Electronic Supplementary Information

A New Type of δ-Vinylvalerolactones for Palladium-Catalyzed Cycloaddition: Synthesis of Nine-Membered Heterocycles

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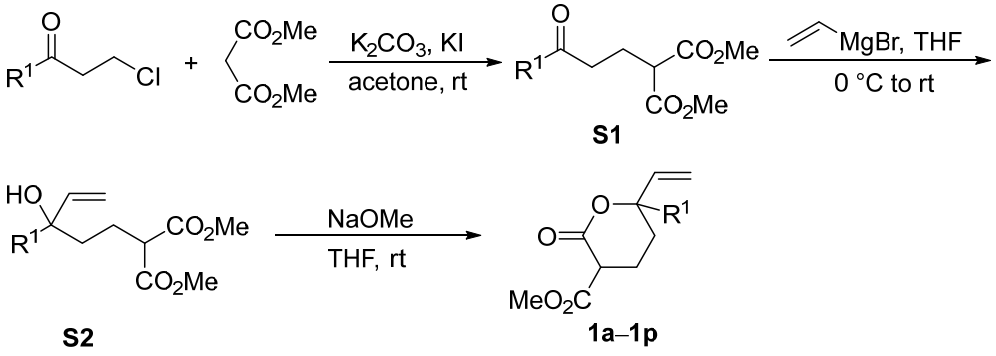
General Information

All reactions were performed in Schlenk tubes under an atmosphere of argon using oven-dried glassware. Commercially obtained reagents were used without further purification, unless otherwise noted. Trichloromethane ($CHCl_3$) was distilled over P_2O_5 and stored over 3Å type molecular sieves. Tetrahydrofuran (THF) and toluene were distilled freshly before use over sodium and benzophenone. Acetonitrile (MeCN), Dichloromethane (DCM) and 1,2-dichloroethane (DCE) were distilled from CaH_2. Reactions were checked for completion by TLC analysis and plates were visualized with short-wave UV light (254 nm). The ^1H, ^{13}C and ^{19}F NMR spectra were obtained in $CDCl_3$ using a Bruker-BioSpin AVANCE III HD NMR spectrometer at 500, 125 and 470 MHz, respectively. Chemical shifts are reported in parts per million (δ value) calibrated against the residual solvent peak. Signal patterns are indicated as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. Coupling constants (*J*) are given in hertz (Hz). The infrared spectra were recorded on a Bruker VERTEX 70 IR spectrometer as KBr pellets, with absorption reported in cm^{-1}. High-resolution mass spectra were recorded on a Bruker Impact II UHR TOF LC/MS Mass Spectrometry. Melting points were determined on a Stuard SMP3 melting point apparatus. X-ray crystallographic data were collected using a MM007HF Saturn724+.

Synthesis of δ-Vinylvalerolactones 1



A solution of 3-chloropropiophenone[1–2] (1.0 equiv.) and dimethyl malonate (2.5 equiv.), K_2CO_3 (1.0 equiv.), KI (0.1 equiv.) in acetone was stirred at 25 °C for 12 h. the insoluble solid was filtered off and the filtrate was concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (Ethyl acetate/Petroleum ether = 1:6) to obtain the crude product **S1** containing dimethyl malonate.

The required Grignard reagent (3.0 equiv.) was added dropwise to a solution of the crude product **S1** (1.0 equiv.) in anhydrous THF at 0 °C under argon atmosphere. The resulting

[1] J. Wang, Y.-B. Pang, N. Tao, R.-S. Zeng and Y. Zhao, *J. Org. Chem*., 2019, **84**, 15315–15322.

[2] H. Uno, T. Imai, K. Harada and N. Shibata, *ACS Catal*., 2020, **10**, 1454–1459.

mixture was stirred at 25 °C for 12 h. The reaction was quenched with aq. NH_4Cl and the organic layer was separated. The aqueous layer was extracted with EtOAc (3×100 mL). The combined organic layers were washed with brine (1×100 mL), dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (Ethyl acetate/Petroleum ether = 1:6) to obtain the product **S2.**

A solution of **S2** (1.0 equiv.) and sodium methoxide (2.0 equiv.) in THF was stirred at 25 °C for 12 h. The reaction was concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (Ethyl acetate/Petroleum ether = 1:6) to obtain the desired δ-vinylvalerolactones **1.**

General Procedure A for Palladium-Catalyzed [6+3] Cycloaddition of δ-Vinylvalerolactones 1 with Azomethine Imines 2[3–4]

To an oven-dried 25 mL of Schlenk tube equipped with a stir bar, $Pd_2dba_3 \cdot CHCl_3$ (5 mol%) and 1,10-Phen (20 mol%) was added along with δ-vinylvalerolactones **1** (0.15 mmol), azomethine imines **2** (0.1 mmol) and DCM (1.0 mL). The reaction was stirring at 25 ℃ under argon atmosphere until consumption of azomethine imines **2** as monitored by thin layer chromatography. The solution directly purified by silica gel column chromatography (Ethyl acetate/Petroleum ether = 1:1) to afford desired cycloadducts **3**.

General Procedure B for Palladium-Catalyzed [6+3] Cycloaddition of δ-Vinylvalerolactones 1 with Azomethine Imines 2

To an oven-dried 25 mL of Schlenk tube equipped with a stir bar, $Pd_2dba_3 \cdot CHCl_3$ (5 mol%) and 1,10-Phen (20 mol%) was added along with δ-vinylvalerolactones **1** (0.15 mmol), azomethine imines **2** (0.1 mmol) and $CHCl_3$ (1.0 mL). The reaction was stirring at 50 ℃ under argon atmosphere until consumption of azomethine imines **2** as monitored by thin layer chromatography. The solution directly purified by silica gel column chromatography (Ethyl acetate/Petroleum ether = 1:1) to afford desired cycloadducts **3**.

General Procedure for Scale-up Reaction

To an oven-dried 50 mL of Schlenk tube equipped with a stir bar, $Pd_2dba_3 \cdot CHCl_3$ (5 mol%) and 1,10-Phen (20 mol%) was added along with δ-vinylvalerolactones **1** (1.5 mmol), azomethine imines **2** (1.0 mmol) and DCM (10.0 mL). The reaction was stirring at 25 ℃ under argon atmosphere until consumption of azomethine imines **2** as monitored by thin layer chromatography. The solution directly purified by silica gel column chromatography (Ethyl acetate/Petroleum ether = 1:1) to afford desired cycloadducts **3**.

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[3] T. Wang, J. Luo, C. Gu, R. Li, X. Tang, D. Yu and J. Li, CN 103172575A.

[4] T. Wang, A.-L. Shao, H.-Y. Feng, S.-W. Yang, M. Gao, J. Tian and A.-W. Lei, *Tetrahedron*., 2015, **71**, 4473–4477.

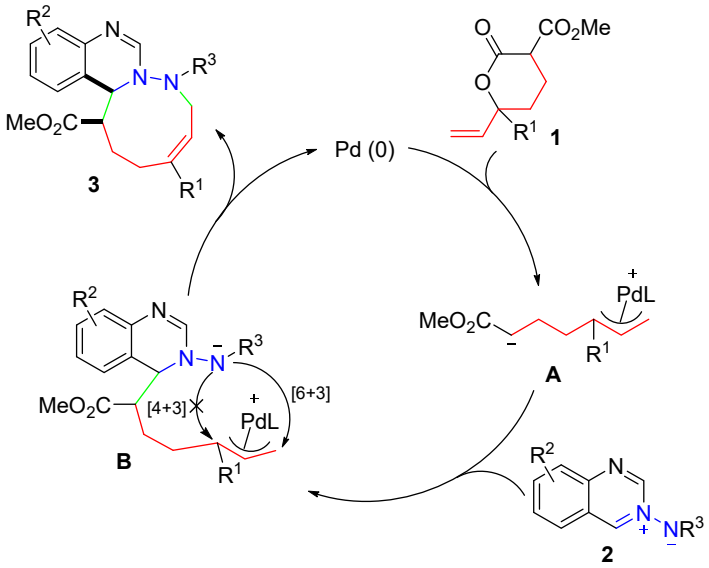
General Procedure for Further Transformation of the Product 3

Under argon atmosphere, the DIBAL (1.5 M in toluene, 10.0 equiv) was added dropwise to a solution of **3** (0.1 mmol) in dry DCM (1.5 mL) at –78 °C, and the resulting solution continued to be stirred at –78 °C for 2 h. The reaction was quenched with 1 N HCl (10.0 mL) and the organic layer was separated. The aqueous layer was extracted with DCM (3×10.0 mL). The combined organic layers were washed with brine (2×10.0 mL), dried over $MgSO_4$, and concentrated under reduced pressure. The resulting solid in DCM (1.5 mL) was added Et_3N (0.3 mmol) and benzoyl chloride (0.3 mmol) at room temperature for one hour. The solution directly purified by silica gel column chromatography (Ethyl acetate/Petroleum ether = 1:5) to afford desired cycloadduct **4**.

General Procedure for Further Transformation of the Product 4

The cycloadduct **4a** (0.1 mmol, 59.1 mg) in dry MeOH (5 mL) was added KOH (10equiv. 50.4 mg). Then the mixture was stirring under refluxing conditions for 3 h. The solvent was removed under reduced pressure and the resulting residue was mixed with 25 mL of H_2O. The mixture was extracted with ethyl acetate (3×20 mL). The combined organic layers were washed with brine (2×10 mL), dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (Ethyl acetate/Petroleum ether = 1:1) to afford the desired cycloadduct **5a**.

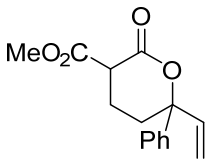
A Plausible Mechanism



In the presence of a Pd catalyst, δ-vinylvalerolactone **1** performs a decarboxylation ring-opening reaction to afford zwitterionic the intermediate **A**, which attacks the azomethine imine **2** to give the intermediate **B**. Subsequent intramolecular annulation led to a [6+3] annulation product **3**. In this reaction, no [4+3] cycloaddition product was observed. It is probably because there a big steric hindrance when nitrogen anion attacks the carbon linking to R^1 group.

Characterization Data for the Compounds 1, 3 and 4

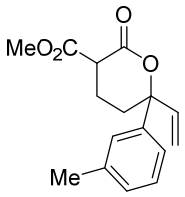
Methyl 2-oxo-6-phenyl-6-vinyltetrahydro-2H-pyran-3-carboxylate



1a

1a was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.43–7.34 (m, 8H), 7.34–7.28 (m, 2H), 6.12–6.00 (m, 2H), 5.38–5.24 (m, 4H), 3.78 (s, 3H), 3.73 (s, 3H), 3.63–3.57 (t, *J* = 7.5 Hz, 1H), 3.45–3.38 (t, *J* = 7.5 Hz, 1H), 2.46–2.27 (m, 4H), 2.26–1.97 (m, 4H). ^{13}C NMR ($CDCl_3$, 125 MHz): δ =169.6, 169.5, 167.0, 166.8, 141.9, 141.7, 140.4, 140.3, 128.8, 128.6, 128.0, 127.9, 125.2, 125.1, 115.6, 115.4, 87.6, 87.4, 52.8, 52.8, 46.9, 31.2, 31.0, 20.8, 20.7. IR (KBr): *v* (cm^{-1}) 2988, 2954, 1723, 1448, 1261, 1028, 930, 764, 750, 701. HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{16}O_4Na$ $[M+Na]^+$: 283.0947, found: 283.0943.

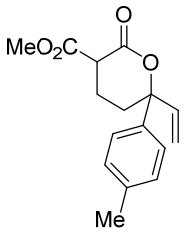
Methyl 2-oxo-6-(*m*-tolyl)-6-vinyltetrahydro-2H-pyran-3-carboxylate



1b

1b was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.28–7.24 (m, 2H), 7.23–7.20 (m, 2H), 7.20–7.15 (m, 2H), 7.15–7.09 (m, 2H), 6.12–5.98 (m, 2H), 5.39–5.21 (m, 4H), 3.78 (s, 3H), 3.74 (s, 3H), 3.65–3.52 (t, *J* = 7.5 Hz, 1H), 3.45–3.39 (t, *J* = 7.5 Hz, 1H), 2.40–2.26 (m, 10H), 2.24–2.00 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.6, 169.6, 167.1, 166.9, 141.8, 141.6, 140.5, 140.4, 138.6, 138.4, 128.8, 128.7, 128.6, 128.5, 125.9, 125.7, 122.2, 122.0, 115.5, 115.2, 87.6, 87.4, 52.8, 46.9, 31.2, 31.0, 21.6, 20.8, 20.7. IR (KBr): *v* (cm^{-1}) 2991, 2954, 1729, 1275, 1261, 1161, 764, 750, 705. HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{18}O_4Na$ $[M+Na]^+$: 297.1103, found: 297.1100.

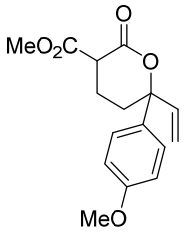
Methyl 2-oxo-6-(*p*-tolyl)-6-vinyltetrahydro-2H-pyran-3-carboxylate



1c

1c was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.32–7.24 (m, 4H), 7.22–7.13 (m, 4H), 6.11–5.94 (m, 2H), 5.37–5.18 (m, 4H), 3.77 (s, 3H), 3.72 (s, 3H), 3.62–3.56 (t, *J* = 7.5 Hz, 1H), 3.44–3.37 (t, *J* = 7.5 Hz, 1H), 2.42–2.23 (m, 10H), 2.23–1.97 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.7, 169.6, 167.1, 166.9, 140.6, 140.5, 138.9, 138.7, 137.8, 137.7, 129.5, 129.3, 125.2, 125.0, 115.4, 115.1, 87.6, 87.5, 52.8, 47.0, 46.9, 31.2, 30.9, 21.0, 20.9, 20.7. IR (KBr): *v* (cm^{-1}) 2991, 2953, 1724, 1275, 1261, 1160, 930, 817, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{18}O_4Na$ $[M+Na]^+$: 297.1103, found: 297.1100.

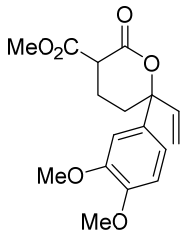
Methyl 6-(4-methoxyphenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1d

1d was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.36–7.27 (m, 4H), 6.95–6.83 (m, 4H), 6.12–5.93 (m, 2H), 5.39–5.18 (m, 4H), 3.83–3.79 (m, 6H), 3.78 (s, 3H), 3.74 (s, 3H), 3.63–3.56 (t, *J* = 7.5 Hz, 1H), 3.44–3.38 (t, *J* = 7.5 Hz, 1H), 2.41–2.26 (m, 4H), 2.22–2.03 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.6, 169.6, 167.1, 166.9, 159.3, 159.2, 140.7, 140.6, 133.8, 133.6, 126.6, 126.5, 115.4, 115.1, 114.1, 113.9, 87.5, 87.3, 55.3, 55.3, 52.8, 52.8, 46.9, 31.1, 30.8, 20.9, 20.8. IR (KBr): *v* (cm^{-1}) 2960, 2845, 1724, 1513, 1275, 1259, 1181, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{18}O_5Na$ $[M+Na]^+$: 313.1052, found: 313.1049.

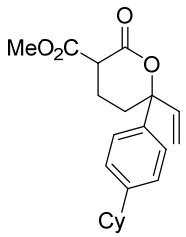
Methyl 6-(3,4-dimethoxyphenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carbo- xylate



1e

1e was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.01–6.79 (m, 6H), 6.11–5.93 (m, 2H), 5.39–5.21 (m, 4H), 3.95–3.83 (m, 12H), 3.79 (s, 3H), 3.74 (s, 3H), 3.65–3.56 (t, *J* = 7.5 Hz, 1H), 3.48–3.37 (t, *J* = 8.0 Hz, 1H), 2.42–2.25 (m, 4H), 2.25–2.01 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.6, 167.1, 166.9, 149.2, 149.0, 148.8, 148.7, 140.6, 140.5, 134.3, 134.1, 117.5, 117.3, 115.4, 115.2, 111.0, 110.9, 109.0, 108.8, 87.5, 87.3, 56.1, 56.0, 55.9, 52.9, 52.8, 46.9, 46.9, 31.2, 30.8, 20.9, 20.8. IR (KBr): *v* (cm^{-1}) 2955, 1724, 1517, 1274, 1261, 1163, 1025, 765, 750. HRMS (ESI, *m*/*z*) calcd for $C_{17}H_{20}O_6Na$ $[M+Na]^+$: 321.1338, found: 321.1338.

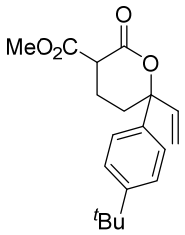
Methyl 6-(4-cyclohexylphenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1f

1f was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.35–7.28 (m, 4H), 7.24–7.16 (m, 4H), 6.11–5.96 (m, 2H), 5.38–5.22 (m, 4H), 3.77 (s, 3H), 3.72 (s, 3H), 3.62–3.55 (t, *J* = 7.5 Hz, 1H), 3.45–3.36 (t, *J* = 7.5 Hz, 1H), 2.58–2.43 (m, 2H), 2.40–2.26 (m, 4H), 2.23–1.99 (m, 4H), 1.91–179 (m, 8H), 1.79–1.67 (m, 2H), 1.47 –1.31 (m, 8H), 1.31–1.19 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.7, 169.6, 167.1, 166.9, 1480, 147.8, 140.6, 140.5, 139.2, 138.9, 127.2, 127.0, 125.2, 125.0, 115.3, 115.1, 87.6, 87.5, 52.8, 52.8, 47.0, 46.9, 44.1, 34.4, 31.1, 30.9, 26.9, 26.1, 20.9, 20.8. IR (KBr): *v* (cm^{-1}) 2923, 2850, 1727, 1193, 1031, 929, 827, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{21}H_{26}O_4Na$ $[M+Na]^+$: 343.1909, found: 343.1911.

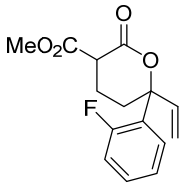
Methyl 6-(4-(tert-butyl)phenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1g

1g was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.42–7.36 (m, 4H), 7.36–7.29 (m, 4H), 6.11–5.97 (m, 2H), 5.40–5.21 (m, 4H), 3.78 (s, 3H), 3.74 (s, 3H), 3.63–3.56 (t, *J* = 7.5 Hz, 1H), 3.44–3.37 (t, *J* = 7.5 Hz, 1H), 2.41–2.26 (m, 4H), 2.26–2.01 (m, 4H), 1.31 (s, 18H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.7, 169.6, 167.1, 166.9, 151.0, 150.9, 140.6, 140.5, 138.8, 138.6, 125.7, 125.5, 124.9, 124.8, 115.3, 115.1, 87.6, 87.4, 52.8, 52.8, 47.0, 46.9, 34.5, 31.3, 31.1, 30.9, 20.9, 20.8. IR (KBr): *v* (cm^{-1}) 2959, 2870, 1727, 1274, 1261, 1158, 928, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{19}H_{24}O_4Na$ $[M+Na]^+$: 339.1573, found: 339.1570.

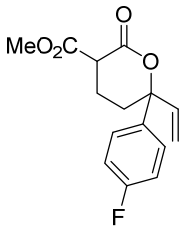
Methyl 6-(2-fluorophenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1h

1h was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.61–7.46 (m, 2H), 7.36–7.28 (m, 2H), 7.23–7.12 (m, 2H), 7.12–7.00 (m, 2H), 6.29–6.17 (m, 2H), 5.47–5.36 (m, 2H), 5.36–5.24 (m, 2H), 3.79 (s, 3H), 3.73 (s, 3H), 3.64–3.58 (t, *J* = 7.5 Hz, 1H), 3.52–3.46 (t, *J* = 8.0 Hz, 1H), 2.55–2.41 (m, 2H), 2.41–2.25 (m, 3H), 2.25–2.11 (m, 1H), 2.09–1.94 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.5, 169.4, 166.6, 166.5, 158.8 (d, *J* = 245.1 Hz), 158.5 (d, *J* = 245.0 Hz), 138.3 (d, *J* = 3.3 Hz), 138.1 (d, *J* = 3.2 Hz), 130.0 (d, *J* = 9.8 Hz), 129.9 (d, *J* = 9.4 Hz) , 129.3 (d, *J* = 3.4 Hz), 129.2 (d, *J* = 3.4 Hz), 127.2 (d, *J* = 3.4 Hz), 126.9 (d, *J* = 3.4 Hz), 124.6 (d, *J* = 2.9 Hz), 124.6 (d, *J* = 3.3 Hz), 116.6, 116.6 (d, *J* = 23.6 Hz), 116.4 (d, *J* = 23.5 Hz), 116.0, 86.0 (d, *J* = 4.5 Hz) , 86.0 (d, *J* = 5.5 Hz), 52.8, 47.4, 47.2, 30.6 (d, *J* = 5.6 Hz), 30.1 (d, *J* = 5.6 Hz), 21.0. ^{19}F NMR (470 MHz, $CDCl_3$) δ = –112.0, –112.2. IR (KBr): *v* (cm^{-1}) 2991, 2954, 1728, 1276, 1261, 1159, 1030, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{15}FO_4Na$ $[M+Na]^+$: 301.0852, found: 301.0848.

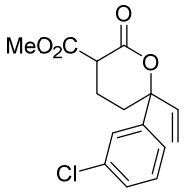
Methyl 6-(4-fluorophenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1i

1i was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.47–7.34 (m, 4H), 7.13–6.97 (m, 4H), 6.12–5.91 (m, 2H), 5.42–5.22 (m, 4H), 3.79 (s, 3H), 3.75 (s, 3H), 3.64–3.59 (t, *J* = 7.0 Hz, 1H), 3.47–3.39 (t, *J* = 8.0 Hz, 1H), 2.39–2.02 (m, 8H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.5, 169.5, 166.7, 166.6, 162.3 (d, *J* = 245.9 Hz), 162.3 (d, *J* = 246.1 Hz), 140.2, 140.1, 137.7 (d, *J* = 17.6 Hz), 137.7 (d, *J* = 17.1 Hz), 127.2 (d, *J* = 7.9 Hz), 127.0 (d, *J* = 7.9 Hz), 115.9, 115.7 (d, *J* = 3.5 Hz), 115.6 (d, *J* = 4.4Hz), 115.4, 87.2, 87.0, 52.9, 52.9, 47.0, 46.8, 31.1, 20.8, 20.8. ^{19}F NMR (470 MHz, $CDCl_3$) δ = –114.1, –114.4. IR (KBr): *v* (cm^{-1}) 2993, 2957, 1729, 1509, 1275, 1260, 1228, 1162, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{15}FO_4Na$ $[M+Na]^+$: 301.0852, found: 301.0849.

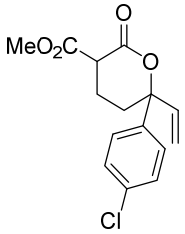
Methyl 6-(3-chlorophenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1j

1j was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.45–7.37 (m, 2H), 7.37–7.19 (m, 6H), 6.11–5.90 (m, 2H), 5.44–5.24 (m, 4H), 3.79 (s, 3H), 3.75 (s, 3H), 3.64–3.59 (t, *J* = 7.0 Hz, 1H), 3.49–3.42 (t, *J* = 8.0 Hz, 1H), 2.39–2.28 (m, 3H), 2.28–2.01 (m, 5H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.4, 166.5, 166.4, 144.1, 144.0, 139.7, 134.8, 134.7, 130.1, 130.0, 128.2, 128.1, 125.6, 125.4, 123.4, 123.2, 116.3, 116.1, 86.9, 86.8, 53.0, 52.9, 47.0, 46.7, 31.2, 31.0, 20.8. IR (KBr): *v* (cm^{-1}) 2954, 2920, 1725, 1275, 1260, 1159, 1118, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{15}ClO_4Na$ $[M+Na]^+$: 317.0557, found: 317.0553.

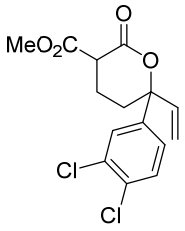
Methyl 6-(4-chlorophenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1k

1k was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.41–7.31 (m, 8H), 6.11–5.91 (m, 2H), 5.43–5.24 (m, 4H), 3.79 (s, 3H), 3.74 (s, 3H), 3.64–3.56 (t, *J* = 7.0 Hz, 1H), 3.48–3.38 (t, *J* = 8.0 Hz, 1H), 2.37–1.98 (m, 8H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.5, 169.4, 166.6, 166.5, 140.5, 140.4, 139.9, 139.9, 134.0, 133.9, 128.9, 128.8, 126.7, 126.6, 116.1, 115.9, 87.1, 87.0, 52.9, 52.9, 47.0, 46.8, 31.1, 20.8, 20.8. IR (KBr): *v* (cm^{-1}) 2993, 2954, 1728, 1492, 1275, 1261, 1012, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{15}ClO_4Na$ $[M+Na]^+$: 317.0557, found: 317.0555.

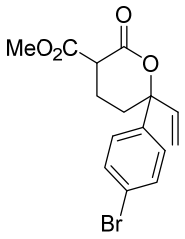
Methyl 6-(3,4-dichlorophenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1l

1l was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.55–7.48 (m, 2H), 7.48–7.41 (m, 2H), 7.30–7.21 (m, 2H), 6.06–5.93 (m, 2H), 5.43–5.28 (m, 4H), 3.80 (s, 3H), 3.76 (s, 3H), 3.64–3.60 (t, *J* = 7.0 Hz, 1H), 3.49–3.44 (t, *J* = 8.0 Hz, 1H), 240–2.25 (m, 3H), 2.25–2.01 (m, 5H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.3, 169.3, 166.2, 166.2, 142.3, 142.2, 139.3, 133.1, 132.9, 132.3, 132.2, 130.7, 130.6, 127.5, 127.3, 124.7, 124.5, 116.7, 116.4, 86.5, 86.3, 53.0, 52.9, 47.1, 46.6, 31.2, 30.9, 20.8, 20.8. IR (KBr): *v* (cm^{-1}) 2991, 2960, 1729, 1275, 1261, 1028, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{14}Cl_2O_4Na$ $[M+Na]^+$: 351.0167, found: 351.0164.

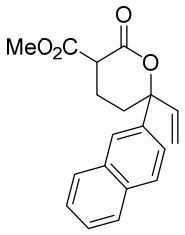
Methyl 6-(4-bromophenyl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1m

1m was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.55–7.43 (m, 4H), 7.36–7.20 (m, 4H), 6.10–5.93 (m, 2H), 5.44–5.21 (m, 4H), 3.78 (s, 3H), 3.74 (s, 3H), 3.64–3.58 (t, *J* = 7.0 Hz, 1H), 3.47–3.40 (t, *J* = 8.0 Hz, 1H), 2.38–2.00 (m, 8H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.4, 169.4, 166.6, 166.5, 141.1, 140.9, 139.9, 139.8, 131.9, 131.8, 127.1, 126.9, 122.2, 122.1, 116.2, 115.9, 87.1, 87.0, 52.9, 52.9, 47.0, 46.8, 31.0, 20.8, 20.8. IR (KBr): *v* (cm^{-1}) 2988, 2953, 1728, 1275, 1261, 1161, 1009, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{15}BrO_4Na$ $[M+Na]^+$: 361.0052, found: 361.0048.

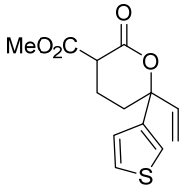
Methyl 6-(naphthalen-2-yl)-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1n

1n was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.93–7.73 (m, 8H), 7.53–7.39 (m, 6H), 6.18–6.01 (m, 2H), 5.43–5.33 (m, 2H), 5.33–5.22 (m, 2H), 3.76 (s, 3H), 3.68 (s, 3H), 3.64–3.59 (t, *J* = 7.5 Hz, 1H), 3.47–3.40 (t, *J* = 8.0 Hz, 1H), 2.48–2.21 (m, 5H), 2.19–1.96 (m, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.6, 169.6, 167.1, 167.0, 140.3, 140.3, 139.1, 139.0, 133.1, 132.8, 132.7, 128.8, 128.6, 128.4, 128.3, 127.6, 127.6, 126.7, 126.6, 124.4, 124.0, 123.2, 123.1, 115.9, 115.7, 87.8, 87.6, 52.9, 47.0, 47.0, 31.1, 31.0, 20.9, 20.8. IR (KBr): *v* (cm^{-1}) 2991, 2953, 1725, 1361, 1275, 1261, 1160, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{19}H_{18}O_4Na$ $[M+Na]^+$: 333.1103, found: 333.1100.

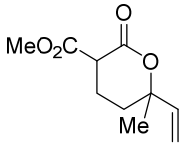
Methyl 2-oxo-6-(thiophen-3-yl)-6-vinyltetrahydro-2H-pyran-3-carboxylate



1o

1o was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.37–7.31 (m, 2H), 7.27–7.22 (m, 2H), 7.06–6.99 (m, 2H), 6.10–5.95 (m, 2H), 5.38–5.23 (m, 4H), 3.78 (s, 3H), 3.74 (s, 3H), 3.61–3.55 (t, *J* = 7.5 Hz, 1H), 3.49–3.43 (t, *J* = 8.0 Hz, 1H), 2.44–2.26 (m, 4H), 2.22–2.00 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.6, 169.6, 166.8, 166.7, 143.1, 139.9, 139.9, 126.9, 126.8, 125.4, 125.3, 121.9, 121.5, 115.8, 115.4, 86.2, 86.0, 52.9, 47.0, 46.9, 31.2, 31.1, 20.9, 20.9. IR (KBr): *v* (cm^{-1}) 2991, 2953, 1725, 1275, 1261, 1195, 1162, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{13}H_{14}O_4SNa$ $[M+Na]^+$: 289.0511, found: 289.0508.

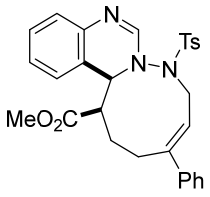
Methyl 6-methyl-2-oxo-6-vinyltetrahydro-2H-pyran-3-carboxylate



1p

1p was obtained as light yellow oil, dr = 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 5.93–5.73 (m, 2H), 5.40–5.14 (m, 4H), 3.85–3.70 (m, 6H), 3.59–3.49 (m, 1H), 3.49– 3.37 (m, 1H), 2.31–1.71 (m, 8H), 1.56–1.43 (m, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ = 169.9, 169.7, 167.1, 167.0, 140.8, 140.4, 115.5, 114.7, 84.9, 84.6, 52.8, 52.7, 47.5, 46.1, 31.9, 30.5, 28.4, 28.1, 21.1, 20.7. IR (KBr): *v* (cm^{-1}) 2991, 2959, 1724, 1457, 1275, 1261, 1112, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{10}H_{14}O_4Na$ $[M+Na]^+$: 221.0790, found: 221.0788.

