Synthesis of (±)-Idarubicinone via Global Functionalization of Tetracene

David G. Dennis, Mikiko Okumura and David Sarlah*

Roger Adams Laboratory, Department of Chemistry, University of Illinois, Urbana, IL 61801, USA.

Table of Contents

I. General Procedures S2

II. Experimental Section S3

- Model Studies (Supplementary Table S1) S3
  - Synthesis of alcohol **S4** and boronic ester **S5** S3
- Synthesis of tetracene quinone **6** S5
- Synthesis of tetracene derivative **7** S5
- Synthesis of tetracene derivative **S6** S6
- Synthesis of boronic ester **10** via dearomative hydroboration S7
  - Images of experimental setup (Supplementary Photo S1) S8
- Synthesis of ketone **11** via Zweifel Olefination S8
- Synthesis of enone **12** S10
- The influence of N-substitution on Mukaiyama hydration (Supplementary Table S2) S11
- Synthesis of α-ketol **13** via Mukaiyama hydration S11
- Preparation of α-ketol **14** S12
- Optimization of final transformation of hydroquinone **14** (Supplementary Table S3) S13
- Preparation of (±)-idarubicinone (**4**) and 7-deoxyidarubicinone (**15**) S13
  - Images of experimental setup (Supplementary Figure S2) S15

III. References S15

IV. ^{1}H NMR and ^{13}C NMR Spectra S17

V. Crystallographic Data S41

I. General Procedures

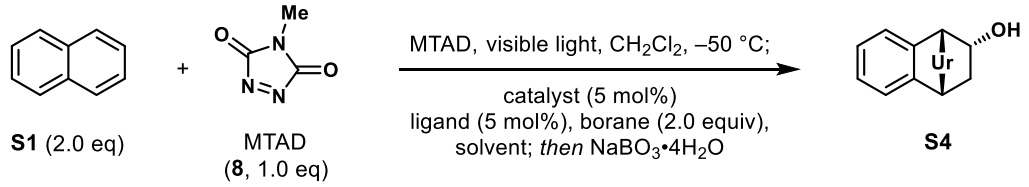
All reactions were performed under a nitrogen atmosphere in oven- or heat-gun-dried glassware unless otherwise indicated. Dichloromethane (ACS grade) and tetrahydrofuran (HPLC grade) were dried for reactions using the MB-SPS solvent purification system containing activated alumina manufactured by MBRAUN. Tetracene is commercially available from several vendors. However, for this study it was prepared via reduction of more affordable tetracenequinone (TCI America) and purified using sublimation.[1,2,3] $[Rh(cod)_2]BF_4$ was prepared following known proceedrues[4] from $[Rh(cod)Cl]_2$ purchased from Pressure Chemical. 1,4-Bis(diphenylphosphino)butane (dppb) was purchased from Oakwood Chemical. Pinacol hexahydrate was rendered anhydrous before use by azeotropic distillation with benzene followed by recrystallizing from benzene.[5] N-Methyl-1,2,4-triazoline-3,5-dione (MTAD) was prepared based on literature procedures.[6,7] The lights used for arene-arenophile cycloaddition were 4W LED corn bulbs (12V, cool white light, 6500K) which were wired to a suitable 12V power supply, then sealed into test tubes and capped with septa (see Photo S1). Catechol borane (HBcat) was prepared in two steps from catechol, boric acid, and borane dimethyl sulfide following literature procedures.[8] Tris(2,2,6,6-tetramethyl-3,5-heptanedionato)manganese(III) ($Mn(dpm)_3$) was purchased from Strem Chemicals. Isopropoxy(phenyl)silane ($Ph(i\text{PrO})SiH_2$) was prepared from phenylsilane ($PhSiH_3$) according to reported procedures.[9] Reaction temperatures correspond to the external temperature of the reaction vessel unless otherwise stated. Reactions were monitored by thin-layer chromatography (TLC) using 0.25 mm Macherey-Nagel silica gel plates (SIL G-25 UV_{254}). Plates were visualized by UV and visible light. Silicycle SiliaFlash® P60 (SiO_2, 40–63 μm particle size, 230–400 mesh) was used for flash column chromatography.

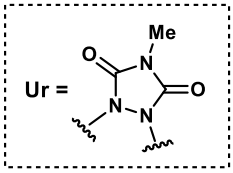
^1H NMR spectra were obtained at 500 MHz and ^{13}C NMR were obtained at 126 MHz. NMR spectra were recorded using a Bruker 500 MHz spectrometer and were referenced to residual chloroform (7.26 ppm, ^1H; 77.16 ppm, ^{13}C) or residual deuterated dimethylsulfoxide (2.50 ppm, ^1H; 39.52 ppm, ^{13}C). Chemical shifts are reported in parts per million (ppm) and multiplicities are as indicated: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), and br (broad). Coupling constants, J, are reported in Hertz (Hz). High resolution mass spectrometry (HRMS) data were collected by the University of Illinois Mass Spectrometry Laboratory using electrospray ionization (ESI) and a time-of-flight (TOF) mass analyzer. Data are reported in the form of m/z. Infrared (IR) spectra were measured neat on a Perkin-Elmer Spectrum Two FT-IR spectrometer. Peaks are reported in cm^{-1} with indicated relative intensities: s (strong, 0–33% T); m (medium, 34–66% T), w (weak, 67–100% T), and br (broad). Melting points were measured on a Buchi B-540 melting point apparatus and are uncorrected. The X-ray diffraction experiments were conducted using Bruker D8 Venture/Photon 100 diffractometer or Bruker APEX-II CCD diffractometer. Using Olex2,[10] the structures were solved with ShelXT[11] structure solution program using the intrinsic phasing solution method, and the XL refinement package using least squares minimization.

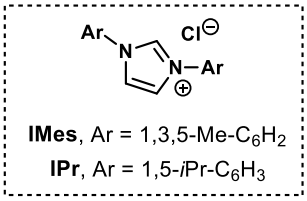
II. Experimental Section

Model Studies: Arenophile-Assisted Dearomative Hydroboration

Table S1: Optimization of dearomative hydroboration:



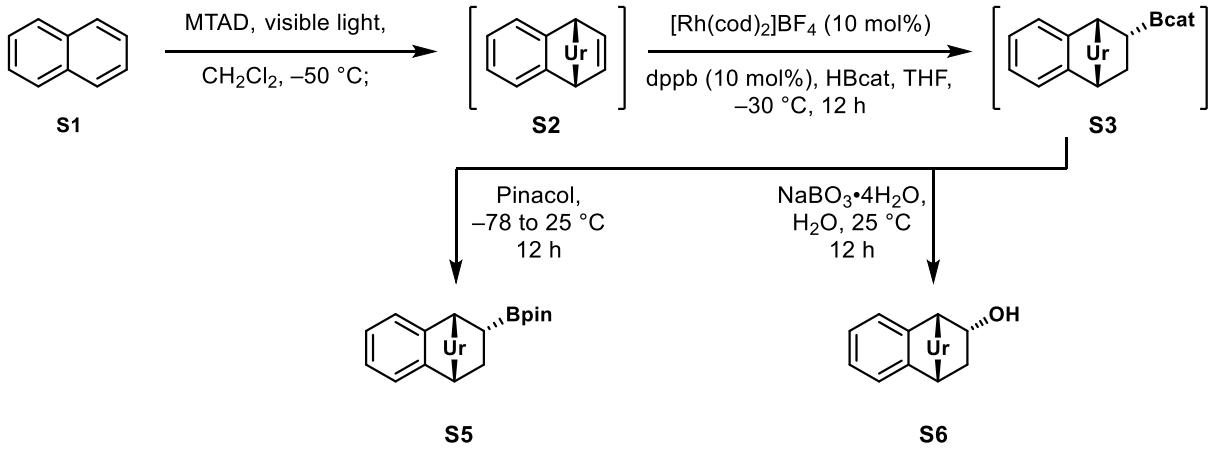




entry	*catalyst*	*borane*	*solvent*	*ligand*	*additive*	*yield*
1[a]	CuCl	B_2pin_2	THF	dppp	LiO*t*Bu/MeOH	*<5%*
2[a]	CuCl	B_2pin_2	Toluene	IMes	KO*t*Bu/MeOH	*<5%*
3[a]	CuCl	B_2pin_2	Toluene	IPr	KO*t*Bu/MeOH	*<5%*
4	$[Rh(COD)Cl]_2$	HBcat	THF	dppp	-	*15%*
5	$[Rh(COD)Cl]_2$	HBcat	THF	dppb	-	*25%*
6	$[Rh(COD)Cl]_2$	HBpin	THF	dppb	-	*<5%*
7[b]	$[Rh(COD)Cl]_2$	HBcat	THF	dppb	$AgBF_4$	*30%*
8[b]	$[Rh(COD)Cl]_2$	HBcat	THF	dppb	AgOTf	*<5%*
9	$[Rh(COD)_2]BF_4$	HBcat	THF	dppb	-	*52%*
10[c]	$[Rh(COD)_2]BF_4$	HBcat	THF	dppb	-	*73%*

a.*5 mol% alkoxide and 2.0 equiv MeOH.* ***b.****5 mol% additive* ***c.****10 mol% catalyst and ligand used.*

Synthesis of alcohol **S4** and boronic ester **S5**:



Naphthalene **S1** (113.3 mg, 0.88 mmol, 2.0 equiv.) and MTAD (**8**, 50.0 mg, 0.44 mmol, 1.0 equiv.) were added to a test tube, which was sealed with a septum and evacuated/purged with nitrogen gas three times. Then CH_2Cl_2 (4.4 mL, 0.10 M) was added, and the reaction was cooled to –50 ºC and irradiated with visible

light. Upon decolorization, the LED lights were turned off and THF was added (4.4 mL, 0.10 M) followed by a solution of $[Rh(cod)_2]BF_4$ (18.0 mg, 44 µmol, 10 mol%) and dppb (18.9 mg, 44 µmol, 10 mol%) in CH_2Cl_2 (0.5 mL). HBcat (95 µL, 0.88 mmol, 2.0 equiv.) was added in a dropwise fashion over two minutes, and the temperature was adjusted to –30 ºC for 12 h, resulting in the formation of **S3**. Catechol ester **S3** could be oxidized with sodium perborate tetrahydrate to give the corresponding alcohol **S4** by preparing a suspension of $NaBO_3•4H_2O$ (680.3 mg, 4.4 mmol, 10 equiv.) in H_2O (8.8 mL), and directly adding the entire reaction mixture to the suspension, followed by 12 h of vigorous stirring. The reaction was then extracted with EtOAc, dried over anhydrous magnesium sulfate, and concentrated under reduced pressure. Purification *via* flash chromatography (SiO_2, EtOAc:hexanes = 1:2) afforded the alcohol **S4** as a white solid (84.2 mg, 0.32 mmol, 73%).

mp: 219.4 – 220.2 ºC;

R_f = 0.16 (EtOAc:hexanes, 1:2 v/v)

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.35 – 7.43 (m, 3H), 7.29 – 7.33 (m, 1H), 5.25 – 5.28 (m, 2H), 4.59 – 4.64 (dt, J = 7.6, 2.7, 2.7, 1H), 2.80 – 2.86 (m, 4H), 1.96 (br, 1H), 1.49 (dt, J = 14.0, 2.7, 2.7 Hz, 1H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 156.9, 156.6, 135.1, 130.9, 129.7, 129.2, 126.9, 123.5, 65.0, 58.3, 53.3, 36.5, 25.5

IR (ATR, cm^{-1}): 3402 (br), 2947 (w), 2931 (w), 1768 (m), 1701 (s), 1461 (s), 1396 (w), 1091 (w), 759 (m), 548 (m)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{13}H_{14}N_3O_3$, 260.1032; found, 260.1036.

Alternatively, a solution of pinacol in THF (440 µL, 2 M, 2.0 equiv.) was added to the reaction mixture containing **S3** at –30 ºC. and the solution was warmed to room temperature slowly over the course of 12 h. The mixture was diluted with saturated NaCl, extracted with EtOAc, combined organic phases dried over $MgSO_4$, and concentrated under reduced pressure. Purification *via* flash chromatography (SiO_2, Et_2O:hexanes = 1:4) afforded the boronic ester **S5** as a white solid (120 mg, 0.32 mmol, 72%), which was readily crystallized from Et_2O.

mp: 148.7 – 150.0 ºC

R_f = 0.56 (EtOAc:hexanes, 1:2 v/v)

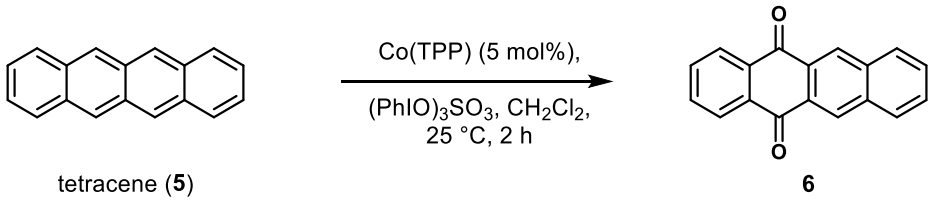
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.23 – 7.32 (m, 4H), 5.43 (d, J = 2.8 Hz, 1H), 5.28 (dd, J = 3.1, 2.6 Hz, 1H), 2.83 (s, 3H), 2.47 (ddd, J = 13.3, 10.6, 3.1 Hz, 1H), 2.11 (ddd, J = 10.6, 4.9, 2.8 Hz, 1H), 1.82 (ddd, J = 13.3, 4.9, 2.6 Hz, 1H), 1.04 (s, 6H), 0.98 (s, 6H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 157.1, 156.7, 135.3, 134.8, 128.7, 128.3, 124.3, 123.4, 84.1, 55.4, 54.2, 26.1, 25.3, 24.8, 24.6, 20.5

IR (ATR, cm^{-1}): 2978 (w), 1769 (w), 1710 (s), 1452 (m), 1372 (m), 1332 (m), 1141 (m)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{19}H_{25}N_3O_4B$, 370.1933; found, 370.1935.

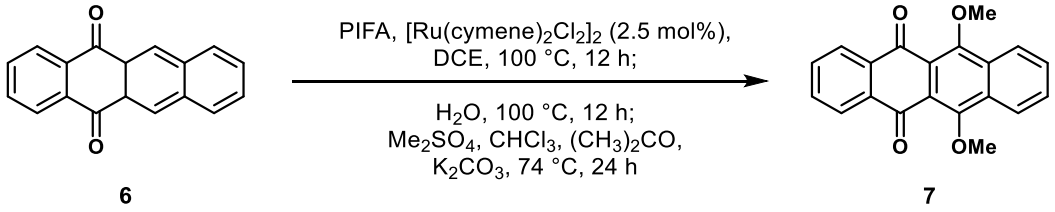
Synthesis of tetracenequinone **6**:



tetracene (**5**) **6**

Tetracene (**5**) (200.0 mg, 876 μmol, 1.0 equiv.), cobalt tetraphenylporphyrin (CoTPP, 29.4 mg, 43.8 μmol, 5 mol%), and $(PhIO)_3SO_3$ (1.62 g, 2.19 mmol, 2.5 equiv.) were combined with in a round-bottom flask purged with nitrogen. Then CH_2Cl_2 (30 mL, 0.03 M) was added and the flask was stirred at 25 ºC for 2 h. The resulting dark solution was filtered through a pad of silica gel using ethyl acetate as an eluent, and the solvent was removed *in vacuo.* The crude yellow-orange solid was purified *via* flash chromatography (SiO_2, CH_2Cl_2:hexanes = 7:3) to afford the title compound **6** as a yellow-orange solid (173.4 mg, 670 μmol, 77%). All spectroscopic data were consistent with those previously reported.[12] This compound is commercially available from several vendors.

Synthesis of tetracene derivative **7**:



6 **7**

Tetracenequinone (**6**, 250.0 mg, 967 μmol, 1.0 equiv.), $[Ru(p\text{-cymene})Cl_2]_2$ (14.8 mg, 24.2 μmol, 2.5 mol%), and (bis(trifluoroacetoxy)iodo)benzene (PIFA, 1.04 g, 2.42 μmol, 2.5 equiv.) were combined in a vial and purged with nitrogen. Dichloroethane (DCE, 390 μL, 2.5 M) was added and the vial and was heated to 100 ºC for 12 h. After cooling the resulting purple solution to room temperature, the reaction was charged with H_2O (349 μL, 19.36 mmol, 20 equiv.) and heated to 100 ºC for 12 h. After cooling the mixture to room temperature, the solvents were removed under reduced pressure, and potassium carbonate (K_2CO_3, 2.68 g, 19.36 mmol, 20 equiv.) was added to the dark red gum. The mixture was purged with nitrogen for 30 min followed by the addition of acetone (4.8 mL), chloroform (4.8 mL) and dimethyl sulfate (1.8 mL, 19.36 mmol, 20 equiv.). The resulting mixture was then heated to 74 ºC for 24 h. After cooling, the orange solution was filtered, the insoluble residue was washed with CH_2Cl_2, and the solvent was removed under reduced

pressure. The crude orange solid was purified *via* flash chromatography (SiO_2, CH_2Cl_2:hexanes = 7:3) to afford the title compound **7** as a yellow solid (118.6 mg, 407 μmol, 42%).

mp: 187–189 ºC (lit.[13] 188 ºC)

R_f = 0.70 (CH_2Cl_2:hexanes, 7:1 v/v)

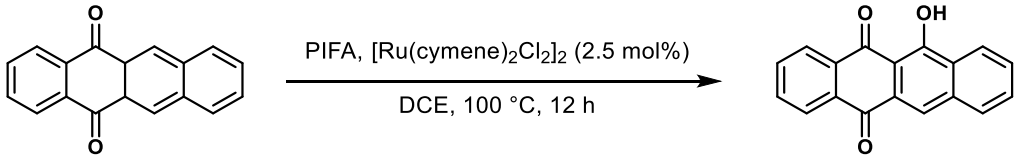
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.40 – 8.42 (m, 2H), 8.25 – 8.27 (m, 2H), 7.73 – 7.75 (m, 4H), 4.13 (s, 6H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 182.9, 156.0, 135.1, 133.7, 132.9, 130.1, 126.9, 124.9, 120.9, 63.3

IR (ATR, cm^{-1}): 2935 (w), 2852 (w), 1666 (s), 1596 (m), 1400 (m), 1349 (s), 1272 (s), 1041 (m), 726 (s)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{20}H_{15}O_4$, 319.0965; found, 319.0970.

Control experiment: Synthesis of tetracene derivative **S6**:



6 **S6**

Tetracenequinone (**6**) (250.0 mg, 967 μmol, 1.0 equiv.), [Ru(*p*-cymene)Cl_2]$_2$ (14.8 mg, 24.2 μmol, 2.5 mol%), and (bis(trifluoroacetoxy)iodo)benzene (PIFA, 1.04 g, 2.42 μmol, 2.5 equiv.) were combined in a vial and purged with nitrogen. Dichloroethane (DCE, 390 μL, 2.5 M) was added and the vial and was heated to 100 ºC for 12 h. After cooling the resulting purple solution to room temperature, water was added and resulting mixture was extracted with CH_2Cl_2 (3×30 mL). The combined organic layers were dried with $MgSO_4$ and the solvent was removed under reduced pressure. The crude orange solid was purified *via* flash chromatography (SiO_2, CH_2Cl_2:hexanes = 7:3) to afford the title compound **S6** as an orange solid (96.2 mg, 351 μmol, 36%).

mp: 312.6 – 313.6 ºC (lit.[14] 306 ºC)

R_f = 0.33 (CH_2Cl_2:hexanes, 7:1 v/v)

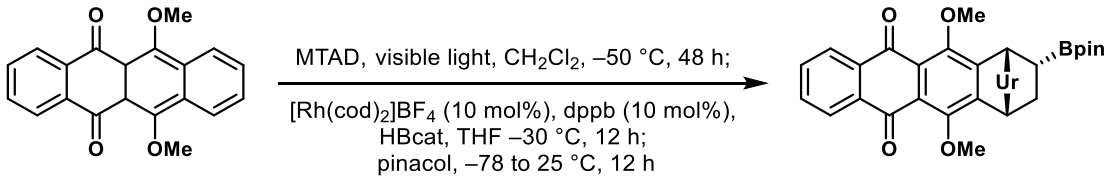
^{1}H NMR (500 MHz, $CDCl_3$): δ 14.57 (s, 1H), 8.54 (d, J = 8.0 Hz, 1H), 8.39 (ddd, J = 13.5, 7.4, 3.4 Hz, 2H), 8.34 (s, 1H), 8.01 (d, J = 8.0 Hz, 1H), 7.82 – 7.84 (m, 2H) 7.67 – 7.69 (m, 2H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 188.0, 182.7, 163.9, 136.5, 134.8, 134.6, 134.3, 131.4, 130.5, 129.1, 128.8, 127.9, 127.8, 127.2 (overlap of two peaks found by HSQC), 124.9, 121.9, 109.7

IR (ATR, cm^{-1}): 2917 (m), 1671 (m), 1615 (w), 1593 (m), 1457 (m), 1389 (m), 1282 (s) 752 (m), 715 (s)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{18}H_{11}O_3$, 275.0703; found, 275.0701. These data are consistent with those reported in the literature.[14,15]

Synthesis of boronic ester **10** via dearomative hydroboration:



7 **10**

A 250 mL Schlenk flask containing tetracene derivative **7** (3.00 g, 9.42 mmol, 1.0 equiv.) and MTAD (**8**, 1.28 g, 11.3 mmol, 1.2 equiv.) was evacuated and refilled with nitrogen five times. CH_2Cl_2 (100 mL) was added and the flask was immediately cooled to –50 ºC and irradiated with visible light. After the pink and yellow solution had become yellow-orange (36–48 h, see Photo S1), the LED lights were turned off and the reaction was cooled to –78 ºC. Then THF (100 mL) was added followed by a solution containing $[Rh(cod)_2]BF_4$ (383.8 mg, 0.94 mmol, 10 mol%) and dppb (389.1 mg, 0.942 mmol, 10 mol%) in CH_2Cl_2 (4 mL). HBcat (2.0 mL, 18.8 mmol, 2.0 equiv.) was added dropwise over two minutes and the flask was placed in a –30 ºC cooling bath for 24 h. The reaction was cooled to –78 ºC, ethanol (550 μL, 9.42 mmol, 1.0 equiv) was added followed by a solution of pinacol (1.11 g, 9.42 mmol, 1.0 equiv.) in THF (4.7 mL). The reaction was warmed to room temperature slowly over 12 h. A solution of saturated sodium chloride (100 mL) was added and the aqueous layer was extracted with CH_2Cl_2 until no color remained in the aqueous layer. Combined organic phases were dried over $MgSO_4$, concentrated under reduced pressure, and purified under and inert atmosphere by flash chromatography (SiO_2, hexanes:CH_2Cl_2:Et_2O = 2:1:1) to afford the title compound **10** as a yellow solid (2.9 g, 9.42 mmol, 55%, 3:1 dr). The two diastereomers were inseparable by chromatography and were used in the following reaction as a 3:1 mixture. The major diastereomer could be isolated by precipitation from diethyl ether.

mp: 126 – 128 °C [decomposition]

R_f = 0.16 (hexanes:CH_2Cl_2:Et_2O, 2:1:1 v/v/v)

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.14 – 8.20 (m, 2H), 7.73 – 7.76 (m, 2H), 5.91 (d, J = 2.8 Hz, 1H), 5.81 (dd, J = 3.5, 2.6 Hz, 1H), 4.04 (s, 3H), 4.02 (s, 3H) 2.89 (s, 3H), 2.51 (ddd, J = 13.5, 10.4, 3.5 Hz, 1H), 2.19 (ddd, J = 10.4, 5.0, 2.8 Hz, 1H), 1.79 (ddd, J = 13.5, 5.0, 2.6 Hz, 1H), 1.01 (s, 6H), 0.98 (s, 6H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 182.9, 182.6, 156.6, 156.1, 151.7, 150.9, 137.7, 137.4, 133.9, 133.955, 133.949, 133.91, 127.8, 127.6, 126.8, 126.7, 84.4, 64.0, 63.9, 49.5, 48.1, 25.5, 25.2, 24.6, 24.6, 19.9

IR (ATR, cm^{-1}): 2978 (w), 2944 (w), 1768 (m), 1707 (s), 1671 (s), 1593 (m), 1577 (m), 1312 (s)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{29}H_{31}N_3O_8B$, 560.2199; found, 560.2216.

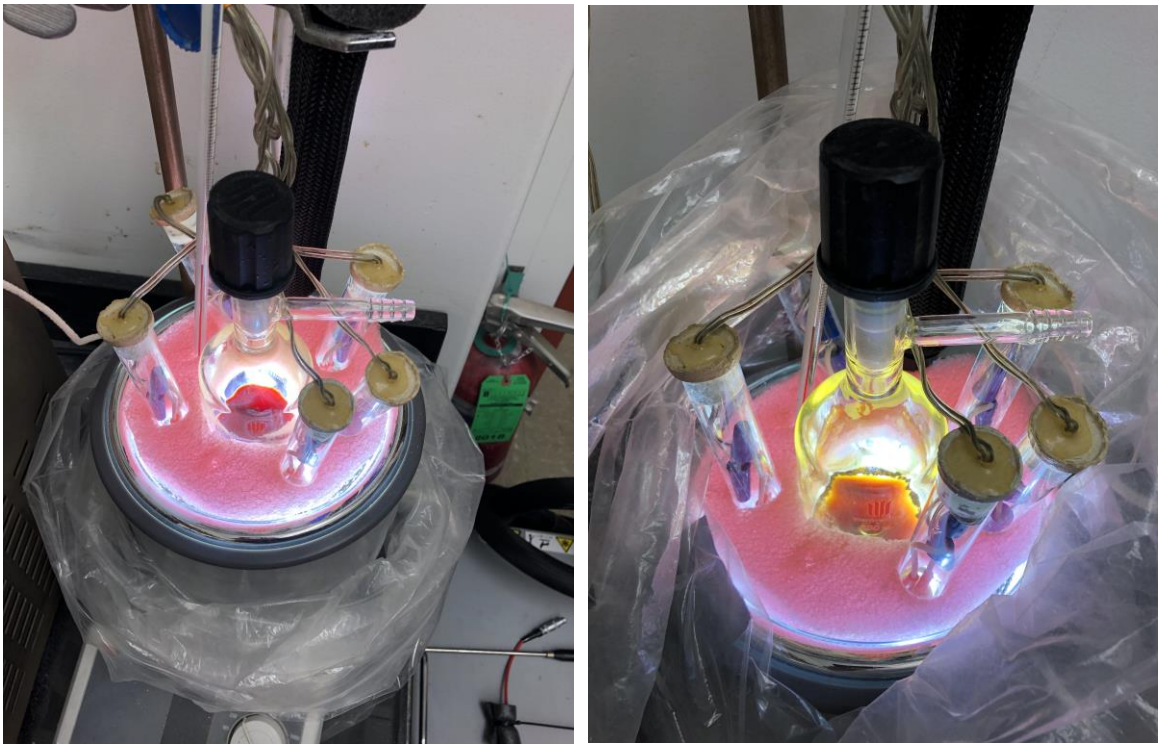
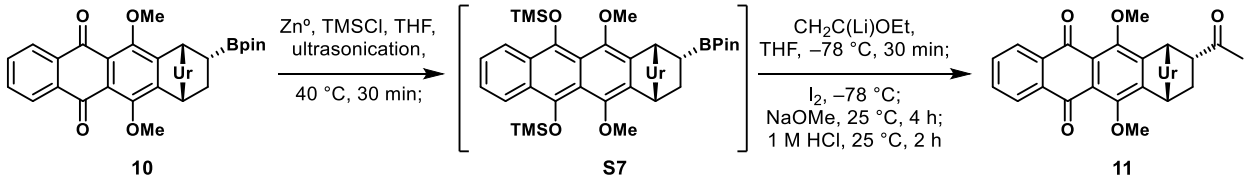


Photo S1. Images of Experimental Setup for Dearomative Hydroboration: *Dearomatization of dimethoxytetracenequinone **7** with MTAD (**8**) at –50 ºC after 5 minutes (left) and 48 hours (right).*

Synthesis of ketone **11** via Zweifel Olefination:



To a flask containing boronic ester **10** (3.0 g, 5.36 mmol, 1.0 equiv.) was added solid zinc powder (701 mg, 10.7 mmol, 2.0 equiv), THF (17.9 mL, 0.3 M), freshly distilled TMSCl (1.4 mL, 10.7 mmol, 2.0 equiv) and the resulting mixture was sonicated at 40 ºC for 30 min resulting in a dark red solution. Separately, to a cold (–78 ºC) solution of freshly distilled ethyl vinyl ether (8.1 mL, 80.5 mmol, 15 equiv) in THF (107 mL, 0.05 M relative to ester **10**) was added *t*BuLi (31.5 mL, 1.7 M in pentane, 53.6 mmol, 10 equiv.) dropwise over five minutes. After stirring at –78 ºC for 30 min, the flask was placed in an ice bath for 20 min, during which time yellow color dissipated, and then cooled again to –78 ºC. The solution of **S7** was removed from the sonication bath, allowed to cool to room temperature, and added dropwise over five minutes to the

solution of ethoxyvinyllithium at –78 ºC resulting in a red solution. After stirring at –78 ºC for 30 min, the cryogenic bath was removed while stirring continued until the reaction reached an internal temperature of –25 ºC (approximately 12 min at this scale). Then the flask was immediately cooled to –78 ºC and a solution of iodine (10.9 g, 42.9 mmol, 8.0 equiv.) in THF (10 mL) was added dropwise over five minutes resulting in a burgundy solution. The reaction was stirred at –78 ºC for 30 min before the cryogenic bath was removed for another 12 min. The flask was once again cooled to –78 ºC before a solution of sodium methoxide (17.1 g, 80.5 mmol, 15 equiv.) in methanol (22 mL) was added dropwise over five minutes, resulting in a dark red solution. After keeping the reaction at –78 ºC for 30 min, the cryogenic bath was removed and stirring continued for an additional 4 hours at room temperature. Then aqueous HCl was added (150 mL, 1 M) and the resulting yellow solution was allowed to stir until hydrolysis of the vinyl ether to the methyl ketone **11** was complete (approximately 2 hours, monitored by TLC). The layers were separated, and the aqueous layer was extracted repeatedly with CH_2Cl_2 until color in the aqueous phase no longer persisted. The organic layers were combined, dried with $MgSO_4$, and concentrated resulting in a black-brown oil. This oil was dissolved in ethyl acetate (250 mL), washed with a saturated solution of $Na_2S_2O_3$ (3×150 mL), washed with a saturated sodium chloride solution (150 mL), dried over $MgSO_4$, and concentrated to afford a brown-yellow oil. Purification by flash chromatography (SiO_2, hexanes:CH_2Cl_2:EtOAc = 2:1:1) afforded the title compound **11** as a yellow solid (1.22 g, 3.58 mmol, 72%).

mp: 156 – 158 °C [decomposition];

R_f = 0.12 (hexanes: CH_2Cl_2:EtOAc, 2:1:1v/v/v)

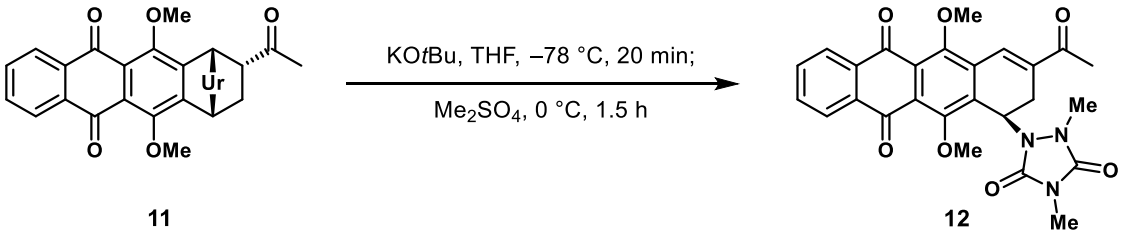
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.14 – 8.16 (m, 2H), 7.74 – 7.76 (m, 2H), 6.15 (d, J = 3.0 Hz, 1H), 5.58 (dd, J = 3.5, 2.6 Hz, 1H), 4.06 (s, 3H), 4.04 (s, 3H), 3.56 (ddd, J = 9.7, 4.5, 3.0 Hz, 1H), 2.92 (s, 3H), 2.44 (ddd, J = 13.7, 9.7, 3.5 Hz, 1H), 2.30 (s, 3H), 2.25 (ddd, J = 13.7, 4.5, 2.6 Hz, 1H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 203.2, 182.61, 182.58, 156.5, 156.4, 151.6, 151.0, 137.1, 134.07, 134.05, 133.89, 133.86, 133.81, 128.7, 128.1, 126.80, 126.78, 64.4, 64.2, 49.2, 48.0, 47.7, 28.6, 25.8, 25.0

IR (ATR, cm^{-1}): 2926 (w), 1714 (s), 1673 (m), 1592 (w), 1458 (m), 1312 (m), 1258 (m), 983 (w)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{25}H_{22}N_3O_7$, 476.1453; found, 476.1481.

