Conformationally Driven Ru(II)-Catalyzed Multiple *ortho*-C–H Bond Activation in Diphenylpyrazine Derivatives in Water: Where is the Limit?

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Supporting Information

1 General information

All reagents were purchased from commercial suppliers and were used without further purification. Starting **1** [1] and **2** [2] were prepared according to literature procedures. The reactions with microwave heating were performed with a CEM Discovery Microwave. The machine consists of a continuous, focused-microwave, power-delivery system with an operator-selectable power output from 0 to 300 W. Reactions were performed in glass vessels (capacity 10 mL) sealed with a septum. The pressure was controlled by a load cell connected to the vessel via the septum. The temperature of the content of the vessel was monitored using a calibrated, infrared, temperature controller mounted under the reaction vessel. All the mixtures were stirred with a Teflon-coated, magnetic stirring bar in the vessel. A ramp temperature of 5 min was set for each experiment. The reactions were monitored by analytical thin-layer chromatography using silica gel plates (Fluka Kieselgel F254) and Al_2O_3 plates (Aluminiumoxid 60 F 254 neutral, Typ E). Radial chromatography purification was performed with a Harrison Research chromatotron, model 7924 T. Commercially available silica gel 60 PF_{254} containing gypsum (Merck, Kieselgel 60 PF_{254}) or mixture of gypsum, fluorescence indicator and Al_2O_3 (Merck, Aluminiumoxid 60 G neutral, Typ E) was used to prepare chromatotron plates. Compounds were visualized by 254 nm UV lamp. Melting points (m. p. [°C]) were determined on a Kofler micro hot stage instrument and are uncorrected. The NMR spectra were recorded either on a Bruker DPX 300 or on an Avance III 500 MHz spectrometer operating at 300 MHz (302 K) or 500 MHz (296 K) and 75.5 MHz or 126 MHz for ^{1}H and ^{13}C nuclei. Variable temperature (230–320 K) ^{1}H NMR spectra were measured with a Bruker DPX 300 MHz. The ^{1}H NMR spectra in $CDCl_3$ are referenced with respect to TMS as the internal standard. The ^{1}H NMR spectra in CD_3CN are referenced with respect to the central line of quintet (δ = 1.94 ppm) of residual solvent peak as the internal standard. The ^{13}C NMR spectra are referenced against the central line of the solvent signal ($CDCl_3$ triplet at δ = 77.0 ppm, CD_3CN septet at δ = 1.32 ppm). The coupling constants (J) are given in Hertz (Hz). For the multiplicity signification, the standard abbreviation was used: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), and br (broad). The infrared (IR) spectra were obtained with a Bruker ALPHA FT-IR spectrophotometer and are reported in reciprocal centimetres (cm^{-1}). The high-resolution mass spectra (HRMS) were recorded with an Agilent 6224 Accurate Mass TOF LC/MS instrument. X-ray structures were recorded on an Agilent Technologies SuperNova Dual diffractometer.

2 Experimental Procedures; Analytical and Spectroscopic Data

2.1 Conventional heating

A thick wall vessel was loaded with 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol), $[RuCl_2(p\text{-cymene})]_2$ (7.7 mg, 0.0125 mmol, 5 mol%), carboxylate ligand (0–20 mol%), PPh_3 (0–10 mol%), base (5 equiv.), 4-bromoacetophenone (199 mg, 1 mmol). The mixture was suspended in 1 mL of deionized water and bubbled with argon for 5 min. The reactions were carried out under conventional heating at temperature as indicated in Table S1 for 24 h. The reaction mixture was then cooled to room temperature and diluted with H_2O (10 mL). The crude product was extracted with DCM (2×10 mL). The combined organic phases were dried over anhydrous Na_2SO_4, filtrated and evaporated in vacuo. The crude reaction mixture was analysed by ^1H NMR spectroscopy.

Table S1: Direct arylation of **1** with 4-bromoacetophenone under various conditions.[a]

Entry	Base	Solvent	Ligands (mol%)	React. temperature (°C)	Conv.[b] (%)	**3a**/**4a**/**5a**/**6a**/**7a**/**8a**/**9a**[b]
1	KOAc	H_2O	PPh_3 (10)	140	71	75/25/0/0/0/0/0
2[c]	KO*t*-Bu	H_2O	PPh_3 (10)	140	90	0/0/0/37/35/28/0
3	K_3PO_4	H_2O	PPh_3 (10)	140	96	0/0/36/33/20/11/0
4[d]	K_3PO_4	1,4-dioxane	PPh_3 (10)	140	100	0/0/0/27/12/61/0
5	K_3PO_4	NMP	PPh_3 (10)	140	100	0/0/0/49/10/41/0
6	K_3PO_4	toluene	PPh_3 (10)	140	100	0/16/9/64/6/5/0
7	K_3PO_4	H_2O	PCCA (10)	140	98	0/0/31/25/33/11/0
8	K_3PO_4	H_2O	KOPiv (10)	140	96	0/0/14/36/33/17/0

9	K_3PO_4	H_2O	KOAc (10), PPh_3 (10)	140	97	0/0/32/39/14/15/0
10	K_3PO_4	H_2O	KOAc (20), PPh_3 (10)	140	99	0/0/21/52/8/19/0
11	**K_3PO_4**	**H_2O**	**PCCA (10), PPh_3 (10)**	**140**	**100**	**0/0/54/23/19/4/0**
12	K_3PO_4	H_2O	PCCA (10), PPh_3 (10)	70	92	38/4/50/0/8/0/0

[a]Reaction conditions: **1** (0.25 mmol), 4-bromoacetophenone (1 mmol), $[RuCl_2(p\text{-cymene})]_2$ (0.0125 mmol), base (1.25 mmol), 24 h, argon. [b]Conversion and ratio determined by NMR analysis. [c]Additional undetermined products detected. [d]Reaction time was extended to 4 days. Entry 1: about 20% of pyrazine **2** formed.

2.2 General procedure for catalytic direct arylation of diphenylpyrazine substrates

A microwave vial was loaded with 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol) or 2,3-diphenylpyrazine (**2**) (58 mg, 0.25 mmol), $[RuCl_2(p\text{-cymene})]_2$ (5–10 mol%), 1-phenylcyclopentane-1-carboxylic acid (10–20 mol%), PPh_3 (10–20 mol%), K_3PO_4 (5 equiv.), corresponding aryl halide (2–10 equiv.). The mixture was suspended in 1 mL of deionized water and bubbled with argon for 5 min. The reactions were carried out under microwave heating at temperature and for indicated period of time. The reaction mixture was then cooled to room temperature and diluted with H_2O (10 mL). The crude product was extracted with DCM (2×10 mL). The combined organic phases were dried over anhydrous Na_2SO_4, filtered and evaporated in vacuo. The crude product was further purified by radial chromatography (SiO_2 or Al_2O_3) using different mixtures of EtOAc and petroleum ether.

2.2.1 Preparation of arylated dihydropyrazine products

Arylation of **1** under various conditions gave different mixtures of dihydropyrazine products and their aromatic analogues arylated at different positions, but only arylation reactions of **1** which gave the best selectivity and isolated yield were selected for the preparation of a particular product **3a**, **5a**, **5b**, **7a**, **7b**, or **9a**.

1-(2'-(3-phenyl-5,6-dihydropyrazin-2-yl)-[1,1'-biphenyl]-4-yl)ethan-1-one (3a)

General procedure for direct arylation was followed using 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol), $[RuCl_2(p\text{-cymene})]_2$ (7.7 mg, 0.0125 mmol), K_3PO_4 (265 mg, 1.25 mmol), 4-bromoacetophenone (99.5 mg, 0.5 mmol), PCCA (4.8 mg, 0.025 mmol) and PPh_3 (6.6 mg, 0.025 mmol). The reaction mixture was heated under microwave irradiation at 140 °C for 0.5 h, and after purification by radial chromatography (SiO_2, petroleum ether/EtOAc solvent gradient from 1/1 to 1/5) compound **3a** was obtained as pale yellow crystals (47 mg; 53%), m. p. 154–157 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.62 (s, 3H), 3.55–3.68 (m, 2H), 3.68–3.80 (m, 2H), 6.64−6.71 (m, 2H), 6.89 (AA'BB', J = 8.3 Hz, 2H), 6.93−7.02 (m, 2H), 7.07 (dd, J = 1.0, 7.7 Hz, 1H), 7.13−7.21 (m, 1 H), 7.42 (td, J = 1.4, 7.6 Hz, 1H), 7.52 (td, J = 1.3, 7.5 Hz, 1H), 7.77 (AA'BB', J = 8.4 Hz, 2H), 7.84 (dd, J = 1.3, 7.7 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 26.7, 45.1, 45.4, 127.3, 127.5, 127.8, 128.5, 129.2, 129.3, 129.4, 129.69, 129.73, 135.8, 136.3, 137.7, 139.1, 144.8, 159.7, 161.9, 197.6. FT-IR (ATR): 3057, 2943, 2820, 1676, 1618, 1579, 1358, 1263, 1231, 985, 960, 835, 772, 698, 657. HRMS (ESI) calcd. for $C_{24}H_{21}N_2O$ $[M+H]^+$ 353.1648, found 353.1644.

1,1'-((5,6-dihydropyrazine-2,3-diyl)bis([1,1'-biphenyl]-2',4-diyl))bis(ethan-1-one) (5a)

General procedure for direct arylation was followed using 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol), $[RuCl_2(p\text{-cymene})]_2$ (7.7 mg, 0.0125 mmol), K_3PO_4 (265 mg, 1.25 mmol), 4-bromoacetophenone (199 mg, 1 mmol), PCCA (4.8 mg, 0.025 mmol) and PPh_3 (6.6 mg, 0.025 mmol). The reaction mixture was heated under microwaves at 140 °C for 1 h, and after purification by radial chromatography (Al_2O_3, petroleum ether/EtOAc solvent gradient from 2/1 to 1/2) compound **5a** was obtained as pale yellow crystals (68 mg; 58%), m. p. 207–210 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.67 (s, 6H), 3.75 (br, 4H), 6.18−6.24 (m, 2H), 6.94−7.05 (m, 8H), 7.26 (td, J = 1.2, 15.1 Hz, 2H), 7.88 (AA'BB', J = 8.4 Hz, 4H).^{13}C NMR (126 MHz, $CDCl_3$): δ = 26.7, 45.1, 127.7, 128.0, 128.9, 129.37, 129.41, 131.1, 135.8, 136.0, 137.9, 144.9, 162.2, 197.6. FT-IR (ATR): 3059, 2933, 2837, 1677, 1601, 1549, 1258, 1232, 1182, 989, 960, 846, 829, 759, 730, 698, 654. HRMS (ESI) calcd. for $C_{32}H_{27}N_2O_2$ $[M+H]^+$ 471.2067, found 471.2065.

5,6-bis(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)-2,3-dihydropyrazine (5b)

General procedure for direct arylation was followed was followed using 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol), $[RuCl_2(p\text{-cymene})]_2$ (7.7 mg, 0.0125 mmol),

K_3PO_4 (265 mg, 1.25 mmol), 1-bromo-4-(trifluoromethyl)benzene (140 µL, 1 mmol), PCCA (4.8 mg, 0.025 mmol) and PPh_3 (6.6 mg, 0.025 mmol). The reaction mixture was heated under microwaves at 140 °C for 1 h, and after purification by radial chromatography (SiO_2, petroleum ether/EtOAc solvent gradient from 10/1 to 5/1) compound **5b** was obtained as pale yellow crystals (59 mg; 45%), m. p. 189–192 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 3.76 (br, 4H), 6.26 (dd, J = 1.1, 7.7 Hz, 2H), 6.94−7.02 (m, 8H), 7.27 (td, J = 1.3, 7.6 Hz, 2H), 7.52 (AA'BB', J = 8.0 Hz, 4H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 45.1, 124.1 (q, ^1J = 272.6 Hz), 125.0 (q, ^3J = 3.6 Hz), 127.9, 129.0, 129.2, 129.4, 129.7 (q, ^2J = 32.6 Hz), 131.1, 135.9, 137.5, 143.7, 161.8. FT-IR (ATR): 3056, 2964, 2840, 1616, 1406, 1324, 1164, 1106, 1066, 1020, 989, 849, 832, 762, 734, 606. HRMS (ESI) calcd. for $C_{30}H_{21}F_6N_2$ $[M+H]^+$ 523.1603, found 523.1599.

1,1'-(2'-(3-(4'-acetyl-[1,1'-biphenyl]-2-yl)-5,6-dihydropyrazin-2-yl)-[1,1':3',1''terphenyl]-4,4''-diyl)bis(ethan-1-one) (7a)

General procedure for direct arylation was followed using 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol), $[RuCl_2(p\text{-cymen})]_2$ (15.3 mg, 0.025 mmol), K_3PO_4 (265 mg, 1.25 mmol), 4-bromoacetophenone (298 mg, 1.5 mmol), PCCA (9.5 mg, 0.05 mmol) and PPh_3 (13.1 mg, 0.05 mmol). The reaction mixture was heated under microwaves at 140 °C for 1 h, and after purification by radial chromatography (Al_2O_3, petroleum ether/EtOAc solvent gradient from 2/1 to 1/2) compound **7a** was obtained as colourless crystals (96 mg; 65%), m. p. 197–200 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.53 (s, 9H), 2.76 (m, 2H), 3.20 (m, 2H), 6.21 (AA'BB', J = 8.4 Hz, 2H), 6.54 (dd, J = 0.8, 7.8 Hz, 1H), 7.04 (td, J = 1.2, 7.7 Hz, 1H), 7.14 (dd, J = 0.9, 7.7 Hz, 1H), 7.19 (AA'BB', J = 8.4 Hz, 4H), 7.32 (d, J = 7.8 Hz, 2H), 7.35 (td, J = 1.2, 7.5 Hz, 1H), 7.56 (d, J = 7.8 Hz, 1H), 7,61 (AA'BB', J = 8.4 Hz, 2H), 7.82 (AA'BB', J = 8.4 Hz, 4H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 26.56, 26.63, 44.0, 44.2, 126.6, 127.5, 127.9, 128.4, 128.8, 129.0, 129.3, 129.6, 130.3, 130.6, 134.3, 135.0, 135.1, 136.0, 140.9, 141.8, 145.1, 145.8, 160.1, 160.7, 197.5, 197.7. FT-IR (ATR): 3059, 2947, 2846, 1673, 1604, 1573, 1399, 1355, 1265, 1183, 980, 959, 841, 759, 745, 703, 603. HRMS (ESI) calcd. for $C_{40}H_{33}N_2O_3$ $[M+H]^+$ 589.2486, found 589.2473.

5-(4,4''-bis(trifluoromethyl)-[1,1':3',1''-terphenyl]-2'-yl)-6-(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)-2,3-dihydropyrazine (7b)

General procedure for direct arylation was followed using 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol), $[RuCl_2(p\text{-cymene})]_2$ (15.3 mg, 0.025 mmol), K_3PO_4 (265 mg, 1.25

mmol), 1-bromo-4-(trifluoromethyl)benzene (210 μL, 1.5 mmol), PCCA (9.5 mg, 0.05 mmol) and PPh_3 (13.1 mg, 0.05 mmol). The reaction mixture was heated under microwaves at 140 °C for 1 h, and after purification by radial chromatography (Al_2O_3, petroleum ether/EtOAc solvent gradient from 10/1 to 5/1) compound **7b** was obtained as pale yellow crystals (67 mg; 40%), m. p. 170–173 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.74 (m, 2H), 3.16 (m, 2H), 6.20 (AA'BB', J = 8.0 Hz, 2H), 6.49 (dd, J = 0.8, 7.8 Hz, 1H), 7.04 (td, J = 1.3, 7.7 Hz, 1H), 7.13 (dd, J = 1.0, 7.7 Hz, 1H), 7.19 (AA'BB', J = 8.0 Hz, 4H), 7.27−7.33 (m, 4H), 7.35 (td, J = 1.2, 7.5 Hz, 1H), 7.50 (AA'BB', J = 8.0 Hz, 4H), 7.58 (t, J = 7.5 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 44.05, 44.11, 123.9 (q, ^1J = 272.8 Hz), 124.1 (q, ^1J = 272.5 Hz), 124.4 (q, ^3J = 3.7 Hz), 124.8 (q, ^3J = 3.6 Hz), 126.6, 128.4, 128.77 (q, ^2J = 32.6 Hz), 128.82, 129.1, 129.2, 129.77, 129.82 (q, ^2J = 32.7 Hz), 130.5, 130.6, 134.4, 134.9, 140.6, 141.6, 143.8, 144.3, 159.9, 160.7. FT-IR (ATR): 3058, 2968, 2845, 1618, 1402, 1322, 1162, 1124, 1109, 1063, 1017, 981, 847, 814, 768, 609. HRMS (ESI) calcd. for $C_{37}H_{24}F_9N_2$ $[M+H]^+$ 667.179, found 667.1804.

1,1',1'',1'''-((5,6-dihydropyrazine-2,3-diyl)bis([1,1':3',1''-terphenyl]-2',4,4''-triyl))tetrakis(ethan-1-one) (9a)

General procedure for direct arylation was followed using 5,6-diphenyl-2,3-dihydropyrazine (**1**) (58.6 mg, 0.25 mmol), $[RuCl_2(p\text{-cymene})]_2$ (15.3 mg, 0.025 mmol), K_3PO_4 (265 mg, 1.25 mmol), 4-bromoacetophenone (498 mg, 2.5 mmol), PCCA (9.5 mg, 0.05 mmol) and PPh_3 (13.1 mg, 0.05 mmol). The reaction mixture was heated under microwaves at 140 °C for 8 h, and after purification by radial chromatography (SiO_2, petroleum ether/EtOAc solvent gradient from 2/1 to 1/1) compound **9a** was obtained as colourless crystals (99 mg; 56%), m. p. 233–236 °C. ^{1}H NMR (300 MHz, $CDCl_3$, 302 K): δ = 2.55 (s, 12H), 6.20–6.92 (br, 8H), 7.01 (d, J = 7.6 Hz, 4H), 7.44 (t, J = 7.7 Hz, 2H), 7.72 (d, J = 8.5 Hz, 8H) (signals corresponding to -CH_2CH_2- protons are not observed). ^{1}H NMR (300 MHz, CD_3CN, 302 K): δ = 2.50 (s, 12H), 2.79 (br, 4H), 6.77 (d, J = 7.2 Hz, 8H), 7.06 (d, J = 8.6 Hz, 4H), 7.49 (t, J = 8.6 Hz, 2H), 7.74 (AA'BB', J = 8.6 Hz, 8H). ^{1}H NMR (300 MHz, CD_3CN, 320 K): δ = 2.51 (s, 12H), 2.77 (br, 4H), 6.78 (AA'BB', J = 8.2 Hz, 8H), 7.06 (d, J = 7.7 Hz, 4H), 7.50 (t, J = 7.7 Hz, 2H), 7.74 (AA'BB', J = 8.5 Hz, 8H). ^{1}H NMR (300 MHz, $CDCl_3$, 230 K): δ = 2.50 (s, 6H), 2.68 (m, 2H), 2.70 (s, 6H), 3.48 (m, 2H), 6.48–6.73 (m, 6H), 7.05 (d, J = 7.6 Hz, 2H), 7.17 (d, J = 7.5 Hz, 2H), 7.27 (d, J = 8.1 Hz, 2H), 7.55 (t, J = 7.7 Hz, 2H), 7.68 (d, J = 8.0 Hz, 2H), 7.81 (d, J = 8.4 Hz, 6H) (signal for CH_2 is overlapped with signal for CH_3). ^{13}C NMR (75 MHz, CD_3CN, 320K): δ = 27.1, 45.2, 128.6, 130.0, 131.3, 131.6, 134.0, 137.1, 143.0,

146.5, 162.0, 198.7. ^{13}C NMR (75 MHz, $CDCl_3$, 230K): δ = 27.2, 27.3, 43.5, 127.1, 127.2, 127.9, 128.1, 128.8, 129.8, 130.3, 130.5, 130.7, 132.0, 134.2, 134.5, 140.3, 142.3, 144.9, 145.4, 160.7, 198.4, 198.7. FT-IR (ATR): 3050, 3005, 2950, 1677, 1604, 1581, 1557, 1404, 1353, 1267, 1183, 1016, 976, 957, 846, 831, 802, 762, 704, 608. HRMS (ESI) calcd. for $C_{48}H_{39}N_2O_4$ $[M+H]^+$ 707.2904, found 707.2894.

2.3 General procedure for preparation of arylated aromatic pyrazine products

Although we were able to isolate some of aromatic arylated products from direct arylations of either **1** or **2**, the best-yielding method for the preparation of a specific aromatic pyrazine product **4a**, **6a**, **6b**, **8a**, **8b**, or **10a** was: arylation of **1** under conditions leading to the best selectivity for the corresponding dihydropyrazine precursor of an aromatic product as described in 2.2, followed by treatment of the crude reaction mixture with HCl. The extracted crude product from the arylation reaction of **1** was dissolved in THF (3 mL), and 6M aqueous HCl (3 mL) was added, and stirred at room temperature for 5 hours. After completion of the reaction, the mixture was diluted with DCM (6 mL) and extracted with saturated aqueous $NaHCO_3$ (3×10 mL). The organic phase was dried over anhydrous Na_2SO_4, filtered and evaporated under reduced pressure. The crude product was further purified by radial chromatography (SiO_2 or Al_2O_3) using mixtures of EtOAc and petroleum ether.