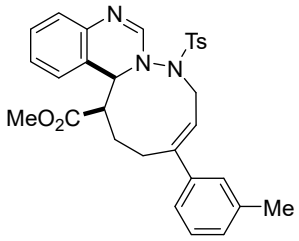
Methyl (14*R*,14a*S*,*E*)-11-phenyl-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazo- nino[1,9-*c*]quinazoline-14-carboxylate



3aa

According to the general procedure A, **3aa** was obtained as white solid, 50.3 mg, 98% yield, dr > 20:1, m. p. 122–124 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.76–7.70 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.33–7.27 (m, 4H), 7.27–7.19 (m, 3H), 7.17–7.10 (m, 1H), 7.07–7.02 (m, 1H), 6.97–6.90 (m, 1H), 6.58–6.49 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 6.46 (s, 1H), 6.24–6.16 (t, J = 8.5 Hz, 1H), 5.77–5.71 (d, J = 3.0 Hz, 1H), 4.54–4.44 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.73–3.64 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.62 (s, 3H), 3.28–3.20 (m, 1H), 2.62–2.46 (m, 2H), 2.37 (s, 3H), 1.89–1.74 (m, 1H), 1.60–1.47 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.1, 146.9, 144.6, 144.5, 139.6, 138.8, 132.5, 129.5, 128.0, 127.7, 127.3, 127.2, 125.2, 125.1, 124.9, 121.2, 60.8, 51.0, 47.0, 44.2, 28.1, 20.7, 20.3. IR (KBr): ν (cm^{-1}) 2950, 1733, 1618, 1596, 1262, 1163, 1087, 764, 750, 682. HRMS (ESI, *m*/*z*) calcd for $C_{29}H_{30}N_3O_4S$ $[M+H]^+$: 516.1957, found: 516.1954.

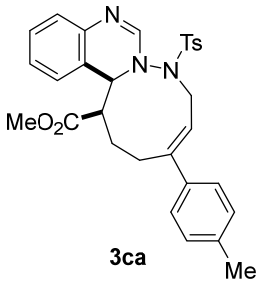
Methyl (14*R*,14a*S*,*E*)-11-(*m*-tolyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazo-nino[1,9-*c*]quinazoline-14-carboxylate



3ba

According to the general procedure A, **3ba** was obtained as white solid, 40.8 mg, 77% yield, dr > 20:1, m. p. 218–220 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.79–7.67 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.37–7.23 (d, J = 8.0 Hz, 2H), 7.16–7.00 (m, 6H), 6.98–6.89 (m, 1H), 6.57–6.48 (m, 1H), 6.45 (s, 1H), 6.23–6.17 (t, J = 8.0 Hz, 1H), 5.77–5.72 (d, J = 3.0 Hz, 1H), 4.54–4.44 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.72–3.64 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.63 (s, 3H), 3.29–3.21 (m, 1H), 2.63–2.45 (m, 2H), 2.38 (s, 3H), 2.27 (s, 3H), 1.87–1.72 (m, 1H), 1.58–1.46 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.2, 147.1, 144.6, 144.5, 139.6, 138.8, 137.3, 132.5, 129.5, 128.0, 128.0, 127.6, 127.3, 125.8, 125.1, 124.9, 122.2, 121.3, 121.0, 60.8, 51.0, 47.0, 44.2, 28.0, 20.7, 20.5, 20.3. IR (KBr): ν (cm^{-1}) 2949, 1735, 1619, 1597, 1275, 1262, 1165, 765, 750, 682. HRMS (ESI, *m*/*z*) calcd for $C_{30}H_{32}N_3O_4S$ $[M+H]^+$: 530.2113, found: 530.2114.

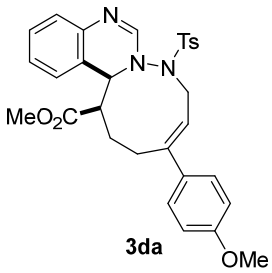
Methyl (14*R*,14a*S*,*E*)-11-(*p*-tolyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ca

According to the general procedure A, **3ca** was obtained as white solid, 49.3 mg, 93% yield, dr > 20:1, m. p. 225–227 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.78–7.67 (dd, J_1 = 6.5 Hz, J_2 = 2.0 Hz, 2H), 7.32–7.26 (d, J = 8.0 Hz, 2H), 7.22–7.12 (m, 3H), 7.10–7.01 (m, 3H), 6.98–6.88 (m, 1H), 6.57–6.48 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.45 (s, 1H), 6.23–6.15 (t, J = 8.0 Hz, 1H), 5.75–5.69 (d, J = 3.5 Hz, 1H), 4.55–4.44 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.72–3.63 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.62 (s, 3H), 3.27–3.19 (m, 1H), 2.62–2.45 (m, 2H), 2.37 (s, 3H), 2.26 (s, 3H), 1.85–1.71 (m, 1H), 1.58–1.46 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.1, 146.7, 144.6, 144.5, 139.6, 137.1, 135.7, 132.5, 129.5, 128.4, 127.9, 127.3, 125.1, 125.0, 124.8, 121.3, 120.4, 60.8, 51.0, 47.0, 44.3, 27.9, 20.7, 20.3, 20.1. IR (KBr): ν (cm^{-1}) 2951, 1735, 1619, 1597, 1261, 1164, 1087, 822, 765, 750. HRMS (ESI, *m*/*z*) calcd for $C_{30}H_{32}N_3O_4S$ $[M+H]^+$: 530.2113, found: 530.2111.

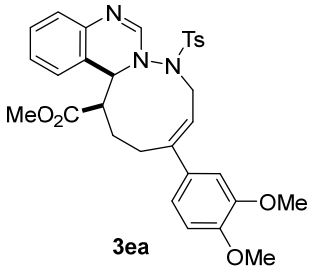
Methyl (14*R*,14a*S*,*E*)-11-(4-methoxyphenyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3da

According to the general procedure A, **3da** was obtained as white solid, 46.8 mg, 86% yield, dr > 20:1, m. p. 236–238 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.84–7.76 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.40– 7.29 (m, 4H), 7.24–7.18 (m, 1H), 7.16–7.09 (m, 1H), 7.06–6.97 (m, 1H), 6.90–6.81 (m, 2H), 6.64–6.56 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.52 (s, 1H), 6.28–6.20 (t, J = 8.5 Hz, 1H), 5.84–5.75 (d, J = 3.5 Hz, 1H), 4.61–4.50 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.80 (s, 3H), 3.78–3.71 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.70 (s, 3H), 3.33–3.25 (m, 1H), 2.68–2.52 (m, 2H), 2.45 (s, 3H), 1.96–1.84 (m, 1H), 1.68–1.54 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.2, 159.7, 147.1, 145.7, 145.5, 140.7, 133.5, 131.9, 130.5, 129.0, 128.4, 127.3, 126.2, 125.9, 122.3, 120.6, 114.1, 61.8, 55.3, 52.0, 48.1, 45.3, 28.8, 21.7, 21.4. IR (KBr): ν (cm^{-1}) 2991, 1734, 1597, 1275, 1261, 1165, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{30}H_{32}N_3O_5S$ $[M+H]^+$: 546.2062, found: 546.2063.

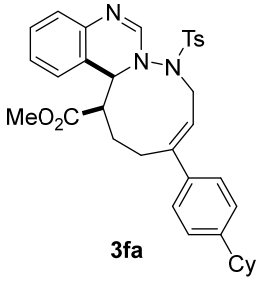
Methyl (14*R*,14a*S*,*E*)-11-(3,4-dimethoxyphenyl)-8-tosyl-8,9,12,13,14,14a-hexahyd- ro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ea

According to the general procedure A, **3ea** was obtained as colorless oil, 55.5 mg, 96% yield, dr > 20:1. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.86–7.73 (m, 2H), 7.42–7.33 (m, 2H), 7.25–7.18 (m, 1H), 7.15–7.08 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 7.07–6.99 (m, 1H), 6.97–6.87 (m, 2H), 6.86–6.77 (d, J = 8.5 Hz, 1H), 6.65–6.58 (m, 1H), 6.51 (s, 1H), 6.31–6.23 (t, J = 8.0 Hz, 1H), 5.86–5.78 (d, J = 3.0 Hz, 1H), 4.66–4.52 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.93–3.84 (d, J = 7.5 Hz, 6H), 3.81–3.72 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.70 (s, 3H), 3.36–3.24 (m, 1H), 2.68–2.51 (m, 2H), 2.45 (s, 3H), 1.96– 1.85 (m, 1H), 1.70–1.55 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.2, 149.3, 149.0, 147.3, 145.6, 145.6, 140.6, 133.5, 132.3, 130.5, 129.0, 128.4, 126.2, 125.9, 125.9, 122.3, 120.9, 118.7, 111.2, 109.2, 61.9, 56.0, 55.9, 52.1, 48.1, 45.4, 29.0, 21.7, 21.4. IR (KBr): v (cm^{-1}) 2952, 1734, 1618, 1597, 1516, 1265, 1164, 765, 750. HRMS (ESI, m/z) calcd for $C_{31}H_{34}N_3O_6S$ $[M+H]^+$: 576.2168, found: 576.2168.

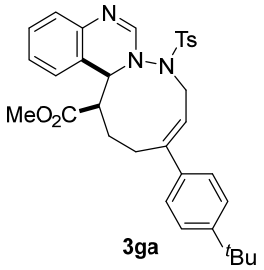
Methyl (14*R*,14a*S*,*E*)-11-(4-cyclohexylphenyl)-8-tosyl-8,9,12,13,14,14a-hexahyd- ro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3fa

According to the general procedure A, **3fa** was obtained as colorless oil, 56.1 mg, 94% yield, dr > 20:1. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.85–7.74 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.40–7.34 (d, J = 8.0 Hz, 2H), 7.33–7.27 (dd, J_1 = 6.5 Hz, J_2 = 2.0 Hz, 2H), 7.25–7.18 (m, 1H), 7.18–7.09 (m, 3H), 7.05–6.99 (m, 1H), 6.62–6.57 (m, 1H), 6.53 (s, 1H), 6.31–6.24 (t, J = 8.0 Hz, 1H), 5.83–5.77 (d, J = 3.0 Hz, 1H), 4.60–4.51 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.79–3.72 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.70 (s, 3H), 3.36–3.27 (dd, J_1 = 11.0 Hz, J_2 = 6.5 Hz, 1H), 2.69–2.41 (m, 6H), 1.95–1.80 (m, 5H), 1.78–1.70 (m, 1H), 1.66–1.54 (m, 1H), 1.48–1.32 (m, 4H), 1.30–1.20 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.3, 148.3, 147.7, 145.7, 145.5, 140.7, 137.1, 133.6, 130.5, 129.0, 128.4, 127.2, 126.2, 126.0, 126.0, 125.9, 122.3, 121.5, 61.9, 52.0, 48.1, 45.4, 44.2, 34.4, 34.3, 28.9, 26.9, 26.2, 21.8, 21.4. IR (KBr): v (cm^{-1}) 2924, 1735, 1620, 1597, 1261, 1165, 765, 750, 682. HRMS (ESI, m/z) calcd for $C_{35}H_{40}N_3O_4S$ $[M+H]^+$: 598.2739, found: 598.2740.

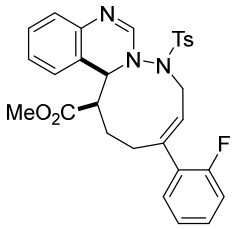
Methyl (14*R*,14a*S*,*E*)-11-(4-(tert-butyl)phenyl)-8-tosyl-8,9,12,13,14,14a-hexahyd- ro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ga

According to the general procedure A, **3ga** was obtained as white solid, 55.1 mg, 96% yield, dr > 20:1, m. p. 207–209 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.85–7.77 (m, 2H), 7.40–7.28 (m, 6H), 7.24–7.19 (m, 1H), 7.16–7.10 (m, 1H), 7.06–6.99 (m, 1H), 6.62–6.56 (dd, J_1 = 7.5 Hz, J_2 = 1.0 Hz, 1H), 6.53 (s, 1H), 6.32–6.25 (t, J = 8.0 Hz, 1H), 5.83–5.76 (d, J = 3.0 Hz, 1H), 4.63–4.50 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.80–3.72 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.71 (s, 3H), 3.36–3.29 (m, 1H), 2.72–2.51 (m, 2H), 2.45 (s, 3H), 2.01–1.86 (m, 1H), 1.68–1.55 (m, 1H), 1.31 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.3, 151.3, 147.6, 145.7, 145.5, 140.7, 136.7, 133.5, 130.5, 129.0, 128.4, 126.2, 125.9, 125.7, 125.7, 122.3, 121.5, 61.9, 52.1, 48.1, 45.3, 34.6, 31.3, 28.9, 21.7, 21.4. IR (KBr): ν (cm^{-1}) 2961, 1737, 1620, 1597, 1359, 1263, 1165, 766, 683, 558. HRMS (ESI, *m*/*z*) calcd for $C_{33}H_{38}N_3O_4S$ $[M+H]^+$: 572.2583, found: 572.2583.

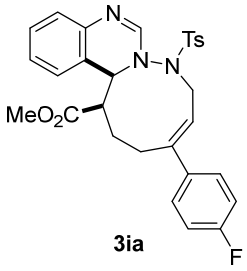
Methyl (14*R*,14a*S*,*E*)-11-(2-fluorophenyl)-8-tosyl-8,9,12,13,14,14a-hexahyd- ro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ha

According to the general procedure A, **3ha** was obtained as white solid, 49.3 mg, 92% yield, dr > 20:1, m. p. 203–205 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.85–7.78 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.43–7.34 (d, J = 8.0 Hz, 2H), 7.27–7.09 (m, 5H), 7.07–6.98 (m, 2H), 6.66–6.57 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.54 (s, 1H), 6.18– 6.06 (t, J = 8.0 Hz, 1H), 5.93–5.85 (d, J = 3.0 Hz, 1H), 4.61–4.49 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.82–3.69 (m, 4H), 3.51–3.38 (m, 1H), 2.66–2.50 (m, 2H), 2.45 (s, 3H), 1.91–1.74 (m, 1H), 1.66–1.46 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.3, 159.7 (d, J = 245.1 Hz), 145.8, 145.6, 144.4, 140.5, 133.5, 130.5, 129.8 (d, J = 3.4 Hz), 129.5 (d, J = 8.6 Hz), 129.0, 128.9, 128.8, 128.4, 126.2, 126.0, 125.9, 124.3 (d, J = 3.6 Hz), 122.3, 116.0 (d, J = 22.4 Hz), 61.7, 52.2, 47.8, 45.1, 30.4, 21.7, 21.2. ^{19}F NMR (470 MHz, $CDCl_3$): δ = –115.4. IR (KBr): ν (cm^{-1}) 2951, 1733, 1619, 1597, 1487, 1213, 1164, 764, 737, 681. HRMS (ESI, *m*/*z*) calcd for $C_{29}H_{29}FN_3O_4S$ $[M+H]^+$: 534.1863, found: 534.1864.

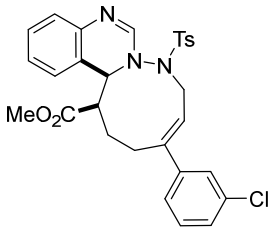
Methyl (14*R*,14a*S*,*E*)-11-(4-fluorophenyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ia

According to the general procedure A, **3ia** was obtained as white solid, 44.4 mg, 83% yield, dr > 20:1, m. p. 224–226 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.87–7.75 (dd, J_1 = 6.5 Hz, J_2 = 2.0 Hz, 2H), 7.43–7.30 (m, 4H), 7.25–7.19 (m, 1H), 7.15–7.09 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 7.06–6.98 (m, 3H), 6.62– 6.56 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.51 (s, 1H), 6.29–6.21 (t, J = 8.0 Hz, 1H), 5.87–5.80 (d, J = 3.0 Hz, 1H), 4.62–4.52 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.78–3.68 (m, 4H), 3.33–3.25 (m, 1H), 2.65–2.57 (m, 2H), 2.45 (s, 3H), 1.92–1.81 (m, 1H), 1.66–1.55 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.1, 162.8 (d, J = 246.1 Hz), 146.9, 145.6, 145.6, 140.6, 135.8 (d, J = 3.3 Hz), 133.5, 130.5, 129.0, 128.4, 127.8 (d, J = 7.9 Hz), 126.3, 125.9 (d, J = 10.5 Hz), 122.3 (d, J = 11.1 Hz), 115.7(d, J = 21.3 Hz), 61.8, 52.1, 48.0, 45.2, 29.2, 21.7, 21.3. ^{19}F NMR (470 MHz, $CDCl_3$): δ = –113.7. IR (KBr): ν (cm^{-1}) 2989, 1734, 1618, 1597, 1508, 1275, 1261, 1165, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{29}H_{29}FN_3O_4S$ $[M+H]^+$: 534.1863, found: 534.1866.

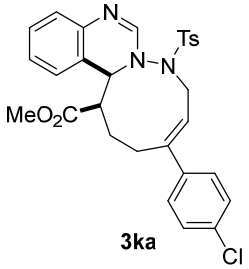
Methyl (14*R*,14a*S*,*E*)-11-(3-chlorophenyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ja

According to the general procedure A, **3ja** was obtained as colorless oil, 44.7 mg, 81% yield, dr > 20:1. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.87–7.76 (d, J = 8.0 Hz, 2H), 7.44–7.31 (m, 3H), 7.27–7.19 (m, 4H), 7.17–7.08 (d, J = 8.0 Hz, 1H), 7.07–6.98 (m, 1H), 6.66– 6.58 (d, J = 7.5 Hz, 1H), 6.53 (s, 1H), 6.32–6.24 (t, J = 8.0 Hz, 1H), 5.88– 5.79 (d, J = 3.0 Hz, 1H), 4.62–4.51 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.78–3.67 (m, 4H), 3.31–3.22 (m, 1H), 2.64–2.53 (m, 2H), 2.46 (s, 3H), 1.92–1.77 (m, 1H), 1.71–1.56 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.1, 146.7, 145.6, 145.6, 141.7, 140.5, 134.7, 133.4, 130.6, 130.0, 129.1, 128.4, 128.4, 126.3, 126.3, 126.0, 125.9, 124.4, 123.4, 122.2, 61.8, 52.2, 47.9, 45.1, 29.0, 21.8, 21.3. IR (KBr): ν (cm^{-1}) 2950, 1733, 1619, 1596, 1355, 1164, 1087, 762, 682. HRMS (ESI, *m*/*z*) calcd for $C_{29}H_{29}ClN_3O_4S$ $[M+H]^+$: 550.1567, found: 550.1568.

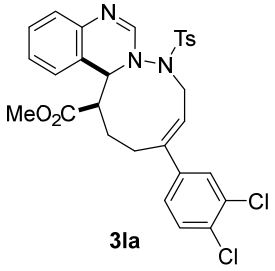
Methyl (14*R*,14a*S*,*E*)-11-(4-chlorophenyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ka

According to the general procedure A, **3ka** was obtained as white solid, 49.2 mg, 90% yield, dr > 20:1, m. p. 239–241 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.76–7.70 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.33–7.27 (d, J = 8.0 Hz, 2H), 7.26–7.20 (m, 4H), 7.18– 7.11 (m, 1H), 7.09–7.02 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.98–6.91 (m, 1H), 6.55– 6.50 (d, J = 7.5 Hz, 1H), 6.44 (s, 1H), 6.24–6.17 (t, J = 8.0 Hz, 1H), 5.78– 5.71 (d, J = 3.5 Hz, 1H), 4.55–4.44 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.71–3.59 (m, 4H), 3.23– 3.15 (m, 1H), 2.57–2.48 (m, 2H), 2.38 (s, 3H), 1.80–1.70 (m, 1H), 1.59–1.46 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.0, 145.7, 144.6, 144.5, 139.5, 137.1, 133.2, 132.4, 129.5, 128.0, 127.9, 127.3, 126.4, 125.2, 124.9, 124.9, 124.8, 121.7, 121.2, 60.8, 51.1, 46.9, 44.1, 28.0, 20.7, 20.2. IR (KBr): v (cm^{-1}) 2951, 1733, 1618, 1597, 1261, 1164, 1087, 830, 765, 750. HRMS (ESI, m/z) calcd for $C_{29}H_{29}ClN_3O_4S$ $[M+H]^+$: 550.1567, found: 550.1568.

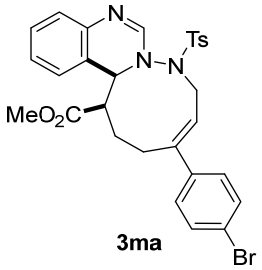
Methyl (14*R*,14a*S*,*E*)-11-(3,4-dichlorophenyl)-8-tosyl-8,9,12,13,14,14a-hexahyd- ro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3la

According to the general procedure A, **3la** was obtained as white solid, 53.3 mg, 91% yield, dr > 20:1, m. p. 209–211 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.85–7.77 (d, J = 8.0 Hz, 2H), 7.48–7.44 (d, J = 2.0 Hz, 1H), 7.43–7.33 (t, J = 8.0 Hz, 3H), 7.26–7.17 (m, 2H), 7.15–7.09 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 7.06–6.98 (m, 1H), 6.65–6.57 (d, J = 7.5 Hz, 1H), 6.52 (s, 1H), 6.34–6.25 (t, J = 8.0 Hz, 1H), 5.87–5.80 (d, J = 3.0 Hz, 1H), 4.63–4.52 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.79– 3.67 (m, 4H), 3.29–3.15 (m, 1H), 2.62–2.53 (m, 2H), 2.46 (s, 3H), 1.90–1.77 (m, 1H), 1.69–1.56 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.0, 145.7, 145.7, 145.5, 140.5, 139.7, 133.3, 133.0, 132.4, 130.7, 130.6, 129.1, 128.4, 128.1, 126.3, 126.0, 126.0, 125.9, 125.5, 123.8, 122.1, 61.7, 52.2, 47.9, 45.0, 28.9, 21.8, 21.3. IR (KBr): v (cm^{-1}) 2952, 1733, 1619, 1597, 1275, 1261, 1164, 1087, 765, 750. HRMS (ESI, m/z) calcd for $C_{29}H_{28}Cl_2N_3O_4S$ $[M+H]^+$: 584.1177, found: 584.1176.

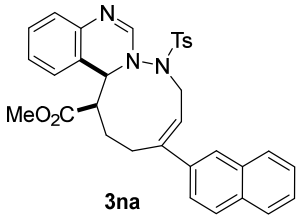
Methyl (14*R*,14a*S*,*E*)-11-(4-bromophenyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ma

According to the general procedure A, **3ma** was obtained as white solid, 54.6 mg, 92% yield, dr > 20:1, m. p. 234–236 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.87–7.76 (dd, J_1 = 6.5 Hz, J_2 = 2.0 Hz, 2H), 7.52–7.42 (m, 2H), 7.42–7.33 (d, J = 8.0 Hz, 2H), 7.29–7.19 (m, 3H), 7.18–7.09 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 7.06–6.98 (m, 1H), 6.65– 6.55 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.51 (s, 1H), 6.33–6.24 (t, J = 8.0 Hz, 1H), 5.87–5.75 (d, J = 3.0 Hz, 1H), 4.62–4.50 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.78–3.65 (m, 4H), 3.31–3.21 (m, 1H), 2.65–2.54 (m, 2H), 2.45 (s, 3H), 1.92–1.78 (m, 1H), 1.69–1.54 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.1, 146.8, 145.6, 145.5, 140.6, 138.7, 133.4, 131.9, 130.6, 129.1, 128.4, 127.8, 126.3, 126.0, 125.9, 122.8, 122.4, 122.2, 61.8, 52.2, 47.9, 45.1, 29.0, 21.8, 21.3. IR (KBr): ν (cm^{-1}) 2951, 1732, 1618, 1597, 1275, 1261, 1163, 1087, 765, 750, 682. HRMS (ESI, *m*/*z*) calcd for $C_{29}H_{29}BrN_3O_4S$ $[M+H]^+$: 594.1062, found: 594.1065.

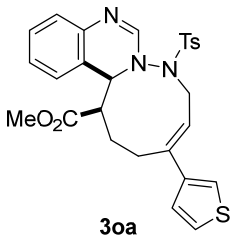
Methyl (14*R*,14a*S*,*E*)-11-(naphthalen-2-yl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3na

According to the general procedure A, **3na** was obtained as white solid, 54.1 mg, 96% yield, dr > 20:1, m. p. 207–209 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.80–7.67 (m, 6H), 7.49–7.42 (dd, J_1 = 8.5 Hz, J_2 = 2.0 Hz, 1H), 7.42–7.33 (m, 2H), 7.32–7.25 (d, J = 8.0 Hz, 2H), 7.16–7.11 (m, 1H), 7.09–7.03 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.97–6.90 (m, 1H), 6.55–6.50 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 6.48 (s, 1H), 6.41–6.33 (t, J = 8.0 Hz, 1H), 5.79–5.72 (d, J = 3.5 Hz, 1H), 4.59–4.48 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.77–3.65 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.57 (s, 3H), 3.34–3.26 (m, 1H), 2.78–2.67 (m, 1H), 2.64–2.53 (m, 1H), 2.37 (s, 3H), 1.92–1.79 (m, 1H), 1.63–1.50 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.1, 147.7, 145.7, 145.6, 140.6, 136.9, 133.5, 133.4, 133.2, 130.6, 129.0, 128.4, 128.4, 128.3, 127.6, 126.4, 126.3, 126.2, 125.9, 125.3, 124.1, 122.7, 122.3, 61.9, 52.1, 48.1, 45.3, 28.9, 21.8, 21.5. IR (KBr): ν (cm^{-1}) 2989, 1734, 1619, 1597, 1275, 1165, 765, 750, 685. HRMS (ESI, *m*/*z*) calcd for $C_{33}H_{32}N_3O_4S$ $[M+H]^+$: 566.2113, found: 566.2113.

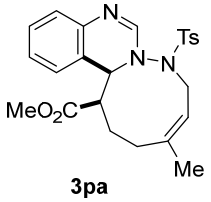
Methyl (14*R*,14a*S*,*E*)-11-(thiophen-3-yl)-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3oa

According to the general procedure A, **3oa** was obtained as colorless oil, 50.5 mg, 97% yield, dr > 20:1. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.83–7.76 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.41–7.34 (d, J = 8.0 Hz, 2H), 7.30–7.20 (m, 4H), 7.17–7.10 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 7.07–6.98 (m, 1H), 6.63–6.57 (dd, J_1 = 8.5 Hz, J_2 = 1.0 Hz, 1H), 6.53 (s, 1H), 6.48–6.39 (t, J = 8.0 Hz, 1H), 5.82–5.74 (d, J = 3.0 Hz, 1H), 4.62–4.51 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.75–3.65 (m, 4H), 3.30–3.21 (m, 1H), 2.65– 2.50 (m, 2H), 2.45 (s, 3H), 2.14–2.02 (m, 1H), 1.75–1.61 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.2, 145.6, 145.6, 141.9, 140.7, 140.6, 133.5, 130.5, 129.0, 128.4, 126.3, 126.2, 125.9, 125.9, 125.3, 122.3, 121.9, 120.7, 61.8, 52.1, 48.0, 45.4, 28.9, 21.8, 21.7. IR (KBr): v (cm^{-1}) 2950, 1734, 1618, 1597, 1275, 1260, 1165, 765, 750, 685. HRMS (ESI, m/z) calcd for $C_{27}H_{28}N_3O_4S_2$ $[M+H]^+$: 522.1521, found: 522.1522.

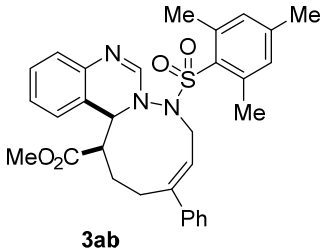
Methyl (14*R*,14a*S*,*Z*)-11-methyl-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazon- ino[1,9-*c*]quinazoline-14-carboxylate



3pa

According to the general procedure A, **3pa** was obtained as colorless oil, 36.8 mg, 81% yield, dr > 20:1. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.74–7.66 (dd, J_1 = 6.5 Hz, J_2 = 1.5 Hz, 2H), 7.32–7.24 (d, J = 8.0 Hz, 2H), 7.17–7.09 (m, 1H), 7.06–7.00 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 6.99–6.92 (m, 1H), 6.60–6.52 (d, J = 7.5 Hz, 1H), 6.39 (s, 1H), 5.79–5.70 (m, 2H), 4.31–4.21 (dd, J_1 = 15.0 Hz, J_2 = 8.0 Hz, 1H), 3.72 (s, 3H), 3.53–3.43 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.20–3.12 (dd, J_1 = 10.5 Hz, J_2 = 3.0 Hz, 1H), 2.37 (s, 3H), 2.32–2.21 (m, 1H), 2.07–1.94 (m, 1H), 1.92–1.83 (m, 1H), 1.67 (s, 3H), 1.55–1.41 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.5, 144.8, 144.4, 144.3, 139.6, 132.6, 129.4, 127.9, 127.3, 125.1, 124.8, 124.8, 121.4, 119.9, 60.6, 51.1, 46.8, 44.3, 30.0, 21.4, 20.7, 19.7. IR (KBr): v (cm^{-1}) 2951, 1734, 1618, 1597, 1275, 1261, 1164, 765, 750, 683. HRMS (ESI, m/z) calcd for $C_{24}H_{28}N_3O_4S$ $[M+H]^+$: 454.1800, found: 454.1799.

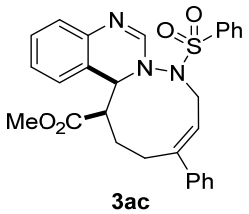
Methyl (14*R*,14a*S*,*E*)-8-(mesitylsulfonyl)-11-phenyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ab

According to the general procedure A, **3ab** was obtained as white solid, 49.7 mg, 91% yield, dr > 20:1, m. p. 235–237 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.51 (s, 1H), 7.31–7.20 (m, 5H), 7.14–7.06 (m, 2H), 6.90–6.79 (m, 3H), 6.26–6.18 (t, J = 8.5 Hz, 1H), 6.11–6.02 (dd, J_1 = 8.0 Hz, J_2 = 1.0 Hz, 1H), 4.83–4.70 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 4.33–4.23 (d, J = 3.5 Hz, 1H), 3.93–3.78 (m, 1H), 3.46 (s, 3H), 2.96–2.86 (m, 1H), 2.71–2.56 (m, 2H), 2.53 (s, 6H), 2.23 (s, 3H), 1.78–1.66 (m, 1H), 1.52–1.38 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 171.6, 147.4, 146.4, 143.2, 140.8, 139.5, 138.9, 131.2, 129.2, 128.0, 127.7, 127.3, 125.0, 124.8, 124.8, 124.2, 121.2, 120.5, 58.8, 50.7, 45.4, 44.1, 28.1, 21.8, 20.1, 19.9. IR (KBr): v (cm^{-1}) 2948, 1739, 1618, 1597, 1330, 1260, 1158, 764, 679. HRMS (ESI, m/z) calcd for $C_{31}H_{34}N_3O_4S$ $[M+H]^+$: 544.2270, found: 544.2270.