Synthesis of enone **12**:



11 **12**

To a cold (–78 ºC) solution of **11** (500.0 mg, 1.05 mmol, 1.0 equiv.) in THF (10.5 mL) was added a solution of *t*BuOK (129.8 mg, 1.16 mmol, 1.1 equiv.) in THF (1.2 mL) dropwise over two minutes. This resulted in the yellow solution turning dark purple. After 20 minutes, dimethyl sulfate (502 μL, 5.26 mmol, 5.0 equiv.) was added and the reaction was warmed to 0 ºC and stirred at this temperature for 1.5 hours. The crude reaction mixture was concentrated under reduced pressure at 0 ºC and used without purification in the next step. To obtain an analytically pure sample, the residue was dry loaded on celite and immediately purified *via* flash chromatography (SiO_2, hexanes:CH_2Cl_2:EtOAc = 1:3:3) to deliver the title compound **12** as a yellow solid (407.3 mg, 0.831 mmol, 79%).

mp: 159 – 161 °C [decomposition]

R_f = 0.25 (hexanes: CH_2Cl_2:EtOAc, 1:3:3 v/v/v)

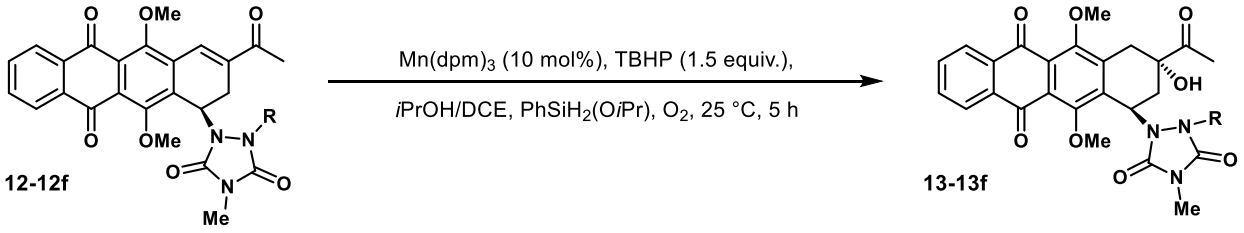
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.19 – 8.21 (m, 2H), 7.92 (d, J = 3.0 Hz, 1H), 7.77 – 7.79 (m, 2H), 5.87 (dd, J = 9.5, 1.2 Hz, 1H), 4.01 (s, 3H), 3.98 (s, 3H), 3.23 (dd, J = 19.3, 1.2 Hz, 1H), 3.05 (s, 3H), 2.75, (s, 3H), 2.61 (ddd, J = 19.3, 9.5, 3.0 Hz, 1H), 2.53 (s, 3H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 197.4, 182.6, 182.1, 156.7, 156.0, 155.3, 153.9, 138.7, 135.8, 134.2, 134.12, 134.05, 133.9, 133.4, 128.4, 127.9, 127.5, 127.0, 126.8, 63.7, 63.0, 48.1, 35.9, 26.1, 26.0, 25.9

IR (ATR, cm^{-1}): 2940 (w), 1772 (m), 1708 (s), 1667 (s), 1476 (m), 1457 (m), 1324 (s) 1239 (s), 1036 (m)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{26}H_{24}N_3O_7$, 490.1609; found, 490.1613.

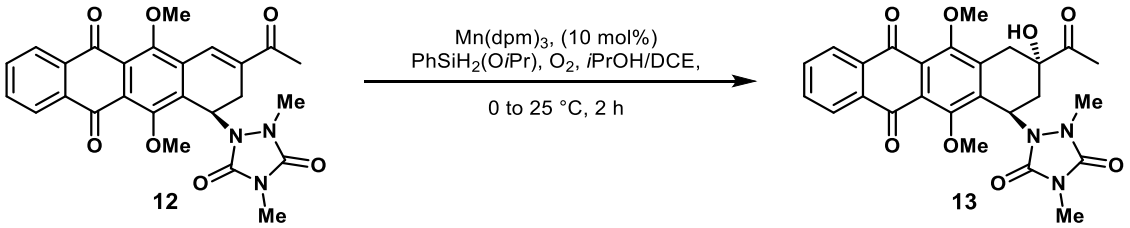
Table S2: The influence of N-substitution on Mukaiyama hydration:



entry	*compound*	***R***	*yield*
1	**12**	CH_3	*56%*
2	**12a**	H	*18%*
3	**12b**	SEM	*29%*
4	**12c**	COPh	*50%*
5	**12d**	MOM	*53%*
6	**12e**	Ac	–
7	**12f**	Boc	–
8[a]	**12**	CH_3	*70%*

a. TBHP was not used, see below for optimized procedure.

Synthesis of α-ketol **13** via Mukaiyama hydration:



To a solution of enone **12** (500.0 mg, 1.02 mmol, 1.0 equiv.) in *i*PrOH (5 mL) and DCE (5 mL) at 0 ºC was added $Mn(dpm)_3$ (61.8 mg, 0.102 mmol, 10 mol%) in a single portion. O_2 was then bubbled through the dark reaction mixture for 5 min. Then, Isopropoxy(phenyl)silane (640 μL, 3.064 mmol, 3.0 equiv.) was added in portions over the course of 1 hour at ambient temperature while oxygen continued to bubble through the reaction mixture. After the addition, the reaction was stirred for an additional hour. Celite (1g) was added to the mixture and solvent was removed *in vacuo* followed by purification *via* flash

chromatography (SiO_2, hexanes: CH_2Cl_2:EtOAc = 1:3:3) to provide the title compound **13** as a yellow solid (365.5 mg, 0.719 mmol, 70%).

mp: 129–130 °C [decomposition]

R_f = 0.11 (hexanes: CH_2Cl_2:EtOAc, 1:3:3 v/v/v)

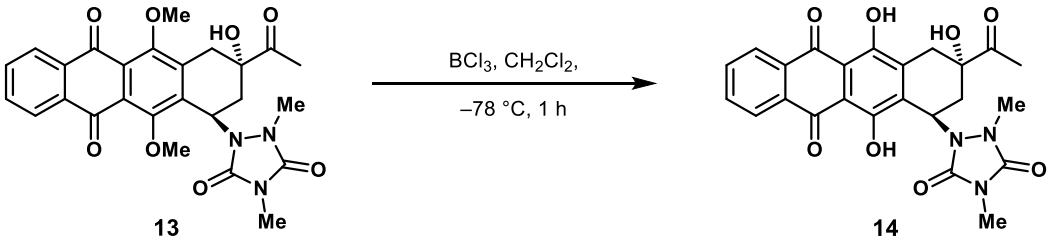
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.13 – 8.17 (m, 2H), 7.71 – 7.74 (m, 2H), 5.76 (t, J = 9.0 Hz, 1H), 3.99 (s, 1H), 3.87 (s, 6H), 3.06 – 3.20 (m, 5H), 2.90 (s, 3H), 2.42, (s, 3H), 2.24 – 2.32 (m, 2H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 209.8, 182.7, 182.3, 156.4, 155.5, 155.0, 154.7, 139.3, 135.71, 134.02, 133.97, 133.9 (overlap of two peaks found by HSQC), 126.8, 126.7, 126.5, 125.0, 77.4, 62.5, 62.0, 51.2, 34.6, 34.3, 32.9, 25.8, 24.3

IR (ATR, cm^{-1}): 3429 (br), 2927 (w), 2854 (w), 1764 (m), 1700 (s), 1672 (s), 1482 (m), 1259 (s), 1101 (m), 1036 (m)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{26}H_{26}N_3O_8$, 508.1714; found, 508.1712.

Preparation of α-ketol **14**:



To a cold (–78 ºC) solution of α-ketol **13** (545.7 mg, 1.07 mmol, 1.0 equiv.) in CH_2Cl_2 (10.7 mL, 0.1 M) was added BCl_3 (10.7 mL, 1M in CH_2Cl_2, 10.7 mmol, 10 equiv.) dropwise over two minutes. Stirring was continued for one hour at which point 10 mL of methanol was added and the reaction mixture was allowed to warm to room temperature. The solution was concentrated under reduced pressure to give a red residue. Purification *via* flash chromatography (SiO_2, CH_2Cl_2:EtOAc = 8:2, 1% AcOH) provided the title compound **14** as a red solid (505.9 mg, 1.05 mmol, 98%).

mp: 248.2 – 248.9 °C

R_f = 0.23 (CH_2Cl_2:EtOAc , 8:2 v/v, 1% AcOH)

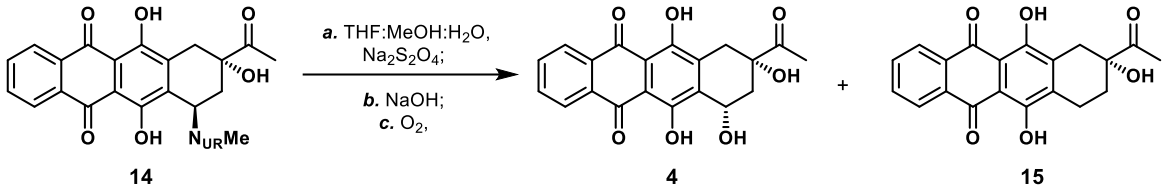
^{1}H NMR (500 MHz, DMSO-d_6): δ 13.49 (s, 1H), 13.24 (s, 1H), 8.23 – 8.26 (m, 2H), 7.96 – 7.98 (m, 2H), 5.94 (s, 1H), 5.61 (dd, J = 10.1, 8.4 Hz, 1H), 3.09 (dd, J = 18.1, 2.8 Hz, 1H) 3.00 (d, J = 18.1 Hz, 1H) 2.97 (s, 3H), 2.85 (s, 3H), 2.36 (ddd, J = 13.2, 8.4, 2.8 Hz, 1H) 2.33 (s, 3H), 2.11 (dd, J = 13.2, 10.1 Hz, 1H)

^{13}C NMR (126 MHz, DMSO-d_6): δ 211.5, 186.7, 186.6, 155.9, 155.2, 155.0, 154.4, 138.5, 135.1, 153.1, 132.9, 132.8, 132.0, 126.7, 126.6, 111.2, 110.0, 76.2, 50.8, 34.51, 34.49, 31.4, 25.3, 24.5

IR (ATR, cm^{-1}): 3259 (br), 2926 (w), 1766 (m), 1704 (s), 1624 (m), 1586 (m), 1403 (s), 1246 (s), 1115 (m), 734 (m)

HRMS (m/z): $[M+Na]^+$ calcd. for $C_{24}H_{21}N_3O_8Na$, 502.1221; found, 502.1233.

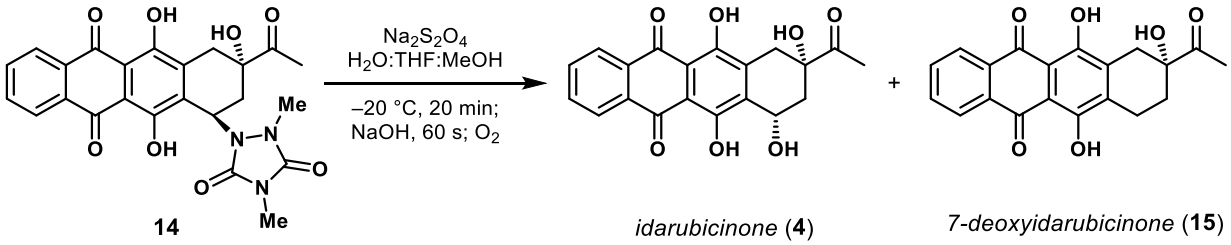
Table S3: Optimization of the final transformation of hydroquinone **14**.



Entry	*THF:MeOH:H_2O*	*$Na_2S_2O_4$ (eq.)*	*NaOH (eq.)*	*time before O_2 quench*	*Temp (°C)*	*result*
1	1:1:1	2.5	-	15 min	–10	**14** only[a]
2	1:1:1	2.5	10	60s	–10	>85% **15**[a]
3	1:1:1	2.5	2.5	60s	–10	**14 + 15** only[a]
4	2:2:1	2.5	2.5	60s	–10	**14 + 15** only[a]
5	2:2:1	2.5	2.5	120s	–10	**14 + 15** only[a]
6	1:1:1	2.0	2.5	120s	–20	**14 + 15** only[a]
7	1:1:1	2.0	5.0	60s	–20	<5% **4**[a]
8	1:1:1	2.0	10	60s	–20	20% **4**[a]
9	1:1:1	2.0	10	30s	–20	10% **4**[a]
10	1:1:1	2.0	10	45s	–20	20% **4**[a]
11	1:1:1	2.0	10	45s[c]	–20	**14 +15** only[a]
12	1:1:1	1.2	10	45s[c,d]	–20	22% **4**, 57% **15**[b]
13	1:1:1	1.2	10	60s[c,d]	–20	31% **4**, 57% **15**[b]

a.yield determined by NMR using 1,1,2,2-tetrachloroethane b.isolated yield c.0.10 mmol scale instead of 0.02 mmol d.gas dispersion tube used to quench with O_2 instead of a needle.

Preparation of idarubicinone (**4**) and 7-deoxyidarubicinone (**15**):



A flask charged with **14** (50.0 mg, 104 µmol, 1.0 equiv.) and sodium dithionite ($Na_2S_2O_4$) (32.2 mg, 85 wt%, 156 µmol, 1.5 equiv.) was purged with nitrogen for 10 min. Degassed THF (2.1 mL, 0.05 M), MeOH (2.1 mL, 0.05 M), and H_2O (2.1 mL, 0.05 M) were sequentially added, and the mixture was stirred at room temperature for 20 min at which time the light-red solution had darkened significantly. The flask was cooled to –20 ºC and an aqueous solution of NaOH (41.7 mg, 1.0 M, 10 equiv.) was added, resulting in a deep blue

solution. After 60 s, the septum was removed, and a gas dispersion tube connected to a balloon of O_2 was submerged into the reaction mixture at –20 ºC, causing the reaction mixture to rapidly turn from deep blue to vibrant purple as the entire balloon was allowed to discharge into the solution via the gas dispersion tube (see Photo S2 for detail). The reaction was then diluted with 1M aqueous HCl, extracted with EtOAc, and concentrated under reduced pressure. Purification *via* flash chromatography (SiO_2, hexanes:EtOAc = 8:2, 1% AcOH) provided idarubicinone (**4**) as a red solid (12.7 mg, 33 µmol, 31%) and 7-deoxyidarubicinone (**15**, 21.4 mg, 59.6 µmol, 57%) also as a red solid.

Idarubicinone (**4**)

mp: 176.5 – 177.8 (lit.[16] 176 – 178 ºC)

R_f = 0.42 (hexanes:EtOAc = 8:2 v/v, 1% AcOH)

^{1}H NMR (500 MHz, $CDCl_3$): 13.60 (s, 1H), 13.33 (s, 1H), 8.34 – 8.37 (m, 2H), 7.83 – 7.86 (m, 2H), 5.31 – 5.35 (m, 1H), 4.53 (s, 1H), 3.78 (d, J = 5.3 Hz, 1H), 3.20 (dd, J = 18.6, 2.1 Hz, 1H), 2.97 (d, J = 18.6 Hz, 1H), 2.43 (s, 3H), 2.36 (dt, J = 14.4, 2.1, 2.1 Hz, 1H) 2.19 (dd, J = 14.4, 4.9 Hz, 1H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 211.7, 187.1, 186.9, 156.6, 156.4, 135.9, 135.0, 134.8, 134.7, 133.62, 133.59, 127.3, 127.2, 111.5, 111.1, 77.0, 61.9, 35.6, 33.4, 24.6

IR (ATR, cm^{-1}): 3416 (br), 2917 (s), 2849 (m), 1715 (m), 1626 (m),1587 (s), 1411 (m), 1373 (m), 1342 (w), 1262 (m), 1236 (s), 1035 (w)

HRMS (m/z): $[M-H]^-$ calcd. for $C_{20}H_{15}O_7$, 367.0823; found, 367.0818

7-deoxyidarubicione (**15**)

mp: 210.9 – 211.6 ºC (lit.[17] 210 – 211 ºC)

R_f = 0.64 (hexanes:EtOAc = 8:2 v/v, 1% AcOH)

^{1}H NMR (500 MHz, DMSO-*d_6*): δ 13.24 – 13.27 (m, 2H), 8.17 – 8.19 (m, 2H), 7.92 – 7.94 (m, 2H), 5.67 (s, 1H), 2.84 (d, J = 18.1 Hz, 1H) 2.68 – 2.77 (m, 3H), 2.30 (s, 3H), 1.90 – 1.97 (m, 1H), 1.73 (ddd, J = 13.2, 9.9, 6.8 Hz, 2H)

^{13}C NMR (126 MHz, DMSO-*d_6*): δ 212.9, 186.0, 186.0, 155.9, 155.3, 137.1, 136.1, 134.8 (overlap of two peaks found by HSQC), 132.8, 132.8, 126.5 (overlap of two peaks found by HSQC), 109.2, 109.1, 74.8, 31.6, 28.0, 24.4, 20.0

IR (ATR, cm^{-1}): 3490 (br), 1702 (m), 1620 (m), 1586 (s), 1408 (s), 1376 (m), 1351 (m), 1315 (w), 1270 (s), 1205 (w)

HRMS (m/z): $[M+H]^+$ calcd. for $C_{20}H_{17}O_6$, 353.1025; found, 353.1022. These data are consistent with those reported in the literature.[16,17]

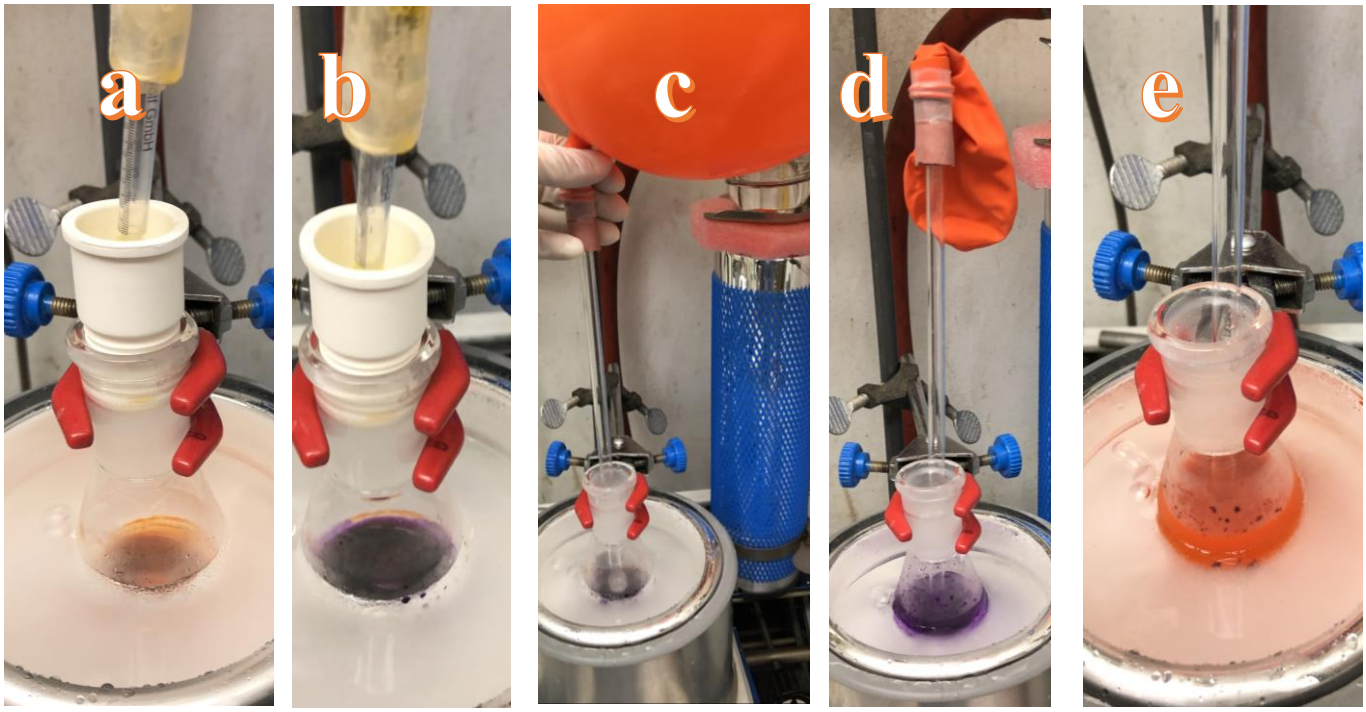


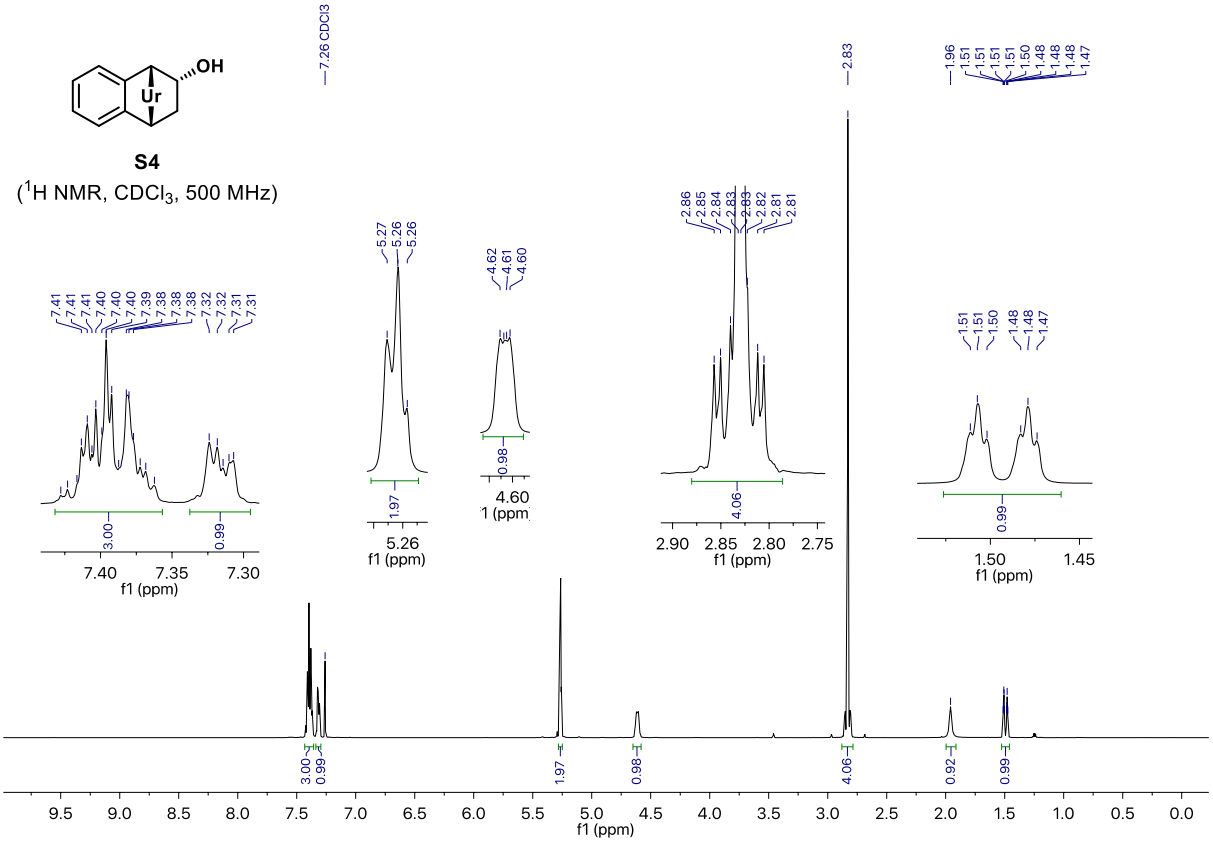
Photo S2. Images of experimental setup for the final transformation of hydroquinone **15:** *The reaction at different time points from left to right:* ***a.*** *before the addition of NaOH;* ***b.*** *10 s after the addition of NaOH;* ***c.*** *60 s after the addition of NaOH;* ***d.*** *after the addition of* O_2*;* ***e.*** *after the addition of 1M HCl.*