1-(2'-(3-phenylpyrazin-2-yl)-[1,1'-biphenyl]-4-yl)ethan-1-one (4a)

Arylation of **1** leading to the best selectivity as described for preparation of **3a** was first performed. Then the general procedure for the preparation of aromatic pyrazine products without isolation of the corresponding dihydro product was followed. The crude product was purified by radial chromatography (SiO_2, petroleum ether/EtOAc solvent gradient from 5/1 to 1/1) to give compound **4a** as colourless crystals (36 mg; 41%), m. p. 155–158 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.54 (s, 3H), 6.53 (AA'BB', J = 8.4 Hz, 2H), 6.76−6.82 (m, 2H), 6.99−7.07 (m, 2H), 7.15−7.23 (m, 2H), 7.48 (td, J = 1.4, 7.5 Hz, 1H), 7.53−7.60 (m, 3 H), 7.76 (dd, J = 1.3, 7.6 Hz, 1H), 8.56 (d, J = 2.4 Hz, 1H), 8.62 (d, J = 2.4 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 26.6, 127.75, 127.79, 128.3, 128.6, 128.86, 128.94, 129.3, 129.7, 131.2, 134.8, 137.4, 137.6, 139.8, 142.0, 142.6, 145.0, 153.0, 153.3, 197.8. FT-IR (ATR): 3050, 2923, 2853, 1675, 1604, 1386, 1355, 1267, 1016, 837, 769, 756, 695. HRMS (ESI) calcd. for $C_{24}H_{19}N_2O$ $[M+H]^+$ 351.1492, found 351.1491.

2-phenyl-3-(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)pyrazine (4b)

Compound **4b** was isolated as a light yellow oil (5 mg, 5%) from the crude reaction mixture in the synthesis of compound **5b** as described above. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 6.52 (AA'BB', J = 8.1 Hz, 2H), 6.75−6.79 (m, 2H), 7.01−7.06 (m, 2H), 7.18 (m, 2H), 7.22 (m, 2H), 7.50 (td, J = 1.3, 7.6 Hz, 1H), 7.59 (td, J = 1.2, 7.6 Hz, 1H), 7.78 (dd, J = 1.2, 7.7 Hz, 1H), 8.58 (d, J = 2.4 Hz, 1H), 8.64 (d, J = 2.4 Hz, 1H). FT-IR (ATR): 3059, 2926, 2855, 1617, 1388, 1322, 1162, 1115, 1067, 1018, 842, 762, 736, 694, 609. HRMS (ESI) calcd. for $C_{23}H_{16}F_3N_2$ $[M+H]^+$ 377.126, found 377.1264.

1,1'-(pyrazine-2,3-diylbis([1,1'-biphenyl]-2',4-diyl))bis(ethan-1-one) (6a)

Arylation of **1** leading to the best selectivity as described for preparation of **5a** was first performed. Then the general procedure for the preparation of aromatic pyrazine products without isolation of the corresponding dihydro product was followed. The crude product was purified by radial chromatography (Al_2O_3, petroleum ether/EtOAc solvent gradient from 5/1 to 1/1) to give compound **6a** as yellow crystals (53 mg; 45%), m. p. 200–203 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.58 (s, 6H), 6.33 (dd, J = 1.2, 7.1 Hz, 2H), 6.54 (AA'BB', J = 8.5 Hz, 4H), 6.97 (td, J = 1.2, 7.6 Hz, 2H), 7.06 (dd, J = 0.9, 7.7 Hz, 2H), 7.28 (td, J = 1.3, 7.6 Hz, 2H), 7.63 (AA'BB', J = 8.5 Hz, 4H), 8.66 (s, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 26.7, 128.1, 128.4, 128.6, 128.7, 129.2, 131.4, 135.0, 136.4, 138.7, 142.6, 145.1, 153.8, 197.7. FT-IR (ATR): 3050, 2962, 2868, 1676, 1603, 1387, 1356, 1265, 1017, 957, 843, 827, 757, 728, 681. HRMS (ESI) calcd. for $C_{32}H_{25}N_2O_2$ $[M+H]^+$ 469.1911, found 469.1911.

2,3-bis(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)pyrazine (6b)

Arylation of **1** leading to the best selectivity as described for preparation of **5b** was first performed. Then the general procedure for the preparation of aromatic pyrazine products without isolation of the corresponding dihydro product was followed. The crude product was purified by radial chromatography (SiO_2, petroleum ether/EtOAc solvent gradient from 20/1 to 10/1) to give compound **6b** as colourless crystals (68 mg; 52%), m. p. 175–179 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 6.37 (d, J = 7.6 Hz, 2H), 6.54 (d, J = 8.0 Hz, 4H), 7.01 (t, J = 7.6 Hz, 2H), 7.05 (d, J = 7.7 Hz, 2H), 7.26–7.32 (m, 6H), 8.69 (s, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 124.2 (q, ^{1}J = 272.5 Hz), 125.1 (q, ^{3}J = 3.7 Hz), 128.5, 128.58, 128.61, 128.63 (q, ^{2}J = 32.4 Hz), 129.2, 131.6, 136.5, 138.2, 142.8, 143.8, 153.6. FT-IR (ATR): 3058, 2919,

2849, 1615, 1386, 1321, 1157, 1116, 1067, 1018, 845, 764, 736, 724, 609. HRMS (ESI) calcd. for $C_{30}H_{19}F_6N_2$ $[M+H]^+$ 521.1447, found 521.1444.

1,1'-(2'-(3-(4'-acetyl-[1,1'-biphenyl]-2-yl)pyrazin-2-yl)-[1,1':3',1''-terphenyl]-4,4''-diyl)bis(ethan-1-one) (8a)

Arylation of **1** leading to the best selectivity as described for preparation of **7a** was first performed. Then the general procedure for the preparation of aromatic pyrazine products without isolation of the corresponding dihydro product was followed. The crude product was purified by radial chromatography (Al_2O_3, petroleum ether/EtOAc solvent gradient from 5/1 to 1/1) to give compound **8a** as light yellow crystals (76 mg; 43%), m. p. 223–226 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.48 (s, 3H), 2.50 (s, 6H), 5.93 (AA'BB', J = 8.5 Hz, 2H), 6.91 (dd, J = 0.9, 7.9 Hz, 1H), 6.99 (AA'BB', J = 8.4 Hz, 4H), 7.10 (td, J = 1.3, 7.6 Hz, 1H), 7.25 (dd, J = 1.1, 7.7 Hz, 1H), 7.34–7.43 (m, 3 H), 7.47 (AA'BB', J = 8.5 Hz, 2H), 7.61 (t, J = 7.7 Hz, 1H), 7.70 (AA'BB', J = 8.5 Hz, 4H), 7.95 (d, J = 2.4 Hz, 1H), 8.17 (d, J = 2.3 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 26.46, 26.52, 126.9, 127.3, 128.0, 128.9, 129.1, 129.2, 129.6, 129.8, 130.5, 131.3, 134.7, 134.8, 135.0, 135.6, 141.17, 141.24, 141.55, 141.62, 145.7; 146.2; 152.1, 152.5, 197.5, 197.7. FT-IR (ATR): 3056, 2924, 2854, 1678, 1603, 1403, 1373, 1356, 1265, 1183, 1016, 956, 840, 803, 762, 704. HRMS (ESI) calcd. for $C_{40}H_{31}N_2O_3$ $[M+H]^+$ 587.2329, found 587.233.

2-(4,4''-bis(trifluoromethyl)-[1,1':3',1''-terphenyl]-2'-yl)-3-(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)pyrazine (8b)

Arylation of **1** leading to the best selectivity as described for preparation of **7b** was first performed. Then the general procedure for the preparation of aromatic pyrazine products without isolation of the corresponding dihydro product was followed. The crude product was purified by radial chromatography (SiO_2, petroleum ether/EtOAc solvent gradient from 20/1 to 10/1) to give compound **8b** as colourless crystals (65 mg; 39%), m. p. 191–194 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.95 (AA'BB', J = 8.0 Hz, 2H), 6.87 (dd, J = 1.0, 7.9 Hz, 1H), 6.99 (AA'BB', J = 8.0 Hz, 4H), 7.10 (td, J = 1.4, 7.7 Hz, 1H), 7.19 (AA'BB', J = 8.0 Hz, 2H), 7.23 (dd, J = 1.2, 7.7 Hz, 1H), 7.33−7.42 (m, 7H), 7.61 (t, J = 7.8 Hz, 1H); 7.98 (d, J = 2.4 Hz, 1H), 8.18 (d, J = 2.3 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 123.9 (q, ^1J = 272.6 Hz), 124.1 (q, ^1J = 272.4 Hz), 124.4 (q, ^3J = 3.7 Hz), 125.0 (q, ^3J = 3.7 Hz), 127.0, 128.4 (q, ^2J = 32.4 Hz), 128.9, 129.0, 129.3 (q, ^2J = 32.6 Hz), 129.4, 129.7, 129.9, 130.6, 131.5, 134.7, 135.1, 141.0, 141.2, 141.4, 141.7, 144.4, 144.9, 152.0, 152.5. FT-IR (ATR): 3059, 2925,

2854, 1616, 1404, 1380, 1319, 1158, 1104, 1065, 1016, 842, 758, 735, 615. HRMS (ESI) calcd. for $C_{37}H_{22}F_9N_2$ $[M+H]^+$ 665.1634, found 665.163.

1,1',1'',1'''-(pyrazine-2,3-diylbis([1,1':3',1''-terphenyl]-2',4,4''-triyl))tetrakis(ethan-1-one) (10a)

Arylation of **1** leading to the best selectivity as described for preparation of **9a** was first performed. Then the general procedure for the preparation of aromatic pyrazine products without isolation of the corresponding dihydro product was followed. The crude product was purified by radial chromatography (SiO_2, petroleum ether/EtOAc solvent gradient from 5/1 to 1/1) to give compound **10a** as colourless crystals (102 mg; 58%), m. p. 227–230 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.39 (s, 12H), 6.43 (br , J = 7.8 Hz, 8H), 7.17 (d, J = 7.7 Hz, 4H), 7.49–7.57 (m, 10H), 7.95 (s, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 26.4, 127.5, 128.9, 129.5, 131.0, 133.3, 135.1, 140.5, 142.2, 145.4, 152.0, 197.4. FT-IR (ATR): 3545, 3078, 2994, 1677, 1666, 1599, 1557, 1356, 1263, 1074, 1015, 960, 843, 828, 800, 764, 704, 612. HRMS (ESI) calcd. for $C_{48}H_{37}N_2O_4$ $[M+H]^+$ 705.2748, found 705.2741.

Preparation of ruthenacycle 11

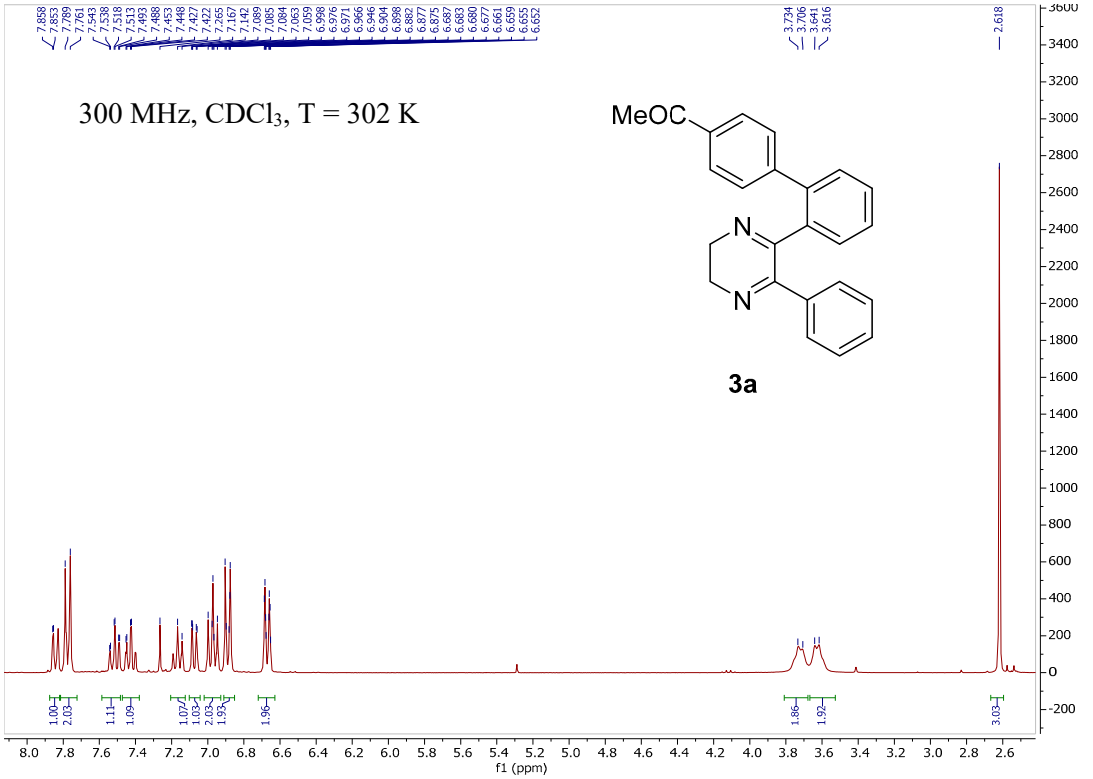
Ruthenacycle **11** was prepared by following literature procedure [3]. A mixture of 5,6-diphenyl-2,3-dihydropyrazine (**1**) (23.4 mg, 0.1 mmol), $[RuCl_2(p\text{-cymene})]_2$ (61.4 mg, 0.1 mmol), KOAc (39.2 mg, 0.4 mmol), and KCl (15 mg, 0.2 mmol) was suspended in MeOH (2 mL) and then mixed at room temperature for 15 h. A solvent was then evaporated in vacuo and the crude product was further purified by radial chromatography on silica gel using mixture of DCM and MeOH (100:1) to give ruthenacycle **11** (70 mg, 0.09 mmol, 90% yield) as an orange semisolid. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (d, J = 7 Hz, 6H), 1.07 (d, J = 7 Hz, 6H), 2.08 (s, 6H), 2.52 (quintet, J = 7 Hz, 2H), 4.23 (m, 2H), 4.63 (m, 2H), 4.98 (d, J = 6 Hz, 2H), 5.10 (d, J = 6 Hz, 2H), 5.61 (d, J = 6 Hz, 2H), 5.66 (d, J = 6 Hz, 2H), 6.90 (dt, J = 1, 7.5 Hz, 2H), 7.12(dt, J = 1, 7.5 Hz, 2H), 7.58 (dd, J = 1, 7.5 Hz, 2H), 8.24 (dd, J = 1, 7.5 Hz, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 19.0, 21.7, 22.7, 31.1, 58.7, 81.5, 82.7, 89.9, 91.9, 102.8, 103.7, 121.6, 129.1, 131.0, 139.7, 142.0, 167.9, 194.0. FT-IR (ATR): 2960, 1572, 1532, 1416, 1359, 1336, 1299, 1239, 1156, 1040, 1019, 911, 855, 765, 721. HRMS (ESI) calcd. for $C_{36}H_{41}Cl_2N_2Ru_2$ $[M+H]^+$ 775.0734, found 775.0744.

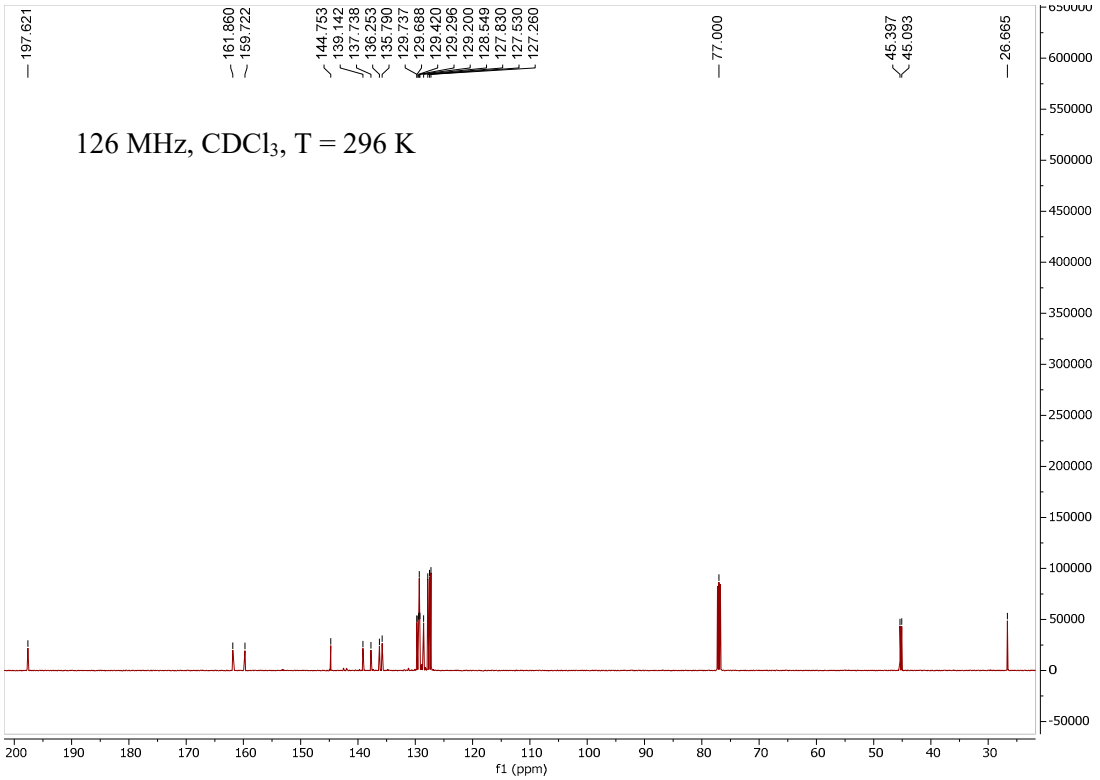
Preparation of ruthenacycle 12

Ruthenacycle **12** was prepared by following literature procedure [3]. A mixture of 2,3-diphenylpyrazine (**2**) (23.2 mg, 0.1 mmol), $[RuCl_2(p\text{-cymene})]_2$ (61.4 mg, 0.1 mmol), KOAc (39.2 mg, 0.4 mmol), and KCl (15 mg, 0.2 mmol) was suspended in MeOH (2 mL) and then mixed at room temperature for 15 h. A solvent was then evaporated in vacuo and the crude product was further purified by radial chromatography on silica gel using mixture of DCM and MeOH (100:1) to give ruthenacycle **12** (7 mg, 0.014 mmol, 14% yield) as an orange semisolid. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.95 (d, J = 7 Hz, 3H), 1.03 (d, J = 7 Hz, 3H), 2.11 (s, 3H), 2.46 (septet, J = 7 Hz, 1H), 5.09 (d, J = 6 Hz, 1H), 5.24 (d, J = 6 Hz, 1H), 5.67 (t, J = 6 Hz, 2H), 6.63 (ddd, J = 1, 7, 8 Hz, 1H), 6.86 (dd, J = 1, 8 Hz, 1H), 7.05 (td, J = 1, 7 Hz, 1H), 7.49 (m, 5H), 8.12 (dd, J = 1, 8 Hz, 1H), 8.24 (d, J = 3 Hz, 1H), 9.24 (d, J = 3 Hz, 1H).

