 mmol, 2.1 equiv) was added dropwise at 0 °C to obtain deep red solution followed by dropwise addition of triflic anhydride (Tf_2O) (150 µL, 0.53 mmol, 2.1 equiv). The resulting mixture was then allowed to attain ambient temperature and stirred at 25 °C for 1 h. Upon completion (monitored by TLC), the reaction mixture was quenched with 3 mL saturated aqueous $NaHCO_3$ solution, diluted with 3 mL of distilled H_2O and 2 mL of CH_2Cl_2. The organic phase was separated, and the aqueous phase was extracted with CH_2Cl_2 (2 × 3 mL). The combined organic phase was washed with brine (2 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain a sticky yellow liquid. The residue was purified by silica gel flash column chromatography (1-2% EtOAc in petroleum ether) to obtain **13** as a yellow solid (81.0 mg, 0.184 mmol, 74% yield); **m.p.** 68-69 °C; **FT-IR (Thin film):** 3067 (w), 2926 (w), 2866 (w), 1680 (s), 1596 (w), 1423 (m), 1286 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):**

δ 8.17-8.13 (m, 1H), 8.04-8.00 (m, 1H), 7.79-7.74 (m, 2H), 7.43-7.41 (m, 2H), 7.34-7.30 (m, 2H), 7.24-7.21 (m, 1H), 4.38 (t, *J* = 7.6 Hz, 1H), 2.47-2.37 (m, 1H), 2.28-2.19 (m, 1H), 1.49-1.40 (m, 1H), 1.35-1.26 (m, 1H), 0.98 (t, *J* = 7.1 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 183.3, 177.3, 149.4, 142.2, 139.4, 135.1, 134.6, 132.1, 129.9, 128.8, 128.7, 127.4, 127.3, 127.0, 118.9 (q, *J* = 325.1 Hz), 43.2, 33.9, 21.6, 14.2; **^{19}F-NMR (376 MHz, $CDCl_3$):** δ –71.6; **HRMS (ESI+):** Calcd. for $C_{21}H_{18}F_3O_5S$ ($[M+H]^+$): 439.0827, Found: 439.0825; **Optical rotation:** $[\alpha]_D^{20}$ –21.0 (*c* 1.0, $CHCl_3$). The absolute stereochemistry of the product **13** was assigned in analogy with *trans*-**10**.

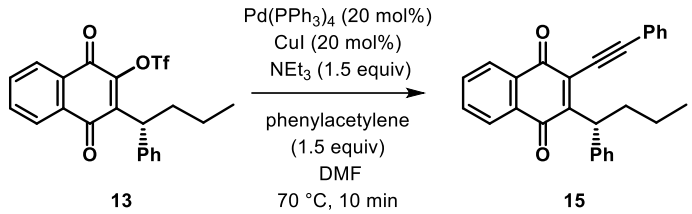
S. Procedure for the Pd-catalyzed reductive cleavage of enol triflate 13:



13 **14**

In an oven dried 10 mL round-bottom flask, **13** (15.0 mg, 0.034 mmol, 1.0 equiv), $Pd(PPh_3)_4$ (7.9 mg, 0.0068 mmol, 20 mol%), and activated (heated at 150 °C for 1.5 h under reduced pressure) LiCl (11.5 mg, 0.272 mmol, 8.0 equiv) were dissolved in 1 mL of DMF under argon atmosphere, heated to 70 °C and stirred for 5 min. To the resulting brown solution, Et_3SiH (11 µL, 0.0.068 mmol, 2.0 equiv) was added dropwise at 70 °C and the mixture was allowed to stir at same temperature for 5 min. Upon completion as revealed by TLC, the reaction mixture was diluted with 10 mL of distilled H_2O and 2 mL of Et_2O. The organic phase was separated, and the aqueous phase was extracted with Et_2O (2 × 3 mL). The combined organic phase was further extracted with H_2O (2 × 3 mL) and washed with brine (2 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain a sticky yellow liquid. The residue was purified by silica gel flash column chromatography (2-3% EtOAc in petroleum ether) to obtain **14** as a sticky yellow liquid (7.0 mg, 0.024 mmol, 71% yield); **FT-IR (Thin film):** 2960 (w), 2871 (w), 1681 (s), 1597 (w), 1423 (m), 1286 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.02 (dd, *J* = 7.6, 0.8 Hz, 1H), 7.96 (dd, *J* = 7.6, 1.0 Hz, 1H), 7.68-7.64 (m, 1H), 7.59-7.55 (m, 1H), 7.45 (s, 1H), 7.41-7.39 (m, 2H), 7.21-7.18 (m, 2H), 7.11-7.08 (m, 1H), 4.44 (t, *J* = 7.6 Hz, 1H), 2.29-2.20 (m, 1H), 2.14-2.05 (m, 1H), 1.29-1.24 (m, 2H), 0.87 (t, *J* = 7.2 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 184.5, 182.0, 153.1, 143.0, 135.2, 133.1, 133.0, 129.3, 128.7, 128.3, 127.2, 126.4, 126.1, 125.9, 40.8, 33.7, 21.7, 14.3; **HRMS (ESI+):** Calcd. for $C_{20}H_{18}O_2K$ ($[M+K]^+$): 329.0944, Found: 329.1146; **Optical rotation:** $[\alpha]_D^{22}$ –35.8 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with >99.9:0.1 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-3 column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C), 254 nm, τ_{minor} = 40.0 min, τ_{major} = 45.9 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **14** was assigned in analogy with *trans*-**10**.

T. Procedure for the Sonogashira coupling of 13 with phenylacetylene:



In an oven dried 10 mL round-bottom flask, **13** (15.0 mg, 0.034 mmol, 1.0 equiv), $Pd(PPh_3)_4$ (7.9 mg, 0.0068 mmol, 20 mol%), and CuI (1.3 mg, 0.0068 mmol, 20 mol%) were dissolved in 1 mL of DMF under argon atmosphere and stirred at 25 °C for 5 min. To this orange solution, phenylacetylene (5.6 µL, 0.051 mmol, 1.5 equiv) and NEt_3 (7.1 µL, 0.051 mmol, 1.5 equiv) were added and the resulting brown solution was heated at 70 °C for 10 min. Upon completion (monitored by TLC), the reaction mixture was diluted with 10 mL of distilled H_2O and 2 mL of Et_2O. The organic phase was separated, and the aqueous phase was extracted with Et_2O (2 × 3 mL). The combined organic phase was further extracted with H_2O (2 × 3 mL) and washed with brine (2 mL), dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain sticky yellow liquid. The residue was purified by silica gel flash column chromatography (2-3% EtOAc in petroleum ether) to obtain **15** as a yellow sticky liquid (10.0 mg, 0.025 mmol, 73% yield); **FT-IR (Thin film):** 2926 (w), 2861 (w), 2195 (w), 1658 (s), 1491 (w), 1452 (m), 1331 (w), 1278 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.04-8.02 (m, 1H), 7.96-7.94 (m, 1H), 7.64-7.56 (m, 4H), 7.47-7.45 (m, 2H), 7.36 (m, 2H), 7.24-7.19 (m, 3H), 7.14-7.12 (m, 1H), 4.76 (t, *J* = 7.0 Hz, 1H), 2.44-2.39 (m, 1H), 2.27-2.22 (m, 1H), 1.40-1.32 (m, 2H), 0.92 (t, *J* = 7.1 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 183.9, 181.9, 153.2, 141.8, 134.1, 133.7, 132.7, 132.3, 131.71, 131.67, 129.9, 128.7, 128.6, 128.4, 126.9, 126.7, 126.6, 122.3, 107.4, 83.9, 46.9, 34.1, 21.8, 14.4; **HRMS (ESI+):** Calcd. for $C_{28}H_{23}O_2$ ($[M+H]^+$): 391.1698, Found: 391.1698; **Optical rotation:** $[\alpha]_D^{20}$ –18.2 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 97:3 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C, 282 nm, τ_{major} = 5.7 min, τ_{minor} = 7.7 min). See Supporting Information: Part B for HPLC chromatograms. The absolute stereochemistry of the product **15** was assigned in analogy with *trans*-**10**.

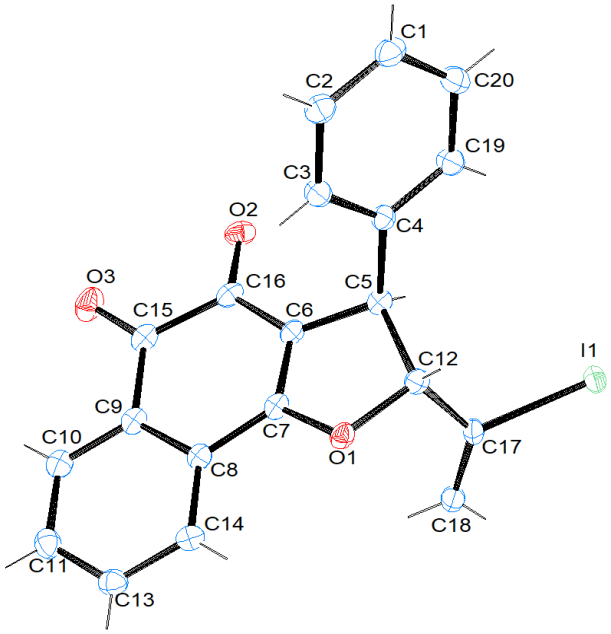
U. Single crystal X-ray diffraction analysis of *trans*-10:

A single crystal of *trans*-**10** (recrystallized from 3:2 *n*-Hexane/$CHCl_3$ at 0 °C) was mounted and the diffraction data were collected at 100 K on a Bruker SMART APEX CCD diffractometer using SMART/SAINT software. Intensity data were collected using graphite-monochromatized Mo-Kα radiation (0.71073 Å). The structures were solved by direct methods using the SHELX-97 and refined by full-matrix least-squares on F^2. Empirical absorption corrections were applied with SADABS. All

non-hydrogen atoms were refined anisotropically and hydrogen atoms were included in geometric positions. The structure was drawn using ORTEP-3. The crystallographic refinement parameters are given below:

Table S3. Crystal data and structure refinement for *trans*-**10**

Identification code	*trans*-**10**
CCDC	2329091
Empirical formula	$C_{20}H_{13}IO_3$
Formula weight	428.20
Temperature/K	100
Crystal system	orthorhombic
Space group	$P2_12_12_1$
a	5.24350(1) Å
b	16.7054(4) Å
c	18.3220(4) Å
α	90°
β	90°
γ	90°
Volume	1604.91(6) $Å^3$
Z	4
Density (calculated)	1.772 Mg/m^3
Absorption coefficient (μ)	2.01 mm^{-1}
F(000)	838.90
Crystal size	0.43 × 0.35 × 0.28 mm^3
Radiation	MoKα (λ = 0.71073)
Theta range for data collection	2.2° to 26.94°
Index ranges	$-7 \leq h \leq 7, -23 \leq k \leq 23, -26 \leq l \leq 26$
Reflections collected	82438
Independent reflections	4912 [R_{int} = 0.0494, R_{sigma} = 0.0195]
Data/restraints/parameters	4912/0/217
Goodness-of-fit on F^2	1.022
Final R indexes [$I \geq 2\sigma(I)$]	R_1 = 0.0193, wR_2 = 0.0389
Final R indexes [all data]	R_1 = 0.0176, wR_2 = 0.0395
Largest diff. peak and hole	0.29/-0.44 e.$Å^{-3}$
Flack parameter	0.000(6)



ORTEP representation of the X-ray structure of enantiopure *trans*-**10** (thermal ellipsoids at 30% probability)

V. Antibacterial Study – Materials and instrumentation:

Bacterial optical density was measured using a ThermoFisher Scientific Microplate Reader. NaCl, KCl, Na_2HPO_4, KH_2PO_4, nutrient agar powder and Luria Broth (LB) powder were obtained from SRL Chemicals and Hi-Media and used without further purification. Milli-Q water was used for the preparation of the desired solutions. The LB media and PBS buffer were autoclaved at 120 ºC before use. For cell viability assay, Dulbecco's modified Eagle medium (DMEM) was obtained from Invitrogen, while Fetal Bovine Serum (FBS) was taken from Cytiva. Dulbecco's PBS (DPBS), Trypsin-EDTA (0.5%, 10X) solution, antibiotic antimycotic solution (100 mM) and glutamax (100 mM) from Gibco (Thermofisher) were used. The MTT (3-[4,5-dimethylthiazole-2-yl]-2,5-diphenyltetrazolium bromide) salt used for the assay was taken from SRL Chemicals. All the reagents were used as obtained, while the solutions were prepared either in DPBS or autoclaved Milli-Q water. The incubation was done in a CO_2 incubator (Sanyo, MCO-18AC, USA). Cell count was obtained on a BioRad TC20 counter using Trypan blue dye. The absorbance@570 nm was recorded on a VARIOSKAN multimode plate reader instrument. DMSO and Acetonitrile used for the study were procured from Finar Ltd. as HPLC grade solvents.

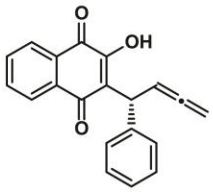
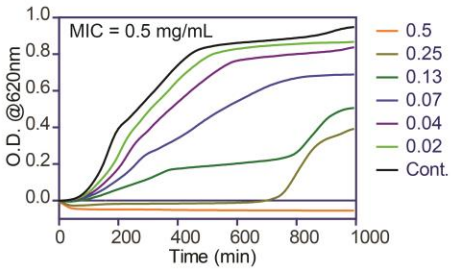
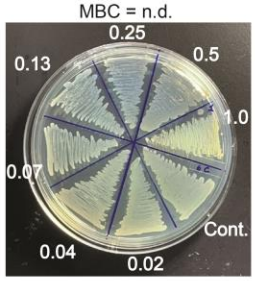
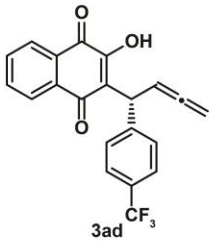
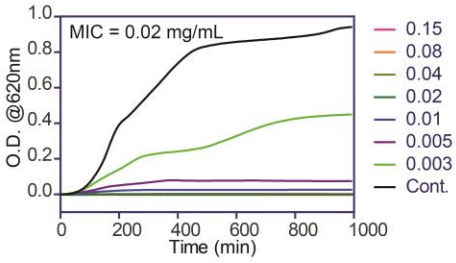
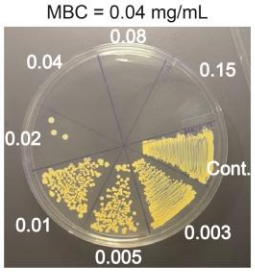
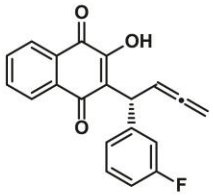
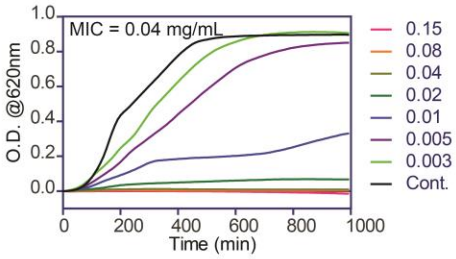
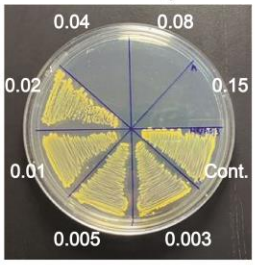
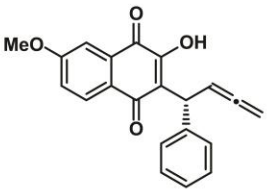
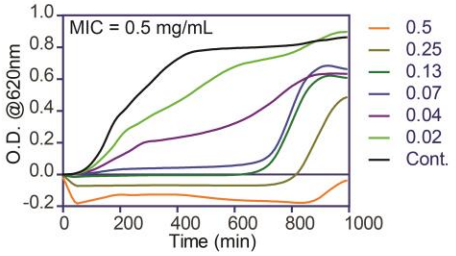
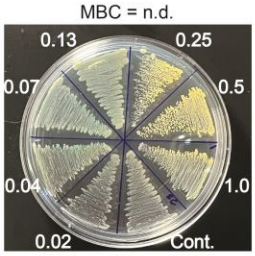
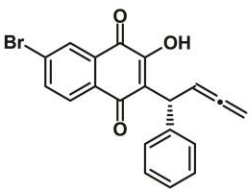
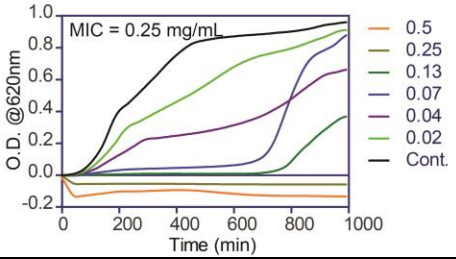
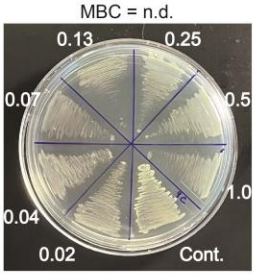
W. Estimation of MIC and MBC:

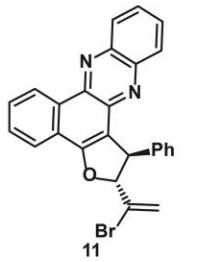
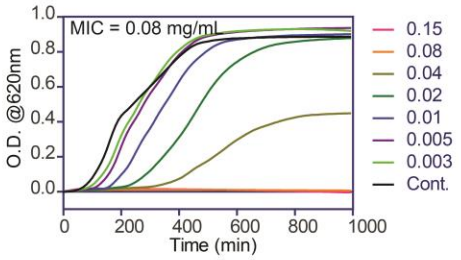
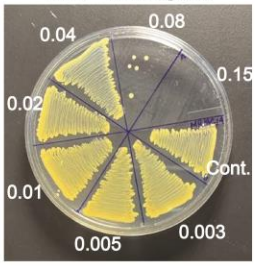
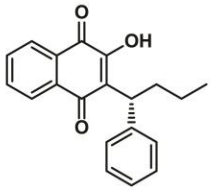
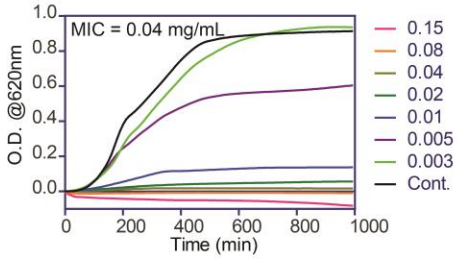
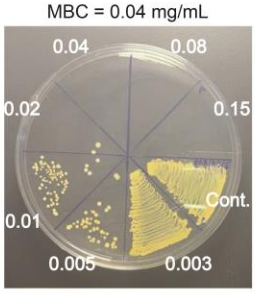
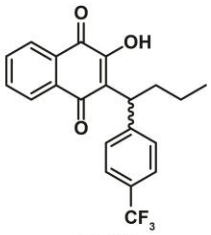
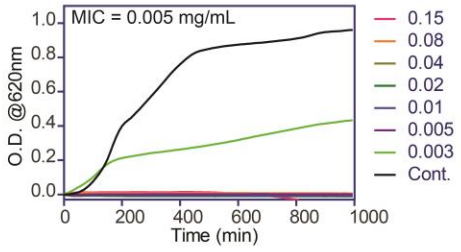
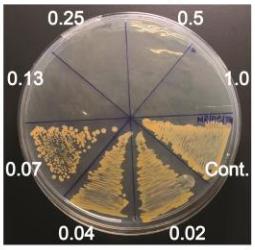
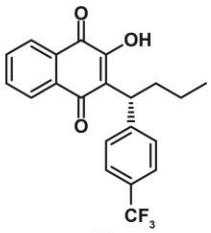
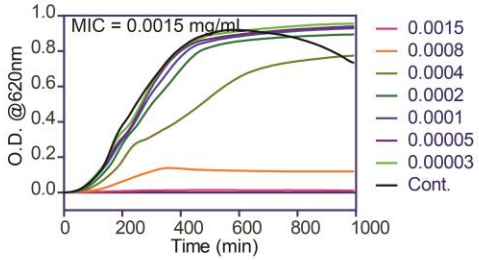
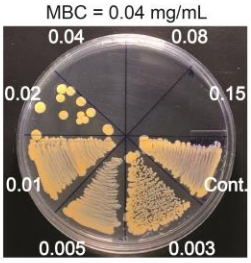
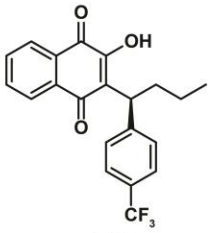
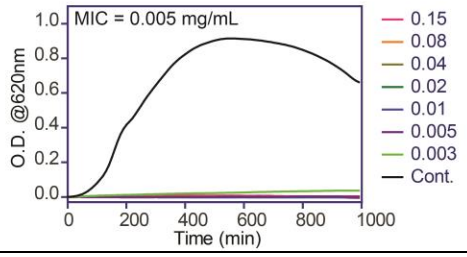
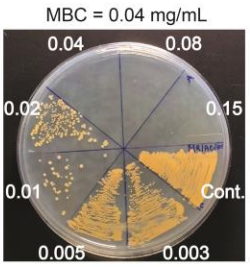
The freeze-dried stock of the bacterial species, *viz*, Methicillin-resistant *Staphylococcus aureus* (MRSA, ATCC USA300) and *Pseudomonas aeruginosa* (PA, ATCC 27853) was taken and revived on nutrient agar plates. To generate the primary culture, a small number of colonies were taken from this plate using a sterile loop and cultured in Luria Broth (LB, 20 g/L) for 10 h approximately. This stock was subsequently used to prepare the secondary culture. In this case, 200 μL of the bacterial solution was taken in 1.7 mL of fresh LB. Incubation was done at 37 ºC until the mid-log phase (Optical Density, $OD_{620nm} \sim 0.3$) was attained. The OD_{620nm} was adjusted to 0.01 (10^6 to 10^7 bacteria/ mL) using LB media.

All the compounds under investigation were prepared as a stock in 1:19, acetonitrile/water solution. To determine the MIC (Minimum Inhibitory Concentration), microbroth dilution technique was employed. Phosphate Buffer Saline (PBS, pH = 7.4) was used for two-fold serial dilution of the stock solution in the 96-well plate. 100 μL of bacterial suspension ($OD_{620nm} = 0.01$) was added to each well. The bacterial growth curves were recorded on a micro-plate reader at 620 nm. The assay was continued for 16 h while the readings were taken at a time interval of 10 mins (with shaking at 100 rpm in between the readings). Throughout the course of the experiment, the thermostat was set to 37 ºC.

The data thus obtained was normalized and plotted by using GraphPad software. The minimum concentration at which there was no growth or at least 95% decline in the growth compared to the control, was designated as the MIC value.

The MBC (Minimum Bactericidal Concentration) was determined as follows. The 96-well plate used for the kinetic growth curve analysis was incubated for 4 h at 37 ºC. The solution from the wells were gently streaked on a nutrient agar plate (compartmentalized and labelled suitably) using a sterile soft loop. The plate was kept in an oven at a temperature of 37 ºC for 24-48 h. The concentration at which no bacterial colonies were observed was assigned as the MBC.

Structure	MIC (mg/mL)	MBC (mg/mL)
 3aa		
 3ad		
 3ah		
 3da		
 3fa		

Structure	MIC (mg/mL)	MBC (mg/mL)
 **11**		MBC = 0.15 mg/mL 
 **12a**		MBC = 0.04 mg/mL 
 *rac*-**12b**		MBC = 0.13 mg/mL 
 **12b**		MBC = 0.04 mg/mL 
 *ent*-**12b**		MBC = 0.04 mg/mL 

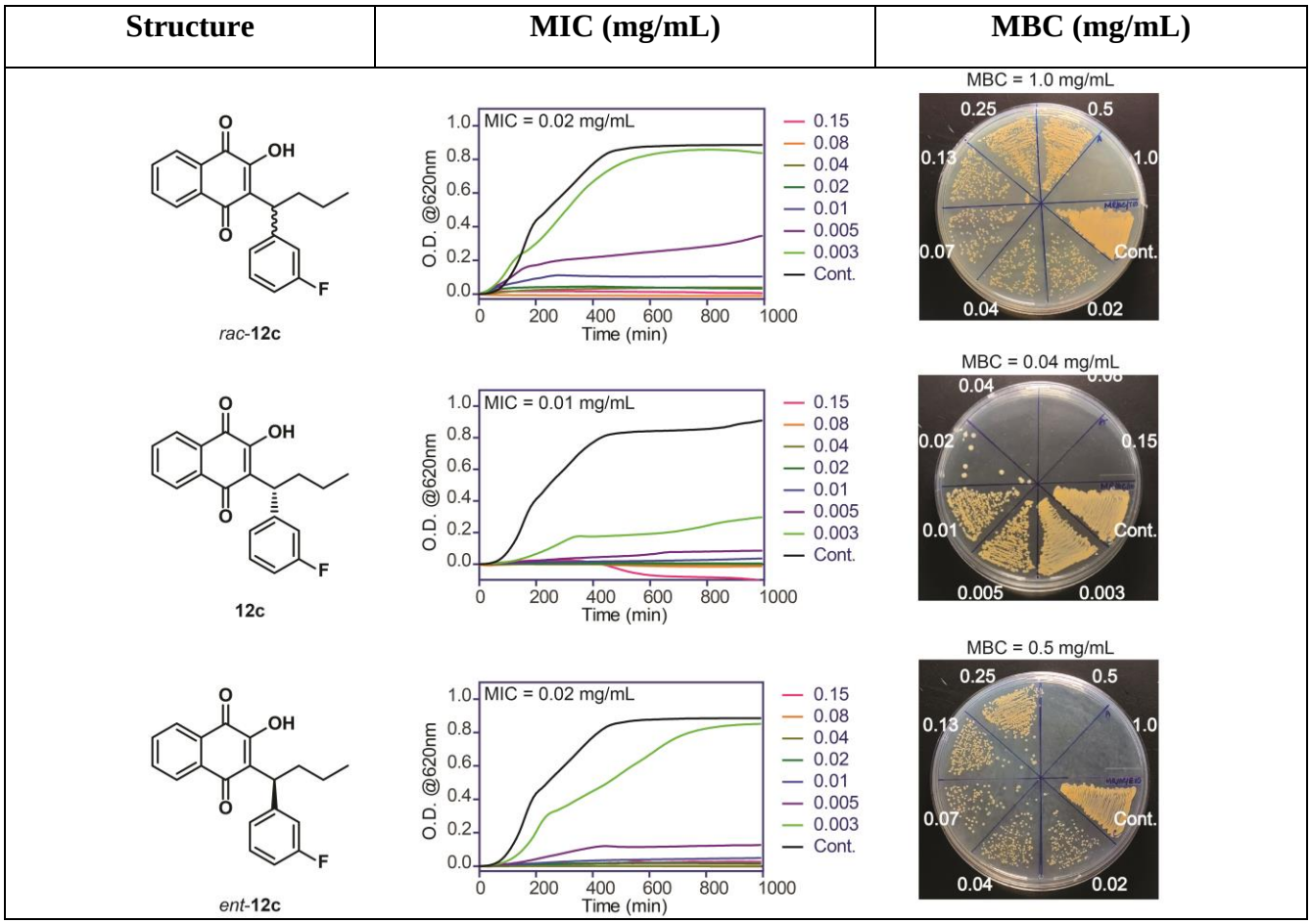


Figure S1: Schematic representation of the bacteriostatic and bactericidal properties of the β-allenylic 2-hydroxy naphthoquinones, their hydrogenated analogs and the opposite enantiomer against MRSA (all concentrations have been expressed as mg/mL).

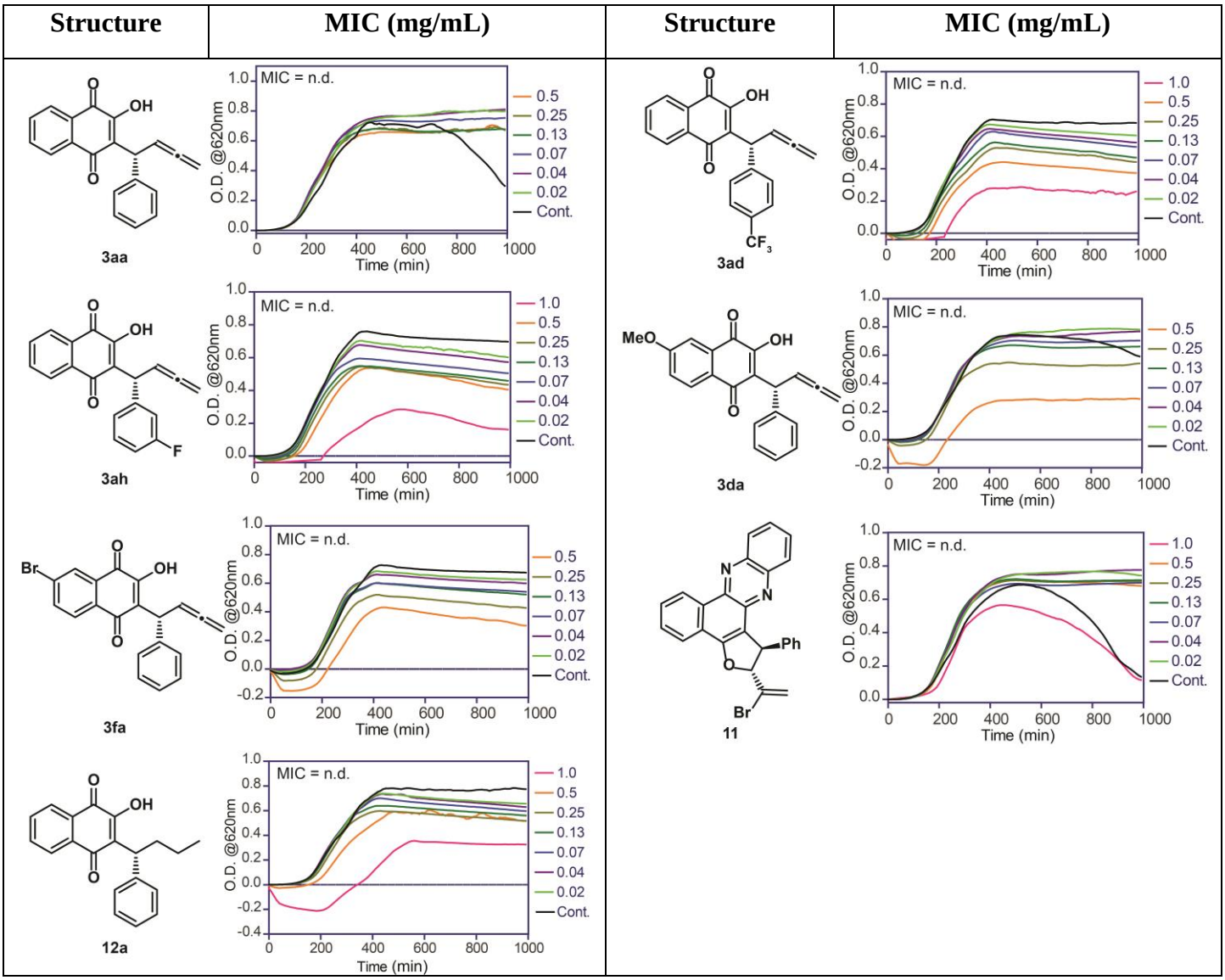
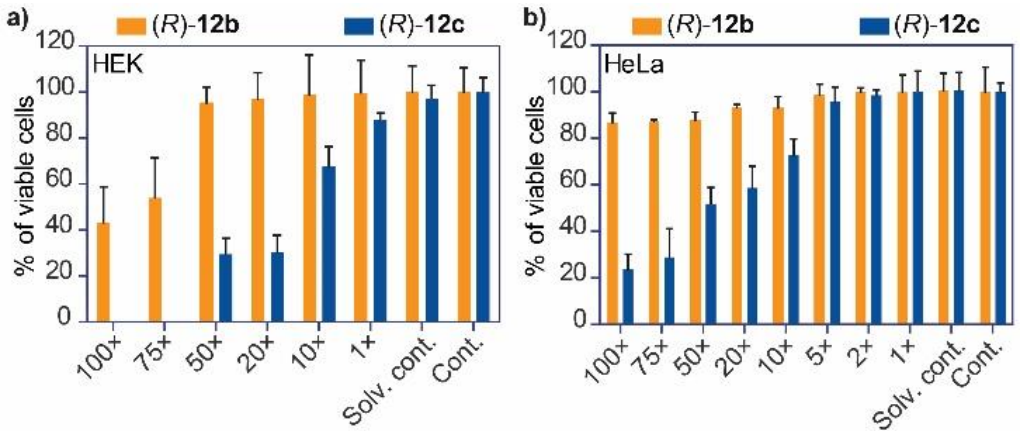


Figure S2: Schematic representation of the bacteriostatic properties of the β-allenylic 2-hydroxy naphthoquinones and their hydrogenated analogs against PA (all concentrations have been expressed as mg/mL).

X. Cell viability assay:

For assessing the toxicity of the compounds, two cell lines were chosen, *viz*, HEK (human embryonic kidney ATCC 293) and HeLa (human cervical cancer cells). The cells were revived from the cryo-preserved stocks using freshly prepared media comprising of DMEM, 20% FBS, 1% antibiotic antimycotic solution and 2 mM L-glutamine. The culture was done in the CO_2 incubator maintained at 37 °C, 95% humidity, and 5% CO_2 levels. As the cells attained a confluency greater than 90%, they

were detached from the surface of the flask using 0.05% Trypsin–EDTA solution. Subsequently, this solution was centrifuged at 1,800 rpm for 5 mins at 4 °C to precipitate the cells as a pellet. The supernatant was discarded carefully, and the cells were re-suspended in 1 mL of media. The cell count was obtained using a 1:1 mixture of the freshly suspended cells and trypan blue dye solution. In a sterile 96-well plate, ~15,000 cells were seeded in each well and incubated for 24 h in fresh media. The adhered cells were treated with the compound (multiple concentrations taken relative to the MIC; for each concentration, a triplicate set was prepared) for 24 h, following which, the MTT assay was performed. The media was carefully removed, and the cells were washed with DPBS. Following this, fresh media, containing 20% MTT@DPBS was added to all the wells and incubated for 4 h. Then, this solution was taken out and the residual formazan crystals were solubilized in DMSO (over 3 h). Finally, the absorbance at 570 nm was measured to obtain the relative cell viability.



Compound	Cytotoxicity conc. (IC_{50}) (μg/mL)	
	HEK ATCC 293	HeLa
(*R*)-**12b**	112.5 (75x)	n.d.
(*R*)-**12c**	100 (10x)	500 (50x)

Figure S3. Dose-dependent cellular toxicity analysis of (*R*)-**12b** and (*R*)-**12c** based on MTT assay on mammalian cell lines: a) HEK cells and b) HeLa cells. All experiments were performed in triplicates.

SUPPORTING INFORMATION: PART B

Rational design of naphthoquinone-based antibacterial agents through iridium-catalyzed enantioselective β-allenylation of 2-hydroxynaphthoquinones

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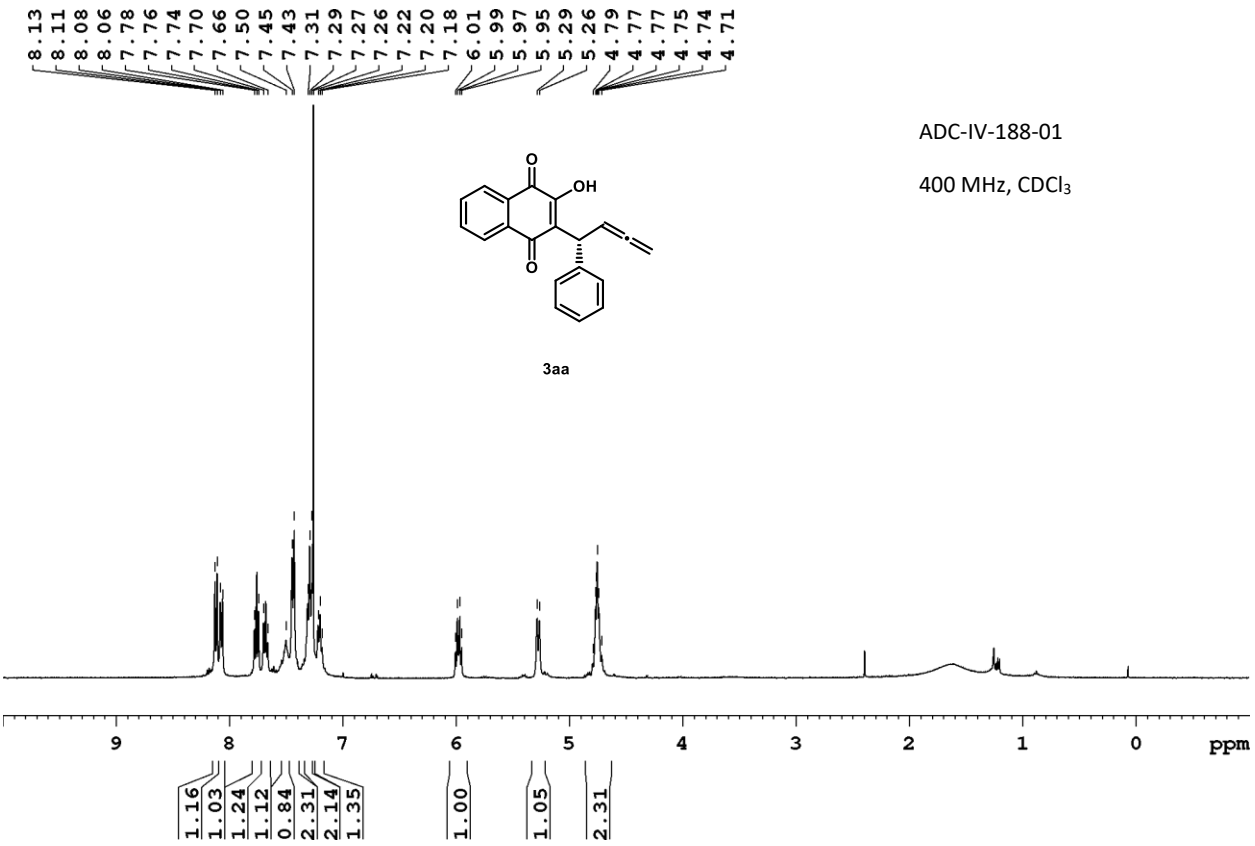
*Corresponding author: E-mail: sm@iisc.ac.in and md@iisc.ac.in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7.66
7.50
7.45
7.43
7.31
7.29
7.27
7.26
7.22
7.20
7.18
6.01
5.99
5.97
5.95
5.29
5.26
4.79
4.77
4.77
4.75
4.74
4.71
ADC-IV-188-01
400 MHz, CDCl3
OH
O
O
3aa
9
8
7
6
5
4
3
2
1
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ppm
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1.24
1.12
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2.14
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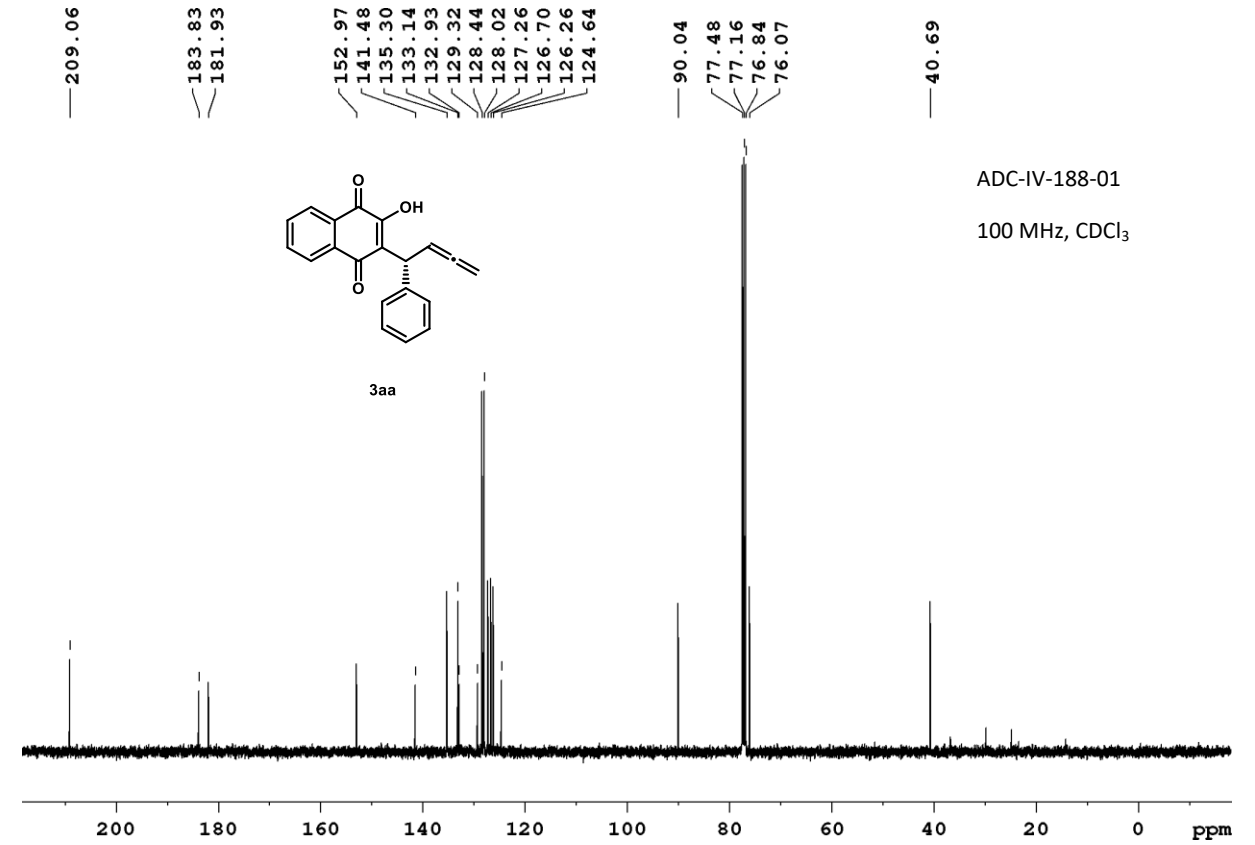
1.00
1.05
2.31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126.26
124.64
90.04
77.48
77.16
76.84
76.07
40.69
ADC-IV-188-01
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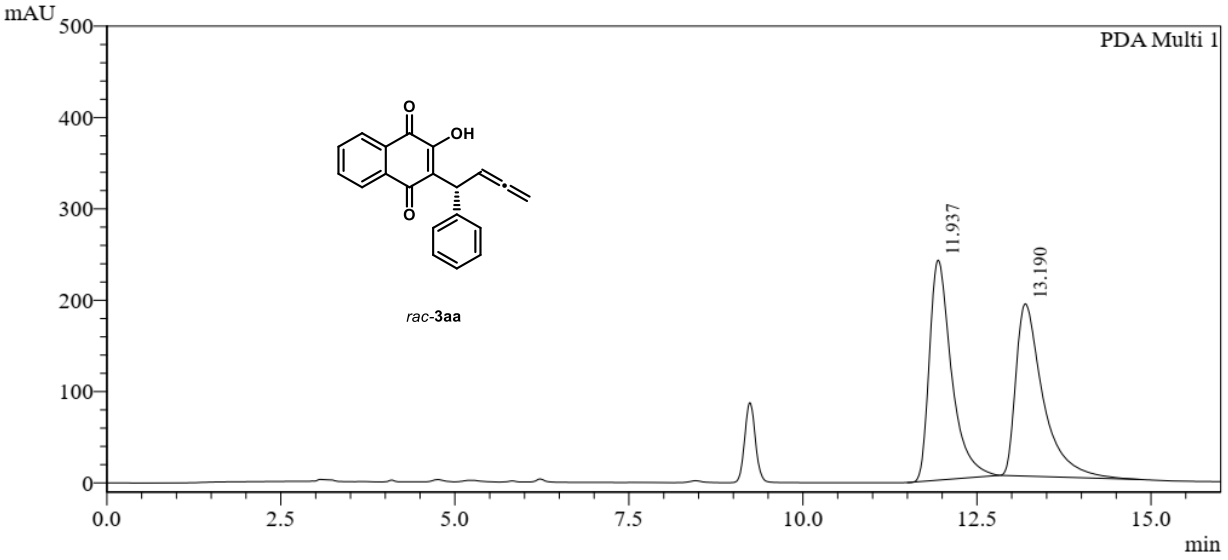

PeakTable

PDA Ch1 241nm 4nm

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2	13.190	5134483	49.058
Total		10466059	100.000

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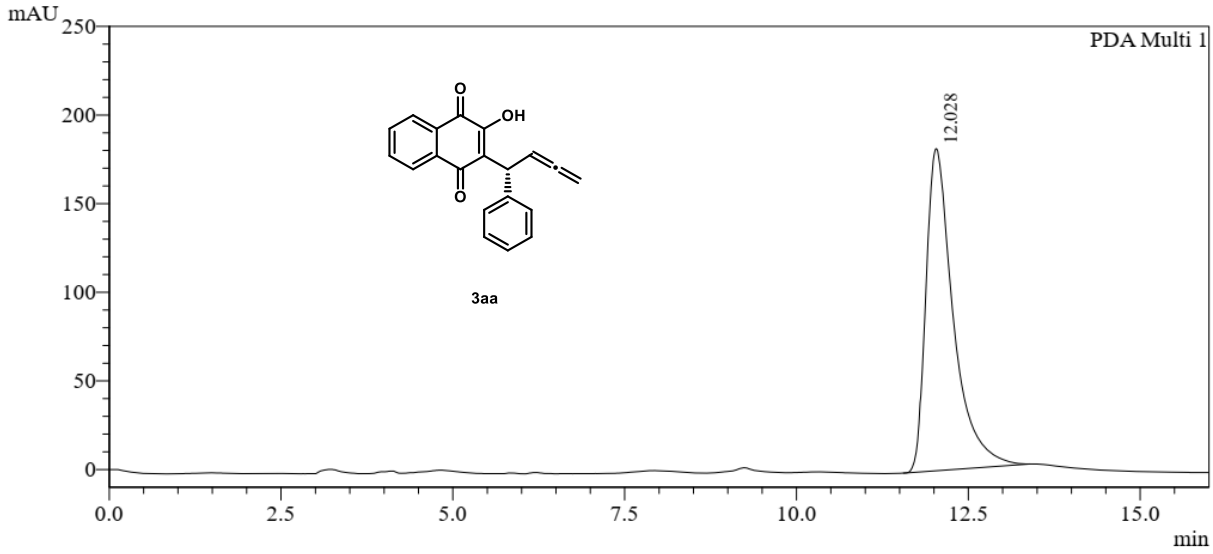

PeakTable

PDA Ch1 241nm 4nm

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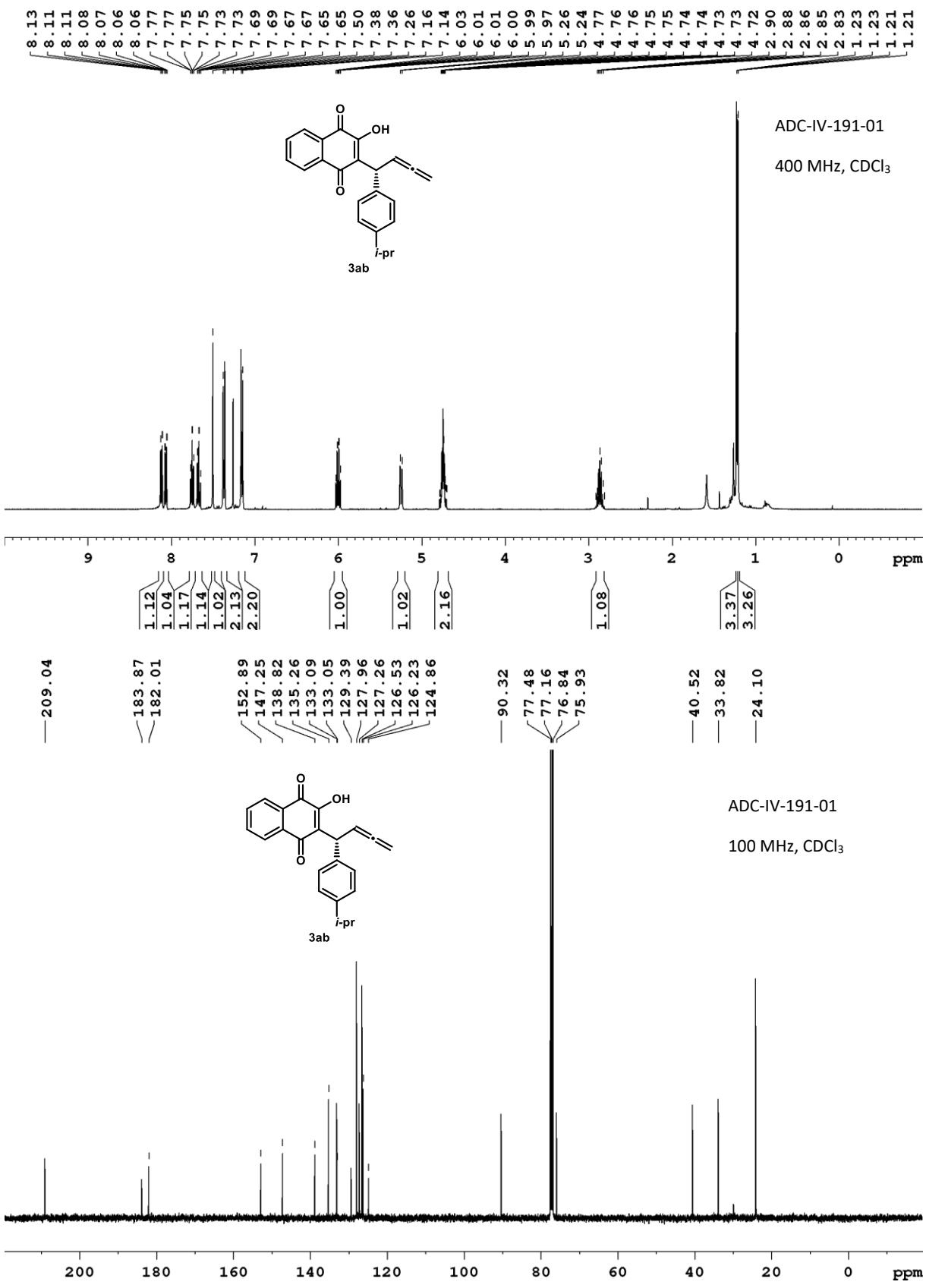
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O
O
i-pr
3ab
ADC-IV-191-01
400 MHz, CDCl3
9 8 7 6 5 4 3 2 1 0 ppm
1.12 1.04 1.17 1.14 1.02 2.13 2.20 1.00 1.02 2.16 1.08 3.37 3.26
209.04 183.87 182.01 152.89 147.25 138.82 135.26 133.09 133.05 129.39 127.96 127.26 126.53 126.23 124.86 90.32 77.48 77.16 76.84 75.93 40.52 33.82 24.10
OH
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O
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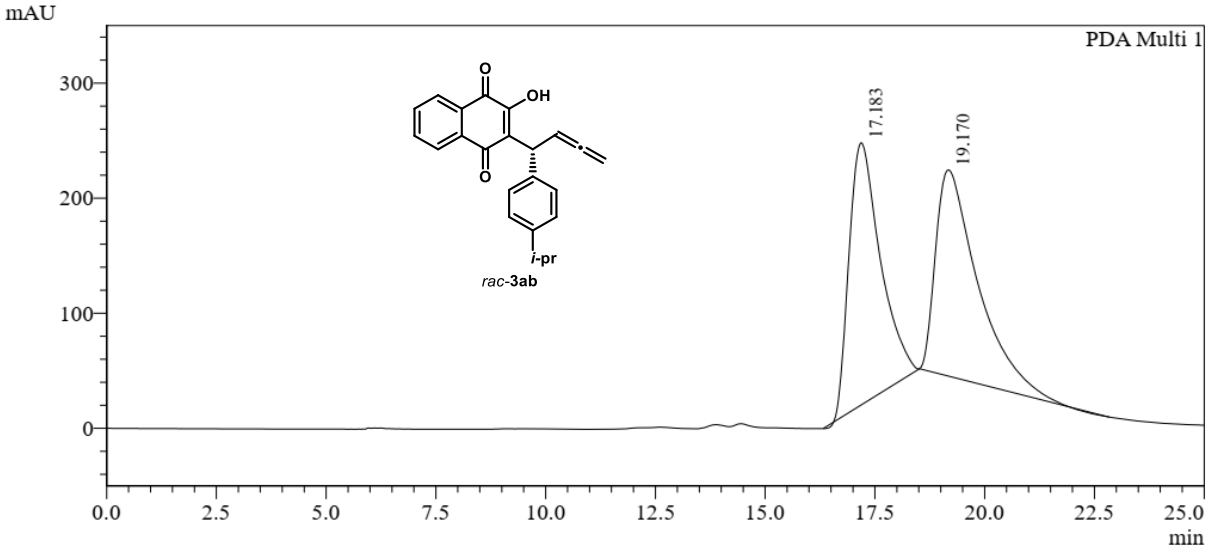

PeakTable

PDA Ch1 260nm 4nm

Peak#	Ret. Time	Area	Area %
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2	19.170	12014378	51.496
Total		23330586	100.000

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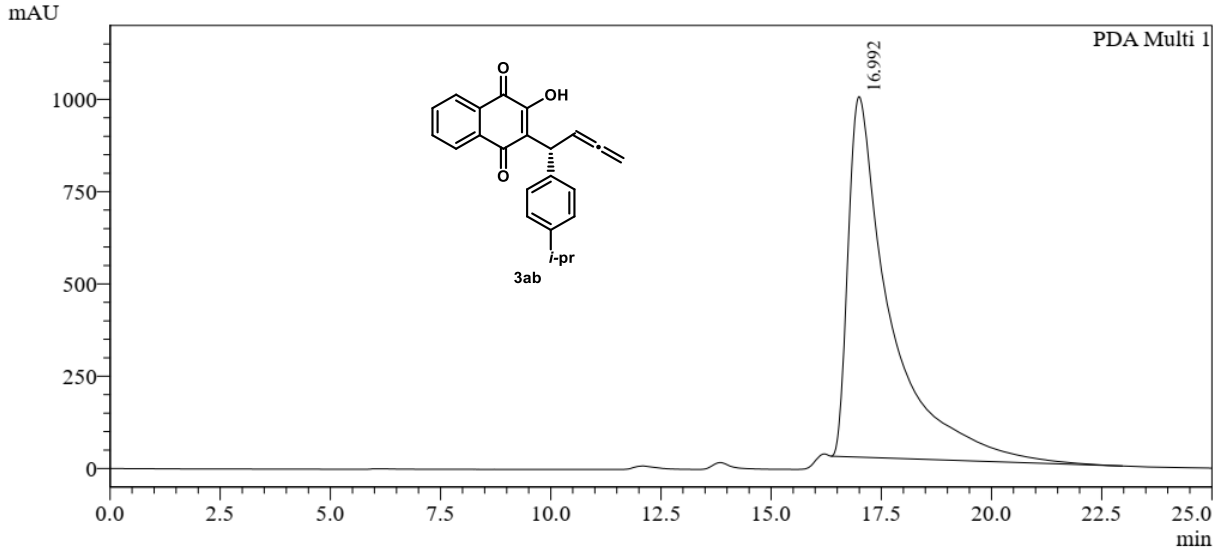