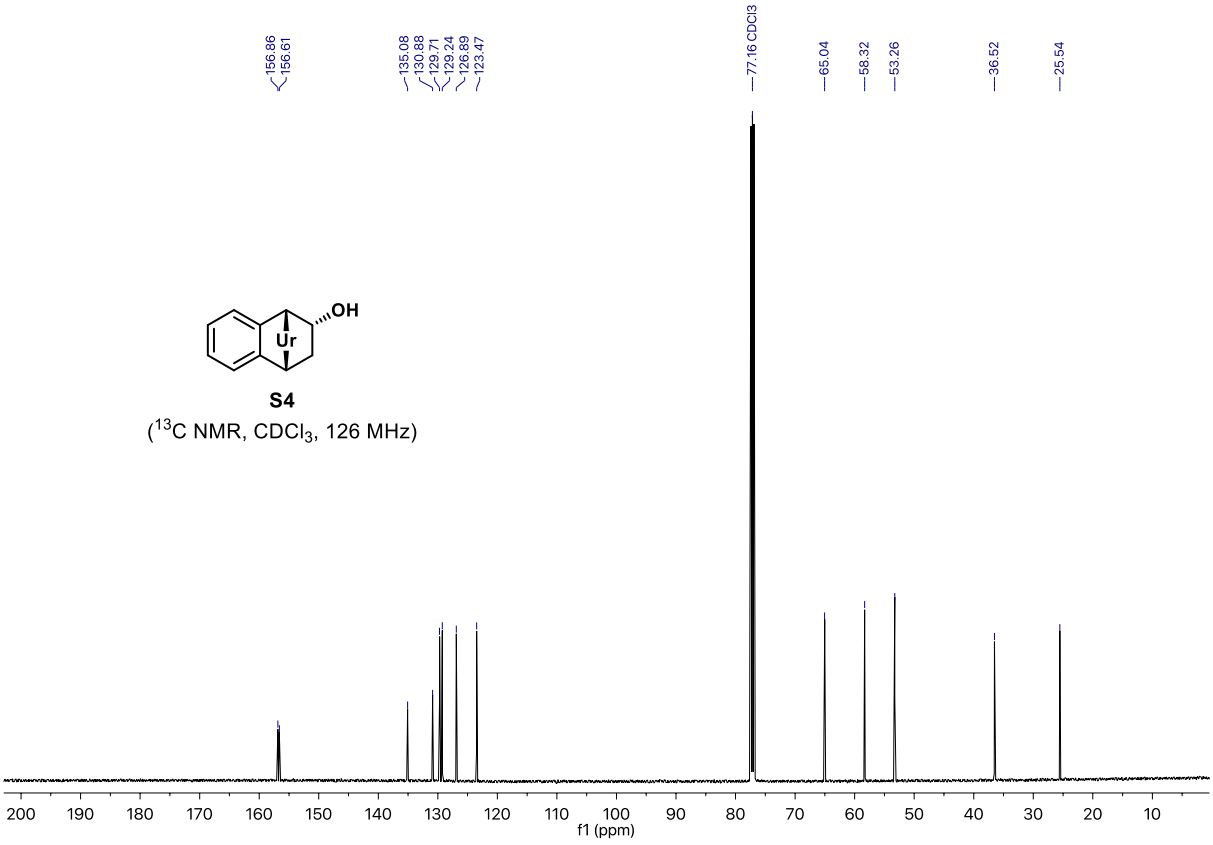
III. References

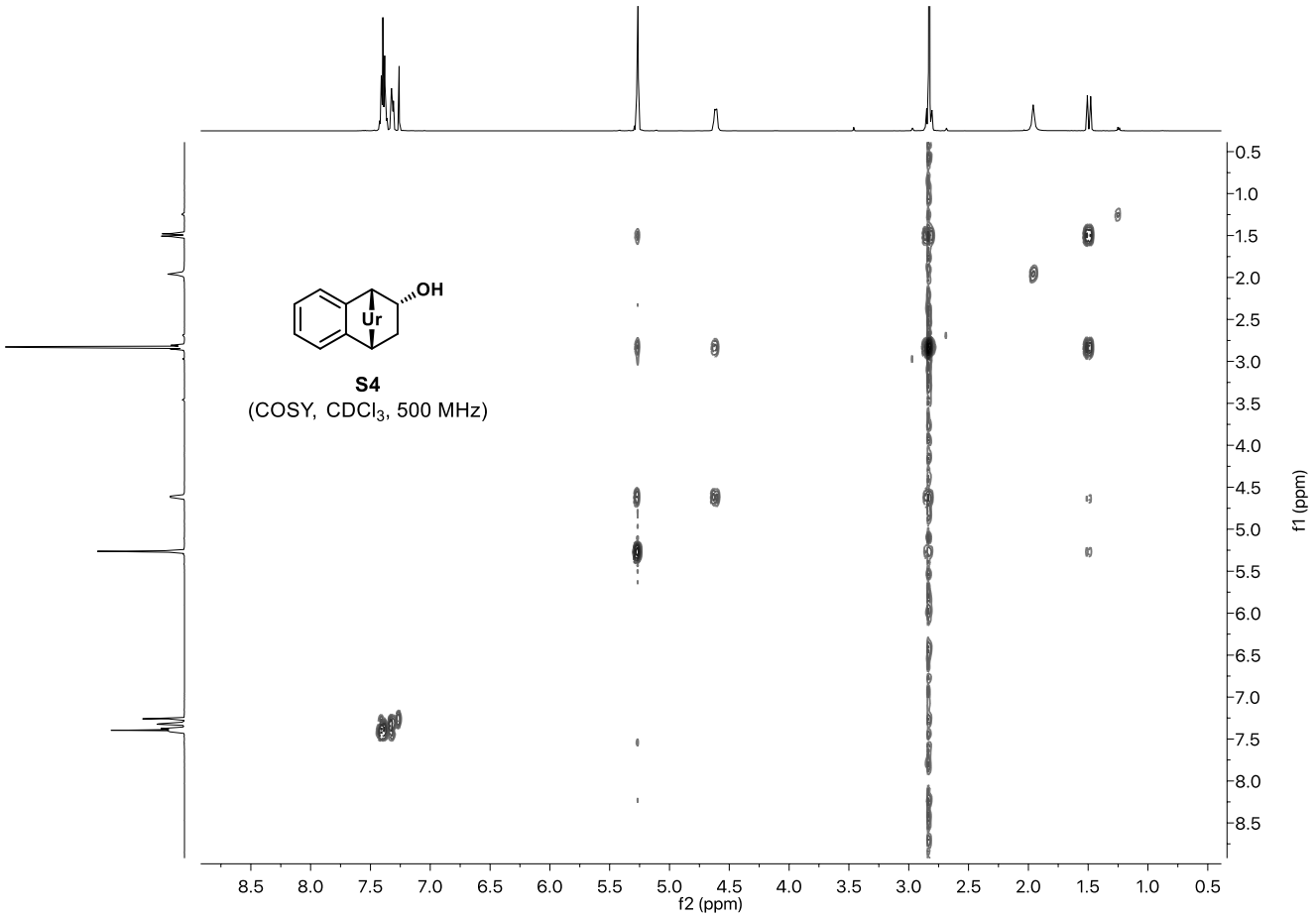
1. Nishina, Y.; Kida, T.; Ureshino, T. *Org. Lett.* **2011**, *13*, 3960.
2. Carey, T. J.; Snyder, J. L.; Miller, E. G.; Sammakia, T.; Damrauer, N. H. *J. Org. Chem.* **2017**, *82*, 4866.
3. Woodward, S.; Ackermann, M.; Ahirwar, S. K.; Burroughs, L.; Garrett, M. R.; Ritchie, J.; Shine, J.; Tyril, B.; Simpson, K.; Woodward, P. *Chem. Eur. J.* **2017**, *23*, 7819.
4. Schenk, T. G.; Downes, J. M.; Milne, C. R. C.; Mackenzie, P. B.; Boucher, T. G.; Whelan, J.; Bosnich, B. *Inorg. Chem*. **1985**, *24*, 2334.
5. Armarego, W.L.F.; Chai C.L.L. *Purification of Laboratory Chemicals*, 6; Butterworth-Heinemann: Burlington MA, **2009**; p 176.
6. Breton, G. W.; Turlington, M. *Tet. Lett*. **2014**, *55*, 4661.
7. Cookson, R. C.; Gupte, S. S.; Stevens, I. D. R.; Watts, C. T. *Org. Synth*. **1971**, *51*, 121.
8. Kanth, J. V. B.; Periasamy, M.; Brown, H. C. *Org. Process Res. Dev.* **2000**, *4*, 550.

9. Obradors, C.; Martinez, R. M.; Shenvi, R. A. *J. Am. Chem. Soc.* **2016**, *138*, 4962.
10. Dolomanov, O. V.; Bourhis, L. J.; Gildea, R. J.; Howard, J. A. K; Puschmann, H. *J. Appl. Cryst*. **2009**, *42*, 339.
11. Sheldrick, G. M. *Acta Cryst.* **2015**, *A71*, 3.
12. Nishina, Y.; Kida, T.; Ureshino, T. *Org. Lett.* **2011**, *13*, 3960.
13. Kotha, S.; Shah, V. R.; Mandal, K. *Adv. Synth. Catal.* **2007**, *349*, 1159.
14. Makhlouf, M. A.; Rickborn, B. *J. Org. Chem*. **1981**, *46*, 2734.
15. Park, I. S.; Heo, E.; Nam, Y.; Lee, C. W.; Kim, J. *J. Photochem. Photobiol. A: Chem.* **2012,** *238*, 1.
16. Allen, J. G.; Hentemann, M. F.; Danishefsky, S. J. *J. Am. Chem. Soc.* **2000**, *122*, 571.
17. Broadhurst, M. J.; Hassall, C. H.; Thomas, G. J. *J. Chem. Soc. Perkin Trans. 1* **1982**, 2239.

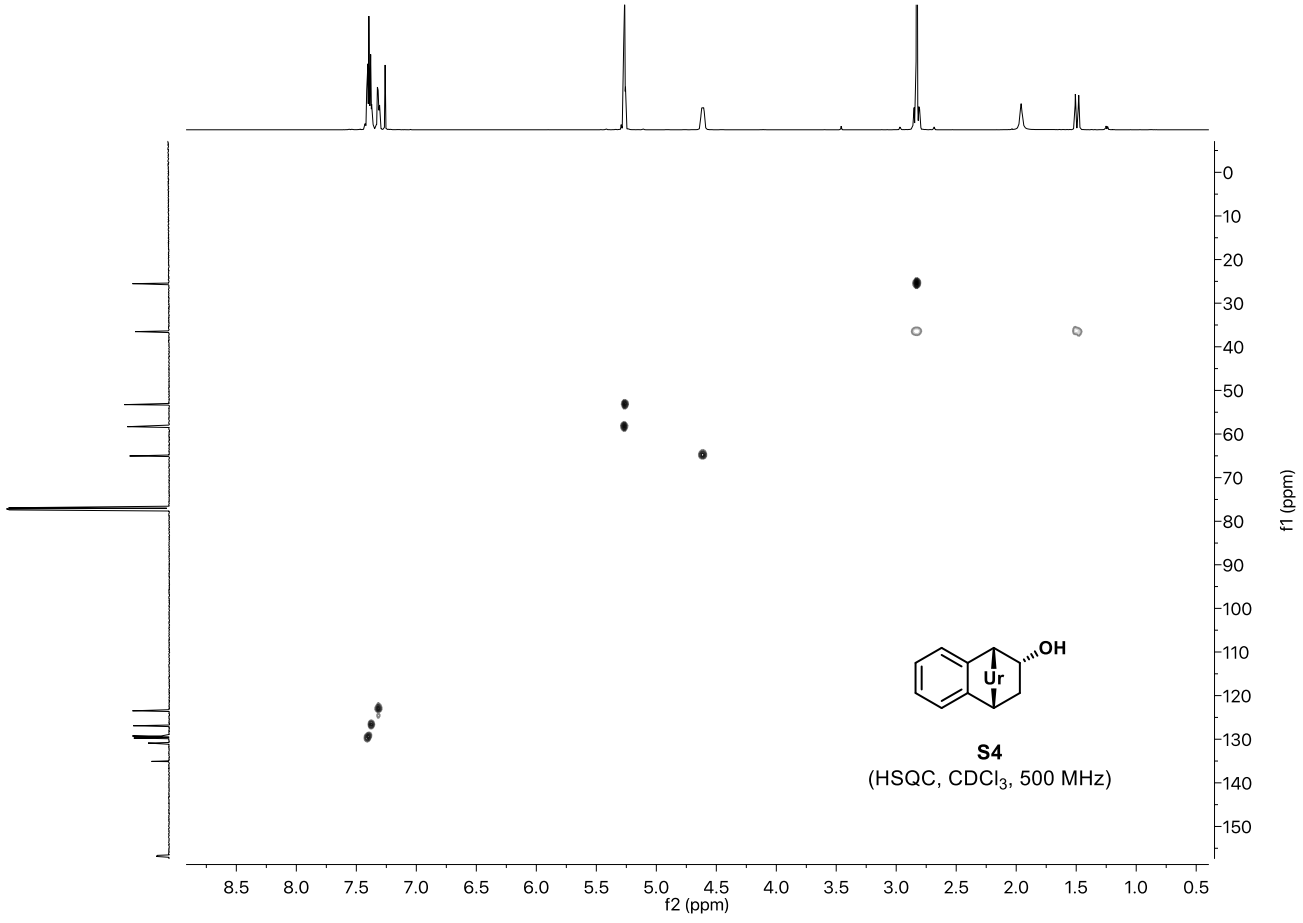
IV. ^{1}H- and ^{13}C-NMR Spectra of Compounds



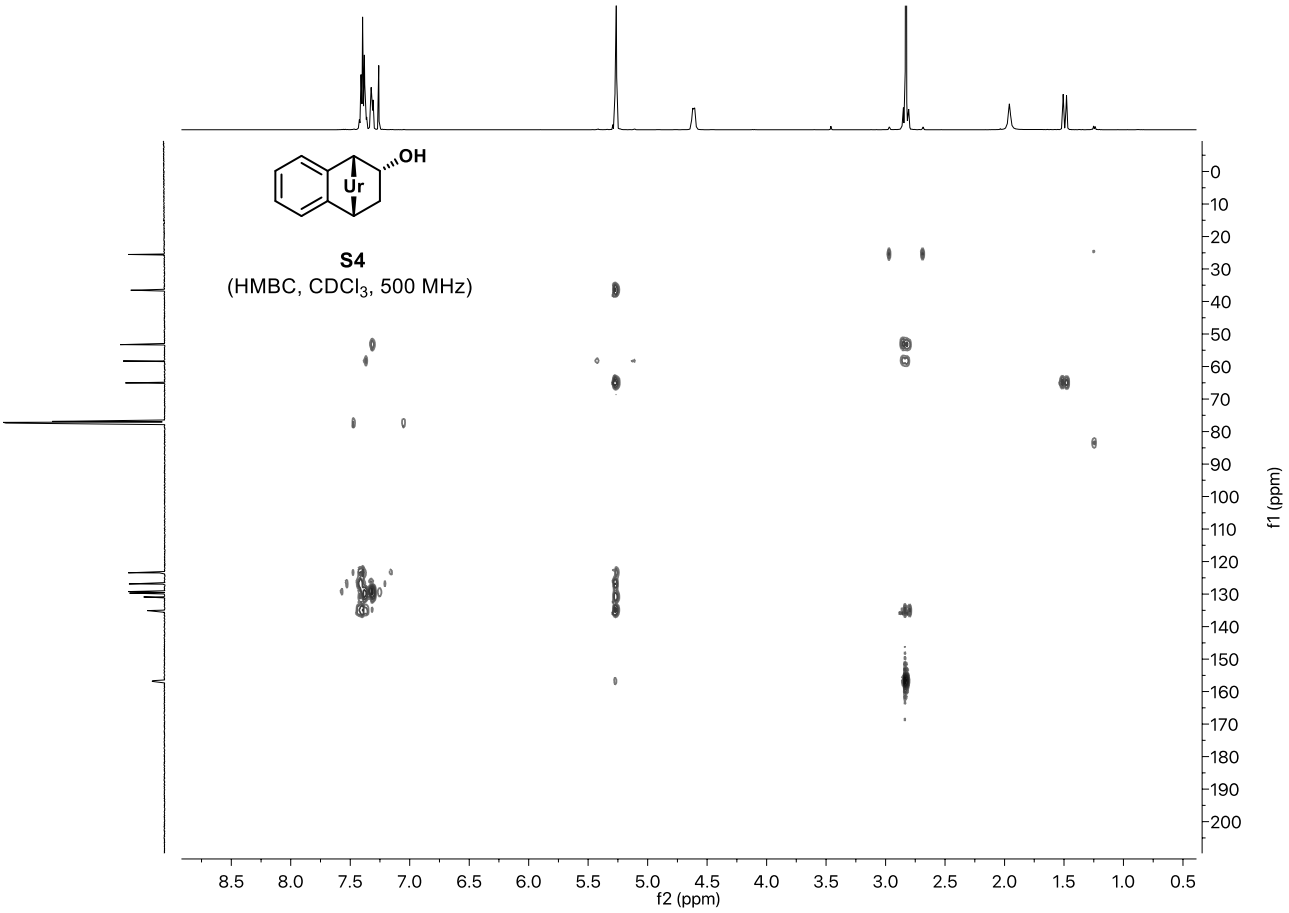




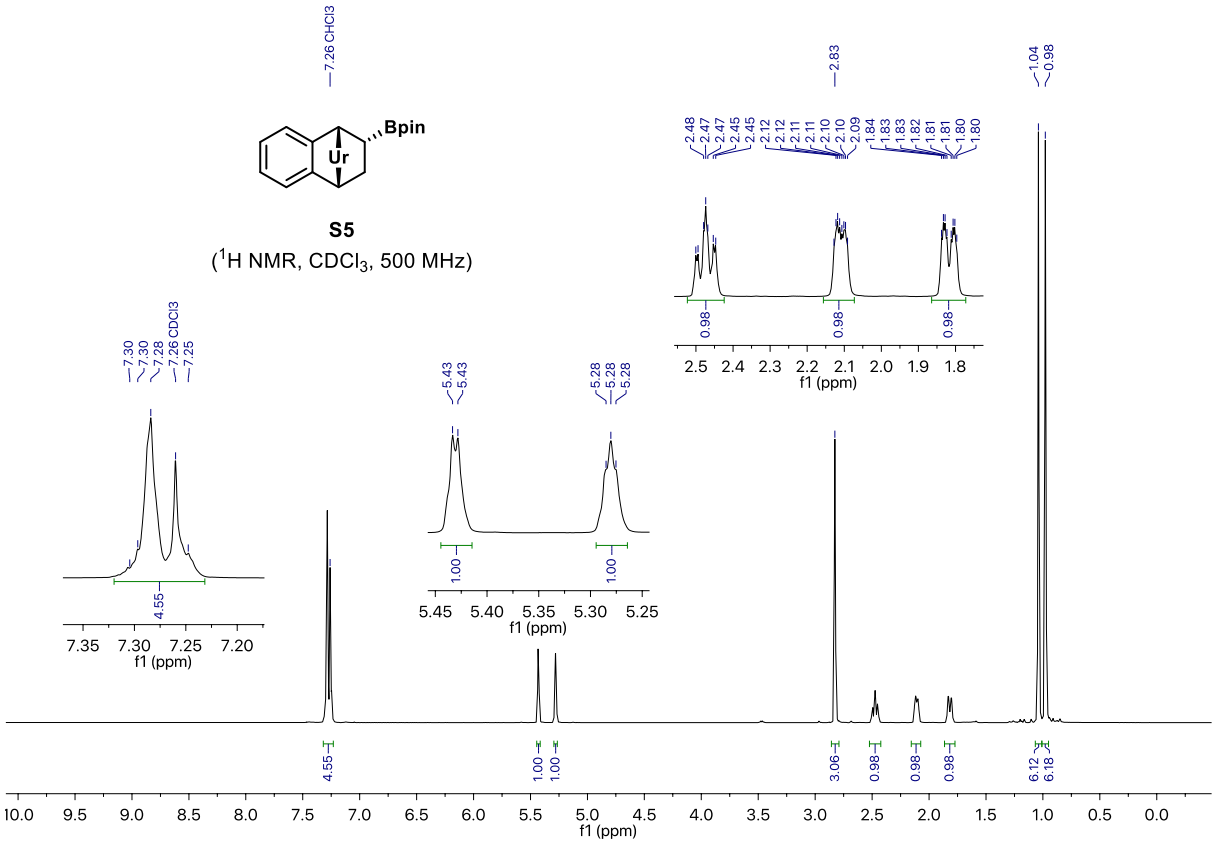
S4
(COSY, $CDCl_3$, 500 MHz)



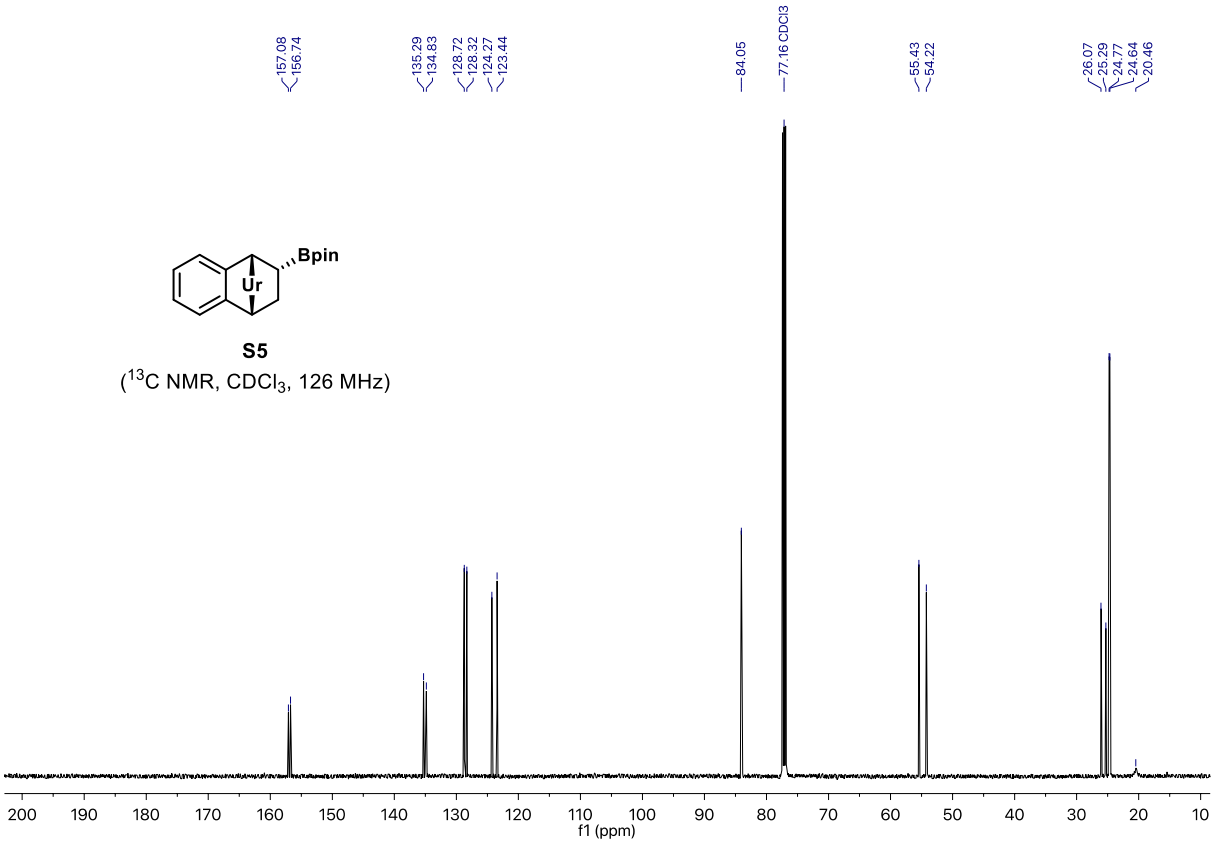
S4
(HSQC, $CDCl_3$, 500 MHz)



S4
(HMBC, $CDCl_3$, 500 MHz)

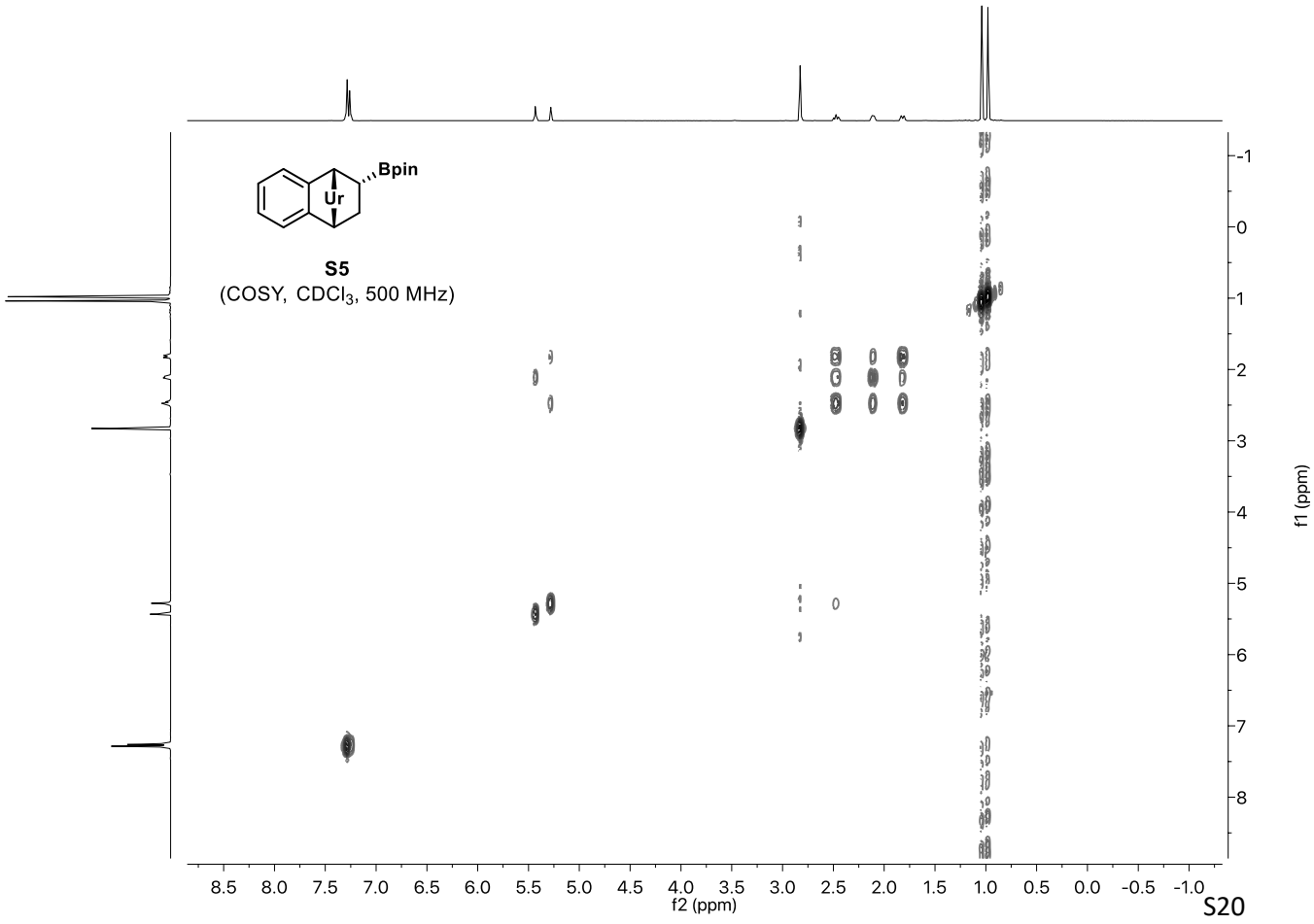


S5
(^{1}H NMR, $CDCl_3$, 500 MHz)