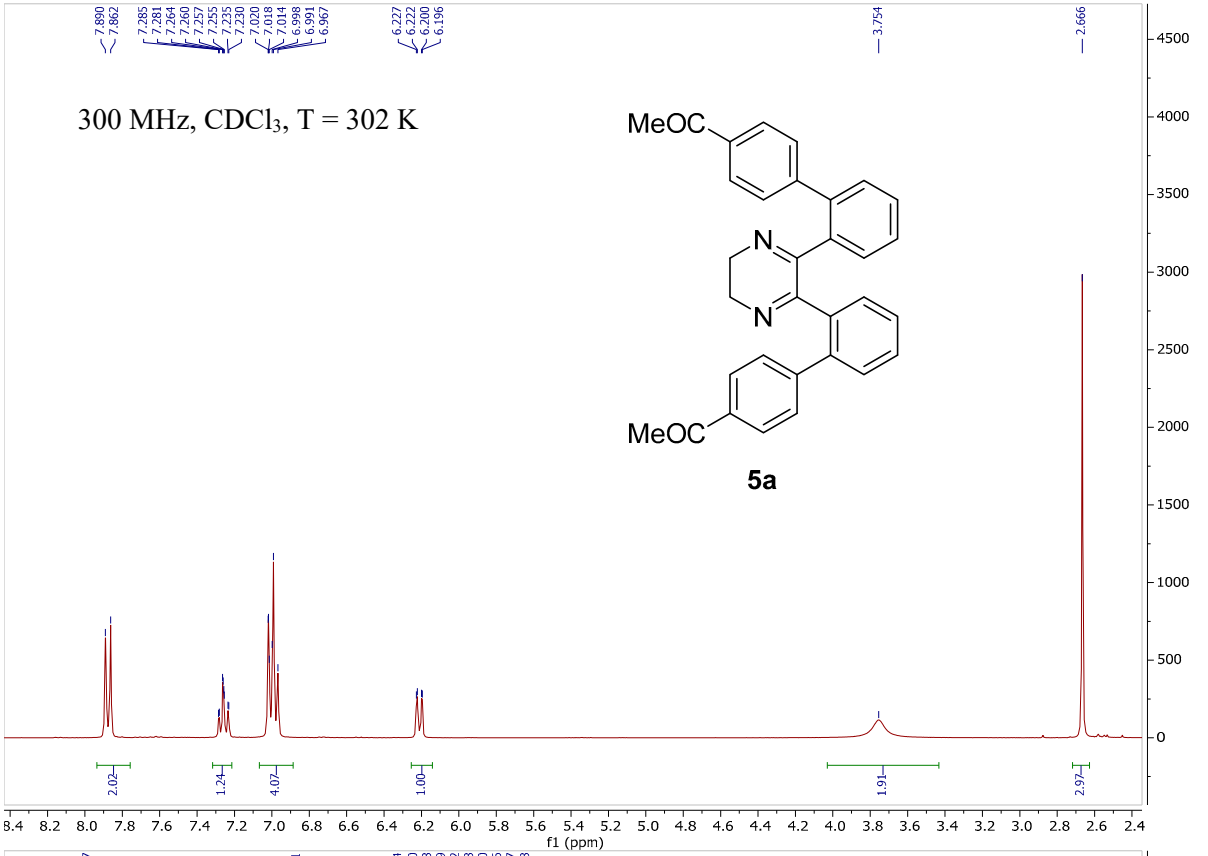
^{1}H and ^{13}C NMR Spectra of new compounds

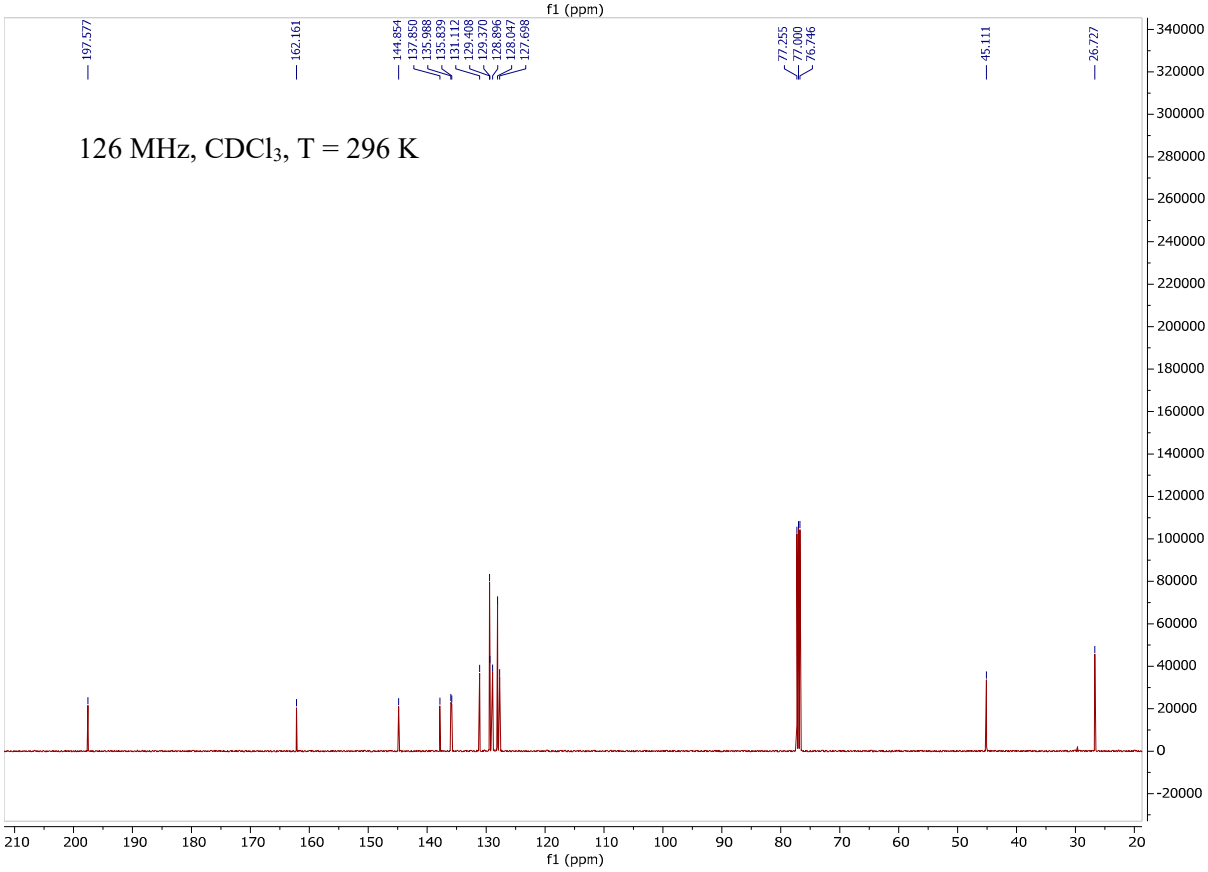
1-(2'-(3-phenyl-5,6-dihydropyrazin-2-yl)-[1,1'-biphenyl]-4-yl)ethan-1-one (3a)



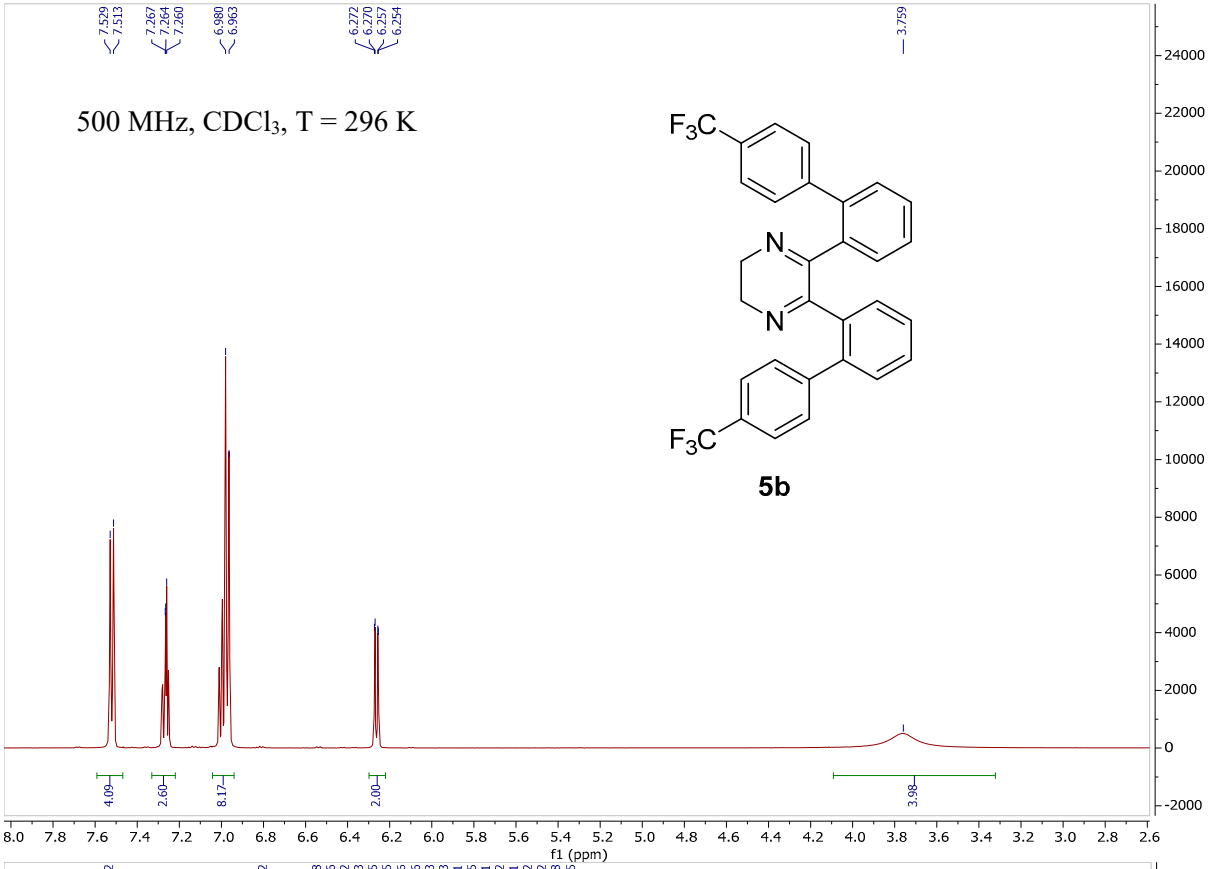


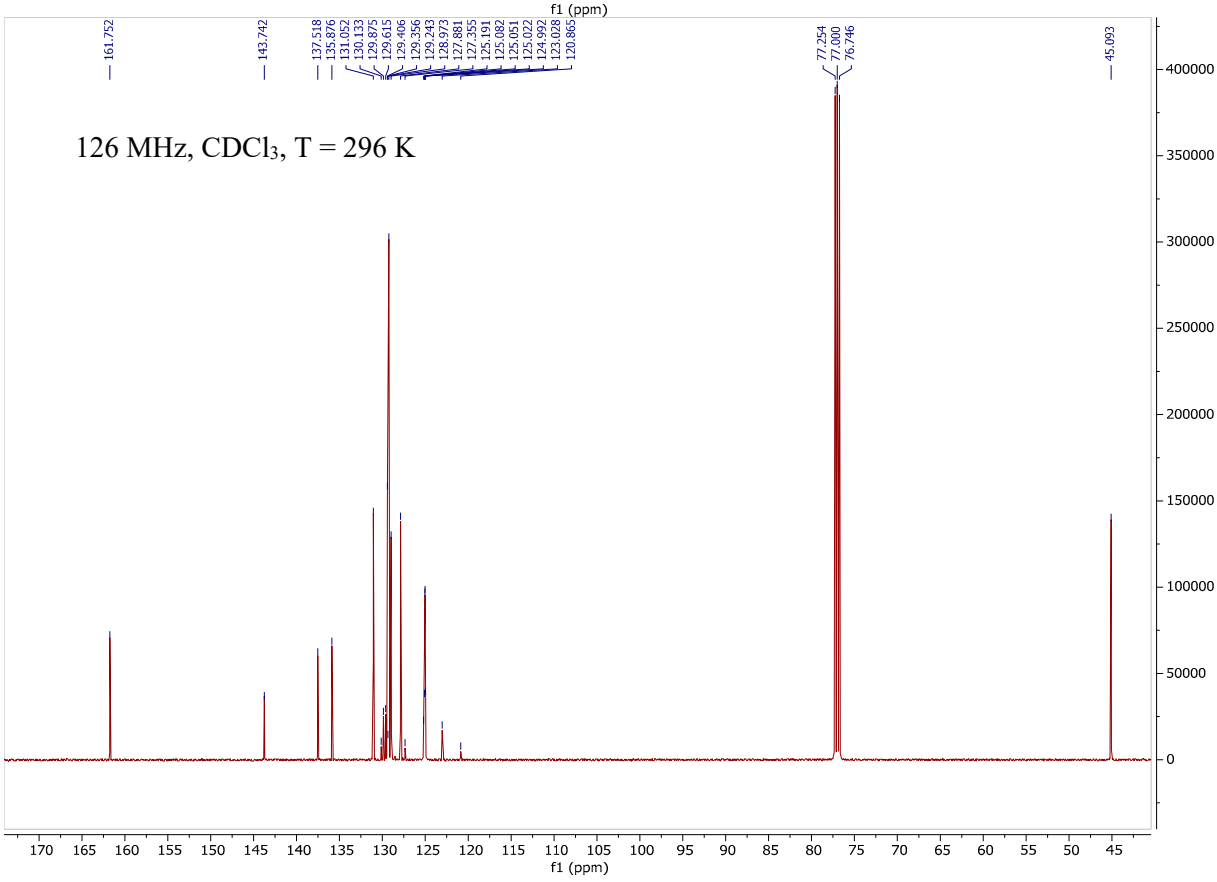
1,1'-((5,6-dihydropyrazine-2,3-diyl)bis([1,1'-biphenyl]-2',4-diyl))bis(ethan-1-one) (5a)



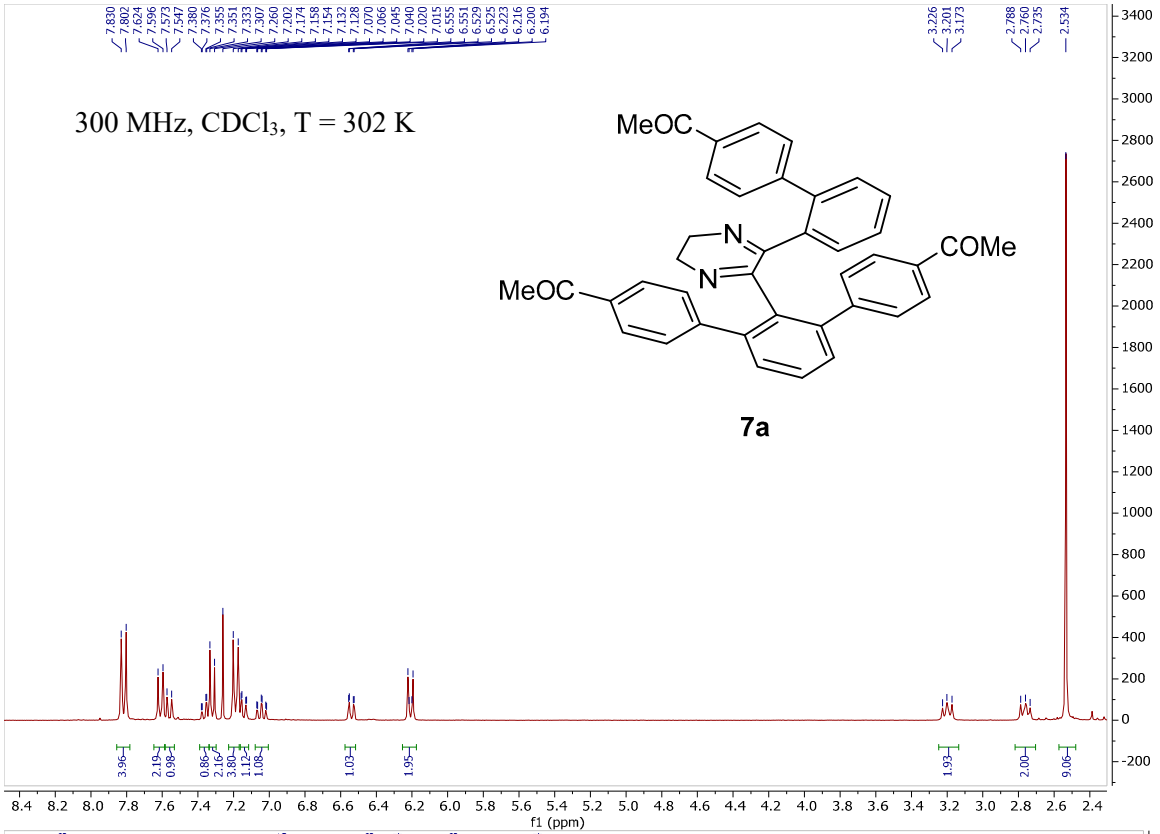


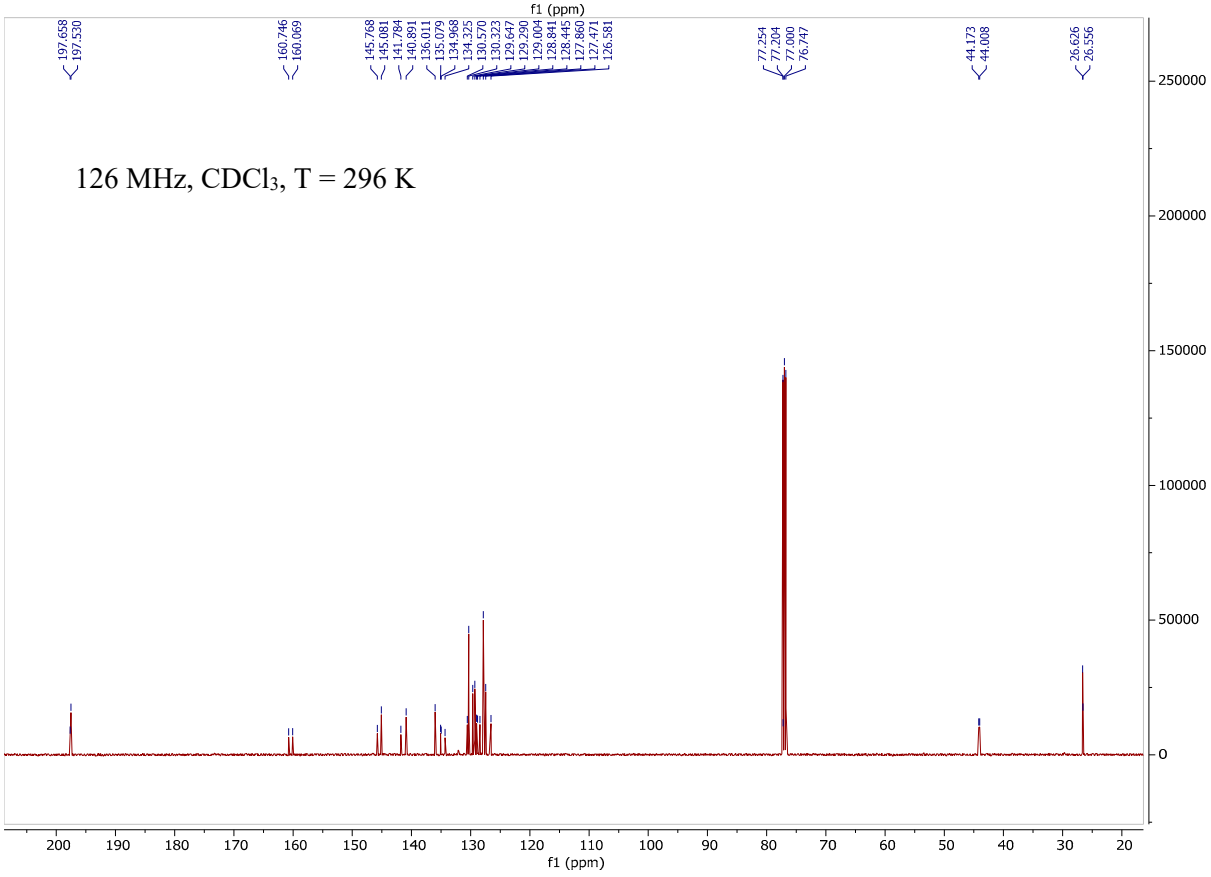
5,6-bis(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)-2,3-dihydropyrazine (5b)