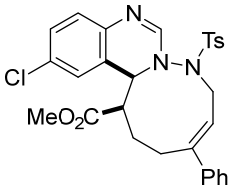
Methyl (14*R*,14a*S*,*E*)-11-phenyl-8-(phenylsulfonyl)-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ac

According to the general procedure A, **3ac** was obtained as white solid, 41.3 mg, 82% yield, dr > 20:1, m. p. 256–258 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.90–7.84 (m, 2H), 7.65–7.57 (m, 1H), 7.56–7.48 (m, 2H), 7.32–7.20 (m, 5H), 7.18–7.12 (m, 1H), 7.09–7.02 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.99–6.91 (m, 1H), 6.55–6.49 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.48 (s, 1H), 6.26–6.16 (t, J = 8.0 Hz, 1H), 5.73–5.69 (d, J = 3.5 Hz, 1H), 4.59–4.44 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.75–3.66 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.62 (s, 3H), 3.27–3.20 (m, 1H), 2.63–2.45 (m, 2H), 1.88–1.74 (m, 1H), 1.59–1.48 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.1, 147.1, 144.6, 139.5, 138.8, 135.6, 133.3, 128.9, 128.0, 127.7, 127.4, 127.3, 125.2, 125.1, 124.9, 124.9, 121.2, 121.1, 60.8, 51.1, 47.0, 44.3, 28.1, 20.3. IR (KBr): v (cm^{-1}) 3005, 1733, 1617, 1275, 1261, 1168, 1087, 764, 750. HRMS (ESI, m/z) calcd for $C_{28}H_{28}N_3O_4S$ $[M+H]^+$: 502.1800, found: 502.1802.

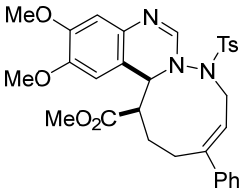
Methyl (14*R*,14a*S*,*E*)-2-chloro-11-phenyl-8-tosyl-8,9,12,13,14,14a-hexahydro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ad

According to the general procedure B, **3ad** was obtained as colorless oil, 43.3 mg, 79% yield, dr > 20:1. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.83–7.75 (dd, J_1 = 6.5 Hz, J_2 = 2.0 Hz, 2H), 7.43–7.28 (m, 7H), 7.22–7.14 (dd, J_1 = 8.0 Hz, J_2 = 2.0 Hz, 1H), 7.09–7.03 (d, J = 8.5 Hz, 1H), 6.63–6.58 (d, J = 2.5 Hz, 1H), 6.56 (s, 1H), 6.33–6.24 (t, J = 8.0 Hz, 1H), 5.71–5.64 (d, J = 3.5 Hz, 1H), 4.64–4.51 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.82–3.71 (dd, J_1 = 15.0 Hz, J_2 = 7.5 Hz, 1H), 3.70 (s, 3H), 3.36–3.23 (m, 1H), 2.76–2.65 (m, 1H), 2.62–2.53 (m, 1H), 2.46 (s, 3H), 1.96–1.83 (m, 1H), 1.67–1.55 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.6, 147.9, 145.8, 145.7, 139.7, 139.5, 133.3, 131.2, 130.5, 129.1, 128.8, 128.4, 128.4, 127.1, 126.1, 123.8, 122.2, 61.5, 52.1, 47.7, 45.6, 29.1, 21.8, 21.3. IR (KBr): ν (cm^{-1}) 2989, 1734, 1594, 1481, 1275, 1261, 1165, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{29}H_{29}ClN_3O_4S$ $[M+H]^+$: 550.1567, found: 550.1569.

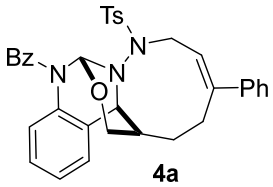
Methyl (14*R*,14a*S*,*E*)-2,3-dimethoxy-11-phenyl-8-tosyl-8,9,12,13,14,14a-hexahy- dro-[1,2]diazonino[1,9-*c*]quinazoline-14-carboxylate



3ae

According to the general procedure A, **3ae** was obtained as white solid, 49.0mg, 85% yield, dr > 20:1, m. p. 224–226 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.85–7.77 (d, J = 8.0 Hz, 2H), 7.41–7.36 (m, 4H), 7.36–7.28 (m, 3H), 6.70 (s, 1H), 6.45 (s, 1H), 6.34–6.24 (t, J = 8.0 Hz, 1H), 6.16 (s, 1H), 5.84–5.76 (d, J = 3.5 Hz, 1H), 4.61–4.49 (dd, J_1 = 15.0 Hz, J_2 = 8.5 Hz, 1H), 3.86 (s, 3H), 3.79–3.72 (m, 4H), 3.70 (s, 3H), 3.33–3.25 (dd, J_1 = 11.0 Hz, J_2 = 3.0 Hz, 1H), 2.71–2.53 (m, 2H), 2.46 (s, 3H), 1.96–1.80 (m, 1H), 1.67–1.57 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 173.6, 149.0, 147.9, 147.0, 145.5, 144.3, 139.8, 134.6, 133.6, 130.5, 128.7, 128.4, 128.3, 126.2, 122.3, 113.6, 109.1, 108.5, 61.8, 55.9, 52.0, 47.9, 45.3, 29.1, 21.7, 21.3. IR (KBr): ν (cm^{-1}) 2952, 1733, 1605, 1510, 1275, 1261, 1164, 764, 750. HRMS (ESI, *m*/*z*) calcd for $C_{31}H_{34}N_3O_6S$ $[M+H]^+$: 576.2168, found: 576.2170.

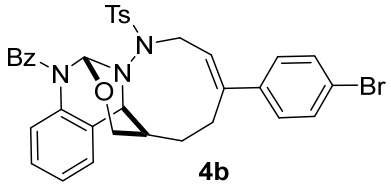
((6*S*,7*R*,14a*R*,*E*)-11-phenyl-8-tosyl-8,9,12,13,14,14a-hexahydro-6,14-(epoxymethano)[1,2]diazonino[1,9-*c*]quinazolin-5(6H)-yl)methanone



4a

4a was obtained as white solid, 39.2mg, 66% yield, dr > 20:1, m. p. 109–111 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.90–7.82 (d, J = 8.5 Hz, 1H), 7.56–7.46 (m, 3H), 7.45–7.39 (m, 2H), 7.39–7.28 (m, 7H), 7.24–7.17 (m, 1H), 7.11–7.04 (d, J = 8.0 Hz, 2H), 6.96–6.90 (m, 1H), 6.59–6.54 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 6.14–6.09 (d, J = 1.5 Hz, 1H), 6.09–6.01 (dd, J_1 = 10.5 Hz, J_2 = 7.0 Hz, 1H), 4.65–4.53 (dd, J_1 = 14.5 Hz, J_2 = 7.0 Hz, 1H), 4.29–4.17 (dd, J_1 = 15.0 Hz, J_2 = 10.0 Hz, 1H), 4.14 (s, 1H), 4.05–3.94 (dd, J_1 = 12.5 Hz, J_2 = 5.5 Hz, 1H), 3.71–3.60 (dd, J_1 = 12.0 Hz, J_2 = 2.5 Hz, 1H), 3.41–3.28 (dd, J_1 = 14.5 Hz, J_2 = 9.0 Hz, 1H), 2.74–2.60 (dd, J_1 = 14.5 Hz, J_2 = 10.0 Hz, 1H), 2.40 (s, 3H), 2.02–1.90 (m, 1H), 1.78–1.63 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 171.3, 146.2, 143.8, 141.7, 136.4, 136.3, 135.9, 131.2, 130.9, 129.3, 128.6, 128.6, 128.4, 128.1, 127.8, 127.0, 126.8, 125.1, 123.2, 122.0, 121.1, 93.9, 62.3, 58.2, 48.3, 38.8, 30.4, 25.0, 21.6. IR (KBr): v (cm^{-1}) 2928, 1663, 1489, 1330, 1159, 1090, 1033, 699, 662. HRMS (ESI, m/z) calcd for $C_{35}H_{34}N_3O_4S$ $[M+H]^+$: 592.2270, found: 592.2270.

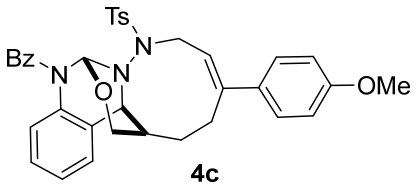
((6*S*,7*R*,14a*R*,*E*)-11-(4-bromophenyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-6,14-(epoxymethano)[1,2]diazonino[1,9-*c*]quinazolin-5(6H)-yl)(phenyl)methanone



4b

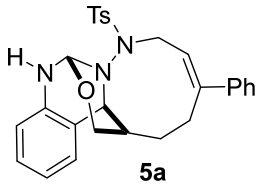
4b was obtained as white solid, 44.6 mg, 67% yield, dr > 20:1, m. p. 220–222 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.87–7.56 (d, J = 8.5 Hz, 1H), 7.54–7.45 (m, 5H), 7.44–7.39 (m, 2H), 7.36–7.30 (d, J = 8.0 Hz, 2H), 7.24–7.16 (m, 3H), 7.12–7.05 (d, J = 8.0 Hz, 2H), 6.98–6.90 (t, J = 7.5 Hz, 1H), 6.63–6.56 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 6.10–6.02 (m, 2H), 4.62–4.53 (dd, J_1 = 14.5 Hz, J_2 = 7.0 Hz, 1H), 4.27–4.18 (dd, J_1 = 15.0 Hz, J_2 = 10.5 Hz, 1H), 4.12 (s, 1H), 4.06–3.97 (dd, J_1 = 12.5 Hz, J_2 = 5.5 Hz, 1H), 3.69–3.60 (dd, J_1 = 12.5 Hz, J_2 = 2.5 Hz, 1H), 3.40–3.29 (dd, J_1 = 15.0 Hz, J_2 = 9.5 Hz, 1H), 2.67–2.57 (dd, J_1 = 15.0 Hz, J_2 = 10.5 Hz, 1H), 2.40 (s, 3H), 2.03–1.92 (m, 1H), 1.74–1.62 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 171.3, 145.0, 143.9, 140.5, 136.4, 136.2, 135.6, 131.8, 131.1, 130.9, 129.3, 128.5, 128.4, 128.1, 127.0, 125.1, 123.2, 121.9, 121.8, 121.7, 93.6, 62.3, 58.4, 48.1, 38.4, 30.6, 24.9, 21.6. IR (KBr): v (cm^{-1}) 2918, 1662, 1599, 1488, 1332, 1287, 1159, 727, 665. HRMS (ESI, m/z) calcd for $C_{35}H_{32}BrN_3O_4S$ $[M+H]^+$: 670.1375, found: 670.1368.

((6*S*,7*R*,14a*R*,*E*)-11-(4-methoxyphenyl)-8-tosyl-8,9,12,13,14,14a-hexahydro-6,14-(epoxymethano)[1,2]diazonino[1,9-*c*]quinazolin-5(6H)-yl)(phenyl)methanone



4c

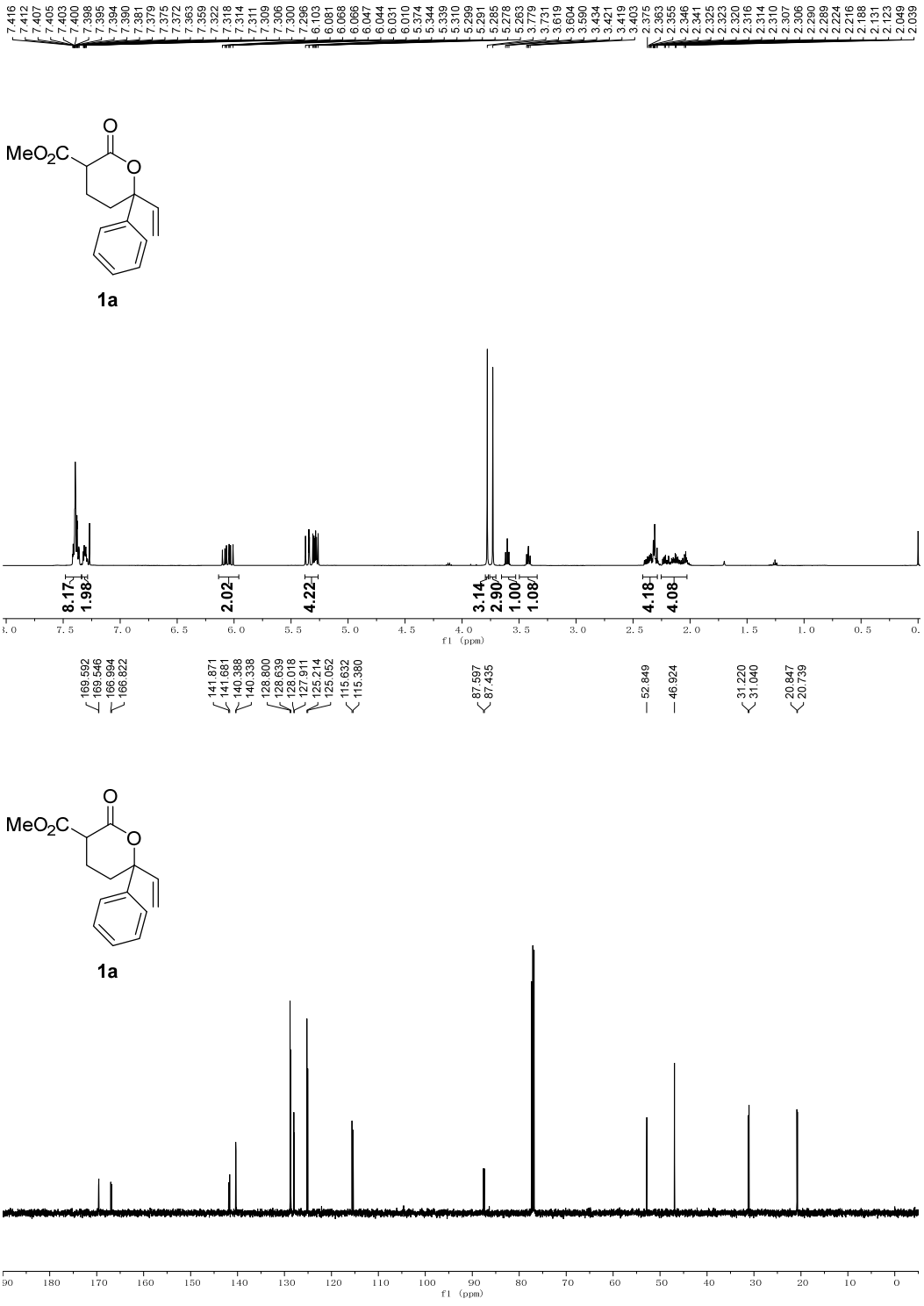
4c was obtained as white solid, 40.5 mg, 65% yield, dr > 20:1, m. p. 211–213 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.89–7.82 (d, *J* = 8.5 Hz, 1H), 7.55–7.46 (m, 3H), 7.45–7.40 (t, *J* = 7.5 Hz, 2H), 7.36–7.32 (d, *J* = 8.0 Hz, 2H), 7.27 (s, 2H), 7.23–7.17 (m, 1H), 7.10–7.05 (d, *J* = 8.0 Hz, 2H), 6.95–6.87 (m, 3H), 6.57–6.52 (dd, J_1 = 8.0 Hz, J_2 = 1.5 Hz, 1H), 6.12–6.08 (d, *J* = 1.5 Hz, 1H), 6.04–5.97 (dd, J_1 = 10.5 Hz, J_2 = 7.0 Hz, 1H), 4.63–4.53 (dd, J_1 = 15.0 Hz, J_2 = 7.0 Hz, 1H), 4.27–4.17 (dd, J_1 = 15.0 Hz, J_2 = 10.0 Hz, 1H), 4.11 (s, 1H), 4.02–3.93 (dd, J_1 = 12.5 Hz, J_2 = 5.5 Hz, 1H), 3.84 (s, 3H), 3.71–3.62 (dd, J_1 = 12.0 Hz, J_2 = 3.0 Hz, 1H), 3.36–3.26 (dd, J_1 = 14.5 Hz, J_2 = 9.0 Hz, 1H), 2.69–2.58 (dd, J_1 = 15.0 Hz, J_2 = 10.0 Hz, 1H), 2.40 (s, 3H), 2.00–1.89 (m, 1H), 1.77–1.62 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 171.2, 159.3, 145.5, 143.7, 136.3, 136.2, 135.9, 133.7, 131.2, 130.8, 129.2, 128.5, 128.4, 128.0, 127.8, 126.9, 125.0, 123.1, 121.9, 119.6, 113.9, 93.8, 62.2, 58.1, 55.3, 48.3, 38.9, 30.4, 24.6, 21.6. HRMS (ESI, *m*/*z*) calcd for $C_{36}H_{35}N_3O_5S$ $[M+H]^+$: 622.2375, found: 622.2373.



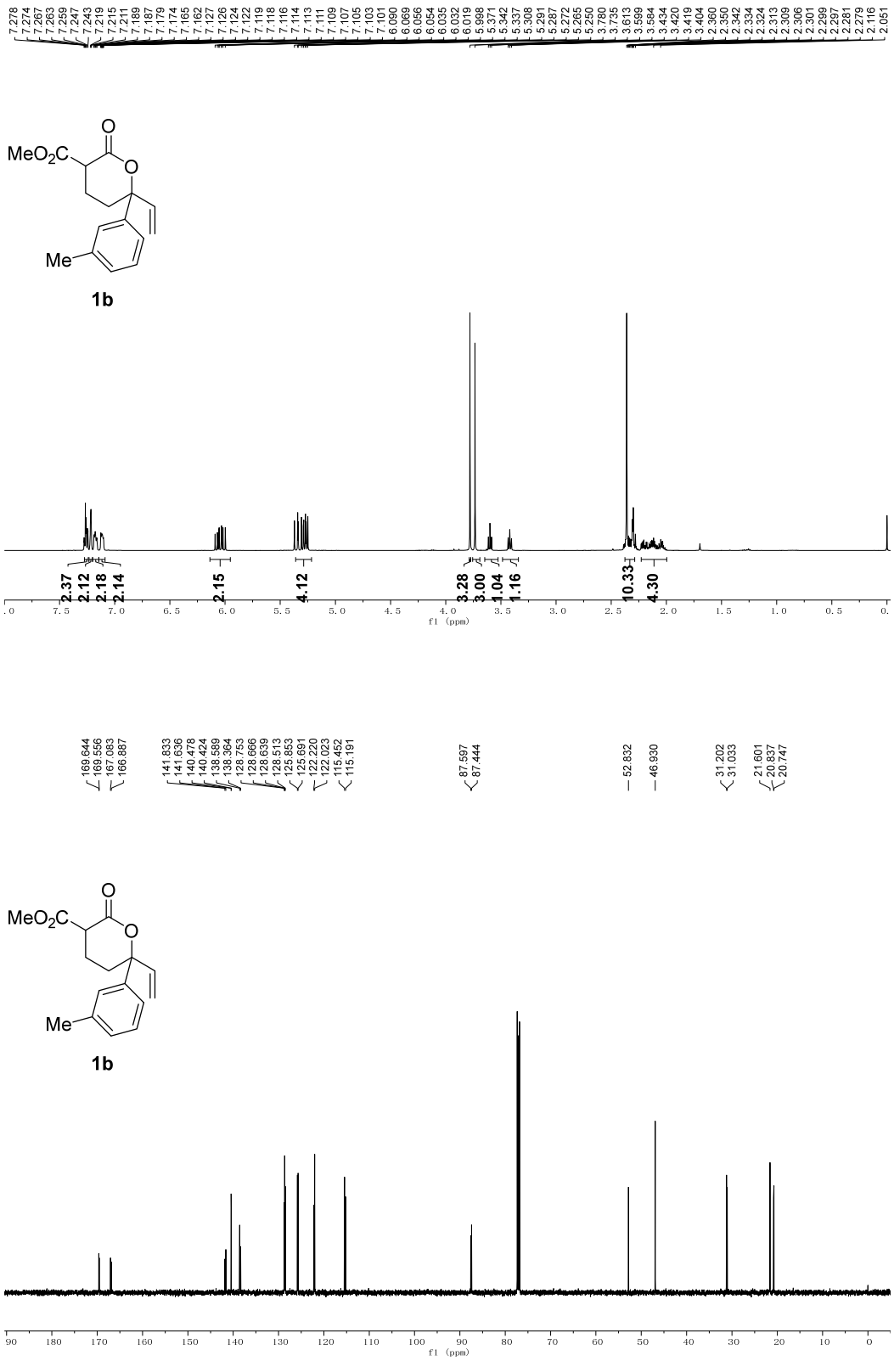
5a

5a was obtained as white solid, 41.6 mg, 85% yield, dr > 20:1, m. p. 213–215 ℃. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.77–7.72 (m, 2H), 7.39–7.35 (m, 2H), 7.35– 7.24 (m, 6H), 7.17–7.13 (dd, J_1 = 7.9 Hz, J_2 = 1.5 Hz, 1H), 7.11–7.06 (m, 1H), 7.03–6.99 (dd, J_1 = 7.9 Hz, J_2 = 1.5 Hz, 1H), 6.58 (s, 1H), 6.28–6.22 (t, *J* = 8.1 Hz, 1H), 5.31–5.25 (d, *J* = 3.7 Hz, 1H), 4.65–4.55 (dd, J_1 = 14.9 Hz, J_2 = 8.5 Hz, 1H), 3.89–3.80 (dd, J_1 = 14.9 Hz, J_2 = 7.8 Hz, 1H), 3.42–3.33 (t, *J* = 10.2 Hz, 1H), 3.17–3.08 (dd, J_1 = 10.8 Hz, J_2 = 7.0 Hz, 1H), 2.72–2.58 (m, 2H), 2.55–2.44 (m, 1H), 2.41 (s, 3H), 1.98 (s, 1H), 1.40–1.28 (m, 1H), 1.03–0.92 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 148.4, 146.3, 145.4, 141.2, 140.2, 133.3, 130.4, 128.7, 128.6, 128.4, 128.2, 127.7, 126.2, 125.7, 125.4, 122.1, 121.6, 63.7, 60.5, 47.6, 41.3, 29.7, 29.7, 22.2, 21.7. IR (KBr): *v* (cm^{-1}) 2184, 2167, 2160, 2139, 2028, 2018, 1614, 1597, 1165, 1088, 762, 687. HRMS (ESI, *m*/*z*) calcd for $C_{28}H_{30}N_3O_3S$ $[M+H]^+$: 488.2008, found: 488.2013.

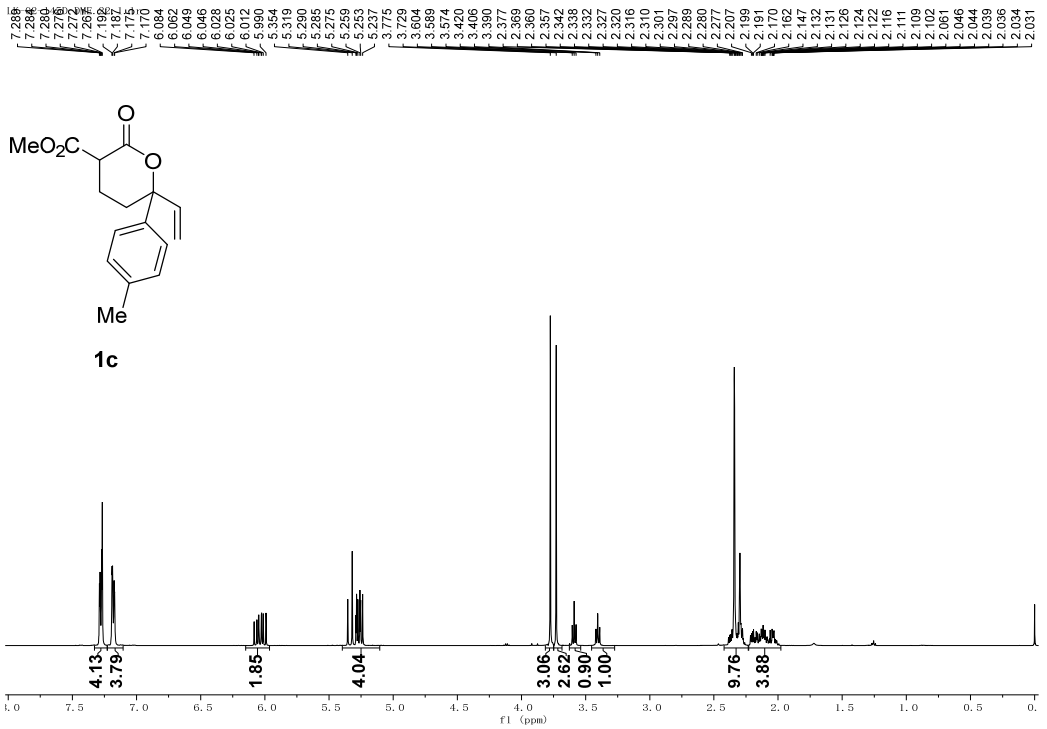
NMR Spectra of the Compounds 1, 3 and 4

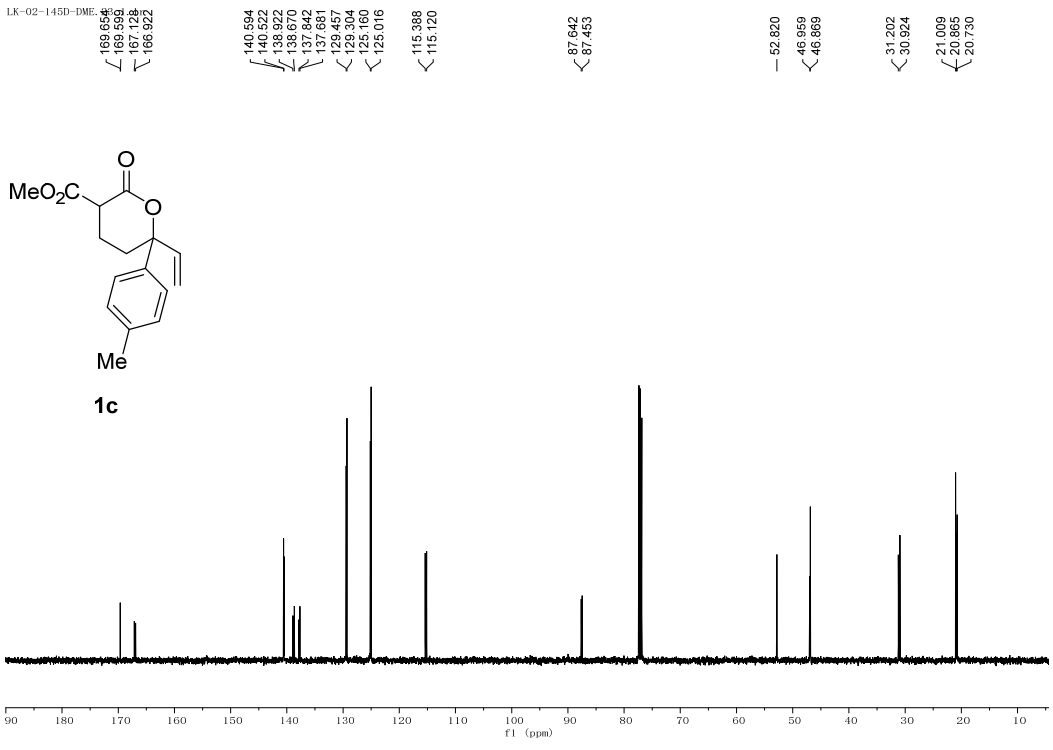


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1a**

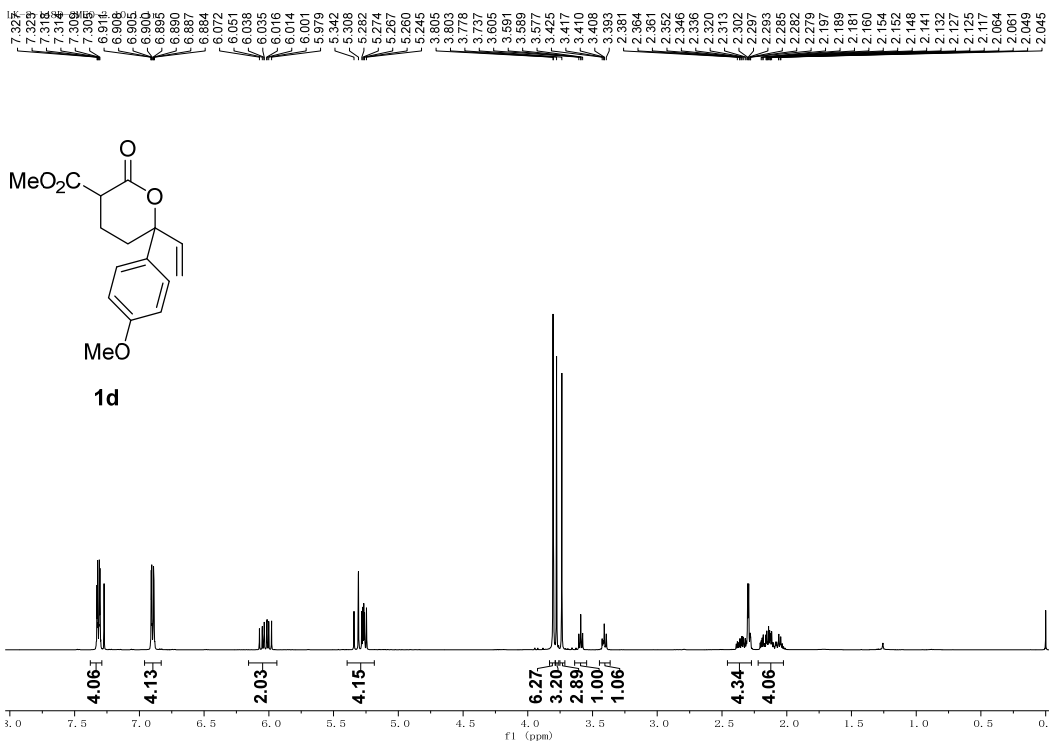


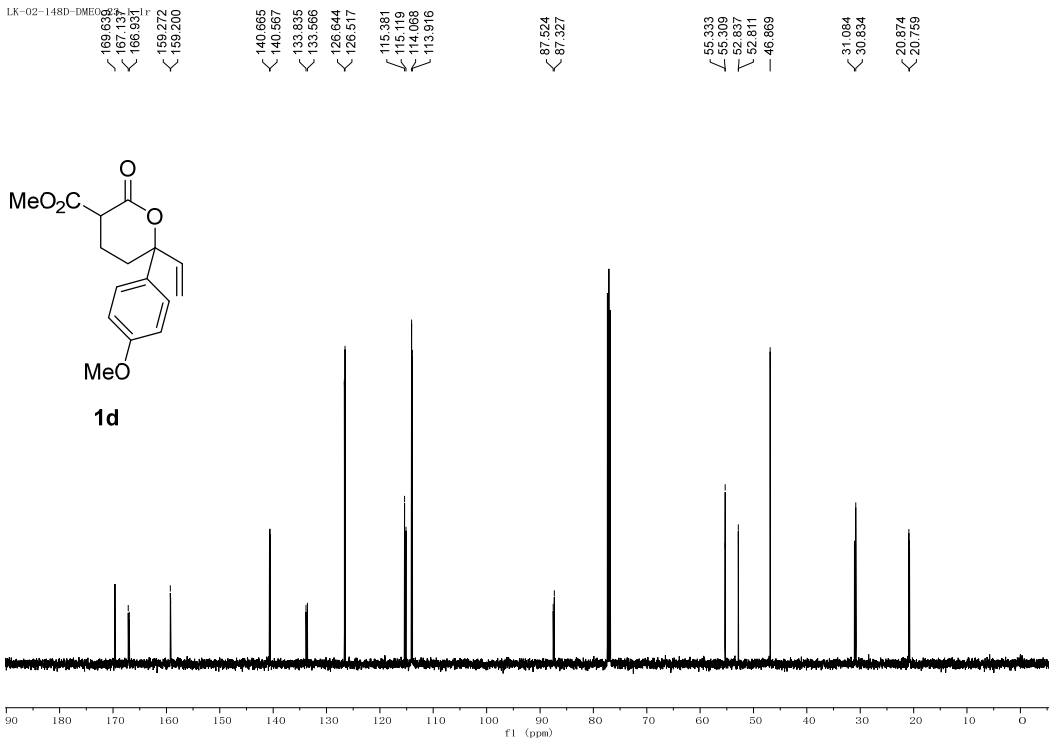
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1b**