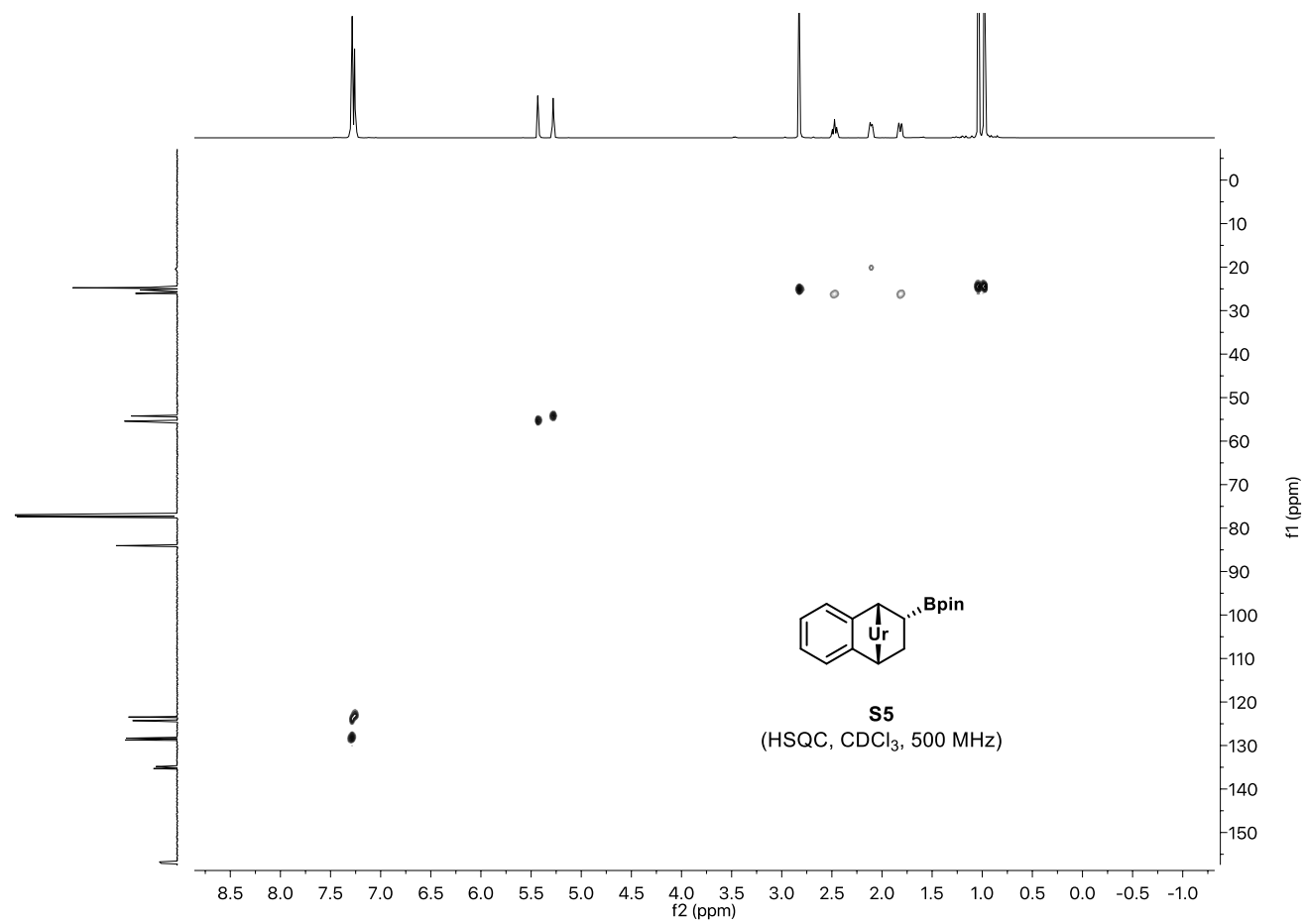
S5

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

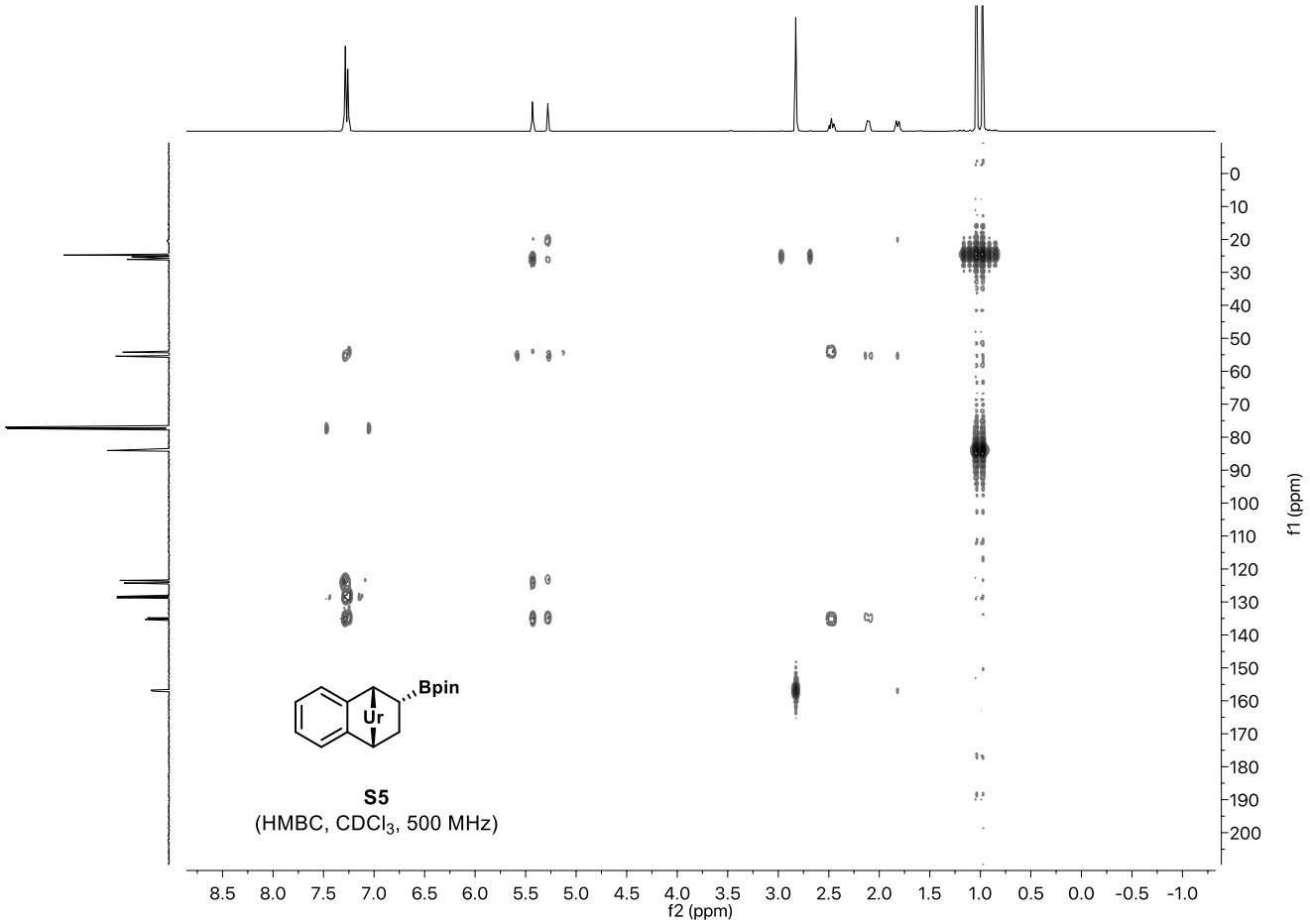


S5

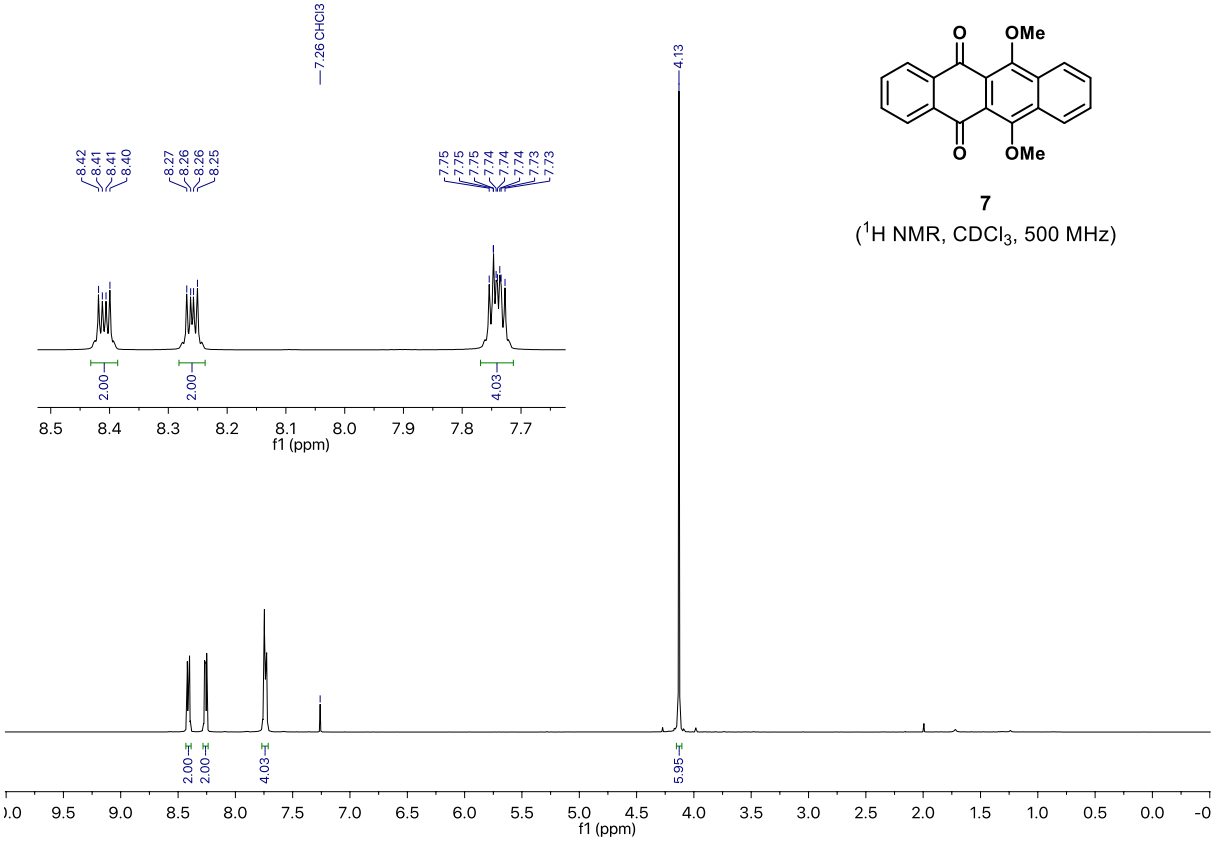
(COSY, $CDCl_3$, 500 MHz)



S5
(HSQC, $CDCl_3$, 500 MHz)

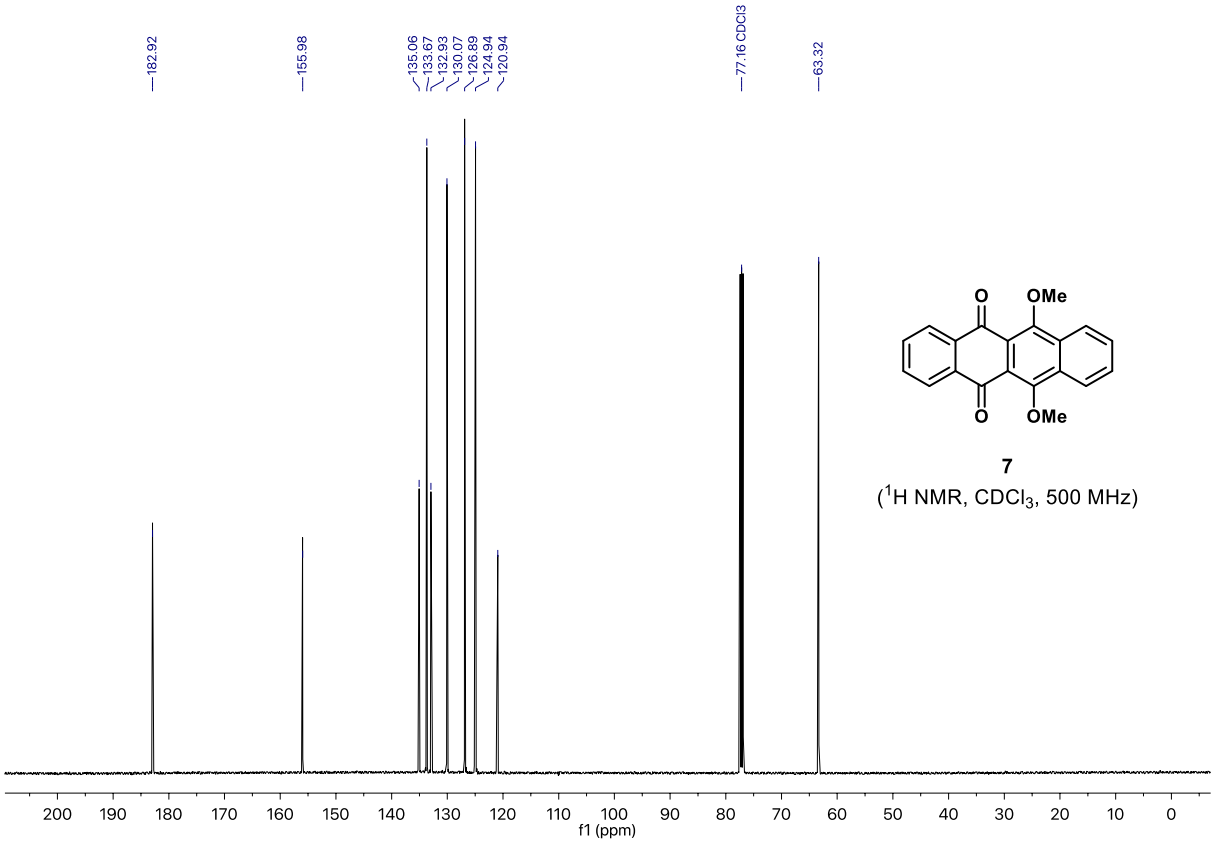


S5
(HMBC, $CDCl_3$, 500 MHz)



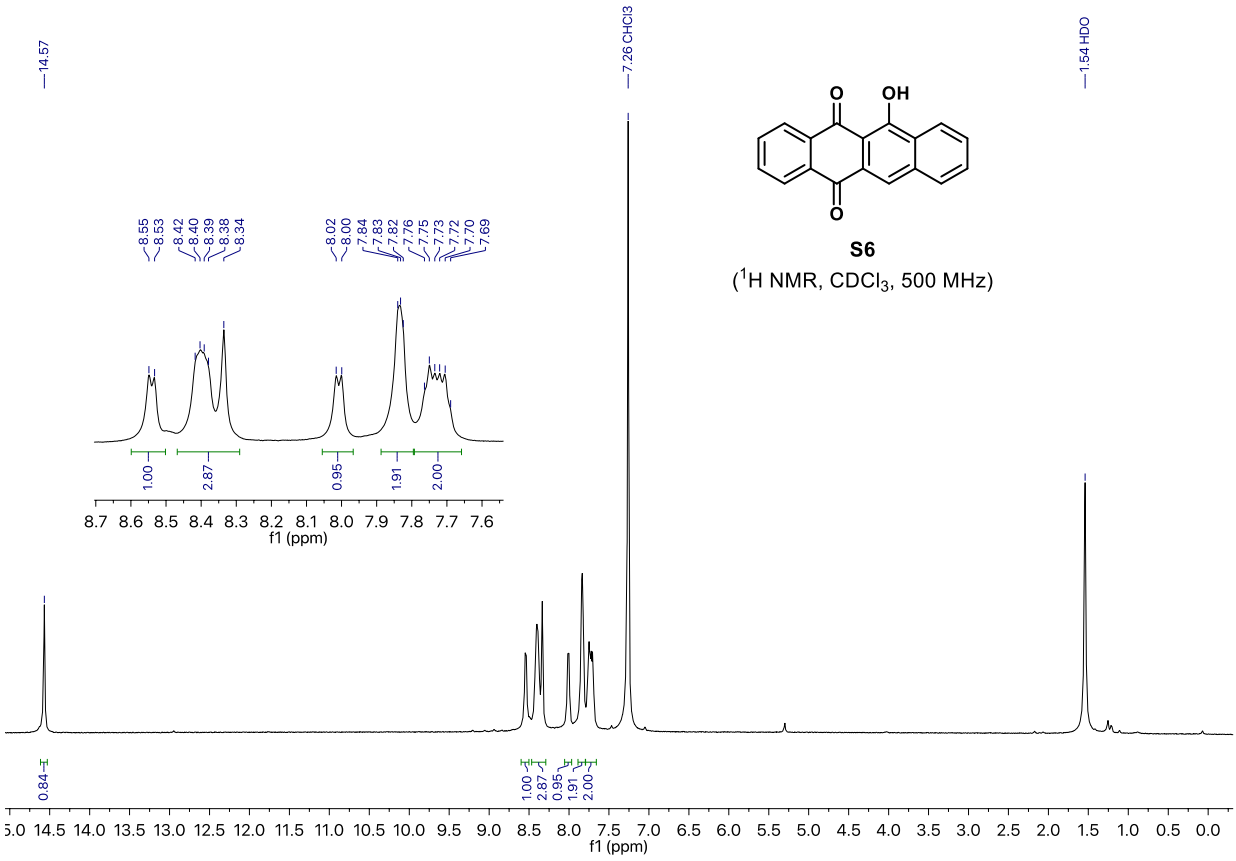
7

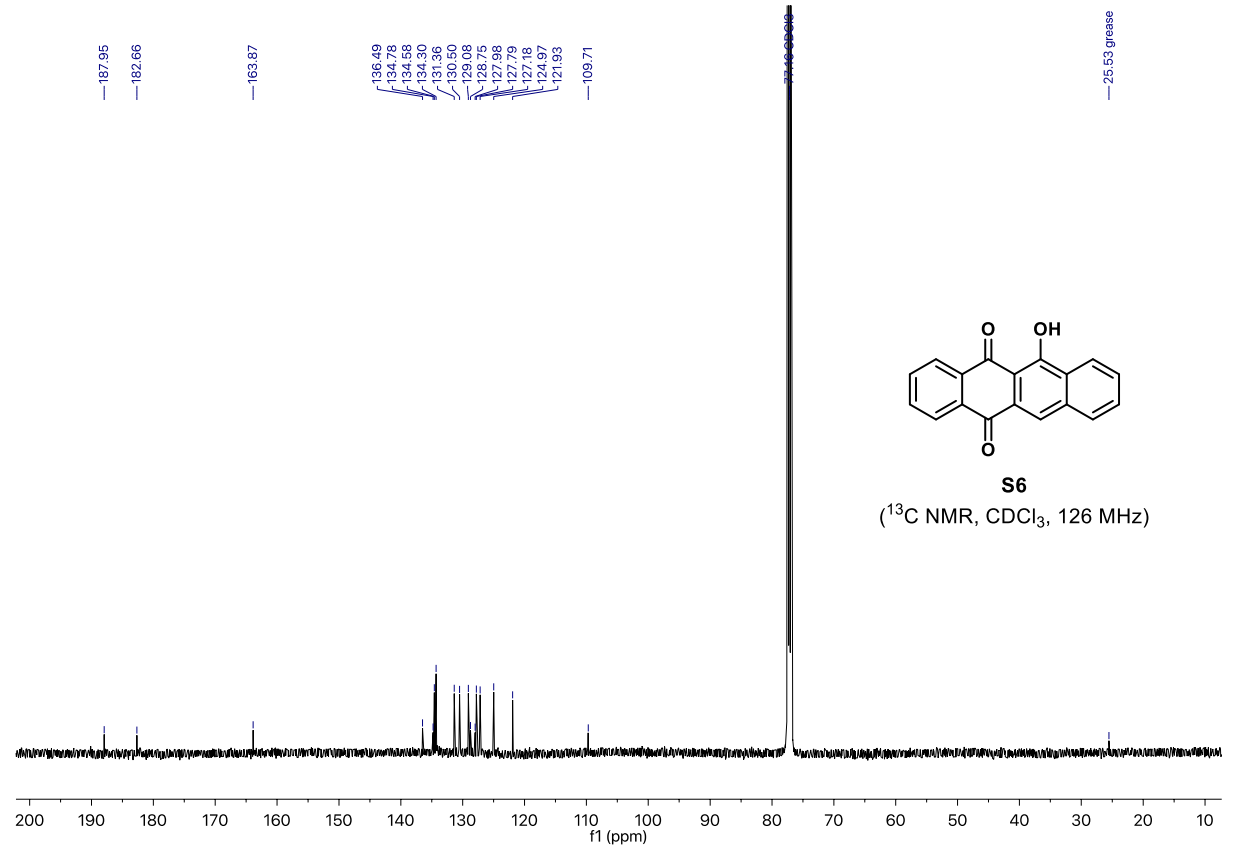
(^{1}H NMR, $CDCl_3$, 500 MHz)

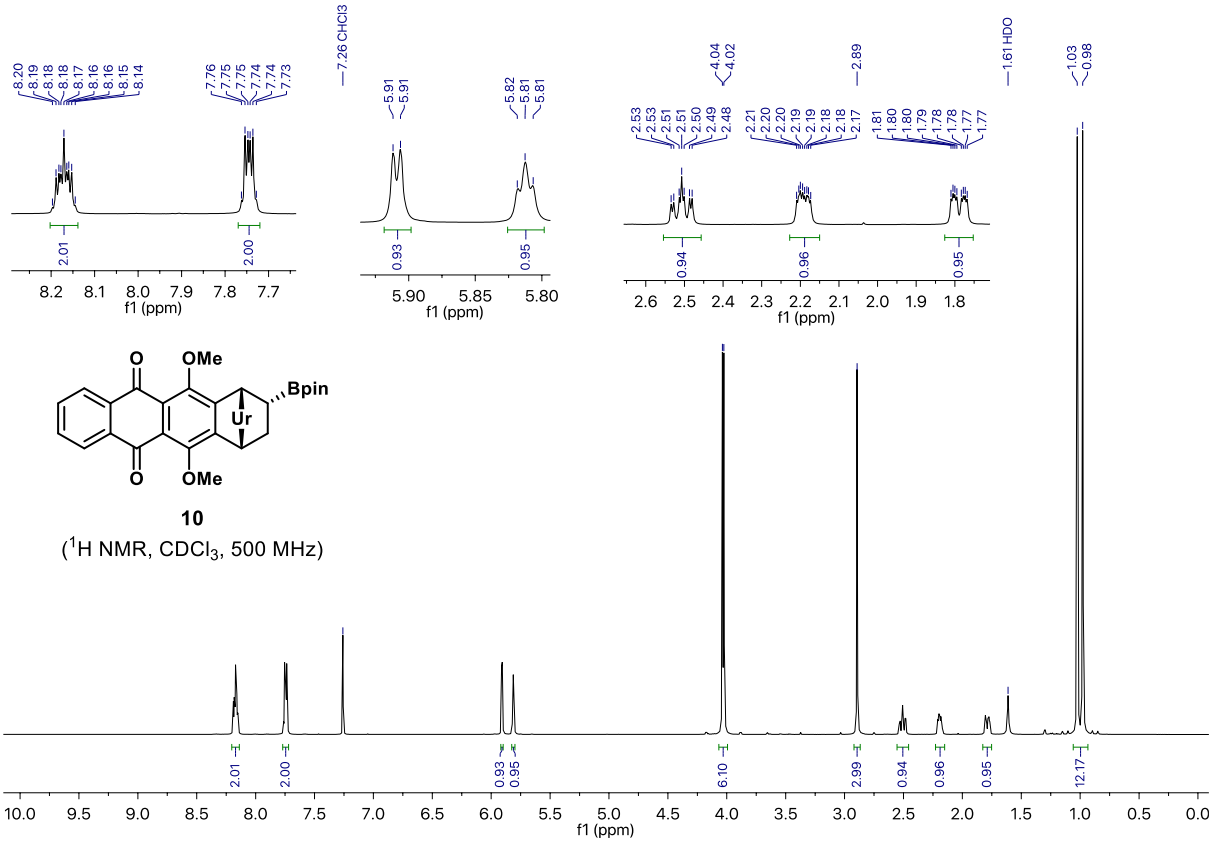


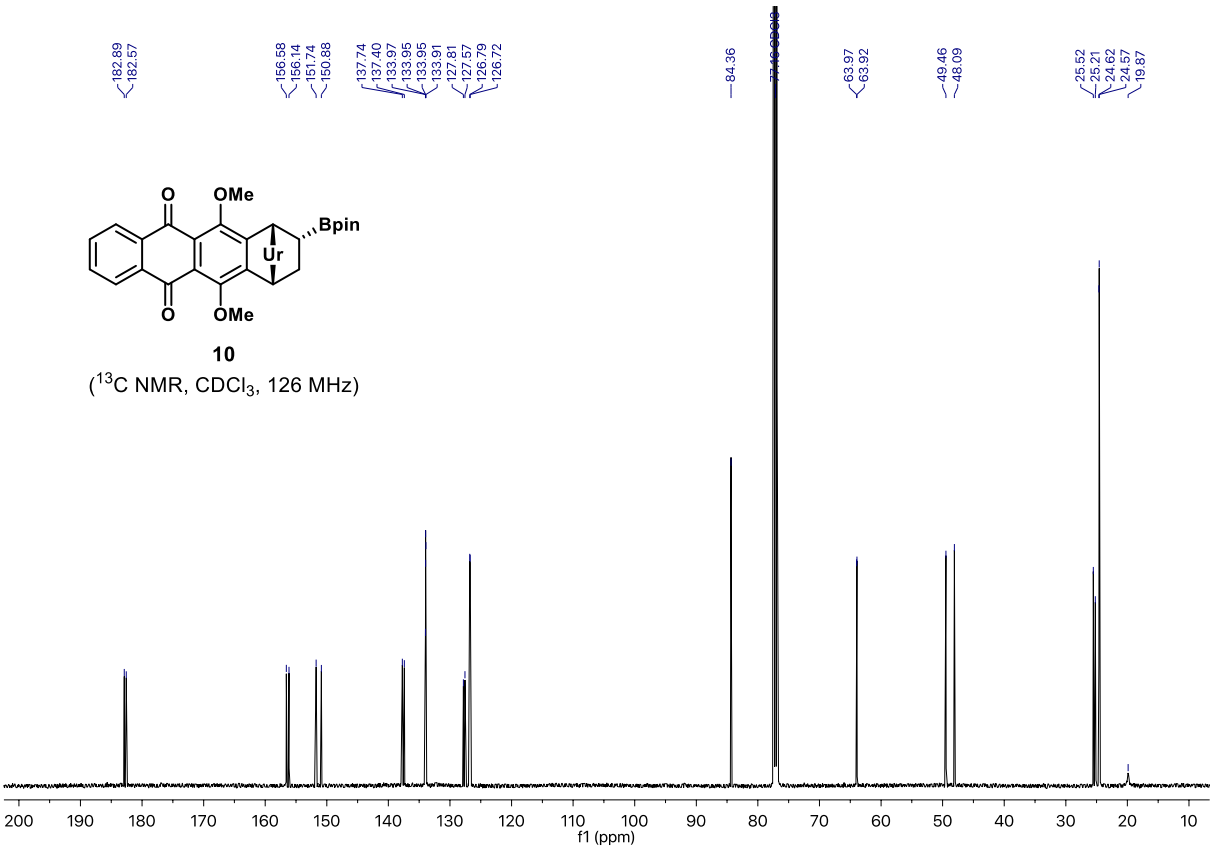
7

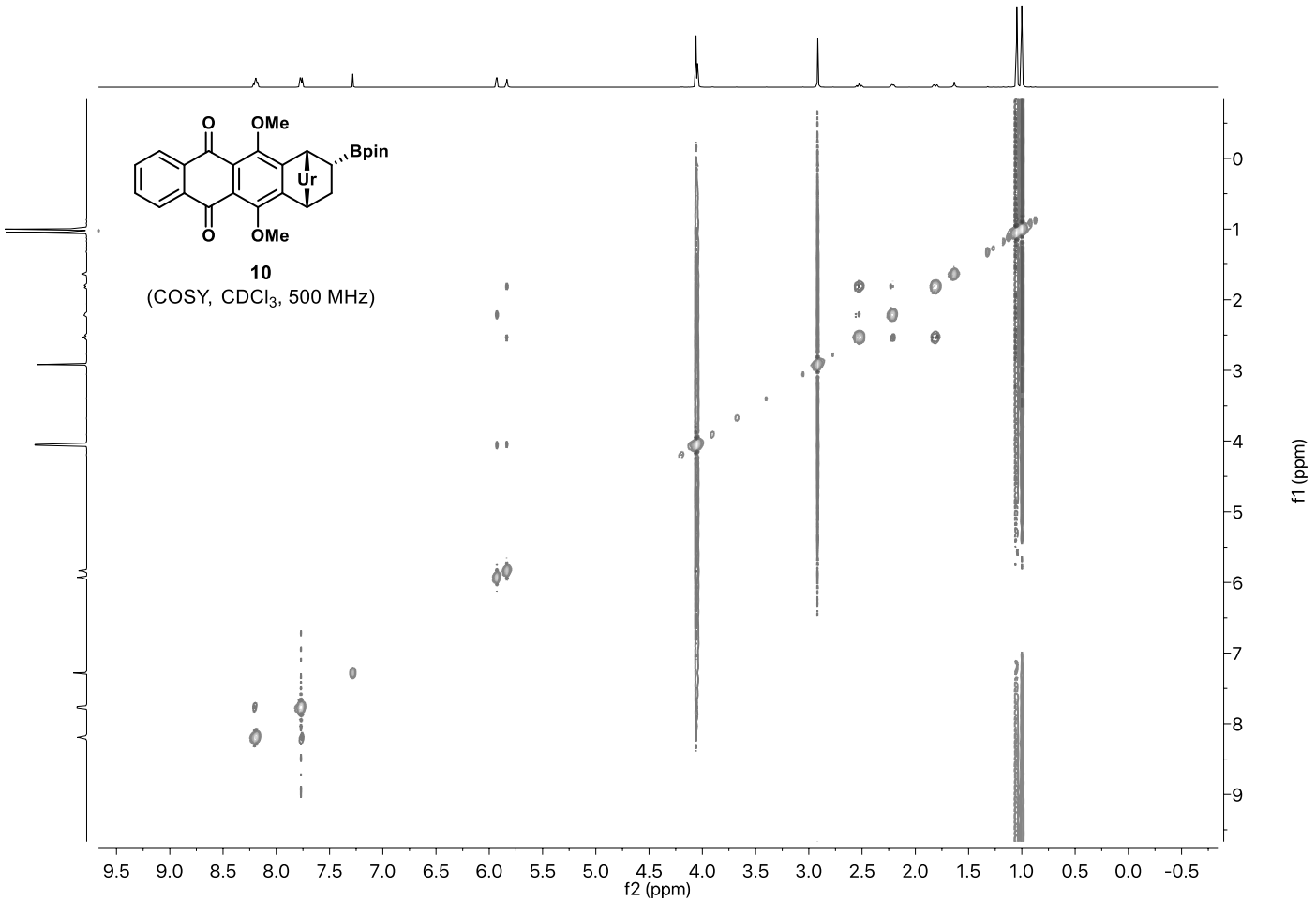
(^{1}H NMR, $CDCl_3$, 500 MHz)


14.57
7.26 CHCl3
1.54 HDO
O
OH
O
S6
(1H NMR, CDCl3, 500 MHz)
8.55
8.53
8.42
8.40
8.39
8.38
8.34
8.02
8.00
7.84
7.83
7.82
7.76
7.75
7.73
7.72
7.70
7.69
1.00
2.87
0.95
1.91
2.00
8.7 8.6 8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6
f1 (ppm)
0.84
1.00
2.87
0.95
1.91
2.00
5.0 14.5 14.0 13.5 13.0 12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