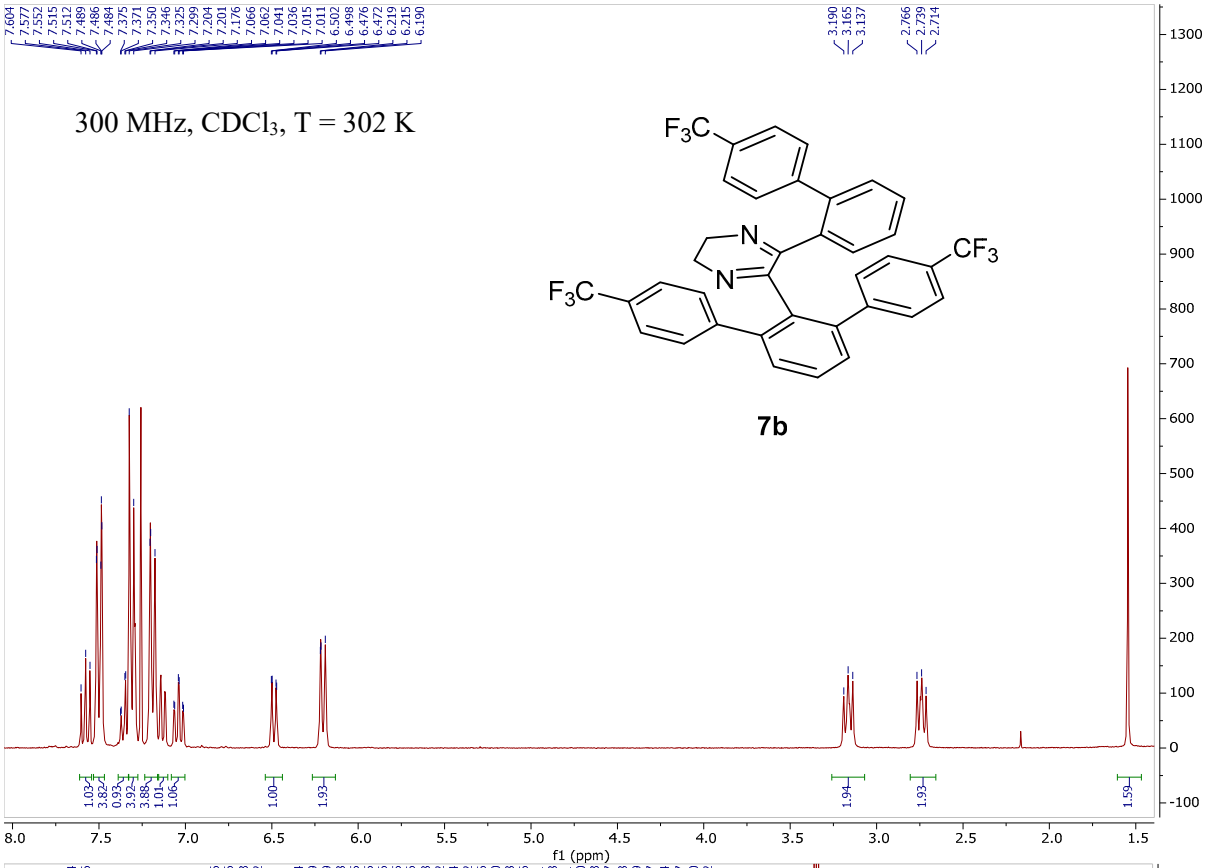


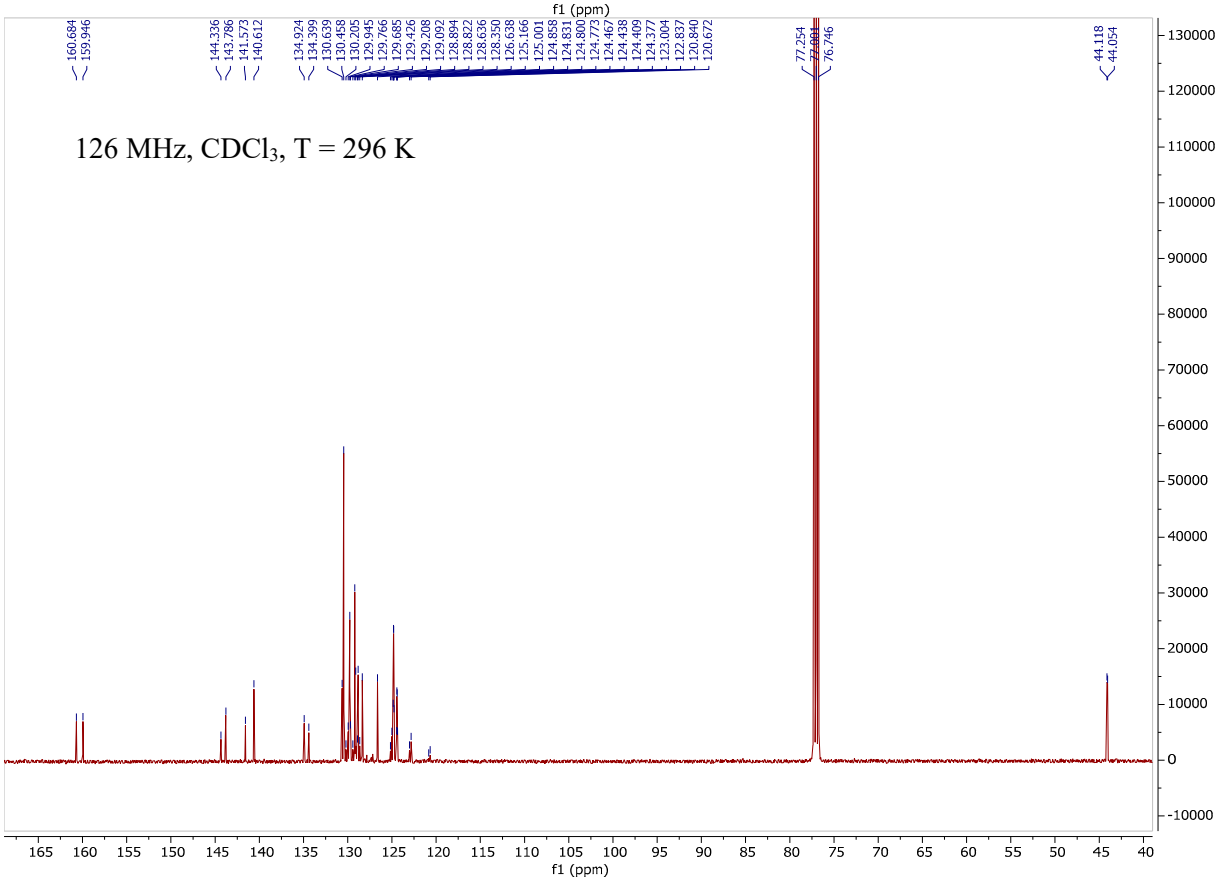
1,1'-(2'-(3-(4'-acetyl-[1,1'-biphenyl]-2-yl)-5,6-dihydropyrazin-2-yl)-[1,1':3',1''terphenyl]4,4''-diyl)bis(ethan-1-one) (7a)



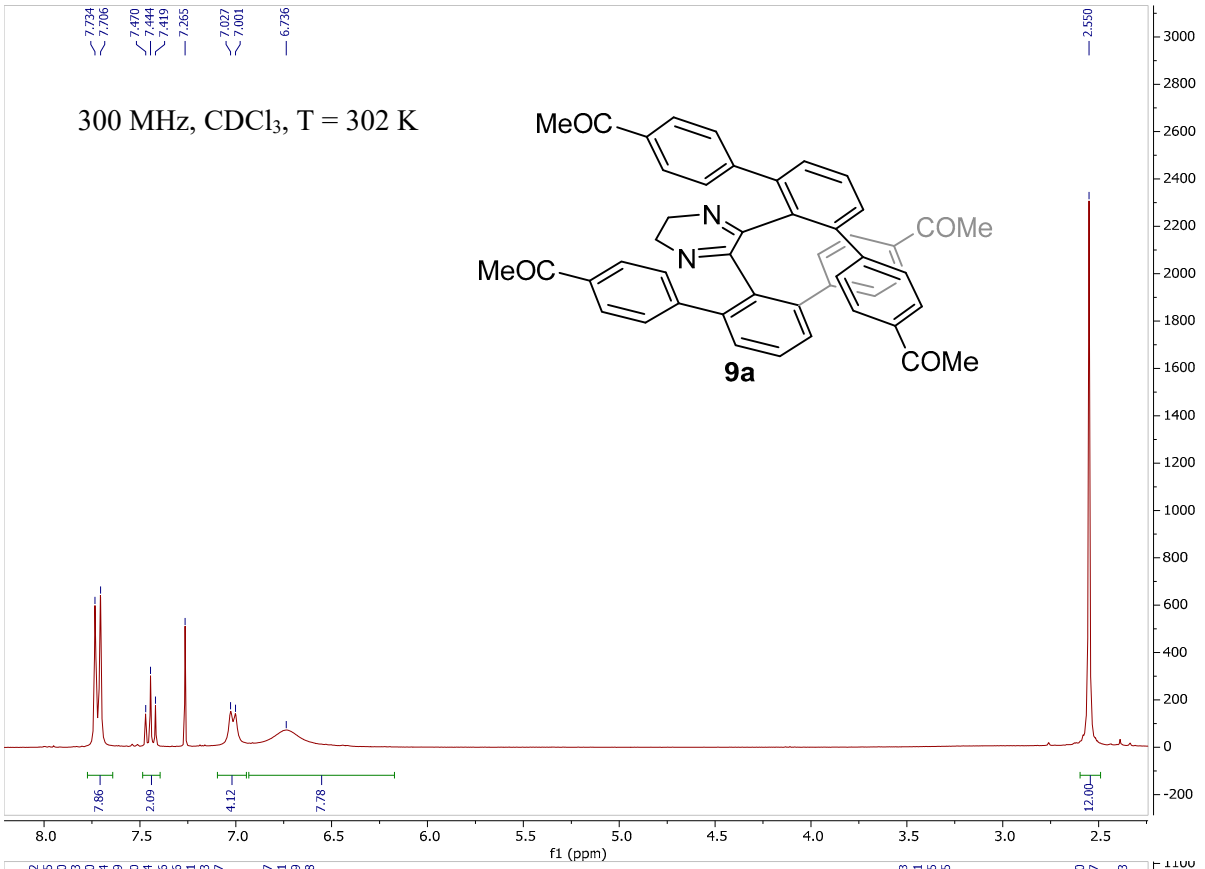


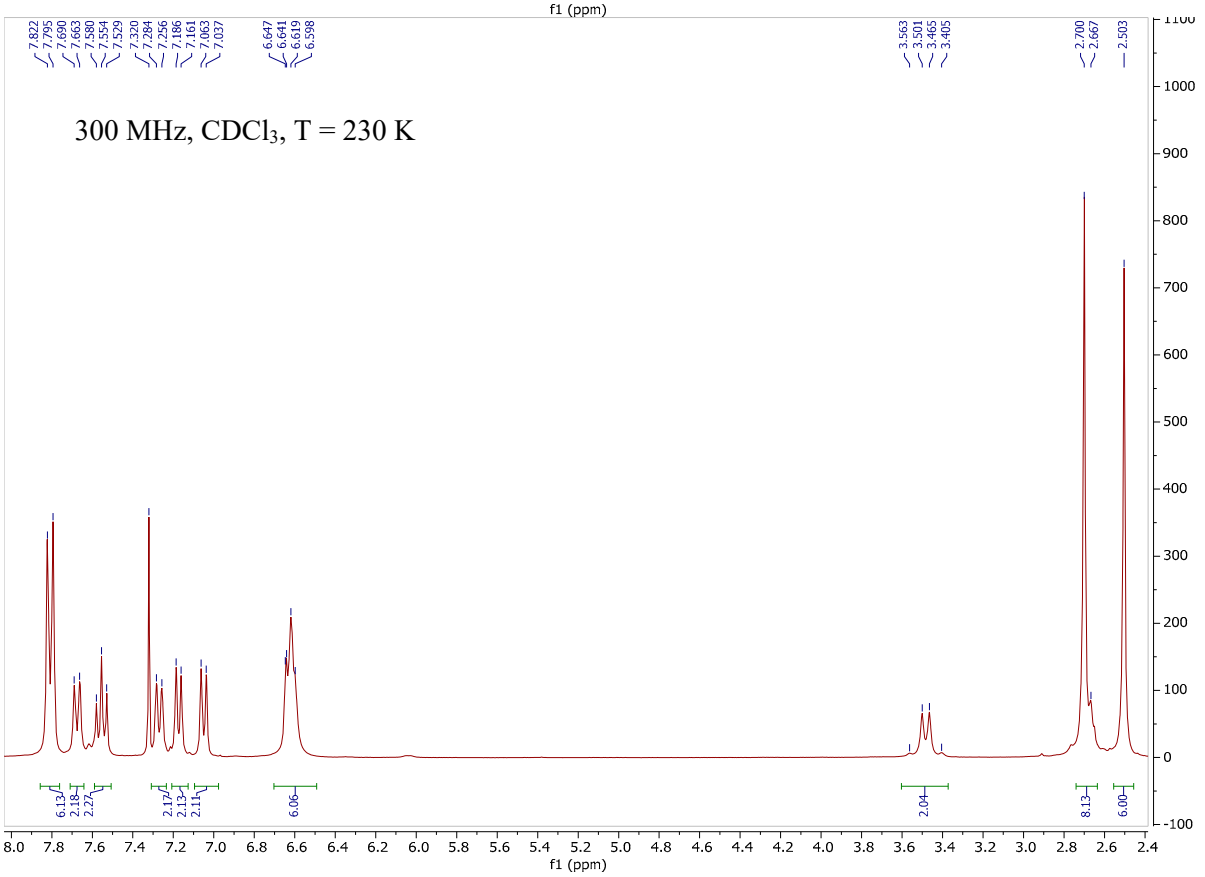
5-(4,4''-bis(trifluoromethyl)-[1,1':3',1''-terphenyl]-2'-yl)-6-(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)-2,3-dihydropyrazine (7b)

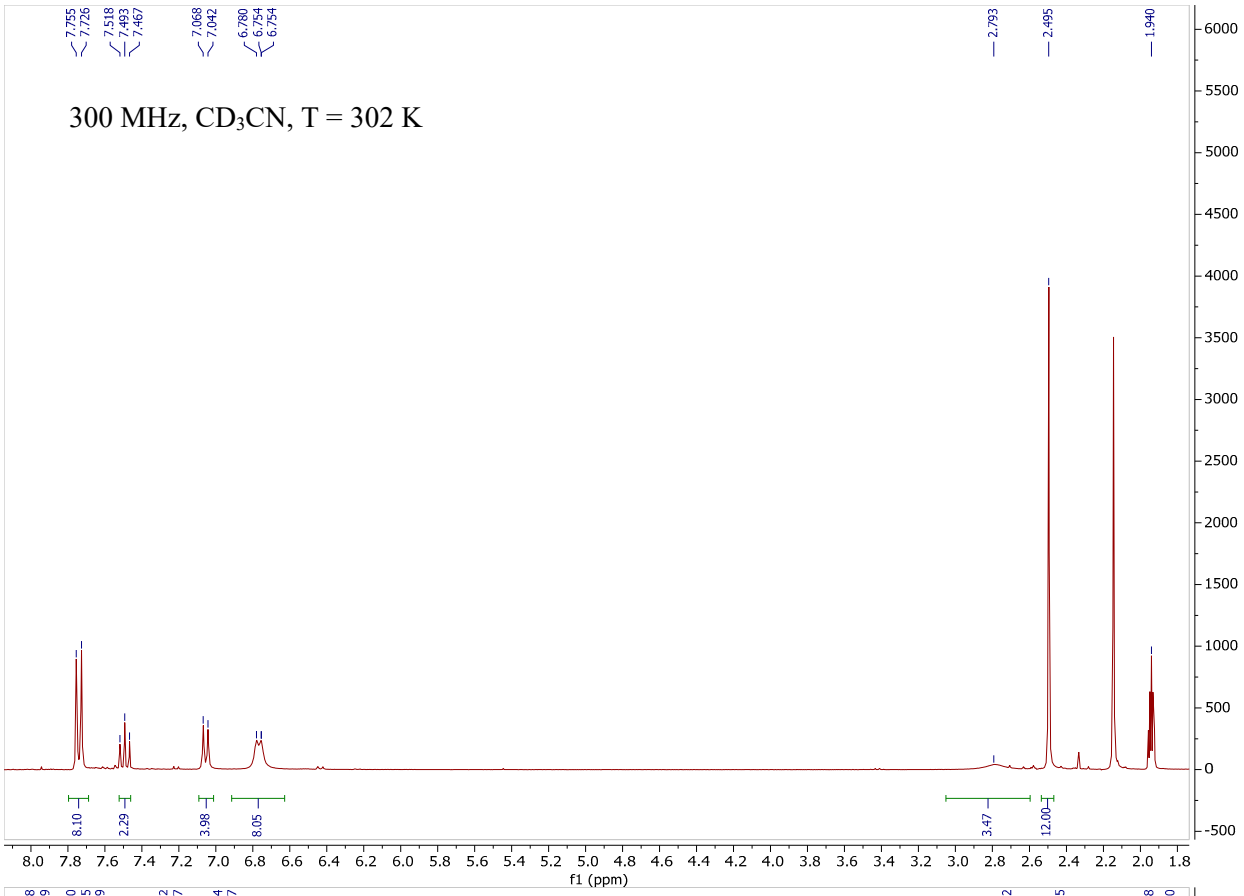




1,1',1'',1'''-((5,6-dihydropyrazine-2,3-diyl)bis([1,1':3',1''-terphenyl]-2',4,4''-triyl))tetrakis(ethan-1-one) (9a)