PeakTable

PDA Ch1 260nm 4nm

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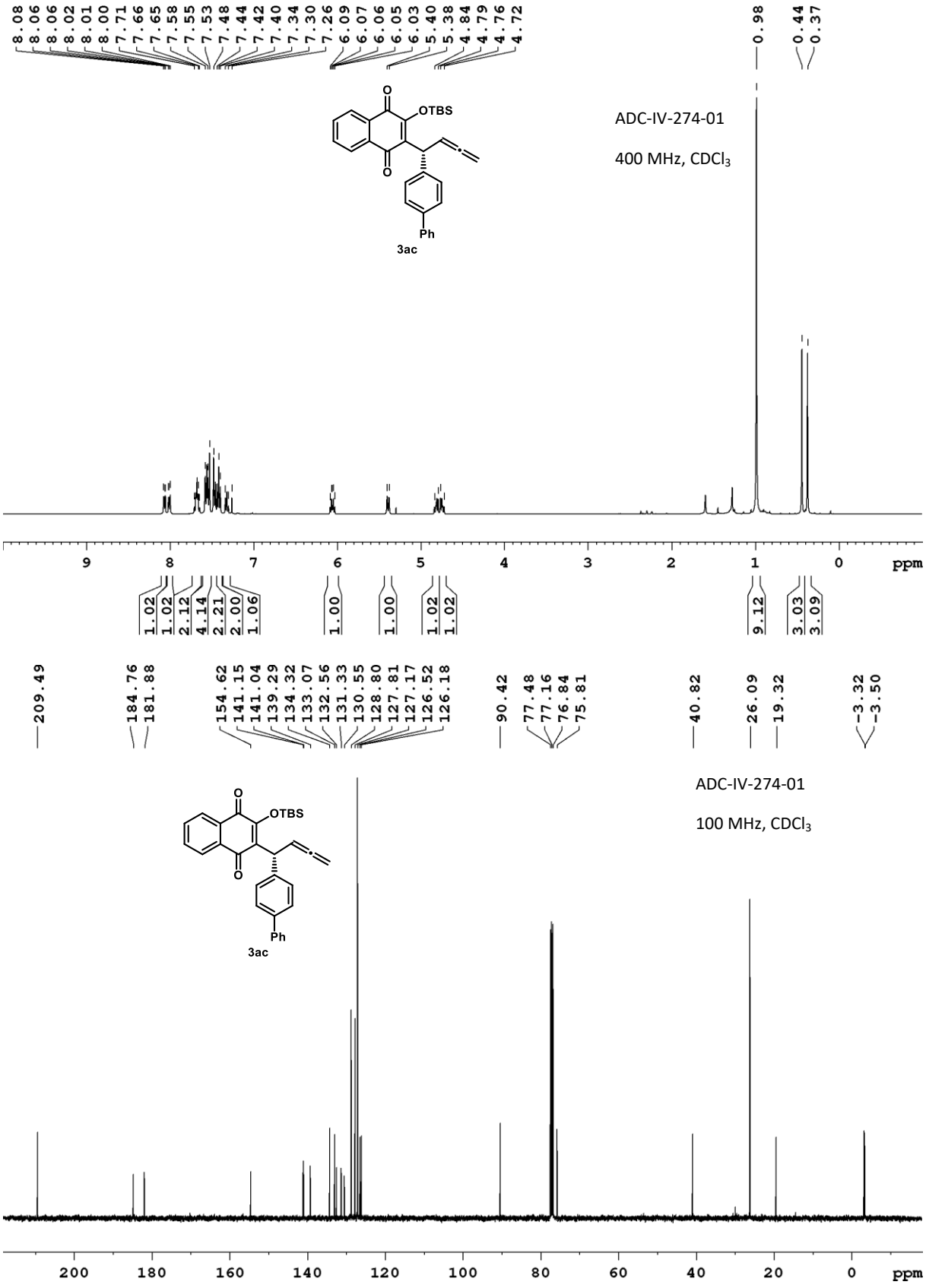
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6.03
5.40
5.38
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4.79
4.76
4.72
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0.44
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O
Ph
3ac
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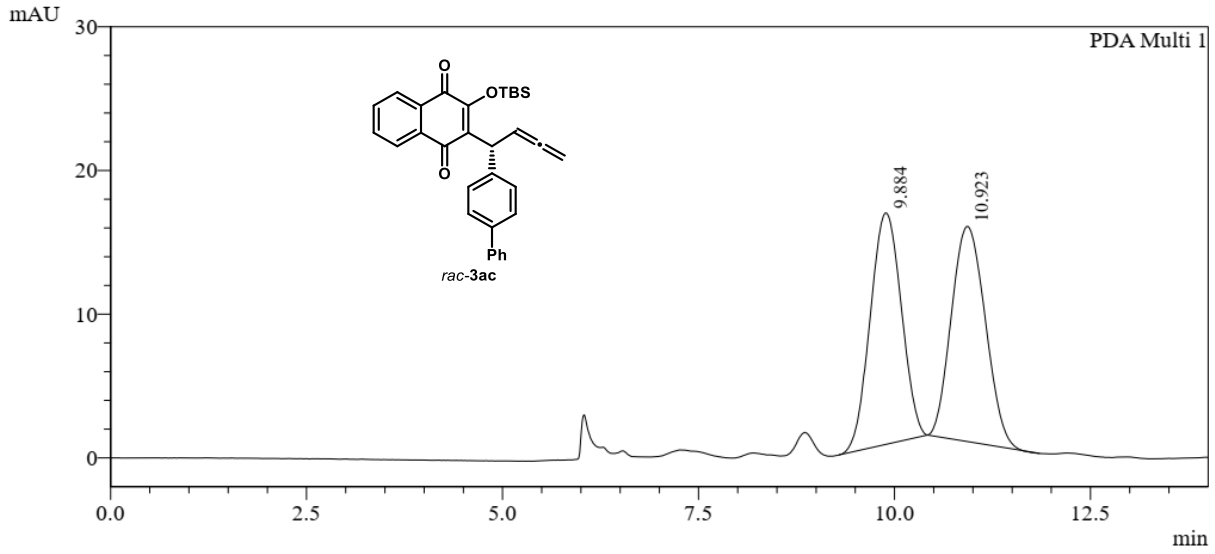
ppm



PeakTable

PDA Ch1 263nm 4nm

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2	10.923	451015	50.332
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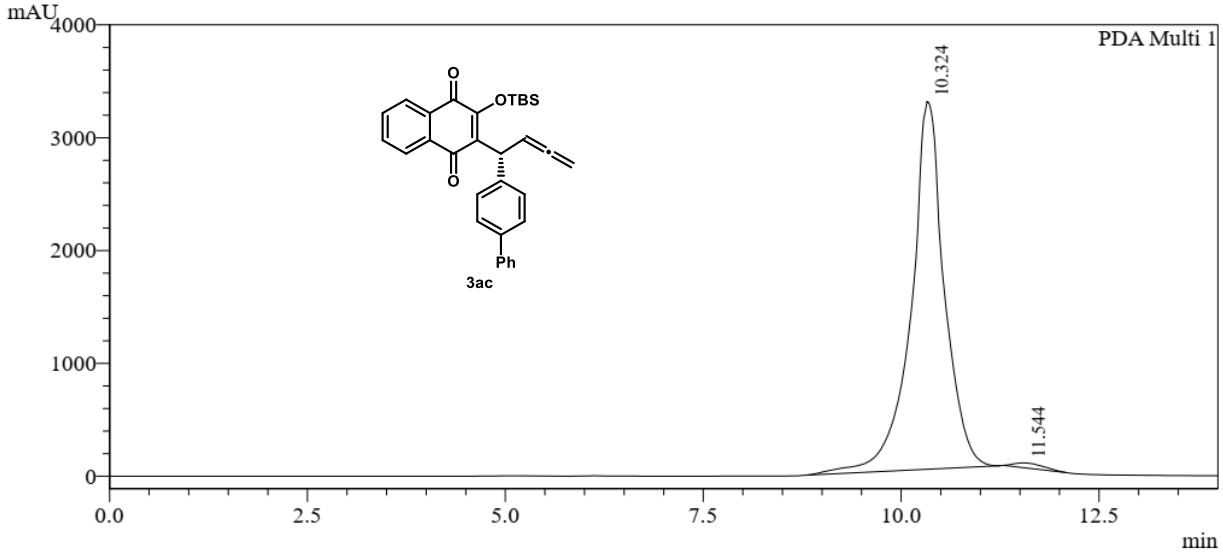

PeakTable

PDA Ch1 263nm 4nm

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2	11.544	1170996	1.209
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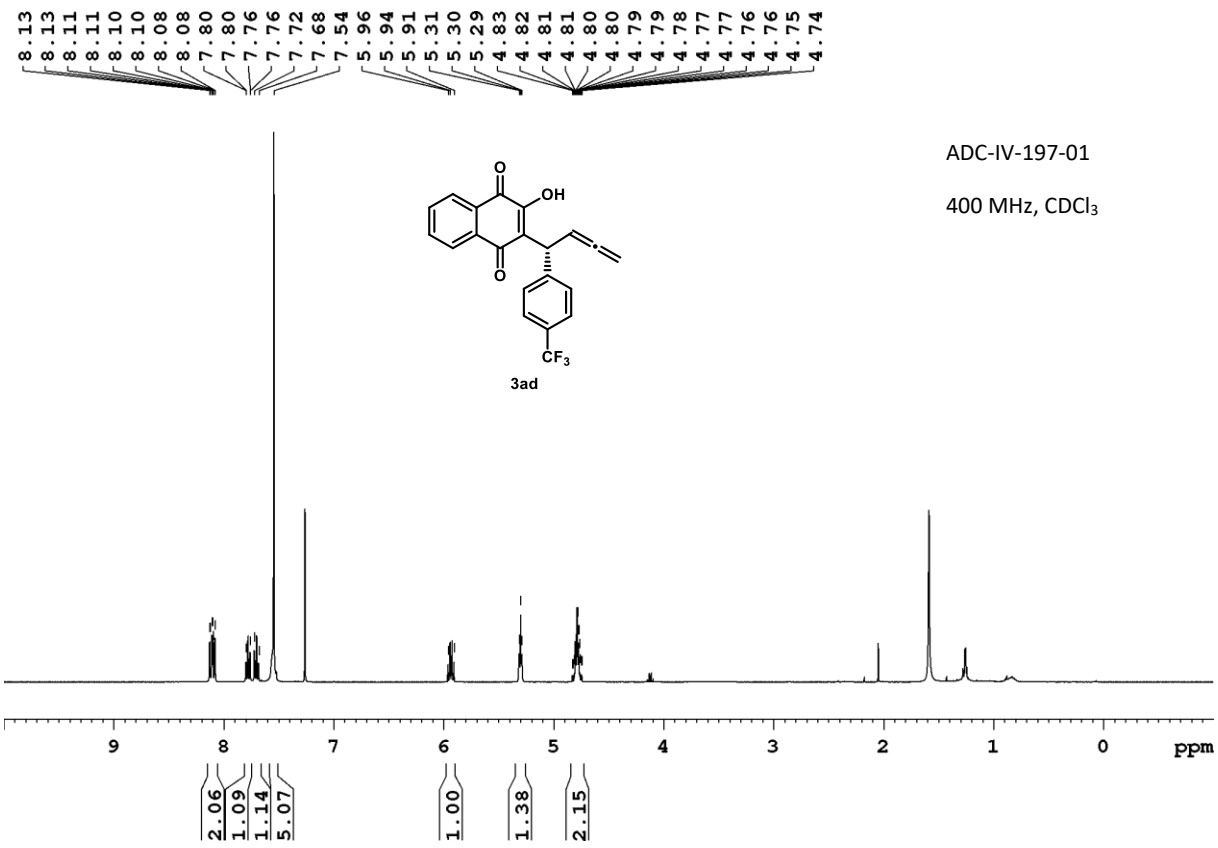
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ADC-IV-197-01
400 MHz, CDCl3
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OH
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CF3
3ad
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8
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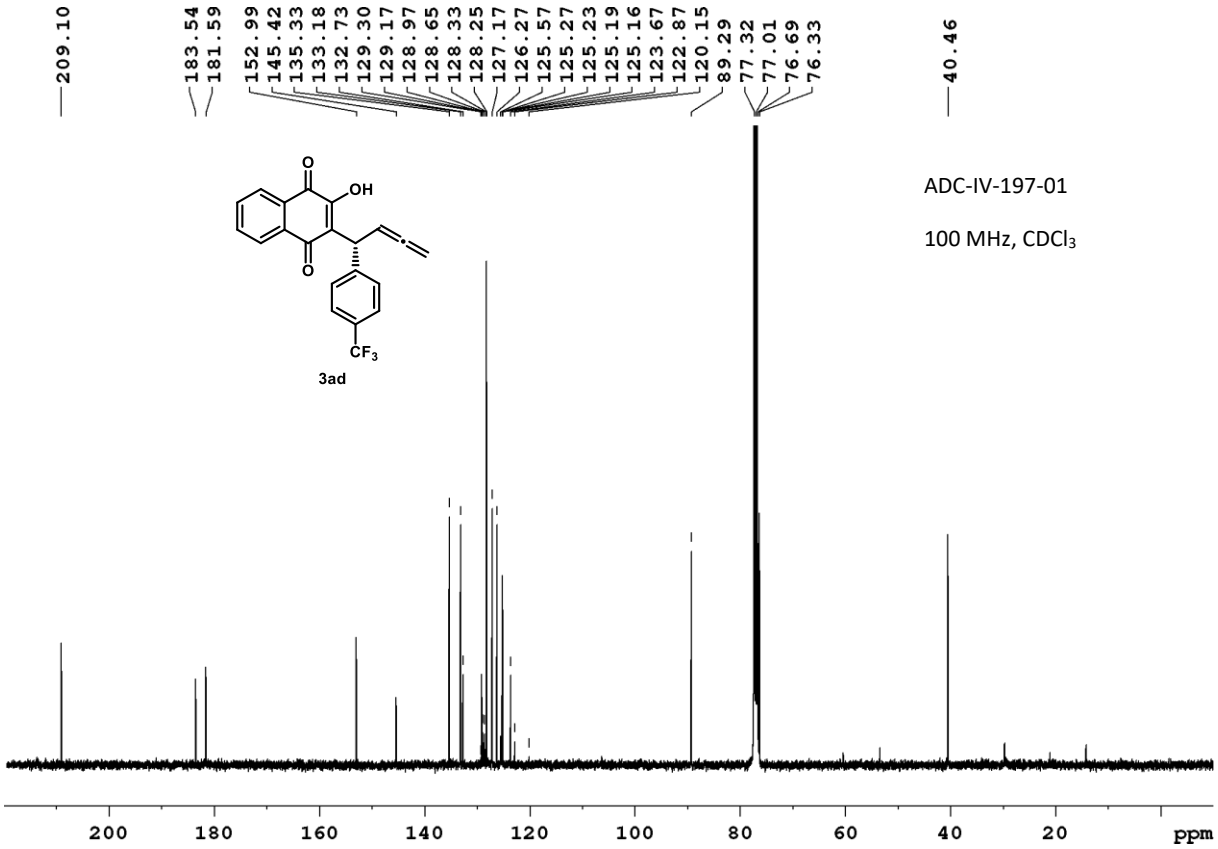
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76.33
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ADC-IV-197-01
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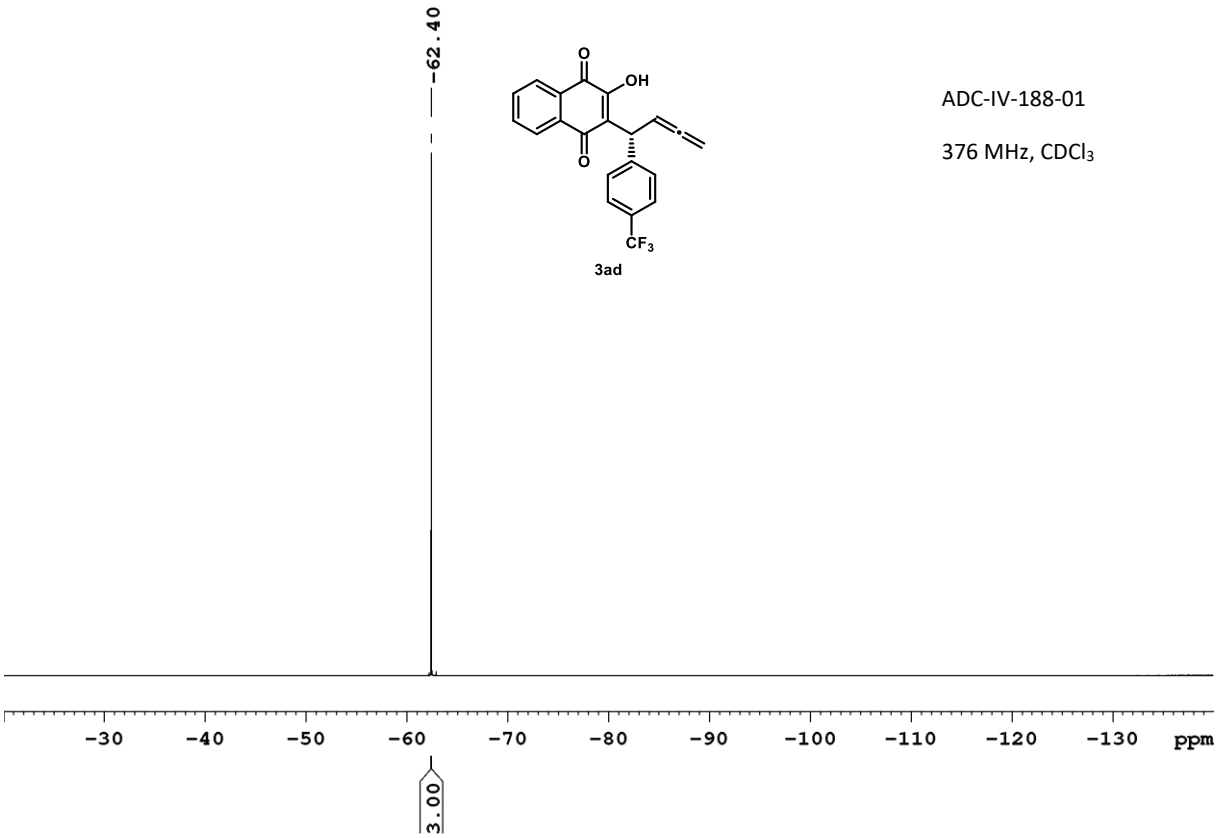
ppm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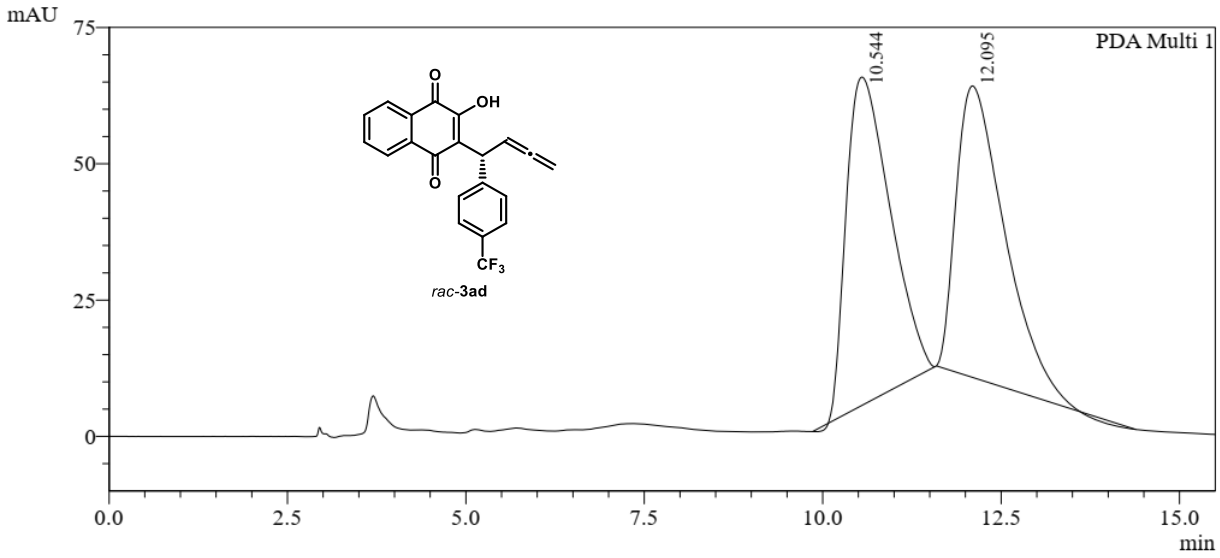
3.00



PeakTable

PDA Ch1 269nm 4nm

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1	10.544	2574865	50.344
2	12.095	2539673	49.656
Total		5114538	100.000

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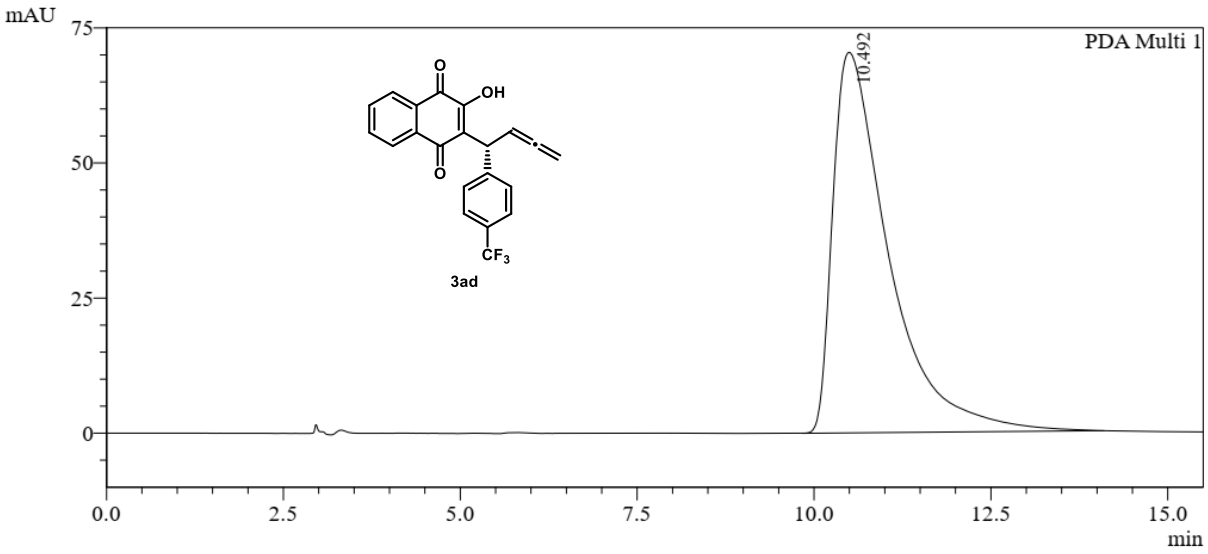

PeakTable

PDA Ch1 269nm 4nm

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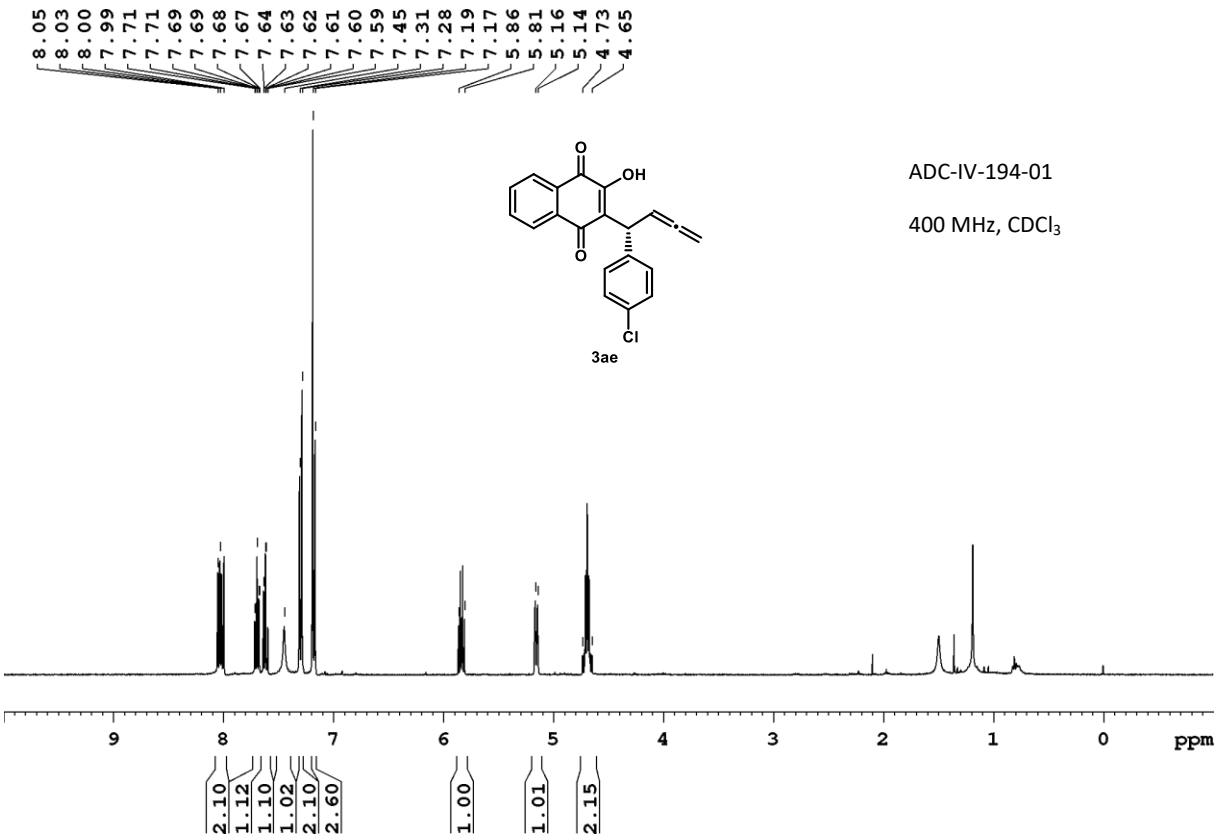
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7.45
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5.16
5.14
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4.65
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OH
O
Cl
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ADC-IV-194-01
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7
6
5
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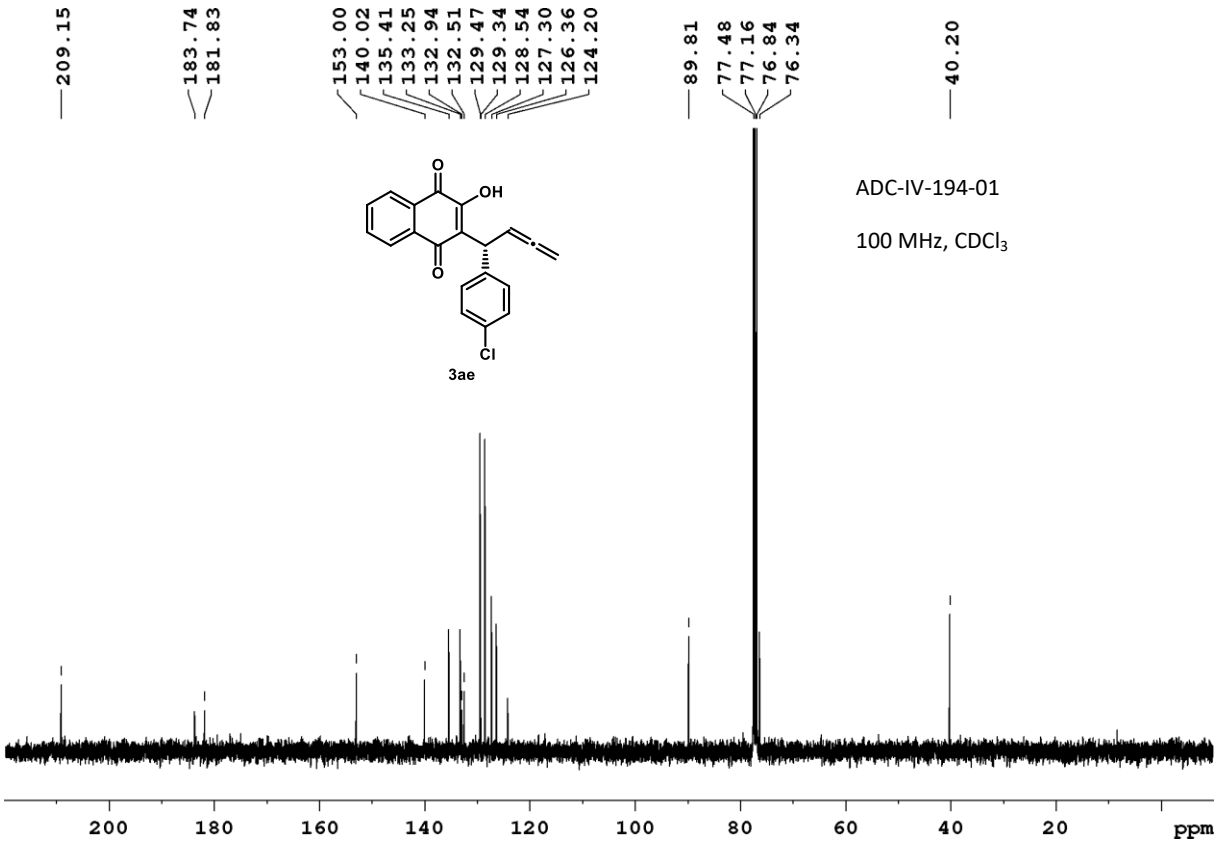
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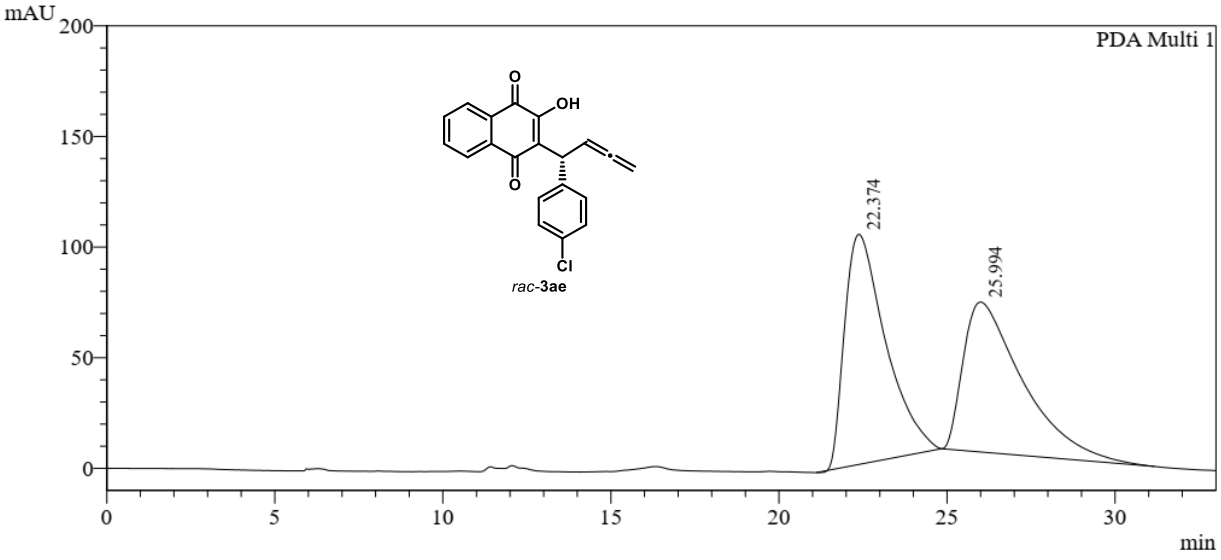

PeakTable

PDA Ch1 241nm 4nm

Peak#	Ret. Time	Area	Area %
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2	25.994	8374509	48.690
Total		17199800	100.000

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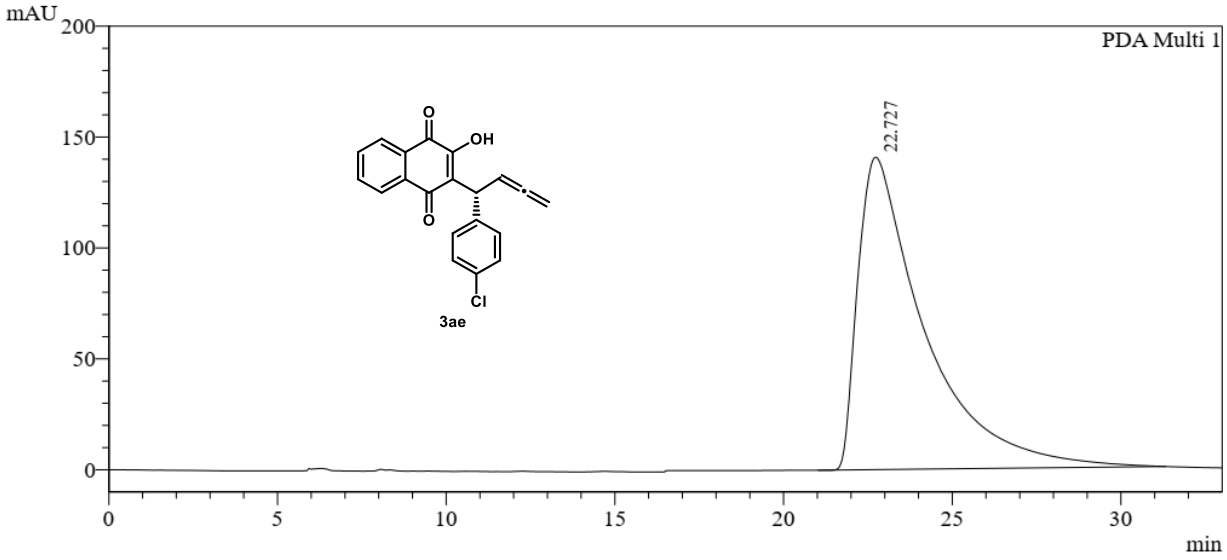

PeakTable

PDA Ch1 241nm 4nm

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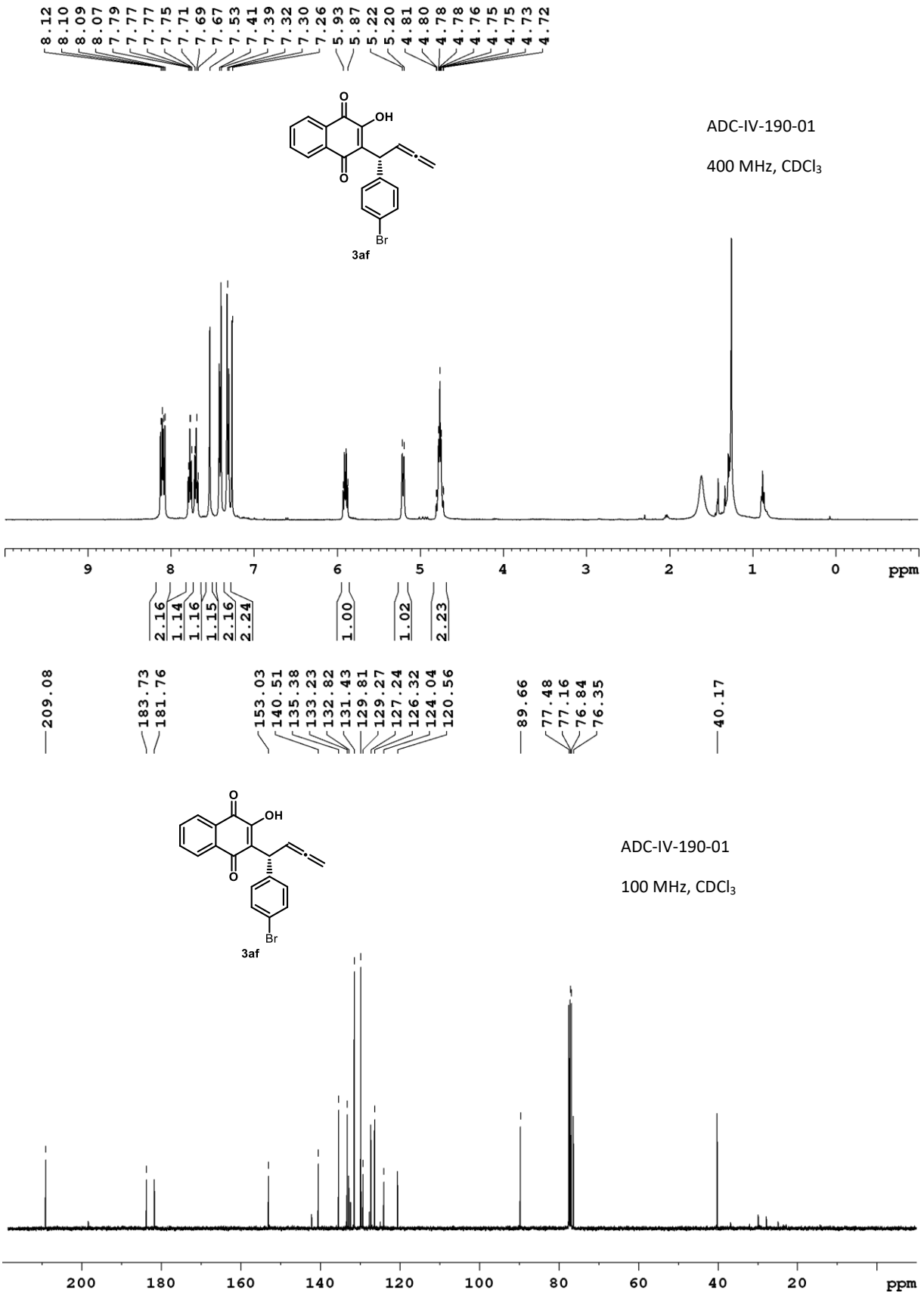
Total		19376672	100.000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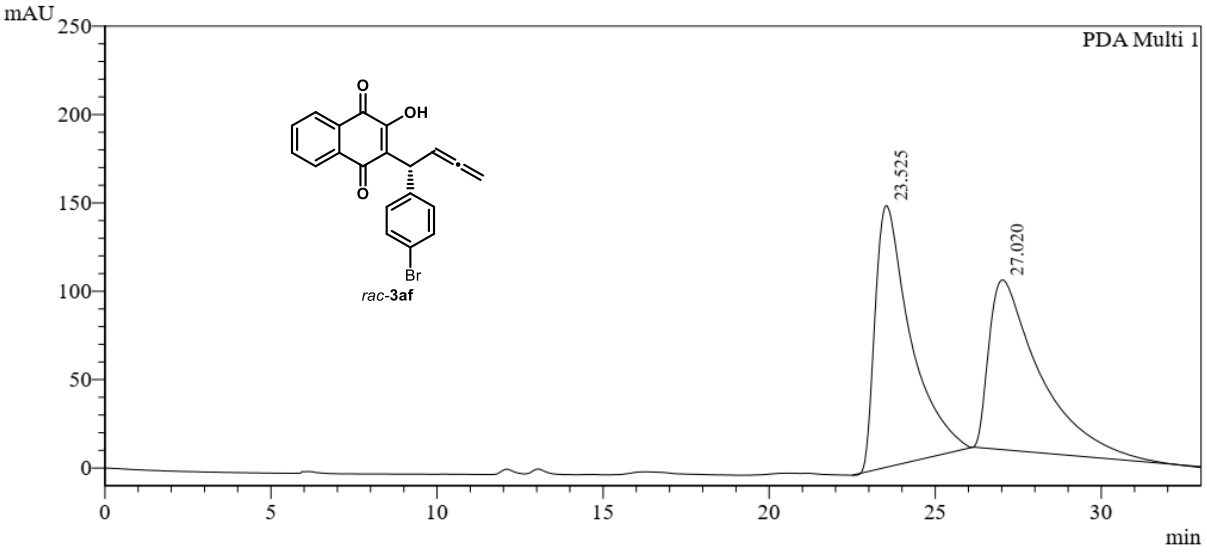
7.39
7.32
7.30
7.26
5.93
5.87
5.22
5.20
4.81
4.80
4.78
4.76
4.75
4.75
4.73
4.72
OH
O
O
Br
3af
ADC-IV-190-01
400 MHz, CDCl3
9
8
7
6
5
4
3
2
1
0
ppm
2.16
1.14
1.16
1.15
2.16
2.24
1.00
1.02
2.23
209.08
183.73
181.76
153.03
140.51
135.38
133.23
132.82
131.43
129.81
129.27
127.24
126.32
124.04
120.56
89.66
77.48
77.16
76.84
76.35
40.17
OH
O
O
Br
3af
ADC-IV-190-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
ppm

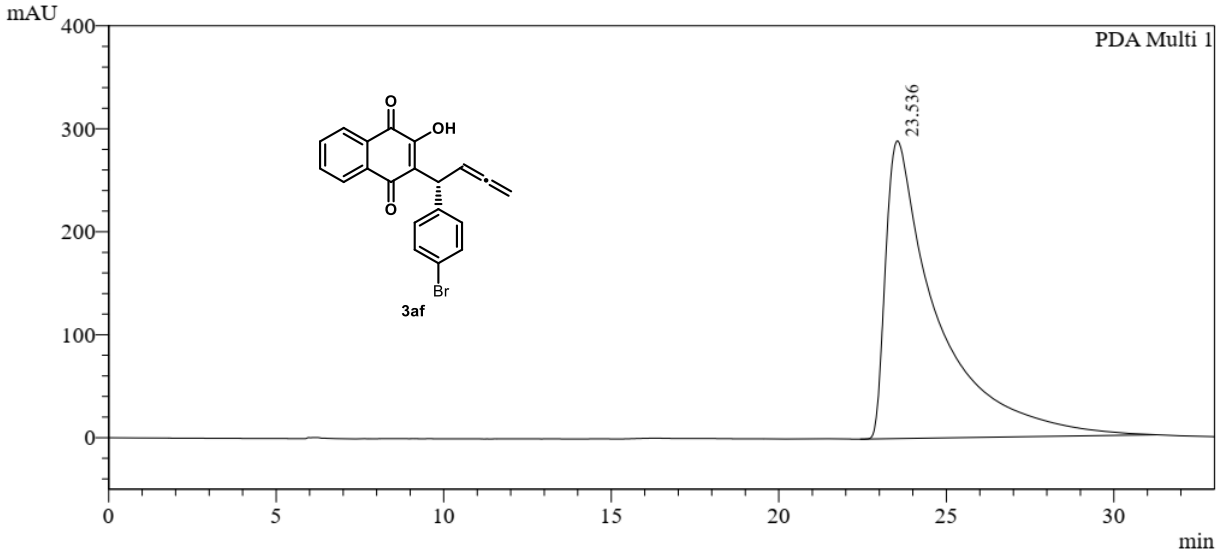


PeakTable

PDA Ch1 258nm 4nm

Peak#	Ret. Time	Area	Area %
1	23.525	10983273	51.657
2	27.020	10278726	48.343
Total		21261999	100.000

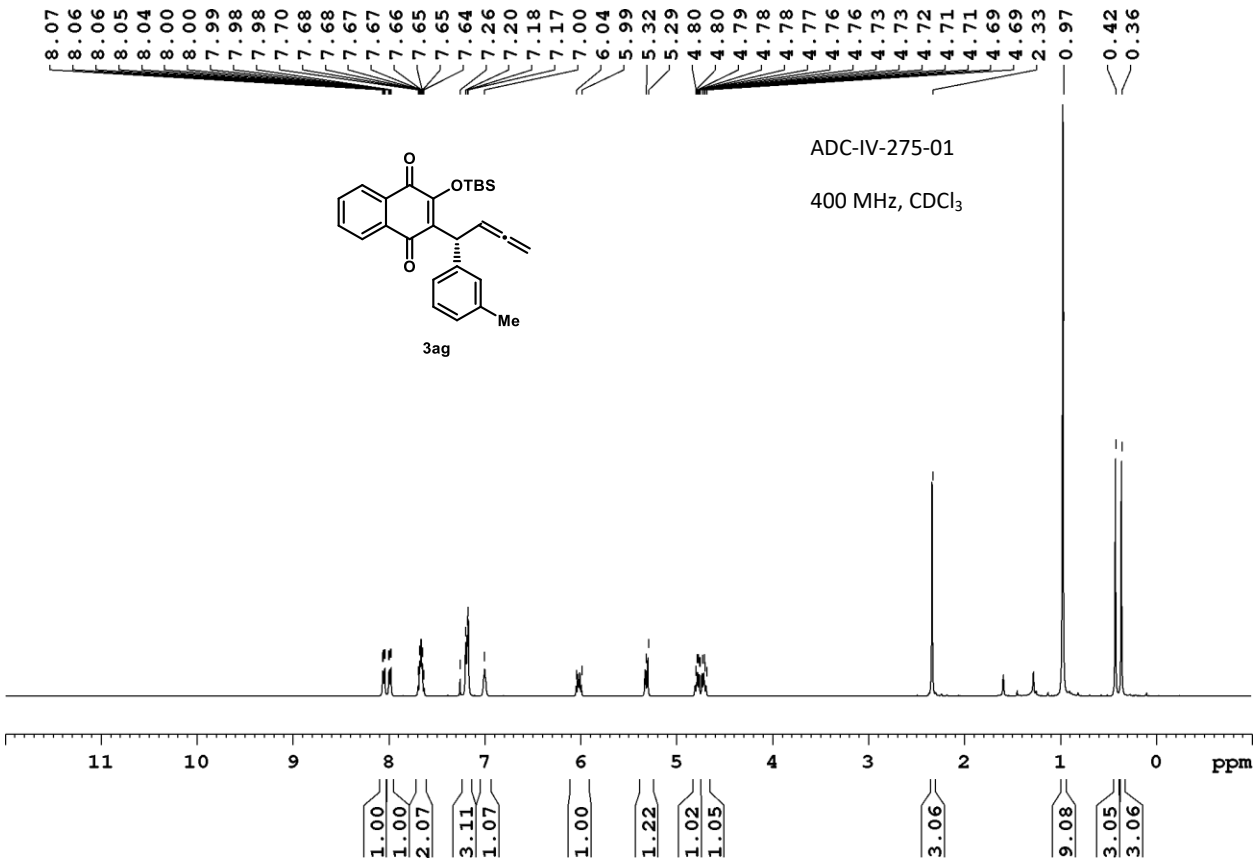
Daicel Chiralpak IG column (90:10 *n*-Hexane/IPA, 0.5 mL/min, 20 °C)

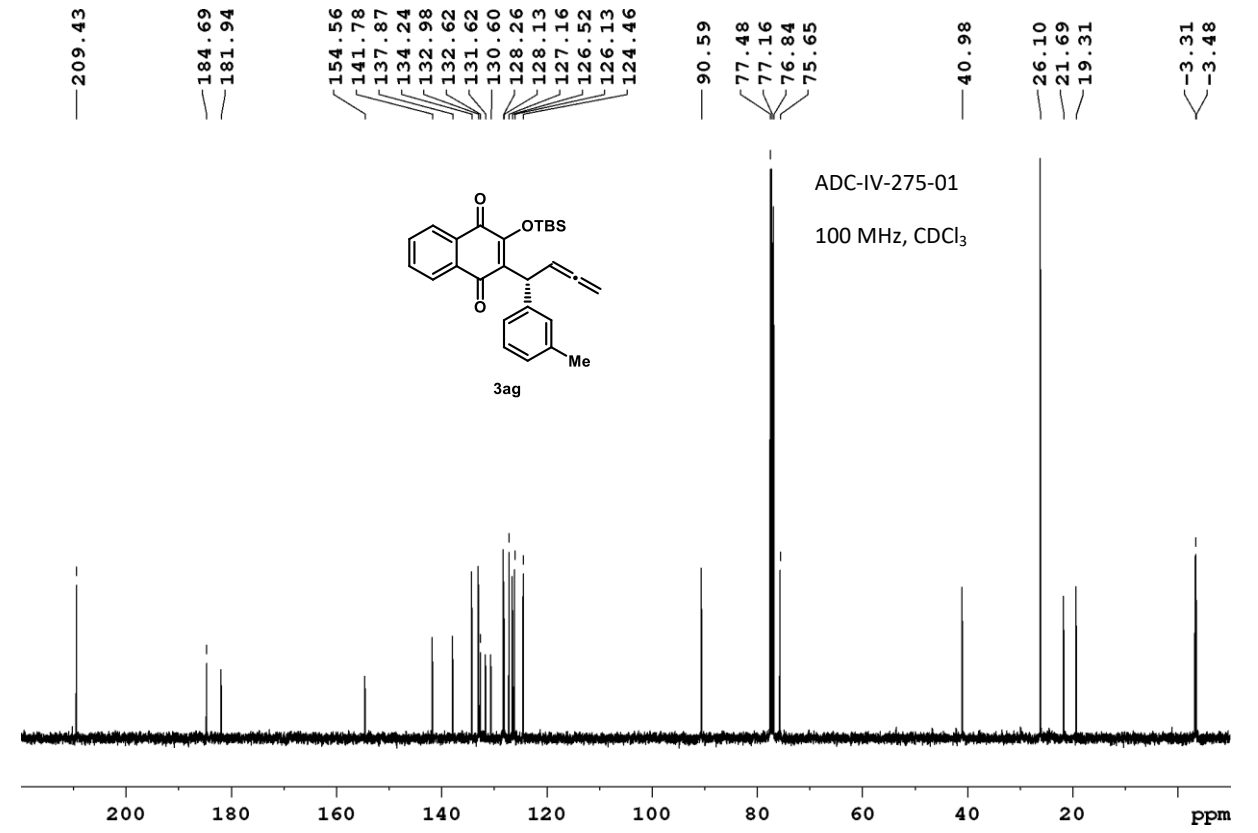


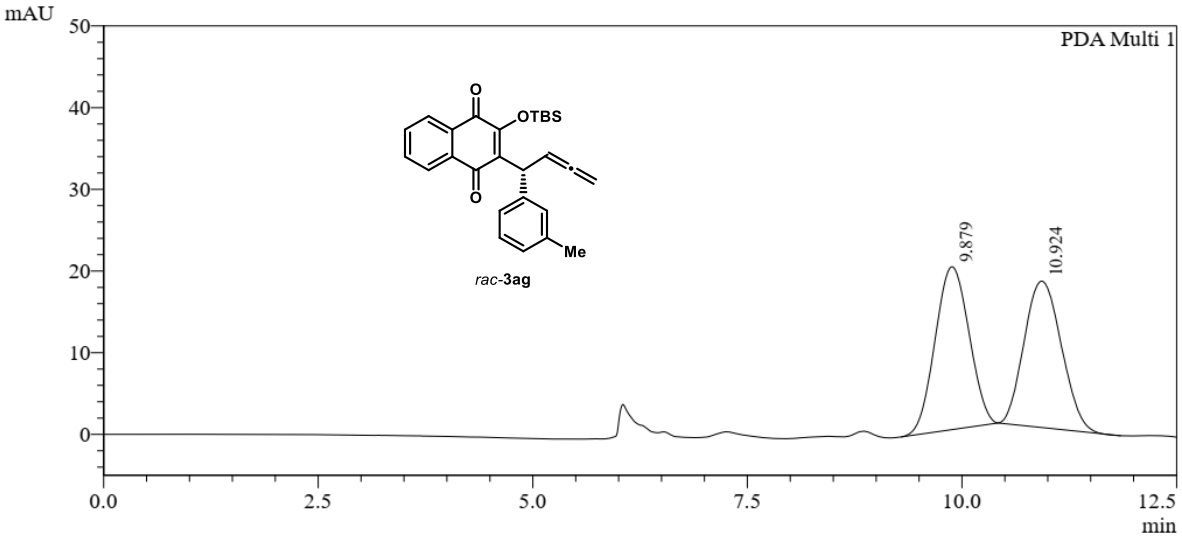
PeakTable

PDA Ch1 258nm 4nm

Peak#	Ret. Time	Area	Area %
1	23.536	31237917	100.000
Total		31237917	100.000


8.07 8.06 8.06 8.05 8.04 8.00 8.00 7.99 7.98 7.98 7.70 7.68 7.68 7.67 7.67 7.66 7.65 7.65 7.64 7.26 7.20 7.18 7.17 7.00 6.04 5.99 5.32 5.29 4.80 4.80 4.79 4.78 4.78 4.77 4.76 4.76 4.73 4.73 4.72 4.71 4.71 4.69 4.69 2.33 0.97 0.42 0.36
ADC-IV-275-01
400 MHz, CDCl3
OTBS
Me
3ag
11 10 9 8 7 6 5 4 3 2 1 0 ppm
1.00 1.00 2.07 3.11 1.07 1.00 1.22 1.02 1.05 3.06 9.08 3.05 3.06


209.43 184.69 181.94 154.56 141.78 137.87 134.24 132.98 132.62 131.62 130.60 128.26 128.13 127.16 126.52 126.13 124.46 90.59 77.48 77.16 76.84 75.65 40.98 26.10 21.69 19.31 -3.31 -3.48
ADC-IV-275-01
100 MHz, CDCl3
OTBS
Me
3ag
200 180 160 140 120 100 80 60 40 20 ppm

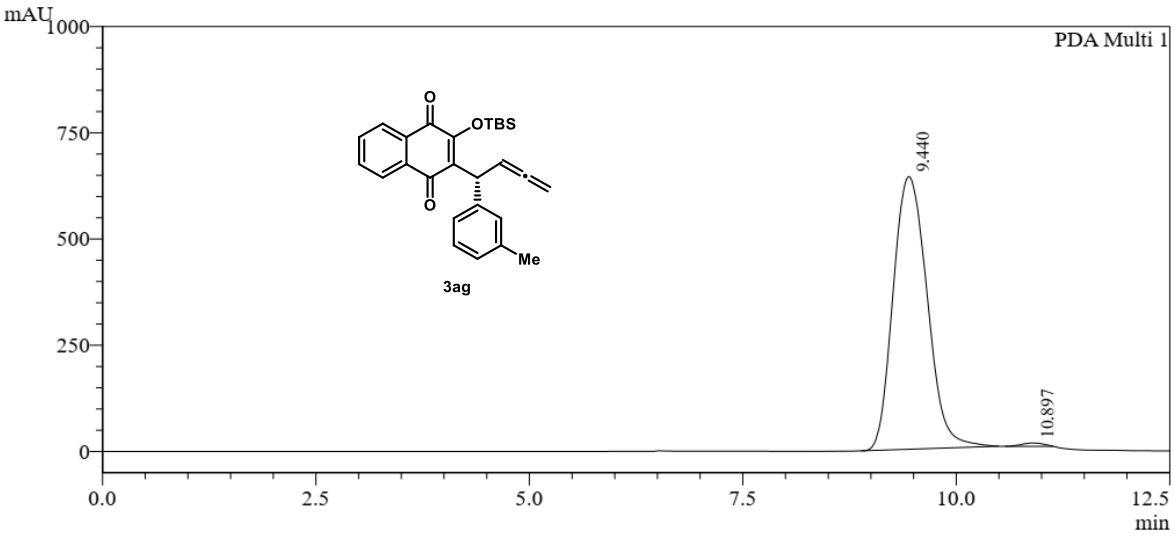


PeakTable

PDA Ch1 247nm 4nm

Peak#	Ret. Time	Area	Area %
1	9.879	548662	50.387
2	10.924	540244	49.613
Total		1088906	100.000

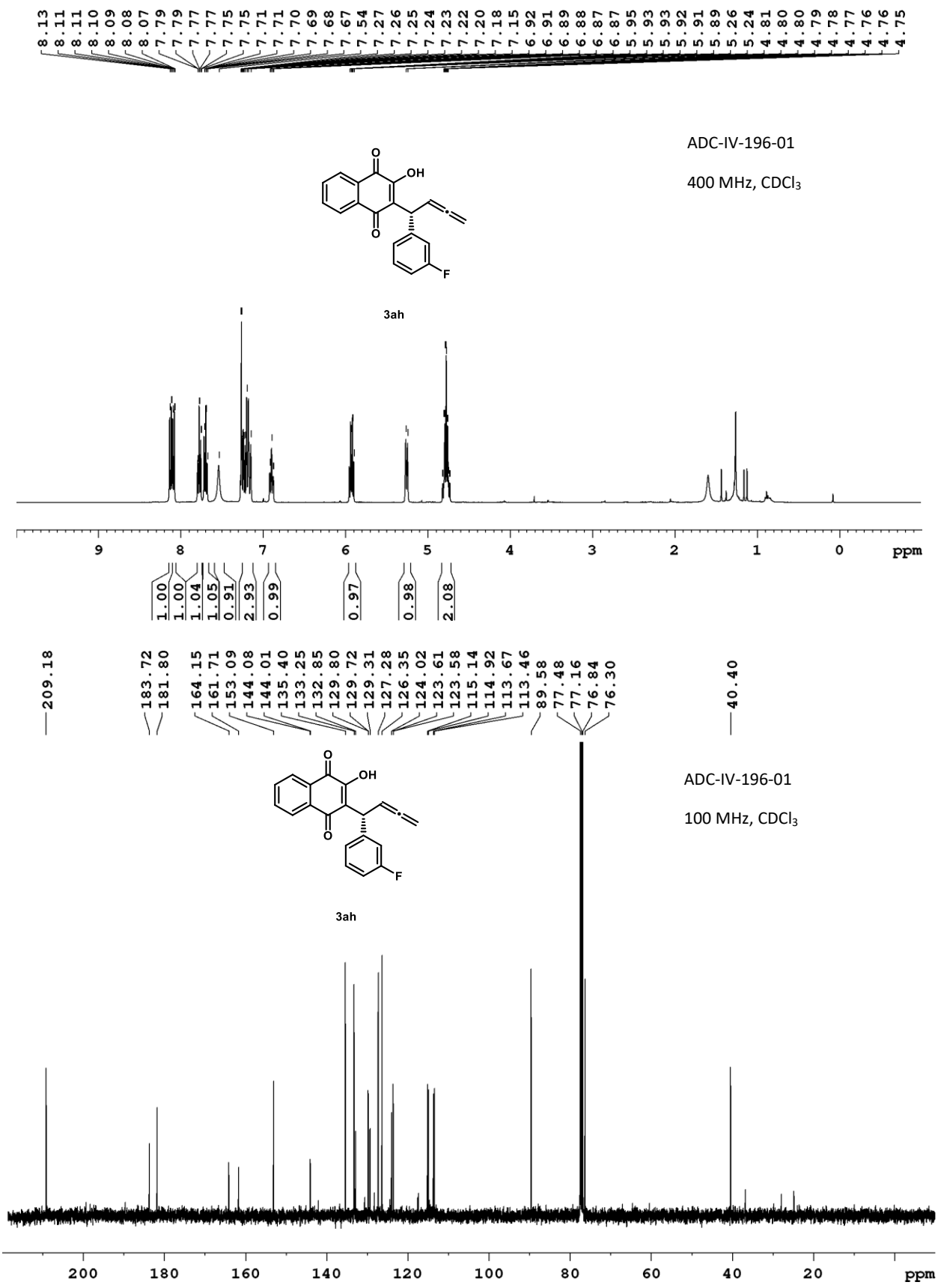
Phenomenex Cellulose-2 column (99:1 *n*-Hexane/IPA, 0.5 mL/min, 20 °C)