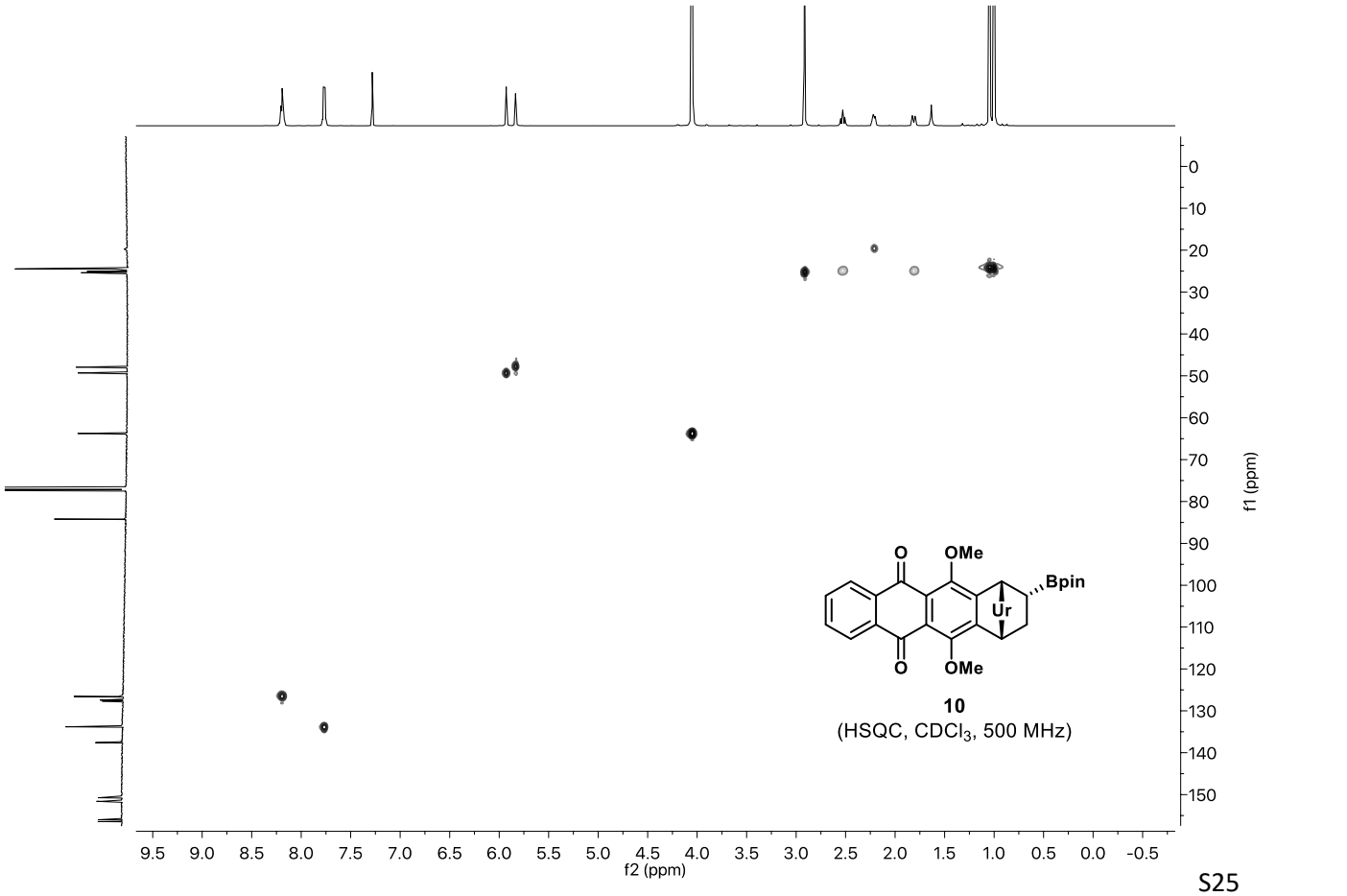

187.95
182.66
163.87
136.49
134.78
134.58
134.30
131.36
130.50
129.08
128.75
127.98
127.79
127.18
124.97
121.93
109.71
77.16 CDCl3
25.53 grease
O
OH
O
S6
(13C NMR, CDCl3, 126 MHz)
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)


OMe
Bpin
Ur
OMe
10
(1H NMR, CDCl3, 500 MHz)
f1 (ppm)

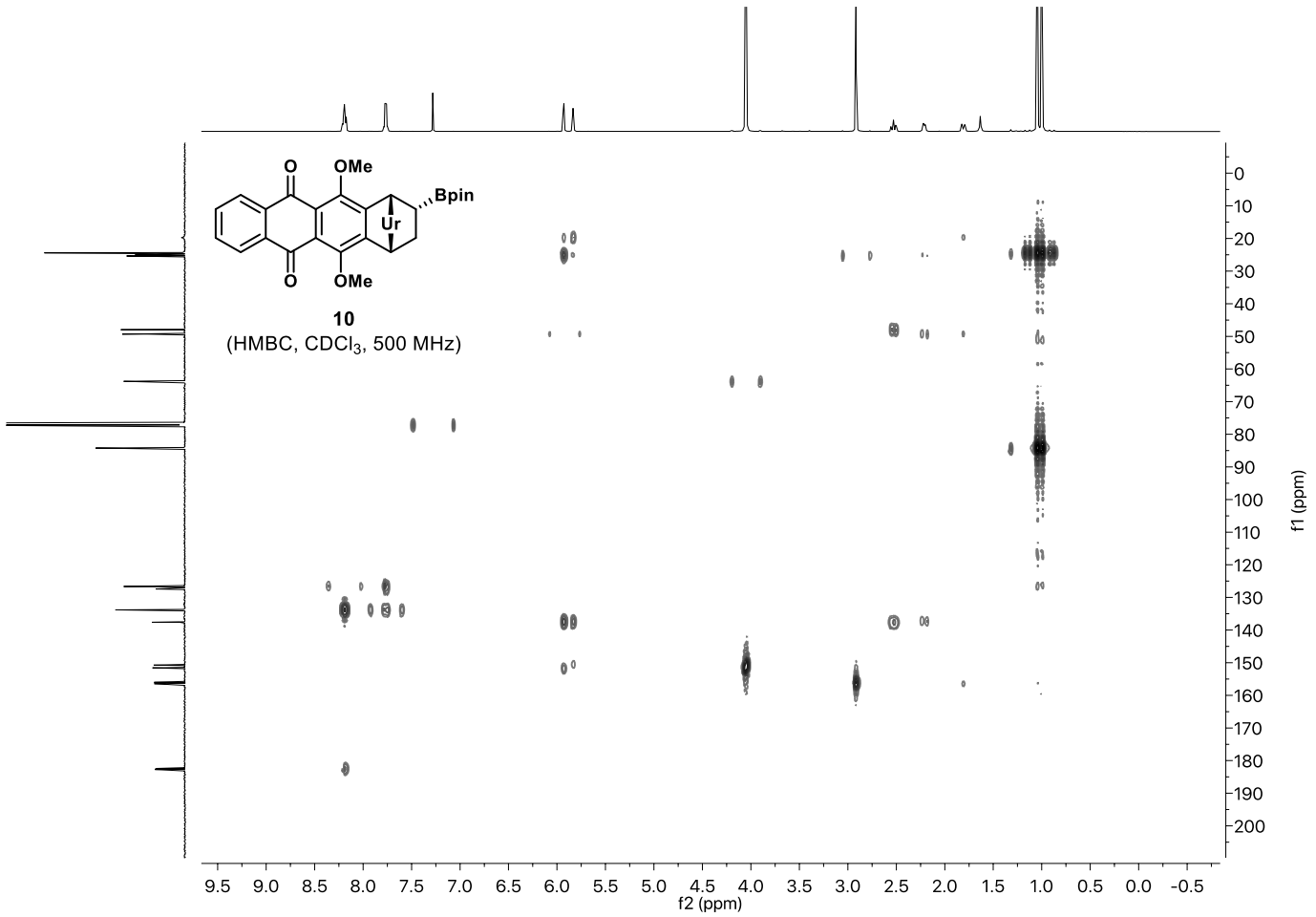

OMe
Bpin
Ur
OMe
10
(13C NMR, CDCl3, 126 MHz)
f1 (ppm)



10
(COSY, $CDCl_3$, 500 MHz)

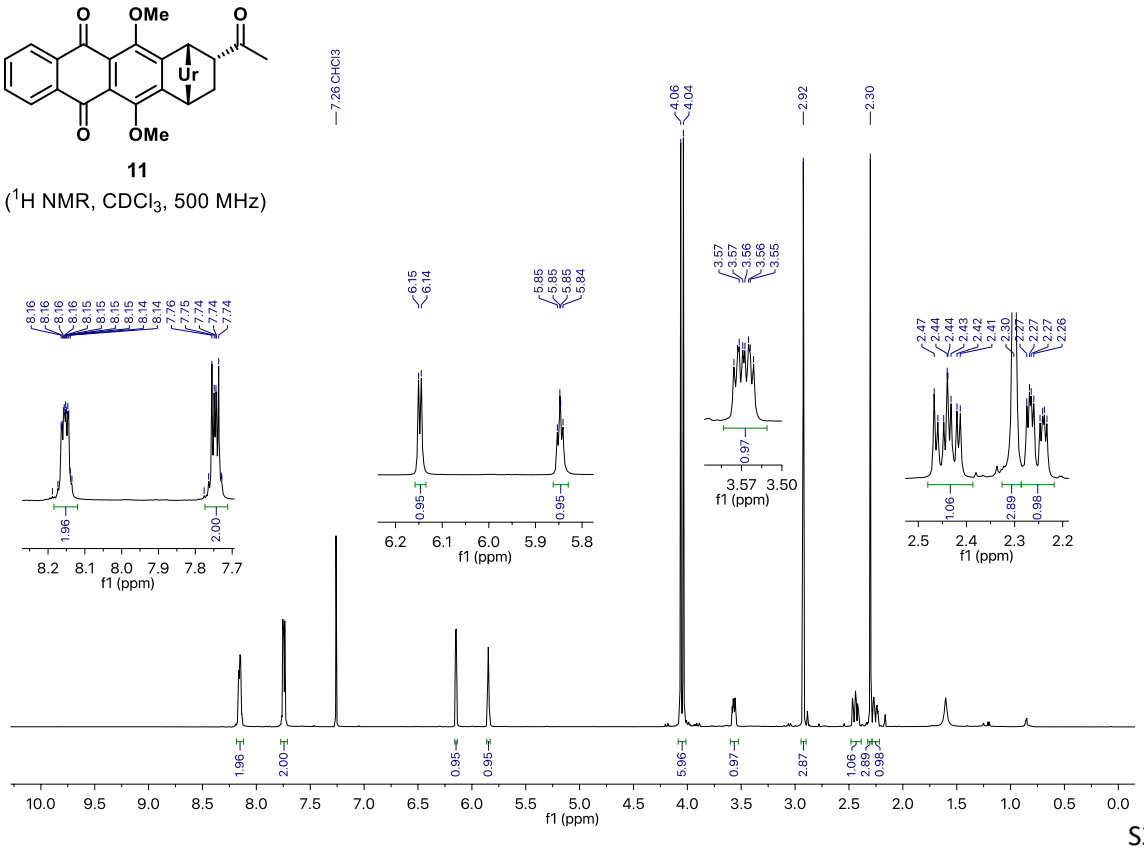


10
(HSQC, $CDCl_3$, 500 MHz)



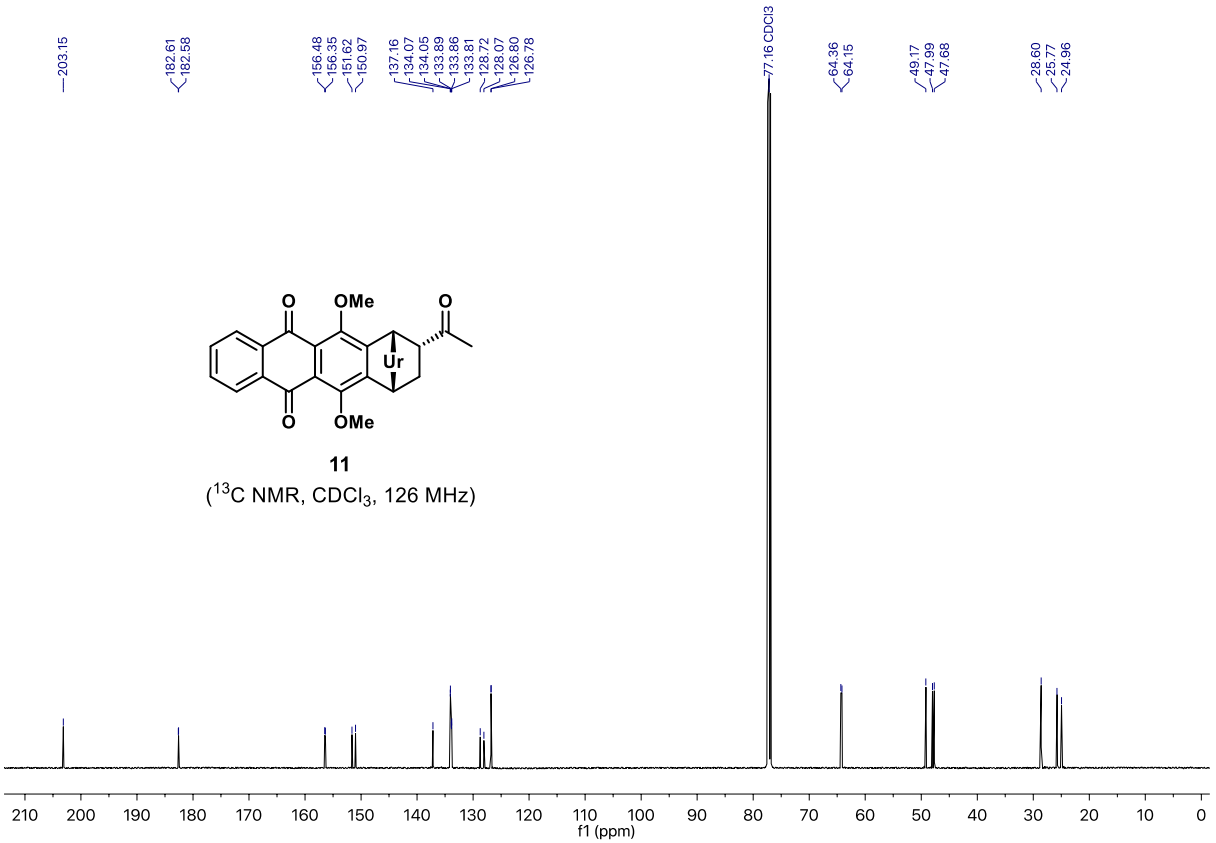
10

(HMBC, $CDCl_3$, 500 MHz)



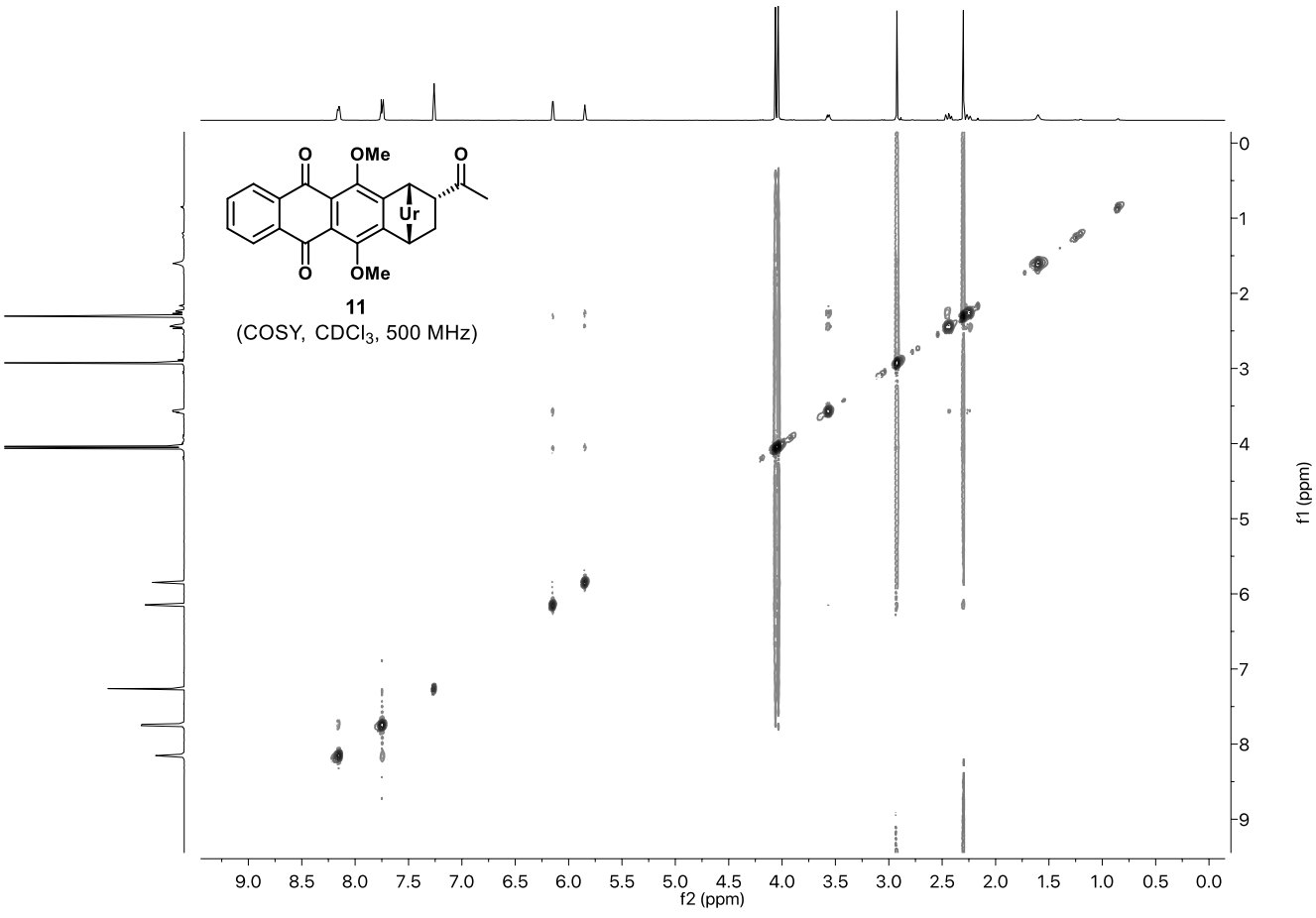
11

(^{1}H NMR, $CDCl_3$, 500 MHz)



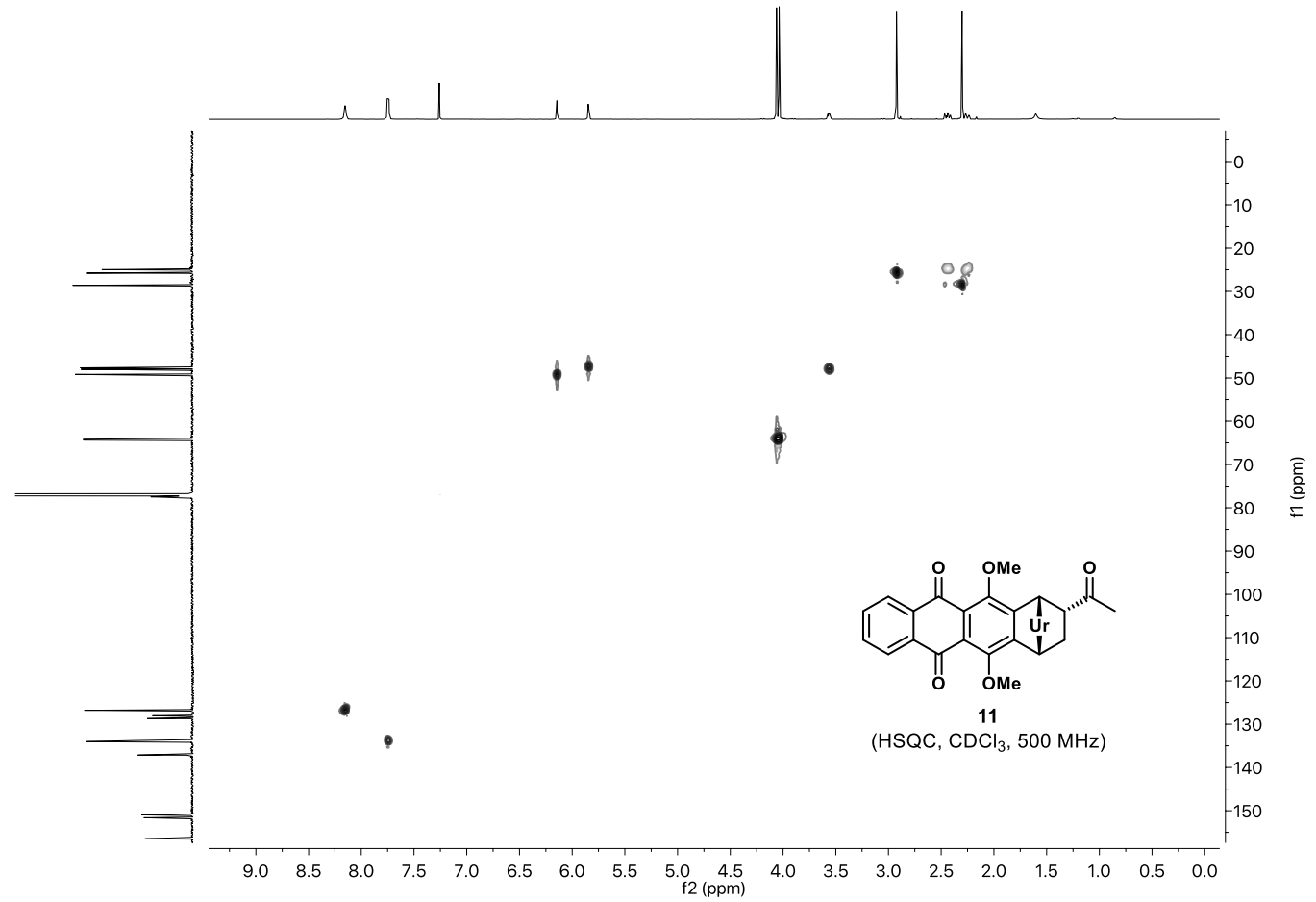
11

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

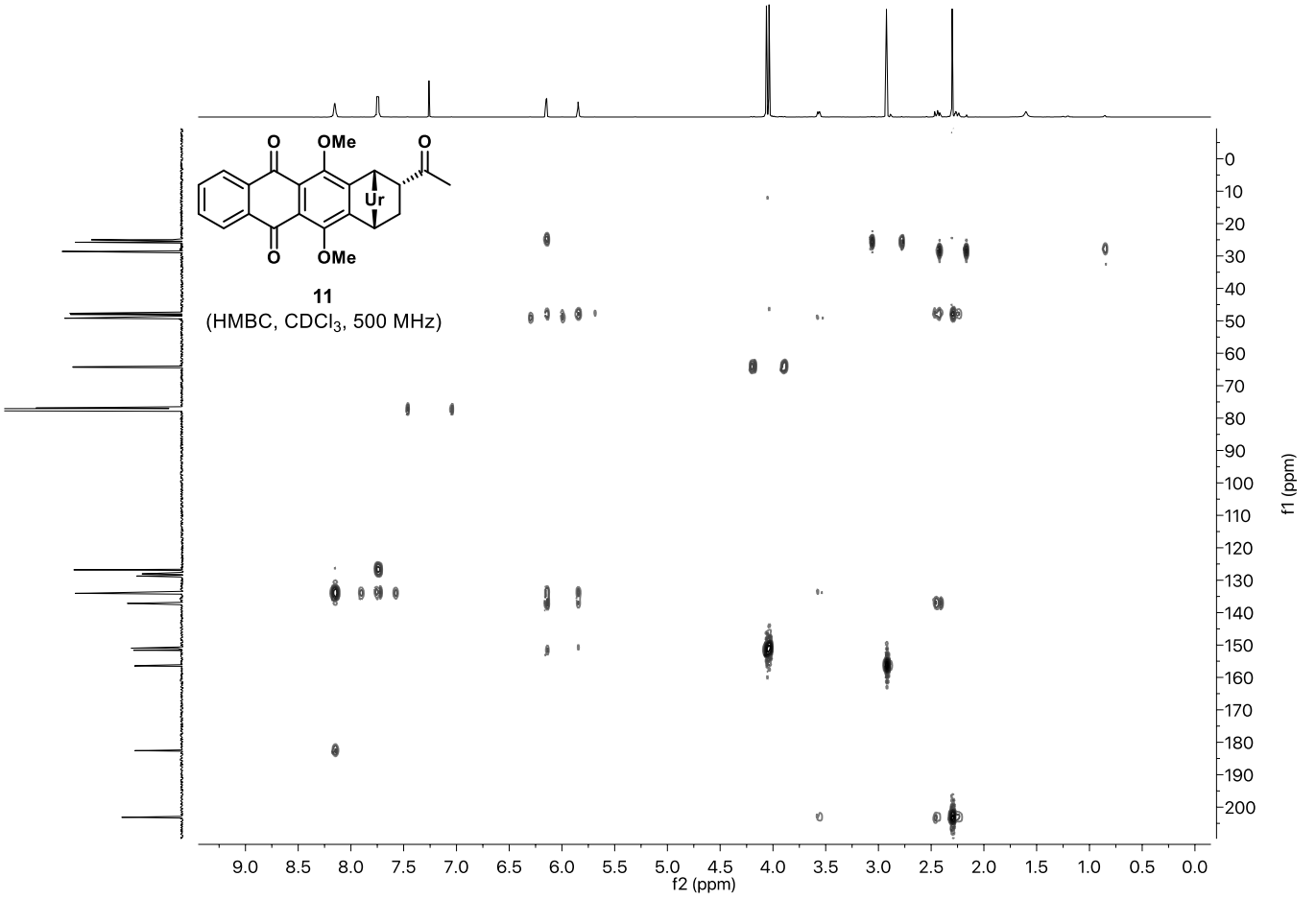


11

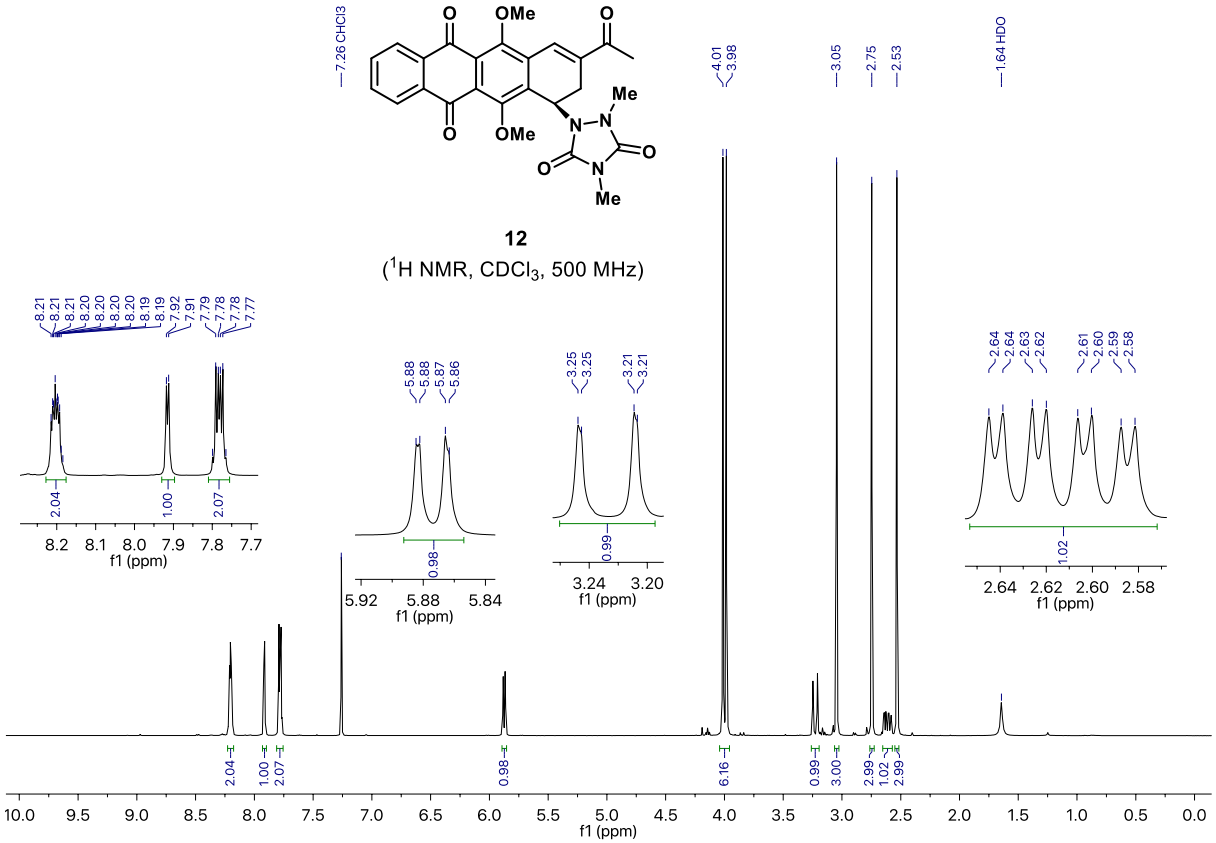
(COSY, $CDCl_3$, 500 MHz)