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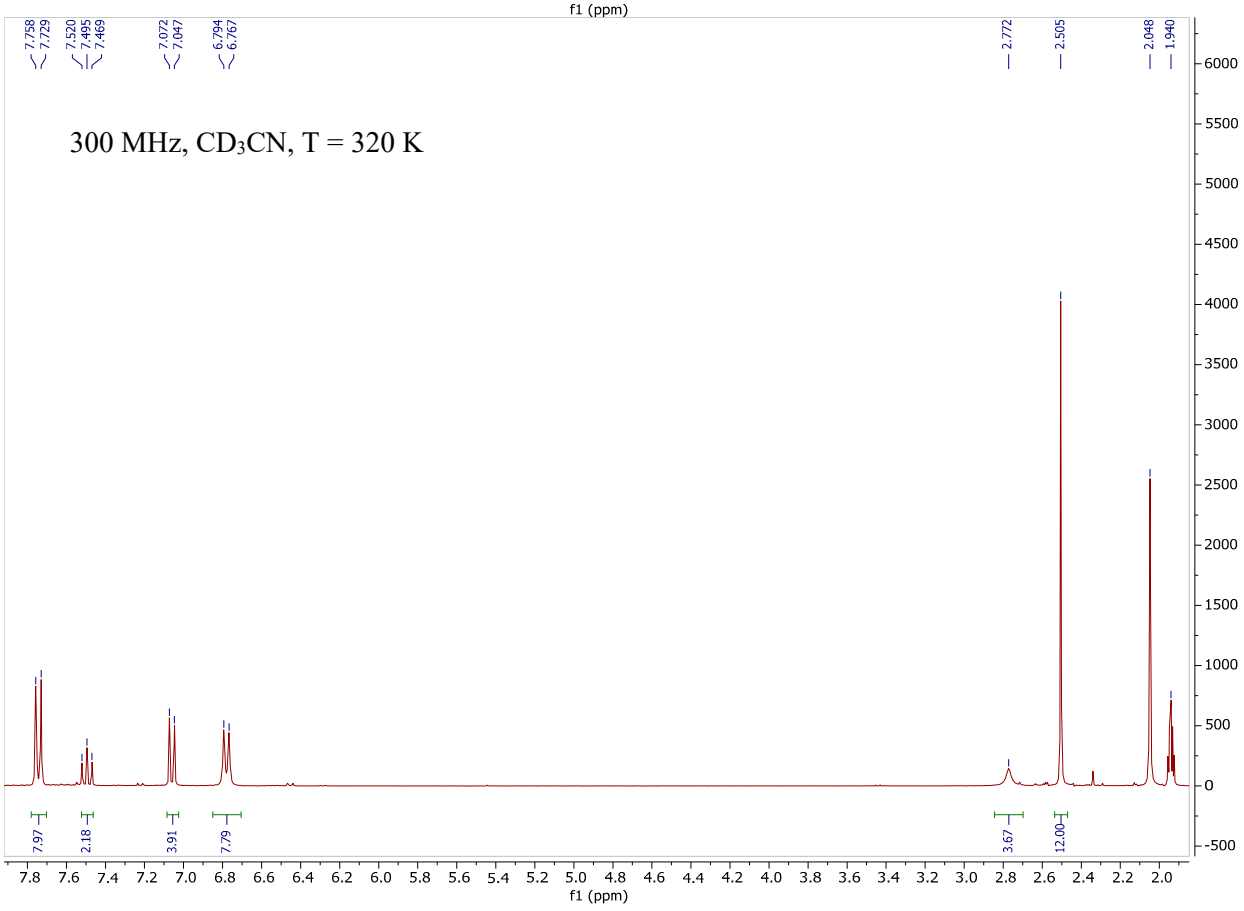
7.726
7.518
7.493
7.467
7.068
7.042
6.780
6.754
6.754
2.793
2.495
1.940
300 MHz, CD3CN, T = 302 K
8.10
2.29
3.98
8.05
3.47
12.00
f1 (ppm)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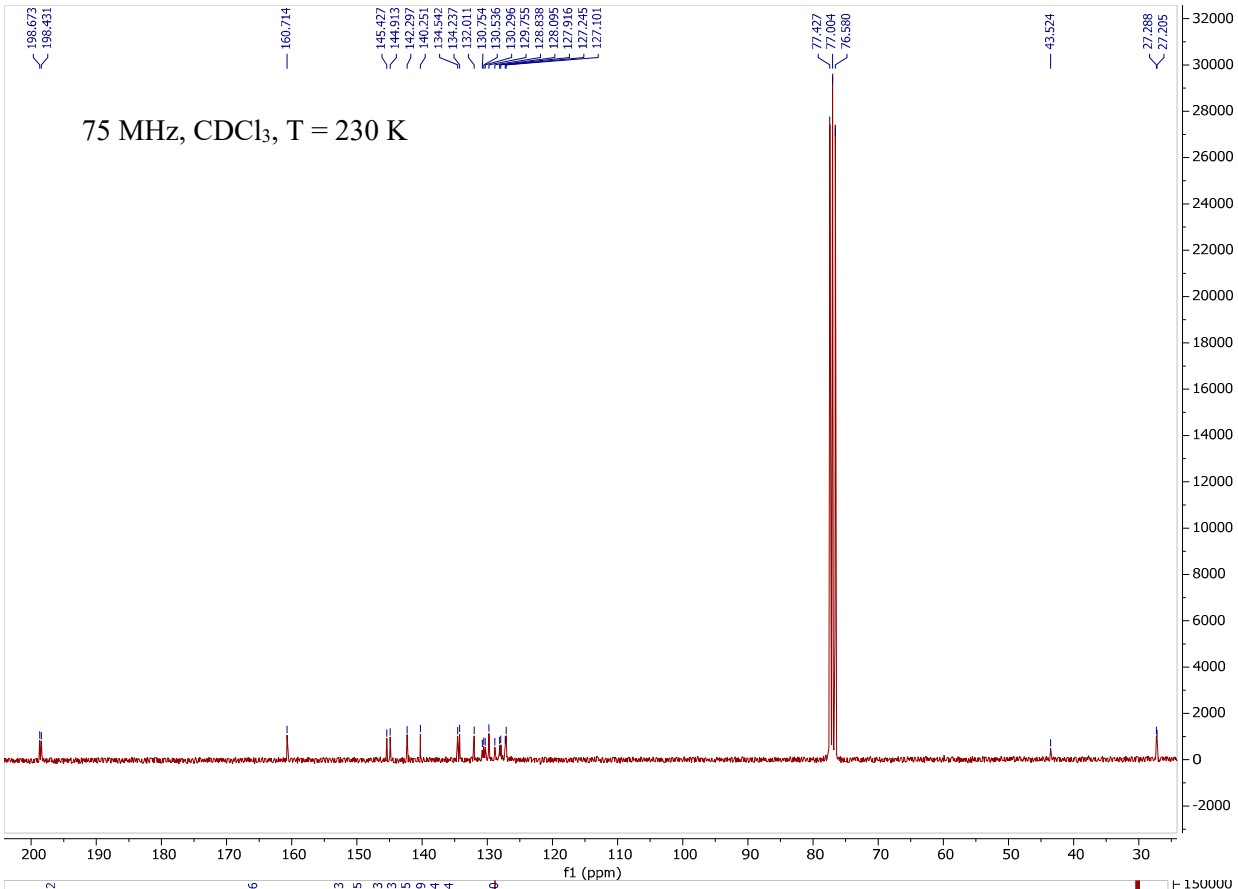
7.729
7.520
7.495
7.469
7.072
7.047
6.794
6.767
2.772
2.505
2.048
1.940
300 MHz, CD3CN, T = 320 K
7.97
2.18
3.91
7.79
3.67
12.00
f1 (ppm)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198.431
160.714
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144.913
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140.251
134.542
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132.011
130.754
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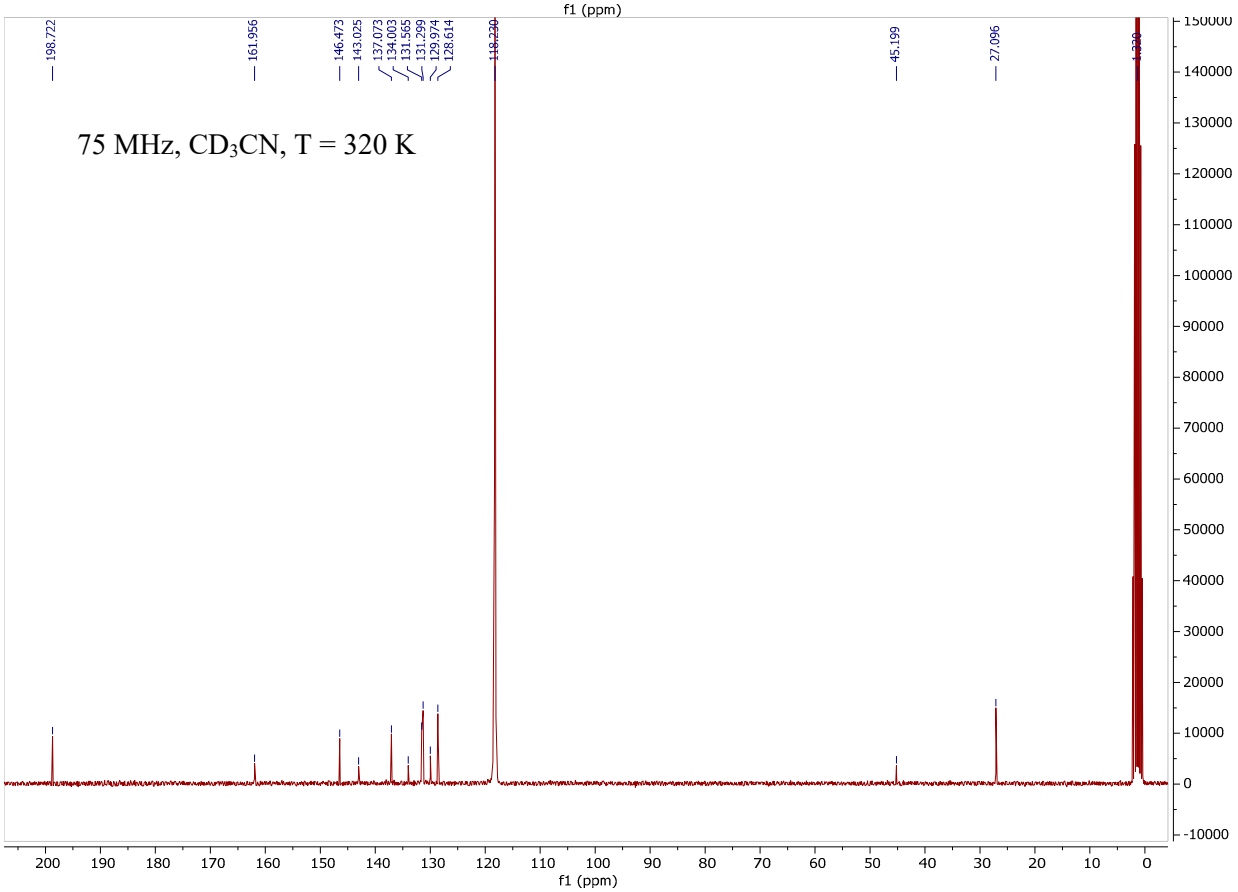
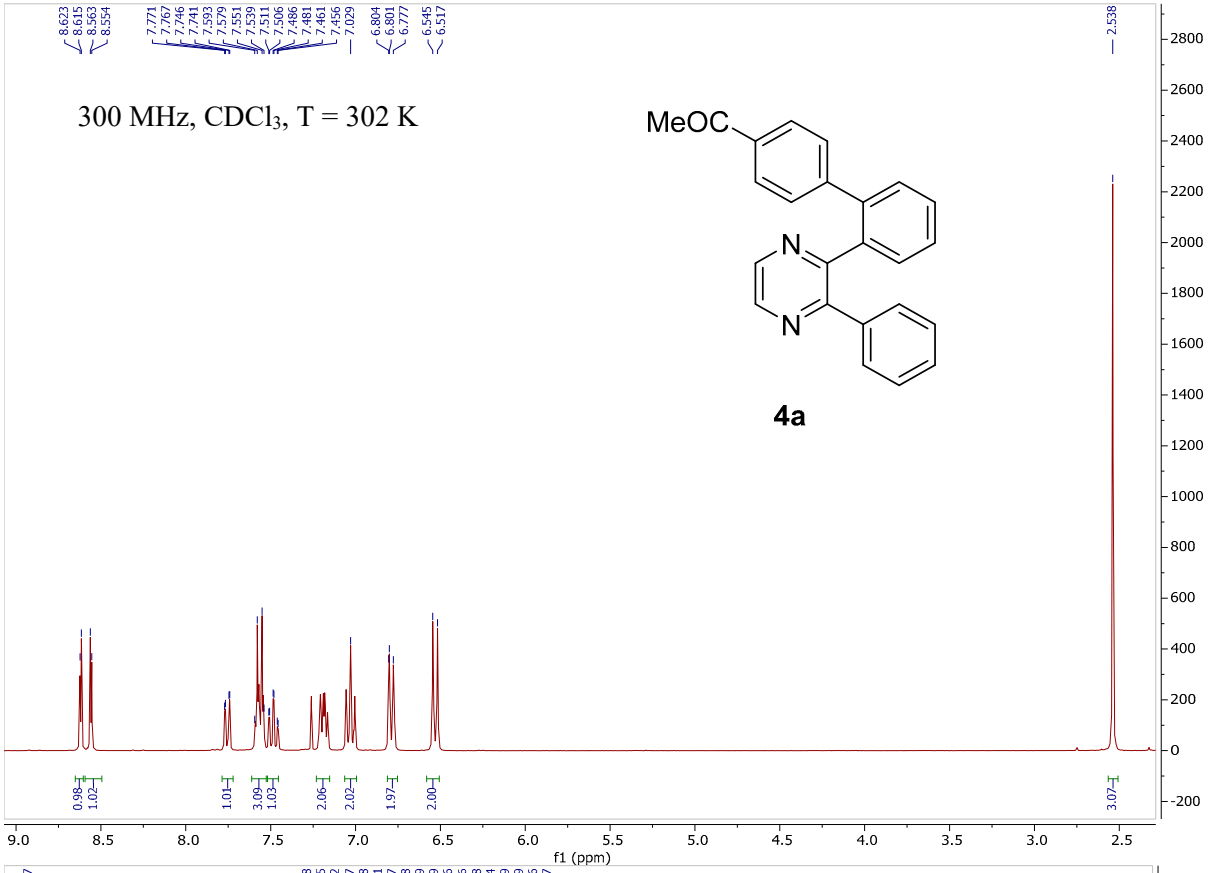
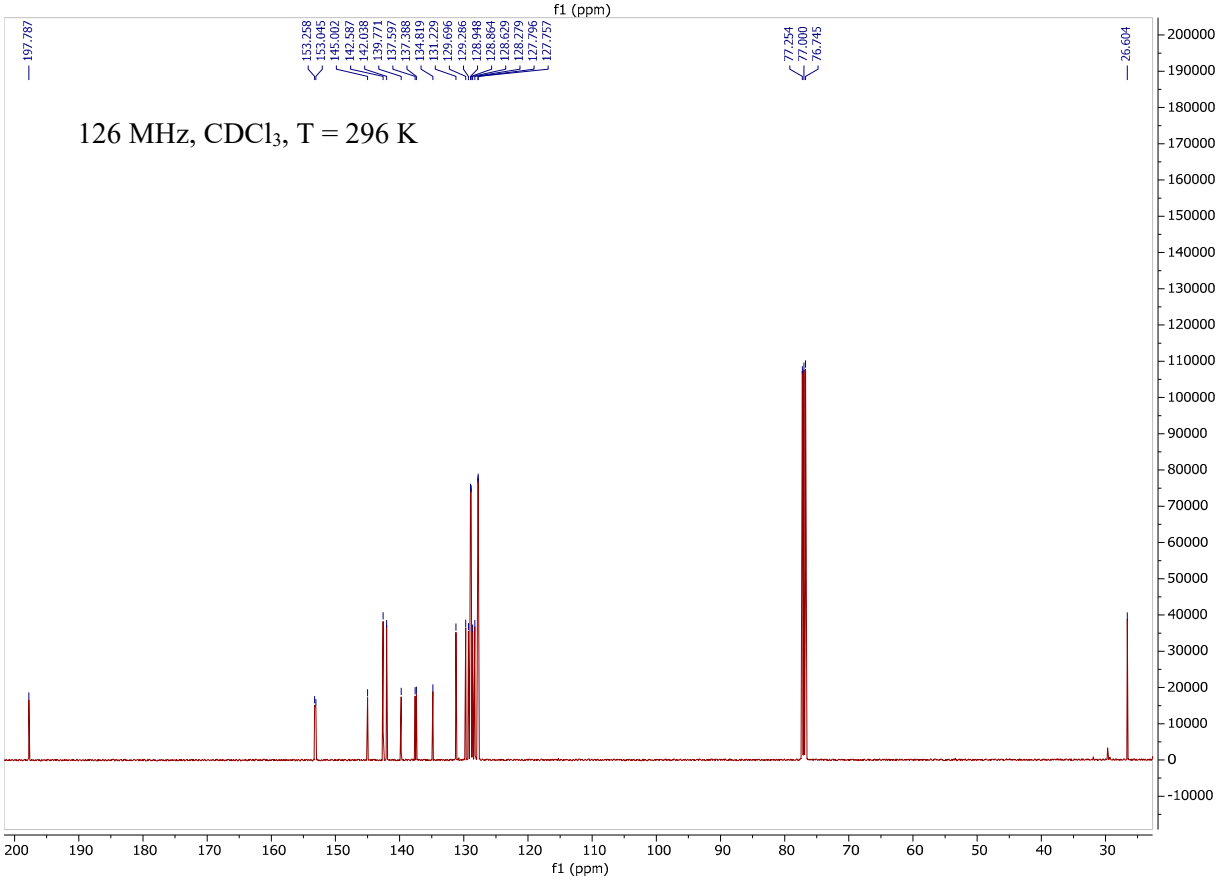
130.296
129.755
128.838
128.095
127.916
127.245
127.101
77.427
77.004
76.580
43.524
27.288
27.205
75 MHz, CDCl3, T = 230 K
f1 (ppm)

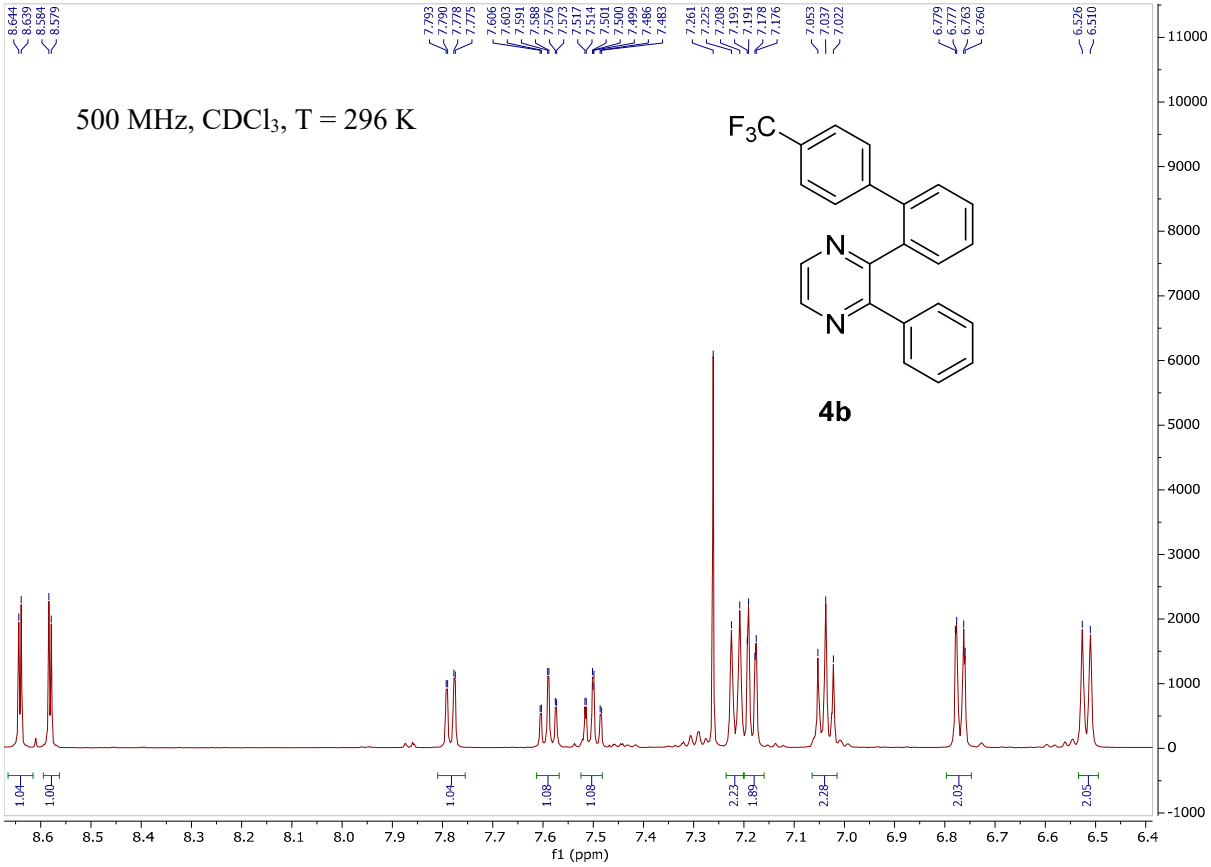

198.722
161.956
146.473
143.025
137.073
134.003
131.565
131.299
129.974
128.614
118.230
45.199
27.096
1.330
75 MHz, CD3CN, T = 320 K
f1 (ppm)

1-(2'-(3-phenylpyrazin-2-yl)-[1,1'-biphenyl]-4-yl)ethan-1-one (4a)

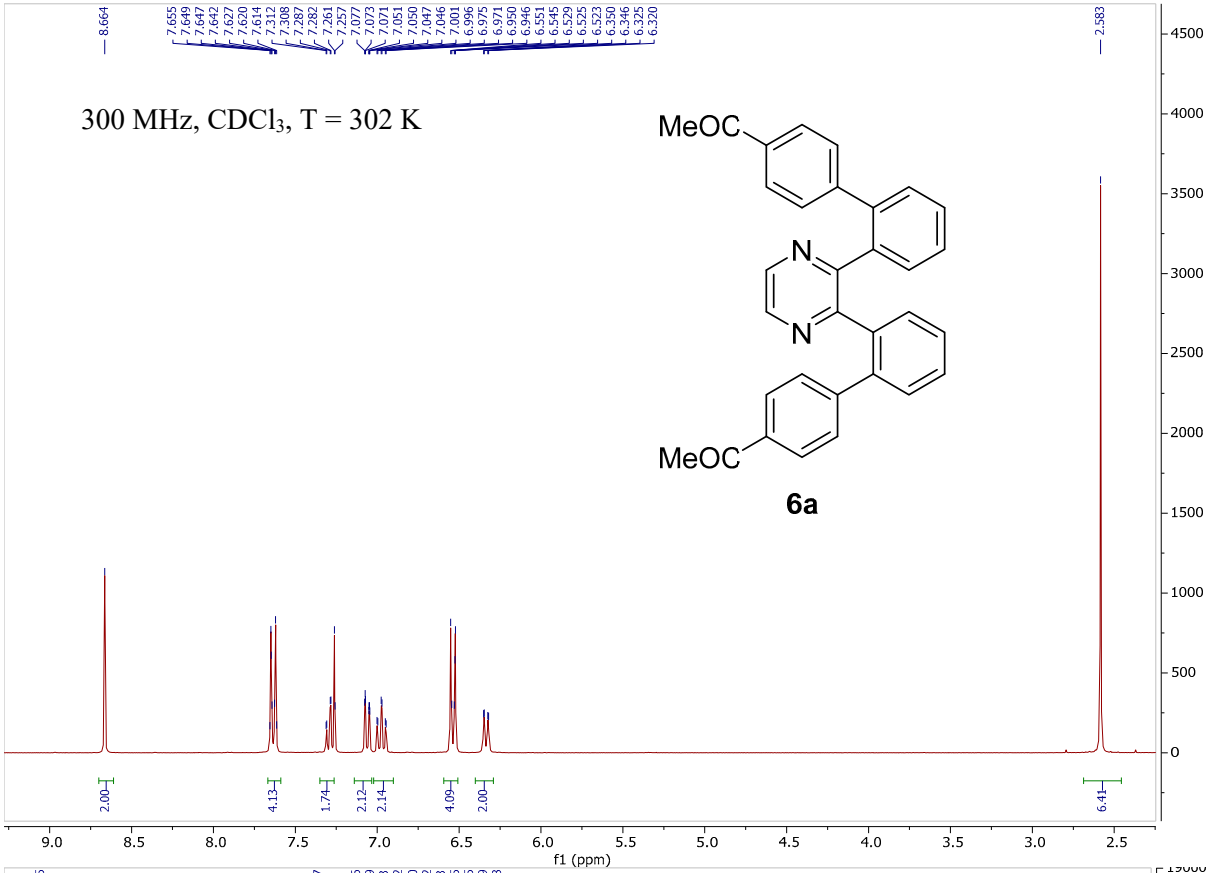


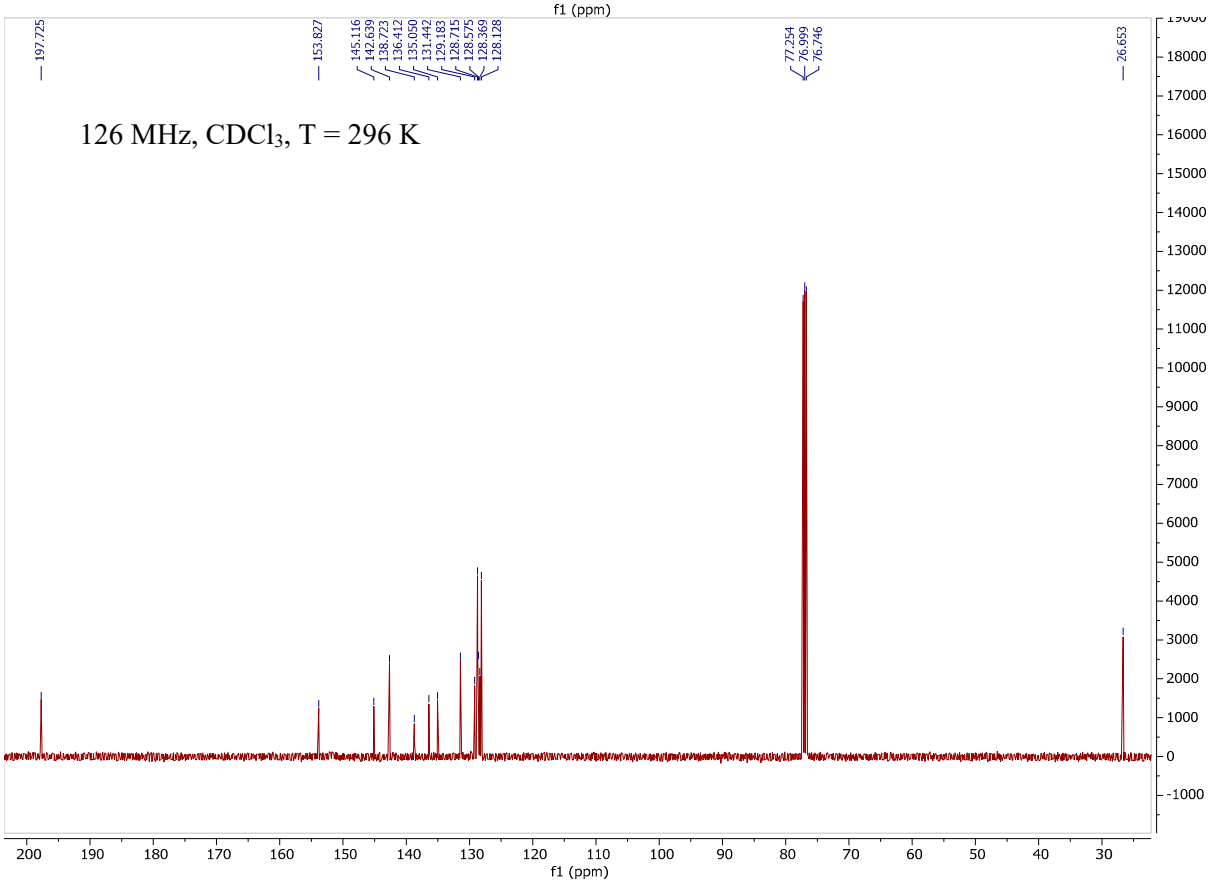


2-phenyl-3-(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)pyrazine (4b)