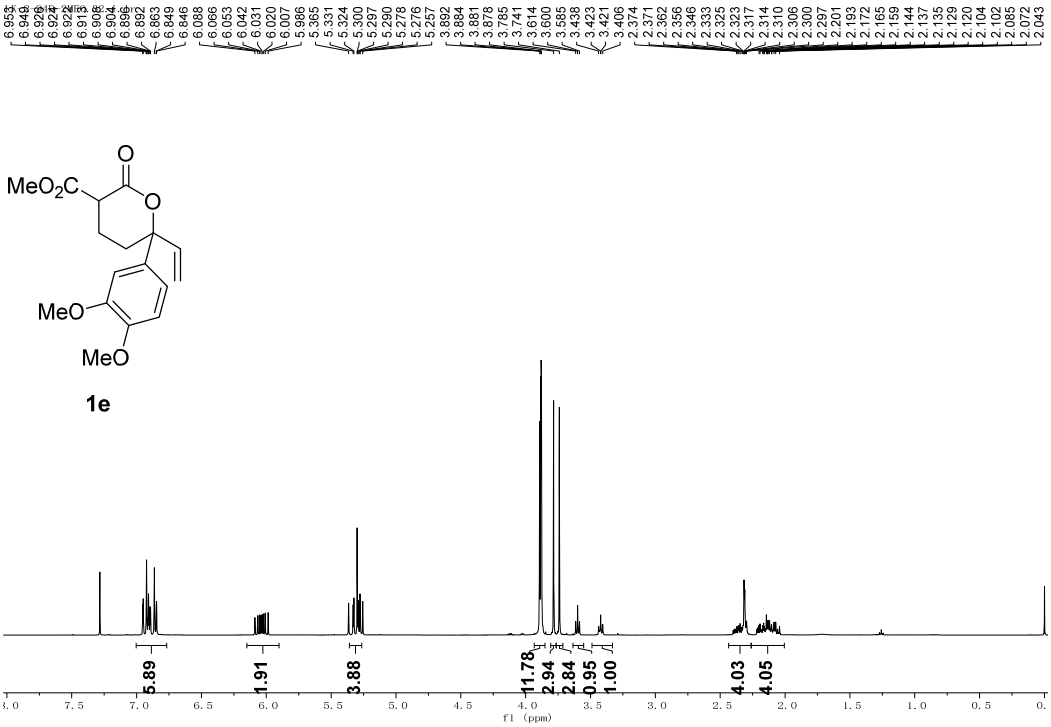


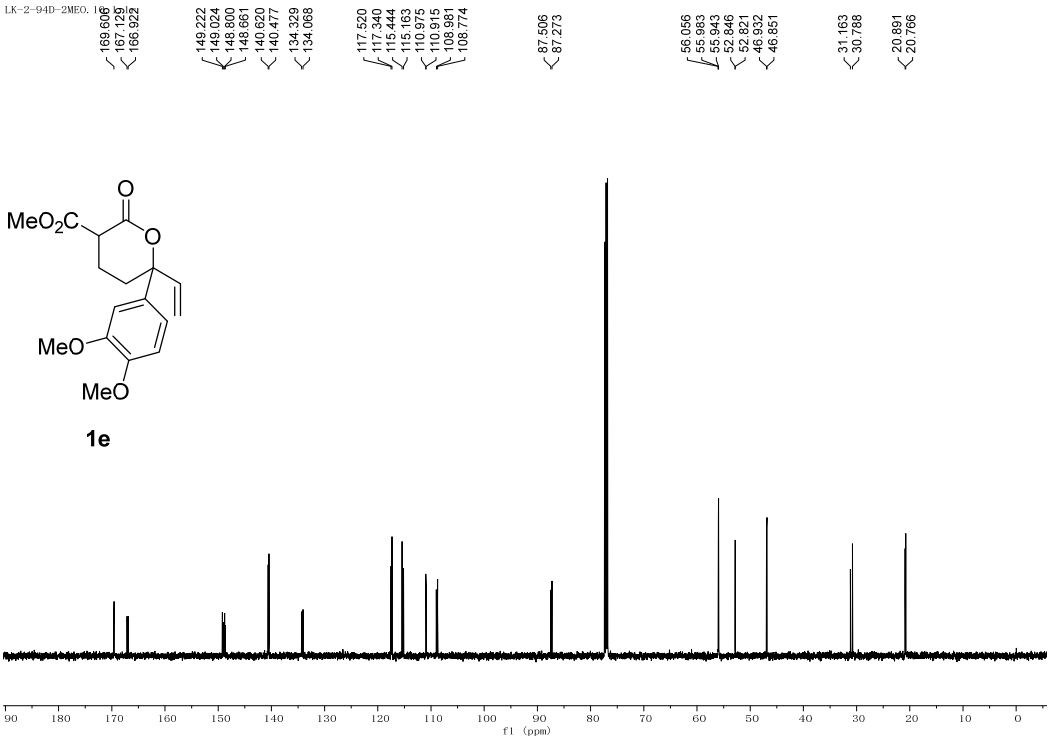
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1c**



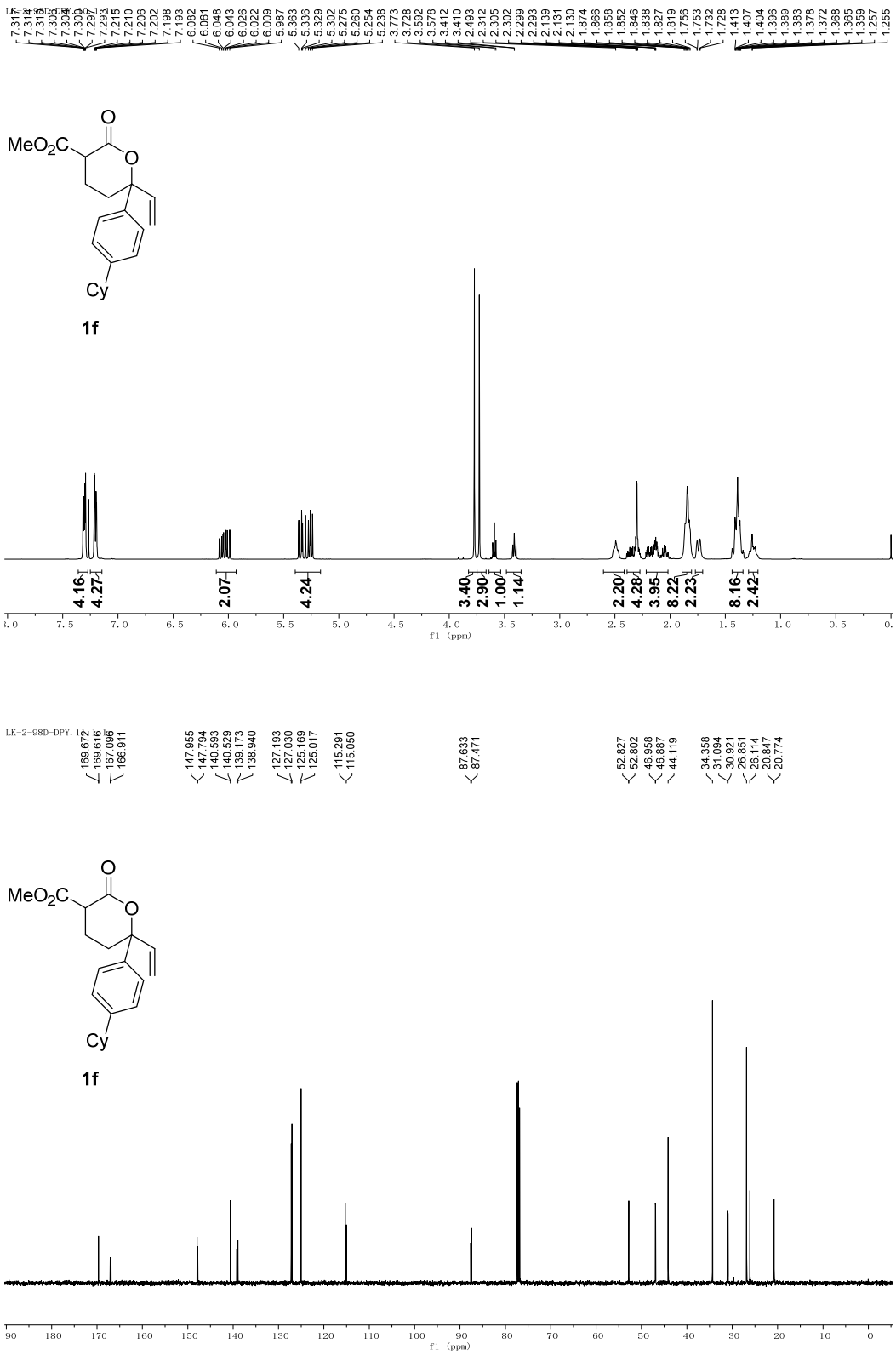


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1d**

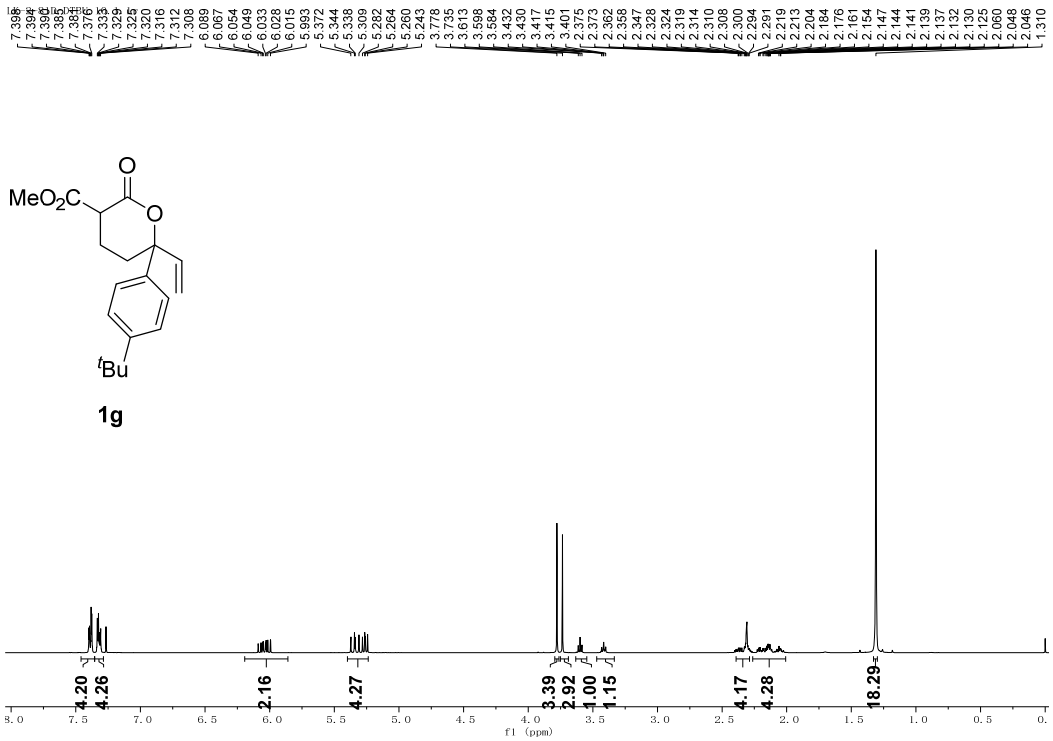


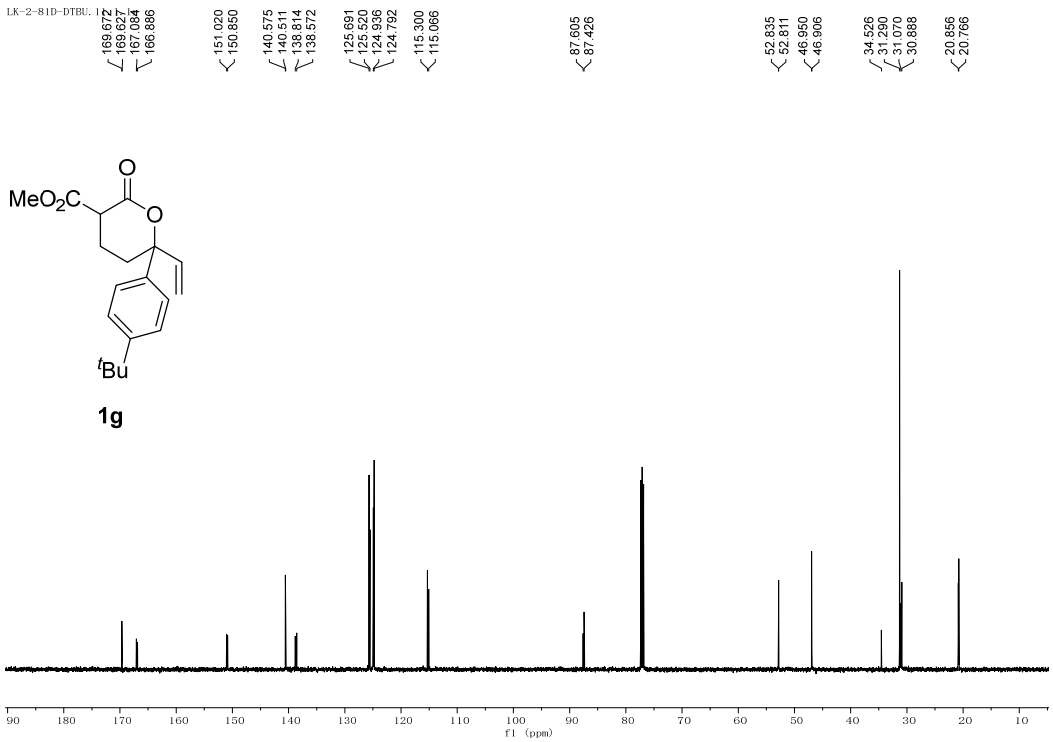


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1e**

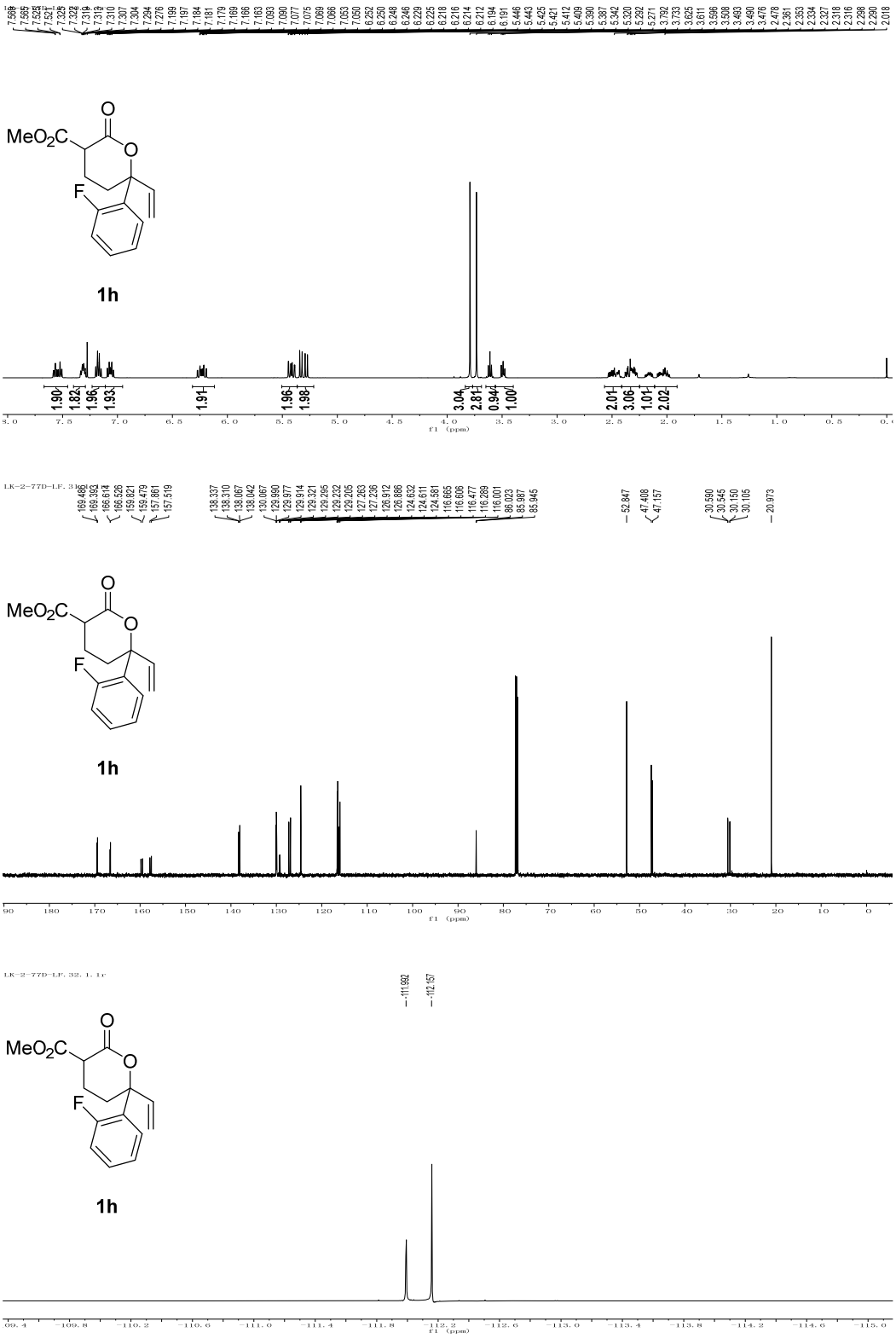


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1f**

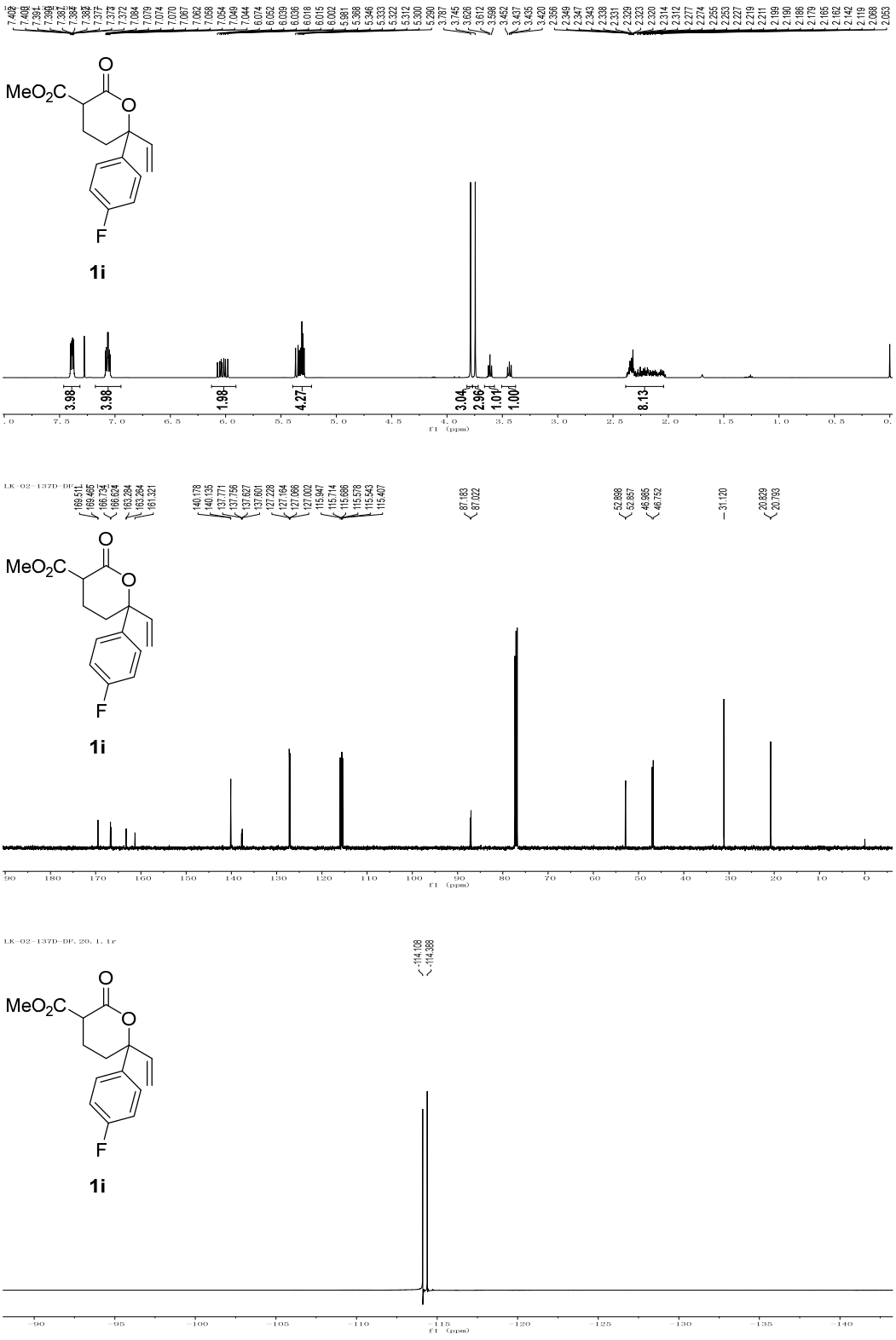




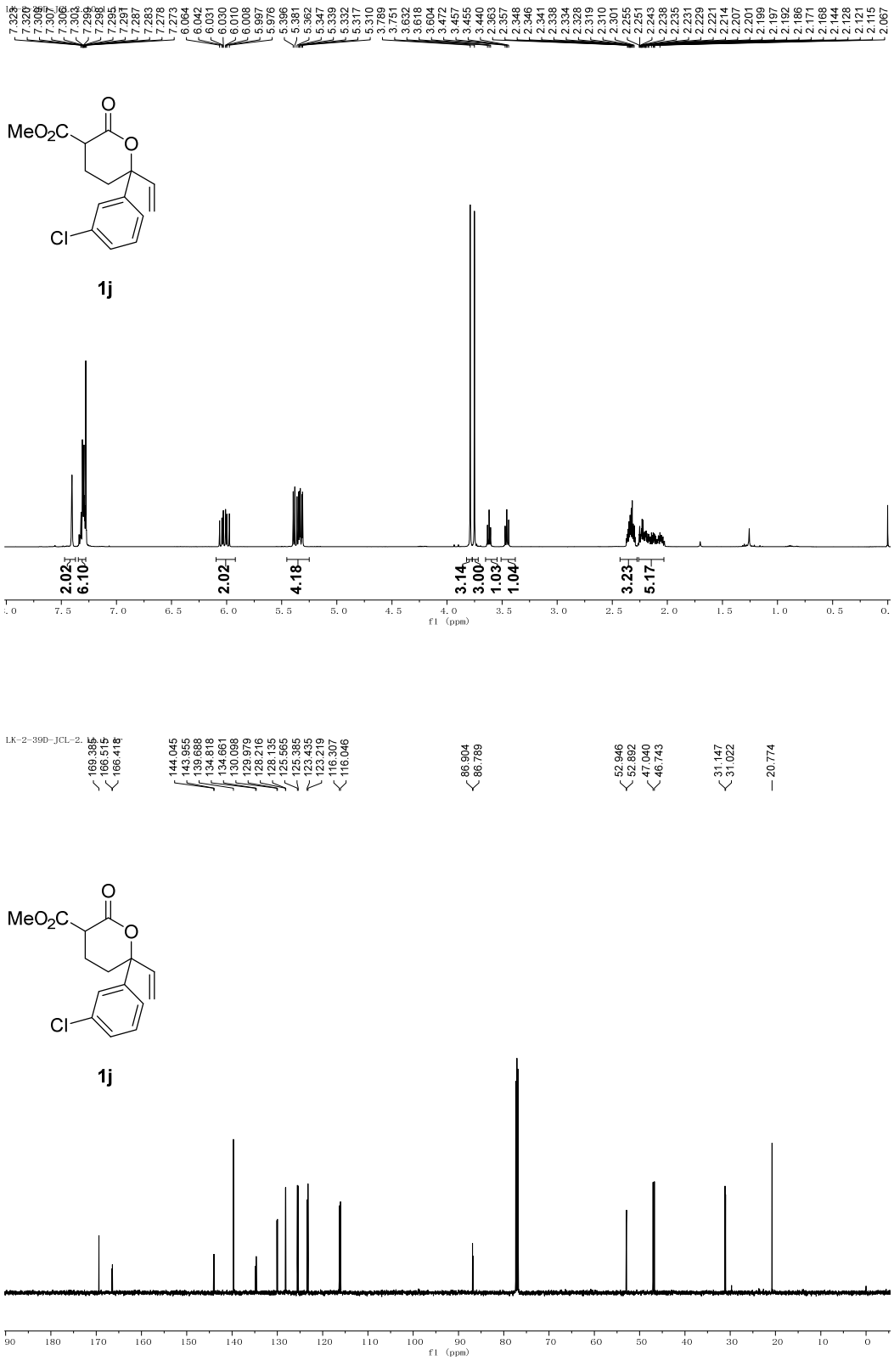
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1g**



^{1}H NMR (500 MHz) ^{13}C NMR (125 MHz) and ^{19}F NMR (470 MHz) spectra of **1h**

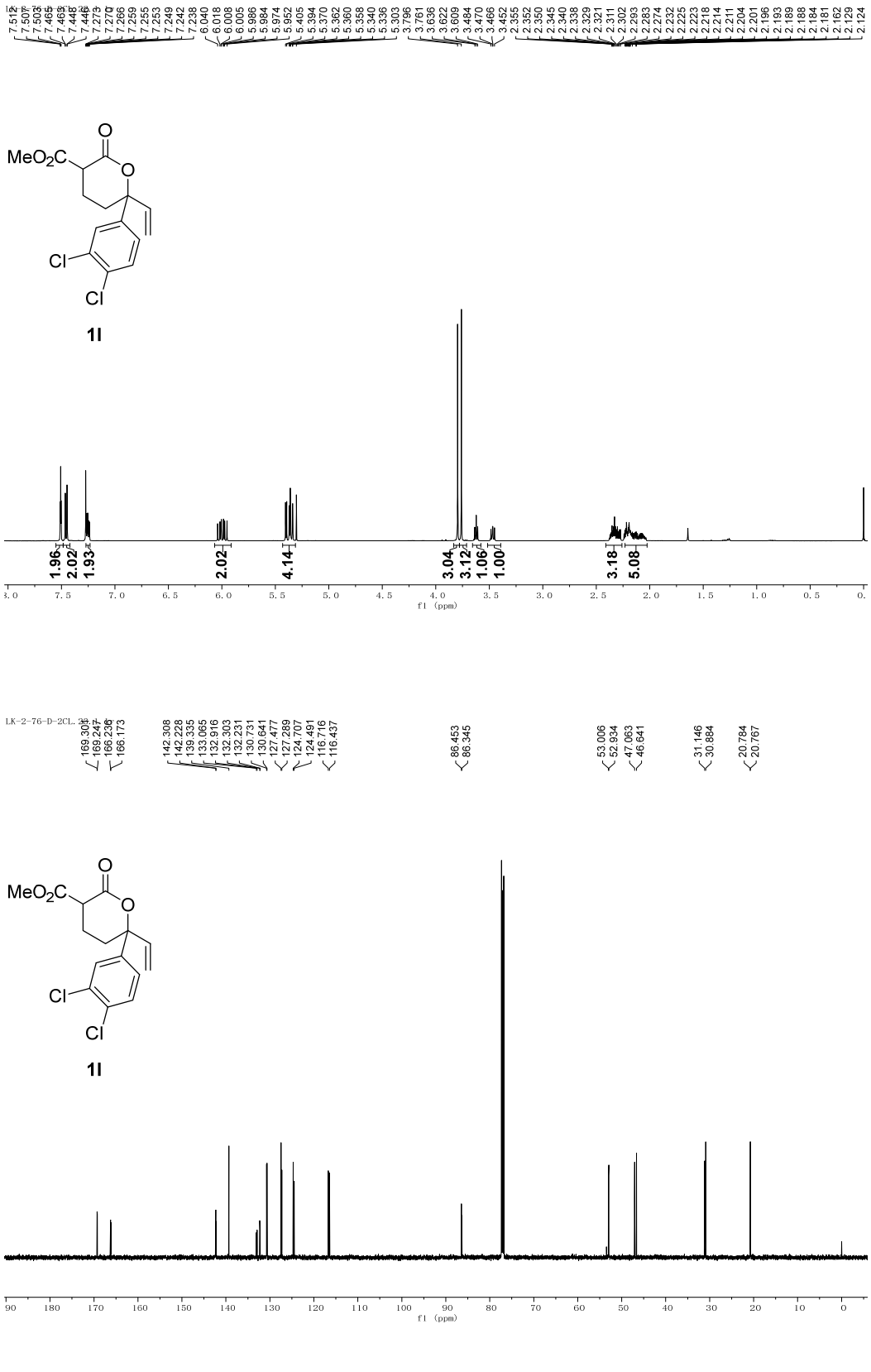


^{1}H NMR (500 MHz) ^{13}C NMR (125 MHz) and ^{19}F NMR (470 MHz) spectra of **1i**