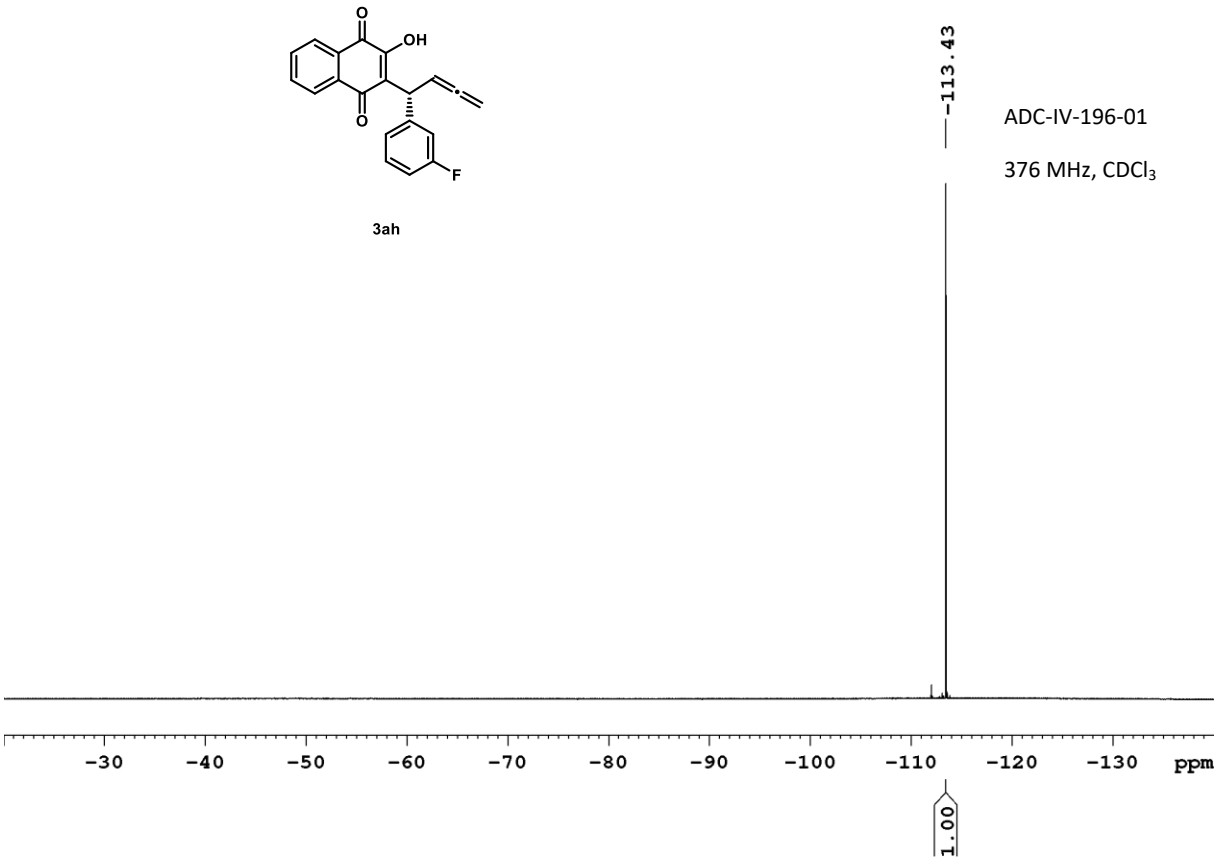


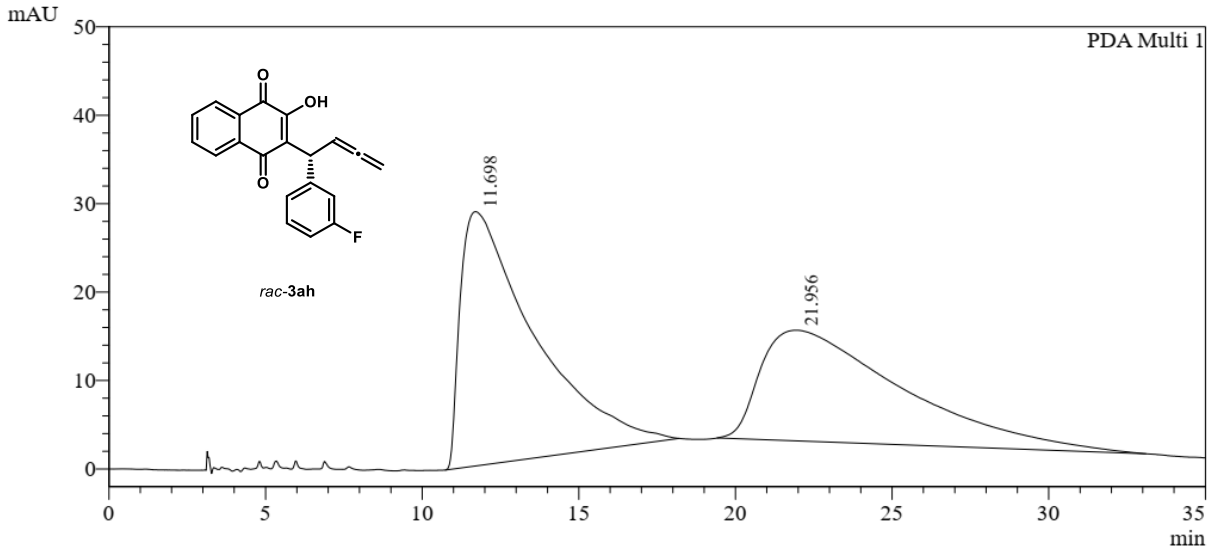
PeakTable

PDA Ch1 247nm 4nm

Peak#	Ret. Time	Area	Area %
1	9.440	17869874	99.194
2	10.897	145197	0.806
Total		18015072	100.000


8.13 8.11 8.11 8.10 8.09 8.08 8.07 7.79 7.79 7.77 7.77 7.75 7.75 7.71 7.71 7.70 7.69 7.68 7.67 7.54 7.27 7.26 7.25 7.24 7.23 7.22 7.20 7.18 7.15 6.92 6.91 6.89 6.88 6.87 6.87 5.95 5.93 5.93 5.92 5.91 5.89 5.26 5.24 4.81 4.80 4.80 4.79 4.78 4.77 4.76 4.76 4.75
ADC-IV-196-01
400 MHz, CDCl3
OH
O
O
F
3ah
9 8 7 6 5 4 3 2 1 0 ppm
1.00 1.00 1.04 1.05 0.91 2.93 0.99 0.97 0.98 2.08
209.18 183.72 181.80 164.15 161.71 153.09 144.08 144.01 135.40 133.25 132.85 129.80 129.72 129.31 127.28 126.35 124.02 123.61 123.58 115.14 114.92 113.67 113.46 89.58 77.48 77.16 76.84 76.30 40.40
ADC-IV-196-01
100 MHz, CDCl3
OH
O
O
F
3ah
200 180 160 140 120 100 80 60 40 20 ppm


O
OH
O
F
3ah
-113.43
ADC-IV-196-01
376 MHz, CDCl3
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
ppm
1.00

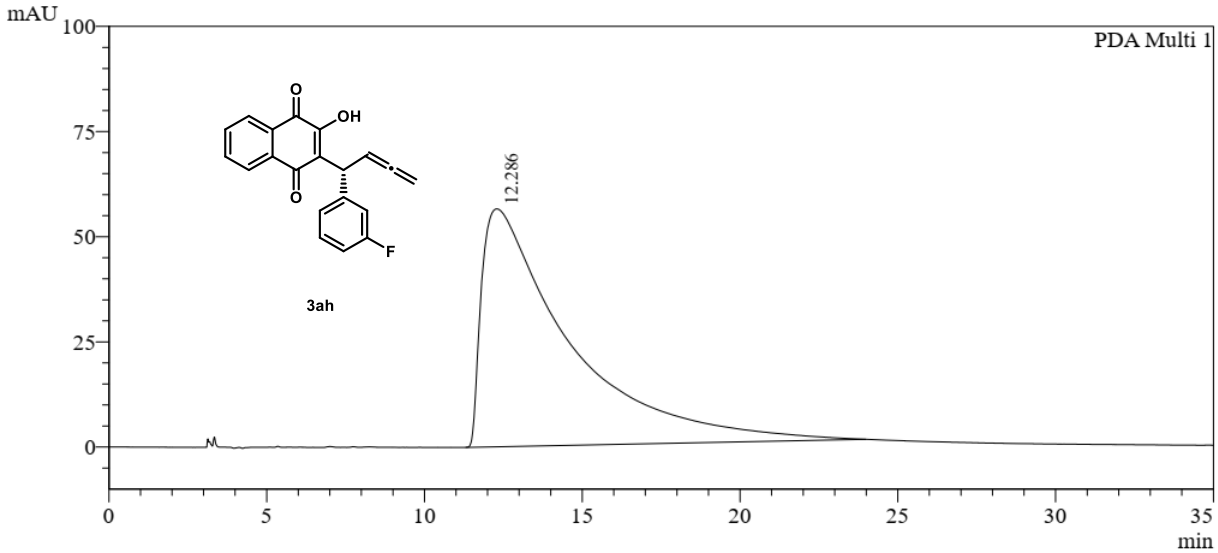


PeakTable

PDA Ch1 252nm 4nm

Peak#	Ret. Time	Area	Area %
1	11.698	4723570	54.406
2	21.956	3958501	45.594
Total		8682071	100.000

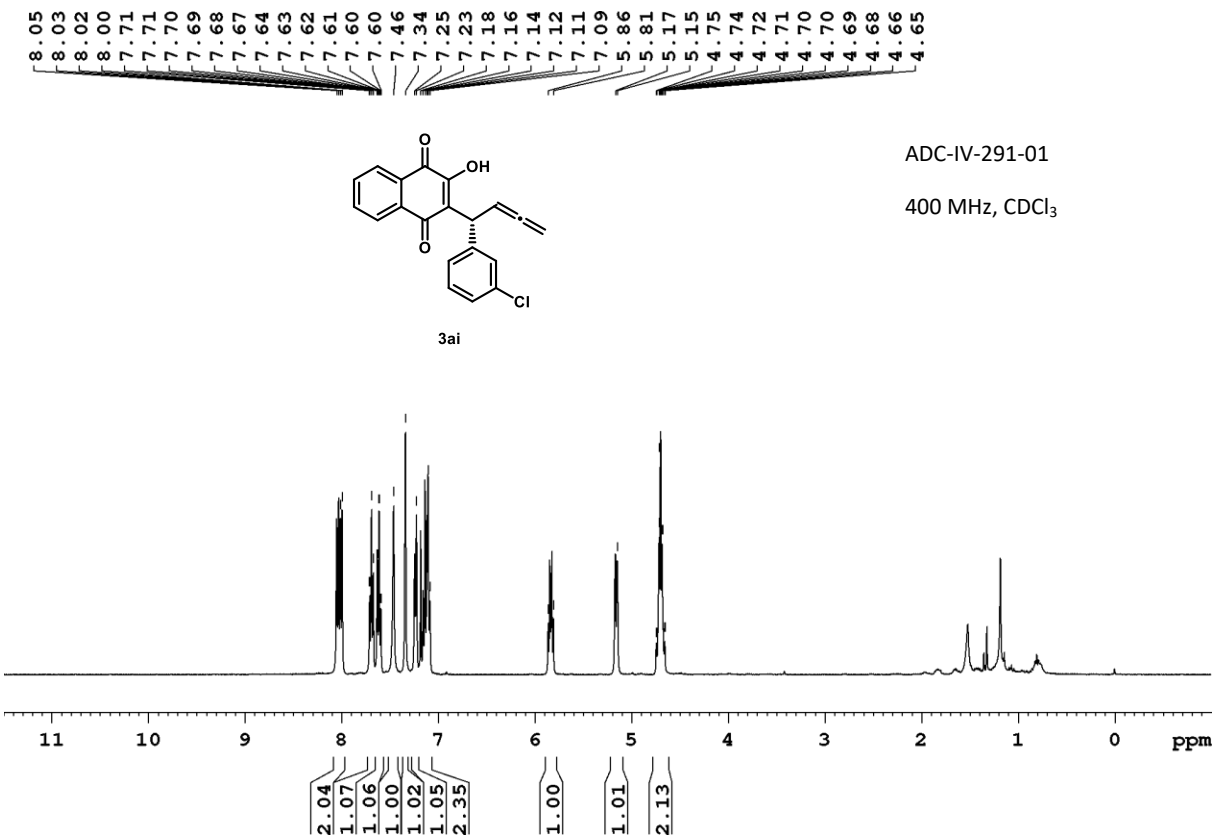
Daicel Chiralpak ID column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

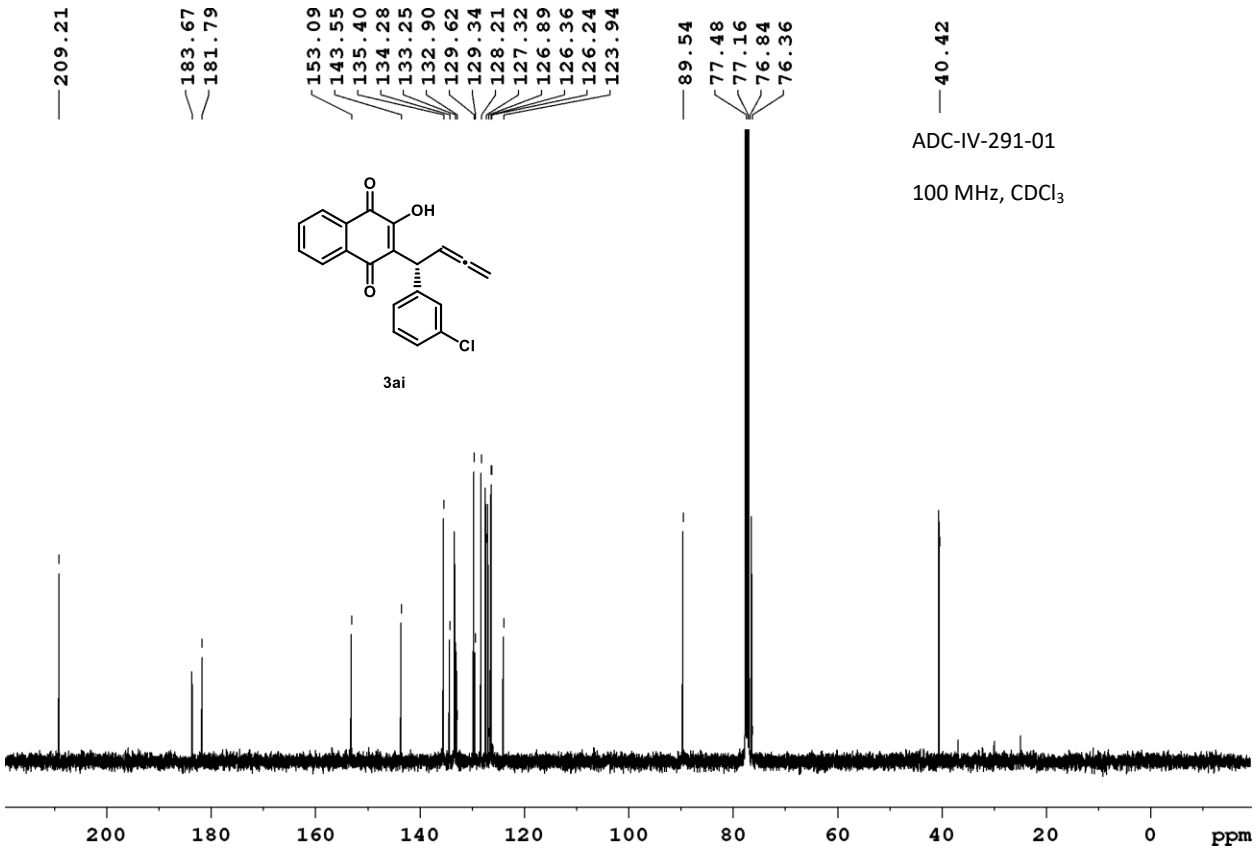


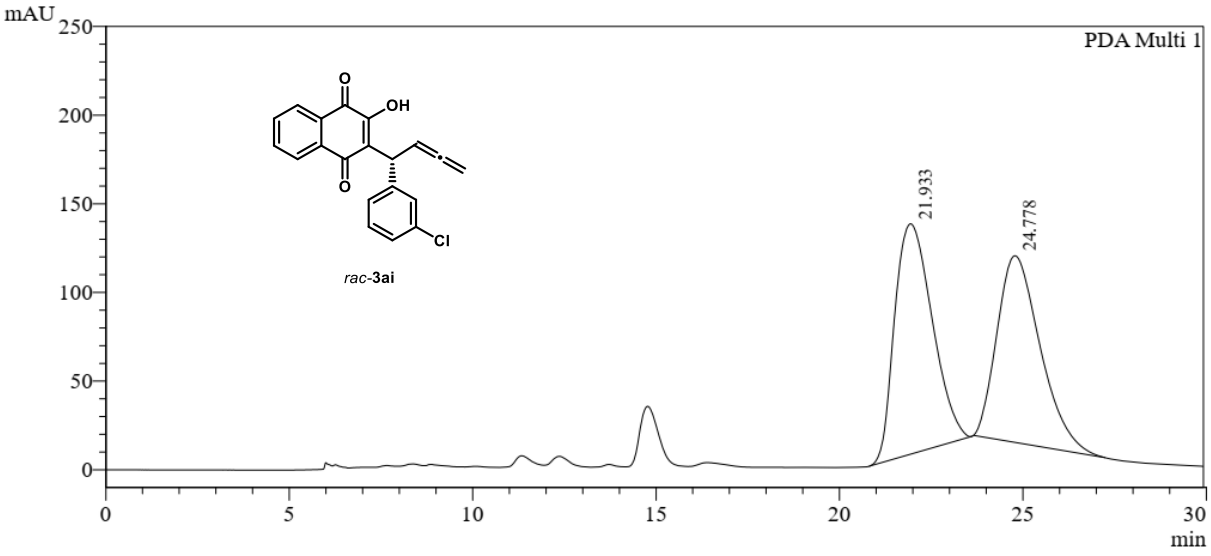
PeakTable

PDA Ch1 252nm 4nm

Peak#	Ret. Time	Area	Area %
1	12.286	10989014	100.000
Total		10989014	100.000


8.05 8.03 8.02 8.00 7.71 7.71 7.70 7.69 7.68 7.67 7.64 7.63 7.62 7.61 7.60 7.60 7.46 7.34 7.25 7.23 7.18 7.16 7.14 7.12 7.11 7.09 5.86 5.81 5.17 5.15 4.75 4.74 4.72 4.71 4.70 4.70 4.69 4.68 4.66 4.65
O
OH
O
Cl
3ai
ADC-IV-291-01
400 MHz, CDCl3
11 10 9 8 7 6 5 4 3 2 1 0 ppm
2.04 1.07 1.06 1.00 1.02 1.05 2.35 1.00 1.01 2.13


209.21
183.67 181.79
153.09 143.55 135.40 134.28 133.25 132.90 129.62 129.34 128.21 127.32 126.89 126.36 126.24 123.94
89.54 77.48 77.16 76.84 76.36
40.42
O
OH
O
Cl
3ai
ADC-IV-291-01
100 MHz, CDCl3
200 180 160 140 120 100 80 60 40 20 0 ppm

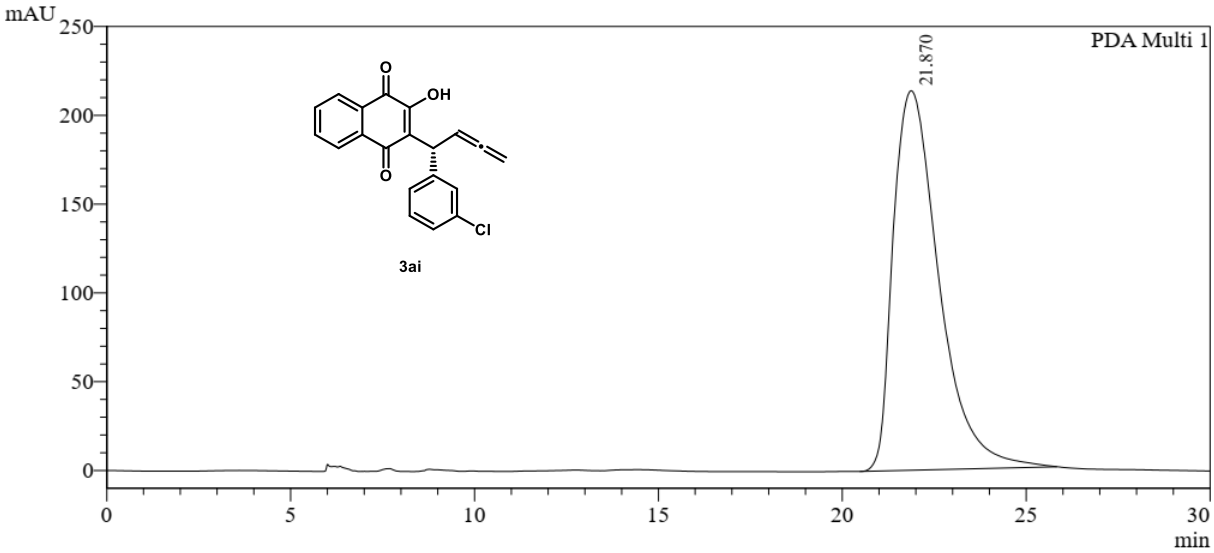


PeakTable

PDA Ch1 242nm 4nm

Peak#	Ret. Time	Area	Area %
1	21.933	9252332	51.757
2	24.778	8624068	48.243
Total		17876399	100.000

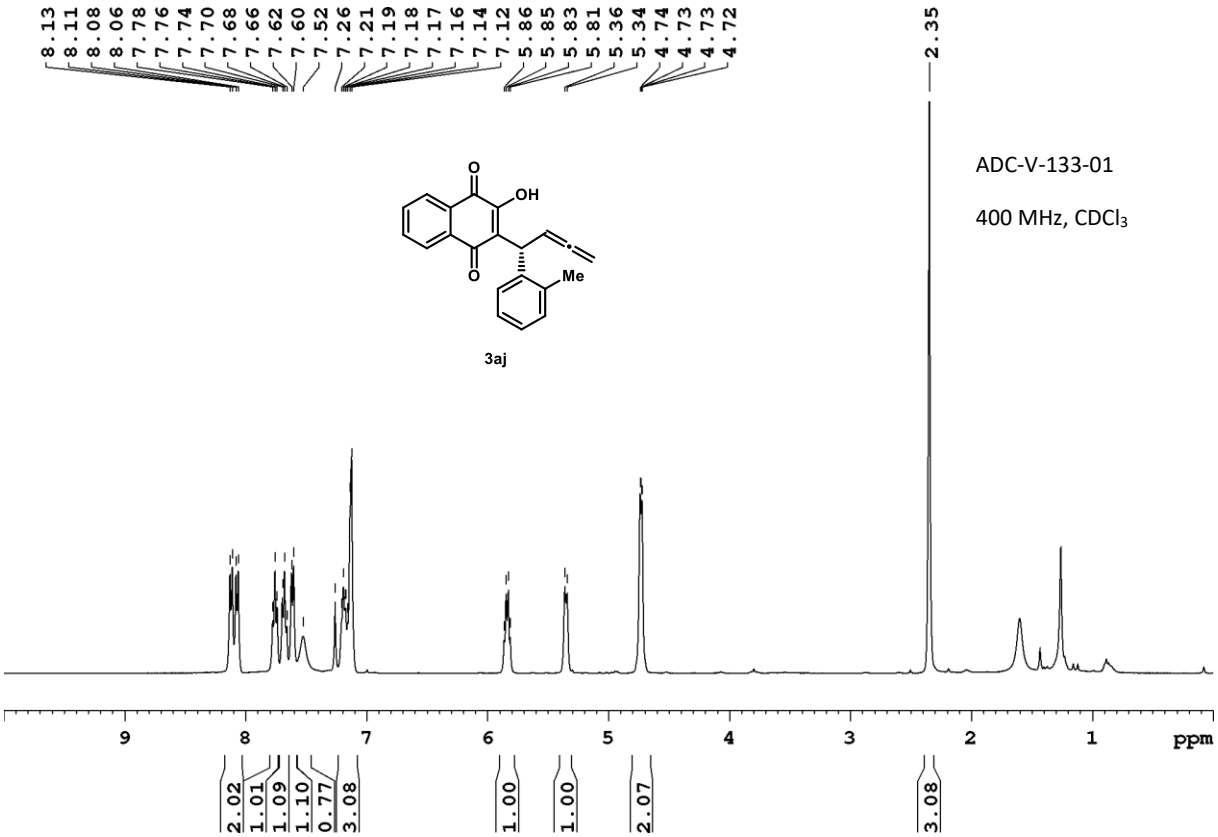
Daicel Chiralpak AD-H column (90:10 *n*-Hexane/EtOH, 0.5 mL/min, 20 °C)

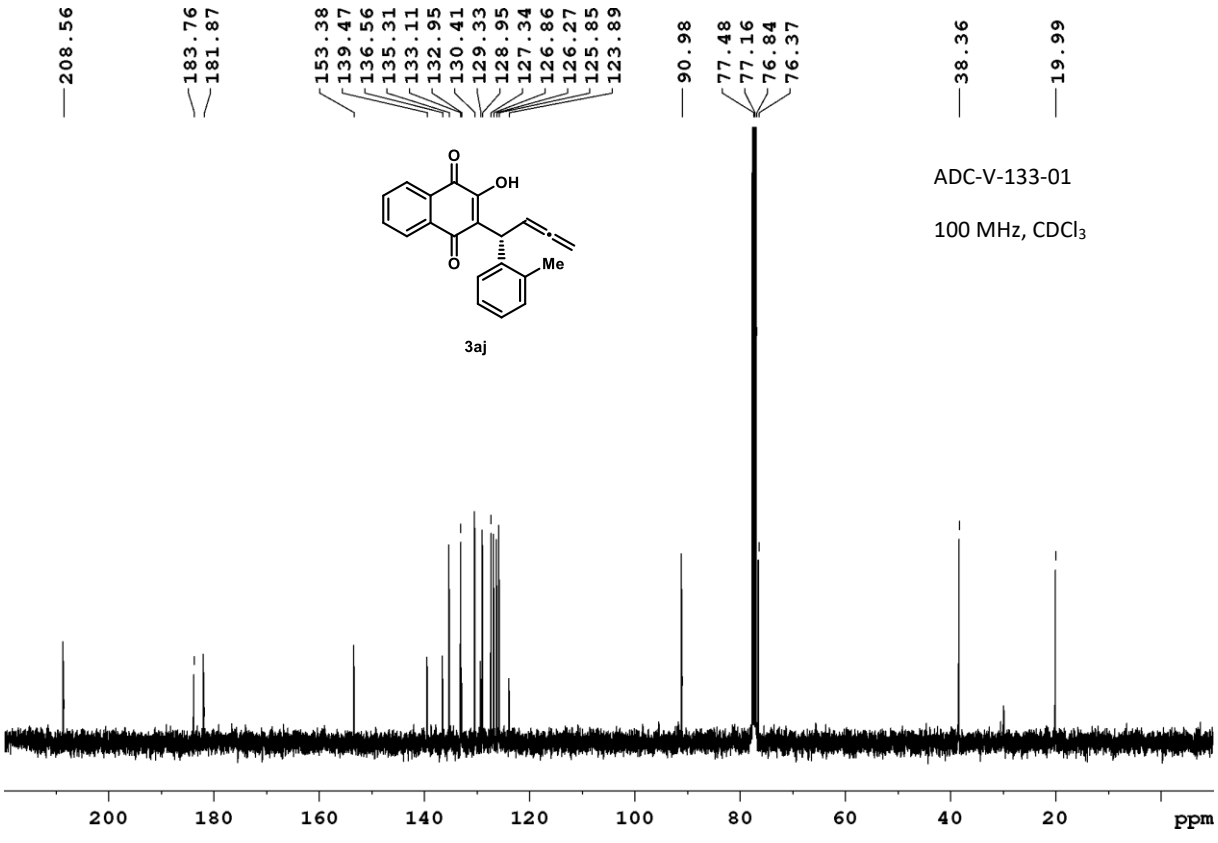


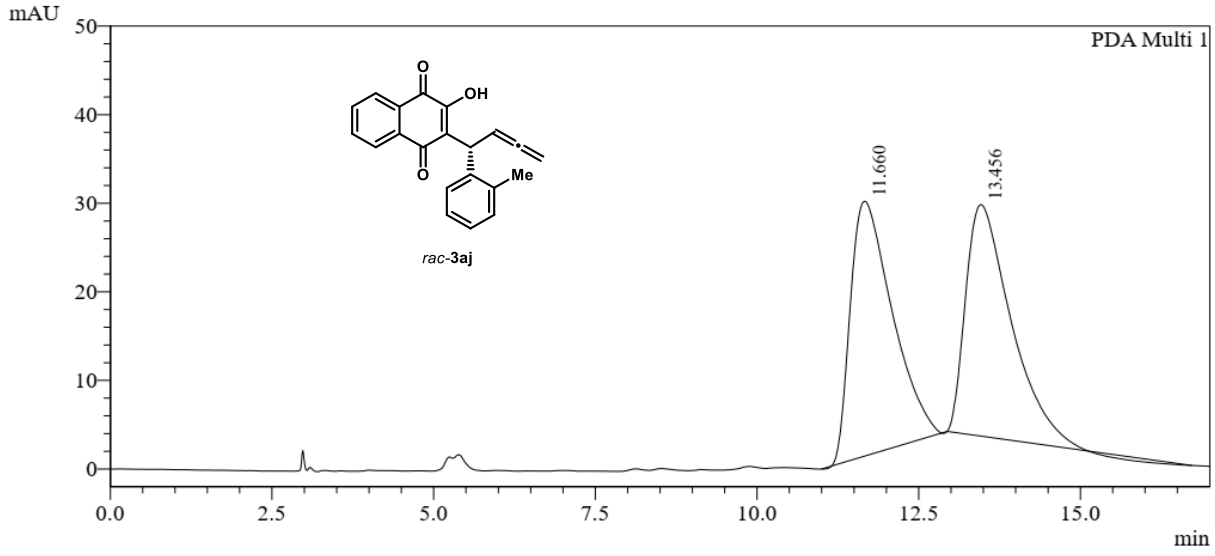
PeakTable

PDA Ch1 242nm 4nm

Peak#	Ret. Time	Area	Area %
1	21.870	18524557	100.000
Total		18524557	100.000


8.13
8.11
8.08
8.06
7.78
7.76
7.74
7.70
7.68
7.66
7.62
7.60
7.52
7.26
7.21
7.19
7.18
7.17
7.16
7.14
7.12
5.86
5.85
5.83
5.81
5.36
5.34
4.74
4.73
4.73
4.72
2.35
ADC-V-133-01
400 MHz, CDCl3
OH
O
O
Me
3aj
9
8
7
6
5
4
3
2
1
ppm
2.02
1.01
1.09
1.10
0.77
3.08
1.00
1.00
2.07
3.08


208.56
183.76
181.87
153.38
139.47
136.56
135.31
133.11
132.95
130.41
129.33
128.95
127.34
126.86
126.27
125.85
123.89
90.98
77.48
77.16
76.84
76.37
38.36
19.99
ADC-V-133-01
100 MHz, CDCl3
OH
O
O
Me
3aj
200
180
160
140
120
100
80
60
40
20
ppm

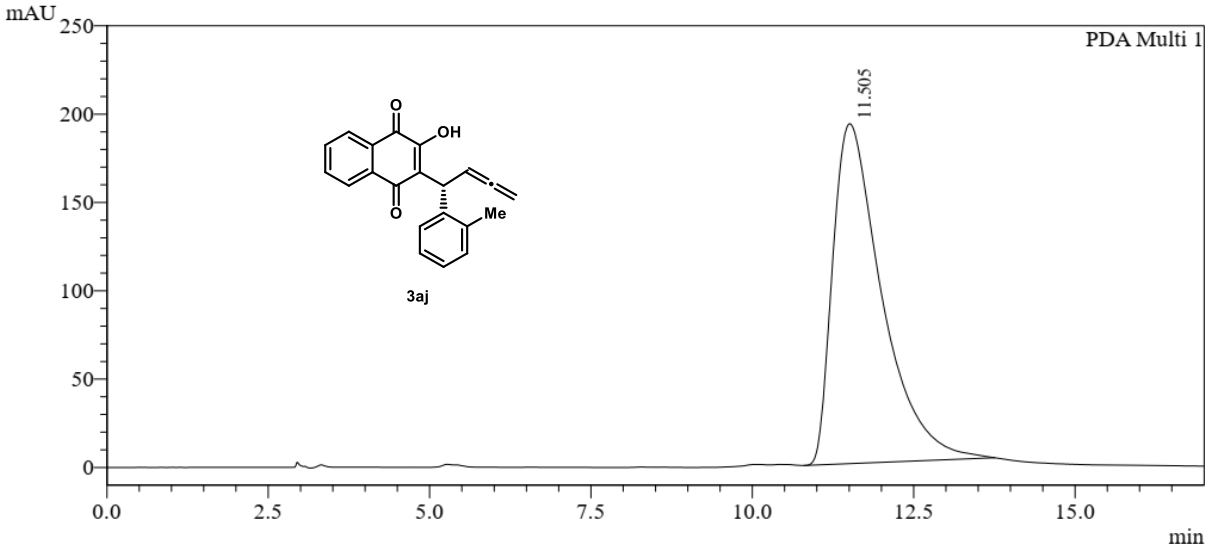


PeakTable

PDA Ch1 274nm 4nm

Peak#	Ret. Time	Area	Area %
1	11.660	1296026	50.611
2	13.456	1264754	49.389
Total		2560780	100.000

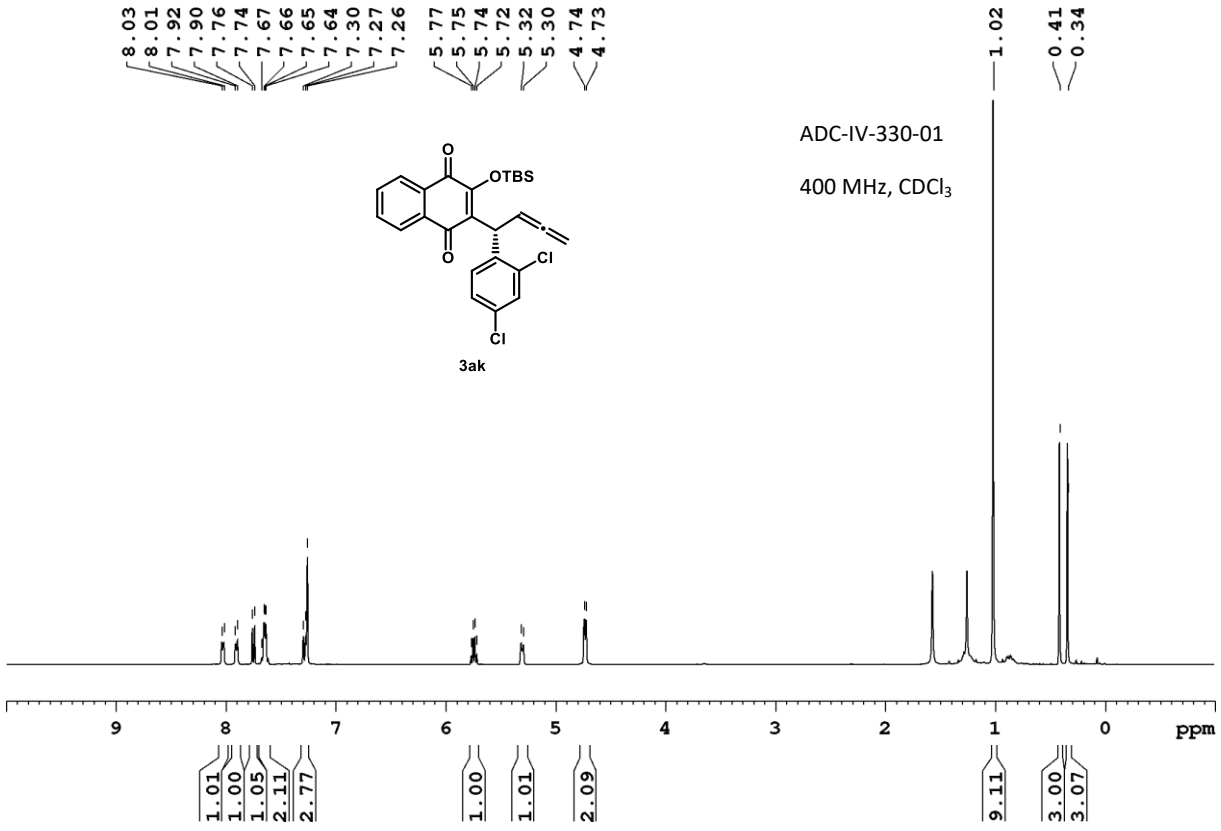
Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

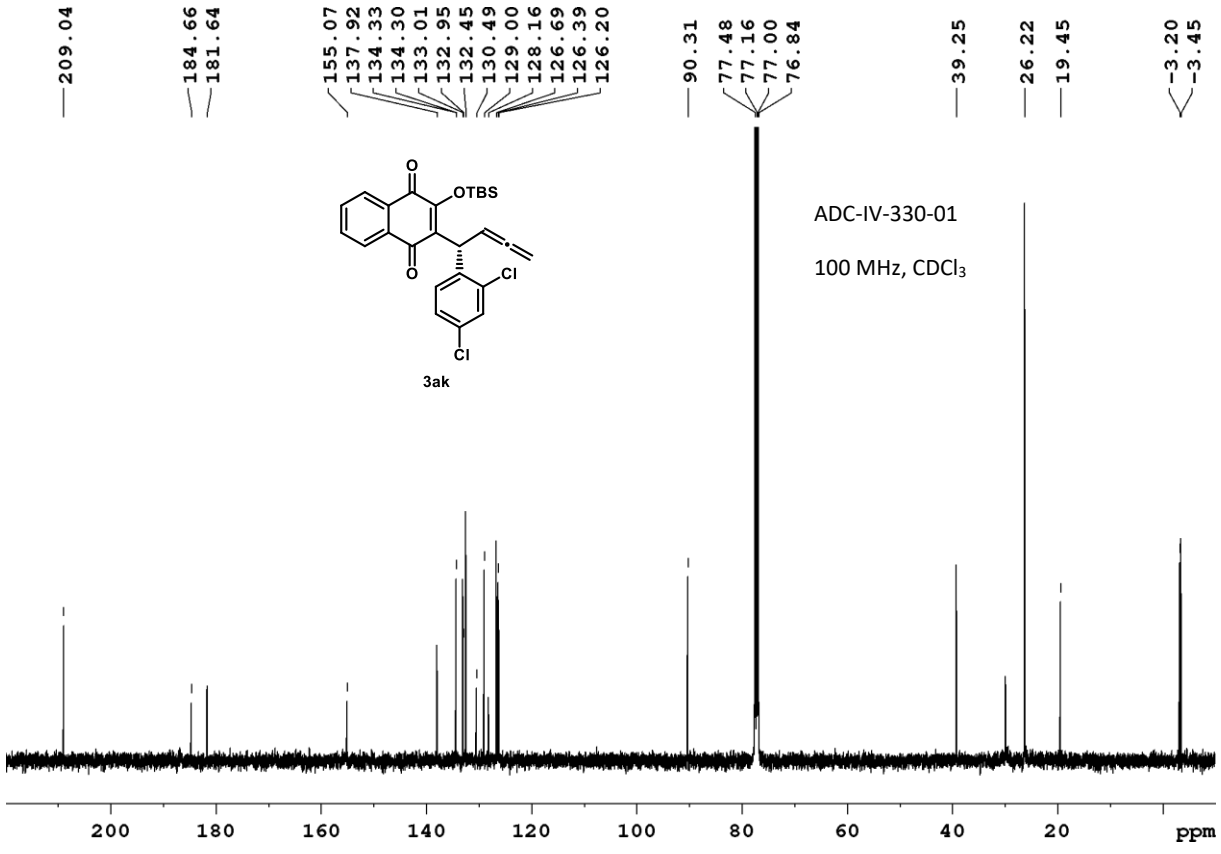


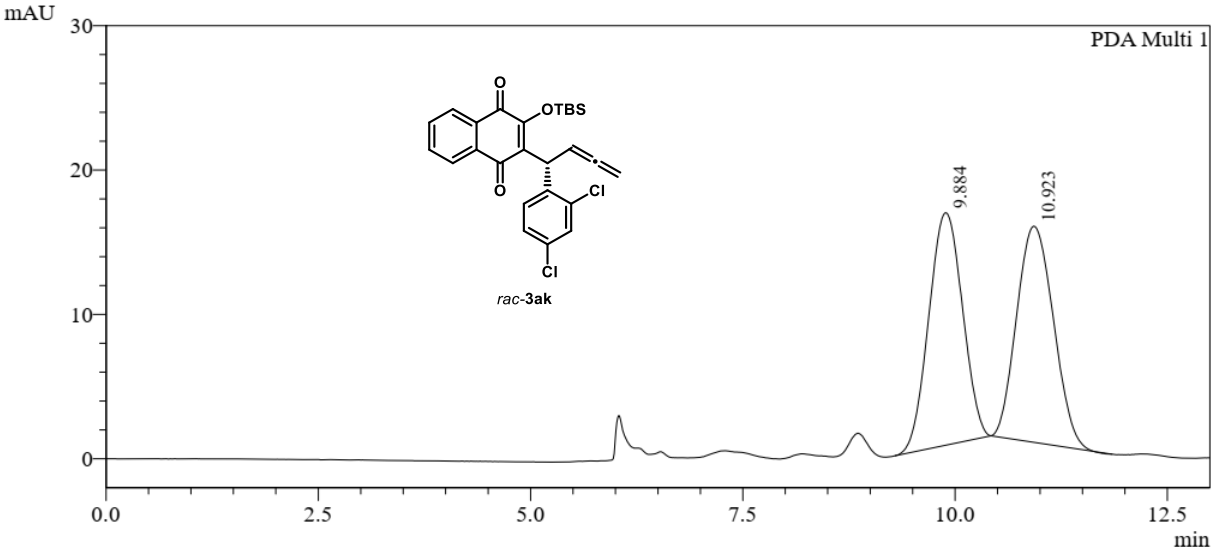
PeakTable

PDA Ch1 274nm 4nm

Peak#	Ret. Time	Area	Area %
1	11.505	10187039	100.000
Total		10187039	100.000


8.03
8.01
7.92
7.90
7.76
7.74
7.67
7.66
7.65
7.64
7.30
7.27
7.26
5.77
5.75
5.74
5.72
5.32
5.30
4.74
4.73
1.02
0.41
0.34
ADC-IV-330-01
400 MHz, CDCl3
OTBS
Cl
Cl
3ak
ppm
1.01
1.00
1.05
2.11
2.77
1.00
1.01
2.09
9.11
3.00
3.07


209.04
184.66
181.64
155.07
137.92
134.33
134.30
133.01
132.95
132.45
130.49
129.00
128.16
126.69
126.39
126.20
90.31
77.48
77.16
77.00
76.84
39.25
26.22
19.45
-3.20
-3.45
OTBS
Cl
Cl
3ak
ADC-IV-330-01
100 MHz, CDCl3
ppm



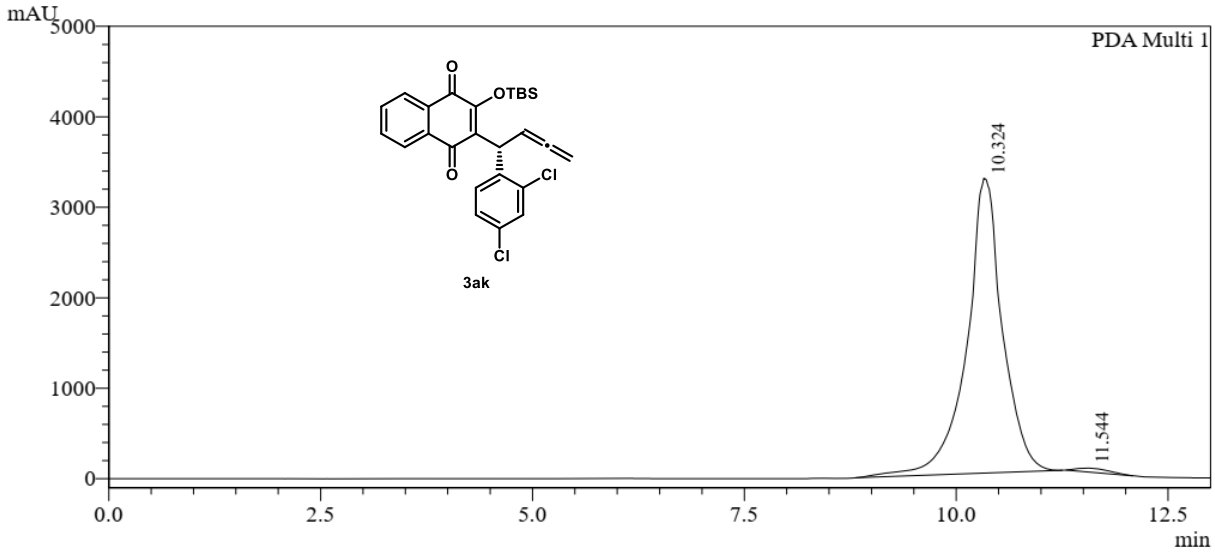
rac-**3ak**

PeakTable

PDA Ch1 263nm 4nm

Peak#	Ret. Time	Area	Area %
1	9.884	445059	49.668
2	10.923	451015	50.332
Total		896075	100.000

Phenomenex Cellulose-2 column (99:1 *n*-Hexane/IPA, 0.5 mL/min, 20 °C)

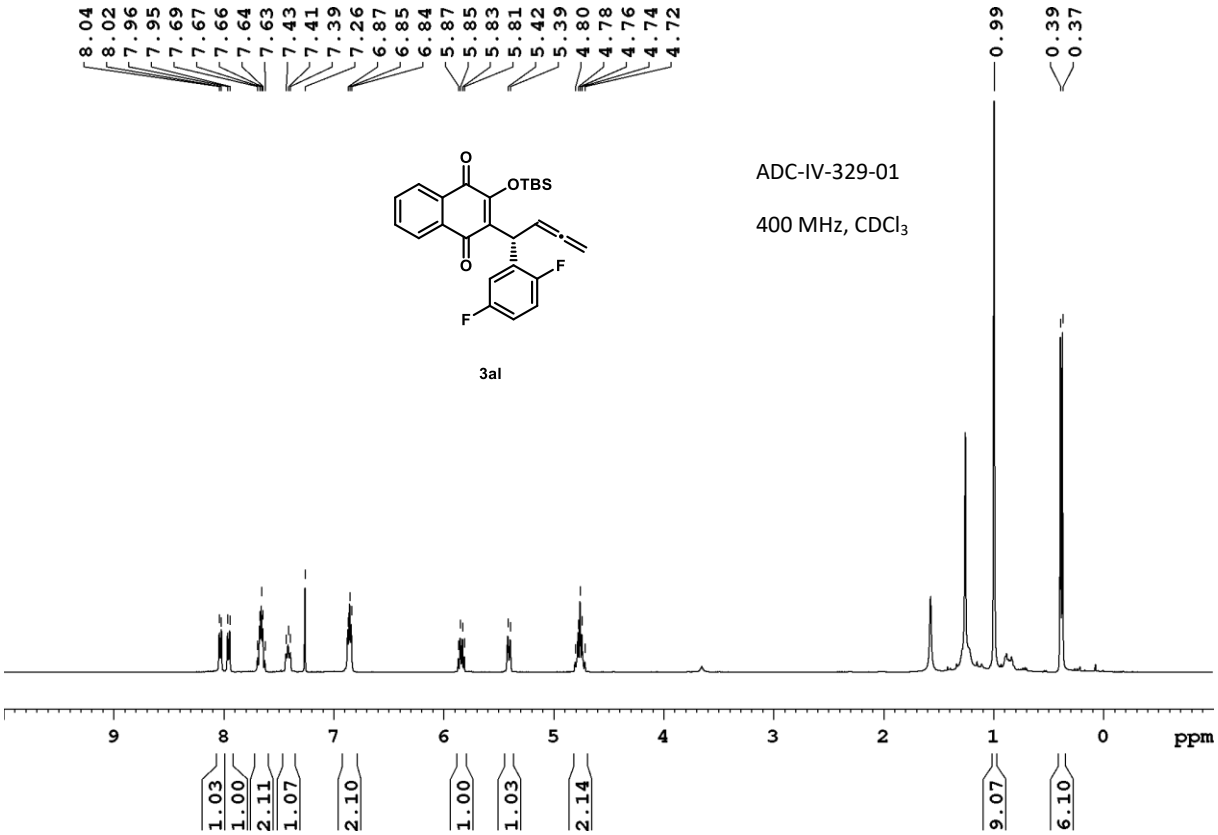


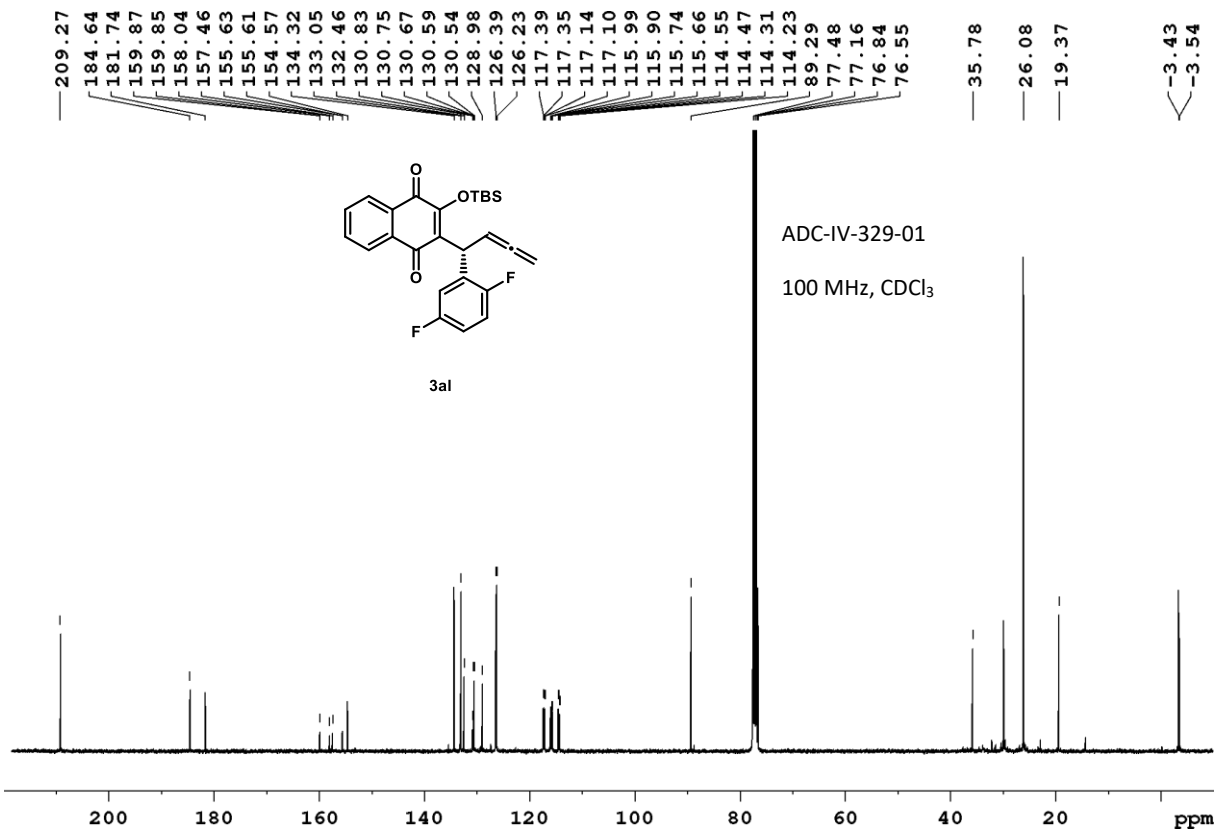
3ak

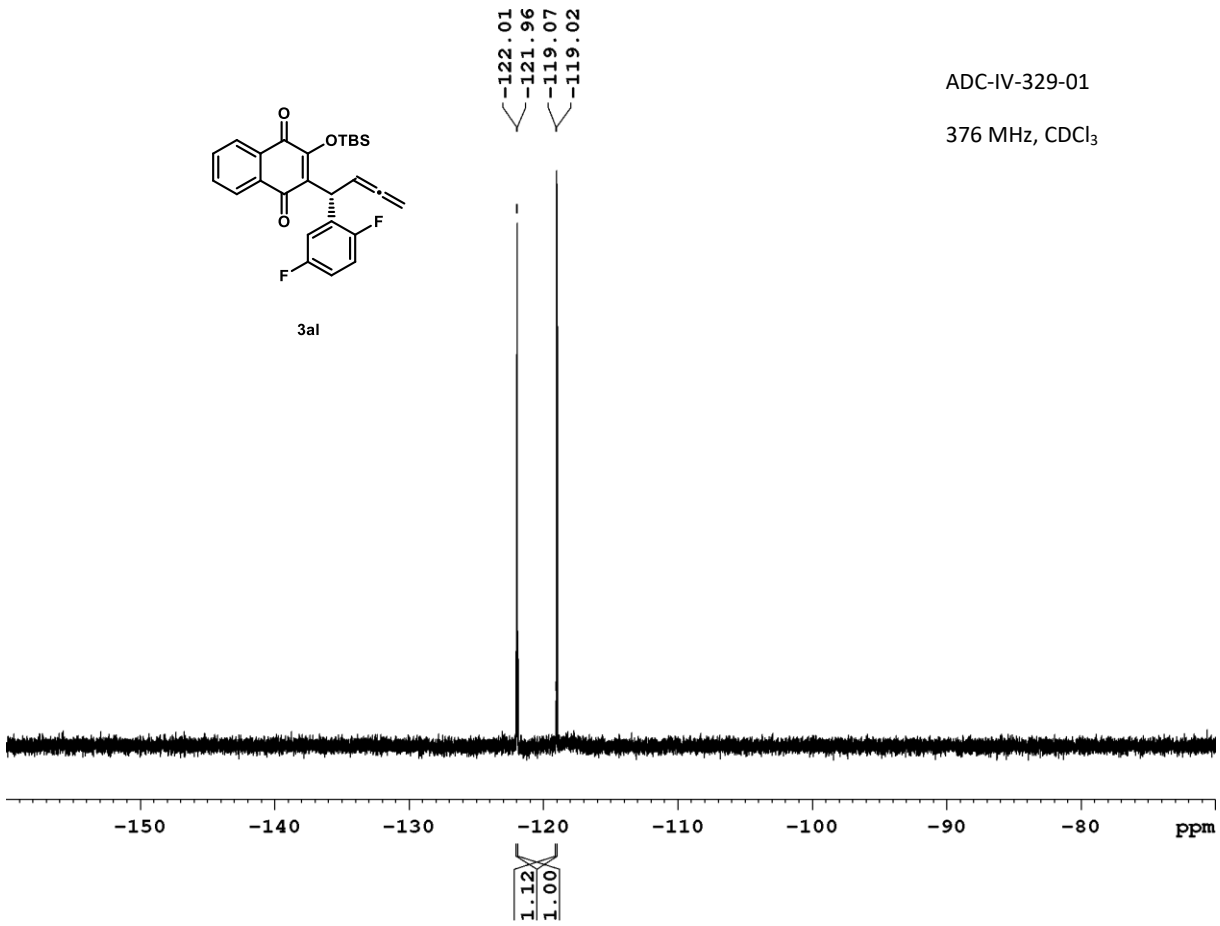
PeakTable

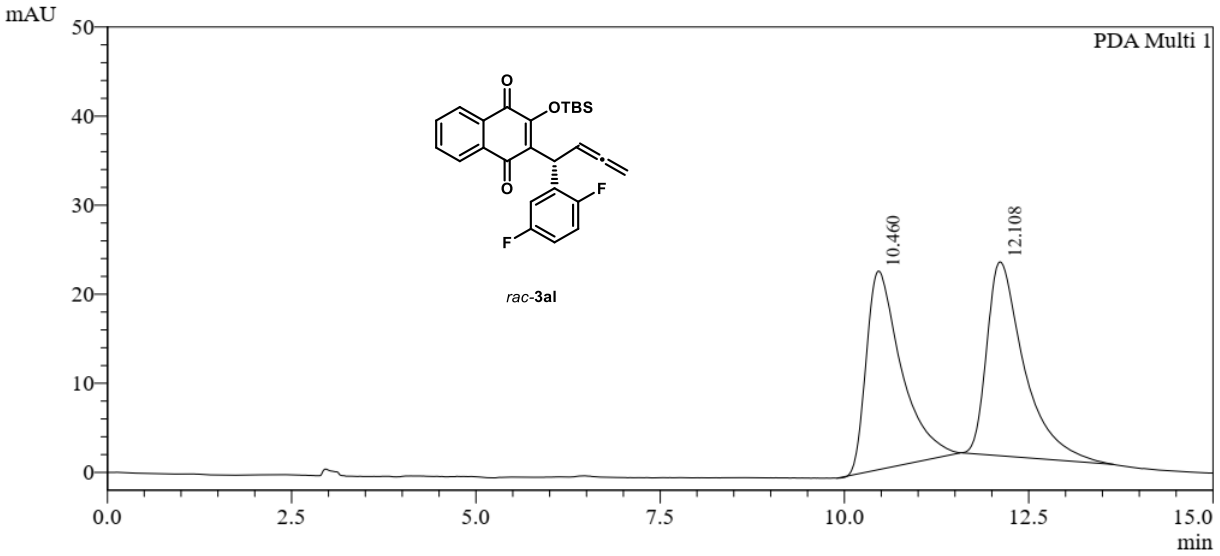
PDA Ch1 263nm 4nm

Peak#	Ret. Time	Area	Area %
1	10.324	95652623	98.791
2	11.544	1170996	1.209
Total		96823619	100.000