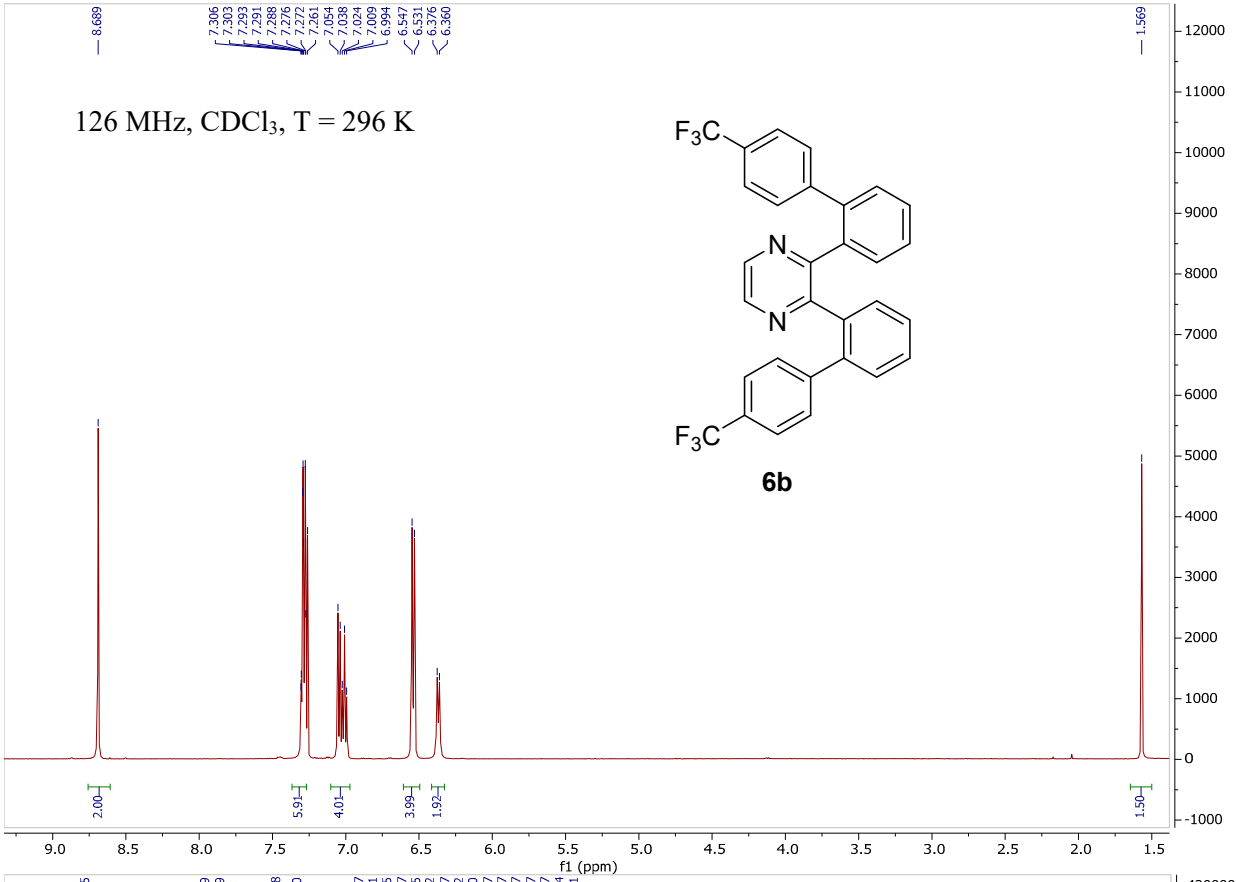


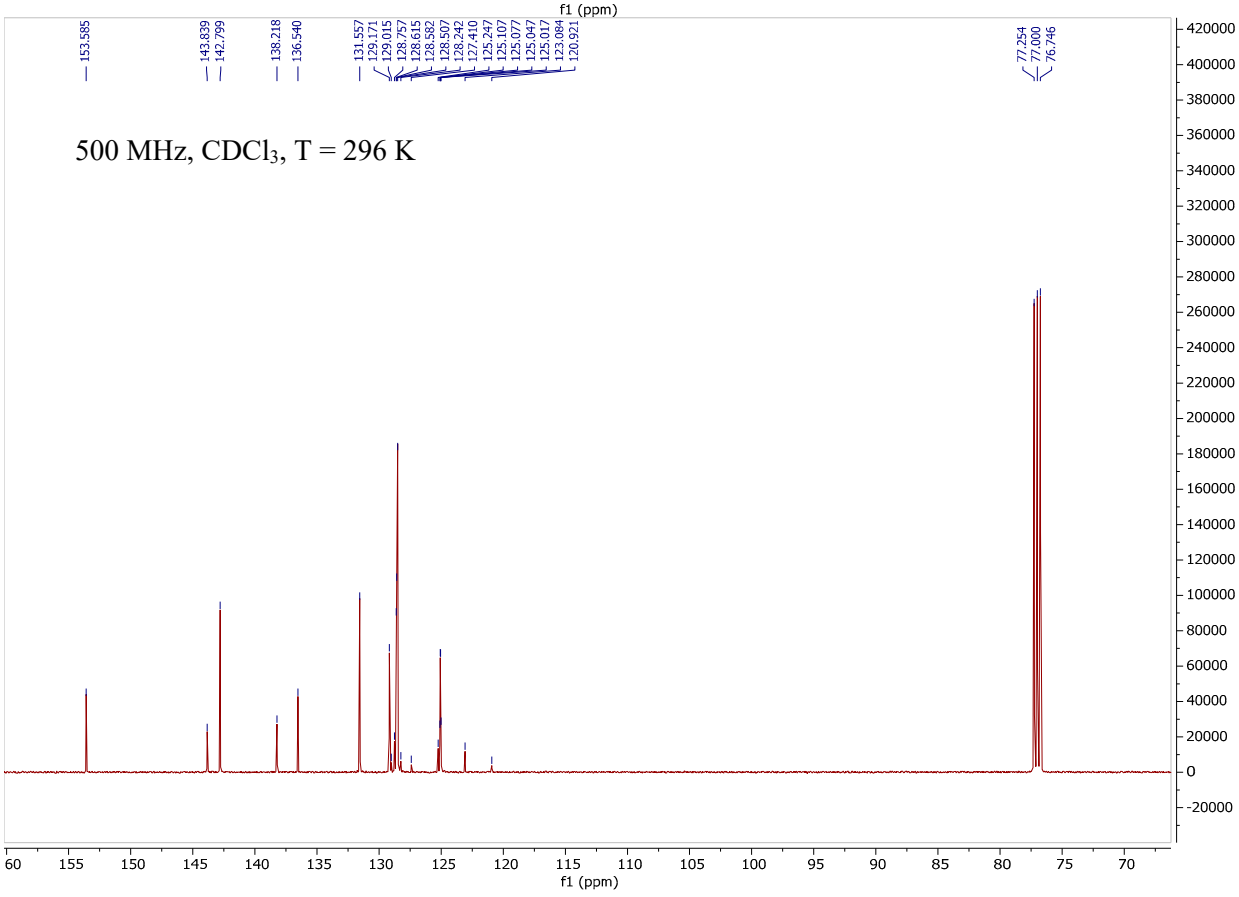
1,1'-(pyrazine-2,3-diylbis([1,1'-biphenyl]-2',4-diyl))bis(ethan-1-one) (6a)



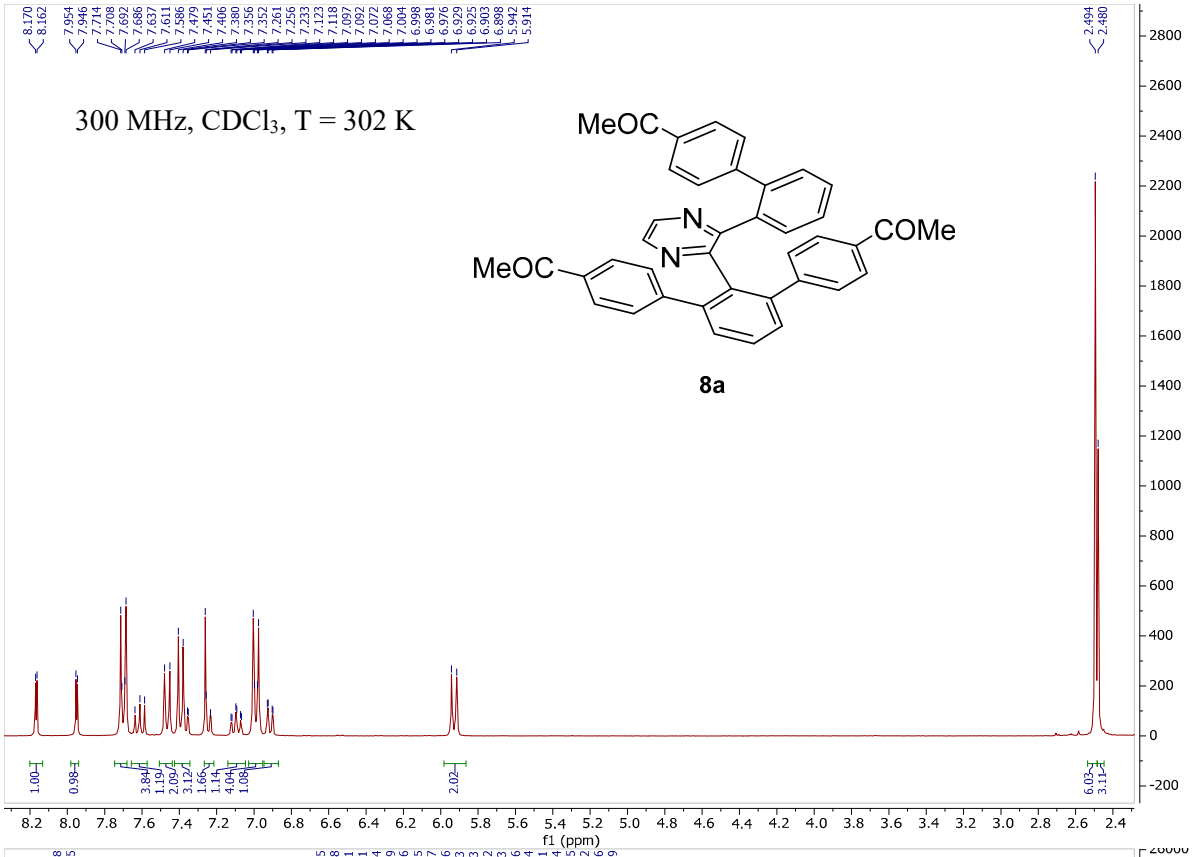


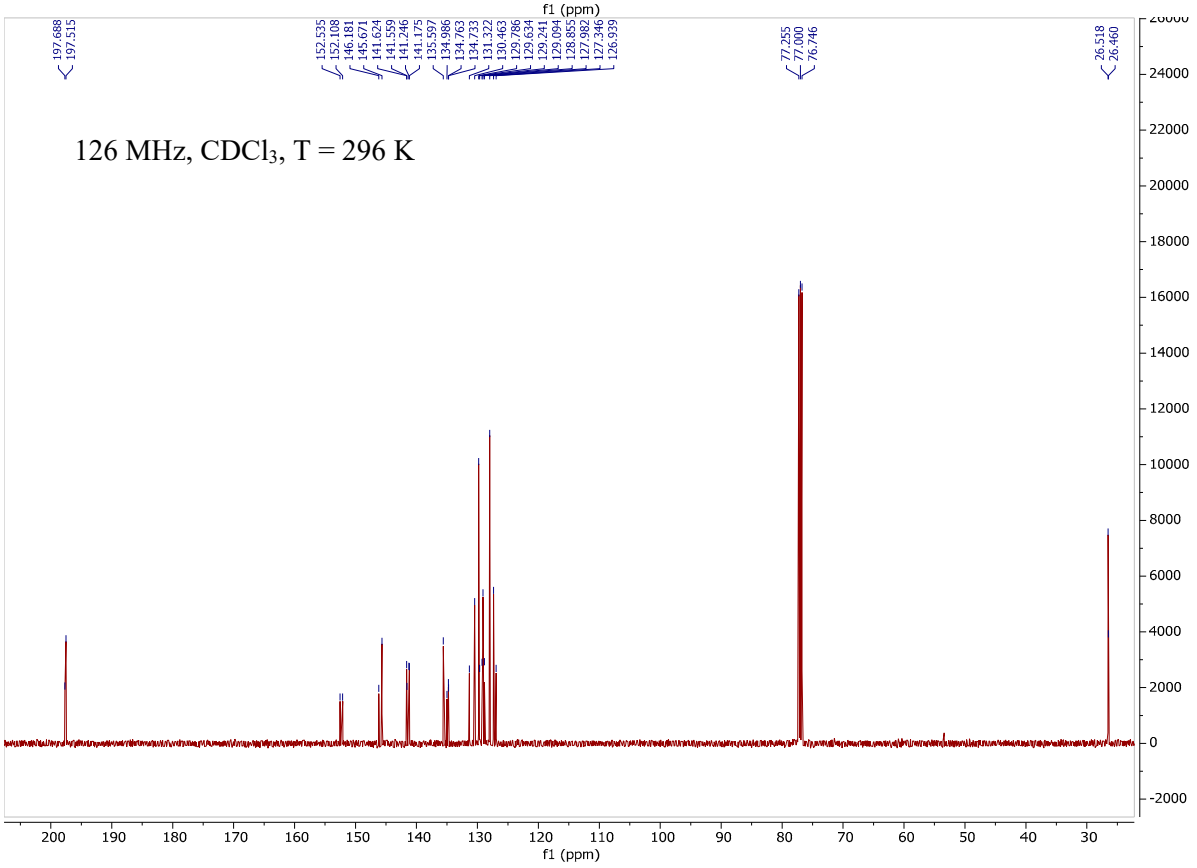
2,3-bis(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)pyrazine (6b)



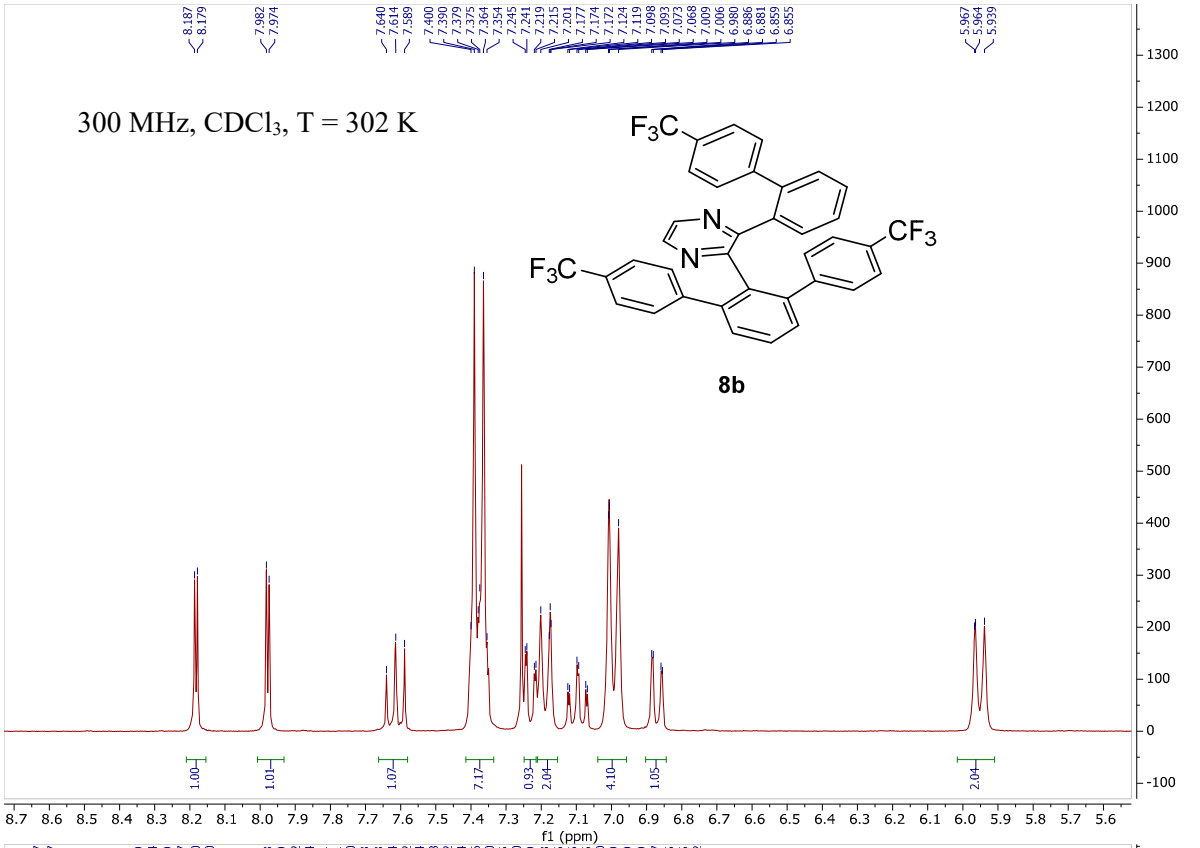


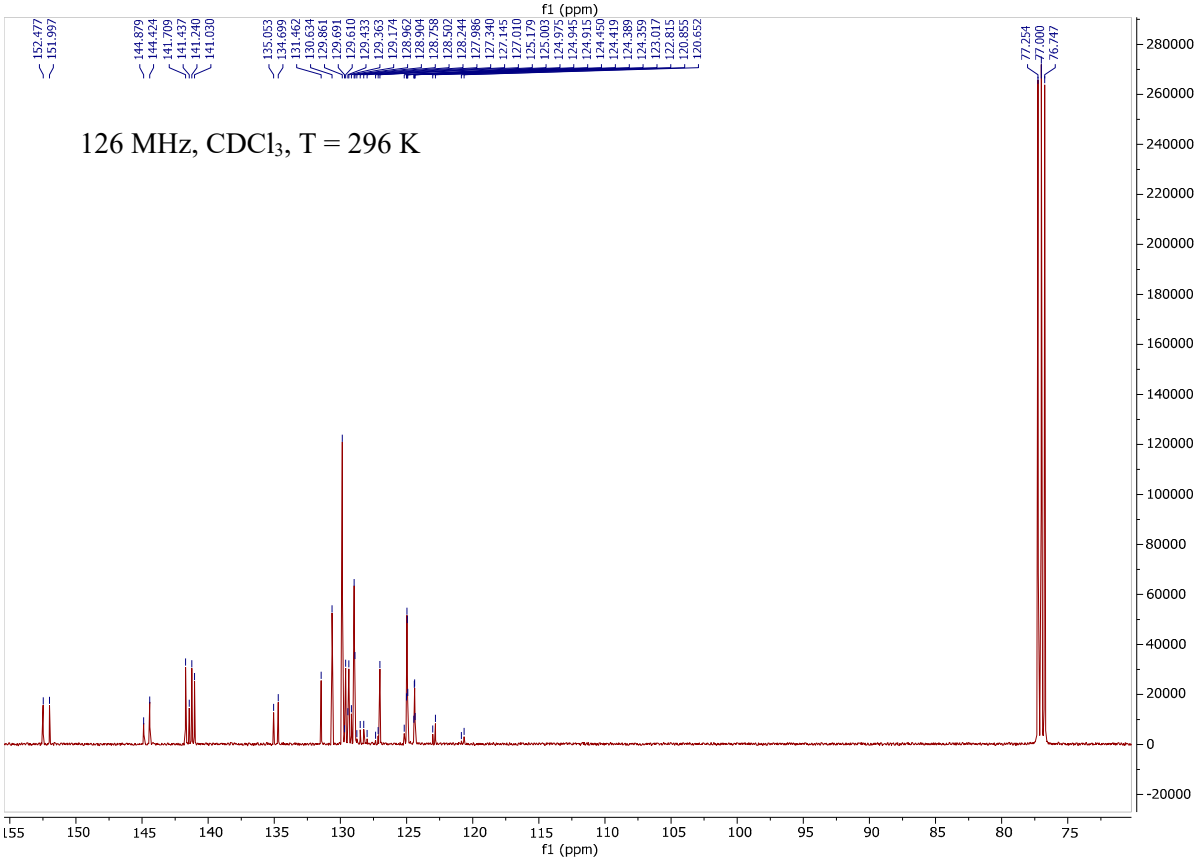
1,1'-(2'-(3-(4'-acetyl-[1,1'-biphenyl]-2-yl)pyrazin-2-yl)-[1,1':3',1''-terphenyl]-4,4''-diyl)bis(ethan-1-one) (8a)