11
(HSQC, $CDCl_3$, 500 MHz)

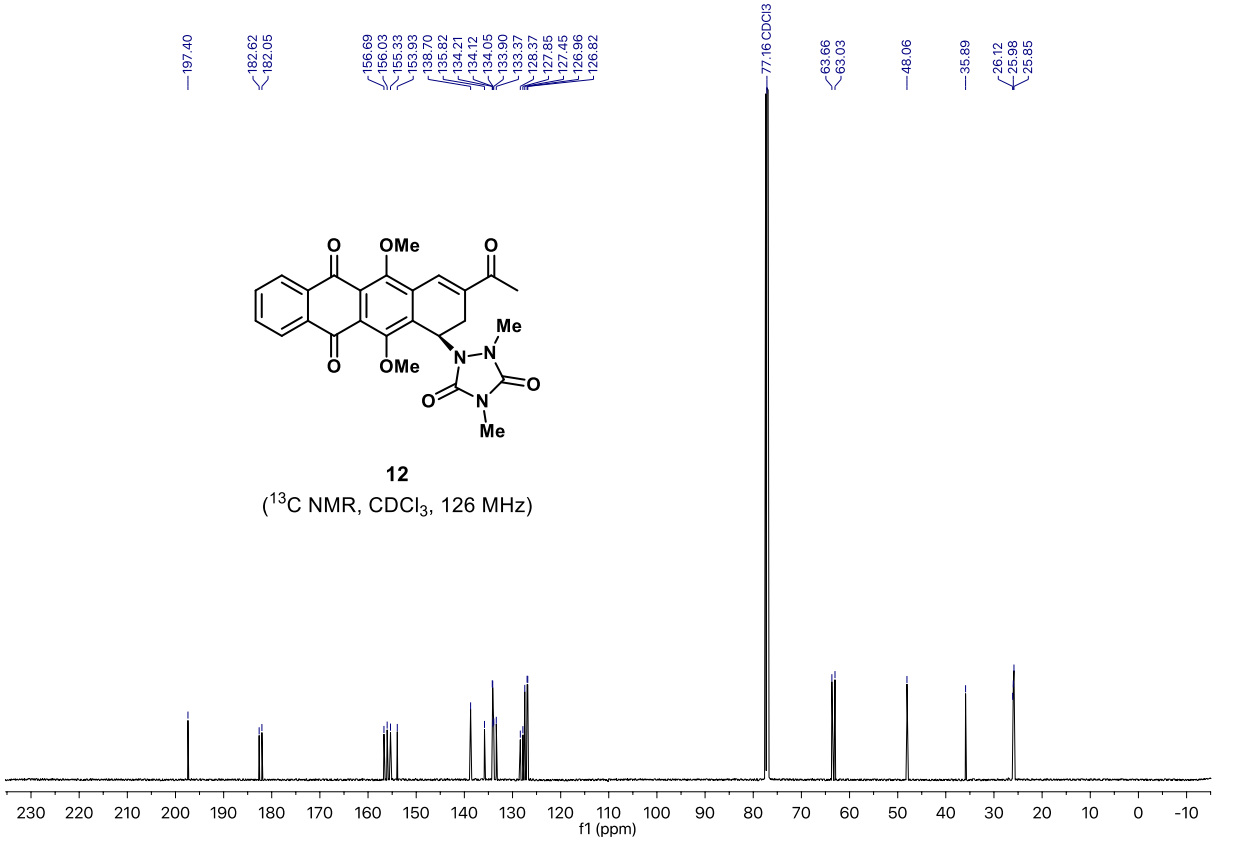


11
(HMBC, $CDCl_3$, 500 MHz)



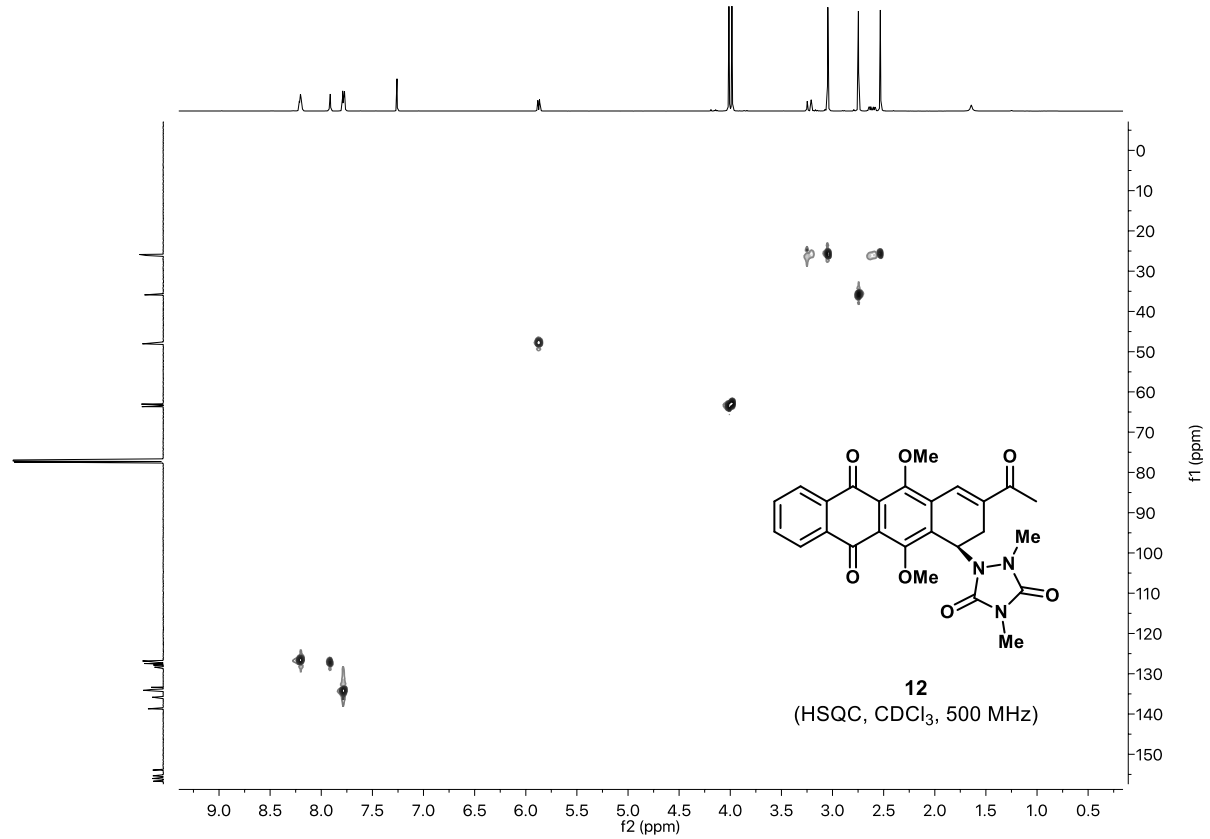
12

(^{1}H NMR, $CDCl_3$, 500 MHz)

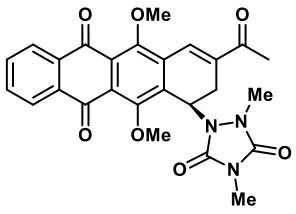


12

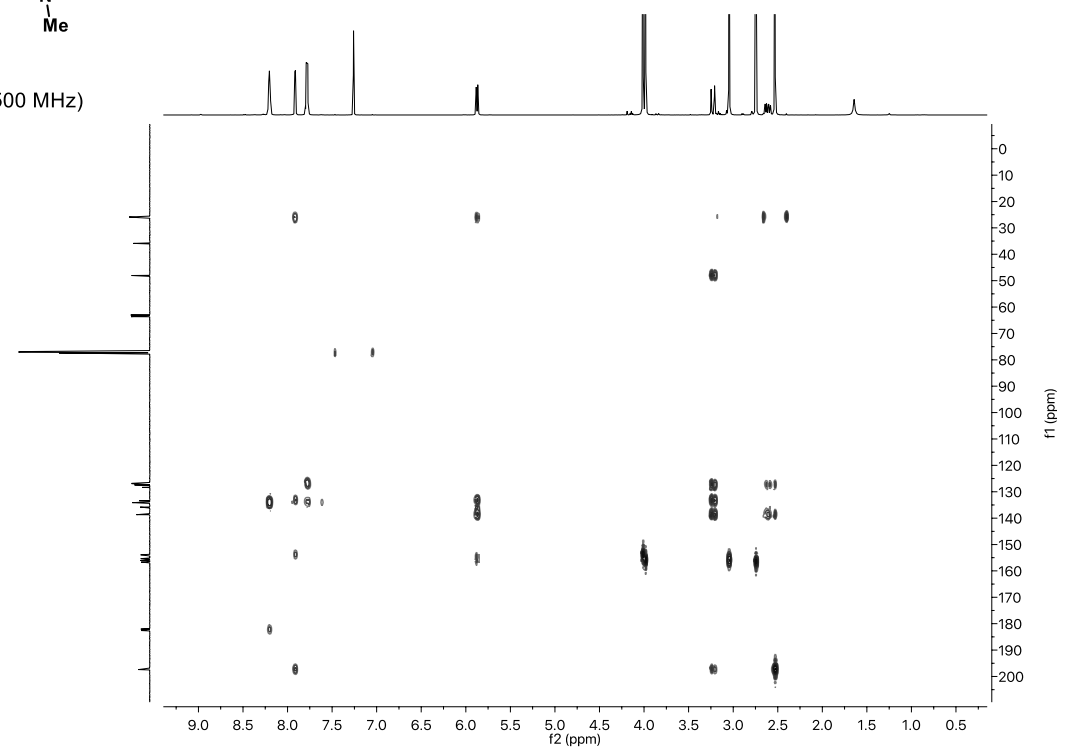
(^{13}C NMR, $CDCl_3$, 126 MHz)

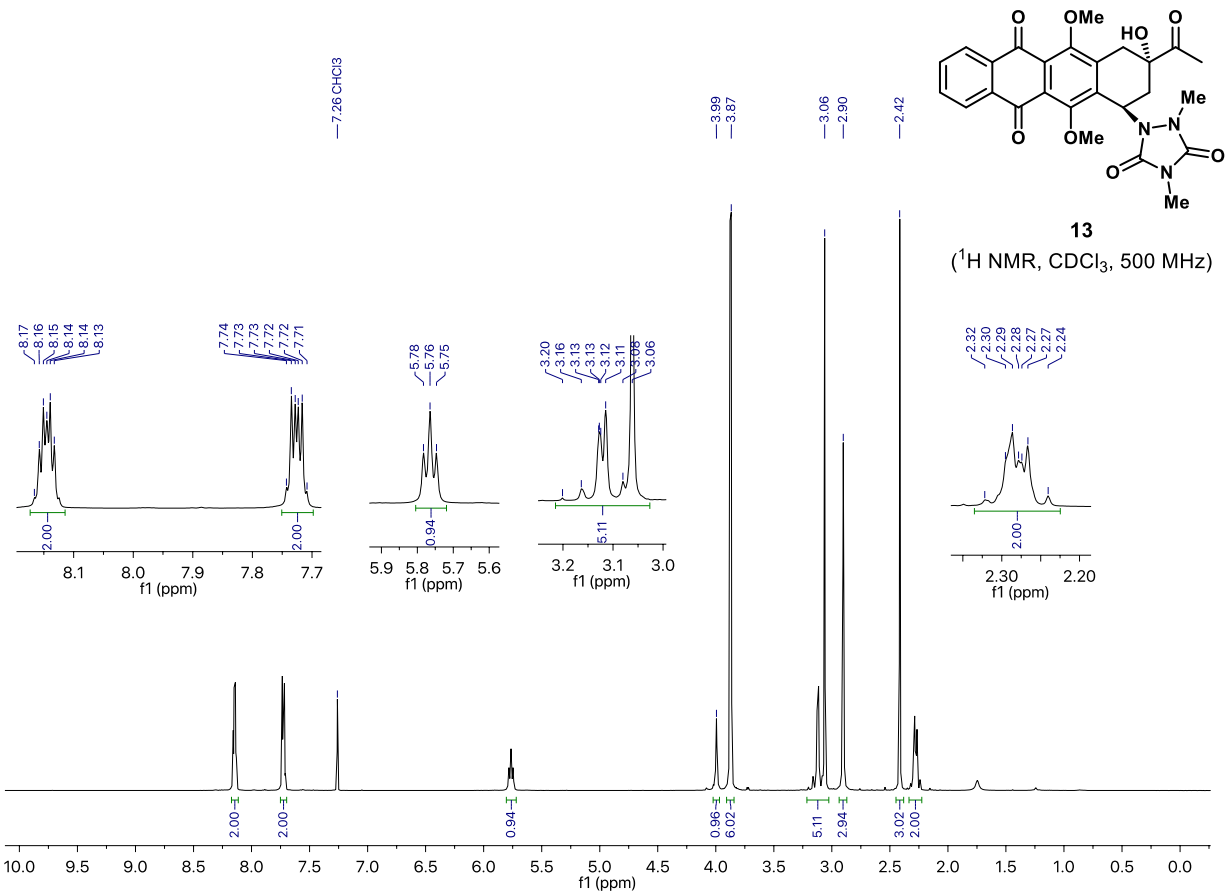


12
(HSQC, $CDCl_3$, 500 MHz)



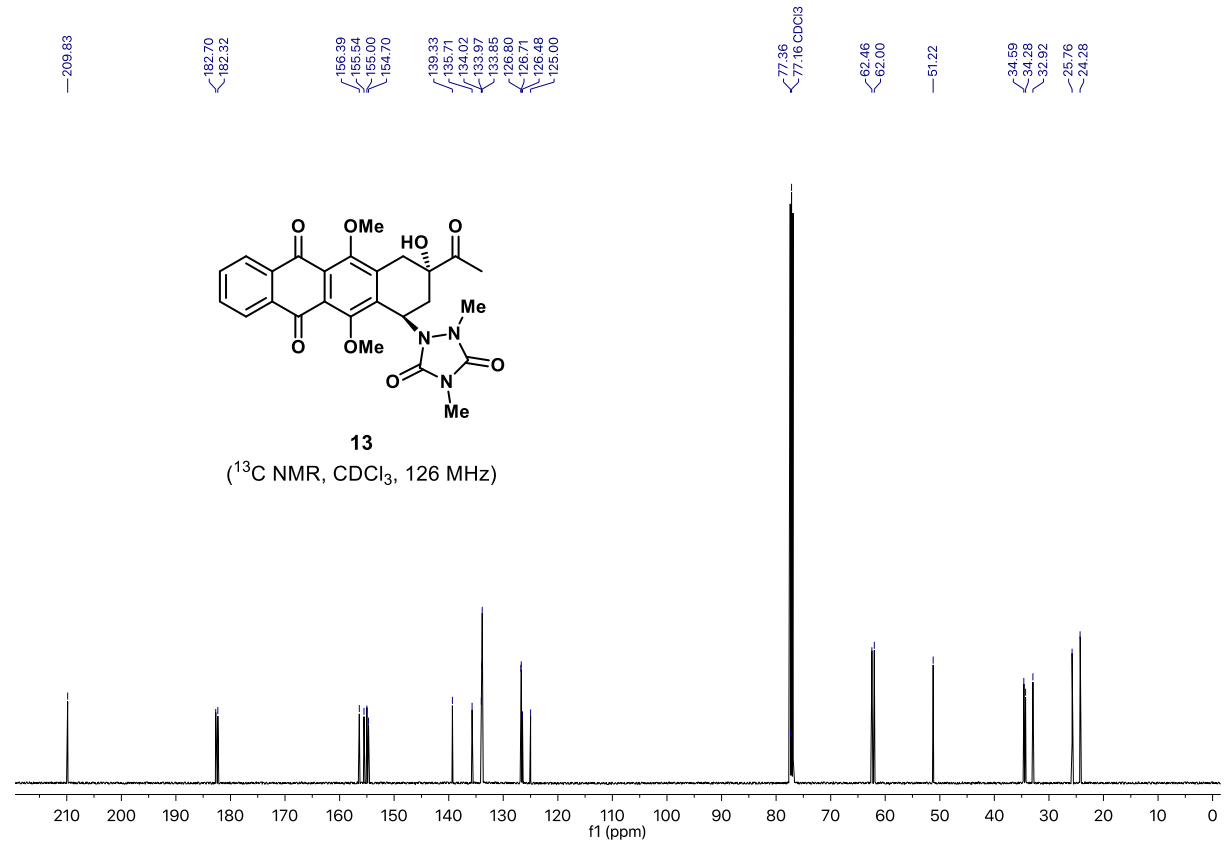
12
(HMBC, $CDCl_3$, 500 MHz)





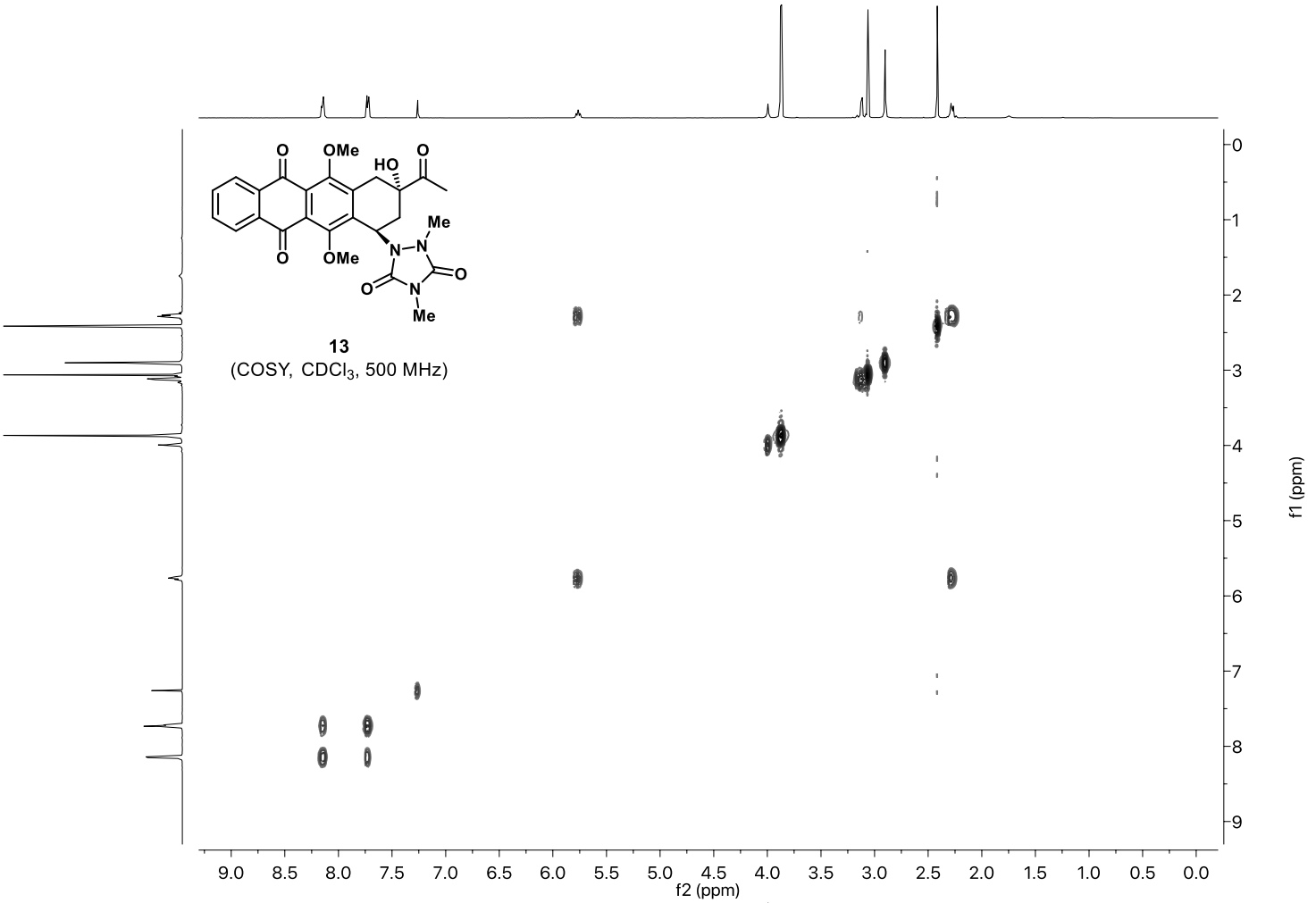
13

(^{1}H NMR, $CDCl_3$, 500 MHz)

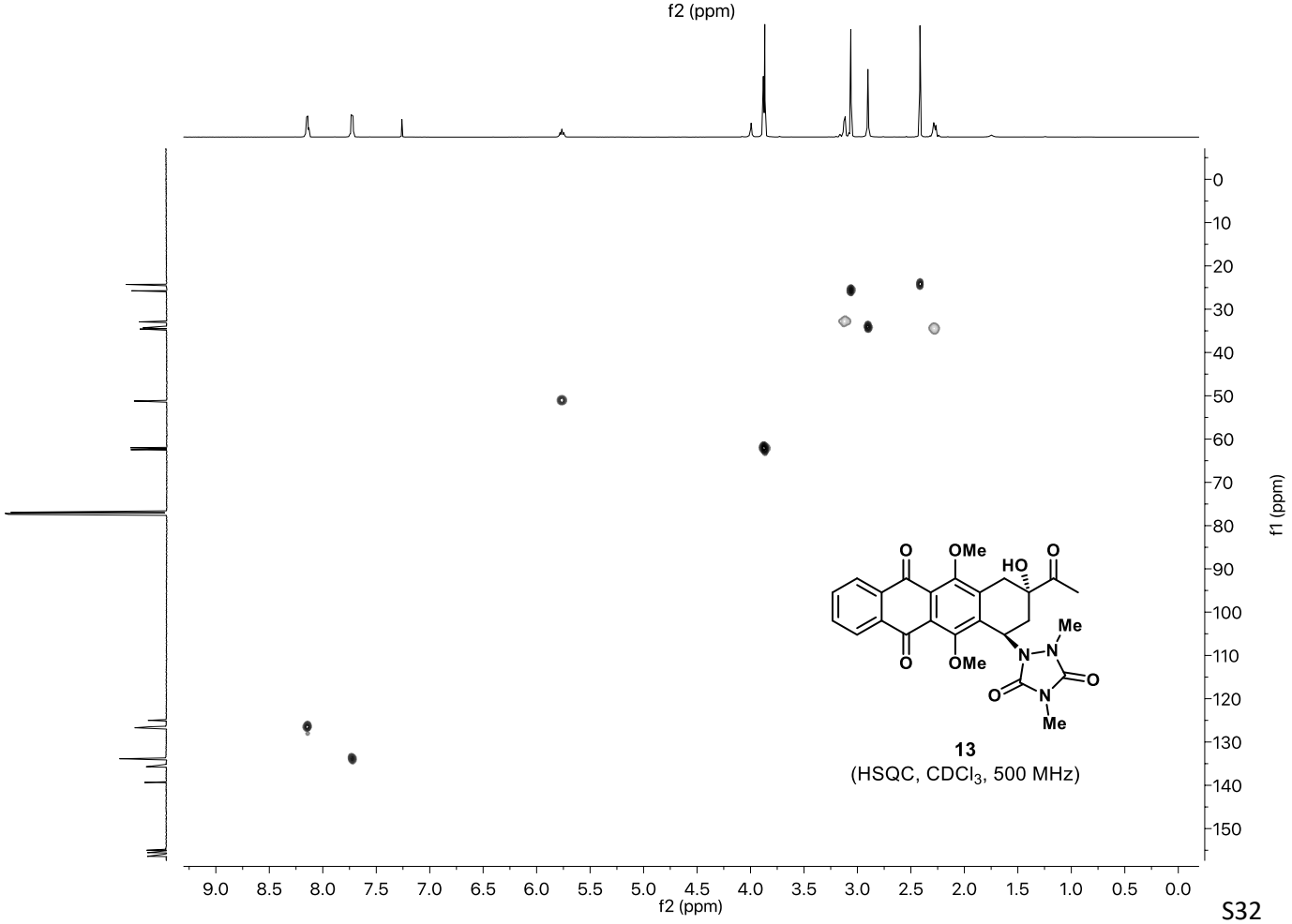


13

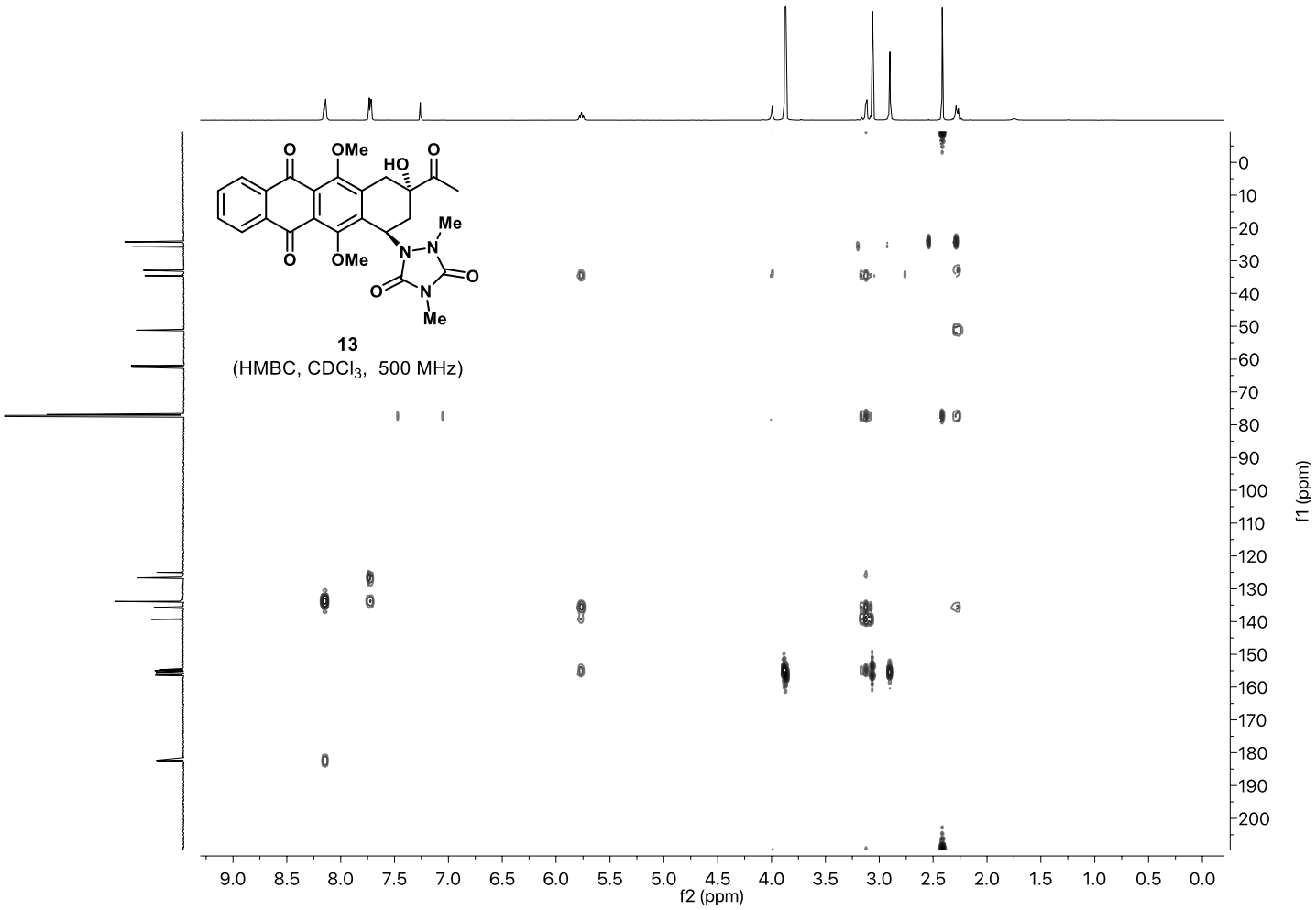
(^{13}C NMR, $CDCl_3$, 126 MHz)



13
(COSY, $CDCl_3$, 500 MHz)