8.04
8.02
7.96
7.95
7.69
7.67
7.66
7.64
7.63
7.43
7.41
7.39
7.26
6.87
6.85
6.84
5.87
5.85
5.83
5.81
5.42
5.39
4.80
4.78
4.76
4.74
4.72
0.99
0.39
0.37
OTBS
F
F
3al
ADC-IV-329-01
400 MHz, CDCl3
9
8
7
6
5
4
3
2
1
0
ppm
1.03
1.00
2.11
1.07
2.10
1.00
1.03
2.14
9.07
6.10


209.27
184.64
181.74
159.87
159.85
158.04
157.46
155.63
155.61
154.57
134.32
133.05
132.46
130.83
130.75
130.67
130.59
130.54
128.98
126.39
126.23
117.39
117.35
117.14
117.10
115.99
115.90
115.74
115.66
114.55
114.47
114.31
114.23
89.29
77.48
77.16
76.84
76.55
35.78
26.08
19.37
-3.43
-3.54
OTBS
F
F
3al
ADC-IV-329-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
ppm


-122.01
-121.96
-119.07
-119.02
ADC-IV-329-01
376 MHz, CDCl3
O
OTBS
O
F
F
3al
-150
-140
-130
-120
-110
-100
-90
-80
ppm
1.12
1.00

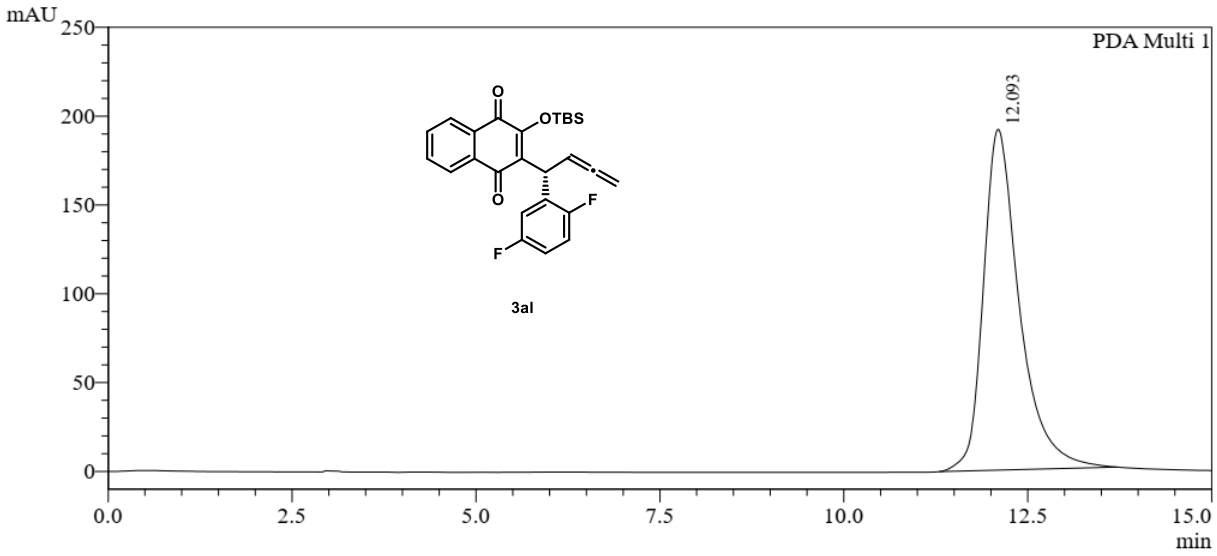


PeakTable

PDA Ch1 290nm 4nm

Peak#	Ret. Time	Area	Area %
1	10.460	736517	48.974
2	12.108	767363	51.026
Total		1503880	100.000

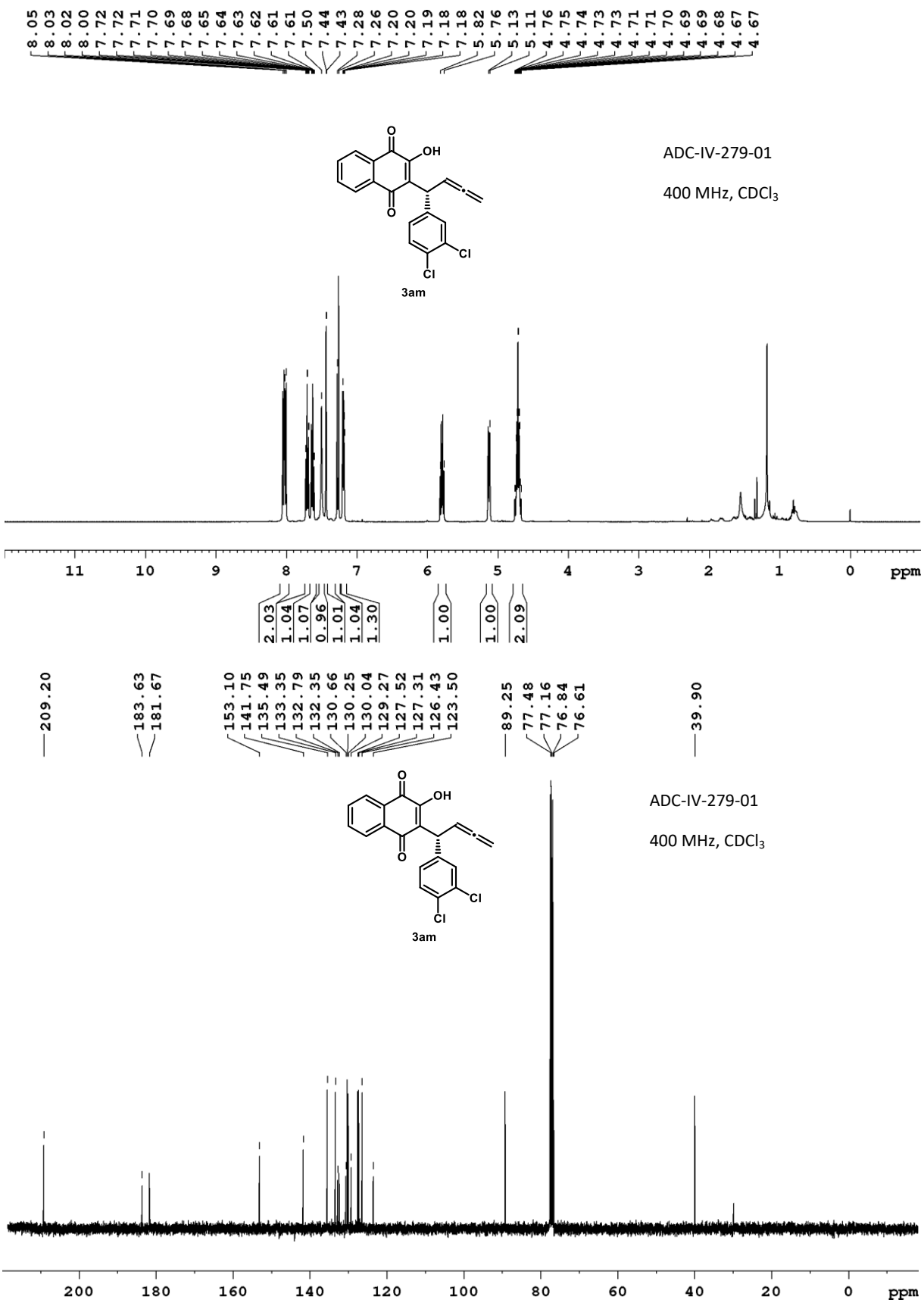
Daicel Chiralpak AD-H column (85:15 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

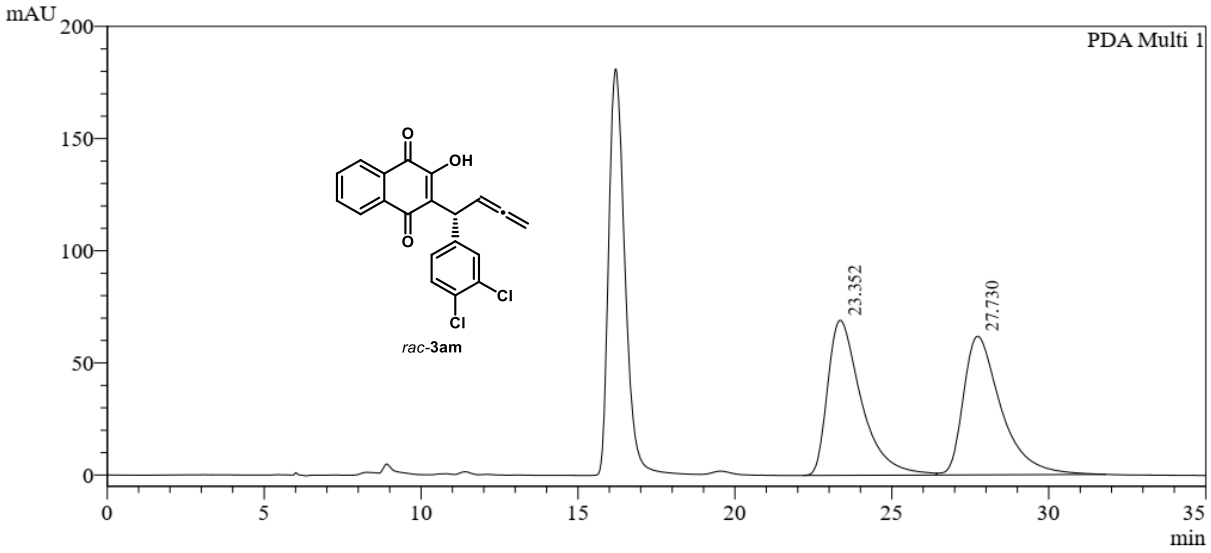


PeakTable

PDA Ch1 290nm 4nm

Peak#	Ret. Time	Area	Area %
1	12.093	6559122	100.000
Total		6559122	100.000


8.05 8.03 8.02 8.00 7.72 7.72 7.71 7.70 7.69 7.68 7.65 7.64 7.63 7.62 7.61 7.61 7.50 7.44 7.43 7.28 7.26 7.20 7.20 7.19 7.18 5.82 5.76 5.13 5.11 4.76 4.75 4.74 4.73 4.73 4.71 4.70 4.69 4.69 4.68 4.67 4.67
OH
O
O
Cl
Cl
3am
ADC-IV-279-01
400 MHz, CDCl3
11 10 9 8 7 6 5 4 3 2 1 0 ppm
2.03 1.04 1.07 0.96 1.01 1.04 1.30 1.00 1.00 2.09
209.20 183.63 181.67 153.10 141.75 135.49 133.35 132.79 132.35 130.66 130.25 130.04 129.27 127.52 127.31 126.43 123.50 89.25 77.48 77.16 76.84 76.61 39.90
OH
O
O
Cl
Cl
3am
ADC-IV-279-01
400 MHz, CDCl3
200 180 160 140 120 100 80 60 40 20 0 ppm

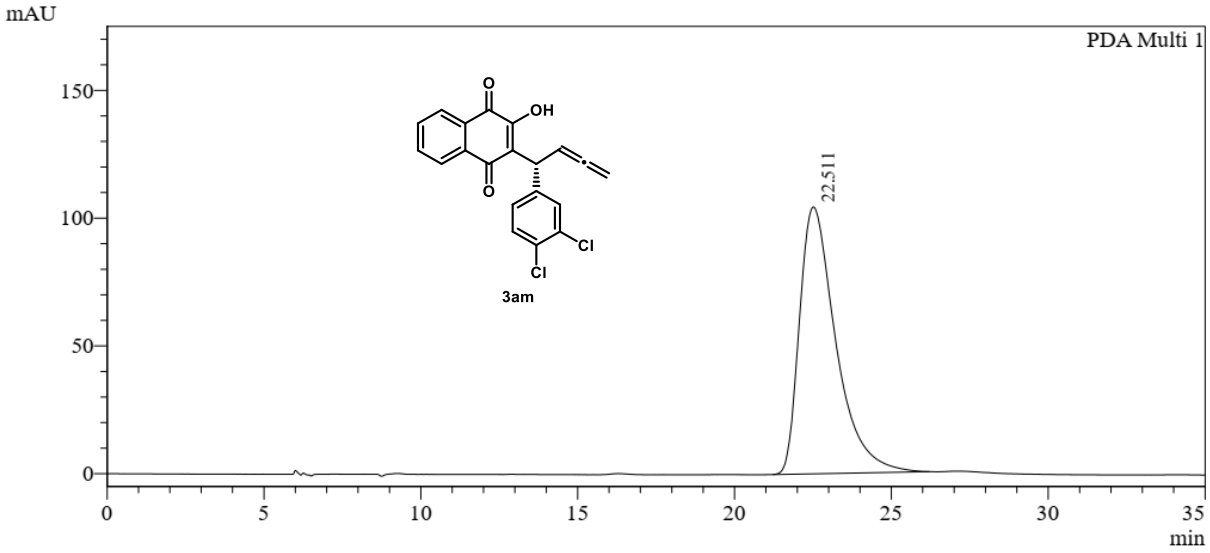


PeakTable

PDA Ch1 299nm 4nm

Peak#	Ret. Time	Area	Area %
1	23.352	5151484	49.960
2	27.730	5159753	50.040
Total		10311237	100.000

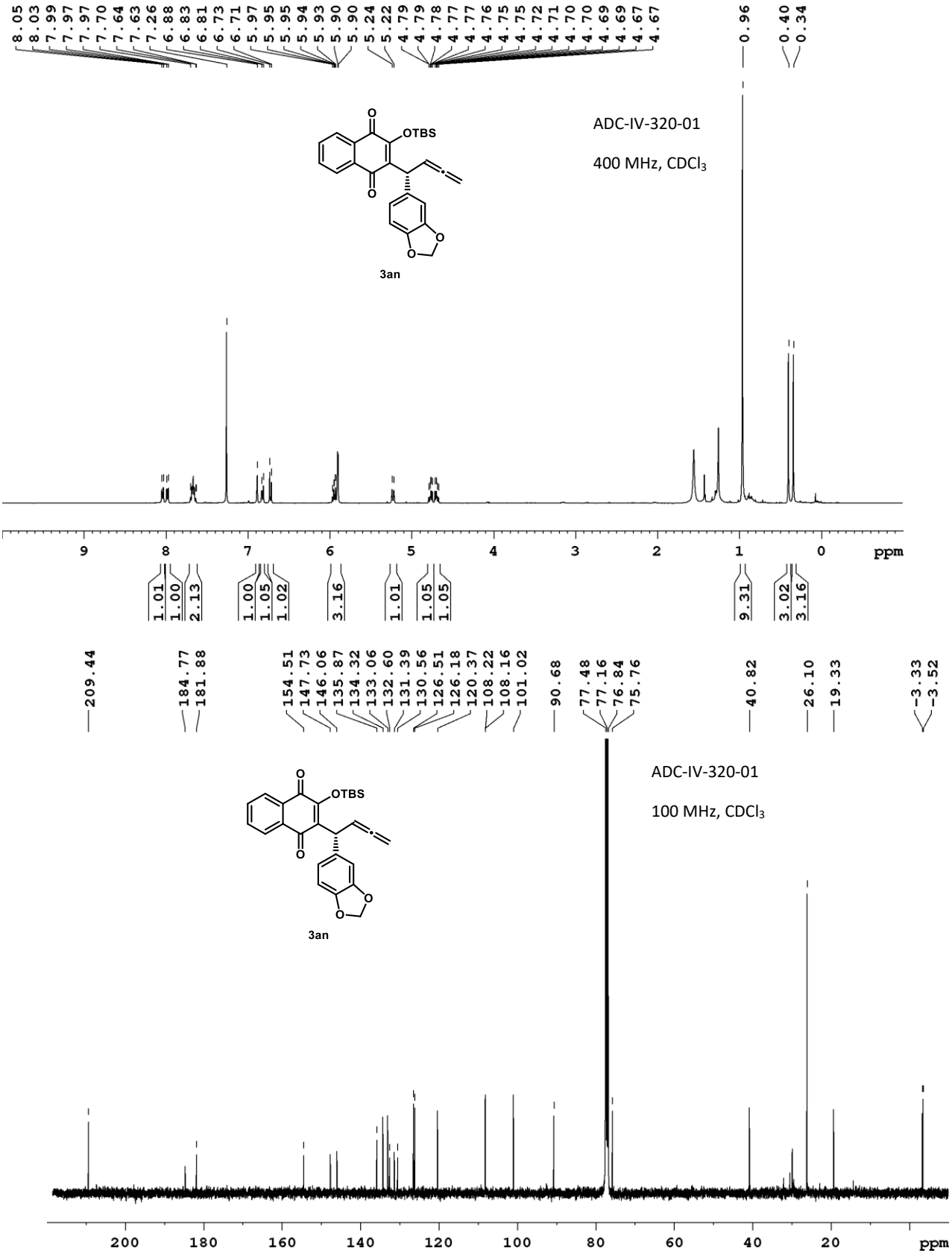
Daicel Chiralpak AD-H column (90:10 *n*-Hexane/EtOH, 0.5 mL/min, 20 °C)

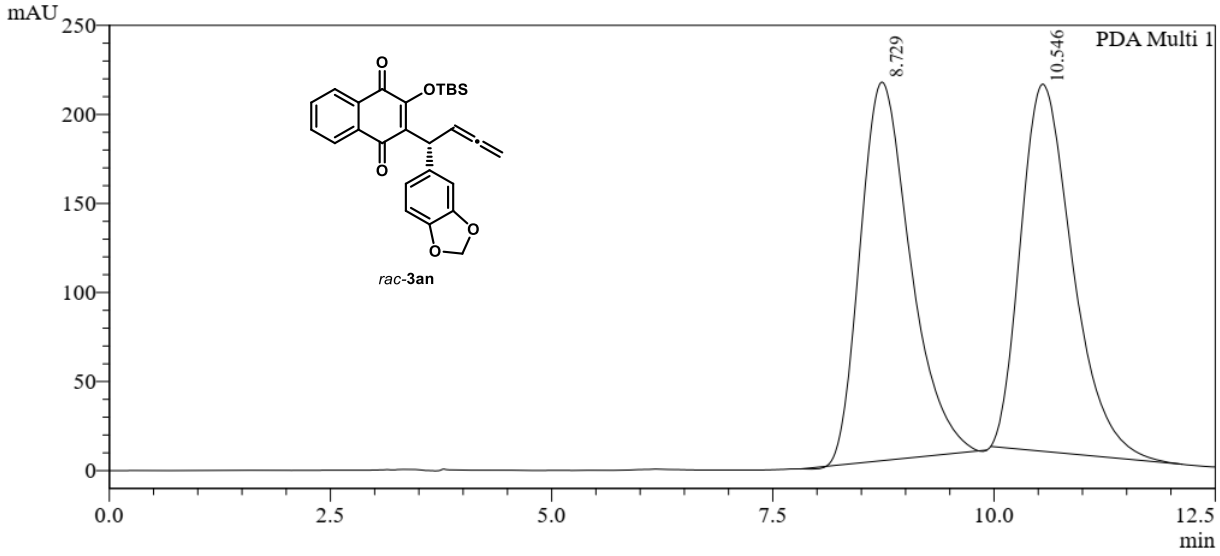


PeakTable

PDA Ch1 299nm 4nm

Peak#	Ret. Time	Area	Area %
1	22.511	8415226	100.000
Total		8415226	100.000


8.05
8.03
7.99
7.97
7.97
7.70
7.64
7.63
7.26
6.88
6.83
6.81
6.73
6.71
5.97
5.95
5.95
5.94
5.93
5.90
5.90
5.24
5.22
4.79
4.79
4.78
4.77
4.77
4.76
4.75
4.75
4.72
4.71
4.70
4.70
4.69
4.69
4.67
4.67
0.96
0.40
0.34
OTBS
O
O
O
O
3an
ADC-IV-320-01
400 MHz, CDCl3
9
8
7
6
5
4
3
2
1
0
ppm
1.01
1.00
2.13
1.00
1.05
1.02
3.16
1.01
1.05
1.05
9.31
3.02
3.16
209.44
184.77
181.88
154.51
147.73
146.06
135.87
134.32
133.06
132.60
131.39
130.56
126.51
126.18
120.37
108.22
108.16
101.02
90.68
77.48
77.16
76.84
75.76
40.82
26.10
19.33
-3.33
-3.52
OTBS
O
O
O
O
3an
ADC-IV-320-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
ppm

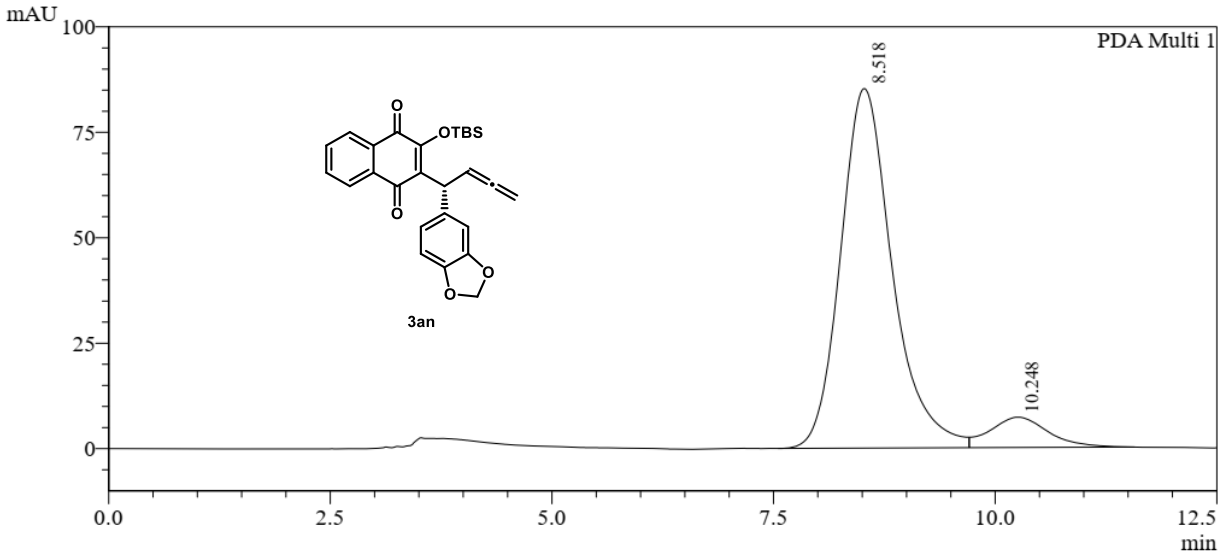


PeakTable

PDA Ch1 254nm 4nm

Peak#	Ret. Time	Area	Area %
1	8.729	8394133	49.901
2	10.546	8427425	50.099
Total		16821558	100.000

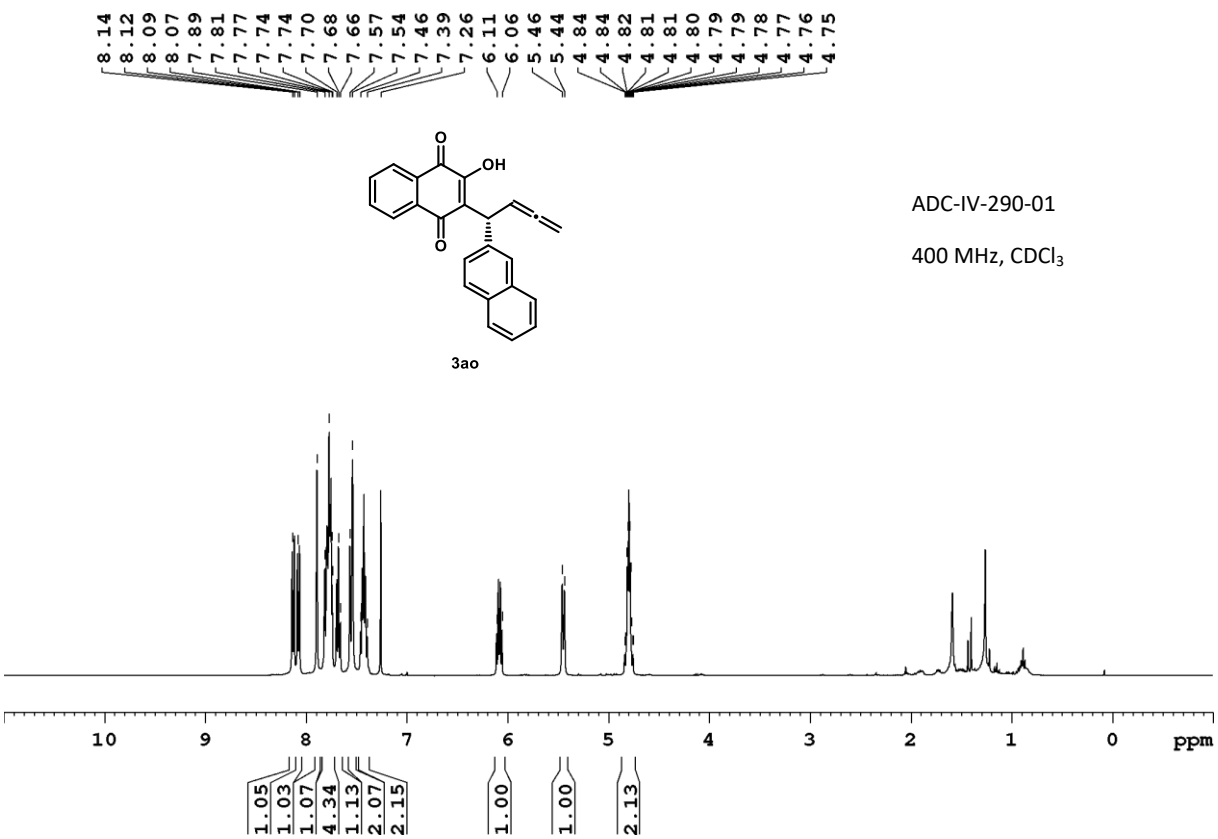
Daicel Chiralpak IG column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C)

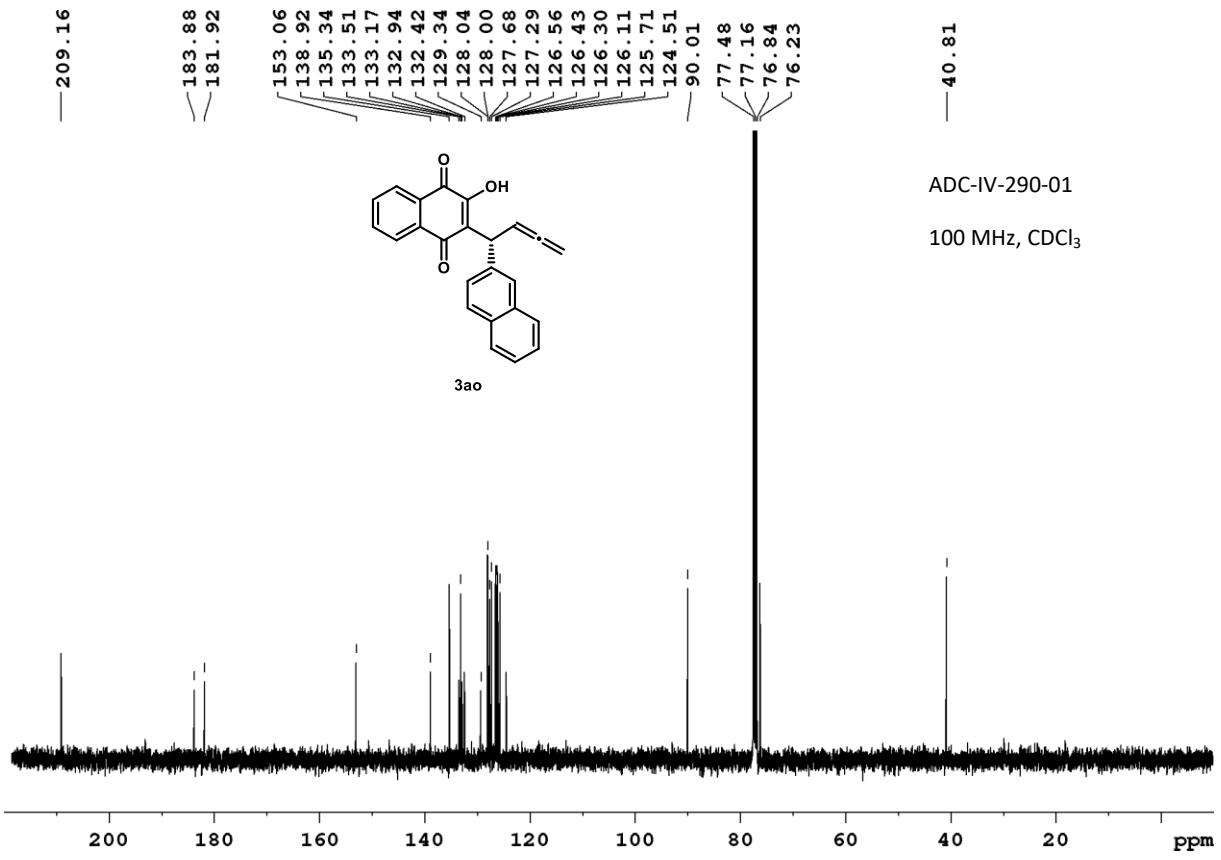


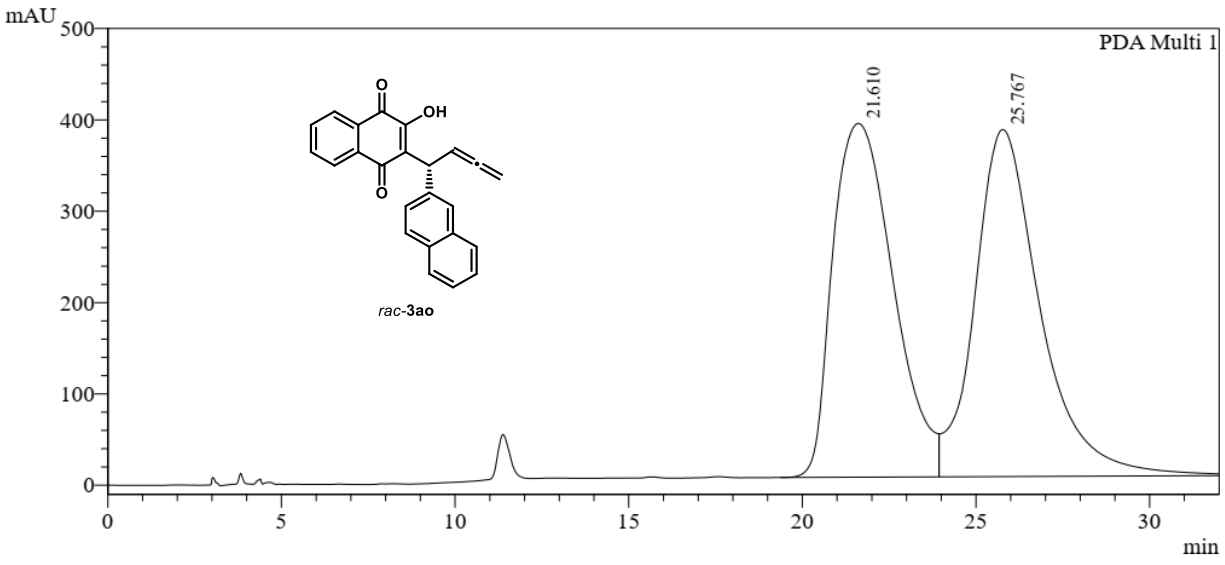
PeakTable

PDA Ch1 254nm 4nm

Peak#	Ret. Time	Area	Area %
1	8.518	3462871	91.335
2	10.248	328519	8.665
Total		3791391	100.000


8.14
8.12
8.09
8.07
7.89
7.81
7.77
7.74
7.74
7.70
7.68
7.66
7.57
7.54
7.46
7.39
7.26
6.11
6.06
5.46
5.44
4.84
4.82
4.81
4.81
4.80
4.79
4.79
4.78
4.77
4.76
4.75
OH
O
O
3ao
ADC-IV-290-01
400 MHz, CDCl3
10
9
8
7
6
5
4
3
2
1
0
ppm
1.05
1.03
1.07
4.34
1.13
2.07
2.15
1.00
1.00
2.13


209.16
183.88
181.92
153.06
138.92
135.34
133.51
133.17
132.94
132.42
129.34
128.04
128.00
127.68
127.29
126.56
126.43
126.30
126.11
125.71
124.51
90.01
77.48
77.16
76.84
76.23
40.81
OH
O
O
3ao
ADC-IV-290-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
ppm

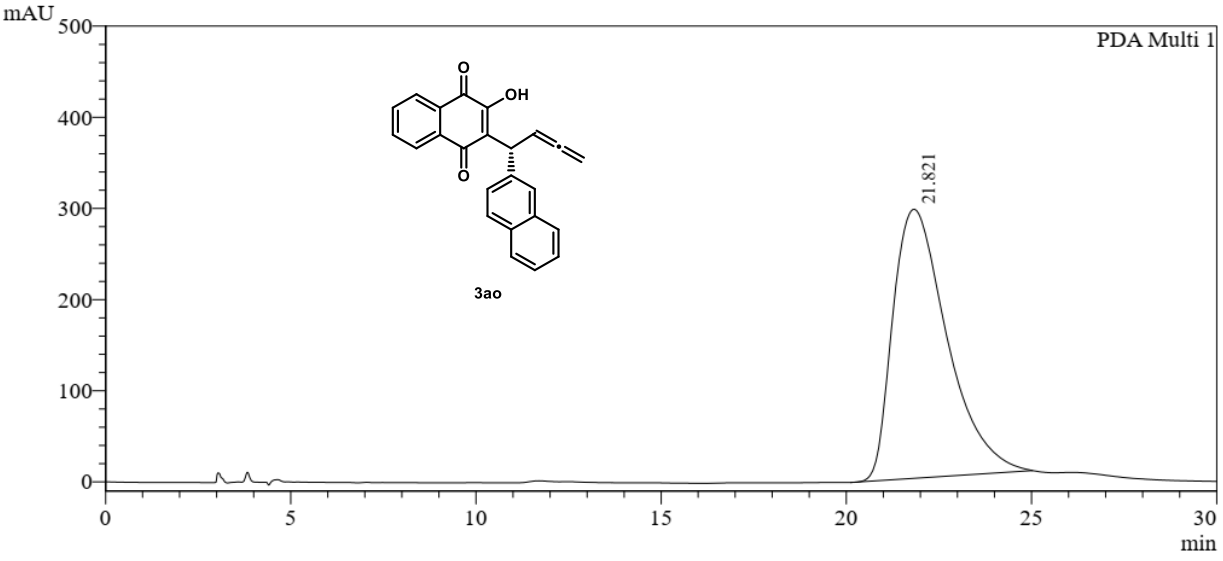


PeakTable

PDA Ch1 226nm 4nm

Peak#	Ret. Time	Area	Area %
1	21.610	47030508	48.574
2	25.767	49791599	51.426
Total		96822107	100.000

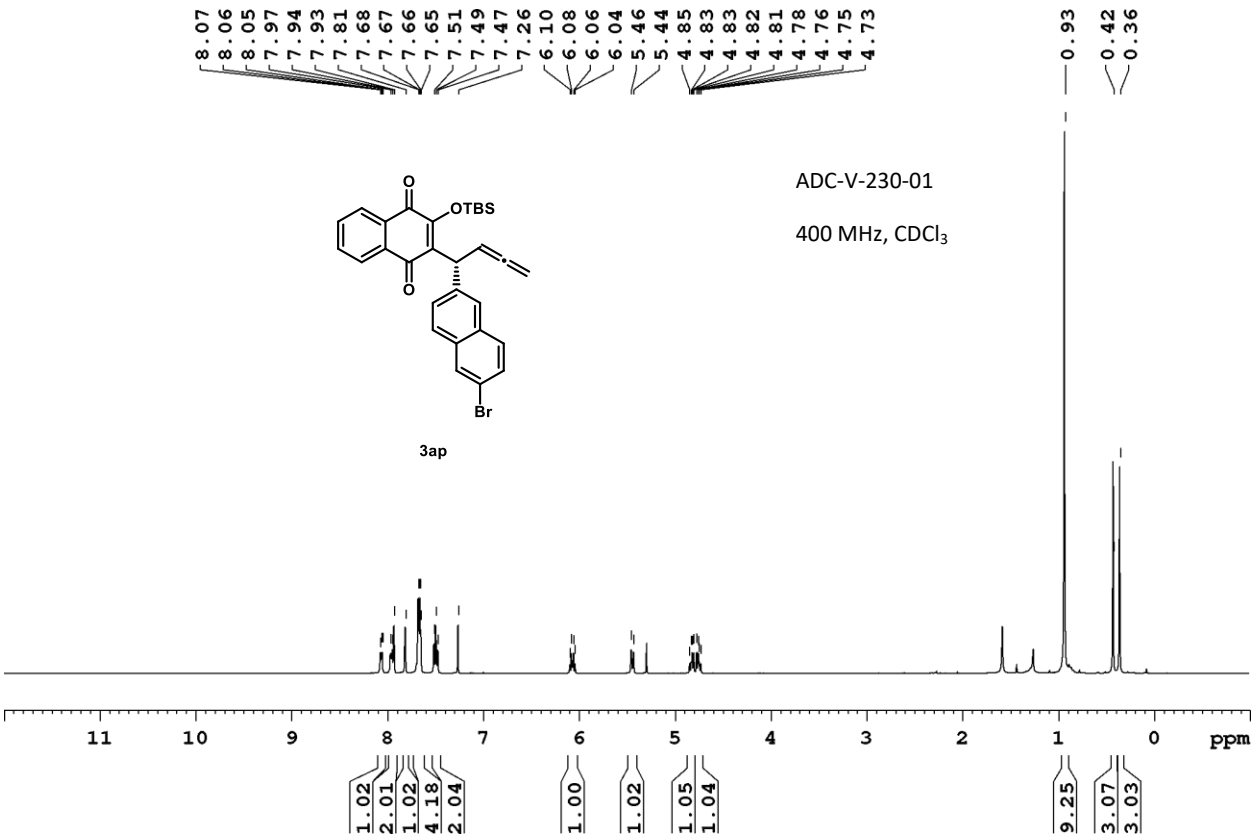
Daicel Chiralpak AD-H column (90:10 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C)

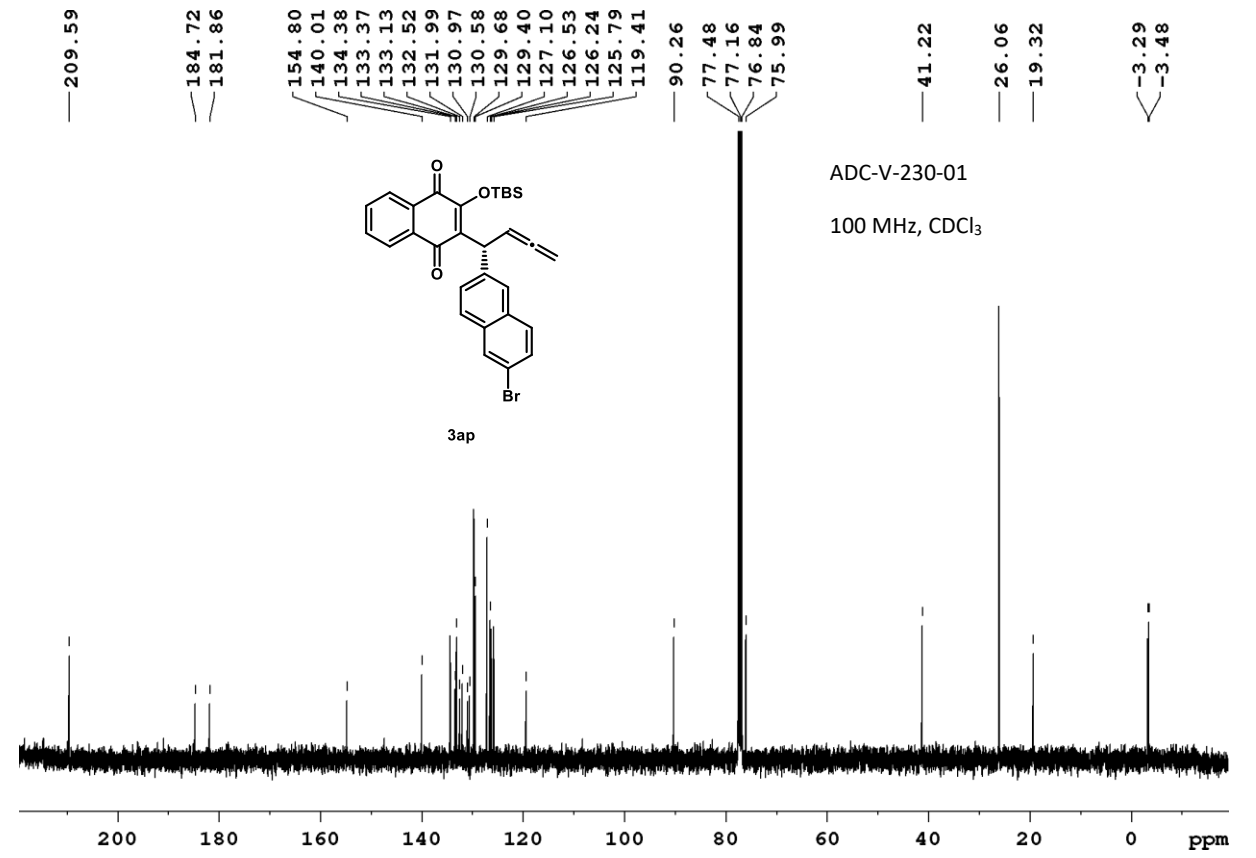


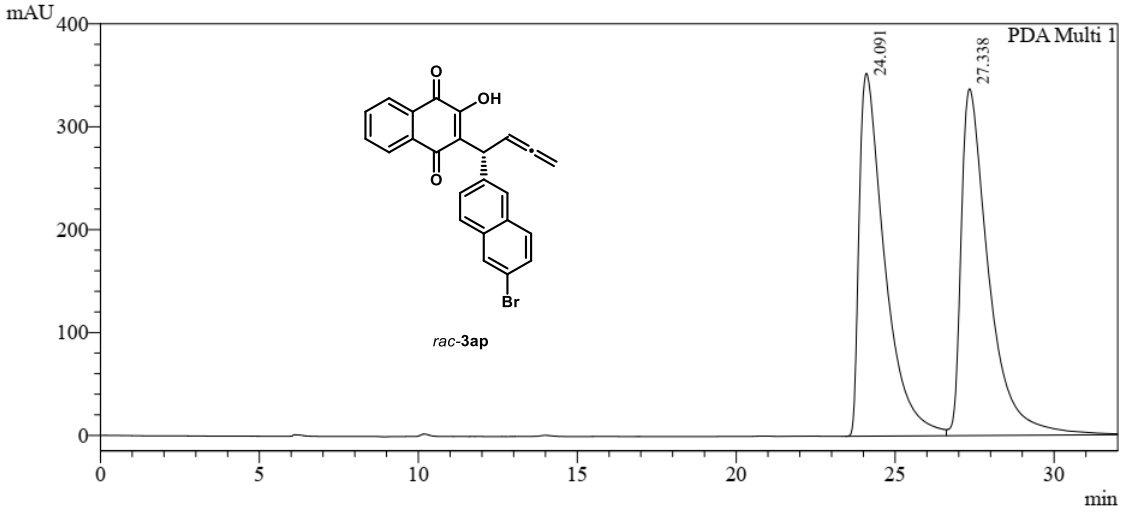
PeakTable

PDA Ch1 226nm 4nm

Peak#	Ret. Time	Area	Area %
1	21.821	30131908	100.000
Total		30131908	100.000


8.07
8.06
8.05
7.97
7.94
7.93
7.81
7.68
7.67
7.66
7.65
7.51
7.49
7.47
7.26
6.10
6.08
6.06
6.04
5.46
5.44
4.85
4.83
4.82
4.81
4.78
4.76
4.75
4.73
0.93
0.42
0.36
O
OTBS
O
Br
3ap
ADC-V-230-01
400 MHz, CDCl3
11
10
9
8
7
6
5
4
3
2
1
0
ppm
1.02
2.01
1.02
4.18
2.04
1.00
1.02
1.05
1.04
9.25
3.07
3.03

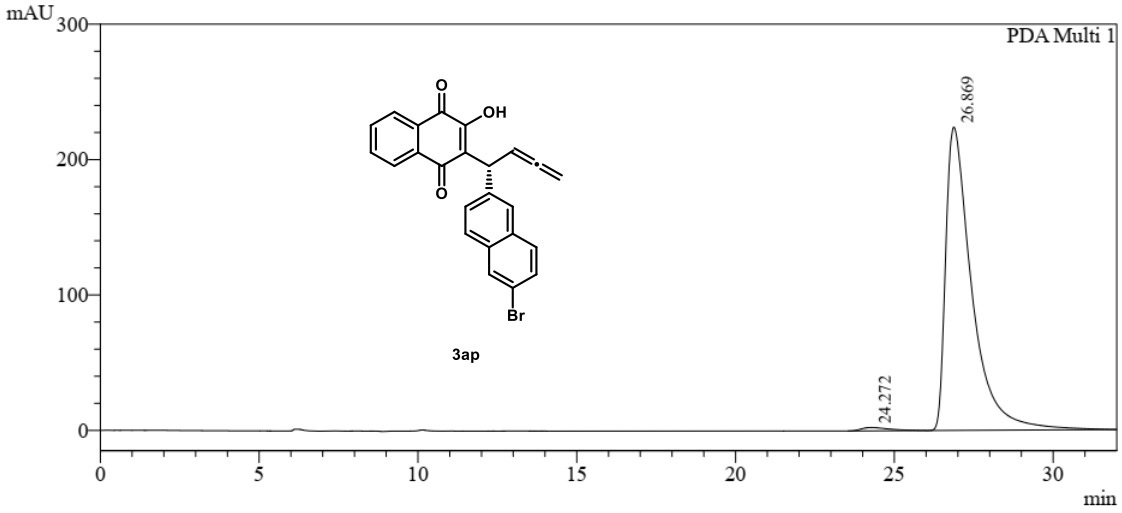

209.59
184.72
181.86
154.80
140.01
134.38
133.37
133.13
132.52
131.99
130.97
130.58
129.68
129.40
127.10
126.53
126.24
125.79
119.41
90.26
77.48
77.16
76.84
75.99
41.22
26.06
19.32
-3.29
-3.48
O
OTBS
O
Br
3ap
ADC-V-230-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
0
ppm



PDA Ch1 269nm 4nm

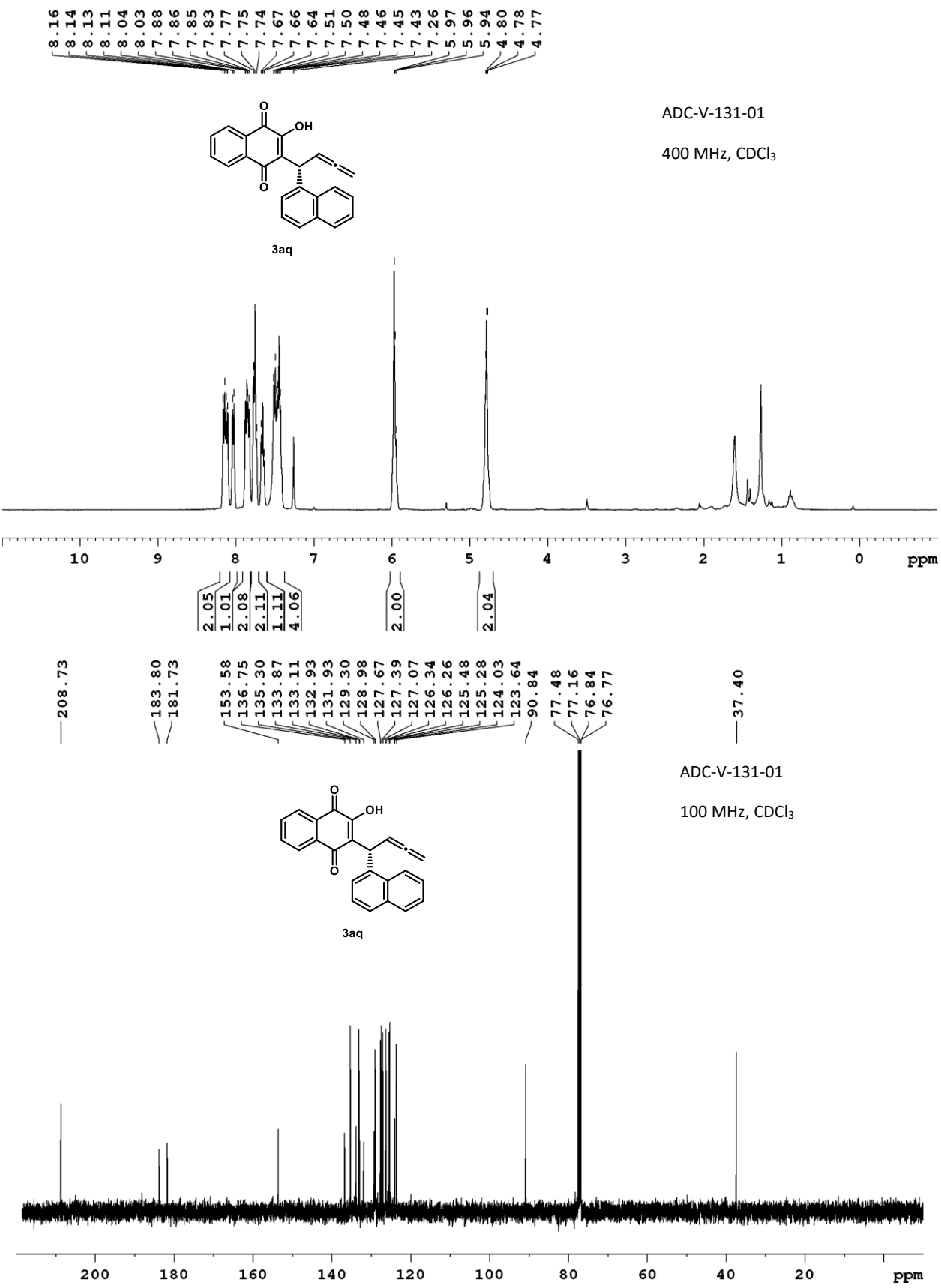
Peak#	Ret. Time	Area	Area %
1	24.091	19718475	49.142
2	27.338	20406720	50.858
Total		40125195	100.000

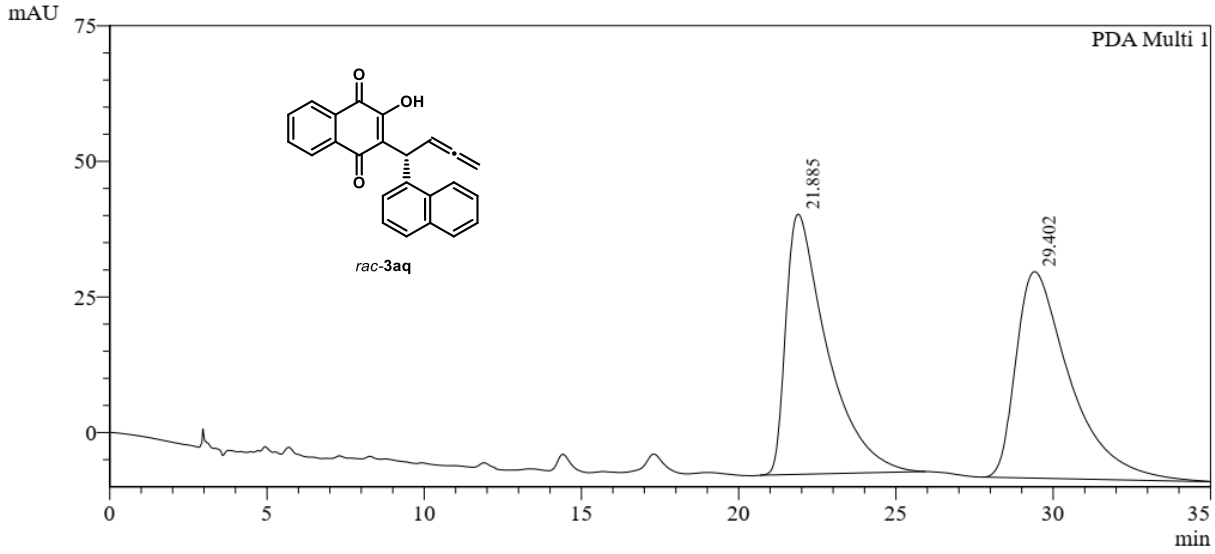
Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)



PDA Ch1 269nm 4nm

Peak#	Ret. Time	Area	Area %
1	24.272	155762	1.195
2	26.869	12875140	98.805
Total		13030902	100.000


8.16
8.14
8.13
8.11
8.04
8.03
7.88
7.86
7.85
7.83
7.77
7.75
7.74
7.67
7.66
7.64
7.51
7.50
7.48
7.46
7.45
7.43
7.26
5.97
5.96
5.94
4.80
4.78
4.77
OH
O
O
3aq
ADC-V-131-01
400 MHz, CDCl3
10
9
8
7
6
5
4
3
2
1
0
ppm
2.05
1.01
2.08
2.11
1.11
4.06
2.00
2.04
208.73
183.80
181.73
153.58
136.75
135.30
133.87
133.11
132.93
131.93
129.30
128.98
127.67
127.39
127.07
126.34
126.26
125.48
125.28
124.03
123.64
90.84
77.48
77.16
76.84
76.77
37.40
ADC-V-131-01
100 MHz, CDCl3
OH
O
O
3aq
200
180
160
140
120
100
80
60
40
20
ppm

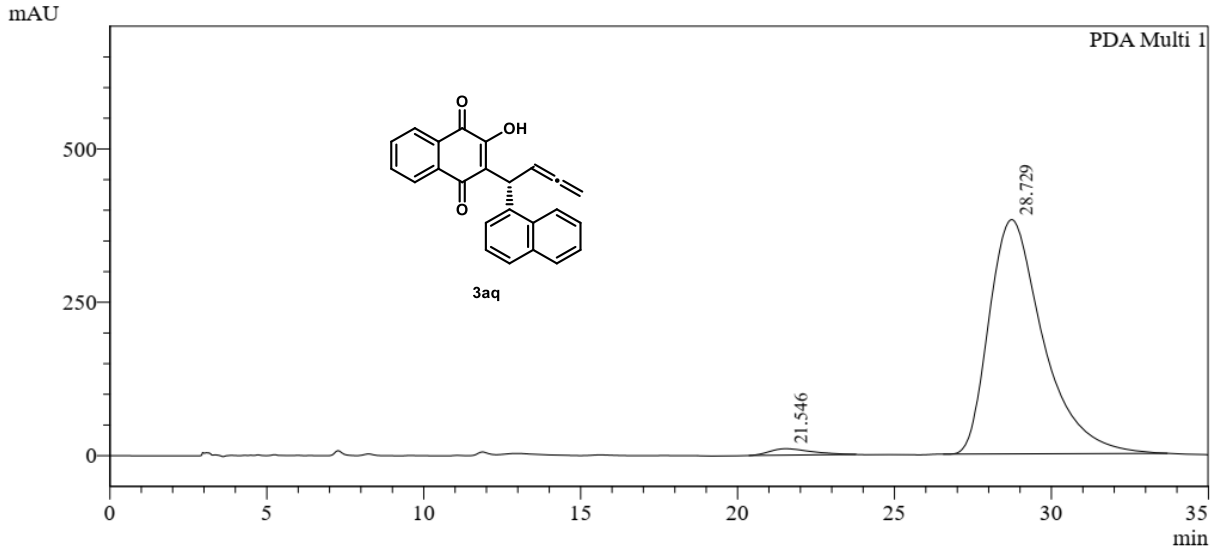


PeakTable

PDA Ch1 230nm 4nm

Peak#	Ret. Time	Area	Area %
1	21.885	4376297	49.039
2	29.402	4547763	50.961
Total		8924061	100.000