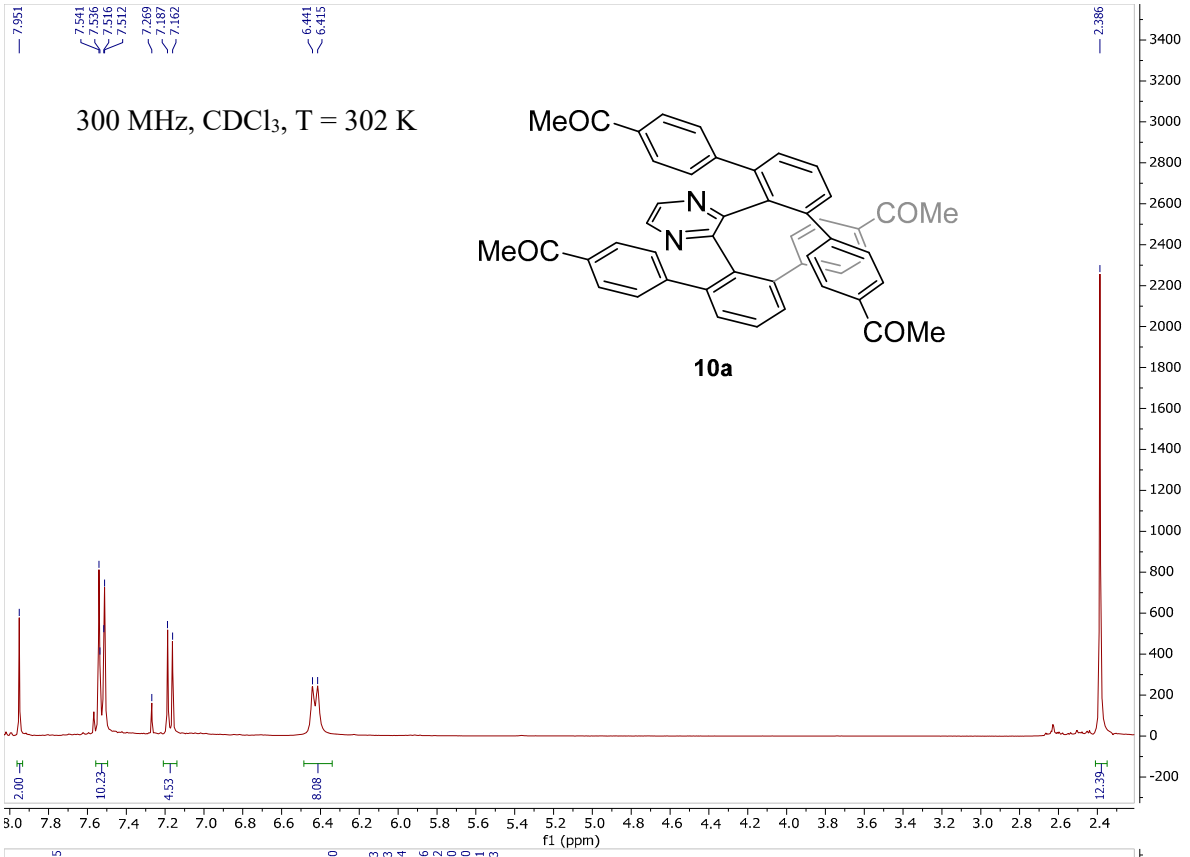


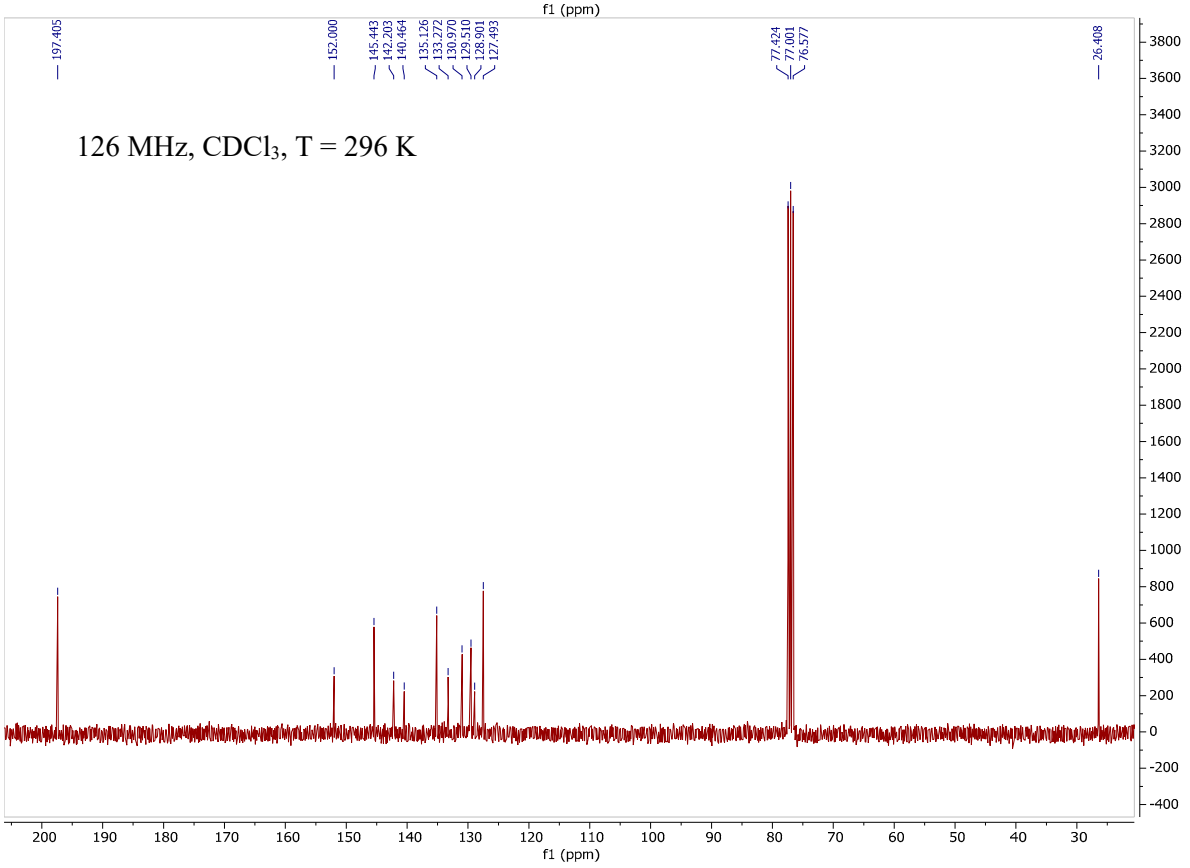
2-(4,4''-bis(trifluoromethyl)-[1,1':3',1''-terphenyl]-2'-yl)-3-(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)pyrazine (8b)



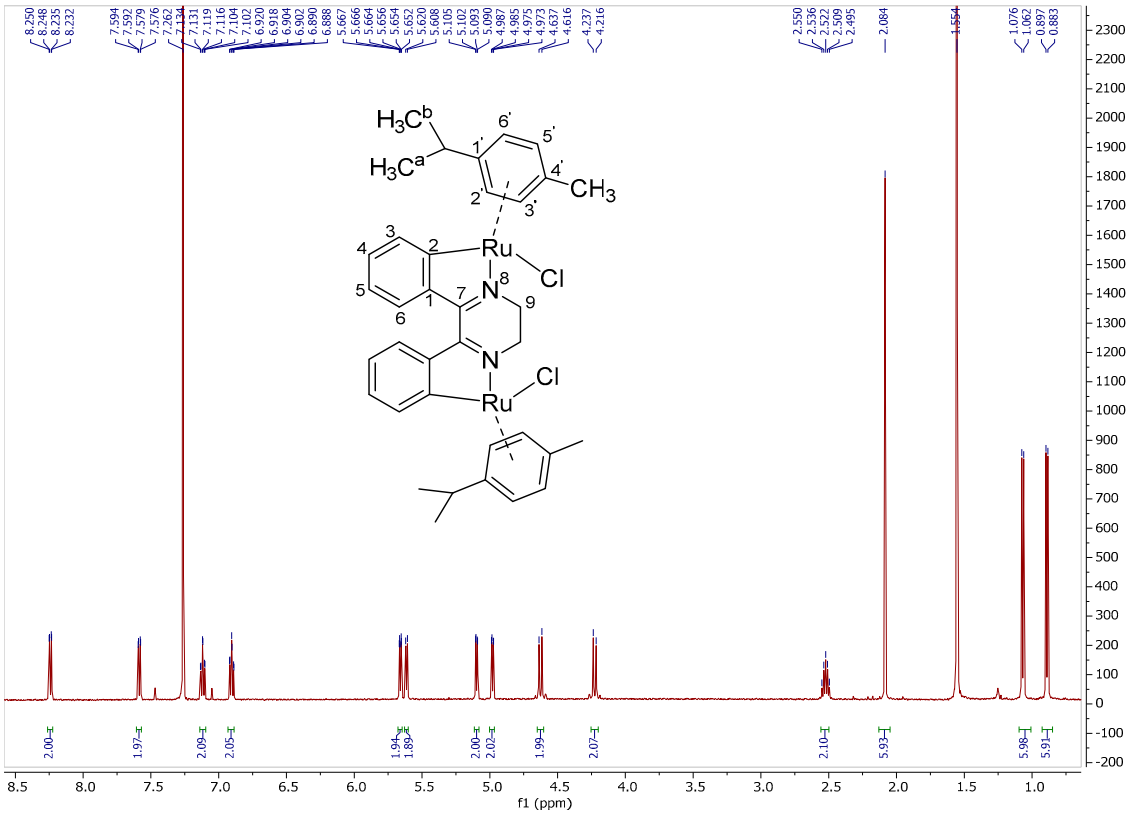


1,1',1'',1'''-(pyrazine-2,3-diylbis([1,1':3',1''-terphenyl]-2',4,4''-triyl))tetrakis(ethan-1-one) (10a)

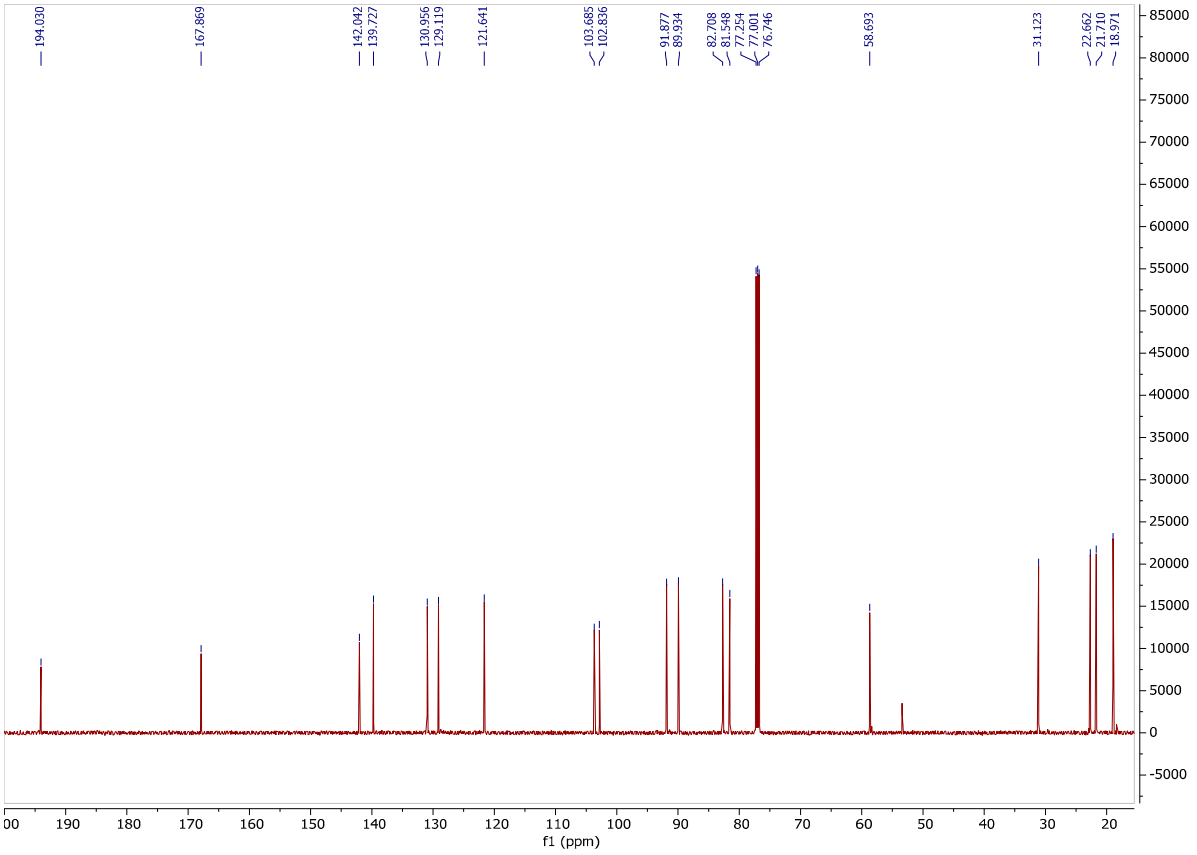




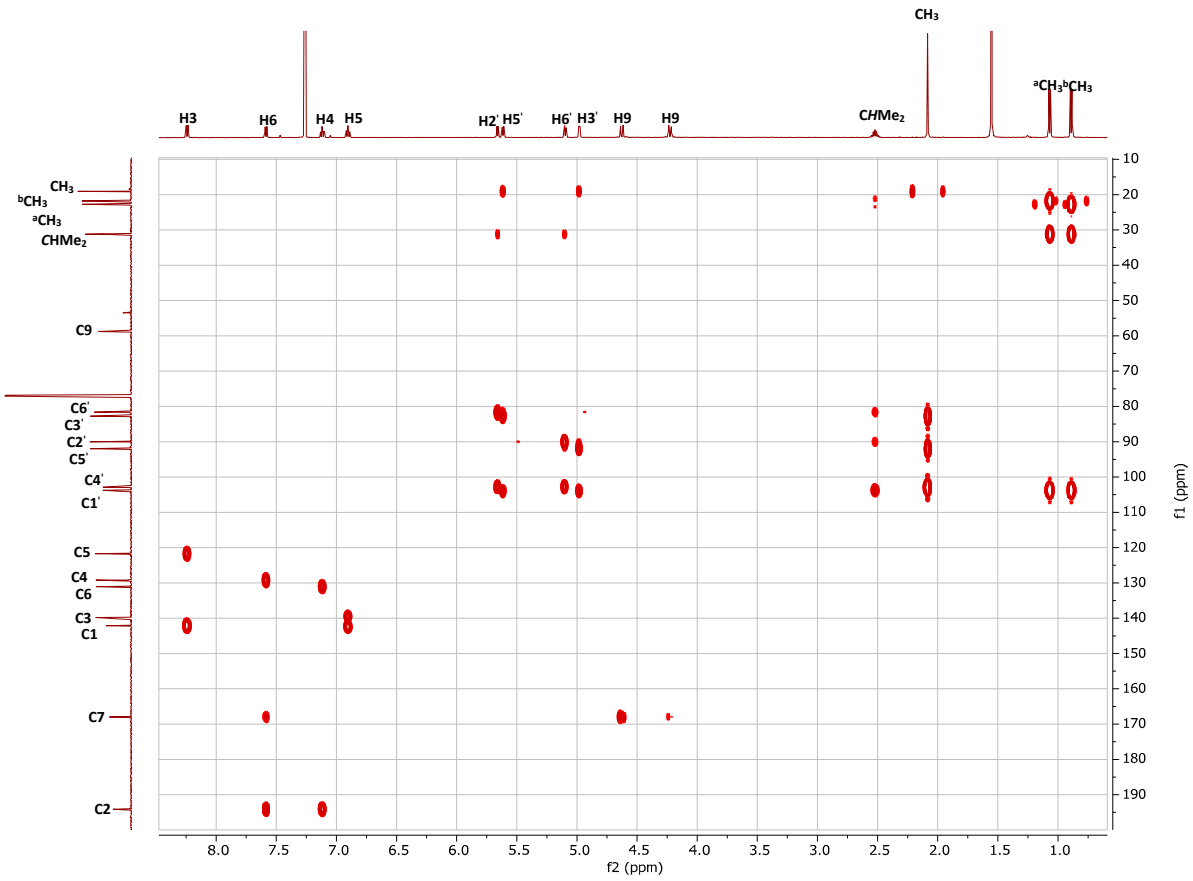
^{1}H NMR of ruthenacycle **11** (500 MHz, 296 K, $CDCl_3$)



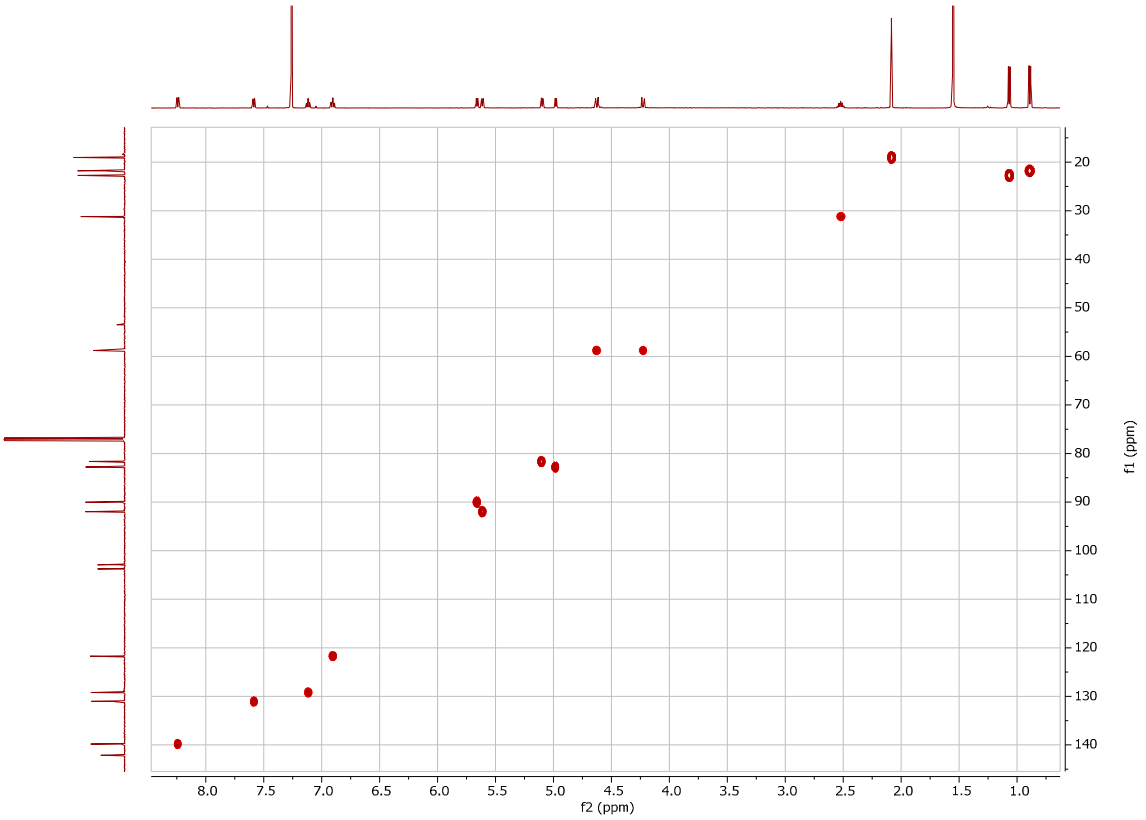
^{13}C NMR of ruthenacycle **11** (126 MHz, 296 K, $CDCl_3$)



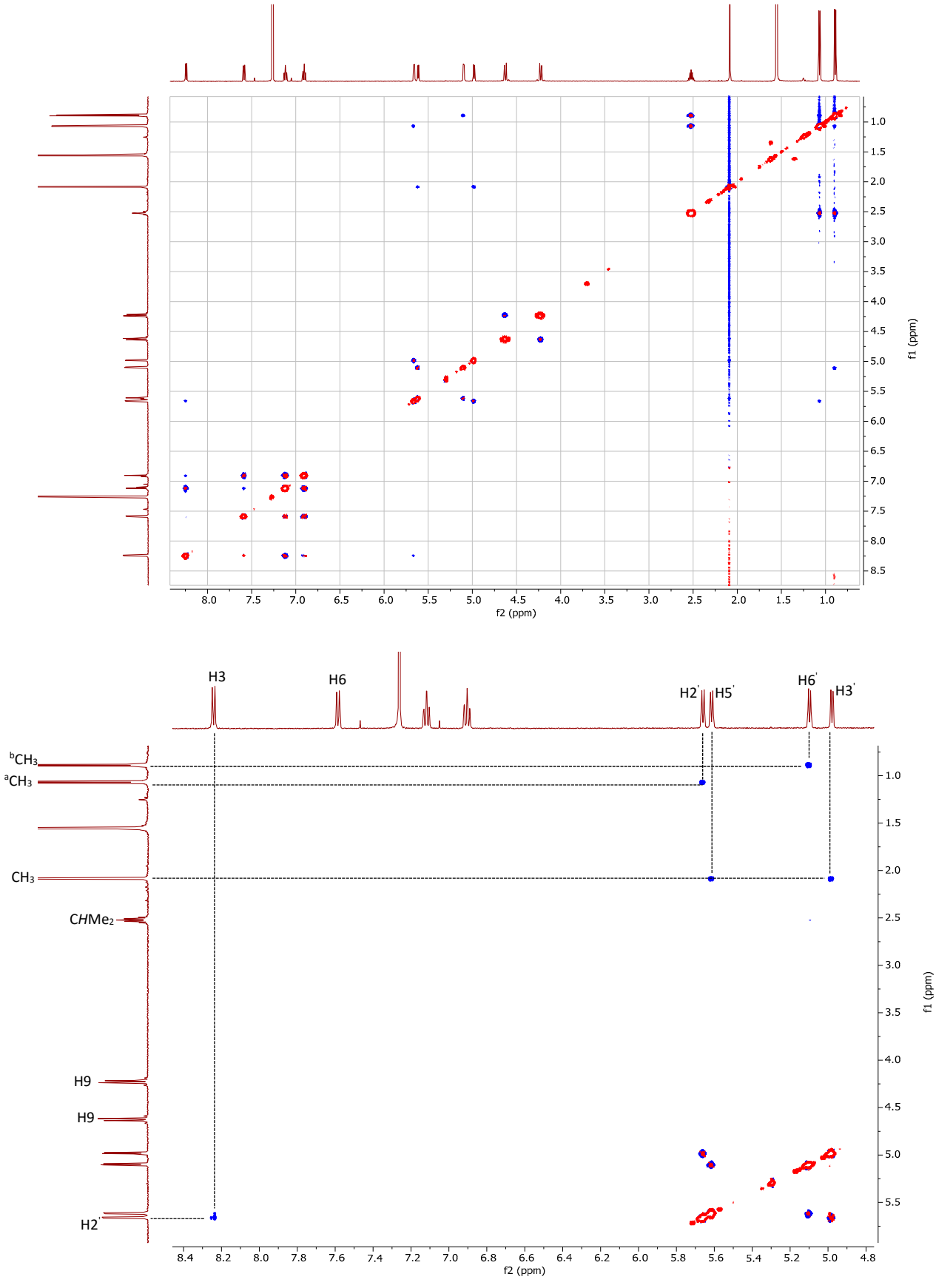
$^{1}H–^{13}C$ HMBC of ruthenacycle **11**