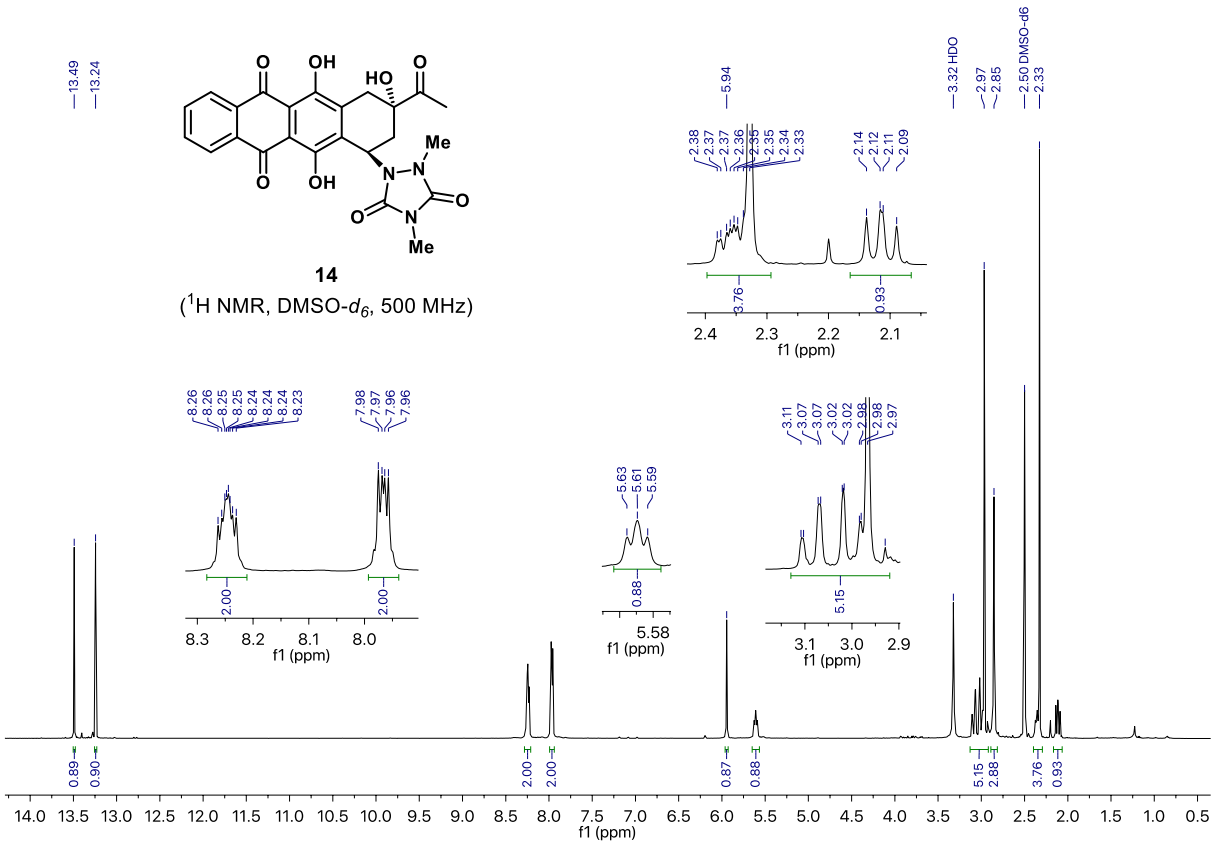


13
(HSQC, $CDCl_3$, 500 MHz)



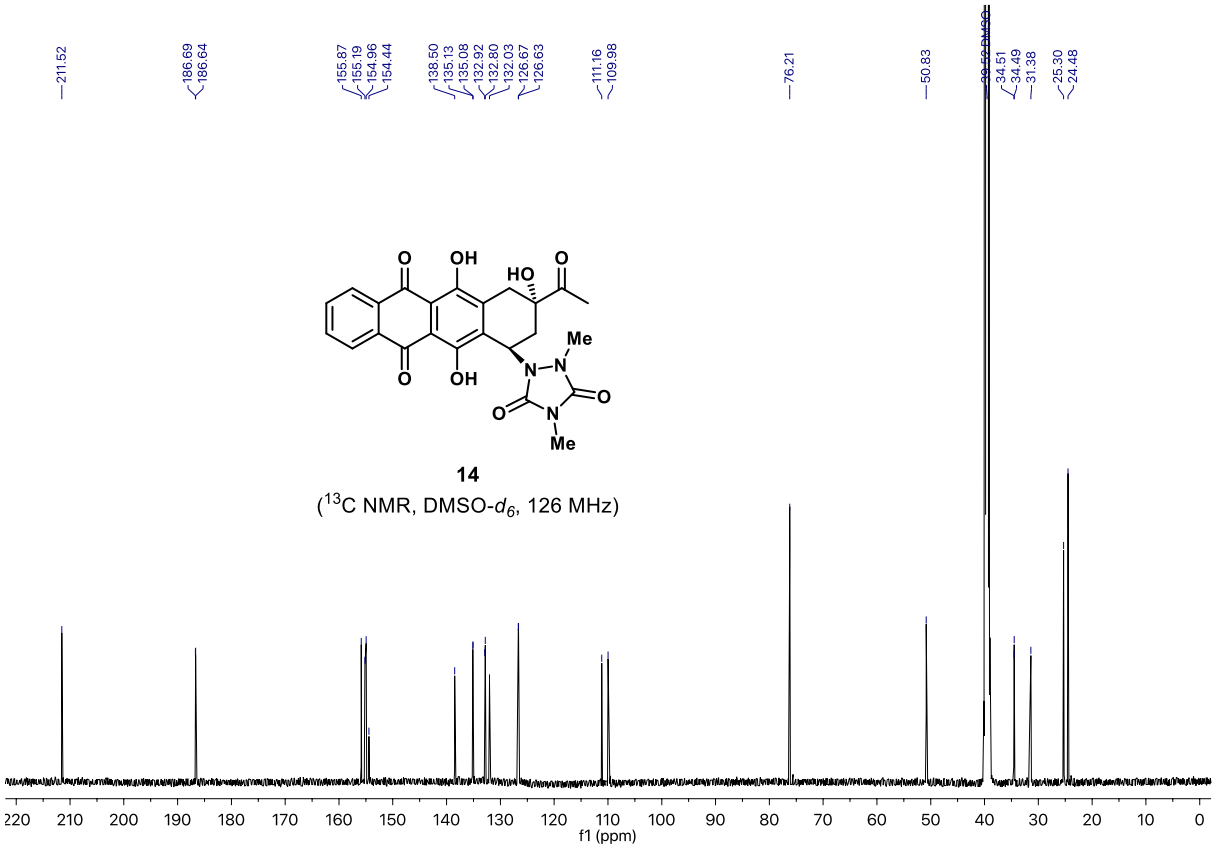
13

(HMBC, $CDCl_3$, 500 MHz)



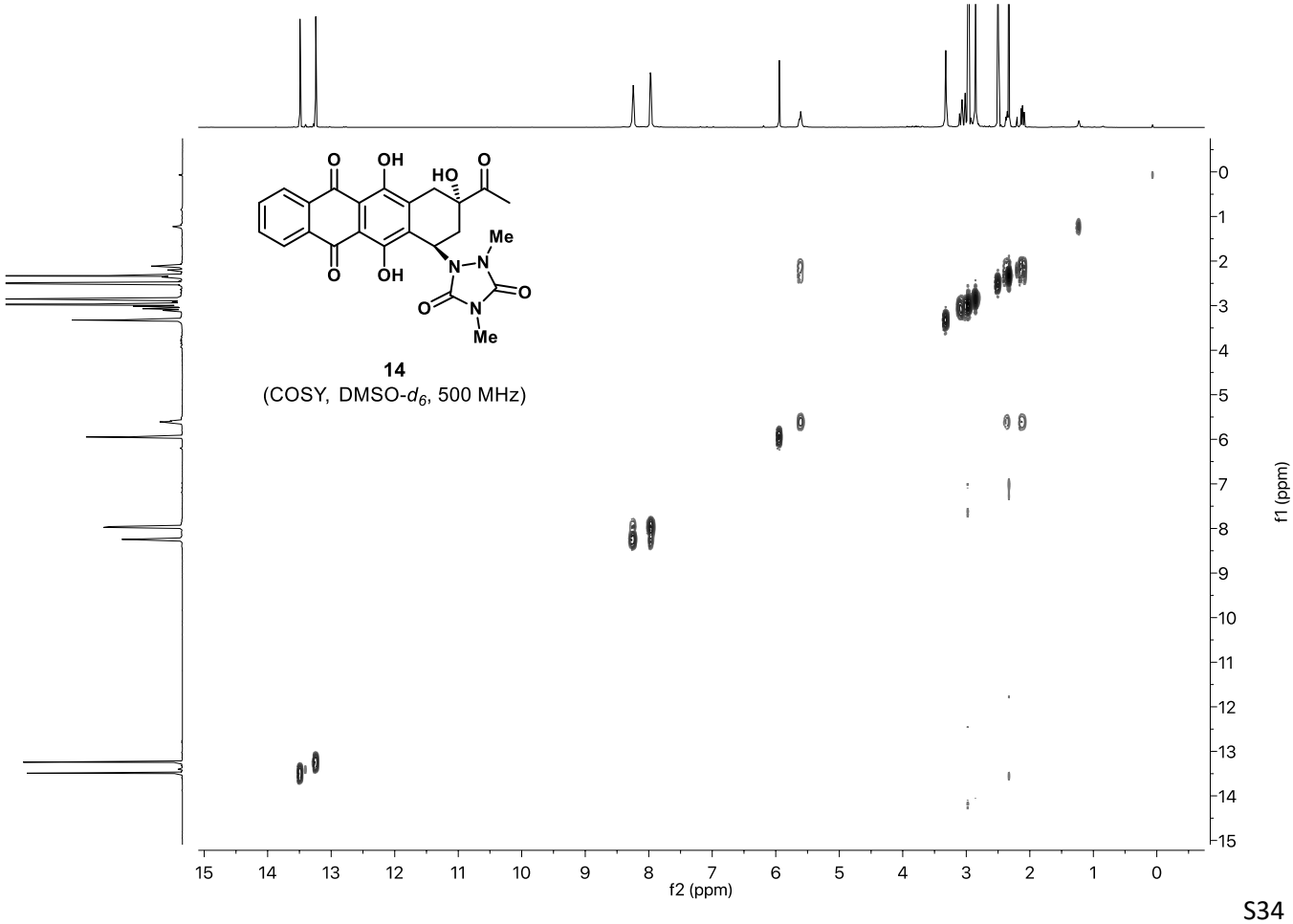
14

(^{1}H NMR, DMSO-d_6, 500 MHz)



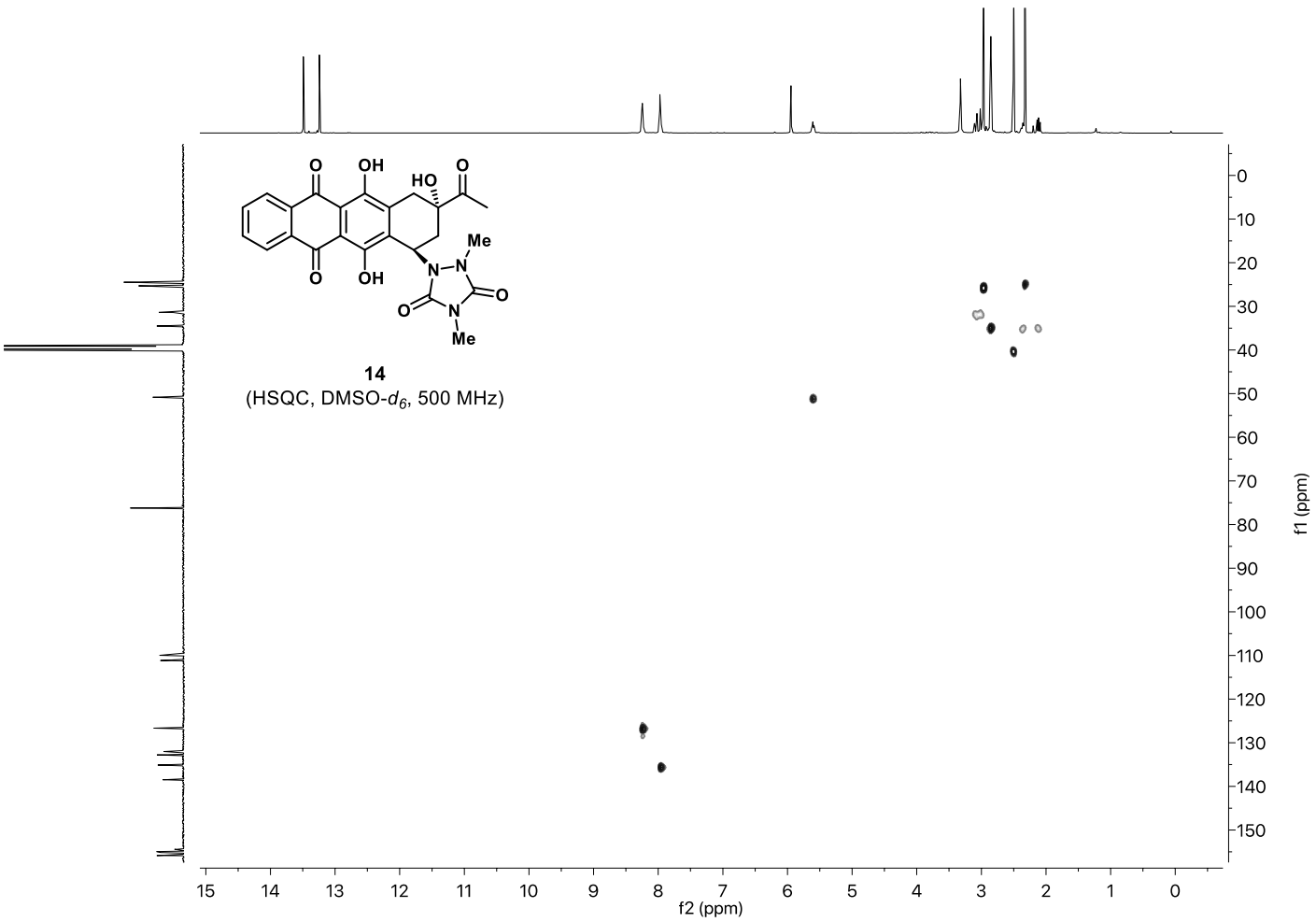
14

(^{13}C NMR, DMSO-d_6, 126 MHz)

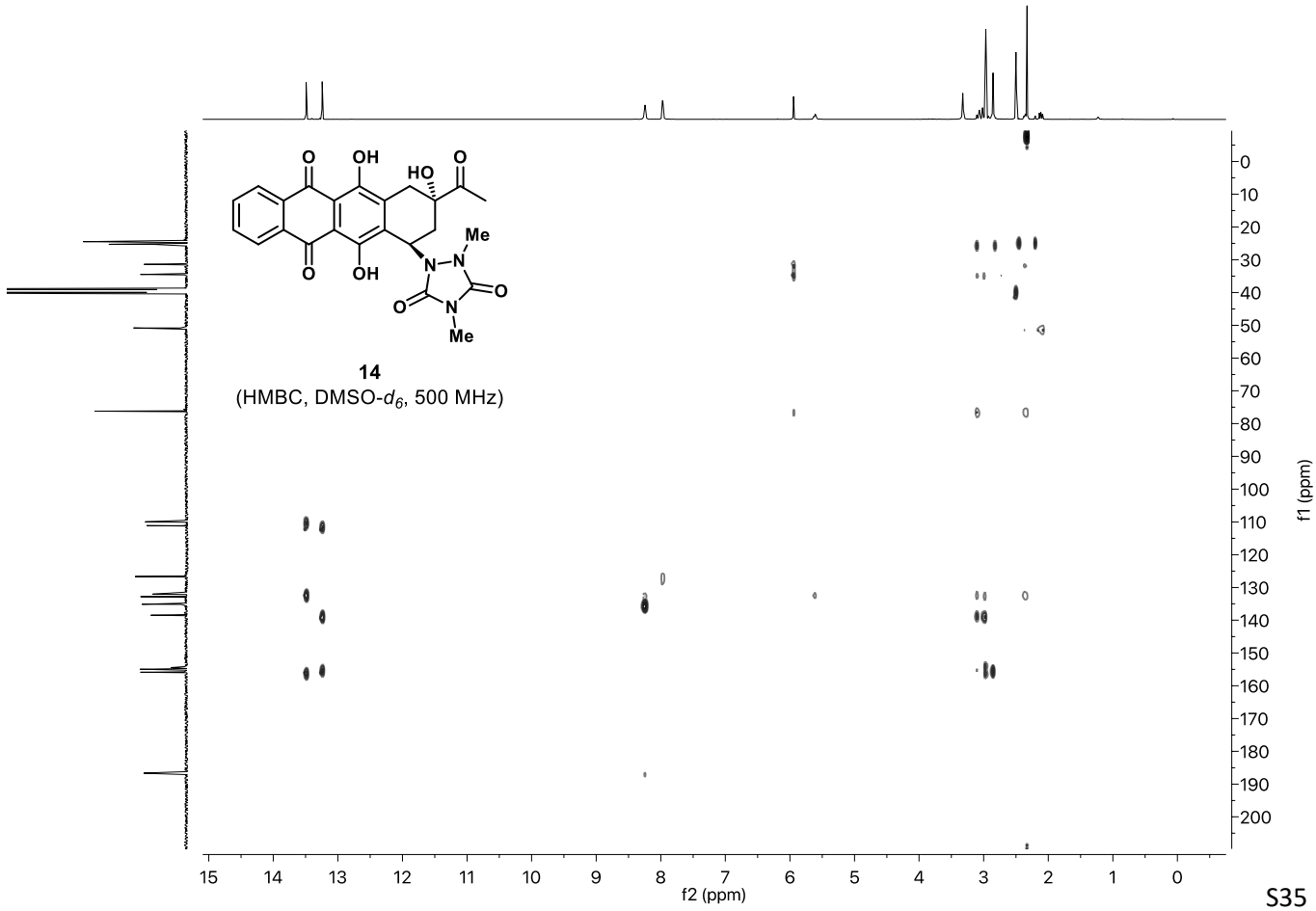


14

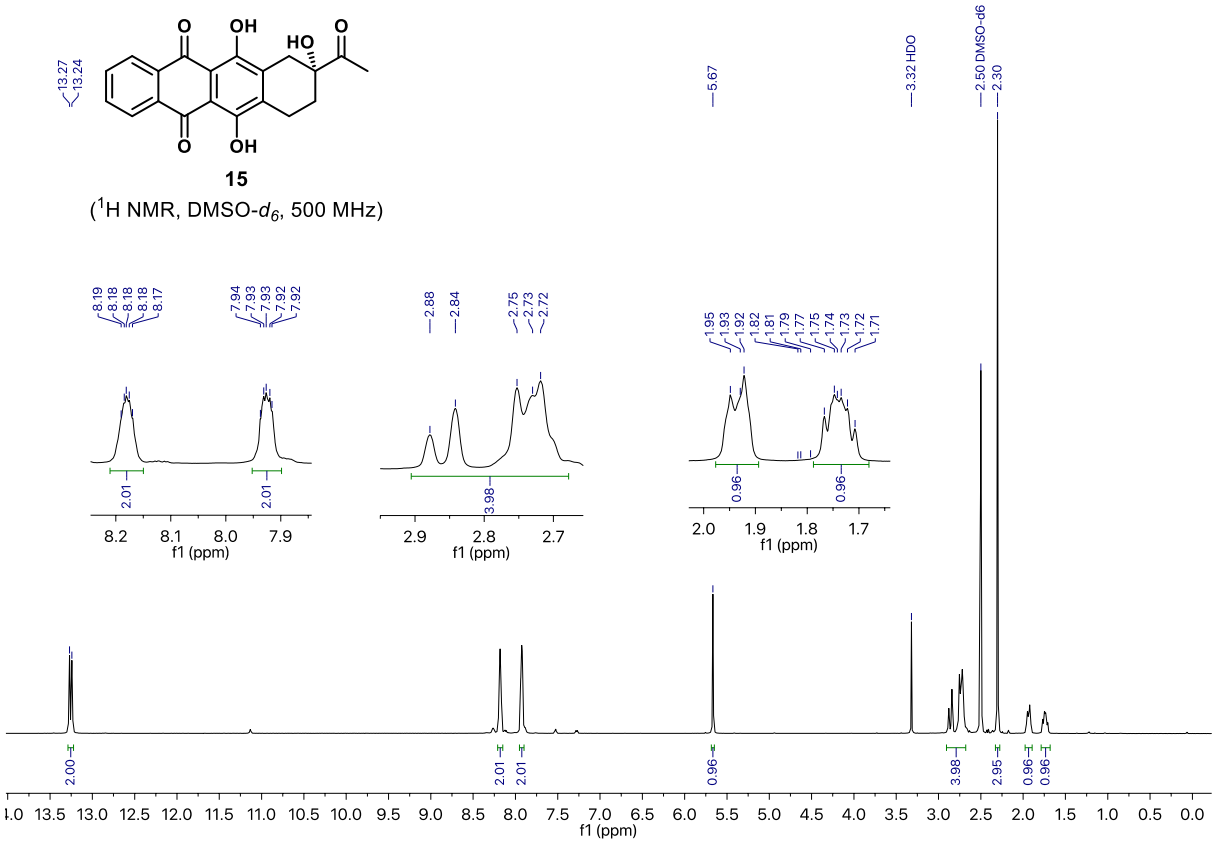
(COSY, DMSO-d_6, 500 MHz)



14
(HSQC, DMSO-d_6, 500 MHz)

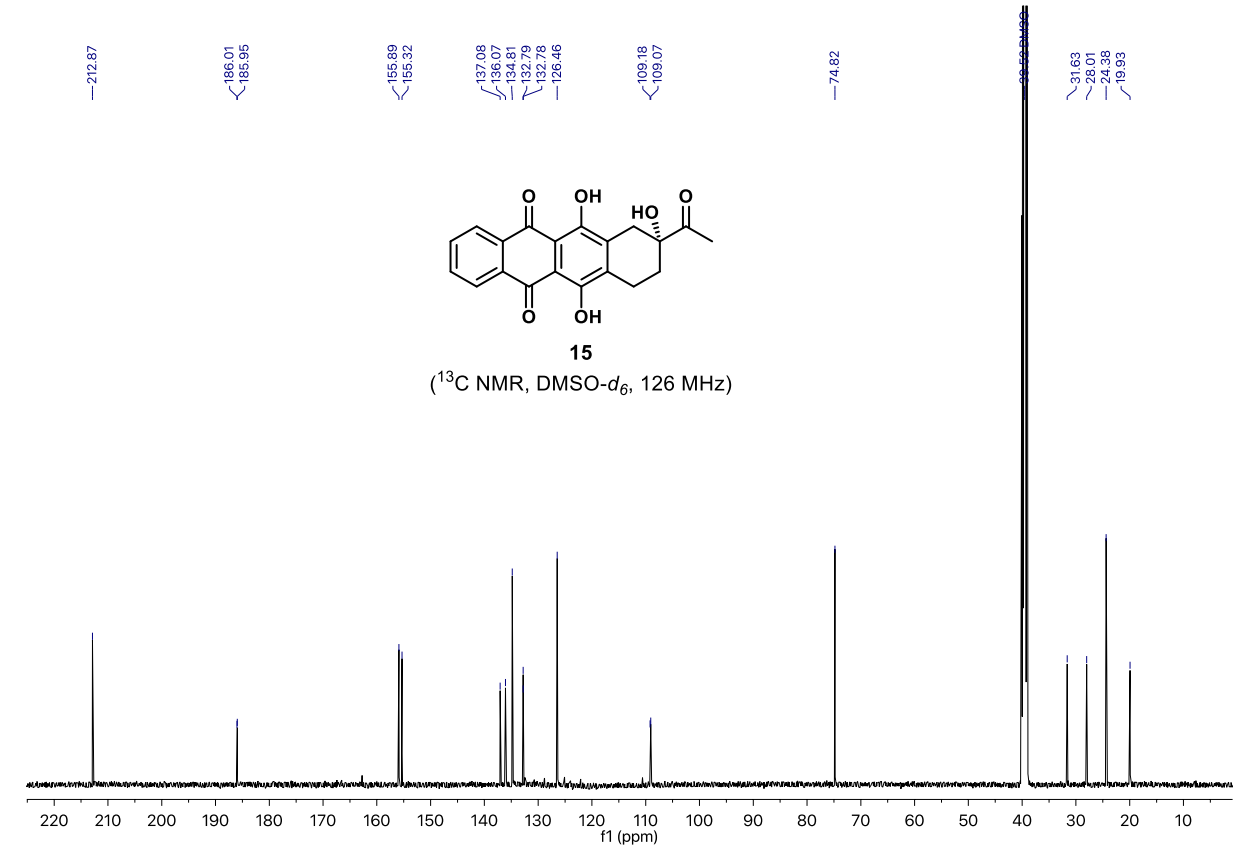


14
(HMBC, DMSO-d_6, 500 MHz)



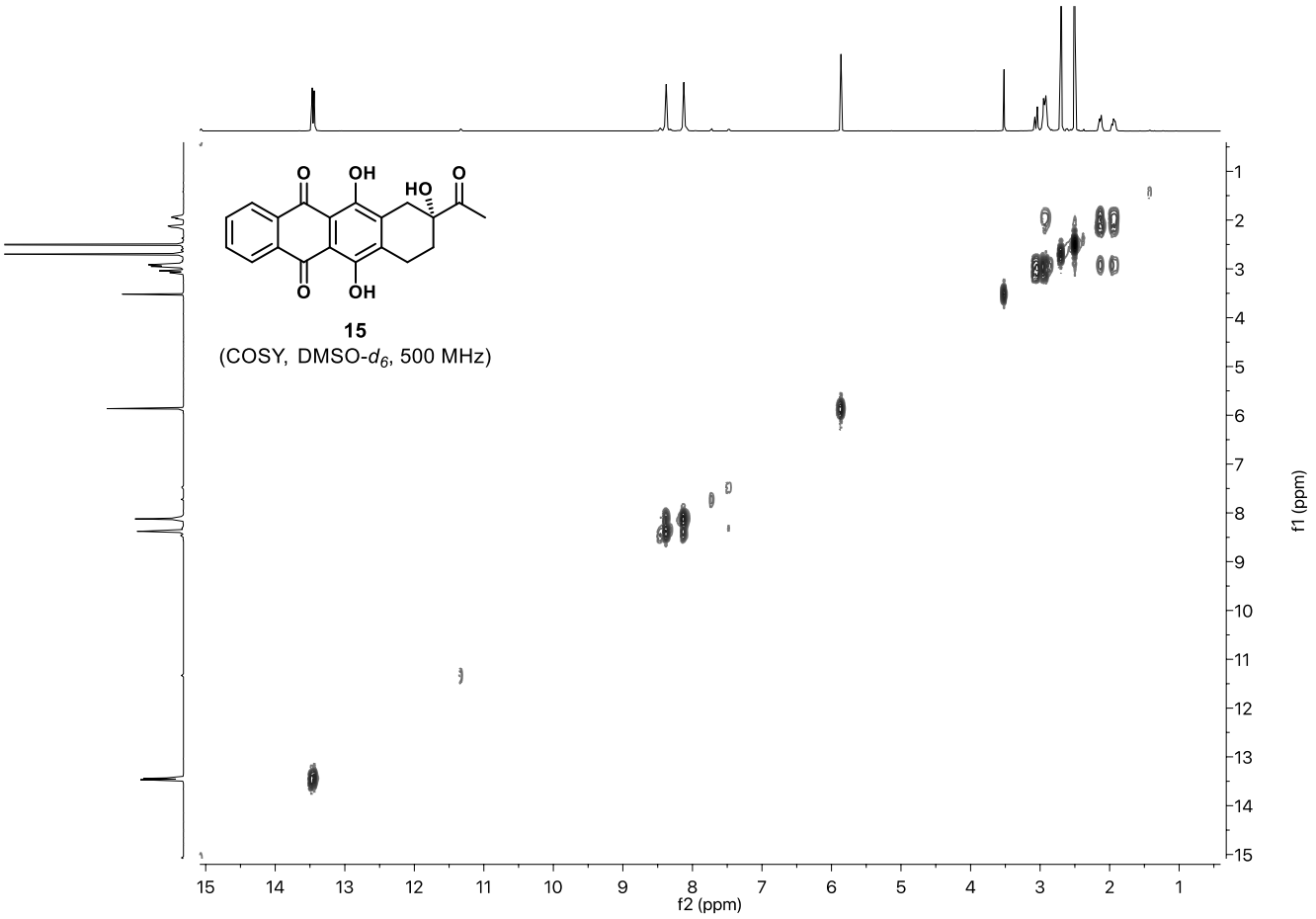
15

(^{1}H NMR, DMSO-d_6, 500 MHz)