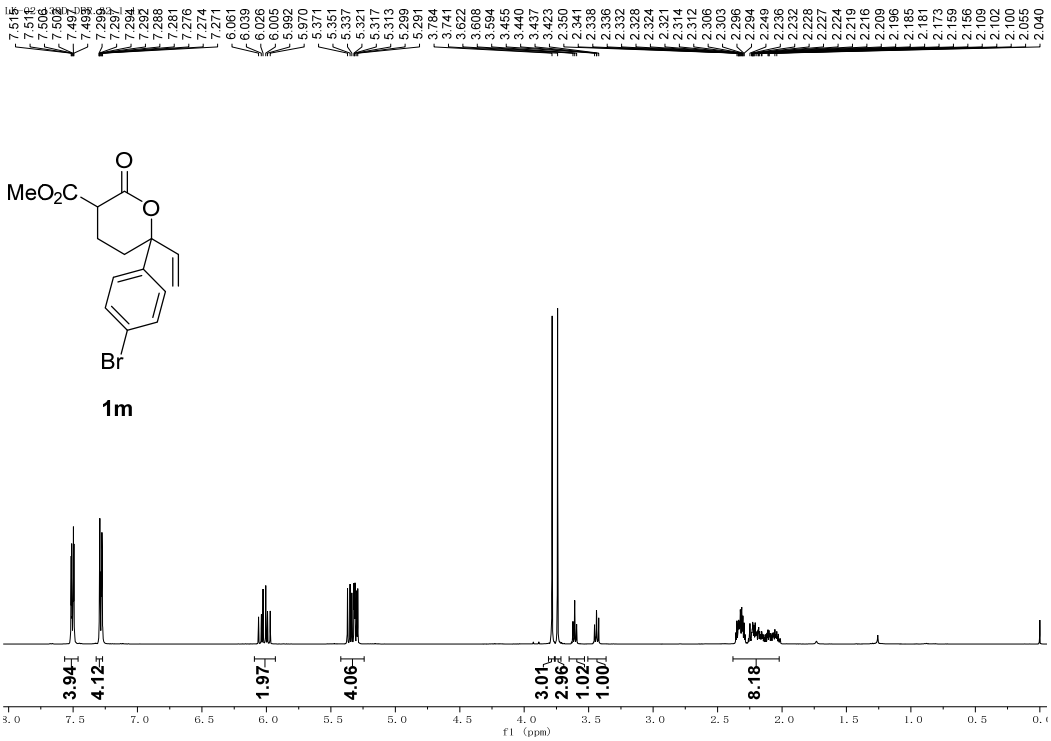


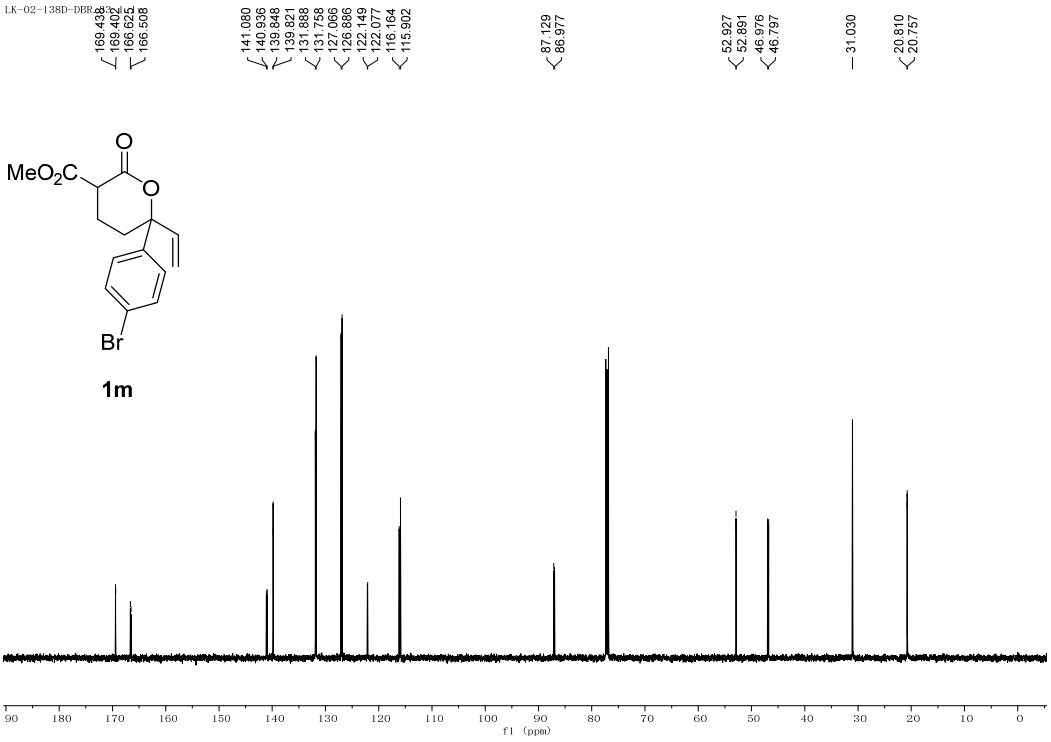
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1j**

^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1k**

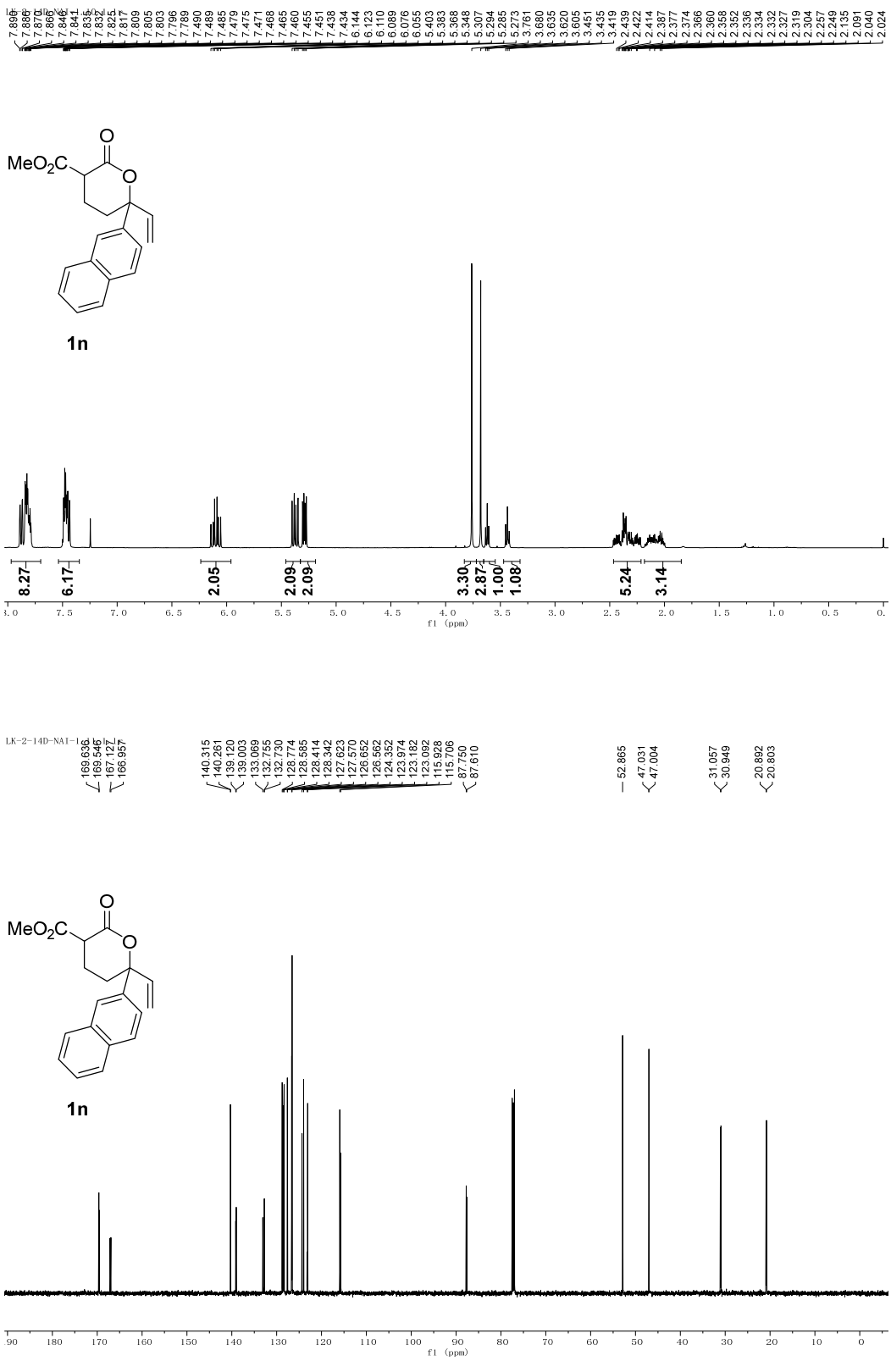


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1l**

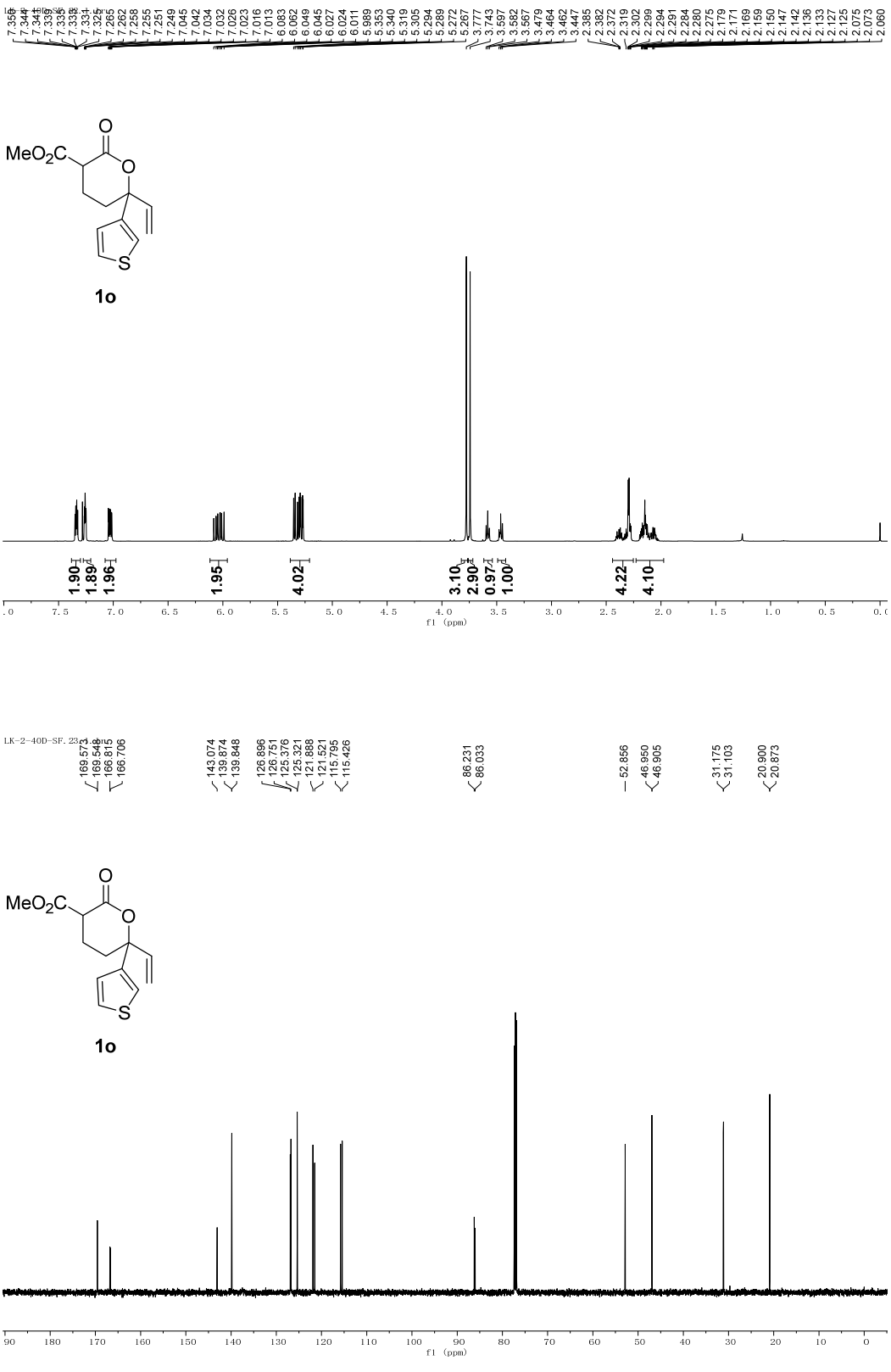




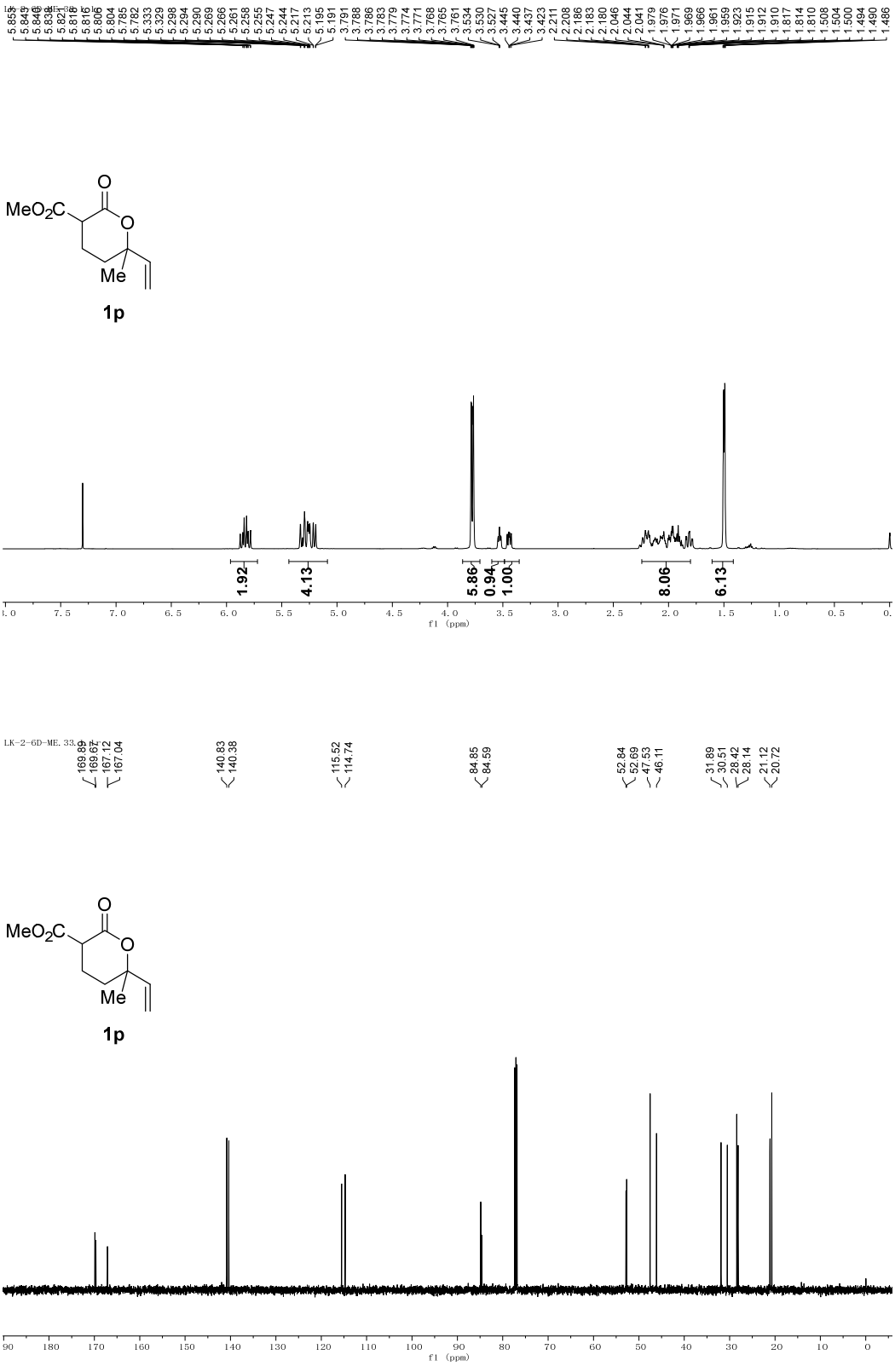
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1m**



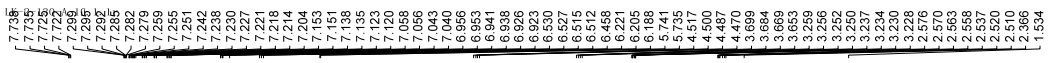
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1n**

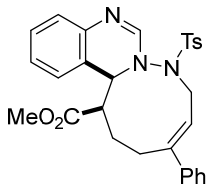


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1o**

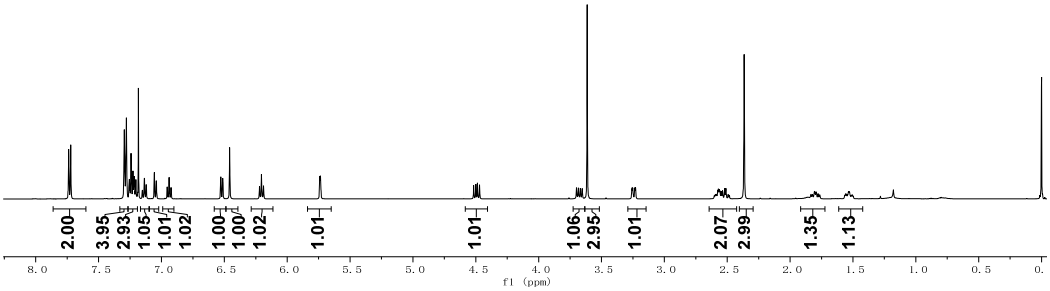


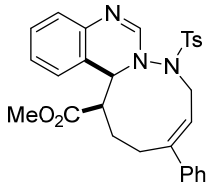
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **1p**



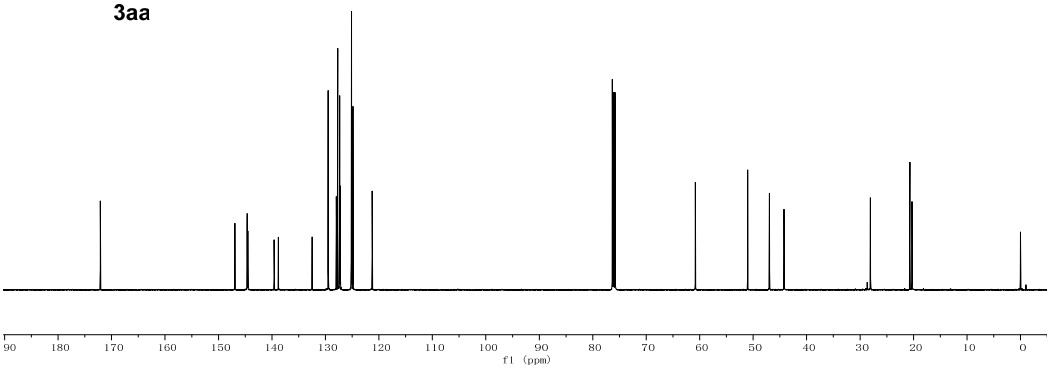


3aa

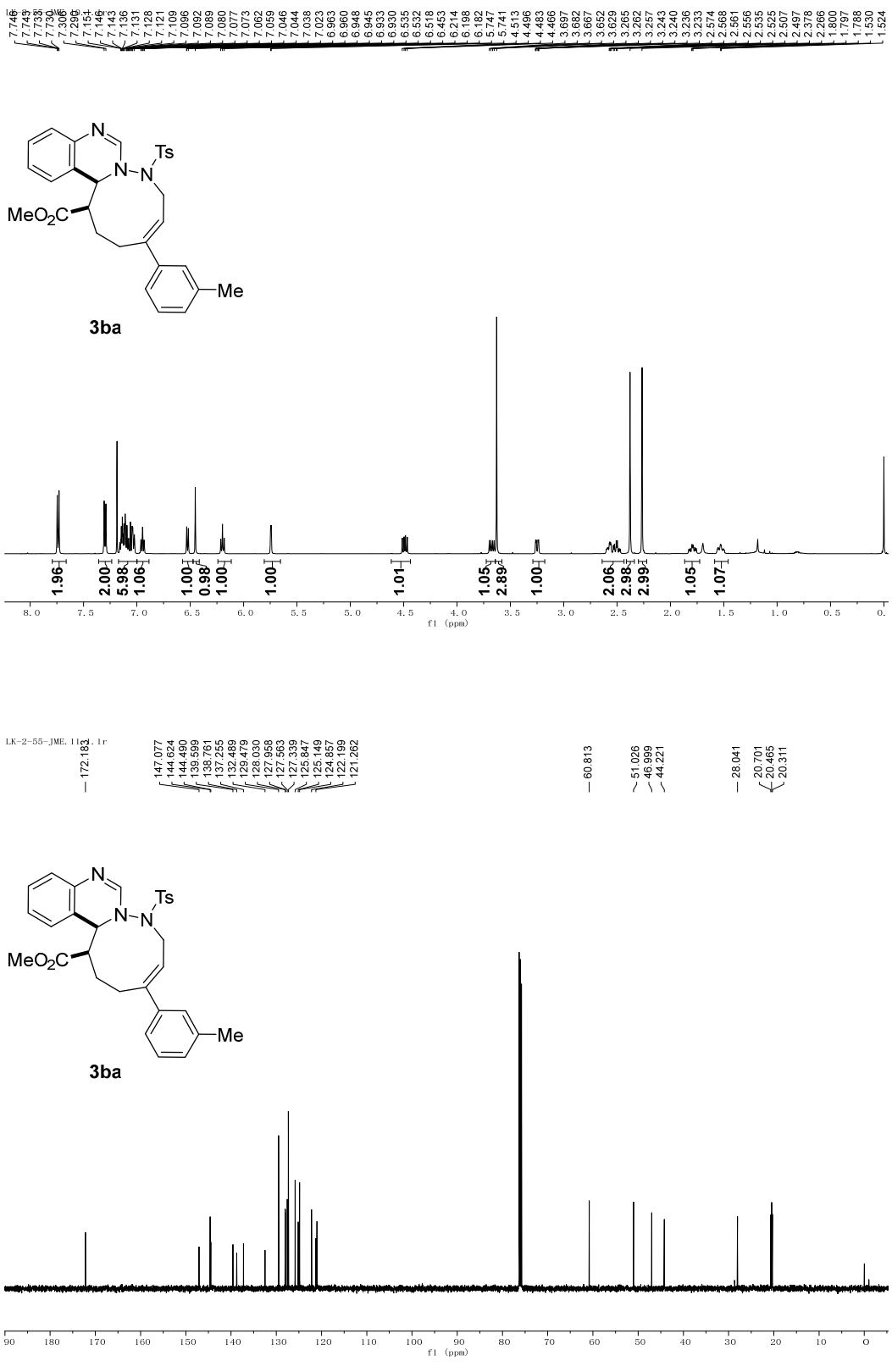




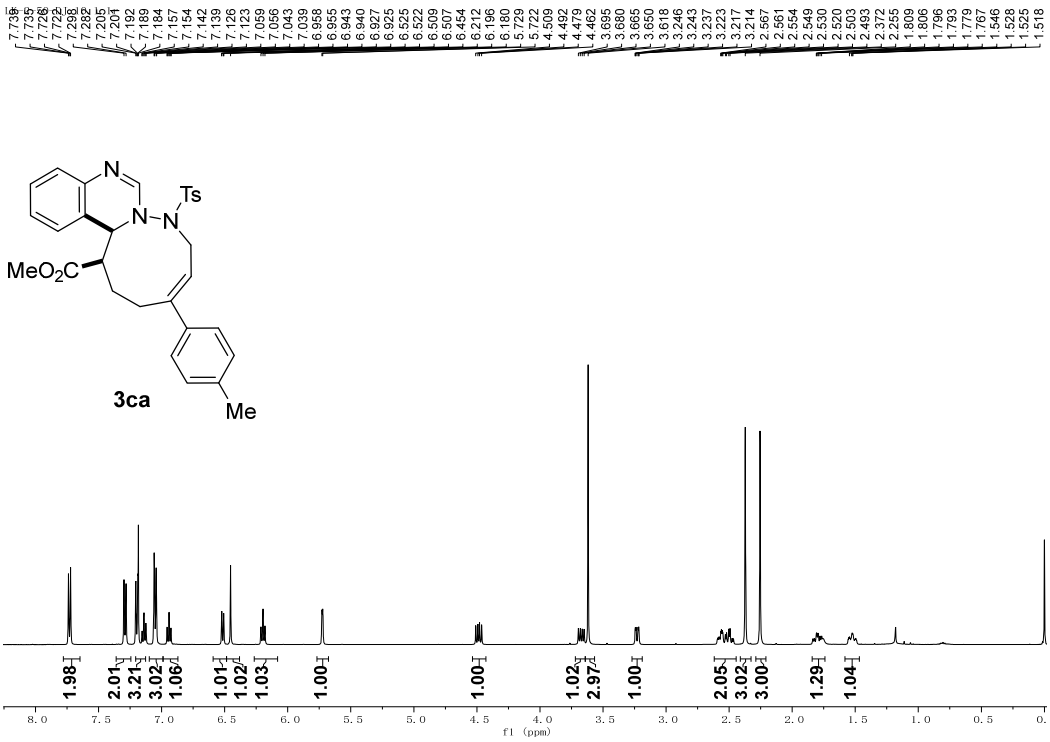
3aa

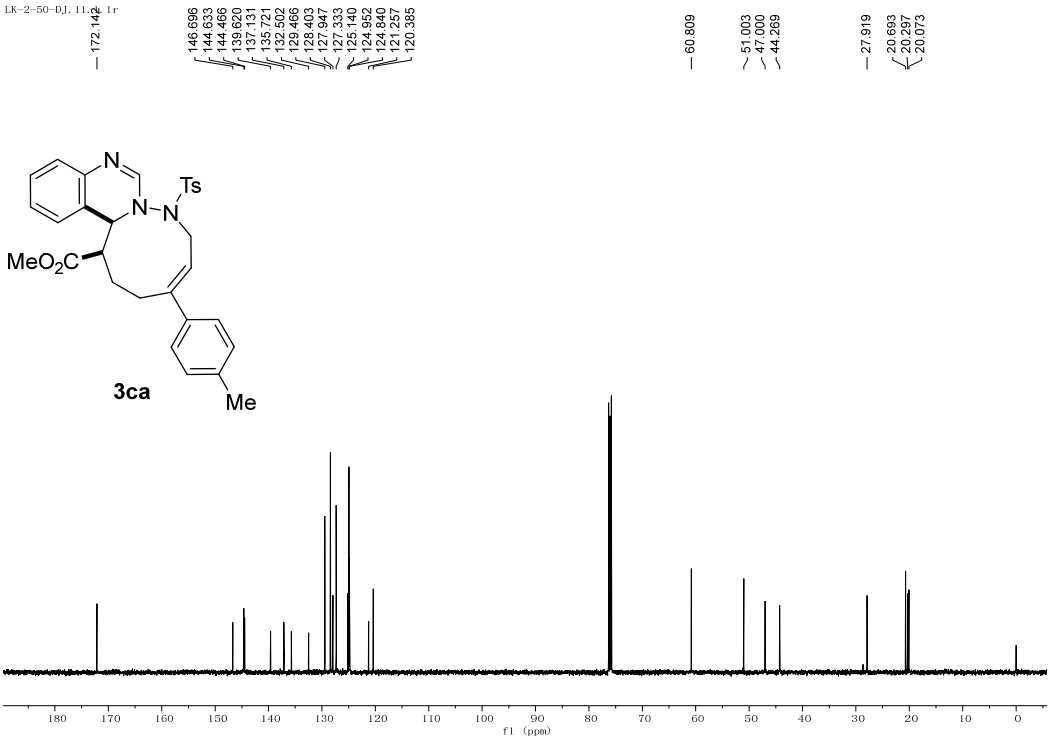


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3aa**

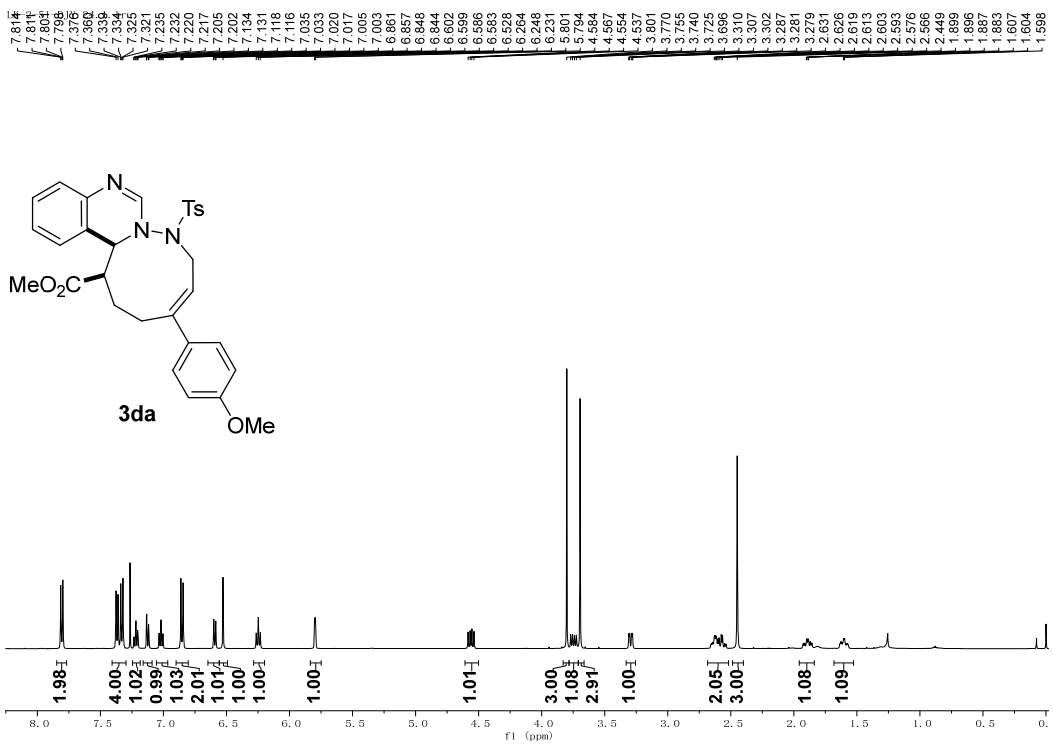


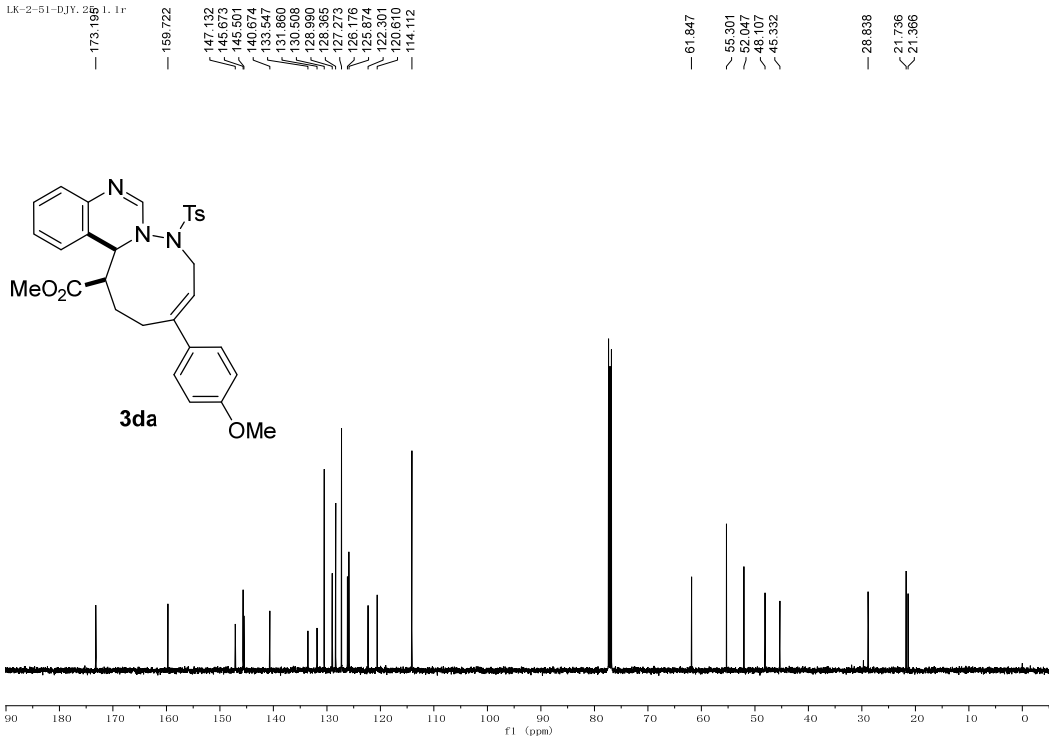
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ba**