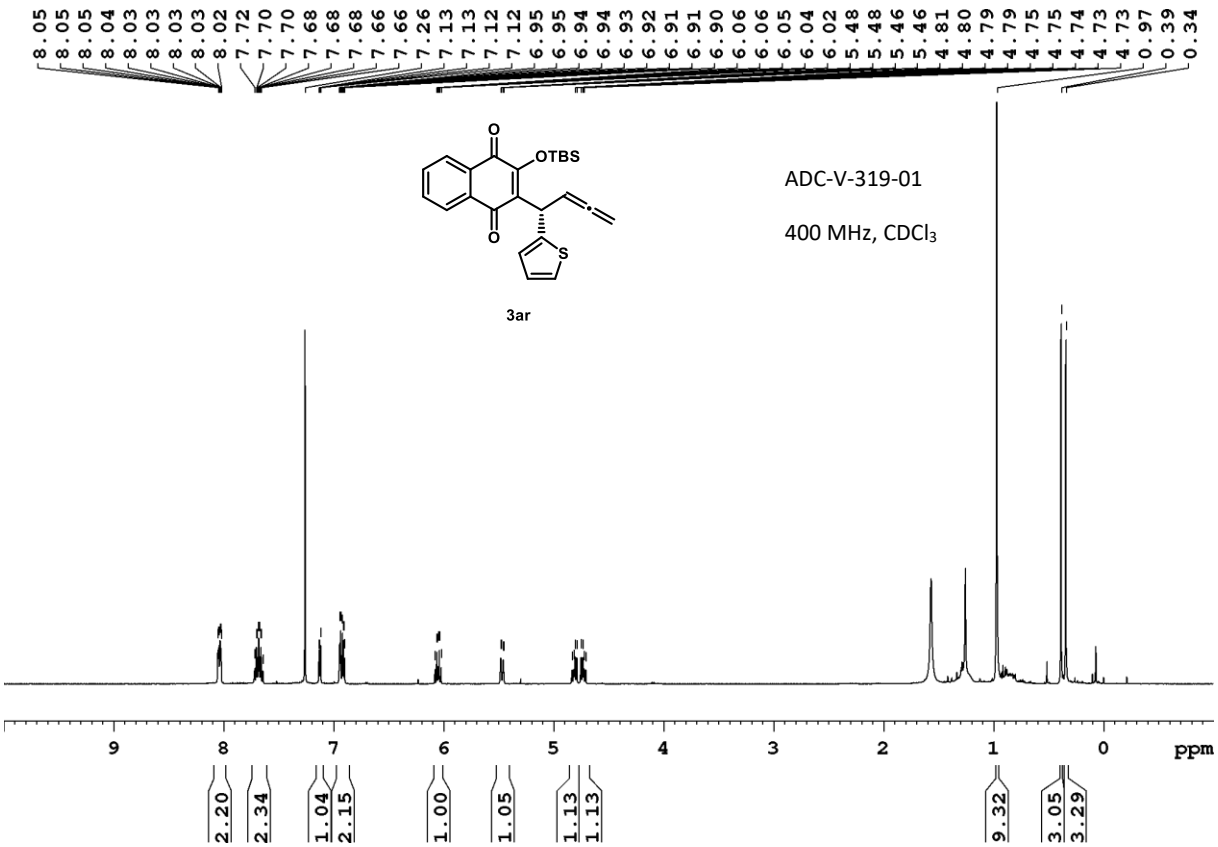
Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

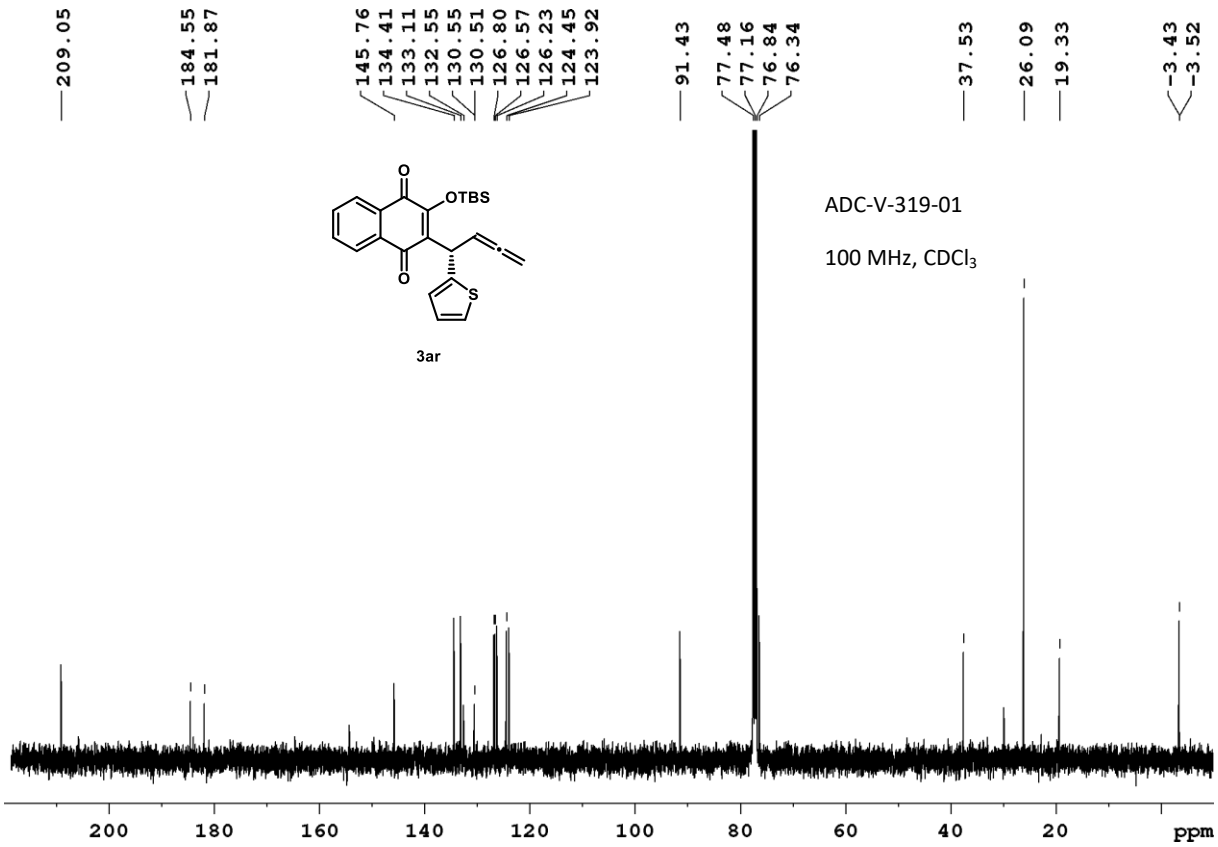


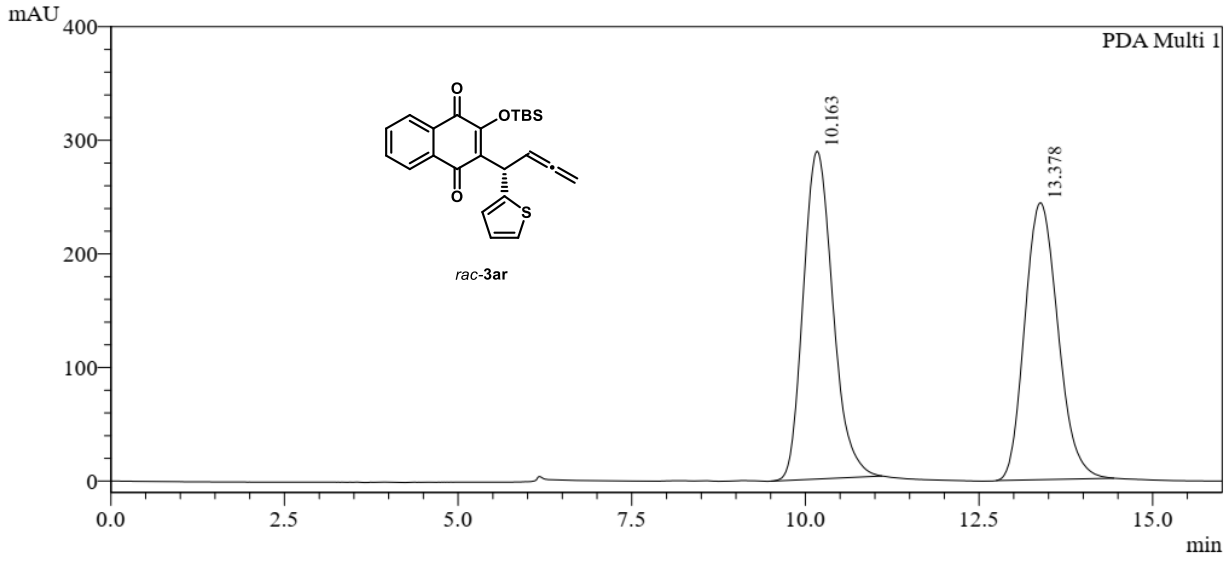
PeakTable

PDA Ch1 230nm 4nm

Peak#	Ret. Time	Area	Area %
1	21.546	971563	2.078
2	28.729	45789679	97.922
Total		46761242	100.000


8.05 8.05 8.05 8.04 8.03 8.03 8.03 8.03 8.02 7.72 7.70 7.70 7.68 7.68 7.66 7.66 7.26 7.13 7.13 7.12 7.12 6.95 6.95 6.94 6.94 6.93 6.92 6.91 6.91 6.90 6.06 6.06 6.05 6.04 6.02 5.48 5.48 5.46 5.46 4.81 4.80 4.79 4.79 4.75 4.74 4.73 4.73 0.97 0.39 0.34
OTBS
O
O
S
3ar
ADC-V-319-01
400 MHz, CDCl3
9 8 7 6 5 4 3 2 1 0 ppm
2.20 2.34 1.04 2.15 1.00 1.05 1.13 1.13 9.32 3.05 3.29


209.05
184.55 181.87
145.76 134.41 133.11 132.55 130.55 130.51 126.80 126.57 126.23 124.45 123.92
91.43
77.48 77.16 76.84 76.34
37.53
26.09
19.33
-3.43 -3.52
OTBS
O
O
S
3ar
ADC-V-319-01
100 MHz, CDCl3
200 180 160 140 120 100 80 60 40 20 ppm

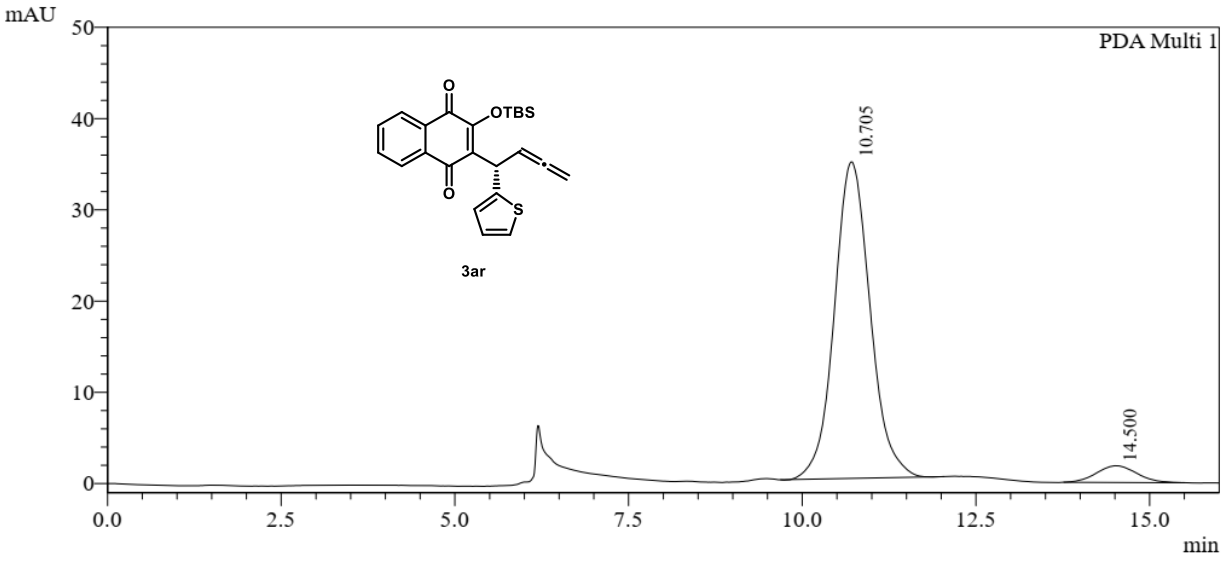


PeakTable

PDA Ch1 254nm 4nm

Peak#	Ret. Time	Area	Area %
1	10.163	8571539	51.346
2	13.378	8122274	48.654
Total		16693813	100.000

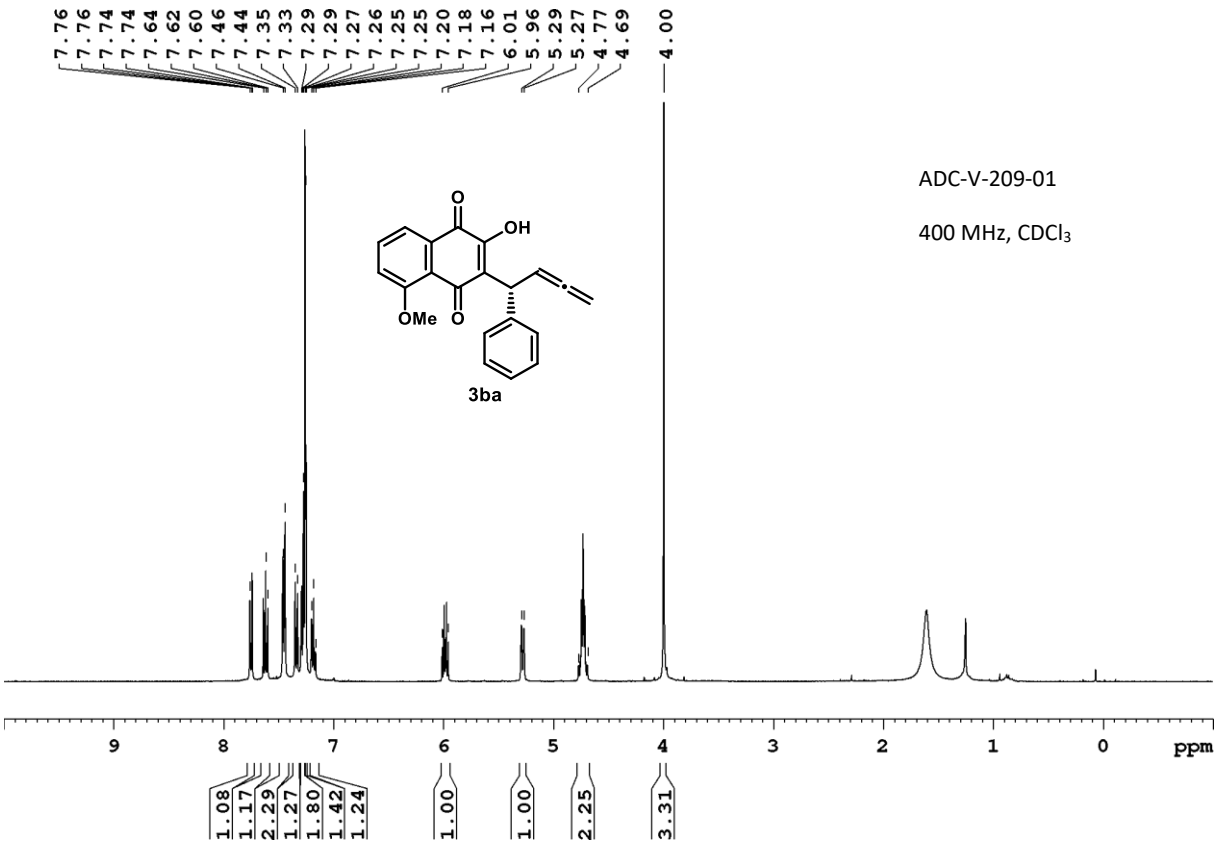
Phenomenex Cellulose-2 column (99:1 *n*-Hexane/IPA, 0.5 mL/min, 20 °C)

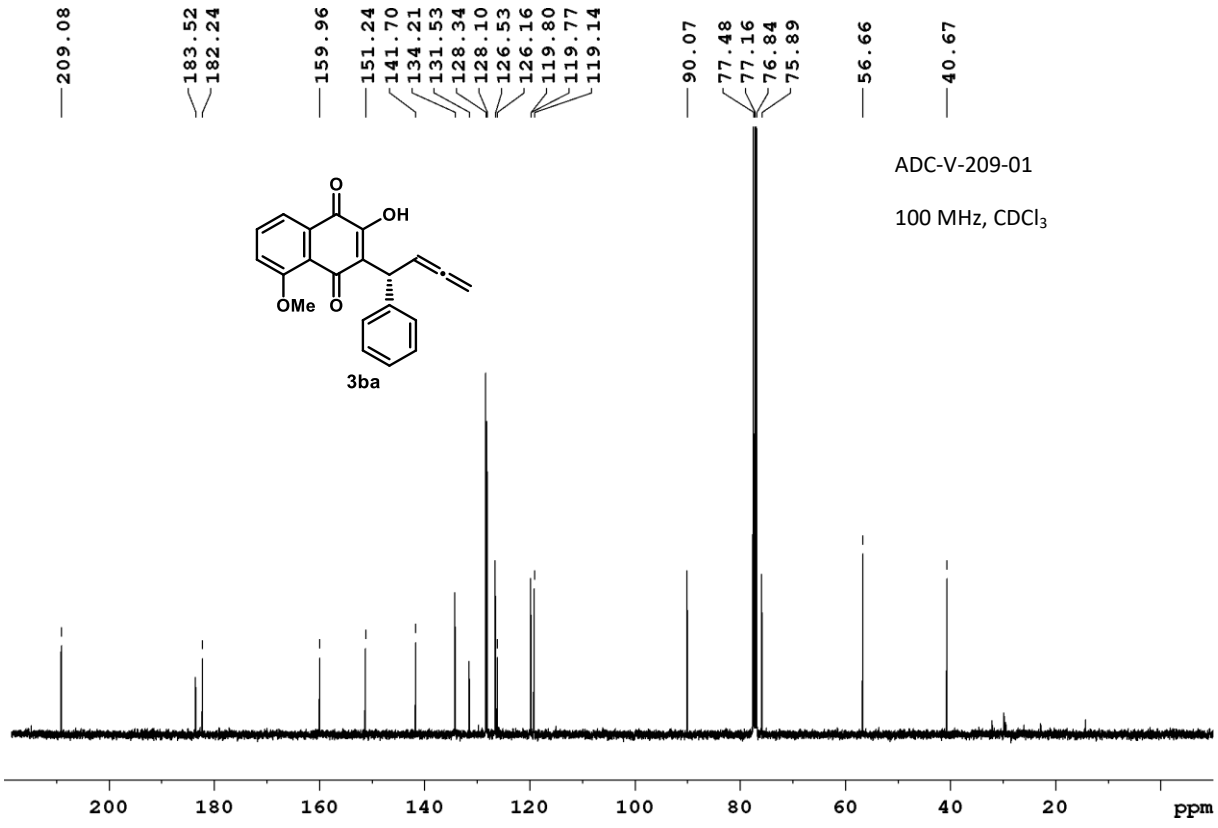


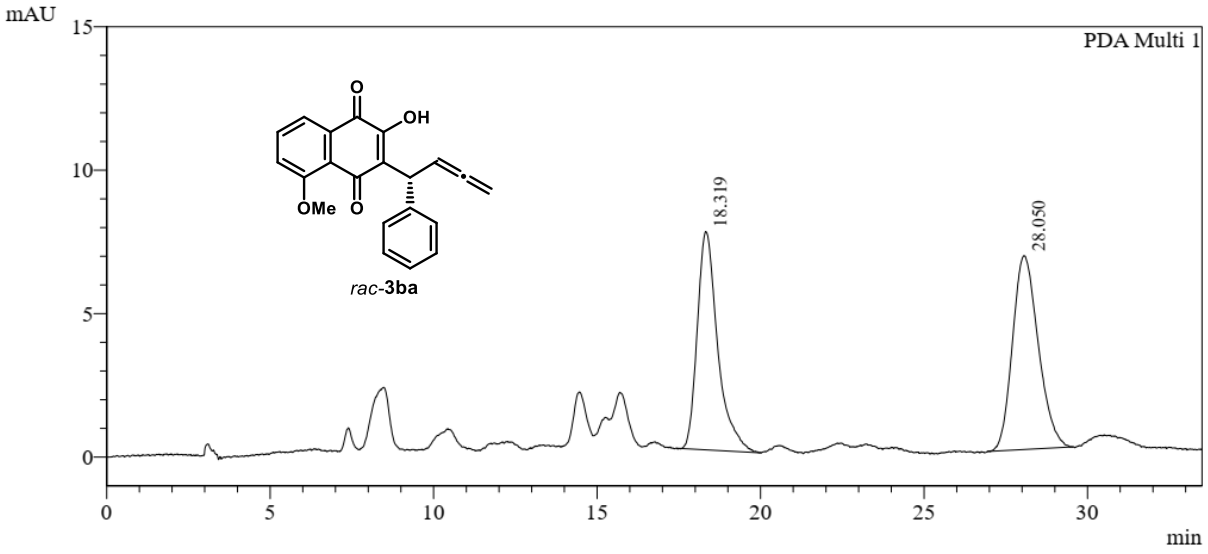
PeakTable

PDA Ch1 254nm 4nm

Peak#	Ret. Time	Area	Area %
1	10.705	1244429	94.433
2	14.500	73357	5.567
Total		1317786	100.000


7.76
7.76
7.74
7.74
7.64
7.62
7.60
7.46
7.44
7.35
7.33
7.29
7.29
7.27
7.26
7.25
7.25
7.20
7.18
7.16
6.01
5.96
5.29
5.27
4.77
4.69
4.00
ADC-V-209-01
400 MHz, CDCl3
O
OH
OMe
O
3ba
9
8
7
6
5
4
3
2
1
0
ppm
1.08
1.17
2.29
1.27
1.80
1.42
1.24
1.00
1.00
2.25
3.31


209.08
183.52
182.24
159.96
151.24
141.70
134.21
131.53
128.34
128.10
126.53
126.16
119.80
119.77
119.14
90.07
77.48
77.16
76.84
75.89
56.66
40.67
ADC-V-209-01
100 MHz, CDCl3
O
OH
OMe
O
3ba
200
180
160
140
120
100
80
60
40
20
ppm

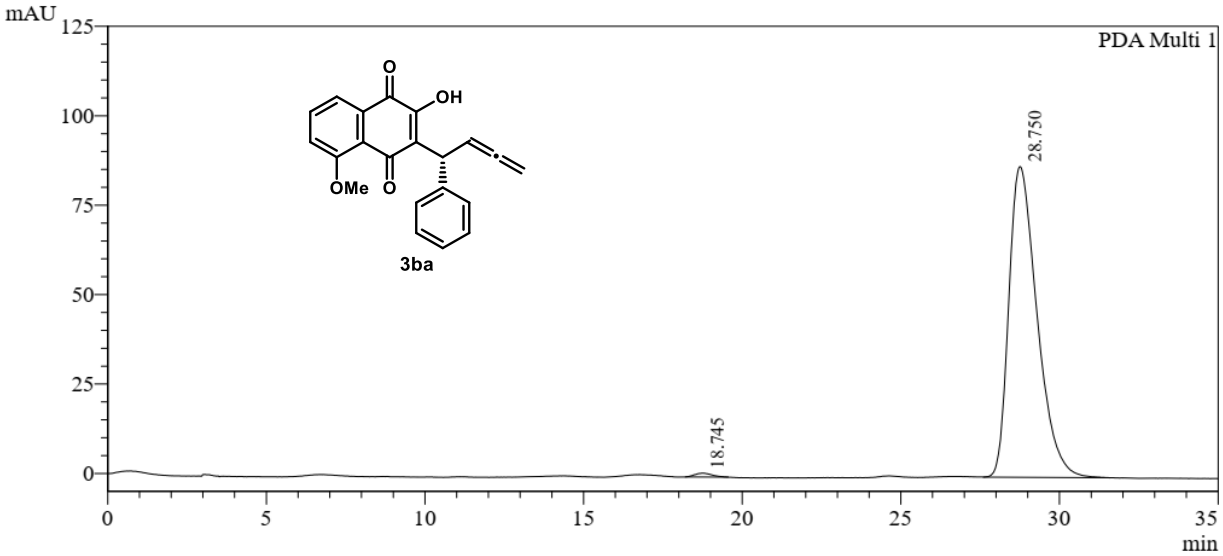


PeakTable

PDA Ch1 343nm 4nm

Peak#	Ret. Time	Area	Area %
1	18.319	330182	47.063
2	28.050	371386	52.937
Total		701568	100.000

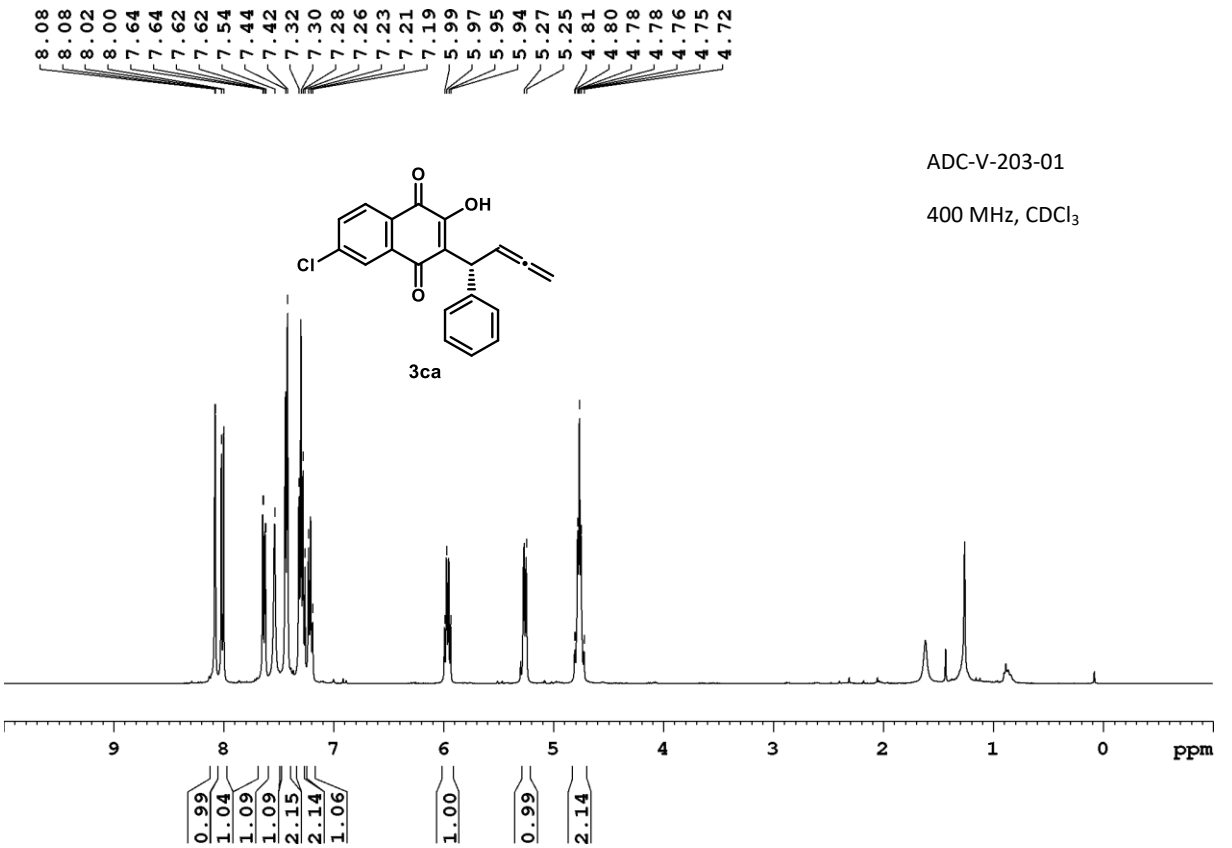
Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

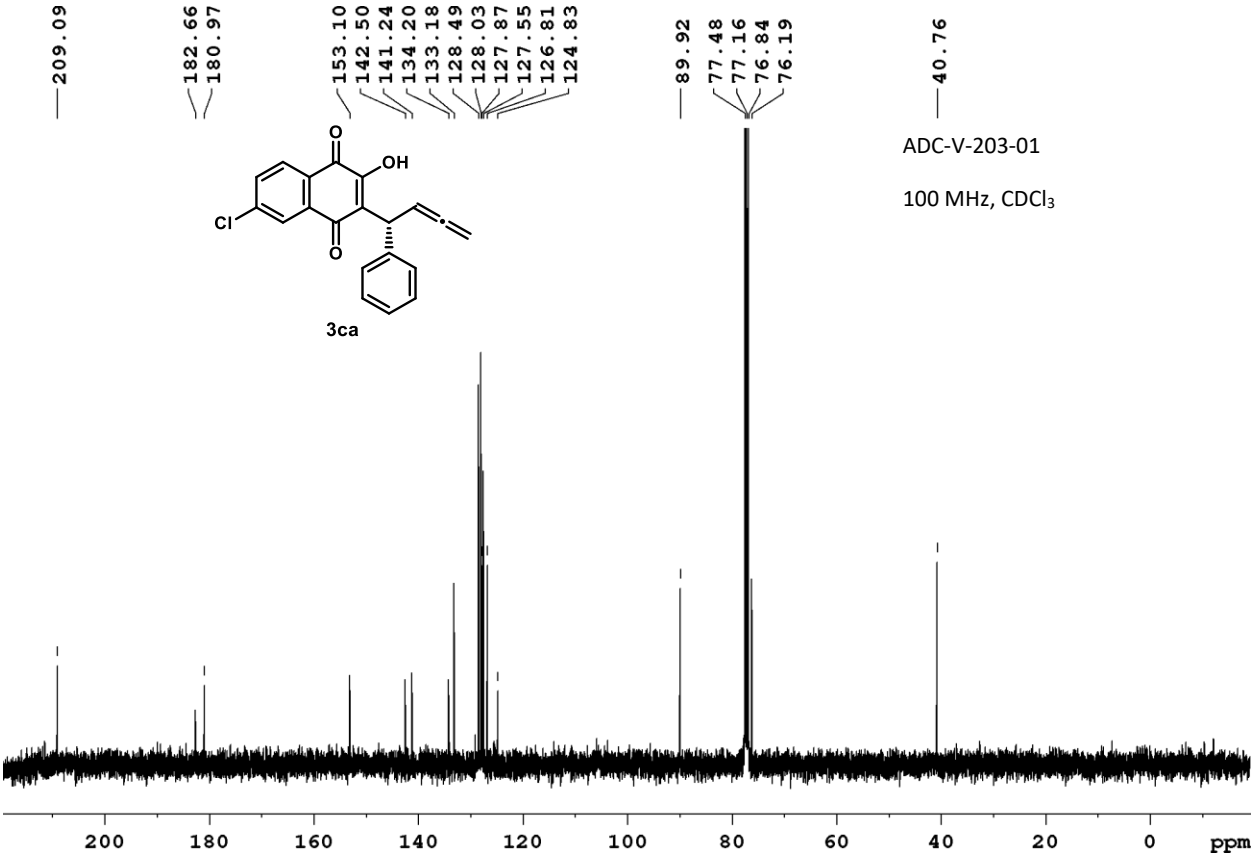


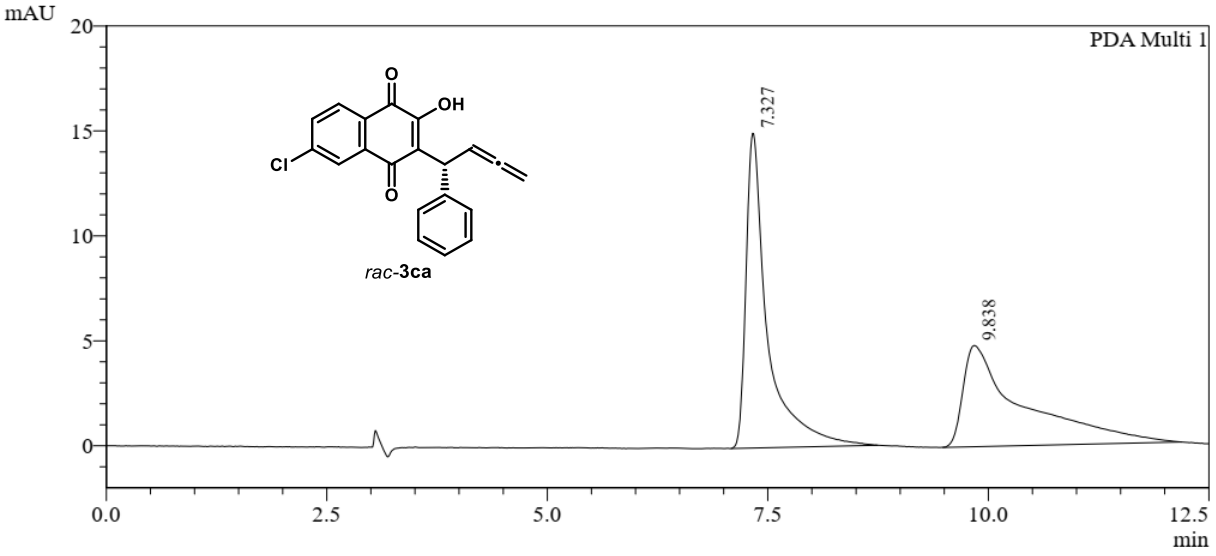
PeakTable

PDA Ch1 343nm 4nm

Peak#	Ret. Time	Area	Area %
1	18.745	41320	0.763
2	28.750	5372226	99.237
Total		5413546	100.000


8.08
8.08
8.02
8.00
7.64
7.64
7.62
7.62
7.54
7.44
7.42
7.32
7.30
7.28
7.26
7.23
7.21
7.19
5.99
5.97
5.95
5.94
5.27
5.25
4.81
4.80
4.78
4.78
4.76
4.75
4.72
ADC-V-203-01
400 MHz, CDCl3
OH
Cl
O
O
3ca
9
8
7
6
5
4
3
2
1
0
ppm
0.99
1.04
1.09
1.09
2.15
2.14
1.06
1.00
0.99
2.14


209.09
182.66
180.97
153.10
142.50
141.24
134.20
133.18
128.49
128.03
127.87
127.55
126.81
124.83
89.92
77.48
77.16
76.84
76.19
40.76
ADC-V-203-01
100 MHz, CDCl3
OH
Cl
O
O
3ca
200
180
160
140
120
100
80
60
40
20
0
ppm

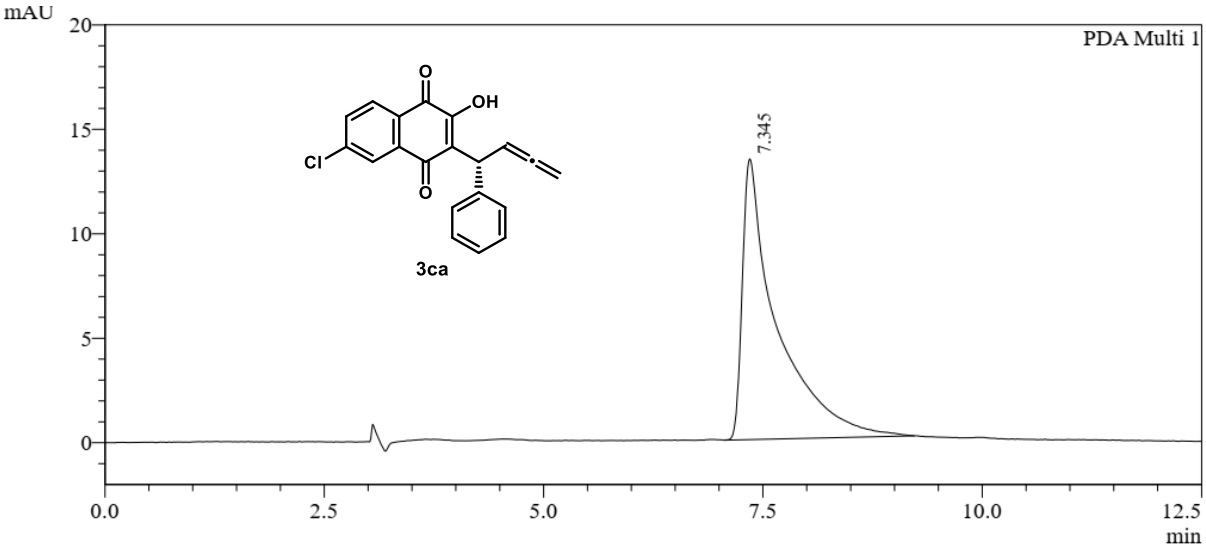


PeakTable

PDA Ch1 380nm 4nm

Peak#	Ret. Time	Area	Area %
1	7.327	255333	52.868
2	9.838	227632	47.132
Total		482965	100.000

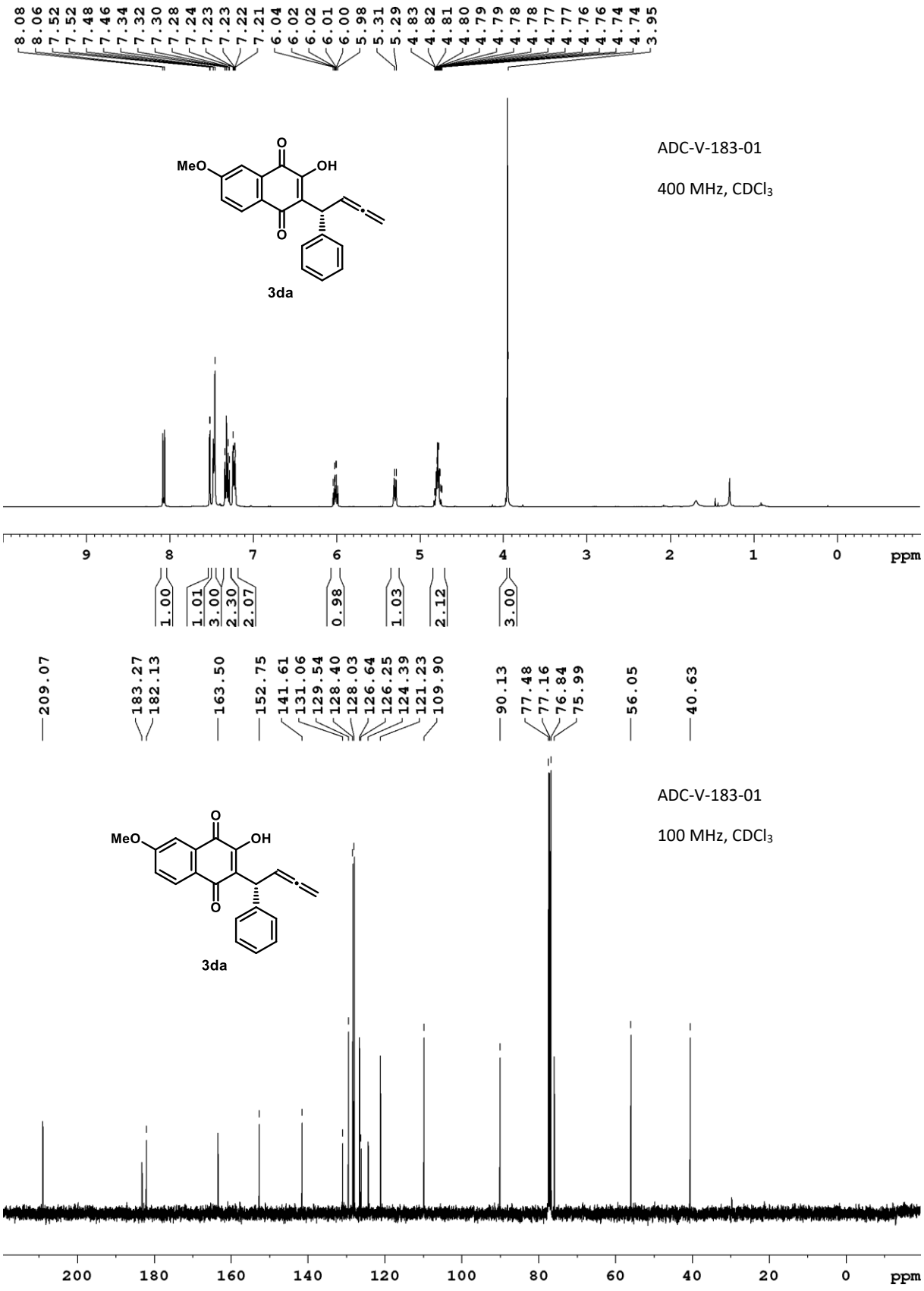
Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

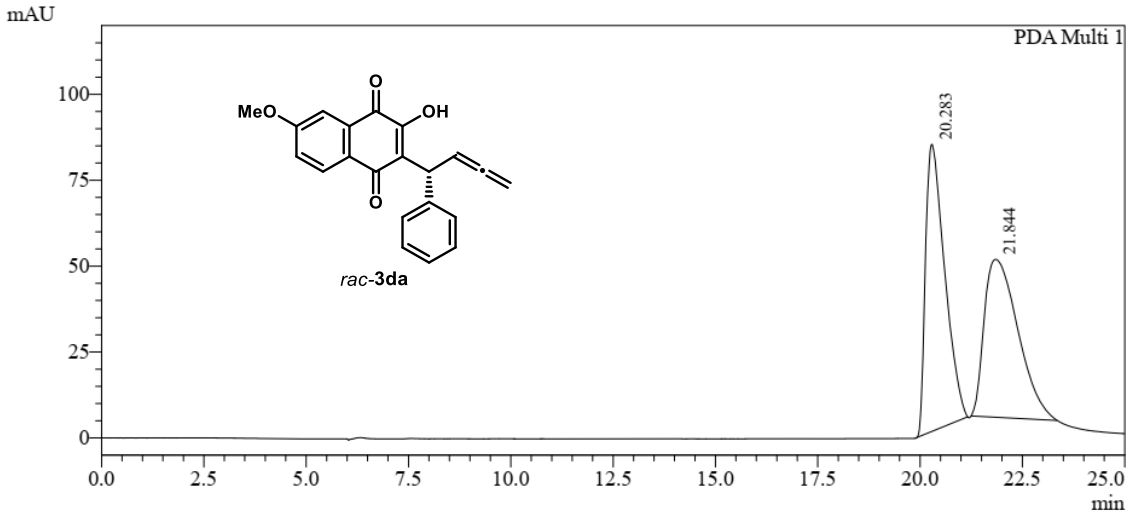


PeakTable

PDA Ch1 380nm 4nm

Peak#	Ret. Time	Area	Area %
1	7.345	368893	100.000
Total		368893	100.000

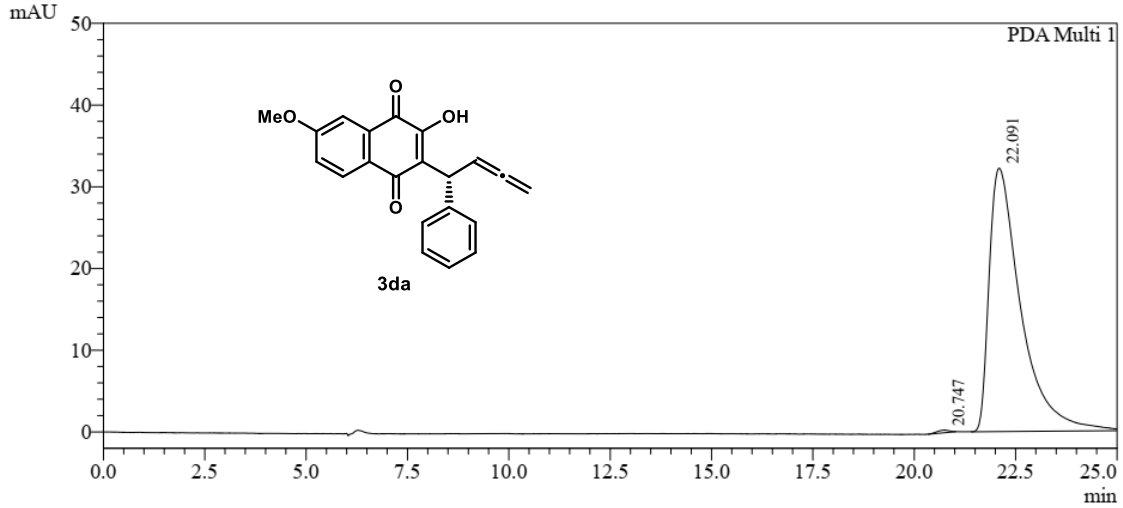

8.08
8.06
7.52
7.52
7.48
7.46
7.34
7.32
7.30
7.28
7.24
7.23
7.23
7.22
7.21
6.04
6.02
6.02
6.01
6.00
5.98
5.31
5.29
4.83
4.82
4.81
4.80
4.79
4.79
4.78
4.78
4.77
4.77
4.76
4.76
4.74
4.74
3.95
MeO
OH
O
O
3da
ADC-V-183-01
400 MHz, CDCl3
9
8
7
6
5
4
3
2
1
0
ppm
1.00
1.01
3.00
2.30
2.07
0.98
1.03
2.12
3.00
209.07
183.27
182.13
163.50
152.75
141.61
131.06
129.54
128.40
128.03
126.64
126.25
124.39
121.23
109.90
90.13
77.48
77.16
76.84
75.99
56.05
40.63
MeO
OH
O
O
3da
ADC-V-183-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
0
ppm



PDA Ch1 327nm 4nm

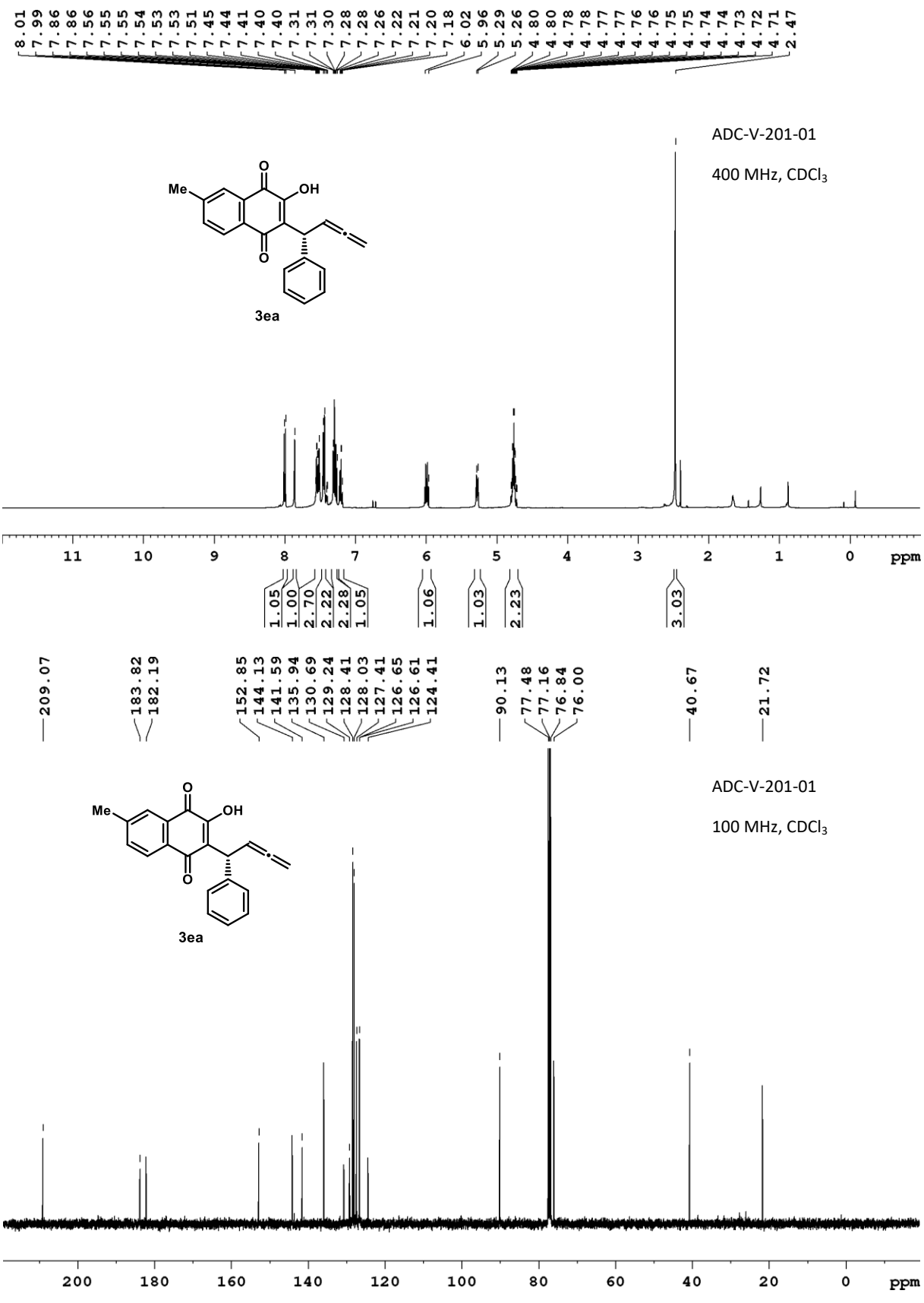
Peak#	Ret. Time	Area	Area %
1	20.283	2727231	50.750
2	21.844	2646668	49.250
Total		5373899	100.000

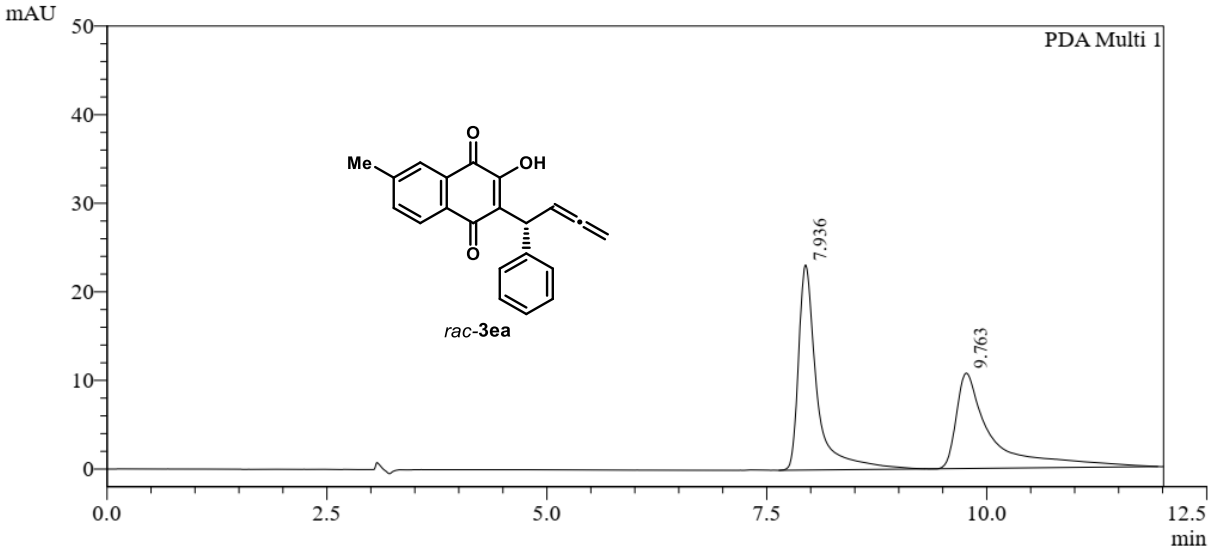
Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)



PDA Ch1 327nm 4nm

Peak#	Ret. Time	Area	Area %
1	20.747	6827	0.388
2	22.091	1754276	99.612
Total		1761102	100.000


8.01 7.99 7.86 7.86 7.56 7.55 7.55 7.54 7.53 7.53 7.51 7.45 7.44 7.41 7.40 7.40 7.31 7.30 7.28 7.28 7.26 7.22 7.21 7.20 7.18 6.02 5.96 5.29 5.26 4.80 4.80 4.78 4.78 4.77 4.77 4.76 4.76 4.75 4.75 4.74 4.74 4.73 4.72 4.71 2.47
ADC-V-201-01
400 MHz, CDCl3
Me
OH
O
O
3ea
11 10 9 8 7 6 5 4 3 2 1 0 ppm
1.05 1.00 2.70 2.22 2.28 1.05 1.06 1.03 2.23 3.03
209.07 183.82 182.19 152.85 144.13 141.59 135.94 130.69 129.24 128.41 128.03 127.41 126.65 126.61 124.41 90.13 77.48 77.16 76.84 76.00 40.67 21.72
ADC-V-201-01
100 MHz, CDCl3
Me
OH
O
O
3ea
200 180 160 140 120 100 80 60 40 20 0 ppm

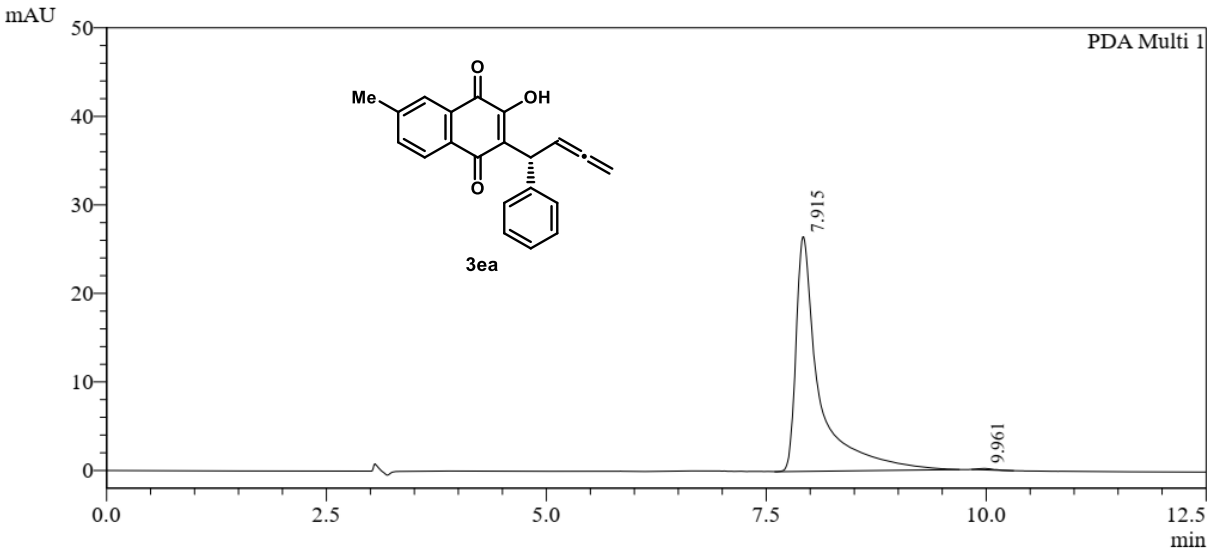


PeakTable

PDA Ch1 380nm 4nm

Peak#	Ret. Time	Area	Area %
1	7.936	339850	52.976
2	9.763	301662	47.024
Total		641512	100.000