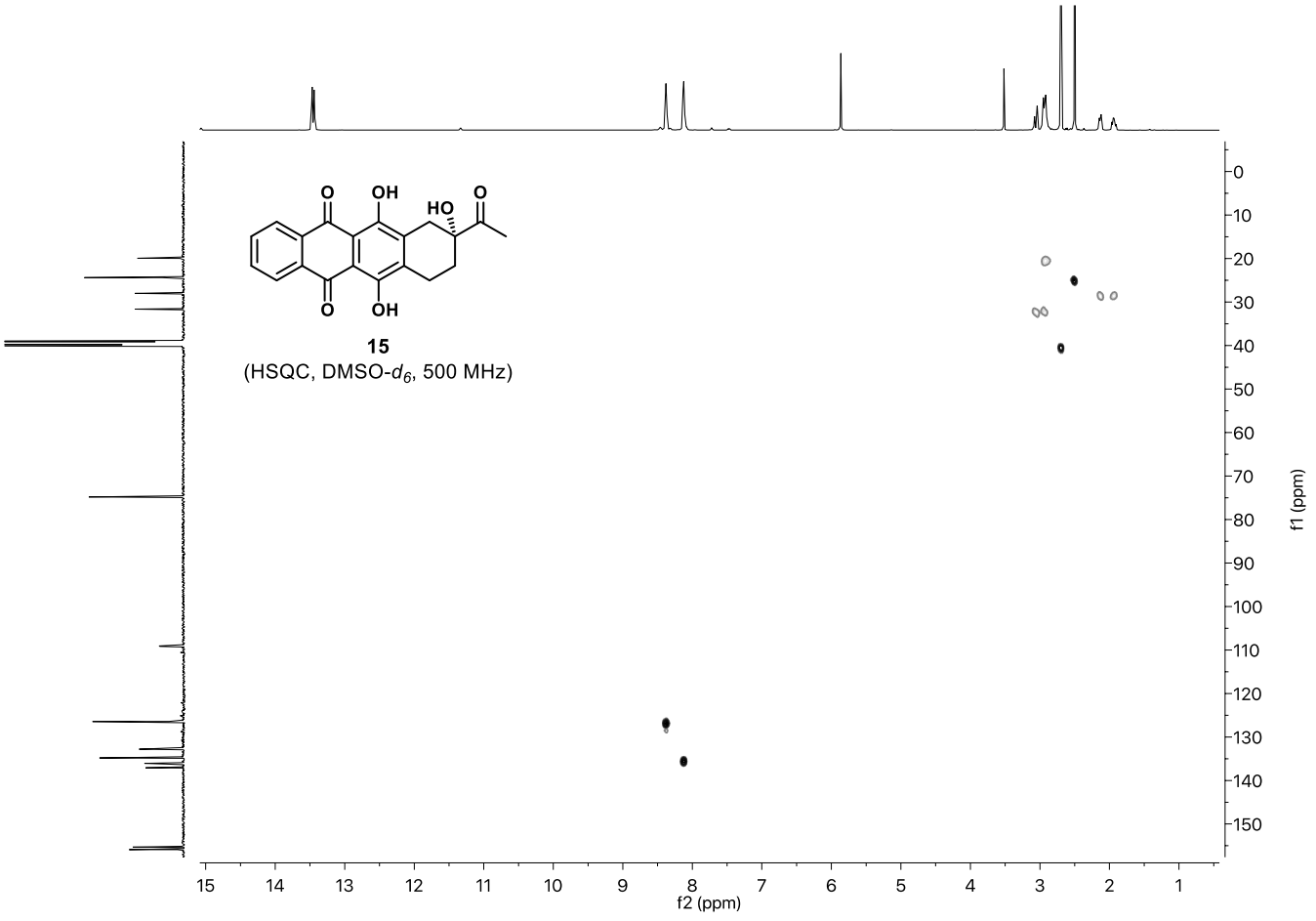


15

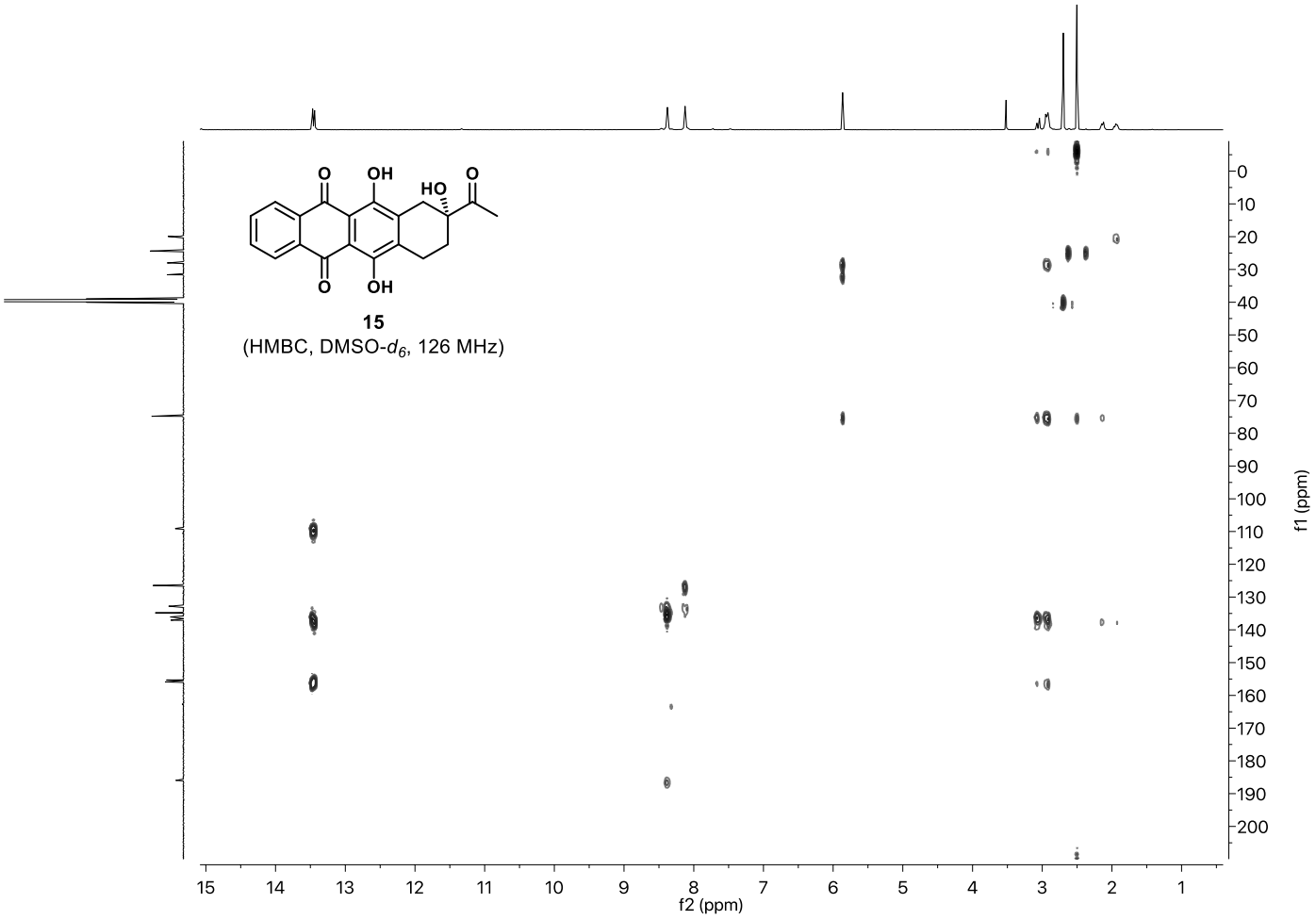
(^{13}C NMR, DMSO-d_6, 126 MHz)



15
(COSY, DMSO-d_6, 500 MHz)

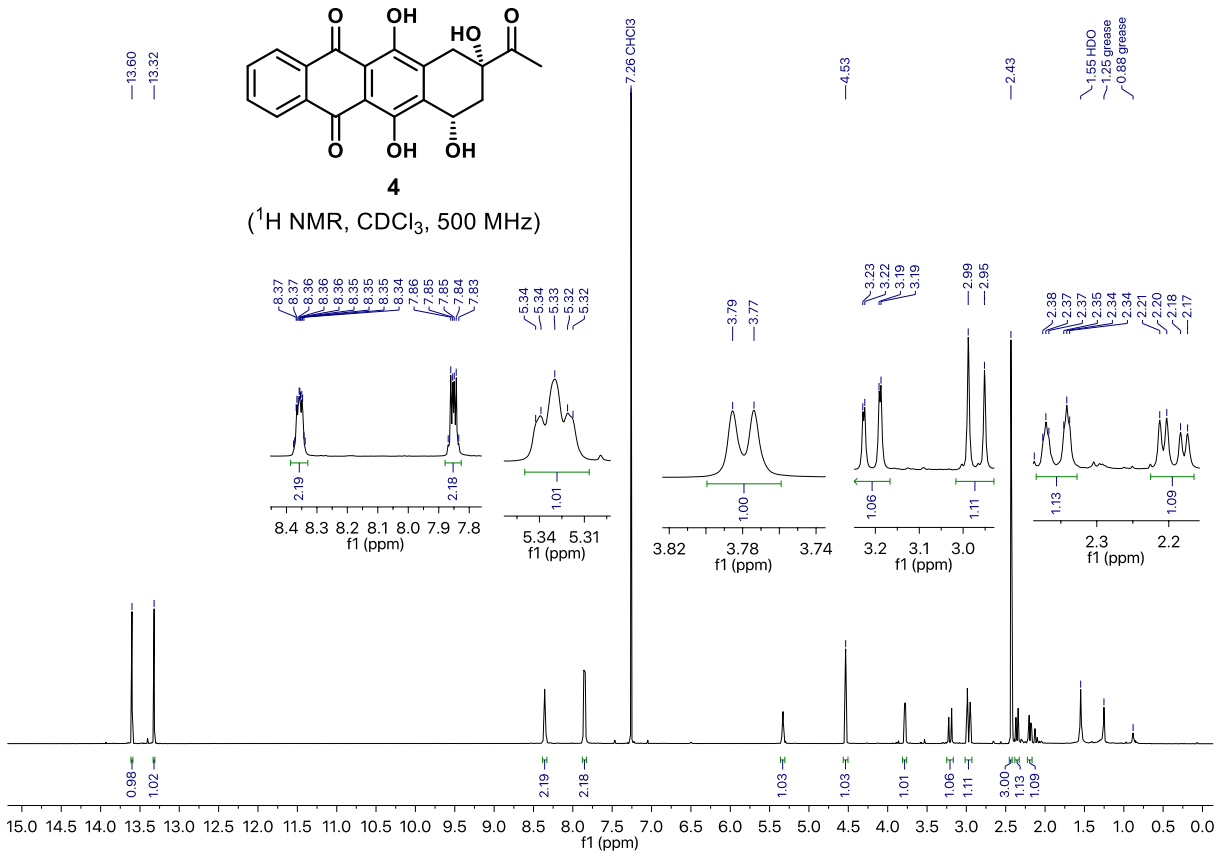


15
(HSQC, DMSO-d_6, 500 MHz)



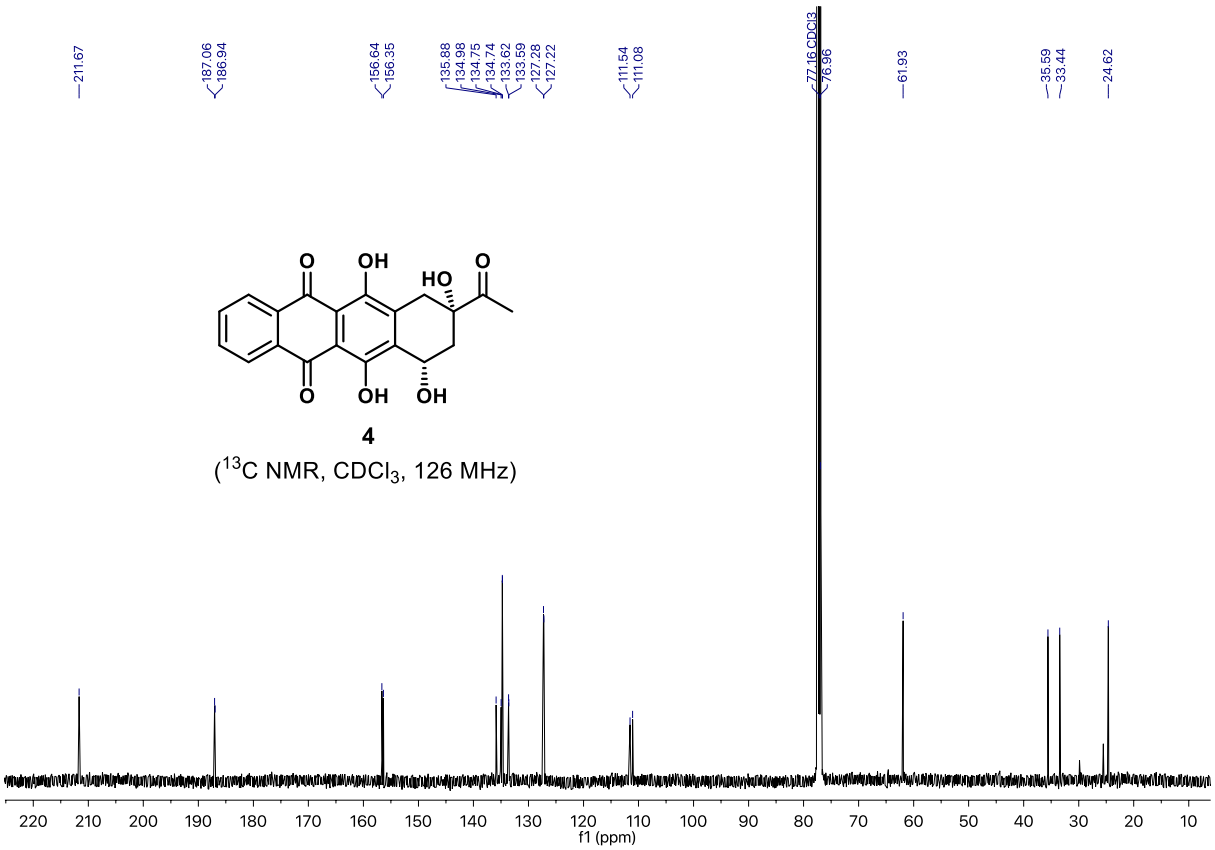
15

(HMBC, DMSO-d_6, 126 MHz)



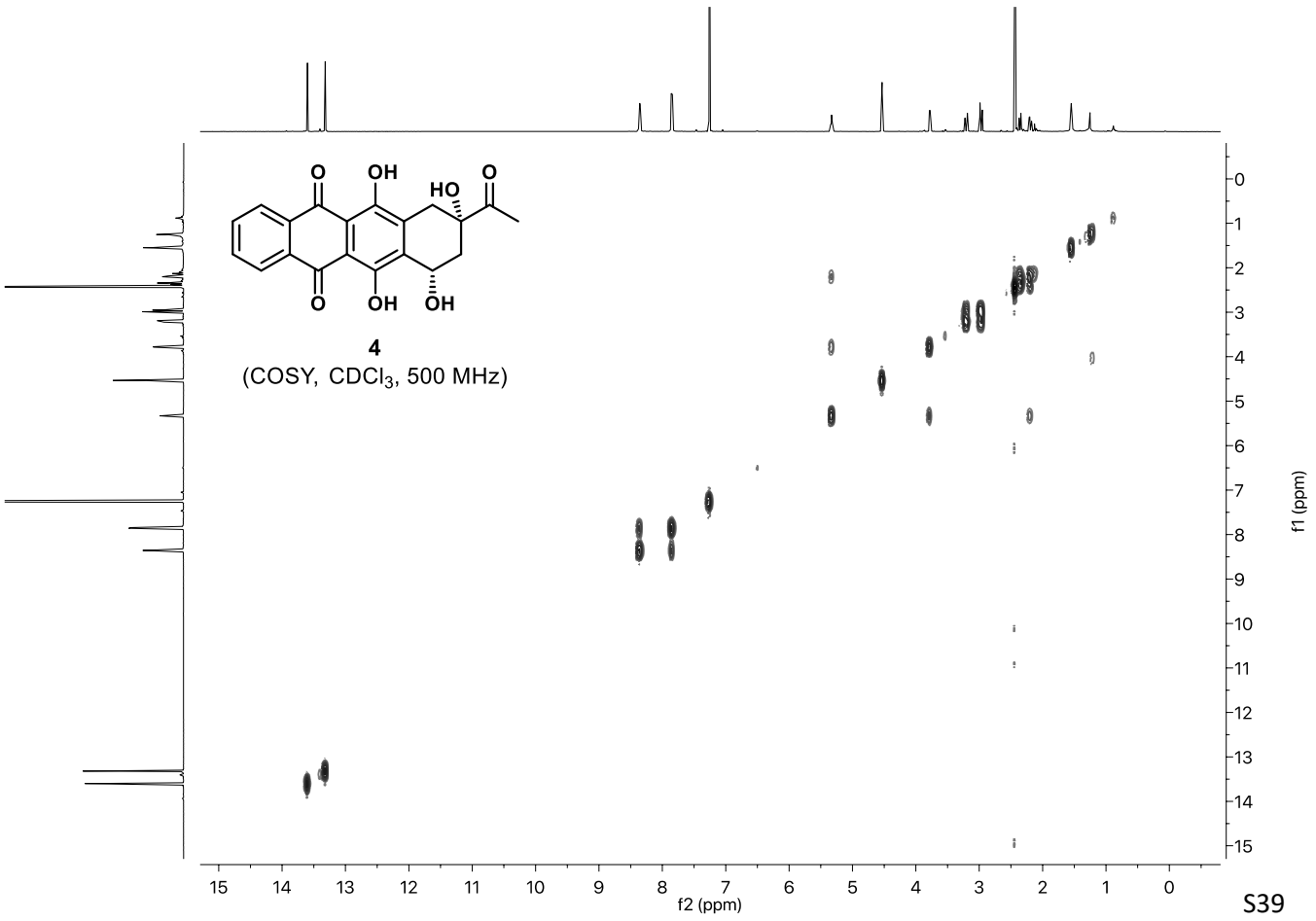
4

(^{1}H NMR, $CDCl_3$, 500 MHz)



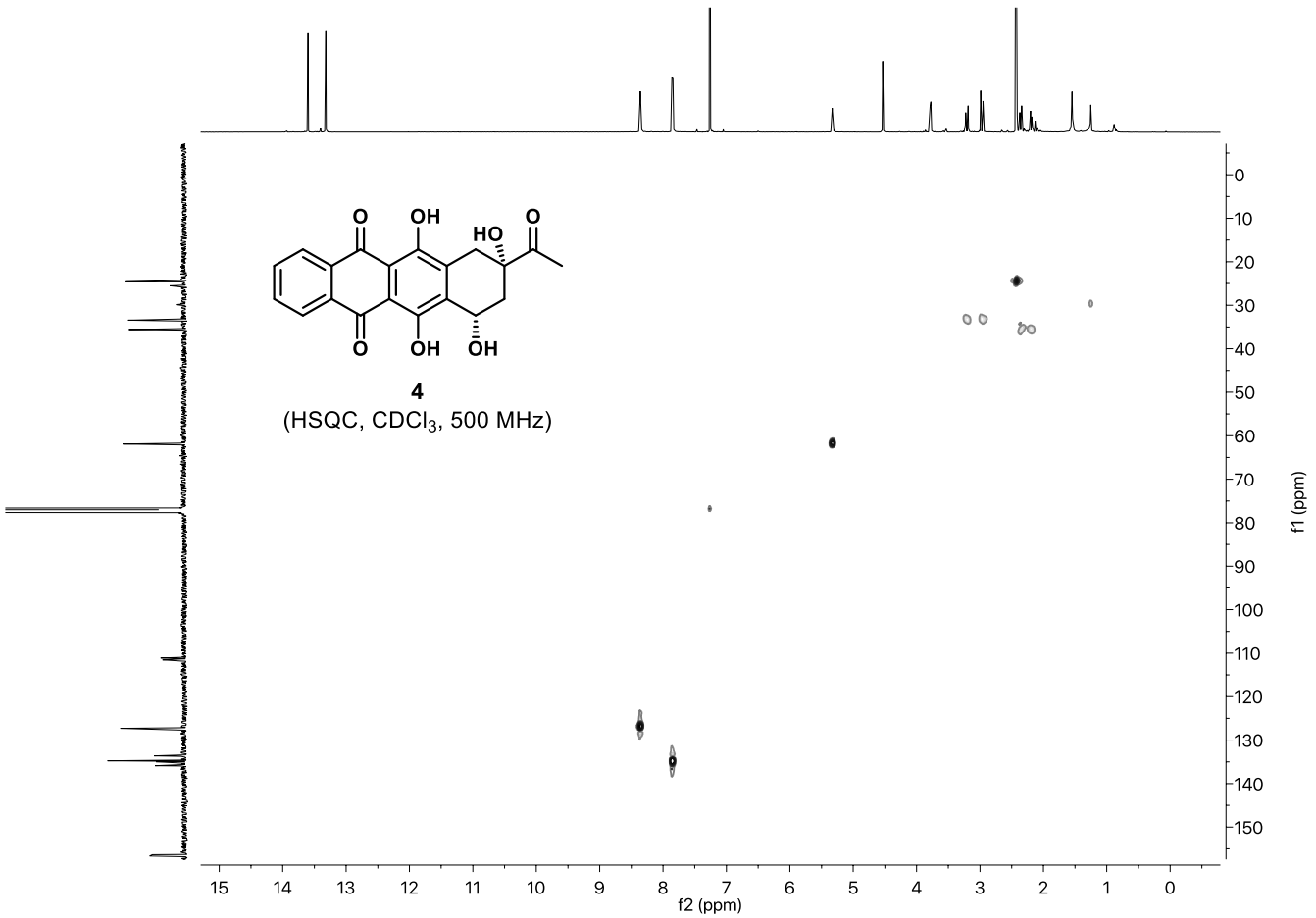
4

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



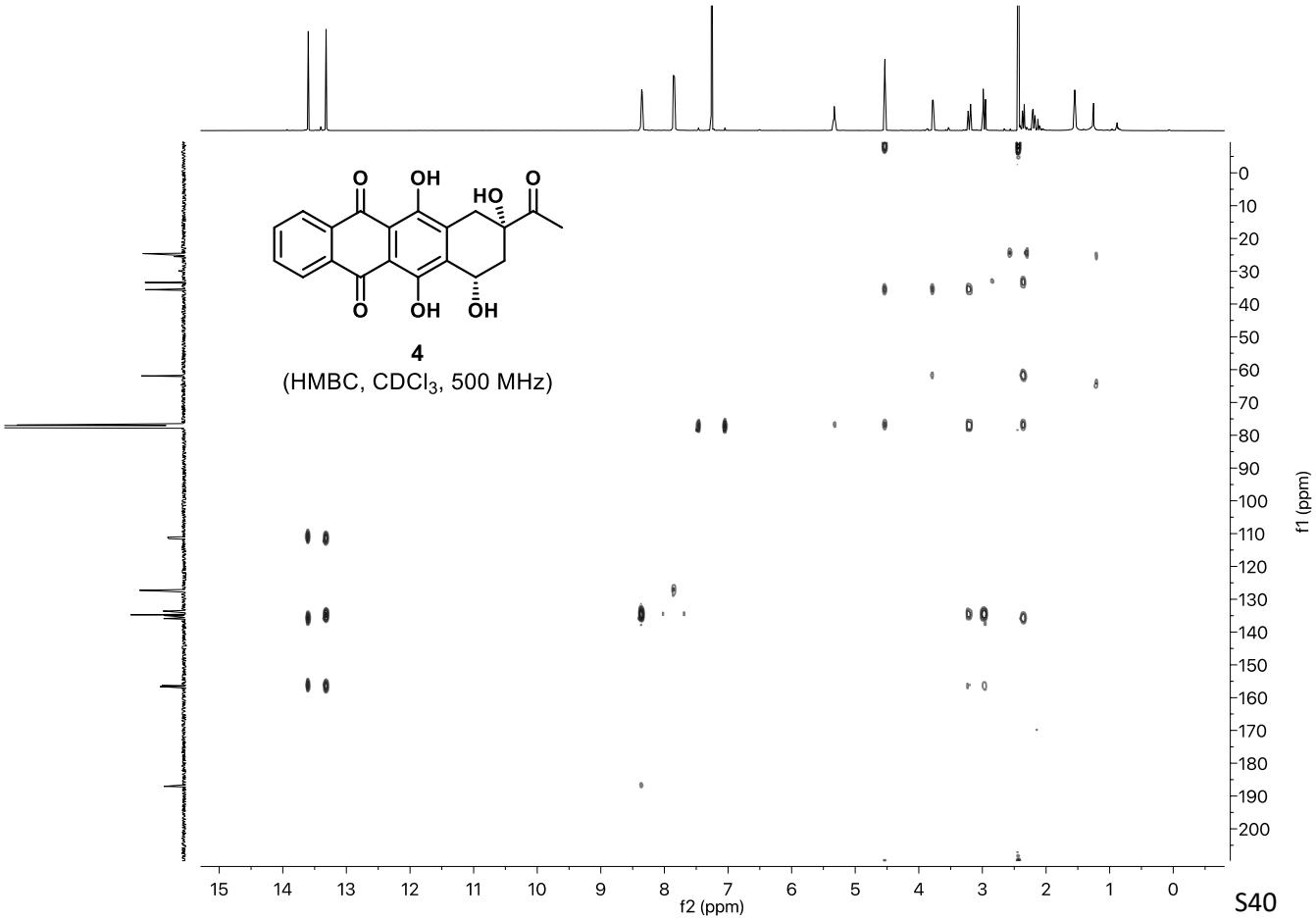
4

(COSY, $CDCl_3$, 500 MHz)



4

(HSQC, $CDCl_3$, 500 MHz)

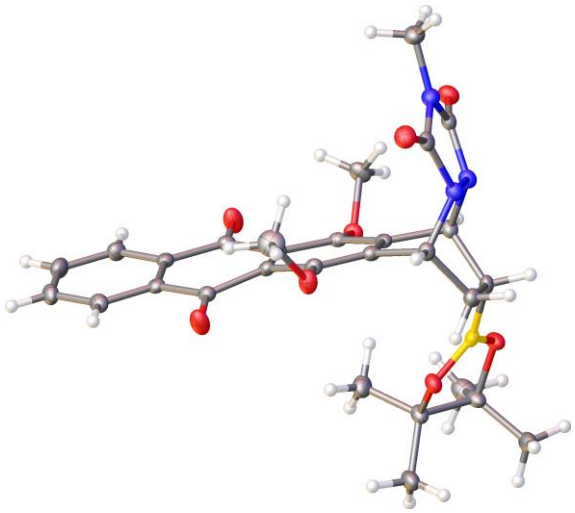


4

(HMBC, $CDCl_3$, 500 MHz)

IV. Crystallographic Data

Crystallographic data for compound 10

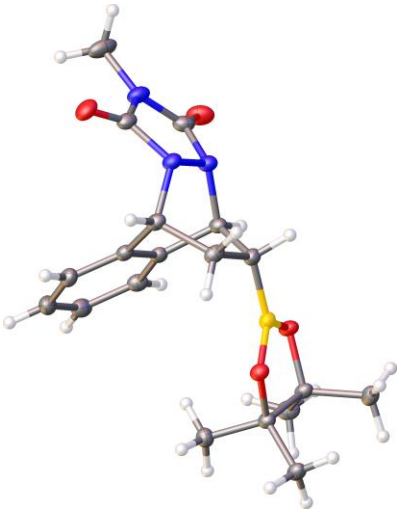


Single crystals of compound **10** were obtained by slow recrystallization from diethyl ether. A suitable crystal was selected and diffraction data were collected on a Bruker D8 Venture/Photon 100 diffractometer. The crystal was kept at 100.2 K during data collection.

Identification code	CCDC 1910638	
Empirical formula	$C_{29}H_{30}BN_3O_8$	
Formula weight	559.37	
Temperature	100(2) K	
Radiation	CuKα (λ = 1.54178)	
Crystal system	Monoclinic	
Space group	$P2_1/n$	
Unit cell dimensions	a = 9.4519(2) Å	α= 90°.
	b = 16.7889(3) Å	β= 101.6745(7)°.
	c = 16.9365(3) Å	γ = 90°.
Volume	2632.00(9) $Å^3$	
Z	4	
Density (calculated)	1.412 Mg/m^3	
Absorption coefficient	0.854 mm^{-1}	
F(000)	1176	
Crystal size	0.169 x 0.063 x 0.060 mm^3	

Theta range for data collection	3.746 to 68.373°.
Index ranges	-10<=h<=11, -19<=k<=20, -20<=l<=20
Reflections collected	29258
Independent reflections	4835 [R(int) = 0.0508]
Completeness to theta = 67.679°	100.0 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.7531 and 0.7005
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	4835 / 242 / 454
Goodness-of-fit on F^2	1.034
Final R indices [I>2sigma(I)]	R1 = 0.0360, wR2 = 0.0775
R indices (all data)	R1 = 0.0490, wR2 = 0.0833
Extinction coefficient	n/a
Largest diff. peak and hole	0.277 and -0.222 e.$Å^{-3}$

Crystallographic data for compound S5



Single crystals of compound **S5** were obtained by slow recrystallization from diethyl ether. A suitable crystal was selected and diffraction data were collected on a Mo Bruker D8 Venture/Photon II diffractometer. The crystal was kept at 100.01 K during data collection.

Identification code	dd62u_0m

Empirical formula	$C_{19}H_{24}BN_3O_4$
Formula weight	369.22
Temperature/K	100.01
Radiation	MoKα (λ = 0.71073)
Crystal system	monoclinic
Space group	$P2_1/n$
Unit cell dimensions	a = 15.5798(3) Å α = 90°
	b = 13.7634(2) Å β = 100.2570(10) °
	c = 17.7218(3) Å γ = 90°
Volume	3739.37(11) $Å^3$
Z	8
Density (calculated)	1.312 Mg/m^3
Absorption coefficient	0.092 mm^{-1}
F(000)	1568.0
Crystal size	0.499 × 0.31 × 0.292 mm^3
Theta range for data collection	4.672 to 56.566 °
Index ranges	$-20 \leq h \leq 20$, $-18 \leq k \leq 18$, $-23 \leq l \leq 23$
Reflections collected	121199
Independent reflections	9271 [R_{int} = 0.0356, R_{sigma} = 0.0141]
Completeness to theta = 28.283°	99.9 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.7457 and 0.7106
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	9271 / 64 / 545
Goodness-of-fit on F^2	1.066
Final R indices [I>2sigma(I)]	R_1 = 0.0361, wR_2 = 0.0937
R indices (all data)	R_1 = 0.0441, wR_2 = 0.1032
Extinction coefficient	n/a
Largest diff. peak and hole	0.38 and -0.22 $e.Å^{-3}$