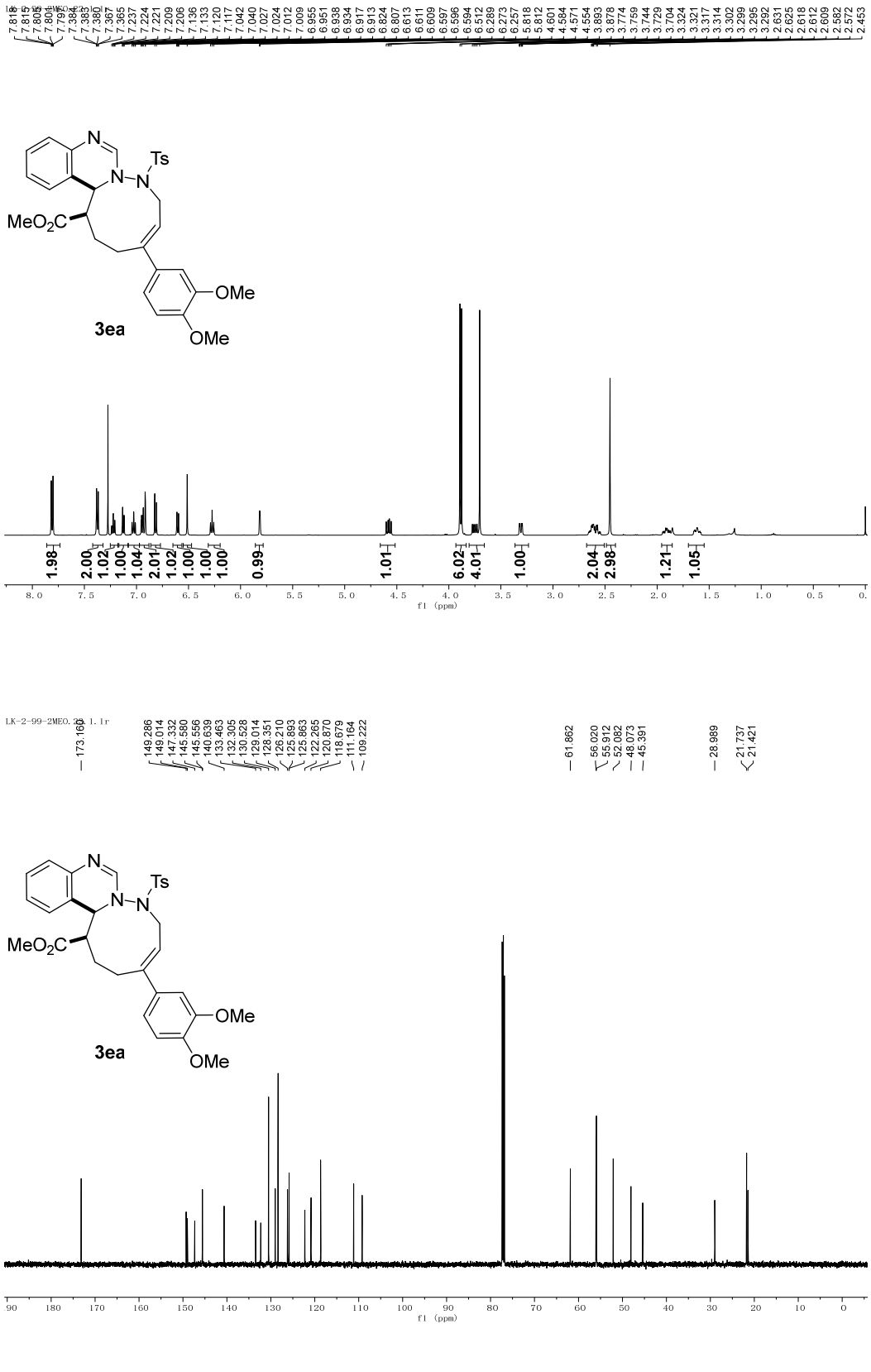


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ca**

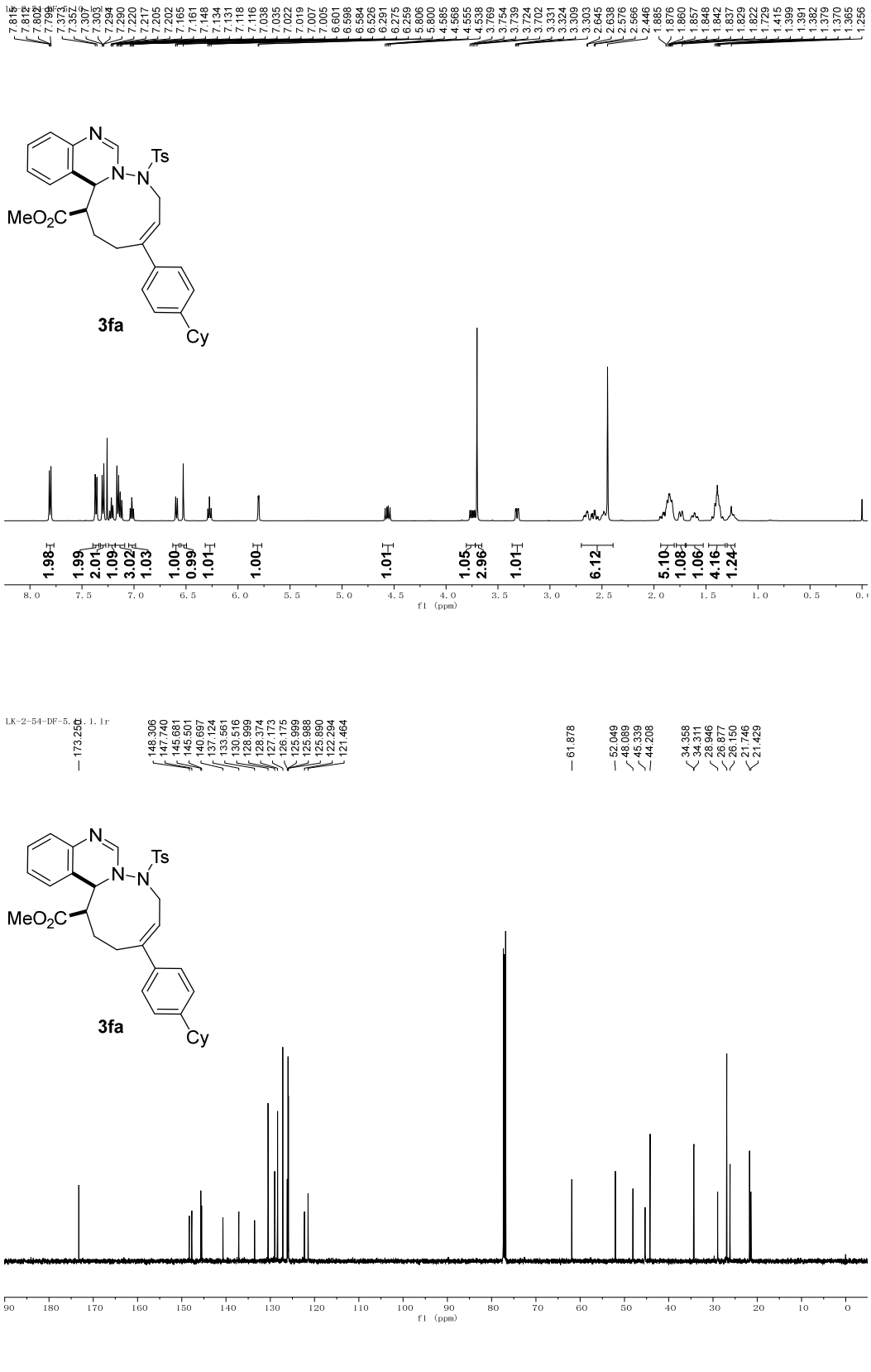




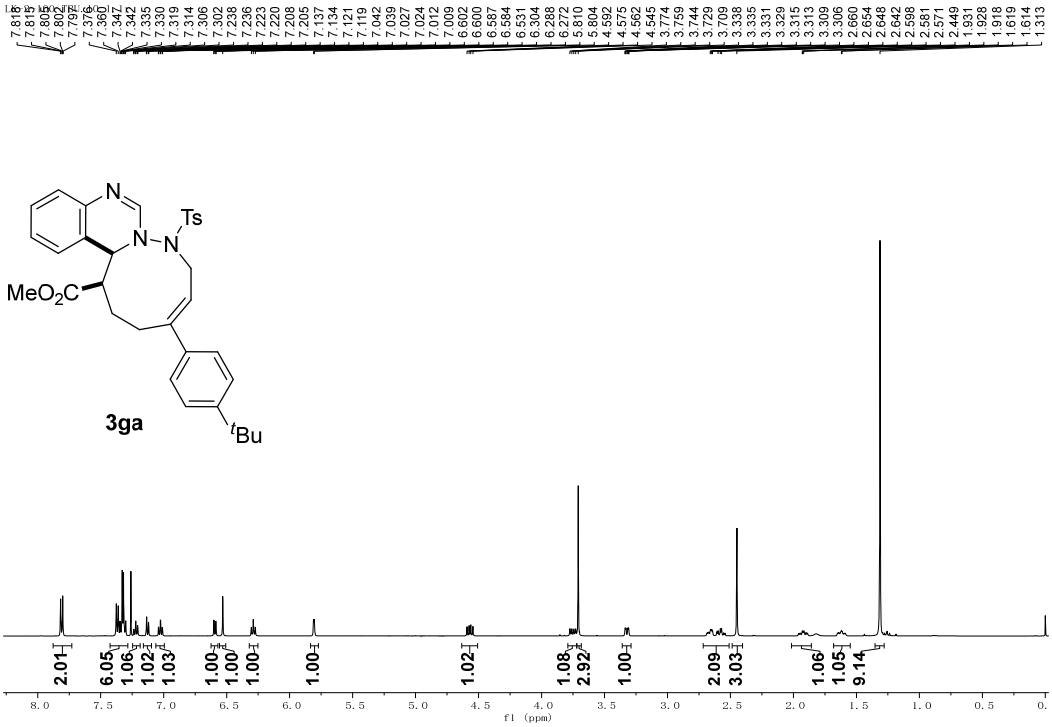
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3da**

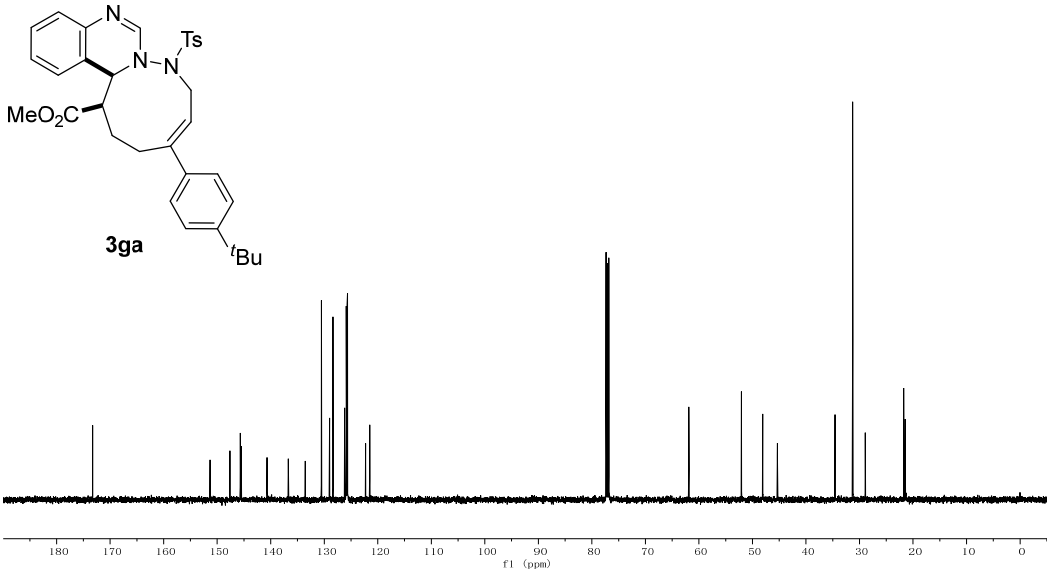


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ea**

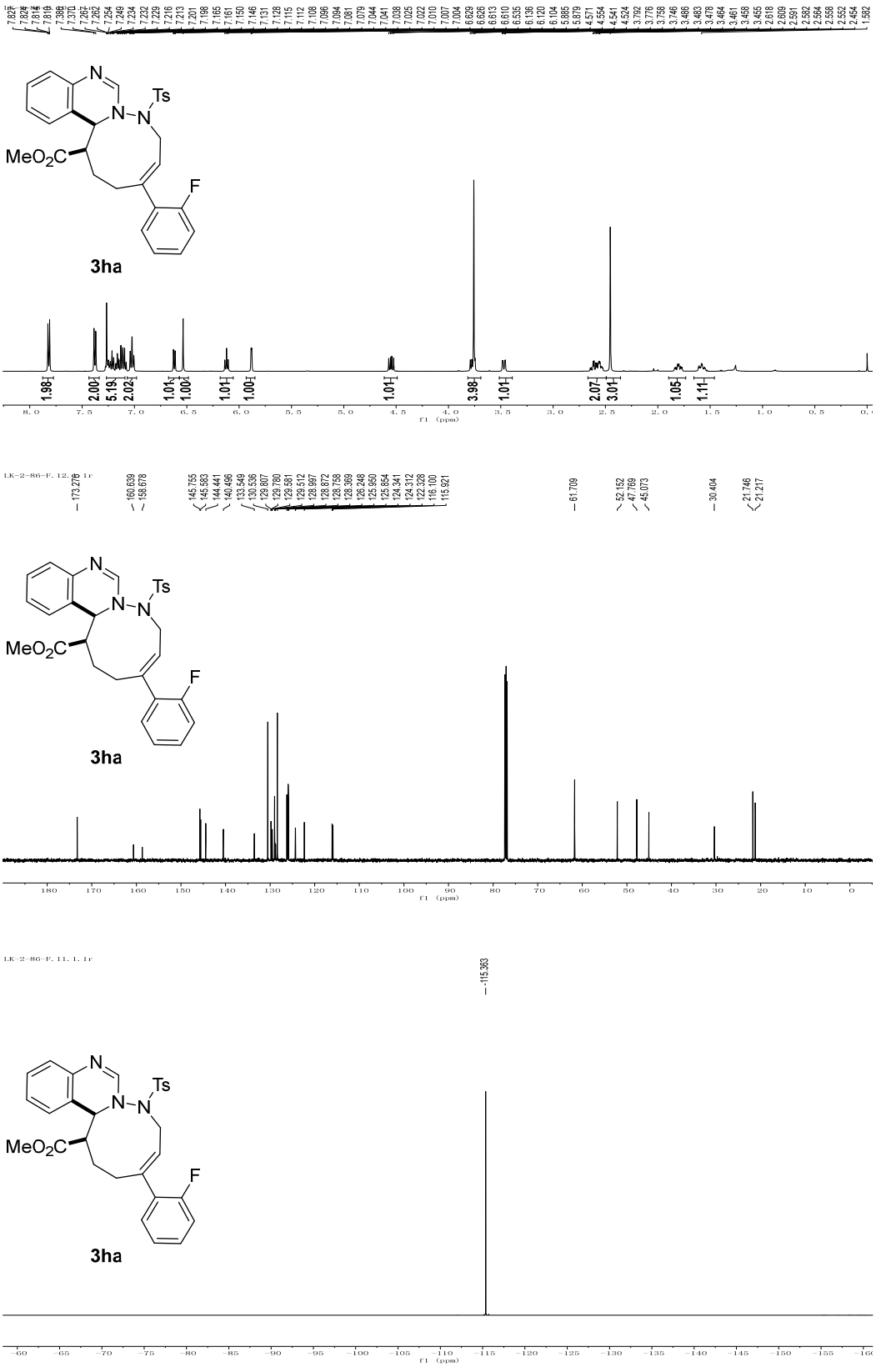


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3fa**

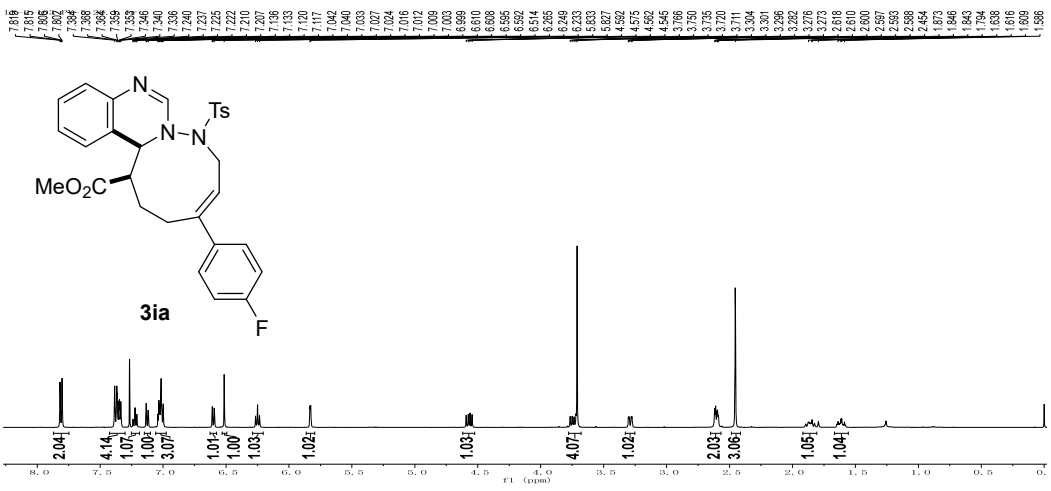


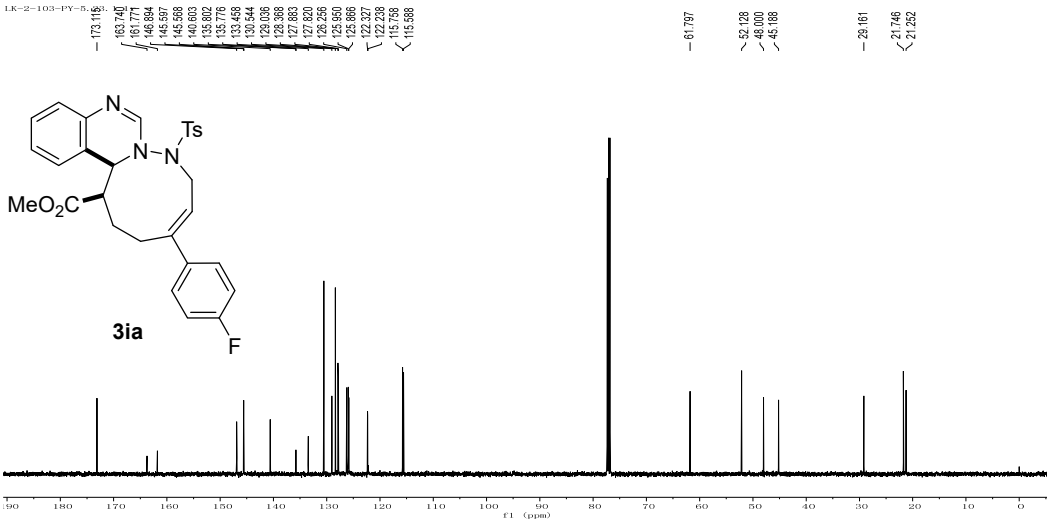


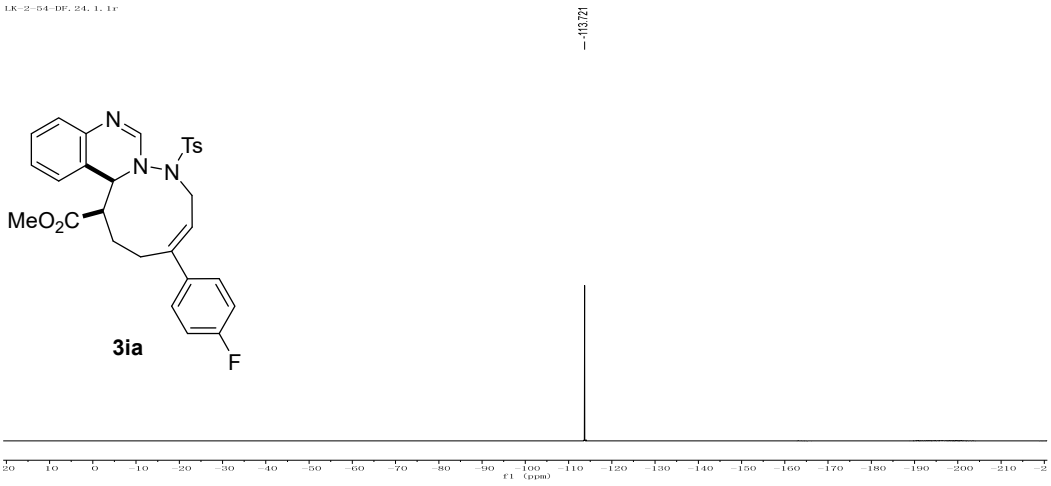
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ga**



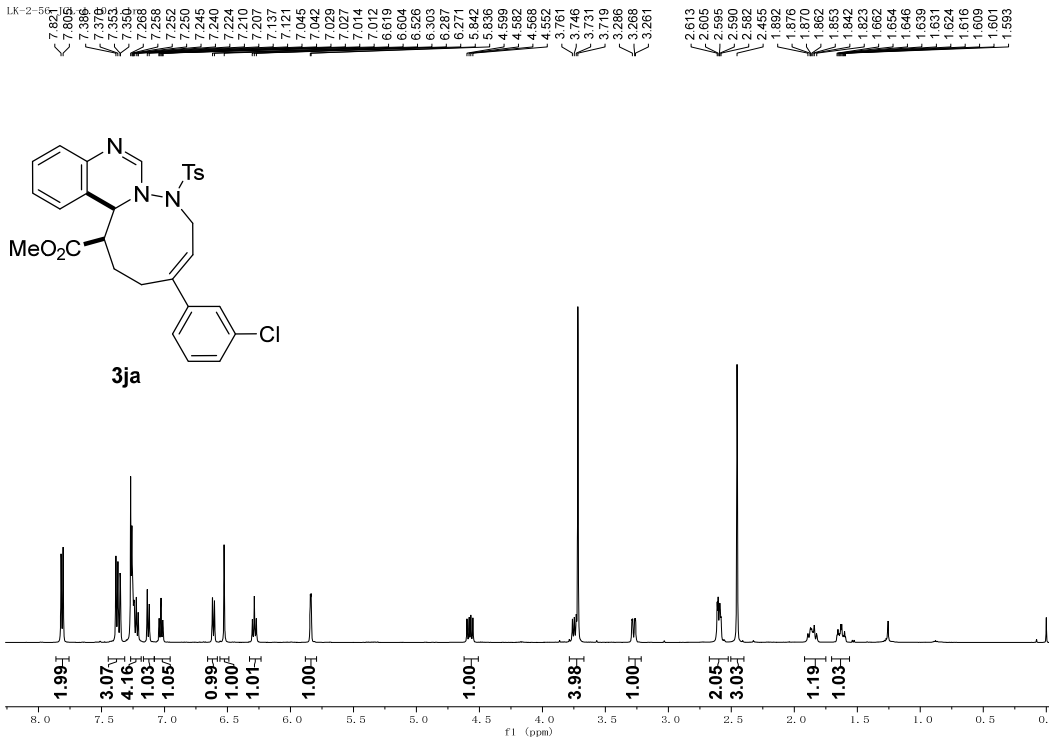
^{1}H NMR (500 MHz) ^{13}C NMR (125 MHz) and ^{19}F NMR (470 MHz) spectra of **3ha**

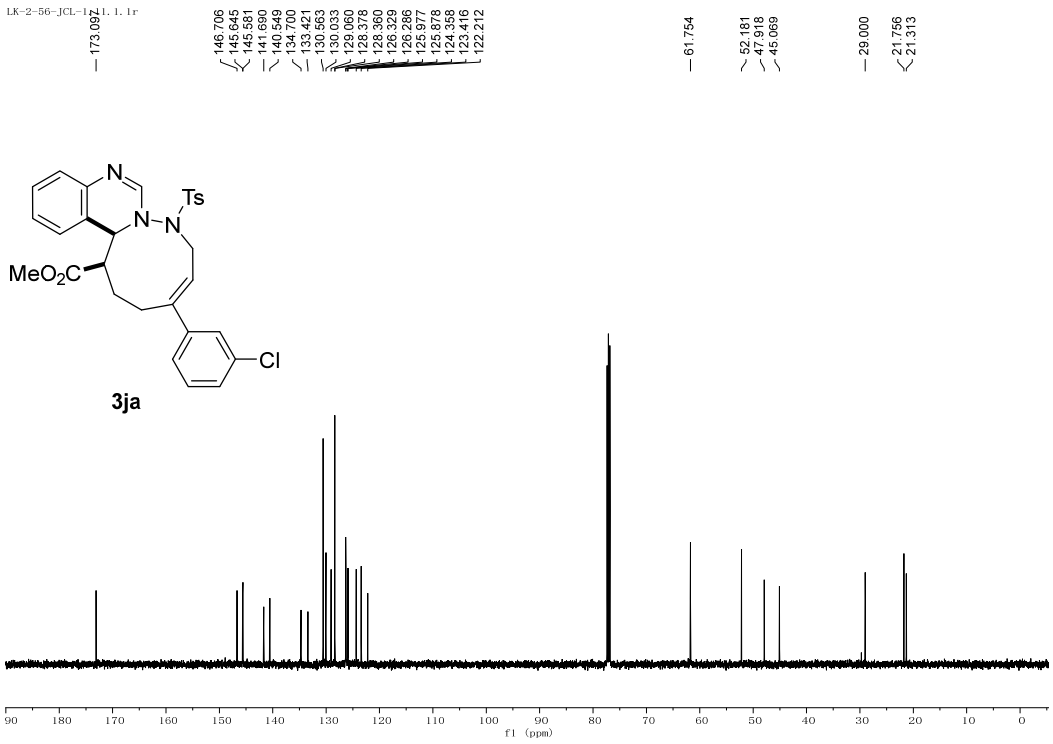




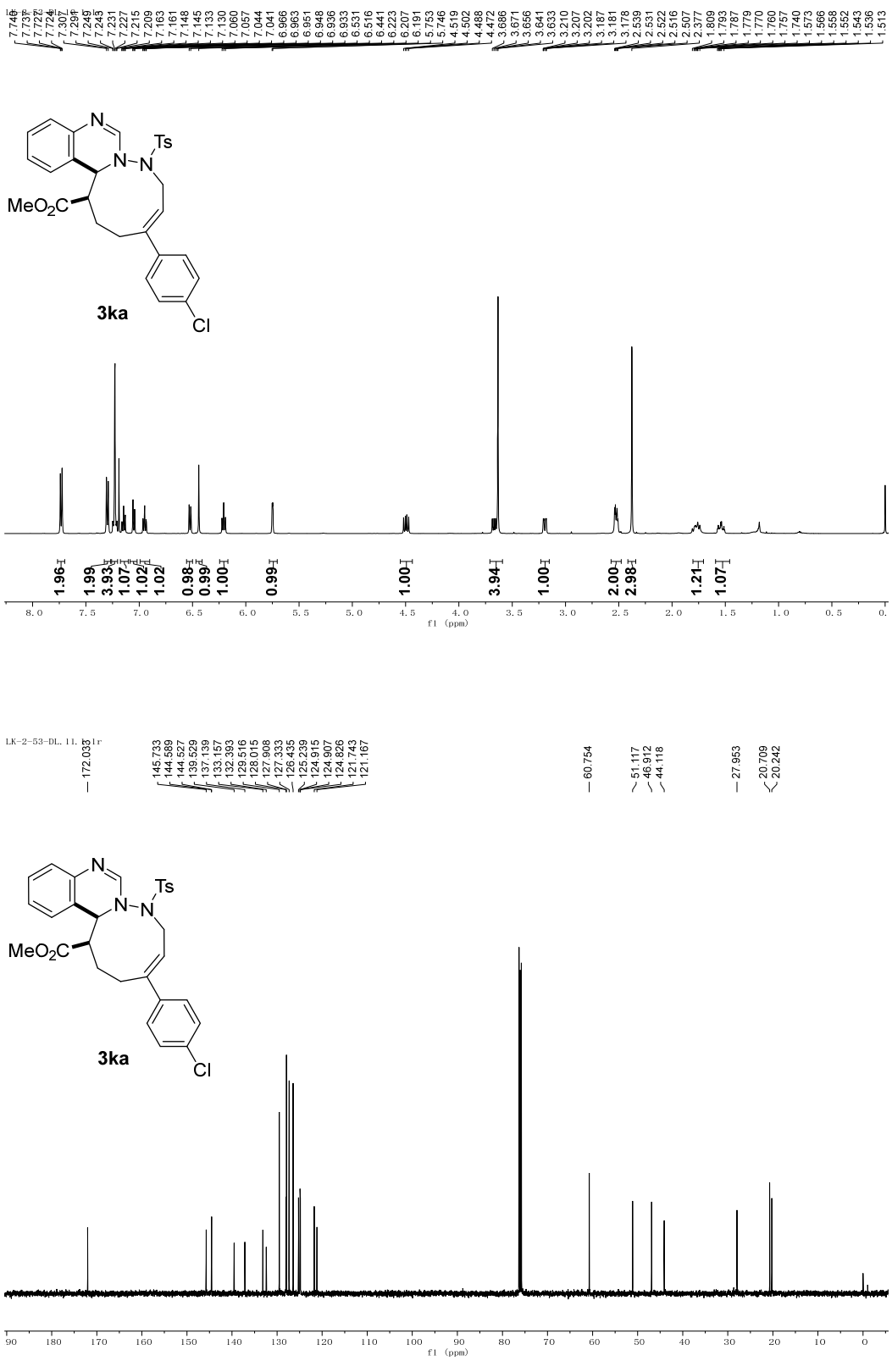


^{1}H NMR (500 MHz) ^{13}C NMR (125 MHz) and ^{19}F NMR (470 MHz) spectra of **3ia**