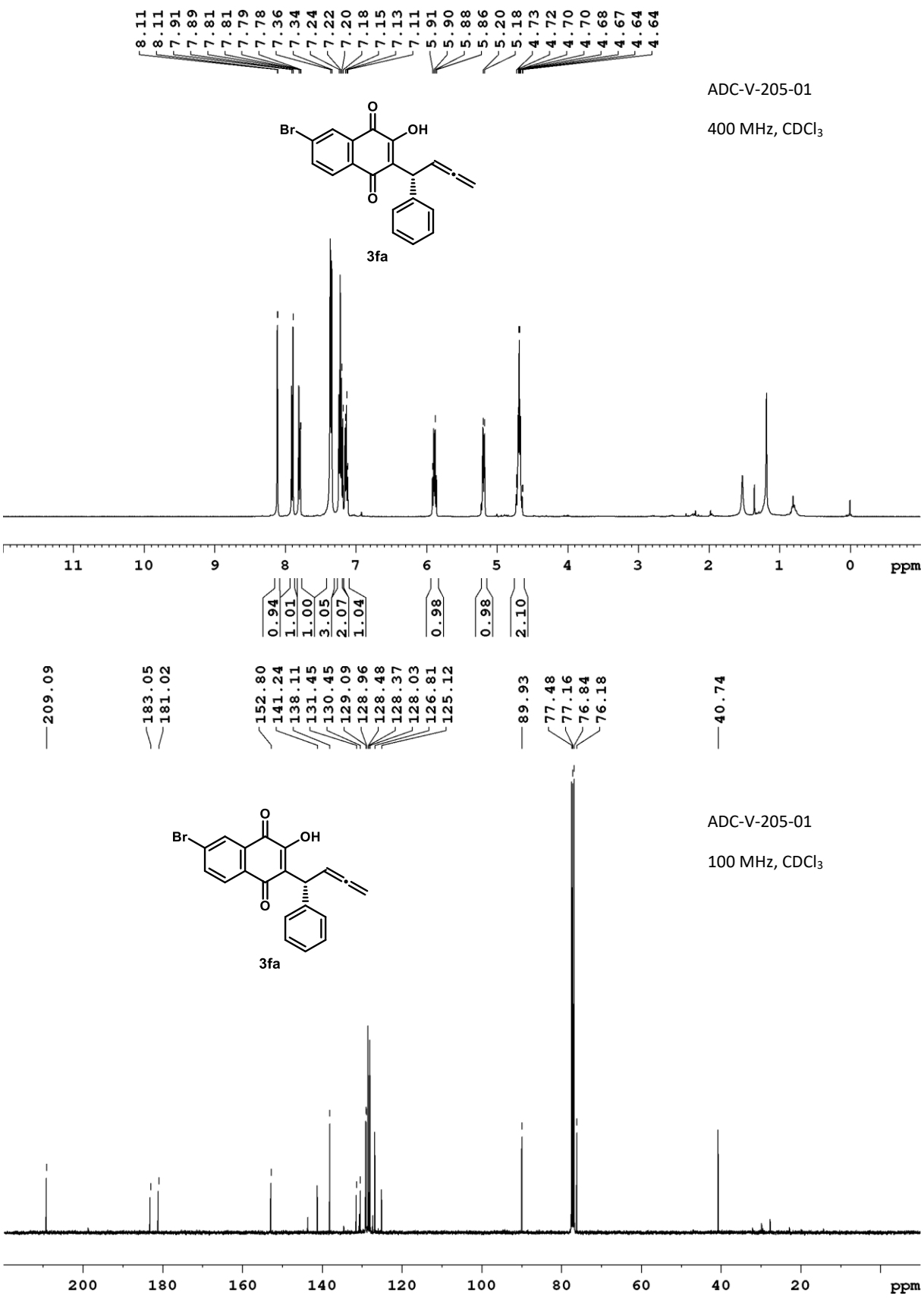
Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

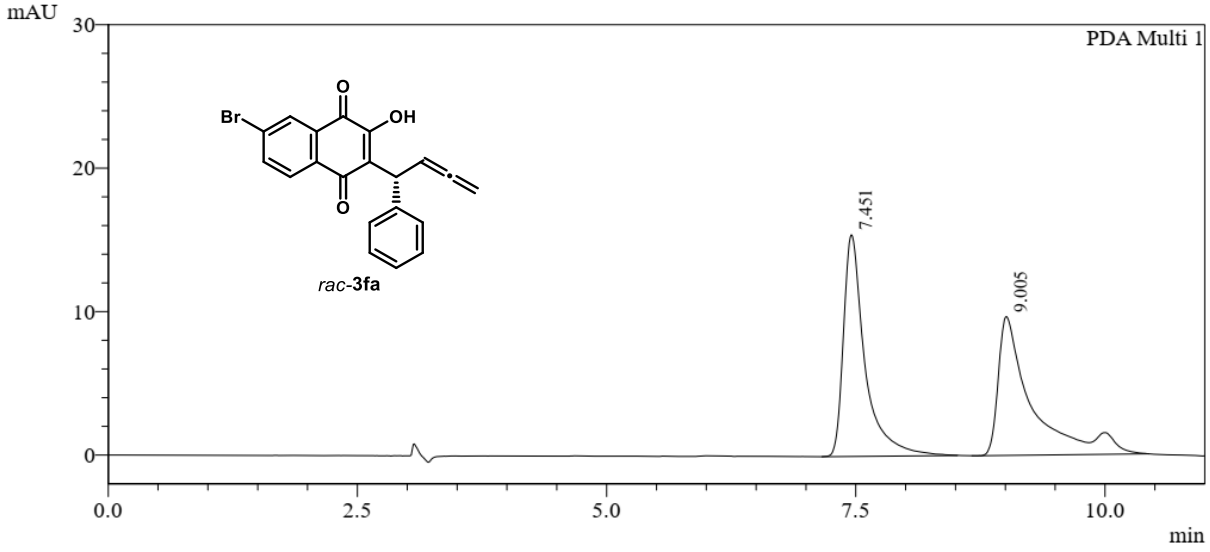


PeakTable

PDA Ch1 380nm 4nm

Peak#	Ret. Time	Area	Area %
1	7.915	492275	99.633
2	9.961	1813	0.367
Total		494088	100.000


8.11
8.11
7.91
7.89
7.81
7.81
7.79
7.78
7.36
7.34
7.24
7.22
7.20
7.18
7.15
7.13
7.11
5.91
5.90
5.88
5.86
5.20
5.18
4.73
4.72
4.70
4.70
4.68
4.67
4.64
4.64
ADC-V-205-01
400 MHz, CDCl3
Br
OH
O
O
3fa
11
10
9
8
7
6
5
4
3
2
1
0
ppm
0.94
1.01
1.00
3.05
2.07
1.04
0.98
0.98
2.10
209.09
183.05
181.02
152.80
141.24
138.11
131.45
130.45
129.09
128.96
128.48
128.37
128.03
126.81
125.12
89.93
77.48
77.16
76.84
76.18
40.74
ADC-V-205-01
100 MHz, CDCl3
Br
OH
O
O
3fa
200
180
160
140
120
100
80
60
40
20
ppm

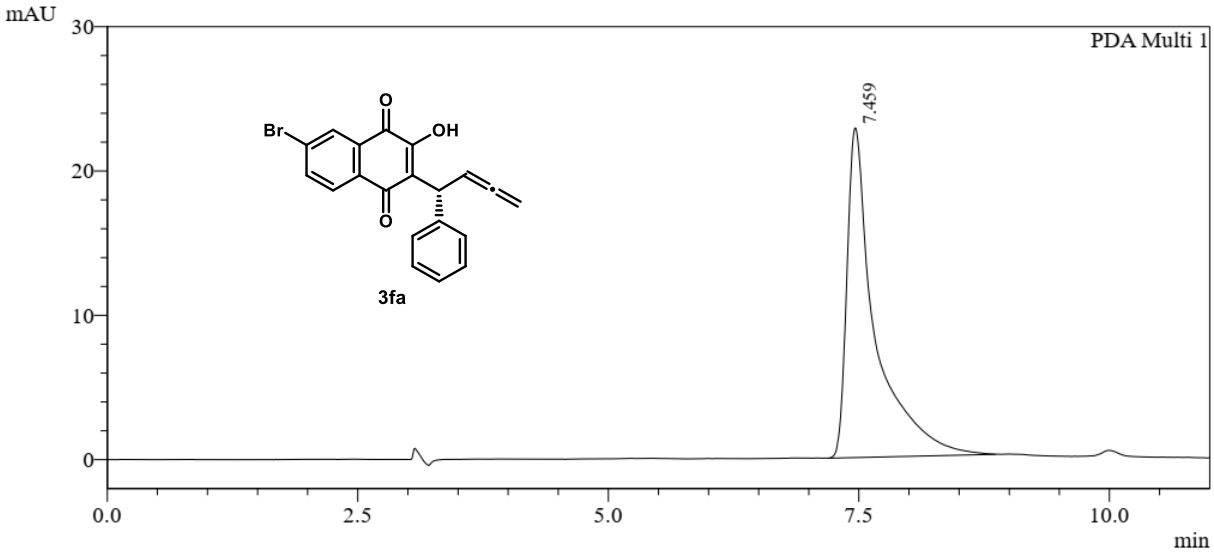


PeakTable

PDA Ch1 380nm 4nm

Peak#	Ret. Time	Area	Area %
1	7.451	231788	50.170
2	9.005	230213	49.830
Total		462002	100.000

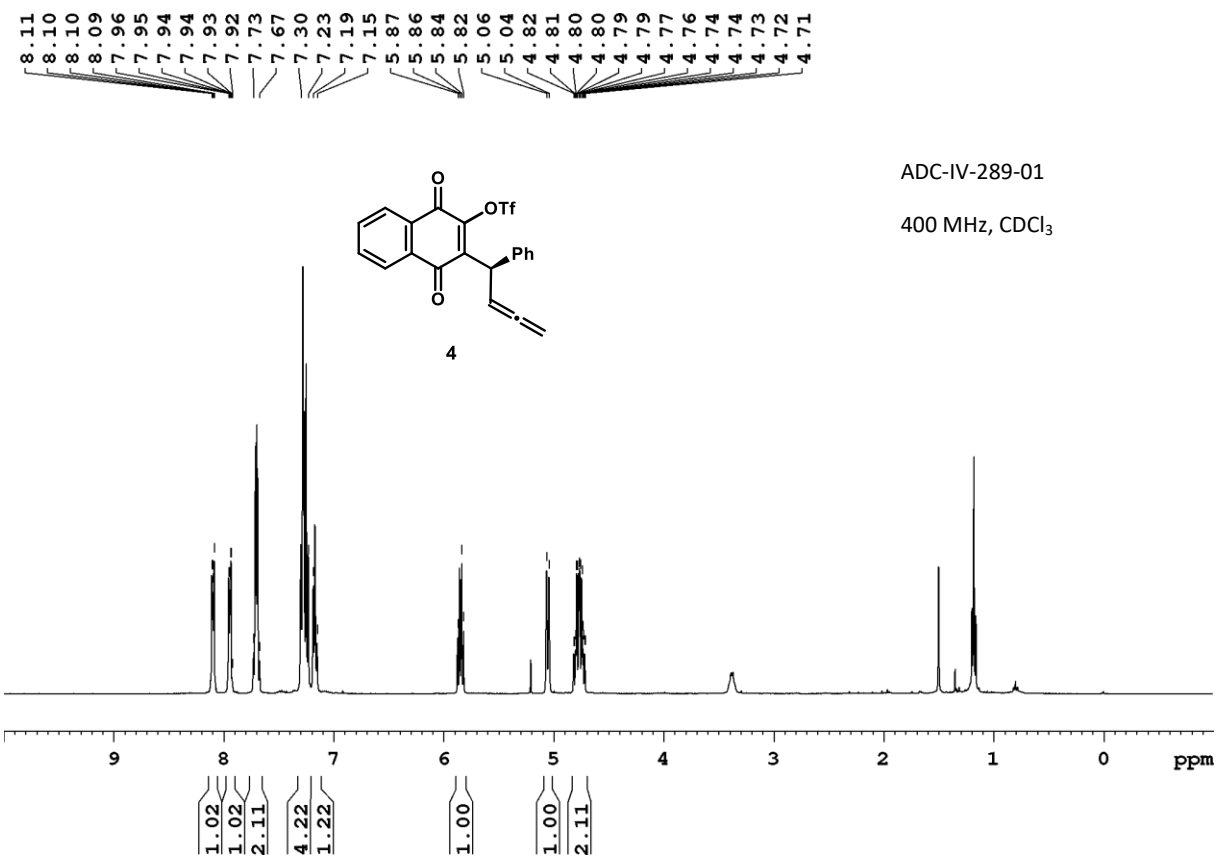
Daicel Chiralpak IK column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

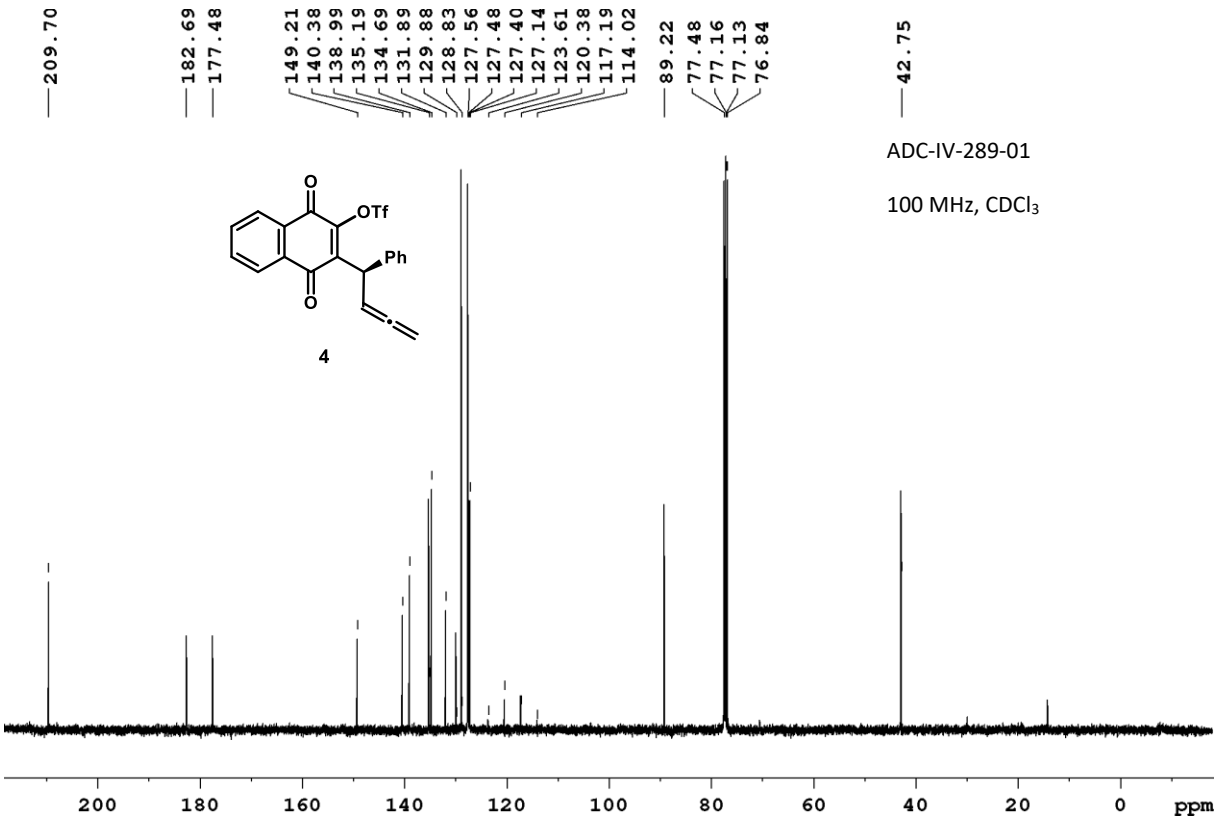


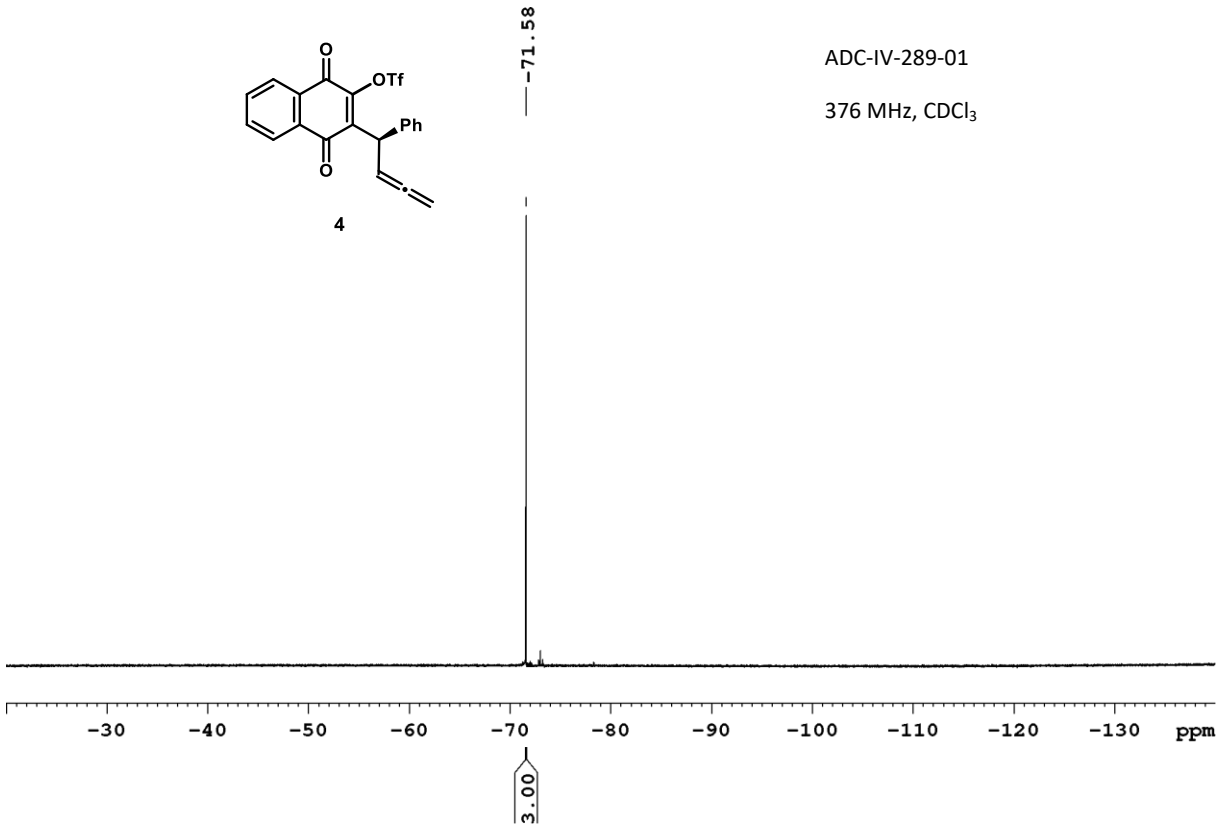
PeakTable

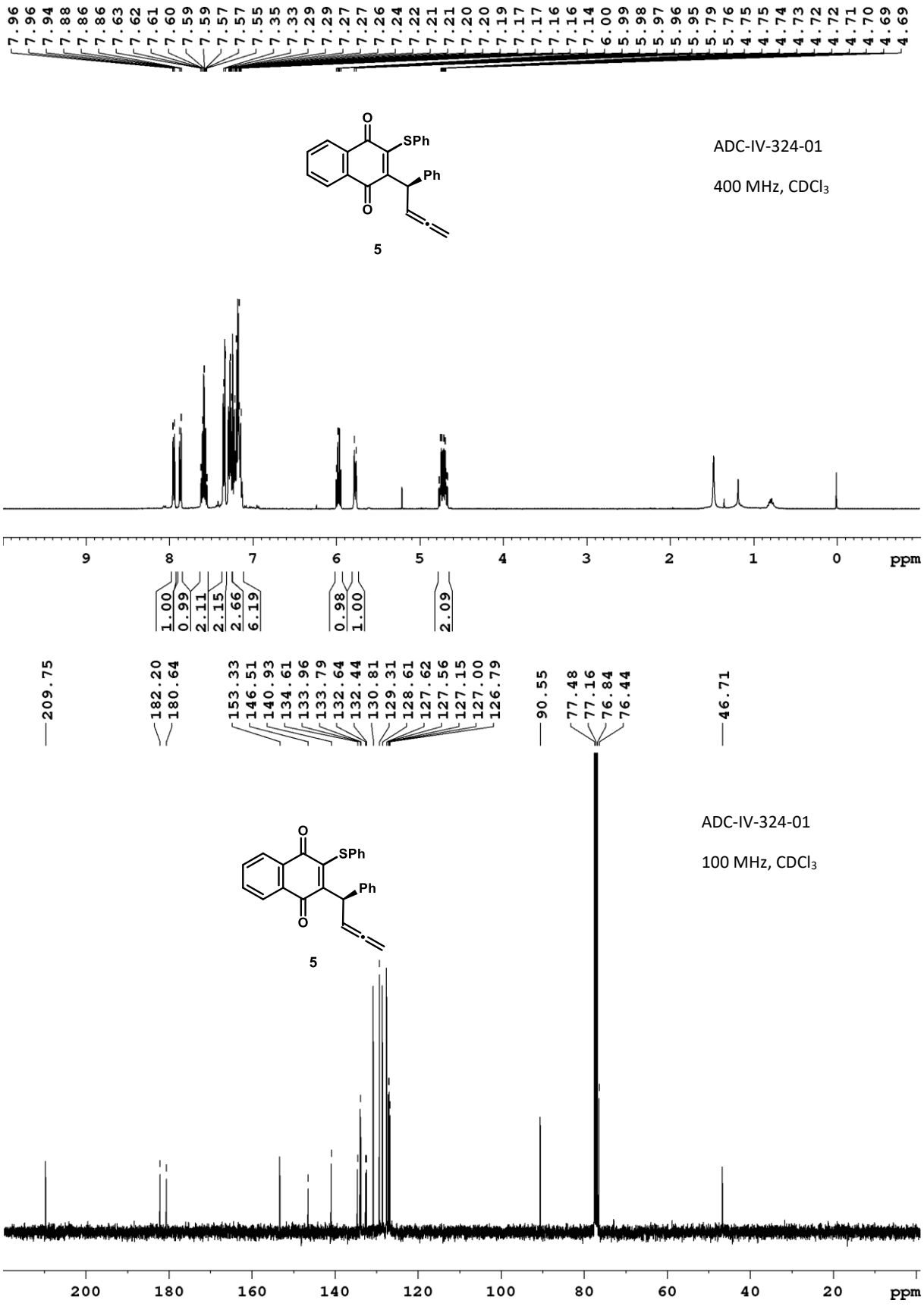
PDA Ch1 380nm 4nm

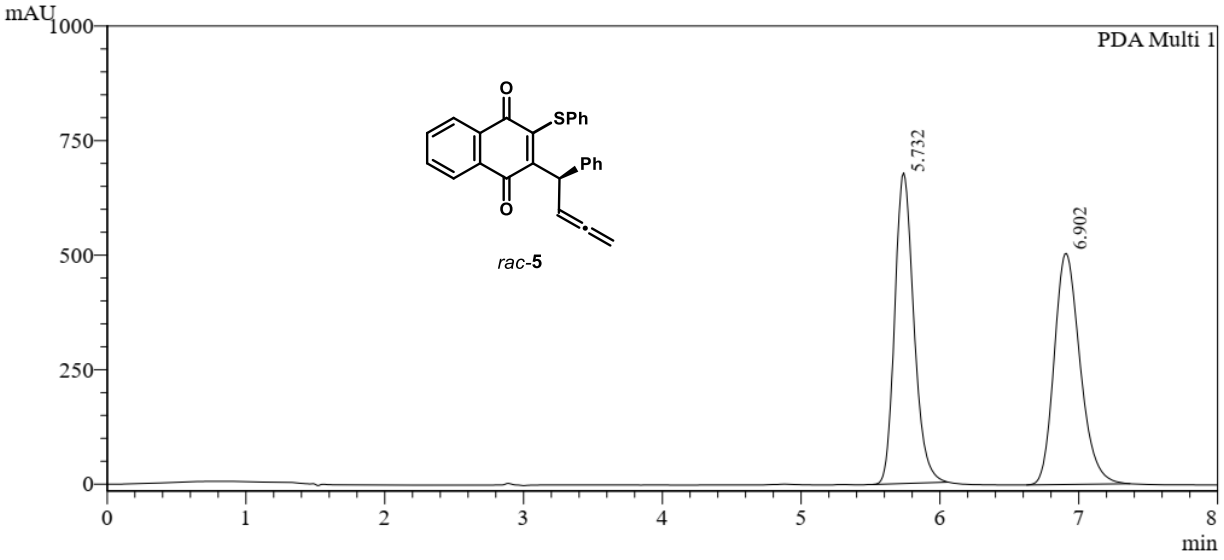
Peak#	Ret. Time	Area	Area %
1	7.459	447670	100.000
Total		447670	100.000


8.11
8.10
8.10
8.09
7.96
7.95
7.94
7.94
7.93
7.92
7.73
7.67
7.30
7.23
7.19
7.15
5.87
5.86
5.84
5.82
5.06
5.04
4.82
4.81
4.80
4.80
4.79
4.79
4.77
4.76
4.74
4.74
4.73
4.72
4.71
ADC-IV-289-01
400 MHz, CDCl3
OTf
Ph
4
9
8
7
6
5
4
3
2
1
0
ppm
1.02
1.02
2.11
4.22
1.22
1.00
1.00
2.11


209.70
182.69
177.48
149.21
140.38
138.99
135.19
134.69
131.89
129.88
128.83
127.56
127.48
127.40
127.14
123.61
120.38
117.19
114.02
89.22
77.48
77.16
77.13
76.84
42.75
ADC-IV-289-01
100 MHz, CDCl3
OTf
Ph
4
200
180
160
140
120
100
80
60
40
20
0
ppm


OTf
Ph
O
O
4
-71.58
ADC-IV-289-01
376 MHz, CDCl3
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
ppm
3.00


7.96 7.96 7.94 7.88 7.86 7.86 7.63 7.62 7.61 7.60 7.59 7.59 7.57 7.57 7.55 7.35 7.33 7.29 7.29 7.27 7.27 7.26 7.24 7.22 7.21 7.21 7.20 7.20 7.19 7.17 7.17 7.16 7.16 7.14 6.00 5.99 5.98 5.97 5.96 5.95 5.79 5.76 4.75 4.75 4.74 4.73 4.72 4.72 4.71 4.70 4.69 4.69
O
SPh
Ph
O
5
ADC-IV-324-01
400 MHz, CDCl3
9 8 7 6 5 4 3 2 1 0 ppm
1.00 0.99 2.11 2.15 2.66 6.19 0.98 1.00 2.09
209.75 182.20 180.64 153.33 146.51 140.93 134.61 133.96 133.79 132.64 132.44 130.81 129.31 128.61 127.62 127.56 127.15 127.00 126.79 90.55 77.48 77.16 76.84 76.44 46.71
O
SPh
Ph
O
5
ADC-IV-324-01
100 MHz, CDCl3
200 180 160 140 120 100 80 60 40 20 ppm



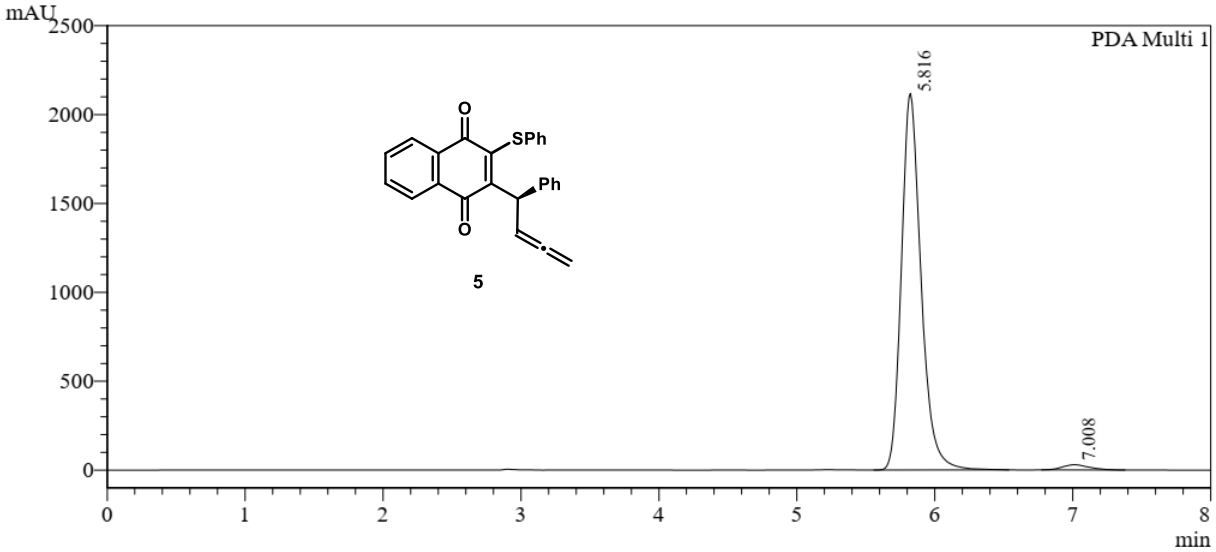
rac-**5**

PeakTable

PDA Ch1 251nm 4nm

Peak#	Ret. Time	Area	Area %
1	5.732	6493055	49.836
2	6.902	6535886	50.164
Total		13028941	100.000

Phenomenex Cellulose-2 column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

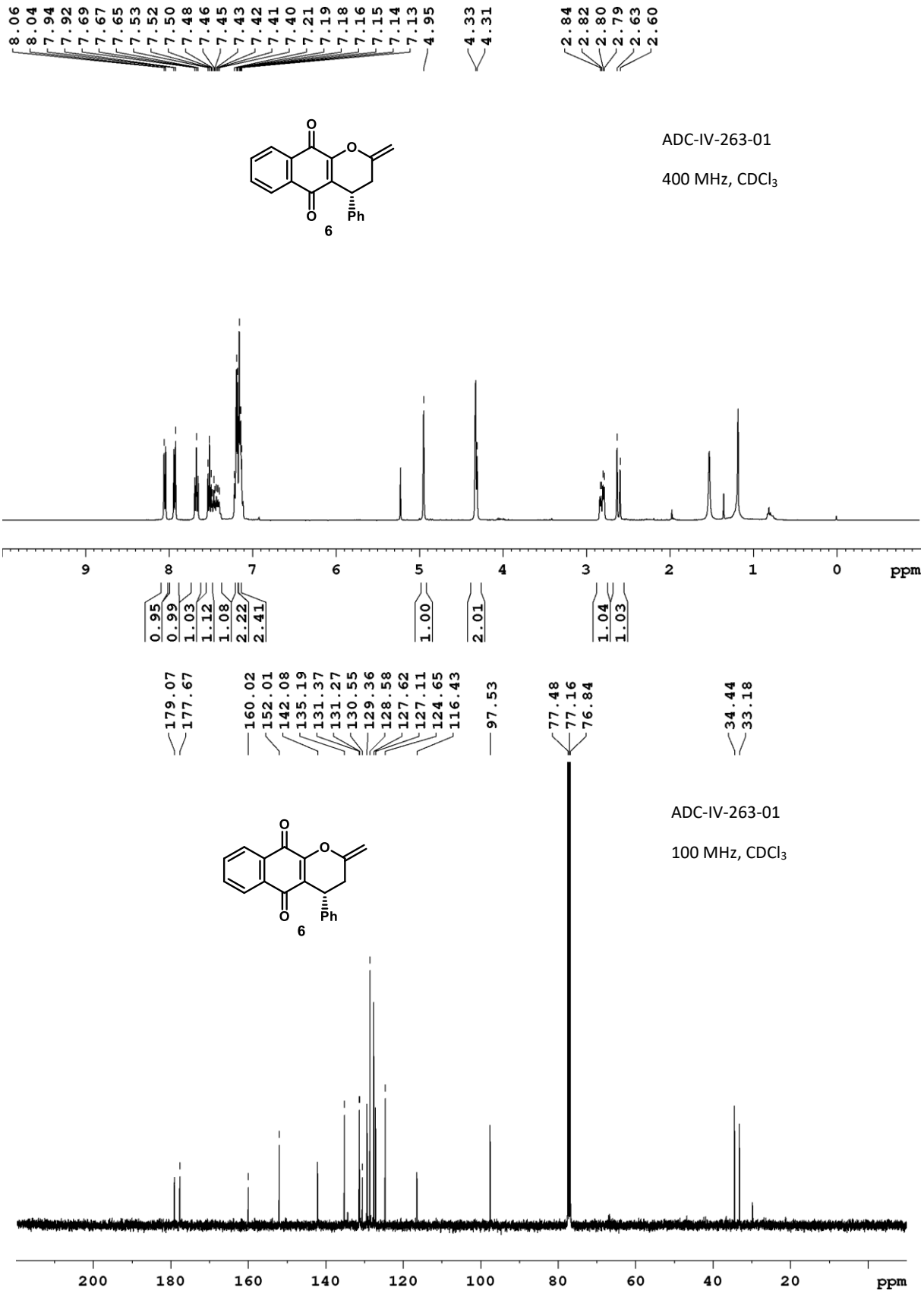


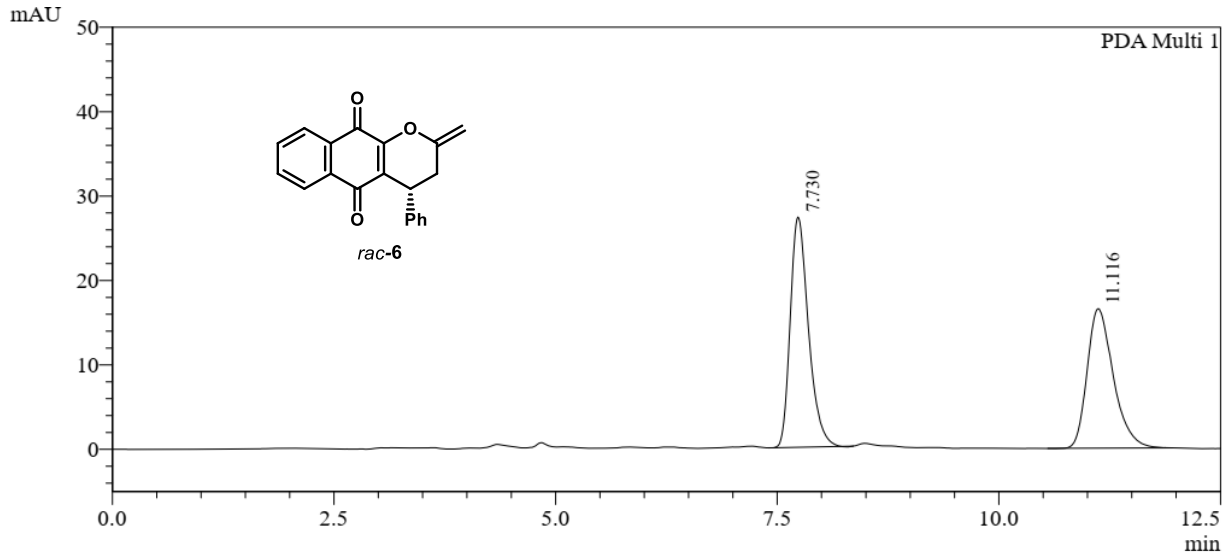
5

PeakTable

PDA Ch1 251nm 4nm

Peak#	Ret. Time	Area	Area %
1	5.816	20961938	98.153
2	7.008	394552	1.847
Total		21356489	100.000


8.06
8.04
7.94
7.92
7.69
7.67
7.65
7.53
7.52
7.50
7.48
7.46
7.45
7.43
7.42
7.41
7.40
7.21
7.19
7.18
7.16
7.15
7.14
7.13
4.95
4.33
4.31
2.84
2.82
2.80
2.79
2.63
2.60
O
O
O
Ph
6
ADC-IV-263-01
400 MHz, CDCl3
9
8
7
6
5
4
3
2
1
0
ppm
0.95
0.99
1.03
1.12
1.08
2.22
2.41
1.00
2.01
1.04
1.03
179.07
177.67
160.02
152.01
142.08
135.19
131.37
131.27
130.55
129.36
128.58
127.62
127.11
124.65
116.43
97.53
77.48
77.16
76.84
34.44
33.18
ADC-IV-263-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
ppm

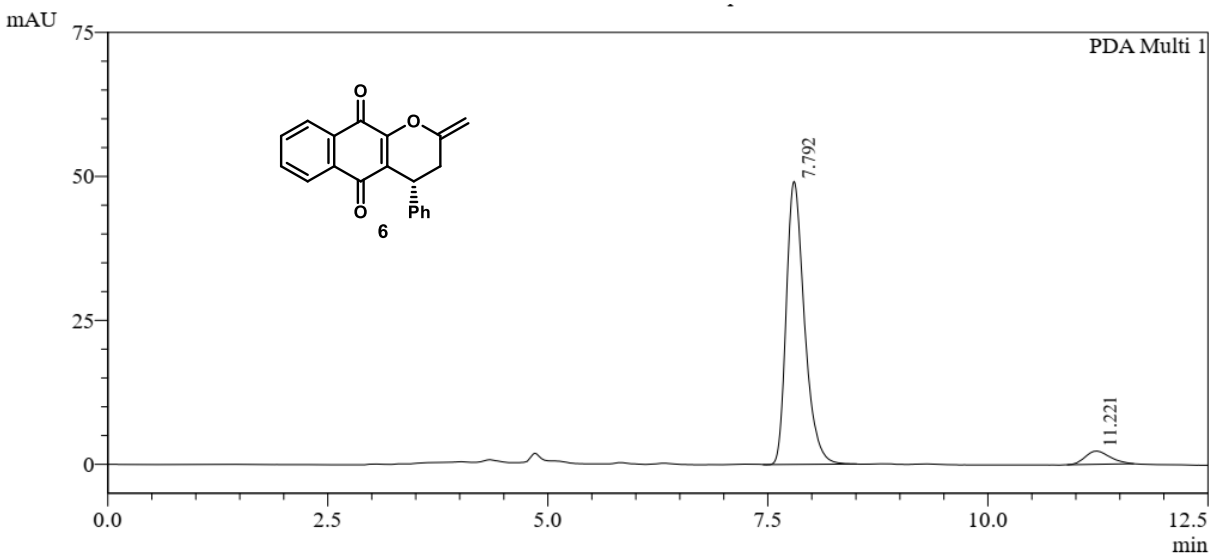


PeakTable

PDA Ch1 317nm 4nm

Peak#	Ret. Time	Area	Area %
1	7.730	388221	53.343
2	11.116	339555	46.657
Total		727775	100.000

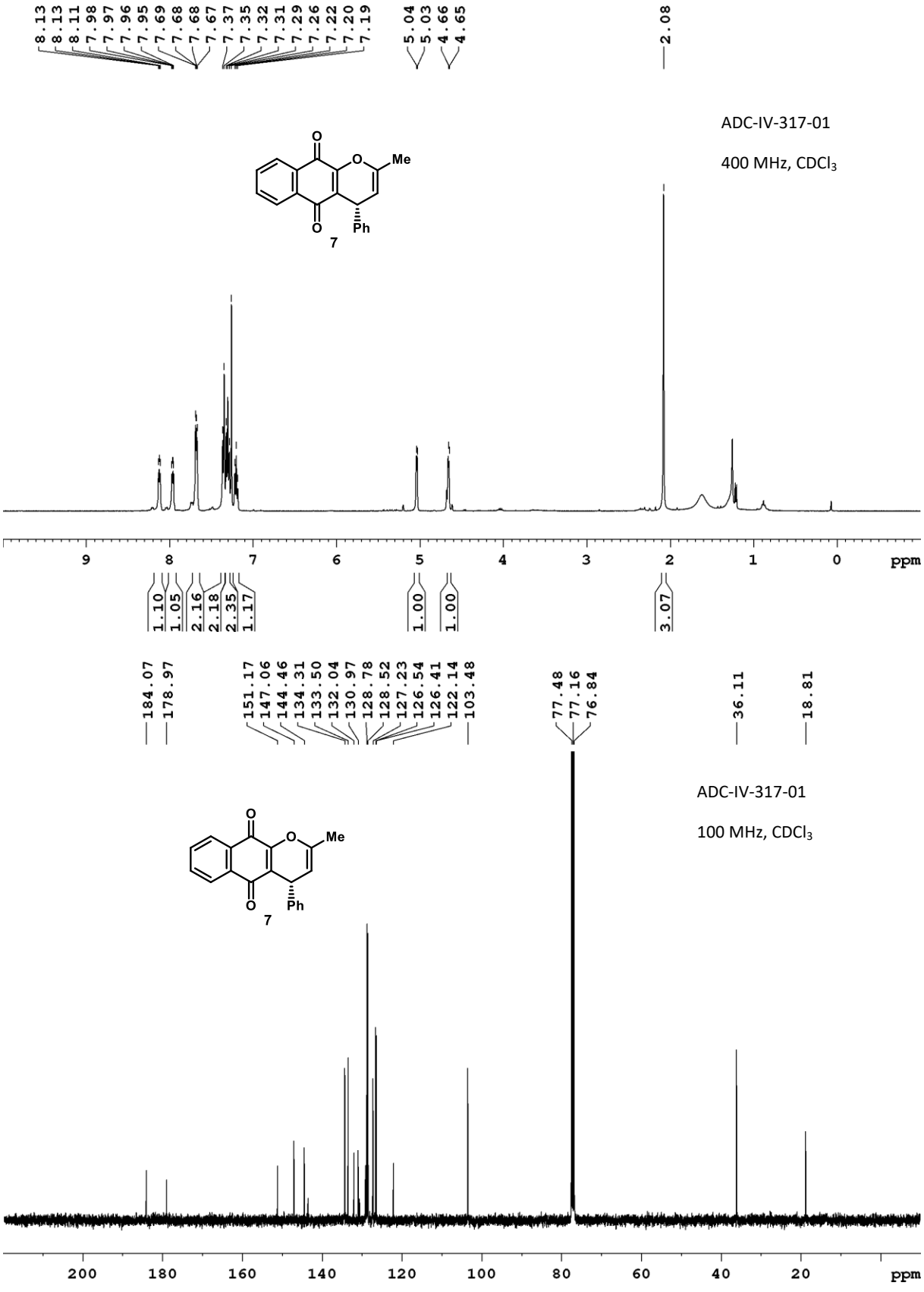
Daicel Chiralpak AD-H column (80:20 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

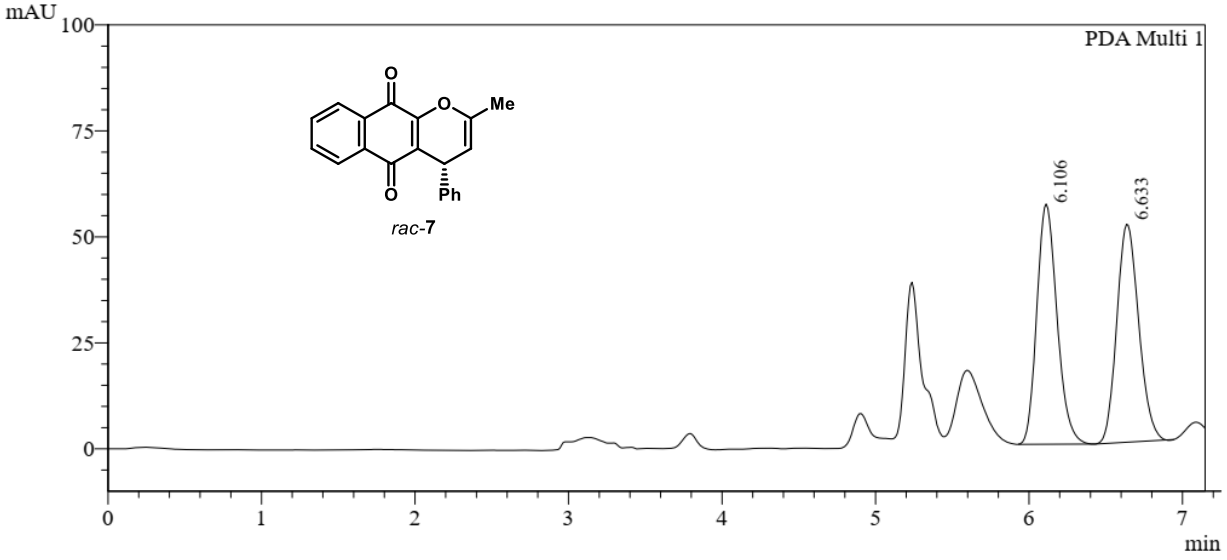


PeakTable

PDA Ch1 317nm 4nm

Peak#	Ret. Time	Area	Area %
1	7.792	703676	93.975
2	11.221	45114	6.025
Total		748790	100.000


8.13
8.13
8.11
7.98
7.97
7.96
7.95
7.69
7.68
7.68
7.67
7.37
7.35
7.32
7.31
7.29
7.26
7.22
7.20
7.19
5.04
5.03
4.66
4.65
2.08
ADC-IV-317-01
400 MHz, CDCl3
Me
Ph
7
ppm
1.10
1.05
2.16
2.18
2.35
1.17
1.00
1.00
3.07
184.07
178.97
151.17
147.06
144.46
134.31
133.50
132.04
130.97
128.78
128.52
127.23
126.54
126.41
122.14
103.48
77.48
77.16
76.84
36.11
18.81
ADC-IV-317-01
100 MHz, CDCl3
Me
Ph
7
ppm

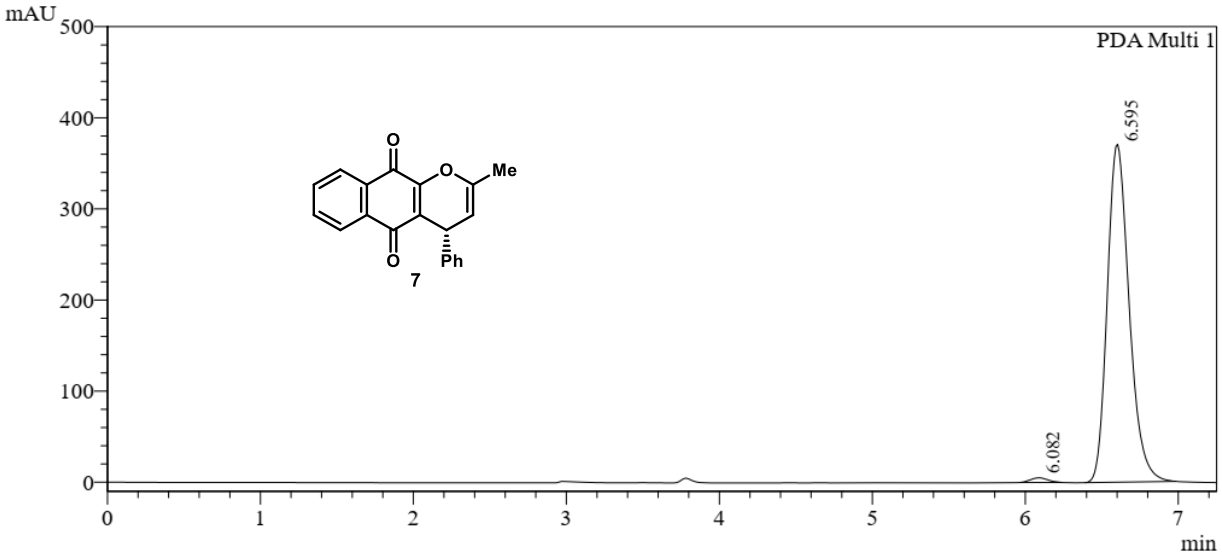


PeakTable

PDA Ch1 234nm 4nm

Peak#	Ret. Time	Area	Area %
1	6.106	517430	50.337
2	6.633	510504	49.663
Total		1027933	100.000

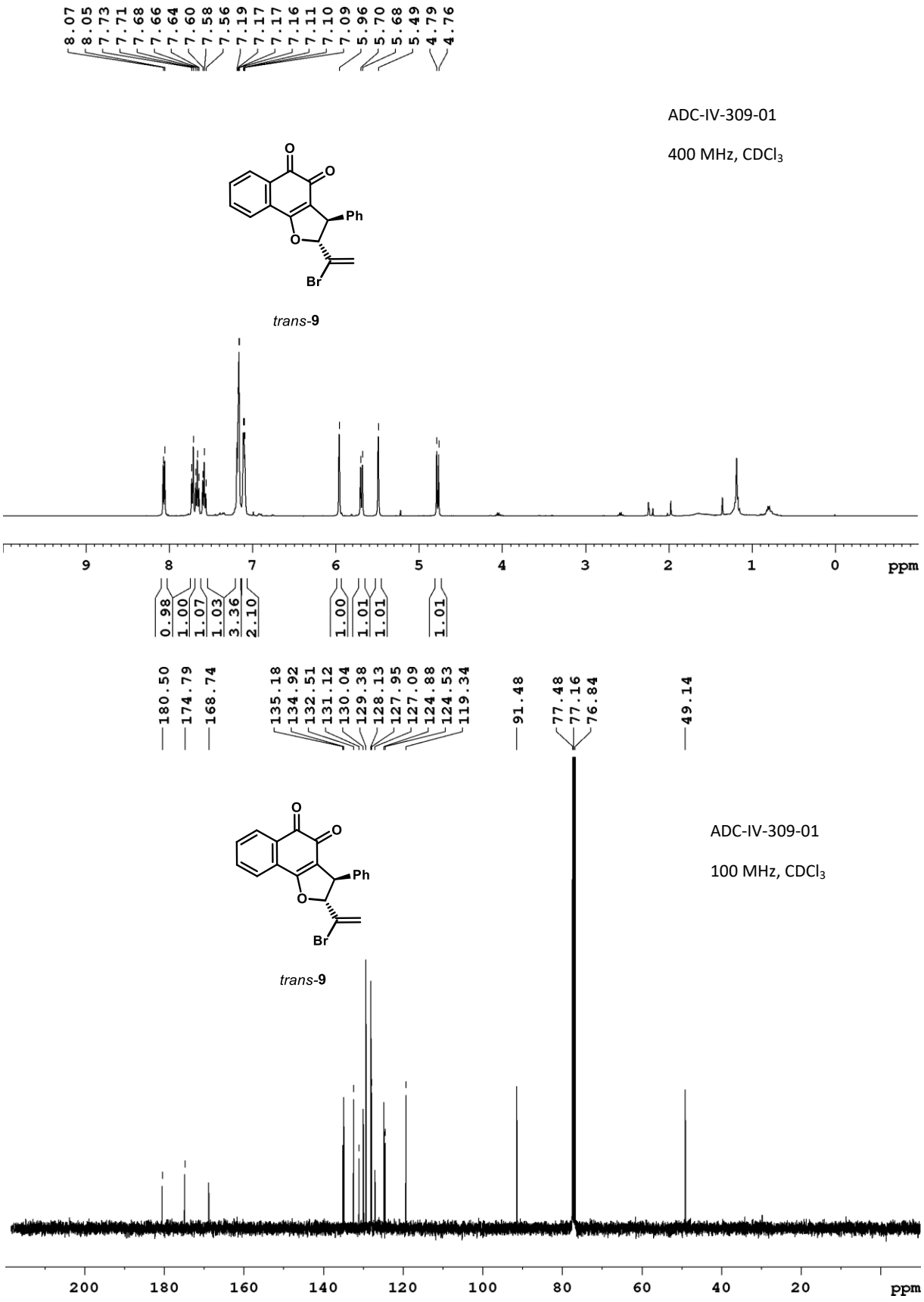
Daicel Chiralpak IH column (80:20 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

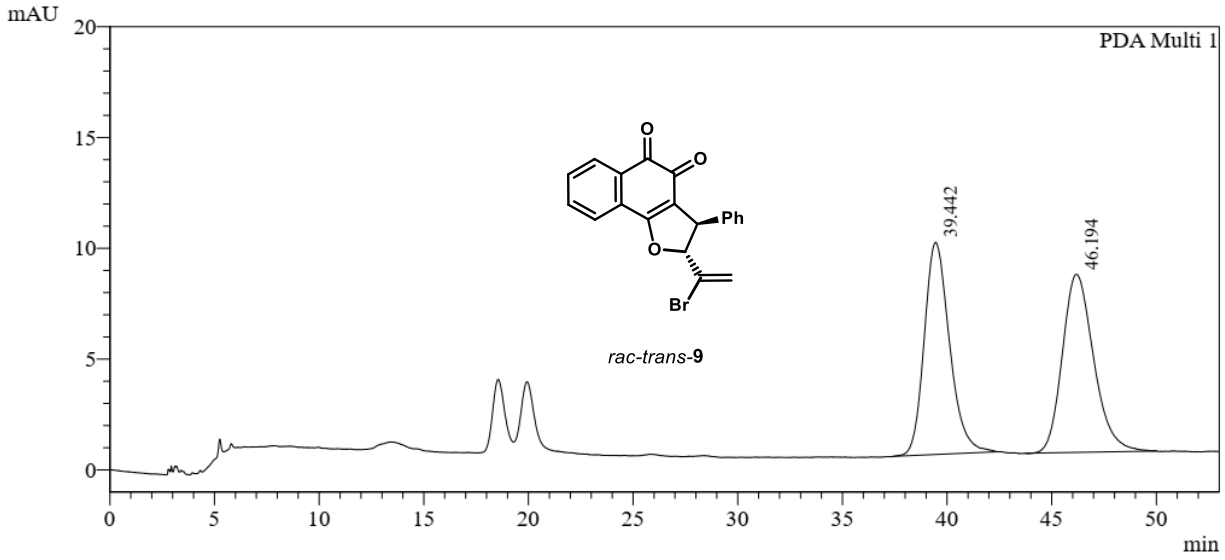


PeakTable

PDA Ch1 234nm 4nm

Peak#	Ret. Time	Area	Area %
1	6.082	40772	1.094
2	6.595	3686188	98.906
Total		3726959	100.000


8.07
8.05
7.73
7.71
7.68
7.66
7.64
7.60
7.58
7.56
7.19
7.17
7.17
7.16
7.11
7.10
7.09
5.96
5.70
5.68
5.49
4.79
4.76
ADC-IV-309-01
400 MHz, CDCl3
O
O
Ph
O
Br
trans-9
9
8
7
6
5
4
3
2
1
0
ppm
0.98
1.00
1.07
1.03
3.36
2.10
1.00
1.01
1.01
1.01
180.50
174.79
168.74
135.18
134.92
132.51
131.12
130.04
129.38
128.13
127.95
127.09
124.88
124.53
119.34
91.48
77.48
77.16
76.84
49.14
ADC-IV-309-01
100 MHz, CDCl3
trans-9
200
180
160
140
120
100
80
60
40
20
ppm

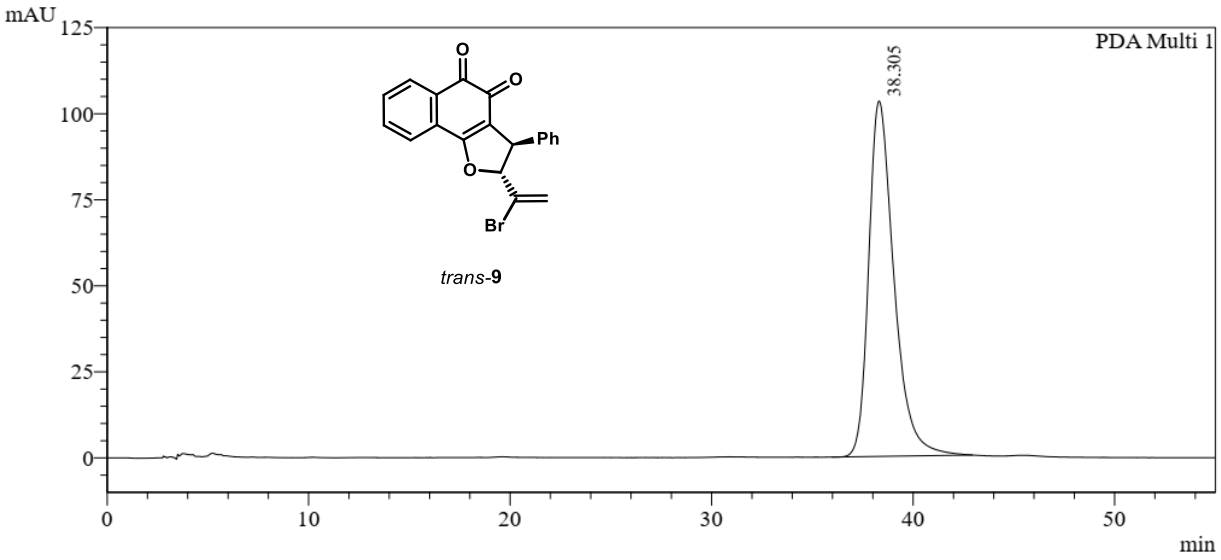


PeakTable

PDA Ch1 274nm 4nm

Peak#	Ret. Time	Area	Area %
1	39.442	806473	49.071
2	46.194	837014	50.929
Total		1643487	100.000