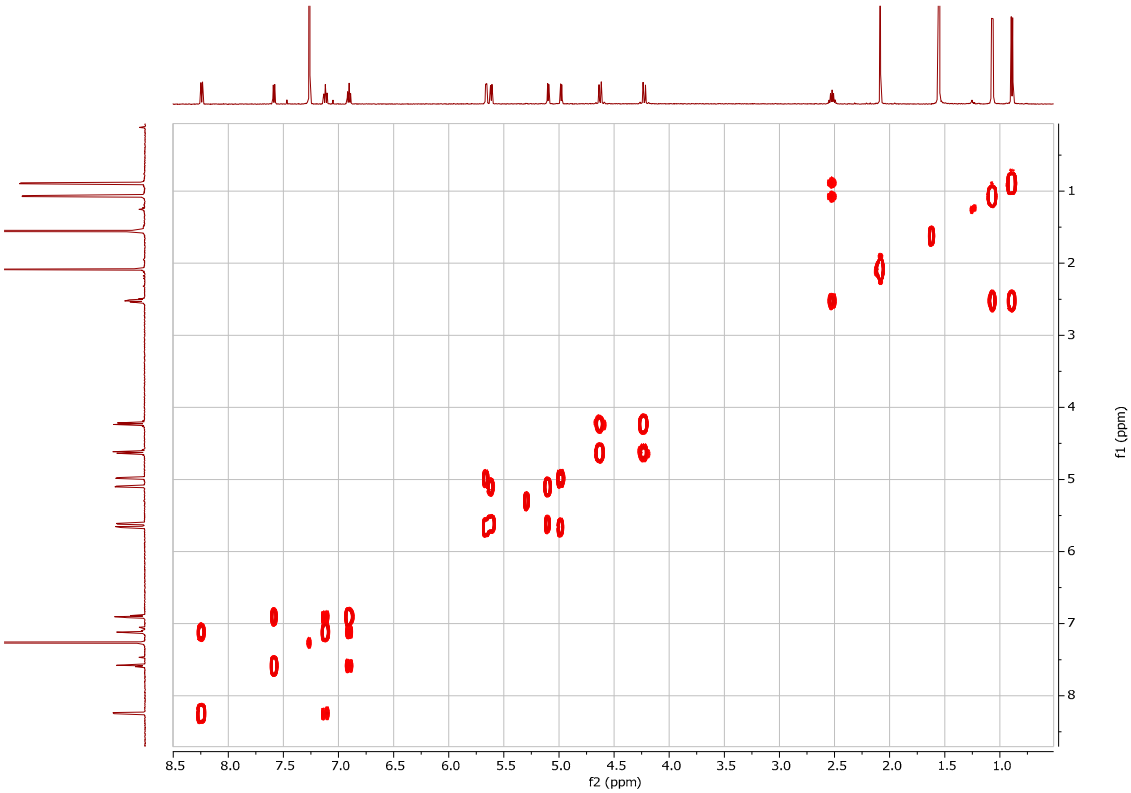
$^{1}H–^{13}C$ HSQC of ruthenacycle **11**



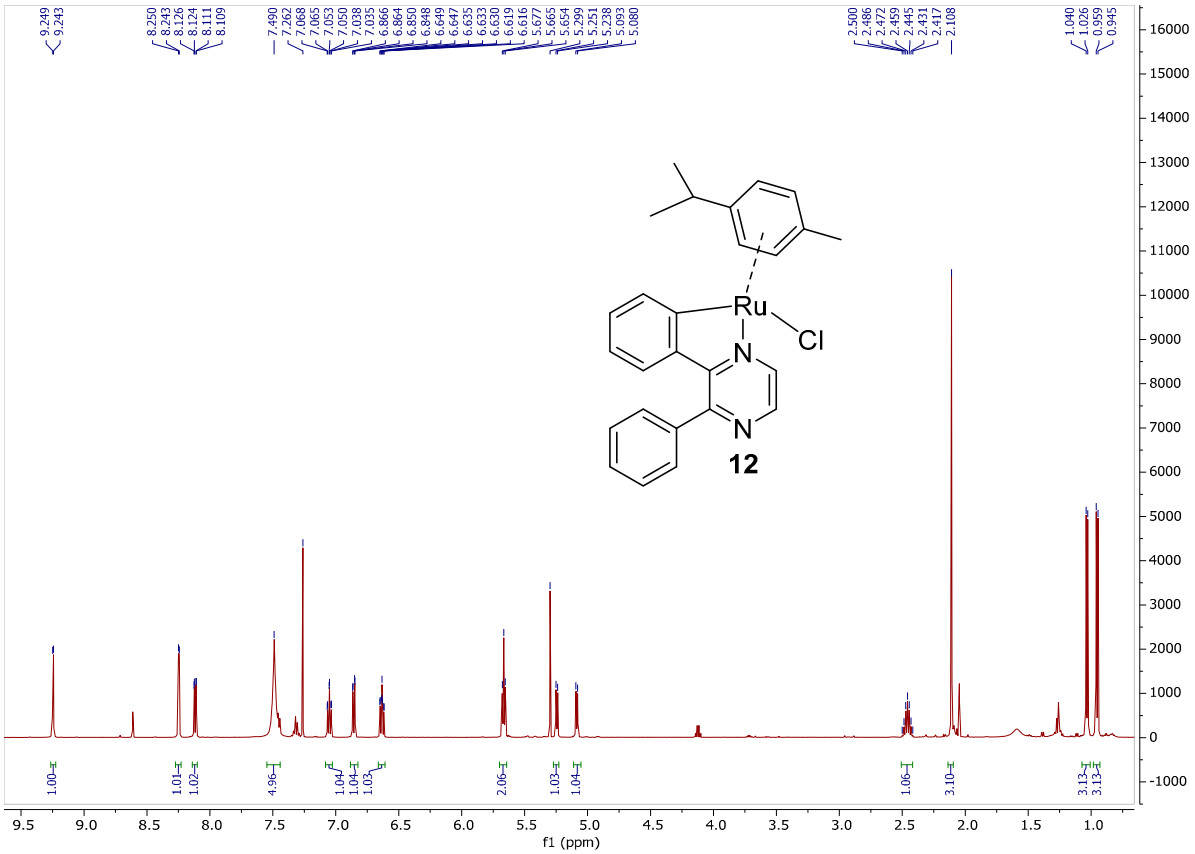
^{1}H–^{1}H NOESY of ruthenacycle **11**



^{1}H–^{1}H COSY of ruthenacycle **11**



^{1}H NMR of ruthenacycle **12** (500 MHz, 296 K, $CDCl_3$)



X-ray Crystallographic studies. Crystal data were collected at room temperature on an Agilent Technologies SuperNova Dual diffractometer with an Atlas detector using monochromated Mo-*K*α radiation (λ = 0.71073 Å) or Cu-*K*α radiation (λ = 1.54184 Å). The data were processed using CrysAlis Pro [4]. Structures were solved with the ShelXT [5] structure solution program using intrinsic phasing and refined by the full-matrix least-squares procedure based on F^2 with ShelXL [6] implemented in Olex^2 program suit [7]. All non-hydrogen atoms were readily located and refined anisotropically. Hydrogen atoms were initially located in the difference Fourier maps and were subsequently included in the model at geometrically calculated positions and refined by using a riding model unless otherwise noted. In **3a** atoms C6–C8 and C30–C32 were refined restraining U^{ij} components. In **5b**, **6b** and **8b** one CF_3 group was refined as disordered over two positions with the refined ratio 0.662(11):0.338(11), 0.637(16):0.363(16) and 0.51(2):0.49(2), respectively. In **7b** all three CF_3 groups were refined as disordered over two positions with the refined ratios 0.56(2):0.44(2), 0.73(2):0.27(2) and 0.580(167):0.420(17) and atoms F7A, F7B, F8A and F8B were refined with restrained U^{ij} components. In **10a** hydrogen atom attached to water oxygen atom was refined fixing the bond length and isotropic temperature factors as U_{iso}(H) = 1.5U_{eq}(O). Crystallographic data are listed in Table S2.

Supplementary Materials: CCDC 1991671–1991677 contain the supplementary crystallographic data for this paper. 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 Crystallography Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

Table S2: Crystal data and structure refinement.

	3a	**5b**	**7b**	**9a**
CCDC number	1991671	1991672	1991673	1991674
Formula	$C_{24}H_{20}N_2O$	$C_{30}H_{20}N_2F_6$	$C_{37}H_{23}F_9N_2$	$C_{48}H_{38}N_2O_4$
M_r	352.42	522.48	666.57	706.80
T (K)	293(2)	293(2)	293(2)	293(2)
Crystal system	Monoclinic	Monoclinic	Monoclinic	Monoclinic
Space group	$P2_1/n$	$P2_1/c$	$P2_1/n$	$C2/c$
a (Å)	12.6225(3)	11.8197(10)	9.7550(5)	21.0221(14)
b (Å)	18.1474(3)	21.7129(16)	9.8351(5)	9.3993(8)
c (Å)	17.1932(4)	10.6868(8)	33.2252(16)	18.9714(14)
α (°)	90	90	90	90
β (°)	106.439(3)	113.994(9)	97.158(5)	93.494(6)
γ (°)	90	90	90	90
Volume (Å^3)	3777.38(15)	2505.7(4)	3162.8(3)	3741.6(5)
Z	8	4	4	4
D_c (g/cm^3)	1.239	1.385	1.400	1.255
μ (mm^{-1})	0.597	0.113	0.119	0.080
F(000)	1488.0	1072.0	1360.0	1488.0
Radiation	Cu-Kα	Mo-Kα	Mo-Kα	Mo-Kα
Reflections collected	15398	14144	19540	9524
Independent reflections (R_{int})	7164 (0.0340)	5743 (0.0244)	7243 (0.0389)	4283 (0.0263)
Data/restraints/parameters	7164/18/490	5743/0/372	7243/24/518	4283/0/246
GOF, S[b]	1.021	1.032	1.040	1.051
R, wR_2 [$I > 2\sigma(I)$][a]	0.0590, 0.1597	0.0589, 0.1505	0.0549, 0.1257	0.0539, 0.1413
R, wR_2 (all data)[a]	0.0849, 0.1858	0.0981, 0.1792	0.1004, 0.1512	0.0888, 0.1614
Largest diff. peak/hole / e Å^{-3}	0.22/–0.18	0.42/–0.33	0.18/–0.14	0.63/–0.23

[a] $R = \sum||F_o| - |F_c||/\sum|F_o|$, $wR_2 = \{\sum[w(F_o^2 - F_c^2)^2]/\sum[w(F_o^2)^2]\}^{1/2}$. [b] $S = \{\sum[(F_o^2 - F_c^2)^2]/(n/p)\}^{1/2}$, where n is the number of reflections and p is the total number of parameters refined.

Table S2: continuation

	6b	**8b**	**10a**
CCDC number	1991675	1991676	1991677
Formula	$C_{30}H_{18}F_6N_2$	$C_{37}H_{21}F_9N_2$	$C_{48}H_{38}N_2O_5$
M_r	520.46	664.56	722.80
T (K)	293(2)	293(2)	293(2)
Crystal system	Monoclinic	Orthorhombic	Monoclinic
Space group	$P2_1/n$	$Pbca$	$C2/c$
a (Å)	10.6015(4)	9.5218(5)	14.9499(10)
b (Å)	19.8023(10)	21.9347(11)	13.2281(7)
c (Å)	11.8366(7)	29.1777(14)	19.9299(11)
α (°)	90	90	90
β (°)	97.223(4)	90	108.960(7)
γ (°)	90	90	90
Volume (Å^3)	2465.2(2)	6094.0(5)	3727.5(4)
Z	4	8	4
D_c (g/cm^3)	1.402	1.449	1.288
μ (mm^{-1})	0.114	0.124	0.083
F(000)	1064.0	2704.0	1520.0
Radiation	Mo-Kα	Mo-Kα	Mo-Kα
Reflections collected	15610	35567	10621
Independent reflections (R_{int})	5646 (0.0223)	6983 (0.0479)	4258 (0.0212)
Data/restraints/parameters	5646/0/371	6983/0/461	4258/1/254
GOF, S^b	1.021	1.033	1.047
R, wR_2 [$I > 2\sigma(I)$]^a	0.0461, 0.1076	0.0580, 0.1572	0.0502, 0.1320
R, wR_2 (all data)^a	0.0734, 0.1251	0.1032, 0.1887	0.0663, 0.1433
Largest diff. peak/hole / e Å^{-3}	0.14/–0.17	0.32/–0.30	0.21/–0.29

^{a} $R = \sum||F_o| - |F_c||/\sum|F_o|$, $wR_2 = \{\sum[w(F_o^2 - F_c^2)^2]/\sum[w(F_o^2)^2]\}^{1/2}$. ^{b} $S = \{\sum[(F_o^2 - F_c^2)^2]/(n/p)\}^{1/2}$, where n is the number of reflections and p is the total number of parameters refined.

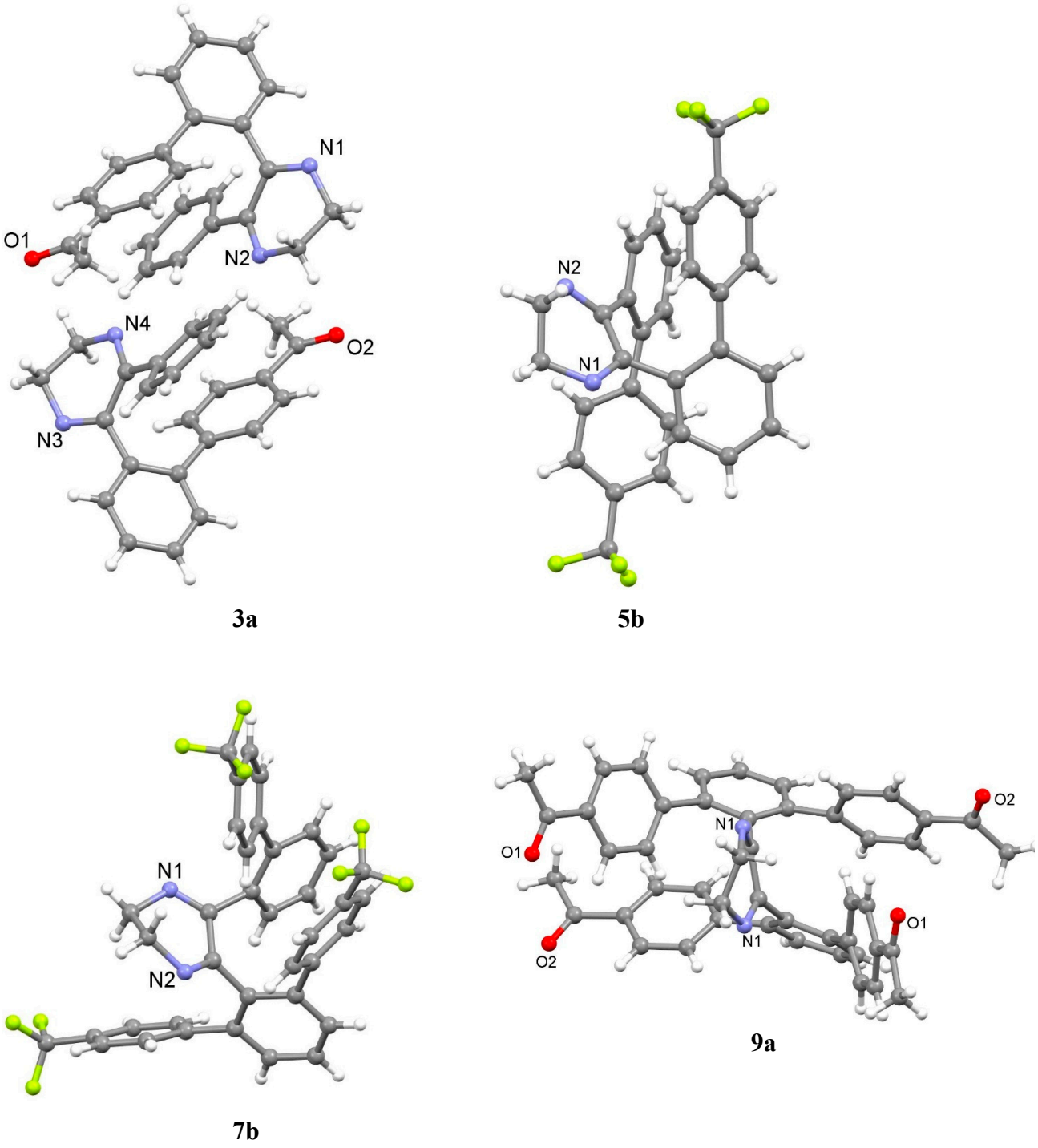
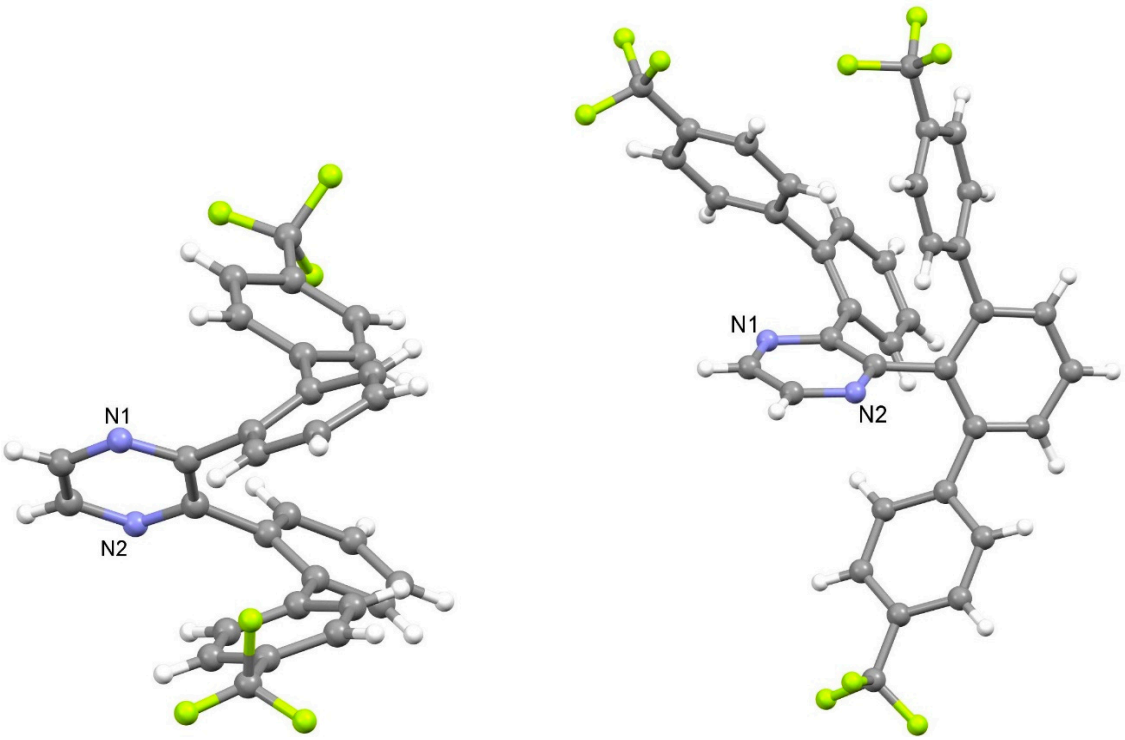
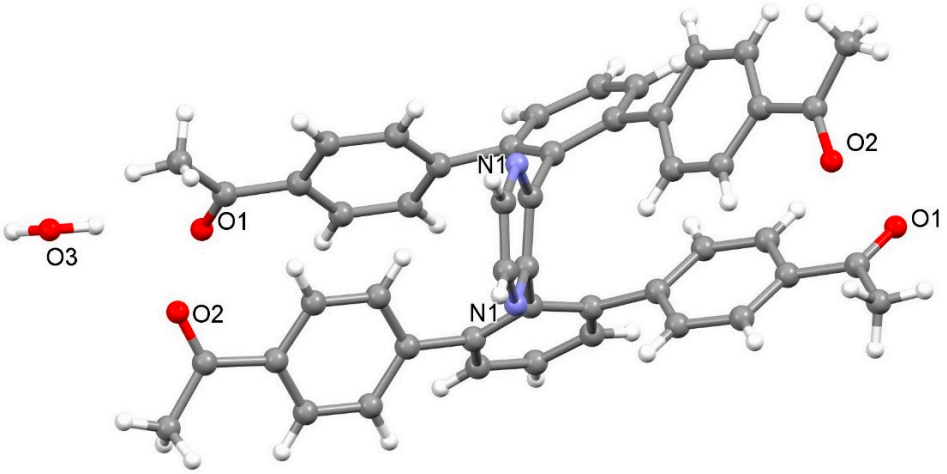


Figure S1: Crystal structures of **3a**, **5b**, **7b** and **9a**. Disorder on CF_3 groups in **5b** and **7b** has been omitted for clarity. Asymmetric unit of **3a** is composed of two crystallographically independent molecules **3a** and asymmetric unit of **9a** is composed of a half of **9a** molecule.



6b **8b**



10a

Figure S2: Crystal structures of **6b**, **8b** and **10a**. Disorder on CF_3 groups in **6b** and **8b** has been omitted for clarity. Asymmetric unit of **10a** is composed of a half of molecule **10a** and a half of water molecule.

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