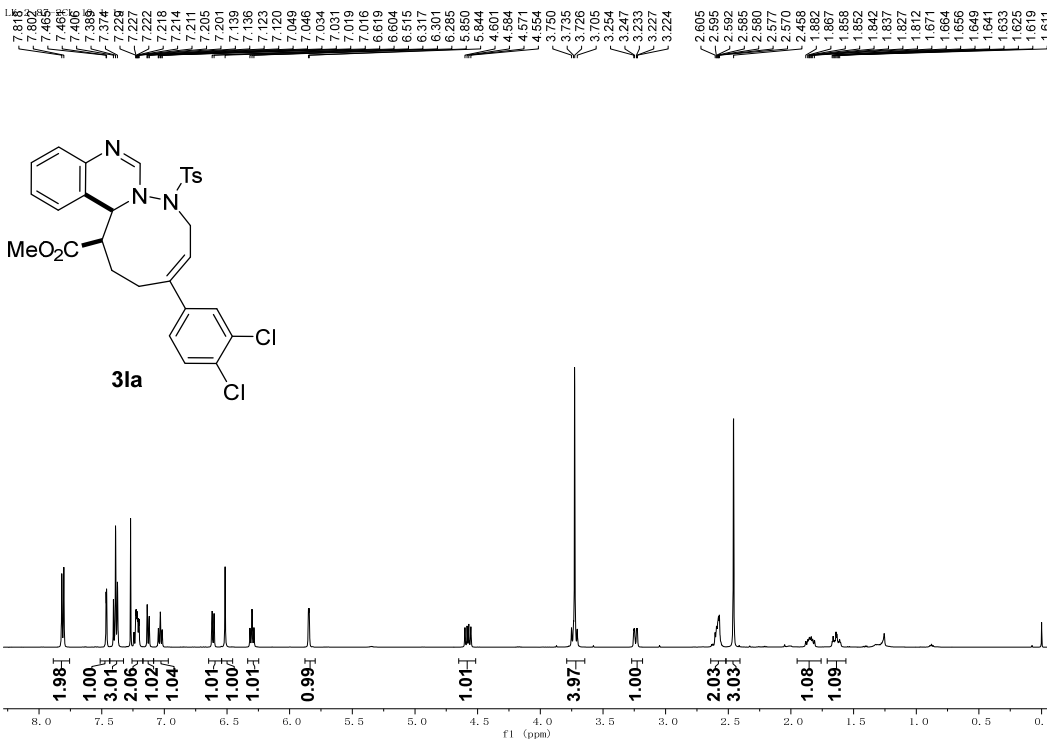


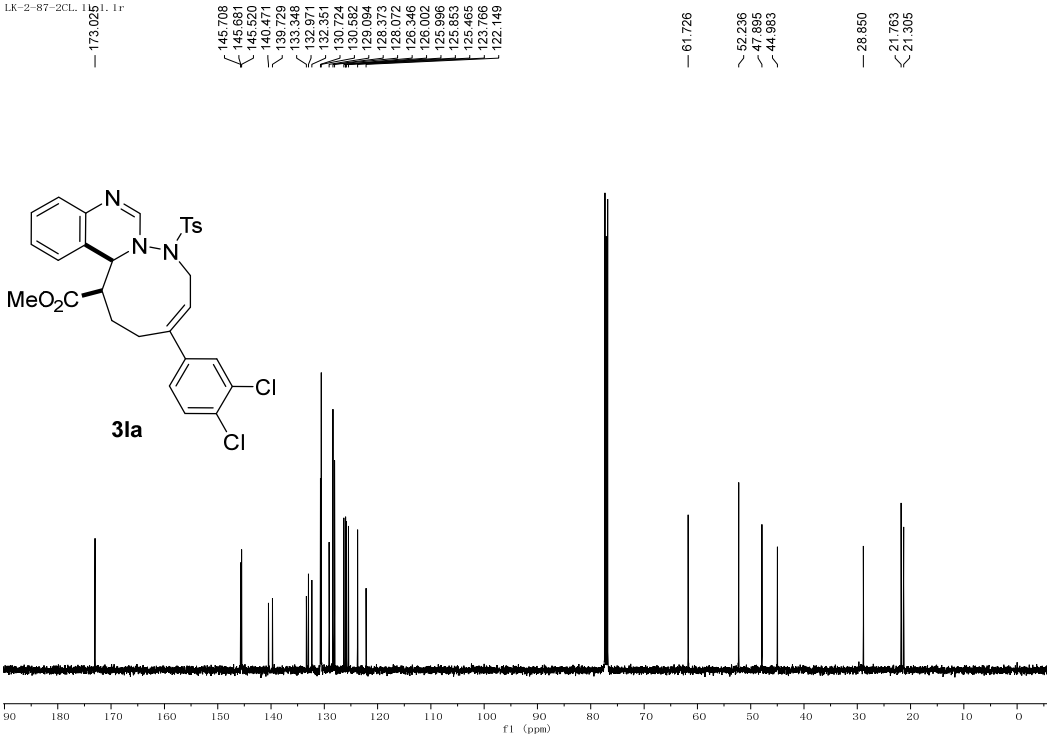


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ja**

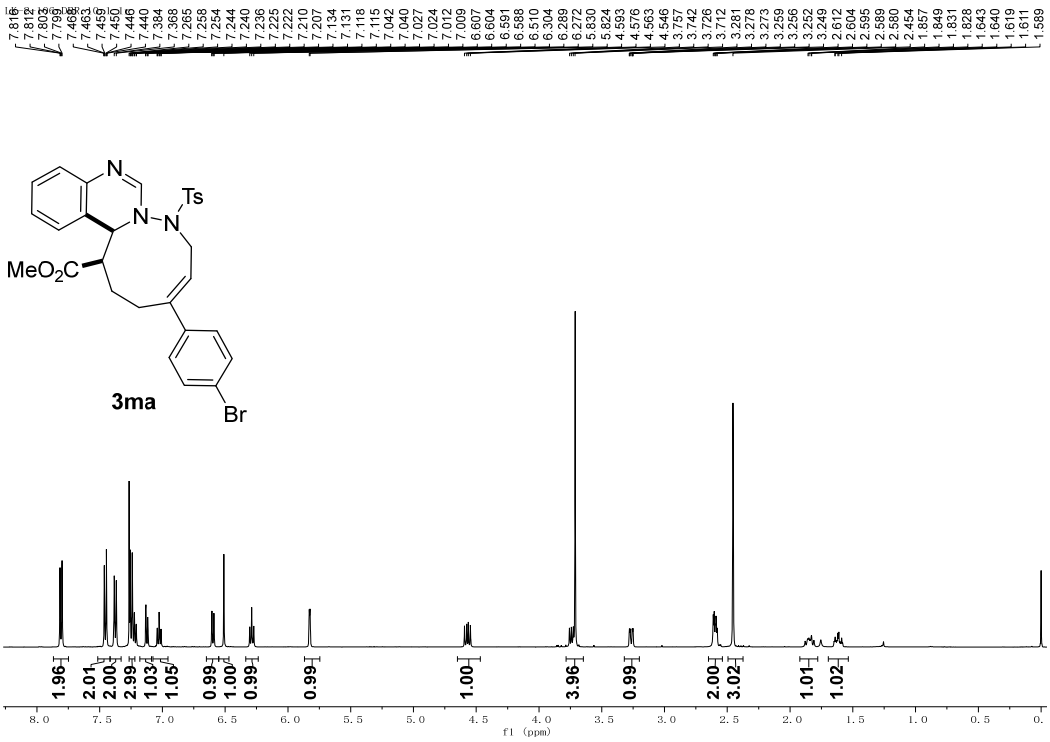


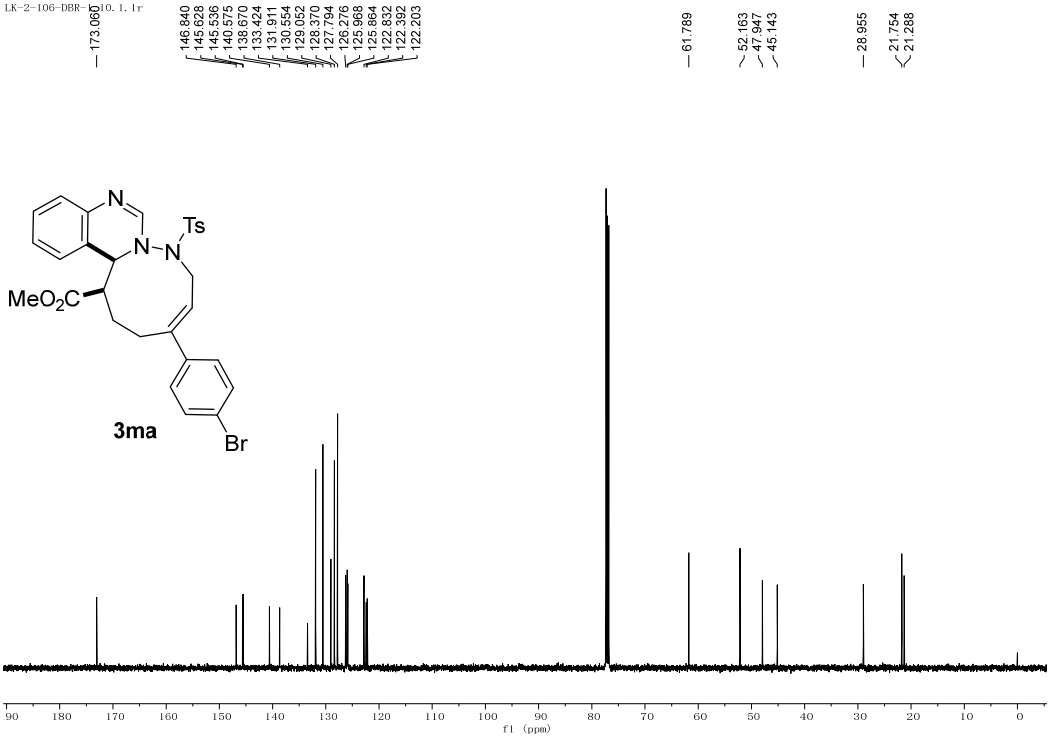
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ka**



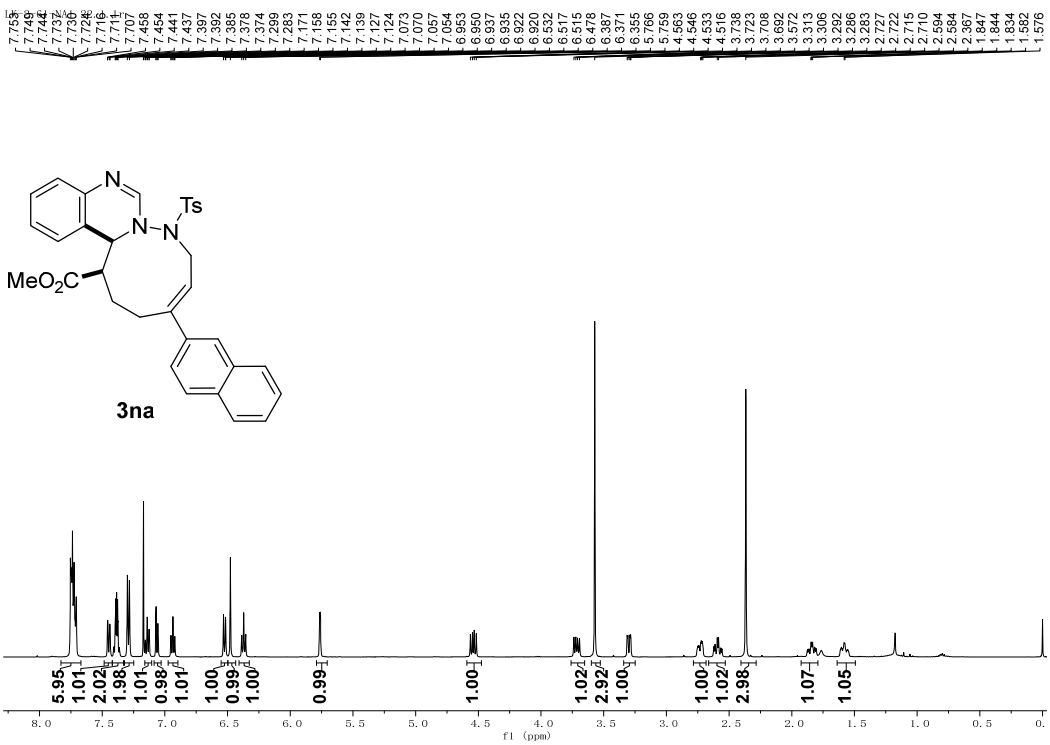


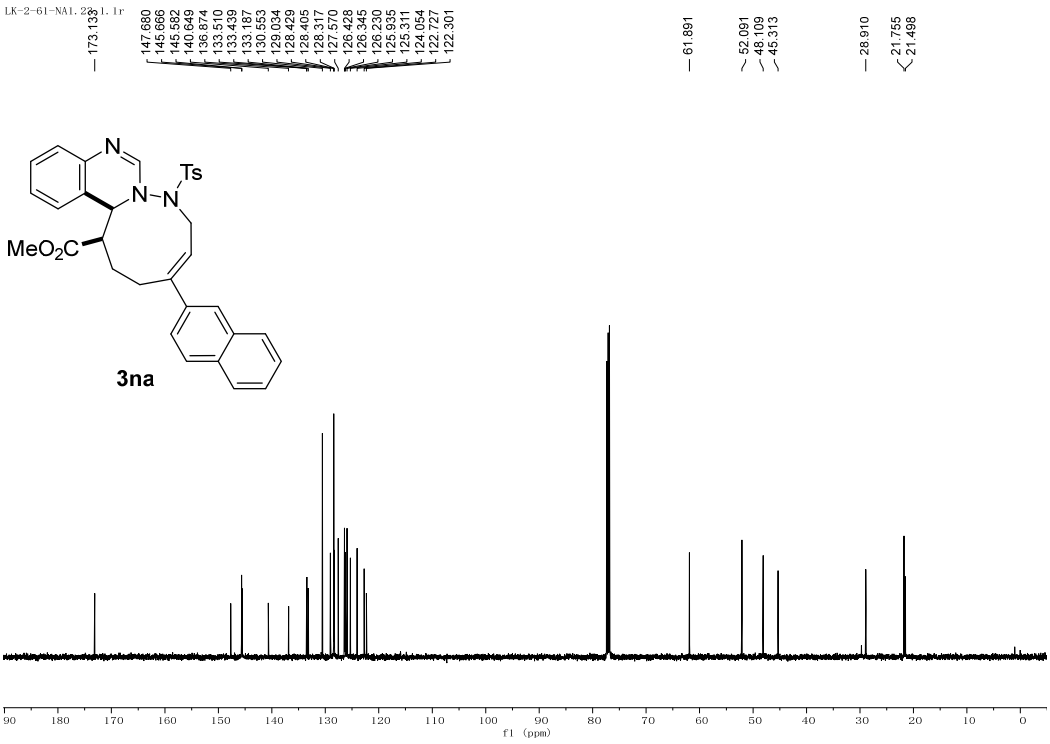
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3la**



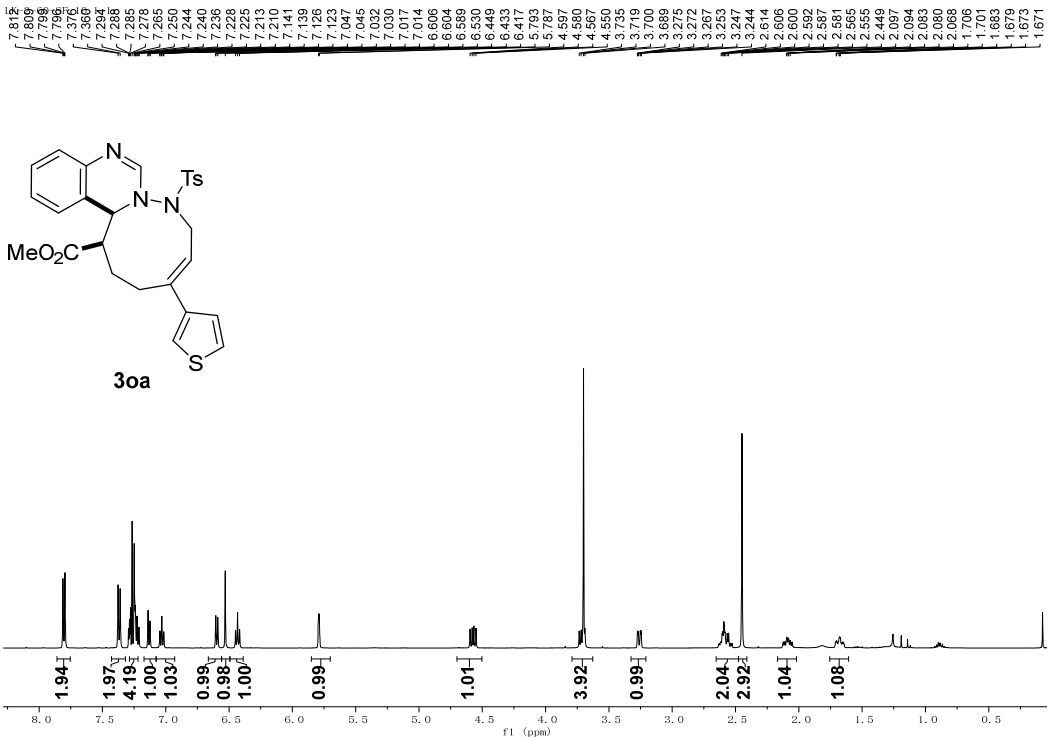


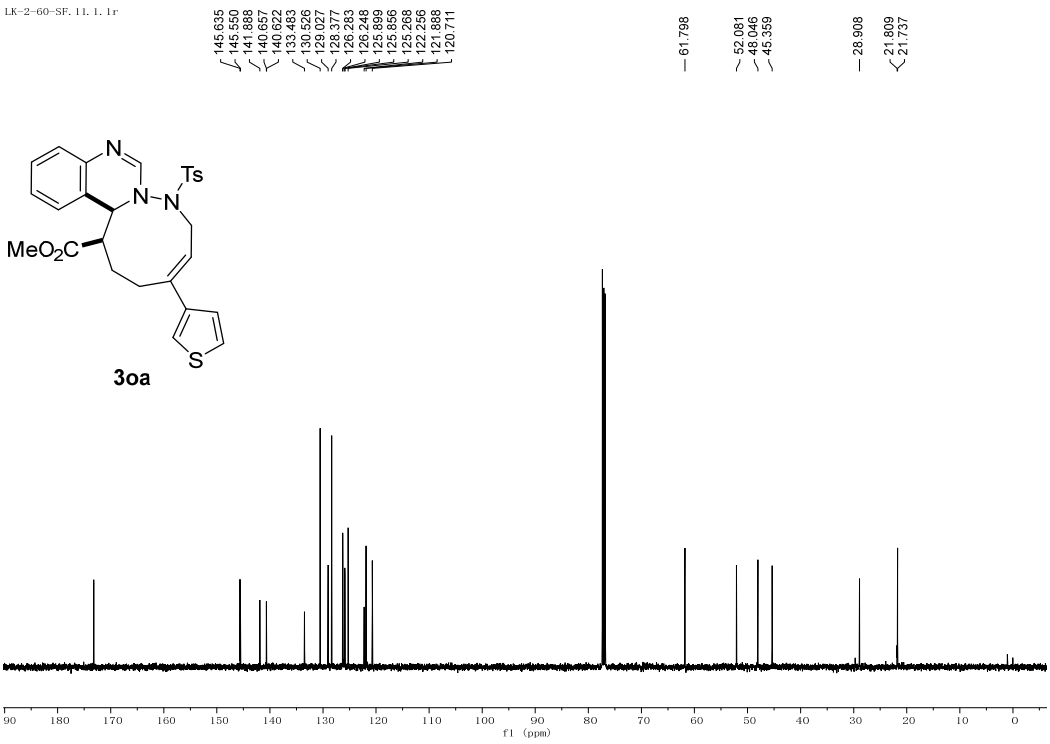
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ma**



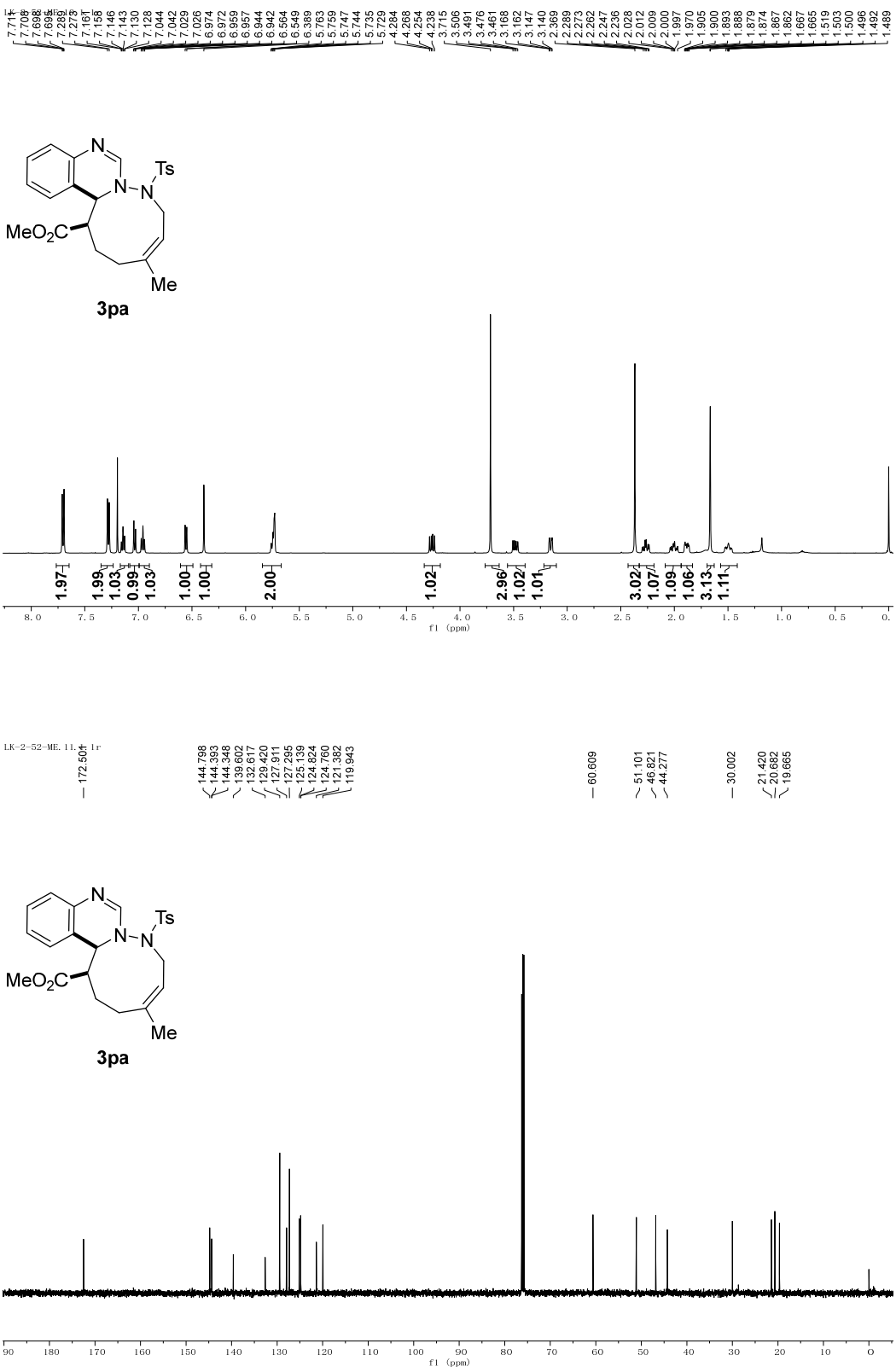


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3na**



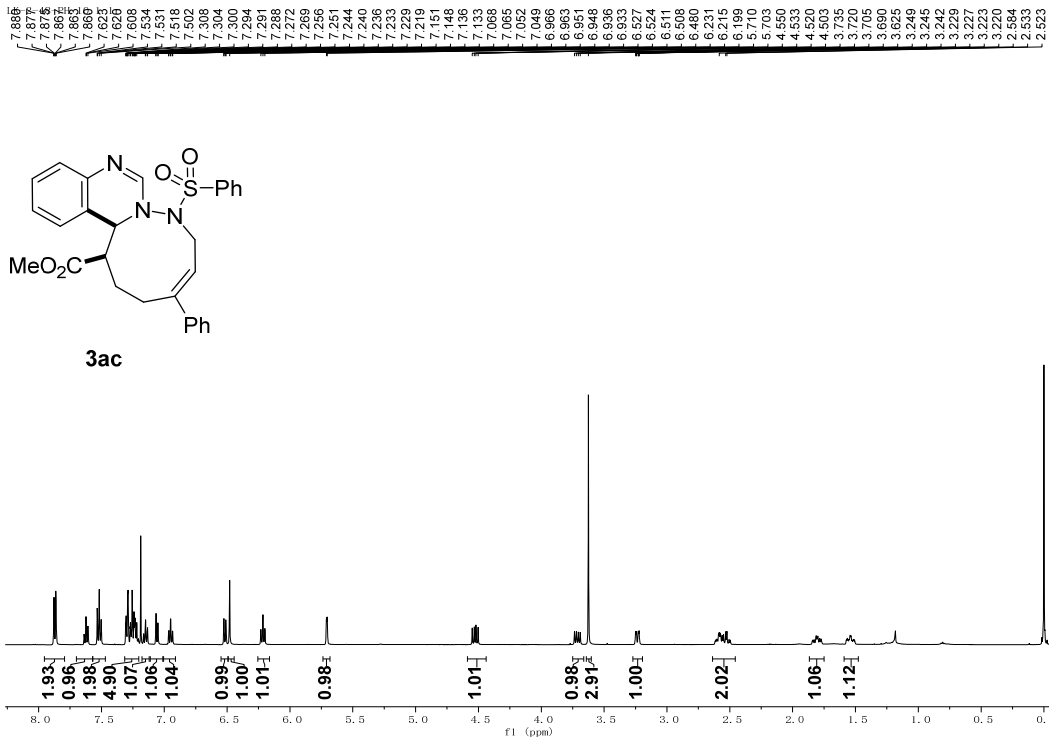


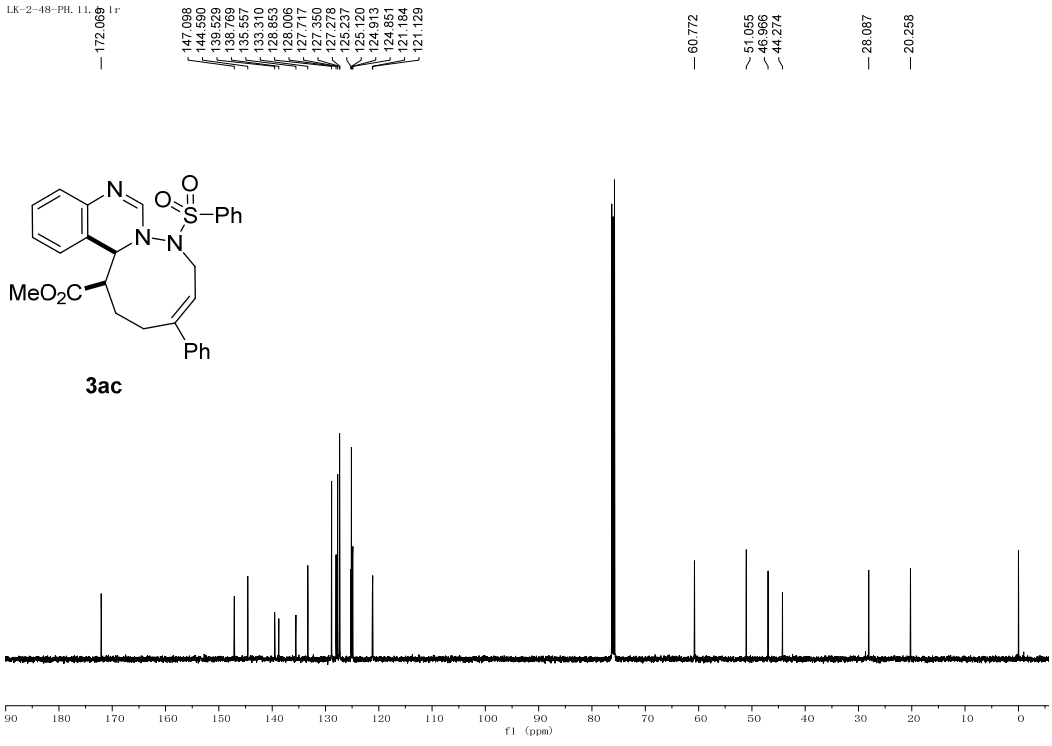
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3oa**