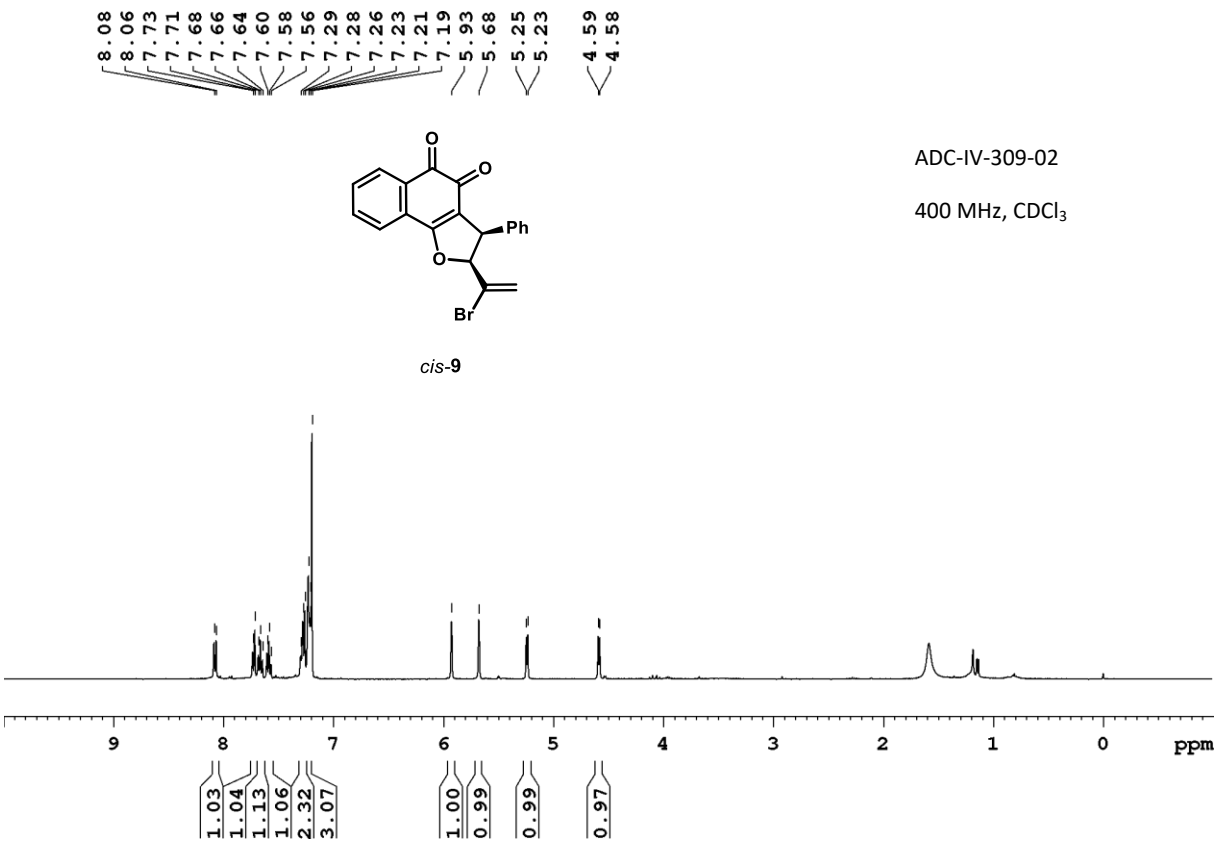
Phenomenex Cellulose-2 column (70:30 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

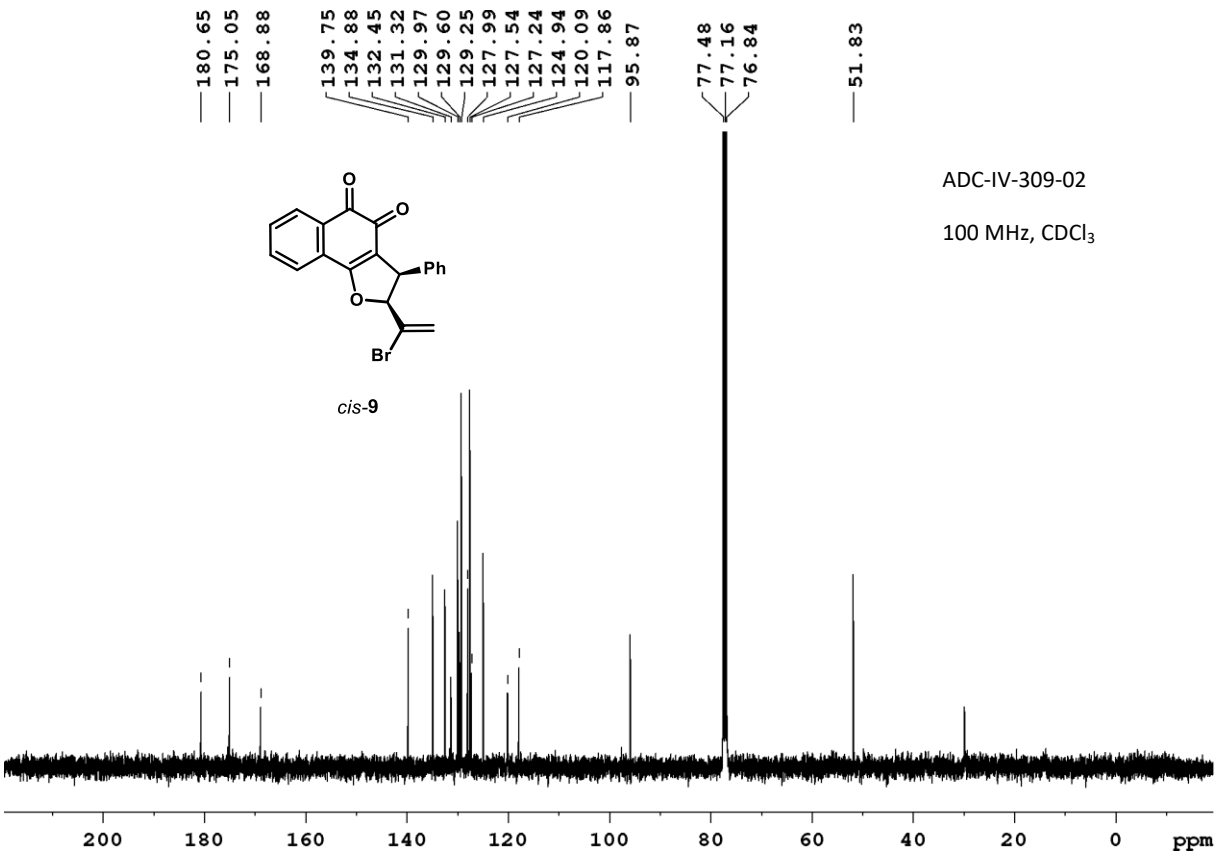


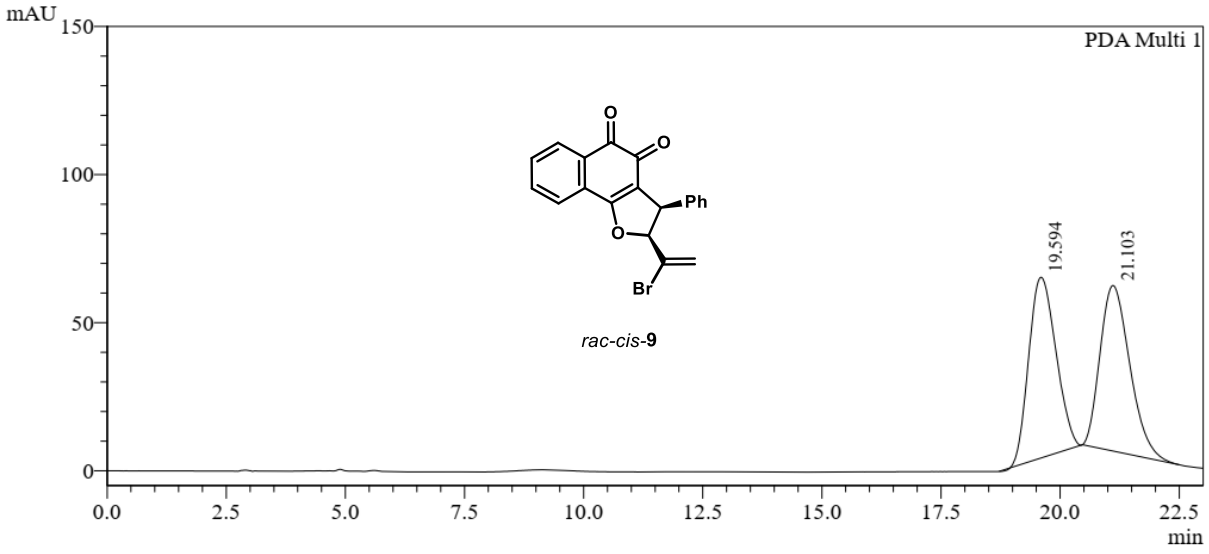
PeakTable

PDA Ch1 274nm 4nm

Peak#	Ret. Time	Area	Area %
1	38.305	9003151	100.000
Total		9003151	100.000


8.08
8.06
7.73
7.71
7.68
7.66
7.64
7.60
7.58
7.56
7.29
7.28
7.26
7.23
7.21
7.19
5.93
5.68
5.25
5.23
4.59
4.58
O
O
Ph
O
Br
ADC-IV-309-02
400 MHz, CDCl3
cis-9
9
8
7
6
5
4
3
2
1
0
ppm
1.03
1.04
1.13
1.06
2.32
3.07
1.00
0.99
0.99
0.97


180.65
175.05
168.88
139.75
134.88
132.45
131.32
129.97
129.60
129.25
127.99
127.54
127.24
124.94
120.09
117.86
95.87
77.48
77.16
76.84
51.83
O
O
Ph
O
Br
ADC-IV-309-02
100 MHz, CDCl3
cis-9
200
180
160
140
120
100
80
60
40
20
0
ppm



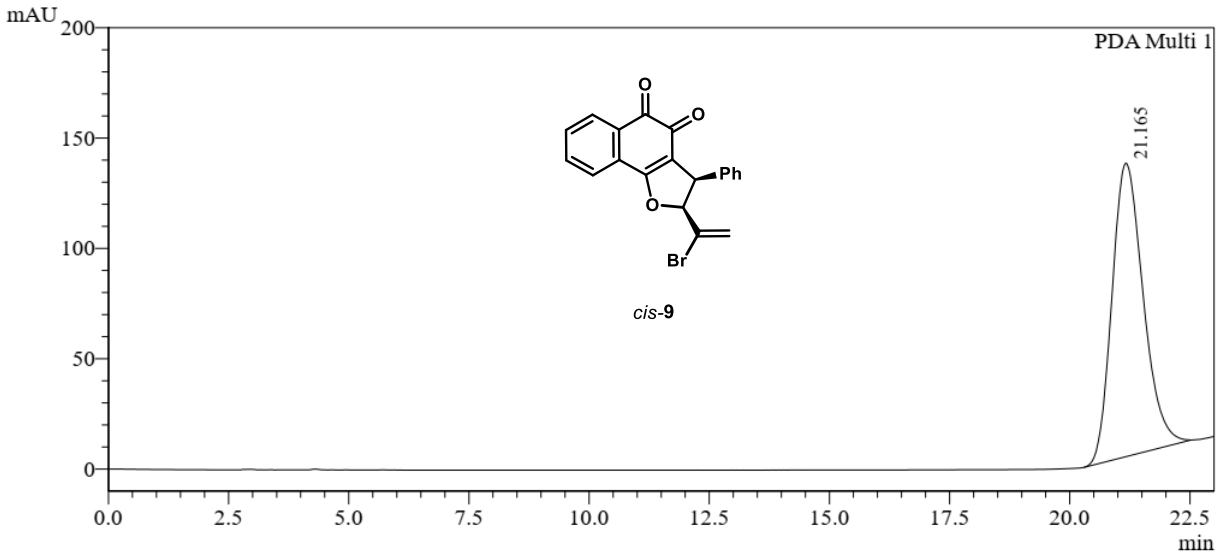
rac-cis-**9**

PeakTable

PDA Ch1 264nm 4nm

Peak#	Ret. Time	Area	Area %
1	19.594	2420707	49.895
2	21.103	2430887	50.105
Total		4851594	100.000

Phenomenex Cellulose-2 column (70:30 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

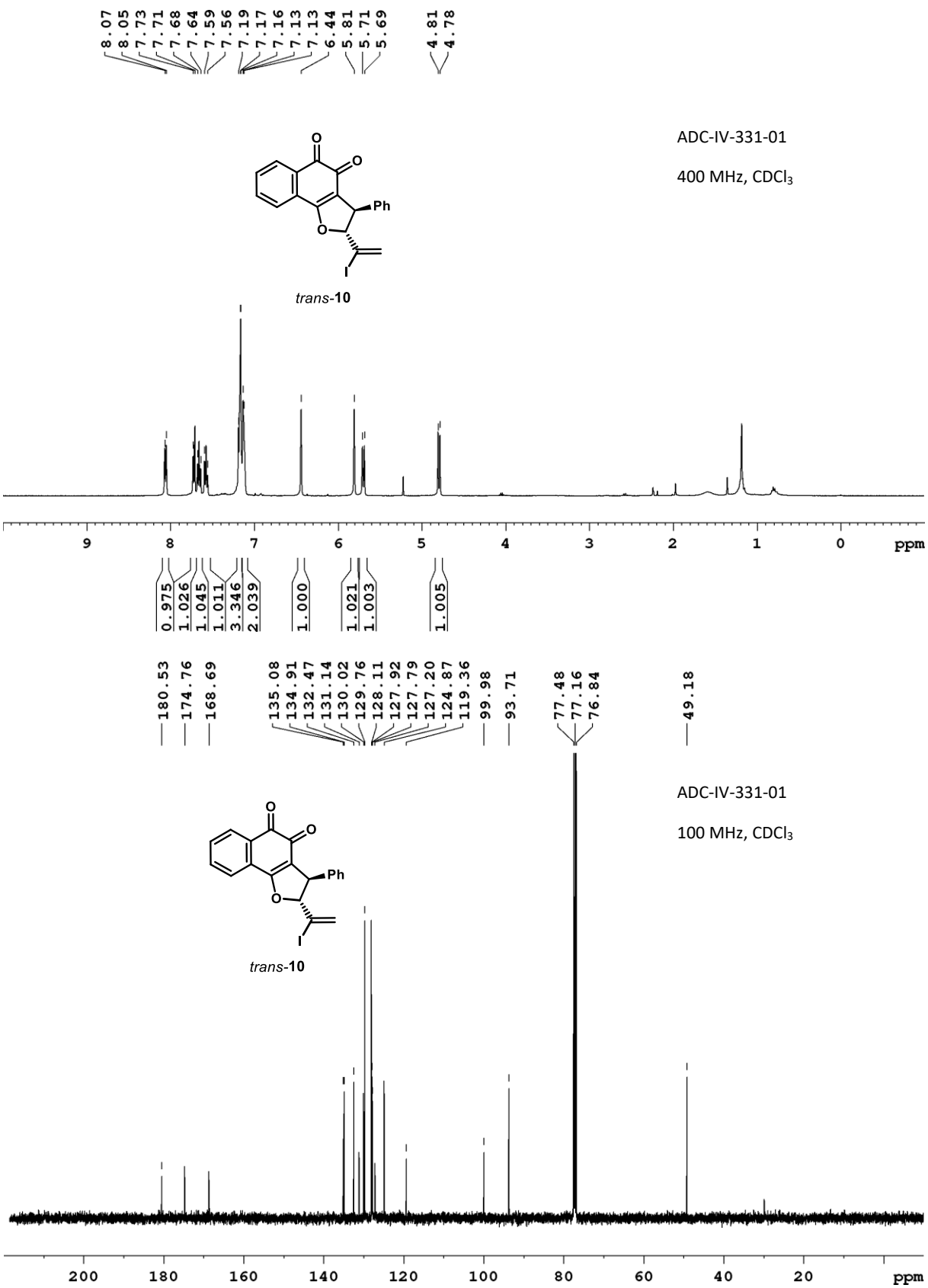


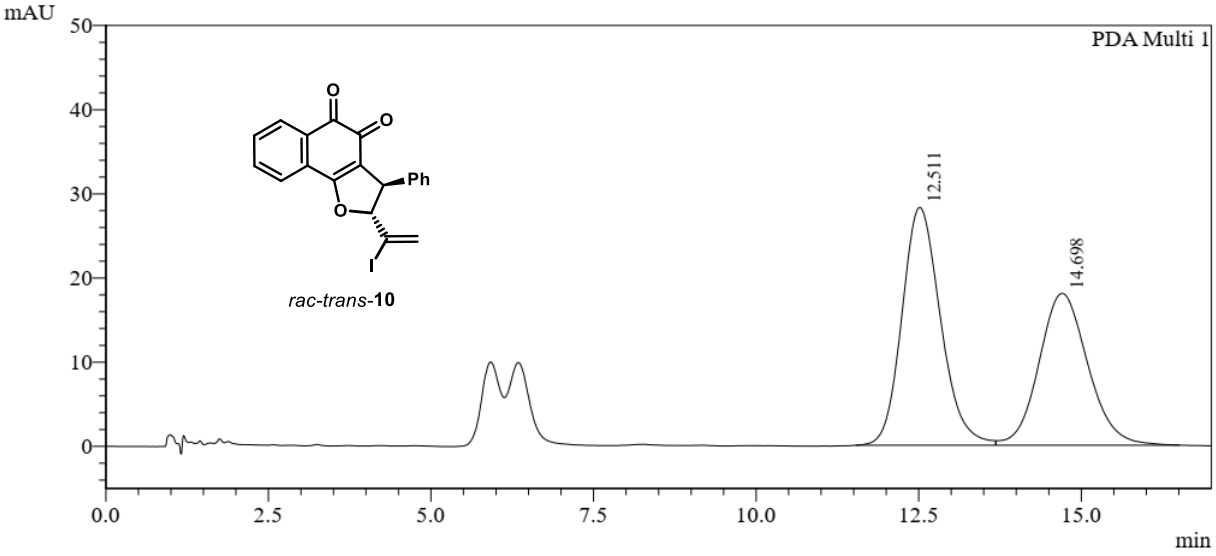
cis-**9**

PeakTable

PDA Ch1 264nm 4nm

Peak#	Ret. Time	Area	Area %
1	21.165	6009441	100.000
Total		6009441	100.000


8.07
8.05
7.73
7.71
7.68
7.64
7.59
7.56
7.19
7.17
7.16
7.13
6.44
5.81
5.71
5.69
4.81
4.78
ADC-IV-331-01
400 MHz, CDCl3
Ph
trans-10
9
8
7
6
5
4
3
2
1
0
ppm
0.975
1.026
1.045
1.011
3.346
2.039
1.000
1.021
1.003
1.005
180.53
174.76
168.69
135.08
134.91
132.47
131.14
130.02
129.76
128.11
127.92
127.79
127.20
124.87
119.36
99.98
93.71
77.48
77.16
76.84
49.18
ADC-IV-331-01
100 MHz, CDCl3
Ph
trans-10
200
180
160
140
120
100
80
60
40
20
ppm

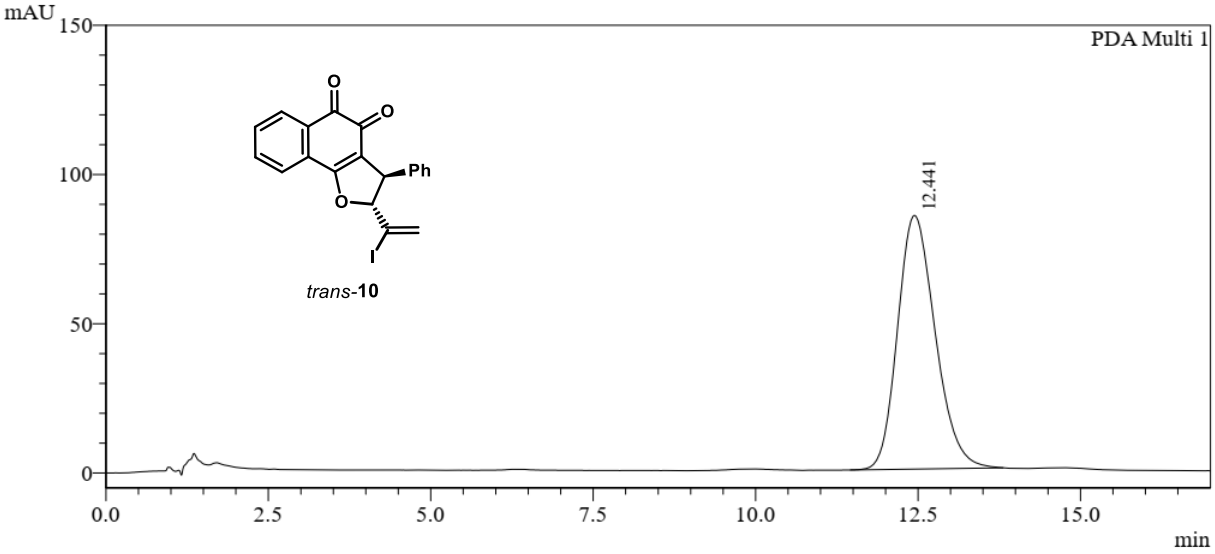


PeakTable

PDA Ch1 257nm 4nm

Peak#	Ret. Time	Area	Area %
1	12.511	1168667	55.371
2	14.698	941954	44.629
Total		2110621	100.000

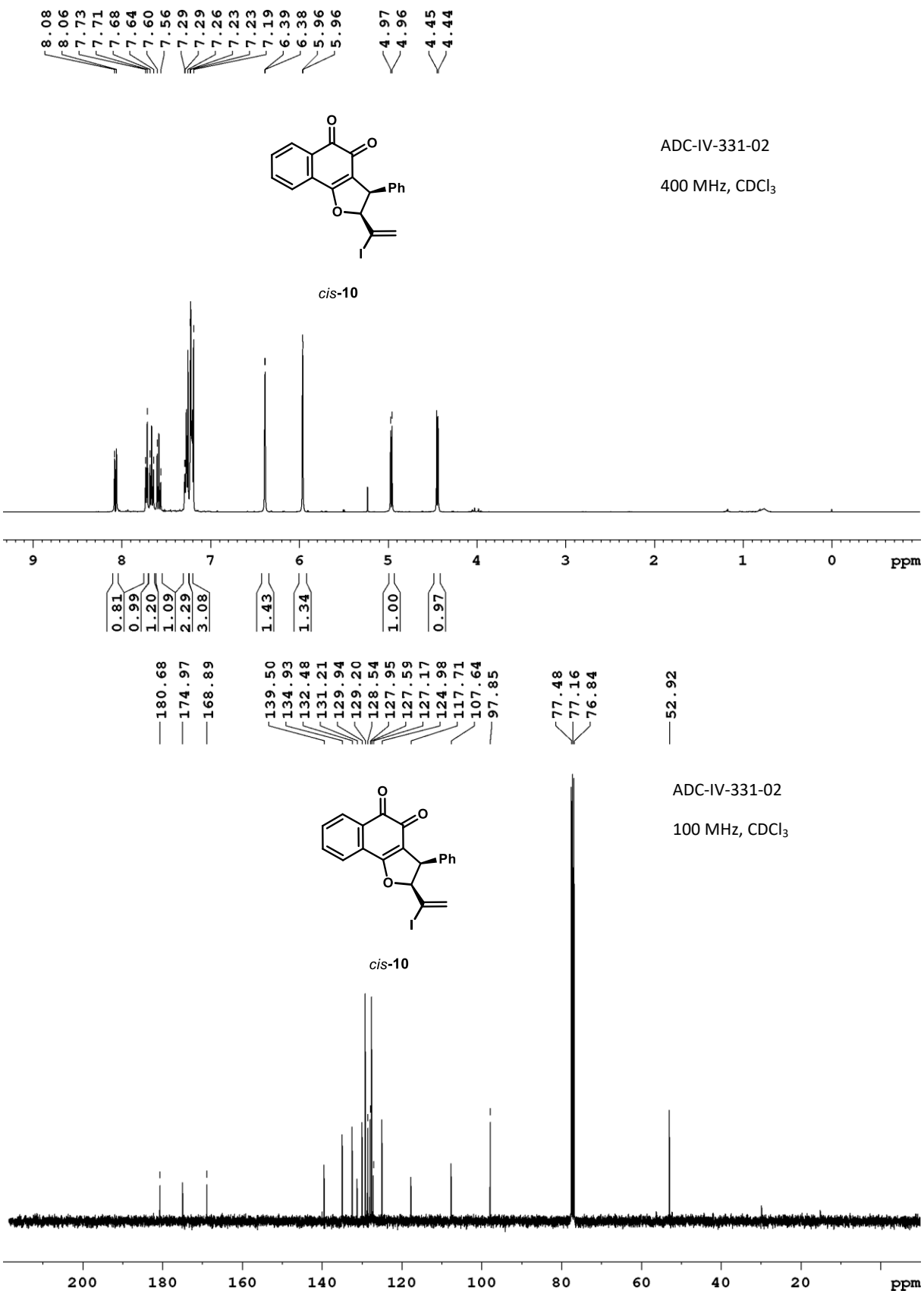
Phenomenex Cellulose-2 column (70:25:5 *n*-Hexane/IPA/EtOH, 3.0 mL/min, 20 °C)

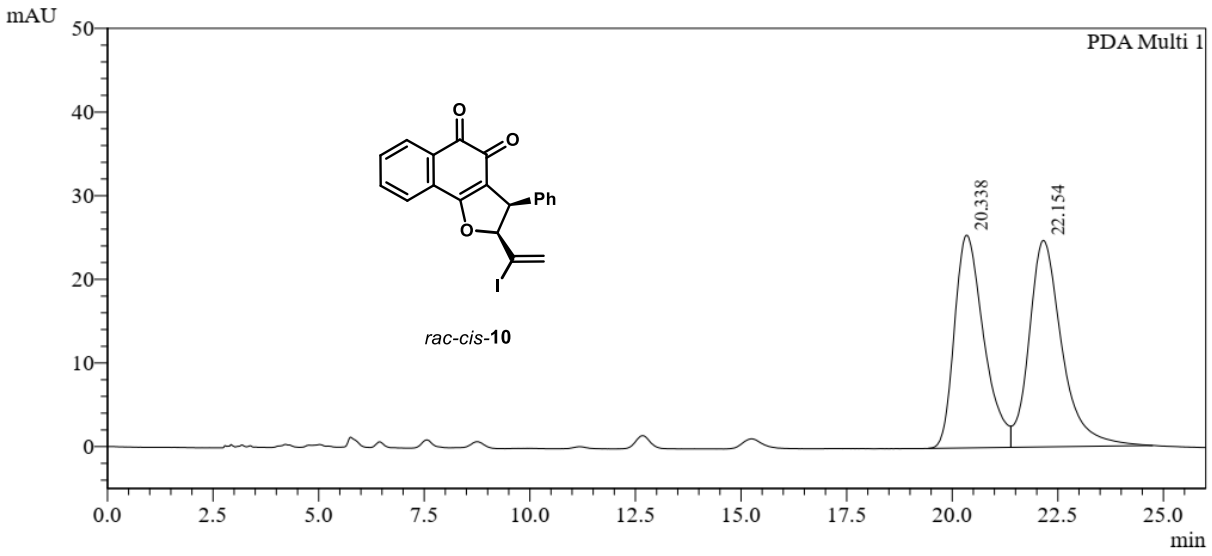


PeakTable

PDA Ch1 257nm 4nm

Peak#	Ret. Time	Area	Area %
1	12.441	3426655	100.000
Total		3426655	100.000


8.08
8.06
7.73
7.71
7.68
7.64
7.60
7.56
7.29
7.29
7.26
7.23
7.23
7.19
6.39
6.38
5.96
5.96
4.97
4.96
4.45
4.44
ADC-IV-331-02
400 MHz, CDCl3
cis-10
0.81
0.99
1.20
1.09
2.29
3.08
1.43
1.34
1.00
0.97
9
8
7
6
5
4
3
2
1
0
ppm
180.68
174.97
168.89
139.50
134.93
132.48
131.21
129.94
129.20
128.54
127.95
127.59
127.17
124.98
117.71
107.64
97.85
77.48
77.16
76.84
52.92
ADC-IV-331-02
100 MHz, CDCl3
cis-10
200
180
160
140
120
100
80
60
40
20
ppm



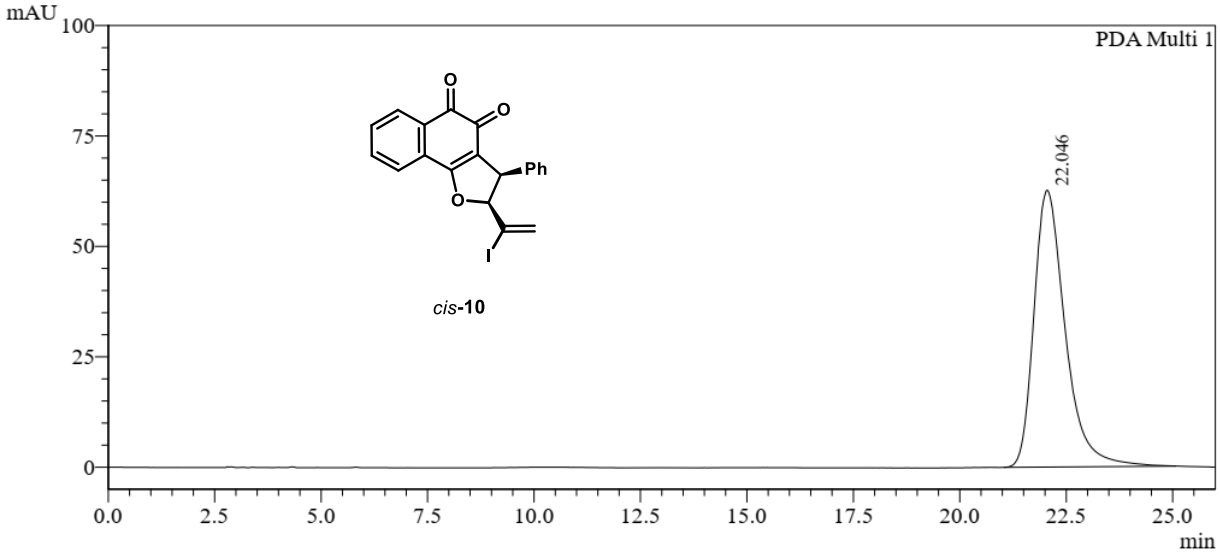
rac-cis-**10**

PeakTable

PDA Ch1 280nm 4nm

Peak#	Ret. Time	Area	Area %
1	20.338	1227489	47.910
2	22.154	1334569	52.090
Total		2562058	100.000

Phenomenex Cellulose-2 column (70:30 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)

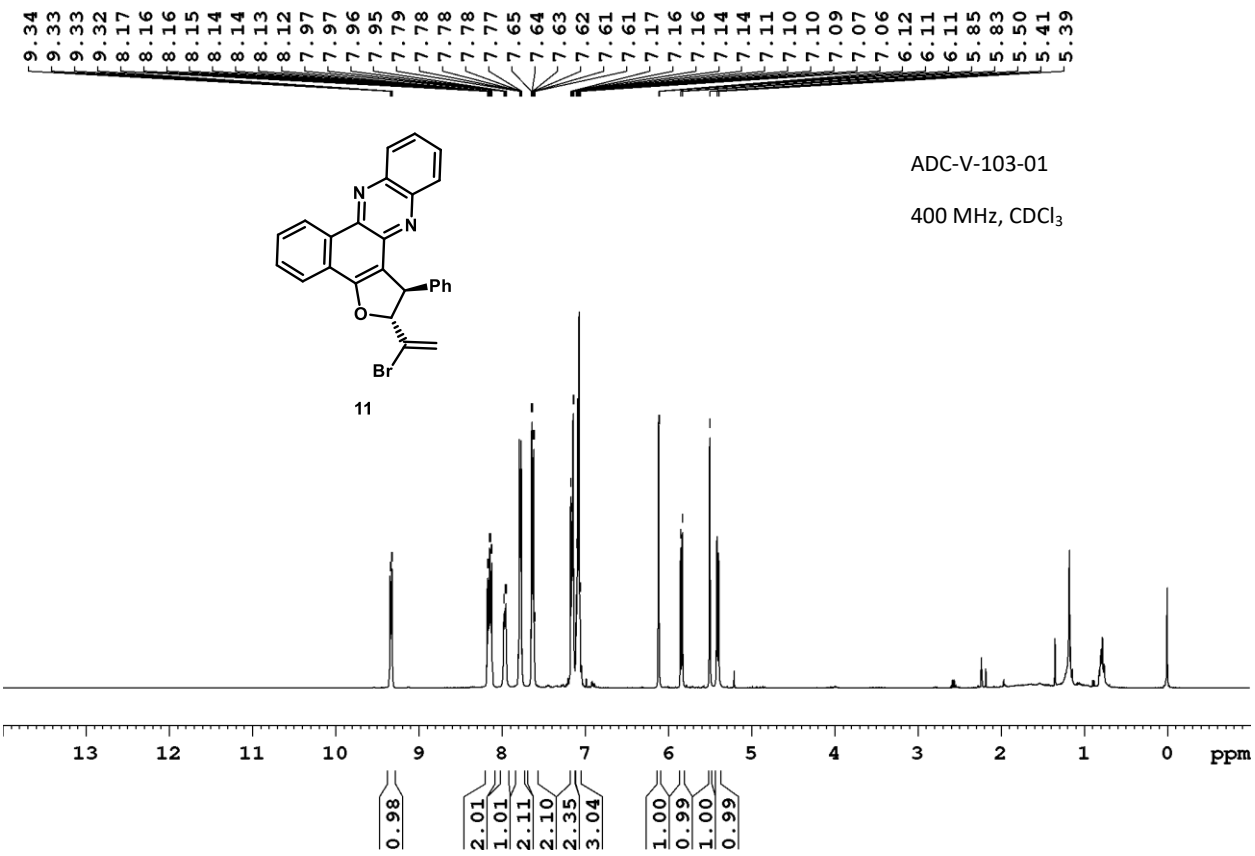


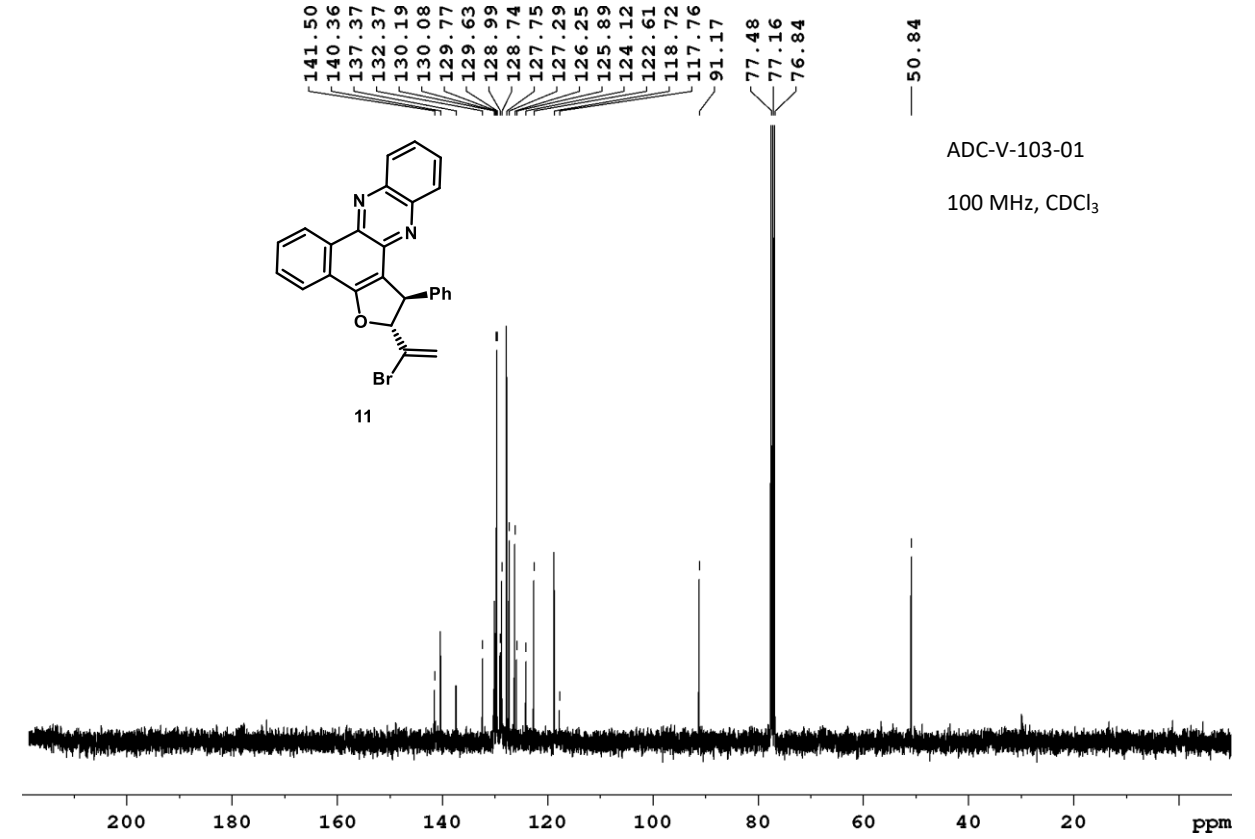
cis-**10**

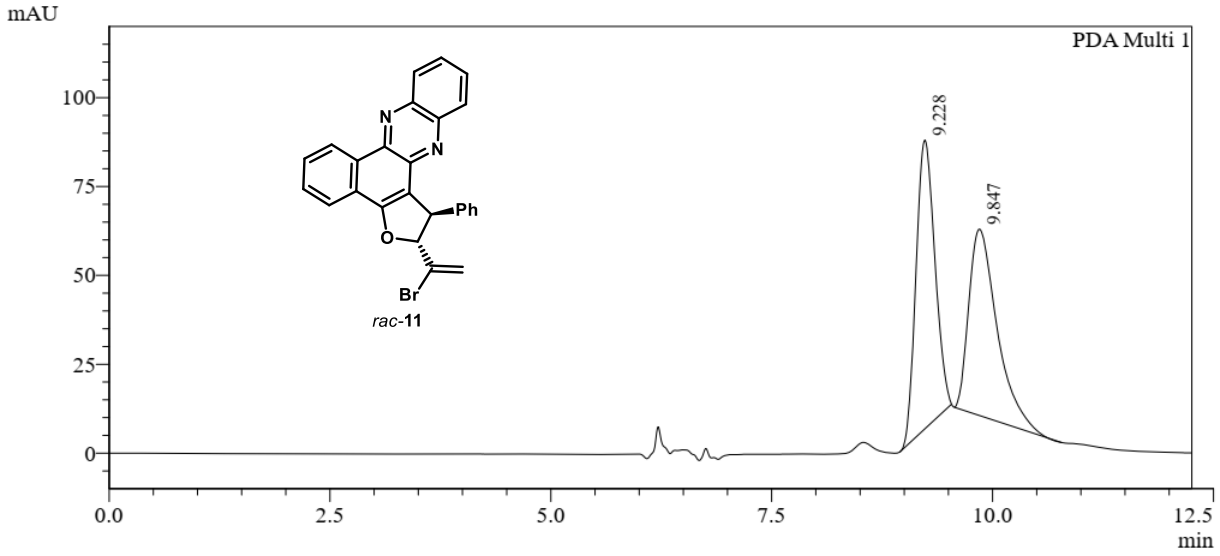
PeakTable

PDA Ch1 280nm 4nm

Peak#	Ret. Time	Area	Area %
1	22.046	3208381	100.000
Total		3208381	100.000


9.34 9.33 9.33 9.32 8.17 8.16 8.16 8.15 8.14 8.14 8.13 8.12 7.97 7.97 7.96 7.95 7.79 7.78 7.78 7.78 7.77 7.65 7.64 7.63 7.62 7.61 7.61 7.17 7.16 7.16 7.14 7.14 7.11 7.10 7.10 7.09 7.07 7.06 6.12 6.11 6.11 5.85 5.83 5.50 5.41 5.39
ADC-V-103-01
400 MHz, CDCl3
N
N
Ph
O
Br
11
13 12 11 10 9 8 7 6 5 4 3 2 1 0 ppm
0.98 2.01 1.01 2.11 2.10 2.35 3.04 1.00 0.99 1.00 0.99


141.50 140.36 137.37 132.37 130.19 130.08 129.77 129.63 128.99 128.74 127.75 127.29 126.25 125.89 124.12 122.61 118.72 117.76 91.17 77.48 77.16 76.84 50.84
ADC-V-103-01
100 MHz, CDCl3
N
N
Ph
O
Br
11
200 180 160 140 120 100 80 60 40 20 ppm

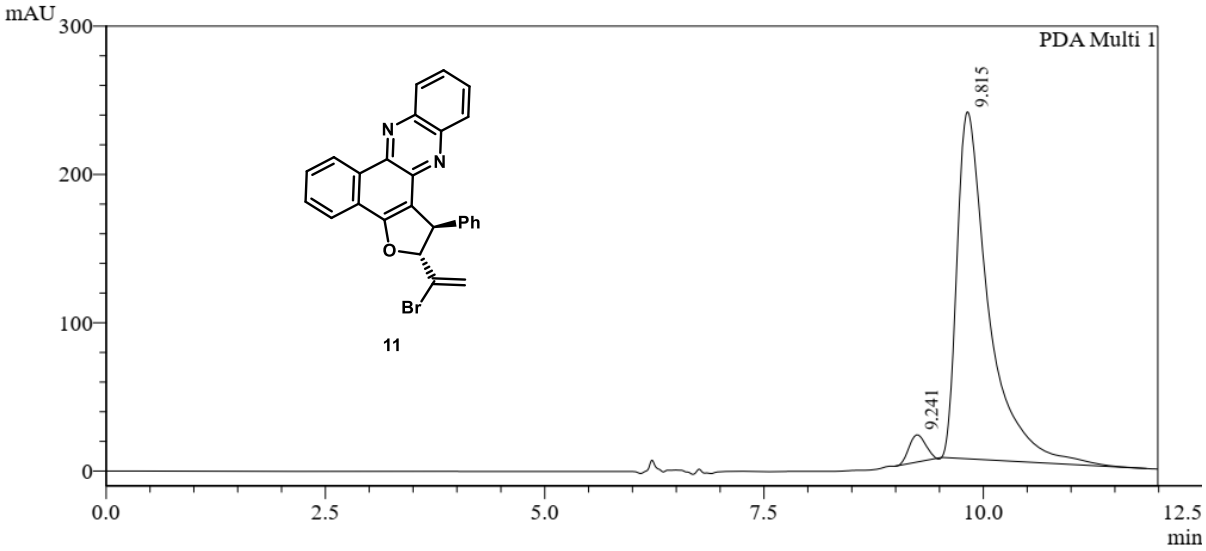


PeakTable

PDA Ch1 280nm 4nm

Peak#	Ret. Time	Area	Area %
1	9.228	1208287	50.857
2	9.847	1167575	49.143
Total		2375862	100.000

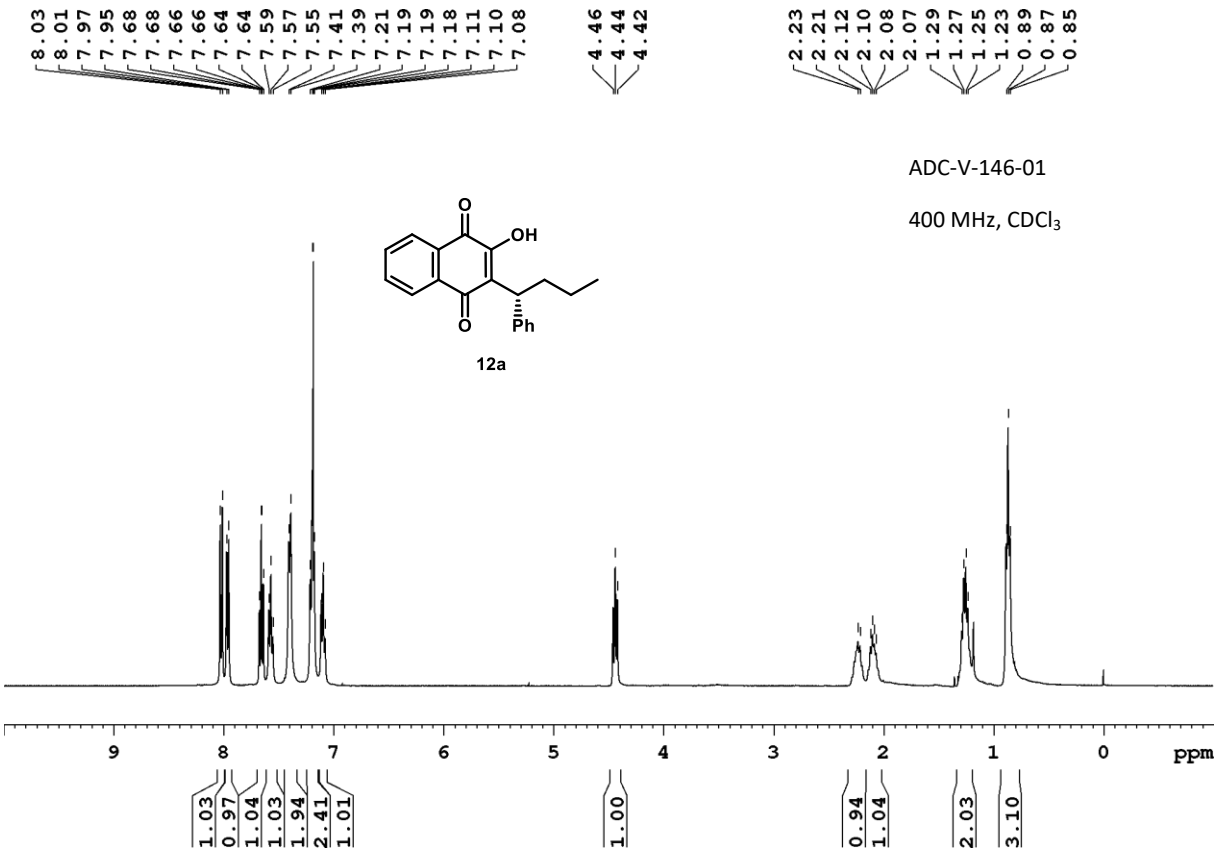
Phenomenex Amylose-2 column (95:5 *n*-Hexane/IPA, 0.5 mL/min, 20 °C)

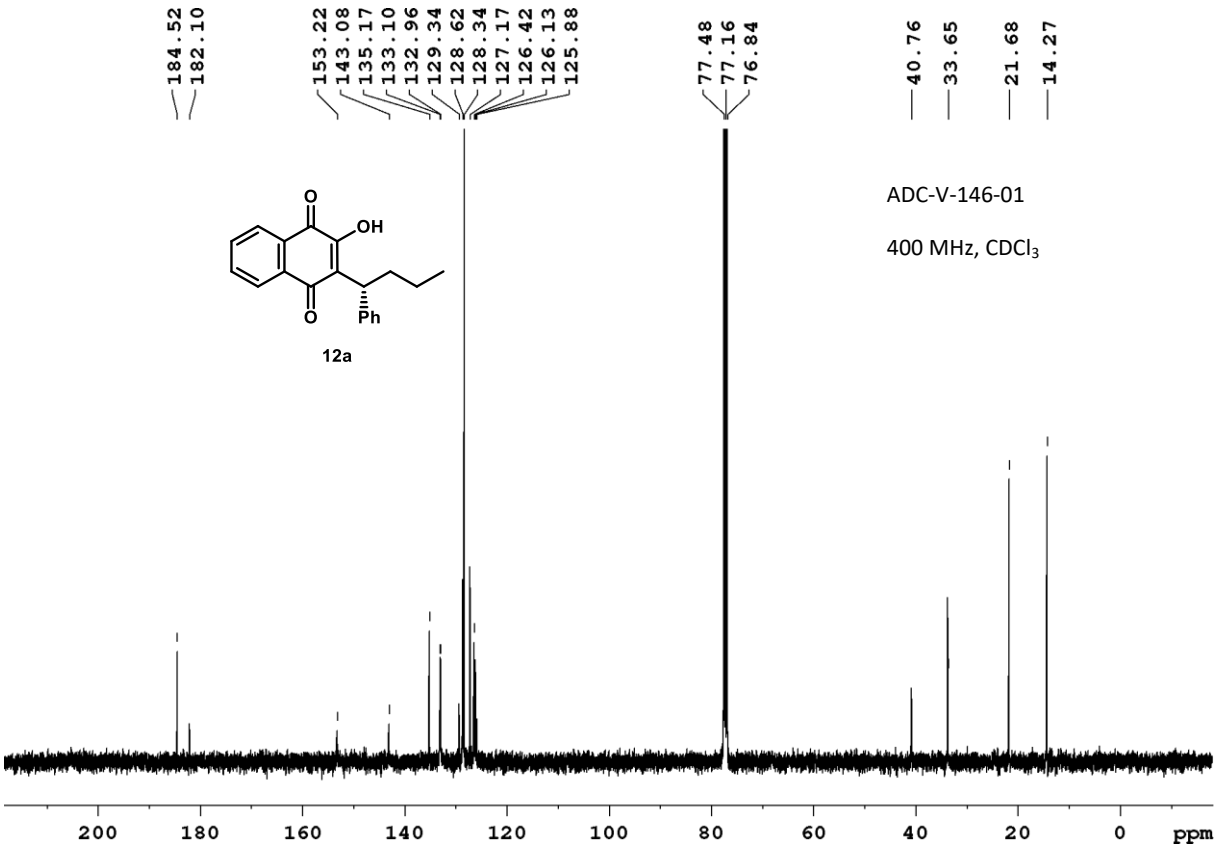


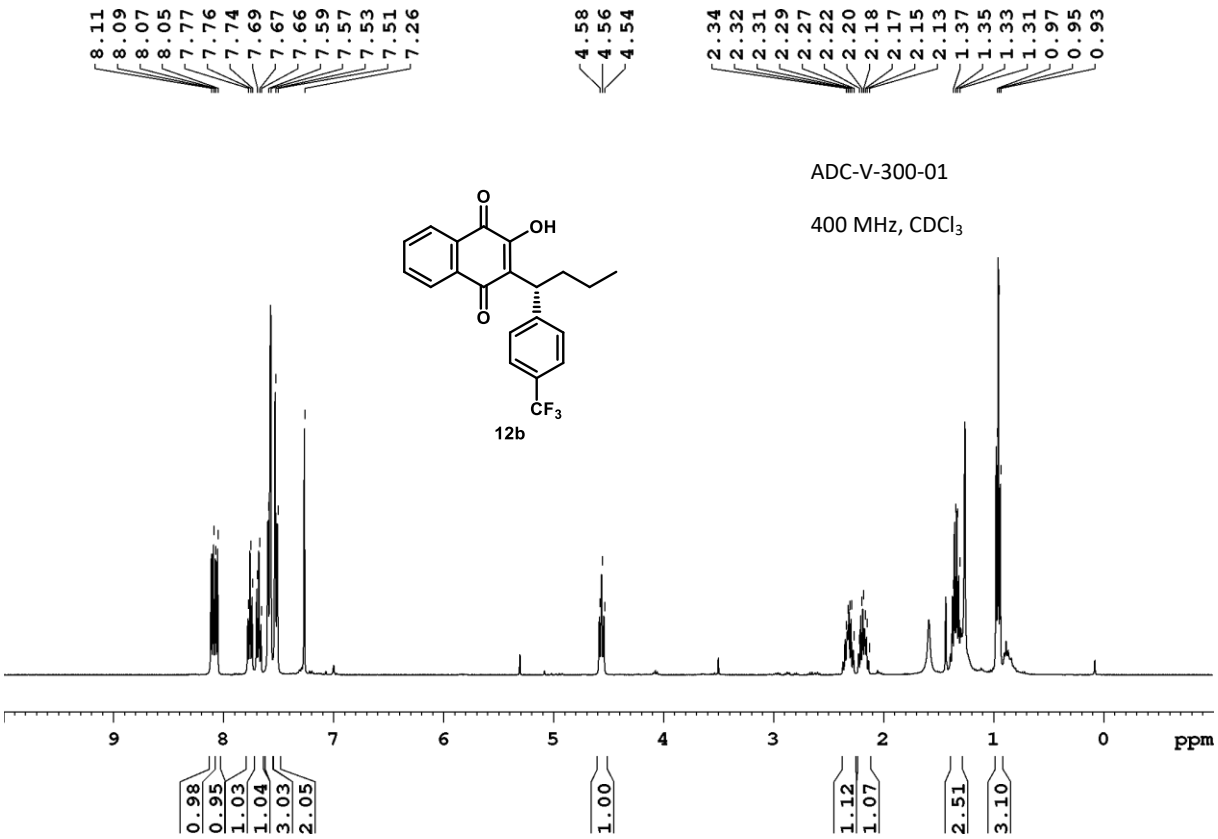
PeakTable

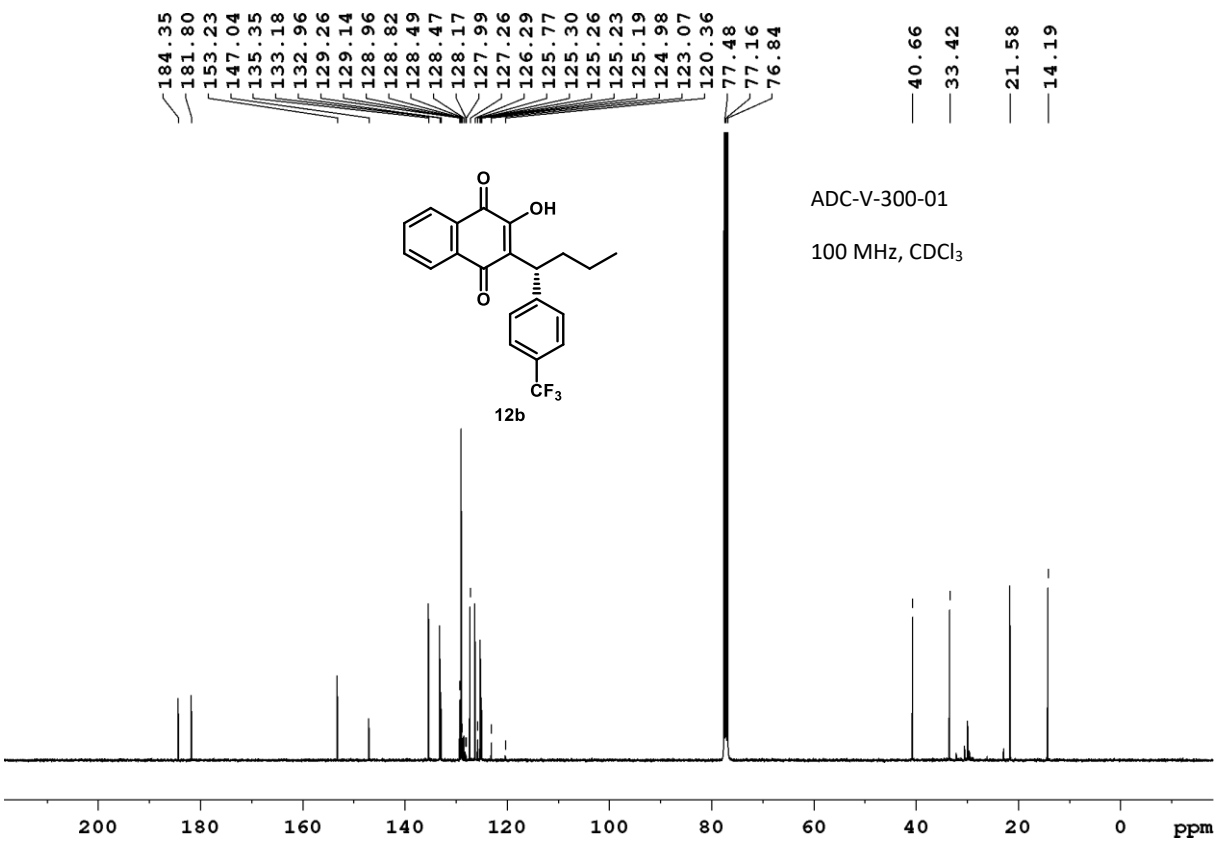
PDA Ch1 280nm 4nm

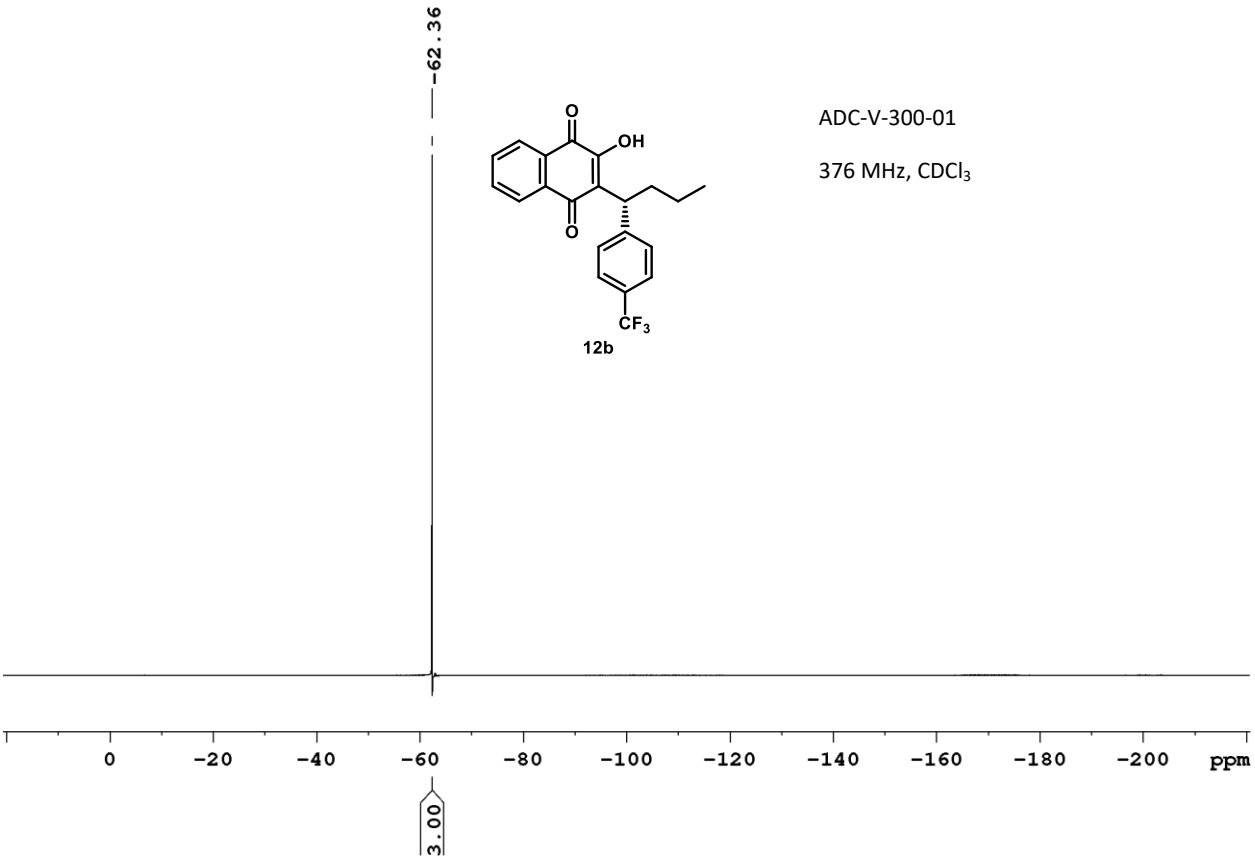
Peak#	Ret. Time	Area	Area %
1	9.241	241506	3.930
2	9.815	5903989	96.070
Total		6145494	100.000