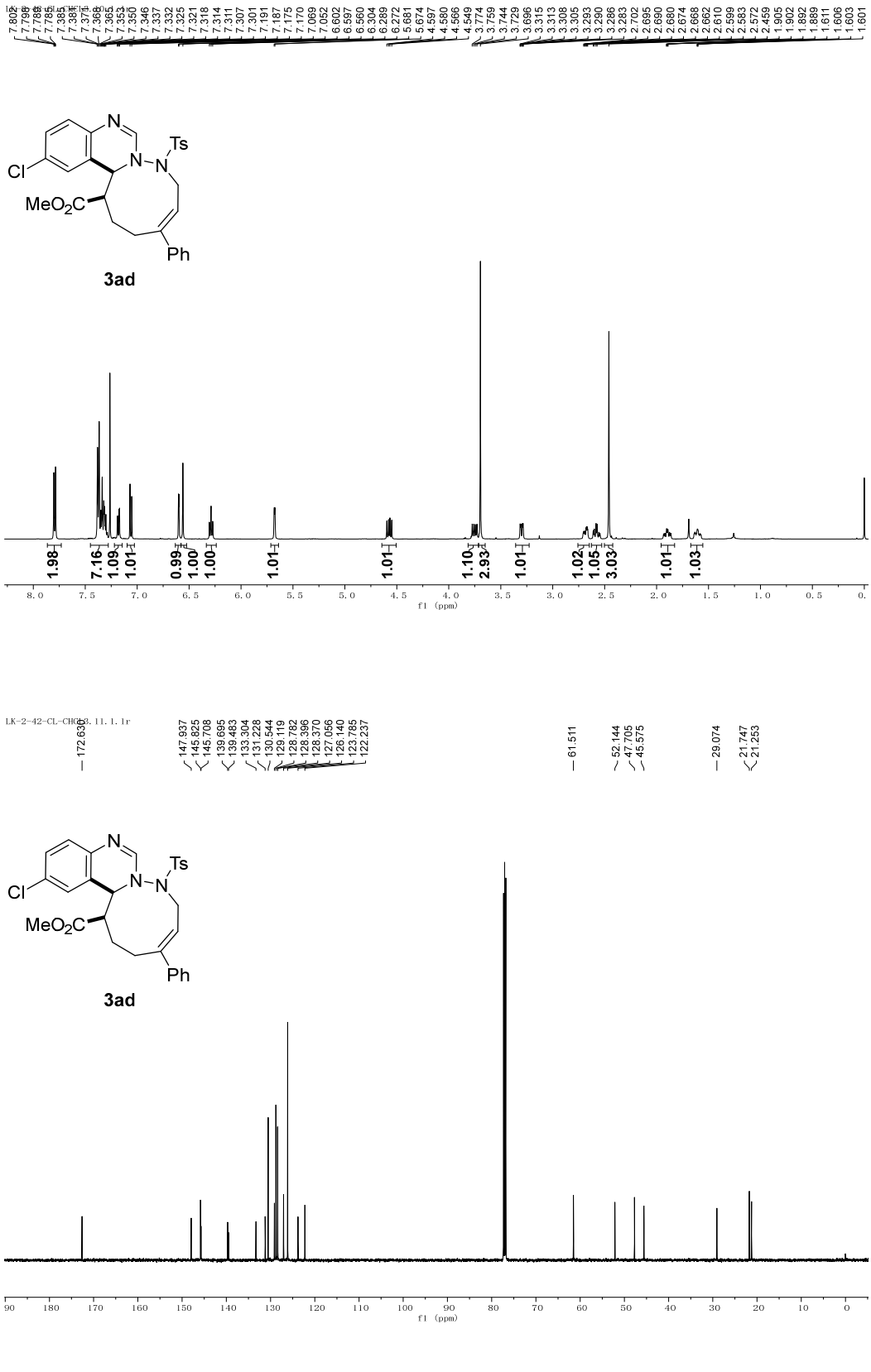
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3pa**

^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ab**

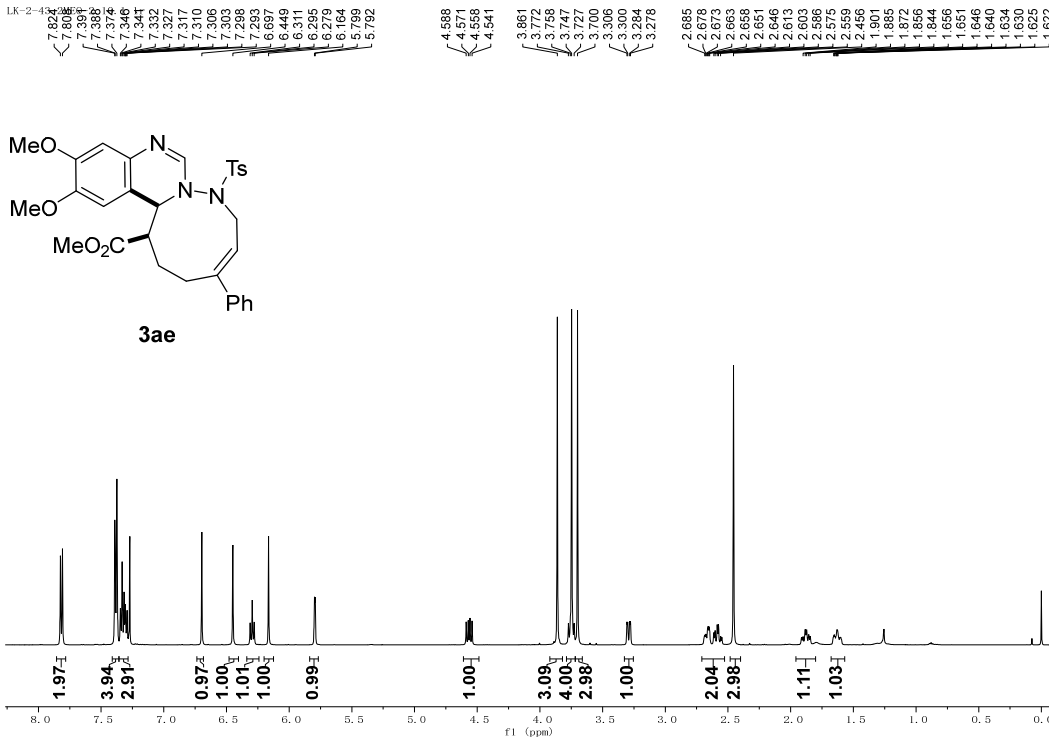


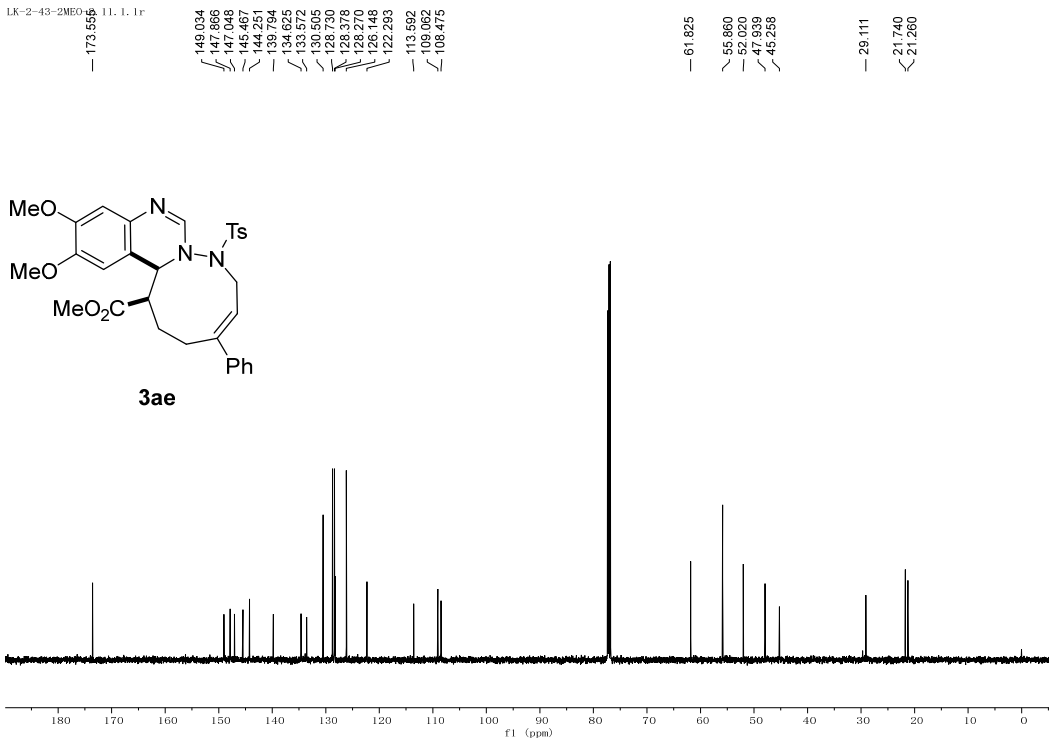


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ac**

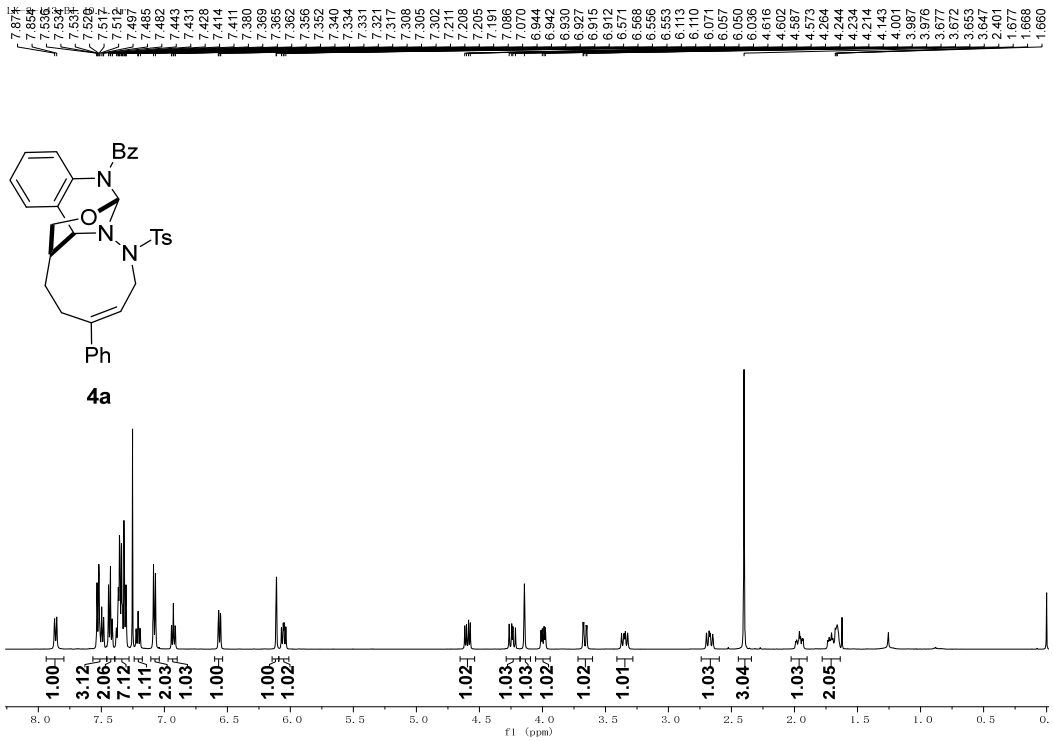


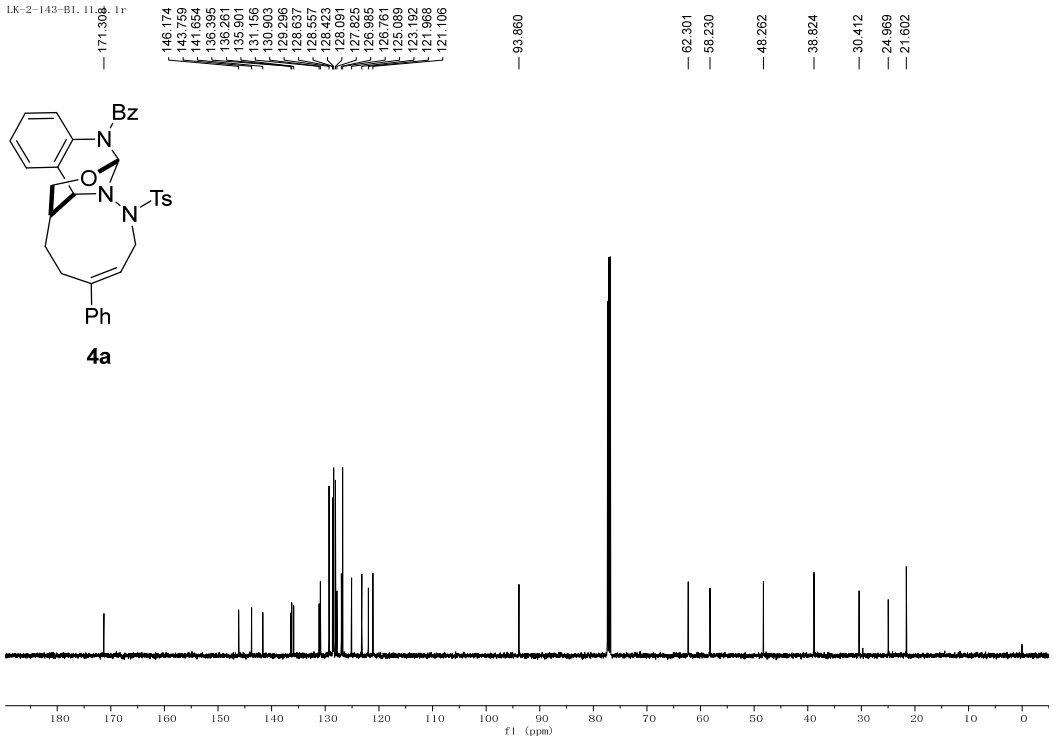
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ad**



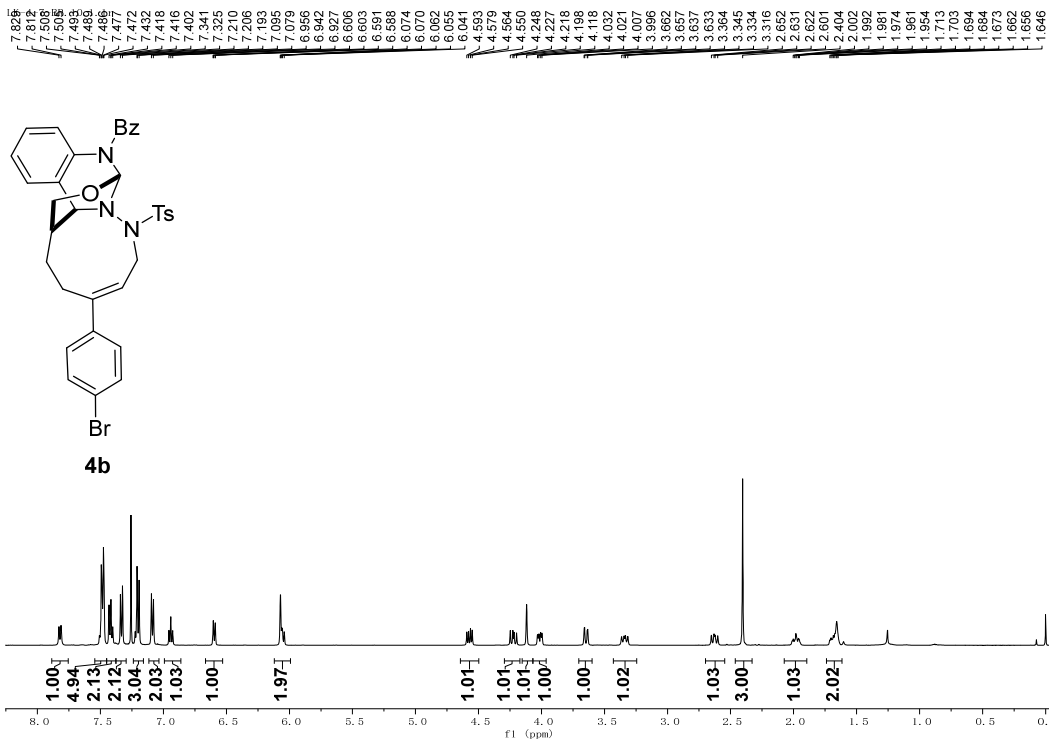


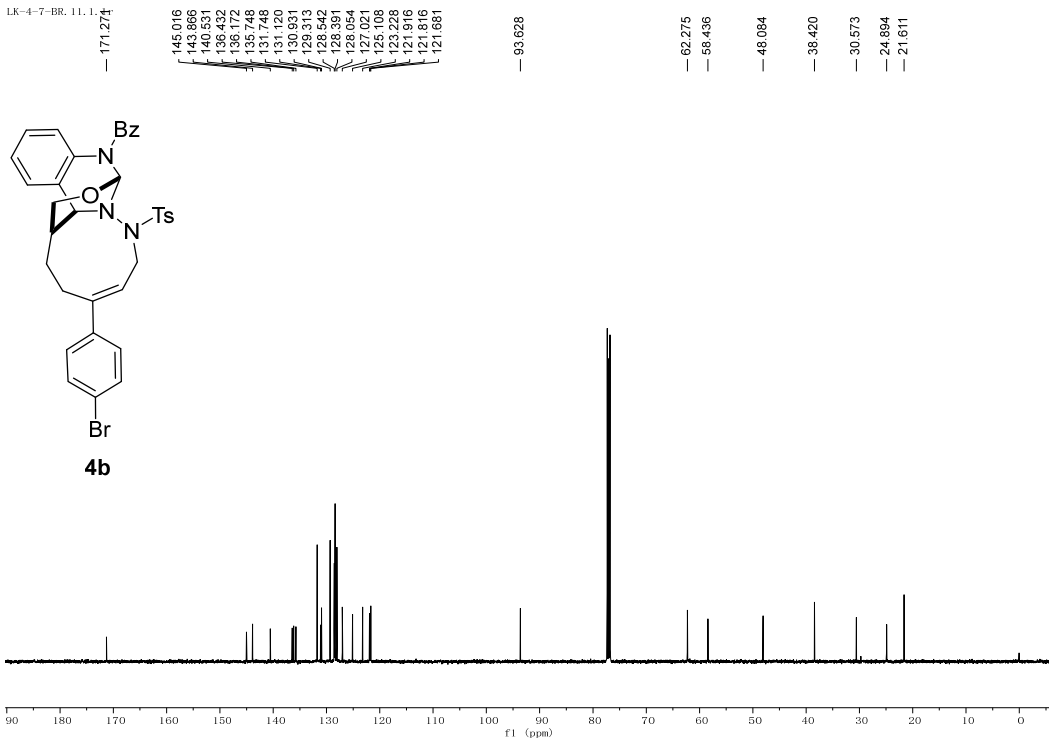
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **3ae**



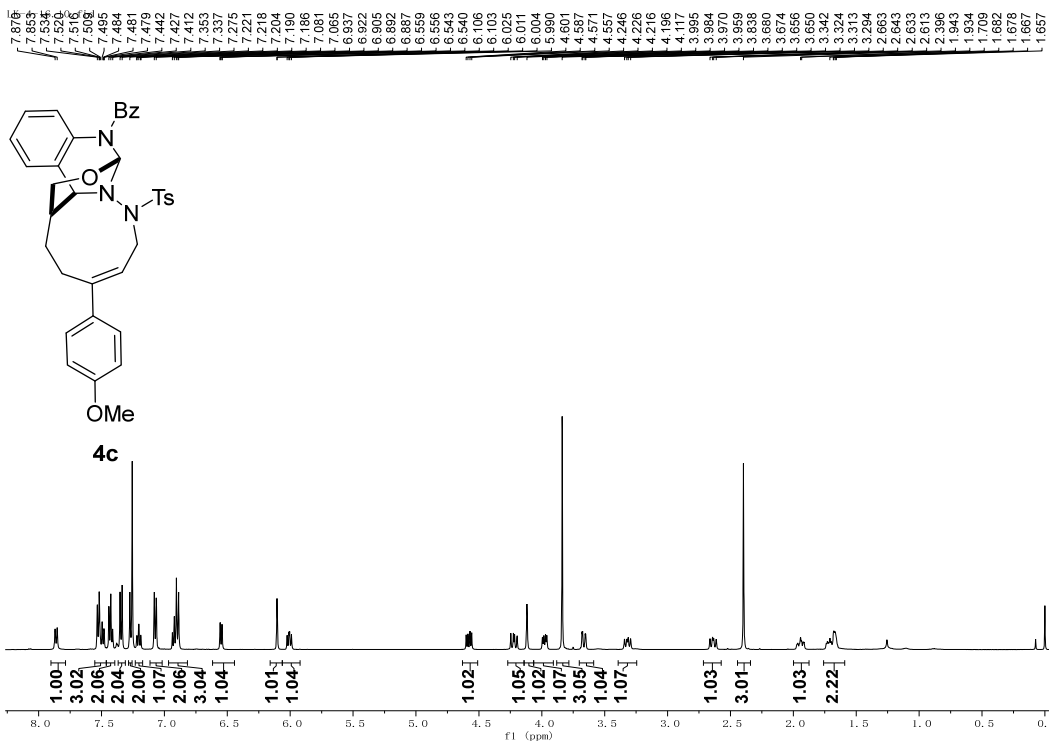


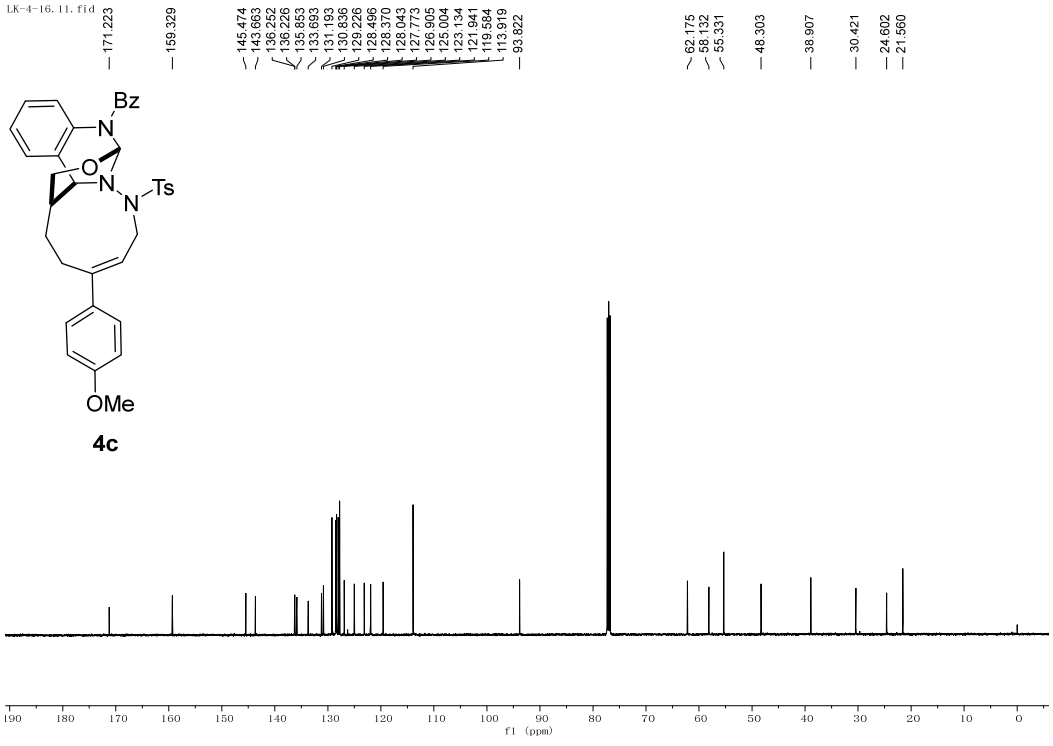
^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **4a**



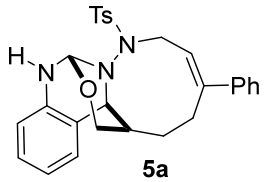


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **4b**

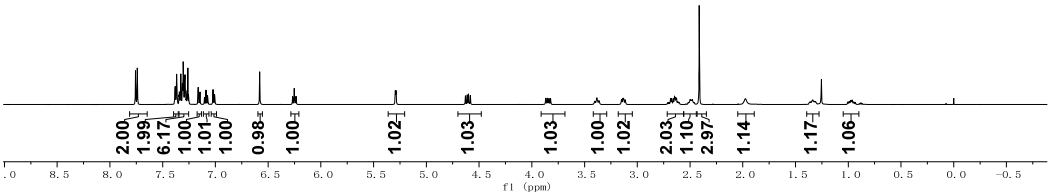


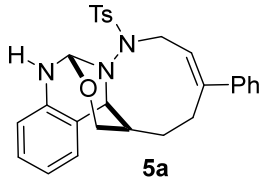


^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **4c**

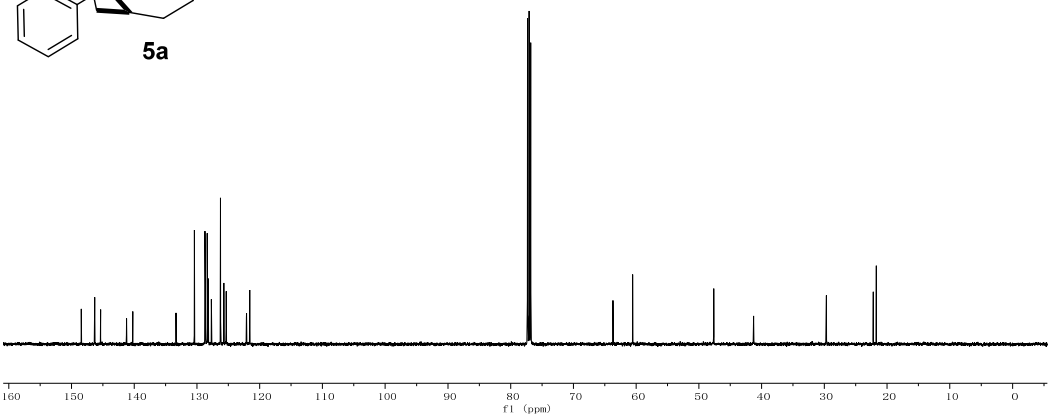


5a





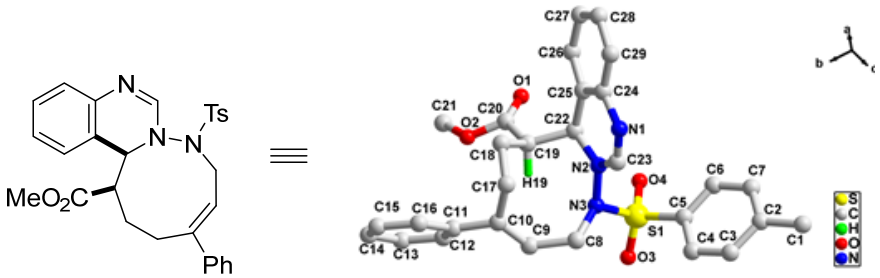
5a



^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra of **5a**

X-ray Crystal data of 3aa and 4a

X-Ray Crystallography Data Crystallographic data for the compound **3aa** has been deposited with the Cambridge Crystallographic Data Centre as deposition number CCDC 2120713. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.



3aa

Table S1. Crystal data and structure refinement for 3aa

Identification code	**3aa**
Empirical formula	$C_{29}H_{29}N_3O_4S$
Formula weight	515.61
Temperature/K	281.0
Crystal system	triclinic
Space group	P-1
a/Å	10.4935(6)
b/Å	11.0890(5)
c/Å	12.2484(6)
α/°	103.579(2)
β/°	101.602(2)
γ/°	97.418(2)
Volume/Å^3	1333.63(12)
Z	2

ρ_{calc}g/cm^3	1.284
μ/mm^{-1}	0.161
F(000)	544.0
Crystal size/mm^3	
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	6.106 to 55.048
Index ranges	-13⩽h⩽13, -14⩽k⩽14, -15⩽l⩽15
Reflections collected	33997
Independent reflections	6117 [R_{int} = 0.0503, R_{sigma} = 0.0331]
Data/restraints/parameters	6117/300/336
Goodness-of-fit on F2	1.020
Final R indexes [I>=2σ (I)]	R1 = 0.0457, wR2 = 0.1077
Final R indexes [all data]	R1 = 0.0692, wR2 = 0.1208
Largest diff. peak/hole / e Å^{-3}	0.33/-0.33

X-Ray Crystallography Data Crystallographic data for the compound **4a** has been deposited with the Cambridge Crystallographic Data Centre as deposition number CCDC 2145461. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

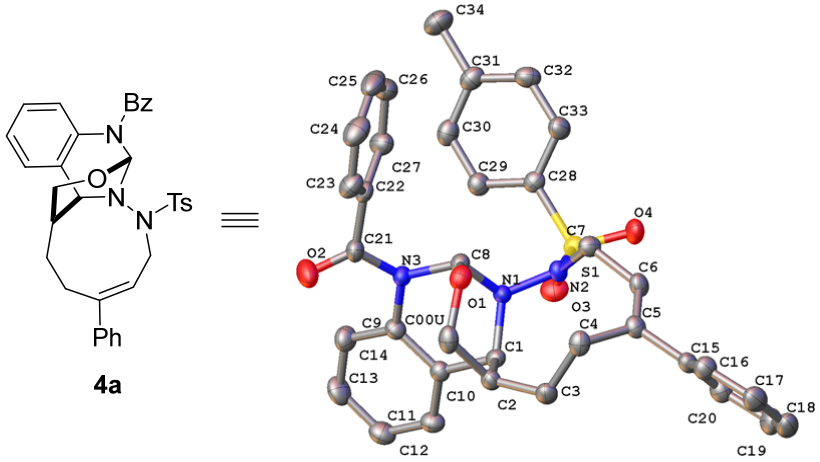


Table S2. Crystal data and structure refinement for 4a.

Identification code	**4a**
Empirical formula	$C_{35}H_{33}N_3O_4S$
Formula weight	591.70
Temperature	296.15 K
Wavelength	0.71073 Å
Crystal system	Triclinic
Space group	P-1
Unit cell dimensions	a = 9.6278(17) Å α= 105.423(3)°
	b = 12.640(2) Å β= 92.048(3)°
	c = 13.195(2) Å γ= 103.570(4)°
Volume	1496.4(5) $Å^3$
Z	2
Density (calculated)	1.313 Mg/m^3
Absorption coefficient	0.153 mm^{-1}
F(000)	624
Crystal size	0.07 x 0.06 x 0.05 mm^3
Theta range for data collection	1.610 to 27.809°
Index ranges	-12<=h<=12, -16<=k<=11, -17<=l<=16
Reflections collected	12556
Independent reflections	7003 [R(int) = 0.0512]
Completeness to theta = 25.242°	99.9 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.7456 and 0.6465
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	7003 / 0 / 389
Goodness-of-fit on F^2	0.927
Final R indices [I>2sigma(I)]	R1 = 0.0565, wR2 = 0.1098
R indices (all data)	R1 = 0.1479, wR2 = 0.1415

Extinction coefficient	n/a
Largest diff. peak and hole	0.262 and -0.325 e.Å^{-3}