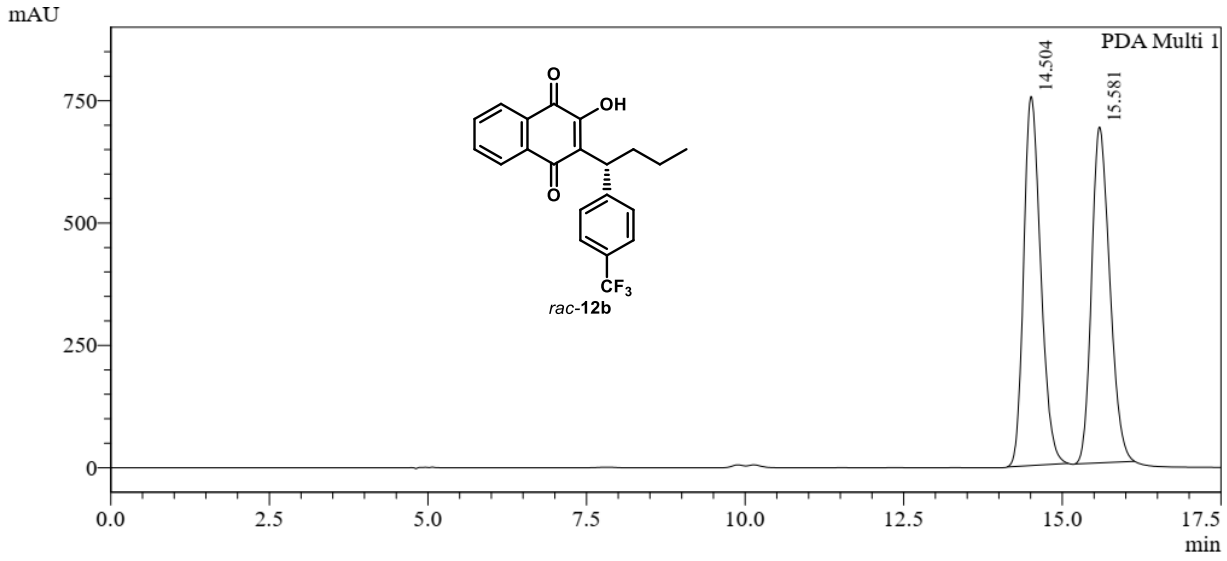

8.03
8.01
7.97
7.95
7.68
7.68
7.66
7.66
7.64
7.64
7.59
7.57
7.55
7.41
7.39
7.21
7.19
7.19
7.18
7.11
7.10
7.08
4.46
4.44
4.42
2.23
2.21
2.12
2.10
2.08
2.07
1.29
1.27
1.25
1.23
0.89
0.87
0.85
ADC-V-146-01
400 MHz, CDCl3
OH
O
O
Ph
12a
9
8
7
6
5
4
3
2
1
0
ppm
1.03
0.97
1.04
1.03
1.94
2.41
1.01
1.00
0.94
1.04
2.03
3.10


184.52
182.10
153.22
143.08
135.17
133.10
132.96
129.34
128.62
128.34
127.17
126.42
126.13
125.88
77.48
77.16
76.84
40.76
33.65
21.68
14.27
ADC-V-146-01
400 MHz, CDCl3
OH
O
O
Ph
12a
200
180
160
140
120
100
80
60
40
20
0
ppm


8.11
8.09
8.07
8.05
7.77
7.76
7.74
7.69
7.67
7.66
7.59
7.57
7.53
7.51
7.26
4.58
4.56
4.54
2.34
2.32
2.31
2.29
2.27
2.22
2.20
2.18
2.17
2.15
2.13
1.37
1.35
1.33
1.31
0.97
0.95
0.93
ADC-V-300-01
400 MHz, CDCl3
O
OH
O
CF3
12b
9
8
7
6
5
4
3
2
1
0
ppm
0.98
0.95
1.03
1.04
3.03
2.05
1.00
1.12
1.07
2.51
3.10


184.35
181.80
153.23
147.04
135.35
133.18
132.96
129.26
129.14
128.96
128.82
128.49
128.47
128.17
127.99
127.26
126.29
125.77
125.30
125.26
125.23
125.19
124.98
123.07
120.36
77.48
77.16
76.84
40.66
33.42
21.58
14.19
ADC-V-300-01
100 MHz, CDCl3
O
OH
O
CF3
12b
200
180
160
140
120
100
80
60
40
20
0
ppm


-62.36
O
OH
O
CF3
12b
ADC-V-300-01
376 MHz, CDCl3
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm
3.00

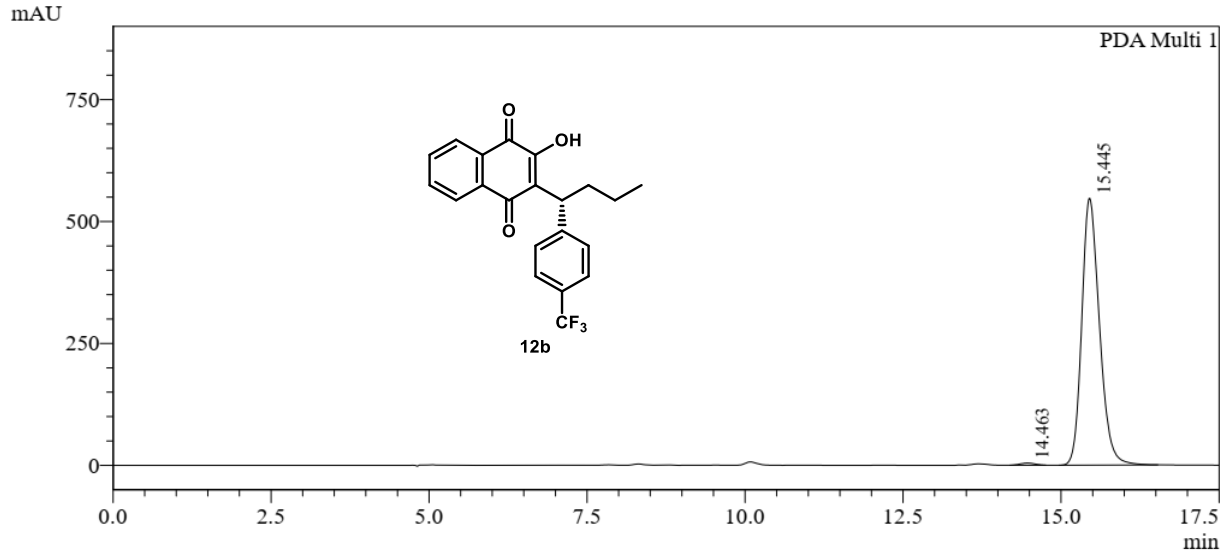


PeakTable

PDA Ch1 280nm 4nm

Peak#	Ret. Time	Area	Area %
1	14.504	14054502	50.657
2	15.581	13690027	49.343
Total		27744529	100.000

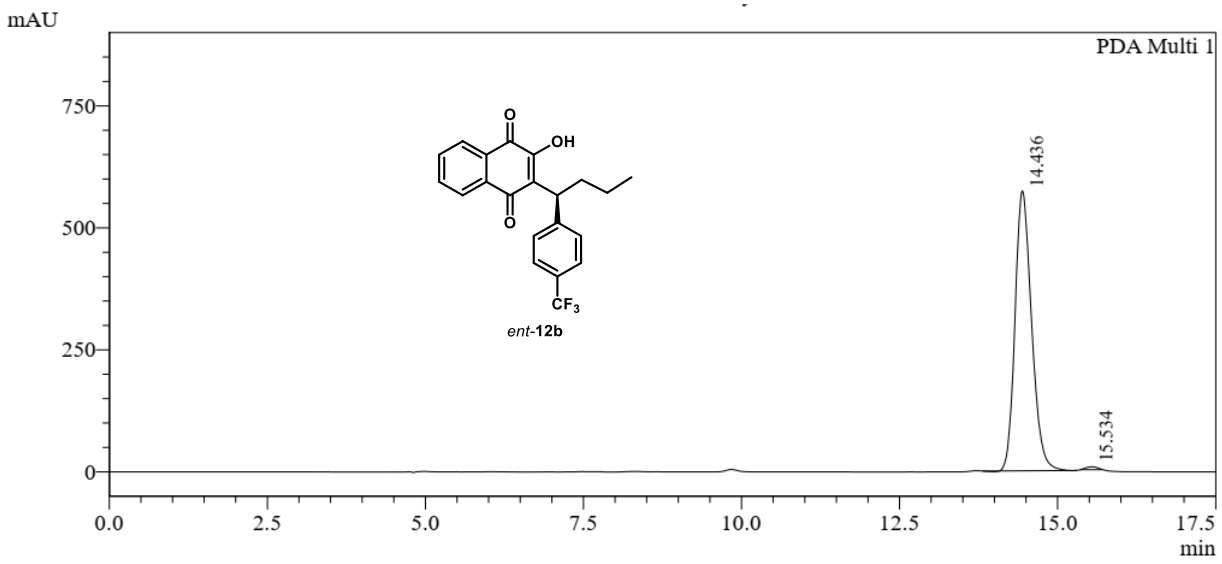
Daicel Chiralpak AD-H column (95:5 *n*-Hexane/IPA, 0.5 mL/min, 20 °C)



PeakTable

PDA Ch1 280nm 4nm

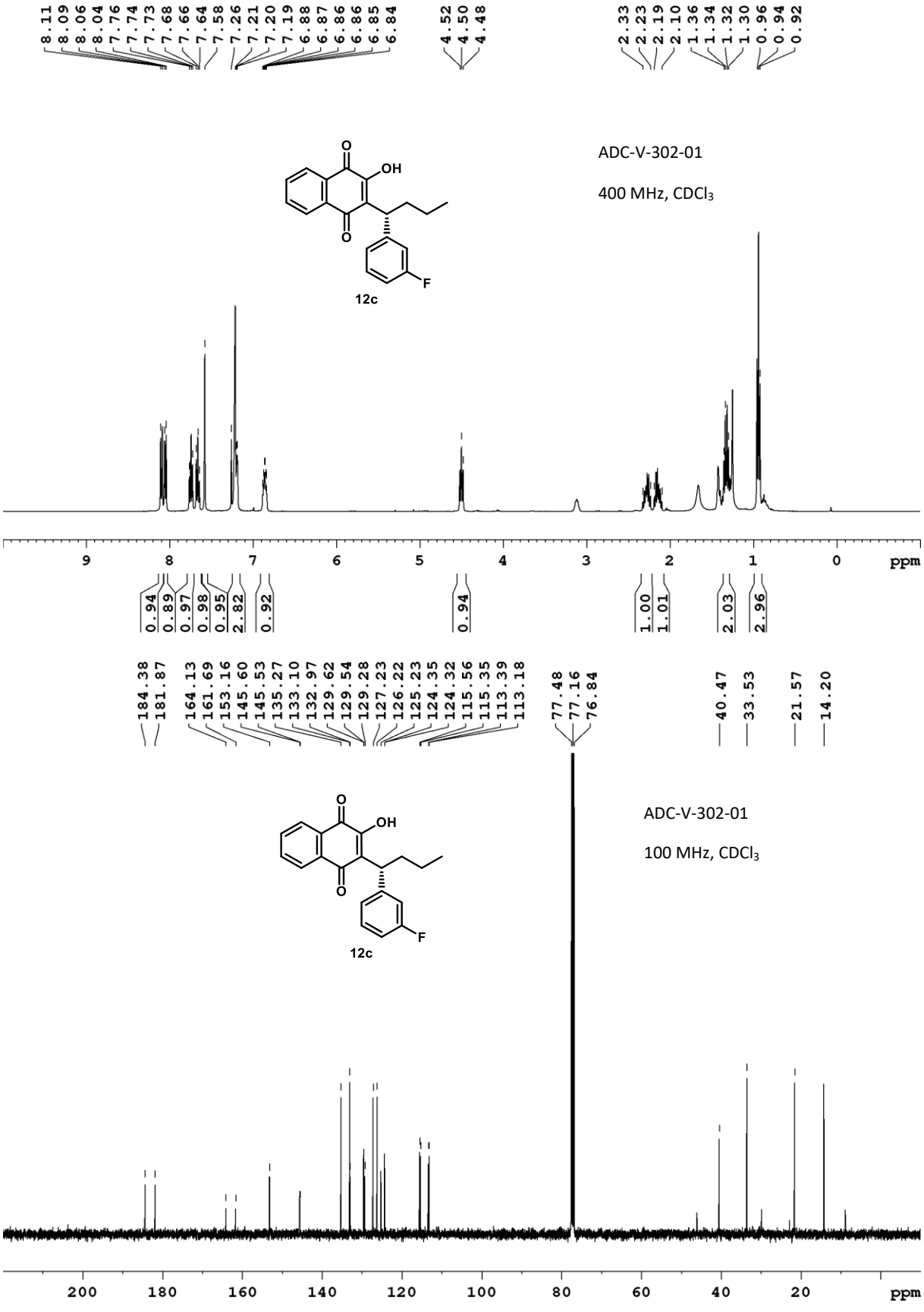
Peak#	Ret. Time	Area	Area %
1	14.463	70737	0.659
2	15.445	10656562	99.341
Total		10727299	100.000

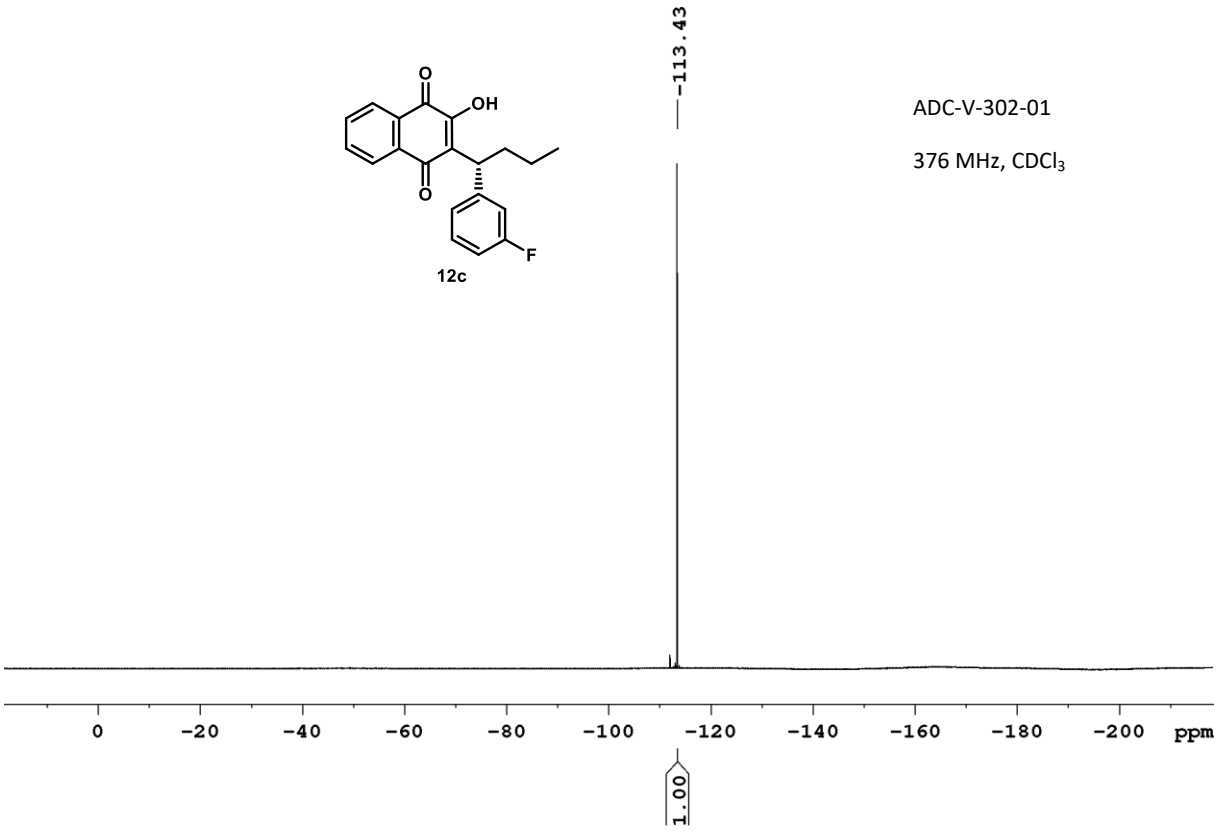


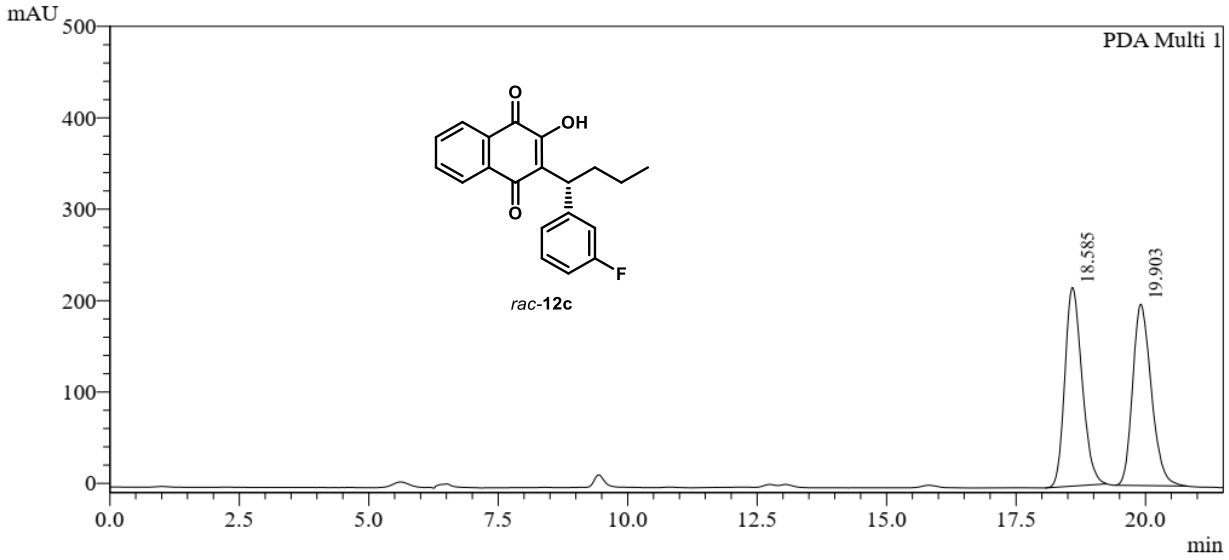
PeakTable

PDA Ch1 280nm 4nm

Peak#	Ret. Time	Area	Area %
1	14.436	10430144	99.282
2	15.534	75458	0.718
Total		10505602	100.000


8.11
8.09
8.06
8.04
7.76
7.74
7.73
7.68
7.66
7.64
7.58
7.26
7.21
7.20
7.19
6.88
6.87
6.86
6.86
6.85
6.84
4.52
4.50
4.48
2.33
2.23
2.19
2.10
1.36
1.34
1.32
1.30
0.96
0.94
0.92
O
OH
O
F
12c
ADC-V-302-01
400 MHz, CDCl3
9
8
7
6
5
4
3
2
1
0
ppm
0.94
0.89
0.97
0.98
0.95
2.82
0.92
0.94
1.00
1.01
2.03
2.96
184.38
181.87
164.13
161.69
153.16
145.60
145.53
135.27
133.10
132.97
129.62
129.54
129.28
127.23
126.22
125.23
124.35
124.32
115.56
115.35
113.39
113.18
77.48
77.16
76.84
40.47
33.53
21.57
14.20
O
OH
O
F
12c
ADC-V-302-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
ppm


-113.43
ADC-V-302-01
376 MHz, CDCl3
O
OH
O
F
12c
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm
1.00

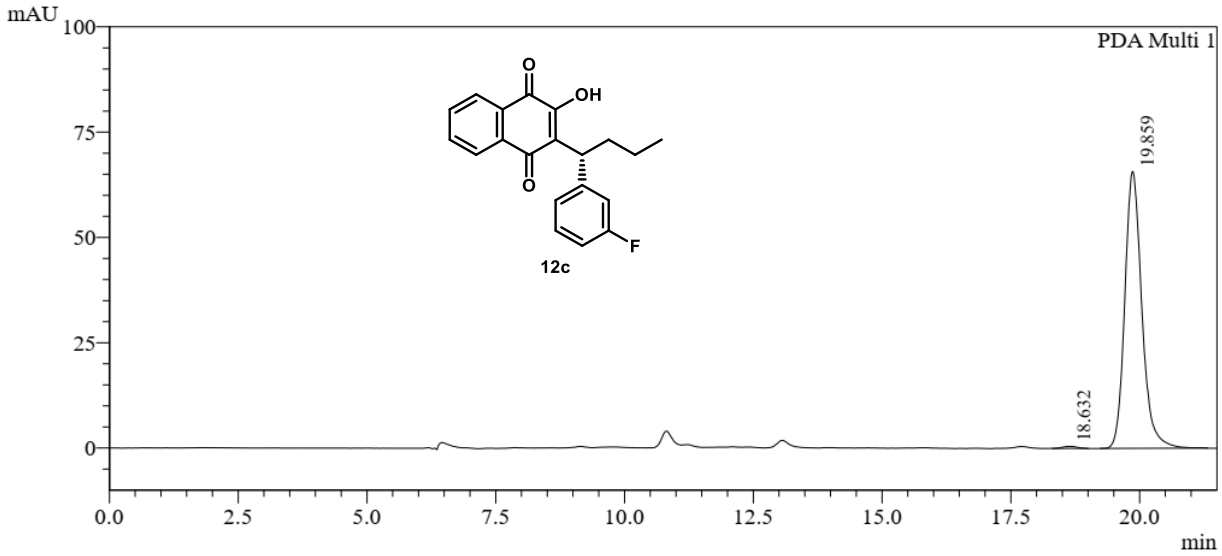


PeakTable

PDA Ch1 253nm 4nm

Peak#	Ret. Time	Area	Area %
1	18.585	5030124	50.214
2	19.903	4987348	49.786
Total		10017472	100.000

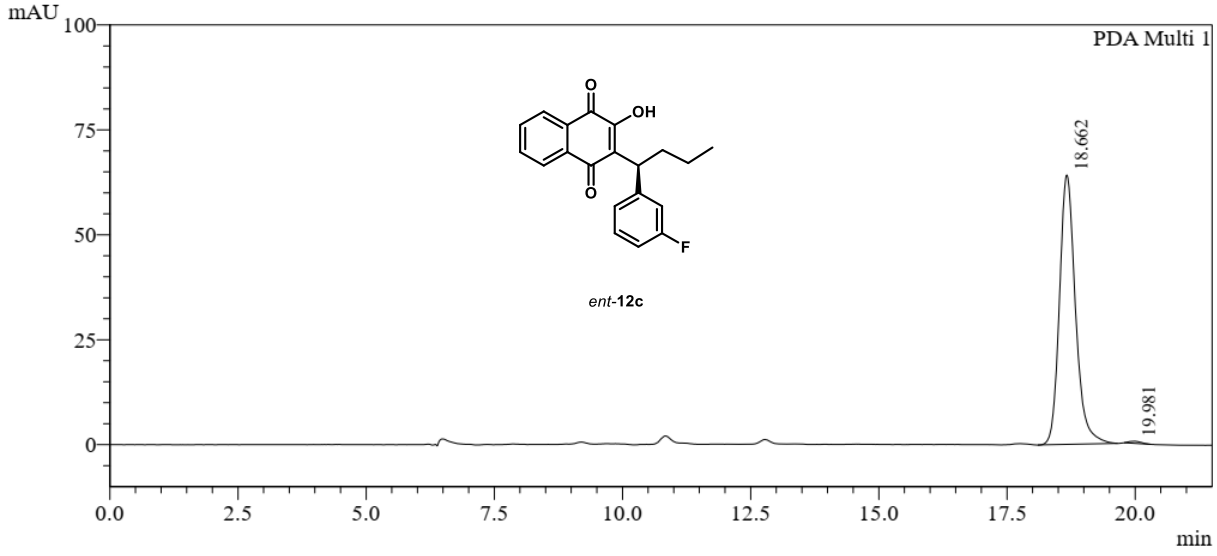
Daicel Chiralpak AD-H column (95:5 *n*-Hexane/IPA, 0.5 mL/min, 20 °C)



PeakTable

PDA Ch1 253nm 4nm

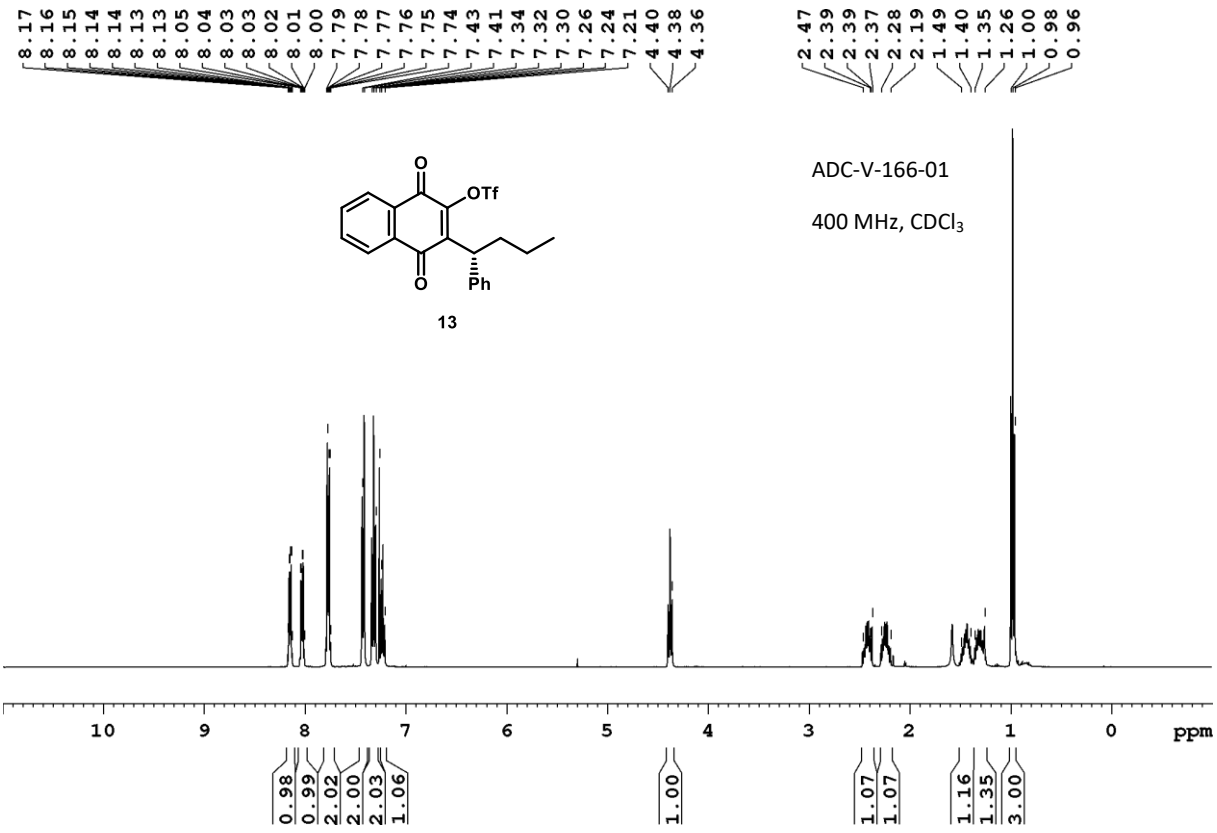
Peak#	Ret. Time	Area	Area %
1	18.632	9576	0.629
2	19.859	1513637	99.371
Total		1523212	100.000

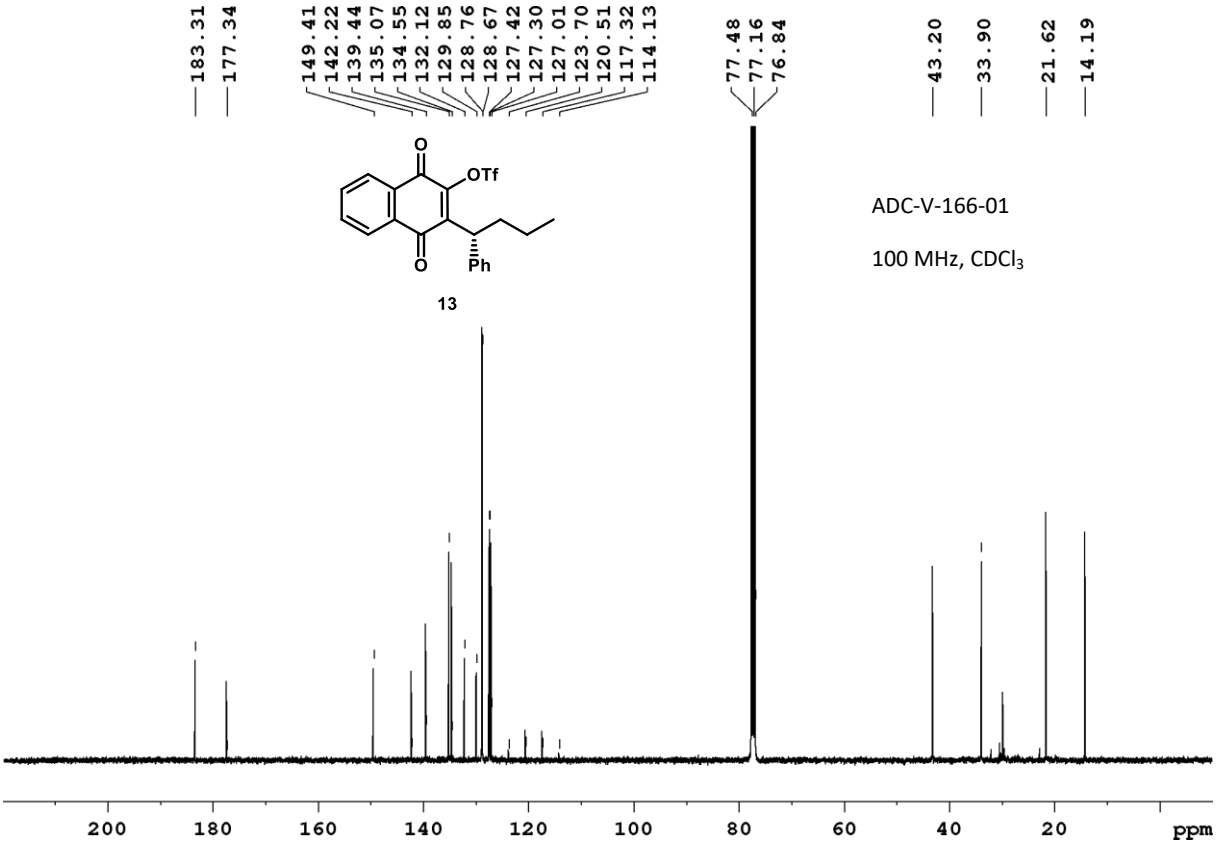


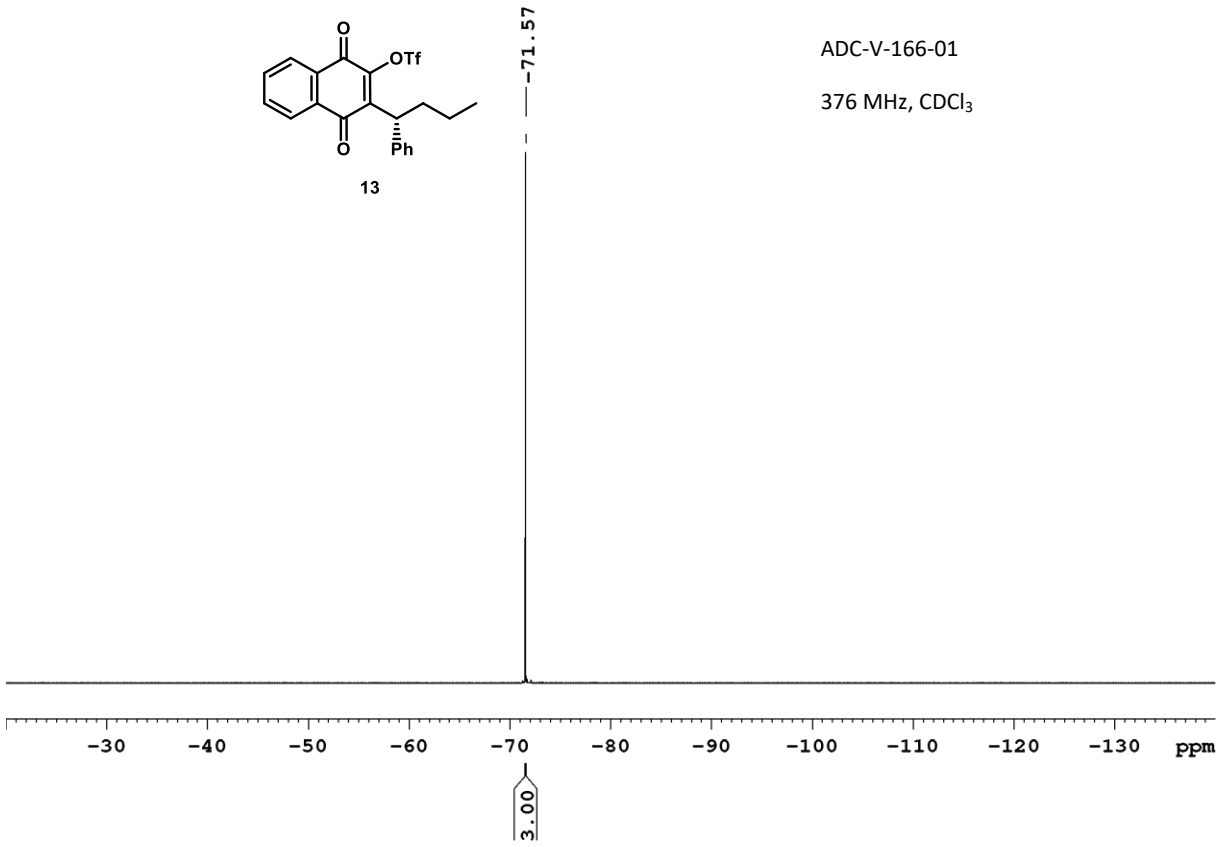
PeakTable

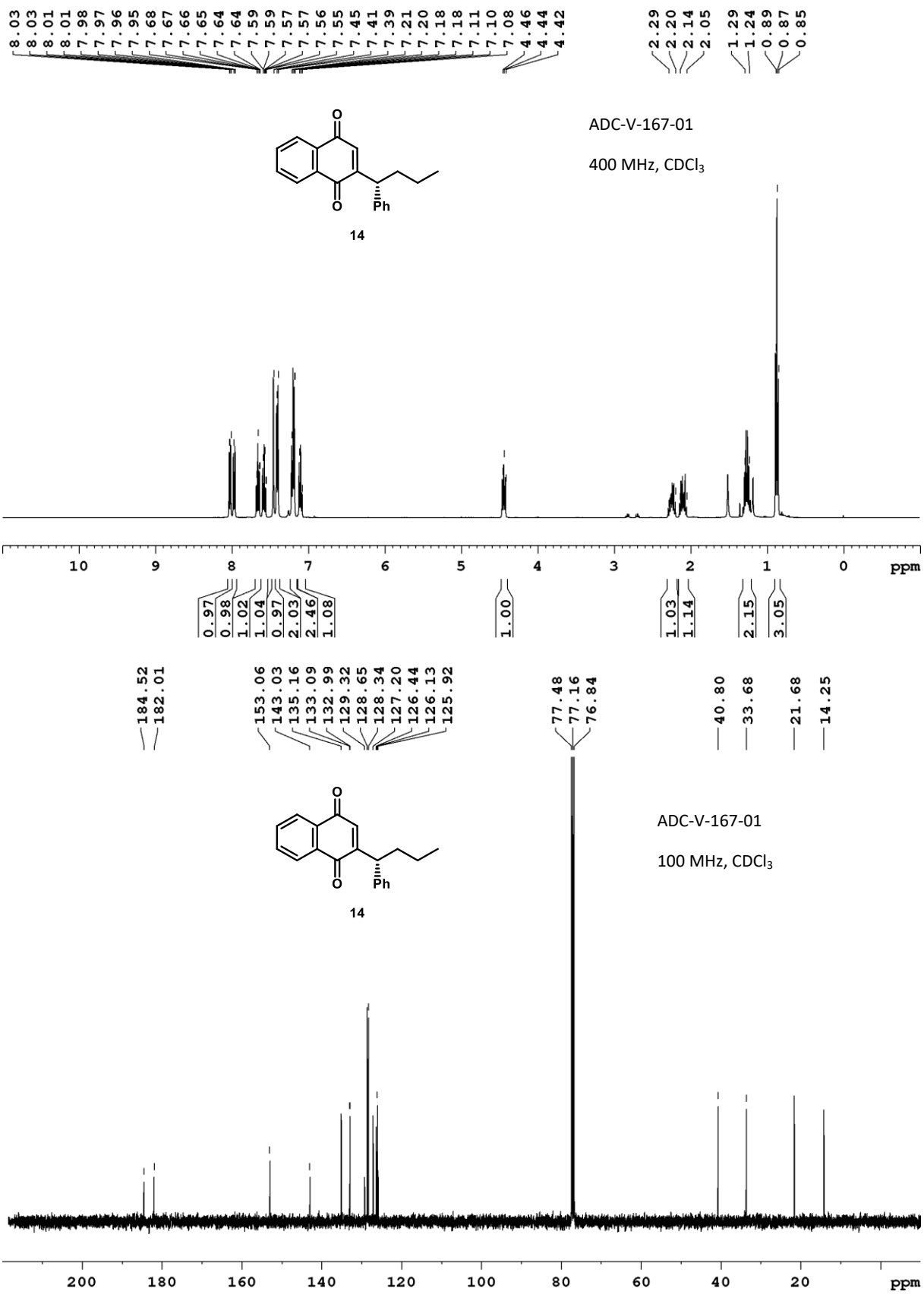
PDA Ch1 253nm 4nm

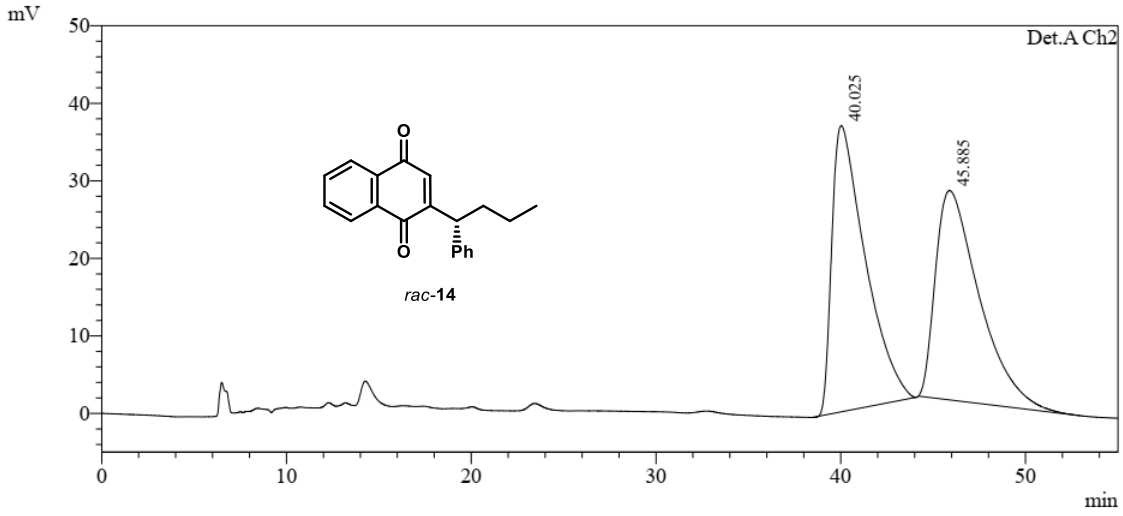
Peak#	Ret. Time	Area	Area %
1	18.662	1395540	99.419
2	19.981	8151	0.581
Total		1403691	100.000


8.17 8.16 8.15 8.14 8.14 8.13 8.13 8.05 8.04 8.03 8.03 8.02 8.01 8.00 7.79 7.78 7.77 7.76 7.75 7.74 7.43 7.41 7.34 7.32 7.30 7.26 7.24 7.21 4.40 4.38 4.36
2.47 2.39 2.39 2.37 2.28 2.19 1.49 1.40 1.35 1.26 1.00 0.98 0.96
OTf
O
Ph
13
ADC-V-166-01
400 MHz, CDCl3
10 9 8 7 6 5 4 3 2 1 0 ppm
0.98 0.99 2.02 2.00 2.03 1.06 1.00 1.07 1.07 1.16 1.35 3.00


183.31 177.34 149.41 142.22 139.44 135.07 134.55 132.12 129.85 128.76 128.67 127.42 127.30 127.01 123.70 120.51 117.32 114.13 77.48 77.16 76.84 43.20 33.90 21.62 14.19
OTf
O
Ph
13
ADC-V-166-01
100 MHz, CDCl3
200 180 160 140 120 100 80 60 40 20 ppm


O
OTf
O
Ph
13
-71.57
ADC-V-166-01
376 MHz, CDCl3
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
ppm
3.00

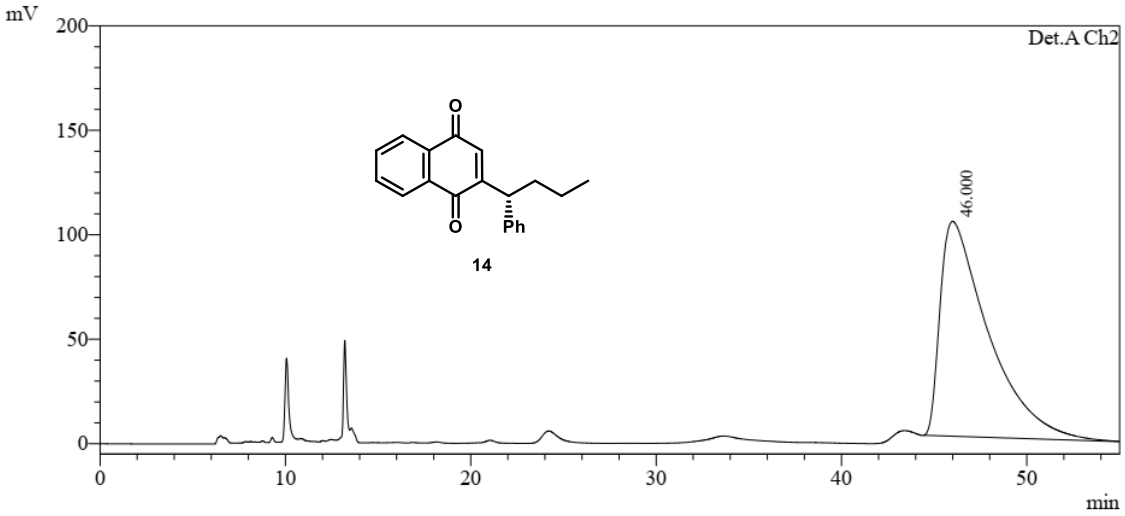

8.03
8.03
8.01
8.01
7.98
7.97
7.96
7.95
7.68
7.67
7.66
7.65
7.64
7.64
7.59
7.59
7.57
7.57
7.56
7.55
7.45
7.41
7.39
7.21
7.20
7.18
7.11
7.10
7.08
4.46
4.44
4.42
2.29
2.20
2.14
2.05
1.29
1.24
0.89
0.87
0.85
O
O
Ph
14
ADC-V-167-01
400 MHz, CDCl3
10
9
8
7
6
5
4
3
2
1
0
ppm
0.97
0.98
1.02
1.04
0.97
2.03
2.46
1.08
1.00
1.03
1.14
2.15
3.05
184.52
182.01
153.06
143.03
135.16
133.09
132.99
129.32
128.65
128.34
127.20
126.44
126.13
125.92
77.48
77.16
76.84
40.80
33.68
21.68
14.25
O
O
Ph
14
ADC-V-167-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
ppm



Detector A Ch2 254nm

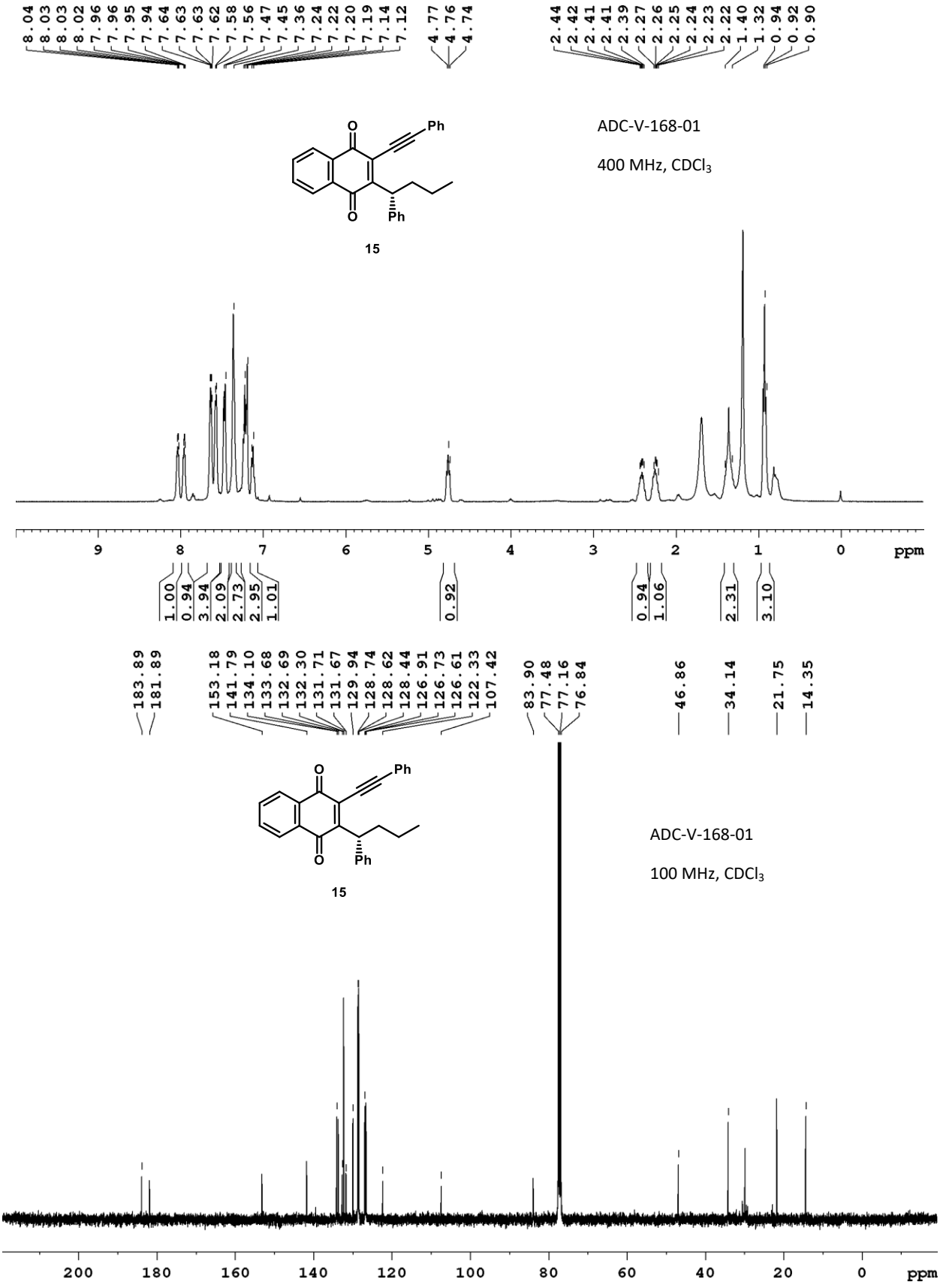
Peak#	Ret. Time	Area	Area %
1	40.025	4645109	51.002
2	45.885	4462520	48.998
Total		9107629	100.000

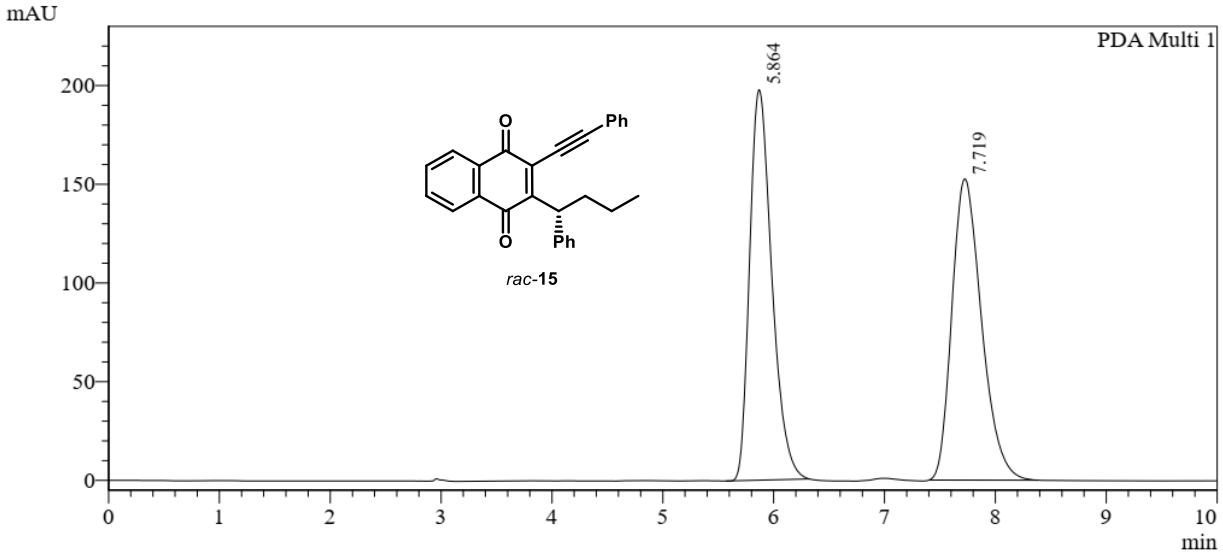
Phenomenex Cellulose-3column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)



Detector A Ch2 254nm

Peak#	Ret. Time	Area	Area %
1	46.000	18653712	100.000
Total		18653712	100.000


8.04
8.03
8.03
8.02
7.96
7.96
7.95
7.94
7.64
7.63
7.63
7.62
7.58
7.56
7.47
7.45
7.36
7.24
7.22
7.20
7.19
7.14
7.12
4.77
4.76
4.74
2.44
2.42
2.41
2.41
2.39
2.27
2.26
2.25
2.24
2.23
2.22
1.40
1.32
0.94
0.92
0.90
O
Ph
O
Ph
15
ADC-V-168-01
400 MHz, CDCl3
9
8
7
6
5
4
3
2
1
0
ppm
1.00
0.94
3.94
2.09
2.73
2.95
1.01
0.92
0.94
1.06
2.31
3.10
183.89
181.89
153.18
141.79
134.10
133.68
132.69
132.30
131.71
131.67
129.94
128.74
128.62
128.44
126.91
126.73
126.61
122.33
107.42
83.90
77.48
77.16
76.84
46.86
34.14
21.75
14.35
O
Ph
O
Ph
15
ADC-V-168-01
100 MHz, CDCl3
200
180
160
140
120
100
80
60
40
20
0
ppm

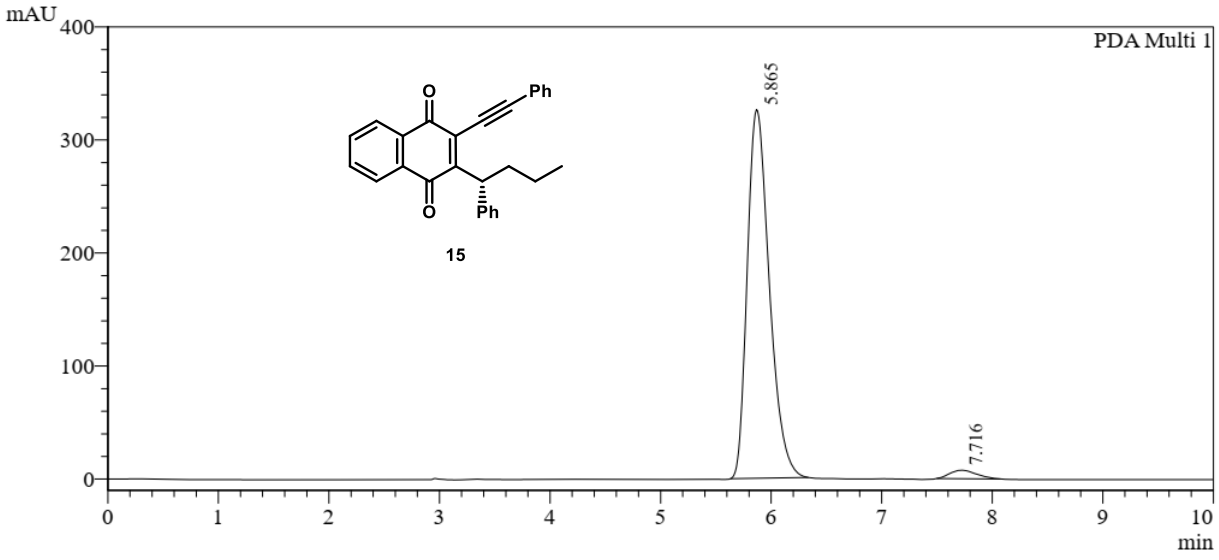


PeakTable

PDA Ch1 282nm 4nm

Peak#	Ret. Time	Area	Area %
1	5.864	2753625	49.204
2	7.719	2842764	50.796
Total		5596389	100.000

Daicel Chiralpak AD-H column (90:10 *n*-Hexane/IPA, 1.0 mL/min, 20 °C)



PeakTable

PDA Ch1 282nm 4nm

Peak#	Ret. Time	Area	Area %
1	5.865	4529210	97.285
2	7.716	126380	2.715
Total		4655590	100.000